MEDIEVAL AND EARLY MODERN SCIENCE

Nicole Oresme's *De visione stellarum* *(On Seeing the Stars)*

A Critical Edition of Oresme's Treatise on Optics and Atmospheric Refraction, with an Introduction, Commentary, and English Translation

DAN BURTON

BRILL

NICOLE ORESME'S
DE VISIONE STELLARUM
(*ON SEEING THE STARS*)

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VOLUME 7

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A CRITICAL EDITION OF ORESME'S TREATISE ON OPTICS AND ATMOSPHERIC REFRACTION, WITH AN INTRODUCTION, COMMENTARY, AND ENGLISH TRANSLATION

BY

DAN BURTON

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To Donna

TABLE OF CONTENTS

PART II. *DE VISIONE STELLARUM*: TEXT, TRANSLATION, AND CRITICAL APPARATUS

PART III. BIBLIOGRAPHY AND INDICES

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University of North Alabama
Florence, Alabama
January 2006

PART I

INTRODUCTION AND COMMENTARY

I. INTRODUCTION

One medieval scribe portrayed the *De visione stellarum* as a *pulcher tractatus,* "a beautiful treatise" – and it is. This text is, to my knowledge, the earliest separate treatise devoted to the study of atmospheric refraction and its deeper implications. The fundamental question it attempts to answer is *Utrum stelle videantur ubi sint* – "Are the stars really where they seem to be?" As with most simple questions, the answers may be more profound than first imagined. The *De visione* builds upon the foundations laid by the great perspectivists such as Ptolemy, Alhacen, Bacon, and Witelo on atmospheric optics, but it also goes further.[1] Two centuries before the Scientific Revolution, it proposes the qualitatively correct solution to the problem of atmospheric refraction, that light travels along a curve through a medium of uniformly varying density, and it arrives at this solution using infinitesimals. This solution had even escaped the great 17th century scholar of optics and astronomy, Johannes Kepler, and up to now, the credit for its first discovery has been given to Robert Hooke and for its mathematical resolution to Isaac Newton.

The *De visione stellarum* was believed anonymous by most scholars of the early 20th century, such as Björnbo and Thorndike.[2] It was not until the 1960s that Graziella Federici-Vescovini proposed that the work was by the brilliant medieval natural philosopher Nicole Oresme.[3] The manuscript copy of the *De visione stellarum* found in Florence, B.N., J.X. 19 is immediately followed by a blank page. This blank page is followed by the final fragment of an otherwise unknown work on the same subject attributed to Nicole Oresme.

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[1] All of whom are quoted in this text; Alhacen and Witelo are referred to frequently.

[2] Axel Anton Björnbo, *Die mathematischen S. Marcohandschriften in Florenz.* Nuova edizione (Pisa: Domus Galilaeana, 1976), pp. 71–72, no. 28.2–28.3. Lynn Thorndike, "Some Medieval and Renaissance Manuscripts on Physics" *Proceedings of the American Philosophical Society* 104 (1960): 188–193. The full nomenclature for this manuscript is Florence, Biblioteca Nazionale, convent. soppr., J.X. 19. It was previously referred to as the Codex S. Marci Florent. 202.

[3] Graziella Federici-Vescovini, *Studi sulla prospettiva medievale,* Università di Torino, Pubblicazioni della Facoltà di lettere e filosofia, Vol. 16, Pt. 1 (Turin: Giappichelli, 1965), ch. 10, pp. 195–204. This was the first scholarly overview of the *De visione stellarum,* though, curiously, she did not note the important section on the curvature of light.

Both Björnbo and Thorndike note these two apparently distinct works, labeling the first anonymous and the second by Oresme, but incomplete. Federici-Vescovini's diligent scrutiny of this codex revealed that these were not two separate works, but that the second was actually an alternative ending of the *De visione stellarum* itself. Thus, she argued that the *De visione* is by Oresme, since the second, alternative ending attributes it so.[4] Comparisons with Oresme's other works have tended to confirm that the *De visione* is indeed by Oresme. Stephen McCluskey has found similarities between the *De visione* and Oresme's *Meteora* commentary, and this present study has found similarities with other works by Oresme. Beyond the Florence manuscript, two other copies of the *De visione* were known to exist, one in the Vatican, the other in Bruges – both are anonymous.[5] I have recently discovered a previously unknown fourth copy of the manuscript in the Lilly Rare Book and Manuscript Library of Indiana University.[6]

[4] This alternate ending is also found in the Vatican manuscript of the *De visione stellarum*, but without an attribution to Oresme. Cf. Vatican Latin 4275, fol. 50^v.

[5] Florence, Biblioteca Nazionale Centrale, Conventi Soppressi, J.X. 19, fols. 31^r–43^v; Vatican Latin 4275, fols. 40^v–50^v; Bruges, Stadsbibliotheek, MS 530, fols. 31^r–40^v.

[6] Lilly Rare Book and Manuscript Library, Indiana University, Medieval and Renaissance MSS., 15th century, "Cum volueris scire gradum solis…", fols. 37^r–56^v. No manuscript number is given by the Lilly; rather, the entire manuscript is referred to by its century and the incipit of its first text, Messahala's *Practica circa astrolabium*, part 2.

II. NICOLE ORESME'S LIFE AND WORKS

Nicole Oresme was a rational mind in a calamitous century.[1] How calamitous may be seen from a mere twenty-year window of his life, from the time he began his theological studies at Paris around 1342 to his relinquishing of the Grand Mastership of the Parisian College of Navarre by 1362. In that brief span, his king had been captured at the Battle of Poitiers, his beloved Paris suffered a bloody insurrection led by a cloth merchant, the dread peasant revolt of the Jacquerie ravaged the countryside outside its walls, and most terrifying of all, the Black Death visited Paris for the first time and then returned a second time, carrying off one-third to one-half the population.

In his lifetime, the three institutions with which Oresme was most closely associated underwent radical changes: the state, the university, and the church. When Oresme was born in the early 1320's, Medieval France was at her most regal and chivalric, the University of Paris was truly international, and the popes had only recently moved from Rome to Avignon (with inklings that they would "soon" return). By his death in 1382, France was shattered by the Hundred Years War, the University of Paris was more insular, having lost most of her English and German students, and the church was

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[1] The 14th century has often, and rightly, been deemed "calamitous." For example, Barbara Tuchman, gave the subtitle "The Calamitous 14th Century" to her stimulating best-seller, *A Distant Mirror* (New York: Alfred A. Knopf, 1978).There is relatively little biographical information available concerning Oresme, and what we know concerning his life has been treated admirably elsewhere, particularly by Grant, Menut, Babbitt, and Courtenay. Thus I will merely sketch the outlines of his life here and refer the reader to these works for a more detailed analysis. Edward Grant in his edition of Oresme's *"De proportionibus proportionum" and "Ad pauca respicientes,"* Publications in Medieval Science (Madison: University of Wisconsin, 1966), pp. 3–10; Albert D. Menut in his *Maistre Nicole Oresme: Le Livre de politiques d'Aristote*, Transactions of the American Philosophical Society, N.S., 60, pt. 6 (Philadelphia: American Philosophical Society, 1970); Susan M. Babbitt, *Oresme's "Livre de Politiques" and the France of Charles v*, Transactions of the American Philosophical Society, vol. 75, pt. 1, 1985 (Philadelphia: American Philosophical Society, 1985), pp. 1–12; William J. Courtenay, "The Early Career of Nicole Oresme," *Isis* 91:3 (Sept. 2000): 542–548. Two of the best overviews of his scientific life are given by Marshall Clagett in his "Nicole Oresme and Medieval Scientific Thought," *Proceedings of the American Philosophical Society* 108 (1964): 298–309, and his "Nicole Oresme," in the *Dictionary of Scientific Biography* (New York: Charles Scribner's Sons, 1970–1980), vol. 10, pp. 223–230.

demeaned by both the Babylonian Captivity of Avignon and the two-headed Schism of the papacy. Oresme never lived to see a resolution to any of these crises suffered by his state, his university, or his church.

Oresme was born around 1320 in the diocese of Bayeux in Normandy, possibly in the village of Allemagne (now Fleury-sur-Orne) on the outskirts of the Norman city of Caen.[2] His birth was in the middle of the Great Famine of 1317–1322, in which 10–15 % percent of the entire population of Europe starved to death.[3] During this time of crop failure and starvation, Normandy suffered horrific windstorms that devastated its agriculture, and the extremely cold winter of 1321/1322 completed its misery, when parts of the North Sea itself froze over.[4] By the time Oresme was some 8 years old, the last of the Capetian Kings had died (1328), leading to a crisis of succession and, ultimately, the Hundred Years War. But we hear nothing about Oresme himself until 1342.

Scholars have long assumed that Oresme was lowborn and without means, because of his entrance into the College of Navarre at the University of Paris in 1348.[5] This college was founded by the crown to subsidize those students too poor to otherwise attend the University of Paris – or so it has seemed.[6] But in two powerful essays, William Courtenay convincingly demonstrates that these fellowships were more likely to be granted to those with seniority, connections, and the ability to pay a fee (!), than to those with financial need.[7] Further, these benefices were most often given to teaching

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[2] Courtenay, "The Early Career of Nicole Oresme," p. 542. Caen was the second largest city in Normandy, after Rouen, with a population between 8,000 and 10,000. See Jonathan Sumption's, *The Hundred Years War: Trial by Battle* (Philadelphia: University of Pennsylvania Press, 1991), p. 507.

[3] For an excellent treatise on the subject, see William C. Jordan's, *The Great Famine: Northern Europe in the Early Fourteenth Century* (Princeton: Princeton University Press, 1996).

[4] Jordan's, *The Great Famine*, pp. 19 and 120.

[5] As noted by Grant, Menut concludes that Oresme probably "came from one of those sturdy peasant families." Grant's quotation of Menut is found in his *De proportionibus proportionum*, p. 4, and n. 7. See also, François Neveux', "Nicole Oresme et le clergé normand au XIVᵉ siècle," in *Autour de Nicole Oresme*, ed. by J. Quillet (Paris: Vrin, 1990), pp. 9–36.

[6] For the most extensive work on this college, see Nathalie Gorochov's, *Le Collège de Navarre: de sa fondation (1305) au dèbut du XVe siècle (1418): histoire de l'institution, de sa vie intellectuelle et de son recrutement* (Paris: H. Champion, 1997).

[7] William J. Courtenay, "The University of Paris at the Time of Jean Buridan and Nicole Oresme," *Vivarium* 42:1 (April 2004), pp. 12–14, and Courtenay, "The Early Career of Nicole Oresme," p. 542.

masters, not students.[8] And, indeed, Courtenay reveals that Oresme had already obtained his masters of arts at the University of Paris by 1341/42 and was probably supporting his studies in theology there by teaching philosophy.[9] For in 1342, a University of Paris supplication list submitted to Pope Clement VI, named Oresme as a master of arts requesting a benefice from the Benedictine monastery of Montebourg, in the diocese of Coutances (in Normandy).[10] Nonetheless, even if the College of Navarre was not just for poor scholars, there are other grounds to suggest that Oresme and his family may not have been well-off by the time of his entry into the College.

Two years before Oresme entered the College of Navarre, England's King Edward III invaded Normandy, claiming that the French throne was rightfully his. According to Jonathan Sumption, there was an "orgy of theft and destruction" with a deliberate plan to destroy all the villages along the coast, as well as burn "a swathe of land between 12 and 15 miles wide" along their path.[11] Many of the towns along the way were pillaged and burned, and there was tremendous upheaval in Caen and its environs, where Oresme and his family were from. According to Froissart and others, King Edward not only captured and pillaged Caen and its surrounding region, his army also carried off some 100 knights, 120 squires and 300 of the wealthiest citizens for ransom. They killed between 2,500 and 5,000 others.[12] So even if Oresme's family had been well-off before 1346, they might have become quickly impoverished due to this early salvo in the Hundred Years War.

In the university supplication to the pope of 1349, Courtenay notes that Oresme was still waiting for his benefice from the abbey of Montebourg, and that he was requesting a canonry at Avranches, even though "the papal letter in response to his petition indicates that he was already in possession of the parish church of St-Pierre at Fontenay, at the mouth of the river Vire, on the western edge of

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[8] Courtenay, "The University of Paris at the Time of Jean Buridan and Nicole Oresme," pp. 12–13.

[9] Courtenay, "The Early Career of Nicole Oresme," pp. 543–544.

[10] Courtenay, "The Early Career of Nicole Oresme," pp. 543–544.

[11] Sumption's, *The Hundred Years War: Trial by Battle*, p. 506.

[12] Concerning the sack of Caen (1346), see Jean Froissart, *Chronicles*, selected, trans. and ed. by Geoffrey Brereton (New York: Penguin Books, 1968), pp. 73–77, Sumption's, *The Hundred Years War: Trial by Battle*, pp. 507–512, and Desmond Seward's *The Hundred Years War: The English in France, 1337–1453* (New York: Atheneum, 1978), pp. 58–60.

the diocese of Bayeux."[13] Placed in the context of the Hundred Years War, Oresme's plea becomes clear. Montebourg had been completely sacked and then burned three years previously, as were all the towns in the area, according to Froissart.[14] Likewise, though Oresme might have been in possession of a benefice from St-Pierre at Fontenay-sur-Mer on paper, it was almost certainly destroyed as well, since according to English reports, "everything had been destroyed or carried off within 5 miles of the sea from Cherbourg to the mouth of the Orne at Ouistrehan."[15] Avranches, on the other hand, while still in Normandy, was south of the devastation wrought by King Edward, and thus Oresme might hope that a canonry from there would provide an income. Unfortunately, by the time of this request, both Normandy and Paris were in the midst of the Black Death, 1348/1349.[16]

Oresme relied upon his intellect for both sustenance and status. It also seemed his refuge – a rock in troubled times – for in all his writings there is almost no mention of the turmoil swirling all about him and the decay of his medieval world.[17] Only a single line in his *De visione stellarum* breathes a word of this tumult, and even here, in

[13] Courtenay, "The Early Career of Nicole Oresme," pp. 544–545.

[14] See both of the following English translations: Jean Froissart, *Chronicles of England, France, Spain, and the Adjoining Countries, in the Latter Part of the Reign of Edward II. to the Coronation of Henry IV*, tr. by Thomas Johnes (London: William Smith, 1839), v. 1, ch. 121, p. 153; and, Froissart's, *Chronicles*, ed. and tr. by Geoffrey Brereton (New York: Penguin Books, 1968), p. 71. For the French, see Jean Froissart, *Chroniques. Livre I. Le manuscrit D'Amiens: Bibliothèque municipale no. 486.* Ed. par George T. Diller (Genève: Droz, 1991–), v. 2, p. 376, §489, lines 16–23; and, Froissart, *Chroniques. Livre I (première partie, 1325–1350) et livre II: rédaction du manuscit de New York, Pierpont Morgan Library M.804.* Ed. par Peter F. Ainsworth et George T. Diller (Paris: Librarie générale française, 2001), p. 541, §257.

[15] As reported by one of King Edward III's clerks, Michael Northburgh, according to Sumption, *The Hundred Years War: Trial by Battle*, pp. 506–507.

[16] The plague hit the Norman city of Caen, 65 miles from Avranches, in the Fall of 1348, from which it quickly spread into all the surrounding region. Ole J. Benedictow, *The Black Death, 1346–1353: The Complete History* (Woodbridge, Eng.: Boydell Press, 2004), pp. 108–109; Philip Ziegler, *The Black Death* (Bath, England: Alan Sutton, 1969, rpt. 1993), pp. 57–58.

[17] This is the opposite of his contemporary, Petrarch, who because of this very decay, rejected much that was medieval and embraced the classical world instead. Huizinga claims that Oresme and Petrarch knew one another while at the court of Charles V, but as Hansen points out he gives no corroborating evidence for this relationship. J. Huizinga, *The Waning of the Middle Ages* (Garden City, NY: Doubleday, 1956), p. 325; Bert Hansen, *Nicole Oresme and the Marvels of Nature: A Study of His "De Causis Mirabilium," with critical edition, translation, and commentary*; Pontifical Institute of Mediaeval Studies, Studies and texts, 68 (Toronto: Pontifical Institute of Mediaeval Studies, 1985), p. 6, n. 9.

melancholy praise, he affirms how precious the intellect is. In that passage, Oresme submits the text for correction to "the reverend Masters of this most excellent University of Paris, and especially to that of the venerable doctors of the faculty of the college of arts, in whom in these evil times, as if in precious vessels, is guarded the pearl of philosophy, whose teaching is more brilliant than all others, just as the morning star [*Lucifer*] is more splendid than all the constellations, and the golden moon [*Phoebe*] is [more splendid] than the morning star itself."[18] This view of his fellow scholars as precious vessels in evil times may not be mere sycophancy. Indeed, if Oresme is describing the cataclysmic period of the late 1340s or 1350s, then "these evil times" is rather understated, and he might well describe his colleagues as "precious vessels" of knowledge, since so many had perished in the plague. Since up to half of the Parisian population is said to have died in this plague from 1348–1350, Oresme must have seen many a colleague and mentor succumb to it.

Further, in the same year that Oresme became grand master of the College of Navarre, 1356, the English nearly destroyed the French army at the battle of Poitiers and captured King John II. John's son, Charles, whom Oresme may have tutored and certainly counseled, became regent while his father was held in England. Meanwhile, Étienne Marcel led a bloody revolution in Paris and took control of the city in 1358, and he found common cause with the terrifying peasant uprising in the French countryside known as the Jacquerie. These were indeed "evil times," for Paris, and for France. In contrast to Oresme's reserve, Petrarch manifestly revealed his heart when he described Paris in 1360 as "defaced up to its very gates by fire and ruin, [it] seemed to be shuddering in dismay at the fate that had befallen it."[19]

A. *Service to University*

Through all, Oresme's triune loyalty to God, King and University never wavered. Reason was his best tool, and with it he served all three – using it as both comforter and sword. He devoted much of his life to the university and the advancement of knowledge. This aspect of Oresme's life has been well documented by many others,

[18] *De visione stellarum*, Bk. II, cap. 2, 216:2–8 (i.e., page 216, lines 2–8).
[19] From Petrarch's, *Familiares*, XXII, 14, as quoted in Ernest Hatch Wilkins, *Life of Petrarch* (Chicago: Phoenix Books, The University of Chicago Press, 1961), p. 174.

thus only a bare example or two will be given here. His innovative scholarship led to developments in mathematics and astronomy such as fractional exponents, the comparison of irrational ratios, and the logical possibility of the axial rotation of the earth. And, as I hope to show in this work, he advanced the concept of the curvature of light and correctly applied it to atmospheric refraction.

From 1356 to 1362, Oresme served as Grand Master of the College of Navarre and was also an active teaching master on the faculty of theology during that time.[20] Since he was incepted as a master of arts in or before 1341/1342, it is likely that Oresme was a teaching master in the arts faculty for several years after this, and he may have continued as a teaching master in arts until his entrance into the College of Navarre in 1348.[21] At the University of Paris, a normal pre-requisite for master's work in theology was the master of arts degree, and a condition for granting the M.A. was teaching in the arts faculty for at least two years after being incepted.[22] It is natural to assume that Oresme composed many of his works on natural philosophy during this period. These texts include his many Aristotelian *quaestio* commentaries (such as on the *Physics, De anima*, and *De caelo*), works on mathematics, and treatises ranging from celestial motion and optics to the intension and remission of forms. His use of the *quaestiones* format – the standard disputational style of textbooks in the schools – strongly implies he taught these texts as well.

Since the *De visione stellarum* is in the *quaestio* format (at least *pro forma*) and he specifically refers to it as a "disputatio," it is likely to date from Oresme's time on the arts faculty.[23] His high praise of the Parisian faculty of arts at the end of the *De visione* (quoted above)

[20] Menut, *Le Livre du ciel et du monde*, p. 9, n. 16; Grant, *De proportionibus proportionum*, p. 7, n. 21.

[21] Courtenay, "The Early Career of Nicole Oresme," p. 544.

[22] Cf. Gordon Leff's, *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries: An Institutional and Intellectual History*, New Dimensions in History, Essays in Comparative History (New York: John Wiley & Sons, 1968), p. 157.

[23] *De visione stellarum*, Bk. I, 80:1–3. Masters of arts were required to "lecture for two years and dispute for forty days." Perhaps this work grew from one such disputation or group of disputations. Leff, *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries*, p. 157, 160. See also Hastings Rashdall, *The Universities of Europe in the Middle Ages*. New Edition, edited by F.M. Powicke and A.B. Emden, 3 vols. (Oxford: Oxford University Press, 1936), vol. 1, pp. 464–465, 492–494. For the most comprehensive recent scholarship on the disputatio, see Olga Weijers', *La "disputatio" à la Faculté des arts de Paris (1200–1350 environ)* (Turnhout: Brepols, 1995), and her *La "disputatio" dans les Facultés des arts au moyen âge* (Turnhout: Brepols, 2002).

would also fit well with such a date – particularly since he makes no specific mention of the faculty of theology.

Though he probably left the university after 1362, his relationship remained cordial, including serving on a variety of committees of theology masters from time to time.[24] For example, over several months in 1372, he represented the Norman Nation at the University of Paris on a committee with two other masters of theology, one from the French, the other from the Picard Nation, to hear complaints from the English Nation.[25]

B. *Service to King*

From 1362 when he left the university until his death in 1382, Oresme served Charles, the dauphin of France, who was regent during his father's captivity (1356–1364) and was crowned King Charles v on his father's death (1364).[26] Serving the king in a variety of capacities over the years, Charles rewarded Oresme with various stipends and positions in his court and in the church.

Though Oresme may have had earlier contact with Charles, it is certain that in 1360, while Oresme was still Grand Master of Navarre, he was sent by the regent dauphin to obtain a forced loan from the city of Rouen for the crown.[27] Oresme was so esteemed that, three years later, he was sent as a royal agent to preach before Pope Urban v in Avignon on Christmas Eve of 1363.[28] In 1369, Oresme referred to himself as "secretaire du roy," and later as "humble chapellain" to King Charles, in the preface of his translation of the *Politics* (probably completed by 1374).[29] In high praise, Oresme was referred to in an

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[24] Grant, *De proportionibus proportionum*, p. 8, and n. 26.

[25] Grant, *De proportionibus proportionum*, p. 8.

[26] For a recent appraisal of this relationship, see Joan Cadden's, "Charles v, Nicole Oresme, and Christine de Pizan: Unities and Uses of Knowledge in Fourteenth-Century France," in *Texts and Contexts in Ancient and Medieval Science*, ed. by E. Sylla and M. McVaugh (Leiden: Brill, 1997), pp. 208–244.

[27] Grant, *De proportionibus proportionum*, p. 6; Clagett, "Nicole Oresme," in the *Dictionary of Scientific Biography*, p. 223. Some scholars have proposed that Oresme was the dauphin's "instructeur," but as both Grant and Babbitt note, the earliest citation of Oresme as "son instructeur" is in a 15th century manuscript. See Babbitt, *Oresme's "Livre de Politiques,"* p. 3 and n. 14; Grant, *De proportionibus proportionum*, p. 6, n. 17.

[28] Babbitt, *Oresme's "Livre de Politiques,"* p. 3.

[29] Concerning the title "secretaire du roy", see Babbitt, *Oresme's "Livre de Politiques,"* p. 3, and p. 3, n. 16; Grant notes that this was cited by Bridrey from a document of the

official act of 1377 as "amé et feal conseillier" to King Charles v, and in the following year, the King gave him two valuable rings.[30]

Undoubtedly, Oresme's most important and influential service to the king was his vernacular translations of four of Aristotle's works into French – the *Ethics, Economics, Politics,* and *De caelo et mundo* – along with his own commentaries on each.[31] Though Charles could read Latin himself, these texts of "practical" philosophy would be more digestible in his native tongue, and, as Babbitt notes, "he wished to make 'les plus notables livres' available to his counselors and to others who needed a French version."[32]

According to some scholars, there is a possibility that Oresme translated another "practical" work for Charles, Ptolemy's *Quadripartitum* (or *Tetrabiblos*) – the bible of astrology.[33] Though the translation is attributed to a certain G. [Guillaume?] Oresme (possibly a relative of Nicole), almost nothing is known of him.[34] And since Nicole

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Chambres des Comptes which is now lost. Grant, *De proportionibus proportionum,* p. 6, n. 16. For the title "humble chapellain" and the dating of the *Politics* translation, see Babbitt, *Oresme's "Livre de Politiques,"* p. 3, and Grant, *De proportionibus proportionum,* p. 9.

[30] Babbitt, *Oresme's "Livre de Politiques,"* p. 3, n. 15, and Menut, *Le Livre du ciel et du monde,* p. 9, n. 16.

[31] These were completed in the years 1369–1377. All four appear in modern critical editions: Albert D. Menut, *Maistre Nicole Oresme: Le livre de ethiques d'Aristote.* New York, 1940; Albert D. Menut, *Maistre Nicole Oresme: Le Livre de Yconomique d'Aristote,* Transactions of the American Philosophical Society, 47, pt. 5 (Philadelphia: American Philosophical Society, 1957); Babbitt, *Oresme's "Livre de Politiques"*; and and Menut, *Le Livre du ciel et du monde.*

[32] Babbitt, *Oresme's "Livre de Politiques,"* p. 8 and n. 65; the quoted portion in Babbitt's sentence is cited as from "Christine de Pisan, *Le Livre des faiset bonnes meurs,* 3.12 (ed. Solente, 2:43)."

[33] Lemay, for example, says the translation is "very probably by Oresme," and that the "G. Oresme" is probably a scribal error. Richard Lemay, "The Teaching of Astronomy in Medieval Universities, Principally at Paris in the 14th Century," *Manuscripta* 20 (1976): 202–204, and p. 203, n. 17. In 1959, Marshall Clagett assumed Nicole Oresme translated the text with no mention of Guillaume, but by 1974, he merely grants the possibility that Nicole was the translator. Marshall Clagett, *The Science of Mechanics in the Middle Ages* (Madison: University of Wisconsin Press, 1959), pp. 338–339, n. 11, and his "Nicole Oresme," in the *Dictionary of Scientific Biography,* p. 230. Examining the evidence more closely, Grant proposes the possibility that Nicole was the translator, but goes no further. Grant, *De proportionibus proportionum,* p. 5 and 11. Menut, however, definitely concludes it is by Guillaume not Nicole Oresme. Menut, *Le Livre du ciel et du monde,* p. 6, and his "A Provisional Bibliography of Oresme's Writings," *Mediaeval Studies* 28 (1966): 297–298. No matter the translator, the work is dated someplace between 1356 and 1360, thus it was completed while Oresme was Grand Master of Navarre.

[34] Cf. Grant, *De proportionibus proportionum,* p. 11, n. 1.

Oresme translated other works for Charles, on the surface it might seem reasonable that he translated Ptolemy's treatise on astrology as well. But if this is so, it is not a little surprising, for Oresme used all his intellectual powers elsewhere to oppose astrology in the most biting terms – in both French and Latin. Indeed, his French *Livre de divinacions* was an exhortation aimed directly for the ears of the king and his court, which was steeped in the beliefs of both magic and astrology.[35]

Oresme's attempts to curb the king's interest in astrology and magic, however, apparently had little effect. For Charles continued to give the "royal touch" for scrofula, collect magic talismans, and retain court astrologers.[36] Further, Charles even founded a college of astrology and astrological medicine at the University of Paris, complete with library, instruments, and two endowed fellowships (all with the pope's approval).[37]

C. *Service to Church*

Whatever their differences on astrology, King Charles rewarded his faithful counselor and translator by helping him obtain a series of clerical positions, from archdeacon to bishop. Apparently with the help of Charles, Oresme acquired his first prebend at Bayeux. However, he was soon forced to decide between serving the church

[35] Oresme's *Livre de divinacions* was almost certainly written before any of his other translations. For Oresme says in the proemium of the *Livre de divinacions*, that he has never set forth or written anything in French. See G.W. Coopland's edition in *Nicole Oresme and the Astrologers. A Study of His "Livre de divinacions"* (Cambridge, Mass.: Harvard University Press, 1952), pp. 50–51; Grant, *De proportionibus proportionum*, p. 5, 11–12; and Clagett, *The Science of Mechanics in the Middle Ages*, p. 338, n. 11. For more on this topic, see Edward Grant's, "Nicole Oresme, Aristotle's 'On the Heavens,' and the Court of Charles v," in *Texts and Contexts in Ancient and Medieval Science*, ed. by E. Sylla and M. McVaugh (Leiden: Brill, 1997), pp. 187–207.

[36] For Charles and the "royal touch" see Hansen, *Nicole Oresme and the Marvels of Nature*, pp. 22–23. For his collection of talismans and astrologers, see Lynn Thorndike's monumental *A History of Magic and Experimental Science*, 8 vols. History of Science Society Publications, New Series iv (New York: Columbia University Press, 1923–1958), vol. 3, pp. 585–589.

[37] The "Le Collège de Maître Gervais" was founded in the 1360s and named after one of King Charles court astrologers, Chréstien Gervais. See Thorndike, *A History of Magic and Experimental Science*, vol. 3, pp. 586, 589; Richard Lemay, "The Teaching of Astronomy in Medieval Universities, Principally at Paris in the 14th Century," *Manuscripta* 20 (1976): 197–217; and see Hansen, *Nicole Oresme and the Marvels of Nature*, p. 22.

and serving the university. For when he gained this archdeaconship at Bayeux in 1361, he was still Grand Master of the College of Navarre in Paris – he wished to relinquish neither position (no doubt for both pure *and* monetary reasons).[38] University regulations forbade additional incomes for those officials receiving more than 60 pounds a year.[39] The case was brought before the Parlement of Paris – Oresme lost; he appealed, and lost again. When forced to choose between the two positions, he chose the university.[40] But not for long. For within a year, Oresme became canon at Rouen Cathedral and left the world of university teaching for good.[41] Within a few months, he also gained a semiprebend at the King's own La Sainte Chapelle in Paris.[42] By March of 1364 he had become dean of Rouen Cathedral – a position he apparently held for the next thirteen years.[43]

While dean of Rouen, Oresme devoted considerable time to serving King Charles as well as serving God, for he refers to himself, at times, as the king's "secretary" and "chapellain" (as mentioned above). Because of his translation work for the king from 1369–1377, Charles even granted special permission for Oresme to continue to gain all the benefits from his deanship of Rouen while completing his translation of Aristotle's *Politics.*[44] Beyond this, he was already

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[38] The archdeacon aided the bishop of a diocese in his many duties, including the administration of church revenues, conducting visitations of lesser clergy, and acting as a judge in ecclesiastical matters; they even had the power to excommunicate (the Council of Trent revoked this power in 1553).

[39] Babbitt, *Oresme's "Livre de Politiques,"* p. 2, n. 11.

[40] Grant, *De proportionibus proportionum,* pp. 6–7.

[41] Oresme became canon on Nov. 23, 1362. *Le Livre du ciel et du monde,* p. 9, n. 16; Grant, *De proportionibus proportionum,* p. 7, n. 21. Cathedral canons were to aid the Dean of a Cathedral in his administrative and ecclesiastical duties.

[42] Feb. 10, 1363. Menut, *Le Livre du ciel et du monde,* p. 9, n. 16; Babbitt, *Oresme's "Livre de Politiques,"* p. 2; Grant, *De proportionibus proportionum,* p. 7, and 7, n. 22. A semiprebend is a near equivalent to a benefice, in which a member of the clergy is entitled to a certain segment of that church's income.

[43] Menut, *Le Livre du ciel et du monde,* p. 9, n. 16; Babbitt, *Oresme's "Livre de Politiques,"* pp. 2–3. The dean of a cathedral served a bishop in much the same way as an archdeacon, having both administrative and ecclesiastical duties. Additionally, the dean would conduct mass when the bishop was unable, and preside over the body of cathedral canons.

[44] From a letter of Charles dated Aug. 28, 1372. Grant, *De proportionibus proportionum,* p. 9, n. 34. Grant continues: "One gets the impression that only for so important and special a task would permission have been granted Oresme to reside away from his official post. Though we cannot argue from silence, it is noteworthy that Oresme's name appears in no university documents in the *Chartularium* in the period 1364–1371, whereas during his stay in Paris for the translations he took part in some official university functions."

receiving a pension from the royal treasury for his translating as early as 1371.[45] With the support of Charles, Oresme became Bishop of Lisieux in 1377.[46] But he does not seem to have taken residence in Lisieux until September 1380, after the death of his beloved king.[47] Still, this does not necessarily mean Oresme was neglectful of his various flocks, since the Bibliothèque Nationale holds one manuscript containing 115 of his sermons, as well as another containing an exposition on the art of preaching.[48] Oresme served as Bishop of Lisieux until his death on July 11, 1382.[49]

Oresme was tangentially involved in several of the major theological controversies of the fourteenth century: the Fratricelli, the *Defensor pacis*, and the Immaculate Conception. Though Oresme had left his faculty position two years previously, in November 1364 he served on a committee of theology masters to create a document of revocation against Dionysius Foullechat, a bachelor of theology.[50] Foullechat was accused of holding the views of the Fratricelli or Spiritual Franciscans, who opposed the possession of property by clergy. Pope John XXII had condemned them as heretics some fifty years earlier in 1317. According to Lea, Foullechat was the only recorded case of the Fratricelli heresy in Northern France. Still, this was no light matter, since the ruling pontiff at the time, Urban V, had nine Fratricelli burned at Viterbo, and several had been burnt in the preceding decade, including at Avignon.[51] But for Dionysius, the situation was

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45 Grant, *De proportionibus proportionum*, p. 9, and n. 36.

46 Menut, *Le Livre du ciel et du monde*, p. 9, n. 16.

47 Grant, *De proportionibus proportionum*, p. 10. In 1378, Oresme was still carrying out duties for the king, including acting as one of several royal agents to escort the Emperor Charles IV to Vincennes, and participating in the funeral of the Queen, Jeanne de Bourbon. Babbitt, *Oresme's "Livre de Politiques,"* p. 3.

48 Menut, "A Provisional Bibliography of Oresme's Writings," *Mediaeval Studies* 28 (1966): 294, D.3 & D.6.

49 Grant, *De proportionibus proportionum*, p. 10. Fifty years later, the notorious judge of Joan of Arc was named bishop of Lisieux, Pierre Cauchon, who was buried there in 1442. Régine Pernoud and Marie-Véronique Clin, *Joan of Arc: Her Story*, trans. and rev. by Jeremy duQuesnay Adams, ed. by Bonnie Wheeler (New York: St. Martin's Griffin, 1999), p. 210.

50 An excellent treatment of this case in context is found in J.M.M.H. Thijssen's, *Censure and Heresy at the University of Paris, 1200–1400* (Philadelphia: University of Pennsylvania Press, 1998), cf. pp. 9–28. For Oresme's involvement, see Grant, *De proportionibus proportionum*, p. 8, and n. 26. Henry Charles Lea gives a more general account in his *A History of the Inquisition of the Middle Ages* ([first publ. in 1887]; reprint ed., New York: Russell and Russell, 1958), vol. 3, p. 168, where he refers to Foullechat as "Denis Soulechat."

51 Lea, *A History of the Inquisition of the Middle Ages*, vol. 3, p. 165, and Philip Schaff, *History of the Christian Church*, 8 vols. (New York: Charles Scribner's Sons, 1882–1923),

resolved slightly more pleasantly – he was forced to publicly abjure his views in 1368.

Earlier in the century, Pope John XXII had also condemned as heretical Marsilius of Padua's *Defensor pacis* (1324). In this treatise, Marsilius espoused, among other things, that the bishop of Rome should have no secular authority, and that the church should be subject to the state. When a French translation of this heretical work surfaced in Paris in 1375, it caused such a stir that a lengthy official inquest was held to find the translator. In December of 1375, three official investigators were chosen to determine if any of the Theology faculty at the University of Paris had translated the banned work from Latin into French. But before they began, these three investigators were themselves asked to give sworn answers to three questions concerning the matter, including whether they had any knowledge of the translator. Oresme was one of three theology masters chosen to ask these questions of the investigators, and in turn was asked the same three questions himself. Thirty-two masters were investigated in all.[52] The translator, apparently, was not discovered. Menut has suggested that there were rumors that Oresme himself was highly suspected of being the translator.[53] But as Grant notes, there is no evidence for this, and it is unlikely that Oresme would have been given such a prominent position as swearing in the investigators themselves if he were under greater suspicion than others on the faculty.[54]

In other theological matters, Oresme had written a tract called *De Concepcione B. Mariae Virginis* (On the Immaculate Conception of the Blessed Virgin Mary), a controversial doctrine heavily debated in the fourteenth century. Unfortunately, no copy of this work is extant.[55] Though a strong supporter of orthodoxy, Oresme nonetheless desired reform of the church, as his Christmas Eve sermon before the pope in Avignon testifies. Menut states that it was "a stirring plea for internal reforms in the Church" and was so highly esteemed by

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vol. 5, part 2: *The Middle Ages, From Boniface VIII, 1294, to the Protestant Reformation, 1517*, p. 501.

[52] See Grant, *De proportionibus proportionum*, p. 8 for Oresme's role, and Lea, *A History of the Inquisition of the Middle Ages*, vol. 3, p. 140 for a more general account.

[53] By this time, Oresme was heavily engaged in translating works from Latin into French for King Charles, including Aristotle's *Politics*. Is this, perhaps, the source of Menut's "rumors"?

[54] Grant, *De proportionibus proportionum*, p. 8, n. 32.

[55] Albert Menut, "A Provisional Bibliography of Oresme's Writings," *Mediaeval Studies* 28 (1966): 299.

later generations that it was "often published in the Protestant countries, where Oresme's arguments were utilized in the 16th and 17th centuries in support of the Reformation." The protestant reformer John Foxe valued this sermon so highly that he translated the entire text into English in his *Book of Martyrs*.[56]

[56] Albert Menut, "A Provisional Bibliography of Oresme's Writings," *Mediaeval Studies* 28 (1966): 294. Oresme's sermon first appears in the 1570 edition of the *Book of Martyrs*; Foxe's Latin source was Flacius' *Catalogus testium veritatis*. John Foxe, [*Actes and monuments*]. *The first volume of the ecclesiasticall history contaynyng the actes and monumentes of thynges passed in euery kynges tyme in this realme, especially in the Church of England* (London: Iohn Daye, 1570), pp. 511–516. Matthias Flacius, *Catalogus testium ueritatis* (Argentinae [i.e. Strasbourg]: [s.n.], 1562), pp. 512–519.

III. THE WRITING OF *DE VISIONE STELLARUM*: AUTHOR, DATE, TITLES, AND INFLUENCE

A. *Authorship*

Of course the single most important argument in favor of Oresme's authorship of the *De visione stellarum* is its direct attribution to him in the second "variant ending" of the Florence manuscript, B.N., Conventi Soppressi, J.X. 19.[1] It simply states: "Explicit N. Orem, etc. De visione stellarum tractatus brevis." All other extant copies of the *De visione* are anonymous, including the "first ending" of the Florence manuscript. The two separate endings in the Florence copy of the *De visione* obscured Oresme's authorship further. For when Axel Björnbo cataloged the Florence codex, he described the first complete copy of the *De visione* as anonymous, and the second variant ending (which bears Oresme's name) as a separate fragment of an otherwise lost treatise by Oresme.[2] Since this fragment attributed to Oresme was thought to be from an entirely different treatise than the *De visione*, the *De visione* itself was deemed anonymous. Later, when Lynn Thorndike examined the same manuscript, he too treated the second ending as a separate fragment, "which consists of only four lines from Nicole Oresme on the same topic of vision of the stars."[3]

Björnbo's and Thorndike's oversight is understandable for two reasons. First, according to Björnbo's description, there appear to be several leaves missing between the *De visione* and the alternate ending (i.e., between fol. 42^v and 43^r), and thus it might be assumed that Oresme's "lost" manuscript had been excised.[4] Second, the explicits of the two endings are not the same.[5] On the other hand, there

[1] Florence, B.N., Conventi Soppressi, J.X. 19, fol. 43^r. The full nomenclature for this manuscript is Florence, Biblioteca Nazionale Centrale, Conventi Soppressi, J.X. 19; and it was previously referred to as the Codex S. Marci Florent. 202.

[2] Björnbo, *Die mathematischen S. Marcohandschriften in Florenz*, pp. 71–72, no. 28.2–28.3.

[3] Thorndike, "Some Medieval and Renaissance Manuscripts on Physics" *Proceedings of the American Philosophical Society* 104 (1960): 193.

[4] Björnbo, *Die mathematischen S. Marcohandschriften in Florenz*, p. 71: "zwischen fol. 42 und 43 fehlen mehrere Blätter."

[5] Neither the second ending of the Florence manuscript nor the Lilly manuscript

were clues that these two pieces were actually part of the same work. For example, Björnbo himself lists the table of contents found on fol. 115^{v} of the Florence manuscript, which does *not* separate the *De visione stellarum* from the so-called "Oresme fragment" (i.e., the second ending), but rather treats them as a single text. Also, there is a figure concerning refraction found *directly beneath* the "Oresme fragment." However, this figure does not correspond to anything in the "Oresme fragment" text above it (i.e., the second ending), but does apply to the *De visione stellarum.*

Nonetheless, it was not until the 1960s that Graziella Federici-Vescovini's efforts revealed the "Oresme fragment" to be a variant ending of the *De visione.*[6] In examining the codex, she discovered that the four lines of the so-called "Oresme fragment" were also found in the anonymous *De visione stellarum.* These four lines are found near the very end of the treatise.[7] Obviously the two are variant endings, not separate works: the first ending has the four lines followed by lavish praise of the Parisian arts faculty (quoted above) but gives no attribution, while the second ending disregards the praise of faculty passage and ends with an attribution of the *De visione* to Oresme. In chapters 9 through 11 of her *Studi sulla prospettiva medievale,* Federici-Vescovini not only analyzed the *De visione* itself, but surveyed all of the perspectivist treatises in the Florence codex that accompany it. From this study, she concluded that the *De visione stellarum* was probably by Nicole Oresme, just as the second ending states.[8] But does the internal evidence validate this scribal attribution?

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include in their explicits the statement of florid praise and submission to the arts faculty at the University of Paris.

[6] Federici-Vescovini, *Studi sulla prospettiva medievale,* ch. 10, pp. 195–198.

[7] *De visione stellarum,* Bk. II, cap. 2, 214:11–15.

[8] While excellent in her analysis of the authorship of the *De visione,* there are a few points in Federici-Vescovini's work that are less probable. For example, in discussing the relationship of Henry of Langenstein and Nicole Oresme, she states: "Determinare chi dei due abbia influito maggiormente sull'altro, specialmente nel campo della filosofia della natura, è difficile …" (p. 196) (In English, roughly: "Determining which of the two have had the greater influence on the other, especially in the field of natural philosophy, is difficult …") This conclusion is curious, as Oresme probably received his master of arts degree by 1342 and had become the Grand Master of the College of Navarre in 1356 – having apparently earned his Doctorate in Theology by that time. On the other hand, Henry of Langenstein, who may have been born around the same time as Oresme (Henry, b. 1325), did not finish his master of arts until 1363 and his masters of theology until 1376. So while they certainly may have been at the University of Paris at the same time, Oresme was definitely the senior of the two. Moreover, Oresme seems to have finished most of his Latin scientific works well before Henry had started his. For biographical

Because Oresme touches upon perspectivist material in some of his other works, one should expect to find parallels between them and the *De visione stellarum* if he is the author. Fortunately, two such works, Oresme's commentary on the *Meteora* and his *De causa mirabilium*, have been recently edited by Stephen McCluskey and Bert Hansen, respectively.[9]

McCluskey, in particular, has found rich correlations between the *Meteora* and the *De visione*. For example, at the beginning of Book II in the *De visione* Oresme divides observation into four distinct categories: straight, refracted, reflected, and mixed rays. These four distinctions are also found in his *Questiones super quatuor libros meteororum*, Bk. III, Q. 20.[10] This appears to be one of the distinguishing features of Oresme's optical views, for neither McCluskey nor I have found it mentioned in any other authors.[11] Thus it is a key support for Oresme's authorship of the *De visione*, since there is little doubt that he authored the commentary on the *Meteora*.

Still, as McCluskey notes, Oresme was not always consistent in his usage, for in his *De causis mirabilium*, he used the more common tripartite division of direct, reflected and refracted rays.[12] But even here, the parallels in the Latin texts are very close, for the order, wording and examples are very similar indeed.[13] Notice the similarities between the following passage of Oresme's *De causis*:

> Ultimo nota quod visio quandoque fit per lineam rectam, quandoque per fractam, patet de denario in fundo vasis, et quandoque per lineam reflexam, ut patet in speculis.

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information on Henry see Nicholas Steneck's, *Science and Creation in the Middle Ages: Henry of Langenstein (d. 1397) on Genesis*. Notre Dame, IN: University of Notre Dame Press, 1976), p. 9.

[9] McCluskey edited the perspectivist portion of Bk. III of Oresme's, *Questiones super quatuor libros meteororum*, for his dissertation: McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12–15, 19–27. Bert Hansen edited Oresme's *De causis mirabilium*, in his *Nicole Oresme and the Marvels of Nature*. Earlier scholars have sometimes referred to the *De causis* by the title *Quodlibeta*, but Hansen believes the *De causis* is only a portion of Oresme's *Quodlibeta*, thus I am following his nomenclature.

[10] Oresme, *Questiones super quatuor libros meteororum*, in McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 20, lines 79–93, pp. 266–267, and his *De visione stellarum*, Bk. II, cap. 1, 112:11–15.

[11] Cf. McCluskey comments concerning it and the *De visione* in his *Nicole Oresme on Light, Color, and the Rainbow*, pp. 50–51 and n. 27, and pp. 442–443, n. 8.

[12] Cf. Oresme, *De causis mirabilium*, ed. by Hansen, Ch. 1, sec. 9, lines 76–78, pp. 150–151: "Note finally that vision sometimes occurs via a straight line, sometimes via a refracted line (as is clear from the penny at the bottom of a [water-filled] vase), and sometimes via a reflected line (as is clear in mirrors)," (Hansen's trans.).

[13] Of course, the two passages might also be relying on a common source.

and that found in the *De visione*:[14]

> Una distinctio est quod quadrupliciter potest fieri visio: Primo, per lineam rectam. Secundo, per lineam fractam, sicut aliquando denarius videtur in fundo aque. Tertio, per lineam reflexam, sicut in speculo. Quarto, per lineam compositam, secundum multas reflexiones vel fractiones vel mixtionem vel per plura specula, et sic diversimode.

Another parallel concerns a man named "Antiphon." The *De visione stellarum* refers to a weak-eyed man called "Antiphon," whom it says is described in Aristotle's *Meteorologia*.[15] Though Aristotle describes such a man, he never gives him a name. But in his commentary on the *Meteora* and his *De causis mirabilium*, Oresme refers to him as Antiphon.[16] So how common is this *nomen* for the weak-eyed man? Both McCluskey and Hansen have conducted considerable research on this mysterious "Antiphon."

Both scholars believe that Oresme's "Antiphon" is an erroneous spelling for "Antipheron," the name Alexander of Aphrodisias assigns to this weak-eyed individual in his Aristotelian commentary. Thus Oresme could have taken the name from Moerbeke's translation of Alexander or perhaps from Aquinas who also uses the name "Antipheron." Other than Oresme, very few medieval schoolmen used the incorrect "Antiphon" for Antipheron. McCluskey found only three: Themon Judaeus and Albert of Saxony in their *Questiones* commentaries, and possibly Peter of Auvergne ("Antiphon" is used in the variant readings of his *Commentarium in Meteorologicorum*).[17] Thus, this "Antiphon" places the *De visione* amongst a very narrow

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14 *De visione stellarum*, Bk. II, cap. 1, 112:11–15. "One distinction is that observing can be done in four ways: First, through a straight line. Second, through a refracted line, as when a penny is seen below water. Third, through a reflected line, as in a mirror. Fourth, through a composite line after many reflections or refractions – either through a mixture, or through many mirrors – and thus in many ways."

15 *De visione stellarum*, Bk. II, cap. 2, 162:3. Aristotle, *Meteorologia*, Bk. III, ch. 4 (373a35–373b13).

16 Oresme, *Questiones super quatuor libros meteororum*, in McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 15, lines 225–229, pp. 218–219, and fn. 18, pp. 429–430, and Oresme, *De causis mirabilium*, ed. by Hansen, in his *Nicole Oresme and the Marvels of Nature*, Ch. I, sec. 9, lines 76–81, pp. 150–151, and fn. 23, p. 151.

17 McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 15, lines 225–229, pp. 218–219, and fn. 18, pp. 429–430; and Oresme (1985), *De causis mirabilium*, ed. by Hansen, Ch. I, sec. 9, lines 76–81, pp. 150–151, and fn. 23, p. 151; Aquinas' commentary on the *Meteorologia*, in Aquinas, *In Aristotelis Libros "De Caelo et Mundo," "De Generatione et Corruptione," "Meteorologicorum" Expositio*, ed. by Fr. Spiazzi (Rome: Marietti, 1952), Appendix II, Bk. III, Lectio V, 280 [2], p. 625; Themon Judaeus', *Quatuor libros Meteororum*, in Albert of Saxony, *Questiones et decisiones physicales insignium virorum*. (Paris: Iodici Badii Ascensii et Conradi Resch, 1518), Bk. III, Q. 10, fol. 188v.

circle of authors, and serves as one more piece of corroborating evidence for Oresme's authorship.

Oresme's commentary on the *Meteora* includes several instances in which he makes very brief summaries of arguments that are quite extensive in the *De visione*. McCluskey found one such instance, and there are others. Some of these "arguments" are so brief that they are little more than bald assertions without any supporting evidence. For example, in Book III, Q. 12, inference 9, Oresme flatly states in a single sentence: "Ninth, I infer [stars on the horizon] would then also appear nearer [due to intervening vapors]."[18] He gives no further justification. In the eighth inference, he declares that stars appear larger on the horizon than in mid-heaven, again with no evidence.[19] And, most important, in the twelfth inference, Oresme asserts the very conclusion of all the arguments of the *De visione stellarum*, that "all stars that are not directly over the zenith appear in another place than they actually are."[20] After a long and rigorous set of proofs, the *De visione*, Book II, conclusion 7, says: "any star which is not over the zenith is seen elsewhere than where it is."[21] It would seem, therefore, that either Oresme in the *Meteora* had not fully formulated his own views on these topics and merely *asserted* them (which seems unlikely), or he had formulated his own views in more detail elsewhere and was merely summarizing them here. If the latter, it requires something like the *De visione stellarum* to precede the commentary on the *Meteora*. No other work in Oresme's corpus is suitable.

[18] Oresme, *Questiones super quatuor libros meteororum*, in McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, line 335, pp. 156–157: "Nono, infero eas tunc etiam apparere propinquiores."

[19] Oresme, *Questiones super quatuor libros meteororum*, Bk. III, Q. 12, lines 331–334, pp. 156–157. A detailed analysis and proof of this and the preceding inference are found in the *De visione stellarum*, Bk. II, cap. 1, 148:14–16: "Et, ex hoc, etiam iudicat eam esse maiorem posito quod non essent vapores qui adhuc quandoque sunt aciunt apparere stellam sub maiori angulo." And Bk. II, cap. 1, 132:8–10: "Et similiter, stelle apparent propter hoc in ortu maiores, scilicet, propter interpositos plures vapores per quos disgregantur radii visuales."

[20] "Infero quod omnes stelle que non sunt in cenit capitis nostri apparent in alio loco quam sint in rei veritate." Oresme, *Questiones super quatuor libros meteororum*, in McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, lines, 343–355, pp. 158–159. McCluskey does a wonderful job of pointing out the parallels between the later portions of this passage and the views concerning stellar parallax in the *De visione*. See McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, pp. 52–53, and 413–414.

[21] *De visione stellarum*, Bk. II, cap. 1, 146:13–14: "Omnis stella que non est supra zenith videtur alibi quam sit."

Not only is there a connection between the text of the *De visione* and that of Oresme's *Meteora* but at least one of the figures in both are nearly identical, including their letter designations. These identical figures concern the effect of refraction on seeing a penny in the bottom of a water-filled vessel. (Cf. Figure 7 in the *De visione* below.)[22] The only major difference between the two diagrams is that the letters *c* and *e* are reversed; other than that, they are the same.[23]

Another support for Oresme's authorship of the *De visione* is his use of specific classical and literary references found in his other works. Most authors have favored quotations that are sprinkled throughout their works, and Oresme is no different.[24] In a variety of his works, Oresme shows familiarity with a number of authors he cites in the *De visione*, which would be considered "uncommon" in a treatise on optics, such as Aratus, Claudian, and Pliny the Elder.[25]

In one passage, the *De visione stellarum* quotes a fairly unlikely source on eclipses, the church father John Damascene. The Damascene describes that during an eclipse, the Sun may seem dimmed, but is actually not; rather, it is a perpetual font of light. Reference to this very passage from John Damascene is found in Oresme's *Le Livre du ciel et du monde*, where he states:[26]

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[22] *De visione stellarum*, Bk. II, cap. 1, 114:16–19.

[23] Cf. Oresme, *Questiones super quatuor libros meteororum* in McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, figure 12.2, p. 142. Also, the non-essential designation for the bottom left-hand corner by the letter *f* is not used in the *De visione* diagram, but this letter is not mentioned in either of the narrative descriptions found in the *De visione* or the commentary on the *meteora*. Of course, these similarities could also be explained by assuming a common source, rather than Oresme's authorship.

[24] Of course to be of use as evidence of authorship, these quotations need to be uncommon for a work of this sort. We would expect Oresme, or almost any other schoolman, to quote from Aristotle or Alhacen or Witelo on meteorological and optical matters. So, literary, classical, or poetical quotes best serve our purposes of comparison here.

[25] Oresme shows familiarity with Aratus' work in his *Livre de divinacions*, but gives only a general reference to him there. See G.W. Coopland's edition in *Nicole Oresme and the Astrologers. A Study of His "Livre de divinacions,"* pp. 56–57, 88–89. Quotes from Claudian's *De Raptu Proserpinae* are not only found in his *Livre de divinacions*, but also in Oresme's commentary on the *Sphere* of Sacrobosco. See Garett Droppers, *The "Questiones De Spera" of Nicole Oresme. Latin Text with English Translation, Commentary and Variants* (Ph.D. dissertation, University of Wisconsin, 1966), Q. 5, p. 103, and p. 363, n. 3.0, and Coopland's edition of *Livre de divinacions*, pp. 82–83, 100–101. Pliny's *Natural History* is a favorite of Oresme's and turns up in most of his works.

[26] Menut's translation. See Menut, *Le Livre du ciel et du monde*, pp. 364–365, and 364, n. 36. In Oresme's French: "Item, le soleil quant eclipsé est aucuns lieus sont en terre ou il ne espant pas sa lumiere, mais pour ce n'est il pas moins perfect

> When the sun is eclipsed, there are certain places on the earth where it does not spread its light, but the sun is no less perfect in itself than at other times. Of this fact John of Damascus said: Although the sun seems to fail at times, nevertheless it always retains within itself its unfailing brilliant light.

Compare this with the passage from the *De visione*:[27]

> Yet, in truth, the sun itself does not undergo a change in color, nor a lack of light [during an interposition of vapors or eclipse]. Hence John Damascene, in a certain *Sermon,* [says] that "the brilliant light-beaming sun – lying hidden for a time behind the body of the moon – seems to be lacking in some way, but it itself is not deprived of light, for within itself it has a perpetual font of light.

Clusters of quotations are strong indicators of common authorship. The introductory passage of the *De visione stellarum* argues that humans were created (both internally and externally) to observe the stars – with both their hearts and their upturned faces. To support this, the author of the *De visione* quotes Plato, Bernard Silvester, Empedocles, and Cicero. Nicole Oresme uses this same argument in his *Livre de divinacions*, employing many of the same authorities:[28]

> Also Bernard Savage [i.e., Silvester] says that the sky and the stars are a book in which are written the fortunes of kings, and things to come in this world, so that it would result that God and nature had shown us this book uselessly if we cannot know any of these things by its means. For,

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en soy que autrefois. Et de ce disoit Johannes Damascenus: Quod quamvis tunc sol ad tempus videatur deficere, ipse tamen semper in se retinet indeficientis luminis claritatem."Menut was unable to identify the passage from the Damascene, but it is almost certainly from one of his sermons on the Assumption of Mary. See John Damascene's (1898) *On the Assumption, Sermon I*, in his *St John Damascene on Holy Images (pros tous diaballontas tas hagias eikonas) Followed by Three Sermons on the Assumption (koimesis)*, tr. by Mary H. Allies (London: Thomas Baker), pp. 164–165.

[27] *De visione stellarum,* Bk. II, cap. 2, 204:15 – 206:2. "Cum tamen secundum rei veritatem in se non patitur coloris alterationem nec lucis defectum. Unde Iohannes Damascenus in quodam *Sermone,* sol iste splendidus lucifluus sub lunari corpore latens ad tempus videtur quodammodo deficere tamen ipse suo non privatur lumine habens in se perennem fontem luminis."

[28] My addition in brackets to Coopland's translation. See Coopland's edition of the *Livre de divinacions*, pp. 66–67, and 197, n. 125–127. The French reads: "Item, Bernart Sauvage dit que le ciel avec les estoilles est le livre ou sont escriptes les fortunes des roys et les choses avenir en ce monde. dont s'ensuit il que pour neant nous aroit dieu et nature moustre ce livre se n'y pouons aucunes de ces choses congnoistre. Car, selon ce que dit Seneque, nature fit le visage des bestes enclins vers terre et nostre teste dreca vers le ciel et la fist tournant ou col affin que nous considerons les estoilles tout environ. Et c'est la sentence de Platon, de Empedocles, de Ovide."

> as Seneca says, nature made the faces of the animals inclined towards the ground and lifted ours towards the heavens and made them to turn at the neck so that we should consider the stars above. And this is also the opinion of Plato, Empedocles and Ovid.

This was a favorite argument of Oresme's, which he also makes in the Prologue of his *Tractatus de commensurabilitate vel incommensurabilitate motuum celi*, there quoting specifically from Seneca and Cicero as well.[29] In the *De visione* this distinct argument also appears, supported by the same authorities:[30]

> Plato in the *Timaeus*, wishing to assign a cause for why sight is present in our eyes, and why God Himself gave an elevated face to man and ordered him to gaze upon the heavens and to raise the face upward towards the constellations, assigned the very cause that Bernard Silvester gives in his poem: "Empedocles, to one asking why he lived, said, 'To see the stars. Take away the Heavens, and I will be nothing.'"

> Brute animals clearly have slow minds; they carry their faces downwards with downcast visages. But with a bodily form bearing testimony to a greatness of mind, man alone lifts his head toward the stars …

In his *Livre de divinacions*, Oresme describes the same passage of Cicero's *De natura deorum* (II, lxii, 155) concerning the beauty of the heavens that is also found in his *Tractatus de commensurabilitate.* This same passage on celestial beauty is in the *De visione stellarum.*[31]

Thus, it is probable that the *De visione stellarum* is by Nicole Oresme, particularly given the cumulative power of the evidence above: its direct scribal attribution, its apparent relationship with both Oresme's *Meteora* and *De causis mirabilium*, the usage of the weak-eyed "Antiphon," the matching illustration, and parallel literary citations. And if it is by Oresme, then the *De visione* is perhaps one of his earliest extant works.

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[29] See Edward Grant's edition in *Nicole Oresme and the Kinematics of Circular Motion: "Tractatus de commensurabilitate vel incommensurabilitate motuum celi,"* University of Wisconsin Publications in Medieval Science, 15 (Madison: University of Wisconsin Press, 1971), pp. 172–175, and 327, n. 1–5.

[30] *De visione stellarum*, Bk. I, 76:6–12, in the Latin: "Plato in *Timeo* volens reddere causam propter quam visus inest nostris oculis, et cur deus ipse os homini sublime dedit celumque videre iussit et erectos ad sidera tollere vultus, non aliam assignavit causam nisi quam Bernardus Silvester metrice tradit dicens: 'Querenti Empedocles cur viveret inquit, ut astra inspiciam, "celum subtrahe: nullus ero'." Bruta patenter habent tardos animalia sensus. Cernua deiectis vultibus ora ferunt, sed maiestatem mentis testante figura, tollit homo suum solus ad astra caput …"

[31] See Coopland's edition in *Nicole Oresme and the Astrologers*, pp. 112–113, and 208, n. 239; and see Grant's edition in *Nicole Oresme and the Kinematics of Circular Motion*, pp. 172–173. *De visione stellarum*, Bk. I, 78:9–11.

B. *Date*

The manuscripts themselves offer no firm date for the *De visione* other than sometime during the fourteenth century.[32] Unfortunately, dating on internal evidence is tenuous at best in this case. One way of determining a relative date for the *De visione* would be citations to his own writings, for in most of his other texts, Oresme was not shy in citing himself. But in the *De visione*, there is a striking lack of citations to his own works. This implies that either the *De visione* is not by Oresme (unlikely given the evidence) or that it is a very early treatise, preceding most of his other works.

Consistent with an early date is his "humble submission" of the *De visione* to the arts masters of the University of Paris for correction. In that passage, Oresme submits the text for correction to[33]

> the reverend Masters of this most excellent University of Paris, and especially to … the venerable doctors of the faculty of the college of arts …

Note that he makes no specific mention of the faculty of theology. Of course, this may merely reflect Oresme's immediate audience at the *disputatio*. On the other hand, if Oresme were already a student of theology (i.e., after ca. 1342) or especially if he were on the theology faculty (after 1356) it would be quite improbable (though not impossible) for Oresme to humbly "submit" his text for correction to the arts faculty alone. After all, most of the regent masters of the arts faculty would be both *younger* and academically *less advanced* than any student of theology, let alone a master of theology.

Oresme makes a similar submission of his work for correction to the Fellows and Masters of the University of Paris in the Prologue of his *De commensurabilitate*:[34]

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[32] Bruges, MS. 530 is dated to the 14th century, Vatican Lat. MS. 4275 to the 14th-15th centuries, and Florence, B.N., MS. Conv. soppr., J.X. 19 is dated to circa 1400 or earlier. The only exactly dated copy is also the latest, the Lilly Library MS. is dated 1465.

[33] *De visione stellarum*, Bk. II, cap. 2, 216:2–5.

[34] Grant's English translation. The Latin reads: "Non ergo dimisi quin hoc opusculum committerem sociis et magistris huius sacratissime universitatis Parisiensis sub eorum correctione qui absque detractionis livore soliti sunt bene dicta reverenter suscipere et minus bene digesta emendare benigne." See Grant's edition in *Nicole Oresme and the Kinematics of Circular Motion: "Tractatus de commensurabilitate vel incommensurabilitate motuum celi," edited with an introduction* (Madison: University of Wisconsin Press, 1971), Prologue, lines 45–48, pp. 174–175, and p. 328, n. 8.

> For this reason I did not release this little book without [first] submitting it for correction to the Fellows and Masters of the most sacred University of Paris, who are accustomed to receive respectfully, without malicious slander, things that are well put, and to alter, in a kindly way, things not adequately formulated.

Notice, however, that Oresme does not single out the arts faculty as in the *De visione*.[35] Grant argues submission of the *De commensurabilitate* for correction to the Masters of the University of Paris implies that the date of that work is "in or before 1362, the year Oresme probably relinquished the grand mastership of Navarre and presumably withdrew from full participation in university affairs."[36] A like argument applied to the *De visione stellarum* suggests that it was probably written while Oresme was still a master of arts student or had recently completed his M.A., in the early to mid-1340s.

McCluskey places the order of composition of three of Oresme's works (including the *De visione*), on internal grounds, to be: 1st) *De visione*; 2nd) *Meteora* commentary; 3rd) *De configurationibus qualitatum et motuum*.[37] He dates the *Meteora* as between 1351 and 1356 – the *terminus ante quem* because Oresme gained the Grand Mastership of Navarre in that year.[38] Clagett dates the *De configurationibus* as between 1351 and 1361, and possibly before 1356.[39] If McCluskey's and Clagett's dates and order of composition are accepted, then the *De visione* was written well before 1356 and perhaps before 1351. Because of Oresme's "humble submission" to the arts faculty, the date of his master in arts, and his lack of self-citation, I would tend to place it well before 1351, probably in the early to mid-1340's – but this is conjectural.

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[35] Likewise, Oresme also submitted his *Algorismus proportionum* for correction to Philippe de Vitry, Bishop of Meaux. See Edward Grant's translation in "Part 1 of Nicole Oresme's 'Algorismus proportionum,'" *Isis* 56 (1965): 328. For a general overview of Oresme's prologues, which includes a discussion of his submitting his works for correction, see Clagett, *Nicole Oresme and the Medieval Geometry of Qualities and Motions*, pp. 139–141.

[36] Grant, *Nicole Oresme and the Kinematics of Circular Motion*, p. 5.

[37] See McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, p. 52.

[38] McCluskey's *terminus post quem* of 1351 seems a bit uncertain, based as it is upon his view that Oresme followed (or even plagiarized) the *Meteorology* commentary of Themon Judaeus, who in turn criticized Albert of Saxony's commentary on the same. Since Albert earned his master of arts in 1351, McCluskey places Oresme's *Meteora* after that date. I am open to this possibility, but remain less than convinced by the argument – particularly since it is now known that Oresme earned his masters of arts by 1342, many years *before* either Albert (in 1351) or Themon (incepted in 1349).

[39] Clagett, *Nicole Oresme and the Medieval Geometry of Qualities and Motions*, pp. 122–125.

C. *Place of Composition.*

Where the text was produced is more firmly established, since all four manuscripts state that "Propter quod De visione stellarum aliqua recollegi dicta in disputatione apud sanctum Bernardum."[40] That is, "some thoughts were collected together concerning the observation of the stars at a *disputatio* at Saint Bernards [in Paris]." The fifteenth-century Italian manuscript in the Lilly Library explicitly names Paris, perhaps to aid a non-French audience.[41] Thorndike argued that this "*apud sanctum Bernardum*" is probably a reference to the Collège des Bernardins at the University of Paris.[42]

Also known as the Collège du Chardonnet, the Collège des Bernardins was founded in 1246 for Cistercians at the University by Stephen Lexington, abbot of Clairvaux.[43] Located fairly near Oresme's Collège of Navarre, the Collège des Bernardins accommodated a variety of functions of the university within its walls. For example, the French Nation of the University of Paris occasionally met at the Cistercian college to conduct its business.[44] It was also one of the customary locations for a theology graduate student to deliver his university required annual sermon.[45] Thus, it would not be surprising if a *disputatio* such as the *De visione* were delivered there.

Concerning the *disputatio*, Leff notes that masters of arts who had been incepted were required to "lecture for two years and dispute for forty days."[46] Perhaps Oresme's *De visione* grew from one such disputation or group of disputations. Students acquiring a bachelor's degree in the arts were also required to hold disputations, but,

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[40] *De visione stellarum*, Bk. I, 80:1–2.

[41] Further confirmation that the *disputatio* took place in Paris is found in an offhand reference to light coming through an aperture in a Parisian church. A reference found in all four manuscripts. *De visione stellarum*, Bk. II, cap. 2, 200:16–18.

[42] Cf. Thorndike, "Some Medieval and Renaissance Manuscripts on Physics," pp. 192–193.

[43] Lynn Thorndike, *University Records and Life in the Middle Ages*, Records of Civilization – Sources and Studies, 38 (New York: Columbia University Press, 1944; reprint ed., New York: Octagon Books, a division of Farrar, Straus & Giroux, Inc., 1971), p. 437; Rashdall, *Universities of Europe in the Middle Ages*, vol. 1, p. 506.

[44] Kibre, Pearl. (1948). *The Nations in the Mediaeval Universities*, Mediaeval Academy of America Publication, 49 (Cambridge, Mass.: Mediaeval Academy of America), p. 74.

[45] Leff, *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries*, p. 167.

[46] Leff, *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries*, p. 157, 160. See also Rashdall, *The Universities of Europe in the Middle Ages*, vol. 1, pp. 464–465, 492–494.

according to Rashdall, these took place in one of the schools on the Street of Straw (Rue du Fouarre).[47] Since Oresme's disputation apparently took place in the Collège des Bernardins (on the Rue des Bernardins), it was much more likely to be a masters, rather than a bachelors, determination.[48]

D. *Variant Titles of the* De visione stellarum *and the Problem of Tracing Influence*

Gauging the scholarly influence that Oresme's *De visione stellarum* had is extremely difficult for at least two reasons. First, Oresme's treatise apparently became "anonymous" very quickly, perhaps by the 15th century in most manuscript copies. In the four surviving manuscripts, his name appears in only one, and even there it appears in a variant ending, overlooked until recently even by great modern scholars such as Lynn Thorndike and Axel Björnbo.

Second, as was typical amongst medieval works, Oresme's treatise bears no single, uniform title. The apt title given by Graziella Federici-Vescovini and by the Florence manuscript's table of contents, *De visione stellarum*, is a phrase used in the introduction of the work, and possibly meant as a title for it. The scribes of several of the surviving copies, however, were not inclined to use this title. The Lilly manuscript at Indiana University refers to the work in a header as "*Tractatus solempnis perspective*" ("A formal [or solemn] treatise on perspective"), placing it in a larger perspectivalist tradition. The Vatican manuscript, however, gives a title in its upper margin based on the major question posed by Oresme: "*Incipit pulcher tractatus: Utrum stelle videantur ubi sint*" ("Here begins a beautiful treatise: Whether the stars are where they seem to be.").[49] The index at the beginning of the Vatican manuscript, in a different hand, refers to Oresme's work with a slight variant of the same title: "*Questio utrum stelle videantur ubi sint.*"

Without an author's name or a uniform title, any later natural philosophers who may have drawn upon Oresme's treatise could not have given any easily traceable citation to it – even if they had been

[47] Cf. Rashdall, *Universities of Europe in the Middle Ages*, vol. 1, pp. 454–455.

[48] For a street map of late medieval Paris south of the Seine, see Thorndike, *University Records and Life in the Middle Ages*, overleaf facing p. 448.

[49] This scribe is profuse with his *pulchers*, for he uses that term to describe two other works by Oresme in the same codex. Apparently he was a true Oresme-ophile.

inclined to do so, and most were not. At most, then, we are left with the possibility of anonymous conceptual influences. Discerning such subtle influences is the bane of the historian, for without signs of direct copying, such wisps of "influence" could plausibly be parallel, but independent, conceptualizations by the later author. This is almost certainly the case concerning the most innovative portions of Oresme's treatise on the curvature of light. There is no evidence that Descartes, Hooke or Newton ever used or even had access to Oresme's *De visione stellarum*, and they almost certainly arrived at their views on light's curvature independently.

E. *Sources and Citations*

Following the practice of many medieval scholastics, Oresme displayed his erudition by interweaving his introduction with a tapestry of quotations from classical and medieval authors. Once he had moved into the body of the text itself, his citations were more limited in scope, seldom venturing beyond the ancient and medieval perspectivists and Aristotle. Oresme makes no mention of his own works, though elsewhere it was his common practice to cite himself rather frequently.[50]

There are over 50 citations, referring to 18 different works in the *De visione*.[51] The vast majority (34) are to just three texts: Alhacen's *De aspectibus*, Witelo's *Perspectiva*, and Aristotle's *Meteorologica*. Of course, these three are foundational to the topic of the *De visione*. There are two surprises however: first, the complete absence of Pecham's optical works, and, second, only two citations of Roger Bacon's *De multiplicatione specierum*. Concerning the latter, Oresme never mentions Bacon by name, merely referring to this work as *De speciebus*. Oresme, nonetheless, may have relied on Bacon more closely than these two references reveal, for there seem to be instances in which he follows both the content and order of Bacon's *De multiplicatione*.[52]

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[50] As mentioned above, this may be another indication that the *De visione* is an early work in Oresme's corpus.

[51] For an alphabetical listing of these citations, see chapter VII.

[52] For two examples, see the experiments in *De visione stellarum*, Bk. II, cap. 1, 142:1–20, and the explanation of reflection and refraction in *De visione stellarum*, Bk. II, cap. 1, 116:20 – 118:2. I certainly am not trying to imply plagiarism in any sense,

Oresme pays homage to Greek authors by opening the work with a quotation from Plato's *Timaeus*. Oresme only refers to two of Aristotle's works, the *De caelo* and the *Meteorologica*, though the later is cited eight times. Absent are Aristotle's *Physics*, *De anima*, and *De sensu* – all of which one might expect to appear occasionally in a work on optical phenomena. Among the other Greek works referenced by Oresme are Euclid's *Elements*, and Ptolemy's *Almagest* as well as his work on optics, the *De aspectibus*.

Oresme also cites several classical Latin authors: the Latin paraphrase of Aratus' *Phaenomena*, Cicero's *De natura deorum*, Claudian's *De raptu Proserpinae*, and Pliny the Elder's *Natural History*. Unlike some of his other compositions, Oresme seldom referred to early Christian authors or the Bible in this work.[53] There is but a single citation to John Damascene's *On the Assumption*, and a single unnamed (but commonly known) quotation from the book of *Joel*, that "the sun shall be turned to darkness, and the moon to blood."

Oresme cited the medieval Arabic author, Alhacen (*De aspectibus*) 15 times, more often than any other author, including Aristotle. He also referred to the *De crepusculis* [On Twilight], and assigned it to Alhacen as well. The *De crepusculis* was actually written by Ibn Muʾadh, as A.I. Sabra has proven. Sabra also notes that this citation in Oresme's *De visione stellarum* is the earliest to attribute the work to Alhacen.[54] The *De crepusculis* was quite popular throughout the Middle Ages and Renaissance where it was widely believed to be written by Alhacen. As A. Mark Smith has postulated, perhaps this attribution was partially because its Latin manuscripts were sometimes bound with Alhacen's *De aspectibus*.[55] It is unclear whether Oresme in his *De visione* was the first to mistakenly attribute the *De crepusculis* to Alhacen, or whether this is merely the earliest extant example of such an attribution.

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for Oresme does cite Bacon in the vicinity of both of these lengthy passages, just not within them.

[53] On the surface, this could be construed as another indication that this work was written before Oresme began his masters work in theology. But the subject of atmospheric optics does not lend itself easily to sermons or biblical doctrine, so not too much should be made of their absence.

[54] A.I. Sabra, "The Authorship of the *Liber de crepusculis*, an Eleventh-Century Work on Atmospheric Refraction," *Isis* 58 (1967): 77, 83–84.

[55] A. Mark Smith, "The Latin Version of Ibn Muadh's Treatise *On Twilight and the Rising of Clouds*," *Arabic Sciences and Philosophy* 2 (1992): 83–84, 89.

Of course Oresme does not ignore the works of Medieval Latin authors, employing Bernard Silvester's *Cosmographia,* Roger Bacon's *De multiplicatione specierum* (mentioned above), and John of Sacrobosco's *De sphaerebus.* The second most cited author of the work, in fact, is the perspectivist Witelo (*Perspectiva*), to whom Oresme refers 11 times.

IV. OVERVIEW AND COMMENTARY ON ORESME'S *DE VISIONE STELLARUM*

A. *General Overview of the* De visione stellarum

Atmospheric refraction is both an astronomical irritant and an intellectual puzzle. A major problem for observational astronomers since Ptolemy, it still baffled Newton who consumed nearly a year of his life finding a correct understanding of the problem in order to aid the astronomer John Flamsteed.[1] Despite its complexity, it has been a delightful puzzle for students of optics and mathematics, and for the armchair astronomer. Further, it also has a philosophical dimension, for it questions our ability to know true reality through the senses. For if everything we observe, from a stone to a star, is shifted and distorted in incalculable ways by the medium we inhabit, then how trustworthy are our perceptions of physical reality? Oresme was uniquely suited to tackle a many-sided scientific and philosophical problem such as refraction since he was a mathematician, a perspectivist, a philosopher, and a bit of an armchair astronomer as well.

His elder colleague, Jean Buridan, noted Oresme's keen interest in meteorological phenomena quite early.[2] In his *Quaestiones super meteorum* this famous arts master said: "The Reverend Master Nicole Oresme said to me himself to have once seen two [mock suns or parhelions], one on either side of the sun."[3] Oresme himself

[1] This was not entirely altruistic: Newton desired to "exchange" his solution for Flamsteed's raw astronomical data.

[2] While influenced by Buridan, Oresme was almost certainly not a student directly under him, or part of a "Buridan School," as Duhem and others had surmised. See the recent scholarship by J.M.M.H. Thijssen, "The Buridan School Reassessed. John Buridan and Albert of Saxony," *Vivarium* 42:1 (2004): 18–42, and Courtenay, "The University of Paris at the Time of Jean Buridan and Nicole Oresme," pp. 6–8.

[3] Jean Buridan, *Questiones super Meteororum*, Bk. III, Q. 20, as quoted in Stephen C. McCluskey, Jr.'s, *Nicole Oresme on Light, Color, and the Rainbow: An Edition and Translation, with intro. and critical notes, of part of book three of his "Questiones super quatuor libros meteororum"* (Ph.D. Dissertation, University of Wisconsin-Madison, 1974), p. 23, n. 31: "Reverendus Magister Nycolaus Oresme dixit mihi se semel vidisse duas [parellies] ex utroque latere solis unum …" McCluskey notes that he collated this passage from the following manuscripts: Erfurt, MS Ampl. F 334, fol. 154^{ra}; Florence, Bibl. Riccardiana, MS 745, fol. 92^{vb}; and Paris, Bibl. Nationale, Latin MS 14723, fol. 257^{ra}.

explained such mock suns by means of atmospheric refraction and reflection in the *De visione*.[4]

> Indeed, in the air, sometimes such refractions or reflections occur in the clouds, which make the sun appear elsewhere than it really is. Further, because of such reflections or refractions, there sometimes appear to be two other [suns] on either side of the true sun – and these are called "mock suns" …

Oresme gives a sprinkling of qualitative observations throughout the *De visione*, and encourages his readers to use *experientia* (i.e., experience or experiment) to confirm his views.[5] Nevertheless, while some of these *experientiae* might depend on actual observations, others are more an appeal to common wisdom, or may merely be thought experiments. Thus, Oresme's *De visione stellarum* is a fully scholastic treatise, relying far more upon reasoned argument than on observational evidence to achieve its ends.

Oresme builds his disputation on a single question: *Utrum stelle videantur ubi sunt*.[6] "Are the Stars [Truly] Where They Appear To Be?" He answers that they are not. Why they are not may be understood in three ways, he says. Some stars appear to be the same distance from us, even though they are not. The reason for this is self-evident, he says, and he will not explore it in the *De visione*. Other stars appear where they are not, though the light ray from them is *straight* (i.e., undistorted). Still other stars appear where they are not when the light ray from them is *"bent" by reflection or refraction.* The *De visione* is divided into two unequal parts that treat the second and third cases; these I have labeled Book I and II. The shorter Book I answers the second case, the longer Book II answers the third.

I have not had an opportunity to examine this passage myself. Babbitt also notes this passage and cites its appearance in an article by Bulliot. Babbitt, *Oresme's "Livre de Politiques,"* p. 2, n. 10: "Oresme does not mention Buridan, but Buridan speaks in his *Quaestiones super tres libros Metheorum* of an observation made to him by 'Reverendus Nicholaus Oresme' (see Jean Bulliot, 'Jean Buridan et la mouvement de la terre,' *Revue de Philosophie* 25 [1914]:12)."

[4] Oresme, *De visione stellarum*, Bk. II, cap. 2, 204:1–5: "Ymo, in aerem, et quandoque fuerit tales refractiones vel reflexiones in nubibus que faciunt solem apparere alibi quam sit. Et adhuc preter verum solem quandoque apparet quod sint, duo alii propter huiusmodi reflexiones aut fractiones, et illi vocantur paralleli …"

[5] In *De visione stellarum*, Bk. I, 110:21–22, Oresme urges the "experimentator" to busy himself in observing comets. Book II is filled with references to "experience" or "experiment" teaching the conclusions that could not be gained otherwise. Conclusion 6 in Book II has almost every paragraph call for an *experientia. De visione stellarum*, Bk. II, cap. 1, 140:7 – 146:12.

[6] *De visione stellarum*, Bk. I, 80:3.

B. *Introduction to Book 1: Whether Deception Occurs in Observing the Celestial Stars When Their Rays are* Undistorted

Oresme postulates in Book 1 that stars and planets could be seen by a direct ray of light without any reflection, refraction or distortion of any kind and, nevertheless, not truly be where they "seem" to be. This may strike the modern reader as a bit odd; after all, if a celestial object is observed without any distortion, surely it is seen where it truly is. But this is because we no longer inhabit an Aristotelian universe, a universe of fixed dimensions and a single center. For Oresme, a celestial body's "true position" is its location as seen against the fixed stars from the center of the world. Yet we live and observe from the surface of the earth, not the center of the universe, therefore any celestial object will be seen through a certain parallax and not in its true place, unless it is directly overhead.

1. *Lunar Parallax (Bk. 1, Conclusion 1)*

Oresme expounds upon the problems of parallax in the first two of his three "conclusions" in Book 1. In Conclusion One, he examines lunar parallax. He notes, for example, that a solar eclipse is not seen everywhere on earth; rather, it varies according to the location of the observer. Therefore, the moon is not seen where it "truly is" by everyone on earth. Likewise, if *any* two celestial objects of varying heights are seen along the same line from the surface of the earth, they will appear to be at the same point against the background of the fixed stars. But this is only appearance, Oresme says, for they are actually not seen in their "true position" (i.e., from the center of the world), unless they are both over the observer's zenith.

2. *The Parallax of Comets (Bk. 1, Conclusion 2)*

In conclusion two, Oresme turns to the parallax of comets. Comets, of course, suffer the same kind of parallax as the moon does, but their parallax is even greater. For in the Aristotelian world, comets (or at least their comas) are sublunar, atmospheric phenomena – and the closer the object, the greater the parallax. Though left unstated, the clear implication for both astronomers and astrologers is that a comet that "appears" to be in one constellation, may "truly" be in another.

In corollary one through six of his second conclusion, Oresme compounds this problem of comets by discussing what I will call "fixed star" comets. Oresme first asks us to hypothesize that a comet is composed of two parts that are actually far apart from one another: a fixed star in the celestial heavens and a coma (the "hairy" nebulous portion of a comet) that is in the terrestrial region of air directly beneath this fixed star. Aristotle in the *Meteorologia*, suggests that *some* comets are indeed fixed stars that generate comas in the atmosphere, much like halos that sometimes surround the sun and moon and appear to follow them as they move.[7]

Oresme points out a difficulty with this two-part comet view of Aristotle: because the coma is much closer than its fixed star, its "stellar" parallax would be much greater, and we would *not* observe the coma under its fixed star, unless the coma and fixed star were directly at zenith. Indeed, Oresme notes, we might observe this shifted coma under some other, unrelated, fixed star instead. He then details this conclusion in a variety of ways in corollaries two through six.

3. *Finding the Altitude of a Circumpolar Comet. (Bk. 1, Conclusion 3)*

In the third and final conclusion of Book 1, Oresme explains how to determine the altitude of any circumpolar comet one may find using a very long and rigorous geometric proof. In this lengthy digression, Oresme strays from his original intent, to show that the stars are not where they appear to be. Nevertheless, his Euclidian-style proof is a fascinating attempt to apply the knowledge of stellar parallax to find the actual height of a comet above the earth.[8]

Oresme first asks us to assume a comet that describes a true, circumpolar circle around the pole star (as seen from the center of the earth, his fixed and "true" reference point). Then an observer on the earth, who is not at the pole, will see this circular orbit at an oblique angle. To the observer the comet's circle will appear,

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[7] While Aristotle does postulate that such two-part comets may occur, he notes that comets are much more likely to form independently of the fixed stars and would lag behind the motion of the universe, thus comets are not normally "halo" comas formed around fixed stars. *Meteorologia*, Bk. 1, ch. 6 (343b8–25), and Bk. 1, ch. 7 (344a34–344b15). Cf. *The Complete Works of Aristotle: The Revised Oxford Translation*, ed Jonathan Barnes (Princeton: Princeton U.P., 1984), v. 1, pp. 562–563.

[8] Unfortunately, to use Oresme's calculations, one must find a comet that travels in a circle around the pole of the earth. With our post-Newtonian knowledge, we now know this is very unlikely indeed. However, the concept could be used to calculate, say, the distance to a very special artificial satellite that was always above the horizon and perfectly circled either the north or south pole.

not as a circle, but as an ellipse (though Oresme does not use that word).[9] The major axis of the ellipse will be from east to west – what Oresme calls the "diameter of the longitude" – this major axis is at right angles to the observer's line of sight toward the north. The squashed circle's shorter axis, the "diameter of the latitude", will be along the observer's line of sight. The diameter of the longitude, therefore, will be at right angles to the longitudinal lines and be measured by the number of lines of longitude it crosses, and vice versa for the diameter of the latitude. Armed with this information, gathered by several observers from different places, the distance to the comet may be determined.[10] So ends Book I. In the second book he explores how stars may not appear where they seem to be when the light ray from them is "bent" by reflection or refraction.

[9] This is similar to looking at a toy train on a circular track. Seen from directly overhead, the track is a perfect circle, but looked at from a different angle, the track appears to be an ellipse, with its longer axis at right angles to the line of sight, and its shorter axis along the line of sight.

[10] Explanations for this type of distortion of shape, in which a distant object such as circle or square is seen from an oblique angle, have a long history in mathematical optics. Among the Greeks, Ptolemy notes that when surfaces do not face the eye directly, those surfaces appear different than when they do, thus circles and squares, seen obliquely, will appear oblong. Ptolemy, *Optics*, II, 72; For the Latin edition, see Albert Lejeune's edition of Ptolemy, *L'optique de Claude Ptolémée dans la version latine d'après l'arabe de l'émir Eugène de Sicile*, ed. by Albert Lejeune (Louvain: Bibliothèque de l'Université, Bureaux de Recueil, 1956), p. 49, lines 12–22; and for an English translation, see A. Mark Smith's, *Ptolemy's theory of visual perception: an English translation of the Optics, with introduction and commentary* (Philadelphia: American Philosophical Society, 1996), p. 101.Likewise, Alhacen and Witelo discuss this subject in great detail. Alhacen, *De aspectibus*, III, ch. 7, (para. 4–6; III 79a–80b); For the Latin, see Alhacen, *Opticae thesaurus: Alhaceni Arabis libri septem, nunc primum editi; eiusdem liber De crepusculis & nubium ascensionibus; item Vitellonis Thuringopoloni libri X; omnes instaurati, figuris illustrati & aucti, adiectis etiam in Alhacenum commentarijs, a Federico Risnero [= Friedrich Risner, d. 1580]. With an introduction to the reprint edition [of 1572] by David C. Lindberg*, Sources of Science, 94 (New York: Johnson Reprint, 1572, rpt. 1972), III, ch. 7, sec. 24–26, pp. 92–93. For an English translation see A.I. Sabra's edition of Alhacen, *The Optics of Ibn Al-Haytham. Books I–III, On Direct Vision. Translated with Introduction and Commentary*, 3 vols., Studies of the Warburg Institute, 40 (London: The Warburg Institute, University of London, 1989), vol. 1, pp. 279–280. For Witelo's views, see his *Perspectiva*, IV, sec. 55, in Alhacen (1572, rpt. 1972), *Opticae thesaurus*, pp. 142–143, mentioned above.Oresme, however, seems to be the first to have applied this principle to cometary orbits, so far as I have found.

C. *Introduction to Book II: Whether Deception Occurs in Observing the Celestia Stars Due to* Refraction

In Book II, Oresme applies his scholastic and scientific skills to prove his primary thesis and to anticipate objections to it. He uses a seven-part proof to assert that any star not over the zenith is seen elsewhere than it truly is, because of some form of refraction. This he calls his "Principal Conclusion." Then he follows with two arguments against the Principal Conclusion, and innovative responses to each. Once he has shown that the Principal Conclusion is sound, he enumerates six corollaries that follow from it – each of which he says may be discovered experimentally.

These six are followed by another 16 corollaries that Oresme calls "logical conclusions, rather than antecedents," since they cannot be discovered by experience as easily.[11] Some of these corollaries are, perhaps, overexuberant; Oresme even suggests in one that the retrograde motions of the planets might be explained by atmospheric refraction.

In a final summation, Oresme suggests that atmospheric refraction and reflection call all visual experience into profound doubt; that we almost never see any object itself, but only its image, and that through distortion. He ends the second book with a final opinion regarding *lux* and *lumen.* Lastly, tying the entire work together, he responds to the single "initial argument" that the stars *do* appear where they seem to be – a straw-man argument he had placed at the very beginning of the treatise to maintain the scholastic *quaestio* format, at least *pro forma.*

1. *A Proof of the Principal Conclusion Using the Optics of Refraction: Any Star Not Over the Zenith Is Seen Elsewhere Than It Truly Is. (Book II, Conclusions 1–7)*

To introduce the proof of the Principal Conclusion, Oresme briefly outlines the four ways in which observation may occur: straight line, refraction, reflection, and composite (i.e., any mixture of the first three), and notes that deception occurs principally because of reflection or refraction. He then builds his proof using a combination of induction, deduction, and appeal to authority.[12]

[11] I have labeled these 16 corollaries with roman numerals (I–XVI) to help distinguish them from the preceding corollaries.

[12] The first conclusion is: "Probatur auctoritate, experientia, et ratione." *De visione stellarum,* Bk. II, cap. 1, 114:14.

First, Oresme advances that everything seen through two media of differing densities is seen along a refracted line, unless the visual ray is perpendicular to the two surfaces. This first conclusion is axiomatic to his argument and he analyzes it in detail. Appealing to authority, Oresme declares that all perspectivists and philosophers in the past have believed this.[13] He then presents both inductive and deductive proofs to support his claim. The famous, and oft used, penny in a vessel experiment draws upon common, inductive experience.[14] If a penny is placed in the bottom of a vessel and

[13] This view of refraction had been well established by the time of Ptolemy and was held by both Arabic and Medieval Latin scholars. For a sampling, see the following: Ptolemy (1989), *Optics, ed. Lejeune,* Bk. v, secs. 1–22 (= Prop. 79–84), pp. 223–237. Alhacen (1572, rpt. 1972), *De aspectibus,* VII, ch. 3, sec. 9–12, pp. 242–247. Robert Grosseteste's, *De lineis, angulis et figuris,* in Grosseteste, *Die philosophischen Werke,* ed. Ludwig Baur (Münster i. W.: Aschendorffsche Verlagsbuchhandlung, 1912), p. 63, an English translation is found in Edward Grant's, *Source Book in Medieval Science* (Cambridge: Harvard University Press, 1974), p. 387. Roger Bacon, *De multiplicatione specierum,* ed. by David C. Lindberg (Oxford: Oxford Univ. Press, 1983), Part II, Ch. 2, lines 36–84, pp. 98–101. John Pecham, in David C. Lindberg's edition, *John Pecham and the Science of Optics. "Perspectiva communis," edited with an introduction, English Translation, and Critical Notes,* University of Wisconsin Publications in Medieval Science, 14 (Madison: University of Wisconsin Press, 1970), Props. I.15{30}, I.16{31}, pp. 89–92. And Witelo (1572, rpt. 1972), *Perspectiva,* X, sec. 1, p. 405.

[14] The penny in a water-filled vessel as an example of refraction has a long history extending back to the Greek perspectivists. Ptolemy in his *Optics* mentions this simple experiment, as does Alhacen, Grosseteste, Bacon, Pecham, Witelo, William of Ockham, and even Alexander Neckham. Specific references to these are as follows: Ptolemy (1989), *Optics, ed. Lejeune,* Bk. v, sec. 5 (= Prop. 79), p. 225; Alhacen (1572, rpt. 1972), *Perspectiva,* VII, ch. 5, sec. 17, p. 253; Robert Grosseteste, *De iride,* in Grosseteste (1912), *Die philosophischen Werke,* ed. Baur, pp. 74, lines 8–24, Engl. tr. in Grant, *Source Book in Medieval Science,* p. 389; [Note that Grosseteste, Bacon, and Pecham merely describe an "object" under water, rather than a "penny"]; Roger Bacon, *Opus majus,* Part V: *Perspectiva,* Part III, Dist. 2, Ch. 4, in *The Opus majus of Roger Bacon,* ed. by John Henry Bridges, (London, 1897–1900; reprint ed., Frankfurt/Main: Minerva G.m.b.H., 1964) vol. 2, p. 155; for an English translation see Roger Bacon, *Opus majus,* trans. by Robert Belle Burke (Philadelphia: University of Pennsylvania Press, 1928), *Perspectiva* Part III, Dist. 2, Ch. 4, vol. 2, pp. 571–572; Pecham, *Perspectiva communis,* Part III, Prop. 7, lines 49–60, pp. 216–217; Witelo (1572, rpt. 1972), *Perspectiva,* X, sec. 11, pp. 414–415; William of Ockham, *Quaestiones in librum tertium Sententiarum (Reportatio).* Ed. Franciscus E. Kelley and Girardus I. Etzkorn. Opera theologica, 6. (St. Bonaventure, NY: St. Bonaventure University, 1982), 3.2, pp. 78 and 95. Cf. Hansen, *Nicole Oresme and the Marvels of Nature,* p. 151, n. 22, who also notes that "Question 53 of the *Tabula problematum* asks, 'Why is a penny at the bottom of a water-filled vase seen from farther away than in an empty vase?' (in Appendix A)." Alexander Neckham, *Alexandri Neckam "De naturis rerum libri duo,"* ed. by Thomas Wright (London: Longman, 1863. Reprint edition: Washington, D.C.: Microcard Editions, 1966), p. 235; for an English tr., see Grant (1974), *Source Book in Medieval Science,* p. 381.

viewed from some distance to the side, it will no longer be seen, but if the vessel is filled with water, the penny will be seen from the very same place, because of the refraction of rays. This example of the penny in a vessel and refracting rays is a favorite of Oresme's, for he repeats it in both his *Questiones super quatuor libros meteororum,* and his *Marvels of Nature.*[15] Having appealed to both authority and induction, Oresme finishes with a reasoned deduction by giving a brief explanation of the causes of refraction and reflection. For this explanation, Oresme relies upon a book he simply calls *De speciebus,* and though he gives no author, it is almost certainly Roger Bacon's *De multiplicatione specierum.*[16]

In conclusions two and three, Oresme elaborates upon the effects of refraction, describing the directions of refracted rays and the apparent position and size of objects seen by refraction. Then, in conclusions four through six, Oresme applies this knowledge to observing the stars themselves. What, he asks, does refraction do to circumpolar stars, always visible above the horizon as they wheel about the north pole? They should, of course, describe perfect circles – but they do not. For, because of atmospheric refraction, their apparent distance from the pole over an evening varies.[17] In this, as in most of the previous conclusions, Oresme is relying heavily upon Bacon, Alhacen, and Witelo.[18] (Though only the later two are cited by name.)

Finally, Oresme arrives at his Principal Conclusion. Using reasoned deduction from his previous six conclusions, in the seventh

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Both McCluskey and Hansen cite many of these authors in their discussions of the penny-in-a-vessel experiment; McCluskey, *Nicole Oresme on Light, Color, and the Rainbow,* p. 409, n. 25, and Hansen, *Nicole Oresme and the Marvels of Nature,* pp. 150–151, n. 22.

[15] See his *Questiones super quatuor libros meteororum,* in McCluskey's, *Nicole Oresme on Light, Color, and the Rainbow,* Bk. III, Q. 12, lines 186–203, pp. 142–145, and Oresme's *De causis mirabilium,* in Hansen's, *Nicole Oresme and the Marvels of Nature,* Ch. I, sec. 9, lines 76–81, pp. 150–151.

[16] Bacon himself sometimes referred to it by the title "*De speciebus*" as noted by David Lindberg in his critical edition of this work. Lindberg, *Roger Bacon's Philosophy of Nature,* pp. xxvi–xxvii. Further, as McCluskey points out, Oresme "closely follows the argument of Bacon's *De multiplicatione specierum* – although he fails to mention Bacon by name" in his *Questiones super quatuor libros meteororum,* Bk. III, Q. 12–13. McCluskey, *Nicole Oresme on Light, Color, and the Rainbow,* p. 21. These two questions have many similarities to Oresme's *De visione stellarum* as well.

[17] *De visione stellarum,* in conclusion 6, Bk. II, cap. 1, 142:1–13.

[18] For example, concerning the circumpolar stars observation, Oresme undoubtedly derives it from Roger Bacon's, *De multiplicatione specierum.* Bacon explains that he originally derives it from Ptolemy and Alhacen. Bacon, *De multiplicatione specierum,*

he establishes that any star not over the zenith is seen elsewhere than it truly is. This is the answer to the initial question of the *disputatio*, but Oresme is far from finishing his analysis.

2. *A Number of Highly Original Concepts by Oresme*

Up to this point, Oresme has given a fascinating synthesis of stellar parallax and atmospheric refraction, but relatively little could be called "new," except for determining the distance to a circumpolar comet. Though a separate treatise on atmospheric refraction is certainly a novelty, most of the material to this juncture could be found in Bacon, Witelo, and Alhacen.

But it is in the second half of the *De visione's* second book that Oresme proposes a number of innovative concepts, startling in both their originality and insight. In particular, his responses to the first of two arguments against the Principal Conclusion appear to be unlike anything proposed before.

a. Light travels along a curve through a medium of uniformly varying density. (Book II, 1st Argument Against the Principal Conclusion, 3rd Response)

In Oresme's Third Response to the "1st Argument Against the Principal Conclusion," he makes a major break with his predecessors – it is arguably the most significant passage in the *De visione*. Oresme's innovations are in at least three separable areas: (1) in *optics*, he argues that light travels on a curved path in a medium of uniformly varying density and that refraction does not require a single, specific refracting surface; (2) in *mathematics*, he contends that convergent infinite series may be used to equate infinitely small straight lines with a curve; and (3) in *astronomy*, he asserts that atmospheric refraction occurs along a curved path, as Hooke and Newton later confirmed. Further, he appears to employ his famous graphical technique of the configuration of qualities, as well as the Merton Rule which measures a uniformly difform quality by its middle degree.

ed. by Lindberg, Part II, Ch. 4, lines 39–54, pp. 120–121; Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 15, pp. 251. The experiment is also detailed in Witelo (1572, rpt. 1972), *Perspectiva*, X, secs. 49, pp. 444.

b. Innovations in Optics

b1. Light is bent along a curved path in a single medium of uniformly varying density

b2. Refraction does not require a single, specific refracting surface

In optics, Oresme argues that a light ray will be bent along a curved path when it passes through a single medium of uniformly varying density, and he also argues that a refraction does not require a single, specific refracting surface. (The example he uses, of course, is the increasing rarity of atmospheric air the further it is from the earth.) Now known to be correct, this view of curving light was apparently not put forward again until the time of Robert Hooke and Isaac Newton, 300 years later.[19]

Before Oresme, the authoritative voices in optics, such as Ptolemy, Alhacen, Bacon, and Witelo had all argued that refraction can only occur at the interface of two media of differing densities. That is, refraction only takes place when an oblique rectilinear ray in the first medium encounters a second medium of a different density, and that light bends precisely at the boundary between the media. This type of refraction is quite apparent in light passing, say, from water to air, or air to glass – just the cases that perspectivists such as Ptolemy and Alhacen studied. From this evidence, the perspectivists before Oresme deduced the incorrect (but reasonable) conclusion that if there are no strongly differing media or densities, or no definite interface between two media, then no refraction will occur. They further concluded that no refraction would take place in a single media whose density varies uniformly.[20]

Of earlier authors in optics, only John Pecham had even hinted at the possibility of light travelling along a curve in a single medium of varying density. He notes that it is a "very perplexing question" and that he is more inclined to believe that perhaps light does curve in such a situation.[21] But Pecham carries this idea no further, for in his explanation of atmospheric refraction, where just such a situation occurs, he repeats the standard view that a single refraction takes place at the interface of the sphere of the heavens and the sphere of

[19] See the Astronomy section below.

[20] Ptolemy (1989), *Optics*, ed. Lejeune, Bk. v, secs. 1–2 (= Prop. 78), pp. 223–224; Alhacen (1572, rpt. 1972), *De aspectibus*, vii, ch. 2, sec. 4, p. 235; Bacon, *De multiplicatione specierum*, ed. by Lindberg, Part ii, Ch. 2, lines 48–52, pp. 98–99; Witelo (1572, rpt. 1972), *Perspectiva*, ii, sec. 43.

[21] Pecham, *Perspectiva communis*, Prop. iii.2, pp. 212–213.

fire.[22] Oresme, however, not only posits refraction occurring along a curved path, he gives a qualitative mathematical argument to support his view.

c. Innovations in Mathematics

c1. Rectification of an arc, using an infinite series of line segments

c2. Possible configuration of qualities applied to a physical system

In the area of mathematics, Oresme creatively applies two concepts seen elsewhere in his works: the convergent infinite series and the graphing of a configuration of a quality. However, neither is used rigorously or at the high level of sophistication found in such treatises as his *De configurationibus*, further corroborating that Oresme wrote the *De visione stellarum* at an earlier stage in his career. But there is something curious about how Oresme employs these techniques here. First, through their use, Oresme gropes toward a non-rigorous, qualitative attempt at what is now called the "rectification of curved lines" which will become so important in the infinitesimal calculus of Fermat and others. Second, he applies both of them outside of pure geometry to a physical system.

c1. *Rectification of an arc, using an infinite series of line segments*

The rectification of an arc, that is, using straight lines to determine (or at least approximate) the length of an arc segment, has a very long history and is closely associated with that most famous problem of ancient Greek geometers: the quadrature of the circle. The classic treatment of this problem is found in Archimedes' *Measurement of the Circle*, where he employs the "method of exhaustion" to determine the area of a circle by successively inscribing and circumscribing it with polygons of an ever increasing number of sides. Crudely put, as the number of sides of these two series of polygons increase, they leave less and less area between themselves and the circle and thus converge towards an approximation of it. And since the areas of polygons of a known number of sides can be computed, the area of the circle will fall within the range of the area of the inner and outer polygons, and this range can be made as small as one pleases.[23]

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[22] Pecham, *Perspectiva communis*, Prop. III.13, pp. 224–229.

[23] For beautiful presentations of this proof, see Marshall Clagett's, *Greek Science in Antiquity*, 2nd ed. (Princeton Junction, NJ: Scholar's Bookshelf, 1963, rpt. 1988), app. I, pp. 227–229, and Margaret Baron's, *The Origins of the Infinitesimal Calculus* (New York: Dover, 1969, rpt. 1987), pp. 33–41.

Oresme would certainly have been familiar with this Archimedean method of exhaustion, probably through one of the several Latin translations of Archimedes' *Measurement of the Circle* itself, or at least through the Archimedean-style *Liber de curvis superficiebus* of Johannes de Tinemue. Oresme quotes Johannes' treatise in his *De configurationibus.*[24]

But in rectifying a curve, Oresme, once again, differs from his predecessors. Since Oresme is trying to prove that the path of a ray of light through a uniformly difform medium should follow a curve, he attempts to rectify the curve itself, rather than the area under the curve – delineation rather than quadrature. Oresme uses what we might call a one-dimensional equivalent of the method of exhaustion to rectify a curve. The first approximation of the curve is a single bent line segment (i.e., a single refraction), then two refractions form two bends (and three line segments), then three refractions form three bends, and so on "ad infinitum." The resulting line will be, according to Oresme, "curva absque aliqua rectitudine" – "a curve without any straightness."[25]

But what does this mean? That these infinitesimals, these ever-shrinking line segments multiplying toward infinity, actually *become* a curve, rather than approximating it? Oresme, apparently, has few qualms concerning the possible paradoxes that might arise from this, for he says, "It is clear that in the end [the line] will have neither angularity nor rectilinearity, but it will be a circular line."[26] The paradoxes of Zeno would instantly spring to the mind of any Greek geometer. The only hint of concern Oresme displays is that such an actual infinite might not exist in the physical world, for "it is not necessary for [the number of refractions] to be infinite, but perhaps the whole is naturally possible."[27]

[24] See Marshall Clagett's, *Archimedes in the Middle Ages,* Vol. 1: *The Arabo-Latin Tradition,* Publications in Medieval Science (Madison: University of Wisconsin Press, 1964), vol. 1, pp. 4–5, 445–522; and Oresme's *De configurationibus qualitatum et motuum* in Clagett, *Nicole Oresme and the Medieval Geometry of Qualities and Motions,* Part I, Ch. xxi, lines, 35–36, pp. 222–223.

[25] *De visione stellarum,* Bk. II, cap. 2, 160:3.

[26] *De visione stellarum,* Bk. II, cap. 2, 160:6: "… patet quod in fine non erit angulus nec etiam rectitudo, sed erit linea circularis."

[27] *De visione stellarum,* Bk. II, cap. 2, 158:15 – 160:1: "Quam non oportet propter hoc esse infinitam, sed forte totum est possibile naturaliter."

C2. *Possible Configuration of Qualities Applied to a Physical System*

At one point in his discussion, Oresme appears to apply the now famous Merton Rule, but in reverse. In modern history of science, the Merton Rule is most closely associated with kinematics and sometimes referred to as the "mean speed theorem," but it was originally formulated to apply to a much larger spectrum of phenomena.[28] In kinematic terms, the Merton Rule can be explained in this way. Imagine two bodies: one starts from a state of rest and undergoes uniform acceleration, the other travels at a constant velocity with no acceleration. What constant speed does the second body need so that, over the same amount of time, both will travel the same distance? The Merton school found the answer: if the second body has a constant velocity exactly one-half the final velocity (the "mean speed") of the accelerating body, both will travel an equal distance over an equal time.

This becomes far more intuitive for those who have seen the graphing of the Merton Mean Speed Rule by Oresme or Galileo.[29] (Cf. Figure A) In this diagram, the uniformly accelerating velocity over a certain time is represented by a right triangle ABC (the lower corner at speed zero (B), the upper corner its final velocity (C)). In the same diagram a uniform velocity over a certain period of time is represented by a rectangle ABGF. To have the distances traveled the same, the two areas of the figures must be the same. Therefore, the size of the rectangle ABGF (i.e., uniform velocity) is chosen so that when it is superimposed on the triangle ABC, it cuts the hypotenuse of the triangle at point E, exactly in the middle – which is the middle, or mean speed of the accelerating body. Thus the Merton Rule states that the distance traveled by a body uniformly accelerated from rest over a given period of time is equal to the distance traveled by a body whose uniform velocity is one-half the final velocity of the accelerated body.

What is important about all of this for our discussion is that the Merton Rule was not merely applied to motion, it was applied to *all* changes of qualities – for in Aristotelian terms, local motion

[28] For the kinematic application, see Clagett's, *Science of Mechanics in the Middle Ages*, especially ch. 4–6.

[29] The diagram in figure A follows Oresme's graph found in his *On the Configurations of Qualities*, see Marshall Clagett's *The Science of Mechanics in the Middle Ages* (Madison: University of Wisconsin Press, 1959), p. 358, fig. 6.5; for Galileo's similar diagram in *The Two New Sciences*, see Claggett, *Science of Mechanics*, p. 409, fig. 6.13.

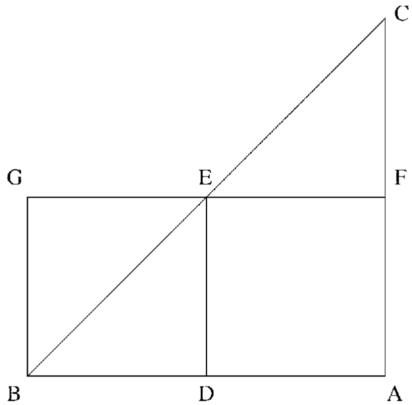

Figure A. Merton Mean Speed Rule As Graphed by Oresme

is just one such quality. These qualities could be anything from changes in sound or color to changes in the levels of fear or happiness. Of course, applying the term "acceleration" in such situations as "the uniform acceleration of the color from green to red" sounds a bit odd. That is why I will, for the most part, use the original Latin term "difform" instead of "accelerated." Once we realize how medieval scholars applied the Merton Rule to such a wide variety of qualities, we can see more easily how Oresme applied the Merton Rule to the changing density of the atmosphere – but in reverse.

Instead of beginning with a uniformly difform quality and then finding the mean uniform quality that would be the equivalent, Oresme does the opposite; he starts with a uniform quality and ends with an equivalent uniformly difform quality. And that quality is atmospheric density. Oresme concludes that the density of a uniform medium is equivalent to the mean density of a uniformly difform medium of the same substance.

Now imagine the same diagram above used to describe a different quality – air density. [Figure A] In this diagram, the rectangle ABGF represents the quality of uniformly dense air, and the right triangle ABC represents the quality of air that is becoming rarified at a uniform rate, that is, the increasing rarity of uniformly difform air. Since the area of the rectangle and the right triangle are equivalent, the two have an equal mean rarity.

Oresme states, "If the whole [atmosphere], aggregated out of air and water, were made uniformly difform with such a density as it now has, then [it] would be equivalent to the original densi-

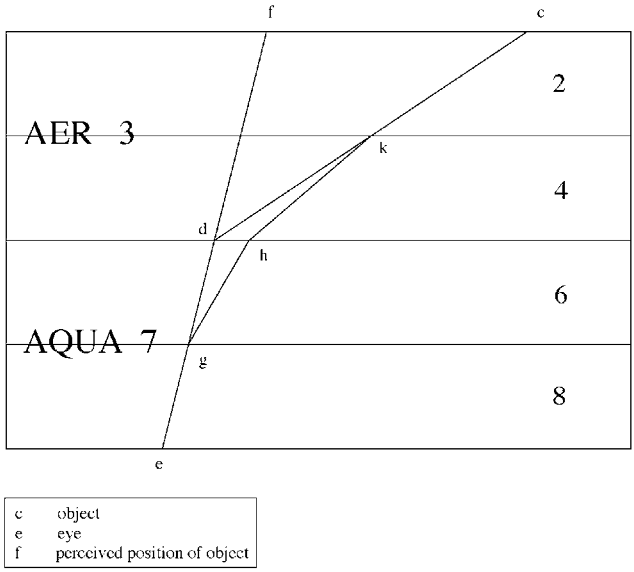

Figure B. Multiple Refractions Along a Curve Through Air and Water; and Through a Uniformly Changing Medium

ty."[30] He then proceeds with a quantitative example in the following paragraph.[31]

Notice, however, that while Oresme seems to *describe* a "reverse Merton Rule" he does not attempt to use his configuration doctrine to graph the rate of change of the atmosphere, which we might expect in one of his more mature works. If displayed in graphical form, the rate of change of this uniformly difform atmosphere would be seen as a sloping straight line, just as we see Oresme describe uniformly difform speed in some of his other writings. [Cf. Figure A] That does not occur here.

The illustration accompanying this portion of the text can be quite confusing. [Figure B][32] For what we moderns would show in several successive illustrations, Oresme combines into one – not unlike a teacher who continually changes an illustration on a chalk-

[30] *De visione stellarum,* Bk. II, cap. 2, 156:6–8: "Item, si totum aggregatum ex aere et aqua fieret uniformiter difforme tanta densitate quantam nunc habet, tunc equivaleret prime densitati."

[31] This is described below. See *De visione stellarum,* Bk. II, cap. 2, 156:6 – 160:8.

[32] This is Figure 18 in the *De visione* text.

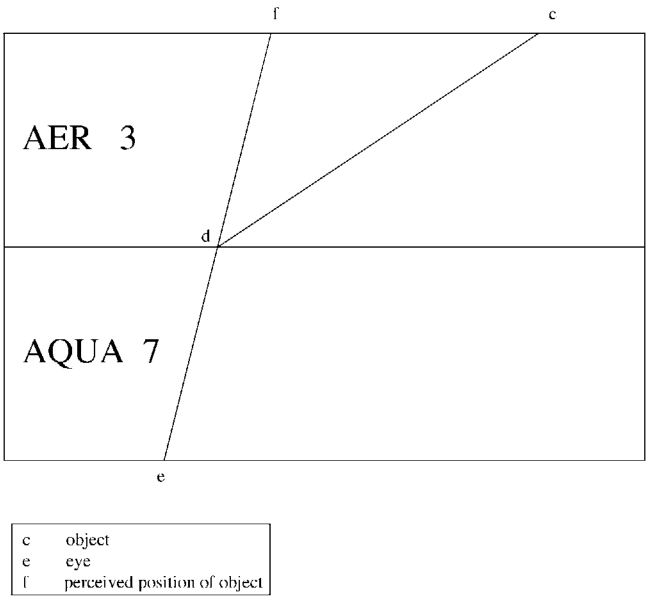

Figure C. Single Refraction Through
Air and Water (First Part of Figure B)

board.[33] First Oresme shows two different mediums (air and water) each of uniform density. [For clarity, see Figure C] Then, on the same illustration (i.e., Figure B), he shows these mediums becoming increasingly uniformly difform, until finally, the two mediums are equivalent to one uniformly difform medium. [Cf. Figure D] Oresme then proceeds to discuss a *single* uniformly difform medium, yet he still appeals to the same figure, using the same letter designations for eye and object.

On an initial reading, the approximation of a curve *ckhge* in this illustration [Figure B] describes the path of a light ray passing through a uniformly difform medium from right to left over a certain distance – and that is correct. Yet for Oresme it may be more. While Oresme does not use the term, the illustration may be seen as the configuration of a quality, since the curve in the illustration not only describes the path of the light ray from right to left over distance, but also over time. That is, this illustration may be seen as a crude graphing technique.

[33] This sometimes occurs in other medieval illustrations, such as the "five-armed" vassal who is shown doing his entire homage ceremony at once.

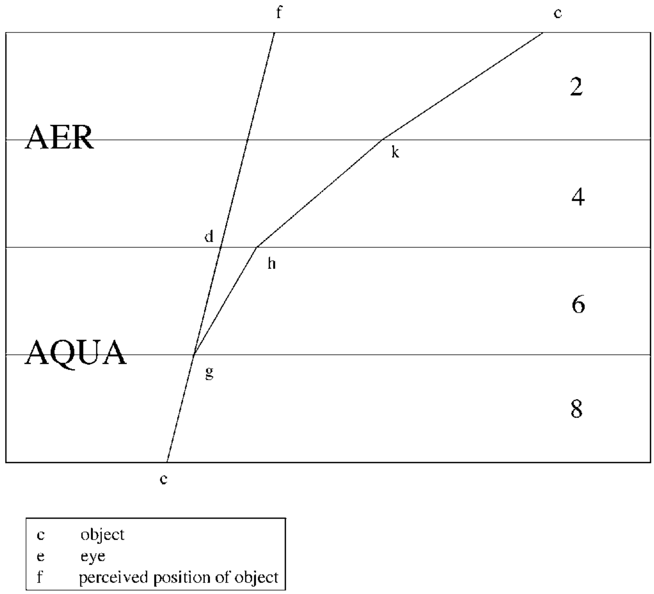

Figure D. Multiple Refractions Along a "Curve"
Through Air and Water (Second Part of Figure B)

Oresme describes the refractions in his example happening over the space of an hour. The first refraction takes place in the first half hour, the second refraction in the first half of the second half hour, then four refractions, then eight, and so on.[34] As the medium becomes increasingly dense, the number of refractions increase to infinity over the remaining proportional parts of an hour. Said in another way, by the 1/2 hour mark, 1 refraction occurs, in 3/4 hour, 2 refractions, in 7/8 hour, 4 refractions, in 15/16 hour, 8 refractions, and so on. And expressed in modern terms: the ratio of $\frac{2^{n-1}-1}{2^{n-1}}$ parts of an hour that have passed, yield $\frac{2^{n-1}}{2}$ total refractions, where $n = 2 \rightarrow \infty$ [n being positive integers, from 2 to infinity]

Therefore, the illustration may be seen as a graphic representation of the number of refractions over time. But, first, we need to orient ourselves to its axes. The zero point is at *c*, time increases horizontally from right to left, while the number of refractions increase vertically down. And because of the uniform change of density in the atmosphere, which also increases vertically down, a curved line is

[34] See *De visione stellarum*, Bk. II, cap. 2, 156:13 – 160:8.

produced. But not just any curve, this is an exponential curve which approaches infinity as time approaches 1.

Since Oresme does not mention the configuration of qualities explicitly, nor use his configuration doctrine to display the Merton Rule above, it may be tentatively argued that the *De visione stellarum* dates from before Oresme's more mature works on these subjects, such as the *De configurationibus.* Certainly it would be surprising if Oresme had already made his configuration doctrine public and then not used it here. Nevertheless, arguing from such negative evidence is always uncertain.

There may also be another possibility. Oresme may not have wanted to give an explicit configuration of the rate of change *over time* for the path of the light ray, since in the following paragraphs he expresses concern over whether it takes any time at all for a light ray to "travel" from source to eye. There may be no "speed of light" at all. Clearly, if the effect of light is "instantaneous," and light has no "speed," then an explicit graph of configuration over time would be inappropriate. Further, it might hinder the force of his argument for curvilinear refraction itself through the atmosphere. And this is where his scientific insight excelled.

d. Innovation in Astronomy

d1. *Atmospheric Refraction Occurs Along a Curve*

Using this optical and mathematical evidence, Oresme proposed that starlight travels along a curve through the atmosphere. (Except, of course, for starlight that was not obliquely incident, such as light entering the atmosphere from directly overhead.)[35] As noted above, Alhacen and other perspectivists believed that refraction occurs only at the interface of two media of differing densities, and not within a single medium. Since Oresme believed that refraction *could* occur in a single medium of varying density, and that the atmosphere was such a medium, then light would refract in it along a curve. This realization has fundamental significance for both observational astronomy and meteorological optics, as the very title of Oresme's treatise suggests.

Of course, earlier astronomers such as Ptolemy had believed that some type of refraction occurred in the atmosphere and that it was most pronounced at the horizon. Indeed, some ancient Greeks

[35] *De visione stellarum,* Bk. II, cap. 2, 154:6 – 164:13.

knew that its effect was so significant that when the sun appears to be sitting on the horizon at sunrise, it is actually still *below* the horizon. This is how the ancient Greek Cleomedes (and possibly Hipparchus) explained the following problem. A lunar eclipse was known to be caused by the earth's shadow cast across the moon, and only occurred when the earth was directly between the moon and the sun. From our middling position on earth, either the moon or the sun should be visible, but not both. But sometimes during a lunar eclipse both the moon *and* the sun were observed to be *above* the horizon, thus Cleomedes concluded some form of atmospheric refraction was responsible.[36]

But given the optical theories of Ptolemy, Alhacen, and the Latin perspectivists, only one major refraction could take place between the heavens and the earth. Why? They concluded that there was only one interface between two media of varying densities in the heavens: the upper boundary of the sphere of fire.[37]

Nonetheless, when Ibn Mu'adh (whom Oresme cites as Alhacen)[38] attempted to determine the height of the atmosphere, he did not even take atmospheric refraction into account.[39] When Kepler endeavored to determine the height of the atmosphere, he employed refraction, but only a single refraction at the upper surface of the atmosphere, just as Ptolemy, Alhacen, and the rest had assumed.[40] As late as 1656, the astronomer Cassini had applied Snell's law to atmo-

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[36] See Moris R. Cohen and I.E. Drabkin's, *Source Book in Greek Science*, (Harvard: Harvard Univ. Press, 1948), pp. 284–285. This insight appears to have been *independently* rediscovered by Oresme. See discussion below.

[37] Ptolemy (1989), *Optics, ed. Lejeune*, Bk. v, secs. 23–30 (= Prop. 84–86), pp. 237–242; Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 51, p. 278; Bacon, *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 12–14, pp. 118–119; Pecham, *Perspectiva communis*, Prop. III.13, pp. 224–229; Witelo (1572, rpt. 1972), *Perspectiva*, x, secs. 54, pp. 448–449.

[38] *De visione stellarum*, conclusion 5, Bk. II, cap. 1, 136:21 – 140:6.

[39] A. Mark Smith, "The Latin Version of Ibn Mu'adh's Treatise 'On Twilight and the Rising of the Clouds.'" *Arabic Sciences and Philosophy: A Historical Journal* 2 (1992): In Smith (1992), p. 115, lines 414–416 (Latin), and p. 131 (English).

[40] Johannes Kepler's *Paralipomena in Vitellionem*, in *Gesammelte Werke*, herausgegeben im auftrag der Deutschen Forschungsgemeinschaft und der Bayerischen Akademie der Wissenschaften, unter der Leitung von Walther Von Dyck und Max Caspar, Vol. 2: *Astronomiae pars optica*, herausgegeben von Franz Hammer (Munich: C.H. Beck'sche Verlagsbuchhandlung, 1939), pp. 76–143. Also see Kepler's epitome of Copernican astronomy, in *Gesammelte Werke*, Vol. 7: *Epitome astronomiae Copernicanae*, herausgegeben von Max Caspar (Munich: C.H. Beck'sche Verlagsbuchhandlung, 1953), pp. 56–69, 195–198. For a good overview, see Bernard R. Goldstein's, "Refraction, Twilight, and the Height of the Atmosphere," *Vistas in Astronomy* 20 (1976): pp. 105–107.

spheric refraction, but he likewise relied upon this single refraction view held by Alhacen and Kepler and thus did not postulate a curved ray.[41] It is only with Descartes and Hooke that the possibility of curved light rays are suggested. And until now, historians have considered them to be the first to do so.

Descartes does no more than suggest curved light rays in a very general sense, and not in the context of atmospheric refraction. Nor does he carry the idea any further.[42] Robert Hooke, on the other hand, gives a marvelous and detailed argument for curved light rays in an unlikely place, his *Micrographia*. Hooke demonstrates through several ingenious experiments that light does indeed travel along a curved path through a single media of varying density.[43] There is no evidence, nor reason to assume, that Hooke had ever read Oresme's *De visione stellarum*; nevertheless, he arrives at strikingly similar conclusions.

Like Oresme, Hooke argues that such curved rays are caused by "*inflection*, or *multiplicate refraction* of those Rays of light within the body of the *Atmosphere*, and that it does not proceed from a *refraction* caus'd by any terminating *superficies* of the Air above, nor from any such exactly defined *superificies* within the body of the *Atmosphere*." [his emphases].[44] Then, taking the curvature of light into account, Hooke proposes the height of the atmosphere to be about three or four miles.[45]

Following Hooke (though he never says as much), Newton also believed that light would continuously refract along a curve through a medium whose density decreases uniformly. That is, light passing through the atmosphere follows a curved path. Because of its key importance to precise astronomical observation, Newton and Flamsteed spent much of the years 1694–1695 on this question of atmospheric refraction, as their frequent correspondence reveals. Newton proposed several solutions to the problem, finally arguing in

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41 See A.I. Mahan's, "Astronomical Refraction: Some History and Theories" *Applied Optics* 1 (1962): 497–501.

42 See René Descartes' *La Dioptrique – Discours II*, in his *Oeuvres de Descartes*, publiés par Charles Adam & Paul Tannery, Vol. 6: *Discours de la Methode & Essais*, Nouv. Prés. (Paris: J. Vrin, 1965), pp. 103–105.

43 Robert Hooke, *Micrographia, or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries Thereupon* (London: Jo. Martyn and Ja. Allestry, Printers to the Royal Society, 1665; reprint ed., New York: Dover Publications, 1961), pp. 217–240.

44 Hooke, *Micrographia*, p. 219.

45 Hooke, *Micrographia*, p. 236.

a precise, mathematical way that light is indeed refracted through the atmosphere along a continuous curve. He then provided Flamsteed with a table of atmospheric refraction, based on observational data.[46]

Even today, nearly all theories of atmospheric refraction are based upon postulating thin concentric layers of atmospheric air around the earth – like the layering of an onion – with each of the stratified layers being infinitely thin and refracting light. This is exactly the concept first proposed by Oresme, and later formulated again by Hooke and Newton. So, while the definitive demonstration of the curvature of light in the atmosphere was Hooke's and Newton's, the original argument for such curvature was Oresme's.

It should also be noted that the *mathematical* problem of light curving through the atmosphere set forth by Oresme, along with his attempt to solve it using infinitesimals, also has close parallels in the history of the literature. Attempts to resolve the "refraction integral", that is, to mathematically determine the curvature of light through the atmosphere using the concentric sphere model, was attempted by some of the great minds of the 18th and 19th centuries, including Bessel, Euler, and Laplace.[47]

Unlike Hooke and Newton, however, Oresme's argument is qualitative, hypothetical and philosophical. Rather than doing actual experiments, Oresme preferred thought experiments "according to the imagination." Hooke, for example, conducted experiments by adding fresh water to salt water in a glass tank to create a single medium of varying density. He carefully observed that the path of sunlight through this mixture was along a curve. He then used the argument from analogy that "this is just like that." By analogy, he

[46] The large majority of letters from 7 Sept. 1694 through 9 July 1695 (no. 470–520) are between Newton and Flamsteed, and concern atmospheric refraction. See Isaac Newton, *The Correspondence of Isaac Newton*, vol. 4, edited by J.F. Scott (Cambridge: Cambridge University Press, 1959–1977), vol. 4, pp. 12–144, no. 470–520. The key illustration of light curving through the atmosphere is on p. 61; for Newton's table of atmospheric refraction, see p. 95.

[47] For the refraction integral and the Concentric Spherical Shell Model, see Mahan's, "Astronomical Refraction: Some History and Theories" *Applied Optics* 1 (1962): 497–501. Mahan's article excels in many ways, though it has a surprising flaw, he barely notes Newton and does not so much as mention Hooke. For modern theories since the Scientific Revolution, see: Frans Bruin's, "Atmospheric Refraction and Extinction Near the Horizon," *Archive for History of Exact Sciences* 25 (1981):1–17; R.A.R. Tricker's, *Introduction to Meteorological Optics* (New York: American Elsevier Publishing, 1970), pp. 11–23; and Robin Green's, *Spherical Astronomy* (Cambridge: Cambridge Univ. Press, 1985), pp. 82–95.

purported that light passing through a medium of increasing density in a glass tank is just like when light passes through the increasing density of the atmosphere.[48]

On the other hand, it is uncertain whether Oresme would have accepted such active, "experimental" evidence, since it would be contrary to the normal course of nature, that is, contrary to the natural conditions of atmospheric refraction. As Dr. Bert Hansen has noted, most scholastics such as Oresme were more likely to subscribe to an Aristotelian "passive empiricism," in which observation of natural phenomena, in natural conditions was more likely to yield knowledge.[49] Experiments such as those of Hooke might be viewed as "preternatural" – that is, neither natural nor supernatural.

It is perfectly obvious, even to us, that the levitation of a table is unnatural or preternatural – outside of nature's common course. What is less obvious is that Oresme and other scholastics would also regard the throwing of a stone as preternatural, because the thrown stone is in "violent motion," travelling contrary to its nature. Hansen implies that medieval natural philosophers might view preternatural experimentation with some suspicion. Throwing rocks might not be the best way to understand the nature of naturally falling bodies. A 14th-century natural philosopher might find Hooke's preternatural experiments interesting, but they would not be as reliable as natural observation, and certainly not as reliable as reasoned argument.

Of course, we don't know why Oresme did not suggest doing Hooke-style experiments on mediums of varying density. He may simply not have thought of them. But I would suggest, at least as a possibility, that this concern about preternatural experiments might be one of the reasons. Indeed, this might be why Oresme opts for either natural observation or reasoned argument when he states: "And since, in such a case [of uniformly difform atmospheric density], it cannot be *experienced* if there is a refraction or not, authorities say there is no [refraction] by [their] authority alone. Therefore, there is another *argument* to demonstrate [that there is refraction along a curve]."[50] Oresme might view reliance upon

[48] Hooke, *Micrographia*, pp. 219–236, esp. pp. 220–221 and plate 37, fig. 1.

[49] See Bert Hansen's, "The Complementarity of Science and Magic before the Scientific Revolution," *American Scientist* 74 (March – April 1986): 128–136; see also Hansen's, *Nicole Oresme and the Marvels of Nature*, pp. 62–64, and his "Science and Magic," in *Science in the Middle Ages*, ed. by David Lindberg (Chicago: University of Chicago, 1978), pp. 495–498.

[50] My emphasis. *De visione stellarum*, Response 3, Bk. II, cap. 2, 156:13–15: "Et quia

philosophical reasoning and mathematics to be far more solid than any argument from analogy based on "preternatural" experiments, as Hooke's would be during the Scientific Revolution.[51]

3. *Is There a "Speed" of Light?: Atmospheric Refraction Applied to the Question (Book II, 1st Argument Against the Principal Conclusion, 3rd Response)*

In this same Third Response, Oresme applies atmospheric refraction to the question of the propagation of light – is it instantaneous, or does it take some finite time. That is, is there a "speed" of light? Compared to his previous arguments, however, Oresme seems a bit muddled. He asks us to once again imagine an object *c* [such as a star, perhaps?] whose ray curves through a difform medium to our sight at *e*. [Cf. Figure 18] "In the end" the object will appear to be in the place *f* along a rectilinear line. But where will it appear "during the entire hour" until the ray arrives?[52] Oresme's answer is a bit unclear, but he appears to imply that the object's position will either be seen to gradually shift along the curved ray he proposes, or it will suddenly jump from one position to another. This involves whether the speed of light is understood to be instantaneous or to have some finite speed.

According to Lindberg, the problem of whether light has a "speed" was a vexing one for fourteenth century scholars. This was for at least two reasons. First, their ancient authorities disagreed and gave valid arguments for both points of view. Second, there was no means to gain more empirical data to resolve the dilemma.[53]

Aristotle and most who followed him, including Galen and Averroes, believed that light was a quality that a medium acquired

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non potest experiri si in tali casu est fractio aut non, sed auctores dicunt quod non sola auctoritate. Ideo adhuc probatur quod sit alia ratione."

[51] On the other hand, Oresme does, on occasion, use arguments from analogy based on terrestrial experiments. For example, see his experiment of the sun shining through a water-filled vessel placed in a flat field. He draws upon it as analogous to a star shining through the atmosphere. But even this could merely be a thought experiment. *De visione stellarum,* Bk. II, cap. 2, lines 172:4–7.

[52] "Sequitur ergo aut quod *c* videbitur in medio difformi per lineam curvam quod est propositum, aut quod in tota hora videbitur in *f* loco propter fractiones, et in fine subito videbitur ubi est per lineam rectam et apparebit subito mutari. Et idem sequitur si ponatur primo quod *c* sit oculus in aere, et *e* sit res visa." *De visione stellarum,* Bk. II, cap. 2, lines 160:9–13.

[53] David C. Lindberg, "Medieval Latin Theories of the Speed of Light," In *Roemer et la vitesse de la lumière* (Paris: Vrin, 1978), pp. 45–72.

all at once, and therefore there was no "speed" of light, since this acquisition was instantaneous. Alhacen, however, was an exception; he believed that light traveled at a finite, though imperceptible, speed.[54] Bacon followed Alhacen in arguing that light has a finite speed, while Pecham seems to have held the opposite.[55] Thus the medieval perspectivists were split on the issue.

What was Oresme's position? In an excellent article on this question, Peter Marshall explicates Oresme's view as found in his commentary on the *De anima.* According to Marshall, Oresme opted in that work to support the Aristotelian position that light propagated instantaneously.[56] But Oresme may not have always held this position, for he appears to support Alhacen's opinion that light has a finite speed in a passage in the *De visione* concerning apertures.

After describing an experiment in which light passes through an aperture (explained more fully below), Oresme approvingly cites Alhacen's, *De aspectibus,* Book II, "where he proves such changes [as light travelling over a distance] cannot occur instantaneously."[57] Oresme is probably referring to Alhacen's curious aperture arguments for a finite speed of light. Alhacen sets forward the following thought experiments. Assume that light falls on a covered aperture, and then the aperture is uncovered: the light enters the aperture, passes through the intervening darkened air, and falls upon an object. So, either the intervening air receives the light one part after another or all at once. Either way will take time, Alhacen says, therefore there is a finite speed of light.[58]

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[54] See A.I. Sabra, *Theories of Light from Descartes to Newton,* New ed. (Cambridge: Cambridge University Press, 1981), pp. 46–48; Alhacen (1572, rpt. 1972), *De aspectibus,* II, ch. 2, sec. 21, p. 37.

[55] Bacon, *De multiplicatione specierum,* ed. by Lindberg, Part IV, Ch. 3, pp. 220–227; Pecham, *Perspectiva communis,* Props. I.53{56}, pp. 134–135.

[56] Peter Marshall, "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 368–374.

[57] "… et contra intentionem Alhacen in 2°, ubi probat tales mutationes non posse fieri subito." *De visione stellarum,* Bk. II, cap. 2, 160:17–18.

[58] Alhacen (1572, rpt. 1972), *De aspectibus,* II, ch. 2, sec. 21, pp. 37–38, and sec. 51, p. 61. For an English translation, see Alhacen, *The Optics of Ibn Al-Haytham. Books I–III, On direct vision,* translation with introduction and commentary by A.I. Sabra (London: The Warburg Institute, University of London, 1989), Book II, 3, para. 60–66, and 184, vol. 1, pp. 146–148, and 195.For the substantial literature concerning the effect of an aperture or a smaller "pin-hole" on light and images, see David C. Lindberg's, "The Theory of Pinhole Images From Antiquity to the Thirteenth Century," *Archive for History of Exact Sciences* 5 (1968): 154–176; and his "The Theory of Pinhole Images in the 14th Century," *Archive for History of Exact Sciences* 6 (1970): 299–325; and Lindberg and Geoffrey Cantor's, *The Discourse of Light from the*

Of course all this begs the question, since Alhacen is assuming what he sets out to prove. For if the air receiving the light "all at once" *takes time*, then, yes, it takes time for the light to do this "all at once" – a finite speed.

Alhacen also stacks the deck in his next thought experiment. He asks us to imagine the same aperture again, but this time, the screen over the aperture reveals first one part of the aperture, then the other. Since the aperture is exposed through motion, and motion takes time, the light will enter the air in a continuous, non-instantaneous fashion. Alhacen says, "For light will not occur anywhere in the air inside the covered aperture unless something of the aperture is exposed to the light; but nothing of the aperture can be exposed in less than one instant; and an instant is not divisible; therefore, no light will occur inside the aperture at the instant of exposing that which was exposed of the aperture."[59] Consciously or unconsciously, Alhacen has linked the finite speed of exposing the aperture to the "speed" at which the light propagates beyond the aperture. This again appears to assume the finite speed of light to prove it.

Oresme's argument is a twist on that of Alhacen's – and possibly as shaky. In his aperture experiment, Oresme asks us to assume that light from a stationary object[60] at *c* shines through an aperture at *e* for some period of time (an hour), then, because of the curved refraction of a difform medium, the object will appear to suddenly jump to another position *f* at the end of that hour.[61] [Cf. Illustration 18] So also, the shadow cast by the aperture would jump as well. This seems improbable to Oresme, so he throws his support towards Alhacen's finite speed of light.[62]

The difficulties with this argument are what Oresme leaves unsaid. First, if the curved refractions take some period of time (say an hour), then it is *assumed* that light is propagating at a finite speed. Second, Oresme asks us to assume that, at the beginning of that time period, the light is "illuminating through an aperture at *e*." This could only mean that, somehow, the light has already made its way,

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Middle Ages to the Enlightenment: Papers read at a Clark Library Seminar, 24 April 1982 (Los Angeles: William Andrews Clark Memorial Library, University of California, 1985).

59 Sabra's translation, in Alhacen, *The Optics of Ibn Al-Haytham. Books I–III, On direct vision*, pp. 146–147.

60 Such as a star perhaps? He specifically applies it to celestial objects later.

61 Oresme does not specifically say "atmosphere" at this point, but merely assumes a difform medium of some type.

62 *De visione stellarum*, Bk. II, cap. 2, 160:14–18.

unrefracted, to the aperture, and then later, *is refracted* by the difform medium, causing the shift in position. Obviously, an observer at *e* can only see the light through the medium, and should not be able to see the object at its original, true position (*c*) at all.

This all could be an excellent thought experiment, but only if one assumed that, at first, there was *no* intervening medium or atmosphere, and then, perhaps by God's omnipotent power, the atmosphere suddenly appeared between the object and the aperture. But problems occur. For then, it seems, there either *would* be an instantaneous jump in the object's apparent position, or (assuming as Oresme does that the atmospheric refractions take time) the object at *c* would disappear and then reappear at *f* at some later time. But Oresme neither makes such initial conditions, nor would this experiment fit his conclusions.

As noted above, Oresme leans toward supporting the concept of a non-instantaneous propagation of light set forth by Alhacen and Bacon. But Oresme in his *De anima* supports the opposite, that light is propagated instantaneously and there is no "speed of light."[63] If Oresme wrote the *De anima* after the *De visione*, then perhaps he saw some of the logical difficulties in both Alhacen's and his own arguments here and decided to revise them. But such speculation is only that. For, first, there is no way of knowing which is the "more mature" view: Aristotle's instantaneous propagation (wisely argued but incorrect), or Alhacen's and the *De visione's* finite speed of light (fallaciously argued but ultimately correct). Second, like Blasius of Parma after him, Oresme might have wavered between both incongruous views, varying his support according to context.[64]

4. *Six corollaries that may be discovered experimentally. (Bk. II, Corollaries 1–6)*

Oresme postulates a second argument against his own principal conclusion, but calls it a mere quibble (*cavillari*). This second argument concedes that perhaps there is a refraction at the surface of the heavens and fire. But if the higher air is colder than the lower air, then perhaps it is denser than the lower air as well. If this were the case, then perhaps a second refraction (between upper and lower air)

[63] See Peter Marshall, "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 368–374.

[64] For Blasius of Parma's vacillation, see Lindberg, "Medieval Latin Theories of the Speed of Light," pp. 61–66.

could exactly counteract the effects of the first refraction (between the heavens and fire). In this way, the stars *could* appear where they seem to be, *contra* the principal conclusion.[65] Oresme dispenses with this *ad hoc* argument in a few paragraphs and moves on to his corollaries.[66]

Since the principal conclusion that "any star not seen over the zenith is seen elsewhere than it truly is" has now been proven to Oresme's satisfaction, he postulates two sets of corollaries from this conclusion. The first set of six corollaries are those which can be discovered "experimentally" through observation, for at the end of the set he concludes: "If, therefore, one can experimentally discover any of these six corollaries through observations and instruments, any of them whatsoever may be boldly affirmed by the three final conclusions and their proofs."[67]

The first four corollaries are variations on a common theme: because of atmospheric refraction, all celestial objects *appear* above the horizon longer than they are in actuality. This has interesting repercussions for astronomy (and astrology). For example, in corollary 2, Oresme notes that the equinoxes (i.e., those days calculated to have equal daylight and darkness) do not actually have equal times of day and night due to atmospheric refraction. Further, in corollaries 3 and 4, celestial bodies that are actually in opposition, will not appear to be in opposition – sometimes by substantial amounts.

The most spectacular and easily observable celestial opposition is that of the sun and moon during a lunar eclipse. A lunar eclipse, of course, is caused by the earth being placed directly between the sun and the moon, thus blocking the sunlight and casting a shadow over the moon. Since they are in nearly 180 degree opposition during such an eclipse, any observer on the earth should only see the moon or the sun, not both. But Oresme quotes a paradoxical astronomical observation found in Pliny: "Seeing that the shadow causing an eclipse ought to be *below* the earth after sunrise, [Hipparchus also discovered] for what exact reason that it happened, on one occasion,

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[65] *De visione stellarum*, Bk. II, cap. 2, 164:14 – 166:3.

[66] *De visione stellarum*, Bk. II, cap. 2, 166:11 – 170:15.

[67] In Latin: "Si ergo per observationes et instrumenta possit aliquod istorum 6ª corollariorum experimentaliter deprehendi audacter affirmetur quodlibet aliorum cum tribus conclusionibus ultimis et probationibus earumdem." *De visione stellarum*, Bk. II, cap. 2, lines 180:7–11. The "three final conclusions and their proofs" refers to the fifth, sixth and seventh conclusions. *De visione stellarum*, Bk. II, cap. 1, 136:21 – 148:19. See also Oresme's "Response to the Second Argument" above. *De visione stellarum*, Bk. II, cap. 2, 166:11 – 170:15.

that the moon was eclipsed [in the west] while both the sun and moon were visible *above* the earth ..."[68] And though Oresme notes that this might have been possible without atmospheric refraction, the obvious implication from the entire passage is that he believes this to be the solution.

Incredibly, Oresme appears to have independently rediscovered the probable solution to this paradoxical observation. As noted above, the Greek Stoic Cleomedes was apparently the first to propose a solution that ultimately proved correct. He postulated that it was atmospheric refraction that caused both sun and moon to appear above the horizon during a lunar eclipse. Thus Cleomedes was the first to give a fairly accurate, qualitative account of this strange effect of atmospheric refraction.[69]

But the works of Cleomedes were not available in Latin until the Renaissance, nor was this idea found in any of the major sources accessible to Oresme, such as Ptolemy's *Optics*.[70] The only source that even mentioned such a phenomenon was Pliny (see quote above), and he gave no solution to the problem, merely saying that Hipparchos had done so. So, remarkably, it appears that Oresme literally reinvented this explanation himself. If so, he was the first since the ancient world to do so.

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[68] My emphasis; I have also supplied the name of Hipparchus as found in Pliny. Pliny, the Elder (1938), *Natural History*, tr. by H. Rackham (Loeb Classical Library), Bk. II, x, 57; vol. 1, pp. 206–207.

[69] For Cleomedes' account in English see: Cohen & Drabkin, *Source Book in Greek Science*, pp. 284–285; a portion of this account, with the original Greek, is found in Ivor Thomas' *Selections Illustrating the History of Greek Mathematics*, Loeb Classical Library (Cambridge, Mass.: Harvard University Press, 1951), vol. 2, pp. 396–401. Robert Todd has created a modern edition of the entire Greek text, though I have not had the opportunity to view it: Cleomedes, *Cleomedis Caelestia (Meteora)*, (Leipzig: Teubner, 1990). The Greek text along with the renaissance Latin translation may be found in the Landmarks of Science microcard series: In Proclus, *Procli De sphaera liber; Cleomedis De mundo, sive Circularis inspectionis meteororum libri duo*, Landmarks of Science (Basileae: Per H. Petri, 1547, reprint 1975), Bk. II, ch. 6.

[70] Sarton notes that Cleomedes book was not available to Arabic and Latin astronomers in the Middle Ages. George Sarton, *A History of Science: Hellenistic Science and Culture in the Last Three Centuries B.C.* (Cambridge, Mass.: Harvard University Press, 1959), pp. 304–305. On Cleomedes himself, see the following: D.R. Dicks', "Cleomedes," In *Dictionary of Scientific Biography* (New York: Charles Scribner's Sons, 1970–1980), v. 3, pp. 318–320; William Stahl, *Roman Science: Origins, Development, and Influence to the Later Middle Ages* (Madison: University of Wisconsin Press, 1962), pp. 53–54; and Thomas Heath's, *Greek Astronomy* (New York: AMS Press, 1932, reprint 1969), pp. 162–166.

A simplified and partial version of this assertion is also found in Oresme's *Questiones super quatuor libros meteororum*, where he states the following, *without* supporting evidence: "Tenth, I infer that it is possible for the sun or a star to appear above our horizon when it is [actually] still below the horizon, and this would be because of the reflection of sunlight or starlight from the intervening vapors."[71] Not only is this a strong link between Oresme's *De visione* and his *Meteora* commentary, but it also makes it likely that the *De visione* (or the argument formulated in it) was written prior to the *Meteora*.

This type of lunar eclipse is obviously not a common event, which may be why Oresme was a bit tentative concerning it. Even today, the very capable Frans Bruin deems the observation of both the sun and moon above the horizon during a lunar eclipse to be impossible. Cohen and Drabkin, however, note that such an eclipse was actually observed on Nov. 7, 1938 in the vicinity of New York.[72]

In the final two corollaries of this set (5 and 6), Oresme explains that the regular, circular motion of the fixed stars will not appear to be so. Atmospheric refraction will not only cause the regular motion of the fixed stars to appear irregular (corollary 5), but it will also cause the circles described by the circumpolar stars to appear, not as perfect circles, but as oblique and oblong (corollary 6).[73]

5. *Sixteen corollaries that are logical conclusions of the above (Bk. II, Corollaries I–XVI)*[74]

From the conclusions and corollaries drawn so far, Oresme spins out sixteen further corollaries that he calls "logical conclusions … not antecedents, since they are not able to be experienced so

[71] In Latin: "Decimo, infero quod possibile est stellam vel solem apparere super nostrum orizontem quando tamen adhuc est sub orizonte, et hoc sit propter reflexionem luminis stelle vel solis super vapores interpositos." In McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, pp. 156–157, Bk. III, Q. 12, lines 336–339.In discussing this passage, McCluskey notes that no perspectivist before Oresme had maintained that a star may be seen that is actually below the observer's horizon. McCluskey lists the relevant passages of perspectivists who had not postulated this, including Ptolemy, Alhacen, Witelo, Bacon, or Pecham. McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, p. 413, fn. 33.

[72] Frans Bruin, "The Equator Ring, Equinoxes, and Atmospheric Refraction," *Centaurus* 20 (1976): 101; Morris Cohen and I.E. Drabkin, *A Source Book in Greek Science* (Cambridge, Mass.: Harvard University Press, 1948), p. 284.

[73] *De visione stellarum*, Bk. II, cap. 2, 178:11 – 180:6.

[74] To help avoid confusion, I have labelled these corollaries with roman rather than arabic numerals.

easily."[75] These corollaries are in no systematic order, but amongst still more examples of how atmospheric refraction might produce celestial deception, Oresme includes ways of possibly locating the true position of the stars (or at least an approximation) and then ponders how changes in the atmosphere cause twinkling. In a final, exuberant set of corollaries, he postulates that atmospheric refraction might save the phenomena of both retrograde motion and accounts of celestial objects moving more slowly, or quickly, or standing still. In closing, he offers a profound doubt about all visual experience: that almost no object is seen of itself, but all is seen through image.

These further examples of celestial deception by atmospheric refraction would, in my view, cause concern for any practicing astrologer in Oresme's audience. Previous conclusions should have already made astrologers uneasy, such as, the Principal Conclusion that no star is seen where it truly is, or that celestial objects that are in opposition do not appear to be so. After all, astrology is built upon exact angular distances such as oppositions (180°), trines (120°), and squares (90°). Knowing Oresme's other works against astrology, it is curious that he never criticizes astrology directly in the *De visione.* Nonetheless, the implications are close to the surface in such passages as "It is clear … how the rays, actions and influences of the sun and stars come to us through twisted lines," because of their multiple refractions.[76] In corollaries II, III, and VII, not only do the angular distances separating stars appear smaller than they truly are (VII), true conjunctions will not appear as true conjunctions (III), and atmospheric refraction causes us to be most deceived about the positions of the fixed stars, since they are furthest away (II).[77]

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[75] In Latin, "Sunt autem et alia corollaria ex predictis consequentia non tamen antecedentia quia non ita bene possunt experiri." *De visione stellarum,* Bk. II, cap. 2, 180:11–13.

[76] "Patet igitur qualiter radii et actiones et influentie solis et astrorum veniunt ad nos per lineas tortuosas." *De visione stellarum,* Bk. II, cap. 2, 164:1–2.

[77] Corollary II: "Secundum est quod stella que est in altiori orbe, ceteris paribus, apparet remotior a suo vero loco." *De visione stellarum,* Bk. II, cap. 2, 184:1–2. Corollary III: "Tertium est quod quando apparet vera coniunctio planetarum tunc non est, et quando est non apparet." *De visione stellarum,* Bk. II, cap. 2, 184:10–11. Corollary VII: "Septimo sequitur quod distantie stellarum aparent minores quam sint et arcus celi inter eas apparent minores quam sint secundum veritatem." *De visione stellarum,* Bk. II, cap. 2, 192:3–5.Nevertheless, no matter how strong these arguments appear to us, Oresme does not appear to add them to his arsenal in his most lengthy and erudite attack on astrology, the *Quaestio contra divinatores horoscopios,* nor in his other works on astrology. Oresme, "Quaestio contra divinatores horoscopios,"

On the other hand, in corollaries V and VI, Oresme gives some hope of actually determining the true place of stars.[78] Oresme assumes that as one approaches the zenith, the effects of atmospheric refraction will decrease proportionally in a simple one to one ratio. Going halfway up the sky (45° above the horizon) decreases its effect by half. Thus by solving relatively simple proportionalities, Oresme can claim to offer a key to determining the true positions of the stars, even though they are seen through atmospheric refraction. Of course, this oversimplifies the problem and does not account for his own concerns about twinkling, multiple refractions, and "twisted lines" of sight. Nonetheless, this "solution" to the problem of atmospheric refraction may be one of the reasons why Oresme does not use this as an argument against astrology in his more polemic works.

Exulting in his conclusions, Oresme pushes the envelope of his theory by even suggesting that the retrograde motions of the planets themselves may be explained by atmospheric refraction phenomena![79] This corollary would "save" two things. It would save the perfect circular motion of the planets, and it would "save the phenomena," relegating their imperfect, irregular motion to the sublunar, atmospheric regions. Of course someone might object, says Oresme, that these retrograde motions themselves are too slow and majestic to be caused by sublunar refraction. To counter this, Oresme takes his theory even further – he suggests the refractions might take place in the ether itself, and thus partake of the celestial region's majestic, regular motions. But after this exalted flight, he

edited by Stefano Caroti *Archives d'Histoire Doctrinale et Littéraire du Moyen Age* 51 (1976): 201–310; Oresme, *Nicole Oresme and the Astrologers. A Study of His "Livre de divinacions,"* ed. and tr. by G.W. Coopland (Cambridge, Mass.: Harvard University Press, 1952).

[78] *De visione stellarum*, Bk. II, cap. 2, 184:21 – 192:2.

[79] Corollary XV: "The fifteenth corollary could be this: That many (though not all) the appearances of the planets' motions in many of their eccentrics or epicycles can be saved, perhaps, by this proposed [atmospheric] refraction. For [as we have] already [seen] concerning the parts [of their motions], it is just for this reason that the regular appears irregular, and the same magnitude [appears to be] a larger or smaller distance." In Latin, "Quindecim correlarium posset esse, scilicet, quod multa licet non omnia que apparent de motibus planetarum forte possent salvari per talem fractionem suppositione tot eccentricorum vel epiciclorum quia iam partum est qualiter propter hoc regularis apparet irregularis et eadem magnitudo et distantia maior et minor." *De visione stellarum*, Bk. II, cap. 2, 206:3–8.

ends cautiously, saying, "I don't assert this, nor do I know if it is true."[80] It might not be accidental that this highly controversial corollary is lacking in two of the four manuscripts, *V* and *F*.[81]

In the previous corollary (XIV), Oresme intimates that atmospheric refraction and reflection might even explain the phenomenon of the sun standing still: "Fourteenth: I say that, through such a medium, it may be possible for the sun to appear to stand still, or remain in place."[82] Though Oresme does not mention it directly, the miracle of the sun standing still immediately springs to mind – as it must have for his audience. The vocabulary used in the book of Joshua is very similar: "Stetit itaque sol in medio caeli."[83] Perhaps Oresme was even hinting at a naturalistic process used by God to bring about such a miraculous occurrence. For he does say that the sun standing still could occur "in one region or country and not everywhere ..." and could occur naturally.[84] But at this juncture, he pulls back and states that the sun standing still could occur "miraculously, if [the effect] were sufficiently large."[85]

In a final summation of the incredible impact that atmospheric phenomena has on our vision, Oresme explores the differentiation between object and image. In the end, he expresses a profound doubt of all visual experience: "We have never seen anything itself," not even the sun or the moon.[86] Certainly a statement to shake the foundations of any certainty based on experience.[87] What began as a concern about observing the heavens, ends by calling all experience into question. A *pulcher tractatus* indeed.

[80] In Latin, "Hec, tamen, non assero, nec scio si est verum." *De visione stellarum,* Bk. II, cap. 2, 208:10.

[81] Corollary XV is lacking in the main text of the Florence manuscript, but it is supplied at the end of the treatise, following the first variant ending.

[82] In Latin, "Quatuordecimo, dico quod, per huiusmodi transmutationem medii, possibile esset apparere quod sol staret, sive quiesceret." *De visione stellarum,* Bk. II, cap. 2, 202:9–11.

[83] See *Joshua* 10:12–13 (Vulgate).

[84] In Latin, "Igitur, propter huius fractionem, et, melius, propter reflexionem, possit apparere solis statio, ac etiam reversio. ... Et in una regione vel patria non ubique, et naturaliter, ..." *De visione stellarum,* Bk. II, cap. 2, 204:5–8.

[85] In Latin, "... et miraculose, si effectus talis esset nimis magnus." *De visione stellarum,* Bk. II, cap. 2, 204:8–9.

[86] The full passage in Latin reads, "Sequitur, itaque, quod numquam videmus aliquid in lumine solis, quin cum hoc per lucem videamus et solem, aut quod numquam vidimus ipsum nec etiam lunam." *De visione stellarum,* Bk. II, cap. 2, 214:1–3.

[87] Could we see here the influence of the more skeptical strains of Nominalism since the time of Ockham?

V. MANUSCRIPTS

Sigla, Descriptions, etc.

This edition of Oresme's *De visione stellarum* is based upon four manuscripts (denoted by the sigla *B, V, F,* and *L*). The following descriptions are from published information, where cited. I have been able to personally examine the Lilly manuscript (*L*); the others have been read from microfilm.

1. *B* = Bruges, Stadsbibliotheek, MS 530.

   Date: 14th century.
   De visione stellarum: fols. 31^r–40^v.

Descriptions and citations: Hoste, *De Hanschriften van ter Doest*; De Poorter, *Catalogue des Manuscrits de la Bibliothèque Publique de la Ville de Bruges*; Lindberg, *Catalogue of Medieval and Renaissance Optical Manuscripts.*[1] This codex also contains Oresme's *Algorismus proportionum.*[2] The rest of the manuscript consists of works on mathematics by Jordanus de Nemore and John of Liniéres, and anonymous tracts on astronomy and astrology.

2. *V* = Vatican City, Biblioteca Apostolica Vaticana, Vat. lat. 4275.

   Date: 14th–15th century.
   De visione stellarum: fols. 40^v–50^v.

Descriptions and citations: Thorndike, *A History of Magic and Experimental Science*; Thorndike, "Vatican Latin Manuscripts"; Grant, *Nicole*

[1] D. Anselm Hoste, *De Handschriften van ter Doest* (Steenbrugge: Sint-Pietersabdij, 1993), p. 221; A. De Poorter, *Catalogue des Manuscrits de la Bibliothèque Publique de la Ville de Bruges*, Catalogue Général des Manuscrits des Bibliothèques de Belgique. (Gembloux, Belgium: J. Ducolot; Paris: Société d'Édition Les Belles Lettres, 1934), v. 2, pp. 627–630. David C. Lindberg, *A Catalogue of Medieval and Renaissance Optical Manuscripts*, Subsidia Medievalia, 4 (Toronto: Pontifical Institute of Mediaeval Studies, 1975), 97A.

[2] Edward Grant, "Part 1 of Nicole Oresme's 'Algorismus proportionum.'" *Isis* 56 (1965): 327–341; Menut, "A Provisional Bibliography of Oresme's Writings," *Mediaeval Studies* 28 (1966): 280–281, A.1.

Oresme and the Kinematics of Circular Motion; Grant, *De proportionibus proportionum*; and Lindberg, *Catalogue of Medieval and Renaissance Optical Manuscripts.*[3] This codex contains five of Oresme's works, all anonymous, including his *Tractatus contra astronomos, Algorismus proportionum, De commensurabilitate,* and the *De proportionibus proportionem,* as well as the *De visione.* It also contains treatises on mathematics by Jordanus de Nemore, as well as works on astronomy by Albertus Magnus and Thabit ibn Qurra, and a tract in defense of astrological interrogations. Outside of natural philosophy, two texts on Church law are also present in the manuscript.

3. *F* = Florence, Biblioteca Nazionale Centrale, Conventi Soppressi, J.X. 19. (It was previously referred to as the Codex S. Marci Florent., 202.)

   Date: ca. 1400 or earlier.
   De visione stellarum: fols. 31ʳ–43ᵛ.

Descriptions and citations: Björnbo, *Die mathematischen S. Marcohandschriften in Florenz*; Thorndike, "Some Medieval and Renaissance Manuscripts on Physics;" Federici-Vescovini, *Studi sulla prospettiva medievale*; Menut, "A Provisional Bibliography of Oresme's Writings"; and Lindberg, *Catalogue of Medieval and Renaissance Optical Manuscripts.*[4] The Florence manuscript includes four works on perspective: the first is anonymous, it is immediately followed by Oresme's *De visione,* and the two after the *De visione* are by Dominic of Clavasio (Chivasso) and Henry of Hesse (Henricus de Langenstein) respectively. The final three anonymous tracts are on the topic of maxima and minima.

4. *L* = Bloomington, Indiana (USA), Indiana University, Lilly Rare Book and Manuscript Library, Medieval and Renaissance MSS., 15th century, "Cum volueris scire gradum solis…". (No manuscript number is given by the Lilly; rather, the entire manuscript is referred to by its century and the incipit of its first text, Messahala's *Practica circa astrolabium,* part 2.)

   Date and Provenance: 1465, Piove di Sacco(?), Italy.

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[3] Thorndike, *A History of Magic and Experimental Science,* vol. 3, p. 400, n. 8; Lynn Thorndike, "Vatican Latin Manuscripts in the History of Science and Medicine," *Isis* 13 (1929): p. 56 (no. 2), and pp. 84–85 (no. 69); Grant, *Nicole Oresme and the Kinematics of Circular Motion,* p. 169, and n. 18; Grant, *De proportionibus proportionum,* pp. 128–129; Lindberg, *Catalogue of Medieval and Renaissance Optical Manuscripts,* 97A.

[4] Björnbo, *Die mathematischen S. Marcohandschriften in Florenz,* pp. 71–72, no. 28, pp. 131–132; Thorndike, "Some Medieval and Renaissance Manuscripts on Physics,"

Following the explicit of the *De visione stellarum* (fol. 56v) is the scribal colophon: "Ego Franciscus Sanuto scripssi in plebe sacis, 1465."[5] Franciscus Sanuto was a well known renaissance Venetian scholar whose famous son, Marcus Sanuto, was a patrician and senator of Venice.[6] The *De visione* section of the manuscript was apparently completed "in plebe sacis." This probably refers to a town just a few miles south of Venice called Piove di Sacco (Italy).[7]

Besides the *De visione stellarum*, the Lilly manuscript includes Part 2 of Messahalla's *Practica circa astrolabium* as well as various texts, tables and regula for calculating lunar phases, Easter cycles and planetary positions.[8] It also contains a partial glossary (ABC-EFG) by Hugo of Pisa, and brief texts on temperance, prudence and oratory.

192–193; Federici-Vescovini, *Studi sulla prospettiva medievale*, ch. 9–11, pp. 165–235; Menut, "A Provisional Bibliography of Oresme's Writings," p. 296, E.5; Lindberg, *Catalogue of Medieval and Renaissance Optical Manuscripts*, 40, 75, 87, 97A.

[5] Two other dates appear in this codex (beyond the dates in the astronomical tables), 30 March 1479 and 8 October 1480. Both appear in a colophon on fol. 104r at the very end of the manuscript. They read: "Text lintrada del chapetania de padoa ms Franciscus Sanudo [i.e., Sanuto] adj 30 maco del 1479," and "Text lintrada ms Jachomo Marcelo suo [or 'sue'?] chanbio adj 8 otubrio del 1480."

[6] See Mario Cosenza, (1962–1967), *Biographical and Bibliographical Dictionary of the Italian Humanists and of the World of Classical Scholarship in Italy, 1300–1800* (Boston: G.K. Hall, 1962–1967), v. 4, 3190.

[7] The *Orbis Latinus* lists a "Plebs Saci" as an alternate name for "Plebisacium," which was the Latin name for the modern town of Piove di Sacco, Italy. *Orbis Latinus: Lexicon lateinischer geographischer Namen des Mittelalters und der Neuzeit*, ed. Graesse, et al. (Braunschweig: Klinkhardt and Biermann, 1972), vol. 3, p. 164.

[8] The work appears to have been rebound and may be lacking one or more manuscripts that were originally bound in the front. Perhaps Part 1 of Messahalla's work on the astrolabe once belonged to this manuscript. It appears to be rebound because some of the letters on the fore-edge are "cut short," while a large margin appears above the letters. Also, there are no spots of paint from the lettering on the binding edge where the lettering is contiguous. The fore-edge bears the letters: "PROSPECT XL.AVCEO." (Or perhaps "PROSPECT KLAUCEO"? or "PROSPECT HLAVCEO"?) The spine reads: MS. L(?).

VI. EDITORIAL PROCEDURES

A. *Relationship of the Extant Manuscripts*

The familial relationships among these four manuscripts is problematic. Generally, *B* and *F* are more closely related for much of the text, but sometimes they diverge and *B* and *L* seem more closely related. The heavily edited Vatican manuscript, *V*, seems most independent of the four.

There are two particular examples that are helpful in understanding the confused interrelationship of the manuscripts: the missing Corollary xv and the confused Figure 14.[1] *V* is lacking the entire Corollary xv in the *De visione* and thus is probably not the direct exemplar for any of the other three manuscripts. The Florence manuscript is also missing Corollary xv, but supplies it – in what appears to be the same hand – following its first variant ending (fol. 42^{r}). This lacuna in *F* shows a strong link with the Vatican manuscript lineage, but through most of the manuscript, *F* is much more closely related to the Bruges manuscript, *B*.

The earliest of the four extant manuscripts appears to be that in Bruges 530, but while generally reliable, it is not always the most accurate of the four. For example, Figure 14 corresponds well to the Oresme text in both *F* and *V*, but it is quite confused in *B* and of little help in explicating the text. The Lilly manuscript, the latest of the four, precisely follows *B* in its confused illustration, thus implying a close relationship to the Bruges family. Yet a text comparison reveals the Lilly copy to be far more remote from *B* than is *F*. On the surface, it would appear that there are several manuscripts, no longer extant, that separate *B, F, V*, and *L*.

Because of *F's* two variant endings (the second containing Oresme's name) and its supplied corollary xv, there is no doubt that the scribe of *F* had two, and possibly three, manuscripts for comparison. It also exhibits the greatest amount of manuscript contamination, for while its text is more closely related to the Bruges family, its lack of corollary xv obviously connects it to the Vatican fam-

[1] The numbering of the figure and of the corollary are supplied by the editor.

ily, even though it is not closely related otherwise. This same cross-contamination is evident to a lesser degree in the other manuscripts as well. Thus any attempt at a stemma would contain many conjectural ghost manuscripts, and lines running from nearly all the extant manuscripts to some ancestor of one of the others. Only confusion would result.

Further, because this was a *disputatio* in a university setting, there is a real possibility that there was no single autograph manuscript in the hand of Oresme. This would be the case if one or more students' lecture notes of the *disputatio* were the only source(s) of the *De visione*, or if Oresme employed an amanuensis to take down his dictated *disputatio*. If the latter, presumably Oresme would have corrected the dictated copy himself. Though all of this is possible, it is more likely that there was a single autograph from Oresme's hand, judging from his common practice in his later works. Even so, this does not preclude the possibility of other student copies made during the *disputatio* from later cross-fertilizing the manuscript tradition.

All this does not include a further possible complication – the problem of *pecia*. Recent scholarship has revealed that the way texts were copied at the medieval university was much more complex than has been generally believed. If a student or colleague wished to copy a school text (particularly from an official "bookstore"), the entire text would not be loaned, but only a section or quire of it. When that section was completed, it could be exchanged for another. There were usually multiple copies of any single work, and each was broken down into these "interchangeable" sections, called *pecia*, for the students to borrow. Though convenient for the medieval student, this is a manuscript editor's nightmare, since any *single* student manuscript copy might have relied upon multiple exemplar *pecia*. And if extant manuscripts are even further removed from these "original(s)," it would be almost impossible to determine the "autograph" from them. Whether the *De visione* was copied in this fashion is unknown.[2]

Thus, for this edition, the pragmatic decision was made to generally follow what appears to be the earliest manuscript, Bruges

[2] For clarifying insight into *pecia* and the construction of texts in the late medieval universities, see Mary A. Rouse and Richard H. Rouse's chapter titled: "The Book Trade at the University of Paris, ca. 1250 – ca. 1350," in their *Authentic Witnesses: Approaches to Medieval Texts and Manuscripts.* Publications in Medieval Studies, vol. XVII (Notre Dame, Ind.: University of Notre Dame Press, 1991), pp. 259–338.

530 (14th century).[3] But this was not done slavishly; the better or more likely readings are supplied from the other manuscripts when called for. Because the manuscript tradition seems mixed and because there are only four extant manuscripts, all major variants have been supplied to ensure the reader has access to the entire tradition. Therefore, anything beyond the most minor of spelling variations is noted.

All figures, unless otherwise noted, are found in the original manuscripts; the English captions have been provided by the editor to aid the reader.

B. *Critical Apparatus*

The following standard abbreviations will be used in the critical apparatus.[4]

a. m.	alia manu (e.g., by another hand)
add.	addidit (e.g., "*post* instrumentum *add.* horum *V*" means that after "instrumentum" "horum" has been added in *V*).
alter.	alteravit (e.g., "plurimum *alter. in* quamplurimum *a.m. F*" means that "plurimum" has been changed to "quamplurimum" by a hand other than the original in *F*).
corr. ex	correxit (e.g., "aliquid *corr. ex* quid *V*" means that the scribe corrected "quid" into "aliquid" in *V*).
del.	delevit (see example for *scr.* below).
interl.	interlineariter (e.g., "et[2] *interl. F*" means that the second "et" in the line was inserted interlinearly in *F*).
mg.	in margine (e.g., "et aliis *mg. V*" means that "et aliis" has been inserted marginally in *V*).
om.	omisit (e.g., "magis *om. L*" means that "magis" is missing in *L*).
rep.	repetivit (e.g., "illud quod *rep. L*" means that the phrase "illud quod" was repeated in *L*).

[3] Unfortunately, the Bruges manuscript was the last that became available to me, after much of the original editing was completed, thereby requiring a wholesale "switch" from the Vatican manuscript that was originally followed.

[4] Here I am relying on a mix of three Latin abbreviation lists found in the following three works (the English explanations of these abbreviations follow those given by A. Mark Smith): David C. Lindberg's, *Roger Bacon's Philosophy of Nature: A Critical Edition, with English Translation, Introduction, and Notes, of "De multiplicatione specierum" and "De speculis comburentibus".* (Oxford: Clarendon Press, 1983), pp. lxxx–lxxxi; A. Mark Smith's, "The Latin Version of Ibn Mu'adh's Treatise *On Twilight and the Rising of the Clouds*" *Arabic Sciences and Philosophy: A Historical Journal* 2 (1992), pp. 94–95; and "Norms for the Publication of Texts in the *Corpus Christianorum.*"

scr. scripsit (e.g., "*ante* ultimum *scr. et del.* de qua non cadit *F*" means that the phrase "de qua non cadit" was written and deleted before "ultimum" in the given line in *F*).

sub l. sub linea (see similar example for *sup. l.* below).

sup. l. supra lineam (e.g.: "Attritae id est comminutae] id est *sup. l. V*" means that "id est" is written above the line in *V*).

transp. transposuit (e.g., "sol est *transp. FV*" means that "sol est" reads "est sol" in *FV*).

(?) signifies a doubtful reading.

[] added by the editor.

| page break in one or more of the manuscripts, with foliation given in section one of the critical apparatus below (e.g., on line 7: "cuius esse | est in" with the note in section one of the critical apparatus "7 *V* 40^{v}" means the first line of fol. 40^{v} in *V* begins with "est in").

Let me make a brief mention of my use of footnotes and endnotes. Quotations in the Latin text will be cited in the second tier of footnotes in the critical apparatus. Full citations to modern editions will be found in the footnotes to the English translation, as will nearly all the notes and explications of passages, both Latin and English. However, I will relegate most long quotations and any other extremely lengthy remarks to the endnotes, which will be signified by roman numerals in the English translation. These endnotes are necessary for both practical and aesthetic reasons. Because the Latin and English texts are linked by line numbering, lengthy footnotes on a page in the English text would result in a large measure of blank space in the Latin text. I should also mention that the English line numbering is only approximately linked to the Latin text and merely given as a rough finding aid for the reader. Any citations given are to the Latin line numbering, not the English.

VII. CITATION LIST OF AUTHORS QUOTED OR ALLUDED TO IN ORESME'S *DE VISIONE STELLARUM*

Note: Citations in the second column for Book I refer to Book, page and line number, e.g., I, 86:5 means Book I, page 86, line 5. For Book II, the chapter number is also given. E.g., II, 2, 166:6 means Book II, cap. 2, page 166, line 6.

Author List	*Line #s in Oresme* De visione stellarum *(In Bk II, sec #, page: line #)*
Alhacen, *De aspectibus* [= *Perspectiva*; or *Optics*]	
VII, ch. 7, sec. 51, p. 278	I, 80:4–7
VII, ch. 3, secs. 9–12, pp. 242–247	II, 1, 122:15–16
VII, ch. 5, secs. 17–33, pp. 253–265	II, 1, 122:21–23
VII, ch. 5, secs. 17–33, pp. 253–265	II, 1, 126:2–4
VII, ch. 7, secs. 38–43, pp. 270–274	II, 1, 134:4
VII, ch. 4, secs. 15–16, pp. 251–252	II, 1, 140:14–17
VII, ch. 7, secs. 51–55, pp. 278–282	II, 1, 148:8–12
VII, ch. 7, sec. 51, p. 278	II, 2, 150:9–11
VII, ch. 7, sec. 51, p. 278	II, 2, 152:8–10
II, ch. 2, sec. 51, p. 61	II, 2, 160:16–18
VII, ch. 4, sec. 15, p. 251	II, 2, 162:19–20
VII, ch. 5, secs. 17–19, pp. 253–256	II, 2, 208:11–21
II, ch. 2, sec. 18, p. 35	II, 2, 210:17–18
II, ch. 2, sec. 18, p. 35	II, 2, 214:3–4
VII, ch. 7, sec. 51, p. 278	II, 2, 214:5–7
Alhacen, *De crepusculis,* See, Mu'adh, Ibn.	
Aratus, *[Phaenomena. Latin Paraphrase] Germanici Caesaris, "Aratea"*	
i, 11–12	I, 78:5–8
Aristotle, *De caelo*	
Bk. II, ch. 8 (290a15–25)	II, 2, 200:13–15
Aristotle, *Meteorologia*	
I, ch. 6 (343b8–25) & ch. 7 (344a34–344b15)	I, 86:16–19
I, ch. 7 (344b5–10)	I, 88:3–4
III, ch. 4 (373a35–373b13)	II, 2, 162:3
I, ch. 3 (340a24–33)	II, 2, 166:1–3
I, ch. 3 (341a13–341a38)	II, 2, 202:6–8
III, ch. 2 (371b18–372a21)	II, 2, 204:2–5

Author List	*Line #s in Oresme* De visione stellarum *(In Bk II, sec #, page: line #)*
I, ch. 1 (338b1–339a1)	II, 2, 206:13–15
III, ch. 4 (373a35–373b35)	II, 2, 210:5–6
Bacon, *De multiplicatione specierum*	
Part II, ch. 3, lines 81–85	II, 1, 116:13–16
Part II, ch. 4, lines 27–32	II, 2, 152:8–10
Bernard Silvester, *Cosmographia*	
Liber II, 14, lines 45–46	I, 76:7–9
Biblia Sacra:	
Joel, 2:31	II, 2, 204:12–15
Cicero, *De natura deorum*	
II, lxii, 155	I, 78:9–11
Claudian, *De raptu Proserpinae*	
III, 41–42	I, 78:1–4
De sperebus, See John of Sacrobosco, *De sphaerebus*	
Euclid, *Elements*	
I, prop. 29	I, 104:1–4
VI, prop. 19	I, 106:3–5
VI, prop. 4	I, 106:5–6
I, prop. 22	I, 108:4–10
John Damascene, *On the Assumption, Sermon I*	
pp. 164–165	II, 2, 204:16 – 206:2
John of Sacrobosco, *De sphaeribus*	
Thorndike (1949), p. 81	II, 1, 140:14–16
Mu'adh, Ibn, *De crepusculis*	
p. 115, lines 414–416	II, 1, 158:15–20
Plato, *Timaeus*	
47A–47D:	I, 76:4–6
Pliny, the Elder, *Natural History*	
Bk. II, x, 57, vol. 1, pp. 206–207	II, 2, 178:4–10
Ptolemy, *Almagest*	
V, cap. 11–12, & 17–19	I, 86:8–10
Ptolemy, *De aspectibus [= Optics]*	
Bk. V, secs. 25–26 (= Prop. 85), pp. 238–240	II, 1, 140:14–17
Witelo, *Perspectiva*	
X, secs. 4–8, pp. 407–413	II, 1, 122:15–16
X, sec. 12, p. 415	II, 1, 122:21–23

Author List	*Line #s in Oresme* De visione stellarum *(In Bk II, sec #, page: line #)*
X, sec. 15, pp. 416–418	II, 1, 126:1–2
X, sec. 12, p. 415	II, 1, 126:2–4
X, secs. 49–50, pp. 444–445	II, 1, 140:16–17
X, sec. 54, pp. 448–449	II, 1, 148:8–10
X, sec. 54, pp. 448–449	II, 2, 152:8–10
X, sec. 41, pp. 439–440	II, 2, 166:3–6
X, secs. 51–53, pp. 445–448	II, 2, 194:7–8
X, sec. 55, pp. 449–450	II, 2, 200:8–9
III, sec. 59	II, 2, 210:17–18

PART II

NICOLE ORESME'S *DE VISIONE STELLARUM*

Latin Critical Edition with English Translation

Nicole Oresme

[De Visione Stellarum]

[Liber 1]

B fol. 31r *F* fol. 31r *L* fol. 37r *V* fol. 40v

| PLATO in Timeo volens reddere causam propter quam visus inest nostris oculis, et cur deus ipse os homini sublime dedit celumque videre iussit et erectos ad sidera tollere vultus, non aliam assignavit causam nisi quam BERNARDUS SILVESTER metrice tradit dicens:

Querenti Empedocles cur viveret, inquit, ut astra
Inspiciam. celum subtrahe: nullus ero.

Bruta patenter habent tardos animalia sensus. Cernua deiectis vultibus ora ferunt. Sed maiestatem mentis testante figura, tollit homo suum solus ad astra caput, ut, celi leges indeflexosque meatus, exemplar vite possit habere sue, inspiciens qualicumque modo talique tenore. Omnia sydereus secula motus agat. Dii superi stelleque

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2–3 [De visione stellarum] Incipit pulcher tractatus Utrum stelle videantur ubi sint *in sup. mg. V*; Tractatus solempnis perspective *in sup. mg. L*   4 Timeo] *Timeo F*; Thimeo *BL*; Tymeo *V*   5 ipse] ipse et *add. et del.*, otios(?) *sup. l. V* | homini] hominum *et add. sup. l.* homini *V* | sublime] sublimum *V*   5–6 celumque videre] *om. L*   6 videre] *post* videre *add. et del.* Iuix(?) *F* | iussit] Iussit *L*; iuxit *F*; posset *V* | erectos] ereptos *L* | sidera] sydera *BLV* | assignavit] adsignavit *F*   7 causam] *om. BLV* | Bernardus] Bernhardus *V* | tradit] reddit *V*   8 viveret] venient *V* | inquit] inquid *FV*   9 subtrahe] substrahe *L*   10 Cernua] Germina *L*   11 maiestatem] magestatem *V*; maiestatis *L* | mentis] mentis *corr. ex* mentes *aut vice versa in L* | testante] tessante *aut* cessante(?) *V*   12 suum] sanctum *BF*; sanctus *L* | solus] *om. L* | caput] capud *FV*   13 vite] vide *F* | inspiciens] inspiciat *BF*; Inspiciant *L* | qualicumque] qualique *L* | talique] qualicumque *F*; qualique *BL*   14 sydereus] sidereus *F* | secula] seculam *F* | Dii superi] Diis superet *scr. et del.*, Dii super *sup. l. V* | superi] superius *F* | stelleque] *post* stelleque *add. et del.* celum *F*

4 cf. PLATO, *Timaeus*, 47A–47D.   7 BERNARD SILVESTER, *Cosmographia*, Liber II, 14, lines 45–46: “Quaerenti Empedocles quid viveret inquit, ut astra / Inspiciam. caelum subtrahe: nullus ero,” and cf. CHALCIDIUS, *Commentary on Plato’s Timaeus*, CCLXVI, lines 2–5, p. 297. Chalcidius may be the source of Bernard’s quote, but it is ascribed by Chalcidius to Anaxagoras, not Empedocles.

Nicole Oresme

On Observing the Stars

[Book I]

Plato in the *Timaeus*,[i] wishing to assign a cause for why sight is present in our eyes, and why God Himself gave an elevated face to man and ordered him to gaze upon the heavens and to raise the face upward towards the constellations, assigned the very cause that Bernard Silvester gives in his poem:[1]

> Empedocles, to one asking why he lived, said, "To see the stars.
> Take away the Heavens, and I will be nothing."

Brute animals clearly have slow minds; they carry their faces downwards[2] with downcast visages. But with a bodily form bearing testimony to a greatness of mind, man alone lifts his head toward the stars,[3] in order that looking upon the laws of heaven with a certain method and tenor and constant courses, he may have a pattern for his own life. Starry motion may effect all periods [of life]. The gods

[1] [NOTE: Long passages are placed in the Endnotes, which are marked by lower case roman numerals; the shorter footnotes are marked by Arabic numerals.] Bernard Silvester, *Cosmographia*, Liber II, 14, lines 45–46: "Quaerenti Empedocles quid viveret inquit, ut astra / Inspiciam. caelum subtrahe: nullus ero," Bernard Silvester, *[Cosmosgraphia]. De Mundi Universitate, Libri Duo, sive Megacosmus et Microcosmus.* ed. by Carl Barach and Johann Wrobel (Innsbruck; reprint, Frankfurt a. Main: Minerva, 1876, rpt. 1964), p. 67, Lib. II, 14, lines 45–46. See also Brian Stock's, *Myth and Science in the Twelfth Century: A Study of Bernard Silvester* (Princeton: Princeton University Press, 1972), p. 215, which notes and translates this verse.It has not been noted elsewhere, so far as I know, but it may well be that Bernard Silvester was thinking of a quotation of Anaxagoras, not Empedocles, found in Chalcidius' *Commentary on Plato's Timaeus.* For Chalcidius refers to a very similar statement purportedly made by Anaxagoras, stating: "Proptereaque Anaxagoras, cum ab eo quaereretur cur natus esset, ostenso caelo sideribusque monstratis respondisse fertur: 'ad horum omnium contemplationem.'" *Platonis Timaeus, interprete Chalcidio, cum eiusdem commentario,* ed. by Dr. Ioh. Wrobel (Leipzig: Teubner, 1876; reprint, Frankfurt am Main: Minerva, 1963), CCLXVI, lines 2–5, p. 297.

[2] The Lilly ms. reads "Germina" for "Cernua"; the scribe may have misinterpreted a "C" for a "G" and miscounted the minims.

[3] The Lilly ms. appears to read: "Holy man[kind] lifts its head towards the stars."

sibi celumque loquetur, ut natura nil occuluisse queat. Sed ait CLAUDIANUS:

> *quid mentem traxisse polo, quid profuit altum erexisse caput, pecudum si more pererrant?*

Id est si non considerent circa corpora celestia plus quam bruta. Ideo ut dicit ARATUS, nos decet

> … *audaces in celis tollere vultus sideraque et mundi varios cognoscere motus.*

De quorum pulchritudine TULLIUS in De natura deorum "*nulla est,*" inquit, "*insatiabilior species nulla pulchrior nec ad solertiam nec ad exercitationem hominum prestantior.*"

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1 nil] nihil *F*; nichil *BV* | occuluisse] oculuisse *FV* 3 quid] quidam *V* | mentem] mente *F* | polo] pollo *L* | caput] capud *FV* | pecudum] peccudum *BL* 4 pererrant] pererrat *V* 5 considerent] consciderent *L* 6 Aratus] Oracius *V* | decet] docet *F*; *post* docet *add. et del.* Aratus *F* 7 celis] celum *BFV* | tollere] tollerere *L* | sideraque] syderaque *BLV* | et] *om. V* | mundi varios] varios mundi *F* 9 pulchritudine] pulcritudine *L* | Tullius] Tulius *F* | De] *om. F* 9–10 nulla est inquit] inquid nulla inquid est *F* 10 insatiabilior] satiabilior *V* | pulchrior] pulcrior *L* | nec ad] et *L* 11 prestantior] prestancior *V*

2 CLAUDIAN, *De Raptu Proserpinae*, III, 41–42. 6 ARATUS, *[Phaenomena. Latin Paraphrase]. Germanici Caesaris, "Aratea"*, i, 11–12. 9 CICERO, *De natura deorum*, II, lxii, 155. Oresme's is an approximate quotation of Cicero's words: "nulla est enim insatiabilior species, nulla pulchrior et ad rationem sollertiamque praestantior."

and heavenly bodies, and the stars, and the heavens will speak for themselves,[4] in order that nature can have concealed nothing. But Claudian says,[5]

> Of what avail that men derived their intelligence from the heavens, that they have held up their heads to heaven, if they wander about in the manner of beasts?

That is, if they do not contemplate the heavenly bodies they are worse than beasts.

Therefore, as Aratus says,[6] it befits us

> … to lift our gaze boldly to the sky and learn of the celestial bodies and the different movements of the heavens.

Of whose beauty, Cicero said, in *On the Nature of the Gods*, "there is no sight of which it is more impossible to grow weary, none more beautiful, none better for the shrewdness and activity of men."[7]

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[4] Lit. "will speak for itself."

[5] English translation based on those of Claire Gruzelier's edition of Claudian's, *De Raptu Proserpinae* (Oxford: Clarendon Press, 1993), III, 41–42, p. 53, and of Maurice Platnauer's edition in *Claudian* (London: W. Heinemann, 1922), *The Rape of Proserpine*, III, 41–42; vol. 2, p. 349. Oresme's quotation in Latin is nearly verbatim to those of modern critical editions. Claudian's fourth century poem, *The Rape of Proserpine*, with its mythic tale of the underworld, was a standard school text in the Middle Ages and would have been quite familiar to most of Oresme's readers. Oresme also quotes from it in his commentary on the "Sphere" of Sacrobosco. See Garett Droppers, *The "Questiones De Spera" of Nicole Oresme. Latin Text with English Translation, Commentary and Variants* (Ph.D. dissertation, University of Wisconsin, 1966), Q. 5, p. 103, and p. 363, n. 3.0.

[6] English translation based in part on D.B. Gain's edition of Aratus, *The Aratus Ascribed to Germanicus Caesar* (London: Univ. of London, The Athlone Press, 1976), i, 11–12, p. 53.

[7] Oresme here gives only an approximate quotation from Cicero, but it bears the same meaning. The English translation is based on that of H. Rackham's edition of Cicero, *De Natura Deorum; Academica*, Loeb Classical Library (Cambridge, Mass.: Harvard Univ., 1961), II, lxii, 155, p. 273, which gives: "for there is no sight of which it is impossible to grow more weary, none more beautiful nor displaying a more surpassing wisdom and skill."

Propter quod de visione stellarum aliqua recollegi dicta in disputatione apud sanctum Bernardum, ubi fuit dubitatum:

Utrum stelle videantur ubi sunt.

Et arguitur quod sic auctoritate ALHACEN in septimo sue Perspective sic dicentis "dico ergo quod stelle in maiori parte comprehenduntur in suis locis, et quod semper comprehenduntur non in suis magnitudinibus."

Oppositum arguitur, quia aliqui planete et alique stelle fixe videntur in eodem loco, et, tamen, non est ita.

Pro questione sciendum quod deceptio in visione stellarum, quo ad locum potest accidere quantum ad profunditatem in celo, seu stelle altitudinem. Et sic, non est dubium quin stella appareat ubi non est et nobis propinquior quam sit. Ymo, quandoque humilior apparet altior aut e contra. Et per hoc solvitur argumentum immediate precedens, nec intelligitur questio illo modo.

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1 quod] *om. B* | de visione] divisione *V* | recollegi] collegi *V* 2 apud] aput *V* | Bernardum] Bernhardum *V*; *post* Bernardum *add.* Parisius *L* | ubi fuit dubitatum] [d]ubitatum fuit ibidem *B* 3 sunt] sint *V* 4 quod sic] *om. V* | auctoritate] autoritate *F* | Alhacen] Alasen *F*; Alacen *V* | septimo] secundo *V* 4–5 sue Perspective] *om. BFL* 5 dicentis] decentis *F*; dicintis *L* | ergo] *om. L* 6 suis locis] locis suis *F* | quod] *post* et *add. et del.* ubi; *add. sup. l.* quod *V* | comprehenduntur non] non conprehenduntur non *V*; *del.* non[2] *V* 8 aliqui] aliqui *corr. ex* alique *V* 9 loco] celo *BF*; *post* loco *add.* et eque alte *V* 10 questione] *sup.* questione *add. sup. l.* conclusione *V* | sciendum] nunc *F* | deceptio] decepcio *V* 13 sit] *post* sit *add. et del.* inde(?) *V* | Ymo] Immo *BF*; Ymmo *sup. l. V* | quandoque] *post* quandoque *add. et del.* melior quandoque *V*; *add.* propinquior et *sup. l. V* 14 per] pro *F*; propter *L* | solvitur] *post* solvitur *add. et del.* arguitur *F* | argumentum immediate] in mediate argumentum *L* 15 intelligitur] intelligebatur *V* | questio] *om. L* | illo] *sup. l. V*

4 ALHACEN, *De aspectibus*, (1572, rpt. 1972) VII, ch. 7, sec. 51, p. 278: "Dico ergo quod stellae in maiore parte comprehenduntur in suis locis: et quod semper comprehendundtur non in suis magnitudinibus."

Because of this, I collected some thoughts concerning the observation of the stars[8] at a disputation[9] at Saint Bernard's [in Paris],[10] where the question was asked:

whether the stars are seen where they [TRULY] are

And it is argued that, yes they are, by the authority of Alhacen, who in the seventh book of the *De aspectibus* says, "Therefore, I say that the stars, for the most part, are perceived in their places, but they are not always perceived in their correct size."[11]

The opposite is argued, since some planets and fixed stars seem to be in the same location and of the same size, but this is not actually so.[12]

For this question, it must be understood that deception in stellar observation, with respect to location, can occur regarding a star's depth or altitude in the heaven. And there is no doubt that a star might appear to be where it isn't and nearer to us than it actually may be. Indeed, sometimes it appears smaller and sometimes larger and the other way round. And by this, the immediately preceding argument is solved, nor is [the original] question to be understood in that way.[13]

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[8] This phrase appears to be the source of the title given in the Florence manuscript's table of contents: "De visione stellarum." Thus we follow Federici-Vescovini, who followed the Florence ms., in giving this treatise the title, *De visione stellarum*, "On Observing the Stars". See Chapter 1 for further titles this treatise has borne.

[9] A disputatio.

[10] The city name of Paris is explicitly supplied in the Lilly manuscript. Thorndike believes that this "*apud sanctum Bernardum*" is probably a reference to the Collège des Bernardins at the University of Paris, cf. Thorndike (1960), "Some Medieval and Renaissance Manuscripts on Physics", pp. 192–193. See introduction.

[11] Alhacen (1572, rpt. 1972), *De aspectibus*, VII, sec. 51, p. 278. In this section of his work, Alhacen discusses why some stars appear larger on the horizon than at mid-heaven. Oresme is putting forward a straw-man argument here, since he knows that Alhacen discusses stellar refraction in the next few sections.

[12] Oresme is following the general outline of a *quaestiones* format – but barely. The standard *quaestio* would first give possible arguments against the view held by the author, usually followed by definitional distinctions, then the author's own views, followed by a rebuttal of the initial arguments. Oresme is following this formalism. But he only gives one opposing view here, and it is a strawman. He keeps the formalism by placing a brief rebuttal of this point at the very end of the last section of Book II.

[13] That is, the illusion that the stars and planets all appear to be at the same depth in the sky is a problem that is easily solved, and it is not the real question that Oresme asks here.

L fol. 37v Sed restant duo alii modi. Primus est quod stella non apparet | sub eodem puncto prime sphere sub quo existit, posito quod videatur per lineam rectam non fractam nec reflexam, vel quod deceptio que ex fractione contingeret deducatur. Secundus modus est quod sit deceptio propter linee fractionem ex dissimilitudine mediorum, sicut de denario in fundo vasis aque, et sicut propter reflexionem accidit stellam apparere in aqua. Et isti duo modi sunt ad propositum, et secundum hoc erit questionis solutio bipartita.

[Utrum deceptio fiat observante astra caelestes cum suis radiis non frangantur.]

[Conclusio 1: Parallax lunae] Quantum ad primum modum, sit prima conclusio quod luna videtur alibi quam sit. Probatur, quia linea egrediens de oculo per corpus lune in celum, que est linea *F* fol. 31v aspectus, et linea exiens de centro mundi | per idem corpus in celum, *V* fol. 41r cuius terminus est verus locus lune | intersecant se. Et quia luna est propinqua terminis et non est super zenith capitis, ideo, terminus linee visualis, et terminus linee veri loci sunt in celo distantes. Ergo, non videtur ubi est, et huius distantia vocatur diversitas aspectus lune.

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1 duo] *om. L* | alii] aliis *L* | modi] *post* modi *add. et del.* primus *F* | apparet] appareat *V* 2 prime sphere] spere prime *B* | sphere] spere *FL* 3 nec] vel *F*; nec *rep. B* | deceptio] decepcio *V* 4–5 que ... sit] *om. L*; Apparently a *saltus* (or *homoeoteleuton)* where either the eye of the scribe of the *L* ms. or some earlier scribe skipped to the next occurance of "deceptio". 5 deceptio] decepcio *V* | fractionem] refractionem *V* | mediorum] radiorum *L* 6 de] *sup. l. V* | aque] *om. V* | sicut] *om. B* 7 accidit] dicunt *L* 8 bipartita] disposita *V* 11 Quantum] [Q]uantum *V* 12 quod] *post* quod *add. et del.* lina *F* | Probatur] Proprius(?) *L* 13 in celum] *om. F* | celum] celo *L* 14 idem corpus] corpus idem *F*; *post* idem *add. et del.* incelum(?) *F* 15 verus] *add. et del.* motus *V* | locus] locus *sup. l. V* | intersecant] intersecans *F* 16 terminis] terris [*sic*] *BV* | zenith] cenith *B*; cenit *F*; zenit *V* | capitis] *post* capitis *add. et del.* nec(?) *F* 17 terminus linee^2] linee terminus *V* | Ergo] Igitur *FV* 18 huius] huiusmodi *FV* | diversitas] igitur *F*

But two other ways to understand this question remain. The first is this: a star that may not appear in its true place below the same point of the first sphere (under which it seems to be placed) may be seen by a straight line that is neither refracted, reflected, or an illusion that might be deduced to occur because of a refracted ray. The second way is that the illusion may be due to the bending of the visual line because of a dissimilarity of the media (just like a penny in the bottom of a vase of water, or like a star appears to be in water because of its reflection). These two ways of understanding the question are more [relevant] to what has been proposed – thus the solution of the question will be in two parts.[ii]

[Whether Deception Occurs in Observing the Celestial Stars When Their Rays are Undistorted.]

[Conclusion 1: Lunar Parallax] Concerning the first way of understanding the question, the first conclusion is that the moon appears to us in a different place than it truly is. This is proved because[14] a line from the eye to the moon in the heaven (that is, the line of sight) *intersects* a line from the center of the world to the moon (whose terminus is the true place of the moon).[15] Because the moon is near the termini [of the lines on earth] and is not over the zenith, the terminus of the line of sight and the terminus of the line of its true place in the heaven are separable.[16] Therefore, the moon does not appear to us where it truly is, and this [angular] distance is called lunar parallax [*diversitas aspectus*].[17]

[14] The Vatican manuscript puts this slightly differently: "…luna videtur alibi quam sit. Probatur quia …", which translates as "the moon appears in a different place than it is. This is proved because …"

[15] Here Oresme describes the parallax of the moon. He uses Lunar parallax as an example of how stellar objects may not appear to us where they actually are, even if there is no optical reflection or refraction. (This sentence literally reads: "[That is] because a line proceeding from the eye to the heavens through the body of the moon (that is, the line of sight) and a line issuing from the center of the world to the heavens through the same body (whose terminus is the true place of the moon) intersect one another.")

[16] For parallax to be detectable, Oresme explains, the moon must first be near enough to the earth to be discernable. Second, he notes that parallax would not be detectable if the moon were directly overhead at the zenith, for then the line of sight and the line from the center of the earth to the moon would be one and the same – there would be no angular distance between them.

[17] "*Diversitas aspectus*" is the term used to describe parallax in the Latin translation of Ptolemy's *Almagest*.

B fol. 31v Et inde est quod ab aliquo loco videtur sol eclipsari et luna sub | ipso, et ab aliquo alio, pro tunc non videtur, nec est eclipsis ubique. Ex ista probatione sequitur quod due sunt cause huius diversitatis,

1 inde] idem *L* | eclipsari] ecclipsari *L* 2 aliquo] *om. BFL* | videtur] videt *B* | nec] et *F* | est] est *sup. l. V* 3 ista] illa *V* | probatione] propositione *BV* | huius] huiusmodi *V*

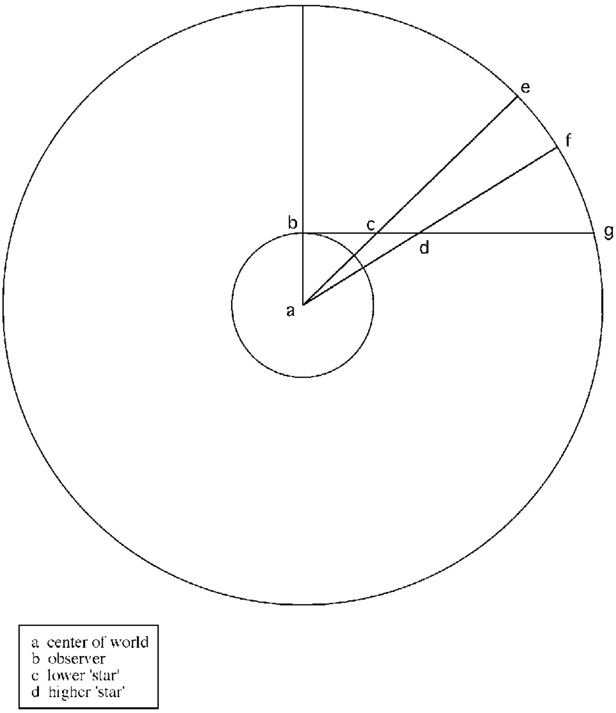

Figure 1. Stellar Parallax

And the same thing is shown by the following: In one place [on earth], the sun is seen to be eclipsed by the moon underneath it, but in another place the eclipse is not seen at the same time, nor is the eclipse seen everywhere [on earth].[18] From this evidence, it follows that there are two causes of this parallax [*diversitas*], namely,

[18] John of Sacrobosco, in his *The Sphere of Sacrobosco*, notes that a solar eclipse is not seen everywhere on earth and varies according to the location of the observer. Cf. John of Sacrobosco (1949), *The Sphere of Sacrobosco* (ed. by Thorndike), pp. 116, 142. The *Sphere of Sacrobosco* was a standard elementary astronomical textbook in the later Middle Ages, and thus most of Oresme's readers would already be familiar with the concept that solar eclipses are not seen everywhere. In Latin, the relevant passage reads: "Notandum etiam quod quando est eclipsis lune, est eclipsis in omni terra. Sed quando est eclipsis solis, nequaquam, immo in uno climate est eclipsis, in alio non, quod contingit propter diversitatem aspectus in diversis climatibus" (p. 116). In Thorndike's translation: "And it is to be noted that when there is an eclipse of the moon, it is visible everywhere on earth. But when there is an eclipse of the sun, that is by no means so. Nay, it may be visible in one clime and not in another, which happens because of the different point of view in different climes," p. 142.

scilicet, propinquitas stelle ad terram, cum distantia eius a zenith super orizontem. Et quod ceteris paribus quanto stella est a terris remotior, tanto huius diversitas est minor et e contra. Ideo, parva est in sole et in superioribus planetis et totum hoc leviter patet in figura. Et sit *a* centrum mundi, *b* est visus, *c* stella inferior, et *d* superior. Et appareant *c* et *d* in *g* loco. Cum, igitur, *c* sit in *e*, et *d* in *f*, maior *L* fol. 38r est arcus *ge* quam *gf*. Igitur, *c* videtur remotior | a suo loco quam *d*. Et hoc diffusius tractat PTHOLOMEUS in quinto Almagesti, et ideo breviter pertransivi. Et ex notitia huius diversitatis posset investigari distantia lune a centro mundi.

[Conclusio 2: Parallax stellarum comatarum] Secunda conclusio, quod stella comata non videtur in loco ubi est, scilicet, sub stella fixa sub qua est, nisi sit supra zenith. Potest statim probari eadem ratione qua prima. Et adhuc maior est diversitas aspectus comete quam lune, quia est in regione aeris, ut dicitur inferior ipsa luna.

[Corollarium 1: Stellae caeli sint comatae] Ex hoc sequitur corellarie. Primo, quod si stelle celi taliter sint comate, ut dicit ARISTOTELES, quod stella est in celo, et coma in aere, tunc coma non est sub stella sub qua apparet, nisi esset supra zenith. Sed valde

1 cum] et *V* | a] ad *V* | zenith] cenith *B*; cenit *F* 2 quanto] quantum *V* 3 huius] huiusmodi *V* | Ideo] Igitur *V* 4 figura] *post* figura *add.* superiorem *F* 5 est] *om. BFL* 6 appareant] *post* appareant *add. et del.* [?] g *F* 7 ge] eg *V* | Igitur] Ergo *L* | remotior] remotius *BFL* 8 Et] *post* Et *add.* de *BF* | tractat] pertractat *V* | Ptholomeus] THOLOMEUS *F* | quinto] libro *F* | Almagesti] Amagesti *L* | et] *om. BFL* | ideo] *post* ideo *add. et del.* diffusius *V* 9 breviter] brevius *B*; *sup. l. V* | pertransivi] transivi *V* | Et] et *sup. l. V* | huius] huiusmodi *V* | diversitatis] diverssitatis *L* | posset] potest *F* 10 a] ad *V* | centro] centrum *V* 12 comata] *add.* quod *L* 13 supra] sup *[sic] L* | zenith] cenith *BF* 14 adhuc] aduc *F* 15 ut] et *V* | dicitur] *post* dicitur *add.* et *B* 17 corellarie] correlarie *B* | taliter sint] sint taliter *F* | sint] sunt *corr. in mg.* sint *B* 19 supra] super *L* | zenith] cenith *B*; cenit *F* | Sed] Et est *V*

8 Cf. PTOLEMY, *Almagest*, V, cap. 11–12, et 17–19. 18 ARISTOTLE, *Meteorologia*, Bk. I, ch. 6 (343b8–25), and Bk. I, ch. 7 (344a34–344b15).

the nearness of the "star"[19] to the earth, with its distance from the zenith over the horizon. All things being equal, the more remote the star is from the earth, the smaller is its parallax [*diversitas*], and vice versa. Therefore, the parallax of the sun and the superior planets is small. All this is easily understood in the following figure. [Figure 1] Let *a* be the center of the world, *b* the observer, *c* a lower star, and *d* a higher one. Let *c* and *d* appear in the place *g* according to the observer. Therefore, since the true place of *c* is in *e*, and the true place of *d* is in *f*, arc *ge* is greater than arc *gf*. Thus *c* is seen further from its true place than *d* is.[20] And Ptolemy discusses this more lengthily in the fifth book of the *Almagest*, and therefore it is passed over briefly here.[21] From the knowledge of this parallax, we could have investigated the distance of the moon from the center of the world.[22]

[Conclusion 2: Parallax of Comets] The second conclusion: that a comet [*stella comata*] is not seen in the place where it truly is – that is, under the fixed star under which it truly is – unless it is over the zenith. This can be proved immediately for the same reason as the first [conclusion]. And further, the parallax of a comet is greater than that of the moon, since it is in the region of the air and is considered lower than the moon itself.

[Corollary 1: "Fixed Star" Comets] Corollaries follow from this. First, that if heavenly stars help compose one part of comets, such that, as Aristotle says, the star itself is in the heaven, while the coma [i.e., the nebulous "hair"] is in the air, then the coma is not actually under the star under which it appears to us, unless the comet were over the zenith. Rather, the coma appears very remote from the star

[19] Note here that "star" [*stella*] can refer to any celestial object.

[20] That is, *c*, the closer star, has a greater parallax than the more distant star *d*. For Oresme, the "place" of stars *c* and *d* (what I translate as "true place") is along the line of sight from the center of the world. This is not mere relative positioning. In the Aristotelian universe, there is both absolute direction and absolute place.

[21] Cf. Ptolemy's *Almagest*, book v; those chapters dealing with parallax are ch. 11–12, and 17–19.

[22] Oresme also has a similar discussion of the problem of stellar parallax in his *Questiones super quatuor libros meteororum*, Book 3, question 12, as noted by McCluskey in his dissertation, McCluskey (1974), *Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, lines 343–355, pp. 158–159, and pp. 413–414, n. 35. Because of the novelty of including such a discussion of stellar parallax in a commentary on the *Meteora*, McCluskey concludes (for this and other reasons) that Oresme was well versed in such material, and therefore the *De visione stellarum* was written before his commentary on Aristotle's *Meteora.*, ibid., pp. 52–53, and 413–414, n. 35.

remote apparet a stella cuius est coma, et apparet sub una alia stella, deinde sub alia vario modo.

Ideo forte talis coma non sit per inflamationem, sed per colorationem ex refractione visus, sicut halo et hoc innuit ARISTOTELES. Et tunc, sequitur quod materia eius est circumquaque diffusa occupans maximam partem aeris, et apparet ille color in modica parte illius materie, et modo in una parte, et post in alia, sicut halo.

[Corollarium 2] Secundo, sequitur quod cometa que fit per inflammationem aliquando movetur ad occidentem. Et pro tunc stella sub qua apparet, movetur versus orientem. Et ita est de coma, si sit per inflammationem, et moveatur motu diurno. Probatur, quia possibile est quod cometa appareat ad septemtrionem in directo unius stelle, vel iuxta stellam, que est sub axe mundi, scilicet, pro-

1 remote] *add.* ubi *V* | a] *om. V* | alia stella] stella alia *V* 2 vario] *del.* vario(?) *et add. sup. l.* alio *V* 3 per] *om. F* 4 refractione] reflexione *V* | halo] haly *L* | et] *add. et del.* ex, *add. sup. l.* et *V* | hoc] *post* hoc *add. et del.* rv(?) *F* 5 tunc] *add. et del.* hoc *V* | diffusa] difusa *L* 7 et] *om. F* | post] postea *L* 8 Secundo] *ante* Secundo *add. et del.* Secundum corellarium *V* 9 inflammationem] inflamationem *L* | pro] *om. B* 11 sit] fit *V* | inflammationem] inflamationem *L* 12 appareat] *post* cometa *add. et del.* apparet; *add.* appareat *sup. l. V* 13–90.1 scilicet propinquior] *rep. L*

4 Cf. ARISTOTLE, *Meteorologia*, Bk. I, ch. 7 (344b5–10).

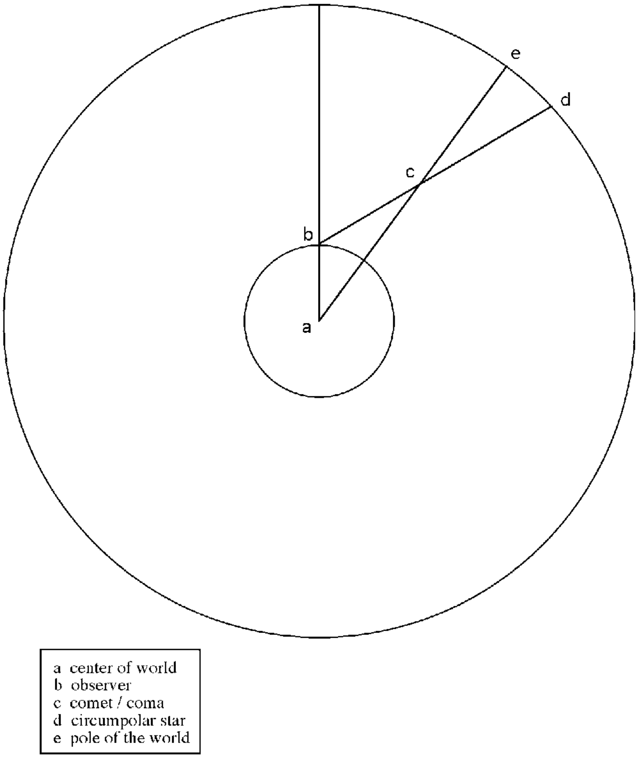

Figure 2. 'Fixed Star' Comet composed of a Circumpolar Star with its Coma in the Atmosphere

to which it truly belongs, and it appears to us now under a different star, and next under still another star by a different means.[iii]

Therefore, perhaps such a coma is not brought about by being set afire [*inflamatio*] but by coloring due to the reflection [*refractio*] of our vision, just like a halo – and Aristotle states this.[iv] Thus it follows that its matter is spread out all around, occupying the largest portion of the atmosphere, and the color appears in only a small part of that matter, now in one part, and later in another, just like a halo.

[Corollary 2] Second it follows that a comet which is produced by being set afire [*inflammatio*] [in the atmosphere by a star] is sometimes moved towards the west, as the star under which it appears is moved towards the east.[v] And this is true of the coma, if it was made by being set afire, and it moved with a daily motion. This is proved because it is possible that a comet might appear in the north, directly under a star (or near a star) that is below the axis of the world, that pinquior orizonti quam sit polus. Et, tamen, cometa sit circa axem mundi, quo posito. Et cum hoc supposito quod cometa moveatur ad motum celi, sequitur quod cometa tendit ad occasum. Et pro tunc stella sub qua videtur regre[d]at ad ortum, et est de stellis sempiterne apparitionis. Patet statim exemplo. Sit *a* centrum mundi, et *b* visus, et [*F* fol. 32^{r} *L* fol. 38^{v}] *c* cometa, *e* polus, et *d* | sit stella sub | qua cometa videtur. Protrahatur que linea *ac* et linea *bcd* et clare statim patet propositum.

[Corollarium 3] Tertio supposito, ut prius, quod cometa moveatur motu diurno, sequitur quod, quando est inter zenith et polum, vel supra zenith, scilicet in linea meridionali, apparet propinquior polo quam in aliqua alia hora. Et cum venit ab ortu videtur appropinquari polo, et videtur ab eo elongari, quando tendit ad occasum [*V* fol. 41^{v}] ocasum. Et hec | est ex parte, et propter hoc multi crediderunt cometam deviare a motu diurno, et attrahi ab aliquo planetarum. Et non erat ita aut saltem non tamen, nec taliter deficiebat a motu diurno, quantum eis videbatur.

[Corollarium 4] Quarto sequitur quod circulus quem describit apparet obliquus, et opponitur visui oblique cuius dyameter de meridie ad septemtrionem opponitur visui oblique, et dyameter de [*B* fol. 32^{r}] ortu ad occasum opponitur visui recte, ideo, apparet | longior quam alia. Ideo, motus eius, si est regularis, apparet irregularis, et si est irregularis apparet regularis aliter quam sit.

1 orizonti] orienti *V* | Et] *post* Et *add.* cum *V* | tamen] *sup. l. V* | sit] *sup. l. F* | circa] *post* sit *add. et del.* circa *V*; *add.* contra(?) *sup. l. V* 2 Et] *sup. l. V* | cum] est *L* 3 tendit] tendens *V* | occasum] ocasum *F* 4 qua videtur] qua videtur *mg. B* | regredat] regirat(?) *B*; regneat(?) *vel* regrat(?) *F*; regeat *L*; regnat *V* | sempiterne] septemtrione *add. et del.*, sempiterne *add. in marg. V* 5 apparitionis] aparitionis *F* | exemplo] *om. FV* | mundi] *post* mundi *add. et del.* b visus(?) *F* | et] *om. BL* 6 sit] *om. BV* 7 que] *om. L* | et] *om. L* | statim] *om. BL* | propositum] probo suppositum *L* 8 Tertio] Tertium *V* 9 zenith] cenith *B*; cenit *F* 10 zenith] cenith *BF* | scilicet] *post* scilicet *add. et del.* ita(?) *F* | meridionali] meridonali *F* 11 cum] cum *sup. l. V* | ab ortu] ad ortum *F* 11–12 appropinquari] adpropinquari *F* 12 occasum] ocasum *F* 13 parte] partum *BFV* | propter] proptter(?) *L* 13–14 cometam] cometa *L*; *post* cometam *add. et del.* debeare(?) *F* 14–15 et … diurno] *om. F*; a "homoeoteleuton" where ms. *F* skips to the next occurance of "diurno". Thus neither *B, L* nor *V* could have relied upon *F* (or at least not solely on *F*). 14 attrahi] atrahi *L*; *add. et del.* (?) *V*, attrahi *add. sup. l. V* 17 sequitur] *add.* et *V* | quod circulus] quod circulus *om. et add. in mg. V* 18 et] quia *V* | oblique] *post* visui *scr. et del.* (?), *add.* oblique *sup. l. V* | cuius] *ante* cuius *add.* et *V* 19–20 visui … recte] *om. et add. sup. mg. V* 19 dyameter] diameter *F* 20 occasum] ocasum *F* | opponitur] opponit *V* 20–21 quam alia] *scr. et del.* quam (?), *add.* quam alia(?) *in mg. V* 21 regularis] reglaris *F* | irregularis] inregularis *L* 22 irregularis] inregularis *L* | regularis] inregularis *L*; iregularis(?) *F*; et *add. sup. l. V*; *om. B*

is, it is nearer to the horizon than the pole is. As was posited, the comet is near the axis of the world. And from the supposition that the comet is moved with the [daily] motion of the heavens, it follows that the comet tends to set toward the west. And yet the star, under which the comet is seen, goes back toward the east, and is among the circumpolar stars.[23] This is immediately clear from this example [Figure 2]: Let *a* be the center of the world, and *b* the observer, and let *c* be the comet, and *e* the pole of the world. And let *d* be the star under which the comet is seen. By drawing lines *ac* and *bcd*, the proposition is clearly obvious at once.

[Corollary 3] Third [corollary]. Having assumed, as before, that a comet may be moved with a daily motion, it follows that when it is between the zenith and the pole, or over the zenith (that is, on the meridian) it appears nearer the pole than at some other time. And whenever it happens to be rising, it seems to be drawn near to the pole, and it seems to be separated from the pole when it begins to set. And because of this, many believed a comet to deviate from its daily motion and be attracted by some of the planets. And this was not so, or at least not in such a way that it was lacking in its daily motion as much as it seemed to them.

[Corollary 4] Fourth, it follows that a comet describes a circle that appears oblique and is set obliquely before the eye. The circle's diameter along the north-south meridian[24] is set obliquely to the observer, and its diameter from east to west is straight, therefore one diameter appears longer than the other. Thus, if the comet's motion is regular, it appears irregular, and if its motion is irregular, it appears "regular" in another way than it actually is.

[23] Literally, "among those stars that are always visible" (de stellis sempiterne apparitionis).

[24] Literally, "from the meridian to the north."

[Corollarium 5] Quinto sequitur quod quandoque cometa est sub stella sempiterne apparitionis, et, tamen, cometa oritur et occidit, similiter, apparet sub stella sempiterne apparitionis. Unde, si nubes, apparens nobis sub polo, moventur motu diurno, orirentur et occiderent. Eodem modo, possibile est quod cometa appareat recte sub polo, et tunc, in rei veritate sit circa axem mundi et sub stella que *L* fol. 39[r] est inter polum et zenith. Ideo, cometa movetur versus oc|casum. Et

1 sequitur] *om. BFL* | quandoque cometa] cometa quandoque *L* 2 sempiterne] *scr. et del.* septemtrione, *add.* sempiterne *sup. l. V* | apparitionis] aparitionis *F* | cometa] *sup. l. V* 3 sub stella] *om. L* | sempiterne] *scr. et del.* septemtrione, *add.* sempiterne *sup. l. V* | apparitionis] *post* apparitionis *add.* et tam oritur et occidit *V* | nubes] nubes *corr. ex* nobes *V* 4 apparens] appareret(?) *V*; aparens *F* | polo] *post* polo *add.* et *sup. l. V* | moventur] moveretur *F* | orirentur] orireretur *B*; oriretur *L*; *add. sup. l.* orirentur *a.m. V* 4–5 occiderent] occideret *BL*; ocideret *F* 5–6 recte sub polo] sub polo recte *F* 6 sit] est(?) *V* | circa] *scr. et del.* circa(?), *add.* circa *sup. l. V* | axem] axis *L* | stella] stela *L* 7 est] *om. F* | zenith] cenith *B*; cenit *F*

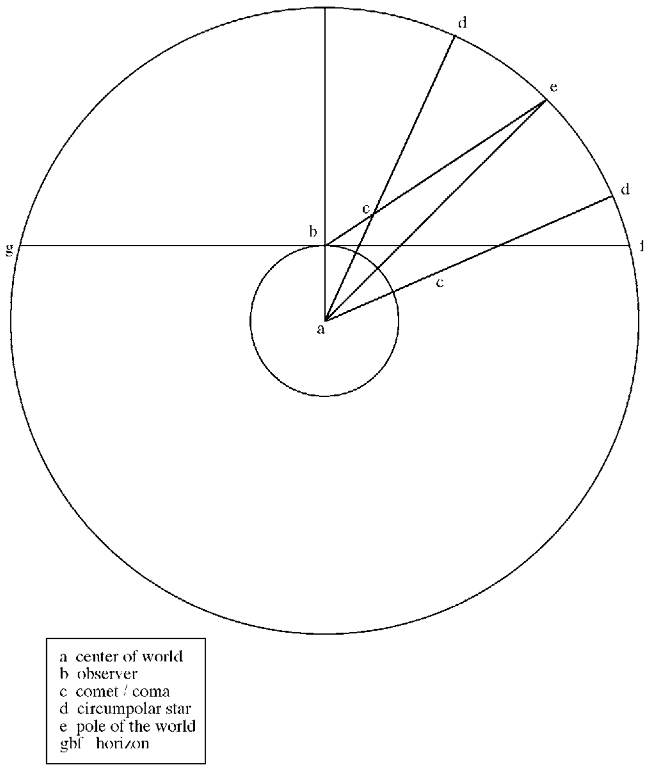

Figure 3. 'Fixed Star' Comet composed of a Circumpolar Star with its Coma in the Atmosphere. While the star always stays above the horizon, the coma may fall below the horizon

[Corollary 5] Fifth, it follows that sometimes a comet is under a circumpolar star, and yet the comet rises and sets and appears in the same way under the circumpolar star. Thus if clouds, which appear to us to be under the pole, are moved with a daily motion, they might rise and set. In the same way, it is possible that a comet might appear to us to be directly beneath the pole,[25] and yet in truth it may actually be circling the axis of the world and under a star which is between the pole and the zenith. Therefore, the comet will be[26] moved towards the west. And when the star (which the comet is actually under) is[27]

[25] I.e., directly under the pole star itself.
[26] Literally "is".
[27] Literally "was" or "may have been".

cum stella sub qua est fuerit sub axe mundi in linea meridionali, stella apparebit et cometa erit sub orizonte, propter eius propinquitatem ad terram.

Verbi gratia sit *a* centrum mundi, *b* visus, *c* cometa, *e* polus, et *d* stella sub qua est cometa. Et *gbf* sit superficies orizontis, pro trahantur que linea *ae*, et linea *bce*, et linea *acd* super axem mundi, et iterum linea *acd* sub axe. Et patet propositum.

[Corollarium 6] Sexto ut prius sit cometa septemtrionalis a zenith capitis, tunc sicut dictum est circulus quem describit apparet obliquus, et dyameter longitudinis videtur maior quam dyameter

1 fuerit] fuit *F* | in] et *L* 2 erit] *scr. et del.* apparebit, *add.* erit *sup. l. V* | propter] propositus(?) *L* 3 terram] centrum *L*; *post* centrum *add.* ut patet in haec figura *L* 4 Verbi gratia] *om. L* | a] *post* a *add.* circa *B* 5 cometa] *post* cometa *add.* c *L* | Et] *om. L* | gbf] bgf *V* | sit] *post* sit *add.* (et?) *F* | superficies] *post* superficies *add. et del.* planities *V* | orizontis] orizonti *F* 6 bce] bcde *V* | super axem mundi] *om. F* | mundi] *om. V* 8 Sexto] *post* Sexto *add.* sequitur *V* 9 zenith] chenith *B*; cenit *F*; cenith *L* 10 dyameter] diameter *F* 10–96.1 videtur…latitudinis] *om. L* 10 dyameter] diameter *F*

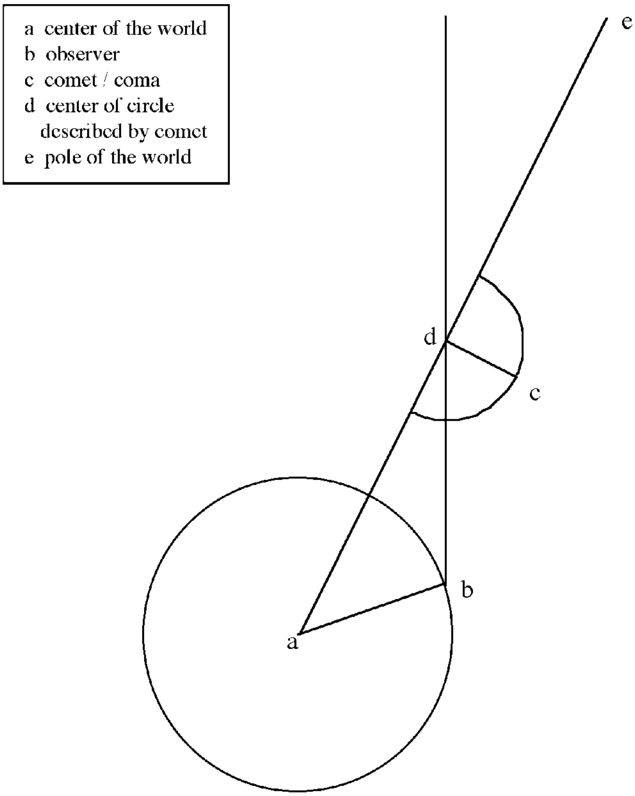

Figure 4. A cirumpolar comet whose orbit describes a circle as seen from the center of the world. As seen by observer *b*, the center of the circle will appear nearer the horizon and the circle will appear as an ellipse. (Cf. Figure 5a for a modern 3-dimensional view

underneath the axis of the world and on the meridian line, the star will [still] be visible, but the comet will be under the horizon, because of its nearness to the earth.

For example [in Figure 3], let *a* be the center of the world, *b* the observer, *c* the comet, *e* the pole, and *d* the star which the comet is under. And let *gbf* be the surface of the horizon, and draw lines *ae* and *bce*, and draw line *acd* both above the axis of the world and again below the axis. And the proposition is clear.

[Corollary 6] Sixth, as before, let a comet be north of the zenith overhead; then, as was said, the circle that it describes appears oblique, and the diameter of the longitude seems greater than the diameter of the latitude.[vi] Also it follows that the center of this circle latitudinis. Sequitur etiam quod centrum huius circuli apparet inferius, et videtur orizonti propinquius quam polus.

Sit ut prius *a* centrum, *e* polus, *b* visus, *d* centrum circuli quam describit cometa, tunc *d* est in linea *ae*. Et quia est propinquum terre, patet quod linea *bd* magis inclinata est super orizontem quam axis mundi.

[Conclusio 3: Quod stellae comatae septemtrionalis altitudinem invenire sit.] Tertia conclusio: quod stelle comate altitudinem invenire sit, si, tamen, cometa huiusmodi taliter sit septemtrionalis, quod aut totus circulus quem describit aut maior pars ipsius sit super orizontem nostrum, quod opportet si centrum huius circuli sit super orizontem.

Tunc ante omnia inveniendus est locus in celo quem terminat linea exiens a visu per centrum illius circuli in celum. Et hoc est invenire elevationem huius centri super orizontem.

Cum, ergo, maior portio huius circuli sit super orizontem, signetur punctus huius circuli propinquior occidenti, scilicet, in quo *F* fol. 32v cometa per instrumenta apparet remotior a polo, | et in quo incipit reg[rede]re ad orientem et apparet reapproximari polo. Et sit *L* fol. 39v ille punctus *l*, et consimiliter, a parte orientis sig|netur talis punctus a quo apparet remotior, etc. Et sit *k* quod potest fieri una nocte

1 quod] quod *rep. F* | huius] huiusmodi *V* 2 propinquius] propinquus *L* 3 quam] quem *BF* 4 propinquum] propinquior *V* 5–11 quam … orizontem] *om. L* [omission of passage because scribe jumped from the word "orizontem" to the same word several lines below] 8 quod] *sup. l. V*; est *B*; *post* quod *add.* que(?) *sup. l. F* 9 sit] *scr. et del.* sit, *add.* est possibile *sup. l. V* | si tamen] *scr. et del.* inde(?), *add.* si tamen *sup. l. V*; *om. F*; *post* sit *add.* causa(?) *vel* tam(?), *et add. et del.* ta *F* | cometa huiusmodi] huius cometa *B*; huiusmodi cometa *F* | taliter sit] *sup. l. V* | sit] *om. B* 10 sit] *om. F*; *sup. l. V* 11 nostrum] *scr. et del.* mundi(?), *add.* nostrum *V* | huius] huiusmodi *V* 13 ante omnia] ante omnia *rep. et del. F* | quem] quam *L* | terminat] *scr. et del.* fiat terra, *add.* terminat *sup. l. V* 15 elevationem] *add. sup. l. V* | huius] huiusmodi *V* | centri] centri *corr. ex* centrum *V* 16 Cum … orizontem] *om. L* [Again the Lilly scribe, or his predecessor omits a phrase skipping from "orizontem" to "orizontem"] | portio] proportio *V* 17 propinquior] *del.* proprior *add.* propinquior *in mg. F* | scilicet] *om. V* 18 cometa] *post* cometa *add.* sit *sup. l. V* | instrumenta] instrumenta *corr. ex* instrumentam *F* | a polo] a celo suum a polo *F* | et] et *rep. et del.* F; *om. V* | in] *om. BL* | quo] *ante* quo *add.* in quo *in sup. mg. F* 18–19 incipit] *post* incipit *add. et del.* i *F* 19 regredere] regirare *BFL*; regnare *V* | apparet] *om. F*; appareret *L*; apparet, *et add.* appropriare(?) *aut* approximare(?) *sup. l. V* | reapproximari] approximari *F*; reaproximari *L*; approximari *corr. ex* reapproximare *V* 21 a quo] *add.* vel in quo *in mg. F*; in quo *V* | etc] *om. B*; *scr. et del.* etc.(?) *V*

appears lower [in the heavens than it truly is], and it seems nearer the horizon than the pole.[28]

As before, let *a* be the center of the world, *e* the pole, *b* the observer, and *d* the center of the circle which the comet describes; then *d* is on line *ae*. [Cf. Figure 4] And because the center of the circle is near the earth, it is clear that line *bd* is more inclined than the axis of the world.

[Conclusion 3: Finding the altitude of a circumpolar comet.] Conclusion three: One may discover the altitude of a comet star, if the comet is of such a kind that it is in the north and describes either an entire circle or the greater part of a circle above our horizon – which is necessarily so if the center of the circle is above the horizon.

Then before anything else, one finds the place in the heaven where a line terminates which goes from the eye through the center of that comet's circle in the heaven – this is to discover that center's elevation above the horizon.

Therefore, since the greater part of this circle is above the horizon, let the center point of this circle be designated nearer the west – that is, when the comet appears further from the pole through instruments, and when it begins to turn towards the east and appears to return towards the pole again.[vii] And let that point [where the comet begins to turn back] be *l*, and similarly let a point be designated from which it appears more remote from the eastern portion, etc. [Cf. Figure 5 and 5a] And let point *k* (which can occur

[28] While the center of the ellipse would, indeed, appear lower in the sky to a (non-polar) observer on earth, whether this center would appear nearer the horizon than the pole depends entirely on the latitude of the observer and the height of the comet in the atmosphere. An observer near the earth's north pole with a comet high in the atmosphere would see the center of the ellipse nearer the pole than the horizon.

longiore quam sit dies, ita quod hec duo puncta terminant dyametrum huius circuli apparentem longiorem, que est *kl*.

Quando, igitur, cometa videbitur inter zenith et polum, vel supra zenith in linea meridionali, tunc sub eadem linea meridionali ymaginetur linea a cometa ad usque ad medium dyametri *kl*, et ille *V* fol. 42^{r} punctus medius sit *d*, quem dico esse centrum circuli | quem cometa

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1 longiore] longior(?) *V* | sit] *om. FV* | dies] *post* dies *add.* et(?) sit *F* | quod] que *B* 1–2 dyametrum] diametrum *F* 2 kl] ka *V* 3 zenith] cenith *BF* 4 zenith] cenith *BF*; *add.* scilicet *V* 5 ymaginetur] imaginetur *F*; ymaginitur *L* | ad usque] *om. BL* | usque] *in mg. F* | dyametri] diametri *F*

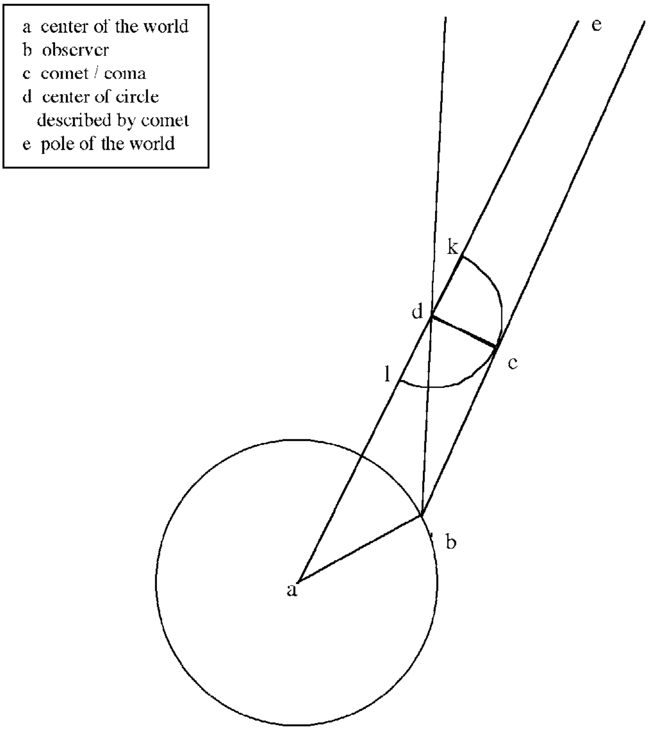

Figure 5. A cirumpolar comet whose orbit describes a circle *kcl* as seen from the center of the world. As seen by observer *b*, the center of the circle will appear nearer the horizon and the circle will appear as an ellipse. (Cf. Figure 5a for a modern 3-dimensional view)

on a night longer than a day) be such that these two points, *kl*, are the termini of the diameter of this circle which appears longer [to observer *b*].[29]

When the comet is seen between the zenith and the pole (or directly above the zenith on the meridian), then, under the same meridian, imagine a line from the comet to the middle of diameter *kl*, and let that mid-point be *d*, which I say is the center of the circle

[29] That is, to the observer, the comet's circular orbit appears to be an ellipse with its major axis being the East-West line *kl*.

describibit. Et linea *cd* a cometa ad illum punctum est perpendicularis super axem mundi, et linea *bd* ulterius protensa ostendit locum apparentie huius centri in celum, et que sit elevatio super orizontem.

Quo habito fiat alia figura, sit *a* centrum mundi, et *b* visus in superficie terre, *c* cometa, *d* centrum circuli a cometa descripti, sit *e* polus | *B* fol. 32v mundi, et *g* zenith capitis, sit *h* punctus in superficie terre directe sub cometa, et *q* punctus in eadem superficie directe sub polo, et *k* punctus celi sub quo apparet cometa, et *p* verus locus

1 cometa] *post* cometa *add.* usque *V* 2 protensa] protenssa *L* 3 huius centri] *om. V* | in] *sup. l. V* 4 fiat] *post* fiat *add. et del.* illa *V* | alia] *om. V* | figura] *post* figura *add.* ut inferius patet *L* | visus] *post* visus *add. et del.* et *F* 5 descripti] descriptum *V* 6 zenith] cenith *BF* | sit] et *V* 8 celi] *post* celi *add. et del.* se(?) *F* | quo] *om. B*

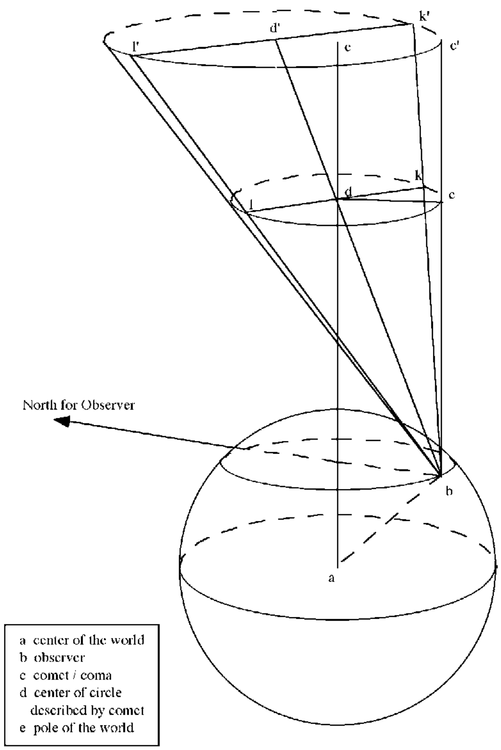

Figure 5a. A cirumpolar comet whose orbit describes a circle *kcl* as seen from the center of the world. Its orbit as seen by observer *b* is described by the ellipse *c'l'k'*. This is a 3-dimensional depiction of Oresme's Figure 5

which the comet describes. And line *cd*, from the comet to that point, is perpendicular to the axis of the world. And further, line *bd*, when extended, shows where this center appears in the heaven, which is the elevation [of the comet] over the horizon.

Knowing this,[30] let another figure be made [Figure 6]: let *a* be the center of the world, *b* the observer on the surface of the world, *c* the comet, and *d* the center of the circle which the comet describes. Let *e* be the pole of the world, *g* the zenith overhead, *h* the point on the surface of the earth directly under the comet, and *q* the point on the same surface directly under the pole. And let *k* be the point

[30] That is, knowing the angular elevation of the center of the circumpolar comet's orbit.

comete. Et sit cometa in linea meridionali, protrahantur que linee, ut patet in figura. Et cum hoc linea *bf* sit linea per quam videmus polum, que est quasi equidistans ab axe mundi, eo quod terra respectu octave sphere est sicut punctus.

1 Et] *post* Et *add. et del.* sicut *F* | ut] que *V* 2 patet] patent *V* | figura] *post* figura *add.* immediata pro prescripta *F* | cum] *om. L* | quam] quem *F* | polum] *post* polum *add.* b et q *V* 3 quasi] *om. V* | ab] *om.* | axe] axi *BFL*

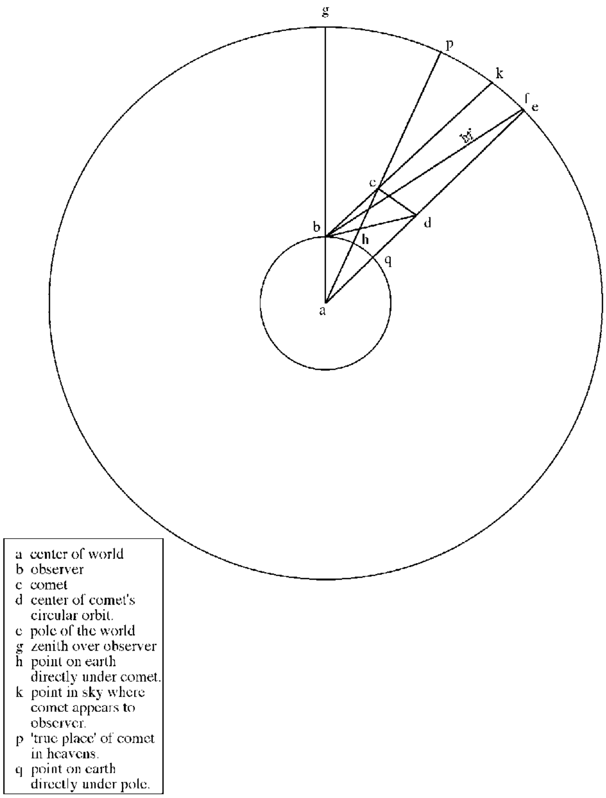

Figure 6. A geometric proof to determine the height of a comet above the earth, and its 'true' location ('p') as projected onto the sphere of the fixed stars

in the sky under which the comet appears, and *p* the true place of the comet. And let the comet be on the meridian, whose lines may be extended, as is clear in the figure. And therefore the line *bf* is the line along which we see the pole, which is nearly equidistant from the axis of the world,[31] because the earth is as a point with respect to the eighth sphere.[32]

[31] This phrase could be interpreted to mean either that lines *bf* and *ae* (the axis of the world) are nearly parallel or nearly the same line. For his proof below, Oresme assumes the two lines are nearly parallel.
[32] The eighth sphere was normally considered the sphere of the fixed stars in the Middle Ages.

[Primo imago] Primo, ergo, ymaginetur triangulus *abd*. Et quia ut premittitur linea *bf* et linea *ae* sunt equedistantes erit per vicesimam nonam [= 29^{am}] primi [libri EUCLIDIS], angulus *gae* vel *bad* quod idem est equalis angulo *gbf*. Et iste angulus *gbf* est notus, quia secundum ipsum distat zenith a polo. Igitur, angulus *bad* erit notus. Similiter, angulus *dba* est notus, quia elevatio *d* super orizontem per preambulum est nota. Igitur, reliquus angulus erit notus, qui cum *L* fol. 40^{r} eis valet duos rectos. Et latus *ba* quod est semi|dyameter terre est notus, ut supponitur. Igitur, reliqua latera erunt nota, quod patet dupliciter. Primo, quia anguli sunt noti, et earum proportio nota, igitur si triangulus esset inscriptus circulo, proportio arcuum angulis

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1 ymaginetur] imaginatur *F* | Et] *om. V* 2 premittitur] premititur *L*; pre(?)titur *F* | equedistantes] equadistantes *B* 2–3 vicesimam nonam] 59^{am}, *et add.* 29^{am} *sup. l. V* 3 angulus] *om. B* | gae] gad *V* 4 iste] ille *V* 5 distat] *post* distat *add. et del.* quia(?) *F* | zenith] cenith *B*; cenit *F* | erit] erit *corr. ex* est *L* 6 super] supra *V* 6–7 per preambulum] per preanbulum *F*; *scr. et del.* per quem angulum, *add.* per triangulum *sup. l. V* 7 Igitur] Ergo *V* | reliquus] relinquus *L* | erit] est *L* 8 semidyameter] semidiameter *F* 9 notus] notum *BV* 10 earum] eorum *V* 11 esset inscriptus] esse inscripturi *L*

3 EUCLID, *Elements*, lib. I, prop. 29.

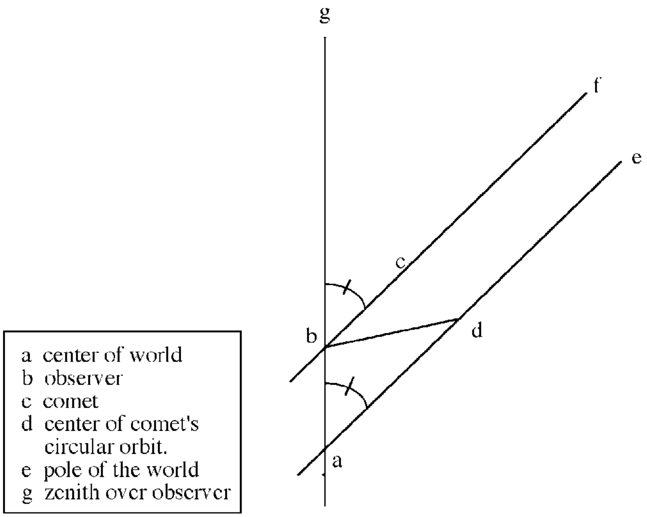

Figure 6a. Lines to the pole (e & f) from both the observer (b) and the center of the earth (a) are assumed parallel for the proof because the earth is a mathematical point in comparison to the sphere of the fixed stars

[1st Conceptual Image][33] First, therefore, imagine triangle *abd.* And since lines *bf* and *ae* are equidistant (as presented above), it will be known from Euclid's *Elements,* Book 1, prop. 29, that angle *gae* or *bad* (which are the same) is equal to angle *gbf.* [Cf. Figure 6 and 6a] And that angle *gbf* is known, because it itself is the [angular] separation of the zenith from the pole. Therefore, angle *bad* will be known. In the same way, angle *dba* is known, because (from the preceding) the elevation *d* above the horizon is known. Therefore the remaining angle will be known, which, when added to those [angles], has the value[34] of two right [angles]. And side *ba,* which is the radius of the earth, is known (as is assumed). Therefore, the remaining sides will be known, which is proved in two ways. First, the angles are known and their proportion is known. Thus if the triangle were inscribed in a circle, the proportion of the arcs of the

[33] Oresme refers to these "conceptual images" as "imaginings" (*ymaginatio*).

[34] Oresme seems to be transferring the idiomatic use of "valeo" concerning money ("to be worth, to have value") to purely numerical "value". This same usage has come down to modern English as well.

correspondentium esset nota. Ergo et cordarum, scilicet, laterum trianguli proportio esset nota per scientiam de sinibus et cordis. Et cum unum latus est notum, igitur reliqua erunt nota.

Item per undevicesimam [= 19^{am}], sexti [libri] Euclidis potest fieri triangulus similis isti ubilibet, ideo, latera huius et illius erunt proportionalia. Per quartam, sexti [libri] Euclidis sed proportio laterum illius per mensuram practicam poterit inveniri. Ergo, proportio laterum istius *abd* erit report[at]a et | *F* fol. 33^{r} scita. Et sicut prius, latus *ba* est notus, igitur reliqua latera erunt nota. Ergo, linea *bd* et linea *ad* sunt note in comparatione ad semidyametrum terre quam supponimus esse notam.

[Secundo imago] Secundo ymaginatur triangulus *bdc* cuius angulus *cbd* est notus, secundum quem est distantia comete a centro circuli quem describit. Et similiter, angulus *cda* est notus, quia est rectus eo quod *cd* est perpendicularis super axem mundi. Et angulus *bda* qui est eius pars est notus per precedentem ymaginationem, ergo, residuum erit notum, scilicet, angulus *cdb* trianguli nunc ymaginati. Igitur, huius trianguli duo anguli sunt noti, igitur tertius angulus erit notus. Et iam ex precedenti ymaginatione habemus quod latus *bd* est notus, igitur arguendo sicut prius latera *bc* et *cd* erunt nota in comparatione ad semidyametrum terre.

[Tertio Imago] Tertio ymaginetur triangulus *abc* cuius latus *ba* est notum ut supponitur. Et similiter, latus *bc* ex precedenti ymaginatione, et etiam angulus *cba* est notus. Quia elevatio comete

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1 correspondentium] *add.* correspondens *sup. l. V* 2 sinibus et] *add. sup. l. V* 3 cum] *om. BFL* | est] erit *V* | notum] notus *FL* | igitur] ergo *L*; *om. V* 4 undevicesimam] decimam [= 10^{am}] *L* | Euclidis] *om. BFL*; *add. sup. l. V* 5 fieri] *om. F* | triangulus] angulus *V*; *post* triangulus *add.* fieri *in mg. F* | ubilibet] ubique *V* | huius] huiusmodi *V* 6 Euclidis] *om. BFL*; *add. sup. l. V* 7 poterit] poteris(?) *V* | Ergo] *post* Ergo *add.* etiam *F* 8 istius] illius *V* | reportata et] *om. L* 9 notus] notum *B* | igitur] Ergo *L*; *scr. et del.* alia *add.* Igitur *sup. l. V* | erunt] *scr. et del.* (?) *add.* erunt *sup. l. V* | Ergo] Igitur *BF* 10 linea] *om. V* | semidyametrum] semidiametrum *F*; *post* semydyametrum *scr. et del.* id est(?) *L*; semydyametrum *V* 11 supponimus] *scr. et del.* superius(?) *add.* supponimus *sup. l. V* 12 ymaginatur] imaginatur *F*; ymaginetur *BV* | bdc] bcd *V* 13 a] *scr. et del.* (?) *add.* a *sup. l. V* 14 rectus] *scr. et del.* rationis *add.* rectus(?) *sup. l. V* 16 qui] que *F* | notus] notus *rep. et del. F* | ymaginationem] imaginationem *F* | ergo] igitur *V* 17 ymaginati] imaginati *F* 18 igitur] ergo *L* | angulus] angulis *L* | erit] est *L* 19 notus] *om. L* | precedenti] precedanti *L*; priore *V* | ymaginatione] imaginatione *F* | bd] db *B* 21 comparatione] comperatione *L* | semidyametrum] semidiametrum *F* 22 ymaginetur] imaginetur *F* 23 notum] notus *FL* 24 ymaginatione] imaginatione *F* | etiam] similiter *V* | elevatio] elevate *L*

4 Euclid, *Elements*, lib. VI, prop. 19. 6 Euclid, *Elements*, lib. VI, prop. 4.

corresponding angles would be known, and thus [the proportion] of the chords, that is, the proportion of the sides of the triangle may be known by the science of sines and chords. And since one side is known, the remaining sides will be known.

Likewise, from Euclid's *Elements*, book VI, prop. 19, a triangle can be made similar to this one any place, thus the sides of both will be proportional. But from book VI, prop. 4 of Euclid, the proportion of the sides of that triangle can be found by practical measure. Therefore, the proportion of the sides of the triangle *abd* will be obtained and known. And, as before, side *ba* is known, thus the remaining sides will be known. Therefore, lines *bd* and *ad* are known in comparison to the radius of the earth, which we assume to be known.

[2nd Conceptual Image] Second, imagine triangle *bdc* whose angle *cbd* is known, since it is the comet's [angular] distance from the center of the circle which it describes. And in the same way, angle *cda* is known, since it is "straight", that is, *cd* is perpendicular to the axis of the world. And angle *bda*, which is part of [the right-angle *cda*], is known from the preceding conceptual image, therefore the rest of the right-angle, that is, angle *cdb* (of the currently imagined triangle) will be known. Thus two angles of this triangle are known, therefore the third angle will be known. And now, from the preceding conception, we maintain that side *bd* is known, therefore arguing, just as before, sides *bc* and *cd* will be known in comparison to the radius of the earth.

[3rd Conceptual Image] Third, imagine triangle *abc*, whose side *ba* is known, as is assumed. And, in the same way, side *bc* (from the preceding conceptual image) and angle *cba* are known. Because the super orizontem est nota, ymo iste angulus patet in instrumento, igitur latus *ca* erit notum, quod patet dupliciter. Primo, quia si huius [*L* fol. 40v] triangulus inscribatur circulo, tunc corda *ba* et cor|da *bc* sunt note, [*V* fol. 42v] et angulus *b* | est notus, ergo, arcus cordarum *ba* et *bc* sunt noti. Ergo, arcus residuus erit notus, ergo corda correspondens erit nota, scilicet, *ac* per sciendam de sinibus et cordis, ergo latus *ca* est notus. Vel sicut prius potest fieri faciliter unus triangulus similis ubilibet faciendo angulum equalem angulo *b* per vicesimam secundam [= 22am], primi [libri] [Euclidis], et resecando lineas secundum proportionem *ba* ad *bc*. Et tunc, sicut prius, mensurando inveniantur proportiones laterum illius trianguli, et taliter se habebunt invicem latera trianguli *abc* similis illi. Et latus *ba* et latus *bc* sunt nota, ergo latus *ac* erit notum.

Ex hiis, igitur argumentationibus, cognoscemus plurium linearum quantitates, in comparatione ad semidyametrum terre. Primo quantitatem linee *ad* que est distantia centri circuli, quem describit cometa a centro mundi a qua de parta semidyametrum terre erit. Secundo, residuum notum, scilicet, *qd* que est elevatio cuiusdam centri [*B* fol. 33r] super terram. Tertio, cognoscitur linea *bd* que est distantia visus | a centro circuli predicti. Quarto, linea *bc* que est distantia visus ad cometam. Quinto, linea *cd* que est semidyameter(?) circuli quem cometa describit. Sexto, linea *ac* que est distantia comete a centro mundi, a qua de parta *ah* semidyameter terre restat. Septimo quod residuum erit notum, scilicet, *hc* que est elevatio, seu altitudo comete super terram, quod fuit propositum principale. Protensa que linea

1 ymo] Immo *B* | iste] ille *V* | angulus] angulus *mg. F* 2 igitur] ergo *V* | notum] notus *L* | quia] *post* quia *add. et del.* h *F* | huius] huiusmodi *V* 3 sunt note] sunt note *rep. L* 4 et] igitur *BF*; ergo *L* | b] *add. sup. l. L* | ergo] Igitur *BF* | arcus] angulus *L* | Ergo] Igitur *BF* 5 erit] est *L* | ergo] Igitur *BF* | correspondens] correspondens *corr. ex* respondens *B* 6 de] *add. sup. l. V* | ergo] Igitur *B* | est] erit *F* | notus] notum *B* 7 faciliter] *om. F* 8 angulum] *om. B* | vicesimam secundam] xxi *add.* per 22 *sup. l. V* 11 latera] latera *rep. F* 12 ergo] Igitur *BF* | erit] *scr. et del.* (?) *add.* erit *sup. l. V* | notum] notus *FL* 13 igitur] ergo *F*; *om. V* 14 semidyametrum] semidyametrum *B*; semidiametrum *F* 16 a] ad *V* | centro] centrum *V* | mundi] *scr. et del.* circuli *add.* mundi *V* | de parta] *scr. et del.(?) V* | parta] parto *B* | semidyametrum] semidyametro *B*; semidiametrum *F*; semidyametrus *V* 17 Secundo] *om. BFL* | notum] notus *FL* | scilicet] *post* scilicet *add. et del.* quod *FV* [i.e., may have misinterpreted the letters "*qd*" for "quod".] | qd] *om. V* | cuiusdam] eiusdem *BF*; cuiusdem *V* 17–18 centri] centrum *F*; center(?) *V* 18 cognoscitur] cognoscetur *BL* 19 a centro] *add. sup. l. V* 20 semidyameter] semidiametrum *F* 21 cometa describit] describit cometa *F* 22 a qua de parta] aqua depta *L* | semidyameter] semidyametro(?) *B*; semidiametrum *F* | restat] *post* terre *scr.* Restat septimo *V* [i.e., begins next paragraph] 23 notum] notus *FL* 24 super] supra *B* | fuit] fit *L* | Protensa] Protenssa *L*

9 Euclid, *Elements*, lib. I, prop. 22.

comet's elevation above the horizon is known (indeed, that angle is accessible by an instrument) side *ca* will be known, which is obvious in two ways. First, because if its triangle is inscribed by a circle, then chord *ba* and chord *bc* are known, and angle *b* is known, thus the arcs of the chords *ba* and *bc* are known. Therefore the remaining arc will be known, thus, through the science of sines and chords, the corresponding chord, *ac*, will be known, therefore side *ca* is known. Or, just as before, a similar triangle can be made anywhere, making an angle equal to angle *b* (following Euclid, book I, prop. 22) and by ending the lines according to the proportion of *ba* to *bc*. And then, just as before, the proportions of this triangle's sides are found by measuring in such a way that the sides of triangle *abc* are similar to it. And sides *ba* and *bc* are known, therefore side *ac* will be known.

Thus, from these arguments, we will know the quantities of more lines in comparison to the radius of the earth. First, the quantity of the line *ad* (which is the distance of the center of the circle which the comet describes to the center of the world) is known. Second, the line *qd* (which is the elevation of the center of the comet's circle above the earth) will be known, being the remainder of *ad* minus the radius of the earth.[35] Third, line *bd* is ascertained, which is the distance from the observer to the center of the circle mentioned above. Fourth, line *bc*, which is the distance from the observer to the comet. Fifth, line *cd*, which is the radius of the circle which the comet describes. Sixth, line *ac*, which is the distance from the comet to the center of the world, part of which is the radius of the earth, *ah*. Seventh, that the rest [of the line *ac*] will be known, namely *hc*, which is the elevation or altitude of the comet above the earth, which was the principal that was proposed. And continuously extending line

[35] As the Latin of this sentence is quite convoluted, I have taken certain liberties in translating it into readable English.

ahc in continuum et directum in celum, ipsam terminabit punctus *p* qui est verus locus comete.

Cum, igitur, totalis *bad* sit notus per primam ymaginationem, et similiter, pars eius *bac* per tertiam, ergo altera pars, scilicet, angulus *cad* erit notus. Ergo, arcus sibi correspondens in celo, scilicet, *pe* erit notus. Et hoc est distantia veri loci comete a polo mundi in circulo *F* fol. 33v meridionali. Et quia ista distantia est nota, verus locus | comete erit *L* fol. 41r notus, et | ergo stella sub qua est cometa erit nota. Et cum locus celi ubi apparet sit notus ad sensum, sequitur quod diversitas aspectus ipsius erit nota, scilicet, arcus *pk* inter verum locum ipsius, et locum apparentie.

Et iterum distantia zenith capitis a vero loco ipsius erit nota, scilicet, arcus *gp*. Ergo, arcus sibi correspondens in terra erit notus, scilicet, *bh*. Ergo, locus ubi caderet si recte descenderet erit notus, scilicet, punctus *h*. Et scietur qui homines habent eam super caput. Isti, ergo, arcus ignoti poterunt esse noti, scilicet, *ep* et *pk* et *pg* et *bh*, et similiter, duo loca, scilicet, *p* in celo, et *h* in terra.

Ergo, in summa, ex ista demonstratione fient note itaque res ignote. Verumtamen, correctioni me subicio, quia nescio si defeci, et si non repperi veritatem corrector benignus in eius inventione ex predictis poterit adiuvari. Dum autem apparverit cometa, experimentator diligens operetur hec de primo.

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3 Cum] tunc *V* | igitur] ergo *V* | bad] abd *F* | ymaginationem] imaginationem *F* 4 ergo] igitur *BF* 5 erit] est *V* | Ergo] Igitur *BV* 6 est] *add. sup. l. V* 7 comete] *ante* comete *add. et del.* er *F* | erit] est *V* 8 stella] *scr. et del.* stella *add.* distantia *sup. l. V* 9 sit] sint *F* 12 zenith] cenith *BFL* 13 gp] gb *L* | Ergo] Igitur *BF* | in terra] *scr. et del.* in terra *add.* in celo *sup. l. V* 14 Ergo] Igitur *BF* | caderet] caret *L*; cadent *F* [note: one line below, the scribe of *F* accidently adds and deletes this same phrase "igitur locus ubi caderet", but this time writes "caderet", not "cadent".] 15 scietur] scientur *L* | eam] ea *L* | super] supra *B*; *post* super *add. et del.* igitur locus ubi caderet *F* | caput] capud *F* 16 ergo] igitur *BF* | ignoti] ingnoti *F* | et bh] *om. L* 17 duo loca] duo loca *rep. F* | loca] *scr. et del.* loca *add.* (?) *sup. l., a. m.(?) V* | scilicet] *om. B* | p] *add. sup. l. V* 18 Ergo] Igitur *BF* | fient] *scr. et del.* erunt *add.* fiunt *sup. l. V* | note] *om. B* 19 ignote] ingnote *F* | Verumtamen] Verumptamen *B* 20 repperi] recepi *F*; reperi *L*(?) *V* | corrector] *ante* corrector *add.* cor *F* | in eius] in eius *rep. F* 21 poterit] poterunt *F* | autem] *scr. et del.* (?) *add.* autem *sub. l. V* | apparverit] aparverit *F* 21–22 experimentator] expitor *L*; experentor(?) *V*; *add.* expertor *in mg. V*; *ante* experimentator *add. et del.* experim *F* 22 hec] hoc *F*

ahc into the heaven, it will end at point *p*, which is the true place of the comet.

Therefore, since the measure of the entire angle *bad* may be known through the first imagining above, and, since part of it, angle *bac*, is known through the third imagining, then its other part, angle *cad*, will be known. Therefore, angle *cad's* corresponding arc in the heaven, *pe*, will be known. And this is the [angular] distance along the meridian between the comet's true place and the pole of the world. And because this [angular] distance is known, the true place of the comet will be known, and thus the star that the comet is under will be known. And since the place in the heaven where the comet appears to us is known to the senses, it follows that the parallax between its true and apparent place will be known, i.e., arc *pk*.

Likewise, the distance from the zenith overhead to the true place of the comet will be known – arc *gp*. Thus its corresponding arc on earth, *bh*, will be known. Therefore, the place on the earth where a line falls straight down from the comet will be known – point *h*. And it will be known which people have the comet directly overhead. Thus, those unknown arcs – *ep, pk, pg*, and *bh* – can be known, and likewise the two points, *p* in the heaven, and *h* on earth can be known as well.

In sum, therefore, from this demonstration, unknown things will become known. Nevertheless, I submit myself to correction, because I do not know if I have erred. And if I have not found truth, the kind corrector will be helped in its discovery from what has been said. Moreover, when a comet appears, let the diligent experimenter[36] work these things out from the beginning.[37]

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[36] Or "expert" (expertor) in manuscripts *LV*.

[37] Oresme, perhaps, means the experimenters should busy themselves with determining the center of the comet's orbit by using instruments – the first portion of Conclusion 3. Or, he may even mean that all his hypotheses should be put to the test of experience.

[Liber II]

[Utrum in visione stellarum celorum accidit deceptio ex fractione radii visualis]

[Cap. 1: Probatio conclusionis principalis: omnis stella que non est supra zenith videtur alibi quam sit propter fractionem.]

B fol. 33r *F* fol. 33v *L* fol. 41r *V* fol. 42v | Nunc, igitur, quantum ad secundum principale loquendo de veris stellis celi et perpetuis videndum est si in visione earum accidit deceptio ex fractione radii visualis, et qualiter et propter quid, quedam generalia premittendo.

V fol. 43r Una distinctio est quod quadrupliciter potest fieri | visio: Primo, per lineam rectam. Secundo, per lineam fractam, sicut aliquando denarius videtur in fundo aque. Tertio, per lineam reflexam, sicut in speculo. Quarto, per lineam compositam, secundum multas reflexiones vel fractiones vel mixtim vel per plura specula, et sic diversimode.

Consimiliter distinguendum est de illuminatione et multiplicatione speciei, et virtutis agentis, et de actione qualibet naturali. Et secundum hoc dicunt auctores quod quadruplex est radius, scilicet, rectus, fractus, reflexus, confusus, seu compositus vel accidentalis. *L* fol. 41v Distinguuntur etiam huiusmodi actiones multipli|cationes specie-

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7 Nunc] *ante* Nunc *add. in a.m.* An in visione verarum [*vel* utrum(?)] stellarum accidat deceptio *F* | igitur] ergo *V* | principale] *add. sup. l. V* 8 stellis] stelis(?) *F* | celi] *om. F* | et] *om. L* | earum] earumdem(?) *F*; *post* earumdem *add. et del.* dect *F* | accidit] acciderit(?) *V* 9 fractione] refractione *F*; refractione *corr. ex* fractione *V* | qualiter] qualis *F* 11 Una distinctio] Una distinctio *rep. sub l. V* | distinctio] destinctio *F*; distintio *corr. ex* distantio *L* | est] *ante* est *scr. et del.* radis visualis *L*; *add.* est *sub l. V* | fieri] simul(?) *V* | visio] visio *corr. ex* divisio *L* 12 fractam] fratam *L* 13 lineam] *post* lineam *scr. et del.* per *V* 15 vel] seu *L* | mixtim] mixtia *L* | vel] ut *BF* | plura] alia *F* | diversimode] *om. V* 16 Consimiliter] Consimili *L* | distinguendum] distinguendo *L*; distinguendem *V* | est] *om. L* | illuminatione] inluminatione *F* | et] *add. in mg. V* 17 speciei] specierum *F* | et] vel *V* | Et] *sup. l. V* 18 auctores] autores *F*; doctores *L* 18–19 scilicet rectus] *in mg. V* 19 fractus] *post* fractus *add.* et *F* | reflexus] reflexus *corr. ex* flexus *V*; *post* reflexus *add.* et *F* | seu] sive *F* 20 Distinguuntur] destinguntur *F*; distinguuntur *L* | huiusmodi] huius *BF* | actiones] *post* actiones *add.* et *sup. l. V*

[Book II]

[Whether Deception Occurs in Observing the Celestial Stars Due to Refraction]

[Section 1: Proof of the Principal Conclusion: Any Star Not Over the Zenith is Seen Elsewhere Than It Truly Is Due to Refraction.]

Now, therefore, to the second principal [part of the question] that should be considered: this concerns the true and eternal stars of the heaven, and whether deception occurs in observing them due to the refraction of visual rays.[38] And certain general things are to be presented as to how and why this occurs.

One distinction is that observing can be done in four ways: First, through a straight line. Second, through a refracted line, as when a penny is seen below water.[39] Third, through a reflected line, as in a mirror. Fourth, through a composite line after many reflections or refractions – either through a mixture, or through many mirrors – and thus in many ways.[i]

In the same way, one must distinguish illumination, the multiplication of species, the power of an agent, and any natural action. And because of this, authorities[40] say that a ray is fourfold: rectilinear, refracted, reflected, [and] mixed (or composite, or accidental). Also, concerning these rays: actions, the multiplications of species and powers, illuminations, observations, and the like, are distinguished

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[38] By using the term "visual rays", Oresme is not implying a belief in some form of the extramission theory in which rays emanate from the eye to the object. Oresme clearly notes his opposition to this theory in book 3, question 12, of his *Questiones super quatuor libros meteororum*, where he defines the visual ray as follows: "radius visualis non dicitur radius missus ab oculo super visibile sed emissus a visibili super oculum," that is, "a visual ray is not defined as a ray emitted from the eye to the visible object, but [as a ray] emitted from the visible object to the eye." In McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, pp. 158–159, Bk. III, Q. 12, lines 360–362. The English translation (revised from McCluskey's) is that found in David C. Lindberg's (1976) *Theories of Vision from Al-Kindi to Kepler*, p. 137.

[39] Literally, "in the bottom of water."

[40] Or, "authors."

rum et virtutum, illuminationes visiones et cetera, per hos radios secundum fortius et debilius. Fortior enim est radius rectus ceteris paribus postea fractus et consequenter.

Et in visione circa loca visibilium principaliter accidit deceptio propter fractionem vel reflexionem, que taliter differunt quod radius fractus procedit ultra, licet non recte, sed recedit ab incessu recto. Sed in reflexione propter nimiam resistentiam non procedit ulterius, sed revertitur ad partem obiecti, et quandoque autores improprie accipiunt reflexionem pro utroque.

B fol. 33v [Conclusio 1] Quia de fractione principaliter est sermo, | sit prima conclusio: quod omnis res visa, per duo media differentia in raritate et densitate, videtur per lineam fractam, nisi radius visualis perpendicularis fuerit ad superficiem illa duo media dividentem. Probatur auctoritate, experientia, et ratione. Unde, ad hoc est omnium perspectivorum et philosophorum auctoritas, nec indiget auctorite probari, quod pluribus patet experientiis. Si enim accipiatur vas in cuius fundo sit denarius, erit aliqua | (*F* fol. 34r) distantia a qua non videbitur si vas fuerit vacuum aqua, et ab illa videbitur si sit plenum, quod non potest salvari, nisi per fractionem radiorum.

1 illuminationes] in luminationes *F*; in illuminationes *L* | visiones] *ante* visiones *add.* vel *sup. l. V* | et cetera] et contra *B*; e contra *L*; *om. V* | per hos] per huius *B*; per huiusmodi *L*; huiusmodi per *V* 2 secundum] sed *L*; secundum *add. sup. lin. V* 3 paribus] partibus *L*; *del. V* | et] et cetera *V* 5 propter] *post* propter *add.* enim *B* | fractionem] fractionem *corr. in mg.* vel refractionem *V* | vel] seu *L* 6 fractus] tractus *L* | ultra] *post* ultra *add. in mg.* Non rectus et procedit ultra non recte *V* | recedit] recedit *corr. ex* precedit(?) *BV* | recto] recto *corr. ex* rectro *L* 7 nimiam] *ante* nimiam *scr. et del.* nima(?) *F* 8 et quandoque] *om. V*; *del.* [?] *et add.* sed *sup. l. V* | autores] actores *B* | improprie] improprie *rep. F* 9 reflexionem] reflexiones *L* 10 Quia] *ante* Quia *add. sup. l.* Sed *V* 11 conclusio] *post* conclusio *add.* ista *F; post* conclusio *add. sup. l.* hec(?) *V* | differentia] differencia *V* 12 densitate] dempsitate *BF* 13 perpendicularis] perpendicular *V* | illa] illam *F*; ista *L* 13–14 dividentem] dividitatem *L; ante* dividentem *scr. et del.* dive(?) *F* 14 auctoritate] autoritate *F* | experientia] *om. B*; experigencia *V* | ad hoc est] est ad hoc *V* 15 omnium] omnis *F* | perspectivorum et philosophorum] philosophorum et perspectivorum *V* | auctoritas] autoritas *F* 16 auctorite] autorite *F* | probari] particulari(?) *V* [abbr.: p[ri]] | experientiis] experimentis *V* 16–17 accipiatur] acipiatur *F* 17 sit] fuerit *V* | erit] erit *corr. ex* [?] *V* 18 sit] fuerit *F* | plenum] *post* plenum *add. sup. l.* aqua *V* 19 radiorum] *post* radiorum *add.* ut patet in figura inferiori *L*

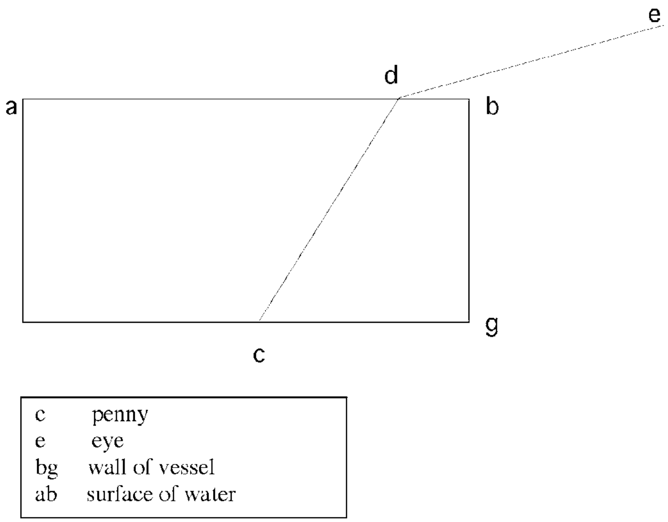

Figure 7. A Penny in a Vessel Seen by Refracting Rays

by a stronger or weaker [effect]. For an [unrefracted] rectilinear ray is stronger, all things being equal, than after it is refracted, and so forth.

In observing the locations of visible objects, deception principally occurs because of refraction or reflection. These differ in this way, a refracted ray keeps going, but not straight – it diverges from the direct path. But in reflection, because of the excessive resistance [from the reflecting medium, the ray] does not penetrate but is rebounded in the direction of the source – sometimes authors improperly use the term “reflection” for both [reflection and refraction].[ii]

[Conclusion 1] Since [this] discussion is principally about refraction, let this be the first conclusion: that every thing seen through two media, differing in rarity and density, is seen along a refracted line, unless the visual ray is perpendicular to the surface dividing the two media. This is proved by authority, experience, and reason. Whence the authority of all perspectivists and philosophers supports this, nor does it need to be proven by authority, as is clear from many experiences.[iii] For if we take a vessel in whose bottom is a penny, there will be some location from which the penny will *not* be seen if the vessel were empty of water, and [yet] from the same place, the penny will be seen if the vessel is full. This can only be explained by the refraction of rays.[iv]

Verbi gratia, sit *ab* superficies aque, et *c* sit denarius in fundo vasis cuius latus sit *bg*, et sit *e* oculus. Tunc patet, quod si vas esset vacuum, *e* non videret *c*, quia latus *bg* impediret. Et, tamen, experitur quod videtur, dum est plenum aqua, igitur per aliam lineam quam per rectam, sicut per lineam fractam *edc*. Item denarius apparet maior quam si videretur solo aere mediante, quod non esset, nisi propter fractionem fieret disgreganto radiorum. Item fractio radii luminosi, qui est etiam radius visualis, experitur in vase vitreo sperico pleno *L* fol. 42r aqua ubi propter fractionem radii | congregantur, et in lumine solis quandoque comburitur.

In omnibus istis et similibus experientiis patet, quia radius perpendicularis non frangitur, et quia omnes alii franguntur qui sunt oblique cadentes super superficiem ambo media dividentem. Et rationem assignaverunt antiqui, ut recitatur in libro De speciebus, quia radius perpendicularis fortior est obliquo, et similiter, actio secundum perpendicularem fortior est quam secundum obliquum. Unde, patet ad sensum quod radius solis perpendicularis fortius calefacit. Ideo, volentes aliquid calefieri applicamus soli vel igni secundum radios perpendiculares.

Similiter casus lapidis perpendicularis fortiorem dat ictum et gladius fortius dividit, quando perpendiculariter cadit. Et si inveniatur nimia resistentia, fit reflexio in eandem partem per eandem viam, tam lapidis quam gladii et etiam radii. Et si casus esset obliquus fieret reflexio in eandem partem per aliam viam, et angulus inciden- *V* fol. 43v tie et reflexionis essent equales. | Verbi gratia, sit *ab* reflectens, et *ed* linea incidentie, et *cd* linea reflexionis. Tunc angulus incidentie

1 Verbi gratia] Verbi gratia *om. L* 2 quod] *sup. l. V* 3 e non] *ante* non *scr. et del.* et nunc; e *sup. l. F* | tamen] *post* Et *scr. et del.* ante; tamen *sup. l. F* 4 plenum] *ante* plenum *scr. et del.* plenum[?] *F* | aqua] aque *F*; *om. V* | igitur] Ergo *L* 5 apparet] *post* denarius *scr. et del.* videtur, *add. sup. l.* apparet *V* 6 si] sibi *L* | propter] per *L* 8 visualis] *ante* visualis *scr. et del.* luminis *F* 11 experientiis] experigentiis *V* | patet] patet *rep. et del. F* 12 alii] *post* alii *add.* non *F; post* alii *add.* radii *sup. l. V* | qui sunt] *om. V* 14 assignaverunt] adsignaverent *F* 17 sensum] senssi *L* | radius] radius *rep. L* 18 applicamus] adplicamus *F*; aplicamus *L* | vel igni] *post* vel *scr. et del.* g(?), *add.* igni *sup. l. V* 20–21 gladius] grladius *F* 22 eandem] aliam *V* 23 tam lapidis quam] *om. V* | gladii et etiam radii] radii et etiam gladii *L*; gladii vel etiam radii *V* [NOTE: These variants imply that *B, F, & L* were NOT directly copied from *V* or any of its descendents (because of the omission), AND the flipped phrase implies that *B & F* are more closely related to one another than to *L*.] 25 reflectens] reflexiones *L*; reflectens *corr. ex* reflectans *V* 26 incidentie] *post* incidentie *scr. et del.* cd *F*

14 Roger Bacon (1983), *De multiplicatione specierum,* ed. by Lindberg, Part II, Ch. 3, lines 81–98.

For example, let *ab* be the surface of the water, and let *c* be a penny in the bottom of a vessel whose side is *bg*, and let *e* be the eye. [Figure 7][v] It is clear that if the vessel were empty, *e* would not see *c*, since the side *bg* would prevent it. And yet we know by experience that the penny is seen when the vessel is full of water, therefore [the penny is seen] by some other line than the straight one, such as by the refracted line *edc*. Also, the penny appears larger than if it were seen through the medium of air alone, which would only occur because refraction was causing the divergence of the [visual] rays. Also, the refraction of a light ray (which is also a visual ray) is experienced in a spherical glass vessel full of water, where the rays are united because of refraction, and in sunlight it sometimes causes combustion.[41]

This is clear in all these and similar experiences, since a perpendicular ray is not refracted, and since all others are refracted which fall obliquely at the surface separating two media. And the ancients furnished a reason [for this], as is reported in the book *De speciebus*,[vi] since a perpendicular ray is stronger than an oblique [ray], and likewise a perpendicular action is stronger than an oblique action. Whence it is clear to the senses that a perpendicular ray of the sun heats more powerfully [than an oblique ray]. That is why when we wish to heat something, we adjust [it] to the perpendicular rays of the sun or of a fire.

Similarly, the perpendicular fall of a stone gives a stronger blow, and the perpendicular fall of a sword cuts more forcefully.[vii] And if a stone or a sword comes upon excessive resistance, a backwards reflection occurs on the same path – so also for a ray. And if it were to fall obliquely, a backwards reflection would occur by a different path, and the angle of incidence and reflection would be equal. For example, let *ab* be the reflecting [surface], and *ed* the line of incidence, and *cd* the line of reflection. [cf. Figure 8] Then the

[41] The final phrase literally reads "and in sunlight it sometimes is burned up." David Lindberg cites many earlier discussions of such refracting vessels (and/or solid crystals) used as burning glasses, including Pseudo-Euclid, Grosseteste, Bacon, Pecham, and Theodoric of Freiberg, in his *Roger Bacon's Philosophy of Nature: A Critical Edition, with English Translation, Introduction, and Notes, of "De multiplicatione specierum" and "De speculis comburentibus"* (Oxford: Clarendon Press, 1983), p. 377, n. 23.

edb equalis est angulo reflexionis *cda*. Aliter, ergo, reflectitur radius perpendicularis et aliter obliquus.

Ergo, similiter, quando ultra procedunt in differentia duorum mediorum, debent aliter et aliter incedere. Et quia incessus rectus fortior est quam fractus, ideo, in isto casu rectus incessus debetur radio perpendiculari. Et obliquus, tamen, incessum fractum et declinat ab incessu recto, propter resistentiam secundi medii dempsioris.

[Conclusio 2] Secunda conclusio est quod radius, aut species *L* fol. 42v transiens, seu veniens a subtiliori medio | in secundum dempsius, frangitur ad perpendicularem, scilicet, inter incessum rectum et lineam perpendiculariti ductam in puncto fractionis ad superficiem illa duo media dividentem. Patet conclusio per experientias pre adductas de denario in fundo aque, et de vase vitreo sperico pleno aqua. Verbi gratia, sit *ab* superficies dividens media sub qua sit *F* fol. 34v aqua, et super quam sit aer. | Sit *e* oculus, et *c* visibile. Tunc *c* videbitur per lineam fractam *edc*, ut docent experientie, et *d* est punctus fractionis. Et quia *dg* est perpendicularis super *ab* et *edf* esset incessus rectus, patet statim qualiter fractio declinat ab incessu recto *B* fol. 34r ad perpendicularem predictam. Hoc autem persuadebant | antiqui rationem sensui concordantes quam sicut iam dictum est radius,

1 ergo] igitur *V* | radius] angulus *F* 3 Ergo] Igitur *V* | differentia] differintia *V* 4 debent] debet *V* 5 fortior est] est fortior *B* 6 perpendiculari] *post* perpendiculari *add. in mg.* incendere *V* | incessum] *post* incessum *add.* rectum *F* | fractum] fractus *F* 7 resistentiam] *post* resistentiam *add.* et *L* | secundi] contra *F* | dempsioris] dempssioris *L*; densioris *V*; *post* densioris *add. et del.* secunda *V*; *add. in sup. mg. a. m.* Sed quia transit per duo media, quaris unum est denspius actus, ideo frangitur et declinat ab incessu recto per resistentiam secundi medii densioris *V* 8 species] spes *B* 9 seu] sive *F*; aut *V* | veniens] *ante* veniens *add. et del.* ver *F* | subtiliori] sutiliori *F*; superiori *V* | secundum] *post* secundum *add.* medium *V* | dempsius] densius *LV*; *ante* dempsius *add. et del.* dess *F* 11 perpendiculariti] perpendicular *F*; perpendicularem *V*, *et rep. in mg.* lineam perpendicularem *V* | ductam] *rep. et del.* ductam *F* 12 illa] alia *F* | duo] *post* duo *add.* puncta *L* | media] *om. F* | experientias] experigentias *V* | pre] de *V* 13 adductas] aductas *FL*; adductas *corr. ex* ductas *add.* ad- *sup. l. V* | de denario in fundo aque] in fundo aque de denario *F* | de] *om. V* 14 aqua] aque *V* | superficies] superficiens *L* | sit] sit *rep. L* 16 videbitur] videtur *V* | edc] cde *L* | experientie] experigentie *V* 17 esset] *sup. l.* est *V* 20 rationem] ratione *L*; per rationem *V* | sensui] senssui *L*; *post* sensui *add. sup. l.* sensuum *V* | concordantes] concordentes *F*

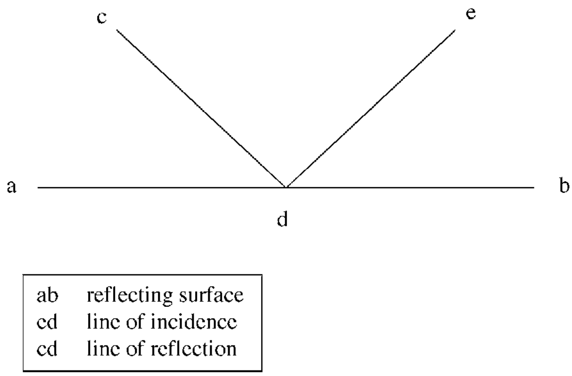

Figure 8. Reflection of an Oblique Ray

angle of incidence *edb* is equal to the angle of reflection *cda*. Thus a perpendicular ray is reflected in one way and an oblique [ray is reflected] in another.

Similarly, when they proceed further in the differentiation of the two media, one ought to pass in one way and one in another. And because a direct path is stronger than a bent [path], then in this case a direct path is due to a perpendicular ray. And an oblique [ray follows] a bent path and bends away from a direct path because of the resistance of the denser second medium.

[Conclusion 2] A second conclusion is this: a ray, either passing through a species or coming from a subtler into a denser [medium], is refracted towards the perpendicular, that is, [it is refracted] between the direct path and a perpendicular line drawn from[42] the point of refraction at the surface dividing those two media. [This] conclusion is clear from the experiences mentioned above concerning the penny under water and a spherical glass vessel full of water.[43] For example, let *ab* be a surface dividing [two] media, below which is water and above which is air. [Figure 9] Let *e* be the eye, and *c* a visible object. Then *c* will be seen through the refracted line *edc*, as experience teaches, and *d* is the point of refraction. And since *dg* is perpendicular to *ab*, and *edf* would have been the direct path, it is immediately clear how the refracted [ray] bends away from the direct path towards the previously mentioned perpendicular. Moreover, the ancients were persuaded by [the above, since] the argument agrees

[42] literally "to".
[43] *De visione stellarum*, Book II, cap. 1, lines 38–49.

seu incessus perpendicularis est fortior. Ideo, incessus sibi vicinior fortior est remotiore; etiam actio fortificatur ex propinquitate ad agens. Et propter hoc si radius in medio dempsiori precederet secundum rectum incessum, esset remotior a perpendiculari et etiam ab agente, igitur actio foret debilior et minus cito debilitaretur. Ergo, ad tenendum maiorem uniformitatem et fortitudinem actionis, fit declinatio ab incessu recto appropinquando ad perpendicularem et ad agens.

[Corollarium] Ex quo sequitur necessario quod, quando est e converso, scilicet, quod secundum medium est subtilius, sic quod radius venit de dempsiori in subtilius, ut de aqua in aerem, tunc sicut

1 seu] suum *F* | fortior] fortior *interl. V* | Ideo] igitur *V* 2 fortior est] *om. F* | etiam] cum *L* | actio] activa *vel* activita(?) *V* | ad] ad *add. et del.* angulum *V* 3 agens] agens *sup. l. V* | dempsiori] depresiori *L*; densiori *V* | precederet] precedent *F* 5 debilitaretur] debitrietur(?) *L* | Ergo] Igitur *V* 6 ad] *post* ad *add.* querendam *V* | tenendum] *sup. l. V* 7 recto] *post* recto *scr. et del.* aprofundo in *F* | appropinquando] ad propinquando *L* 7–8 et ad agens] et ad agens *rep. F* 9 sequitur] *rep. et del.* sequitur *F* 10 quod] *post* quod *add.* quando *V* | secundum] *post* secundum *add.* quod *F* | sic] secundum *V* 11 venit] venit *mg. V* | de] *scr. et del.* (?), de *sup. l. V* | dempsiori] densiori *LV* | in] *scr. et del.* in(?), *add.* est *sup. l. V* | in] ad *V*

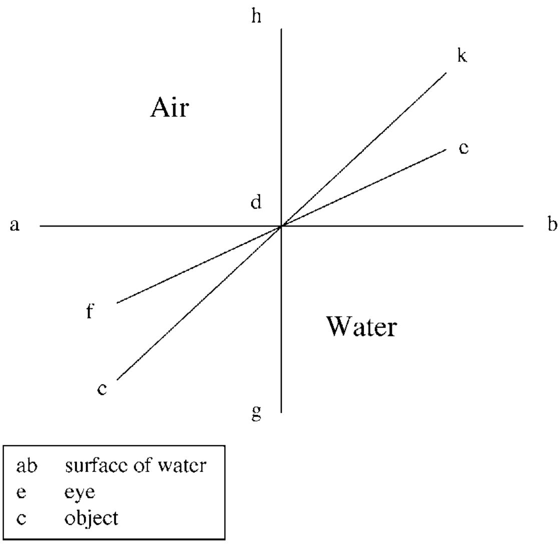

Figure 9. Ray Passing From a Rarer to a Denser Medium Is Refracted Toward the Perpendicular [Figures 9 & 10 are combined in the mss.]

with sense experience – how, as was already said, the perpendicular ray or path is stronger. Therefore, the path nearer [to the perpendicular][44] is stronger than the more remote [path]; also the action is strengthened because of the nearness to the agent. For this reason, if a ray at a denser medium were to proceed along a direct path, it would be more remote from the perpendicular, and also from the agent, therefore the action would pierce more weakly and would have been weakened less quickly [*sic*].[45] Thus, to maintain greater uniformity and strength of action, a bending occurs away from the direct path by [the ray] approaching toward the perpendicular and toward the agent.

[Corollary] From this it follows necessarily that when this occurs the other way around, namely, that the second medium is more subtle, such that a ray [now] comes from a denser into a subtler

[44] Literally: "to itself."

[45] [Did Oresme mean to say the action would be weakened "more quickly"? Or is this talking about the *ray* being weakened less quickly? Even so, it seems the ray would be weakened more quickly by being further removed from the agent. See next sentence.]

prius erat declinatio ab incessu recto approximando ad perpendicularem, ita nunc e converso: declinatio fit elongando a perpendiculari, et est incessus rectus inter perpendicularem et fractionem. Probatur in priori figura, nisi quod *c* quod erat visibile, nunc cum hoc sit oculus, seu visus in aqua. Tunc per eandem *L* fol. 43^{r} | lineam per quam *e* oculus videt *c*, videt etiam *c* ipsum *e*. Igitur, *c* videt *e* per lineam *edc*, et *cdk* esset incessus rectus et *hd* est perpendicularis. Patet, ergo, qualiter fractio *de* remotior est a perpendiculari quam incessus *dk*. Igitur, incessus rectus est inter fractionem et perpendicularem. Et ab alia parte, ut visum est fractio, est inter perpendicularem et incessum.

Istud idem sicut et conclusio patet per experientias et per omnes auctores et potest persuaderi sicut prius propter uniformitatem actionis et quia contrariarum causarum contrarii sunt effectus. Ideo, fractionem quam dempsitas facit approximari perpendiculari subtilitas faciet elongari. Et hoc probat per instrumenta VITELO, in 4^{a}, et 9^{a}, 10^{i} *Perspective*, et ALHACEN in 7^{o}, capitulo 3^{o}.

[Conclusio 3] Tertia conclusio est quod, quando res videtur per lineam fractam, tunc apparet in linea *V* fol. 44^{r} | precedente de oculo per locum fractionis in continuum et directum, et secundum incessum rectum. Verbi gratia, in priori figura *e* visui *c* apparet esse in linea *edf*. Et similiter, e converso, *c* visui *e* apparet esse in linea *cdk*. Istud probant auctores per experimenta sicut ALHACEN in 7^{o}, capitulo 5^{o}, et VITELO in 12^{a}, 10^{i}. Demonstrant quod ymago et ipsa res apparet

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1 declinatio] declinato *V* | approximando] adproximando *F*; ad proximando *L* 2 ita] igitur *L* | declinatio] declinato *L* 4 cum] est *L* | hoc] h *L*; hoc(?) *sup. l. V* 5 seu] sive *F* 6 videt] vide *L* | c] se *V* [apparently a scribal listening error, with the homophone "se" written for "c." *ed.*] | Igitur] Ergo *FL* 7 hd] kd(?) *B* | ergo] *om. F* 8 Igitur] Ergo *L* 11 Istud] Illius *V*, *post* Illius *add. et del.* istud *V* | sicut] sic *V* | experientias] experigentias *V* 12 auctores] actores *B*; autores *F*; doctores *V* [apparently a scribal listening error *ed.]* | et] *post* et *scr. et del.* perpen-(?) *V* | sicut] ut *V* | prius] *om. F* | propter] per *L* 13 causarum] *ante* causarum *scr. et del.* earum(?) *F* 14 dempsitas] densitas *LV* 15 faciet] facit *L* | probat] probatur *V* | Vitelo] WITELO *B*; *post* VITELO *add.* et *V* 16 10i] 11 *L* | Alhacen] ALASEN *F*; ALACEN *V* 17 est] *om. V* | quod] *om. L* | videtur] videre *L* 18 tunc] *post* tunc *scr. et del.* videtur *V* | apparet] *om. FV* | linea] figura *L* | de oculo] *scr. et del.* de oculo *V* 20 c apparet esse] apparet esse "c" *V* | esse] *om. L*; esse *sup. l. V* 21 edf] def *L* | esse] esse *sup. l. V* | linea] *post* linea *add. et del.* in *F* | cdk] cdk *corr. ex* cdh *F* 22 auctores] autores *F* | Alhacen] ALASEN *F*; ALACEN *V* 23 Vitelo] WITELO *B*; VITELLO *L* | 12a] 12 *V* | 10i] 11 *V* | quod] *post* quod *add.* ipsa res vel *V* | ymago] immago *F* | et ipsa res] *om. V*

15 WITELO (1572, rpt. 1972), *Perspectiva,* X, secs. 4–8, pp. 407–413. 16 ALHACEN (1572, rpt. 1972), *De aspectibus,* VII, ch. 3, secs. 9–12, pp. 242–247. 22 ALHACEN (1572, rpt. 1972), *De aspectibus,* VII, ch. 5, secs. 17–33, pp. 253–265. 23 WITELO (1572, rpt. 1972), *Perspectiva,* X, sec. 12, p. 415.

[medium] (for example, from water into air), then, before, the bending was away from the direct path [and] drawing toward the perpendicular, now [it is] the other way round: the bending occurs away from the perpendicular, and the direct path is [now] between the perpendicular and the refracted [ray]. This is shown in the previous figure [Cf. Figure 9], except that *c*, which was the visible object, is now an eye or the line of sight in water. Then through the same line along which the eye *e* sees *c, c* itself also sees *e*. Therefore *c* sees *e* along line *edc*, and *cdk* would be the direct path, and *hd* is the perpendicular. It is clear therefore how the refracted [ray] *de* is further from the perpendicular than the path *dk*. Therefore, the direct path is between the refracted [ray] and the perpendicular. And from the other point of view, such as [now making the direct path] the line of sight [instead], the refracted [ray] is between the perpendicular and the [direct] path.

This is just the same – the conclusion is clear through experience and in every author, and, just as before, this can be defended because of the uniformity of action and because contrary causes produce contrary effects.[46] Thus density produces a refraction which approaches the perpendicular, rarity will produce a separation [from the perpendicular]. And this is demonstrated with instruments [in] Witelo's *Perspectiva*, [Book] x, [sections] 4 and 9, and Alhacen, *[De aspectibus*, Book] vii, chapter 3.[47]

[Conclusion 3] A third conclusion is this: when a thing is seen by a refracted line, then it appears on a line proceeding from the eye, through the place of refraction, in a continuous and straight [line] and along the direct path. For example, in the previous figure [Cf. Figure 9], [the object] *c* appears to be on the line *edf* to an observer [at] *e*. And similarly, vice versa: to an observer [at] *c*, [the object] *e* appears to be on the line *cdk*. Authors demonstrate this through experiments, such as Alhacen in *[De aspectibus*, Book]

[46] Oresme uses almost these same words in his *Meteora* "contrariorum contrarii sunt effectus": contraries produce contrary effects. Bk iii, Q. 12. Bacon, also, uses a similar phrase: "Et cum contrariorum contrarie sunt cause et contrariarum causarum contrarii effectus ...", (in English) "And since contraries are causes of contraries and the effects of contrary causes are contrary..." Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part ii, Ch. 3, lines 143–144, pp. 114–115.

[47] Concerning Witelo, Oresme probably meant to refer to Book x, sections 4–8, rather than section 9, since that section is not pertinent. Witelo (1572, rpt. 1972), *Perspectiva*, x, secs. 4–8, pp. 407–413; Alhacen (1572, rpt. 1972), *De aspectibus*, vii, ch. 3, secs. 9–12, pp. 242–247.

in concursu huius linee protense de oculo per punctum fractionis ulterius, cum linea perpendicularis ducta a re visa ad superficiem illa duo media dividentem.

Si est plana et si sperica, tunc ad superficiem planam contingentem spericam in puncto fractionis. Verbi gratia, de plana *c* apparet *F* fol. 35r visui *e* in puncto *m*, | et *e* apparet visui *c* in puncto *n*.

[Corollarium] Ex quo statim sequitur quod *c* apparet propinquius visui quam sit, vel quam si videretur per lineam rectam non fractam. Et e converso, *e* apparet remotius *c* visui quam sit, aut quam

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1 concursu] concursibus *F*; concurssu *L* | protense] protensse *L* | de oculo] *post* protense *scr. et del.* de luculo(?), *add. a. m.* de oculo *V* [apparently a scribal listening error *ed.]* 2 perpendicularis] perpendicular *V* | illa] ista *L* 3 duo] et sic *L* 5 spericam] spericum *corr. ex* spericam *V* | plana] plano *corr. ex* plana *V* 6 apparet] appareat *L* | c] c *sup. l. V* 7 statim sequitur] sequitur statim *F* | c] c *sup. l., corr. ex* (?) *V* | apparet] appareat *L* 7–8 propinquius] propinquis *F*; propinquus *L* 8 sit] sit *corr. ex* se(?) *V* | vel] "L" *L*; aut *V*, *post* aut *scr. et del.* quando *V* | quam] quam *sup. l. V* | videretur] videre *L* | rectam] *om. V* 9–126.1 Et … fractam] *in sup. mg. V* 9 remotius] remota *V* | quam] *om. F*

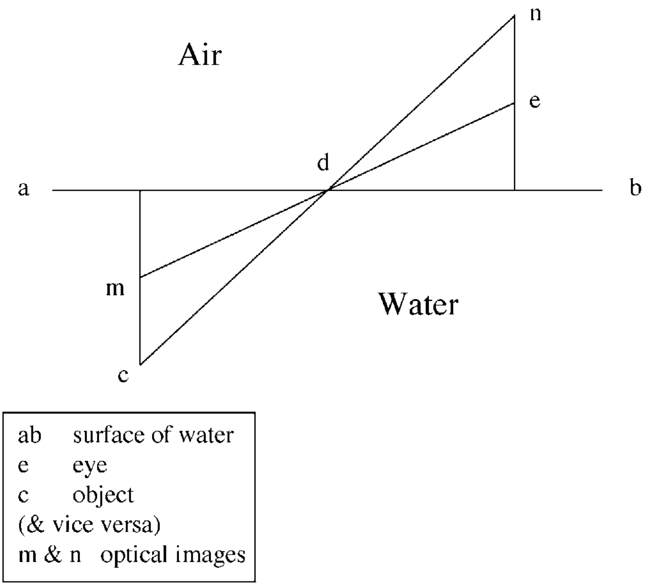

Figure 10. Finding the Optical Image

VII, chapter 5, and Witelo in *[Perspectiva*, Book] 10, [section] 12.[48] They demonstrate that the image of the thing itself appears at the intersection of this line drawn from the eye through the point of refraction [and] beyond, with a perpendicular line drawn from the thing seen to the surface dividing those two media.[viii] [Cf. Figure 10 below]

[This also applies] if there is a planar [surface] and a spherical [surface], with the flat surface touching the spherical at the point of refraction.[49] For example, concerning the planar [surface, the object], *c*, appears to the eye, *e*, at point *m*, and *e* appears to the eye, *c*, at point *n*. [Figure 10]

[Corollary] From this it follows at once that *c* appears nearer the eye than it is, or than if it were seen by an unrefracted straight line. And conversely, [an object at] *e* appears further away to the eye at

[48] Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 5, secs. 17–33, pp. 253–265, see especially sections 17 and 19; Witelo (1572, rpt. 1972), *Perspectiva*, X, sec. 12, p. 415.
[49] Oresme does not elaborate concerning this statement, nor does his following example take a spherical surface into account.

si videretur per lineam non fractam. Et hoc patet ex 15^{o}, 10^{i} VITELONIS. Sequitur etiam quod in situ rei est deceptio, et quod res apparet alibi quam est, et hoc dicitur 12^{a}, 10^{i} VITELONIS et ALHACEN in 7^{o}, capitulo 5^{o}.

Et propter hoc apparet baculus fractus cuius medietas est in aqua, quia pars que est in aqua apparet visui propinquior quam est. *L* fol. 43^{v} Et si oculus esset in aqua ab eadem | parte baculi, tunc propter idem apparet fractio e converso. Verbi gratia, sit *cdf* baculus rectus. Dico,

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1 videretur] videre *L* | patet] apparet *F* | 15o] 15 *L* | 10i] 11 *L* 1–2 Vitelonis] WITELONIS *B* 2 situ] *post* situ *scr. et del.* ubi *V* | rei] rei *sup. l. V* | est] sit *B* | et] et *sup. l. V* 3 et…Vitelonis] *in mg. V* | 12a] 22 *L* | 10i] *om. L* | Vitelonis] WITELONIS *B* | Alhacen] ALASEN *F*; ALACEN *V* 5 apparet] appareat *L* | baculus fractus] fractus baculus *V* | fractus] *om. B* 7 si] *post* si *add.* e. *sup. l. V* | propter] *del.* propter *add.* per *sup. l. V* 8 apparet] apareret *F*

1 WITELO (1572, rpt. 1972), *Perspectiva,* X, sec. 15, pp. 416–418. 3 WITELO (1572, rpt. 1972), *Perspectiva,* X, sec. 12, p. 415. | ALHACEN (1572, rpt. 1972), *De aspectibus,* VII, ch. 5, secs. 17–33, pp. 253–265.

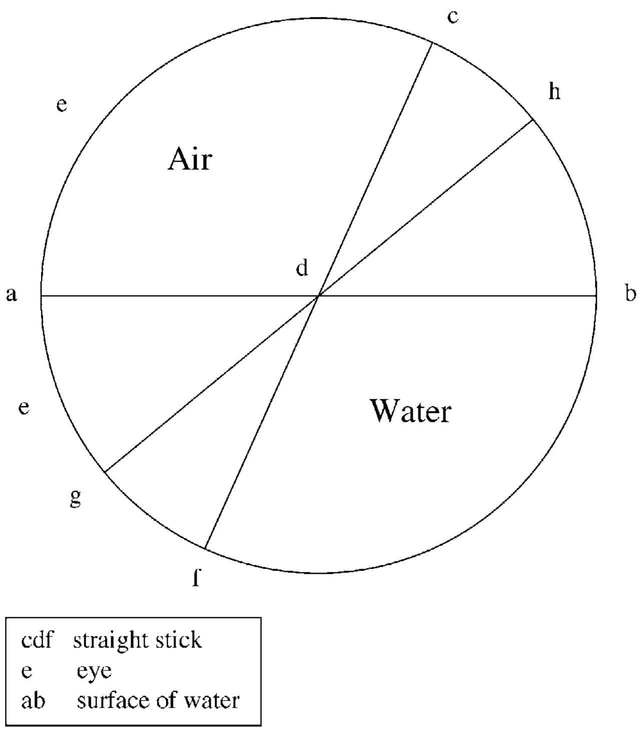

Figure 11. Placement of a Straight Stick Halfway into Water at an Angle

c than it is, or than if it were seen by an unrefracted line. And this is clear from Witelo in [*Perspectiva*, Book] x, [section] 15.[50] It also follows that there is deception [with regard to] the position of the object, and that the object appears elsewhere than it [really] is. This is said by both Witelo in [*Perspectiva*, Book] x, [section] 12 and by Alhacen in *[De aspectibus*, Book] VII, chapter [5].[51]

For this reason, a stick which is half in water appears bent, because the part which is in water appears nearer to the eye than it [really] is. And if the eye were in water from the same point of view as the stick, then the refraction would appear the other way round for the same reason. For example, let *cdf* be a straight stick. I say,

[50] Witelo (1572, rpt. 1972), *Perspectiva*, x, sec. 15, pp. 416–418.

[51] Witelo (1572, rpt. 1972), *Perspectiva*, x, sec. 12, p. 415; Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 5, secs. 17–33, pp. 253–265.

igitur, quod si *e* oculus sit in aere, tunc baculus apparebit secundum *B* fol. 34r figuram fractam *cdg*. Quod si *e* oculus sit in aqua, tunc baculus | apparebit secundum figuram e contrario fractam *fdh*.

Item si baculus staret perpendicular ad superficiem *ab*, tunc non appareret fractus, quia omnis concursus radiorum incidentie cum perpendicularibus essent in ipsomet baculo, ut patet faciliter ex predictis. Sed cum ab oculo existente in aere medietas baculi que esset in aqua appareret brevior quam sit, vel quam si videretur per idem medium. Et e converso ab oculo existente in aqua medietas que est in aere apparet longior quam sit. Et sic tam ab aere quam ab aqua medietas baculi que est in aere apparet longior quam sit illa que est in aqua.

Verbi gratia, si *e* oculus sit in aere, punctus *f*, scilicet, extremitas baculi apparebit in puncto *m*, et sic baculus apparebit secundum lineam *mc*. Et si oculus sit in aqua, tunc extremitas *c* apparebit in

1 e oculus] oculus e *V* | apparebit] *post* apparebit *add. et del.* quod(?) *V* | secundum] secundum *sup. l. V* 2 figuram] lineam *V* [possibly a scribal listening error, *ed.]* | sit] fuerit *V* 3 fdh] *om. F* 4 perpendicular] perpendiculariter(?) *B* 5 non] *rep. et del.* non *F* | appareret] appareret *corr. ex* apparebit *B*; appareat *L* | omnis] omnes *B* | concursus] concurssus *L* | incidentie] incidentium(?) *F* 7 Sed cum ab] Sed cum ab *corr. ad* Sequitur ratio ab eodem quod cum *a. m. V* | cum] tamen *FL* 8 appareret] appareat *L* | si] *om. F* 10 apparet] appareat *L* 11 illa] ista *L* 14 apparebit] aparebit *F* 14–15 secundum lineam mc] mc secundum lineam *B*

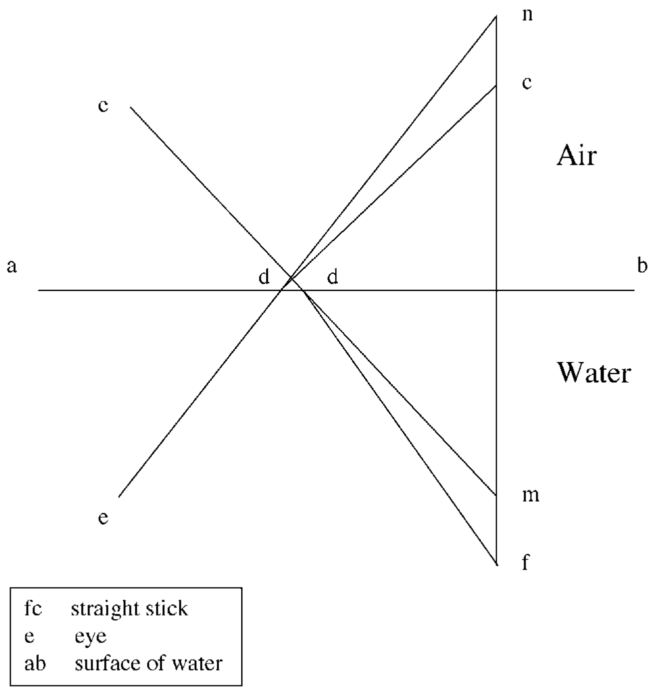

Figure 12. Placement of a Straight Stick Halfway into Water and Perpendicular to Its Surface

therefore, that if the eye, *e*, were in air, then the stick would appear bent along the path *cdg*. [Figure 11] If the eye, *e*, were in water, then the stick would appear bent the other way round along the path *fdh*.

Likewise, if the stick were standing perpendicular to the surface *ab*, then it would not appear bent because every intersection of the incident rays with the perpendicular would be in the stick itself, as is easily apparent from what has been said. But from an eye located in the air, the half of the stick which would be in water would appear shorter than it [really] is, or [shorter] than if it were seen through the same medium. And conversely, from an eye located in water, the half [of the stick] which is in the air appears longer than it [really] is. And thus both from the air and from the water, the half of the stick which is in the air appears longer than that which is in the water.

For example, if the eye, *e*, were in air, [then] the end of the stick, point *f*, would appear at point *m*, and thus the stick would appear according to the line *mc*. [Figure 12] And if the eye were in water, then the end [of the stick], *c*, would appear at point *n*, as per the

L fol. 44^{r} puncto *n* per conclusionem, | et sic baculus apparebit secundum lineam *fn*. Quare, etiam, apparebit longior ab aqua quam ab aere, et hoc docet experientia.

Ex conclusione etiam patet causa quare denarius vel res in fundo aque apparet maior quam si videretur tantum per unum medium, sicut per aerem vel aquam, quia videtur sub maiori angulo propter huiusmodi fractionem, eo quod non omnes linee sunt perpendiculares. Sed necesse est aliquas esse obliquas et frangi. Verbi gratia, sint *c* et *f* extremitates rei vise, et *e* sit oculus, tunc *c* videbitur per lineam fractam *edc*, ut patet etiam per secundam conclusionem. Et similiter, *f* per lineam fractam *egf*; et in aere solum videretur per lineas rectas *ec* et *ef*; constat autem quod angulus totalis *deg* est maior

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2 Quare] quia *L*; *om.*, quia *sup. l. V* 3 experientia] experigentia *V* 4 Ex] *ante* Ex *add.* In conclusio(??) *sup. l. V* | patet] apparet *F* | quare] qualiter *L* 5 apparet] apparet *corr. ex* apparit *V* | videretur] videretur *corr. ex* divideretur *V* | tantum] *ante* tantum *scr. et del.* solum *F* 6 vel] *post* vel *add.* per *V* | maiori] maiore *B* 7 propter] per *L* | huiusmodi] huius *BF* | eo] esse(?) *F* | sunt] sunt *rep. et del. 3 times(!) F* 8 perpendiculares] *om. F* 9 oculus] *post* oculus *add. et del.* (?) *V* | tunc] tunc *sup. l. V* | videbitur] videtur *F* 11 egf] cdf *L* | videretur] videtur *L*; videretur *corr. ex* videbitur *V* 12 rectas] obliquas *L* 12–132.1 constat … cef] *om. BFL*

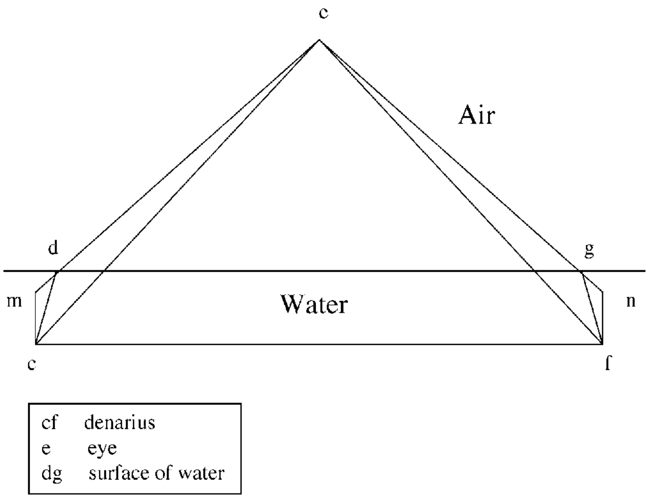

Figure 13. An Object Placed Under Water Appears Larger Than When Seen Through Air Alone

conclusion, and thus the stick would appear according to the line *fn*. Therefore [the stick] will appear longer from the water than from the air – and experience teaches this.

From [this] conclusion it is also clear why a penny or something [else] under water appears larger than if it were seen through only one medium, such as air or water [alone], since it is seen under a greater angle, due to such a refraction by [the medium] in such a way that not all the lines are perpendicular; rather, some will necessarily be oblique and refracted. For example, let *c* and *f* be the ends of a thing seen, and let *e* be the eye. Then *c* will be seen through the refracted line *edc*, as is clear from the second conclusion, and likewise *f* [will be seen] through the refracted line *egf*. [Figure 13][52] And in air alone it would be seen through the straight lines *ec* and *ef*, thus it is established that the entire angle *deg* is larger than angle *cef*, when

[52] For very similar figures and explanations see Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 39, pp. 271–272; Witelo (1572, rpt. 1972), *Perspectiva*, X, sec. 31, pp. 431–432; Roger Bacon, *Opus majus*, Part V: *Perspectiva*, Part III, Dist. 2, Ch. 2–3, in *The Opus majus of Roger Bacon*, ed. by Bridges, vol. 2, pp. 148–153, for Burke's trans., *Opus majus*, Part V: *Perspectiva*, Part III, Dist. 2, Ch. 2–3, vol. 2, pp. 565–566; Pecham (1970), *Perspectiva communis*, Props. III.4, pp. 214–215, and III.13, pp. 224–229; and Oresme's *Questiones super quatuor libros meteororum*, Bk. III, Q. 12, lines 312–330.

angulo *cef*, sub quo videtur per unicum medium. Igitur, in isto casu apparet maior, quam si videretur per aerem tantummodo vel per *V* fol. 44v aquam, et sine fractione. |

Sequitur etiam quod apparet propinquius quia per conclusionem, extremitas *c* apparet in puncto *m*, ubi est concursus perpendicularis cum radio incidentie. Et similiter, extremitas *f* apparet in puncto *n*, ubi est consimilis concursus.

Et similiter, stelle apparent propter hoc in ortu maiores, scilicet, propter interpositos plures vapores per quos disgregantur radii visuales. Unde, patet etiam quod si, e converso, secundum medium sit rarius, ut quando oculus est in aqua, et res visa est in aere, tunc res apparet minor, quam si solum videretur per unicum medium. Eo quod linee franguntur, e converso, ideo, apparet sub angulo minori. Unde, patet in ista alia figura quod angulus *cef* maior est angulo *F* fol. 35v *deg* qui est ex lineis fractis a perpendiculari. | Ex quo etiam patet

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1 videtur] videbitur *V* | isto] illo *V* 2 vel] seu *V* 6 similiter] simillter *F* 7 consimilis] consimillis *F*; eum *L*; similiter *V* 8 Et similiter stelle apparent] *om. B* | similiter] *ante* similliter *add.* equaliter(?) *F* | stelle] *om. F* | propter hoc] *om. V* | scilicet] *om. V* 9 interpositos plures vapores] plures vapores interpositos *V* | per quos] *om. F*; ex quibus *V* | disgregantur] *ante* disgregantur *add.* etiam *B*, *add.* et *F* 10 patet etiam] etiam patet *F* | etiam] *om. B*; etiam *sup. l. V* | quod] *om. L* 11 rarius] rarius *corr. ex* radius *V* | est] sit *V* | est] *om. F*; sit *V* 12 res] *post* res *add. et del.* u *F* | medium] *om. L* 13 linee] *post* linee *add. et del.* (?) *L* | franguntur] franguntur *corr. ex* frang(?)ur *V* | angulo] angulo *rep. et del. F* 14 patet] apparet *F* | ista] *om. LV; post* in *scr. et del.* illa *V* | alia] inferiori *L* 15–134.1 patet quod] *om. V*

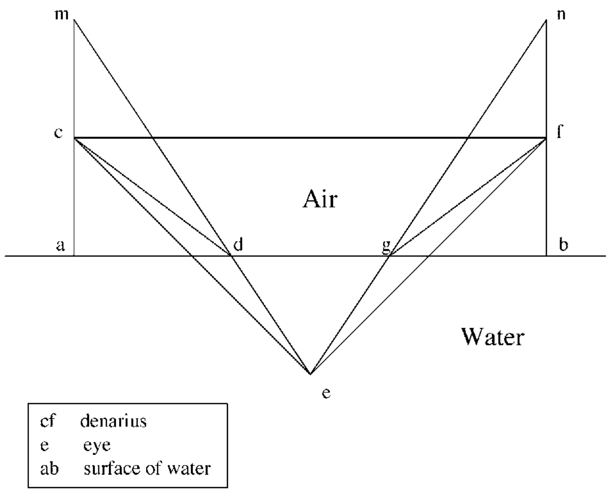

Figure 14. An Object Placed in Air and Seen Through Water Appears Smaller and Further Away Than When Seen Through Water Alone

it is seen through one medium. Therefore, in this case [the object] appears larger than if it were seen through air or water alone and without refraction.

It also follows from this conclusion that [the object] will appear nearer. The end [of the object at] *c* appears at point *m*, where the perpendicular is intersected by the incident ray. And likewise, the end [of the object at] *f* appears at point *n*, where there is a similar intersection.

Similarly, stars [*stelle*] appear larger when they rise because of this, that is, because of the interposition of more vapors through which the visual rays are dispersed.[ix] On the other hand, it is also clear that if the second medium were rarer – as when the eye is in water and the thing seen is in air – then the thing would appear smaller than if it were seen through one medium alone. Since the lines are refracted, [the object] would appear under a smaller angle. Whence it is clear in another figure that angle *cef* is larger than angle *deg*, where [angle *deg*] is from the refracted lines to the perpendicular. [Figure 14][53]

[53] For figure 14, I follow the Florence and Vatican manuscripts. The Bruges manuscript figure is rather confused and the Lilly manuscript follows in that confusion. This shows a strong link between the Lilly manuscript and the Bruges manuscript family.

L fol. 44^{v} quod apparet remotius, quia punctus *c* apparet | in *m*, et *f* apparet in *n*, per tertiam conclusionem, quia ibi concurrunt radii incidentie cum perpendicularibus ab extremitatibus rei vise ad superficiem *ab* media dividentem. Et hoc habentur in 7^{o} capitulo 7^{i} Perspective.

[Conclusio 4] Quarta conclusio est quod omnis radius vel linea protensa de aliqua stella ad visum nostrum est oblique cadens super superficiem ignis spere aut aeris, nisi stella fuerit super zenith. Pro

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1 apparet] *post* apparet *scr. et del.* mediorum et obliquitatem linearum, quia secundum ista variantur quantitates angulorum. Et quia hic est speculatio difficilis et pulcra ut abreviem non potest negari quod per ymagin *add. mg.* vacat *L* | apparet] *om. L* 2 ibi] *post* ibi *scr. et del.* appar- *F* 3 superficiem] *post* superficiem *scr. et del.* (?) *F* | ab] ad *BFL* 4 dividentem] dividentes *L* | habentur] habetur *L* | capitulo] *post* capitulo *add.* et *V* | Perspective] *post* Perspective *add.* ALACEN *V* 5 est] *om. V* 6 de] ab *F* 7 ignis spere] spere ignis *LV* | aut] vel *V* | zenith] cenith *BF* | Pro] Propter *F*

4 Cf. ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 38–43, pp. 270–274.

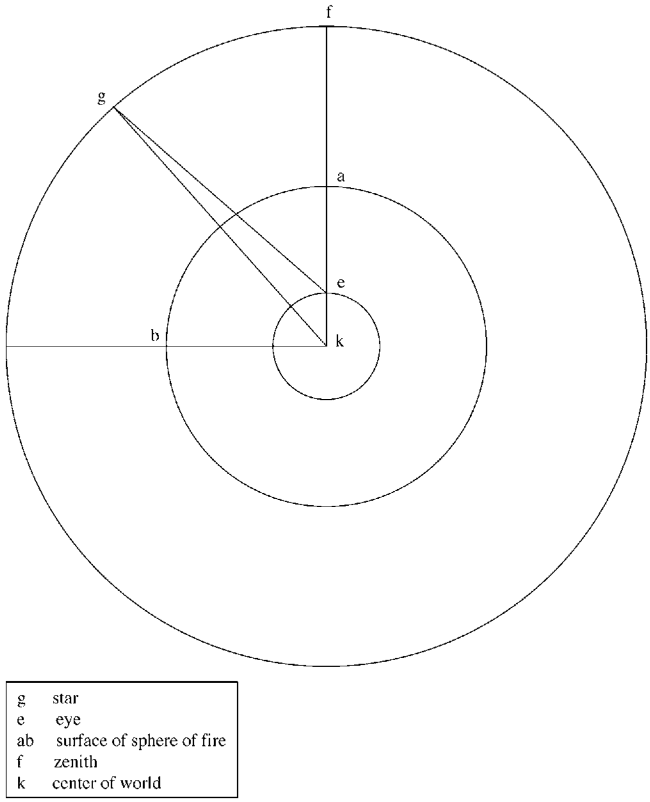

Figure 15. Light From Any Star Falls Obliquely on the Surface of the Sphere of Fire or Air, Unless the Star is Over the Zenith

It is also clear from this that [the object] appears more remote, for point *c* appears in *m*, and *f* appears in *n*, by the third conclusion, because the incident rays intersect there with the perpendiculars from the ends of the thing seen at the surface *ab*, which divides the media. And this is found in [Alhacen], *Perspectiva* [i.e., *De aspectibus*, Book] VII, chapter 7.[54]

[Conclusion 4] A fourth conclusion is this: every ray or line drawn from any star to our sight falls obliquely on the surface of the sphere of fire or air, unless the star is over the zenith. For it should

[54] Cf. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 38–43, pp. 270–274. Though Alhacen does not appear to explicitly mention this type of an example here, the general principles follow.

quo sciendum quod linea perpendicularis super aliquam superficiem spericam est illa que ulterius protensa iret ad centrum, quia solum talis causat circa se angulos equales. Et sic, omnis alia est [*B* fol. 35r] obliqua et nulla veni|ens a stella transiens per oculum procedit ad centrum, nisi venerit a puncto qui est supra zenith capitis. Igitur, omnis alia super speras mundo concentricas cadit oblique.

Verbi gratia, sit *k* centrum mundi, *e* oculus, et *g* stella que non est super zenith, quod est *f*, et *ab* superficies ignis. Tunc facile est probare quod linea *ge* non est perpendicularis super *ab* superficiem, et quod facit angulos inequales, nec ulterius protensa procedit ad centrum.

Dico etiam quod due sunt cause huius obliquitatis, scilicet, [*L* fol. 45r] distantia a zenith, ut notum | est, et propinquitas huius superficiei sperice ad terram vel elongatio a stella. Manifestum est enim quod quanto est maior distantia a puncto *g*, tanto magis distant linee *ge* et *gk*, ergo tanto *ge* magis oblique cadit et longius a perpendiculari. Igitur, magis est obliqua super aeris superficiem quam super superficiem ignis, et ignis quam spere lune vel solis, et sic de aliis. Igitur, ceteris paribus, tanto est maior fractio si fiat, et si in subtilitate fuerit differentia mediorum.

[Conclusio 5] Quinta conclusio quod aer est grossior quam corpora superiora, sicut ignis aut celum. Probatur primo, quia sicut terra gravissima omnibus aliis elementis substans cunctis est dempsior et grossior. Ita videtur quod ignis levissimus qui omnibus superfertur

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1 quo] quod *F* | quod linea] est linea *L*; quod alia *V* | aliquam] *post* aliquam *add.* in *L* 2 protensa] protenssa *L* 3 solum] sola *L* | talis] *post* talis *scr. et del.* erat(?) *V* | causat] *mg. V* | se] *post* se *rep.* quia solum talis causat circa se *B* | omnis] omnis *sup. l. V* 5 venerit] veniret *FL* | zenith] cenith *BF* | Igitur] Ergo *L* 7 k] b *F* 8 zenith] cenith *BF* | ab superficies ignis] superficies ignis ab *V* | ignis] ingnis *L* | facile est] est facile *V* 9 ge] eg *V* | ab superficiem] superficiem ab *V* 10 protensa] protenssa *L* 12 etiam] ergo *L* | obliquitatis] propinquitatis *L* 13 zenith] cenith *BF* | ut] ut *sup. l. F* | propinquitas] propinquas *L* | huius] huiusmodi *V* | superficiei] superficiei *corr. ex* superficies *L* 14 stella] terra *V* 16 ge magis] magis ge *V* 17 Igitur] ergo *F* 18 Igitur] ergo *V* 19 fiat] *post* fiat *scr. et del.* et secundum s *F* | si] si *corr. ex* s(?) secundum(?) *F* 20 mediorum] medioris *L* 21 Quinta] Quinta *corr. ex* Quarta *F*; Secunda *L*; *add. a. m. in sub mg.* Quinta conclusio est quod aer est grossior quam corpora superiora. Patet prima quod superficies(?) terre et aqua. Secunda per respectum ad ignem, quia si ignis esset(?) ita(?) corpulentia stelle non possent a nobis videri. Tertio per crepusculam, et quia radii solis ibi frangitur secundum Alacen. Quarto patet per antidictis(?), tunc sequitur Sexta(?) conclusio quod quelibet stella, etc.(?) *V* 22 aut] vel *B* | celum] *post* celum *scr. et del.* pro quo *L* | quia] *om. L* | terra] *post* terra *add.* est *L* 23 substans] substat *V* | cunctis] punctis *V* | dempsior] dempssior *L*; densior *V* 24 grossior] *post* grossior *scr. et del.* ist *L*

be understood that a line perpendicular to any spherical surface, if extended further, would go to the center [of the sphere], since only such [a line] forms equal angles around itself. And thus every other [ray] is oblique, and no [ray] coming from a star crossing over through the eye proceeds to the center [of the world] – unless it were coming from a point which is above the zenith overhead. Thus, every other [ray] falls obliquely on the concentric spheres of the world.

For example, let *k* be the center of the world, *e* the eye, and *g* a star which is not over the zenith *f*, and let *ab* be the surface of fire. [Figure 15] Then it is easily proved that line *ge* is not perpendicular to the surface *ab*, and that [it] forms unequal angles, nor would the line proceed to the center if extended further.

I also say that there are two causes of this [varying] obliquity: (1) the distance from the zenith (as noted), and (2) the nearness of the surface of the sphere to the earth, or the distance [of the sphere] from the star. Now it is clear that the greater the distance from point *g*, the more separated the lines *ge* and *gk* are, thus the more obliquely incident and further from the perpendicular *ge* is. Therefore [the ray *ge*] is more oblique to the surface of [the sphere of] air than to the surface of [the sphere of] fire, and of fire than to the sphere of the moon or the sun, and likewise in regard to the others.

Thus, all things being equal, [the more oblique to the surface of a sphere the ray is] the more refracted it is – if [refraction] occurs, and if a differentiation in subtlety of the media will have been made.

[Conclusion 5] A fifth conclusion is this: air is denser than a superior body, such as fire or the heavens. First, this is proven because, just as earth is heavier than all other elements put together, [so also] it is denser and thicker. Likewise it is seen that fire [is] sit; etiam subtilissimus superexcedens alia elementa levitate et raritate. Et sicut terra grossior est quam aqua, et aqua quam aer, ita verisimile videtur quod aer sit grossior ipso igne, licet forte non proportionaliter. Et potissime videtur quod corpus celeste excellit alia mundi elementa subtilitate, sicut etiam loco ipsis stellis exceptis que sunt corpora lucida.

Secundo, videmus quod magna aeris quantitas interposita visui, et visibili valde debilitat visionem, et per elongationem rerum in aere apparent magis obscure. Sed elongatio maxima et incomparabilis per speram ignis, et per speras celi non facit multum magnam | *V* fol. 45r obscuritatem. Et istud est signum manifestum quod huius spere non sunt tante grossitiei sicut aer. Unde, si tanta spissitudo aeris esset inter lunam et stellas fixas quanta est corpulentia intermedii celi, stelle non possent a nobis videri.

Tertio, ex tractatu Alhacen De crepusculis apparet quod propter aeris spissitudinem reflectentem radios solis fiunt crepuscula et in vespere | *F* fol. 36r et de mane. Igitur, saltem aliqua pars spere aeris est grossior | *L* fol. 45v quam illud quod est supra et quod non potest reflectere lumen solis et summitatem huius grossi aeris vaporosi concludit Alhacen in 10 fore altitudinis 52 milia passuum.

Quarto, arguitur ad conclusionem evidentis, quia stelle fixe videntur per lineam fractam a perpendiculari. Ergo, videntur per

1 sit] sic *F* | superexcedens] *post* superexcedens *add.* omnia *B* | elementa] *om. B* 1–2 levitate et raritate] raritate et levitate *F* 3 verisimile] verissime *L* 4 potissime] propriissime *V* | videtur] noster *L* | celeste] celicum *V* | excellit] *post* excellit *add.* omnia *V* 5 elementa] ellementa *L* | ipsis] ipssis *L* 8 visibili] *om. F* | per] *om. V* | rerum] res *L* 9 apparent] apparet *V* | magis] *om. F* | obscure] *rep. et del.* obscure *F* | maxima] maximo *L*; maxime *V* | et] est *V* 10 speras] speram *LV* | multum] multam *L* 11 obscuritatem] *post* obscuritatem *scr. et del.* q *F* | istud] illud *FL* | manifestum] maximum *LV* | huius] huiusmodi *V* 12 grossitiei] grossiores *F* | sicut] *post* sicut *add.* est *V* | tanta] *post* tanta *scr. et del.* (?) *V* 14 stelle] stelli *L* 15 Alhacen] Alasen *F*; Alacen *V* 16 reflectentem] reflectionem *L* | radios] radiis *L* 17 in] de *V* | de] in *B* | saltem] *om. L*; semper(?) *V* | spere] *om. L* 18 illud] id *B* 19 et] *post* et *add.* hanc(?) *L* | summitatem] sumitatem *L* 20 Alhacen] Alachen *F*; Alacen *V* | 10] 4° *V* | milia] millia *L* 22 Ergo] Igitur *V*

15 Ibn Mu'adh, *De crepusculis,* in Smith (1992), "The Latin Version of Ibn Mu'adh's Treatise," p. 115, lines 414–416. Oresme attributed this work to Alhacen. 20 This is the height of the atmosphere (rounded up) given in Ibn Mu'adh's *De crepusculis.*

the lightest [of the elements and] rises above all [of them]; also, it may be the subtlest, surpassing other elements in lightness and rarity. And just as earth is denser than water, and water than air, so it seems likely that air is denser than fire itself, although perhaps not proportionally. And above all it seems that celestial substance excels the world's other elements in subtlety, as the place of the stars themselves, excepting that they are luminous bodies.

Second, we see that a large quantity of air between the eye and a visible object greatly weakens the vision, and things in air appear more obscure through [increasing] distance. But the huge, incomparable distance through the sphere of fire and the heavenly spheres does not cause a huge obscuration. And this is a clear sign that these spheres are not so dense as air. Whence, if as great a density of air as the grossness between us and the heaven were between the moon and the fixed stars, the stars could not be seen by us.

Third, from Alhacen's treatise *De crepusculis* [= *On Twilight*],[55] it appears that twilights are formed both in the evening and the morning because the density of the air bends the solar rays. Therefore, at least some part of the sphere of air is denser than that which is above it and cannot bend sunlight. And in [section?] 10 [of *On Twilight*], Alhacen concludes the highest part of this dense, vaporous air to be at an altitude of 52 miles.[56]

Fourth, one can argue for this manifest conclusion [in this way]: fixed stars are seen through lines refracted from the perpendicular.

[55] The *De crepusculis* was actually written by Ibn Mu'adh, as A.I. Sabra has proven. Sabra also notes that this citation in Oresme's *De visione stellarum* is the earliest to attribute the work to Alhacen. A.I. Sabra, "The Authorship of the *Liber de crepusculis*, an Eleventh-Century Work on Atmospheric Refraction," *Isis* 58 (1967): 77, 83–84.The *De crepusculis* was quite popular throughout the Middle Ages and Renaissance where it was widely believed to be written by Alhacen. As A. Mark Smith has postulated, perhaps this attribution was partially because its Latin manuscripts were sometimes bound with Alhacen's *De aspectibus*. A. Mark Smith, "The Latin Version of Ibn Muadh's Treatise *On Twilight and the Rising of Clouds*," *Arabic Sciences and Philosophy* 2 (1992): 83–84, 89.It is unclear whether Oresme, in his *De visione*, was the first to mistakenly attribute the *De crepusculis* to Alhacen, or whether this is merely the earliest extant example of such an attribution.

[56] This is the height of the atmosphere (rounded up) as determined by Ibn Mu'adh in his *De crepusculis*, which Oresme attributed to Alhacen. Cf. the Latin and English translation of Ibn Mu'adh's, *De crepusculis*, in Smith (1992), "The Latin Version of Ibn Mu'adh's Treatise," p. 115, lines 414–416 (Latin), and p. 131 (English). Smith does not indicate any book, chapter, or section divisions found in the manuscripts of this work, so Oresme's designation of "10" (or "4°" in the Vatican manuscript) is unclear.

diversa media, quorum superius est rarius. Seu, secundum antecedens probatur per experientias adducendas in probatione sexte conclusionis.

Et consequentia tenet, quia non propter aliud frangitur radius visualis. Et propter istud frangitur hoc modo, ut patet ex corollario secunde conclusionis.

[Conclusio 6] Sexta conclusio quod quelibet stella que non est supra zenith videtur per lineam fractam a perpendiculari. Probatur, quia radius visualis de oculo ad stellam cadit super aeris superficiem oblique, per quartam conclusionem. Et aer est grossior quam celum per quintam conclusionem. Igitur, radius huius frangitur per primam conclusionem. Igitur, frangitur a perpendiculari, per corollarium secunde. Et ne videatur quod sit adinventio novitas ficta, probatur auctoritabus et experientiis manifestis antiquorum. Istud enim determinat PTHOLOMEUS in 5^{to} De aspectibus, ut recitatur in libro De speribus. Et similiter, hoc probat ALHACEN in 7^{o} capitulo *B* fol. 35^{v} 4^{o}, et VITELO in 10, | conclusione 47^{a} Perspectivarum suarum.

1 diversa] diverssa *L* 2 probatur] *post* probatur *add.* quare *F* | experientias] *om. V* | adducendas] aducendas *F* 4 frangitur] frangetur *V* | radius] radius *rep.F* 5 istud] illud *FL* 7 Sexta] Secunda *F* | conclusio] *post* conclusio *add.* est *F* 8 zenith] cenith *BF* 10–12 Et … conclusionem] *om. L* 10 quam] *om. BF* 11 celum] celo *BF* | conclusionem] *om. V* | Igitur] Ergo *F* 12 conclusionem] *om. V* | Igitur] Ergo *FL* 12–13 corollarium] correllarium *BV*; corellarium *F* 13 secunde] tertie *B* 14 auctoritabus] autoritatibus *F*; auctoribus *L* | et] *post* et *scr. et del.* (?) *F* | experientiis manifestis] manifestis experientiis *FL* | antiquorum] *post* manifestis *scr. et del.* (?), *add.* antiquorum *sup. l. V* | Istud] Illud *sup. l. V* 15 Ptholomeus] THOLOMEUS *FL; in mg. V*: Alias: PTOLOMEUS 2^{a}(?) De aspectibus, ut recitatur in libro De sperebus. Et probat ALACEN in 7^{o} capitulo 4^{us}, et VITELO in 10^{mo}, conclusione 97^{a}(?) Perspectivarum suarum | 5to] 3^{o} capitulo 4^{i} *V* 15–17 De … 40] *om. V* 15 ut] *post* ut *scr. et del.* l *F* 16 Alhacen] ALACHEN *F* 17 40] 7^{o} *L* | Vitelo] WITELO *B*; VOATELO *L* | 10] 1^{a} *L*; 4^{o} *V* | conclusione] *ante* conclusione *add.* in *V* | 47a] 47 *L*; 4^{pla} 7^{a} *V* | Perspectivarum] Perspective(?) *L* | suarum] *om. L*

15 PTOLEMY (1989), *Optics, ed. Lejeune*, Bk. V, secs. 25–26 (= Prop. 85), pp. 238–240. 16 Cf. JOHN OF SACROBOSCO, *De spera*, in Lynn Thorndike (1949), *The "Sphere" of Sacrobosco and Its Commentators*, p. 81. | ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 4, secs. 15–16, pp. 251–252. 17 WITELO (1572, rpt. 1972), *Perspectiva*, X, secs. 49–50, p. 444–445.

Therefore, they are seen through different media, of which the higher is more rare. Or, the second antecedent[57] is proved through experiments cited in the proof of the sixth conclusion [below].

And the consequence is valid [i.e., that air is denser than any superior body] because the refraction of a visual ray [in air] is not due to anything else but comes about in this way, as is clear from the corollary of the second conclusion.[58]

[Conclusion 6] The sixth conclusion is this: any star which is not over the zenith is seen through a line refracted from the perpendicular. This is clear, since a visual ray from the observer to the star falls obliquely on the surface of the [sphere of] air, as per the fourth conclusion.[59] And air is denser than the heaven, as per the fifth conclusion.[60] Therefore this ray is refracted, as per the first conclusion, and it is refracted away from the perpendicular, by the corollary of the second [conclusion].[61] And lest it seem that this is a discovery newly contrived, let it be proven by authorities and experiments manifested by the ancients. For Ptolemy determines this in the fifth [book] on *Optics*, as related in the book *De speribus*.[62] Similarly, Alhacen proves this in [his *De aspectibus*, Book] VII, chapter 4, and Witelo, in his *Perspectiva*, [Book] X, conclusion 47.[63]

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[57] The "second antecedent" appears to refer to the phrase "the higher [media] is more rare." This statement is supported by the "experiments" in the sixth conclusion.

[58] *De visione stellarum*, Bk. II, cap. 1, 120:9 – 122:16.

[59] *De visione stellarum*, Bk. II, cap. 1, 134:5 – 136:20.

[60] *De visione stellarum*, Bk. II, cap. 1, 136:21 – 140:6.

[61] *De visione stellarum*, Bk. II, cap. 1, 114:10 – 118:7, 120:9 – 122:16.

[62] Ptolemy (1989), *Optics, ed. Lejeune*, Bk. V, secs. 25–26 (= Prop. 85), pp. 238–240.Oresme here cites a *De speribus*; almost certainly he is referring to the *Sphere of Sacrobosco*, which briefly explains that celestial objects near the horizon appear larger than when they are at the zenith due to refraction by diaphanous vapors. John of Sacrobosco, "De spera", in Lynn Thorndike's, *The "Sphere" of Sacrobosco and Its Commentators*, (Chicago: University of Chicago Press, 1949), p. 81 (Latin), pp. 120–121 (English tr.).However, Sacrobosco does *not* refer to Ptolemy's *Optics* in this passage, though he does cite Alfraganus. Oresme himself wrote a commentary on the *Sphere* but he does not seem to be referring to it here, for I have found no reference to atmospheric refraction in the modern edition of that text by Garrett Droppers. Garett Droppers, *The "Questiones De Spera" of Nicole Oresme. Latin Text with English Translation, Commentary and Variants* (Ph.D. dissertation, University of Wisconsin, 1966).

[63] Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 4, secs. 15–16, pp. 251–252. Oresme was probably referring to Witelo, Book X, sections 49–50, rather than section 47. Witelo (1572, rpt. 1972), *Perspectiva*, X, secs. 49–50, pp. 444–445.

Una experientia est de stellis sempiterne apparitionis. Quoniam, si una illarum notetur in circulo meridiano quando est circa zenith, et per instrumentum armillarum capiatur eius distantia a polo mundi. Deinde alia vice, dum eadem stella fuerit in puncto medio noctis prope orizontem, iterum per instrumentum notetur eius distantia a polo. Et invenietur multo minor distantia eius a polo quam fuerit primo, scilicet, dum erat circa zenith. Et, tamen, in rei veritate equaliter distat a polo, nisi forte propter motum 8^{ve} spere. Sed hoc non faceret differentiam sensibilem. Et quia istud non potest accidere, si stella semper videretur per lineam rectam, et quando est super zenith radius est perpendicularis et non frangitur. | Ergo, quando est prope orizontem non videtur per rectam lineam, sed per fractam.

L fol. 46^{r}

Alia experientia est consimilis priori. Si notetur aliqua de stellis que transeunt supra zenith, vel prope, et tunc, ut prius videatur per instrumentum distantia eius a polo, quando erit versus orientem, et deinde, quando erit circa zenith. Et apparebit per instrumentum minor distantia eius a polo, quando est versus ortum, quam dum est circa zenith. Quod non potest fieri ut supradictum est, nisi stella, dum est versus orientem, videatur per lineam fractam.

Aliud experimentum est de luna. Quia tempore ortus sui adequetur per tabulas distantia eius a polo et declinatio eius ab equinoc-

1 experientia] *add. in mg. a. m.* experimentum *F* | stellis] stelis *L* 2 illarum] istarum *L* | zenith] cenith *BF* 3 per] per *rep. et del. F* | eius] *ante* eius *scr. et del.* inter(?) *L* | distantia] *post* distantia *add.* eius *F* 4 medio] medie *FV* 5 iterum] rectum *F*; *ante* Iterum *scr. et del.* Ite(?) *V* 6 invenietur] *post* invenietur *scr. et del.* multa(?) *V* | multo] multum *sup. l. V* | minor] brevior *L* | fuerit] sit *V* 7 primo] prima *F* | dum] quando *V* | zenith] cenith *BF* 8 nisi] *post* nisi *add.* hoc *V* | forte] *post* forte *add.* fuerit *V* | 8ve spere] spere 8^{ve} *V* 9 sensibilem] senssibilem *L* | istud] illud *L* | potest] posset *B* 10 accidere] acidere *F* | videretur] videre *L* | quando] *post* quando *scr. et del.* s *F* 11 est] est *sup. l. V* | super] supra *B* | zenith] cenith *BF* | est] *post* est *scr. et del.* super *F* | et non frangitur] *sup. l. V* | Ergo] Ideo *V* 12 rectam lineam] lineam rectam *B* 14 consimilis] similis *B*; sensibilis *L* 15 zenith] cenith *BF* | prope] propter *V* 16 eius] eius *sup. l. V* | quando] *post* quando *add.* est *sup. l. V* | orientem] orizontem *F* [abbr. in *B* could be either "orientem" or "orizontem"] 17–20 et … orientem] *om. L* 17 zenith] cenith *BF* 18 distantia eius] eius distantia *F* | quando] quam *LV* 19 zenith] cenith *BF* | supradictum] supra dictum *V* | nisi] nisi *rep. et del.* [twice!] *F* 20 orientem] orizontem *F* | lineam] *post* lineam *add.* rectam *V* | fractam] fractam *scr. mg. V* 21 est] *om. F* | Quia] quod *F*, *post* quod *add.* si *F* | tempore] si ipse *V*, ipse *corr. ex* ipsa *V* 21–22 adequetur] adequetur *rep. F* 22 polo] *post* polo *scr. et del.* (?) *V* | et] et *sup. l. V* | eius] *om. L*

One experiment concerns the circumpolar stars.[64] Let one of them be observed on the meridian circle when it is near the zenith, and its distance from the pole of the world be taken by using an armillary sphere. Then at another time during the night, when the same star is at a point near the horizon, its distance from the pole should be observed through the instrument a second time. And one will discover its distance from the pole [to be] much smaller than it was the first [time], that is, when it was near the zenith. And yet in actuality it is equally distant from the pole – unless, perhaps, because of the motion of the eighth sphere.[65] (But this would not make a perceptible difference.) And since this [experimental observation] could not happen if the star were always seen through a straight line, and when [the star] is over the zenith the ray is perpendicular and is not refracted, then when [the star] is near the horizon it is not seen through a straight line but through one that is refracted.

Another experiment is similar to the previous one. Let any of the stars which pass over or near the zenith be noted, and then, as before, let its distance from the pole be observed through an instrument when it is towards the east, and then again when it is near the zenith.[66] Its distance from the pole will appear smaller when it is near [its] rising[67] than when it is near the zenith. As was said above, this cannot occur unless the star is seen through a refracted line when it is in the east.

Another experiment concerns the moon.[68] Let the time of its rising be calculated using tables of its distance from the pole and its

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[64] Oresme probably derives this and the following experiment from Roger Bacon, who describes them both in the same passage of his *De multiplicatione specierum* (a work Oresme cites later in this text). Bacon explains that both originally derive from Ptolemy and Alhacen. Witelo is another possible source for this experiment, since he details it as well. Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 39–54, pp. 120–121, and lines 74–107, pp. 122–125; Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 15, pp. 251. Witelo (1572, rpt. 1972), *Perspectiva*, X, secs. 49, pp. 444.

[65] That is, the sphere of the fixed stars.

[66] This same experiment is found in Alhacen, Bacon, and Witelo; for citations, see the footnote in the preceding paragraph.

[67] That is, when it is in the east.

[68] This same demonstration concerning the moon is found in Alhacen, Bacon, and Witelo. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 15, pp. 251–252; Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 108–120, pp. 124–125; and Witelo (1572, rpt. 1972), *Perspectiva*, X, secs. 49, pp. 444.

F fol. 36v tiali, et deinde iterum adequetur, quando est prope | zenith. Tunc experientia facta per instrumenta discordabit adequationi facte per tabulas, quando luna est in ortu, et non ita, quando est prope zenith. Ex quo, patet quod, dum oriebatur, non videbatur recte, sed fracte.

Et ex quolibet istorum experimentorum sequitur neccessario, *V* fol. 45v quod fractio | linee precedens de oculo ad stellam fit recedendo a perpendiculari. Verbi gratia, sit *k* centrum mundi, *e* oculus, et *c*

1 zenith] cenith *B*; cenit *F* 2 facta] *ante* facta *scr. et del.* fata(?) *F* | discordabit] discordabitur *L* | adequationi] ab equatione *V* | facte] *om. V* 3 zenith] cenith *BF; post* zenith *scr. et del.* tunc experientia factam per instrumenta discordabit *L* 4 patet quod] *om. V, add.* sequitur *sup. l. V* | quod] quod *sup. l. B* 5 Et] *om. FL*; *scr. et del.* Sed(?), *add.* Et *sub. l. V* | istorum] illorum *V* | neccessario] neccesse *B* 6 precedens] precedentis *FLV* 7 k] a *BFL* [NOTE: The diagrams in *B, V* and *F* have *k* as the center of the world, yet the descriptions in *BFL* place *a* at the center. Yet, further on, all but the late ms. *L* speak of "k" at the center again. Therefore, it is likely that *k* was the original reading.]

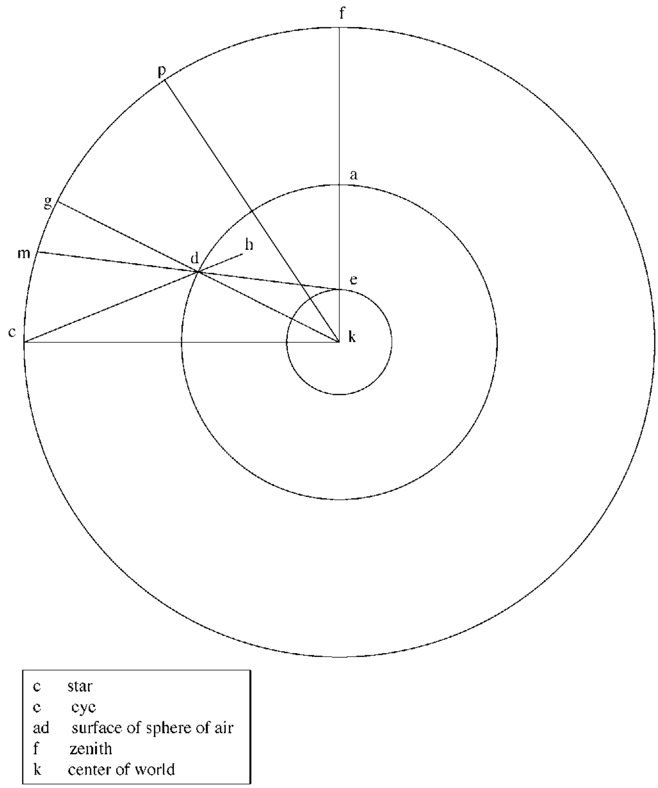

Figure 16. Light From Any Star not over the Zenith
is Refracted at the Surface of the Sphere of Air

declination from the [celestial] equator,[69] and then let [its position] be calculated again for when it is near the zenith. Then, using an instrument, the experimental observations will disagree with the data calculated from tables when the moon is rising, and [they will] not when [the moon] is near the zenith. From this it is clear that when [the moon] was rising it was not seen directly but through refraction.

And from any of these experiments it necessarily follows that the refraction of the line preceding from the observer to the star is bent away from the perpendicular. For example, let *k* be the center

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[69] Literally, "from the equinoctial", implying the equinoctial circle, a name for what is now called the celestial equator. This term "equinoctial" is described at length in John of Sacrobosco's *De sphaera.* In Thorndike (1949), *The "Sphere" of Sacrobosco,* p. 86 (Latin), pp. 123 (English tr.).

stella, et *p* sit polus. Et quia stella, dum est prope orizontem, apparet propinquior polo quam sit in rei veritate, sit, ergo, in *c* et appareat in *m*. Et sit fractio in puncto *d* sitque *gdk* perpendicularis super superficiem aeris. Patet, ergo, quod linea fractionis *dc* plus recedit a perpendiculari, quam rectus incessus *dm*, quod si, e converso, incipiatur a stella veniendo versus oculum, tunc secundum medium erit densius, scilicet, aer. Et linea *de* erit fractio ad perpendicularem, scilicet, inter incessum rectum *cdh* et perpendicularem *gdk*. Sit, igitur, ex ista conclusione evidenter probata per experientias demonstratur quinta in quarto argumento, et ex quinta probata per terties *L* fol. 46^{v} rationes ostenditur sexta. Est, igitur, exper|ientia veritatis, quia ratio concordat sensui, et sensus non obviat rationem.

[Conclusio 7] Septima conclusio est quod omnis stella que non est supra zenith videtur alibi quam sit. Et hec est solutio questionis. Probatur statim, quia per immediate precedentem, omnis talis videtur per lineam fractam. Ergo, per tertiam conclusionem et per secundam correllarium ipsius apparet alibi quam sit. Ut in priori figura, *c* stella apparet visui *e* in directo linee *ed* et tali elevatione super orizontem, et in concursu linee *ed* pretense ulterius cum kateco,

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1 dum] quando *V* 2 ergo] igitur *V* | in] *ante* in *add.* quod *L* 3 sitque] sit que *F*; *scr.* fit(?) que *del. a. m., add. mg.* sitque *V* | gdk] gda *L*; dgk *V* | super] *scr. et del.* puncto, *add.* super *sup. l. V* 4 ergo] igitur *V* 6 stella] stela *L* | versus] verssus *L* | erit] est *L* 7 densius] depsius *B*; denpsius *F*; denssius *L* | scilicet aer] *om. F* | Et] *ante* et *scr. et del.* en, *scr.* En *F* | de] ed *V* | fractio] *om. F* 7–8 scilicet] *rep. et del.* scilicet *F* 8 gdk] gdb *BF*; gda *L* | Sit] Sic *L* 9 ista] illa *L* | experientias] *ante* experientias *add.* ex *F* 10 quinta] convictam(?) *L* | terties] *post* tertias *add.* primas *V* 11 Est] *ante* Est *add.* que *sup. l. V* | igitur] gratia *L*; *om. V* | quia] quod *F* 12 sensui] sensum *L* 14 est] est *sup. l. V* | supra] super *L* | zenith] cenith *BF* 15 quia] *om. LV* | immediate] inmediate *LV* | precedentem] *post* precedentem *add.* quia *sup. l. V* 16 Ergo] Igitur *LV* 17 correllarium] corellarium *F* | Ut] *om. FV* 18 directo] directam *V* | linee] linea *V* | ed et] edc *L*; edc *corr. ex* ed et *V* 19 in] in *corr. ex* ex(?) *V* | concursu] concurssu *L* | linee] *post* linee *scr. et del.* e(?) *F* | ed] cd *F* | kateco] catheto *F*; kteco *L*

of the world, *e* an observer, *c* a star, and *p* the pole [of the world]. [Figure 16] And since the star, when it is near the horizon, appears nearer to the pole than it actually is, let it be in *c* and appear in *m*. And let *d* be the point of refraction, and let *gdk* be perpendicular to the surface of the air. It is clear, therefore, that the line of refraction *dc* recedes more from the perpendicular than [does] the rectilinear extension *dm*, because, conversely, if [this line] were beginning from the star [and] coming towards the eye, then [this implies] the second medium (that is, the air) will be denser. And the line *de* will be refracted towards the perpendicular, that is, between the direct path *cdh* and the perpendicular *gdk*. Therefore, from this [sixth] conclusion, [which] is clearly proven by experiences, the fifth [conclusion above] is demonstrated in [its] fourth argument.[70] And from [that] fifth [conclusion], proven through [its first] three arguments, [this] sixth [conclusion] is shown.[71] Therefore, this is the experience of truth, because reason agrees with the senses, and the senses do not oppose reason.[72]

[Conclusion 7] The seventh conclusion is this: any star which is not over the zenith is seen elsewhere than it is. And this is the solution of the question. It is proven at once by the immediately preceding [conclusion]:[73] every such [star] is seen through a refracted line. Therefore, as per the third conclusion and its second corollary,[74] [a star] appears elsewhere than it [really] is. As in the previous figure [Figure 16], the star *c* appears to the observer *e* along the direct line *ed* and at a certain elevation above the horizon, and at the intersection of [three lines]: the further extension of the line *ed*, the

[70] The fifth conclusion argued that the sphere of air is denser than the spheres above it, and the fourth argument in support of this concluded that the stars are seen along refracted lines. *De visione stellarum*, Bk. II, cap. 1, 138:21 – 140:6. There, Oresme stated that the fourth argument could be supported by experiments which would be fully explained here in the sixth conclusion.

[71] *De visione stellarum*, Bk. II, cap. 1, 136:21 – 138:20. Oresme's three rational arguments that support the fifth conclusion "that the sphere of air is denser than the spheres above it" are here seen to indirectly support the sixth conclusion that "any star not over the zenith is seen through a refracted line."

[72] A Fascinating phrase on the relationship of experience/experiment and reason.

[73] That is, conclusion six: any star which is not over the zenith is seen through a line refracted from the perpendicular. *De visione stellarum*, Bk. II, cap. 1, 140:7 – 146:12.

[74] The third conclusion is: when a thing is seen by a refracted line, then it appears on a line proceeding from the eye, through the place of refraction, in a continuous and straight [line] and along the direct path. *De visione stellarum*, Bk. II, cap. 1, 122:17 – 134:4.

seu perpendiculari a superficie plana contingente superficiem aeris in puncto *d* ducta per centrum stelle in continuum et directum, verbi gratia, in *m* et sit illa perpendicularis *lcm*, et alter punctus *m* correspondet in arcu per *c*. Et est eadem elevatio utriusque super orizontem et propinquitas ad polum secundum gradus celi.

Sequitur, igitur, per primum corollarium tertie quod apparet *B* fol. 36^{r} remotius a nobis | quam si videretur recte, sicut quando est supra zenith. Et preter illud, est alia causa quare visus iudicat stellam magis distare, quando est prope orizontem, ut ponit VITELO in 4^{o}, et ALHACEN in capitulo finali Perspective. Quia quando stella elevata est versus zenith, visus non comprehendit nec distinguit visibilia interposita. Sed quando stella est prope orizontem, tunc visus comprehendit visibilia interposita que sunt in orizonte. Et ex hoc virtus distinctiva iudicat stellam magis distare. Et ex hoc, etiam, iudicat eam esse maiorem, posito quod non essent vapores qui adhuc quandoque sunt faciunt apparere stellam sub maiori angulo.

Ad maiorem declarationem predictorum arguitur de hoc: quod dictum est quod radius stelle frangitur in divisione aliquarum sperarum, sicut ignis et aeris, vel celi et ignis, etc.

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1 perpendiculari] perpendicularis *L*; perpendiculas *V* | plana] plane *L* | contingente] continente *F*; contingentem(?) *L* 2 per] *rep. et del.* per *F* | stelle] stele *L* 3 sit] sint *F* | illa] a *V* | lcm] scm *L* | alter] alteriusque *L* 4 correspondet] conrespondet(?) *FL* | arcu] arcus(?) *L* | per c] pc *B*; bc *V* 5 propinquitas] propinquas *L* | polum] *post* polum *add.* c *V* 6 igitur] ergo *L* | per] quod *F* | primum corollarium] *scr. et del.* primum corollarium *add.* per primum angulum *F* | corollarium] corollarii *V* 7 sicut] *om. BL* 8 zenith] cenith *BF*; *post* zenith *add.* capitur *sup. l. V* | illud] istud *L* 9 Vitelo] WITELO *B*; VITELLO *L* 10 Alhacen] ALASEN *F*; ALACEN *V* | capitulo finali] 7^{o} capitulo *V* | Perspective] *post* Perspective *add.* finali *V* | stella] *post* stella *add.* est *sup. l. V* 11 elevata] ellevata *L* | est] *scr. et del.* est *V* | zenith] cenith *BF* 12 visibilia] visibillia *L* 12–13 Sed … interposita] *om. BF* 13 visibilia] visibillia *L* | orizonte] oriente *V*, *add. a. m.* in orizonte *mg. V* 14 distinctiva] distantiam *FL* | iudicat] iudicans *V* 15 vapores] *post* vapores *add. a. m.?* inter fractio *V* | qui] qui *corr. ex* que *V* 16 quandoque] quando *FV* | apparere stellam] stellam apparere *V* | stellam] eam *L* 17 Ad] *ante* Ad *add.* Sequitur *sup. l. V* | predictorum] *post* predictorum *scr. et del.* dis(?), *add.* dicitur *sup. l. V* | arguitur] *om. V* | de] de *sup. l. V* 18 stelle] *sup.* stelle *add. et del.* solis *sup. l. V* | aliquarum] *scr. et del.* aliquarum, *add.* aliarum *sup. l. V* 19 et] vel *corr. ex* et *V* | vel] vel *corr. ex* per(?) *V* | et ignis etc] *post* celi *scr. et del.* et ignis, etc. *V*

10 WITELO (1572, rpt. 1972), *Perspectiva*, X, sec. 54, pp. 448–449; ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 51–55, pp. 278–282.

cathetus or perpendicular from a plane surface touching the surface of [the sphere] of air at point *d* drawn through the center of the star [*m*] in a continuous and straight [line]. And let that perpendicular be *lcm*, and the point *m* correspondingly on the arc through *c*. And this is the same elevation of each above the horizon and [their] nearness to the pole [of the world] according to the gradation of the heaven.[75]

Therefore, it follows from the first corollary of the third [conclusion] that [the star] appears further from us than if it were seen in a straight line, as when it is over the zenith. And beyond this, there is another reason why the eye judges the star to be more distant when it is near the horizon, as Witelo says in [*Perspectiva*, Book] IV [sic], and Alhacen in the final book [i.e., Book VII] of the *De aspectibus*.[76] For when a star is elevated towards the zenith, the eye does not perceive nor distinguish intervening visible objects. But when the star is near the horizon, then the eye perceives intervening visible objects which are on the horizon. And from this, the [eye's] distinguishing ability judges the star to be more distant. And also from this, [the eye] judges [the star] to be larger – granting that there were no vapors which, at times, further make the star seem under a larger angle.[77]

One can argue for a *broader explanation* of the preceding from this: it has been said that the ray of a star is refracted at the division of some of the spheres, such as [at the division of] the sphere of fire and air, or the heavens and fire, etc.[78]

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[75] A rather tortuous passage to explain the degree of elevation of the apparent position of the star as seen by an observer.

[76] In referring to Witelo, Oresme probably meant book X, rather than book IV. Witelo (1572, rpt. 1972), *Perspectiva*, X, sec. 54, pp. 448–449; Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 51–55, pp. 278–282.

[77] Oresme is referring once again to the famous "Moon Illusion," in which the Moon appears larger on the horizon than at the zenith. Here, it seems he attributes this to at least two causes: first, visible objects on the horizon juxtapositioned to the celestial object cause the celestial object to appear larger, and, second, intervening vapors cause the object to appear larger. See the Corollary to Conclusion 3 above, *De visione stellarum*, Bk. II, cap. 1, 122:17 – 134:4. See also endnote ix below.

[78] My emphasis.

[Cap. 2: Rationes contra conclusionem principalem, responsiones, et eorum corollarii.]

[Primo ratio contra conclusionem principalem] Contra primo non est notum quod sit aliqua talis spera ignis. Et si est dicetur quod densitas aeris remittitur paulatim ascendendo versus | [*F* fol. 37r] ignem, et ita ordinate quod ibi est | [*L* fol. 47r] difformitas sine saltu et sic nulla est superficies que super eam immediate habeat certum gradum subtilitatis et sub ea immediate gradum notabiliter differentem, quod, tamen, requireretur ad fractionem. Et hoc est quod dicit Alhacen in 7° capitulo 7°, quod scilicet aer quanto magis appropinquat celo, tanto magis purificatur donec fiat ignis. Ergo, eius subtilitas fit ordinate, secundum successionem, et non in differentia terminata. Et ideo, concludit quod non fit fractio inter aerem et ignem.

Et consimiliter, dicetur de spera ignis, quod subtiliatur paulatim quousque finiatur exclusive | [*V* fol. 46r] ad gradum densitatis in orbe lune. Et ita

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3 Contra] Dicitur *L*; *ante* Contra *add.* Sed *sup. l. V*; *post* Contra *add.* hoc arguitur *sup. l. V* | primo] primum *F*   4 sit] *om. V* | aliqua] *post* aliqua *add.* est *V* | est] *post* est *add. (a. m.?)* et si debitur et dicetur *sup. l. et in mg. V* | dicetur] *post* dicetur *add. et del.* prius(?) *V* | quod] quod *sup. l. V*; *post* quod *add. et del.* de *F* 5 densitas] dempsitas *BF* | remittitur] remittetur(?) *F*; remitittur *L* | paulatim] paulatine *BF*; *ante* paulatim *add.* tamen *sup. l. V* | ascendendo] adscendendo *F* | versus] *rep. et del.* versus *F*   5–6 et … saltu] *scr. et del.* et ita ordinate quod in(?) est difformitas sine saltu *V*, *add.* et ibi negare(?) est multa difformitas *sup. l. V*   6 quod] *post* quod *add. et del.* sicut(?) *F* | difformitas] diformitas *F* | est] *post* est *add.* ibi *sup. l. V*   7 super] *scr. et del.* super, *add.* supra *sup. l. V* | eam] *scr. et del.* eum(?), *add.* eam *sup. l. V* | immediate habeat] habeat immediate *F* | certum] *scr. et del.* aliquam, *add.* certum *sup. l. V* | subtilitatis] suptilitatis(?) *L* | et] etiam *L*   8 immediate] *scr. et del.* immediate *V* | tamen] *post* tamen *scr. et del.* requ(?) *V*   9 requireretur] requiretur *L*; requiretur *sup. l. V* | Alhacen] Alasen *F*; Alacen *V*   10 quod scilicet aer quanto] scilicet quod quanto aer *V* | appropinquat] adpropinquat *F*   11 donec] *scr. et del.* d(?)de(?), *add.* donec *sup. l. V* | fit] *om. V*   12 et] est *V* | differentia] *post* differentia *add.* determinata *sup. l. V* | Et] *om. F*   14 consimiliter] consimilliter *F*; similiter *V* | dicetur] dicatur *V*   15 quousque] donec *F* | exclusive] *post* exclusive *add. in sub mg.* Et sic dicende [*scr. et del.* d] igne usque ad circulum lune, et luna usque ad ultimam speram. Respondendo dico *V* | densitatis] dempsitatis *BF* | ita] sic *V*

9 Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 51, p. 278.

[Section 2: Arguments Against the Principal Conclusion, Responses, and Their Corollaries.]

[1st Argument Against the Principal Conclusion] First, against [this principal conclusion]: it is not known that there is any such [division at the] sphere of fire. And it will be said that the density of air decreases gradually [while] ascending towards [the sphere of] fire, and it is so gradual that there is change without discontinuity, and thus there is no surface which has a clear degree of rarity immediately above it, [or] a notably different degree [of density] immediately below it, which, however, would be required for refraction. And this is what Alhacen says in [his *De aspectibus*, Book] VII, chapter 7, namely, "that the closer air approaches the heaven the more it is purified until it becomes fire. Therefore, its rarity increases gradually, and not in discrete steps."[79] And thus he concludes that refraction does not occur between [the spheres of] air and fire.

In the same way, this will be said concerning the sphere of fire, that it is rarified gradually until it is exclusively limited to the degree of density [found] in the lunar sphere. And likewise

[79] Alhacen says,"Et non dividitur a corpore aeris superficies, quae distinguit unam partem ab alia, sed quanto magis appropinquat aer coelo, tanto magis purificatur, donec fiat ignis. Subtilitas ergo eius fit ordinate secundum successionem, non in differentia terminata. Formae ergo eorum, quae sunt in coelo, quando extenduntur ad visum, non refringuntur apud concavitate sphaerae ignis, cum non sit ibi superficies concava determinata."(Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 51, p. 278.)Almost the same exact quote is found in Bacon's *De multiplicatione specierum*, which may have been the guide, if not the source, of Oresme's explication here. Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 159–161, pp. 126–128.

orbis lune ad orbem superiorem, et sic consequenter, quare sequitur quod nullicubi fiet fractio.

[1° Responsio] Respondendo dico primo quod istud non facit dubitare quin sit fractio attentis predictis, quia hoc est demonstratum per experientias certissimas antiquorum, ut patuit in probatione sexte conclusionis. Sed ratio bene facit dubitare ubi fit huiusmodi fractio. Et propter hanc rationem dicit ALHACEN quod talis fractio non fit in divisione ignis ab aere, sed in divisione celi ab aere. Et intelligit per aerem totum ex spera ignis et aeris, ut dicit auctor libri De speciebus, et similiter, VITELO in 10^mo^. Ergo, in superficie concava orbis lune fit huiusmodi fractio, et non inferius secundum istos, existente, tamen, aere puro a grossis vaporibus. Nec etiam superius, quia secundum ipsos orbes celi non differunt notabiliter in subtilitate.

[2° Responsio] Secundo, posset dici probabiliter quod fractio fit notabilis inter aerem superiorem et illum qui est vaporibus subtilioribus in grossatum. Et quia per reflexionem causantem crepuscula apparet quod ibi est magna et notabilis differentia in subtilitate cum inferior aer reflectet radios, et, tamen, superior hoc non potest.

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1 superiorem] *ante* superiorem *scr. et del.* suorum *F* | consequenter] consequentis *FL* | quare] quam *F*; *post* quam *add.* e *F* | sequitur] patet *V* 2 nullicubi] nulli in(?) *L*; *post* nullicubi *scr. et del.* que *V* | fiet] est *V* 3 Respondendo] Respondenda *L*; *add.* Responsio *mg. F* | primo] *om. V* | istud] illud *L* 4 attentis] atentis *F*; actentis *L* | quia] *om. V* 5 experientias] experientiam *L* 5–6 probatione…conclusionis] conclusionis probatione [*post* probatione *add. et del.* Sed] seu demonstratione *F* 6 fit] sit *V* 7 Alhacen] ALASEN *F*; ALACEN *V* 8 non] non *sup. l. V* | fit] *post* fit *scr. et del.* non *V* | ignis…divisione] *om. BFL* 9 intelligit] intendit *add. (a. m.?)* incipit *sup. l. V* | auctor] actor *BL*; autor *F* 10 libri] *om., add.* in libro *sup. l. V* | Vitelo] WITELO *B*; VOITELO *L* | 10mo] 10 *BF*; 1° *L* | Ergo] Igitur *V* 11 concava] *ante* concava *add. et del.* c *F* | orbis] orbis *rep. et del. V* | huiusmodi] huius *L*; *post* huiusmodi *scr. et del.* sed(?), *add.* et *sup. l. V* | et] *om. LV* 12 istos] illos *V* | tamen] cum *B*; contrari(?) *corr. ex* cum(?) *V* | grossis] grosis *L* 13 ipsos] istos *L* | orbes] orbis *F* | differunt] *rep.* differunt *sup. l. V* 14 subtilitate] suptilitate *L* 15 probabiliter] probabitur *L* 16 notabilis] notabiliter *F* 17 Et] *om. V* | per] *om. B* | reflexionem] refractionem *F* | causantem] cornentem(?) *L* 18 quod] *post* quod *add.* quia *sup. l. V* | magna] magis *L* | et] *om. L* | notabilis] multa *F* | differentia] *post* differentia *add.* et notabilis *F* | cum] *scr. et del.* cu(?) *add.* et *F* 19 inferior] inferiori *F* | reflectet] reffllectet *L*; reflectat *V* | et tamen] *scr. et del.* (?), *add. (a. m.?)* quod *sup. l. V* | hoc] hic *L*; *scr. et del.* hoc(?) *V*

7 Cf. ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 51, p. 278. 9 BACON (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 27–32, pp. 120–121. 10 WITELO (1572, rpt. 1972), *Perspectiva*, X, sec. 54, pp. 448–449.

the lunar sphere [has the same relationship to the next] higher sphere, and consequently it follows that nowhere is [the ray from a star] refracted.

[Response 1] In response, first, I say that this does not make one doubt that a refraction [of such a ray from a star] occurs (if one heeds what has been said), since this [type of refraction] has been demonstrated by the clearest observations of the ancients, as was obvious in the evidence of the sixth conclusion.[80] But this argument clearly causes one to doubt *where* such a refraction occurs. Because of this argument, Alhacen says that such a refraction does not occur at the division of fire from air, but at the division of the heaven from air.[81] And he means by [the phrase] "all the air" [both] the sphere of fire and of air, as the author of the book *De speciebus*[82] says, and likewise Witelo [in *Perspectiva*, Book] x.[83] Therefore, according to them, such a refraction occurs at the concave surface of the lunar sphere and not below it – as long as the air is clear of dense vapors. Nor, according to them, [does such refraction occur] above [the concave surface of the moon], because the celestial spheres do not differ notably in [their] subtlety.[84]

[Response 2] Second, it could credibly be said that [such rays] are noticeably refracted in the upper air and from the subtler vapors into the dense [vapors]. And since twilight is caused by reflection, it appears that there is a large and notable difference in subtlety since lower air will reflect rays and yet upper [air] cannot do this.[i]

[80] Oresme's sixth conclusion, given above, stated: any star which is not over the zenith is seen through a line refracted from the perpendicular. *De visione stellarum*, Bk. II, cap. 1, 140:7 – 146:12.

[81] Cf. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 51, p. 278.

[82] This is a confirming example that by "De speciebus" Oresme is referring to Roger Bacon's *De multiplicatione specierum*, which Oresme follows closely here. Bacon notes that in the context of atmospheric refraction, both Ptolemy and Alhacen use the term "air" to include the sphere of fire. Bacon gives the following citations: "Ptolemy says: We can discern that where air and ether adjoin rays are bent," and "Likewise, Alhacen is not concerned about the difference between fire and air." Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 27–32, pp. 120–121.

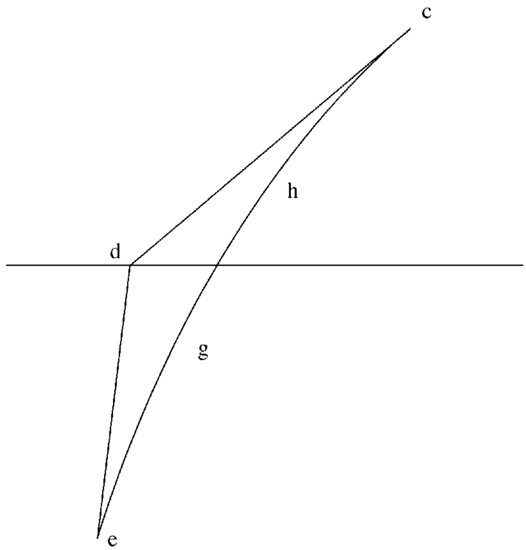
[83] Witelo (1572, rpt. 1972), *Perspectiva*, x, sec. 54, pp. 448–449.

[84] Bacon, for example, says that "… orbes celestes sunt eiusdem dyaphanitatis … propter quod radii stellarum fixarum non reputantur frangi in speris planetarum." ("… the celestial spheres are all of the same transparency … and therefore the rays of the fixed stars are judged not to be refracted in the planetary spheres.") Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, lines 12–14, pp. 118–119.

Item si huius vapores subtiles possunt radios reflectere, videtur quod, similiter, possunt radios frangere. Quod patet, quia in tempore *L* fol. 47v estivo in meridie lucente sole quandoque | tales vapores faciunt res quiescentes apparere moveri et tremere, per eorum interpositionem quod non potest fieri sine fractione radiorum.

[3° Responsio] Tertio posset rationabiliter sustineri quod quamvis aer subtilietur ordinate ascendendo, et non sit superficies terminata, sed difformitas continua usque ad ignem. Verumtamen, talis difformitas tollit rectitudinem radiorum. Quod probatur, quia sicut alia difformitas terminata facit fractionem ad angulum, ita hic fit plicatio secundum curvitatem. Unde, quam admodum in divisione aque

1 huius] huiusmodi *V* 2 quod similiter] similiter quod *V* | quia] *om. L* 3 estivo] extivo *L* 4 quiescentes] quiesscentes *F* | eorum] earum *V* | interpositionem] inter rationem *F*; intra rationem *L* 5 potest] *scr. et del.* patet, *add.* potest *sup. l. V* 6 posset] possunt *FL* | rationabiliter] *sup.* rationabiliter *add.* notabiliter *sup. l. V* | sustineri] substineri *FL* 7 aer] *post* aer *add. et del.* possunt *F* | ascendendo] adscendendo *F* | sit] *om. F* 8 Verumtamen] Verumptamen *B* 9 difformitas] diformitas *F* | tollit] *ante* tollit *scr. et del.* tolliter *F* 10 difformitas] diformitas *F*; differentia *V* | ita] In *F*; Igitur *V* 11 admodum] amodum *F*



c	star
e	eye
edc	previous view of refraction at the surface of the sphere of fire
eghc	refraction along a curve in a uniformly increasing rarification of the atmosphere (air & fire)

Figure 17. Light From a Star is Refracted Along a Curve Through a Uniformly Increasing Rarification of Fire and Air

Again, if [the atmosphere's] subtle vapors can reflect rays, likewise it seems that they can refract rays. This is clear because in the summertime, with the mid-day sun shining, such vapors sometimes make things at rest appear to move and tremble through their interposition – this cannot be done without the refraction of rays.

[Response 3] Third, it could be reasonably maintained that air is rarified gradually as it ascends and [has] no limiting surface, [rather it undergoes] a continuous difformity all the way to [becoming] fire. But nevertheless, such difformity destroys the straightness of rays. This is proven since just as some difformity [at a] limited [surface] causes refraction at an angle, so this [difformity] causes winding along a curve.[85] Thus, in the same way, at the division of

[85] Oresme appears to be the first to argue that light can indeed travel along a curved path. Earlier experts in optics, from Ptolemy to Witelo, spoke only in terms

et aeris sunt quidam radii perpendiculares, et alii obliqui. Eodem modo, in tali difformitate, illi sunt perpendiculares qui perpendicularitur cadunt super superficies uniformes, et qui incidunt oblique super eas sunt obliqui. Est autem illa superficies in densitate uniformis que in quolibet eius puncto equaliter est intensa.

Item, si totum aggregatum ex aere et aqua fieret uniformiter dif- *B* fol. 36^{v} forme tanta densitate quantam nunc habet, tunc equivale|ret prime densitati. Et videtur quod illi radii qui prius erant perpendiculares *F* fol. 37^{v} adhuc sunt perpendiculares et qui obliqui | obliqui. Et quod prius videbatur per lineam *edc* fractam, nunc videbitur ubi prius per lineam curvam *eghc*, et apparebit in directo linee contingentis huiusmodi curvitatem.

Et quia non potest experiri si in tali casu est fractio aut non, sed auctores dicunt quod non sola auctoritate. Ideo, adhuc probatur quod sit alia ratione. Et sint inter oculum *e* et rem visam *c*, aqua et aer eiusdem quantitatis. Et oculus sit in aqua sitque densitas aeris uniformis, sicut tria in intensione, et aque densitas, sicut 7, *L* fol. 48^{r} sitque fractio *edc*. | Deinde, ymaginetur quod medietas aque inferior fiat sicut 8 in intensionem grossitiei, et medietas superior sicut 6. *V* fol. 46^{v} Et medietas aeris | inferior sicut 4, et superior sicut 2. Ita quod, per ymaginationem, unus gradus densitatis amoveatur a medietate

1 sunt] apparent *V* | quidam] quidem *L* 2 difformitate] diformitate *F* 2–3 perpendicularitur] *om. F*; perpendicular *L* 4 sunt] dicuntur *F* | autem] aut *B* | densitate] dempsitate *BF* 5 que] qui *F* | quolibet] quodlibet *L* 6 aggregatum] agregatum *FL* | aere et aqua] aqua et aere *V* 6–7 difforme] difformatus *L* 7 tanta] *ante* tanta *scr. et del.* terminata *F* | densitate] dempsitate *BF* | equivaleret] equivalet *V* 8 densitati] dempsitati *BF* | qui] qui *sup. l. V* | erant] essent, *add.* erant *sup. l. V* 10 videbitur] videtur *F* | ubi] ubi *sup. l. F; scr. et del.* ubi, *add.* ut *sup. l. V* | prius] prius *sub. l. F* 11 contingentis] continentis *F*; contingenti *L* 13 experiri] *post* experiri *add. et del.* ubi *F* 14 auctores] autores *F* | auctoritate] autoritate *F* | probatur] probabitur *V* 15 quod] *om. L* | sit] sic *L* | alia] *scr. et del.* alia, *add. (a. m.?)* sola *sup. l. V* | sint] *sup.* sint *add.* sit *sup. l. V* 16 eiusdem] consimillem(?) *L* | sit] *rep. et del.* sit *F* | in] *ante* in *scr. et del.* inqu(?) *F* | densitas] dempsitas *BF* 17 tria] 3 *L* | intensione] intensionem *LV* | densitas] dempsitas *BF* 17–18 sicut 7 sitque] dempsitas sicut patet *F* 17 7] 7^{m} *L* 18 Deinde ymaginetur] Ymaginetur deinde *V* | ymaginetur] inmaginetur *F* 19 fiat] sit *F*; *scr. et del.* facit, *add.* fiat *sup. l. V* | 8] octo *V* | intensionem] intensione *V* | superior] *scr. et del.* superficie, *add.* superficiei *sub. l. V* | 6] sex *F* 20 4] 4^{or} *BF* | et] *post* et *add.* medietas *F* | 2] duo *BV* 21 ymaginationem] inmaginationem *F* | densitatis] dempsatis *B*; *om. F* | amoveatur] admoveatur *F*

of rectilinear rays. Pecham was the only figure to even suggest the vague possibility of curvilinear rays, but he does nothing with the concept. After Oresme, the idea of light following a curved path will not resurface again for another 250 years, in the works of Descartes and Hooke. See the introductory chapter for a full explanation.

water and air there are perpendicular rays and obliquely incident [ones]. Likewise, in such a difformity, those [rays] are perpendicular which fall perpendicularly upon uniform surfaces, and those [rays] which fall obliquely upon [uniform surfaces] are oblique. However, a surface with uniform density is [one] in which [a ray] is equally bent at any point upon it.

Again, if the whole [atmosphere], aggregated out of air and water, were made uniformly difform with such a density as it now has, then [it] would be equivalent to the original density.[86] And it is seen that those rays which were previously perpendicular are still perpendicular, and [those] which [were] oblique [are still] oblique. And [a ray] previously seen by the refracted line *edc*, will now be seen just where [it was] before [but] by the curved line *eghc*, and [it] will appear in the direction of the tangent line of such a curve. [Figure 17]

And since, in such a case [of uniformly difform atmospheric density], it cannot be experienced if there is a refraction or not, authorities say there is none by [their] authority alone.[87] Therefore, there is another argument to further demonstrate [that there may be refraction along such a curve]. Let there be water and air of the same quantity, between an eye *e* and an object seen *c*, and let the eye be in the water. [Figure 18] And let the density of the air be uniform, for example, at an intensity [of] 3, and the water [at intensity] 7, and let *edc* be a refracted ray. Next, imagine that the density of the lower half of the water becomes, say, 8 in intensity, and the upper half [of the water becomes] 6, and the lower half of the air [becomes an intensity of] 4, and the upper [half of the air becomes] 2. In this way, through this conceptual image, one degree of density is removed

[86] In some sense, this is a reverse application of the Merton Rule. See the introduction for a more complete explanation.

[87] Oresme realized that he was making a major break with previous authorities in optics on this matter. He argued that one could not tell by looking whether light rays were being bent in a uniformly difform atmosphere, that is, an atmosphere whose density was changing at a constant rate. Therefore, according to Oresme, previous authorities had based their view that no bending occurs in such an atmosphere on their own authority alone. He countered that with some intriguing arguments which follow. This bold break shows Oresme was no slave to previous authority when reason led him elsewhere.

superiori aque et ponitur in inferiori, et consimiliter, fit de aere. Tunc, sunt 3 fractiones que simul sumpte equivalent prime vel faciunt adhuc maiorem deceptionem. Quod patet considerando proportiones mediorum et obliquitates linearum, quia secundum ista variantur quantitates angulorum.

Et quia hic est speculatio difficilis et pulchra. Tamen, ut abbreviem, non potest negari quin, per ymaginationem, medium possit taliter disponi quod res per duas fractiones videbitur, ubi prius videbatur per unam, vel per 3, vel per 4, aut per quotlibet ad eandem partem factas minores prima, et sibi equivalentes simul sumptas. Ymagineretur, ergo, quod in prima medietate hore videatur per unam fractionem. Et in prima mediante(?) medietatis residue medium taliter se habeat quod videatur res per duas fractiones, deinde per 4^{or}, postea per 8, et sic in infinitum per partes hore continue proportionales propter alterationem medii. Quam non oportet propter hoc

1 superiori] superficiei *V* | ponitur] ponatur *FV* | consimiliter fit] fit consimiliter *V* | fit de aere] *rep. et del.* fit de a- *F* 2 3] tres *BL*; 3^{es} *F* 3 considerando] consciderando *L* 4 secundum] *ante* secundum *scr. et del.* sint(?) *F* 5 ista] ita *F* | quantitates] quantitas *L* 6 difficilis et pulchra] pulchra et difficilis *B* | pulchra] pulcra *FL* 6–7 abbreviem] abreviem *LV* 7 quin] quid *L*; *ante* quin *add. et del.* p(?) *F* | ymaginationem] inmaginationem *F* 8 duas] 2^{as} *F* | fractiones] refractiones *F* | videbitur] *ante* videbitur *scr. et del.* unus(?) *F* 9 3] tres *B*; 3^{es} *F*; tria *L* | per] *om.* *F* | 4] 4^{o} *B*; 4^{or} *F*; quatuor *L* | per] *om.* *V* | quotlibet] quodlibet *L*; quamlibet *V* 10 factas] fractas *B* | minores] minoris *L* | sibi] sibi *sup. l.* *V* | simul] sinit *L; ante* simul *scr. et del.* sub(?) *F* | sumptas] sumpte *FV* 10–11 Ymagineretur] Ymaginetur *B*; Inmaginetur *F*; Ymaginatio *L* 11 ergo] igitur *V* | videatur] videbatur *F* 13 duas] 2^{as} *F* | 4or] 4 *V* 14 8] 6 *F* | infinitum] *post* infinitum *add.* et *F* | partes] parte *L* 14–15 proportionales] proportionalis *L* 15 propter] *scr. et del.* propter, *add.* per *sup. l.* *V* | Quam] Quod *L* | oportet] oppositum(?) *L* | hoc] *post* hoc *scr. et del.* fieri *B*

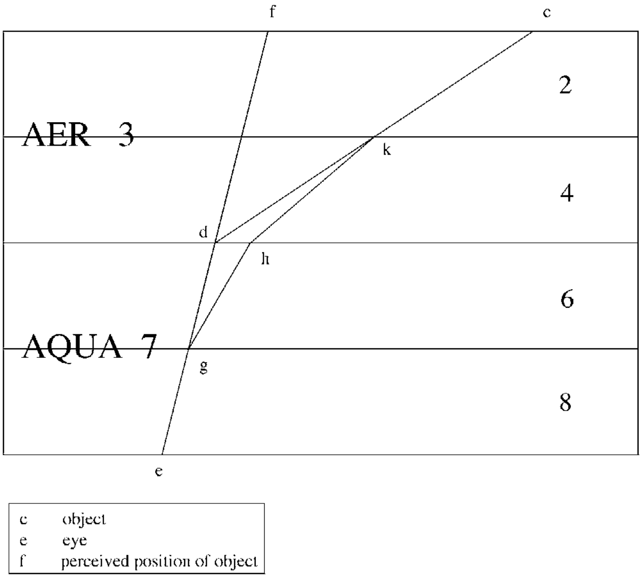


Figure 18. Multiple Refractions Along a Curve Through Air and Water; and Through a Uniformly Changing Medium

from the upper half of the water and placed in the lower [half], and likewise concerning the air. Then there are three refractions which together are assumed equivalent to the single [refraction of the initial conditions], or they [are assumed to] make an even greater [total refraction]. This is clear considering the proportions of the media and the obliquities of the lines, since they change with respect to the sizes of the angles.

This speculation is difficult and beautiful. Yet so that I may shorten [it], it cannot be denied that, where previously the object was seen through one [refraction], the medium could be arranged (by the imagination) in such a way that the object will be seen through two refractions, or three, or four, or through any [number whatever of] smaller ones made in the same part, and together [they] are assumed equivalent to the first [refraction]. It could be imagined, therefore, that in the first half an hour it is seen through one refraction. And in the first half of the remaining half [an hour], the medium [is arranged] in such a way that the object is seen through two refractions, then, through four [refractions], later through eight [refractions], and thus to infinity, through the continuously proportional parts of an hour due to the alteration of the medium. It is not necessary for this to be infinite, but perhaps the esse infinitam, sed forte totum est possibile naturaliter. Tunc in fine *L* fol. 48v hore medium erit difforme, absque aliqua uniformita|te et linea *ec* erit curva absque aliqua rectitudine. Quod patet exemplo, si in prima parte proportionali hore de una linea fiat triangulus equilaterus, in secunda fieret ex eadem quadratus, in 3ª pentagonus. Et sic ultra, patet quod in fine non erit angulus nec etiam rectitudo, sed erit linea circularis ut posset faciliter demonstrari. Et ita in proposito erit *ec* linea curva.

Sequitur, ergo, aut quod *c* videbitur in medio difformi per lineam curvam quod est propositum, aut quod in tota hora videbitur in *f* loco propter fractiones, et in fine subito videbitur ubi est per lineam rectam et apparebit subito mutari. Et idem, sequitur, si ponatur primo quod *c* sit oculus in aere, et *e* sit res visa.

Similiter, si luminosum quiescens luceret per foramen quod esset in *e* loco, sequitur quod radius esset continue per horam in *c*. Et in fine subito mutaretur in *f*, et non iret per intermedium. Et similiter, *B* fol. 37r de umbra que omnia videntur improbabilia, et contra | intentionem ALHACEN in 2°, ubi probat tales mutationes non posse fieri subito.

Satis enim videtur mirabile quod casu, posito naturaliter possi- *F* fol. 38r bili. | Res videretur in loco *f*; et postea subito in loco *c* distanti multum, nec ipsa re nec etiam visu aliqualiter transmutatis, sed solum propter alterationem medii successivam. Et quod radius vel umbra esset primo in loco *f*, postea subito in loco *c* valde distanti, et numquam in intermedio. Et hoc ipso luminoso non mutato, sed solum ut dictum est alterato medio successive.

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1 esse] esse *in mg. B*; *post* esse *add. et del.* in *V* | forte] *om. F* | possibile] possibille *L* 2 hore] horem *F* | uniformitate] difformitate *V* 4 parte] *ante* parte *scr. et del.* per *F* 5 quadratus] *sup.* quadratus *add. a. m.* quadralaterus *V* | 3a] tertia *L* | pentagonus] penthagonus *L* 6 non] nec *V* | nec] necque *BF* | etiam] erat *V* | rectitudo] radii *F* 8 linea] *ante* linea *add. et del.* li(?) *F* 9 ergo] igitur *V* | difformi] differmi(?) *L* 13 primo] *om. F* | aere] aerem *F* 14 quiescens] quiesscens *F* 15 loco] *rep. et del.* loco *F* | sequitur] *ante* sequitur *add.* Et primus *F* | c] e *L* | Et] Etiam *F* 16 mutaretur] mutaretur *corr. ex* mutaret(?) *B* | similiter] *scr. et del.* sequitur, *add.* similiter *sup. l. V* 17 improbabilia] *scr. et del.* in probabilia, *add. in mg.* inprobabilia *V* | intentionem] intationem *L*; intentionem *corr. ex* intensionem *V* 18 Alhacen] ALASEN *F*; ALACEN *V* 19 Satis enim videtur] *scr. et del.* Enim videtur satis, *add. a. m.* Satis enim videtur mirabile *mg. V* | videtur] videtur *sub l. F* | mirabile] mirabille *L* | quod] quia *F* 19–20 posito naturaliter possibili] possibili naturaliter posito *F* 20 videretur] videtur *V* | distanti] distanti *corr. ex* distante *V* 21 nec] neque *V* | visu] visa *F* | transmutatis] mutatis *V* 22 alterationem] *ante* alterationem *scr. et del.* transformationem *F* | umbra] umor(?) *L* 23 distanti] distante *V* 24 in] *om. L* | Et hoc] Adhuc *V*

18 ALHACEN (1572, rpt. 1972), *De aspectibus*, II, ch. 2, sec. 51, p. 61.

whole is naturally possible.[88] Then at the end of an hour, the medium will be difform without any uniformity. And the [resulting] line *ec* will be a curve without any straightness. [cf. Figure 18] This is clear, for example, if in the first proportional part of an hour, some one line may make an equilateral triangle, in the second [proportional part of an hour], out of the same [line], it might make a quadrilateral, in the third, a pentagonal. And thus, further, it is clear that in the end [the line] will have neither angularity nor rectilinearity, but it will be a circular line as may be easily demonstrated. And so, in the proposed, *ec* will be a curved line.

It follows, therefore, that in [this] difform medium, *c* will either be seen through the curved line that is proposed, or that during the entire hour, it will be seen in the place *f* because of refraction, and in the end it will suddenly be seen where it is through a straight line and will suddenly appear to be changed [in its location].[ii] And the same [result] follows if [the opposite] is posited, that *c* is an eye in air, and *e* is a thing seen.

Likewise, if a stationary light [= *luminosum*] were to illuminate through an aperture at *e*, it follows that the ray would continually be at *c* throughout the hour. [cf. Figure 18] And at the end [of the hour, the ray] would suddenly be changed [in its location] to *f*, and it would not go through the intermediate [space]. And likewise concerning [the aperture's?] shadow, which all seems improbable, and against the intent of Alhacen in [book] 2, where he proves such changes cannot occur instantaneously.[iii]

Indeed, it seems quite marvelous that the posited case [would be] naturally possible. The object would be seen in the place *f*, and later [*sic*] in the very distant place *c*, being changed neither by the thing itself, nor also by the [observer's] vision, but only because of the gradual alteration of the medium.[89] [cf. Figure 18] And a ray or a shadow would first be in the place *f*, later suddenly in the very distant place *c*, and never in the intervening [space]. And this light [= *luminosus*] itself is not changed, but, as was said, only the medium is gradually altered.

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[88] Oresme here seems to be attempting to avoid the paradoxes of an actual infinite, such as those expressed by Zeno. But by implying that one may approach the limit by successive partitioning, he concludes in the next sentence that an entirely difform curve will be produced.

[89] Oresme or the manuscript tradition has inadvertently switched the letters *f* and *c* in this passage.

Restat, ergo, propositum, quod adhuc probatur, quia tale medium [*L* fol. 49^{r}] | difforme reflectit lumen non solum recte sed oblique in varias partes. Et patet 3^{o} Metheororum de ANTIPHANO. Sed in medio transparenti nulla fit reflexio obliqua sine fractione, vel equipollenti, quia radii transeunt ulterius. Igitur, sicut ubi est notabilis differentia in subtilitate, ibi fit notabilis deviatio a rectitudine per angulum. Ita ubi propter difformitatem continuam non est notabilis distinctio, fit non notabilis deviatio a rectitudine non per angulum, sed per curvitatem aut per plicationem.

Sicut, ergo, se habet uniformitas ad rectitudinem et dissimilitudo uniformitatis ad fractionem rectarum linearum, ita difformitas ad [*V* fol. 47^{r}] curvitatem. Ideo, inter uniformitatem et difformitatem | continuam fit fractio, secundum angulum ex recta et curva, et in differentia notabili mediorum difformium fit fractio ad angulum ex curvis lineis.

Sequitur, ergo, ex hiis quod, dum aer est clarus, radius stelle in tribus locis, notabiliter deviat a rectitudine per fractionem aut per plicationem. Scilicet, inter celum et ignem, inter ignem et aerem, inter aerem puriorem et aerem vaporibus subtilibus ingrossatum.

Similiter, frangitur inter orbes celi, quia sicut dicit ALHACEN in 7^{o}, omnes sunt finite subtilitatis, et forte non equaliter, sed illa fractio

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1 Restat] Resta *L* | ergo] igitur *V* | quia] quod *L* 2 lumen] lumine *L* | non] nota *L* 3 Metheororum] Metharorum *F*; Methaurorum *L* | Antiphano] ANTIPHONTE *BF*; ANTIPHANTE *L*; *ante* ANTIPHONTE *scr. et del.* Anthi- *F* 4 transparenti] transferenti *L* | reflexio] reflexio *corr. ex* reflectio *F* | equipollenti] equipolenti *L*; equivalenti *V*, *sup.* equivalenti *add.* equipolenti *sup. l. V* [apparently a scribal listening error, *ed.*] 5 Igitur] *scr. et del.* Igitur *V* | sicut] sic *L* | est] *om. BFL* | notabilis] *post* notabilis *scr. et del.* diferentia(?) *V* 5–6 differentia in subtilitate] in subtilitate differentia *V* 6 subtilitate] *post* subtilitate *add.* ita *F* 7 propter] per *L* | distinctio] destintio *F* 9 curvitatem] curvitate *B* | per] *om. V* 10 ergo] igitur *V* | uniformitas] difformitas *L* | et] vel *L* 11 uniformitatis] uniformiter *F* | rectarum linearum] linarum rectarum *L* | ita] igitur *L* 12 difformitatem] defformitatem *F* 13 ex] et *V* 14 difformium] *ante* difformium *scr. et del.* diffor- *F* 15 ergo] igitur *V* | ex hiis] ex hiis *sup. l. V* | clarus radius] *rep.* clarus radius *mg. V* | in] in *sup. l. V* 16 per] *om. V* 17 inter] *add. a. m.* inter ignem et aerem, et inter aerem puriorem, inter(?) vaporibus plenum, similiter frangitur a(?) *mg. V* 18 inter] *ante* inter *add.* et *F* | et] *post* et *add.* inter *V* | aerem] angulum *V* | subtilibus] subtilioribus *F* 19 frangitur] *om. F* | dicit Alhacen] ALACEN dicit *V* | Alhacen] ALASEN *F*; ALACEN *V* 20 illa] ista *V*

3 ARISTOTLE, *Meteorologia*, Bk. III, ch. 4 (373a35–373b13). 19 Cf. ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 4, sec. 15, p. 251.

Therefore, the [original] proposition holds, which is now proven [correct], since such a difform medium not only bends light [= *lumen*] directly, but [also bends it] obliquely into various parts. And this is clear in the 3rd [book] of [Aristotle's] *Meteorology* concerning Antiphon.[iv] But in a transparent medium, no oblique bending occurs without refraction, or the equivalent, because rays pass through. Thus, where there is a notable difference in subtlety, there will be a notable deviation from the direct [path] at an angle. But where there is no notable distinction because of continuous difformity, there will not be a notable deviation from the direct [path] at an angle, but [there will be a deviation] through a curve or a winding [path].

Therefore, just as uniformity is related to straightness, and a difference of uniformity to the refraction of straight lines, so difformity [is related to] curvature. Thus, between a uniformity and a continuous difformity, a refraction occurs at an angle along a straight [line] and a curved [line], and in a notable diversity of difform media refraction occurs at an angle along curved lines.[90]

It follows from this that, when the air is clear, a star's ray deviates perceptibly from a straight [path either] by a refraction or by a winding [path] in three places. Namely [it will deviate] between the [spheres of] heaven and fire, between [the spheres of] fire and air, [and] between purer air and air thickened by subtle vapors.

Likewise, [a stellar ray] is refracted among the spheres of the heaven, because as Alhacen says in [his *De aspectibus*, Book] 7, all [the heavenly spheres] are of finite subtlety, and perhaps [are] not equally

[90] The meaning of this sentence is a bit muddled, but Oresme's intent will become clear in the following paragraphs.

non est notabilis. Patet, igitur, qualiter radii et actiones et influentie solis et astrorum veniunt ad nos per lineas tortuosas.

Item, sequitur ex dictis quod vix vel numquam aliquid videtur per lineam rectam, quia semper aut propter vapores, aut propter condensationem ex frigore, vel ex motu aer est difformis difformiter in subtilitate, quamvis aliquando insensibiliter. Ergo, quodlibet videtur aliqualiter per lineas fractas, seu aliqualiter plicatas, ergo, semper est deceptio in situ vel loco.

Eodem modo, est de actione naturali et influentia et illuminatione, quod semper fiunt per lineas non rectas. Sed sepe in parvo *L* fol. 49[v] spatio est error inperceptibilis, sicut probant perspectivi | de illuminatione et visione per sua instrumenta. Sic, ergo, istud dubium expeditum.

[Secundo ratio contra conclusionem principalem] Secundo, contra principalem conclusionem, posset cavillari dicendo quod quamvis radius stelle frangatur inter celum et ignem, vel quando

1 Patet] *post* Patet *add.* ex hiis *sup. l. V* | et] *om. V* | et] *om. L* | influentie] *sup.* influentie *add.* influx *sup. l., et post* influx *add.* quod *in mg. V* 2 tortuosas] *post* tortuosas *add.* ergo etc. *F* 3 ex dictis] ex dictis *sup. l. V* | vix...numquam] numquam vel vix *V* | aliquid] aliquis *V* 4 quia] sed *corr (a. m.?) ex* quia *V* | aut] autem *L* | aut] autem *L* 5 condensationem] condempsationem *F*; condenssitatem *L* | ex] ex *sup. l. B* | difformiter] difformiter *corr. ex* difformitas *V* 6 quamvis] *post* quamvis *scr. et del.* quamvis aliquando, *rep.* quamvis *F* | insensibiliter] in senssibiliter *L* | Ergo] Igitur *V* | quodlibet] quolibet *L* 6–7 videtur aliqualiter] aliqualiter videtur *V* 7 aliqualiter] *om. F* | fractas] *scr. et del.* rectas, *add.* fractas *mg. V* 8 deceptio] deceptus *B* | vel] *post* vel *add.* in *F* 9 modo] *rep. et del.* modo *V* | naturali] *scr. et del.* centrali, *add.* naturali *sup. l. V* 10 parvo] parva *L* 11 spatio] spera *L* | error] eror *L* | probant] *ante* probant *scr. et del.* probatum *F* | perspectivi] *post* perspectivi *scr. et del.* de ALACEN et visione *V* 11–12 de illuminatione et visione] *om. V* 12 sua] *om. B* | instrumenta] *post* instrumenta *add. a. m.* sicud etiam fit etiam illuminatione et visione *mg. V* | Sic] Sicut *F* | ergo] igitur *LV*; *post* ergo *add.* similiter(?) *F* | istud] illud *L* | dubium] *om. F* 13 expeditum] expedit *L; ante* expeditum *scr. et del.* exper- *F* 14 Secundo] *add. a. m. in sub mg.* Secundo contra principalem conclusionem posset cavillari dicendo quod [quamvis *sup. l.*] radius stelle frangatur inter celum et ignem, id est(?), in media regione aeris, ubi(?) est aer densior, tamen cum sustineri(?) pervenitur ad puriorem reformatur radius. Et sic videretur in propie loco, sicud nec(?) [OR 'nunc'?] VITELO in 4[a], 10[mi]. Quia quando secundum medium est densius frangitur et quando tertium medium est rarius, iterum refrangitur ad oppositum prime fractionis. Igitur poterit videri in proprie loco. *V* 15 conclusionem] conclusionem principalem *F* | dicendo] dicendo *sup. l. V* 16 stelle] *ante* stelle *rep. et del.* stell- *F*

so – but this refraction [of stellar rays among the heavenly spheres] is not perceptible.[91] It is clear, therefore, how the rays, actions and influences of the sun and stars come to us through twisted lines.[92]

It also follows from what has been said that nothing, or almost nothing, is ever seen by a straight line. [This is] because air is always difformly difform in [its] rarity (although sometimes imperceptibly) due to vapors, or condensation from cold, or from motion. Therefore, anything whatever is seen in some measure by bent or curved lines, hence there is always deception [with regard to] position or place.[93]

It is the same way concerning natural action, influence and illumination – they never occur along straight lines. But often, there is an imperceptible error in a small interval, just as the perspectivists demonstrate concerning illumination and vision by their instruments. Hence, this doubt is disposed of easily.[94]

[Second Argument Against the Principal Conclusion.] Second, against the principal conclusion: One could quibble by saying that although a stellar ray may be refracted between [the spheres of]

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[91] Though I have found no specific reference where Alhacen says that the heavenly spheres have a finite subtlety, this might be inferred from Alhacen's assertion that celestial bodies are both more subtle and more transparent than airy bodies. "Nam corpus coeli est subtilius corpore aeris, id est maioris diaphanitatis." Cf. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 4, sec. 15, p. 251.

[92] According to Bacon, a "twisted line" (*linea tortuosa*) is one of the four lines of propagation of a species when they are incident on a line. The four are: straight, concave, convex, and twisting. Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 3, lines 8–18, pp. 104–105.This strongly implies problems for astrology, which depends upon predicting stellar influences. Oresme here states that such influences come to us through twisted or tortuous lines, and below he says stellar influences are always upon refracted lines. Nevertheless, Oresme does not appear to add this argument to his arsenal in his most lengthy and erudite attack on astrology, the *Quaestio contra divinatores horoscopios*, nor in his other works on astrology. See Oresme, *"Quaestio contra divinatores horoscopios,"* edited by Stefano Caroti, *Archives d'Histoire Doctrinale et Littéraire du Moyen Age* 51 (1976): 201–310, and *Nicole Oresme and the Astrologers: A Study of His "Livre de divinacions,"* ed. and tr. by G.W. Coopland (Cambridge, Mass.: Harvard University Press, 1952).

[93] Oresme devotes an entire chapter of his *De causis mirabilium* to visual deception, though he does not give such an all encompassing view of atmospheric deception there. Rather, he is as concerned with internal and psychological visual deception as external illusions in his *De causis*. Oresme (1985), *De causis mirabilium*, ed. by Hansen, Ch. I, pp. 140–165.

[94] This "doubt" was the first argument against the principal conclusion, namely: that atmospheric air gradually rarifies as it ascends towards the sphere of fire, and therefore there is no discontinuity – no surface – at which a refraction could possibly occur. *De visione stellarum*, Bk. II, cap. 2, 150:3 – 152:2.

pervenit ad aerem grossiorem, tamen, aer in media regione, seu in medio interstitio, est multo frigidior, ut dicitur primo Metheororum, et per consequens densior quam sit inferius. *F* fol. 38^{v} | Ideo, cum radius pervenit ad aerem inferiorem sub media regione calidiorem et puriorem contiguatum nostro visui, tunc ille radius refrangitur ad partem oppositam, sicut habetur in 41^{a}, 10 VITELONIS. Unde, quando secundum medium est densius frangitur et quando tertium medium est rarius, iterum refrangitur ad oppositum prime fractionis. Et tunc, in proposito, per secundam fractionem, poterit reformari deceptio que contigebat ex prima. Et sic, adhuc stelle videbuntur in suis locis.

[Responsio] Respondetur, quod quando aer est purificatus a nebulis, tunc non est densior in media regione quam sit infra ubi sunt venti, exalationes et vapores tantum vel magis quam supra, ideo, non fit. Secundo, talis refractio quod si fiat non, tamen, recompensatur deceptio que ex priori fractione. Sicut evidenter demonstrant experimenta in 6^{a} conclusione pre adducta. Sed semper stat quod stelle videntur alibi *B* fol. 37^{v} | quam in suis locis.

Verumtamen, si fiat secundo refractio e converso, tunc minus decipimur quam si ex alto videremus stellas de media aeris regione, post primam fractionem, et ante secundam. Et sic obesset scientie stellarum ascendere Turrim Babel, aut in vertice montis Olympi, seu

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1 tamen] tunc *V* | regione] *post* regione *add.* aeris *sup. l. V* 2 interstitio] *post* interstitio *add.* ubi(?) *V* | dicitur] *ante* dicitur *scr. et del.* dice- *F* 2–3 Metheororum] Methaurorum *FL* 3 densior] dempsior *BF* 4 pervenit] pervenitur *V* | calidiorem] *ante* calidiorem *rep. et del.* ca- *F* 5 nostro] modo *V* 6 habetur] *om. L* | 41a 10] 4^{o} in 10 *L*; 41^{a}, 10^{i} *F*; Perspectiva *V* | Vitelonis] WITELONIS *B*; VITELEONIS *L* 7 densius] dempsius *BF* 8 refrangitur] frangitur *L* | fractionis] refractionis *V* 10 sic] sicut *F* | suis locis] locis suis *B* 11 quando] *add. a. m. in mg.* quando aer est purificatus a nebulis. Media regione densior quam alie partes aeris, et si ita fiat non tamen recompensatur, vel recompensatur radius, vel deceptio que ex priori fractione et(?) cadit. Sed per latum est sed semper stat quam stelle videntur alibi quam suit. Verumtamen si fiat secundo refractio, etc. *V* 11–12 a nebulis] *om. B* 12 tunc] *om. V* | non] nota *L* | densior] dempsior *BF* | sit] *om. F* | infra] igitur(?) *L* 12–13 ubi sunt] *om. V* 13 et] *om. V* 15 recompensatur] reconpenssatur *L* | que] *post* que *add.* fit *B* | fractione] *post* fractione *add.* fit *F* | evidenter] evidentis *BL*; evidentis(?) *corr. ex* evidenter(?) *F* 16 demonstrant] demonstratur *L* | adducta] aducta *F* 18 Verumtamen] Verumptamen *B* | secundo] secunda *FL* | refractio] fractio *F* | tunc minus] *om. F* 19 decipimur] descipimur *F*; deccipimur *L* | aeris regione] regione aeris *V* 20 obesset] obesset *corr. ex* obviat *V* 21 ascendere] adscendere *F* | Turrim] [sic, not a normal ending for 'turris, -is: tower'] | Olympi] Olimpi *BFL*

2 ARISTOTLE, *Meteorologia*, Bk. I, ch. 3, (340a24–33). 6 WITELO (1572, rpt. 1972), *Perspectiva*, X, sec. 41, pp. 439–440.

the heaven and fire, or when it reaches the denser air, nevertheless, the air in the middle region (or in the middle interstice) is much colder, as is said in the 1st [book] of [Aristotle's] *Meteorology*, and as a result, it may be more dense than [the air] below.[95] Therefore, when a ray reaches the lower air under this middle region, [which is] betwixt the purer [air above] and the warmer [air below], then that ray is re-refracted in the opposite direction, [and] to our sight – as is maintained in Witelo's [*Perspectiva*, Book] x, [section] 41.[96] This being the case, when the second medium is denser [the ray] is refracted, and when the third medium is rarer, it is refracted again, [but] in the opposite [direction] of the first refraction. And so, in the proposed, [a ray] could form the illusion – through a second refraction – that it came from its original [position].[97] Thus the stars will be seen in their true places.

[Response] It is responded: When air is purified of vapors, it is no denser in the middle region than if it were [in] the lower [regions], where there are winds, exhalations and vapors as great or greater than [those] above – therefore [such a refraction] does not occur. Second, if such a refraction did occur, it would, nevertheless, not compensate for the deception caused by the previous refraction – as the experiments in the sixth conclusion above clearly demonstrate.[98] But it always holds true that stars are seen elsewhere than in their true places.

Nonetheless, if a second refraction did occur in the opposite direction, then we would be deceived *less* than if we observed the stars from high in the middle region of the air – that is, after the first refraction and before the second. Thus it would actually hinder our knowledge of the stars to ascend the Tower of Babel, or the summit of

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[95] Aristotle, *Meteorologia*, Bk. i, ch. 3 (340a24–33).

[96] It is not at all clear that this reference is pertinent, since Witelo here states that refraction on the surface of a spherical transparent body will enlarge the image of an object. Witelo (1572, rpt. 1972), *Perspectiva*, x, sec. 41, pp. 439–440. A cursory review of Witelo's rather large Book x has not revealed the passage to which Oresme is referring, though I may have overlooked it.

[97] That is, the second refraction will exactly counteract the effects of the first refraction, making the star appear in its original position.

[98] Those observational experiments demonstrated variable atmospheric refraction of light from circumpolar and non-circumpolar stars and from the moon over a single evening. *De visione stellarum*, Bk. ii, cap. 1, 142:1 – 146:12.

super Atlantis humeros residere. Verum est etiam quod per plures fractiones oppositas res potest videri in suo loco, licet non ita clare, nec est radius ita fortis.

V fol. 47v *L* fol. 50r Verbi gratia, sint tria media | quorum | intermedium sit grossius. Et sit *e* oculus, et *c* visibile, tunc radius *cd* frangitur primo ad per-

1 super] si *F* | Atlantis] Athlantis *BFL* | per] *om. L* 2 potest] potest *rep.B* | suo] *post* suo *add. (a. m.?)* ex prio(?) *sup. l. V* | licet] scilicet *L* 4 sint] sunt *L* 5 oculus] *om. F*; *scr. et del.* ocular(?), *add.* oculus *sup. l. V* | radius] *ante* radius *add. et del.* r- *F* 5–170.1 perpendicularem] perpendicularem *corr. ex* perppendicularem(?) *V*

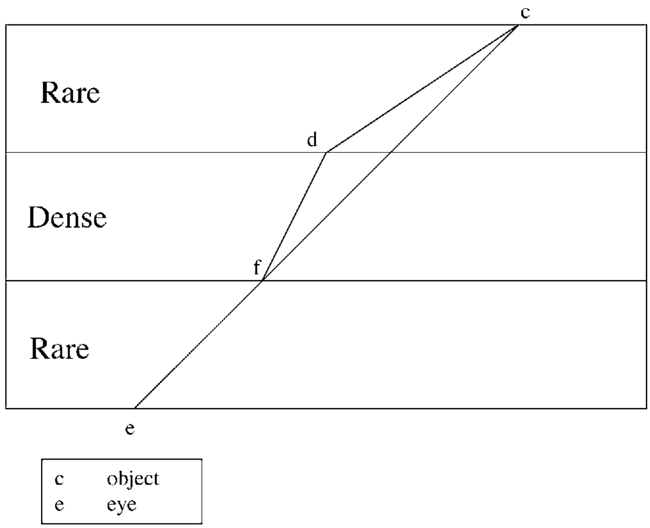

Figure 19. Refraction of a Ray Through
Three Media, the Middle Being More Dense

Mount Olympus, or to reside upon the shoulders of [Mount] Atlas.[99] It is also true that a thing can be seen in its true place through *many* opposite refractions, although not so clearly, nor is the ray so strong.

As an example [of two refractions], let there be three media, the middle one being the most dense. And let *e* be an observer, and *c* a visible object. [Figure 19] Then the ray *cd* is first refracted

[99] All three were counted amongst the highest points on earth by ancient and medieval scholars. The Tower of Babel, of course, was a physical symbol of man's hubris, an attempt to build a tower that would reach to the heavens. Its story is recorded in Genesis 11:1–9. In recounting this story in his *City of God*, Augustine speaks of Nimrod and his Babylonian followers hoping to build a tower that would be higher than all the mountains and the clouds of the atmosphere. (*City of God*, Bk. 16, ch. 4) Certainly a very high vantage point for peering into the heavens.Located between Macedonia and Thessaly, the famous Mt. Olympus was so high that it was regarded as the home of the gods in ancient Greek mythology. Ancient Greek and Latin sources are replete with references to the mountains of Atlas in North Africa as well. One of the rebellious Titans, Atlas was forced to uphold the world on his shoulders as punishment; later, Persius turned him into a mountain located in North Africa. Virgil's *Aeneid* poetically describes Mount Atlas as propping heaven on its peak and its steep "shoulders" being cloaked in snow. While prosaic Pliny records (quite seriously) that its peak not only reaches beyond the clouds, but nearly to the orb of the Moon. Virgil, *Aeneid*, Bk. IV, lines 246–251; Pliny, the Elder, *Natural History*, trans. by H. Rackham (Loeb Classical Library) (Cambridge, Mass.: Harvard University Press, 1938), Bk. V, 1, 5–7; vol. 2, pp. 222–223.

pendicularem, quia secundum medium est densius, et fiet fractio *df*. Postea, *df* frangitur a perpendiculari, quia tertium medium est rarius secundo, et fit *fe*. Si, igitur, contingat sicut, est possibile, licet difficile, quod *ef* protensa in continuum et directum attingeret ad *c*. Tunc *c* videretur ubi est, potest etiam accidere quod *c* videatur superius aut inferius quam sit in rei veritate.

In proposito, tamen, non contingit quod propter duas fractiones stelle videantur in suis locis, sed semper alibi quam sint, sicut est demonstratum. Et sic inviolata manet nostra conclusio principalis. Ex qua cum prius dictis sequuntur, aliqua que possent experiri. Ex quorum quodlibet sequitur quodlibet aliorum cum 5^{a} et 6^{a} et 7^{a} conclusionibus demonstratione a posteriori, et per effectus ita quod est talis connexio quod numerando 3 primas experientias per 6^{a} conclusione adductas, cum 5^{a} et 6^{a} conclusionibus. Et cum istis sequentibus ex unoquoque istorum sequitur quodlibet aliorum.

[Corollarium 1] Est, igitur, primum quod, in orizonte plano, quelibet stella que est in equinoctiali circulo per maius tempus appa- ret super orizontem quam sit subtus. Quia per 6^{am} conclusionem, videtur per lineam fractam a perpendiculari.

Sit, igitur, superficies orizontis *ab*, et stella potest videri per *F* fol. 39^{r} lineam *cde*. Igitur, videbitur ante eius verum ortum, | et similiter, post *L* fol. 50^{v} occasum. Cum, | igitur, arcus equinoctialis qui est super orizontem et arcus qui est sub orizonte sint equales, et tempora motuum equalia.

1 medium] *ante* medium *scr. et del.* me- *F* | densius] dempsius *BF* 2 rarius] rarius *corr. ex* radius *V* 3 fe] fc *F* | igitur] ergo *L* | contingat] contigat *L* | possibile] possibille *L* | licet] *post* licet *add. et del.* p- *F* 4 protensa] protassa *L*; *post* protensa *add. et del.* cum(?) *F* | attingeret] adtingeret *F* 5 etiam] *post* etiam *add. et del.* et *F* 7 contingit] contigit *L* 8 semper alibi] superius *V* | sint] sit *FL* 9 demonstratum] *ante* demonstratum *scr. et del.* d- *F*; *post* demonstratum *add.* superius *sup. l. V* | sic] sit *V* | inviolata] inviolata *corr. ex* inviolent(?) *V* | manet nostra conclusio] conclusio nostra *V* 10 prius] primis *L* 11 quodlibet] quolibet *B* | 5a et 6a et] 5^{a}, 6^{a} et *B*; et 5^{a} [5^{a} *in mg.; ante* 5^{a} *rep. bis et del.* et] et [*post* et *scr. et del.(?)* huius(?)] 6^{a} et *F*; contra cum(?) *L* 12 posteriori] priori *L* | et] *om. V* 13 connexio] *post* connexio *add.* ita *V* | 3] tries *BF*; 3^{es} *L* | experientias] experigentias *V* 14 adductas] aductas *FL* 15 istorum] illorum *V* 16 primum] *add. in mg.* primum corollarie(?) *V* | in] *ante* in *scr. et del.* inq- *F* 17 maius] magis *V* 18 subtus] sumptus *F*; subito *V*; *sup.* subito *add.* ortus *sup. l. V* 19 per] *ante* per *scr. et del.* per l- *F* 20 Sit] Sicut *F* | igitur] ergo *V* | per] *scr. et del.* super *add.* per *sup. l. V* 21 cde] cd *FL* | Igitur] Ergo *L*; Ideo *V* | eius] *om. V* | ortum] *post* ortum *add. et del.* eius *V* 22 occasum] ocasum *F* | super] supra *V*

towards the perpendicular, since the second medium is more dense, and the refraction *df* will occur. Later, [the ray] *df* is refracted away from the perpendicular and becomes *fe*, because the third medium is rarer than the second. Therefore, if it were to happen just so, it is possible – but unlikely – that [line] *ef* would reach [point] *c*, if [it were] extended in a continuous and direct way. Then *c* would be seen where it truly is. [But] it could also happen that *c* would be seen higher or lower than it truly is.

Nevertheless, concerning the proposed [argument], it does *not* happen that stars are seen in their true place because of two refractions, but [they are] always [seen] somewhere else than [where] they truly are – just as was demonstrated. And thus our principal conclusion remains intact. Thus, with what has been said, other [conclusions] follow which may be experienced. [And] from any one of them at all, follows any of the others, since the fifth, sixth, and seventh conclusions [are shown] by demonstration *a posteriori*,[100] and by their effects when the three primary experiments in conclusion six are considered, in the sense that there is such a connection between the fifth and sixth conclusions. And since those [conclusions] follow from each of those [experiments], any one [of the conclusions] at all follows from [any of] the others.

[Corollary 1] The first [corollary], therefore, is this: Given a flat horizon, any star that is on the celestial equator will appear for a longer time above the horizon than below it. For according to the sixth conclusion, it is seen through a line refracted away from the perpendicular.

For example, let the surface of the horizon be *ab*, and let there be a star that can be seen along the line *cde*. [Figure 20] Therefore, this star will be seen before its true rising [in the east], and likewise [it will still be seen] after its [true] setting [in the west]. But the equatorial arc above the horizon is equal to the arc below the horizon, and

[100] "*a posteriori*", that is, demonstrated from the effects to the cause.

Et iam stella videtur in parte arcus inferioris. Statim sequitur quod per maius tempus apparet super terram quam lateat sub orizonte recondita.

Sicut etiam, experimento patet quod sol diutius lucet in fundo vasis pleni aqua positi in campo plano quam si ibi non esset aqua. Et, similiter, piscis citius videret solem propter talem fractionem quam per lineam rectam sine aqua.

1 quod] *om. L* 2 lateat] latea *F* 3 recondita] abscondita *F* 4 Sicut] Sic *BL* 5 plano] plano *corr. ex* plana *V* 5–7 Et … aqua] *om. V*; *add. a. m.* Et similiter piscis citius videt solem prope talem fractionem quam per lineam rectam sine aqua *in mg. V* 6 piscis] *ante* pisscis *scr. et del.* piq-(?) ps-(?) *F*; pisscis *F* | citius] *om. L* | videret] vident *F*

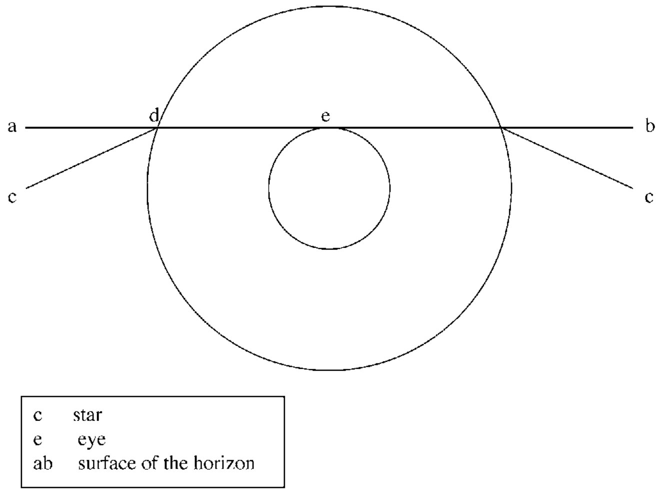

Figure 20. Effect of Atmospheric Refraction
on the Rising and Setting of a Star

the times of their motions are equal.[101] And yet the star is seen in part of the arc below the horizon. It follows at once that the star will appear for a longer time above the earth than concealed beneath the horizon.

In a similar way, it is clear from the following experiment that the sun shines longer into the bottom of a water-filled vessel (placed in a flat field) than if there were no water in it.[102] Likewise, a fish would see the sun more quickly because of such a refraction than [if it saw] along a straight line without water.

[101] This is only true if one regards the Earth as a mere point in comparison to the size of the heavens. And this is exactly as medieval scholars saw it. For an example, see John of Sacrobosco's *De sphaera*, in Thorndike (1949), *The "Sphere" of Sacrobosco*, p. 84 (Latin), pp. 122 (English tr.). For excellent discussions of this, see Edward Grant's, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200–1687* (Cambridge: Cambridge University Press, 1994), pp. 620–622; Albert Van Helden, *Measuring the Universe: Cosmic Dimensions from Aristarchus to Halley* (Chicago: University of Chicago Press, 1985), pp. 33–40; and C.S. Lewis' profound work, *The Discarded Image: An Introduction to Medieval and Renaissance Literature* (Cambridge: Cambridge University Press, 1964), pp. 97–102.

[102] Notice that, on occasion, Oresme does use arguments from analogy based on terrestrial experiments – just as Hooke does in the Scientific Revolution. (See discussion in the Introduction.) But this is not as common with Oresme.

[Corollarium 2] Secundum est quod non est equinoctium sole existente in primis punctis ARIETIS et LIBRE, quoniam dies artificialis est apparitio solis super terram. Modo propter huius fractionem radiorum, sol apparet super orizontem planum ante quam sit ibi in rei veritate. Et sic, dies non solum est latio solis super orizontem, que tunc est equalis lationi sub orizonte, sed est apparitio solis super orizontem que est diuturnior latione, ut patet ex dictis. Ergo, tunc dies artificialis est longior nocte, et sic non est equinoctium.

[Corollarium 3] Tertium est quod de duabus stellis fixis, quarum una apparet oriri et alia occidere. Quando erit e converso, quod illa que nunc occidit apparebit in ortu, tunc alia non apparebit occidere, sed ante occasum. Et poterunt apparere simul super orizontem elevate.

Quoniam ex predictis patet quod huius stelle non sunt opposite, que sic apparent prima vice. Sed arcus qui est sub terra minor est illo qui est supra terram. Igitur, secunda vice, quando iste arcus est super terram adhuc propter huius fractionem apparebit minor quam sit, et stelle iste propinquiores quam sint.

1 est] *om. B* 2 primis] primo *F* | punctis] puncto *F* 3–5 est ... dies] *om. V*; *add. a. m.* quam dies artificialis est apparitio solis super terram. Modo prope h[uius] fractionem radiorum, sol apparet super orizontem planum a[nte] quam sit [ibi] in rei veri[tate]. Et sic d[ies] artificialis *in mg. V* [Some words and letters in the inner margin were obscured by tight binding, conjectures were supplied in brackets by the ed.] 4 quam] *post* quam *scr. et del.* a-(?) *F* | ibi] *om. F* 5 est] est *sup. l. V* | super] in *F* 6–7 tunc ... que] *om. L* 6 est] *om. F* | apparitio] apparitio *corr. ex* apparet(?) *V* 8 non] nunc *F* 9 duabus] *scr. et del.* 2^{bus}(?), *add.* duabus *sup. l. V* 10 una] *add. in mg. B* | occidere] ocidere *F* | erit] est *L* 11 occidit] ocidit *F* | occidere] ocidere *F* 12 occasum] ocasum *F* | poterunt] potuerunt *L* | apparere simul] simul apparere *B* | super] *scr. et del.* sub, *add.* super *sup. l. V* 14 predictis] dictis *BL* | patet] *ante* patet *add.* a *F* | huius] huiusmodi *V* 16 supra] super *FL* 16–17 Igitur ... terram] *om. BV* 17 huius] huiusmodi *V* | apparebit] apparet *V* 18 iste] ille *V*; *sup.* ille *add.* due *sup. l. V*

[Corollary 2] The second [corollary] is this: an equinox[103] does not occur with the sun at the beginning points of Aries and Libra,[104] in as much as this scientifically determined day[105] is [based on] the appearance of the sun above the earth. Because of the refraction of its rays, the sun appears above a flat horizon before it is truly there. And thus, [on] the day [calculated], the sun's [location] is not only shifted above the horizon (with an equal shift below it), but because of this shifting, the sun appears above the horizon for a longer time [than it really is] – as is clear from what has been said. Therefore, this artificial day actually has a longer night, and thus it is not an equinox.

[Corollary 3] The third [corollary] concerns two fixed stars, of which one appears to rise [while] the other [appears] to set. When they will be vice versa, so that the star now setting will appear to rise, the other one will *not* be appearing to set, but will have already set.[v] Also, they can both appear elevated above the horizon at the same time.

It is clear that these [two] stars are not [truly] opposite, as they appeared [to be] in the first instance, rather, the arc [between them] below the earth is smaller than that which is above the earth. Thus, in the second instance, when that [smaller] arc is above the earth, it will appear even smaller than it is because of this refraction, and those stars [will appear] nearer [to one another] than they [truly] are.

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[103] An equinox is a day of equal daylight and darkness.

[104] The beginning points of Aries and Libra are the vernal and autumnal equinoxes – the two days of the year when the length of the day and night are equal. Oresme, by the way, is referring to the *signs* of Aries and Libra, not the constellations. The ancient Greek astronomers divided up the ecliptic into 12 equal "signs" of 30 degrees each, and medieval Latin astronomers did the same. Thus, by definition, the sign of Aries was (and is) the first 30 degrees going east along the ecliptic from the vernal equinox.Because of the precession of the equinoxes, however, the actual constellations were no longer in their signs by Oresme's day, but had long since shifted. For both Oresme and for us, for example, the sign of Aries is roughly occupied by the constellation Pisces. James Evans gives an excellent discussion of precession in ancient and medieval astronomy, see Evans, *The History and Practice of Ancient Astronomy* (New York; Oxford: Oxford University Press, 1998), pp. 95–96, 245–247.

[105] Literally "artificial day," *dies artificialis,* that is, the artfully or scientifically deduced length of day. This is the term John of Sacrobosco uses to describe the equinox as well. See his *De sphaera,* in Thorndike (1949), *The "Sphere" of Sacrobosco,* p. 86 (Latin), pp. 123 (English tr.).

[*B* fol. 38r] Et faciliter patet in figura. Sint stelle *c* et *g*, et *f* sit zenith, | et *q* punctus oppositus sub terra, et *ab* orizon. Tunc, prima vice, magnus arcus *cfg* apparet semicirculus, et, secunda vice, arcus *gfc* qui est idem [*L* fol. 51r] quod arcus *gqc* apparet minor semicirculo, et adhuc minor | quam sit quia apparet sicut *mfm*.

[Corollarium 4] Quartum est quod aliquas stellas oppositas [*V* fol. 48r] simul apparere super | terram est possibile. Et non apparebunt opposite, sicut si una esset in *a* et alia in *b*, quelibet apparet altior quam sit propter predictam fractionem. Et ita est de sole et luna.

1 Et faciliter] Et faciliter *rep. et del. F* | Sint] Sint *rep. et del. F* | c] c(?) *sup. l. F* | et] *om. F* | sit] *post* sit *add.* id est *F* | zenith] cenith *BF* 3 apparet] apparebit *B* | secunda] illa *V* 4 quod] q-*L* | gqc] gqc *BL*; gac *F*; gbc *V* | apparet] apparebit *B* | semicirculo] *add. a. m.* sed minor semicirculo *in mg. V* 5 sicut] sic *F*; sicut *rep. L* | mfm] mfn *L*; efm *V*; *sub* efm *add.* sicut nfm *in sub mg. V* 6 quod] *om. L* 7 simul] *om. F* | apparebunt] erunt *F* 8 si una esset] *scr. et del.* signa essent, *add. a. m.* si una esset *sup. l. V* | et] *om. BL* | apparet] appareret *V*; *add. a. m.* appareret *in mg. V* 9 luna] *post* luna *add.* et *V*

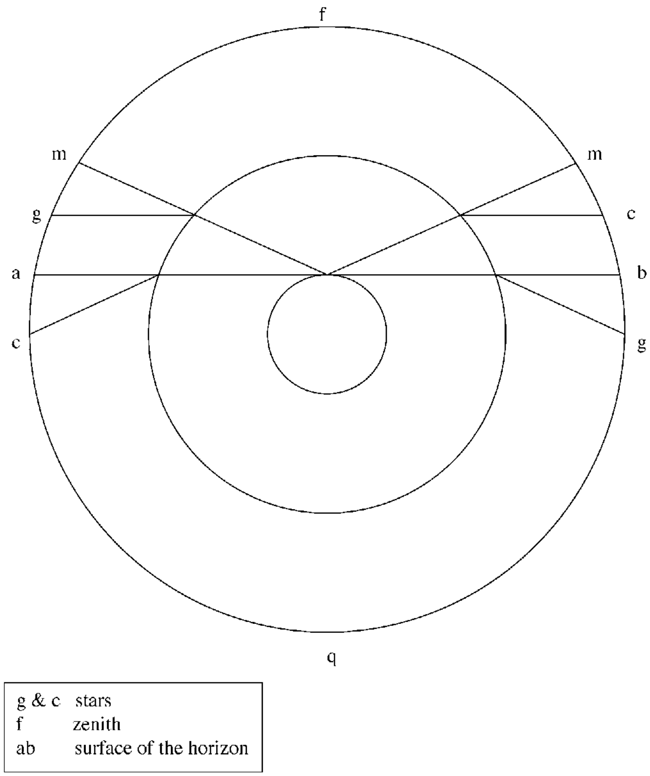

Figure 21. Stars Appearing to Be in Opposition at the Horizon are Not

And this is readily evident in a figure. [Figure 21] Let *c* and *g* be the [two] stars, *f* be the zenith, *q* the opposite point under the earth, and *ab* the horizon. Then, in the first instance, the large arc *cfg* appears as a semicircle, and in the second instance, the arc *gfc*, which is the same as the arc *gqc*, appears smaller than a semicircle, and even smaller than it truly is, because it appears as *mfm*.

[Corollary 4] The fourth corollary is this: it is possible for any [two] stars[106] in opposition to both appear above the earth at the same time. And they will not appear [to be] opposite [one another], as if one were in *a* and the other in *b*. Any star whatever will appear higher than it truly is because of the aforementioned refraction. And so it is concerning the sun and moon. Thus, on a flat horizon, it is possible

[106] "Stars" in the broad sense of any celestial objects.

Igitur, in orizonte plano, possibile est simul videre solem et lunam eclipsatam, lunam versus orientem et solem versus occasum. Et hoc idem appareret de montibus altis, et si nulla foret talis fractio.

Quod autem possibile sit lunam eclipsatam et solem lucentem simul apparere super orizontem in plano patet per Plinium qui narrat sic fuisse libro 2° Naturalis Historie, capitulo 13°, D: "quanam ratione cum solis exortu umbra illa hebetatrix sub terra esse debeat, semel iam accidere in occasu ut luna deficeret utroque super terram conspicuo sydere … et nostro evo accidit Imperatoribus Vespasiano patre ac filio eius."

[Corollarium 5] Quintum est quod motus stellarum fixarum qui est regularis, aut valde prope, apparebit irregularis. Verbi gratia, supposito circulo quem describit aliqua stella transiens prope zenith. Cum huius circuli pars, seu medietas inferior, videatur magis oblique et per maiorem fractionem quam alia, sequitur quod apparebunt | [*F* fol. 39^{v}] inequales. Igitur, et motus qui super eas fuerit temporibus equalibus apparebunt inequales. Et medietas inferior videbitur minor, et motus super eam apparebit tardior. Et ita de qualibet alia stella, quia nullius circuli, quelibet puncta, apparent per similes fractiones.

[Corollarium 6] Sextum est quod circuli descripti a stellis septemtrionalibus circa polum non ap|[*L* fol. 51^{v}]parent perfecti circuli, sed oblongi, sicut ovales aut lenticulares, quam si aliquis talis circulus videretur recte, tunc apparet circulus, aut si quelibet puncta circuli viderentur eque indirecte. Sed iam patet ex dictis, quod non omnium punctorum linee, protense ad visum, eque oblique cadunt super superficiem

2 eclipsatam] eclipsari *L* | versus] verssius *L*; versus *sup. l. V* | orientem] orizontem *V*, *sup.* orizontem *add. a. m.* orientem *sup. l. V* | versus] verssus *L* | occasum] ocasum *F* 3 appareret] apparet *B* | si] *post* si *add. et del.* unam foret nulla *F* 4–10 Quod … eius] *om. V* 4 eclipsatam] eclisatam *F* 6 narrat] narat *L* | sic] se *L* | Historie] Hystorie *B*; Istorie *F* | 130] 13 *L* | D] de *F* 7 cum] cuius *L* | exortu] ortu *F* | umbra] umbro(?) *L* | hebetatrix] ebetantis *F*; heletatix *L* 8 iam] tam *L* | occasu] ocasu *F* 9 sydere] subitum(?) *F* | evo] [i.e., 'aevo' – age] | accidit] acidit *F* | Imperatoribus] in pactibus *F* 10 Vespasiano] Vaspasianas *F*; Vaspasianis *L* | ac] et *L* 11 fixarum] *ante* fixarum *scr. et del.* si- *F* 12 qui est] fiat *V*, *sup.* fiat *add. a. m.* qui est *sup. l. V* | irregularis] irregulariter *L* 13 zenith] cenith *BF* 14 huius] huiusmodi *V* 16 inequales] *sup.* inequales *add.* equales *sup. l. V* | Igitur] Ergo *L* | qui] *post* qui *add.* sunt *L* | fuerit] fiunt *L* 17 minor] brevior *L* 18 eam] *scr. et del.* cum *add.* eam *sup. l. mg. V* | nullius] ultimus *F* 19 circuli] *post* circuli *add. et del.* i- *L* | per] per(?) *V* 22 ovales] obvales *L* | lenticulares] lenticlares *F* | quam] *add. a. m.* quam si aliquis talis circulus, aut si quelibet puncta circuli equaliter indirecte. Sed iam patet etc. *in mg. V* 23 apparet] appareret *B*; apparere *F* 24 omnium] omni *V* 25 protense] protansse *L* | visum] vissum *L* | oblique] olique *V*

5 Pliny, *Natural History*, Bk. II, x, 57.

to see the sun and the eclipsed moon simultaneously – the moon towards the east, and the sun in the west.[vi] And this same thing would appear from high mountains, even if there were no such refraction.

Moreover, that it might be possible for the eclipsed moon and the shining sun to appear above a flat horizon at the same time is clear from Pliny, who reports this to have occurred in his *Natural History*, Book II, chapter 13, D: "Seeing that the shadow causing an eclipse ought to be *below* the earth after sunrise, [Hipparchus also discovered] for what exact reason that it happened, on one occasion, that the moon was eclipsed [in the west] while both the sun and moon[107] were visible *above* the earth … for this has occurred even in our time under the Vespasian Emperors, father and son."[vii]

[Corollary 5] The fifth corollary is this: The motion of the fixed stars, which is regular (or very nearly so), will appear irregular. For example, assume a circle describes [the path of] any star passing near the zenith. Since part of this circle, [particularly] the lower half, is seen more obliquely and through a larger refraction than the other [part of the circle], it follows that the parts will appear unequal. Therefore, on those [parts of the circle] which will have been [actually traversed by the star] in equal times, [there, the star's] motion will appear unequal. And the lower half [of the circle] will be seen as smaller, and the motion on that [part] will appear slower. And the same concerns any other star whatever, because no [stellar] circles, at any [of their] points, are seen through [exactly] similar refractions.

[Corollary 6] The sixth corollary is this: The circles described by circumpolar stars do not appear as perfect circles, but [more] oblong – like an egg or a lentil[108] – than if such a circle were seen directly (then it would appear as a circle), or if any points on the circle were seen equally indirectly. But now it is clear from what has been said, that none of the points of [that circular] line, [when] extended to the eye, fall equally obliquely upon the surface of [the

[107] "sun and moon": literally "shining ones" or "starry ones" *sydere.*
[108] That is, oval-shaped or lenticular.

aeris sive ignis. Quare, non omnia videntur equaliter indirecte, sed secundum fractiones inequales.

Quod patet etiam ex probatione 6^{e} conclusionis. Quia quando stella est prope zenith, videtur remotior a polo quam dum est inferius versus orizontem. Et similiter, a centro circuli quem describit, quod non potest esse, nisi huius circulus obliquus appareat vel oblongus.

[Alia Corollaria.]

Si, ergo, per observationes et instrumenta possit aliquod istorum 6^{a} corollariorum experimentaliter deprehendi audacter affirmetur, quodlibet aliorum cum tribus conclusionibus ultimis et probationibus earumdem. Sunt, autem, et alia corollaria ex predictis, consequentia, non tamen antecedentia, quia non ita bene possunt experiri.

[Corollarium I] Primum est quod quelibet stella apparet magis elevata super orizontem et propinquior zenith quam ipsa sit, nisi ipsa esset recte supra zenith. Quia, per conclusionem 6^{am}, quelibet talis videtur per lineam fractam a perpendiculari. Igitur, per 3^{am}

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3 ex probatione] ex probatione *corr. ex* exemplione(?) *V* | 6e] 1º *L* 4 zenith] cenith *BF* | videtur] apparet *F*; *post* apparet *scr. et del.* p- *F* 5 versus] versus *rep. B*; verssus *L* | orizontem] *post* orizontem *add.* orientem *sup. l. V* 6 non potest esse] *om. B* | huius] huiusmodi *V* | obliquus] *om. FV* | appareat] *post* appareat *add. a. m.* obliquus *mg. V* 7 Alia Corollaria] [Roman numerals are used for these other corollaries to avoid confusion. ed.] 8 ergo] igitur *FV* | istorum] illorum *V* 9 6a] 6 *BV*; seu *F* | experimentaliter] experimentis *BF* | deprehendi] depreindi *L*; comprehendi *V* | affirmetur] affirmarem *L* 10 aliorum] *ante* aliorum *scr. et del.* illorum *V* 11 autem] aut *B* | corollaria] corellaria *B* 12 quia] *sup.* quia *add.* que *sup. l. V* | non ita] ita non *L* 15 elevata] ellevata *L* | super] supra *V*, *post* supra *add. et del.* ad *V* | zenith] cenith *BF* 16 supra] super *L* | zenith] cenith *BF* | conclusionem 6am] 6^{am} conclusionem *V* 17 Igitur] Ergo *L*

sphere of] air or fire. And for that reason, not all [of the points of that line] are seen equally indirectly, but [rather] according to unequal refractions.

This is also clear from the proof of the sixth conclusion.[109] For when a star is near the zenith, it is seen farther from the pole than when it is nearer the horizon. And in the same way [a star near the zenith is seen farther] from the center of the circle which it describes – which cannot be unless its circle appears oblique or oblong.

[Other Corollaries]

If, therefore, one can experimentally discover any of these six corollaries through observations and instruments, any of them whatsoever may be boldly affirmed by the three final conclusions and their proofs.[110] Moreover, there are also other corollaries from what has been said – [they are] logical conclusions,[111] however, not antecedents, since they are not able to be experienced so easily.

[Corollary 1] The first [corollary] is this: Any star appears more elevated above the horizon and nearer the zenith than it truly is, unless it is directly over the zenith. For, from the sixth conclusion,[112] any such [star] is seen through a line refracted away from the perpen-

[109] Oresme's sixth conclusion stated that any star which is not over the zenith is seen through a line refracted from the perpendicular. *De visione stellarum*, Bk. II, cap. 1, 140:7 – 146:12.

[110] That is, the fifth, sixth and seventh conclusions. *De visione stellarum*, Bk. II, cap. 1, 136:20 – 148:19. See also Oresme's "Response to the Second Argument" above. *De visione stellarum*, Bk. II, cap. 2, 166:11 – 170:15.

[111] That is, "consequents" = *consequentia*.

[112] The sixth conclusion states: any star which is not over the zenith is seen through a line refracted from the perpendicular. *De visione stellarum*, Bk. II, cap. 1, 140:7 – 146:12.

conclusionem, et per corollaria ipsius, apparet magis elevata quam sit. Et patet faciliter ex figuris prioribus.

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1 corollaria] correllaria *B*; corellaria *F*; corollariam *V* | elevata] ellevata *L* 2 faciliter] *om. F* | figuris] figuras *F* | prioribus] precedentibus *F*; *post* precedentibus *add.* faciliter *F*

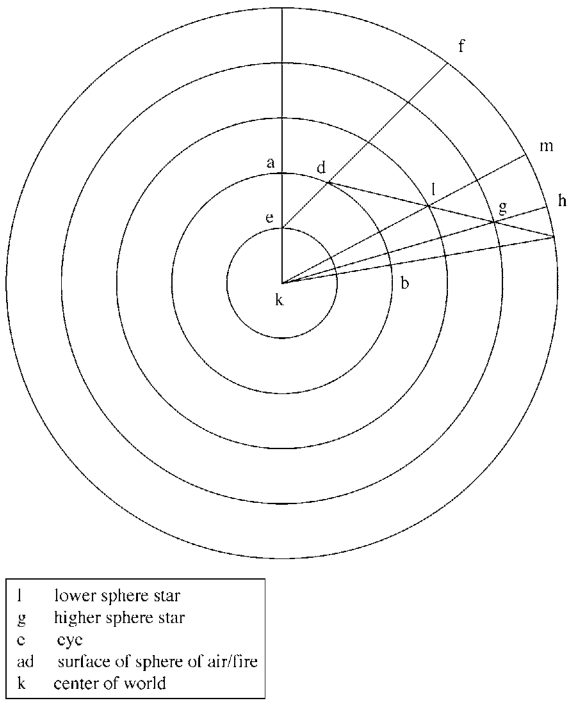

Figure 22. A 'Star' in a Higher Sphere Appears Further From Its True Place Than a Star in a Lower Sphere

dicular.[113] Therefore, from the third conclusion[114] and its corollaries, [any star] will appear more elevated than it truly is. And this is easily demonstrated from the previous figures.

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[113] The great naked-eye astronomer Tycho Brahe concluded from his observations that atmospheric refraction was imperceptible for any altitude above 45°, and so he took no account of them above that angle. Unfortunately, he was incorrect in this, and so his measurements above 45° were off by the slight amount of roughly 40" of arc. Here, Oresme's theoretical view notes that there should be some amount of refraction all the way to the zenith.See Victor Thoren's, *The Lord of Uraniborg: A Biography of Tycho Brahe* (Cambridge: Cambridge University Press, 1990), pp. 226–235; A.I. Mahan, "Astronomical Refraction – Some History and Theories" *Applied Optics* 1 (1962): 498–499; and A. Pannekoek, *A History of Astronomy* (New York: Dover, 1961, rpt. 1989), p. 212.

[114] The third conclusion states: when a thing is seen by a refracted line, then it appears on a line proceeding from the eye, through the place of refraction, in a continuous and straight [line] and along the direct path. *De visione stellarum*, Bk. II, cap. 1, 122:17 – 124:6.

[Corollarium II] Secundum est quod stella que est in altiori orbe, ceteris paribus, apparet remotior a suo vero loco. Verus locus *B* fol. 38^{v} stelle est punctus quem terminat lineam exiens de centro | terre, in primum celum, per centrum stelle. Tunc, probatur corollarium. Sint due stelle, *l* inferior, et *g* superior, que videntur per lineam fractam *L* fol. 52^{r} *edlg*. Et, per 3^{am} conclusionem, apparent in directo linee *edf*. | Et cum verus locus *l* sit *m*, et locus *g* sit *h*, patet statim quod *g* videtur remotius a suo loco quam *l*. Et ideo, maxima deceptio ex tali fractione est circa stellas fixas.

[Corollarium III] Tertium est quod quando apparet vera coniunctio planetarum, tunc non est, et quando est, non apparet. Et voco *V* fol. 48^{v} veram coniunctionem eorum quando sunt in eadem | linea precedente de centro mundi in celum. Tunc patet propositum, quia stante priori dispositione, *l* et *g* apparent coniungi in *f*, et non sunt coniuncti per idem. Patet quod quando coniunguntur videntur disiuncti, sicut si *g* esset in linea *klm*.

[Corollarium IV] Quartum est quod elevatio poli non est tanta sicut apparet, quia videtur per lineam fractam, etc. Et sic de elevatione primi puncti Capricorni aut Arietis, et sic de aliis, sicut dictum est in primo corollario.

[Corollarium V] Quintum est elevationem poli veraciter inve- *F* fol. 40^{r} nire, suppono quod quasi proportionaliter, et ceteris paribus, | quanto est maior distantia a zenith tanto est maior deceptio in

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2 orbe] nube *F* | apparet] *om. B* | Verus] *ante* Verus *add.* Et *F* 3 quem] quam *LV* | lineam] linea *B* | de] a *V* 4–5 Tunc...stelle] *om. V*; *add. a. m.* Tunc probatur corollarium, sint due stelle 'l' inferior, et 'g' superior *in mg. V* 4 corollarium] correllarium *B* 7 locus] *post* locus *rep. et del.* 'l' inferior, et 'g' superior, que videntur per lineam fractam (*cf. supra*) *F* | g] h *L* 8 loco] *post* loco *scr. et del.* i- *L* | deceptio] deceptio *sup. l. V* | tali] *post* tali *add.* est *sup. l. V* 10 quod] *om. L* | quando] quando *sup. l. V* 11 planetarum] planum *F*; *del. et add. a. m.* planetarum *mg. F*; *post* planetarum *scr. et del.* i- *L* | quando] *post* quando *scr. et del.* non *V* | est] *post* est *add.* tunc *V* 12 coniunctionem] conclusionem *L* | eorum] eorum *corr. ex* earum(?) *V*; *post* eorum *add.* planetarum *V* 13 de] a *V* | mundi] *sup.* mundi *add. a. m.* terre *V* 14 g] *post* 'g' *add. a. m.* et *in mg. V* | apparent] apparet *LV* | sunt] *om. L* 14–15 coniuncti] coniuncta *B* 15 quod] *om. L* | coniunguntur] *scr. et del.* coniunguntur(?) *add. a. m.* coniunguntur *sup. l. V* | disiuncti] difficile *L*; *ante* disiuncti *scr. et del.* disiuntum(?) *F* 16 sicut] sic *corr. ex* sicut *L* | si] si *rep. et del. F* 17 quod] *om. L* | non] *scr. et del.* nunc *add. a. m.* non *sup. l. V* 18 videtur] videre *L* | fractam] *post* fractam *scr. et del.* (?) *V* | etc] esse(?) *L*; *om. V* 18–19 elevatione] *ante* elevatione *scr. et del.* elev- *F* 20 corollario] corellario *F; post* corellario *scr. et del.* (?) *F* 22 suppono] suppono *alter. in* supposito *a. m. V* | quasi] q *V* | et] *post* et *add.* quasi *F* 23 est] *scr. et del.* est *V* | maior] *post* maior *add.* est *V* | zenith] cenith *BF* | deceptio] decepto *L*

[Corollary II] The second [corollary] is this: a "star" which is in a higher sphere, all things being equal, appears further from its true place. The true place of a star is the point which terminates a line proceeding from the center of the earth, into the first heaven, [and] through the center of the star. Then this corollary is proved thus. Let there be two stars – *l* the one in the lower [sphere], and *g* the one in the higher [sphere] – which are both seen through the refracted line *edlg*. [Figure 22] And, from the third conclusion, they both appear in the direction of line *edf*. And since the true place [of star] *l* is in *m*, and the [true] place [of star] *g* is in *h*, it is immediately clear that *g* is seen further from its true place than *l*. And therefore the greatest deception from such a refraction is of the fixed stars [themselves].[115]

[Corollary III] The third [corollary] is this: When there appears to be a true conjunction of the planets, there is no [true conjunction], and when there is [a true conjunction], it does not appear so. And I call it their true conjunction when they both are on the same line proceeding from the center of the world into the heaven. Consequently this proposition is obvious, since in the disposition of the previous example, [the stars] *l* and *g* appear conjoined in *f*, and [yet] they are not [truly] in conjunction. It is clear that when they *are* conjoined they are seen as separate, just as if, [for example], *g* were on line *klm*.

[Corollary IV] The fourth [corollary] is this: The elevation of the [celestial] pole is not so great as it appears, since it is seen through a refracted line, etc. And so also concerning the elevation of the beginning points of Capricorn and Aries,[116] and so also concerning the others,[117] as is said in the first corollary.[118]

[Corollary V] The fifth [corollary is this]: To find the real elevation of the [celestial] pole, I assume that [it is] roughly proportional [to the following]. All things being equal, the greater the distance something is from the zenith, the greater the deception in seeing

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115 Since they are the furthest away.

116 The Winter Solstice and the Vernal Equinox, respectively.

117 That is, all other signs and constellations.

118 Corollary I stated: "Any star appears more elevated above the horizon and nearer the zenith than it truly is, unless it is directly over the zenith." So it naturally follows that all constellations of stars would do the same. *De visione stellarum*, Bk. II, cap. 2, 180:14 – 182:2.

videndo loca stellarum propter huius fractionem. Sit, igitur, *c* una stella que sit supra zenith, aut prope. Et consideretur distantia eius a loco *f*, ubi apparet polus, et sit illa distantia apparens secundum

1 videndo] videre *L* | huius] huiusmodi *LV* 2 zenith] cenith *BF* 3 sit] sic *V*

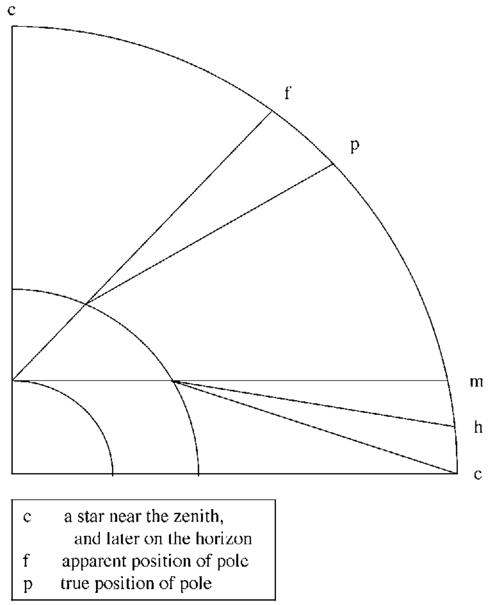

Figure 23. Finding the True Elevation of the Celestial Pole. (Illustration as presented in the Oresme manuscripts. See Figure 23a for a depiction with the Earth as a point)

the stars' places because of this refraction.[119] Therefore, let *c* be a star which is over the zenith, or near it. [Figure 23 and 23a][120] And determine its distance from the place *f* where the [celestial]

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[119] Oresme assumes that as one approaches the zenith, the effects of atmospheric refraction will decrease proportionally in a simple one to one ratio. Going halfway up the sky (45°) decreases its effect by half. The effect of refraction on star *c* at the zenith is zero, and at the horizon is the arc *mc'*. [See Figure 23a] Therefore, since the pole is halfway between *c* and *c'*, the effect of refraction will be half as well. Thus he concludes that half of arc *mc'* (i.e., arc *mh*) is equal to the refraction at the pole, arc *fp*. This is how he can claim to determine the true position of the celestial pole.

[120] Figure 23 is that found in the Oresme manuscripts. To make this argument a little clearer, I have drawn Figure 23a assuming (as Oresme apparently does) that the earth is a point in comparison to the heavens. The celestial pole, of course, will bisect the angle formed by the star's travel about it, that is, the true celestial pole *p* will be at the midpoint between *c* at the zenith and *c'* nearer the horizon. (Oresme creates confusion by labeling both positions of the star as *c*.) I have added two lines to the drawing: the line of the true celestial pole *pe*, and what Oresme would call the 'true position' of the star *c'* near the horizon, the line *ec'*. Notice that the angles have been exaggerated for clarity's sake. Also, I have removed the line *he* and merely made a mark at *h* the midpoint of arc *mc'*.

L fol. 52^{v} arcum | *cf.* Dictum cum eadem stella fuerit in opposito, scilicet, prope orizontem sub polo observetur. Iterum, apparens distantitia eius a loco ubi apparet polus que distantia sit arcus *fm,* qui erit minor quam erat arcus *cf,* ut patet per experientias adductas in probatione 6^{o} conclusionis. Tunc sic, si nulla esset deceptio in visione poli,

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1 Dictum] Deinde *L* | opposito] opposito *corr. ex* o(?) *V* 2 Iterum] *ante* Iterum *scr. et del.* Verum(?) *V* | apparens] aparens *F* 3 que] *post* que *scr. et del.* et sit illa *L* | arcus] *om. B* | erit] est *L* | minor] brevior *L* 4 erat] *sup.* erat *add. a. m.* erat(?) *sup. l. V* | patet] *om. L* | experientias] experigentias *V* | adductas] aductas *FL* 5 6o] 6^{e} *BF* | sic] sicut *B*

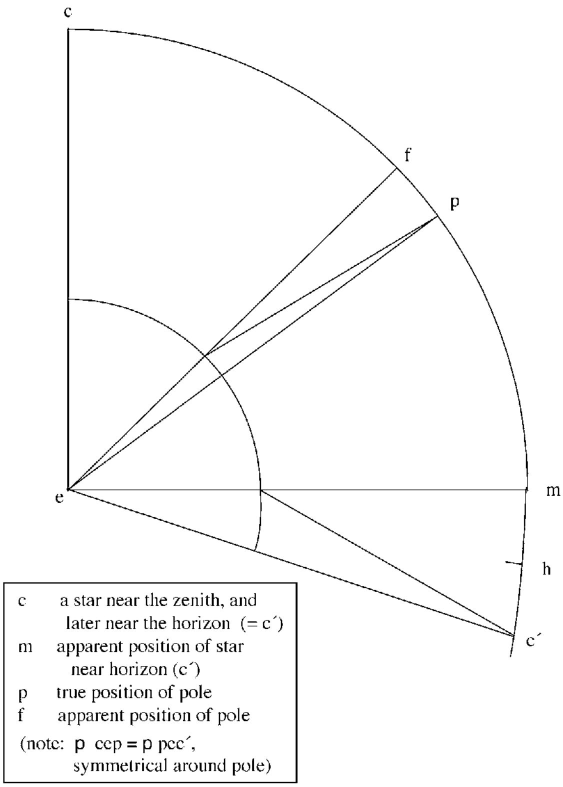

Figure 23a. Finding the True Elevation of the Celestial Pole. (Figure 23 redrawn with Earth as a point. Angles are exaggerated for clarity)

pole appears, and let that apparent distance be arc *cf.* Say that that same star is observed when it is in the opposite position, that is, near the horizon under the [celestial] pole. This time, let its apparent distance from the ostensible place of the [celestial] pole be arc *fm.* This distance will be smaller than arc *cf* is,[121] as is clear from the observations [= *experientias*] adduced in proving the sixth conclusion.[122] Thus, if there were no deception in seeing the [celestial] pole's distance from the zenith, then the [original]

[121] That is, *c′f* in Figure 23a.

[122] The experimental observations of circumpolar stars in the sixth conclusion apply particularly well here. See conclusion six, *De visione stellarum,* Bk. II, cap. 1, 142:1–13.

secundum distantiam eius a zenith, tunc deceptio circa locum stelle quando est prope orizontem esset precise de tanto quanto arcus *fm* minor est quam arcus *cf.*

Sed nunc, est duplo maior deceptio, per suppositum, quia duplo plus distat stella a zenith quam polus. Quia, igitur, excessus quo arcus *cf* excedit arcum *fm,* est notus quem oportet duplicare. Sequitur quod deceptio in visione stelle quando est prope orizontem est nota, et verus locus ipsius erit notus. Quia ipsa erit propinquior orizonti et minus elevata quam apparet per excessum duplicatum arcus *cf* super arcum *fm* duplicatum. Et quia deceptio circa visionem poli est duplo minor ipsa erit nota. Ergo, polus est minus elevatus quam apparet per excessum quo arcus *cf* excedit arcum *fm.* Et ille arcus est notus, quare, sequitur propositum.

Sit itaque *p* polus, et arcus *fh* sit equalis arcui *cf.* Tunc arcus *fp* et arcus *mh* sunt equales, et arcus *mc* inferior cuilibet istorum est duplus.

[Corollarium VI] Sextum est in inquirendo vera loca stellarum huiusmodi, deceptionem posse invenire quem ex premisso corollario, patet quanta est deceptio in visione *c* stelle que est prope orizontem in linea meridionali. Et prius fuit supra zenith, vel in visione poli.

L fol. 53[r] Et quia supponitur quod quasi proportionaliter | est deceptio secundum distantiam a zenith, considerandum est de stella cuius locus inquiritur per instrumentum, quanto plus vel minus distat a

1 zenith] cenith *BF* 2 precise] presize *F*; precise *corr. ex* pre(?) *V* | de] *post* de *add.* minor *sup. l. V* | quanto] quantum *V* | arcus] *om. L* 3 minor est] est minor *F* | cf] ef *L* 4 est] *post* est *add.* in *V* | deceptio] *ante* deceptio *scr. et del.* dep- *F* 5 zenith] cenith *BF* 6 est] *post* est *scr. et del.* sunt(?) *L* | quem] quam *L* | oportet] opportet *L* | duplicare] duplare *L* | Sequitur] Sequitur *corr. ex* Sequitur igitur(?) *V* 7 est] erit *V* 8 erit] est *L* | erit] est *L* 9 elevata] ellevata *L* | duplicatum] *om. V* 11 ipsa] *post* ipsa *add.* igitur *V* | erit] est *L* | Ergo] Igitur *V* 12 quo] quo *sup. l. F* | ille] iste *V* 13 quare] igitur *V* 14 itaque p polus] polus p *F* | p] p *sup. l. V* | cf] cf *corr. ex* f *V* 15 mh] fmh *F* | mc] me *L*; mc(?) *vel* me(?) *B* | inferior] *post* inferior *add.* est *F* | cuilibet] quodlibet *F*; quilibet *V* | istorum] illorum *V* | est] *om. F* 17 est] *om. B* | in] *om. LV* | stellarum] stellarum *in mg. V* 18 deceptionem] decceptionem *L* | invenire] evitare *V* 18–19 corollario] correlario *B*; corellario *F*; corrollario *L* 19 quanta] quanto *B* | deceptio] decceptio *L* | in visione c stelle] stelle c in visione *F* | c] e *L* 20 supra] super *L* | zenith] cenith *BF* 22 quasi] quaxi(?) *L*; quasi *sup. l. V* | proportionaliter] equalis *F* | est] *om. F* | deceptio] decceptio *L*; *ante* deceptio *scr. et del.* distantia *F* 23 secundum] sed *L*; scilicet *V* | zenith] cenith *BF* | considerandum] considerandi *L* 24 distat] *ante* distat *scr. et del.* di- *F*

deception of the star's place near the horizon would be precisely the quantity of arc *cf* minus the smaller arc *fm*, [that is, the arc *cm*].[123]

But now, by this assumption, it is a greater deception by double, for the star [on the horizon] is more than double the distance from the zenith than from the [apparent celestial] pole.[124] Therefore, since we know the excess by which arc *cf* exceeds arc *fm* (which ought to be double), the deception in seeing the star near the horizon is known, and [thus, the star's] true place will be known. For [the star] itself will be nearer the horizon[125] and less elevated than it appears [to be] by the [amount of the] duplicate excess of arc *cf* beyond arc *fm*. And since the deception in seeing the [celestial] pole is less than double, its [deception] can be known. Therefore, the pole is less elevated than it appears by the excess that arc *cf* exceeds arc *fm*. And that arc is known, so for that reason, the proposition follows.

Accordingly, let *p* be the [celestial] pole, and let arc *fh* equal arc *cf*.[126] Then arc *fp* and arc *mh* are equal, and the lower arc *mc*[127] is double any one of those [arcs].

[Corollary VI] The sixth [corollary] is [this]: In searching for the true locations of stars, [one] can find the deception [from refraction by using the previous corollary]. From the previous corollary, it is clear how large the deception is when viewing the star, *c*, while it is near the horizon on a meridian.[128] And previously [the star] had been over the zenith [where there is no deception], or in sight of the [celestial] pole.

And since it is assumed that this deception is roughly proportional to the [star's] distance from the zenith, [then] for a star whose location is sought, one must use an instrument to determine

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123 For figure 23a this phrase would read: "the quantity of arc *c'f* minus the smaller arc *fm*, that is, the arc *c'm*.

124 I am assuming by this that Oresme means the star's actual position is below the horizon (*c'* in fig. 23a). His phrase, "the star is more than double the distance" probably means that the distance from the zenith to *c'* is more than twice the distance from the zenith to the apparent position of the pole *f*. He certainly cannot mean that arc *c'p* is more than double the distance of arc *cp*, since by definition these are equal.

125 The opposite is the case. The star would be further from the horizon, not nearer.

126 *c* here refers to the star at the zenith.

127 That is, *mc'* in figure 23a.

128 A celestial meridian is a great circle that runs through both north and south poles and through the observer's zenith. Since the star *c* in the previous corollary was directly below the pole when near the horizon, it fell upon the meridian at that point. John of Sacrobosco gives a brief description of the term meridian in his *De sphaera*. In Thorndike (1949), *The "Sphere" of Sacrobosco*, p. 91 (Latin), pp. 126 (English tr.).

zenith quam *c* aut etiam quam polus. Et tanto maior vel minor erit deceptio in ipsius visione propter huius fractionem.

[Corollarium VII] Septimo, sequitur quod distantie stellarum apparent minores quam sint, et arcus celi inter eas apparent minores quam sint secundum veritatem. Hoc patet faciliter in figura. Si una stella sit ab una parte zenith, et alia ab alia, unde *c* stella apparet in *f*, et *g* in *m*, ideo, apparent propinquiores quam sint.

B fol. 39r Et similiter, si fu|erint ab eadem parte ipsius zenith, tunc fractiones non sunt equales. Verbi gratia, quia *c* apparet in *f*, et *n* in *h*, et

1 zenith] cenith *BF* | erit] est *V* 2 huius] huiusmodi *V* 3 distantie] distantia *L* 4 apparent] apparet *L* 4–5 et arcus celi inter eas apparent minores quam sint] *om. BFL* 5 Si] Sit *L* 6 zenith] *om. B*; cenith *F* | alia] *post* alia *add.* parte *L* 7 apparent] apparet *L* | sint] sit *L* 8 fuerint] fuerit *L* | ipsius] *om. V* | zenith] cenith *BF* 9 n] h *BFV* | h] n *B*; m *FV*

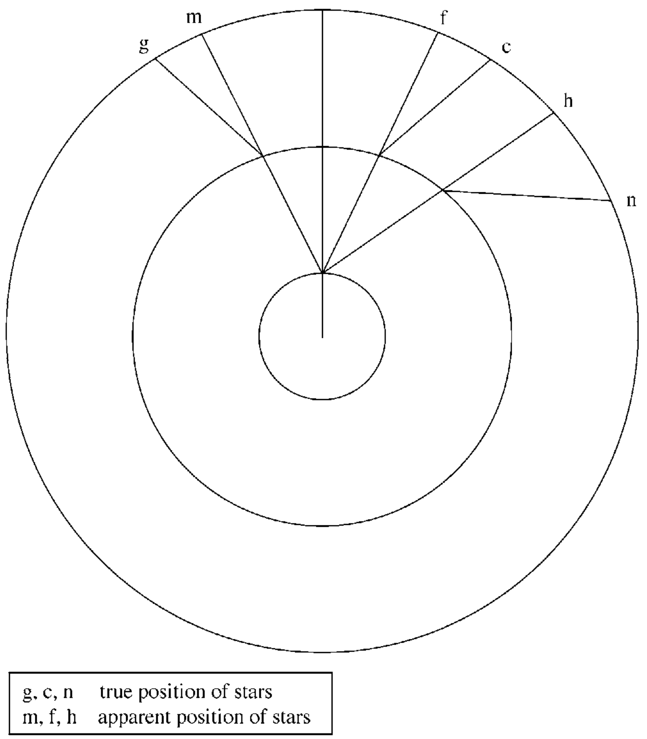

Figure 24. The Distances Separating the
Stars Appear Smaller Than They Truly Are

how much more or less distant [that star] is from the zenith than [from the star] *c* or even [from the celestial] pole. And the deception in its apparent [location] will be [proportionally] larger or smaller because of this refraction.

[Corollary VII] Seventh: It follows that the distances separating the stars appear smaller than they truly are, and the arcs of the heaven between them appear shorter than they are in truth. This is immediately clear in the figure. [Figure 24] If one star were on one side of the zenith and another on the other side, such that the star *c* appears in *f*, and [star] *g* [appears] in *m*, they appear nearer [one another] than they really are.

And similarly, if [two stars] were on the same side of the zenith, then their refractions would not be equal. For example, let *c* appear maior est arcus *hn* quam arcus *fc*. Igitur, utrobique addito contrari *V* fol. 49^{r} arcu *ch* erit arcus | *cn*, que est vera distantia stellarum maior quam arcus *fh*, qui est apparens distantia earundem. Igitur, magis distant huiusmodi stelle quam apparent distare.

Et similiter, est deceptio in visione dyametrorum stellarum, sed non ita magna. Unde, dyametrus stelle apparet minor propter huius fractionem, et sub minori angulo quam si esset supra zenith. Et hoc *F* fol. 40^{v} totum, et propter eandem causam, ponit Vitelo in 49^{a}, 10^{i}. | Et iam, ex immediate precedenti, patet qualiter a deceptione huiusmodi sit cavendum.

[Corollarium VIII] Octavo, dico, consequenter, quod sol et luna et quelibet stella prius lucet, et apparet super orizontem planum quam veraciter oriatur, et quam si videretur per lineam rectam. Et

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1 hn] kn *L*; hm *V* | fc] fc *corr. ex* fg *L*; fg *F* | addito] adito *F*; aditto *L* 2 arcu] arcui *V* | cn] c et n *L* | que] qui *LV* 3 arcus] *om. V, add. a. m.* arcus *sup. l. V* | fh] fg *L* | qui] que *F* | Igitur] Ergo *L* 4 huiusmodi] huius *FL* | quam apparent] appareant *V* 5 dyametrorum] diametrorum *F* 6 ita] infra *L* | dyametrus] diametrus *F* | stelle] stelle *sup. l. V* | huius] eius *V* 7 supra] super *L* | zenith] cenith *BF* 8 et] *om. F*; est *corr. ex* et *V* | causam] *post* causam *scr. et del.* V- *F; post* causam *add.* quam *sup. l. V* | Vitelo] Witelo *B*; Vintelo *F* | 49a 10i] 4^{a}, 9^{a}, 10^{a} *L*; 49^{a}, 4^{i} *V* 9 immediate] *post* immediate *add.* in *L* | precedenti] precedente *B* | qualiter] qualibet *L* | huiusmodi] huius *F* 12 stella] (?) *F* | super] supra *F* 13 videretur] videret *L; ante* videretur *scr. et del.* vid(?)– *F*

8 Witelo (1572, rpt. 1972), *Perspectiva*, X, secs. 51–53, pp. 445–448.

in *f*, and *n* in *h*, and arc *hn* is greater than arc *fc*.[129] Therefore, adding arc *ch* to both sides will yield arc *cn*, (which is the true separation of the stars) [which is] greater than arc *fh* (which is the apparent separation of them).[130] Therefore, these stars are really more separate than they appear to be.

And the deception in observing the diameters of stars is similar, but not so large. Hence, because of this refraction, a star's diameter appears smaller and under a smaller angle than if it were over the zenith. And Witelo posits all this, and for the same reason, in [his *Perspectiva*, Book] x, [section] 49.[131] And now, from the immediately preceding, it is clear how one must be on one's guard about a deception of this sort.

[Corollary VIII] Eighth: Consequently, I say that the sun, moon, and any star whatsoever [both] shines and appears above the horizon earlier than it actually arises, and [earlier] than if it were seen

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[129] None of the manuscript diagrams completely agree with their own texts, nor do most of the texts even agree with themselves. Three of the four manuscripts, *BLV*, have diagrams that agree. Therefore, I am assuming (for clarity) that the lettering in this diagram is nearer to the original and more accurate than the extant texts themselves.

[130] The separation between the apparent and true position of each star is arc *hn* and arc *fc*, respectively. When the arc between them, *ch*, is added to each of these, we get the following: $hn + ch = cn$ (the true separation of the stars); and $fc + ch = fh$ (the apparent separation of the stars). And *cn* is larger than *fh*, therefore, the true separation of the stars is larger than the apparent separation.

[131] Concerning Witelo, Oresme probably meant to refer to Book x, sections 51–53, rather than section 49, since they deal more directly with this corollary's topics. Witelo (1572, rpt. 1972), *Perspectiva*, x, secs. 51–53, pp. 445–448. Alhacen, Bacon, and Pecham also take up the question of refraction affecting stellar distances and diameters. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, secs. 51–55, pp. 278–282; Bacon, *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 4, pp. 126–129; and Pecham (1970), *Perspectiva communis*, Props. I.82{86}, pp. 152–153, and III.12–13, pp. 222–229, and again by Oresme in his *Questiones super quatuor libros meteororum*, Bk. III, Q. 12, lines 331–334.This last paragraph deals tangentially with what is often called the "moon illusion," which I have referred to in previous footnotes. From Ptolemy to today, the question of why the moon appears larger on the horizon than it really is has been hotly debated. The perspectivists were almost unanimous in rejecting atmospheric refraction as a reason for it appearing larger, since, as Oresme implies here, atmospheric refraction near the horizon would make any celestial object appear smaller in diameter, not larger. Oresme had taken up this question previously in Bk. II, Conclusion 3, Corollary, and in Bk. II, Conclusion 7. See the notes there for a more complete explanation.

apparet, similiter, post verum occasum. Sit itaque *c* sol aut stella, et *ab* superficies orizontis. Patet, ergo, quod *c* incipit apparere *e* visui *L* fol. 53v per lineam fractam | *edc* antequam sit in *a*, et apparet in *a* antequam sit ibi, et ita in occasu. Hoc autem est verum, si orizon capiatur pro plano circulo contingente terram ubi est visus. Si, autem, accipiatur

1 similiter] *ante* similiter *scr. et del.* simil(?)– *F* | occasum] ocasum *F* 2 ergo] igitur *V* | apparere] *post* apparere *add.* in *F* 3 antequam] ante-(?)-quam *F* | et apparet in a] *om. L* | in] in *sup. l. V* 4 ita] *post* ita *add.* similiter *sup. l. V* | occasu] ocasu *F* | capiatur] su(?)mater(?) *F*; capitur *V* | pro] *post* pro *add.* uno *F* 5 circulo] *ante* circulo *scr. et del.* conti- *F* | contingente] contingente *rep. et del. F*; continginte *L* | visus] *post* visus *add.* e *V* | Si] *ante* Si *scr. et del.* aut *V* | autem] aut *B*; autem *sup. l. V* | accipiatur] acipiatur *F*

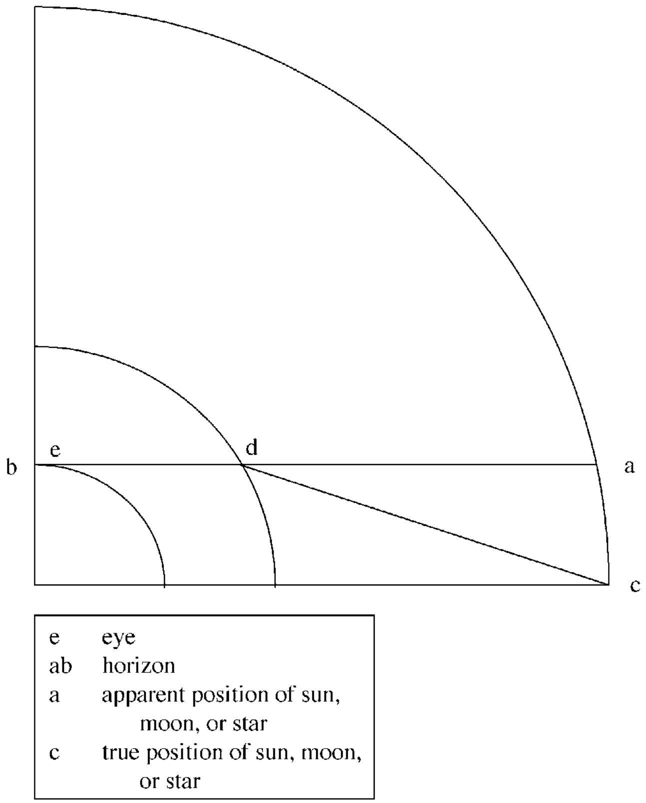

Figure 25. Refraction of Light From a Celestial Object Below the Horizon

through a straight line.[132] And the same thing occurs after they actually set. So, [for example], let *c* be the sun or a star, and *ab* the surface of the horizon. [Figure 25] It is clear, therefore, that *c* begins to appear to the eye, *e*, along the refracted line *edc* before it is in *a*, and it appears in *a* before it is actually there, and so also when it sets. This is true if the horizon is taken to be a flat circle [that is] tangent to the earth where the eye is [located]. On the other hand, if [the horizon] is taken to terminate at the observer or at the eye, then the

[132] This is a variation upon Corollary 3 above (see notes there, *De visione stellarum*, Bk. II, cap. 2, 174:9 – 176:5.). What makes this corollary differ from Corollary 3 is that Oresme adds a further layer of complexity by introducing the possible effects of atmospheric refraction on the visual cone rather than merely a single ray.

pro terminatore visus vel visionis, tunc orizon non est superficies plana sed angularis que describitur ex circumductu linee fracte *edc* circa centrum *e*, et est pyramis obtusa.

[Corollarium IX] Nono, patet ex eodem quod plus quam medietas celi videtur ab existentibus in plana terra, vel in mari.

[Corollarium X] Decimo, quod habitantibus sub equinoctiali libere, patet uterque polus manifestus. Et quod etiam sub unoquoque polorum manentes non habent per medium anni noctem. Sed sol existens sub equinoctiali apparet utrique elevatus, et habitantibus in regione illa umbrosa lux orta est eis.

[Corollarium XI] Undecimo, dico quod predicta possent iuvare ad inquirendum proportionem celi ad aerem vel ignem in subtilitate. Quia quanto est maior differentia in grossitie et subtilitate mediorum ubi fit fractio, ceteris paribus, tanto maior est fractio, et e converso. Notis, igitur, obliquitate incidentie, quantitate anguli, fractionis loco, seu locis fractionum, inde posset investigari propositum.

[Corollarium XII] Duodecimo, suppono quod, ceteris non mutatis, propter maiorem et minorem differentiam in huius subtilitate

1 terminatore] terminatoret(?) *F* | vel] seu *L* 2 describitur] describeretur *corr. ex* scriberetur *V* | ex circumductu] *ante* ex circumductu *scr. et del.* ex circa(?) ductu *F* | circumductu] circumdutu(?) *L* | linee] *scr. et del.* hoc, *add.* linee *sup. l. V* 3 et…obtusa] *om. FV* | est] etiam *L* | pyramis] pyramus *L* 4 eodem] eadem *L* 5 celi] *sup.* celi *add.* terre *sup. l. V* | plana] planitie *B* | terra] recta *B* | mari] maiori *V; sup.* maiori *add. a. m.* in mari *V* 6 Decimo] *scr. et del.* Ideo *add.* Decimo *mg. L* | equinoctiali] *post* equinoctiali *add. a. m.* qui(?) *sup. l. V* 7 polus] *om. V* | manifestus] *scr. et del.* maioribus(?), *add.* polus *in mg. V* | quod] *om. FV* 8 polorum] polo *L* | Sed] *add. a. m.* Sed plus de die(?) quam de nocte. Undecimo dico etc. *in mg. V* 9 sub] in *BF* | et] *post* et *add.* in *F* 10 illa] ista *L; om. V* | umbrosa] umbroxa *L* | est] *om. B* | eis] *post* eis *add.* etc.(?) *V* 11 Undecimo] Quinto *F* | dico] *om. L* | iuvare] vidicari *V, sup.* vidicari *add. a. m.* vivari *sup. l. V* 13 Quia … subtilitate] *om. V; add. a. m.* Quia quanto maior differentia in grossitie et subtilitate, tanto maior fractio, et quantitate(?) illa maior, tanto maior deceptio. Duodecimo supposito etc. *in mg. V* | grossitie] grossititie *B* | subtilitate] *ante* subtilitate *scr. et del.* subti- *F* 13–14 mediorum … fractio] *scr. V, sed del. a. m.(?) V* 14 fit fractio] fractio fit *F* | maior est] est maior *F* 15 Notis] Nota *FL* | igitur] ergo *L* | obliquitate] obliquitatem *BL* | quantitate] *om. F* | anguli] angularis *L* | fractionis] *post* fractionis *add.* et *BF* 16 propositum] propositionem *L* 17 ceteris] *post* ceteris *add.* paribus *B* 18 huius] huiusmodi *V*

horizon is not a flat surface but has angles which are described by the circumference of the refracted line *edc* around the center, *e*. And [the horizon] is an obtuse pyramid.[133]

[Corollary IX] Ninth: It is clear from the same that *more* than half of the heaven is seen while on flat ground or on the sea.[134]

[Corollary X] The tenth [corollary is] this: For those living on the equator,[135] it is obvious [that] both [celestial] poles [are] clearly observable. And, also, those staying under the [north and south] poles do not have night for half of the year.[136] But the sun appears higher [than it really is, while] it is under the [celestial] equator to both [groups],[137] and to those living in that shadowy region, light [still] comes to them.[138]

[Corollary XI] Eleventh, I say that the things previously mentioned are able to be of assistance in inquiring into the proportions of air or fire in the atmosphere. For, all things being equal, the greater the difference between density and subtlety of a medium where a refraction occurs, the greater is the refraction – and vice versa. Thus, by knowing the obliquity of the incident [ray], along with the size of the angle, the location of the refraction or the places of the refractions, we might be able to investigate this proposition [further].

[Corollary XII] Twelfth, I assume that, other things being equal, according to a larger or smaller difference in their subtlety and

[133] "Pyramid," in this context, can also mean a figure with a round base. Thus, this is describing a visual cone (or visual pyramid) with the apex at the eye. See Lindberg's (1970a), *John Pecham and the Science of Optics, "Perspectiva communis,"* p. 243, n. 8 for an explanation and references to the usage of "pyramid" in this context.

[134] That is, since atmospheric refraction makes celestial objects below the horizon visible, then an observer sees the half of the heavens above the horizon, plus that part of the heavens refracted from below the horizon.

[135] Literally, "For those living under the equinoctial/celestial equator". A variant manuscript reading of John of Sacrobosco's *De sphaera*, uses the same phrase to describe those who live on the equator: "id est, qui habitant sub equinoctiali." See Sacrobosco's *De sphaera*, in Thorndike (1949), *The "Sphere" of Sacrobosco*, p. 104, fn. 60 (Latin), p. 134 (English tr.).

[136] This is discussed in Sacrobosco as well. See Sacrobosco's *De sphaera*, in Thorndike (1949), *The "Sphere" of Sacrobosco*, p. 109 (Latin), p. 138 (English tr.).

[137] The sun will appear "higher" to all three positions, only if we mean north as absolute up.

[138] OR "and to those living in that region, shadowy light rises to them." Apparently, Oresme means that those regions near the poles still receive light during times when the sun is below but near the horizon. (I have changed the tenses in this passage for clarity.)

et grossitie, et obliquitate incidentie radii super locum fractionis, fit fractio maior aut minor. Ex quo, patet quod illud quod movetur regulariter potest apparere scintillare, propter motum localem varium aut alterationem, scilicet, rarefactionem aut condensationem circa locum fractionis, sicut quando in lumine solis aliquid videtur mediate fumo illud apparet scintillare. Et similiter, si oculus sit in aqua cuius superficies vacillet, sibi videbitur quod sol vacillabit, vel aliud visibile. Ideo, dicit Viteloin 52^{a}, 10^{i}, quod causa quare alique
L fol. 54^{r} stelle ap|parent scintillare.

Et similiter, quandoque sol circa ortum est propter huiusmodi fractionem variabilem, propter transmutationem aeris superioris vel ignis circa locum fractionis. Sicut etiam superficies maris continue movetur. Verumtamen, Aristoteles 2° Celi dicit quod quandoque causa talis apparentie est in oculo, propter motum spirituum et debilitatem visus.

[Corollarium XIII] Tredecimo, patet etiam causa cuiusdam ex-
V fol. 49^{v} perientie, unde, quando sol lucet per foramen | altum super pavimentum, sicut in ecclesia Parisiensi, tunc illud lumen apparet vacillare

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2 quod] *om. L* 2–3 movetur] movere *L; post* movere *scr. et del.* i- *L* 3 potest apparere] *om. V; add a. m.* potest apparere scintillare et propter motum varium *in mg. V* 4 alterationem scilicet] *add. in mg. B* | rarefactionem] refractionem *F*; rarefractionem *L* | aut] vel *V* | condensationem] condempsationem *BF*; condensationem *corr. (a. m.?) ex* condempsationem *V* 5 solis] sol *V* 6 illud] illud *sup. l. V* 7 vacillet] vacillat *alter in* vacillet *a. m. V* | videbitur] videtur *L* 8 visibile] *scr. et del.* verisimile, *add.* visibile *sup. l. V* | Vitelo] Witelo *B*; Vitello *L* | 52a 10i] 5, 2^{a}, 10 *L*; 5^{a}, 4^{i} *V* 10 quandoque] *scr. et del.* quandoque *V* | sol] *sup.* quandoque *scr.* sol *sup. l. V* | est propter] *scr. et del.* est propter, *add.* potest(?) est *in mg., add.* propter *sup. l. V* | huiusmodi] huius *BF* 11 variabilem] variabillem *L* | transmutationem] transmutationem *corr. ex* mutationem *V* 12 Sicut] *post* Sicut *add. a. m.* alia(?) cum(?) *sup. l. V* | maris] *sup.* maris(?) *add.* maiores *sup. l. V* 13–12 continue] contingentie *V* 13 movetur] *scr. et del.* moto(?), *add.* movetur *sup. l. V* | Verumtamen] Verumptamen *B* 14 apparentie] apparere *L* 16 etiam] *om. F; post* etiam *scr. et del.* per(?) *add.* quod *sup. l. V* 16–17 experientie] experigentie *V; sup.* experigentie *add. a. m.* apparentie *sup. l. V* 17 altum] altus(?) [*vel* alter(?)] *L* 18 sicut...Parisiensi] *om. V* | ecclesia] eclesia *F* | Parisiensi] Parisii(?) *B*; Parisienssi *L* | vacillare] vacilare *F*; vaccillare *L*

8 Witelo (1572, rpt. 1972), *Perspectiva*, X, sec. 55, pp. 449–450. 13 Aristotle, *De caelo*, Bk. II, ch. 8 (290a15–25).

density, and the obliquity of the incident ray at the point of refraction, there results a larger or smaller refraction. From this, it is clear that something which is moved regularly can appear to sparkle. [This sparkling is] due to a change in local motion or an alteration in quality, for example, by rarefaction or condensation around the point of refraction; just as when something appears to glimmer in the sunlight when seen through smoke. And similarly, if the eye were in water whose surface is wavering, the sun or any other object will seem to vacillate. Therefore, Witelo says in [his *Perspectiva*, Book] x, [section] 52, that this is the reason that some of the stars appear to twinkle.[viii]

And similarly, at sunrise, the sun sometimes [scintillates] due to such variable refraction. [This variable refraction is] because of changes [in the region of the] upper air or fire around the point of refraction – much like the surface of the sea is continually moved. Nevertheless, Aristotle, in [Book] II [of his] *De caelo*, says that sometimes the cause of such an appearance is in the eye, due to the motion of spirits [in the eye?] and the weakness of vision.[139]

[Corollary XIII] Thirteenth: The cause of the same experience is also clear [from this]: when the sun shines through a high aperture above the pavement, such as in a Parisian church,[140] then that light

[139] Aristotle, *De caelo*, Bk. II, ch. 8 (290a15–25). For the Latin *De caelo*, see Aristotle, in Thomas Aquinas' *In Aristotelis Libros "De Caelo et Mundo," "De Generatione et Corruptione," "Meteorologicorum" Expositio, cum Textu ex Recensione Leonina*, ed. Fr. Raymund M. Spiazzi (Rome: Marietti, 1952), Bk. II, ch. 8, p. 200.In this passage, Aristotle appears to speak as if he held the extramissionist view of visual rays emanating from the eye. He firmly opposes such a view elsewhere, but here he states that the distant fixed stars twinkle because of the weakening and quivering of our vision, while the planets, being closer, do not twinkle.It is uncertain what Oresme meant to attribute to Aristotle by the phrase "the motion of airs/spirits," since this is not explicit in Aristotle. Perhaps, Oresme was implying either that some sort of Galenic spiritual virtues of the eye could waver and cause twinkling, or that the motion of the intermediate airs themselves caused it.

[140] Another strong indication that this was composed in Paris, for a Parisian audience. J.L. Heilbron has written an excellent book on the use of apertures in the ceilings of cathedrals as "solar observatories," in which a shaft of light falls upon a meridian line on the cathedral floor. Among other things, these solar observatories had the practical merit of helping determine the dating of Easter and giving accurate local time. Though he does mention one such aperture in the Parisian cathedral of St. Sulpice, all of his examples come from the early modern period (including St. Sulpice) and none suggests using the apertures for weather prediction. J.L. Heilbron, *The Sun in the Church: Cathedrals as Solar Observatories* (Cambridge, Mass.: Harvard University Press, 1999). Whether Oresme is making an oblique reference to such a "solar observatory" or merely a hole in the ceiling is unclear.

ac si sol discontinue moveretur, et quasi titubando vel tremendo. Et causa huius est variatio huius fractionis propter ipsius medii transmutationem.

Ideo, forte quia iste motus fit una vice uno modo, et alia ali-
B fol. 39v ter, | inde posset coniecturari de qualitate aeris, et pronosticari de tranquillitate vel tempestate futura. Quia, secundum ARISTOTELEM primo M e t h e o r o r u m, aer per prius alteratur superius, et ibi attingit primo actio stellarum non impedita.

[Corollarium XIV] Quatuordecimo, dico quod, per huiusmodi transmutationem medii, possibile esset apparere quod sol staret,
F fol. 41r sive quiesceret. Et consimiliter | eius umbra. Et quod dies artificialis prolongaretur plus solito, aut quod retrocederet et quod eius umbra reverteretur pluribus lineis sive punctis. Aut quod velocius moveretur quam solebat, et abbreviaretur dies, vel quod moveretur tardius, seu irregularius. Et consimiliter, de luna et de aliis stellis.

Quod patet natura aliquando per reflexionem, ut in speculo vel in aqua, res quiescens apparet moveri, et res mota quiescere, aut moveri tardius vel velocius, aut e contrario quam moveretur. Et hec fuerit propter variationem reflexionis. Et eodem modo, potest contingere per variationem fractionis. Unde, oculo existenti in aqua sol aliquando apparet quiescere sive retrocedere et variabiliter
L fol. 54v moveri | propter motum aque circa superficiem.

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1 et] etiam *V* | quasi] quod *V* 4 iste] ille *V* | uno] una *LV; scr. et del.* una, *add. a. m.* una modo *sup. l. V* | modo] *om. V* | alia] *post* alia *add.* vice *mg. V* 5 inde] *scr. et del.* inde, *add. a. m.* tamen *sup. l. V* 7 Metheororum] M e t h o r o r u m *B*; M e t h a r o r u m *FL* | attingit] acidit *F* 8 impedita] impendita *L* 9 per] *scr. et del.* propter, *add. (a. m.?)* per *sup. l. V* | huiusmodi] huius *F* 10 medii] medium *V* 11 quiesceret] quiessceret *F* | Et consimiliter] Et consimiliter *rep. in proximo folio F* | consimiliter] similiter *V* | artificialis] accidentalis(?) *F* 12 prolongaretur] prolongetur *L* | quod] *post* quod *add.* sol *V* | retrocederet] retro cederet *F*; retro cederet *corr. ex* retro caderet *V* 13 reverteretur] revertereretur *L* | pluribus] *sup.* pluribus *add. a. m.* aliquis(?) *sup. l. V* 14 abbreviaretur] abreviaretur *FL* | quod] post *V* | seu] sive *V* 15 irregularius] *scr. et del.* irrem(?)arius(?), *add.* irregularius *sup. l. V* | de] *om. BF* 16 Quod] Quia *L* | natura] naturam *L* | reflexionem] reflectionem *L* | ut] aut *V* 17 vel] aut *V* | quiescens] quiesscens *F* | quiescere] quiesscere *F* 18 vel] aut *V* | e contrario] *sup.* e contrario *add. a. m.* e converso *V* | moveretur] movetur *L*; moto(?) *V; sup.* moto(?) *add. a. m.* moveretur *sup. l. V* 19 fuerit] factum(?) *L* 20 per] propter *F* | existenti] existentem *F*; existente *V* 21 aliquando apparet] apparet aliquando *B* | quiescere] quiesscere *F* | sive] seu *B* | retrocedere] recedere *V, sup.* recedere *add. a. m.* retrocedere *sup. l. V* | variabiliter] *sup.* variabiliter *scr. (a. m.?)* vacil-(?) *F*; vacillabiliter *V* 22 superficiem] superiorem(?) *L*

6 ARISTOTLE, *Meteorologia*, Bk. I, ch. 3 (341a13–341a38).

[shining on the floor] appears to quiver, as if the sun were moving discontinuously, and wavering or trembling. And the cause of this is the refraction's variation due to changes in the medium itself.

Thus, perhaps because this motion occurs in one way at one time, and in another way at another, the quality of air could be surmised from this, and it could be used to predict a future calm or storm.[141] For, according to the first [Book] of Aristotle's *Meteorology*, the upper air is altered first, and the unimpeded action of the stars first occurs there.[142]

[Corollary XIV] Fourteenth: I say that, through such a change of medium, it may be possible for the sun to appear to stand still, or remain in place.[143] And likewise for its shadow. And [it may be possible for] the artificial day[144] [to appear] more prolonged than usual, or that [the sun might appear to] go backwards and that its shadows might be turned back by more lines or points. Or [the sun may appear to] be moved more swiftly than usual and the day be shorter, or it might [appear to] be moved more slowly, or irregularly. And so likewise concerning the moon and the other stars.[145]

This is sometimes apparent in nature due to reflection (such as in a mirror, or in water), [when] a thing at rest appears to be moved, and a thing in motion to be at rest, or [it appears] to be moved more slowly or more quickly, or in the opposite [direction] than it really is moved. And this occurs because of variation in reflection. And in the same way, it can occur through variation in refraction. Thus, for an observer under water, the sun sometimes appears to be at rest or go backwards and move in various ways because of the motion of the water on the surface.

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[141] Using observations of atmospheric refraction to help predict the weather.

[142] I am uncertain, but Oresme is probably referring to Aristotle's explanation of how the sun generates heat in the sublunar region, even though it and the other celestial bodies are not hot themselves. Aristotle argues that motion can cause heat. And it is the sun's rapid motion that generates great heat, especially in the upper air. (The motion of the fixed stars is rapid too, but they are far off; while the moon is too slow to generate such heat.) Aristotle, *Meteorologia*, Bk. 1, ch. 3 (341a13–341a38).

[143] Though Oresme does not mention it directly, the miracle of the sun standing still immediately springs to mind – as it must have for his audience. The vocabulary used in the book of Joshua is very similar: "Stetit itaque sol in medio caeli." *Joshua* 10:12–13. Perhaps Oresme was even hinting at a naturalistic process used by God to bring about such a miraculous occurrence.

[144] That is, the artfully or scientifically deduced length of day.

[145] The moon, like the sun, stops in the Joshua miracle.

Ymo, in aerem, et quandoque fuerit tales refractiones vel reflexiones in nubibus, que faciunt solem apparere alibi quam sit. Et adhuc, preter verum solem quandoque apparet quod sint, duo alii propter huiusmodi reflexiones aut fractiones, et illi vocantur paralleli, ut patet 3º Metheororum. Igitur, propter huius fractionem, et, melius, propter reflexionem, possit apparere solis statio, ac etiam reversio. Et similiter, de umbra, et cetera prius dicta. Et in una regione vel patria non ubique, et naturaliter, et miraculose, si effectus talis esset nimis magnus.

Et, tamen, secundum communem usum loquendi, concedendum esset quod sol stetit, vel quod umbra reversa est, sicut dicitur quando est eclipsis, quod obscuratur et quod obtenebrescit. Et quandoque, propter interpositos vapores, dicitur rubeus, vel croceus, vel aliter coloratus, et quod "sol convertatur in tenebras et luna in sanguinem." Cum, tamen, secundum rei veritatem, in se non patitur coloris alterationem, nec lucis defectum. Unde, IOHANNES DAMASCENUS, in quodam Sermone, sol iste splendidus lucifluus sub lunari

1 Ymo] Immo *BF* | aerem] aere *FV* | et] met *F* | quandoque] aliquando *corr. ex* quando *V* 1–2 refractiones vel reflexiones] reflexiones sive fractiones *V* 2 in nubibus] in nubibus *rep. L* 3 preter] *scr. et del.* propter, *add. a. m.* preter *sup. l. V* | solem] solis *L* | quod] quam *L* | sint] sit *L* | duo] 2º *V* 4 propter] per *L; post* propter *scr. et del.* d- *F* | huiusmodi] huius *F* | reflexiones] *ante* reflexiones *scr. et del.* fractiones *L* | fractiones] refractiones *L* 4–5 paralleli] parelli *B*; paralelli *FL; scr. et del.* parallii(?), *add.* paralelli *sup. l. V* 5 Metheororum] Methororum *B*; Metharorum *F*; Methaurorum *L* | Igitur] Ergo *L* | huius] huiusmodi *V* | fractionem] fractiones *L* 7 reversio] reverssio *L; ante* reversio *add. a. m.* reverberatio(?) actio(?) *sup. l. V* | prius] primum *L* 8 patria] patriam(?) *F* | non] nisi *F* | et] est *V* | et] vel *V* 9 magnus] *post* magnus *scr. et del.* i- *L* 11 esset] est *V* | quod] *om. F* 12 eclipsis] *post* eclipsis *add.* solis(?) *sup. l. V* | quod] *post* quod *add.* sol *V* | et quod] *scr. et del.* et quod, *add. (a. m.?)* vel *sup. l. V* | obtenebrescit] obtenebresscit *F*; obtenebresit *L* 14 et quod] *scr. et del.* Et quod, *add. (a. m.?)* ex quo *sup. l. V* | convertatur] convertitur *V* 15 sanguinem] saguinem *V* | in…patitur] non patiatur in se *F* 16 coloris] *ante* coloris *scr. et del.* colorem *F; post* coloris *add.* variatatem seu *F* 17 iste] ille *V*

5 ARISTOTLE, *Meteorologia*, Bk. III, ch. 2 (371b18–372a21). 14 *Joel* 2:31. 16 JOHN DAMASCENE, *On the Assumption, Sermon I.*

Indeed, in the air, sometimes such refractions or reflections occur in the clouds, which make the sun appear elsewhere than it really is. Further, because of such reflections or refractions, there sometimes appear to be two other [suns] on either side of the true sun – and these are called "mock suns," as is clear in the third [Book] of the *Meteorology*.[146] Therefore, due to this [type of] refraction and, better, due to reflection, the sun can appear to stand still, or even go backwards. And similarly concerning [its] shadow, and the other things previously mentioned. And [likewise, this standing still or going backwards could occur] in one region or country and not everywhere. And [it could occur] naturally. Or [it could occur] miraculously, if [the effect] were too large.

And nevertheless, according to the common way of speaking, it may be granted that the sun has stood still, or that its shadow is "turned back," just as when there is an eclipse, [and the sun] is obscured and darkened. Sometimes, [the sun] is called red, or saffron, or some other color, because of the interposition of vapors, and that "the sun shall be turned to darkness, and the moon to blood."[147] Yet, in truth, the sun itself does not undergo a change in color, nor a lack of light. Hence John Damascene, in a certain Sermon, [says] that "the brilliant light-beaming sun – lying hidden

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[146] Mock suns (or "sun-dogs" as they are popularly called) are termed "perelii" in the medieval Latin translation of Aristotle's *Meteorology*. We still use a form of this term today to describe them technically as "22 degree parhelia". These mock suns are caused by refraction through ice-crystals present in the atmosphere, and they most commonly appear when the sun is near the horizon. Apparently, Oresme himself had seen these mock suns and reported this to his colleague Jean Buridan. (See the Introduction for further information on this exchange.)Aristotle explained them as due to reflection in the atmosphere. Aristotle, *Meteorologia*, Bk. III, ch. 2 (371b18–372a21). For the Latin, see Aristotle, *Meteorologia*, in Aquinas', *In Aristotelis Libros "De Caelo et Mundo," "De Generatione et Corruptione," "Meteorologicorum" Expositio*, ed. by Fr. Spiazzi (Rome: Marietti, 1952), Bk. III, ch. 2, pp. 617–618, 621. For a wonderful, modern description of these phenomena, see Robert Greenler's, *Rainbows, Halos, and Glories* (Cambridge: Cambridge University Press, 1980), pp. 26–32.

[147] A reference to the prophecy of *Joel* 2:31. In the New Testament, it is alluded to by Jesus (*Matthew* 24:29), quoted by Peter (*Acts* 2:20), and elaborated upon by John in *Revelation* 6:12.

corpore latens ad tempus videtur quodammodo deficere tamen ipse suo non privatur lumine habens in se perennem fontem luminis.

[Corollarium XV] Quindecim correlarium posset esse, scilicet, quod multa, licet non omnia, que apparent de motibus planetarum forte possent salvari, per talem fractionem, sine positione tot eccentricorum vel epiciclorum. Quia iam probatum est qualiter, propter hoc, regularis apparet irregularis, et eadem magnitudo et distantia maior et minor.

Et si obiciatur quia directiones retrogradationes planetarum et *L* fol. 55r similia fiunt certis temporibus | et determinatis, et non videtur verisimile quod aeris condensatio vel rarefactio, que est causa huiusmodi fractionis, fieret ita ordinate, cum sit de numero impressionum. De quibus, dicit ARISTOTELES primo Metheororum, quod fiunt "secundum naturam inordinatiorem quam ea que est primi elementi," scilicet, celi.

Fortassis responderetur quod illa que fiunt supra mediam aeris regionem ordinatius fiunt propter propinquitatem ad celum influens. Nec sunt ibi venti, aut turbines, vel huiusmodi impressiones cito variabiles, sed aer tranquillus, cuius signum est quod cometa,

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1 quodammodo] *scr. et del.* quodam, *add. (a. m.?)* quodammodo *sup. l. V* | deficere] defficere *L* | tamen] *post* tamen *add. a. m.* cum *sup. l. V* 2 privatur] privaretur *V* | perennem] perhennem *BLV* 3–208.10 Quindecim … verum] *om. FV*; Ed. note: The entire Corollary XV is omitted in both mss. *F* and *V*, and both misnumber Corollary XVI as 'XV'. The Florence ms., however, does supply Corollary XV at the end of the manuscript as a postscript found between the first and second variant endings. 3 correlarium … scilicet] *om. L* 5 talem] tallem *L* 5–6 eccentricorum] ecentricorum *B*; excentricorum *L* 7 apparet] *post* apparet *add.* et *B* 8 minor] brevior *L* 10 fiunt] fuerit *B* 11 quod] quia *L* | rarefactio] rarifactio *L* 12 fieret] fierent *L* | ita ordinate] inordinate *L* 13 Metheororum] Methororum *B*; Metharorum *L* 14 fiunt] fuerit *B* | inordinatiorem] inordinatore *L* 15 scilicet] *om. B* 16 Fortassis] Forte *L* | responderetur] respondetur *L* | illa] ista *L* | fiunt] fuerit *B* | supra] super *L* 17 fiunt] fuerit *B*

3 Ed. note: Corollary XV is lacking in both the Florence and the Vatican manuscripts — showing a close connection between them. It is supplied at the end of the Florence manuscript as a postscript — in what looks to be the same hand. This precedes the alternate manuscript ending supplied by the Florence manuscript, with Oresme's name mentioned. So perhaps the Florence scribe used two manuscripts to compile his work, the main one lacking cor. XV and a second one that supplied it, but not the alternate ending of the manuscript with Oresme's name, since that is in a different hand? At any rate, it seems that the Bruges and Lilly mss. are related in the same family here. Though the Bruges and Florence mss. are more nearly the same up to this point. 13 ARISTOTLE, *Meteorologia*, Bk. I, ch. 1 (338b1–339a1).

for a time behind the body of the moon – seems to be lacking in some way, but it itself is not deprived of light, for within itself it has a perpetual font of light."[148]

[Corollary xv] The fifteenth corollary could be this: That many (though not all) the appearances of the motions of the planets could be saved, perhaps, by this proposed [atmospheric] refraction without positing so many eccentrics and epicycles.[149] For it is already proven how, on account of this, regular [motion] appears irregular, and the same magnitude and distance [appear to be] larger or smaller.

One might object that the retrograde motions of the planets and the like have established and fixed times, and that it does not seem likely that the condensation or rarefaction of air, which is the cause of such [atmospheric] refraction, could become so orderly, since it is ranked among the atmospheric conditions. About this, Aristotle says in the first [Book] of the *Meteorology*, that "[the atmosphere] is more disorderly by nature than that of the first element," that is, of the heaven.[ix]

Perhaps one could respond that those [refractions] that occur above the middle region of [the sphere of] air are more orderly because they are nearer to the influencing heaven. Nor are winds, storms, or such swiftly varying atmospheric conditions present there,

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[148] Quoted from a series of sermons on the Assumption of Mary by the Greek Father, John Damascene. Mary Allies' translation from the Greek renders the passage this way: "Just as the glorious sun may be hidden momentarily by the opaque moon, it shows still though covered, and its rays illumine the darkness [165] since light belongs to its essence. It has in itself a perpetual source of light, or rather it is the source of light as God created it." See John Damascene's, *On the Assumption, Sermon I*, in his *St John Damascene on Holy Images (pros tous diaballontas tas hagias eikonas) Followed by Three Sermons on the Assumption (koimesis)*, tr. by Mary H. Allies (London: Thomas Baker, 1898), pp. 164–165.Damascene details his views on solar and lunar eclipses in Book two of his *Orthodox Faith*. See John Damascene's, *The Orthodox Faith*, in his *Saint John of Damascus: Writings*, tr. by Frederic H. Chase, Jr., The Fathers of the Church: A New Translation, 37 (New York: Fathers of the Church, Inc., 1958), Bk. II, ch. 7, pp. 220–221.

[149] Oresme is pushing the envelope of his theory by even suggesting that the retrograde motions of the planets may be explained by atmospheric refraction phenomena! This would "save" two things. It would save the perfect circular motion of the planets, and it would "save the phenomena", relegating their imperfect, irregular motion to the sublunar, atmospheric regions. Then, later in the corollary, he goes even further, suggesting that these refractions might take place in the ether itself, and thus partake of their majestic, regular motions. But after this exalted flight, he ends cautiously, saying, "I don't assert this, nor do I know if it is true."It is possible that this entire passage was too radical for some scribes, for corollary xv is lacking in the main text of two of the four extant manuscripts, *F* and *V*.

que est impressio superior. Et in loco ubi, iam, aer movetur cum celo, est diuturne durationis, et motus eius est quasi uniformis. Et forte corrumpitur, propter descensum ad inferiorem ordinationem.

Et huiusmodi fractio que nos decipit circa stellas forsitam est adhuc superior, in ethere propinquo celo, recipiente influentiam libere, sine impedimento, et translato circulariter. Cum ipso celo *B* fol. 40^{r} motu | ita regulato, tam rato ordine moderato, et sic temporibus certis, et accedentibus planetis ad determinata loca celi. Cum aliis circumstantiis nobis ignotis, forte potest per fractiones predictas talis diversitas apparere. Hec, tamen, non assero, nec scio si est verum.

[Corollarium XVI] Sextodecimo, dico, quod si ALHACEN in 7^{o} capitulo 5^{o} dicat verum, quod quando visio fit per reflexionem, ut in speculo, aut per fractionem, sicut in proposito, tunc res non videtur, sed eius ymago. Statim sequitur quod numquam vidimus solem, nec etiam lunam, nec aliquem planetam, nec etiam omnino *L* fol. 55^{v} stellam, nisi dum fuerit supra zenith, sed tamen ym|agines. Ymo, quod plus est ex solutione primi dubii, cum isto sequitur quod rare *V* fol. 50^{r} aut numquam aliqua res videtur, | sed semper ymago, quia ut in pluribus est diformitas medii, que tollit rectitudinem perfectam radii visualis. Et, secundum ALHACEN, res non videtur, nisi videatur recte, sed tantum ymago.

[Opinor] Opinor, tamen, quod si est aliqua talis ymago vel species rei vise, huiusmodi species vel ymago omnino est invisibilis, sed mediate ipsa res videtur quandoque, tamen, secundum aspectum

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1 impressio] imprenssio *L* | movetur] moratur *L* 3 descensum] descenssum *L* 4 huiusmodi] huius *L* | decipit] deccipit *L* 5 recipiente] reccipiente *L* 7 regulato] *post* regulato *add.* et *B* 8 certis] *om. L* 10 diversitas] diverssitas *L* | nec scio] nescio *L* 11 Sextodecimo] Quindecimo *FV* | Alhacen] ALASEN *F*; ALACEN *V* 12 5o] hoc *F* | fit] fit *alter. in* fiat *(a. m.?), add.* fit *sup. l. V* 13 sicut] ut *L* | res] res *rep. F* 14 ymago] immago *F; scr. et del.* quod magis(?), *add.* ymago *sup. l. V* | vidimus] vidimus *alter. in* videmus(?) *a. m. V* 15 nec etiam] vel *F* | aliquem] aliquam *alter. in* aliquem *a. m. V; post* aliquam *add.* aliam, *et* aliam *alter. in* alium *a. m. V* | nec] neque *V* | etiam omnino] *om. V* 16 fuerit] fuit *FL*; sint *V* | zenith] cenith *BF* | ymagines] immagines *F*; ymaginens(?) *L* | Ymo] Immo *BF* 17 isto] illo *V* | rare] vix *V* 18 aut] vel *V* | videtur] videtur *corr. ex* dividetur *V* | semper] *post* semper *scr. et del.* est *V* | ymago] immago *F* | ut] *ante* ut *scr. et del.* u- *F* 19 diformitas] defformitas *L* | perfectam] *post* perfectam *add.* medii *F* 20 visualis] *ante* visualis *scr. et del.* vide- *F* | secundum] *ante* secundum *scr. et del.* secunduma(?) *F* | Alhacen] AHLACEN *B*; ALASEN *F*; ALACEN *V* | recte] recte *rep. et del. F* 21 sed] secundum *L* 22 ymago] immago *F* | Opinor] Oppinor *L* | ymago] immago *F* 23 species] sensus *V* | huiusmodi] huius *FL* | species] sensus *V* | ymago] immago *F; post* ymago *add.* re(?) *sup. l. V* | omnino] non *L; scr. et del.* omnino(?), *add.* non *sup. l. V* 24 res] re *V*

11 ALHACEN (1572, rpt. 1972), *De aspectibus*, VII, ch. 5, secs. 17–19, pp. 253–256.

rather [it is] calm air, whose sign is the comet, which is a higher atmospheric phenomenon. Now, in such a place, the air is moved along with the heaven, thus it has a long duration and its motion is nearly uniform. And perhaps [this motion] is corrupted because of its descent into the lower orders.

And perhaps this refraction which deceives us concerning the stars is even higher, in the ether near the heaven. Thus it receives its influence freely, without hindrance, and is moved circularly. Since [it takes] to itself the regulated motion of the heaven, [it is] conferred with a moderated order, and thus [it has fixed], established times [in which it] befalls the planets at a determined place in the heaven. Since other circumstances are unknown to us, perhaps such diversity can appear due to these types of refractions. However, I do not assert this, nor do I know if it is true.

[Corollary XVI] Sixteenth, I say that if what Alhacen says in [his *De aspectibus*, Book] VII, chapter 5 is true, then when an observation occurs through reflection (as in a mirror) or through refraction (as in this proposition), then the object [itself] is not seen, but [only] its image.[150] It immediately follows that we never see the sun, the moon, a planet, or any star at all, but only [their] images – except when they are over the zenith. Indeed, this follows from the solution of the first doubt, since in many cases there is an irregularity[151] of the medium [through which an object is seen] which destroys the perfect straightness of the visual ray. And thus [we] hardly ever see any object [itself], but always [its] image.[152] And, according to Alhacen, unless an object is seen directly, it will only be seen as an image.

[Oresme's Opinion] I think, however, that if there is some such image or species of a thing seen, such a species or image is entirely invisible, but [I think] the object, however, is itself sometimes seen indirectly[153] by rectilinear sight or through a straight line, or some-

[150] Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 5, secs. 17–19, pp. 253–256.
[151] I.e., difformities.
[152] This is a rather profound doubt of sensual experience, but Oresme has arrived at this conclusion through both empirical and rational means.
[153] Literally, "mediately" or "by means of".

rectum vel per lineam rectam, sive rectam quandoque etiam fracte sive reflexe. Et quo ad hoc est simpliciter idem iudicium de fractione et reflexione, quia si res non videtur sed ymago, quando est visio reflexe neque, similiter, quando fit fracte.

Cum aut ita sit quod omne corpus opacum sit natum reflectere, et hoc dupliciter, secundum quod habetur in 3° M e t h e o r o r u m. [*F* fol. 41v] Unde, quoddam est opacum politum quod | per reflexionem simul representat colorem et figuram. Aliud asperum et non planum quod tantummodo representat colorem aut lucem, non, tamen, figuram, propter divariationem radiorum qui non consimiliter reflectuntur, sed propter asperitatem disperguntur huc et illuc. Et, similiter, quandoque in fractione propter talem variationem, fallitur visus de figura rei vise.

Sic igitur, omne opacum visibile reflectit lucem corporis luminosi in cuius lumine conspicitur. Et idem, est quod aspiciendo quod cumque visibile, simul videmus reflexe lucem et corpus luminosum in cuius lumine videtur. Propter quod, bene dicunt ALHACEN et VITELO quod tantum sunt duo visibilia per se, scilicet, lux et color. Et intelligo per lucem non qualitatem que est in medio invisibili, sicut [*L* fol. 56r] in | aere potentia, quia talis omnino est invisibilis, sed qualitatem que est subiective in sole vel alio luminoso que proprie vocatur lux.

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1 vel] *om. F* | sive] sive *rep. et del. F* | rectam] *scr. et del.* ratione, *add.* rectam *sup. l. V* | fracte] *scr. et del.* rectam(?), *add.* fracte *sup. l. V* 2 sive] seu *V* | Et] *scr. et del.* Ex, *add. (a. m.?)* Et *sup. l. V* | ad] quid *F* | idem iudicium] iudicium idem *V* | iudicium] indicium *L; post* indicium *add.* et *L* | fractione] refractione *F* 3–4 quia … reflexe] *om. L* 3 ymago] immago *F* 4 reflexe] refle[xe] *F, foramen [a hole] in ms.* | neque] neque *rep. et del. F* 5 aut] autem *FV* | omne] om[ne] *F, foramen [a hole] in ms.* | natum] nature *L* 6 dupliciter] *ante* dupliciter *scr. et del.* dupl- *F* | secundum quod] ut *V* | in] *om. V* | Metheororum] M e t h o r o r u m *B*; M e t h a r o r u m *F*; M e t h a u r o r u m *L* 7 quoddam] quodam *L* | quod] *post* quod *scr. et del.* re-(?) *F*; quod *rep. in proximo folio F* 8 representat] reprensentat *L* | Aliud] Aliquod *L; ante* Aliud *add.* Et *F* 11 et] *om. L* 12 fallitur] falitur *L*; fallit *V* 15 lumine] luminatione *L* | idem] inde *BF* | aspiciendo] *scr. et del.* asperitendo, *add.* aspiciendo *sup. l. F* 17 lumine] luminatione *L* | videtur] *post* videtur *scr. et del.* videtur et *V* | quod] hoc *V* | Alhacen] ALASEN *F*; ALACEN *V* 18 Vitelo] WITELO *B*; VITELLO *L* | sunt duo] duo sunt *V* | visibilia] visibiliam *BF* | scilicet] verum *V* 19 intelligo] intellige *L; add. a. m.* et intelligo *in mg. V* | non] *scr. et del.* una, *add. a. m.* nunc *sup. l. V* | que] *sup.* que *add. a. m.* quantem *sup. l. V* 20 potentia] ponitur *L*; posito *corr. ex* ponitur(?) *V* | quia] quod *L* | sed] secundum *L*; sed *corr. ex* secundum *V*

6 ARISTOTLE, *Meteorologia*, Bk. III, ch. 4 (373a35–373b35). 17 ALHACEN (1572, rpt. 1972), *De aspectibus*, II, ch. 2, sec. 18, p. 35; Witelo (1572, rpt. 1972), *Perspectiva*, III, sec. 59.

times even along a straight [line] by refraction or reflection. And with respect to this, I hold absolutely the same opinion concerning refraction and reflection, for if the object is not seen but the image [is] when vision is reflected, so also in the same way, [the object is not seen but the image is] when refraction occurs.

It seems that it is the nature of every opaque body to reflect, and this in two ways, according to the third [book] of [Aristotle's] *Meteorology*.[x] Hence, when an opaque [body] is polished, [then] its reflection shows both color and shape at the same time. [While] another [opaque body that is] rough and not flat only shows color or light, but not shape; this is due to the diversity of rays which are not reflected in the same direction, but because of its roughness are scattered here and there. And, in the same way, [this] sometimes [occurs] in refraction because of such variation, [thus our] vision is deceived about the shape of a thing seen.

Therefore, every opaque visible [object] reflects light [*lux*] from a luminous body in whose light [*lumen*] it is observed. Likewise, when looking at a visible [object] by reflection, we simultaneously see the light [*lux*] and the luminous body in whose light [*lumen*] it is seen. Because of this, Alhacen and Witelo correctly say that there are only two visible [things] *per se*: light and color.[154] And I understand by light [*lux*] not a quality that is in an invisible medium, such as potentially in air, since all such [air] is absolutely invisible, but [I understand light to be] a quality that is subjectively in the sun or another luminous [body] which is properly called light [*lux*].[xi]

[154] Alhacen states: "Therefore, that which light perceives by pure sensation is light *qua* light and colour *qua* colour. But nothing of what is visible, apart from light and colour, can be perceived by pure sensation, but only by discernment, inference and recognition, in addition to sensation; for all visible properties that are perceptible by discernment and inference can be perceived only by discerning the properties in the sensed form." (Sabra's translation, p. 142). Alhacen (1572, rpt. 1972), *De aspectibus*, II, ch. 2, sec. 18, p. 35. For the English translation, see Alhacen (1989), *[De aspectibus]. The Optics of Ibn Al-Haytham. Books I–III, On direct vision.* trans. by A.I. Sabra, Book II, 3, para. 52, vol. 1, pp. 142–143. Witelo (1572, rpt. 1972), *Perspectiva*, III, sec. 59.

Et cum hoc, quod lux est per se visibilis, ut per se distinguitur contra per accidens. Et etiam visibilis per se id est solitarie aut aspiciendo corpus luminosum directe, aut per reflexionem que fieret a corpore nullum habente colorem. Color vero quia non potest videri nisi in lumine, ideo, numquam videtur per se, id est solitarie, quin semper cum hoc videatur lux reflexe.

Illud, ergo, quod per se videmus est aggregatum ex colore et luce, nec est possibile videre colorem distincte, sed semper confuse. Sicut etiam dum respicimus solem mediate vitro, simul videmus colorem vitri cum luce solis. Et quando aspicimus mediantibus pluribus vitris diversorum colorum, apparet nobis quasi color medius sive mixtus. Similiter, quando respicimus parietem in radio solis transeunte per vitrum coloratum, simul videmus confuse colorem parietis et vitri medii et lucem solis.

Sunt, igitur, tria propter que diversificatur apparentia visionis, scilicet, mutatio coloris corporis obiecti, alteratio corporis medii per quod transit lumen, et variatio lucis. Primum manifestum est. Et secundum, similiter, patet ad sensum. Unde, si esset unus orbis celi rubeus, omnia aliter apparerent nobis colorata quam nunc. Patet etiam tertium, quia aliqua videntur ad lucem solis unius coloris, et in *V* fol. 50v lumine lune apparent aliter colorata. Et hoc est quia reflexe videmus | lucem corporis luminosi.

1 est] *scr. et del.* sic, *add. a. m.* est *sup. l. V* 2 Et] *post* Et *add. et del.* con- *F* | etiam visibilis] est contra visibilis *F*; est invisibilis *V* 3 que] *scr. et del.* que, *add. (a. m.?)* quod *sup. l. V* 4 non] *sup.* non *add.* numquam *sup. l. V* 5 numquam] nunquam *L* | quin] *ante* quin *scr. et del.* quod *F; scr. et del.* quando, *add.* quin *sup. l. V* 6 semper] *ante* semper *add.* cum(?) *F* 7 ergo] igitur *V* | quod] *om. L* | videmus] videamus *L* | aggregatum] agregatum *F* | ex] *post* ex *add. et del.* l- *F* | luce] *post* luce *add. a. m. in mg.* nec est possibile colorem videre distincte sed semper confuse. Sicut etiam dum respicimus solem mediate vitro, simul videmus confuse colorem parietis et vitri medii et lucem solis. Sunt igitur tria per contra diversificatur, etc. *V* 8 videre colorem] *om. V; post* possibile *add. (a. m.?)* colorem videre *sup. l. V* 9 respicimus] aspicimus *F* | vitro] vitro *corr. in mg. ex* vitreo *B; post* vitro *add. et del. a. m. in mg.* simul videmus confuse colorem parietes et vitri medii et lucem solis *V* | videmus] *post* videmus *add. a. m.* confuse *sup. l. V* | colorem] *post* colorem *add. a. m.* perietis et *sup. l. V* 10 aspicimus] *sup.* aspicimus *add. a. m.* videmus *sup. l. V* 11 quasi] quod *V* 12 transeunte] transeuntem *F*; transeunte *corr. ex* transeuntem *L* 13 simul] *ante* simul *rep. et del.* simul vi- *F* | videmus] videus *V* 15 igitur] ergo *V* | propter] propter *alter. in* per *a. m. V* | diversificatur] diverssificatur *L* 16 corporis] *om. L* | corporis] coloris *V* 17 quod] quos *V* 18 sensum] senssum *L* 19 rubeus] *post* rubeus *add. et del.* i- *L* | aliter … nobis] nobis apparerent aliter *L*; apparent nobis aliter *FV* 20 quia] quod *V* | unius coloris] *om. V* 21 apparent] *om. L* | hoc est] etiam *L*

And with this, light [*lux*] is visible *per se* – when "*per se*" is distinguished from "*per accidens*." And light [*lux*] is also visible by itself (*per se*), either [when] looking at a luminous body directly, or by reflection occurring from a body that has no color.[155] Moreover, since color cannot be seen without light [*lumen*], it is never seen "*per se*", that is solitarily, but it is always seen with light [*lux*] by reflection.[156]

Therefore, that which we see *per se* is an aggregate of color and light [*lux*], nor is it possible to see a color distinctly, but only confusedly. Just as when we look at the sun through glass, we see the color of the glass together with the light [*lux*] of the sun. And when we look through several [pieces of] glass of various colors, it appears to us as if the color [was] intermediate or mixed. In the same way, when we look at a wall in the sun's rays [when they are] passing through colored glass, we see the color of the wall, the [color] of the glass, and the light [*lux*] of the sun confusedly [i.e., all mixed together].

Therefore, there are three ways in which visual phenomena are changed, namely, changing the color of the object, altering the medium through which the light [*lumen*] passes, and varying the light [*lux*]. The first is clear. Likewise, the second is obvious to the senses. Whence, if one of the heavenly spheres were red, everything would appear a different color to us than it does now. The third is also clear, since things are seen by the light [*lux*] of the sun as one color, and in the light [*lumen*] of the moon they appear another color. And this is because we are seeing the light [*lux*] of a luminous body by reflection.[157]

155 Oresme also discusses colorless reflecting surfaces in his *Questiones super quatuor libros meteororum*, in McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, pp. 222–225, Bk. III, Q. 15, lines 277–290.

156 In discussing the rainbow, Oresme likewise argues that color cannot be seen without light [*lumen*] in his *Questiones super quatuor libros meteororum*, in McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, pp. 264–265, Bk. III, Q. 20, lines 60–70.

157 That is, the light of the moon is reflected light, therefore it is *lumen* rather than *lux*.

Sequitur, itaque, quod numquam videmus aliquid in lumine solis, quin cum hoc per lucem videamus et solem, aut quod num- [*L* fol. 56^{v} *B* fol. 40^{v}] quam vidimus ipsum, nec etiam | lunam. | Et hec ultima pars disiunctive, sequitur ex dictis ALHACEN,ut prius est ostensum.

[Ad rationes] Ad auctoritatem ALHACEN in principio questionis adductam, quando dicit quod stelle, in maiori parte, comprehenduntur in suis locis, non in suis magnitudinibus. Patet statim, quod si, per hoc, intenderet excludere deceptionem de qua dictum est, ipse contradiceret sibi ipsi. Ideo, ob ipsius reverentiam, potest dici quod volebat ut non sit tanta deceptio circa loca stellarum, sicut [*F* fol. 42^{r}] circa magnitudines | earundem, quia etiam stella supra zenith comprehenditur proprie in suo loco, non est autem ita de magnitudine. Et cum hoc stella videtur inter illas inter quas existit et in eadem constellatione vel ymagine celi in qua est. Et hoc sufficit ne concedamus dicta ipsius repugnare.

1 quod] quod *corr ex.* qua(?) *L* | videmus aliquid] aliquid videmus *V* 2 quin] *scr. et del.* quando, *add.* quin *sup. l. V* 2–3 numquam] nunquam *L* 3 vidimus] *scr. et del.* videmus(?), *add. a. m.* vidamus(?) *sup. l. V* | lunam] *post* lunam *add.* etc. *B* 3–4 disiunctive] diquiuntive(?) *F; scr. et del.* disiunctive, *add. a. m.* distincte *sup. l. V* 4 Alhacen] ALASEN *F*; ALACEN *V* | ostensum] ostenssum *L; post* ostensum *add.* est *F* 5 Ad] *ante* Ad *add.* Tunc *sup. l. V* | Alhacen] ALASEN *F*; ALACEN *V* | principio] prima *V; post* prima *add.* parte *V* | questionis] conclusionis *L* 8 excludere] concludere *V* | deceptionem] decceptionem *L* 9 ipsi] *om. L* | reverentiam] *post* reverentiam *scr. et del.* ipsius *V* 10 ut] *scr. et del.* ut, *add. a. m.* dicere quod *sup. l. V* 11–15 earundem … repugnare] *rep. in F2 on fol. 43^r^*; Ed. note: This second ending given in the Florence ms. begins at the same point as the beginning of 42^{r}. That is, it is obvious that the editing scribe decided to begin this added ending so that it would be easier for the reader to know where it began. The reader could turn from fol. 41^{v} to 43^{r} and read it fluently. Perhaps he even had in mind the possibility of excising fol. 42 from the manuscript altogether (thus he would need to leave fol. 42^{v} blank. 11 quia] quia *alter. in* quod *a. m.(?) V* | etiam] *om. V* | zenith] cenith *BF F2* 12 proprie in suo loco] proprie in suo loco *del. a. m., et add. a. m.* in prope suo loco, sed non in magnitudine, et sic finitur(?) *sup. l. V* | suo loco] loco suo *B* | est autem] autem est *V* 13 cum] *om. L* | stella] *post* stella *add.* non *FV* | videtur] videatur *V* 14 ymagine] immaginem *F*; ymaginatione *V* | qua] contra *F2* | sufficit] suificint(?) *F* | concedamus] videamus *L* 15 dicta] dicta *del. a. m. et add.* dictis *sup. l. V*

4 ALHACEN (1572, rpt. 1972), *De aspectibus,* II, ch. 2, sec. 18, p. 35. 5 ALHACEN (1572, rpt. 1972), *De aspectibus,* VII, ch. 7, sec. 51, p. 278.

It follows, therefore, that we never see anything in the light [*lumen*] of the sun, unless we see it by *lux* and the sun, and that we have never seen the sun, nor the moon either. And when separated off, this last part follows from what has been said by Alhacen, as was previously shown.[158]

[In Response to the Initial Argument] [Let me give a response] to the authority of Alhacen cited at the very beginning of this question, when he says that "the stars, for the most part, are perceived in their places, but they are not always perceived in their correct size."[159] It is immediately clear that if he intended by this to exclude deception from what was said, he would be contradicting himself. Therefore, out of respect for him, one can say that his intention [in this passage] was that there would not be as large a deception concerning the place of the stars as [there would be] concerning their magnitudes, for a star over the zenith is actually perceived, properly speaking, in its place, but it is not so concerning its magnitude. For this star is seen among those [stars] with which it exists and in the same constellation or pattern of the sky in which it truly is. And this is sufficient to keep up from conceding that he is being inconsistent.

[158] Oresme cites Alhacen above as saying that there are only two visible [things] *per se*: light and color. Therefore we do not see anything itself *per se*, including the sun and moon. Alhacen (1572, rpt. 1972), *De aspectibus*, II, ch. 2, sec. 18, p. 35.

[159] This refers back to the very beginning of this treatise, where Oresme asks the question: "Whether the Stars Truly Are Where They Appear To Be." In the typical *quaestiones* format, scholastics would put forward arguments that they disagree with first, and then, at the very end of the question, they would answer these objections one by one. In the *De visione*, however, this is merely done *pro forma*, for Oresme puts forward only one such argument against his own view, and it is an obvious straw-man. This work, therefore, is really more of a treatise than a *quaestio*, just as the scribe of the Florence manuscript described it in his explicit: "Explicit N. Orem, etc. De visione stellarum tractatus brevis." The original opposing argument stated: Yes, the stars truly are where they appear to be, "by the authority of Alhacen, who in the seventh book of the *De aspectibus* says, 'Therefore, I say that the stars, for the most part, are perceived in their places, but they are not always perceived in their correct size.' *De visione stellarum*, Bk. I, 80:4–7. Cf. Alhacen (1572, rpt. 1972), *De aspectibus*, VII, ch. 7, sec. 51, p. 278. In this section of his work, Alhacen discusses why some stars appear larger on the horizon than at mid-heaven.

Hec pauca dicta sunt ad excitandum mentes iuvenum in speculatione rerum nobilium. Et cum humili subiectione correctione REVERENDORUM MAGISTRORUM huius excellentissime UNIVERSITATIS PARISIUS, et precipue quo ad istud venerabilium doctorum facultatis artium collegium, in quibus istis malis temporibus, tanquam in pretiosis vasculis, custoditur phylosophie margarita, quorum doctrina plus cunctis lucida tanto quanto splendidior quam cetera sydera fulget lucifer, et quanto quam lucifer aurea phebe.

[Explicits:]

[*B*:] Explicit feliciter.

[*F1 (f. 42*[r]*)*:] Explicit feliciter. Deo gratias.

[*F2 (f. 43*[r]*)*:] Explicit N. Orem, etc. De visione stellarum tractatus brevis.

[*L*:] Deo gratias. Amen. Ego Franciscus Sanuto scripssi in plebe sacis, 1465.

[*V*:] Et sic sit finis istius questionis. Amen.

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1 excitandum] determinandum *V; post* excitandum *scr. et del.* m-(?) *F* 2–8 Et … phebe] *om. L* 4 ad] *post* ad *add.* hoc *FL; post* ad *add. et del.* hoc *B* | istud] istuum (?) *F* | facultatis] FACULTATUM *F* 5 artium] ARTUUM *F* | collegium] *om. BF* | istis] *post* istis *add.* et *V* | malis] in aliis *V* 6 vasculis] vasis *V* 7 sydera] sidera *F* 8 fulget] sulget *V* | lucifer] *ante* lucifer *scr. et del.* luc- *F* | lucifer] iupiter *V* 11 Explicit feliciter Deo gratias] *post* gratias *add.* Alium correlarium post quatuordecimo [i.e., the 'Quindecim correlarium' omitted above] posset, scilicet, quod multa licet non omnia que apparent de motibus planetarum forte possent salvari per talem fractionem sine positione tot excentricorum vel epiciclorum quia iam probatum est qualiter regularis et irregularis et eadem magnitudo et distantia maior et minor. Et si obiceretur quia directiones retrogradationes planetarum et similia fiunt certis temporibus et determinatis et non videtur verisimile, quia aeris condempsatio vel refractio que est causa huiusmodi fractionis fierent ita ordinate cum sint de numero impressionum. De quibus dicit ARISTOTELES primo Methaurorum quod fuerit "secundum naturam inordinatiorem quem eam que est primi elementi," scilicet, celi. Fortasse respondetur quod illa que fuerit supra mediam regionem aeris ordinatius fuerit propter propinquitatem ad celum influens. Nec sunt ibi venti aut turbines vel huiusmodi impressiones ceto variabiles, sed aer tranquillus cuius signum est quod cometa que est impressio superior. Et in loco ubi iam aer movetur cum celo est diuturne durationis et motus eius est quasi uniformis. Et forte arguitur, propter descensum ad inferiorem ordinationem. Et huiusmodi fractio que nos decipit circa stellas forsitam est adhuc superior in ethere propinquo celo recipiente influentiam libere sine impedimento et translato circulariter. Cum ipso celo motu ita regulato, tam rato ordine moderato et sic temporibus certis et accedentibus planetis ad loca determinata celi. Cum aliis circumstantiis nobis ignotis, forte potest per fractiones predictas talis diversitas apparere. Hec tamen non assero nec scio si est verum.

These few things are said in order to excite the minds of young men to speculate on noble things.[160] And with humble subjection to the correction of the reverend Masters of this most excellent University of Paris,[xii] and especially to that of the venerable doctors of the faculty of the college of arts, in whom in these evil times, as if in precious vessels, is guarded the pearl of philosophy, whose teaching is more brilliant than all others, just as the morning star [*Lucifer*] is more splendid than all the constellations, and the golden moon [*Phoebe*] is [more splendid] than the morning star itself.[161]

[Explicits:]

[B:] Happily, it is finished.
[F1 (fol. 42r):] Happily, it is finished. Thanks be to God.
[F2 (fol. 43r):] Here ends the brief treatise of N. Orem, etc., "On Observing the Stars."
[L:] Thanks be to God. Amen. I, Franciscus Sanuto, copied this in Plebe Sacis, 1465.
[V:] And so ends this question. Amen.

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[160] In the preface of his *De proportionibus proportionum*, Oresme uses a comparable phrase to describe the purpose of that work. "Ut igitur studiosi in ulteriorem inquisitionem excitentur ...", in English, "In order that students may be stimulated to further inquiry..." See Grant's edition of Oresme's *De proportionibus proportionum and Ad pauca respicientes, edited with an introduction, translation and critical notes by Edward Grant.* (Madison: University of Wisconsin Press, 1966), Introduction, lines 14–17, pp. 136–137.

[161] This view of his fellow scholars as precious vessels in evil times may not be mere sycophancy. Indeed, if Oresme is describing the cataclysmic period of the late 1340s or 1350s, then "these evil times" is rather understated, and he might well describe his colleagues as "precious vessels" of knowledge, since so many had perished in the plague. See Chapter one for further details.

II. NOTES

Book 1

[i] [NOTE: Long passages are placed in the Endnotes, which are marked by lower case roman numerals; the shorter footnotes are marked by Arabic numerals.]

Cf. Plato, *Timaeus*, 47A–47D, which reads in the English translation of Jowett (*The Dialogues of Plato*, 3rd ed. (Oxford: Clarendon Press, 1892), v. 3, pp. 466–467):

> "Of the second or co-operative causes of sight, which help to give to the eyes the power which they now possess, enough has been said. I will therefore now proceed to speak of the higher use and purpose for which God has given them to us. The sight in my opinion is the source of the greatest benefit to us, for had we never seen the stars, and the sun, and the heaven, none of the words which we have spoken about the universe would ever have been uttered. But now the sight of day and night, and the months and the revolutions of the years, have created number, and have given us a conception of time, and the power of enquiring about the nature of the universe; and from this source we have derived philosophy, than which no greater good ever was or will be given by the gods to mortal man. This is the greatest boon of sight: and of the lesser benefits why should I speak? even the ordinary man if he were deprived of them would bewail his loss, but in vain. Thus much let me say however: God invented and gave us sight to the end that we might behold the courses of intelligence in the heaven, and apply them to the courses of our own intelligence which are akin to them, the unperturbed to the perturbed; and that we, learning them and partaking of the natural truth of reason, might imitate the absolutely unerring courses of God and regulate our own vagaries."

And in the Latin translation of the *Timaeus* by Chalcidius, *Platonis Timaeus*, ed. by Dr. Ioh. Wrobel (Leipsig: Teubner, 1876; reprint, Frankfurt am Main: Minerva, 1963), 47A–47D, pp. 56–57:

> "Et de oculorum quidem ministerii causa, ob quam nacti sunt eam quam habent virtutem, satis dictum. De praecipua tamen utilitate operis eorum mox erit aptior disserendi locus. Visus enim iuxta meam sententiam causa est maximi commodi perisque non otiose natis atque institutis ob id ipsum quod nunc agimus. Neque enim de universa re quisquam quaereret nisi prius stellis sole caeloque visus. At nunc diei

noctisque insinuata nobis alterna vice menses annorumque obitus et anfractus nati sunt, eorumque ipsorum dinumeratio et ex dinumeratione perfectus et absolutus extitit numerus. Tum temporis recordatio, quae naturam universae rei quarerere docuit curamque investigationis iniecit mentibus quasi quoddam seminarium philosophiae pandens, quo bono nihil umquam maius ad hominum genus a divina munificentia commeavit. Hoc igitur maximum beneficium visus oculorumque esse dico. Minora alia praetereo quibus, qui a philosophia remoti sunt, carentes debiles caecique maestam vitam lugubremque agunt. Nobis vero causa dicenda demonstrandaque videntur divini muneris, quod providentia commenta est salubriter hactenus. Deum oculos hominibus idcirco dedisse, ut mentis providentiaeque circuitus, qui fiunt in caelo, notantes eorum similes cognatosque in usum redigerent suae mentis circuitusque animae, qui animadversiones seu deliberationes vocantur, quam simillimos efficerent divinae mentis providis motibus placidis tranquillisque perturbatos licet, confirmatoque ingeneratae rationis examine, dum imitantur aplanem mundi intellegibilis circumactionem, suae mentis motus erraticos corrigant."

[ii] Thus Oresme divides the question between visual lines that are straight and those that are bent by refraction and reflection. As Bert Hansen notes, Oresme also makes this tripartite division of straight, refracted, and reflected visual lines in both his commentary on the *Meteora* and his *De causis mirabilium* (earlier referred to by some scholars by the title *Quodlibeta*, though Hansen believes the *De causis* is only a portion of the *Quodlibeta*). See McCluskey's edition of Oresme, *Oresme on Light, Color, and the Rainbow: An Edition and Translation with Introduction and Critical Notes, of Part of Book Three of His "Questiones super quatuor libros meteororum,"* ed. and trans. by Stephen C. McCluskey. (Ph.D. Dissertation, University of Wisconsin, 1974), pp. 136–137, Bk. III, Q. 12, lines 128–134; and Bert Hansen's edition of Oresme, *Nicole Oresme and the Marvels of Nature: A Study of His "De causis mirabilium" with Critical Edition, Translation and Commentary by Bert Hansen.* (Toronto: Pontifical Insititue of Mediaeval Studies, 1985), pp. 150–151, n. 22, and ch. 1.9, lines 76–81.

The passage in the *De causis mirabilium* is fairly similar to that in the *De visione stellarum*, including using the common example of the penny in the water-filled vase. The Latin and English in Hansen's edition reads: "Ultimo nota quod visio quandoque fit per lineam rectam, quandoque per fractam, patet de denario in fundo vasis, et quandoque per lineam reflexam, ut patet in speculis," and translated, "Note finally that vision sometimes occurs via a straight line, sometimes via a refracted line (as is clear from the penny at the bottom of a [water-filled] vase, and sometimes via a reflected line (as is clear in mirrors)." Oresme (1985), *De causis mirabilium,* ed. by Hansen, pp. 150–151, ch. 1.9, lines 76–79.

[iii] Oresme first asks us to hypothesize that a comet is composed of two parts that are actually far apart from one another: a fixed star in the celestial heavens and a coma (the "hairy" nebulous portion of a comet) that is in the terrestrial region of air directly beneath this fixed star. Aristotle in the *Meteorologia,* suggests that *some* comets are indeed fixed stars that generate comas in the atmosphere, much like halos that sometimes surround the sun and moon and appear to follow them as they move. But Aristotle notes that comets are much more likely to form independently of the fixed stars and they lag behind the motion of the universe, thus comets are not normally "halo" comas formed around fixed stars. *Meteorologia,* Bk. 1, ch. 6 (343b8–25), and Bk. 1, ch. 7 (344a34–344b15). Cf. *The Complete Works of Aristotle: The Revised Oxford Translation,* ed Jonathan Barnes (Princeton: Princeton U.P., 1984), v. 1, pp. 562–563. Oresme here points out a difficulty with this two-part comet view of Aristotle: because the coma is much closer than its fixed star, its "stellar" parallax would be much greater, and we would *not* observe the coma under its fixed star, unless the coma and fixed star were directly at zenith. Indeed, Oresme notes, we might observe this shifted coma under some other, unrelated, fixed star instead.

[iv] Cf. Aristotle, *Meteorologia,* 1, ch. 7, 344b5–10. Oresme seems to be saying the *opposite* of Aristotle but attributes this view to Aristotle nonetheless. Aristotle says the coma of a fixed star's comet is like a halo of the sun or moon, but that the coloration of a halo of the sun or moon is caused by "reflection", while the color of a "halo" coma of a fixed star comet is *not* caused by "reflection" but is inherent in the coma itself. The Latin translation of the pertinent passage in Aristotle's *Meteorologia* is: "Attamen halo quidem fit propter refractionem talis coloris: ibi autem in ipsis exhalationibus color apparens est." *Meteorologia,* Bk. 1, ch. 7, 344b6–9; Novae Translationis of William of Moerbeke, in Aquinas (1952), *In Aristotelis Libros ... " "Meteorologicorum" Expositio,* p. 427.

Oresme is being ambiguous, for Aristotle does say that halos of the sun and moon are caused by reflection. This raises a problem for Oresme's view that these comas would suffer stellar parallax. For if they are not separate entities in the air, but are instead caused by "reflection/refraction", then they would not undergo a differing amount of parallax but instead would be entirely observer dependent. After all, we never see solar or lunar halos separated by parallax from the sun and moon themselves. However, Oresme's apparent solution to this problem is that the matter of the halo itself is diffused over a broad area in the airy regions. Thus only a small portion of this diffuse matter is seen by reflective coloration as a coma halo.

[v] In this corollary, Oresme again considers the notion that some comets are caused by fixed stars, whereby the "head" of the comet is the fixed star itself, and the coma is produced in the atmosphere and acts as a nebulous halo around the fixed star. What if such a coma were caused by an "inflammation" (i.e., by being set afire) in the atmosphere? Oresme notes that it is possible that sometimes the coma would travel west, while at the same time the fixed star would travel east. For example, suppose this fixed star were a circumpolar star that appeared someplace between the pole star (i.e., the "axis of the world" for Oresme) and the horizon. If this star's coma – produced in a fiery manner in the atmosphere – partook of the daily celestial motion of the heavens, then the coma would travel and set toward the west. But the circumpolar star, initially positioned below the pole star, would just be beginning its upward climb, and thus would be rotating counterclockwise, up and to the east. Thus Oresme proves his point, the coma goes west while the star goes east.

In the Aristotelian world view, the basic motion of the four elements is up and down, straight-line motion. But when he comes to explain comets and the milky way, Aristotle runs into a difficulty – because he believes they are sublunar phenomena present in the upper atmosphere, they should have up and down motion, but they do not. Comets, and particularly the Milky Way, obviously have daily circular motions. Therefore, Aristotle greatly softens his view of sublunar motion, saying that the region of fire, and a large portion of the region of air *do have daily circular motion*, similar to and influenced by the celestial regions. Aristotle, *Meteorologia*, Bk. 1, ch. 7 (344a10–13).

Oresme, of course, follows Aristotle in this view. If Oresme believed that the atmosphere does indeed rotate with a daily, westward motion, then it was not such an implausible jump for him to propose (and finally reject) that this rotation extend to the earth as well.

[vi] Oresme appears to mean the following: Assume a comet describes a true, circumpolar circle around the pole star (as seen from the

center of the earth, his fixed and "true" reference point). Then an observer on the earth, who is not at the pole, will see this circular orbit at an oblique angle. To the observer the comet's circle will appear, not as a circle, but as an ellipse (though Oresme does not use that word). The major axis of the ellipse will be from east to west – what Oresme calls the "diameter of the longitude" – this major axis is at right angles to the observer's line of sight toward the north. The squashed circle's shorter axis, the "diameter of the latitude", will be along the observer's line of sight. The diameter of the longitude, therefore, will be at right angles to the longitudinal lines and be measured by the number of lines of longitude it crosses, and vice versa for the diameter of the latitude.

This is similar to looking at a toy train on a circular track. Seen from directly overhead, the track is a perfect circle, but looked at from a different angle, the track appears to be an ellipse, with its longer axis at right angles to the line of sight, and its shorter axis along the line of sight.

Explanations for this type of distortion of shape, in which a distant object such as circle or square is seen from an oblique angle, have a long history in mathematical optics. Among the Greeks, Ptolemy notes that when surfaces do not face the eye directly, those surfaces appear different than when they do, thus circles and squares, seen obliquely, will appear oblong. Ptolemy, *Optics*, II, 72; For the Latin edition, see Albert Lejeune's edition of Ptolemy, *L'optique de Claude Ptolémée dans la version latine d'après l'arabe de l'émir Eugène de Sicile*, ed. by Albert Lejeune (Louvain: Bibliothèque de l'Université, Bureaux de Recueil, 1956), p. 49, lines 12–22; and for an English translation, see A. Mark Smith's, *Ptolemy's theory of visual perception: an English translation of the Optics, with introduction and commentary* (Philadelphia: American Philosophical Society, 1996), p. 101.

Likewise, Alhacen and Witelo discuss this subject in great detail. Alhacen, *De aspectibus*, III, ch. 7, (para. 4–6; III 79a–80b); For the Latin, see Alhacen, *Opticae thesaurus: Alhaceni Arabis libri septem, nunc primum editi; eiusdem liber De crepusculis & nubium ascensionibus; item Vitellonis Thuringopoloni libri X; omnes instaurati, figuris illustrati & aucti, adiectis etiam in Alhacenum commentarijs, a Federico Risnero [= Friedrich Risner, d. 1580]. With an introduction to the reprint edition [of 1572] by David C. Lindberg,* Sources of Science, 94 (New York: Johnson Reprint, 1572, rpt. 1972), III, ch. 7, sec. 24–26, pp. 92–93. For an English translation see A.I. Sabra's edition of Alhacen, *The Optics of Ibn Al-Haytham. Books I–III, On Direct Vision. Translated with Introduction and Commentary*, 3 vols., Studies of the Warburg Institute, 40 (London:

The Warburg Institute, University of London, 1989), vol. 1, pp. 279–280. For Witelo's views, see his *Perspectiva,* IV, sec. 55, in Alhacen (1572, rpt. 1972), *Opticae thesaurus,* pp. 142–143, mentioned above.

Oresme, however, seems to be the first to have applied this principle to cometary orbits, so far as I have found.

[vii] Oresme continues to describe a comet star which has a circular, circumpolar orbit. He has already implied that this type of orbit will appear as an ellipse according to an observer (*b*) on the northern hemisphere of the earth. Here he adds further details to make the example more complex. As the comet revolves in its orbit around center point *d*, there is a point *l* at which the comet will appear, to observer *b*, to begin to go toward the east. This point is near, but not exactly, the westernmost limit of the comet's orbit as seen from the center of the world *a*. Nonetheless, Oresme and the illustrators of the manuscripts equate the two. (See Figure 5. For simplicity, I have followed this in Figure 5a.) The scribes of the manuscripts do illustrate Oresme's description correctly, but unfortunately the two-dimensional limitations of these illustrations, as well as Oresme's description itself, leave the passage rather vague. In the three-dimensional drawing of Figure 5a, I give a tentative depiction of what I surmise Oresme had in mind.

Book II, Section I

[i] Oresme's division of observation into four distinct categories is also found in his *Questiones super quatuor libros meteororum,* Bk. III, Q. 20. It appears to be one of the distinguishing features of Oresme's optical views, for neither McCluskey nor myself have found it mentioned in other authors. Thus it is one of the key supports for Oresme's authorship of the *De visione.* Cf. McCluskey, *Nicole Oresme on Light, Color, and the Rainbow,* Bk. III, Q. 20, lines 79–93, pp. 266–267; see also his comments concerning it and the *De visione* at pp. 50–51 and n. 27, and pp. 442–443, n. 8.

More common is the tripartite division of direct, reflected and refracted rays, which Oresme sometimes used, such as in his *De causis mirabilium,* ed. by Hansen, Ch. I, sec. 9, lines 76–78, pp. 150–151. "Ultimo nota quod visio quandoque fit per lineam rectam, quandoque per fractam, patet de denario in fundo vasis, et quandoque per lineam reflexam, ut patet in speculis." In English, "Note finally that vision sometimes occurs via a straight line, sometimes via a refracted line (as is clear from the penny at the bottom of a [water-filled] vase), and sometimes via a reflected line (as is clear in mirrors)." (Hansen's trans.)

[ii] Beyond this confusion over the term "reflexio," which could mean either reflection or refraction, further confusion resulted from the intromission-extramission theory of vision, in which rays are sent *both* from the object to the eye, and from the eye towards the object. Roger Bacon proposed such an intromission-extramission theory to accommodate and synthesize the various opposing theories of vision held by the extramissionists (such as Euclid and Ptolemy) and the intromissionists (such as Aristotle and Alhacen).

Bacon agreed with the intromissionists that the eye receives an impression from the visual object, but he also wished to accommodate the extramissionists, proposing that the eye sends forth visual rays that ennoble the medium and prepare the incoming visual species to make them acceptable to the eye. In this way, Bacon hoped to unify all his authorities and their conflicting theories to produce a grand unified theory of vision. This Baconian optical synthesis was also supported and modified by the two greatest perspectivists of the Middle Ages, John Pecham and Witelo, whose works Oresme knew well. Cf. Lindberg (1976), *Theories of Vision from Al-Kindi to Kepler*, pp. 114–120.

[iii] This view of refraction had been well established by the time of Ptolemy and was held by both Arabic and Medieval Latin scholars. For a sampling, see the following: Ptolemy (1989), *Optics, ed. Lejeune*, Bk. v, secs. 1–22 (= Prop. 79–84), pp. 223–237. Alhacen (1572, rpt. 1972), *De aspectibus*, vii, ch. 3, sec. 9–12, pp. 242–247. Robert Grosseteste's, *De lineis, angulis et figuris*, in Grosseteste, *Die philosophischen Werke*, ed. Ludwig Baur (Münster i. W.: Aschendorffsche Verlagsbuchhandlung, 1912), p. 63, an English translation is found in Edward Grant's, *Source Book in Medieval Science* (Cambridge: Harvard University Press, 1974), p. 387. Roger Bacon, *De multiplicatione specierum*, ed. by David C. Lindberg (Oxford: Oxford Univ. Press, 1983), Part ii, Ch. 2, lines 36–84, pp. 98–101. John Pecham, in David C. Lindberg's edition, *John Pecham and the Science of Optics. "Perspectiva communis," edited with an introduction, English Translation, and Critical Notes*, University of Wisconsin Publications in Medieval Science, 14 (Madison: University of Wisconsin Press, 1970), Props. i.15{30}, i.16{31}, pp. 89–92. And Witelo (1572, rpt. 1972), *Perspectiva*, x, sec. 1, p. 405.

[iv] The example of the penny in a vessel and refracting rays is a favorite of Oresme's, for he repeats it in both his *Questiones super quatuor libros meteororum*, Bk. III, Q. 12 and his *Marvels of Nature (De causis mirabilium)*, Ch. I, sec. 9. Cf. McCluskey's, *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, lines 186–203, pp. 142–145, and Hansen's, *Nicole Oresme and the Marvels of Nature*, Ch. I, sec. 9, lines 76–81, pp. 150–151.

The penny in a water-filled vessel as an example of refraction has a long history extending back to the Greek perspectivists. Ptolemy in his *Optics* mentions this simple experiment, as does Alhacen, Grosseteste, Bacon, Pecham, Witelo, William of Ockham, and even Alexander Neckham.

Specific references to these are as follows: Ptolemy (1989), *Optics, ed. Lejeune*, Bk. V, sec. 5 (= Prop. 79), p. 225; Alhacen (1572, rpt. 1972), *Perspectiva*, VII, ch. 5, sec. 17, p. 253; Robert Grosseteste, *De iride*, in Grosseteste (1912), *Die philosophischen Werke*, ed. Baur, pp. 74, lines 8–24, Engl. tr. in Grant, *Source Book in Medieval Science*, p. 389; [Note that Grosseteste, Bacon, and Pecham merely describe an "object" under water, rather than a "penny"]; Roger Bacon, *Opus majus*, Part V: *Perspectiva*, Part III, Dist. 2, Ch. 4, in *The Opus majus of Roger Bacon*, ed. by John Henry Bridges, (London, 1900; reprint ed., Frankfurt/Main: Minerva G.m.b.H., 1964) vol. 2, p. 155; for an English translation see Roger Bacon, *Opus majus*, trans. by Robert Belle Burke (Philadelphia: University of Pennsylvania Press, 1928), Part V, Dist. 2, Ch. 4, vol. 2, pp. 571–572; Pecham (1970), *Perspectiva communis*, Part III, Prop. 7, lines 49–60, pp. 216–217; Witelo (1572, rpt. 1972), *Perspectiva*, X, sec. 11, pp. 414–415; William of Ockham, *Quaestiones in librum tertium Sententiarum (Reportatio)*. Ed. Franciscus E. Kelley and Girardus I. Etzkorn. Opera theologica, 6. (St. Bonaventure, NY: St. Bonaventure University, 1982), 3.2, pp. 78 and 95. Cf. Hansen, *Nicole Oresme and the Marvels of Nature*, p. 151, n. 22, who also notes that "Question 53 of the *Tabula problematum* asks, 'Why is a penny at the bottom of a water-filled vase seen from farther away than in an empty vase?' (in Appendix A)." Alexander Neckham, *Alexandri Neckam "De naturis rerum libri duo,"* ed. by Thomas Wright (London: Longman, 1863. Reprint edition: Washington, D.C.: Microcard Editions, 1966), p. 235; for an English tr., see Grant (1974), *Source Book in Medieval Science*, p. 381.

Both McCluskey and Hansen cite many of these authors in their discussions of the penny-in-a-vessel experiment; McCluskey, *Nicole Oresme on Light, Color, and the Rainbow*, p. 409, n. 25, and Hansen, *Nicole Oresme and the Marvels of Nature*, pp. 150–151, n. 22.

[v] This figure, with its accompanying letter designations, is nearly identical to that found in Oresme's *Questiones super quatuor libros meteororum*, Bk. III, Q. 12, and thus might be seen as another corroborating piece of evidence that the author of the *De visione stellarum* is Oresme. The only major difference between the two diagrams is that the letters *c* and *e* are reversed. Also, the non-essential designation for the bottom left-hand corner by the letter *f* is not used in the *De visione* diagram, but this letter is not mentioned in either of the narrative descriptions found in the *De visione* or the commentary on the *meteora.* Cf. McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, Bk. III, Q. 12, figure 12.2, p. 142.

[vi] This almost certainly refers to Roger Bacon's *De multiplicatione specierum.* Bacon himself sometimes referred to it by the title "*De speciebus*" as noted by David Lindberg in his critical edition of this work. David C. Lindberg, *Roger Bacon's Philosophy of Nature*, pp. xxvi–xxvii. Further, as McCluskey points out, Oresme "closely follows the argument of Bacon's *De multiplicatione specierum* – although he fails to mention Bacon by name" in his *Questiones super quatuor libros meteororum*, Bk. III, Q. 12–13. McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, p. 21. And these two questions have many similarities to Oresme's *De visione stellarum.*

Bacon assigns this explanation of perpendicular rays being stronger than oblique rays to Ptolemy and Alhacen, whom Oresme no doubt means by the term "ancients". Bacon says,

> "Causam autem huius fractionis assignant per hoc, quod casus speciei perpendicularis fortis est, sicut patet in lapide cadente deorsum, si non obliquetur eius casus, ut si aliquis impediverit casum perpendicularem et fecerit lapidem deviare ab incessu perpendiculari, manifestum est sensui quod debilem faciet penetrationem,"

in English,

> "However, they" [i.e., Ptolemy and Alhacen] "assign the cause of this refraction as follows. Since the descent of a perpendicular species is strong, as is evident in a falling stone, provided its descent is not diverted from the vertical, if something should impede perpendicular descent and make the stone deviate from a perpendicular course, it is manifest to sense that its ability to penetrate is weakened.
>
> ("Roger Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part II, Ch. 3, lines 81–85, pp. 110–111.)

Bacon is right in assigning this view to Alhacen, but not in assigning it to Ptolemy. Ptolemy and Alhacen's own opinions on the cause of refraction are found in Ptolemy, *L'optique de Claude Ptolémée, dans la version latine d'après l'arabe de l'émir Eugène de Sicile. Édition critique et exégétique augmentée d'une traduction française et de compléments par Albert Lejeune*, Collection de travaux de l'Académie Internationale d'Histoire des Sciences, 31 (Leiden: E.J. Brill, 1989), Bk. v, sec. 19 (= Prop. 83), pp. 234–235; and, Alhacen (1572, rpt. 1972), *De aspectibus,* VII, ch. 2, sec. 8, pp. 240–242.

For an excellent analysis on various medieval theories of the cause of refraction, including those of Ptolemy, Alhacen, Grosseteste and Bacon, see David C. Lindberg's, "The Cause of Refraction in Medieval Optics," *The British Journal for the History of Science* 4 (1968): 23–38.

[vii] These same examples of a stone and a sword are found in Bacon and, with slight modifications, in Alhacen (where the "stone" is an iron ball that is thrown towards the perpendicular surface of a board, rather than falling). For the perpendicular fall of a stone in Bacon, see the previous note. Concerning the perpendicular fall of a sword, Bacon says,

> "Similiter ensis vel securis vel aliud natum scindere, si aptetur a manu percutientis perpendiculariter super lignum, penetrat et dividit illud; si oblique, tunc vel non scindet vel minus longe quam quando fuit perpendicularis."

In English,

> "Similarly, if a sword or axe or some other instrument designed to cut is applied to a rod perpendicularly by the hand of the one wielding the instrument, it penetrates and divides the rod; [however,] if the instrument is applied obliquely, either it does not cut [at all] or it cuts much less than when perpendicular."
>
> (Roger Bacon (1983), *De multiplicatione specierum,* ed. by Lindberg, Part II, Ch. 3, lines 88–91, pp. 110–113.)

Concerning these two examples, Alhacen says:

> "Si enim aliquis acceperit tabulam subtilem et paxillaverit illam super aliquod foramen amplum, et steterit in oppositione tabulae, et acceperit pilam ferream, et eiecerit eam super tabulam fortiter, et observaverit, ut motus pilae sit super perpendicularem super superficiem tabulae: tunc tabula cedet pilae aut frangetur, si tabula subtilis fuerit, et vis, qua sphaera movetur, fuerit fortis. Et si steterit in parte obliqua ab oppositione tabulae, et in illa eadem distantia, in qua prius erat, et eiecerit pilam super tabulam illam eandem, in quam prius eiecerat: tunc sphaera labetur de tabula, si tabula non fuerit valde subtilis, nec

movebitur ad illam partem, ad quam primo movebatur, sed declinabit ad aliquam partem aliam.

"Et similiter, si acceperit ensem, et posuerit coram se lignum, et percusserit cum ense, ita ut ensis sit perpendicularis super superficiem ligni: tunc lignum secabitur magis: et si fuerit obliquus, et percusserit oblique lignum: tunc lignum non secabitur omnino, sed forte secabitur in parte, aut forte ensis errabit deviando: et quanto magis fuerit ensis obliquus, tanto minus aget in lignum: et alia multa sunt similia: ex quibus patet, quod motus super perpendicularem est fortior et facilior: et quod de obliquis motibus ille, qui vicinior est perpendiculari, est facilior remotiore."

(Alhacen (1572, rpt. 1972), *De aspectibus,* VII, ch. 2, sec. 8, pp. 241.)

Lindberg quotes this passage of Alhacen and translates it as follows:

"If one takes a thin board [he declares] and fastens it over a wide opening, and if he stands opposite the board and throws an iron ball at it forcefully and observes that the ball moves along the perpendicular to the surface of the board, the board will yield to the ball; or, if the board is thin and the force moving the ball is powerful, the board will be broken [by the ball]. And if he [then] stands in the position oblique with respect to the board and at the same distance as before and throws the ball at the same board, the ball will be deflected by the board (unless the latter should be excessively delicate) and will no longer be moved in its original direction, but will deviate toward some other direction.

"Similarly, if one takes a sword and places a rod before him and strikes the rod with the sword in such a way that the sword is perpendicular to the surface of the rod, the rod will be cut considerably; and if the sword is oblique and strikes the rod obliquely, the rod will not be cut completely, but perhaps partially, or perhaps the sword will be deflected. And the more oblique the sword [and its motion], the less forcefully it acts on the rod. And there are many other similar things, from which it is evident that motion along the perpendicular is stronger and easier and that the oblique motion which approaches the perpendicular is [stronger and] easier than that which is more remote from the perpendicular."

(Lindberg (1968a), "The Cause of Refraction," pp. 26–27.)

[viii] This method of finding an optical image is sometimes referred to in the literature as "The Ancient Principle" or "The Ancient Optical Principle". Though incorrect (due to psychological factors), this principle stood from the time of the ancient Greeks through the time of Kepler, as noted by Colin Turbayne in his article on the subject. Colin M. Turbayne, "Grosseteste and an Ancient Optical Principle," *Isis* 50 (1959): 467–472.

See also Vasco Ronchi's discussion of it in his *Optics: The Science of Vision,* trans. and rev. by Edward Rosen (New York: New York University Press, 1957), pp. 156–157. This work was originally published in Italian as *L'Ottica scienza della visione* (Bologna: Nicola Zanichelli, 1955).

This principle is certainly found in sources familiar to Oresme, such as Alhacen, Bacon, Pecham, and Witelo. Alhacen (1572, rpt. 1972), *De aspectibus,* VII, ch. 2, secs. 18, pp. 253–255; Roger Bacon, *Opus majus,* Part V: *Perspectiva,* Part III, Dist. 2, Ch. 2, in *The Opus majus of Roger Bacon,* ed. Bridges, vol. 2, pp. 148–149; for an English translation see Bacon, *Opus majus,* Part V, trans. by Burke, *Perspectiva,* Part III, Dist. 2, Ch. 2, vol. 2, pp. 565–566; Pecham (1970), *Perspectiva communis,* Part III, Prop. 4, lines 25–35, pp. 214–215; Witelo (1572, rpt. 1972), *Perspectiva,* X, sec. 15, pp. 416–418.

[ix] It is not quite clear from this passage whether Oresme means that stars rising on the horizon appear larger than they really are, or that they appear larger than when seen at the meridian, where the amount of intervening atmosphere is smaller. Since he speaks of "more vapors" (*plures vapores*), it is probable that he means the latter.

That celestial objects appear larger on the horizon than at the meridian has long been attested, but whether this is due to atmospheric refraction (as Oresme here implies) or to optical illusion has been debated since the time of Ptolemy. (Though the atmospheric refraction explanation is incorrect and was certainly questioned by Alhacen and perhaps by Ptolemy himself, there is still debate over whether this phenomena is due to psychological factors alone, or to physiological factors as well. Cf. J.T. Enright, "The Moon Illusion Examined from a New Point of View," *Proceedings of the American Philosophical Society* 119 (April, 1975): 87–107. See also, A.I. Sabra's, "Psychology Versus Mathematics: Ptolemy and Alhacen on the Moon Illusion," in *Mathematics and Its Applications to Science and Natural Philosophy in the Middle Ages: Essays in Honor of Marshall Clagett,* ed. by Edward Grant and John E. Murdoch (Cambridge: Cambridge University Press, 1987), pp. 217–247.)

That the vapors of the atmosphere are somehow involved in making celestial objects on the horizon appear larger is mentioned as early as Aristotle in his *Meteorologia,* Bk. III, ch. 4 (373b10–15) and in Ptolemy, *Almagest,* Bk. I, cap. 3, and in his *Optica,* Bk. III, sec. 59. This view is rejected by the Perspectivists, but Bacon tries to take a middle ground, citing both atmospheric refraction and optical illusion as causes.

The question is taken up in Alhacen (1572, rpt. 1972), *De aspectibus,* VII, ch. 7, sec. 51–55, pp. 278–282; Roger Bacon, *Opus* *majus,* Part v: *Perspectiva,* Part III, Dist. 2, Ch. 4, in *The Opus majus of Roger Bacon,* ed. by Bridges, vol. 2, pp. 155–157; in English, see Burke's trans. of Bacon's *Opus majus,* Part v: *Perspectiva,* Part III, Dist. 2, Ch. 4, vol. 2, pp. 572–573; and Bacon's *De multiplicatione specierum,* ed. by Lindberg, Part II, Ch. 4, pp. 126–129; Witelo (1572, rpt. 1972), *Perspectiva,* x, sec. 54, pp. 448–449; and Pecham (1970), *Perspectiva communis,* Props. I.82{86}, pp. 152–153, and III.13, pp. 224–229, and again by Oresme in his *Questiones super quatuor libros meteororum,* Bk. III, Q. 12, lines 331–334.

Oresme also refers to this question below in Book II, Conclusion 7, (Bk. II, cap. 1, lines 347–379), and in the second set of corollaries, Book II, Corollary VII, (Bk. II, cap. 2, lines 386–405).

Book II, Section 2

[i] Ibn Muʾadh's treatise on twilight, *De crepusculis,* which Oresme cited earlier, attributes twilight to reflection alone and not refraction. Of course, this may have been partially for computational reasons, since his geometric proof for the height of the atmosphere depends upon the upper atmosphere reflecting sunlight. In Smith (1992), "The Latin Version of Ibn Muʾadh's Treatise," p. 115, lines 414–416 (Latin), and p. 131 (English).

Much later, Johannes Kepler presented a proof depending instead upon a single atmospheric refraction rather than a reflection at the upper surface of the air. Johannes Kepler's *Paralipomena in Vitellionem,* in *Gesammelte Werke,* herausgegeben im auftrag der Deutschen Forschungsgemeinschaft und der Bayerischen Akademie der Wissenschaften, unter der Leitung von Walther Von Dyck und Max Caspar, Vol. 2: *Astronomiae pars optica,* herausgegeben von Franz Hammer (Munich: C.H. Beck'sche Verlagsbuchhandlung, 1939), pp. 76–143. Also see Kepler's epitome of Copernican astronomy, in *Gesammelte Werke,* Vol. 7: *Epitome astronomiae Copernicanae,* herausgegeben von Max Caspar (Munich: C.H. Beck'sche Verlagsbuchhandlung, 1953), pp. 56–69, 195–198. For a good overview, see Bernard R. Goldstein's, "Refraction, Twilight, and the Height of the Atmosphere," *Vistas in Astronomy* 20 (1976): pp. 105–107.

And because of its key importance to precise astronomical observation, Newton and Flamsteed spent much of the years 1694–1695 on this question of atmospheric refraction, as can be traced in their frequent correspondence. Newton proposed several solutions to the problem, finally arguing that light passing through the atmosphere is refracted along a continuous curve. For this correspondence of Flamsteed and Newton, see: Isaac Newton, *The Correspondence of Isaac Newton,* (Cambridge: Cambridge University Press, 1959–1977), the large majority of letters ranging from no. 470–520 (7 Sept. 1694 to 9 July 1695), vol. 4, pp. 12–144.

[ii] It is a bit unclear, but Oresme appears to be implying that the object's position will either be seen to gradually shift along the curved ray he proposes, or it will suddenly jump from one position to another. This involves whether the speed of light is understood to be instantaneous or to have some finite speed. Aristotle and most who followed him, including Galen and Averroes, believed that light was a quality that a medium acquired all at once, and therefore there was no "speed" of light, since this acquisition was instantaneous. Alhacen, however, was an exception; he believed that light traveled at a finite, though imperceptible, speed. Alhacen (1572, rpt. 1972), *De aspectibus,* II, ch. 2, sec. 21, p. 37. See A.I. Sabra, *Theories of Light from Descartes to Newton* (Cambridge: Cambridge University Press, 1981), pp. 46–48.

Bacon followed Alhacen in arguing that light has a finite speed, while Pecham seems to have held the opposite. But as Peter Marshall points out, Oresme in his commentary on the *De anima* opted to support the Aristotelian position that light propagated instantaneously; on the other hand, Oresme here appears to go against this view in the next paragraph. According to Lindberg, the problem of whether light has a "speed" was a vexing one for fourteenth century scholars. This was for at least two reasons. First, their ancient authorities disagreed and gave valid arguments for both points of view. Second, there was no means to gain more empirical data to resolve the dilemma. David C. Lindberg, "Medieval Latin Theories of the Speed of Light," In *Roemer et la vitesse de la lumière* (Paris: Vrin, 1978), pp. 45–72; Peter Marshall, "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 368–374; Bacon (1983), *De multiplicatione specierum,* ed. by Lindberg, Part IV, Ch. 3, pp. 220–227; Pecham (1970), *Perspectiva communis,* Props. I.53{56}, pp. 134–135.

[iii] Oresme is probably referring to Alhacen's curious aperture argument for a finite speed of light. Alhacen sets forward the following thought experiments. Assume that light falls on a covered aperture, and then the aperture is uncovered: the light enters the aperture, passes through the intervening darkened air, and falls upon an

object. So, either the intervening air receives the light one part after another or all at once. Either way will take time, Alhacen says, therefore there is a finite speed of light. Of course this begs the question, since Alhacen is assuming what he sets out to prove. For if the air receiving the light "all at once" *takes time*, then, yes, it takes time for the light to do this "all at once" – a finite speed.

Alhacen also stacks the deck in his next thought experiment. He asks us to imagine the same aperture again, but this time, the screen over the aperture reveals first one part of the aperture, then the other. Since the aperture is exposed through motion, and motion takes time, the light will enter the air in a continuous, non-instantaneous fashion. Alhacen says, "For light will not occur anywhere in the air inside the covered aperture unless something of the aperture is exposed to the light; but nothing of the aperture can be exposed in less than one instant; and an instant is not divisible; therefore, no light will occur inside the aperture at the instant of exposing that which was exposed of the aperture." (Sabra's translation, pp. 146–147.) Consciously or unconsciously, Alhacen has linked the finite speed of exposing the aperture to the "speed" at which the light propagates beyond the aperture. This again appears to assume the finite speed of light to prove it. Alhacen (1572, rpt. 1972), *De aspectibus,* II, ch. 2, sec. 21, pp. 37–38, and sec. 51, p. 61. For an English translation, see Alhacen, *[De aspectibus]. The Optics of Ibn Al-Haytham. Books I–III, On direct vision.* Trans. with intro. and commentary by A.I. Sabra. (London: The Warburg Institute, University of London, 1989), Book II, 3, para. 60–66, and 184, vol. 1, pp. 146–148, and 195.

Oresme's argument is a twist on that of Alhacen's – and possibly as shaky. Oresme asks us to assume that light from a stationary object [such as a star?] at *c* shines through an aperture at *e* for some period of time (an hour), then, because of the curved refraction of the atmosphere, the light will appear to suddenly jump to another position *f* at the end of that hour. So also, the shadow cast by the aperture would jump as well. This seems improbable to Oresme, so he throws his support towards Alhacen's finite speed of light.

The difficulties with this argument are what Oresme leaves unsaid. First, if the curved refractions take some period of time (say an hour), then it is *assumed* that light is propagating at a finite speed. Second, Oresme asks us to assume that, at the beginning of that time period, the starlight is "illuminating through an aperture at *e*." This could only mean that, somehow, the light has already made its way, *unrefracted*, to the aperture, and then later, *is refracted* by the atmosphere, causing the shift in position. Obviously, an observer at *e* can only see the starlight through the atmosphere, and should not be able to see the starlight at its original, true position (*c*) at all.

This all could be an excellent thought experiment, but only if one assumed that, at first, there was *no* intervening atmosphere, and then, perhaps by God's omnipotent power, the atmosphere suddenly appeared between the star and the aperture. But problems appear. For then, it seems, there either *would* be an instantaneous jump in the star's apparent position, or (assuming as Oresme does that the atmospheric refractions take time) the star at *c* would disappear and then reappear at *f* at some later time. But Oresme neither makes such initial conditions, nor would this experiment fit his conclusions.

As noted above, Oresme leans toward supporting the concept of a non-instantaneous propagation of light set forth by Alhacen and Bacon. But Oresme in his *De anima* supports the opposite, that light is propagated instantaneously and there is no "speed of light." (See previous footnote.) If Oresme wrote the *De anima* after the *De visione*, then perhaps he saw some of the logical difficulties in both Alhacen's and his own arguments here and decided to revise them. But such speculation is only that. For, first, there is no way of knowing which is the "more mature" view: Aristotle's instantaneous propagation (wisely argued but incorrect), or Alhacen's and the *De visione's* finite speed of light (fallaciously argued but ultimately correct). Second, like Blasius of Parma after him, Oresme might have wavered between both incongruous views, varying his support according to context. (See Peter Marshall, "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 368–374; for Blasius of Parma's vacillation, see Lindberg (1978b), "Medieval Latin Theories of the Speed of Light," pp. 61–66.)

For the substantial literature concerning the effect of an aperture or a smaller "pin-hole" on light and images, see David C. Lindberg, "The Theory of Pinhole Images From Antiquity to the Thirteenth Century," *Archive for History of Exact Sciences* 5 (1968): 154–176; Lindberg's, "The Theory of Pinhole Images in the 14th Century," *Archive for History of Exact Sciences* 6 (1970): 299–325; and David C. Lindberg and Geoffrey Cantor's, *The Discourse of Light from the Middle Ages to the Enlightenment: Papers read at a Clark Library Seminar, 24 April 1982* (Los Angeles: William Andrews Clark Memorial Library, University of California, 1985).

[iv] Actually, it is not so clear, but Oresme appears to be referring to the following: Aristotle, *Meteorologia*, Bk. III, ch. 4 (373a35–373b13). In

this passage, Aristotle speaks of a man whose eyesight is so weakened that he constantly sees his own image before him. Why? Following the extramission theory, Aristotle postulates that the mans vision is so weak that it cannot push the air aside, instead the air acts as a mirror, reflecting his own image back to him.

The name "Antiphon" is of particular interest for us. Aristotle never names the weak-eyed man, but Oresme refers to him as Antiphon in both his commentary on the *Meteora* and his *De causa mirabilium.* This is another strong link between the *De visione stellarum* and Oresme's other works, thus giving further support for Oresme's authorship. Stephen McCluskey and Bert Hansen have conducted considerable research on this mysterious "Antiphon," thus I could do no better than to summarize their views here.

Both McCluskey and Hansen believe that Oresme's "Antiphon" is an erroneous spelling for "Antipheron," the name Alexander of Aphrodisias assigns to this weak-eyed fellow in his Aristotelian commentary. Thus Oresme could have taken the name from Moerbeke's translation of Alexander or perhaps from Aquinas who also uses the name "Antipheron." Other than Oresme, very few use the incorrect "Antiphon" for Antipheron. McCluskey found that Antiphon is used in the variant readings of Peter of Auvergne's *Commentarium in Meteorologicorum,* and in the Questiones commentaries of Themon Judaeus and Albert of Saxony as well. Cf. McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow,* Bk. III, Q. 15, lines 225–229, pp. 218–219, and fn. 18, pp. 429–430; and Oresme (1985), *De causis mirabilium,* ed. by Hansen, Ch. I, sec. 9, lines 76–81, pp. 150–151, and fn. 23, p. 151; Aquinas' commentary on the *Meteorologia,* in Aquinas, *In Aristotelis Libros "De Caelo et Mundo," "De Generatione et Corruptione," "Meteorologicorum" Expositio,* ed. by Fr. Spiazzi (Rome: Marietti, 1952), Appendix II, Bk. III, Lectio V, 280 [2], p. 625; Themon Judaeus', *Quatuor libros Meteororum,* in Albert of Saxony's, *Questiones et decisiones physicales insignium virorum.* (Paris: Iodici Badii Ascensii et Conradi Resch, 1518), Bk. III, Q. 10, fol. 188[v].

[v] Oresme discusses a variation of this in Corollary VII below. A simplified and partial version of this assertion is found in Oresme's *Questiones super quatuor libros meteororum,* where he states the following inference, without supporting evidence: "Decimo, infero quod possibile est stellam vel solem apparere super nostrum orizontem quando tamen adhuc est sub orizonte, et hoc sit propter reflexionem luminis stelle vel solis super vapores interpositos," that is, "Tenth, I infer that it is possible for the sun or a star to appear above our horizon when

it is [actually] still below the horizon, and this would be because of the reflection of sunlight or starlight from the intervening vapors." In McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow,* pp. 156–157, Bk. III, Q. 12, lines 336–339.

In discussing this passage, McCluskey notes that no perspectivist before Oresme had maintained that a star may be seen that is actually below the observer's horizon. McCluskey lists the relevant passages of perspectivists who had not postulated this, including Ptolemy, Alhacen, Witelo, Bacon, or Pecham. McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow,* p. 413, fn. 33. On the other hand, at least one ancient, the Stoic Cleomedes, had held such a position. And it is possible that Hipparchos had held such a view as well – if Pliny may be believed. For a full discussion of this, see the notes to Corollary 4 below.

[vi] Incredibly, Oresme has independently rediscovered the solution to a paradoxical astronomical observation found in Pliny. (Oresme quotes Pliny in the following paragraph.) A lunar eclipse, of course, is caused by the earth being placed between the sun and the moon, thus blocking the sunlight and casting a shadow over the moon. According to Greek astronomers, however, there was at least one occasion in which the earth did not appear to be directly between sun and moon, yet a lunar eclipse occurred nonetheless.

The Greek Stoic Cleomedes was apparently the first to propose a solution that ultimately proved correct. He proposed that during a lunar eclipse, it might happen that both sun and moon appear to be above the horizon. Why? Atmospheric refraction. Thus Cleomedes was the first to give a fairly accurate, qualitative account of this strange effect of atmospheric refraction.

But the works of Cleomedes were not available in Latin until the Renaissance, nor was this idea found in any of the major sources accessible to Oresme, such as Ptolemy's *Optics.* The only source that even mentioned such a phenomenon was Pliny, and he gave no solution to the problem, merely saying that Hipparchos had done so. (See following footnotes.) So, remarkably, it appears that Oresme literally reinvented this explanation himself. If so, he was the first since the ancient world to do so.

Even today, the observation of both the sun and moon above the horizon during a lunar eclipse is deemed impossible by the very capable Frans Bruin, though Cohen and Drabkin note that such an eclipse was actually observed on Nov. 7, 1938 in the vicinity of New York. Bruin, "The Equator Ring, Equinoxes, and Atmospheric Refraction," *Centaurus* 20 (1976): 101; Morris Cohen and I.E. Drabkin, *A Source Book in Greek Science* (Cambridge, Mass.: Harvard University Press, 1948), p. 284.

For Cleomedes' account in English see: Cohen & Drabkin (1948), *Source Book in Greek Science*, pp. 284–285; a portion of this account, with the original Greek, is found in Ivor Thomas', *Selections Illustrating the History of Greek Mathematics*, (Loeb Classical Library) (Cambridge, Mass.: Harvard University Press, 1951), vol. 2, pp. 396–401. Robert Todd has created a modern edition of the entire Greek text, though I have not had the opportunity to view it: Cleomedes, *Cleomedis Caelestia (Meteora)*, (Leipzig: Teubner, 1990).

The Greek text along with the renaissance Latin translation may be found in the Landmarks of Science microcard series: In Proclus, *Procli De sphaera liber; Cleomedis De mundo, sive Circularis inspectionis meteororum libri duo* (Basileae: Per H. Petri, 1547, rpt. 1975), Bk. II, ch. 6. Sarton notes that Cleomedes book was not available to Arabic and Latin astronomers in the Middle Ages. Sarton, *A History of Science: Hellenistic Science and Culture in the Last Three Centuries B.C.* (Cambridge, Mass.: Harvard University Press, 1959), pp. 304–305.

On Cleomedes himself, see the following: D.R. Dicks', "Cleomedes," In *Dictionary of Scientific Biography* (New York: Charles Scribner's Sons, 1970–1980), v. 3, pp. 318–320; William Stahl, *Roman Science: Origins, Development, and Influence to the Later Middle Ages* (Madison: University of Wisconsin Press, 1962), pp. 53–54; Thomas Heath's, *Greek Astronomy* (New York: AMS Press, 1932, rpt. 1969), pp. 162–166.

[vii] Pliny, the Elder (1938), *Natural History*, tr. by H. Rackham (Loeb Classical Library), Bk. II, x, 57; vol. 1, pp. 206–207. Oresme uses a different chapter division than that found in Rackham's edition. The citation style and chapter divisions of Oresme matches that found in Holland's 1601 translation of Pliny, in which the designation "D" is a citation letter in the margin used as a finding aid. Oresme's is almost an exact quotation of the Latin found in both Rackham's edition and the 1469 Venice edition. See, Pliny the Elder, *Naturalis Historia* (Venetis: Spira Ioannes, 1469, [Reprint, (Landmarks of Science). New York: Readex Microprint, 1975]). Pliny the Elder, *The Historie of the World: Commonly Called the Naturall Historie of C. Plinius Secundus*, tr. Philemon Holland, 2 vols. (London: Impensis G.B., 1601 [Reprint (Landmarks of Science). New York: Readex Microprint, 1973]), Bk. II, ch. 13, D; vol. 1, p. 9.

Curiously, however, the later portion of Oresme's quotation is misleading. Because of his elision, Oresme gives the impression that this lunar eclipse, with both sun and moon above the horizon, occurred during the time of the Vespasians. In actuality, Pliny is referring to a different event. At the elision, the text continues (in Rackham's translation): "For the eclipse of both sun and moon within 15 days of each other has occurred even in our time, in the year of the third consulship of the elder Emperor Vespasian and the second consulship of the younger."

[viii] Concerning Witelo, Oresme probably meant to refer to Book x, section 55, rather than section 52. Witelo (1572, rpt. 1972), *Perspectiva,* x, sec. 55, pp. 449–450: "Scintillatio accidit semper omnibus stellis fixis propter divaricationem formae in loco imaginis ex motu subiecti corporis accidentem." Alhacen does not appear to take up the question of stellar scintillation.

Oresme gives much the same explanation found in Witelo and Bacon, while Pecham takes a decidedly different view, postulating that stars twinkle because they reflect solar rays. Much later, Newton echos the explanations of Witelo and Bacon (and Oresme), arguing that stars twinkle due to fluctuations in the atmosphere itself. Newton goes on to explain that there is no way to construct a telescope that will remedy the situation. Rather, one must go to places of "serene and quiet air" such as the highest mountaintops for the best viewing.

Roger Bacon, *Opus majus,* Part v: *Perspectiva,* Part II, Dist. 3, Ch. 7, in *The Opus majus of Roger Bacon,* ed. by Bridges, vol. 2, pp. 120–126; for Burke's English translation see Bacon, *Opus majus,* Part v: *Perspectiva,* Part II, Dist. 3, Ch. 7, vol. 2, pp. 535–542; Pecham (1970), *Perspectiva communis,* Part II, Prop. 56, lines 631–661, pp. 208–211; Isaac Newton, *Opticks, or A Treatise of the Reflections, Refractions, Inflections, and Colours of Light,* Based on the 4th edition, London, 1730, preface by I. Bernard Cohen (New York: Dover Publications, 1952), Bk. I, Part 1, Prop. viii, Prob. 2, pp. 110–111.

For Oresme's views on the scattering of light, as set forth in his *De anima,* see Marshall's, "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 362–367.

[ix] This is a description of the very subject matter of Aristotle's *Meteorology,* as found in his first paragraph:

> "Haec [i.e., Meteorologia] autem sunt quaecumque accidunt secundum naturam quidem, inordinationem tamen ea quae primi elementi corporum, circa locum maxime propinquum lationi astrorum; puta de lacte et cometis et ignitis et motis phantasmatibus."

Aristotle, *Meteorologia*, Bk. I, ch. 1 (338b1–339a1). This Latin quotation is from Aristotle, *Meteorologia*, in Aquinas', *In Aristotelis Libros "De Caelo et Mundo," "De Generatione et Corruptione," "Meteorologicorum" Expositio*, ed. by Fr. Spiazzi (Rome: Marietti, 1952), Bk. I, ch. 1, p. 391.

H.D.P. Lee translates the passage from the Greek as:

> "Its [i.e. Meteorology's] province is everything which happens naturally, but with a regularity less than that of the primary element of material things, and which takes place in the region which borders most nearly on the movements of the stars. For instance the milky way, comets, shooting stars and meteors ...,"

Aristotle, *Meteorologica*, tr. by H.D.P. Lee, Loeb Classical Library (Cambridge: Harvard University Press, 1962), Bk. I, ch. 1, p. 5.

[x] Cf. Aristotle, *Meteorologia*, Bk. III, ch. 4 (373a35–373b35). It is uncertain, at least to me, whether Oresme is saying that opaque bodies reflect in two ways (i.e., reflecting color and shape) or that they reflect in both directions. I have translated the passage to mean the former. But if he means the later, that is reflection occurs both to and from the eye, then Oresme would seem to be ascribing the intromission-extramission theory of vision to Aristotle himself.

Aristotle was certainly not an extramissionist when he wrote his *De sensu*, ch. 2 (438a25–27), for there he states it is irrational to believe that the eye sees by something issuing from it. But in his *Meteorology*, Aristotle *does* appear to hold this extramissionist view. In the passage cited above, Aristotle speaks of a weak-eyed man whose sight was so frail that it could not push the air aside, and thus his sight was reflected back to him. (This is the fellow Oresme calls "Antiphon." See note above.)

Modern scholars rightly maintain that Aristotle's *Meteorology* was probably an earlier work, while he was still under the influence of the extramissionist Plato, and that Aristotle's more mature, intromissionist views are expressed in his *De sensu* and *De anima*. But rather than see Aristotle changing his opinion over time, Oresme implies that Aristotle held both views simultaneously. In this, Oresme is no doubt following Roger Bacon, who had proposed just such a synthetic intromission-extramission theory himself, and ascribed it to Aristotle as well.

For Aristotle's and Bacon's views, see Lindberg (1976), *Theories of Vision from Al-Kindi to Kepler*, pp. 6–9, 114–116, and 217–218, n. 39.

[xi] On the surface, Oresme appears to be rejecting Aristotle's view of light as a state of a transparent medium, but that is not the case. Aristotle used a single term for light, but in his commentaries, Avicenna (Ibn Sina) made a distinction between two types of light, *lux* and *lumen*, in which *lux* is the quality of a luminous body, and *lumen* a quality of the medium bearing the light. This distinction was used by Roger Bacon in his initial explanation of the multiplication of species, and Oresme is almost certainly echoing Bacon here. Bacon says, "Et, ut in exemplo pateat hec species, dicimus lumen solis in aere esse speciem lucis solaris que est in corpore suo; et lumen forte cadens per fenestram vel foramen nobis satis est visibile, et est species lucis stelle." In English: "And to explain this meaning of 'species' with an example, we say that the *lumen* of the sun in the air is the species of the solar *lux* in the body of the sun; and *lumen* falling, perchance, through a window or an aperture is sufficiently visible to us, and it is the species of the *lux* of a star." Roger Bacon (1983), *De multiplicatione specierum*, ed. by Lindberg, Part I, Ch. 1, lines 29–32, pp. 2–5. According to Peter Marshall, this distinction was also a key component of the visual theory of Aristotelians, such as Aquinas and Buridan. Marshall (1981), "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 358–359.

Oresme repeats this distinction in his commentaries on the *De anima*, the *Meteorology*, Euclid's *Geometry*, and in the *De configurationibus qualitatum et motuum.* (See citations below) For example, in his *De anima* commentary, Oresme defines *lux* in almost the exactly the same way as found here: *lux* is "the quality of a luminous body – that is, of a body which generates light, such as the sun … *lumen* is said to be the quality of a transparent medium through which illumination takes place – a medium such as air, heaven, or water. And thus *lux* is in the sun and *lumen* is in the air." (Marshall's translation) See Marshall (1981), "Nicole Oresme on the Nature, Reflection, and Speed of Light," *Isis* 72 (1981): 359; his translation is based on his edition of Oresme's *De anima: Nicholas Oresme's "Questiones super libros Aristotelis de anima": A Critical Edition with Introduction and Commentary.* (Ph.D. Diss., Cornell University, 1980), pp. 406–407, lines 64–69 (no. 13).

For Oresme's use of *lux* and *lumen* elsewhere, see his *Questiones super quatuor libros meteororum*, in McCluskey (1974), *Nicole Oresme on Light, Color, and the Rainbow*, pp. 162–163, Bk. III, Q. 13, lines 13–21, and pp. 415–416, n. 2; McCluskey (1974), p. 415 also quotes the relevant passage from Oresme's *Questiones super Geometriam Euclidis,* which he cites as Q. 17, lines 26–31, p. 49 in Busard's (1961) edition; and, as McCluskey notes, there is an oblique reference to this view in Oresme's *De configurationibus qualitatum et motuum*, in Clagett, *Nicole Oresme and the Medieval Geometry of Qualities and Motions*, (Madison: University of Wisconsin Press, 1968), Part 1, Ch. i, lines, 35–38, pp. 166–169.

For a brief exposition of Aristotle's view, see Lindberg (1976), *Theories of Vision from Al-Kindi to Kepler*, pp. 6–9.

[xii] Oresme makes a similar submission of his work for correction to the Fellows and Masters of the University of Paris in the Prologue of his *De commensurabilitate.*

> "Non ergo dimisi quin hoc opusculum committerem sociis et magistris huius sacratissime universitatis Parisiensis sub eorum correctione qui absque detractionis livore soliti sunt benedicta reverenter suscipere et minus beene digesta emendare benigne."

Grant's English trans. reads:

> "For this reason I did not release this little book without [first] submitting it for correction to the Fellows and Masters of the most sacred University of Paris, who are accustomed to receive respectfully, without malicious slander, things that are well put, and to alter, in a kindly way, things not adequately formulated."

See Edward Grant's edition in Oresme's, *Nicole Oresme and the Kinematics of Circular Motion: "Tractatus de commensurabilitate vel incommensurabilitate motuum celi," edited with an introduction, English translation, and commentary by Edward Grant.* (Madison: University of Wisconsin Press, 1971), Prologue, lines 45–48, pp. 174–175, and p. 328, n. 8.

Likewise, Oresme also submitted his *Algorismus proportionum* for correction to Philippe de Vitry, Bishop of Meaux. See Edward Grant's translation in "Part 1 of Nicole Oresme's 'Algorismus proportionum,'" *Isis* 56 (1965): 328.

Grant rightly argues that the submission of the *De commensurabilitate* for correction to the Masters of the University of Paris implies the possibility of dating that work to "in or before 1362, the year Oresme probably relinquished the grand mastership of Navarre and presumably withdrew from full participation in university affairs." Grant (1971), *Nicole Oresme and the Kinematics of Circular Motion*, p. 5. A similar argument for the dating of the *De visione stellarum* can be made for the same reasons.

For a general overview of Oresme's prologues, which includes a discussion of his submitting his works for correction, see Clagett (1968b), *Nicole Oresme and the Medieval Geometry of Qualities and Motions*, pp. 139–141.

PART III

BIBLIOGRAPHY AND INDICES

I. BIBLIOGRAPHY

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INDEX OF LATIN WORDS

In each reference, the page number is followed by the line number in superscript. For example, "202^{14}" cites page 202, line 14.

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