

Is there a violation of the Copernican principle in radio sky?

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Cosmic Microwave Background Radiation (CMBR) observations from the WMAP satellite have shown some unexpected anisotropies, which surprisingly seem to be aligned with the ecliptic^{1,2}. This alignment has been dubbed the “axis of evil” with very damaging implications for the standard model of cosmology³. The latest data from the Planck satellite have confirmed the presence of these anisotropies⁴. Here we report even larger anisotropies in the sky distributions of powerful extended quasars and some other sub-classes of radio galaxies in the 3CRR catalogue, one of the oldest and most intensively studied sample of strong radio sources^{5,6,7}. The anisotropies lie about a plane passing through the two equinoxes and the north celestial pole (NCP). We can rule out at a 99.995% confidence level the hypothesis that these asymmetries are merely due to statistical fluctuations. Further, even the distribution of observed radio sizes of quasars and radio galaxies show large systematic differences between these two sky regions. The redshift distribution appears to be very similar in both regions of sky for all sources, which rules out any local effects to be the cause of these anomalies. Two pertinent questions then arise. First, why should there be such large anisotropies present in the sky distribution of some of the most distant discrete sources implying inhomogeneities in the universe at very large scales (covering a fraction of the universe)? What is intriguing even further is why such anisotropies should lie about a great circle decided purely by the orientation of earth’s rotation axis and/or the axis of its revolution around the sun? It looks as if these axes have a preferential placement in the larger scheme of things, implying an apparent breakdown of the Copernican principle or its more generalization, cosmological principle, upon which all modern cosmological theories are based upon.

Copernican principle states that earth does not have any eminent or privileged position

in the universe and therefore an observer's choice of origin and/or orientation of his/her coordinate system should have no bearing on the appearance of the distant universe. Its natural generalization is the cosmological principle that the universe on a sufficiently large scale should appear homogeneous and isotropic, with no preferred directions, to all observers. However to us on earth the universe does show heterogeneous structures up to the scale of superclusters of galaxies and somewhat beyond, but it is assumed that it will all appear homogeneous and isotropic when observed on still larger scales, perhaps beyond a couple of hundreds of megaparsecs. Radio galaxies and quasars, the most distant discrete objects (at distances of many gigaparsecs or further) seen in the universe should trace the distribution of matter in the universe at that large scale and should therefore appear isotropically distributed from any vantage point in the universe including that on earth. One of the earliest and best studied source of radio galaxies and quasars is the 3CRR (3rd Cambridge twice revised) catalogue^{5,6,7}, which is radio complete in the sense that all radio sources brighter than a certain sensitive limit are included and also it has complete optical identification content with detailed optical spectra to classify radio sources in to radio galaxies and quasars. The catalogue with the latest updates is downloadable from <https://www.astrosci.ca/users/willottc/3crr/3crr.html>.

The radio galaxies are broadly divided into two classes, Fanaroff-Riley type I and II (FRI and FRII), based on their radio morphologies⁸. When compared to FRIs, the FRII types are almost always found amongst the more powerful radio galaxies. Included among quasars are what are termed as weak quasars (WQ) or broad line radio galaxies (BLRGs), with broad emission lines seen in polarized optical emission, or/and compact optical nuclei detected in infrared or X-rays. FRII type radio galaxies are further sub-divided by their optical spectra into low excitation galaxies (LEGs) and high excitation galaxies (HEGs). The conventional wisdom⁹ is that steep spectrum ($\alpha > 0.5$) HEGs and quasars belong to the same parent population, excluding of course a small number of compact steep spectrum sources (CSSS, with angular size $\lesssim 2$ arcsec). In this unification scheme, the observed numbers and sizes of quasars are expected to be about a factor of two lower as compared to those of HEGs.

It was while investigating the unification scheme that we noted that the relative number of quasars and HEGs varies heavily within the 3CRR sample if we compared it in two adjacent and contiguous regions of the sky. A close investigation showed that HEGs, which are the largest number of the 3CRR constituents, are quite uniformly distributed over the

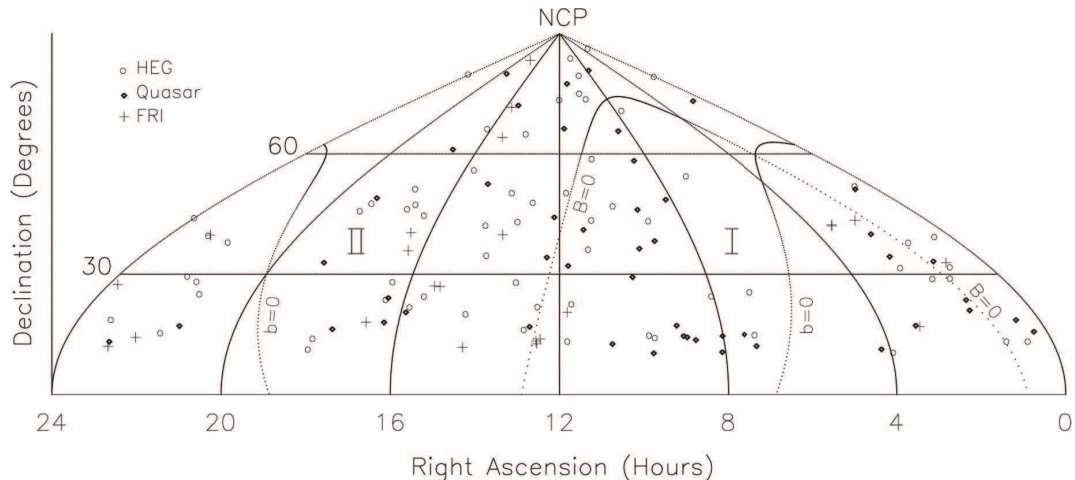


FIG. 1: The sky distribution of HEGs (empty circles), quasars (solid dots) and FRI type sources (plus signs) from the 3CRR sample shown in the sinusoidal (equal-area) projection. Region I extends in right ascension from 0 to 12 hour and region II from 12 to 24 hour. The dotted $b=0$ curve shows the path of the galactic plane, and $B=0$ shows the Supergalactic plane.

TABLE I: Counts of radio sources in two regions of the sky.

| RA(hours) | N(HEG) | N(Q) | N(LEG) | N(FRI) |
|-----------|--------|------|--------|--------|
| 00 – 24 | 65 | 48 | 17 | 23 |
| 00 – 12 | 32 | 33 | 11 | 6 |
| 12 – 24 | 33 | 15 | 6 | 17 |

observed sky, however quasars are quite unevenly distributed. To a first order, the maximum difference seems to occur when sky is divided into 0-12 hour (say, Region I) and 12-24 hour (Region II) in right ascension (RA). This division amounts to passing a great circle between the equinoxes (intersection points of the equatorial plane and the ecliptic) and the NCP. While slightly more than two thirds of the quasars in the catalogue lie in region I, the remainder of them appear in region II. Probability of such an anomaly occurring (at $\sim 2.6\sigma$ level) in a binomial distribution due to statistical fluctuations is less than one percent¹⁰.

Figure 1 shows the distribution of 3CRR sources in the sinusoidal (equal area) projection in sky, where we readily see the uneven distribution of quasars between regions I and II. The zone of avoidance ($\pm 10^\circ$) about the galactic plane ($b=0$) is almost evenly distributed between the two regions, with only a marginal excess in region I. If anything, due to this the number of quasars should only be lower in region I, opposite to what actually seen. Also a

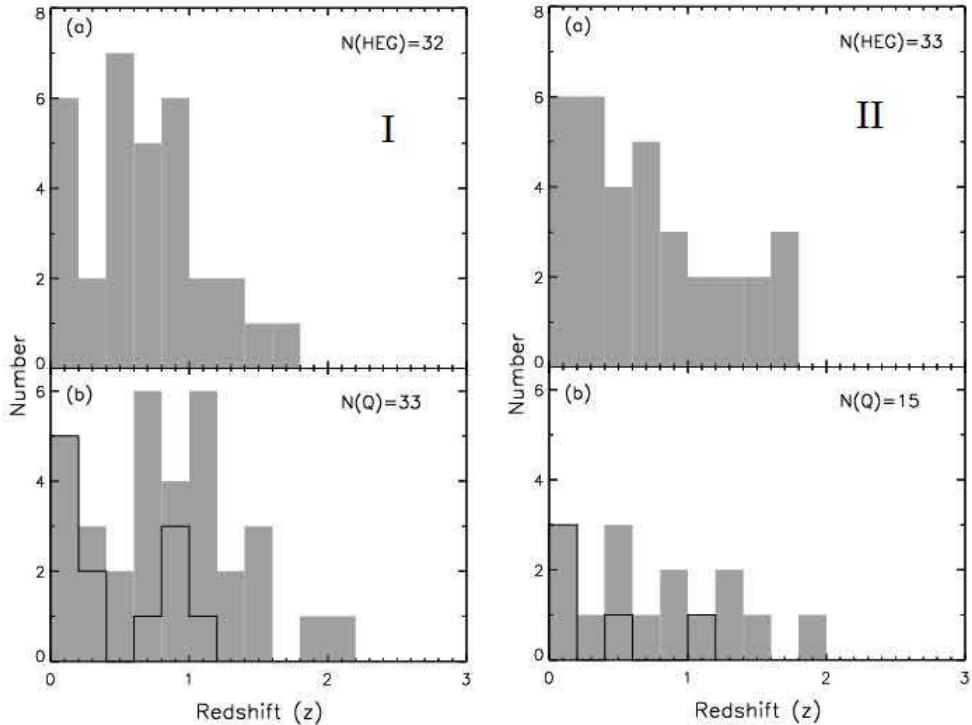


FIG. 2: Histogram of the redshift distributions of the 3CR sample in regions I and II of the sky (a) for HEGs (b) for quasars. In the lower panels, the region under the overlaid dark line represents weak quasars (WQs) or BLRGs. $N(\text{HEG})$ and $N(\text{Q})$ give the number of high excitation galaxies and quasars respectively, in each plot.

number of quasars which seem to lie in the supergalactic plane ($B=0$) at $ra \sim 0-03$ hour are actually at high redshifts, the lowest being at $z=0.425$. Therefore being at least hundred times more distant than the local virgo-supercluster, they are in no way physically related to it or other local objects. We also note from Figure 1 (and Table 1) that even FRI types have a highly asymmetric number ratio of about 1 to 3 in the two regions, but in opposite sense to that of quasars. Similarly LEGs also have a number ratio of about 2 to 1 in regions I and II (Table 1). It is to be noted that all of these asymmetries have independent binomial probabilities if these are due to a random statistical fluctuation, and then their combined probability of occurrence due to being simply a statistical fluctuation is only about 5×10^{-5} .

These results are robust. There is little likelihood that these anomaly could be the result of, e.g., some missing sources in the 3CRR catalogue, as this is one of the most thoroughly studied radio complete sample of sources, in the sense that all source above the sensitivity

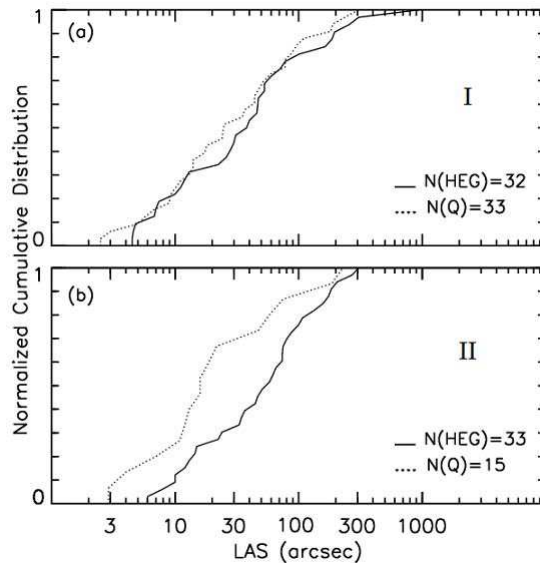


FIG. 3: Normalized cumulative distributions of largest angular size (LAS) of HEGs (continuous curves) and quasars (broken curves) for the 3CR sample (a) for region I (b) for region II. $N(\text{HEG})$ and $N(\text{Q})$ give the number of High Excitation galaxies and quasars respectively, in each case.

limit of the catalogue have been detected and listed. Additionally in the distribution of quasars (and as well of HEGs) there does not appear to be any gross changes with redshift, in the two regions (Figure 2). Even the weak quasars (WQs) have a similar redshift distribution as the quasars, so any anomaly in quasar distribution is certainly not due to a differential number of WQs. This almost rules out that the difference in the number of quasars between the two regions has any local galactic or supergalactic origin.

Figure 3 shows normalized cumulative plots of angular size distributions of HEGs and quasars in the two regions. As expected in the unification scheme, quasar sizes should be smaller than those of HEGs, and we do see such a thing in region II. However in region I, there seems no such systematic foreshortening of the quasar sizes. Since redshift distribution is very similar, it is not necessary to convert the angular sizes into linear sizes (using a particular cosmological model) for the comparison of their sizes. The number and size distribution data in region I seems to punch a hole in the unification scheme, however here we have even bigger things at stake.

It is to be noted that a large scale dipole anisotropy in radio source distribution at much fainter levels was seen earlier, and was interpreted due to motion of the solar system with respect to a reference system based on an average universe, though the motion was found

to be about a factor of four larger¹¹ (1500 km s^{-1}) than for CMBR by COBE¹² or WMAP¹³ (369 km s^{-1}). However the present anisotropies could not be caused by a motion of the solar system as it could not give rise to different anisotropies for different objects. We have seen that while HEGs numbers are evenly distributed, quasars and LEGs have excess in region I, but FRI's are found to be more in region II. Further, observer's motion cannot in any case explain the very different radio size distributions of quasars and radio galaxies in the two regions.

There is certainly a cause for worry. Is there a breakdown of the Copernican principle as things seen in two regions of sky divided purely by a coordinate system based on earth's orientation in space, shows a very large anisotropy in source distribution? Why should the equinox points and the NCP should have any bearing on the large scale distribution of matter in the universe? Even if in future it does turn out one could explain away these anomalies due to some subtle local effect, still these will be important as number counts or many other cosmological evolution studies of radio population have been made using 3CRR source distributions and where implicit assumption was an isotropic distribution of radio sources in the 3CRR sample (or at least presence of no such big anomalies), whether for quasars or other radio objects. And all these might require at least a relook at some of these results.

The apparent alignment in the cosmic microwave background (CMB) in one particular direction through space is called "evil" because it undermines our ideas about the standard cosmological model^{1,2,3}. But it has to be kept in mind that all such observations are obscured by the disc of the milky way galaxy, and one has to be extra careful while interpreting the data. But no such effect will be expected in number ratios of discrete sources, and certainly not in their radio size ratios. The axis of evil passes very close to the line joining the two equinox points, and so does the dipole direction representing the overall motion of the solar system in the universe^{1,2,3}. Also our plane dividing the two regions of asymmetry passes through the same two equinox points. But it is not clear whether the asymmetries seen by us are related to that in the CMBR, as it is not presently possible to see if the anomalous distribution of radio sources is really related to ecliptic coordinates as the region covered by the 3CRR, unlike equatorial coordinates, is not divided equally in two ecliptic hemispheres. Perhaps an all-sky coverage in future will help resolve this issue. But irrespective of that there is no denying that from the large anisotropies present in the radio sky, independently

seen both in the discrete source distribution and in the diffuse CMBR, the Copernican principle seems to be in jeopardy.

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