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Distribution of Quasars on the Sky

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Abstract. It is shown that high-redshift quasars of bright apparent magnitude are concentrated in the direction of the centre of the Local Group of galaxies. A number of them are distributed along a line originating from the Local Group companion galaxy, M 33. A similar, but shorter and fainter line of quasars is seen emanating from the spiral galaxy NGC 300 in the next nearest, Sculptor Group of galaxies.

The concentration of bright quasars in the Local Group direction is supported by bright radio sources catalogued in high-frequency surveys. One of the consequences of this large-scale inhomogeneity is to explain the different gradient of radio source counts in the direction of the Local Supercluster, a result discovered in 1978 but never investigated further.

Previously reported homogeneity and isotropy of radio-source counts over the sky would seem to be an effect of integrating nearby, large-scale groupings with more distant, smaller-scale groupings over different directions in the sky. More careful analyses as a function of flux strength and spectral index on various scales over the sky are now required. Previous conclusions about radio source and quasar luminosity and number evolution drawn from log *N*–log *S* counts would then need to be re-evaluated.

Key words: quasars, alignment—galaxies, Local Group, Sculptor Group—radio sources, counts

1. Introduction

Evidence that quasars are not at the great distances which conventional interpretations of their redshifts would require was first put forward eighteen years ago (Arp 1966). The evidence consisted of quasars falling closer to low-redshift galaxies than expected by chance, alignments with active galaxies, and associations with radio sources which are aligned with galaxies (Arp 1967, 1970). One consequence of associating quasars with nearby galaxies (galaxies with redshifts of the order of $v \simeq 1000$ km s^{-1}) was that many quasars were seen between galaxies; in areas where they seemed unassociated. This required that quasars must be distributed over a large angular extent of the sky around each galaxy of association. There needed to be field regions in which adjoining associations overlapped. Of course it was clear that very nearby galaxies would then have associated quasars which would appear projected over very large regions of the sky. Since there were far fewer very nearby galaxies, however, it was anticipated that they would only contribute small numbers of brighter quasars to the observed population.

The clue that these very nearby quasars were more important than originally perceived came from quasar surveys which showed groupings of quasars which favoured certain redshifts. Surveys which searched for ultraviolet excess candidates to faint apparent magnitudes over moderately large areas of the sky (Arp, Sulentic & di Tullio 1979; Arp & Hazard 1980; Surdej *et al.* 1983) showed some small groupings of $z \simeq 1$ quasars (Arp 1983b). The implication was that these quasars were relatively distant and that therefore the $z \simeq 1$ quasars were intrinsically more luminous than quasars of other redshifts. This conclusion was supported when tested on a group of quasars which had been identified as belonging to the Local Supercluster (Arp 1970). A plot of these quasars in the redshift-apparent-magnitude diagram revealed a preponderance of quasars near $z \simeq 1$, with quasars of higher and lower redshift having systematically fainter apparent magnitude (for analysis see Arp 1983b). If any quasars of redshift $z \sim 2$ were present in the Local Supercluster, they were apparently too faint to be seen. The crucial question then presented itself in the following form: If the quasars of redshift $z = 2$ are the least luminous, then those of the brightest apparent magnitude should be, of all quasars, the ones closest to us in space. Where were they located in the sky? The answer to that question proved to be quite stunning. First of all, it appeared that the quasars of $z \sim 2$ were concentrated toward one area of the sky. Secondly, that area was the direction of the centre of the Local Group of galaxies.

Since then, investigations of quasar groupings from this new perspective has led to some interesting results which are described in the present paper. In turn these results suggest new lines of analysis which may be able to promote further understanding of the spatial distribution of different kinds of quasars and radio sources.

2. The concentration of quasars in the Local Group

A striking example of an inhomogeneous distribution of a particular kind of quasar can be seen by noting that the distribution of radio quasars in the general direction of the Local Supercluster (9^h < R.A. < 15^h) shows a marked sparsity of quasars with $z \sim 2$. In contrast there is a strong concentration (by about a factor 3.5) of these kinds of quasars in the direction of the centre of the Local Group of galaxies (21^h < R.A. < 3^h). The plots are shown in Fig. 20 of Arp (1983b). This can hardly be a selection effect because all these quasars are from complete radio surveys of strong sources such as 3C and Parkes which are uniform around the sky in the declination zones involved. (Additional discussion of this point will be made in Section 4).

But if we look within the region of greatest concentration in the direction of the Local Group, we see a distinct line of high-redshift quasars extending from the region of the Local Group companion galaxy, M33. This line was first shown in Figs 21 and 22 of Arp (1983b), then in Arp (1984a, b). In Fig. 1 of the present paper, however, the line is shown at its most conspicuous because only those high-redshift quasars with radio fluxes between $0.3 \leqslant S_{11} \leqslant 1.0$ are plotted.

The enhancement of this line is an important feature because if there were a physically associated group of quasars we would expect these quasars to be distinguished from others in the area by characteristic values of parameters such as radio strength. On the other hand, if they were not physically associated there would be no particular parameters which should artificially create a line.

The statistical significance of the line needs to be tested taking into account the

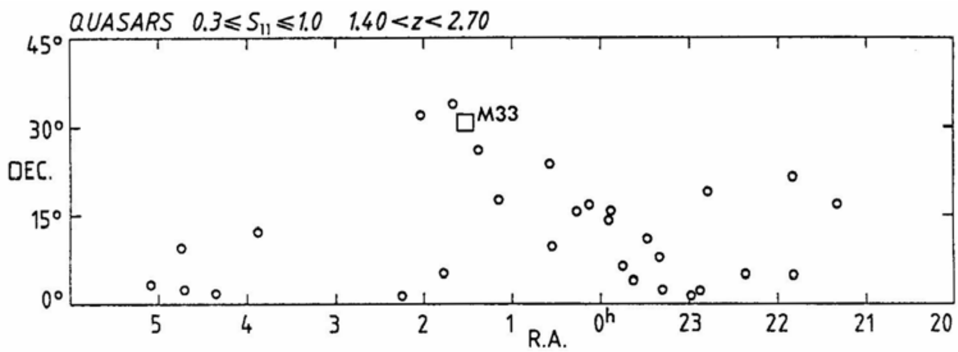

Figure 1. All radio quasars between the indicated limits of flux strength and redshift are plotted in the direction of the Local Cluster of galaxies. Data is from quasar catalogue of Veron-Cetty & Veron (1984).

effective boundaries of the region and the curvature of straight lines projected onto the sky in these coordinates. Such tests are being carried out by J. V. Narlikar and his associates (personal communication). Pending those results I will take the standpoint that the line is *prima facie* significant. Some questions that naturally arise about the line, I will try to comment on at this point.

2.1 *Comments on the Line*

Why a line and why M33? From the earliest associations of quasars with low-redshift galaxies the conclusion was that the quasars, like some other radio sources, were ejected out on either side of active galaxies. Evidence throughout the years has tended to empirically support the association of quasars in lines and pairs across the central galaxy (Arp 1980, a). Furthermore, by about 1975 (Arp, Baldwin & Wampler 1975), it began to become apparent that while quasars could be associated with a range of morphological types of galaxies, there was a distinct preference for them to be associated with galaxies which were companions in groups (for latest summary see Arp 1983a). M33, of course, is the most conspicuous companion to M31, the dominant member of the Local Group of galaxies. Finding quasar associations with this nearby companion galaxy fulfilled the predictions of the earlier work. Moreover, since our own Milky Way galaxy is also a companion in the Local Group, we would predict that the nearest quasars of all would belong to our own galaxy (see Arp 1984b).

Another aspect of the line as shown in Fig. 1 and perhaps even better in Fig. 2, is that toward the southwest end the line becomes broader and the quasars tend to become brighter and more radio-strong. This implies that the line of quasars to the SW of M33 is oriented at least somewhat toward us, reaches an appreciable portion of the distance toward us, and this to some extent accounts for the broadening of the line toward the SW end. Of course, the line of quasars does appear to extend on the other side of M33 to the NE. But it is difficult to be certain of the nature of the line in this direction for two reasons: (1) The galactic latitude N of M33 is becoming quite low and it is unclear how completely even strong radio quasars are known at very low galactic latitudes. (2) The Perseus cluster of galaxies is NE of M33 in the general direction of the line, and just on the basis of radio sources, may become entangled.

Finally, we can comment that some quasars fall off the line to the east of the line.

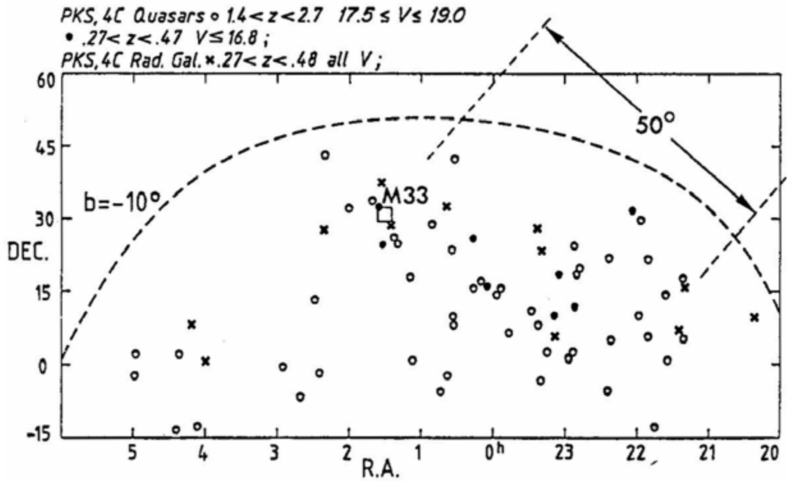

Figure 2. Radio quasars between the indicated limits of redshift and apparent magnitude. All quasars from the catalogue of Hewitt & Burbidge (1980). Open circles are high-redshift quasars as in Fig. 1. Filled circles are quasars of $0.27 < z < 0.47$ and crosses are radio galaxies in the same redshift range.

From a study of quasars and radio sources of all types which fall in this region it is my opinion that there are two subconcentrations of quasars; one associated with NGC 520 ($1^h22^m + 3°32'$) and a line to the SW (see Arp 1983b), and the other with 3C120 ($4^h + 5°14'$). This identification would probably require that both NGC 520 and 3C120 be peculiar, anomalously high-redshifted members of the Local Group.

2.2 *Concentrations of Other Kinds of Quasars toward the Local Group Centre*

It was noted in the Introduction that quasars of redshifts lower than the $1.4 < x < 2.7$ ones we have been considering turn out to have generally higher intrinsic luminosities. If we include, therefore, brighter quasars of lower redshift we should obtain a sample containing the remaining quasars in the Local Group. As Fig. 2 shows, these quasars, which are like 3C48, fall in a line extending SW from M33. This line may be rotated slightly anticlockwise from the line of the high-redshift quasars but it is close enough to give very good confirmation of that line which appeared in Fig. 1. Similarly, the radio galaxies which have the same redshifts as the low-redshift quasars (crosses in Fig. 2), corroborate the low-redshift quasar line.

One very strong conclusion we can come to from Fig. 2 is that even if the quasars were not associated with M33, this strong concentration of quasars of widely different redshifts in one area of the sky would by itself rule out the cosmological interpretation of the quasar redshifts. This is because if the redshifts were to be interpreted as distance indicators, we would have a long tube of quasars pointing at the observer.

3. High-redshift quasars in the region of the Sculptor Group of galaxies

Objective prism searches are particularly effective at discovering quasars with $z > 1.8$ because the Lyman-alpha emission line, the strongest in the quasar spectrum, comes

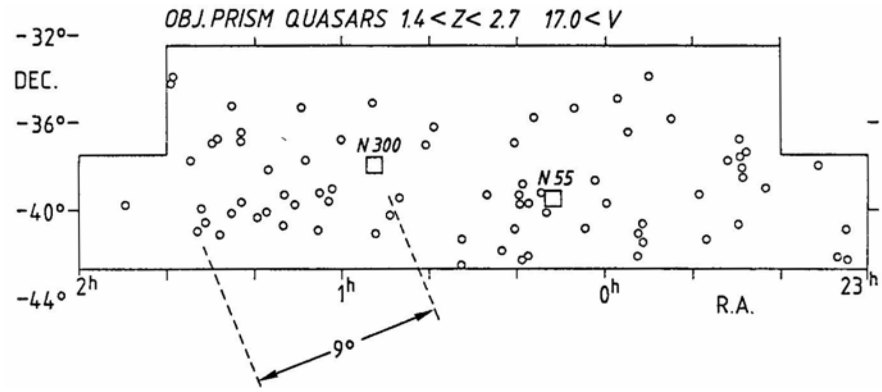

Figure 3. All quasars discovered by objective prism search techniques in and around the region of the Sculptor Group of galaxies. Quasars tabulated in Osmer & Smith (1980) and in Arp (1984c). The Sculptor Group galaxies, NGC 300 and NGC 55 are marked by open boxes

into the recorded spectral window at this redshift. Objective prism searches for quasars were carried out in the Dec. = –40° strip (Osmer & Smith 1980) and in a smaller supplementary region in the Dec. = –35° zone by Arp (1984c). This region, as outlined in Fig. 3, passes over the southern part of the Sculptor Group of galaxies. NGC 253, the largest angular extent galaxy in the Group is outside the frame at Dec. = –25°. But two of the larger Sculptor Group galaxies, NGC 300 and NGC 55 are shown by open boxes in Fig. 3.

Since the Sculptor Group is only about a factor of two more distant than M33, it is interesting to test whether in this Sculptor Group of high-redshift quasars there are any similar phenomena as those observed around M33. There are! As the earliest results in this strip showed (Osmer 1981; Arp 1980b) there is a strong concentration of quasars some degrees away from NGC 300. This line SE of NGC 300 shows conspicuously in Fig. 3 where it has been estimated to have about 9° projected length on the sky. If the line of quasars from M33, estimated at ~ 50° on the sky from Fig. 2, were moved to twice the distance, in the Sculptor Group, it would appear ~ 25° long. Considering the arbitrary angle of orientation which these lines can have toward the observer, the agreement between the projected length of the M33 and NGC 300 line of quasars is quite satisfactory.

It is of interest then to compare the apparent magnitudes of the quasars in these two lines. Fig. 4 does this. It is seen that the quasars in the M33 line are about $1\frac{1}{2}$ magnitudes brighter than those in the NGC 300 line. This is just the amount expected from the relative distances of the two galaxies.

Several comments could be made about Fig. 4. One is that the M33 quasars are radio quasars that come from larger areas of the sky than the objective prism quasars. This is a selection in the direction of brighter quasars. Also, the radio quasars are given in broad-band magnitudes—not in continuum magnitudes which are somewhat fainter for an individual quasar (Arp 1983a). On the other hand, the NGC 300 quasars seem to be still increasing in number toward the plate limit which is usually about 19.5 mag for these objective prism plates. So, the average apparent magnitude could be fainter than indicated in Fig. 4. In summary it seems fair to say about Fig. 4 that although there are

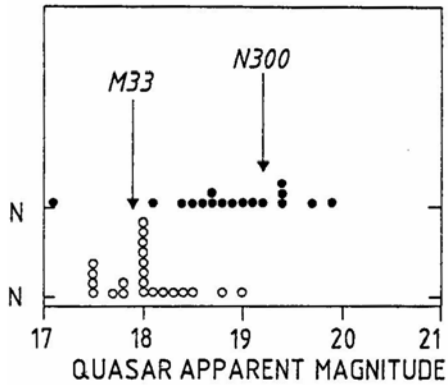

Figure 4. Distribution of apparent magnitudes in the M33 and NGC 300 lines of quasars. M33 magnitudes from Hewitt & Burbidge (1980), NGC 300 magnitudes from Osmer & Smith (1980).

these factors of uncertainty, if the two sets of quasars differed in distance by a factor of two then the average magnitude difference would be close to the one observed.

An opportunity to confirm the physical reality of the line of quasars coming SE from NGC 300 comes from H I observations of NGC 300. Matthewson, Cleary & Murray (1975) discuss an apparent extension of hydrogen from NGC 300 in a direction which coincides with the line of quasars (see discussion in Arp 1980b, p. 467). A similar, extended cloud of H I (Wright 1974) lies SW of M33 in the approximate direction of the line of quasars discussed in this paper.

It is also of considerable importance to note in Fig. 3 that there is a quite plausible line of quasars extending to the NW of NGC 300, marking a possible extension of the quasar line to the other side of NGC 300. Also of importance in Fig. 3 is the obvious grouping of high-redshift quasars around NGC 55. This grouping could also be part of line extending away to the SW and on the other side in a direction which would take it just north of NGC 300. We must also remember that NGC 253 is a large, active galaxy (Ulrich 1978) just north of the frame in Fig. 3 and that there are other companion galaxies in the Sculptor Group. The point is that if companion galaxies generally have lines of quasars coming from them they will, in many groups, appear to intersect and become confused. Only the cases of strong concentrations and favourable orientation may, if we are fortunate, be clearly identifiable.

4. The overall asymmetry between the Local Group and Local Supercluster direction

In the Introduction it was mentioned that there is a strong factor of 3 to 4 times as many high-redshift quasars in the Local Group direction than there is in the Local Supercluster direction. This difference was noted as long ago as 1966 by Strittmatter, Faulkner & Walmsley in the sense that they reported that the high-redshift quasars were distributed on the sky differently from the low-redshift quasars*. In an analysis by Arp (1984a, Fig. 3) it was shown that the kinds of quasar redshifts present in the line and region SW of M 33 were completely different from the kinds of redshifts present over

* After the writing of this paper the article by Shastri & Gopal-Krishna (1983) appeared. They independently report an inhomogeneous distribution over the sky of quasars with $z > 2$.

the R.A. = 12^h region. This result is so devasting for the cosmological interpretation of quasar redshifts that I expect that it will be attacked intensely. Therefore, I would like to discuss here some of the possible criticisms of this result.

First of all, the quasars which establish this asymmetry are all radio quasars from 3C and Parkes radio surveys. The 4C survey quasars also support the result. At any given declination zone these surveys are complete in right ascension. Therefore there should be no reason why radio quasar candidates in the 0^h right ascension region should be different from radio quasar candidates in the 12^h region. It might be argued that high-redshift quasars are preferentially flat spectral-index quasars (Kraus & Gearhart 1975) and that the Greenbank high-frequency survey (Pauliny-Toth *et al.* 1972) and the Ohio State Survey (Dixon & Kraus 1968; Fitch, Dixon & Kraus 1969) detected 3C and Parkes sources preferentially in the 21^h < R.A. < 4^h region which were then measured optically. The counterarguments to this scenario are that the Ohio State surveys observed about the same total area in the 12^h region as the 0^h region. Moreover, the University of Texas Deep Radio Survey from which the complete quasar samples of Wills & Wills (1979) were drawn, were from 03^h30^m < R.A. < 23^h30^m, specifically excluding the 0^h region. The 3C radio sources have, of course, been exhaustively observed all over the sky (Kristian, Sandage & Katem 1974). Therefore, though there may be minor sampling inhomogeneities, the conclusion would seem to be that—on the average—3C and Parkes quasar, candidates were observed about equally around the sky.

But to make the argument completely rigorous it would be helpful to find a high-frequency radio survey which identified radio quasar candidates all around the sky. Then we could check the frequency of the quasar candidates *before* they had been measured for redshift. Fortunately, the Parkes 2700 MHz survey fulfils these conditions ideally. In a zone 4° < Dec. < 25° which passes through the concentration toward the Local Group centre which we have discussed in Figs 1 and 2. Shimmins, Bolton & Wall (1975) have identified all blue stellar candidates which coincide with their measured radio source positions. Fig. 5 shows a plot of these candidates all around the sky in R.A. The clear-cut result which emerges from this plot is that the 2700 MHz quasar *candidates* are just about 3 times more numerous in the previously named direction of the Local Group than they are in a comparable section in the 12^h region. This high-frequency survey therefore demonstrates a strong excess of quasars in the Local Group direction and the argument cannot be made that the two regions have equal numbers of high-frequency quasar candidates from which 0^h region candidates were favoured for optical measurement.

There is a concentration of quasar candidates between 16^h30^m > R.A. > 14^h30^m in Fig. 5. That region of the sky encompasses the Hercules Supercluster (Tarenghi *et al.* 1980). The Hercules cluster itself is well-known for containing numerous disrupted and active galaxies. Presumably it is more distant than the groups we have been discussing so far and we would therefore expect quasars nearer $z \simeq 1$ in redshift. A survey of flat spectrum radio quasars in the Dec. ± 4° zone shows six quasars in the range 14^h < R.A. < 16^h with $1.3 < z < 1.6$ (Wampler, personal communication). That there are concentrations of quasars over the sky on different scales and at different distances can hardly be doubted. What is important now is to measure systematically their redshifts and magnitudes and to try to identify where they are located in distance. Systematic measurement of all 2700 MHz quasars pictured in Fig. 5 would be a very interesting start on this problem.

Table 1. 2.7 GHz radio sources, $4° < \text{Dec.} < 25°$.

R.A.	6^h		5^h		4^h		3^h		2^h		1^h		0^h		23^h		22^h		21^h		20^h
No.		7		14		4		14		11		13		11		11		6		7	
R.A.	18^h		17^h		16^h		15^h		14^h		13^h		12^h		11^h		10^h		9^h		8^h
No.		13		12		8		9		2		10		6		6		2		3	

$N(0^h) = 66$
$N(12^h) = 35$

Table 2. Bologna radio sources, $1 \leqslant \text{peak flux} \leqslant 14$.

R.A.	6^h	5^h	4^h	3^h	2^h	1^h	0^h	23^h	22^h	21^h	20^h	
Integ. flux*	23	26	27	23	41	31	27	25	27	23		$34°02' > \text{Dec.} > 29°18'$
Integ. flux*	47	25	30	34	49	26	37	25	25	30		$29°30' > \text{Dec.} > -24°02'$
Total	70	51	57	57	90	57	64	50	52	53		

* Sums of integers of fluxes only

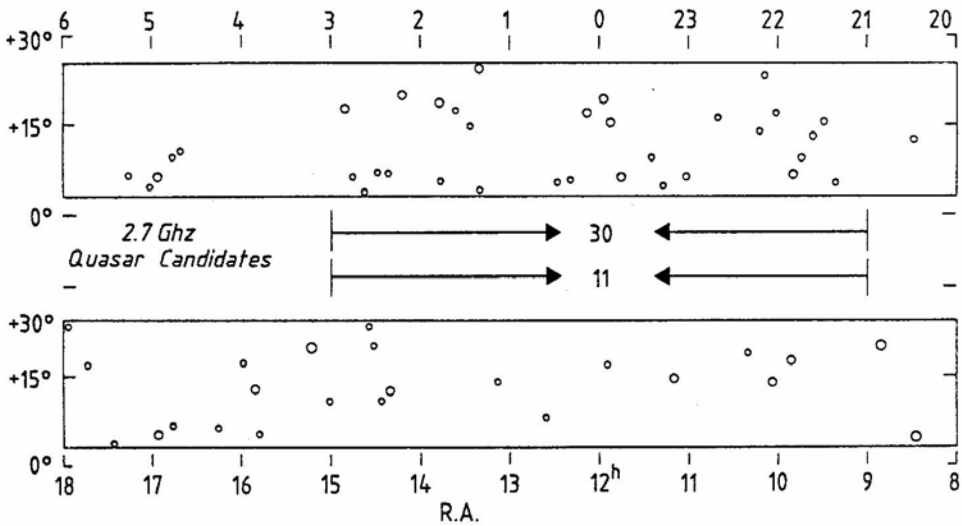

Figure 5. Plot of all quasar candidates (blue stellar objects at the position of radio source) from Parkes 2.7 GHz survey between 4° < Dec. < 25° (Shimmins, Bolton & Wall 1975). Total numbers are shown for a 6^h stretch of R.A. centred on 0^h and 12^h respectively.

5. Distribution of radio sources on the sky

The high-frequency quasar candidates pictured in Fig. 5 lead us to some interesting considerations about the distribution of radio sources. The question that is posed is whether the asymmetries and groupings shown by the radio quasars are reflected in distributions of radio sources in general.

Table 1 shows that the concentration of 2.7 GHz radio sources in the 0^h region relative to the 12^h region is present in all the radio sources taken together as well as in just the radio quasar candidates. The radio N (0^h)/N (12^h) is greater for just the quasar candidates alone but because of the larger numbers involved in the total radio source count the imbalance is as significant or perhaps even more significant for the latter. In Table 2 we give the approximate integrated flux of Bologna radio sources (Colla *et al.* 1970, 1972) across the 0^h region. For all sources including the faint ones, the Bologna counts are rather level from R.A. = 20^h to 6^h. But for brighter sources, f.u. > 1, the summed flux rises significantly going across the centre of the 0^h region. Particularly across the position of M33, the total sum of bright-source flux reaches about 90, far in excess of base values on either side of the position of M 33. This is true even though we have omitted the strong radio source 3C48 at 37 Jy which is so close to M33. Previously it had been shown that the high-frequency radio sources from Galt & Kennedy (1968) (see Arp 1984b for analysis) peaked at the position of M33. All the radio surveys seem to show this peaking around M33.

Additionally, we can remark that the 5 GHz source counts between 70° > Dec. > 35° peak in 23^h < R.A. < 1^h region (Pauliny-Toth *et al.* 1978). This last point is a little difficult to interpret because so much of this region is at low galactic latitude. Taken together, however, all these sample cuts indicate a general increase in raw radio source counts as one crosses a position toward the centre of the Local Group.

Such a result confirms in a little more detail the significant difference found for the gradient of radio source counts off and on the position of the Local Supercluster (Pauliny-Toth *et al.* 1978). Careful inspection of that result shows that it was the presence of strong radio sources *away* from the Virgo region which gave the steeper gradient of log *N*-log *S* counts for the Local Supercluster. This would be interpreted, in terms of the discussion here, as due to the relatively bright radio sources contributed by the large area of the 0^h region which encompasses the Local Group direction.

The conclusion from this discussion would seem to be that there are significant groupings of radio sources in various regions of the sky. The claim that the radio sources are uniformly distributed over the sky (Webster 1977; Fanti, Lari & Olori 1978) must have come from having integrated over regions of different characteristics in different directions. The consequences of this are quite serious because the log *N* –log *S* curves which were supposed to be uniformly applicable have been used to derive conclusions about strong evolution as a function of look-back time in the universe. It would not have been very satisfactory to obtain different evolution rates in different directions in the universe.

In summary, it has been the supposed homogeneous distribution of quasars and radio sources which were used to support the interpretation of distant quasars and distant radio sources. These distributions, when looked at closely as we have started to do here, are in fact not homogeneous at all, but instead show groupings and concentrations which support specific local concentrations of radio sources and quasars. It would seem necessary now to make a re-analysis of radio-source distributions *de novo* paying close attention to distributions as a function of flux strength and testing for associations on a variety of angular scales.

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