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Quasars in the Central Region of the Virgo Cluster

Halton Arp* *Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington, 813 Santa Barbara Street, Pasadena, CA 91101–1292, USA*

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Abstract. Quasars found from objective prism searches have been reported to show no association with galaxies in the Virgo Cluster. A simple analysis here shows significant association of the brightest of these quasars with core galaxies in the Virgo Cluster.

Key words: quasars, associations, redshift periodicities—galaxies, Virgo Cluster, alignments

1.Introduction

In 1978 three objective prism photographs were obtained of the central region of the Virgo Cluster with the United Kingdom Schmidt telescope in Australia. The plates were searched for quasar candidates by X.T. He. He reported that the quasars fell closer to the bright galaxies in the area than they did to the faint galaxies (personal communication). The analysis did not appear, however, until 1984 (He, Cannon, Peacock, Smith, & Oke, 1984). The conclusion was then put forward that there was '. . . no conclusive evidence for quasar-galaxy associations in this field. . . '. Actually within the body of the paper a different statement was made: that with the one-dimensional Kolmogorov-Smirnov test, '. .. no significant [associations] were found for any galaxy sample with the exception of the 15 galaxies brighter than m = 12.’

There is an obvious association in the data, however, an association of quasars and galaxies of just the kind evidenced by many previous investigations. I discuss this association in the following note.

2. The bright quasars and Virgo core galaxies

Selection of quasar candidates was limited to the central 5° × 5° area of the objective prism Schmidt plate (He *et al.* 1984). Virgo galaxies occur throughout this area but the brightest galaxies are concentrated toward the centre. When an association of the quasar candidates with the 15 galaxies brighter than m = 12 was found it is surprising that association with even brighter galaxies were not tested. It is visually obvious that the very brightest galaxies are even more centrally concentrated and of course the very brightest galaxies best define the core or apparent centre of the Virgo Cluster.

*Alexander von Humboldt Senior Scientist, awardee at the Max-Planck-Institut für Astrophysik, Garching, FRG.

But an even more obvious association is present in the data in just the sense which has been predicted by previous quasar-galaxy associations. The observations have shown (Arp 1970; Burbidge, O'Dell & Strittmatter 1972; Sulentic 1981; Arp 1983) that galaxies closer to the observer have quasars closer to the observer also, and therefore, in general, brighter galaxies are associated with brighter quasars. If we were to concentrate our attention instead on just the galaxies at the exact distance of the Virgo Cluster, of course the brightest galaxies would be generally the largest and most massive. If these more massive galaxies produced more massive, luminous quasars or gravitationally bound such quasars, then these galaxies would be expected to have the strongest association of quasars. So on either grounds the brightest quasars would be expected to be associated with the brightest galaxies.

Fig. l(a) shows the quasar candidates which He *et al.* tested for association with the galaxies in the region. Directly below, Fig. l(b) shows just the brightest quasars ($m \lesssim 18.5$ mag). The different distribution of these bright quasars is very striking. In addition, the location of the four brightest E galaxies in this region is shown. The general association of these bright galaxies and these bright quasars is so evident that it scarcely requires statistical testing although a simple test will be applied below.

2.1 *The Virgo Core*

It is well known that the stellar populations of which E galaxies are composed have the largest mass-to-light (*M/L*) ratios, more than an order of magnitude higher than for spiral galaxies. Therefore E galaxies are vastly more massive than spirals of comparable brightness. It was shown many years ago (Arp 1968) that the E galaxies in the Virgo Cluster defined a line coincident with the jet and counterjet which emerges from the dominant galaxy, M 87. This line is shown dashed in Fig. l(b). (The alignment is also discussed in the immediately preceding paper.) Since the E galaxies which define this line are among the brightest in the Virgo Cluster they are by far the most massive. This line therefore defines the core mass of the Virgo Cluster. It is an extremely interesting result that it is the most massive galaxies in Virgo with which the brighter quasars are associated.

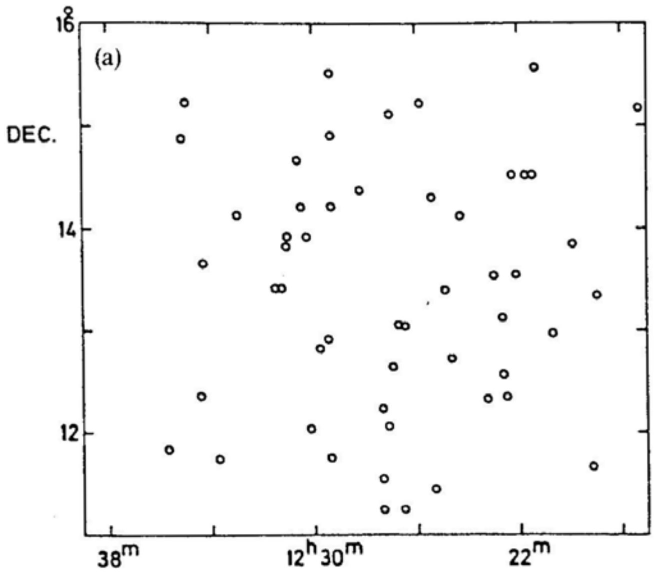
2.2 *Statistical Association with the Core of the Virgo Cluster*

The simplest statistical test of association we can perform involves these core galaxies. Of all the galaxies classified in 1961 by de Vaucouleurs in this region, only 13 were designated E galaxies. In 1968 Arp showed that these were the galaxies which formed the core of the Virgo Cluster, aligned across M 87 as discussed above and indicated in Fig. l(b). The most recent classification of all E galaxies in the region is by Sandage & Tamman (1981) in the Revised Shapley-Ames Catalog. The 11 E galaxies they list give an even tighter definition of the line through M87 than the 1961 de Vaucouleurs' classification.

Now we see from the work of He *et aï* that two of the galaxies in this alignment of 11 have bright quasars which fall astonishingly close by. For all quasars on the sky, a conservatively large density would be 0.4 deg $^{-2}$ brighter than continuum magnitude m =18.5 mag (Arp 1981,1983), Quasars selected by objective prism searches show less than half such densities.The eight quasars pictured in Fig. 1(b),computing for an area

THE CORE OF THE VIRGO CLUSTER

a) QUASAR CANDIDATES



b) BRIGHTEST CONFIRMED QUASARS AND CORE GALAXIES

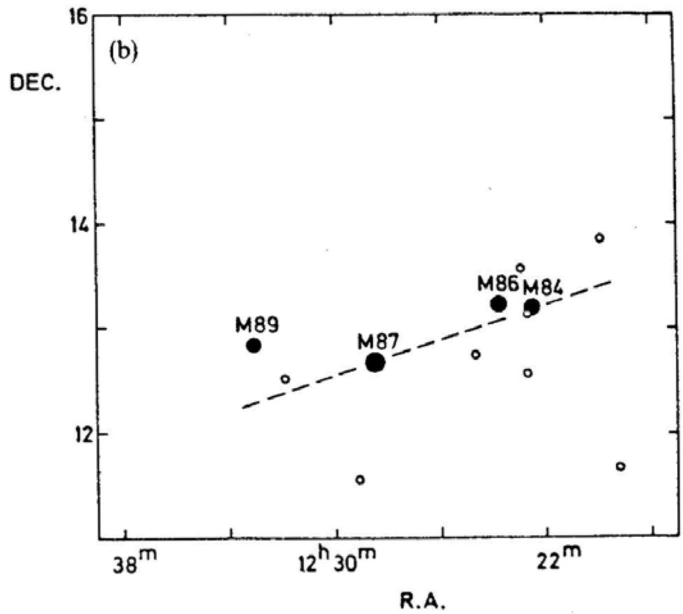


Figure 1. (a) Plot of all objective quasar candidates from He *et al.* (1984) in region near the centre of the Virgo Clustei. Note that Fig. 5 in He *et al.* (1984) is plotted with incorrect direction of right ascension, (b) Plot of all confirmed quasars with continuum magnitude $m \lesssim 18.5$ mag. Filled circles represent the four brightest E galaxies in the field. The dashed line represents the alignment of all E galaxies in the field along the M 87 jet and counterjet as defined in 1968. One object of $z = 0.235$ has been omitted and one quasar found from ultraviolet excess has been included. There are no further quasar candidates brighter than the present, 18.5 mag limit in Tables 2 and 3 (a) of He *et al.*

of $\frac{1}{2} \times 25$ deg^{-2}, give a local density of about 0.64 deg^{-2}. This is already beginning to be an excess density in an absolute sense. We adopt an average expected density for computational purposes of 0.5 deg^{-2}. This yields individual probabilities for the two quasars very near galaxies as:

$P \simeq 2 \times 10^{-3}$ for quasar at 2.3 projected distance from m84.
$P \simeq 3 \times 10^{-4}$ for quasar at 0.8 arcmin projected distance from NGC 4550.

We can ask the simple question of how likely it is, in a sample of 11 objects to find two events with probability of $\simeq 2 \times 10^{-3}$. The answer from the binomial distribution function is 2×10^{-4}. But, of course, this is an overestimate of the probability because one of the associations has a probability of much less than 2×10^{-3}.

A more simple and straightforward calculation is that the chance of finding the closest quasar to one of the 11 E galaxies is $11 \times 3 \times 10^{-4} \simeq 3 \times 10^{-3}$. The chance of finding the next closest is $11 \times 2 \times 10^{-3} \simeq 2 \times 10^{-2}$. The chance of finding both in one sample is $\lesssim 10^{-4}$. In other words the chance of finding two of the brightest quasars on this plate within the observed distance to members of the M 87 chain as defined in 1968, is less than one in ten thousand!

3. Discussion

Quasars have heretofore been shown to be associated with galaxies much closer than in the Virgo Cluster. For example M 33, NGC55, and NGC300 (Arp 1984b) and with spirals predominantly of redshift considerably less than $z \lesssim 1500$ km^{-1} (Arp 1983, Figs 14 and 15). The quasars associated with Virgo galaxies discussed above must therefore be among the most intrinsically luminous yet identified It is interesting to see whether there are any differences between these quasars and the kinds of quasars most commonly observed.

The first parameter we would examine is their redshifts. The quasars falling close to the Virgo core line have unusual redshifts. The most commonly observed redshift over the rest of the sky is near $z \simeq 2.0$.Quasarsofthisredshift are conspicuously absent from the centre of the Virgo Cluster. Redshifts in the sample of all quasars known over the sky fit peaks governed by a law $\Delta\log(1 + z) = 0.089$ (the peaks are z = 0.30,0.60,0.96, 1.41, 1.96 as shown by Depaquit, Pecker & Vigier 1984). Objective prism quasars, dominated by the surveys over the region of the Sculptor group of galaxies, obey the same periodicity with a slightly larger constant, $\Delta \log (1 + z) = 0.096$ (Box & Roeder 1984). But a set of the quasars falling close to the Virgo line obey a periodicity with an even slightly larger constant. This is shown in Table 1.

Table 1. Quasar redshifts near the centre of Virgo Cluster.

Observed	$\Delta\log(1+z) = 0.098$
0.42	0.42
0.72 (near NGC 4550)	0.78
1.25 (near M84)	1.23
1.79	1.79
2.50, 2.46 (fainter)	2.50
(5 others near $z \simeq 2.2$)	

This redshift periodicity of 0.098 represents the highest interval constant encountered in any group so far. It is implied that this is a consequence of the relatively high luminosity of the quasars. (There are 5 other quasars in the vicinity, all with redshifts near $z \simeq 2.2$. It is not clear whether they are foreground or background quasars, or represent dispersion or exceptions from the relation, or belong to other kinds of galaxies in the Virgo Cluster.

Finally the equivalent widths of the quasar emission lines in Virgo should be measured. The Baldwin effect as measured by Baldwin *et al.* (1978), Wampler *et al.* (1984), and Arp (1984a) would predict that the high luminosity quasars should tend to have emission lines of relatively small equivalent width.

In summary, just a simple examination of the quasars reported by He *et al.* reveals that the brightest quasars are significantly associated with the most massive galaxies in the core of the Virgo Cluster. This evidence is consistent with, and expected from, all the previous evidence for the association of quasars with galaxies. More accurate and complete measurements of quasars in this region and in various comparison regions in the sky would represent an opportunity to study the detailed properties of quasars as a function of their luminosity and possibly also as a function of the types of galaxies with which they are associated.

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