

# A concentration of quasars around the jet galaxy NGC1097

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## ABSTRACT

A quasar search in the region of the active galaxy NGC 1097 yielded 31 quasars in 1984. After completion of the 2dF survey in 2004 the number of catalogued quasars just within 1 degree of the galaxy increased to 142. About  $38 \pm 10$  of these are in excess of average background values.

The evidence in 1984 is confirmed here by an increasing density of quasars as one approaches NGC 1097. Quasars within 1 degree differ from the background by being significantly brighter. There also appear two elliptical rings or arcs of quasars at  $r \sim 20'$  and  $40'$ .

*Subject headings:* galaxies: individual (NGC1097) - quasars: general

## 1. INTRODUCTION

The galaxy NGC 1097 has long been known as an unusually bright Seyfert with long, straight jets emerging from its active nucleus (Wolstencroft and Zealey 1975; Arp 1976; Lorre 1978). Analysis of X-ray emission shows connections with quasars (Arp 1999). The nucleus of NGC 1097 has been much studied as the site of strong X-ray, radio and optical emission (see for example Nemmen et al. 2006). Wolstencroft, Perley and Tully (1984) interpreted the jets in terms of thermal bremsstrahlung. But varying opinions have been expressed as to the nature of these exactly straight, low surface brightness features (Higdon and Wallin 2003; Wehrle et al. 1997). Fig. 1 here, shows the stacked, low surface brightness enhanced, image of NGC 1097 from CTIO 4 meter plates taken by Arp (Lorre 1978).

Adding to the interest in this exceptionally active Seyfert galaxy, a high density of a small number of bright quasars near NGC 1097 was found by Wolstencroft et al. (1983). Shortly thereafter two objective prism plates were taken at the UK 1.2 meter schmidt telescope. Mr. X. T. He identified lengthened spectra of 104 quasar candidates in the central 8.1 sq.deg. of NGC 1097. The most likely of these were spectroscopically confirmed by redshifts observed by Arp at the 2.5 meter Du Pont telescope in Las Campanas, Chile.

Well determined redshifts of 31 quasars to slightly fainter than  $V = 20.0$  magnitude then became available and their distribution with respect to NGC 1097 was analyzed in Arp et al. (1984). There Figs. 5, 9, and 10 demonstrated the excess of quasars around NGC 1097 compared to the background. Figs. 11 and 12 showed the distribution of these quasars increased in density with decreasing distance to the galaxy. From a  $\chi^2$  test the chance of this observed distribution being consistent with a uniform distribution turned out to be extremely small (0.008). Fig. 12 from that 1984 paper shows most clearly the two peaks in quasar distribution for the quasars with  $V \leq 19.5$  which is confirmed here.

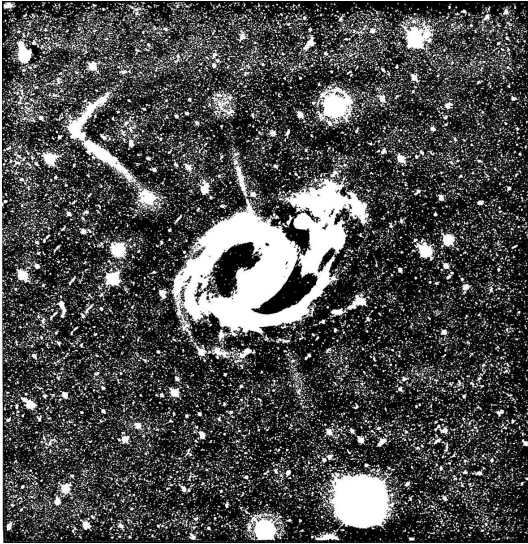


Fig. 1.— Faint surface brightness jets in NGC 1097 (30x30')

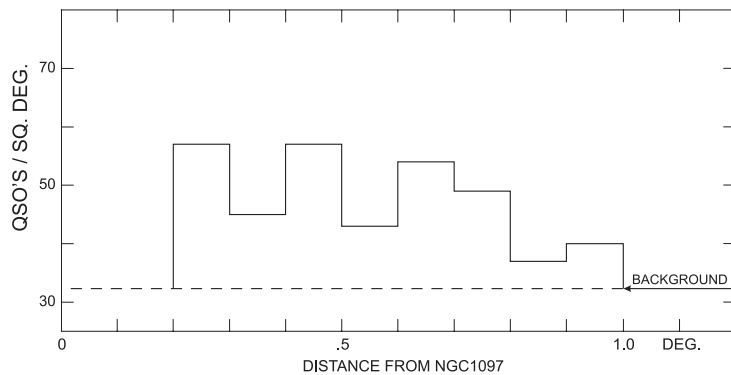


Fig. 2.— Density of 142 quasars in concentric annular rings around NGC 1097.

## 2. New Quasars from the 2dF Survey

When the 2dF survey was completed (Croom et al. 2004; Smith et al. 2005) a homogeneous survey of quasars down to apparent magnitude  $b_J = 20.85$  mag. became available for two strips across the sky of 5 degrees width in declination. Serendipitously, NGC 1097 at Dec. = -30deg. 17 min., was closely centered in the southern strip. The important question then arose as to how many of this large number of quasars around NGC 1097 were in excess of expected background counts. We calculate here the excess and its significance in two ways.

1) The 2dF survey quotes 23,338 QSO's in a total survey area of 721.6 sq. deg. for an average density of 32.34 QSO's/sq.deg. Within a circle of radius 1 deg. that would predict 101.6 QSO's as an average background.

The brightest jet reaches out past the nearest quasar at  $r \sim 11'$ . Inside of this there is evidence for considerable absorption and if we take the area from which NGC 1097 blocks out background quasars it is .10 sq. deg. A minimum of about 3.4 quasars would be obscured or not identified. We could then calculate the excess of quasars over normal background as:

$$(142 + 3.4 - 101.6) = 43.8/\sqrt{101.6} = 4.3 \text{ sigma}$$

2) However it might be objected that six of the 142 NED quasars within 1 deg. of NGC 1097 are not 2QZ objects. They are bright apparent magnitude (17.1 to 19.5 mag.) mostly discovered in the homogeneous, wide field search in 1984. Perhaps from extended blockage by the galaxy or crowding by bright stars the 2dF has missed them. Nevertheless, leaving out these six still gives a significant excess of NGC 1097 quasars of:

$$(136 + 3.4 - 101.6) = 37.8/\sqrt{101.6} = 3.8 \text{ sigma.}$$

We adopt the second result as the more conservative but note that the reddening/absorption extending over the furthest jets probably obscures more than we have assumed and therefore raises the counts appreciably (Arp 1999).

In the southern 2dF strip the region most clear of blank squares is west of NGC 1097. The average of seven 1 deg. radius samples of only 2QZ quasars give  $108 \pm 8.5$  (p.e). compared to the 101.6 value for the entire 2DF. The quasar distribution is not strongly non random. The large signals then give probabilities which are significant. As the sample size increases so does the tolerance for deviations from the Gaussian.

### 3. Increase of quasar density near NGC 1097

Taking the 142 quasars discovered in uniform surveys covering the area within a radius of 60' we can ask the very important question: "How are these quasars distributed in radial distance from NGC 1097?" Figure 2 here shows that the density of quasars is conspicuously above background from about 12 arcmin to about 48 arc min from the galaxy and then begins to fall until at about 1 degree it joins the expected background counts. Such a consistent increase toward the galaxy of a large number of objects argues that the association with NGC 1097 is not accidental.

Secondly there are apparent rings at about 20 and 40 arcmin. The same peaks in the radial distribution showed clearly in the brighter quasars of Figs. 11 and 12 of Arp et al.(1984). Circles and arcs have been observed around other active galaxies (UGC 8584 and others as reported in Fulton and Arp 2007, in preparation). They could be a consequence of multiple ejections of shells of matter.

The association is further supported by quasars which show an azimuthal concentration along the lines of the NE and SW optical jets. These concentrations are shown particularly well in the bright quasars in Fig. 13 of the 1984 paper on NGC 1097. One can also see this in Fig. 3 here, where the string of 9 quasars is seen crossing the outer ellipse in the NE direction.

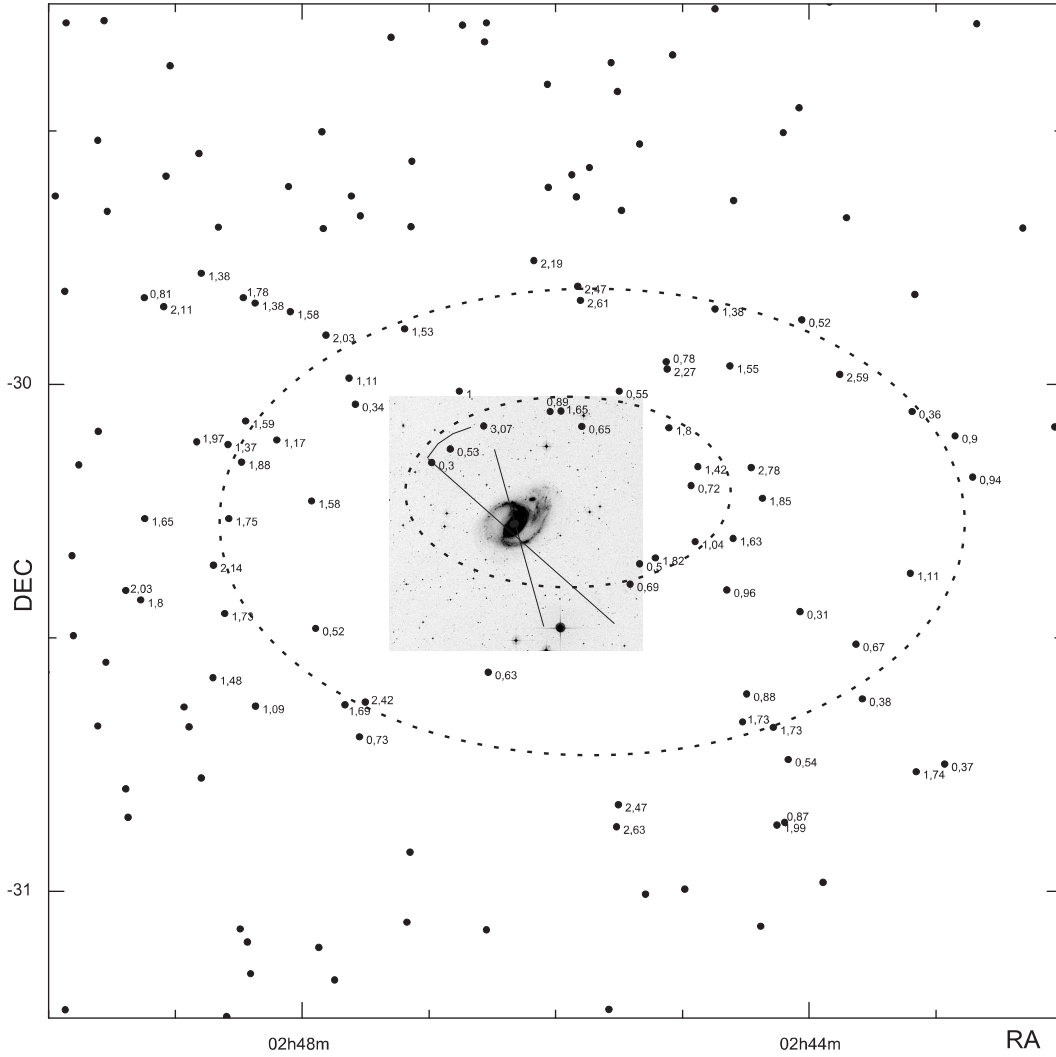


Fig. 3.— Distribution of catalogued quasars around NGC 1097.

#### 4. Distribution of Quasars in rings and ellipses

The plot of quasars in Fig. 3 shows that there is an inner distribution of about 18 quasars which fill out an ellipse which is cleanly defined except in the southern portion where the jets become very faint and red - just in the direction in which Arp (1999) concludes there is overlying absorption. If rings and arcs are the result of ejection in a plane it would in general be expected to view the features at an angle. So ellipses could be common. Observationally the “rings” seen in the radial distributions of Fig. 2 are quite broad but, fitted to the Fig.3 ellipses they are remarkably sharp as shown in Fig4.

They perhaps suggest an event or epoch of ejection. Note the curious double quasars N and S in the outer ring/ellipse with redshifts  $z = 2.47$  and  $2.61$  opposite a pair with  $2.47$  and  $2.63$ . Also a pair NW - SE at  $z = .52$  and  $.52$ .

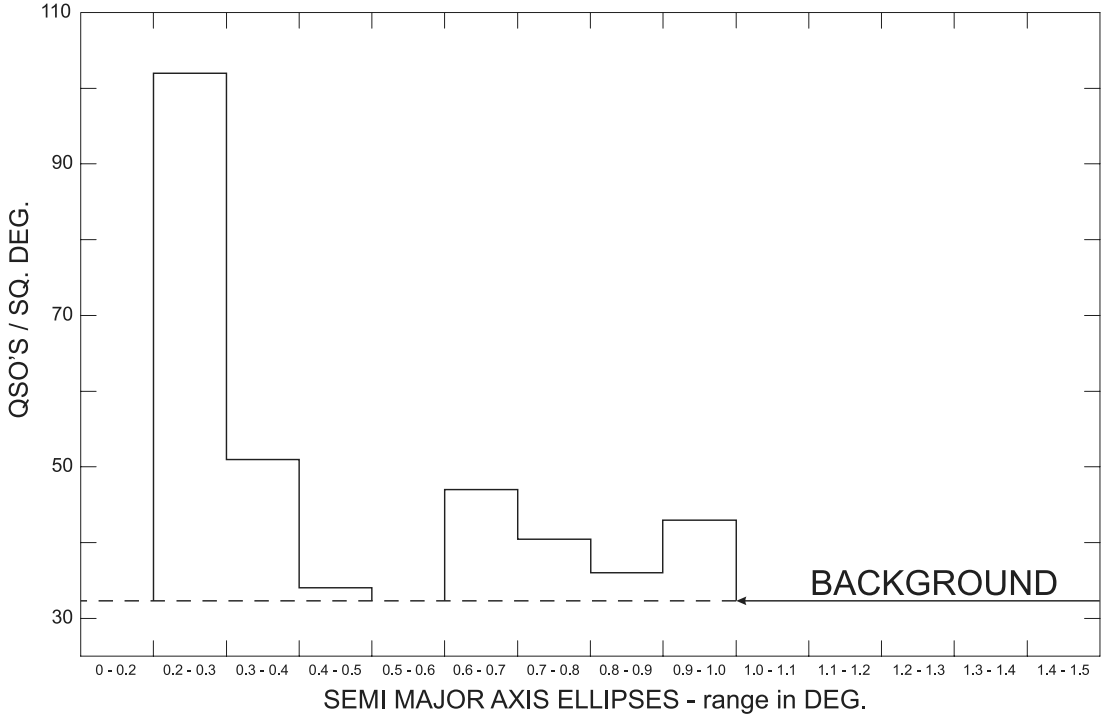


Fig. 4.— Density of quasars in concentric, elliptical annular rings around NGC 1097.

### 5. Another way to test associations

Fig. 5 shows that the apparent magnitudes of the quasars within 1 deg. of NGC 1097 are systematically brighter than the quasars in a control ring between 1.4 and 1.9 deg. For QSOs with  $z \leq 1.9$  and mag.  $\leq 19.6$  mag., there are 24 which are found near NGC 1097 compared to 4 found in the more distant comparison ring. There were 142 QSOs around NGC 1097 and 147 in the ring. The area in the annular ring is 5.18 sq. deg. and the area within 1 deg. of NGC 109 is 3.14 sq. deg. Therefore the observed number of bright, field QSOs should be reduced by  $4 \times 142 / 147 \times 3.14 / 5.18 = 2.34$  on just area considerations.

But restricting the test to only the sample pictured in Fig. 5 we can say: If the 24 + 4 bright quasars were an even mixture from around NGC 1097 and from the ring control field, then the chance of accidentally choosing 24 which were around the galaxy would be  ${}^{24}P(.5)_{28} = 7.6 \times 10^{-5}$ . Even if we left out 4 QSOs in this range which 2dF did not detect we would still have  ${}^{20}P(.5)_{24} = 2.9 \times 10^{-4}$ . Correcting for the larger area covered in the ring would lessen the latter probability by about another factor of 7.

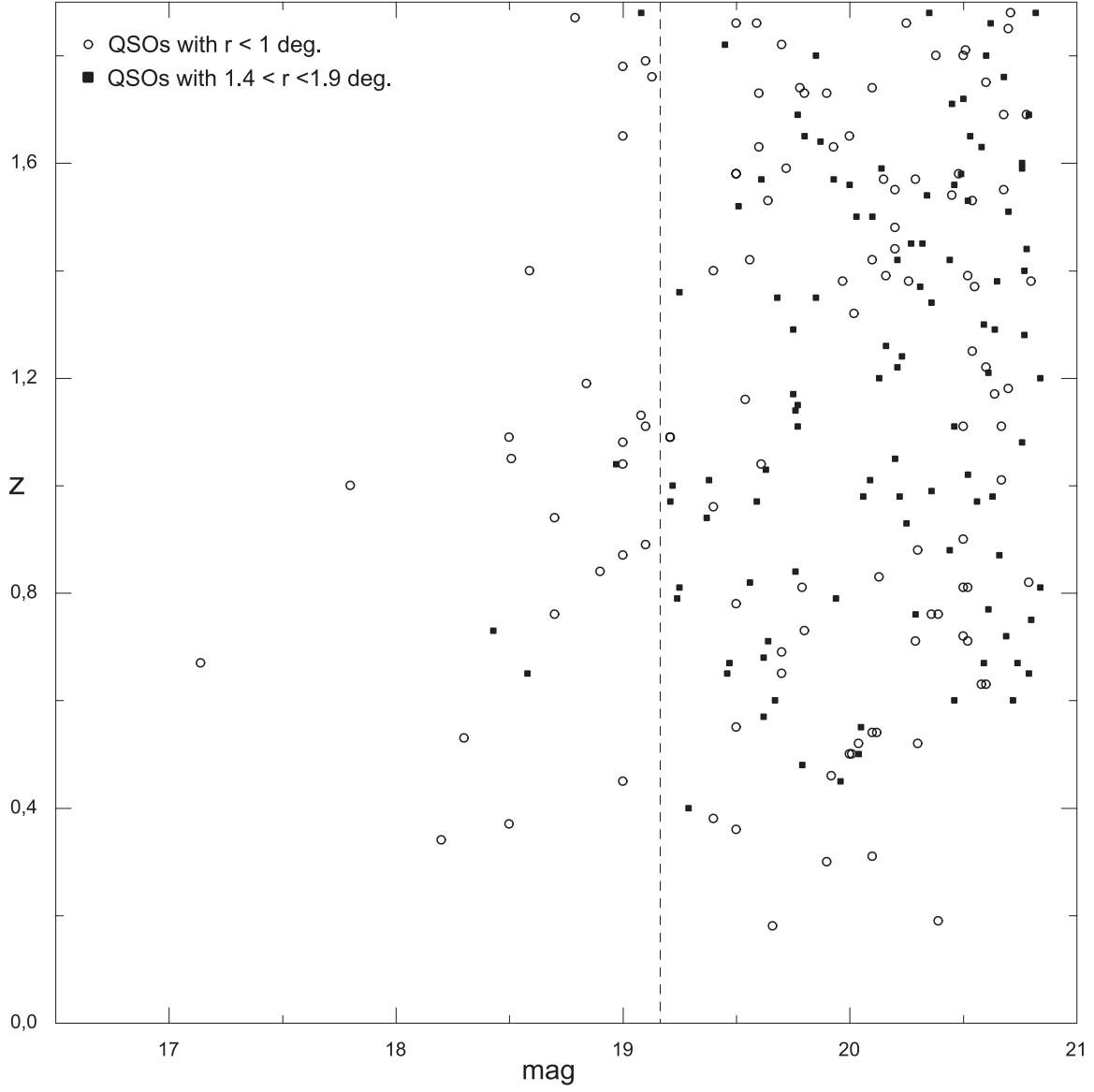


Fig. 5.— Redshift,  $z$ , vs apparent magnitude. Open circles are QSOs  $\leq 1$  deg from NGC 1097. Filled squares are from outer annulus between 1.4 and 1.9 deg. Limit to bright sample at 19.16 mag.

## 6. Conclusions

In 1984 and again in 1999 evidence was presented that a number of quasars were physically associated with the very bright, active Seyfert Galaxy NGC 1097 (Arp et al. 1984; Arp 1999.) Twenty years later this evidence is confirmed by a homogeneous survey with modern detection techniques which accidentally happened to cover NGC 1097 and adjoining regions. Of the order of 38 quasars have been found in excess of background and in high density concentration around the galaxy.

It has been clear for all this time that the origin of quasars must have something to do with the central galaxy. Since it is evident from early investigations that NGC 1097 is ejecting material into its surrounding regions, it would be an obvious conclusion that these quasars have been ejected from the active nucleus of the Seyfert galaxy. For example, although the nature of the optical jets is still uncertain, study of the 4 meter CTIO direct images showed where ejected material associated with the jets had broken through the spiral arms of the galaxy (Arp 1976). Some material has clearly come out of the nucleus.

In the intervening years there has been much further evidence for such an origin for quasars (see e.g. Arp 1998; 2003). The greatest number of quasars aligned across galaxies was six for NGC 3516 (a Seyfert) and five for NGC 5985 (another Seyfert). Now we have a much larger number, of the order of 38, associated with one of the brightest and most active Seyferts known, NGC1097. The question then arises as to whether all quasars have origins in relatively nearby galaxies.

In a very complete and informative discussion, of their own and 23 other analyses, Nollenberg and Williams (2005) establish that there are strong quasar cross correlations on the sky with galaxies up to 110 arcmin separation. They note qualitative agreement with gravitational lensing models but point to the need for much greater quantities of cold dark matter (CDM). They also mention a few cases of “physical associations” and the possibility of “something much more exotic such as photon decay.”

NGC 1097 represents an approach through studying quasar associations with individual active galaxies. From the many cases so far found the obvious generalization is to all quasars. As for theory, for 13 years there has been a solution for elementary particles with increasing mass (Narlikar and Arp 1993) which yields the general case of greater redshift for younger objects. However, even if there were only a few cases of intrinsic redshifts of quasars one would have to consider continuity of physical properties between quasars and galaxies as requiring the current fundamental assumption about redshift distances in general to be reexamined.

### 6.1. Epilogue

It was commented on the title page of this web posting that the paper had been rejected by the *Astrophysical Journal Letters*. Thus the editor spake: “Your paper has not been able to convince either of two independent referees. . . . “No suppression of your work has been done through my action since you are welcome to submit your paper to a different journal.”

The information supplied here should enable the readers to decide for themselves the value of the data and its discussion. But perhaps more important it enables a judgment on the core structure of current science.

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