An anomalous concentration of QSOs around NGC3079

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ABSTRACT

It is shown that there are at least 21 QSOs within 1° of the nearby active spiral galaxy NGC3079. Many of them are bright (mag < 18) so that the surface density of those closer than 15′ to the galaxy centre is close to 100 times the average in the field. The probability that this is an accidental configuration is shown to be ≤ 10−6. Discovery selection effects and microlensing fail by a large factor to explain the phenomenon, suggesting that the QSOs lie in the same physical space as NGC3079. However, two of them make up the apparently lensed pair 0957+561A, B whose lensing galaxy lies at z = 0.355. This problem is discussed in the concluding section.

Key words: QSOs – galaxies

1 INTRODUCTION

NGC 3079 is a bright spiral galaxy (type Sc) which shows many signs of activity in its central region. Several studies of it have been made in optical, radio and X-ray energies (cf Filippenko and Sargent 1992; Pietsch et al 1998, Kondratko et al 2005) and it is generally agreed that it is in the process of ejecting hot gas and plasma clouds and streams which are emitting large fluxes of radio waves and X-rays (cf Pietsch et al 1998). The most energetic known wind-blown superbubble, with kinetic energy ∼ 2 × 10^56/ν_e erg, emerges from its nucleus.

Three of us (EMB, GB, HCA), and others, have shown that there are many other bright active galaxies similar to NGC 3079, around which are found many QSOs with large redshifts, (for example Burbidge et al 2003; Chu et al 1998; Arp et al 2001, 2002; Galianni et al 2005). In those papers we concluded that the QSOs are very probably at the same distances as the active galaxies, that they are physically associated with them, and that they have been ejected from them. Thus on this hypothesis the redshifts of these QSOs are of non-cosmological origin.

In this paper we analyze the population of QSOs lying close to NGC 3079, which is one of the nearest of the active galaxies. We find that there is a highly significant excess of bright QSOs around the galaxy, and that this excess cannot be explained by selection effects or microlensing.

2 OPTICAL QSOS

From the compilation of QSOs with measured redshifts by Veron & Veron (2003), and Gutiérrez (2005), we list in Table 1 twenty one QSOs which lie with 1° of the center of NGC 3079. Fig. 1 shows that they are strongly clustered in a highly asymmetrical way very near NGC 3079. It is clear from studying these papers and in some cases from the names of the objects, that they have not been found following a deliberate hunt for QSOs in that region. For example, one of them was found in the 4C radio survey, one is a Markarian object with a very high redshift for that class, a number of them were first identified as X-ray sources, later shown to be QSOs, two were indeed found in looking for candidate QSOs near the adjacent galaxy NGC 3073 (Mk 231), and of course the very close pair 0957+561A&B was identified originally from a radio position and is generally believed to be the prototype gravitational lens pair.

In the general field the best estimate of surface density of QSOs suggests that there are no more than 0.3 per square degree for QSOs brighter than 18.0 (Boyle et al 1991; Kilkenny et al 1997; Fig. 1 of Myers et al 2005). But from Table 1 we see that there are seven QSOs with m < 18 within 35′ of the centre of NGC 3079, six of them within 15′ of the centre. Thus the surface density of bright QSOs very close to NGC 3079 is close to 100 times the average for bright QSOs.

Similar high density clustering of QSOs had previously been found about the Seyfert galaxy NGC 6212 and the QSO 3C345 (Arp 1997, Burbidge 2003), though in that case the clustering tendency was seen first, before it was realized that NGC 6212 is a very active Seyfert. NGC 6212 is further away than NGC 3079, and more QSOs are present within 1° of it.
Table 1. QSOs within 1° of NGC 3079. $F_x$ is in units of $10^{-14}$ erg cm$^{-2}$ s$^{-1}$. That for 0957+561 refers to both images. $d$ represents the angular distance from the nucleus of the galaxy, $b$ the magnitude of the QSO.

| Object                  | $\Delta\alpha \cos \delta$ | $\Delta\delta$ | $d$ | $b$    | $F_x$ | $z$ |
|-------------------------|-----------------------------|-----------------|-----|-------|------|----|
| SBS0953+556             | -4.0                        | -19.8           | 48.3| 18.00 | 1.410|    |
| 4C55.17                 | -36.7                       | -17.9           | 40.8| 17.40 | 0.900|    |
| Q0955+5623              | -28.2                       | 28.4            | 40.0| 18.31 | 0.066|    |
| SBS0955+560             | -28.3                       | 10.1            | 30.1| 17.60 | 1.021|    |
| RXJ10005+5536           | -12.2                       | -4.4            | 13.0| 17.50 | 0.216|    |
| I3WGAJ1000.9+5541       | -8.8                        | -0.2            | 8.8 | 19.10 | 1.037|    |
| NGC3073UB1              | -7.6                        | 5.5             | 9.4 | 19.20 | 1.530|    |
| ASV1                    | -7.0                        | 12.3            | 14.1| 17.28 | 0.072|    |
| SBS0957+557             | -6.8                        | -12.2           | 14.0| 17.60 | 2.102|    |
| I3WGAJ1000.3+554        | -5.5                        | 5.1             | 7.5 | 21.00 | 2.680|    |
| 0957+561A               | -5.3                        | 13.1            | 14.1| 17.00 | 1.413|    |
| 0957+561B               | -5.4                        | 13.0            | 14.1| 17.00 | 1.415|    |
| ASV23                   | -4.9                        | 10.9            | 12.0| –     | 0.900|    |
| ASV24                   | -4.8                        | 14.7            | 15.5| 23.03 | 1.154|    |
| ASV31                   | -4.4                        | 14.6            | 15.3| 21.14 | 0.352|    |
| MARK132                 | -4.1                        | 13.8            | 14.4| 16.00 | 1.760|    |
| Q0958+5625              | -2.2                        | 29.7            | 29.8| 20.08 | 3.216|    |
| NGC3073UB4              | 1.1                         | 2.1             | 2.3 | 18.10 | 1.154|    |
| I3WGAJ1002.7+5558       | 6.5                         | 17.1            | 18.3| 21.70 | 0.219|    |
| I3WGAJ1002.7+5541       | 10.0                        | 0.7             | 10.0| 18.50 | 15.673|    |
| 87GB100156.9+553816     | 24.0                        | -17.0           | 32.0| –     | 65.431|    |

According to Sandage and Tammann (1981) the distance of NGC 3079 is $\sim 20.5$ Mpc. If the QSOs are at the same distance as NGC 3079, 14 of them in Table 1 lie within 100 kpc of the center of the galaxy, eight of which are brighter than 18.5 mag. The most distant QSO listed in the Table is still only about 300 kpc from the center of the galaxy.

3 X-RAY EMITTING QSOs

Of the 21 QSOs listed in Table 1 ten have been identified as powerful X-ray sources (their fluxes are given in the Table). The five most powerful x-ray emitters, with $F_x > 50 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, lie with about 36′ of NGC 3079 and are roughly aligned in the direction of the major axis of the galaxy. They are shown in Fig. 1. The log $N$ $-$ log $S$ data from the RIXOS counts (Page et al 1996, their Fig. 3) reveal that for $N = 50 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, the surface density in the field is about 0.1 deg$^{-2}$. However, in the area of about 1.1 deg$^2$ we find four sources (or five if we count 0957+561 A&B as two) where we should only see about 0.12 sources.

There are 7 X-ray emitting QSOs lying within 15′ of NGC 3079, with $F_x > 10 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ corresponding to a surface density of about 30 per degree square. From the results of Hasinger et al (1998), the density of such sources in the field is about 3.2 deg$^{-2}$ (their Fig 4b), and once again we find a density about ten times that expected. Thus we find the same effect for the X-ray QSOs as we do for the optically bright ones, although as the X-ray QSOs tend also to be bright in this sample, the datasets are not independent.

4 STATISTICAL SIGNIFICANCE OF THE CLUSTERING

In Fig. 2 the magnitude distribution of the QSOs around NGC 3079 is compared with that from the Sloan survey. It is clear that they are systematically brighter than QSOs in the general field. A $t$-test on the two samples reveals that the difference remains highly significant (99% confidence level) when the magnitude distributions are cut off at $b=20$, and significant (93%) at $b=19$.

As we have seen most of the QSOs around NGC 3079 were discovered as part of radio or x-ray surveys rather than due to selective scrutiny of the neighbourhood of the galaxy. However, even if the latter were the case, this would not account for the excess since the number density of bright
QSOs around NGC3079

Figure 2. Magnitude distribution of QSOs within 1° of NGC 3079, compared with that of QSOs in the Sloan survey (represented by the dotted line, normalised).

Figure 3. Upper curve: cumulative distribution of QSOs $b < 18.0$ around NGC 3079. Lower curve: expected background count assuming 100% completeness of discovery. Error bars are 1σ limits based on Poissonian estimates.

Table 2. Cumulative number of QSOs with magnitudes $m < 18.5$ mag within angular distance $\theta'$ of NGC 3079, compared with expectations from background count $n_b$, counting errors $\sqrt{n_b}$.

| $\theta$ | $n(\leq \theta)$ | $n_b$ | $\sqrt{n_b}$ |
|----------|-----------------|-------|--------------|
| 6        | 1               | 0.06  | 0.24         |
| 12       | 2               | 0.23  | 0.48         |
| 18       | 7               | 0.51  | 0.71         |
| 24       | 7               | 0.90  | 0.95         |
| 30       | 7               | 1.41  | 1.19         |
| 36       | 8               | 2.04  | 1.43         |
| 42       | 10              | 2.77  | 1.66         |
| 48       | 10              | 3.62  | 1.90         |
| 54       | 11              | 4.58  | 2.14         |
| 60       | 11              | 5.65  | 2.38         |

Figure 4. Chance probabilities of finding QSOs brighter than $b_t$ as a function of angular distance from NGC 3079. These are based on an assumed 100% discovery of QSOs and so are a severe upper limit. The curves are labelled with the threshold magnitudes.

Poisson statistics can be used to put formal probabilities on the concentration of bright QSOs around NGC 3079, as a function of threshold magnitude $b_t$ and angular distance $\theta$ from the nucleus of the galaxy. The results are shown in Fig. 4 and confirm that the concentration is very unlikely to be due to chance. In particular the presence of four QSOs brighter than magnitude 18 within 20' of the nucleus has a chance probability of about one in a million. The calculation is made on the assumption that the list of bright QSOs in Table 1 is 100% complete, which is probably not the case, and so the probabilities represent upper limits. Of course a posteriori statistics will readily yield low probabilities for coincidences of no true physical significance; however the present probabilities should probably not be put in this category since there are several pre-existing claims in the literature for QSO excesses around many bright, nearby, active spirals (loc. cit.); thus a QSO excess is reasonably seen as an a priori hypothesis to be tested. A completely rigorous test for a physical association would require a full sampling of such galaxies down to a prescribed magnitude limit and range of morphologies.

An alternative hypothesis to be considered is that NGC 3079 lies fortuitously close to an unexplained concentration of bright QSOs but otherwise has no connection with it. However the galaxy is amongst the brightest 150 spirals in the sky, only a few percent of which are active and therefore candidates for testing the hypothesis of QSO/active spiral correlation. If the mean separation between such galaxies is say $45^\circ$, chance proximity of one to the QSO concentration has probability $(0.25/45)^2 \sim 3 \times 10^{-5}$.

5 MICROLENSING

A background QSO may be microlensed if it lies along the line of sight of foreground sources in the halo of NGC 3079 to within a few Einstein radii. The Einstein ring has angular radius, in arcseconds,
\[ \theta_E = 3\sqrt{\frac{m}{D}} \]  
(1)

where \( m \) is the mass of the lens in solar masses and \( D \) is its distance in Gpc (Narayan & Bartelmann 1996). If there are \( n \) such lenses in the halo of NGC 3079, whose distance \( D \approx 0.02 \) Gpc, then the total lensed area is, in \( \mu \)arcsec,

\[ A = n\pi\theta^2_E = 9\pi M/D = 67M^{1/2} \]  
(2)

from eqn (1), where \( M = nm \) is the total mass of lensing objects in the halo. Thus the proportion of QSOs lying within an Einstein ring is independent of the adopted lensing parameters (Narayan & Bartelmann 1996).

For lensing masses totalling \( M = 10^{12} M_\odot \), the total lensed area is equivalent to a single disc of Einstein radius \( \Theta \approx 21 \) arcsec and area \( \sim 10^{-4} \) square degrees. For comparison, there are about 20 QSOs per square degree down to magnitude 20 and 100 down to magnitude 22 (Myers et al. 2005). Thus with these figures there is an expectation that \( \sim 0.002 \) background QSOs with \( b < 20 \) lie within Einstein rings in the halo, and \( \sim 0.01 \) QSOs with \( b < 22 \).

A microlensed QSO an angular distance \( \theta = \theta_E \) from a lens is brightened by \( \Delta b \sim 0.2 \) mag, one within \( 0.1\theta_E \) by up to two magnitudes. Assume that the 12 QSOs around NGC 3079 with \( b < 18.5 \) are for the most part microlensed, being enhanced above background number density by a factor \( \sim 10 \), say. The number density of QSOs to \( b = 20 \) is about ten times that down to \( b = 18.5 \), but since there are only 0.002 QSOs with \( b < 20 \) available for magnification within the Einstein rings, these QSOs are about four powers of ten short of supplying the excess. For background QSOs with \( b < 22 \) the \( \Delta b \) required is now 3.5 or more, requiring \( \theta \lesssim 0.1\theta_E \), and the area available to supply this degree of lensing is \( \sim 10^{-6} \) sq deg. With background number density \( \sim 100 \) per square degree, QSOs with \( b < 22 \) are five powers of ten short of yielding a factor 10 above background of the bright QSOs around the galaxy. Thus as one attempts to boost progressively fainter background QSOs, microlensing increasingly fails to account for the observed excess around NGC 3079 (the argument is conservative since it neglects the lowering of density of background QSOs caused by the magnification). This deficiency arises from the increasing flatness of the slope of the QSO number-magnitude distribution with increasing \( b \); an increase in the QSO count is expected behind lenses when the slope of the QSO number-magnitude count \( > 0.4 \), a deficit otherwise, with the break-even point occurring around magnitude 19.1 – 19.6 (Myers et al. 2005).

The failure of lensing to account for the excess of QSOs around galaxies generally on sub-Mpc scales had previously been pointed out by Arp (1990).

The galaxy between the archetypal lensed image 0957+561A&B lies near the centre of a cluster of redshift \( z = 0.355 \), mass \( \sim 3.5 \times 10^{14} M_\odot \) and angular radius \( \sim 2 \) arcmin (Angonin-Willaume et al. 1994, Fischer et al. 1997). Remarkably, four other QSOs lie remarkably close to 0957+561: the angular distances of (AVS23, AVS24, AVS31, MARK132) from it are respectively (2.36, 1.35, 0.69, 0.74) arcmin, which also places them, angularly, within or close to this cluster of galaxies. The QSOs have magnitudes \( (\sim, 23.03, 21.14, 16.00) \) respectively. The probability that they lie within one or two arc minutes of 0957+561 and each other by chance is \( \sim 10^{-5} \).

In this case the optical depth of the cluster to microlensing is of order unity, but with an area \( \sim 3 \times 10^{-3} \) sq deg there is an expectation of only \( \sim 0.3 \) QSOs with \( b < 22 \) lying behind it, and arguments similar to those presented above reveal that microlensing within the \( z = 0.355 \) galaxy cluster is also incapable of producing this degree of concentration of bright QSOs. For multiple imaging, typical angular separations are \( 2\theta_E \). Apart from 0957+561, there is no sign of multiple imaging or arclets in the sample. Thus, within 14 arc minutes of NGC 3079, we find what seems to be a second ‘anomaly’: a group of bright QSOs whose close proximity to each other is not readily explicable in terms of conventional lensing.

If this group of QSOs, including 0957+561, is unconnected with NGC 3079, then the chance probabilities computed in the previous Section are affected. However only two of them are brighter than magnitude 18.5, and the clustering of the remaining galaxies with NGC 3079 has still \( \lesssim 10^{-4} \) probability of being due to chance.

6 DISCUSSION

A straightforward analysis of the numbers of optical and X-ray QSOs around the highly active galaxy NGC 3079 reveals that there is a high density of these objects very near to the galaxy. For the most luminous ones, which in all surveys of QSOs are very rare, the density of QSOs near to the galaxy is about two orders of magnitude higher than the density in the field. We have shown that this excess cannot be accounted for by selective searches for QSOs around the galaxy, and that the probability of accidental concentration is \( \lesssim 10^{-6} \), or \( \lesssim 10^{-4} \) if we – somewhat arbitrarily – exclude the little group close to 0957+561. The close mutual proximity of this little group itself seems to be anomalous. The active nature of the galaxy corresponds to that around which other QSO concentrations have been claimed.

If not due to an extraordinary chance, the concentration of bright QSOs around NGC 3079 must arise either because they are physically associated with it, or because they are background objects whose brightness is amplified by gravitational lensing or microlensing by condensed objects in the halo of the galaxy. The former hypothesis is discussed by Arp et al (2005), who describe evidence from the radio and x-ray studies that some of the QSOs and the nucleus of NGC 3079 may be physically associated. Here we have confined ourselves to exploring the lensing hypothesis. We have found that, at least with conventional scenarios, lensing fails quantitatively to account for the phenomenon. A similar problem has been met in numerous other studies of QSO concentration around galaxies (e.g. Kaiser 1992, Rodrigues-Williams & Hogan 1994). Myers et al (2005), in a comprehensive study of statistical lensing involving 2df QSOs, find correlations and anti-correlations consistent with the predictions of statistical lensing, except that on 100 kpc scales – those considered here – the results require more mass present than is predicted by current \( \Lambda \)CDM models.

This might argue for the QSO ejection hypothesis by default. However there is a problem here too: one of the QSOs is the famous pair 0957+561 A&B, considered by many to be the prototype gravitationally lensed pair. In this case, the lensing galaxy has been identified, and a good model for
the system has been made. If the QSO is indeed gravitation-
ally lensed, it would presumably be a background object. As
far as we are aware only Weymann (1995) has ever pointed
out before that 0957+561A,B lies so close to NGC 3079.
However the concentration of QSOs very close to this lensed
pair is also anomalously high. It is therefore conceivable that
these excesses, occurring around both NGC 3079 and the
cluster of galaxies aligned with 0957+561, are manifesta-
tions of the same phenomenon.

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