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The reality of anomalous redshifts in the spectra of some QSOs and its implications

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Abstract. The evidence for the physical association of close pairs involving bright QSOs with large redshifts and bright nearby galaxies with small redshifts, is reviewed and, in Table 1, a list of the best cases is given. It is shown that in a series of statistical studies using catalogs of QSOs and catalogs of galaxies, very strong correlations of high redshift radio QSOs have been found successively with

a. The Shapley Ames Catalog of the brightest galaxies. Here the correlation is with powerful radio QSOs with $S \geq 9Jy$ (0.4 GHz). The result is significant at the 7-10 σ level.

b. The Bright Galaxy Catalog ($z \leq 0.05$). Here the QSO sample is dominated by radio emitting QSOs, largely identified from the 3CR, Molonglo, Parkes, and 4C radio catalogs.

c. The galaxies in the Lick Catalog ($m \lesssim 17,\ z \lesssim 0.2$). Again the sample of QSOs is a radio sample.

d. The IRAS galaxy catalogs, where some fraction of the galaxies may have z up to 0.4, and where a few galaxies may be identical in position with the QSOs, but where the larger fraction have much smaller redshifts than the QSOs. Again the QSO sample is a radio sample.

e. Finally strong correlations on scales $\lesssim 10'$ have been found between optically bright, high redshift radio loud QSOs and the diffuse X-ray emission seen by ROSAT. Bartelmann et al. (1994) believe that this diffuse X-ray emission is due to galaxy clusters at redshifts significantly less than the observed redshifts of the QSOs.

All of this evidence taken together suggests that a subset of QSOs at least, are physically associated with galaxies and lie at the distances of the galaxies. Since the correlations have been made with galaxies over a wide range of distances, it is concluded that in general QSOs must have both an intrinsic redshift component, and a cosmological component. Thus the debate is no longer about "local" versus "cosmological" QSOs. There is a cloud of "local" QSOs where we interpret local to mean distances $\leq$ 200 Mpc. The remaining QSOs are "cosmological" but they have a significant intrinsic redshift component.

Using this as an empirical model we attempt to understand the total population of QSOs. The nearest ones are associated with nearby galaxies like M 82 and NGC 4258, and the galaxies in the Virgo cluster. As Arp has pointed out, on this model 3C 273 and 3C 279 are members of the Virgo cluster. The many examples of dense groups of QSOs which have apparently been ejected from galaxies within $\sim$ 100 Mpc, and have been reported over many years, are discussed.

In Sect. 5, we discuss QSOs and their parent galaxies and show that the current observations of fuzz and other luminous matter close to QSOs are compatible with this interpretation. The absolute magnitudes of the local QSOs listed in Table 1 lie in the range -13 to -18, and the most luminous ones tend to lie closest to the parent galaxies (Figs. 1 and 2).

In Sect. 7, we discuss absorption in the spectra of QSOs and argue that in cases where there is good statistical evidence that QSO and galaxy lie together in space, *and* absorption at the redshift of the galaxy is seen in the spectrum of the QSO, the QSO must lie in an extended halo about the galaxy. Thus the cosmological distance of the QSO is given by the galaxy redshift. A similar situation applies in QSOs in which a damped Lyα system is found. Since a strong case has been made that such systems arise in thick disks or halos of otherwise undetected galaxies, we argue that these are the parent galaxies of the QSOs. Using many of the cases that have been found, we conclude that for these QSOs, the intrinsic redshift components lie in the range 0.1-0.5. As is the case in the conventional scheme, much of the absorption is due to intervening clouds or galaxies, though it is suggested that some attention be paid to the idea that some of the gas giving rise to absorption is ejected from the QSOs.

Other properties which are briefly discussed include the situation with regard to relativistic motion for QSOs which are comparatively closeby, (Sect. 8) and the contribution to the X-ray background from QSOs in this model (Sect. 9).

The model makes a first attempt at explaining all of the properties of QSOs including the evidence that intrinsic redshift components are present. The conclusion is that a small fraction of the bright QSOs have originated in galaxies close to us and have redshifts largely intrinsic in origin. However the vast majority have been ejected from more distant galaxies and lie at cosmological distances (the distances of the parent galaxies). Their redshifts are largely of cosmological origin. The intrinsic

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redshift component is $z_i = [(1+z_o)/(1+z_g) - 1]$ where z_o is the observed redshift, and z_g is the redshift of the parent galaxy.

Key words: galaxies: general – quasars: general – galaxies: redshift – cosmology: observations

1. Introduction

It has been known for some time that there are many high redshift QSOs which lie so close to bright, comparatively nearby galaxies that probability arguments strongly suggest they are physically associated with the galaxies and lie in the same volumes of space (Burbidge et al. 1971, Burbidge 1979, 1981, Burbidge et al. 1990, Arp 1967, Arp 1987 and many other references given there). The statistical evidence is supported by a strong inverse correlation between the galaxy redshift (proportional to distance), and the angular separation between galaxy and QSO for a large number of pairs (Burbidge et al. 1990 and earlier references).

The statistical evidence is also further supported by morphological evidence. Detailed investigations of several QSO-galaxy pairs show that the galaxy and QSO are connected. For example, the connection is by a luminous bridge for NGC 4319 and MK 205 (Sulentic & Arp 1987) or by neutral hydrogen clouds in 3C 232 and NGC 3067 (Carilli et al. 1989, Carilli & van Gorkum 1992). Also, there is evidence of alignment between optical features in the galaxy and the direction of ejection of the QSOs in NGC 3079 (Womble 1992). Other examples are shown in a recent paper by Hoyle & Burbidge (1995).

An ingenious way of explaining the existence of the close pairs of galaxies and QSOs which would still allow them to lie at their respective redshift distances was proposed by Canizares (1981) who argued that it could be due to microlensing and hence amplification of the images of distant QSOs by faint stars in the halos of the galaxies.

However this argument was demonstrated to fail by Arp (1990) and Ostriker (1989) because the density on the sky of faint QSOs is far too small to give the required frequency of occurrence of the close pairs. The failure of this argument has also been stressed by Schneider, Ehlers & Falco (1992) and by Schneider (1994).

Thus for pairs involving bright QSOs ($m \lesssim 18$) and bright galaxies ($m \lesssim 14.5$) and for separations $\theta \lesssim 3'$ (Burbidge et al. 1990) the existence of anomalous - (non-cosmological) redshifts is well established, but this is only a very small fraction of the known QSOs. We can argue either by extrapolation that this is true for the whole population of QSOs, or work on the assumption that it only applies to a subset of QSOs. In what follows we shall attempt to explain the whole observed population of QSOs in terms of a model in which they all have intrinsic redshift components.

Because there is now a good deal of new statistical information available, we bring all of these ideas together in this paper.

We give in Table 1 a list of all of the close pairs of QSOs and bright galaxies known to us. There are 46 pairs here, nearly all with separations $\leq 3'$, with the galaxies in 34 of the pairs brighter than $14^m.5$. These are prime cases for physical associations. There are many more known cases involving fainter galaxies, but because the surface density of fainter galaxies is much larger than for the bright galaxies, the possibility that many of these are chance projections cannot be excluded. Also there are many cases involving bright galaxies and QSOs with larger angular separations. Some of the best examples of these are reviewed in Sect. 3.

2. Numbers and surface densities of galaxies and QSOs

None of the original probability arguments or statistical analyses which have led to these results will be repeated in this paper, since they can all be found in the literature which is fully referenced. However, it is worthwhile listing the data on which the arguments are based, namely the numbers and surface densities on the sky of galaxies and QSOs.

There is extensive literature on this subject and the data are well established. For galaxies, using B magnitudes, $N(\leq m) = 0.6m - 9.1$ (Sandage, Tamman, & Hardy, 1972). Over the whole sky this gives total numbers for $m \leq 12.5$, 13.5 and 14.5 of 1100, 4500 and 18000 respectively. In Table 1 there are 9 galaxies brighter than $12^m.5$, 23 brighter than $13^m.5$ and 30 brighter than $14^m.5$.

As far as the QSOs are concerned the surface density for bright QSOs ($B \leq 16.5$) is 0.024/sq degree (Goldschmidt et al. 1992) or about 1000 over the whole sky and it increases to about 0.1 sq degree^{-1} at $17^m.5$ and to 0.3 sq degree^{-1} at $18^m.5$ (Arp 1990; Goldschmidt et al. 1992; Boyle et al. 1990). In Table 1 there are 3 QSOs brighter than $16^m.5$, 6 brighter than $17^m.5$ and 14 brighter than $18^m.5$.

The number of pairs that we would expect to find by chance, n, with separations of θ (minutes of arc) for random distributions of both QSOs and galaxies is given by

$$n = 8.64 \times 10^{-4} \Gamma \theta^2 N \quad (1)$$

where Γ is the surface density of QSOs and N is the number of cases that have been investigated. The number of pairs for different limits on the brightness of QSOs and galaxies which have been found, compared with the number expected by chance were given by Burbidge (1979, 1981) and by Burbidge et al. (1990). Also, as was stressed when they were discovered, the existence of more than one QSO near a galaxy, including three in the cases of NGC 1073 and NGC 3842, gives extremely small probabilities that these configurations are accidental.

While significant numbers of close pairs have already been identified, it is important to realise that only a small fraction of the pairs involving both bright QSOs and bright galaxies can have been found. The reasons for this are the following. First there has never been a systematic search made to look for bright QSOs around the ~ 10000 brightest galaxies. A few were found

Table 1. QSOs close to Bright Galaxies ($m \leq 15.5$)

Galaxy	m_v	QSO	m_v	z_Q	sep($''$)	*Remarks*
UGC 0439	14.4	PKS 0038-019	16.86	1.674	72	
NGC 470	12.5	(0117+0317g)	19.9	1.875	93	
NGC 470	12.5	(0117+0317g) 68D	18.2	1.533	95	
NGC 622	14.0	0133+004 (UB 1)	18.5	0.91	71	
NGC 622	14.0	0133+004 (UB 1)	20.2	1.46	73	
IC 1746	14.5	0151+048 (PHL 1226)	17.5	0.404	6.4	
NGC 1073	11.3	BS0 1	19.8	1.945	104	
NGC 1073	11.3	BS0 2	18.9	0.599	117	
NGC 1073	11.3	RSO	20.0	1.411	84	
NGC 1087	11.5	0243-007 (UB 1)	19.1	2.147	170	
ZW 0745.1+5543	15.3	0745+557	17.84	0.174	100	
IC 2402	13.5	0844+319 (4C 31.32)	18.87	1.834	30	QSO in direction of radio jet
NGC 2534	14.0	0809+358 (UB 1)	18.7	2.40	121	
NGC 2693	13.1	0853+515 (UB 1)	19.5	2.31	188	
UGC 05340	14.8	0950+080	17.69	1.45	103	
NGC 3067	12.8	0955+326 (3C 232)	15.8	0.533	114	21cm contours connect galaxy to QSO Absorpt. in QSO at z of galaxy; active galaxy
NGC 3073	14.1	0958+558 (UB 1)	18.8	1.53	144	
NGC 3079	11.5	0958+559	18.4	1.154	114	Extremely active galaxy; Absorption in QSO at z of galaxy
ZW 1022.0-0036	15.5	PKS 1021-006	18.2	2.547	122	
NGC 3384	10.8	1046+129	20.6	0.497	149	
NGC 3407	15.0	1049+616 (4C 61.20)	16.3	0.422	173	
NGC 3561	14.7	1108+289	20.0	2.192	66	extremely disturbed galaxy
NGC 3569	14.5	1109+357	18.1	0.91	31	
NGC 3842	13.3	QSO 1	18.5	0.335	73	
NGC 3842	13.3	QSO 2	18.5	0.946	59	

serendipitously, and some through the early work of Burbidge et al. (1971). Apart from this only Arp looked carefully at a fraction of the bright galaxies and he only examined $\sim$ 200 before his observing program was abruptly stopped. What about examining the fields around bright QSOs? For $m \leq 16^{m}_{\cdot}5$, the total number is about 1000 over the whole sky. However in the most recent QSO catalog (Hewitt & Burbidge 1993) there are only 270 QSOs with $m \leq 16.5$. Thus only about 27% of the brightest QSOs discovered have yielded several pairs in Table 1.

As we go to fainter galaxies and fainter QSOs the numbers increase rapidly, thus increasing the likelihood according to (1) that the pairs will be accidental.

There are a number of very close pairs involving bright QSOs and much fainter galaxies and we give a list of them in Table 2. Many of these were found serendipitously, but some have been found because following the discovery of a low$-z$ absorption line system in the QSO a galaxy with the same redshift was looked for close to the QSO. We shall return to these in Sects. 6 and 8.

We now turn to a summary of the statistical investigations.

3. Statistical tests of associations between QSOs and galaxies

Many statistical studies have been made of complete samples of QSOs and galaxies. In the original work of Burbidge et al. (1971) we used all of the QSOs in the 3CR catalog (50) and compared them with the positions of the galaxies in the Shapley Ames Catalog ($\sim$1200 galaxies). We concluded that 4 of these are very likely to be physically associated with galaxies. This analysis was confirmed by a study by Kippenhahn and de Vries (1974) using Monte Carlo techniques. The four (and later five) close pairs identified in this analysis are included in Table 1.

Table 1. (continued)

Galaxy	m_v	QSO	m_v	z_Q	$sep^{('')}$	*Remarks*
NGC 3842	13.3	QSO 3	21.0	2.205	73	
NGC 4138	12.1	3CR 268.4	18.1	1.400	174	
NGC 4319	13.0	Mk 205	14.5	0.070	43	Luminous bridge joining QSO to galaxy Absorption in QSO at z of galaxy
ZW 1210.9+7520	15.4	1219+753	18.16	0.645	94	
NGC 4380	12.8	1222+102 (Wdm 6)	17.6	cont.	88	
NGC 4550	12.6	1233+125 (Wdm 8)	17.2	0.728	44	Galaxy in the Virgo Cluster
NGC 4651	11.8	3CR 275.1	19.0	0.557	210	Active galaxy with jet & counterjet
NGC 5107	13.8	1319+38	19.5	0.949	40	
ESO 1327-2041	13.2	1327-206	17.0	1.169	38	Jet or bridge pointing to QSO; abs. at z of galaxy
ZW 1338+0350	14.9	1333+0.35	17.98	0.85	41	
NGC 5296	15.0	1342+440 (BSO 1)	19.3	0.963	55	
NGC 5406	13.1	1358+392	17	3.30	95	
NGC 5682	15.1	1432+489	19.2	1.940	95	
ZW 1640.1+3940	15.2	1640+396	18.16	0.54	180	
NGC 5832	13.3	3CR 309.1	16.8	0.905	372	
NGC 5981	13.9	1537+595	19.0	2.132	10.7	
IC 1417	13.6	2158-134	17.8	0.73	76	
Anon	15	2237+0305	17.3	1.41	$\leq$0.3	
NGC 7465	13.3	2259+157	19.2	1.66	128	
NGC 7413	15.2	3CR 455	19	0.543	24	
NGC 7714-15	13.1	2333+019 (UB 1)	18.0	2.193	120	Pair of interacting galaxies

The fifth pair (involving NGC 7413) was not in the original analysis because the radio source had originally been identified with the galaxy and not the QSO. When a correct position was obtained it was shown that the radio source was the QSO (Arp et al. 1972).

Seldner and Peebles (1979) found statistically significant evidence for a correlation of the angular position of QSOs taken from the original Hewitt & Burbidge catalog (Burbidge et al. 1977) and the galaxies in the Lick catalog (Shane and Wirtanen 1967). Nieto and Seldner (1982) carried out a further study based on a QSO catalog of Véron, a portion of the Burbidge et al. catalog and a corrected catalog of Shane and Wirtanen (1967) and reported that they could not find statistically significant evidence for general QSO-galaxy associations, but they found marginal evidence for associations between *radio* QSOs and galaxies.

Chu et al. (1984) carried out a further study using the Hewitt and Burbidge (1980) catalog of QSOs and the Second Reference Catalog of Bright Galaxies (de Vaucouleurs et al. 1976). This catalog contains 4364 galaxies, all brighter than 16^m, with redshifts $\leq$ 15000 km s^{-1} ($z \leq 0.05$). In that study (Chu et al) we restricted ourselves to objects with $|b| \geq 30°$ so that the number of galaxies fell to 3460. As far as the QSOs were concerned we removed from the list all of those found originally by Arp and others by searching around bright galaxies. Using the cross-correlation function technique and the nearest neighbor technique we found strong statistical evidence for the association of QSOs at all redshifts with galaxies with $z \leq 0.05$.

Fugmann (1990) has claimed that the correlations exist only between galaxies and radio emitting QSOs. However this may be simply due to observational selection. The reasons are as follows. QSOs were originally identified as radio sources and the first catalogs of QSOs were dominated by radio emitting QSOs while the most recent ones contain a majority of radio quiet QSOs. This can be seen for example if we compare the contents of the 1980 and 1993 Hewitt/Burbidge QSO catalogs (Hewitt and Burbidge 1980, 1993). The radio surveys cover very much larger areas of the sky (many steradians) than do the optical surveys for QSOs, so that large areas of the sky containing many bright galaxies are involved, whereas the optical surveys cover much smaller areas, often only a few square degrees, (cf. the plots in Hewitt & Burbidge 1993) which only contain very few bright galaxies.

Recently Bartelmann & Schneider (1993, 1994), motivated by the idea that correlations between high redshift radio QSOs and low redshift galaxies, which were claimed to exist by Fugmann (1990), could be due to gravitational lensing effects of dark matter associated with the low redshift galaxies, have studied the correlations between a complete sample of high redshift radio QSOs in the 1 Jansky catalog of Stickel and Kuhr (Kuhr et al. 1981; Stickel, Fried & Kuhr 1993a,b) and several galaxy samples.

Table 2. Very Close QSO – Galaxy Pairs ($m > 15.5$)

Galaxy	z	m	QSO	m_v	z_Q	$sep^{('')}$	*Remarks*
Anon	–	19.7	0109+176	18.0	2.157	8	bridge joining galaxy to QSO
Anon	0.535	–	0109+200	17	0.746	7.1	abs. at galaxy redshift
Anon	0.133	20.0	PKS 0119-046	16.47	1.948	14	abs. at galaxy redshift
Anon	0.4176	–	PKS 0229+131	17.0	2.065	6.8	abs. galaxy redshift
Anon	0.051	–	GC 0248+430	17.45	1.311	3.5	QSO aligned with double nucleus galaxy; abs. at galaxy redshift
Anon	0.0669	–	0446-208	17	1.896	13	abs. at galaxy redshift
Anon	0.726	–	0453-423	17.1	2.661	30.3	abs. at galaxy redshift
Anon	0.071	–	PKS 0454+036	16.53	1.345	4	abs. at 0.8596 and 1.154 not at galaxy redshift
Anon	–	20.2	0809+483 (3C R196)	17.8	0.871	1.6	
Anon	0.153	–	PKS 0952+179	17.2	1.478	22.8	
Anon	0.441	21	1038+064	16.81	1.27	9.4	abs at galaxy redshift
Anon	0.359	–	1101-264	11.0	2.148	12.2	abs. at galaxy redshift
Anon	0.030	16.3	1107+036	19	0.964	20	
Anon	0.313	–	1127-145	16.9	1.187	8	abs at galaxy redshift
Anon	0.392	21.9	1209+107	17.76	2.191	7.1	abs at galaxy redshift
Anon	0.450	21.7	1441+522 (3C 303C)	19.97	1.57	4	abs. at galaxy redshift
3C 303	0.414	17.3	1441+522 (3C 303C)	19.97	1.57	20	QSO in lobe of radio emission
Anon	0.199	–	PKS 1229-021	16.7	1.045	8.6	
Anon	0.4359	–	1511+103	17.73	1.546	6.9	abs. at galaxy redshift
Anon	0.121	18.5	PG 1522+101	15.7	1.321	5	
Anon	0.076	–	1543+489	16.1	0.400		
Anon	0.434	–	1548+114B	19	1.901	10	second QSO 1548+114A 5″ from 1548+1148
Anon	0.091	–	1704+607 (3C 351)	16.1	0.371	34	abs. at galaxy redshift also other absorption
Anon (Several galaxies)		– –	1622+238 (3C 336)		0.927	2-10	abs. at z of one galaxy Steidel & Dickinson (1992)
Anon	0.366	–	1632+391 (4C 39.46)	18	1.082	4.2	
Klemola 31 A & B	0.029	16	PKS 2020-370	17.5	1.048	20	abs. at galaxy redshift
Anon	0.430	21.5	PKS 2128-123	15.46	0.501	8.6	abs. at galaxy redshift; axis of galaxy aligned with QSO
Anon	0.075	–	PKS2135-147	15.19	0.200	49	abs. at galaxy redshift also other absorption
Anon	0.790	–	PKS 2145+067	16.47	0.990	5.5	abs. at galaxy redshift
3C 771	0.707	–	2203+292B	22	4.399	51	QSO lies along optical radio axis of 3C 771
Anon	0.2	–	2203+292B	22	4.399	7	
Abell 2854 (2 galaxies) G_1 & G_2	0.12	–	2319+272 (4C 27.50)	18.6	1.253	17(G_1) 25(G_2)	QSO on line joining centers of galaxies

They first looked for correlations between the galaxies in the Lick catalog (Shane and Wirtanen 1967) and optically identified QSOs in the 1 Jansky catalog. A correlation between 1 Jy QSOs and Lick galaxies on a 10′ scale is detected with a significance level of up to 98%. Next they investigated the same sample of QSOs and looked for correlations with the IRAS Faint Source Catalog. Again they found highly significant correlations. They found that the 1 Jy QSOs with $z \geq 1.25$ are correlated with IRAS galaxies at the 95% confidence level which increases to more than 99% for QSOs with $z \gtrsim 1.5$.

Most recently Bartelmann, Schneider and Hasinger (1994) have looked for correlations between the same sample of QSOs and diffuse extended X-ray sources observed by ROSAT. Again they find correlations with significance levels up to 99.8%. The scale of these correlations is $\lesssim 10'$. They conclude that for the lower redshift QSOs in the sample with $z \approx 0.5 - 1.0$, the correlations might be due to the fact that the X-ray sources are unidentified galaxy clusters at these redshifts. However, the strong correlations (99.8%) with those QSOs with $z \geq 1.5$ cannot be explained by clusters at those redshifts, since the X-ray luminosities of such clusters would have to be much greater than is normally the case, i.e. the X-ray luminosities would have to be $\gtrsim 10^{46}$ erg sec^{-1} (for $H_\circ$ = 50 km sec^{-1} Mpc^{-1}), and there is no independent evidence that such luminous clusters exist.

In summary very strong correlations of high redshift radio QSOs have been found successively with:

a. The Shapley Ames Catalog of the brightest galaxies. Here the correlation is with powerful radio QSOs with $S \geq 9Jy$ (0.4 GHz). the result is significant at the 7-10 σ level.

b. The Bright Galaxy Catalog ($z \leq 0.05$). Here the QSO sample is dominated by radio emitting QSOs, largely identified from the 3CR, Molonglo, Parkes, and 4C radio catalogs.

c. The galaxies in the Lick Catalog ($m \lesssim 17$, $z \lesssim 0.2$). Again the sample of QSOs is a radio sample.

d. The IRAS galaxy catalogs, where some fraction of the galaxies may have z up to 0.4, and where a few galaxies may be identical in position with the QSOs, but where the larger fraction have much smaller redshifts than the QSOs.

e. Finally strong correlations on scales $\lesssim 10'$ have been found between optically bright, high redshift radio loud QSOs and the diffuse X-ray emission seen by ROSAT. Bartelmann et al. (1994) believe that this diffuse X-ray emission is due to galaxy clusters at redshifts significantly less than the observed redshifts of the QSOs.

f. In addition to all of this work on radio QSOs, Stocke et al (1987) took a sample of X-ray emitting QSOs and showed that their associations with moderate-redshift galaxies ($z \leq 0.15$) was statistically significant at a high level of confidence (> 97.5%).

Bartelmann, Schneider and their colleagues carried out all of their work apparently believing that such strong correlations could only be explained by gravitational lensing due to dark matter underlying the Lick galaxies, the IRAS galaxies and the ROSAT extended X-ray sources. They make no reference to the earlier statistical work involving bright radio QSOs and brighter galaxies.

It is surprising that they nowhere mention the alternative explanation. That is that we are seeing in all of these samples evidence that QSOs with large non-cosmological redshift components are concentrated where the galaxies are concentrated i.e. we *are* seeing at large distances the phenomena discussed in Sect. 1, with examples shown in Table 1.
To summarize :

Close by, far more QSOs with high redshifts are found very close to bright galaxies than are expected by chance. The best statistics come from the 3C sample, and the Shapley Ames galaxies, but some weight must be given to the many remarkable configurations mostly discovered by Arp (cf Sect. 4). There are also a number of galaxies with two or three QSOs very close to the galaxy (e.g. NGC 622, NGC 1073, NGC 3842 in Table 1), and there are many where chains of QSOs suggesting ejection in specific directions are found. In addition to this the luminous connections and other morphological features indicate physical associations. These are discussed in Sect. 4.

With the exception of the one early study by Nieto & Seldner, the statistical studies starting with the brightest galaxy catalog, and then successive ones, the Lick catalog, the IRAS catalog, and the ROSAT survey, all show strong positive correlations between the positions of high redshift radio QSOs and peaks in the distribution of much lower redshift galaxies or clusters. While it is possible that some of these effects might be explained by gravitational lensing involving dark matter underlying the bright galaxies, a strong case can be made for the following interpretation.

The results for the brighter, nearer, close pairs cannot be explained by any form of gravitational lensing, and thus they must be real. This means that we have evidence that low redshift galaxies are able to eject high redshift QSOs. While we will only know from which galaxy they came when they are very close to the parent, they will tend to cluster in the regions where galaxies cluster, and thus all of the statistical results are explainable in terms of the non-cosmological redshift hypothesis.

Roughly speaking, the brightest, nearest QSOs will have cosmological redshift components $z_c \lesssim 0.03$, so that for them the observed redshifts $z_\circ \simeq z_i$, where z_i is the intrinsic redshift component.

As we move out to the QSOs associated with the galaxies in the Lick survey where $z_c \leq 0.2$, the QSOs will have $z_c \leq 0.2$, and $z_i = (z_\circ - z_c)/(1 + z_c)$. Thus already the QSOs will have appreciable components of cosmological redshift and intrinsic redshift.

Thus the debate is no longer about "local" versus "cosmological" QSOs. There is a cloud of "local" QSOs where we interpret *local* to mean distances $\lesssim 200$ Mpc. In this volume $z_\circ \simeq z_i$. The remaining QSOs are "cosmological" but they have significant intrinsic redshift components.

As we move yet further out the results using the IRAS catalog and the ROSAT survey of X-ray clusters show that the cosmological components of the QSOs may be as large as ~ 0.5, so that if the measured redshift is 2, $z_i \approx 1$.

In the following section we shall discuss, among other nearby systems, QSOs which apparently lie in the Virgo cluster.

4. The nearest QSOs

We identify these as the QSOs which are closely associated with nearby galaxies. All of the pairs we know of involving bright galaxies and separations $\lesssim 3'$ are included in Table 1. The majority of the NGC galaxies have redshifts < 10000 km sec^{-1}($z_c < 0.03$) so that for them $z_Q \simeq z_i$. Since they are closeby it is not surprising that some of the QSOs associated with them are the brightest radio sources in the 3CR catalog. It is likely that more of the 50 3CR QSOs than the 10% that lie very close to bright galaxies (Burbidge et al. 1971) are also at comparable distances.

The QSO-galaxy pairs with separations $\lesssim 3'$ have typical galaxy redshifts $cz \lesssim 10000$ km sec^{-1}, or distances $\lesssim 200$ Mpc (for $H_\circ$ = 50 km sec^{-1} Mpc^{-1}). Thus the projected separations are $\lesssim$ 60 kpc. For much larger separations than this there is no strong evidence for physical associations from probability arguments. At the same time, once evidence is available that QSOs and galaxies are physically associated, and that the QSOs are ejected from the galaxies, it is natural to expect to find QSOs with a wide range of distances from their parent galaxies.

It was pointed out in the very early days of radio astronomy that there appeared to be an asymmetry of the bright radio sources on the sky. This was deduced from the source counts by Hanbury-Brown (1962). He suggested that the supergalactic structure as defined by de Vaucouleurs based on the distribution of the bright galaxies might be responsible. (See also Shaver & Pierre (1989)). Arp (1970, 1983) pointed out there is good correlation between the position of the 3C and the Parkes radio QSOs on the sky, and the Shapley-Ames galaxies. These are the bright galaxies many of which lie in the Virgo cluster which itself makes up the central part of the local supercluster. Sulentic (1988) has shown that the density on the sky of the bright QSOs in the Palomar Survey is about five times greater in the direction of the Virgo supercluster than elsewhere. This correlation is exactly what we would expect if many of the (nearest) and brightest QSOs have been ejected from galaxies in the Virgo cluster, and the local supercluster.[1]

Because of its position and because it is optically the brightest radio emitting QSO, there has always been a suspicion that 3C 273 might be a member of the Virgo cluster ($d \simeq 21$ Mpc). Arp has suggested that both 3C 273 and 3C 279 were ejected from galaxies in the central region of the Virgo cluster. There is considerable evidence from the morphology (cf. Arp & Burbidge 1990) and from the X-ray emission (Arp 1994) that this may be the case. In addition to this, the very active Virgo cluster galaxy M87 shows evidence of ejection of QSOs in the direction of its jet (Arp 1987), which points directly to, and may have ejected M84 (Wade 1960). NGC 4550 which is also a member of the Virgo cluster has a bright QSO ($17^{m}.2$) only 44″ from its center. (cf. Table 1).

Apart from the Virgo cluster, and the close pairs listed in Table 1 there are a number of groupings of QSOs which have been noted over the years to lie in the vicinity of comparatively nearby galaxies.

The major ones are as follows:

1. A compact group of 4 QSOs lie within 10′ of M82 ($d \simeq$ 2.5Mpc). Three were found serendipitously (Burbidge et al. 1980) and a fourth was discovered by Arp (1981). They lie in the direction of the cone of ejection of high energy matter from M82.
2. A recent ROSAT study of x-rays from NGC 4258 ($d \simeq$ 7 Mpc) has led to the identification of two compact X-ray sources equally distant from the center of NGC 4258 (Pietsch et al. 1994). They lie along a line passing almost through the nucleus. These two sources are identified with two candidate QSOs which Pietsch et al. suggested were ejected from NGC 4258. NGC 4258 is clearly an active galaxy. Recently Burbidge (1995) has shown that both of these sources are genuine QSOs with redshifts of 0.398 and 0.653 respectively.
3. In Table 1 one QSO close to NGC 3079 ($d \simeq$ 16 Mpc) is listed. There is extensive evidence for explosive ejection of gas etc. from NGC 3079 (Filippenko & Sargent 1992). Earlier Arp (1974, 1977) identified the QSO listed in Table 1, and three more QSOs around NGC 3079.
4. A dense group of QSOs with different redshifts is found in an area ∼50 sq. arc. min. within 2° of NGC 3810 ($d \simeq$ 21 Mpc) (Hazard, Arp & Morton 1979; Arp 1983)
5. A dense group of 5 QSOs with different redshifts is found in an area $\lesssim$ 4.5 sq. arc min about 2° SW of NGC 450 (Arp 1983).
6. Ten QSOs have been found to surround a faint galaxy close to NGC 2639 ($d \simeq$ 91 Mpc) (Arp 1980).
7. NGC 1097 (d = 32 Mpc) shows evidence of activity in the form of two or more optical jets (Wolstencroft & Zealey 1975, Arp 1976). It is surrounded by a large number of QSOs. There is a dense cluster of them within 24′ of the center of NGC 1097 (Wolstencroft et al. 1983). This involves at least 6 QSOs within about 100 sq arc min. Outside this region there is an extended cluster containing ∼ 40 QSOs. (Arp et al. 1984).
8. Five QSOs lie near NGC 2916 which itself is a companion to the bright galaxy NGC 2903 (d = 12.3 Mpc) some 40′ away (Arp 1981).
9. Eight QSOs approximately aligned and apparently associated with the triple system NGC 3379, 3389 and 3384 ($d \simeq$17 Mpc) have been found by Arp, Sulentic & di Tullio (1979).
10. Arp & Duhalde (1985) discovered a chain of QSOs apparently ejected from the highly irregular active galaxy NCC 520 (cf Stanford 1992). The chain extends over ∼ 7° from NGC 520 ($d \simeq$48 Mpc) (Arp 1987). Because of the large distance involved (∼ 6 Mpc) the physical reality of the chain is less likely than in the other groupings described here. Arp (1987) has given an extended discussion of the controversy surrounding this grouping which he originally pointed out much earlier.

[1] After this manuscript was completed and immediately before it was submitted for publication a paper by Zhu and Chu (1995) appeared. This strongly supports the view that there is a cloud of QSOs associated with the Virgo cluster of galaxies. They have used a quasar sample from the Large Bright Quasar Survey (Foltz et al. 1987, Hewett et al. 1991) and the galaxies of the Virgo cluster from the BST catalog (Bingelli et al. 1985). The overlap field of 80.2 sq. deg. contains 178 QSOs and 1436 galaxies. Using cross correlation techniques, they have found strong evidence for associations between QSOs and galaxies in the angular distance range $5' < \theta < 40'$. This clearly adds further to the evidence discussed in this section.

11. Recently Arp (1994) has identified more QSOs close to the pair NGC 4319 - Mk 205 (shown in Table 1). Again there is alignment suggesting ejection from Mk 205 of the QSOs which are further away.
12. Arp & Hazard (1980) discovered two triplet systems of QSOs, each precisely aligned, with redshifts (a) 2.1, 0.51 and 1.7, and (b) 2.1, 0.54 and 1.6. The triplet lines lie less than $10'$ apart and lie very roughly parallel to each other ($\Delta\theta \approx 10°$). There is no obvious bright galaxy nearby but Narlikar (1980) has shown that if one joins together the positions of the pairs with roughly equal redshifts, the three lines intersect in a point (close to the QSO with $z = 1.7$) which may represent an origin.

All of these groups show the same characteristics, namely a large over-density of QSOs in the vicinity of a bright galaxy, and in a number of cases a preferred direction suggesting that the objects have been ejected in a narrow cone. Very frequently there is independent evidence that the galaxy is active and is giving rise to non-thermal radio emission and the generation of hot gas with high velocities from its central region.

5. QSOs and their parent galaxies

The classical picture of QSOs is grounded in the continuity (of redshifts) argument in which it is argued that there is continuity between the classical Seyfert galaxies which are found at very low redshifts like NGC 1068, 4151, 3516, 5548, etc. where the galaxy of stars surrounding the Seyfert nucleus is clearly seen, and the QSOs, where it has been argued that host galaxies are present, but are very hard to detect, because they are very distant and very faint compared with the QSO. Starting with the work of Kristian (1973) it has been argued that the idea is borne out by the observations, though even in that first discussion, the brightest QSO with the smallest redshift, 3C 273, was omitted.

Low redshift bright QSOs and bright galaxies

There have been a number of studies of bright QSOs with small redshifts. The studies have been restricted to QSOs with small redshifts since it has been tacitly assumed that the hypothesis to be tested, namely that QSOs lie in galaxies at the same redshift, is correct. Obviously the only unbiased way of testing this hypothesis would have been to observe QSOs with a wide range of redshifts, but this still remains to be done.

Direct imaging of the low redshift QSOs shows that nearly all of them are surrounded by nebulosity. Many of the authors (cf. Hutchings, Crampton & Campbell 1984; Gehren et al. 1984; Malkan, Morgan & Chanon 1984) have claimed from ground based observations that the results are compatible with the view that the nebulosity is due to galaxies, though there is no consensus as to what galactic types are involved. Miller (1978) strongly argued that he could find no evidence of nebulosity around QSOs of the kind associated with genuine galaxies associated with BL Lac objects.

Recently observations with HST (Bahcall et al. 1994, 1995; Hutchings & Morris 1995) have shown that for some QSOs there are no host galaxies, while for others there is evidence for faint galaxies or irregular (often called interacting) systems. As far as the spectroscopy is concerned, spectra have been taken of the fuzz around 3C 48 (Wampler et al. 1975; Boroson & Oke 1982), 3C 249.1 (Richstone & Oke 1977), 3C 273 (Wyckoff et al. 1980) and 3C 37.43 (Stockton 1976) and they show narrow emission lines at the same redshift as the QSOs, and only in the case of 3C 48 has absorption characteristic of *early type* spectra of stars also been detected (Boroson & Oke 1982). Otherwise only continuum radiation is observed (Boroson & Oke 1984).

How are these observations to be interpreted within the framework of the model being developed here?

We argue that rather than having the QSO be part of the galaxy, it is being ejected from it. This is entirely compatible with the evidence described above. In some cases of ejection, the QSO will have travelled far enough so that its image is not confused with the image of the parent galaxy. This is how some of the observations of Bahcall et al. are to be interpreted. That there are more galaxies present than in the field is also what we would expect. That many of them are active or disturbed is also what we would expect since cases of this kind are seen in Table 1. In all of these cases of physical pairs the intrinsic redshift component $z_i = \left[(1+z_e)/(1+z_G) - 1\right]$.

It is obvious that if there is a significant separation between the QSO and parent galaxy we would expect to see the bare or dominant QSO as it is observed by Bahcall et al. Also if the QSOs in Table 1 are typical of those ejected from nearby galaxies, they will be intrinsically fainter than the galaxies, rather than being much brighter, as is the case in the conventional theory. A few like 3C 273 may be comparable in brightness to the galaxies in its vicinity. Here we are comparing 3C 273 with galaxies in the Virgo cluster. However many of them will be very faint. (cf Sect. 4). Thus often we would not expect that the QSOs would necessarily stand out, even if they were close to the galaxies and were not projected on to the extended images of the galaxies. This means that if the parent galaxies have appreciable cosmological redshifts, say $z \geq 1$, and the projected linear separation between parent galaxy and QSO has the same value as a typical closeby pair in Table 1, the angular separation will be only $\lesssim 2''$ to $3''$. Moreover the ejected QSO will be very faint ($> 22^m$). If it is a radio emitting QSO, it is most likely that the *parent galaxy* and not the QSO will be identified as the optical source of radio emission. This may be the situation for many of the faint radio sources. If the QSO is not a radio source, it will not be identified at all, unless it is as bright or brighter than the parent galaxy!

If some QSOs can be found to be superposed on the images of galaxies a key observation will be to measure *separately* the redshift of the QSO and the redshift of the galaxy. The only case of this kind in which such measurements have been made is the galaxy and QSO 2237+305 which was found serendipitously (cf. Table 1). It is interesting that in this case the galaxy ($z = 0.039$) is brighter than the QSO. Since the separation between the nucleus of the galaxy and the QSO is extremely small ($\leq 0\farcs3$) the probability that this is a chance effect is incredibly small (Burbidge 1985). However, the resolution of the QSO image into four components has convinced most members of the community that this is a gravitational lens (the Einstein cross, Huchra et al. 1985). The alternative hypothesis that four QSOs are being ejected from the galaxy has been suggested by Arp & Crane (1992).

Bright QSOs of any redshift and faint galaxies

There have been a number of studies of faint galaxies clustered about QSOs. In one type of investigation QSOs have redshifts low enough so that galaxies with similar redshifts are not too faint for spectroscopic investigation. In these cases (Stockton 1978, Hutchings, Johnson & Pyke 1988; see also the list in Burbidge, et al. 1990) many galaxies have been found with redshifts very similar to the redshifts of the QSOs. In the other type of investigation studies have been made of possible associations between bright QSOs and faint galaxies. Since the redshifts of the QSOs in these latter studies have covered a wide range, the investigators have always assumed that the faint galaxies must be foreground objects. In most of these studies (Tyson 1986; Webster et al. 1988; Fugmann 1988, 1989; Hintzen, Romanishin & Valdes 1991) a statistically significant excess of galaxies has been found. However some authors (e.g. Yee, Filippenko & Tang 1992) have claimed that there is no statistical excess. In the most recent study, Thomas, Webster & Drinkwater (1995), using a statistic based on the separation of the QSO and its nearest neighbor galaxy, find a significant excess of close neighbors with separations of less than 10 arcsec.

How do we interpret the associations between QSOs and faint galaxies? We have just pointed out that QSOs with absolute magnitudes in the range of those given in Table 1 will not have been detected if they are associated with galaxies of appreciable redshifts.

The fact that faint galaxies do appear to be clustered around QSOs often at high redshifts means that they have been ejected from the faint galaxies. Thus we predict that the faint galaxies may often have redshifts *smaller* than the QSO redshifts, and that the cosmological redshifts of these pairs are measured by the *galaxy redshift* so that the intrinsic redshifts are given by $\left[(1+z_e)/(1+z_G)-1\right]$. In the cases where it can be conclusively shown that the galaxies of stars have similar redshifts to the QSOs (cf Stockton 1978 and other references given earlier), the intrinsic redshift components must be very small.

This may also be the case in 3C 48 where Oke and Boroson have reported that there is a stellar component of early type with the same redshift as the QSO.

In this model the major difference between the QSOs physically associated with bright galaxies, and those physically associated with faint galaxies is that in the first case we are looking at QSOs which come from the faint end of the QSO luminosity function and in the second we are looking at QSOs at the bright end of the luminosity function. Some of the QSOs in both categories are included in Table 1 and 2.

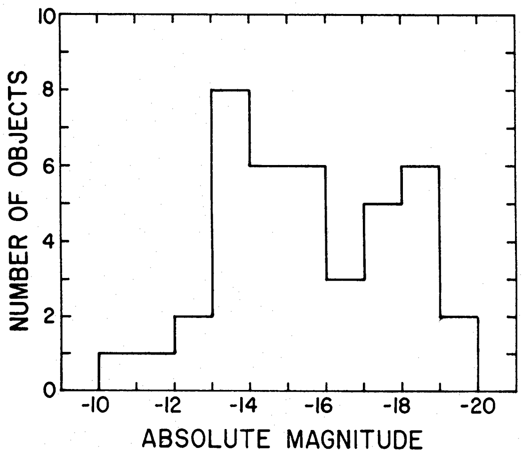

Fig. 1. Histogram of the distribution of absolute magnitudes of the QSOs listed in Table 1 based on the assumption that they lie at the distances of the galaxies in Table 1

6. Absolute magnitudes of local QSOs

If we accept that the close pairs in Table 1 are physically associated, and that only the galaxies are at cosmological redshifts, we can determine the absolute magnitudes of these nearby QSOs. We show in Fig. 1 the absolute magnitude distribution for the QSOs in Table 1 calculated from the redshifts of the galaxies ($H_\circ$ = 50 km sec^{-1} Mpc^{-1}).

Most of them lie in the range -13 to -18. In Fig. 2 we plot the absolute magnitudes of the QSOs against the angular separations between the QSOs and the nuclei of the parent galaxies. While there is a large scatter in this plot, it does suggest that the QSOs are more luminous when they are very close to the centers of the galaxies, and fall off in luminosity as they move farther away. We have practically no points beyond $\triangle\theta \simeq 180''$. This is the trend that might be expected in a physical model. However, as we have emphasized on several occasions (Burbidge 1981; Burbidge et al. 1990) the statistical evidence for associations involving individual pairs is very weak once the separations become greater than $\sim 3'$ and/or when the QSOs become fainter [because the surface density of QSOs increases rapidly as we go fainter (cf Arp 1990, Fig. 1) and Goldschmidt et al. 1992)]. Thus it is possible that the plot of $\triangle\theta$ against absolute magnitude may not be valid beyond $\triangle\theta = 3'$. At the same time it is worth pointing out that in special circumstances where the geometry suggests that ejection has taken place, e.g. the QSOs close to M82 (Sect. 3) and those apparently ejected from NGC 4258, this trend is followed with the absolute magnitudes in those cases falling to the values of M close to -10 when $\triangle\theta \simeq 10'$.

7. Absorption in the spectra of QSOs

After the first absorption lines were discovered in the spectra of QSOs (cf. Burbidge, Lynds & Burbidge 1966; Lynds & Stockton 1966) it was realized that there were several possible interpretations:

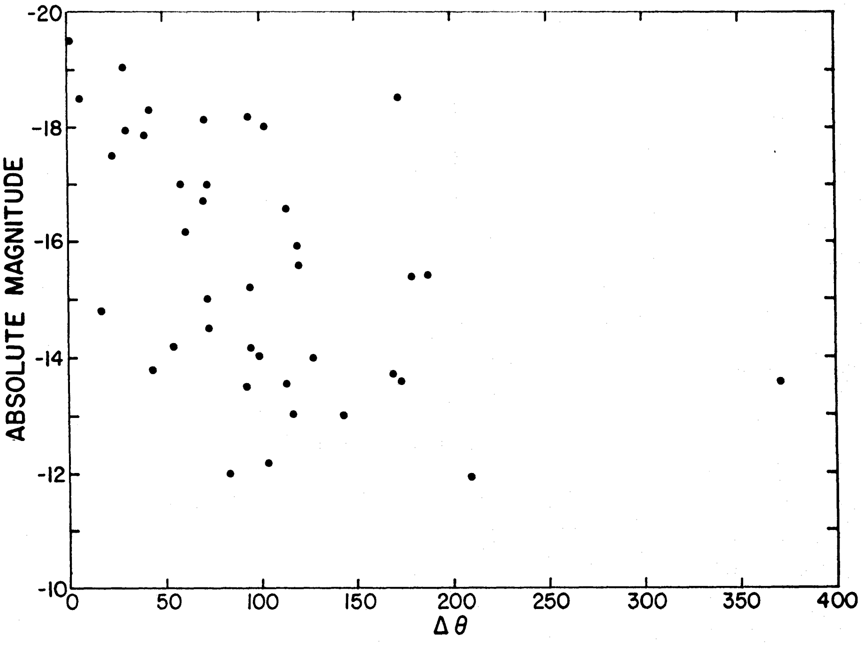

Fig. 2. Plot of the absolute magnitudes of the QSOs in Table 1 as a function of their projected separations from the galaxies. Again it is assumed that they lie at the distances of the galaxies in Table 1

1. Absorption at or very close to the emission redshift of the QSO, $z_a \approx z_{em}$, can only be interpreted as meaning that the absorbing gas is physically very close to the QSOs.
2. For $z_a < z_{em}$ there are two possible interpretations:
   a. that the absorption is taking place in an intervening cloud or galaxy halo (Bahcall & Spitzer 1969).
   b. that the absorption is associated with gas that is ejected at high speed from the QSO, or with an intrinsic redshift component Perry, Burbidge & Burbidge 1978).

Sargent et al. (1980) investigated the distribution of Lyα absorption redshifts in a sample of QSOs and concluded that the distribution of z_a was compatible with a Gaussian distribution of clouds or galaxy halos. This together with later studies has led to the general view that the absorbers are individual clouds lying at much smaller distances from us than the QSO.

This conclusion was strengthened in the eyes of most astronomers by the results provided by Bergeron and her associates who investigated high redshift QSOs each of which has a much lower absorption redshift system identified in its spectrum and who have been able to find a galaxy with the same redshift close to the line of sight in a comparatively large sample (cf. Bergeron & Boissé 1991; see also Le Brun et al. 1993).

There are at least two results which are in conflict with this simple interpretation. First in a recent study Borgeest and Mehlert (1993) have shown that the numbers of absorption redshifts per unit interval of z are proportional to the emission redshifts of the QSOs, thus suggesting that the absorption redshifts are related to the emission redshifts. The would not occur if the absorption was due to intervening clouds. Secondly there are a number of QSOs with many widely distributed absorption redshifts such as PKS 0237-23 which cannot be understood simply in terms of a random distribution of clouds or halos (Duari and Narlikar 1995).

Table 1 is restricted to pairs involving bright galaxies. However in a few of these, absorption is seen in the spectrum of the QSO at the redshift of the galaxy. On the other hand, we have constructed Table 2 which contains pairs with very small separations and galaxies which tend to be much fainter than the QSOs. Many of them were found by the method of Bergeron. Thus a far higher fraction of these show absorption at the redshift of the nearby galaxy than do the pairs in Table 1.

As we have already pointed out, for the pairs in Table 1, there is often strong statistical or morphological evidence for physical association. For the pairs in Table 2, there is also sometimes morphological evidence for physical associations as is indicated in the table. However for all of the pairs in Table 1 and Table 2, when absorption at the redshift of the galaxy has been reported, astronomers have tended to ignore the statistical or morphological evidence for physical association and have claimed that the presence of absorption means that the absorbing galaxy must lie far in front of the QSO.

If we accept the evidence for physical association, this cannot be correct. Instead it must be supposed that the QSO, with an intrinsic redshift component, *lies in the halo of the galaxy*. In this case if a fixed optical path length for absorption is chosen for a sample of pairs with similar galactic halos we would expect that in the average 50% would show absorption, and 50% would not. In their study Bergeron & Boissé only chose QSOs in which *absorption was already detected.* If our hypothesis is correct, for a sample of QSOs without low redshift absorption we would expect to see a similar distribution of galaxies as far as $\Delta\theta$ and apparent magnitude are concerned. This is apparently now being found (Drinkwater et al. 1993; Lanzetta et al. 1995).

Another important point is that in some of the best cases where interaction between ejected QSO and galaxy are implied e.g. 3C 232 and NGC 3067, and the QSOs near NGC 3079, there is every indication that the gas which is doing the absorbing is not quiescent halo gas, but is gas that is being ejected from the galaxy.

Since we see evidence for activity in many of the galaxies listed in Table 1, it is possible that much of all of the absorption is associated with gas that has been ejected from the galactic disks. We know that in our own galaxy much of the neutral gas at high latitudes is due to ejection from the galactic disk (cf. Heiles 1992).

Evidence that galaxy halo and/or disks are responsible for some of the absorbing systems in the spectra of QSOs comes not only from the direct detections of galaxies very close to the QSOs (cf Bergeron & Boissé 1991) but also from the identification in QSOs with redshifts in the range $z \approx 1.8$ to 4 of the so-called Ly-α damped systems where Wolfe and others (Wolfe et al. 1986, 1993; Lanzetta et al. 1995) have made a good case for supposing that these systems are due to gaseous disks of spiral galaxies.

Those observations are also compatible with the view developed in this paper that the QSOs have both an intrinsic redshift component z_i and a cosmological component z_c. In this model in which the QSO and galaxy are physically associated a damped Lyα at absorption redshift z_a must define the cosmological redshift of the parent galaxy. Thus the damped Lyα absorption redshift z_a will be the cosmological redshift z_c of the system, and the difference between it and the emission redshift z_e is due to the intrinsic redshift term, i.e. $z_i = \left[(1+z_e)/(1+z_a) - 1\right]$.

For the systems in which a galaxy with $z_g = z_a$ has been detected, cf (Bergeron & Boissé 1991) the values of z_i turn out to lie in the range 0.3-0.7. For the systems in which the galaxy is identified only through the identification of the Lyα damped systems (cf. Wolfe et al. 1986, Lanzetta et al. 1991, Wolfe et al. 1993) $z_a \approx z_c$, and the values of z_i lie in the range 0.05-0.3.

In all of those cases $z_c > z_i$, and in the Ly-α systems $z_c \gg z_i$.

Thus in this interpretation, the investigations of galaxies at high redshifts being made by studying the absorption systems in high redshift QSOs are still valid and can be used to set limits to cosmological models.

The damped Lyα systems are comparatively rare (Rao et al. 1995). However in the spectra of high redshift QSOs the frequency of absorption is high. In this model the Lyα damped systems are associated with the parent galaxies of the QSOs and when they are not present we conclude that the QSOs have moved sufficiently far away from their parent QSO so that they are outside the thick disk. What about the situation in which more than one absorption redshift each of which has all of the spectral characteristics associated with either disk or halo absorption is found? In this case we must relax the condition that it is the lowest value of z_a that is due to the parent galaxy, and argue instead that it is the highest value of z_a compatible with absorption in a galactic disk that defines the cosmological redshift. The lower value is then attributed to an *intervening* galaxy as is currently believed. A good example is found in HS 1946+76 (Fan & Tytler 1994; Lu et al. 1995). This QSO with $z_e = 3.05$ has damped Lyα systems at $z_a = 2.844$ and 1.738. On our picture this QSO has an intrinsic redshift $z_i = 0.053$ and its cosmological redshift is 2.844. There is an intervening galaxy at $z = 1.738$.

How do we account for the other absorption systems, both those containing metals, and those which make up those so-called Lyα forest systems which are commonplace in the spectra of high redshift QSOs? Since we have accepted that the damped Lyα systems are galaxies at high redshifts, these QSOs also must lie at large cosmological redshifts. Thus some of the Lyα forest absorption and absorption involving metals could be due to intervening gas as is commonly assumed. However, the problems raised by Borgeest and Mehlert (1995) previously referred to, and the difficulty of explaining the very wide range of z_a seen in some QSOs make us believe that at least some of the absorption is due to ejection of gas from the QSOs at the appropriate velocities, so that the redshift is made up of a cosmological component, an intrinsic component due to the QSO, and a Doppler component due to ejection towards us.

In cases which are often found, where $z_a \approx z_{em}$ the absorption must be due to gas associated with the QSO with nearly the same intrinsic component as the QSO.

It is curious that the ejection hypothesis has been neglected. It clearly bears further study. In some cases the velocities must be quite high, but they are never as high as those tacitly accepted by those who believe in the existence of superluminal motions in the compact radio sources (see the following section).

A good example of the manifestation of ejection may be associated with the Lyα forest systems seen in the spectrum of 3C 273.

Several Lyα forest systems ranging all the way from $z_e = 0.158$ to the redshift of the Virgo cluster have been detected (Morris et al. 1991; Bahcall et al. 1991) and the search for galaxies at those (cosmological) redshifts has given null results (Morris et al. 1993). With 3C 273 in the Virgo cluster (Sect. 4) ejection of gas from it at quite modest velocities would explain these systems. Even if 3C 273 were at a cosmological distance, it is possible that the Lyα absorption is due to ejection.

8. Superluminal motions

The physical problems posed by the observations of flux variations in QSOs with large redshifts on timescales $\sim$ years or less (Hoyle, Burbidge & Sargent 1966) first led to the view that either the redshifts were not true measures of distance (Hoyle et al. 1966) or that highly relativistic motions must be invoked (Woltjer 1966, Rees 1967). Up until now that latter view has prevailed, and the idea of superluminal sources now pervades the literature (cf Porcas 1987). Interferometric measures (VLBI) have been made of many of the bright radio QSOs. Changes in position requiring bulk motion of radiating plasma at levels of $\lesssim 1$ milliarcsec (mas)/yr are commonly measured and the interpretation is that the variability is due to so-called superluminal motions with values of $\gamma = (1-\beta^2)^{-\frac{1}{2}} \approx 3-10$, and values of $\beta = 0.95$ to >0.99.

In Sect. 3 we pointed out that Arp has suggested that 3C 273 and 3C 279 which are both reported to be superluminal sources, lie in the Virgo cluster. Putting $d = 21$ Mpc (Sandage 1994), and using the observed values of the proper motion (Porcas 1987) which range for different components between 0.30 and 1.20 mas yr^{-1} (for 3C 273) and 0.1 - 0.5 mas yr^{-1} (for 3C 279) we find that the actual velocities range between 0.26c and 0.38c for 3C 273, and 0.03c and 0.16c for 3C 279. Thus although the velocities are relativistic, they are not superluminal. In fact they are comparable to the velocities found in so-called subluminal sources which include the radio galaxies Perseus A (NGC 1275) and M87 (Porcas 1987).

None of the other radio QSOs which have been studied by VLBI can be assigned distances through association with bright galaxies. However many are 3C sources, and the values of μ which are measured mostly lie in the range 0.1-1 mas yr^{-1}. If this means that if the actual velocities are no greater than those in 3C 273 and 3C 279, these QSOs e.g. 3C 345, which is surrounded by a group of bright QSOs, must lie within $\sim$ 200 Mpc.

Are there any variable radio sources which on this model are genuinely superluminal? The best cases will be those BL Lac objects in which we have unequivocal spectroscopic evidence for the presence of a bright elliptical galaxy, and also evidence that they follow the Hubble law (Burbidge & Hewitt 1987). This is true of BL Lac itself which has z_c = 0.07, and thus lies at a distance of about 420 Mpc. In this case it has been shown to have motions of 0.7 mas yr^{-1} (Porcas 1987) and this means that the apparent motion is about 4 ly/yr. Thus this on our picture is a genuine superluminal source.

9. The X-ray background

The X-ray background is thought to arise in large part from X-ray emitting QSOs. It has been reviewed by Fabian & Barcon (1992) and more recently by Hasinger (1995). One serious objection to the non-cosmological redshift hypothesis has been made over the years by Setti & Woltjer (1979, 1989) (see also Burbidge & Narlikar (1983). In its essentials the argument has been that the background radiation sets a lower limit to the average distances of the QSOs since they make up at least a fraction of the discrete sources which gives rise to the low energy X-ray background. This is simply the Olbers effect. However within the framework of the model discussed here the bulk of the QSOs have significant cosmological redshift components and only a small fraction are truly local and lie with 200 Mpc. In this model the space distribution of QSOs must follow the space distribution of normal spiral galaxies from which they are ejected, and it is known that out to redshifts $\sim$ 1 this latter distribution is compatible with the zero evolution models (Koo & Kron 1992). Thus it is possible to calculate the average cosmological redshift of the QSOs contributing to the background. If the ratio of the background flux contributed by known sources to the total background is r, then

$$r = \left[1 - (1 + z_o)^{-5/2}\right]^{-1}$$

where z_o is the average cosmological redshift of the QSOs. Since according to the results given by Hasinger, $r \simeq 3$, $z_o = 0.18$ (Burbidge & Hoyle 1995). It is of some interest that Jahoda et al. (1991) have found a weak correlation of the HEAO-1A2 X-ray background with bright galaxy counts. This would agree with the model here since a small fraction of the sources may be the nearby QSOs associated with bright galaxies.

10. Conclusion

In this paper we have shown that in order to accommodate all of the observational evidence concerning the nature of QSOs it is necessary to invoke the existence of intrinsic redshift components in QSO spectra. In a separate paper Hoyle and the author (Hoyle & Burbidge 1995) have shown that within the framework of the quasi-steady state theory (Hoyle, Burbidge & Narlikar 1993, 1994a,b) it is possible for samples of material of different ages to have different mass scales, and thus it appears likely that QSOs are ejected from galactic nuclei with those different properties, thus having intrinsic redshift components.

Of course, this is only one theory, and alternative ideas may be considered, but the observational results force us to the conclusion that intrinsic non-cosmological redshifts are present and must be explained in some way. The only other way out is to attribute all of the statistical, morphological and physical evidence discussed here and referenced over many years, as due to an amazing number of uncorrelated accidents.

In developing the empirical model discussed here, it has become clear that what we have discovered so far about QSOs is overwhelmingly biased by observational selection effects.

For example, as we have shown, there are many good arguments which show that there are physical connections between QSOs and both bright nearby and faint distant galaxies. This means that QSOs which are very faint with $M \approx -10$, can be ejected from galaxies and QSOs which are very bright with $M \approx -25$ can also be ejected. The very local QSOs come from the faint end of the true QSO luminosity function while the QSOs associated with faint high redshift galaxies come from the bright end of the QSO luminosity function. Is the QSO luminosity a function of the type of parent galaxy, and does that luminosity change with time? Simple arguments would suggest that the QSO luminosity is a function of time t since its ejection, i.e. $L \propto \exp(-t/t_o)$. What the dependence is on the type of galaxy and its evolutionary state is less obvious though the majority of the cases shown in Table 1 involve active spiral galaxies. However it is probable that the galaxy is only able to eject QSOs when it is active as seen from its other energetic properties.

We see only one QSO, 3C 273, which is comparable in absolute brightness to the galaxies near it, and none which is brighter. This is compatible with the idea that the very bright QSOs are rare. At the other extreme, we have not so far detected the vast number of QSOs which are fainter than the galaxies that have ejected them, since even for galaxies at modest redshifts such QSOs will go undetected.

A friendly referee has suggested that this model, like all models, should be falsifiable and asks for tests.

This is not easy, since what has been done here is to build a model based on *all* of the observational evidence concerning the QSOs, and not only on that part which in the simplest interpretation, or following a favorite theory, has been thought by most people to exclude the idea that any parts of the redshifts of QSOs are intrinsic.

In the original model of Hoyle and Burbidge (1966) it was argued that all of the QSOs identified at that time were local and were ejected from comparatively nearby galaxies. This idea was clearly falsifiable, but most claims that this had been done simply amounted to arguing that none of the associations between galaxies and QSOs with different redshifts was real, and everything which supported our idea was due to observational accidents, or due to incorrect statistical analysis. Unfortunately it is these statements which have been repeated over and over in textbooks and elsewhere without any evidence being provided to support them. The only evidence which showed fairly early on that the model needed to be modified was the discovery that some QSOs have redshifts approximately equal to those of nearby faint galaxies. This showed that some QSOs have a cosmological redshift component, i.e. they are not all nearby, and second, that the intrinsic redshift component is small. But of course they do not disprove the existence of discrepant redshift pairs.

Thus, the problem is not that the original proposal of Hoyle and Burbidge (1966) was not falsifiable, but that evidence which is in its favor has been continuously ignored, and other interpretations have been preferred.

I have now modified the original idea significantly because the newer evidence has shown that only a fraction of the QSOs originate in galaxies which are so close that the redshifts of those QSOs are almost completely intrinsic. It is clear that the majority of the QSOs are associated with galaxies which lie at appreciable distances so they must have both a cosmological component and an intrinsic component of redshift.

In the future observational programs carried out without the belief that the answers are already known are required. For example, detailed studies of the environments of high redshift QSOs similar to those which have been made about a few low redshift QSOs, are badly needed. Based on the fragmentary studies so far available we would predict that many of the galaxies very close to QSOs will show evidence for violent activity.

Also searches for QSOs about many of the $\sim$10000 bright galaxies, and all active galaxies, with appropriate control samples, are badly needed.

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