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COMMENT ON QUASAR-GALAXY ASSOCIATIONS

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ABSTRACT

The 259 Tololo quasar candidates are compared with positions of 62 bright galaxies. The number of close quasar-galaxy pairs predicted from a random distribution lies within 1 standard deviation of the number actually found. Quasar-quasar pairs also agree with the number expected by chance. Suggestions are made as to why the results do not confirm the seemingly high frequency of quasar-galaxy pairs reported, primarily by Arp.

Subject headings: galaxies: clusters of — quasars

I. INTRODUCTION

Arp has continued to present examples of highly redshifted quasars close to galaxies as evidence for noncosmological redshifts (e.g., Arp 1977; Arp and Sulentic 1979). G. Burbidge (1979) has recently reviewed this evidence comprehensively and concludes that such quasar-galaxy associations are found improbably often. He suggests that these quasars represent a subset with noncosmological redshifts, while other quasars probably do have cosmological redshifts. Wills (1978) reviewed somewhat earlier data and concluded that there is no statistical evidence that quasar-galaxy associations are more than random alignments. One source of controversy in such analyses is what the surface density of quasars on the sky actually is. The number of discoverable quasars appears to increase by a large factor—as much as 6 to 8 times—for each magnitude increase in the survey limit (e.g., Sandage and Luyten 1969; Osmer 1980). Consequently, a few tenths of a magnitude uncertainty in the estimate of a quasar magnitude leads to a factor of 2–3 uncertainty in the chance of finding the quasar in a given sky area. It is this effect that makes many astronomers skeptical about the statistical significance of Arp's configurations.

One obvious way to test the association hypothesis is a careful search for quasars in a large area of the sky without regard to the proximity of galaxies. The search needs to find a surface density of quasars which is comparable to that of the galaxies with which correlations are sought. Two useful surveys which meet these criteria have been conducted with the Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory (MacAlpine and Lewis 1978; Osmer and Smith 1980). The Michigan group published four lists of emission-line objects containing 174 quasar candidates. Subsequent spectroscopic observations confirm that at least 80% of these are quasars with $z > 1$ (Lewis, MacAlpine, and Weedman 1979). Osmer and Smith (1980) published 108 confirmed quasars in a different area of the sky. All of these Tololo quasars can be checked for association with bright galaxies. If quasar redshifts are all cosmological, no physical associations can exist.

II. THE RESULTS

To test for quasar-galaxy associations I used only NGC or IC galaxies contained in the *Second Reference Catalogue of Bright Galaxies* (de Vaucouleurs, de Vaucouleurs, and Corwin 1976). This should be a legitimate test for Arp pairs. In his summary of quasar-galaxy associations Burbidge (1979) lists 46 "main galaxies" with which quasars are associated. Of these 46, 37 are in the Catalogue. On the advice of G. MacAlpine, I considered only the last three Michigan-Tololo lists (MacAlpine, Smith, and Lewis 1977; MacAlpine, Lewis, and Smith 1977; MacAlpine and Lewis 1978). These are considered to be more homogeneous and to go to a fainter magnitude limit than the first list, when searchers were still inexperienced. These three lists cover $23^h.2 \lesssim \alpha \lesssim 02^h.4$ for $-2°.5 \lesssim \delta \lesssim +2°.5$ and $1^h.3 \lesssim \alpha \lesssim 2^h.0$ for $+2°.5 \lesssim \delta \lesssim +7°$, or an area taken as 287 deg^2. Within this area are 151 quasar candidates. In the same area are 52 NGC galaxies contained in the *Second Reference Catalogue*. Some of these galaxies are in groups, however, so that search areas around each would overlap. A correction for this is made by including only half of the galaxies in such groups, which gives a total of 42 independent search areas associated with bright galaxies. The Osmer and Smith (1980) list is intended to be complete in the 340 deg^2 region bounded by $21^h50^m \leq \alpha \leq 04^h00^m$ and $-42°.5 \leq \delta \leq -37°.5$. Within this area are 108 quasars and 20 independent bright galaxy search areas.

Following Burbidge (1979), the number of quasars n expected by chance within an area of radius r centered on any galaxy is $n = \pi r^2 N_G N_Q A^{-1}$, where N_G is the number of galaxies, A is the total area surveyed, and N_Q is the number of quasars in the area. For the cases being considered, A and N_Q are given by the Tololo surveys, and questions about magnitude limits and quasar surface density as a function of magnitude do not enter. In Table 1 are given the results, comparing the number of quasars found and the number expected. For comparison, Burbidge's results for an estimated limiting magnitude of 18 are shown. Within a 2′ radius from any bright galaxy, the Tololo surveys found no quasars, although

TABLE 1

QUASAR-GALAXY AND QUASAR-QUASAR PAIRS[a]

	Quasar-Galaxy								Quasar-Quasar					
	Michigan		Osmer-Smith		Total		Burbidge		Michigan		Osmer-Smith		Total	
r	n	Found	n	Found	n	Found	n	Found	n	Found	n	Found	n	Found
2′..........	0.08	0	0.02	0	0.09	0	0.68	10	0.28	2	0.11	0	0.37	2
5′..........	0.48	2	0.14	0	0.56	2	4.3	11	1.7	2	0.75	0	2.3	2
10′..........	1.9	5	0.55	0	2.2	5	17	17	6.9	9	2.9	1	9.3	10
15′..........	4.3	7	1.2	0	5.0	7	...	...	15	13	6.7	3	21	16

[a] The number of pairs within separation r expected by chance is designated by n. The numbers found are from the Michigan-Tololo survey, the Osmer and Smith Tololo survey, these two combined (total), and those in Burbidge's (1979) summary of results from Arp and others.

this is the area in which the greatest excess is found in Arp's results. Within 5′, the excess factors are comparable, taking the Michigan results alone. For the Osmer and Smith sample, the results do not exceed those expected by chance at any r. Combining the Tololo samples gives a total of 259 quasars and 62 bright galaxies in 627 deg^2. At no value of r from 2′ to 15′ does the number of quasars expected by chance differ by more than 1 standard deviation from the number actually found.

The Tololo candidates that are within 15′ of a bright galaxy are described in Table 2. Any hint of quasar-galaxy association is based only on these seven quasars out of 259 candidates. Furthermore, all objects in Table 2 may not be real quasars, as confirmation spectra do not exist for four of them. The candidates in Table 2 show no similarities, such as the common redshifts that Arp has suggested characterize quasars associated with galaxies (Arp, Sulentic, and di Tullio 1979).

A nonrandom incidence of quasar-quasar pairs having components with different redshifts would also be evidence of noncosmological redshifts (e.g., Bolton *et al.* 1976). The Tololo samples can be checked for such pairs using a calculation analogous to that above for quasar-galaxy association. As the search areas are now centered on the quasars, the number expected by chance within a radius r of any other is $n = \pi r^2 N_Q(N_Q - 1)A^{-1}$. This gives values of n in agreement with the number of pairs actually found (Table 1).

III. DISCUSSION AND CONCLUSIONS

If there are real physical associations between galaxies and quasars, why do they not show up in the Tololo samples? An example of a Tololo survey area, with galaxies and quasars, is shown in Figure 1. This illustrates the general absence of any obvious correlation between the two kinds of objects. Having examined a number of Tololo plates, I know of no reason why searchers of these objective prism plates would systematically avoid regions near bright galaxies. While the extended spectrum of the bright center of a galaxy could obscure nearby quasar spectra, such obscuration rarely extends as much as 1′ from a galaxy center. (Examples of Tololo plates illustrating this can be found in Smith 1975.)

Furthermore, there do not seem to be different kinds of quasars in the Arp pairs compared to the Tololo surveys. Some comparisons of the samples are in Table 3. The redshift distribution of Tololo quasars is more concentrated near $z \approx 2$, but this is because the survey is very efficient in finding quasars with Lα emission. As such highly redshifted quasars also occur in association with galaxies, there is no reason to reject them from statistical evaluation of such associations. The magnitude distributions of the samples are also similar. Magnitudes from Osmer and Smith (1980) for Tololo quasars are monochromatic, chosen to correspond to certain wavelengths in the quasar rest frame. While V magnitudes are given for the Arp quasars, differences would be no more than a few

TABLE 2

QUASAR CANDIDATES WITHIN 15′ OF BRIGHT GALAXY

QSO	NGC	θ[a]	Comments
UM 130.............	664	7′.2	Possible quasar appearing as BSO
UM 228.............	78B	8′.6	Confirmed redshift of $z = 0.102$
UM 245.............	120	4′.0	Probable quasar with estimated $z \approx 1.46$
UM 247.............	132	5′.0	Confirmed $z = 2.35$
UM 268.............	227	7′.6	Possible quasar wtih estimated $z \approx 1.66$
UM 322.............	558	12′.4	Probable quasar with estimated $z \approx 1.99$
UM 328.............	565	11′.7	Confirmed quasar with weak line at 5111 Å

[a] Separations calculated by using quasar coordinates in the discovery lists, which seem generally to be accurate within 15″, and comparing to galaxy coordinates in Dressel and Condon (1976), which are even more accurate.

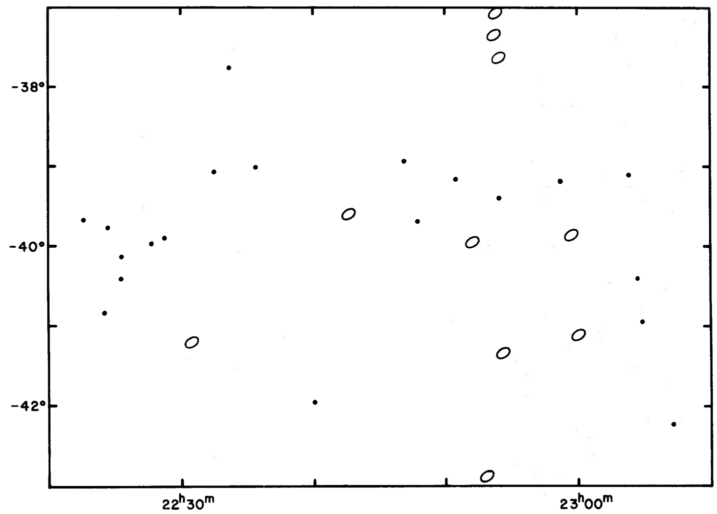

FIG. 1.—A portion of the survey by Osmer and Smith (1980), showing quasars (*filled circles*) and galaxies (*open ovals*)

tenths of a magnitude for typical quasar spectra, as long as no strong emission lines are in the V band. Consequently, magnitudes from the two different systems are compared directly in Table 3.

The Tololo results provide a check on the quasar surface density used by Burbidge (1979) to deduce the statistical reality of the Arp pairs. For example, he adopted one quasar deg^{-2} brighter than 18th magnitude. The Osmer and Smith sample contains only 0.082 quasars deg^{-2} with $m < 18$, but does not include quasars of all redshifts having this magnitude limit. If the redshift distributions are compared for the Arp sample and the Osmer-Smith sample, the former has only 14.3% of all quasars with $2.0 < z < 2.4$, whereas the latter has 51.8%. This is the redshift range for which the Tololo survey is most efficient. If the number of quasars at all redshifts really is 0.143^{-1} of those with $2.0 < z < 2.4$, then the surface density of the Osmer-Smith sample should be increased by a factor of 3.6. This would give a total quasar density of 0.3 deg^{-2} for $m < 18$. This agrees with the number from the Michigan-Tololo survey, because lower redshift quasars are included as blue continuum objects (Lewis, MacAlpine, and Weedman 1979), with early estimates by Sandage and Luyten (1969), and with the Anglo-Australian Schmidt results by Bolton and Savage (1978). By overestimating the quasar surface density, Burbidge would increase the number of quasar-galaxy pairs expected by chance. Were a surface density of 0.3 deg^{-2} adopted for quasars with $m < 18$, the contrast between the number of pairs expected and those found would be even more striking.

Burbidge's best case, that with the greatest contrast between pairs found and pairs expected, is for quasars with $V < 18$ that are within 2′ of a bright galaxy. There are 10 of these pairs in his summary, whereas only 0.68 are expected by chance (and only 0.23 expected if the quasar density above is used). Given this striking excess, it is extremely puzzling that

TABLE 3

COMPARISON OF QUASARS IN TOLOLO AND ARP SAMPLES

	z BIN							
QUASAR	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8
Arp	3.2%	28.6%	19.0%	12.7%	19.0%	14.3%	3.2%	0%
UM	9.8	6.6	8.2	19.7	22.9	21.3	1.6	9.8
OS	5.6	0.9	0.9	10.2	12.0	51.8	8.3	10.2

	m BIN									
QUASAR	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5
Arp	1.5%	3.0%	4.5%	10.4%	19.4%	10.4%	20.9%	11.9%	8.9%	1.5%
OS	0	0.9	7.4	17.6	16.7	28.7	20.3	7.4	0	0

NOTE.—"Arp" quasars are those summarized by Burbidge (1979); UM quasars are from the Michigan-Tololo survey (Lewis *et al.* 1979); and OS quasars are from Osmer and Smith (1980). Redshift bins are 0.4 wide, beginning at the redshift listed. Magnitude bins are 0.5 wide, beginning at the magnitude listed. Totals are not all 100%, because a few values fall outside bins included.

similar associations are not also found in the Tololo survey. For this reason, I will now consider whether this large excess could be explained by other factors.

Two of the 10 pairs include quasars found in a deliberate search for blue stellar objects near galaxies (Weedman 1971). These objects cannot fairly be used to contribute to excess quasar-galaxy pairs. Burbidge based his probability calculations on the assumption that 200 fields near bright galaxies had been searched for quasars. The blue objects I found, however, were based upon examination of every galaxy on the Sky Survey prints having a diameter more than about 1′. This means that thousands of search fields were involved, and only nine candidates were found in all. The same objection applies to Markarian 205, another of the 10. This remains the only Markarian quasar near a galaxy, even though the Markarian survey encompasses the entire northern sky. We are left with seven pairs: (NGC 227, PKS 0038−019), (NGC 3067, 3C 232), (NGC 5669, UB 1), (IC 1417, BSO), (NGC 7714, UB 1), (IC 1746, PHL 1226), and (ANON, PKS 2020−37.0). Note that three of these are 3C or Parkes sources. This means that they, too, came from surveys that encompassed many more than 200 galaxies in the sky, but were later selected as the only 3C or Parkes quasars near galaxies. The pairing does not require that the galaxy be especially bright, either, as evidenced by the association of one Parkes source with an anonymous galaxy.

Four pairs remain. The UB object near NGC 7714 was found by a radio survey of isolated pairs of galaxies; observations of NGC 7714–7715 showed the nearby quasar (see Stocke and Arp 1978). It is not stated how many other galaxies were observed in this survey. This quasar magnitude is estimated, not measured, to be 18. There is reason to believe this estimate is too bright, which would be important because of the rapid increase of quasar surface density with magnitude. NGC 7714 is included in the search area of the Michigan-Tololo survey (emission-line galaxy number 167 in the second list), but the associated quasar was not found. With a redshift of 1.87 and magnitude of 18, it should have been conspicuous. This is in the redshift bin containing the highest percentage of Michigan-Tololo quasars, and the majority of these are fainter than 18 mag (Lewis, MacAlpine, and Weedman 1979).

For two of the remaining pairs, those with IC 1417 and IC 1746, it is not possible to determine from the discovery observations how many galaxies were examined to find them. Both were discovered on the Sky Survey. For IC 1417 (Arp, Baldwin, and Wampler 1975), "Arp noticed that in another region of the sky a galaxy, IC 1417, had the appearance of a companion 12′.3 from the large spiral galaxy NGC 7171. This configuration is very similar to that of NGC 5682 and 5689 [other objects in the paper quoted]. Inspection of the area around IC 1417 revealed that one of the closest stars was blue." For IC 1746 (Burbidge *et al.* 1971): "We have recently come upon what appears to be a good example of such an object [quasar connected to galaxy].... It is immediately obvious [from Sky Survey print] that there appears to be a bridge of luminous material joining the galaxy to the QSO...." (This apparent bridge was subsequently found to be a faint galaxy.) I am not dismissing these two cases as uninteresting. The point is that there is simply no way of judging how much of the sky was examined in order to find these two configurations. Only one of the 10 pairs remains undiscussed. This is NGC 5669, which has only been reported recently by Arp (at the 1978 Texas Symposium in Munich), so the details of its discovery are not available.

Dismissing the significance of quasar-galaxy associations on a case-by-case basis in this way has the appearance of a strained effort to defend the paradigm of cosmological redshifts. It is tempting to feel that, while a few of these associations can be explained away, surely they cannot all be dismissed. Yet we see arguments can be made that, indeed, they all should be. Note that these arguments were not forced upon us simply by prejudice in favor of cosmological redshifts. They arose because large samples of quasars now exist, such as those in the Tololo survey, that show no evidence of quasar-galaxy associations. If these associations are physically real, they have to show up in objective samples of quasars.

No doubt, further interesting examples of quasars near galaxies will continue to turn up. All should be considered as honestly as possible. Likewise, wide-area surveys will continue to produce large numbers of quasars. Low-dispersion spectroscopic surveys are still being conducted with Schmidt telescopes at Cerro Tololo and the Anglo-Australian Observatory, and with the 4 m telescopes at Cerro Tololo and Kitt Peak. The techniques and some results are reviewed by Smith (1978). Less than 10% of the plates obtained with just the Tololo Schmidt have been analyzed and/or published. Analogous surveys are also planned in the north with the Schmidt telescope of the Warner and Swasey Observatory, now transplanted to Kitt Peak. It is reasonable to expect all sky samples of several thousand quasars within a few years from such surveys. The statistical base for considering quasar-galaxy associations should continue to improve.

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