Astron. Astrophys. 143, 451–454 (1985)

ASTRONOMY AND ASTROPHYSICS

A study of quasar pairs

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Received April 17, accepted October 4, 1984

Summary. A study of QSO pairs from large samples shows that the sky distribution of QSOs of different redshifts is random over scales from arcminutes to tens of degrees. Limits have been placed on brightness and colour changes in the background members of close QSO pairs which could be caused by matter associated with the foreground QSOs.

Key words: quasars – clusters – cosmology

1. Introduction

Interest in QSO pairs was kindled a decade ago when the first close pairs were found by Stockton (1972), Wampler et al. (1973), and Bolton et al. (1976). The existence of such pairs of QSOs, close to each other on the sky but of very different redshifts, was considered by those authors as evidence for a non-cosmological origin of redshifts, but others regarded such a conclusion to be premature (Bahcall and Woltjer, 1974; Burbidge et al., 1974; Gott and Gunn, 1974).

In the course of time, the significance of these early findings has in fact diminished. Only a few of the pairs studied by Bolton et al. (1976) have turned out to be confirmed QSO pairs which clearly satisfy their criteria, and subsequent searches made specifically to find other QSO pairs have been disappointing (Wills, 1978). And while the QSO pair (Q1548+114A, B, separation 4.8″) discovered by Wampler et al. in 1973 is still the closest known pair of distinct QSOs, the total number of known QSOs has increased by an order of magnitude, so the statistical significance of that pair is much reduced.

The larger samples of QSOs now available make possible objective studies of the pairing and clustering of QSOs. They show that QSOs of different redshifts are not significantly clustered on the sky.

Chance pairings of QSOs on the sky can be extremely useful in a variety of ways. The twin lines of sight probe the intervening medium on a range of scales, and, through absorption-line observations, provide information on the lateral sizes and clustering of the absorbing clouds. The line of sight to the background QSO probes the immediate vicinity of the foreground QSO, giving information on clusters of galaxies or gaseous halos associated with the foreground QSO. Such absorption-line observations also provide tests of the intervening hypothesis for the origin of the narrow absorption lines in QSO spectra and the cosmological interpretation of QSO redshifts as a by-product (Shaver and Robertson, 1984, and references therein).

One may also look for brightness differences in the background QSO due to extinction or gravitational lens brightening caused by matter associated with the foreground QSO. In addition, the brightness (or colours) of the two QSOs may be significantly altered by material in front of both, and this could show up as a correlation between the properties of the two QSOs in a pair. Preliminary tests of this nature are reported below.

All of the work reported in this paper is based on the Véron catalogue (Véron-Cetty and Véron, 1984), which contains 2251 QSOs with measured redshifts. The advantage of using such a catalogue is that it provides a sample containing only QSOs (to a high degree of reliability), with known redshifts. The disadvantage is that it is heterogeneous, the QSOs having been found using a variety of different techniques. Special efforts must therefore be made to minimize selection effects; this is greatly facilitated by the fact that we are dealing here with QSO *pairs* rather than individual QSOs.

2. The sky distribution of QSOs

If QSOs are distributed at random over the sky, then the number of QSO pairs with separation between θ and $\theta+\Delta\theta$ should increase linearly with θ. In such a test, different surveys with different sensitivity limits can be used together – this affects only the total number of pairs, not the slope or shape of the differential frequency distribution. The only requirement is that each survey should uniformly cover an adequate area. This test therefore has the advantage that it can be applied to larger samples of QSOs, and it is independent of the surface density of QSOs, a quantity which is difficult to determine accurately.

The QSO surveys which have been used here are listed in Table 1. There are three distinct types – objective prism surveys, grism surveys, and a *UVX* survey. In all cases only QSO pairs of different redshifts ($\Delta z>0.05$) have been used, as this is a study of the sky distribution of QSOs of different redshifts; a study of QSO pairs of similar redshifts is given elsewhere (Shaver, 1984). The samples used here may be incomplete for a variety of reasons – the usual selection effects, QSOs which were missed or whose redshifts are not yet known, and QSOs which were previously known and whose discovery was ascribed in the catalogue to other references. However, so long as these occur randomly they will not affect the outcome of this study, and any non-random effects would in any case most likely show up as deviations from a random distribution.

Figure 1 shows the distribution of QSO pairs from the objective prism surveys listed in Table 1 (a). Also shown are curves representing various degrees of clustering. Curve 1 is a Monte

Table 1. QSO surveys used in studying the sky distribution of QSOs

a) Objective Prism surveys with Michigan/Curtis and U.K. Schmidt telescopes, 521 QSOs

- Clowes and Savage (1983)
- Kunth et al. (1981)
- MacAlpine and Feldman (1982)
- MacAlpine and Lewis (1978)
- MacAlpine and Williams (1981)
- MacAlpine et al. (1977a)
- MacAlpine et al. (1977b)
- MacAlpine et al. (1977c)
- Osmer and Smith (1977)
- Osmer and Smith (1980)
- Savage and Bolton (1979)
- Smith (1976)

b) Grism surveys with 4 m telescopes, 276 QSOs

- Bohuski and Weedman (1979)
- Gaston (1983)
- Hoag and Smith (1977)
- Hoag et al. (1982)
- Sramek and Weedman (1978)

c) *UVX* survey, 92 QSOs

- Schmidt and Green (1983)

Carlo simulation of a purely random distribution of objects over a 5° square field. For curves 3 and 10, half the objects are distributed at random, and half are in clusters of arbitrary size and location; the surface density of objects in the cluster areas is respectively 3 and 10 times that in the non-cluster area. Curve *G* represents the clustering of galaxies from the Zwicky catalogue, as given by Peebles (1975). In the horizontal direction the curves are fixed, the field size in the simulations corresponding to the actual search area (5°). In the vertical direction all curves have been normalized at the peak where the observational uncertainties are relatively small.

The observations are consistent with a purely random distribution (curve 1). This is especially impressive as almost any non-random effects (reduced sensitivity at the plate edges, etc.) would mimic clustering, and flatten the distribution. The point at the extreme right lies above the theoretical curve because some of the observed fields were adjacent to each other, allowing pair separations greater than the plate dimensions (restricting the sample to QSOs from fields well isolated from each other fixes both the vertical and horizontal scales, and further improves the agreement with curve 1, although the error bars are larger). Any clustering of QSOs is obviously far less than galaxy clustering, and even less than that represented by curve 3, for which half the objects are in clusters of surface density just three times the background.

The bottom part of Fig. 1 shows that there is no measurable difference between the correlation functions of low and high redshift QSOs. Both groups appear to be randomly distributed on the sky.

In Fig. 2, similar distributions are also shown for the grism and *UVX* surveys. In these cases it is not so easy to define a unique survey area; a lower limit is fixed by the plate size in each case (34′ and 9°.5 respectively), but aside from that the theoretical curves can be shifted both vertically and horizontally with respect to the observed distribution. Nevertheless, it is clear that all three distributions are well matched by curve 1, representing a random distribution, and that even clustering with a contrast of 2 or 3 seems to be excluded. It should be noted that the median redshift of the QSOs in the *UVX* sample is only 0.3, compared to 2.1 for both the grism and objective prism samples, so once again there is no evidence for any significant difference between low and high redshift QSOs with respect to their distribution on the sky – they all appear to be distributed randomly. These three distributions conveniently overlap in angular scale, and we may conclude that the sky distribution of QSOs appears to be random on all scales from arcminutes to tens of degrees.

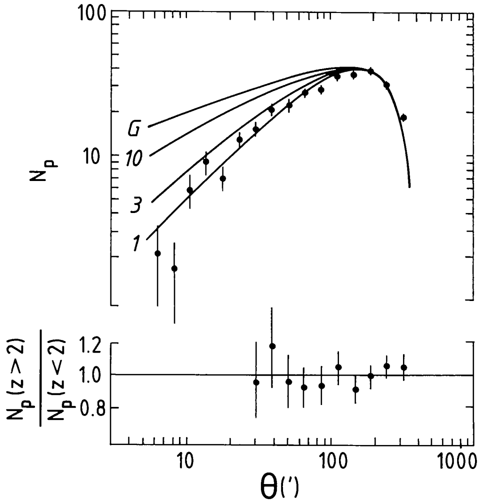

Fig. 1. Differential frequency distribution of QSO pairs of different redshifts as a function of angular separation. The data points are from the objective prism surveys listed in Table 1a, and the error bars correspond to $\sqrt{\Delta N}$. Curves *1*, *3*, and *10* represent Monte Carlo simulations of possible distributions – Curve *1* represents a purely random distribution, and Curves *3* and *10* include various degrees of clustering as described in the text. Curve *G* represents galaxy clustering, from Peebles' (1975) analysis of the Zwicky catalogue. All curves have been normalized to the peak of the distribution. In the lower part of the figure the normalized ratio of the number of pairs of high and low redshift QSOs is shown as a function of angular separation

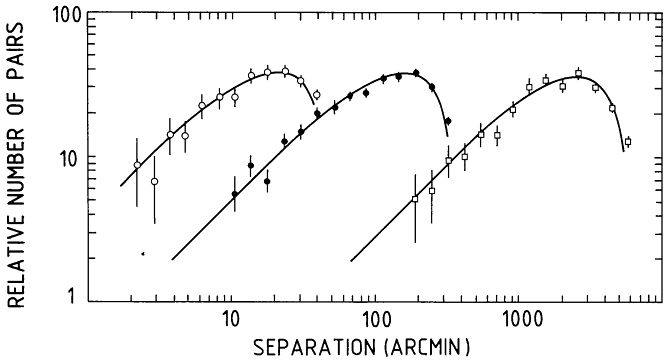

Fig. 2. Differential frequency distribution of QSO pairs of different redshifts as a function of angular separation. The data points are from the objective prism surveys listed in Table 1a (●), the grism surveys listed in Table 1b (○), and the *UVX* survey indicated in Table 1c (□), and the error bars correspond to $\sqrt{\Delta N}$. The curves are identical to Curve *1* in Fig. 1, representing random distributions as described in the text

It therefore appears, on the basis of presently available data, that QSOs of different redshifts are randomly distributed on the sky. There is no evidence for any excess of pairs with small separations, which should have shown up strongly if the early pairs discovered a decade ago were statistically significant. Other types of studies, using smaller samples of confirmed QSOs, have also revealed no detectable clustering (Osmer, 1981; Webster, 1982; Chu and Zhu, 1983), with the possible exception of one field at (02 h, $-50°$) (Chu and Zhu, 1983; Boyle et al., 1983). Weak clustering (too weak to be seen in Figs. 1 and 2) has recently been reported in a large sample of *UVX* objects, of which some fraction are presumably QSOs (Shanks et al., 1983; Boyle et al., 1983), but it has been attributed to an observed anticorrelation with clusters of galaxies, which could in turn be due to extinction within the clusters.

Groups, pairs, and alignments of QSOs can of course be found whose probability of occurrence appears low as calculated a posteriori, but which in fact are only random fluctuations or the results of selection effects [see, e.g., discussions in Webster (1982), and Zuiderwijk and de Ruiter (1983)]. There is, however, no consistent or compelling evidence for any statistically significant clustering, grouping, or pairing from *objective* studies of QSOs of different redshifts.

The absence of clustering strongly suggests that QSOs are not physically associated with low-redshift galaxies, and that close QSO pairs of large redshift difference are not physical associations.

On the other hand, QSOs of similar redshifts ($\Delta V \lesssim 2500$ km s^{-1}) *do* appear to be clustered, on scales similar to the clustering of galaxies at the present epoch ($\lesssim 5\,h^{-1}$ Mpc) (Shaver, 1984). This, and the lack of clustering amongst QSOs of different redshifts, are consistent with the notion that QSOs are the active nuclei of galaxies at cosmological distances.

3. Absorbers and lenses

It is possible to test for the presence of matter in the vicinity of QSOs by determining whether the background members of close QSO pairs are significantly abnormal in brightness. Here again, possible selection effects must be circumvented – in particular, the fact that closer pairs tend to be from fainter samples. The obvious solution is to simply compare the background QSO with the foreground QSO from the same pair. Then it is necessary to correct for the dependence of apparent magnitude on redshift, which can readily be done using the average relationship from the same samples as the pairs.

Figure 3 shows no obvious dependence of the magnitude difference between background and foreground members of QSO pairs on angular separation. Restricting the pairs to those in which the lower redshift is close to half of the higher redshift (the optimum configuration for gravitational lensing) only increases the scatter – again, no trend is evident. The standard deviation of the points in Fig. 3 is 0.5 mag, comparable to the gravitational lens brightening which may be expected (e.g. Peacock, 1983) due to a cluster of galaxies displaced by $1'-2'$ from the line of sight. The sensitivity achieved in this test is therefore not sufficient to detect such effects, at present. The scatter in the observed magnitudes is too large – partly observational, partly intrinsic – and nothing can be done about the intrinsic scatter except to increase the sample. The test could be improved by using only *isolated pairs*, in which each member is the nearest neighbour of the other by a large margin, but to be effective such a restriction would have to apply to all QSOs (and galaxies!) near the pair, not just those which are known and appear in catalogues. The present results put a 2σ upper limit of 0.9 mag on any brightness changes in background members of QSO pairs due to matter associated with the foreground members.

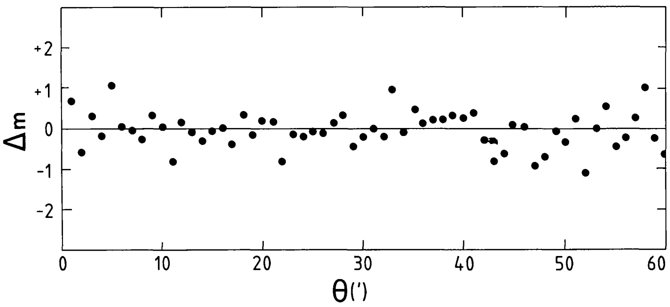

Fig. 3. Relative magnitude difference between background and foreground members of QSO pairs, as a function of angular separation

Another test for the presence of absorbing matter near QSOs is to look for possible colour anomalies in the background members of close pairs. Here it is presumably only necessary to compare the colours of these QSOs with those of all QSOs in the catalogue. The number of QSOs with measured colours is relatively small, but when allowance is made for observational uncertainties and the (very considerable) influence of emission lines on the observed magnitudes, no significant abnormalities in the colours of background QSOs is found, with an upper limit of about 0.3 mag.

QSO pairs can in principle also be used to probe for any material which may be located in front of both, as mentioned above, by looking for correlations in the brightness or colours of QSOs in pairs. No significant correlation has been found, but this is not surprising in view of the large scatter in intrinsic magnitudes and the small number of QSOs with measured colours. Furthermore, evidence for a correlation between colour and redshift, which could arise due to increasing dust absorption along the line of sight, is marginal at most (Richstone and Schmidt, 1980; Wright, 1982), so it is unlikely that colour differences between different lines of sight would be detectable.

These tests will obviously become more sensitive in the future, as more and better data become available, but whether a foreground QSO and any associated matter would noticeably affect the observed properties of a background QSO will depend on whether it is dominant along the line of sight. If there are many intervening objects scattered along the line of sight which produce similar effects but are less visible themselves, the relative influence of the intervening QSO and its environment may be small – just one further perturbation among many.

Acknowledgements. I am grateful to several colleagues for discussions on these subjects, and would particularly like to thank Guido Chincarini, Bob Sanders, Philippe Véron, and Joe Wampler.

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