QUASAR PAIRS

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ABSTRACT. This paper summarizes various uses which have been made of QSO pairs. Statistical studies using pairs show that the sky distribution of QSOs of arbitrary redshifts is random, and that QSOs of similar redshifts are clustered on a linear scale similar to that of galaxies today. Close pairs are used to set limits on the masses of QSOs. And absorption line studies of QSO pairs support the extrinsic hypothesis for the origin of the narrow absorption lines and the cosmological interpretation of the redshift, they demonstrate the presence of absorbing matter around QSOs, and they set limits on the sizes of the absorbers.

1. INTRODUCTION

An angular separation of one arcmin corresponds to 300-400 h^{-1} kpc at redshifts of ~1-2, for H_o = 100 h km s^{-1} Mpc^{-1} and q_o = 0 (used throughout this paper). Comparison with typical scales for galaxies and clusters of galaxies then shows that QSO pairs with angular separations up to several arcmin can be useful in a variety of astrophysical and cosmological studies. There is no scarcity of such pairs: at magnitudes brighter than 20th there is roughly one QSO pair of separation <1 arcmin for every 100 QSOs, and 10,000 such pairs over the whole sky. In the following we summarize briefly some of the uses that have already been made of such pairs.

2. SKY DISTRIBUTION OF QSOs

The use of QSO pairs can by-pass many of the problems encountered in studying the sky distribution of QSOs from variations in their surface density, a difficult quantity to measure accurately. The cumulative number of QSO pairs should increase as the square of the angular separation if QSOs are distributed randomly on the sky, regardless of the limiting magnitude of the sample used. Fig. 1 shows that this is indeed the case, up to angular separations comparable to the field

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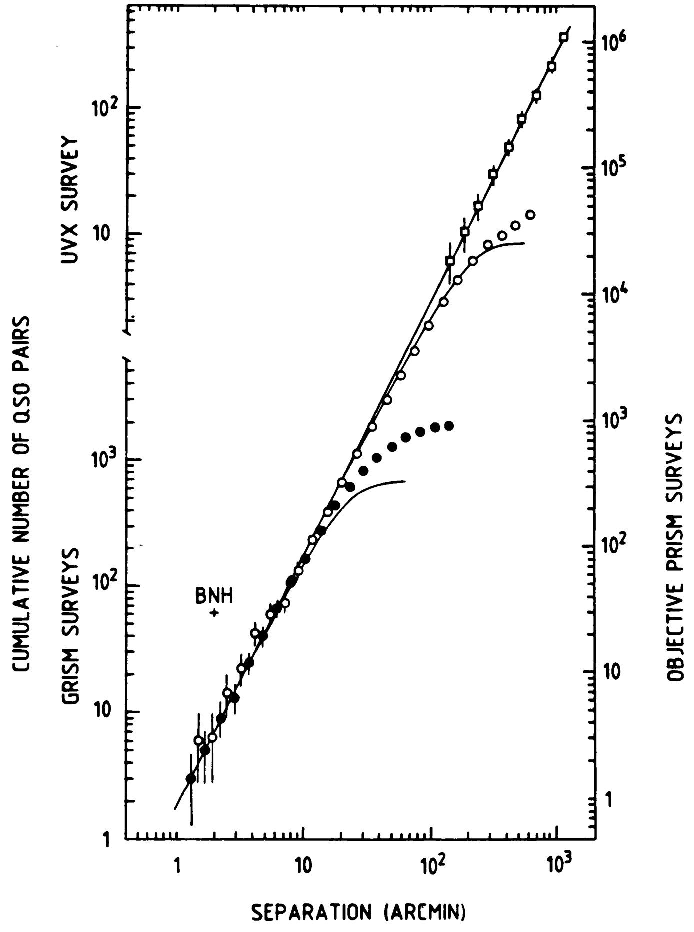

Figure 1. Cumulative frequency distribution of QSO pairs as a function of angular separation. The open circles, filled circles, and open squares are from the objective prism, grism, and UVX surveys listed in Shaver (1985, 1986) respectively. The error bars correspond to $\sqrt{N}$. The straight line has a slope of +2, the theoretical slope for a random distribution; the curves are Monte Carlo simulations for single fields. The cross marks the position expected for the data point at θ = 2' if QSOs were clustered as suggested by BNH.

size. Burbidge, Narlikar and Hewitt (BNH, 1985) find an excess of pairs of small angular separation in a study of published radio QSOs, but their result is clearly in conflict with the results in fig. 1, and it is not reproduced in an unbiased sample of radio QSOs studied by Wills (1978; 1986); Shaver (1986) has shown that the BNH result is heavily biased by the "publication selection effect" (cf. Wills, 1978). The sky distribution of QSOs of arbitrary redshifts appears to be random on all scales from arcminutes to tens of degrees.

3. PHYSICAL CLUSTERING OF QSOs

Homogeneous samples can in principle be used to study the physical clustering of QSOs, but they must be either very large or very deep because of the low space density of QSOs. An alternative approach is to use very large (but heterogeneous) catalogues of QSOs (in this case that of Véron-Cetty and Véron, 1985). Physical clustering should show up amongst QSO pairs of small redshift difference and projected linear separation, but not amongst those of large redshift difference and/or projected separation, and so can be studied by simply comparing these two groups. The observational selection effects are the same for both, and cancel out in the comparison.

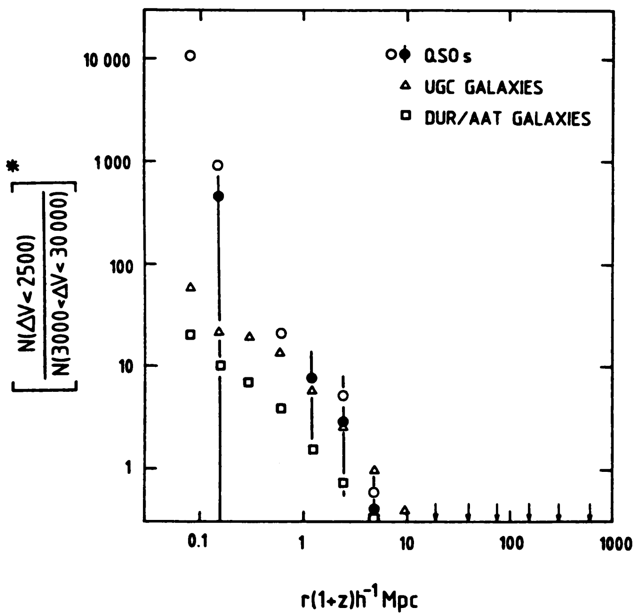

Figure 2. Number of pairs with small redshift difference (<2500 km s^{-1}) divided by the number with large redshift difference, as a function of projected linear separation and normalized to the largest separations, for QSOs and two samples of galaxies. A random (unclustered) distribution produces a normalized ratio of zero at all separations. The filled circles exclude those QSO pairs thought to be gravitational lenses or subject to the "publication selection effect".

Fig. 2 shows such a comparison using exactly the same technique for QSOs and two samples of galaxies. After allowance is made for those QSO pairs thought to be gravitational lenses and a few others possibly biased by the "publication selection effect", the agreement between the QSOs and the galaxies is striking: clustering is evident in all three samples below 10 h^{-1} Mpc, and at about the same amplitude, as first noted by Shaver (1984). If QSOs can legitimately be compared with galaxies, this implies that clustering on these scales has evolved very little since z ~ 2. Furthermore, the fact that QSO clustering shows up at all in this analysis provides further support for the standard cosmology, and further analysis may conceivably help to discriminate between different cosmological and evolutionary models. A more detailed analysis of this work will be published shortly.

4. GRAVITATIONAL LENSING

If the gravitational lens pairs are left in the above analysis, the clustering derived for QSOs exceeds that of galaxies today. As clustering is supposed to increase with time, this could be construed as statistical evidence for the reality of gravitational lensing. It is difficult to distinguish between close physical pairs and gravitational lenses, even for separations of arcminutes which could conceivably be produced by cosmological strings (e.g. Vilenkin, 1984; Hogan and Narayan, 1984; Gott, 1985). One possibility is to compare the redshifts of low-excitation forbidden lines, which should be relatively constant; if they differ in the two spectra, the images are almost certainly distinct QSOs.

Very close pairs of distinct QSOs with different redshifts are also of interest in connection with gravitational lensing. The foreground QSO acts as a lens, and this provides information about its mass. The pair Q1548+114AB, with separation 4".8 and redshifts 0.4 and 1.9, has been studied by Gott and Gunn (1974) and Iovino and Shaver (1986); the absence of a secondary image of the background QSO B implies an upper limit of $2 \cdot 10^{12}$ $M_\odot$ for A, and an ST search for the secondary image will give information on the central mass concentration of A.

5. ABSORPTION LINES IN QSO PAIRS

The twin lines of sight of a QSO pair probe the intervening medium on useful scales, and make possible a variety of studies. The line of sight to the background QSO passes close by the foreground QSO, and the spectrum of the former may contain absorption at the redshift of the latter ("associated absorption"). This has been found in a number of cases (e.g. Shaver, Boksenberg, and Robertson, 1982; Robertson et al., 1986, and references therein), demonstrating that at least some of the high-redshift, high-excitation, narrow-line absorption systems are due to intervening material. Such observations also show that the foreground QSO has the lower redshift, in accordance with the cosmological interpretation (Shaver and Robertson, 1983). The implied excess of absorbing material in the vicinity of QSOs could be due to clusters of galaxies, or possibly large (10^5-10^6 pc) gaseous halos around the QSOs such as that found around MR2251-178 by Bergeron et al. (1983).

The nature of intervening absorbing material, located in front of both QSOs, can be studied by examining the incidence of absorption systems which show up in both spectra at the same redshift as a function of projected linear separation. In this way it has been found that the absorbers, both metal-rich and Lyα systems, have sizes in the range ~10-400 h^{-1} kpc. This is consistent with the metal-rich systems originating in galaxy halos, but does not yet distinguish between various possibilities for the origin of the Lyα systems - more QSO pairs with a range of separations must be studied for this purpose.

6. CONCLUSIONS

This paper summarizes several uses of QSO pairs, and results obtained so far. Clearly much more can be done along these lines as the number of useful pairs increases. Nor are these applications exclusive; a close pair of radio QSOs has already been used to provide mutual phase reference in a VLBI study of their structure (Marcaide and Shapiro, 1984), and with relative positions accurate to microarcseconds, proper motion studies on interesting scales are now feasible. More possibilities using QSO pairs will undoubtedly be conceived in the future, further enhancing the value of QSOs in astrophysical and cosmological studies.

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DISCUSSION

Kunth : What happens to your evidence for QSO clustering at small scales if one redistributes the redshifts among all QSO from the Veron catalogue by Monte Carlo Simulation ?

Shaver : Scrambling the redshifts completely destroys the clustering. Furthermore, the clustering only shows up only amongest QSO pairs with redshift differences less than 2500 km s^{-1}, and not, for example, amongst QSO pairs with redshift differences between 5000 and 7500 km s^{-1} (using the same technique) which are not expected to be physically clustered.

Roberts : Do you find any differences between the "associated absorption systems" and the typical absorption systems seen in other quasars ? Have you detected $L\alpha$ in absorption in the former ?

Shaver : No pronounced difference has been found. The associated absorption systems may be of somewhat higher excitation, but $L\alpha$ is still seen.