The Space Distribution of Quasars
ASP Conference Series, Vol. 21, 1991
David Crampton (ed.)

QUASAR PAIRS AT LARGE REDSHIFTS

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ABSTRACT A sample of apparently close physical pairs of quasars at large redshifts has been compiled. There are at least a half-dozen such systems now known. They seem to divide into two groups with about equal frequencies, $\sim 10^{-3}$ pairs per catalogued quasar: a set of wide, Mpc-scale pairs (arcmin separations), and a set of close pairs, with projected separations of a few arscec, or $\lesssim$100 kpc. A simple hierarchical clustering model matches well the observed frequency of the wide pairs, but the close pairs are about two orders of magnitude overabundant relative to the predictions of this model. This is interpreted as a signature of galaxy interactions, which trigger the nuclear activity in both members of close quasar pairs. These systems may represent birth events of quasars at the epoch where the comoving density of quasars was near its maximum.

If quasars represent relatively rare events in galactic nuclei, physically close pairs of quasars seem at first extremely unlikely. Yet, several such quasar pairs at large redshifts are now known. These are *not* gravitational lenses: their spectra, redshifts, and other properties are usually sufficiently different, so that the physical pair interpretation seems more likely than the gravitational lens plus variability explanation. They seem to fall into two groups, "wide" pairs, with separations of a couple of arcmin ($\sim 1h^{-1}$ Mpc in projection), and "close" pairs, with separations of a few arcsec (tens of kpc in projection). Pairs selected for this study also have redshift differences corresponding to $\Delta V_{rest} \lesssim 1000$ km s^{-1}, as to guard against optical pairs with radial separations of $\gtrsim$10 Mpc.

Wide pairs (Table 1) include QQ 0107–025 (Surdej *et al.* 1986), QQ 1146+111 (Hazard, Arp & Morton 1979), and a triplet(!) 0953+698 (Burbidge *et al.* 1980). These systems were found from among $\sim 3,000$ quasars known at the time of their discoveries, and thus a rough estimate of the frequency of wide pairs is $\sim 10^{-3}$. Additional pairs with projected separations of a few arcmin are now known, but with redshift differences corresponding to $\Delta V_{rest} > 1000$ km s^{-1}, with error bars of the same order, which makes the estimates of their physical separations more difficult. Particularly interesting are the large groupings discovered by Crampton, Cowley & Hartwick (1989), and by Clowes & Campusano (1991). Some of them may qualify for our pair critera, but since there is a corresponding increase in the number of catalogued quasars, our estimate of the frequency of pairs would not change by much.

Close pairs (Table 2a) include binary quasars PKS 1145–071 (Djorgovski *et al.* 1987*b*), QQ 0151+048 = PHL 1222 (Meylan *et al.* 1990*ab*), QQ 1343+266 (Crampton *et al.* 1988), and, tentatively a quasar-AGN pair PKS 1614+051

(Djorgovski *et al.* 1985, 1987*a*). In addition, the available evidence for some of the gravitational lens candidates, e.g., QQ 1120+019 = UM 425 (Meylan & Djorgovski 1989), QQ 1635+267 (Djorgovski & Spinrad 1984), QQ 2345+007 (Weedman *et al.* 1982) (Table 2b), and maybe others, is still ambiguous, and it is possible that one or more of these systems will turn out to be physical pairs, rather than lenses. These objects are selected out of a sample of at most a few hundred quasars, imaged with a resolution adequate to resolve the companions, and thus their frequency of occurence may be as high as $\sim 10^{-2}$, but in any case is not less than $\sim 10^{-3}$ (which assumes that there are *no* additional pairs among the thousands of known quasars which have not been imaged in detail yet).

Table 1

Known quasar pairs with arcmin-scale separations, and $\Delta V_{rest} < 1000$ km/s

Name	z	$\Delta\theta$ arcsec	ΔR kpc h^{-1}
QQ 0107–025 AB	0.954	77	740
QQ 1146+111 BC	1.012	157	1580
QQQ 0953+698 = Hoag 1,2,3	2.049	121	1980
(a triplet!)		128	2090
		214	3500

Table 2a

Known quasar pairs with arcsec-scale separations, and $\Delta V_{rest} < 1000$ km/s

Name	z	$\Delta\theta$ arcsec	ΔR kpc h^{-1}
PKS 1145–071 AB	1.345	4.2	52
PHL 1222 = 0151+048 AB...	1.91:	3.3	51
QQ 1343+266 AB	2.030	9.5	155
(PKS 1614+051 QSO+AGN)	3.215	6.3	136

Table 2b

Gravitational lens candidates, which may be actually physical quasar pairs

Name	z	$\Delta\theta$ arcsec	ΔR kpc h^{-1}
UM 425 = 1120+019 AB	1.465	6.8	89
QQ 1635+267 AB	1.961	3.8	60
QQ 2345+007 AB	2.156	7.3	123

Notes: Projected separations are shown; the actual separations may be greater. The corresponding comoving separations were computed by assuming a simple Friedman model with $\Omega_0 = 0.3$. For all pairs in Tables 2ab, the observed $\Delta V_{rest} < 1000$ km/s, and in many cases is consistent with zero.

An estimate of the expected abundance of quasar pairs can be made as follows. Related discussions have been published by Phinney & Blandford (1986) and by Bahcall, Bahcall & Schneider (1986).

Several independent studies of quasar clustering at large redshifts have produced essentially the same result: the amplitude of the quasar-quasar two-point correlation function at $z \sim 1-3$ is about equal to that of the bright galaxies at $z \sim 0$ (e.g., papers by Iovino, Bahcall, and others in these proceedings; Iovino & Shaver 1988; see the review in Hartwick & Schade 1990, and references therein). It is reasonable to represent the quasar-quasar correlation function as: $\xi_{QQ} = (r/r_0)^\gamma$, where $r_0 \sim 5h^{-1}$ Mpc, uncertain by about a factor of two, and $\gamma \simeq -1.8$. The expected probability of finding a quasar companion at a distance R is then:

$$P(R) = 4\pi\langle\rho\rangle r_0^3 x^3 \left(1 + \frac{3}{3+\gamma} x^\gamma\right),$$

where $x \equiv R/r_0$, $\langle\rho\rangle$ is the average comoving number density of quasars at that redshift. Following Hartwick & Schade (1990), at $z \sim 1-3$, $\langle\rho\rangle \simeq 500$ Gpc^{-3}, uncertain also by about a factor of two.

The solution for the best-guess parameters is shown in Figure 1, along with two solutions spanning the reasonable range of parameters . The the ranges of separations and observed frequencies of pairs are indicated by the dashed line error boxes. We ignore the difficult questions of selection effects, luminosity function, etc., except to note that in general we may be underestimating somewhat the actual frequencies of quasar pairs.

The first result is that the observed number of wide quasar pairs (arcmin, or Mpc scale) is about as expected within this simple clustering model. This suggests that the input model assumptions and parameters are reasonable.

However, the close pairs (arcsec, or 100 kpc scale) appear to be overabundant by about two orders of magnitude. This is unlikely to be just a small number statistics effect: the observed frequency is *certainly* not lower than 10^{-3}, and the selection effects all go in the directions that some pairs may have been missed, and the true frequency of close pairs may well be close to 10^{-2}. Basically, the model predicts that no close pairs should have been seen until there are $> 10^5$ quasars known, and examined with an arcsec resolution.

This result indicates a breakdown of the clustering hierarchy model at scales corresponding to that of galaxies (or, more precisely, of their dark halos). The close pairs are clearly not there by chance, and not a manifestation of the density noise field. Their presence must be due to some other physical reason.

Perhaps the most likely explanation for the apparent overabundance of close quasar pairs that they are a consequence of dissipative interaction events. Our simple clustering model is mute about any such dissipative or nonlinear processes. Galaxy interactions have been long implicated as a mechanism for fueling, and perhaps even the formation, of active galactic nuclei. There is now an extensive body of evidence that host galaxies of low-z quasars are often members of interacting systems, or apparent merger products (for a recent review, see, e.g., Heckman 1990, and references therein). Numerical models of dissipative tidal encounters also show them to be a viable and efficient mechanism for radial transport of the gas to the central regions of interacting galaxies, while solving the angular momentum problem (Hernquist 1989). Galaxies in interacting systems would then be more likely to exibit nuclear activity. Interestingly, the observed close quasar pairs separations are comparable to what may be expected from interacting galaxies.

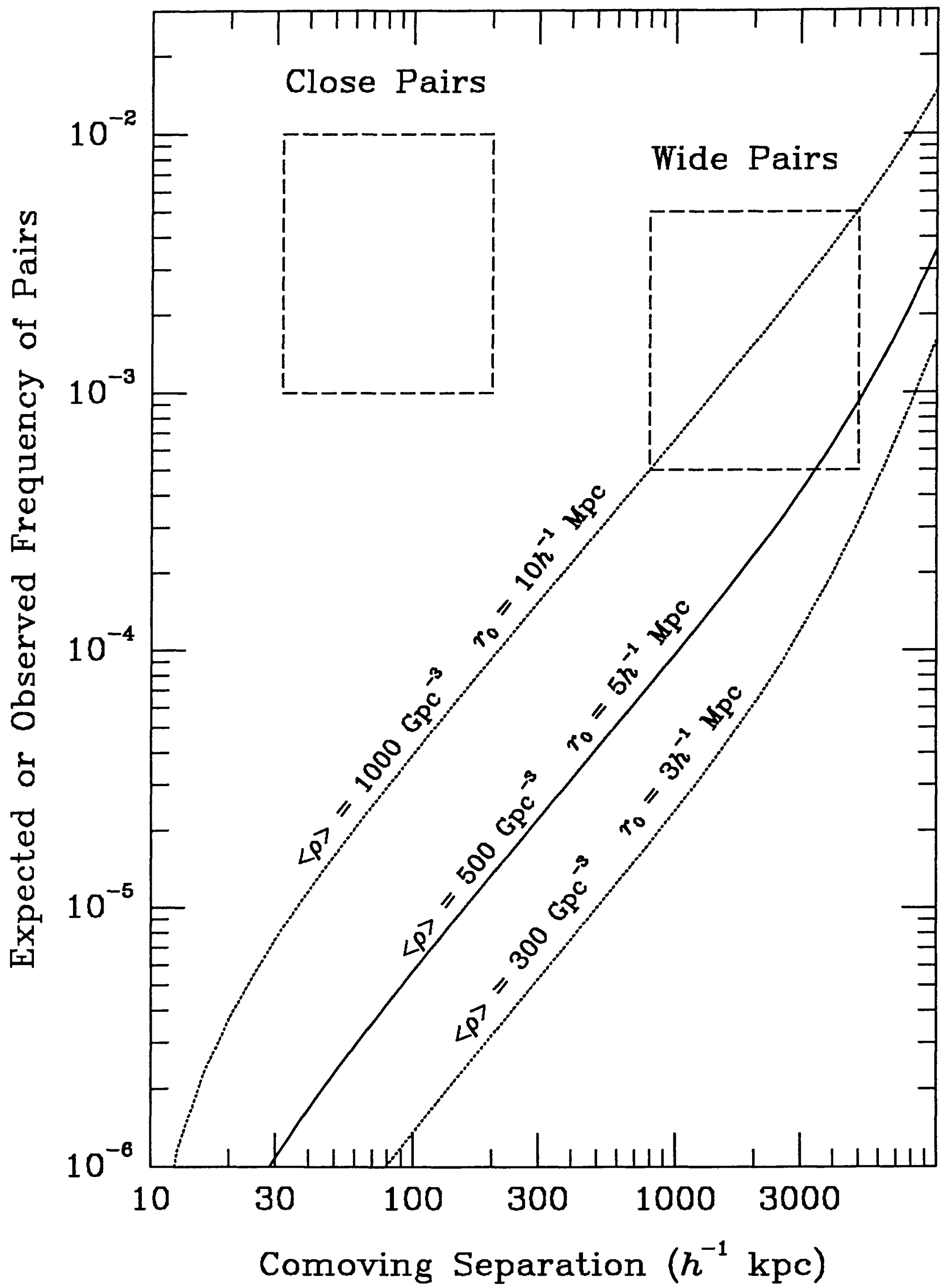

Fig. 1. Observed and predicted relative frequencies of quasar pairs. The solid line represents the predictions of our simple clustering model with the best-guess parameters, and the dotted lines span a reasonable range of the parameter uncertainties. The dashed line boxes indicate the observed ranges of pair separations and frequencies.

This mechanism should be even more effective at large redshifts, since there was more gas available, and interactions should have been more frequent (the Toomre argument). Several authors (cf. Carlberg 1990, and references therein) attempted to model the evolution of quasar birthrate governed by the merger rate. In these close pairs of quasars we may be seeing their birth events, at the epoch when the quasar number density was at its maximum.

Two of the close pairs contain strong radio sources (PKS 1145–071 and PKS 1614+051), but otherwise there is no obvious correlation with radio emission for this sample of quasar pairs.

This paper is based in part on the work done in collaboration with Dr. G. Meylan, and supported in part by an Alfred P. Sloan Foundation fellowship. I also wish to thank to the organizers of this Workshop for their efforts and hospitality, and for a partial travel support.

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