CLUSTERING, ISOTROPY, AND REDSHIFT CUTOFF

Patrick S. Osmer *
National Optical Astronomy Observatories
Cerro Tololo Inter-American Observatory[1]
Casilla 603, La Serena, Chile

The topics of clustering, isotropy, and redshift cutoff are in reality just different aspects of the problem of the three-dimensional distribution of quasars, assuming, of course that the redshifts are cosmological and therefore an indication of radial distance. The distribution in redshift has additional interest because of the substantial lookback times involved, up to four fifths of the age of the universe. The radial variation of quasar density between redshift zero and two, and the attendant questions of density and luminosity evolution, are discussed elsewhere in this symposium by Green and shall not be treated here. Rather we shall concern ourselves with the behavior at redshifts larger than two and the specific question of a steep decline of quasar density at redshifts near three. For simplicity we may characterize the problem as one of studying either the formation of quasars as we normally see them in a cosmologically short time or of the properties of the universe and its optical depth, should intergalactic absorption contribute significantly to blocking our view at redshift three. Of course other hypotheses are also possible.

The topic of quasar clustering is analogous to that of clusters of galaxies and superclusters at low redshift. One wishes to see if quasars at large redshifts exhibit clustering properties, and, if so, what bearing they have on the development of clustering with time in the universe. Quasars provide our only chance of seeing the state of clustering at redshifts or cosmic epochs intermediate between those of the microwave background, which is very smooth, and the present, which is very clumpy on scales up to at least those of superclusters. The association of low redshift quasars with galaxies is an important topic that is to be discussed by Yee at this symposium. Here we shall limit the discussion to that of quasar clustering itself.

The topic of isotropy concerns the distribution of quasars on much larger scales than those considered for clustering and therefore bears on the structure of the universe at very large scale. If it can be established that the density of quasars in regions of the sky separated by tens of degrees varies significantly, then the implications for cosmology would be profound indeed.

Let us examine recent results on these three topics one by one.

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Previous symposia volumes may be consulted for earlier work (e.g. Abell and Chincarini 1983, Mardirossian, Giuricin, and Mezzetti 1984).

REDSHIFT CUTOFF

The concept of a significant decrease in the space density of quasars at redshifts greater than two was discussed fifteen years ago by Schmidt (1970, 1972) and Sandage (1972), who noted that it could represent the epoch of quasar formation. With the subsequent discovery of quasars with redshift three and greater, the question was reopened. After the development of the objective prism technique (see review by Smith 1978) enabled a new approach to the problem, Osmer (1982) claimed that the absence of quasars in a deep survey over the redshift interval 3.7 to 4.7 was definite evidence for a decrease in their space density. Then PKS2000-330, with redshift 3.78 was discovered by Peterson, Savage, Jauncey, and Wright (1982), and questions were raised about possible selection effects in Osmer's survey (Savage and Peterson 1983). Subsequently more quasars with redshifts greater than 3.5 were discovered by a variety of techniques (see Table 1), so that it is timely to re-examine the observational state of the so-called redshift cutoff.

TABLE 1

Quasars with $z > 3.5$

Object	z	Mag.	Technique	Reference
1159+123	3.51	18	obj. prism	Hazard et al.1984
OQ172 (1442+1011)	3.53	17.8	radio source id.	Wampler et al. 1973
DHM0054-284	3.61	19.6	multi-color photom.	Shanks et al. 1983
0055-2659	3.7	17	obj. prism	Hazard & McMahon 1985
1351-018	3.71	19	radio source id.	Dunlop et al. 1985
PKS2000-330	3.78	19	radio source id.	Peterson et al. 1982

Obviously quasars exist with redshifts up to 3.78. The questions are what is their space density and how is it varying with redshift. Hazard and McMahon (1985) consider from an analysis of UK Schmidt fields at 00 h 53 m -28° and 15 h 0 m +11° that the decline in space density with increasing redshift sets in already near redshift two. They give arguments in addition that the failure to find faint quasars at high redshifts can be explained by a combination of luminosity and density evolution as proposed by Koo (1983).

Dunlop et al. (1985) discuss the properties of faint radio sources in the Parkes survey. Even though their discovery of 1351-018 as a faint, high-redshift quasar with weak emission lines raises the possibility that other such objects are missed in optical surveys, they conclude that the luminosity function for radio quasars declines for redshifts larger than two.

Recently Schmidt, Schneider, and Gunn (1985) have completed two major surveys with the Palomar 5m telescope that add significantly to our knowledge of quasar densities at faint magnitudes. They used a grism technique and CCD to search 0.9 sq deg to a considerably fainter limit than can be reached photographically. Spectra of more than 9000 objects were examined, and 45 emission-line candidates selected with observed equivalent widths greater than 50Å and high signal-to-noise ratio. Followup spectroscopy confirmed 10 as quasars, with redshifts between 0.9 and 2.7 (but none higher), with the remainder of confirmed objects being emission-line galaxies of lower redshift. The incidence of the observed quasars is in good agreement with the luminosity function arguments of Schmidt and Green (1983), but the complete absence of quasars with $z > 2.7$ is in strong contradiction to the expected numbers of 40 to 121. Thus these new results also indicate a cutoff in the space density of quasars with absolute magnitudes of -25 at a redshift less than three.

In a related survey with the 5m telescope used in a transit mode, the same group has surveyed 7.5 sq deg and covered 43000 objects. Subsequent slit spectroscopy of the 52 emission-line candidates confirms 24 to be low redshift galaxies and 8 to be quasars with $1.0 < z < 2.8$. Again the number of quasars found is consistent with expectations, while the lack of quasars at $z > 2.8$ contrasts with the predicted discovery of 30 - 62 such quasars. This survey provides additional convincing evidence for their absence, now at a higher luminosity.

Thus, independent studies by three different groups now point toward a decline in the space density of quasars at redshifts below three. This is in contrast to the first results for bright quasars in the Curtis Schmidt survey, where enough quasars with redshifts up to 3.3 were found to be consistent with a constant space density in the interval 2.0 to 3.3 (Osmer and Smith 1980, MacAlpine and Feldman 1982). Whether this result is only a statistical fluctuation in the small sample of objects or whether it represents a luminosity dependence of the space density is a matter that needs further study. In any case, the recent findings for fainter quasars definitely point to a decline in their space density setting in below redshift three.

What are the possible explanations for these observed effects? Obviously we do not yet have adequate data, let alone certain explanations, but three possibilities are being actively explored. One is that quasars first formed and became visible at redshifts near three. This would be remarkable, as the cosmological epoch is rather late. In this case, the data could be interpreted to mean that the formation time depends on luminosity. A second hypothesis is that the universe is becoming opaque near redshift three because of increasing intergalactic absorption. Ostriker and Heisler (1984) have shown that dust in the universe could well cause an apparent drop in the number of quasars observed above redshift three. This hypothesis immediately suggests that observable effects on the reddening of quasars should occur at high redshifts, effects that should be looked for. A third hypothesis is that the nature of quasars changes near redshift three. For example, if their emission lines weakened, they would not be detectable with the grism technique. Their colors could be difficult to distinguish from faint stars (see, for example, Dunlop et al. 1985).

Now that more than fifty quasars with z > 3 are known, observational programs can be designed to investigate these hypotheses in significant detail, so that we may expect further progress in the next few years.

CLUSTERING

The topic of quasar clustering is important for the reasons discussed in the introduction, but so far it has proved a difficult observational problem. The main reasons are that extreme care must be taken to have properly calibrated and uniform data and to eliminate the various selection effects that inevitably creep in. Unfortunately, nearly all selection effects tend to make clsutering falsely appear, not disappear, in quantitative analyses, examples being non-uniformity in sensitivity from field to field, non-uniform sensitivity to all redshifts in the interval under study, and patchy interstellar absorption in the galaxy. The steep increase in the apparent luminosity function of quasars at the magnitudes so far studied is also a problem, since a change of only 0.3 mag in the limiting sensitivity can change the apparent surface density by a factor of two. For these reasons, studies to data of clustering of the quasar population as a whole have not turned up convincing evidence (Osmer 1981, Webster 1982, Clowes 1985). Nonetheless, a variety of interesting groups and pairs have been found that merit further study regardless of the behavior of the overall population (op. cit.). It is certainly possible that subsets of the quasar population cluster.

Indeed the strongest claims in favor of clustering made to date are those by Shaver (1984) for quasar pairs. As he is discussing the topic elsewhere in this symposium, we will not pursue the matter here, except to say that the association of quasar groups or pairs with superclusters and clusters of galaxies will become a very important topic once Space Telescope or large groundbased telescopes can reliably image galaxies at redshift 2.

In a completely different approach to the problem, Burbidge et al. (1985) argue that the observed number of quasar pairs with different redshifts is significantly in excess of expectations and therefore a challenge to the cosmological hypothesis for redshifts. Shaver (1985), however, comes to the opposite conclusion, that the sky distribution of quasars with different redshifts is random.

Now that automated quasar detection techniques have been developed (Clowes et al. 1984, Hewett et al. 1985), we may expect definite progress in the analysis of existing and new surveys for clustering (e.g. Osmer 1983). Given the difficulties inherent in tying different photographic plates together, the application of automatic techniques to single UK Schmidt plates offers a very attractive approach. In any case, the acquisition of followup spectroscopic data is key to all work on the subject, so that reliable redshifts can be established.

ISOTROPY

A related topic to clustering is isotropy, which we may define as the quasar distribution on scales larger than those investigated for clustering. Let us adopt scales of tens of degrees or more on the sky as the province of the isotropy question. Fliche, Souriau, and Triay (1982) have called attention to possible anisotropies in the quasar distribution over the whole sky. Obviously the confirmation of effects such as they describe would have extremely important cosmological consequences. However, it is vital to establish the observational basis first. Considering the inhomogeneous and generally uncalibrated manner in which different quasar surveys have been carried out, I think it is premature to ascribe significance to inhomogeneities found in the all-sky quasar compilations produced to date.

Another discussion of possible inhomogeneities in the quasar distribution has been published by Arp (1984a,b), who calls attention to non-uniformities in the area of the Sculptor group ofgalaxies. He discusses the deficit of quasars in the 2 -4 hour region of the -40° zone of the Curtis Schmidt survey (Osmer and Smith 1980). He notes that the weak-lined quasars in the -40° zone have a uniform distribution with right ascension, but the strong-line ones concentrate toward the Sculptor group. Because the weak-lined quasars are more difficult to detect, and therefore more sensitive to selection effects, he argues for the reality of the non-uniformity. However, he also noted a deficit of fainter quasars in the 2 -4 hour region, which could be a result of the lowered sensitivity originally proposed by Osmer (1981) as the reason for the deficit.

In contrast, the one survey for anisotropy that has been carried out in a well-calibrated manner is that of Hawkins (1985). He analyzed two UK Schmidt fields separated by 13° on the sky and found no significant differences in the number of quasars in the two fields with a sensitivity at the 6% level.

Thus, we may conclude that despite some tantalizing possible inhomogeneities in some quasar surveys, there is as yet no evidence based on carefully calibrated, quantitative searches for significant large-scale anisotropies in the distribution of quasars.

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DISCUSSION

Malkan : Ostriker & Heisler's explanation of the high-z cutoff by intergalactic reddening is unlikely. When you look at optical/UV colors of 2 dozen (mostly radio-selected) high-z (2.5 to 3.5) quasars, such as the flux ratio from rest wavelengths of 4200 and 1770 A, you find they are the same as the colors of lower-z QSOs. This limits their diffuse intergalactic reddenings to $E_{B-V} \leq 0^m.1$. As Ned Wright has pointed out (1986), you cannot get off the hook by saying that reddened QSO's are simply invisible, because any realistic absorbing clouds would not have hard edges. So we ought to find moderately-reddened QSO's at high-z, but we do not

Kembhavi : Would the scarcity of quasars beyond $z \gtrsim 3$ still remain significant if there were no evolution in the luminosity function as claimed by Wampler ?

Schmidt : Yes, I believe the observations require a decrease in co-moving density at constant luminosity, for increasing redshift.

Rees : Regarding the possible quasar anisotropies of scales $\gtrsim 10°$, probably the X-ray background isotropy constraints are stronger than any we are likely to get from direct surveys of optical quasars, if we accept that quasars are important contributors to that background.

Schmidt : The constraint would be tempered if quasars contribute only around 10% of the 2 keV background, as suggested by Schmidt and Green.

Wandel : In light of the possibility suggested in the talk, that quasars may be forming as late as z = 3, it would be physically plausible to consider a "reversed" density evolution (in the sense of space-density increasing with cosmic time) for say, $z \gtrsim 3$, imposed on the ordinary luminosity evolution. Could such a combination fit the data, and in particular, could it account for the knee in the luminosity function ?

Burke : With respect to clustering on large scales, the MIT-Green Bank (MG) radio source survey was examined by J. Mahoney. About half the sources are quasars, so it is a sample of high luminosity quasars with a small statistical corruption by radio galaxies. No significant pair correlation was found, and the sample, covering two steradians between 0° and 20° declination appears to be isotropic on a 10° scale.

"Even the most carefully studied complete samples of quasars seem to have sufficient discrepancies as to throw into doubt the assertion that they show strong quasar evolution over cosmic time scales."

- E.J.Wampler and D.Ponz (p.443)