QUASAR CLUSTERING AND THE EVOLUTION OF STRUCTURE

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ABSTRACT. Quasar clustering has now been confirmed at a high level of significance, and there is evidence for its evolution. A review is given of these developments, and of other evidence related to the evolution of structure.

1. INTRODUCTION

The study of the physical clustering of quasars has proved to be a project of the 1980s. The first suggestions of possible physical pairs of quasars, and the first attempts to detect quasar clustering, were both reported about 1980. Clustering has now been confirmed and measured, and the emphasis is shifting to the evolution of this clustering, in the hope that it pertains not just to quasars, but reflects the evolution of structure generally.

The existence of isolated possible "physical pairs" of quasars has been noted for some time (Hazard et al., 1979; Oort et al., 1981; Margon et al., 1981; Webster, 1982; Woltjer & Setti, 1982; Arp, 1983; Oort, 1983; He et al., 1986; Crampton et al., 1987). These were suggestive of possible widespread clustering of quasars, although in individual cases it was always difficult to gain an appreciation of their true significance from the a posteriori statistics. It is perhaps noteworthy, however, that about 70 percent of these cases occur at $z < 1.5$.

Systematic searches for quasar clustering began with the pioneering work of Osmer (1981). The results of this and several other such studies (Webster, 1982; Chu & Zhu, 1983; He et al., 1986; Kunth & Sargent, 1986; Clowes, 1986; Drinkwater, 1986; Clowes et al., 1987) were negative, in part because of the small sizes of some of the samples. It is noteworthy, though, that these samples were all based on objective prism surveys, and therefore concentrated towards higher redshifts.

The tentative first detections of quasar clustering were made using a large, inhomogeneous catalogue (Shaver, 1984) and a small but deep UVX survey (Boyle, 1986; Shanks et al., 1986, 1987), and the

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first hints of possible evolution came from Fang et al. (1985) and Chu & Fang (1986, 1987), who noted that any indications of clustering were predominantly at relatively low redshifts. Very recently the evidence for both clustering and its evolution has become much stronger.

2. QUASAR CLUSTERING

The most straightforward and reliable method of measuring the quasar correlation function is to compare the observed sample with a large randomly-generated sample which is subject to exactly the same selection effects. The random sample can be generated by carefully reproducing the actual envelopes of the distributions in redshift and sky coordinates, and randomly populating that volume. Comparison of the observed and random samples as a function of linear separation of pairs of quasars then yields the correlation function.

Iovino & Shaver (1987), and Shanks et al. (1987) have applied this method to two deep samples of 376 and 354 quasars respectively, and in both cases clustering on comoving scales $< 10\ h^{-1}$ Mpc is detected at the 4-5σ level. When these results are combined, and allowance is made for overlap in the two samples, the significance level for the clustering found (including all redshifts together) is 5.5σ. Furthermore, the clustering at $z < 1.5$ is twice that at $z > 1.5$, with a significance of $\sim 2\sigma$. Thus, independent analyses of deep, homogeneous samples of quasars with confirmed redshifts establish the clustering of quasars beyond any doubt, and suggest the possible presence of evolution.

Another method of generating a random comparison sample is to reassign the observed redshifts randomly amongst the quasars in the sample. In this way the redshift distribution is randomized, while preserving the "selection envelope". Kruszewski (1987) has applied this technique to nine homogeneous samples totalling 629 quasars. He also finds clustering at a high significance level, predominantly at lower redshifts.

The correlation functions at low and high redshifts from Iovino & Shaver (1987) and Kruszewski (1987) are shown in fig. 1. A positive signal is prominent only at comoving separations $\lesssim 10\ h^{-1}$ Mpc, and at low redshifts.

A different approach to quasar clustering is based on a technique which may be called "normalization to large scales" (Shaver, 1984). Here it is assumed that the clustering is predominantly on small scales, so that it can be detected by comparing the incidence of quasar pairs of small projected and/or radial separation with those of large separation. Both groups are subject to the same selection effects, which therefore cancel out in the comparison, so the method can be applied to large but inhomogeneous catalogues. Recent applications of this technique by both Kruszewski (1987) and the author to the Véron catalogue (Véron-Cetty & Véron, 1987), the present version of which contains about 3500 quasars, reveal significant (6σ) redshift-dependent clustering.

All of these recent results are summarized in fig. 2, showing the

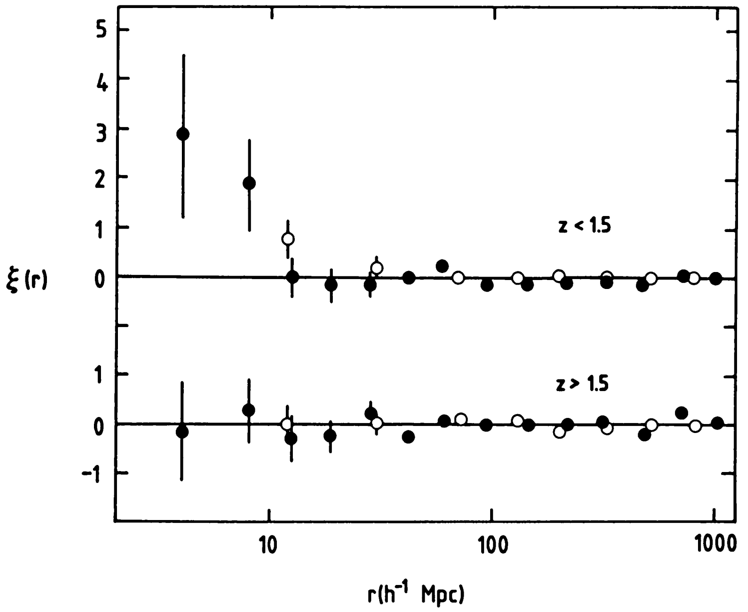

Figure 1. - Quasar two-point correlation function at low (z < 1.5) and high (z > 1.5) redshifts, with q_o = 0.5. The filled circles are from Iovino & Shaver (1987), and the open circles are from Kruszewski's (1987) analysis of 9 homogeneous samples.

correlation function at 10 h^{-1} Mpc (comoving) as a function of redshift. The correlation function evidently increases rapidly towards lower redshifts - more rapidly than expected for a constant physical clustering scale, for example. An extrapolation to the lowest redshifts would be well in excess of the correlation function for galaxies, but it may be consistent with that for radio galaxies or clusters of galaxies.

It is, of course, not immediately obvious whether this evolution tells us about the development of structure generally, or just about changes in the environment and/or properties of quasars. It could, for example, be a luminosity (selection) effect, with lower-luminosity objects more clustered, although that would be opposite to the known clustering behavior or galaxies. Perhaps the presence of one quasar influences the formation of another nearby, in a manner which depends on redshift. It does not appear to be related to the radio properties of quasars, as the deep samples studied by Iovino & Shaver (1984) and Shanks et al. (1987) were optically-selected, and analysis of the non-radio quasars in the Véron catalogue reveals the same clustering and evolution. Unless some concrete evidence to the contrary appears, therefore, it seems reasonable to assume that the evolution shown in fig. 2 is a direct reflection of the evolution of structure in the universe.

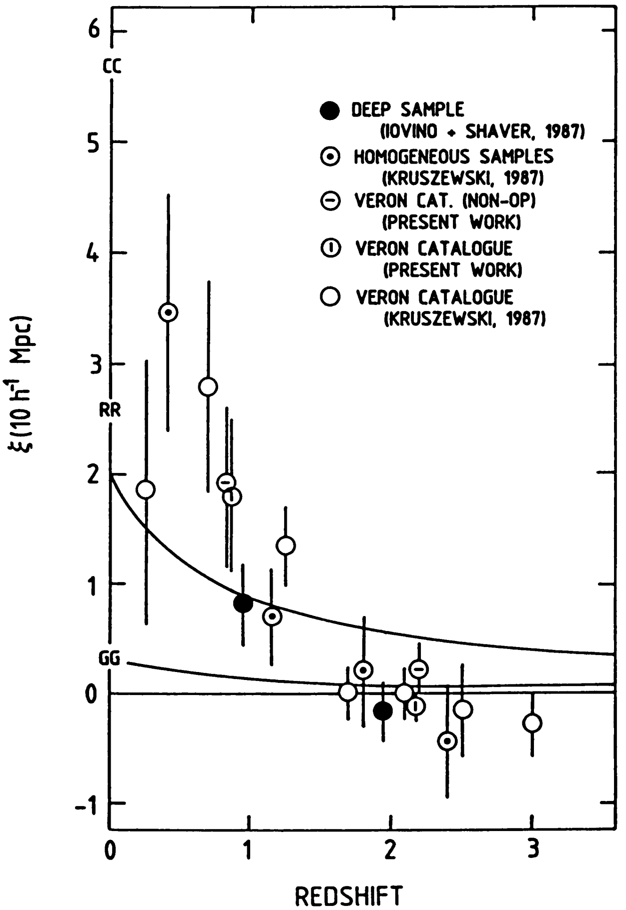

Figure 2. - Amplitude of the quasar correlation function at 10 h^{-1} Mpc (comoving, $q_0 = 0.5$), as a function of redshift, from several different studies as indicated. On the left axis are marked the amplitudes of the correlation function at $z \lesssim 0.1$ for galaxies (GG), clusters (CC - Bahcall & Soneira, 1983), and radio galaxies (RR - Peacock et al., 1987). The two curves show the expected evolution for stable clustering.

3. OTHER EVIDENCE REGARDING HIGH-REDSHIFT CLUSTERING

There is now abundant evidence for the close association of quasars with galaxies at modest redshifts (e.g., Stockton, 1978, 1982; Hutchings & Campbell, 1983; Yee & Green, 1984; Heckman et al., 1984; Gehren et al., 1984; Hutchings et al., 1984; Gilmore, 1984; Hintzen, 1984; Stockton, 1986; Tyson, 1986; Chen & Zou, 1986; Surdej et al., 1986; Yee & Green, 1986, 1987; Boyle et al., 1987; Stockton &

MacKenty, 1987). Quasars often have close distorted or compact companions, and extended emission-line regions reminiscent of debris from tidal interactions. They are located preferentially in dense, compact groups or clusters, with typical velocity dispersions of $\lesssim$ 400 km s^{-1} and core radii $\sim$ 60 h^{-1} kpc. The quasar-galaxy correlation function is intermediate in amplitude between those of galaxies and clusters of galaxies; the power law is about the same. The strongest quasar-galaxy correlation is for radio quasars, and it increases rapidly with redshift - by a factor of three from z = 0.4 to z = 0.6, where the associations are comparable to Abell clusters (Yee & Green, 1986, 1987; Yee, 1987). This is consistent with the fact that the fraction of active galaxies in clusters is higher at higher redshifts (Dressler et al., 1985).

At high redshifts there is a very high incidence of heavy-element absorption systems near the emission redshift z_{em} of steep-spectrum radio quasars (Foltz et al., 1986) (not so for radio-quiet quasars, however - Sargent, 1987). The density of Lyα absorption systems decreases markedly near z_{em}, again particularly for radio quasars (Bechtold, 1987). These facts are consistent with radio quasars being located in particularly dense clusters, inhospitable to the Lyα absorbers in the same way that they are to spiral galaxies today (Haynes & Giovanelli, 1986). One may also deduce that high-redshift quasars are located in dense environments from the high incidence of associated absorption in quasar pairs (Shaver & Robertson, 1984; Phillipps, 1986), or from the distortions and small sizes of the radio emission associated with high-redshift quasars (Barthel, 1986; Swarup et al., 1986). The associated absorption could also be due to debris from interactions and mergers, as suggested for the large emission-line regions around 3C-type galaxies at high redshifts (Djorgovsky et al., 1987). Finally, there is the direct evidence of a possible quasar-galaxy pair at z = 3.2 (Djorgovsky et al., 1985; Hu & Cowie, 1987; Djorgovsky et al., 1987).

It thus appears that quasars are located in groups or clusters of galaxies at all redshifts, and a plausible inference is that they are activated and/or fuelled by interactions (e.g. de Robertis, 1985; Gaskell, 1985; Roos, 1985; Byrd et al., 1987; Pringle et al., 1987).

The clustering of galaxies themselves can now be studied directly out to significant redshifts ($\sim$ 0.5-1.0). Results so far indicate that the shape of the correlation function remains constant with redshift, and the amplitude decreases at a rate at least as fast as that for stable clustering, possibly much faster (Koo & Szalay, 1984; Loh, 1987; Jones et al., 1987).

The clustering of quasar absorption lines amongst themselves also gives information about high redshift structure and its evolution (e.g. Salmon & Hogan, 1986), although it is difficult at present to relate these absorbers with certainty to known objects at low redshifts. It is well known that heavy-element absorption systems have a strong autocorrelation peak at a splitting of $\sim$ 150 km s^{-1} (e.g. Sargent et al., 1980). This has been attributed to galaxy clusters (Young et al., 1982), or absorbing clouds in the halos of individual galaxies (Bahcall, 1975; Sargent, 1977; Sargent et al., 1980). Blades et al. (1985), Hunstead et al. (1986), and Murdoch et al. (1986) have recently argued that the velocity structure and ionization variations in some high-redshift heavy-element absorption systems support the cluster interpretation. Possible difficulties with the cluster hypothesis, however, include the fact that the autocorrelation is several times stronger than the extrapolated galaxy correlation, that there are too many absorptions per cluster, and that at least some multiple-component systems at low redshifts are associated with single galaxies (Bergeron, 1987). Studies of the shape, extent, and evolution of the autocorrelation function,and of common absorption in quasar pairs (Shaver & Robertson, 1984) will eventually distinguish between these interpretations; the common absorption studies may also make possible an independent study of large-scale structure (Crotts, 1985).

Weak clustering of Lyα lines has recently been detected at $z \sim 2$-3 at the 3-4σ level by Webb et al. (1984), Webb & Carswell (1987); there is also 2σ evidence for rapid evolution, with no detectable clustering above $z \sim 3$. This clustering is considerably below the extrapolated galaxy correlation (assuming stable clustering), as might be expected from the fact that the Lyα absorbers avoid dense clusters (above). It could, however, still correspond to the clustering of galaxies if the clustering amplitude decreases rapidly with redshift, as suggested by the rapid evolution of the correlation functions for galaxies, quasars, and these Lyα clouds.

On large scales, evidence based on common absorption has been presented for the possible existence of a large supercluster at $z \sim 2$ (Jakobsen et al., 1986). Some doubts have been expressed, however, related to possible selection effects and other problems (Cristiani et al., 1987; Robertson, 1987), and in any case the absence of common absorption in other quasar pairs of smaller separation, and the low amplitude of the quasar correlation function at $z \gtrsim 2$, make it clear that this cannot be a widespread phenomenon. Carswell and Rees (1987) have also shown that large (50 h^{-1} Mpc) voids are rare in the Lyα forest, and must occupy < 5% of the volume at the corresponding high redshifts if they are also devoid of Lyα clouds.

Finally, the X-ray background may also provide a sensitive test for structure at $z \sim 3$ (Barcons & Fabian, 1987; Meszaros, 1987); if quasars contribute significantly to the X-ray background, they can probably not be strongly clustered at high redshifts. Boughn et al. (1986) have discussed similar limits at 2μm possibly relevant to the distribution of primeval galaxies. It should be noted that the upper limits now available on any clustering at $z > 2$ will in themselves be of considerable interest. Aside from directly constraining models of the evolution of structure, they can be used to place limits on gravitational lensing by intervening massive objects, including cosmic strings and supermassive black holes (e.g. Vilenkin, 1984; Hogan & Narayan, 1984; Gott, 1985; Paczyński, 1986a,b; Gott, 1986; Fang et al., 1986).

4. DISCUSSION

Thus, there are now several independent pieces of evidence regarding structure at high redshift and its evolution, and they are beginning to fit together. There is strong evidence that quasars are located in groups or clusters of galaxies at both low and high redshift: the observed quasar-galaxy associations at low redshift, particularly for radio quasars, the high incidence of heavy-element absorption systems and low incidence of Lyα absorption systems near the emission redshifts of radio quasars, the high incidence of associated absorption in quasar pairs, and the distortions of high-redshift radio quasars. This is consistent with the high amplitude of the quasar correlation function, comparable to that of radio galaxies or clusters of galaxies

Table 1. Normalized Correlation Amplitudes

z < 0.1		z ~ 2				
			α = -1.2		α = -3	
			$q_0=0$	$q_0=0.5$	$q_0=0$	$q_0=0.5$
CC[1]	18					
QQ[2]	3-15	QQ[2]		<5		<36
RR[3]	9					
GC[4]	~5-13					
Q_RG[5]	3-20	Q_RM[10]	6	4	43	29
Q_0G[6]	1-2	Q_0M[11]	<2	<1.3	<14	<9
		MM[12]	7	3	51	22
GG[7]	1	GG[7]	1	1	1	1
II[8]	0.2					
DD[9]	0.2	LL[13]	0.2	0.06	1.4	0.4

The symbols are as follows: G - galaxy, D - dwarf galaxy, I - IRAS galaxy, R - radio galaxy, C - cluster of galaxies, Q - quasar, Q_R - radio-loud quasar, Q_0 - radio-quiet quasar, M - metal-line (CIV) absorption system, L - Lyα-line absorption system. The correlation amplitudes are normalized to the galaxy-galaxy correlation amplitude, which is assumed to decrease with redshift as $(1+z)^{\alpha}$, with α = -1.2 (stable clustering) and α = -3.

References are as follows: 1 - Bahcall & Soneira (1983), 2 - this paper (fig. 2), 3 - Peacock et al. (1987), 4 - Longair & Seldner (1979), 5 & 6 - Yee & Green (1986), 7 - Davis & Peebles (1983), 8 - Rowan-Robinson (1987), 9 - Davis & Djorgovski (1985), 10 - Weymann et al. (1979), 11 - Young et al. (1982), 12 - Sargent et al. (1980), 13 - Webb & Carswell (1987).

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at low redshift. There are three independent possible indications of a rapid decrease in the correlation amplitude with redshift: the quasars, galaxies at $z < 1$, and Lyα absorbers at $z > 2$.

Some idea of the interrelationships between these assorted facts is given by the rudimentary normalized correlation amplitudes in Table 1. There it can be seen that, from the point of view of clustering, the relationship between quasars and heavy element absorption systems at high redshifts is consistent with that between quasars and galaxies at low redshifts. The autocorrelation amongst heavy-element absorption systems appears to be too strong relative to the extrapolated galaxy correlation function, but this could be due to the presence of several absorbers in the halo of each galaxy. The Lyα clustering would be consistent with galaxy clustering if the evolution is sufficiently great, but it is perhaps more reasonable to associate the Lyα absorbers with the spiral (IRAS) or dwarf galaxies; they all have relatively small correlation amplitudes, and they all avoid rich clusters, as noted above. From such considerations we may hope that a consistent picture for the evolution of structure will emerge, one which may ultimately make it possible to estimate the epochs of formation of galaxies, clusters, and superclusters.

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REFERENCES

Arp, H. 1983, in Quasars and Gravitational Lenses, 24th Liège Internat. Astrophys. Colloq., p. 307.
Bahcall, J.N. 1975, Astrophys. J. **200**, L1.
Bahcall, N.A., Soneira, R.M. 1983, Astrophys. J. **270**, 20.
Barcons, X., Fabian, A.C. 1987, Mon. Not. R. astr. Soc. in press.
Barthel, P.D. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 181.
Bechtold, J. 1987, in High Redshift and Primeval Galaxies, in press.
Bergeron, J. 1987, this volume.
Blades, J.C., Hunstead, R.W., Murdoch, H.S., Pettini, M. 1985, Astrophys. J. **288**, 580.
Boughn, S.P., Saulson, P.R., Uson, J.M. 1986, Astrophys. J. **301**, 17.
Boyle, B.J. 1986, thesis, University of Durham.
Boyle, B.J., et al. 1987, this volume.
Byrd, G.G., Sundelius, B., Valtonen, M. 1987, Astron. Astrophys. **171**, 16.
Carswell, R.F., Rees, M.J. 1987, Mon. Not. R. astr. Soc. **224**, 13p.
Chen, J.-S., Zou, Z.-L. 1986, Chinese Astron. Astrophys. **10**, 190.
Chu, Y.-Q., Fang, L.-Z. 1986, in Structure and Evolution of AGN, p. 517.
Chu, Y.-Q., Fang, L.-Z. 1987, in Observational Cosmology (ed. A. Hewitt, G. Burbidge, L.-Z. Fang; Reidel), p. 627.
Chu, Y.-Q., Zhu, X.-F. 1983, Astrophys. J. **267**, 4.
Clowes, R.G. 1986, Mon. Not. R. astr. Soc. **218**, 139.

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Clowes, R.G., Iovino, A., Shaver, P.A. 1987, Mon. Not. R. astr. Soc. (in press).
Crampton, D., Cowley, A.P., Hartwick, F.D.A. 1987, Astrophys. J. **314**, 129.
Cristiani, S., Danziger, I.J., Shaver, P.A. 1987, Mon. Not. R. astr. Soc. (in press).
Crotts, A. 1985, Astrophys. J. **298**, 732.
Davis, M., Peebles, P.J.E. 1983, Astrophys. J. **254**, 437.
Davis, M., Djorgovski, S. 1985, Astrophys. J. **299**, 15.
Djorgovski, S., Spinrad, H., McCarthy, P., Strauss, M.A. 1985, Astrophys. J. **299**, L1.
Djorgovski, S., Spinrad, H., Pedelty, L., Rudnick, L., Stockton, A. 1987, Astron. J. **93**, 1307.
Djorgovski, S., Strauss, M.A., Perley, R.A., Spinrad, H., McCarthy, P. 1987, Astron. J. **93**, 1318.
Dressler, A., Gunn, J.E., Schneider, D.P. 1985, Astrophys. J. **294**, 70.
Drinkwater, M. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 503.
Fang, L.-Z., Chu, Y.-Q., Zhu, X.-F. 1985, Astrophys. Sp. Sci. **115**, 99.
Fang, L.-Z., Chu, Y.-Q., Zhu, X.-F. 1986, Astrophys. Sp. Sci. **122**, 213.
Foltz, C.B., Weymann, R.J., Peterson, B.M., Sun, L., Malkan, M.A., Chaffee, F.H. 1986, Astrophys. J. **307**, 504.
Gaskell, M. 1985, Nature **315**, 386.
Gehren, T., Fried, J., Wehinger, P.A., Wyckoff, S. 1984, Astrophys. J. **278**, 11.
Gilmore, G. 1984, Mon. Not. R. astr. Soc. **211**, 25p.
Gott, J.R., III 1985, Astrophys. J. **288**, 422.
Gott, J.R., III 1986, Nature **321**, 420.
Haynes, M., Giovanelli, R. 1986, Astrophys. J. **306**, 466.
Hazard, C., Arp, H.C., Morton, D.C. 1979, Nature **282**, 271.
He, X.-T., Chu, Y.-Q., Fang, L.-Z., Smith, M.G. 1986, Chinese Astron. Astrophys. **10**, 252.
Heckman, T.M., Bothun, G.D., Balick, B., Smith, E.P. 1984, Astron. J. **89**, 958.
Hintzen, P. 1984, Astrophys. J. Suppl. **55**, 533.
Hogan, C., Narayan, R. 1984, Mon. Not. R. astr. Soc. **211**, 575.
Hu, E.M., Cowie, L.L. 1987, Astrophys. J. **317**, L7.
Hunstead, R.W., Murdoch, H.S., Pettini, M., Blades, J.C. 1986, Astrophys. Sp. Sci. **118**, 505.
Hutchings, J.B., Campbell, B. 1983, Nature **303**, 584.
Hutchings, J.B., Crampton, D., Campbell, B. 1984, Astrophys. J. **280**, 41.
Iovino, A., Shaver, P.A. 1987, this volume.
Jakobsen, P., Perryman, M.A.C., Ulrich, M.H., Macchetto, F., di Serego Alighieri, S. 1986, Astrophys. J. **303**, L27.
Jones, L.R., Shanks, T., Fong, R. 1987, this volume.
Koo, D.C., Szalay, A.S. 1984, Astrophys. J. **282**, 390.
Kruszewski, A. 1987, preprint.
Kunth, D., Sargent, W.L.W. 1986, Astron. J. **91**, 761.

Kunth, D., Sargent, W.L.W. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 505.
Loh, E.D. 1987, this volume.
Longair, M.S., Seldner, M. 1979, Mon. Not. R. astr. Soc. **189**, 433.
Margon, B., Chanan, G.A., Downes, R.A. 1981, Nature **290**, 480.
Meszaros, P. 1987, this volume.
Murdoch, H.S., Hunstead, R.W., Blades, J.C., Pettini, M. 1986, Astrophys. Sp. Sci. **118**, 501.
Oort, J.H. 1983, in Quasars and Gravitational Lenses, 24th Liège Internat. Astrophys. Colloq., p. 301.
Oort, J.H., Arp, H.C., de Ruiter, H. 1981, Astron. Astrophys. **95**, 7.
Osmer, P.S. 1981, Astrophys. J. **247**, 762.
Paczyński, B. 1986a, Nature **319**, 567.
Paczyński, B. 1986b, Nature **321**, 419.
Peacock, J.A., Miller, L., Collins, C.A., Nicholson, D., Lilly, S.J. 1987, this volume.
Phillipps, S. 1986, Mon. Not. R. astr. Soc. **223**, 173.
Pringle, J.E., Lin, D.N.C., Rees, M.J. 1987, BAAS **19**, 695.
Robertis, M. de 1985, Astron. J. **90**, 998.
Robertson, J.G. 1987, Mon. Not. R. astr. Soc. (in press).
Roos, N. 1985, Astrophys. J. **294**, 486.
Rowan-Robinson, M. 1987, in Observational Cosmology (ed. A. Hewitt, G. Burbidge & L.-Z. Fang; Reidel), p. 229.
Salmon, J., Hogan, C. 1986, Mon. Not. R. astr. Soc. **221**, 93.
Sargent, W.L.W. 1977, in The Evolution of Galaxies and Stellar Populations (ed. B.M. Tinsley & R.B. Lawson; Yale), p. 427.
Sargent, W.L.W., Young, P.J., Boksenberg, A., Tytler, D. 1980, Astrophys. J. Suppl. **42**, 41.
Sargent, W.L.W. 1987, this volume.
Shanks, T., Fong, R., Boyle, B.J., Peterson, B.A. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 37.
Shanks, T. et al. 1987, this volume.
Shaver, P.A. 1984, Astron. Astrophys. **136**, L9.
Shaver, P.A., Robertson, J.G. 1984, in Frontiers of Astronomy and Astrophysics (ed. R. Pallavicini), p. 201.
Stockton, A. 1978, Astrophys. J. **223**, 747.
Stockton, A. 1982, Astrophys. J. **257**, 33.
Stockton, A. 1986, Astrophys. Sp. Sci. **118**, 487.
Stockton, A., MacKenty, J.W. 1987, Astrophys. J. **316**, 584.
Surdej, J., Arp, H., Gosset, E., Kruszewski, A., Robertson, J.G., Shaver, P.A., Swings, J.P. 1986, Astron. Astrophys. **161**, 209.
Swarup, G., Saikia, D.J., Beltrametti, M., Sinha, R.P., Salter, C.J. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 195.
Tyson, J.A. 1986, Astron. J. **92**, 691.
Véron-Cetty, M.-P., Véron, P. 1987, ESO Scientific Report No. 5.
Vilenkin, A. 1984, Astrophys. J. **282**, L51.
Webb, J.K., Carswell, R.F., Irwin, M.J. 1984, BAAS **16**, 733.
Webb, J.K., Carswell, R.F. 1987, in preparation.
Webster, A. 1982, Mon. Not. R. astr. Soc. **199**, 683.
Weymann, R.J., Williams, R.E., Peterson, B.M., Turnshek, D.A. 1979, Astrophys. J. **234**, 33.

Woltjer, L., Setti, G. 1982, in Astrophysical Cosmology (ed. H.A. Bruck, G.V. Coyne, M.S. Longair; Pontificia Academia Scientarium), p. 315.
Yee, H.K.C. 1987, in Observational Cosmology (ed. A. Hewitt, G. Burbidge, L.-Z. Fang; Reidel), p. 685.
Yee, H.K.C., Green, R.F. 1984, Astrophys. J. **280**, 79.
Yee, H.K.C., Green, R.F. 1986, in Quasars (ed. G. Swarup & V.K. Kapahi; Reidel), p. 481.
Yee, H.K.C., Green, R.F. 1987, Astrophys. J. **319**, in press.
Young, P., Sargent, W.L.W., Boksenberg, A. 1982, Astrophys. J. Suppl. **48**, 455.