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Large Quasar Groups — A Short Review

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Abstract. This short review describes the discovery and properties of the Large Quasar Groups (LQGs), which are the largest structures seen in the early universe. Some 17 examples are now known. Recent work is producing important new results on the large-scale galaxy environment of quasars in LQGs (and also field quasars) and on the mechanisms of quasar formation. Quasars tend to lie on the *peripheries* of clusters of galaxies. Mergers of clusters (or cluster sub-units) may constitute a previously unrecognised mechanism for forming quasars and associated regions of star-forming galaxies.

1. Introduction

Large Quasar Groups (LQGs) are rare "clusters" of quasars that have sizes in the range 50–200h^{-1} Mpc. Structures of such sizes — superclusters and great walls — are known in the relatively local universe, of course, but the LQGs exist at quite high redshifts when the universe was much younger. Good evidence is now emerging that LQGs are associated with mass enhancements and the plausible interpretation is that they are the precursors of the present-epoch superclusters, great walls and great attractors. There are some 17 examples of LQGs known at present. At present the interest in LQGs is centred on what LQGs can tell us about: (i) the development of structure in the early universe and the morphology of structure then; and (ii) the galaxy environment of quasars and the mechanisms of quasar formation and their evolution.

2. The History of LQGs

2.1. LQG 1: the Webster LQG

The first LQG was discovered by Webster (1982) in the data from the Curtis Schmidt survey (Osmer & Smith 1980). Of the 108 quasars in that survey only seven had $z < 0.5$. Of these, the four quasars with $z = 0.36, 0.37$ have a very obviously clustered distribution on the sky, shown in Figure 1. With a rigorous statistical analysis, Webster estimated the probability of a chance event to be very low: $\sim 10^{-4}$–10^{-7}. Thus the LQG comprises four quasars at $z \sim 0.37$ with size $\sim 75h^{-1}$ Mpc. It was the largest structure known in 1982.

The LQG impinges on the northern and southern boundaries of the survey and could extend beyond. Indeed, Maza et al. (1995) have since found a possible

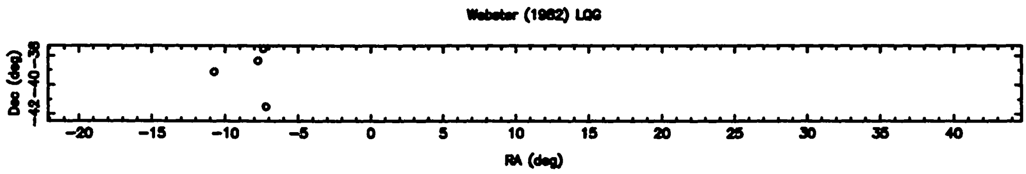

Figure 1. The Webster (1982) LQG at $z \sim 0.37$, shown in the area covered by the entire Osmer & Smith (1980) quasar survey.

further member at $z = 0.36$. Phillipps (S. Phillipps, private communication) noted that each of two of the four LQG quasars lies *near* an uncommonly rich, faint cluster.

2.2. LQG 2: the Crampton et al. LQG

The second LQG was discovered by Crampton, Cowley, & Hartwick (1989, 1987). It appears as a prominent excess of $z \sim 1.1$ quasars in the 1338+27 field of their CFHT grens survey. Twenty-three quasars with $1.0 < z < 1.2$ formed a LQG of size $\sim 60h^{-1}$ Mpc. Tanaka et al. (2000b) mention that five further members were found later, their redshifts having been supplied to the NASA Extragalactic Database (NED). This LQG also impinges on the boundaries of its survey and could extend beyond. Sub-clustering within the LQG is apparent on scales $\sim 15h^{-1}$ Mpc. For the whole original sample of 270 quasars, clustering on the small scales $< 10h^{-1}$ Mpc is mostly attributable to the LQG. This suggested the hypothesis that for quasar samples in general, the small-scale clustering will be found to be mostly concentrated in LQGs.

Hutchings, Crampton, & Johnson (1995) and Hutchings, Crampton, & Pesram (1993) imaged a total of 11 quasars from the LQG, with both broad- and narrow-band (for redshifted [OII] λ3727Å) filters. From their results, at least eight of the 11 quasars are surrounded by excesses of galaxies, with blue and/or emission-line galaxies being prominent in most cases. The conclusion is that the LQG members tend to be associated with regions of star-forming galaxies.

The environment of one of these quasars, the radio-loud 1335.8 + 2834, has been investigated further by Tanaka et al. (2000a). They find that the quasar is near, on the sky, to a cluster of galaxies, the photometric redshift of which is consistent with the quasar redshift. Note that the quasar is on the *periphery* of the cluster — the same result as for the Webster LQG and the same result that will be mentioned in the following section for the Clowes & Campusano (1991) LQG and also for low-redshift "field" quasars. Tanaka et al. find a substantial population of blue galaxies and of red galaxies with a blue excess, again suggesting that quasars are associated with regions of star-forming galaxies. Tanaka et al. (2000b) have imaged in a continuous strip the environment of an elongated concentration of five quasars (including 1335.8 + 2834) in the LQG. They find that the quasars trace the large-scale structure in the galaxies, with the quasars tending to lie on the peripheries of the clusters. Again, these results are very similar to what we are finding.

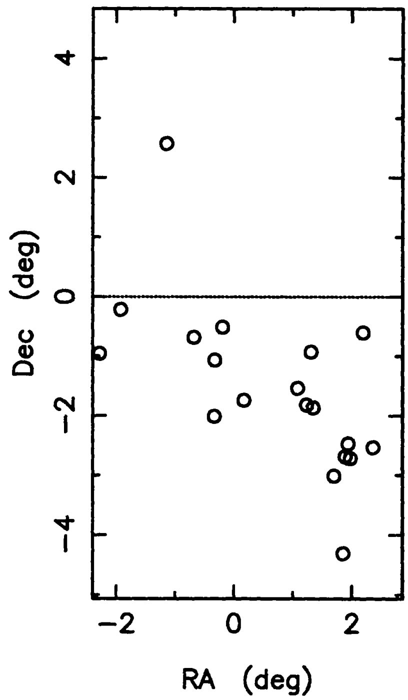

Figure 2. The positions on the sky of the 18 quasars with $1.2 \leq z < 1.4$, corresponding to the Clowes & Campusano LQG in field 927 (lower half) and field 999 (upper half). Note that there are, in total, nearly 2.5 times as many confirmed quasars in field 927 as in field 999.

2.3. LQG 3: the Clowes & Campusano LQG

The third LQG, at $z \sim 1.3$, was discovered by Clowes & Campusano (1991). Cannon & Oke ($\sim$ 1980, private communication) had originally noticed that the field, ESO/SERC field 927, was unusual. With a size of $\sim 200h^{-1}$ Mpc, the LQG is the largest structure known in the early universe.

Thirteen quasars were known to be members of the LQG in Clowes & Campusano (1991). Subsequent observations brought the total to 18 (Clowes, Campusano, & Graham 1999). The distribution on the sky of these 18 quasars with $1.2 \leq z < 1.4$ is shown in Figure 2, which also includes a northern extension of the survey to ESO/SERC field 999. Clearly the LQG is an impressive structure. Note that this LQG too impinges on the boundaries of its survey and could extend beyond. Still later observations for the Chile-UK Quasar Survey, not yet fully analysed, indicate a current total of about 23 member quasars. Given that observations have been by spatially uniform sampling and that there are still many candidate quasars to observe, the complete membership could be much larger.

The Clowes & Campusano LQG has now been detected *three* times, as follows. (1.) In the original objective-prism survey. (2.) In the Chile-UK Quasar Survey (CUQS). This survey covers a larger area than the original survey, but to a brighter limiting magnitude (Newman et al. 1998). (3.) In MgII absorption in the spectra of background quasars. We looked for MgII absorption in a $2° \times 2°$

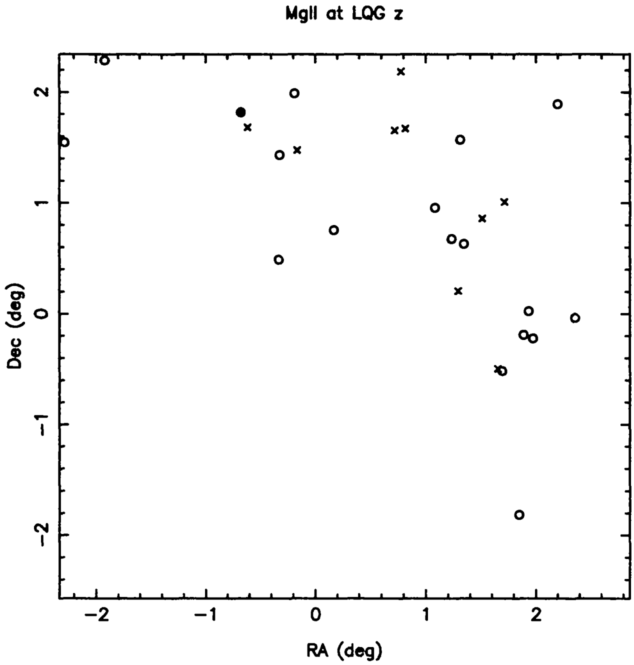

Figure 3. Positions of the background quasars with MgII absorbers (crosses) at the redshift of the LQG with respect to the LQG members (circles). Background quasars have been observed across a $2° \times 2°$ area of the LQG. See Williger et al. (2001).

area across the LQG. The resulting redshift histogram of the MgII systems shows a significant peak at the redshift of the LQG. See Williger et al. (2001) for full details. This result indicates that the LQG is indeed associated with a mass enhancement. Note that the absorbing galaxies are well distributed across the LQG and not obviously concentrated towards LQG quasars (Figure 3).

Work on imaging the galaxy environment of quasars in the Clowes & Campusano LQG has been carried out contemporaneously wih the work by Tanaka et al. (2000a,b) for the Crampton et al. LQG, and the results are strikingly similar. A new view of quasar environment is emerging with consequent implications for the mechanisms of quasar formation. Haines et al. (2001a,b) report on V, I imaging across 0.5° with the BTC at CTIO of a dense group of three LQG quasars plus UFTI K imaging at UKIRT of one of them. The BTC images also contain a background quasar at slightly higher redshift. The LQG quasar, with VIK imaging, appears to lie in a band of blue galaxies between two clusters of red galaxies. They suggest that the merger of clusters (or cluster units) can instigate the formation of a quasar together with star-formation in other galaxies. For the other quasars in the BTC images and in conjunction with initial results from Söchting et al. (2001) for low-redshift "field" quasars, the indications are that quasars tend to be located either on the *peripheries* of clusters, with some on the peripheries of two clusters, or in relatively undistinguished environments. When viewed on these larger scales (> 1 Mpc) the environment of quasars thus appears to be rather different from what was previously thought.

2.4. More LQGs

There have been some 14 further discoveries of LQGs. Graham et al. (1995) found two: 10 quasars at $z \sim 1.9$ and size $\sim 120h^{-1}$ Mpc; 7 Seyfert galaxies at $z \sim 0.19$ and size $\sim 60h^{-1}$ Mpc. Komberg, Kravtsov, & Lukash (1996) found 10 (actually 12, but two were previously known) with $0.5 < z < 2$ and sizes from 70 to $160h^{-1}$ Mpc. Newman et al. (1998) found a LQG of 13 quasars with $z \sim 1.5$ and size $\sim 150h^{-1}$ Mpc. This LQG is of particular interest because one branch of its MST lies directly behind the Clowes & Campusano LQG at $z \sim 1.3$, suggesting that parallel sheets or cellular structure might already have existed at these early times. Note, however, that this new LQG is mostly outside the original Clowes & Campusano survey. Finally, Tesch & Engels (2000) found the first X-ray selected LQG — seven quasars at $z \sim 0.27$ and size $\sim 140h^{-1}$ Mpc.

2.5. Statistical methods

The traditional statistical methods in astronomy for assessing clustering and structure (e.g. the 2-point correlation function) are usually unsuitable for finding LQGs and for assessing their significance. In particular, these methods typically have low power for: (i) structure of size $\sim$ survey-size; (ii) directed structures (e.g. filaments); and (iii) isolated, embedded structures. Fortunately there exist useful techniques from other fields (e.g. biology, chemistry, geophysics etc.) that can be adopted or adapted for use in astronomy. Wide-field astronomers in general have perhaps not yet fully realised the potential usefulness of these methods involving computational geometry combined with statistical analysis of the properties of the geometrical constructs.

Graham et al. (1995) adapted a method used in biology, the "MST m, σ" method, to find their two new LQGs. Tesch & Engels (2000) found their LQG by using a slightly modified form of this method. Komberg et al. (1996) developed a kindred method involving "friends of friends" to find their LQGs, but it involves somewhat arbitrary criteria.

An unresolved question is whether LQGs are really so rare or are we missing lesser examples, perhaps because of limitations in the algorithms and the power of statistical tests for detecting and assessing large-scale features.

3. What Are LQGs?

Komberg et al. (1996) (see also Komberg & Lukash 1994) estimated that the density of LQGs is about the same as the density of superclusters and great attractors at the present epoch. Their consequent suggestion that LQGs are the precursors at high redshifts of the largest structures seen today seems most plausible. There could be a connection also between LQGs and the indications (e.g. Deng, Xia, & Fang 1994) of a characteristic scale $\sim 100h^{-1}$ Mpc in the universe.

4. Summary

- Some 17 LQGs are now known. They probably indicate the precursors of superclusters and great attractors.
- The Clowes & Campusano LQG appears to be the largest structure known in the early universe.
- The galaxy environment of quasars, when viewed on scales > 1 Mpc, appears different from what was previously thought. Initial results suggest that quasars tend to lie either on the peripheries of clusters or in relatively undistinguished areas. Cluster mergers may constitute a previously unrecognised mechanism for forming quasars and associated star-forming galaxies.

References

Clowes, R. G., & Campusano, L. E. 1991, MNRAS, 249, 218

Clowes, R. G., Campusano, L. E., & Graham, M. J. 1999, MNRAS 309, 48

Crampton, D., Cowley, A. P., & Hartwick, F. D. A. 1987, ApJ, 314, 129

Crampton, D., Cowley, A. P., & Hartwick, F. D. A. 1989, ApJ, 345, 59

Deng, Z. G., Xia, X. Y., & Fang, L. Z. 1994, ApJ, 431, 506

Graham, M. J., Clowes, R. G., & Campusano, L. E. 1995, MNRAS, 275, 790

Haines, C. P., Clowes, R. G., Campusano, L. E., & Adamson, A. J. 2001a, MNRAS, in press

Haines, C. P., Clowes, R. G., & Campusano, L. E. 2001b, these proceedings

Hutchings, J. B., Crampton, D., & Johnson, A. 1995, AJ, 109, 73

Hutchings, J. B., Crampton, D., & Pesram, D. 1993, AJ, 106, 1324

Komberg, B. V., Kravtsov, A. V., & Lukash, V. N. 1996, MNRAS, 282, 713

Komberg, B. V., & Lukash, V. N. 1994, MNRAS, 269, 277

Maza, J., Wischnjewsky, M., Antezana, R., & González, L. E. 1995, RevMexAA, 31, 119

Newman, P. R., Clowes, R. G., Campusano, L. E., & Graham, M. J. 1998, in Large Scale Structure: Tracks and Traces, ed. V. Müller, S. Gottlöber, J. P. Mücket & J. Wambsganss (Singapore: World Scientific), 133

Osmer, P. S., & Smith, M. G. 1980, ApJS, 42, 333

Söchting, I. K., Clowes, R. G., & Campusano, L. E. 2001, these proceedings

Tanaka, I., Yamada, T., Aragón-Salamanca, A., Kodama, T., Miyaji, T., Ohta, K., & Arimoto, N. 2000a, ApJ, 528, 123

Tanaka, I., Yamada, T., Turner, E. L., & Suto, Y. 2000b, astro-ph/0009229

Tesch, F., & Engels, D. 2000, MNRAS, 313, 377

Webster, A. S. 1982, MNRAS, 199, 683

Williger, G. M., Campusano, L. E., & Clowes, R. G. 2001, these proceedings