J. Astrophys. Astr. (1997) **18,** 241–249

Evidence for Evolution as Support for Big Bang

Gopal-Krishna, *National Centre for Radio Astrophysics, TIFR, Pune University Campus, Pune 411007, India*

Abstract. With the exception of *ZERO,* the concept of *BIG BANG* is by far the most bizarre creation of the human mind. Three classical pillars of the Big Bang model of the origin of the universe are generally thought to be: (i) The abundances of the light elements; (ii) the microwave background radiation; and (iii) the change with cosmic epoch in the average properties of galaxies (both active and non-active types). Evidence is also mounting for redshift dependence of the intergalactic medium, as discussed elsewhere in this volume in detail. In this contribution, I endeavour to highlight a selection of recent advances pertaining to the third category.

The widely different levels of confidence in the claimed observational constraints in the field of cosmology can be guaged from the following excerpts from two leading astrophysicists:

"*I would bet odds of 10 to 1 on the validity of the general 'hot Big Bang' concept as a description of how our universe has evolved since it was around 1 sec. old"*

—M. Rees (1995), in 'Perspectives in Astrophysical Cosmology' *CUP.*

"With the much more sensitive observations available today, no astrophysical property shows evidence of evolution, such as was claimed in the 1950s to disprove the Steady State theory"

—F. Hoyle (1987), in 'Fifty years in cosmology', B.M. Birla Memorial Lecture, Hyderabad, India.

The burgeoning multi-wavelength culture in astronomy has provided a tremendous boost to observational cosmology in recent years. We now proceed to illustrate this with a sequence of examples which reinforce the picture of an evolving universe. Also provided are some relevant details of the data used in these studies so that their scope can be independently judged by the readers.

Key words. Galaxies—galaxies: active, cluster, evolution, intergalactic medium—cosmology.

1. The evolving abundance of neutral gas in galactic disks

Whereas at the present epoch most of the baryonic mass of disk galaxies is locked up in stars and only ~10% of it is in the form of neutral (H I + He I) gas, the gas was apparently the dominant phase at $z \simeq 2 - 3$, concentrated in Damped Lyman-α systems which have been detected all the way up to $z \sim 4.5$ in absorption against background quasars (e.g., Storrie-Lombardi *et al.* 1996; Lanzetta *et al.* 1995; Wolfe 1995). In particular, it is found that over the redshift range $2 \lesssim z \lesssim 3$, the cosmological mass density, Ω_g, in neutral gas associated with the Damped Lyman-α systems alone is quite comparable to the total cosmological mass density, Ω_s, in visible stars in the disks of the present-day galaxies (e.g., Storrie-Lombardi *et al.* 1996). The agreement improves further if a plausible correction for obscuration of quasars by the intervening dust is applied (see Pei & Fall 1995). *Thus, these data provide evidence for a gradual conversion of the gas of the galactic disks into stars, with increasing cosmic epoch.*

It may be noted that for $z \lesssim 1.6$ where the Lyman-α line falls in the UV range, the estimate of Ω_g has been derived from the *IUE/HST* archival data on the AGN spectra (Lanzetta *et al.* 1995; Rao *et al.* 1995). Thus, for moderate redshifts ($z \sim 0.8$) the value of Ω_g is found to be a few times lower than that for high redshifts ($z \sim 2$–3). Further, this evolutionary trend is found to continue to $z \sim 0$ for which Ω_g has been estimated from the population of optically selected galaxies and is therefore not compromised by dust obscuration of background quasars (Rao & Briggs 1993; Fall & Pei 1993). Note that the implicit assumption that only an insignificant amount of neutral gas is associated with optically sub-luminous galaxies appears to be substantiated by an unbiased extragalactic HI survey carried out with the Arecibo telescope (Zwaan *et al.* 1997).

2. The evolution of space density of radio-loud quasars

Onward 1960s, it has been inferred from the radio source counts that between $z = 0$ and $z \sim 2$, a large increase in the abundance and/or luminosities of powerful radio sources has occurred; their co-moving space density at $z \sim 1$ being a factor $\sim 10^3$ higher than the local value (e.g., Longair 1966; Wall *et al.* 1981; Dunlop & Peacock 1990; Condon 1993; Dunlop 1997). A similar degree of evolution has been inferred for optically selected quasars (e.g., Boyle *et al.* 1990; Miller *et al.* 1993; Hawkins & Véron 1996). The crucial question whether such positive evolution continues unabated to much higher redshifts has been forcefully addressed only during the last few years. Already in 1982, based on a 4-m grim search, Osmer had claimed detection of a decrease in the space density of quasars, though it could even be an artefact of obscuration by dust in intervening galaxies (Ostriker & Heisler 1984; see, however, Pei & Fall 1995). To resolve this ambiguity, Shaver *et al.* (1996) have made a search for $z \geq 5$ objects in a large sample of 878 flat-spectrum radio sources selected from the Parkes radio survey, which is not affected by any dust obscuration. **All** stellar objects present in the sample are either too bright, or too blue to be $z > 5$ quasars, or their spectroscopy had confirmed $z < 5$. From these data, Shaver *et al.* have concluded *a decrease in the (co-moving) space density of quasars beyond* $z \sim 2$–3. Conceivably, even this decrease could be an artefact if the most distant quasars suffer from *intrinsic* obscuration arising from unusually large amount of dust and gas in their interior. But, again, this would require them to be different from the nearer quasars and an evolution would still be implied.

Interestingly, the high redshift turnover in the space density of radio-loud quasars lends credence to the similar trend noted earlier for radio-quiet quasars by several groups (e.g., by Warren *et al.* 1994; Schmidt *et al.* 1995) and even for powerful radio sources, in general (Dunlop & Peacock 1990; Dunlop 1997).

3. The evolution of linear sizes of powerful radio galaxies

Back in 1959, Hoyle advocated the use of edge-brightened (FR II) double radio sources as a probe of the geometry of the universe. However, early observations indicated that radio quasars were physically smaller at earlier cosmic epochs, leading astronomers to use radio sizes as a tracer of cosmic evolution (e.g., Miley 1968; Legg 1970; Kellermann 1972). To reliably address the issue of redshift dependence of the radio sizes, efforts have been concentrated on widening the coverage of the luminosity-size-redshift ($P - l - z$) plane, so that the dependences of l on z and P can be disentangled (Oort *et al.* 1987; Singal 1988, 1993; Kapahi 1989). In order to retain focus on the extended structure, the samples of sources are usually selected at metre wavelengths and, customarily, the size evolution is parameterized as: $l_{\text{mediam}} \propto (1 + z)^{-n}$. Even for powerful (FR II) radio galaxies within fixed luminosity bins, the degree of inferred evolution varies from steep ($n \sim 3$; Oort *et al.* 1987; Kapahi 1989; Singal 1996), to mild ($n \sim 1.5$; Nesser *et al.* 1995), to practically non-existent ($n \sim 0$; Nilsson *et al.* 1993).

Of the recent studies, the one by Nesser *et al.* appears to be based on by far the best controlled dataset: the 3CRR and 6C samples, both of which were selected at metre wavelengths and consist mostly of FR II type radio galaxies. For each sample, improved radio maps and virtually complete spectroscopic redshifts are available. The relatively milder evolution ($n \sim 1.5$) found by these authors, as compared to that inferred by Oort *et al.* (see above), may be due to inclusion in the latter work of edge-darkened (FR I) radio galaxies with high redshifts (whose radio sizes would be under-estimated due to sensitivity limitations, cf. Nesser *et al.* 1995). Recently, Singal (1996) has argued that the data of Nesser *et al.* are not inconsistent with a steep size evolution of radio galaxies, ($n \sim 3$). On the other hand, only a mild evolution ($n \sim 1$) has generally been inferred for radio quasars (e.g., Barthel & Miley 1988; Singal 1993). Quite plausibly, this difference from radio galaxies can be understood by considering the *temporal* evolution of powerful double radio sources, without resorting to postulate that radio galaxies are fundamentally different from quasars (Gopal-Krishna *et al.* 1996).

Unless the radio-active phase was systematically shorter at early cosmic epochs, a plausible explanation for the linear size evolution is a systematic increase in the density of the hot gaseous haloes of elliptical galaxies towards higher redshifts (Subramanian & Swarup 1990; Gopal-Krishna & Wiita 1991). The higher efficiency of radio emission in the denser halo environment at early epochs could then account for roughly half of the apparent linear size evolution (GopalKrishna & Wiita 1991).

4. Evolving cluster environments of powerful radio sources

It has long been suspected that the space-density evolution of powerful radio sources may be linked to an evolution of their local environment with cosmic epoch. Yee & Green (1987) showed that at $z \sim 0.5$, a significant fraction of optically bright, steep-spectrum radio quasars are located in environments as rich as Abell class 1 clusters. This is in contrast to lower redshifts where few bright quasars are found to reside even inside Abell class 0 clusters (e.g., Yee & Ellingson 1993).

For radio galaxies, the evolution of cluster environment has been investigated by Hill & Lilly (1991) using Rband CCD images of a sample of 45 radio galaxies near

z = 0.5 (which corresponds to the epoch by which a distinct increase is observed in the fraction of blue luminous galaxies near the centres of clusters, cf. Butcher & Oemler 1978; Oemler 1992). The low-z comparison sample used by Hill & Lilly contains 77 radio galaxies with a mean redshift of 0.05, selected from Prestage & Peacock (1989). Since their sample covers a wide range in radio luminosity at $z \sim 0.5$, Hill & Lilly were able to separate unambiguously the effects of radio luminosity and redshift, an advance over previous studies. Thus, they were able to show *that FR II radio galaxies often inhabit rich-cluster environments at* $z \sim 0.5$, *whereas they almost totally avoid such sites at low redshifts.* On the other hand, they found no significant evolution of the cluster environments for FR I type radio sources up to $z \sim 0.5$. A crucial question posed by these results is: which property of rich clusters or their central galaxies has undergone a change since $z \sim 0.5$, which adversely affects their ability to generate a FR II radio source?

5. The evolution of early-type galaxies in clusters

'Passive' evolution of early-type galaxies (i.e., uncomplicated by any cosmic evolution of starburst activity in them) can be effectively studied by optical CCD photometry of the galaxy samples selected in the *K*-band (2μ) and covering a substantial range in redshift. One such investigation of over 100 faint galaxies selected from 10 rich clusters with $0.5 \lesssim z \lesssim 0.9$ has been reported by Aragon-Salamanca *et al* (1993). It has revealed that by $z \sim 0.9$ there are no cluster galaxies as red as present-day ellipticals, indicating a passive ageing of an old stellar population formed prior to $z \sim 2$ (also, Rakos & Schombert 1995; Oke *et al.* 1996). Clearly, the very small scatter in their colour distributions at long wavelengths suggests that these *K*-band selected early-type cluster galaxies are a remarkably homogeneous, co-eval population. This is further supported by the very tight *K*-band Hubble diagram with a scatter, σ_K of just 0.30-mag at $z \simeq 0.9$ (Aragon-Salamanca *et al.* 1993).

(Another expected manifestation of the passive ageing of early-type galaxies is the changing luminosity with cosmic epoch (Tinsley 1972) One recent search for this is based on the *HST* images of a sample of 209 early-type galaxies in 8 clusters with $0.17 \lesssim z \lesssim 1.21$ (Schade & Barrientos 1997). These galaxies, located within 1 Mpc from the respective cluster centres, were selected solely because their two-dimensional light distributions could be well-fit with the $R^{1/4}$ law. For each galaxy, the fitting procedure yielded a half-light radius (R_e) and $M_{B,}$ and it was found that, on average, the $M_B - logR_e$ sequence shifts steadily towards higher luminosity with increasing z (implying an increase in the surface brightness). The average shift, $\Delta M_{B,}$ at $z = 0.9$ amounts to -1.27 ± 0.21 for a galaxy of a given size. This redshift-dependence could be interpreted either as some sort of dynamical evolution/merger, or luminosity evolution with redshift. A shift of similar amplitude had earlier been inferred from ground-based imaging of early-type (bulge-dominated) galaxies located in the field and outer areas of clusters (Schade *et al.* 1996a).

6. The evolution of galactic disks in clusters and the field

A recent evidence for cosmic evolution of galactic disks has come from a morphological analysis of 351 *late-type* galaxies at $0.06 \lesssim z \lesssim 0.065$, taken from the field and

7 clusters (Schade *et al* 1996b). These galaxies were imaged mostly with the *CHFT* in the *r*-band. A two-component fit ($R^{1/4}$ bulge and exponential disk) was applied to each galaxy image and only those with a bulge fraction *Bulge/Total* $\leq$ 0.5 were considered. The main trend emerging from these observations is that the surface brightness of disks in blue shows a progressive increase with redshift; by z $\sim$ 0.6 they are brighter by $\sim$ 1– mag over the Freeman value for local galaxies. Moreover, the cluster and field galaxies show a similar evolutionary trend (note, however, that the cluster population considered in this study is dominated by galaxies at large distances of up to 3 Mpc from the cluster core). Interestingly, as pointed out by Schade *et al.* (1996b), the surface brightness evolution of the disks shows the same redshift dependence [$\propto (1+z)^{2.7\pm0.5}$] as that inferred by Lilly *et al.* (1996) for the B-band luminosity density enchancement, which implies a *global* star-formation rate (including galaxies of all morphological types and colours) at $z \sim 1$ is about an order-of-magnitude higher compared to the rate at the present epoch. Apparently, galaxy formation was a much more vigorous process at those earlier epochs.

7. Irregular galaxies: Dominant players in the evolution

The unique resolving power of *HST* has provided a plausible answer to this outstanding question springing from the discovery of a dramatic excess of ‘faint blue galaxies’ in deep optical surveys (e.g., Broadhurst *et al.* 1988). The basic dataset employed by Glazebrook *et al.* (1995) to probe this question came from the *HST Medium Deep Survey.* They carried out a visual morphological classification of all 301 galaxies down to m_I = 22 found in their sample. For the purpose of ‘counting’ galaxies, they smoothed the *HST* frames with a 1″ Gaussian, so that the *HST* counts can be meaningfully compared with the ground-based optical counts. The most striking result is a steep rise in the space density of irregular/peculiar galaxies, compared to the local value (see, also, Colless *et al.* 1994). It is interesting that the cosmic evolution of the irregulars alone can account for the observed faint blue galaxy excess, since the counts of galaxies classified as spirals or ellipticals are found to be broadly consistent with no-evolution expectation (Glazebrook *et al.* 1995).

8. Further clues on evolution from near-IR selected samples

8.1 *Keck spectroscopy of Hawaii Deep Fields*

A major boost to the study of the normal galaxy population *beyond* $z \sim 0.7$ has come from the spectroscopy programme with the 10-metre *Keck* telescope. Particularly well suited for such studies are the deep samples selected in the near-infrared because *K*-corrections remain small up to large redshifts and are, moreover, relatively invariant of the galaxy type. In contrast, optically selected samples are severely biased against early-type galaxies at higher redshifts.

Recently, based on spectroscopy with the *KECK* telescope, Cowie *et al.* (1996) have presented results for a *K*-band selected sample of 346 galaxies, down to

m_K = 20 (completeness level of 77% at K = 19 – 19.5 and 57% at fainter magnitudes). For each galaxy, the authors carried out spectroscopy to estimate, in addition to its redshift, the rest-frame equivalent width of [O II] 3727 emission line. It roughly measures the rate of star-formation relative to the existing stellar mass (broadly, galaxies with an [O II] equivalent width of ≥ 25 Å are undergoing rapid star formation corresponding to a mass doubling time of less than 10^{10} yr). Recalling that for older galaxies, M_K, is a rough measure of the total mass in stars, these data reveal a remarkable trend: with increasing redshift, progressively more massive galaxies fall within the rapid-formation category, such that by $z \sim 1$ even the most massive galaxies ($M_K \sim -25$) are frequently seen to he rapidly converting their gas into stars. It is striking that at small redshifts, such massive galaxies are rarely found to be undergoing rapid star-formation. Thus, it appears that *of the galaxies populating the upper end of the luminosity function, the more massive ones got assembled at progressively earlier epochs.* This phenomenon of *downsizing* is also mirrored in some other studies. For instance, Ellis *et al.* (1996) found that the luminosity function of strong [O II] line emitting galaxies evolves rapidly with redshift, whereas that of weak [O II] emitters has remained largely unchanged.

8.2 *The Canada-France Redshifts Survey*

This near-infrared selected sample contains 730 *I*-band selected galaxies, out of which spectroscopic redshifts have been secured for 591 (81%) and 350 are found to lie at $z \geq 0.5$, going up to $z \sim 1.3$ (Lilly *et al.* 1995). This database allowed the construction of a statistically robust tri-variate ate luminosity function ϕ (M, colour, z). *Over the range* $0.2 \lesssim z \lesssim 1$, *the luminosity function of red galaxies undergoes little change, whereas the population of galaxies bluer than the present-day Sbc evolves significantly.* Between $z \sim 0.3$ and $z \sim 0.75$. this evolution can be described as an increase in space density by a factor of 3, or an increase by ~ 1-mag in luminosity (or, an appropriate combination of the two).

8.3 *Sighting the earliest 'forming' galaxies?*

To overcome the limitation of obtaining spectroscopic redshifts of very faint normal galaxies, a promising alternative technique of broad-band photometry has been developed in recent years. Basically, it makes use of two prominent spectral signatures, the Lyman-limit spectral discontinuity and the Ly-α forest spectral decrement (e.g., Steidel *et al.* 1996 and references therein). In an important application of this technique to the Hubble Deep Field images, a catalogue of 1104 objects, complete to AB(8140 Å) ≲ 30-mag has been assembled. Of these, 38 objects are estimated to lie at $z \geq 4$, including 4 objects with estimated redshifts $z \geq 6$ (Lanzetta *et al.* 1996). Thus, these authors find that the high-z objects with $2.5 \lesssim z \lesssim 6$ have sizes of ~ 1 kpc, (ii) ultra-violet luminosities ~ 10^9 – 10^{10} $L_\odot$ and co-moving spatial density of order 0.03 Mpc^{-3} which is quite comparable to that of luminous galaxies at the present epoch. *Thus, in these distant objects one may well be witnessing the progenitors of present-day normal galaxies, during the early starburst phase associated with the formation* (Lanzetta *et al.* 1996).

9. Concluding remarks and a dose of caution

The impressive growth of multi-wavelength astronomy combined with the availability of superior telescopes in recent years has lent a new edge to observational cosmology. On balance, this has strengthened the case for evolution of the populations of many different constituents of the universe on cosmological time scale. Various manifestations of such evolution process are found to be associated with normal galaxies of different morphological types, radio galaxies/quasars, their cluster environments, and even proto-galactic disks (the Damped Lyman-α systems). All this adds up to a formidable, albeit somewhat indirect, evidence in favour of the Big Bang description of the Universe. At the same time, it is reassuring that new observational initiatives have *not* always reinforced the case for cosmological evolution, which goes to underscore Hoyle's cautionary remark over the interpretation of observations, cited at the outset.

To exemplify this important point, recall the recent debate over the proposed rapid *negative* cosmic evolution of X-ray luminous clusters. This result, originally based on a sample of clusters serendipitously discovered in the *Einstein* Medium Sensitivity Survey (*EMSS*), was confirmed by ROSAT observations which showed a substantial deficit of medium-redshift clusters, compared with the no-evolution expectation (Castander *et al.* 1995 and references therein). However, this finding is not substantiated by a recent search for serendipitously detected X-ray clusters in the *ROSAT* data archive. Moderately extended sources picked up in this search were followed up with multi-object spectroscopy. This led to confirmation of 36 clusters out to $z \sim 0.7$, thereby greatly weakening the case for cosmological evolution (Collins *et al.* 1997). A similar conclusion has been reached from an improved *EMSS* sample, based on follow-up *ROSAT* observations and additional redshift data (Nichol *et al.* 1997).

Another case in point is the *radio-optical alignment effect* (Chambers *et al.* 1987; McCarthy *et al.* 1987). Originally discovered in high-z radio galaxies, it was widely acclaimed to be a property of the high redshift universe ($z \geq 0.7$). However, optical images of such galaxies correspond to the rest-frame ultraviolet which is difficult to image from ground for their low-z counterparts. Moreover, high-z radio galaxies are, typically, much more luminous than those populating the low-z samples. In fact, morphologies of lower luminosity radio galaxies found at high-z hardly exhibit any radio-optical alignment, suggesting that the phenomenon may be primarily related to radio luminosity rather than redshift (see, Dunlop & Peacock 1993).

References

Aragon-Salamanca, A., Ellis, R. S., Couch, W. J., Carter, D. 1993, *Mon. Not. R. astr. Soc.,* **262**, 764.

Barthel, P. D., Miley, G. K. 1988, **333**, 319.

Boyle, B. J., Shanks, T., Fong, R., Peterson, B. A. 1990, *Mon. Not. R. astr. Soc.,* **243, 1**.

Broadhurst, T. J., Ellis, R. S., Shanks, T. 1988, *Mon. Not. R. astr. Soc.,* **235,** 827.

Butcher, H., Oemler, A., Jr. 1978, *Astrophys. J.,* **219**, 18.

Castander, F. J. *et al.* 1995, *Nature,* **377,** 39.

Chambers, K. C., Miley, G. K., van Breugel, W. J. M. 1987, *Nature,* **329,** 604.

Colless, M., Schade, D., Broadhurst, T. J., Ellis, R. S. 1994, *Mon. Not. R. astr. Soc.,* **267,** 1108.

Collins, C. A., Burke, D., Romer, A., Sharpies, R., Nichol, R. 1997, *Astrophys. J. Lett,* **479,** L117.

Condon, J. J. 1993, *Astrophys. J.,* **338,** 13.
Cowie, L. L., Songaila, A., Hu, E. M., Cohen, J. G. 1996, *Astr. J.,* **112,** 839.
Dasgupta, P., Narlikar, J. V., Burbidge, G. R. 1988, *Astr. J.,* **95,** 5.
Dunlop, J. S. 1995, in *High-sensitivity radio astronomy,* Eds. N. Jackson & R. J. Davis, Cambridge University Press, p. 167.
Dunlop, J. S., Peacock, J. A. 1990, *Mon. Not. R. astr. Soc.,* **247,** 19.
Dunlop, J. S., Peacock, J. A. 1993, *Mon. Not. R. astr. Soc.,* **263,** 936.
Ellis, R. S., Colless, M. Broadhurst, T., Heyl, J., Glazebrook, K. 1996, *Mon. Not. R. astr. Soc.,* **280,** 235
Fall, S. M., Pei, Y. C. 1993, *Astrophys. J.,* **402,** 479.
Glazebrook, K., Ellis, R., Santiago, B., Griffiths, R. 1995, *Mon. Not. R. astr. Soc,* **275,** L19.
Gopal-Krishna, Wiita, P. J. 1991, *Astrophys. J.,* **373,** 325.
Gopal-Krishna, Kulkarni, V. K., Wiita, P. J. 1996, *Astrophys. J. Lett.,* **463,** L1.
Hawkins, M. R. S., Véron, P. 1996, *Mon. Not. R. astr. Soc.,* **281,** 348.
Hill, G. J., Lilly, S. J. 1991, *Astrophys. J.,* **367,** 1.
Hoyle, F. 1959, in *Paris Symp. on Radio Astronomy,* Stanford Univ. Press, Stanford, p. 529.
Kapahi, V. K. 1989, *Astr. J.,* **97**, 1.
Kellermann, K. I. 1972, *Astr. J.,* **77,** 531.
Lanzetta, K. M., Wolfe, A. M., Turnshek, D. A. 1995, *Astrophys. J.,* **440,** 435.
Lanzetta, K. M., Yahil, A., Fernández-Soto 1996, *Nature,* **381,** 759.
Legg, T. H. 1970, *Nature,* **226,** 65.
Lilly, S. J., Tresse, L., Hammer, F., Crampton, D., Le Févre, O. 1995, *Astrophys. J.,* **455,** 108.
Lilly, S. I, Le Fevre, O., Hammer, F., Crampton, D. 1996, *Astrophys. J. Lett.,* **460,** L1.
Longair, M. S. 1966, *Mon. Not. R. astr. Soc.,* **133,** 421.
McCarthy, P. J., van Breugel, W. J. M., Spinrad, H., Djorgovski, S. G. 1987, *Astrophys. J. Lett.,* **321,** L29.
Miley, G. K. 1968, *Nature,* **218,** 933.
Miller, L, Goldschmidt, P., La Franca, F., Cristiani, S. 1993, in *Observational cosmology,* Eds. G. Chincarini, *et al.* ASP Conf. Ser. 51, Astron. Soc. Pacific, p. 614.
Nesser, M. J., Eales, S. A., Law-Green, J. D., Leahy, P. J., Rawlings, S. 1995, *Astrophys. J.,* **451,** 76.
Nichol, R. C, Holden, B. P., Romer, A. K., Ulmer, M. P., Burke, D. J. 1997, *Astrophys. J.,* **481,**644.
Nilsson, K., Valtonen, M. J., Kotilainen, J., Jaakkola, T. 1993, *Astrophys. J.,* **413,** 453.
Oke, J. B., Gunn, J. E., Hoessel, J. G. 1996, *Astr, J.,* **111,** 29.
Oemler, A. 1992, in *Clusters and superclusters of galaxies,* Ed. A. Fabian, Kluwer-Dordrecht, p. 29.
Oort, M. J. A., Katgert, P., Windhorst, R. A. 1987, *Nature,* **328,** 500.
Osmer, 1982, *Astrophys. J.,* **253,** 28.
Ostriker, J. P., Heisler, J. 1984, *Astrophys. J.,* **278,** 1.
Pei, Y. C, Fall, S. M. 1995, *Astrophys. J.,* **454,** 69.
Prestage, R. M., Peacock, J, A. 1989, *Mon. Not. R. astr. Soc.,* **236,** 959.
Rakos, K., Schombert, J. 1995, *Astrophys. J.,* **439,** 47.
Rao, S., Briggs, F. 1993, *Astrophys. J.,* **419,** 515.
Rao, S. M., Turnshek, D. A., Briggs, F. H. 1995, *Astrophys. J.,* **449,** 488.
Schade, D., Barrientos, F. 1997, *Astrophys. J. Lett.,* **477,** L17.
Schade, D., Carlberg, R., Yee, H. K., López-Cruz, O., Ellingson, E. 1996a, *Astrophys. J. Lett.,* **464,** L63.
Schade, D., Carlberg, R., Yee, H. K., López-Cruz, O., Ellingson, E. 1996b, *Astrophys. J. Lett.,* **465,** L103.
Schmidt, M., Schneider, D. P., Gunn, J. E. 1995, *Astr. J.,* **110,** 68.
Shaver, P. A., Wall, J. V., Kellermann, K. L, Jackson, C. A., Hawkins, M. R. S. 1996, *Nature,* **384,** 439.
Singal, A. K. 1988, *Mon. Not. R. astr. Soc.,* **233,** 87.
Singal, A. K. 1993, *Mon. Not. R. astr. Soc.,* **263,** 139.
Singal, A. K. 1996, in *Extragalactic Radio Sources,* Eds. R. D. Ekers *et al.,* Kluwer, p. 563.
Steidel, C.C, Giavalisco, M., Pettini, M., Dickinson, M., Adelberger, K. L. 1996, *Astrophys. Lett.,* **462,** L17.

Storrie-Lombardi, L. J., McMohan, R. G., Irwin, M. J. 1996, *Mon. Not. R. astr. Soc.,* **283,** L79.
Subramanian, K., Swamp, G.1990, *Mon. Not. R. astr. Soc.,* **247,** 237.
Tinsley, B. 1972, *Astrophys. J.,* **178,** 319.
Wall, J. V., Pearson, T. J., Longair, M. S. 1981, *Mon. Not. R. astr. Soc.,* **196,** 597.
Warren, S. J., Hewett, P. C, Osmer, P. S. 1994, *Astrophys. J.,* **421,** 412.
Wolfe, A. M. 1995, in *QSO absorption lines,* Ed. G. Meylan, Springer-Heidelberg, p. 13.
Yee, H. K. C., Ellingson, E. 1993, *Astrophys. J.,* **411,** 43.
Yee, H. K. C., Green, R. F. 1987, *Astrophys. J.,* **319,** 28.
Zwaan, M., Briggs, F., Sprayberry, D. 1997, *PASA,* **17,** 126.