GALAXIES IN FORMATION

THE QUEST FOR PROTOGALAXIES

S.G. DJORGOVSKI
Palomar Observatory, Caltech
Pasadena, CA 91125, USA

Abstract.

The current state and the future prospects of searches for protogalaxies (PGs) are reviewed. Many high-redshift objects are now known, mostly associated in some way with AGN, and at least some of them may be young galaxies. Quasars at $z > 4$ and high-z quasar pairs may mark galaxy formation sites. Deep field surveys for Lyα luminous galaxies powered by star formation alone have failed so far to reveal a large population of such objects, and the observed limits are in conflict with simple model predictions by three orders of magnitude. Some extinction by dust can account for this. However, strong limits from COBE place severe constraints on models of completely obscured PGs. New searches in the near IR are now beginning to probe the relevant line flux and number density regime, and first interesting PG candidates are being discovered. Searches from mid-IR to mm wavelengths would complement these efforts.

1. Introduction

Understanding of galaxy formation is one of the central goals of modern cosmology. Thanks to the great advances in observational technologies in the last few years, the quest for protogalaxies (PGs) is now becoming one of the most exciting and lively fields of extragalactic astronomy.

We have a reasonably good, if mostly qualitative understanding of the processes leading to galaxy formation (cf. White & Frenk 1991, Silk & Wyse 1993, and references therein). Most models and simulations deal with the assembly of dark matter into galaxy-sized chunks, a process which is not directly observable. The weakest link in the models now seems to be the physics of star formation and other dissipative processes in PGs.

R. Bender and R. L. Davies (eds.), New Light on Galaxy Evolution, 277–286.

Observations are now reaching the flux levels and the volume coverage at high redshifts where models can be tested. An excellent recent review of the subject is by Pritchet (1994); see also Djorgovski & Thompson (1992) or Djorgovski (1992). This review is intended mostly as an update to them.

The relevant observable parameters of PGs are discussed in these reviews, as well as in a number of the recent survey papers, listed below. Briefly, depending on the cosmology and formation redshifts, we expect to find $\sim$ 1 to 10 PGs/arcmin^2, depending on the net total duration of the formation phases, with typical visible/near-IR continuum magnitudes $\sim 23^m - 26^m$ for proto-L_* objects, depending on the bandpass, and with recombinant line fluxes (including Lyα) of $\sim 10^{-17\pm1}$ erg/cm^2/s, if they were unobscured. Most of the energy released would come from the young, massive stars which generated the metals we see in the spectra of old stellar populations today along with the corresponding amounts of helium. Up to $\sim$ 10% of the total luminosity of PGs would be contributed by the release of the binding energy of PGs themselves, and the protostars within them. AGN, if present, would make all of the fluxes higher.

Redshifts of formation ranging from $z \sim 0$ to $z \sim 100$ have been proposed, but probably the most likely range is from $z \sim 2$ to $z \sim 5$ or 10 (cf. Peebles 1989 for a discussion). Deep field redshift surveys and absorption line studies indicate that most (at least non-dwarf) galaxies do not evolve very much out to $z \sim 1$ or 1.5. The comoving number density of quasars peaks near $z \sim 2.5$, and falls of steeply at $z > 3$ or 4; this may be indicative of a general merging history in the universe. Yet, quasars at $z \sim 4$ or 5 seem to reside in already chemically evolved galaxy cores, and some galaxy formation must have started at $z > 5$.

The key problem is that of the recognition of PGs. Unwise and unsubstantiated claims have been made in the literature about ostensible discoveries of PGs or even protoclusters, simply on the basis of the objects being faint, or being blue, or being red, or being numerous, or being rare, etc. There is no substitute for real redshifts and spectra which can be used to constrain the physical nature of the candidates, e.g., if an AGN is present.

The observable aspect of galaxy formation is the collapse of the baryonic component and star formation – dark matter is dynamically important and may be driving the process, but it is hard to observe! An observer's definition of PGs may be: massive galaxies undergoing their first, major bursts of star formation at high redshifts. This probably means most ellipticals and massive bulges; disks seem to form their stars at a nearly uniform pace over the Hubble time scales. Some dwarf galaxies, e.g., objects like I Zw 18 may be only forming now. The early evolution of disk systems can be probed indirectly through absorption line studies (cf. Wolfe 1993, Steidel & Dickinson 1995, and references therein).

Even within the restricted class of young ellipticals and bulges there was likely some spread of star formation histories. The AGN phenomena may be also ubiquitous among PGs (Djorgovski 1994). The real phenomenology of galaxy formation may be very diverse, with a complicated interplay of astrophysical processes at a range of redshifts. PGs are unlikely to be a simple, uniform class of objects.

2. High Redshift Galaxies and Protogalaxy Candidates

Most likely, PGs have already been discovered. Aside from an obvious possibility that some or all high-z quasars reside in PGs, there are many high-z galaxies now known, almost all of them associated in some way with AGN. Proto-disks may have been discovered indirectly, as damped Lyα absorbers (DLAs) and/or metallic line and Ly limit absorption systems.

Powerful radio galaxies remain the most distant non-QSO objects known, and some of them may well be objects in early stages of formation. Some examples include: 3C 326.1 at $z = 1.825$ (McCarthy *et al.* 1987), B2 0902+34 at $z = 3.395$ (Lilly 1988, Eisenhardt & Dickinson 1992), 4C 41.17 at $z = 3.800$ (Chambers *et al.* 1990), or 8C 1435+635 at $z = 4.25$ (Lacy *et al.* 1994). However, it remains impossible to disentangle the effects of AGN from those of star formation. For a good review, see McCarthy (1993).

The first galaxy at $z > 3$, the companion of the quasar PKS 1614+051 at $z = 3.215$ (Djorgovski *et al.* 1985, 1987), was discovered using the Lyα narrow-band imaging technique, which remained the method of choice for PG searches ever since. Other high-z quasar companions include galaxies near QSO 1548+0917 at $z = 2.749$ (Steidel *et al.* 1991), Lyα objects near the gravitational lens MG 2016+112 at $z = 3.273$ (Schneider *et al.* 1987), and several cases of Lyα and possibly also continuum nebulosities near radio-loud quasars at $z \sim 2 - 3$ (Heckman *et al.* 1991ab, Hu *et al.* 1991, Moller & Warren 1993). Several cases of Lyα companions of high-z radio galaxies are also now known (cf. Windhorst *et al.* , this volume).

Narrow-band imaging was also used to look for Lyα galaxies at the redshifts of DLAs near the lines of sight towards background quasars. The best cases so far include active galaxies (high-ionization lines are present) at $z = 2.309$ (Lowenthal *et al.* 1991), and at $z = 3.428$ (Macchetto *et al.* 1993, Giavalisco *et al.* 1994). A possible Lyα nebulosity at $z = 2.466$ was reported by Wolfe *et al.* (1992), but it remains unconfirmed. Other cases have been found recently (Bechtold *et al.* , in prep.; Djorgovski *et al.* , in prep.). A related approach has been made by Francis *et al.* (1996), who discovered a possible group of galaxies at $z = 2.38$, associated with a proposed cluster of C IV absorbers; their one object with a secure redshift also contains an AGN. Obviously, DLA and other absorber fields present very promising targets for future searches. The success of these studies also suggests that some clustering is present at $z \sim 2-3$ (Wolfe 1993).

3. Deep Lyα Searches and the Question of Dust Obscuration

Objects containing or located near AGN may be unrepresentative of the general PG population (but see Sect. 5). A considerable effort has been expended in deep field searches for PGs powered by star formation alone. There, one is looking for a large *population* of PGs, rather than a few interesting but rare objects.

Some emission line signature may be necessary, both as a probe of redshifts and physics (i.e., AGN vs. star formation), and Lyα has always been the line of choice. From case-B recombination and the semiempirical conversion of star formation rate to Hα luminosity (Kennicutt 1983), we get a conversion of $L(\mathrm{Ly}\alpha) \sim 10^{42}$ erg/s or slightly less for $SFR = 1 M_\odot/\mathrm{yr}$, assuming a normal IMF (a top-heavy IMF would be more efficient in producing the Lyα photons). Additional Lyα flux may come from shock ionization, or cooling of the first stars. However, its detection requires that PGs were not obscured by dust. For a discussion, see Charlot & Fall (1993).

Both narrow-band and long-slit searches are reaching typical line fluxes $F_{\mathrm{Ly}\alpha} \sim 10^{-17}$ erg/cm^2/s, or even fainter, which, at the redshifts of interest translates into the rest-frame line luminosities of $L(\mathrm{Ly}\alpha) \sim 10^{42}$ erg/s, and unobscured SFR of a few $M_\odot$/yr, over typical comoving volumes surveyed of $\sim 10^5 h_{75}^{-3}$ Mpc^3 (De Propris *et al.* 1993, Thompson *et al.* 1995, Thompson & Djorgovski 1995; cf. Pritchet 1994 for a review and further references). Some faint PG candidates *have* been found in these surveys, but none have been confirmed yet, due to their extreme faintness. Assuming that no PGs are found, the observed limits are some 3 orders of magnitude in conflict with simple model predictions, for unobscured PGs. The key question is then, were PGs obscured by dust?

We see prominent Lyα emission from many high-z galaxies, but most or all of them seem to involve AGN. The earliest stages of a PG must have been dust-free, on the account of absence of metals in the ISM; that phase might have lasted up to $\sim 5 \times 10^7$ yr. On the other hand, most starbursts at $z \sim 0$ tend to be dust-obscured, and their counterparts do exist at high-z, e.g., IRAS FPS 10214+4724 (Rowan-Robinson *et al.* 1991), even if AGN are also involved. Thermal emission from dust has been detected from several high-z radio galaxies and quasars (McMahon *et al.* 1994, Chini & Krugel 1994, Ivison 1995, and references therein). Lyα emission has been seen from some low-z starforming dwarfs, but usually at a level lower than what is expected from the simple case-B photoionization by young stars (cf. Terlevich *et al.* 1993, Calzetti & Kinney 1992, and references therein). The data suggest that the extinction from these objects can be modeled effectively as a patchy dust foreground screen, so some Lyα leakage is expected. UV radiation from young starbursts or AGN can also destroy dust (Hartquist *et al.* 1995, Calzetti *et al.* 1995). Lyα emission may be also filling up stellar Lyα absorption lines in PG spectra (Valls-Gabaud 1993).

The strongest limits on dusty PGs come from the COBE FIRAS experiment (Mather *et al.* 1994, Wright *et al.* 1994). The integrated energy density today generated by stars which produced the observed metals and helium in old, metal-rich stellar populations is of the order of a few percent of the energy density of the CMBR, viz., $\sim 10^{-15}$ erg/cm^3 (cf. Djorgovski 1992, or Djorgovski & Thompson 1992 for a discussion). A comparable integrated background is expected from AGN at all redshifts (Chokshi & Turner 1992). Yet the maximum allowed deviations from the pure blackbody CMBR spectrum in the sub-mm regime, where an integrated background from putative dusty PGs would be observable now, are $\sim 0.03\%$ of the CMBR peak intensity. This suggests, in a fairly model-independent way, that at most a few percent of all star formation in PGs was obscured by dust. A more detailed modeling by Blain & Longair (1993b) suggests that a sub-mm background may be just in conflict with the COBE FIRAS limits. However, Puget *et al.* (1995) have claimed a detection of a sub-mm background in the very same COBE data, but with a different analysis approach. This is indicative of the difficulty of the problem. PGs, evolving galaxies, and AGN should all contribute to an integrated FIR/sub-mm background, and even if a positive detection is made, disentangling the PG contribution may be hard.

An approach complementing Lyα based surveys is to select PG candidates (which then must be followed up spectroscopically) on the basis of their stellar continuum Lyman break at 912Å (Guhathakurta *et al.* 1990, Steidel & Hamilton 1992, 1993, DeRobertis & McCall 1995). This promising technique is now yielding results (Steidel, priv.comm.).

4. Searches in the Near Infrared

Emission-line searches in the near-IR are the natural next step: nebular oxygen and Balmer lines are much less affected by the dust. One can imagine a scenario in which PGs contain modest amounts of dust, sufficient to extinguish the Lyα emission, but not dusty enough to generate a substantial sub-mm background, detectable by COBE. The modern NIR imaging technology is now good enough to make such searches viable.

An early attempt, and a discussion of observable parameters of near-IR PGs were presented by Thompson *et al.* (1994). Mannucci & Beckwith (1995) provide a detailed discussion of detectability of PGs in the near-IR. The early results from the Keck were presented by Pahre & Djorgovski

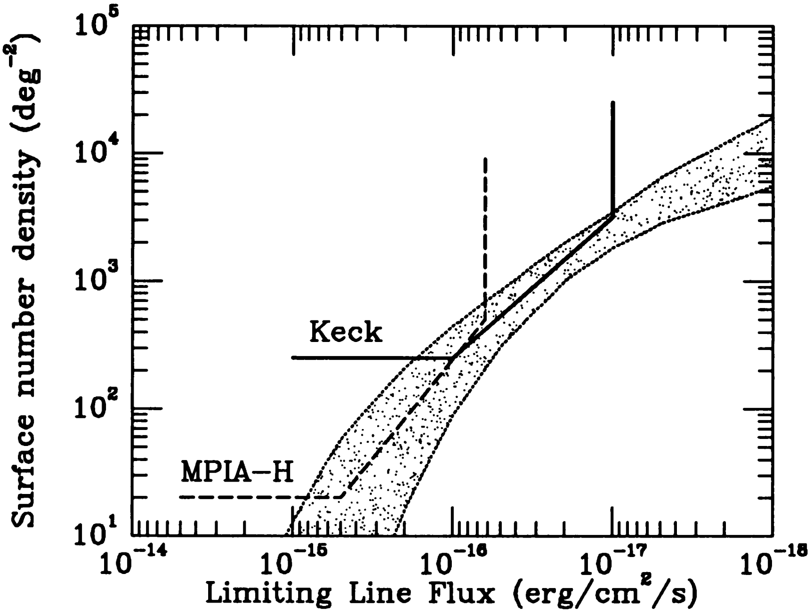

Figure 1. Estimated line flux limits and sky coverage in K band PG surveys. The dotted area indicates the range predicted by the simple models from Mannucci & Beckwith (1995). Estimated limits as of late 1995 are indicated for two of the most extensive surveys to date: dashed line = MPIA-H group (Beckwith & Thompson, priv. comm.); solid line = Keck (Djorgovski & Pahre, in prep.). Both groups are now probing the relevant portion of the parameter space, and both have found some PG candidates.

(1995); as of late 1995, their coverage has been increased by about a factor of 4, and a few good candidates have been found. Another, as yet unconfirmed candidate has been reported by Malkan *et al.* (1995). The object found by Lowenthal *et al.* (1991) was detected in Hα both by Hu *et al.* and by Bunker *et al.* (1995). Most of the work so far has been in the K band, looking for the Hα, Hβ, [O III] 5007, and [O II] 3727 lines. An optimistic, albeit unsuccessful search for the Lyα line at $z \sim 7-9$ in the J band was reported by Parkes *et al.* (1994). The MPIA-H group (Beckwith *et al.*) is continuing their search over a wide area, down to moderate fluxes; this is a good strategy if one believes that PG starbursts would be rare, but intense, so that a large volume should be covered. Figure 1 summarizes some of the IR limits to date.

These searches are already starting to produce interesting candidates, and may be the most promising method to look for PGs at the present. It is also possible that some PGs have been detected in the deepest K band surveys to date (cf. Djorgovski *et al.* 1995, and references therein); their expected magnitudes are $K \sim 23^m - 24^m$. An integrated NIR background from PGs is now being constrained by the COBE DIRBE (cf. Hauser

1995 for a review). Observations in the as yet poorly explored cosmological window at $\lambda \sim 3-6$ μm are particularly interesting. Deep surveys with HST+NICMOS, ISO, and SIRTF, perhaps in a conjunction with the ground-based spectroscopy, may lead to great advances in this area.

5. AGN and Galaxy Formation

The same kind of astrophysical processes, dissipative merging and infall of gas, are believed to be essential both for massive starbursts and the onset and fueling of AGN. It is thus natural to expect that at least some, and perhaps all PGs would undergo an immediate AGN phase, which could mask the underlying starburst. The idea that high-z quasars *are* PGs was proposed by Meier (1976) and expanded by Terlevich (1992; see also Terlevich & Boyle 1993, and references therein). In a less extreme form, both a traditional AGN and a starburst can coexist in young PG, and primordial starbursts can lead to a formation of the first quasars (cf. Norman & Scoville 1988, Williams & Perry 1994, Djorgovski 1994).

It is perfectly possible that most or all ellipticals and luminous bulges today contain remnants of the former AGN, and that every one of them has undergone an early AGN phase, at least once (Chokshi & Turner 1992, Small & Blandford 1992, or Haehnelt & Rees 1993, and references therein). There is a kinematical evidence for the quiescent central mass concentrations in the nuclei of several nearby galaxies, including M31, M32, and others (cf. Kormendy & Richstone 1995 for a review).

Metallicities in quasars at $z > 4$ suggest that they reside within already considerably chemically evolved stellar populations, presumably cores of giant ellipticals (Hamann & Ferland 1993, Matteucci & Padovani 1993). The very existence of numerous $z > 4$ quasars suggests that galaxy formation must have started at higher redshifts (Turner 1991).

The fate of a protogalaxy may be severely affected by an early AGN, if one is rapidly formed, while the bulk of its host is still gaseous. The feedback from an AGN could have regulated some of the global properties of its host galaxy, e.g., the total mass, density, etc. (Ikeuchi & Norman 1991). Quasar-endowed PGs may even create an inverse bias and suppress star formation in their vicinity, by ionizing the ISM in companion objects.

Another intriguing possibility is that the high-z quasars can be used as probes of the primordial large scale structure. The first object should be forming at the highest peaks of the initial density field, and such peaks should be strongly clustered (Kaiser 1984). For a CDM cosmogony, quasars at $z > 4$ should be clustered as strongly as the bright galaxies today (Efstathiou & Rees 1988). If this is true, then practically all $z > 4$ quasars should be pointing towards protoclusters in the early universe, and the optimal sites for galaxy formation. This would also be consistent with their interpretation as being the nuclei of young giant ellipticals.

Possible examples of such structures include three quasar pairs at $z > 3$, found in a complete survey by Schneider, Schmidt & Gunn (1994). The quasars are separated by a few Mpc, and the Poissonian probability of finding these 3 pairs in their survey is $P \simeq 10^{-13}$! The implied clustering length is $r_0 \sim 50h^{-1}$ Mpc, comparable to the richest Abell clusters today.

6. Conclusions and Future Prospects

There may be some PGs among the various high-z objects already discovered, including quasars (especially those at $z > 4$), their companions, radio galaxies, and other AGN at $z > 3$ or 4. Deep Lyα based surveys have placed severe limits on a population of unobscured, luminous PGs, but some of the faint candidates may yet turn out to be PGs. Searches based on the 912 Å break, or in the vicinity of DLAs are also starting to yield interesting candidates. Modern near-IR searches based on the nebular oxygen and Balmer lines are also starting to probe the relevant flux and number density regime, and to yield the first candidates.

A virtually unexplored territory lies from the mid-IR through sub-mm regime, where dusty PGs may be hiding (cf. Blain & Longair 1993a, Franceschini *et al.* 1994, Braine 1995, and references therein). Analysis of integrated extragalactic backgrounds is already providing interesting constraints on galaxy formation, but eventually one must resolve and study individual sources of this emission. New bolometer arrays and receivers from the ground, and ISO and SIRTF from space may lead to great advances in this area. The [C II] 154 μm line, and possibly molecular lines of H_2 and CO, may be good redshift indicators for dusty PGs.

Gravitational lenses may yet prove to be an important tool in discovering and studying distant galaxies or even PGs to faint to detect otherwise. Examples may be the Lyα nebulosities near MG 2016+112 (Schneider *et al.* 1987), the notorious IRAS FPS 10214+4724 (Graham & Liu 1995), the object discovered by Warren *et al.* (1995), some cluster arcs, etc.

Observational study of galaxy formation is now a reality, at a range of wavelengths and search strategies, even if we are not quite sure what to look for: PGs were probably a very diverse bunch. We have probably already found some of them, and hopefully we shall find many more.

I wish to thank my collaborators, and in particular D. Thompson, M. Pahre, and J. Kennefick, and to the staff of Palomar and W. M. Keck observatories for their expert help. This work was supported in part by the NSF PYI award AST-9157412, and the Bressler Foundation.

References

Blain, A., & Longair, M. 1993a, MNRAS, 264, 509
Blain, A., & Longair, M. 1993b, MNRAS, 265, L21
Braine, J. 1995, A&Ap, 300, 20
Bunker, A., Warren, S., Hewett, P. & Clements, D. 1995, MNRAS, 273, 513
Calzetti, D. & Kinney, A. 1992, ApJ, 399, L39
Calzetti, D., Kinney, A. & Storchi-Bergmann, T. 1995, ApJ, in press
Chambers, K., Miley, G. & van Breugel, W. 1990, ApJ, 363, 21
Charlot, S. & Fall, S.M. 1993, ApJ, 415, 580
Chini, R., & Krügel, E. 1994, A&Ap, 288, L33
Chokshi, A. & Turner, E. 1992, MNRAS, 259, 421
De Propris, R., Pritchet, C., Hartwick, F.D.A., & Hickson, P. 1993, AJ, 105, 1243
DeRobertis, M. & McCall, M. 1995, AJ, 109, 1947
Djorgovski, S., Spinrad, H., McCarthy, P., & Strauss, M. 1985, ApJ, 299, L1
Djorgovski, S., Strauss, M., Perley, R., Spinrad, H., & McCarthy, P. 1987, AJ, 93, 1318
Djorgovski, S. 1992, in: Cosmology and Large-Scale Structure in the Universe, ed. R. de Carvalho, ASPCS vol. 24, 73
Djorgovski, S. & Thompson, D. 1992, in: IAU Symp. #149, The Stellar Populations of Galaxies, eds. B. Barbuy & A. Renzini, Dordrecht: Kluwer, p. 337
Djorgovski, S., Thompson, D. & Smith, J.D. 1993, in: First Light in the Universe, eds. B. Rocca-Volmerange *et al.* , Gif sur Yvette: Editions Frontières, p. 67
Djorgovski, S. 1994, in: Mass-Transfer Induced Activity in Galaxies, ed. I. Shlosman, Cambridge: CUP, p. 452
Djorgovski, S., *et al.* 1995, ApJ, 438, L13
Efstathiou, G. & Rees, M. 1988, MNRAS, 230, 5P
Eisenhardt, P. & Dickinson, M. 1992, ApJ, 399, L47
Franceschini, A., Mazzei, P., De Zotti, G. & Danese, L. 1994, ApJ, 427, 140
Francis, P., *et al.* 1996, preprint
Giavalisco, M., Macchetto, F., & Sparks, W. 1994, A&Ap, 288, 103
Graham, J. & Liu, M. 1995, ApJ, 449, L29
Guhathakurta, P., Tyson, J.A. & Majewski, S. 1990, ApJ, 357, L9
Haehnelt, M. & Rees, M. 1993, MNRAS, 263, 168
Hamann, F. & Ferland, G. 1993, ApJ, 418, 11
Hartquist, T., *et al.* 1995, ApJ, 453, 77
Hauser, M. 1995, in: IAU Symp. #168, Examining the Big Bang and Diffuse Background Radiations, ed. M. Kafatos, Dordrecht: Kluwer, in press
Heckman, T., Lehnert, M., van Breugel, W., & Miley, G. 1991a, ApJ, 370, 78
Heckman, T., Lehnert, M., Miley, G., & van Breugel, W. 1991b, ApJ, 381, 373
Hu, E., Songaila, A., Cowie, L., & Stockton, A. 1991, ApJ, 368, 28
Hu, E., Songaila, A., Cowie, L., & Hodapp, K. 1993, ApJ, 419, L13
Ikeuchi, S. & Norman, C. 1991, ApJ, 375, 479
Ivison, R. 1995, MNRAS, 275, L33
Kaiser, N. 1984, ApJ, 284, L9
Kennicutt, R. 1983, ApJ, 272, 54
Kormendy, J. & Richstone, D. 1995, ARAA, 33, 581
Lacy, M., *et al.* 1994, MNRAS, 271, 504
Lilly, S. 1988, ApJ, 333, 161
Lowenthal, J., *et al.* 1991, ApJ, 377, L73
Macchetto, F., Lipari, S., Giavalisco, M., Turnshek, D. & Sparks, W. 1993, ApJ, 404, 511
Malkan, M., Teplitz, H. & McLean, I. 1995, ApJ, 448, L5
Mannucci, P. & Beckwith, S. 1995, ApJ, 442, 569
Matteucci, F,. and Padovani, P. 1993, ApJ, 419 485
McCarthy, P., *et al.* 1987, ApJ, 319, L39
McCarthy, P. 1993, ARAA, 31, 639

McMahon, R., *et al.* 1994, MNRAS, 267, L9
Meier, D. 1976, ApJ, 203, L103
Moller, P., & Warren, S. 1993, A&Ap, 270, 43
Norman, C. & Scoville, N. 1988, ApJ, 332, 124
Pahre, M.A. & Djorgovski, S.G. 1995, ApJ, 449, L1
Parkes, I., Collins, C. & Joseph, R. 1994, MNRAS, 266, 983
Peebles, P.J.E. 1989, in: The Epoch of Galaxy Formation, eds. C. Frenk *et al.*, Dordrecht: Kluwer, p. 1
Pritchet, C. 1994, PASP, 106, 1052
Puget, J.-L., Abergel, A., Bernard, J.-P., Boulanger, F., Burton, W., Désert, F.-X. & Hartmann, D. 1995, A&Ap, in press
Rowan-Robinson, M., *et al.* 1991, Nature, 351, 719
Schneider, D., *et al.* 1987, AJ, 94, 12
Silk, J. & Wyse, R. 1993, Phys. Rep., 231, 295
Small, T. & Blandford, R. 1992, MNRAS, 259, 725
Steidel, C., Sargent, W., & Dickinson, M. 1991, AJ, 101, 1187
Steidel, C. & Hamilton, D. 1992, AJ, 104, 941
Steidel, C. & Hamilton, D. 1993, AJ, 105, 2017
Steidel, C. & Dickinson, M. 1995, in: Wide Field Spectroscopy and the Distant Universe, eds. S. Maddox & A. Aragon-Salamanca, London: World Scientific, p. 349
Terlevich, E., Diaz, A., Terlevich, R., & Vargas, M. 1993, MNRAS, 260, 3
Terlevich, R. 1992, in: The Stellar Populations of Galaxies, IAU Symp. #149, eds. B. Barbuy & A. Renzini, Dordrecht: Kluwer, p. 271
Terlevich, R. & Boyle, B.J. 1993, MNRAS, 262, 491
Thompson, D., Djorgovski, S. & Beckwith, S. 1994, AJ, 107, 1
Thompson, D., Djorgovski, S. & Trauger, J. 1995, AJ, 110, 963
Thompson, D. & Djorgovski, S. 1995, AJ, 110, 982
Turner, E. 1991, AJ, 101, 5
Valls-Gabaud, D. 1993, ApJ, 419, L7
Warren, S., *et al.* 1995, MNRAS, in press
White, S., & Frenk, C. 1991, ApJ, 379, 52
Williams, R., & Perry, J. 1994, MNRAS, 269, 538
Wolfe, A., Turnshek, D., Lanzetta, K. & Oke, J.B. 1992, ApJ, 385, 151
Wolfe, A. 1993, ApJ, 402, 411
Wolfe, A. 1993, Ann. N.Y. Acad. Sci., 688, 281

7. Discussion

Windhorst: If the luminous galaxies of today formed by the rapid mergers of $\sim 20 - 50$ smaller subclumps at high z, shouldn't you be looking for different things?

Djorgovski: Such a scenario cannot account for the observed properties of elliptical galaxies and their stellar populations today, viz., their high metallicities and luminosity and phase space densities, the existence of the mass – metallicity relation, metallicity gradients, etc. These properties are easily understood if *most* star formation in ellipticals happened within their own potential wells. Disks and dwarfs are another matter: there you could have a sporadic flicker of star formation and a gradual assembly.