GALAXIES AT INTERMEDIATE REDSHIFTS

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ABSTRACT: Faint object spectroscopy and deep infrared imaging is providing exciting opportunities to understand the astrophysical nature of normal galaxies up to $\simeq$8-10 Gyr ago (H_o=50). Deep photometry of 10 distant clusters with 0.5< z <1 shows a systematic bluing of *red members* with look-back time, in good agreement with the view that the bulk of the early type population must be genuinely old (z_f >2) and remarkably homogeneous. Statistically complete redshift surveys of the highly abundant population of faint blue field galaxies, however, indicate sizeable changes must have occurred in the galaxy luminosity functions as recently as z$\simeq$0.5. Possible explanations include widespread merging of star-forming sub-units of present day galaxies, or an entirely new population of sources whose present-day remnants are intrinsically faint. The contrast between the long term evolution of the spheroidal population and that seen in the faint counts is striking. I finally discuss some new opportunities to identifying field galaxies with z>1 using gravitational lensing and QSO absorber identifications.

1. INTRODUCTION

My aim is to bridge the gap between the detailed studies of local stellar populations presented elsewhere in this symposium and the truly high redshift objects (QSOs and radio galaxies) whose present-day counterparts remain uncertain. We wish to use redshifted sources to deduce the evolutionary properties of *normal* galaxies studied locally. Since such galaxies cannot be readily identified beyond redshifts $z \simeq$1 with 4-m class telescopes, I will define the 'intermediate redshift' range to be 0.1< z <1.

In examining the evolutionary properties of moderate z galaxies, we must recognise the severe limitations of the unresolved data compared to the detailed studies of nearby stellar systems. We need to ask simpler questions and aim for *statistical* conclusions. We must also realise that our selection procedures may play a critical role in determining the visibility of various kinds of sources. It is all too easy to compare a faint dataset with a bright counterpart and falsely attach differences that are purely induced by selection to some evolutionary process. Furthermore, whilst there is a temptation to construct detailed theoretical models of the data based on preconceived ideas of how local galaxies might have evolved (e.g. as self-contained systems parameterised by mass functions, star formation histories and luminosity functions), it is hardly surprising, given the uncertainties, that self-consistent solutions usually emerge. There have been enough surprises in recent faint galaxy data to warn us against such a detailed approach. At this stage, it is preferable to adopt an empirical analysis of the data with the minimum number of parameters.

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I will focus on two topics which serve to highlight very contrasting views of the star formation history of normal galaxies. Firstly, local and distant *cluster* data reveal a remarkable homogeneity and synchronised evolution for luminous early-type galaxies. To first order, ellipticals galaxies appear to be passively evolving old systems. In the low density *field* however, a plethora of faint blue galaxies are found whose redshifts are surprisingly local, indicating changes in the galaxy luminosity function on much shorter timescales.

2. STAR FORMATION HISTORY OF LOCAL ELLIPTICALS

We begin with a simple question: did luminous elliptical galaxies form the bulk of their stars in a single burst at a well-defined epoch (i.e. coeval origin) and, if so, when was this epoch of principal star formation?

As a local benchmark, consider the colours of ellipticals in the contrasting environments of the Coma and Virgo clusters. Earlier studies of the homogeneity of the colour-luminosity (c-L) relation gave conflicting results. Sandage & Visvanathan (1977) claimed their universal $u-V$ relations demonstrated a simple evolutionary picture for early-types with little environmental dependance. On the other hand, Aaronson *et al* (1981) found the relative distance modulus of Coma and Virgo as determined from the $u-V$ c-L relation differed significantly from that using $V-K$. The implication was that Virgo ellipticals are redder in $V-K$ by as much as 1.0±0.3 magnitudes. Aaronson *et al* suggested that an asymptotic giant branch contribution in Virgo arising from recent star formation might account for the result.

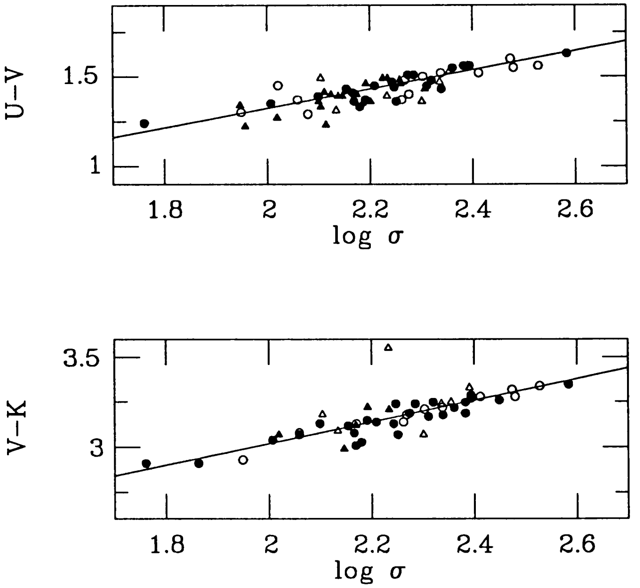

Figure 1: $U-V$ and $V-K$ vs velocity dispersion σ, for early-type galaxies in the Virgo (open symbols) and Coma (filled symbols) clusters from the survey of Bower, Lucey & Ellis (1991). Ellipticals are denoted by circles, S0s by triangles. The solid line is the best fit relation for the combined dataset.

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We have recently completed a precision photometric survey of those 21 Virgo E/S0s and 50 Coma E/S0s with reliable velocity dispersions (σ) to re-examine this question (Bower, Lucey and Ellis 1991). By using colour - σ relations we can work independently of distance. The $U-V$ and $V-K$ vs σ relations are reproduced in Figure 1 for the ellipticals and S0s; colours refer to a $5h^{-1}$ kpc aperture and have been corrected for redshift and reddening effects. Adopting a common slope for each colour-σ relation, no significant colour offset is found between Virgo and Coma ($< 0.^m01$). Bower, Lucey & Ellis claim Aaronson *et al*'s result probably arose from their use of inhomogeneous photometry together with a systematic error in the K photometry of their faintest Coma galaxies.

More interestingly, however, is the remarkably small rms scatter found about these relations for the ellipticals. In Coma, the scatter, $\delta_{(U-V)}$=$0.^m035$, is consistent with observational error. Since the bulk of the U light arises from main sequence stars (c.f Buzzoni 1989), the homogeneity in colour can be converted into physical constraints on the age of single burst ellipticals in different environments. The time evolution of $U-V$ is given straightforwardly for any mass function from the main sequence lifetimes. Adopting a scatter of $0.^m04$, we can write:

$$\frac{\partial(U-V)}{\partial t} \leq \frac{0.^m04}{\beta(t_H - t_f)}$$

where t_H is the Hubble time, t_F is the look-back time to the initial burst, and β is a 'synchronicity' parameter. β=1 would correspond to no coordination of galaxy formation within the time interval $t_H - t_F$, β <1 to coordinated formation. If there is no coordination between forming galaxies ($\beta \simeq 1$), ages of >13 Gyr are derived. Even if β=0.3, ages exceed 10 Gyr. Ages of less than 6-7 Gyr are only possible if $\beta \simeq 0.1$, i.e. remarkably synchronous formation. These conclusions are not sensitive to the adopted slope of the initial mass function. Whilst the age *scales* are metallicity-dependent, ellipticals appear to be a homogeneous population across different environments, and whose main star formation probably occurred before $z \simeq 2$.

3. EVOLUTION IN DISTANT CLUSTER GALAXIES

Do we see the systematic colour evolution expected if the local ellipticals were produced by single bursts prior to $z \simeq 2$? By z=0.7, we are probing look-back times of $\simeq 4h^{-1}$ Gyr where significant changes might be detected. Clusters of galaxies beyond z=0.5 have been compiled by Gunn *et al* (1986) and Couch *et al* (1991), and Aragón-Salamanca and I have recently completed an optical and infrared photometric survey of 10 such clusters whose results can be compared directly with those of Figure 1 (for a preliminary discussion see Aragón-Salamanca 1991).

Galaxies in each cluster were selected from deep K images since calculations (Aragón-Salamanca 1991) show that optical selection beyond $z \simeq 0.5$ would lead to an artificially-increased proportion of blue galaxies. At z=0.75, for example, the R band samples rest-frame U, which is sensitive to young hot stars (§2) whereas K samples rest wavelengths above 1μm. Figure 2 shows the most distant cluster in the sample. To a strict K magnitude limit, $V-K$ and $I-K$ aperture colours are determined for typically $\simeq$20 galaxies per cluster of which $\simeq$16 are expected to be members. Field contamination becomes more serious for the more distant clusters and for bluer colours, but to the precision required, it is sufficient to subtract appropriate K-limited field colour distributions from Cowie *et al* (1991)'s VIK deep survey.

The clusters group naturally in 3 narrow redshift intervals at $\overline{z_i}$=0.56, 0.70 and 0.86. Accordingly, we reduce the individual galaxy colours to those appropriate at a fixed luminosity (i.e. corrected for the c-L slope) and make minor corrections to bring the cluster to the closest of the 3 mean redshifts. The present-day 'no-evolution' prediction at that $\overline{z_i}$ is made by interpolating between appropriate rest-frame colours in local Virgo+Coma+field datasets.

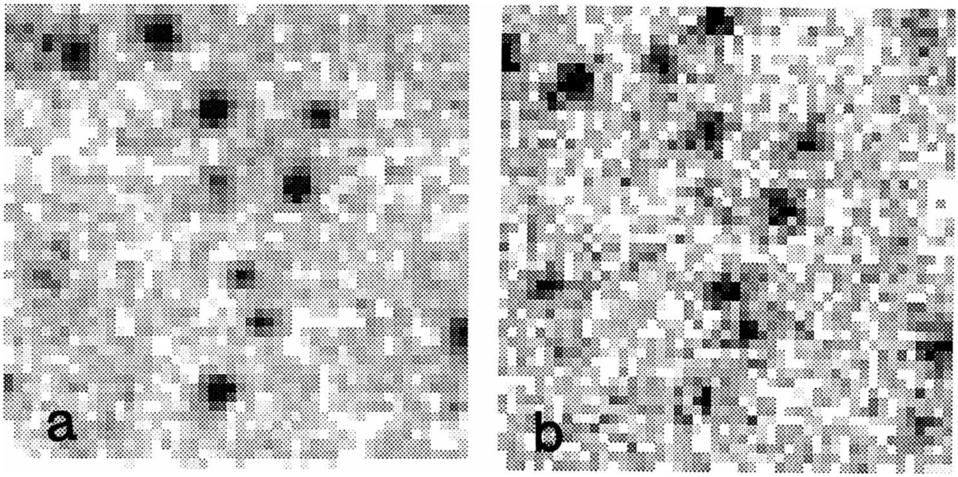

Figure 2: (a) K image of the distant cluster 1603+4329, z=0.92 secured with the IRCAM InSb array on the 3.8m UK Infrared Telescope, (b) corresponding I image using a EEV CCD on the 2.5m Isaac Newton telescope.

The $V-K$ colour distributions, before and after field subtraction, are shown for the 3 $\overline{z_i}$ samples in Figure 3; $V-K$=0 is defined to be the present-day expectation at that redshift. Not only does the mean colour move systematically blueward with redshift, but there is a complete absence of galaxies with present day colours beyond z$\simeq$0.7, i.e. we see clear evolution of the ridge-line in the c-L diagram. This observations is distinct from an increasing fraction of blue galaxies discovered in lower z clusters by Butcher & Oemler (1978). Unlike the B-O effect, imprecise field subtraction *cannot* explain the paucity of red cluster members.

A similar evolutionary phenomenon was reported by Dressler & Gunn (1990) for a similar sample using the spectroscopic discontinuity at 4000 Å , D_{4000}. Their sample is optically-selected, however, and therefore less reliable for quantitative work because of the 'UV bias' discussed above. However, it is satisfying to note an excellent one-to-one correlation between our $V-I$ colours and Dressler & Gunn's D_{4000} where common data has been compared.

The colour evolution expected by z$\simeq$1 in the single burst case (e.g. Bruzual's (1983) *c*-models with a burst of 1 Gyr) depends on the epoch of the burst, z_F, and the cosmological parameters, H_o and q_o. For H_o=50 and q_o=0.5, the observed evolution of $\Delta(V-K) \simeq 1.^m4\pm0.2$ by z$\simeq$0.9 suggests a high $z_F \geq$5-10, although formally $z_F \simeq$2 is allowed if q_o is small. Of course, if the star formation era is more extended than 1 Gyr, z_F must generally be pushed higher to maintain the same evolutionary trend. The available data on elliptical galaxies at $z \simeq 0$ and to $z \simeq 1$ are *both* consistent with the simple picture of a single burst of star formation at $z > 2$ and the subsequent passive evolution of that stellar population.

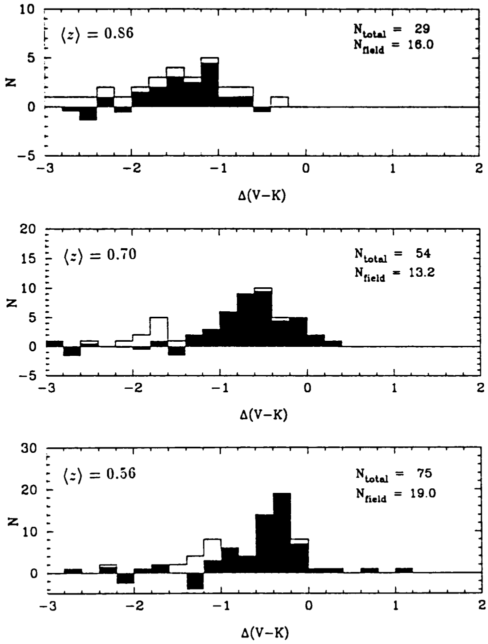

Figure 3: $V - K$ distributions for distant cluster galaxies, with $\Delta(V - K)=0$ defined for a non-evolving present day elliptical. Each panel shows the colour distribution for 2 or more clusters reduced to the indicated common redshift. Shading shows the effect of subtracting appropriately-scaled field data from Cowie et al (1991).

4. RECENT STAR FORMATION IN ELLIPTICALS?

The single burst hypothesis for spheroidal populations has been challenged by evidence for recent (<3-5 Gyr) star formation in certain ellipticals and bulge populations (e.g. O'Connell 1980, Pickles 1985). For example, Bruzual (1984) showed that whilst a 12 Gyr c-model evolutionary model reproduces the observed spectral energy distribution (SED) for $\lambda \geq 3200$ Å , there is flux shortfall at shorter wavelengths. The 'extra' component could be due to recent star formation or a missing evolved component in the models; the dilemma has been reviewed by Burstein *et al* (1988), Greggio & Renzini (1990). Longward of 2000 Å the mean SED is fairly well-determined amongst ellipticals, so any recent star formation would be a fairly widespread phenomenon. A 12 Gyr μ=0.8 declining star formation model fits the data but would indicate a greater amount of colour evolution by $z \simeq 1$ than observed.

On the other hand, Rose (1985) and Bower *et al* (1990) have demonstrated how diagnostic Sr II, Fe I and Hδ absorption lines can determine the mean surface gravity of a stellar population *independently of metallicity and reddening.* By studying representative ellipticals in various environments (rich clusters, groups and isolated fields), they find ellipticals in low density environments contain a stellar component $\simeq$ 6-7 Gyr younger than those found in the rich cluster counterparts. The separation of Virgo and Coma ellipticals on Rose's Sr/Fe/Hδ plane (Figure 4) demonstrates this but is in marked conflict with the identical integrated $U - V$ galaxy colours discussed earlier. It may be that the intermediate age component is strictly confined to the cores of the ellipticals where the spectral signal is sampled, i.e. a strong age gradient exists. Alternatively there could a metallicity difference between the two samples which compensates for the age difference in the integrated colours. Neither explanation is particularly convincing, however.

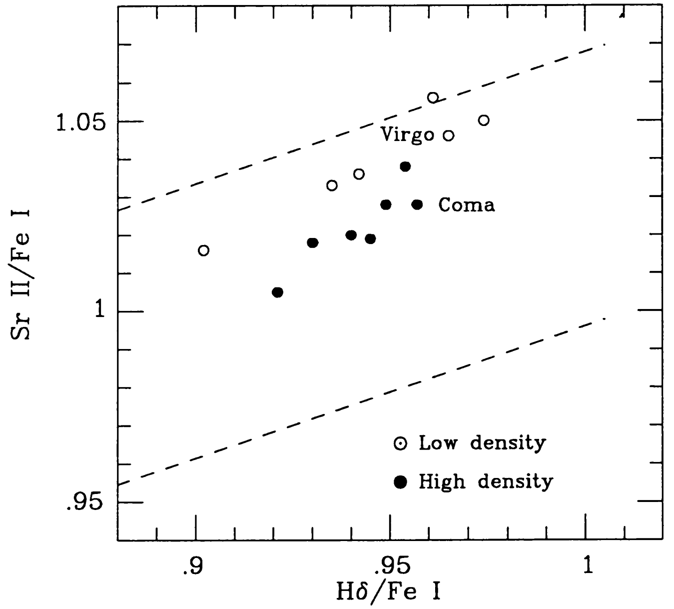

Figure 4: Sr II-Fe I-Hδ plane for ellipticals in various environments using preliminary data from Rose et al (1991) strengthening the environmental dependence of recent star formation claimed by Bower et al (1990). Dashed lines indicate the sequence for dwarf (upper) and giant (lower) Galactic stars.

Further evidence for recent activity in cluster galaxies includes the many manifestations of the Butcher-Oemler effect reviewed by Dressler (1984) and MacLaren *et al* (1988). There are blue members undergoing a short-term burst of star formation (Dressler & Gunn 1983); red members revealing an excess of UV flux (Ellis *et al* 1986) or post-starburst spectral features (Couch & Sharples 1988), and possibly red galaxies with an infrared excess attributable to an AGB population (Aragón-Salamanca *et al* 1991). Modest bursts of star formation draw our attention to what appear to be dramatic evolutionary differences at z≃0.2–0.5. A secondary burst at z≃0.3, whose strength is ≃10% of that at z_F, would explain the moderate z cluster data without destroying the small $U-V$ scatter seen in local systems (Figure 1). Thus, these phenomena, whilst important in their own right, should not deter from understanding the overall trends defined by the high z cluster data. Additionally, in the local data, continuing star formation appears to be confined to galaxies in the lower density systems.

5. EVOLUTION IN FIELD GALAXIES

The gradual evolution witnessed for the spheroidal population in clusters contrasts with events occurring in the field at surprisingly recent times. Many reviews (e.g. Ellis 1990) have addressed the significant excess population of faint galaxies whose mean colour becomes bluer with increasing apparent magnitude. At $b_J \simeq 24$, the observed surface density of galaxies in randomly-chosen fields exceeds the 'no evolution' prediction (based on local luminosity functions) by a factor $\simeq 6$ and the median colour of $b_J - R \simeq 0.6$ (Tyson 1988) corresponds to that of the bluest Sm/Irr galaxies observed today (irrespective of redshift since the optical SED is flat). The predominantly blue faint sky undoubtedly indicates much star formation and perhaps a significant contribution to the present-day metallicity (Cowie 1988).

Whilst it is difficult to constrain the redshifts of the faint blue galaxies from photometry, the absence of any U band drop-out for the faintest detected in b_J and R suggests virtually all have z<3 if the Lyman limit is as strong as seen in the QSO population (Guhathakurta *et al* 1991). Regardless of any evolution, the sheer number of faint galaxies within such a volume then presents a challenge to the inflationary ($\Omega=1$, $\Lambda=0$) cosmological model if numbers are conserved (Yoshii & Takahara 1988). Resolving the faint galaxy problem is thus an outstanding question of modern cosmology.

Great strides in this area have been made in the last 5 years via multiple object spectroscopy on 4-m telescopes. Statistically-complete redshift surveys have been published by Broadhurst *et al* (1988, $20< b_J <21.5$), Colless *et al* (1990, $21< b_J <22.5$) on the AAT and deeper surveys are in press to $b_J=24$ (Colless *et al* 1991, Cowie *et al* 1991). Figure 5 shows the available redshift-magnitude data from these surveys. I have also included an unpublished intermediate depth ($17< b_J <20.5$) survey by Broadhurst & Ellis which aids greatly in delineating the general trend.

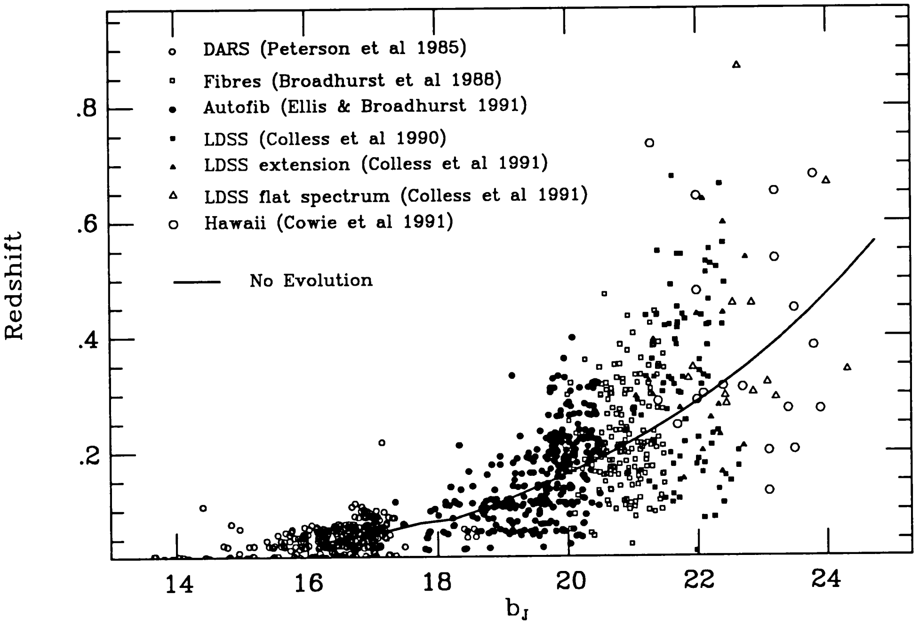

Figure 5: Redshift vs. b_J magnitude for recently completed faint galaxy surveys (see legend for details). The solid line represents the mean redshift at each b_J magnitude in the no evolution case; this evidently fits the data rather well despite the excess number seen in the counts beyond $b_J \simeq 21$.

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Broadhurst *et al* (1988) demonstrated that the faint excess cannot reasonably arise from an underestimated faint end slope of the galaxy luminosity function since the mean redshift, $\overline{z}$, of their survey to b_J =21.5 is too high. Likewise Colless *et al* (1990) eliminated a high z tail in their distribution to b_J=22.5 as a possible source of the extra blue galaxies. Recently, Colless *et al* (1991) reduced the incompleteness of a portion of their earlier survey via additional observations (included in Fig. 5) from 19% to 7% with no change to their $N(z)$ distribution despite extending their [O II] spectral sensitivity to z=1. Although 7% of the b_J <22.5 population could still strictly lie beyond z$\simeq$1, $N(z)$ would now have to be bimodal. For the monotonic $N(z)$ decline expected in most models, the likely evolution in the bright end of the luminosity function since z$\simeq$1 cannot be significant. The Hawaii survey (Cowie *et al* 1991, 22.5< b_J <24) contains 13 redshifts deeper than Colless *et al*'s (1990) sample but $\overline{z}$ is barely increased providing valuable confirmation of the trend established in the AAT surveys (see Fig. 5).

The most significant new result, perhaps, is provided by Colless *et al*'s (1991) survey of objects with 22< R <23 whose $b_J - R$ and $R - I$ colours indicate the source to be very blue or *flat-spectrum* (f_ν ~const.). Tyson (1988) and Cowie & Lilly (1990) argued that beyond b_J $\simeq$23-24, a dominant population of much bluer objects are found that may differ from the z$\simeq$0.3 sources identified in brighter surveys. Of 8 flat spectrum sources surveyed with LDSS at the AAT, 7 redshifts yield $\overline{z}$ =0.43. Continuity of redshift and colour trends with b_J is a very important feature. Broadhurst, Ellis & Glazebrook (1991) demonstrate, by measuring [O II] equivalent widths for most of the sample plotted in Figure 5, that the *slope*, $\gamma = d \log N / dm$, of the galaxy counts is distinctly steeper for the strong star forming population over 17< b_J <22.5, than for the quiescent population which matches the no-evolution prediction. This demonstrates rather convincingly that it is these star forming galaxies, examples of which occur at apparent magnitudes at bright as b_J $\simeq$20-21, that provide the count excess.

6. PUZZLES AND POSSIBLE SOLUTIONS

The field surveys provide three puzzles. Firstly, increased star formation in any subset of the current luminosity function (LF) should imply a greater average luminosity for those objects (even if temporary) and hence an increased depth in any magnitude-limited survey. Yet the redshift distribution is similar to the no-evolution prediction. In short, there is an apparent increase in the comoving volume density of luminous galaxies with redshift.

Secondly, whilst the integrated number of faint galaxies cannot be reconciled with the present day space density and the volume bound by z <3 for the inflationary Ω=1, Cowie's (1991) K counts present no such dilemma and indicate no large excess over no evolution to K=22.

Finally, the absence of *any* high z luminous precursors to normal L* galaxies will soon become an embarrassment. The apparent magnitude at which one expects to see beyond z$\simeq$1 depends on the evolutionary model. For example, Tinsley's (1977) pioneering work predicted primaeval galaxies at z_F $\simeq$2 undergoing strong initial bursts would appear at B$\simeq$20. Likewise, Koo's (1990) mild evolutionary models predicts some z>1 flat-spectrum objects would be seen with b_J $\simeq$23. The absence of *any* high z objects other than QSOs and radio galaxies to b_J=24 is beginning to place a strong constraint on the likelihood of any luminous phase for normal sources unless this occurred at very high redshift.

Two explanations have been offered for the above paradoxes (earlier suggestions of a $\Lambda \neq 0$ cosmology are now inconsistent with the K counts). Broadhurst, Ellis & Glazebrook (1991) consider the faint blue galaxies to be precursors of the normal population and suggest they represent a gas-rich merging population whose star formation rate (SFR) declines with time. Looking back, a typical galaxy breaks into fragments whose optical luminosity is governed by the increasing SFR, but whose K luminosity declines in proportion to the decreasing mass. They show how it is possible to match both the b_J and K counts and the available redshift data in a simple model. Merging has the important effect of maintaining the average blue luminosity despite the smaller mass, and hence the increasing numbers are not accompanied by a high z tail. The model also explains the absence of high redshift L* galaxies in a natural way and predicts that a K-selected sample would yield a redshift distribution whose $\bar{z}$ is *less* than the no evolution value. Self-similar merging is a feature of standard cold dark matter models explaining many present day observations (e.g Frenk *et al* 1990) . Additionally, IRAS has shown merging occurs in low density environments (Soifer *et al* 1986) at a rate that appears to increase with redshift (Saunders *et al* 1990). The main difficulty is in reconciling the abundance of present day spirals with fragile disks which would be affected merging that extends to recent epochs (Ostriker 1990).

Alternatively, Babul & Rees (1991, see also discussion in Cowie 1991, Cowie *et al* 1991) invoke an entirely new population of star forming dwarfs which undergo spectacular star formation at modest $z(\simeq 1)$ but then decay beyond detection (or possibly to dE galaxies) by the present epoch. Detailed predictions are not possible because the new population is not physically constrained before or after its luminous phase. Although an *ad hoc* solution, we can place some constraints on an *additional* population from the counts alone. If the dwarfs are added to an unchanging mass function of normal galaxies, the ×2 excess number over no evolution at $b_J \simeq 22.5$ and the absence of any excess at $K \simeq 20$ enables us to conclude that the average dwarf must have $b_J - K < 2.5$. But the median $b_J - K$ colour at K=20 is ≃5 (Cowie *et al* 1991). Thus it is difficult to reconcile the photometric data with a 2-component population. The merger model provides an elegant solution to this remarkably simple problem. Instead of *adding* sources to the no evolution prediction, merging and star formation are in effect *transforming* the counts. In K there is a very rapid redistribution to fainter magnitudes since the luminosity fades more quickly with redshift: the excess seen in b_J only appears at K magnitudes well beyond the current counting limits.

The two hypotheses are radically different in their implications. The star forming mergers picture implies the optically faint sky is telling us about remarkably recent dynamical evolution of galaxies like our own. The dwarf picture would, however, make it much harder to determine the history of L* galaxies since the faint optical sky rapidly becomes confused by local events. Regardless of which is correct, however, it is clear there must have been significant changes in the field galaxy luminosity function since z≃1.

7. OTHER PROBES OF HIGH REDSHIFT GALAXIES

In view of the above, it is important to consider alternative ways of finding high redshift field galaxies. If the merger picture is correct, one expects a paucity of luminous galaxies, especially at infrared wavelengths. Two methods appear promising: studies of gravitationally-lensed arcs and QSO absorption lines.

Soucail *et al* (1988) demonstrated beautifully how the giant arc in Abell 370 (z=0.37) is the single gravitationally-lensed image of a background z=0.72 galaxy. Since an arc image is produced only because a field galaxy happens to lie behind an unrelated foreground cluster, one might take such arcs as a serendipitous field sample. With the Toulouse group, Aragón-Salamanca, Smail & I have determined $B-R$ and $R-K$ colours for the sample of known arcs with spectroscopic data. Those with $z_{arc} < 1$ appear to be normal spirals, whereas those with $z_{arc} > 1$ are extraordinarily blue. The drawback of the lensing picture is that it tells us little about the *luminosity* of the source. Additionally, surface brightness dimming could play nasty tricks. At large z we might be restricted to examining high surface brightness *portions* of galaxies which would reflect an untypically high SFR: such blue colours might not that surprising.

More promising perhaps is the examination of matter at high redshift via its absorbing effect on distant QSOs. Bergeron & Boissé (1991) claim that the bulk of z_{abs} <1 Mg II systems are luminous galaxies with strong star formation. With Bergeron, we are searching for CIV absorbers with 1.2< z_{abs} <2 via deep *RIK* imaging, paying particular attention to absorbing systems *clustered* in redshift in order to maximise detections. An L* galaxy at z$\simeq$1.5 has K$\simeq$19-20 regardless of type and should be readily visible in a modest integration on UKIRT. Preliminary results indicate that those candidate objects lying close to the QSO are *fainter* than L^* in K even at the absorber redshift (and thus considerably fainter if foreground). Many of these candidates have colours typical of flat-spectrum galaxies. The preliminary results agree well with the star-forming mergers hypothesis.

8. CONCLUSIONS

There are no convincing conclusions. Our view of the intermediate redshift Universe is in turmoil. On the one hand, cluster galaxies are evolving passively on timescales of 5-10 Gyr as predicted by the most simple evolutionary models we can imagine. On the other hand, the field galaxy luminosity function has been transformed dramnatically in the past 3-5 Gyr. A consistent picture must weave together the old spheroidal population with a remarkably recent era of disk and metal formation. The past few years has demonstrated well how difficult observations acquired with large telescopes and good instrumentation have defined the problems and how theory has squirmed to accommodate the results. To me this seems an ideal state of affairs.

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DISCUSSION:

O'CONNELL: The idea that secondary star formation in ellipticals depends on the environment, and is therefore likely to be more common in the Local Group and Virgo than in dense clusters, makes good sense. Most of the evidence for late star formation is also confined to the *centers* of nearby galaxies, as pointed out by Sandy Faber earlier, so there is not necessarily any inconsistency with the homogeneity of large aperture colors which you find.

ELLIS: Agreed.

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ELSTON: Since your faint galaxies are resolved, what are their morphologies and surface brightnesses? Surface brightness would increase by 2-3 magnitudes from evolutionary considerations, but fade by $(1+z)^4$. What would a present-day blue galaxy look like?
ELLIS: Good resolution (0.8 arcsec FWHM) NTT imagery of the [O II]-strong galaxies at z$\simeq$0.3 failed to reveal any obvious pecularities in terms of surface brightness or morpholgy. The typical star-forming galaxies are neither compact objects nor low surface brightness fuzzballs and do not show a strong excess of closeby companions, although the sample surveyed so far is small. The blue light appears to be shared by the bulk of the galaxy rather than, say, being confined to the nuclear region. However, better resolution data is needed to make progress. These objects are not faint and 0.3-0.4 arcsec FWHM would be sufficient to say a lot more.
SILK: The faint blue galaxies seen in the very deep counts are dwarfs, hence their relics, if they represent a new population that subsequently faded, would be metal poor and blue, rather than red and with low surface brightness. Also, if the triggering of the star formation bursts in galaxies is associated with denser regions, such as groups and clusters, one should search in those regions (rather than in the field) for the low surface brightness relics.
ELLIS: I think you have to be careful what you mean by 'blue'. A low luminosity dwarf elliptical is bluer than a giant elliptical but still much redder than the bulk of the faint population. The K counts eliminate such a red population unless they have very low surface brightnesses. Secondly, if the bursts were more common in groups/clusters, the [O II]-selected galaxies would be distributed differently to the remainder. With $\simeq$1000 faint redshifts in hand, no obvious separation is yet evident.
MELNICK: If the blue population you find in deep redshift surveys consists of dwarf galaxies, you'd expect to find them significantly less clustered than if their absolute magnitudes were $\simeq$ -18 as in your merger hypothesis. Have you looked at the clustering (e.g. $\xi(r)$) of these galaxies?
ELLIS: Spatially, there is no difference (see answer to Silk), but preliminary evidence by other groups to much fainter limits suggests the faint blue galaxies are less strongly clustered, in terms of their angular correlation function $w(\theta)$, than would be expected for normal galaxies at the observed surface density. However, the angular measurements are only currently available on small separations (<1 Mpc) and the comparison is notoriously difficult to make. With large format CCD data becoming available, it will be interesting to see more extensive results.
OSTRIKER: You need a candidate set of objects to be the numerous blue galaxies seen in the counts. Lyman limit systems seen in absorption between us and high redshifts QSOs contain metal lines and presumably star formation. If these numerous objects fade to dwarf spheroidals, could they be your blue systems at an intermediate epoch?
ELLIS: Transforming a blue galaxy close to L*, as required by the redshift surveys, to a M_B=-12 dSph would be a dramatic change, and one would have little time in which to manoevre. I should stress that these blue galaxies are bursting at remarkably recent lookback times, may be directly related to the IRAS phenomenon and thus I prefer to consider them as precursors of normal galaxies rather than to hide them away in uncharted regions of the luminosity function.
BERSHADY: Is the redshift distribution the same for the high and low [O II] equivalent width galaxies?
ELLIS: The distributions do not differ to any great extent. The proportion with strong [O II] increases with *apparent magnitude* but they populate a wide range in redshift and hence luminosity. We are just getting to the point where it will be possible to track the luminosity functions of the burst/non-burst components independently with redshift. If the burst+merger model is correct we would expect a steepening of the faint end slope with redshift at the expense of the non-burst LF.

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RENZINI: You said the Strontium method is independent of the metallicity, but do you think it is also independent of the Strontium abundance?
ELLIS: I don't know. We checked the integrated spectrum of the globular 47 Tuc and M32 and the surface gravities derived by Rose's Strontium method is in good agreement with those implied by the turn offs seen in the resolved colour magnitude diagrams. I'd be surprised if such a clear distinction between rich cluster ellipticals and those in low density environments arises by Strontium variations, but I guess it can't be excluded at this stage.
KURUCZ: If you evolve a large elliptical galaxy backward, there is a point where it becomes transparent because the stars we see as giants are back on the main sequence. At that point, all the dwarf companions of a galaxy are visible, whereas today they are hidden or they cannot be seen because they are overwhelmed by the brightness of the large galaxy.
ELLIS: Interesting idea, but note that when a giant elliptical has all its stars on the main sequence it would become extraordinarily blue and luminous. No such objects are seen (excluding Terlevich's interesting suggestion concerning QSOs) either because this epoch lies at redshifts where the Lyman limit has passed through the optical, or because dust obscures such objects. In both cases, you would never see behind such an object and in any case, you would not resolve companions as independent objects. As I explained to others above, the extra blue objects are not strongly correlated in position with the quiescent population.