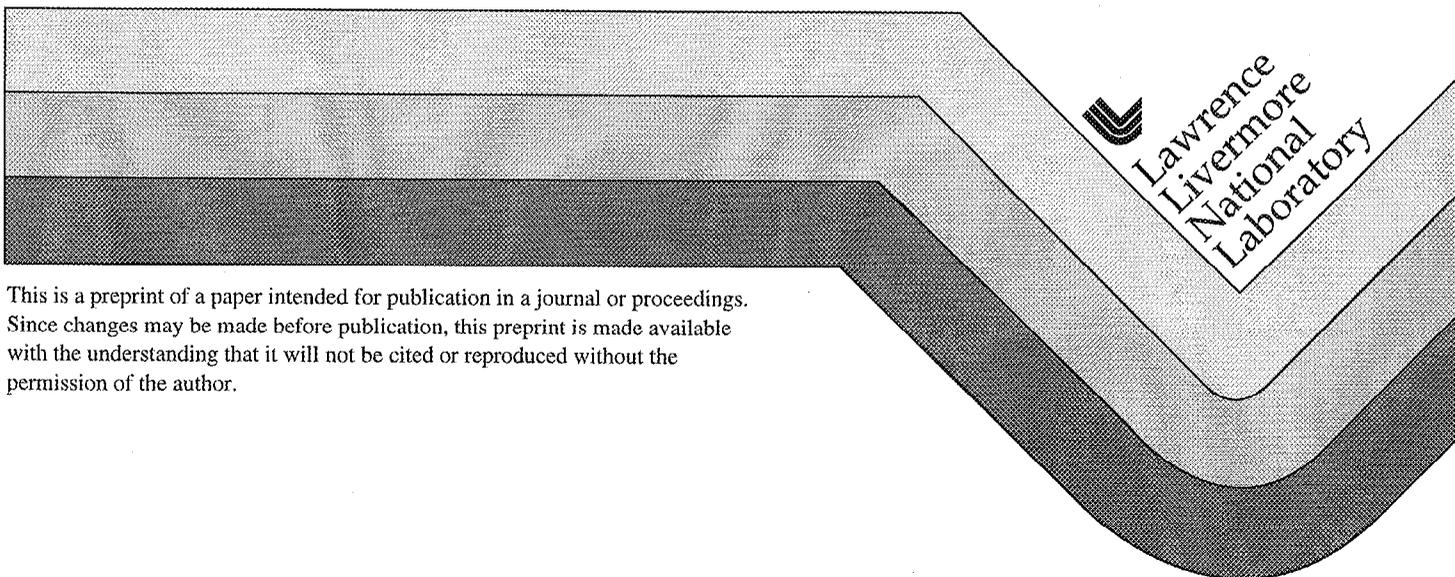


Elliptical Galaxies in High- z Clusters: How old are they?

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Elliptical Galaxies in High- z Clusters: How old are they?

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Abstract

I review recent research on the evolution of elliptical galaxies in high redshift galaxy clusters. Significant progress is being made on many fronts using the powerful tools of e.g. *HST* and 10 m class telescopes. But determining the actual age of composite stellar populations in distant galaxies is still beyond our capabilities.

1 Introduction

Galaxy clusters in the present epoch are dominated by early-type galaxies. Because they can be recognized out to high redshifts, they offer an ideal way to study the evolution of E/S0s over large lookback times. Ellipticals in particular are attractive tools for the cosmologist obsessed with knowing the elusive redshift of galaxy formation because, at least in the present epoch, they are thought to consist of simple stellar populations with a single age. However, it must be kept in mind that the work of Worthey and collaborators [1] suggests that ellipticals may have formed over a relatively long time period.

To keep my review to a tractable size, I will use the following definitions, which will become particularly useful at higher redshifts, where a number of very high- z cluster candidates have been reported. By clusters I mean those massive bound-objects which have associated extended X-ray sources, and in which member galaxies have been spectroscopically-identified. High redshift clusters are those at $z > 0.3$. Finally, elliptical galaxies are those identified as a result of morphological selection, usually using *HST* images.

2 Galaxy Clusters at $z < 1$

Several studies of the colors of E/S0 samples in $z < 1$ clusters have established a widely-held view of their apparent evolution. Ellipticals in clusters become bluer with redshift, relative to present epoch early-types [2], [3]. The measured color changes are consistent with the predictions of a passive-evolution elliptical model constructed from the Bruzual & Charlot GISSEL (solar metallicity case) for $z_f > 3$, $q_0 = 0.1$, $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ [3]. The intrinsic scatter in the optical-IR colors of the E/S0s is small, and roughly constant with redshift. Assuming some coherence in their formation times, this result indicates that the stellar populations of E/S0s formed at $z_f > 3$ [4]. Finally, the slope of the color-magnitude

relation is constant to $z = 0.9$, indicating that the relation is most likely a result of metallicity [5], not age differences.

The existence of the Fundamental Plane in the present-epoch has long been seen as a valuable tool to investigate elliptical galaxy evolution at high redshift. *HST* imaging has been able to provide the r_e, μ_e parameters for some time now, enabling construction of projections of the FP, such as the Kormendy relation, to be made in high redshift clusters [6], [7], [8]. The amount of luminosity evolution inferred from these comparisons of several clusters at redshifts $z = 0.4 - 1.2$ is in agreement with the results on elliptical formation at $z > 3$ obtained from the color analyses discussed above. The advent of 10 m class telescopes has made it possible to obtain the necessary velocity dispersion measurements so as to be able to exploit the full Fundamental Plane. Initial FP work on ellipticals in clusters up to $z = 0.83$ has shown that the M/L ratio slowly decreases with redshift in a manner consistent with a high z formation epoch [9], [10].

One of the key questions which the FP analyses are attempting to answer is how the mass of the ellipticals changes with time. The basic premise of the monolithic collapse model [11] for elliptical formation is that the stellar mass stays constant. In the hierarchical formation scenario the elliptical grows by mergers so that the mass grows by a factor of 2-3 at $z < 2$ [12]. Another way to investigate these competing predictions is to measure the near-IR light of ellipticals, which is a good measure of the stellar mass. Up to $z \sim 1$ the observed K band still samples the rest frame near-IR, so that the construction of K -band luminosity functions for clusters in this redshift range should enable an interesting probe of the mass vs redshift question. While early investigations relying on relatively small cluster samples covering $0.2 < z < 0.5$ indicated that no significant change had occurred in K^* for the early-type galaxies [13], a larger sample of 38 clusters spanning $0.02 < z < 0.9$ shows that the value of K^* determined from fitting Schechter luminosity functions has evolved with redshift as shown in Figure 1. The sense of the evolution is that cluster ellipticals were more luminous in the past, and the amplitude of the change is fairly well fit by a Bruzual & Charlot model of a single burst of star formation lasting 10^8 years beginning at $z = 3$ for [14].

3 Clusters at $z > 1$

To more conclusively test the predictions for the monolithic collapse vs the hierarchical assembly models it is useful to investigate clusters at ever higher redshifts, where the two scenarios entail very different histories for elliptical galaxies. Some targeted searches using various types of AGN have met with success in finding clusters at $z > 1$, notably 3C 324 at $z = 1.20$ [6]. However, these clusters may be unrepresentative of the typical cluster population at such high redshifts—it would be better to assemble a sample of clusters identified from large area field surveys. Though such a project is still very difficult to carry out, some progress has been made along these lines by using a combination of near-IR imaging and Rosat/PSPC data.

First discovered by virtue of a concentration of galaxies with very red $J - K$ colors in a ground-based near-IR field survey, ClG J0848+4453 was subsequently confirmed to be at $z = 1.27$ by Keck/LRIS spectroscopy of its member galaxies [15]. To date 15 galaxies have been identified at the cluster redshift, with an estimated velocity dispersion $\sigma = 700 \text{ km s}^{-1}$. The cluster was found to be coincident with a very faint X-ray source in the Rosat Deep Cluster Survey of Rosati et al. [16], and appears to be spatially extended, though this has yet to be confirmed. The estimated $L_x = 1.5 \times 10^{44} \text{ ergs}^{-1}$ is somewhat less than the L^* value found at low redshifts for galaxy clusters [16].

Recently NICMOS images in the F160W filter were obtained of ClG J0848+4453 to in-

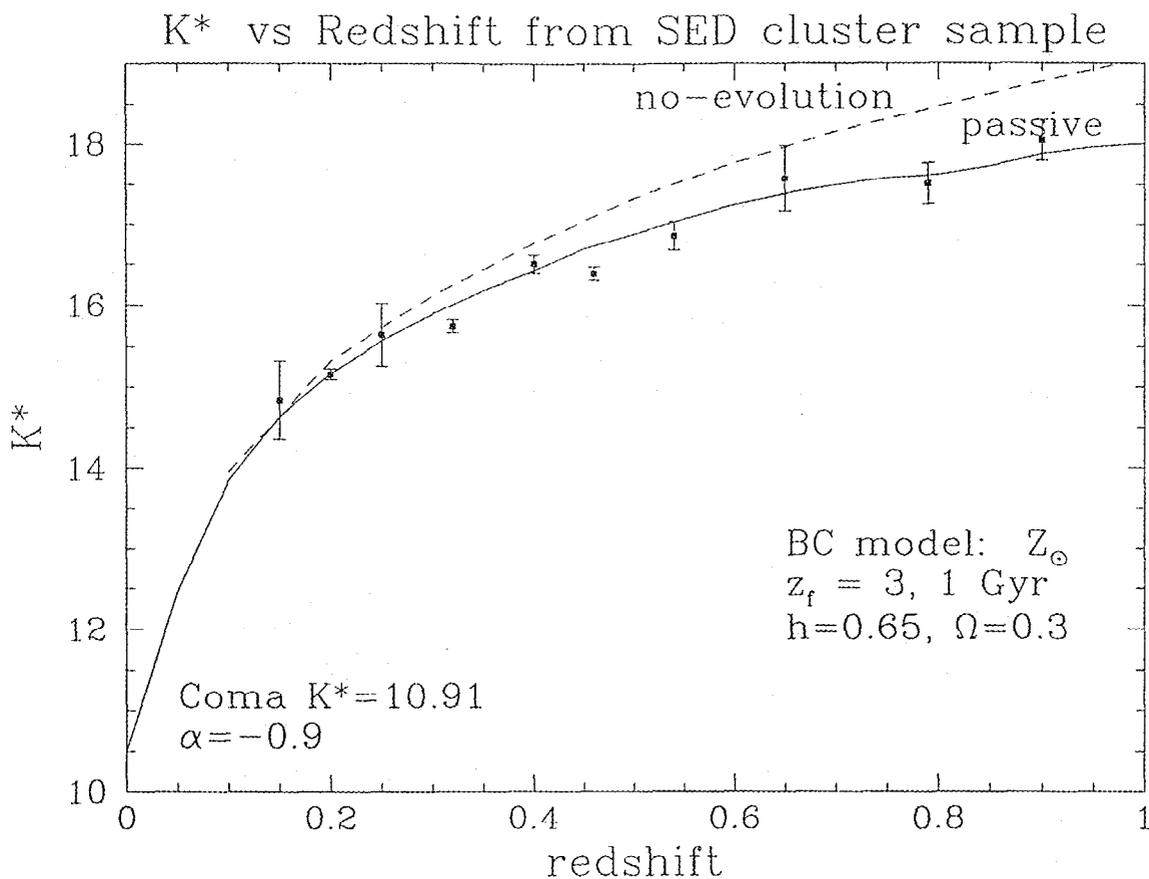


Figure 1: K^* vs redshift from Schechter luminosity functions fitted to background-corrected galaxy counts in moderate-redshift galaxy cluster fields from the sample of Stanford, Eisenhardt, and Dickinson [14]. The dashed line shows the no-evolution value of K^* based on the Coma cluster photometry of Eisenhardt et al. The solid line is the prediction from a passively evolving model constructed from the Bruzual & Charlot GISSSEL. The cluster counts were binned by redshift, after applying small k -corrections to the K -band photometry.

investigate the galaxy morphologies. Figures 2 and 3 show cutout images, along with surface brightness profiles and the LRIS spectra, for two of the member galaxies. These objects illustrate the uncertainty in using either spectroscopy or imaging to ascertain the galaxy type in very distant clusters. Judging only from its spectrum, Object#65 would seem to be a normal elliptical given the large D4000 and lack of emission lines. However, the NIC3/F160W image clearly shows that this galaxy is undergoing a merger.

If we throw caution to the wind and attempt to age date the member galaxies in 0848+4453, perhaps the best way is to use the D4000 value which is measured from our LRIS spectroscopy. These values are shown in Figure 4, where D4000 is plotted against age for several model galaxies constructed from the Bruzual & Charlot GISSSEL. If it is assumed that solar metallicity best describes the luminosity-weighted average for these objects, then the inferred ages for single 0.1 Gyr burst stellar populations range from less than 1 Gyr to ~ 3 Gyr. The redshifts corresponding to the ages for $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega = 0.25$ are shown along the top axis. Dating from the cosmic time at the redshift of the cluster, this pushes the formation redshift for these galaxies back to $1.5 < z < 4.3$.

4 Summary

But the elliptical galaxy age estimates are rather uncertain because of the degeneracy of metallicity with age. Substantially better spectra combined with larger numbers of ellipticals in more complete samples of very high redshift clusters are necessary before it will be possible to obtain more reliable age estimates. It is worth noting that the age estimates discussed above really only tell us about the stars, not when the galaxies "formed" in the way they appear to us today. Relatively old stellar populations could have formed in sub-galactic units which merged much later. The key in this process, which is favored in the CDM scenario for galaxy formation, to dating the formation of ellipticals is if substantial star formation occurs during the merging process. It will be necessary to obtain accurate mass estimations of cluster ellipticals, preferably through their velocity dispersions, in order to better test the predictions of the hierarchical assembly models.

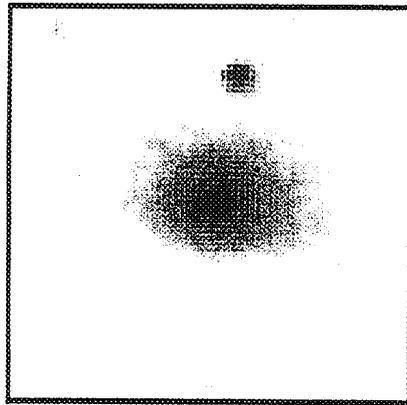
5 Acknowledgements

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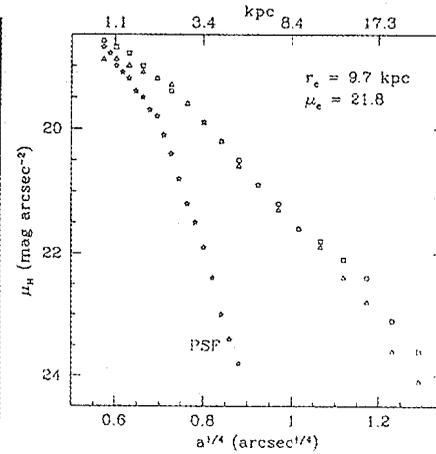
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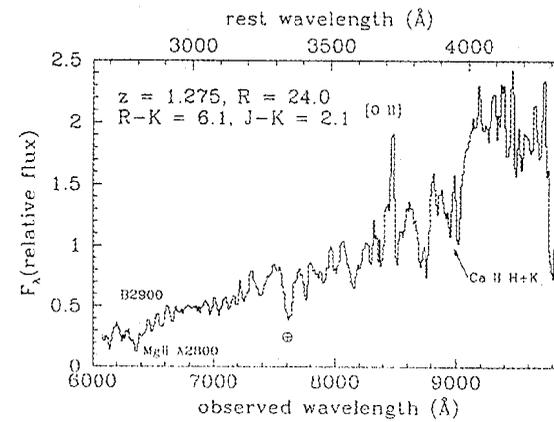
CIG J0848+4453: #70



7'' NIC3 cutout



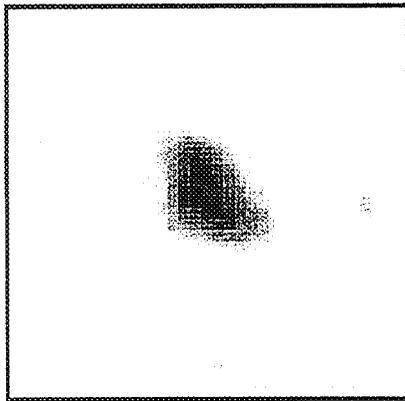
F160W S.B. profile



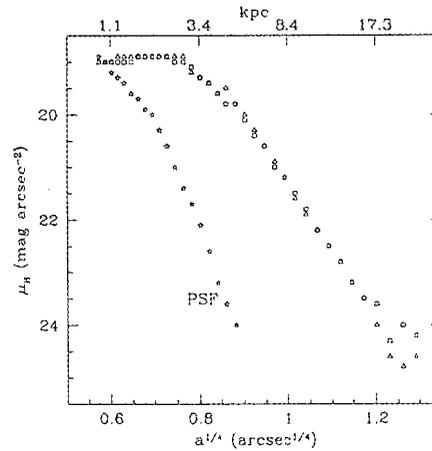
Keck/LRIS spectrum

- $M_V = -23.5$
- $D4000 = 2.0$

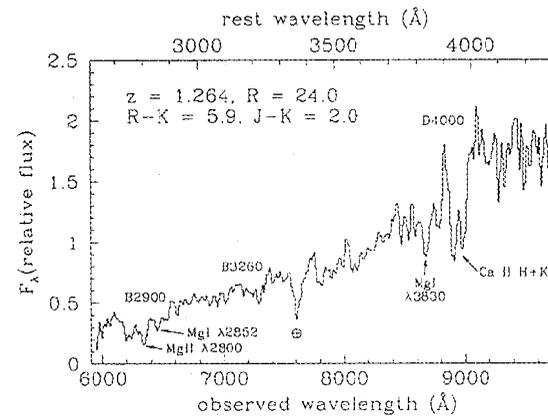
CIG J0848+4453: #65



7'' NIC3 cutout



F160W S.B. profile



Keck/LRIS spectrum

- $M_V = -23.5$
- $D4000 = 1.8$

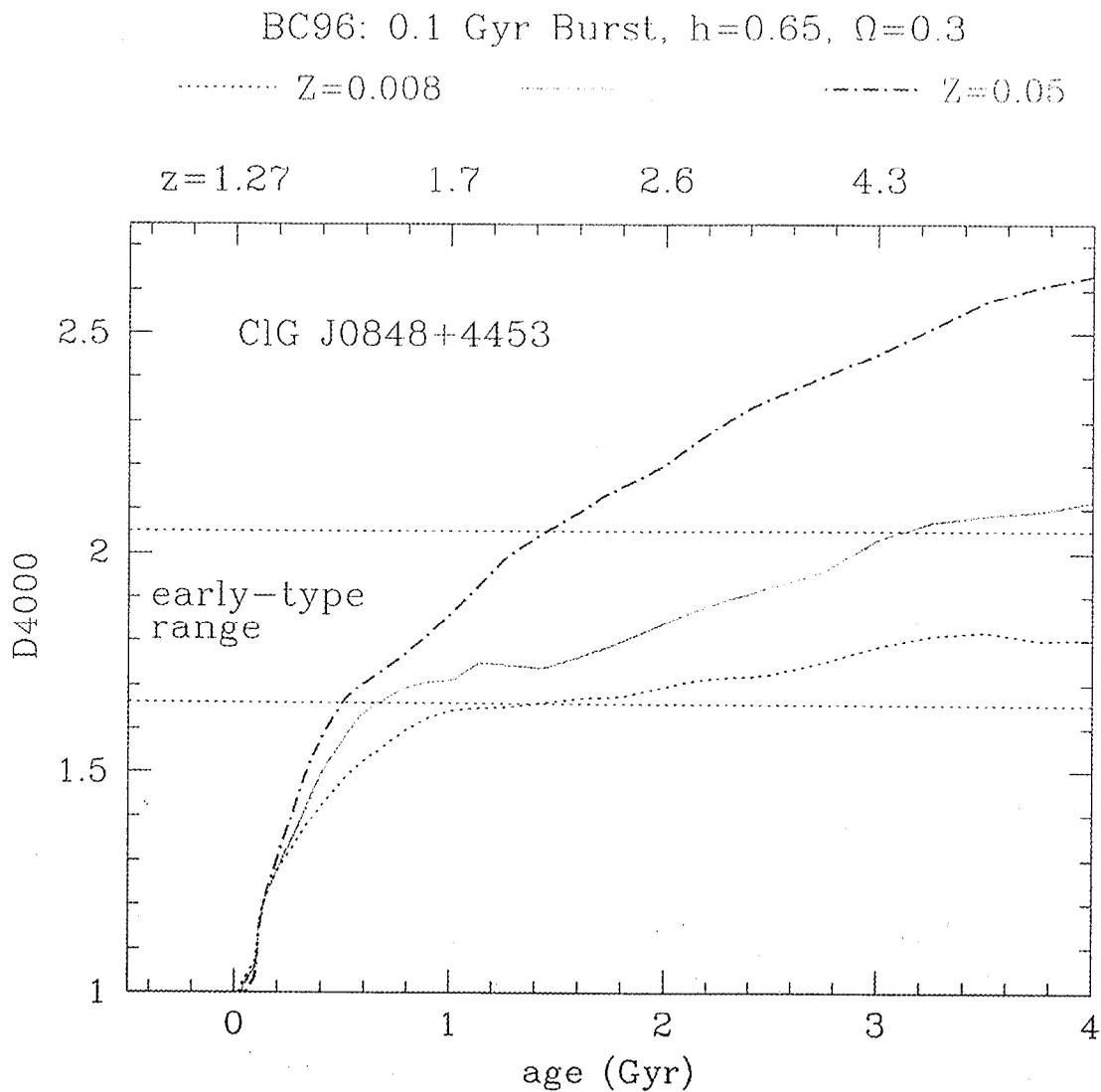


Figure 2: The strength of the 4000Å break vs age of a stellar population for three galaxy models with varying metallicity. The range of measured D4000 for member galaxies in the $z = 1.27$ cluster are shown by the dashed lines.

