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# The ages and metallicities of early-type galaxies in the Fornax cluster

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## ABSTRACT

We have measured central line strengths for a complete sample of early-type galaxies in the Fornax cluster, comprising 11 elliptical and 11 lenticular galaxies, more luminous than $M_B = -17$. In contrast to the elliptical galaxies in the sample studied by González (and recently revisited by Trager) we find that the Fornax ellipticals follow the locus of galaxies of fixed age in Worthey's models and have metallicities varying from roughly solar to three times solar. The lenticular galaxies, however, exhibit a substantial spread to younger luminosity-weighted ages, indicating a more extended star formation history. We present measurements of the more sensitive indices: C4668 and H$\gamma_A$; these confirm and reinforce the conclusions that the elliptical galaxies are coeval and that only the lenticular galaxies show symptoms of late star formation. The inferred difference in the age distribution between lenticular and elliptical galaxies is a robust conclusion as the models generate consistent relative ages using different age and metallicity indicators even though the absolute ages remain uncertain. The young luminosity-weighted ages of the S0s in the Fornax cluster are consistent with the recent discovery that the fraction of S0 galaxies in intermediate-redshift clusters is a factor of 2–3 lower than found locally, and suggest that a fraction of the cluster spiral galaxy population has evolved to quiescence in the 5-Gyr interval from $z = 0.5$ to the present. Two of the faintest lenticular galaxies in our sample have blue continua and strong Balmer-line absorption, suggesting starbursts $\lesssim$2 Gyr ago. These may be the low-redshift analogues of the starburst or post-starburst galaxies seen in clusters at $z = 0.3$, similar to the H$\delta$-strong galaxies in the Coma cluster.

**Key words:** galaxies: abundances – galaxies: clusters: individual: Fornax – galaxies: elliptical and lenticular, cD – galaxies: formation – galaxies: starburst.

## 1 INTRODUCTION

The conventional view that luminous elliptical galaxies are old, coeval and created about 15 Gyr ago has been established over many decades. In this picture the global spectrophotometric relations observed for ellipticals, for example the colour–magnitude relation (Sandage & Visvanathan 1977; Bower, Lucey & Ellis 1992), are accounted for by the steady increase in the abundance of heavy elements with increasing galaxy mass which arises naturally in galactic wind models such as that of Arimoto & Yoshii (1987) and Kodama & Arimoto (1997). This view has received support from the small scatter observed in the Fundamental Plane (Renzini & Ciotti 1993) and from the small scatter in the Mg$_2$–$\sigma$ relation (Bender, Burstein & Faber 1993), both of which appear to be difficult to establish if there is any significant age spread amongst elliptical galaxies. Recent observations have, however, challenged this conventional interpretation of the data (González 1993, hereafter G93; Faber et al. 1995) and suggested that large age variations may be present amongst elliptical galaxies. The integrated light spectral energy distributions derived from single-age, single-metallicity models of early-type galaxy spectra show that the broad-band colours and the widely used Mg$_2$ index are largely degenerate in age and metallicity, making these parameters difficult to determine independently. Worthey (1994, hereafter W94), however, identified spectral features that are largely sensitive to age and metallicity individually and was thus able to determine these parameters.

These studies are based on measurements of the Faber–Burstein indices defined initially for the Lick/IDS spectra and described in W94. The age-sensitive absorption features are the Balmer lines, in particular H$\beta$. The metallicity indicators are iron and magnesium absorption features, in particular the [MgFe] index (defined in G93) which combines two strong iron lines and the Mgb feature. The 41 elliptical galaxies studied by González have a large range in H$\beta$ absorption strength and a limited range in metal line strength [MgFe]. Combined with Worthey's models these indicate a large range in age, from ~2 to $\geq$12 Gyr, with a modest spread in metallicity from solar to roughly three times solar (see Fig. 1b, later).

Jones & Worthey (1995) identified more sensitive features for metallicity and age: the C4668 feature and H$\gamma_{HR}$ measured at high resolution. Trager (1997) recently revisited the G93 data and analysed the original Lick sample using C4668 and the new higher order Balmer line indices modelled by Worthey & Ottaviani (1997, hereafter WO97) to extend the application of the models with greater certainty. He confirmed the G93 result and ascribed the differences in the absolute ages of galaxies derived from different pairs of indices to the well-known over-abundance (compared with the solar ratios) of magnesium compared with iron in luminous ellipticals (Peletier 1989; Worthey, Faber & González 1992; Davies, Sadler & Peletier 1993; Greggio 1997).

González's sample includes galaxies that are largely drawn from relatively low-density environments with a few galaxies taken from nearby clusters. It was not intended to be a complete sample. Here we present a *complete* sample of early-type galaxies in the Fornax cluster brighter than $M_B = -17$. In Section 2 we describe the observations and data analysis. In Section 3 we present our measurements of line strengths in the Fornax galaxies and make a direct comparison of these with the González sample. We then apply the new, more precise, age/metallicity indices and show that these reinforce our conclusions that the Fornax ellipticals are coeval and that ongoing star formation occurs in the S0 galaxies. We briefly discuss two galaxies with remarkably blue spectra before bringing together our conclusions in Section 4, where we also speculate on the implications for the role of morphology and environment in the star formation history of early-type galaxies.

## 2 OBSERVATIONS AND DATA REDUCTION

Our sample of 22 early-type galaxies have been selected from the catalogue of Fornax galaxies (Ferguson 1989, hereafter F89), in order to obtain a complete sample down to $B_{\mathrm{T}} = 14.2$ or $M_B = -17$.[1] We have adopted the morphological classifications given by F89 and checked them with images that we obtained on the Siding Spring 40-inch telescope. From these we noted a central dust lane in ESO359-G02 and a central disc in ESO358-G59 which led us to classify them as lenticular galaxies. We classified IC2006 as elliptical, as it was not classified by F89. NGC 1428 was not observed because of the bright star close to its centre. The observations were carried out with the Anglo-Australian Telescope (3.9 m) on the nights of 1996 December 6–8 using the RGO spectrograph equipped with a Tek 1K detector. We used the 600V grating, resulting in a useful wavelength range from 4243 to 5828 Å. The slit width of 2.3 arcsec produced a spectral resolution of 4.1 Å (FWHM). One pixel along the slit spanned 0.77 arcsec. Typically, exposure times were between 300 and 1800 s per galaxy. The slit was centred on the nucleus at PA = 90°. The seeing was generally better than 1 arcsec. Additionally we observed 15 different standard stars (mainly K giants) during twilight to act as templates for velocity dispersion measurements as well as to calibrate our line-strength indices. The flux standard GD 108 (Oke 1990) was observed to enable us to correct the continuum shape of our spectra.

The standard data reduction procedures (flat-fielding, cosmic ray removal, wavelength calibration, sky subtraction and fluxing) were performed with IRAF. The central spectrum for each galaxy was extracted by fitting a low-order polynomial to the position of the centre along the wavelength direction, re-sampling the data in the spatial direction and finally co-adding the spectra within a 3.85-arcsec aperture (5 pixels). The spectra, logarithmically rebinned in wavelength, were used to derive redshifts and central velocity dispersions using a simple Fourier cross-correlation method (FXCOR in IRAF).

We measured line strengths for [MgFe], C4668, H$\beta$ and H$\gamma_{\mathrm{A}}$ in the Lick/IDS system described in detail in W94 and WO97. The pass-bands that we used are shown overplotted on example spectra in Fig. 3 (later). The transformation from the observed system to the Lick/IDS system was performed following previous authors and the suggestions by WO97. In particular the fluxed spectra were artificially broadened with a Gaussian of wavelength-dependent width, such that the Lick resolution was best matched at each wavelength (see fig. 7 in WO97). We corrected our indices for velocity dispersion using broadened star spectra (see e.g. Davies et al. 1993). Using stars and galaxies that we observed in common with the Lick/IDS data (Trager 1997) we established small offsets to bring our measurements on to the Lick system.

## 3 RESULTS

### 3.1 The H$\beta$ versus [MgFe] diagram

G93 successfully used a combination of H$\beta$ and [MgFe] to disentangle the effects of age and metallicity. To make a direct comparison we will first plot our data in the same coordinates as González and explore the use of improved indices in Section 3.2.

In Fig. 1(a) we present a plot of H$\beta$ equivalent width versus [MgFe] equivalent width for our 22 galaxies. The error bars on the data points represent the photon noise and the error in the velocity dispersion correction. The elliptical galaxies in Fornax (filled circles) have weak H$\beta$ absorption spanning a modest range in [MgFe]. The S0s (open circles) on the other hand span a larger range of values in this diagram, typically having stronger H$\beta$ absorption.

Following G93 we overplot predictions from single-burst stellar population models (W94). Although the absolute age calibration may be insecure, we see that our sample of Fornax ellipticals are old and of similar age. According to the models the metallicity ranges from just sub-solar to about three times solar. The Fornax S0 galaxies, however, have much lower luminosity-weighted ages and a greater range in metallicity. This is very much in contrast to what G93 found. His sample is shown in Fig. 1(b); the galaxies exhibit a large spread in luminosity-weighted age from greater than 12 Gyr to less than 2 Gyr; in fact González's sample looks much more like the Fornax S0s than that of the Fornax ellipticals. Only four galaxies of the G93 sample are classified as disc galaxies in the RC3 (de Vaucouleurs et al. 1991).

We interpret the stronger H$\beta$ absorption found in S0s as indicating a younger 'mean' age, but recall that line-strength indices reflect only the integrated, luminosity-weighted, properties in a galaxy. As young populations tend to be much more luminous than old ones, a small (in mass) young population can dramatically change the strength of indices, in particular H$\beta$. de Jong & Davies (1997) and Trager (1997) have demonstrated this and showed that the high-H$\beta$ galaxies in G93 tend to have discy isophotes. de Jong & Davies suggested that the ongoing star formation might be associated with the presence of a disc. In our sample, Fornax A, often cited as the product of a recent merger, might be a typical example of an 'old' galaxy which looks young as a result of ongoing star formation in a disc. Less dramatically, the same effect could occur in many lenticular galaxies.

### 3.2 New indices: C4668 and H$\gamma_{\mathrm{A}}$

Here we discuss the application of a more sensitive and more accurately determined metallicity index C4668, and an age index,

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[1] Adopting a distance modulus of $m - M = 31.2$.

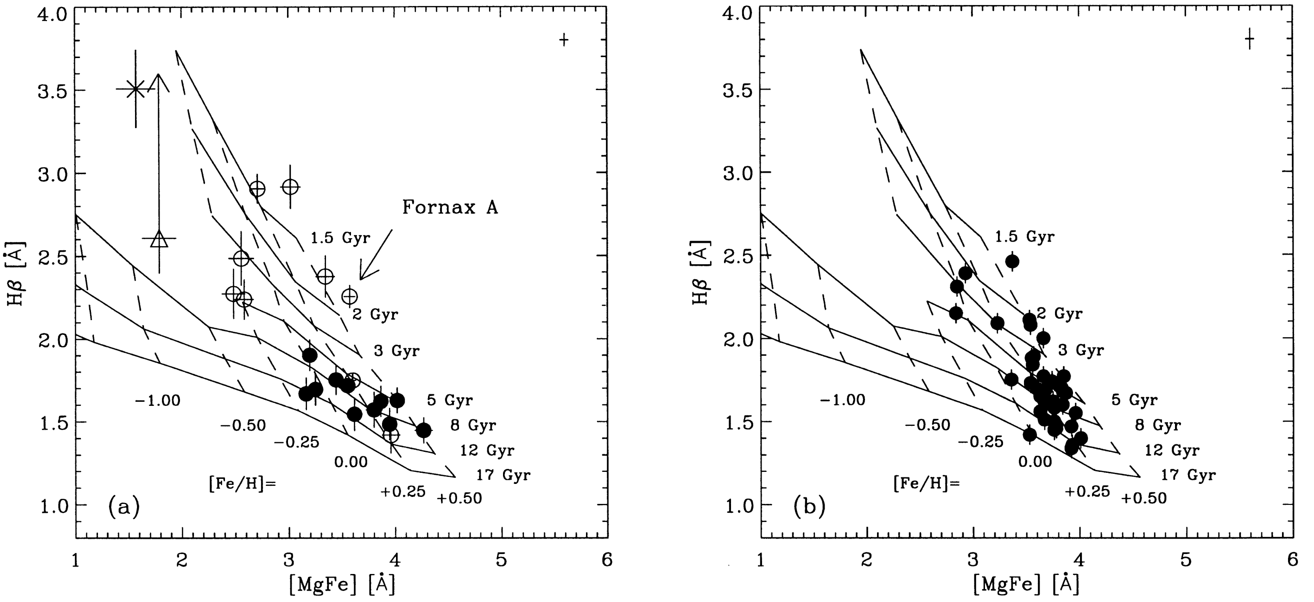

**Figure 1.** (a) Hβ equivalent width versus [MgFe] equivalent width diagram for the complete sample of Fornax early-type galaxies. Overplotted are models by W94. Filled circles and open circles represent ellipticals and S0s respectively. The cross and open triangle represent possible post-starburst and starburst galaxies respectively. The cross in the right upper corner indicates the rms uncertainty in the transformation to the Lick/IDS system. The arrow attached to the galaxy ESO358-G25 (open triangle) indicates an emission correction: for details see text. (b) The González (1993) sample ($R_e/8$ aperture) in the same coordinates as in (a). Note that these elliptical galaxies show a large range in age and a modest range in metallicity.

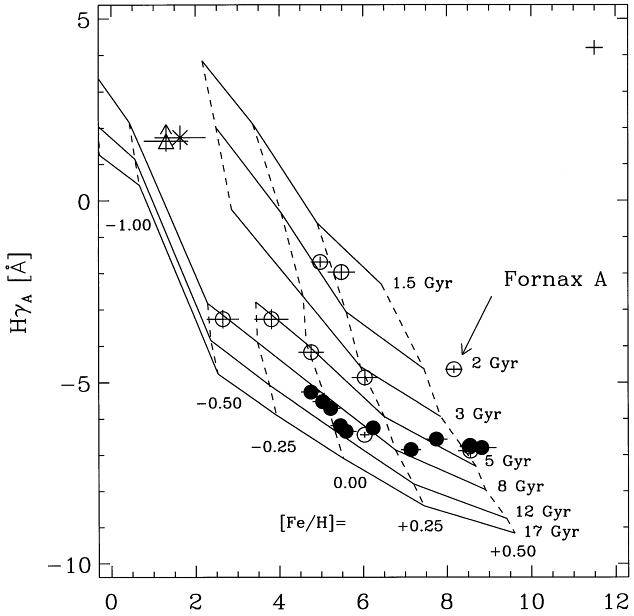

**Figure 2.** $H\gamma_A$ equivalent width versus C4668 equivalent width diagram for a complete sample of Fornax early-type galaxies. Symbol definitions as in Fig. 1(a). Overplotted are models by WO97. The negative values in $H\gamma_A$ *do not* indicate emission but are created entirely by the definition of the pseudo-continuum bands (see WO97). Note that ESO358-G25 (open triangle) moves to a much lower age with respect to Fig. 1(a). The ellipticals with metallicities greater than solar have roughly constant $H\gamma_A$.

$H\gamma_A$, which is also more precisely determined and less sensitive to contamination by emission.

Mg appears to be overabundant compared with Fe in luminous elliptical galaxies, whereas the models are based on solar abundance ratios. As a result of this the use of different metallicity indices can result in quite different estimates for the absolute ages of the same galaxies. Worthey (1995) identified C4668 as a particularly sensitive metallicity feature which, while overabundant compared with Fe, is less overabundant than Mg. He points out, however, that using a different metallicity indicator does not change the relative distribution of the ages and metallicities of galaxies much, but simply shifts the distribution of all galaxies together so that their relative ages should be insensitive to the choice of diagnostic.

G93 found nebular emission in more than half of the galaxies in his sample. The strength of the *stellar* absorption at Hβ is therefore uncertain and requires a correction for the estimated infilling resulting from emission. González adopted an empirical prescription based on the strength of the O III emission but the correctness of this has been challenged by Carrasco et al. (1996) who propose that no correction should be made. We did not attempt to correct Hβ for emission; rather, we used $H\gamma_A$ which is less sensitive to contamination by emission. The relative strength of nebular emission decreases rapidly with the order of the Balmer line (Osterbrock 1989) so that the dilution effect is much reduced. $H\gamma_A$ is a more sensitive age indicator than Hβ because the models predict a much wider range in equivalent width for the same age difference. In addition $H\gamma_A$ is more precisely determined, as (i) the wide side-bands produce improved photon statistics, and (ii) there is a smaller rms error in the dispersion velocity corrections.

In Fig. 2 we present a plot of $H\gamma_A$ equivalent width versus C4668 equivalent width. The symbol definitions are the same as in Fig. 1(a). The subscript ‘A’ on Hγ indicates a ‘wide’ (~40 Å) central passband. We have overplotted new model predictions (WO97). In this diagram the ellipticals follow a tight relation at low $H\gamma_A$ values, varying mostly in C4668. S0s are distributed to much higher values of $H\gamma_A$ absorption. The distribution is similar to that in the Hβ versus [MgFe] diagram and the precision of both age and metallicity is increased. Remarkably, the scatter of elliptical

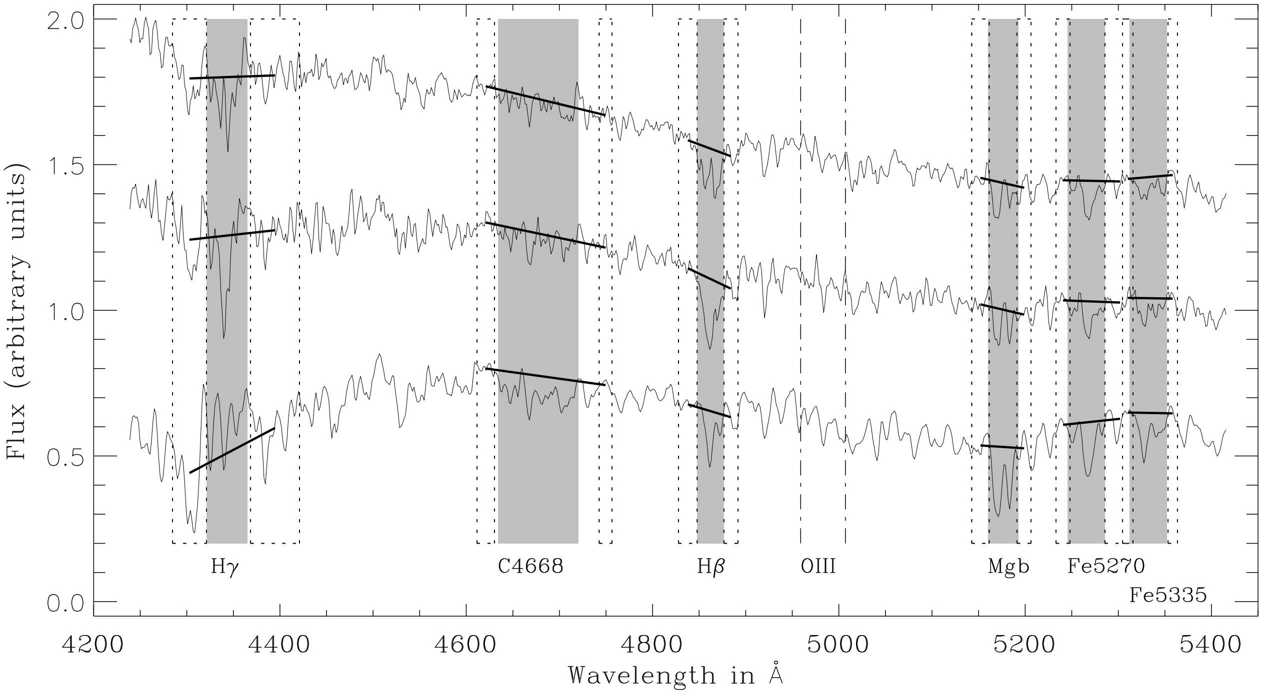

**Figure 3.** The spectra of ESO358-G25, ESO359-G02 and NGC 1336 (from the top) are shown. The shaded areas mark the central passbands of the indices considered in this Letter. The thick solid lines indicate the pseudo-continuum defined by two side-passbands (dashed boxes). We have also marked the position where O III emission at 4959 and 5007 Å would be found if present. The spectra are *not* broadened to the Lick resolution in order to illustrate the different line strengths. Note the emission in H$\beta$ and H$\gamma$ for ESO358-G25, and that the spectra of both ESO galaxies do not drop bluewards of 4500 Å but stay constant.

galaxies is reduced, and for metallicities greater than solar they exhibit more-or-less constant H$\gamma_A$. The new, more accurate, indicators confirm our principal result that the lenticular galaxies in the Fornax cluster have lower luminosity-weighted ages than the elliptical galaxies, which appear to be roughly coeval and vary mainly in metallicity.

There is a hint that the most metal-rich ellipticals seem to be younger by ~3 Gyr than their metal-poor brethren. While the absolute age calibration is not secure, the relative ages should be valid; nevertheless the apparent reduction in the luminosity-weighted ages of the most luminous galaxies may be an artefact in the models.

### 3.3 Two post-starburst or starburst galaxies

One of the most striking differences in using H$\gamma_A$ instead of H$\beta$ is seen in the behaviour of ESO358-G25 represented by an open triangle. This galaxy moves to much lower ages compared with the rest of the sample. In fact it shows emission in H$\beta$ and H$\gamma$ filling in the absorption (see Fig. 3). The arrows in Figs 1(a) and 2 indicate an estimated emission correction determined by a rough subtraction of the emission features. ESO358-G25 is the only galaxy in our sample that shows obvious Balmer emission, and as a result it is the only galaxy that moves to significantly lower ages or greater relative index values in Fig. 2. The two lenticular galaxies ESO358-G25 (open triangle) and ESO359-G02 (cross) have remarkable spectra for early-type galaxies: they show blue continua, strong Balmer lines and weak metal lines, and there is a hint of weak O III emission (see Fig. 3). These galaxies are amongst the faintest in our sample and are ~3° away from the centre of the cluster. They are reminiscent of the high-H$\delta$ galaxies in the Coma cluster found by Caldwell et al. (1993) or the galaxies in redshift $z = 0.3$ clusters identified by Couch & Sharples (1987) and by Barger et al. (1996) as being in the post-starburst phase (ESO359-G02) or starburst phase (ESO358-G25).

## 4 CONCLUSIONS AND SPECULATIONS

### 4.1 Conclusions

We have measured the central line-strength indices in a complete sample of early-type galaxies brighter than $M_B = -17$ in the Fornax cluster, and have applied the models of W94 and WO97 to estimate their ages and metallicities. We find the following results.

(i) The elliptical galaxies appear to be roughly coeval although their absolute ages remain uncertain. They form a sequence in metallicity varying from just below solar metallicity to about three times solar metallicity. This result is consistent with the conventional view of old, coeval elliptical galaxies and contrasts remarkably with the results from the G93 sample.

(ii) The lenticular galaxies have metallicities ranging from one-third to three times solar metallicity and *have luminosity-weighted ages that are much lower than those of the ellipticals*, spanning from less than ~2 Gyr to 12 Gyr. In this respect the distribution of G93 galaxies follows that of Fornax S0s more closely than that of the Fornax ellipticals.

(iii) We have discovered that two of the fainter lenticular galaxies appear to have undergone star formation in the last 2 Gyr (in one case very much more recently). These appear to be the low-redshift analogues to the post-starburst or starburst galaxies seen by Couch & Sharples (1987) and recently by Barger et al. (1996) in redshift $z = 0.3$ clusters. We note that, like Fornax A, these galaxies lie on the periphery of the cluster.

### 4.2 Speculations

We are now in a position to speculate on the role of galaxy morphology and environment in the star-forming history of early-type galaxies.

(i) In the Fornax cluster only lenticular galaxies exhibit symptoms of recent star formation. Is it possible that this is a general result? This would be consistent with the findings of Dressler et al. (1997), that in clusters at $z = 0.5$ the fraction of elliptical galaxies remains constant but the fraction of S0 galaxies is 2–3 times lower than is found in local clusters. They suggest that a fraction of the spiral galaxy population has evolved to quiescence in the 5-Gyr interval from $z = 0.5$ to the present. This would indeed produce a cluster population of youthful S0 galaxies as we observe. The occurrence of late star formation only in S0 galaxies supports the view that early-type galaxies appear young because a modest mass fraction of young stars influence their spectra, rather than that they formed recently. de Jong & Davies (1997) and Trager (1997) have noted the tendency for high-H$\beta$ or young galaxies to have discy isophotes, reinforcing the suggestion that they may originate as exhausted spirals. It seems possible that at least *some* of the young galaxies in the G93 sample may be mis-classified lenticular galaxies. We are undertaking an imaging survey of the G93 sample to explore this.

(ii) Alternatively, it may be that elliptical galaxies in dense environments are older and show less age spread than those in loose groups and the field. This has certainly been suggested by others: e.g. Larson, Tinsley & Caldwell (1980) and Guzman & Lucey (1993). If we interpret the difference in the age distribution between the G93 and Fornax samples as reflecting the difference in environment between field and cluster galaxies, we should also recall that the fraction of early-type galaxies that have discs increases dramatically at lower densities (Dressler 1980). There is an urgent need to construct complete data sets for other nearby clusters, and to construct a well-defined low-density sample to test whether it is morphology, environment or both that generates the age differences that we see.

(iii) We note that in the H$\gamma$ versus C4668 diagram the most metal-rich (luminous) galaxies appear to be younger by $\sim$3 Gyr than the galaxies of lower metallicity. It is possible that this age difference is an artefact of the models. However, if true this supports the hierarchical picture for the construction of galaxies in which massive galaxies are the last to be assembled and are therefore the youngest.

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## REFERENCES

Arimoto N., Yoshii Y., 1987, A&A, 173, 23
Barger A. J., Aragón-Salamanca A., Ellis R. S., Couch W. J., Smail I., Sharples R. M., 1996, MNRAS, 279, 1
Bender R., Burstein D., Faber S. M., 1993, ApJ, 411, 153
Bower R. G., Lucey J. R., Ellis R. S., 1992, MNRAS, 254, 601
Caldwell N., Rose J. A., Sharples R. M., Ellis R. S., Bower R. G., 1993, AJ, 106, 473
Carrasco L., Buzzoni A., Salsa M., Recillas-Cruz E., 1996, in Buzzoni A., Renzini A., Serrano A., eds, ASP Conf. Ser. Vol. 86, Fresh Views of Elliptical Galaxies. Astron. Soc. Pac., San Francisco, p. 235
Couch W. J., Sharples R. M., 1987, MNRAS, 229, 423
Davies R. L., Sadler E. M., Peletier R. F., 1993, MNRAS, 262, 650
de Jong R. S., Davies R. L., 1997, MNRAS, 285, L1
de Vaucouleurs G., de Vaucouleurs A., Corwin H. G., Jr, Buta R. J., Paturel G., Fouqué P., 1991, Third Reference Catalogue of Bright Galaxies. Springer Verlag, Berlin (RC3)
Dressler A., 1980, ApJ, 236, 351
Dressler A. et al., 1997, ApJ, 490, 577
Faber S. M., Trager S. C., González J. J., Worthey G., 1995, in Van Der Kruit P. C., Gilmore G., eds, Proc. IAU Symp. 164, Stellar Populations. Kluwer, Dordrecht, p. 249
Ferguson H. C., 1989, AJ, 98, 367 (F89)
González J. J., 1993, PhD thesis, Univ. California, Santa Cruz (G93)
Greggio L., 1997, MNRAS, 285, 151
Guzman R., Lucey J. R., 1993, MNRAS, 263, L47
Jones L. A., Worthey G., 1995, ApJ, 446, L31
Kodama T., Arimoto N., 1997, A&A, 320, 41
Larson R. B., Tinsley B. M., Caldwell C. N., 1980, ApJ, 237, 692
Oke J. B., 1990, AJ, 99, 1621
Osterbrock D. E., 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei. University Science Books, Mill Valley, CA
Peletier R. F., 1989, PhD thesis, Univ. of Groningen, Groningen
Renzini A., Ciotti L., 1993, ApJ, 416, L49
Sandage A., Visvanathan N., 1977, ApJ, 216, 214
Trager S. C., 1997, PhD thesis, Univ. California, Santa Cruz
Worthey G., 1994, ApJS, 95, 107 (W94)
Worthey G., 1995, in Leitherer C., Fritze-von Alvensleben U., Huchra J., eds, ASP Conf. Ser. Vol. 98, From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution. Astron. Soc. Pac., San Francisco, p. 467
Worthey G., Ottaviani D. L., 1997, ApJS, 111, 377 (WO97)
Worthey G., Faber S. M., González J. J., 1992, ApJ, 398, 69

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