Ages and Metallicities of Galaxies along the Cluster “Red Sequence”

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Abstract

We use spectroscopic data from the NOAO Fundamental Plane Survey to determine mean stellar ages and stellar metallicities of “red-sequence” cluster galaxies. We find that the metallicity, the relative abundance of α-elements and the mean stellar age all increase with galaxy mass.

The last of these trends - “down-sizing” - is the most surprising as it conflicts with the expectations of models of galaxy formation.

Full details can be found in Nelan et al. 2005, ApJ, in press.

1. Introduction

The colour-magnitude diagram of galaxies in clusters is dominated by galaxies on a “red sequence”. This has long been thought to be a metallicity sequence, with metal-rich stars dominating the stellar populations of massive galaxies, but with decreasing mean metallicity at lower galaxy masses. It is also possible that there is an age trend along the sequence. In broadband colours, however, the effects of age and metallicity are degenerate.

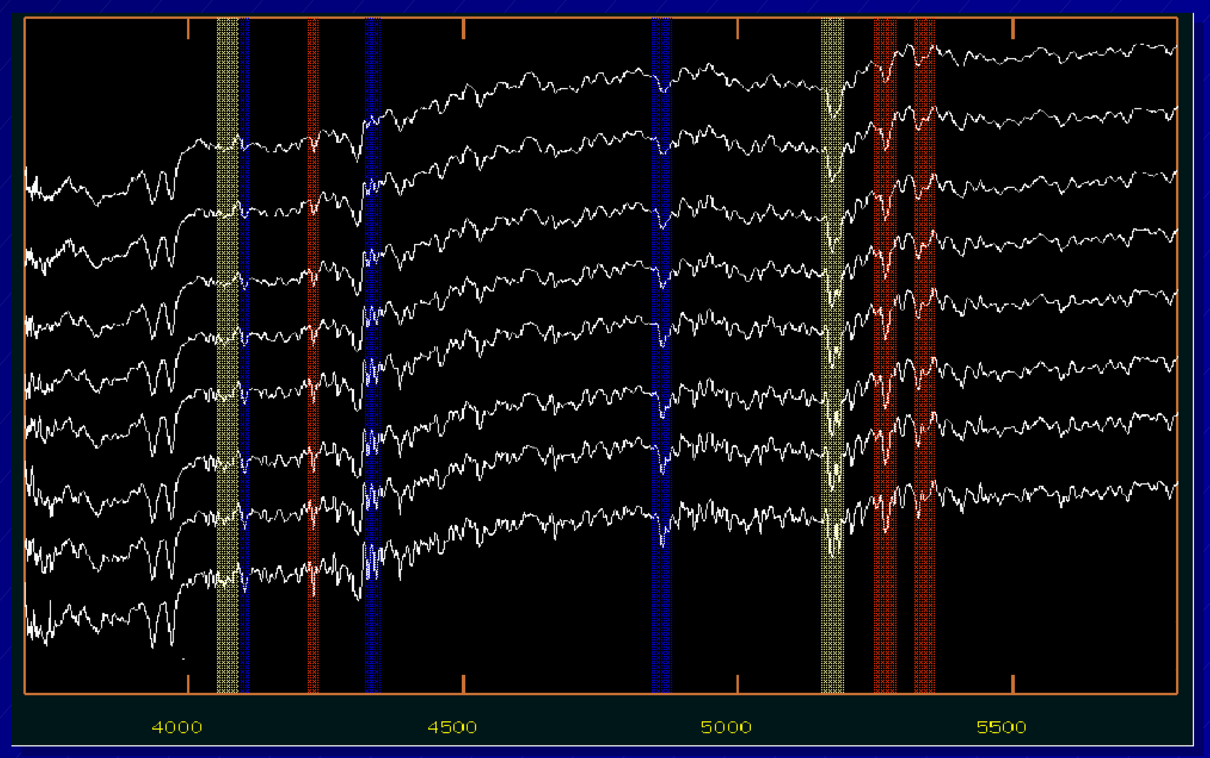
Here we break this degeneracy from detailed modelling of spectroscopic absorption linestrength indices. Our spectroscopic data is from the NOAO Fundamental Plane Survey.

2. Data: The NOAO Fundamental Plane Survey

We have undertaken an all-sky survey of 93 X-ray luminous clusters in the nearby Universe. For each cluster we target red galaxies from our B and R imaging for spectroscopic follow-up, yielding spectra of 4000 red galaxies, most of which are early type.

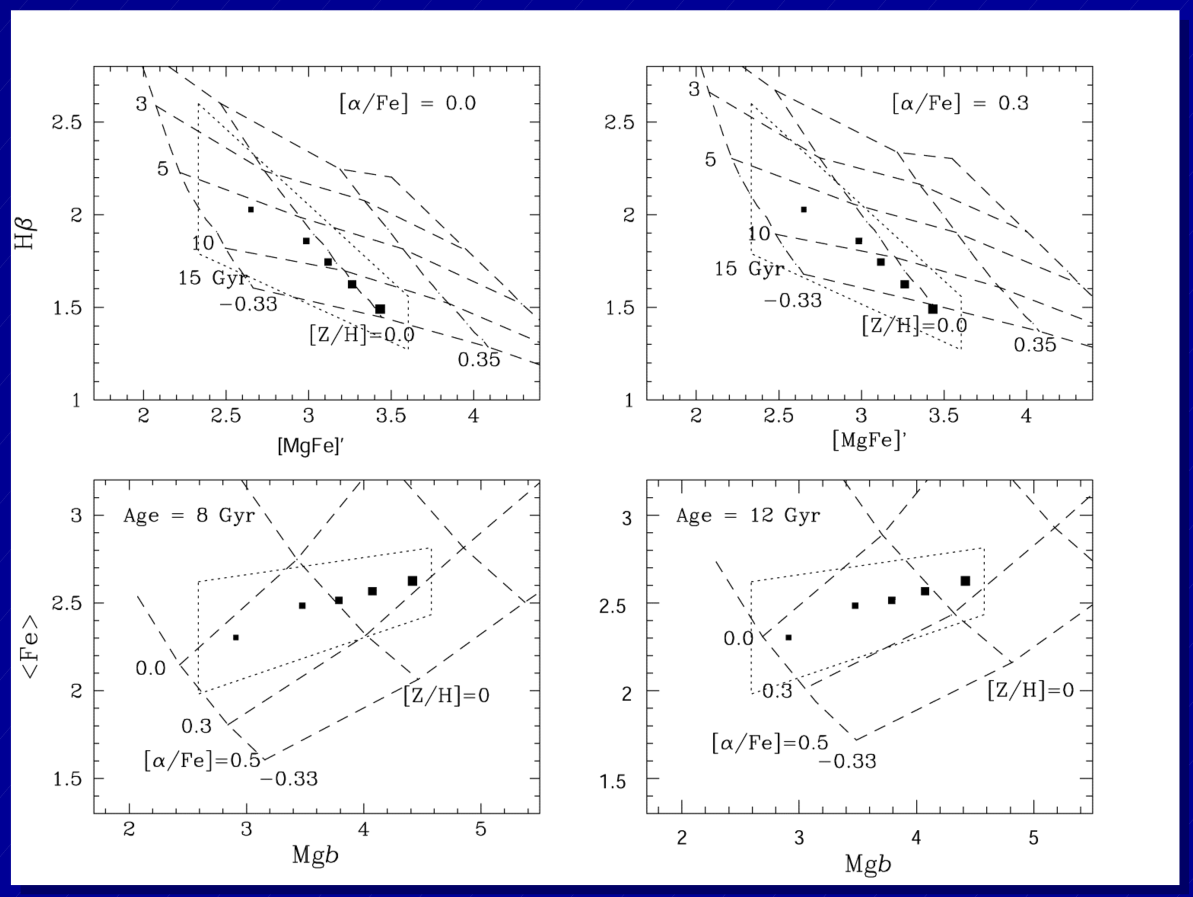
Spectra

Figure 1 (below) shows composite (stacked) spectra (with effective S/N ~ 200), binned by velocity dispersion, for a subset of our 4000 galaxy sample. The spectra are arranged by velocity dispersion (mass), increasing upward. Blue vertical bands indicate the age-sensitive Balmer lines, red bands several alpha-element indices and yellow bands iron-sensitive indices. Note the increasing strength of the Balmer lines for galaxies with smaller masses (lower velocity dispersion).



Linestrength Indices

From each individual galaxy spectrum, we measure “Lick indices” for 20 stellar absorption lines.



The top panels of Figure 2 (above) show mean Hb and MgFe linestrengths for 5 bins of velocity dispersion (large symbol sizes indicate more massive galaxies). The model grids (dashed lines) are from the single-stellar population (SSP) synthesis models of Thomas and collaborators.
The higher mass galaxies have higher metallicities and older stars.

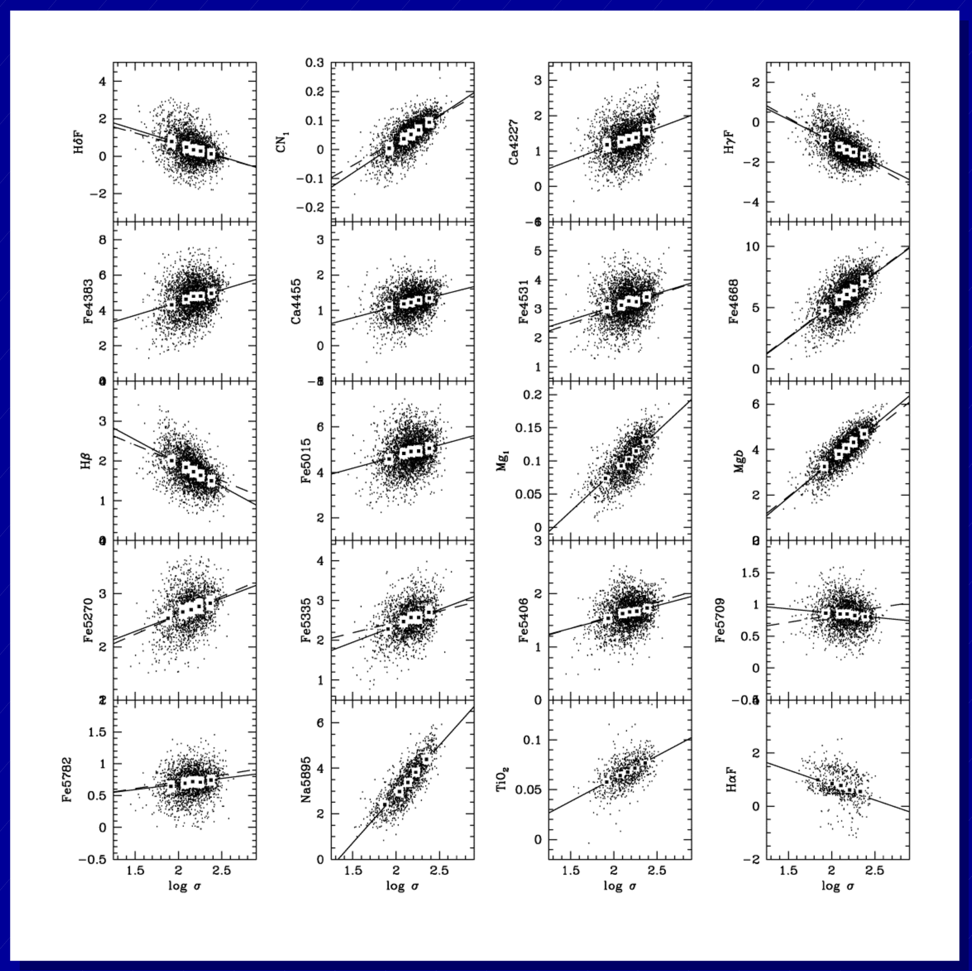
The bottom two panels show Mgb vs. <Fe> which can be used to separate alpha-element metallicity from non-alpha element metallicity.

3. Results

Modelling the ages and metallicities of red galaxies

A more detailed fit involves using 16 linestrength-velocity dispersion slopes, and fitting these simultaneously with a model which allows for variation in age, α-element abundance and metallicity along the mass sequence.

Figure 3 (right) shows the fits to 20 linestrength indices as a function of log (velocity dispersion). The small points are the data for individual galaxies and the embedded squares are the means for galaxies binned by velocity dispersion. Note that all linestrengths, except for the Balmer lines and Fe5709 increase with increasing velocity dispersion.



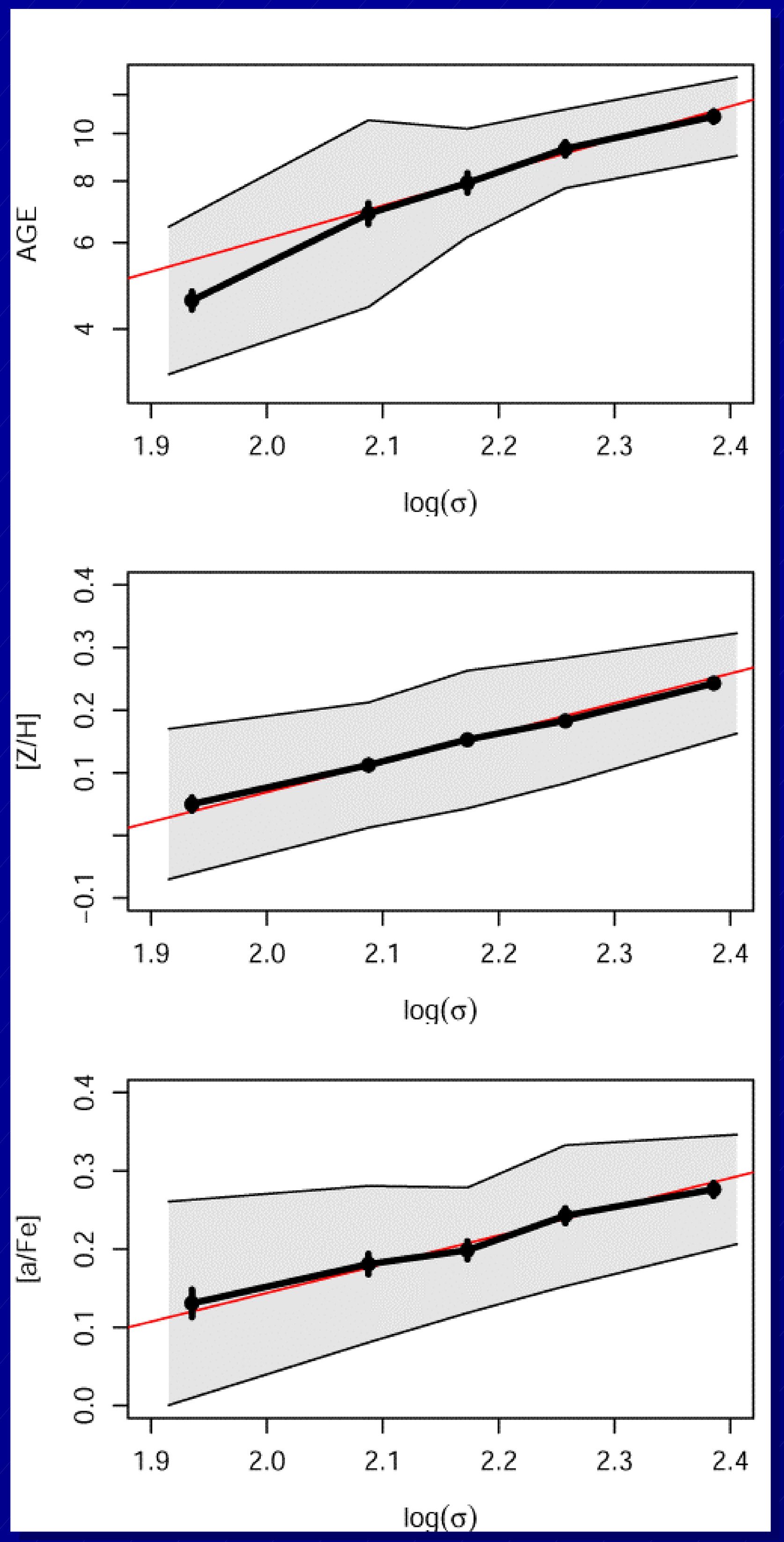


Figure 4 (left) shows the resulting model fits as a function of velocity dispersion (a proxy for mass). The red and black lines represent two methods of analysis.

The grey regions are an estimate of the intrinsic scatter at a given velocity dispersion, thus there is tentative evidence of an increase in the spread of ages galaxy-to-galaxy at the low mass end of the sequence.

The spectroscopic linestrengths require that age, metallicity and alpha-element abundance (relative to iron) all increase with increasing mass.

We find the following results:
age ~ $s^{0.59}$
Z/H ~ $s^{0.53}$
α/Fe ~ $s^{0.31}$.

The sense of the age trend is such that if the largest galaxies in our sample have an age of 13 Gyr, the least luminous (0.01 L) would have an age of 4 Gyr.*

4. Discussion

Robustness of the results

• This result is insensitive to which Balmer lines (Hβ, Hγ, Hδ) are used in the fit. Indeed, an independent analysis by Smith (2005) using Hα yields consistent results.

• We also find that our results are not strongly sensitive to the morphological mix along the red sequence.

• However, it is important to remember that these results are for the luminosity-weighted mean of the population on the red sequence, as measured within the central 2 arcseconds.

At the low mass end, it is difficult to distinguish between, for example, a single population with an age of 4 Gyr, and a 1 Gyr burst superimposed on an old (13 Gyr) population.

Comparison with High Redshift Clusters

A simple prediction is that high redshift clusters should be deficient in red galaxies at the faint end. Just such an effect is seen at z ~ 0.75 in the data of de Lucia et al (2004), reproduced in the top panel of Figure 5 (right).

Notice the deficit of galaxies at the faint end of the red-sequence luminosity function, compared to Coma (bottom panel).

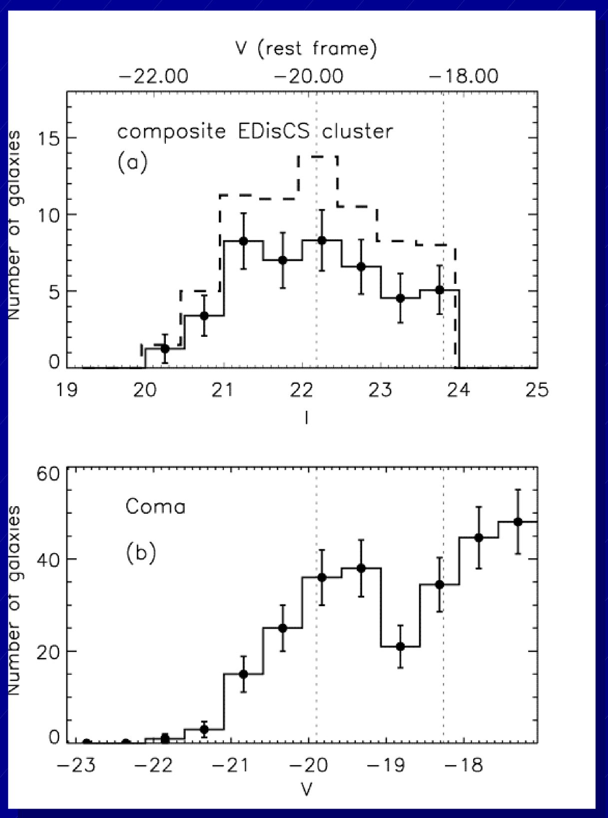
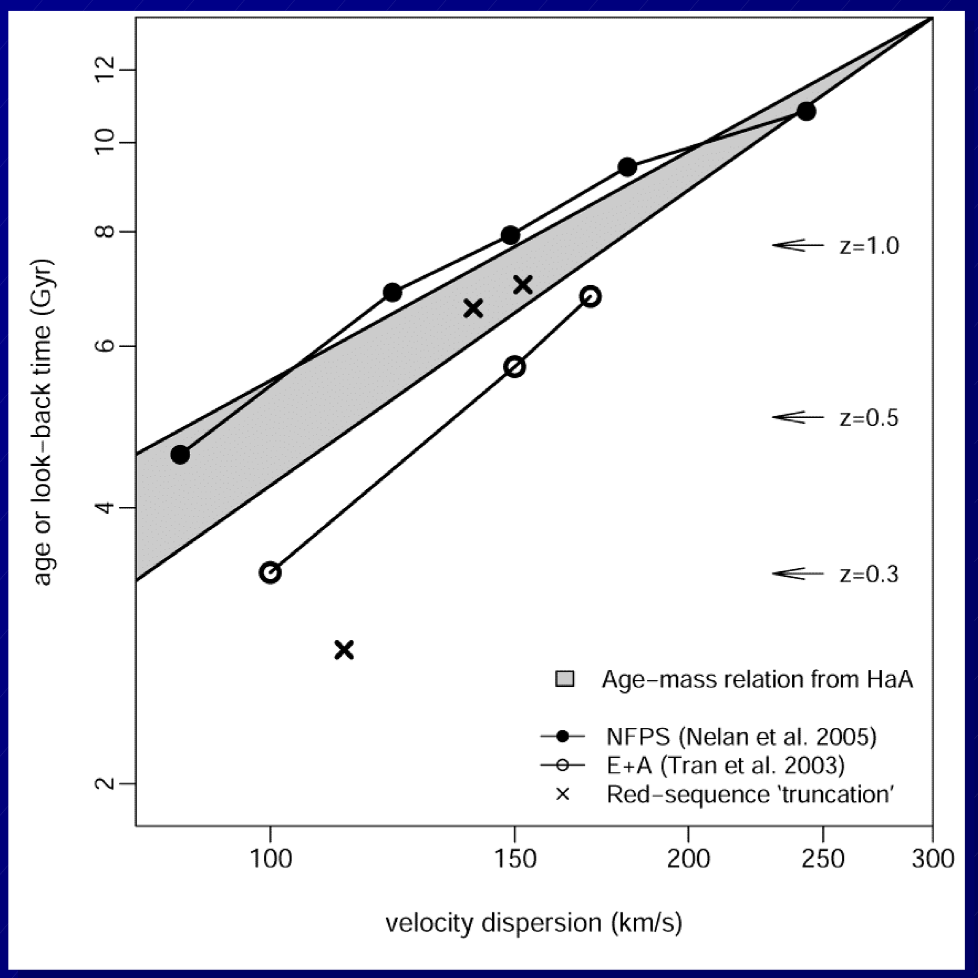


Figure 6 (below) summarizes “downsizing” trends both from the fossil record (this work plus the Hα analysis of Smith 2005, which yields consistent results), and from studies of high redshift clusters (with cluster redshift converted to lookback time): the mass at which truncation of the red sequence is observed (as in Fig 5 above) and the characteristic mass at which the E+A (post-starburst) phenomenon is observed (Tran et al. 2003) There is remarkable agreement between these very different studies.



It is worth noting that similar “downsizing” trends have been seen in the field from the fossil record in the Sloan Digital Sky Survey (Heavens et al. 2004) and from spectroscopy of high redshift galaxies (e.g. Juneau et al. 2005's study based on data from the the Gemini Deep Deep Survey). It remains to be seen whether there is a in difference in the age trend between field and cluster samples.

Implications for Galaxy Formation

The anti-hierarchical or “downsizing” pattern of galaxy formation is in marked contrast to the predictions of semi-analytic models of galaxy formation. The models predict that either there should be no trend of mean stellar age with mass, or that the more massive galaxies should have younger mean stellar populations, which is he opposite to the trend that we find from analysis of nearby galaxies.

Acknowledgments

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