[α/Fe] in the SAMI Galaxy Survey

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What is [α/Fe]?

- **α-elements** such as ^{16}O, ^{24}Mg, and ^{40}Ca contain an **integer number** of ^{4}He nuclei, or α particles. These are mostly formed in **Type II supernovae**.
- Elements with an atomic number close to **^{56}Fe** are mostly formed in **Type Ia supernovae**.
- [α/Fe] is the **abundance ratio** of α-elements to Fe, normalised to solar values.

The Role of Quenching

- When stars form, the relative **abundance of elements reflects the composition of the ISM** at that time.
- If all star formation ceases, then the integrated [α/Fe] of the galaxy reflects the duration of star formation.
- A very **high [α/Fe] implies a very rapid quenching timescale**, as there has not been enough time for Type Ia SNe to affect the ISM composition.

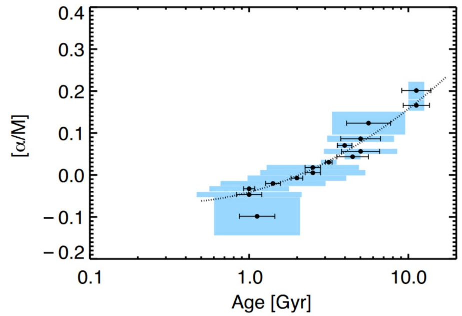

Figure 2: The α-abundance of red giants in the Milky Way, against their age, from Feuillet et al. (2018). The youngest stars have the lowest α-abundance, reflecting the ISM at their formation time.

Supernovae Timescales

- **Type II** progenitors are **high mass** stars ($> 8M_\odot$), with very **short lifetimes** (< 50 Myr).
- Type Ia progenitors are the opposite, with much lower mass ($< 1.4M_\odot$) and longer lifetimes (∼ 1Gyr).
- If we have an instantaneous burst of star formation, contributions to the interstellar medium (ISM) will initially be dominated by Type II SNe, polluting it with a very high abundance of α-elements.
- Over longer timescales, the α-abundance will be diluted by the relative prevalence of Type Ia SNe.

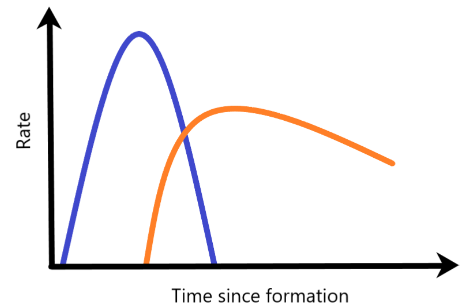

Figure 1: An illustration of how the relative rate of SNe can affect the ISM. If we have one type of SN with a short progenitor lifetime (blue line), this quickly dominates shortly after the galaxy forms. After some period of time, the second type (orange line) becomes dominant, as the potential progenitors for the first type are exhausted.

Why do we care?

Although there's been a vast amount of previous research into how, when, and why galaxies form in the way that they do, we still don't have good answers to a lot of questions. The ones that I'm particularly interested in answering are:

- We already know that there's a strong link between [α/Fe] and the size of a galaxy (expressed as either mass or velocity dispersion σ). Is this relationship the same for all galaxies?
- Does the environment make a difference to the way galaxies form?

SAMI

- SAMI is the **S**ydney-**A**ustralian-Astronomical-Observatory **M**ulti-object **I**ntegral-Field Spectrograph.
- It contains **13 fibre bundles**, each with 61 individual fibres.
- For many areas of research, having the **additional spatial information** is crucial – for us, we can **normalise the effective aperture** based on the galaxy radius r_e.
- The full sample contains **∼3000 galaxies** spanning a broad range of morphologies and environments.

Galaxy Colours

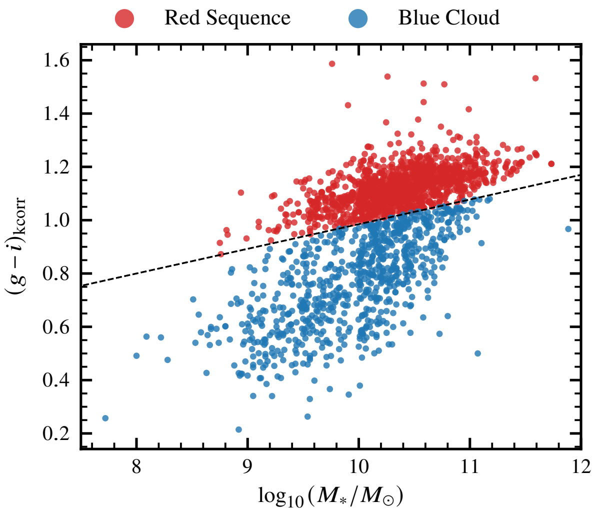

Figure 3: The distribution of k-corrected galaxy colours in the SAMI sample. Several previous studies have found that the fraction of red galaxies f_r is the most significant change with environment, and so we examine the two populations separately.

Measuring [α/Fe]

- We determine [α/Fe] through the use of simple stellar population (SSP) models.
- These predict how the integrated spectrum of a galaxy changes, given some combination of age, metallicity, and α-abundance.
- They focus on so-called **absorption-line indices** – regions of interest where the spectrum is dominated by particular elements.
- By measuring a set of 20 indices, we can determine the most likely SSP model through χ^2 minimisation, using the models of Thomas et al. (2011).

Environmental Residuals

We begin by fitting relationships between [α/Fe] and σ for both groups, and then investigating residual correlations. We use the local surface density Σ_5 as our measure of environment, the distance to the fifth-nearest neighbour.
Not only are the **red sequence galaxies systematically α-enhanced** over their blue sequence counterparts by ~ 0.05 dex, we also find that the residuals $\Delta[\alpha/\text{Fe}]$ correlate with Σ_5. Surprisingly, this **environmental dependency does not exist for blue cloud galaxies**.

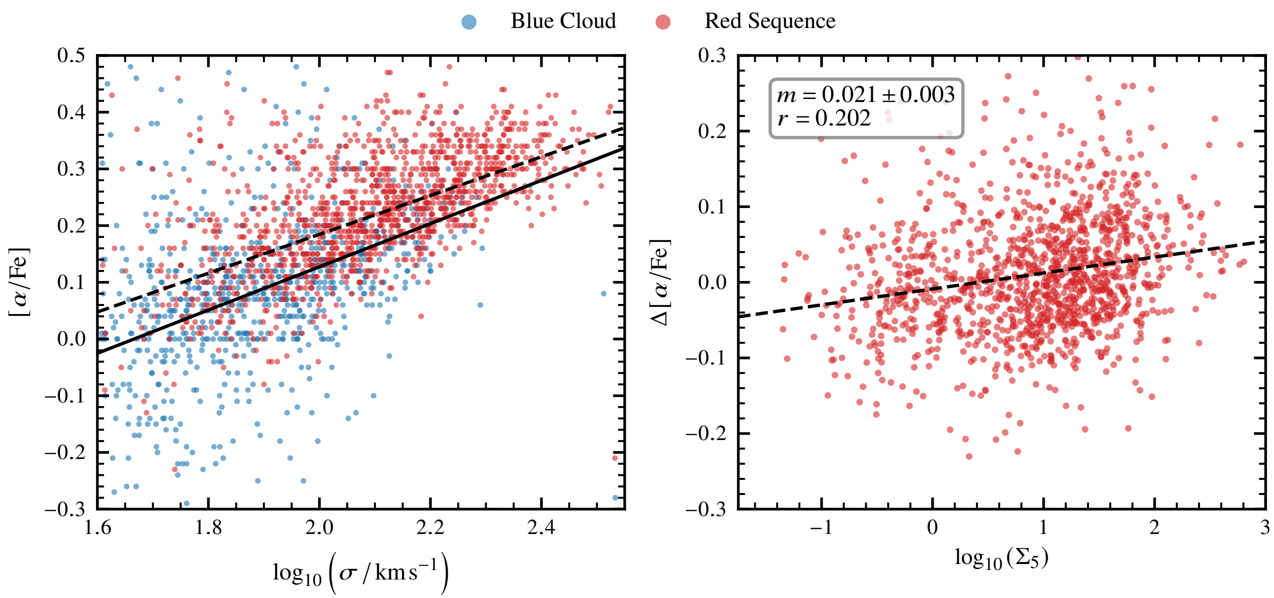

Figure 4: On the left, the dashed line represents the best linear fit to the red sequence, and the solid line for the blue cloud. On the right, we only display the red sequence for clarity, with the gradient m and correlation coefficient r inset (for the blue cloud $m = 0.000 \pm 0.006$ and $r = 0.002$).

Morphology

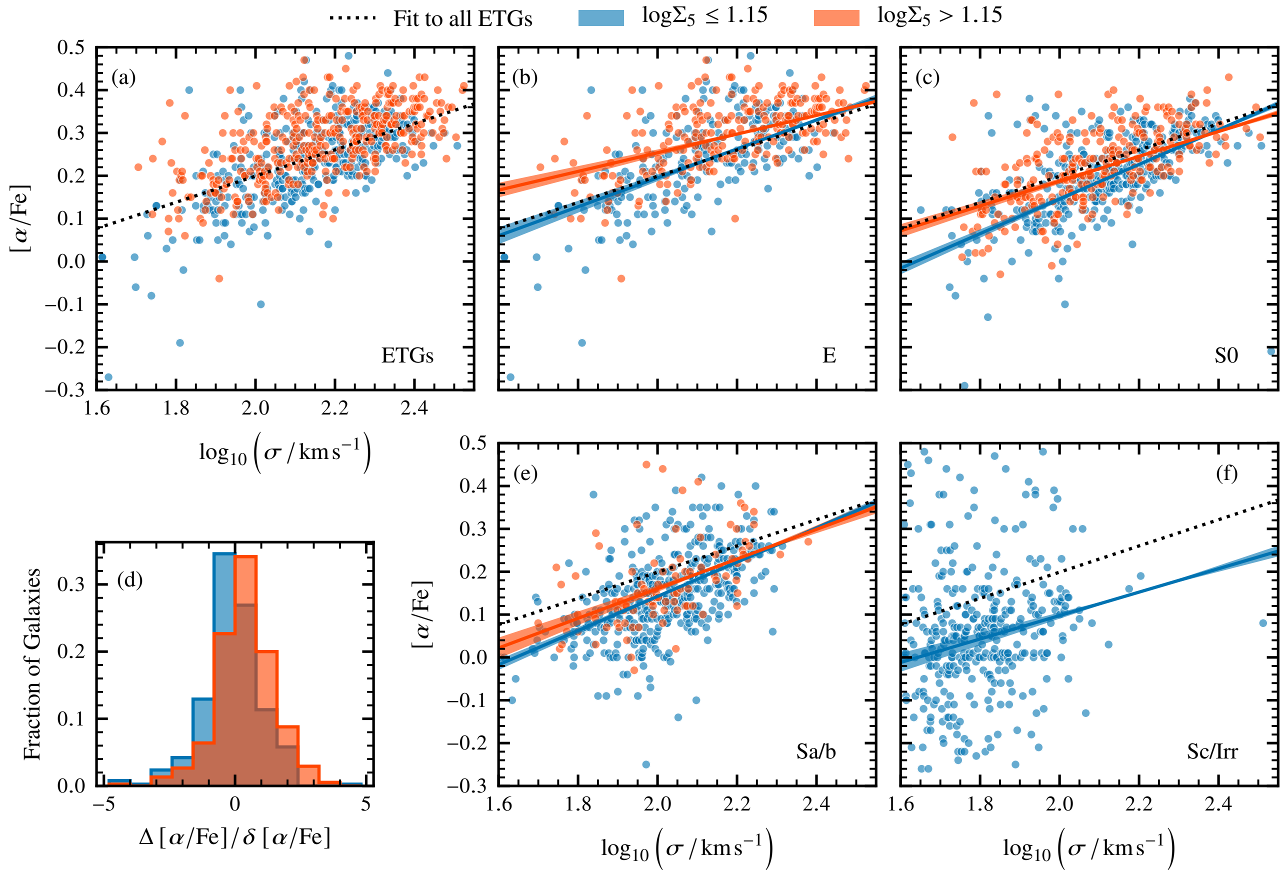

Figure 5: (a) We fit a linear trendline to all early-type galaxies (ETGs) in our sample, displayed as a dashed line on all plots as a point of reference. The residuals are shown in (d), and all galaxies are coloured according to their local environmental density. In (b), (c), (e), and (f), we show the different optical classifications of galaxies, from ellipticals through to late-type spirals. Here, we fit galaxies in low-density environments and high-density environments separately.

The morphology, or shape, of a galaxy can also be a significant factor in the way it forms. Here, we separate out galaxies into various types, based on a visual inspection of colour images (Cortese et al., 2016).
On the one end, we have ellipticals (E) – round galaxies, typically old and red, with no distinguishing features. At the other extreme, we have late-type spirals (Sc) – with intricate blue spiral arms, and plenty of ongoing star formation. What do we find when we look at their stellar populations?

- **At low velocity dispersions, galaxies in dense environments are α-enhanced** over those in low-density environments.
- This depends on morphology – **ellipticals show a larger offset than spirals.**
- There's a **secondary offset** also depending on the type – in all environments, ellipticals and S0s apppear to have higher [α/Fe] than spirals.
- At the **highest velocity dispersions, there doesn't seem to be much difference between galaxies**, regardless of morphology or environment. The sole exception is the Sc sample – but they don't actually have any galaxies at high σ!

Summary and Future Research

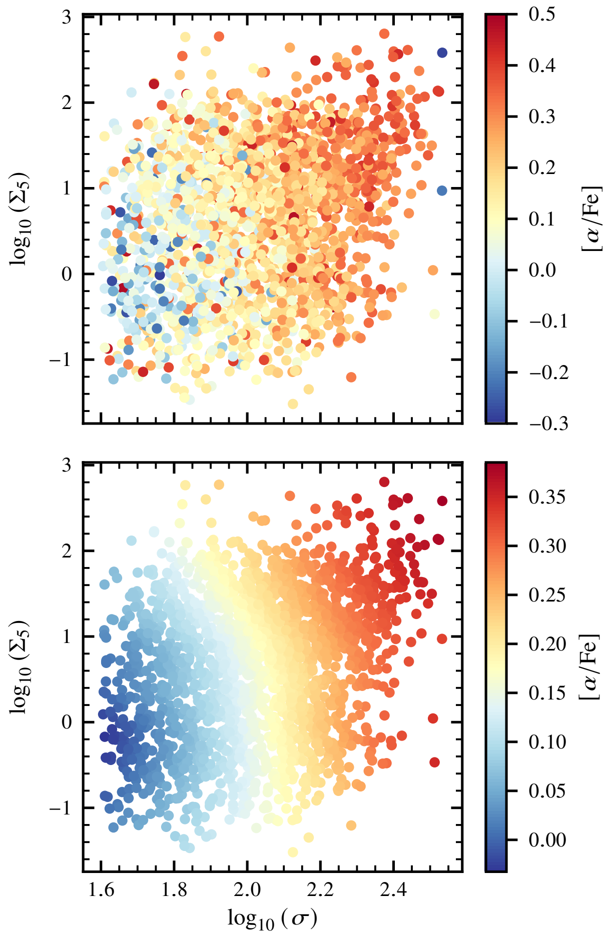

Figure 6: The distribution of galaxies in σ-Σ_5 space. Galaxies are coloured by their associated measurements of [α/Fe]. Above, we show the original measurements, and below, a smoothed version using the locally-weighted regression technique (LOESS) of Cappellari et al. (2013).

What have we learnt so far?

- There's a **clear link between the local environmental density and the [α/Fe] of a galaxy**. This seems to imply that environmental quenching mechanisms, such as ram pressure stripping, play a big role in determining the likely duration of star formation.
- This is **most obvious at low galaxy velocity dispersions**. There's plenty of support for this elsewhere, particularly Peng et al. (2010), who suggested that the dominant quenching mechanism at low masses would be environmental. This isn't unexpected either - **smaller galaxies will be more susceptible to external influences**.
- The effect is also much **more pronounced for early-type galaxies**. Using low-σ ellipticals, we estimate the difference in [α/Fe] between environments amounts to a **difference in half-mass formation time of ~0.9 Gyr**.

Where do we go next?

- **Expand the sample size.** Although we're confident in these results, checking the **reproducibility** with other surveys will reduce the possiblity of any bias in the sample selection.
- **Investigate the kinematics**. An alternative method of separating galaxies, kinematic morphologies provide a more **quantitive** description of galaxies. Preliminary results already show a significant anti-correlation between the spin proxy λ_{R_e} and the residuals Δ[α/Fe] – **galaxies spinning slowly have higher [α/Fe] than expected.**

References

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Feel free to get in touch with any questions or suggestions! Unless otherwise stated, all figures and data are taken from Watson et al. (2021, submitted). Download the paper here:

Acknowledgements

This work could not have taken place without the SAMI team and collaborators, who are listed on the above paper with their acknowledgements. Additionally, this work was supported by the Hintze Family Charitable Foundation, travel and computer grants from Christ Church, Oxford, and STFC grants ST/H002456/1, ST/K00106X/1 and ST/J002216/1.