The stellar initial mass function: radial variations in early-type galaxies?

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With thanks to Russell Smith, John Lucey, and Ray Sharples
Outline

Introduction to SSP modelling: how spectra can be used to infer the IMF of an unresolved stellar population

Review of evidence and theoretical support for radial dependence of the IMF in ETGs

VLT-KMOS observations of 8 nearby ETGs and our results

Questions
Simple Stellar Population Models

Can we reconstruct underlying stellar populations from galaxy spectra?

C. Conroy
Simple Stellar Population Models

Wing-Ford (FeH) molecular band

Na I 1.14 μm doublet

Al I 1.31μm doublet

\( \sigma = 230 \text{ kms}^{-1} \)

degeneracies
Bottom heavy IMFs

Correlation in ETGs between steeper (more bottom-heavy) IMFs and increasing galaxy mass.

See also:
Spiniello et al. 2012;
Smith, Lucey, and Carter 2012;
La Barbera et al. 2013

But galaxy-by-galaxy mismatch with M/L methods (Smith et al. 2014)!

Method works best on high S/N data ... so spectra taken from cores.
IMF radial variations

Radial variations of the IMF motivated by ‘inside-out’ ETG formation (e.g. Oser et al. 2010). Rapid starburst builds up the galaxy core, outer regions assembled later, primarily via accretion of smaller systems.

Attempts to constrain: Martin-Navarro et al. 2015, McConnell et al. 2015, La Barbera et al. 2015...

...but small samples (1-2 galaxies) and conflicting conclusions.
Our work

Advances in instrumentation and development of SSP models in the IR allow us to move out of the optical and into the infrared: spectra dominated by cool stars and contain many IMF-sensitive features - essential for breaking degeneracies.

KMOS (Sharples et al. 2003): able to observe multiple targets simultaneously using 24 arms.

We observe 8 ETGs in the IZ band (0.78-1.08μm) and 6 of these in the YJ band (1.03-1.34μm) also.
Our work

Observing strategy: arms arranged on isophotal lines out to the effective radius – create composite spectra at a range of different radii.
Feature radial trends

Focus on radial trends here: larger sample than all other studies put together & investigate unexplored spectral features.

Median stack of spectra in each radial regime: pool information across sample and wash out galaxy-galaxy variations:
Radial trends

Wing-Ford band (FeH 0.99 μm)

- Blue: fiducial
- Red: X=3 IMF
- Green: [α/Fe]=+0.4
- Orange: [Na/Fe]=+0.9

Equivalent width (Å)

Log(R/R_eff)

-2.0 to 0.0
Radial trends
Interpretation of results

What can we do with this data? Goal is to reconstruct trends with radius in properties of underlying stellar population...

\[
\frac{dI_i}{dx} = g_i = \frac{\partial I_i}{\partial P_1} \frac{\partial P_1}{\partial x} + \ldots + \frac{\partial I_i}{\partial P_n} \frac{\partial P_n}{\partial x}
\]

(where \(I_i\) is the equivalent width of index \(i\), \(x\) is e.g. \(\log(R/R_{\text{eff}})\), and the \(P_j\) are the parameters of interest, e.g. IMF slope)

\[
g_i = \frac{\partial I_i}{\partial P_j} \cdot \frac{\partial P_j}{\partial x}
\]

... invert to recover \(\partial P_j\) terms.
Derived parameters

Some radial abundance trends (\([\text{Fe/H}], [\alpha/\text{H}], [\text{Ca}/\alpha]\) ) well constrained from optical spectra of ETGs: makes sense to impose these prior to fitting!

Allows us to constrain unknown parameters more tightly. Of chief interest here are the IMF and \([\text{Na}/\text{H}]\) (unconstrained parameters which our features have good sensitivity to).

Results:

\[
\text{Change in } f_{\text{dwarf}} = 0.004 \pm 0.014 \text{ per dex}
\]
\[
\text{Change in } [\text{Na}/\text{H}] = -0.41 \pm 0.16 \text{ per dex}
\]
Summary

We looked for spatial variations in the stellar populations of 8 ETGs using KMOS data.

We recovered radial trends in the strengths of various IMF-sensitive absorption features.

Scenario in which the IMF does not vary radially favoured: trends in IMF sensitive feature strengths best explained by abundance gradients (including very steep sodium trend). Can’t exclude modest changes in the IMF.

Question: is the IMF bottom-heavy throughout massive ETGs, or is it simply Milky-Way-like after all? Challenges either way!