Gradient in the IMF slope and Sodium abundance of M87 with MUSE

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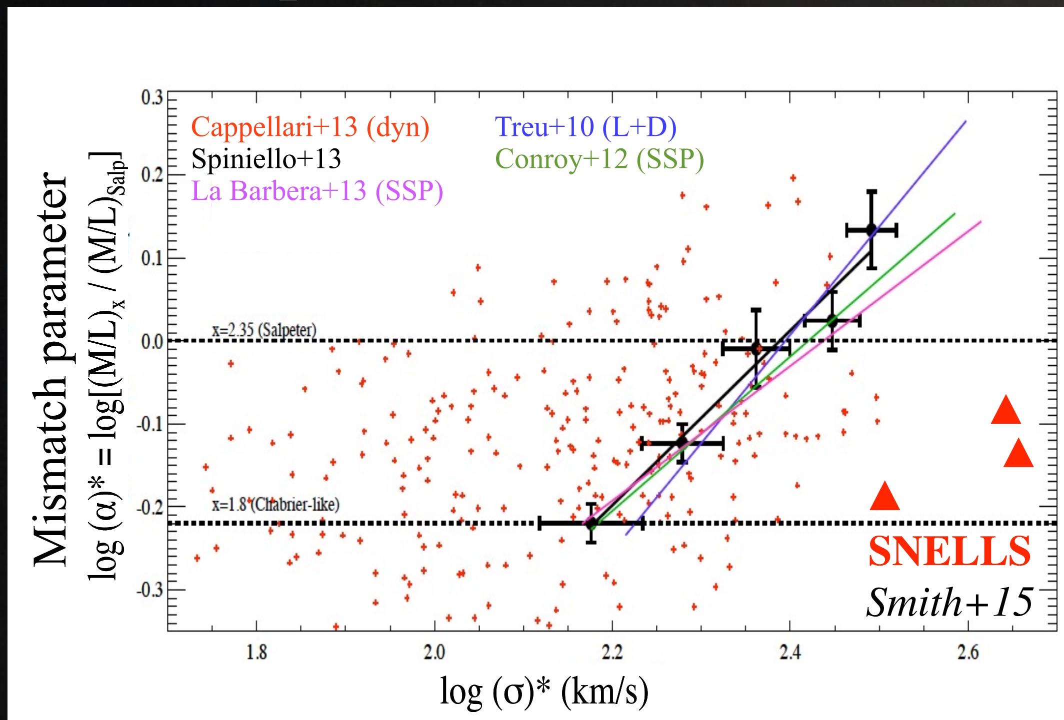
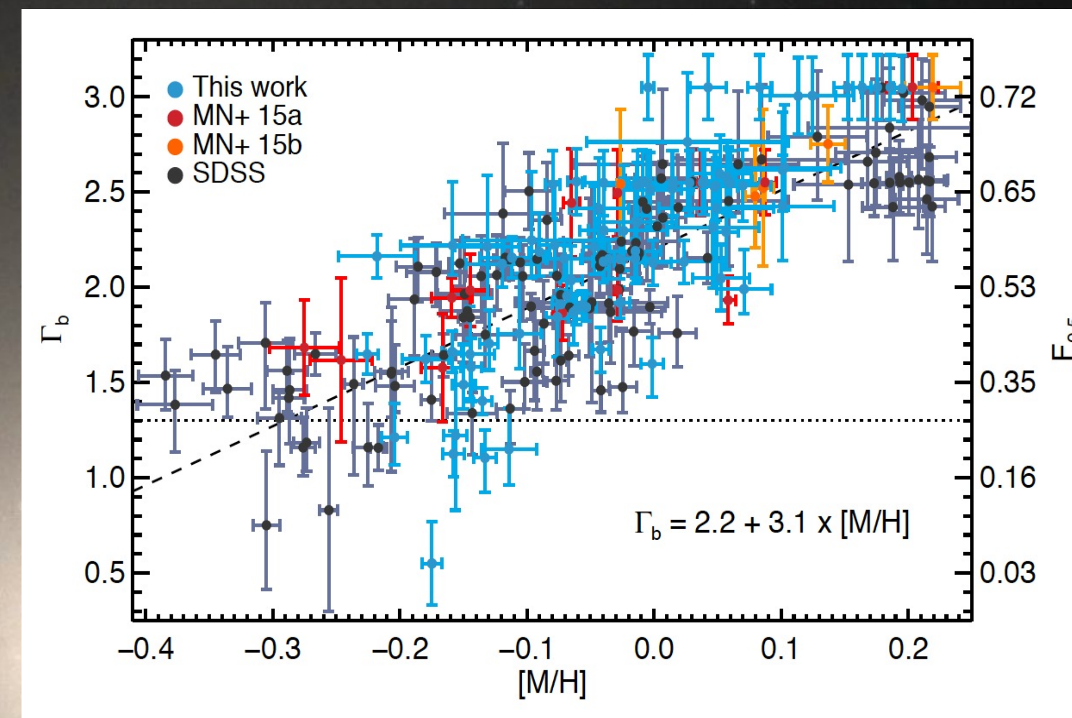
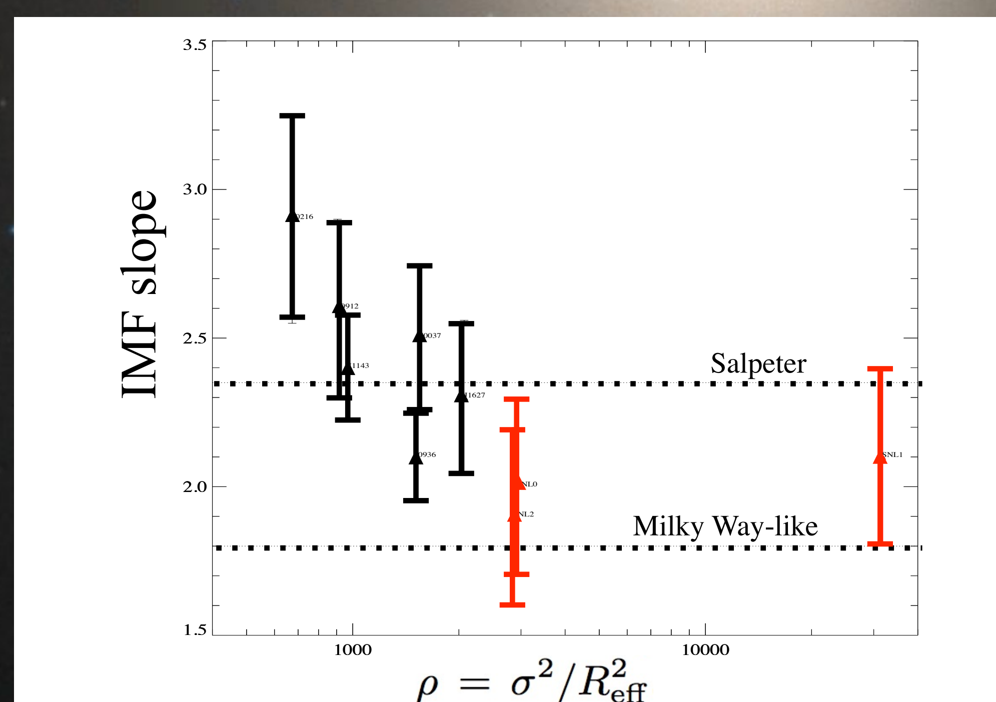
IS THE LOW-MASS END OF THE IMF UNIVERSAL?

- IMF-velocity dispersion
(Spiniello et al 2013)



- IMF-metallicity
(Martin-Navarro et al. 2015)





- IMF-total density
(*Spiniello et al. 2015b*)

WHAT DRIVES IMF VARIATIONS?

Mergers and accretion of galaxies with pre-enriched gas play an important role in the evolution of the most massive ETGs (e.g. Hopkins et al. 2007) ⟶ IMF steeper in the center and flatter in the outer region

we expect to see:

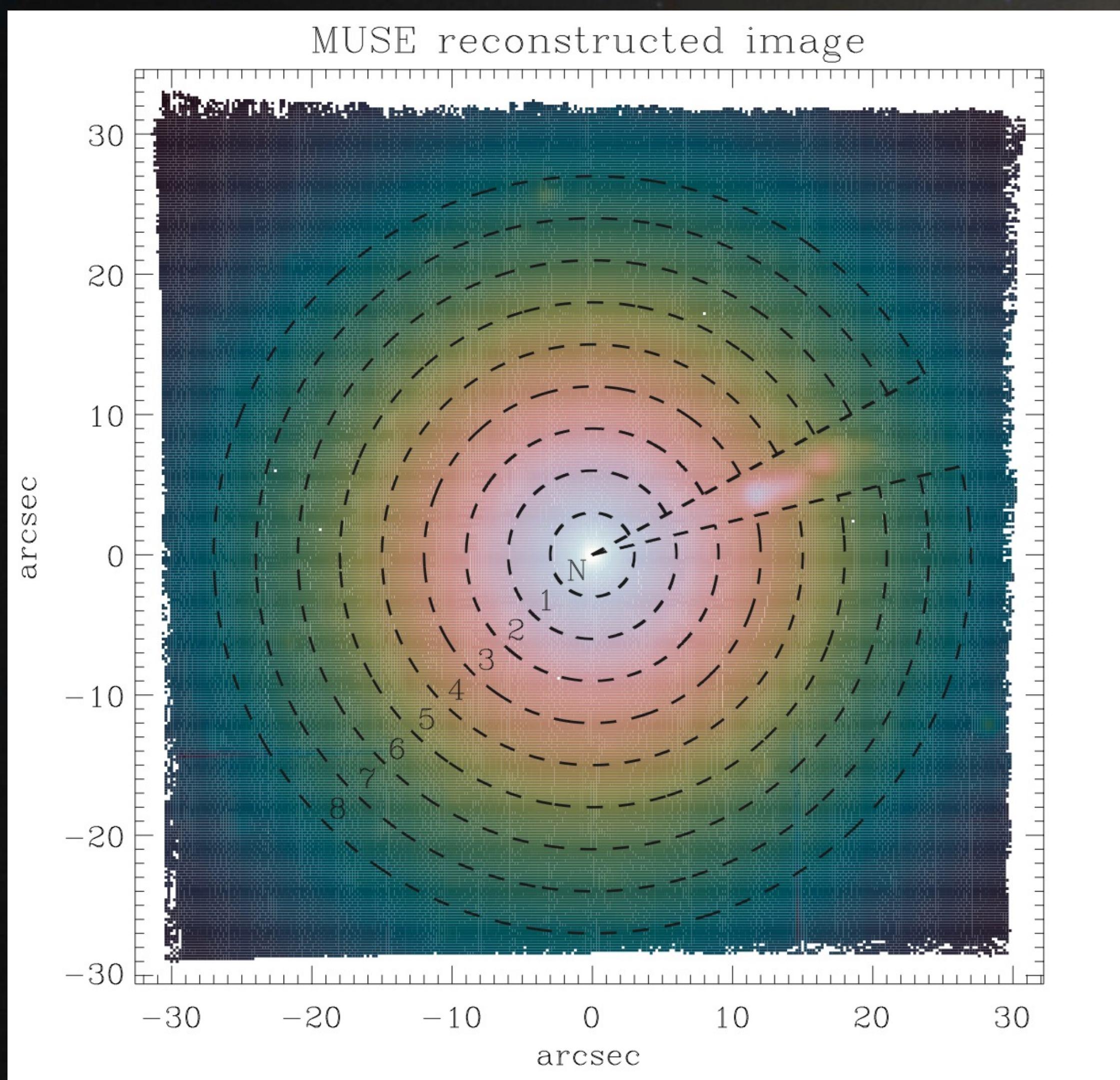
SPATIAL VARIATIONS IN THE IMF

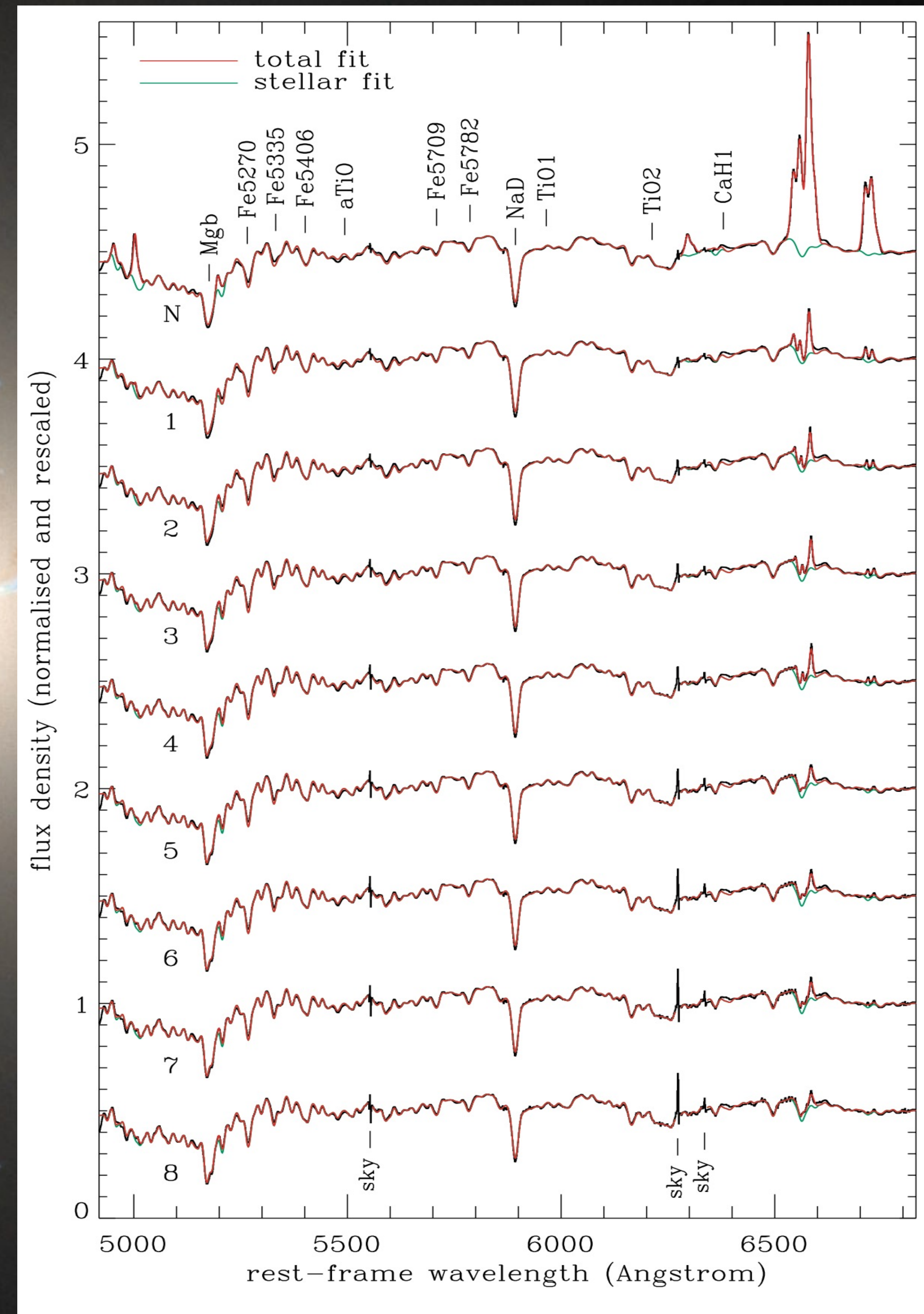
Is the perfect instrument thanks to :

- **integral field spectrography with big fov** —> spatial gradients within central region
- **spectral coverage** —> IMF-sensitive indices in the red, age and Z indices in the blue
- **sensitivity** —> High signal-to-noise spectra in few hours integration time

THE DATA

2x1800s exposure on target
2x 900s on sky
wavelength coverage 4800-9000A



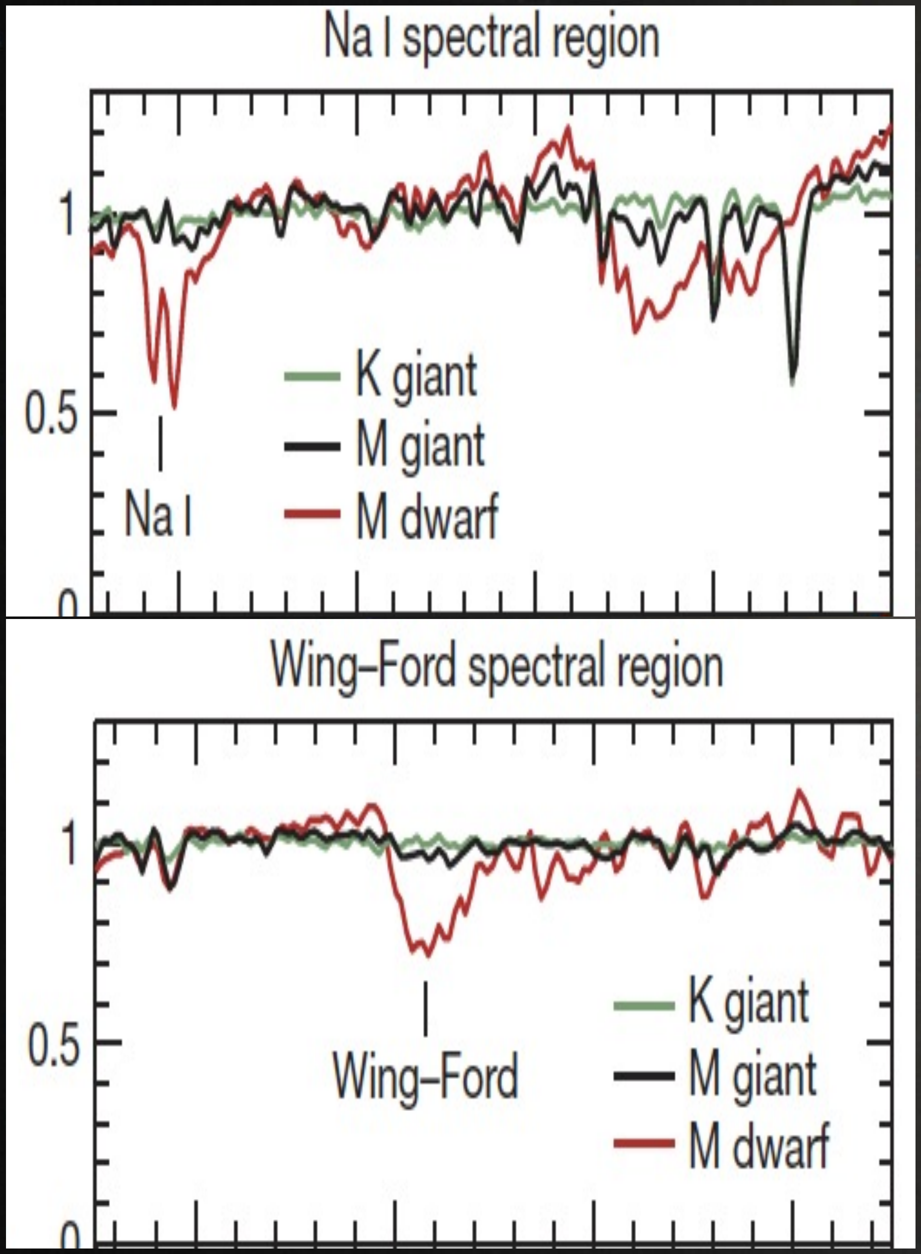


TWO APPROACHES

1. Nine anular aperture spectra (S/N > 2000)
2. Voronoi-binned spectra (target S/N = 300)

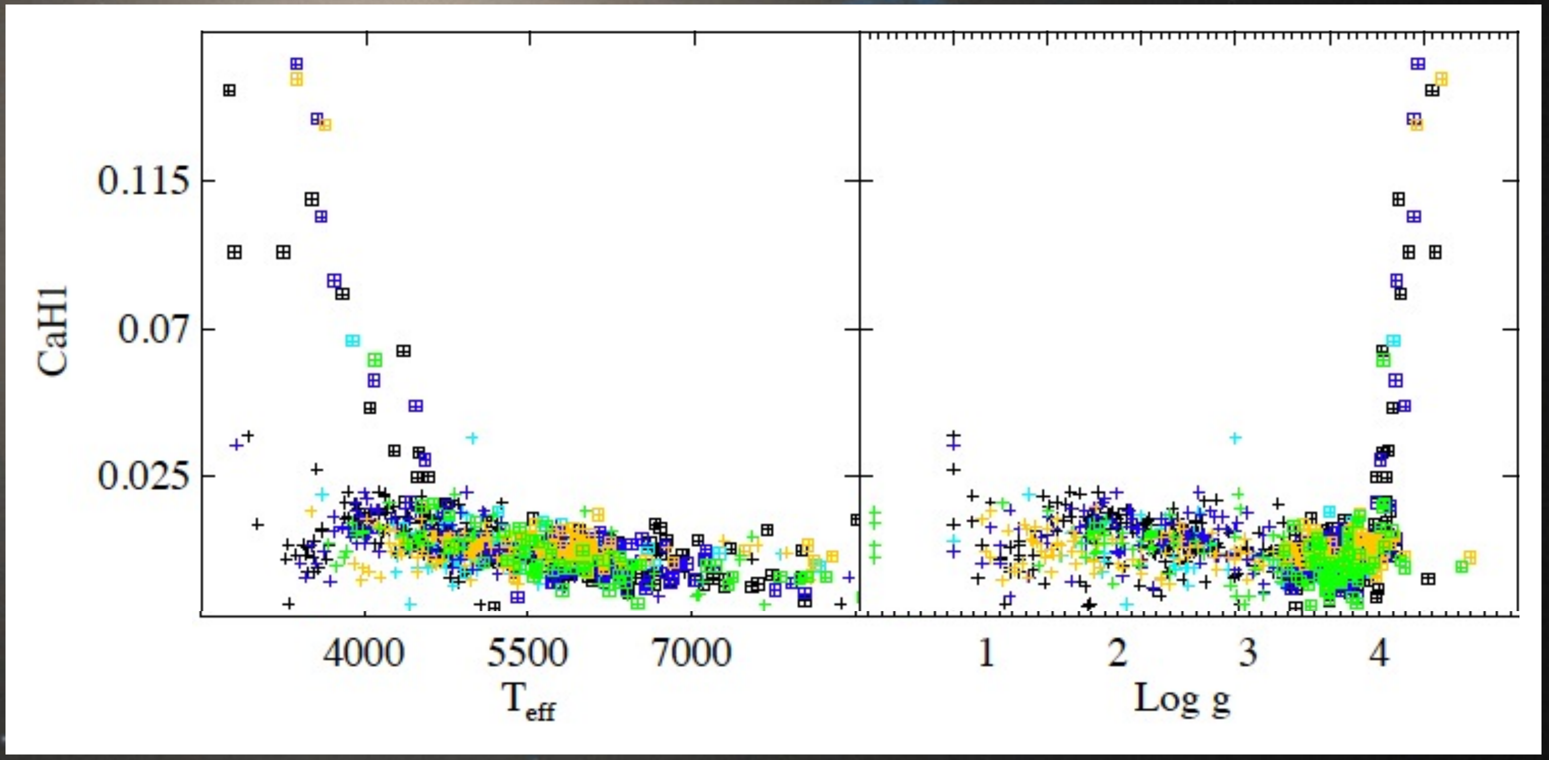
THE METHOD

- Measure <u>"IMF-sensitive"</u> features



(Conroy & van Dokkum 2012)

Equivalent Widths (EWs) strong only in COOL and DWARF stars



(Spiniello et al. 2013)

- At the same time, measure EWs of spectral absorption lines sensitive to metallicity, age, [α/Fe] (e.g. Hβ, Mg, Fe)

THE METHOD

▸ Compare EWs of each spectrum with EWs of SSP models varying IMF, metallicity and [α/Fe] :

11 [α/Fe] {-0.1 - +0.4, step 0.05} × 18 IMF{1.8 - 3.5, step 0.1} × 20 [Z/H] {-0.4 - +0.1, step 0.05}

Age fix to 11 Gyrs (Montes et al. 2014) —> Hβ is contaminated by emission

No age-gradients reported for M87

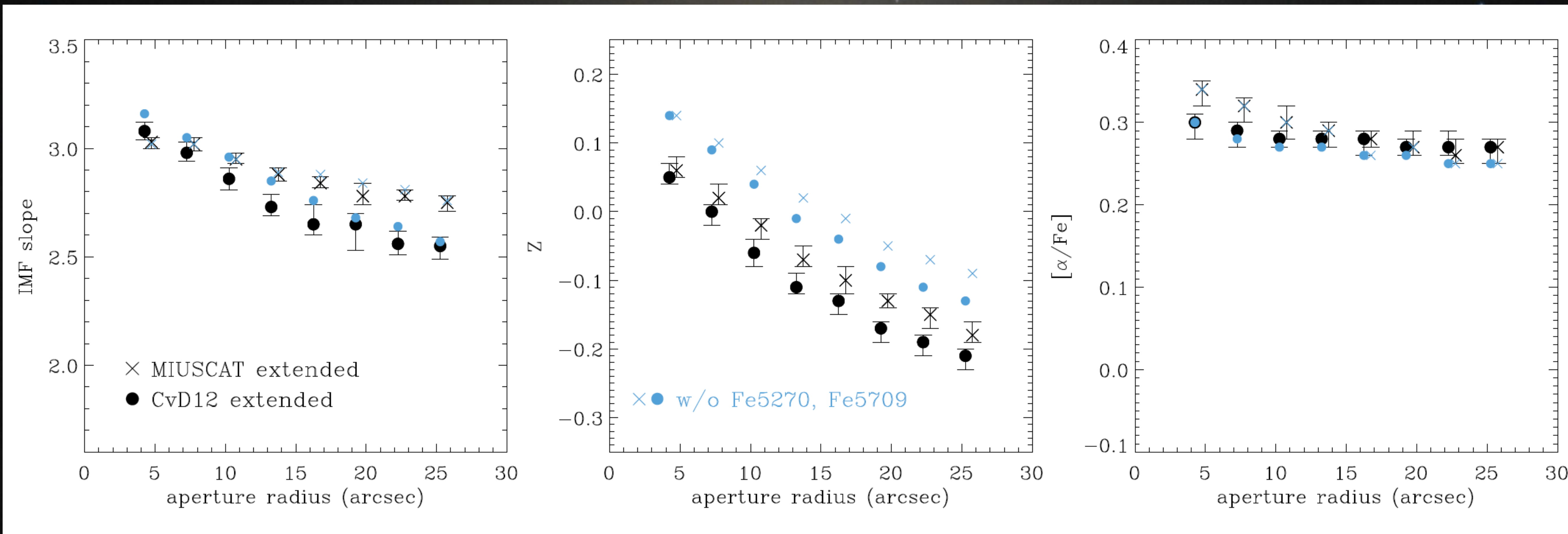
Chi-square:

$$\chi_n^2 = \sum_{ind=1}^{10} \chi_{ind,n}^2 = \sum_{ind=1}^{10} \frac{(EW_{ind} - EW_n)^2}{\sigma_{EW_{ind}}^2}$$

▸ Obtain the best-fit parameters for each spectrum (for both aperture and voronoi spectra)

RESULTS:
STELLAR POPULATION GRADIENTS

- **Aperture results**



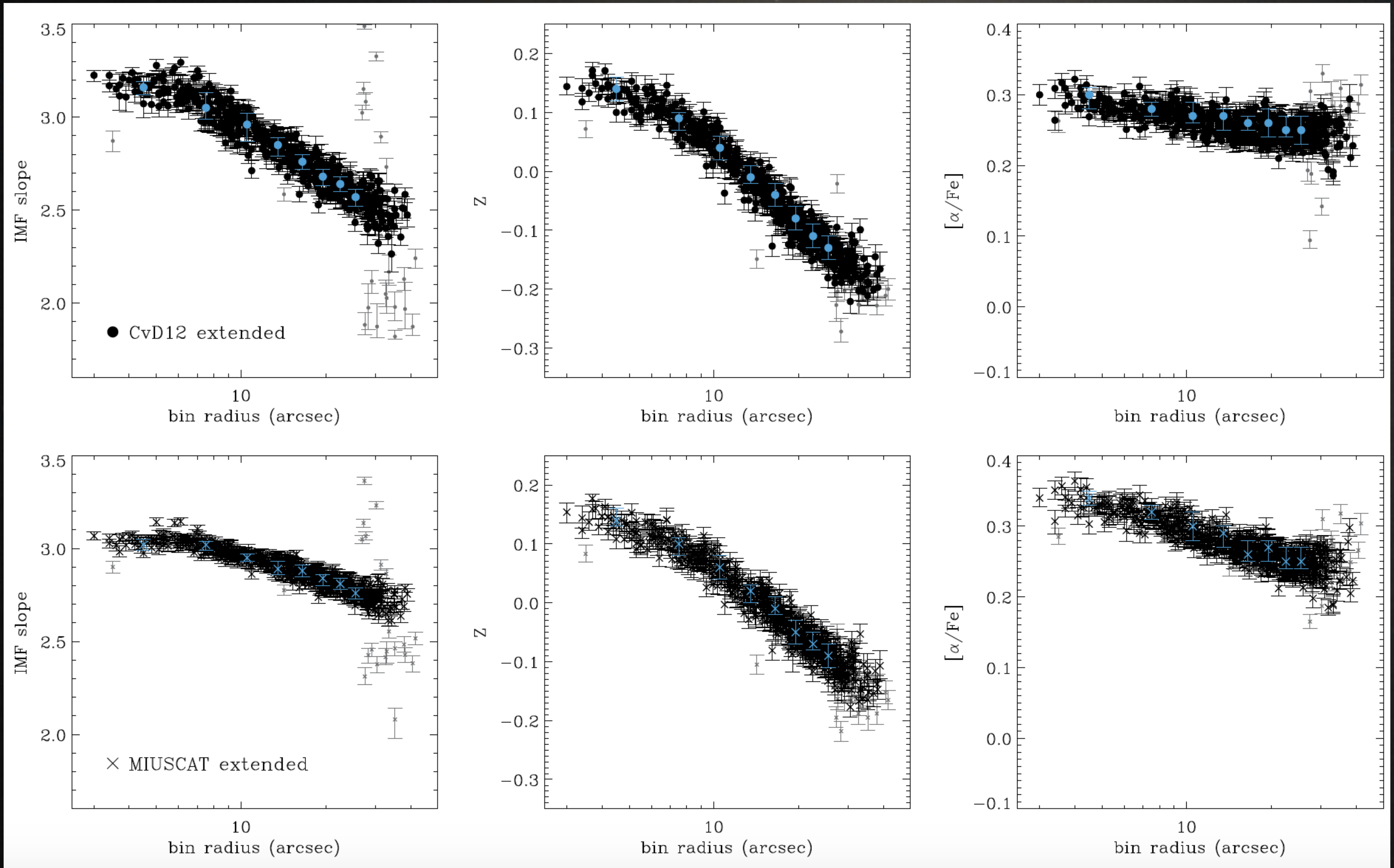
IMF gradient depends on the adopted SSP models

Strong metallicity gradient with offset that depends on the adopted set of indices

Flat [α/Fe] profile (supersolar everywhere)

RESULTS:
STELLAR POPULATION GRADIENTS

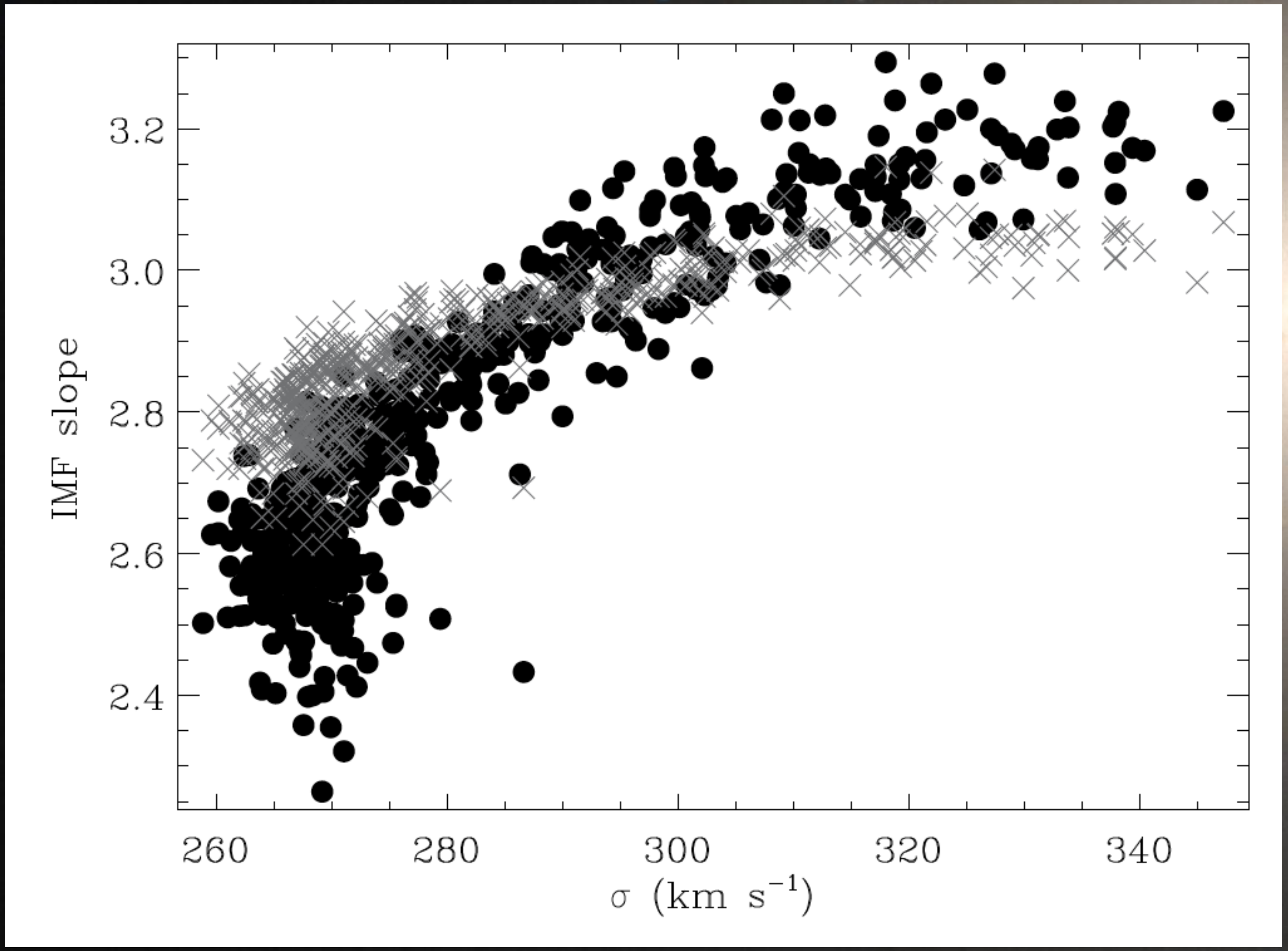
- Voronoi bin results



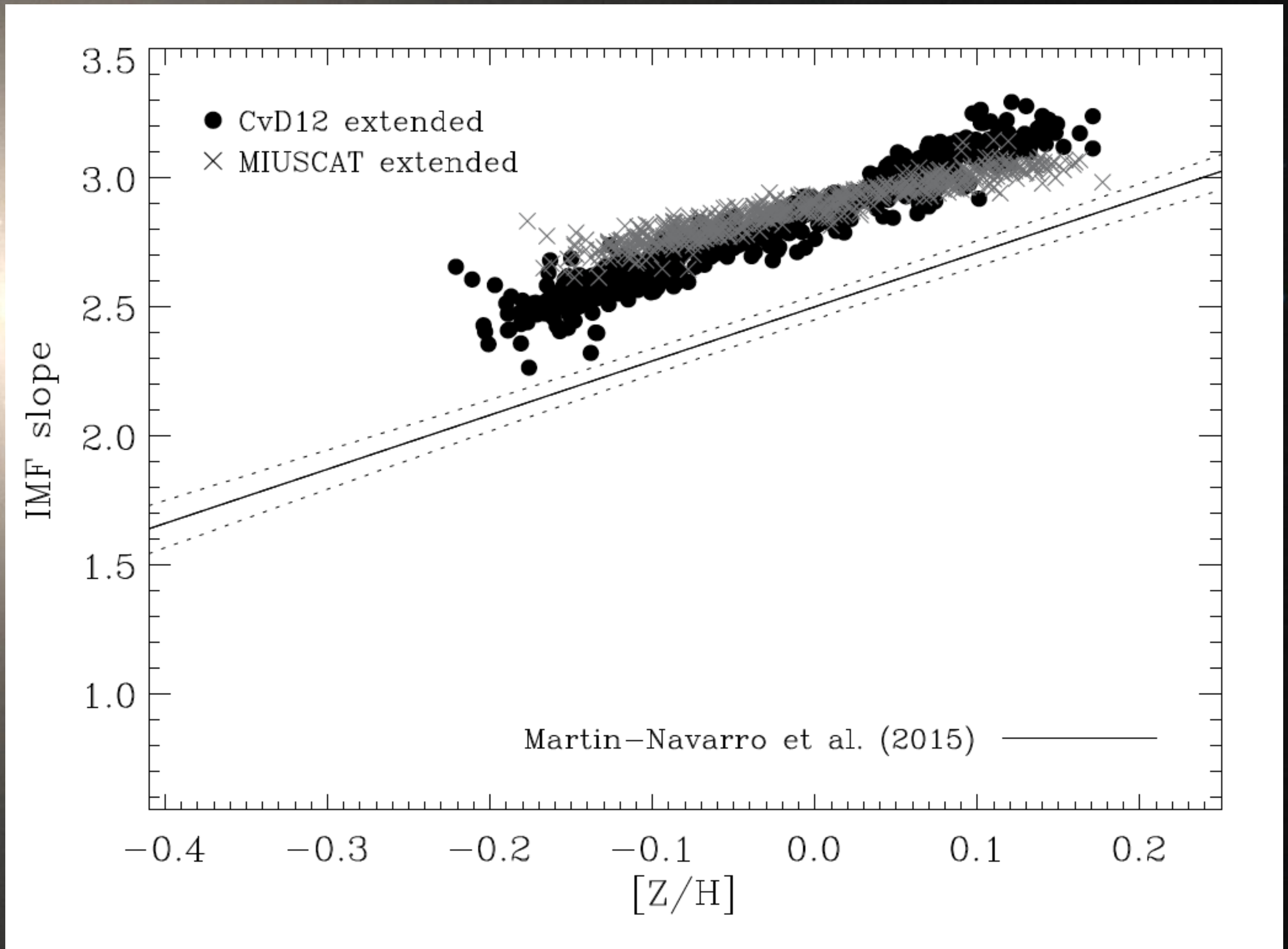
There's more structure in the radial profiles, in particular in the innermost regions

RESULTS: IMF GRADIENTS

- IMF gradients does not follow velocity dispersion

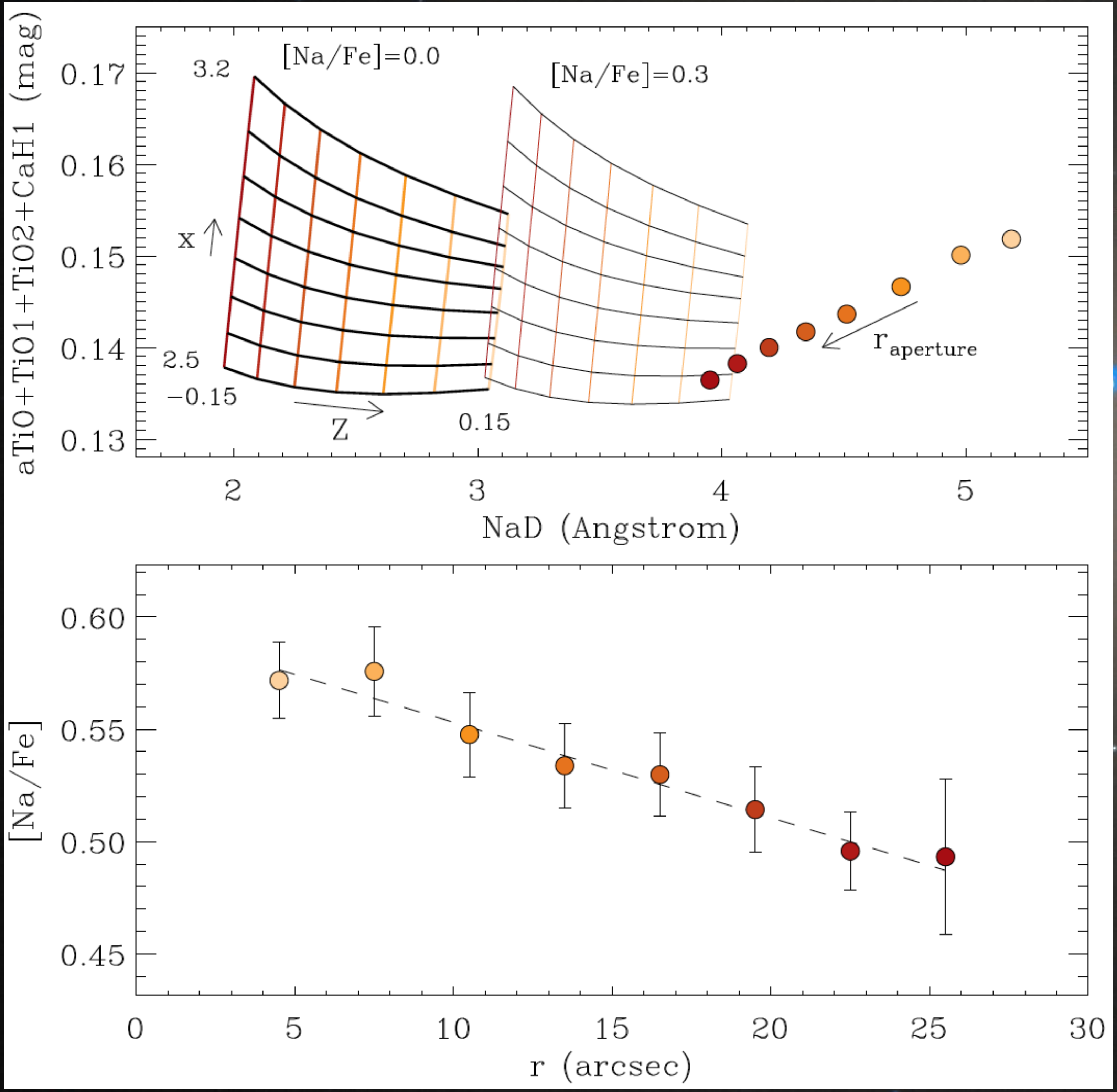


- IMF gradient runs parallel to metallicity gradient.



RESULTS: [Na/Fe] GRADIENTS

- [Na/Fe] varies a lot in M87 and it is super-solar everywhere



Super-solar [Na/Fe] expected for ETGs, formed through short star-formation events

(Observed already by: Zieleniewski et al. 2015, Jeong et al. 2013; Park et al. 2015).

Variation in [Na/Fe] should be taken into account when using Na features to measure IMF gradients

CONCLUSIONS

GRADIENTS IN THE STELLAR POPULATION OF M87 WITH MUSE

1. **Strong metallicity gradient**

2. **IMF gradients** (steepness depends on adopted SSP models and used set of indices)
   - The IMF slope follows better the V_{esc} than the velocity dispersion
   - IMF and metallicity gradients very similar (also Z follows V_{esc})

3. **Strong [Na/Fe] gradients**

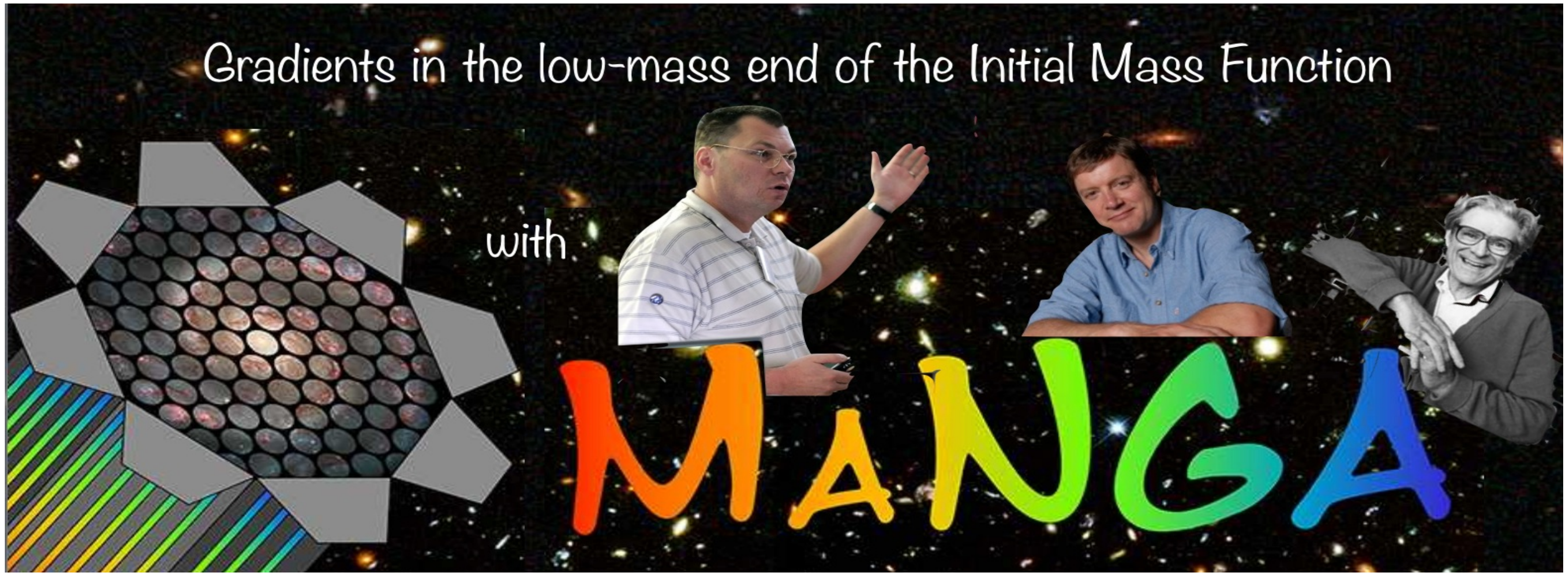
4. **Na and α are enhanced everywhere** —> short and quick star-formation events

FUTURE WORK

- SPATIALLY-RESOLVED IMF TO UNDERSTAND WHAT DRIVES IMF VARIATION

MUSE (IFU) Data
(with Dr. N.Napolitano)

CALIFA (IFU) Data
(with G.Mensinga)



- SEARCHING FOR NEW IMF-INDICATORS IN NIR X-SHOOTER SPECTRA

CaT (λ8600), Wing Ford Band (λ9916), CaI (λ19800), CO (λ 23000)

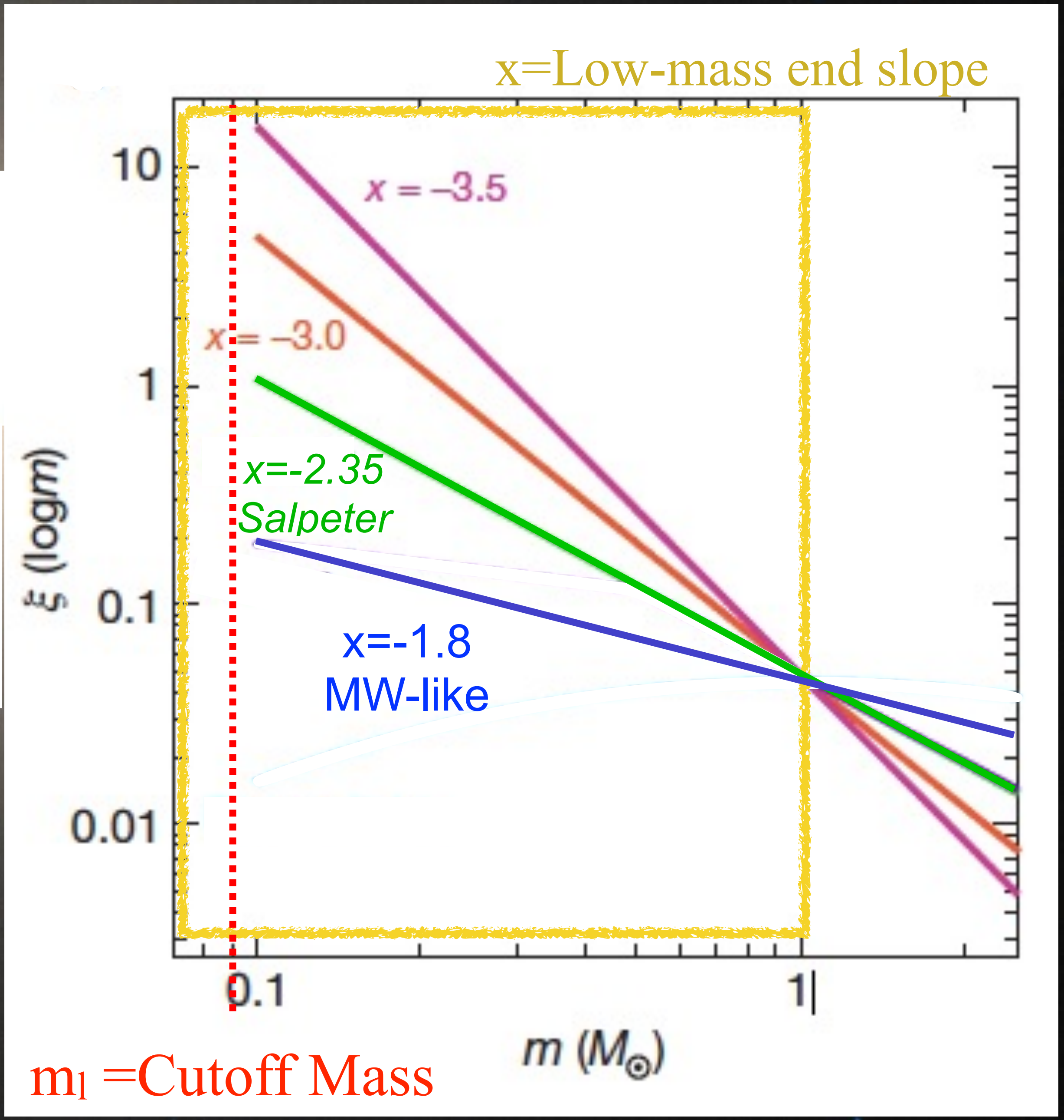
Introduction
What is the Initial Mass Function?

The number of stars formed at any given mass in a *single burst* of star formation

$$\Phi(m) = \frac{dN}{dm} \propto m^{-x}$$

$$f(\lambda) = \int_{m_l}^{m_h(t)} s(\lambda, m)\,\phi(m)\,dm$$

In ETGs with old (>8-9 Gyr) stellar population … stars with masses above 1-1.5 solar masses are dead



THE LOW CUTOFF MASS

Using a (or more) set of isochrones and stellar libraries stellar population synthesis models construct the integrated light spectra:

$$f(\lambda) = \int_{m_l}^{m_h(t)} s(\lambda, m)\,\phi(m)\,dm$$

where φ(m) is the <u>IMF</u>:

$$\Phi(m) = \frac{dN}{dM} = M^{-x}$$

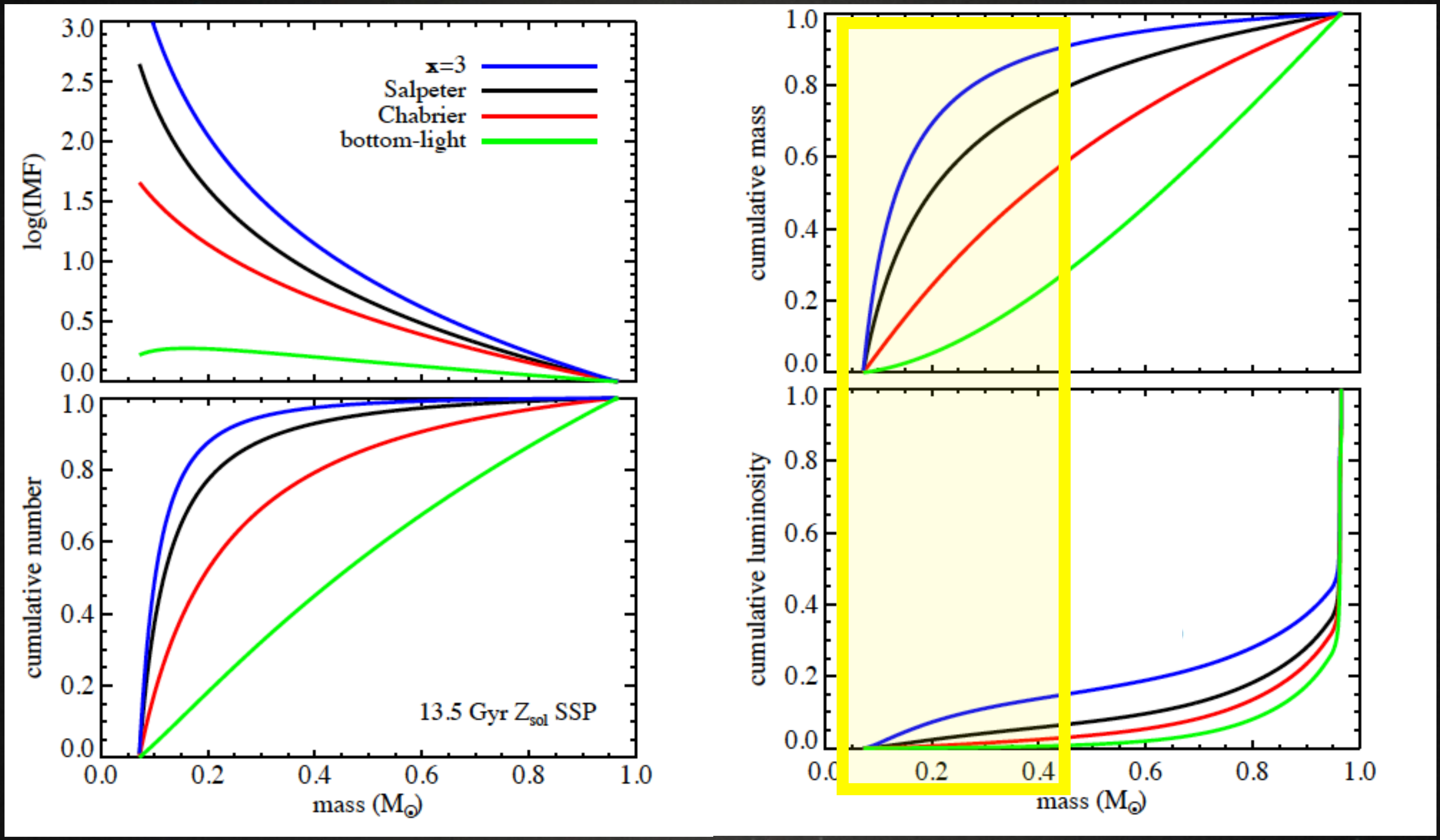
LOWER-MASS LIMIT

<u>Until now fully unconstrained parameter, despite critical to determine stellar M/L.</u>

<u>Different codes -> different assumptions !!!</u>

<u>Impossible to determine Mlow from spectroscopic studies alone</u>

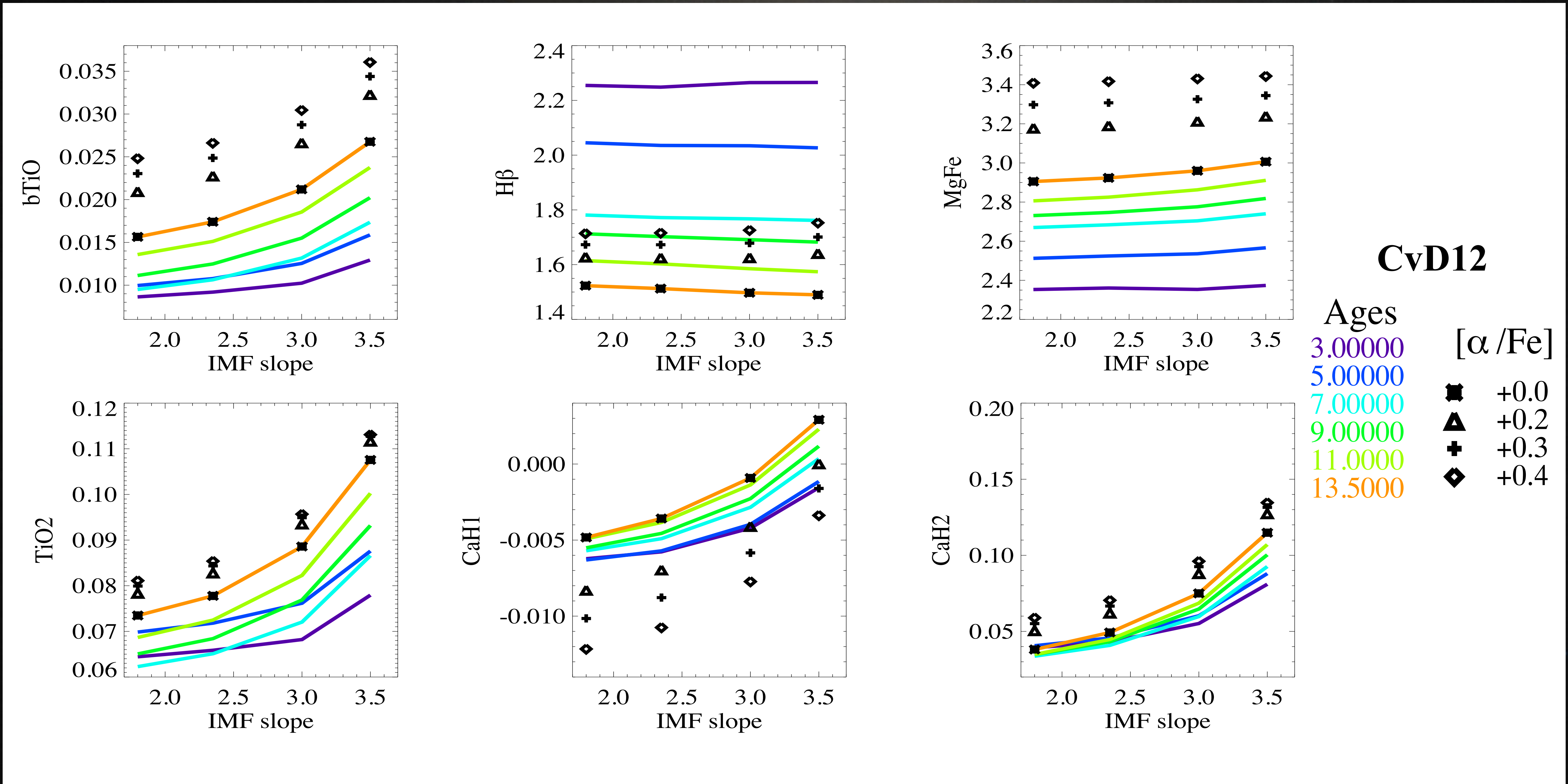
Introduction
WHY IS THE LOW-MASS END IMPORTANT?

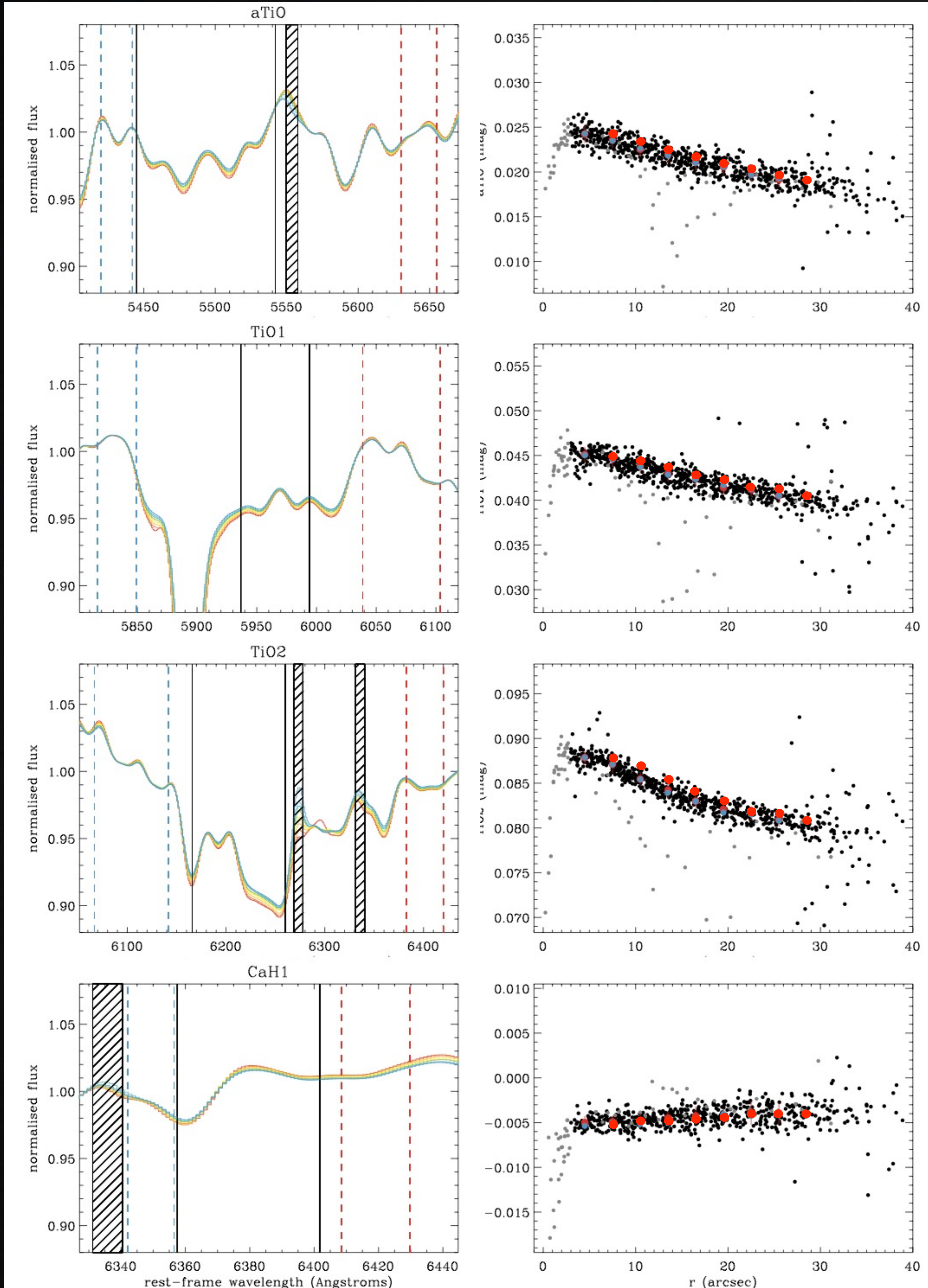


Dwarf stars are critical for the stellar mass-to-light ratio (M/L)
Observational evidence suggests that the M/L increases with galaxy mass…

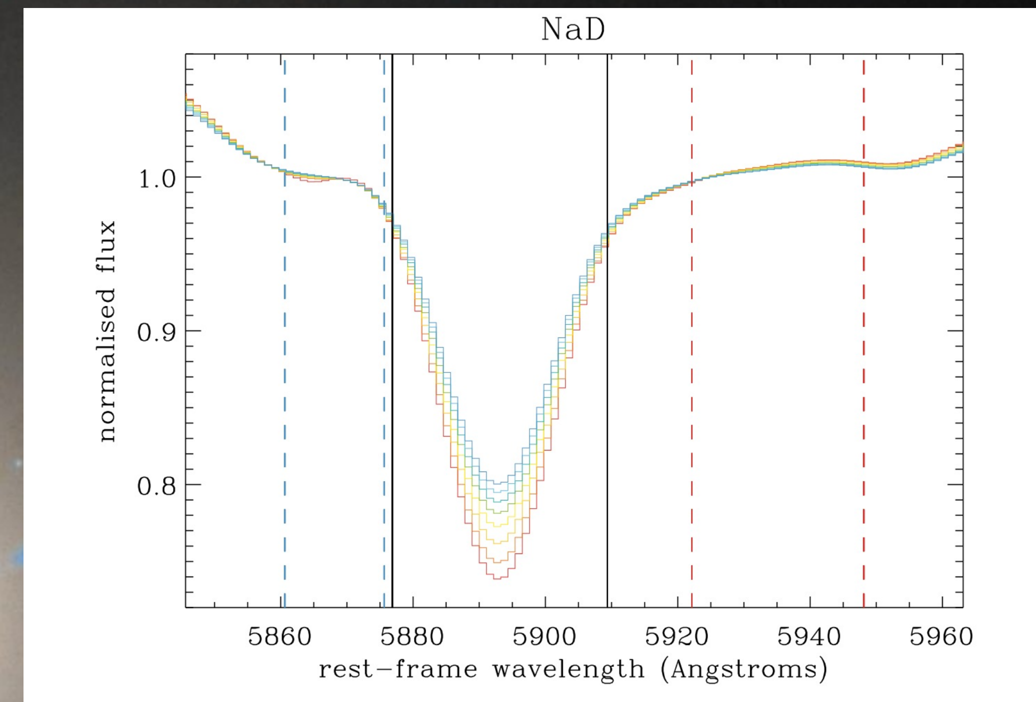
THE METHOD

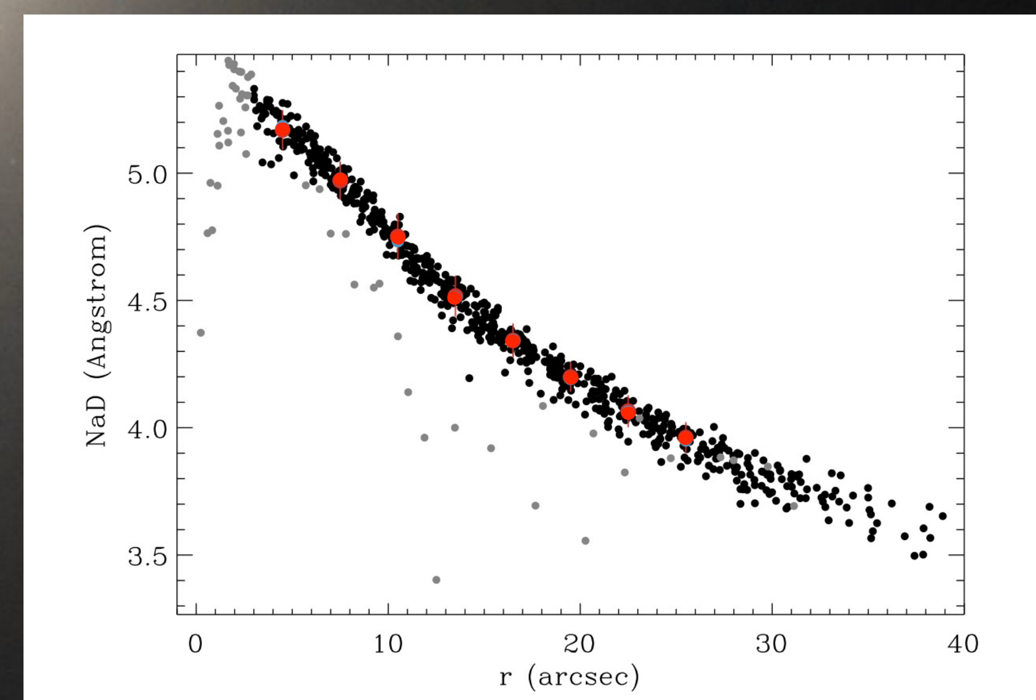
- Study their behaviour in single stellar population models (SSP)





INDICES VARIATIONS

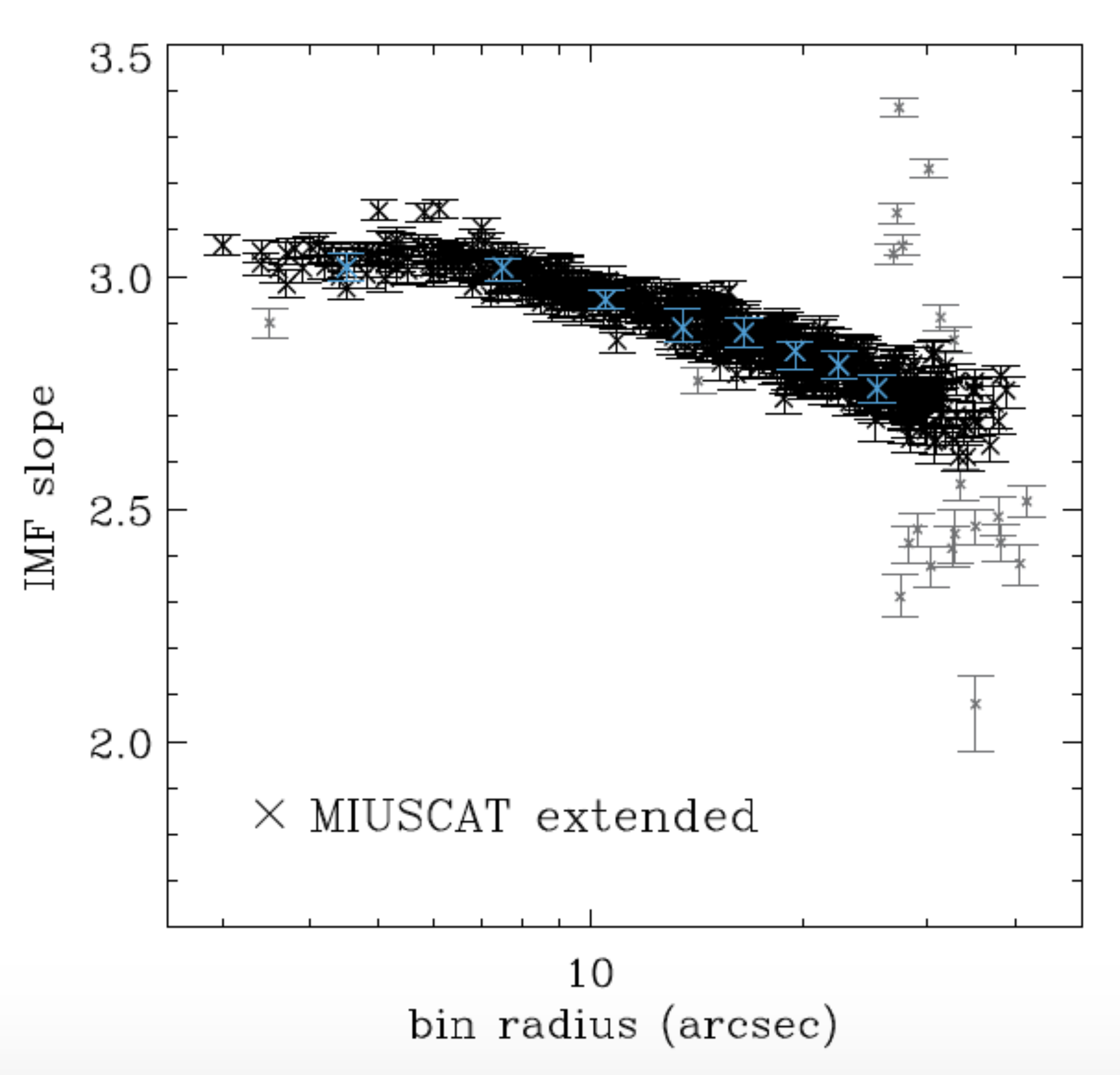


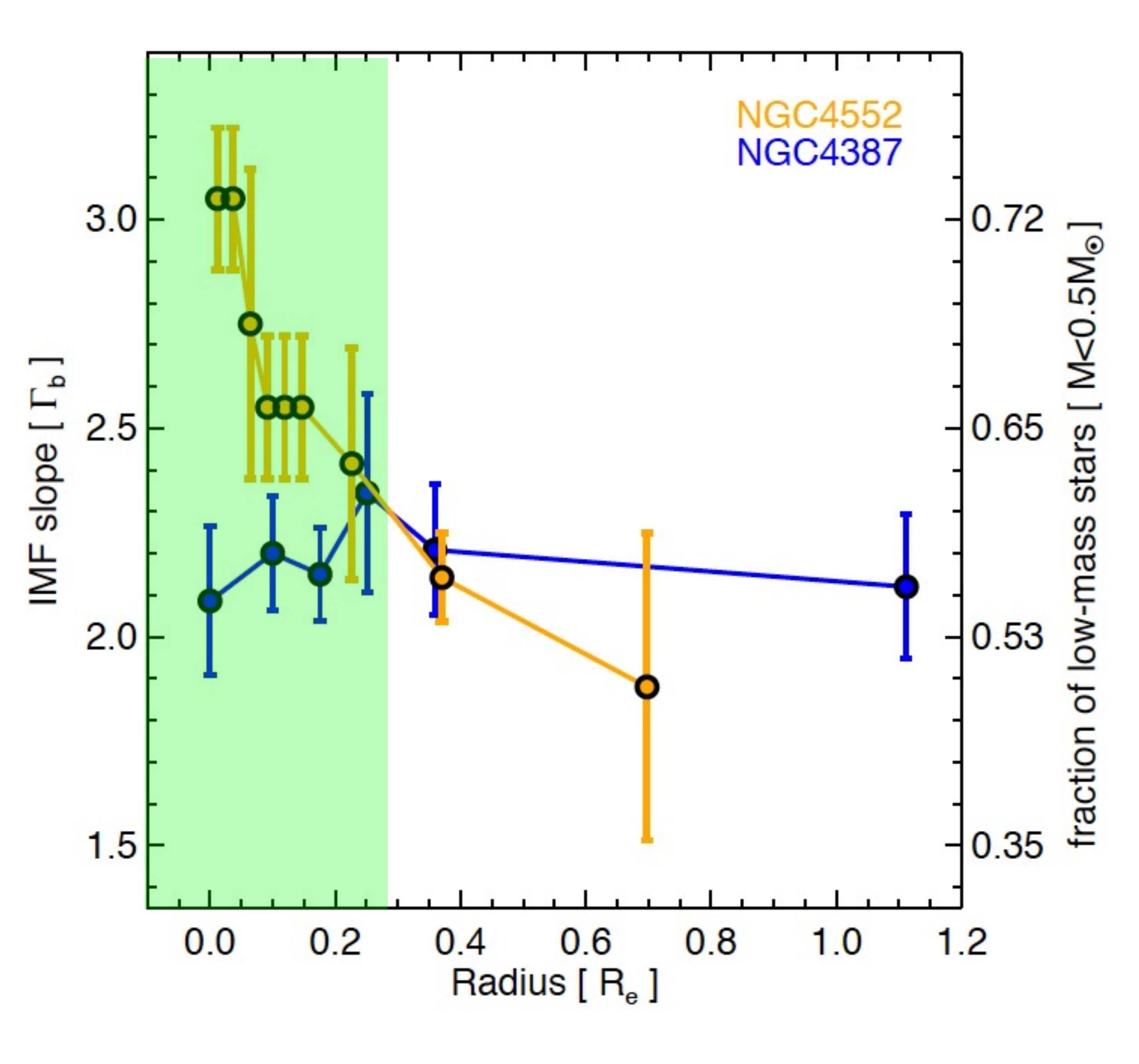


RESULTS: IMF GRADIENTS

- Comparison with literature results

Martín-Navarro et al. (2015a) found similar gradient in the IMF slope of a massive ETG





These results naturally explains the IMF-central velocity dispersion relation of ETGs, as a luminosity-weighted average of the underlying IMF radial gradient *to overcome this limitation … we build*

RESPONSE FUNCTIONS

to Z

from MIUSCAT

$$\Delta Z(\tau, x) = \frac{\mathrm{MIU}(\tau, x, Z)}{\mathrm{MIU}(\tau, x, Z_{\odot})}$$

to [α/Fe]

from CvD

$$\Delta[\alpha/\mathrm{Fe}](\tau, x) = \frac{\mathrm{CvD12}(\tau, x, [\alpha/\mathrm{Fe}])}{\mathrm{CvD12}(age, x, [\alpha/\mathrm{Fe}]_{\odot})}$$

EXTENDED MODELS

$$\mathrm{MIU}_{\mathbf{ext}}(\tau, x, [\alpha/\mathrm{Fe}]) \equiv \mathrm{MIU}(\tau, x) \times \Delta[\alpha/\mathrm{Fe}](\tau, x),$$

$$\mathrm{CvD12}_{\mathbf{ext}}(\tau, x, Z) \equiv \mathrm{CvD12}(\tau, x) \times \Delta Z(\tau, x)$$

DIFFERENT MODELS DIFFERENT ANSWER?

For most of the gravity-sensitive indicators

(bTiO, TiO2, CaH1, CaT)

the two SSP models give similar prediction of the IMF slope variation with velocity dispersion.

DIFFERENT MODELS DIFFERENT ANSWER?

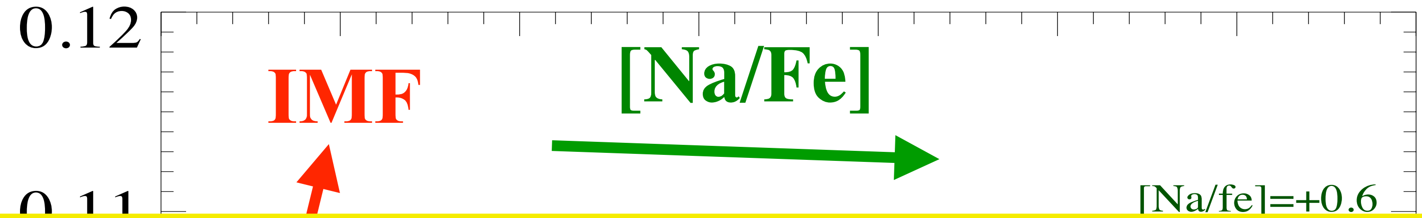
For Na indices

Slopes derived using NaD go against the upper-limit set by Strong Gravitational Lensing

THE SODIUM INDICES

[Na/Fe] vs IMF variation

Massive ETGs are Na-enriched



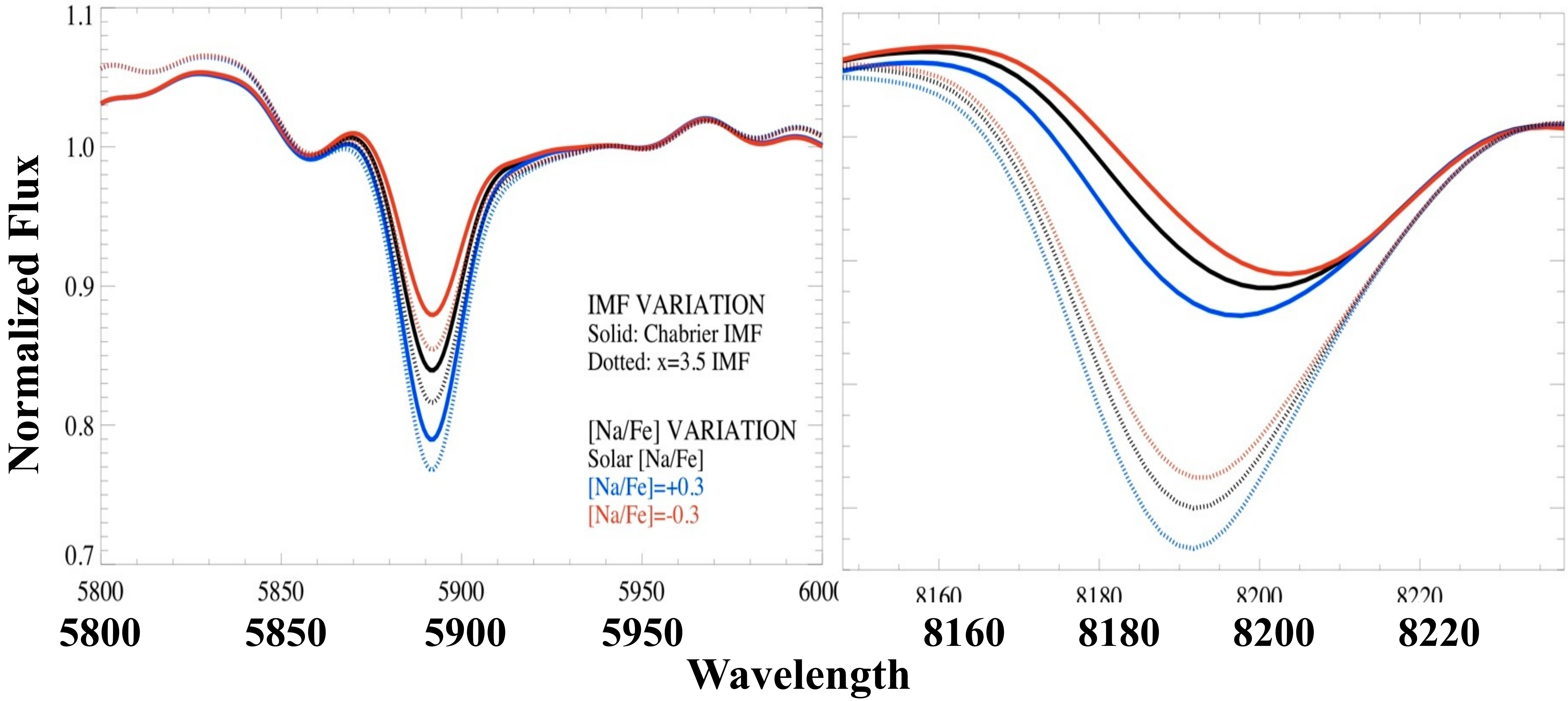
<u>Elemental abundance pattern is crucial !!!</u>

$$\left(\frac{\Delta \mathrm{IMF}}{\Delta[\mathrm{Na/Fe}]}\right)_i = \frac{I_i(x=3.5)_{[\mathrm{Na/Fe}]=0} - I_i(x=1.8)_{[\mathrm{Na/Fe}]=0}}{\langle I_i([\mathrm{Na/Fe}]=+0.3) - I_i([\mathrm{Na/Fe}]=-0.3)\rangle_{x=[1.8-3.5]}}$$

Spiniello et al. 2014b

WHAT IS GOING ON WITH NaD ?

The Sodium indices: [Na/Fe] vs IMF variation



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Index	ΔIMF/Δ[Na/Fe]
NaD	0.29
Na I	4.21

Spiniello et al. 2014b