Stellar populations in the cD galaxy NGC 3311

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Introduction

Cluster MACS J0717.5+3745

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- Galaxy clusters are large concentrations of galaxies, where thousands of galaxies live and interact.
- Almost every one of these dots is a distant galaxy that is bound to the same cluster; each of these galaxies is the home to billions of stars.
- The innermost regions of clusters host some of the largest galaxies of the universe: the Brightest Cluster Galaxies (BCGs).

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  - May be used to constrain models of galaxy formation, such as the two-phase scenario (de Lucia & Blaizot 2007; Oser+2010).
- The following material is based on Barbosa+2016 (accepted) and Hilker+2016(in prep.).

Dresler 1979

THE DYNAMICS AND STRUCTURE OF THE cD GALAXY IN ABELL 2029

ALAN DRESSLER
Hale Observatories,* Carnegie Institution of Washington
Received 1979 January 11; accepted 1979 February 9

ABSTRACT

Spectra of the envelope of the cD galaxy in A2029 out to over 100 kpc have been obtained with the Hale 5 m and the SIT digital spectrograph. A Fourier cross-correlation program was used to measure the position, strength, and width of the H and K lines of Ca II and the G band. From these data it is concluded that the galaxy is not supported by rotation and that the line strength and implied metal abundance are relatively constant throughout the envelope.

The primary result is that the velocity dispersion is *increasing* as a function of radius in the galaxy, in contradiction with the prediction of constant $\mathfrak{M}/L$ models. A rough dimensional argument suggests that $\mathfrak{M}/L_V$ has risen from its nuclear value of ~ 12 to $\sim 67\ \mathfrak{M}_\odot/L_\odot$ at $R \approx 100$ kpc.

We present a detailed three-component isotropic King model which accounts for the luminosity profile of the cD galaxy and the increasing velocity dispersion, and provides the mass necessary to bind the cluster. The three components are interpreted as (1) a normal elliptical galaxy ($\mathfrak{M}/L_V \approx 10$) which has acquired (2) a halo of luminous material ($\mathfrak{M}/L_V \approx 35$) through the accretion of other cluster members, positioned in the middle of (3) a dark ($\mathfrak{M}/L_V > 500$) cluster-filling and cluster-binding superstructure. This superstructure may be composed of material which at one time belonged to individual cluster galaxies.

The necessity of determining whether cD galaxies are uniquely associated with the dynamical centers of rich clusters is discussed in connection with the model.

Subject headings: galaxies: clusters of — galaxies: internal motions — galaxies: structure

Dresler 1979

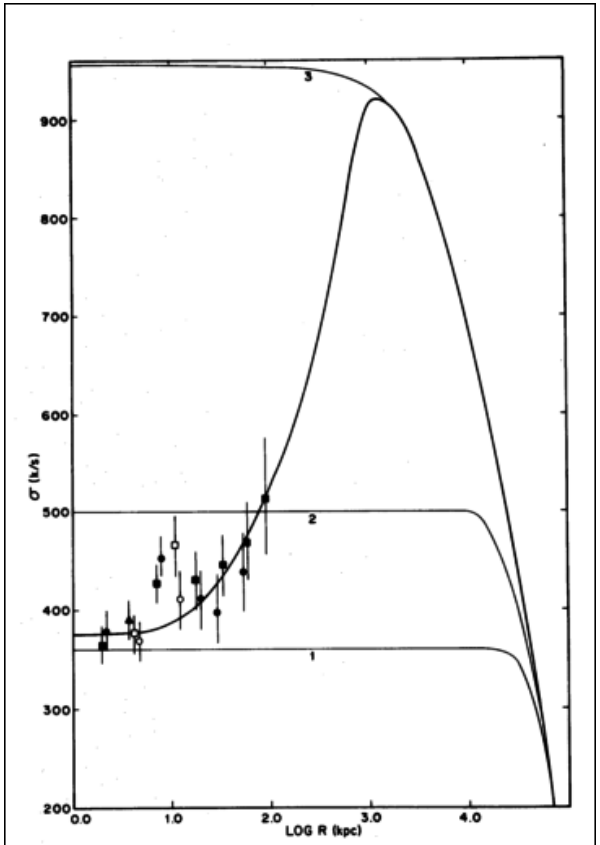
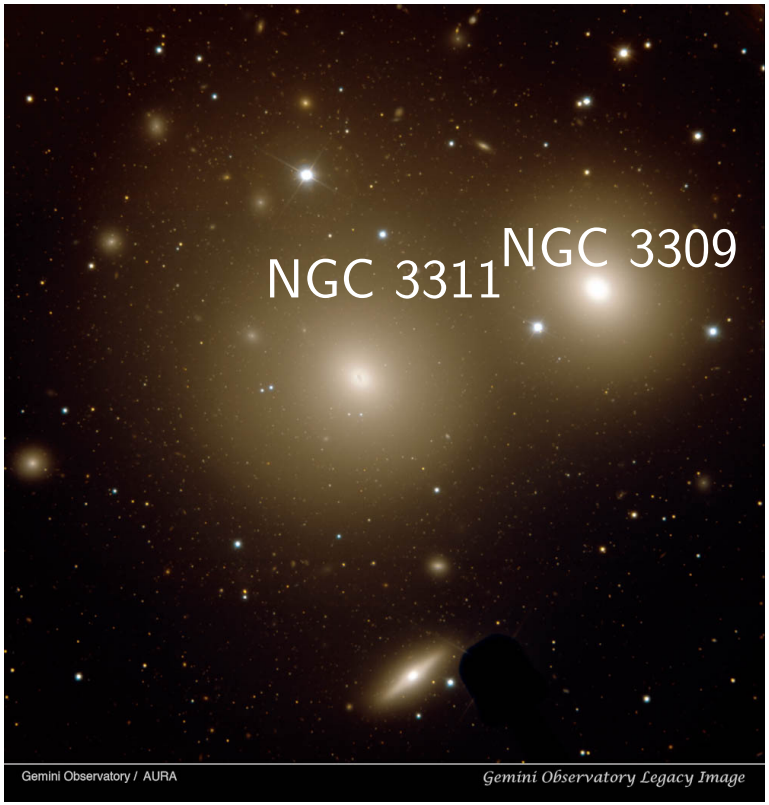


FIG. 6b

- The interpretation is that cD galaxies are formed by tidal stripping of neighbor galaxies (White 1976, Ostriker and Tremaine 1976); or
- luminouus but normal elliptical galaxies in a sea of material stripped from cluster galaxies (Richstone 1976).
- *"increase in velocity dispersion is a necessary (but not sufficient) condition of the stripped debris hypothesis."* (Dressler 1979)

Observational properties of NGC 3311

- Central galaxy of the cluster Abell 1060 (Hydra cluster) at $D \approx 50$ Mpc ($R_e \approx 8.4$ kpc).



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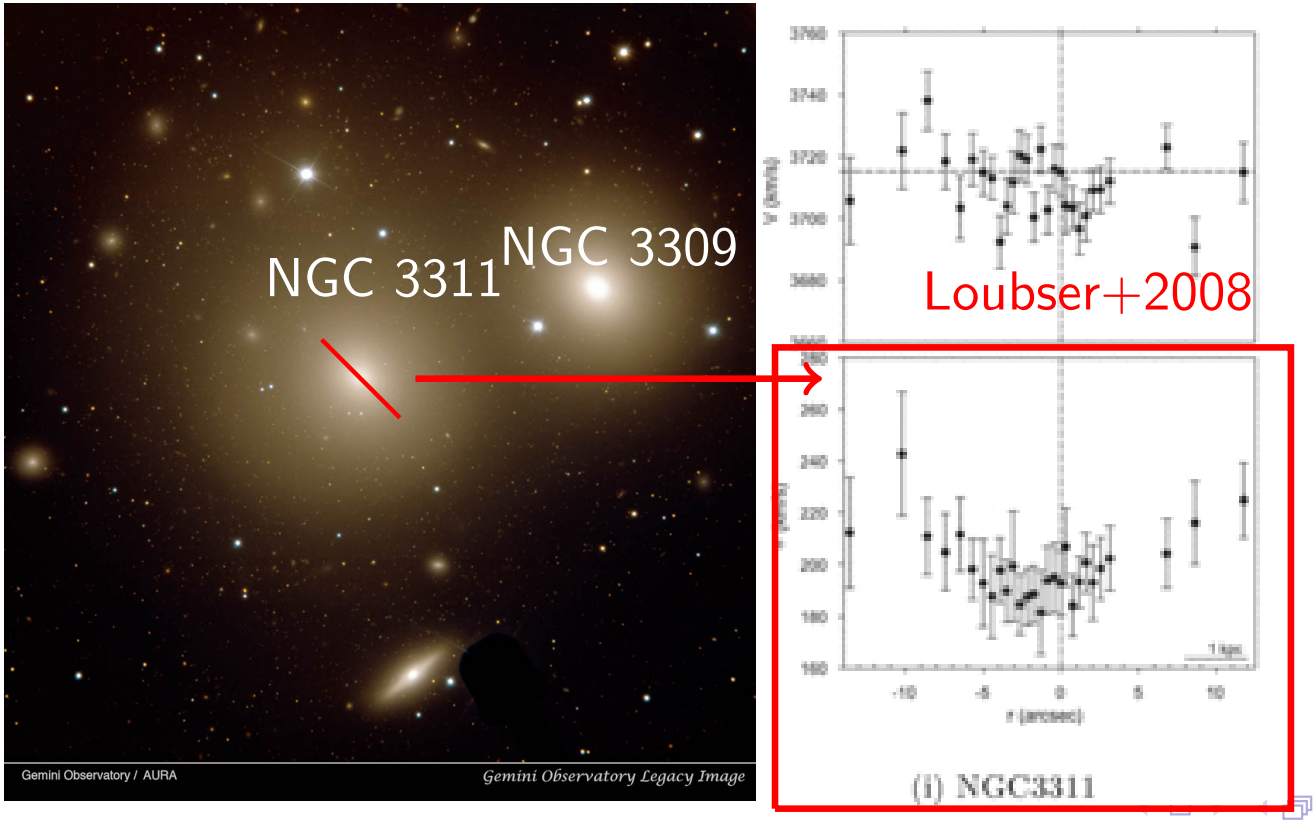

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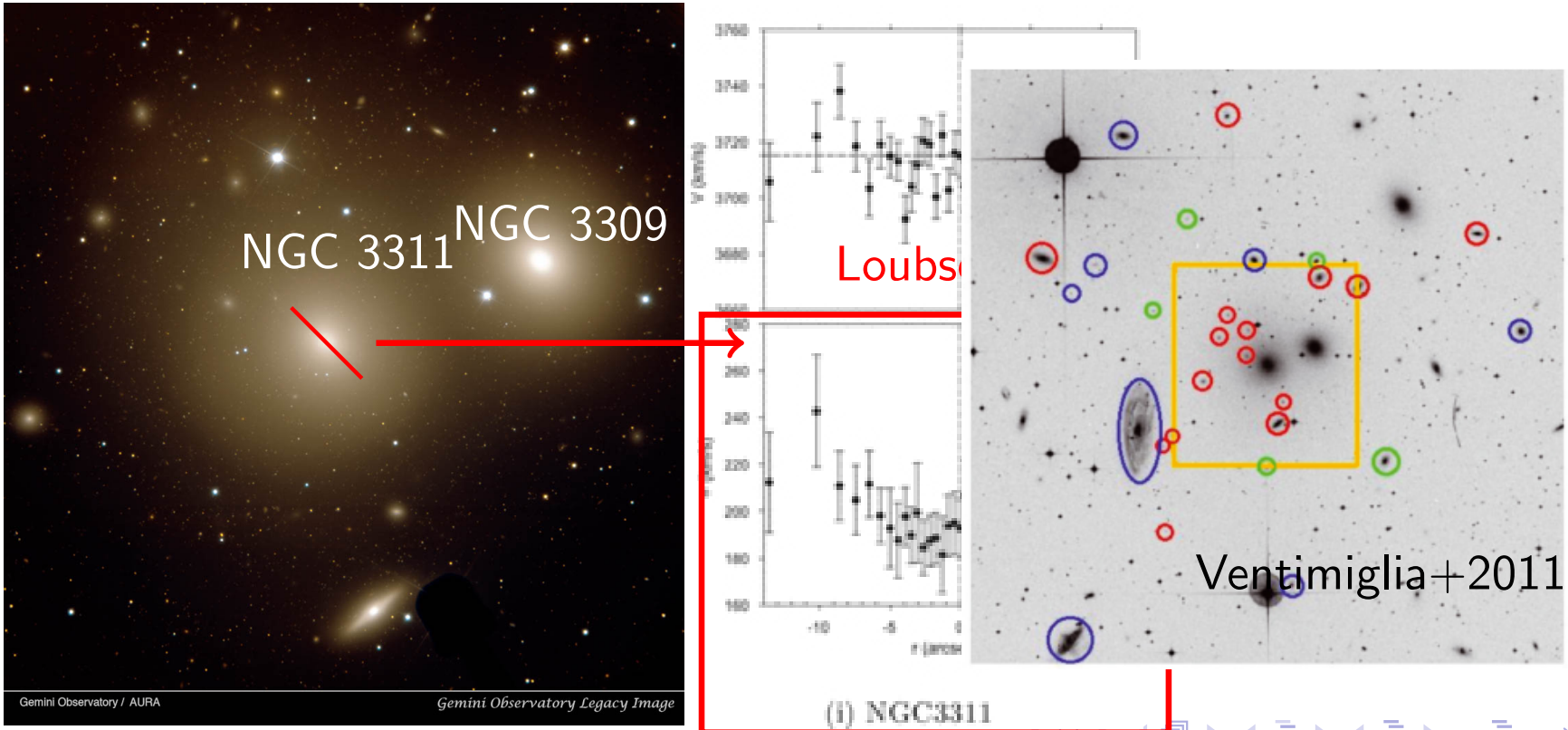
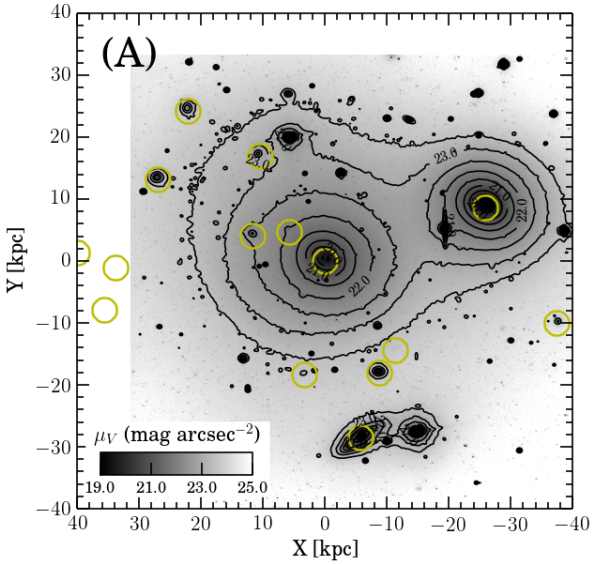
- Three unmixed populations of PNe (Ventimiglia+2011).



The case of NGC 3311



- (A) V-band image + dwarf galaxies from Misgeld+2008;

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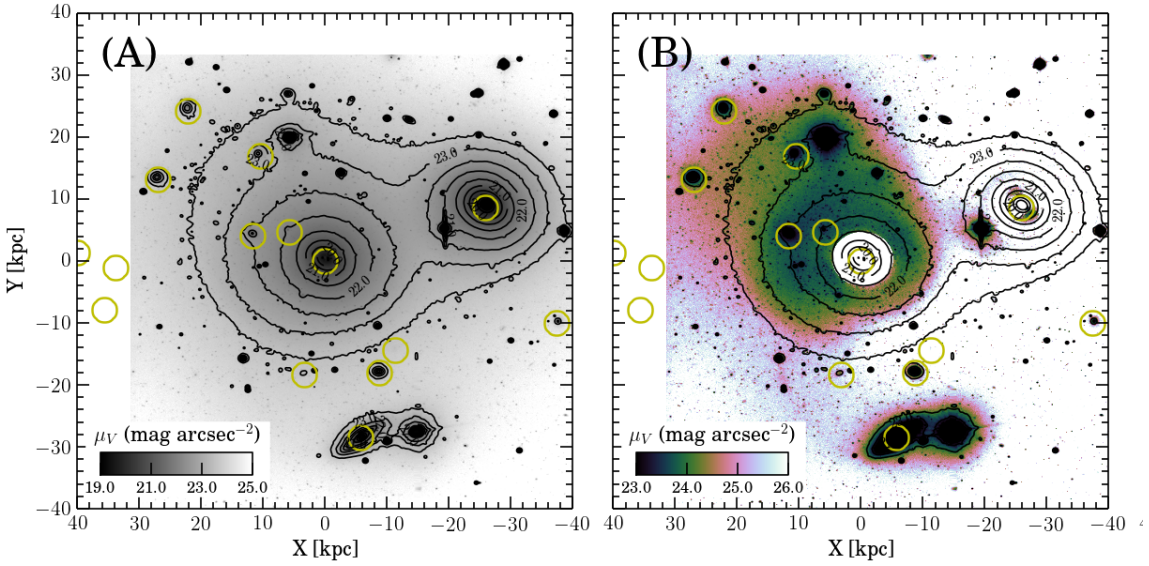

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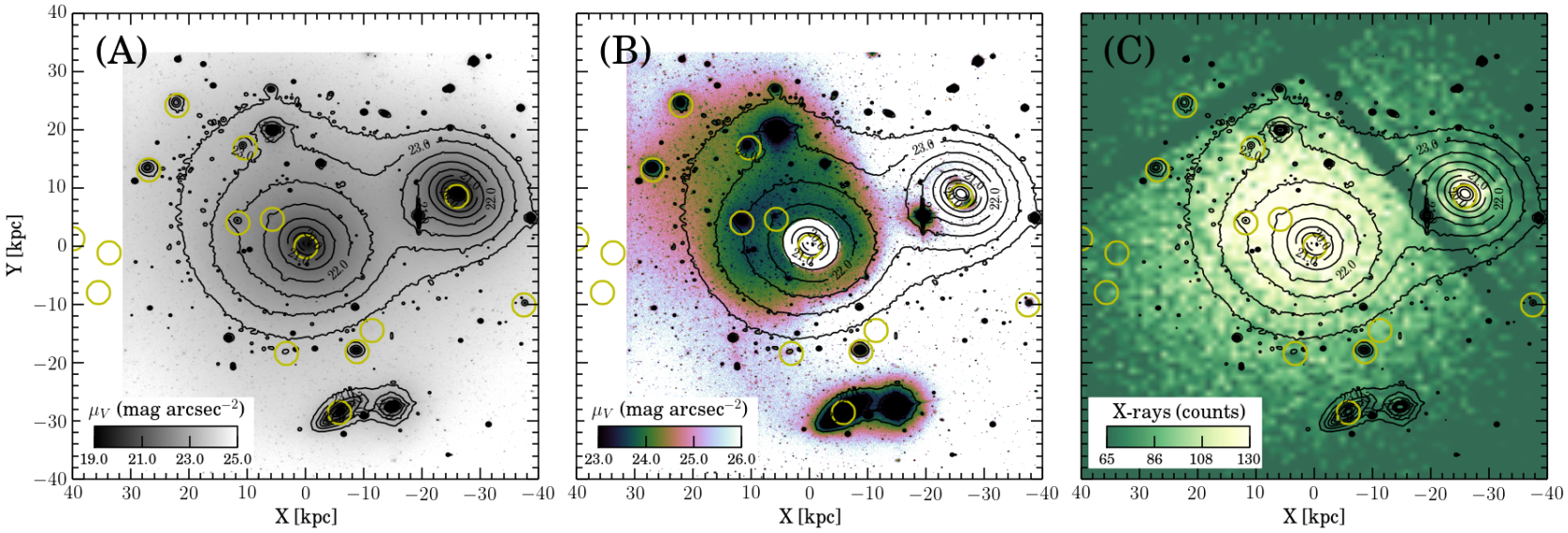

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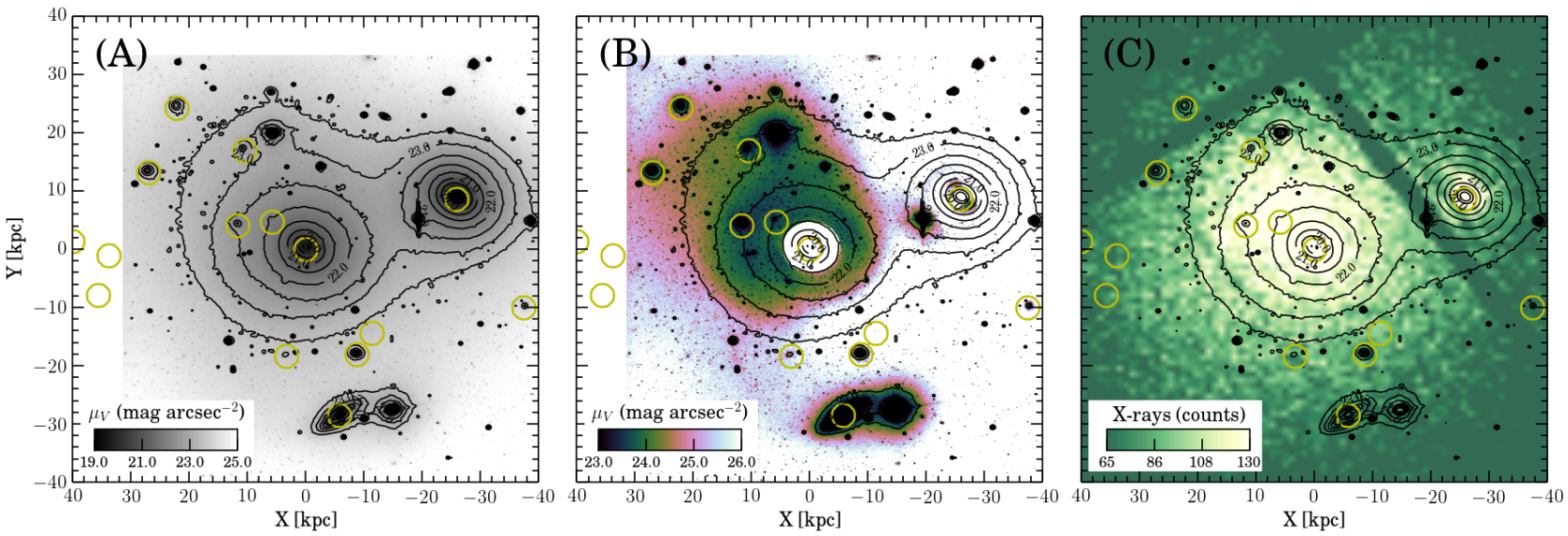
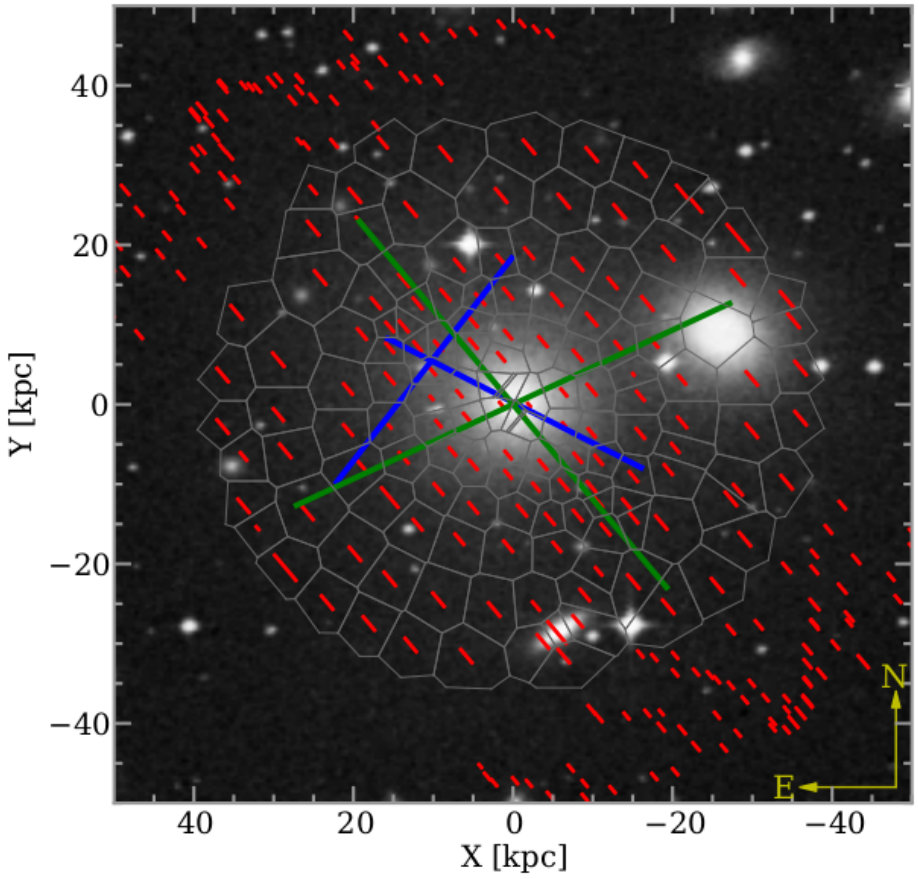


- (A) V-band image + dwarf galaxies from Misgeld+2008;
- (B) V-band residuals from maximum symmetric model of Arnaboldi+2012;
- (C) X-rays from Hayakawa+2004.
- Presence of a large substructure in the N-E quadrant.

Observations



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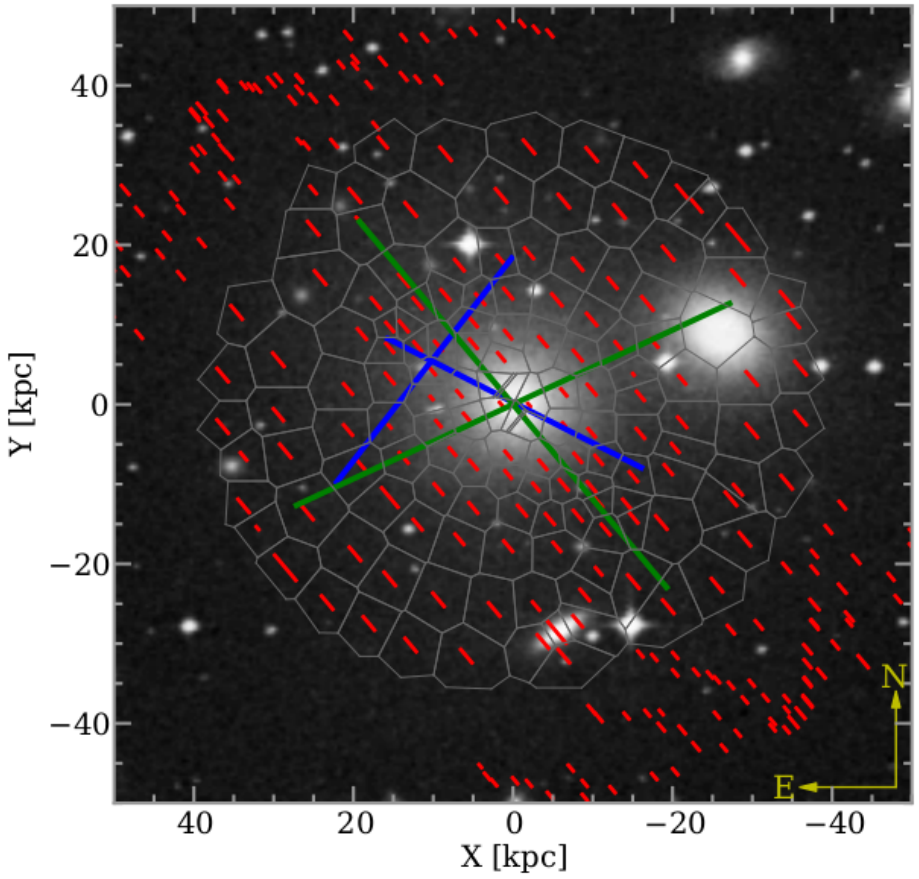

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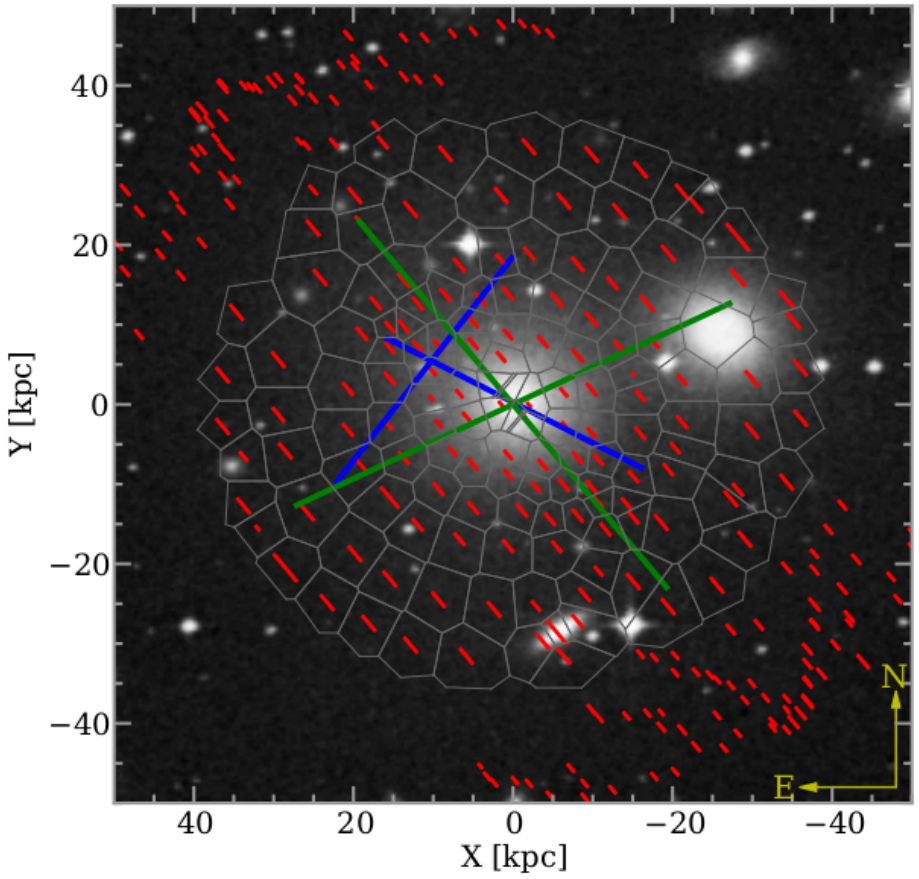
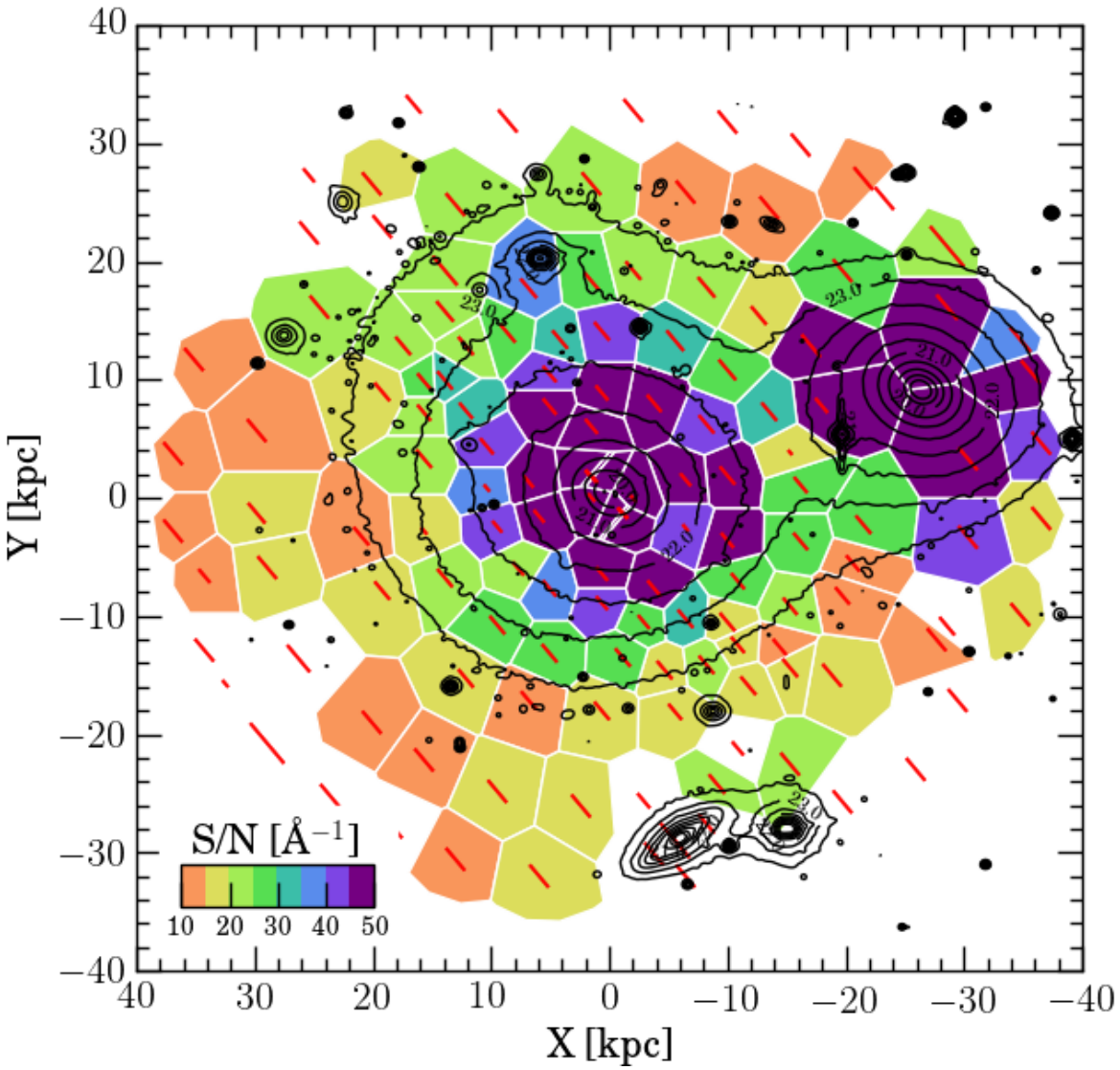


- FORS2 observations at VLT in MXU masking mode (ESO programme ID 088.B-044B, PI: Richtler).
- Onion-like pattern produced with 6 masks.
- Long-slits from previous works (Richtler+2011 in green; Coccato+2011 in blue)

Methods



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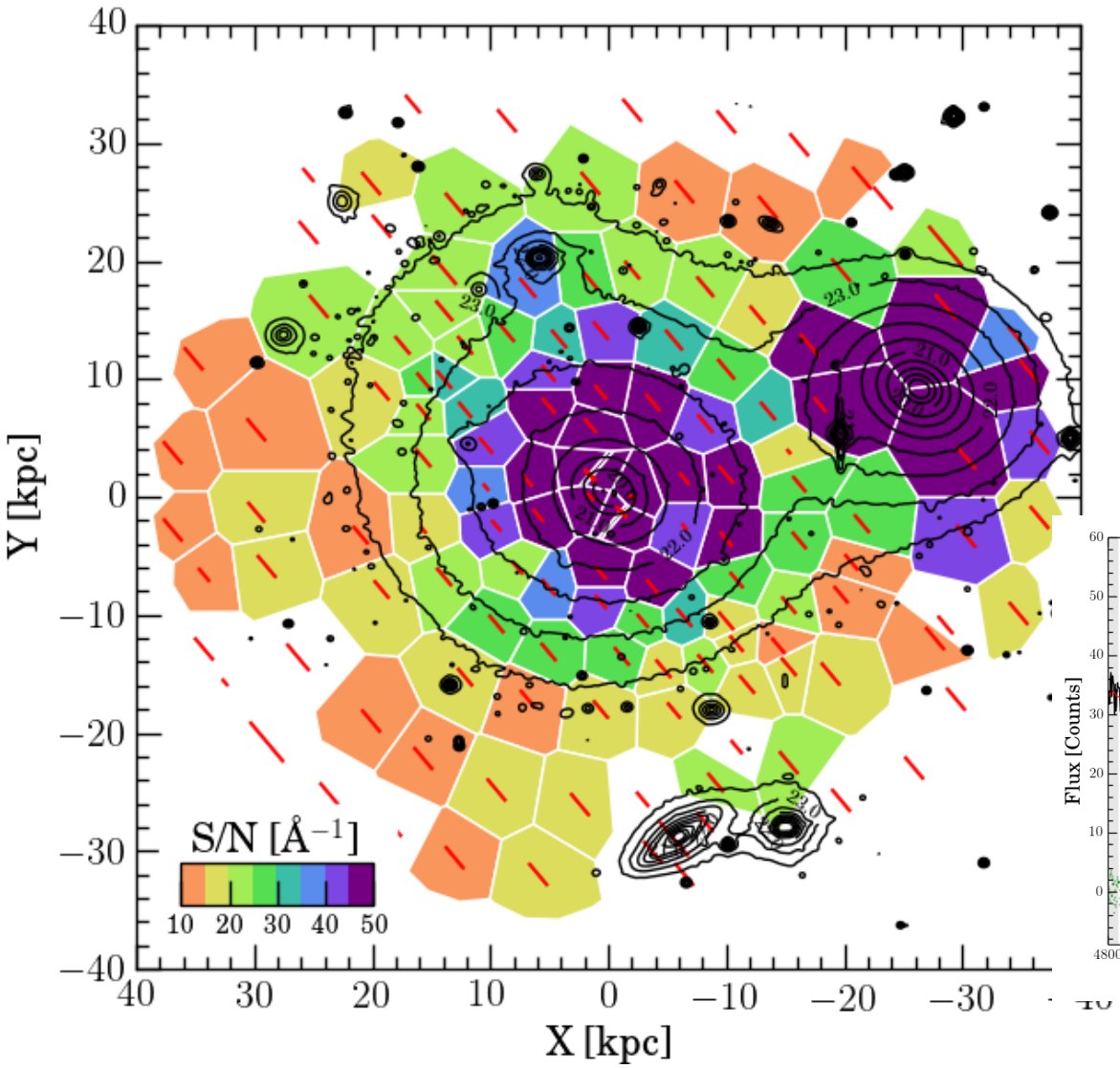
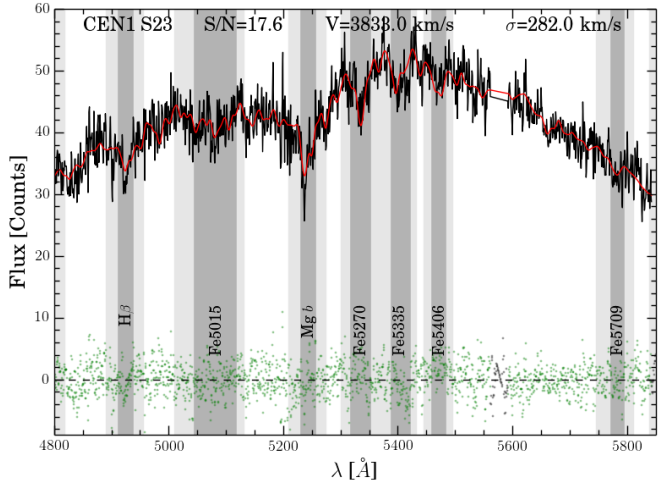
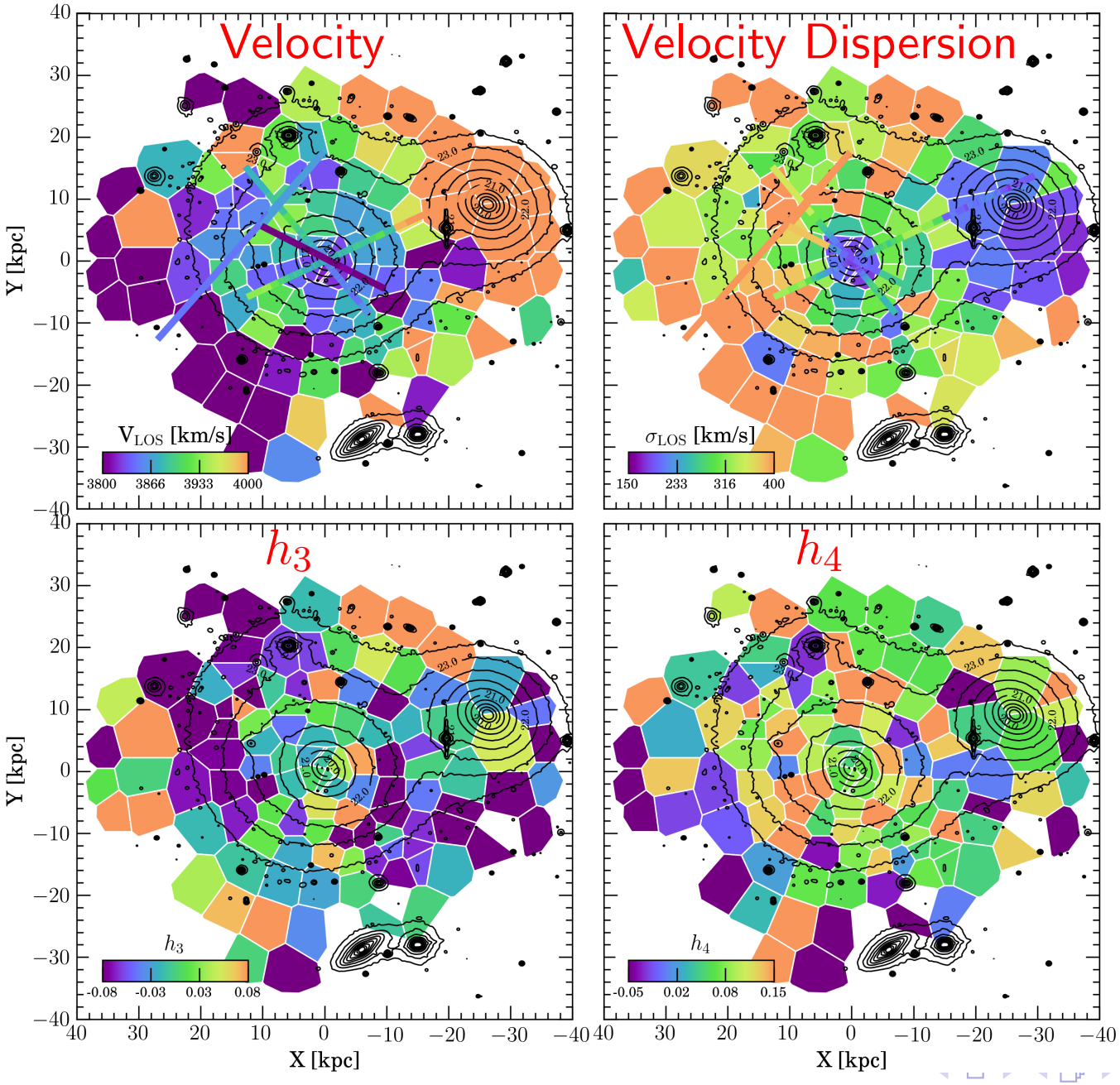


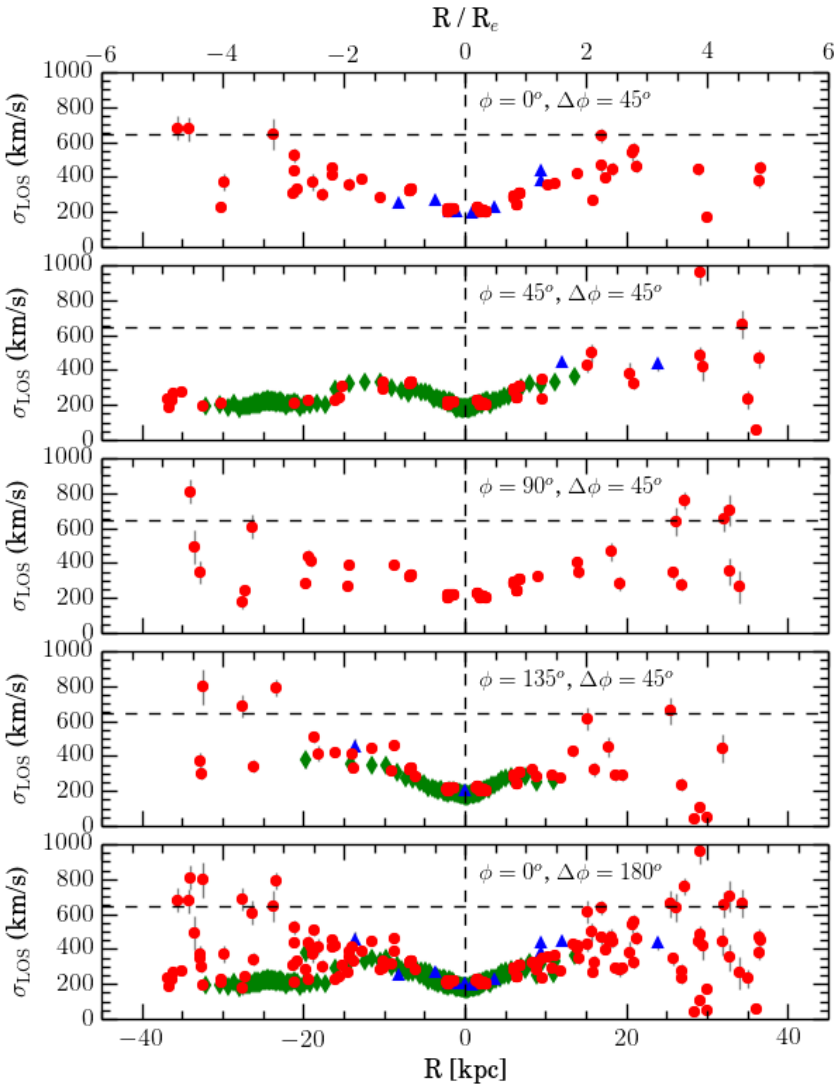
- S/N $>$ 10 required;
- LOSVD with pPXF (Cappellari & Emsellem 2004);
- Absorption-line strength in the Lick/IDS system.



Four moments of velocity distribution

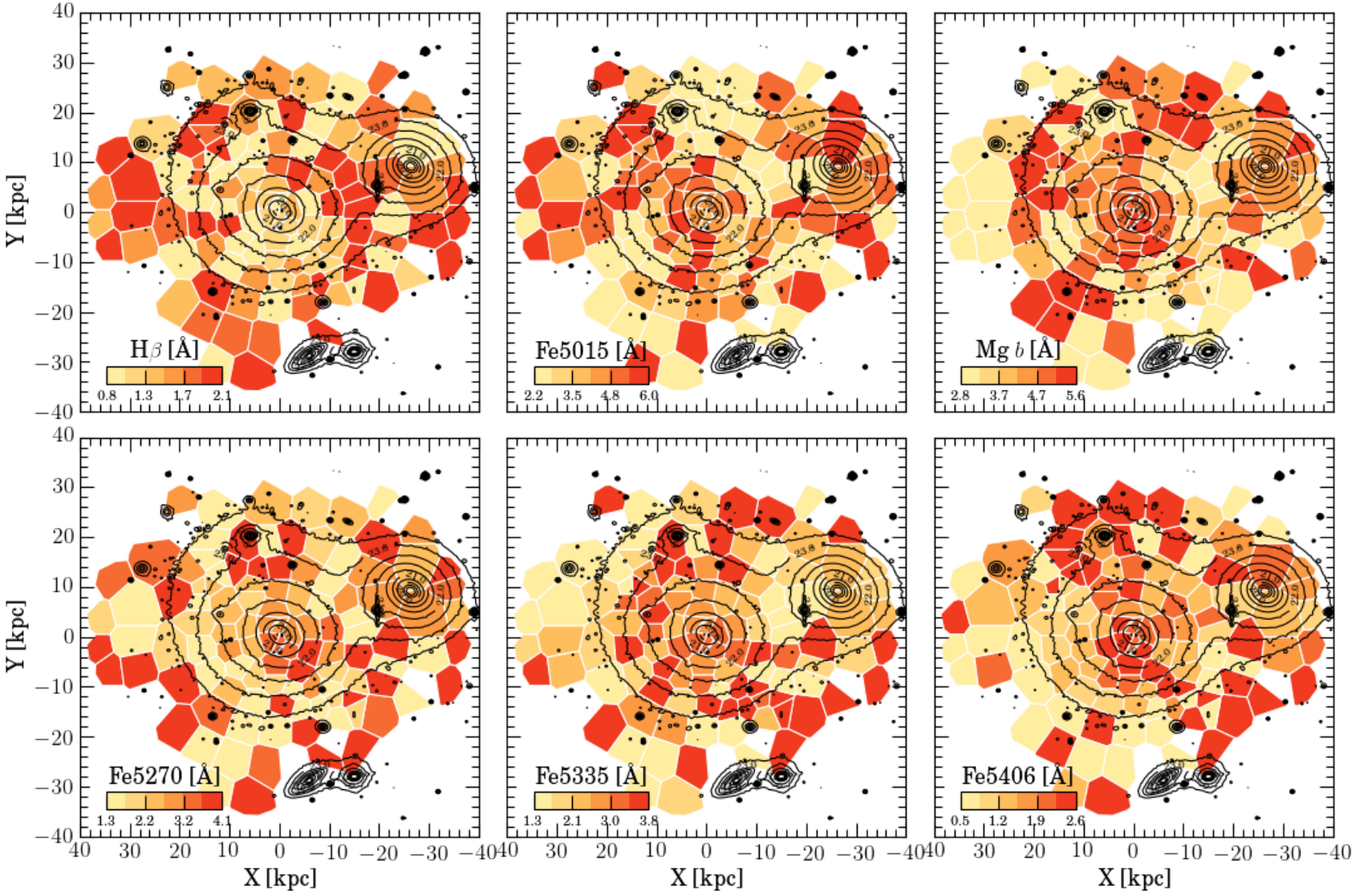


Velocity dispersion profile

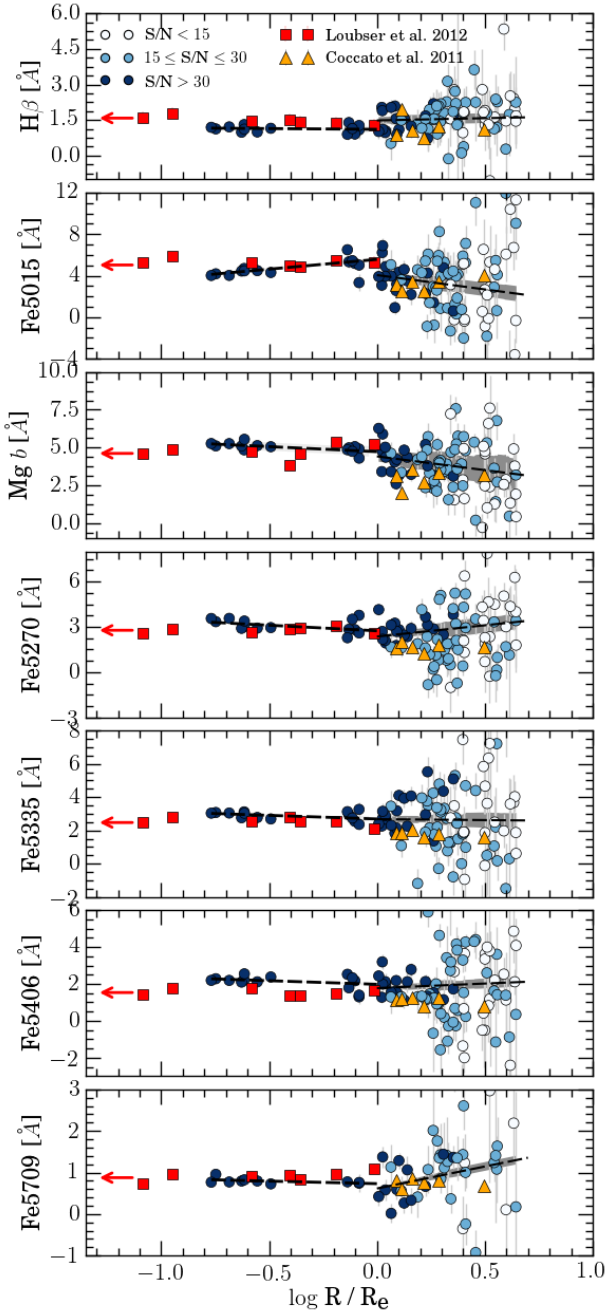


- Agreement with previous long-slit analysis.
- Asymmetric profile.
- Extension to the cluster galaxies velocity dispersion ($\sigma_{\text{gal}} = 647$ km/s, Struble & Rood, 1999).
- Superposition of different stellar populations in the line-of-sight may be causing the high velocity dispersion in some regions.

Mapping the Lick indices



Radial profiles of the Lick indices



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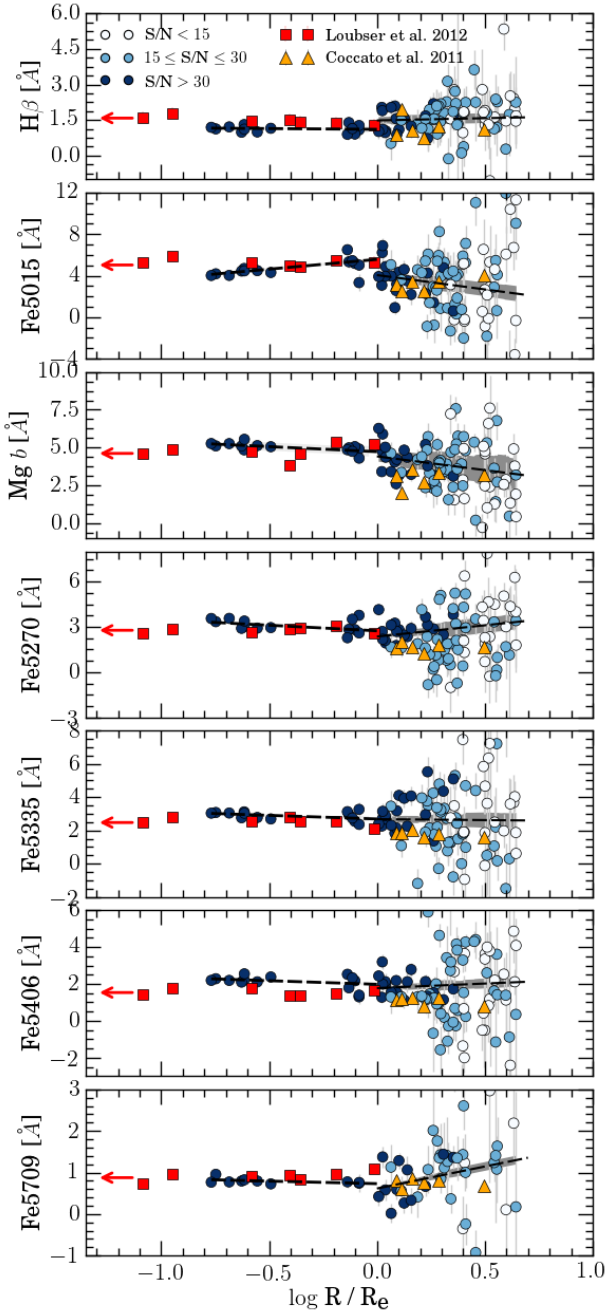

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- Large scatter in the outskirts in not produced by S/N limitations, but it a intrinsic property of the observations.
  - Different colors indicate the measured S/N.
  - Gray shades represent the scatter due to an erroneous sky subtraction by 1%.

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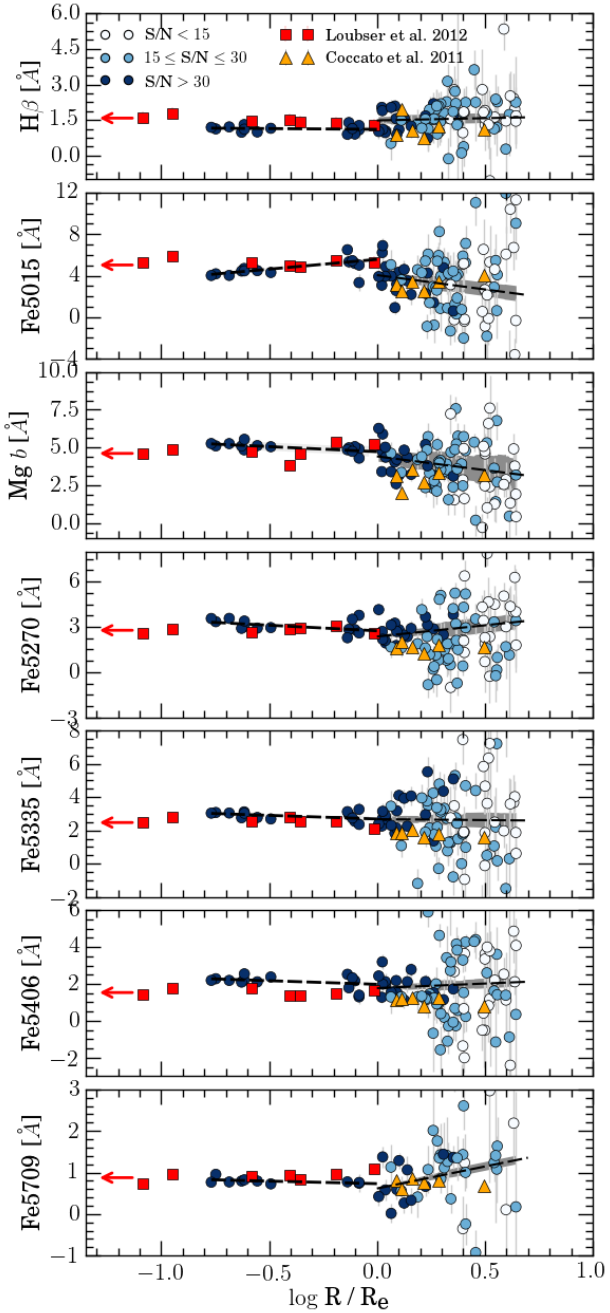

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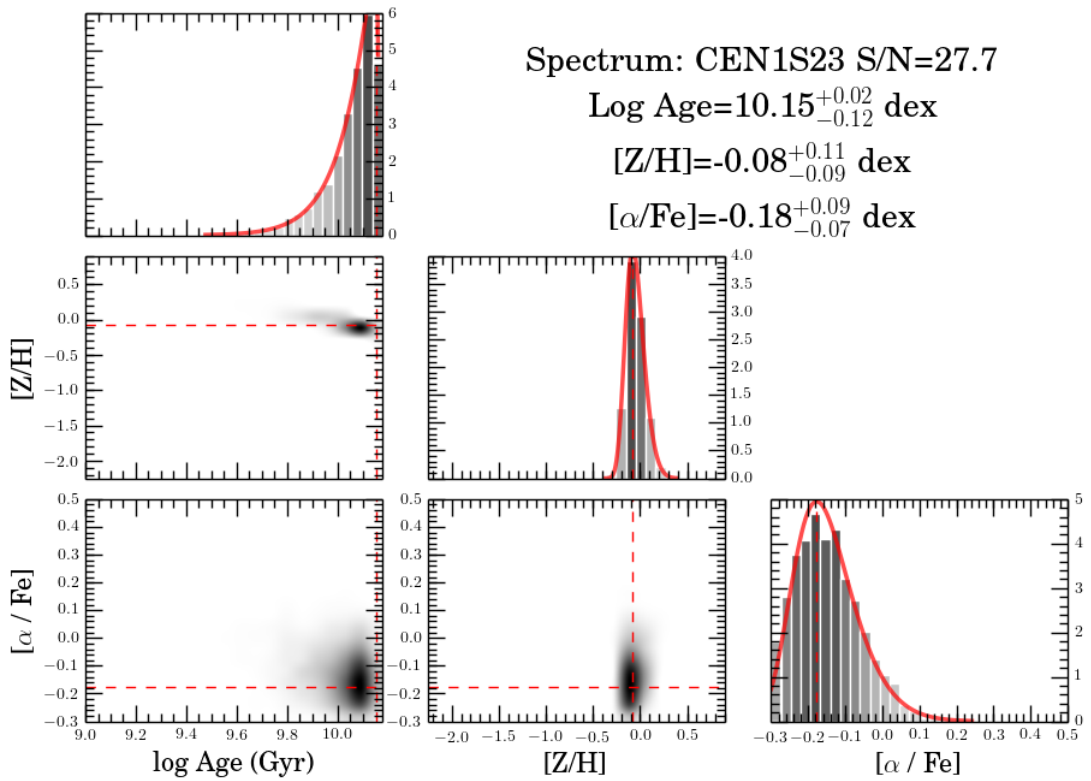
- Inner galaxy have defined gradients while the outer halo is dominated by the sccater.

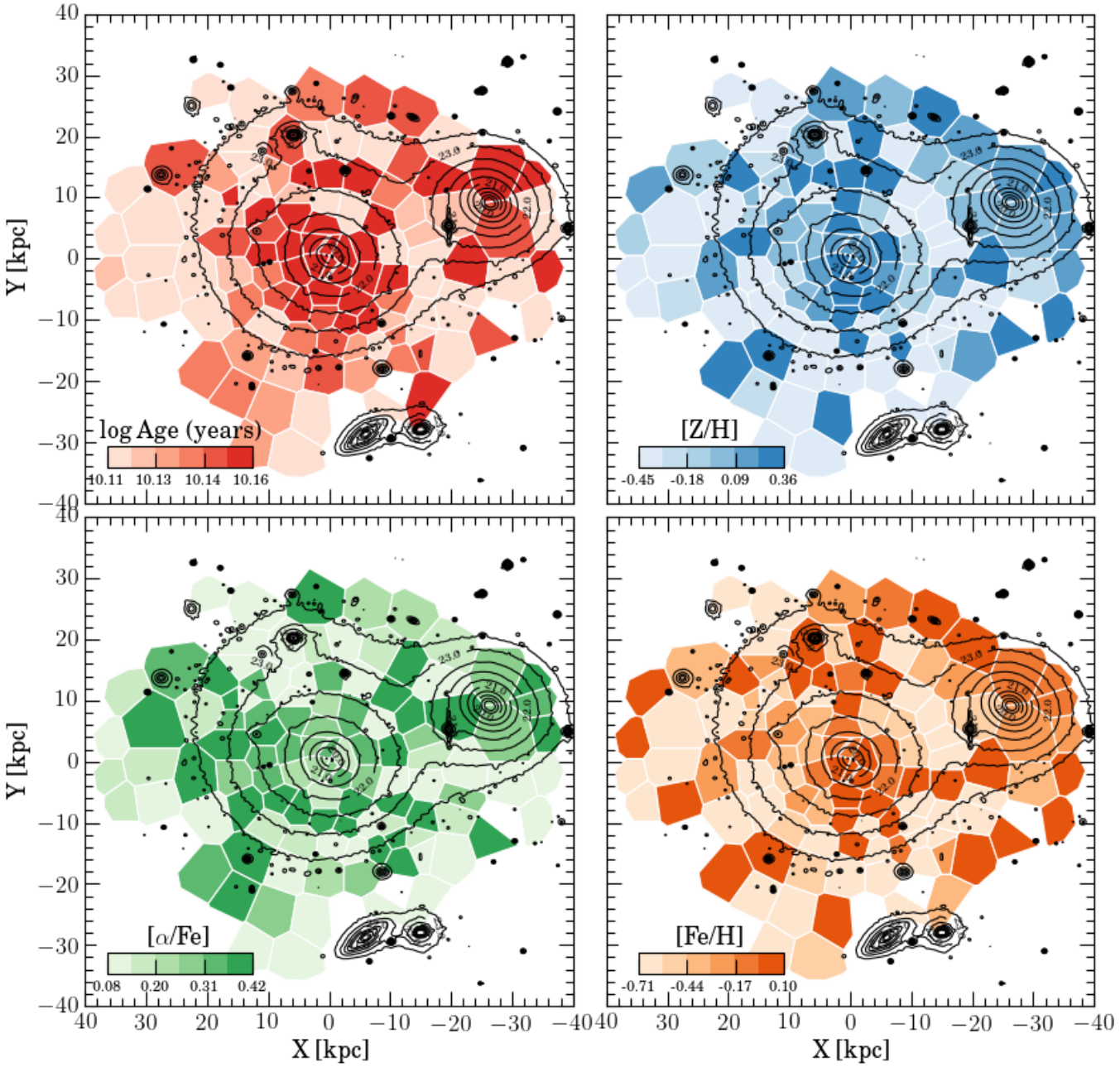
Modeling of the stellar populations



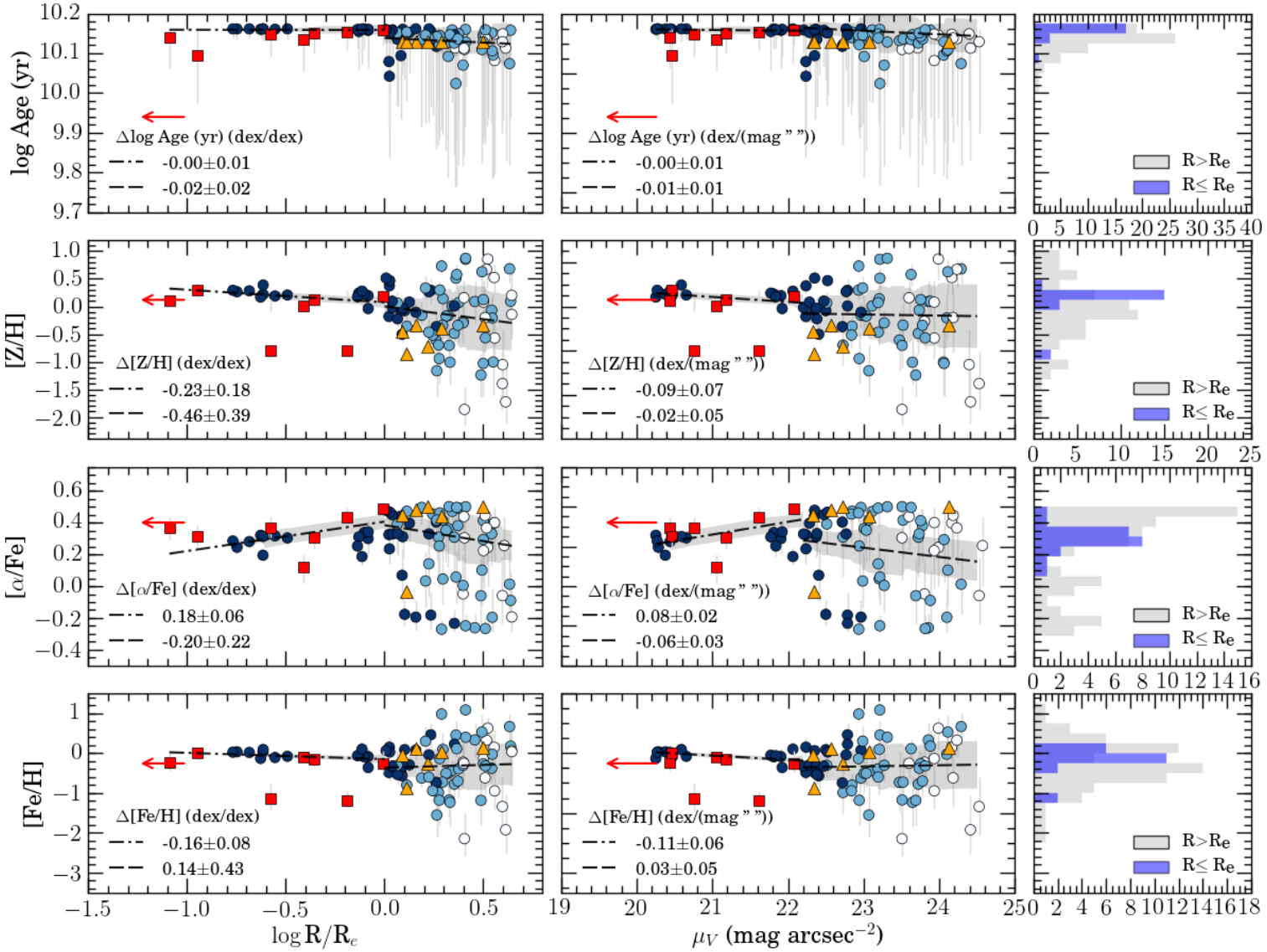
Stellar populations were obtained by using the joint information of all Lick indices using Monte Carlo Markov Chains.

- Models from Thomas+2011:
  - $0.1 \leq$Age (Gyr)≤ 15
  - $-2.25 \leq$[Z/H]≤ 0.9
  - $-0.3 \leq$[α/Fe]≤ 0.5
- Robust estimation of parameters and errors.

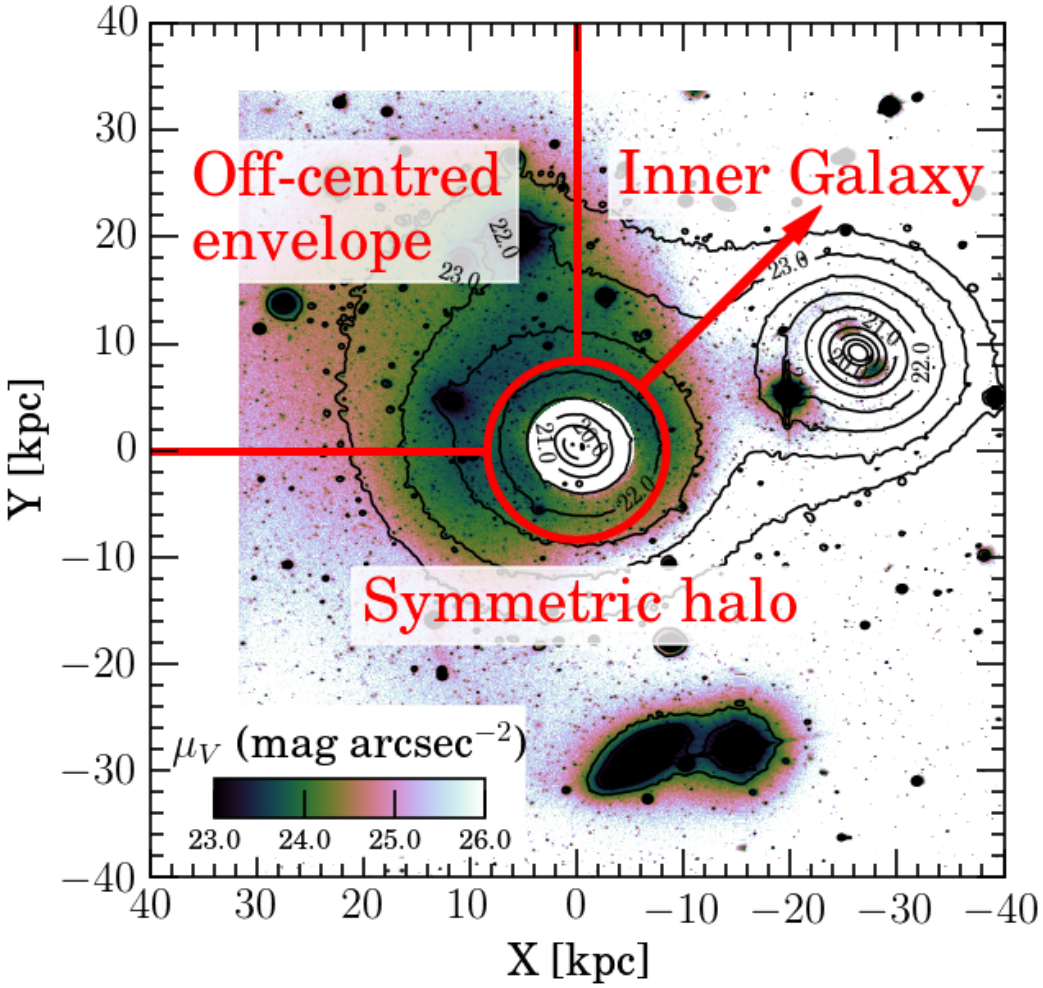
Mapping of the stellar populations



Radial profile of the stellar population parameters.



Stellar populations analysis



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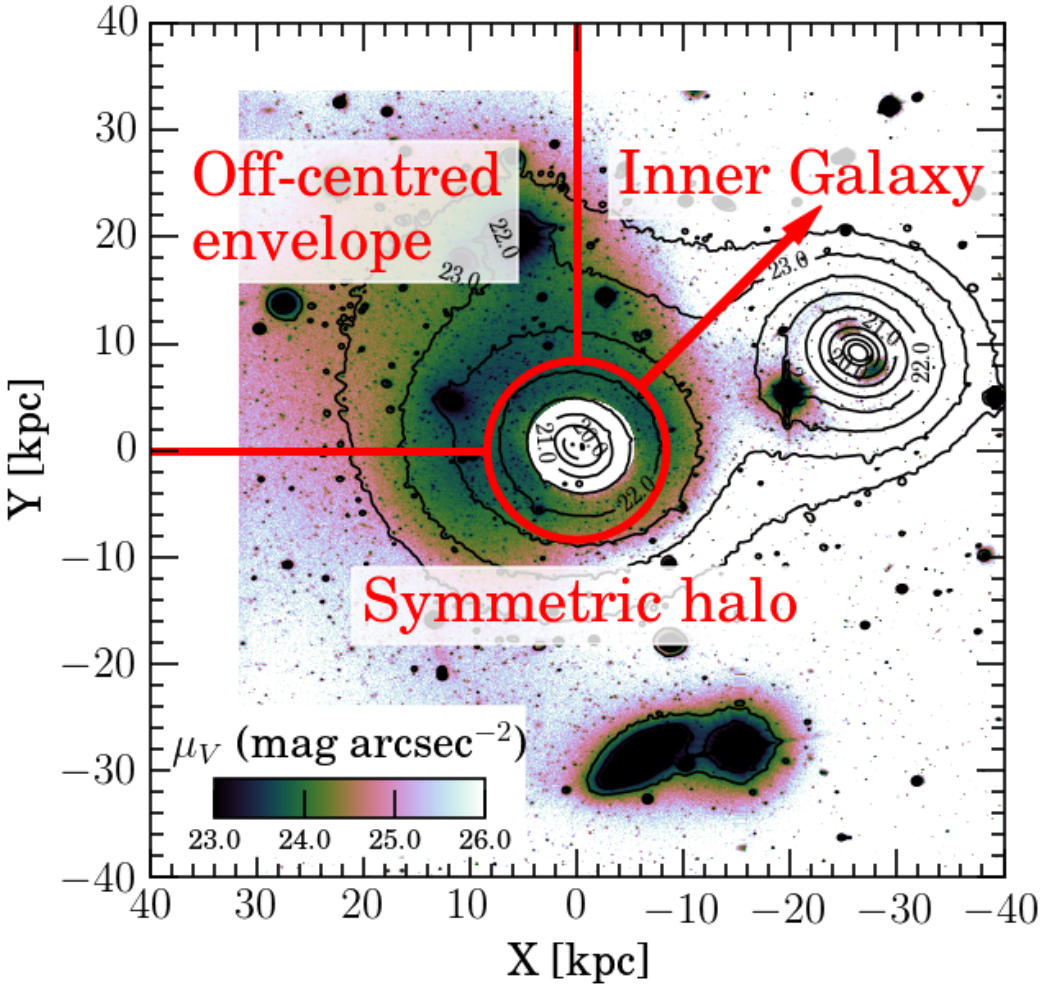

- Different gradients in the inner/outer galaxy indicate different stellar populations.
  - Break at $R \approx R_e$.
- Substructure in the NE has to be taken into account in the outer halo.
  - Off-centred envelope: $0 \lesssim$PA$\lesssim 90$ (Arnaboldi+2012).
  - Symmetric halo (PA$\gtrsim 90$).

Results: the inner galaxy ($R < R_e$)

- Central region has super-solar metallicity ([Z/H]~ 0.3) and high element abundance ([α/Fe]~ 0.3).

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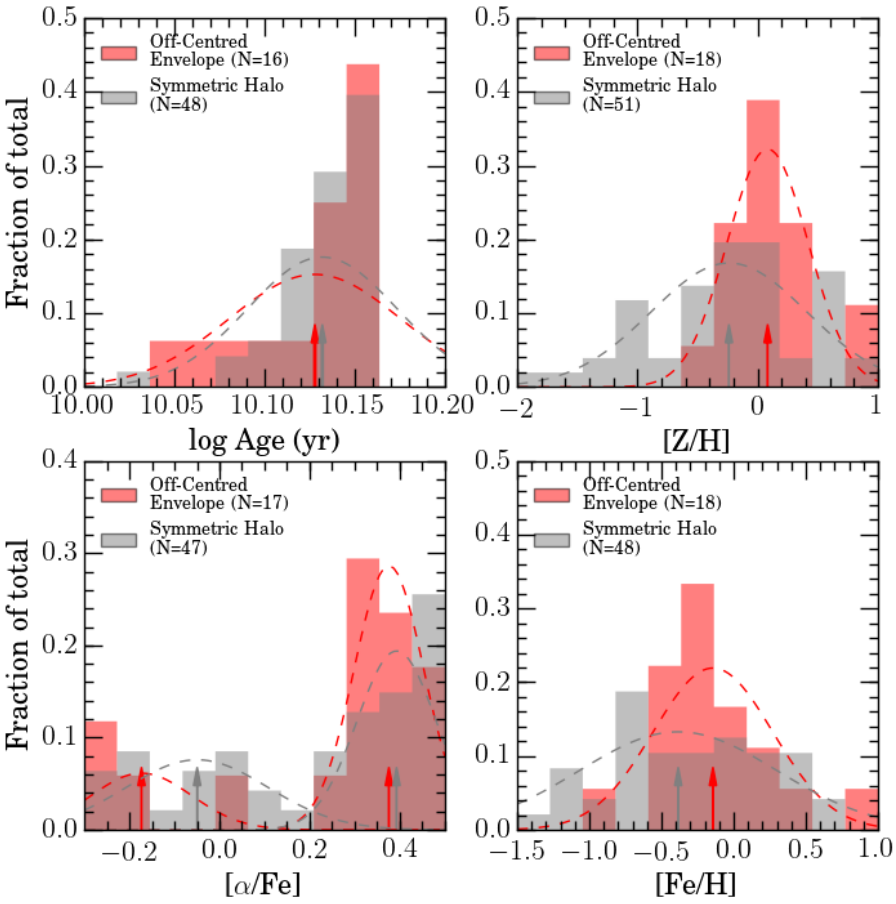
- Agreement with gradients of other BCGs (Oliva-Altamirano+2015) and non-BCGs (Kuntschner+2010)
- A quasi-monolithic scenario including a few episodes of dry mergers is able to reproduce the observed gradients (e.g., Pipino+2010).

Results: the outer halo



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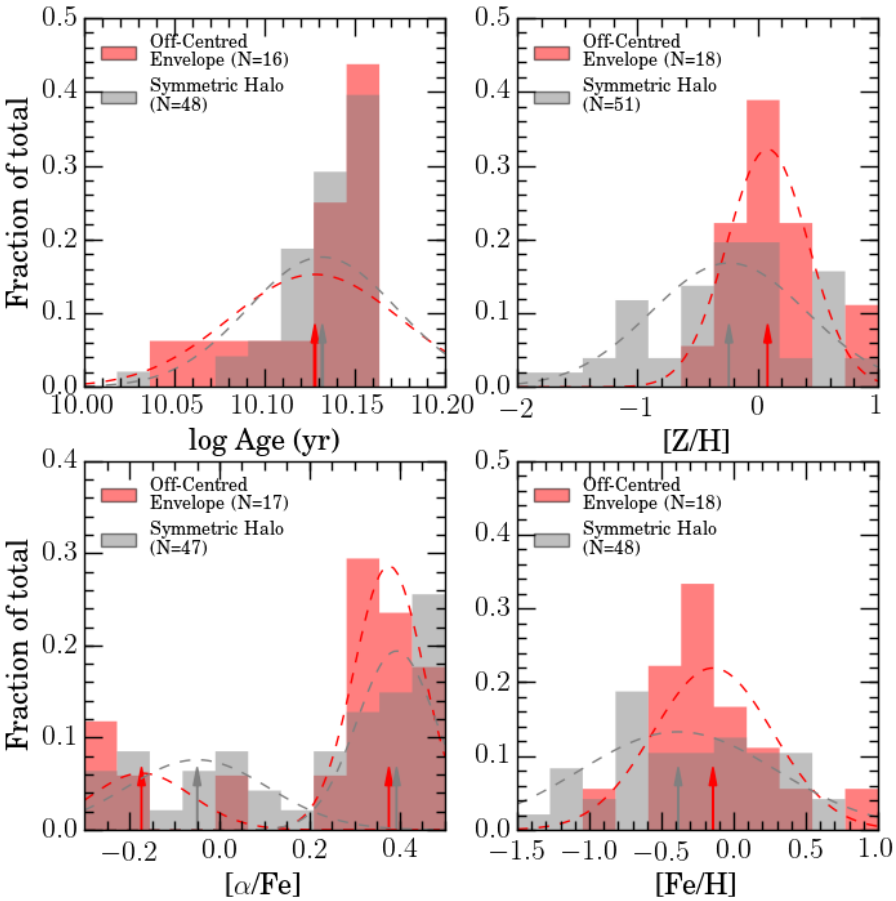

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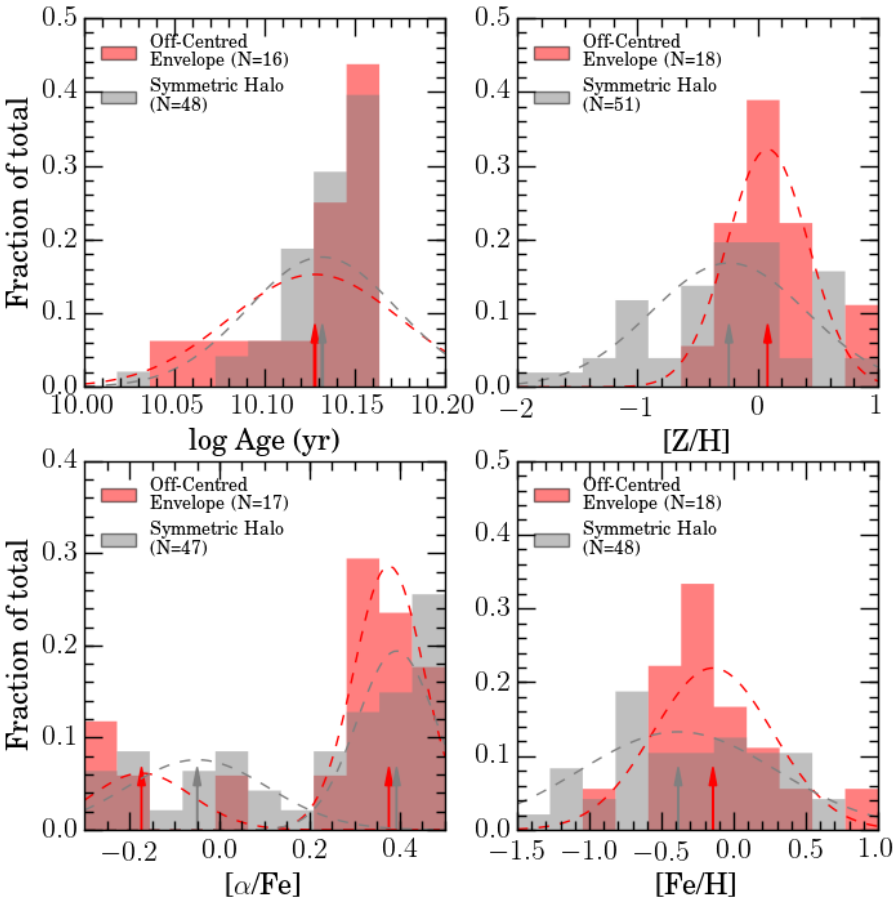

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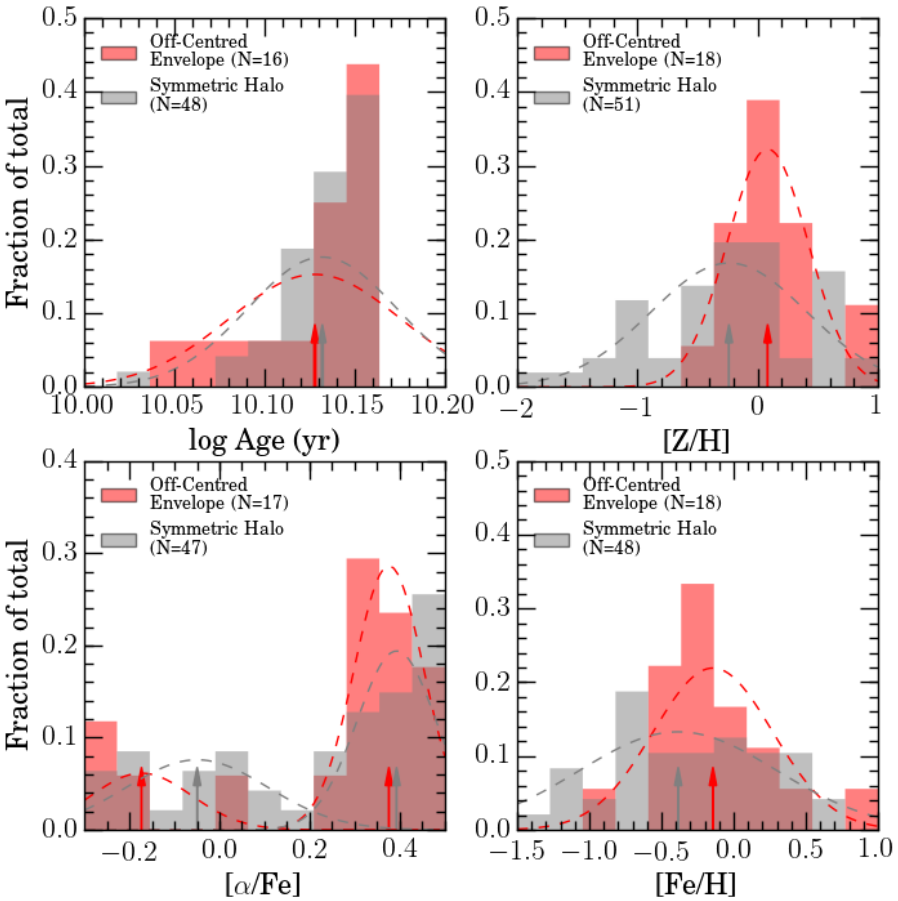

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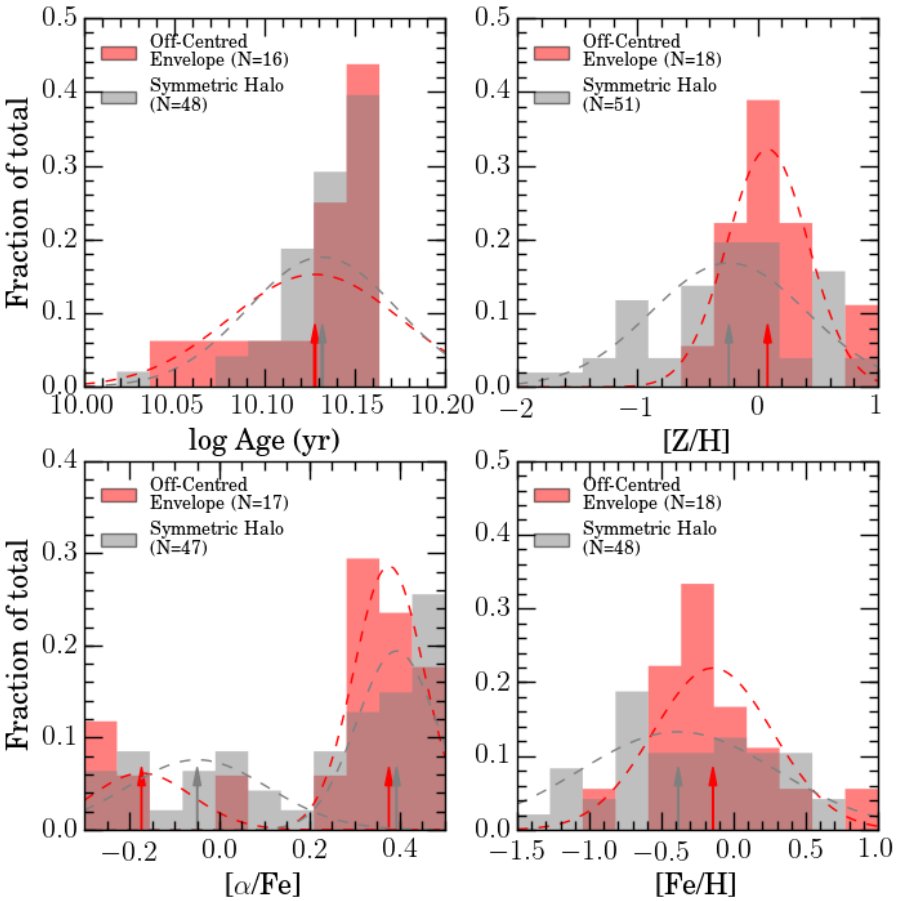

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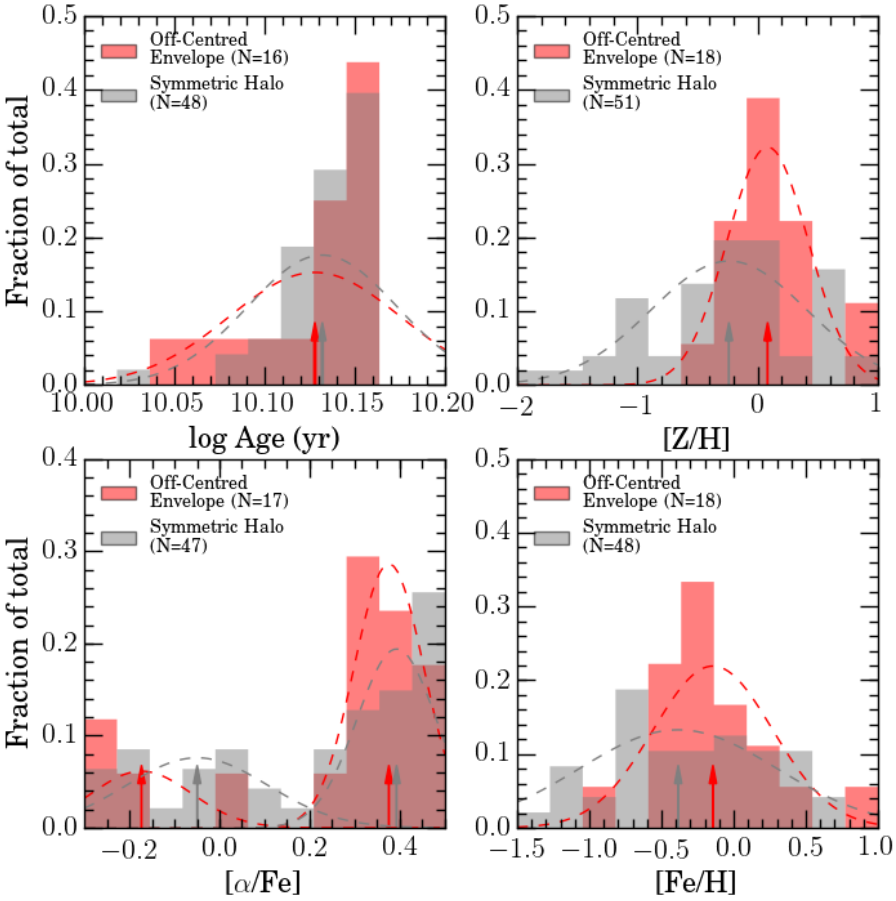
- Metallicities are typical of galaxies with masses in the range $\sim 10^{10} M_{\odot}$ to $\sim 10^{12} M_{\odot}$.
- Stars unbound from their host galaxies in major mergers related to the formation of BCG.

Results: the outer halo



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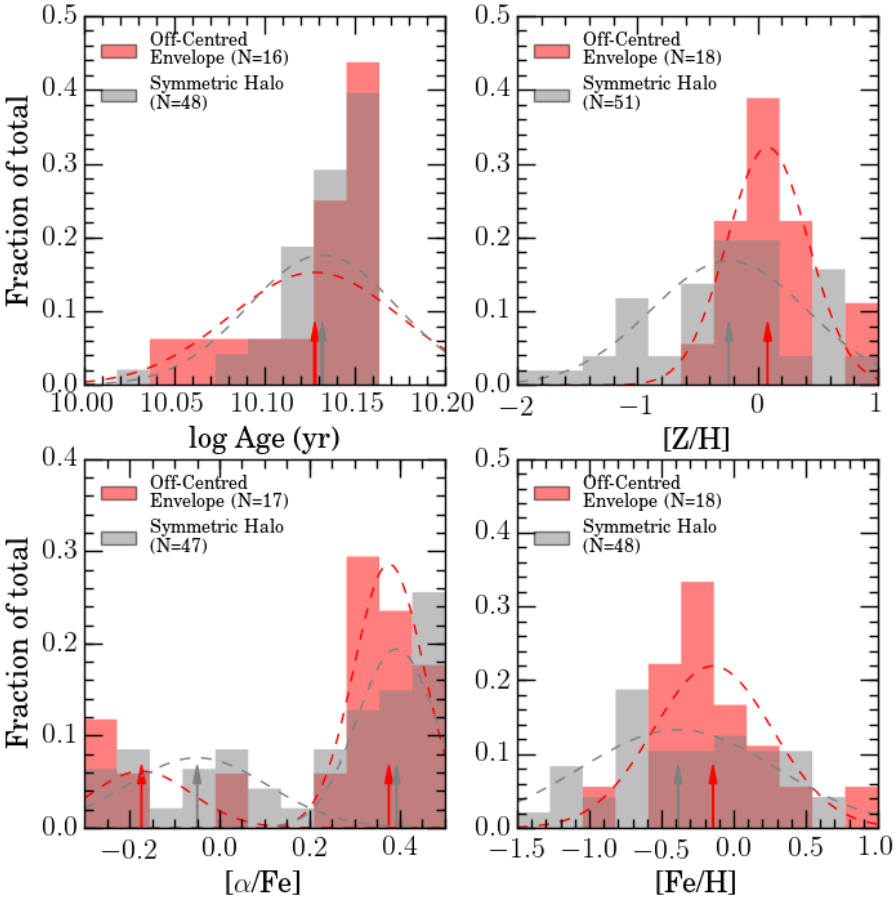

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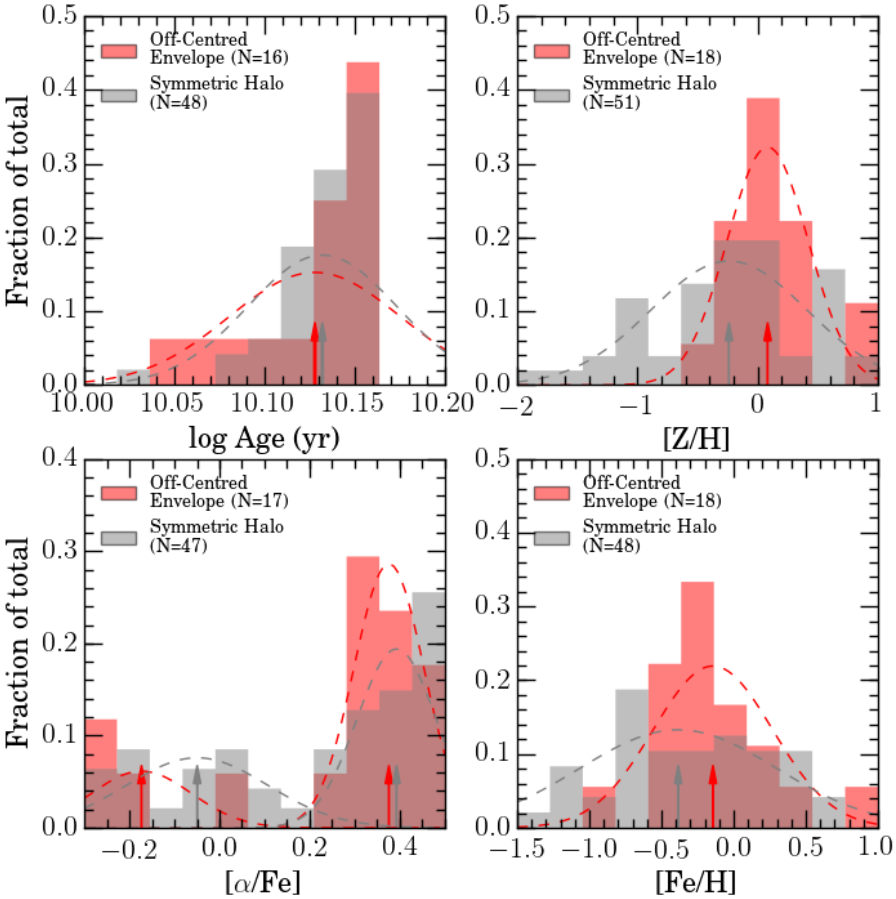

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- Abundance matches the values of the only dwarf galaxy with known abundances in the outer halo.
- Accretion of stars from disrupted dwarf galaxies is an important channel for late build-up of the external halo.

Summary

- We performed a spatially extended survey of the stellar populations of NGC 3311.
  - Ages, [Z/H], [α/Fe] and [Fe/H] out to $3R_e$.
- The inner stellar halo presents stellar populations typical of massive early-type galaxies, including old ages, high metallicities and high alpha element abundances.
- The outer halo is characterized by a large spread of the stellar parameter values rather than by clearly defined radial gradients.
  - The majority of stars in the symmetric halo are generated in galaxies with a rapid star formation and short time-scales.
  - A substantial fraction of stars, about 40%, has a low [α/Fe] value, which indicates that stars from less massive galaxies are also added to the cD halo.