Stellar populations in the cD galaxy NGC 3311

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Introduction

Cluster MACS J0717.5+3745

- 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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THE DYNAMICS AND STRUCTURE OF THE cD GALAXY IN ABELL 2029

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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 $M/L$ models. A rough dimensional argument suggests that $M/L_V$ has risen from its nuclear value of $\sim 12$ to $\sim 67 M_\odot/L_\odot$ 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 ($M/L_V \approx 10$) which has acquired (2) a halo of luminous material ($M/L_V \approx 35$) through the accretion of other cluster members, positioned in the middle of (3) a dark ($M/L_V > 500$) 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
The interpretation is that cD galaxies are formed by tidal stripping of neighbor galaxies (White 1976, Ostriker and Tremaine 1976); or

luminous 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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- Three unmixed populations of PNe (Ventimiglia+2011).
The case of NGC 3311

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

- S/N > 10 required;

LOSVD with pPXF (Cappellari & Emsellem 2004);
Absorption-line strength in the Lick/IDS system.
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Four moments of velocity distribution

Velocity

Velocity Dispersion

\( h_3 \)

\( h_4 \)
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

▶ Direct evidence of distinct stellar populations from $R \approx R_e$.
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- Large scatter in the outskirts is not produced by S/N limitations, but it is an 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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- Inner galaxy have defined gradients while the outer halo is dominated by the scatter.
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:
  - $0.1 \leq \text{Age (Gyr)} \leq 15$
  - $-2.25 \leq [Z/H] \leq 0.9$
  - $-0.3 \leq [\alpha/Fe] \leq 0.5$

- Robust estimation of parameters and errors.
Mapping of the stellar populations
Radial profile of the stellar population parameters.
Stellar populations analysis

- 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 ($PA \gtrsim 90$).

![Diagram with labeled features: Off-centred envelope, Inner Galaxy, Symmetric halo.](image)
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  - Symmetric halo (PA $\gtrsim 90$).
Results: the inner galaxy ($R < R_e$)

- Central region has super-solar metallicty ([Z/H]~ 0.3) and high element abundance ([α/Fe]~ 0.3).
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- Central region has super-solar metallicty ($[Z/H] \sim 0.3$) and high element abundance ($[\alpha/Fe] \sim 0.3$).
- Gradients with small scatter.

- $\Delta \log \text{Age} = 0.00 \pm 0.01$
- $\Delta [z/H] = -0.23 \pm 0.18$
- $\Delta [\alpha/Fe] = 0.18 \pm 0.06$
- $\Delta [Fe/H] = -0.16 \pm 0.08$

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).
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- Age and [\(\alpha/Fe\)] have similar distribution in the off-centred envelope and at the symmetric halo.
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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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- Secondary peak with $[\alpha/\text{Fe}] \approx 0$ indicates more extended star formation contributes to 40% of the observations.
- 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.
We performed a spatially extended survey of the stellar populations of NGC 3311. Ages, [Z/H], [\(\alpha/\text{Fe}\)] and [Fe/H] out to 3\(R_e\).

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 [\(\alpha/\text{Fe}\)] value, which indicates that stars from less massive galaxies are also added to the cD halo.