The role of environment in galaxy evolution

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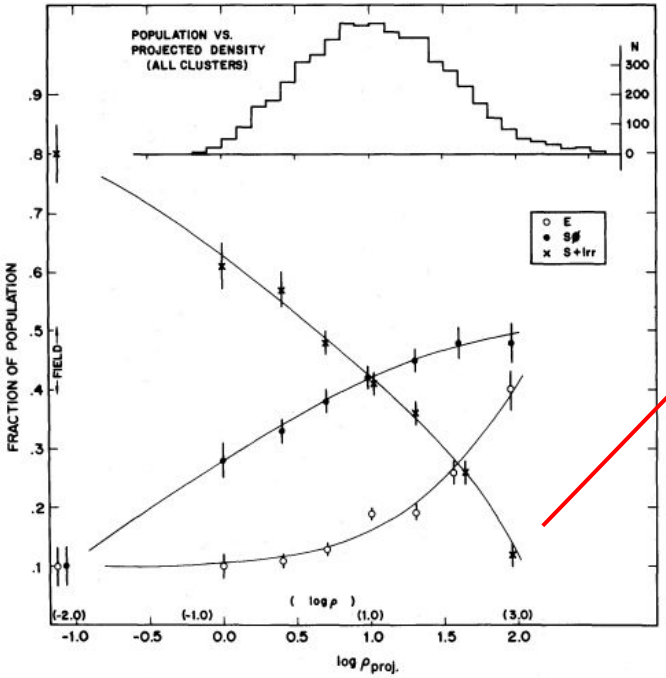
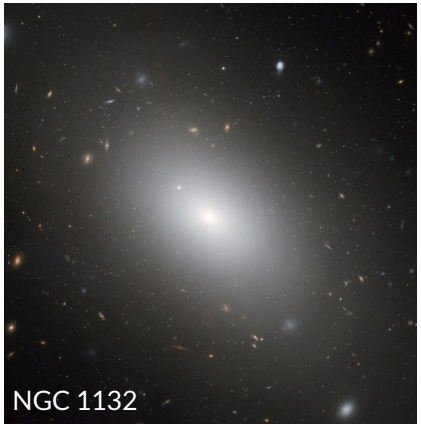
➔ Introduction

- The morphology-density relationship for galaxies is well established:





- Not only **ETGs** galaxies are preferentially found in **galaxy clusters**
  - **they also dominate the center (and denser) regions of clusters**

➔ Introduction

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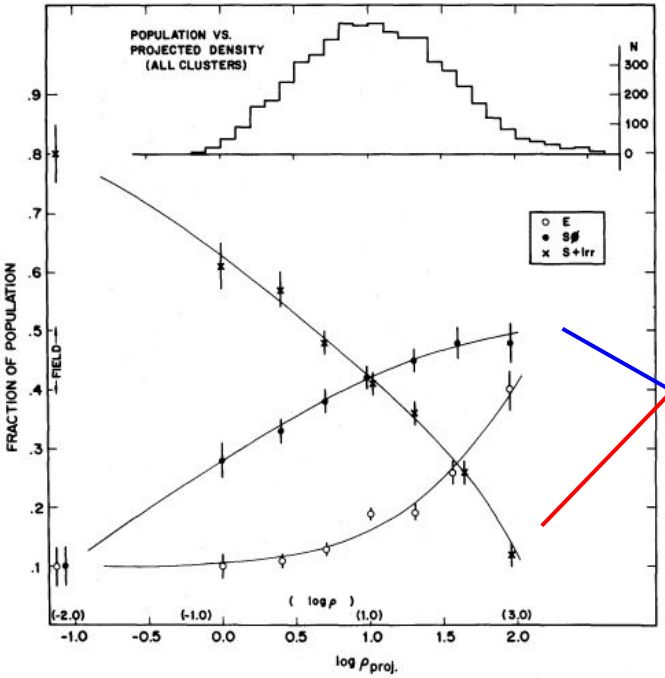
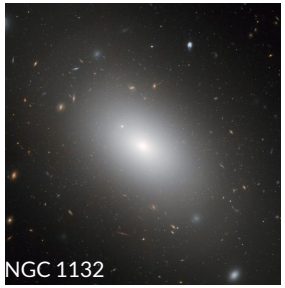


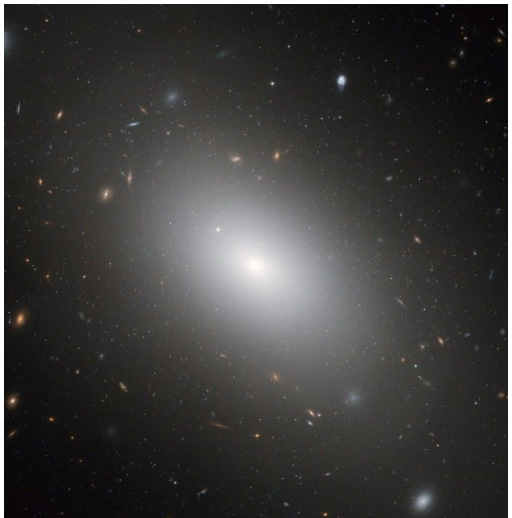


- Not only **ETGs** galaxies are preferentially found in **galaxy cluster**
  - **they also dominate the center (and denser) regions of clusters**

- Late-type galaxies are preferentially found in the field
  - inside clusters, they are located in the outskirts

➔ Introduction

- Besides the location preferences, Early and late type galaxies also display very different properties



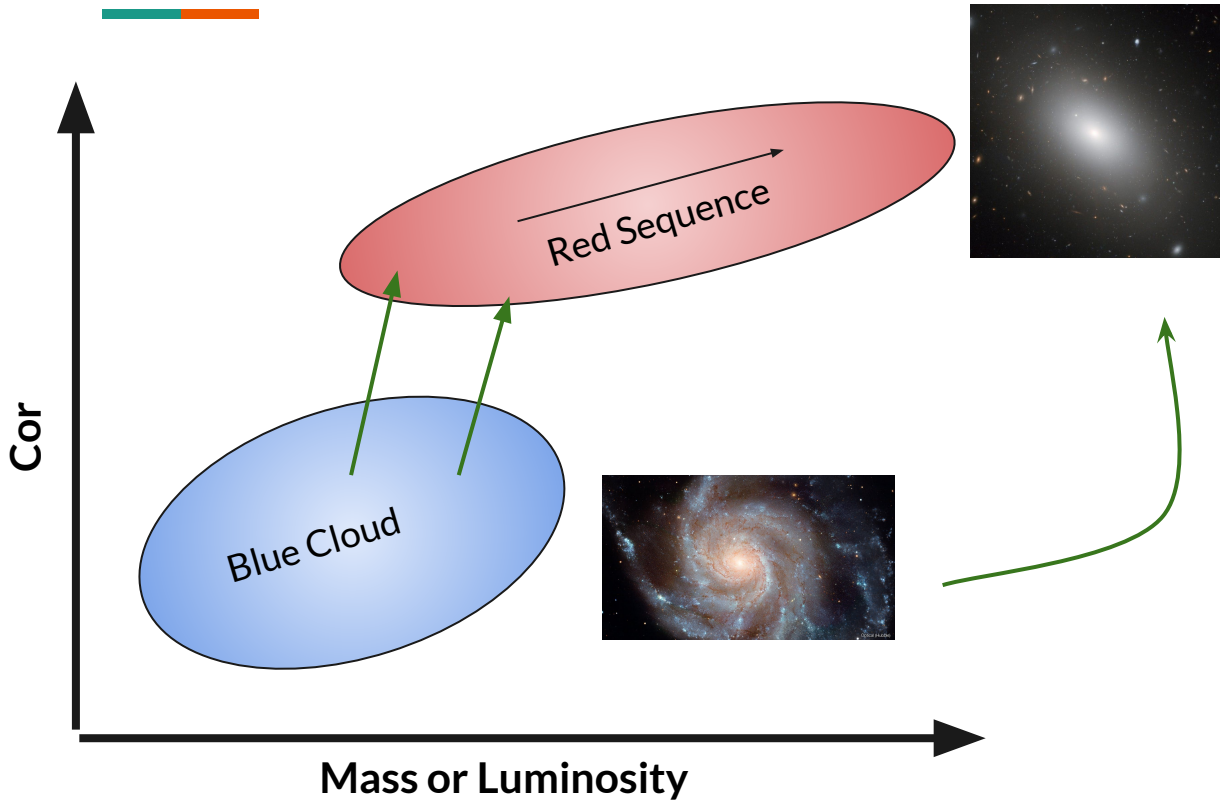
- Early-type galaxies possess:
  - older stellar population
  - reddish color
  - lack of gas
  - lack of star-formation
  - lack of complex structures

➔ Introduction

- Besides the location preferences, Early and late type galaxies also display very different properties

- Late-type galaxies possess:
  - young stellar population
  - bluish color
  - presence of gas
  - presence of star-formation
  - presence of complex structures

➔ Introduction



- **What is the role of clusters in this transition from blue SF LTGs to red and dead ETGs**
  - Nature *vs.* Nurture
    - Is the driving factor for galaxy transformation and evolution internal or external?

➔ Data

We want to investigate how galaxies are affected by the different environments where they live:

- **82** Clusters (**49** relaxed; **39** non-relaxed)
- **1183** galaxies inside R200 of relaxed clusters
- **952** galaxies inside R200 of non-relaxed clusters
- **2284** field galaxies

We investigate if galaxies in those different regions show different properties related to the environment

Relaxed clusters:
Those that are relaxed clusters are in dynamical equilibrium (no signs of recent interactions).

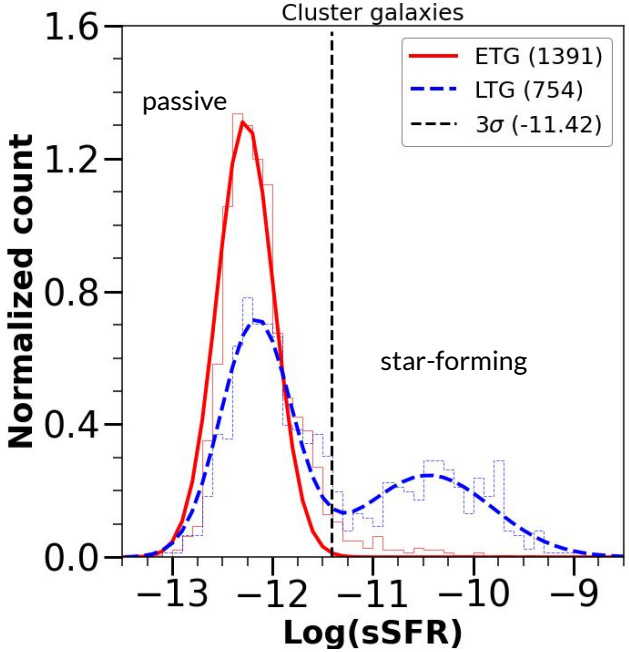
Non-relaxed clusters:
Those that are non-relaxed clusters are not in dynamical equilibrium and show signs of a recent interaction with others clusters or groups.

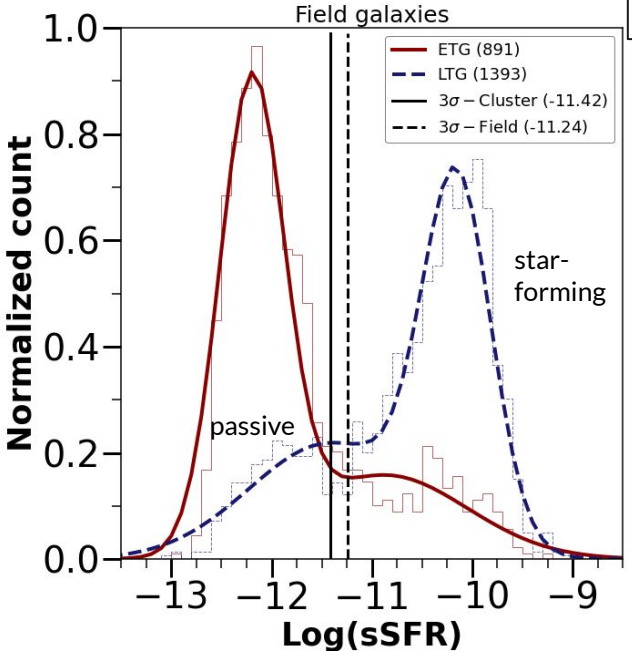
Field:
Galaxies that are not members of groups and clusters

➔ Data

- Morphology was obtained using **Domínguez Sanchez+18** (DS18)
  - Deep Learning

- When data was absent in DS18 we used data from Huertas-Company+11 (HC11)
  - Machine Learning





In this work we consider galaxies with **Log (sSFR) ≥ 3σ** as Star-forming objects

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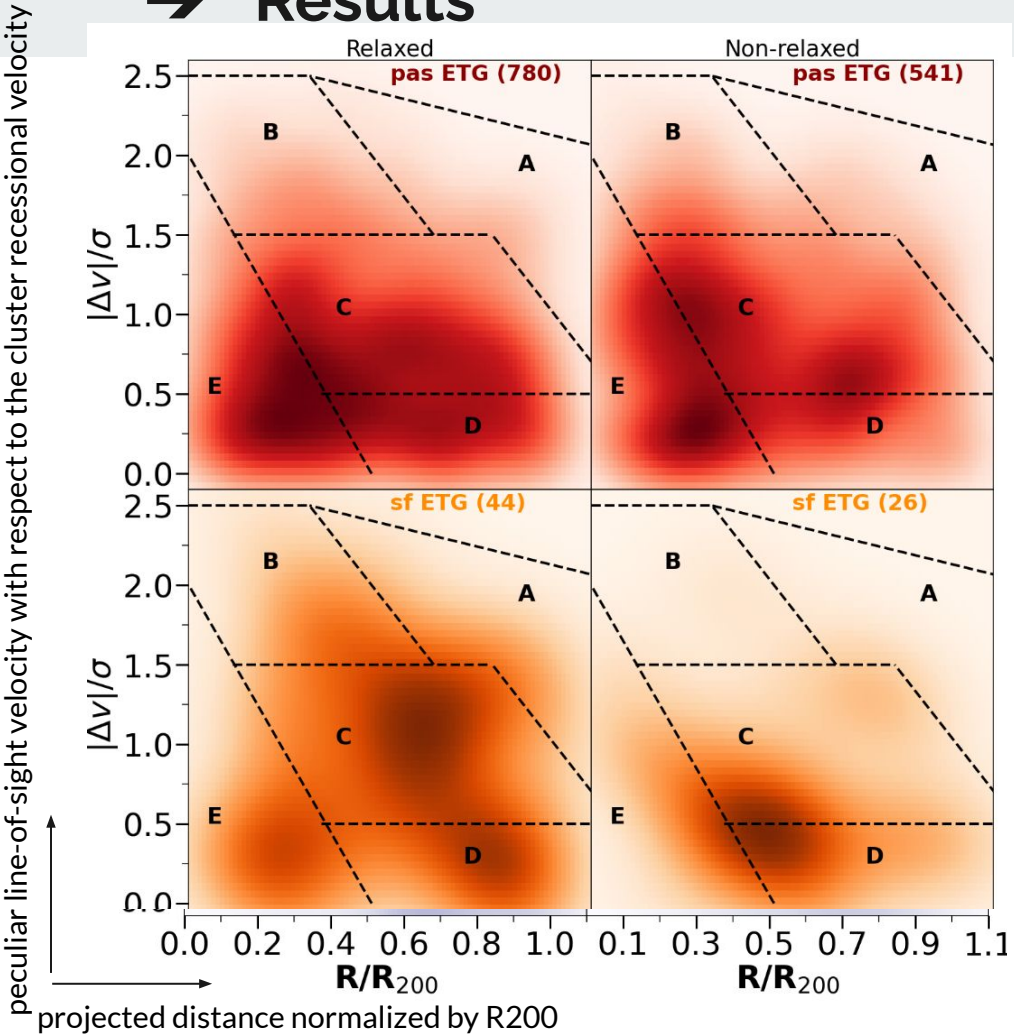
$10^{9.6} \leq M/M_{\odot} \leq 10^{11.9}$

$0.48 \times 10^{14} \leq M_{200}/M_{\odot} \leq 12.68 \times 10^{14}$

~~$0.01 \leq z \leq 0.1$~~

Ou main interest is in Star-forming ETGs as they can be seen as transitional galaxies!

➔ Results



Rhee+17

A → infall region

B → 0.00 Gyr ≤ t_{infall} ≤ 3.63 Gyr

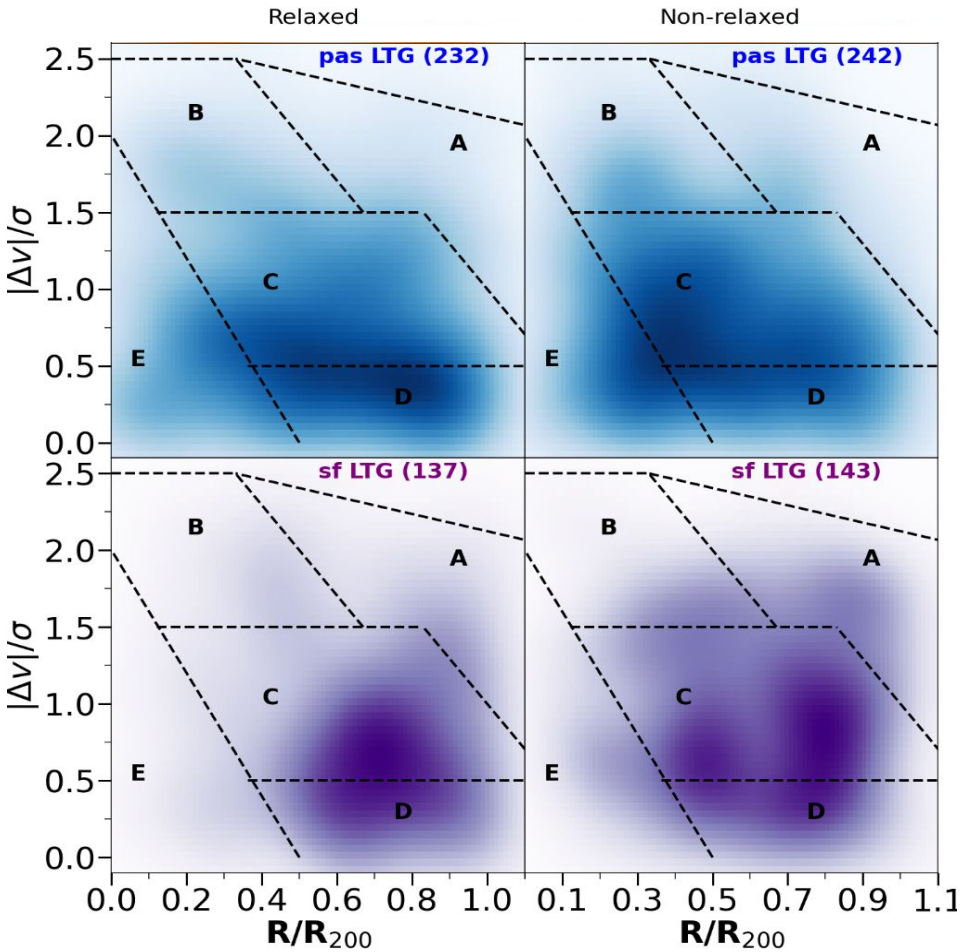
C, D → 3.63 Gyr ≤ t_{infall} ≤ 6.45 Gyr

E → 6.45 Gyr ≤ t_{infall} ≤ 13.7 Gyr

See also **Pasquali+19** for alternative infall time measurements

- **Passive ETGs are present in the cluster for longer than Star-forming ETGs**
  - **The star formation activity can be the result of:**
    - **Residual SF**
    - **Rejuvenation**

➔ Results



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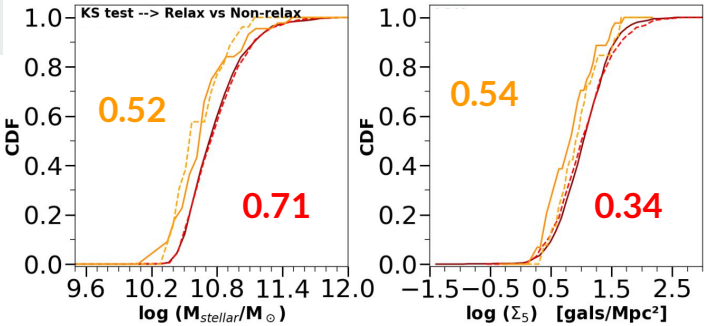
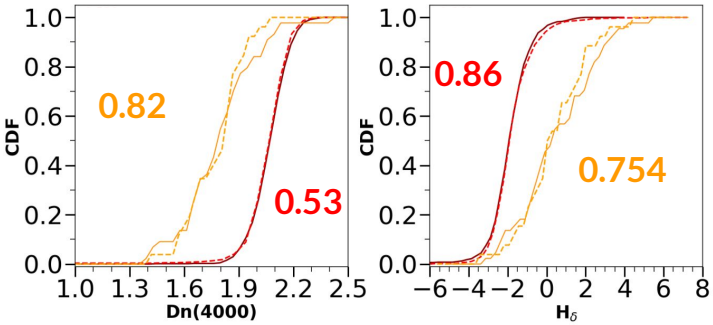
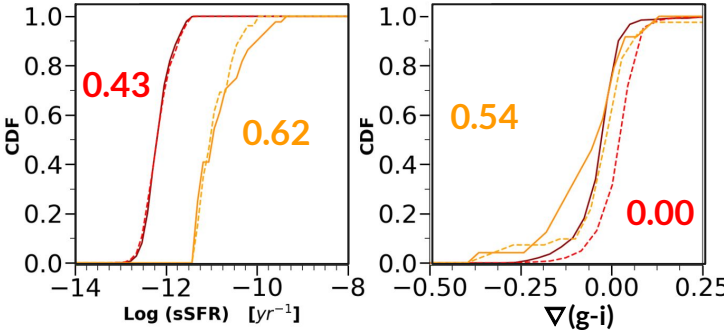
See also **Pasquali+19** for alternative infall time measurements

- **LTG galaxies inhabit the same regions in the phase-space diagram**
  - **similar infall time intervals**
  - **quenching without morphology transformation**

Relax *vs.* Non-relax







Relax

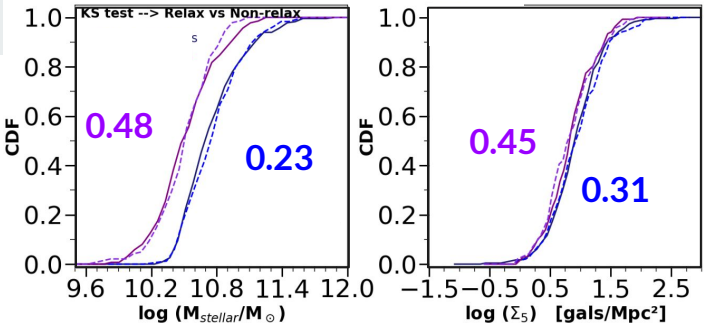
Non-relax

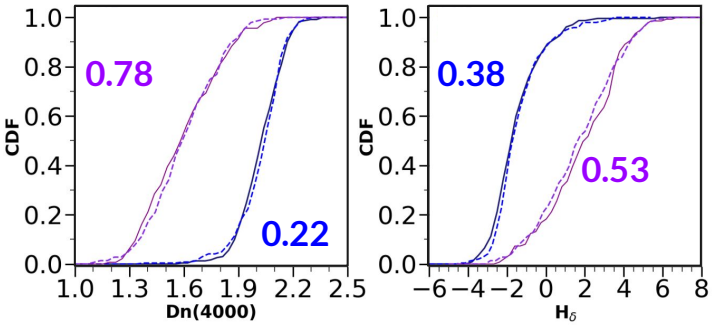
Pas ETG

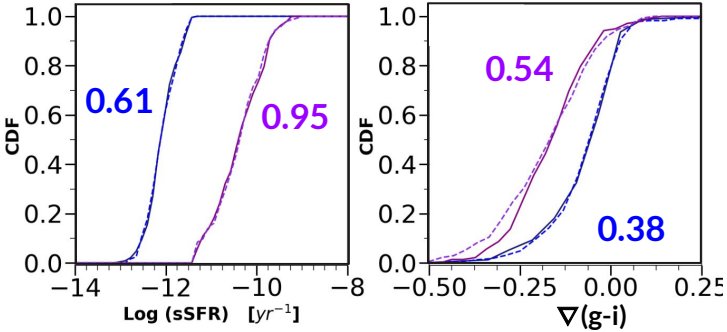
SF ETG

Pas LTG

SF LTG







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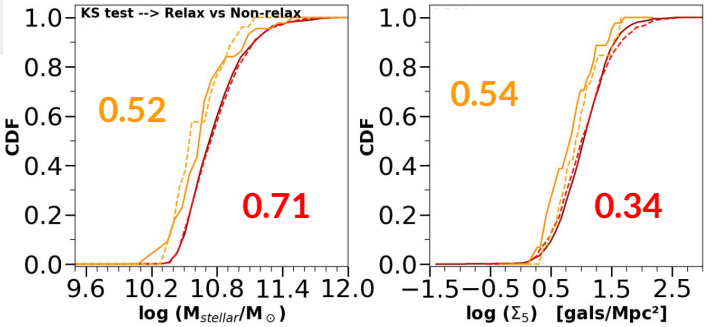
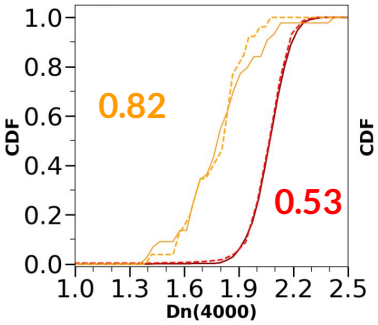
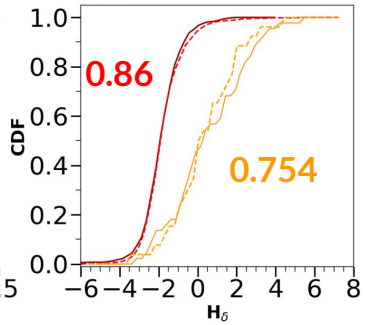
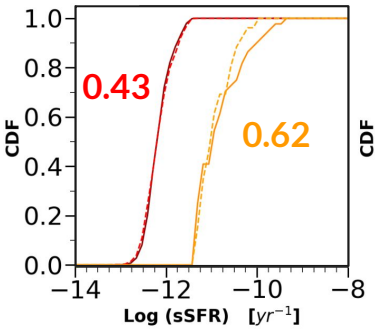
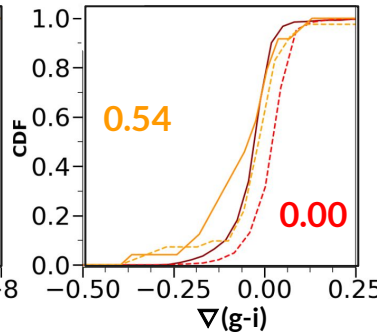






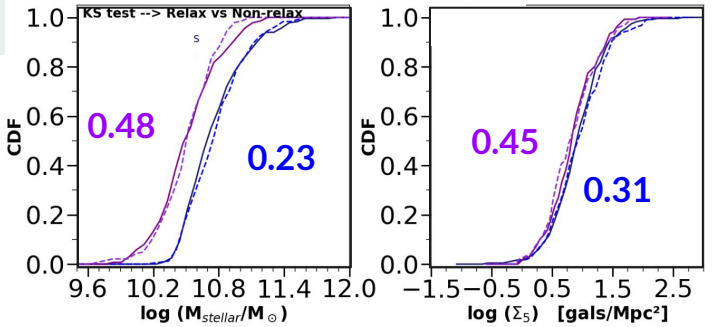


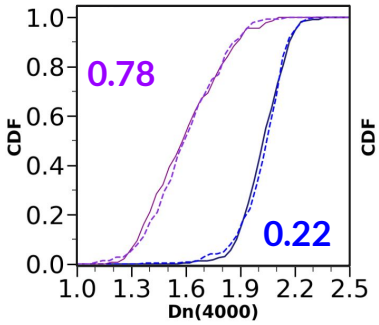


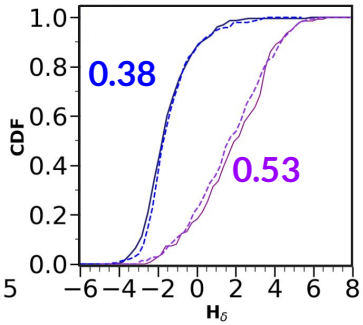
- p-value < 0.05
  - distinct distribution

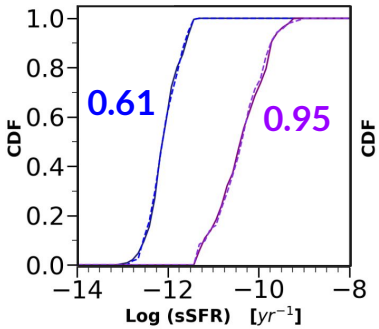
When compared, relaxed vs non-relaxed cluster galaxies <u>show statistically similar</u> distributions (except for color gradient in Pas ETGs)

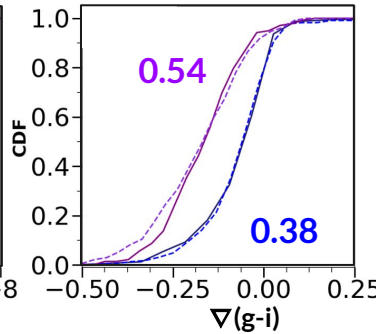
From now on we will consider both cluster samples as one.



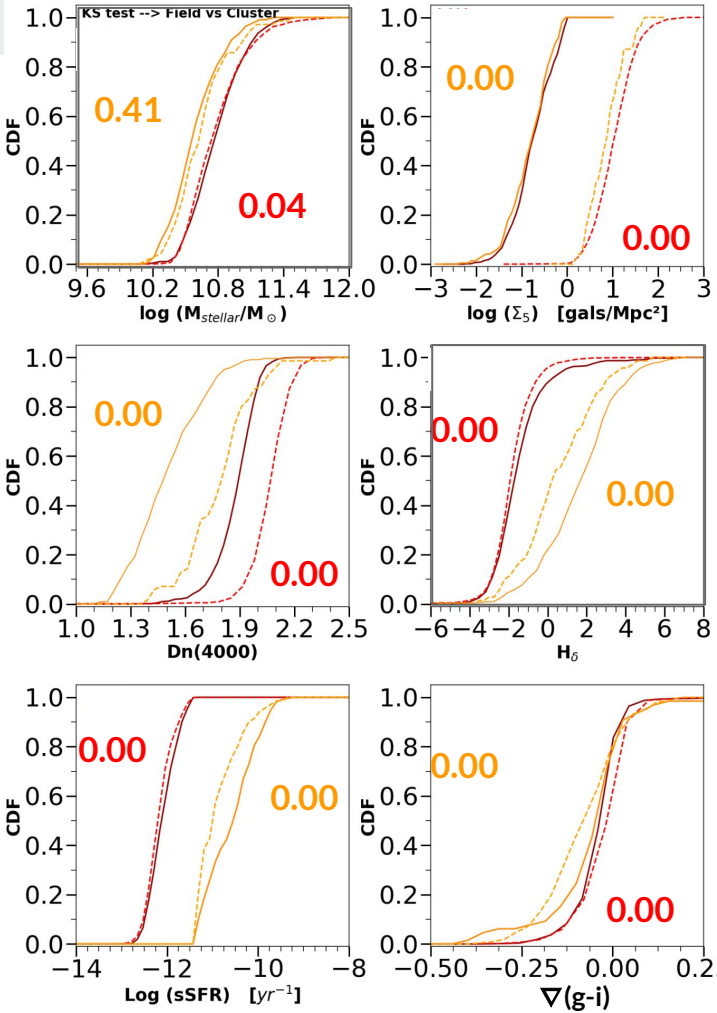








Field *vs.* Cluster

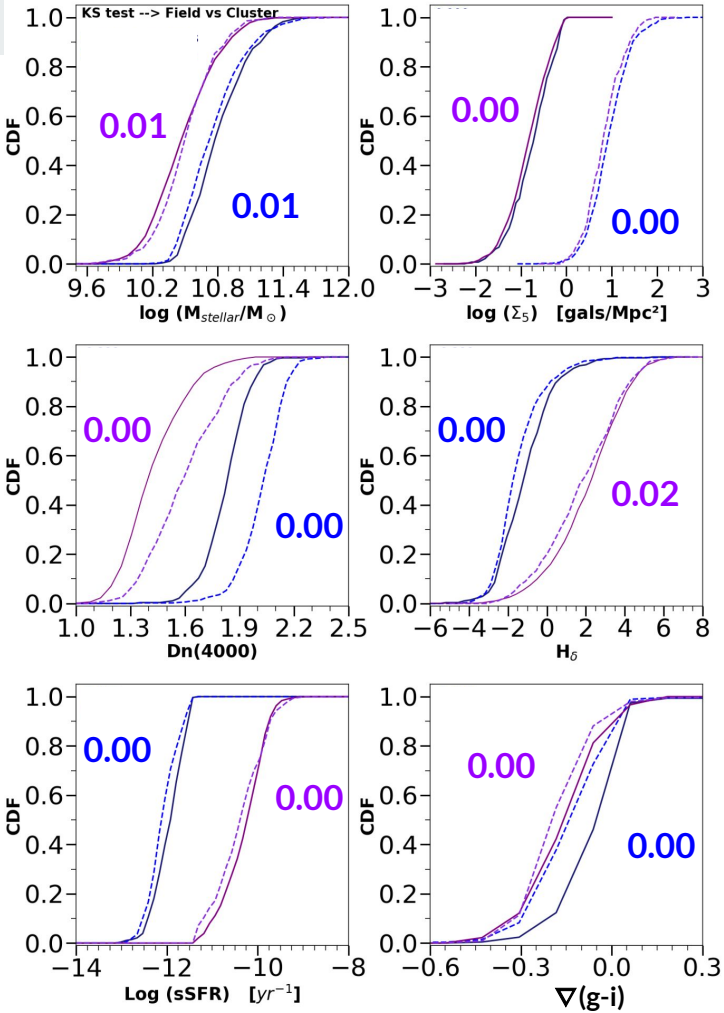


Field

Cluster

- p-value < 0.05
  - distinct distribution

When compared, Field and Cluster galaxies show <u>statistically distinct distributions</u> (except for stellar mass for SF ETGs)



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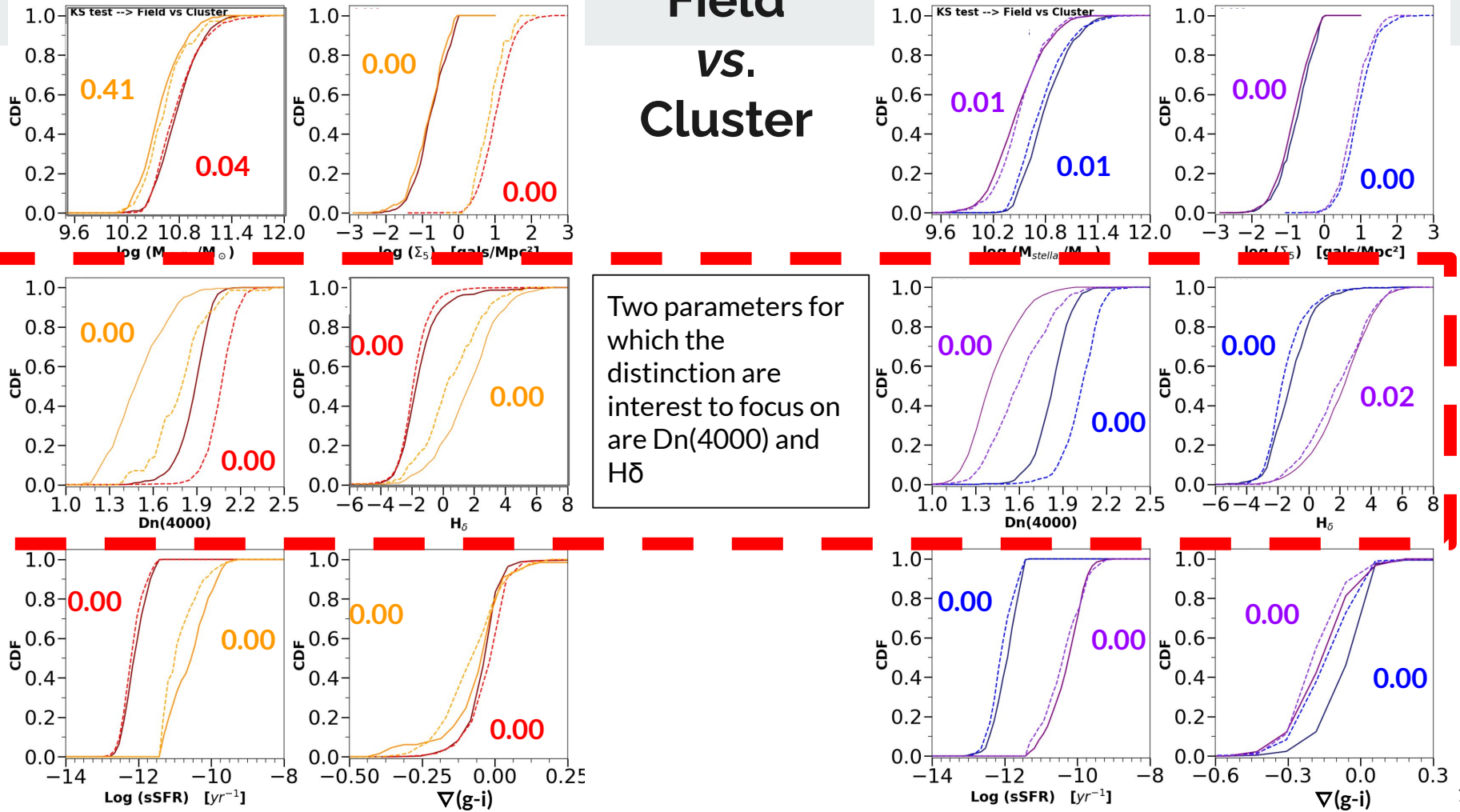
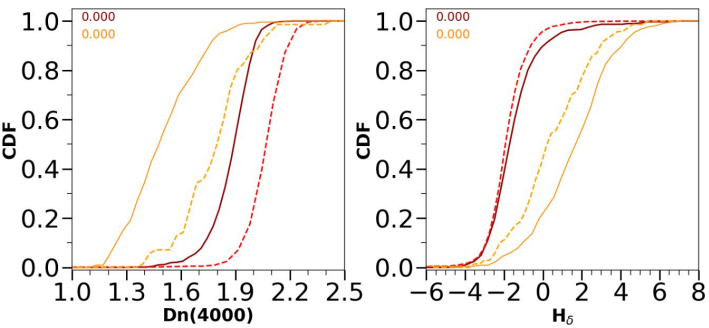


Two parameters for which the distinction are interest to focus on are Dn(4000) and Hδ



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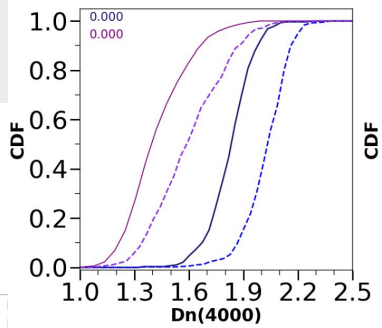
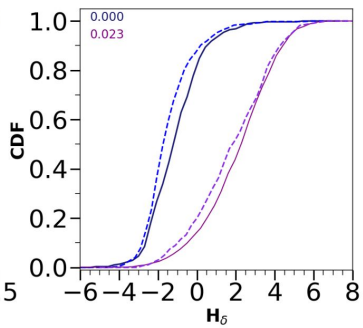
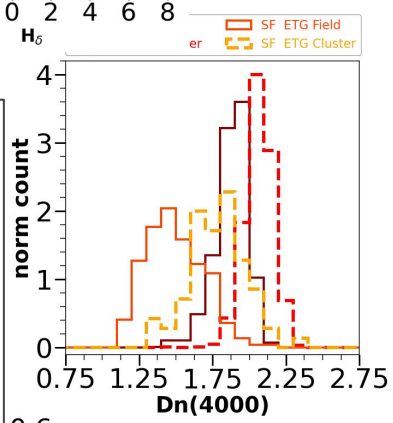


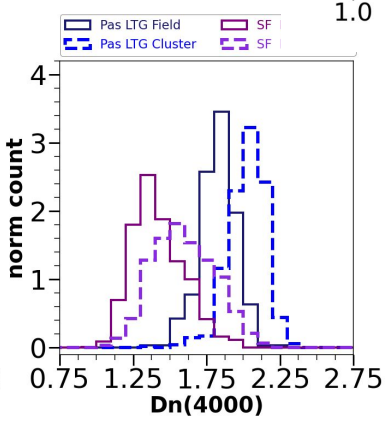


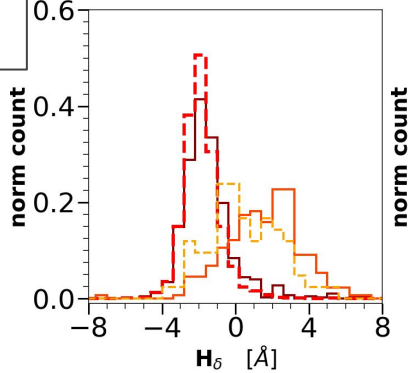
Dn(4000) → measurement of the 4000 Å break

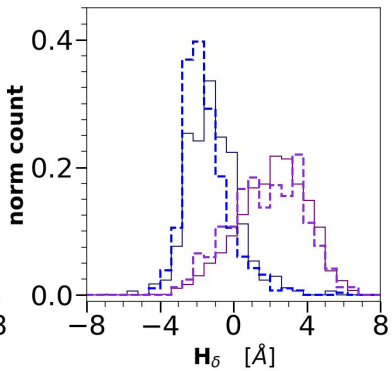
Low mass stars absorb a great amount of high energy photons

- Strong break
  - older stellar population









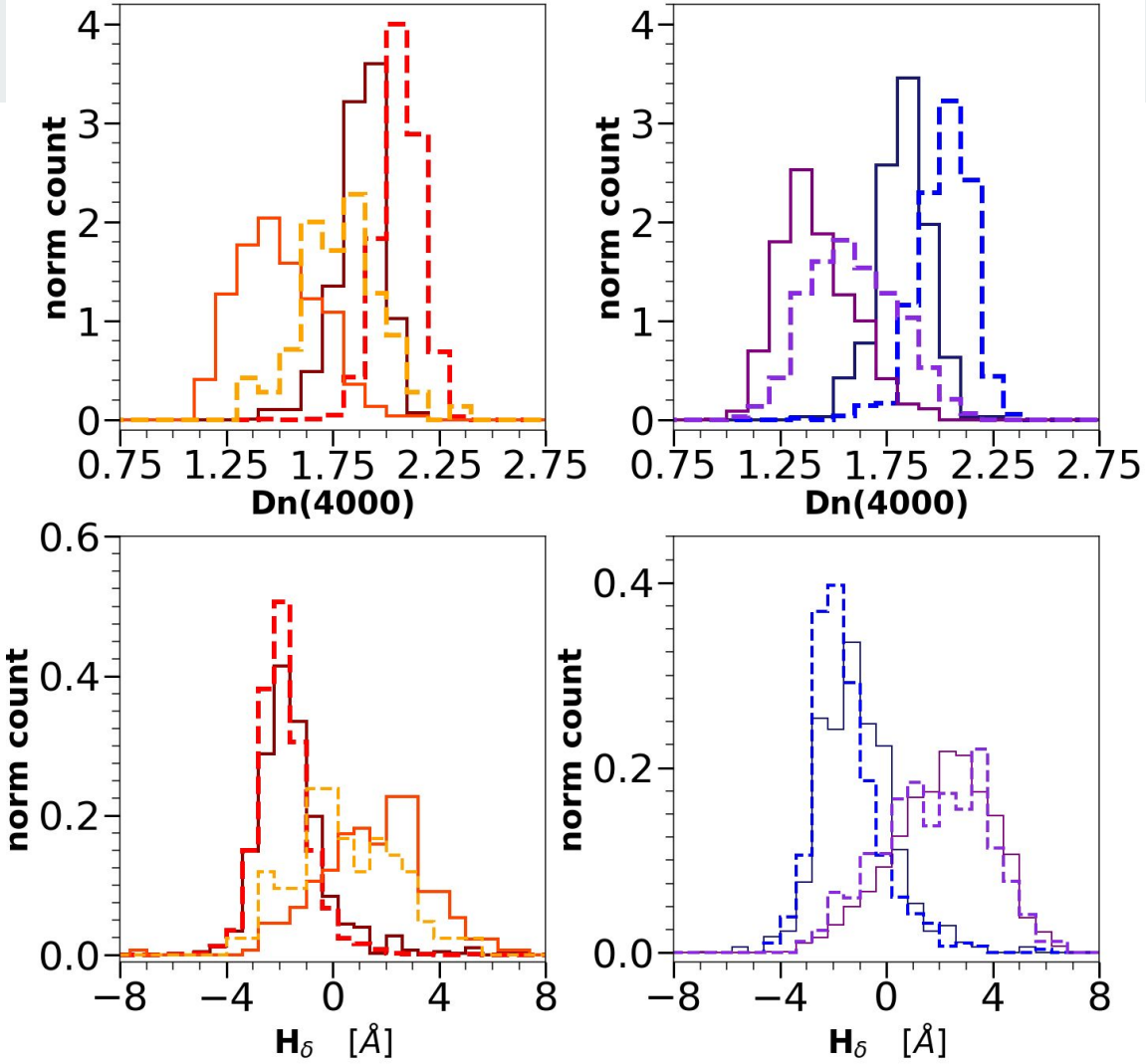
Hδ → Balmer line

Emission related to ionization caused by high mass stars

- more emission, more relevant the recent star-formation

Passive ETG

SF ETG



Cluster

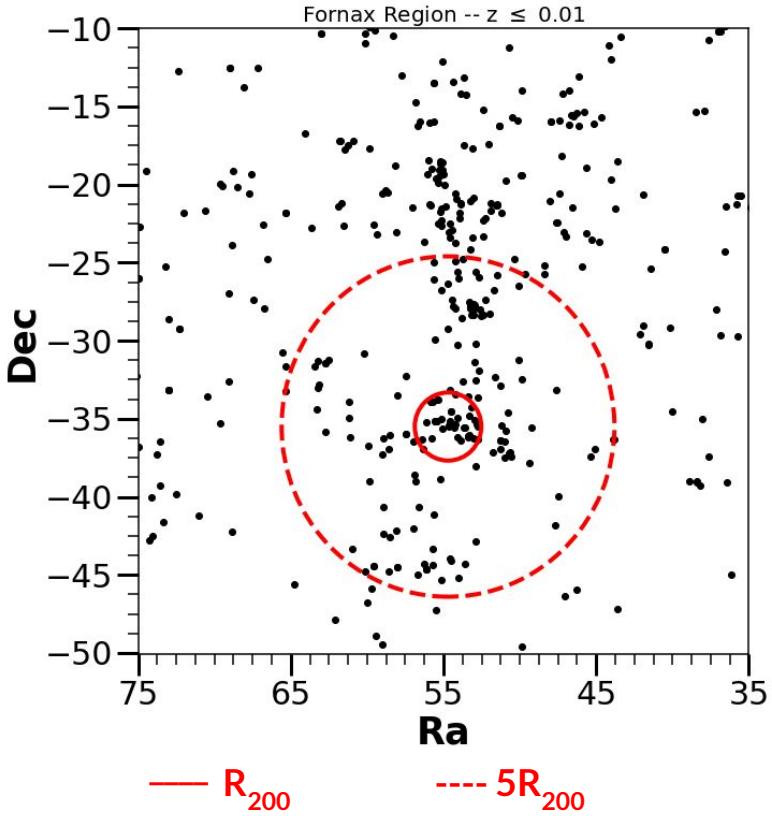
Field

Passive LTG

SF LTG

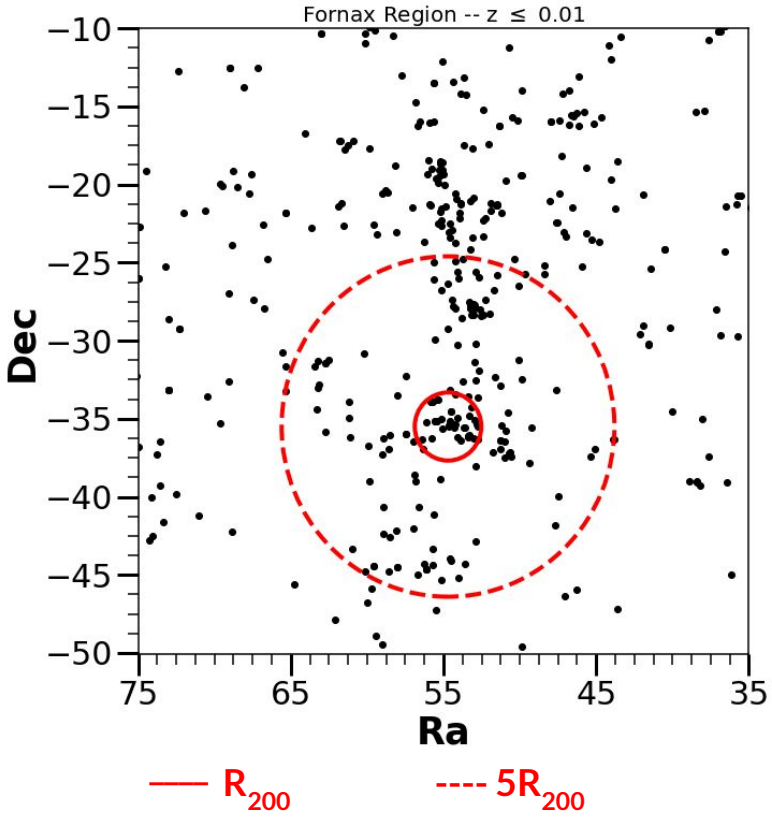
→ S-PLUS

- We are starting to use S-PLUS idr3 to apply a similar study for Fornax Cluster (will be extended to other clusters):
  - **Search for blue ETGs** in the Fornax region:
    - investigating their **properties in the projected phase-space (PPS)**,
      - including the Fornax A subgroup (and beyond, up to $5R_{200}$ if possible).



→ S-PLUS

- In our SDSS sample we do not observe the influence of the global dynamic state of the cluster in the presence and properties of SF ETGs:
  - In the Fornax region, we will have the opportunity to investigate the the **environmental influence**, not only for the **global** state of the cluster , but also for the **different galaxy locations**:
    - Main cluster body
    - Fornax A sub-group
    - Filament



→ Conclusion

- SF Early-type Galaxies have similar infall time to Late-type Galaxies
  - Passive ETGs infall a longer time ago
- Low influence of the dynamic state of the cluster in the galaxies properties in our sample
- There is a clear distinction between Field vs Cluster galaxies:
  - Especially looking to Dn(4000) and Hδ:
    - SF ETGs in clusters have an **older stellar population**, and **less relevant ongoing SF** than the SF ETGs in the field.
- To answer the question if the SF ETGs are the result of rejuvenation or are showing residual SF, more data are required:
  - but the differences between the SF ETGs with the passive ones, and the similarities with the SF LTGs can indicate that is it probably not a rejuvenation process taking place at these galaxies

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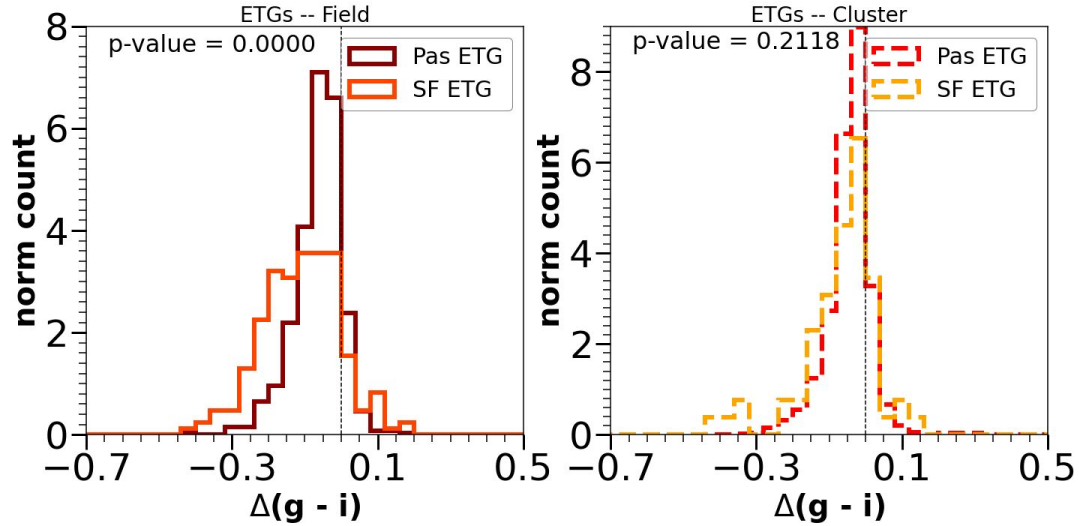
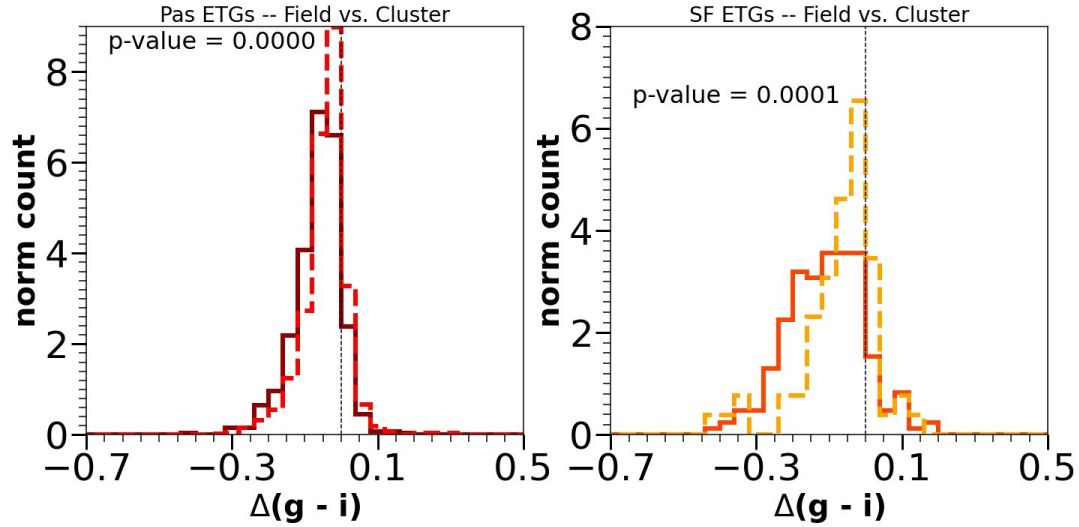
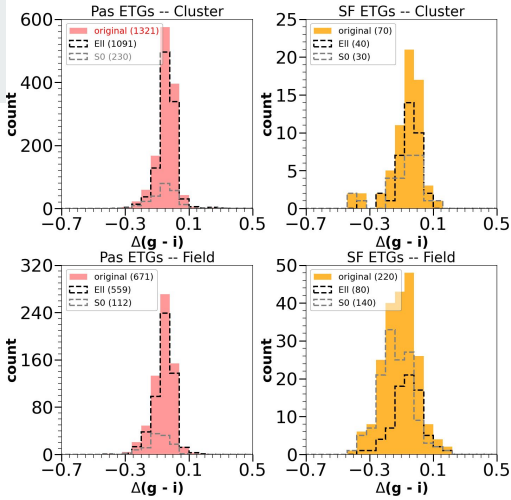
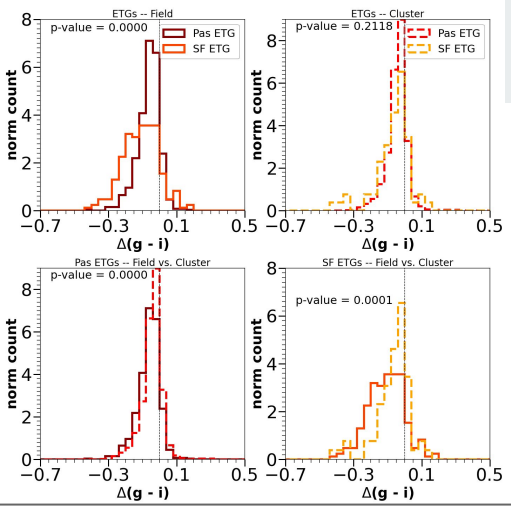






- Measurement of the color variation inside the galaxy:
  - Differents evolutionary pathway affects the gradient differently
    - in **monolithic evolution**, the central part retain more gas in the center causing a bigger enrichment in the center region
      - **more strong gradient**
    - **mergers** cause mixing of gas
      - **less steep gradient**



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