On the Growth of Diffuse Light from Simulations of Galaxy Clusters

Betelehem Bilata Woldeyes

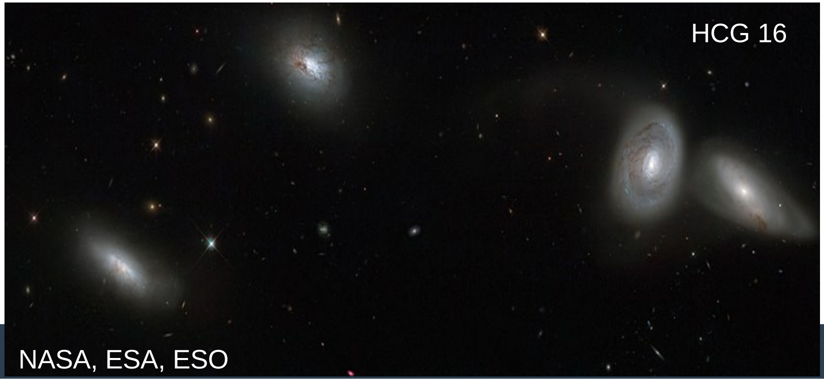
Jaime Perea
José María Solanes

ICCUB Winter Meeting
February 6 - 7, 2024
Barcelona, Spain

Outline

- Galaxy groups and clusters
- Intracluster light (ICL)
- Our work
- Results
- Preliminary conclusions

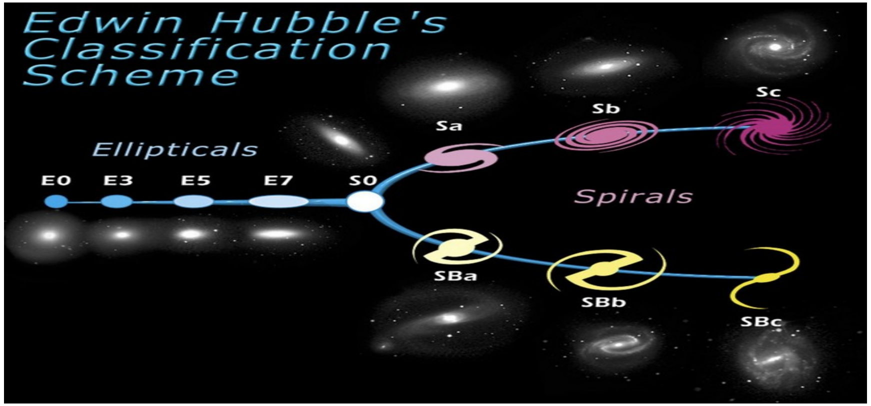
Galaxy groups and clusters

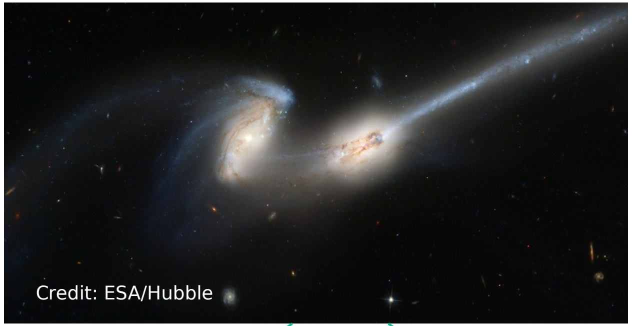


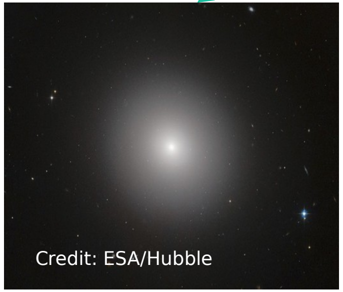
- A structure that consists of galaxies that are bound together by gravity.
- Based on the size and number of galaxies, we can differentiate groups and clusters (no clear dividing line between them).
- Galaxy groups typically contain a few dozens of bright galaxies and their mass is ~ $10^{13} M_\odot$.
- Clusters are larger than groups which can have hundreds to thousands of galaxy members with typical masses ranging from $(10^{14} – 10^{15}) M_\odot$.

Galaxy groups and clusters

- Interaction and mergers among the system
  - ➔ *Change the galaxy's morphology*



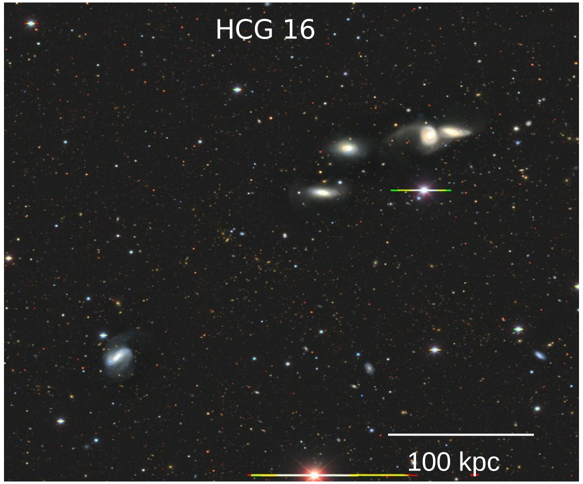


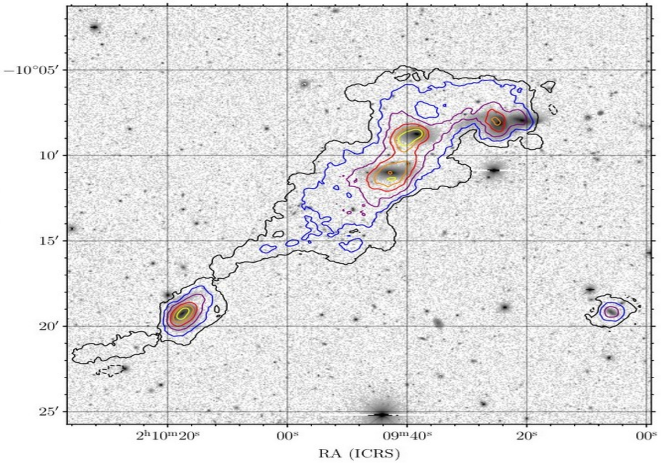


- A merger between disk galaxies → massive ellipticals (Toomre & Toomre 1972).
- It may lead also to the formation of lenticulars (Querejeta et al. 2015) under some particular relative orientations and spins of the progenitors.
- Morphological evolution of galaxies are mainly driven by merging processes; at least in groups.

Galaxy groups and clusters

- *A significant amount of material will be removed and form a halo of material around the galaxies*
  - **Stripped interstellar gas (mainly in the form of neutral hydrogen (HI))**; redistributed differently depending on the level of interaction (Verdes-Montenegro et al. 2001; Jones et al. 2023).



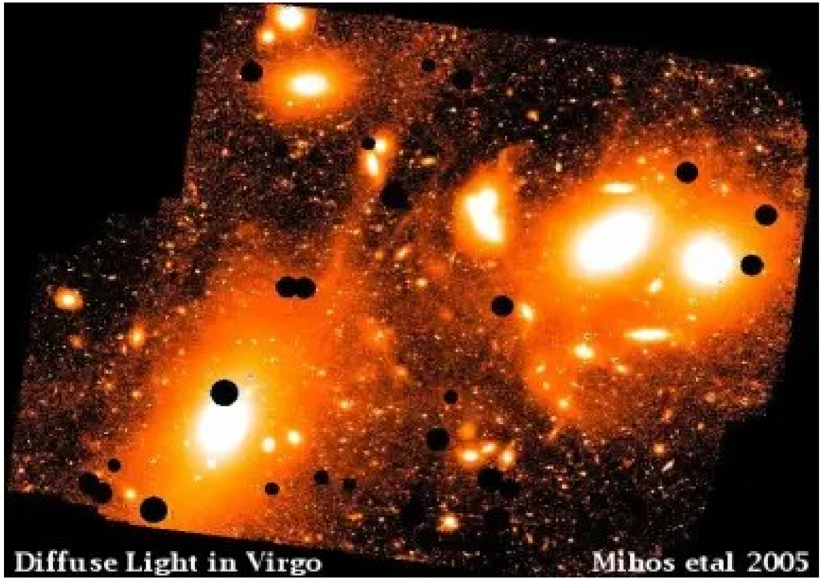


Jones et al. 2019

HCG 16, the HI gas is in the process of leaving the discs of the galaxies and filling the intragroup medium with significant amounts of HI (Jones et al. 2019).

Galaxy groups and clusters

- **Form of stars**; it will be detected as diffuse light between galaxies.

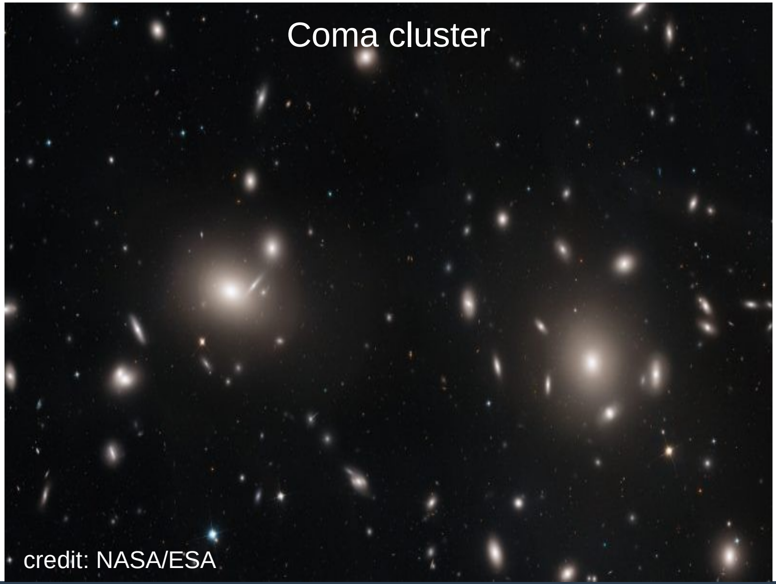


- **Intracluster light (ICL)**: an extended low-surface-brightness component formed by stars stripped from their host galaxies and floating without bounding to any of the galaxies in the cluster.


Intracluster Light

Intracluster light

- The existence of diffuse components in between galaxies in a cluster was first proposed by Zwicky (1937).
- Then he observed in the Coma Cluster, a diffuse and extended component (Zwicky 1951, 1957).



- An extended low surface brightness (SB) component formed by stars → difficult to detect (limited availability of images deep enough to detect them)

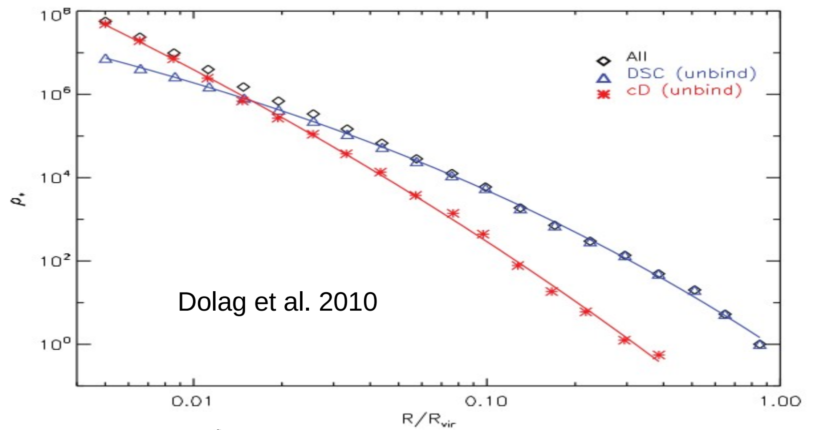
An urban/city sky → a SB ~ 17 mag arcsec^{-2} V-band

A perfect dark sky → a SB ~ 22 mag arcsec^{-2} V-band

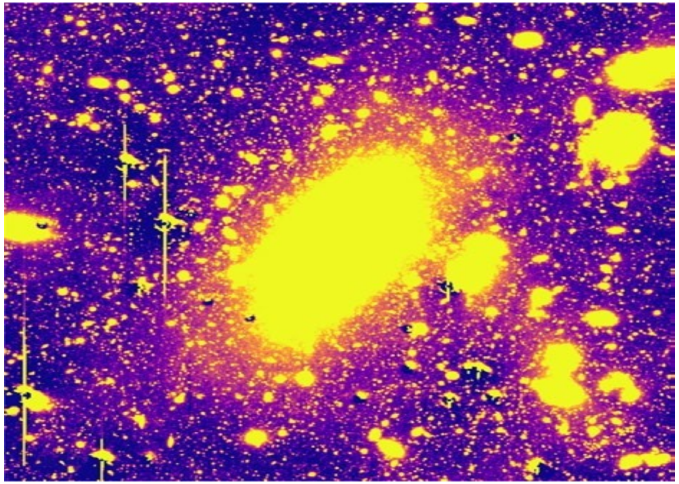
ICL → μ_V > 26 mag arcsec^{-2} (Feldmeier et al. 2004; Mihos et al. 2005; Rudick et al. 2010; Rudik et al. 2011; Montes 2022)

Intracluster light

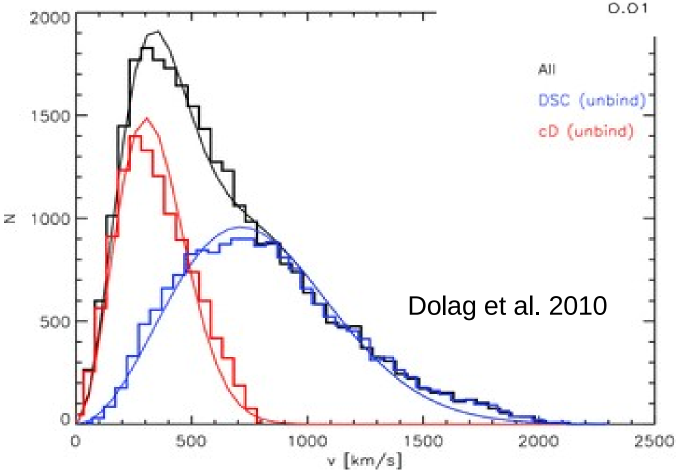
- Stars that are not gravitationally bound to any of the galaxies in the cluster.
- It's often found concentrated around brightest cluster galaxy (BCG).



Stellar density profiles of cD (red) and diffuse stellar component (DSC) (blue).



Abell 85 in the g-band (Montes 2022)



Velocity histogram of the main halo stellar component (black line), red and blue histograms show the velocity distribution of the cD and DSC (Dolag et al. 2010)

Intracluster light

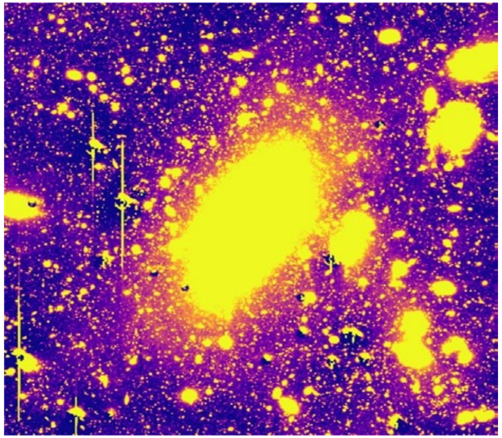
- Formation mechanism of ICL - mergers, stellar stripping, in situ star formation, etc.
- Usually stellar stripping is the dominant formation channel of ICL (i.e., Contini 2021).

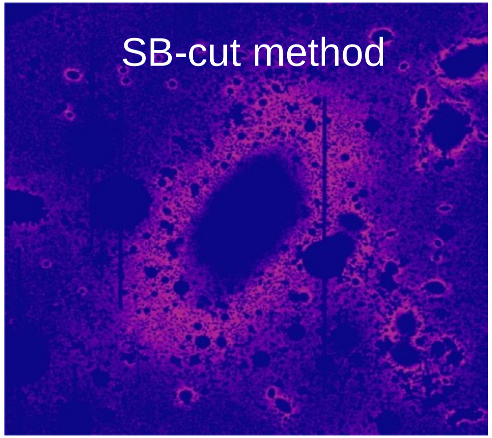
Why do we study ICL?

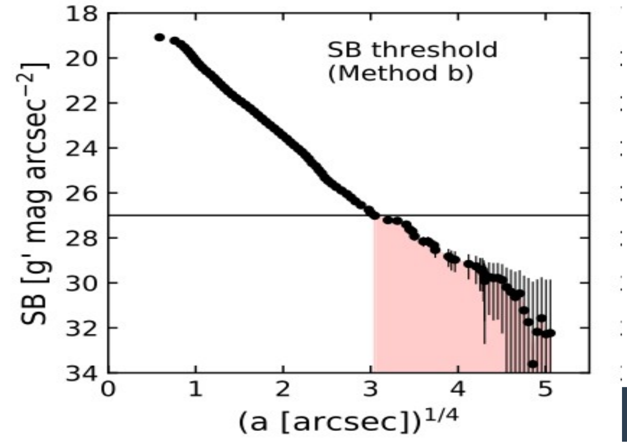
- It gives information about the accretion history and evolutionary stage of clusters (Rudick et al. 2006).
- It has a potential to describe the assembly history of clusters and the growth of BCG with time (Montes 2019).
- It can be a luminous tracer of dark matter potential in galaxy groups and clusters (Montes & Trujillo 2019; Contini & Gu 2020; Yoo et al. 2022).

Intracluster light

Abell 85 in the g-band (Montes 2022)







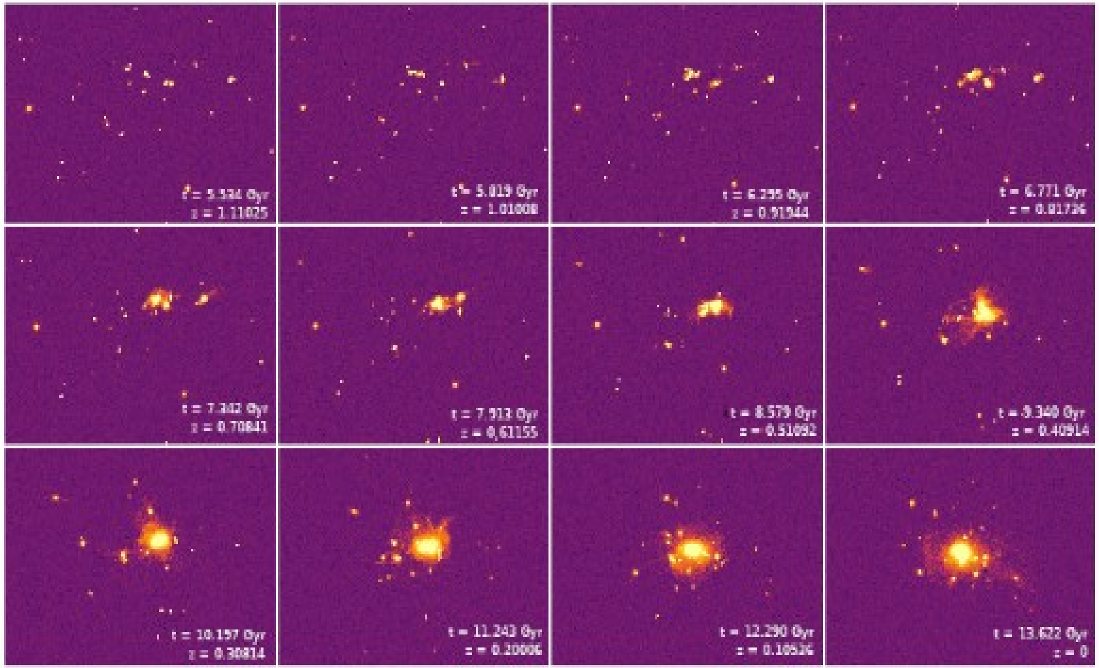
Kluge et al. 2021

Detection methods:

- **From observations:**
  - Surface brightness cut (SB-cut)
  - Profile fitting with functional forms to model BCG + ICL component (Contini 2021)
- **From simulations:**
  - Binding energy
  - Three dimensional mass density
  - SB-cut

Our work

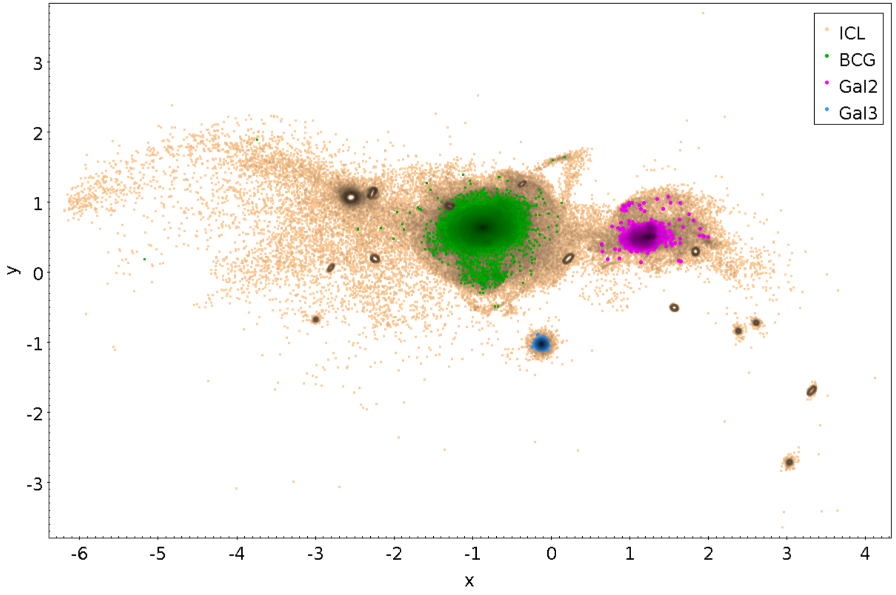
We aim to study the **formation of the ICL**, **track its growth over cosmic time**, and investigate **its potential to describe the assembly history of clusters during their pre-virialized state**.



- 100 simulated galaxy clusters created as nearly uniform isolated spherical primordial overdensity at z=3 that first expand linearly, then turnaround, and finally undergo a completely non linear collapse (see Solanes et al. 2016, Perea & Solanes 2016).
- Our clusters have galaxies between 20-69 galaxies with a median of 31 galaxies.

Results

- Separated the ICL from the galaxies using SB-cut (μ_V = 26.5 mag arcsec^{-2}) method and mapped the ICL, BCG, and the second and third massive galaxies.



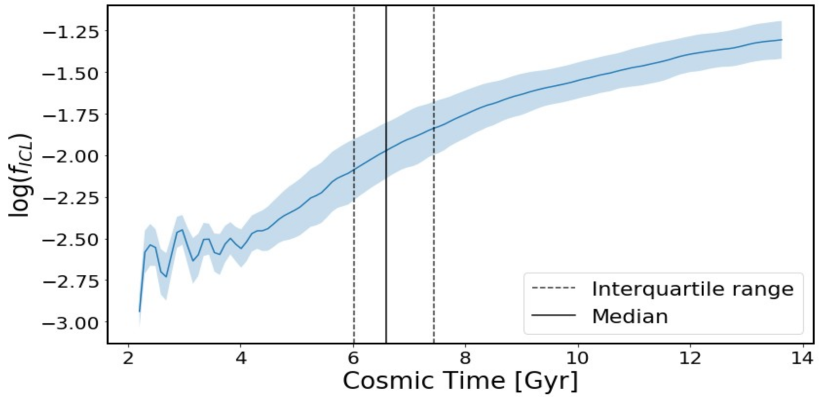
- Investigated the degree to which a series of parameters related to the **mass** and **fraction** of ICL are correlated (0<z<1).

log(x)	log(y)	m	c	r	t	p
M_{tot}	M_{ICL}	0.85	-1.0	0.38	37.3	1.0
M_*	M_{ICL}	1.11	-2.95	0.55	60.0	1.0
M/L	M_{ICL}	-1.08	11.84	0.36	35.0	1.0
M_{BCG}	M_{ICL}	1.78	-9.76	0.71	91.1	1.0
M_{tot}	f_{ICL}	0.12	-3.0	0.07	6.43	1.0
M_{BCG}	f_{ICL}	1.78	-21.7	0.55	59.3	1.0
σ_v	f_{ICL}	0.87	-3.29	0.6	68.2	1.0
M_{tot}	M_{BCG}	0.22	8.32	0.15	14.1	1.0
M_*	M_{BCG}	0.63	3.81	0.51	54.2	1.0
r_c	M_{BCG}	-0.2	11.84	0.23	21.6	1.0
r_m	M_{BCG}	-0.32	12.22	0.35	33.9	1.0

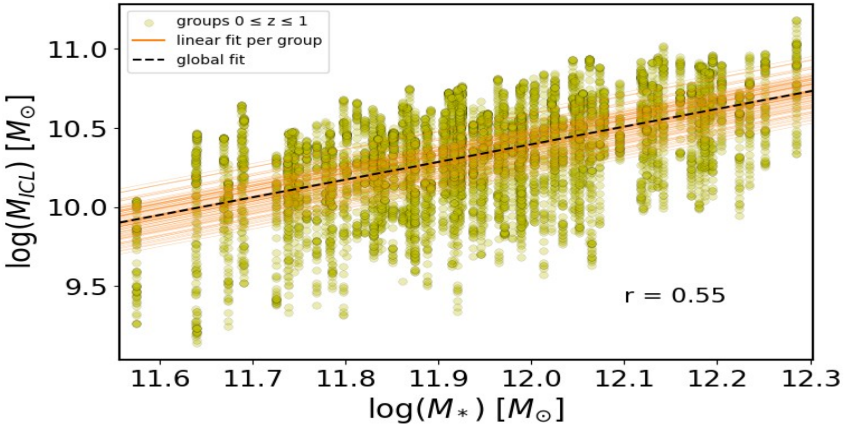
r – Pearson correlation coefficient

p – Probability that the two parameters are correlated

Results

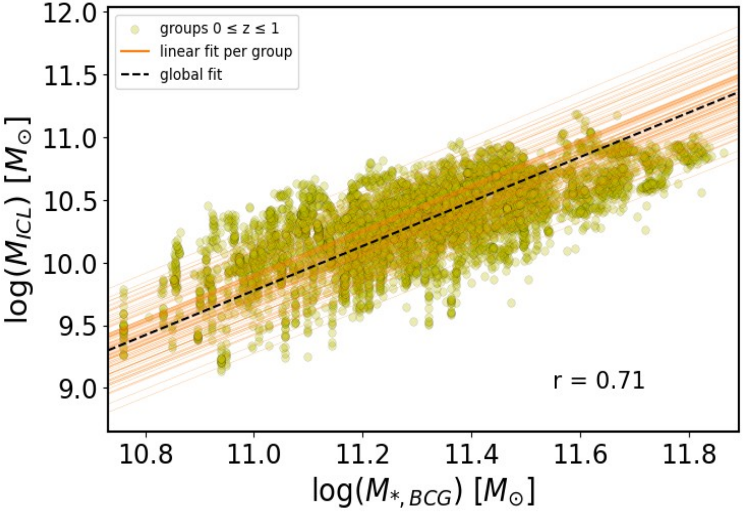


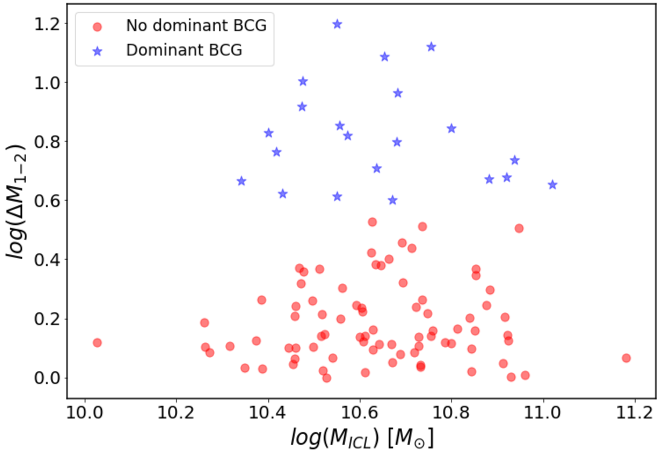
- The ICL begins to form in substantial amounts during the turnaround and keeps growing steadily with cosmic time.



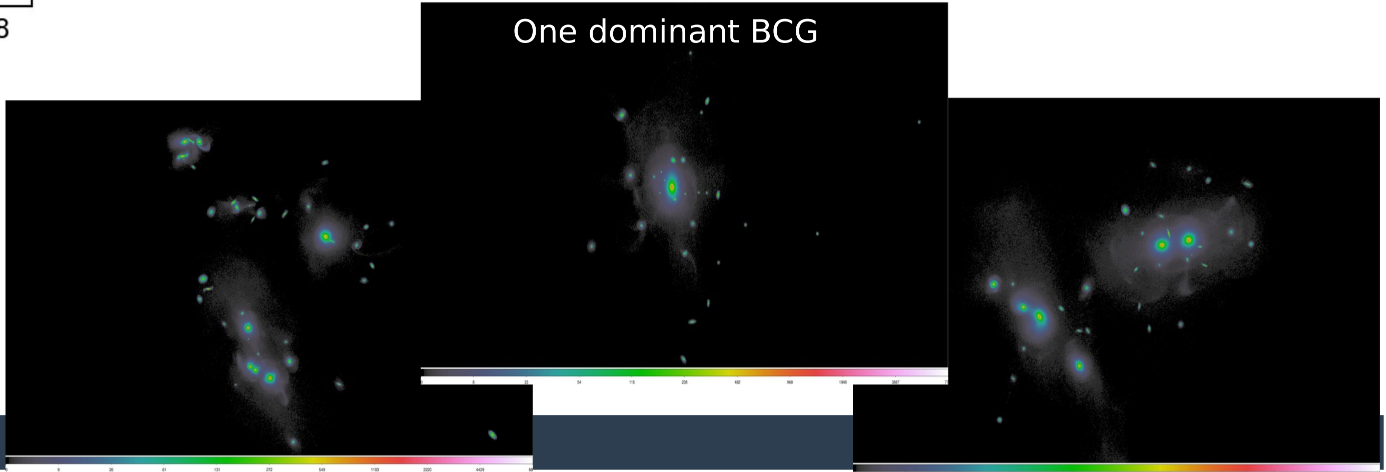
- The larger the initial M_*, the larger the amount of ICL.

Results



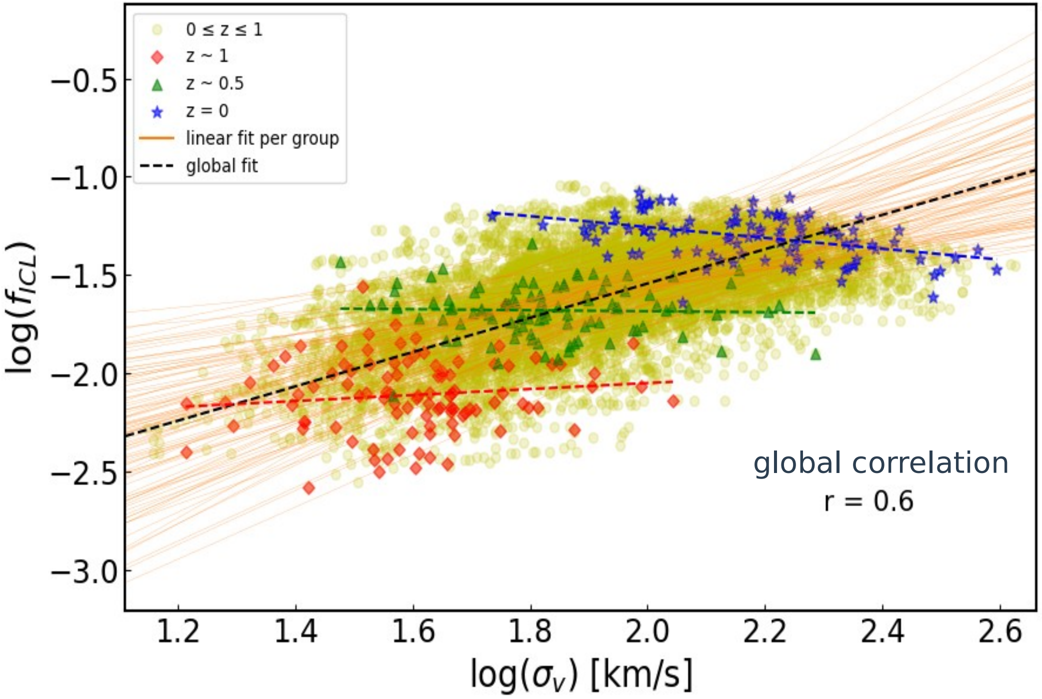


- There exist ICL in a clusters with more than one dominant galaxy.



- The M_{ICL} shows a linear growth with the M_{BCG}. At the z=0, it shows a sub-linear correlation (with a logarithmic slope of 0.65).

Results



- The f_{ICL} show a negative correlation (r = 0.42) with the cluster's velocity dispersion at z=0.
- The slope of the linear fit progressively changes from flat at z ~ 1 to negative at z=0.

Preliminary conclusions

- The ICL grows steady with cosmic time and grows linearly below z~1.
- The larger the initial M_* of a cluster, the larger the amount of ICL the cluster will have.
- The growth of the M_{ICL} is connected with the growth of BCG, however, their growth rate is not one-to-one. BCGs are not necessarily needed to have a significant amount of ICL.
- The f_{ICL} vs σ_v relation at $z = 0$ suggests that the σ_v of the galaxies in the cluster is inversely related to the f_{ICL}.

Thank you!

We acknowledge financial support from the Spanish state agency PID2019–106027GB–C43. MCIN/AEI/10.13039/501100011033 has also provided additional support through the Centre of Excellence Severo Ochoa's award for the Instituto de Astrofísica de Andalucía under contract SEV–2017–0709 and the Centre of Excellence María de Maeztu's award for the Institut de Ciències del Cosmos at the Universitat de Barcelona under contract CEX2019–000918–M. BBW acknowledges financial support by the PRE2020-093715 grant from the SEV–2017–0709 project.