Properties of the IntraCluster Light as predicted by a Semi-Analytic Model of Galaxy Formation

Emanuele Contini (Purple Mountain Observatory, Nanjing)

Gabriella De Lucia (INAF), Alvaro Villalobos (INAF), Stefano Borgani (UNITES, INAF, INFN)

Sydney 9-12/02/2015
• Introduction
• Modelling stellar stripping in a Semi-Analytic Model (SAM)
• ICL properties (model predictions)
• Recent observations
• Future perspectives
• Summary
ICL: diffuse component made of stars not bound to galaxies

Courtesy of V. Presotto (Presotto et al. 14)
1) Disruption of dwarf galaxies (Purcell+07, Murante+07, Conroy+07)

2) Tidal stripping of intermediate/massive galaxies (Rudick+09, Watson & Conroy+13, Laporte+13, Contini+14)

3) Mergers between galaxies
   (Purcell+07, Murante+07, Conroy+07, Contini+14)

4) Pre-processing/accretion (Rudick+06, Sommer-Larsen 06, Contini+14)

5) In situ star formation (Puchwein+10)
ICL should be the light after having removed the contribution of all galaxies that are cluster members, including the BCG

**Observations**
Isophotal cuts and/or two-dimensional profile fittings to model the surface brightness profile of brightest cluster galaxies (Zibetti+05, Gonzalez+05, Krick-Bernstein 07, Presotto+14, Montes+14)

**Simulations**
Binding energy definitions plus dynamical information (Murante+07, Puchwein+10, Rudick+11, Cui+14)

**SAMs**
By construction (Monaco+07, Somerville+08, Guo+12, Contini+14)
MACS1206 (CLASH survey), a massive cluster, $M_{200} = 1.4 \cdot 10^{15} M_{\odot}$ at $z \sim 0.44$

**GOAL:** Understanding possible systematics/bias using different ICL detection techniques

- **SBlimit method** provides higher ICL fractions (larger effect at lower SB limit)
- **GALtoICL method** provides safer ICL detections almost free of contamination, but more time consuming
Implementing Stellar Stripping

Model Disruption:  
- we estimate the pericentric distance of any single satellite
- we compute the halo density within the pericenter and the galaxy density
- if $\rho_{\text{halo}} > \rho_{\text{sat}}$ we assume the satellite to be destroyed (Guo+12)

Model Tid. Radius:  
- we estimate the tidal radius: $R_t = \left( \frac{M_{\text{sat}}}{3 \cdot M_{\text{halo}}} \right)^{1/3} \cdot D$ (Binney & Tremaine 08)
- if $R_t < R_{\text{bulge}}$ we assume the satellite to be destroyed
- we strip the stellar mass in the shell $R_t - 10 \cdot R_{sl}$ assuming an exponential profile for the disk

Model Cont. Stripping:  
- we use a fitting formula set by simulations

$$M_{\text{lost}}^* = M_{\text{accr}}^* \exp \left[ \left( \frac{-16}{1 - \eta} \right) \left( \frac{M_{\text{sub}}}{M_{\text{par}}} \right)^{1/2} \left( 1 - \frac{t}{t_m} \right) \right]$$

by computing all quantities at the time of accretion (Villalobos+12)

Mergers: 20% of the stellar mass of the merging satellite is added to the ICL component of the other galaxy
Main Points

1) Stellar Mass Function and BCG luminosity
2) ICL/ICL+BCG fraction from groups to clusters
3) Contribution to the ICL from different channels
4) ICL metallicity
**Stellar Mass Function and BCG Luminosity**

**BCG sample:** 341 Brightest Cluster Galaxies (BCGs) in haloes with mass in the range $10^{13} < \log M_{200}[h^{-1}M_\odot] < 10^{15.3}$

- Conditional Stellar Mass Function (CSMF) improved in the low-mass end
- Models Disruption and Tid. Radius reproduce the observed K-band luminosity
- Model Cont. Stripping predicts BCGs too bright on cluster scale (shorter merging times)
ICL Fraction in Clusters

\[ M_{\text{tot}}^* = M_{BCG}^* + M_{ICL}^* + M_{\text{sat}}^* \] within \( R_{500} \) (right panel) and within \( R_{200} \) (left panel)

\[ M_{\text{ICL}}/M_{\text{tot}} \]

\[ (M_{\text{ICL}} + M_{BCG})/M_{\text{tot}} \]

Contini+14

- Models predict a constant ICL fraction in clusters, in good agreement with observations (10% − 40%, e.g. Feldmeier+04, Zibetti 08, McGee & Balogh 10, Toledo+11)
- Model Cont. Stripping over-predicts the observed ICL+BCG fraction
- Mergers increase the ICL+BCG fraction (different merging history of BCGs)
What Contributes Most to the ICL?

- Massive satellites contribute most to the ICL
- Massive BCGs accrete a significant amount of ICL
- Mergers play an important role mostly in Model Cont. Stripping

Contini+14
ICL Metallicity

- Models predict sub-solar metallicity, in agreement with observations (Virgo, William+07; A2744, Montes & Trujillo 14; CLASH, De Maio+15)
- Metallicity distributions cover a wide range
Abell Cluster 2744, a rich cluster at $z \sim 0.3$ with virial mass $\sim 7 \cdot 10^{15} M_\odot$ and virial radius $\sim 3.7 \, \text{Mpc}$, undergoing a major merger

**GOAL:** characterize age and metallicity of the ICL in A2744

- The ICL is the result of the disruption of infalling galaxies with mass around $3 \cdot 10^{10} M_\odot$
- The ICL metallicity is $Z = 0.018 \pm 0.007$ and age around $6 \pm 3 \, \text{Gyr}$
- Fraction of stellar mass in ICL at least 6%
- The ICL has been formed recently, $z < 1$
De Maio+14

Sample: 4 clusters from CLASH survey at $0.44 < z < 0.57$, with mass range $[0.6-2.6] \cdot 10^{15} M_\odot$

- Negative metallicity gradients, from supersolar in the inner regions (BCG dominated), to subsolar at larger radii (ICL dominated)
- Tidal stripping of L* galaxies and/or disruption of dwarf as the main mechanism/s of ICL formation
- The little evolution of the faint-end slope of the luminosity function rules out disruption of dwarfs as the main mechanism
- Results disfavour significant contribution to the ICL by major mergers with the BCG
* A better description of merger channel (the fraction of stripped stars might be a function of some properties of the merging satellites, such as stellar mass or orbital parameters;
* ICL colors are still missing!
Conclusions

* ICL fractions in good agreement with observations and not significantly dependent on the halo mass;
* Massive galaxies are the major contributors to the ICL component (70% from galaxies $\gtrsim 10^{10.5} \, \text{M}_\odot$);
* Mergers contribute most in Model Cont. Stripping (30% of the total ICL);
* Pre-processing/accretion important for the largest BCGs (from 20% to 40%);
* Models predict sub-solar ICL metallicity;
* ICL forms relatively late. About 80% of the ICL forms after redshift $z \sim 1$ (not shown);
* No numerical convergence: the ICL fraction is resolution dependent.
"I think you should be more explicit here in step two."

Thank you!
Numerical Convergence

There is a larger number of Type2s for lower resolutions. Type2s are the main contributors.
Two different kinds of satellites: type1 (still associated with a dark subhalo); type2 (no longer associated with a dark subhalo)

ICL component is assumed to be gas free and made of stars

Cold gas (and its metals) stripped from satellites is added to the hot component of the central galaxy.

Galaxies are assumed to have a uniform metallicity distribution

If a type1 becomes type2, it loses its ICL component (added to the ICL component of the central galaxy)
• In Model Disr. (but also Tid. Rad.) BCGs are more massive due to a more efficient cooling

• In Model Cont. Strip. cooling is less efficient and the different merging history of BCGs makes them more massive
Dependency on halo concentration and formation time

Halo sample: 53 haloes with $M_{200}[h^{-1}M_{\odot}] > 10^{14}$.

More concentrated haloes are supposed to have a larger fraction of ICL, since tidal forces get stronger and galaxies are more easily disrupted.