Galaxy Populations in MACSJ1206

A. Mercurio
INAF-Osservatorio Astronomico di Capodimonte

P.I.: P. Rosati
I. Balestra, A. Biviano, M. Girardi, C. Grillo, M. Nonino, V. Presotto, the VLT-CLASH team and the CLASH-team
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Published papers: Zitrin et al. 2012, Unetsu et al. 2012

Cluster Lensing And Supernova survey with Hubble

MACSJ1206-08 (z=0.44)
ACS+WFC3

The CLASH Science Team: ~50 researchers, 24 institutions, 10 countries
Cluster Lensing And Supernova survey with Hubble
HST multi-cycle Treasury Program (530 orbits) - PI: M.Postman

- Panchromatic (ACS+WFC3 16 filters) imaging of 25 massive intermediate-z galaxy clusters
- Measure DM mass profiles over 10-3000 kpc with unprecedented precision
- “Wide-field” gravitational telescopes on the very high-z Universe
- SNe Ia search at 1<z<2 from parallel fields (doubling SNe at z>1.2), combined w/ CANDELS
CLASH: panchromatic view of galaxy clusters

16 filters will yield photometric redshifts with rms error of $\sim 2\% \times (1 + z)$ for sources down to $\sim 26$ AB mag, using $>10^4$ spec-$z$’s for calibration.

 Courtesy of P. Rosati
X-ray images of 23 of the 25 CLASH clusters. 20 are selected to be “relaxed” clusters (based on their X-ray properties only). 5 are selected specifically because they are strongly lensing $\theta_E > 30''$.
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CLASH-VLT

VIMOS Large Programme (230 hr over 2 years) - PI: P.Rosati


• Panoramic spectroscopic survey of 14 southern CLASH clusters at z=0.2-0.6
• Dynamical analysis out to R_{vir} and beyond with ~500 members per cluster
• Highly magnified galaxies out to z~7
• Galaxy structure and stellar pop properties from high to low density environments
CLASH multiple facilities: DM & Baryonic Mass Distribution from independent probes over the 10 kpc ~ 3 Mpc range

Chandra
PI: S.Ettori
Baryon mass distribution
X-ray masses
ICM physics & metallicity

XMM
PI: P. Rosati
VIMOS Large Prog (230 hr)
~500 members per cluster
+ arcs redshifts

Bolocam, Mustang
PI: K. Umetsu
ICM physics
DM&Baryon masses
SZ observations

Spitzer
PI: W. Zheng R. Bowuens
Strong Lensing
Mass profile in the core

HST
Treasury Program
(530 orbits)
PI: M. Postman

VLT
High-z gals
Dynamical analysis
Stellar masses

LBT
High-z gals
WL masses profile
Stellar masses

Subaru (+ ESO-WFI)

DM and Baryons in Clusters

PI: M. Donahue
Baryon mass distribution
X-ray masses
ICM physics & metallicity

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Subaru (+ ESO-WFI)
The VLT-CLASH sample

The VLT-CLASH is a panoramic spectroscopic survey of 14 massive clusters at $z=0.2-0.6$, spanning almost an order of magnitude in mass ($\sim 5$ to $\sim 30 \times 10^{14} M_\odot$), drawn from the sample of the CLASH HST multi-treasury program.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>RA</th>
<th>Dec</th>
<th>z</th>
<th>E(B-V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abell 383</td>
<td>02:48:06.9</td>
<td>-03:29:32</td>
<td>0.187</td>
<td>0.033</td>
</tr>
<tr>
<td>Abell 209</td>
<td>01:31:57.5</td>
<td>-13:34:35</td>
<td>0.209</td>
<td>0.019</td>
</tr>
<tr>
<td>RXJ2129+0005</td>
<td>21:29:40</td>
<td>+00:05:21</td>
<td>0.234</td>
<td>0.041</td>
</tr>
<tr>
<td>MS2137-2353</td>
<td>21:40:12.8</td>
<td>-23:39:27</td>
<td>0.313</td>
<td>0.05</td>
</tr>
<tr>
<td>MACSJ2248-44</td>
<td>22:48:54.3</td>
<td>-44:31:07</td>
<td>0.348</td>
<td>0.012</td>
</tr>
<tr>
<td>MACSJ1115+01</td>
<td>11:15:53.3</td>
<td>+01:29:47</td>
<td>0.352</td>
<td>0.039</td>
</tr>
<tr>
<td>MACSJ1931-26</td>
<td>19:31:49.6</td>
<td>-26:34:34</td>
<td>0.352</td>
<td>0.111</td>
</tr>
<tr>
<td>MACSJ0429-02</td>
<td>04:29:36.1</td>
<td>-02:53:08</td>
<td>0.399</td>
<td>0.061</td>
</tr>
<tr>
<td>MACSJ1206-08</td>
<td>12:06:12.1</td>
<td>-08:48:02</td>
<td>0.440</td>
<td>0.039</td>
</tr>
<tr>
<td>MACSJ0329-02</td>
<td>03:29:40.8</td>
<td>-02:11:54</td>
<td>0.450</td>
<td>0.059</td>
</tr>
<tr>
<td>RXJ1347-1145</td>
<td>13:47:32.0</td>
<td>-11:45:42</td>
<td>0.451</td>
<td>0.062</td>
</tr>
<tr>
<td>MACSJ1311-03</td>
<td>13:11:01.6</td>
<td>-03:10:40</td>
<td>0.494</td>
<td>0.031</td>
</tr>
<tr>
<td>MACSJ2129-07</td>
<td>21:29:26.0</td>
<td>-07:41:28</td>
<td>0.570</td>
<td>0.074</td>
</tr>
<tr>
<td>MACSJ0416-24</td>
<td>04:16:09.9</td>
<td>-24:03:58</td>
<td>0.42</td>
<td>0.041</td>
</tr>
</tbody>
</table>
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<tr>
<th>Activity</th>
<th>Team members</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 2 &amp; Data Reduction</td>
<td>Rosati, Nonino, Mercurio, Scodellaro, Benitez, Czoske, Grillo, Lombardi, Medezinski</td>
<td>Multi-band catalogs, photometric redshifts, slit mask: preparation, QEs prep, data reduction with the VIFGI pipeline, redshift measurements</td>
</tr>
<tr>
<td>Gravitational Lensing analysis</td>
<td>Bartelmann, Boehmer, Broadhurst, Grillo, Halkola, Lombardi, Medezinski, Rosati, Seitz, Zitrin</td>
<td>Lensed source detection and characterization, strong lensing model, weak lensing analysis, mass profile reconstruction, comparison with theory</td>
</tr>
<tr>
<td>High-z galaxies</td>
<td>Benitez, Broadhurst, Ford, Grillo, Lombardi, Nonino, Monna, Postman, Rosati, Seitz, Zheng, Vanzella</td>
<td>Computation of magnification maps from SL mode, photo-z's, search for high-z candidates, analysis of spectra</td>
</tr>
<tr>
<td>Dynamical analysis</td>
<td>Biviano, Borgani, Czoske, Girardi, Lemze, Postman, Ziegler, Kuchner</td>
<td>Cluster velocity dispersion analysis, substructures, mass profile reconstructions from Jeans analysis and caustics method</td>
</tr>
<tr>
<td>Combined X-ray/Lensing analysis</td>
<td>Balestra, Bartelmann, Ettori, Lemze, Rosati, Tozzi, Seitz</td>
<td>Chandra and XMM data analysis, total and gas density profile, baryon fraction measurements, scaling relations</td>
</tr>
<tr>
<td>Galaxy Evolution</td>
<td>Biviano, Borgani, Czoske, Demarco, Ford, Graves, Mei, Mercurio, Postman, Rosati, Scodellaro, Strazzullo, Ziegler, Kuchner</td>
<td>Galaxy population across environments, star formation rates, stellar pop modeling, correlations with ICM, luminosity functions</td>
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The VLT-CLASH sample

The VLT-CLASH is a panoramic spectroscopic survey of 14 massive clusters at z=0.2-0.6, spanning almost an order of magnitude in mass (~5 to ~30 x 10^{14} M_\odot), drawn from the sample of the CLASH HST multi-treasury program.

• Research Interests: To investigate properties of galaxies
  vs. dynamical properties of structures where galaxies reside;
  vs. environments in terms of local density;
  vs. spectral classes/luminosities/colors;
Motivation and Overview

The primary objectives of this study are:

To determine the global dynamical properties and the internal structure of the cluster (by M. Girardi).

To study the relation between cluster dynamics and properties/evolution of the stellar populations.

To study the effect of the cluster environment on the properties of the galaxies through the galaxy luminosity function and colours.

To investigate the velocity anisotropy profiles of both the passive and star-forming cluster members (by A. Biviano).
Motivation and Overview

CLASH/VLT clusters are ideal targets:

• clusters dynamically relaxed (as indicated by a circularly symmetric X-ray surface brightness distribution);
• massive clusters (as indicated by X-ray gas temperature $>5$ keV),
• large z-samples of member galaxies (minor substructure $\sim10\%$ of the richness of the parent cluster; e.g., Girardi et al. 97);
• presence of different environments;
• we expect more substructure at higher $z$ (0.2-0.6) than $z=0$. 
MACS J1206: X-ray data

The cluster appears relatively relaxed in projection, with a pronounced X-ray peak at the BCG position (Ebeling et al. 2009; Postman et al. 2012). This cluster was classified to be relaxed by Gilmour et al. (2009) on the basis of a visual examination of its X-ray morphology.
MACS J1206: X-ray data

The temperature profile can be considered approximately constant around $kT \approx 10$ keV, although several fluctuations are observed in the profile and the temperature shows a drop of $\sim 3.5$ keV between the center and the adjacent radial bin.
MACS1206 Subaru imaging

$z = 0.439$

Courtesy of P. Rosati
30x30 arcmin$^2$ SUBARU $B, V, R, I, z$ imaging (1$'$~0.341 Mpc)

Exp Time (in sec): 2400, 2160, 2880, 3600, and 1620, respectively.

FWHMs (arcsec): $B$ ~ 1.1, $V$ ~ 0.95, $R$ ~ 0.85, $I$ ~ 0.75, $z$ ~ 0.75.
MACSJ 1206

30x30 arcmin$^2$ SUBARU $B, V, R, I, z$ imaging ($1^\prime \sim 0.341$ Mpc)

$R=25, (~M^*+4.5, N_{\text{gal}} \sim 28000)$
MACSJ 1206

~3000 VLT-VIMOS Spectra

~ 600 galaxies at the cluster redshift
MACS1206: z-survey

~600 spec members!

2776 good redshifts

~600 members

 Courtesy of P. Rosati
MACSJ 1206

R-band number counts

Courtesy of A. Biviano
Photo-z have obtained through neural network method (MLPQNA, for details see Cavuoti et al. 2012, Brescia et al. 2012). This method was applied on the whole dataset of 31905 objects with available and reliable photometry down to $R=25.0$, after an optimization of the model performed by using a subsample of 1607 available spectroscopic redshifts as a training set.
MACSJ 1206

Photometrically selected member galaxies up to R=24  (\sim M^*+3.5, N_{memb} \sim 2700)
What about dynamical analysis?
Internal dynamical analysis
(performed by M. Girardi)

Internal dynamical analysis aimed at:

• verifying the absence of major substructure;
• Identifying minor subgroups useful to study cluster formation:
  subgroups provide a preferred direction for the infall (Cohn+11);
  possible core remnants trace past cluster mergers;
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OPERATIVE POINT OF VIEW

* member selection;
* different galaxy colours (e.g., red and luminous trace cores);
* 1D(velocity), 2D(spatial position), 3D tests, sensitive to different view angles;
* statistical significance of substructure, with Monte Carlo sims., too;
Member selection

1D-DEDICA (adaptive kernel method of density reconstruct.) + shifting gapper (MG+96).

595 members

Subsample of 454 members with optimal spectroscopic redshift determination

Courtesy of M. Girardi
Red gals: R-B colors within 0.3 mag from CMR. **RedU** and **redD** are upper & lower than CMR. **Blue** gals are lower than CMR.

 Courtesy of M. Girardi
Red gals: R-B colors within 0.3 mag from CMR. RedU and redD are upper & lower than CMR. Blue gals are lower than CMR.

2D-DEDICA isodensity contours for redU, redD and blue galaxies.

ESE-clump (zphot-sample, too) No kinem.confirm.

Several clumps, NE the most important (kinematic confirmation).

Courtesy of M. Girardi
MEAN VELOCITY & VELOCITY DISPERSION PROFILES

for the four sectors:

NE NW
SE SW

Excess of low-V gals at NE

Courtesy of M. Girardi
1D-analysis
*Some Gaussianity tests;
*No peculiar BCG velocity;

*1D-DEDICA:
asymmetry in the v-distribution of blue gals within 2Mpc, excess of low-V gals.

Courtesy of M. Girardi
What about different spectral classes?
Spectral classes

Cluster members classified according to spectral features \((D_n(4000), H_\delta, \text{OII}, \text{OIII}, H_\alpha)\) quantified by Equivalent Widths (EW).

\[
\text{EW} = \sum_{i=1}^{N} \frac{F_{C_i} - F_i}{F_{C_i}} \Delta \lambda
\]

- **Emission Line Galaxies** \(\text{EW(}\text{OII}) < 0.0 \, \text{Å} / \text{EW(}\text{OIII}) < 0.0 \, \text{Å} / \text{EW(}H_\alpha) < 0.0 \, \text{Å}

- **H_δ strong galaxies** (HDS\text{blue}) \(D_n(4000) < 1.45 \, \& \, \text{EW}(H_\delta) > 5.0 \, \text{Å}

- **H_δ strong galaxies** (HDS\text{red}) \(D_n(4000) > 1.45 \, \& \, \text{EW}(H_\delta) > 3.0 \, \text{Å}

- **Passive** \(D_n(4000) < 1.45 \, \& \, \text{EW}(H_\delta) < 3.0 \, \text{Å}
- galaxies in the sample selected according to photo-z+col
- member galaxies in the spectroscopic sample [including FLAG=2]
- passive galaxies
- red H\(\alpha\)-strong galaxies
- blue H\(\alpha\)-strong galaxies
- emission-line galaxies
galaxies in the sample selected according to photo-z+col
- member galaxies in the spectroscopic sample (including FLAG=2)
  - passive galaxies
  - red Hα–strong galaxies
  - blue Hα–strong galaxies
  - emission-line galaxies
Spatial segregation?

Density contours of member galaxies selected according to photometric redshifts.
Spatial segregation of galaxies belonging to different spectral classes:

- H-delta strong red galaxies and passive galaxies trace the global structure of the cluster.
Gal/arcmin

- Emission-line galaxies
- H-deep strong blue galaxies
- H-deep strong red galaxies
- Passive galaxies
Spatial segregation of galaxies belonging to different spectral classes:

- concentration of blue galaxies in the NE region.
Velocity segregation of galaxies belonging to different spectral classes:

~ 61.4% of Emission Line galaxies.

~ 35.5% of Emission Line galaxies.

We observe a spatial and dynamical segregation of galaxies.

Courtesy of M. Girardi
Velocity segregation of galaxies belonging to different spectral classes:

Large fraction of emission line galaxies

Red passive galaxies

mainly red H\(\delta\)-strong galaxies

We observe a spatial and dynamical segregation of galaxies.

Courtesy of M. Girardi
What about Luminosity functions and colours?
Galaxy Luminosity Function

All regions
\[ \alpha = -1.05 \]
\[ R^* = 20.71 \]
Galaxy Luminosity Function vs. environment
Galaxy Luminosity Function vs. environment
Galaxy Luminosity Function vs. environment

Low
Galaxy Luminosity Function vs. environment

No significant environmental trend seen in $M^*$. On the other hand it seems that the shape of the GLF and the faint-end slope depend on the environment.
galaxies in the sample selected according to photo-z+col
- member galaxies in the spectroscopic sample [including FLAG=2]
  - passive galaxies
  - red H\&strong galaxies
  - blue H\&strong galaxies
  - emission-line galaxies
• galaxies in the sample selected according to photo-z+col
• member galaxies in the spectroscopic sample (including FLAS=2)
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• blue H\(_\alpha\)-strong galaxies
• emission-line galaxies
galaxies in the sample selected according to photo-z+col

- member galaxies in the spectroscopic sample (including FLAS=2)
- passive galaxies
- red H\textsc{\textalpha}—strong galaxies
- blue H\textsc{\textalpha}—strong galaxies
- emission-line galaxies
• LFs of galaxies with different colours

LF of passive galaxies is less steep than total LFs, while LF for star-forming is steeper. The slopes depend on colours.
Summary of results

We find hints for a scenario where galaxy populations are both spatially and dynamically segregated.
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The cluster is elongated in NW-SE direction.
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Infall of small groups.
Summary of results

We find hints for a scenario where galaxy populations are both spatially and dynamically segregated.

The cluster is elongated in NW-SE direction.

Infall of small groups.

There are indications that galaxies are transformed by environmental related processes.
This is just the beginning of the story.....

Investigation of structural of galaxies e.g. sersic indices (correlation with colours and spectral classes).

More studies about populations of member galaxies (Ages, SFRs, metallicity).
This is just the beginning of the story.....

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Comparison with the dark matter distribution.
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Umetsu et al. 2012
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Analysis of sub-clumps at low/high velocity
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Comparison with the dark matter distribution.

Analysis of sub-clumps at low/high velocity

.....This kind of analysis has to be applied to all clusters in the VLT-CLASH sample
Thanks!
Cluster Lensing And Supernova survey with Hubble

HST multi-cycle Treasury Program (530 orbits) - PI: M. Postman

- Panchromatic (ACS+WFC3 16 filters) imaging of 25 massive intermediate-z galaxy clusters
- Measure DM mass profiles over 10-3000 kpc with unprecedented precision
- “Wide-field” gravitational telescopes on the very high-z Universe
- SNe Ia search at 1<z<2 from parallel fields (doubling SNe at z>1.2), combined w/ CANDELS

CLASH-VLT

MAIN GOALS

- Accurate mass profiles using high-quality, homogeneous strong+weak lensing, dynamics, X-ray methods
  ➡ Test specific predictions of $\Lambda$CDM Structure Formation Models on DM and baryonic mass distribution in cluster-scale halos: universality/validity of NFW profile, concentration, baryon fraction profiles, collisionless nature of DM, ...

- Highly magnified galaxies at z~5-10 ➡ first stars, reionization

- Galaxy structure and stellar pop properties from high to low density environments

Courtesy of P. Rosati
• 47 new multiple images of 13 sources identified
• over $1 \lesssim z \lesssim 5$, $3 \text{ arcsec} \lesssim R \lesssim 1 \text{ arcmin}$

⇒ Very robust model of the inner mass profile

(Zitrin et al. 2012)
30x30 arcmin$^2$ SUBARU $B, V, R, I, z$ imaging

Photometrically selected member galaxies up to R=24 (M$_* \sim 3.5$, N$_{memb} \sim 2700$)