Clusters of galaxies as probes of cosmology, dark matter, and the evolution of cosmic structures
Report for LSST-Italy

The LSST-Italy Cluster's of Galaxies collaboration

December 2018

Abstract

Aim: build clusters catalog to constrain cosmology and the internal structure of clusters. Results: (1) development, testing, and application to real data-sets, of the AMICO clusters detection algorithm. (2) Calibration of the AMICO richness-mass relation using weak lensing. (3) Development and testing of algorithms to compute the 2-and 3-point correlation functions of clusters. (4) Realization of cosmological simulations including massive neutrinos for comparison of observed cluster power spectrum. (5) Development, testing, and application to real data-sets, of an algorithm for the determination of the cluster stellar mass distribution. (6) Development of a theoretical relation relating cluster internal structure to the property of dark matter particles.

1 Quintuplet Information 2017

- A. Biviano, PI, INAF-Osservatorio Astronomico di Trieste
- F. Bellagamba, young researcher, University of Bologna
- D. De Cicco, student, University of Napoli
- M. Roncarelli, young researcher, University of Bologna
- B. Sartoris, young researcher, University of Trieste
- *M. Radovich, co-PI, INAF-Osservatorio Astronomico di Padova*

2 Quintuplet Information 2018

- A. Biviano, PI, INAF-Osservatorio Astronomico di Trieste

- M. Baldi, young researcher, University of Bologna
- R. Bastone, student, University of Napoli
- F. Marulli, young researcher, University of Bologna
- M. Sereno, young researcher, University of Bologna
- *M. Radovich, co-PI, INAF-Osservatorio Astronomico di Padova*

3 Quintuplet Information 2019

- C. Grillo, PI, University of Milano
- G. Angora, student, University of Ferrara
- M. Costanzi, young researcher, INAF-Osservatorio Astronomico di Trieste
- C. Giocoli, young researcher, University of Bologna
- L. Ingoglia, student, University of Napoli
- *G. Covone, co-PI, University of Napoli*

1. **Scientific Collaborations:** Dark Energy (main), Galaxies (secondary).

4 Scientific Activity

The aim of the LSST-Italy Clusters of Galaxies collaboration is to build a catalog of clusters of galaxies up to redshift $z \sim 1.5$ to constrain cosmological models and the internal structure of clusters. To achieve our goals we need to develop tools to **1)** *identify clusters of galaxies,* **2)** *measure cluster number density and spatial distribution,* **3)** *determine how these observables depend on cosmological models, and* **4)** *determine the total, stellar, and diffuse plasma distributions within clusters.*

1) *We have developed a clusters of galaxies detection algorithm, AMICO (Adaptive Matched Identifier of Clustered Objects), based on the optimal filtering technique, which allows to maximize the signal-to-noise (S/N) ratio of the data (Bellagamba et al. 2018a). One of novelties of AMICO is its iterative approach. When a cluster is detected, it can be removed from the data-set to allow a deeper search of otherwise undetectable lower S/N clusters, because hidden by their prominent neighbors (See Fig. 1). The AMICO approach provides excellent deblending of close-by and aligned clusters.*

Runs of AMICO on simulated data-sets have allowed to constrain the selection function of this code in terms of purity and completeness of the clusters catalog as a function of the cluster z and S/N (see Fig. 2), as well as to calibrate the mass-observable relation, where the observable is the amplitude of the signal or the richness (number of member galaxies) of the detected cluster. AMICO has also been tested on Euclid mocks, and it has been selected as the best-performing code among eight competitors (Adam et al. 2019).

Application of AMICO to the KiDS DR3 data has allowed detection of $\sim$ *7000 clusters at* $0.1 < z < 0.8$ *(Maturi et al. 2018). By a weak lensing stacking analysis it has been possible to calibrate the mass-observable relation on real data, and the relation has been found to be consistent with that derived on mock data (Bellagamba et al. 2018b).*

2) *We have developed algorithms*[1] *to measure cluster number counts, the 2-point and 3-point cluster correlation functions, and to construct likelihood functions from these observables, as well as to perform statistical analyses to extract cosmological constraints in a MonteCarlo Markov Chain approach. These codes have been validated on both simulated and real data-sets (Marulli et al. 2017, 2018).*

3) *We have developed DUSTGRAIN (Dark Universe Simulations to Test GRAvity In the presence of Neutrinos) pathfinder cosmological simulations that include simultaneously* $f(R)$ *modified gravity and massive neutrinos (Giocoli, Baldi & Moscardini 2018, Baldi 2019). For these simulations we can currently provide access to 33 full comoving snapshots, 256 independent realisations of weak-lensing maps in 25* deg^2 *light cones for sources at* $z = 0.5, 1, 2, 3, 4$*, as well as (sub)halo catalogs. These simulations will be extended soon to the DUSTGRAIN full scale setup (same resolution but a much larger box), with 73 snapshots and full-sky 2-d weak-lensing cones. Mock galaxy catalogs will be produced along the light cone using a new, calibrated SHAM algorithm.*

4) *We have developed a Maximum Likelihood estimator of the number density profile of galaxies in a cluster*[2]*, that can be extended to estimate the stellar mass density profile.*

In addition, we have theoretically determined the relation between the position of the brightest cluster galaxy (BCG) and the minimum of the gravitational potential of the cluster (Bastone & Covone 2019). If dark matter is made of self-interacting particles, the inner structure of clusters of galaxies is characterized by a core, so that following a collision of the cluster with another, smaller structure, the BCG oscillates about the minimum of the gravitational potential. The latter can be measured by weak-lensing observations. More specifically,

$$\sigma/m \leq 1.1 \left(\frac{0.1 M_\odot pc^{-3}}{\rho}\right)^{3/2} \left(\frac{1kpc}{A_w}\right) \left(\frac{1Gyr}{t_{coll}}\right) cm^2 g^{-1} \qquad (1)$$

where σ/m *is the ratio between the cross-section and the mass of the dark matter particle,* A_w *is the amplitude of the BCG oscillation amplitude,* ρ *the mass density, and* t_{coll} *the collision time.*

[1] These C++ and Python codes are available at https://github.com/federicomarulli/CosmoBolognaLib

[2] In C++, available at https://github.com/sfarrens/cluster_profile

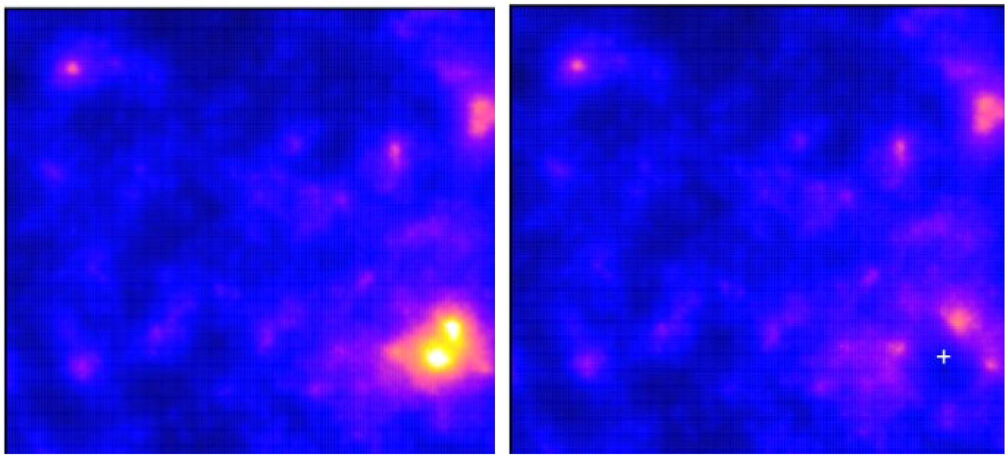

Figure 1: AMICO iteration procedure. Amplitude map of 1×1 deg^2 at redshift $z = 0.33$ from a mock field. Left panel: initial map produced by AMICO. Right panel: after the highest S/N detected cluster has been removed, new cluster over-densities become apparent (adapted from Bellagamba et al. 2018a)

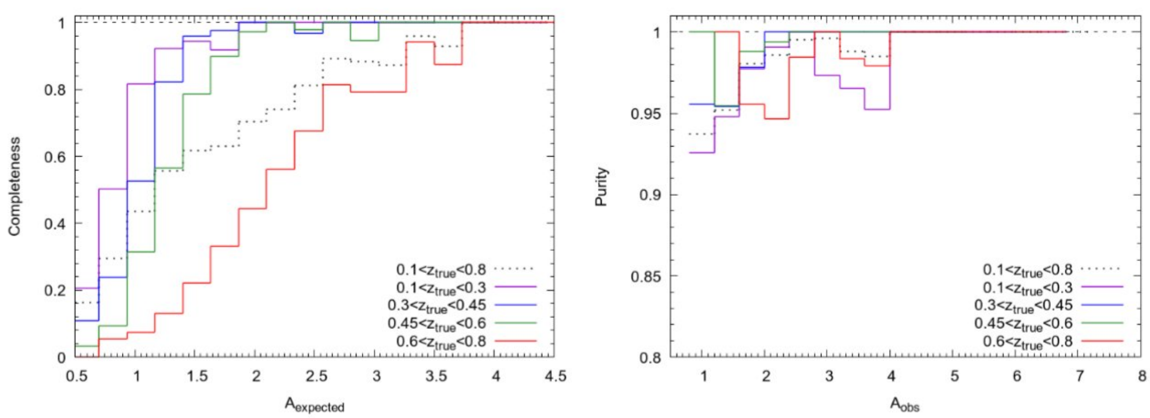

Figure 2: AMICO performance. Left panel: completeness estimated for the catalog of clusters detected in KiDS as a function of the amplitude of the AMICO detection and of the cluster estimated redshift. Right panel: purity estimated for the catalog of clusters detected in KiDS as a function of the amplitude of the AMICO detection and of the cluster estimated redshift (Maturi et al. 2018). As expected, the completeness increases with the amplitude of cluster detection and with decreasing redshift. The purity of the catalog is always above 90%.

5 Scientific and technical deliverables

No LSST-specific product.

6 Other information

Regular participation to telecons of the LSST-DESC Clusters Working Group. Presentation of the teams and of updates on the activities by the quintuplet during these telecons. The convener of the LSST-DESC Clusters Working Group, Anja von der Linden, has visited the Trieste Astronomical Observatory in January 2018, where she has discussed with the PI, the organization of the activities of our group within the context of the LSST-DESC Clusters Working Group.

7 References

1. Adam et al. 2019, in preparation.

2. Baldi 2019, in preparation.

3. Bastone & Covone 2019, in preparation.

4. Bellagamba et al. 2018a, MNRAS, 473, 5221: "AMICO: optimized detection of galaxy clusters in photometric surveys"

5. Bellagamba et al. 2018b, arXiv:1810.02827: "AMICO galaxy clusters in KiDS-DR3: weak-lensing mass calibration"

6. Giocoli, Baldi & Moscardini 2018, MNRAS, 481, 2813: "Weak lensing light-cones in modified gravity simulations with and without massive neutrinos"

7. Marulli et al. 2017, A&A, 599, A106: "Redshift-space distortions of galaxies, clusters, and AGN. Testing how the accuracy of growth rate measurements depends on scales and sample selections"

8. Marulli et al. 2018, A&A, 620, A1: "The XXL Survey. XVI. The clustering of X-ray selected galaxy clusters at $z \sim 0.3$"

9. Maturi et al. 2018, arXiv:1810.02811: "AMICO galaxy clusters in KiDS-DR3: sample properties and selection function"