Galaxy Clusters

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Galaxy Clusters

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A key challenge of modern Astrophysics is to achieve a complete understanding of galaxy evolution. Since the pioneering work based on photographic surveys (e.g., Abell 1965, Zwicky 1968), we know that galaxies can be located in different environments, with some of them distributed in aggregations called *galaxy clusters* and some others in isolated or low-density regions called *field galaxies*. Observations of clusters show how fundamental the role of the environment is in shaping galaxy properties. In clusters, the fraction of early-type galaxies, defined either morphologically or by the amount of current star formation, is much higher than in the field. This is a manifestation of the morphology-density relation (Dressler 1980), which shows a strong dependence of the galaxy morphological mix on galaxy density. The morphology-density relation is particularly strong for dwarf galaxies. In the centres of rich clusters the fraction of late-type dwarfs is vanishingly small. This morphology-density relation has several consequences: cluster galaxies have different structural parameters than field galaxies (e.g., Aguerri et al. 2004); cluster galaxies possess much less cold gas than field galaxies (e.g., Cayatte et al. 1990; Serra et al. 2011); clusters have a lower fraction of star-forming galaxies (e.g., Popesso et al. 2007); and galaxies in clusters and the field have different luminosity functions (e.g., de Propris et al. 2003).

These observational differences between cluster and field galaxies are believed to be caused, at least in part, by the different processes that take place in the high-density environments. Thus, a comprehensive theory of galaxy formation and evolution must account for the influence of the environment on galaxy evolution. The unanswered questions are many, including: How do dense environments act to quench star-formation in spirals to form S0 galaxies? How are dwarf irregulars transformed into early-type dwarfs? Do galaxy transformations occur predominantly in the cluster in-falling regions? How do clusters and the galaxies therein evolve over the last 6 Gyrs of cosmic time?

The main goal of the WEAVE Galaxy Cluster survey is to provide a better understanding of the different physical mechanisms acting in galaxy clusters and their environment. To achieve this aim, we have structured the survey into three different science areas (layers), each addressing specific issues.

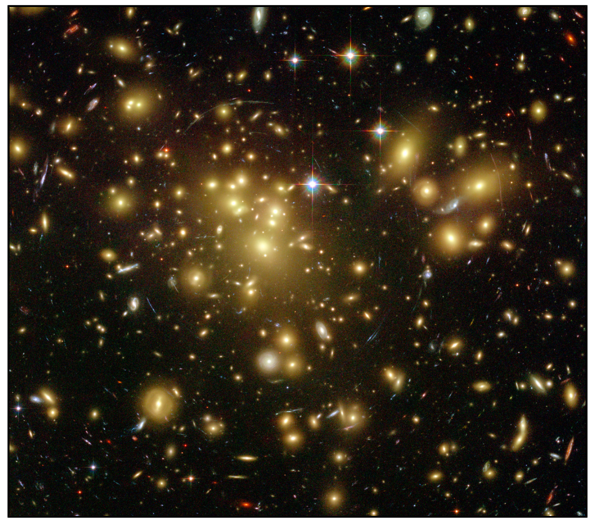

***Figure 1. Left Panel*. Hydrodynamical simulation of a galaxy cluster formation (Credit. C. Dalla Vecchia & J. A. L. Aguerri). *Right panel*. HST image of the galaxy cluster Abell 1689 (Credit. NASA/ESA).**

LAYER 1: Nearby Cluster Survey

Scientific Aims

The main goal of this survey layer is to understand the formation history of dwarf galaxies in high-density environments. Dwarf galaxies are by far the most numerous local galaxy type. Still, the total number of dwarfs is much lower than expected from current models of galaxy formation. Furthermore, the processes driving the formation of dwarf galaxies and how the environment is affecting their evolution is poorly understood. Specific scientific questions that will be addressed include:

- Are dwarf galaxies primordial or the end-products of galaxy transformations?
- What processes drive the dwarf galaxy transformation in clusters?
- What are the internal dynamics of the dwarf galaxies? Are they DM-dominated systems? What is the angular momentum of dwarfs?
- How do these processes depend on galaxy properties and/or local environment?

Observational Strategy

The WEAVE Nearby Cluster Survey is a low-spectral-resolution programme combining the MOS and mIFU WEAVE modes. This survey will observe an X-ray flux-limited sample of 47 nearby galaxy clusters ($z < 0.04$) covering a large range in cluster mass ($13.2 < \log(M/M) < 14.5$) and environment.

This survey will provide single-fibre spectroscopic information for several thousands of dwarf cluster members, and spatially resolved spectroscopic data for ~1000 of them. This will constitute the largest sample of dwarf galaxies in clusters with high-quality spectroscopic data to date.

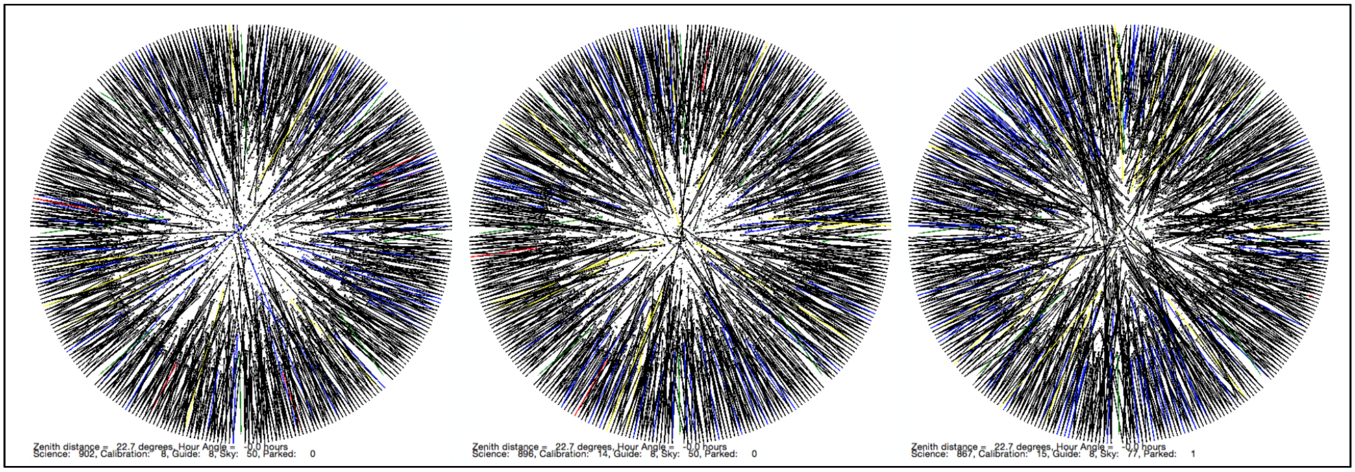

Figure 2. **Example of three WEAVE configurations covering 2665/2997 (89%) targets in nearby cluster.**

LAYER 2: WEAVE Wide-Field Cluster survey (WWFCS)

Scientific Aims

The main goal of this survey layer is to study the properties and evolution of galaxies as they fall into clusters along the filamentary cosmic web. It is increasingly clear that galaxy properties and their evolution are not only affected by the highest-density cluster core environment, but lower-density environments such as galaxy groups, filaments and the “infall” regime are important sites of galaxy transformation. Most cluster studies have concentrated on the cores and virialised regions of clusters and groups, and detailed information on the galaxy properties in the infall regions and filaments remains largely unavailable. Specific scientific questions that will be addressed include:

- What is the nature, extent and importance of the filamentary structure around clusters?
- What fraction of the galaxies fall into clusters as part of distinct groups? And what fraction do so as individual galaxies along filaments?
- What is the main parameter that governs the environmental transformation on galaxies? Clustercentric distance? Local density? Belonging to a group or a cluster? Belonging to a filament?
- What are the main physical mechanisms driving galaxy transformation in each environment?

Observational Strategy

The WEAVE Wide-Field Cluster survey (WWFCS) is a low-spectral-resolution programme using the MOS WEAVE mode. This survey will observe a total of 16-20 galaxy clusters at a mean z= 0.055 and will obtain LR spectra of the galaxies located up to 5 virial radii away from the cluster centres. Every cluster will be observed with 6–20 pointings in order to cover adequately the infall regions of the clusters and the filamentary structures that surround them. Thus, a total of 155 pointings are foreseen in order to observe the 16-20 clusters proposed. At a rate of ~900 galaxies/pointing we plan to obtain ~4000 spectra of galaxies belonging to each cluster structure, with ~1000-1500 in the infall regions themselves.

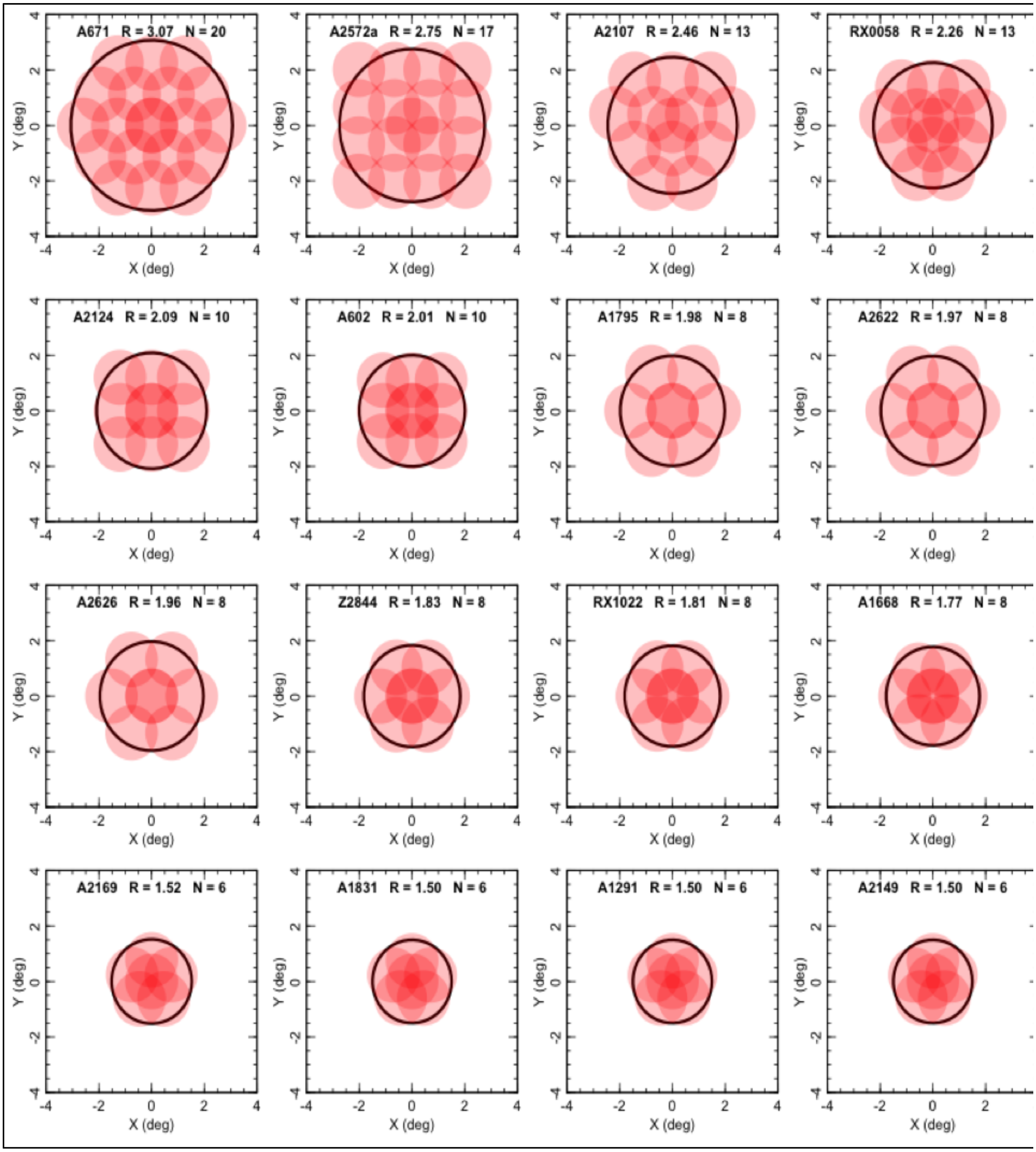

Figure 3. **Example of the WEAVE tiles planned for the 16 clusters in the Layer 2 Survey. The solid circle enclose 5 virial radii of the clusters.**

LAYER 3: Cosmological Clusters Survey

Scientific Aims

The main goal of this survey is to study the evolution of galaxies in the cores of clusters out to z=0.5 and to place constraints on cosmological parameters and global scaling relations using a complete sample of Sunyaev–Zeldovich (SZ) clusters. The baryonic component of clusters contains a wealth of information about the processes associated with galaxy formation, including the efficiency with which baryons are converted into stars and the effects of the resulting feedback processes on galaxy formation, which permits to estimate the total baryon ($_b$) and dark matter densities.

Moreover, cluster abundance studies as a function of mass and redshift, N(M,z), are powerful cosmological tools allowing us to set constraints on cosmological parameters such as the dark matter and dark energy densities, or the equation of state of the dark energy. Specific scientific questions that will be addressed include:

- Obtain an accurate mass calibration and global scaling relations for a sample of 100 SZ clusters selected from Planck.
- Use the calibration to provide error bars a factor of 2 smaller than the existing ones on the key cosmological parameters ($_{8, m}$).
- Study the evolution of the stellar populations for a large sample of massive galaxies in the central regions of galaxy cluster in the last 6 Gyrs of evolution.
- Compare to the z=0 cluster galaxies in WEAVE-Clusters Layers-1 and -2, and to the z~0.5 field galaxies in StePS to understand how and when do early-type galaxies cease their star formation and quench onto the red sequence.

Observational Strategy

The WEAVE Cosmological Clusters Survey will use both the LIFU and MOS modes with the Low Resolution mode. This survey will observe a total of 100 cluster selected based on the SZ method split into two different subprograms: 1.- Clusters at *z* < 0.25 will be observed with the MOS mode and clusters with *z* > 0.25 will be observed with the LIFU.

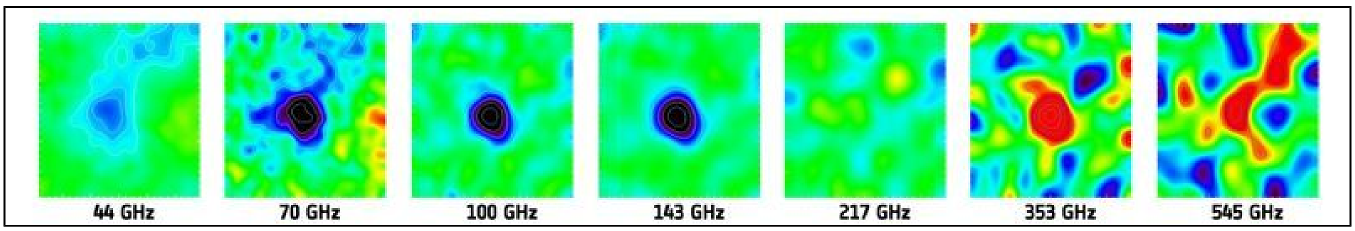

Figure 4. **Example of a detection of the Sunyaev-Zeldovich signature of a massive galaxy cluster with PLANCK. We show the case of A2319 in seven frequency bands. At frequencies below 217 GHz, the cluster is detected as a negative signal (decrement), while it is an increment at frequencies above this threshold. At 217 GHz, a null signal is observed as expected. Credits: ESA/LFI & HFI Consortia. Obtained from http://sci.esa.int/**