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Multi-line Diagnostics of the Interstellar Medium

Gas condensation in Brightest Group Galaxies unveiled with MUSE

Valeria Olivares[1,*]

[1]Department of Physics and Astronomy, University of Kentucky, 505 Rose Street, Lexington, KY 40506, USA

Abstract. How central galaxies in groups acquired their cold gas is still not fully understood. To unfold this unknown, we map the kinematics and distribution of the optical emission-line gas using MUSE observations of 18 optically selected local brightest group galaxies (BGGs). The observations reveal a distribution of gas morphologies, including complex networks of filaments extending up to ∼10 kpc to compact (<3 kpc) and extended (>5 kpc) disk-dominated structures. By exploring the thermodynamical properties of the X-ray atmospheres, we find most of the filaments and compact have are likely cooled out from the intragroup medium (IGrM).

1 Introduction

Traditionally elliptical galaxies have been described as "red and dead" galaxies. Observational evidence, however, has challenged this view revealing that a significant fraction of the population of ellipticals contains large quantities of cold gas, which can fuel both their Active Galactic Nuclei (AGN) and star formation activity. Massive elliptical galaxies located at the cluster cores show extended multiphase filamentary structures [e.g. 1], that follow the cavities dug by the radio jet in the hot intracluster medium (ICM) [2, 3]. Extensive multiwavelength observations of Brightest Cluster Galaxies (BCGs) are consistent with predictions of chaotic cold accretion (CCA), precipitation from the hot ICM, and stimulated feedback models [e.g., 4–6].

While there is considerable evidence from observations and simulations that cold gas in BCGs forms through ICM cooling, less attention has been paid to their lower-mass counterparts in galaxy groups. Overall, BGGs have remained relatively unstudied as a population, compared to both BCGs and the general population of elliptical galaxies, despite representing the intermediate-mass range and being the building blocks of massive clusters. Several groups show remarkable similarities to clusters. They host a hot intragroup medium (IGrM) [e.g., 7], that cools through X-ray emission in a similar form to the ICM in clusters. However, groups are a more diverse class, and their low-velocity dispersions and small galaxy separation make mergers more common than in clusters. This allows a greater fraction of the cold gas from infalling gas-rich spirals to reach the core, affecting the overall gas content. Moreover, cold molecular gas is more common in BGGs galaxies than in other ellipticals. The single-dish survey of 53 BGGs found that about 40% of the galaxies contain cold molecular gas, although the cold gas mass is usually low, on the order of a few 10^8 M$\odot$ [8].

*valeria.olivares@uky.edu

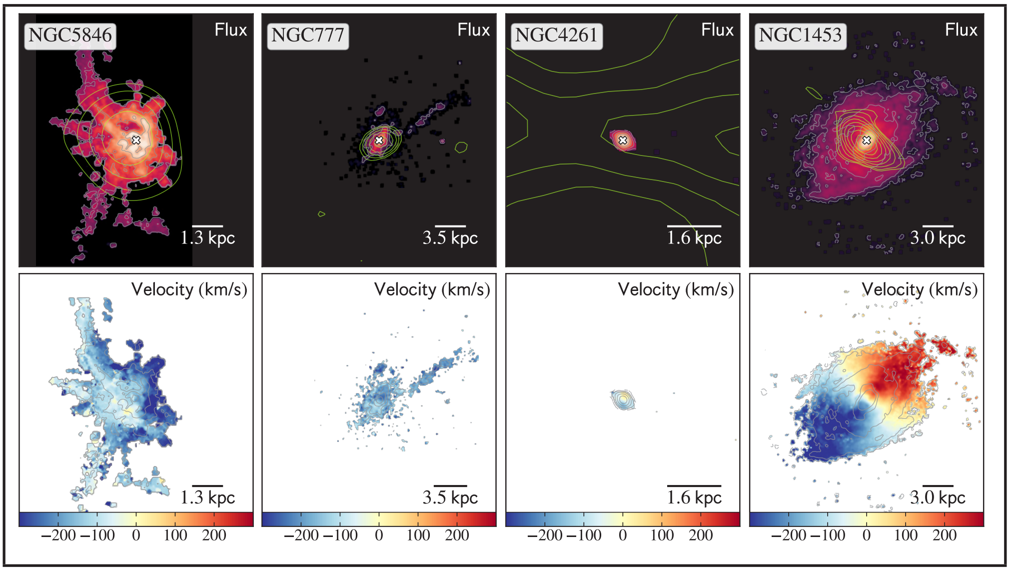

Figure 1. Example of ionized gas distribution (top row) and velocity (bottom row) for systems with extended and compact filaments and disks. The radio emission is displayed with green contours, while the center of the galaxy is marked with a cross.

2 CLoGS - Complete Local-Volume Groups Sample

To study AGN feedback in galaxy groups and identify groups with molecular gas reservoirs, a survey has been constructed: the Complete Local-Volume Groups Sample (CLoGS, [7]). CLoGS is the first statistically complete optically selected, representative sample of local galaxy groups. The sample consists of 53 groups in the local universe, covering a Richness (R)[1] between 2 and 8. All have been studied its molecular gas content using single-dish observations [8, 9], and have X-ray and radio observations [10, 11].

3 A large variety of ionized gas distribution

To explore the nature of the optical line-emitting gas in nearby BGGs observed with MUSE 18 sources drawn from the CLoGS high-richness subsample [12]. These observations reveal optical emission lines in 17/18 systems, with filamentary structures in most (10/18) BGGs (see Fig. 1 for a few examples). The projected sizes of the filaments in groups are shorter than those found in central cluster galaxies, consistent with the different sizes of the condensation regions of the hot halos [13]. Another significant difference with cluster galaxies is the presence of several (7/18) disks and ring-dominated structures found in our sample, of which two disks are very compact, ∼1–3 kpc. In contrast, the rest of the disks can reach projected sizes of up to ∼21 kpc. The extended disks also reveal clumpy rings and extended structures. The velocity structure of the ionized gas in the sources with filaments is often chaotic, but some shallow velocity gradients are noticed along some filaments that typically host extended filamentary nebulae.

[1] Number of large galaxies within the galaxy group.

4 Origin of the gas

Several scenarios have been discussed for the origin of cold gas in elliptical galaxies over the past years. Those scenarios are the acquisition of cold gas from the cooling of gas ejected by the stellar population (stellar-mass loss), through mergers or interactions with gas-rich galaxies, or cooling from the hot atmosphere (cooling-flows). A mixture of these different processes is also and likely possible. [14] suggested that in elliptical galaxies, the gas produced by the stellar-mass loss should form a kiloparsec-scale rotating disk aligned with the stellar component. In contrast, the gas brought into the system through mergers is likely to be misaligned or to create multiple tails, rings, or disks. Numerical simulations of cool-core clusters and groups also found kiloparsec rotating disks of raw material at the center of the galaxy. The formation of the kiloparsec cold rotating disk may thus also occur via the condensation of the hot gas via thermal instabilities [e.g., 4, 6] or merger events.

4.1 IGrM cooling

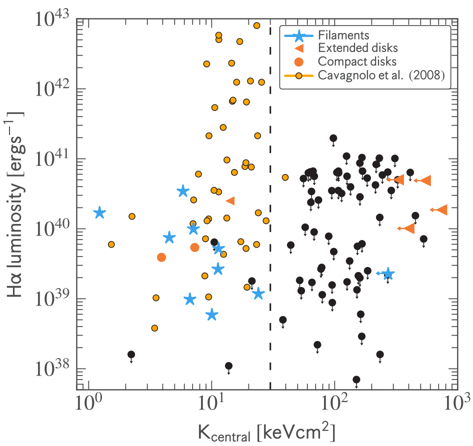

Figure 2. Hα luminosity versus central entropy values at 1 kpc. Filamentary sources are shown with blue stars, compact disks with orange circles, and extended disks with orange left-pointing triangles. As a matter of comparison, we have included the sample from [15]. The dashed gray line is the entropy value of 30 keV cm^2.

A few systems own extended X-ray halos (>65 kpc) with luminosities and temperatures typical of group-scale haloes, while others have X-ray distributions with galaxy-scale sizes of 10–65 kpc [7]). These systems reveal mostly ionized gaseous filaments or compact disks. On the other hand, extended gaseous disks usually lack detection of an IGrM. The disturbed kinematics and filamentary distribution, combined with low central entropy hot gas and short central cooling times, indicates that the cold gas is an outcome of thermally unstable cooling from the X-ray emitting gas, driven possibly by the AGN feedback, as shown in central cluster galaxies [e.g., 16, 17]. For the entropy, we use K = kT/n$_e$, where kT is the temperature of the hot gas and n_e the electron number density. From the systems with detected IGrM, we found that almost all filamentary sources (expect NGC584) and compact disks, plus one extended rotating disk (NGC1453), have low central entropy, <30 keV cm^2 (Fig. 2), and cooling times, Consistent with being a by-product of IGrM condensation. On the contrary, extended disks have larger central entropy values that are inconsistent with hot gas cooling.

Another interesting cooling criteria is the C-ratio, defined as the ratio of the gyration time scale of turbulent eddies, $t_{\rm eddy}$, and the cooling time, $t_{\rm cool}$, which is expected to be around unity for the onset of gas condensation via turbulence [4]. With the filamentary sources and one compact disk (NGC4261) have a C-ratio (0.5–1.6 at 10 kpc) consistent with the predicted values by numerical simulations (C=0.6–1.8, [4]).

4.2 Mergers and interaction

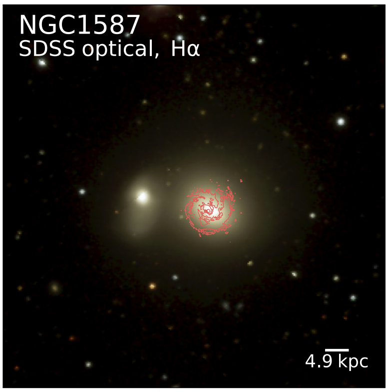

Figure 3. Optical image of NGC 1587 overlied with he distribution of the optical emission-line gas shown with red contours.

Two sources show signs of interaction showing how diverse galaxy groups are as a population. A clear example of a tidal interaction is seen in NGC 1587 with its elliptical neighbor (Fig. 3), as the ionized gas appears to be spirally inflowing towards the central galaxy [12]. Accordingly, we suspect that at least a fraction, if not all, of the colder gas detected in this source may have been acquired through this interaction.

Extended gas disks lack radio and are found in systems where the current X-ray observations do not detect the IGrM. The latter may indicate cold gas formed through gas-rich mergers or galaxy interactions, which could also potentially form central disks and rings in the final stages of mergers, as suggested by studies on elliptical galaxies [14]. The larger fraction of rotating disks in central group galaxies than in clusters may hint toward a non-negligible contribution of mergers or gas stripped from satellites that are more prone to happen in low-mass halos.

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