The Complete Local-Volume Groups Sample (CLoGS): progress in X-ray, radio continuum, and CO line observations

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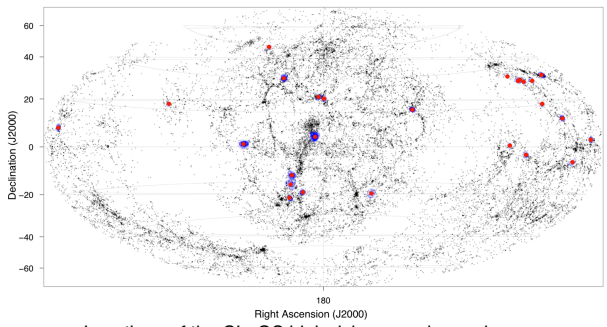
Abstract

The Complete Local-Volume Groups Sample (CLoGS) was created in response to the lack of unbiased galaxy group samples and is designed to avoid the selection biases generally present particularly in X-ray selected samples (strongly biased in favor of the X-ray bright, centrally-concentrated cool-core systems). This statistically-complete sample of 53 groups within 80 Mpc is intended to serve as a representative survey of groups in the local Universe. In addition to X-ray data from Chandra and XMM (100% complete at this point, using both archival and new observations), we have added GMRT radio continuum observations (at 235 and 610 MHz, complete for the entire sample) and IRAM 30 m and APEX telescope observations of CO(1-0) and CO(2-1) lines (complete for the group-dominant early-type galaxies in the sample).

We find that 14 of the 26 high-richness groups are X-ray bright, and that ~53–65 per cent of the X-ray bright groups have cool cores, a somewhat lower fraction than found by previous archival surveys. Approximately 30 per cent of the X-ray bright groups show evidence of recent dynamical interactions (mergers or sloshing), and ~35 per cent of their dominant early-type galaxies host active galactic nuclei with radio jets.

In the 26 high-richness groups, 92% of the dominant galaxies host detected radio sources, with a four order-of-magnitude range in luminosities. Roughly half are point-like, with another quarter hosting jets and most of the rest showing a diffuse morphology. Jet sources are more common in X-ray bright groups, with radio non-detections found only in X-ray faint systems. We find that central AGN are not always in balance with cooling, but may instead produce powerful periodic bursts of feedback heating.

Of the 53 CLoGS dominant galaxies, 21 are detected in CO and we confirm our previous findings that they have low star formation rates (0.01–1 Msun/yr) but short depletion times (<1 Gyr) implying rapid replenishment of their gas reservoirs. A much higher fraction of our group-dominant galaxies (~60%) are AGN-dominated than is the case for the general population of ellipticals.



Locations of the CLoGS high-richness subsample among the filamentary structures of the local volume. Blue circles mark member galaxies, red points are dominant ellipticals, all other galaxies in the local volume are marked in black.

Introduction

Motivation

We lack representative, unbiased samples of galaxy groups:

- Optically-selected catalogs include false groups (chance associations, uncollapsed groups)
- SZ selection ineffective for low-mass groups
- X-ray selection guarantees bound groups but:
  - RASS-based surveys biased toward cool core systems (e.g., Eckert et al. 2011)
  - Samples from deeper surveys tend to be at moderate redshift where detailed morphology, AGN / cool core, interactions are tough to resolve

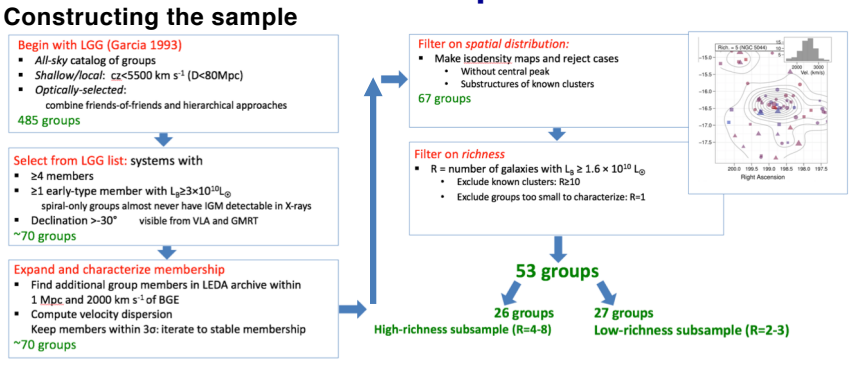
CLoGS is intended to provide a statistically complete sample of nearby, optically-selected groups with high-quality X-ray and radio data.

Goals

- Determine physical properties of the nearby group population:
  - •What fraction of optically-selected groups contain a hot IGM?
  - •What is their range of mass, temperature, metal abundance, etc?
  - •What fraction have cool cores?
  - ~50% of clusters are CC (Sanderson et al 2006); archival samples of groups have up to 85% CC (e.g., Dong et al 2010)
  - •Can we find unusual groups of types not identified by prior surveys? (e.g., the high entropy systems predicted by McCarthy et al. OWLS simulations)
- Understand central AGN as a group-scale feedback mechanism:
  - •Do group-central AGN balance cooling? What is duty cycle, power?
  - •How are central AGN affected by environment? Cool cores, entropy?
- Gauge impact of group environment on member galaxies:
  - •Is star formation rate affected by group environment?
  - •What fraction of member galaxies host AGN? Radio, X-ray, optical? Significant cold molecular gas?

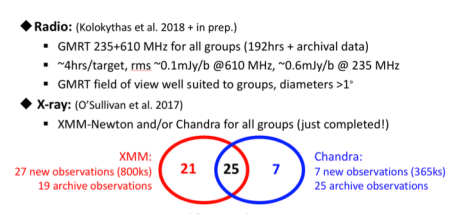
The Sample

Constructing the sample



Status of the data

- ◆ **Radio:** (Kolokythas et al. 2018 + in prep.)
  - GMRT 235+610 MHz for all groups (192hrs + archival data)
  - ~4hrs/target, rms ~0.1mJy/b @610 MHz, ~0.6mJy/b @ 235 MHz
  - GMRT field of view well suited to groups, diameters >1°
- ◆ **X-ray:** (O'Sullivan et al. 2017)
  - XMM-Newton and/or Chandra for all groups (just completed!)



- Minimum sensitivity goal for new observations: $L_x \geq 1.2\times10^{42}$ erg s^{-1} within R_{200}
- ◆ **CO:** IRAM 30m/APEX for all dominant galaxies (O'Sullivan et al. 2018b,2015)
- ◆ 70% Hα imaging (Bok 2.3m or WIYN 0.9m), long-slit spectra, etc.

Combined X-ray (blue) and optical (white) image of CLoGS group LGG 402 (centered on NGC 5982).

References

Dong , R., et al. 2010, ApJ, 712, 883
Eckert, D., et al. 2011, A&A, 526, A79
Li, Y., Ruszkowski, M., & Bryan, G. 2016 (arXiv:1611.05455)
McCarthy, I. G., et al., 2011, MNRAS, 412, 1965
O'Sullivan, E., et al. 2015, A&A, 573, 111
Panagoulia, E. K., et al., 2014, MNRAS, 438, 2341
Sanderson, A. J. R., et al., 2006, MNRAS, 372, 1496
Young, L. M., et al., 2014, MNRAS, 444, 3408

For a complete presentation of this work, please see:

- O'Sullivan, E., et al. 2018, *A&A*, **618,** 126 (Cold gas in a complete sample of group-dominant early-type galaxies)
- Kolokythas, K., et al. 2018, *MNRAS*, **481**, 1550 (The Complete Local-volume Groups Sample - II. A study of the central radio galaxies in the high-richness sub-sample)
- O'Sullivan, E., et al. 2017, *MNRAS*, **472**, 1482 (The Complete Local Volume Groups Sample - I. Sample selection and X-ray properties of the high-richness subsample)
- O'Sullivan, E. et al. 2015, *A&A*, **573**, 111 (Cold gas in group-dominant elliptical galaxies)

Initial results

X-ray overview

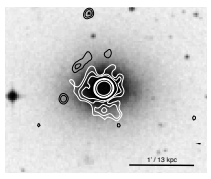
Of the 26-groups in the high-richness subsample:
- *14 (54%) have an X-ray bright IGM (extent >65 kpc, Lx>10^{41} erg/s)*
- 3 (12%) have a galaxy-scale X-ray halo (extent < 65kpc, Lx=10^{40}-10^{41} erg/s)
- 9 have no detected X-ray halo (8 are Richness *R*=4)

Typical X-ray bright kT ≈ 0.4-1.4 keV ➔ $M_{500} \approx (0.5 - 5) \times 10^{13}$ M⊙
Dynamically-active groups:
- 2/14 are group-group mergers
- 2/14 "sloshing"

Fraction of Cool Cores = 53% (64% in high-richness subsample)
9/14 have declining central kT (Compare to ~50% in clusters)

Radio overview

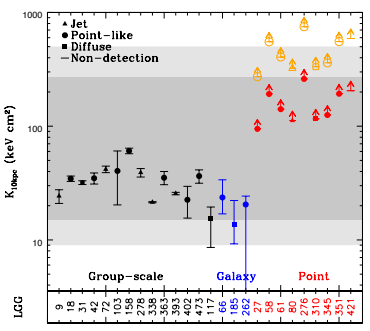
Group-central galaxies (Kolokythas et al., 2018.):
- *46/53 (87%) detected at 610, 235 or 1400 MHz*
- 13 host jet sources
  - 11 in X-ray bright groups
  - 1 in a galaxy-scale halo
  - 1 X-ray faint (cold-gas-rich merger)
- 5 diffuse sources
- 28 point-like sources



← ESO507-25: Diffuse source at 610 MHz

Entropy & cooling

Group-scale halos:
- All have short core T_{cool} < 7.7Gyr and low core entropy < 50 keVcm^2
- Most have K<30 keVcm^2
- Entropy profiles flatter than $r^{1.1}$ in core, comparable to Panagoulia et al. (2014) profile.
- Central jet sources only seen in cool cores - systems with central temperature decline.
- Thermal instability (T_{cool} / $T_{free\text{-}fall}$ <15) a good predictor of current jet activity.



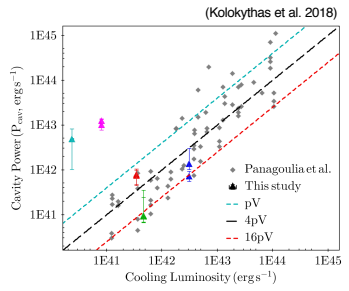
Entropy at 10 kpc for each high-richness CLoGS group, or the 3σ lower limit on entropy for systems where no extended gas component is detected. Colors indicate systems with group-scale (black) or galaxy- scale halos (blue), or systems where no extended gas was detected (red and orange, representing limits assuming 0.5 keV and 1 keV halos respectively). Symbols indicate the radio morphology of the AGN in the dominant early-type galaxy. The dark (light) grey shaded region indicates the 1σ (2σ) range of entropies expected from the OWLS simulations. We detect no groups with entropies at the high end of the range predicted by OWLS, and our lower limits demonstrate that our data are sensitive to such systems.

(Kolokythas et al. 2018)

AGN fedback

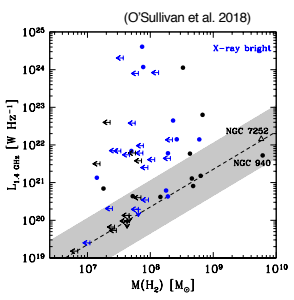
5 X-ray bright, cool core groups with central jet sources
- Jet sizes: 12-80 kpc
- Jet powers: ~10^{41}- 10^{43} erg s^{-1}
- $P_{cav} = 0.1\text{-}100 \times L_{cool}$

(c.f. models showing variation in jet power, e.g., Li, Ruszkowski & Bryan 2016)



Molecular gas

(O'Sullivan et al. 2018)



(Gray region shows radio luminosity predicted from star formation expected from the mass of molecular gas.)

CO detection rate in dominant : 40±9% (O'Sullivan et al. 2015)
- Compare with 22±3% in Atlas3D ellipticals (Young et al 2014)
- >50% show HI

CO is not limited to systems with X-ray bright IGM.

Most have low SFR <1M_{sun}/yr and short depletion time (<10^8 yr).

Large CO masses are not required for AGN outbursts.