
The Complete Local-Volume Groups Sample:
X-ray observations of optically selected groups
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The CLoGS collaboration

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Background: why do we need another group sample?

- We lack representative, unbiased samples
  - *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.

CLoGS: Goals

- 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)

- 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?

- 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?

Sample selection

Begin with Lyon Galaxy Groups (Garcia 1993)

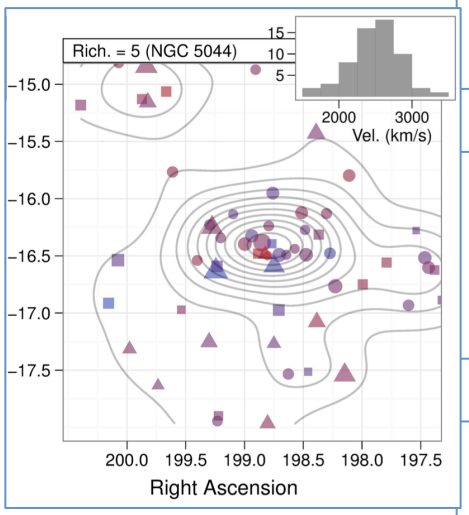
- *All-sky, optically-selected*, cz<5500 km s^{-1} (D<80Mpc)

485 groups

Select from LGG list: systems with

- ≥4 members
- ≥1 early-type member with $L_B \geq 3\times10^{10} L_\odot$
- Declination >-30° (visible from VLA and GMRT)

67 groups



Expand and refine membership

- Update membership from HyperLEDA
- Use isodensity maps to reject problem cases

Filter on *richness* (*R* = N_{gal} with $L_B \geq 1.6\times10^{10} L_\odot$)

- Exclude known clusters: R≥10
- Exclude groups too small to characterize: R=1

53 groups

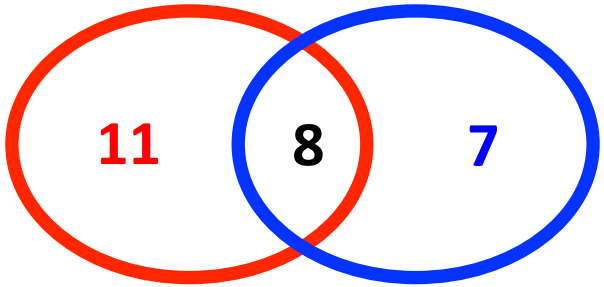
26 groups
High-richness subsample (R=4-8)

27 groups
Low-richness subsample (R=2-3)

Observational data

- **X-ray:** complete for the high-richness subsample (26 groups)

XMM:
9 new observations (300ks)
10 archive observations



Chandra:
4 new observations (50ks)
11 archive observations

  - Minimum sensitivity goal for new observations:
    $L_x \geq 1.2\times10^{42}$ erg s^{-1} within $R<R_{500}$
    $L_x \geq 3.9\times10^{41}$ erg s^{-1} within R<65 kpc
  - 72% of *entire* sample has X-ray observations.

- **Radio:** GMRT 235/610 MHz observations complete for all 53 groups
  - Analysis of high-richness sample complete (Kolokythas et al., in prep.).
  - ~4hrs/target, rms ~0.1mJy/b @610 MHz, ~0.6mJy/b @ 235 MHz.

- **Other bands:** For subsets of systems we have IRAM 30m CO observations of dominant galaxies, Hα imaging (Bok 2.3m or WIYN 0.9m) archival HI, etc.

CLoGS high-richness: 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)
- 4 (15%) have a galaxy-scale X-ray halo (extent < 65kpc, Lx=10^{40}-10^{41} erg/s)
- 8 have no detected X-ray halo (all are Richness *R*=4)

Typical kT ≈ 0.5-1.6 keV

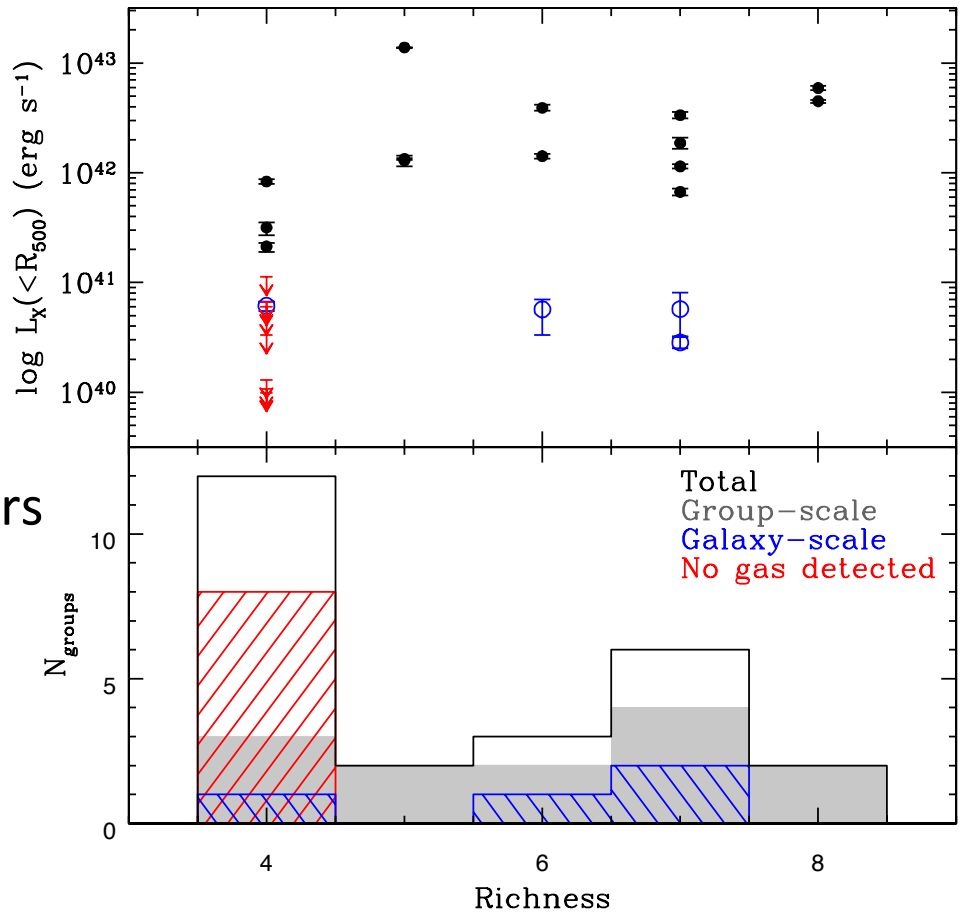
➔ $M_{500} \approx 8\times10^{12} - 6\times10^{13}\ M_{\odot}$

Dynamically-active groups:

- 2/14 are group-group mergers
- 2/14 "sloshing"

Fraction of Cool Cores = 64%

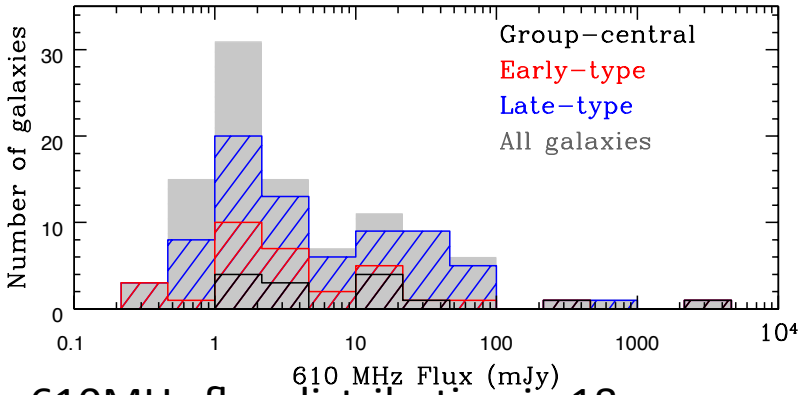
- 9/14 have declining central kT
- Compare to ~50% in clusters.



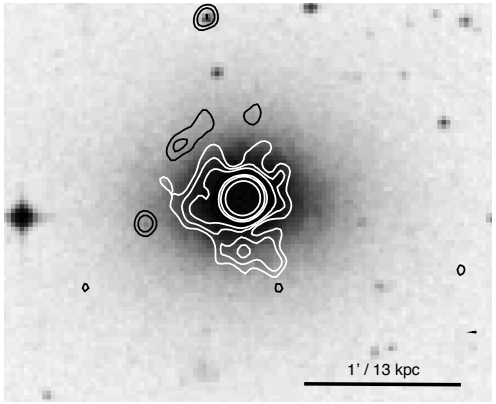
CLoGS high-richness: Radio overview

Group-central galaxies:
(Kolokythas et al., in prep.)

- 24/26 (92%) detected at 610, 235 or 1400 MHz
- 6 host jet sources
  - 5 in X-ray bright groups
  - 1 X-ray faint (cold-gas-rich merger)
- 4 are diffuse, 15 point-like



610MHz flux distribution in 18 groups

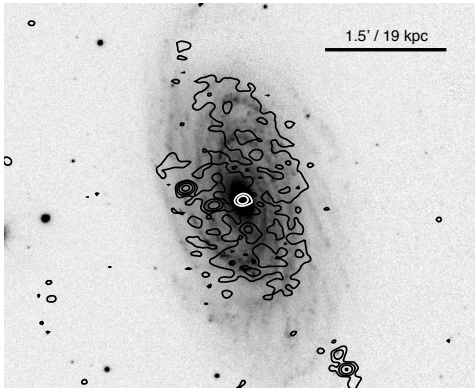


← ESO507-25: Diffuse source 610 MHz contours at (0.4,0.8,1.6,… mJy/b)

Non-central galaxies:

- 44% of group member galaxies detected at 610 or 235 MHz
- 69% of late-type
- 27% of non-central early-type
- 27% of irregular / unclassified

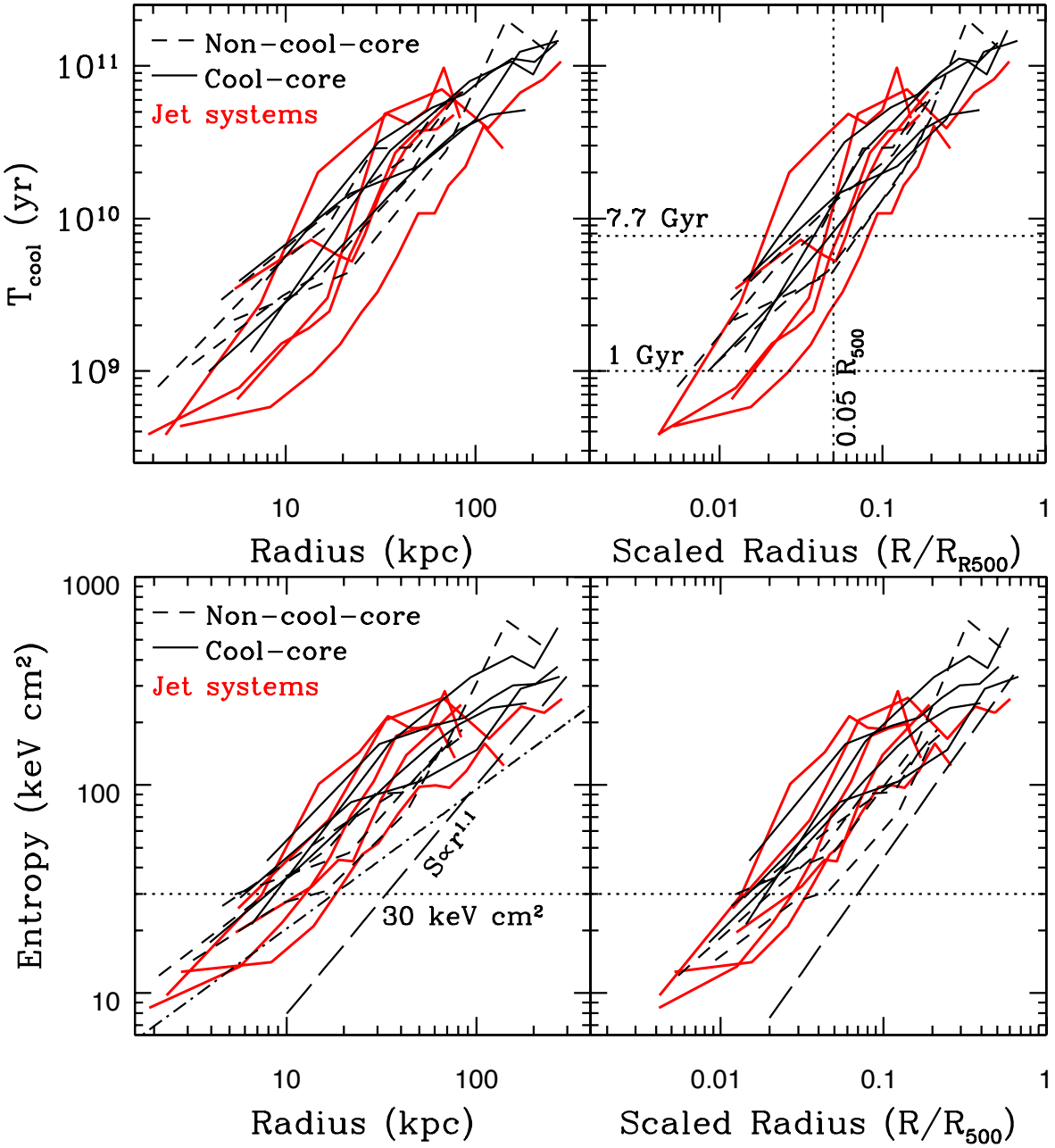
NGC 5985 → AGN+SF disk 610 MHz contours at (0.8,1.6,3.2,… mJy/b)



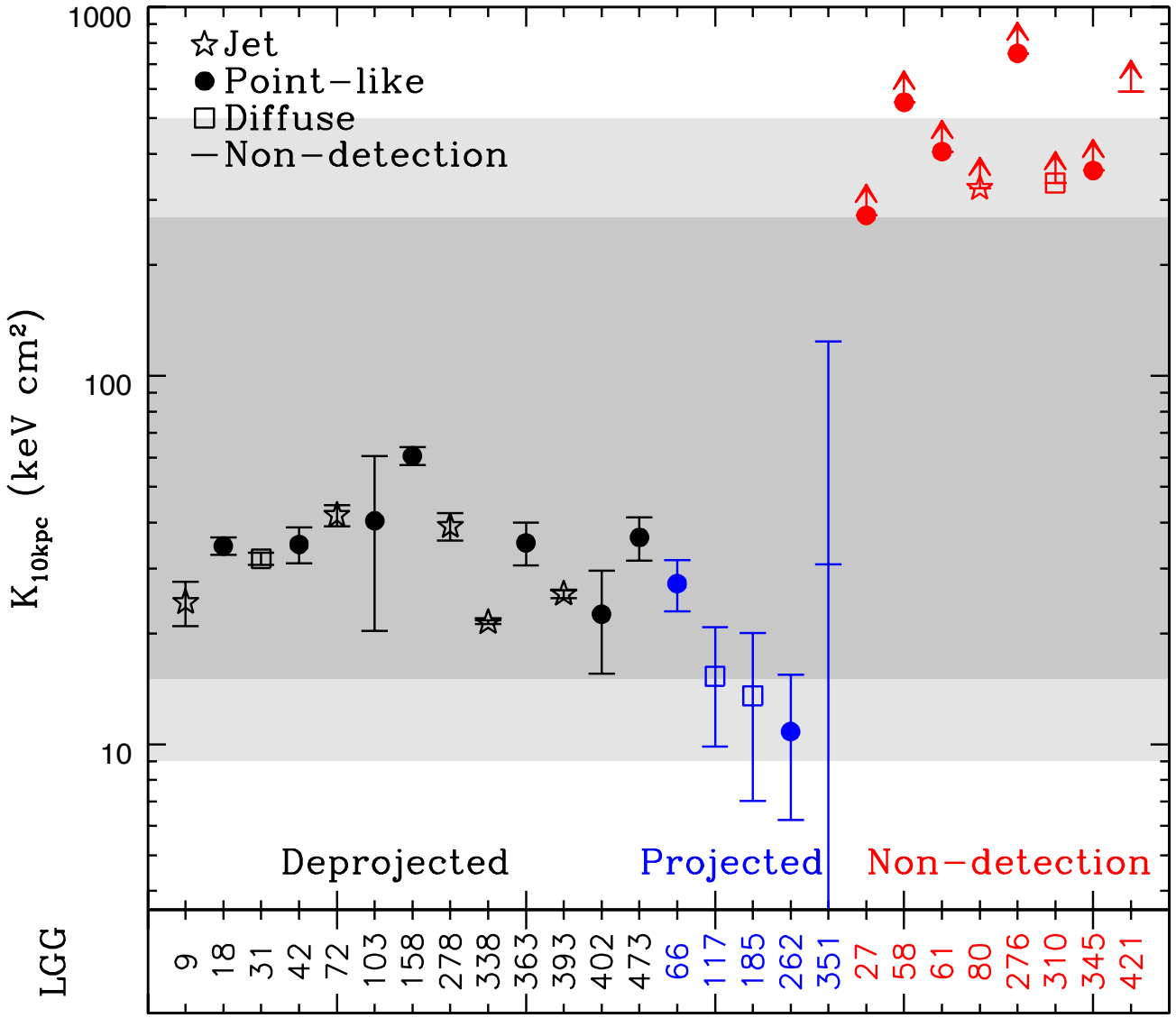
Entropy and cooling time

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.



High entropy groups



Lower limits for 1.0 keV halo

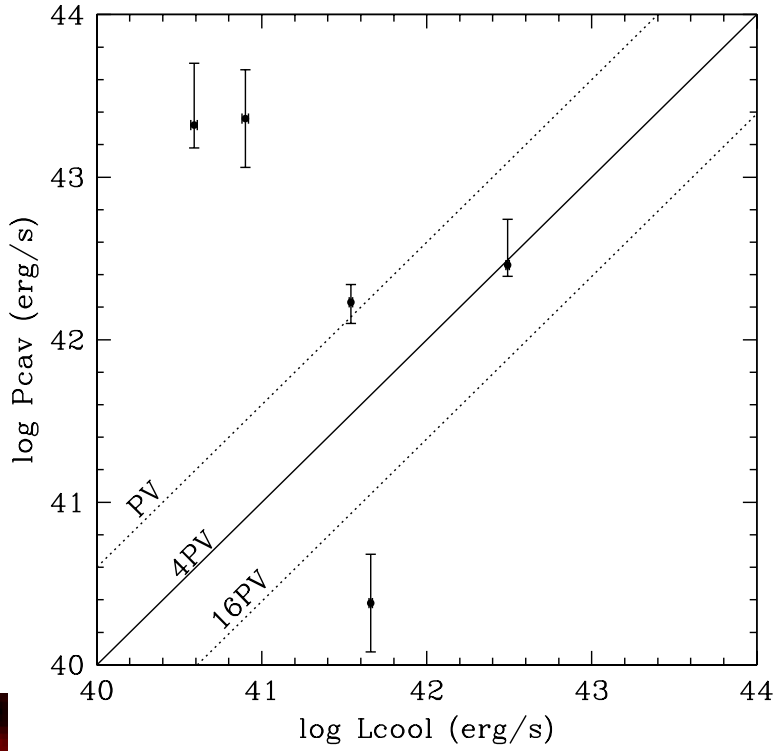
Lower limits for 0.5 keV halo

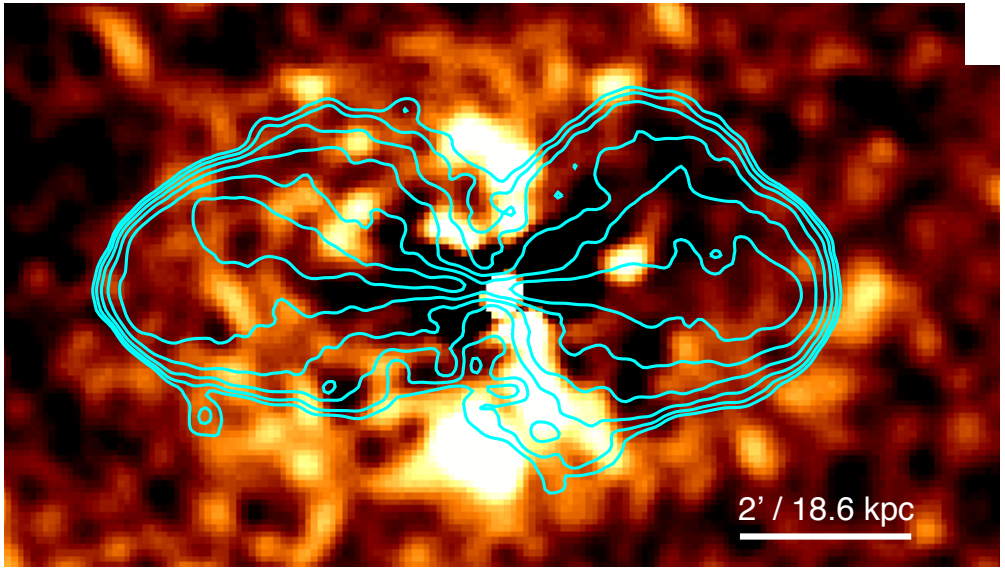
Predicted range of entropy for from OWLS simulations (dark grey = 1σ, pale grey = 2σ)

AGN feedback

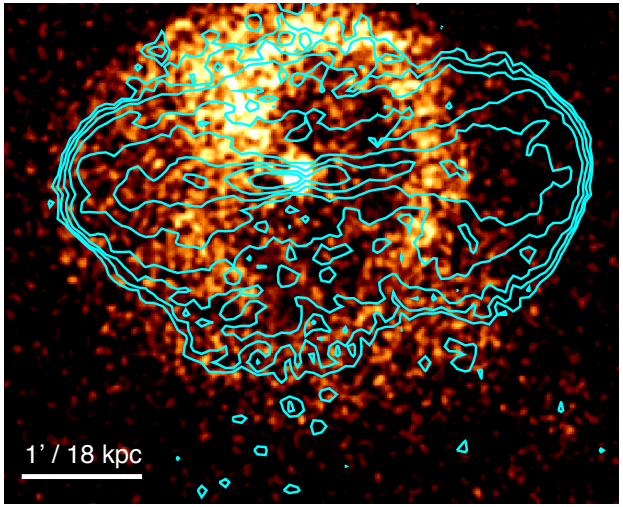
5 X-ray bright, cool core groups with central jet sources

- Jet sizes: 5-40 kpc
- Jet powers: 2×10^{40}-2×10^{43} erg/s
- Pcav = 0.1-100 x Lcool
  (c.f. models showing variation in jet power, e.g., Li, Ruszkowski & Bryan 2016)





NGC 4261 (O'Sullivan et al '11, Kolokythas et al '15)



UGC 408 (Bogdan et al 2014)

Molecular gas

23/53 CLoGS dominant galaxies observed in CO

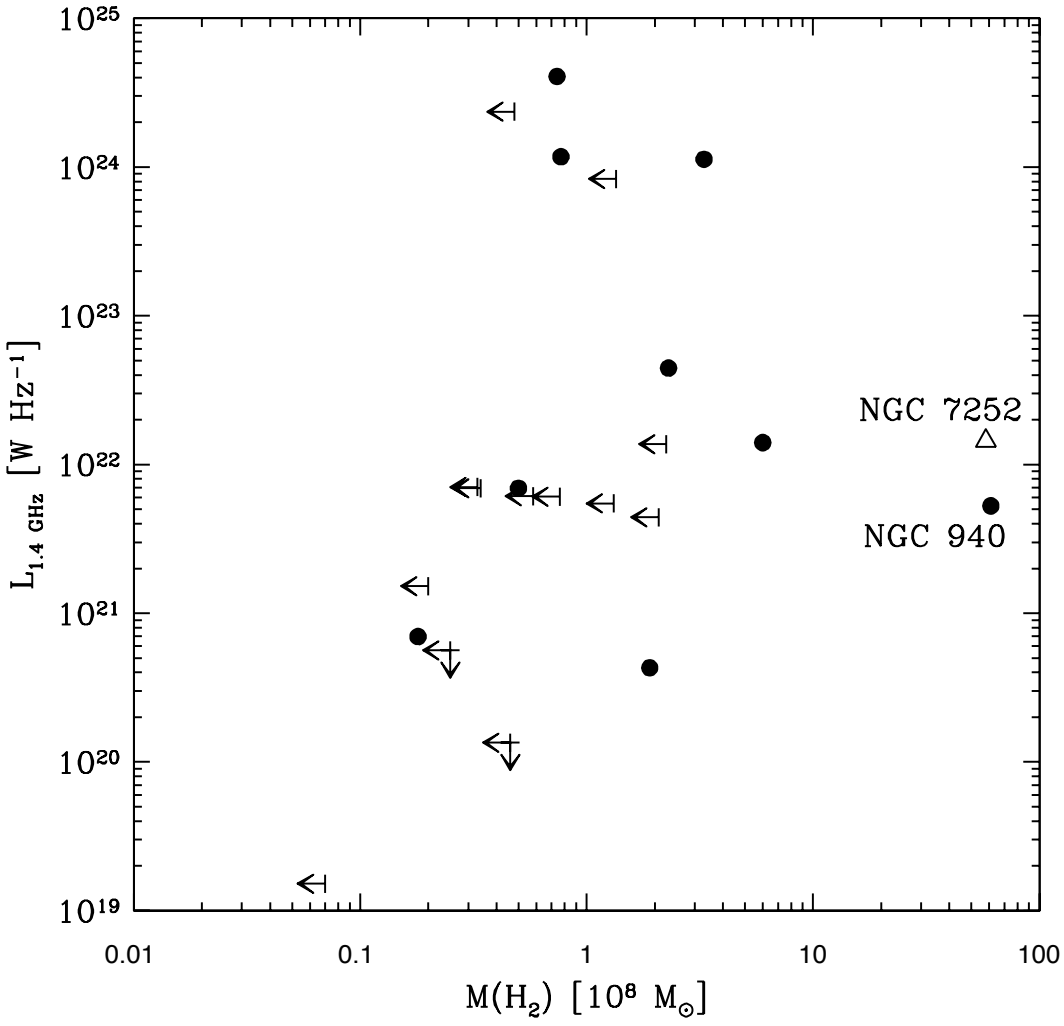
Detection rate 43±14%

- Compare with 22±3% in Atlas3D ellipticals (Young et al 2013)

CO not limited to systems with X-ray bright IGM

Most have low SFR <1$M_\odot$/yr short depletion time <10^8 yr

Data suggest CO is more common in galaxies with radio-loud AGN, but more data needed.



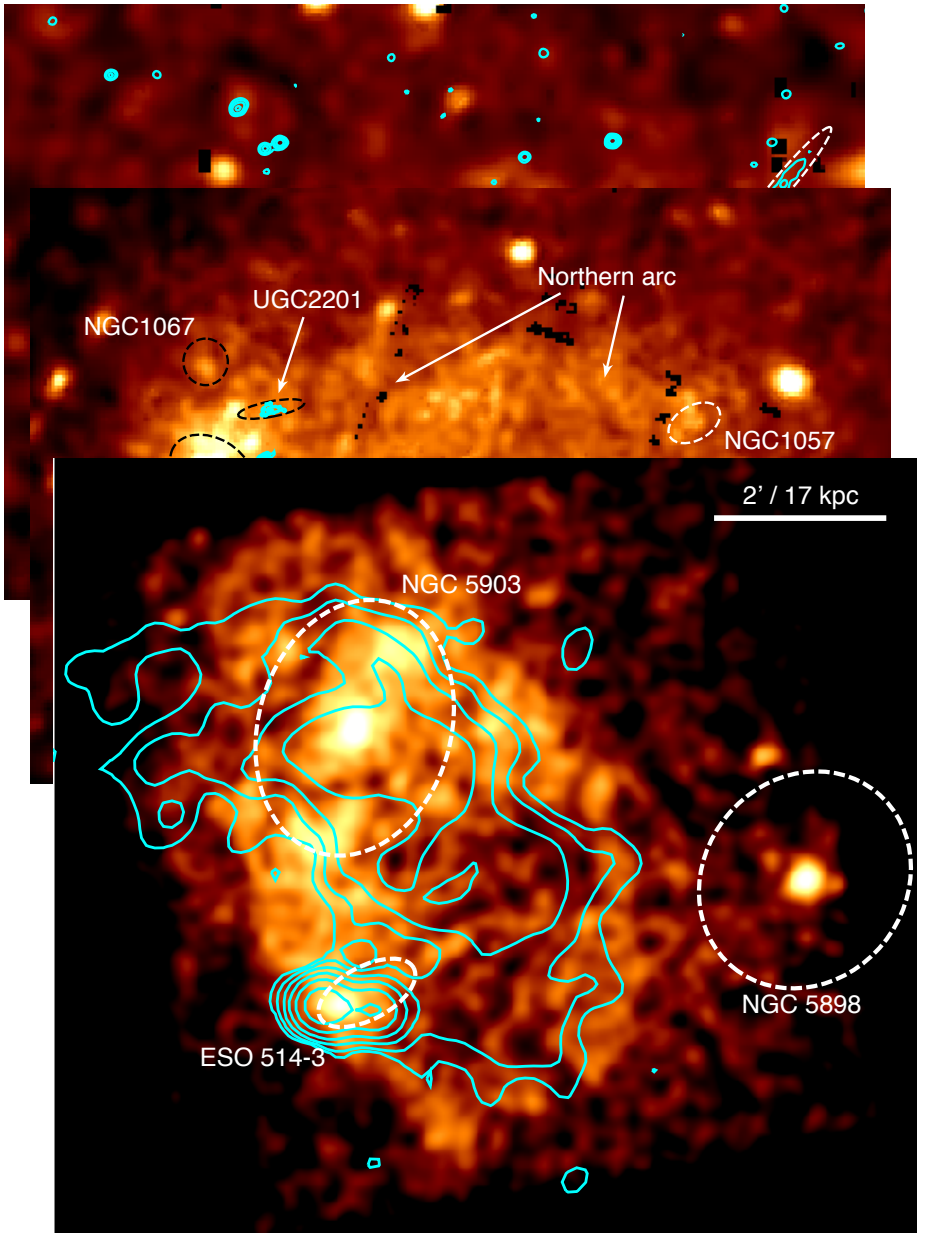
O'Sullivan, Combes, Hamer et al. 2014

What kinds of groups were missed by RASS?

CLoGS X-ray bright groups missed or mis-identified in RASS:

- Faint, non-cool core
- Mergers
- AGN disrupted

3/14 in high-richness subsample ➔~20% of X-ray bright groups in local volume as yet unidentified?



Summary

CLoGS is a statistically complete, optically-selected sample of 53 nearby groups with 100% radio and >70% X-ray coverage.

- High-Richness sample of 26 contains 14 X-ray bright groups +4 galaxy-scale X-ray halos.
- ~30% of X-ray bright groups show recent interactions, ~35% have currently or recently active central radio jets.
- No sign of high-entropy groups, most have ≤50 kev cm^2 at 10kpc.
- In X-ray bright systems, active jets found in cool cores. In some cases Jet power greatly exceeds cooling luminosity.
- CO detection rate in group-dominant galaxies roughly double that in general population of ellipticals.
- 3/14 X-ray bright groups previously unknown ➔ ~20% of X-ray bright groups in local volume may be as yet unidentified.