

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

Ewan O'Sullivan (SAO)

The CLoGS collaboration

C.f.A.: E. O'Sullivan, J. Vrtilek, L. David, C. Jones, W. Forman

U. Of Birmingham, UK: T. Ponman

IUCAA, India: S. Raychaudhury, K. Kolokythas

Observatoire de Paris: F. Combes, P. Salome

U. of Victoria, Canada: A. Babul

NCRA-TIFR, India: N. Kantharia

NRL, USA: S. Giacintucci

INAF-O.A. Bologna, Italy: M. Gitti

INAF-O.A. Brera, Italy: C. Haines

All credit for radio analysis to
Konstantinos Kolokythas
Simona Giacintucci



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, $cz < 5500 \text{ km s}^{-1}$ ($D < 80 \text{ Mpc}$)*

485 groups

Select from LGG list: systems with

- ≥ 4 members
- ≥ 1 early-type member with $L_B \geq 3 \times 10^{10} L_\odot$
- Declination $> -30^\circ$ (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 ($R = N_{\text{gal}}$ with $L_B \geq 1.6 \times 10^{10} L_\odot$)

- Exclude known clusters: $R \geq 10$
- Exclude groups too small to characterize: $R = 1$

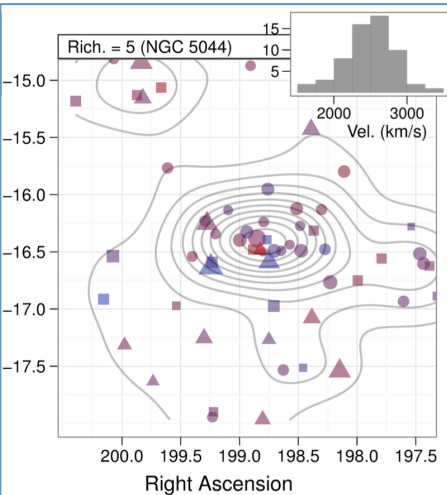
53 groups

26 groups

High-richness subsample ($R=4-8$)

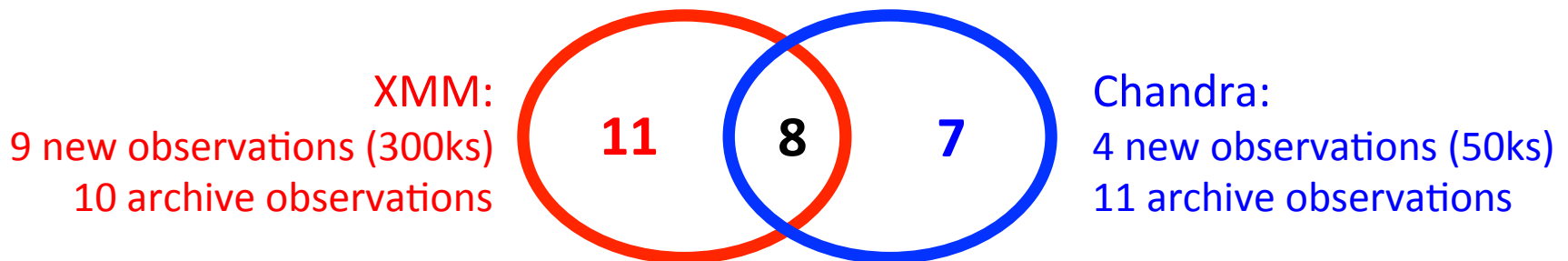
27 groups

Low-richness subsample ($R=2-3$)



Observational data

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



- Minimum sensitivity goal for new observations:

$$L_x \geq 1.2 \times 10^{42} \text{ erg s}^{-1} \text{ within } R < R_{500}$$

$$L_x \geq 3.9 \times 10^{41} \text{ erg s}^{-1} \text{ within } R < 65 \text{ kpc}$$

- 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, H α 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, $L_x > 10^{41}$ erg/s)
- 4 (15%) have a galaxy-scale X-ray halo (extent < 65 kpc, $L_x = 10^{40} - 10^{41}$ erg/s)
- 8 have no detected X-ray halo (all are Richness $R=4$)

Typical $kT \approx 0.5 - 1.6$ keV

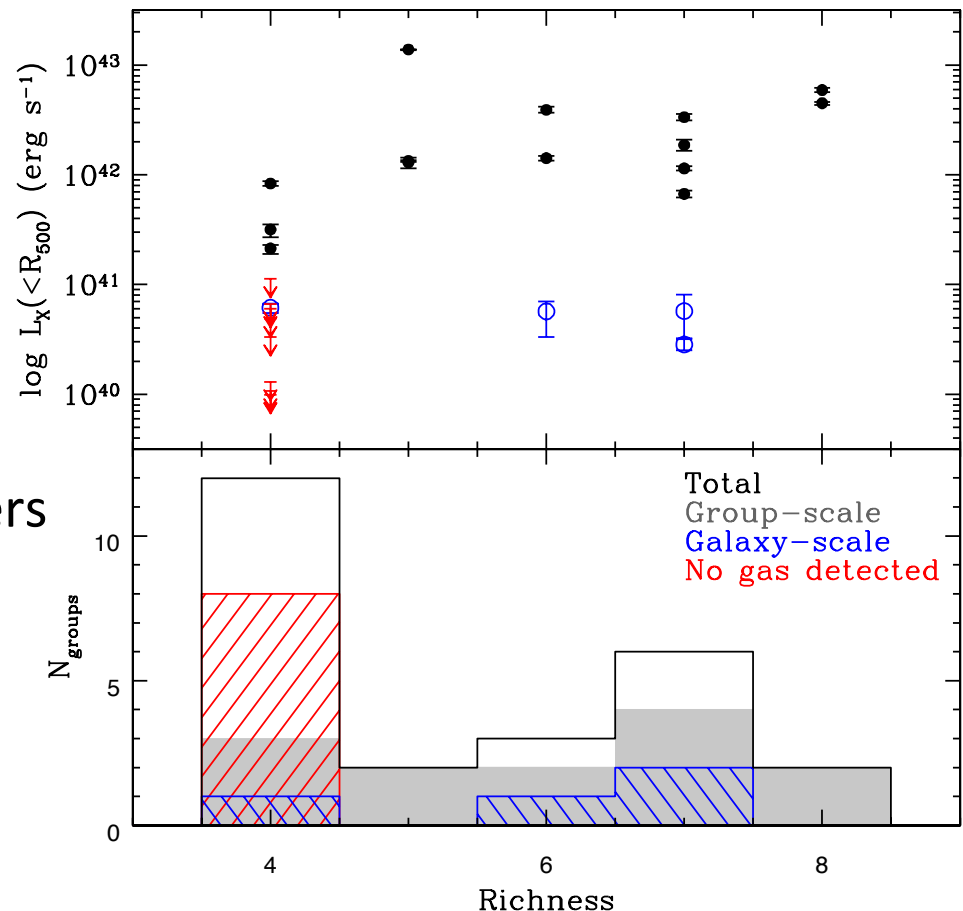
➔ $M_{500} \approx 8 \times 10^{12} - 6 \times 10^{13} M_{\odot}$

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 $\sim 50\%$ in clusters.



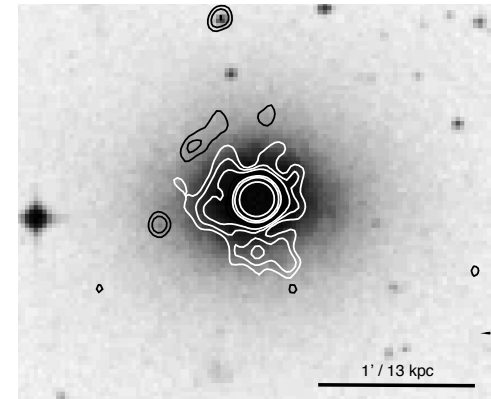
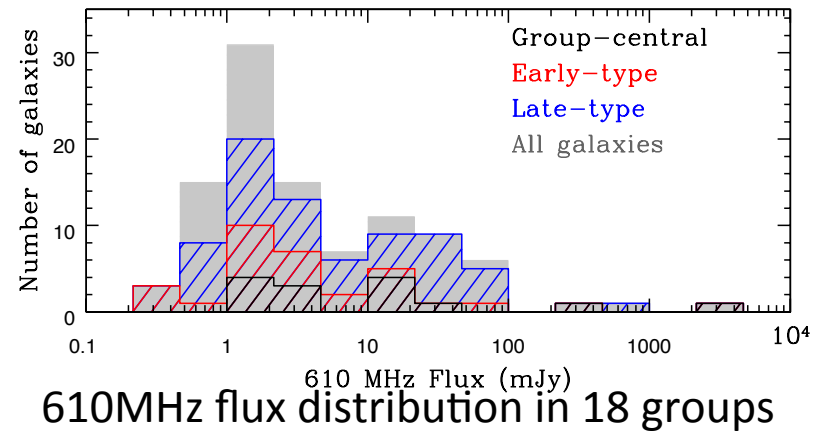
CLoGS high-richness: Radio overview

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

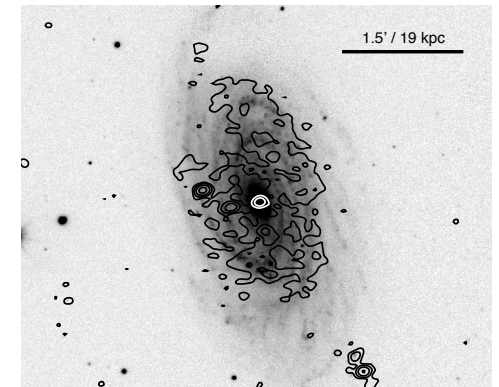
Non-central galaxies:

- 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



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

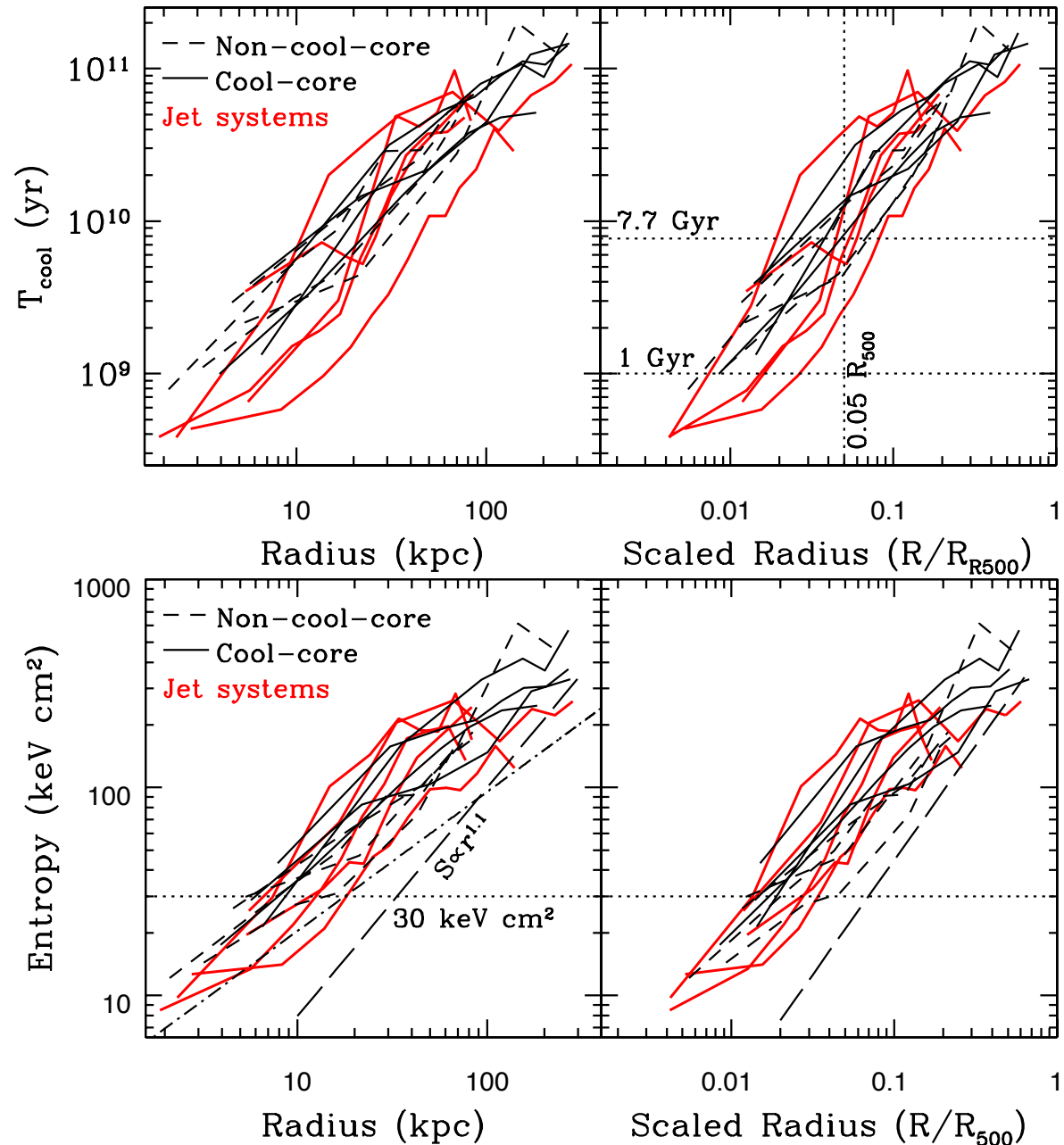
NGC 5985 →
AGN+SF disk
610 MHz
contours at
(0.8,1.6,3.2,...
mJy/b)



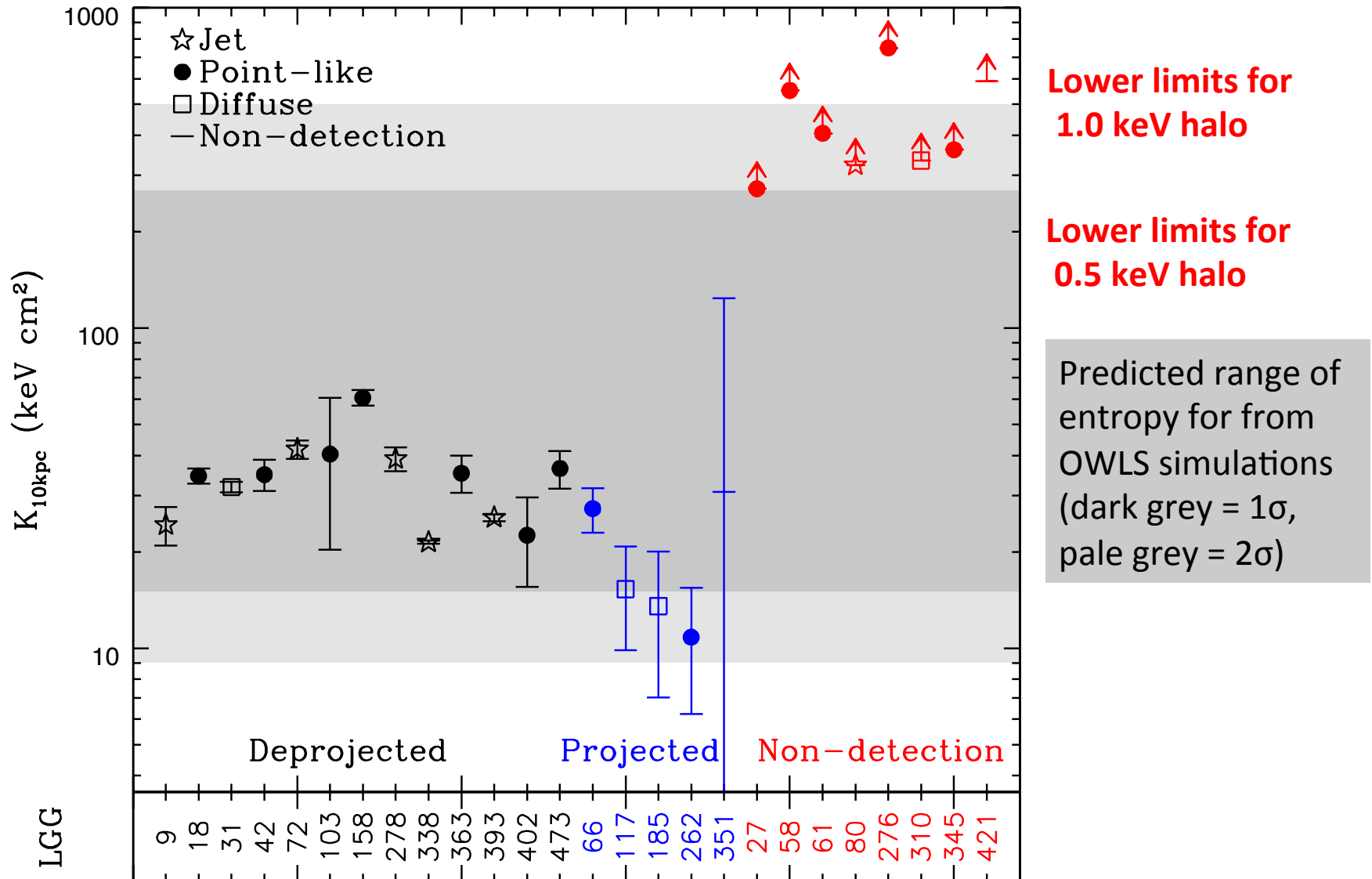
Entropy and cooling time

Group-scale halos:

- All have short core
 $T_{\text{cool}} < 7.7 \text{ Gyr}$
 and low core
 entropy $< 50 \text{ keV cm}^2$
- Most have $K < 30 \text{ keV cm}^2$
- 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.



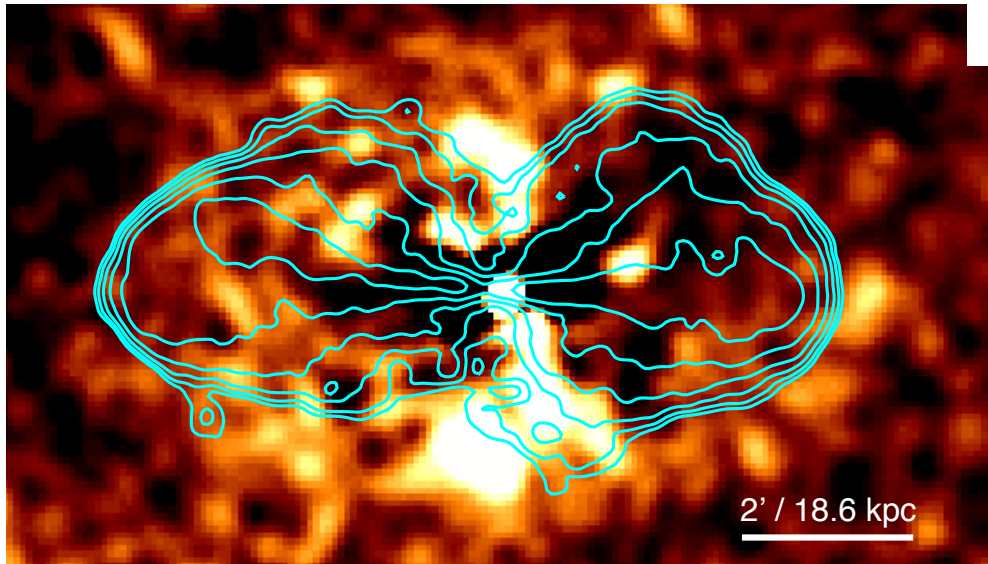
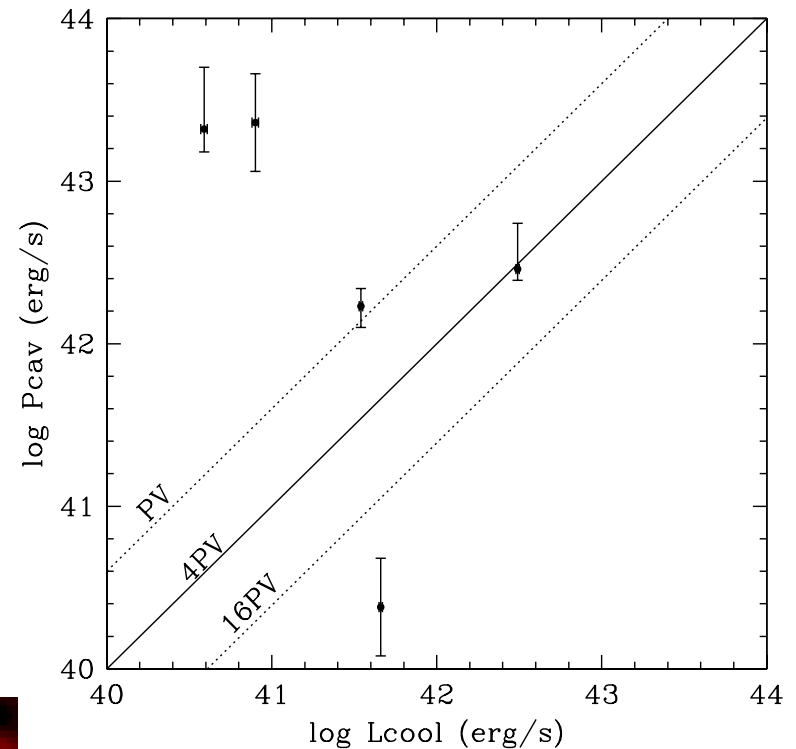
High entropy groups



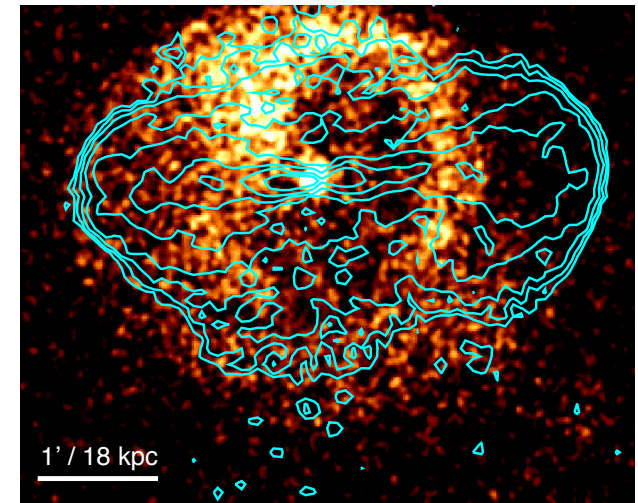
AGN feedback

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
- $P_{\text{cav}} = 0.1\text{-}100 \times L_{\text{cool}}$
(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

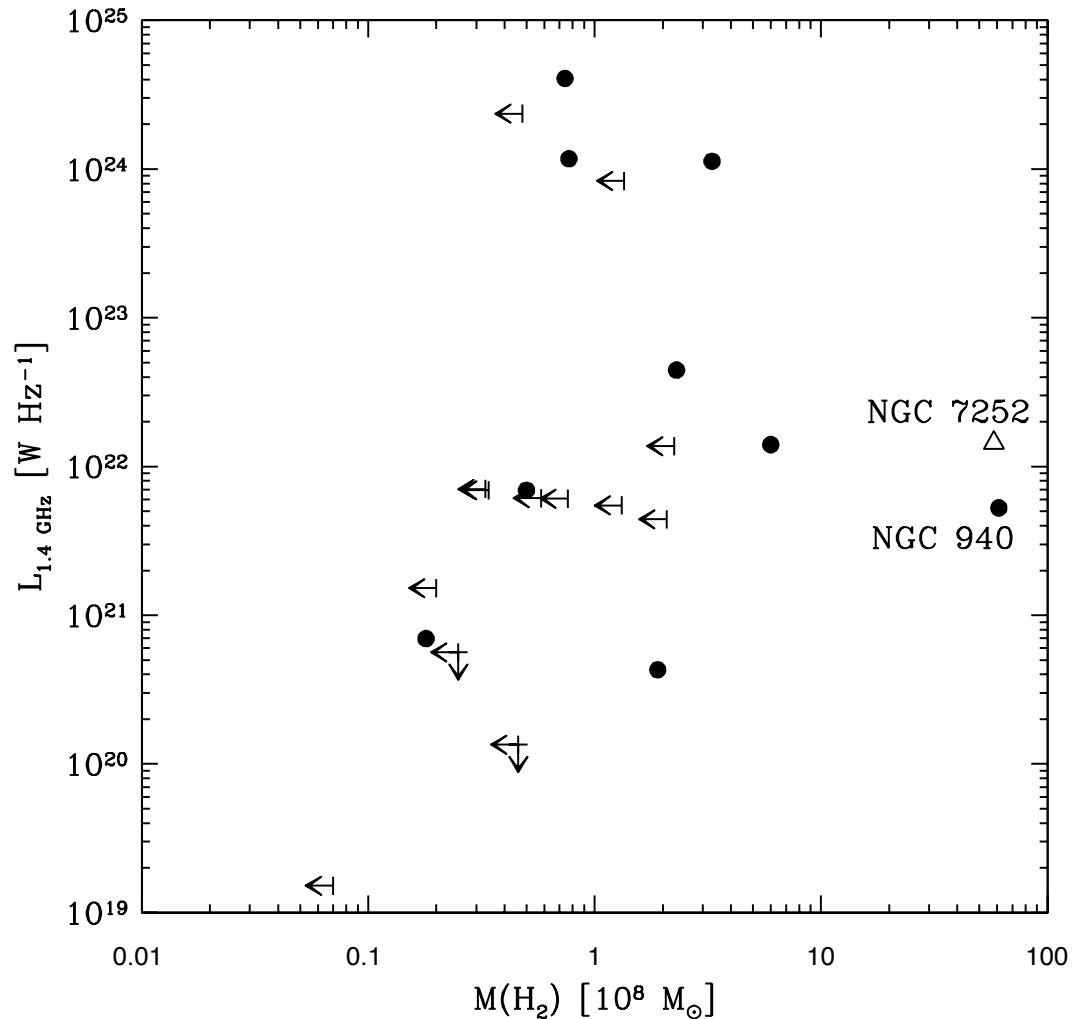
Detection rate $43 \pm 14\%$

- Compare with $22 \pm 3\%$ in Atlas3D ellipticals (Young et al 2013)

CO not limited to systems with X-ray bright IGM

Most have low SFR $< 1 M_{\odot}/\text{yr}$
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



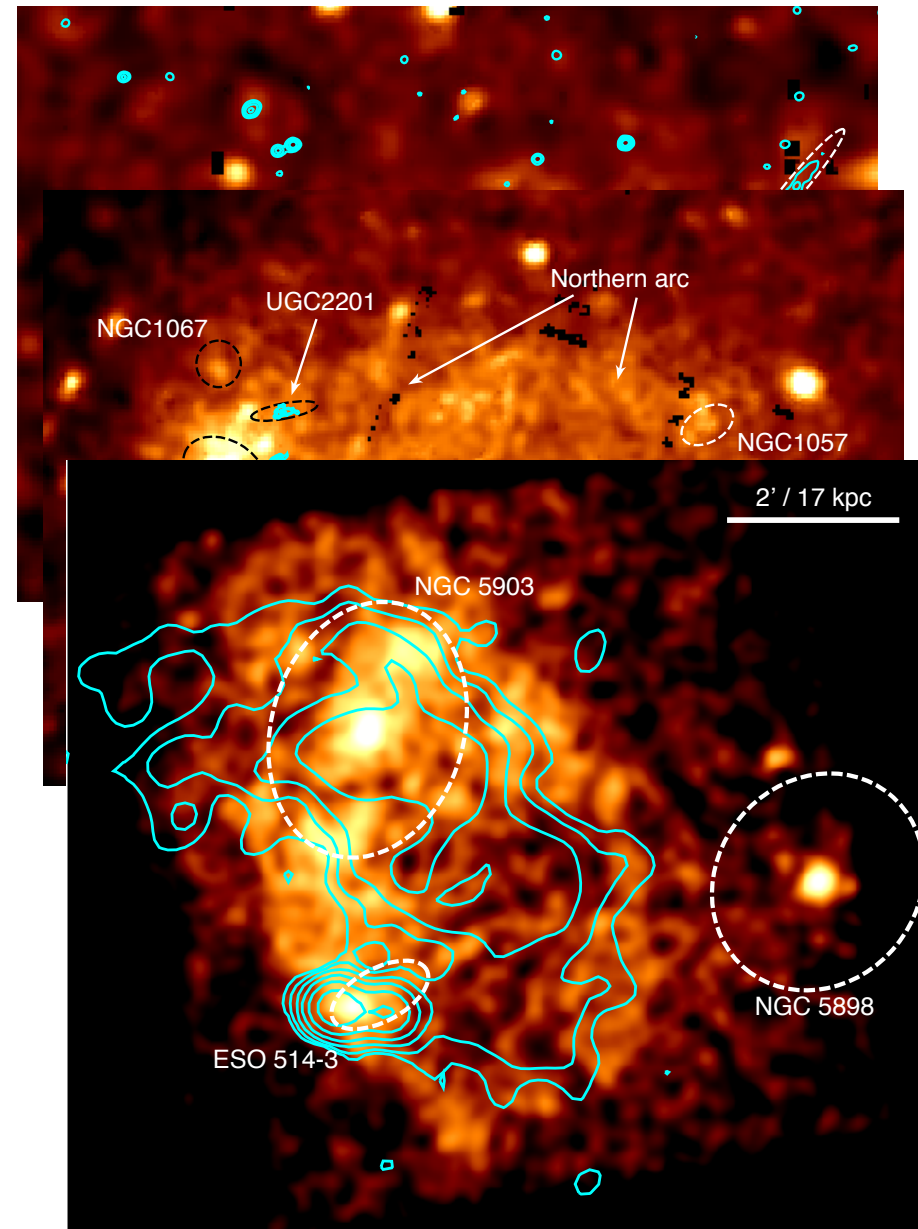
What kinds of groups were missed by RASS?

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?

0.5-2 keV X-ray 610 or 235 MHz radio



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 $\leq 50 \text{ keV cm}^2$ 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.

