The Complete Local-Volume Groups Sample

AGN feedback in nearby groups

Ewan O'Sullivan (SAO)

Thanks to: K. Kolokythas, S. Raychaudhury, G. Schellenberger, J. Vrtilek, L.P. David, S. Giacintucci, T. Ponman, C.P. Haines, A. Babul, M. Gitti, F. Combes, P. Salomé, and N. Kantharia

Background: why do we need another group sample?

- Groups are a key environment for galaxy evolution and AGN feedback
  - >50% of all galaxies reside in groups
  - Galaxy mergers and tidal interactions are common
  - Shallow potential well ⇒ AGN, mergers have greater impact
- But we lack representative, unbiased samples
  - *Optically-selected* catalogs include false groups (chance associations, uncollapsed 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: 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 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)
  - What fraction and what types of groups are missed by RASS?

- Central AGN as a group-scale feedback mechanism:
  - Do group-central AGN balance cooling?
  - How are central AGN affected by environment?

- Impact of group environment on member galaxies:
  - Is star formation rate affected by group environment?
  - What fraction of member galaxies host AGN?

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

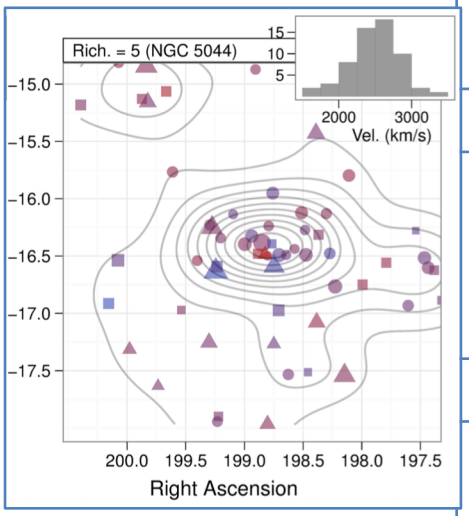
Sample selection

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 GMRT and VLA)

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)

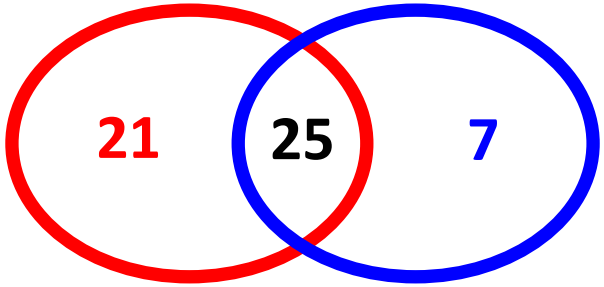
27 groups
Low-richness subsample (R=2-3)

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Observational data

- **Radio:** (Kolokythas et al. 2018 + in prep.)
  - GMRT 235+610 MHz for all groups (192hr + archival data)
  - ~4hrs/target, rms ~0.1mJy/bm @610 MHz, ~0.6mJy/bm @ 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!)

XMM:
27 new observations (222hr)
19 archive observations



Chandra:
7 new observations (102hr)
25 archive observations

  - Minimum sensitivity goal for new observations:

    $L_x \geq 1.2\times10^{42}$ erg s^{-1} within R_{500}

    $L_x \geq 3.9\times10^{41}$ erg s^{-1} within 65 kpc

- **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.

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

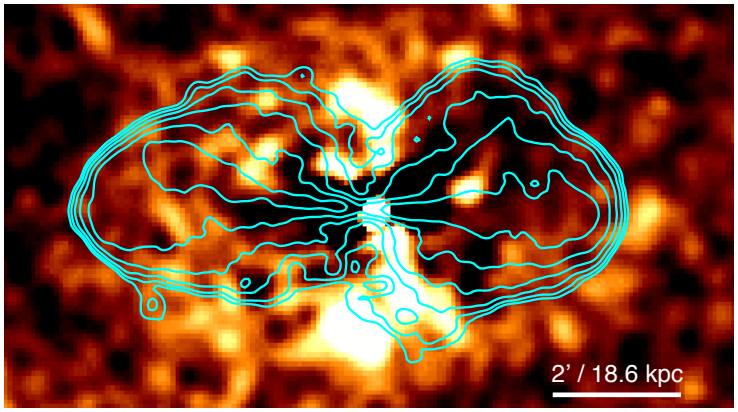
CLoGS: Radio/X-ray overview

Group-central galaxies:

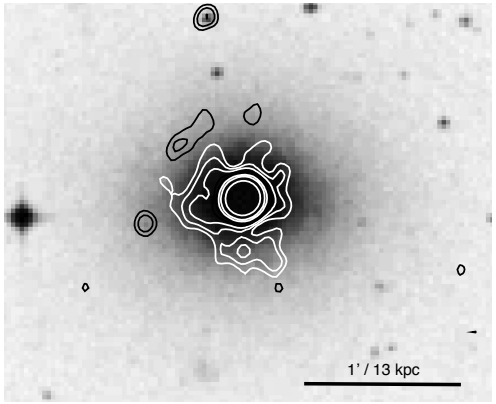
- 46/53 (87%) detected at 610, 235 or 1400 MHz
- 13 host jet sources
- 5 are diffuse, 28 point-like
- $L_{235} = 10^{20} – 10^{25}$ W/Hz
- + 100s non-central galaxies

X-ray properties of high-richness sample:

- 14/26 (54%) have an X-ray bright IGM (extent >65 kpc, Lx>10^{41} erg/s)
  - 1/3 dynamically active (sloshing/mergers)
  - Cool Core fraction = 65%
- 3/26 (12%) have a galaxy-scale X-ray halo (extent < 65kpc, Lx=10^{40}-10^{41} erg/s)

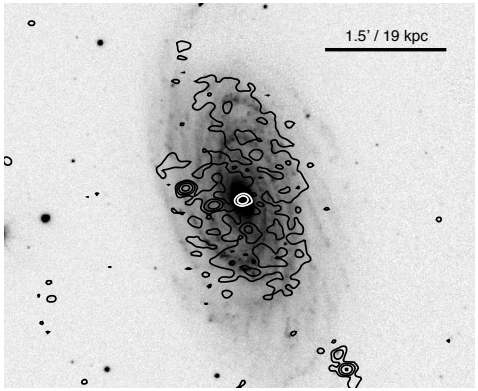


NGC 4261 (O'S 2011, Kolokythas 2015)



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

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

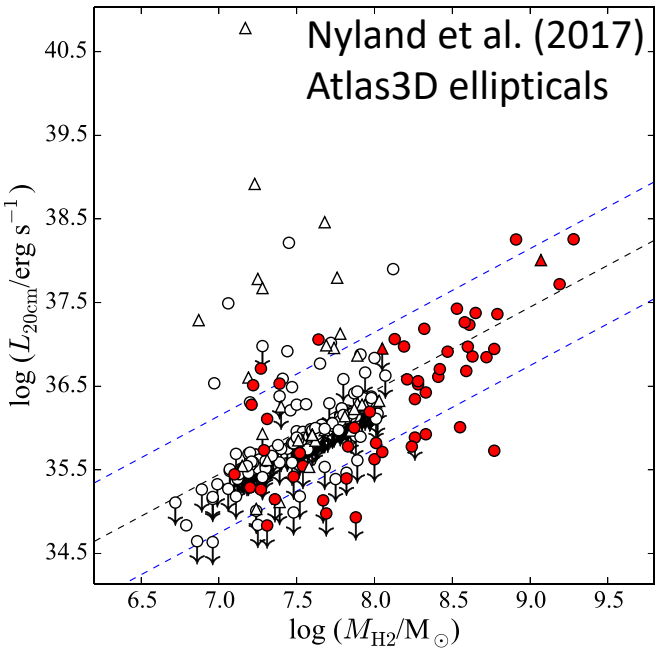


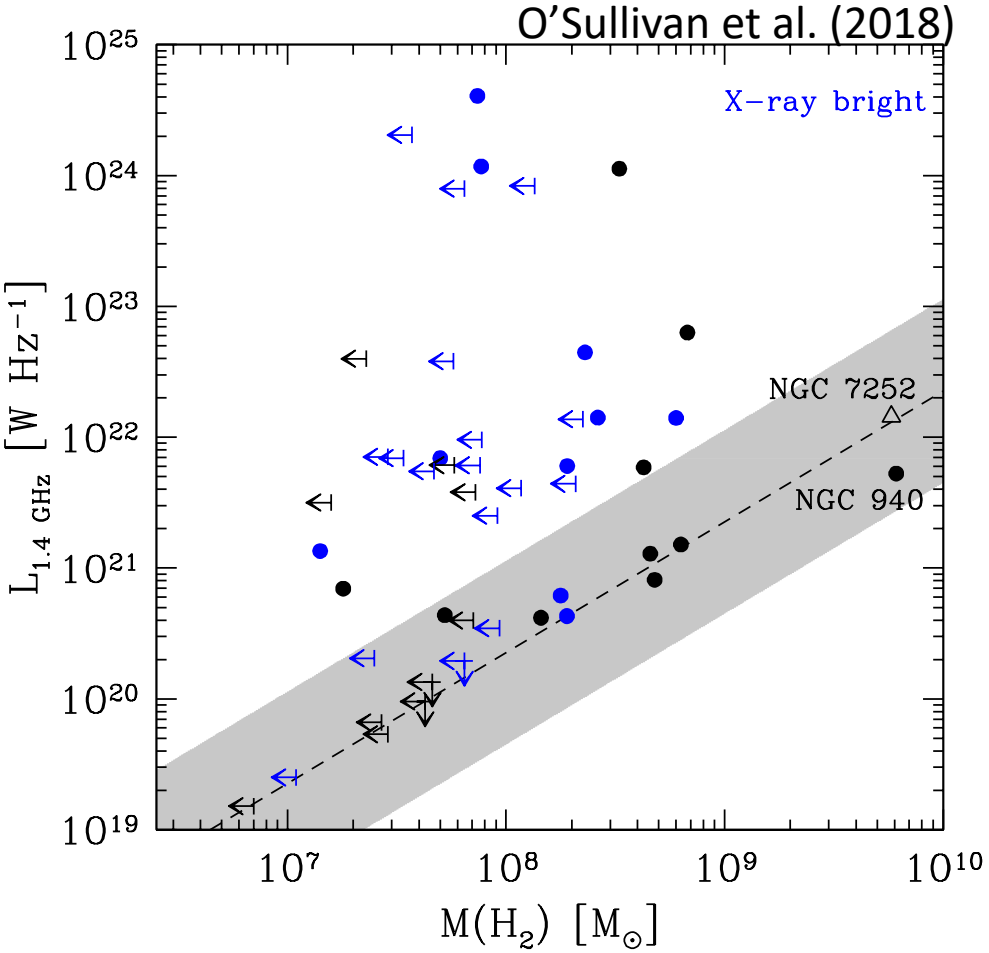
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Molecular gas

CO Detection rate in group-dominant galaxies: 40±9%

- Compare with 22±3% in Atlas3D ellipticals (Young et al 2013)
- >50% have HI





- CO in both X-ray bright and X-ray faint systems ⇒ cooling and merger origins?
- Low SFR <1M$_\odot$/yr, short depletion time <10^8 yr
- Large CO mass not required for AGN outburst

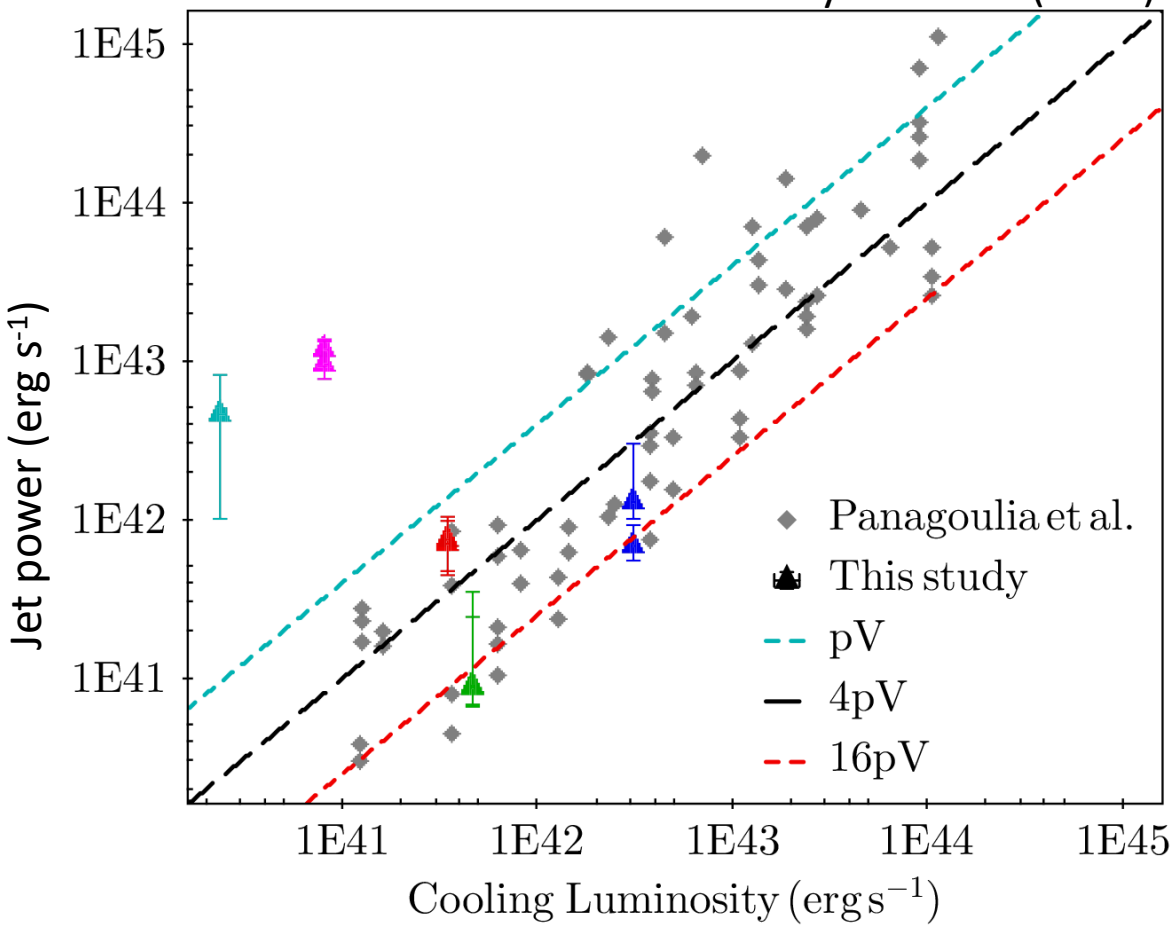
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

AGN Feedback: Jet Power

- 11/13 jet sources reside in X-ray bright groups

- 5 in high-Richness subsample
  - Jet sizes: 12-80 kpc
  - P_{jet} ~10^{41}-10^{43} erg/s
  - P_{jet} = 0.1-100 x Lcool (c.f. models showing variation in jet power, e.g., Li, Ruszkowski & Bryan 2016)

Kolokythas et al (2018)

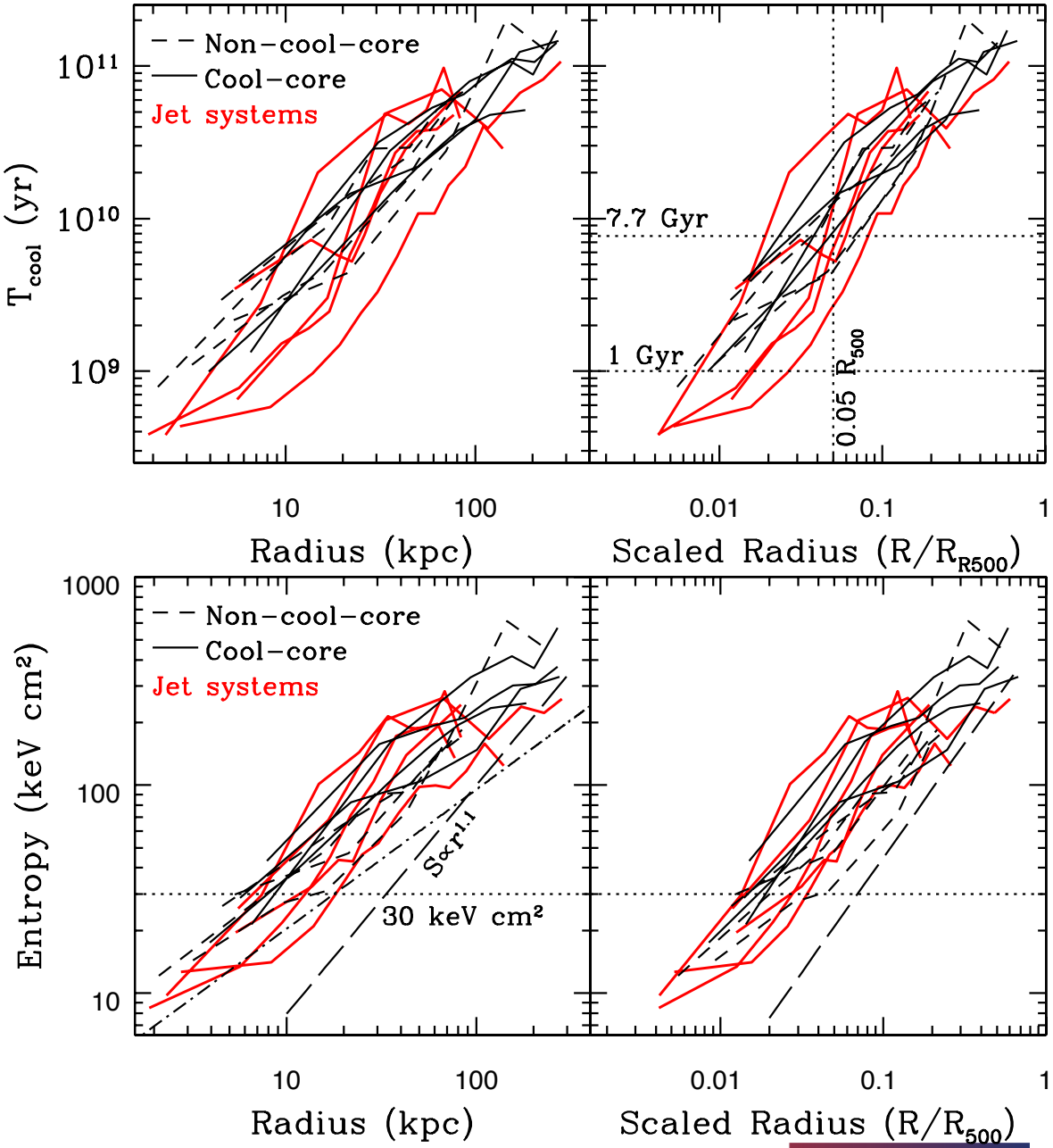


CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

AGN feedback: Entropy and cooling time

Group-scale halos:

- Central jet sources only seen in systems with central temperature decline.
- Entropy or t_{cool} at fixed radius is poor predictor of jet activity
- Jet sources have $\min(t_{cool}/t_{ff})<15$
- All have short core $t_{cool} < 7.7$Gyr – by cluster standards, all groups are cool cores!



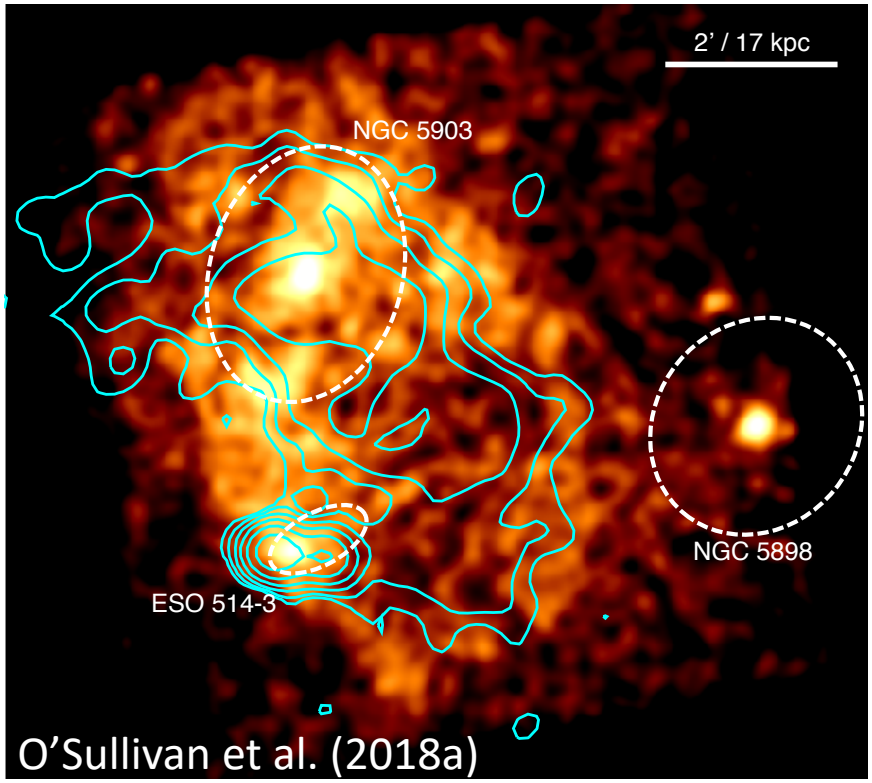
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Groups missed by RASS

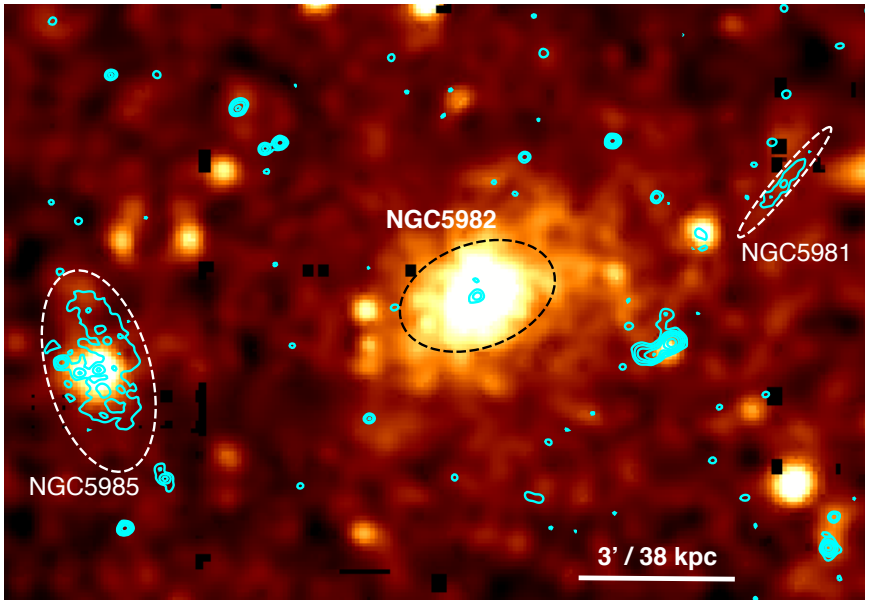
3/14 in high-R sample (+7 in low-R!)

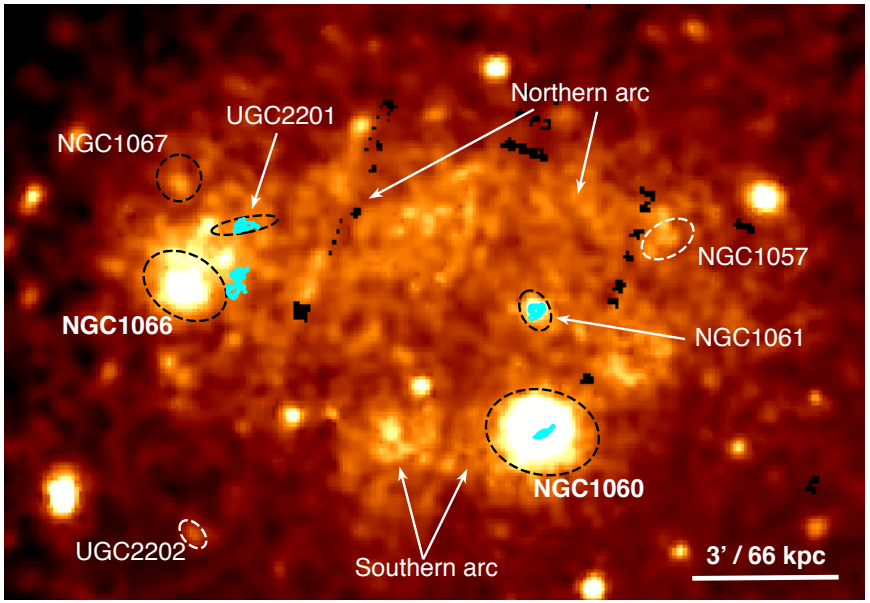
- Faint, non-cool core
- Mergers
- AGN disrupted

>20% of X-ray bright groups as yet unidentified?



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



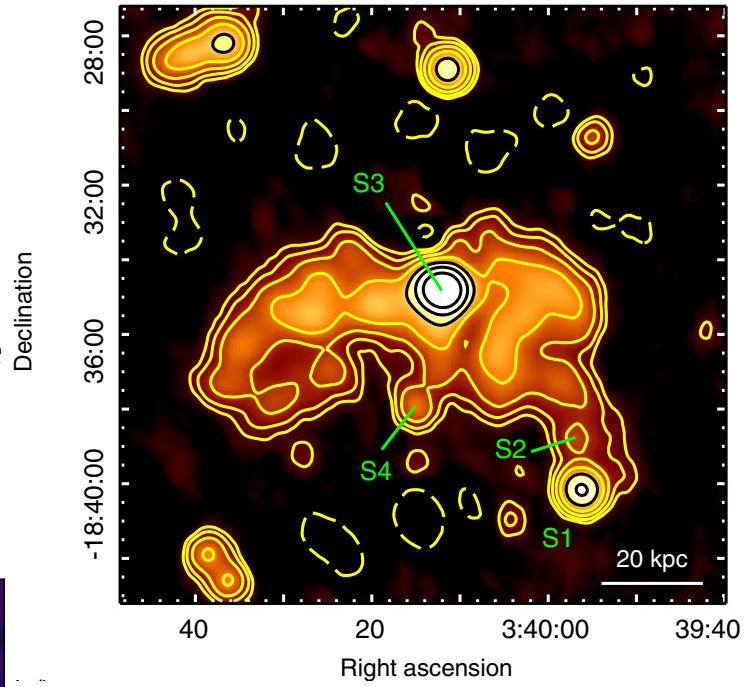


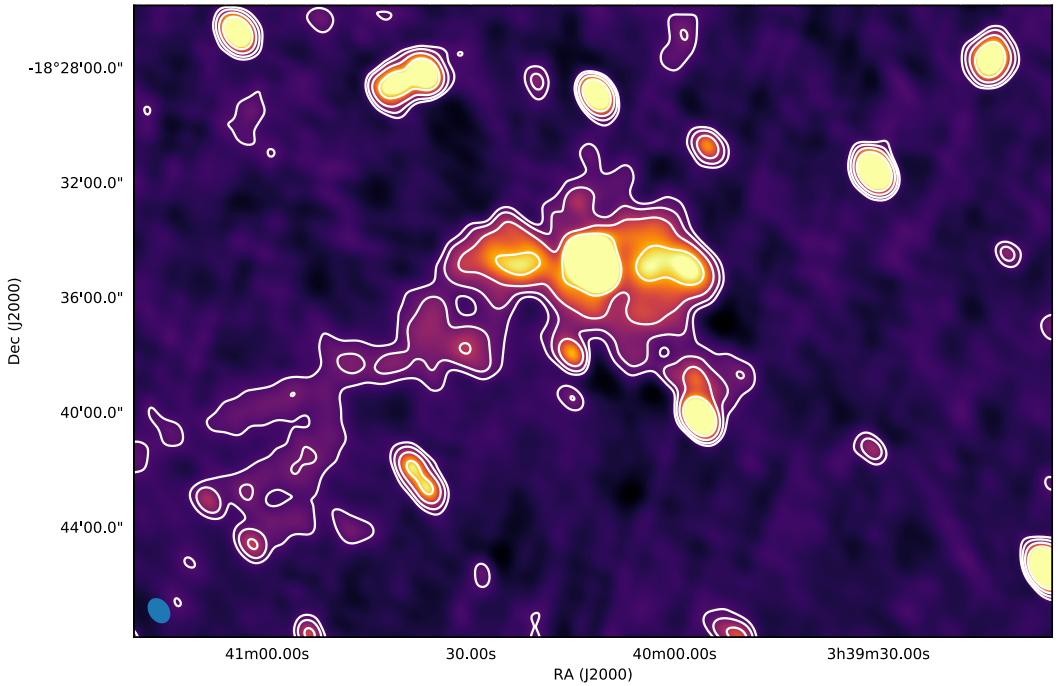
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

uGMRT follow-up: NGC 1407

See Gerrit Schellenberger's poster

GMRT 330MHz, Giacintucci et al. (2012)➔
rms=160μJy/bm, BW=32MHz, 5.5hr on source
45"x45" beam, contours=3σ,6σ,12σ,24σ,…





←uGMRT band 3
300-500MHz, rms=80μJy/bm,
~2.3hr on source,
57"x43" beam, contours=3σ,6σ,12σ,…

poor ionospheric conditions, bright sources in the field.

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Summary

CLoGS is a statistically complete, optically-selected sample of 53 nearby groups with high-quality radio + X-ray coverage (+ CO for BGGs).

- 87% of group-dominant galaxies host radio sources, 25% have jets.
- 14/26 high-richness groups have X-ray bright IGM +3 galaxy-scale halos.
- ~35% of X-ray bright groups host currently or recently active central radio jet sources ➔ duty cycle 1/3.
- In X-ray bright systems, active jets found in cool cores. Jet power can exceed cooling luminosity by a factor of 100.
- CO detection rate in group-dominant galaxies 40%, 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.
- See Konstantinos Kolokythas and Gerrit Schellenberger's posters for more details of our GMRT and uGMRT work!