Galaxy Groups in the Local Universe

gas content and AGN feedback in a complete sample

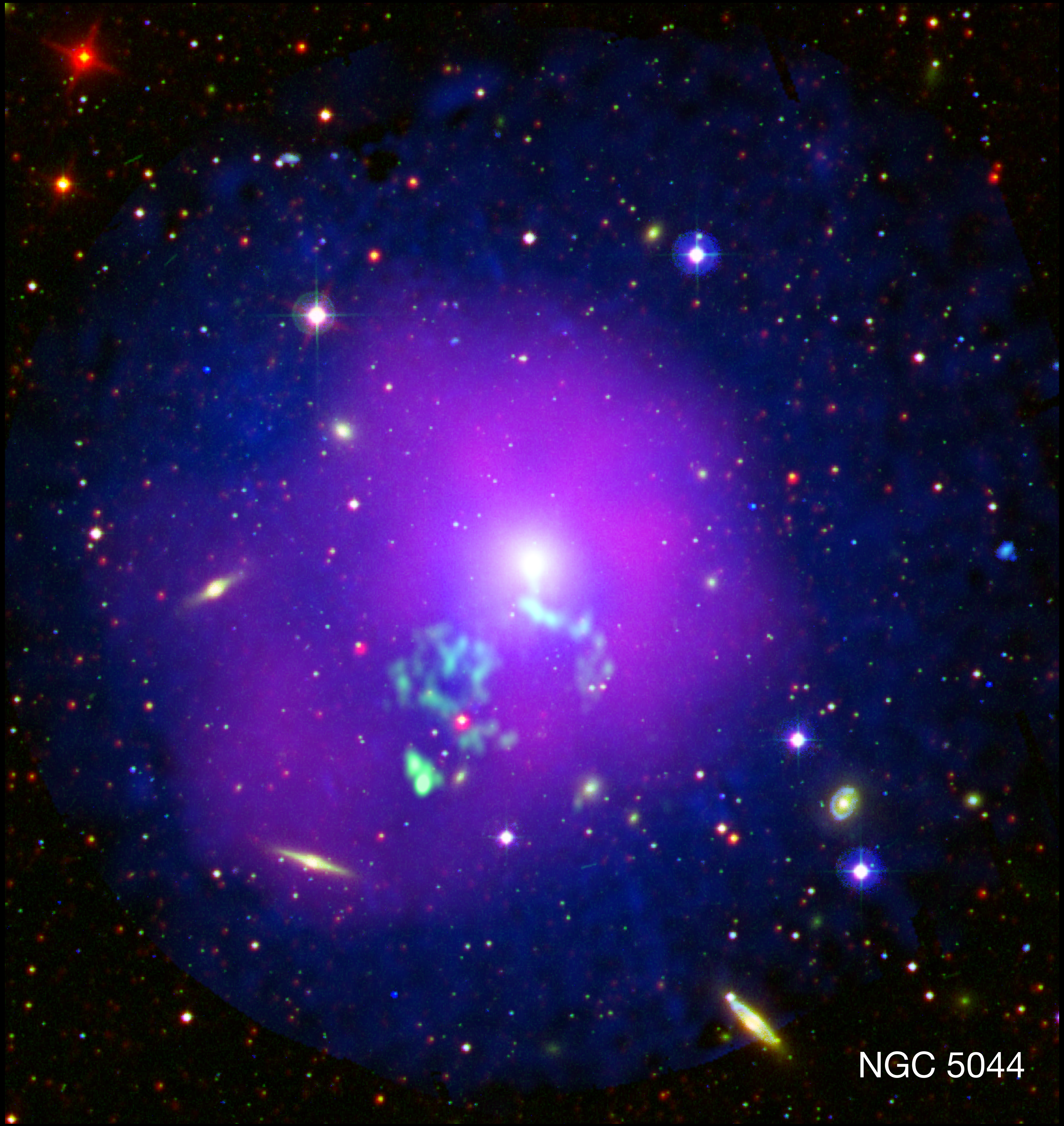
Ewan O'Sullivan

K. Kolokythas, J.M. Vrtilek, L.P. David, G. Schellenberger, F. Combes, P. Salomé, V. Olivares, S. Giacintucci, M. Gitti, T.J. Ponman, S. Raychaudhury, A. Babul

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Why study feedback in groups?

- Most galaxies are located in groups
- Shallow potential wells compared to clusters
  ➜ AGN heating may have a greater impact
- Environment drives interesting physics: galaxy interactions, gas stripping/heating
- Selection problems:
  - RASS biased toward X-ray bright, centrally-concentrated groups (Eckert et al. 2011).
  - Optical selection becomes unreliable for small numbers of members (e.g., Pearson et al. 2015)

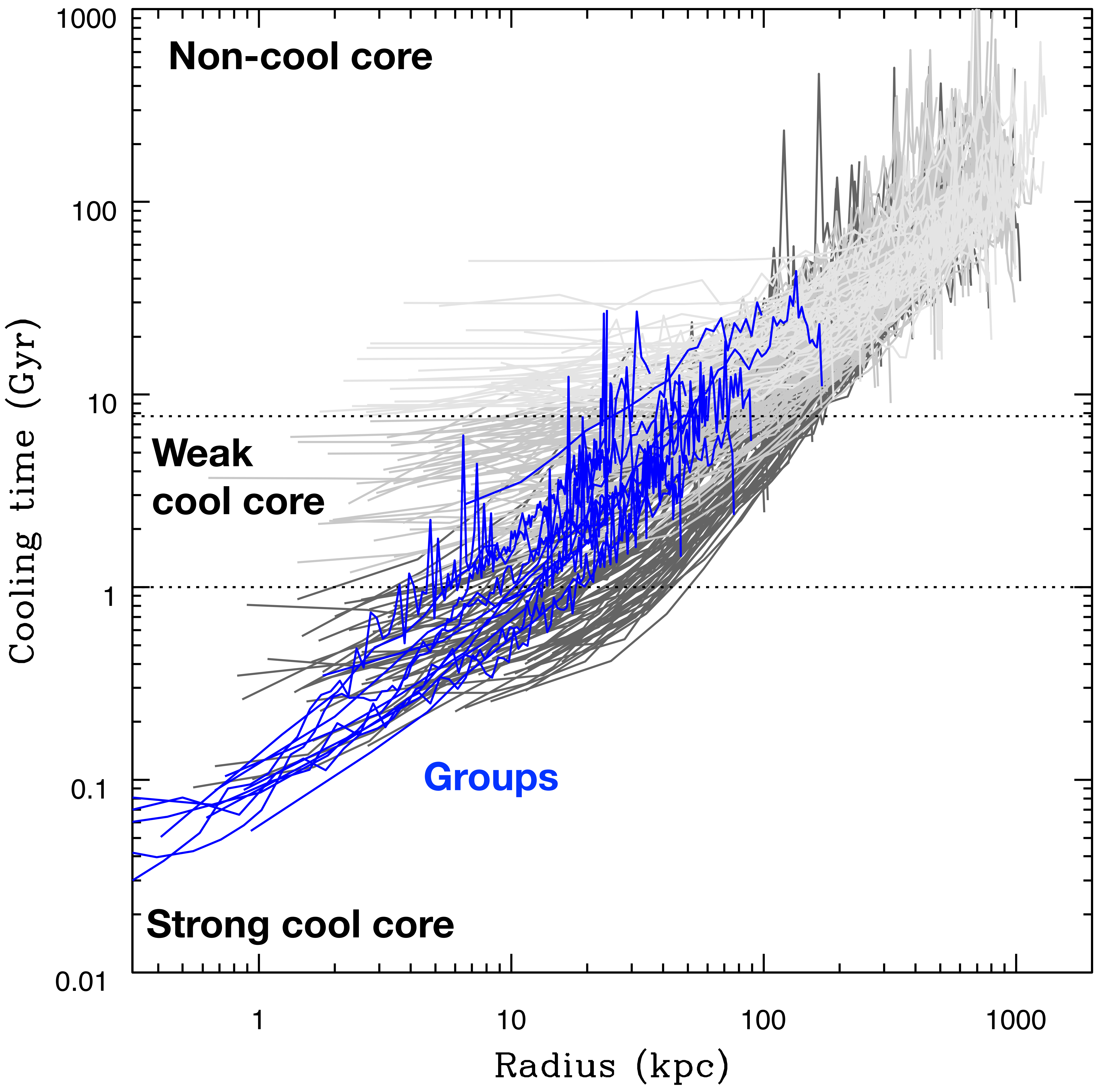


Cooling and feedback: clusters vs groups

- X-ray line emission at ≲1.5 keV means groups cool their hot halos more effectively than clusters

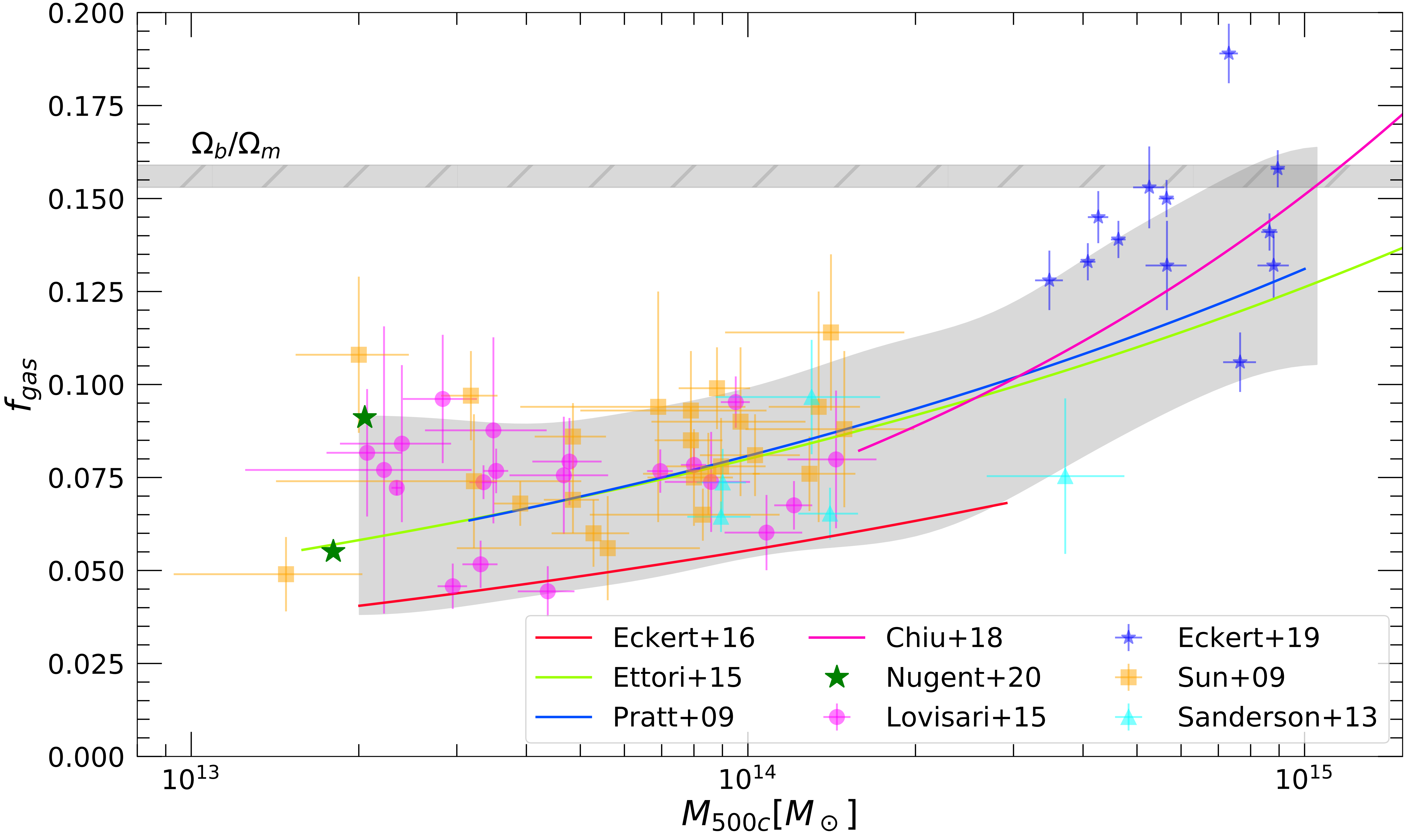
➜ most groups are strong CC, no NCC groups?

ACCEPT sample, Cavagnolo et al. (2010)



Cooling and feedback: clusters vs groups

- AGN must heat gas less efficiently in groups than clusters if they are not to eject the IGrM (Best et al. 2007, Giodini et al. 2010).
  ➜ Groups operate in low-power “bubbling” mode?
- Lower gas fractions in groups suggests this has partially happened.



Eckert et al. (2021)

CLoGS: a Complete Local-volume Group Sample

Statistically complete optically selected sample of 53 nearby groups

- within 80 Mpc
- ≥4 member galaxies, ≥1 early-type member with $L_B \geq 3\times10^{10}\ L_\odot$
- Declination ≥ -30° (covered by VLA sky surveys, visible from GMRT)

X-ray: *XMM* and/or *Chandra* observations of all groups (O'Sullivan et al. 2017 + in prep.)
typically 20-40 ks *XMM* observations

Radio: GMRT 610 & 235 MHz for all groups (Kolokythas et al. 2018, 2019)
~4 hrs/target, rms ~0.1mJy/bm @610 MHz, ~0.6mJy/bm @ 235 MHz

CO: IRAM 30m or APEX for all dominant galaxies (O'Sullivan et al. 2015, 2018)
1-2 hrs/target, detecting $M_{H2} = 10^7 - 6\times10^9\ M_\odot$

Hα: MUSE IFU for 18 dominant galaxies (Olivares et al. 2022)
1 hr/target, 1.5" seeing

CLoGS: X-ray & radio results

Detection fraction

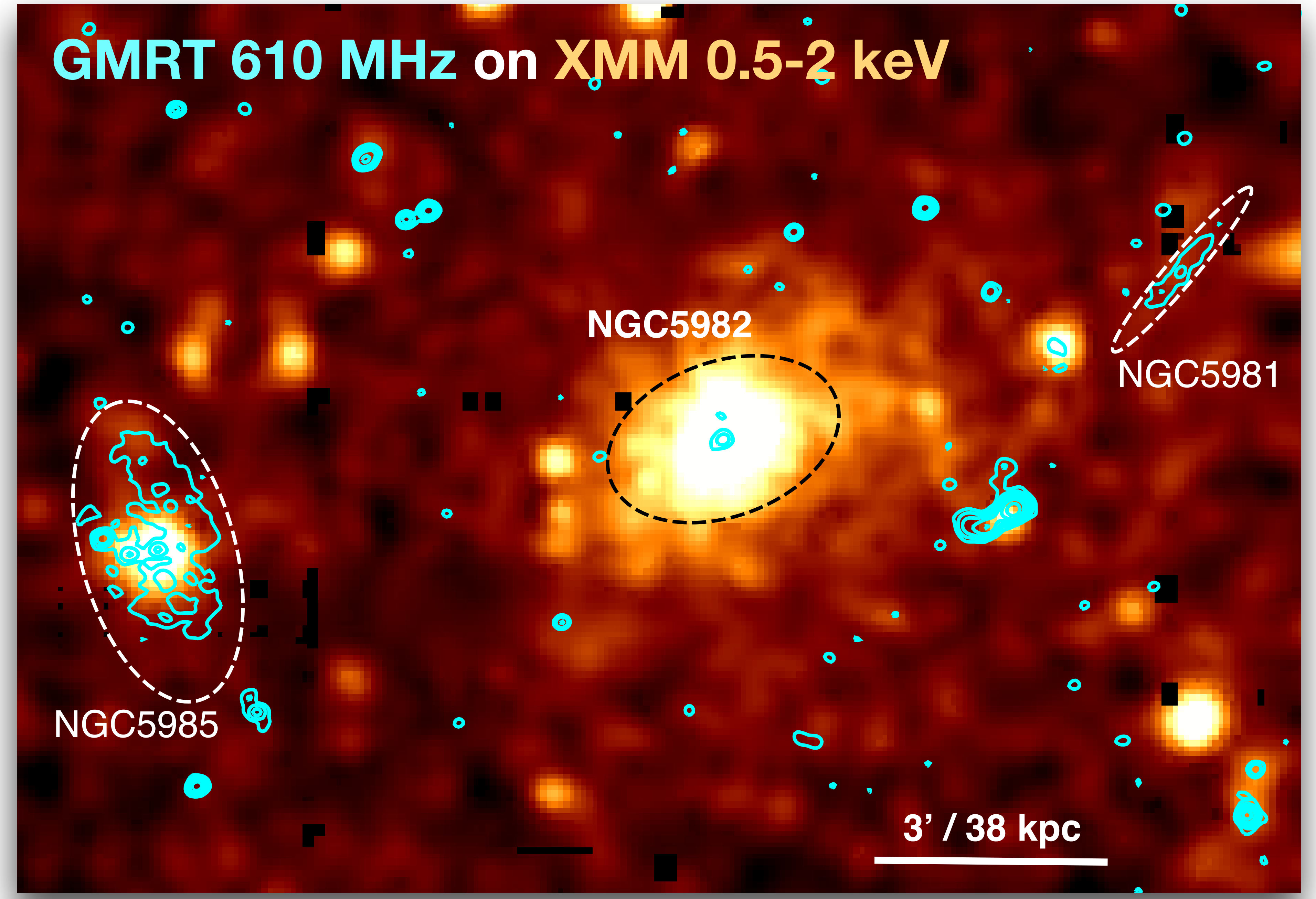
- ~50% (26) have group-scale halos (>65kpc, $L_X > 10^{41}$ erg/s)
- ~30% (16) have galaxy-scale halos ($L_X = 10^{40}$-10^{41} erg/s)
- ~20% have no detected diffuse X-ray emission

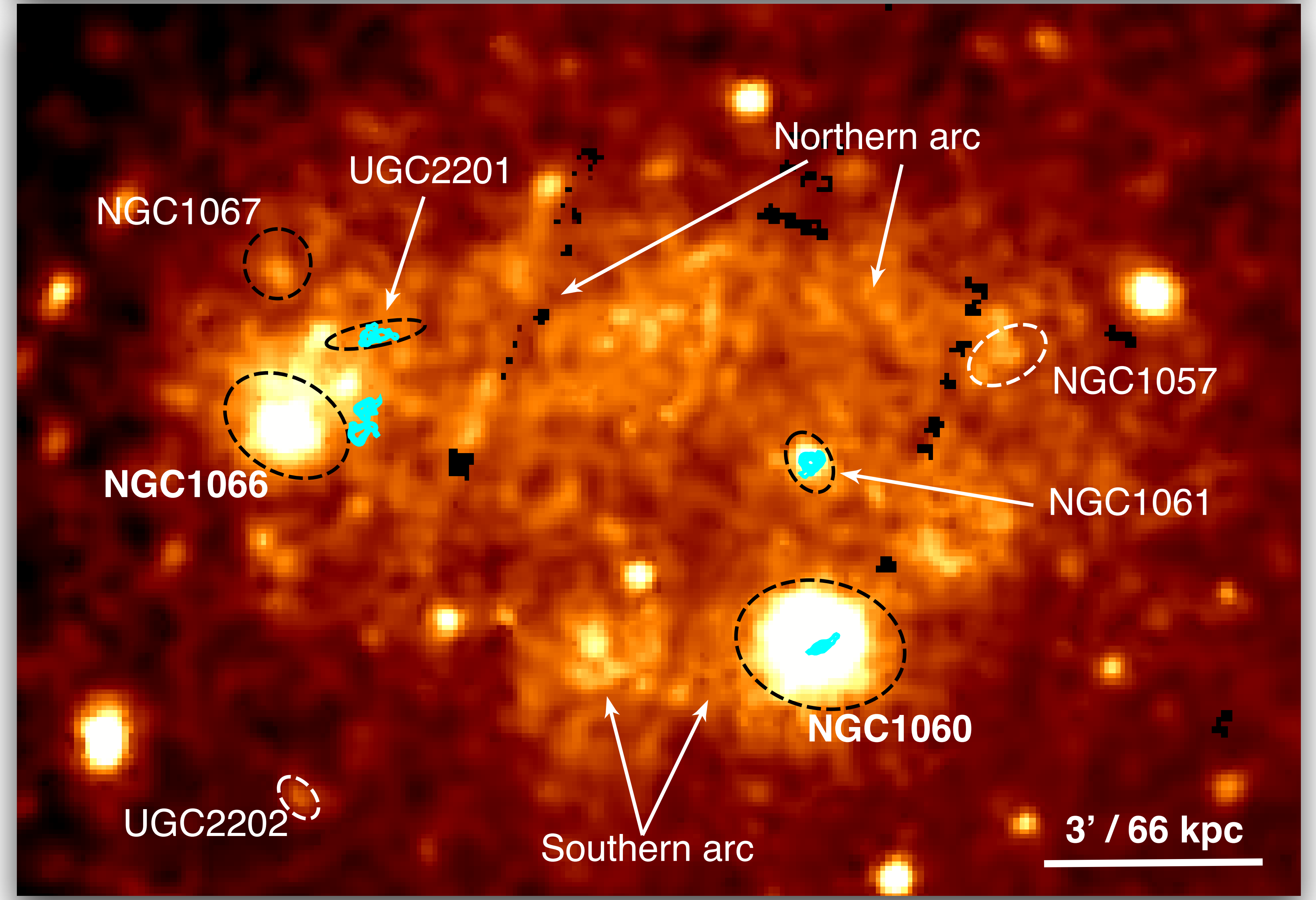
Temperature range: 0.4-1.5 keV

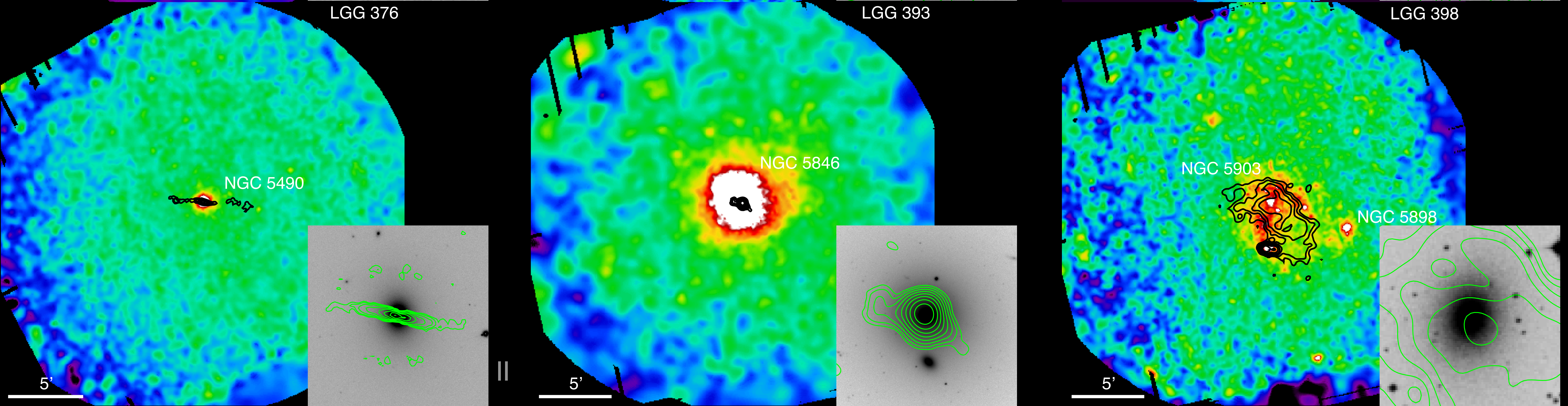
Mass range: $M_{500} = 0.5\text{-}5 \times 10^{13}\ M_\odot$

Of the group-scale halos:

- ~1/3 are dynamically active (mergers or sloshing)
- 12 of 26 not previously identified as X-ray bright groups of which 8 not detected by RASS
  ➜ >40% of nearby groups excluded from previous studies?
- 11 (42%) host radio jet sources
  [+3 more in X-ray faint systems]







Jet sources in X-ray bright groups

Jet scales 10-1000 kpc

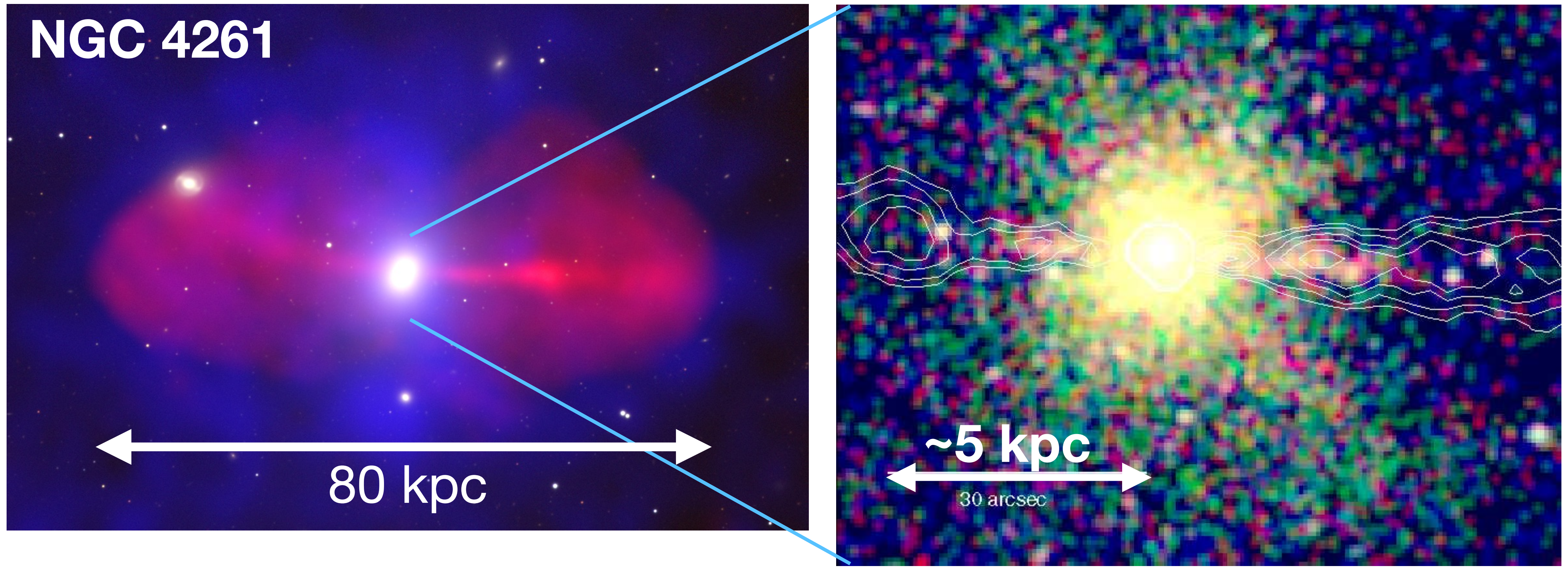
Sesto, Italy, June 2022

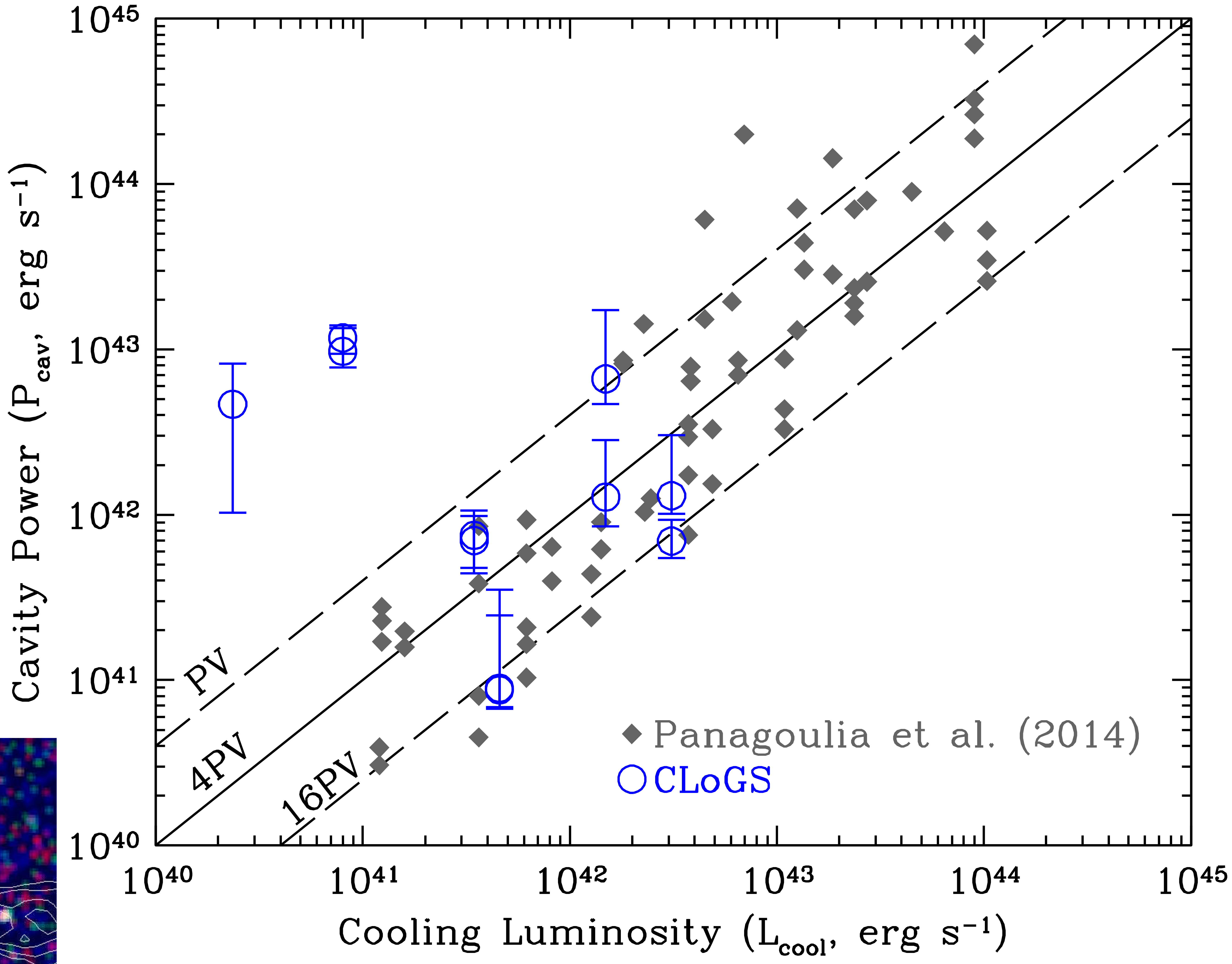
CLoGS: thermal balance

Smaller jet systems (≲50 kpc) in thermal balance

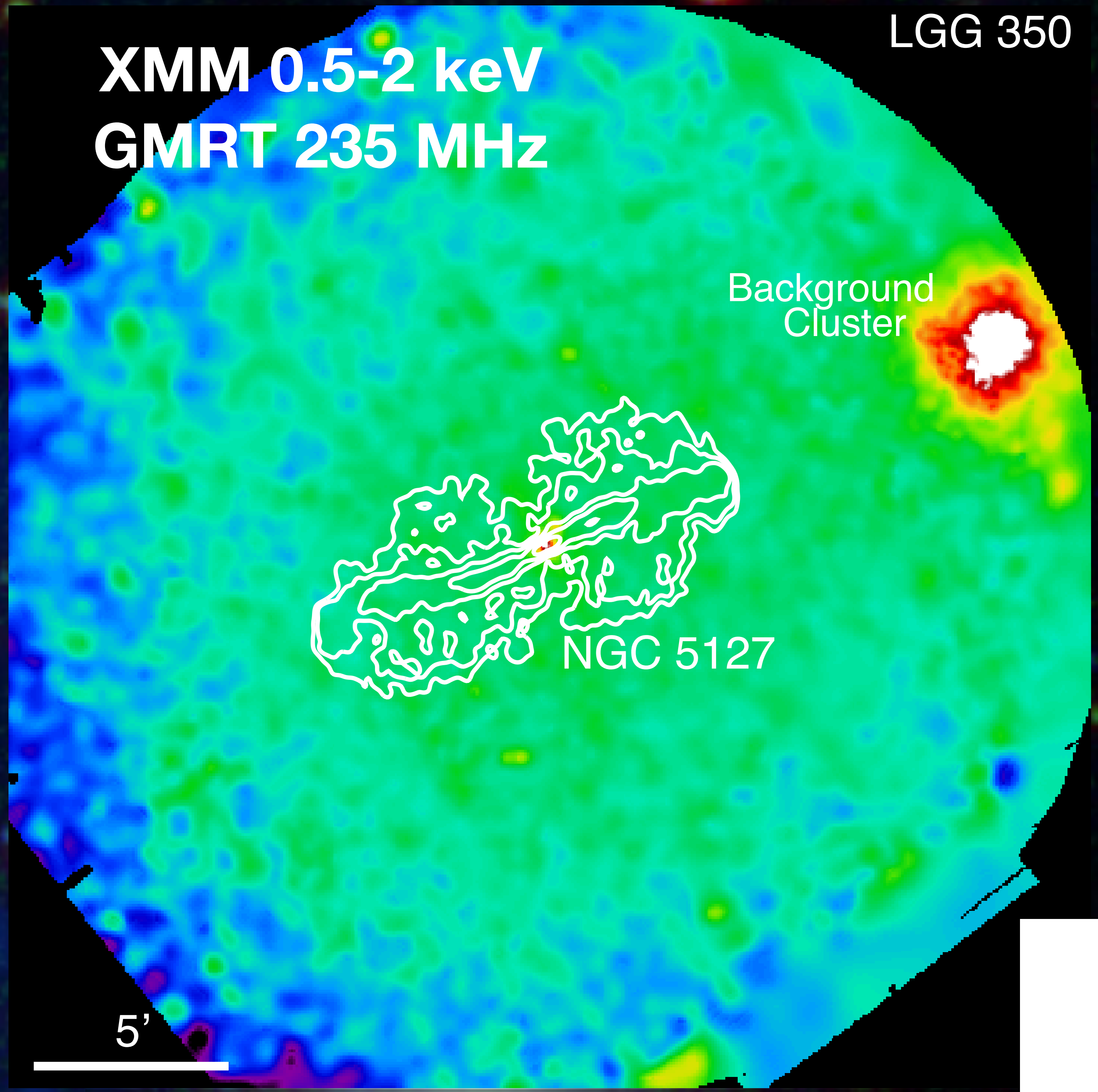
Larger jet systems over-powered relative to cooling

- $P_{cav} \geq 100x\ L_{cool}$
- But there are some problem cases…



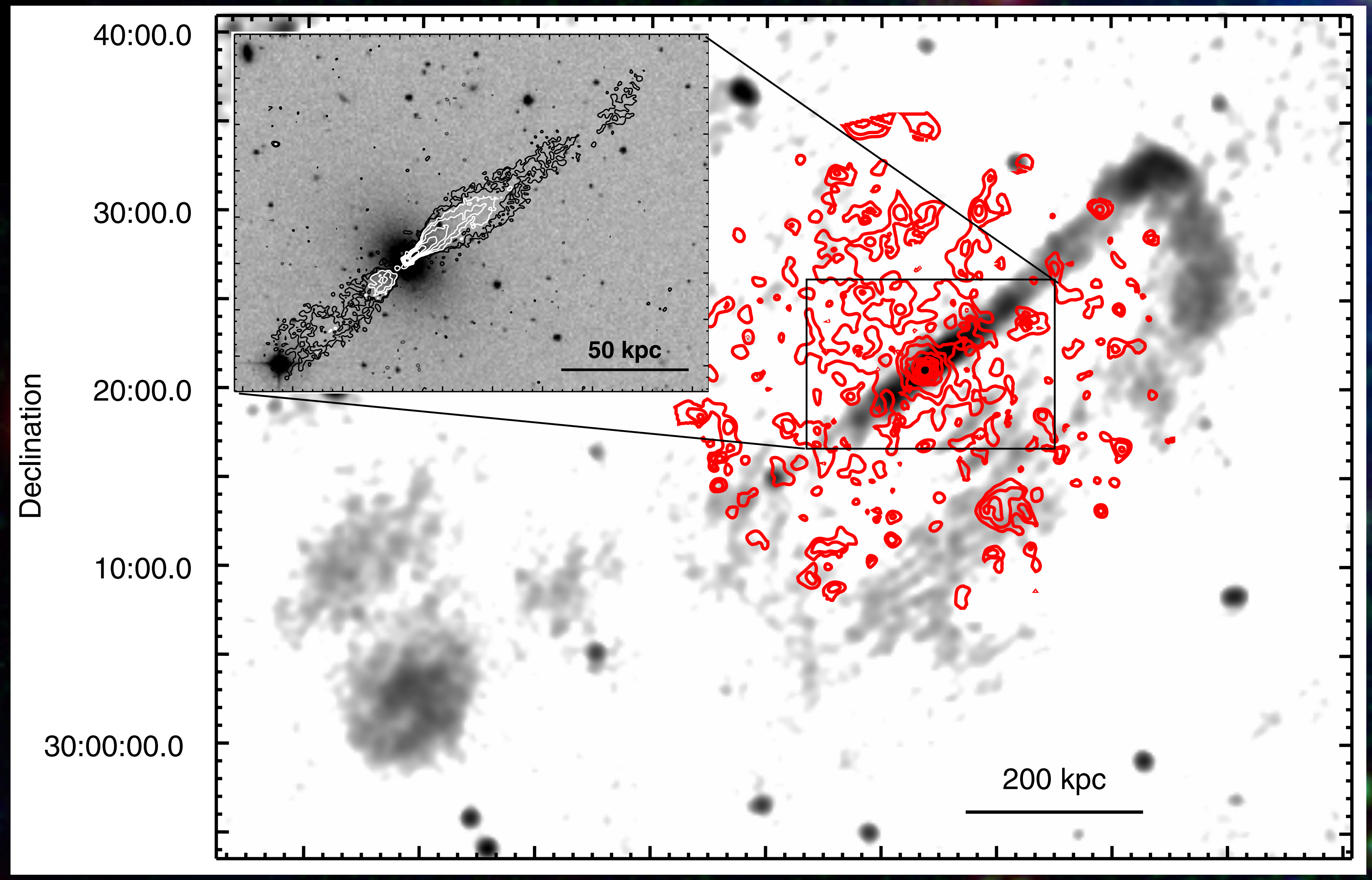


CLoGS: problem cases



NGC 5127
- ~80 kpc lobes/cavities
- Central T_{cool}~4.5 Gyr

NGC 315
- Lobe/plume 100s kpc outside cool core



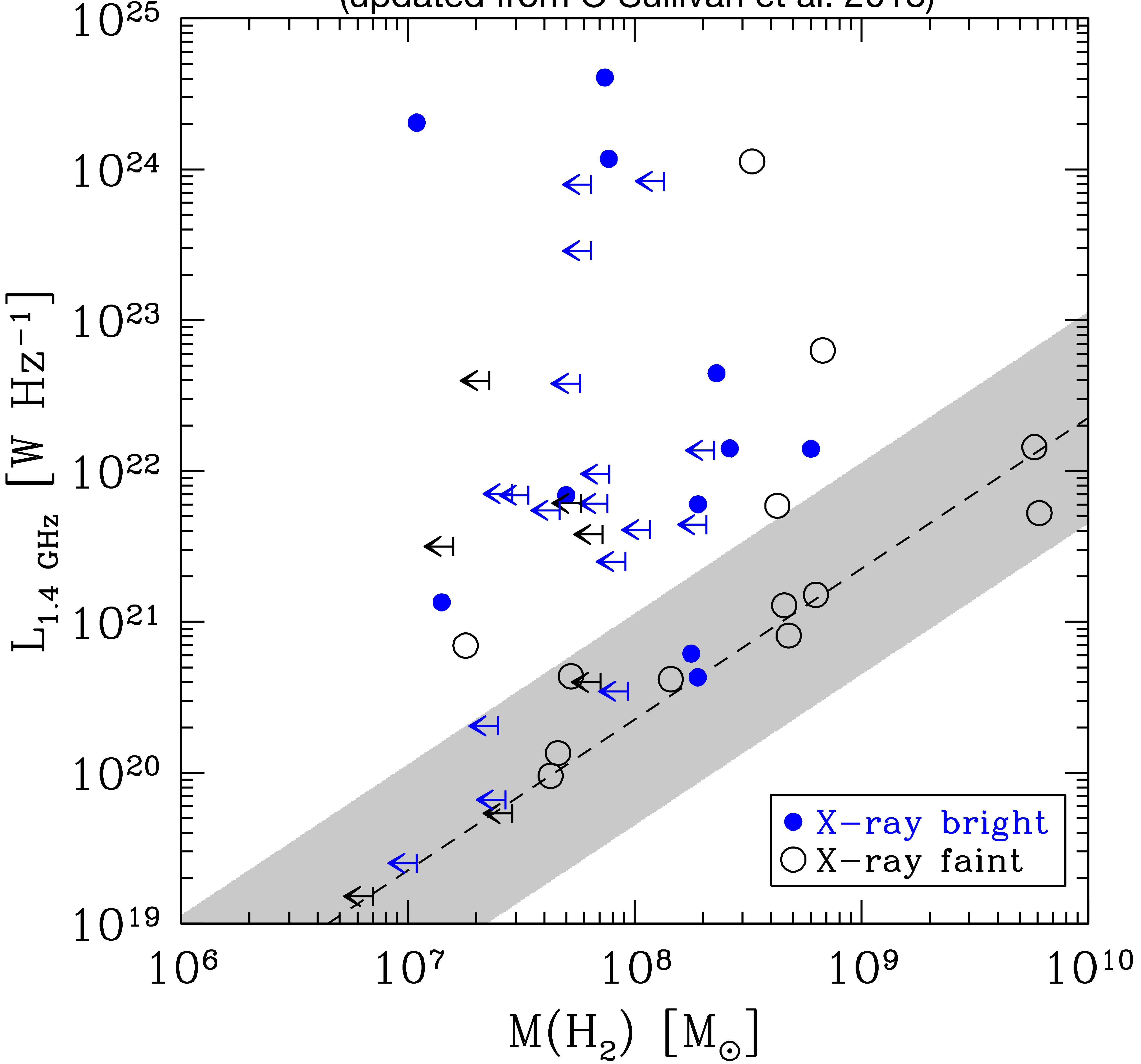
NGC 5903
- 75 kpc single radio lobe / cavity
- central T_{cool} ~4.5 Gyr
- 100 kpc tidal HI filament being accreted

~45% of group-central radio galaxies over-powered compared to L_X

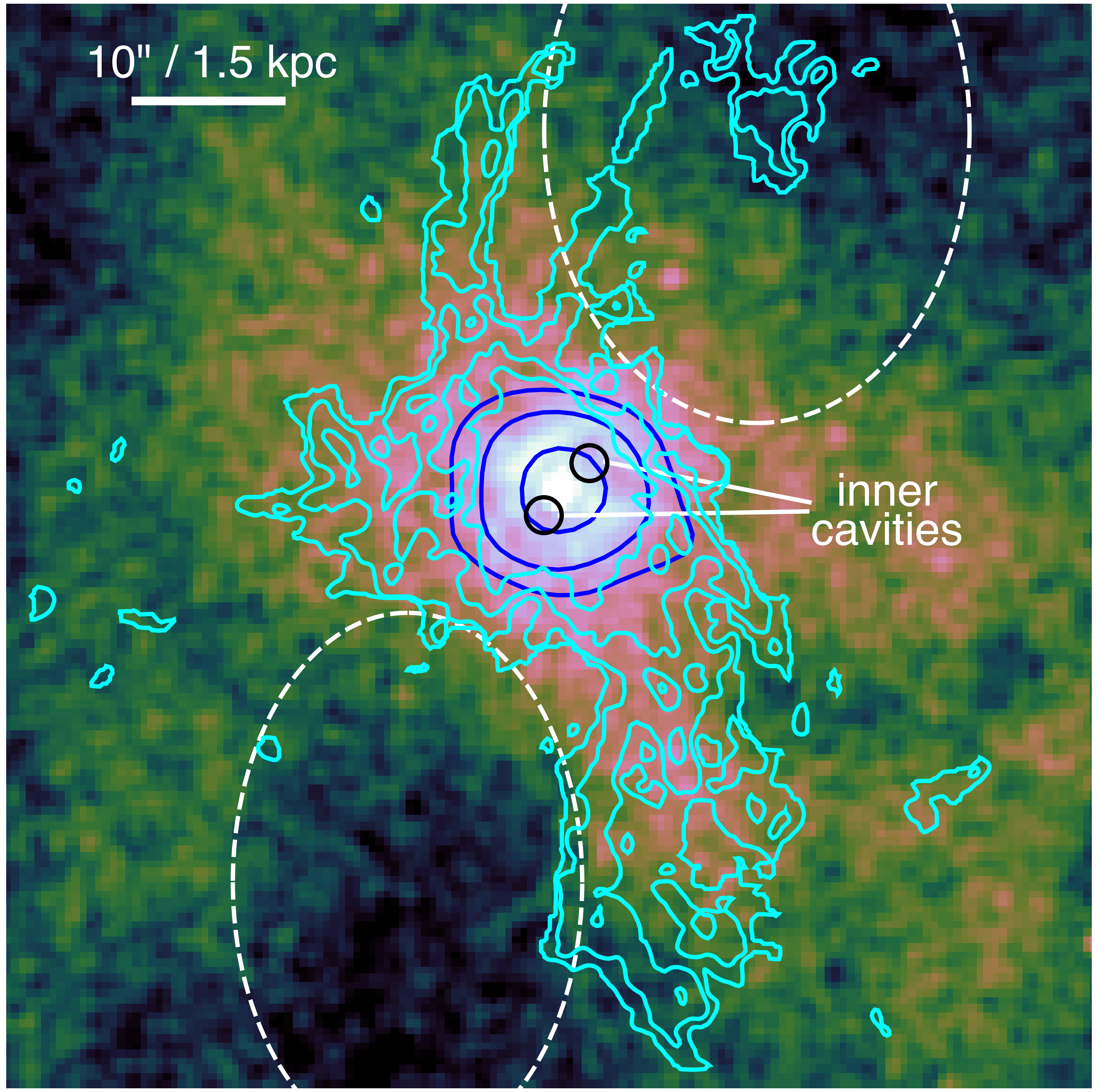
CLoGS: Cool gas

- CO detection fraction: 49±9%
  $M_{H2} = 10^7 - 6x10^9 M_{\odot}$
- compare with 22±3% for Atlas3D ellipticals (similar survey depth)
- HI detection fraction >50% (from literature)
  $M_{HI} = 5x10^6 - 3x10^{10} M_{\odot}$
- Large gas mass not required for AGN outburst
- Largest CO masses found mainly in X-ray faint groups ➜ difficult to explain as IGrM cooling

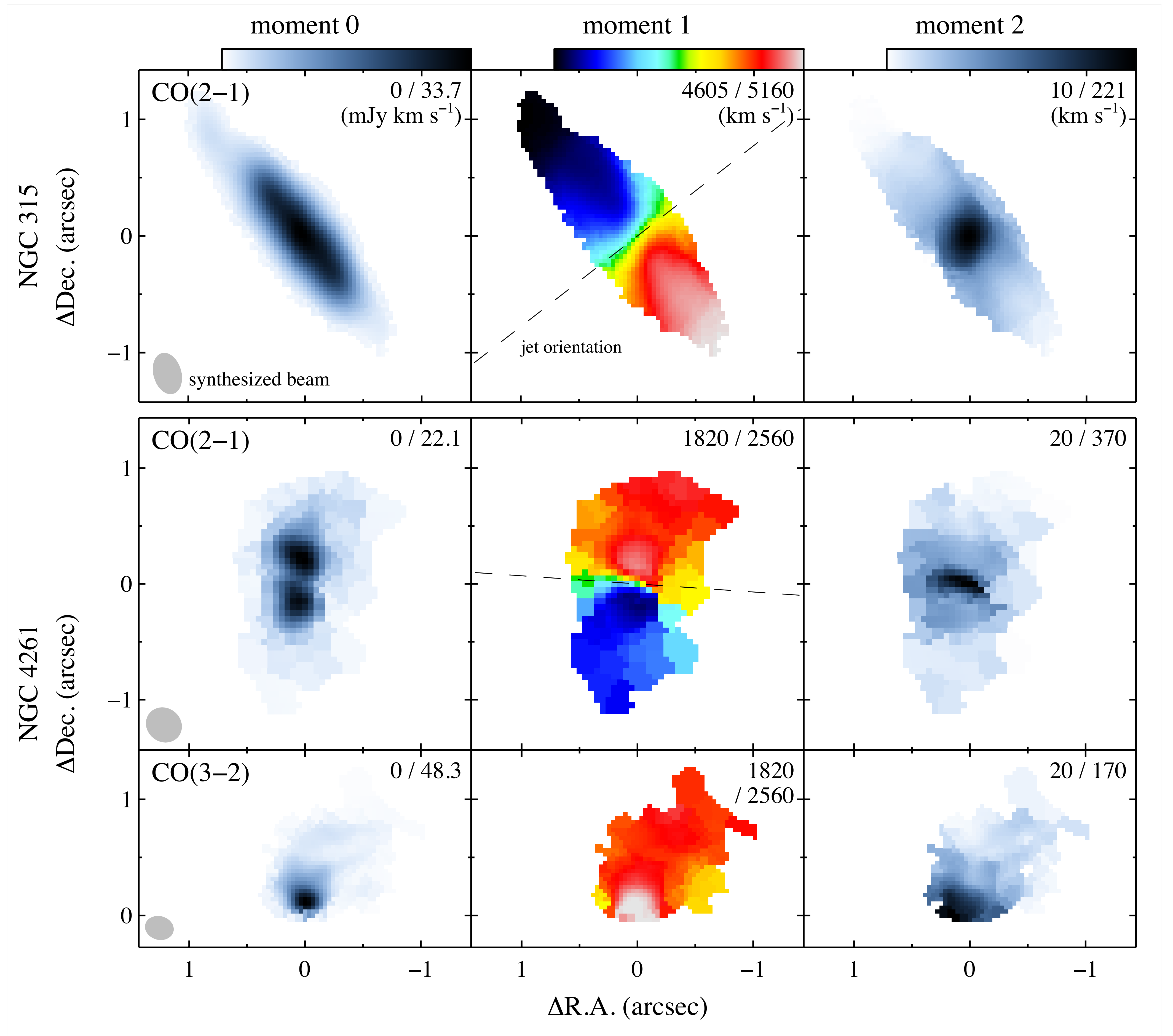
(updated from O'Sullivan et al. 2018)



Cold gas: filaments and disks



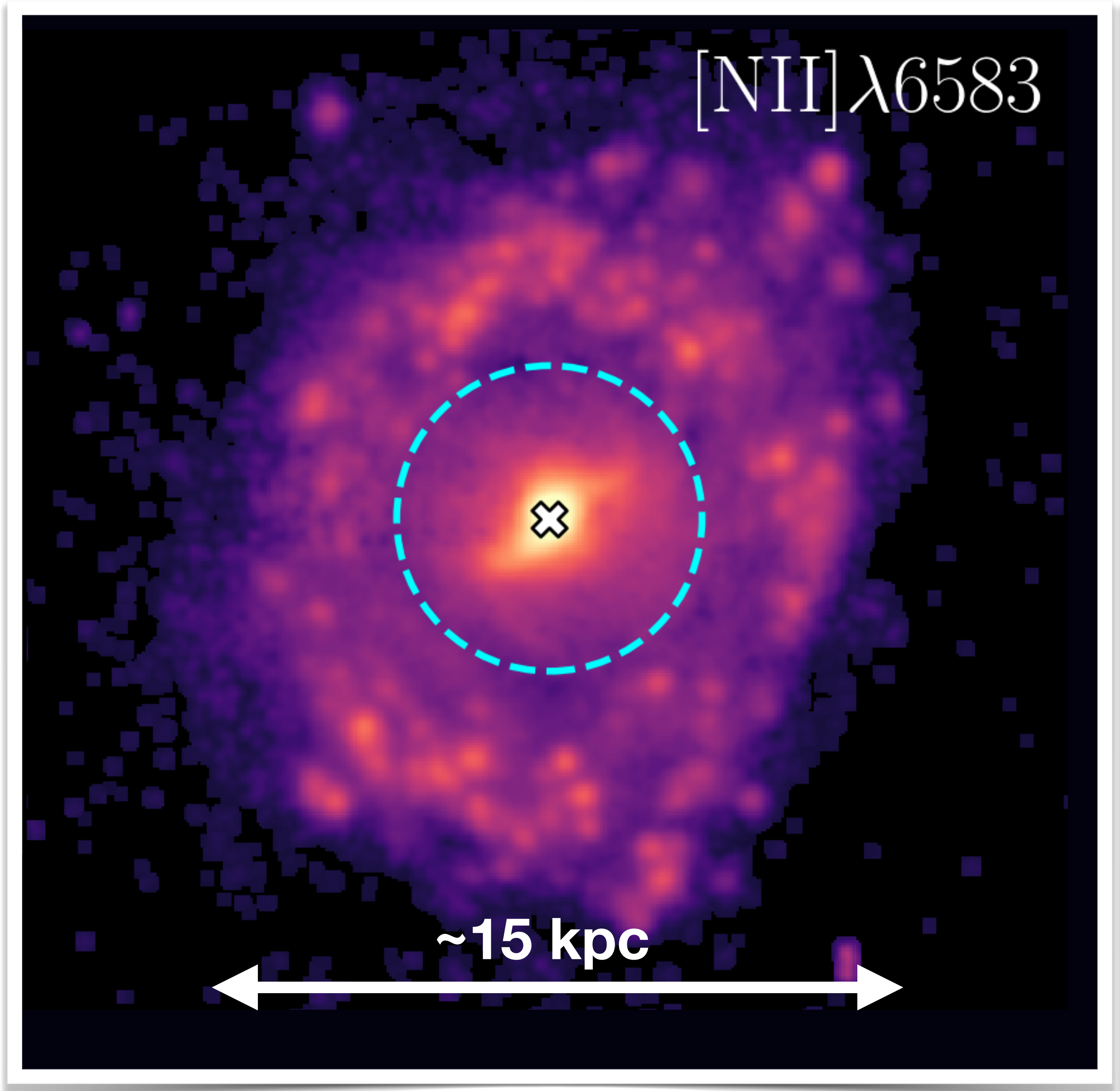
NGC 5044, Schellenberger et al. (2020)



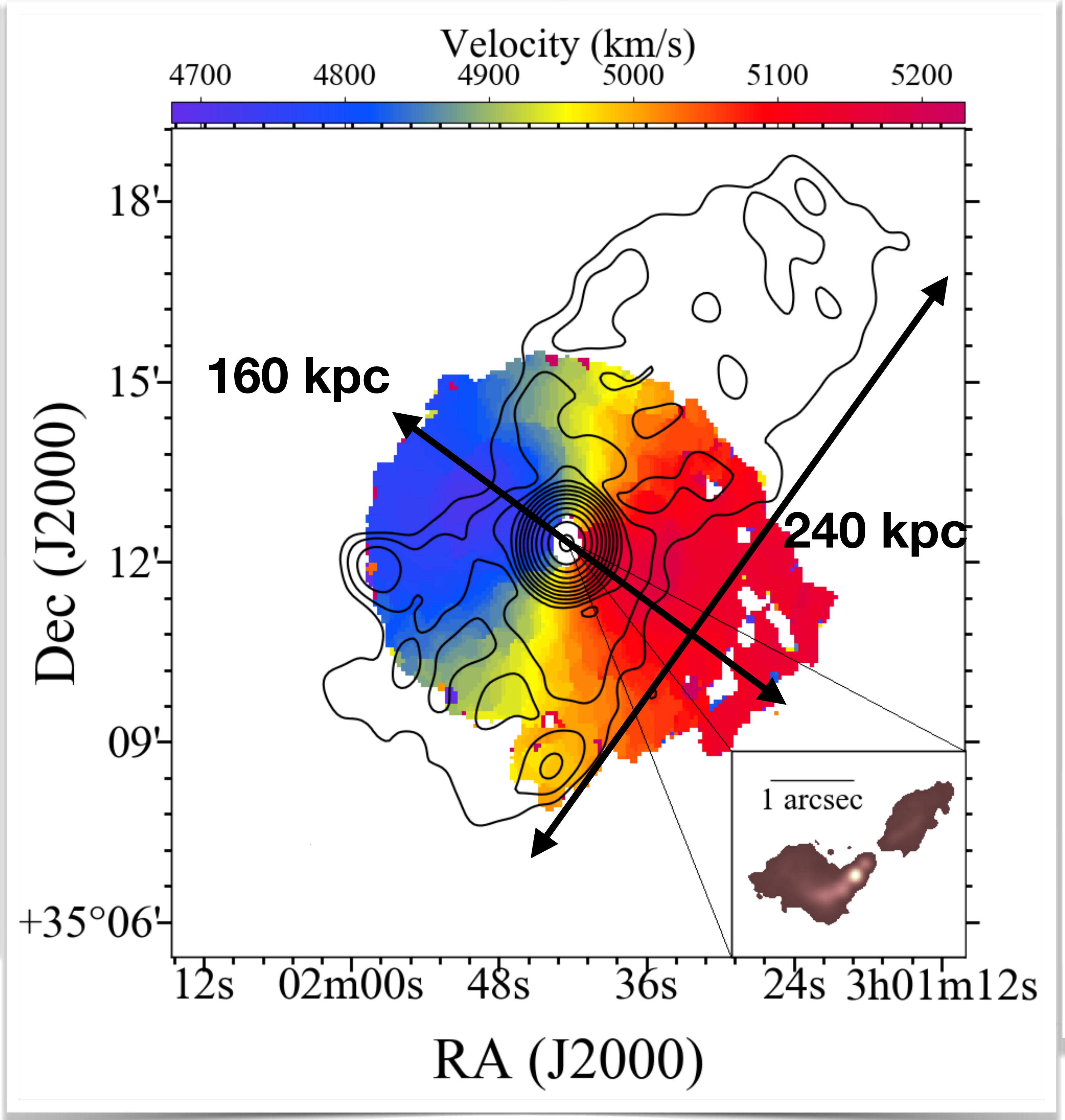
NGC 315 & NGC 4261, Boizelle et al. (2020)

- IGrM cooling: clumps, filaments, kpc-scale disks in X-ray bright systems (David et al. 2017, Temi et al. 2018, Schellenberger et al. 2020, Ruffa et al. 2019, Boizelle et al. 2020) consistent with Chaotic Cold Accretion (Olivares et al 2022)

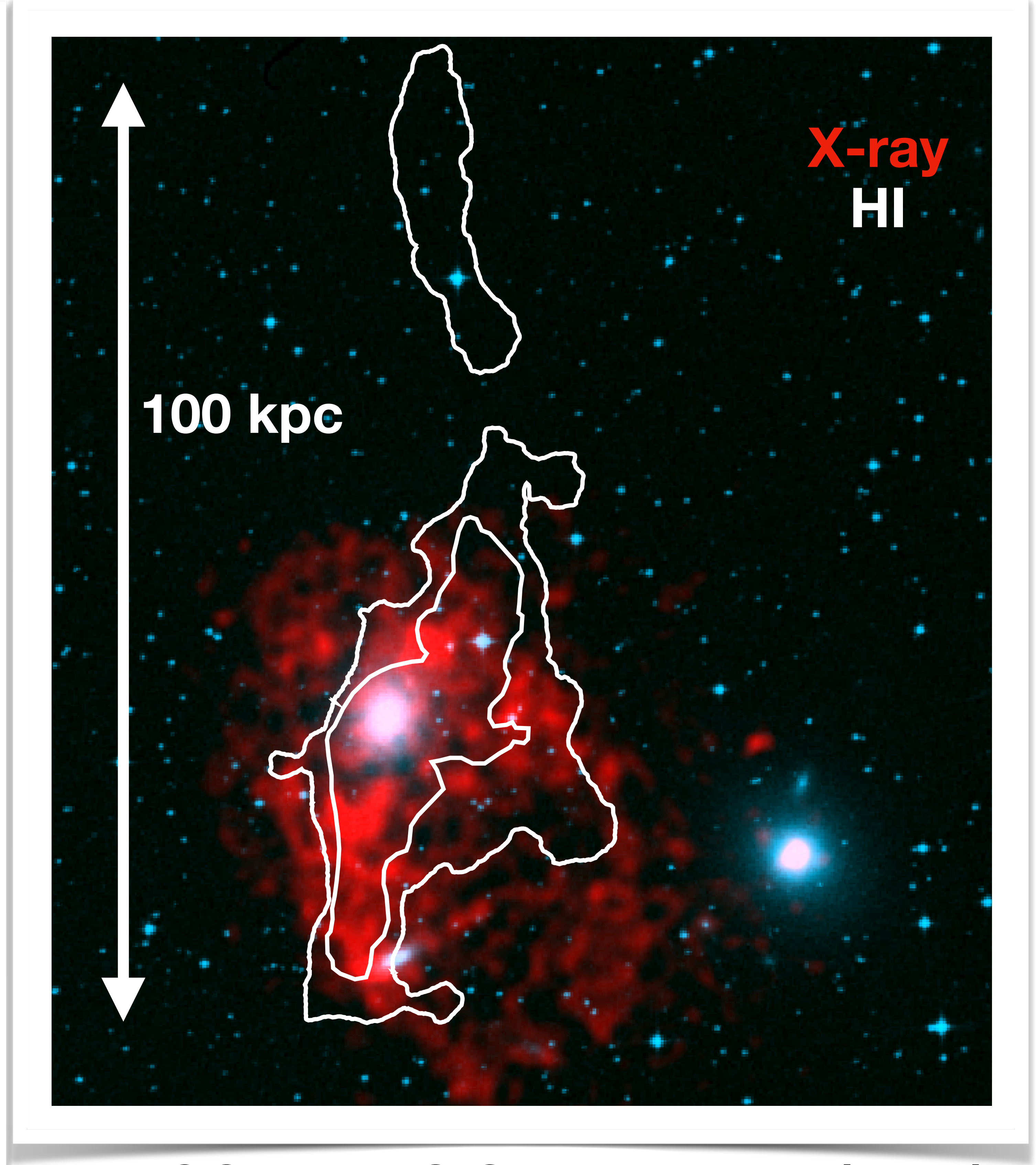
Cold gas: filaments and disks



ESO 507-25, Olivares et al. (2022)



NGC 1167, Murthy et al. (2019)



NGC 5903, O'Sullivan et al. (2018)

- Larger CO/HI/Hα disks/rings: found in X-ray faint systems with star forming, fast rotating BGGs, misaligned w.r.t. stellar component (Olivares et al. 2022, Kolokythas et al. 2022, Loubser et al. in prep.).
- Tidal gas structures seen in some X-ray bright and faint systems.

Summary

Based on CLoGS, an optically-selected, statistically complete sample of nearby groups, including several newly detected in X-rays:

- Recent / current jet activity observed in ~40% of X-ray bright groups.
  - ~45% of jets appear over-powered relative to cooling and in some cases are inflating lobes outside the cooling region.
- Cool gas (CO, HI) is detected in >50% of group-central galaxies.
  - BGGs of X-ray bright groups typically host filamentary nebulae and/or kpc-scale disks, consistent with gas cooling from the IGrM.
  - Greatest cold gas masses seen in BGGs of X-ray faint groups, typically in large-scale disks. These BGGs are often fast rotators, star-forming.
  - Galaxy interactions can be a significant source of cold gas for BGGs.

Complete Local-Volume Group Sample (CLoGS): Selection

485

Begin with Lyon Galaxy Group Sample (Garcia 1993)
all-sky, optically selected, cz<5500 km/s, D<80 Mpc

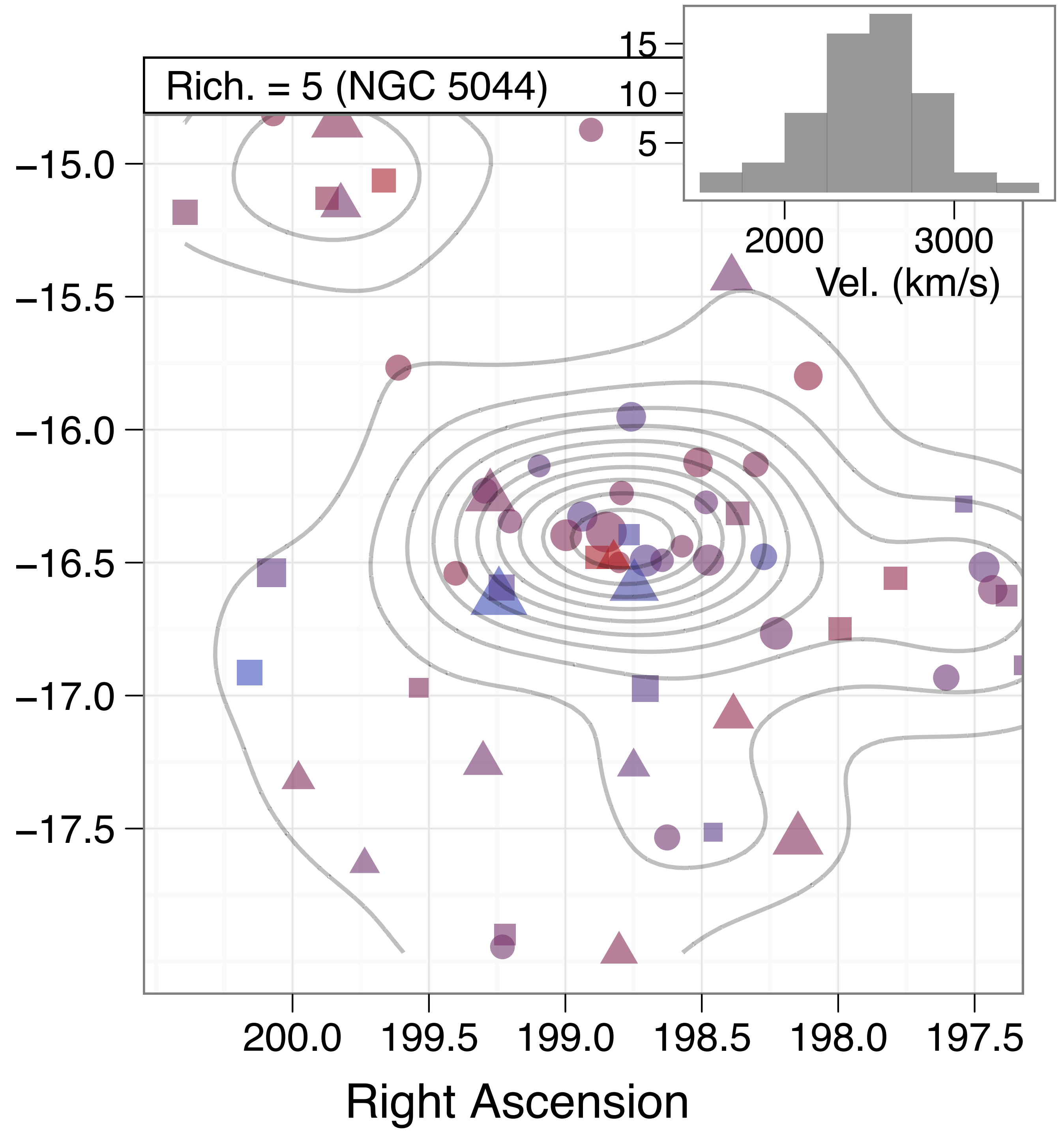
67

Select groups with:
- ≥4 members
- ≥1 early-type member with $L_B \geq 3\times10^{10}\ L_\odot$
- Declination > -30° ➜ *visible from VLA, GMRT*

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

53

Filter on Richness (*$R = N_{gal}$ with $LB \geq 1.6\times10^{10}\ L_\odot$*)
- Exclude known clusters: R≥10
- Exclude groups too small to characterize: R=1



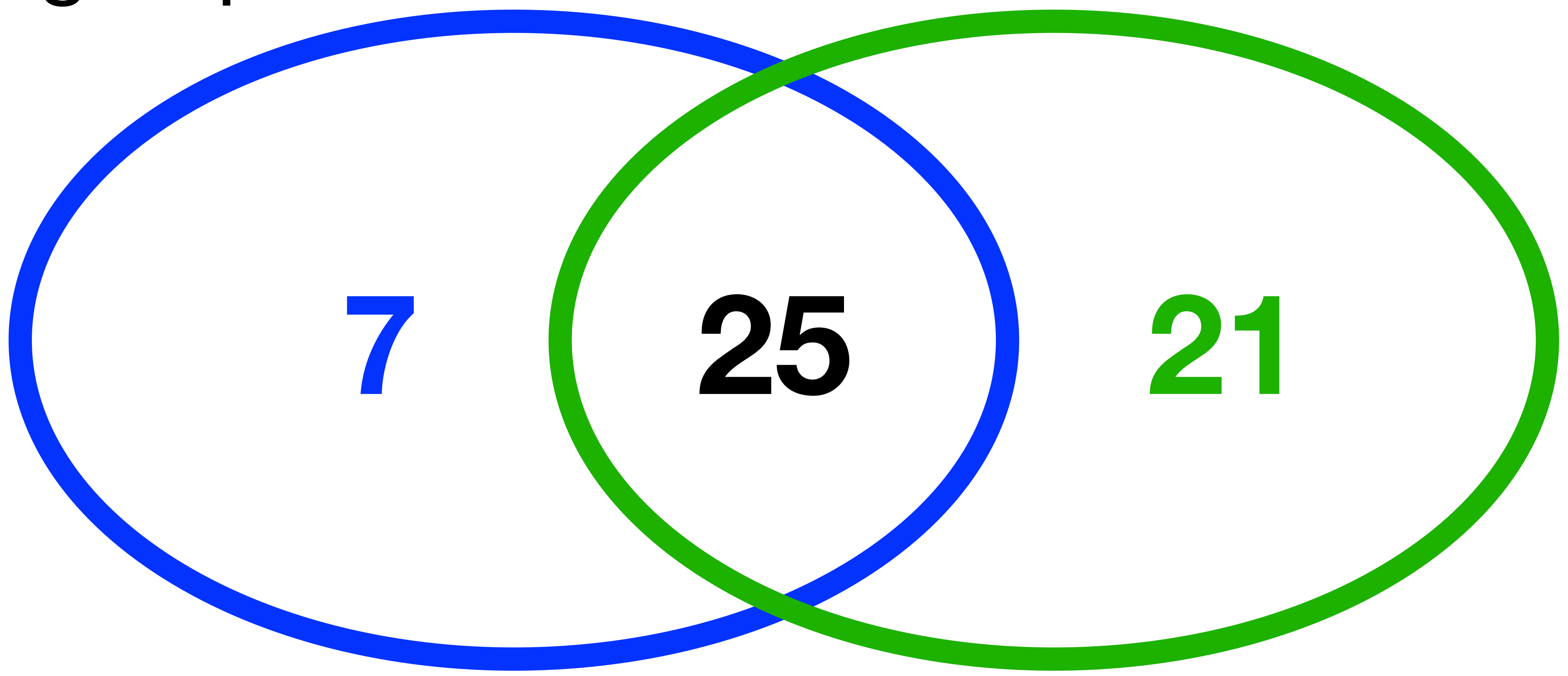
High-richness subsample:
R=4-8, 26 groups

Low richness subsample:
R=2-3, 27 groups

CLoGS: Observational data

- **X-ray:** (O'Sullivan et al. 2017)
  Chandra and/or XMM for all 53 groups

Chandra:
7 new observations (~360ks)
25 archive observations



XMM:
27 new observations (~800ks)
19 archive observations

- **Radio:** (Kolokythas et al. 2018, 2019)
  GMRT 610 & 235 MHz for all groups (~4 hrs/target, rms ~0.1mJy/bm @610 MHz, ~0.6mJy/bm @ 235 MHz)

- **CO:** (O'Sullivan et al. 2015, 2018)
  IRAM 30m or APEX for all dominant galaxies (1-2 hrs/target, detecting $M_{H2} = 10^7 - 6x10^9 M_\odot$)

- **Hα:** (Olivares et al. 2022)
  MUSE IFU for 18 dominant galaxies in high-richness groups (1 hr/target, 1.5" seeing)

- + long-slit spectra, wide-field optical imaging, etc.