Cooling and AGN Feedback in Galaxy Groups

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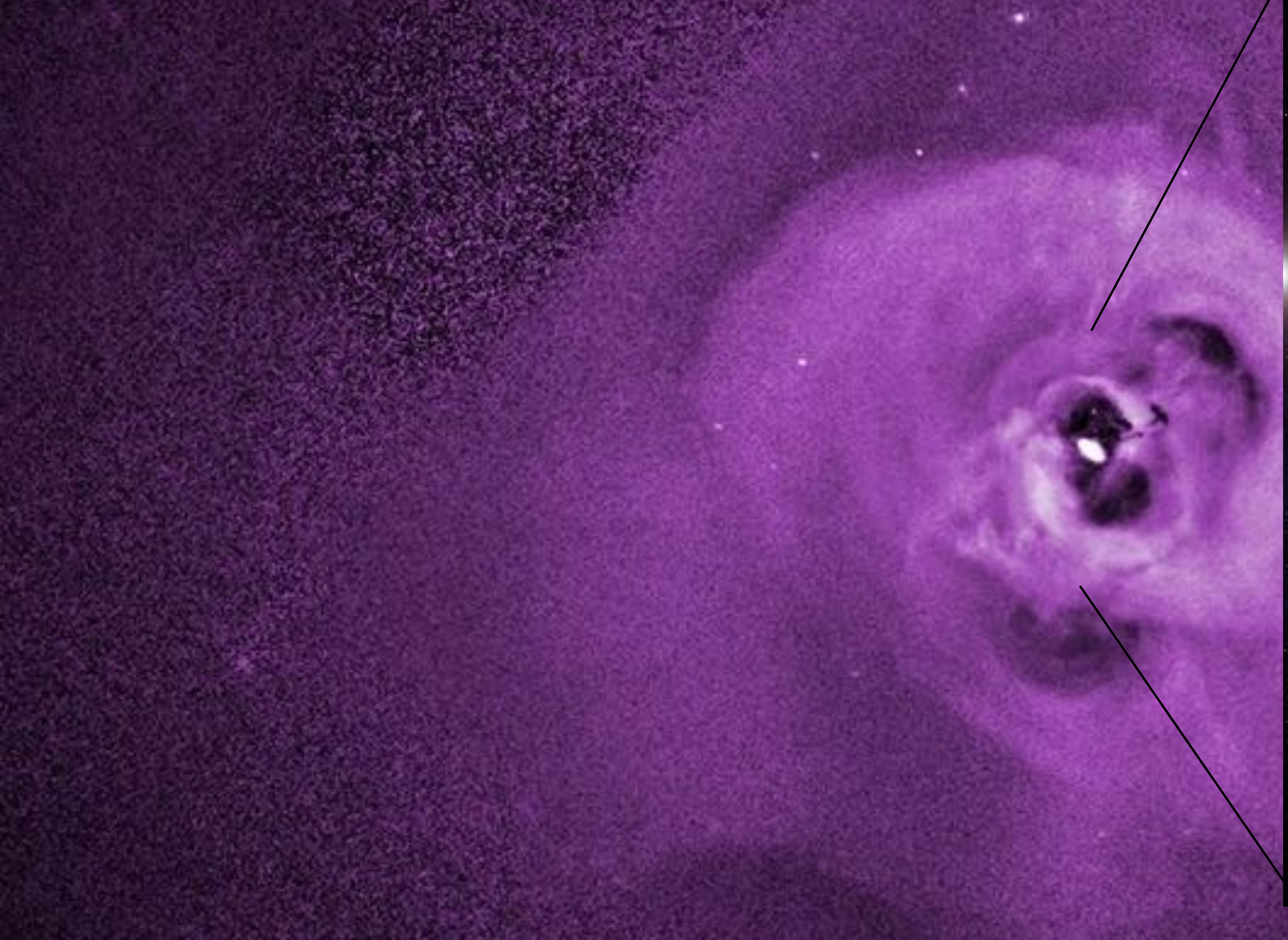
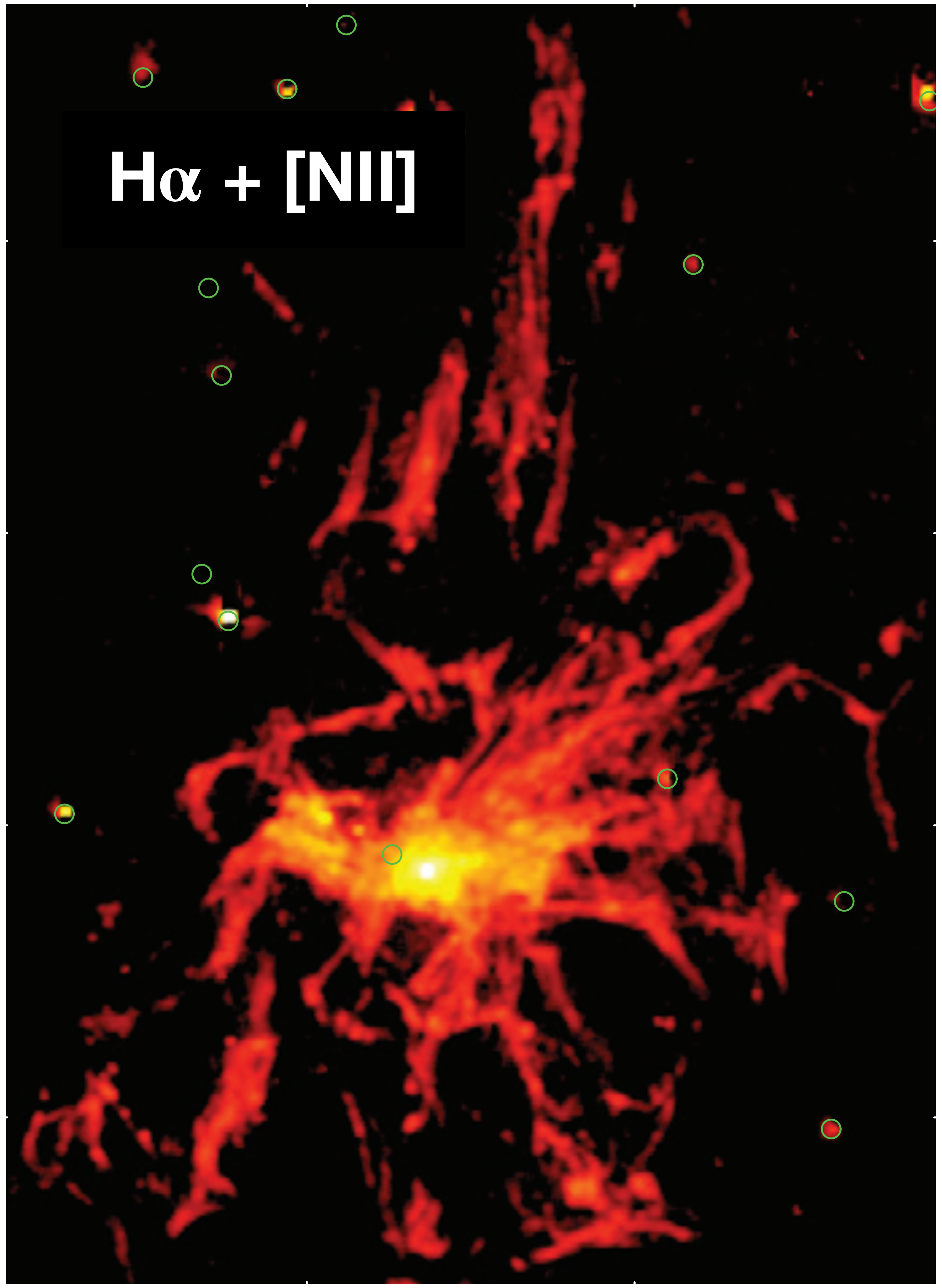
AGN Feedback: The Perseus cluster



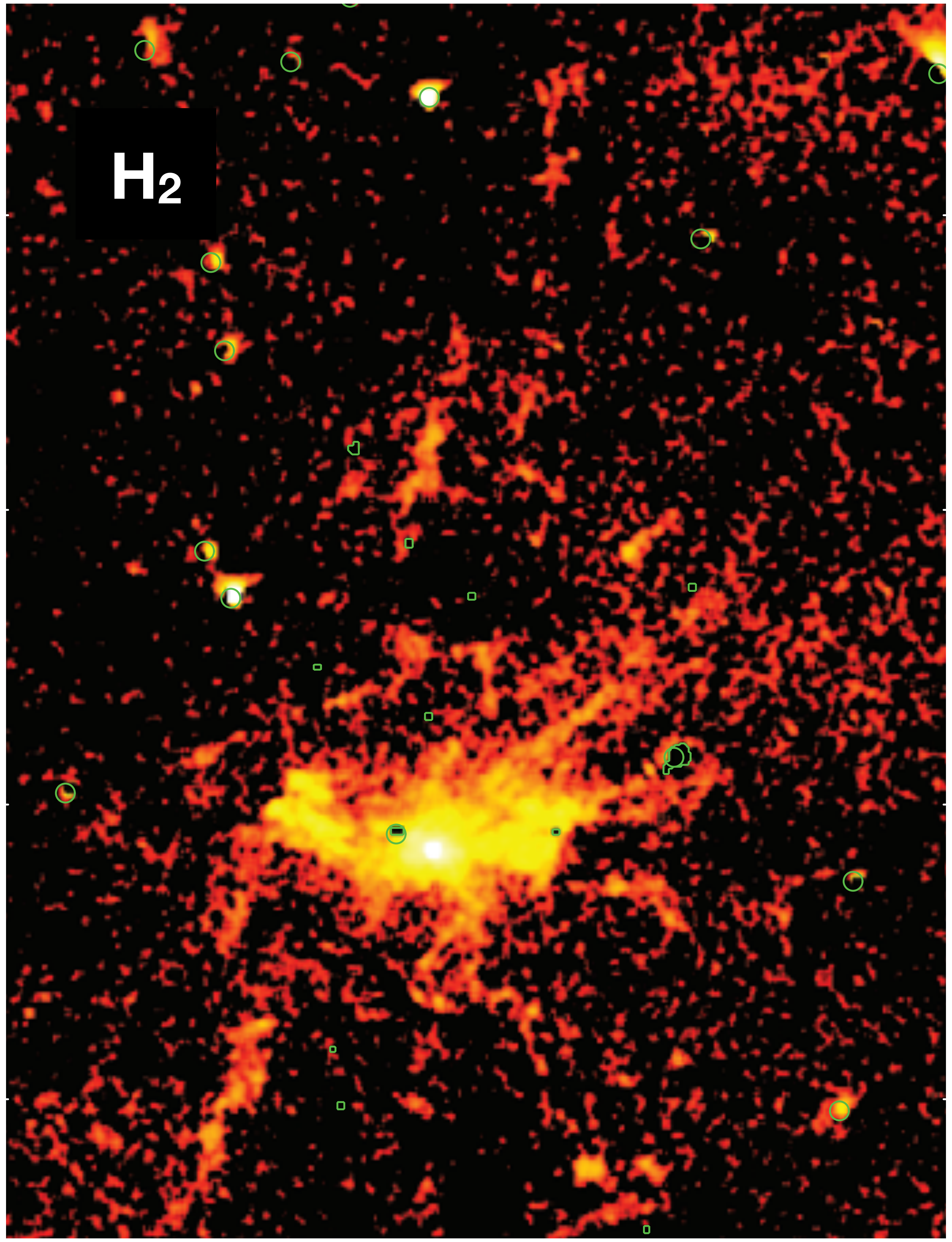
NASA/CXC/Stanford/I. Zhuravleva et al.

NASA/CXC/IoA/A.Fabian et al.; NRAO/VLA/G. Taylor; NASA/ESA/Hubble Heritage (STScI/AURA)

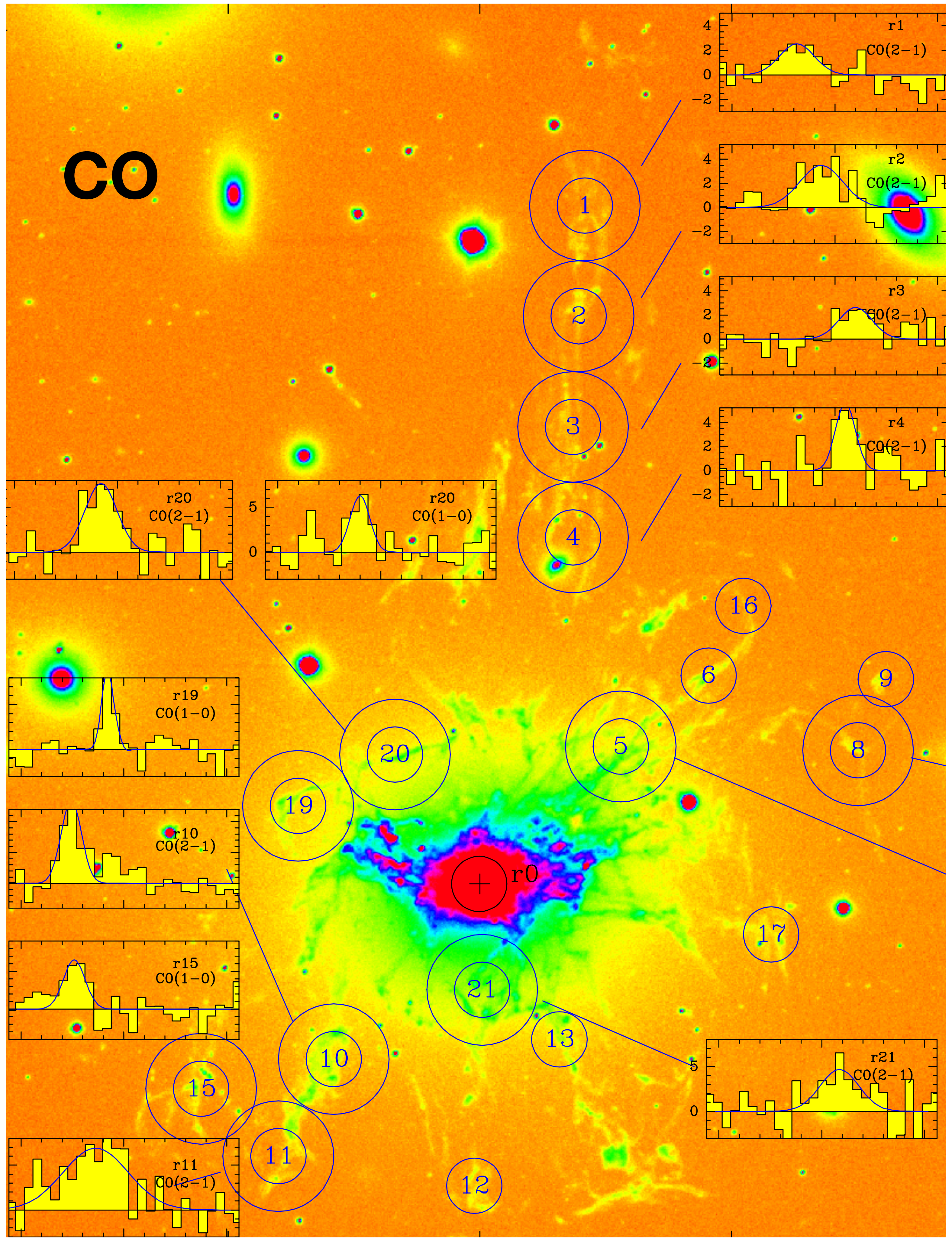
Perseus: Cooling gas



Conselice et al. (2001)



Lim et al. (2010)

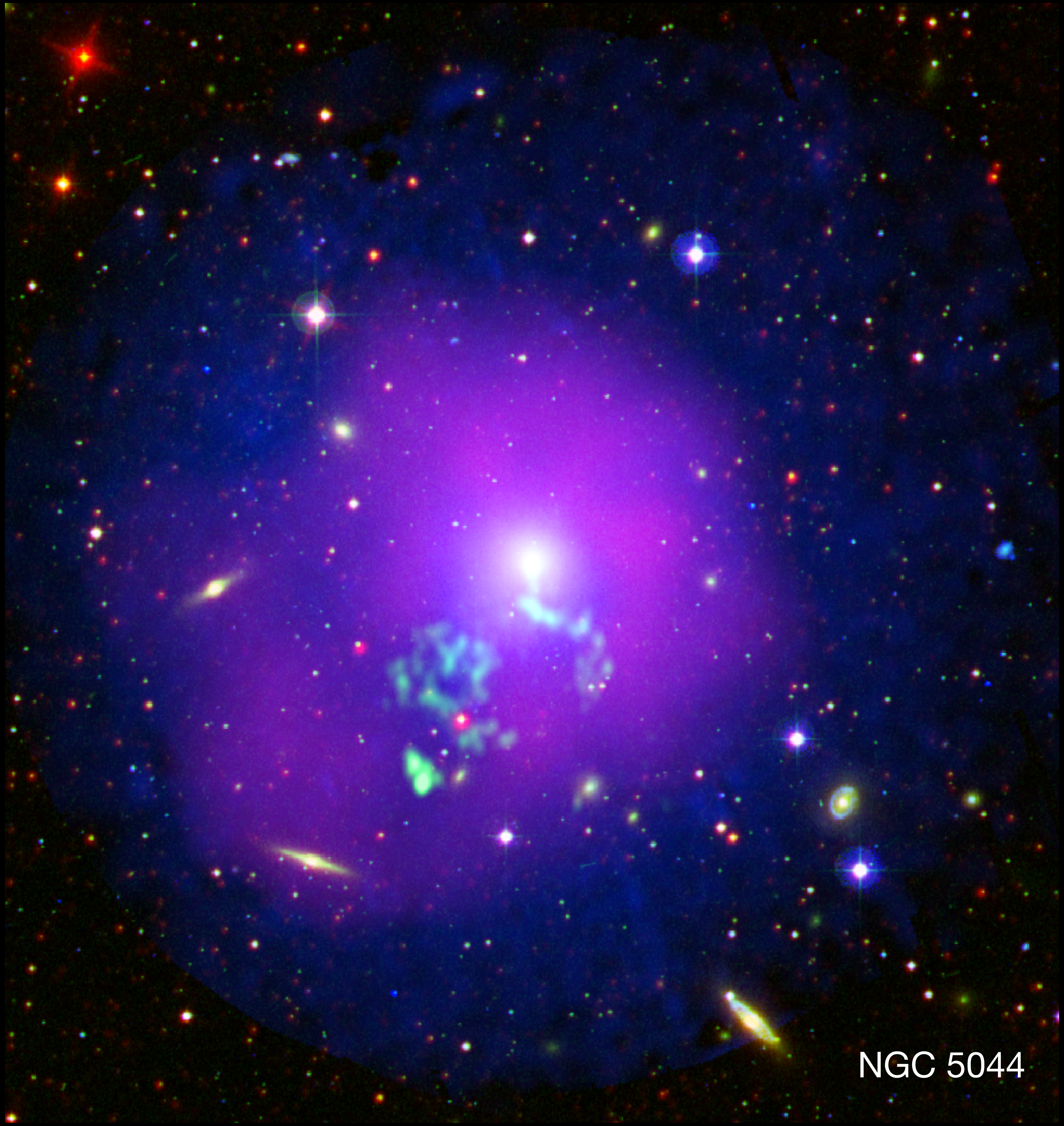


Salomé et al (2011)

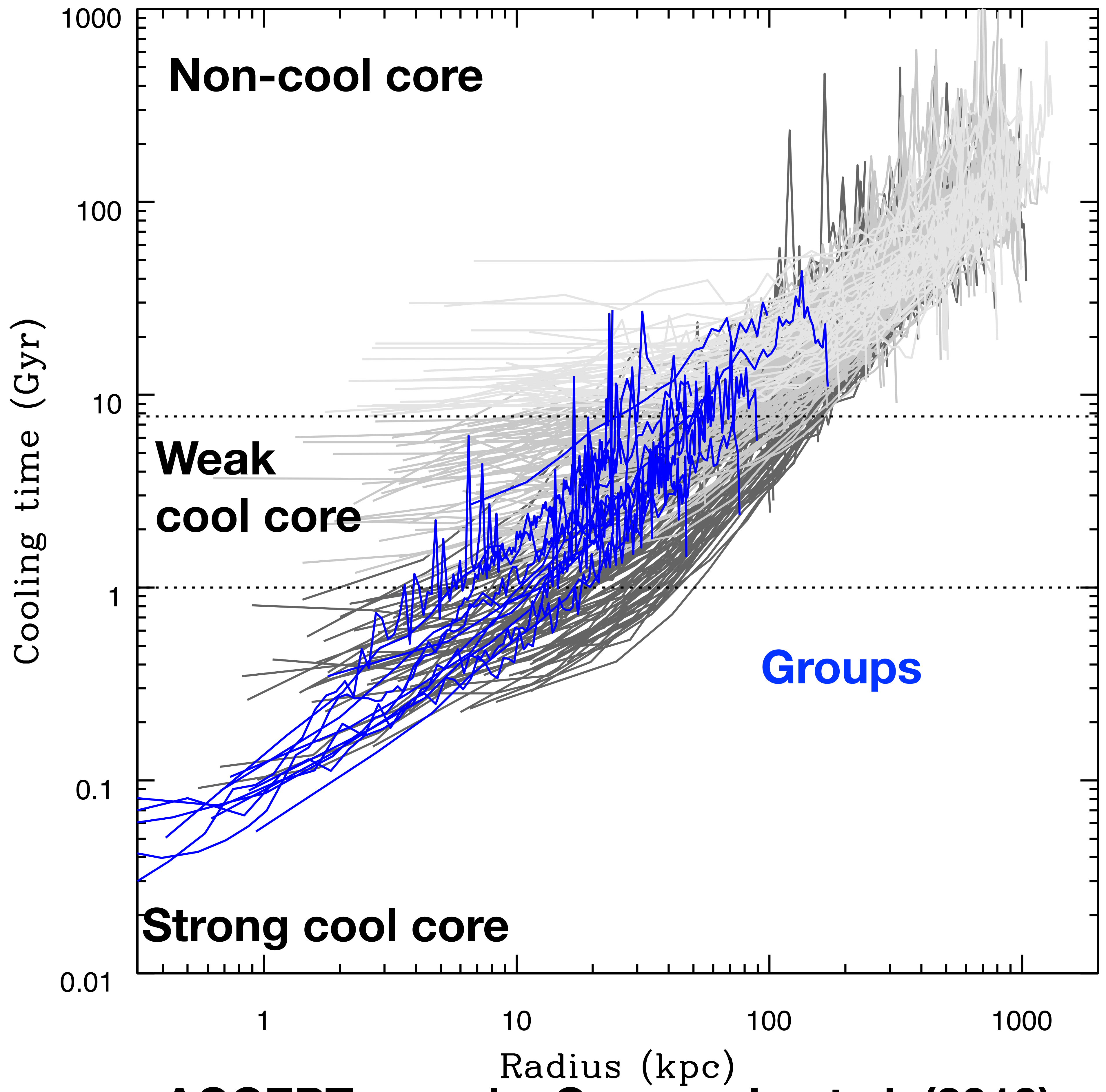
Filamentary nebula of gas with temperatures 10-10^5 K, but relatively little star formation

Why study feedback in groups?

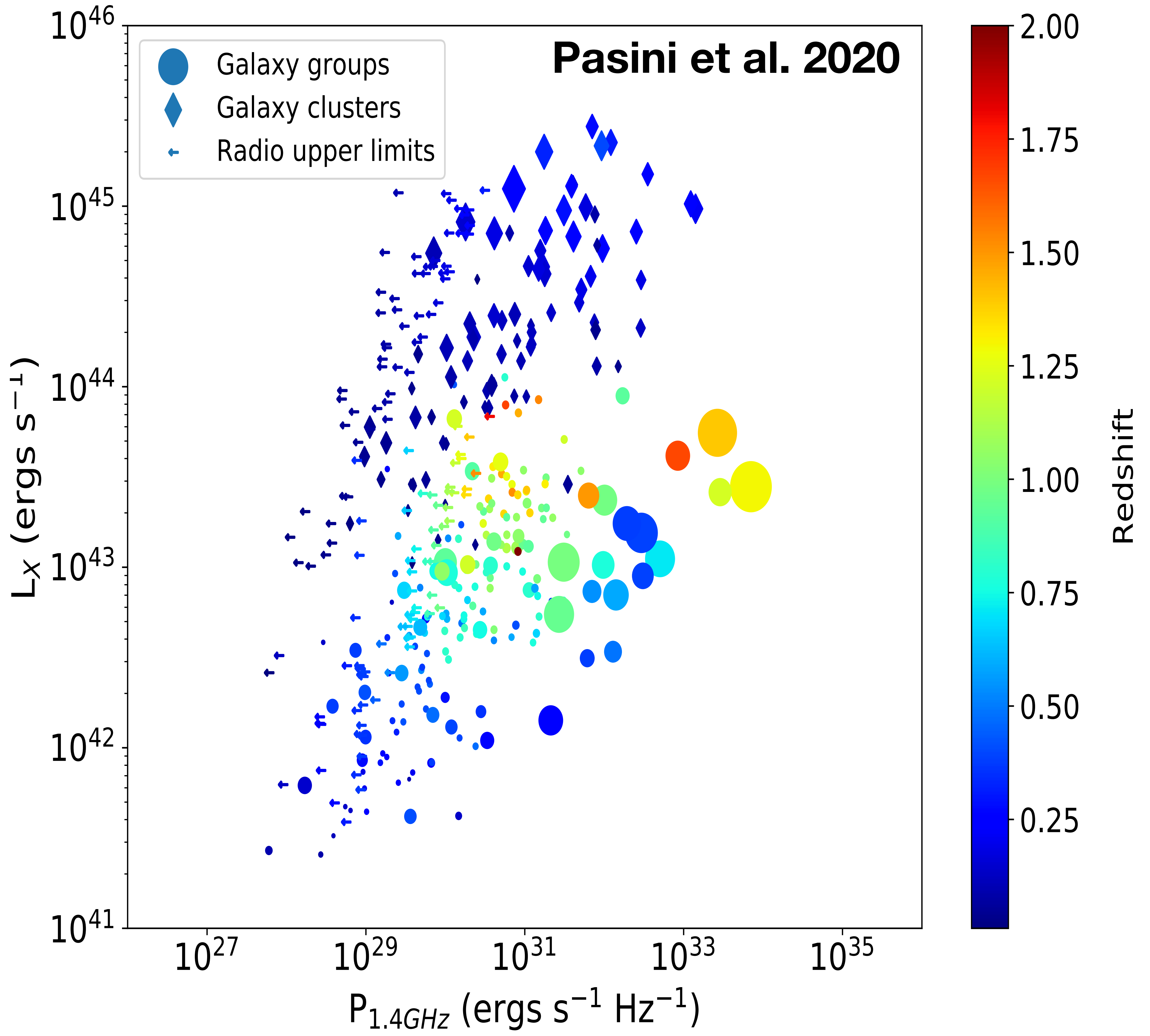
- Selection problems:
    - RASS biased toward X-ray bright, centrally-concentrated groups (Eckert et al. 2011).
    - Optical selection becomes unreliable for small numbers of members (e.g., Pearson et al. 2015)
- Most galaxies are located in groups
- Environment drives interesting physics: galaxy interactions, gas stripping/heating
- Groups are not simply scaled-down clusters



Cooling and feedback: clusters vs groups



ACCEPT sample, Cavagnolo et al. (2010)



X-ray line emission means groups cool more rapidly than clusters
➜ most groups are strong CC, no NCC groups?

AGN must be less efficient in groups than clusters if they are not to eject the IGrM (Best et al. 2007, Giodini et al. 2010) but large, powerful group-central radio galaxies are common (Pasini et al. 2020)

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 $L_B \geq 3\text{x}10^{10}\ L_{\odot}$
- 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 $M_{H2} = 10^7 - 6\text{x}10^9\ M_{\odot}$

Hα: MUSE IFU for 18 dominant galaxies (Olivares et al. 2022, Lagos et al. 2022, Loubser et al. 2022)
1 hr/target, 1.5" seeing. +20 more targets accepted in July 2022.

CLoGS: X-ray & radio results

Detection fraction

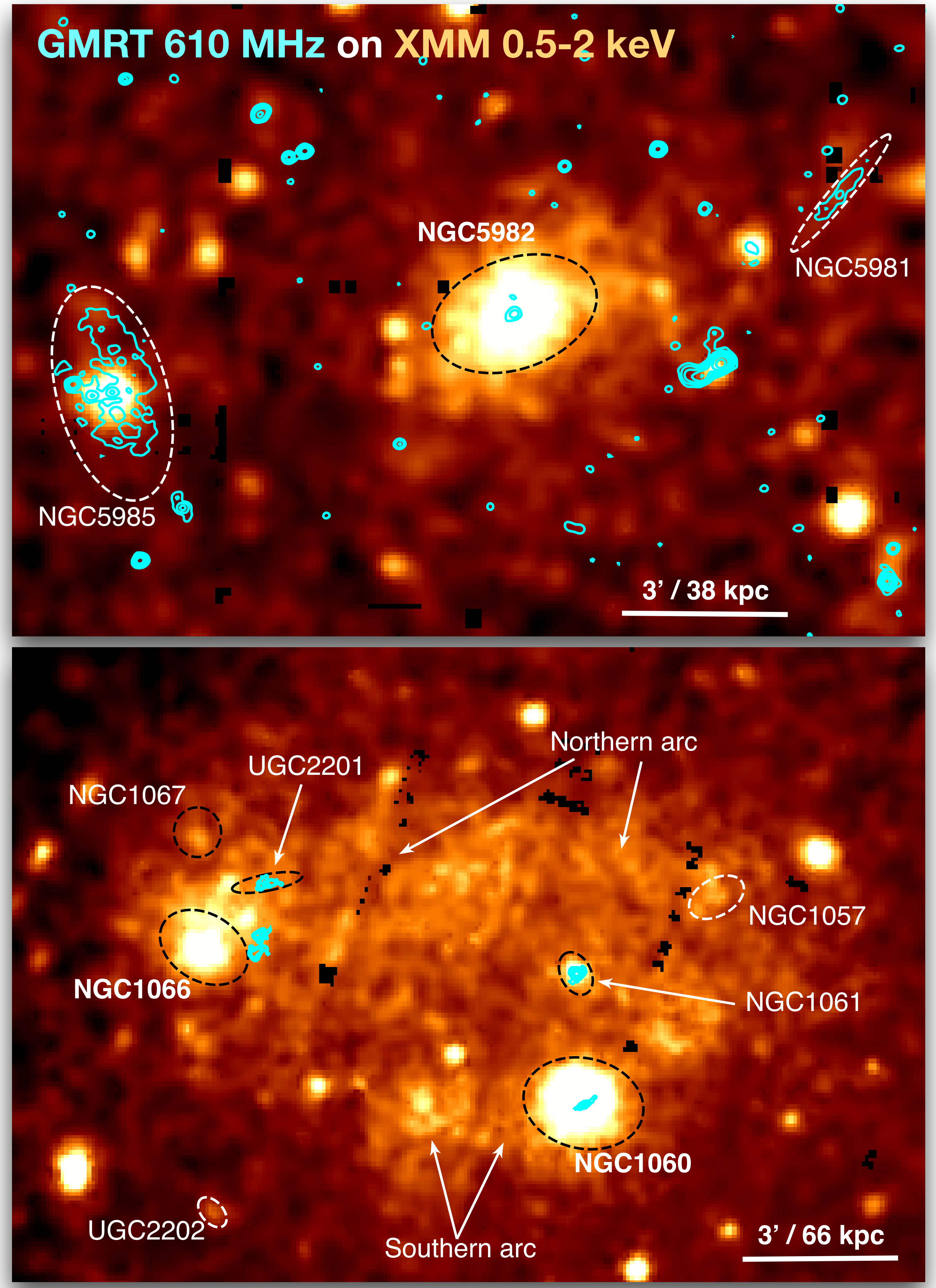
- ~50% (26) have group-scale halos (>65kpc, $L_X > 10^{41}$ erg/s)
- ~30% (16) have galaxy-scale halos ($L_X = 10^{40}$-10^{41} erg/s)
- ~20% have no detected diffuse X-ray emission

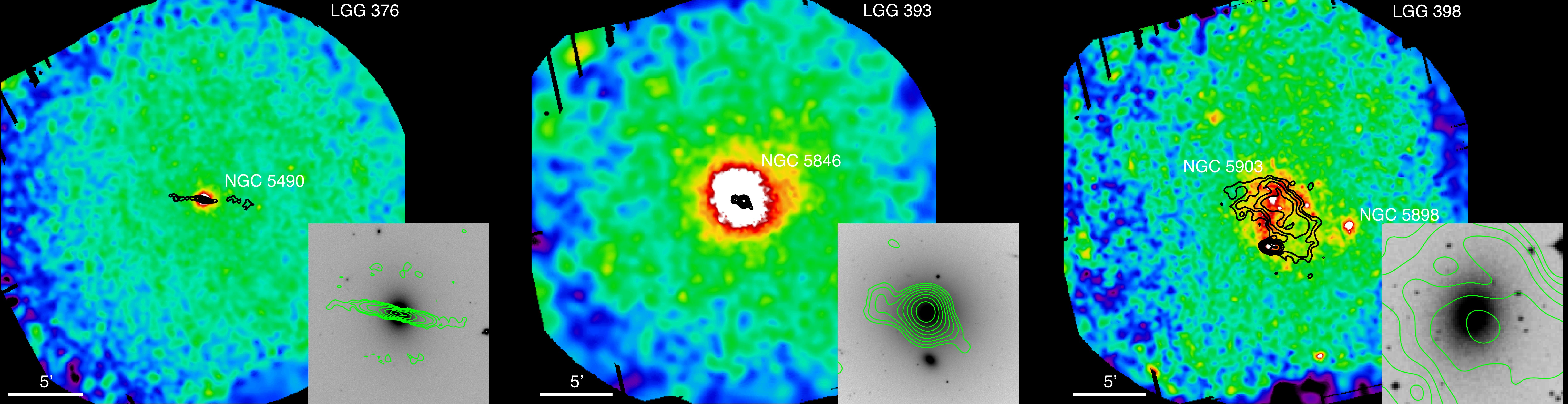
Temperature range: 0.4-1.5 keV

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

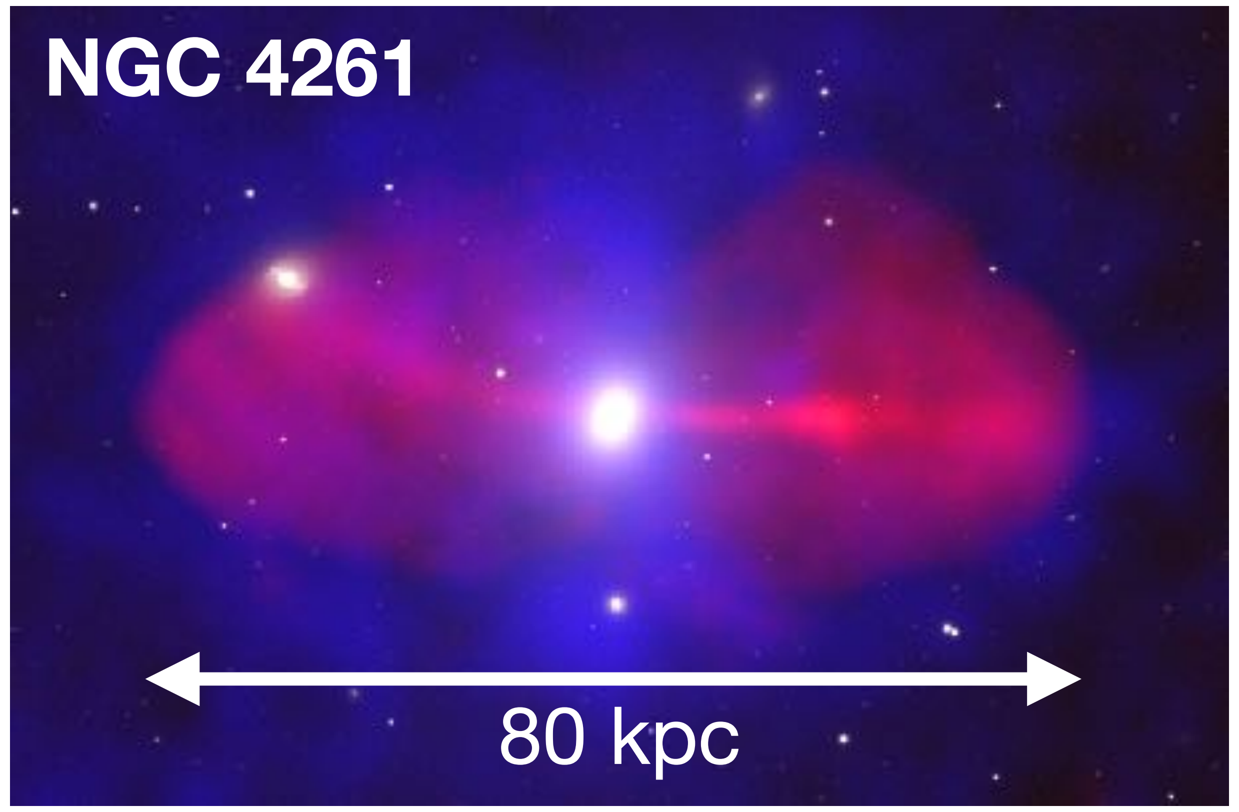
Jet scales 10-1000 kpc

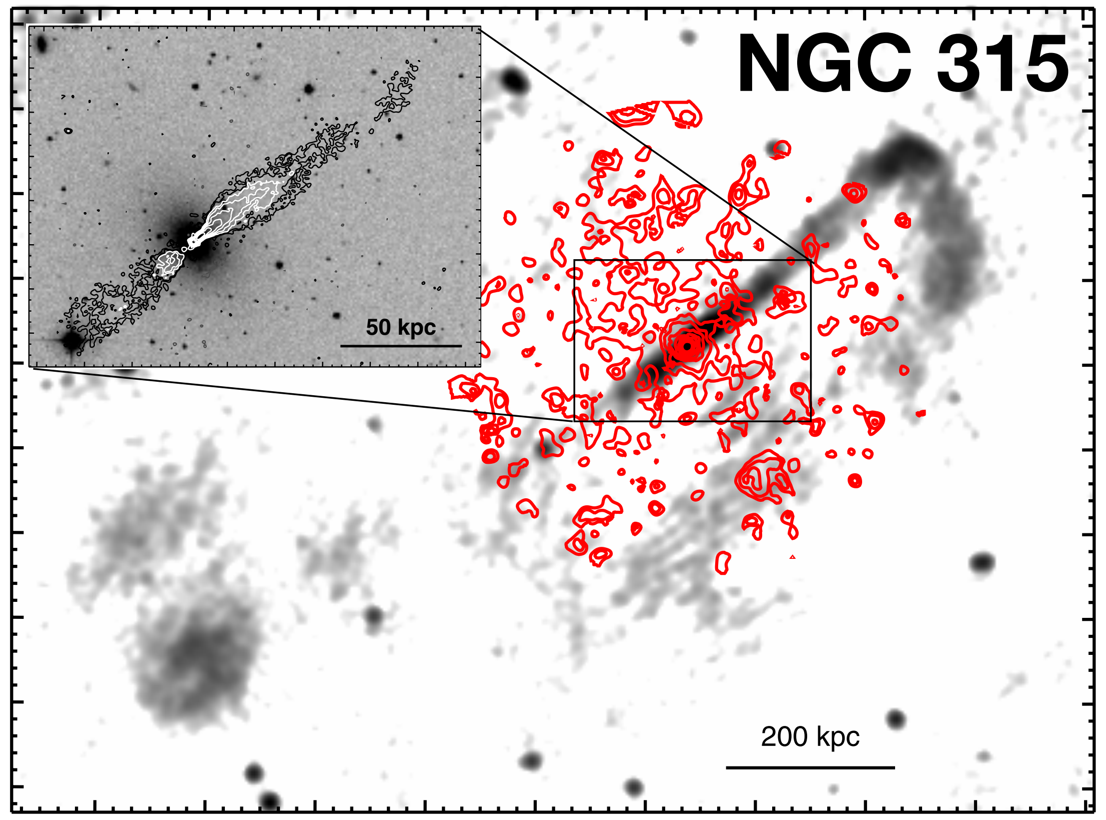
CLoGS: thermal balance

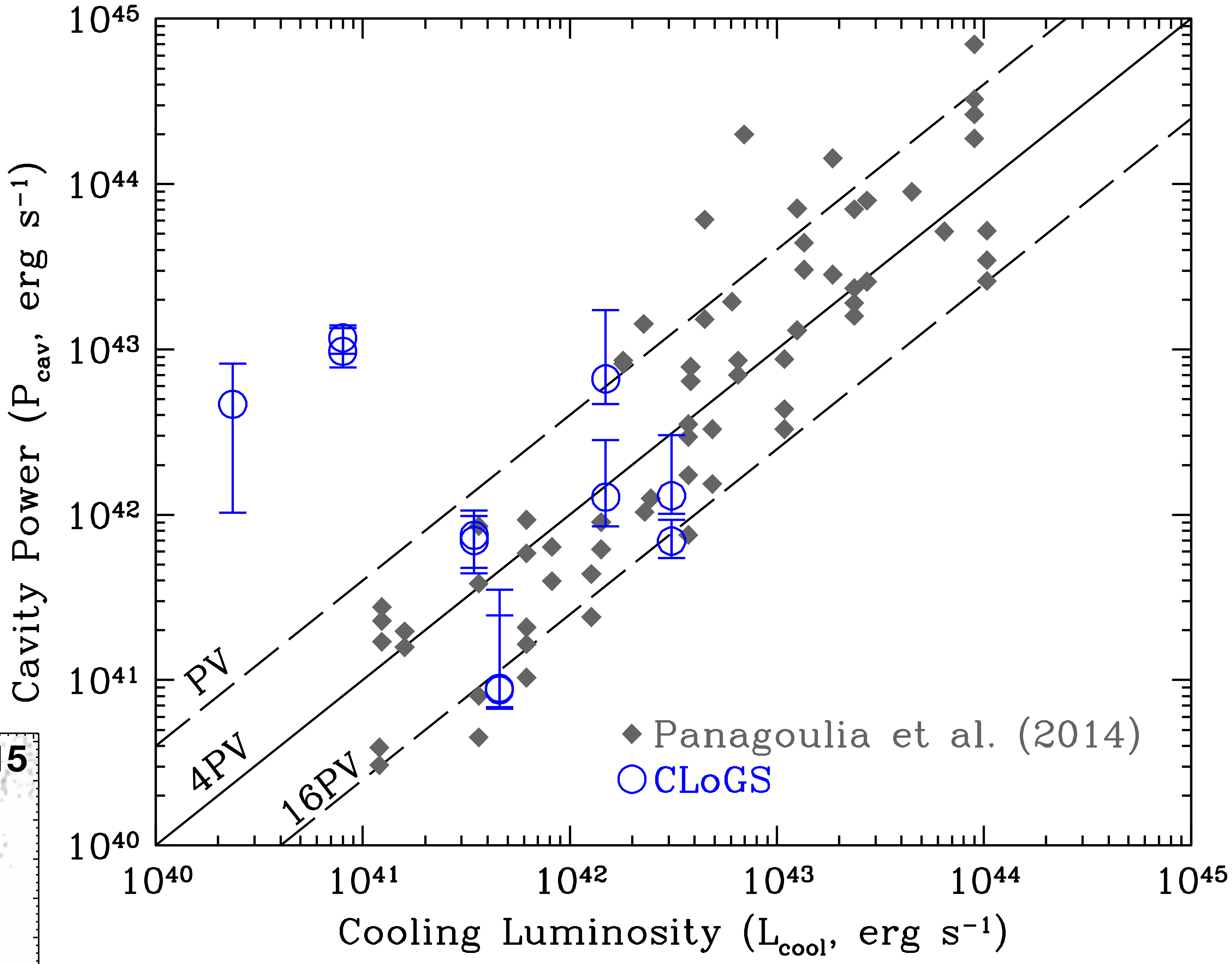
Smaller jet systems (≲50 kpc) in thermal balance

Larger jet systems over-powered relative to cooling

- $P_{cav} \geq 100x\ L_{cool}$
- 2 weak cool core systems central T_{cool} >4 Gyr
- lobes/cavities can be located outside cool core

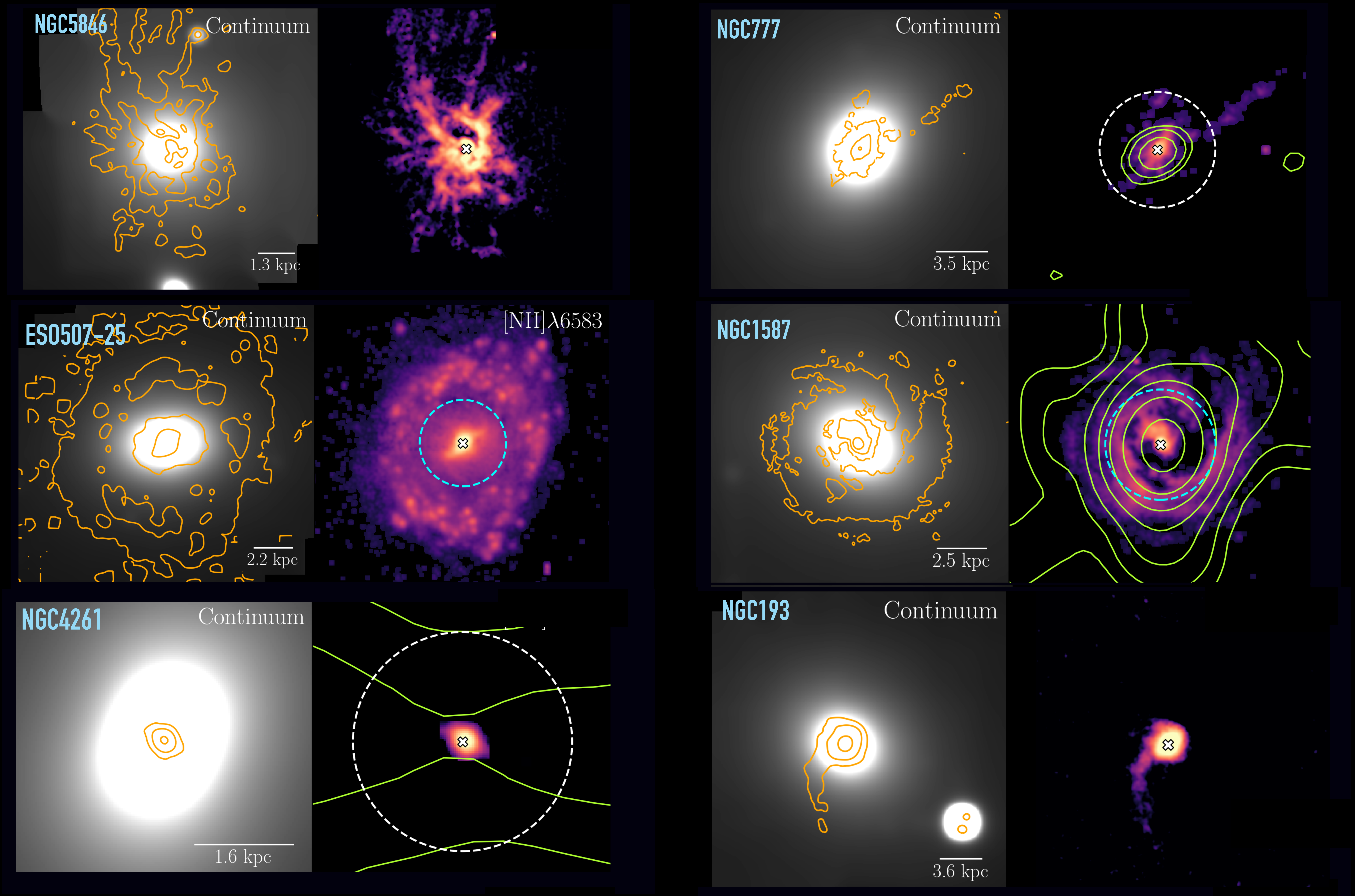






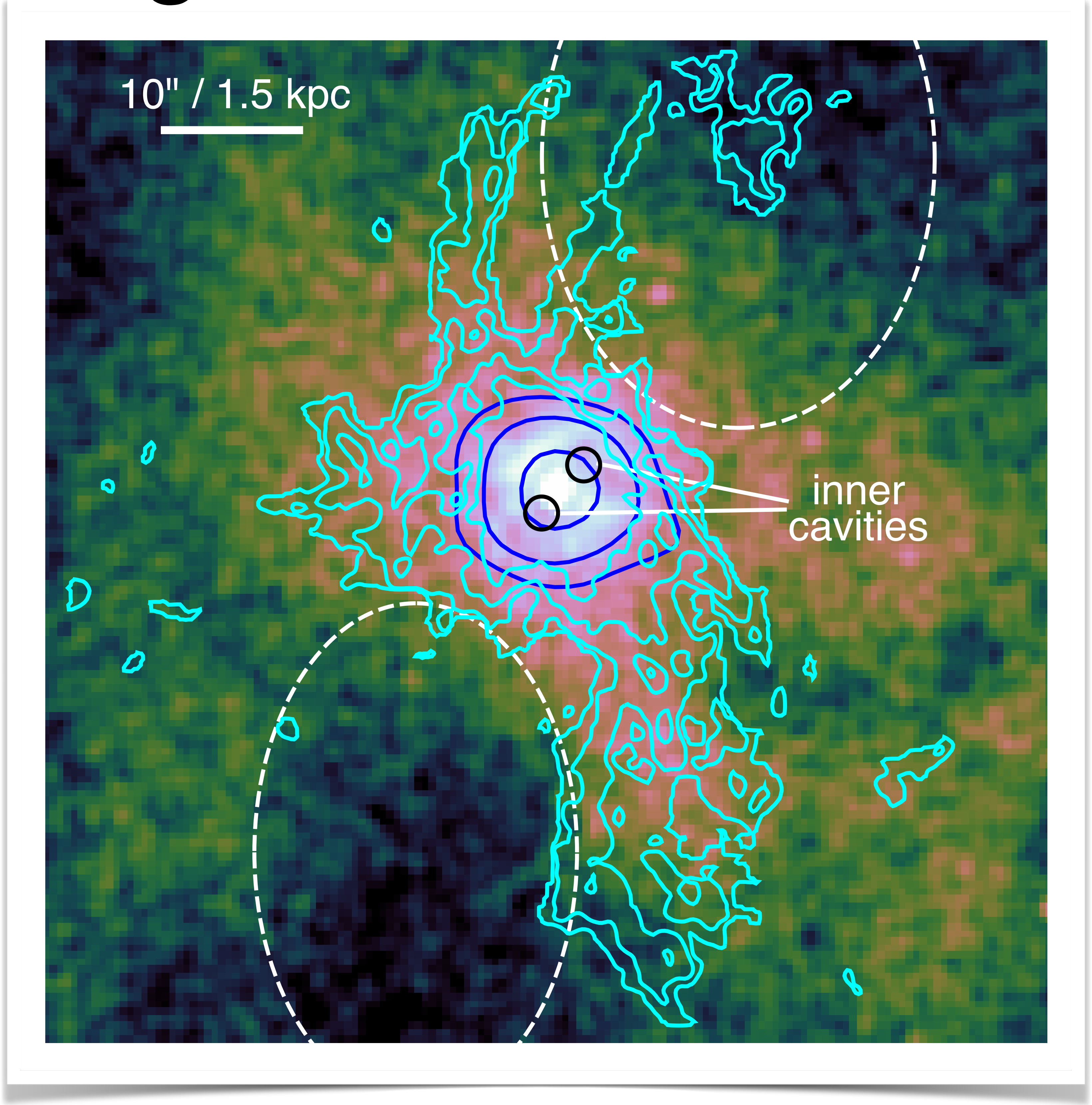
~45% of group-central AGN over-powered and/or inflating cavities outside cool core (c.f. Donohue & Voit 2022)

Warm gas morphology (Olivares et al. 2022)

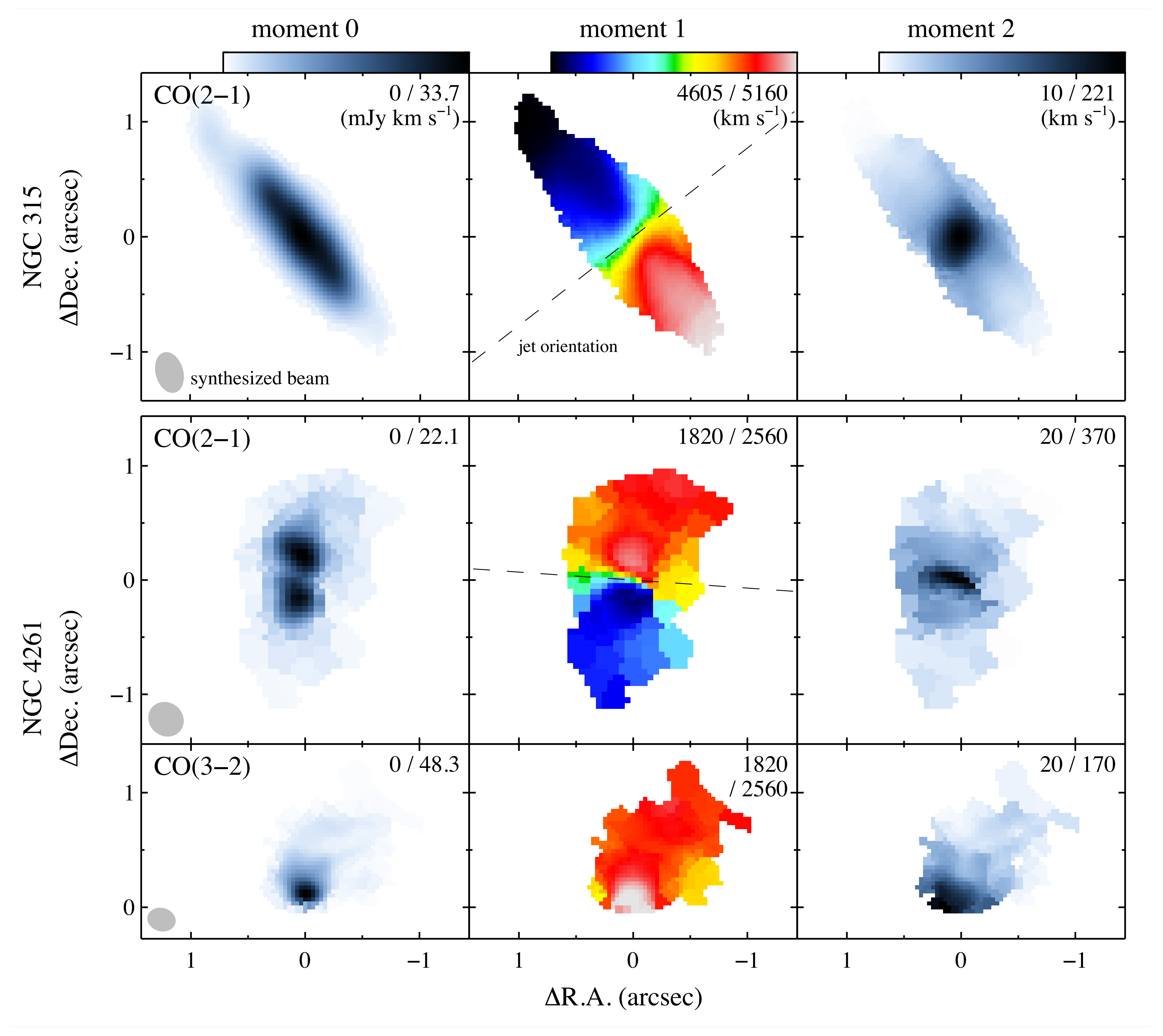


Orange contours:
MUSE Hα+[NII]
Green contours:
GMRT 610 MHz radio
Cyan circles:
IRAM 30m/APEX beam size

Cold gas: filaments and disks



NGC 5044, Schellenberger et al. (2020)

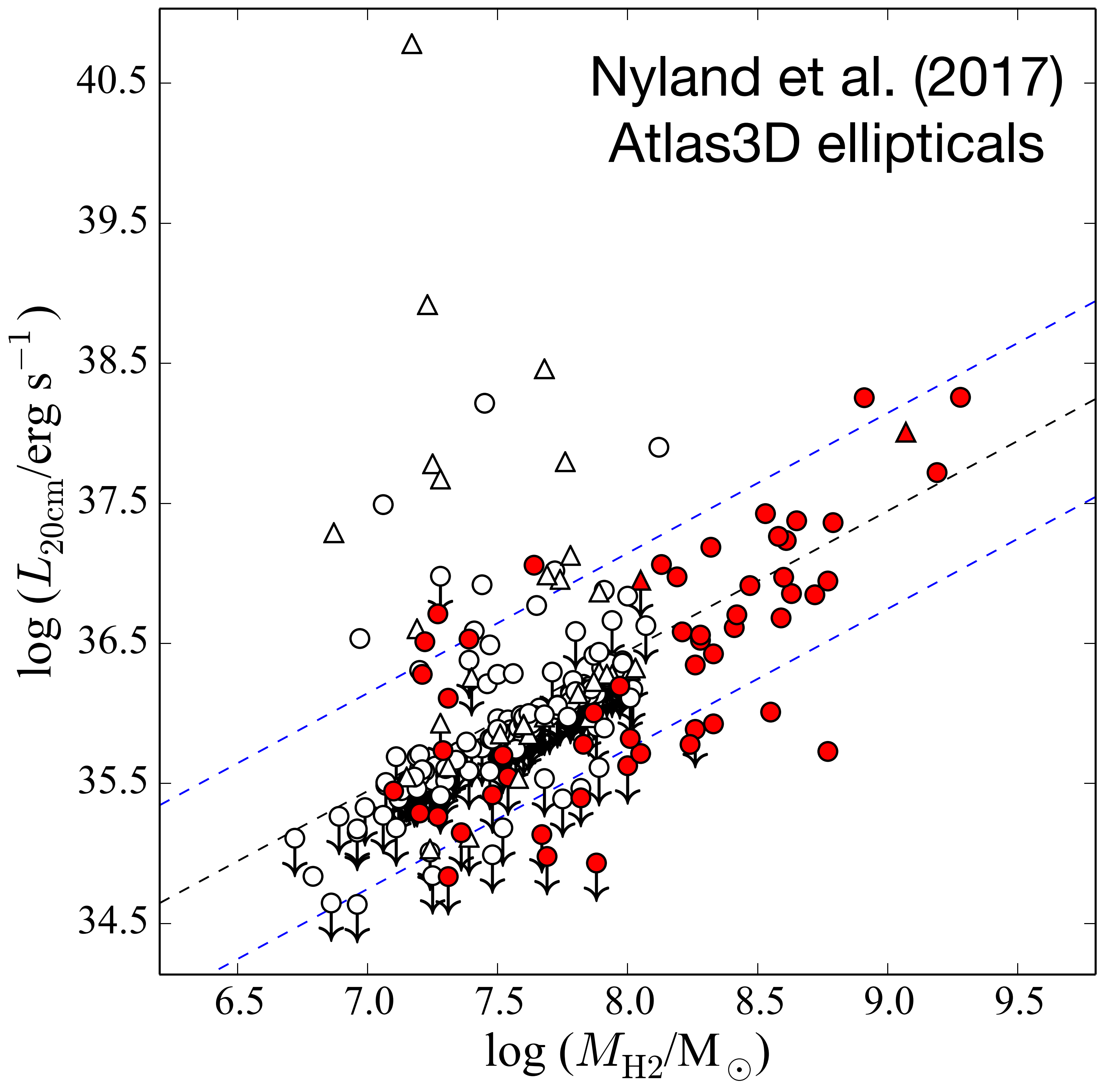


NGC 315 & NGC 4261, Boizelle et al. (2020)

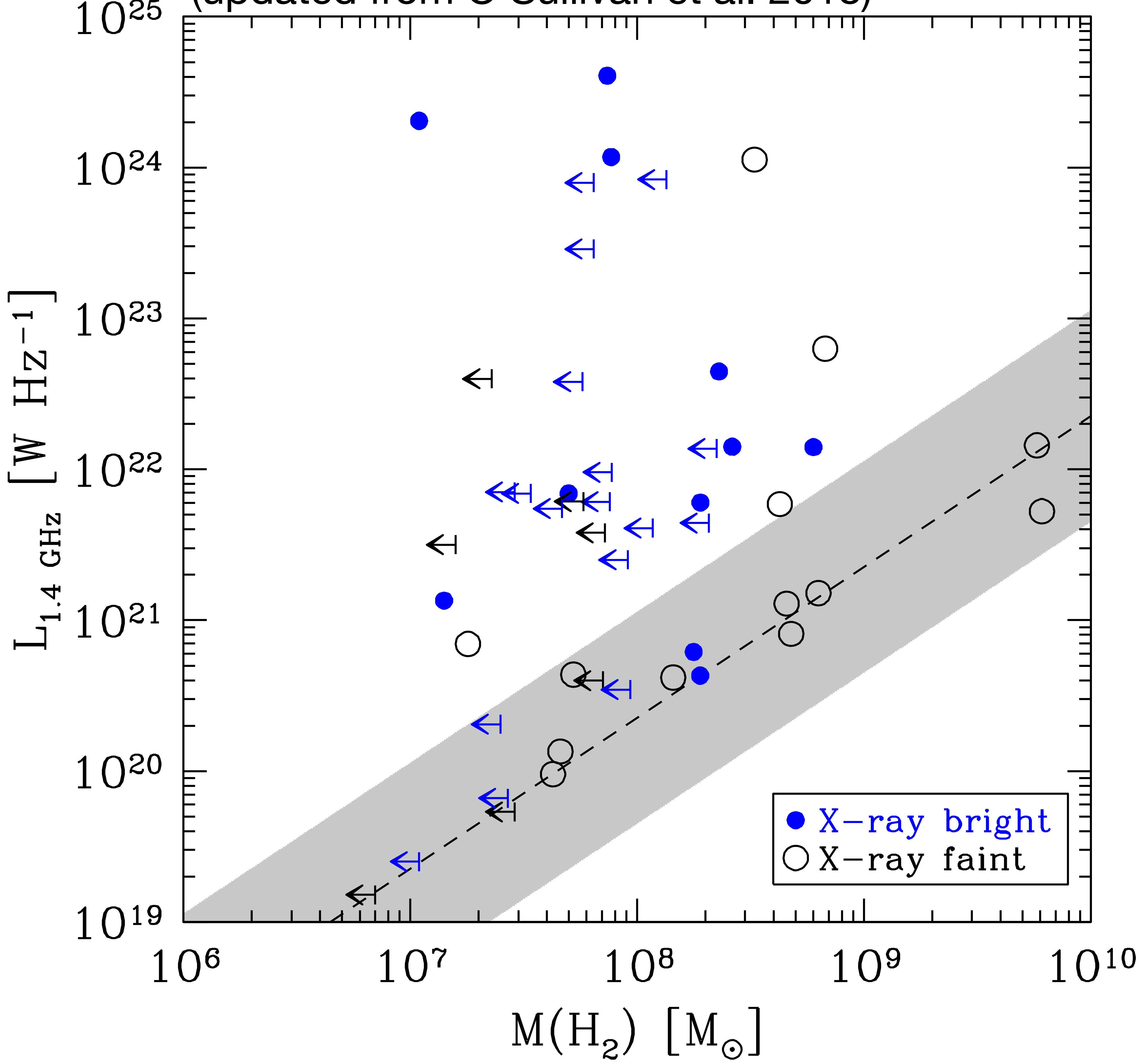
- IGrM cooling: clumps, filaments, kpc-scale disks in X-ray bright systems (David et al. 2017, Temi et al. 2018, Schellenberger et al. 2020, Ruffa et al. 2019, Boizelle et al. 2020) consistent with Chaotic Cold Accretion (Olivares et al 2022)
- Most powerful radio galaxies hosted by galaxies with small CO disks, limited filamentary nebulae (but small number statistics)

CLoGS: Cool gas

- CO detection fraction: 49±9%
  $M_{H2} = 10^7 - 6\times10^9\ M_\odot$
- compare with 22±3% for Atlas3D ellipticals (similar survey depth)



CLoGS group-dominant galaxies
(updated from O'Sullivan et al. 2018)



- Large gas mass not required for AGN outburst
- Largest CO masses found mainly in X-ray faint groups ➜ acquired through mergers/stripping?

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.
    - Central AGN maintain thermal balance in ~55% of those groups.
    - Powerful jet sources are common: ~45% appear over-powered relative to cooling and/or extend beyond the cooling region.
- Cool gas (CO, HI, Hα) 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 Chaotic Cold Accretion (see Olivares et al. 2022).
    - Small, low mass CO disks fuel our most powerful radio galaxies.
- Next steps: MeerKAT HI+continuum observations, ALMA+ACA, X-ray follow-up.