Cooling and AGN Feedback in Galaxy Groups

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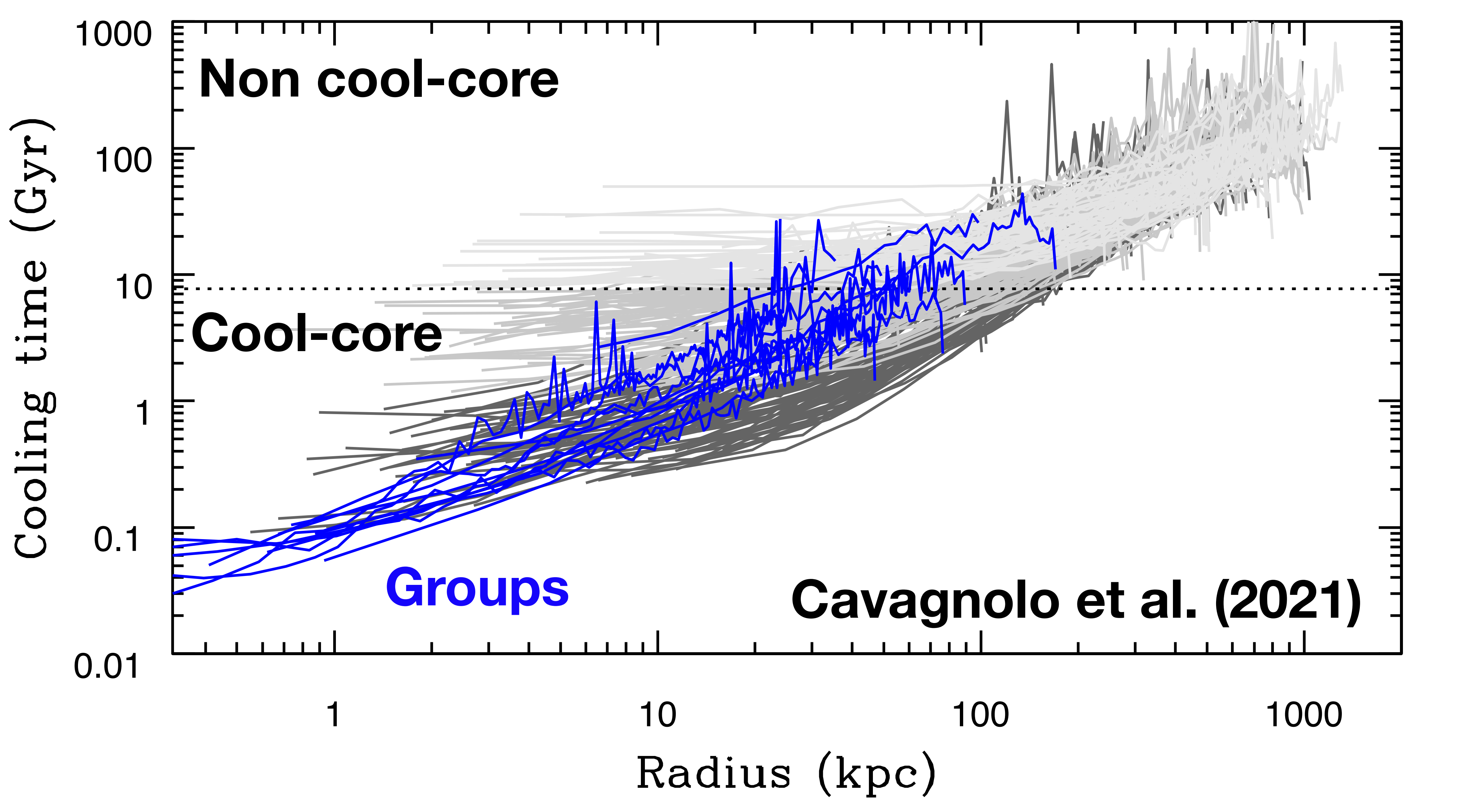
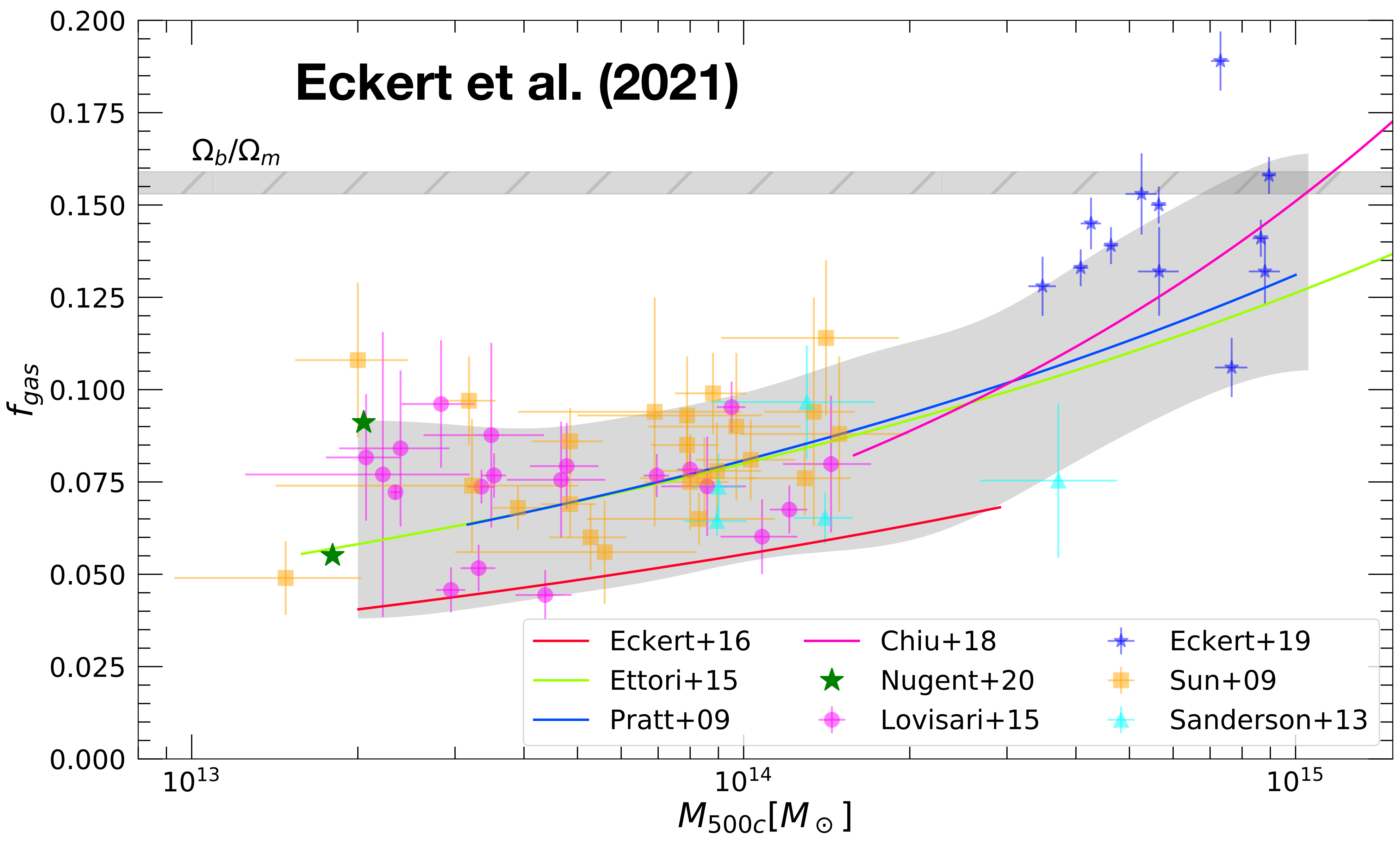
Why study feedback in groups?

- Most galaxies are located in groups
- Groups cool more efficiently than clusters
  ➜ There are no non-cool-core groups!
- Shallow potential wells compared to clusters
  ➜ AGN heating may have a greater impact
- Groups have reduced gas fractions
  ➜ Evidence of AGN over-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)





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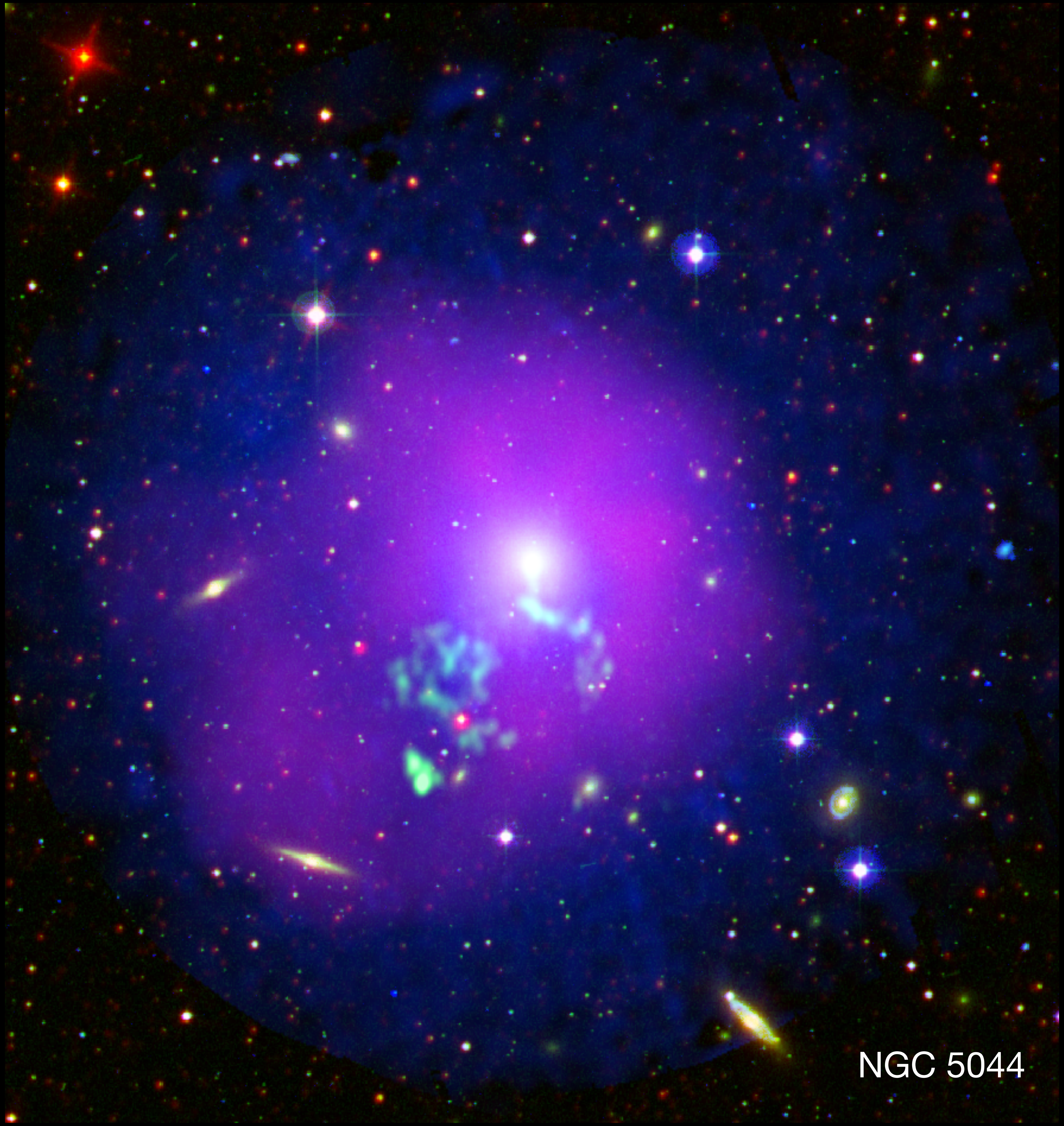


CLoGS: a Complete Local-volume Group Sample

Statistically complete optically selected sample of 53 nearby groups

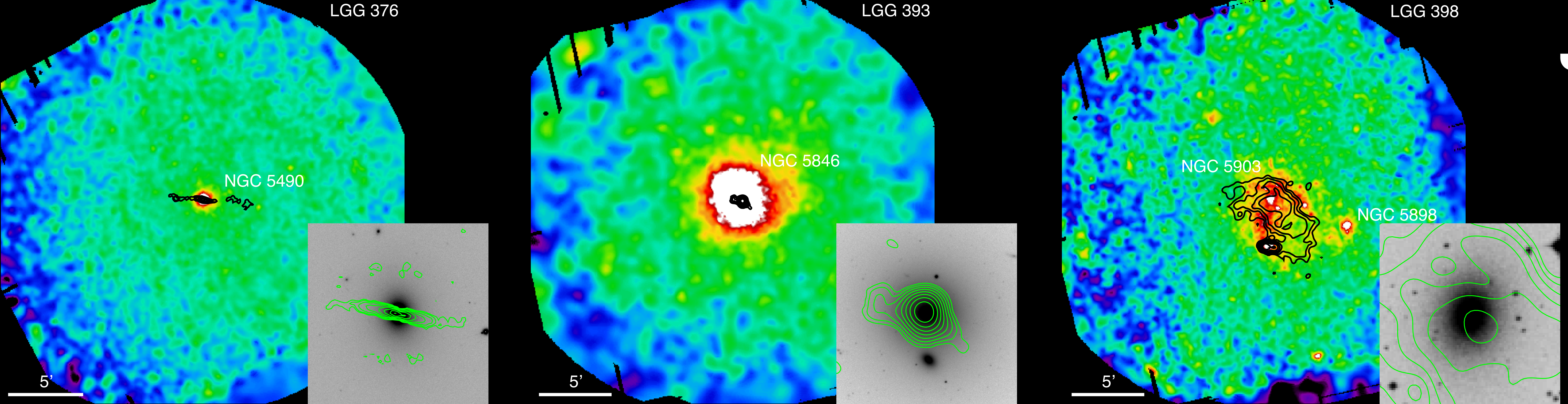
- within 80 Mpc
- ≥4 member galaxies, ≥1 early-type member with $L_B \geq 3x10^{10}$ $L_\odot$
- Declination ≥ -30° (covered by VLA sky surveys, visible from GMRT)

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 $M_{H2} = 10^7 - 6x10^9$ $M_\odot$

Hα: MUSE IFU for 18 dominant galaxies (Olivares et al. 2022) +20 more approved
1 hr/target, 1.5" seeing



Jet sources in ~40% X-ray bright groups

Jet scales 10-1000 kpc

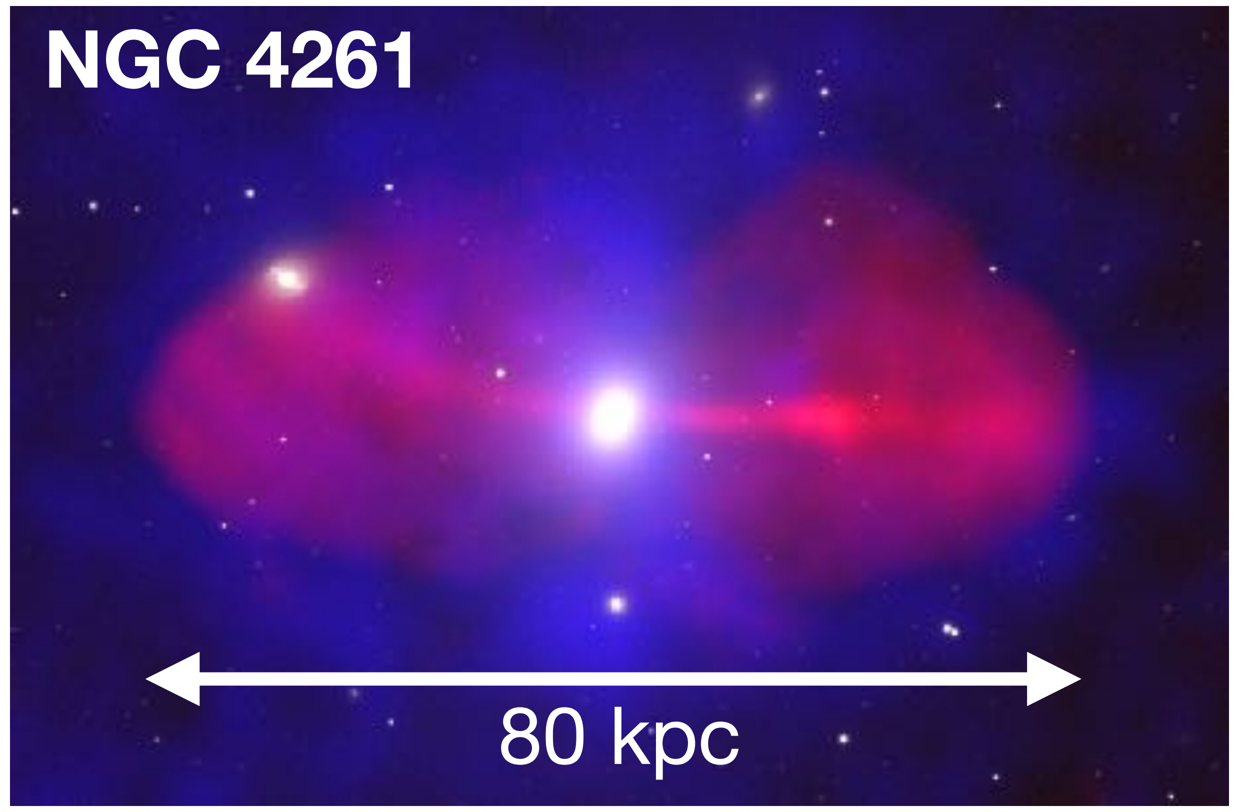
Athens, Greece

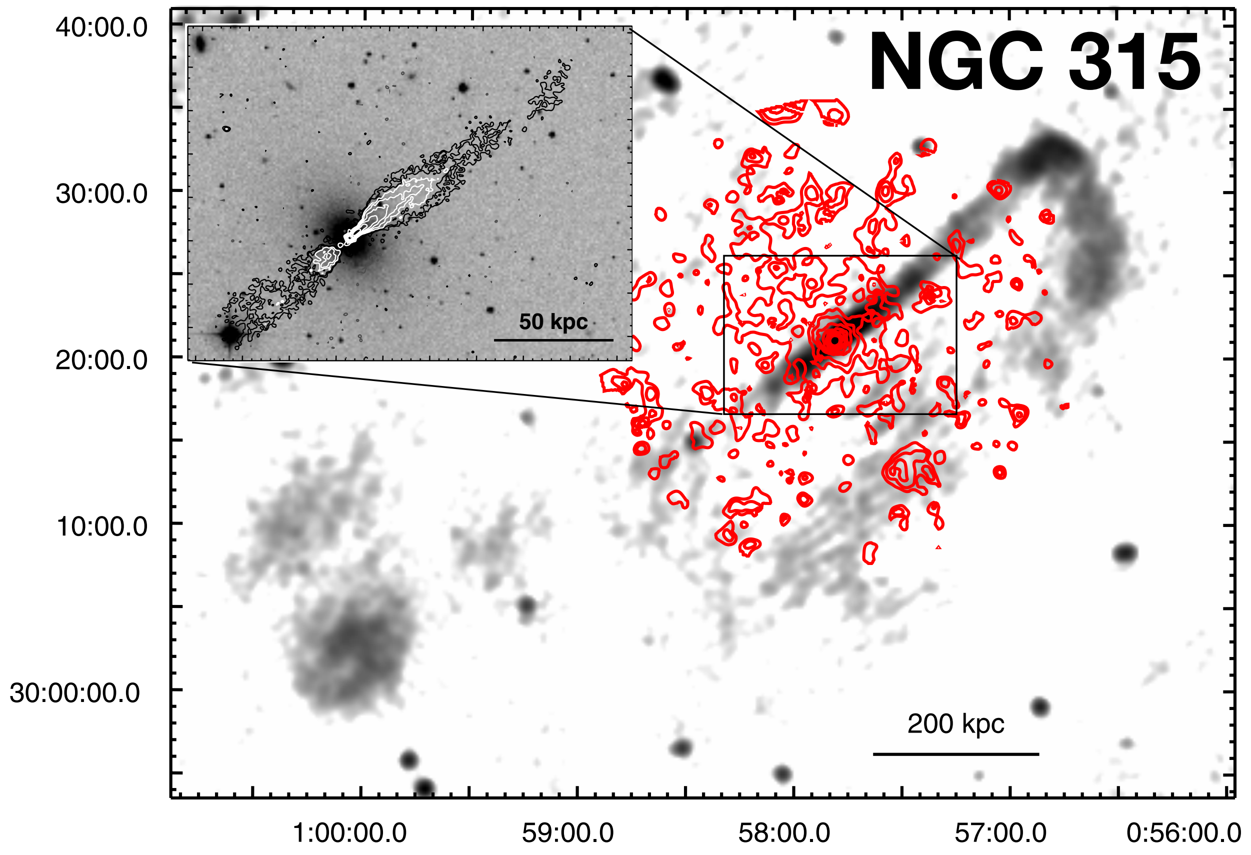
CLoGS: thermal balance

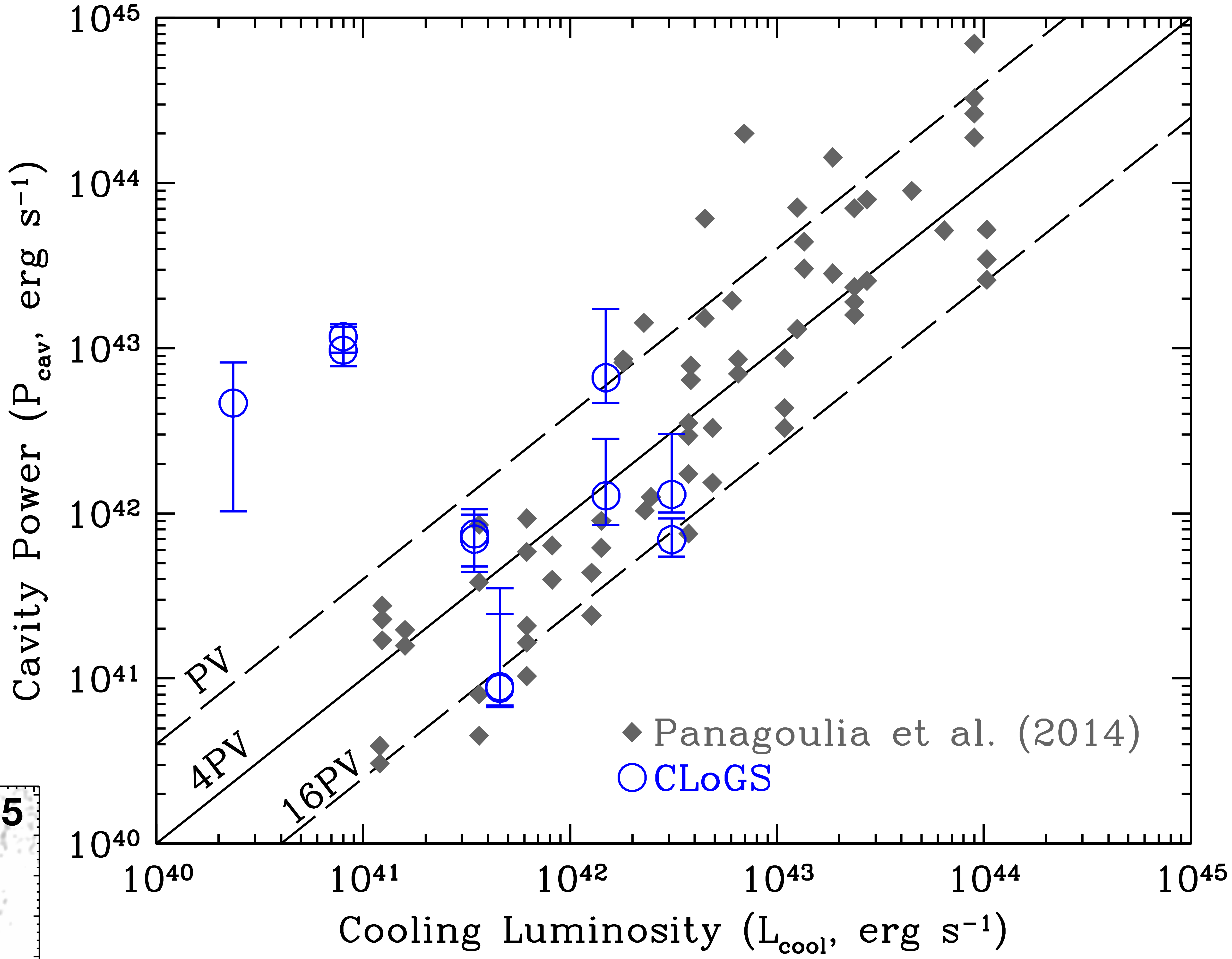
Smaller jet systems (≲50 kpc) in thermal balance

Larger jet systems over-powered relative to cooling

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



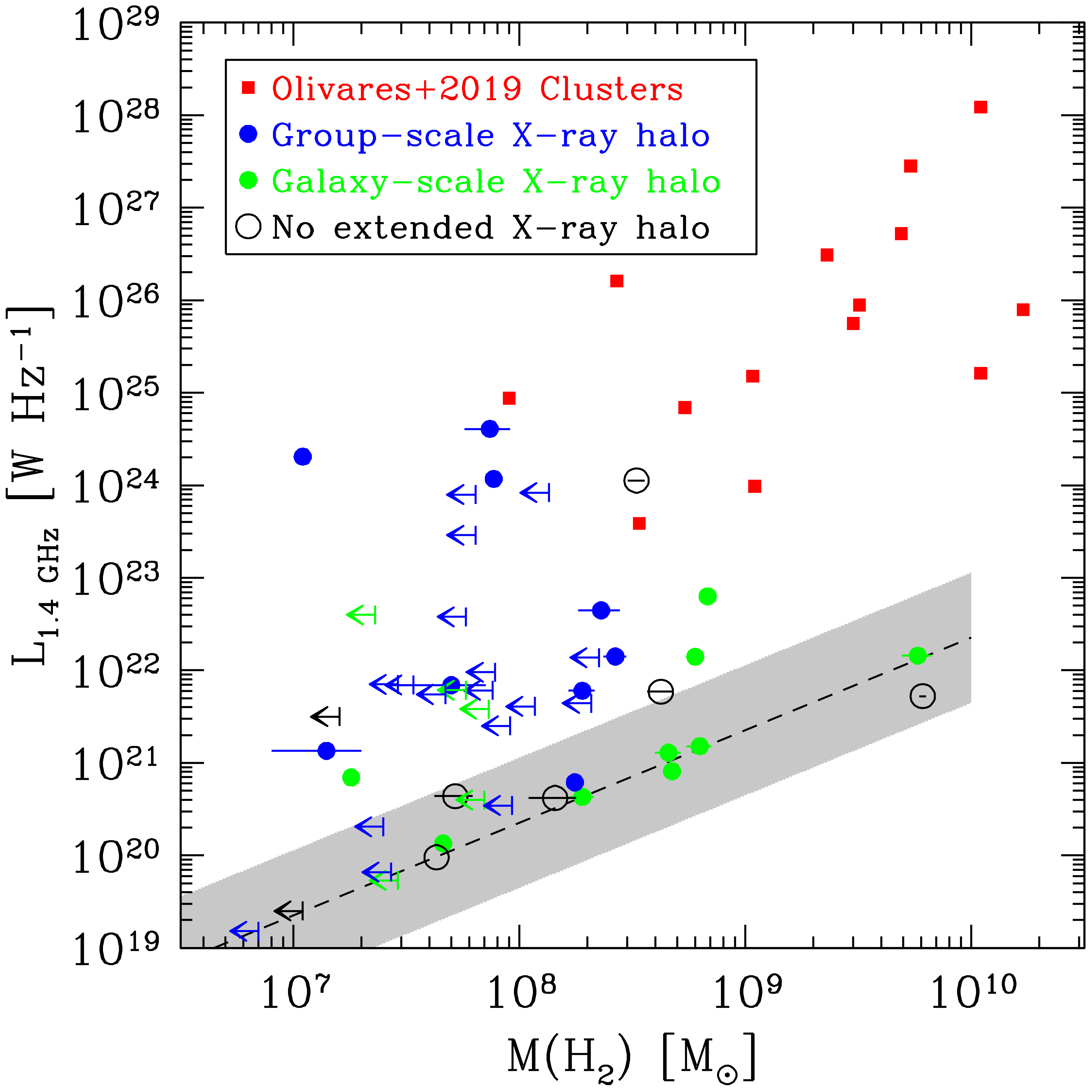




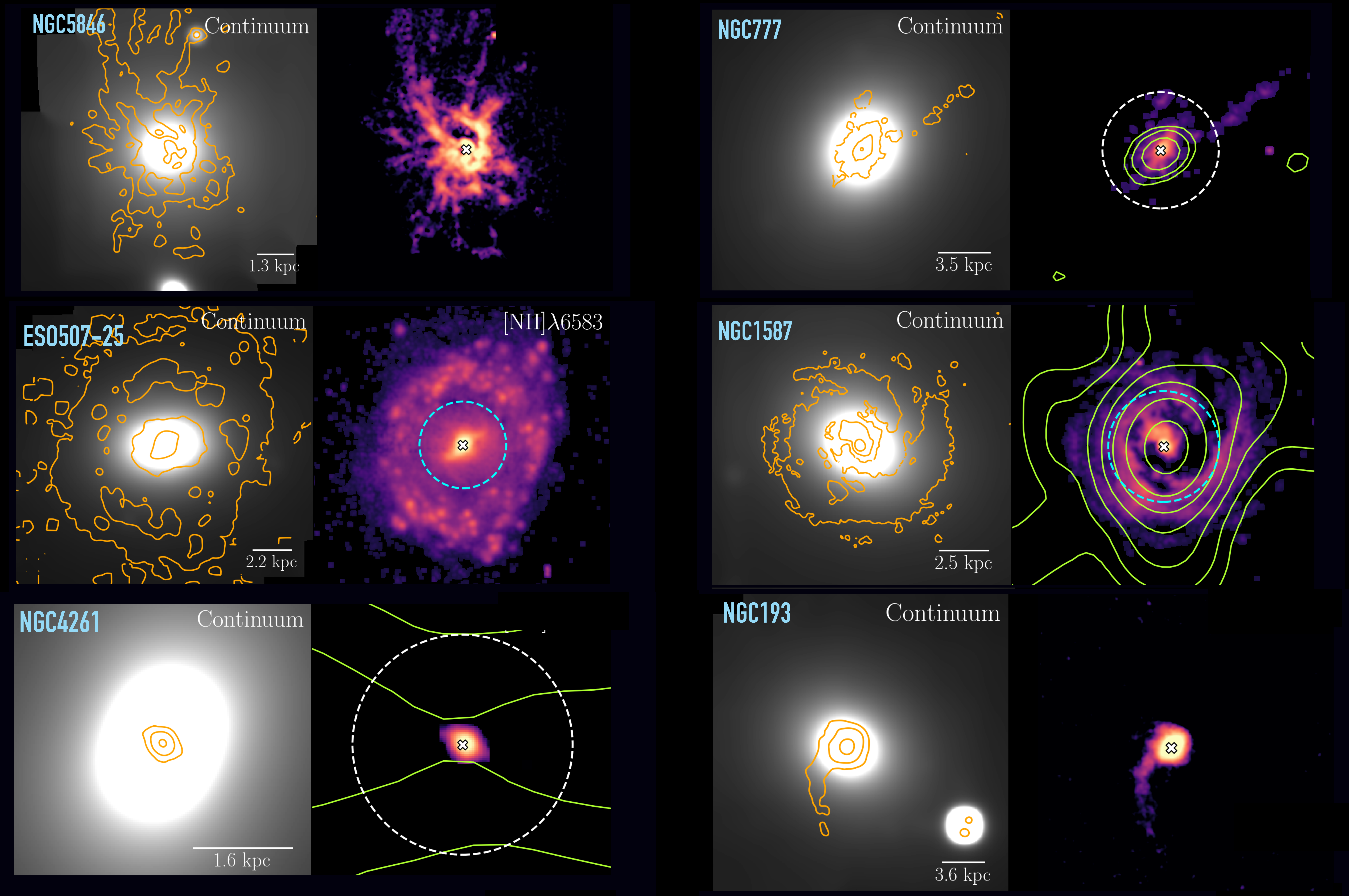
~45% of group-central AGN over-powered and/or inflating cavities outside cool core
(c.f. Donohue & Voit 2022)

CLoGS: Evidence of cooling

- CO detection fraction: 49±9%
- 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



Ionized gas morphology (Olivares et al. 2022, see also Loubser et al. 2022, Lagos et al. 2022)

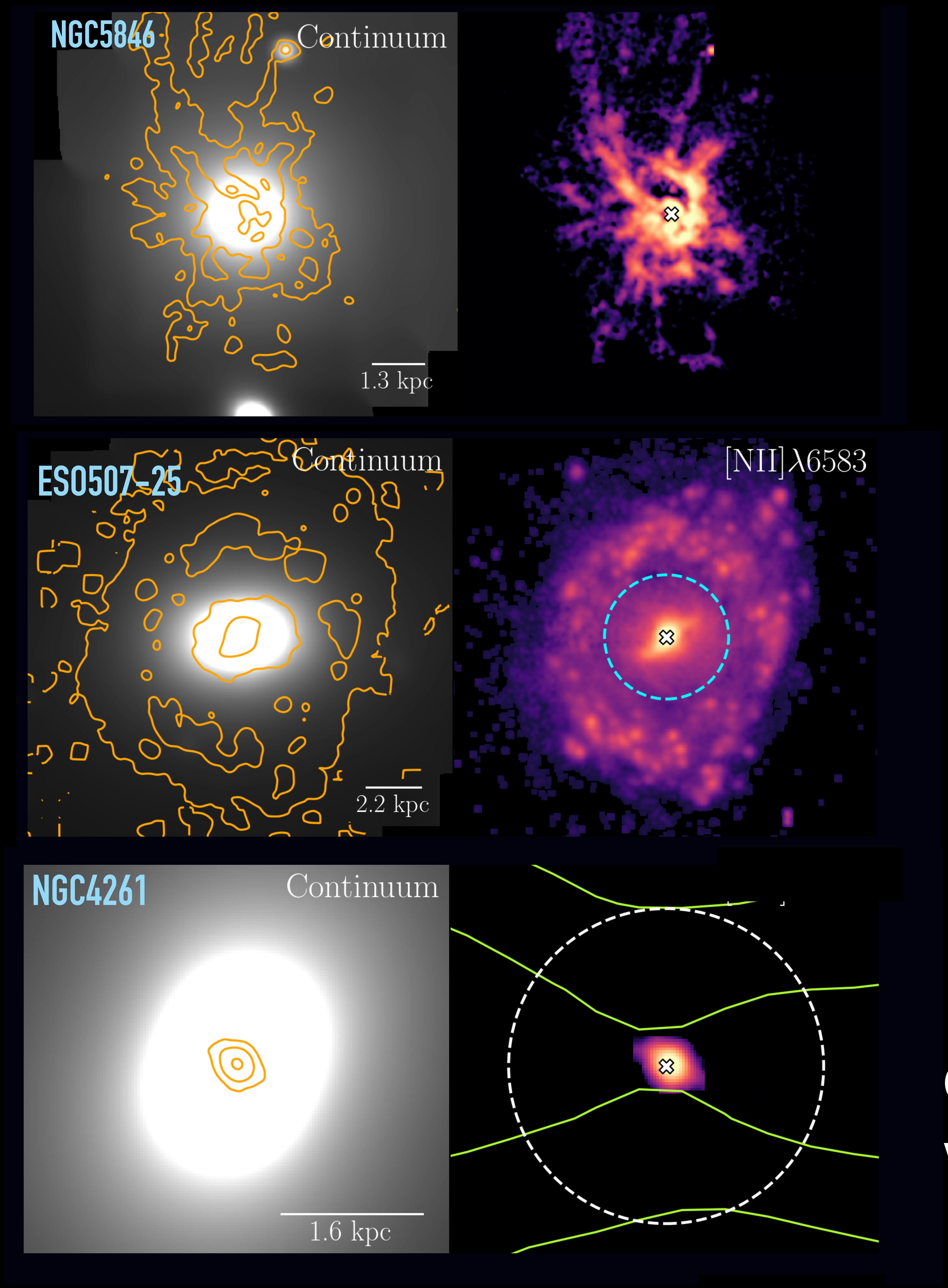


Orange contours:
MUSE Hα+[NII]
Green contours:
GMRT 610 MHz radio
Cyan circles:
IRAM 30m/APEX beam size

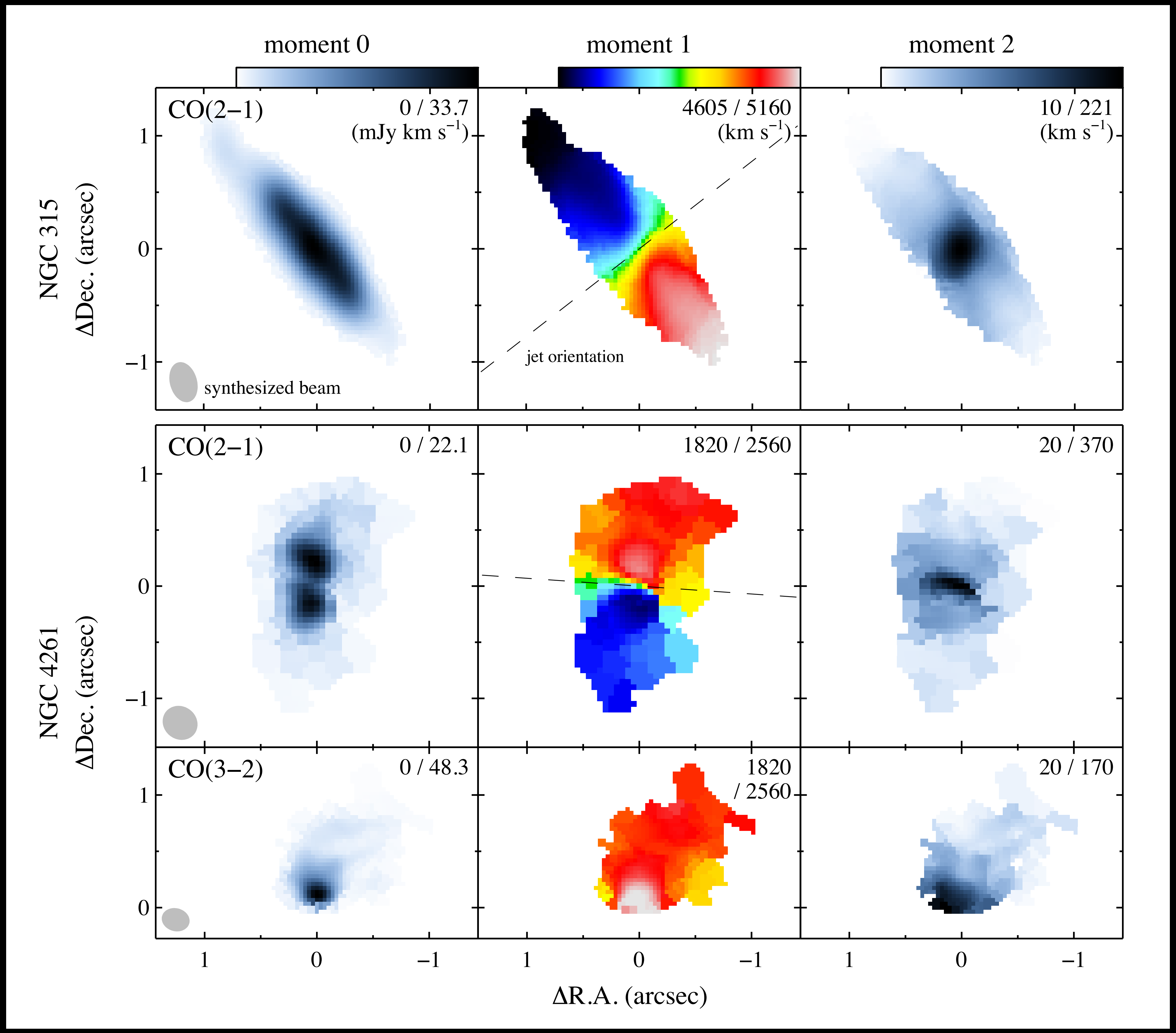
Most X-ray bright systems consistent with Chaotic Cold Accretion:
gas located in clumps, filaments, kpc-scale disks
(David et al. 2017, Temi et al. 2018, Schellenberger et al. 2020, Boizelle et al. 2020)

Larger-scale disks formed through galaxy interaction?

Gas morphology



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



Our most powerful radio galaxies are fuelled by sub-kpc CO disks with limited Hα nebulae - small gas mass but in the right place?

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, $H\alpha$) 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.
    - Powerful radio galaxies can be fueled by relatively small gas reservoirs.