CLoGS: the complete local-volume groups sample

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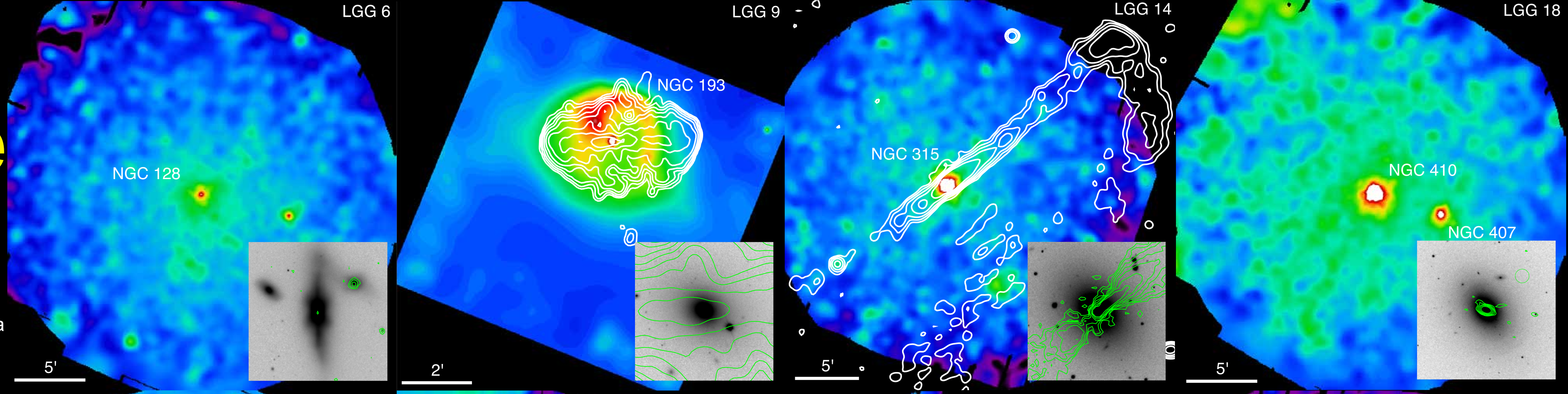
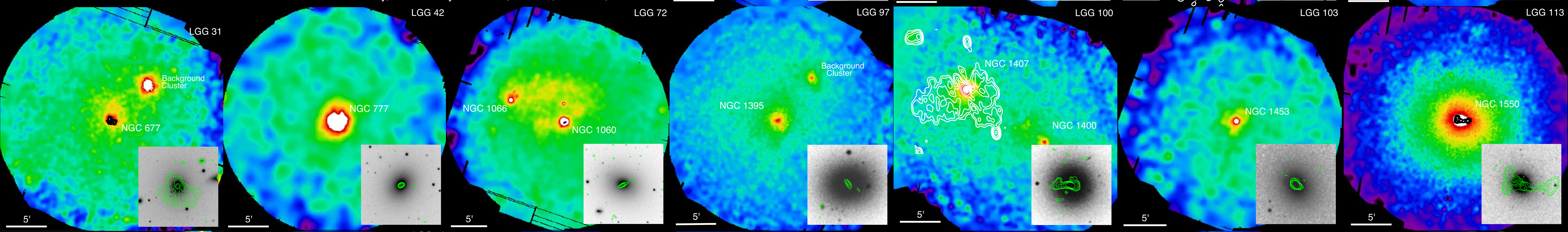
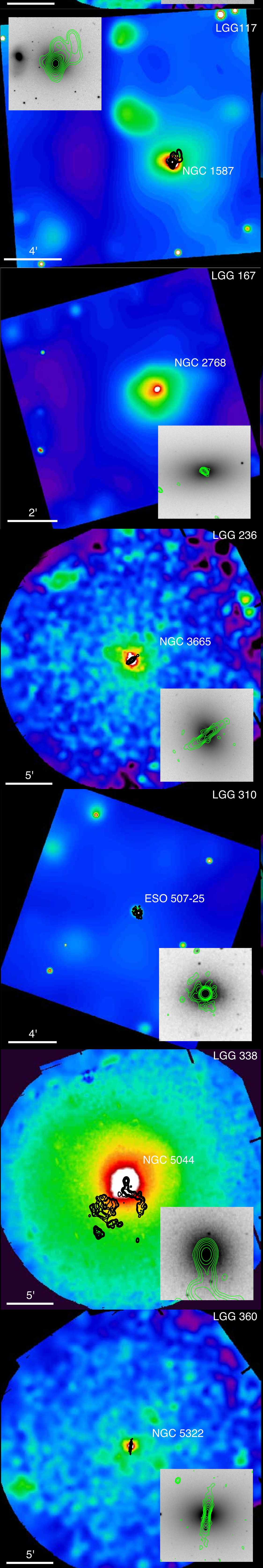






Galaxy groups in the local universe: results from a complete sample

Background: Galaxy groups are arguably the most important environment for our understanding of galaxy evolution, AGN feedback, and the development of the hot intra-group and intra-cluster medium. Most previous studies of groups have either used optically-selected samples to examine galaxy populations, or X-ray selected samples (usually derived from the *Rosat* All-Sky Survey) to investigate gas properties. While these approaches have yielded important results, their selection methods mean they are subject to significant biases. Optically-selected samples often include false groups, since at low masses selection must be made using only a few galaxies. X-ray selection tends to produce samples dominated by cool-core systems with centrally-concentrated surface brightness, since these central peaks are most easily detected.

Sample: We have created the Complete Local-Volume Groups Sample (CLoGS), an optically-selected statistically-complete sample of 53 groups in the nearby Universe (D<80 Mpc), with complete coverage in the X-ray (*Chandra* and *XMM-Newton*), multi-frequency radio (GMRT 235 and 610 MHz) and, for the dominant galaxies, CO (IRAM 30m and APEX). This combination of data allows us to examine the gas content of the groups, their dynamical state, and the role of AGN feedback in maintaining their thermal balance.

We select our sample from the Lyon Galaxy Group catalogue (LGG, Garcia 1993, A&AS 100, 47), choosing groups which have:

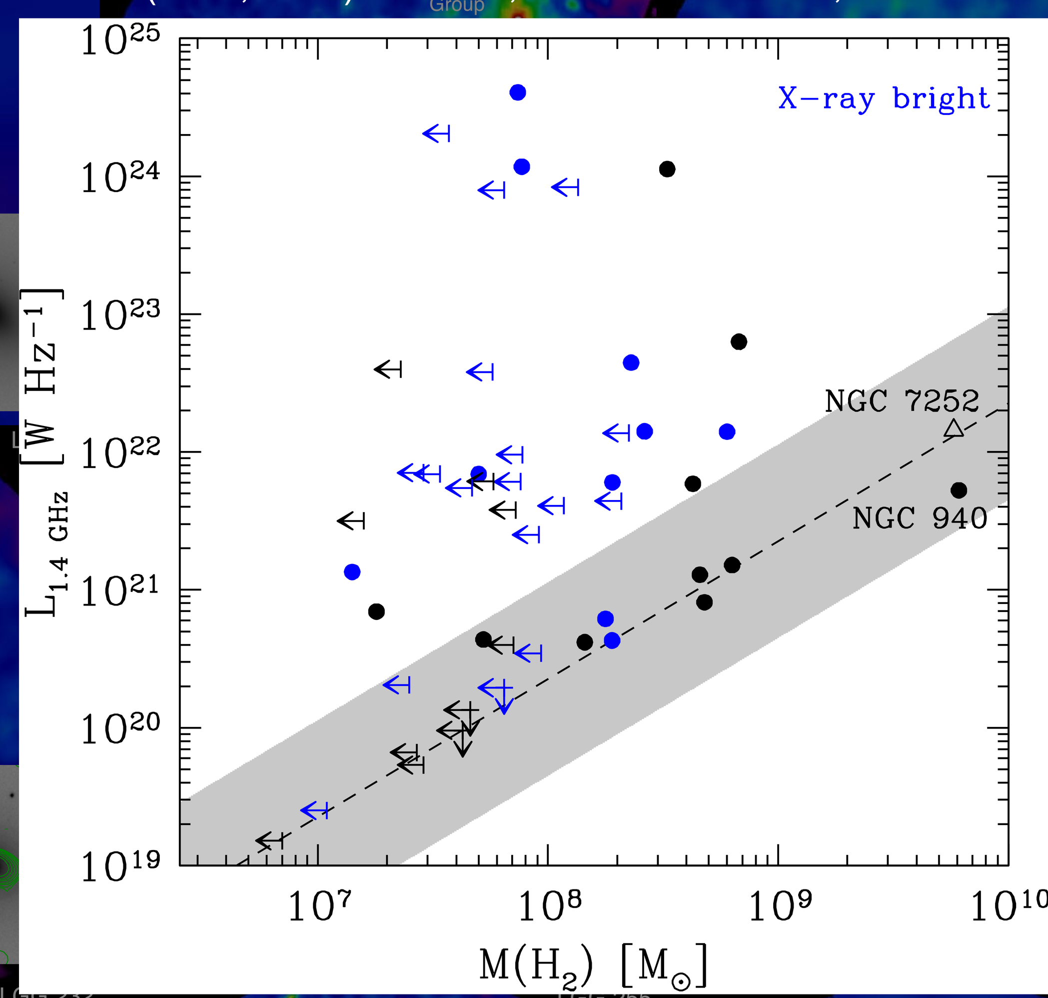
- ≥ 4 member galaxies (excluding pairs & triples which may lack a common halo)
- ≥ 1 early-type member (as spiral-only groups tend to be hot gas poor)
- Optical luminosity $L_B > 3\times10^{10}$ $L_\odot$ for the brightest member
- Declination > -30° (to ensure visibility from GMRT and VLA)

We then expand and refine the galaxy membership using the LEDA galaxy catalogue, and exclude systems judged to be too rich (clusters) or too poor (too few galaxies to characterize the population).

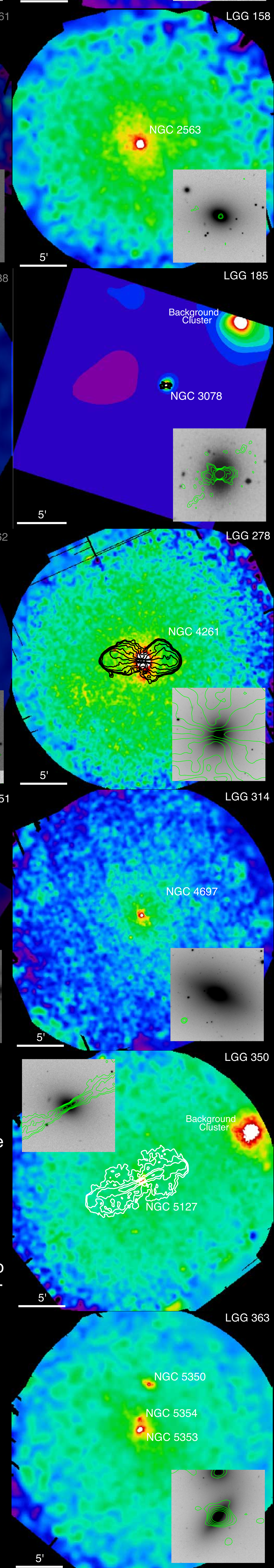
For more details of sample selection and X-ray properties, see O'Sullivan et al. (2017, MNRAS 472, 1482).

CO survey

O'Sullivan et al. (2015, 2018) A&A 573, A111 and A&A 618, A126

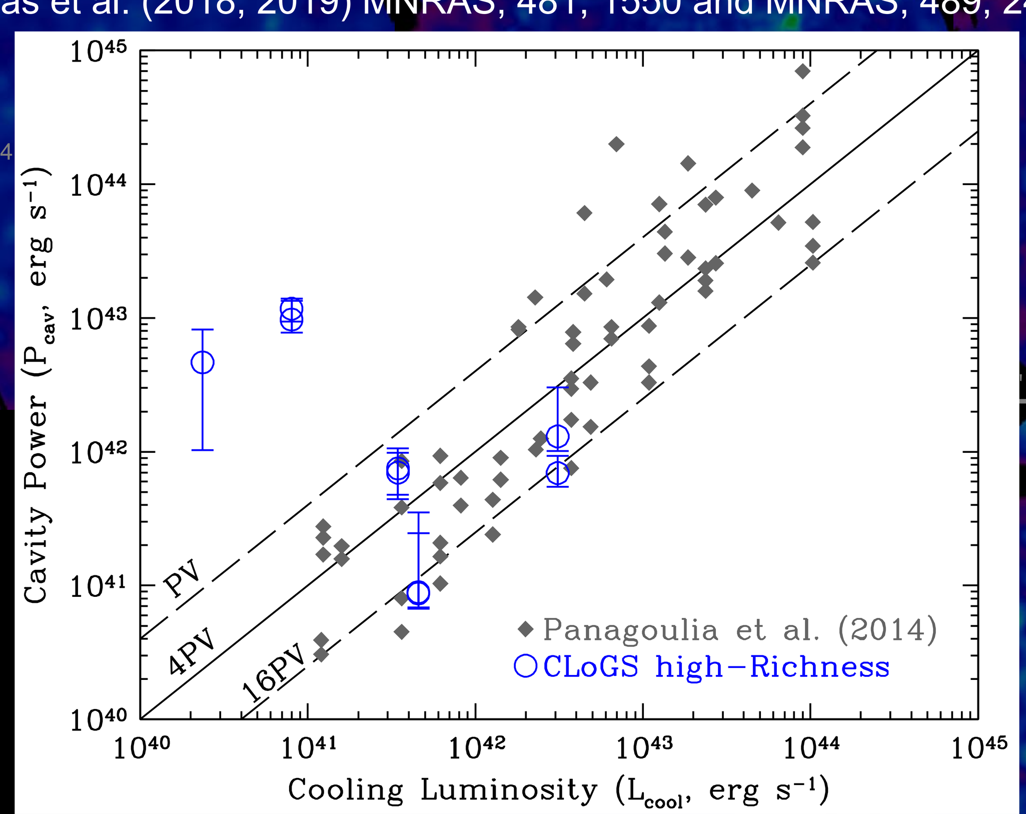


All 53 group-dominant early-type galaxies have been observed in CO(2-1) and/or CO(1-0) using the IRAM 30m or APEX telescopes. We detect CO in 21 galaxies (~40%), with masses 1-610 $\times10^7$ $M_\odot$. This detection rate is roughly double that of the general early-type population. Comparing radio luminosity to molecular gas mass (see Figure above), we find that while some of our galaxies have properties consistent with star formation (the grey band), a large fraction are AGN dominated. However, the presence of CO is not clearly linked to radio power, or to the presence of hot gas. This suggests that while group-dominant galaxies can build up a CO reservoir through cooling from the hot halo (as in galaxy clusters), many acquire it through gas-rich mergers.



Radio properties

Kolokythas et al. (2018, 2019) MNRAS, 481, 1550 and MNRAS, 489, 2488



Our GMRT 235 and 610 MHz observations (~4hrs/target, rms ~0.1mJy/bm @610 MHz, ~0.6mJy/bm @ 235 MHz) are well suited to identifying AGN over a wide range of scales and ages. For the group-dominant ellipticals we find:

- 46/53 (87%) are detected in our GMRT data (or the NVSS or FIRST surveys)
- 13 host jet sources (implying a duty cycle ~1/3)
- 28 host point-like sources
- 5 host diffuse sources (e.g., LGGs 31, 117, 185, 310). The origin of emission in these sources is unclear (star formation? disrupted jets? radio phoenices?)

11 of the 13 galaxies with jet sources reside in systems with group-scale X-ray halos and cool cores. The plot above shows cavity enthalpy vs. cooling time (P_{cav} vs L_{cool}) for 5 of our richest groups. Three fall on the relation, with cooling and heating in balance, but two (LGGs 9 and 278) have $P_{cav}=50L_{cool}$, suggesting that these AGN may be dramatically over-heating their groups.

X-ray properties

Group detection fraction: Of our 53 systems,

- 26 (~50%) have a full group-scale X-ray halo (>65 kpc extent, $L_X>10^{41}$ erg/s)
- 16 (~30%) have a galaxy-scale halo ($L_X=10^{40}$-10^{41} erg/s)
- the remainder have only point-source emission in the dominant galaxy.

Of the group-scale halos, ~1/3 are dynamically active, showing signs of ongoing mergers or sloshing (indicating a recent minor merger or tidal encounter). Roughly 65% have cool cores, a higher fraction than in clusters (~50%). Unlike clusters, many of the merging groups retain their cool cores. The temperature range of our systems is ~0.4-1.5 keV, equivalent to masses of ~0.5-5 $\times10^{13}$ $M_\odot$.

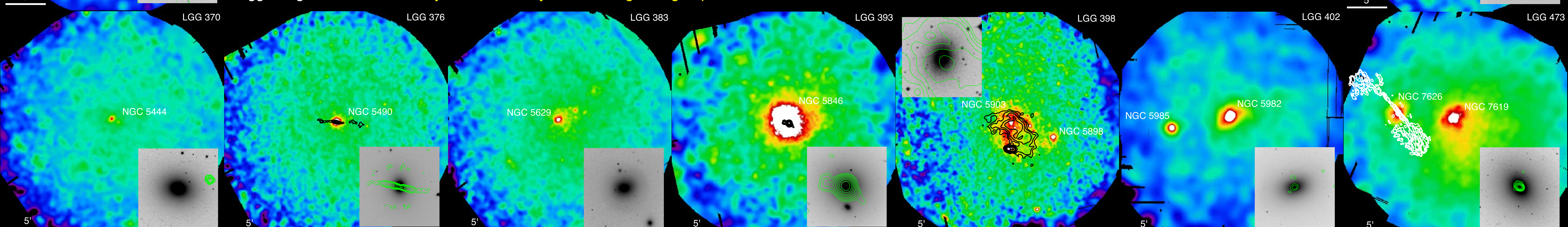
New groups

One goal of our sample was to search for new groups, previously undetected in the X-ray. Of our 26 systems with a full-scale intra-group medium (IGM), 12 were identified as X-ray bright groups for the first time, of which 8 were undetected in the *Rosat* All-Sky Survey (RASS). Examples include: LGG 402 / NGC 5982 (bottom row) a faint ($L_X=3\times10^{41}$ erg/s), cool (0.59 keV) group which lacks a cool core; LGG 72 / NGC 1060 (above left) a train-wreck merger with a 100 kpc arc of stripped gas linking the two cores; and LGG 398 / NGC 5903 (bottom row) in which a combination of galaxy interactions and a powerful AGN outburst seem to have disrupted the group core (see O'Sullivan et al. 2018 MNRAS, 473, 5248 for more details). In each case, the lack of a relaxed cool core with a strong surface brightness peak probably explains the RASS non-detection.

Future plans

We are currently working on several aspects of the sample, including:

- MUSE observations of 17 dominant galaxies, providing information on stellar populations and cooling from the hot gas halo.
- Collecting interferometric observations of our CO-detected systems (via NOEMA and ALMA/ACA) to map the gas and understand its origin.
- Detailed studies of particularly interesting individual systems, e.g., the asymmetric radio source in LGG 113 / NGC 1550.
- Expanding the sample to include southern and spiral-dominated groups.



CLoGS gallery: Each panel shows an adaptively smoothed 0.5-2 keV image of a CLoGS group, with an 2.5'x2.5' optical (DSS or SDSS) image of the dominant early-type galaxy inset. For radio-detected systems, GMRT 610 or 235 MHz contours are overlaid.

http://www.sr.bham.ac.uk/~ejos/CLoGS.html