CLoGS: The Complete Local-Volume Groups Survey

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Galaxy groups contain >50% of the galaxies in the local Universe, and a similar fraction of the total mass. Groups bring galaxies into close proximity at low relative velocities, promoting tidal interactions and mergers, and represent the mass scale at which the hot intergalactic medium (IGM) begins to make up an important fraction of baryon content. The group environment is therefore important to our understanding of cosmic structure, galaxy evolution, and the role of AGN in governing star formation and IGM cooling. Unfortunately there is currently no statistically complete, representative sample of groups with which to investigate these issues.

Selecting a representative group sample is difficult. Their small number of member galaxies mean that optically-selected catalogues are usually contaminated by uncollapsed systems and chance superpositions. X-ray-selected samples are known to be biased toward systems with cool cores, which produce an easily-detected central surface brightness peak (e.g., Eckert et al. 2011). CLoGS aims to resolve these problems by assembling the first statistically complete, optically-selected sample of nearby groups observed in the X-ray, optical and radio.

Group selection: Groups are chosen from the Lyon Galaxy Group catalogue (Garcia 1993), and are required to contain ≥4 galaxies with L_B>3x10^{10} $L_\odot$, of which ≥1 must be early-type. Groups containing early-type galaxies are more likely to have a detectable IGM (Mulchaey et al. 2003) and have evidently undergone some galaxy evolution. Groups are also required to have Dec.>-30° to ensure coverage by the VLA and GMRT observatories.

Observations: GMRT 610 and 235 MHz observations of the full sample (totalling 168 hours) have been completed and are now being processed. *XMM-Newton* (279ks) and *Chandra* (50ks) observations to complete the richer half of the sample have also been completed, and we expect to publish the first results from the survey during 2013. Below we show some example groups from the sample with a range of morphologies, X-ray and radio properties.

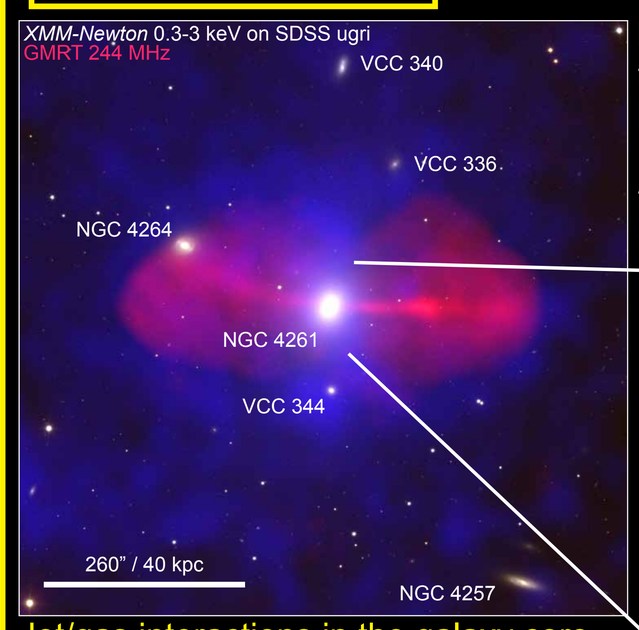
High-Richness Subsample

The 26 group subsample, itself statistically complete, contains those groups with richness R≥4 (i.e., 4+ galaxies with L_B>3x10^{10} $L_\odot$). X-ray and low-frequency radio observations of the subsample are now complete.

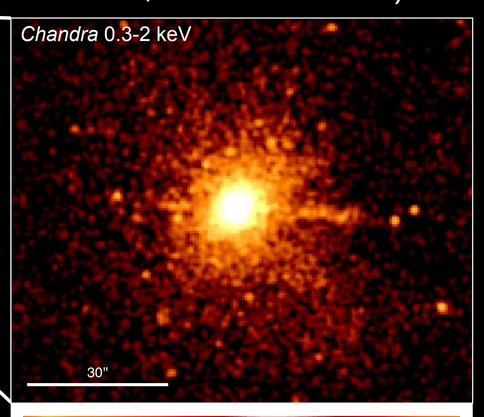
LGG	BGE	D (Mpc)	R	σ (km/s)	X-ray	Radio	LGG	BGE	D (Mpc)	R	σ (km/s)	X-ray	Radio
072	NGC1060	76	8	496	**X**	**610,235**	473	NGC7619	54	8	466	X,C	610,235
009	NGC193	74	7	493	C	610,235	031	NGC677	78	7	249	**X**	**610,235**
066	NGC978	69	7	209	**X**	**610,235**	278	NGC4261	32	7	743	X,C	610,235
351	NGC5153	60	7	251	**C**	**610,235**	363	NGC5353	35	7	240	X,C	**610,235**
018	NGC410	77	6	393	X,C	**610,235**	158	NGC2563	65	6	379	X,C	**610,235**
185	NGC3078	34	6	1013	C	**610,235**	042	NGC777	73	5	291	X,C	**610,235**
338	NGC5044	38	5	336	X,C	610,235	393	NGC5846	26	5	717	X,C	610,**235**
027	NGC584	25	4	160	**C**	**610,235**	058	NGC940	74	4	229	**X**	**610,235**
061	NGC924	64	4	126	**X**	**610,235**	080	NGC1167	72	4	94	X	**610,235**
103	NGC1453	63	4	537	**X**	**610,235**	117	NGC1587	51	4	126	C	610,235
262	NGC4008	54	4	230	**X**	**610,235**	276	NGC4169	45	4	93	X	**610,235**
310	ESO507-25	45	4	557	**C**	**610,235**	345	NGC5084	23	4	680	**C**	**610,235**
402	NGC5982	44	4	230	**X**	**610,235**	421	NGC6658	63	4	241	**X**	**610,235**

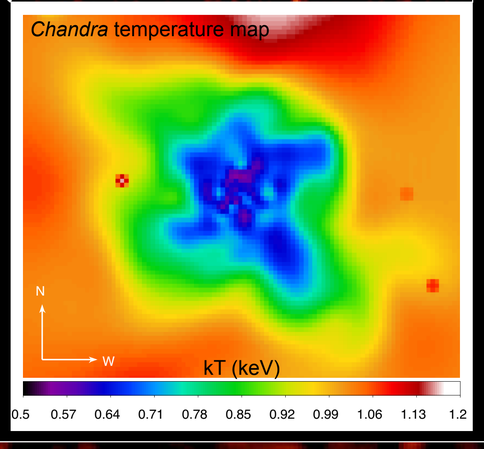
LGG is Lyon Galaxy Group number (from Garcia et al. 1993), BGE indicates the Brightest Group-member Elliptical, D is distance to the group in Mpc, R is richness, σ is the estimated group velocity dispersion, X-ray indicates whether *Chandra* (C) or *XMM-Newton* (X) observations are available, and Radio shows the frequencies of GMRT observations which are available (in MHz). **Bold, yellow entries indicate new observations made for the CLoGS project**

LGG 278 / NGC 4261



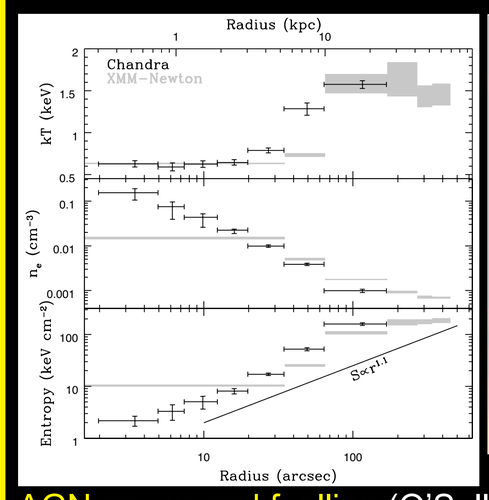
LGG 278 is a 1.6 keV group on the outskirts of the Virgo cluster. Its dominant elliptical, NGC 4261, hosts the brightest radio source in the CLoGS sample, 3C270 (19 Jy at 1.4 GHz, Condon et al. 2002)

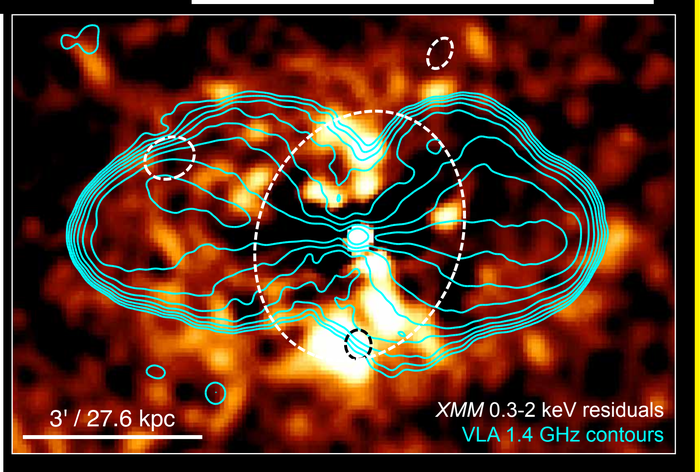




Jet/gas interactions in the galaxy core

- Chandra imaging (right) shows 2-sided X-ray jets → axis close to plane-of-sky.
- Wedge-shaped intensity depressions north & south of jets → ~20% of volume in the central 10 kpc has been cleared of hot gas by the jets (Worrall et al. 2011).
- X-ray temperature map shows an X-shaped structure in the coolest gas → jets have pushed aside gas without driving shocks into the cool core.





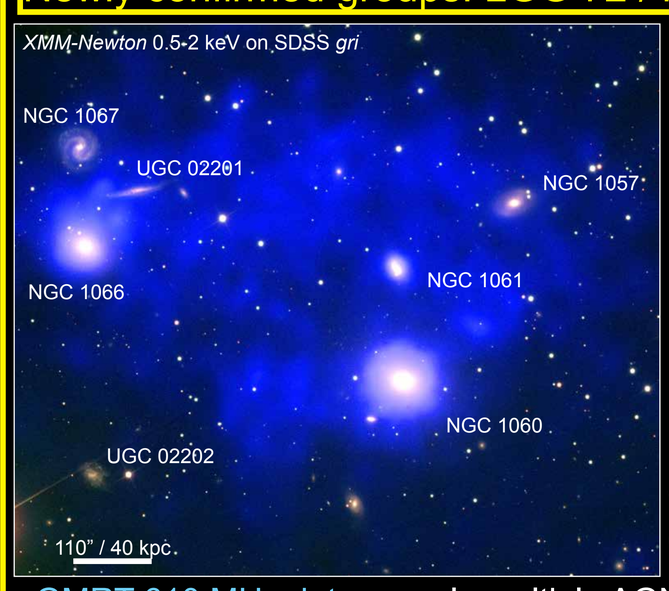
AGN power and fuelling (O'Sullivan et al. 2011)

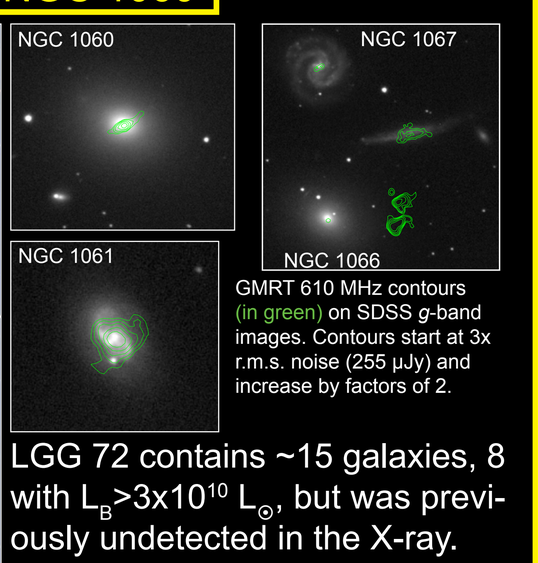
- *XMM* residual map (above) shows IGM cavities associated with both lobes, total enthalpy of the two cavities is 4pV = 2.4x10^{58} erg.
- Bright rims of compressed gas suggest that the source is expanding at roughly the local sound speed, so age < 75Myr → AGN power = 10^{43} erg/s.
- Since the core is still cool, jet heating must be ≤3.5% efficient, and conduction from group halo must be suppressed to ~20% of the Spitzer rate.
- NGC 4261 has a galactic corona, a 10 kpc cool core capable of fuelling the AGN and which is formed from and maintained by stellar mass loss from the stars in that small volume. No group-scale cooling flow is required!

Future plans

We are using spectral index maps to investigate the interaction between radio source and X-ray halo. Steep spectral indices between the two lobes correlate with a bar-like X-ray structure and depolarization (Guidetti et al. 2011), possibly indicating gas mixing.

Newly confirmed groups: LGG 72 / NGC 1060



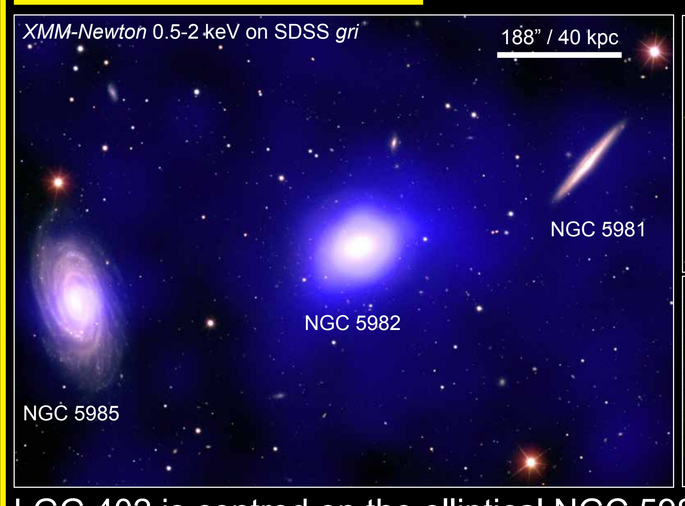


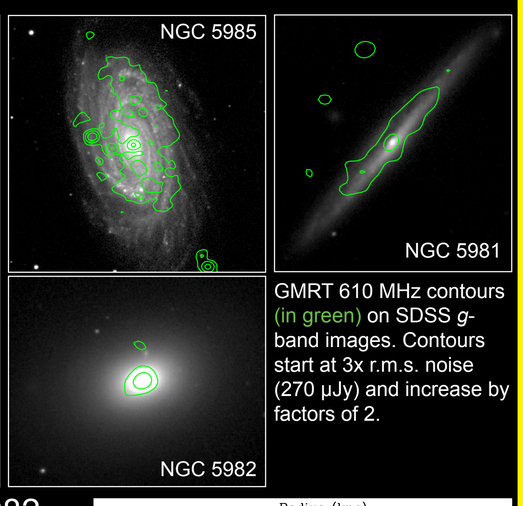
GMRT 610 MHz contours (in green) on SDSS *g*-band images. Contours start at 3x r.m.s. noise (255 μJy) and increase by factors of 2.

LGG 72 contains ~15 galaxies, 8 with L_B>3x10^{10} $L_\odot$, but was previously undetected in the X-ray.

- GMRT 610 MHz data reveals multiple AGN, including small-scale jets in NGC 1060, and star-formation emission from two disk galaxies.
- A ~36 ksec *XMM* observation reveals a disturbed, merging system.
- NGC 1066 has a line-of-sight velocity of ~840 km/s relative to NGC 1060, equivalent to Mach ~2 in the 1.1 keV IGM → We have proposed a *Chandra* observation to examine the expected shock and ram-pressure stripping.

LGG 402 / NGC 5982

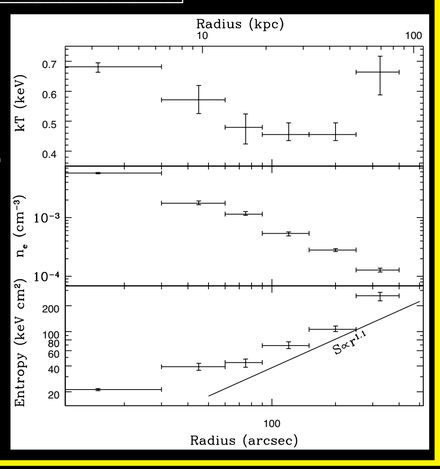




GMRT 610 MHz contours (in green) on SDSS *g*-band images. Contours start at 3x r.m.s. noise (270 μJy) and increase by factors of 2.

LGG 402 is centred on the elliptical NGC 5982, with two large spiral galaxies nearby.

- GMRT 610 MHz observations reveal AGN in all three galaxies, star formation in the disk galaxies.
- ~12 ksec XMM pointing detects a relatively faint (L_X=2x10^{41} erg/s) IGM which falls on scaling relations (L:T, σ:T, etc).
- No cool core detected at 6.4 kpc resolution, despite low central entropy (13.6±0.1 keV cm^2) .
- We have proposed a short (20 ksec) *Chandra* pointing to confirm the lack of a cool core.



Project website: http://www.sr.bham.ac.uk/~ejos/CLoGS.html
Poster: http://figshare.com/article/HEAD_2013_pdf/654621

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