Radio observations of nearby groups of galaxies with CLoGS: The Complete Local-Volume Groups Survey

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More than 50% of galaxies and most of the baryonic matter in the local Universe reside in groups (Eke et al. 2004). Many of them host radiative cooling gas halos, which can fuel a central SMBH, thus groups are probably the key environment for the study of AGN/hot gas interactions. The CLoGS sample consists of 53 candidate groups in the local Universe (<80 Mpc), with optical data already available (from, e.g., LEDA), X-ray data from the Chandra and XMM-Newton X-ray observatories and low-frequency radio data from the Giant Metrewave Radio Telescope. By focusing on low-frequency radio emission from GMRT (240 MHz and 610 MHz), past as well as current AGN activity can be identified with the use of radio spectral index maps by taking advantage of the combination of good spatial resolution at 610 MHz and the sensitivity to older electron populations at 235 MHz. The combination then of radio with optical and X-ray bands reveals the complex interactions with their environment and the physical processes that govern galaxy transformations. These are all important for the investigation of the IGM/AGN connection and the understanding of the physical mechanisms of the energy injection (AGN feedback). **Unfortunately, the study of AGN feedback in groups is currently hindered by an important obstacle: the lack of a statistically complete radio/X-ray sample of nearby groups.**

The CLoGS project aims to be the first statistically complete survey of galaxy groups observed in the X-ray, optical and radio wavebands. While complete, representative samples of galaxy clusters with high-quality X-ray data are available, the best available samples of groups are non-statistical collections of systems. The small number of member galaxies in groups means 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).

Main science goals include:

- Determining the basic physical properties of a representative sample of groups for the first time
- Examining the temperature and density structure of the gaseous halos of groups, the ability of groups to retain gas, and the fraction of systems with central cooling cores
- Characterization of the AGN population in groups, and examination of their impact on the intra-group gas and member galaxies
- Identification of new groups and new classes of groups, such as the high entropy systems predicted by simulations (e.g., McCarthy et al. 2010)
- Study of the galaxy population of groups, and the relationships between galaxies, their groups, star formation and nuclear activity

High-Richness Subsample

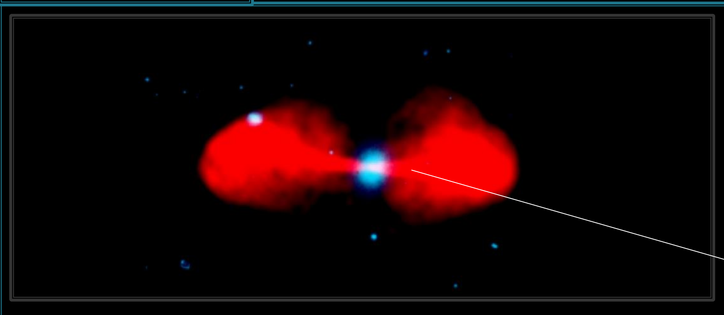
The 26 group subsample, itself statistically complete, contains those groups with richness R≥4 and galaxies with $L_B > 3\times10^{10}\ L_\odot$.

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	493C		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**

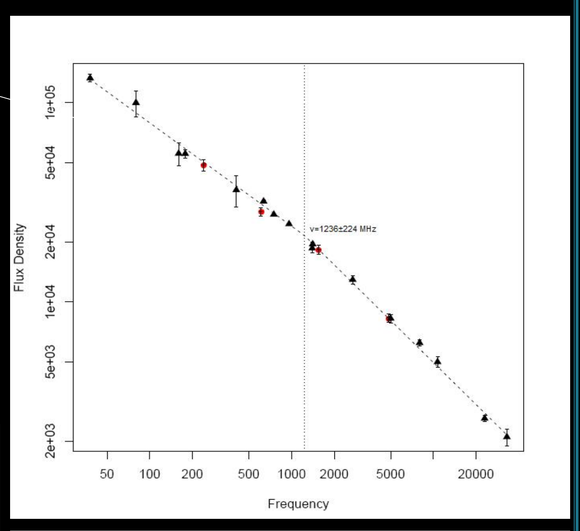
LGG is Lyon Galaxy Group number (from Garcia et al. 1993), BGE indicates the Brightest Group-member Elliptical, D is distance to the group in Mpc, R is richness, σ is the estimated group velocity dispersion, X-ray indicates whether Chandra (C) or XMM-Newton (X) observations are available, and Radio shows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

Group selection: Groups are chosen from the Lyon Galaxy Group catalogue (Garcia 1993), and are required to contain ≥4 galaxies, of which ≥1 must be early-type, with $L_B > 3\times10^{10}\ L_\odot$. 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.

LGG 278 / NGC 4261

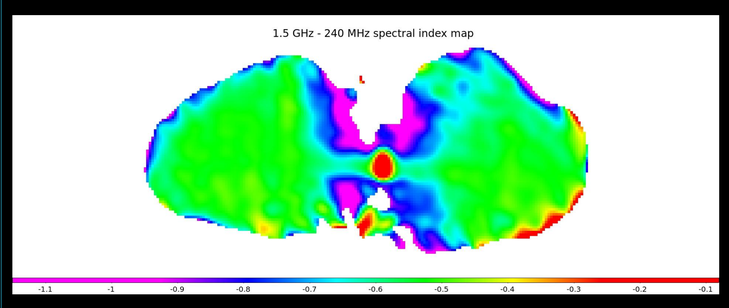


LGG 278 is a group at the outskirts of the Virgo cluster (z~0.0075) and its brightest elliptical NGC 4261 hosts the brightest radio source in the CLoGS sample, 3C270 (19 Jys at 1.4 GHz, Condon et al 2002)



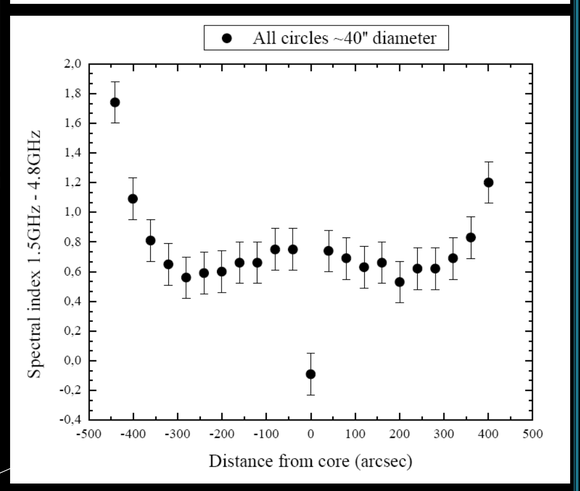
Analysis and timescales

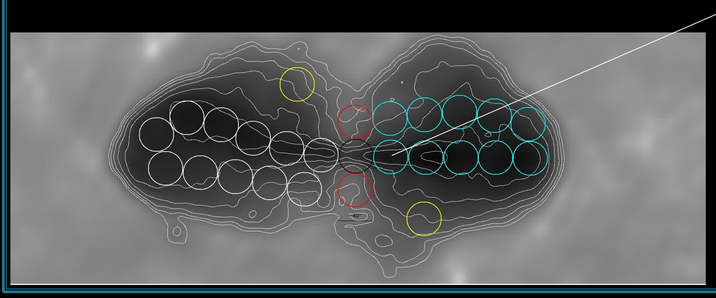
- Red points on the right represent GMRT (240 MHz, 610 MHz) & VLA (1.5 GHz, 4.8 GHz) data coupled with data from literature ⟶ Broken powerlaw fit gives a break frequency: 1236±224 MHz
- Radiative age of a radiosource is calculated by the break frequency (Myers & Spangler 1984) ⟶ Estimated age of NGC 4261 radiosource is ~74.6 Myrs (in agreement with X-ray upper limit, 75 Myrs, noted in O'Sullivan et al. 2011)



Spectral index map

- The core appears with a flat spectral index of ~0.15 ⟶ New radio emitting e^- population
- Jets appear with a spectral index of ~0.5
- Lobes have almost uniform spectral index of ~0.55 ⟶ Wide frequency range reduces sensitivity of the spectral features (steepenings or curvatures)
- Steeper values of ~1.2 between the two lobes ⟶ Possibly indicates gas mixing (Guidetti et al. 2011)





Radio spectral index profile

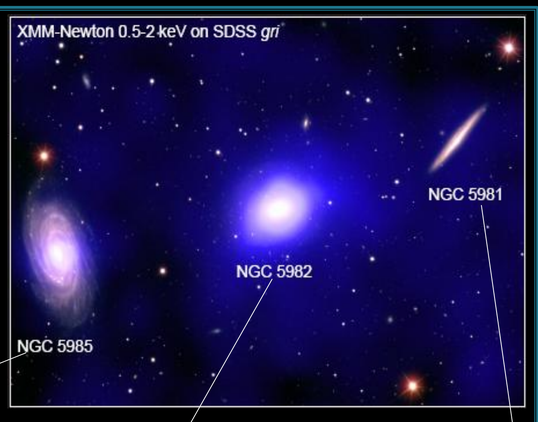
- Each point above ⟶ Average over a circular region ⟶ presumed course of the radio plasma
- Steep spectrum beyond 300 arcsecs (>1) ⟶ Ageing of electron population ⟶ Backflow of radio plasma from the hotspots
- Spectral indices (>0.5) along the jet, 0-300 arcsec, indicate mixture of e^- populations along the line of sight (Kolokythas et al. 2013 in prep)

Future Plans for NGC4261

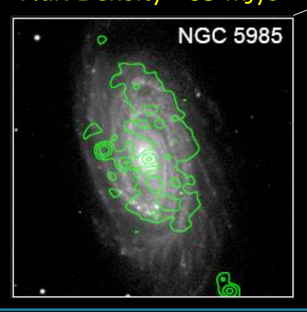
- Improve the calculation of the internal properties of the radio lobes (B_{eq}, pressure, k/ϕ, etc), and estimate the age from the spectral index profile.
- An integrated spectra of the different source components using all frequencies available. This could help us to understand better the spectral index distribution over the source.

LGG 402 / NGC 5982

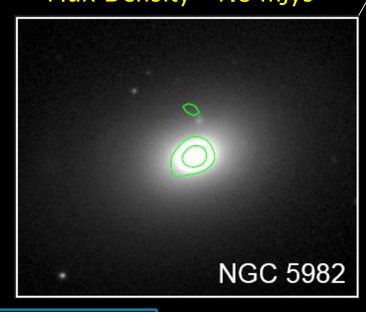
- In LGG 402 group the elliptical NGC 5982 is in the center, with two large spiral galaxies nearby ⟶ face on NGC 5985 and edge on NGC 5981
- GMRT 610 MHz observations reveal AGN in all three galaxies, as well as star formation emission from the disk galaxies.
- ~12 ksec XMM pointing detects ~0.5 keV group halo out to ~85 kpc
- The three images below show the 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



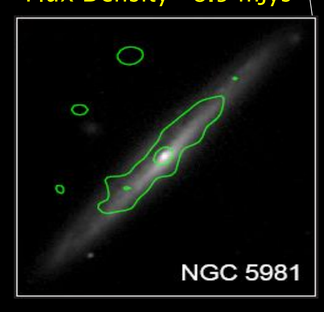
Flux Density ~83 mJys



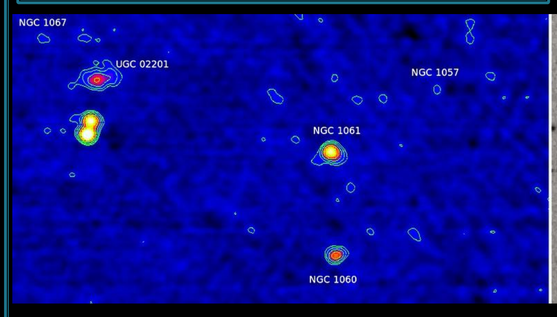
Flux Density ~1.8 mJys

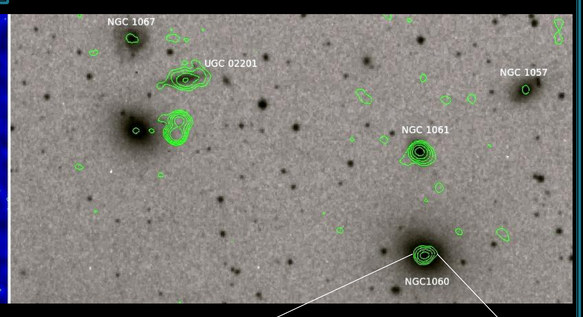


Flux Density ~8.5 mJys



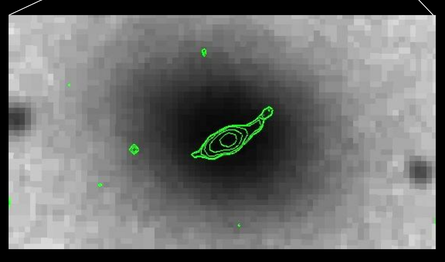
Newly confirmed group: LGG72 / NGC 1060



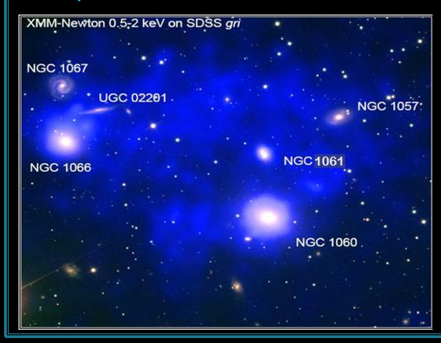


Top: GMRT 235 MHz contours (in green) on SDSS g-band image. Contours start at 3 x r.m.s. noise (1.56 mJy) and increase by factors of 2

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



- GMRT 610 MHz data reveals multiple AGN, including small-scale jets in NGC 1060 and star-formation emission from two disk galaxies
- Linear size of the NGC1060 jet at 610 MHz is ~10Kpc



- Flux Densities of NGC1060: ~12 mJys at 610 MHz, ~30 mJys at 235 MHz

X-rays

- LGG 72 contains ~15 galaxies, 8 with $L_B > 3\times10^{10}\ L_\odot$, and was previously undetected also in the X-ray
- A ~36 ksec XMM observation traces the ~1 keV halo out to 310 kpc
- The X-ray halo is disturbed - NGC 1066 may be falling through the group

Full project team:

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

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