AGN Feedback in Galaxy Groups: Joint X-ray and Radio Studies

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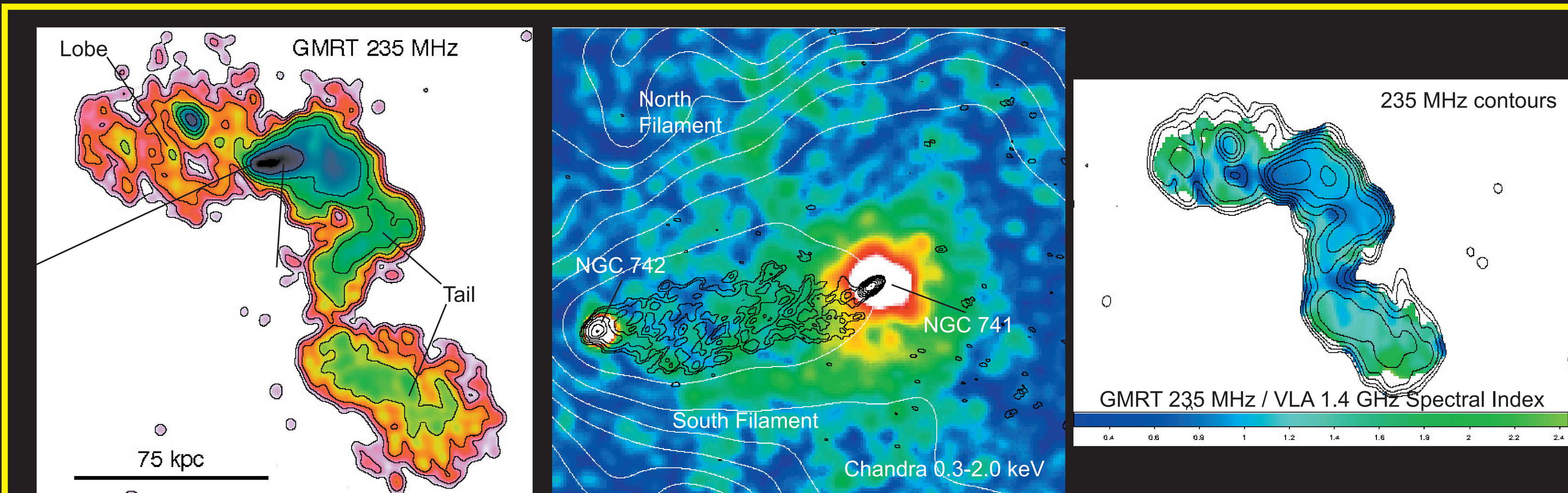
Motivation and Results

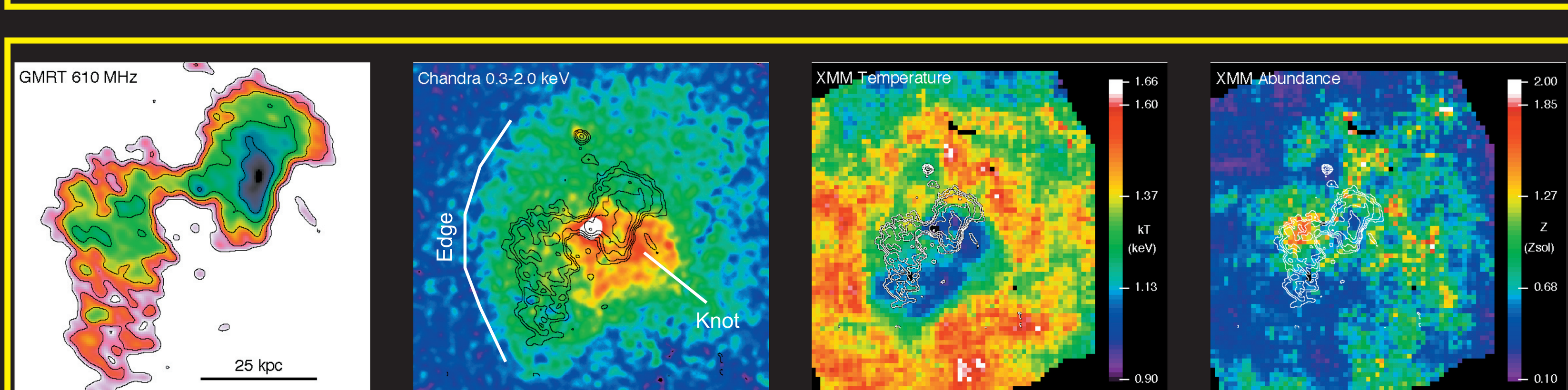
Elliptical galaxies with powerful radio sources frequently occupy the central regions of galaxy groups and clusters. The interactions of these radio sources with the hot X-ray emitting gas, visible through cavities and edges often spatially correlated with radio emission, form part of the motivation for the growing acceptance of AGN feedback as a principal mechanism for the regulation of cooling flows. While most studies of AGN feedback to date have focused on galaxy clusters, the majority of galaxies in the Universe reside in galaxy groups (Eke et al. 2004). Outbursts in groups are less energetic and physically smaller, but as the group potential is shallower their impact, both energetically and structurally, can be very significant (e.g., Croston et al. 2005). We have therefore chosen to carry out a study of gas-AGN interactions at the group scale.

Results.

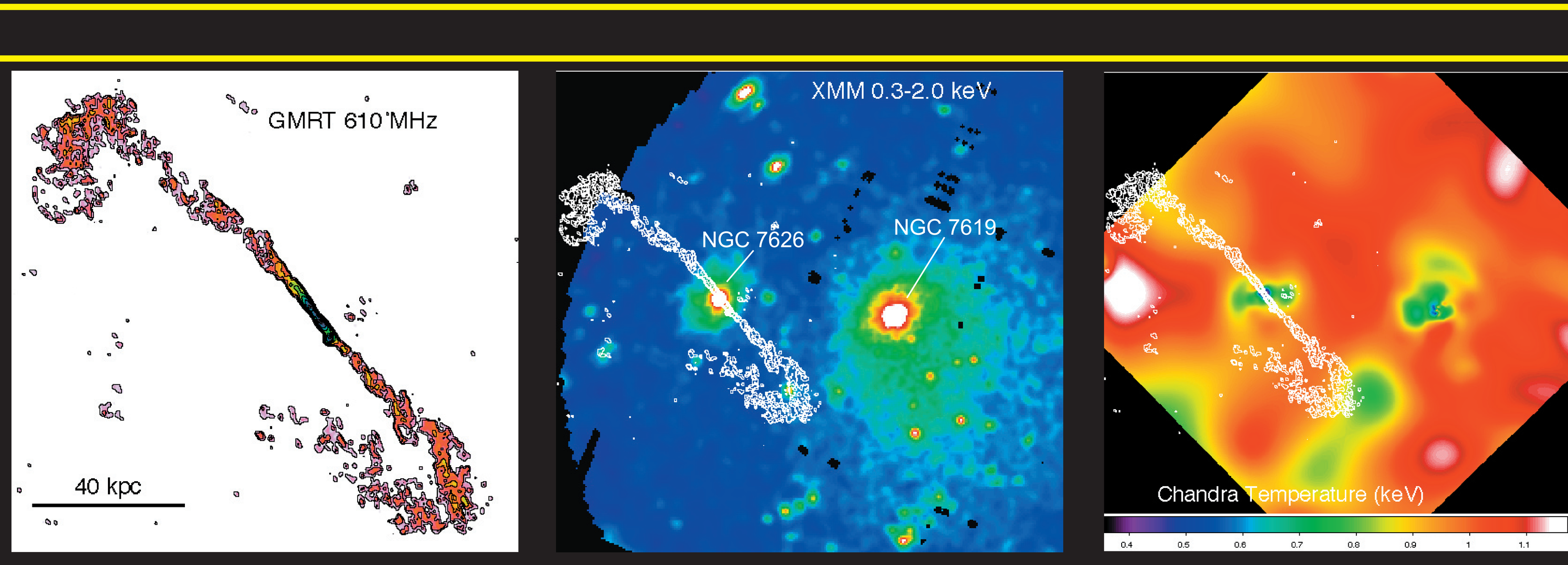
Below we present a gallery of observations from some of the more interesting systems for which observations are complete. The NGC 3411 group (below right) is used to illustrate the detailed analysis that is possible. For further results from this project, please see also the talk by Gitti et al on HCG 62 (Wednesday afternoon) and the posters by Giacintucci et al on AWM 4 and by David et al on NGC 5044. An extension of this work to spiral-dominated groups is shown in the poster by O'Sullivan et al on Stephan's Quintet (HCG 92).



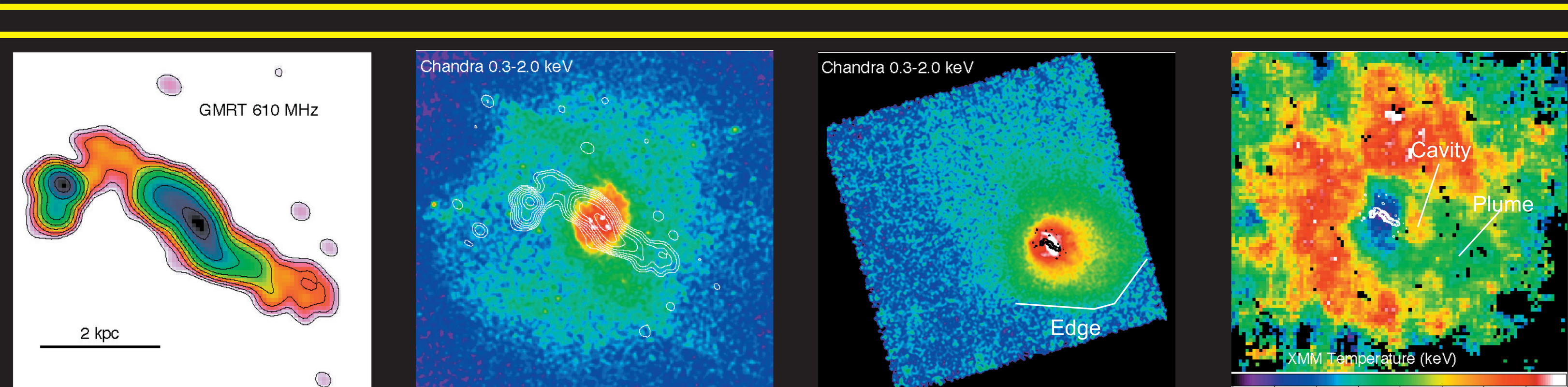
NGC 741: A complex system of two radio galaxies. The ~100 kpc tail has been left behind by the smaller elliptical NGC 742, which is passing through the group core at high speed (>400 km/s). Older outbursts from NGC 741 have formed a lobe to the east and a ghost cavity to the west (Jetha et al. 2008). X-ray filaments are found in the core, one linking the two galaxies and running along the edge of the southern jet of NGC 742.



NGC 507: A powerful FR-I radio galaxy, the two radio lobes are distorted. The Eastern lobe correlates with an X-ray surface brightness edge, formed by a combination of low temperature and high abundance regions. The Western lobe wraps around a knot of high density, low temperature gas, and correlates with a region of low abundance - a possible cavity.



NGC 7626 / NGC 7619: This group is dominated by two ellipticals. NGC 7626 is a luminous radio galaxy with straight jets which curl to the south at their ends. NGC 7619 is more X-ray luminous but shows signs of motion, a surface brightness edge and tail extending southwest. A prior interaction between the two may have triggered the AGN outburst.



NGC 4636: This system shows strong disturbed features at a variety of scales; a complex of shocks and cavities at small scales, correlating with the radio lobes (Jones et al. 2002). At larger scales, there is a surface brightness edge to the south and southwest, correlating with an extended region of cool, high abundance emission, which contains a ghost cavity only visible in the temperature map (O'Sullivan et al. 2005b). This may be a plume of material drawn out of the core by entrainment behind a series of previous rising bubbles.

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Targets and Observations

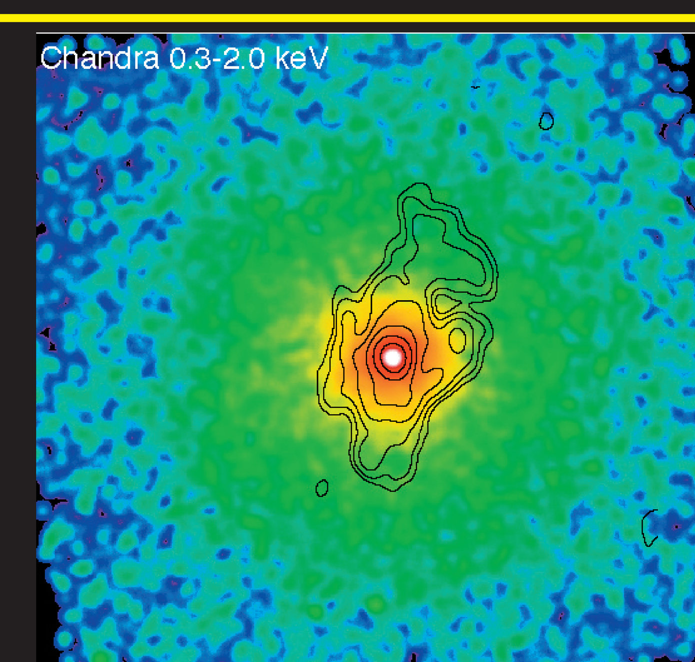
18 Groups selected from the Chandra and XMM-Newton archives.

Systems were selected to have disturbed X-ray structures and/or radio morphology. 13 have exposures from both satellites available, providing the high spatial resolution necessary to identify shocks and cavities, and the deep integrations necessary to allow temperature/abundance mapping. Low-frequency observations are most sensitive to the faint, aging populations of old radio sources. We are therefore performing a survey of our sample using the Giant Metrewave Radio Telescope, initially at 610 and 235 MHz, and supplemented by 325 MHz and, recently, 150 MHz data. Typical integrations are 2-4 hours.

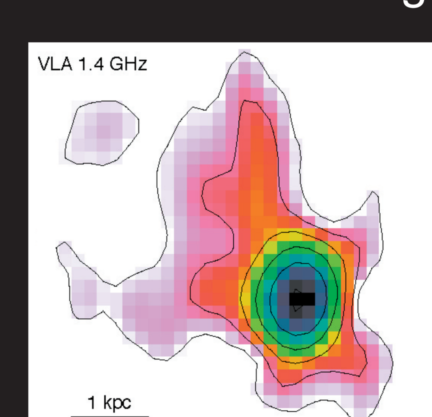
		$\log L_x$	S(1.4 GHz)	X-ray exposures (ks)			GMRT data		
Group name	z	(erg s^{-1})	(mJy)	ACIS-I	ACIS-S	XMM	235 MHz	325 MHz	610 MHz
UGC 408	0.0147	41.40	1710		108		X		X
NGC 315	0.0165	41.57	2010	50		18	X		X
NGC 383	0.0170	42.72	4862		43	73	X		X
NGC 507	0.0165	42.95	99	17	43	33	X		X
NGC 741	0.0185	42.50	1066		28	8	X		X
HCG 15	0.0208	42.25	25			31	X		X
NGC 1407	0.0059	41.92	86		30	38	X		X
NGC 1587	0.0123	41.53	132		19		X		X
MKW 2	0.0368	42.32	385			40	X		X
NGC 3411	0.0153	42.51	38		18	22	X		X
NGC 4636	0.0031	41.71	78	148	38	58	X		X
HCG 62	0.0137	43.20	5	9	167	96	X		X
NGC 5044	0.0090	43.09	36		100	34	X	X	X
NGC 5813	0.0066	42.06	15		148	28	X		
NGC 5846	0.0057	42.04	21	90	18	25			X
AWM 4	0.0318	43.30	608		74	16	X	X	X
NGC 6269	0.0348	43.20	50	39			X		X
NGC 7626	0.0114	42.05	860	26	27	33	X		X

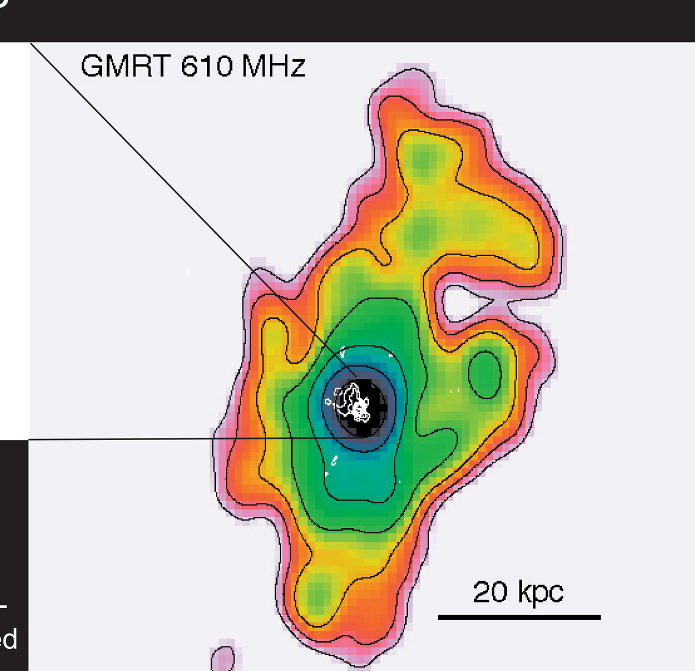
NGC 3411: Heating without Jets?

- NGC 3411 is the dominant elliptical of an X-ray luminous (L_X=6.5x10^{43} erg/s), ~0.8 keV group.
- VLA 1.4 GHz observations find only a faint (~8.3 mJy), marginally extended radio source, with no indication of jets.
- Chandra and XMM-Newton imaging reveal no structures in the IGM.
- X-ray temperature maps reveal central hot core surrounded by a cool shell, suggesting the core has been reheated. Minimum energy required: 2x10^{57} erg (O'Sullivan et al. 2007)
- GMRT 610 & 235 MHz observations reveal extended radio emission, spatially correlated with hot region, with core-halo configuration.

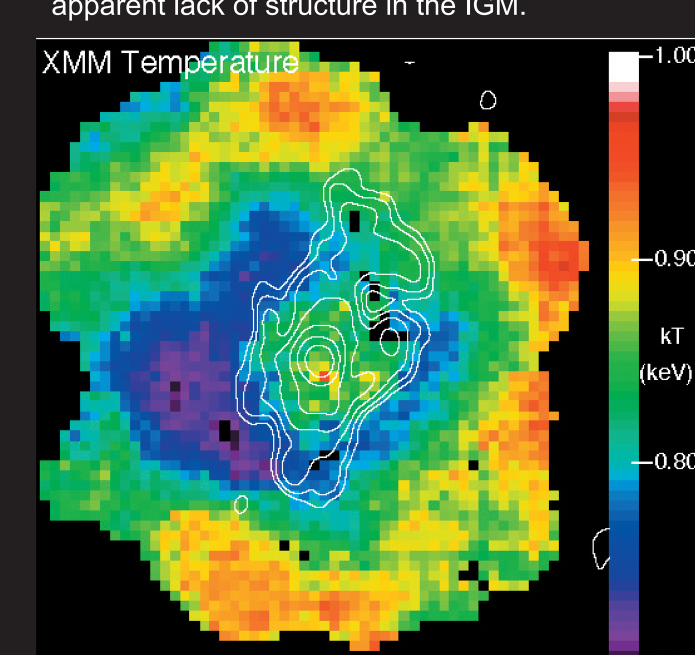


Gaussian smoothed Chandra 0.3-2.0 keV image with GMRT 610 MHz contours overlaid. Note the apparent lack of structure in the IGM.





Above: VLA 1.4 GHz A-array observation showing marginally extended source in the galaxy core.
Right: GMRT 610 MHz observation showing more extended radio halo.

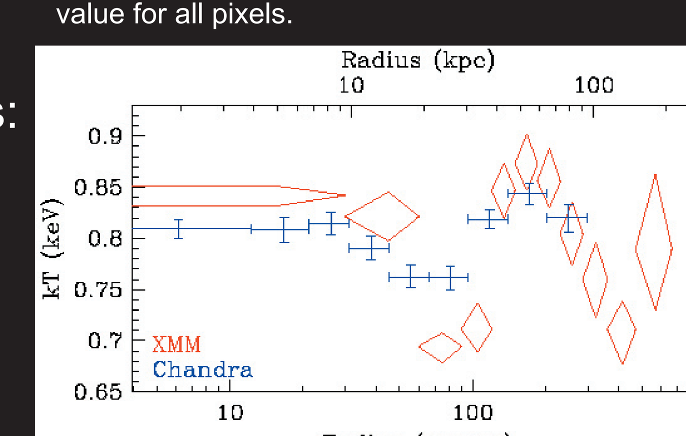


XMM-Newton temperature map of NGC 3411. 90% uncertainties on kT are <7.5% of the fitted value for all pixels.

Two possible structures could explain the observations:

1) A jet-lobe source aligned along the line of sight. But we see no evidence of cavities in the core.

2) There are no jets. The hot core is a region of mixed radio and X-ray plasma, probably heated by shocks. NGC 3411 may be an example of a new type of AGN/IGM interaction, allowing feedback on small scales without the need to sustain jets or form cavities.



Chandra and XMM-Newton deprojected gas temperature profiles with 90% uncertainties.

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