A Combined X-ray/Low-Frequency Radio Survey of Feedback in Galaxy Groups

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Motivation and Sample

While most studies of AGN feedback to date have focussed 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.

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

Systems were selected to have disturbed X-ray structures and/or radio morphology. 12 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.

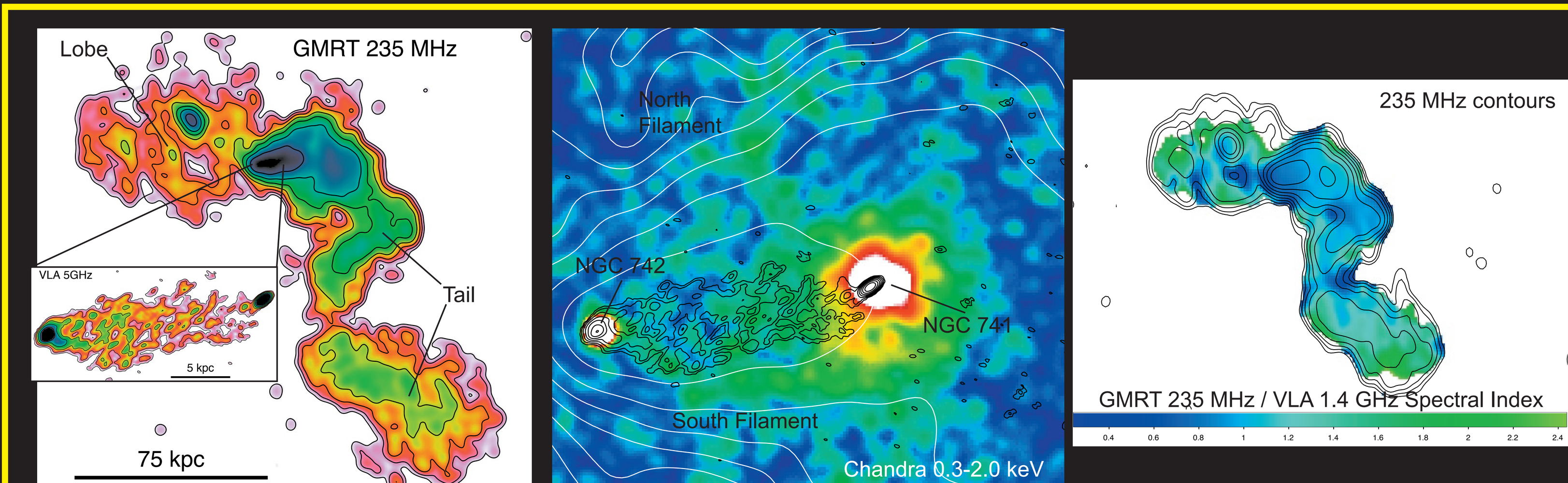
A GMRT radio survey.

Low-frequency observations are most sensitive to the faint, aging populations of old radio sources, and offer the opportunity to detect systems which never produced high-energy electrons. We are therefore performing a survey of our sample using the Giant Metrewave Radio Telescope, initially at 610 and 235 MHz, with typical exposures of 2-4 hours. Archival VLA data are available for most of our groups at higher frequencies.

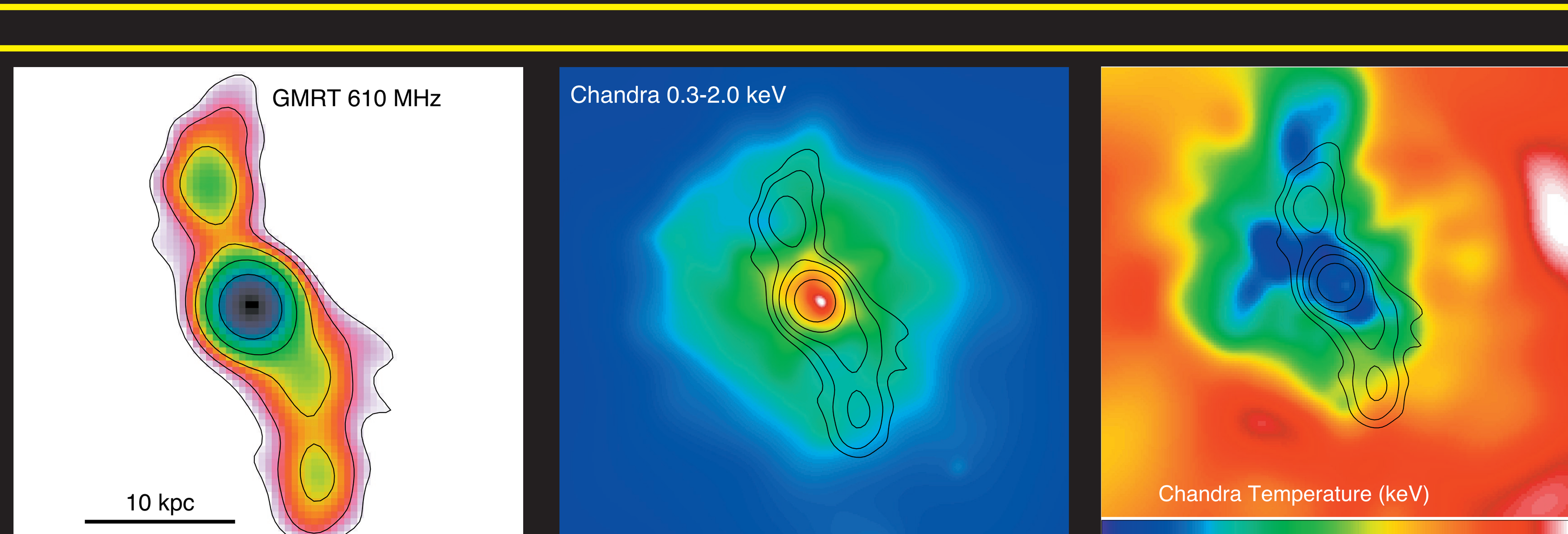
Results:

In this poster we present a gallery of observations from some of the more interesting systems in our sample for which observations are complete. Below right we show an example of the more detailed analysis we plan to carry out for each system, using the NGC 3411 group.

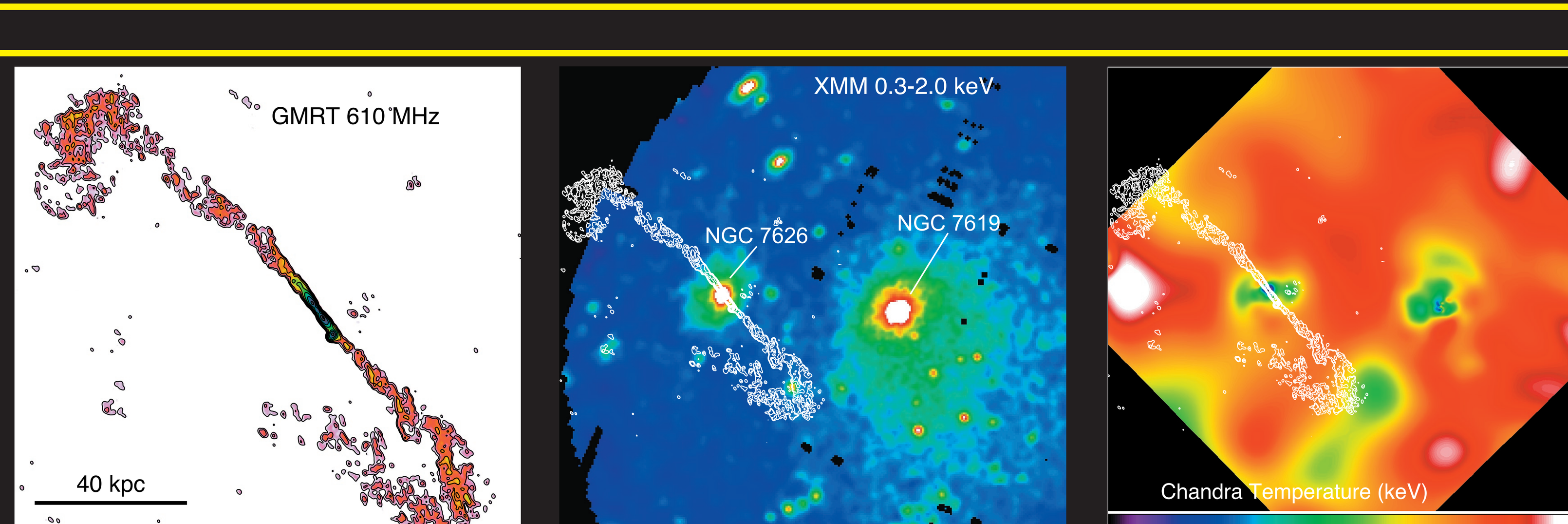
See also talks by Giacintucci and Raychaudhury (Thursday, session VI) for analyses of our hottest system, AWM 4 (Giacintucci et al. 2008), and new results from NGC 741 and HCG 62.



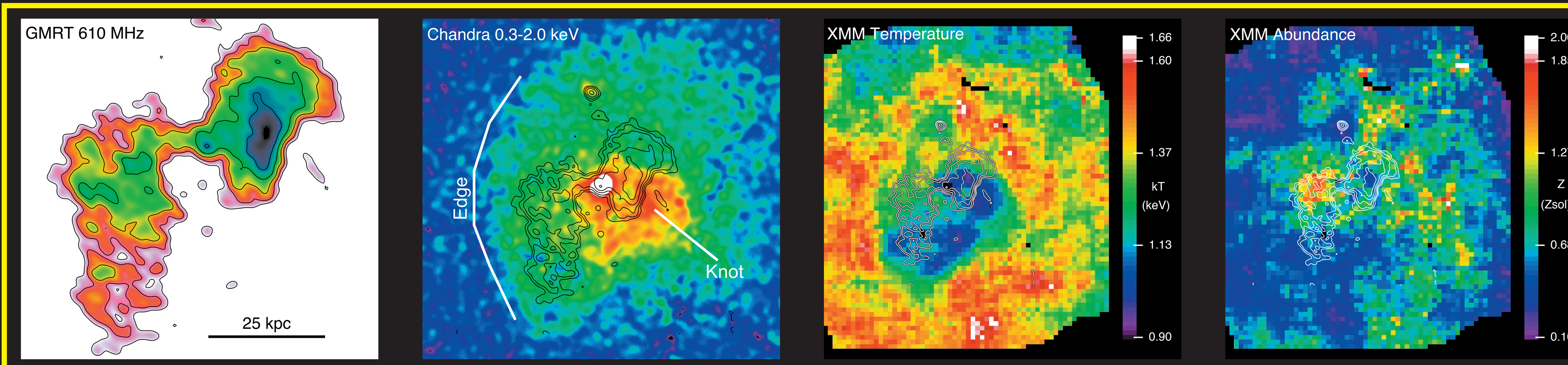
NGC 741: A complex system of two radio galaxies. The ~100 kpc tail has been left behind by the smaller elliptical NGC 742, which is passing through the group core at high speed (>400 km/s). Older outbursts from NGC 741 have formed a lobe to the east and a ghost cavity to the west (Jetha et al. 2008). 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. For more details, see talk by Raychaudhury (Thursday).



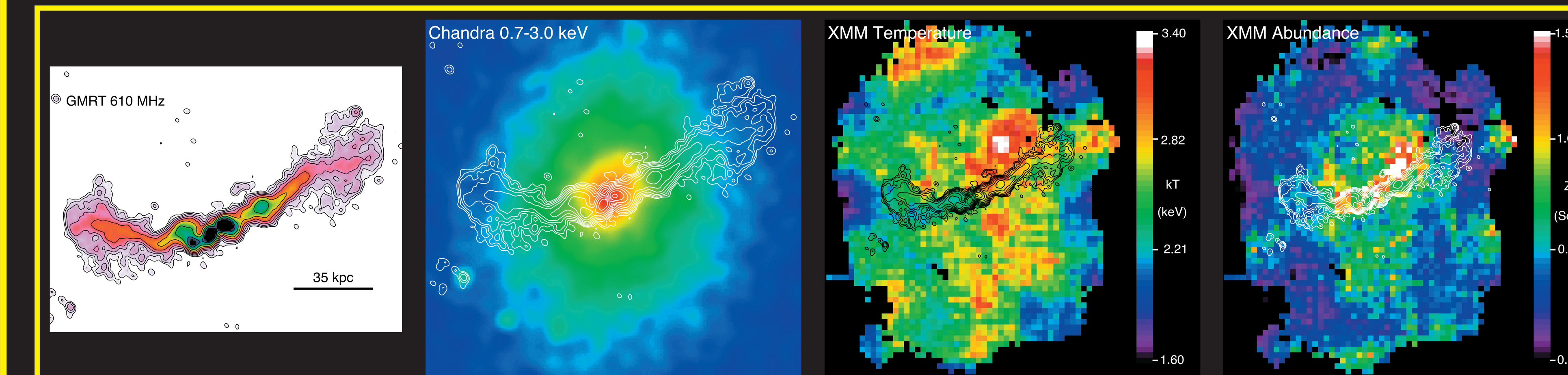
HCG 62: The system has some of the clearest cavities of any galaxy group (e.g., Bîrzan et al. 2004). At high frequencies little radio emission is seen, but our 610 and 235 MHz observations find emission coincident with the southern lobe and partially overlapping the northern lobe and a cool region along one of the cavity limbs. See Raychaudhury talk (Thursday).



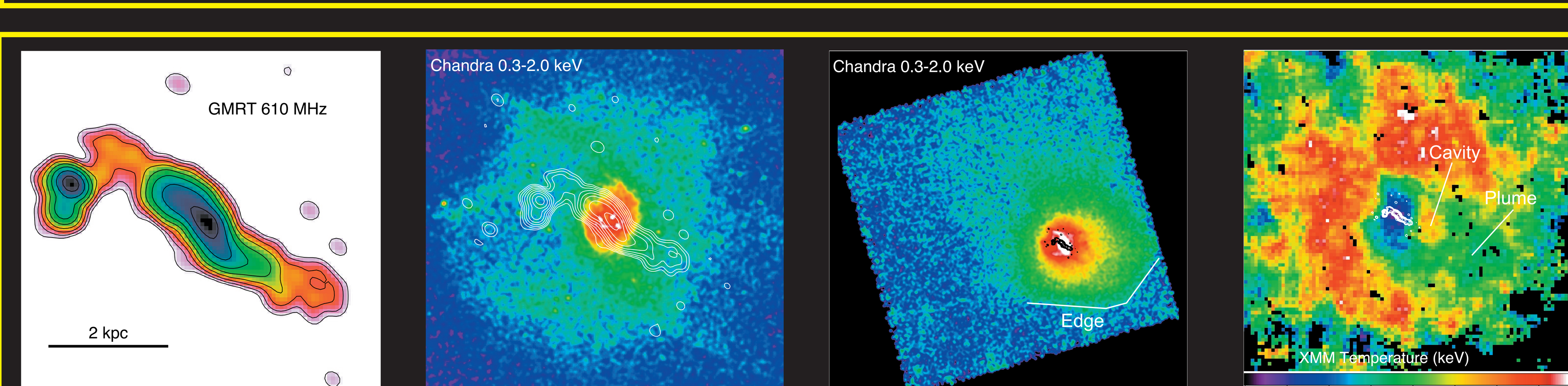
NGC 7626 / NGC 7619: This group is dominated by two ellipticals. NGC 7626 is a luminous radio galaxy with straight jets which curl to the south at their ends. NGC 7619 is more X-ray luminous but shows signs of motion, a surface brightness edge and tail extending southwest. A prior interaction between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



NGC 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.



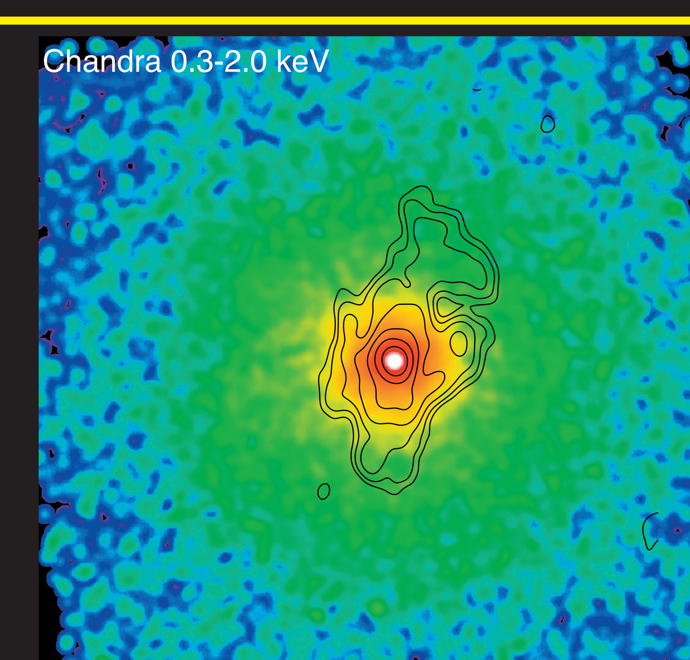
AWM 4: The hottest system in our sample (~2.7 keV) and the most powerful radio galaxy, a wide-angled tail source. There is no sign of a cool core, indicating that the group has been reheated by the AGN outburst. Despite this, there are no cavities or other strong surface brightness features. There are temperature and abundance features associated with the jets, possibly arising from shocks. For more details, see Giacintucci et al (2008), O'Sullivan et al. (2005a), talk by Giacintucci (Thursday).



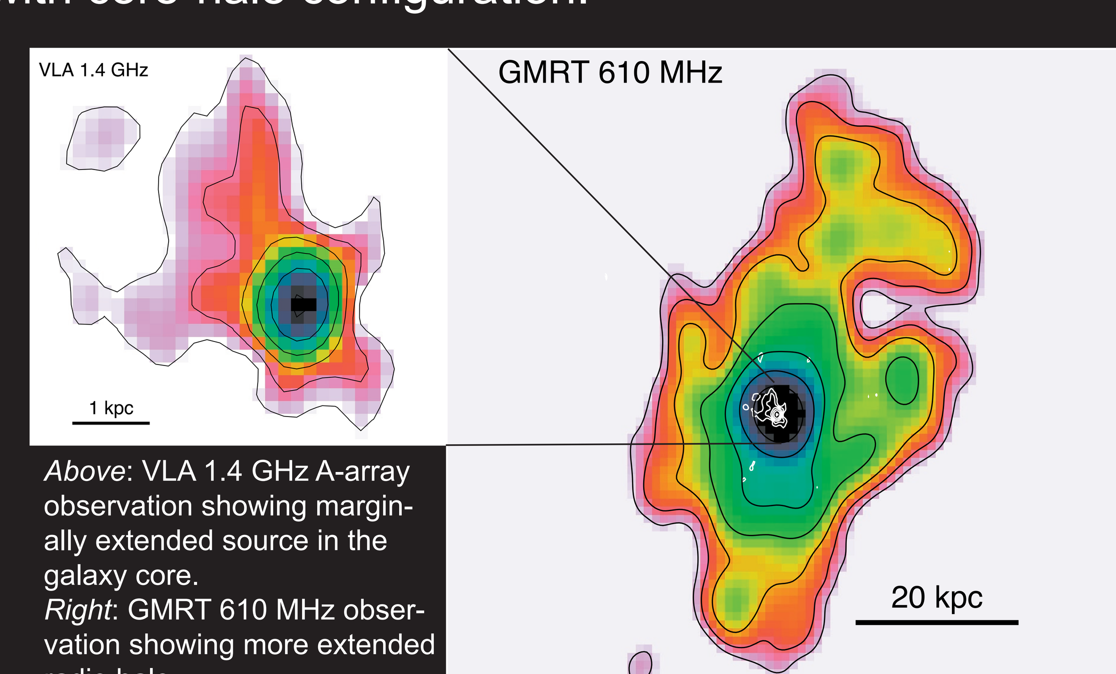
NGC 4636: This system shows strong disturbed features at a variety of scales; a complex of shocks and cavities at small scales, correlating with the radio lobes (Jones et al. 2002). At larger scales, there is a surface brightness edge to the south and southwest, correlating with an extended region of 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.

NGC 3411: Heating without Jets?

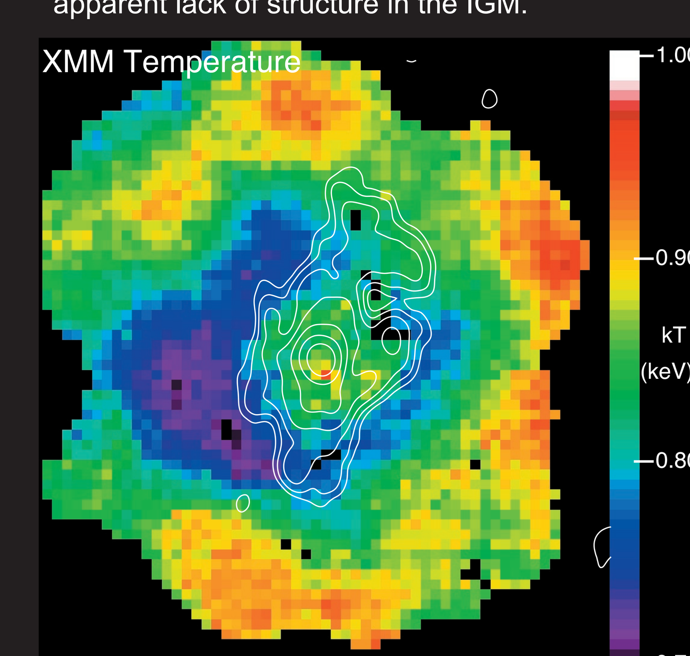
- NGC 3411 is the dominant elliptical of an X-ray luminous (L_X=6.5x10^{43} erg/s), ~0.8 keV group.
- VLA 1.4 GHz observations find only a faint (~8.3 mJy), marginally extended radio source, with no indication of jets.
- Chandra and XMM-Newton imaging reveal no structures in the IGM.
- X-ray temperature 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.



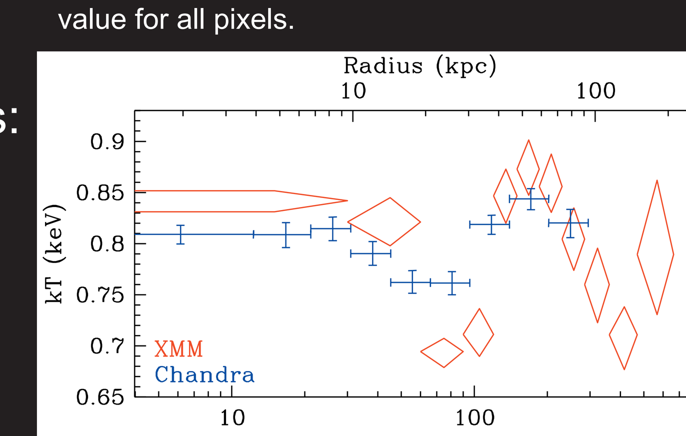
XMM-Newton temperature map of NGC 3411. 90% uncertainties on kT are <7.5% of the fitted value for all pixels.

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.

References

Bîrzan, L. et al., 2004, ApJ, 607, 800
Croston, J.H., Hardcastle, M.J. & Birkinshaw, M., 2005, MNRAS, 357, 279
Eke, V.R. et al., 2004, MNRAS, 355, 769
Giacintucci, S. et al., 2008, ApJ accepted, arXiv 0804.1906
Jetha, N.N. et al., 2008, MNRAS, 384, 1344
Jones, C. et al., 2002, ApJL, 567, 115
O'Sullivan, E. et al., 2007, ApJ, 658, 299
O'Sullivan, E. et al., 2005b, MNRAS, 357, 1134
O'Sullivan, E. et al., 2005a, ApJL, 624, 77

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