BEAMED AND UNBEAMED X-RAY EMISSION IN FR1 RADIO GALAXIES

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Final Report

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The grant funded a number of ROSAT investigations into the soft-X-ray properties of radio-loud AGN. A full publication list is given at the end of the report.

The research exploited ROSAT's sensitivity, together with its spatial and spectral resolution, to separate X-ray emission components in the sources. Prior to ROSAT, the dominant X-ray emission mechanism in radio galaxies as a class was unclear, with correlations between the X-ray and radio emission used on one hand to argue for a nuclear origin for the X-rays, and on the other hand for a thermal origin. Our observations (normally between 10 and 25 ks in length) routinely detected the target sources, and demonstrated that both resolved (thermal) and unresolved X-ray emission are typically present.

Highlights of our work included two of the first detections of high-power radio galaxies at high redshift, 3C 280 and 3C 220.1 (Worrall et al. 1994; Hardcastle, Lawrence & Worrall 1998). When combined with the work of two other groups, we find that of the 38 radio galaxies at $z > 0.6$ in the 3CRR sample, 12 were observed in ROSAT pointed observations and 9 were detected (see summary in Hardcastle & Worrall 1999), with the four most significant detections exhibiting source extent, including 3C 280 and 3C 220.1. Moreover, we discovered extended emission around five 3CRR quasars at redshift greater than about 0.4, one of which is at $z > 0.6$ (Hardcastle & Worrall 1999). Unification predicts that the X-ray environments of powerful radio galaxies and quasars should be similar, and our results show that powerful radio sources are finding some of the highest-redshift X-ray clusters known to date, pointing to deep gravitational potential wells early in the Universe.

To study nearby, low-power (FRI), radio galaxies we turned primarily to the B2 radio galaxy sample. This sample of 50 radio galaxies is now the largest unbiased sample of exclusively low-power radio galaxies studied with sensitive pointed X-ray observations. 40 of the sources were observed in ROSAT pointings, half by us through the various announcements of opportunity as, taking into account sources observed by others, we defined sub-samples with increasingly broader selection criterion so that the largest possible and least biased subset would have been observed at any one time. Following the demise of ROSAT, a summary of the X-ray results for the B2 sample appears in Canosa et al. (1999), where the identification of a beamed radio-related component to the emission is stressed. (Similar results for sources from the 3CRR sample, from our observations and the analysis of archival data, appear in Hardcastle & Worrall 1999.)

The nearby sources permit the most detailed analysis of the gaseous X-ray emitting atmospheres, with particularly useful data for sources observed with the PSPC (Worrall and Birkinshaw 1994; Worrall et al. 1995; Hardcastle, Worrall & Birkinshaw 1998; Worrall & Birkinshaw 1999). As summarized in Worrall & Birkinshaw (1999), we find that X-ray emitting gas of group to cluster scale engulfs the radio structures, but the lack of correlation between radio-source size, and size or central density of the X-ray emitting medium, means that the gas has not had sufficient time to adjust to the presence of the radio source, and it must be small-scale processes, on size scales less than those of the overall gaseous environments, which are the major influence on radio-source dynamics and propagation.

The PSPC-derived luminosities and temperatures of the environments of B2 radio galaxies lie close to an extrapolation of the luminosity-temperature correlation for more luminous optically-selected clusters, implying the the presence of the radio galaxy does not affect the gas fraction of the environment. Whereas the gas densities around low-power radio galaxies are typically too low to suggest the presence of cooling flows, the pressures are high enough to confine the kpc-scale radio structures.

ROSAT has routinely placed radio-galaxies under the X-ray microscope for the first time, but this work is only the stepping stone to what will be possible with Chandra, XMM, Astro-E and Constellation-X. Our research under this grant has formed the basis for a number of approved AO1 observing proposals with Chandra and XMM.

Publications in refereed journals

Worrall, D.M., Lawrence, C.R., Pearson, T.J. & Readhead, A.C.S. 1994, ApJ (Letters), 420, L17–L20. "Extended and Compact X-ray Emission in Powerful Radio Galaxies."

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Worrall, D.M., Birkinshaw, M. & Cameron, R.A. 1994, BAAS, 26, 957. "ROSAT Discovery of Asymmetrical Cluster Gas around the Radio Galaxy NGC 326."

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