First results from the Chandra Environments of Radio-loud AGN (ERA) survey

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Background

Radio galaxy properties appear to depend to some extent on their environment. At low redshifts, powerful radio galaxies are usually found in galaxy groups rather than clusters. Conversely, FRI galaxies tend to inhabit richer environments, implying that environment has an effect on radio galaxy morphology[1,2,3]. At about redshift 0.5, however, more FRIIs are found in rich environments than in poor environments, suggesting that there is also evolution with epoch[4]. More recent work has found that between redshifts 0.45 and 1.0, powerful radio galaxies inhabit a wide range of environments with no obvious relationship between radio power and environment[5].

It is already known that AGN activity evolves with redshift – luminous QSOs peak at about redshift 2 [6], and moderate luminosity AGN peak more recently, at redshifts 1 to 1.5, with an exponential decline in numbers beyond redshift 3 [7]. Therefore there appears to be both population and environmental evolution of AGN.

It is also likely that the environment is affected by the radio galaxy. It has been known for some time that the gas at the centre of massive galaxies is not condensing into stars, despite the observed cooling time being less than the system age[8]. Peterson and Fabian[9] review the evidence for a large discrepancy between theoretical and observed cooling of massive galaxies, and discuss a number of possible causes; predominant among these is heating from radio galaxies. Evidence for feedback is provided by cavities and shocks associated with radio lobes[10].

There is clearly a complex interdependence between radio galaxies and their environments, but we still do not fully understand the relationships between radio galaxy properties, feedback, behaviour and environment. In particular, previous work on radio galaxy environments has been limited by the Malmquist bias of well-studied samples such as 3CRR, making it impossible to separate the effects of luminosity and redshift.

The ERA programme

In the ERA survey, we intend to make a systematic examination of the epoch and environmental dependence of radio-loud AGN feedback. We have started by carrying out a deep X-ray survey of a sample of 24 radio galaxies covering the widest range of radio luminosities explored to date and containing both high and low excitation sources. The sources are all at around redshift 0.5, where some evolution with respect to local radio galaxies is observed. Our sample is unique in spanning a large luminosity range at a single redshift, meaning that we can isolate luminosity trends for the first time. We are currently characterising the environment richness using ICM X-ray luminosity and temperature, which we will use initially to look for correlations with radio luminosity and radio galaxy type.

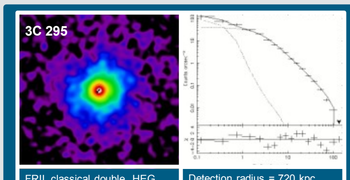
Sample

McLure *et al*[11] drew the ZP5 sample from the complete, low-frequency selected radio samples 3CRR, 6CE, 7CRS, TexOx-1000, selecting all narrow-line radio galaxies lying between redshifts 0.4 and 0.6. We are using a subset of 24 galaxies from the ZP5 sample, covering three decades of radio luminosity. It contains both high and low excitation galaxies and FRI and FRII morphologies. Fourteen of the objects had already been observed in X-ray by Chandra or XMM-Newton; the remaining ten were observed for this programme.

Method

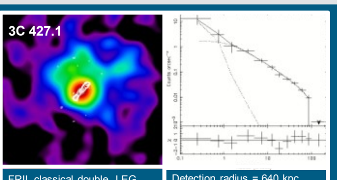
Having removed point sources and contamination from the radio lobes, we create surface brightness profiles of the X-ray environments, and use these to define the extent of the environment and contamination from the nucleus. We then extract spectra for the environments and determine the temperature using Xspec.

We use a beta model to obtain the X-ray luminosity. We fit the telescope point source function to the surface brightness profile to check that there is extended emission beyond the nucleus. We then fit the model to the extended emission, and integrate this to obtain the X-ray luminosity.



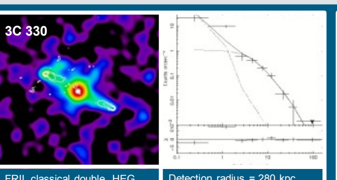
FRII, classical double, HEG
L_{151} = 478x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.461

Detection radius = 720 kpc
L_x = 115x10^{43} erg.s^{-1}
Temperature = 5.0 keV



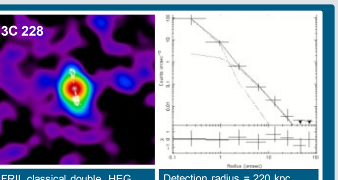
FRII, classical double, LEG
L_{151} = 339x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.572

Detection radius = 640 kpc
L_x = 2.08x10^{43} erg.s^{-1}
Temperature = 5.5 keV



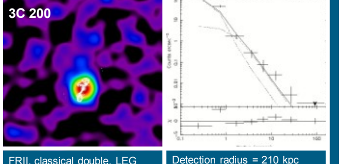
FRII, classical double, HEG
L_{151} = 269.15x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.549

Detection radius = 280 kpc
L_x = 2.35x10^{43} erg.s^{-1}
Temperature = 1.6 keV



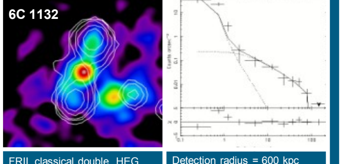
FRII, classical double, HEG
L_{151} = 234.42x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.552

Detection radius = 220 kpc
L_x = 2.19x10^{43} erg.s^{-1}
Temperature = 3.0 keV



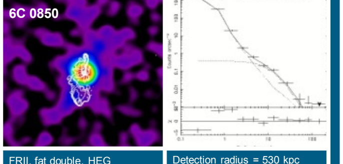
FRII, classical double, LEG
L_{151} = 83.18x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.458

Detection radius = 210 kpc
L_x = 0.84x10^{43} erg.s^{-1}
Temperature = 1.5 keV



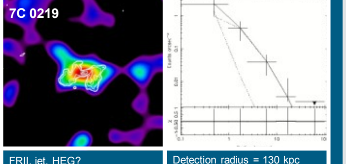
FRII, classical double, HEG
L_{151} = 21.38x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.512

Detection radius = 600 kpc
L_x = 5.23x10^{43} erg.s^{-1}
Temperature = 1.6 keV



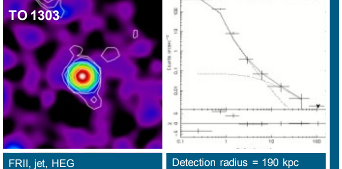
FRII, fat double, HEG
L_{151} = 14.13x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.407

Detection radius = 530 kpc
L_x = 3.11x10^{43} erg.s^{-1}
Temperature = 3.6 keV



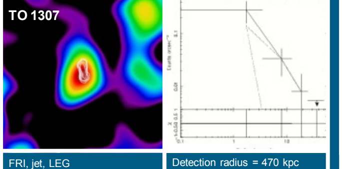
FRII, jet, HEG?
L_{151} = 9.55x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.595

Detection radius = 130 kpc
L_x = 0.29x10^{43} erg.s^{-1}
Temperature = 1.2 keV



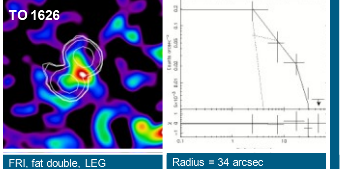
FRII, jet, HEG
L_{151} = 4.57x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.565

Detection radius = 190 kpc
L_x = 1.78x10^{43} erg.s^{-1}
Temperature = 2.0 keV



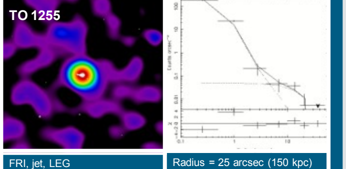
FRI, jet, LEG
L_{151} = 2.0x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.583

Detection radius = 470 kpc
L_x = 2.08x10^{43} erg.s^{-1}
Temperature = 2.2 keV



FRI, fat double, LEG
L_{151} = 1.07x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.458

Radius = 34 arcsec
L_x = 1.09x10^{43} erg.s^{-1}
Temperature = 1.9 keV



FRI, jet, LEG
L_{151} = 1.02x10^{25} WHz^{-1}sr^{-1}
Redshift = 0.471

Radius = 25 arcsec (150 kpc)
L_x = 0.66x10^{43} erg.s^{-1}
Temperature = 1.5 keV

Progress

We present here the initial results from the Chandra data. Of the fifteen sources, one does not yet have a radio map and two had insufficient evidence of X-ray emission associated with the radio galaxy to analyse. The images above show the X-ray emission of the remaining twelve sources overlaid with the radio contours, and the surface brightness profiles overlaid with the results of the PSF and beta models. We have calculated ICM temperatures and X-ray luminosities for these twelve sources.

Figure 2 plots X-ray vs radio luminosity for the twelve sources. These are preliminary results and, as can be seen from the profiles, more work is needed on some of the models. However, there are hints of a relationship between radio luminosity and environment. We hope that when the modelling has been finished and the XMM data added that we can establish some relationships between radio galaxy power, environment richness and other properties of the radio galaxies and their environments.

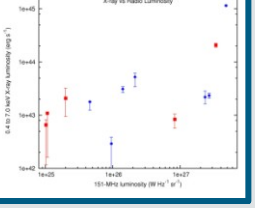


Figure 2: Radio galaxy luminosity vs environment X-ray luminosity.
Red squares are low excitation galaxies, and blue diamonds are high excitation galaxies.

Future work

We will process the nine sources imaged by XMM-Newton next, to calculate their environment luminosities and temperatures. We will then examine the complete data set for relationships between the environment properties and radio galaxy type and power.

We will look at epoch dependence by comparing our results with existing data at other redshifts – 3CRR galaxies with redshifts up to 0.1, and 3C FRII galaxies at redshifts between 0.5 and 1.0[5]

Once this is complete, there are several other areas to explore:

- Relationships with the black hole properties, host galaxy properties, optical cluster characterizations and fuelling processes
- Whether scatter in the X-ray luminosity – temperature relationship is related to radio properties
- Comparisons of the properties of clusters with and without radio galaxies
- Whether catastrophic outbursts, resulting in loss of ICM, are more common in particular AGN classes, and what causes them.

References

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