Chandra Measurements of Non-thermal-like X-ray Emission from Massive, Merging, Radio-halo Clusters

Evan Million\textsuperscript{1} \& S. W. Allen

\textsuperscript{1}emillion@stanford.edu KIPAC (Stanford/SLAC)

Abstract

We report the discovery of spatially-extended, non-thermal-like emission components in Chandra X-ray spectra for five of a sample of seven massive, merging galaxy clusters with powerful radio halos. The emission components can be fitted by power-law models with mean photon indices in the range $1.5 < \Gamma < 2.0$. A control sample of regular, dynamically relaxed clusters, without radio halos but with comparable mean thermal temperatures and luminosities, shows no compelling evidence for similar components. Detailed X-ray spectral mapping reveals the complex thermodynamic states of the radio halo clusters. Our deepest observations, of the Bullet Cluster 1E 0657-56, demonstrate a spatial correlation between the strongest power-law X-ray emission, highest thermal pressure, and brightest 1.4 GHz radio halo emission in this cluster. We confirm the presence of a large scale M\textsubscript{EKAL} threshold is met. Regions are small enough to be reasonably approximated by an optically-thin, spherically symmetric temperature plasma model (MEKAL) model.

The introduction of a power-law component with fixed photon index $\Gamma = 2.0$ leads to larger improvements in the fits for the same radio halo clusters. Again the control sample shows no comparable significant improvement when comparing models B and A.

The Sample

Our targets are drawn from the sample of X-ray luminous clusters with large, extended radio halos discussed by Feretti & Giovannini (2008). These clusters have high quality X-ray data available on the Chandra archive. All of the clusters show clear evidence for recent, major merger activity with no cooling cores. Clusters with radio halos are expected to produce non-thermal X-ray emission via Inverse Compton (IC) scattering of the Cosmic Microwave Background (CMB). However, other processes can also contribute to a non-thermal-like X-ray emission signature including shocks (see Markertvich & Vikhlinin 2007 and references within), a range of non-thermal bremsstrahlung processes (eg.Wolfe & Melia 2008) and synchrotron emission by ultra-relativistic electrons and positrons (eg. F"{u}rst et al 2005). Our targets include 1E 0657-56 (the Bullet Cluster), A2218, A2255, A2219, and 2204 (Feretti & Giovannini 2008). Most are highly relaxed and contain central cooling cores.

Spectral Regions and Analysis

Individual regions for the spectral analysis were determined using the contour binning technique of Sanders (2006). Regions follow contours of constant surface brightness until a desired signal to noise threshold is met. Regions are small enough to be reasonably approximated by an optically-thin, single temperature plasma model (MEKAL). For our standard analysis, each independent spectral region contains $> 10^3$ net counts which results in a statistical uncertainty in temperature of $\sim 10\%$. Radio halo contours are from Liang et al. 2000. The radio halo morphology corresponds well with that of the pressure map.

Statistical Evidence for Non-thermal-like Components

Using the F-test to compare the results for the simplest single-temperature models, A and B, we see that for four out of six radio halo clusters, allowing the absorbing column to fit freely leads to significantly better fits than the Galactic value determined from H\textsuperscript{i} studies. This suggests that model B does not provide a complete description of the spectra. Conversely, none of the control sample of non-radio halo clusters show comparable significant improvement when comparing models B and A.

REFERENCES:


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Physical Interpretations

It has been common in the literature to interpret limits on non-thermal X-ray emission from clusters in terms of simple IC models. However, the flat spectrum and low implied magnetic fields appear at odds with the simplest IC models. Strong theoretical challenges also exist for non-thermal bremsstrahlung processes and ultra-relativistic electrons emitting X-ray synchrotron emission.

We have generated and analyzed simulated X-ray data sets with characteristics similar to the Chandra observations of Abell 2319. We incorporate a broad range of temperature and metallicity distributions (metallicity gradients) and fit with the same basic models. If both metallicity gradients and temperature variations are allowed, then a significant 'non-thermal-like' signal, of order the one detected here, can be obtained if $\sim 30\%$ of the flux originates from a lower metallicity component. The photon index and flux level are consistent with that observed here. In this case, the physical difference between the radio halo sample and the control sample becomes the presence of large surface brightness, cool core regions. Fig. 3b shows a 3 dimensional representation of the surface brightness for the control cluster Abell 2029, and the radio halo cluster Abell 2319. For Abell 2029, most of the flux is from the bright, cool core whereas for Abell 2319, $\sim 50\%$ of the flux is from projection effects. This may also explain previously reported claims of soft X-ray excesses in galaxy clusters though a true non-thermal origin is still a possibility.

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