AGN feedback and iron enrichment in the powerful radio galaxy, 4C+55.16

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Abstract

We present a detailed X-ray analysis of 4C+55.16, an unusual and interesting radio source, located at the centre of a luminous cool core cluster of galaxies ($L_{x\text{-}ray}$=29.6×10^{44} erg/s). By combining deep Chandra (100 ks) with 1.4 GHz VLA observations, we find evidence of multiple outbursts from the central AGN ($P_{bubbles}$=6.7×10^{44} erg/s). Furthermore, 4C+55.16 has an unusual intracluster iron distribution showing a plume-like feature rich in Fe L emission that seems to run along one of the X-ray cavities. The iron excess associated with the plume is around $10^7 M_{\odot}$, and is more consistent with it being Solar-like, suggesting that both SNIa and SNII contribute to the enrichment. At the edge of this plume, we find a clear jump in temperature, consistent with it being a cold front. However, we also suggest that it could be caused by metal enrichment from the central AGN, where cool metal-rich gas has been uplifted along one of the cavities.

Introduction and Method

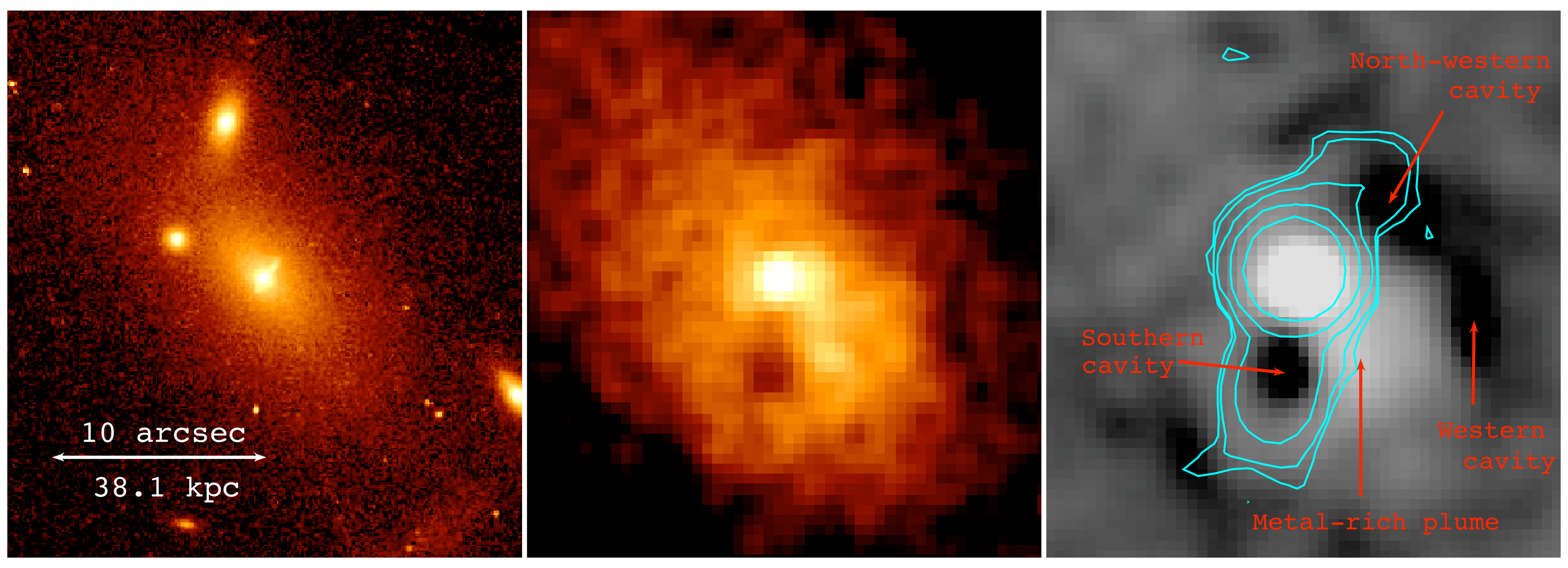


Fig. 1 – Images are in same-scale. Left: HST image of the central galaxy. Middle: Exposure-corrected Chandra image of 4C+55.16 (0.5-7.0 keV). Right: unsharp-masked Chandra image where a σ=10 pixels smoothed image was subtracted from a σ=2 pixels smoothed image (this technique reveals deviations in the original image). In light blue are the VLA contours (1.4 GHz), configuration A. The three X-ray cavities and plume-like feature associated with the central galaxy are shown in red.

The AGN lying at the centre of cool core clusters can energetically offset cooling of the intracluster medium by inflating large cavities correlated with radio lobes, inducing weak shocks and propagating energy through sound/pressure waves (see a review by McNamara & Nulsen 2007). However, the detail of how AGN feedback operates remains unclear.

To provide further insight, we present a study of 4C+55.16, a radio galaxy located at the centre of a cool core cluster of galaxies (z=0.241). We use a combination of Chandra X-ray observations (100 ks) and 1.4 GHz VLA data from the archive. The X-ray data are processed, cleaned and calibrated using the latest version of the ciao software (ciaov4.3, caldb4.4.1), and the radio data are reduced in AIPS using the standard procedures. In Fig. 1 and Fig. 2, we show the imaging results, and in Fig. 3, we show the temperature and metallicity maps, as well as the spectral profiles along the plume-like feature associated with Fe excess.

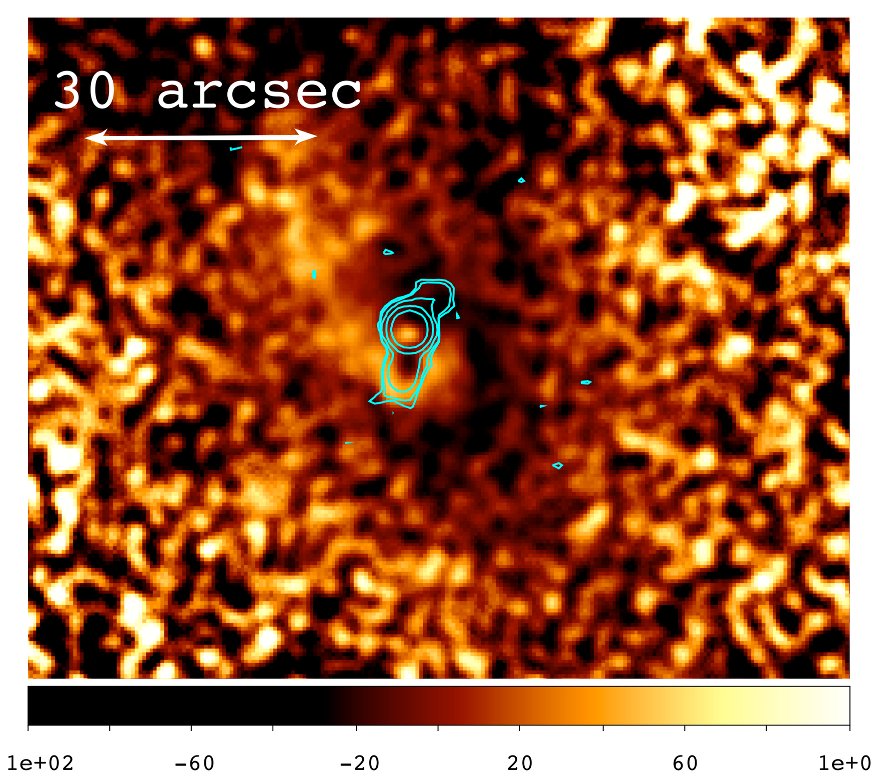
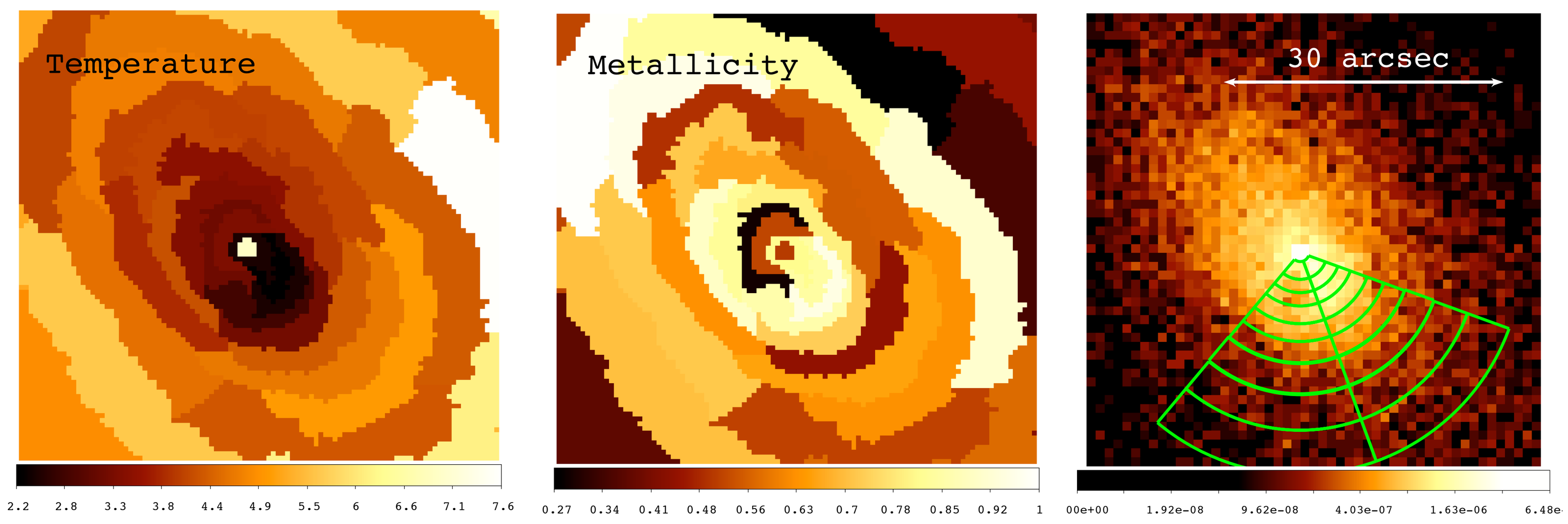


Fig. 2 –Fractional difference between each pixel and the average of an ellipse centred on the X-ray point source and passing through the pixel (the image was then smoothed). The ellipses follow the geometry of the surface brightness distribution. In light blue we show the 1.4 GHZ VLA contours. This figure enhances the surface brightness deviations, and shows that there is a tail-like excess of emission going from the southern cavity towards the north-east. These tail-like features are seen in cold front simulations.

Results



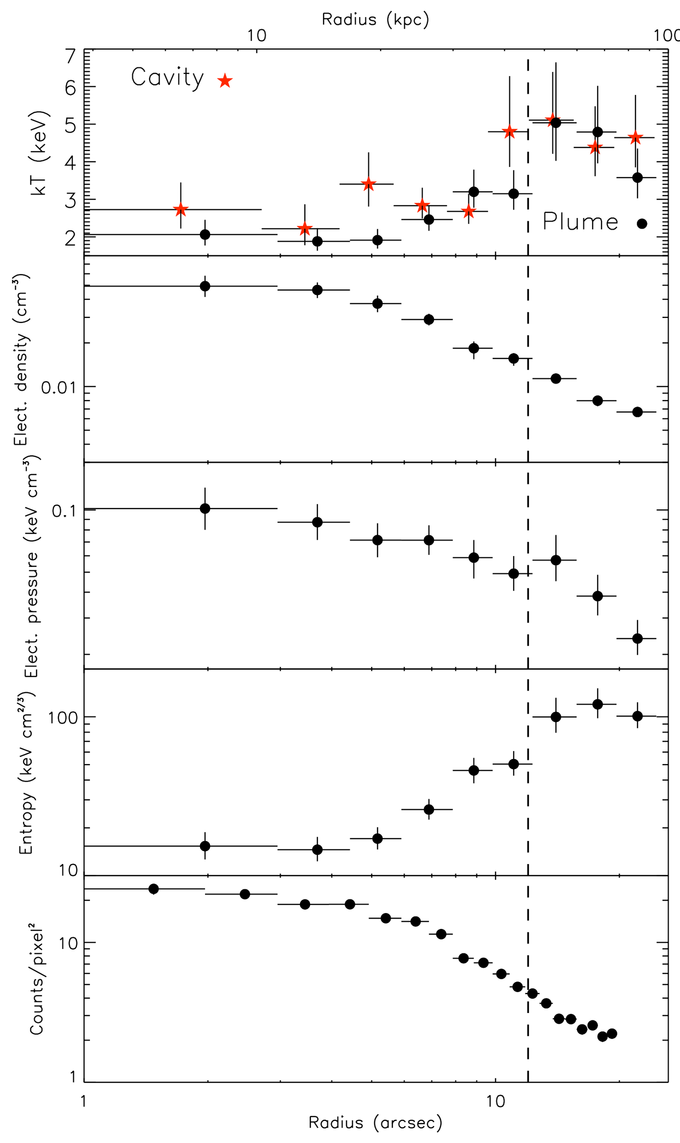


Fig. 3 – Top: Temperature (keV; left), metallicity (Z; middle), and exposure-corrected map (right) of the cluster core. Regions were binned within 190×190 kpc and with a signal-to-noise of 30, following the Contour Binning algorithm by Sanders (2006). Bottom: Temperature profiles along the southern cavity (red) and plume (black), derived using a single mekal model, as well as electron density, electron pressure and entropy profiles of the plume-like feature. The potential cold front is located at ~40 kpc (shown with the dashed line). Selected regions are shown in green in the top-right image.

Our main results are shown in Fig. 2 and Fig. 3, and are summarised as follows:

- First, we find that 4C+55.16 has at least two, and possibly three X-ray cavities, two of which are filled with radio emitting particles (see Fig. 1). The energy stored within them is around 6.7×10^{44} erg/s, and is sufficient to prevent the ICM from cooling.
- Our study also confirms earlier results suggesting that there is a plume-like feature, running along one of the cavities, rich in the Fe L emission feature (Iwasawa et al. 2001). However, we also find that the plume and cavity form a region of cool metal-rich gas that has a temperature and metallicity jump (by a factor of 2), and a slight density jump (see Fig. 3), consistent with it being a cold front. Fig. 2 shows a tail-like feature that supports the idea that this is a cold front.
- However, metal enrichment by the central AGN, which has the potential to uplift cool metal-rich gas from the central galaxy, could also explain our results.
- Finally, we find that the plume has an excess of Fe emission on the order of $10^7 M_{\odot}$, and by fitting spectral models to the data, we find that its enrichment is more consistent with it being Solar-like, suggesting that both SNIa and SNII contribute. This is in disagreement with the more general view that only SNIa enrich in the central regions of clusters (Matsushita et al. 2003).

In summary, 4C+55.16 provides a good example of the large impact that AGN feedback can have on the surrounding medium, by significantly quenching star formation (through the heating power of X-ray cavities), by enriching the surrounding medium with metals (while dragging cool metal-rich gas along the cavities), and by fuelling the supermassive black hole of the host galaxy.

References

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