Analyzing Sloshing Dynamics and AGN Feedback in Abell 2029

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ABELL 2029

Abell 2029 (A2029) is a nearby (z=0.0767) cool core cluster that has been known as one of the most relaxed clusters in the universe [1,2]. Previous Chandra observations revealed the longest continuous sloshing spiral seen in a cluster [3], extending over 400 kpc, with a potential reach of 750 kpc. A2029 also hosts PKS1508+059, a wide-angle tail (WAT) source associated with the central cD galaxy, providing insight into the interactions between these radio sources and the surrounding ICM.

OBSERVATIONS

- Reduced a total of 24 Chandra observations with a final cleaned exposure time of 485 ksec (Fig 1)
  - 3/24 obs (97 ksec on ACIS-S + 10 ksec on ACIS-I) taken <2005
  - 9/24 obs (137 ksec) taken in 2022
  - 12/24 obs (241 ksec) taken in 2023

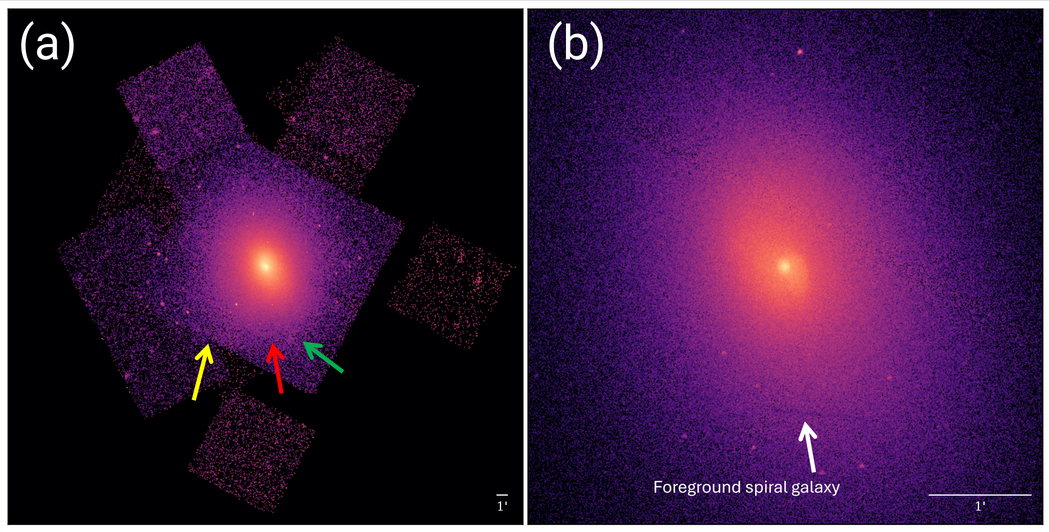

Figure 1. Background subtracted and exposure corrected X-ray image of A2029 in the 0.7-7 keV range. Panel (a) shows the X-ray image smoothed with a Gaussian of radius 1.5" and covering 45'x45'. Panel (b) shows the same image but with no smoothing applied and zoomed into the inner 5'x5' to highlight just how well the sloshing ICM is observed in our data. The shadow of an edge-on foreground spiral galaxy can be seen south of the cluster core. Colored arrows highlight features of interest seen in residual emission image (Fig. 2a). Note: 1' ~ 87 kpc

ICM SUBSTRUCTURE

- Fit a 2D beta-model, including background and exposure corrections, to X-ray source image
- Excess emission seen in residual image as large-scale spiral (Fig. 2a)
- Large 'splash' feature seen in excess to SE along with a ~20" region of excess emission located ~480" SSW from the cluster core (yellow arrow in Fig. 2a)
- Bay feature in the S (red arrow) -- small region of excess ~400" SSW, could be group/subcluster or KHI 'horn' (green arrow)

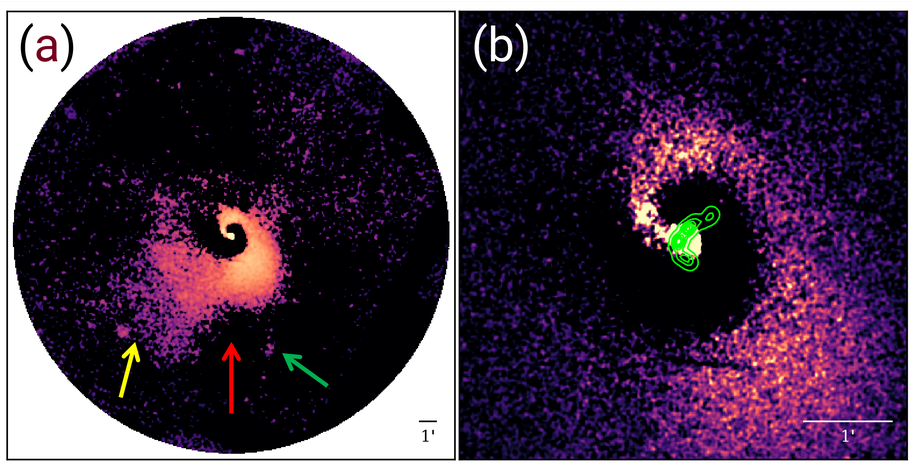

Figure 2. Residual X-ray emission, after subtraction of 2D beta model, in the 0.7-7 keV band. The first panel (a) shows the residual image smoothed using a Gaussian of radius 7.5" and covering 25'x25'. Colored arrows highlight features of interest. The second panel (b) shows the same residual image but smoothed using a 2" Gaussian, zoomed into the inner 5', and includes contours of 1.4 GHz VLA FIRST radio emission from the WAT source.

SPECTRAL MAPS

- Photons extracted from circular region with radius allowed to increase such that it contained >5,000 (temperature map, Fig 3a) or >20,000 (abundance map, Fig. 3b) net counts
- Spectra were fit with a single absorbed APEC model
- Sloshing, cool, metal rich gas corresponds with spiral excess seen in Fig. 2 – as expected if central gas is sloshed to larger radii
- Cool ~6 keV clump south of core associated with region of excess emission ~400" south
- Large high-T (~10 keV) region to NW potentially indicating shock heating

RADIAL PROFILES

- Defined 4 sets of sectors of opposing angular extents (A1/A2--D1/D2; see Fig. 4e)
- Surface brightness extracted from radial bins within each region, excluding point sources, such that each bin contains >5,000 net counts
- Sloshing ICM traced through X-ray excesses on opposing sides of the cluster, assuming circularly symmetric emission for typical ICM of relaxed cluster, i.e. can trace the sloshing through the "criss-crossing" of radial surface brightness profiles (vertical lines in Fig. 4 a-d) from opposite sides of the cluster center

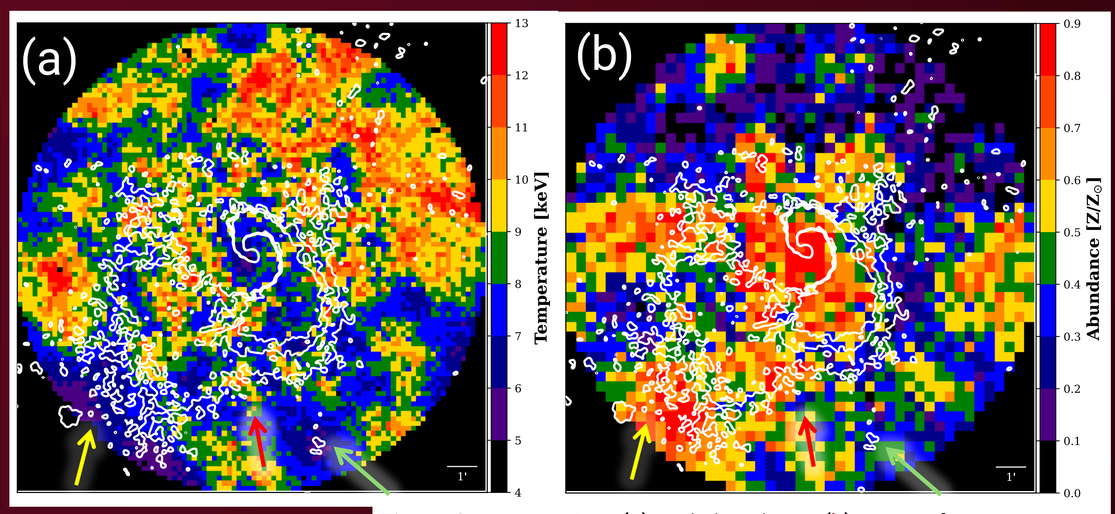

Figure 3. Temperature (a) and abundance (b) maps of A2029 (16'x16') with contours of excess emission (see Fig. 2a) overlaid in white. The sloshing spiral contains cool, metal-rich gas, as expected if central gas is being sloshed to higher radii in this cool core system. The colored arrows highlight features of interest seen in the residual emission image (Fig. 2a).

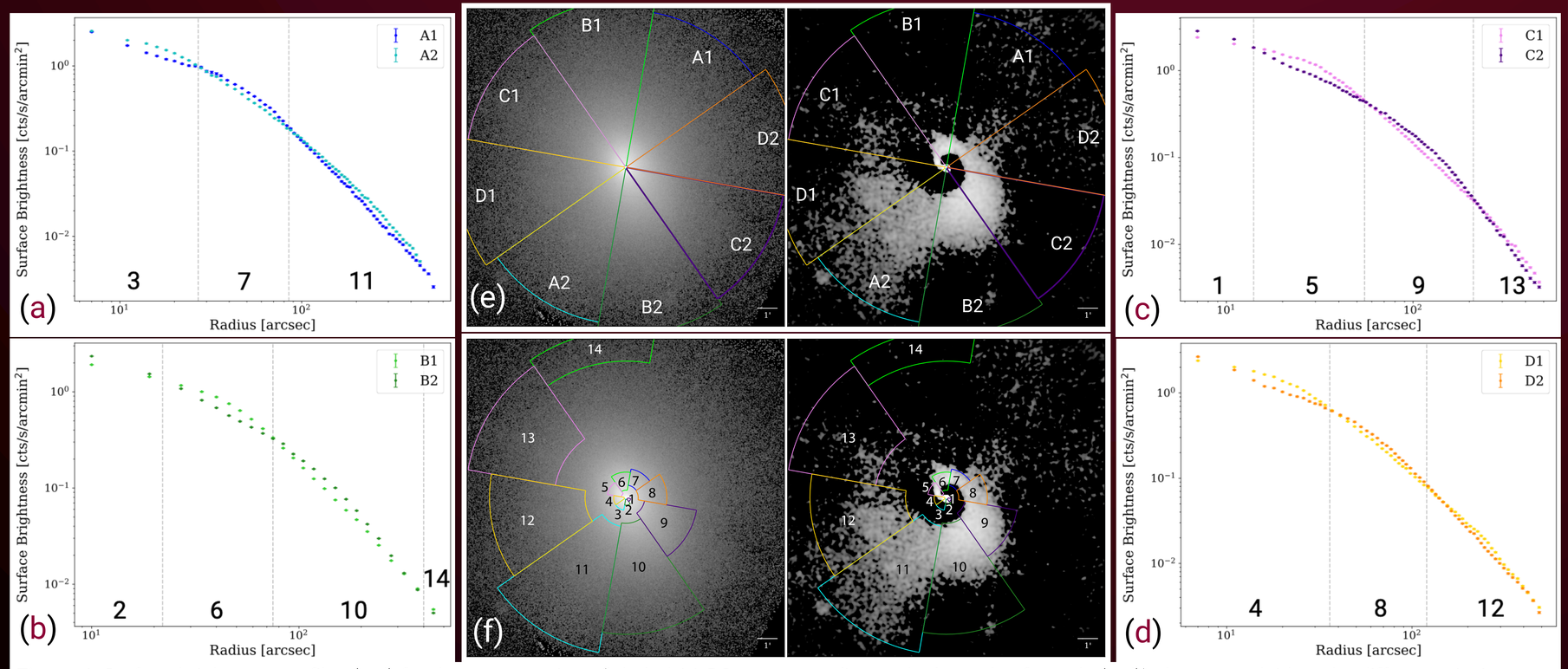

Figure 4. Surface brightness profiles (a-d) for the sector regions (labeled A1-D2; corresponding to the legends of panels (a-d)) shown overlaid on the diffuse emission image (center top left) and residual emission image (center top right) in panel (e). For each plot in (a)-(d), we show the surface brightness, with 1-sigma error bars, from regions of opposing angles, with points colored to match the regions shown in panels (f-e). Panel (f) shows the regions of excess brightness observed in the opposing region pairs, overlaid on the image of diffuse emission (center bottom left) and the residual emission image (center bottom right). The dashed vertical lines in the surface brightness profiles (a-d) mark the edges of the radial bins shown in panel (f). The regions shown in panel (f) indicate the radial range (marked by the dashed lines, and numbered labels, in panels (a-d)) where the surface brightness is higher than in the same radial range on the opposite side of the cluster center.

Summary

- Sloshing spiral traced out to ~450" (~654 kpc)
- Evidence for bay like feature, potentially due to KHI [4]
- Extended region of excess emission in SE of cooler, metal-rich gas apparently connected to the sloshing spiral
- High temperature region to the NW potentially indicating shock heating even in this apparently relaxed system

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