Building a cluster: Group-Group Merger NGC6338

Shocks, Cavities, and Cooling Filaments

O'Sullivan et al. 2019, MNRAS 488, 2925

E. O'Sullivan[1], G. Schellenberger[1], D.J. Burke[1], M. Sun[2], J.M. Vrtilek[1], L.P. David[1], C. Sarazin[3]

[1] Harvard-Smithsonian Center for Astrophysics, [2] University of Alabama, Huntsville, [3] University of Virginia

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

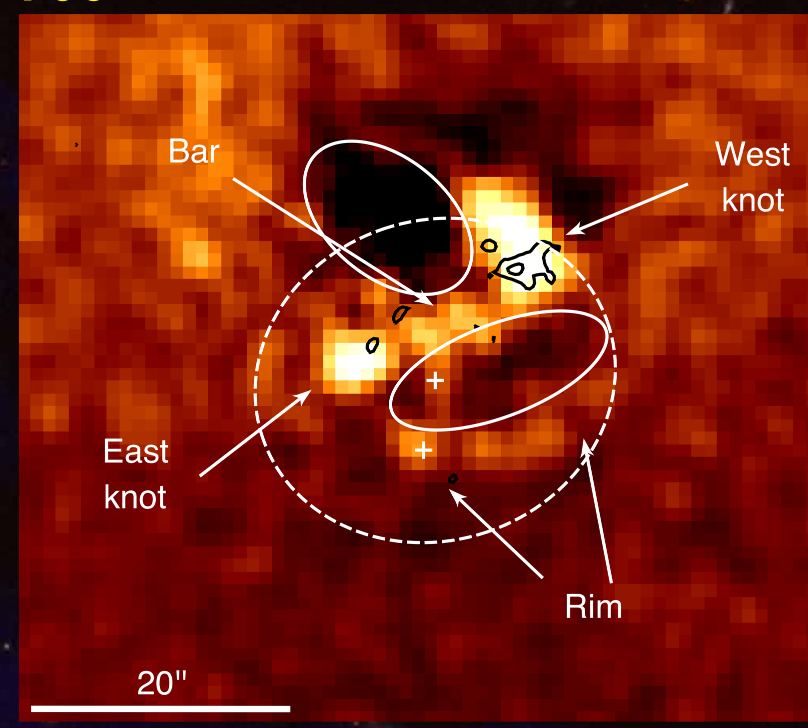
Introduction

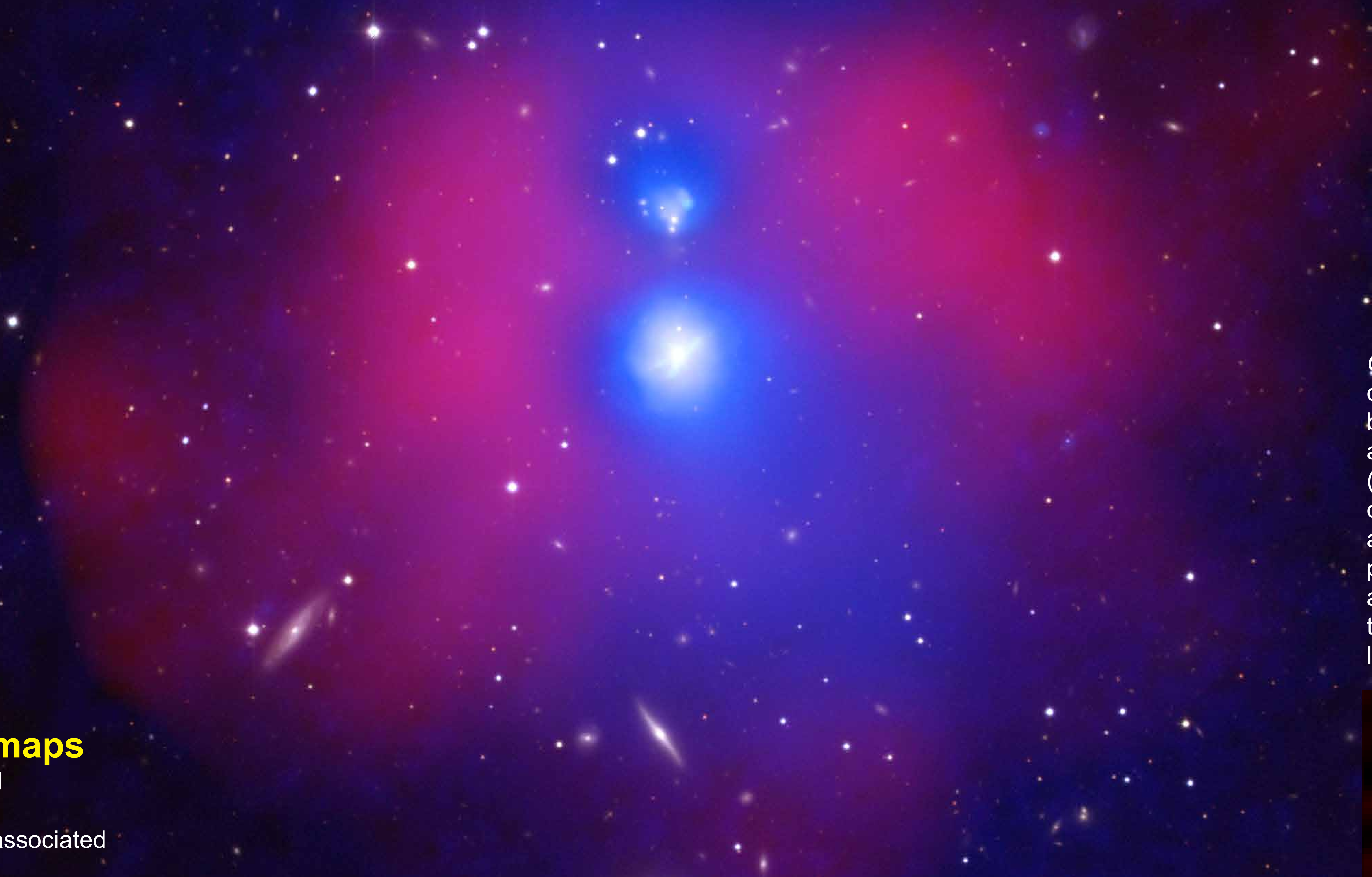
Using deep *Chandra* (288ks total), *XMM-Newton*, GMRT and Hα observations, we have investigated the exceptional group-group merger NGC 6338. *Chandra* and *XMM* reveal two cool cores with stripped tails of enriched gas to north and south, surrounded by an extended region of shock-heated gas with temperatures rising to ~5 keV. The velocity difference between the two dominant galaxies is ~1400 km/s, and comparison with simulations shows the temperature distribution to be consistent with a near-line-of-sight merger with a small impact parameter. We estimate the Mach number of the merger to be M = 2.3 - 3.1, making this perhaps the most violent group-scale merger observed to date. The total mass of the combined system (from X-ray and SZ estimates) is ~10^{14} $M_\odot$, suggesting that we are viewing the formation of a galaxy cluster.

Despite this, the two group cores still show signs of cooling. In NGC 6338 (south core) we find cospatial Hα and X-ray filaments whose gas has very short cooling times, 200-300 Myr, and entropies <10 keV cm^2. In VII Zw 700 (north core) we find an X-ray bar with an Hα clump associated with its coolest, densest part. Both cores have cavities characteristic of AGN feedback, with enthalpies capable of balancing radiative cooling. However, we find no active radio jets or old lobe emission; the AGNs are quiescent. Interestingly, the gas structures in VII Zw 700 appear to have become partially detached from the galaxies, pushed back by the ram-pressure of their motion through the intra-group medium, suggesting that the cooling and feedback cycle may have been disrupted in the north core.

The North Core / VII Zw 700

Chandra 0.5-2 keV residual image of the north core, after subtraction of the best-fitting surface brightness model. Bright regions reveal a bar of cool X-ray gas, with Hα emission (black contours) in its dense west knot, and a rim enclosing one of two cavities (solid ellipses). The gas structures are all offset northward relative to the dominant galaxy pair, VII Zw 700 (dashed ellipse = D_{25}, crosses = optical centroids), indicating that ram-pressure is beginning to detach the gas from the galaxies.





Main image

Blue = *Chandra* & *XMM* 0.5-2 keV emission

Red = Shock-heated gas, temperature > 2 keV

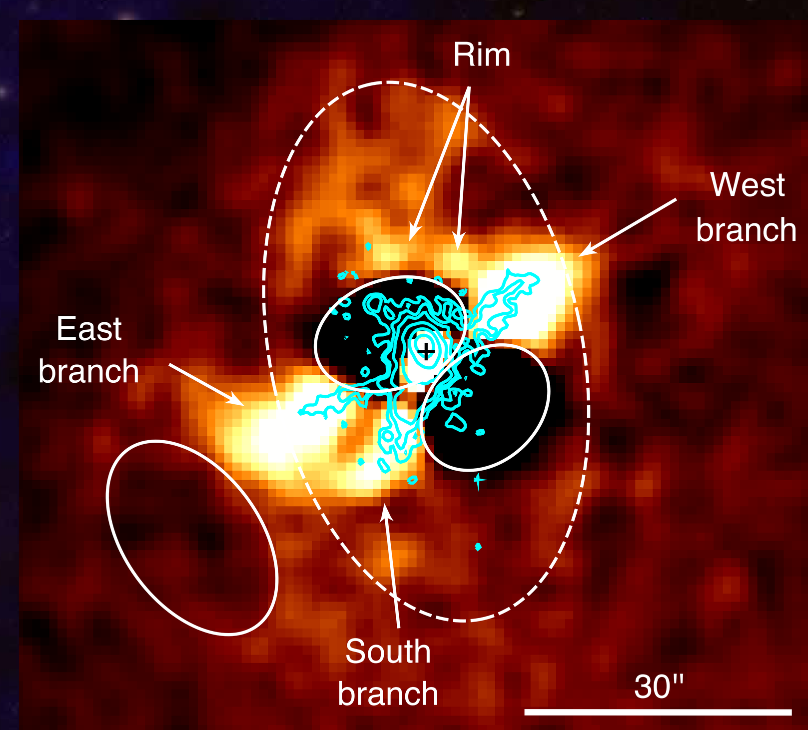
Background = SDSS *ugri*

Group properties

- Redshift of NGC 6338, z=0.027427
- Distance D_A=109 Mpc (0.528 kpc/")
- Total mass, M_{200} = 1.1x10^{14} $M_\odot$
- Gas mass, $M_{gas,200}$ = 1.8x10^{13} $M_\odot$
- Radius R_{200} = 980 kpc

The South Core / NGC 6338

Chandra 0.5-2 keV residual image of the south core, after subtraction of the best-fitting surface brightness model. NGC 6338 is marked by a cross (optical centroid) and dashed ellipse (D_{25} contour). X-ray and Hα emission (cyan contours) trace cooling filaments that extend across the galaxy in three branches. We find potential cavities (solid ellipses) in the core and at the end of the eastern filament, suggesting that the AGN jet axis may have changed in the last ~15 Myr.



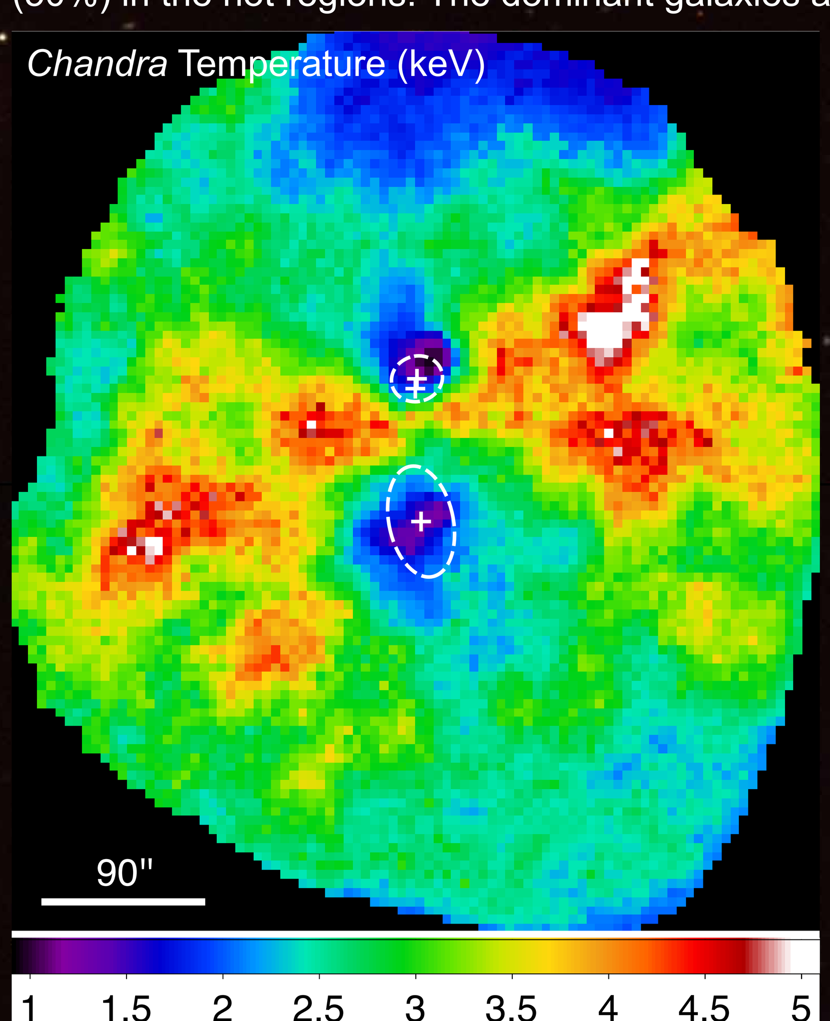
Temperature and Abundance maps

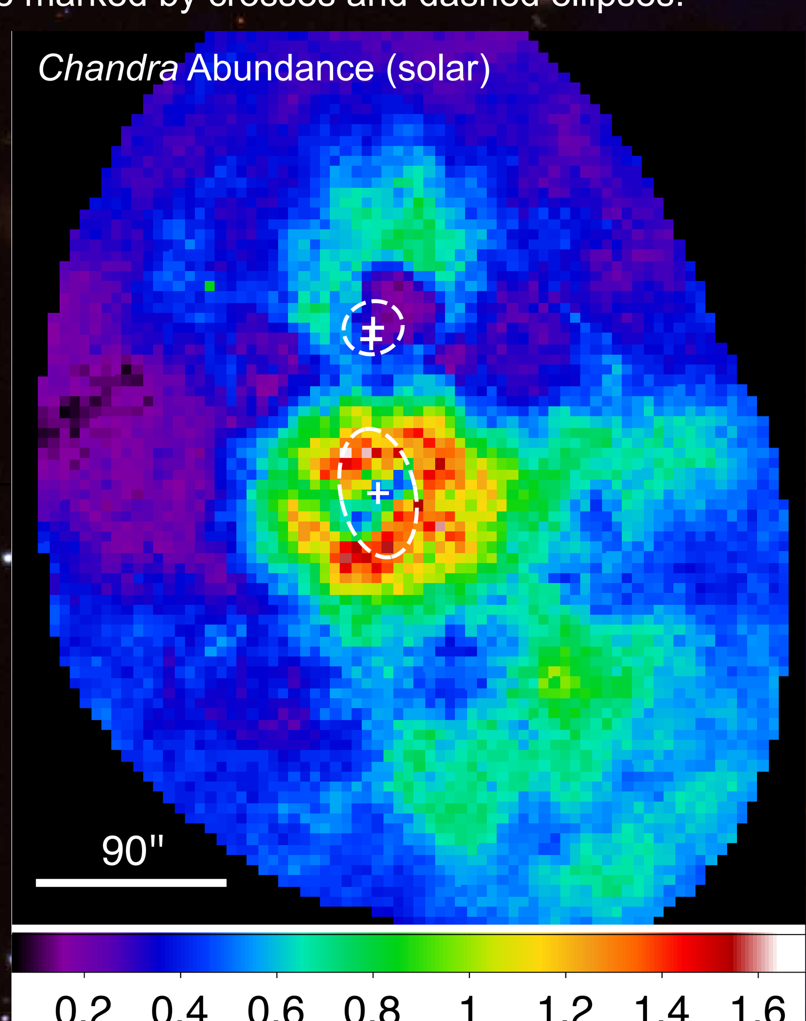
The adaptively-binned *Chandra* temperature and abundance maps reveal:

- Cool (1-2 keV) enriched gas in the two cores, associated with the dominant galaxies.
- Hot (4-5 keV), low abundance (0.2-0.4 $Z_\odot$) gas between and surrounding the cores in broad regions to their east and west. This is shock-heated material, whose low metallicity shows it originated in the outer halos of the two colliding groups.
- Cool (2 keV), enriched (0.75 $Z_\odot$) tails extending north and south of the cores, probably consisting of gas that has been stripped from them by the motion of the cores through the surrounding medium.

Based on the coolest gas we see in the outskirts (1.3 keV) we estimate the pre-shock peak temperature was ~2 keV. This implies the shock has Mach number M = 2.3-3.1, equivalent to ~1700 km/s, and comparable to the velocity difference between the dominant galaxies.

The maps use spectra with >1500 net counts (temperature) or S/N>50 (abundance) in the 0.5-7 keV band. Typical temperature (abundance) uncertainties are 2-5% (10-20%) in the cool, and 15% (50%) in the hot regions. The dominant galaxies are marked by crosses and dashed ellipses.





Comparison with Simulations

A simulation of a 3:1 mass ratio cluster merger with a small impact parameter (from the Galaxy Cluster Merger Catalog, ZuHone et al. 2018) shows features similar to our observations. Mergers in the plane of the sky show sharp surface brightness and temperature fronts associated with the bow shock. Mergers along the line of sight show no edges, but a broad figure-of-eight hot region of shock-heated gas between and to either side of the cool cores - in qualitative agreement with our kT map.

NGC 6338 may be the first system to clearly show this characteristic temperature distribution.