Shaken and Stirred Galaxy Clusters Through Athena's Eyes

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Galaxy clusters are metropoles of interconnected galaxies embedded in hot plasma atmospheres and dark matter halos.

As the largest organized structures of the Universe, they provide important clues on how structure forms and evolves in the deep, dark-matter potential wells. Located in the connecting knots of the cosmic web, they grow by accreting material from their surroundings.

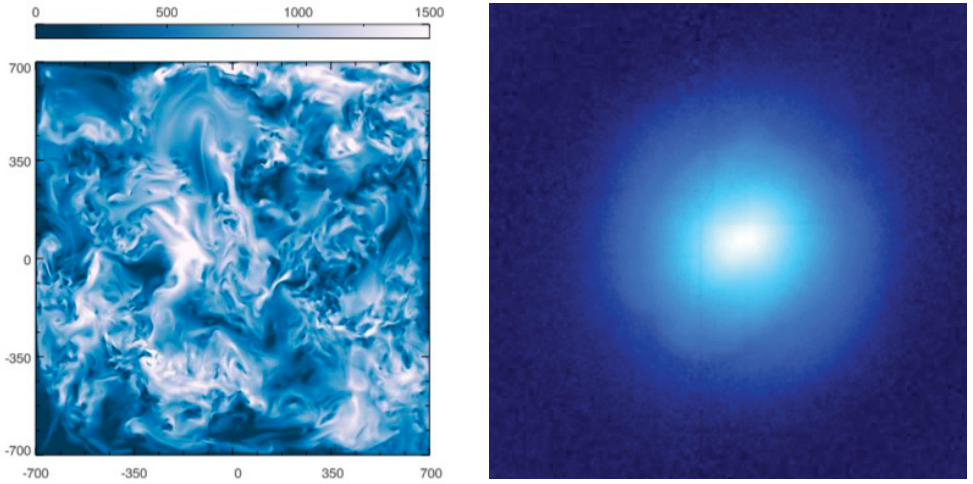
The pristine material accreting onto the cluster outskirts stirs the gas, generating plasma instabilities and increasing the total pressure within the cluster. While often neglected, such non-thermal pressure support (in particular in the form of turbulence) is a vital part of the galaxy cluster ecosystem.

The hot plasma found within clusters, i.e., the intracluster medium (ICM), primarily emits in the X-ray band and can be exquisitely detected with the *Athena* Observatory. Moreover, the electrons within the ICM interact with the cosmic microwave background in a phenomenon known as the Sunyaev-Zel'dovich (SZ) effect. Combined X-ray and SZ observations of cluster outskirts will provide key clues on how the structures in our Universe form and evolve.

Owing to its large effective area and superb spectral/spatial resolution, *Athena* will be the most sensitive X-ray telescope probing the faint suburbs of clusters. *Athena* X-ray Integral Field Unit (X-IFU) observations will provide direct measurements of the bulk and turbulent motions, which strongly shape the cluster outskirts. This can be done through the detection of X-ray line broadening and centroid shifts (e.g., highly ionized Fe).

At the same time, the *Athena* Wide Field Imager (WFI), due to its large field-of-view, will map the entire cluster in a single pointing and provide the most precise measurement of the variations in X-ray surface brightness generated by the turbulent and bulk flows from the surrounding cosmic web.

Together with the pressure fluctuations measured via SZ maps from ground-based radio telescopes (such as the South Pole Telescope, CMB-S4, CCAT-prime, and the Simons Observatory), *Athena* will provide groundbreaking information on the magnitude of turbulence, the level of thermal conduction, and energy transport mechanisms (e.g., sound waves versus buoyancy waves) in the cluster outskirts.



Left: Cross-section of the total turbulent velocity magnitude (in km/s unit) for a turbulent ICM simulation in a massive Coma-like cluster. Credit: left - Gaspari, M., Churazov, E., Nagai, D., Lau, E. T., & Zhuravleva, I. 2014,A&A, 569.
Right - *Athena* WFI image of a simulated Coma-like cluster at a redshift of 0.1 (Bulbul et al. in prep., 2019).

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