Athena's Sharper View of Black Hole Feedback in Clusters of Galaxies

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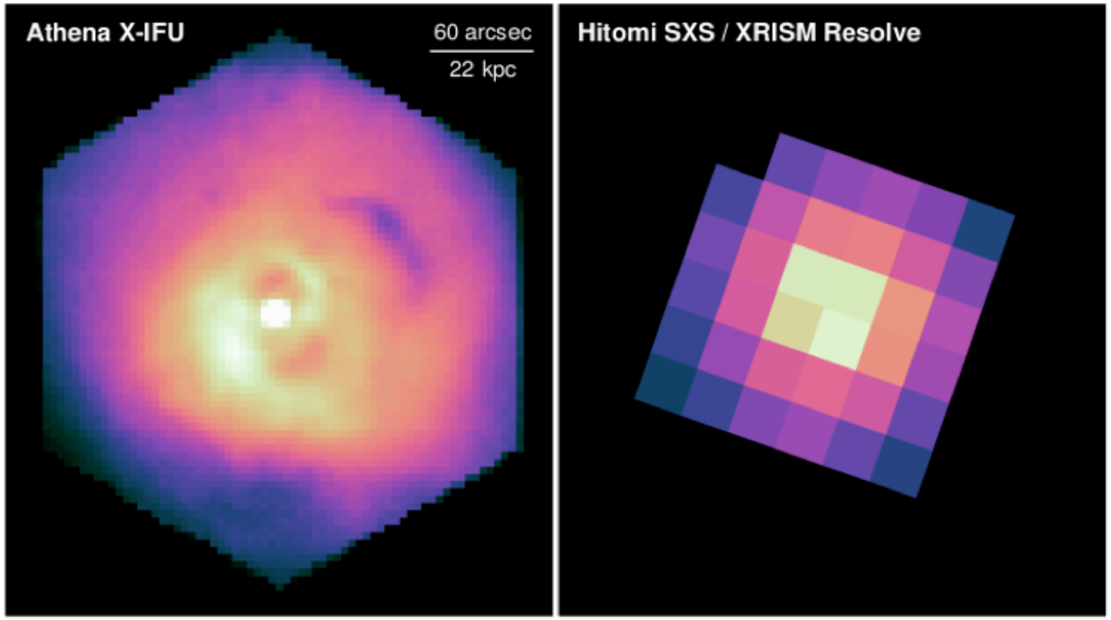
Galaxy clusters contain huge hot atmospheres of gas, heated up to temperatures of tens of millions of degrees, forming a plasma. This gas, composed of hydrogen, helium, and traces of heavier elements, shines brightly in X-rays and is thus visible to X-ray telescopes. The radiating plasma at the cluster centre is expected to cool into molecular gas and form stars.

However, X-ray spectra show little evidence for rapid cooling, suggesting that energy must be injected from some source to replace the heat that is lost by radiation. Indeed, high-resolution X-ray images show that the central active galactic nuclei, supermassive black holes in the large galaxies found in the core of clusters, affect the surrounding atmosphere. The high-speed jets from the nuclei inflate radio-emitting bubbles in clusters. The radio bubbles, in turn, displace the gas, forming cavities seen in X-ray images, and injecting enormous power into the cluster. The agreement between the estimated power output of these nuclei and that being lost by X-ray radiation indicates that these active nuclei do indeed prevent rapid cooling, a process known as "feedback".

Black hole feedback occurs in many environments in the universe, but clusters are one of the few places we can observe it directly. Despite this, we do not truly understand how the energy is distributed in just the right places to prevent cooling from occurring anywhere in the cluster. Atmospheric gas motions around these bubbles and jets will provide strong clues. Mapping the gas velocities will reveal where energy is streaming throughout the core of the cluster. High-resolution X-ray spectroscopy will be required to measure the position and shape of Doppler-shifted emission lines from the moving gas.

Hitomi made pioneering measurements of the motions in the core of the Perseus cluster in 2016. Unfortunately, the telescope failed soon afterwards. A replacement mission called XRISM with capabilities similar to Hitomi's will be launched in 2022 and will produce exciting results. Nevertheless, *Athena* will surpass Hitomi's capabilities by a large factor due to its larger light gathering power and sharper imagery.

Shown is a comparison between a simulated *Athena* observation of Perseus and a real one by Hitomi. *Athena* will have a much better spatial resolution compared to Hitomi/XRISM (5 vs 120 arcsec). It will also have many more detector pixels and much more collecting area. These massive improvements in imaging quality will allow us to measure with unprecedented precision the spectra on the small spatial scales we need around the cavities and black hole. *Athena* will enable astronomers to make detailed maps of the gas motions in the core of a cluster for the first time, directly mapping the effect of feedback.



A simulated image of the Perseus cluster using the X-IFU detector on Athena (left). The real image of Perseus with the same spatial scale and observing time with the SXS detector on Hitomi (right). Credit: Jeremy Sanders (MPE).

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