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Earth & Space

Digging up a dinosaur in a galaxy cluster

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X-ray and radio observations of the Ophiuchus galaxy cluster revealed a "fossil" of a giant explosion that happened in its center several hundred million years ago. It is the most powerful known explosion in the Universe since the Big Bang. If such dinosaurs show up in low-frequency radio images of other clusters, they would shatter our current view of these massive objects.

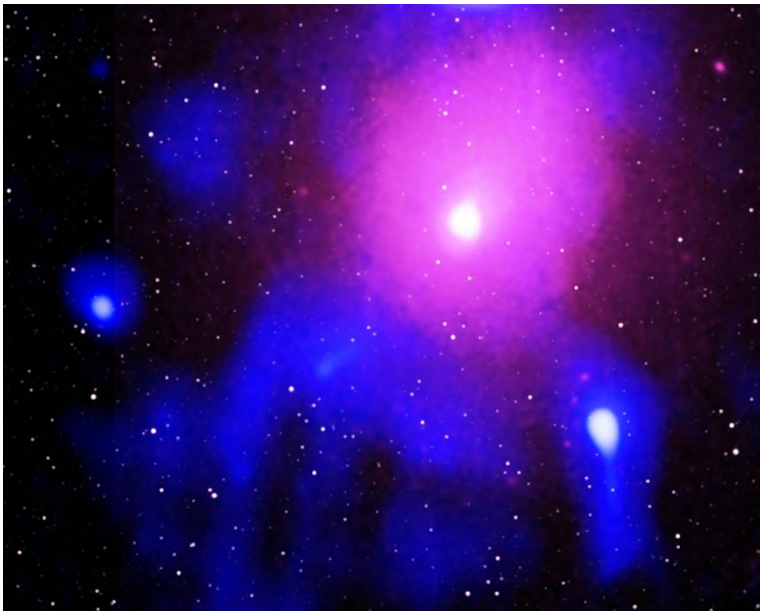

Image credits: X-ray: Chandra: NASA/CXC/NRL/S. Giacintucci, et al., XMM: ESA/XMM; Radio: NCRA/TIFR/GMRT; Infrared: 2MASS/UMass/IPAC-Caltech/NASA/NSF

Galaxy clusters are the biggest gravitationally-bound objects in the Universe, millions of light years across, some as massive as a quadrillion (10^15) suns. They contain thousands of galaxies and are filled with 100-million-degree plasma, so tenuous it is a million times less dense than the best vacuum we achieved on Earth. Yet, we can see it in great detail through its X-ray emission using space telescopes such as Chandra and XMM-Newton.

The intra-cluster plasma slowly loses heat by emitting it away. Near the cluster centers, the plasma is dense enough to cool quite fast, on the timescale under a billion years. The higher the plasma's density, the more X-rays it emits and the faster it cools. As it cools down, it contracts, becomes denser still and so on, entering a runaway cooling process. This process should deposit vast quantities of cold gas in the cluster centers but we don't find nearly as much of it as we expected. This means there must be some source of heat in cluster cores that doesn't let the plasma cool below 10 million degrees or so.

One likely source of heat is supermassive black holes (SMBH) that live in the cluster central galaxies. Their mass can be of order a billion suns, and due to their huge gravitational pull, they accrete copious amounts of surrounding matter. While most matter sinks irretrievably into the black hole, a tiny part of it is turned back and ejected at nearly the speed of light into the surrounding gas. Where those jets of matter hit the gas, they blow huge hot bubbles in it. The current theory is that this process provides enough heat to offset the cooling, and that the SMBH jet eruptions are just powerful enough to heat the gas but gentle enough to avoid blowing up the entire plasma cloud.

What we found in the Ophiuchus cluster seems far outside this scenario. Like many clusters, it has a dense plasma core that is cooling down. Earlier researchers who looked at this cluster with the Chandra telescope noticed a curiosity - a concave edge in the X-ray emission at one side of the core. They briefly entertained an idea that this edge may be a part of a wall of a giant bubble blown by a jet emanating from the cluster center. But when they estimated how much energy is required to blow such a bubble, it came out unbelievably high, and they concluded that it must be something else.

We decided to look at this cluster using the MWA radiotelescope in Australia. This revealed an unexpected radio glow in that position. We overlaid the radio image onto the X-ray image and realized that the radio source is located right outside the concave X-ray edge. Intrigued, we've looked at a sharper image from another radio telescope, GMRT in India. It showed very clearly that the radio source fits the X-ray edge like hand in glove - confirming the implausible hypothesis of a giant cavity in the cluster plasma filled with super-energetic electrons that generate the radio emission.

This newly discovered structure is exactly like the bubbles created by black holes in other clusters, except its energy is enormous - 1000 times that in a typical cluster and 5 times that of the previous record holder. This makes it the biggest known explosion in the Universe since the Big Bang. The central black hole should have accreted a galaxy-sized chunk of matter to create such an outburst.

Because the bubble is seen only at low radio frequencies, the event must have happened long ago - a few hundred million years ago. As the energetic electrons age after their acceleration and ejection by the black hole, their emission at high radio frequencies fades, while the low-frequency one lingers. The cluster does not exhibit SMBH activity at present. So the SMBH has quieted down, the jets are long gone, and all that remains from the enormous explosion is the faint radio glow from this fossil cavity filled with aged electrons.

This has been like discovering a dinosaur, with just a little piece (the unusual X-ray edge) sticking out at first and then suddenly a new kind of creature coming out from the ground. High-sensitivity imaging at very low radio frequencies is a recent capability, with new telescopes just starting to report their first findings. It is possible that more such dinosaurs will soon be unearthed. If so, our current physical picture of galaxy clusters, their energy budgets and their evolution would be seriously challenged.