National Centre for Radio Astrophysics (NCRA-TIFR), Pune

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GMRT discovers the oldest known fossil radio galaxy trapped inside a cluster of galaxies

Recently, a team of Indian astronomers led by Dr Surajit Paul of Savitribai Phule Pune University (SPPU) has discovered an extremely aged remnant of the 'lobes' of a once active radio galaxy. This pair of gigantic lobes of a radio galaxy spanning 1.2 million light-years is located inside the galaxy cluster Abell 980 and it was created about 260 million years ago. The detection of these 'fossil lobes' via their low radio-frequency radiation, became possible due to the high sensitivity of the Giant Metrewave Radio Telescope (GMRT) which is located near Khodad village, 80 km north of Pune. This front-ranking radio telescope was established and is operated by the National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research (TIFR). The other telescopes which have contributed to this technically challenging study are: the Very Large Array (VLA), Low-Frequency Array (LoFAR) and Chandra X-ray observatory.

Large galaxies are the assembly of billions of stars. Many of them reside in clusters containing 100s to 1000s of galaxies, all held together by their mutual gravity. Furthermore, all large galaxies are now believed to harbour a supermassive black hole (SMBH) at the center of the galaxy, typically of mass equivalent to several million to billions of Suns. Upon entering an 'active' state, these black holes eject two oppositely-directed collimated 'jets' of magnetised relativistic plasma, each feeding into an expanding lobe, which makes it radiate at radio-frequencies. Such 'radio lobes' can thus be detected with large radio telescopes up to distances of billions of light-years. An episode of jet production by a supermassive black hole in a galaxy (called the 'active' phase) often lasts for tens of millions of years, after which the production of jets and thus the energy supply by them into the radio lobes ceases. The two radio lobes then fade away rapidly beyond detection. In fact, the universe is likely to be infested with faded relics of radio lobes blown up by billions of large galaxies during their multiple active phases over the age of the universe.

Just like the fossil records of animals, plants and terrestrial events, relics or fossils lobes of radio galaxies too are repositories of valuable information about the conditions prevailing in the bygone era of the universe. Unfortunately, the rapid fading of the fossil radio lobes renders their detection a tough challenge. If, however, the parent galaxy happens to be inside a cluster of galaxies, the expansion and consequent fading of the radio lobes can be effectively slowed down by the pressure of surrounding hot gas, which normally permeates galaxy clusters and is detectable with X-ray telescopes. This external confinement of the radio lobes during their relic stage can hugely prolong their detectable lifespan, particularly at metre wavelengths where the radiative losses are comparatively modest. The second critical requirement for the detectability of the fossil radio lobes is that the galaxy cluster harbouring them remains in a dynamically quiescent state, in order that the fossil lobes can escape disruption despite their long existence. Fortunately, the cluster Abell 980 is found to be in a relaxed state, as inferred from its thermal X-ray emission. According to Dr. Paul and Prof. Gopal Krishna, the GMRT discovery of the two extremely old fossil radio lobes with a record age of nearly 260 million years (a record so far), owes to a combination of these two extraordinarily rare favourable circumstances. Dr Paul, who initiated and long perused the study of radio-wave emission from the environments within relatively low-mass clusters of galaxies, holds the view that low-mass clusters of galaxies, such as Abell 980, are uniquely suited for meeting the requirement of a less disturbed internal environment because their shallow gravitational potential is dominated by at most a few large galaxies.

It is now well established that the jet production activity, which creates a pair of rapidly advancing radio lobes on opposite sides of an active galaxy, is of episodic nature. In fact, a massive galaxy can undergo such 'active' phases recurrently, each time producing a pair of radio lobes, called a 'double radio source'. In a sense, the two pairs of radio lobes seen flanking the parent galaxy in such sources can be viewed as 'siblings' parented by the same galaxy situated in their middle. By now, a few dozen examples of such 'double-double radio galaxies' (DDRG) have been found. Prof. Gopal Krishna and collaborators have succeeded in solving the mystery of the 'missing' parent galaxy of the two fossil radio lobes mentioned above, by showing that during the long lifespan of those radio lobes, their parent galaxy has drifted away towards the gravitational centre of the galaxy cluster, thus covering a distance of 250000 light-years. On reaching the cluster core, that galaxy has entered a new phase of activity, creating a new pair of radio lobes which are smaller and brighter. They are thus the younger siblings of the two fossil radio lobes. The novel aspect of this newly proposed model invoking motion of the parent galaxy is that the younger pair of radio lobes would not be collinear with the two fossil radio lobes but have instead a huge lateral separation from them. Due to this large positional offset, the pair of younger radio lobes could be easily mistaken as an independent double radio source, unrelated to the fossil lobes. Gopal Krishna and collaborators have christened this new morphological type of radio galaxies as 'detached double-double radio galaxies' (dDDRGs). Highly sensitive radio observations in future might reveal more such examples, enabling a deeper probe into the origin of recurrent jet activity in supermassive black holes located at the centres of galaxies.

These results have recently been published in two research articles appearing in prominent international journals, authored by Sameer Salunkhe et al. (2022) in Astronomy & Astrophysics (A&A) published by EDP Sciences for European Southern Observatory (ESO), and by Gopal Krishna et al. (2022) in the Publications of the Astronomical Society of Australia (PASA) published by Cambridge University Press.

Publication links:

1. https://doi.org/10.1051/0004-6361/202243438 (*Salunkhe et al., 2022, A&A, in press*)

2. https://doi.org/10.48550/arXiv.2207.05166 [10.1017/pasa.2022.30](*Gopal-Krishna et al., 2022, PASA, in press*)

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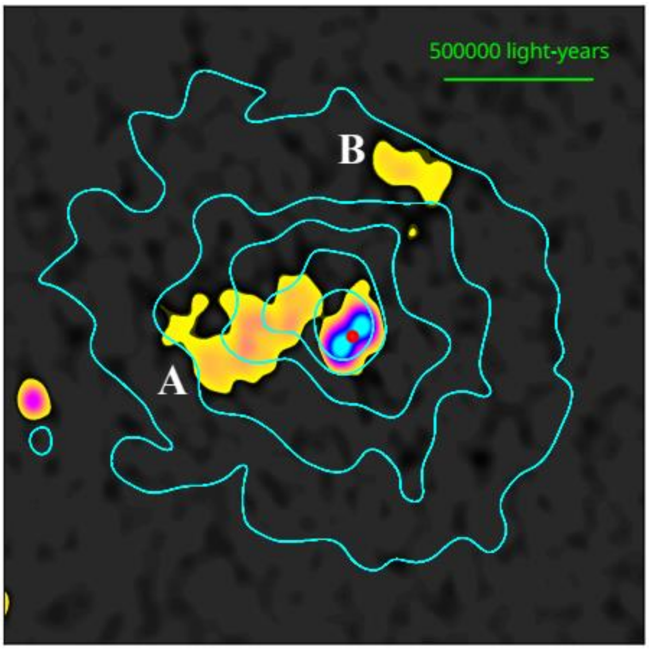
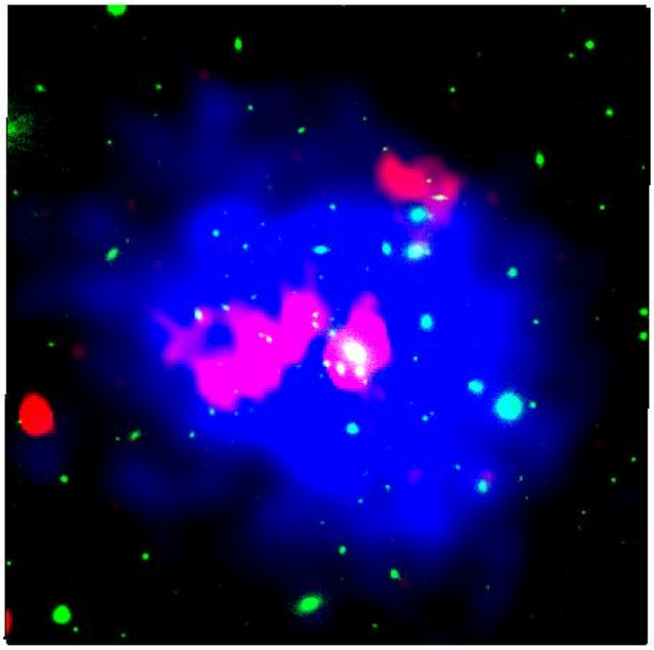
Images:





Left panel: The recurrently active giant galaxy is marked with a red dot at the centre of the image. It is flanked by two compact (young) radio lobes (cyan/blue/purple shading). The 'fossil' radio lobes A and B, aged about 250 million years, are shown in yellow colour. These pairs of young and fossil radio lobes were created by the same active galaxy in two independent episodes of jet activity separated by about 100 million years, during which the galaxy has drifted to its present location. The green iso-intensity contours depict the halo of X-ray emission. This halo envelopes the entire radio source and is filled with hot gas at a temperature of around 80 million degrees.

Right panel: Optical photograph of the cluster of galaxies, whose central giant elliptical galaxy (white elliptical patch) is the parent of the radio lobes shown in red. The blue shaded region displays the halo of X-ray emission due to the hot gas associated with this cluster of galaxies and have an overall size of around 1.7 million light-years.