

A Phoenix in the Radio Universe  
A giant radio galaxy ... born again, and again, and again

**J023721.13-010528.5: A giant S-shaped radio galaxy showing four episodes of jet activity**

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**IISER Pune:** Institution of Excellence under the Ministry of Education, Govt of India

**NCRA:** of the Tata Institute of Fundamental Research, Dept of Atomic Energy, Govt of India.

Astronomers from IISER Pune and NCRA-TIFR have discovered the first radio galaxy that shows evidence for 4 separate episodes of jet activity. In contrast, most of the tens of thousands of radio galaxies known till date appear to live only once. The team consisting of Mr. Pavan Khadekar, a PhD student, Prof. Dharam Vir Lal and Prof. Ramana Athreya reported this discovery in a paper published in *The Astrophysical Journal*.

Athreya, who supervises Khadekar's PhD research, described that he (Khadekar) was studying radio galaxies with unusual structure, but this particular discovery was entirely unexpected. "Initially, I was not convinced, despite Dharam's insistence, that this object was into its fourth life! It took a while to extract convincing evidence of the same. Clearly, Dharam has good scientific antennae."

Pavan used his own high quality observations with the Giant Metrewave Radio Telescope (GMRT) in India, and archival data from Very Large Array (VLA) in the USA and MeerKAT in South Africa. Pavan said, "Many radio telescopes freely provide their data to researchers across the world. This collaborative philosophy of observatories makes for a more comprehensive investigation, and more efficient use of data – different scientists can use the same observations for exploring differing ideas."

The images produced by the team showed different episodes of activity superposed on each other, like debris of multiple civilisations. Data at several frequencies were combined to show that the current, fourth, life started a few million years ago, while the first one ended 21 million years ago. Dharam Vir Lal, who is also Khadekar's co-supervisor, explained that radio galaxies with multiple lives – more the better – are needed to understand the evolution of processes which lead to the phenomenon of radio emission. Before this discovery, only six radio galaxies with three lives had been known. The current discovery, the first one with four lives, is an important addition to the list. Very interestingly, the current research suggests a strategy for more efficient discovery of such objects, perhaps with an even larger number of lives.

The GMRT is a world-class, low frequency radio telescope built and operated by the National Centre for Radio Astrophysics (NCRA), a unit of the Tata Institute of Fundamental Research (TIFR), an aided institute under the Department of Atomic Energy (DAE). Prof. Oberoi of NCRA-TIFR, who was not involved in this work, commented, "Phenomena associated with radio galaxies are interesting in and of themselves; they are also probes for investigating some of the fundamental questions of the origin of the

Universe. The GMRT was conceived to help Indian astronomers compete at the highest level, and as India's contribution to the global quest to understand the Cosmos."

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Some images of the GMRT can be found here -

<https://www.ncra.tifr.res.in/ncra/picture-gallery>.

<https://wm1.ncra.tifr.res.in/index.php/s/tBWLCdCLX6efBxB>

## Explanatory Notes from the Researchers

*Radio Galaxies* are the largest structures created by a single phenomenon in the Universe. They look like two large balloons of enhanced emission (called hotspots) straddling a galaxy. In some, these hotspots can be seen linked to the central galaxy by a thin thread – a pair of very slender jets of highly energetic ions. The largest radio galaxy spans 8 Megaparsec, a length that light would take 26 million years to cross – several hundred times larger than the galaxy which gave rise to it.

Paradoxically, the phenomenon of radio galaxies originates in a tiny region at the centre of a galaxy. A largish galaxy like the Milky Way consists of a hundred billion stars and spans 100,000 light years. In a small minority of galaxies called *Active Galaxies*, their very central region – perhaps even smaller than the Solar system – emits as much radiation as all the stars in the rest of the galaxy.

The source of this radiation is believed to be a huge central black hole weighing up to a billion Suns. Gas, dust and even stars from the rest of the galaxy are dragged in towards this black hole by its enormous gravitational field. As they swirl inwards, faster and faster, they gain huge energy and reach temperatures of millions of degrees Celsius.

In some Active Galaxies this energy is redirected outwards as highly collimated, oppositely directed, pair of jets of ions at speeds of up to 99.5% of the speed of light. These jets interact with the material around the galaxy in the manner of a water jet hitting a sand bank: they bore a tunnel through the circum-galactic material. The clash between the head of the jet and the surrounding medium results in a pair of hotspots of intense emission, a fascinating spectacle of turbulent flows of extremely energetic electrons and twisted magnetic fields and a blaze of radio waves.

Radio astronomers have studied tens of thousands of radio galaxies till date. In most of them it seems that the jets turn on sometime during the life of the galaxy resulting in the paired hotspots (hence the name double radio galaxies), stay turned on for millions of years and then switch off. Depending on the strength of the jets, the amount of surrounding material hindering their outward motion and the duration for which they are on, radio galaxies come in a wide range of sizes – from a few parsecs (the distance between the sun and the nearest star) to the giant mentioned earlier.

However, in 2000, European astronomers sprang a surprise by reporting a radio galaxy which had had two episodes of these radio jets – an older pair of jets which had burnt itself out but left behind the dispersing debris of its hotspots, and a younger pair of still active jets which had created a new pair of hotspots which were working their way through the cavity already carved out by the first pair. Apparently, a radio galaxy, like a Phoenix, can arise from the ashes! About 200 of such **double-double** radio galaxies (DDRG for short) have been discovered by astronomers till date: the first **double** is for the two episodes, and the second **double** refers to the two hotspot structures.

Over the last decade other researchers, some of them Indian, have identified 6 double radio galaxies with three episodes of jet activity – hence triple-double radio sources.

This work by astronomers from IISER-Pune and NCRA reports the discovery of the first double radio galaxy with 4 episodes of jet activity in the radio galaxy *J023721.13-010528.5*

– a quadruple-double radio galaxy. They used high quality observations at multiple radio frequencies from several telescopes across the world including the Giant Metrewave Radio Telescope (India), MeerKAT (S. Africa), and the Very Large Array (USA) to identify 4 pairs of hotspots in the source. The question was whether these 4 pairs of hotspots were all from a single episode of jet activity or if they were from 4 different episodes. They confirmed their hunch that these were indeed hotspots from different epochs of jet activity by calculating the ages of the hotspots – the ages varied between 6 and 21 million years. They also used the symmetrical locations of the hotspots to determine that the second model (multiple episodes) was more probable than the first (single episode) by a factor of more than 3 million.

The discovery of double-double radio galaxies was a paradigm shift but the combination of one dead and another active jet makes it difficult to answer many questions. With three and now four episodes – i.e. with multiple jets which reached the end of their life – scientists can investigate the phenomenon in more detail: does the power of the jet reduce with each successive episode? Does the on-time of the jets reduce with age? What is the quiescent period between the active jets? The data from the newly discovered object *J023721.13-010528.5* suggests that either the power or the lifetime of the jets, or both, decreases with each episode. Does this indicate that the energy falling into the black-hole is reducing with time? or, is the efficiency of the black-hole in forming the jets reducing? These are questions which can only be answered when more such objects are discovered.

Even apart from its quadruple episodes of radio emission, *J023721.13-010528.5* is a very unusual object. With a size of 4.2 million light-years it is one of the largest radio sources known, almost double the threshold used by astronomers to identify *Giant Radio Galaxies*. It also belongs to a small fraction of radio galaxies which, instead of being entirely linear, have a twisted *S-shape*. Astronomers believe that this *S-shape* arises from precession of the axis of the central black-hole powering the extended radio jets that are observed.

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