MeerKAT

MeerKAT dwarfs the hexagonal, honeycomb-like HERA telescope.

Large data release reveals beautiful new cosmic puzzles

An international team led by a young South African researcher, Dr Kenda Knowles, announced a comprehensive overview paper for the MeerKAT Galaxy Cluster Legacy Survey (MGCLS) in November. The paper, to be published in the journal *Astronomy & Astrophysics*, presents some novel results, and is accompanied by the public release of a huge trove of curated data. This will allow astronomers worldwide to address a variety of challenging questions, such as those relating to the formation and evolution of galaxies throughout the universe.

Using the MeerKAT telescope operated by the South African Radio Astronomy Observatory (SARAO), this first observatory-led survey demonstrates MeerKAT's exceptional strengths by producing highly detailed and sensitive images of the radio emission from 115 clusters of galaxies. The observations, amounting to approximately 1 000 hours of telescope time, were done in the year following the inauguration of MeerKAT in 2018.

"In those days we were still characterising our new telescope, while developing further capabilities required by numerous scientists," said Dr Sharmila Goedhart, SARAO head of commissioning and science operations. "But we knew that MeerKAT was already very capable for studies of this sort, and we observed galaxy clusters as needed to fill gaps in the observing schedule."

This was only the start. More than two years of work followed to convert the raw data into radio images, using powerful computers, and to perform scientific analysis addressing a variety of topics. This was done by a team of 40 scientists representing 19 institutions, including 10 in South Africa. Team leader Knowles completed her PhD at the University of KwaZulu-Natal at the end of 2015 and stayed on there as a postdoctoral fellow until taking up a research fellowship at Rhodes University in March 2021.

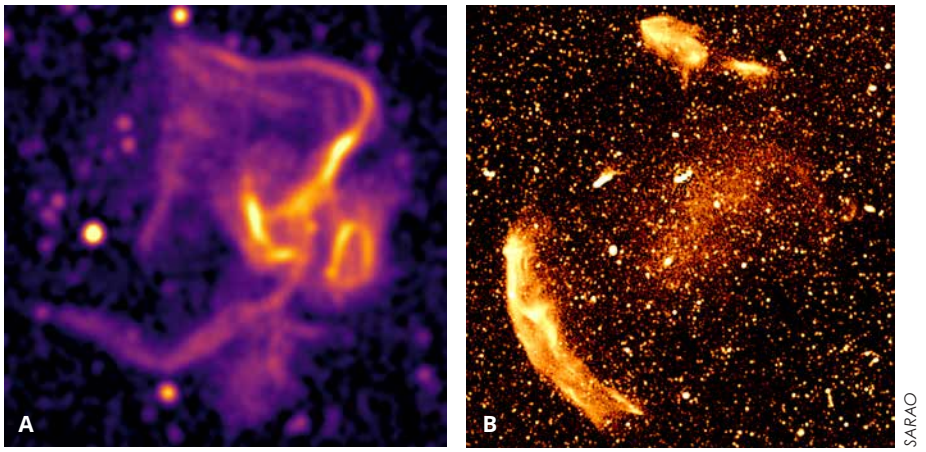
Mysteries of the universe

The force of gravity has filled the expanding universe with objects extending over an astounding range of sizes,

SARAO

The MeerKAT telescope is an array of 64 interlinked receptors, each consisting of an antenna positioner (a steerable dish on a pedestal), a set of radio receivers, and associated digitisers and other electronics.

from comets that are 10 km (one thirty-thousandth of a light-second) across, to clusters of galaxies that can span 10 million light-years. These galaxy clusters are complex environments, host to thousands of galaxies, magnetic fields, and large regions of extremely hot gas, electrons and protons moving close to the speed of light, as well as dark matter. Those 'relativistic' electrons, spiralling around the magnetic fields, produce the radio emission that MeerKAT can 'see' with unprecedented sensitivity, opening new horizons for the deeper understanding of these structures.

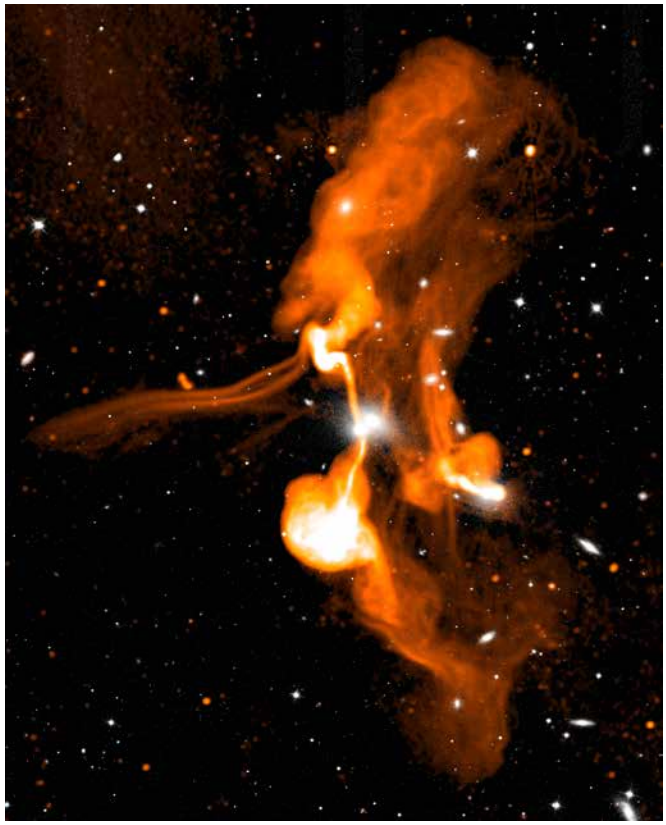


SARAO SARAO

A) MeerKAT view of a complex network of radio filaments and diffuse structure, spanning more than half a million light-years. B) MeerKAT evidence of a powerful merger taking place between two or more massive groups of gas and galaxies.

This means that MeerKAT, particularly when supplemented with information from optical and infrared and X-ray telescopes, is exceptionally well suited to studying the interplay between the components that determine the evolution of galaxy clusters – the largest structures in the universe held together by gravity.

Just as we live in air that we cannot see unless it's filled with smoke or dust or water droplets, creating visible gusts, streams and swirls, so are the motions of the X-ray-glowing plasma in galaxy clusters usually hidden from us. Radio emission from the sprinkling of relativistic electrons in this plasma can reveal the dramatic storms stirred up when clusters collide with each other, or when jets of material spew out of supermassive black holes in the centres of galaxies.



SARAO, SDSS

Two giant radio galaxies (more than one million light-years from end to end) at the centre of a large group of galaxies in the cluster Abell 194, revealing the presence of relatively narrow magnetic filaments in the region, as well as complex interactions between the radio emission from the two galaxies. The MeerKAT radio image is shown in orange, with an optical image dominated by normal galaxies shown in white.

The MGCLS paper accepted for publication presents more than 50 such newly discovered patches of emission. Some of them we can understand and others remain a mystery, awaiting advances in our understanding of the physical behaviour of cluster plasmas. A few examples are shown here, some associated with the bright emission from so-called 'radio galaxies,' powered by the jets of supermassive black holes. Others are isolated features, illuminating winds and intergalactic shock waves in the surrounding plasma.

Other types of science enriched by the MGCLS include the regulation of star formation in galaxies, the physical processes of jet interactions, the study of faint, cooler hydrogen gas – the fuel of stars – in a variety of environments, and as yet unknown investigations to be facilitated by future discoveries.

The MGCLS has produced detailed images of the extremely faint radio sky, while surveying a very large volume of space. "That's what's already enabled us to serendipitously discover rare kinds of galaxies, interactions, and diffuse features of radio emission, many of them quite beautiful," explained Knowles.

But this is only the beginning. A number of additional studies delving more deeply into some of the initial discoveries are already under way by members of the MGCLS team. Beyond that, the richness of the science resulting from the MGCLS is expected to grow over the coming years, as astronomers from around the world download the data from the SARAO MeerKAT archive, and probe it to answer their own questions.

- Knowles, K, Cotton, WD, Rudnick, L et al., The MeerKAT Galaxy Cluster Legacy Survey. I. Survey Overview and Highlights. *Astronomy & Astrophysics*, in press.

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