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# UCT and MeerKAT unlock cosmic secrets: gravitational waves revealed in record time

Regular observations of 80 millisecond pulsars (shown here as bright point sources emitting white radio beams) over the last five years with MeerKAT have revealed evidence for a gravitational wave background. These ripples in spacetime are likely caused by a population of inspiraling supermassive black holes that reside at the heart of massive galaxies (depicted as pink spirals). Photo: Carl Knox, OzGrav, Swinburne University of Technology and South African Radio Astronomy Observatory.

The University of Cape Town (UCT), in collaboration with the South African Radio Astronomy Observatory (SARAO) and leading international institutions, has made groundbreaking strides in unveiling the mysteries of the universe. Harnessing the extraordinary capabilities of South Africa's world-renowned MeerKAT radio telescope, the collaboration has found compelling evidence for a low-frequency gravitational wave background–cosmic ripples in spacetime that stretch and squeeze the fabric of the Universe.

The MeerKAT Pulsar Timing Array project, a five-year initiative that began in 2019, utilises the precision of pulsars – rapidly spinning neutron stars – as natural cosmic clocks. These celestial bodies, located thousands of light-years away, act as the largest galactic gravitational wave detector of its kind, leading to the most detailed gravitational wave maps created.

"To find evidence for a gravitational wave background, we first need to model the timing behaviour of each of the pulsars in our network very precisely," explained Dr Marisa Geyer, co-author and lecturer at UCT and former commissioning scientist of MeerKAT. "Once we know the individual pulsars well, we can start analysing the combined behaviour of the group of pulsars. If we see pulsars in the same direction in the sky lose time in a connected way, we start suspecting that it is not the pulsars that are acting funny, but rather a gravitational wave background that has interfered."

**Groundbreaking insights published**

The findings, published in the *Monthly Notices of the Royal Astronomical Society*, represent a collaboration amongst international partners from UCT, Australia, Europe and SARAO. The results offer unprecedented insights into the likely sources of these spacetime ripples – primarily the colossal mergers of supermassive black holes.

UCT postdoctoral fellow Dr Jaikhomba Singha remarked: "Pulsar timing array experiments are long term in nature and searching for a gravitational wave background is a slow process. From past experience, we know that this may need 15 years of data. It is amazing to see that with MeerKAT evidence for the signal is possible even in a data-span of just 4.5 years."

**Key discoveries**

- **Quickest to a gravitational wave signal**
  In just one-third of the time compared to other global experiments, the MeerKAT team is seeing signs of a gravitational wave background. The background, likely from merging supermassive black holes, is also a stronger signal than other published results. Researcher at OzGrav and Swinburne University of Technology, and a lead author of the studies Matt Miles explained: "The signal we're seeing hints at a more interesting and active Universe than we were expecting. We know that supermassive black holes are out there merging, but now we're starting to ask where and how many?"
- **Detailed gravitational wave maps with unexpected hotspots**
  The researchers also used the pulsar timing array to construct a precise gravitational wave sky map. Kathrin Grunthal, a PhD researcher at the Max Planck Institute for Radio Astronomy and one of the lead authors, pointed out: "By looking for variations in the gravitational waves across the sky, we hunt for the fingerprint of the astrophysical processes behind the signal." The researchers improve upon existing methods to identify a bright spot – an intriguing anomaly suggesting a directional bias in the gravitational wave signal. "The presence of a hotspot could suggest a distinct gravitational wave source, such as a pair of black holes billions of times the mass of our Sun," explained Rowina Nathan, a researcher at Monash University and another lead author of the studies.

**MeerKAT: A testament to South African innovation**

MeerKAT's state-of-the-art design, developed by SARAO and operated as a National Research Foundation (NRF) facility, continues to push the boundaries of astronomical research. SARAO's Science Operations Lead Sarah Buchner celebrated the telescope's exceptional sensitivity: "We have achieved fantastic pulsar sensitivity and timing precision

with MeerKAT. It is deeply moving to see the exquisite results from the pulsar timing array project."

**Future horizons**

This research lays the foundation for deeper exploration into the evolution of galaxies and the formation of supermassive black holes. The upcoming SKA-Mid telescope, incorporating MeerKAT and currently under construction in the Karoo, promises to expand these discoveries even further, positioning South Africa at the forefront of the next generation of cosmic exploration.

"It is a wonderful time to work in the field of gravitational waves using pulsar timing experiments. While PTA experiments are seeing increasing evidence for a gravitational wave background, the source of this is not fully known. In my project we are searching for the presence of unconventional polarisation modes of the gravitational wave signals, to understand their origins better," said UCT PhD student Atiqur Rahman.

As Africa's leading research institution, UCT is committed to pushing the boundaries of knowledge to unleash human potential and create a fair and just society. This discovery underscores UCT's vital role in global scientific innovation, affirming its Vision 2030 to lead transformative research with profound global impact.

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