Early science with the Karoo Array Telescope test array KAT-7

AUTHORS:
Patrick A. Woudt[1]
Rob P. Fender[1,2]
Richard P. Armstrong[1,3]
Claude Carignan[1]

AFFILIATIONS:
[1]Astrophysics, Cosmology and Gravity Centre, Department of Astronomy, University of Cape Town, Cape Town, South Africa
[2]Physics and Astronomy, University of Southampton, High Field, United Kingdom
[3]SKA South Africa, Pinelands, South Africa

CORRESPONDENCE TO:
Patrick Woudt

EMAIL:
Patrick.Woudt@uct.ac.za

POSTAL ADDRESS:
Department of Astronomy, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa

HOW TO CITE:
Woudt PA, Fender RP, Armstrong RP, Carignan C. Early science with the Karoo Array Telescope test array KAT-7. S Afr J Sci. 2013;109(7/8), Art. #a0030, 2 pages. http://dx.doi.org/10.1590/sajs.2013/a0030

One year after the site selection decision of the Square Kilometre Array (SKA),[1] the first significant scientific results from South Africa's Karoo Array Telescope test array KAT-7 have appeared in the astronomical literature.[2,3] This marks one of the many major milestones on the path to the SKA in Africa and highlights the commencement of cutting-edge science observations with South Africa's new radio interferometer.

The SKA project is the largest basic science project ever undertaken in South Africa[1] and has been developing in a number of closely linked phases: (1) the construction (Carnavon) and remote operation (Cape Town) of the technology demonstrator KAT-7, (2) the highly essential human capacity development programme in South Africa and associated SKA Africa partner countries (Youth in Science and Engineering), (3) the construction (Carnavon) and remote operation (Cape Town) of the SKA-precursor array MeerKAT and (4) the integration of the MeerKAT array into the first phase of the international SKA project. The potential spin-offs from this project for other areas of science and industry are tremendous,[4] not least through the computational requirements for large-scale processing of 'big data' in real time.

The construction of the technology demonstrator KAT-7 – a radio interferometer consisting of seven fully steerable 12-m dishes built on-site in Carnavon – was completed in 2011. Following engineering commissioning of the new array, science commissioning, focusing on testing a wide range of operational modes required for MeerKAT science, started in 2012. Designed as a technology and system demonstrator for MeerKAT, KAT-7 was completed on time and within budget by a team of young engineers, who, in the process of building KAT-7, have gained much of the essential experience to construct MeerKAT to full SKA specifications. KAT-7 now moves beyond its initial role of an engineering test facility to full science operations involving the growing community of radio astronomers, physicists and engineers in South Africa.

The human capacity development programme of the SKA SA project office, initiated in 2005, is an integral part of the SKA in Africa. By 2012 this programme delivered scholarships to over 400 students and fellowships to 22 postdoctoral researchers in astrophysics, physics and engineering.[1,4] Given the success of this programme and the long-term investment by the Department of Science and Technology in the training of skilled SKA scientists and engineers in South Africa, it is not surprising that SKA SA scholars have fulfilled key roles in the recent KAT-7 publications.

In 2009, the SKA SA project released an international call[5] for large legacy-style projects on MeerKAT during the first 5 years of its scientific operation. A total of 21 proposals were received from the international community and after peer-review 10 projects were selected[6] – hereafter referred to as the MeerKAT Large Survey Projects (LSP) – which cover a range of science topics at the very heart of the SKA science case. The MeerKAT LSPs represent large international teams of astronomers, physicists and engineers combining a broad spectrum of expertise required for SKA science. Four of the MeerKAT LSPs are co-led by astronomers in South Africa. The South African scientists involved in the two recent papers are all part of teams preparing for the implementation of the MeerKAT LSPs and are closely involved in the science commissioning of KAT-7.

In the first of the two recent papers[2], the KAT-7 array was used in combination with the 26-m Hartebeeshoek Radio Astronomy Observatory (HartRAO) radio telescope near Johannesburg to study the energetic outflow of matter from Circinus X-1, an accreting neutron star in a compact binary system with a highly eccentric orbit. A daily monitoring campaign over a period in excess of 1 month (13 December 2011 – 16 January 2012) showed strong repeated flares from this binary system (Figure 1), modelled as relativistic jets originating from the neutron star every time the companion star reached periastron. After decades of low-level activity, this binary system has returned to a state of bright flares, presumably as a result of changes in the accretion rate of matter onto the neutron star. It is an ideal object to study with the KAT-7 array over extended periods of time; the brightness of the flares is a good match to the sensitivity of the KAT-7 array and the object itself is one of the best laboratories to study relativistic jet astrophysics on an accessible timescale (hours to days to months). The study of transient phenomena in the radio sky is one of the niche areas of research for KAT-7, and the scientific focus of two of the MeerKAT LSPs.

The second paper recently published[3] reported 120 h of KAT-7 observations of the nearby galaxy NGC 3109 (Figure 2). Mapping the distribution of its neutral hydrogen gas content through a spectral line transition (the spin flip of the electron in atomic hydrogen), astronomers were able to model the dark matter distribution in this galaxy. The amount and distribution of dark matter is inferred from the kinematics of the neutral hydrogen gas traced from the centre of the galaxy out to large radial distances; in the case of NGC 3109, neutral hydrogen was measured with KAT-7 out to much larger radial distances than observed before. Because of the compact design of the KAT-7 array, it is more sensitive to faint extended emission compared with other radio interferometers. Combined with a large field of view and good receivers, mapping neutral hydrogen in nearby galaxies is another niche area for KAT-7. The KAT-7 observations of NGC 3109 put stronger constraints on an alternative explanation for dark matter, namely Modified Newtonian Dynamics (MOND). MOND cannot represent the observed rotational velocities of the gas in NGC 3109.

KAT-7 is now at a stage where it is able to respond regularly to requests from the international community for observations of specific objects. Flexible scheduling in combination with state-of-the-art receivers will make KAT-7 a very attractive radio telescope until MeerKAT comes online. The MeerKAT LSPs will continue to look to KAT-7 to test new and novel data analysis techniques ultimately designed for MeerKAT.

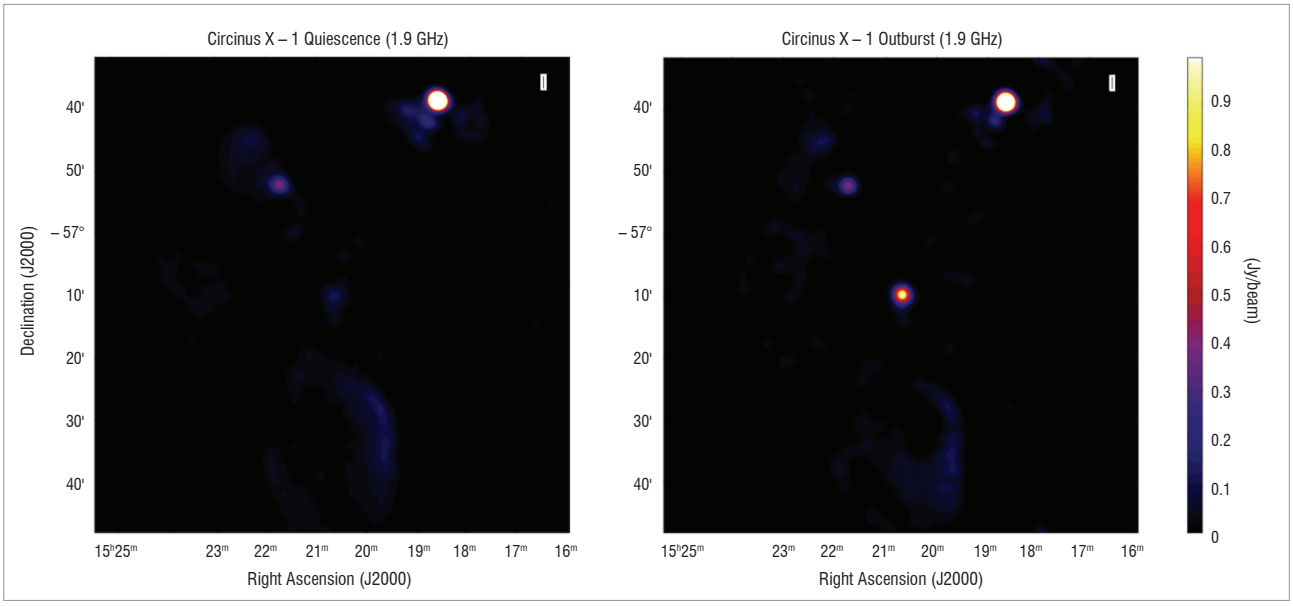

Figure 1: Variable radio emission from Circinus X-1 in images from the KAT-7 interferometer. The left panel shows a fiducial profile image obtained during the quiescent phase of the binary flare cycle averaged over a 10-day period. Circinus X-1 is located at the centre of the field. The right panel shows an image taken during the radio flaring phase (23 December 2011) for comparison.

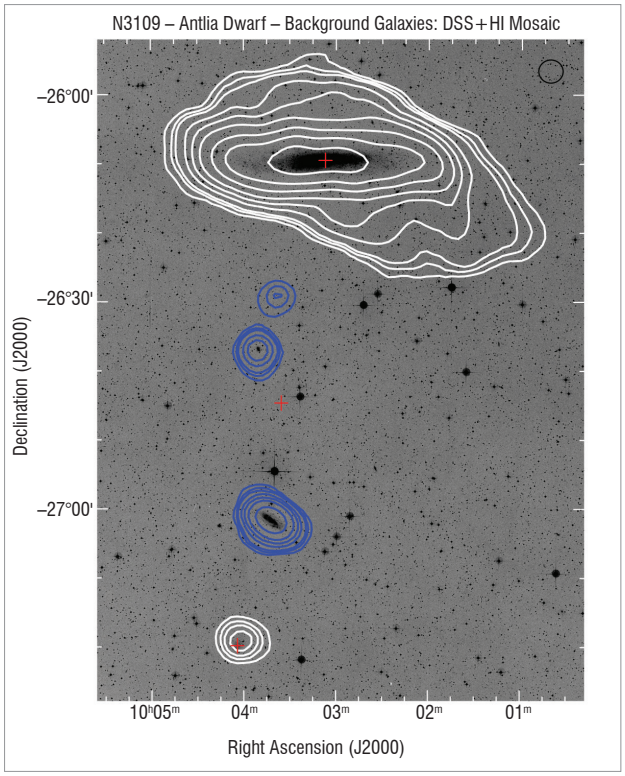

Figure 2: Neutral hydrogen gas (white contours) in NGC 3109 (top) and the Antlia dwarf galaxy (bottom) as observed with KAT-7.[3] The observations are overlaid on an optical image of this part of the sky. The blue contours correspond to background galaxies.

With only seven 12-m dishes spread over a 200-m baseline, KAT-7 is a modest radio telescope compared to MeerKAT and the SKA, both in terms of resolution and sensitivity. MeerKAT, to be completed in 2016, will be the most sensitive radio telescope in the southern hemisphere only to be overtaken by the SKA around 2020. What is perhaps the most pertinent conclusion of the recent milestone is the rapid coming-of-age of the SKA community in South Africa and the exposure of the next generation of African radio astronomers, largely thanks to the successful human capacity development programme in a joint effort by the universities involved and the SKA SA project office. In both publications there are leading contributions from young South African students and postdoctoral fellows who have completed the scholarship programme. The success of involving the next generation in novel science during the earliest phases of a new facility, benchmarked by the international community, certainly bodes well for the future science commissioning of MeerKAT and early science with this SKA precursor.

Acknowledgements

We thank the SKA South Africa project and the KAT-7 commissioning team for the generous time allocated for the Circinus X-1 and NGC 3109 observations.

References

1. Cherry M. Square Kilometre Array decision bodes well for South Africa. S Afr J Sci. 2012;108(7/8), Art. #1371, 1 page. http://dx.doi.org/10.4102/sajs.v108i7/8.1371
2. Armstrong RP, Fender RP, Nicholson GD, Rafcliffe S, Linares M, Horrell J, et al. A return to strong radio flaring by Circinus X-1 observed with the Karoo Array Telescope test array KAT-7. Mon Not Roy Astr Soc. In press 2013. Available from: http://mnras.oxfordjournals.org/content/early/2013/06/13/mnras.stt860
3. Carignan C, Frank BS, Hess KM, Lucero D, Randriamampandry TH, Goedhart S, et al. KAT-7 science verification: Using HI observations of NGC3109 to understand its kinematics and mass distribution. Astron J. In press 2013. Available from: http://arxiv.org/abs/1306.3227
4. Davidson DB. Potential technological spin-offs from MeerKAT and the South African Square Kilometre Array bid. S Afr J Sci. 2012;108(1/2), Art. #1050, 3 pages. http://dx.doi.org/10.4102/sajs.v108i1/2.1050
5. Booth RS, De Blok WJG, Jonas JL, Fanaroff B. MeerKAT key project science, specifications and proposals. arXiv:0910.2935; 2009. Available from: http://arxiv.org/abs/0910.2935
6. Square Kilometre Array (SKA) Africa. MeerKAT science [homepage on the Internet]. No date [cited 2013 Jul 10]. Available from: http://public.ska.ac.za/meerkat/meerkat-large-survey-projects