Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Maser Science with the African VLBI Network and MeerKAT

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Abstract. The African VLBI Network (AVN) is slowly becoming a reality. A couple of successful fringe test observations have been conducted even as single-dish maser monitoring observations constitute the main activity on the telescopes (HartRAO 26 m and Ghana 32 m). Some of the recent observational results from the AVN telescopes includes detection of velocity drifts in masers. Although MeerKAT is largely designed for high sensitivity continuum and HI science, its bands cover some masers and is already making impressive discoveries. The need to grow the critical mass of radio astronomers in the African continent persists. The NWU 4-dish interferometer, the Nigeria 3.7 m radio telescope and the African Millimeter Telescope (AMT) are some of the initiatives that will significantly improve the statistics of radio astronomers in Africa.

Keywords. Masers, stars: formation, ISM: jets and outflows

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1. Introduction

The landscape of radio astronomy research in Africa is rapidly improving with the advent of the Square Kilometer Array (SKA) and its precursor, MeerKAT. Hartebeesthoek Radio Astronomy Observatory's 26 m radio telescope has played an active rule in its involvement in the very long baseline interferometric (VLBI) observations of the European VLBI Network (EVN) and the Australian Long Baseline Array (LBA). The Ghana 32 m radio telescope came online in 2018 after a few successful VLBI fringe test experiments with the EVN and the single baseline 6.7 GHz fringe detection with HartRAO 26 m telescope. These two telescopes constitute the current operational components of the AVN.

Prior to the coming into operations of MeerKAT telescope,

2. Maser science results of the AVN telescopes and MeerKAT

HartRAO 26 m telescope has played a key in the hunt for accretion burst events in massive protostellar objects, e.g. the case of NGC 6334I (MacLeod *et al.* 2018; Hunter *et al.* 2017; Burns *et al.* 2022; Chibueze *et al.* 2021). In recently times, it has contributed to the discovery of a second period in the periodic behavior of G9.62, including the identification of Zeeman pair in the same source using the velocity drift property of the masers (MacLeod *et al.* 2022, 2021). High cadence observations of the "bunny hop" periodic maser source is being explored as a means of confirmation the existence of or not of quiescent phase in the lowest flux density phase of the periodic masers.

The Ghana 32 m telescope, on the other hand, have continued to monitor bright maser sources due to its sensitivity limitation cause by the ambient receiver system installed on the telescope. It has also been a handy facility for observational radio astronomy training of African students and cohorts of the Development in Africa through Radio Astronomy (DARA) project [PI: Melvin Hoare]. The most recent development of Ghana 32 m telescope is the acquisition of a H-maser clock which will replace the existing Rubidium clock, making it a more functional VLBI station with improved phase.

The MeerKAT debuted its maser science with the discovery of "Nkalakatha", a luminous OH megamaser at $z > 0.5$ (Glowacki *et al.* 2022). The MeerKAT Galactic Plane Legacy Survey (MGPLS) conducted in L-band focuses on continuum imaging, however, the coarse spectral resolution of the MGPLS data could still be used for OH maser detection and could be useful for mapping the most complete distribution of the OH maser in the Milky Way yet. However, this will require spectral imaging of the MGPLS data. A proof of concept for the OH maser imaging has already been conducted.

3. Growing the critical mass of African users of the SKA

Th MeerKAT and the SKA have strongly underscored the gross deficiency in the availability of human resources in the field of radio astronomy and interferometry. In fact, there are less than a dozen African professional radio astronomers. The implication of the current human capacity situation is that Africa could host revolutionary facilities but contribute minimally to the scientific output of the facility. This lack of critical mass of prospective users on future facilities like the SKA informed my desire to drive the growth of the critical mass of radio astronomers in the continent.

One way to ensure proper hands-on training that will stimulate interest among African in radio astronomy is to develop cheap radio telescope that can be used effectively for such training. Understanding interferometric data handling without proper understanding of how the individual single-dish telescopes work and the principle of radio interferometry/aperture synthesis, make the field a bit of a "blackbox" to new entrants into the field.

There are a number of initiatives toward growing the number of radio astronomers in Africa, and I will highlight three of them, namely, North-West University 4-dish interferometer, the Nigeria 3.7 m radio telescope and the African Millimeter Telescope (AMT).

3.1. *NWU 4-dish interferometer*

North-West University Potchefstroom Campus is home to the Centre for Space Research, and recently acquired and installed four 3.7 m prime focus, altitude-azimuth radio telescopes supplied by POAM Electronics United Kingdom. The installation of the telescopes took place in August, 2022. The telescope site is located ~ 35 km from Potchefstroom at the sparsely populated place called Nooitgedacht. The location is fairly radio quiet with only a few mobile phone/GSM and wifi potential radio frequency interference (RFI) sources.

Each of the four telescopes has C-band and L-band front-end, with a wideband band end to enable the switching of band to enhance the scientific output of the instrument. The C-band covers the 6.7 GHz methanol maser frequency, with the L-band front-end covers the 21 cm neutral hydrogen (HI) line frequency.

The science goals of the NWU 4-dish interferometer includes but not limited to the following;

(1) Intensive monitoring observations of bright 6.7 GHz methanol maser sources
(2) Focus observations of bright radio transient events
(3) High cadence monitoring of bright radio galaxies and spectral index measurement
(4) Future of observation of pulsars (pending the availability of the pulsar back-end)

Figure 1. Antenna 1 of the NWU 4-dish interferometer.

Figure 2. Aerial view of the four telescopes of the NWU 4-dish interferometer.

Beside the possibly observational work that could be done with the interferometer, it can be used for hands-on training. In fact, the assembly and installation of the four telescopes were done by DARA cohorts from the Southern African region. It is important to mention that the NWU 4-dish interferometer is already being used by postgraduate students of NWU as the solid part of their research project. The interferometer has already started attracting new collaborations for NWU. For example, the radio receiver development teach at the University of Pretoria led by Prof Tinus Stander. And we look forward to more collaboration and the improvements in the front and back-ends that this collaboration will deliver to the array. Figures 1 and 2 show a close view of one of the four 3.7 m radio telescopes and an aerial view of the array, respectively.

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Figure 3. Photo of the Nigeria 3.7m radio telescope at the manufacturer's site undergoing drive tests.

3.2. *Nigeria 3.7 m radio telescope*

The NWU 4-dish interferometer has attracted a lot of interests from the astronomy community of the African continent and the demand to install similar system in many African countries have grown. South Africa has the highest number of radio astronomers in Africa, followed by Nigeria, thus it made sense to consider Nigeria as the next destination of a 3.7 m that could be used for training and some level of research.

Global Emerging Radio Astronomy Foundation (https://www.gerafoundation.com), a non-profit organization registered in Canada, in collaboration with the Centre for Basic Space Science (CBSS) of the National Space Research and Development Agency of Nigeria, raised funds and acquired 3.7 m telescope from POAM Electronic to be installed in Nigeria in the 2nd half of 2023 (see Figure 3). The telescope will be fitted with an L-band receiver for a start and more bands can be added to the front-end subsequently.

The Nigeria telescope will be used extensively for teaching and for HI mapping observations.

3.3. *African Millimeter Telescope (AMT)*

Event Horizon Telescope (EHT) imaging of the blackholes' event horizon have received a lot of publicity in recent times. The importance of the addition of a millimeter telescope on the African continent to the EHT array cannot be over-emphasized. Such addition will evidently improve the imaging capabilities of the eastern components of the array. Radboud University in collaboration with the University of Namibia are planning to install the first ever millimeter telescope on Mount Gamsberg, close to the High Energy Stereoscopic System (HESS) telescope site in Namibia.

This project is now significantly funds and we will be seeing a millimeter telescope on the continent soon. The priority project of the AMT will be participation in the annual blackhole imaging campaigns. However, there will be 1000s of hours available for single-dish observing projects, and these will include but not limited to, intensive monitoring of millimeter masers, monitoring of AGN, mapping observations of giant molecular line.

Yes, the radio astronomy landscape looks promising, but there is dire need to train more radio astronomer who will play some role in the science output of our society.

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