Expanding radio astronomy in Africa

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Abstract.

The Square Kilometre Array (SKA) Organisation announced in May 2012 that its members had agreed on a dual site solution for the SKA [1]. South Africa’s bid for hosting the SKA has caused a ramp up of radio astronomy in Africa. To develop technology towards the SKA, the South African SKA Project (SKA SA) built a prototype radio telescope in 2007, followed in 2010 the seven antenna Karoo Array Telescope (KAT-7). Next is the 64 antenna MeerKAT, which will merge into SKA Phase 1 in Africa.

As SKA Phase 2 is intended to add a high resolution capability with baselines out to 3000 km, the SKA SA brought in partner countries in Africa to host outstations. South Africa has been working with the partners to build capacity to operate the SKA and to benefit from it. The SA Department of Science and Technology (DST) developed a proposal to establish radio telescopes in the partner countries to provide hands-on learning and a capability for Very Long Baseline Interferometry (VLBI) research. Redundant 30 m class satellite antennas are being incorporated in this project.

1. The SKA in Africa
Radio astronomy in Africa is set for radical change with the announcement on 25 May 2012 of dual siting for the SKA in Southern Africa and Australia. The majority of SKA Phase 1 dishes will be built in a ~100 km radius around the core site near Carnarvon in the arid Karoo region of South Africa, and will incorporate MeerKAT, comprising 64 13.5-m dishes. The balance of the dishes will be built in Australia to work with the ASKAP array of 36 12-m antennas. All the dishes and mid-frequency aperture arrays for Phase 2 will then be built in Africa. The Phase II dishes will add to the core, and also provide outstations on baselines to 3000 km. In Phase 1 the dishes will operate from 0.45 to 3 GHz and in Phase 2 this will be extended to 10 GHz.

2. SKA precursors in Africa - XDM, KAT-7 and MeerKAT
In addition to bidding for siting the SKA, SKA SA also worked on developing technologies for the project, including reflector antennas to be suitable for mass production at low cost. The first prototype antenna was a 15-m, prime focus, symmetric paraboloid called the “eXperimental Development Model” (XDM). This was constructed at the existing Hartebeesthoek Radio Astronomy Observatory (HartRAO), west of Johannesburg, in 2007. An accurate mould of the dish shape was assembled on site. A releasant layer was sprayed on it, followed by a flamesprayed aluminium layer. Foam blocks wrapped in fibreglass were placed on top and resin sucked in to create a one-piece dish. The steel backing frame was bonded to this. Two receivers for 1.4 - 1.7 GHz were fitted. After completion of testing HartRAO re-equipped the telescope with a dual-band cryogenic receiver for 2.3 and 8.4 GHz, intended primarily for geodetic VLBI.
This was followed by the Karoo Array Telescope KAT-7 array of seven 12-m antennas, again of prime-focus symmetric paraboloid design. They are equipped with single 1.4 - 1.8-GHz cryogenic receivers with Stirling coolers taking them to liquid nitrogen temperatures (77 K). These were built using an improved version of the process employed for XDM, and were constructed on the plain near Carnarvon where the SKA will be built. The maximum baseline is 185 m. Completed in 2010, the KAT team has since been commissioning an expanding range of observing modes. Some science research has been carried out during this phase.

The next iteration in development is MeerKAT (more KAT), which is designed to provide a competitive science instrument. It will comprise 64 offset Gregorian antennas of 13.5 m effective diameter. Three receivers will cover 0.58 - 1.015 GHz, 0.9 - 1.76 GHz and 8 - 14 GHz. Array baselines will be out to 10 - 20 km. The winning bid for the antennas provided conventional construction of aluminium panels on steel structure. Large scale survey projects have already been accepted for MeerKAT, but it is also to be integrated into SKA Phase 1.

3. HartRAO and long baseline astronomy
The 26-m antenna at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) was built as a NASA spacecraft tracking antenna in 1961 and it was operated for NASA until 1974. Since then it has operated as a South African National Facility for radio astronomy. The antenna has been subject to many upgrades and is currently equipped with seven receivers. Its primary science function today is for VLBI, but it also used for research operating as a single dish. For astronomical VLBI it operates with the European VLBI Network (EVN) and Australia Telescope Long Baseline Array (AT-LBA), and for astrometric and geodetic VLBI it operates with the International VLBI Service for Geodesy and Astrometry (IVS). Its value lies in providing long baselines to other continents, but for astronomical imaging the drawback is that there are no other VLBI-capable telescopes in Africa or adjacent islands to fill the long gaps to Europe and Australia. This means images cannot be unambiguously created from the data.

4. Radio astronomy development in partner countries
South Africa’s DST and SKA SA identified the need to provide training for the African partner countries to maximise the benefit of the SKA for Africa. The training needs are both scientific, to be part of the exploitation of SKA’s research capabilities, and technical, to be part of the operation of the SKA outstations. DST developed a proposal for relatively modest telescopes to be established in partner countries, which would also have a VLBI capability.

5. Satellite Earth stations and fibre-optic communication
Communication via geostationary satellites was introduced to carry voice, data and TV signals, using the 5.9 - 6.4 GHz band for uplink and 3.7 - 4.2 GHz band for downlink. About 30 Satellite Earth Stations built in Africa from 1970 to 1985 were equipped with Intelsat Standard A antennas of 30 - 32-m diameter. New wideband fibre optic links have made the large antennas redundant. The DST proposal has incorporated the conversion of redundant large antennas to radio telescopes. Their location in partner countries is shown on the SKA SA developed layout for SKA outstations shown in Fig. 1. The feasibility of the proposed conversions is indicated by the success of previous conversions, at Ceduna in Australia and Yamaguchi and Ibaraki in Japan, New Zealand, Peru, Ireland and England are also carrying out conversions. The 34-m NASA DSS-28 beam waveguide antenna in California has also been converted for radio astronomy [2].

6. Astronomical applications for large antennas in Africa
For astronomical imaging with existing VLBI networks it would be very helpful to have antennas filling the gap between SA and Europe and SA and Australia. To create an independent VLBI
Development of the science case is guided by usage of existing VLBI networks and by the science case developed for the SKA [3], [4]. VLBI is used to observe radio-bright sources of small angular size. Large objects physically meet this requirement if they are distant. Active galactic nuclei and radio-bright supernovae in external galaxies are examples of objects whose evolution can be studied with VLBI. Masers in star-forming regions in the Milky Way are examples of nearby bright, compact sources. Methanol masers at 6.668 GHz and 12.178 GHz are of particular interest currently. Measurement of their annual parallaxes by repeated VLBI observations enables their distances to be determined, and thus also the locations of the spiral arms in the Milky Way. The same technique can be used to measure pulsar distances. Transient sources and gamma-ray bursters are both potential targets.

Antennas equipped with 2.3+8.4 GHz receivers could participate in geodetic and astrometric VLBI with the current generation of radio telescopes carrying out this research. This technique provides very precise absolute location for the telescope, to which co-located relative position measuring systems such as GPS and satellite orbit measuring systems can be tied.

VLBI is not expected to run continuously on African telescopes. The time available for single-dish astronomy would be valuable for student training purposes and for selected research projects. Radiometry, spectroscopy and pulsar timing capabilities would be established.

7. Towards an African VLBI Network - conversion of existing antennas

The Ghanaian government has taken over the redundant 32 m antenna at the Kutunse Satellite Station outside Accra from Vodafone. SKA SA and HartRAO have built up an engineering team to assist the Ghana Space Science and Technology Centre (GSSTC) with its conversion. This antenna is well placed to fill the gap between Europe and Africa for VLBI with the EVN. The aim is to establish an initial operational capability in the 5 GHz VLBI band. Discussions are also underway with Kenya and Zambia regarding their large antennas.
Figure 2. Location of Mauritius between African and Australian radio telescopes.

Figure 3. UV coverage for a southern source observed with the AT-LBA and HartRAO. The red tracks show the improved coverage provided by adding a radio telescope on Mauritius.

8. Towards an African VLBI Network - potential new telescopes
Four partner countries do not have large antennas, so the feasibility of establishing new radio telescopes for training and VLBI is being investigated. Mauritius has a history of radio astronomy using the 151 MHz Mauritius Radio Telescope (MRT), and so it has taken the lead in joining this study. The design and siting of potential new telescopes is driven by the science case, the need for compatibility with existing networks and converted antennas, the provision of services, minimisation of radio frequency interference, and of course, costs. A two day workshop was held on Mauritius on 21 and 22 September 2012 to introduce Mauritian role players to the subject and establish work groups. Mauritius is well situated to fill the gap between Africa and Australia, as shown in Fig. 2. The UV plot for a typical southern source is shown in Fig. 3.

9. Summary
The coming of the SKA is greatly expanding radio astronomy in Africa through multiple precursor projects. The potential for converting obsolete large antennas for radio astronomy has been recognised World-wide, and this is an opportunity for Africa too. The case for potential new-build telescopes is being developed with the participation of Mauritian radio astronomers.

References
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