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Review of Australian Concept Demonstration Activities (document dated May 7, 2004)

A. R. Thompson and D. Kant

In pursuing the SKA concept in Australia, the attention is being turned away from the Luneberg Lens (LL) concept and focussed towards aperture arrays and concentrators (particularly cylindrical reflectors) and related technology. A major goal is the development of a New Technology Demonstrator (NTD), which will have a collecting area of 3000 sq. m, located at a relatively quiet site in western Australia. This will be based on aperture array or cylindrical reflector technology. Technological developments relevant to the SKA are being pursued through the improvement of several existing instruments. This includes development in the areas of line feeds, wide bandwidth hardware for continuum observations, modern correlator technology, signal connectivity and signal processing. It is pointed out that the existing collecting area in Australia includes almost 6000 sq. m (the ATCA and the Parkes dish), plus 18,000 sq. m in the Molonglo cross telescope. Thus it is economically more efficient to make use of these existing instruments in demonstrating the SKA technology than to build a demonstrator of comparable area.

Development Areas

The program includes development of MMIC amplifiers using various semiconductor technologies. Since neither AA nor cylinder technology is suited to the use of cryogenically cooled front ends, developing the best uncooled systems is clearly important. Integrated receivers and wide bandwidth amplifiers for use with photonic data transportation are also mentioned.

Signal processing and connectivity involves work by Swinburne University and includes disk-based recording for VLBI observations and new computer systems for pulsar observations at the Parkes telescope and the AT compact array.

A new broadband backend and correlator for the AT compact array will increase the maximum bandwidth from 128 MHz to 2 GHz. This project commenced in 2002, and is listed as providing technological development useful to the SKA.

Molonglo Telescope

Upgrading the Molonglo telescope (SKAMP project) to cover a frequency range of 300-1400 MHz will involve a number of new technologies including the linefeed, beamformers, digital filtering, wideband spectral correlator, control system, and RFI mitigation, all of which are of relevance to SKA concepts. A milestone calls for the upgrade to be completed for commissioning tests in June 2007. It is interesting to note that the Molonglo cross came into operation about 40 years ago with a linefeed capable of operation at 408 MHz (Mills et al. Proc. IRE Aust., 24, 156-165, 1963). At that time there were to be 22 front-end amplifiers along the mile-long E-W arm and 177 N-S. For the proposed 1400 MHz feed system with dual polarization there will be approximately 1.5 x 10^4 dipoles per arm. A modern low-noise implementation will require many more front end transistors than in the original linefeed. The relative cost of electronics has greatly decreased over 40 years, but the development of a linefeed with sufficiently low system temperature and adequate beamforming flexibility, within a reasonable cost, is a crucial task for the Australian concept.

New Technology Demonstrator (NTD)

As mentioned above, the demonstrator would have a collecting area comparable to the Parkes telescope, (3000 sq. m) but its usefulness will be greatly enhanced by having an instantaneous field of view of 50 deg^2. This will provide high speed for surveys including pulsars. Although the basic technology is not specified, it is stated under the SKAMP program that the NTD project will link closely with SKAMP, and acceleration of the linefeed development is specifically mentioned. Thus it seems reasonable to conclude that the cylinder technology is likely to be the choice for the NTD. Provided that a sufficiently low-cost line feed can be developed, the use of cylinders offers a very practical way to produce a large collecting area. The NTD project plan is being developed in collaboration with MIT, and the milestone for completion is 2007. In addition to antenna and receiver technology, the NTD will provide experience with the low RFI environment that the Western Australia site is hoped to provide, connectivity with eastern observatories, and provision of electrical energy at the site.

Strengths and Weaknesses of the Cylinder

Strengths and weaknesses of the cylinder concept are briefly discussed in the 2003 review (see the IEMT Report dated 3 Oct. 2003). Strengths include the wide instantaneous field of view and the mounts, which are mechanically simpler than for circular paraboloids. Weaknesses include the complexity of the linefeed, and the impracticality of cryogenic cooling. Also, pointing of the beams in elevation is restricted by the mechanical pointing of the reflector, and multibeaming is possible only in the orthogonal direction.

RFI

Under RFI mitigation, it is stated that RFI surveys will be undertaken at the ATCA and Parkes sites, using the equipment already available there. Under the NTD it is mentioned that the Western Australia site is expected to be very RFI-quiet. Since most interference to radio astronomy originates from satellites, it is not clear how much better the RFI environment in an area of low population density can be expected to be. There is no specific mention of an interference survey at the Western Australia site. It is mentioned that the political and social aspects of protecting the radio quiet environment at the NTD site are being pursued. Mitigation studies using data from the ATCA and Parkes are planned and a milestone in Section 2.7 calls for mitigation in real time at the correlator to be implemented in mid 2007. It presumably remains to be seen how effective this will be, i.e. how close to the noise any residual interference responses will be.

Science Goals for the Demonstrators

Section 5 gives brief details of astronomically important programs that will result from the planned demonstration activities on the Molonglo telescope, the NTD, and the ATCA.

A Question on Rotation of the Beams

It was pointed out in Section 11(vi) of the cylinder review in the 2003 IEMT Report that the non-circularity of the cylinder beam contours, and their rotation on the sky with hour angle, could be a complicating factor in observations requiring several hours of tracking. This would cause variation of the synthesized beam and the SNR over the field of view. The cylinder details given last year include overall dimensions of 110 x 15 m and construction as four mechanically separate units. Individual units would be 27.5 x 15 m, with uniform illumination in the long dimension, resulting in roughly 2 to 1 variation on beamwidth for the individual unit. Is the beamforming done in such a way that roughly circular beams are formed from different sections of the linefeed? Or perhaps the 2 to 1 variation is acceptable if one takes account of the fact that the scan angle is limited to +/- 60 deg. and rotation is most important at declinations approaching the pole, where the area of sky is relatively small? It is important to make sure that correction for the beam rotation would not require a major increase in the computing load.

Beamwidth in Elevation

The beamwidth of the proposed cylinders in elevation is determined by the 15 m dimension of the reflectors. At the lower frequencies, the wide elevation beamwidth could result in a serious increase in the computing load. This increase would result from the requirement to compensate for non-coplanar baselines, as discussed by Cornwell in SKA Memo 49. Cornwell considers antennas with circular apertures, and finds, for example, that a decrease in antenna diameter from 25 m to 12.5 m at 1.4 GHz results in an increase in computing costs by a factor of approximately 256. Since, for the cylinders, the wide beamwidth occurs in one dimension only, the effect on computing costs will presumably be less serious. Further study is required on this point.

General Conclusions on the Cylinder Concept

The question of the upper frequency limit of operation with the cylinder technology is not discussed, and proposed science demonstrator projects with the NTD are largely H1 studies. Since the number of radiating elements in a linefeed increases in proportion to the observing frequency, and losses in transmission lines also increase, the number of front-end amplifiers etc., and hence the cost, will increase with frequency. An upper limit above 1400 MHz is certainly to be hoped for. Overall the concept demonstration plan makes a very good case for the practicality of pressing ahead with the proposed demonstrators for the lower frequency end of the SKA coverage.

Questions Provided by Peter Hall, April 23, 2004

The following are brief answers to the questions that Peter listed. I would rate the answers as generally in the range of very good to satisfactory, except for question 12 on supplementary questions raised in the IEMT 2003 Report.

1) Main purpose is judged to be a technology demonstrator (the NTD). Also testing SKA-relevant technology in upgrades to some existing instruments.

2) Demonstrates major part of the cylinder concept. In particular the crucial linefeed cost and performance.

3) $18.4M over 4 years. Reviewer has not analyzed manpower requirement.

4) Appears to be largely funded except for expenses of location of NTD in Western Australia (see para. 3 of Section 1).

5) Institutions involved include CSIRO (ATNF), U. of Sydney, Swinburne U., MIT.

6) Management structure is not discussed in detail, but CSIRO should be capable of handling a program like this.

7) Milestones are defined and should help to track progress.

8) Milestones seem plausible if no major problems arise.

9) By 2006, should be able to say something about the cost of linefeeds, which is a crucial point for assessment of the cylinder concept.

10) Delivery of major outcomes, such as linefeed testing and accurate costing, seem possible by 2008. Plan calls for NTD to be completed within 2007, but it is likely to take more than a year to get good experience with its operation.

11) Key questions concerning the performance of the cylinder array include the upper frequency limit, which depends upon the linefeed technology and the noise performance of the uncooled amplifiers. These will be answered by the ongoing studies. Other questions include the possible effects on computing costs of the rotation of the beam on the sky and of the wide beamwidth in elevation at the lower frequencies.

12) Further questions (section 11 on p. 19 of IEMT Report dated 3 Oct. 2003) have generally not been specifically addressed.

13) Connectivity and signal processing are being addressed by people at Swinburne U. (Section 2.2).

14) Contingency etc. probably OK but reviewers cannot be sure.

15) Some computing component is presumably required with in the Swinburne U. work and in testing of new high bandwidth backend at ATCA. See also remarks on international cooperation on SKA software in Section 3.3.

16) Mechanical engineering will be involved in development of cylinders for NTD.

17) Infrastructure development will be required for locating of NTD in Western Australia.

18) Impressive astronomical programs for the NTD and other instruments involved in the technology demonstration are listed in Section 5.

19) A number of aspects are applicable to other SKA concepts, e.g. connectivity, signal processing, wideband correlator, RFI mitigation, experience at remote Western site.

20) International groups with which there are links include MIT, PHAROS (EU FP6 RadioNet), EMBRACE (EU FP6 SKADS). (see Section 3.)

21) Four areas of collaborative work with Australian industry are listed in Section 4.

<u>Rating Table</u>
On most points we would give the Australian demonstrator plan high marks. However, we are reluctant to award numerical scores because we think that that this depends too much on the response of the individual reviewer. We suggest that it would be better if we get together in Penticton and jointly discuss numerical scores.

<u>Luneberg Lens Concept</u>
The decision to set aside further work on the LL concept, and to concentrate on concepts that offer more certain promise of a successful outcome, has led to a plan that should certainly result in practical demonstration of a number of essential aspects of SKA technology within a few years. This is a decisive step forward, and resulted from giving full attention to the dielectric loss of the LL elements, which was the basic problem. Although the attenuation of the dielectric was improved, the resulting performance was not competitive with that of reflector antennas for the

high-frequency end of the SKA range. From the science viewpoint, this disadvantage was judged to outweigh the multi-fielding at centimeter wavelengths which was a major strong point of the LL concept. Also, the dielectric loss would require the use of relatively small apertures for the individual receiving elements, resulting in increased computing load at the low end of the frequency range as discussed in SKA Memo. 49. The various reports and studies of the LL concept contain contributions to aspects of the SKA system in the areas of signal processing and distribution etc., which should be useful in development of other concepts.