Prototype SKA technologies at Molonglo

– 1. Overview & Science Goals


Joint project between the University of Sydney, Australia Telescope National Facility and CSIRO Telecommunications and Industrial Physics

Goal: To equip the Molonglo telescope with new feeds, low-noise amplifiers, digital filterbank and FX correlator with the joint aims of (i) developing and testing SKA-relevant technologies and (ii) providing a new national research facility for low-frequency radio astronomy

Funding proposal: Part of Australian astronomy community’s bid to 2001 Major National Research Facilities scheme.
Current wide-field imaging with MOST
(843 MHz, 12hr synthesis, 2.7° diameter field)

**Current Survey** (1997-2003):
The Sydney University Molonglo Sky Survey (SUMSS), imaging the whole southern sky ($\delta < -30^\circ$) at 843 MHz to mJy sensitivity with 45″ resolution (i.e. similar to NVSS).

**Next:** Use existing telescope as SKA testbed **and** science facility:
- Large collecting area (18,000 m$^2$)
- Wide field of view
- Continuous $uv$ coverage
Continuous uv coverage gives excellent image quality:

- Continuous uv coverage from 90 m to 1.6 km in 12hr synthesis
- SKA will also have fully-sampled uv data

(Bock et al. 1999)
Key features of the Molonglo SKA prototype

Collecting area = 1% of SKA (i.e. equivalent to 1 SKA station)

- Multibeamming
- Wide instantaneous field of view
- Digital beamforming
- Wide-band FX correlator (2048 channels)
- Frequency and pointing agility

- Wide-band line feeds and LNAs
- Cylindrical antenna prototype
- Adaptive null steering and adaptive noise cancellation
Signal Path and Antenna Pattern

Cylindrical Parabolic Collectors
(Two collinear 778 m x 12 m)

300-1420 MHz Feed and LNA
(7,400 feeds, 14,800 LNAs)

Delay line beamforming

Analog to Digital Converter
(1,600 8 bit 250 MHz BW ADCs)

Digital delay beamforming
(80 x10 m x 10 m patches)

Digital filterbank (160)
(Two polarisations @ 250 MHz/patch)

FX Correlator
(3,160 baselines, 2,048 channels)

Signal processing & storage
(imaging, spectrometer, searching...)

Single feed beam

Delay line beam

Independent fanbeam

Imaging beam

Independent fanbeam

Digital Beamformer
(64 fanbeams within imaging beam)
[Requires extra funding]
## Target specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1420 MHz</th>
<th>300 MHz</th>
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</thead>
<tbody>
<tr>
<td>Frequency Coverage</td>
<td>300–1420 MHz</td>
<td>300 MHz</td>
</tr>
<tr>
<td>Bandwidth (BW)</td>
<td>250 MHz</td>
<td></td>
</tr>
<tr>
<td>Resolution ($\delta &lt; -30^\circ$)</td>
<td>26&quot; x 26&quot; csc</td>
<td>$\delta$</td>
</tr>
<tr>
<td>Imaging field of view</td>
<td>1.5° x 1.5° csc</td>
<td>$\delta$</td>
</tr>
<tr>
<td>UV coverage</td>
<td>Fully sampled</td>
<td></td>
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<tr>
<td>$T_{\text{sys}}$</td>
<td>$&lt; 50$K</td>
<td>$&lt; 150$K</td>
</tr>
<tr>
<td>System noise (1σ) 12 hr:</td>
<td>11 $\mu$Jy/beam</td>
<td>33 $\mu$Jy/beam</td>
</tr>
<tr>
<td>8 min:</td>
<td>100 $\mu$Jy/beam</td>
<td>300 $\mu$Jy/beam</td>
</tr>
<tr>
<td>Polarisation</td>
<td>Dual Linear</td>
<td></td>
</tr>
<tr>
<td>Correlator</td>
<td>I and Q (Full Stokes at 125 MHz BW)</td>
<td></td>
</tr>
<tr>
<td>Frequency resolution</td>
<td>120–1 kHz (FXF mode: 240 Hz)</td>
<td></td>
</tr>
<tr>
<td>Independent fanbeam</td>
<td>1.3’ x 1.5°</td>
<td>6.2’ x 7.7°</td>
</tr>
<tr>
<td>Indep. fanbeam offset</td>
<td>$\pm$6°</td>
<td>$\pm$27°</td>
</tr>
<tr>
<td>Sky accessible in &lt; 1 s</td>
<td>180 deg$^2$</td>
<td>1000 deg$^2$</td>
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Links between technology and science goals: 1. High-redshift radio galaxies

FX correlator: wide-band radio spectrometry

Radio spectral index measurements over the range 300 – 1400 MHz are an efficient way of selecting high-redshift (z>3) radio galaxies (e.g. de Breuck et al. 2000).

Radio galaxy TN0924-2201 at z=5.19 (van Breugel et al. 1999)
The Molonglo telescope will reach HI mass limits typical of bright spiral galaxies at $z=0.2$ (lookback time $\sim 3$ Gyr), allowing a direct measurement of evolution in the HI mass function.
Links between technology and science goals: 3. Other science projects

**FX correlator**
(2048 channels, each 0.2–25 km/s)
- Redshifted HI absorption (z=0 to 3)
- OH megamasers
- Galactic recombination lines (H,C)

**Pointing agility**
- Rapid response to GRBs

**Independent fan beam**
- Monitoring programs (pulsars etc.)

**Optional 64 fanbeams within main beam**
- SETI, pulsar searches (high sensitivity, wide field of view)
Timescales

2002: Design studies

2003: 2 x 10m test patches instrumented with filterbanks and single-baseline correlator

2004: Whole telescope instrumented, commissioning and test observing

2005: Science program begins
For more information:

Three papers at this meeting:

*Prototype SKA technologies at Molonglo:*
1. *Overview and science goals* (Green et al.)
2. *Antenna and front end* (Warr et al.)
3. *Beamformer and correlator* (Bunton)

**Web pages:**

www.physics.usyd.edu.au/astrop
www.atnf.csiro/ska
RFI at Molonglo 200-1500 MHz
(Measured 25 June 2001)

Measured Power (dBm)

VHF TV
UHF TV
GSM

Frequency (MHz)
Molonglo continuum confusion
(10 beams/source) at $\delta = -60^\circ$

Rengelink et al 1997
WENSS 325 MHz

Bock et al 1999
SUMSS 843 MHz

Wall 1994
1420 MHz
Molonglo parabola design accurate to > 1400 MHz

• Mesh supported at 0.6 m (2 ft) intervals in $x$ direction.
• Each section gives the same error for a linear fit to a parabola.
• Gives only 0.1 dB loss at 1420 MHz.
Beam Shape

The synthesised beam shape for a possible configuration of antenna patches on the telescope is shown.

This configuration has a contiguous patch covering a third of the telescope area for forming 1.3’ beams for pulsar or SETI searches.

The remaining part of the telescope is more sparsely covered (with positions calculated from a simple grading function) to give good imaging resolution.
**Beamformer and Correlator**

Analog delay line beamforming
- Accuracy $\lambda/4$

- Each polarization
- RF 0.3 to 1.4 GHz
- LO 2.2 to 0.9 GHz
- IF at 2.5 GHz
- Quadrature baseband detection
- Dual 250 MSamples/s 8-bit A/Ds generating a complex 250 MHz signal

Digital Beamforming
- Fine delays accuracy $\lambda/16$
- Delay corrects for average analog delay error
- Arbitrary and time varying grading
- Modifiable beam shape with meridian distance
- Resources for adaptive null steering

- 250 MHz complex digital filterbanks
- 120 kHz frequency channels
- Single FPGA implementation
- Adaptive noise cancellation on a per channel basis

**Beamforming and Digital Filterbanks for one of 44 bays**

Dual Pol. Line feed
- Delay line beamformer, 1m section
- Upconverter, IF, IQ Downconverter and 8-bit Digitiser

Multi Output Digital Beamformer
- FAN Beam
- Connection to Adjacent Beamformer
- Analogue
- Optical

Digital Filterbank
- To Correlator

Dual Pol. Line feed
- Delay line beamformer, 1m section
- Upconverter, IF, IQ Downconverter and 8-bit Digitiser
- 18 sections per bay