Multi-beaming & Wide Field Surveys

Anne Green
University of Sydney
Outline

- Multibeaming definitions
- Molonglo Observatory Synthesis Telescope
- The SKAMP Project
- SKA & Multiple possibilities
Everyone is doing it!
Let’s get the terms right
Primary beam – individual element
Fields of view & multiple beams
Multi beams

- Station beams
- Element antenna pattern = primary beam
- Synthesized beams from correlator

- Observing teams with their own beams
  - Can have all beams simultaneously

15 May, 2003
Molonglo Observatory Synthesis Telescope

Photo: G. Warr

15 May, 2003
Current Observing Statistics

- 843 MHz continuum
- 3 MHz bandwidth
- 43” spatial resolution
- Field of view 23’ – 160’
- Number of beams formed 128 - 896
- Sensitivity ~1 mJy/beam
- Dynamic range ~200:1
- Full synthesis in 12 hr
\[ V(\theta) = \sum_{n=-N}^{N} e^{\frac{2\pi}{\lambda}(n\Delta x)\sin(\theta)} \sim \frac{\sin(\pi L \theta / \lambda)}{(\pi L \theta / \lambda)} \]
Rotation of fan beams during an observation

(a) $HA = -6^h$
(b) $HA = -3^h$
(c) $HA = 0^h$
A wider field of view with minimum grating artefacts
Instantaneous versus synthesis visibility functions & beamshapes
Continuous uv coverage gives excellent image quality:

(Bock et al. 1999)

Continuous uv coverage from 15 m to 1.6 km in 12hr synthesis
Faxplot and image for Field 2144 (J0127-366)
Faxplot and image for Field 971 (J2018-557)
Real time beam-forming at Molonglo
Coverage with small Field of View (1982 – 1997)
SUMSS Survey Fields
Molonglo Galactic Plane Survey image at 843 MHz
The Square Kilometre Array
Molonglo Prototype (SKAMP)

**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 capability for low-frequency radio astronomy in Australia
Key features of SKAMP

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
## Target specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1420 MHz</th>
<th>300 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Coverage</td>
<td>300–1420 MHz</td>
<td></td>
</tr>
<tr>
<td>Bandwidth (BW)</td>
<td>250 MHz</td>
<td></td>
</tr>
<tr>
<td>Resolution (δ &lt; -30°)</td>
<td>26&quot; x 26&quot; csc</td>
<td>δ</td>
</tr>
<tr>
<td>Imaging field of view</td>
<td>1.5° x 1.5° csc</td>
<td>δ</td>
</tr>
<tr>
<td>UV coverage</td>
<td>Fully sampled</td>
<td></td>
</tr>
<tr>
<td>T_{sys}</td>
<td>&lt; 50K</td>
<td>&lt; 150K</td>
</tr>
<tr>
<td>System noise (1σ) 12 hr: 8 min:</td>
<td>11 µJy/beam</td>
<td>33 µJy/beam</td>
</tr>
<tr>
<td></td>
<td>100 µJy/beam</td>
<td>300 µJy/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>±6°</td>
<td>±27°</td>
</tr>
<tr>
<td>Sky accessible in &lt; 1 s</td>
<td>180 deg²</td>
<td>1000 deg²</td>
</tr>
</tbody>
</table>
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]

15 May, 2003
Science outcomes & goals

- Imaging survey at range of frequencies
- High redshift HI absorption in galaxies
- Transient source monitoring
- Pulsar survey
- Radio recombination lines & absorption observations of HII regions
- SNR searches – ISM structure
Science goals: High-redshift radio galaxies using continuum data

Radio spectral index measurements using MOST and other catalogues below about 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)

15 May, 2003
Science goals: HI absorption spectra from distant galaxies

820-870 MHz range and 2048 spectral channel FX correlator enables:

- Measurements of HI absorption at $z \sim 0.75$ that capitalise on the large collecting area of MOST

Stage II enables $\Omega_{HI}$ measurements at $z \sim 0.75$, where other methods are not well constrained

(Lane and Briggs 2001)

15 May, 2003
RFI at Molonglo 200-1500 MHz
(Measured 25 June 2001)
The Square Kilometre Array (SKA) Project

- Multiple beams & multiple FOV
- Benefits of baseband recording
Multibeam with the SKA

- Primary beam – individual element
- Field of view – continuous image area
  * whole SKA or sub-array
  * single station (or core)
- Multiple beams – within FOV
Large, imaging Fields of View

- Contiguous FOVs: blind survey over large area, continuous Galactic structures
- HI in emission and the Cosmic web
- Formation & evolution of galaxies: clustering, lensing
- Separated FOVs: parallel projects, deep survey
Multiple beams – in one FOV

- Pulsar timing
- Multiple targets – X-ray binaries (XRBs), γ-ray bursters (GRBs), supernovae (SNe)
- Simultaneous, multi-frequency studies of intra-day variables (IDVs)
- RFI mitigation
Baseband recording

- By the Nyquist theorem, we can store all the information by sampling at twice the bandwidth and saving the data to tape.
- Expensive on computer time.
- Hold up to 1 hour data in buffer – save when triggered, limited to one FOV.
- Targets – GRBs, pulsar glitches & timing, SNe, polarisation, RFI mitigation.
Practical Demonstration of reciprocity

Molonglo Observatory Synthesis Telescope

Light Emitting Analogue of Synthesis Telescope