Prototype SKA technologies at Molonglo – 1. Overview & Science Goals

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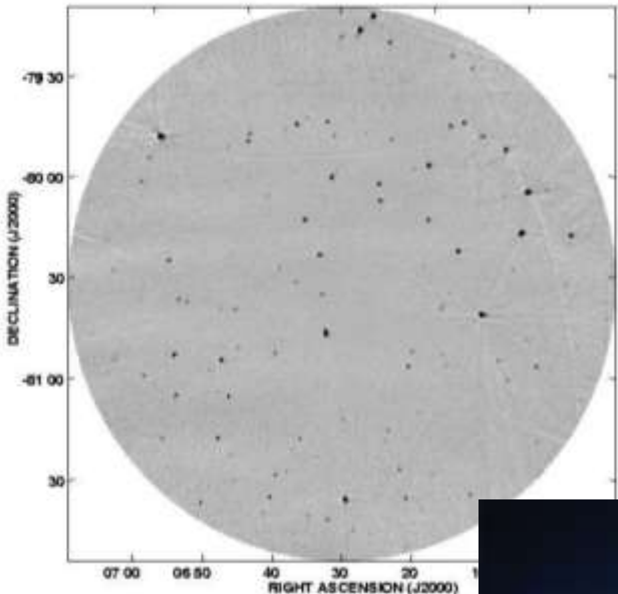
Joint project between the University of Sydney, Australia Telescope National Facility and CSIRO Telecommunications and Industrial Physics

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)

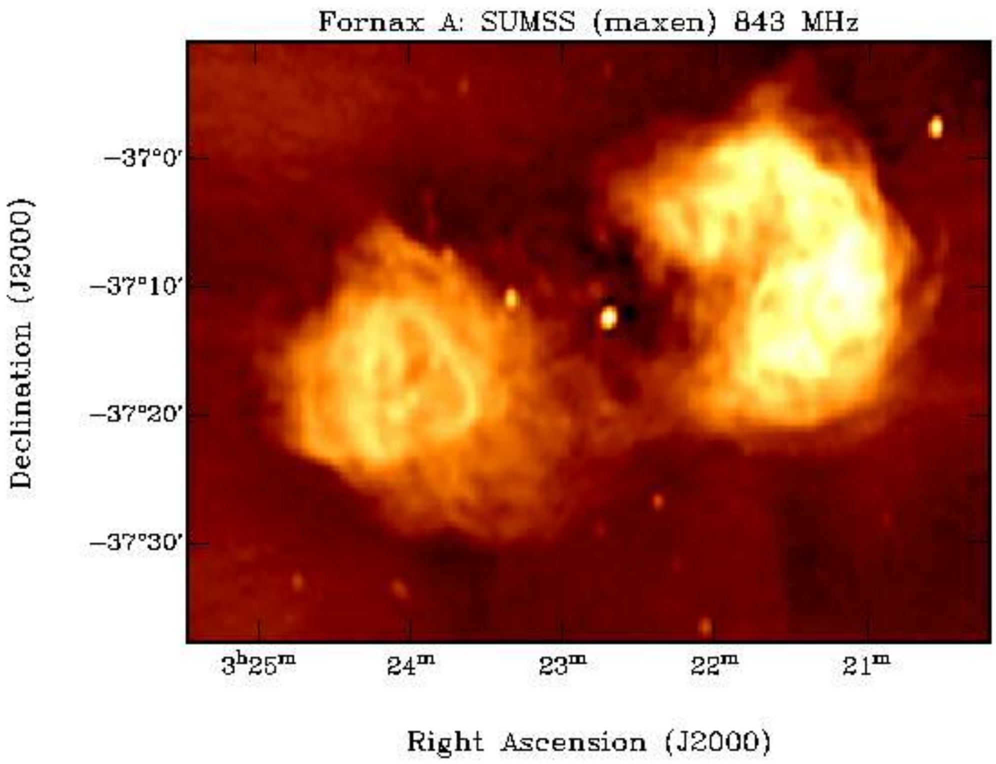


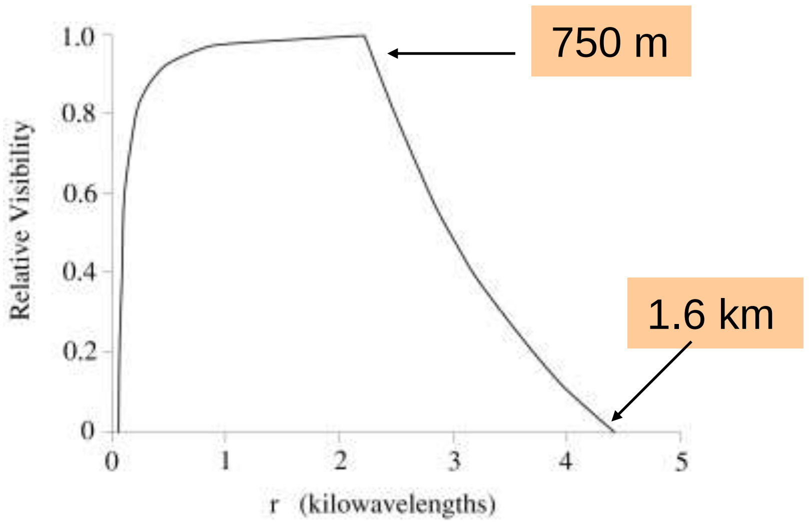
Current Survey (1997-2003):
The Sydney University Molonglo Sky Survey (SUMSS), imaging the whole southern sky (δ<-30°) at 843 MHz to mJy sensitivity with 45″ resolution (i.e. similar to NVSS).

Photo: D. Bock

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:





(Bock et al. 1999)

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

Key features of the Molonglo SKA prototype

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

- Multibeaming
- 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)

↓

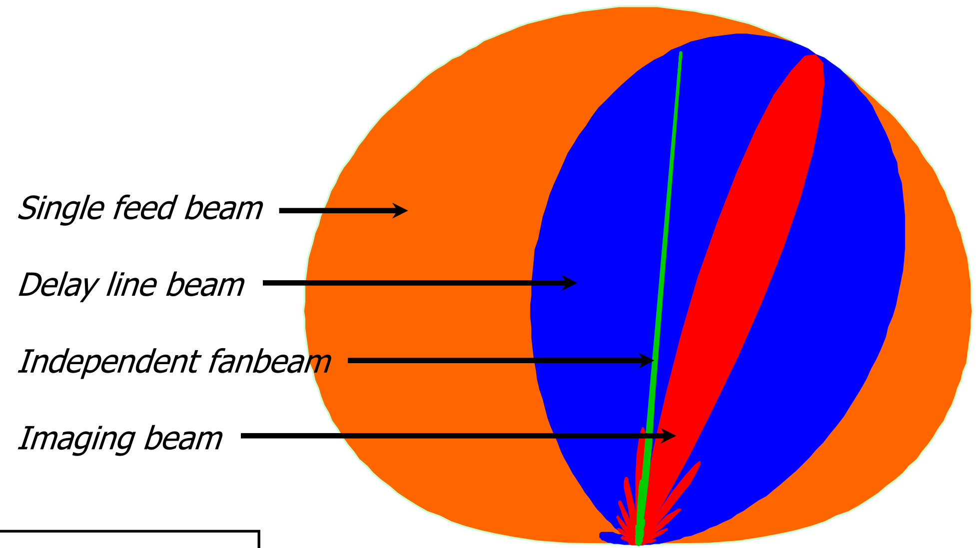
FX Correlator
(3,160 baselines, 2,048 channels)

↓

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

Digital delay beamforming → Independent fanbeam

Digital filterbank - - → Digital Beamformer
(64 fanbeams within imaging beam)
[Requires extra funding]

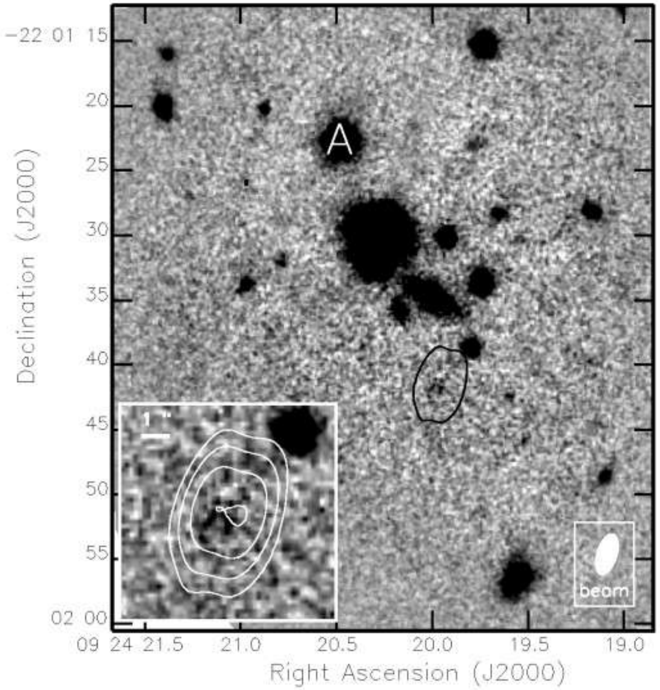


Target specifications

Parameter	1420 MHz	300 MHz
Frequency Coverage	300–1420 MHz	
Bandwidth (BW)	250 MHz	
Resolution ($\delta < -30°$)	26" x 26" csc|δ|	123" x 123" csc|δ|
Imaging field of view	1.5° x 1.5° csc|δ|	7.7° x 7.7° csc|δ|
UV coverage	Fully sampled	
T_{sys}	< 50K	< 150K
System noise (1σ) 12 hr: 8 min:	11 μJy/beam 100 μJy/beam	33 μJy/beam 300 μJy/beam
Polarisation	Dual Linear	
Correlator	I and Q (Full Stokes at 125 MHz BW)	
Frequency resolution	120–1 kHz (FXF mode: 240 Hz)	
Independent fanbeam	1.3′ x 1.5°	6.2′ x 7.7°
Indep. fanbeam offset	±6°	±27°
Sky accessible in < 1 s	180 deg^2	1000 deg^2

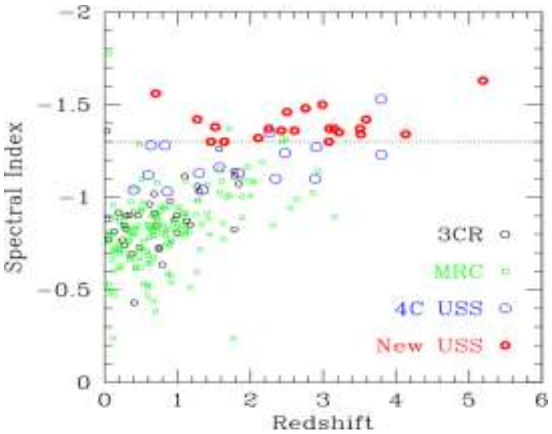
Links between technology and science goals: 1. High-redshift radio galaxies

FX correlator: wide-band radio spectrometry

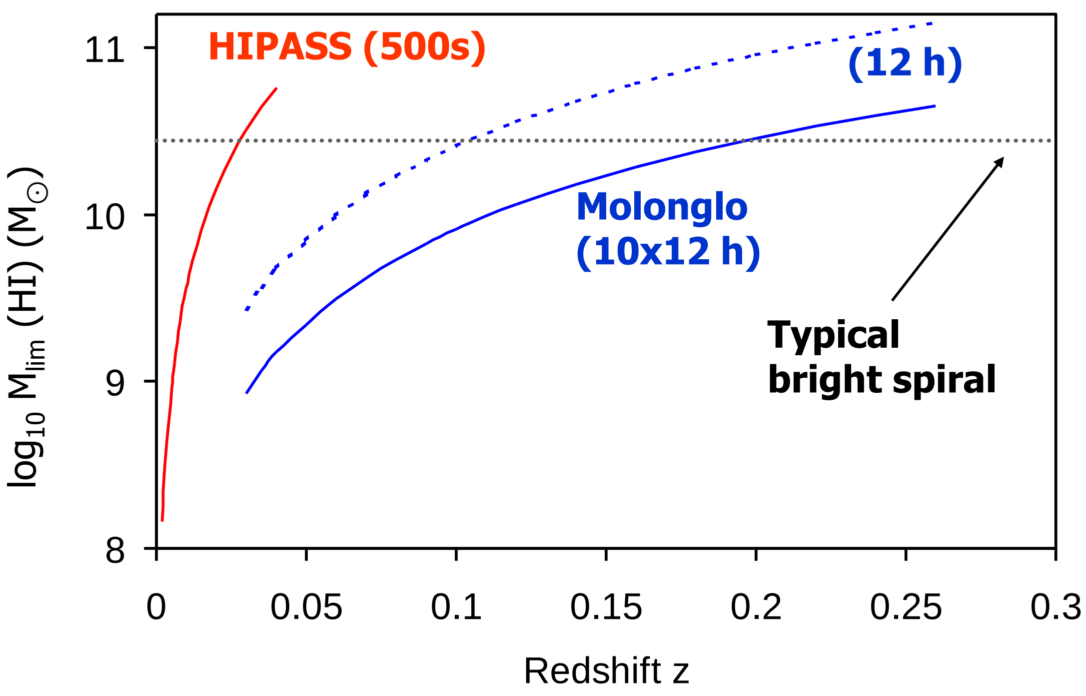


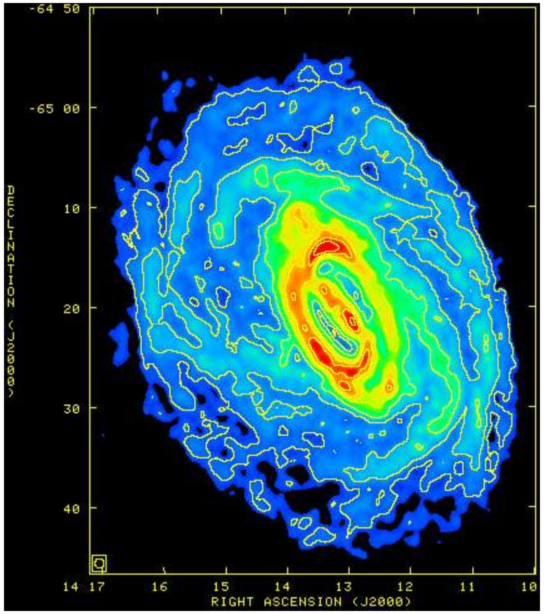
Radio galaxy TN0924-2201 at z=5.19
(van Breugel et al. 1999)

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).



Links between technology and science goals: 2. High-redshift HI in galaxies





HI in the nearby Circinus galaxy (Jones et al. 1999)

The Molonglo telescope will reach HI mass limits typical of bright spiral galaxies at z=0.2 (lookback time ~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:

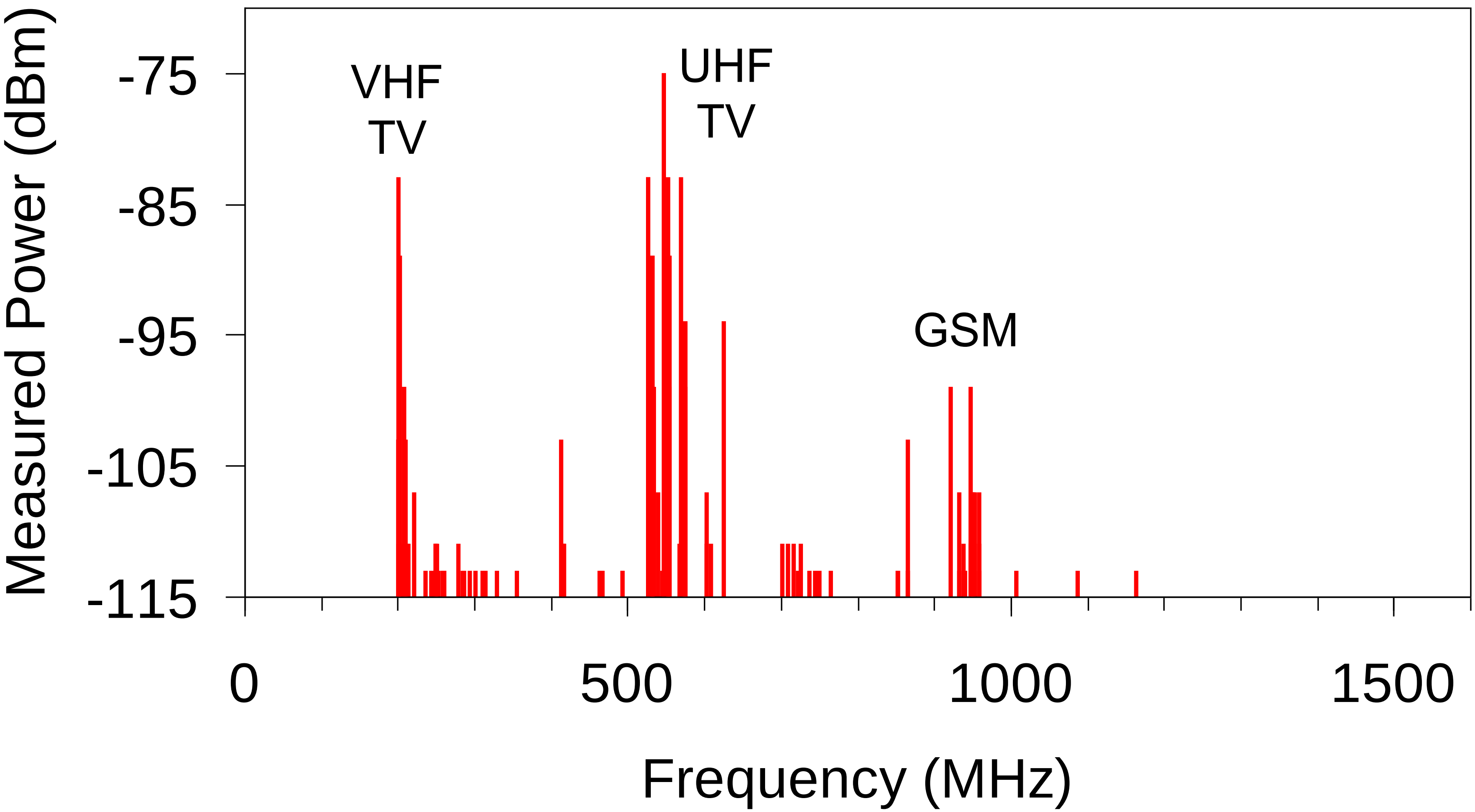
Three papers at this meeting:

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)

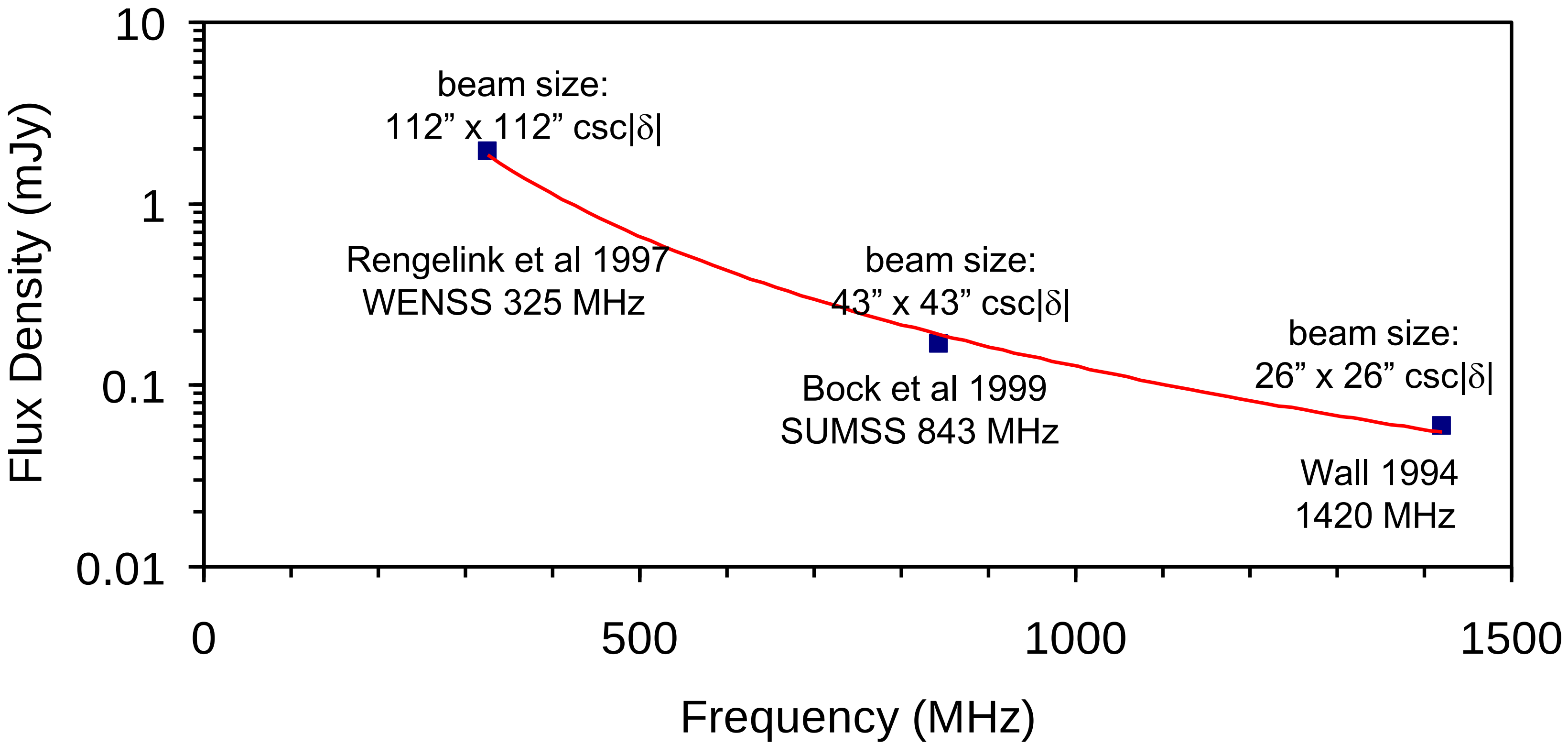
Web pages:

www.physics.usyd.edu.au/astrop
www.atnf.csiro/ska

RFI at Molonglo 200-1500 MHz
(Measured 25 June 2001)

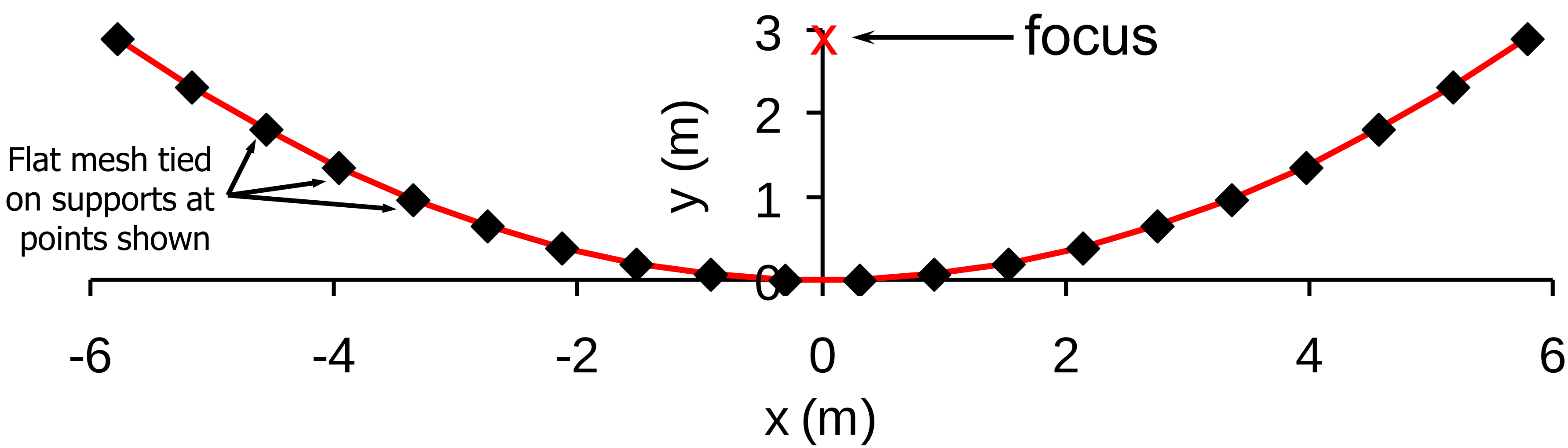


Molonglo continuum confusion
(10 beams/source) at δ = –60°



Molonglo parabola design accurate to > 1400 MHz

Piecewise linear fit to parabola shape



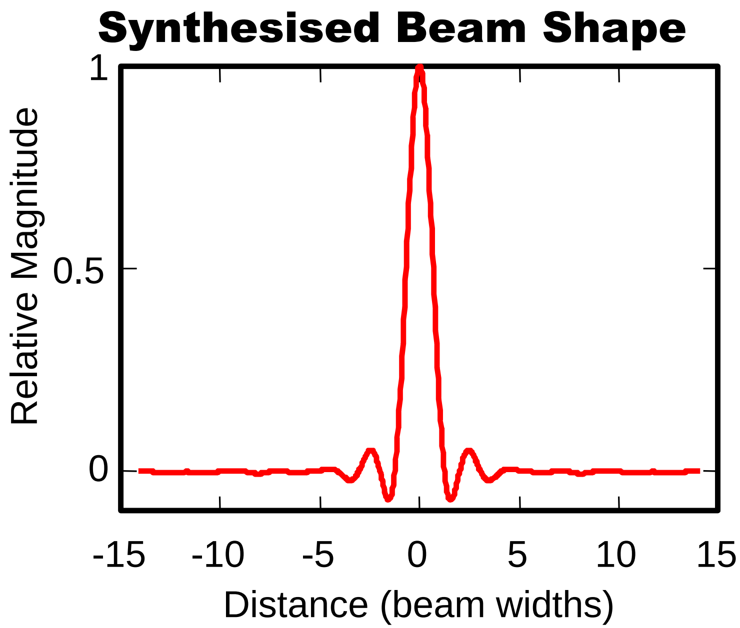
- Mesh supported at 0.6 m (2 ft) intervals in *x* direction.
- Each section gives the same error for a linear fit to a parabola.
- **Gives only 0.1 dB loss at 1420 MHz.**

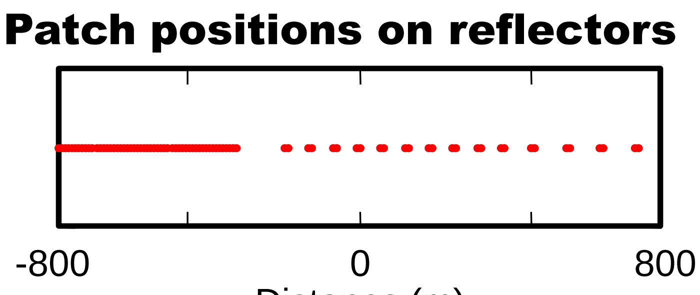
Beam Shape

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 polarisation
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