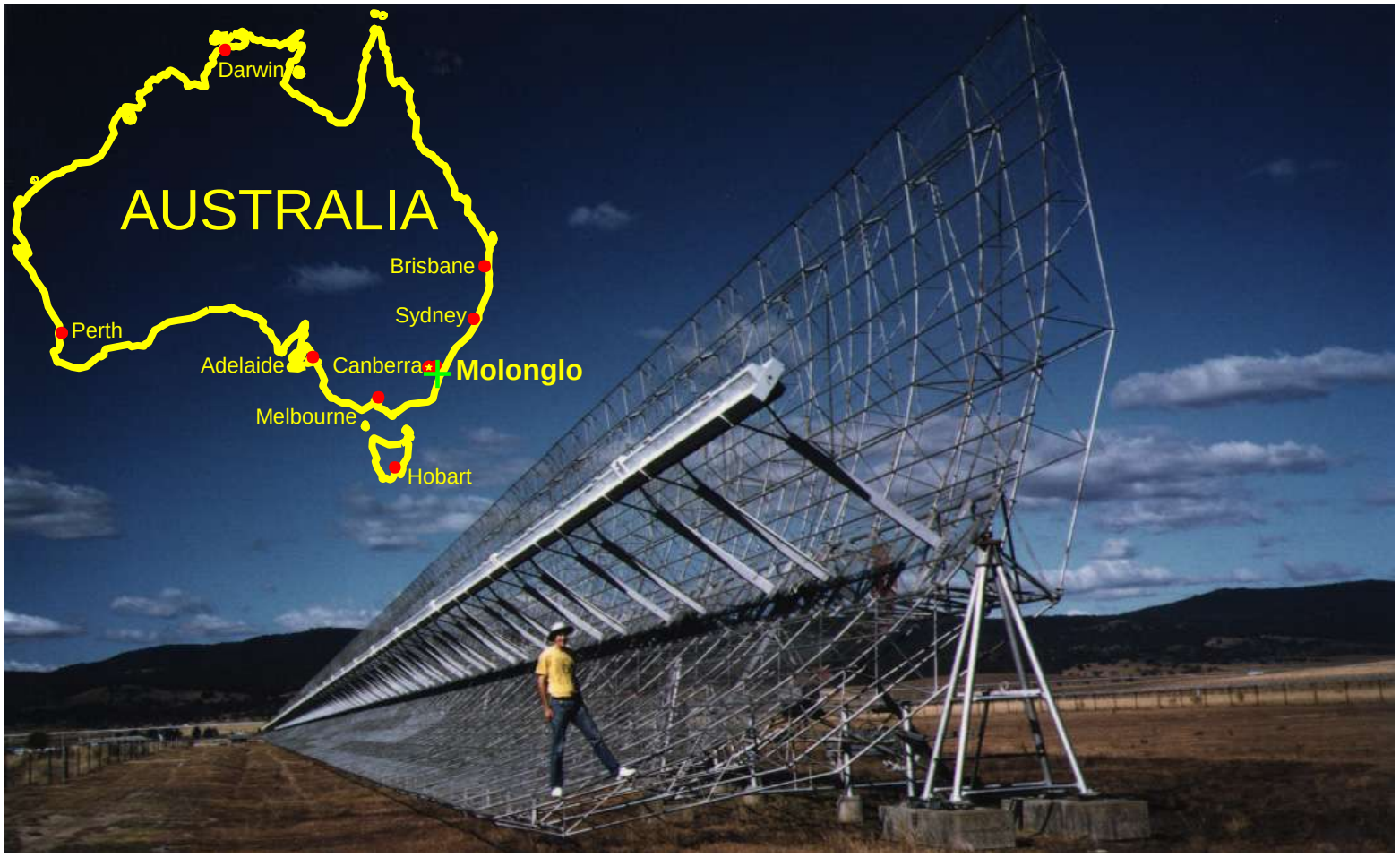
Prototyping SKA Technologies at Molonglo



Molonglo SKA Prototype and MNRF

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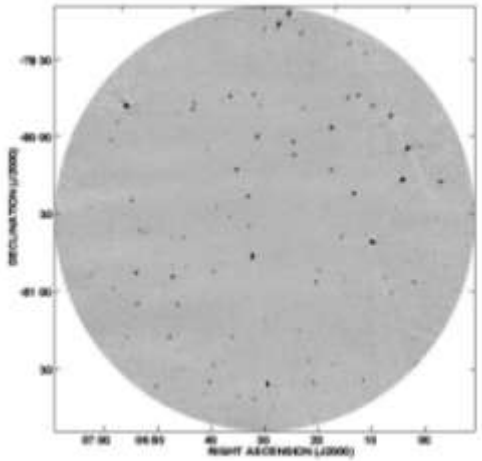
Molonglo SKA Prototype and MNRF

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

From MOST to SKA Prototype



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).
[843 MHz, 12hr synthesis, 2.7° diameter field]

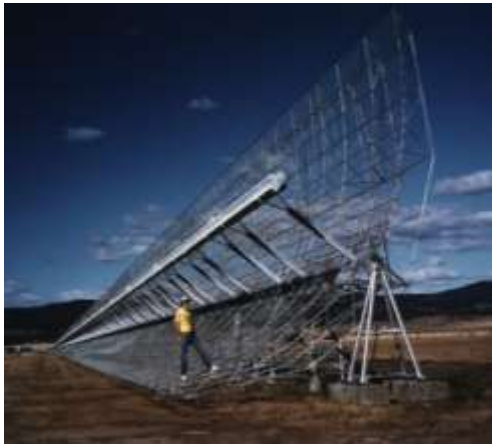


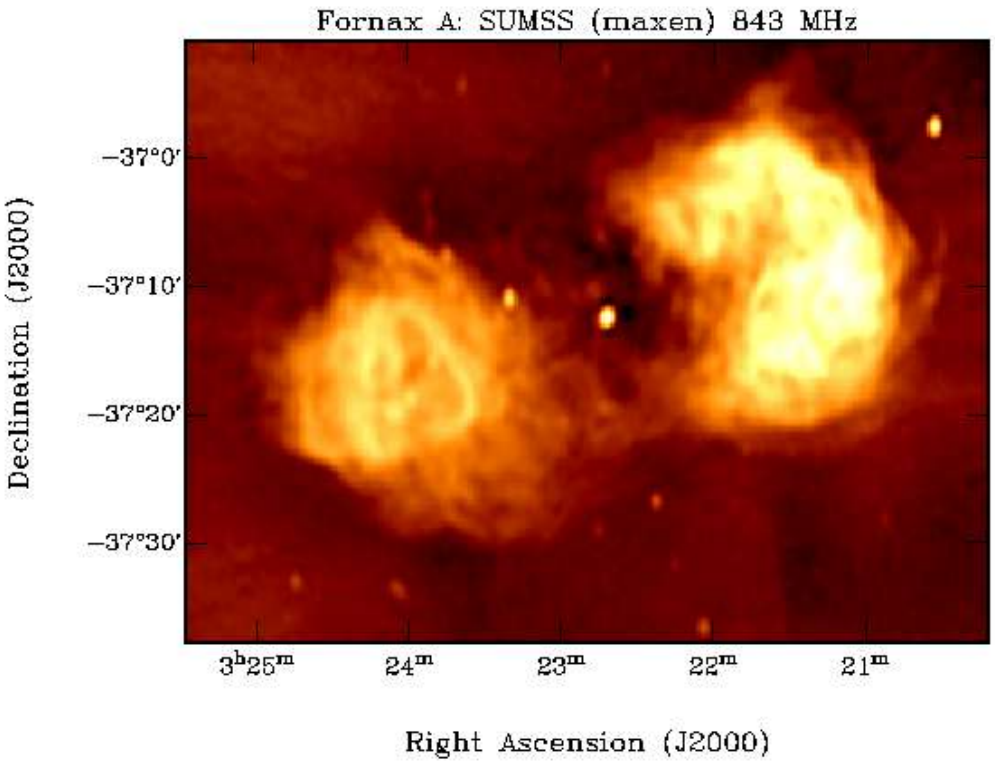
Photo: D. Bock

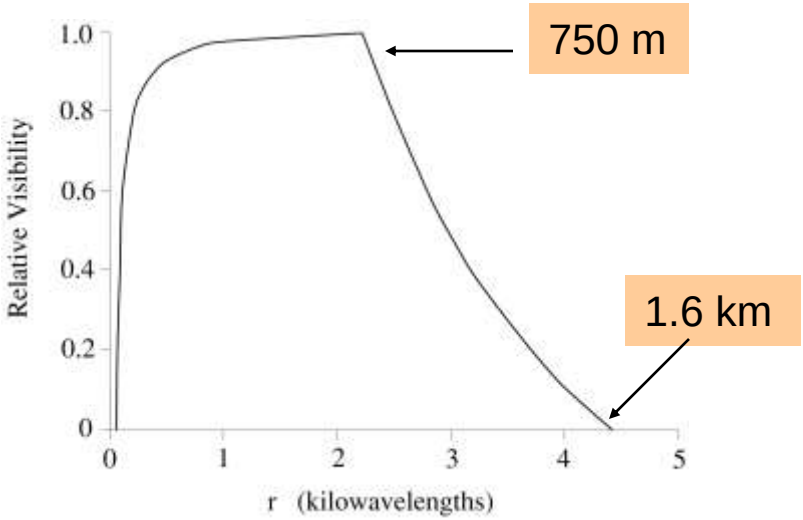
Next: Use existing telescope as SKA testbed **and** science facility:

- Frequency agility: 300-1420 MHz (250 MHz BW)
- Multi-beaming (3 independent fanbeams)
- 2048 Spectral channels, 3828 baselines
- Continuous *uv* coverage
- Wide field of view (1.5°-1420 MHz, 8°-300 MHz)

Cylindrical Paraboloid

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

Molonglo SKA Prototype Technologies

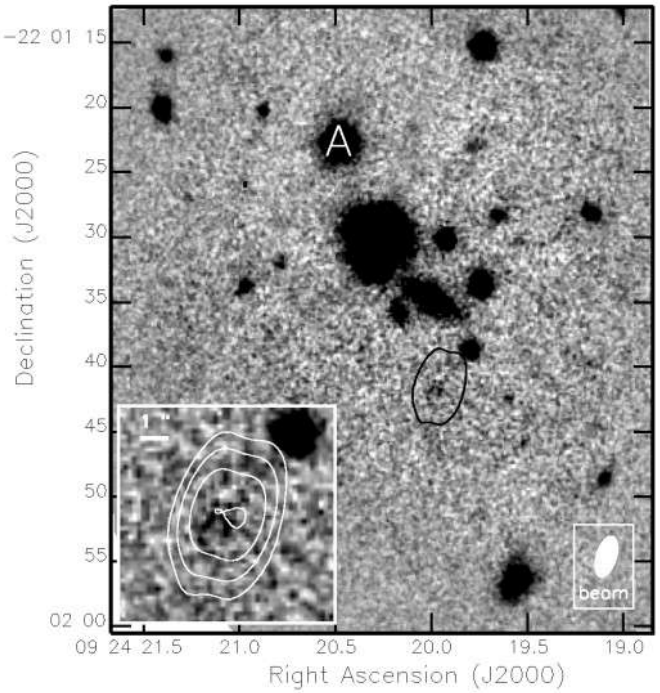
- Multibeaming
- Wide instantaneous field of view
- Digital beamforming
- Wide-band FX correlator (2,048 channels, 3,828 baselines) "Mega MOST" ~1 million frequency-image points on sky
- Remote operation

- Frequency and pointing agility
- Wide-band line feeds and LNAs
- Cylindrical antenna prototype
- Adaptive null steering and adaptive noise cancellation (RFI)

Collecting area 18,000 m^2 ~= 1% of SKA (i.e. equivalent to 1 SKA station)

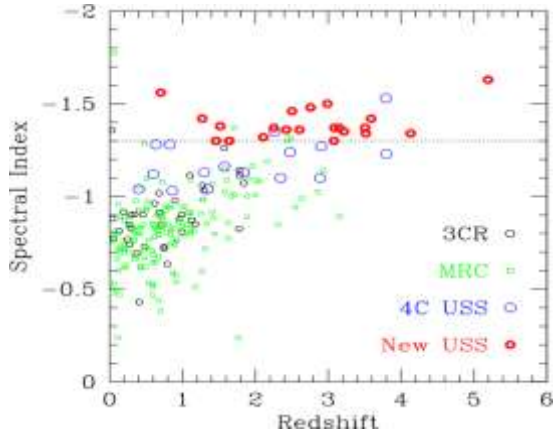
Science Goals:
1. Radio galaxy spectral index

FX correlator: wide-band radio spectrometry

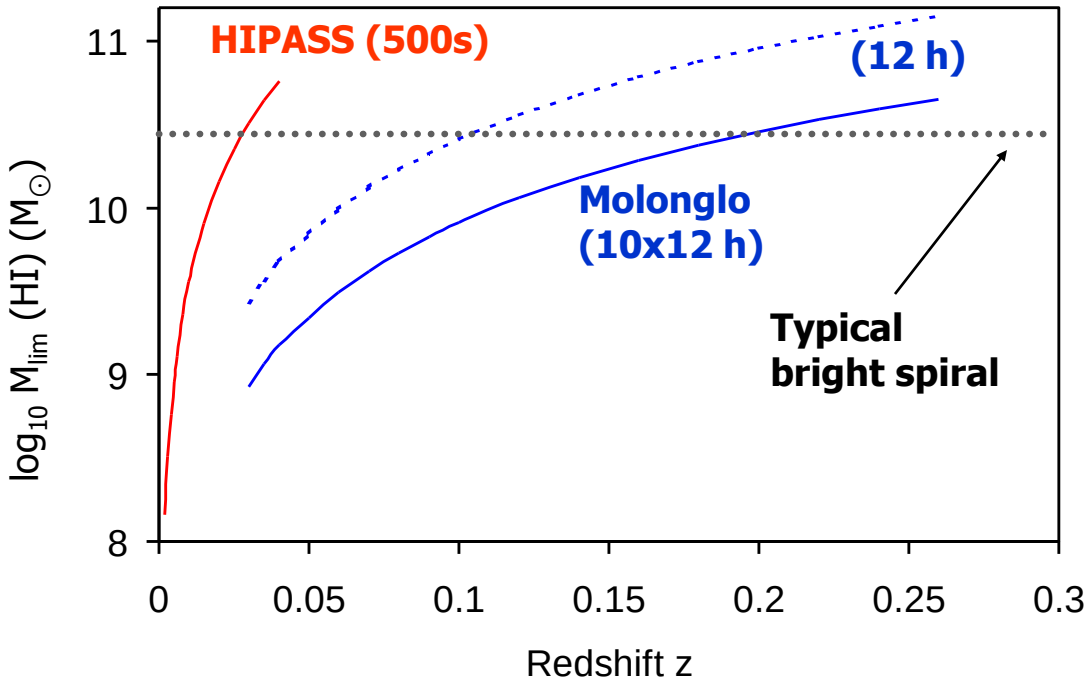


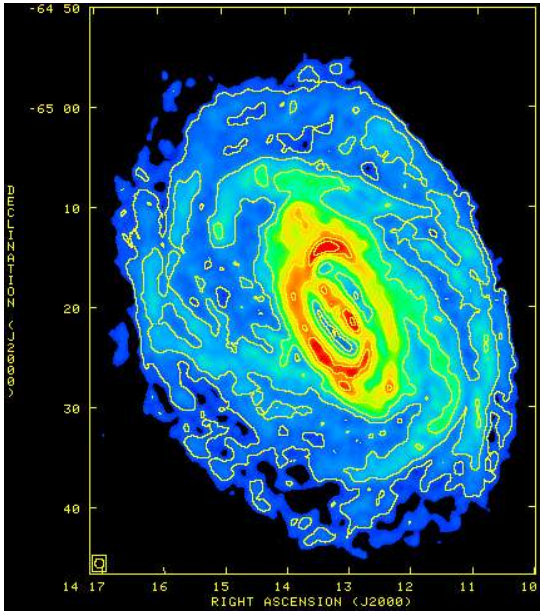
Radio galaxy TN0924-2201 at z=5.19
(van Breugel et al. 1999)

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).



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.

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 beams	▪ Monitoring programs (SETI, pulsars etc.)
Optional 64 fanbeams within main beam	▪ Pulsar searches (high sensitivity, wide field of view)

Target Specifications

Parameter	1420 MHz	300 MHz
Frequency Coverage	300–1420 MHz	
Bandwidth	250 MHz	
Resolution (δ < -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 bandwidth)	
Frequency resolution	120–1 kHz (FXF mode: 240 Hz)	
Independent fanbeam	1.3′ x 1.5°	6.2′ x 7.7°
Independent fanbeam offset	±6°	±27°
Sky accessible in < 1 s	180 deg^2	1000 deg^2

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
(Over 9 feeds)

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

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

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

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

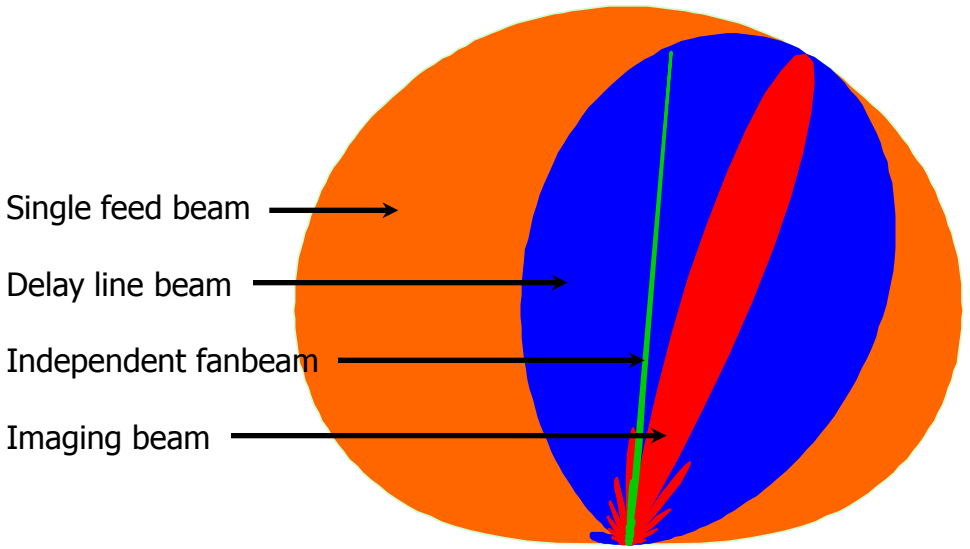
Signal processing & storage
(imaging, spectrometer, searching...)

Independent fanbeams
(3 within 9 feed field of view)

[SETI Institute interest]

Digital Beamformer
(64 fanbeams within imaging beam)

[Requires extra funding]



Beamformer and Correlator

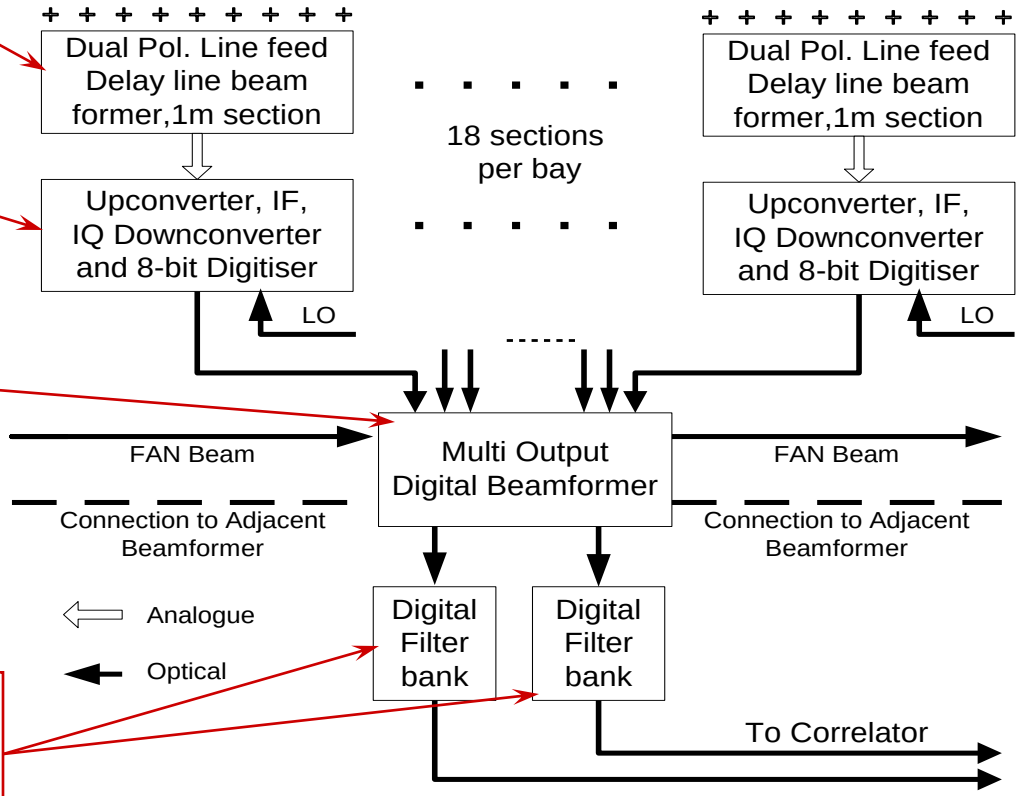
Analog delay line beamforming
Accuracy λ/4

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 λ/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

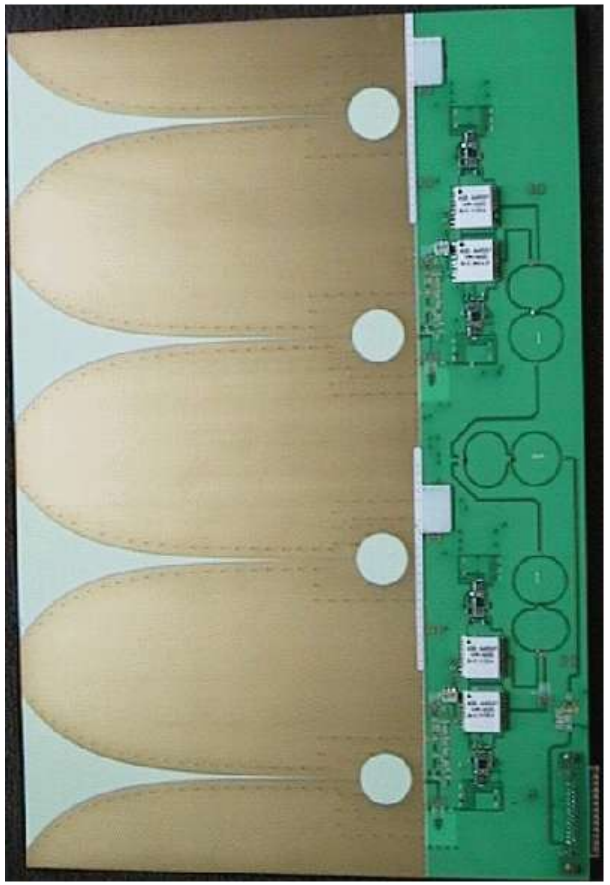
Beamforming and Digital Filterbanks for one of 44 bays



Wide Band Feed Development

Single feed covering 300-1420 MHz desirable

- Vivaldi antenna array?
  - ASTRON THEA prototype patch demonstrated operation over 750-1500 MHz. Theoretical 7:1 bandwidth ratio possible, 5:1 achievable.
- Design study for active antenna dipole array underway. [G. Warr & A. Parfitt]

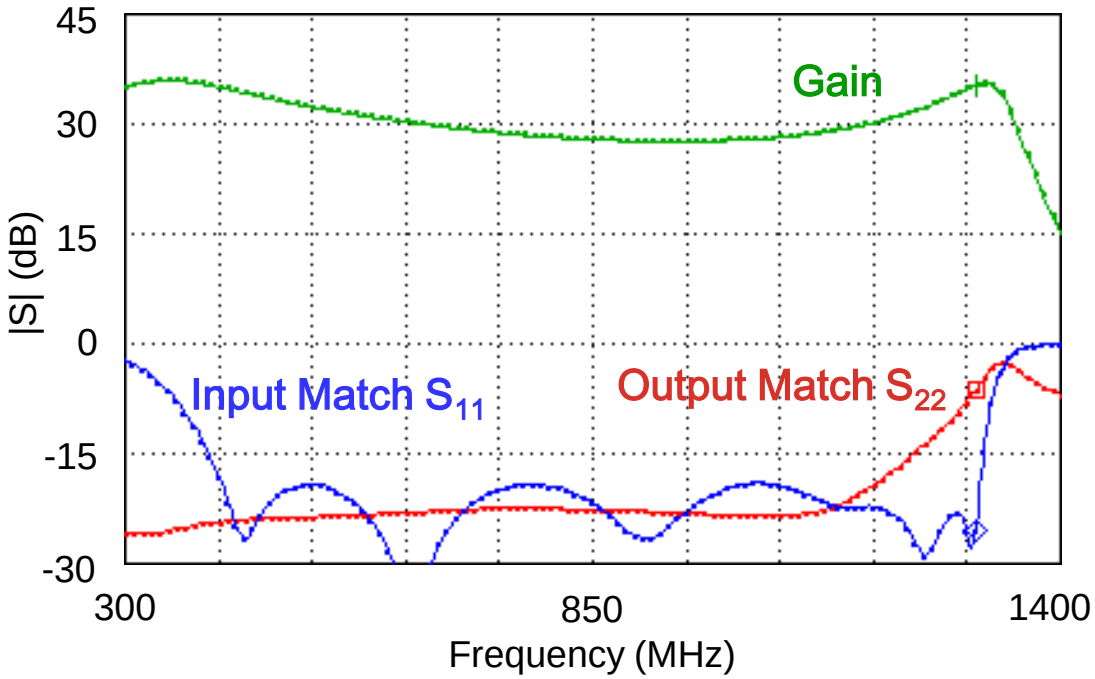


ASTRON THEA Vivaldi Antenna

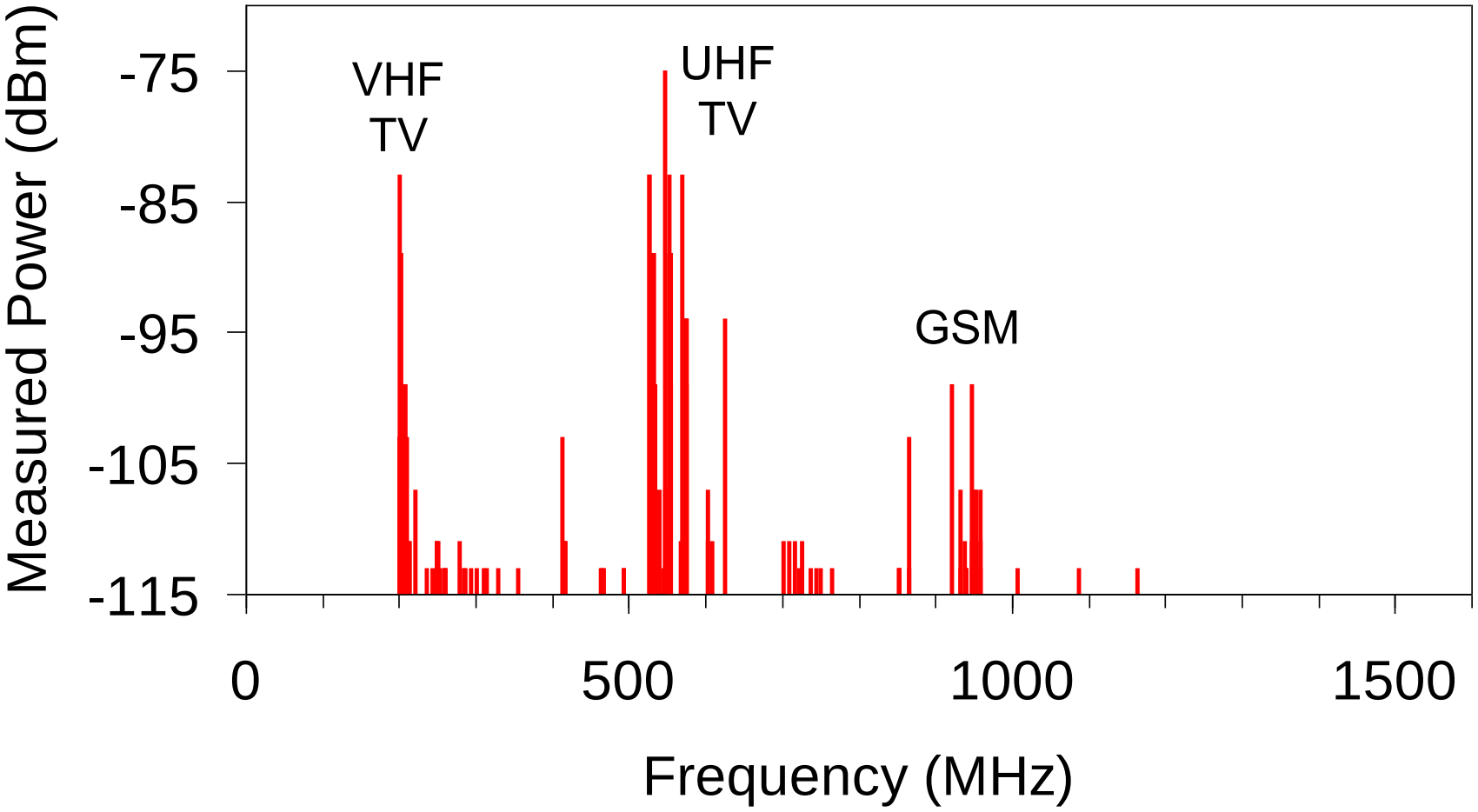
Wide-band low-cost ambient-temperature LNAs

Prototype design for 400-1200 MHz HEMT based LNA (Ralph Davison)

- ~20K noise temperature
- Ambient temperature operation
- Likely to be able to extend to operate over 300-1400 MHz
- Design simplifications possible if higher input impedance from antenna (designed for 50Ω input impedance)
- Good starting point for migration to MMIC design



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



Prospective Development Path

2002: 3 MHz correlator (USyd funding proposal)

- 3 MHz bandwidth @ 843 MHz, 88 stations + 2 for RFI mitigation
- Implement self-cal (for > 10 × increase in dynamic range) and signal processing data pipeline (in AIPS++ ?)

2003: IFs, filterbanks, 50 MHz correlator, photonic LO distribution and signal gathering

- 50MHz bandwidth @ 843MHz, RFI mitigation required

2005: Wideband feeds, LNAs, analog and digital beamforming, more filterbanks, fibre and correlator. **Main science program begins.**

Summary

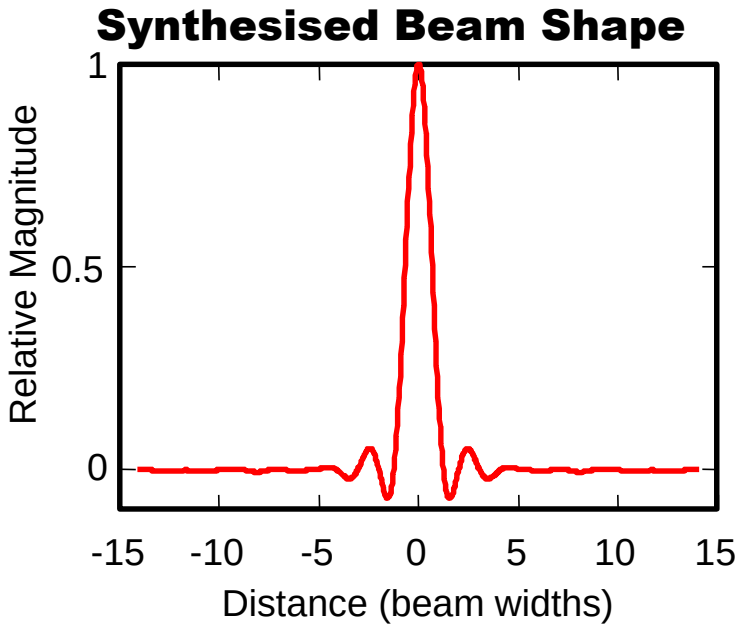
- **Science:** Studies of the high-redshift universe (high-z galaxies, evolution of HI mass function)
- **Technology:** prototype for SKA cylindrical antennas, software beamforming, high dynamic range imaging with fully-sampled *uv* plane
- **Community use:** New capability that opens the radio spectrum below 1.4 GHz, operating by 2005 as a fully-automated telescope with a data reduction pipeline

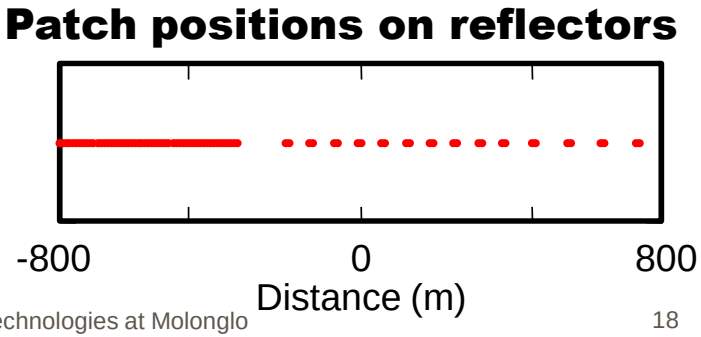
Beam Shape

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.

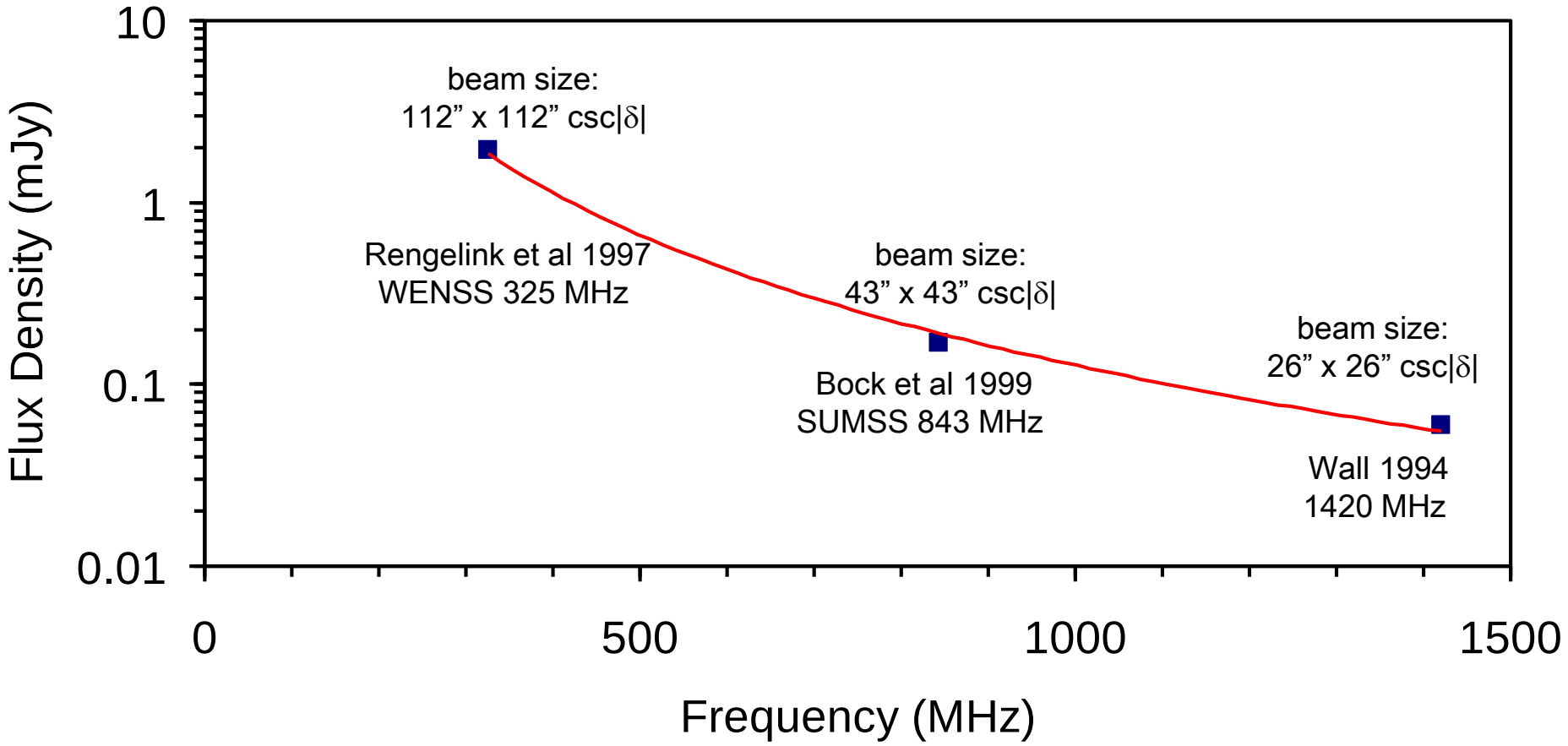
The remaining part of the telescope is more sparsely covered (with positions calculated from a simple grading function) to give good imaging resolution.





Molonglo Continuum Confusion

10 beams/source at δ = –60°



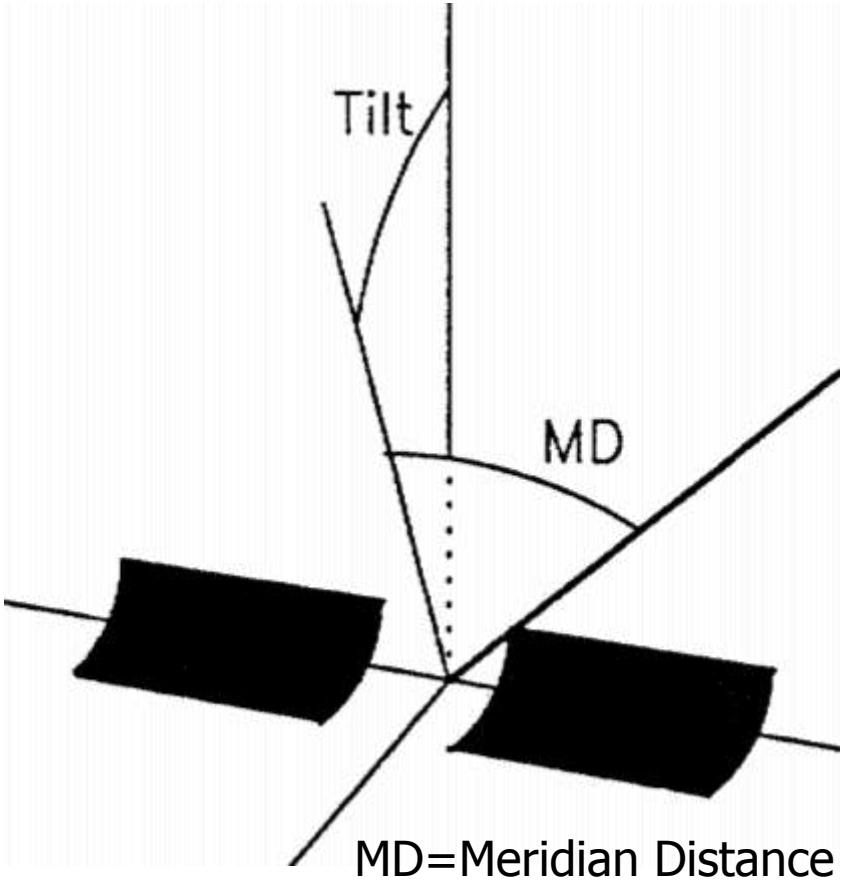
Collector

The telescope's collector consists of two cylindrical paraboloids, 778m x 12m, separated by 15m and aligned east-west (total area 18,000 m^2).

The telescope is steered by mechanical rotation of the cylindrical paraboloids about their long axis, and by electronic delays of the feed elements along the arms. The resulting 'alt-alt' system can follow fields south of declination -30° for ±6 hours.

The original parabola shape was designed to be accurate for operation at 1.4 GHz. The reflecting mesh was designed for operation at 408 MHz and will need to be replaced for operation above ~1 GHz.

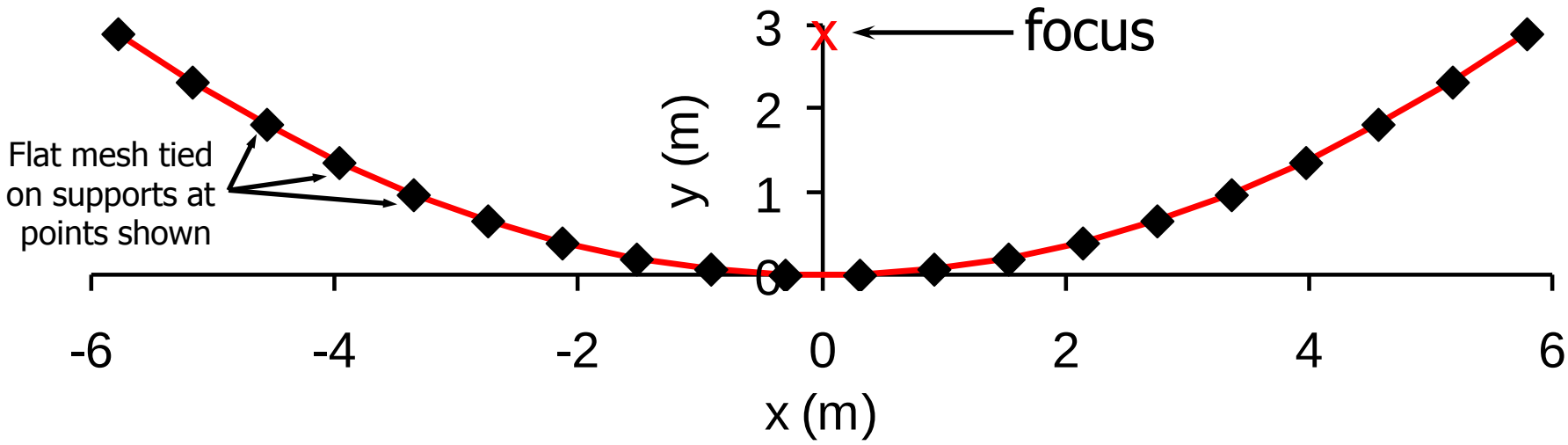
Geometry



MD=Meridian Distance

Molonglo parabola shape designed for 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.**

Replace 408 MHz mesh for operation above ~1 GHz