Multi-beaming & Wide Field Surveys

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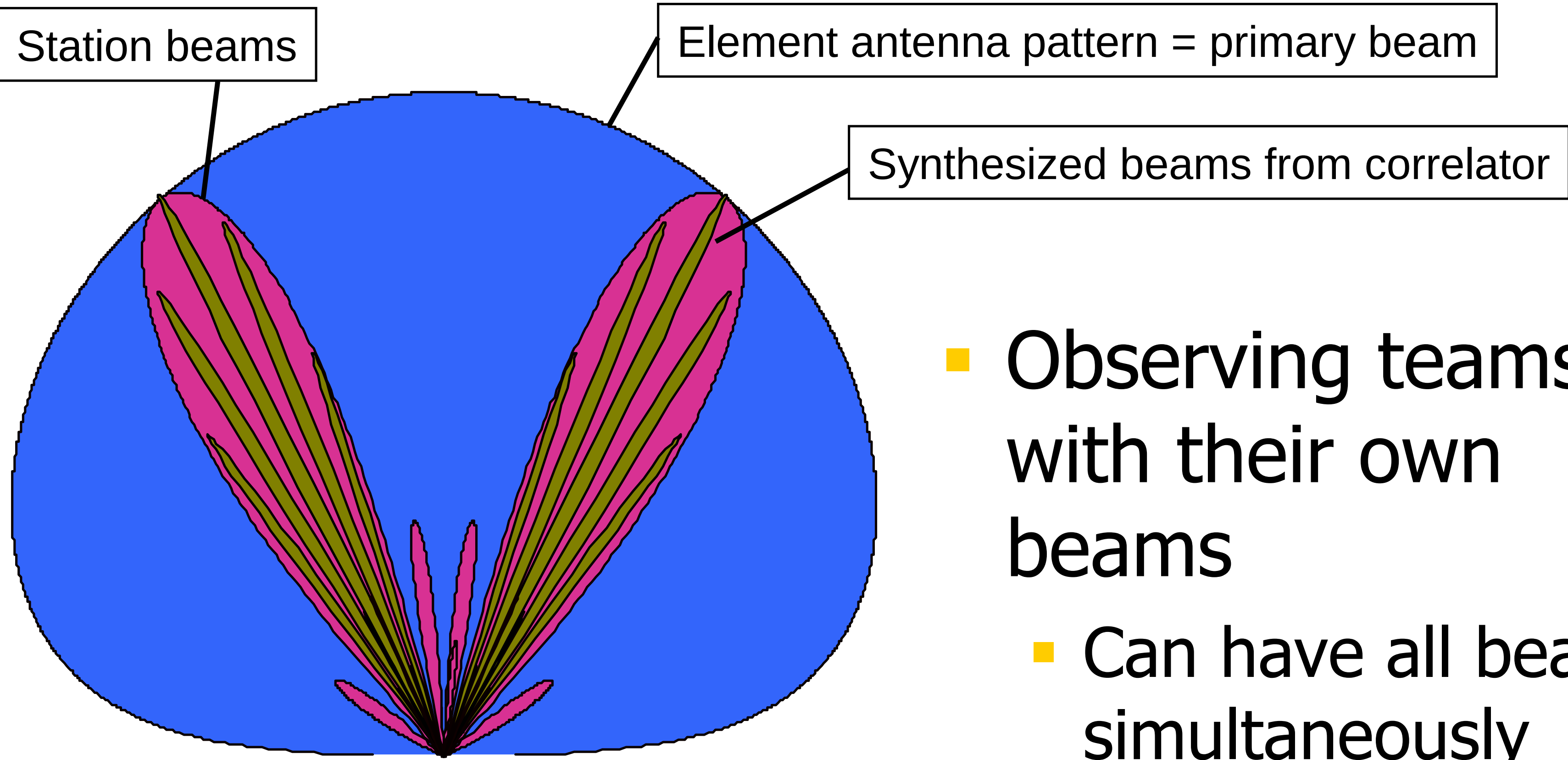
Outline

- Multibeaming definitions
- Molonglo Observatory Synthesis Telescope
- The SKAMP Project
- SKA & Multiple possibilities

Multibeaming principles and definitions

- Everyone is doing it!
- Let's get the terms right
- Primary beam – individual element
- Fields of view & multiple beams

Multi beams



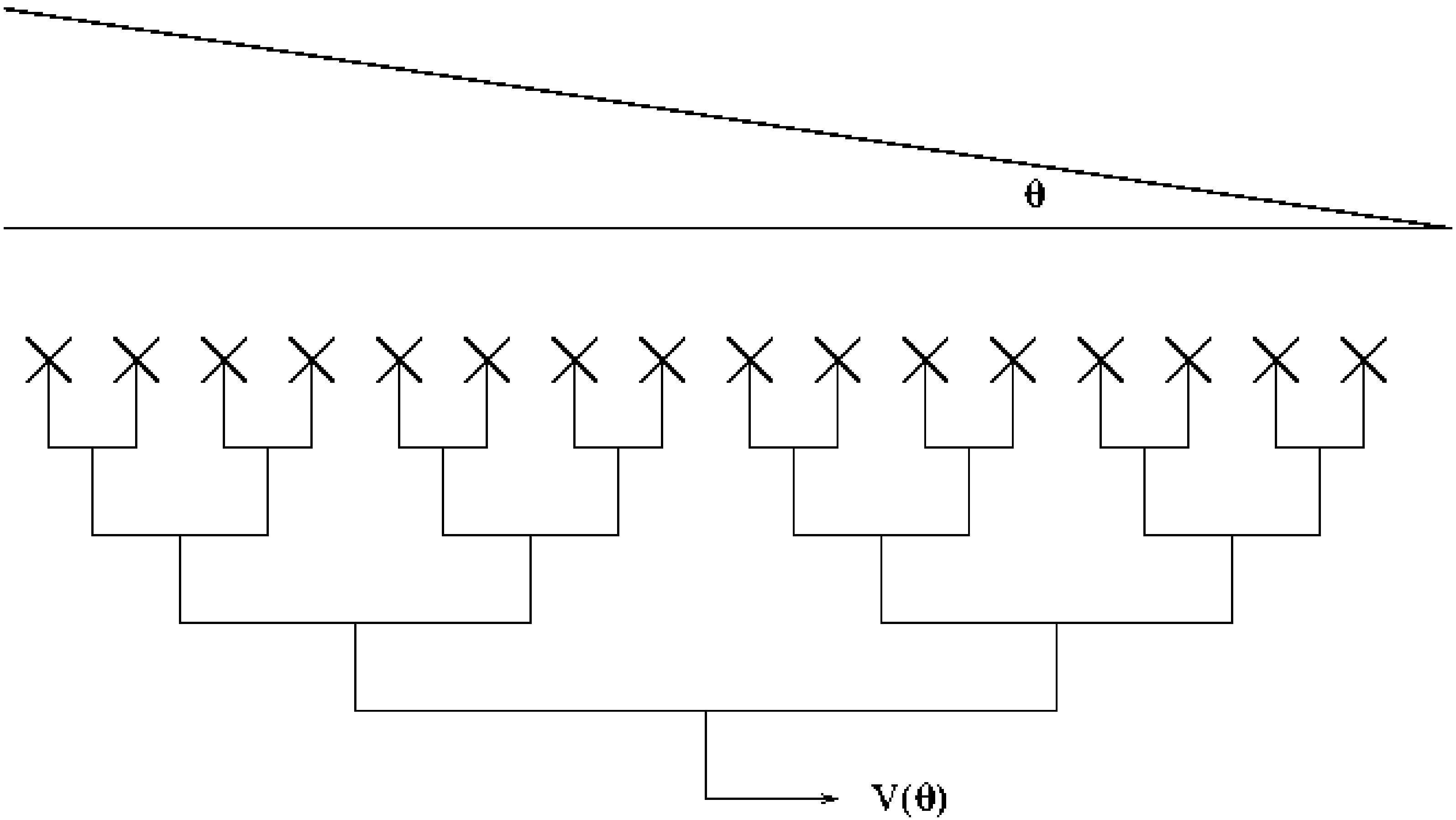
- Observing teams with their own beams
  - Can have all beams simultaneously

Molonglo Observatory Synthesis Telescope

Photo: G. Warr

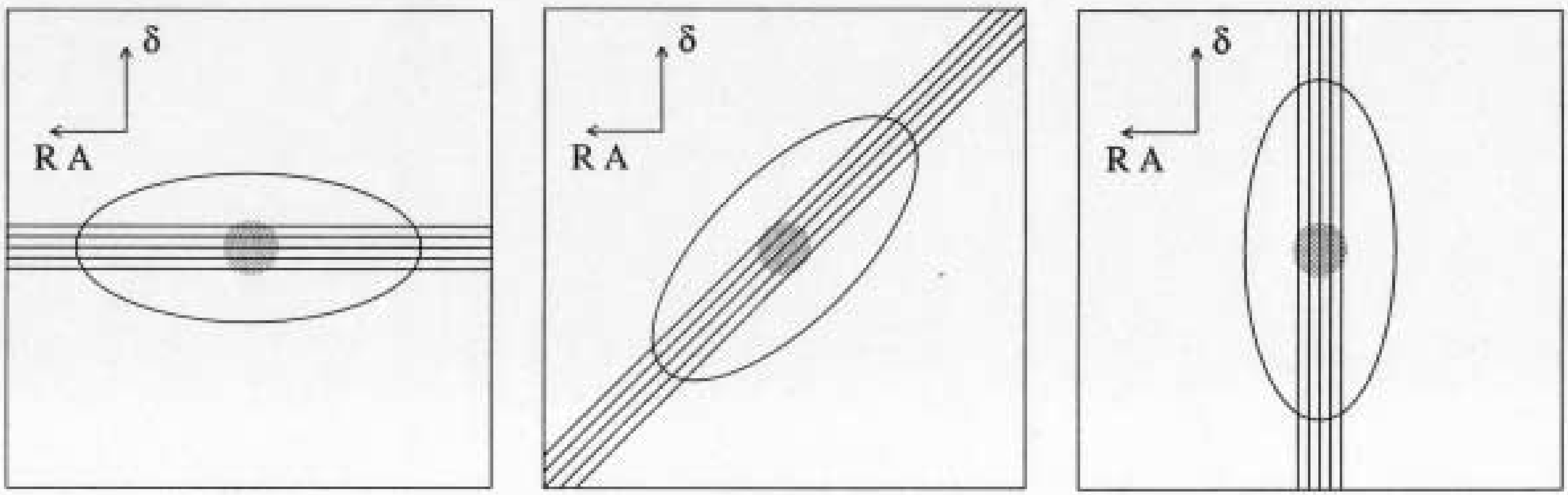
Current Observing Statistics

- 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



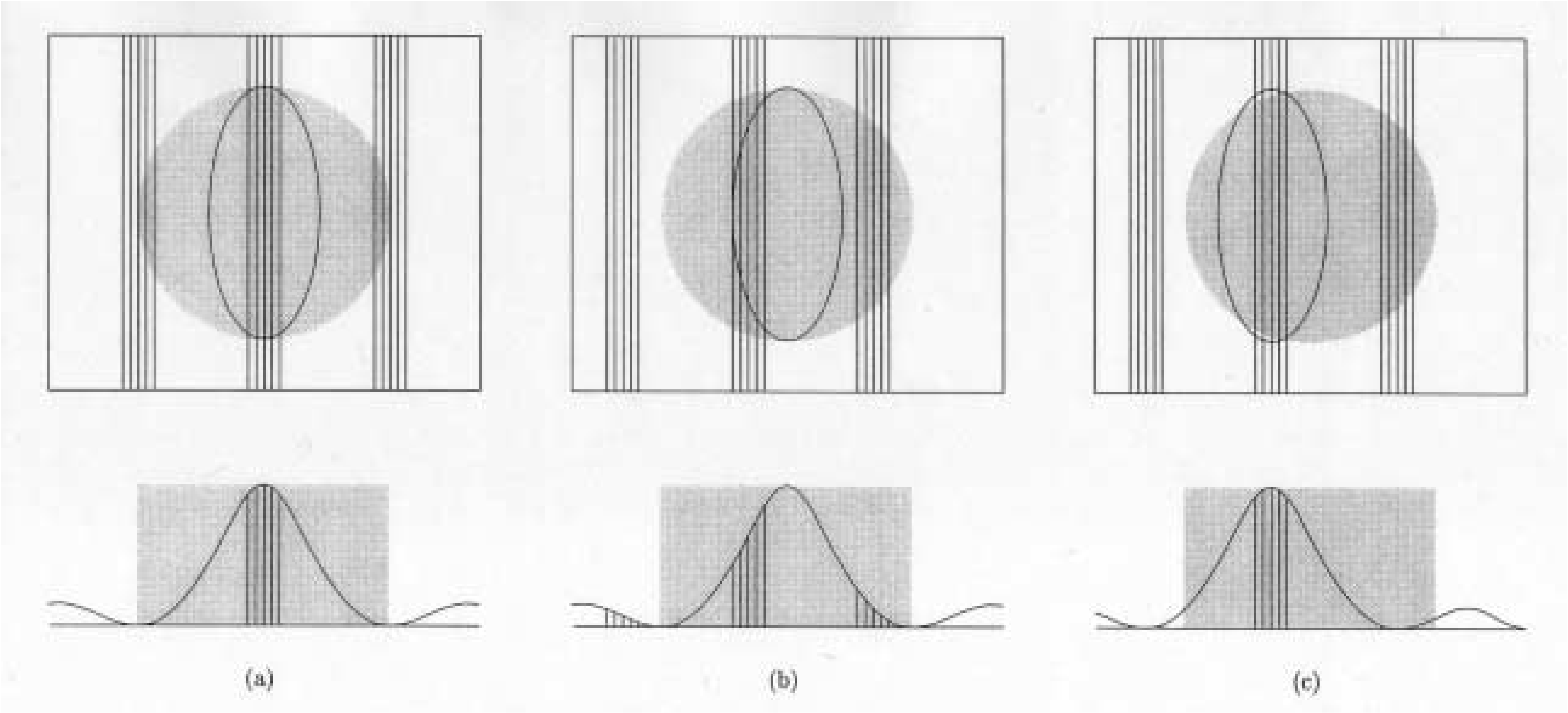
$$V(\theta) = \sum_{n=-N}^{N} e^{j\frac{2\pi}{\lambda}(n\Delta x)\sin(\theta)} \sim \frac{\sin(\pi L\theta/\lambda)}{(\pi L\theta/\lambda)}$$

Rotation of fan beams during an observation

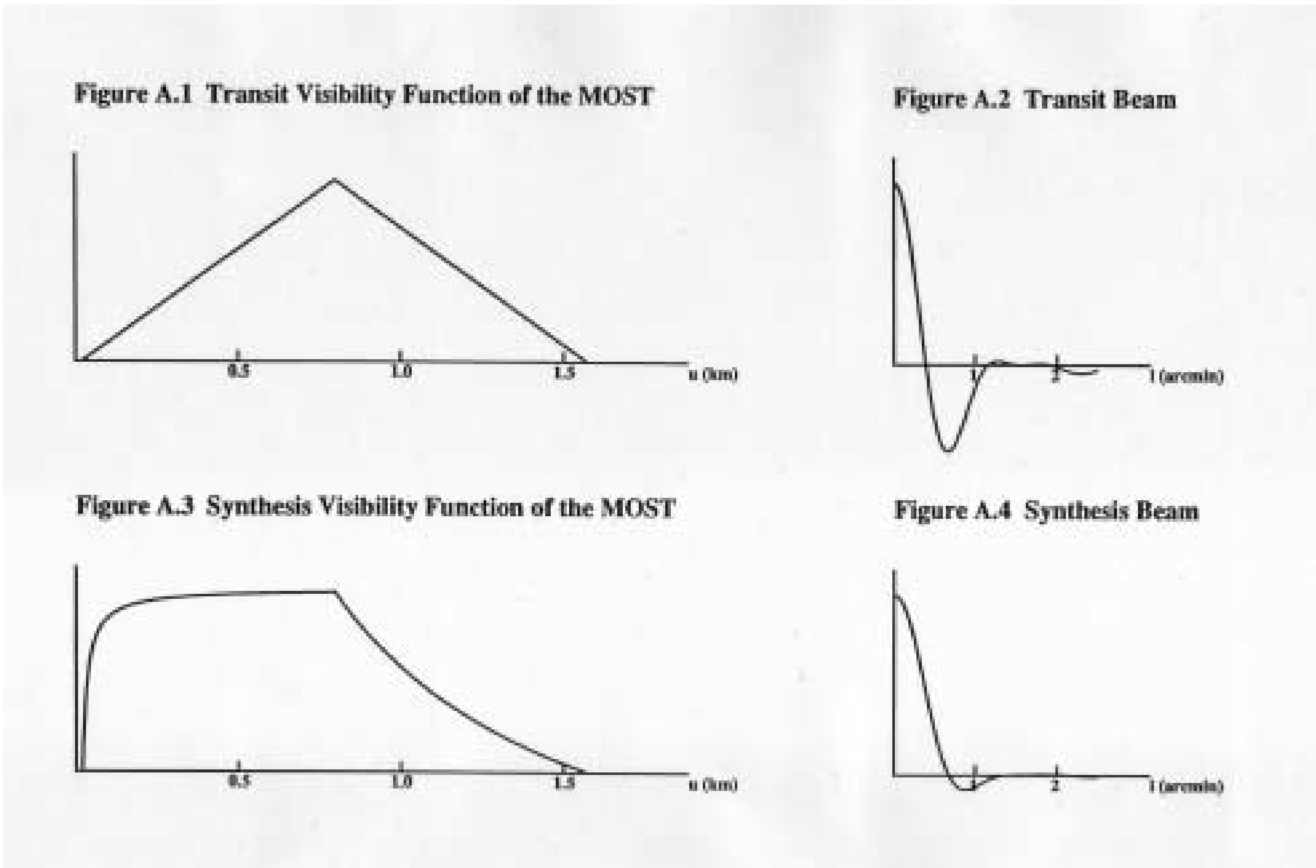


(a) $HA = -6^h$ (b) $HA = -3^h$ (c) $HA = 0^h$

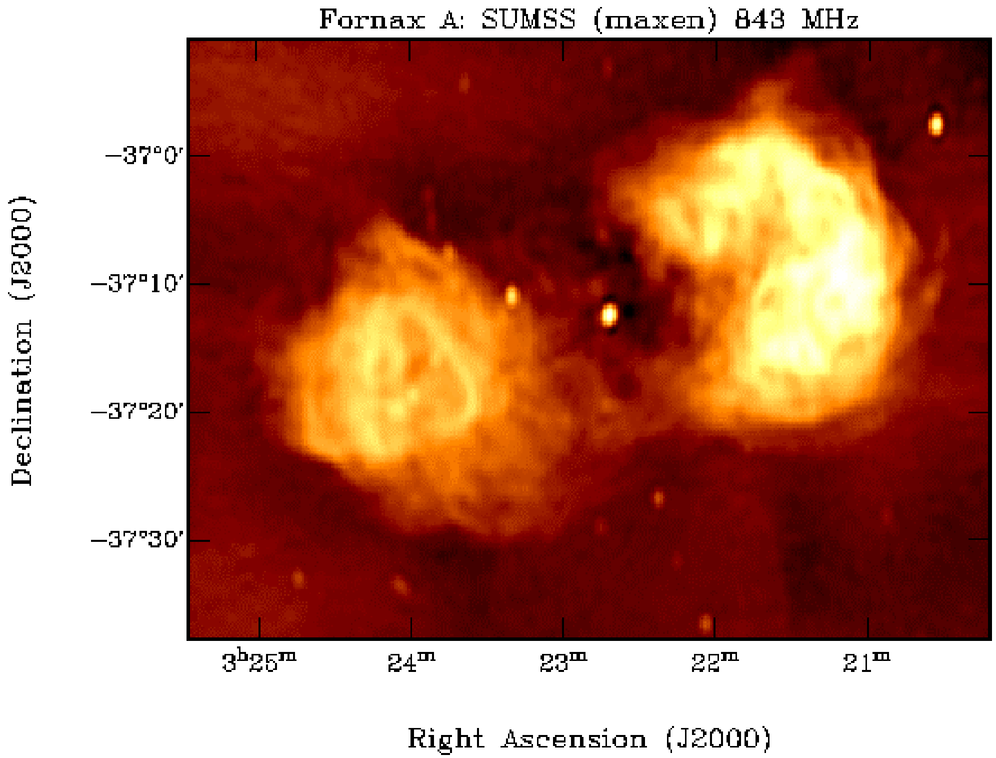
A wider field of view with minimum grating artefacts

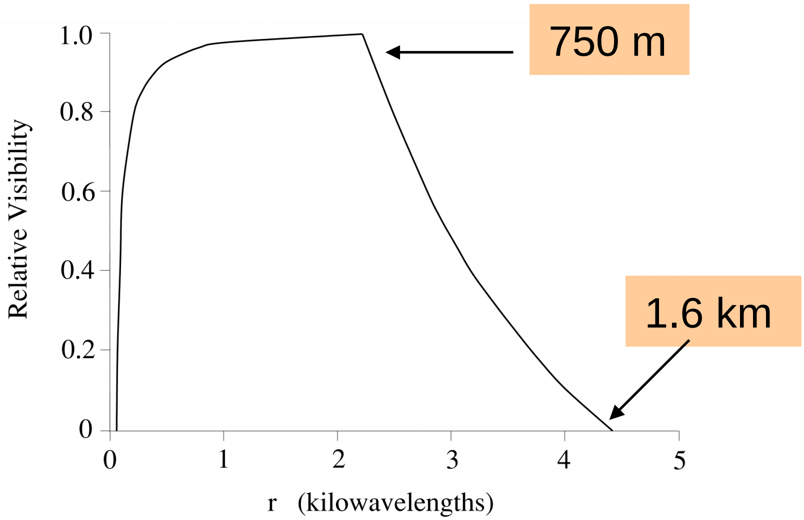


Instantaneous versus synthesis visibility functions & beamshapes



Continuous *uv* coverage gives excellent image quality:

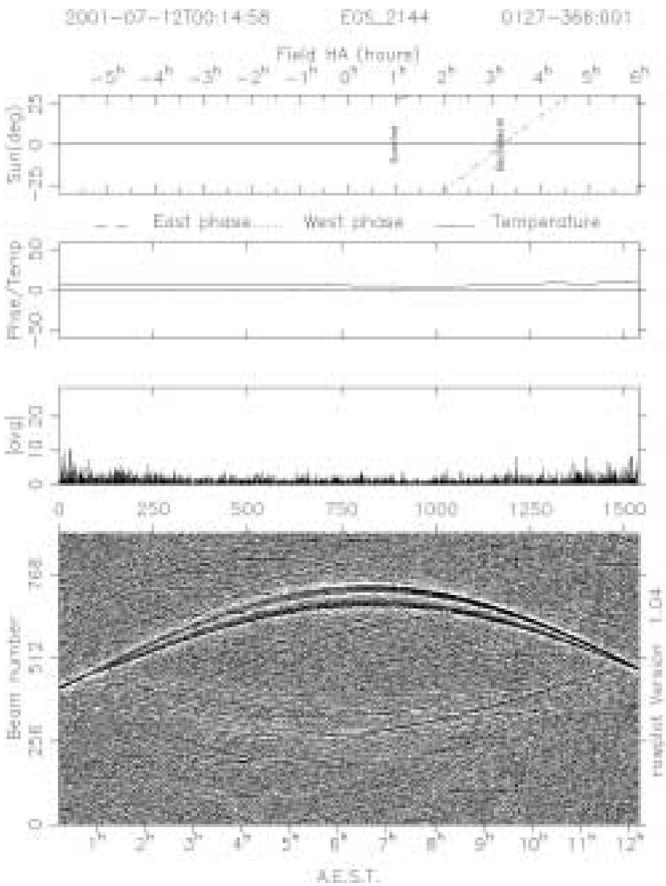


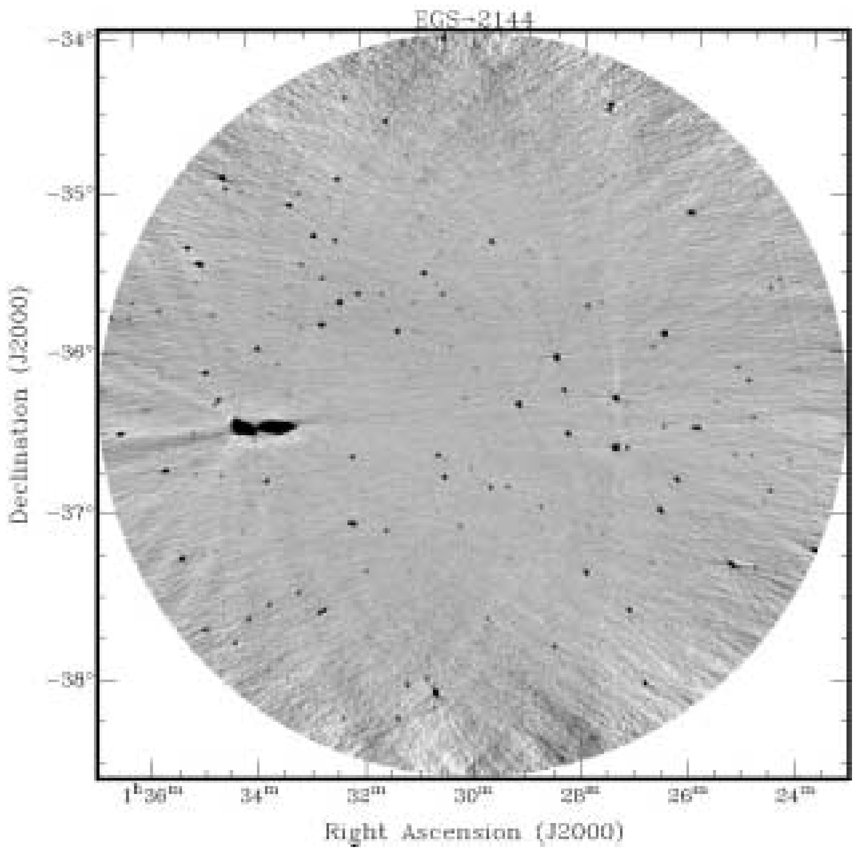


(Bock et al. 1999)

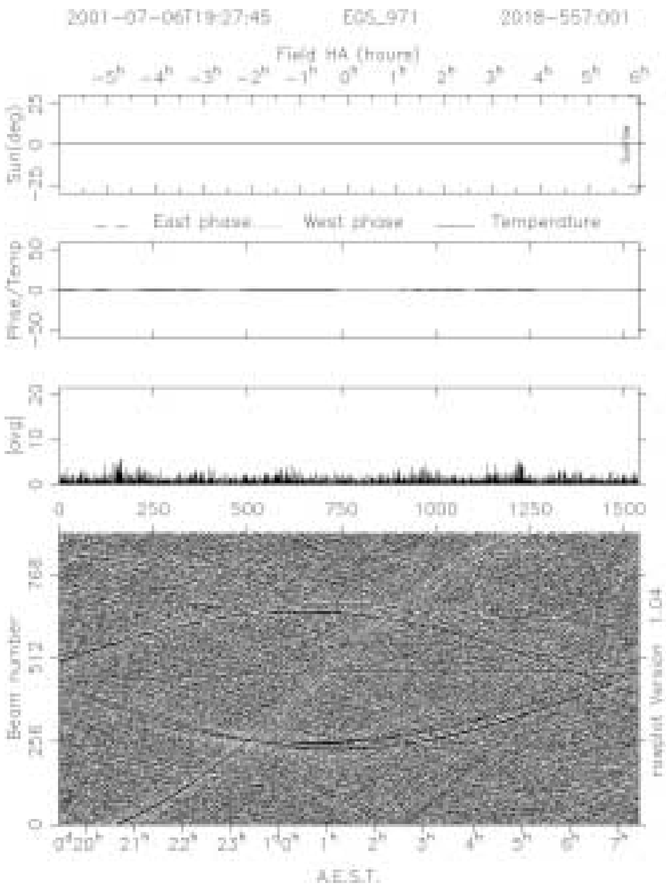
- Continuous uv coverage from 15 m to 1.6 km in 12hr synthesis

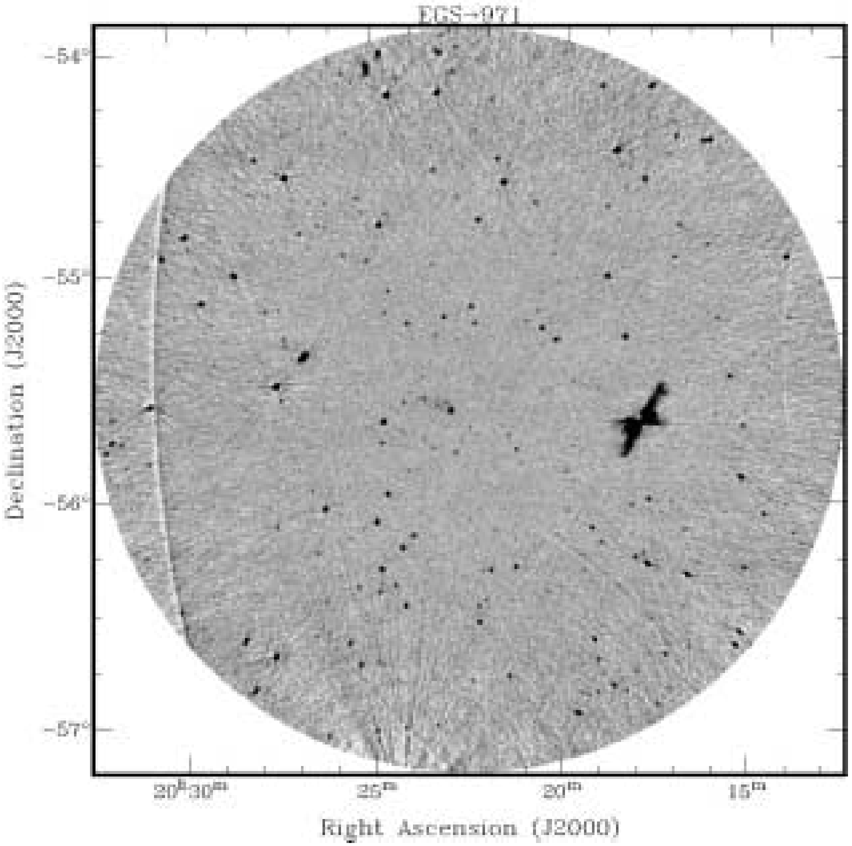
Faxplot and image for Field 2144 (J0127-366)



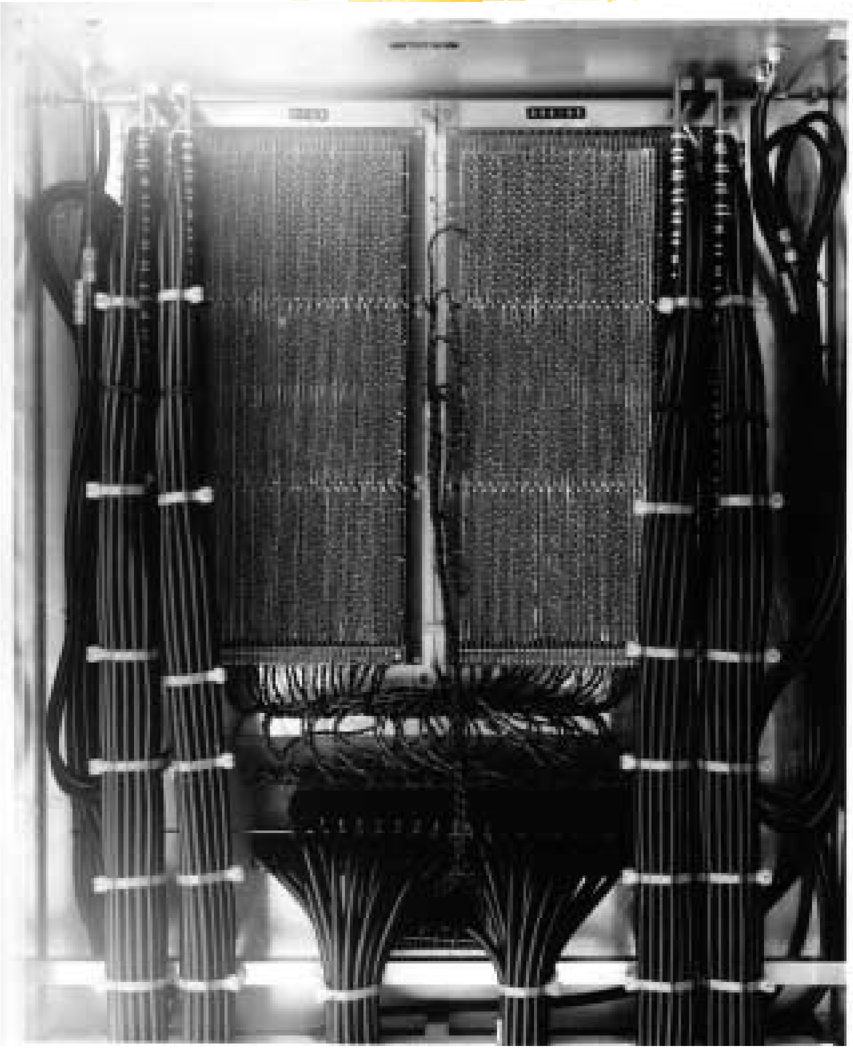


Faxplot and image for Field 971 (J2018-557)

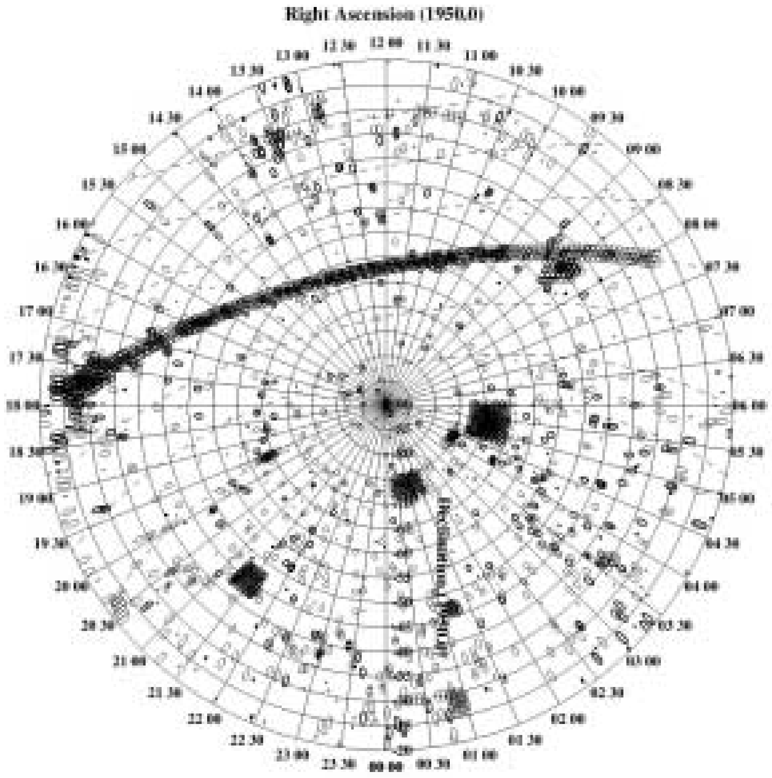




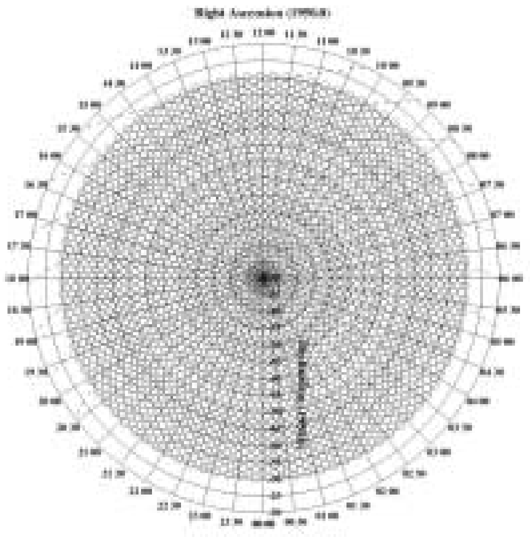
Real time beam-forming at Molonglo

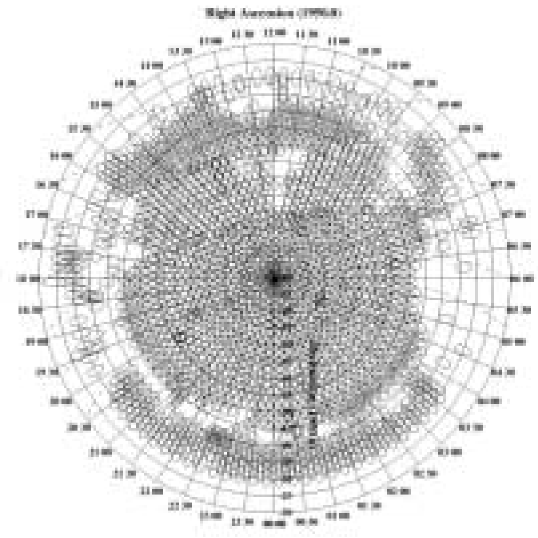


Coverage with small Field of View (1982 – 1997)

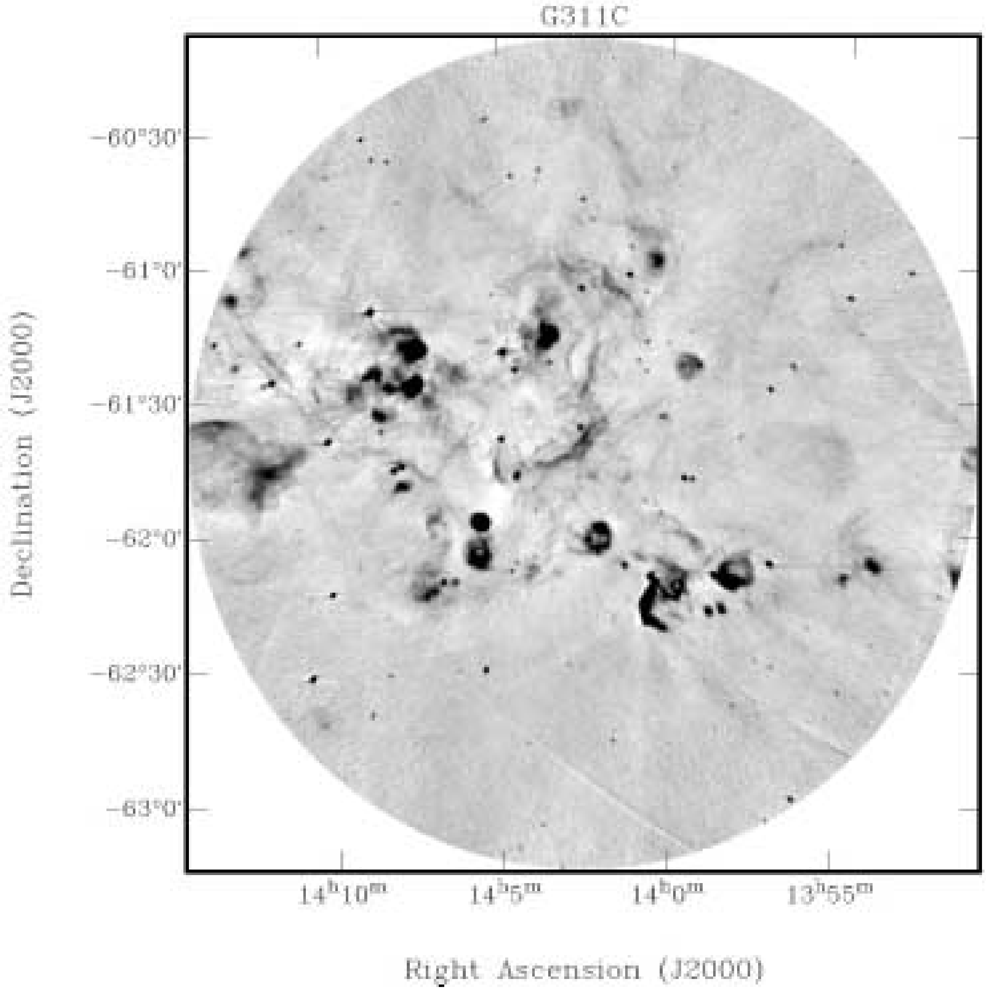


SUMSS Survey Fields
δ < -30 degrees (1997 – 2003)





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)

- 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

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

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)

↓ (also → Independent fanbeam)

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

↓ (also ⇢ Digital Beamformer)

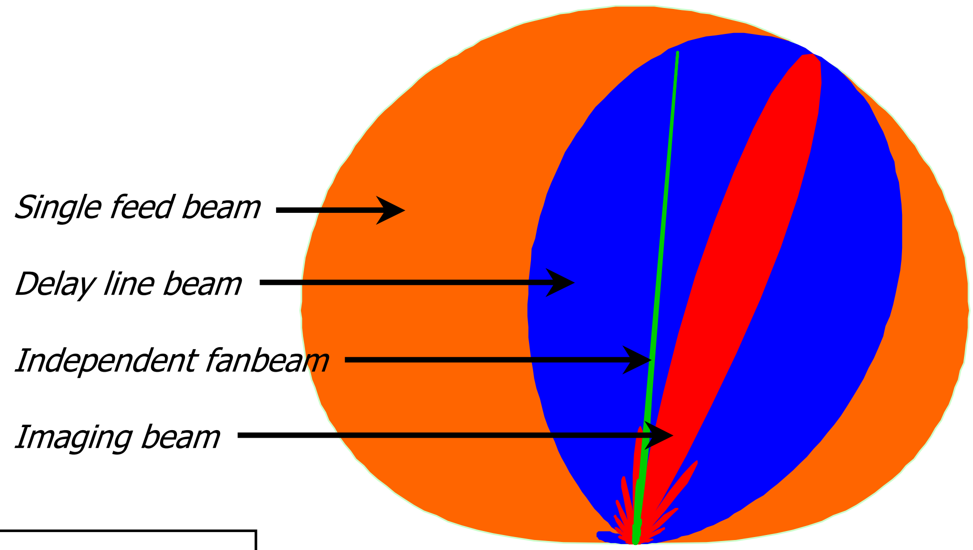
FX Correlator
(3,160 baselines, 2,048 channels)

↓

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

Independent fanbeam

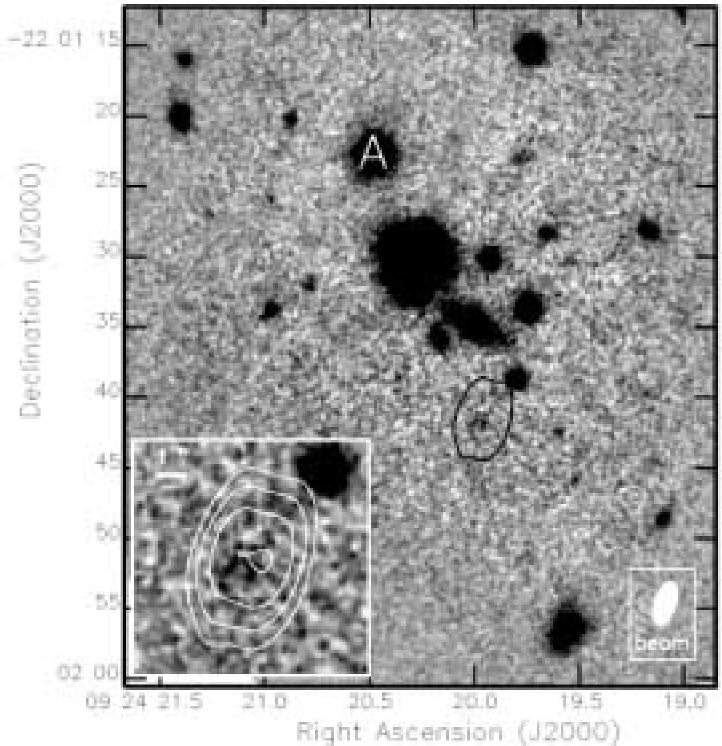
Digital Beamformer
(64 fanbeams within imaging beam)
[Requires extra funding]



Science outcomes & goals

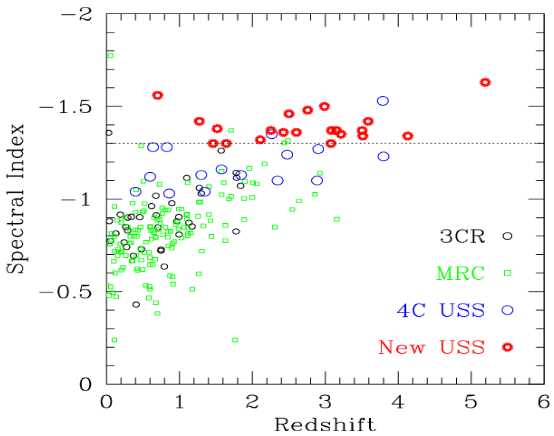
- Imaging survey at range of frequencies
- High redshift HI absorption in galaxies
- Transient source monitoring
- Pulsar survey
- Radio recombination lines & absorption observations of HII regions
- SNR searches – ISM structure

Science goals: High-redshift radio galaxies using continuum data

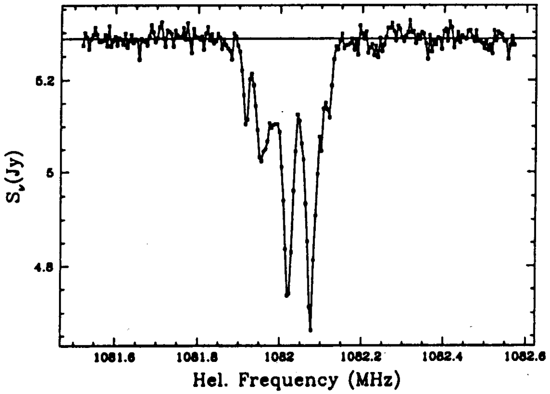


Radio galaxy TN0924-2201 at z=5.19
(van Breugel et al. 1999)

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).



Science goals: HI absorption spectra from distant galaxies

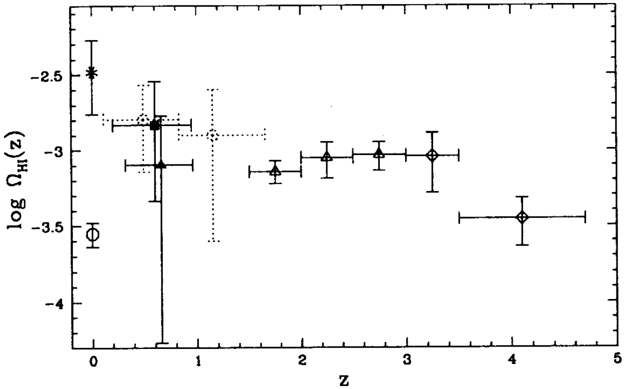


(Lane 2000)

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

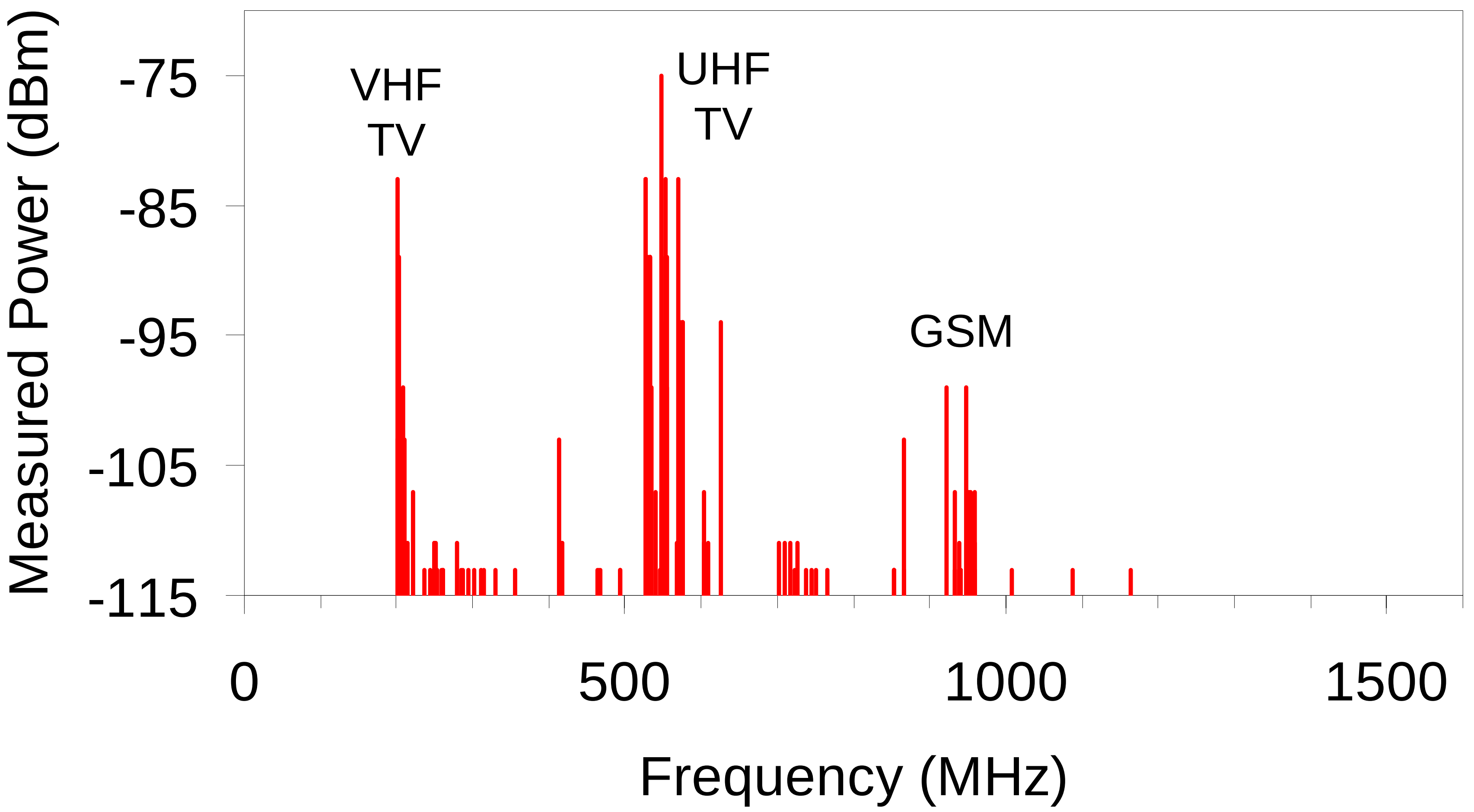
- Measurements of HI absorption at z ~ 0.75 that capitalise on the large collecting area of MOST

Stage II enables Ω_{HI} measurements at z ~ 0.75, where other methods are not well constrained



(Lane and Briggs 2001)

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

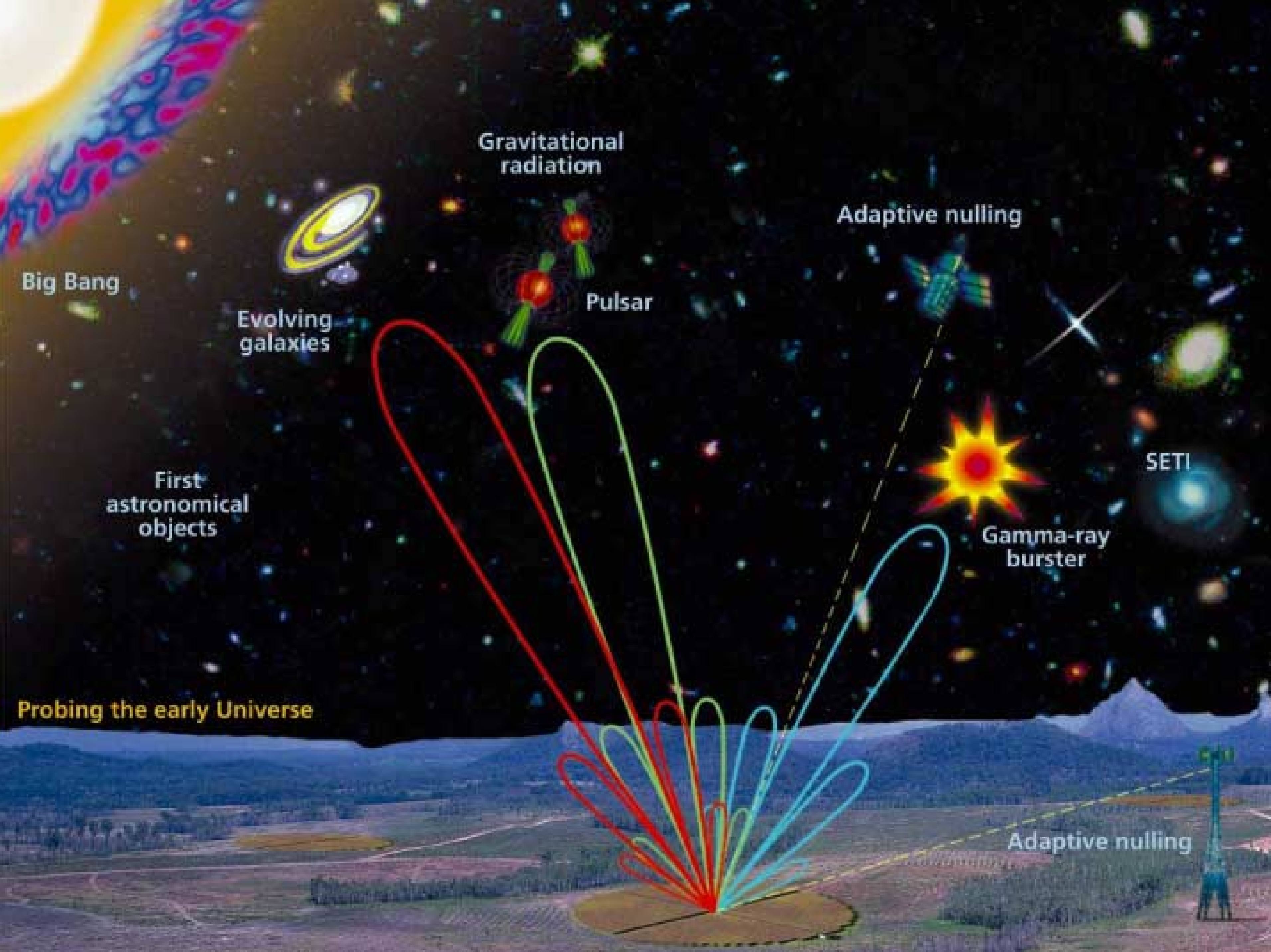


The Square Kilometre Array (SKA) Project

- Multiple beams & multiple FOV
- Benefits of baseband recording
- http://www.atnf.csiro.au/ska

Multibeaming 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


Gravitational radiation
Adaptive nulling
Big Bang
Evolving galaxies
Pulsar
First astronomical objects
SETI
Gamma-ray burster
Probing the early Universe
Adaptive nulling

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