

# The Murchison Widefield Array

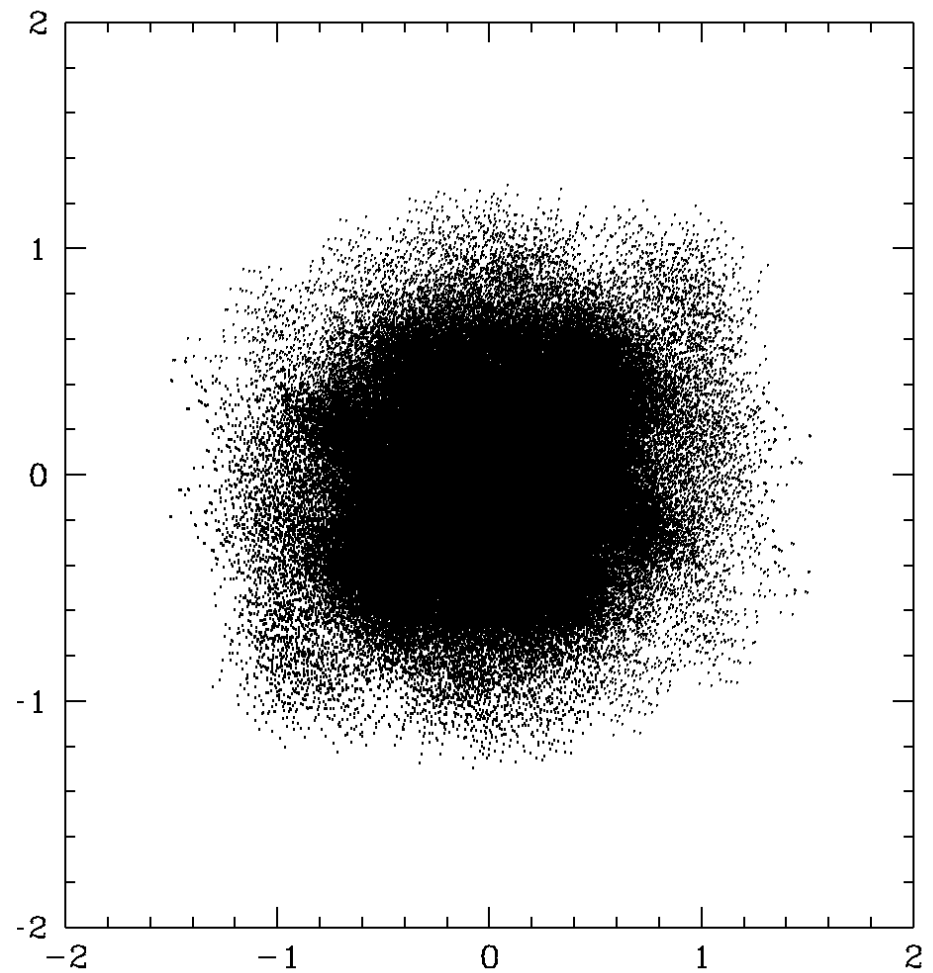
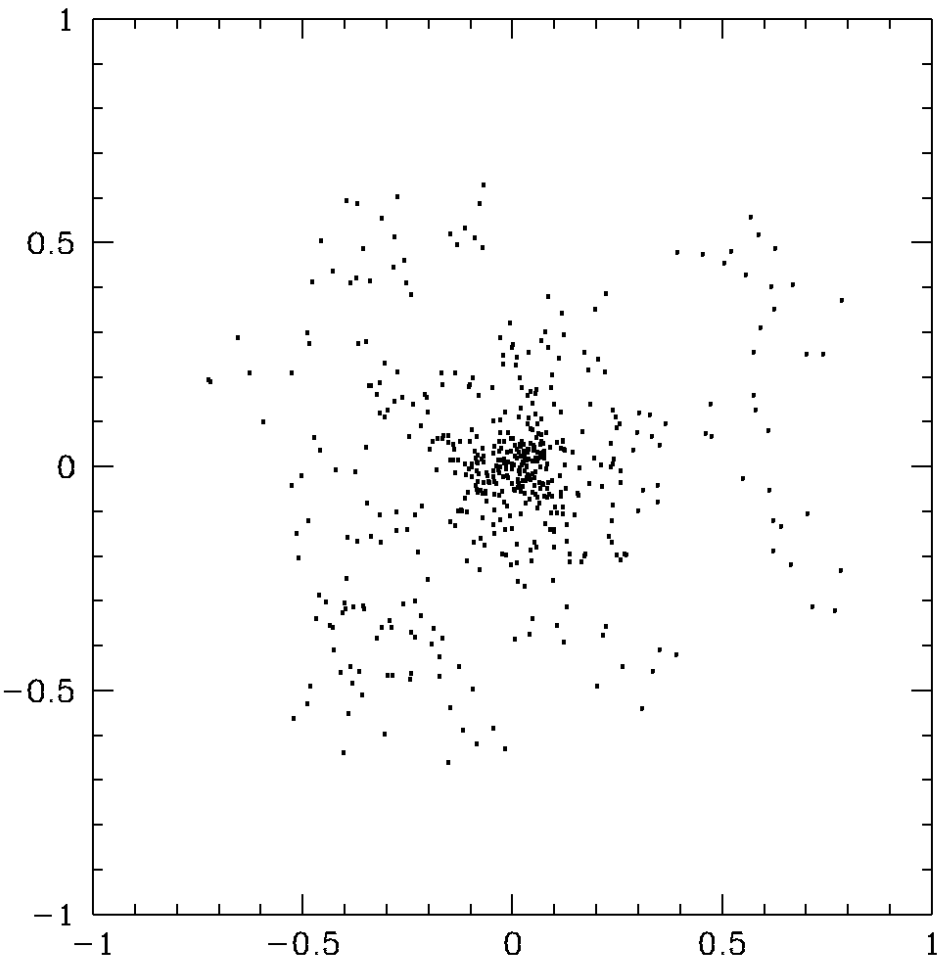
Colin J. Lonsdale

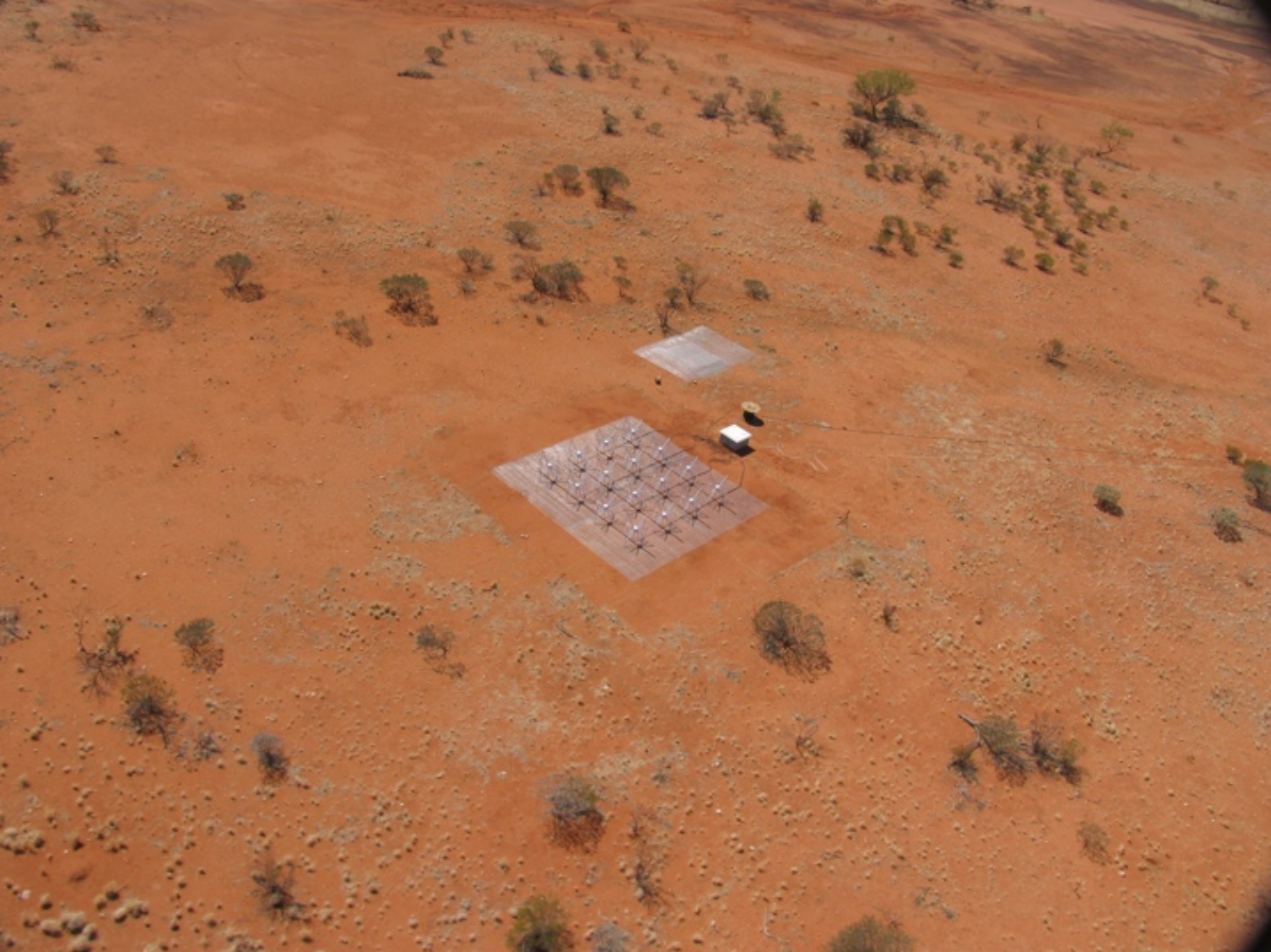
MIT Haystack Observatory

# The Collaboration

- Massachusetts Institute of Technology
  - Haystack Observatory (Project Office)
  - Kavli Institute
- Harvard SAO
- CSIRO (synergy with ASKAP)
- Melbourne, Curtin, ANU (founding partners)
- Sydney, Tasmania, UWA, and others, ...
- Raman Research Institute, India

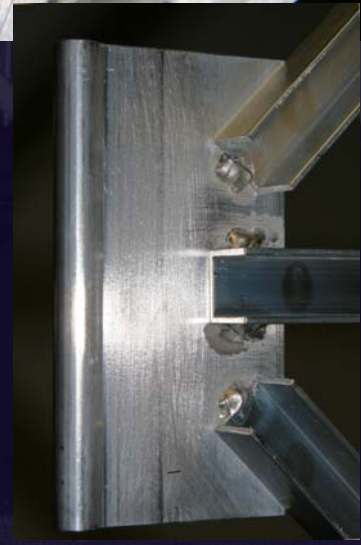
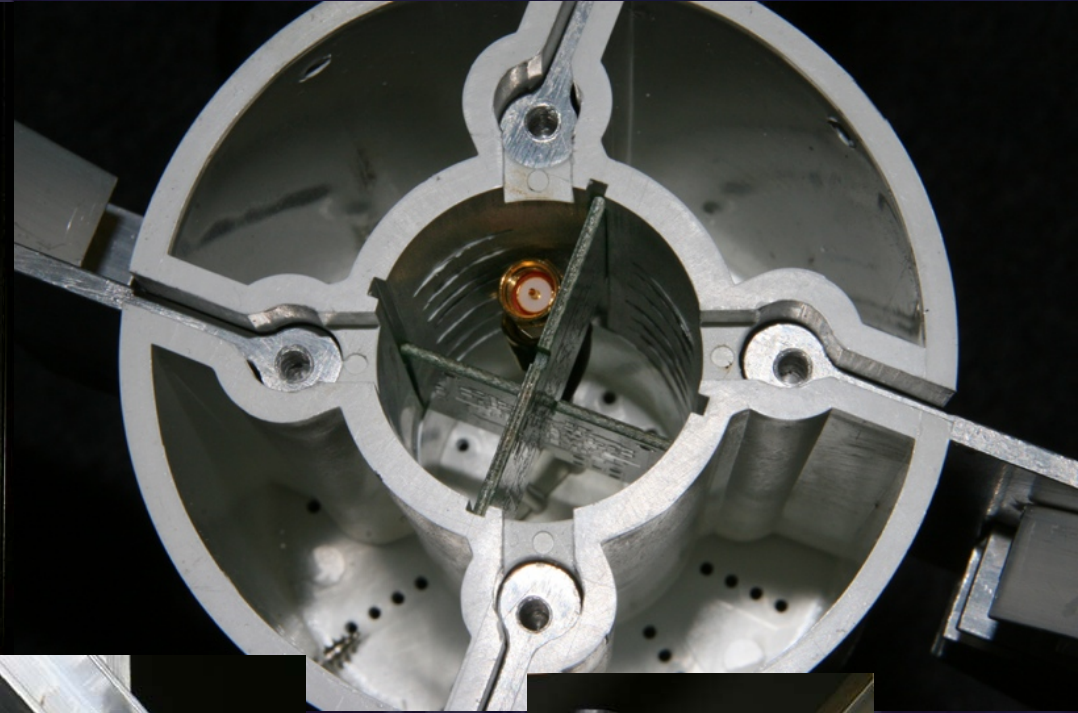
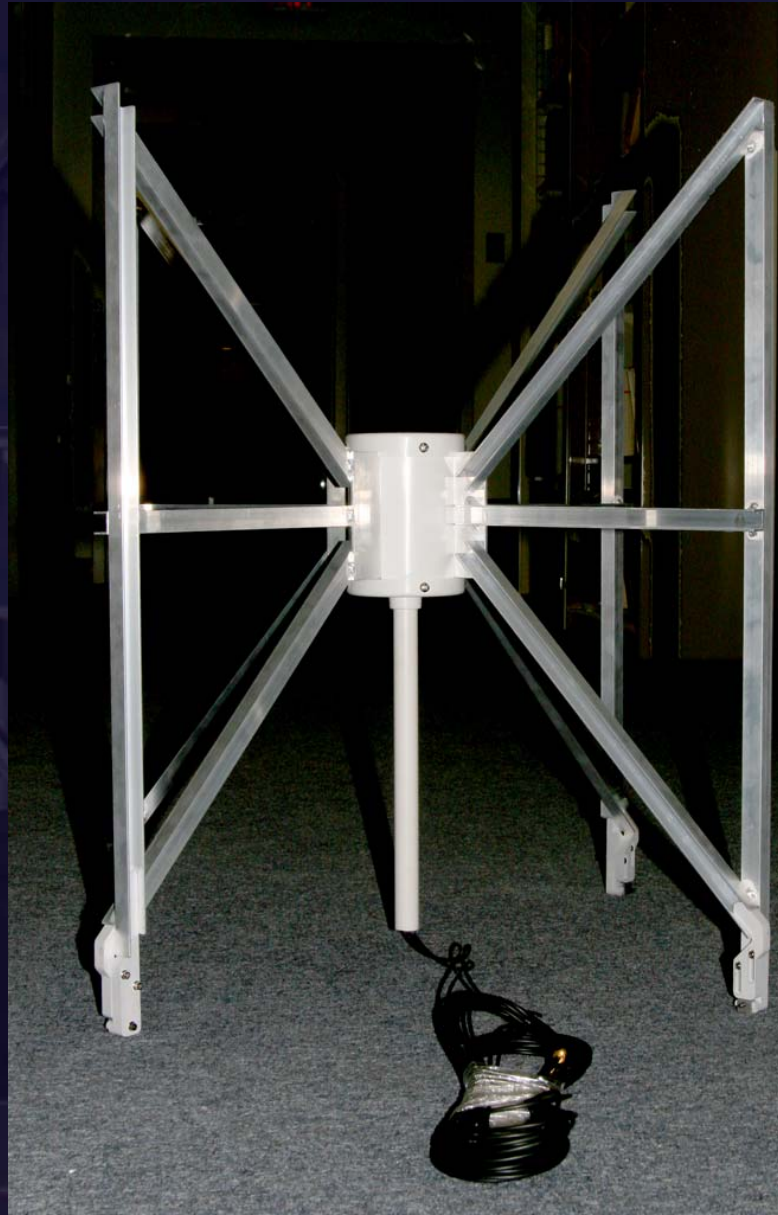
# Physical Layout





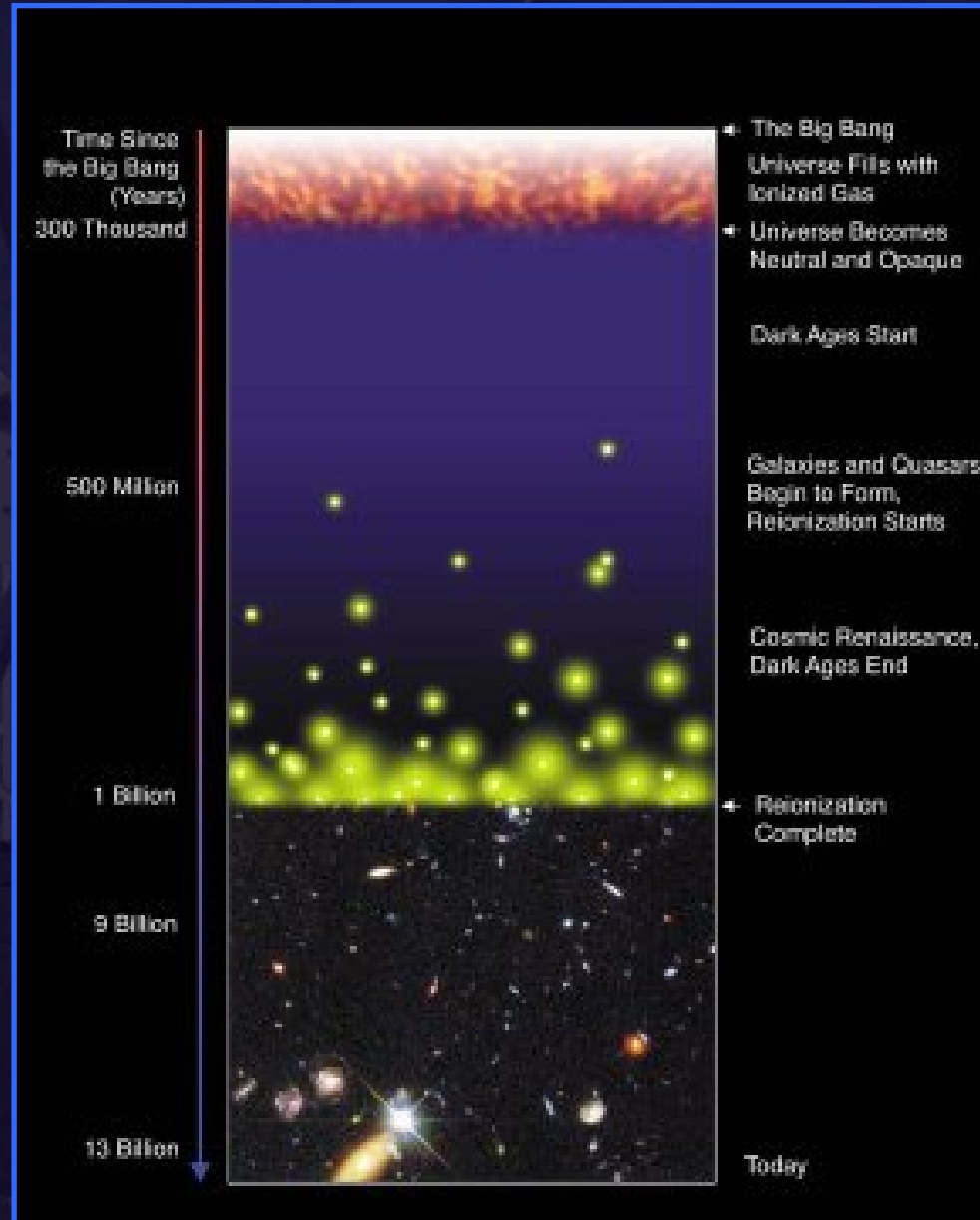


# Manufactured Antenna Design

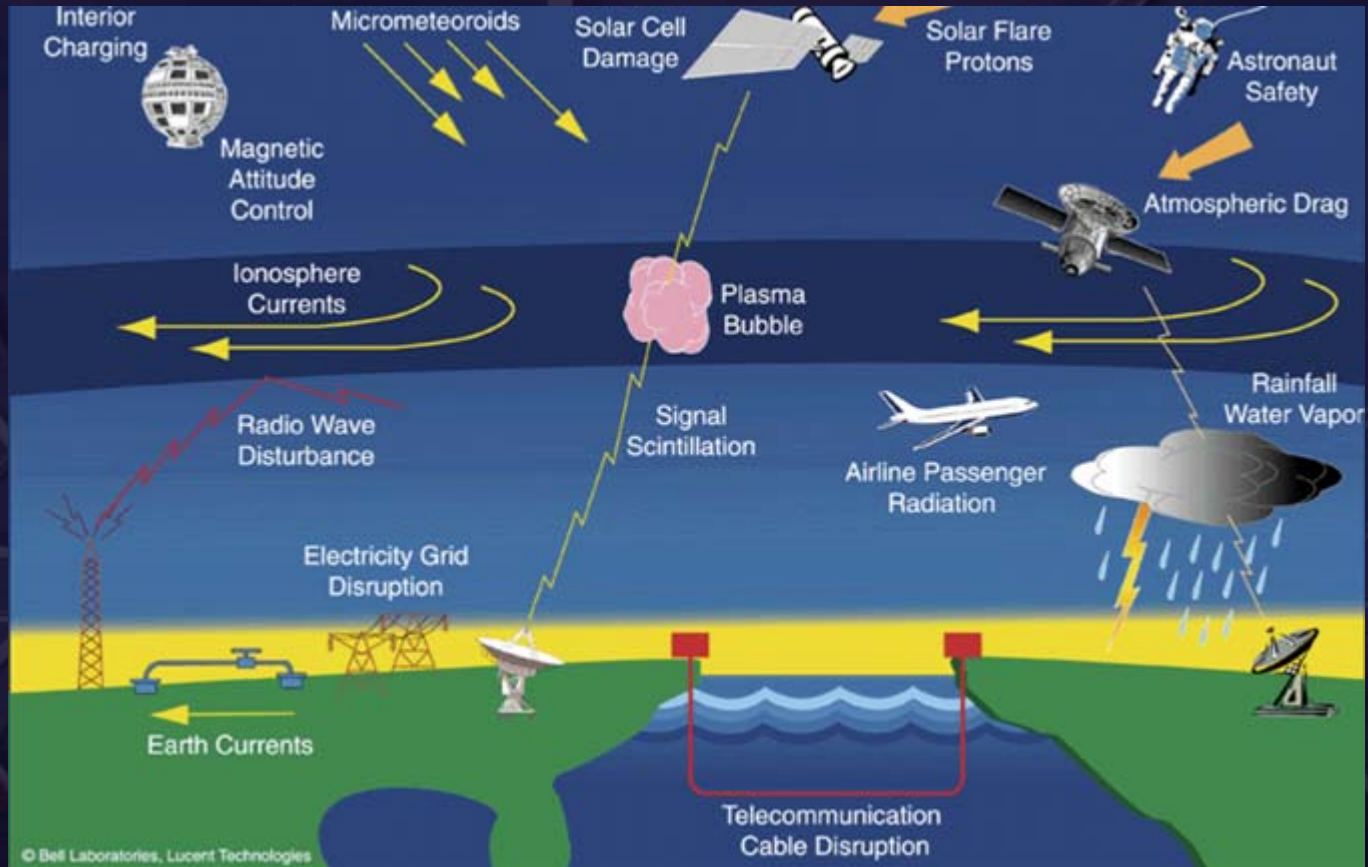


# The Epoch of Re-ionization

- After  $\sim 300,000$  years electrons and protons combine to form hydrogen
- After  $\sim 1$  billion years stars and quasars ignite, radiation splits hydrogen into protons and electrons.
- In between are the **Dark Ages**



# The need for predicting Space Weather



**Geomagnetic Storms Disrupt Technological Systems**

**Radiation Hazards**

**Damage to Satellites**

**Communications Failures**

**GPS Navigation Problems**

# Transients are “killer” science

- MWA - a powerful observatory for transients
- 5 different software analysis methods, or “transient camera backends”
  - All Sky Monitor
  - Beamformer Light Curve
  - Imager Light Curve
  - Short Term Synoptic Survey
  - Long Term Synoptic Survey
- Each has different parameters, teams

<b>Science Topics</b>	<b>A</b>	<b>B</b>	<b>I</b>	<b>S1</b>	<b>S2</b>
Blind Transient Search	X				
Periodic Survey				X	X
Pulsars		X			
Radio supernovae	X			X	X
LIGO events	X				
GRB prompt emission	X				
GRB afterglows	X			X	X
X-ray binaries	X		X		
Pulsar giant pulses	X	X			
Local gas giants	X	X	X		
Extrasolar planets	X	X	X		
Flare stars		X	X		
Scintillation events	X	X	X		
Microlensing events		X		X	X
Burpers	X	X			
RRAT's		X			

# Galactic/Extragalactic (GEG)

<u>Name</u>	<u>Institute</u>	<u>Areas of Interest</u>
Judd Bowman	Caltech	Surveys
Shami Chatterjee	U. Sydney	Supernova remnants, pulsar winds
Mousumi Das	RRI	Galaxies
Tracey DeLaney	MIT	Supernova remnants
A. A. Deshpande	RRI	Faraday tomography, MW magnetic field
John Dickey	U. Tasmania	RRLs, diffuse ISM, Faraday tomography
K. S. Dwarkanath	RRI	Diffuse emission (MW, MCs, ICM, IGM)
Bryan Gaensler	U. Sydney, chair	SNRs, H II, cosmic rays, MW, MCs, Faraday
Anne Green	U. Sydney	Supernova remnants, H II regions
Lisa Harvey-Smith	U. Sydney	<i>[starts 1 Oct, 2007]</i>
Merv Lynch	Curtin U.	RRLs, supernova remnants
Greg Madsen	U. Sydney	RRLs, H II regions
Tara Murphy	U. Sydney	Supernova remnants
Divya Oberoi	Haystack	Supernova remnants, diffuse ISM
John Raymond	CfA	Supernova remnants
D. Anish Roshi	RRI	RRLs, diffuse ISM
Lakshmi Saripalli	RRI	Radio galaxies, quasars, AGN
Lister Staveley-Smith	UWA	Magellanic Clouds, RRLs, tomography
Ravi Subrahmanyan	RRI	Radio galaxies, quasars, AGN, clusters
N. Uday Shankar	RRI	LSB galaxies, Faraday tomography, RRLs
Randall Wayth	CfA	Surveys

# Where is it + why?

$$\rho_{humans} \sim 3 \times 10^{-3} \text{ km}^{-2}$$



DATA DIRECTORY		
THEME	SOURCE	DATE
Cultural	DOLA / DME / DRD / W.A. Fishing Council	1987
Transport	DOLA	2000
Hydrography	DOLA	1987
Terms	CALM	June 1995
LGA Boundaries	DOLA	1987
Aboriginal Communities	Aboriginal Affairs Department	1995
REVISED		Feb 2001

Data source scales vary greatly.  
Map product is to be used for broad based planning only.

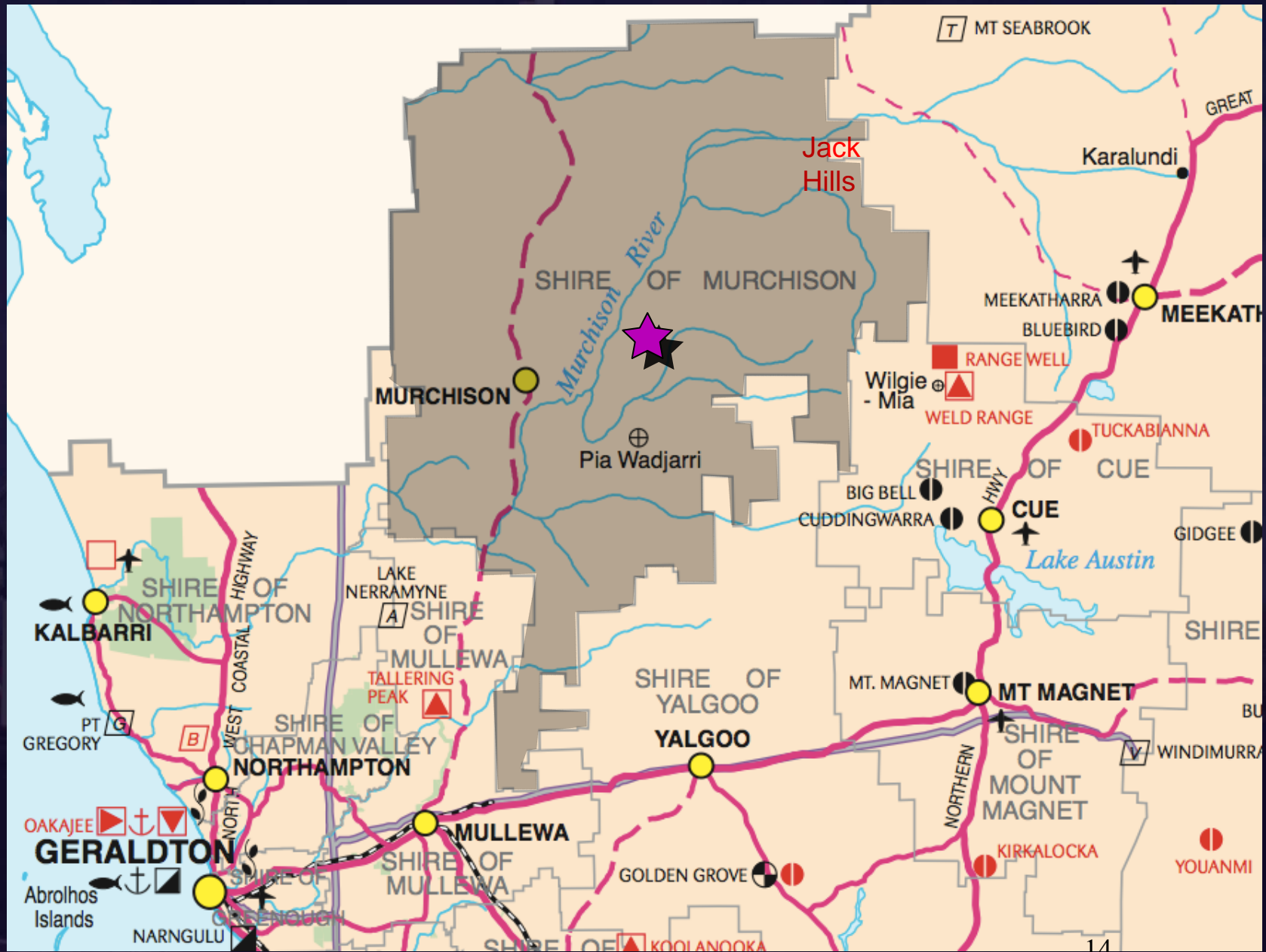


- Major Mines**
- Potential projects in red**
- [A] Attapulgitte
  - [B] Base Metals
  - [C] Cement / Lime
  - [D] Chalk
  - [E] Coal
  - [F] Direct Reduced Iron Plant
  - [G] Garnet
  - [H] Gas
  - [I] Gold
  - [J] Gypsum
  - [K] Iron Ore
  - [L] Lead
  - [M] Limestone
  - [N] Mineral Sands
  - [O] Natural Gas Condensate
  - [P] Natural Gas Plant
  - [Q] Nickel
  - [R] Oil
  - [S] Platinum Group Metals
  - [T] Steel
  - [U] Synthetic Rutile
  - [V] Taic
  - [W] Uranium
  - [X] Vanadium
  - [Y] Zinc / Copper

# MID WEST REGION

## KEY FEATURES



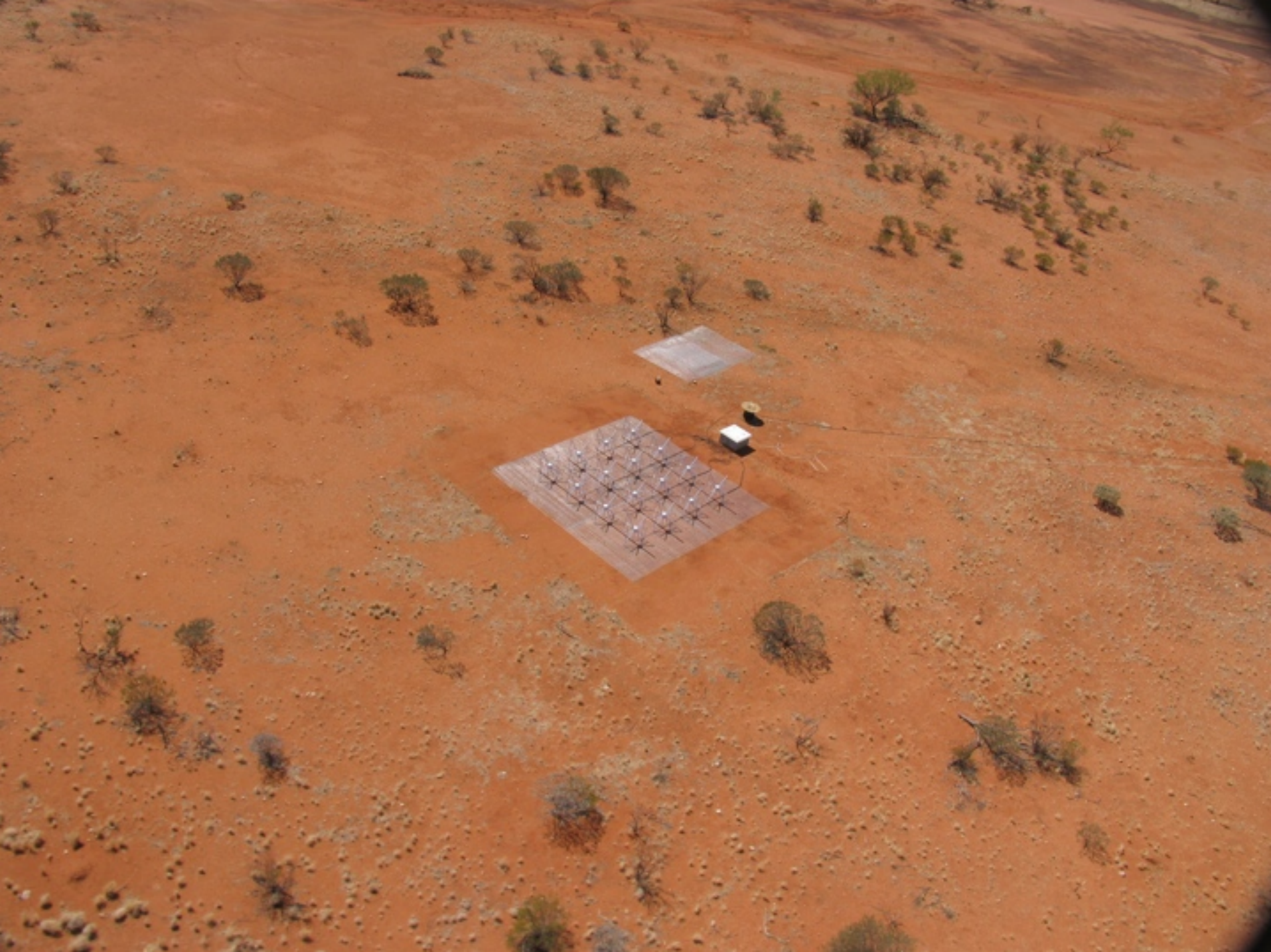


An aerial photograph of a vast, flat, arid desert landscape. The terrain is a mix of light tan sand and reddish-brown soil, with scattered small green shrubs and bushes. In the foreground, there is a prominent, irregularly shaped rock formation with a reddish-brown hue, possibly a natural rock shelter or a large rock overhang. The horizon is flat and extends to the top of the frame under a clear, pale blue sky.

**100,000,000 times quieter than  
“remote” desert sites in US**

# A new breed of Telescope

- Replace steel with silicon
  - Traditional designs use steerable reflectors
  - Can replace reflection with *calculation!*
  - Sample wavefront with myriad small antennas
  - Digitize and number-crunch
  - Revolutionary potential gains in precision and flexibility
- MWA design part of the way there
  - 512 antennas, 1024 analog signal paths
  - 16,000 dipole antennas - ideal is to digitize them all
  - Still forced to do 15/16ths of the work with analog devices
  - Replacing steel takes *lots* of silicon!



# Some Data/Computation Rates

- Sampler output
  - $1024 \times 660 \text{ MHz} \times 8 \text{ bits} = 5.3 \text{ Terabits/sec}$
- Polyphase filterbank
  - Performed on full data rate in real time
  - Number crunching done by 512 Xilinx SX-35 FPGAs
  - Of order 20 Tflops, massively parallel
  - High-quality channelization to 1.3 MHz
  - Discard all but 32 MHz
- Post-filterbank
  - Data resampled to 5 bits
  - Aggregate rate transmitted over fiber = 330 Gbits/sec
  - Transmission distance = several km

# Rates (cont'd)

- More filtering, then *cross-correlation*
  - Basic operation - cross-multiply + accumulate (CMAC)
  - 523,776 signals pairs to be combined
  - Repeated for each of 3200 frequency channels
  - Each signal pair is 2 x 100 kbits/sec
  - Aggregate internal data flow = 320 Terabits/sec
  - Aggregate computation rate = 18 TeraCMACs/sec
  - Results accumulated to 0.5 seconds
  - Output data rate ~128 Gbits/sec
- Implemented in FPGAs
  - 64 boards, each with 8 Xilinx SX-35s, plus support Xilinx
  - Major challenge is efficient in-chip data routing/replication
  - Total system <\$1M in hardware, ~15 kW power consumption

# Rates (cont'd)

- Real-time calibration/processing
  - Performed by general-purpose parallel computer
  - Minimum performance class  $\sim 1$  Tflop
  - Low power consumption critical
  - Could be moved off-site given fast-enough link
- Astronomical data products
  - “EOR” database,  $\sim 1$  petabyte/year = 1 Gbit/sec for 1/3 time
  - Transient science data streams, typically 1 Gbit/sec sustained
  - High time-resolution data streams - up to 16 at 1 Gbit/sec each
  - Very heavy offline number-crunching anticipated

# Growth

All these data and computing rates are  
tip of the iceberg

- MWA solutions are data/computing limited
- 2010-2013 times 10 at least
- 2014 and beyond, times 100 or more

# Initial Operational Mode

- No high-bandwidth fiber off-site
  - Perhaps by 2010? What capacity? Gigabit minimum ...
- All real-time computations on-site
  - By necessity - not desirable in long-term
- Data products transported by disk drive
  - Several Tbytes/day feasible
  - Truck to Geraldton or Perth 2-3 times/week?
  - Strong immediate demand for remote access to these data
  - More is better, 1 Gbit/sec a practical minimum

# Remote Operation Issues

## What level of interaction is required?

- MWA as technical experiment
  - Technique development is an important objective
  - Deliberate use of “bleeding edge” solutions
  - Lots of “tinkering” required/desired
  - Ongoing technical development in the field
- Current connectivity insufficient
  - Increased automation software development effort
  - Reduced capability
  - Engineers need tight development/testing loop, *remotely*

# Collaboration Challenges

- Diversity of groups and activities
  - Engineering, science, project management, outreach, ...
  - Wide range of cultures
  - Distributed technical development is *hard*
  - Communication is the lifeblood
- High stakes
  - Killer science to be had
  - Precursor instrument for much bigger things
- Goodwill “half-life” about 6 months
  - Heavy overhead for effective remote communication
    - Timezones - personal commitment is only solution
    - Low communication efficiency
  - Face-to-face meetings essential every 6 months
    - Costly and time-consuming

This style/scope of international project would be easier with MUCH better videoconferencing

- Quality

- Timelag, resolution, reliability etc.
- Availability at **typical** locations (setup and bandwidth)

- Spontaneity

- “Walk down the hall” type of interactions
- “Always on” look and feel
- Unlimited duration

- Benefits would be profound

- Forging a genuine team from scattered experts
- Large efficiency gains possible
- New types of project become feasible

# Summary

- MWA is first in a new wave of radio telescopes
  - Massively data intensive
  - At limits of computation/dataflow for foreseeable future
- Connectivity to site is critical
  - The more bandwidth the better
  - Challenging for small projects to justify the last mile investment
- Collaboration on highly innovative projects
  - Limited by access to talent
  - Often possible only through international efforts
  - Better communication tools would expand possibilities