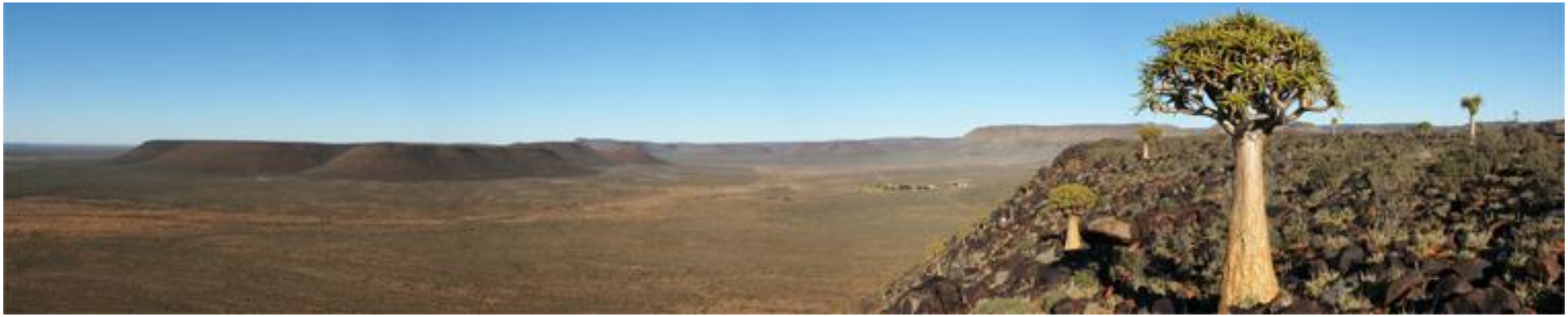
The MeerKAT radio telescope
(and some other animals)



Justin Jonas

and

Roy Booth

SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY

SKA
SQUARE KILOMETRE ARRAY

NASSP-north discussion

Overview

- Context
- MeerKAT Science & Specifications
  - System engineering and design
- Establishing the Karoo site
- XDM
- KAT-7
- African VLBI Network

The SKA in Africa

The MeerKAT Programme

- Africa will have a legacy of a large radio telescope.
  - Irrespective of the outcome of the SKA site competition (but happy with the SKA decision!)
  - But not independent of the SKA.
  - Largest radio telescope in southern hemisphere, one of the largest in the world.
- MeerKAT is an SKA “precursor”.
  - Engineering prototype and early science (SKA-mid “Phase 0”). Now constitutes 25% SKA1
  - Drive the establishment of the Karoo Radio Astronomy Reserve.
  - SA funding about 400 million USD (including a large HCD programme.

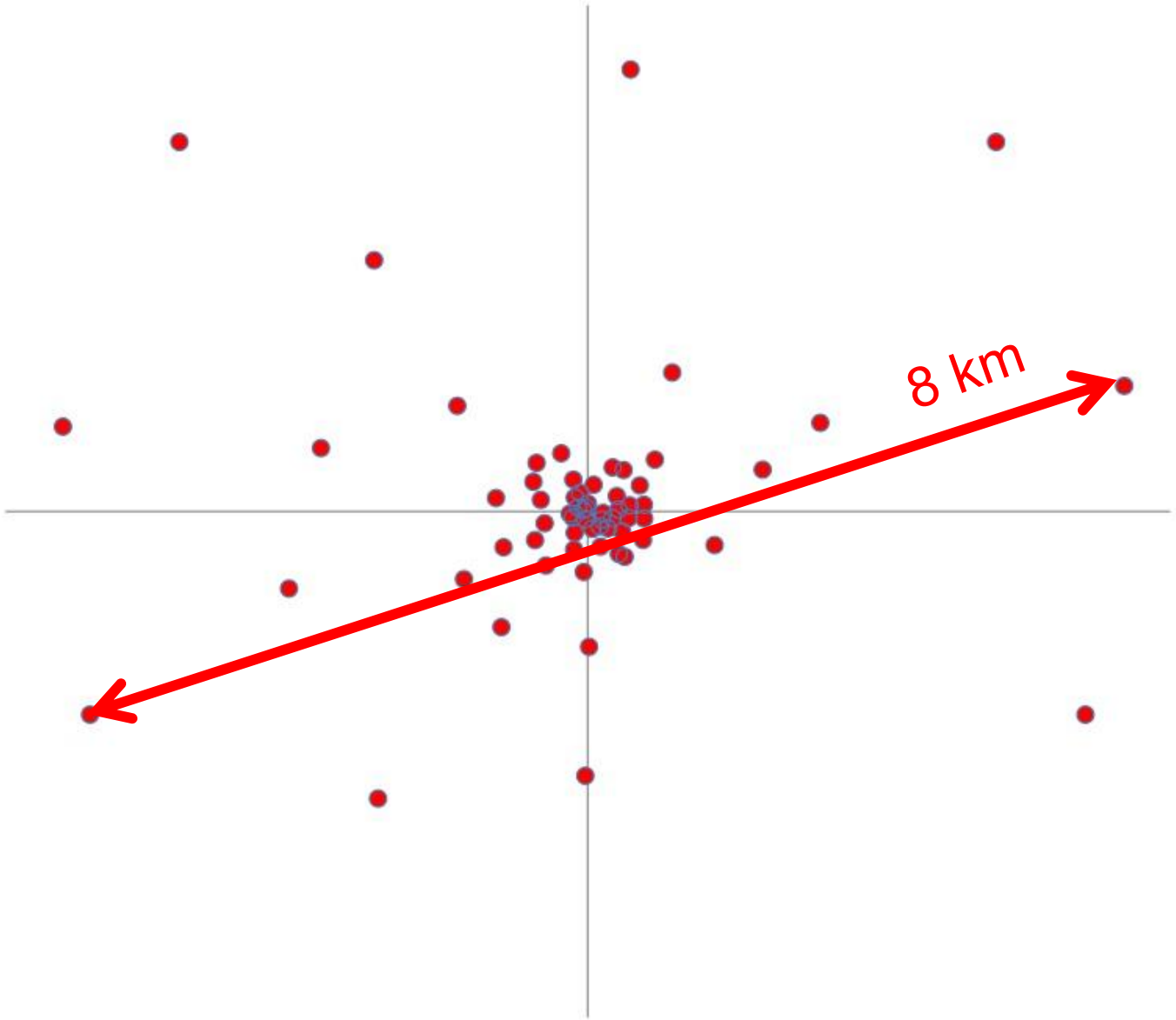
MeerKAT high-level spec

- The most sensitive cm-wavelength telescope in the southern hemisphere (aspiration: world)
- 580 MHz – 15(+) GHz (i.e. SKA-mid +)
- Imaging and non-imaging modes
- High filling factor for baselines < 1 km
- Baselines out to ~8 km (but longer baselines planned – now through SKA1)

MeerKAT High Level Spec

	KAT-7 (2011)	MeerKAT Phase 1 (2016)	Future Phases/ SKA Phase 1
Frequency Bands (GHz)	1.2 – 1.95	0.9 – 1.726	0.58 – 1.015 0.9 – 1.726 8 – 14.5 1.5 – 3 (cont. funding) 5 – 22
BW_{RF}	256 MHz	770 MHz	6500 MHz
ADC	800 MSa/s	1712 MSa/s	15 GSa/s
$BW_{Processed}$	256 MHz	770 MHz	2000 MHz (goal 4000 MHz)
B_{min}	20 m	29 m	29 m
B_{max}	200 m	8 km	20 km (SKA1)
Sens		>> 220 m^2/K *(300 m^2/K goal)*	
No. Dishes	7	64 x 13.5m gregorian offset	

Configuration (64 antennas)



Future Phases

- Phase 2: 580-1000 MHz (UHF)
- Phase 3: 8-14.5 GHz (X/Ku-band)
- Aspirations (contingent on money and/or technology availability):
  - 20+ km baselines (SKA1)
  - 1.5-3 GHz for NanoGrav
  - 5-22 GHz wideband receiver

MeerKAT Large Surveys

- Radio Pulsar Timing (Bailes) [7860 h]
- LADUMA: Ultra-deep pencil beam HI survey (Blyth, Holwerda, Baker) [5000 h]

- MESMER: MeerKAT Search for Molecules in EoR (Heywood) [6500 h]
- MeerKAT Absorption Line Survey (Gupta, Srianand) [4000 h]
- MHONGOOSE: MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters (de Blok) [6000 h]
- A MeerKAT HI Survey of Fornax (Serra) [2450 h]
- MeerGAL: MeerKAT High Frequency Galactic Plane Survey (Thompson, Goedhart) [3300 h]
- MIGHTEE: MeerKAT International GigaHertz Tiered Extragalactic Exploration (Jarvis, van der Heyden) [1950 h]
- TRAPUM: Transients and Pulsars with MeerKAT (Stappers, Kramer) [3080 h]
- ThunderKAT: The Hunt for Dynamic and Explosive Radio Transients with MeerKAT (Woudt, Fender) [3000 h = 100 min/day for 5 years] **+ commensal search for transients**

- VLBI (Bietenholz)

MeerKAT Large Survey PIs (17-18 April 2011)

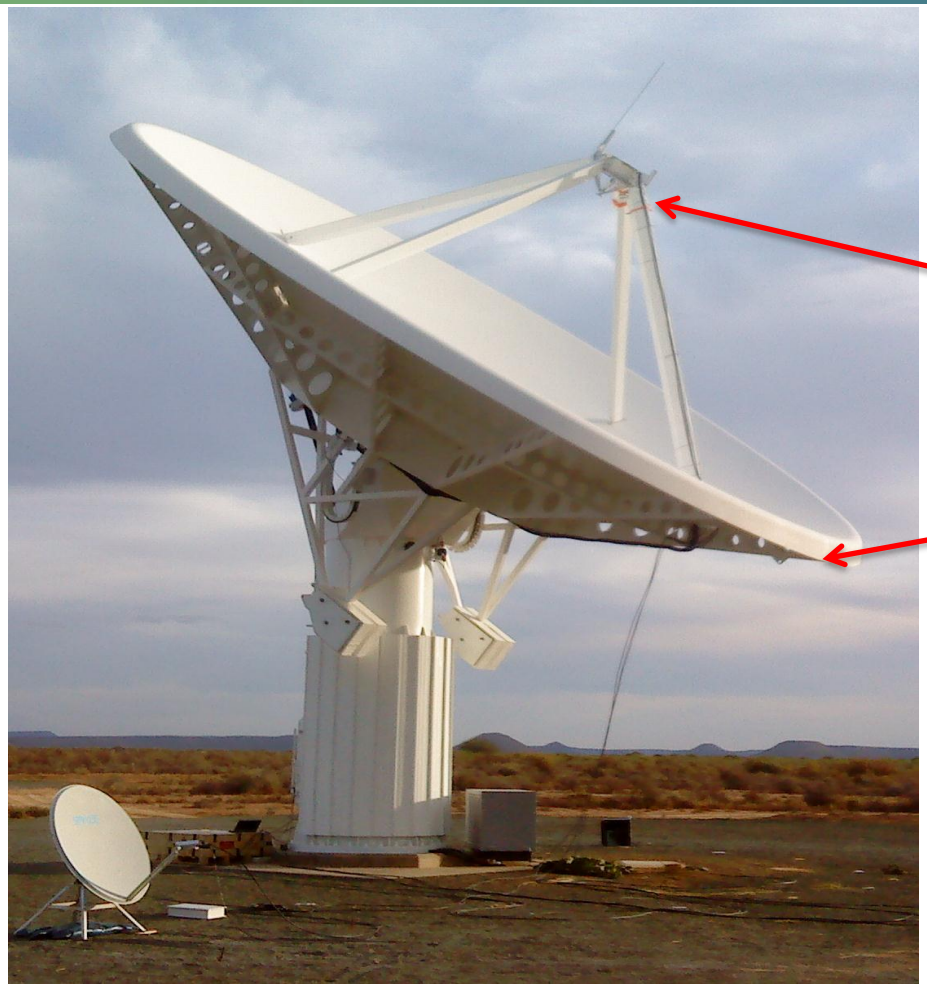
System CoDR (5-8 July 2010)

- Gregorian offset antennas
  - Multiple receivers
  - RFI rejection
  - Spectral & imaging dynamic range
  - Sensitivity
  - 64 x 13.5 m
- Cryo-cooled, octave band, single pixel receivers
  - Sensitivity
- Direct digitization
  - Spectral dynamic range
- Software collaboration
  - CASA

Implications for receptor

- Low contributions to T_{sys}
  - Low spillover & correlated ground signals
  - Minimize scattering structures
- Maximize A_e for specified sidelobe envelope
  - Minimize/eliminate aperture blockage
- Multiple receivers
  - A_e/T_{sys} and DR have priority over Rx BW, therefore >1 Rx
- Predictable, time-stable, frequency-smooth and limited *(l,m)* support E-Jones
  - Solid angle used for calibration/imaging
  - Pointing variation within characteristic calibration timescale
  - Polarization
  - Gain ripple
- Rotational symmetry of inner beam pattern (P-Jones)
  - Gain variation within characteristic calibration timescale
- Low far-out sidelobes
  - Minimize scattering structures
- Clean RF signal path (G- and B-Jones)
  - Cable routing
  - Direct digitization
  - Self-generated RFI

Prior to Concept Design Review



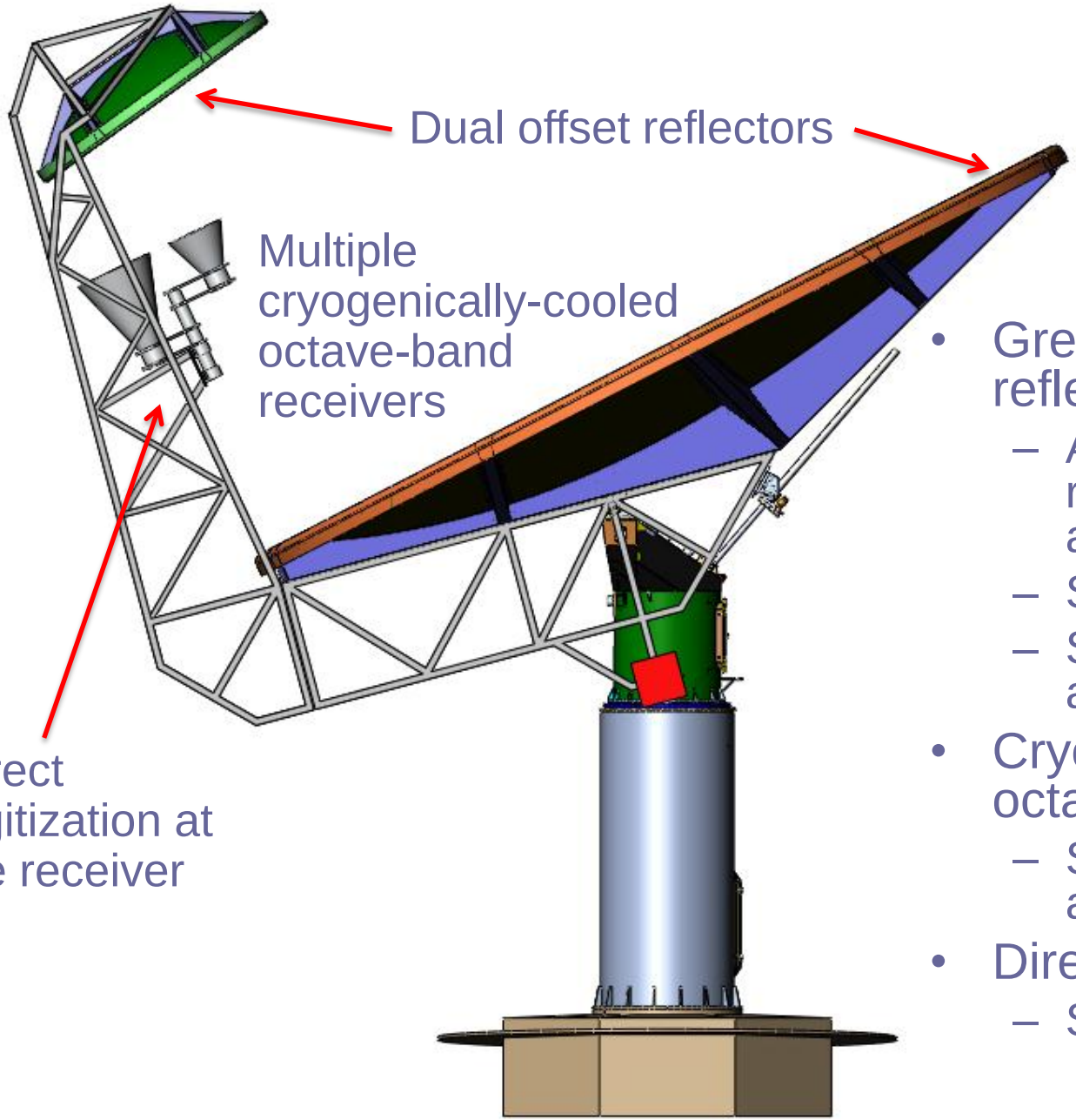
KAT-7 antenna

Single cryogenic octave-band receiver

Single-reflector symmetric centre-fed antenna with aperture blockage

Analogue signal transport and remote digitization

Baseline design



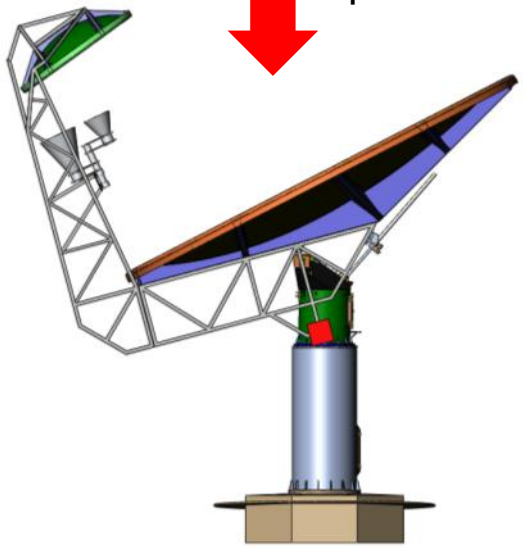
•nb SKA1

- Gregorian offset dual-reflector antennas
  - Allows multiple receivers without aperture blockage
  - Superior RFI rejection
  - Superior sensitivity and signal fidelity
- Cryogenically cooled octave-band receivers
  - Superior sensitivity and signal fidelity
- Direct digitization
  - Superior signal fidelity

Antenna Status

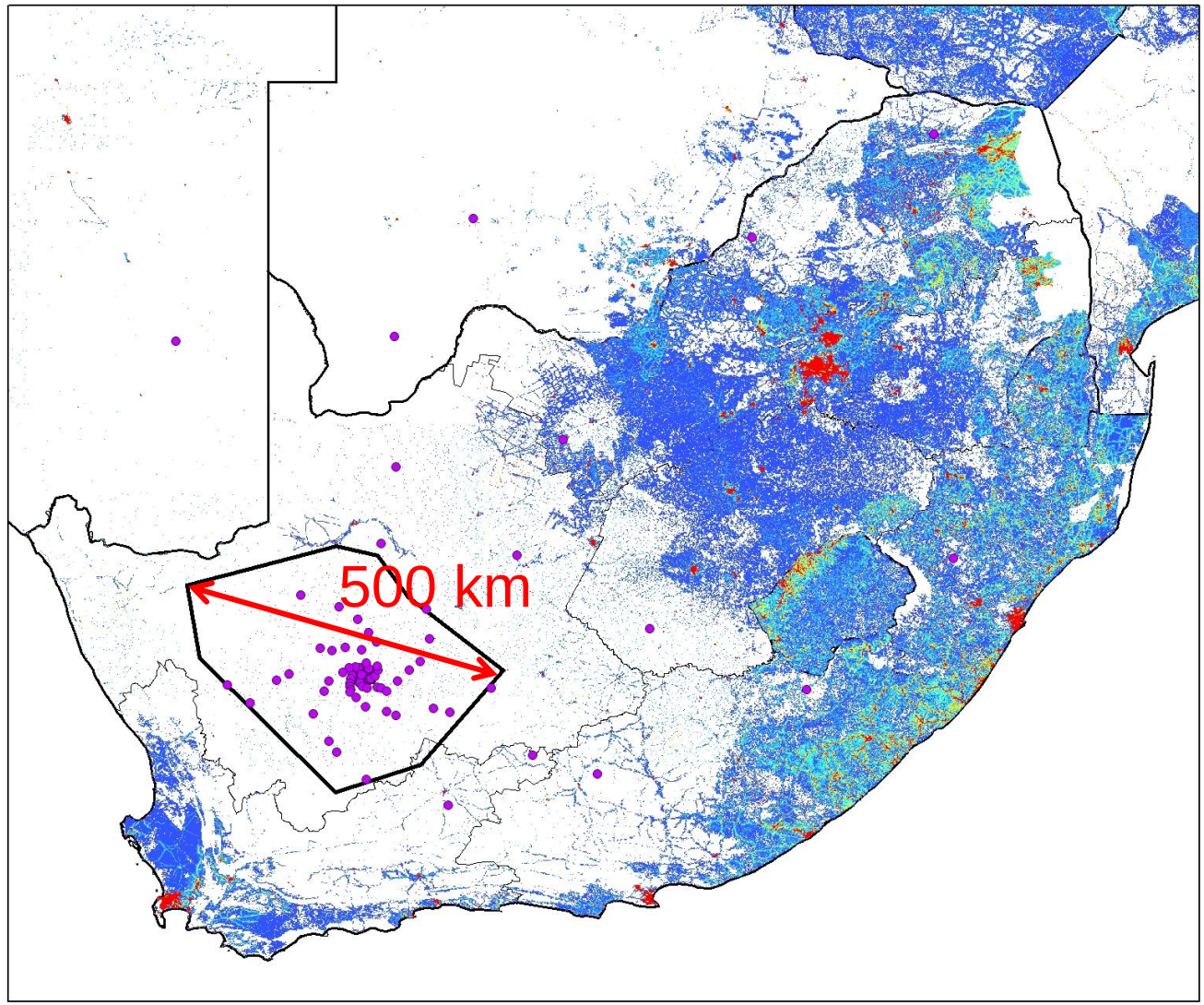
- Extensive EM and mechanical modelling completed
- All reviews completed, including international participants
  - Gregorian offset
    - No aperture blockage with multiple receivers
    - Superior RFI rejection
  - Cryo-cooled receivers
  - Direct digitisation
- Tender published and awarded last month
  - 64 x 13.5m gregorian offset dishes

Optimisation



Virtual MeerKAT

Karoo Radio Astronomy Reserve



Legend

- SKA_Configuration_SPDO_Dish_Full
- AA1_SPDO_Version1
- AA2_SPDO_Version2
- KCAAA1

Population (per sq km)

Value

- 0 - 4
- 4.000000001 - 14
- 14.00000001 - 29
- 29.00000001 - 47
- 47.00000001 - 68
- 68.00000001 - 91
- 91.00000001 - 116
- 116.0000001 - 142
- 142.0000001 - 169
- 169.0000001 - 197
- 197.0000001 - 225
- 225.0000001 - 255

N

0 145 290 580 870 1,160 Kilometers

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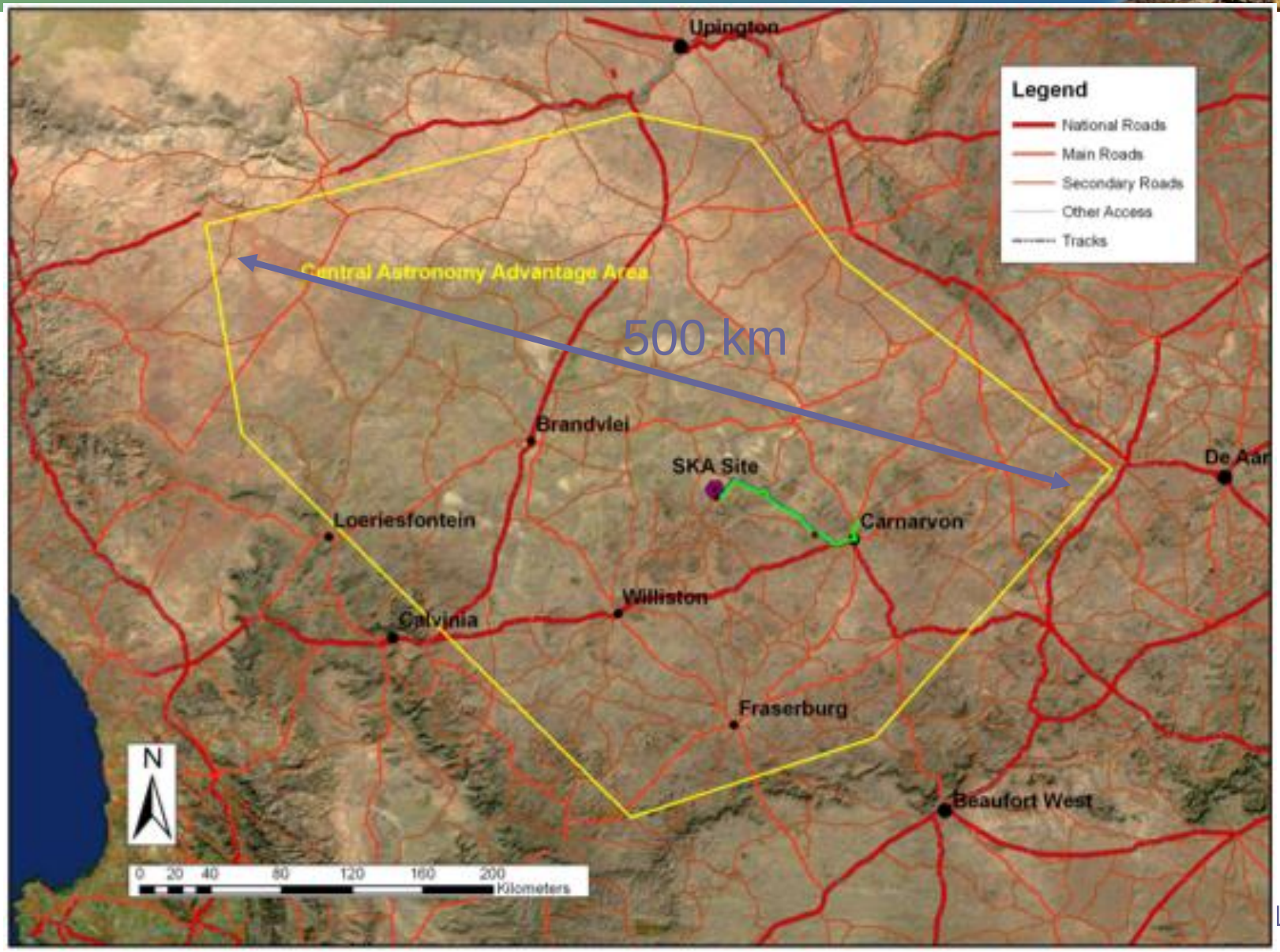
Karoo Radio Astronomy Reserve



C-BASS

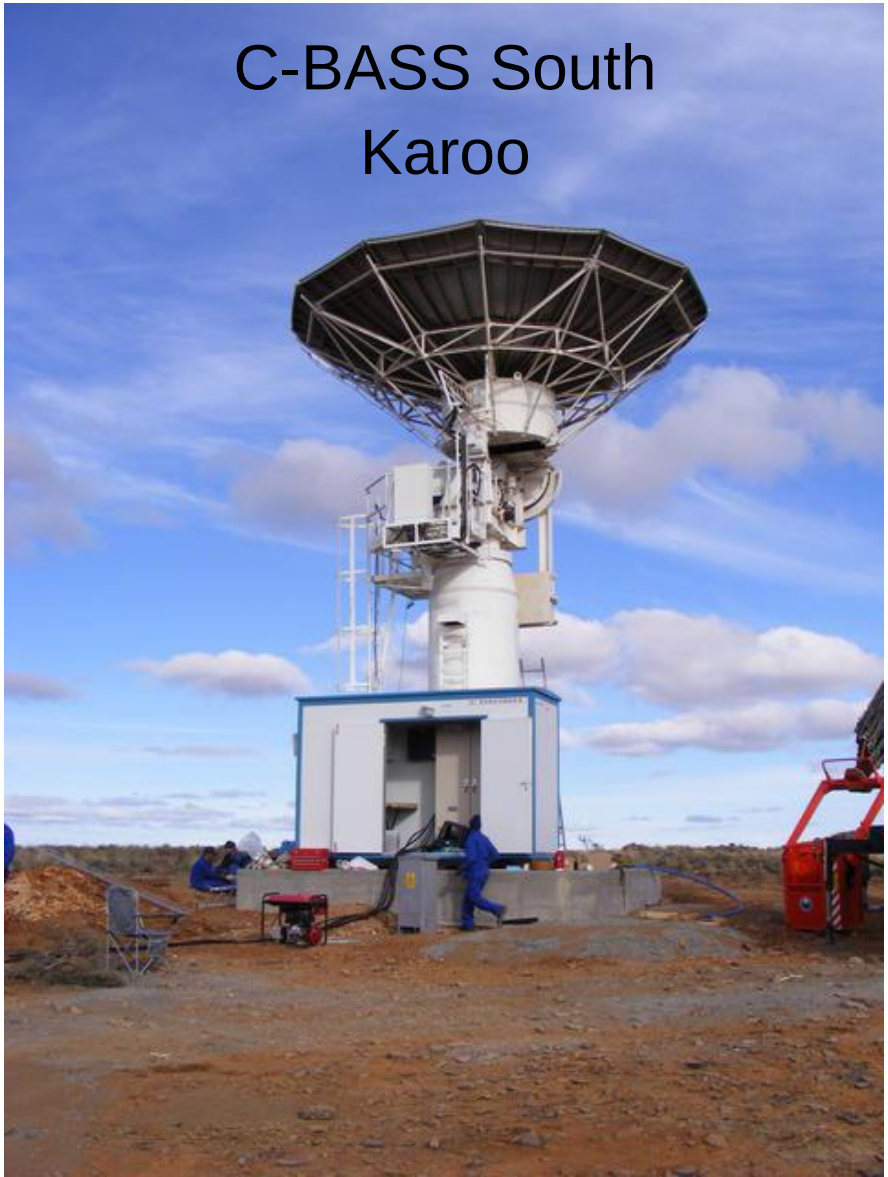
Oxford Physics

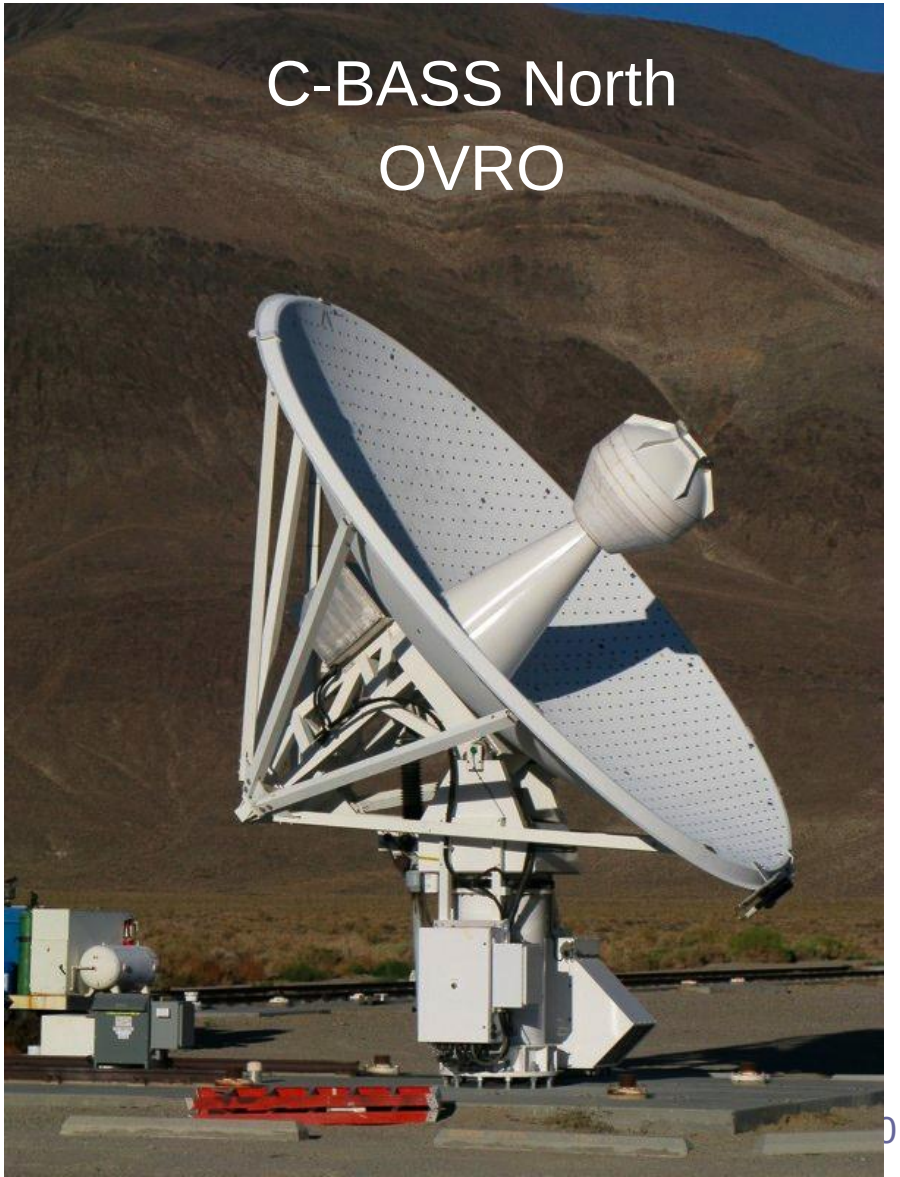
MANCHESTER 1824

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

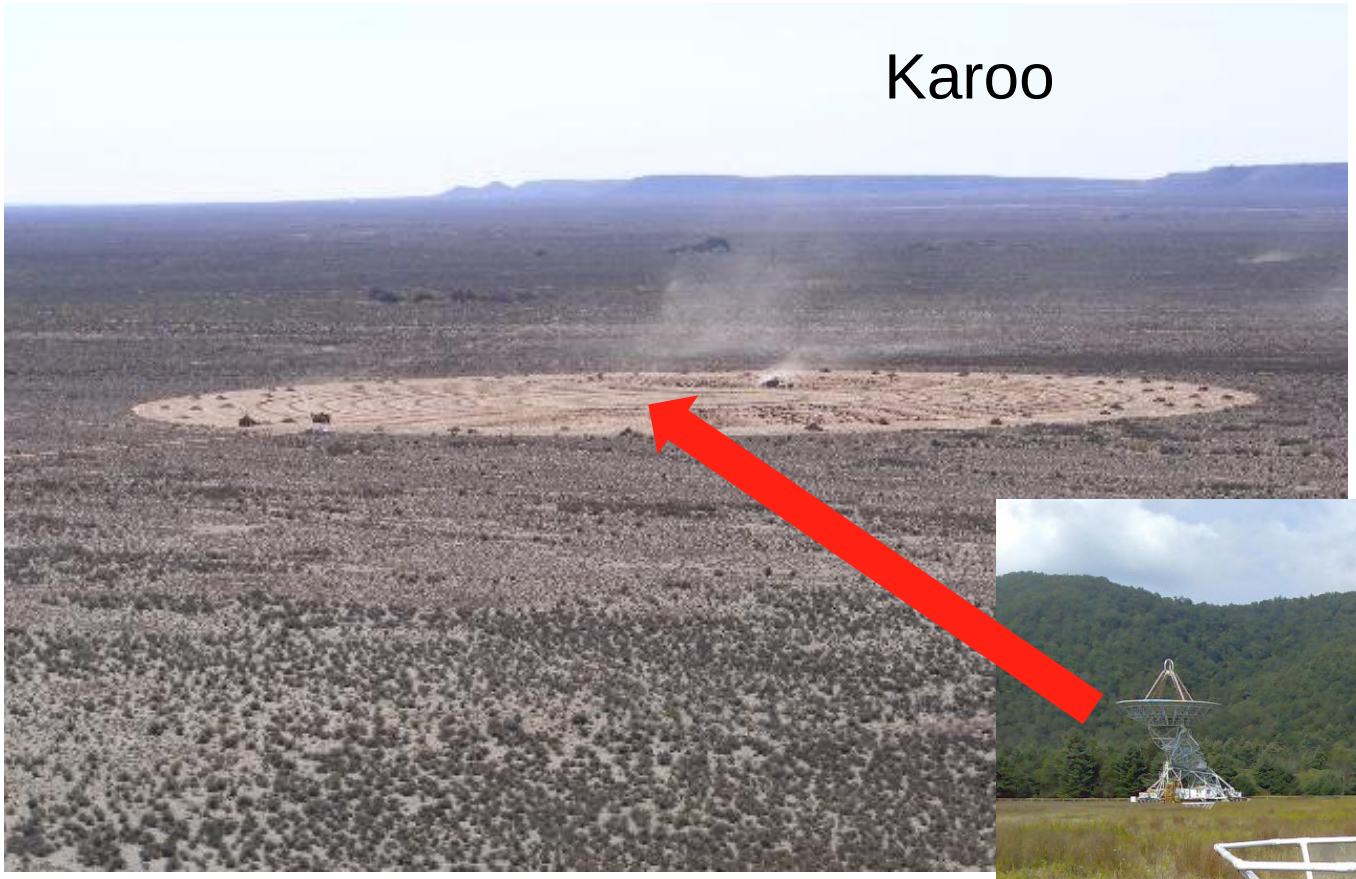
JPL Jet Propulsion Laboratory California Institute of Technology

مدينة الملك عبدالعزيز للعلوم والتقنية KACST



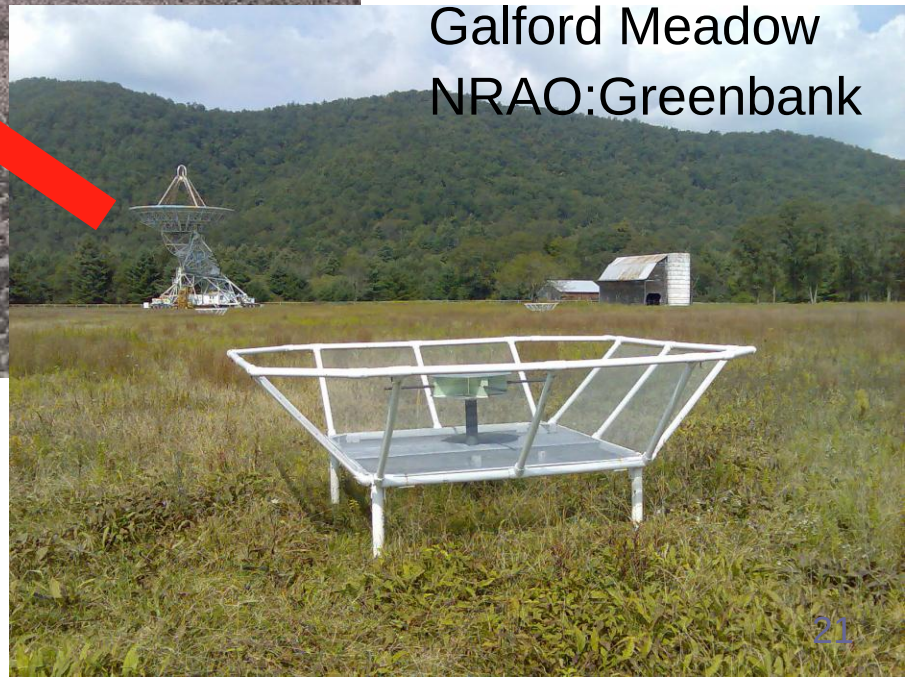


PAPER (Precision Array to Probe Epoch of Reionization)



Berkeley
UNIVERSITY OF CALIFORNIA

Penn
University of Pennsylvania



University of Virginia 1819

National Radio Astronomy Observatory
A facility of the National Science Foundation

10 min – minimal RFI flagging

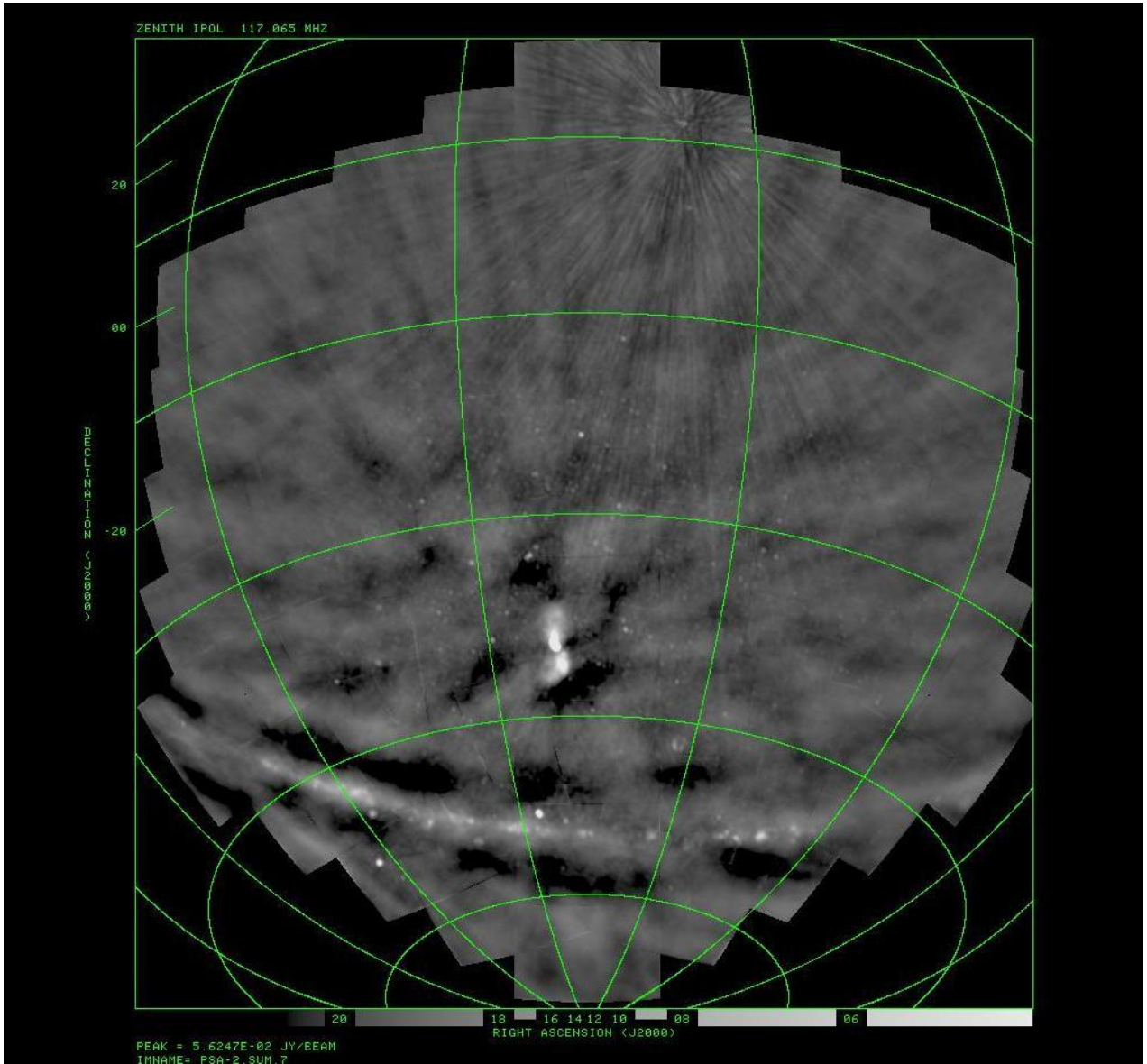
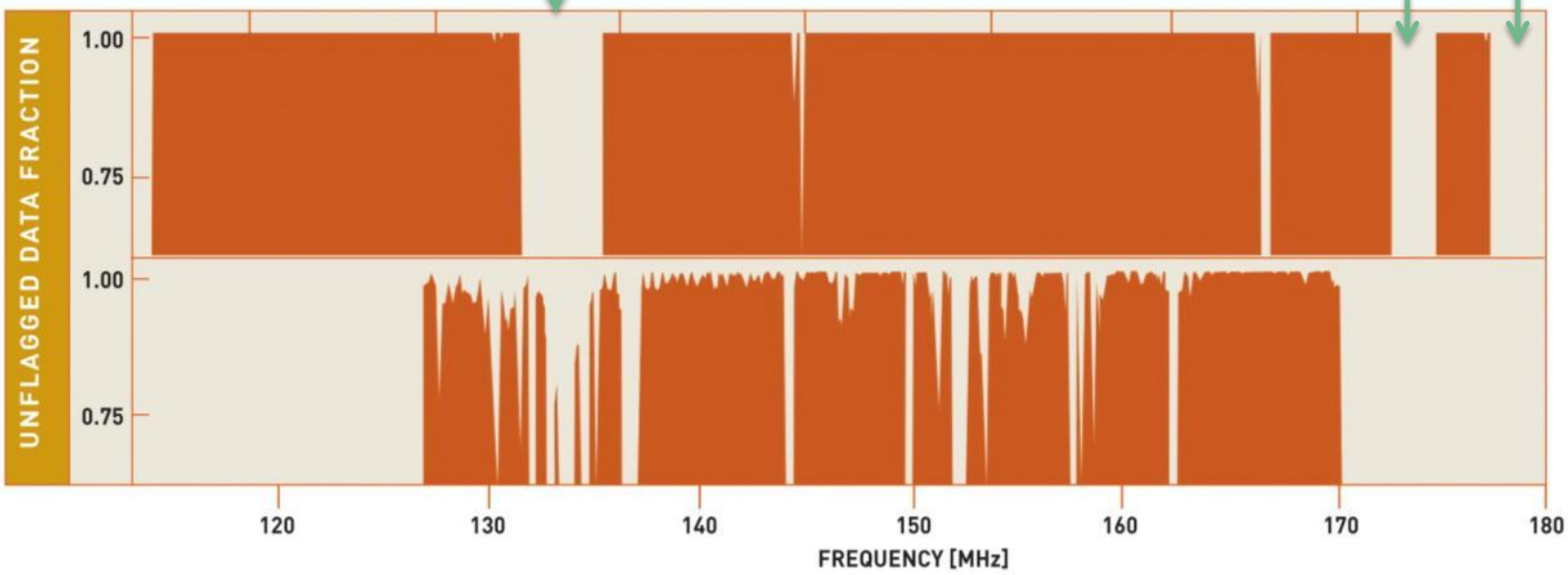


Image courtesy of Chris Carilli and PAPER consortium

Minimal RFI flagging with PAPER

Global satellite band

VHF TV that will migrate to UHF digital



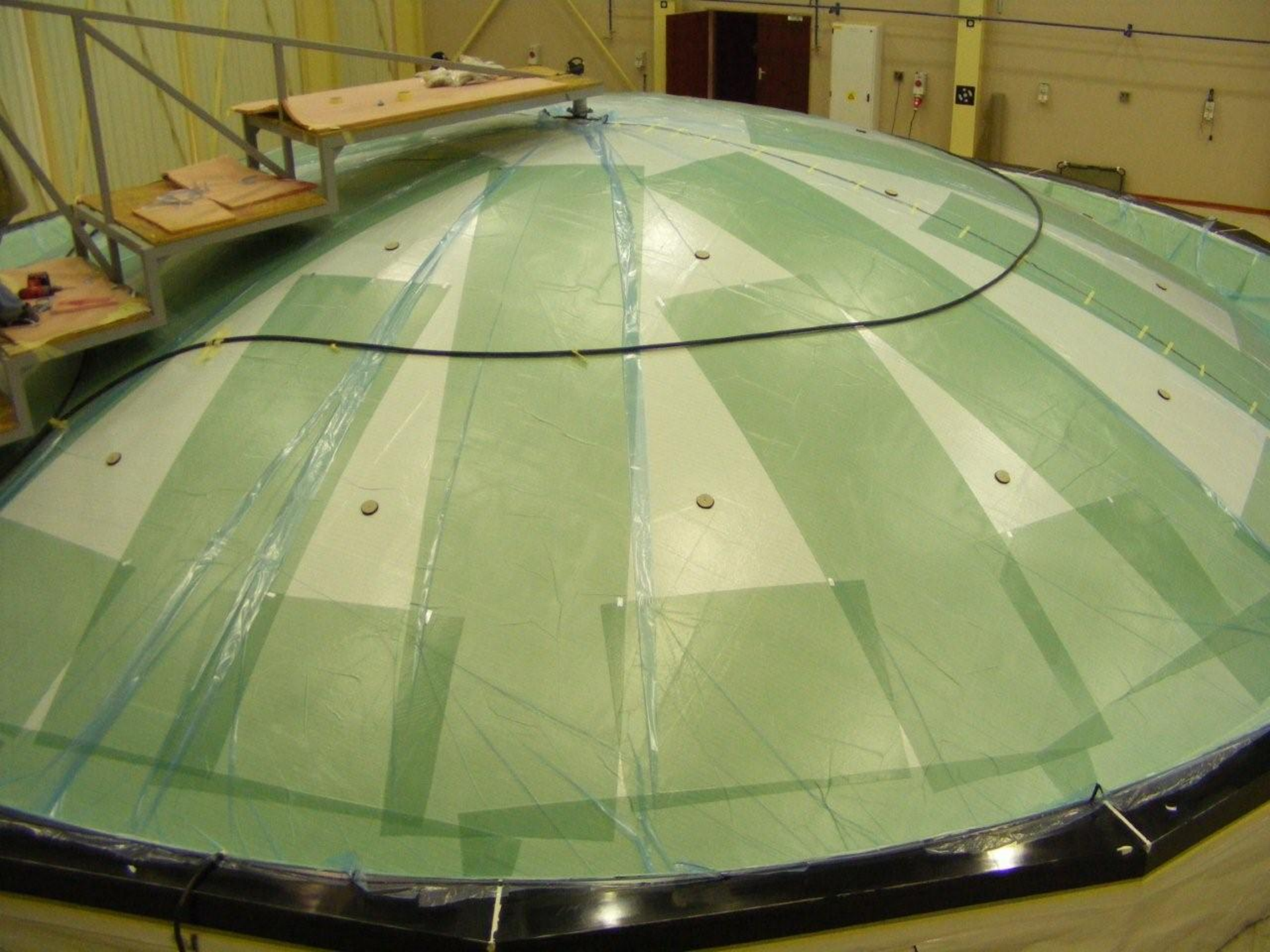
Spectrum availability of the Karoo site (top) and Green Bank (below)

XDM 15-m

- First MeerKAT prototype antenna
- Composite structure
- Being fitted with S/X-band receiver for (geodetic) VLBI

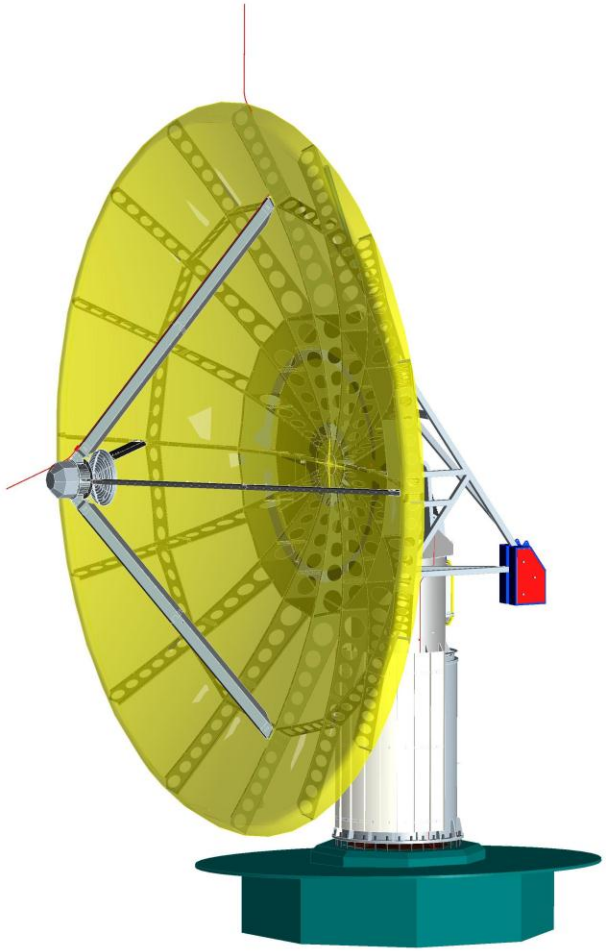
KAT-7

- Array of 7 antennas
- Component and system level prototyping
- Build experience in science and engineering teams
- Establish infrastructure in the Karoo
- Engage with local industry
- Produce publishable science




MORRIS

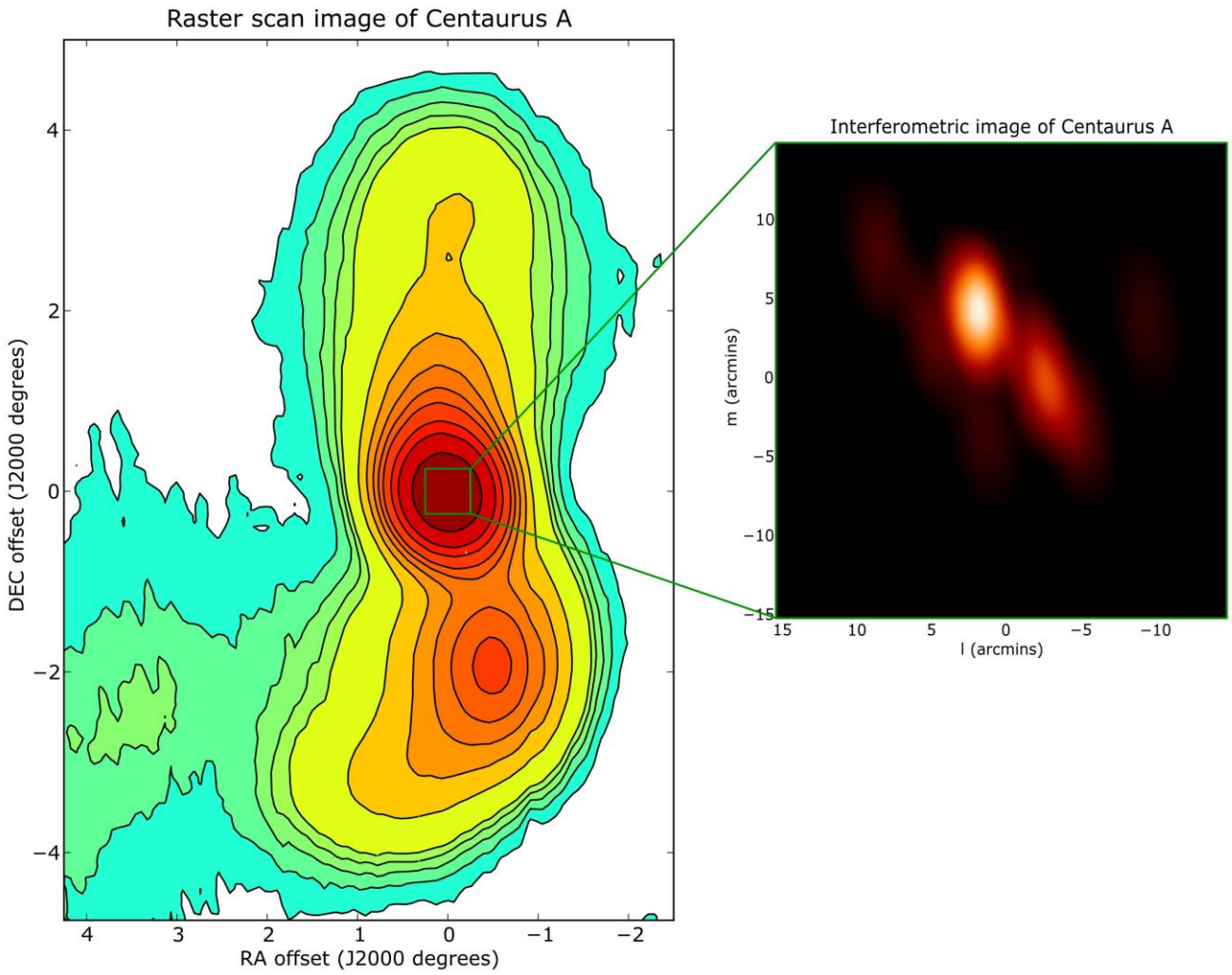
KAT-7 Dish



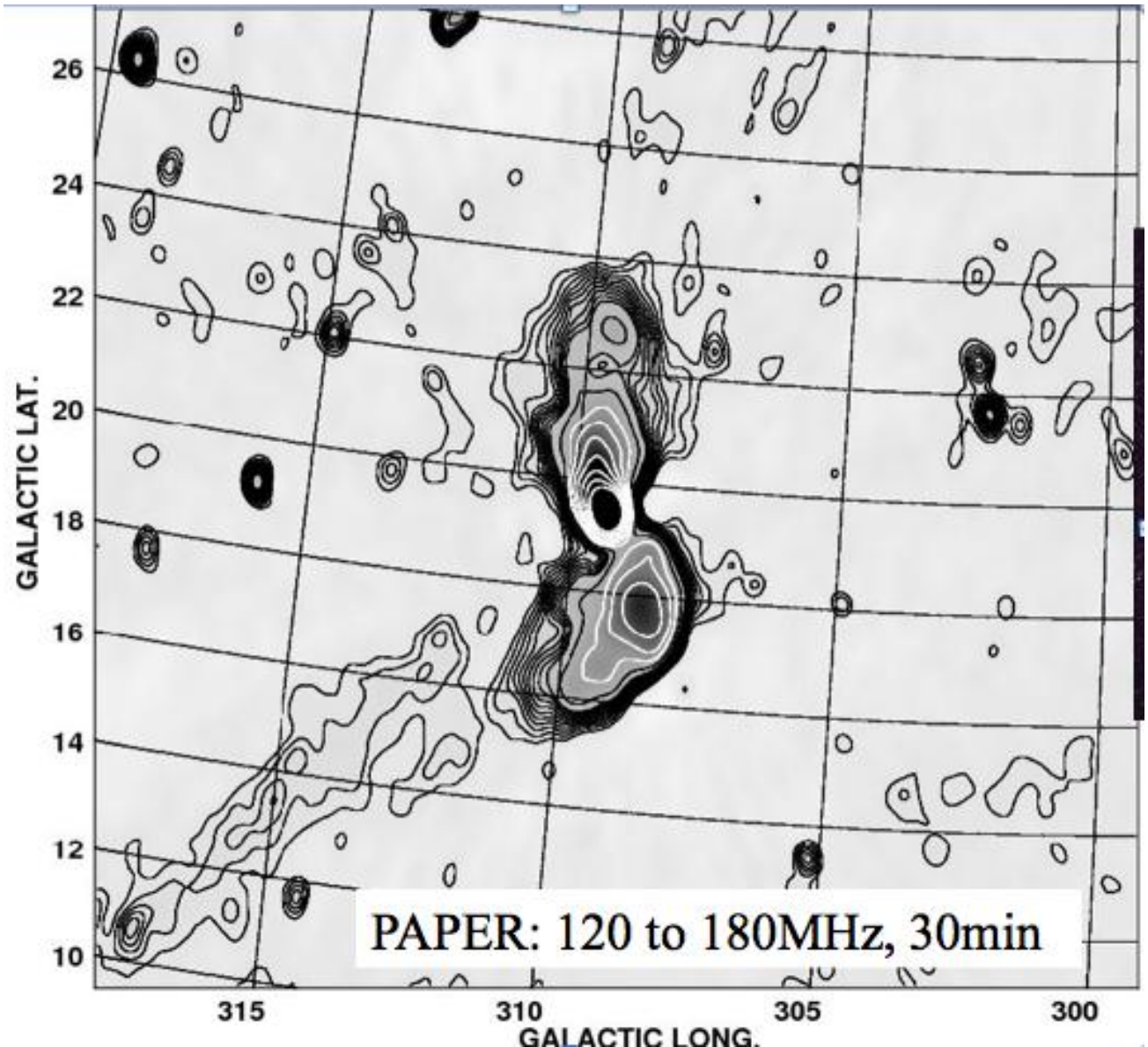
KAT-7

Cape Town KAT-7 Control Room

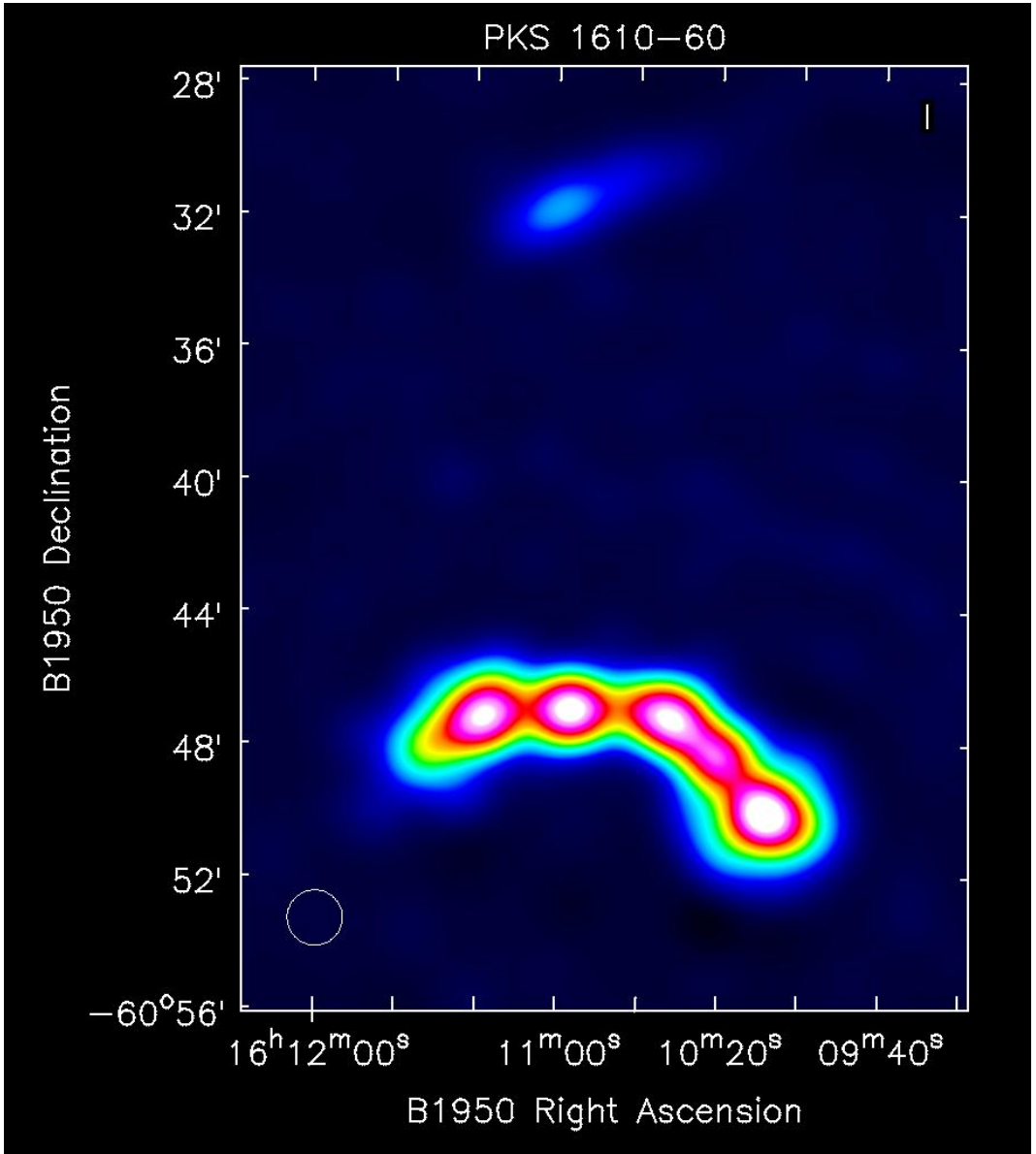
CEN A


Raster scan image of Centaurus A
DEC offset (J2000 degrees)
RA offset (J2000 degrees)
4
2
0
−2
−4
4
3
2
1
0
−1
−2
Interferometric image of Centaurus A
m (arcmins)
l (arcmins)
10
5
0
−5
−10
−15
15
10
5
0
−5
−10

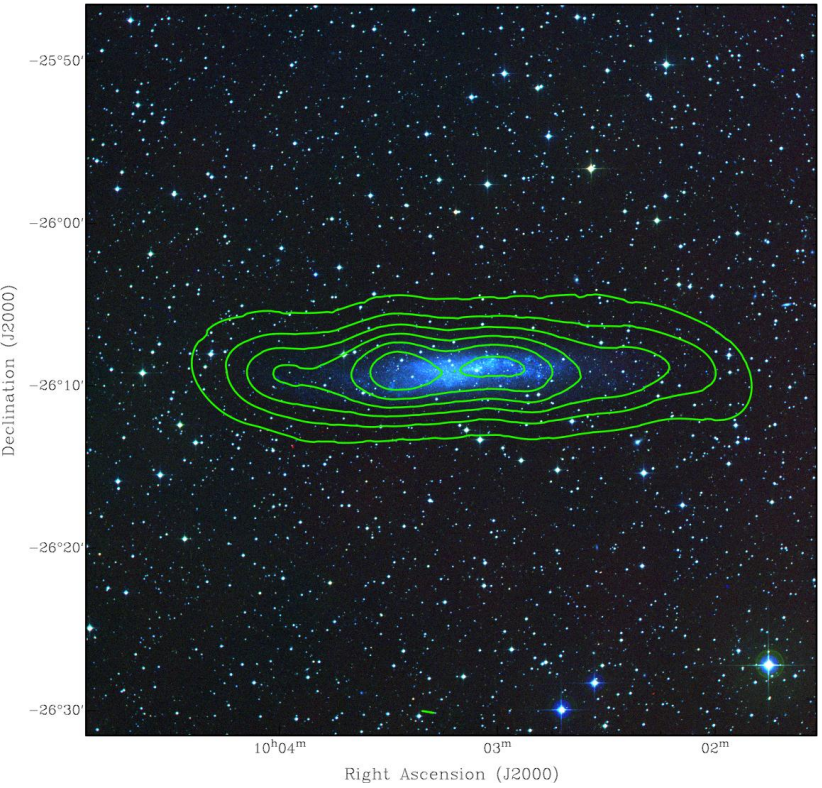
Cen A (PAPER – Carilli)

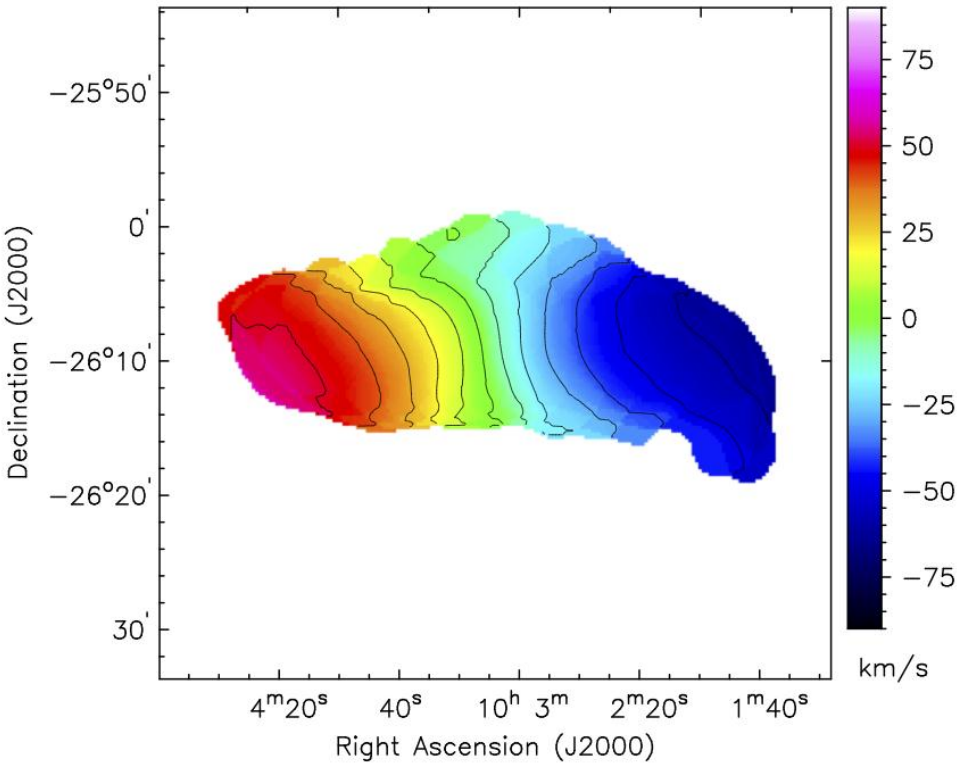


PKS 1610-60


PKS 1610−60
28'
32'
36'
40'
44'
48'
52'
−60°56'
B1950 Declination
16h12m00s
11m00s
10m20s
09m40s
B1950 Right Ascension

NGC 3109 (HI)


−25°50′
−26°00′
−26°10′
−26°20′
−26°30′
Declination (J2000)
10h04m
03m
02m
Right Ascension (J2000)


−25°50′
0°
−26°10′
−26°20′
30′
Declination (J2000)
4m20s
40s
10h 3m
2m20s
1m40s
Right Ascension (J2000)
75
50
25
0
−25
−50
−75
km/s