The MeerKAT radio telescope - the path to the SKA mid-frequency array

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SKA South Africa

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Rhodes University

SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY

RHODES UNIVERSITY
Where leaders learn

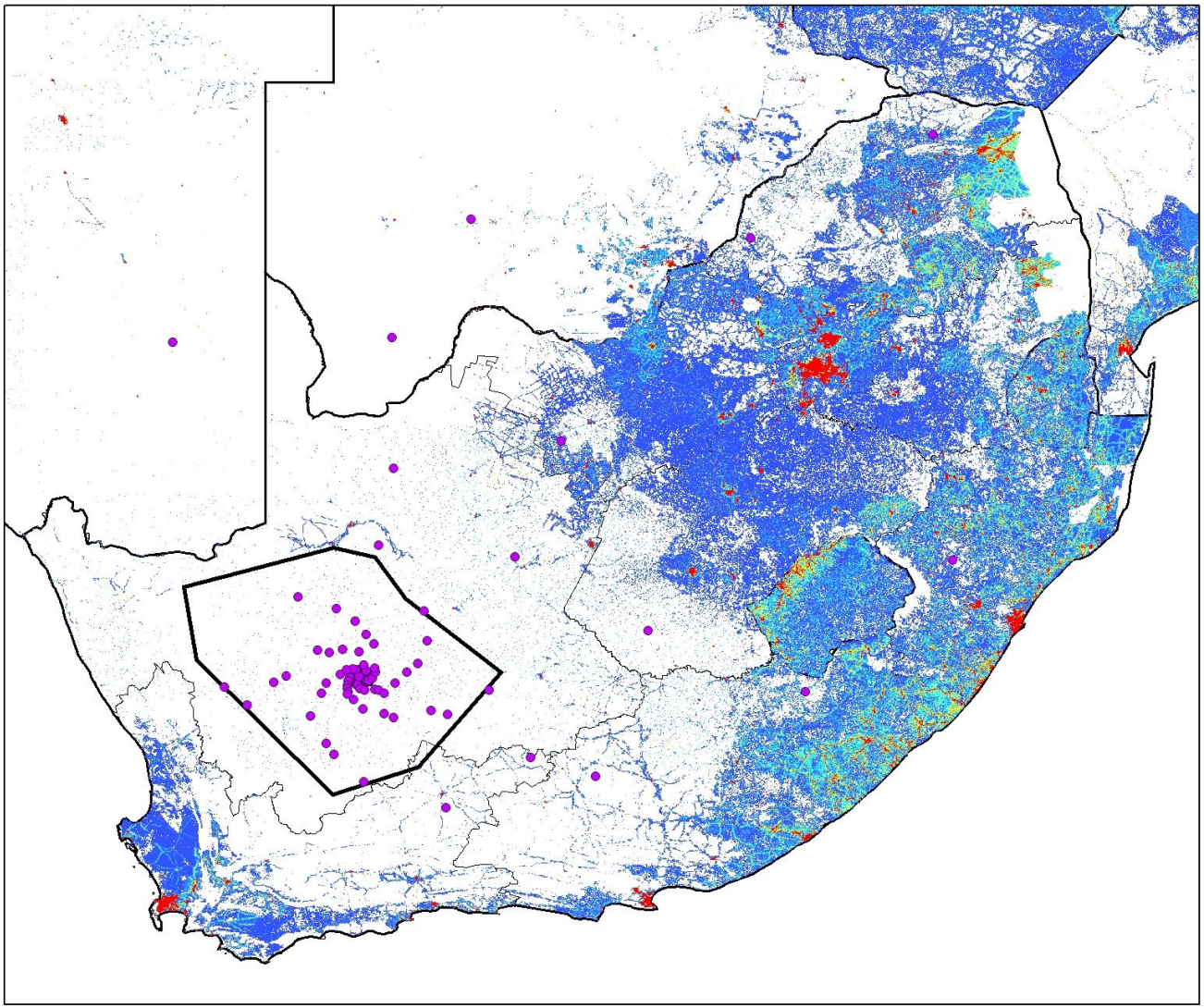
ASSA Symposium – SAAO, Cape Town – 13th October 2012

Other things we do…

Brief History

- DACST/NRF workshop in 2000.
- First SA representation on ISSC in July 2001 (Berkeley).
- SKA SA project office established January 2003.
- Initial offer to host SKA in May 2003.
- First formal proposal submitted in December 2005.
- South Africa and Australia sort-listed in August. 2006 (Dresden ISSC meeting).
- Final proposal submitted September 2011.
- Face-to-face meeting with SSAC December 2011.
- SSAC recommendation receiver by Board of SKA Organization on 22 February 2012.
- Site Options Working Group considered split site implementations (April/May 2012).
- SKA Organization announcement on 25 May 2012.
- Vague blur ever since.

Finding a Site



Contact:
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17 Baker Street
Rosebank
2196
South Africa
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Email: atiplady@ska.ac.za


11.11.2003 13:29


12.11.2003 08:54


Important!!!!!
Open the cover on the front outside of the aircon unit before switching the aircon on.
Close the cover on the front outside of the aircon unit before transportation of the system!!!!!

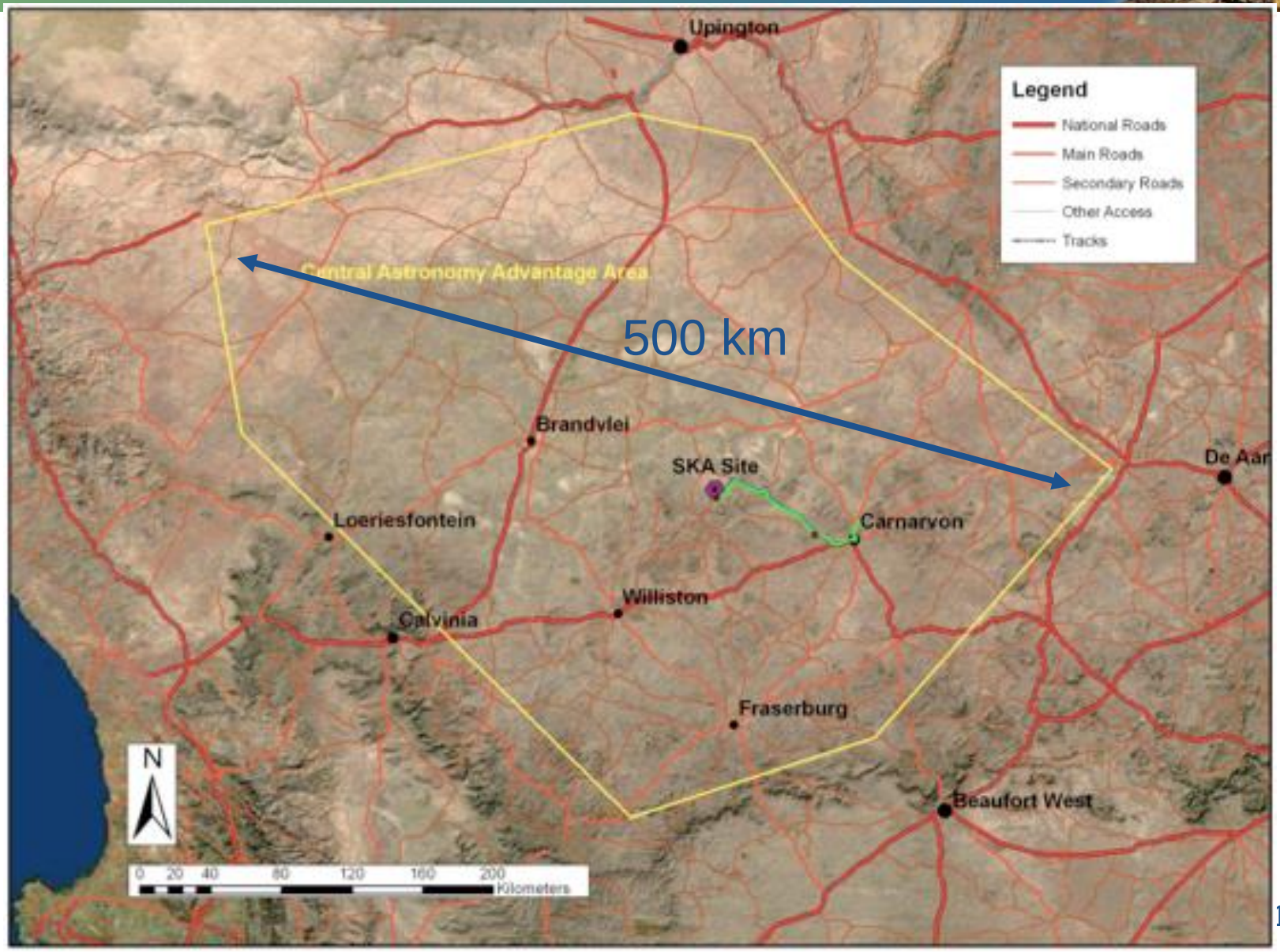

DBS 795 EC


SKA
SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY
www.ska.ac.za

Losberg

Bloukoppie & PAPER

Karoo Radio Astronomy Reserve

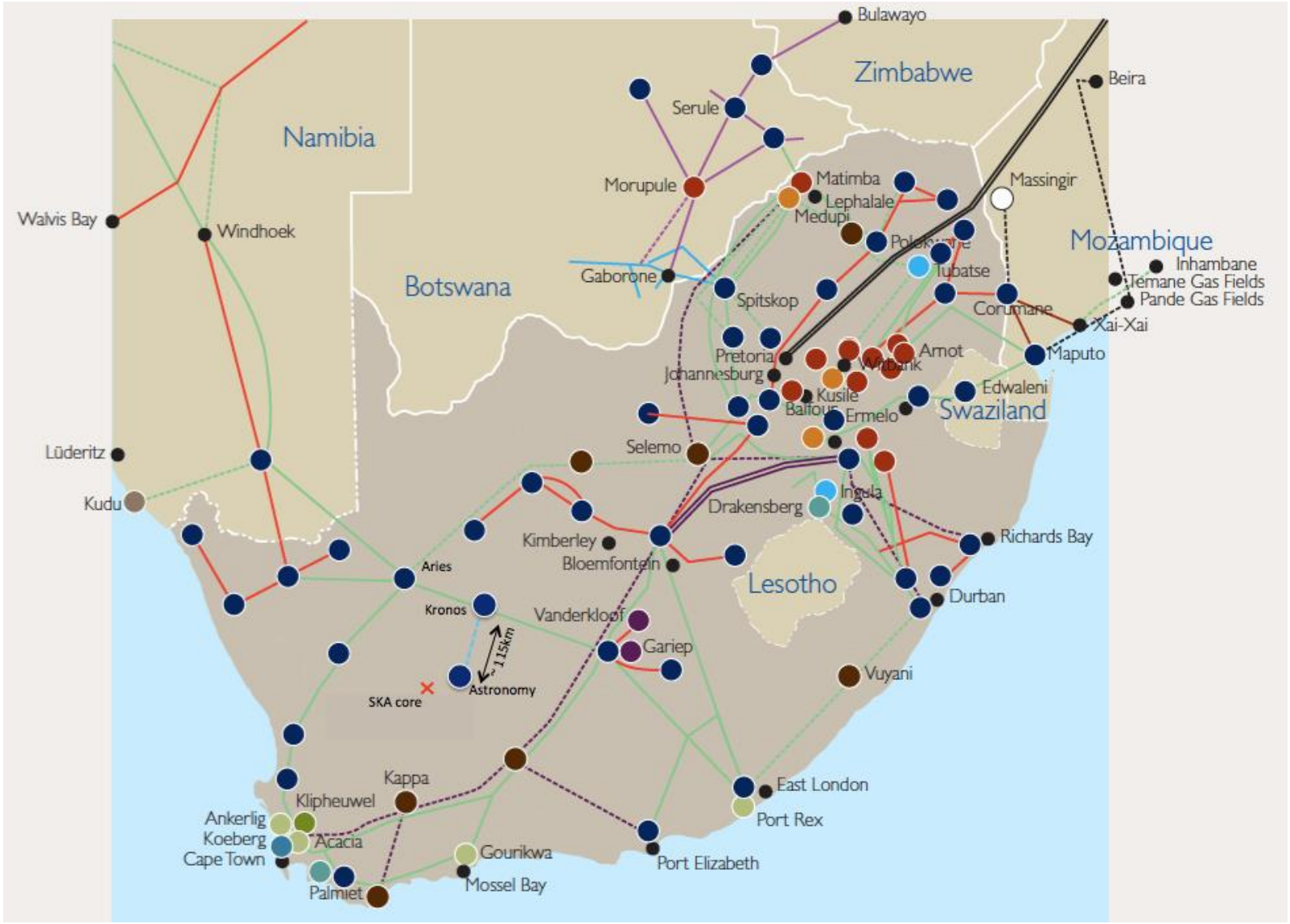


SKA Site Proposal

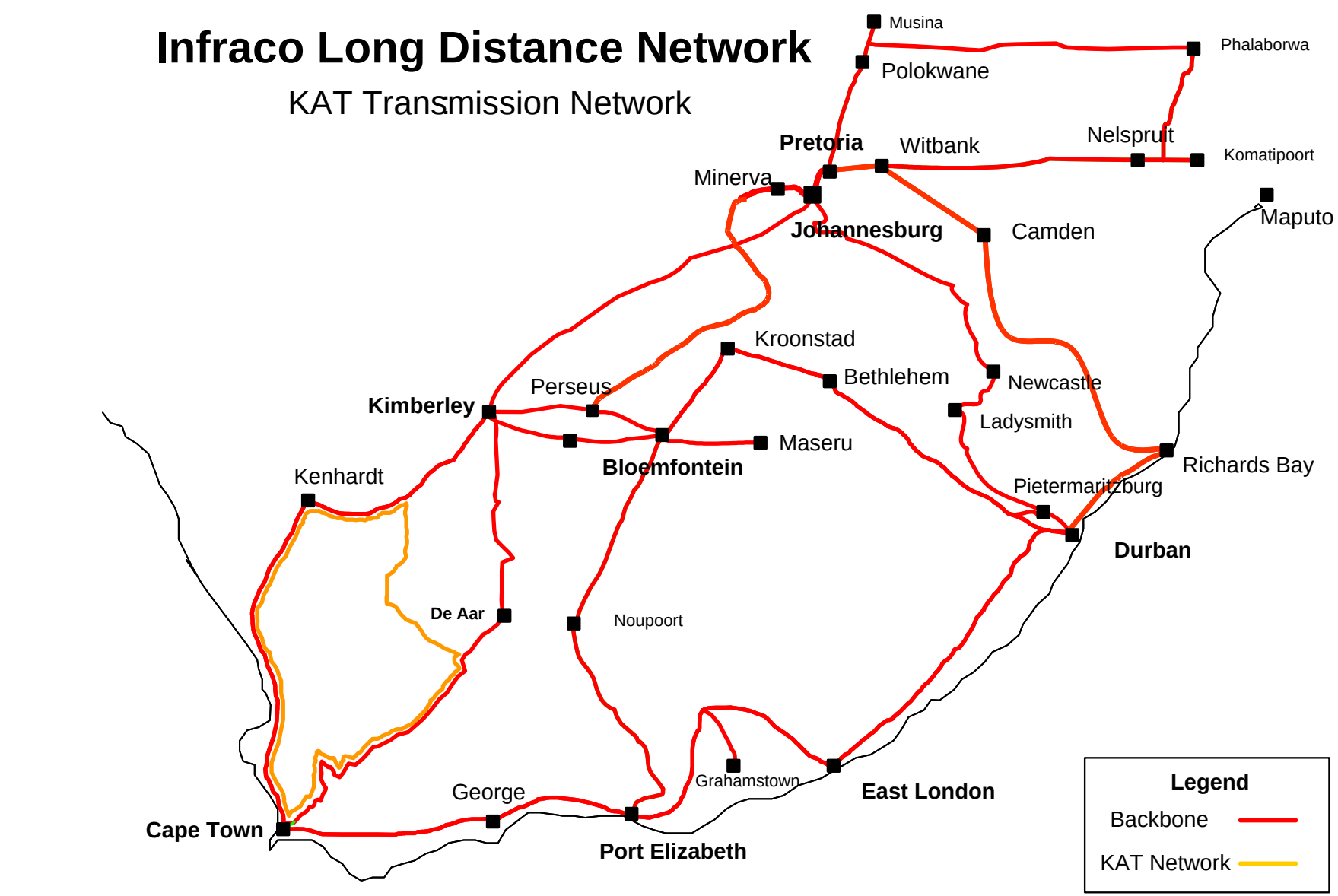
- 150 page main document with 10 sections:
  - Basic Infrastructure
  - Electric Power
  - Data Transport
  - Physical Characteristics
  - Radio Frequency Interference
  - Political, Socio-economic & Financial
  - Customs & Excise
  - Legal
  - Security
  - Working & Support Environment
- Over 500 annexures totaling 2 GB

The Team

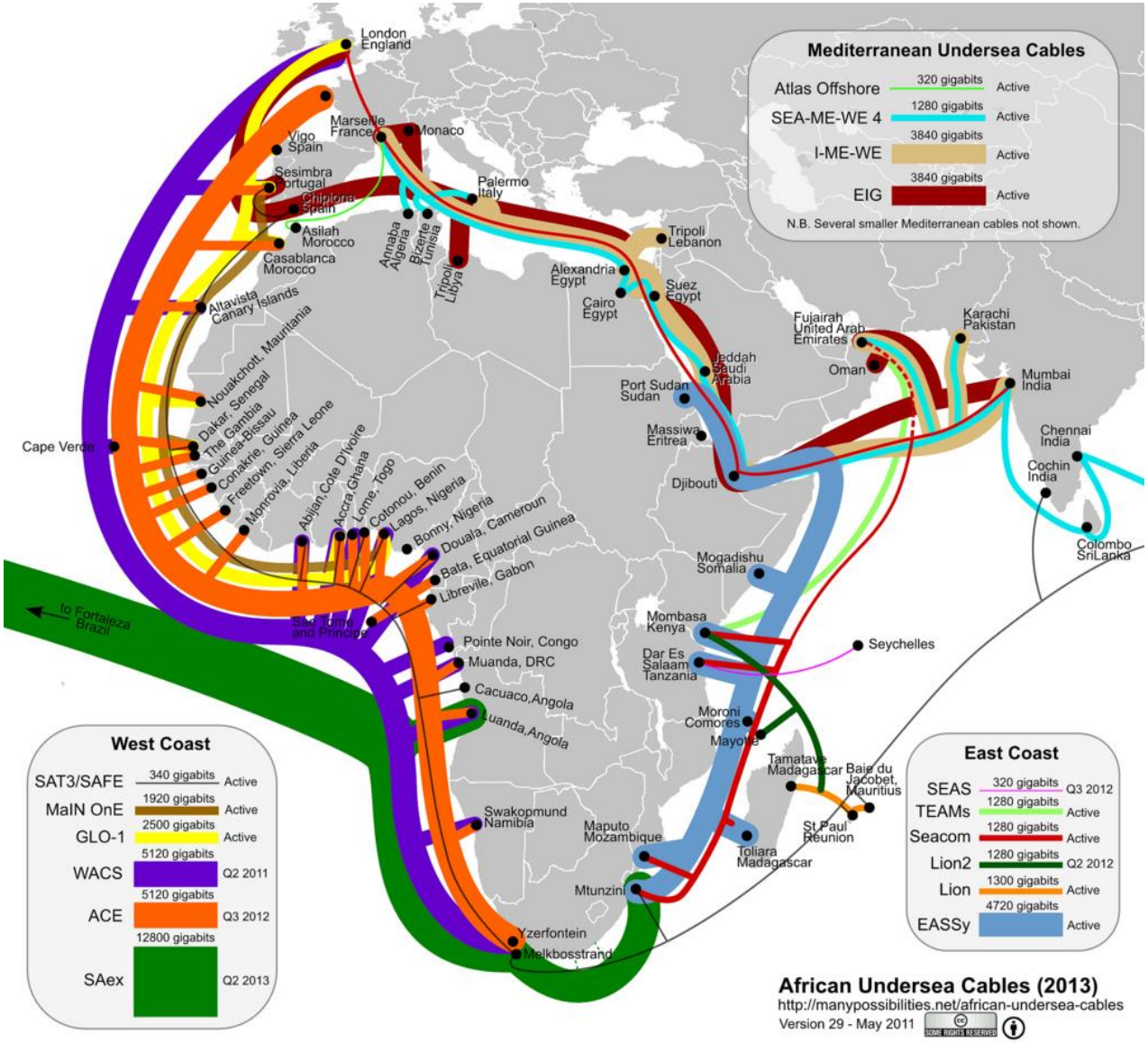
Power


Bulawayo
Zimbabwe
Beira
Serule
Namibia
Morupule
Matimba
Lephalale
Medupi
Massingir
Walvis Bay
Windhoek
Mozambique
Inhambane
Temane Gas Fields
Pande Gas Fields
Botswana
Gaborone
Tubatse
Spitskop
Corumane
Xai-Xai
Pretoria
Arnot
Maputo
Johannesburg
Edwaleni
Kusile
Swaziland
Ermelo
Lüderitz
Selemo
Ingula
Kudu
Drakensberg
Kimberley
Richards Bay
Bloemfontein
Aries
Lesotho
Durban
Kronos
Vanderkloof
115km
Gariep
Vuyani
SKA core
Astronomy
Kappa
East London
Klipheuwel
Ankerlig
Port Rex
Koeberg
Acacia
Cape Town
Gourikwa
Port Elizabeth
Palmiet
Mossel Bay

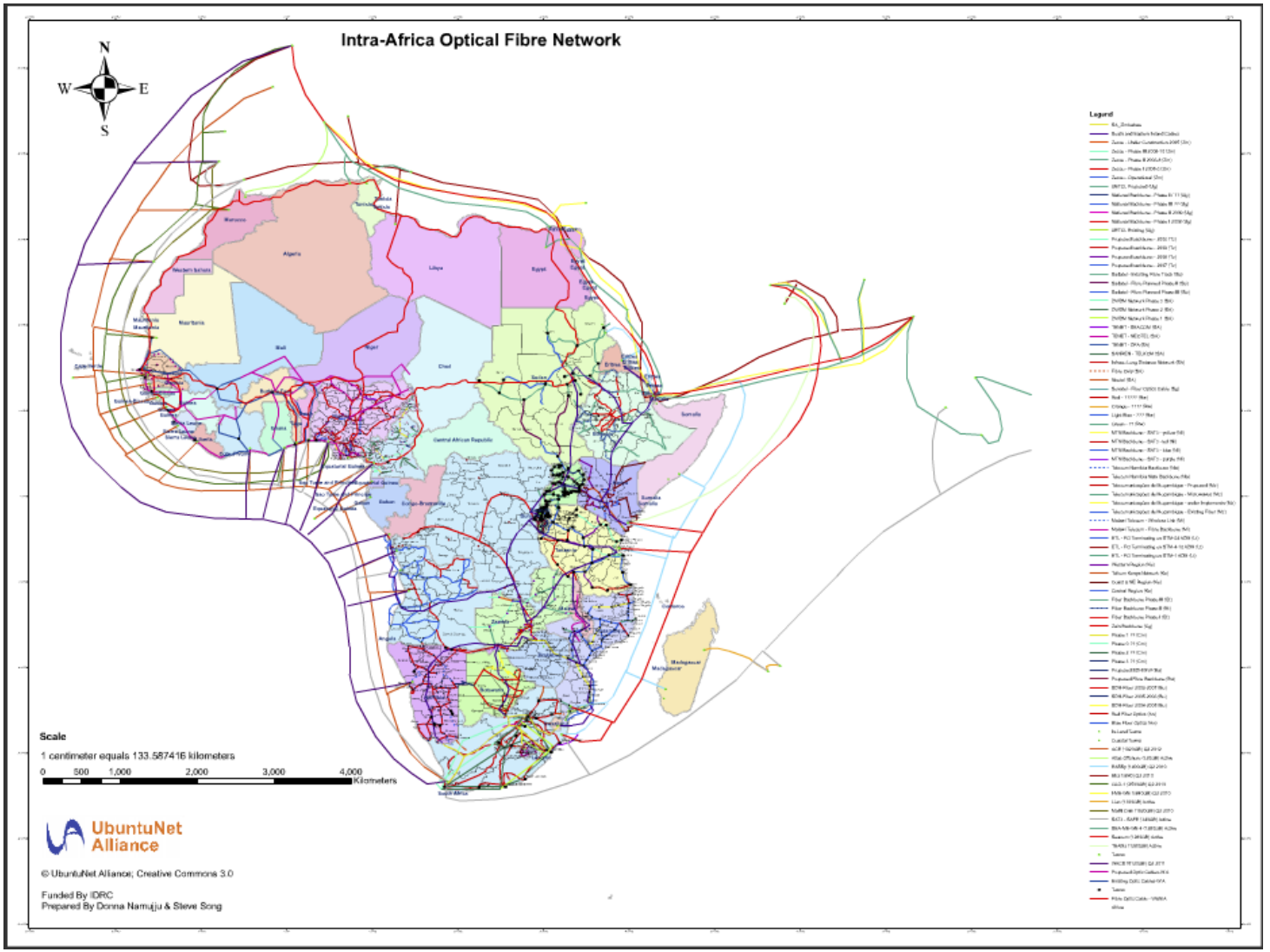
Data connectivity



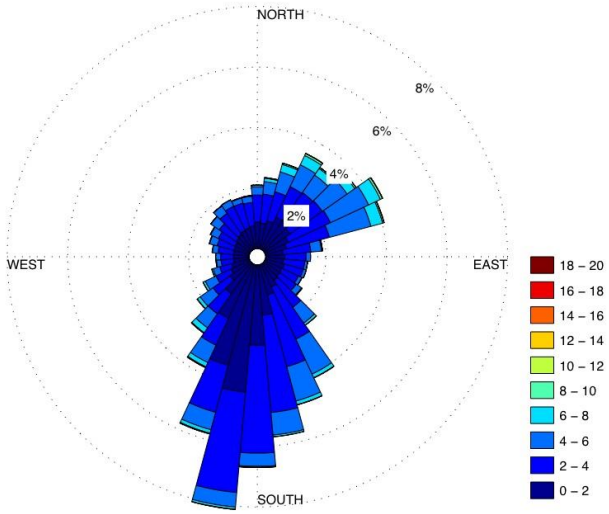
African Submarine Cable Systems

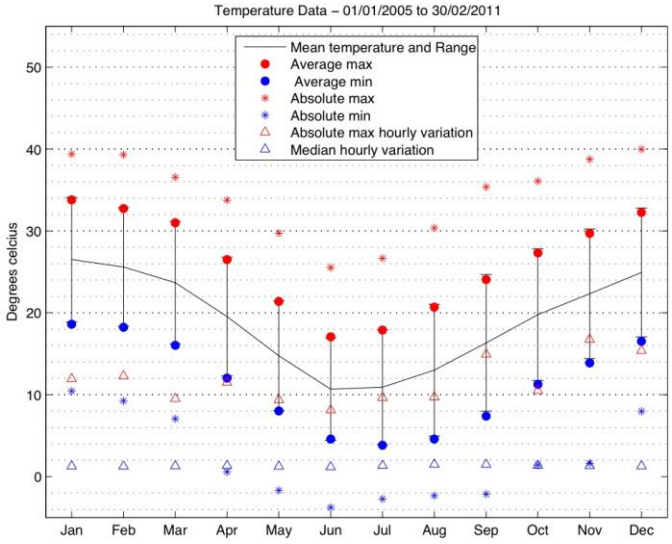


Africa Terrestrial Cable Systems

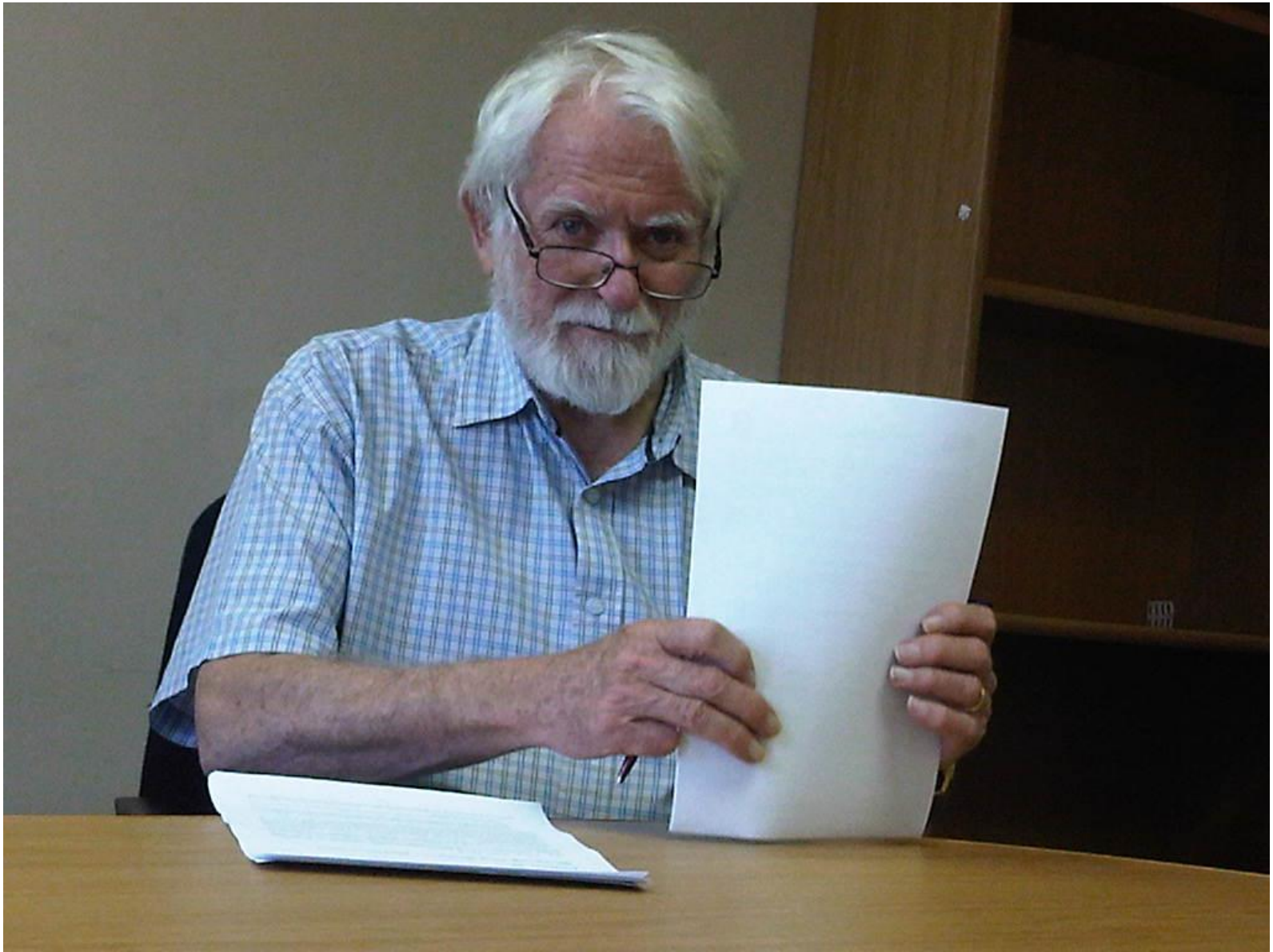


Weather and Troposphere





George Nicolson and “The Bid”



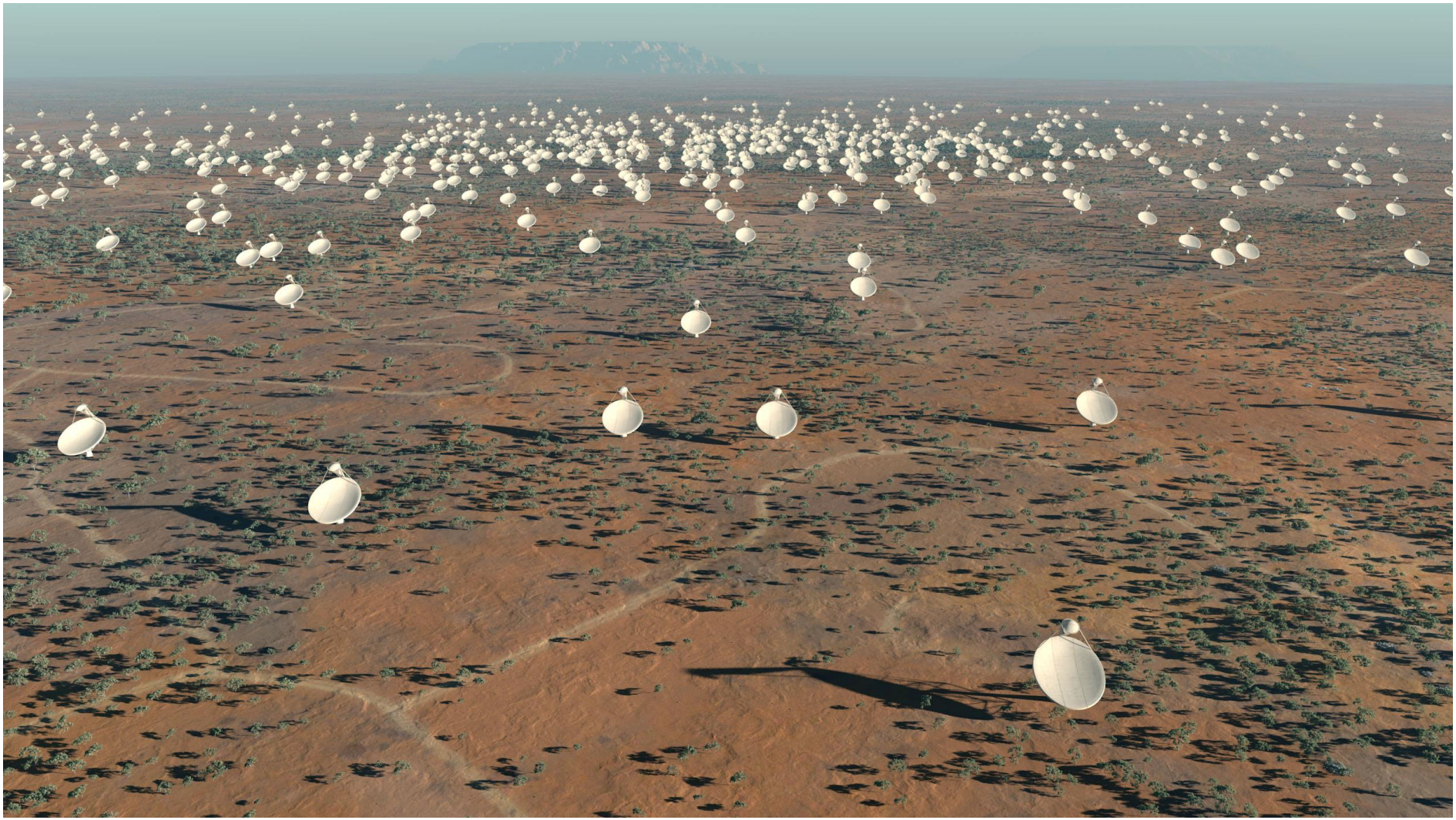
SKA Site Announcement

SKA antennas

Africa (mid-frequency)

Australia (low-frequency)

The “Core” in the Karoo



The SKA in Africa

"Our commitment to the SKA is firm and steadfast. It is our hope that others will emulate this engagement"
Minister Naledi Pandor, SKA Forum 2011

The MeerKAT Programme

- Africa must have a legacy of a large radio telescope
  - Irrespective of the outcome of the SKA site competition
  - But not independent of the SKA
- MeerKAT is an SKA “precursor”
  - Engineering prototype
  - Early science (SKA “Phase 0”)
  - Largest radio telescope in southern hemisphere, one of largest in the world
  - Phased development: XDM, KAT-7, MeerKAT, SKA_1, SKA_2
  - MeerKAT will be the first 25% of SKA_1
    - Our strategy was successful !

System engineering & Design

- Science-led process
  - Science case
  - ➔ User Requirement Specification
  - ➔ Requirements Review
  - ➔ System Specification
  - ➔ Concept exploration and prototypes
  - ➔ Concept and Preliminary design reviews (system)
  - ➔ Subsystem specifications, design and reviews

MeerKAT SAC – June 2009

- Bruce Bassett
- Erwin de Blok
- Mike Garrett
- Michael Kramer
- Robert Laing
- Scott Ransom
- Steve Rawlings
- Lister Staveley-Smith
  - Also: Roy Booth, Bernie Fanaroff, Justin Jonas

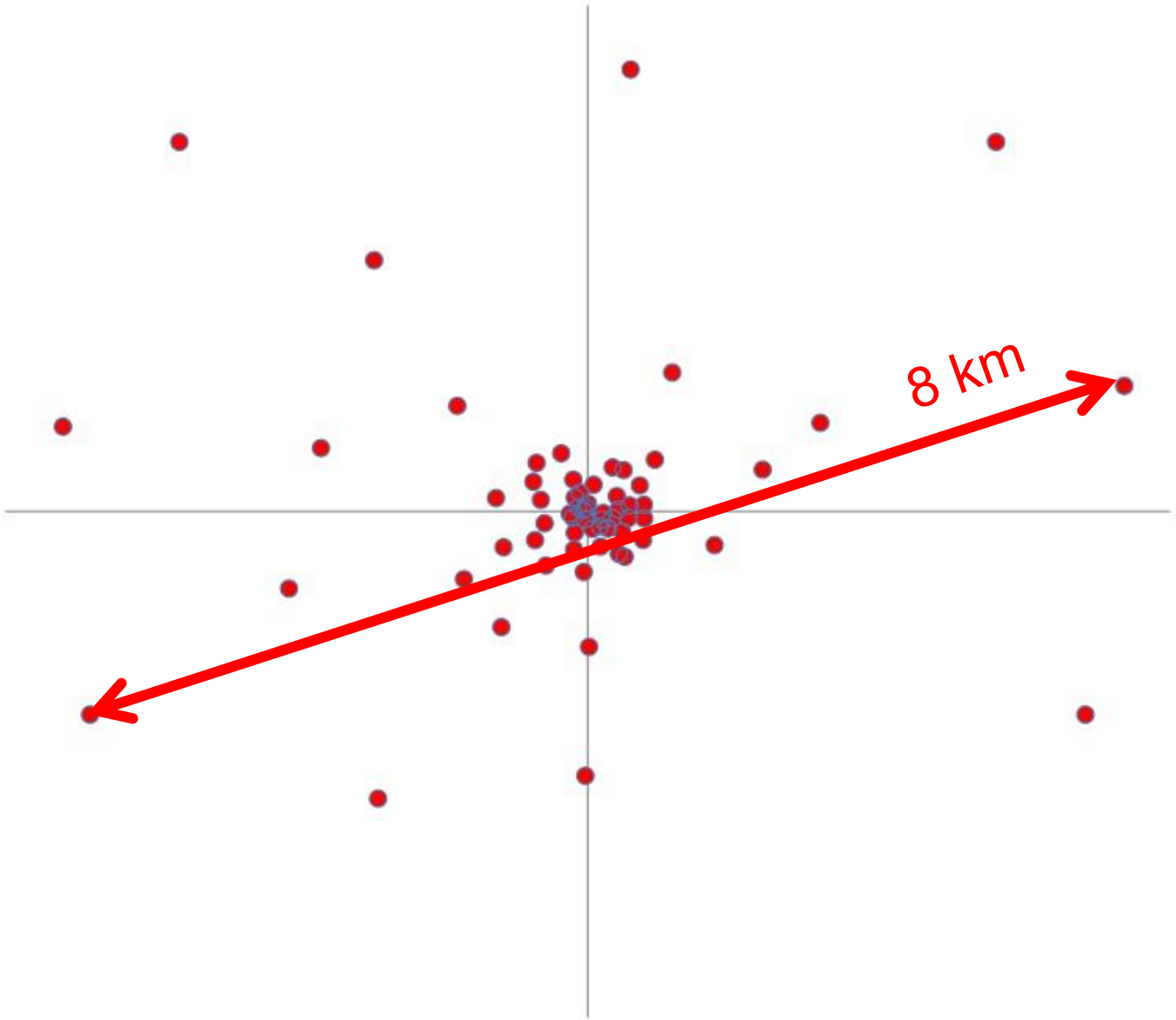
Highlights of SAC meeting

- MeerKAT as per specifications provided to the SAC was an good instrument, but lacked defined niches and “killer apps”.
  - Legacy science also important
- Needs to be distinct from from VLA, ASKAP, GMRT
  - Extend to lower frequencies (580 MHz), limit to L/S-band to 2 GHz
  - Extend to X/Ku-band
  - Exclude C-band?
- Needs to capitalize on sensitivity and DR
  - Longer baselines
  - Extend to lower frequencies
- Needs to capitalize on extended, low-brightness sensitivity
  - Higher filling-factor in the core
- Capitalize on VLBI capability

High Level Specifications

Metric	KAT-7	MeerKAT Pre-SAC	MeerKAT Post-SAC
F_{low}	1.2 GHz	700 MHz	580 MHz
F_{high}	1.95 GHz	10 GHz	15 GHz
A_e/T_{sys}	16 m^2/K	200 m^2/K	200 m^2/K
DR_{imag}	30 dB	60 dB	60 dB
DR_{spec}	30 dB	50 dB	50 dB
Xpol	-20 dB	-25 dB	-25 dB
BW	256 MHz	1 024 MHz (2 048 MHz)	1 024 MHz (4 096 MHz)
N_{chan}	4 096	32 768	32 768?
T_{int}	<1 s	0.1 ms	0.1 ms

Configuration (64 antennas)



MeerKAT Science: UHF, L & S-band

- Low column density HI associated with the Cosmic Web and galaxy environments
- Ultra-deep narrow-field HI survey out to z=1.4 using gravitational lense amplification
- High spatial dynamic range HI imaging of 1000 galaxies
- Ultra-deep narrow-field continuum surveys down to micro-jansky detection limits
- Mapping magnetic fields in clusters
- All-sky continuum survey at 600 MHz
- Pulsar timing and monitoring
- SNR detection and GRB follow-up
- OH mega-masers and Zeeman splitting
- Galactic gas dynamics and magnetic fields

MeerKAT Science: X & Ku-band

- **Future high-frequency upgrade**
- All-sky continuum survey at 8 GHz
- Detection of CO lines at high redshift
- Mapping of S-Z clusters
- Transients sources in the Galactic centre

MeerKAT RfP

An open invitation to the Astronomical Community
to propose Key Project Science with the South African
Square Kilometre Array Precursor

MeerKAT

R.S. Booth
Hartebeesthoek Radio Astronomy Observatory, P.O.Box 443, Krugersdorp 1740, South Africa
email: roy@hartrao.ac.za
W.J.G. de Blok
Department of Astronomy, University of Cape Town, Rondebosch 7700, South Africa.
email: edeblok@ast.uct.ac.za
J.L. Jonas
Rhodes University, Dept. Physics & Electronics, PO Box 94, Grahamstown 6410, South Africa
email: j.jonas@ru.ac.za
B. Fanaroff
SKA South Africa Project Office, 17 Baker St, Rosebank, Johannesburg, South Africa
email: bfanaroff@fanaroff.co.za

Proposal Submission deadline: March 15, 2010

MeerKAT TAC – Sept 2012

- Frank Briggs
- Simon Johnson
- Athol Kemball
- Robert Laing
- Joe Lazio
- Jay Lockman
- Andrew Lyne
- Roy Maartens
- Thijs van der Hulst
  - Also: Roy Booth, Bernie Fanaroff, Justin Jonas

MeerKAT Large Surveys

- Highest priority:
  - Deep HI field
  - Radio Pulsar Timing
- Compelling:
  - HI and continuum mapping of 30 nearby galaxies
  - Absorption line survey
  - Molecules in the EoR
  - Detecting fast transients and pulsars
  - HI survey of Fornax
  - X-band Galactic plane survey
  - Tiered continuum survey
  - Slow radio transient survey
- Also
  - VLBI
  - Cosmic Magnetism

MeerKAT Large Surveys

22 Countries

UK (26 Institutions, 89 individuals)

- ATC
- Birmingham
- Bristol
- Cambridge
- Dublin
- Durham
- Edinburgh
- Exeter
- Hertfordshire
- JCU
- Lancaster
- Leeds
- Leicester
- Liverpool
- Manchester
- MSSL
- Newcastle
- Nottingham
- Open U
- Oxford
- Portsmouth
- RAL
- Southampton
- Sussex
- UCL
- Warwick

Rest of EU (34 institutions, 93 individuals)

- Germany (8,24)
  - Bamburg
  - Bochum
  - Bonn
  - (ESO)
  - Jacobs
  - MPE
  - MPIfR
  - MPIA
- Netherlands (7,28)
  - Amsterdam
  - ASTRON
  - JIVE
  - Kapteyn
  - Leiden
  - Nijmegen
  - SRON
- France (7,19)
  - Bordeau
  - Inst Ast
  - Marceille
  - Obs Paris
  - OCA
  - Orleans
  - Saclay
- Italy (4,9)
  - Cagliari
  - INAF
  - Padova
  - SISSA
- Sweden (2,4)
  - Chalmers
  - Onsala
- Spain (2,3)
  - IAA
  - Valencia
- Portugal (2,3)
  - Lisbon
  - UTL
- Poland (1,2)
  - Cracow
- Belgium (1,1)
  - Brussels

Time Allocated – > 5 years

Survey	L-Band	UHF	X/Ku-Band
Deep HI	5 000	5 000	
Pulsar Timing	7 860		
30 Galaxies	6 000		
HI Absorption	2 000	2 000	
EoR Molecules			6 500
Fast Transients	3 080		?
Fornax HI	2 450		
X/Ku-band Galaxy			3 300
Deep Continuum	1 950		
Slow Transients	3 000	?	?
TOTAL	31 340	7 000	8 800

1 yr = 8 760 hr

MeerKAT Phase 1 (2016)

- 64 x 13.5 m gregorian offset antennas
  - >> 220 m^2/K *(300 m^2/K goal)*
- 8 km maximum baseline
  - 70 % in < 1km diameter core
- 0.9-1.726 GHz (following ECP) cryogenic single-pixel receiver (L-band)
  - Multiple feed indexer
- Direct digitization
  - DFX architecture

Future Phases

- 580-1000 MHz (UHF-band)
- 8-14.5 GHz (X/Ku-band)
- Aspirations (contingent on money and/or technology availability):
  - 20+ km baselines
  - 1.5-3 GHz for NanoGrav
  - 5-22 GHz wideband receiver
- SKA-mid Phase 1

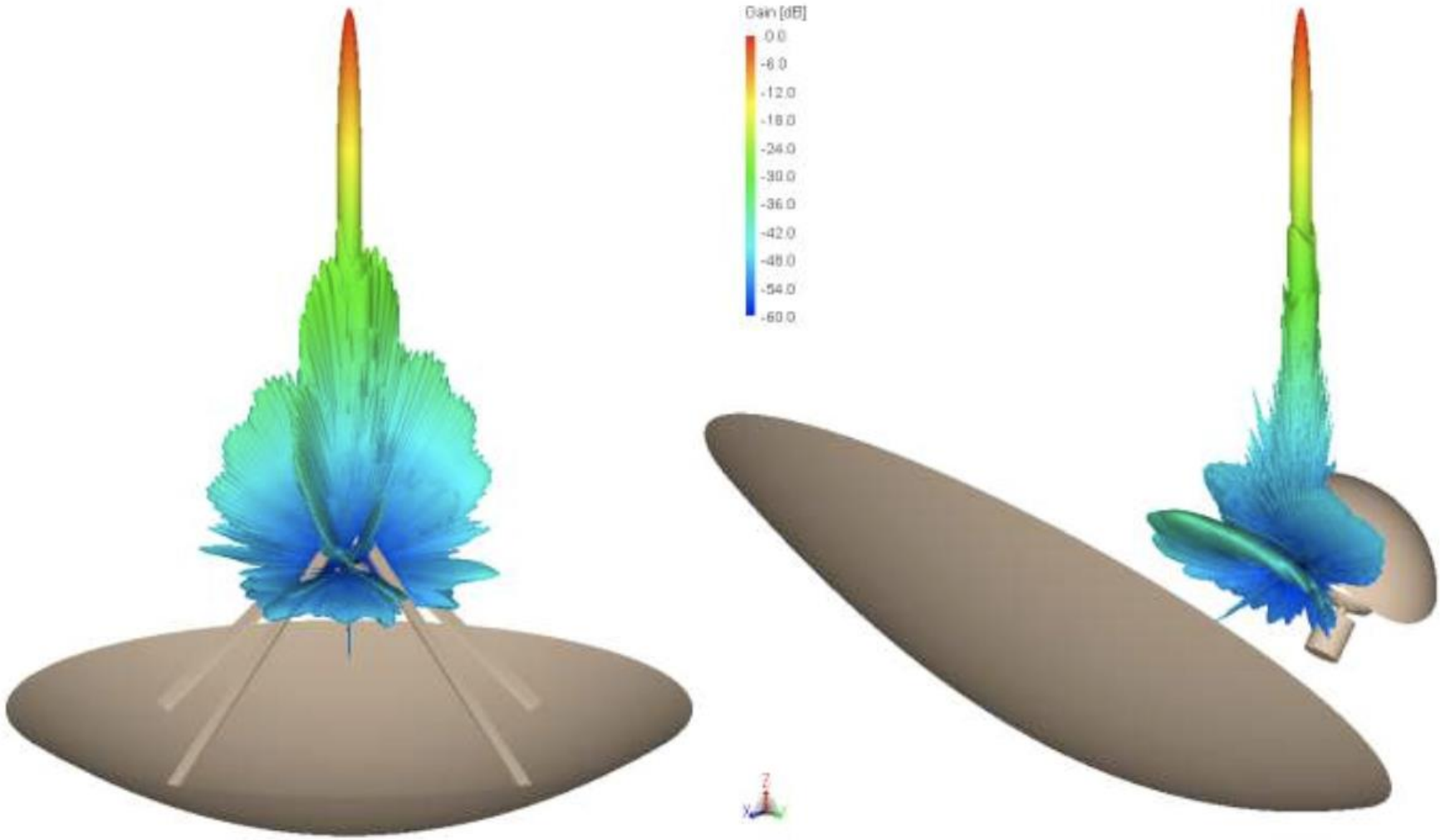
System CoDR (5-8 July 2010)

Concept exploration:

- Antenna geometry
  - Symmetric centre-fed / Gregorian offset
- Receivers
  - Octave / wide bandwidth
  - Cooled / uncooled
  - Single / multiple pixel
- Array configuration
  - Number of dishes
  - Distribution of dishes
- Signal conditioning and digitization
  - Heterodyne / direct RF
  - Location of digitizer (digital or RF signal transport)
- Software
  - Custom / consortium

MeerKAT with Offset Gregorian

Comparison of beam patterns

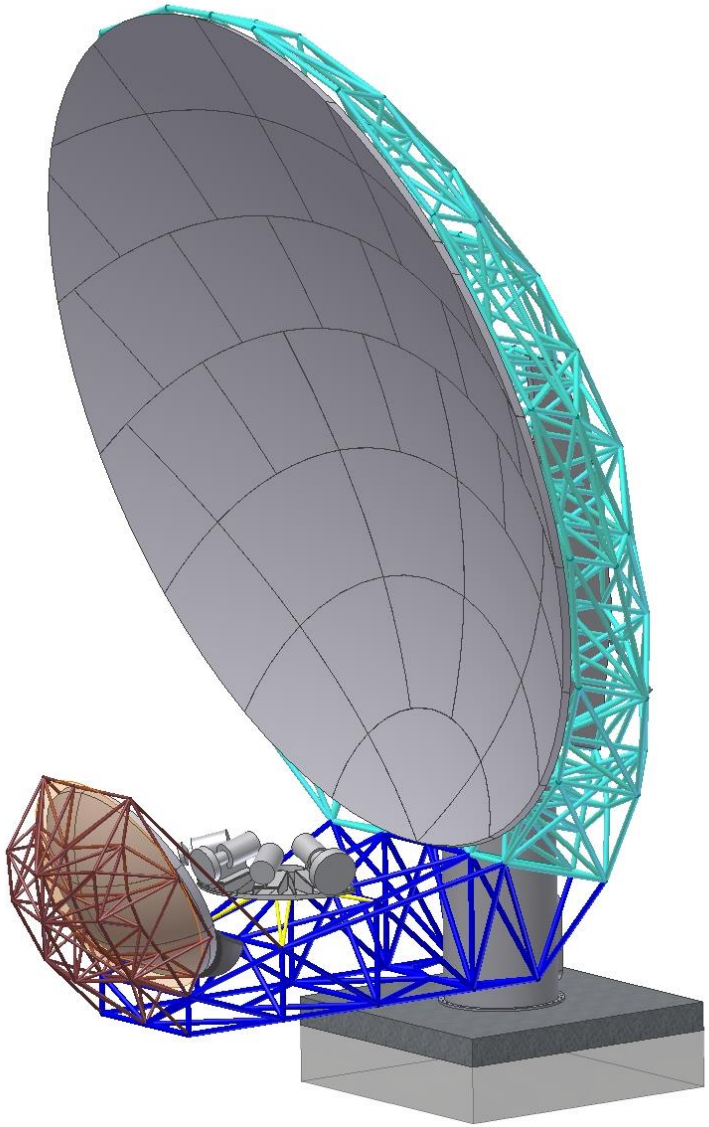


PDR Panel 18-22 July 2011

MeerKAT PDR – July 2011

- Extensive trade off between optical and mechanical aspects of antenna
  - Mechanical tolerance impacting optical performance
- Materials testing and component durability
  - Accelerated environmental and operational tests
- Receiver cryogenic refrigeration options
  - Stirling cycle vs G-M cycle

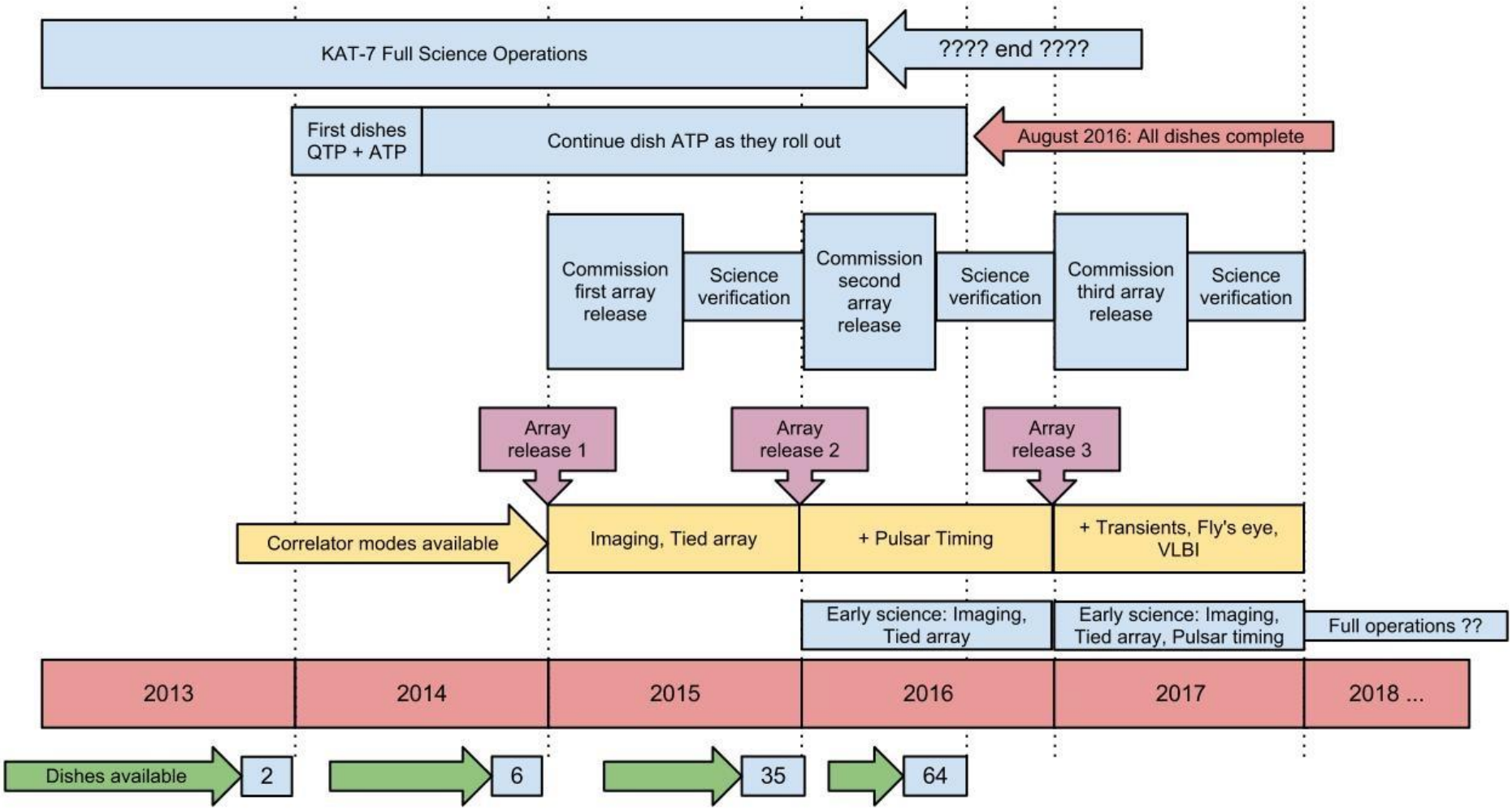
MeerKAT dish concept



Performance @ 1420 MHz

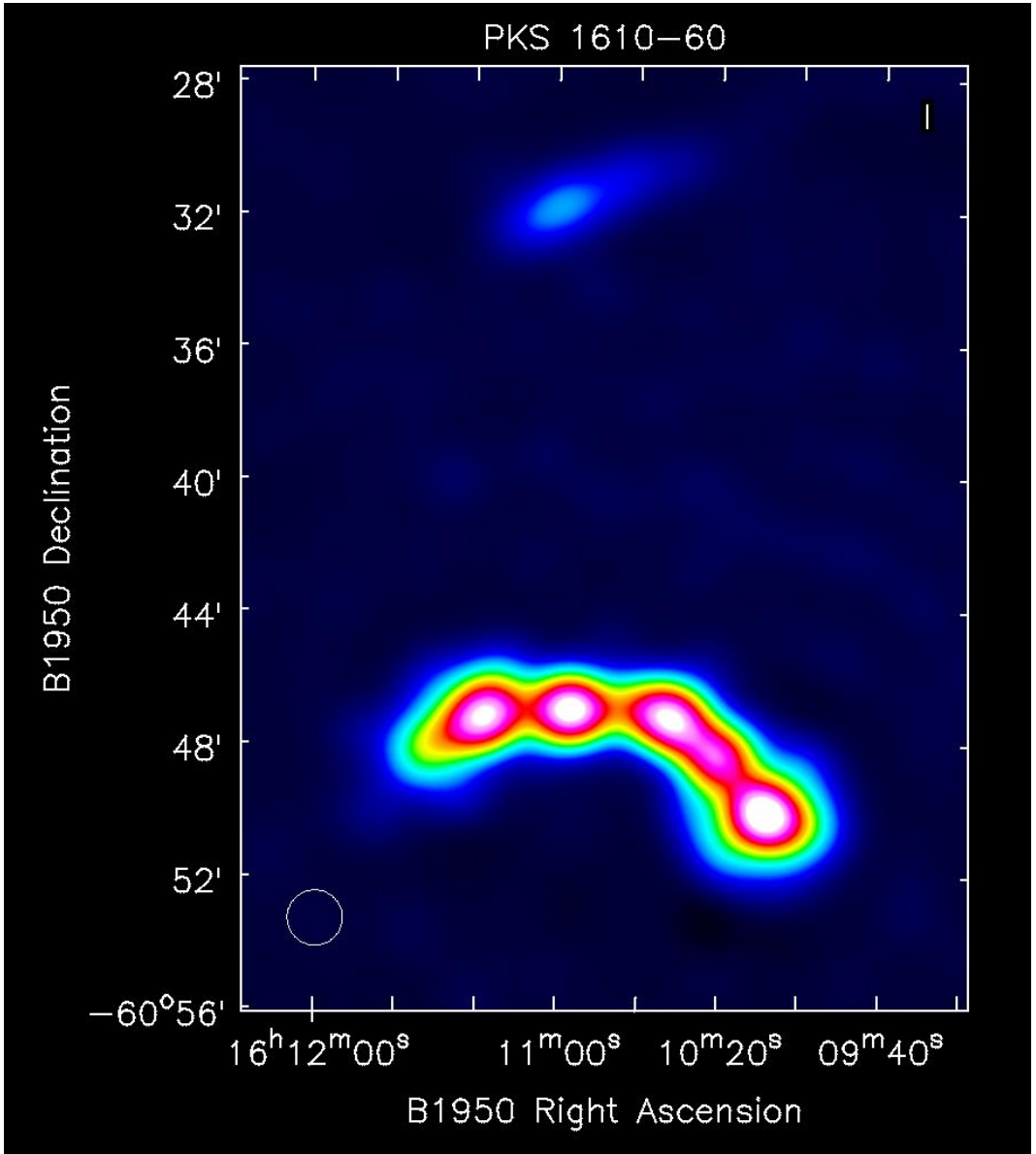
	JVLA	ASKAP	SKA-Survey	MeerKAT	SKA-Mid
N_{dish}	27	36	96	64	254
D_{dish}	25 m	12 m	(15 m)	13.5 m	(13.5 m)
T_{sys}/ε_a	47.3 K	62.5 K	62.5 K	29.4 K	29.4 K
N_{beam}	1	30	30	1	1
BW	1 GHz	300 MHz	300 MHz	750 MHz	750 MHz
A_e/T_{sys}	280 m^2/K	65 m^2/K	271 m^2/K	311 m^2/K	1 236 m^2/K
SS $m^4\,K^{-2}\,deg^2$	17 368	127 312	2 210 286	73 510	1 157 857

Commissioning and early science

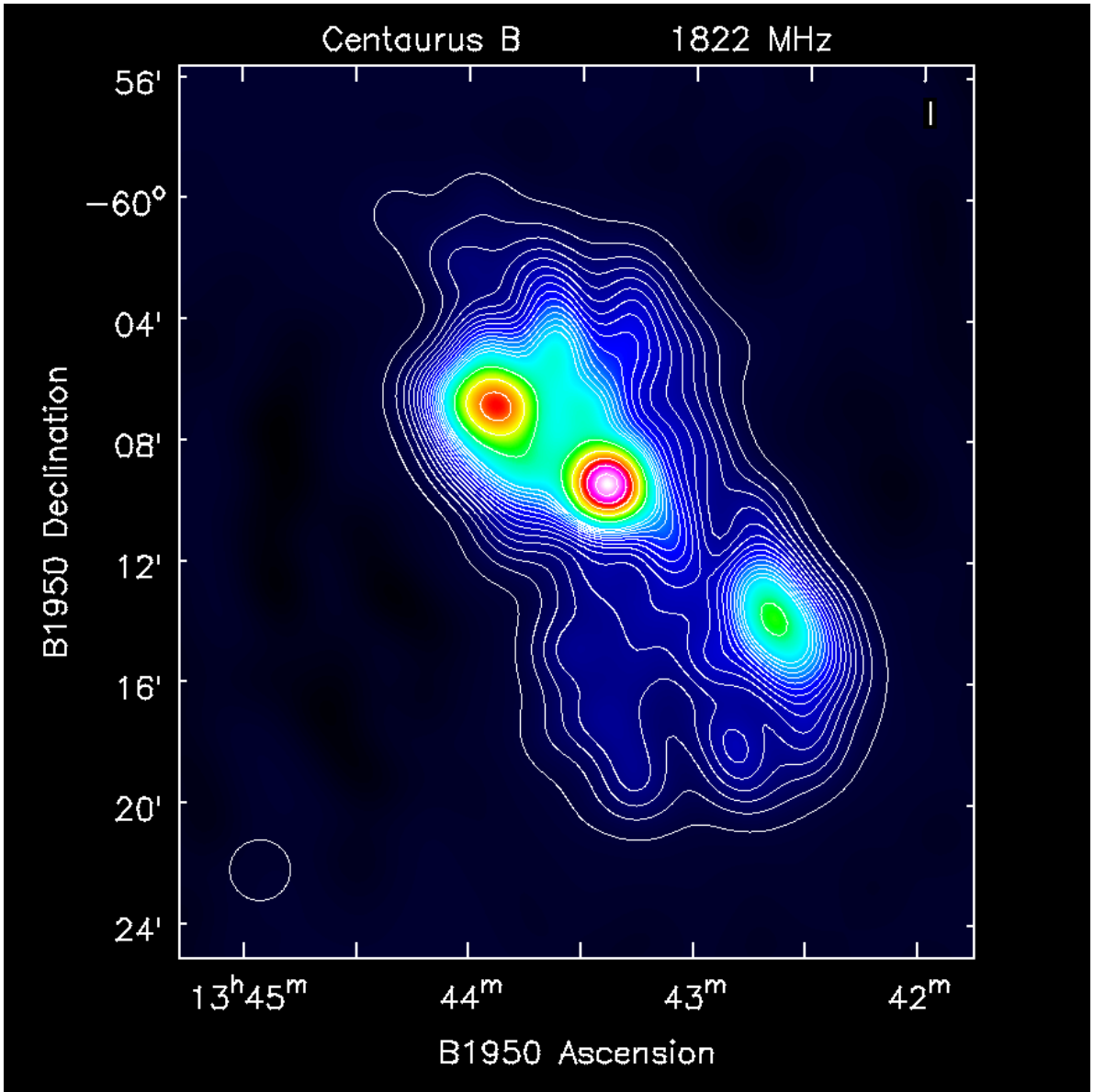


KAT-7

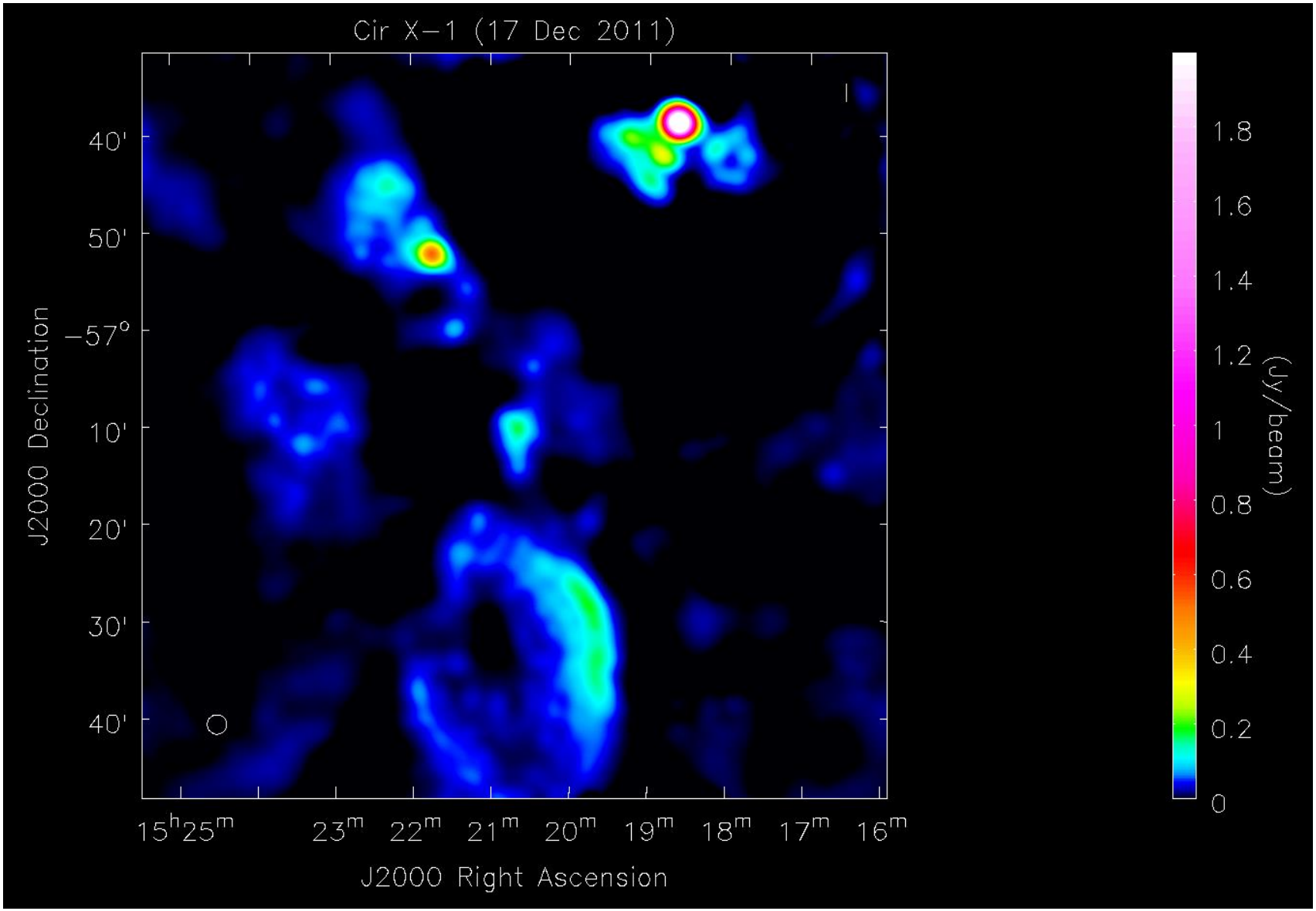
PKS 1610-60


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

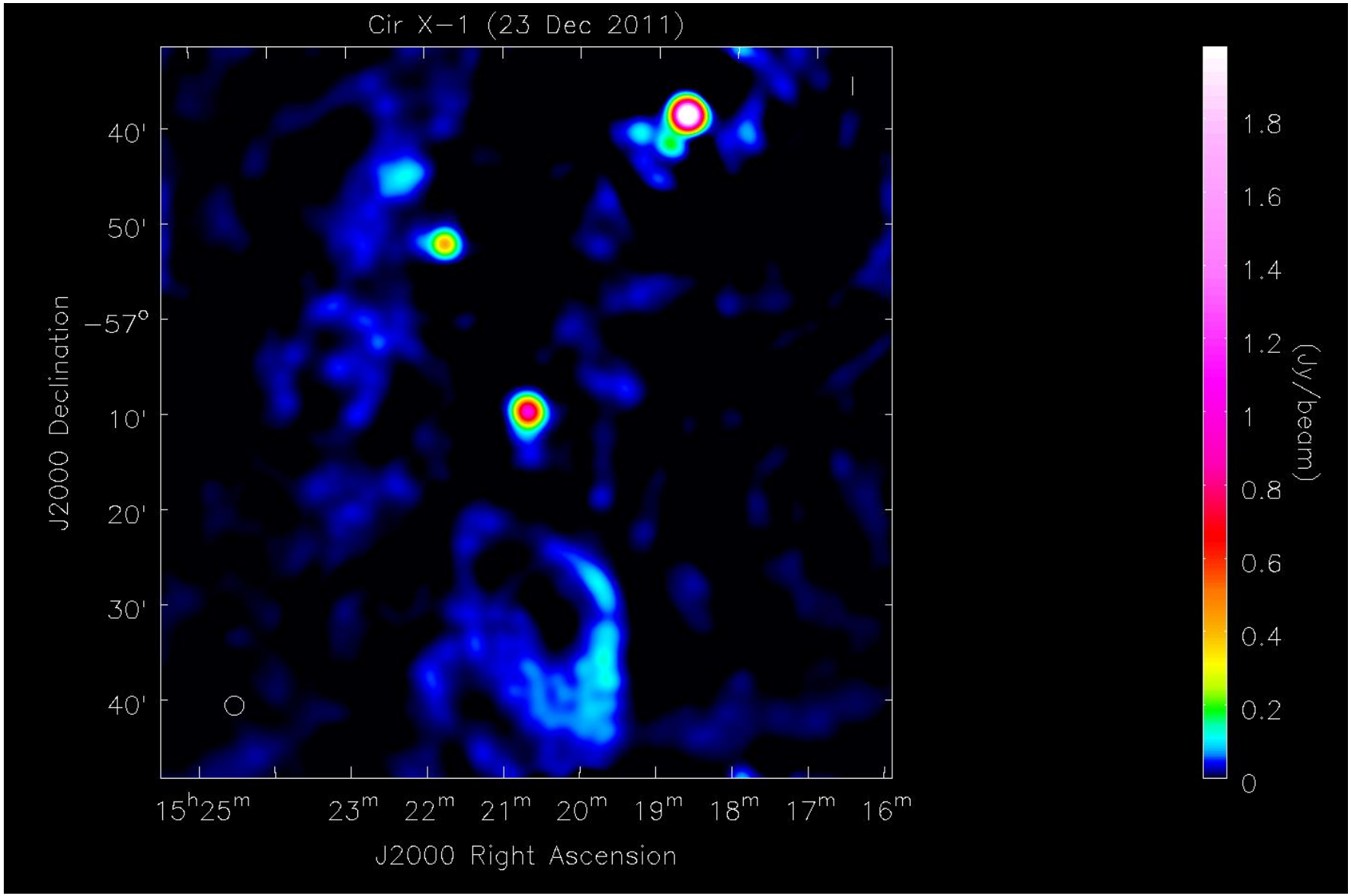
Cen B


Centaurus B
1822 MHz
56'
−60°
04'
08'
12'
16'
20'
24'
B1950 Declination
13h45m
44m
43m
42m
B1950 Ascension

Cir X-1 - off


Cir X−1 (17 Dec 2011)
40'
50'
−57°
10'
20'
30'
40'
J2000 Declination
15h25m
23m
22m
21m
20m
19m
18m
17m
16m
J2000 Right Ascension
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
(Jy/beam)

Cir X-1 - on


Cir X−1 (23 Dec 2011)
40'
50'
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10'
20'
30'
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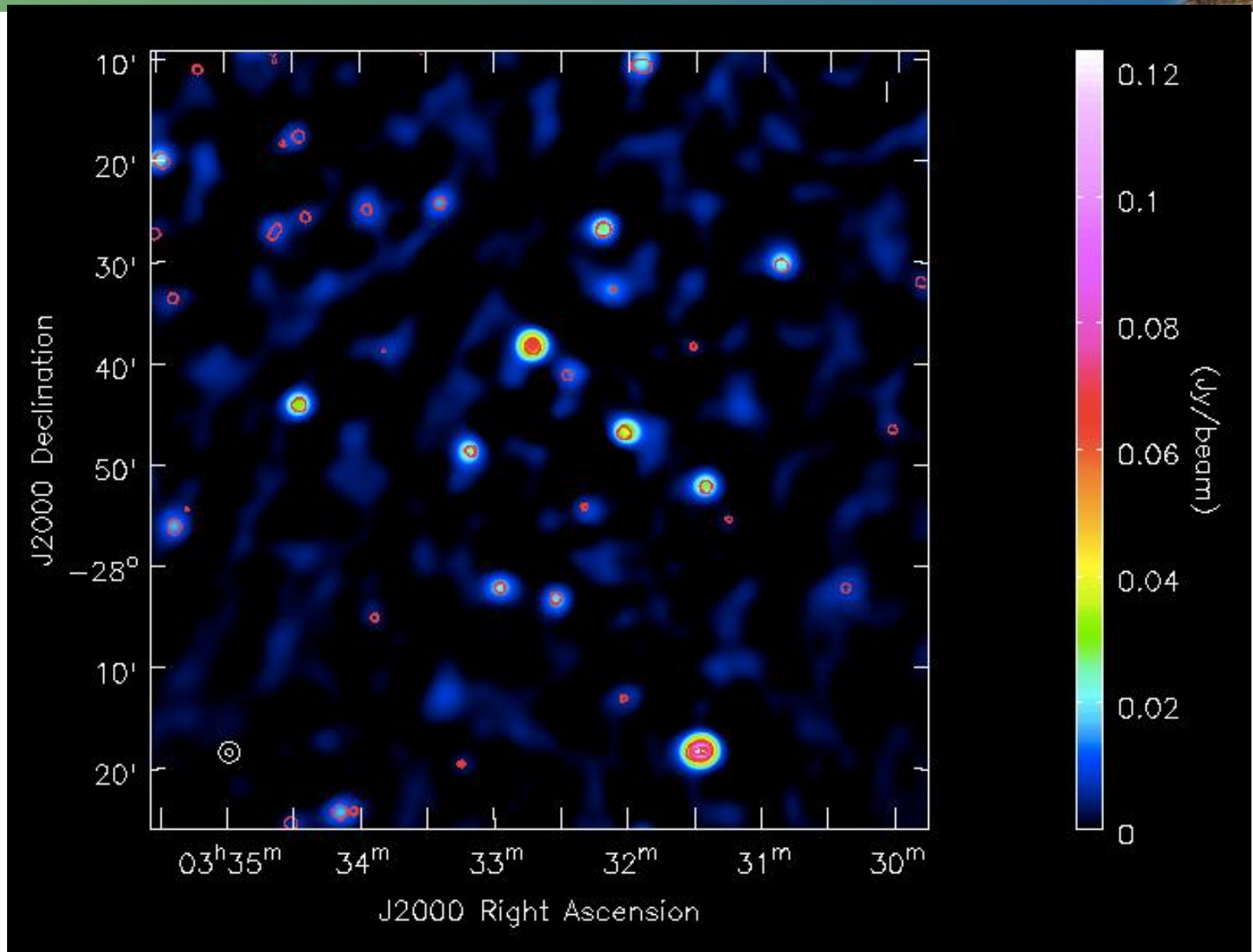
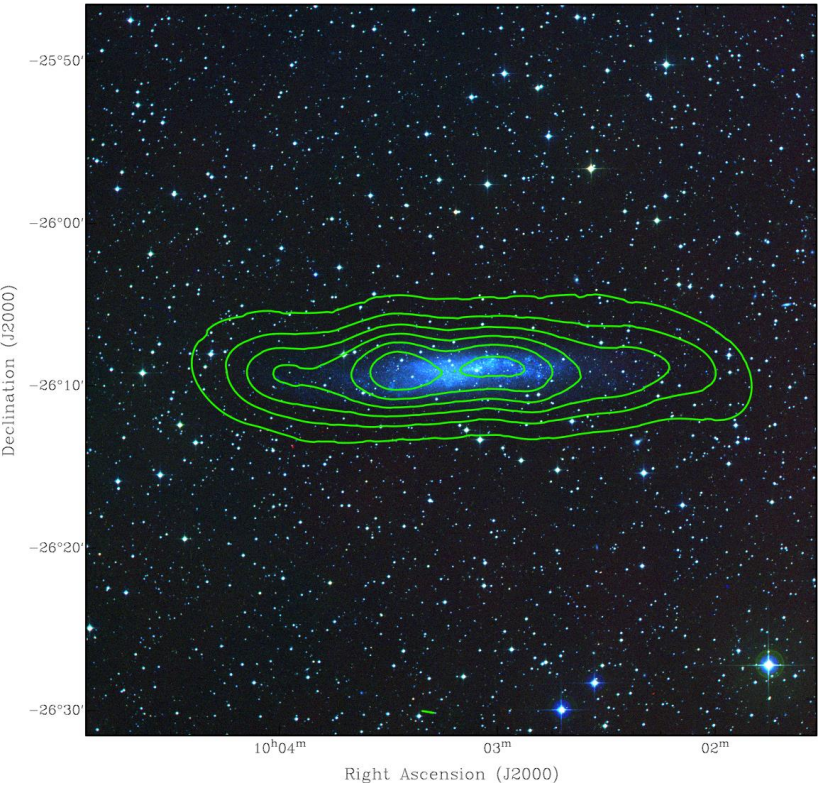
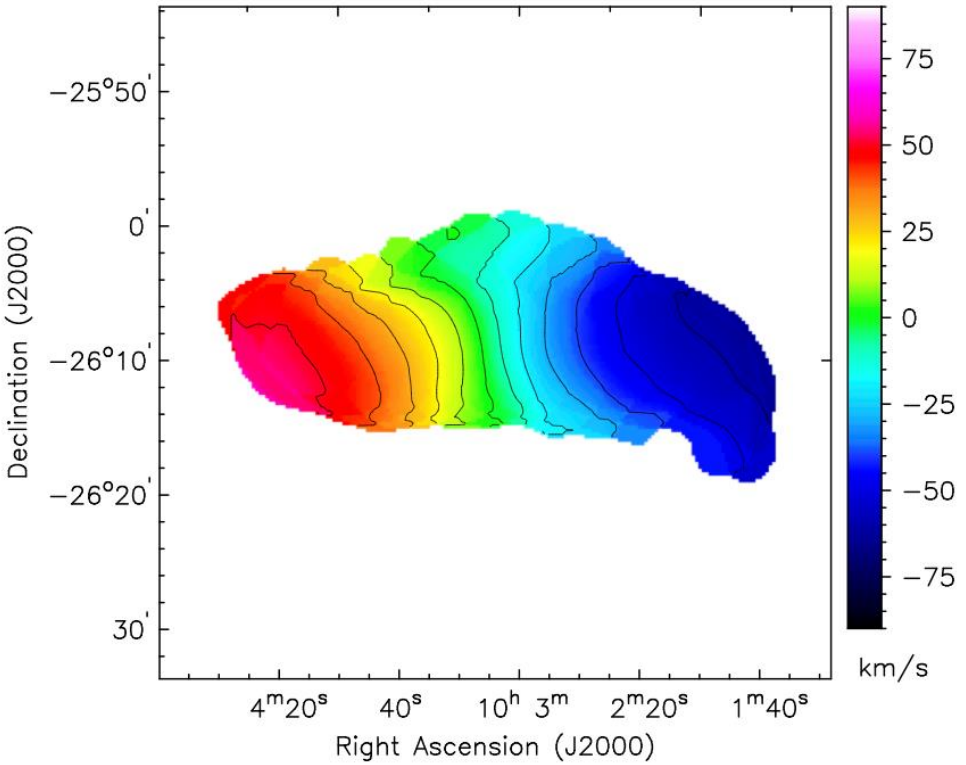
J2000 Declination
15h25m
23m
22m
21m
20m
19m
18m
17m
16m
J2000 Right Ascension
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
(Jy/beam)

HUDF & NVSS contours

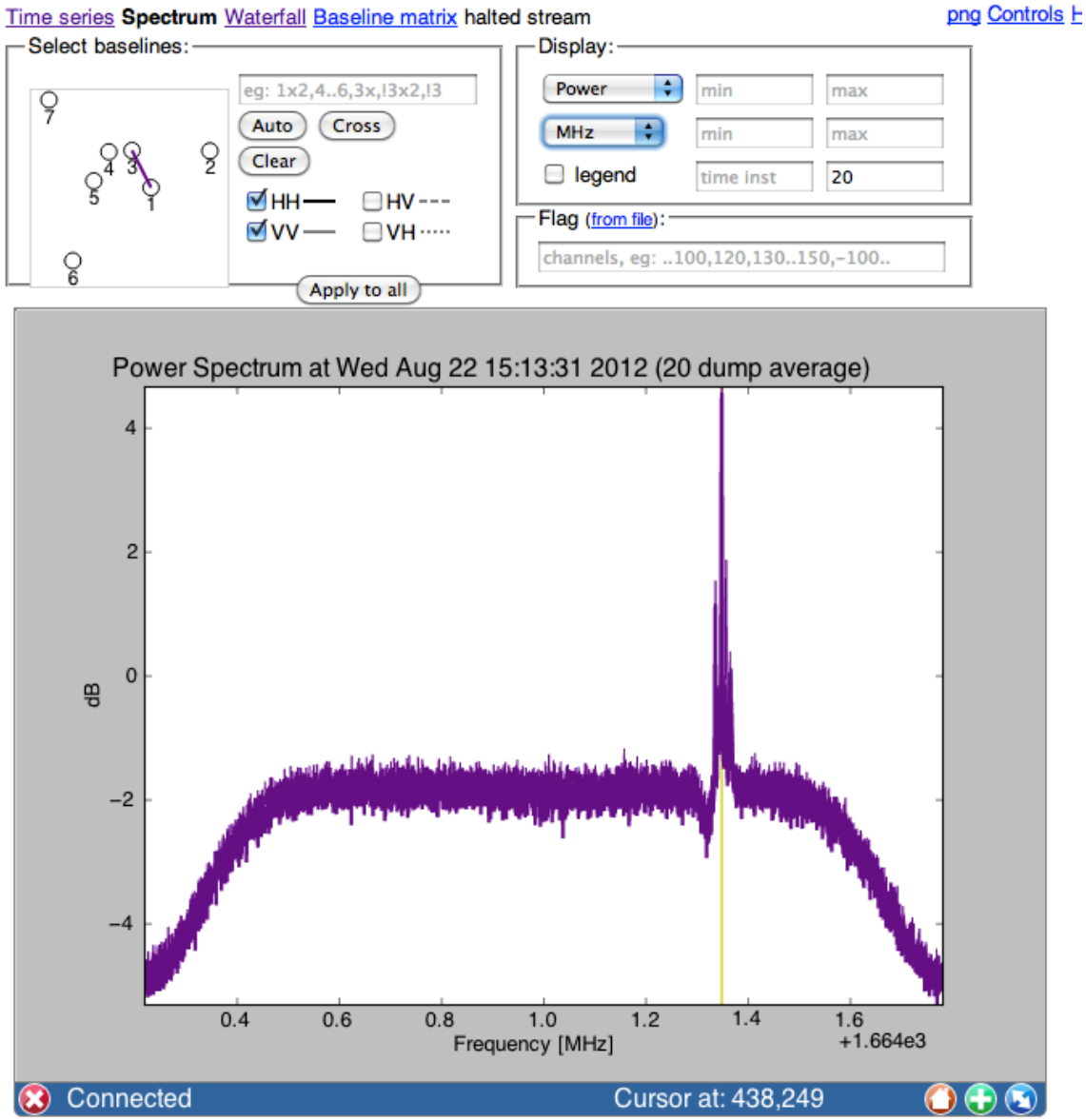


NGC 3109 (neutral hydrogen)

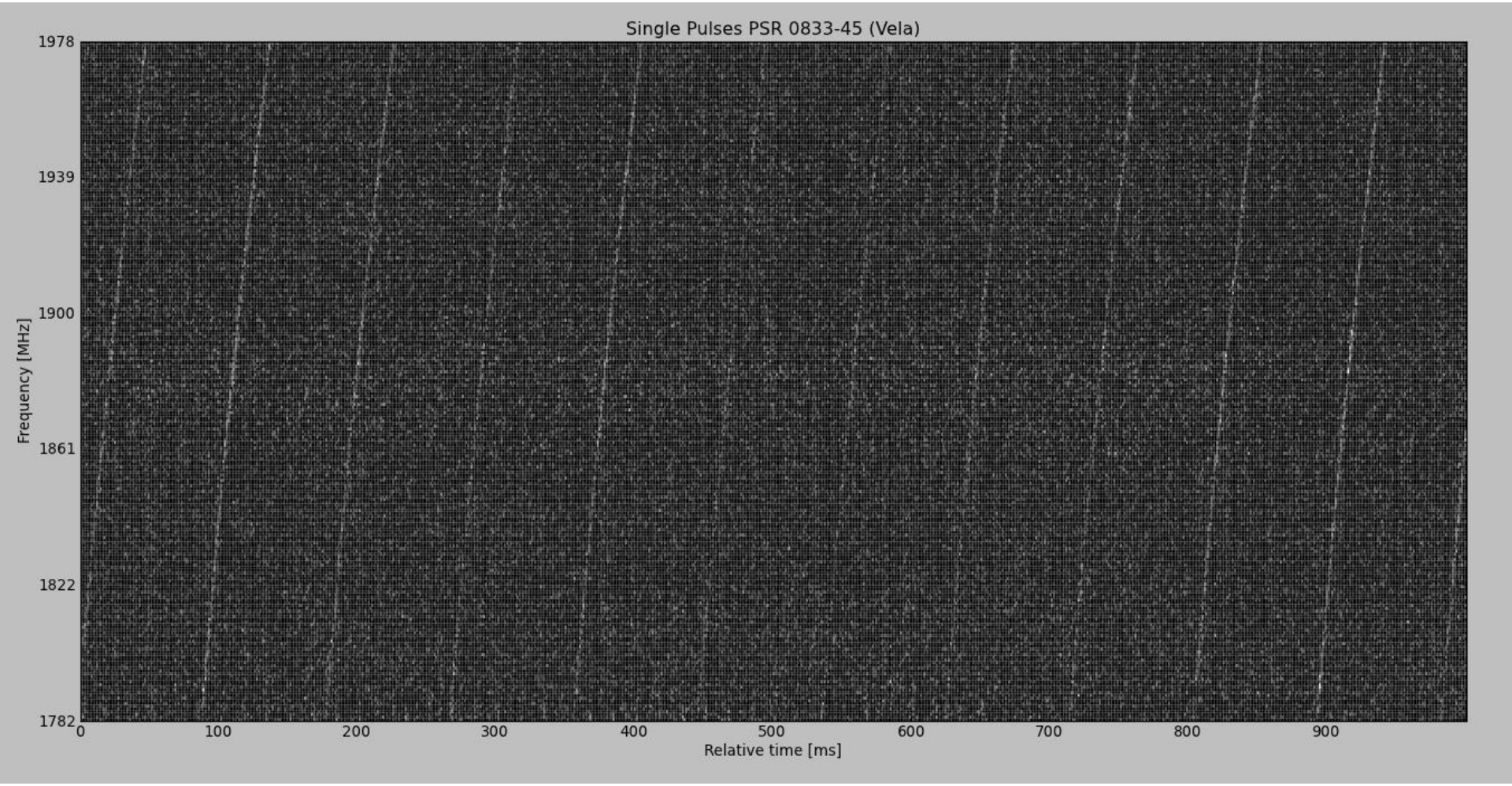




Single Baseline OH spectrum

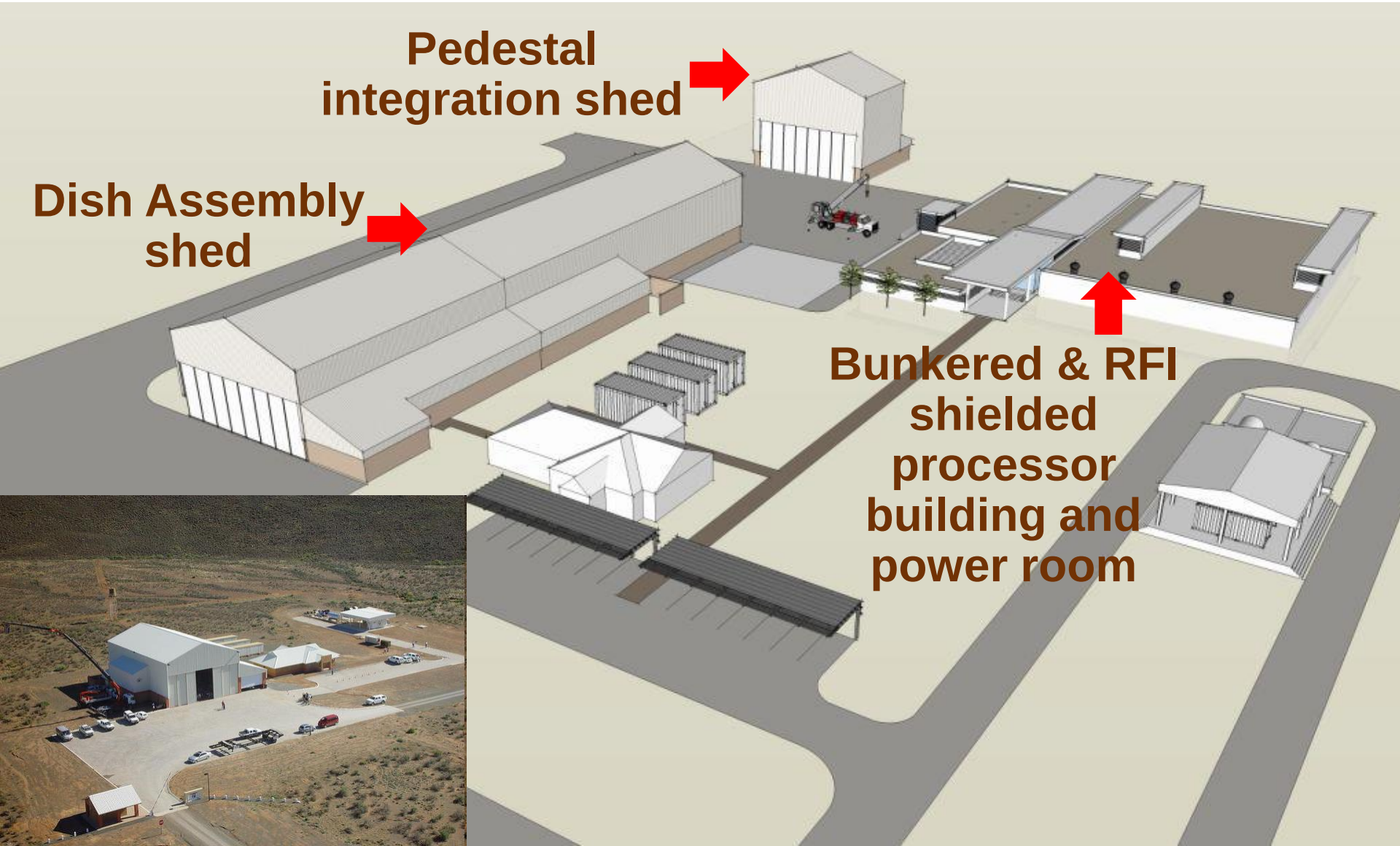


Vela Single Pulse Baseband



Klerefontein Support Base

Site Complex extension for MeerKAT



Grid power to site

Carnarvon S/S upgrade to 10 MVA

10 Gb/s to the heart of the Karoo

Broadband InfraCo container arrives at Carnarvon SKA POP Station

New overhead optical fibre cable being installed between Hutchinson and Carnarvon as part of Broadband InfraCo's long-haul fibre network

On-Site power & data reticulation

Road network near core

SKA Office site visit

The President at KAT-7

www.ska.ac.za