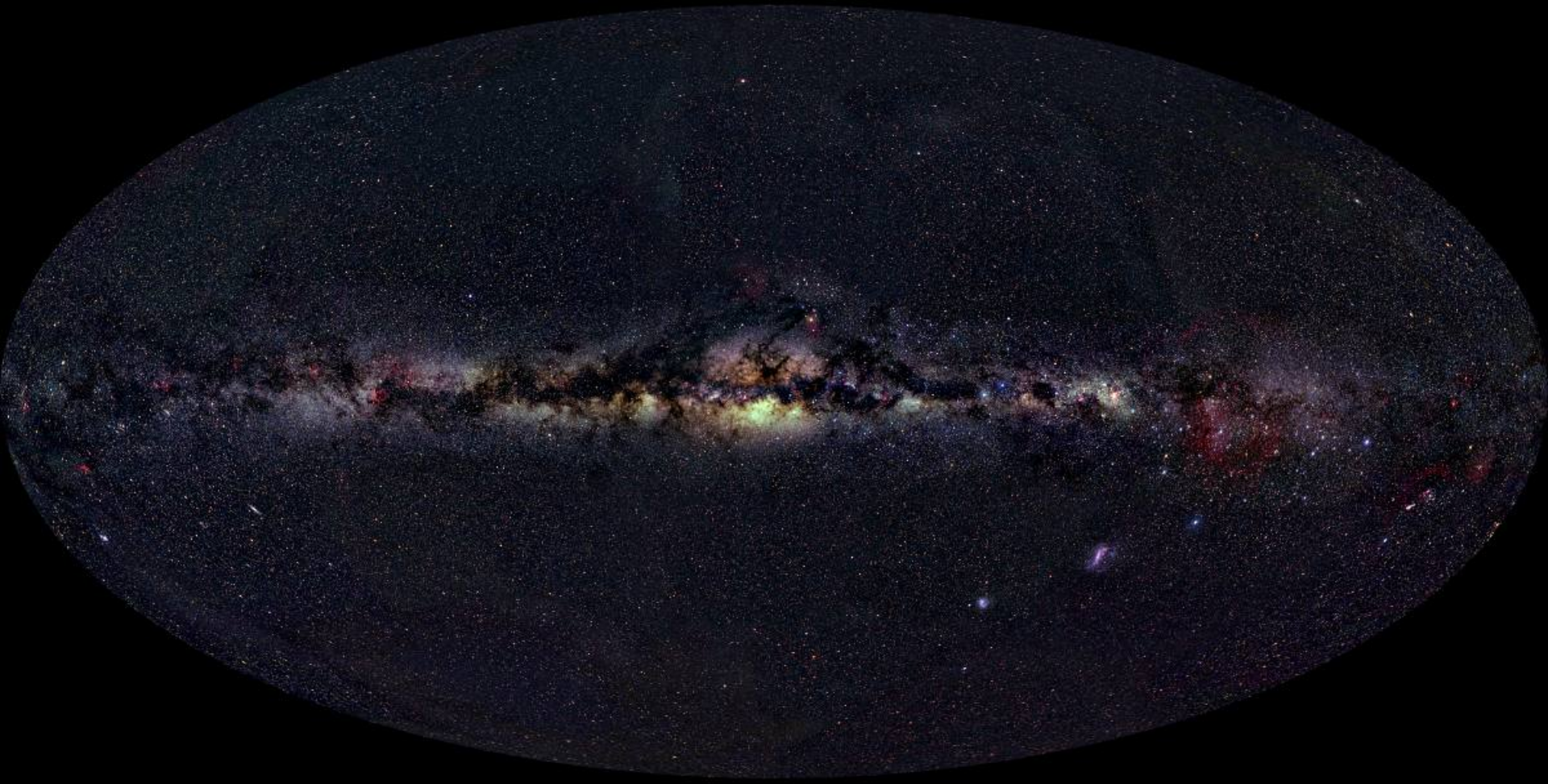
An Engineering Challenge for Next-Generation Astronomical Research : The Square Kilometre Array

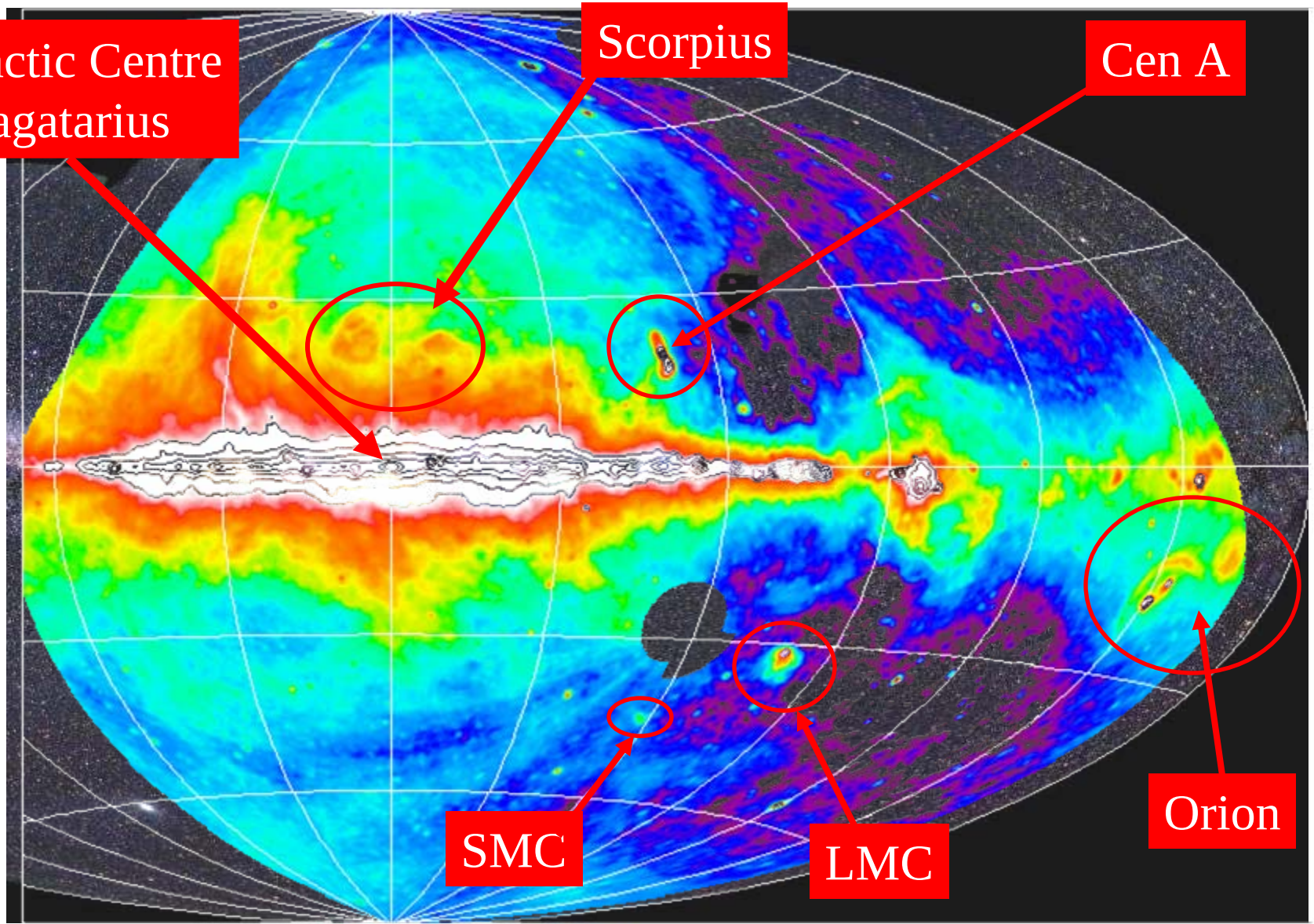
Dr. Adrian Tiplady, SKA South Africa

SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY

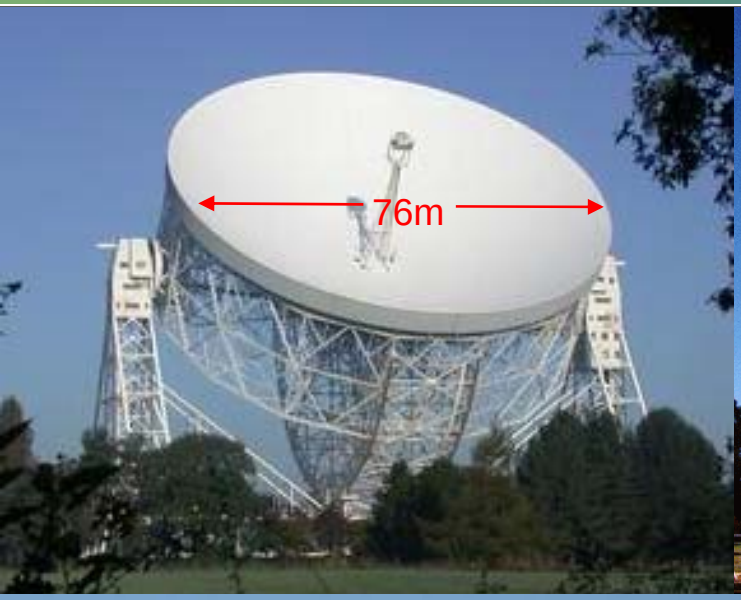
SKA
SQUARE KILOMETRE ARRAY

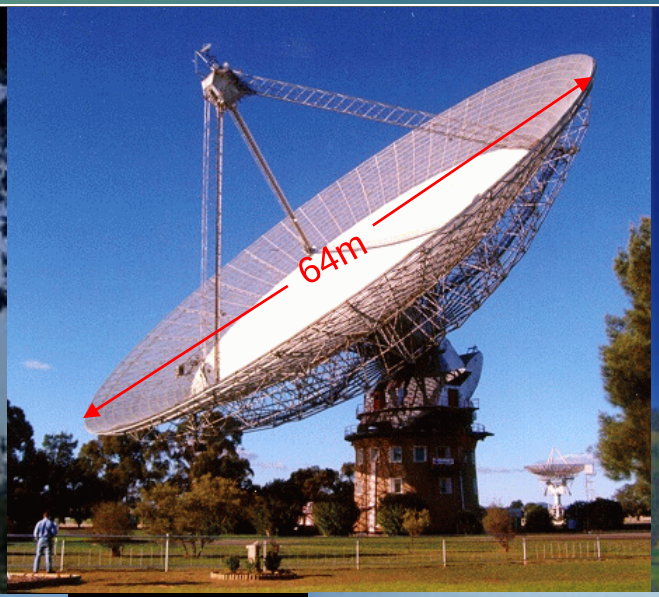
The Deep Sky

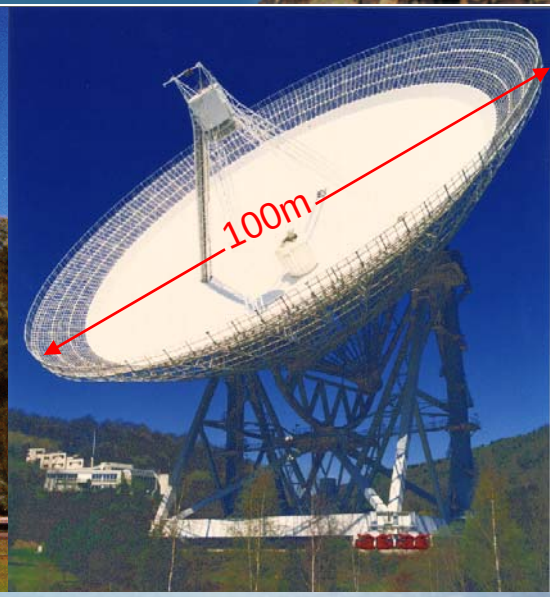


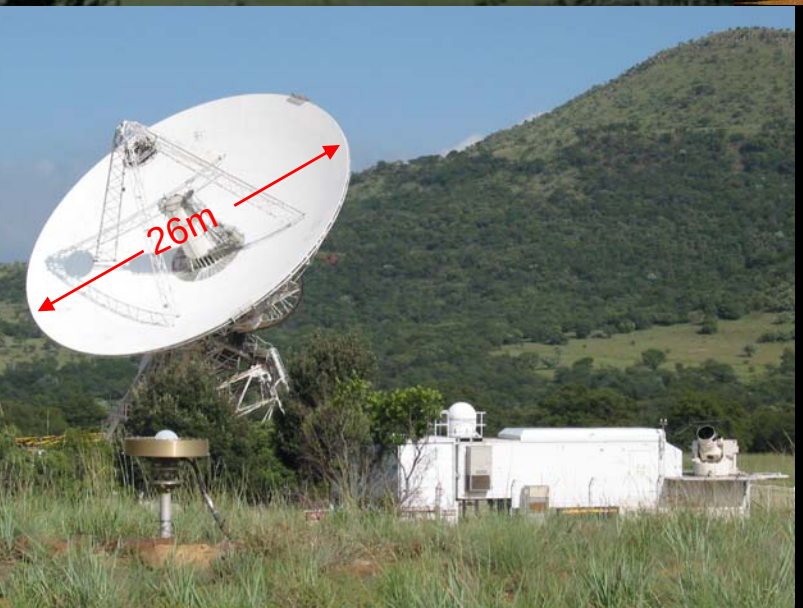

Galactic Centre
Sagatarius
Scorpius
Cen A
SMC
LMC
Orion

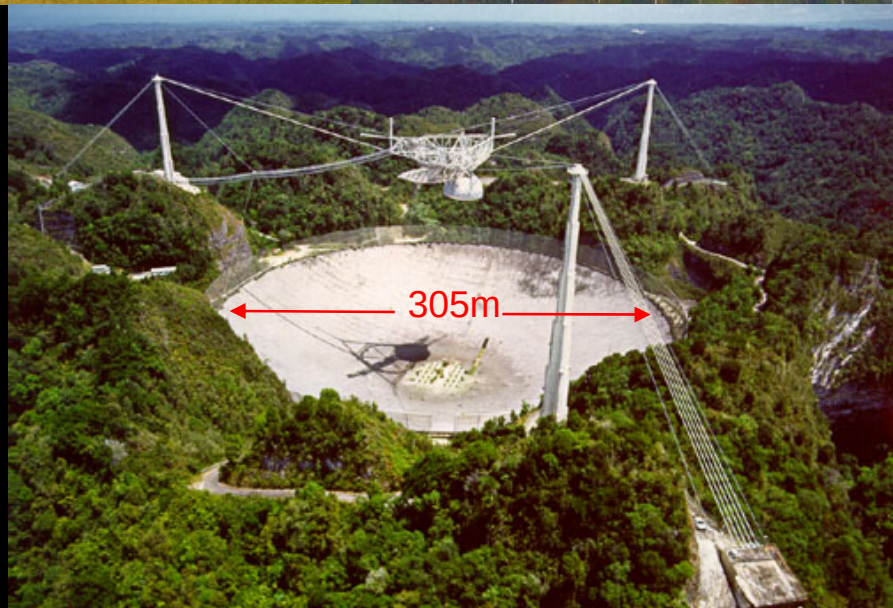
Traditional radio telescopes







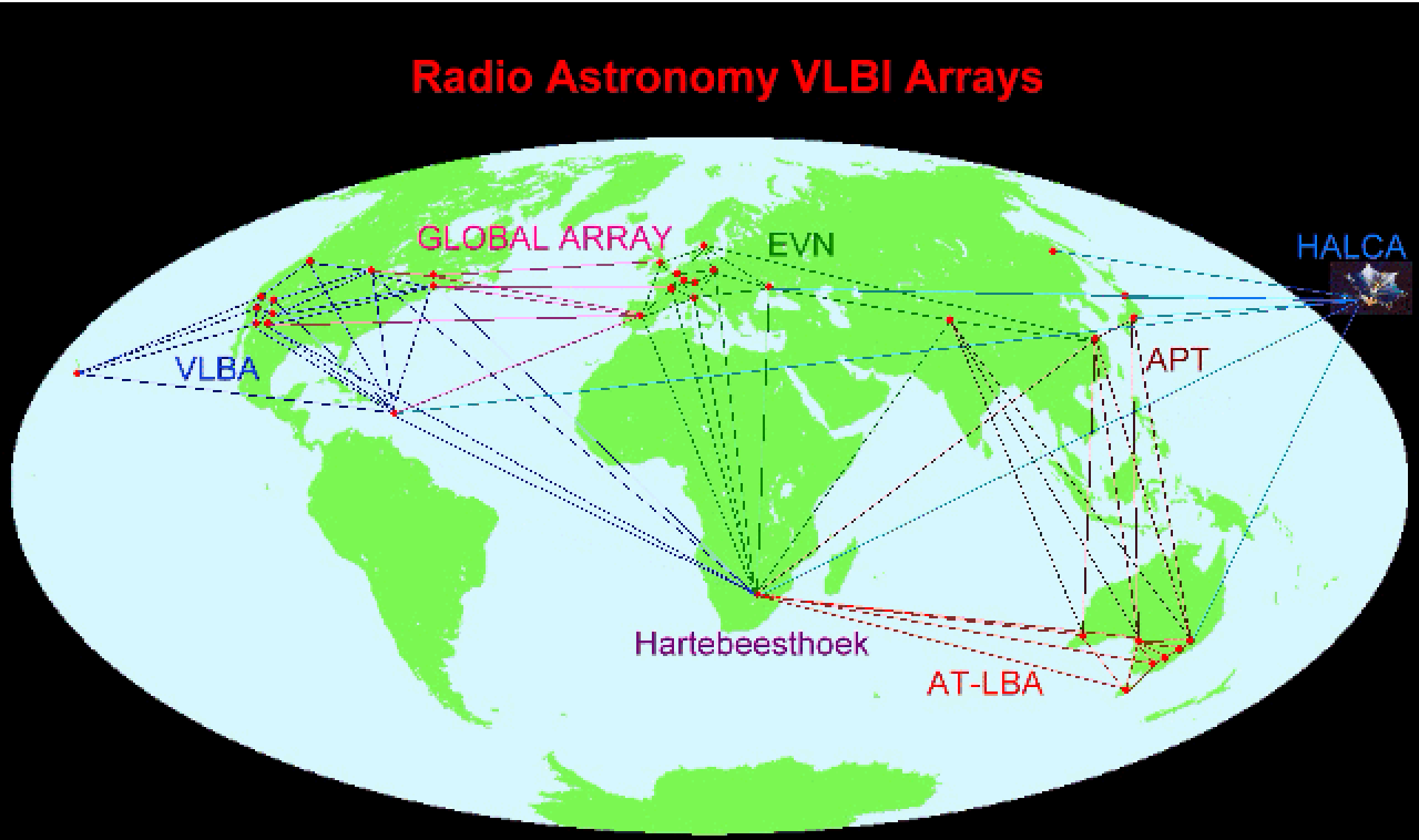




A radio telescope array – the VLA

- VLA
  - 27 x 25m dishes
  - Array configuration expands from 1km to 35km
  - Most productive radio telescope in the world

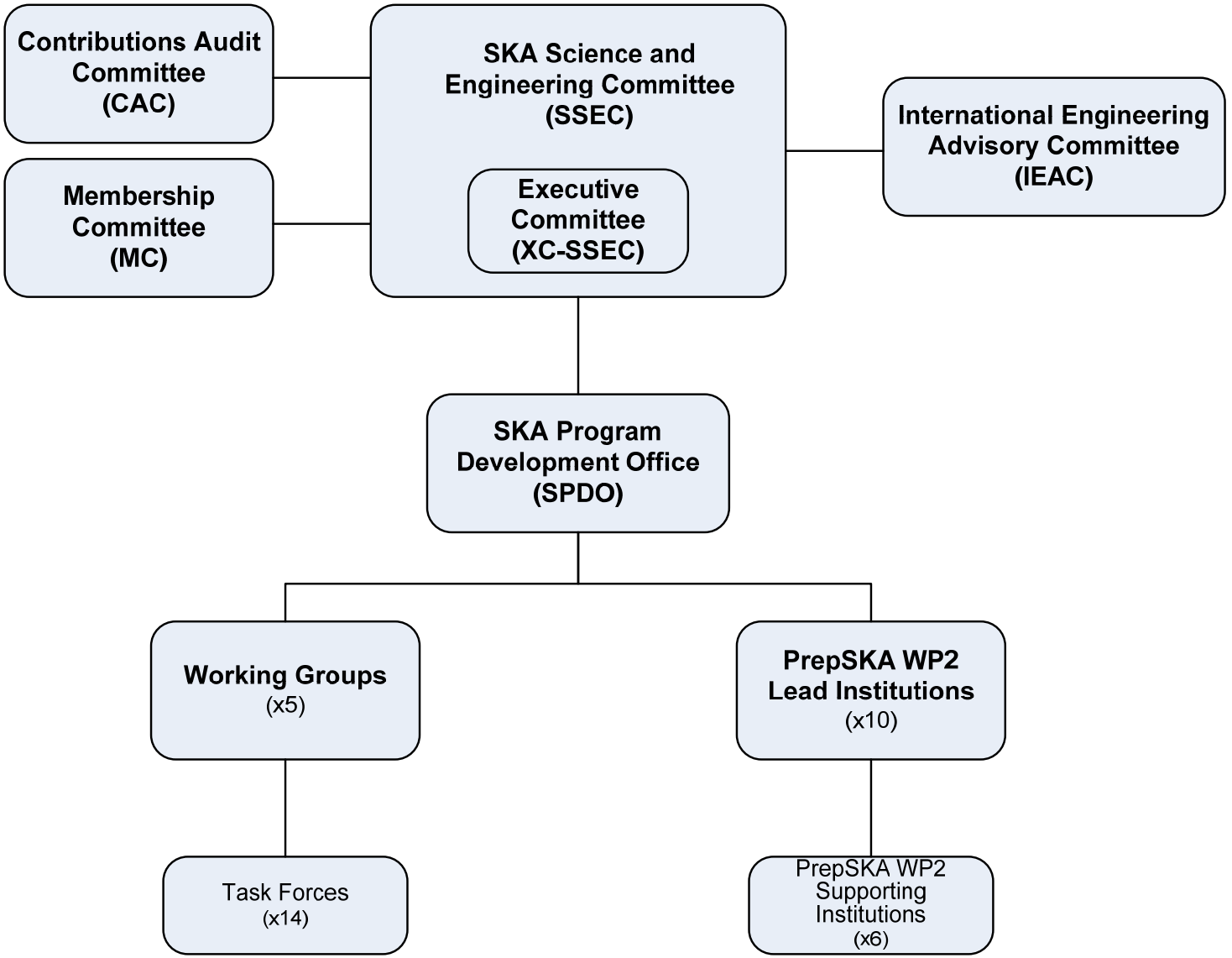
Trans-continental interferometric observations

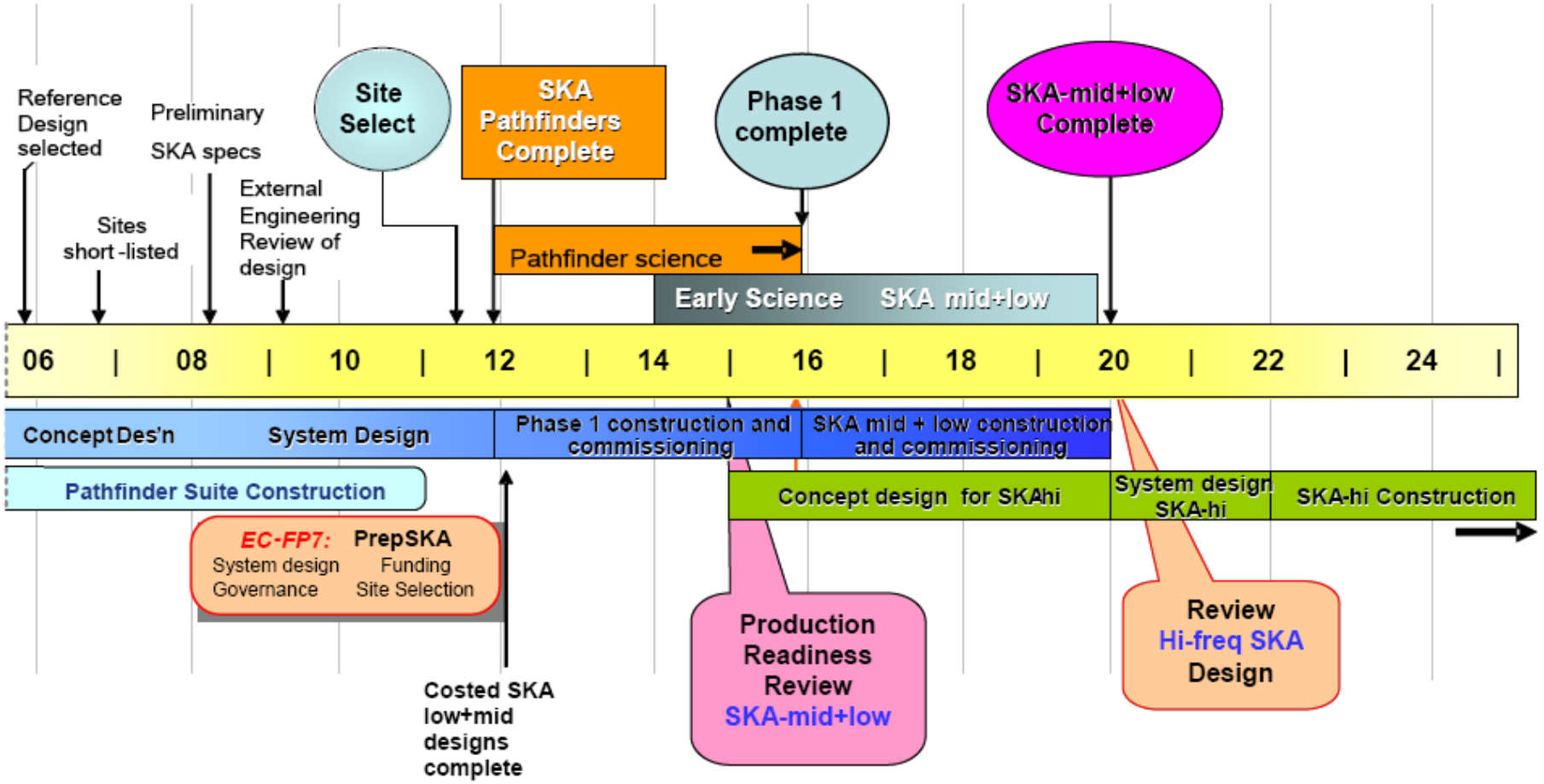


The SKA

- An international `megascience project'
  - 55 institutes in 19 countries
  - 15 Funding Agencies in the "Informal Funding Agencies Workgroup"
  - 100 FTE on SKA R&D
  - 120 astronomers and engineers on committees and workgroups
- 100 times more sensitive than today's best instruments
- Proposed capital budget of 1.5 billion €/£/$'s
- Operational circa 2021

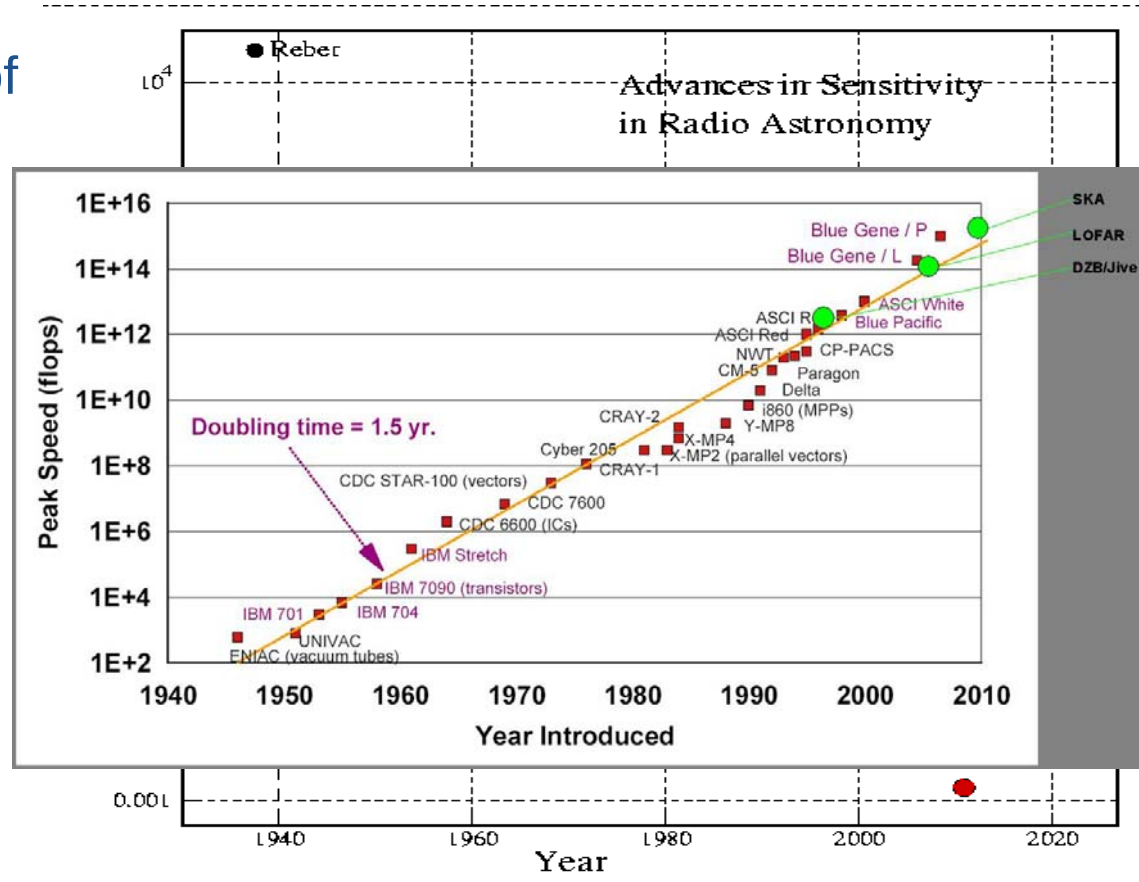
International organisation




Reference Design selected
Preliminary SKA specs
Sites short-listed
External Engineering Review of design
Site Select
SKA Pathfinders Complete
Phase 1 complete
SKA-mid+low Complete
Pathfinder science
Early Science
SKA mid+low
06
08
10
12
14
16
18
20
22
24
Concept Des'n
System Design
Phase 1 construction and commissioning
SKA mid + low construction and commissioning
Pathfinder Suite Construction
Concept design for SKAhi
System design SKA-hi
SKA-hi Construction
EC-FP7: PrepSKA
System design
Funding
Governance
Site Selection
Costed SKA low+mid designs complete
Production Readiness Review SKA-mid+low
Review Hi-freq SKA Design

Square Kilometre Array

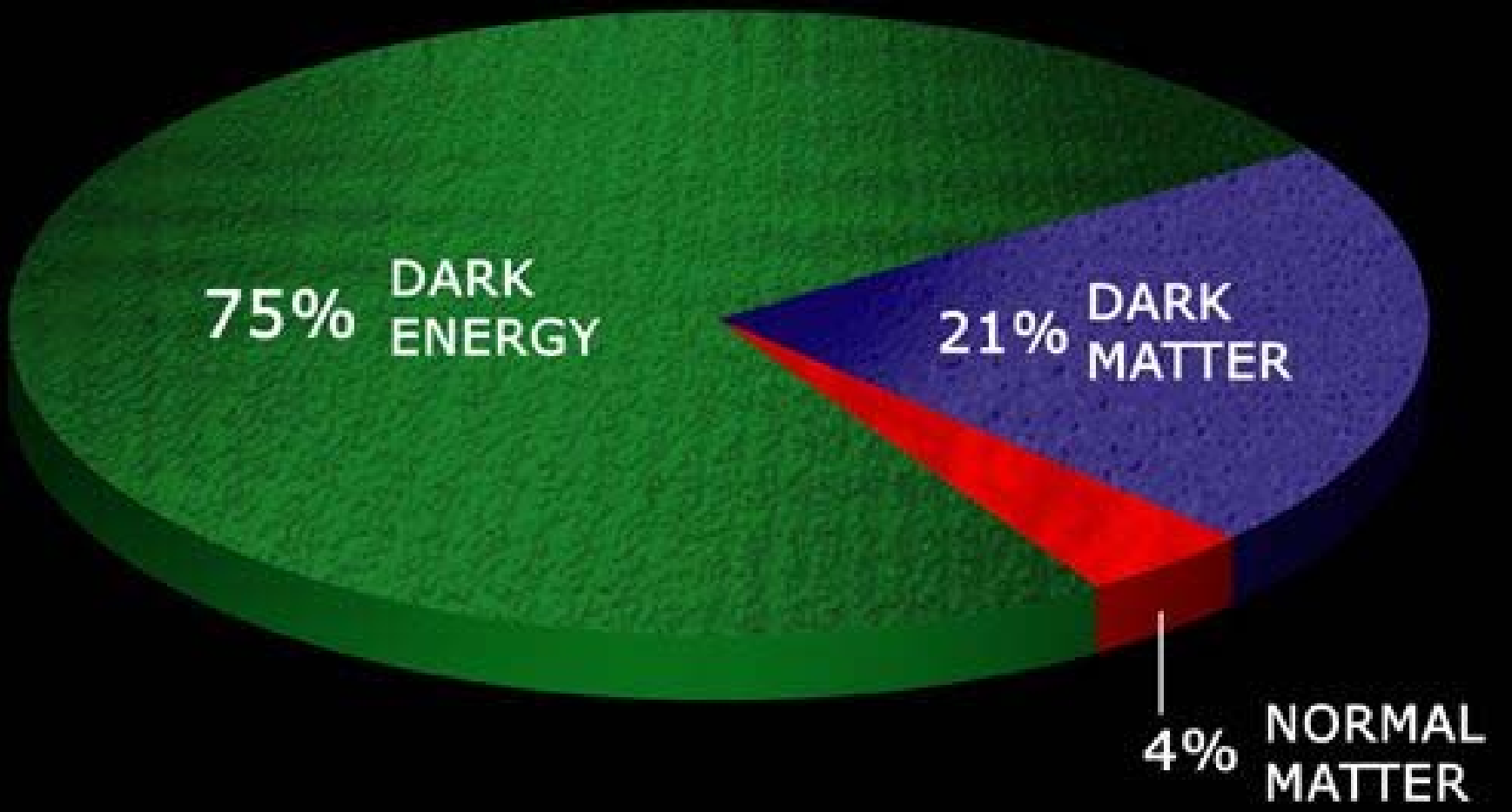
- Distributed array of some 4500 dishes, the equivalent of 1 million DSTV dishes in collecting area
- It will rely heavily on new technologies, both unique and consumer-driven.
  - The cost per unit collecting area must be less than one tenth that of current technologies
  - Take advantage of Moore's law in radio and software engineering
  - Will include COTS components
  - Will drive innovation in generic technologies



Why build it?

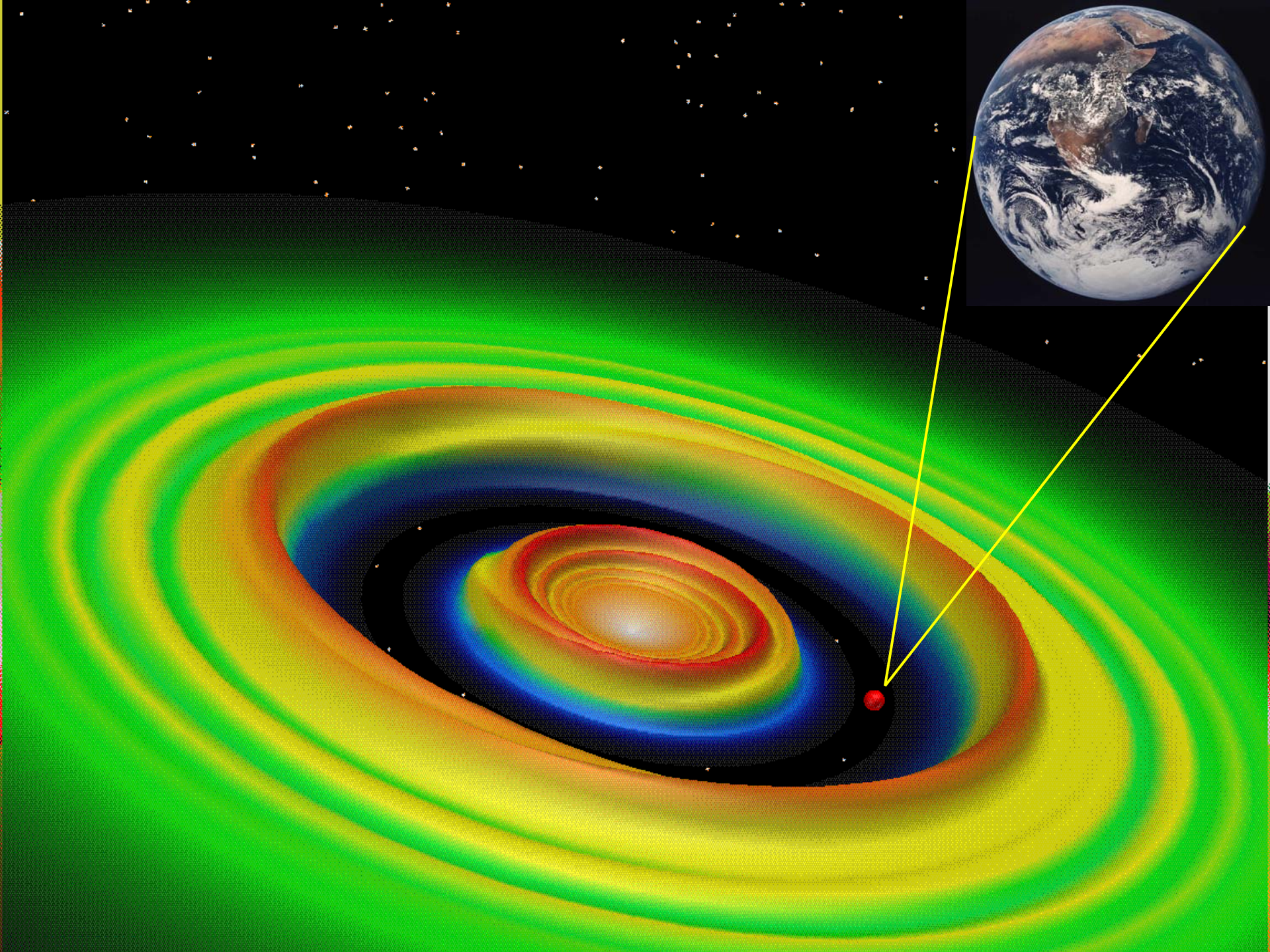
- Fundamental questions in physics and astronomy
  - "What are the basic properties of the fundamental particles and forces?"
    - Neutrinos, Magnetic Fields, Gravity, Gravitational Waves, Dark Energy
  - "What constitutes the missing mass of the universe?"
    - Cold Dark Matter (e.g. via lensing), Dark Energy, Hot Dark Matter (neutrinos)
  - "What is the origin of the Universe and the observed structure and how did it evolve?"
    - Atomic hydrogen, epoch of reionization, magnetic fields, star-formation history……
  - "How do planetary systems form and evolve?"
    - Movies of Planet Formation, Astrobiology, Radio flares from exo-planets……
  - "Has life existed elsewhere in the Universe, and does it exist elsewhere now?"
    - SETI

The universe as we don’t know it



What Is the Reionization Era?

A Schematic Outline of the Cosmic History



International R&D : Dishes+Single Pixel Feeds

USA

ATA 6m hydroformed dish

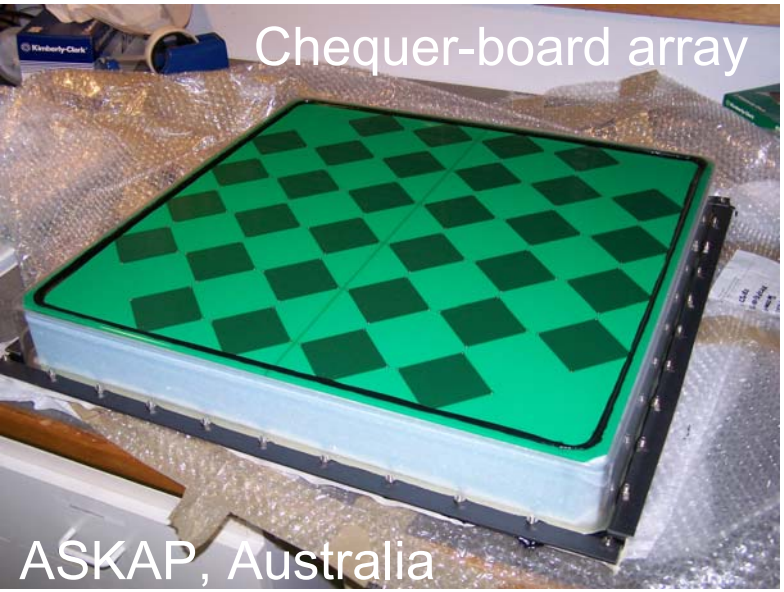
Canada

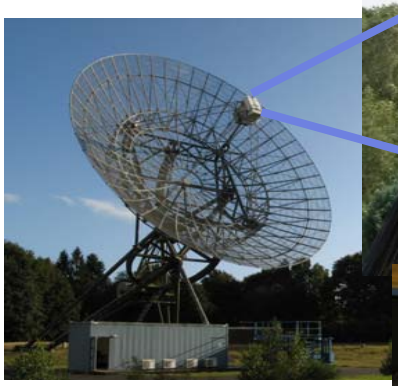
10 m composite dish

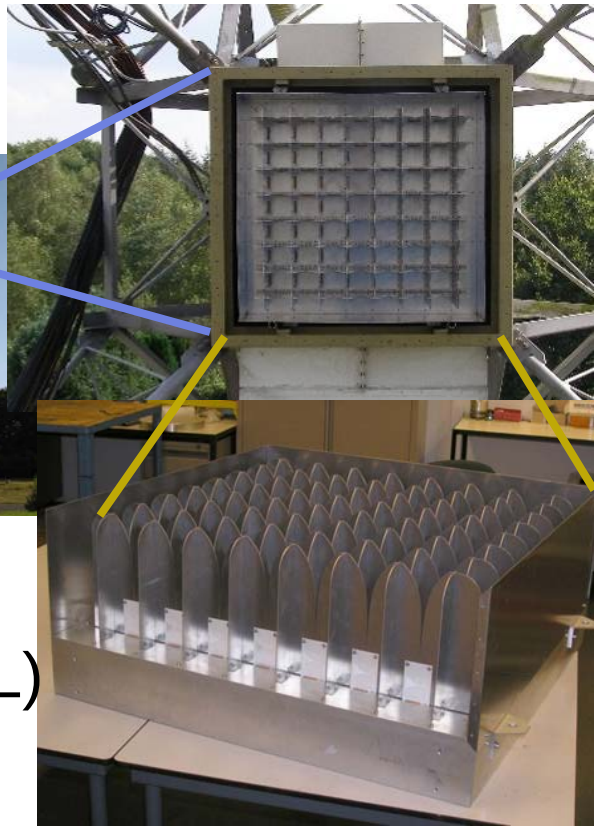
South Africa

15 m composite dish

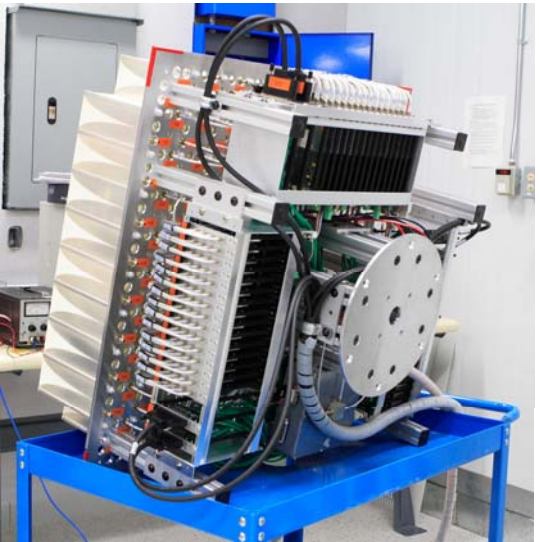
International R&D: Dishes+Phased Array Feeds







APERTIF
(Astron, NL)

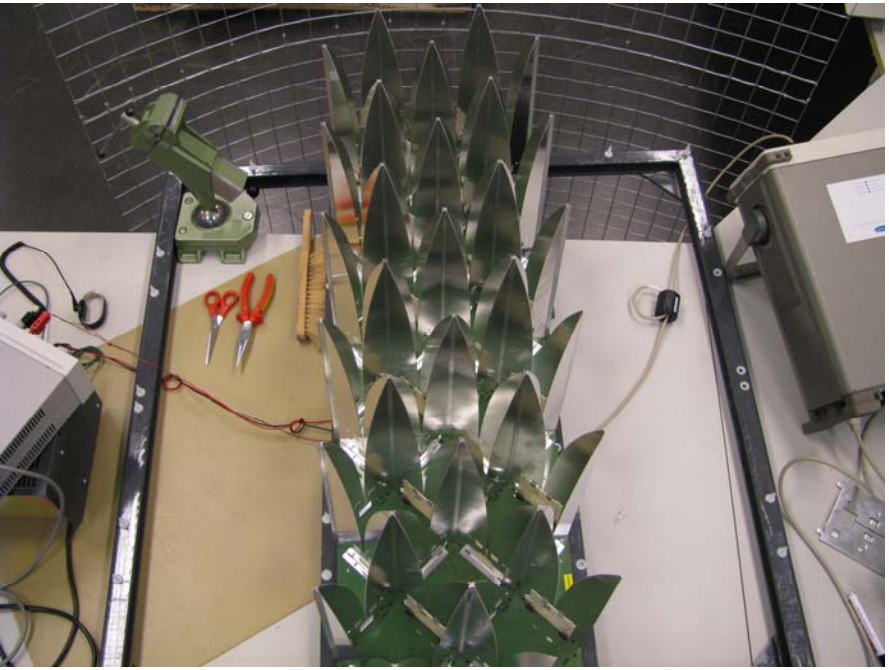


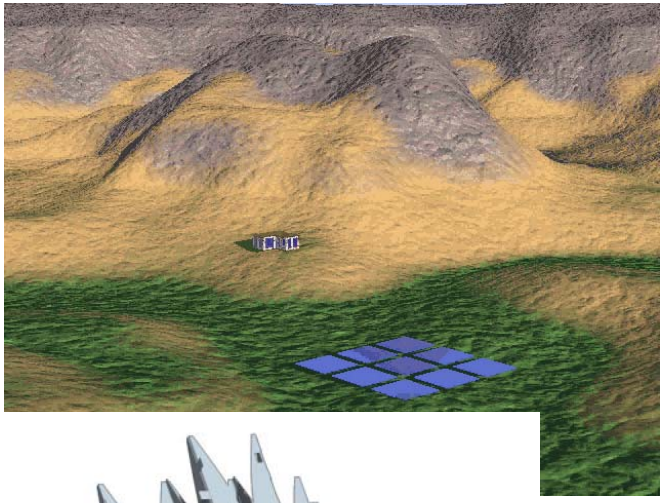
DRAO
Canada

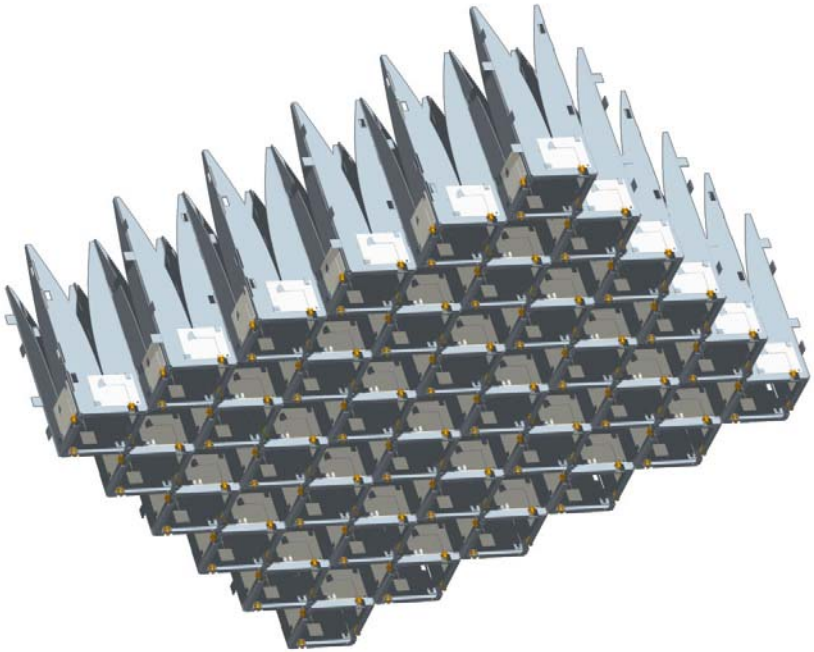
Vivaldi arrays

International R&D: Multi-beaming with a dense aperture array

SKA Design Study (Europe)
EMBRACE (ASTRON)







International R&D : Sparse aperture arrays

LOFAR (Netherlands et al)

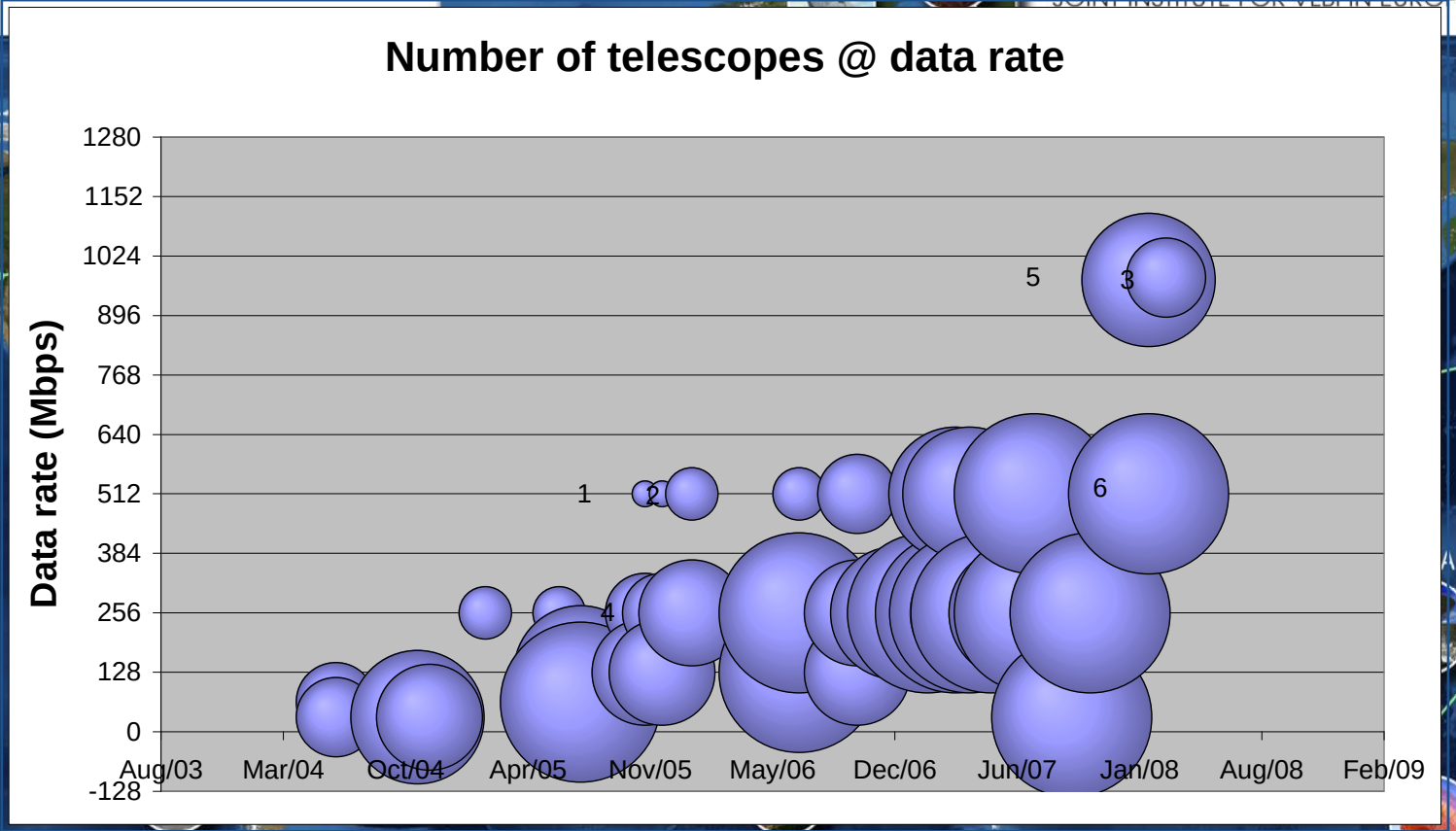
LWA (USA)

MWA (USA, Australia)

International R&D: Data transport

Status of the e-EVN

JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

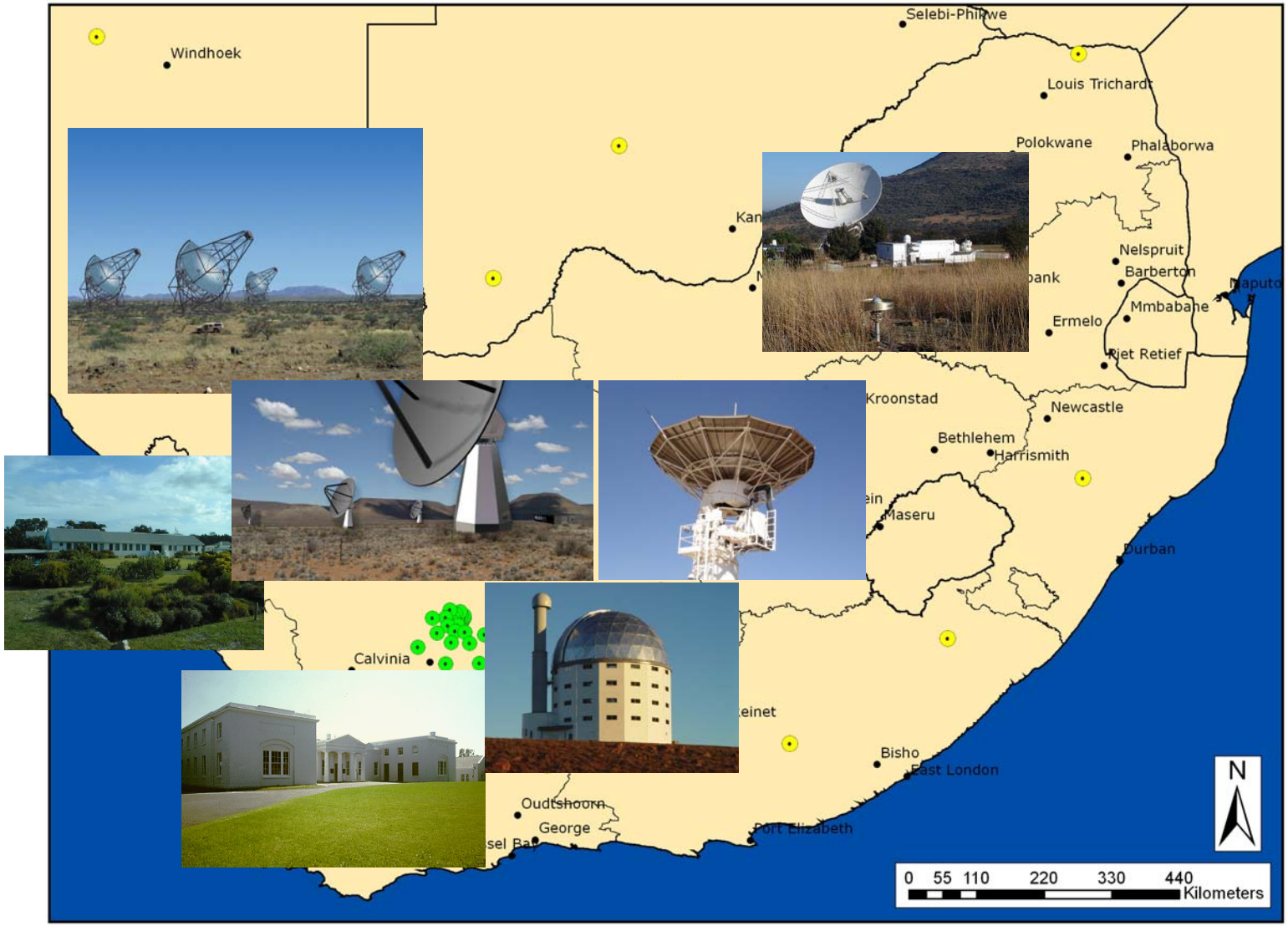


TIGO

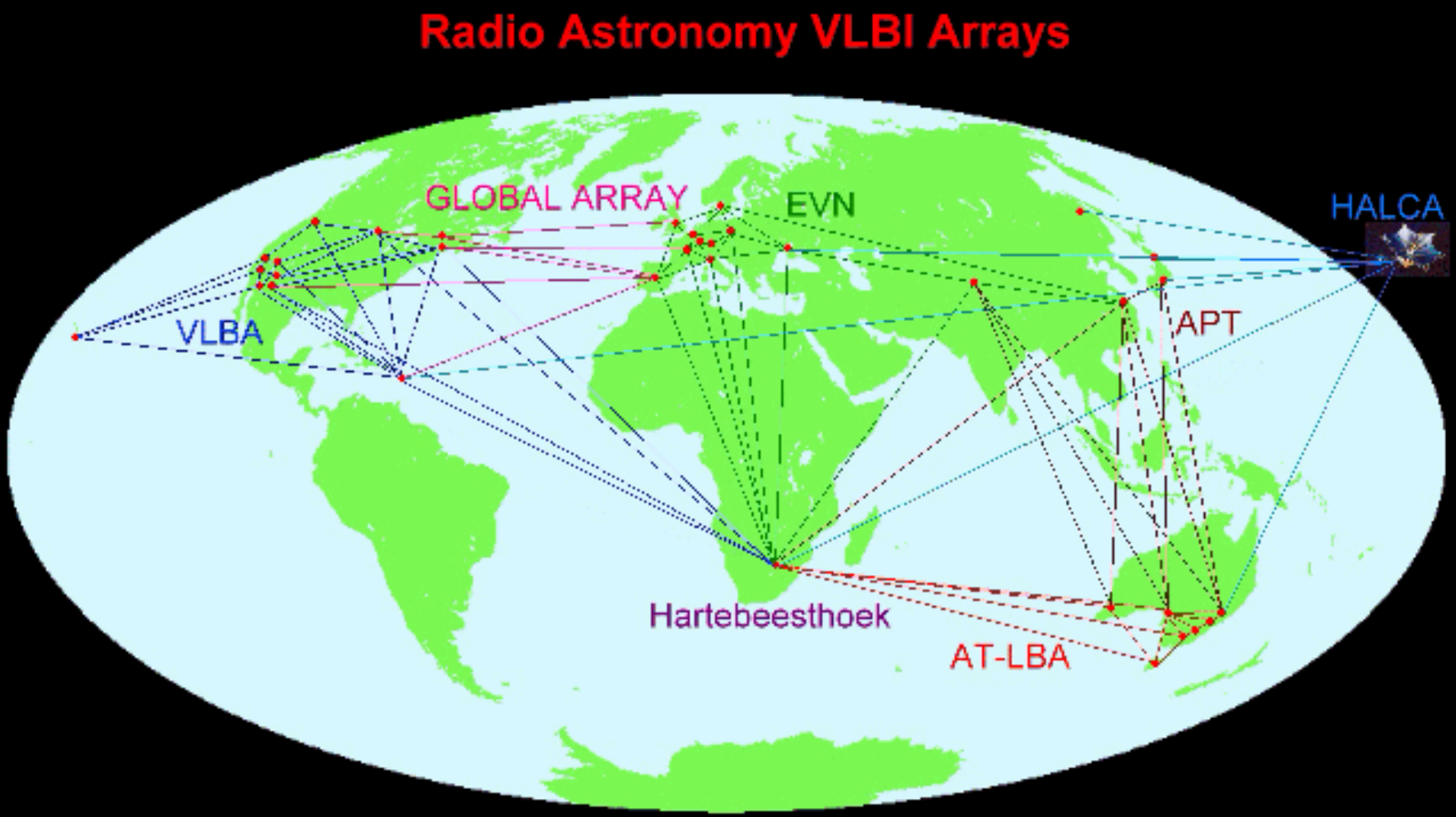
Hartebeesthoek

Parkes

South Africa – International Hub of Astronomy



South Africa – International Hub of Astronomy



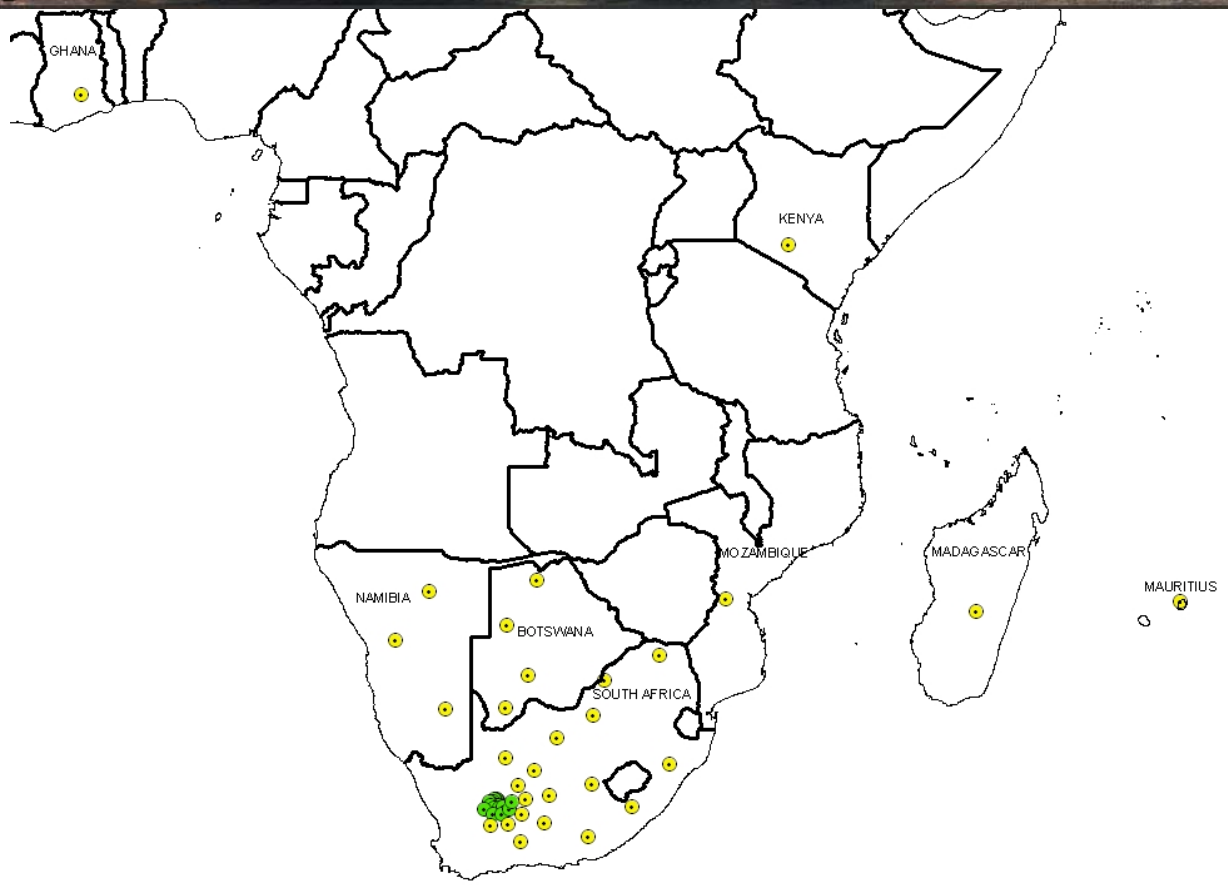
South African SKA Participation… Why?

- We have an excellent site
  - Good RFI environment
  - Stable ionosphere
  - Dry and stable troposphere
  - Remote but accessible
  - Common sky coverage with existing telescopes
- Capacity to construct and support the SKA
  - Proven project management track record
  - World-class manufacturing and construction industry
- Government commitment
  - Astronomy Geographic Advantage Act
  - Astronomy Geographic Advantage Programme
  - Implementation of basic infrastructure

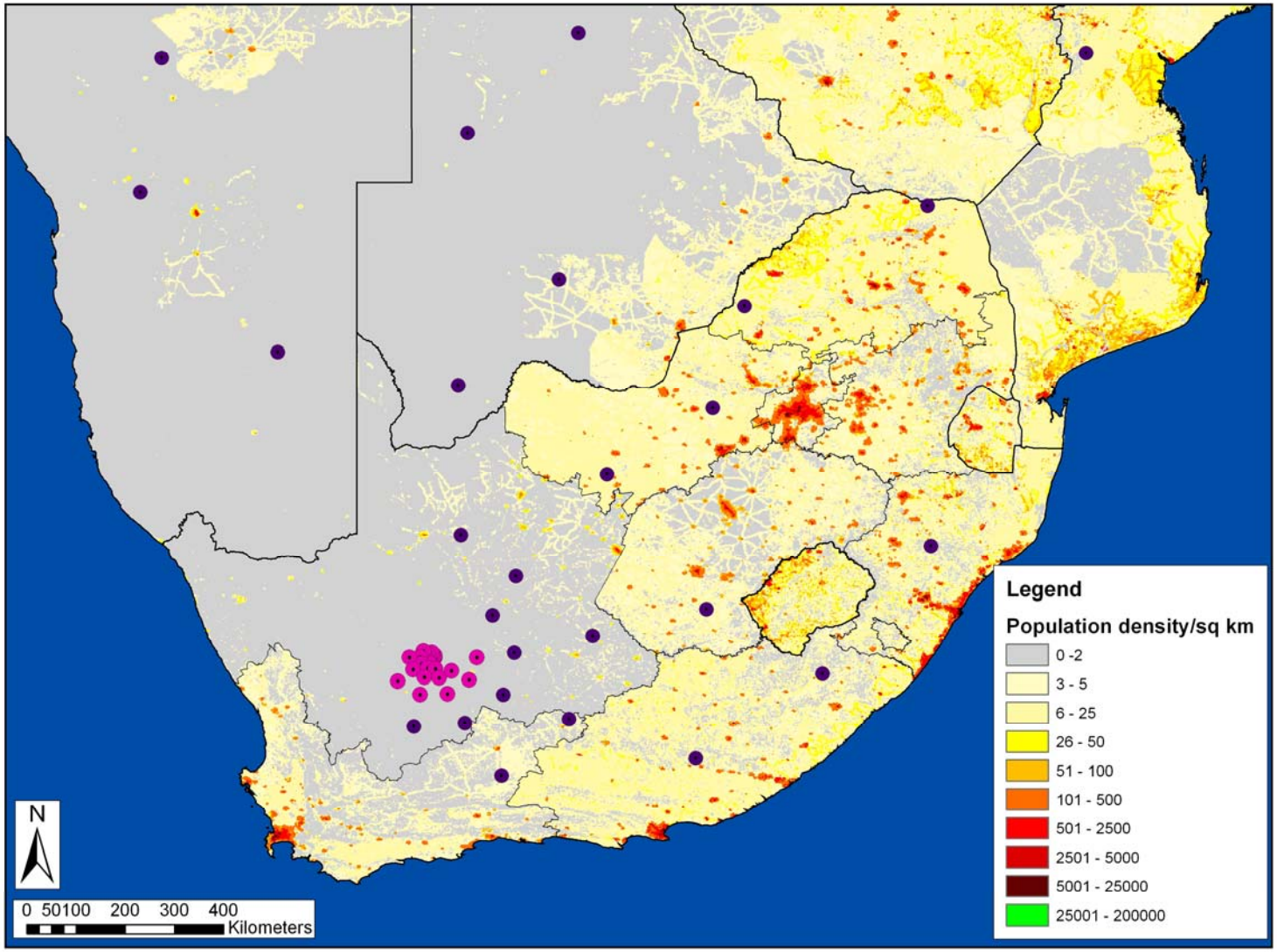
The SKA SA Steering Committee

SKA South Africa Project Office, JHB

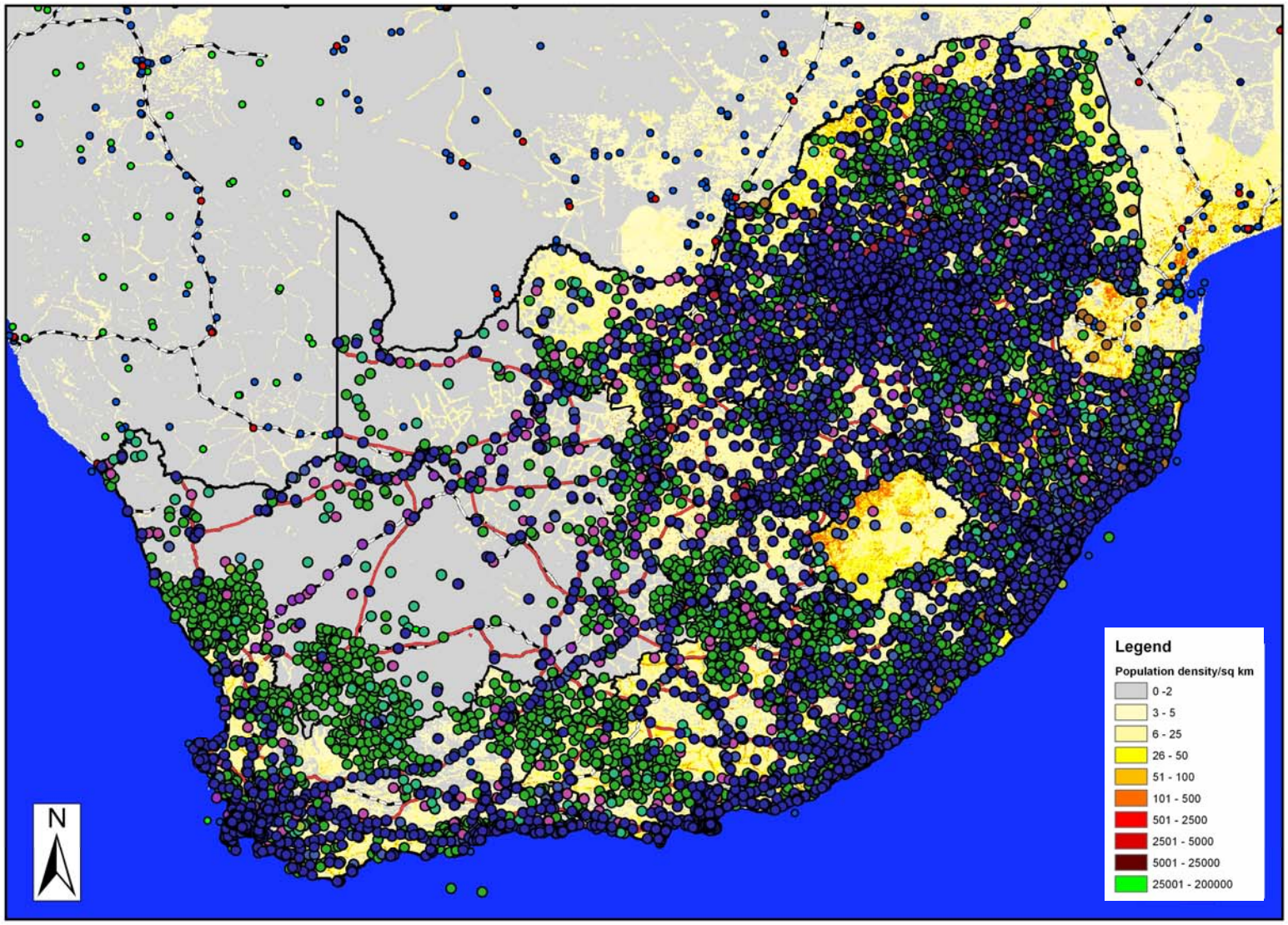
South African SKA



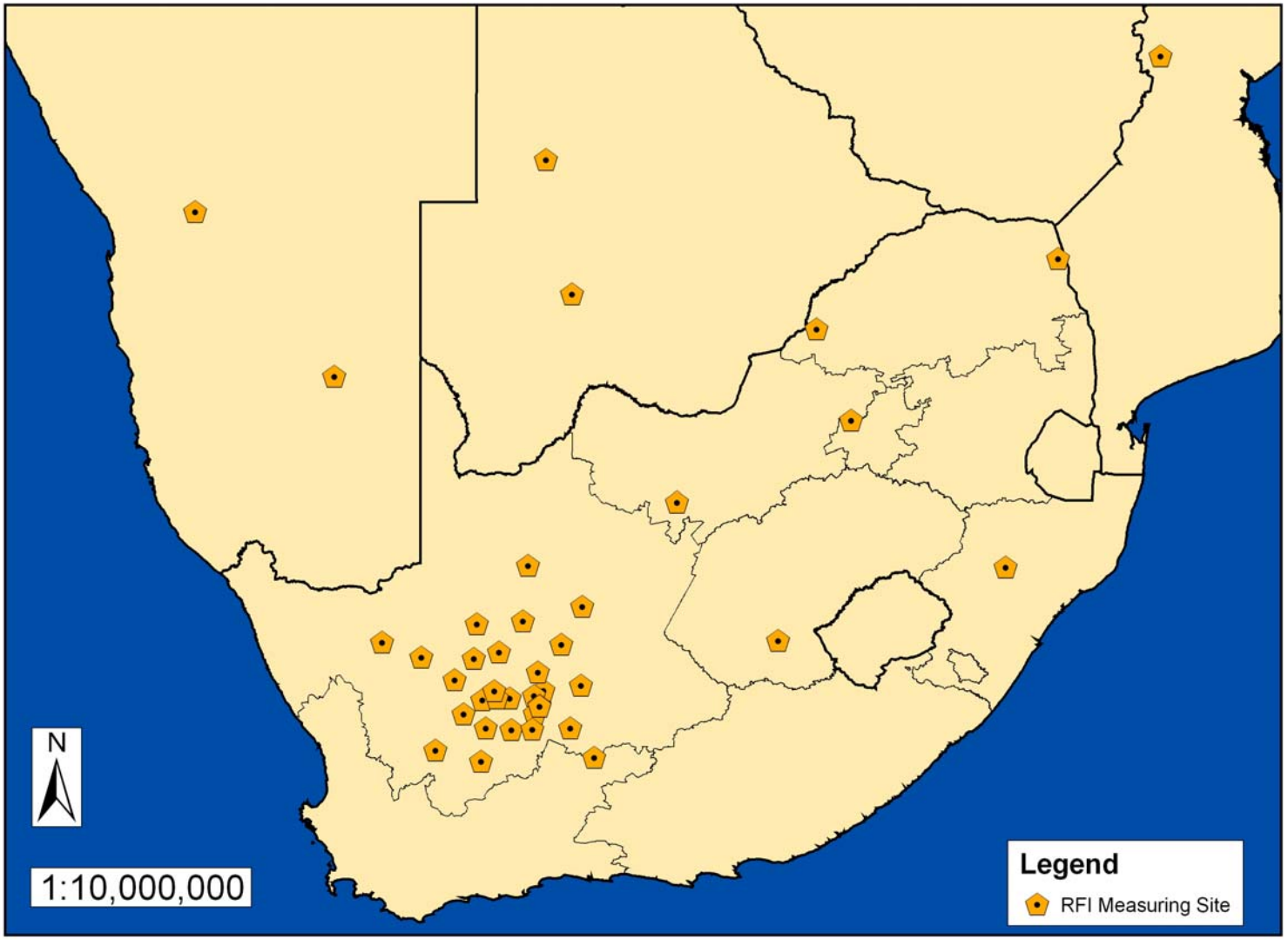
South African SKA



Population density, transport infrastructure and RF transmitters



South African Radio Frequency Measurement Campaign



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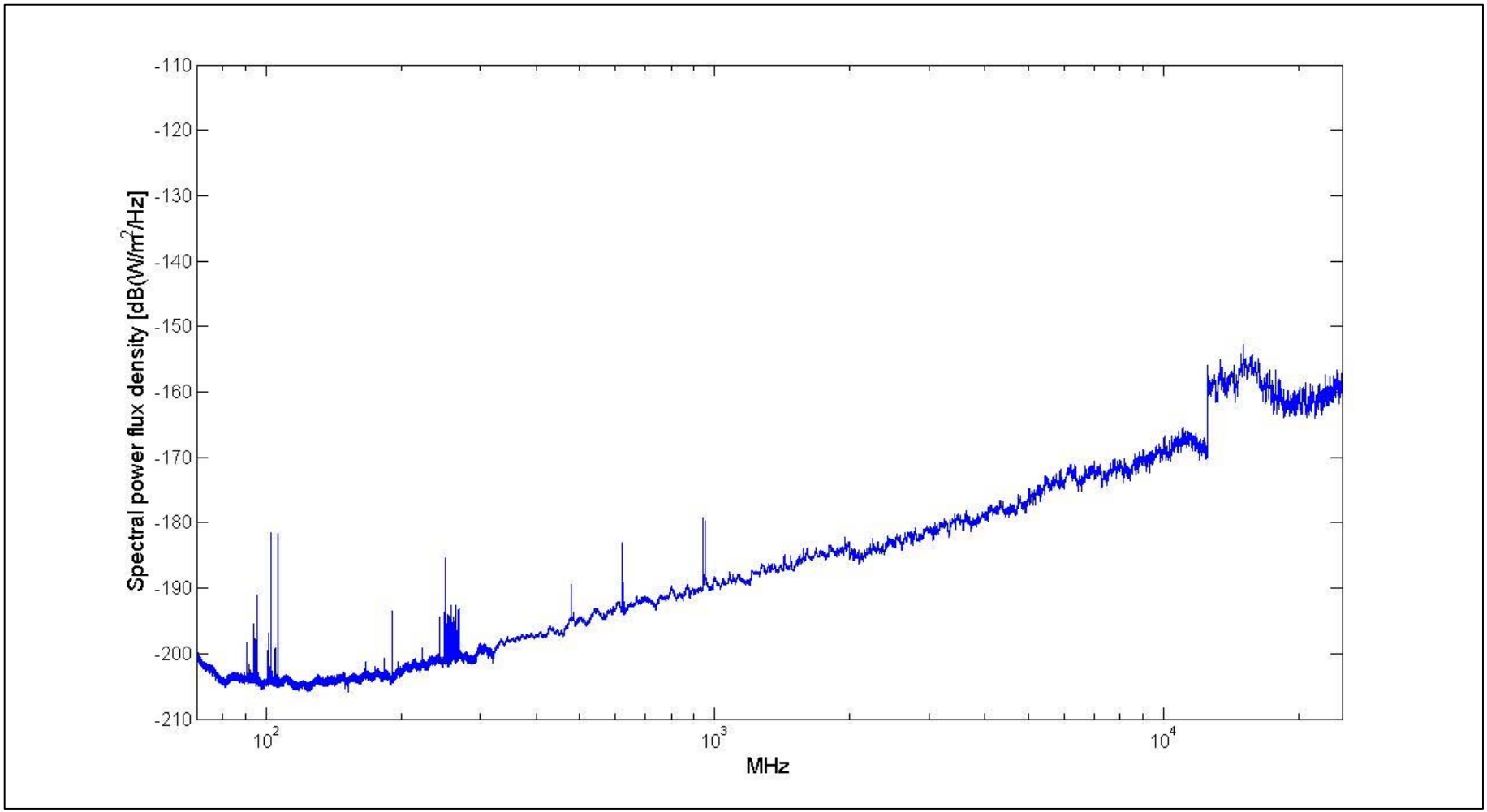
www.ska.ac.za

South African Radio Frequency Measurement Campaign

South African Radio Frequency Measurement Campaign



Astronomy Geographical Advantage Act

- Empowers the Minister for Science and Technology to declare protected areas around strategic astronomy sites by publication in the Government Gazette.
- The Act empowers the Minister to prohibit over-flights
- The Act covers both radio and optical astronomy
- Three tiers of protected areas:
  - Core area – the physical area of the observatory / instrument
  - Central area – surrounds the core area. Minister prohibits certain activities / categories of activities in this area
  - Coordination area –Minister sets standards which activities must comply with
- Protected areas apply to existing and new activities

Government Gazette
Staatskoerant

REPUBLIC OF SOUTH AFRICA
REPUBLIEK VAN SUID-AFRIKA

Vol. 516 Cape Town, Kaapstad, 17 June Junie 2008 No. 31157

THE PRESIDENCY

No. 666 17 June 2008

It is hereby notified that the President has assented to the following Act, which is hereby published for general information:—

No. 21 of 2007: Astronomy Geographic Advantage Act, 2007.

MOPRESIDENTE

No. 666 17 June 2008

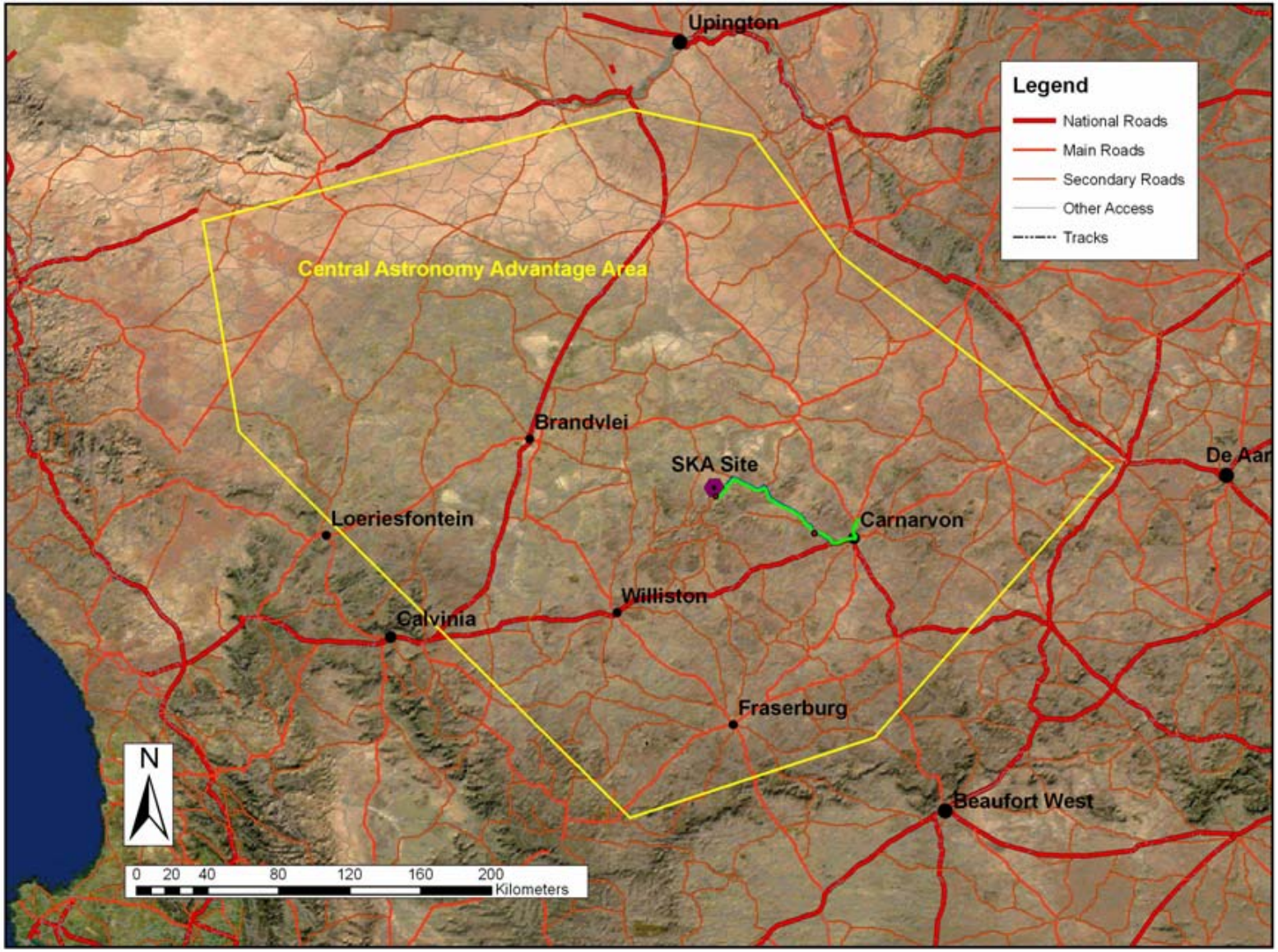
Go itsisiwi fano gore MoPresidente o saennwe Molao o o latelang o o phasalediwang kitso ya botlhe fano:—

No. 21 2007: Molao wa Mafelo a a Siametseng Bolepanaledi wa 2007.

31157

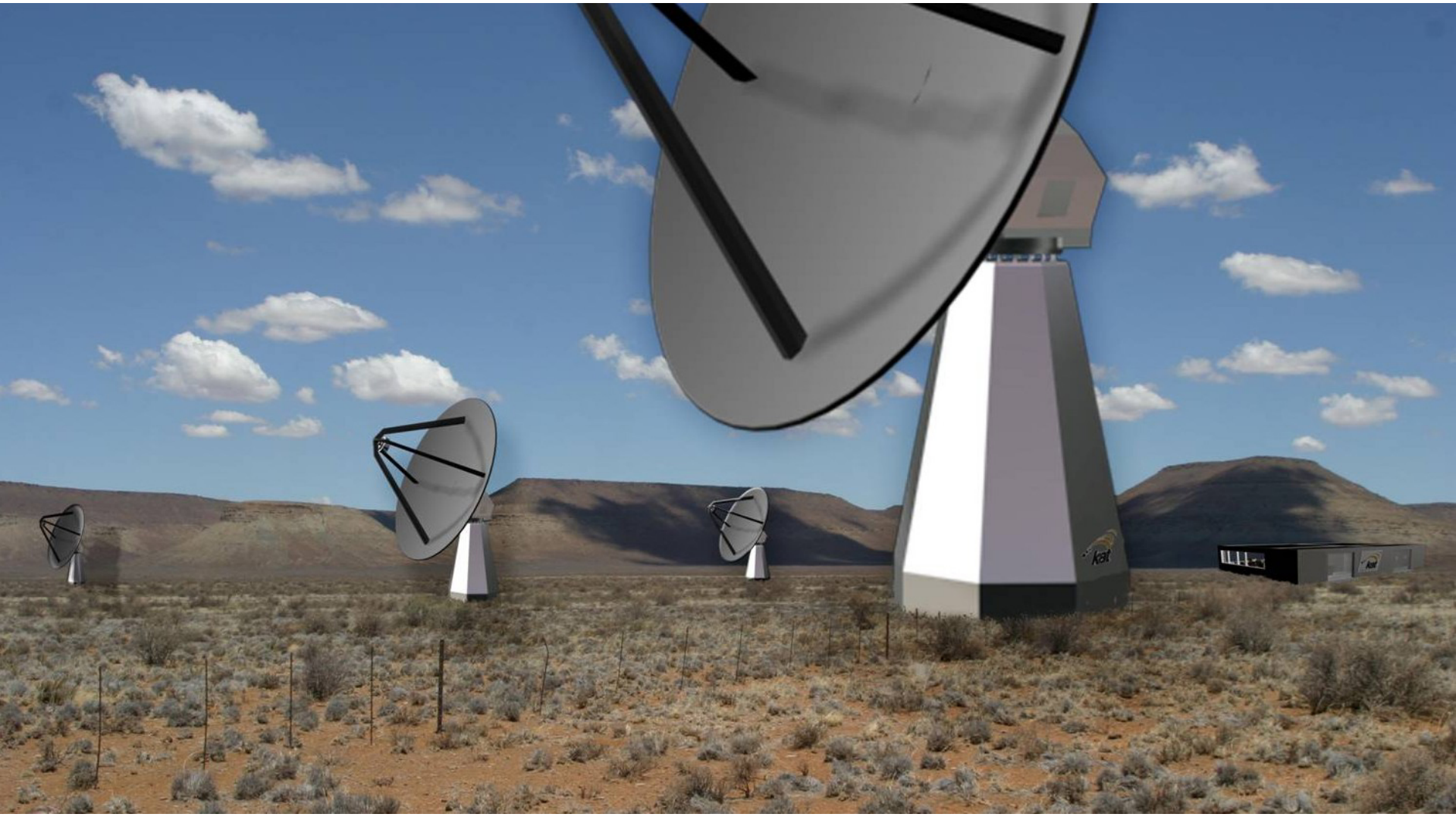
AIDS HELPLINE: 0800-0123-22 Prevention is the cure

Radio Astronomy Reserve



Carnarvon, the town closest to SA SKA site

MeerKAT (Karoo Array Telescope)



MeerKAT

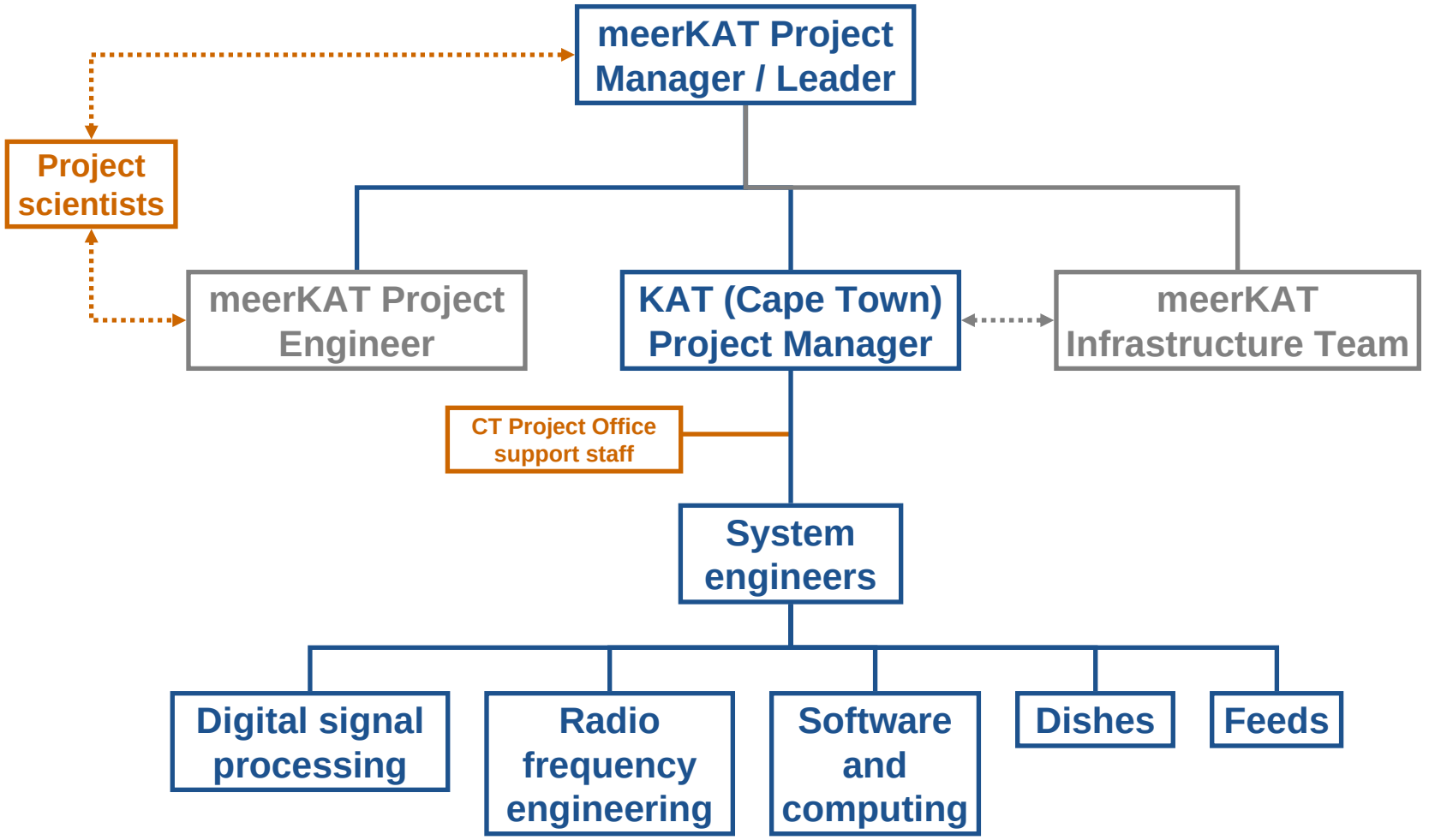
Parameter	MeerKAT
A	>80x15m=14139m^2 (or area equivalent)
T_{sys}	27K
ν [GHz]	0.5-10
$\Delta\nu$	512 MHz
Spectral channels	65536
$\Delta\nu_{min}$	300 Hz
Nominal baseline (max)	5 km
Spatial resolution	10” x (1420MHz/ν) x (5km/L)
Instantaneous FoV	0.73 x (1420MHz/ν)^2 x (15m/D)^2 deg^2
Post-calibration polarisation purity	40 dB

- Includes planning for mid/low frequency aperture array
- Maximum baseline not yet settled – imaging vs. point sources
- Dish diameter not yet settled – cost function dependent on more than just science

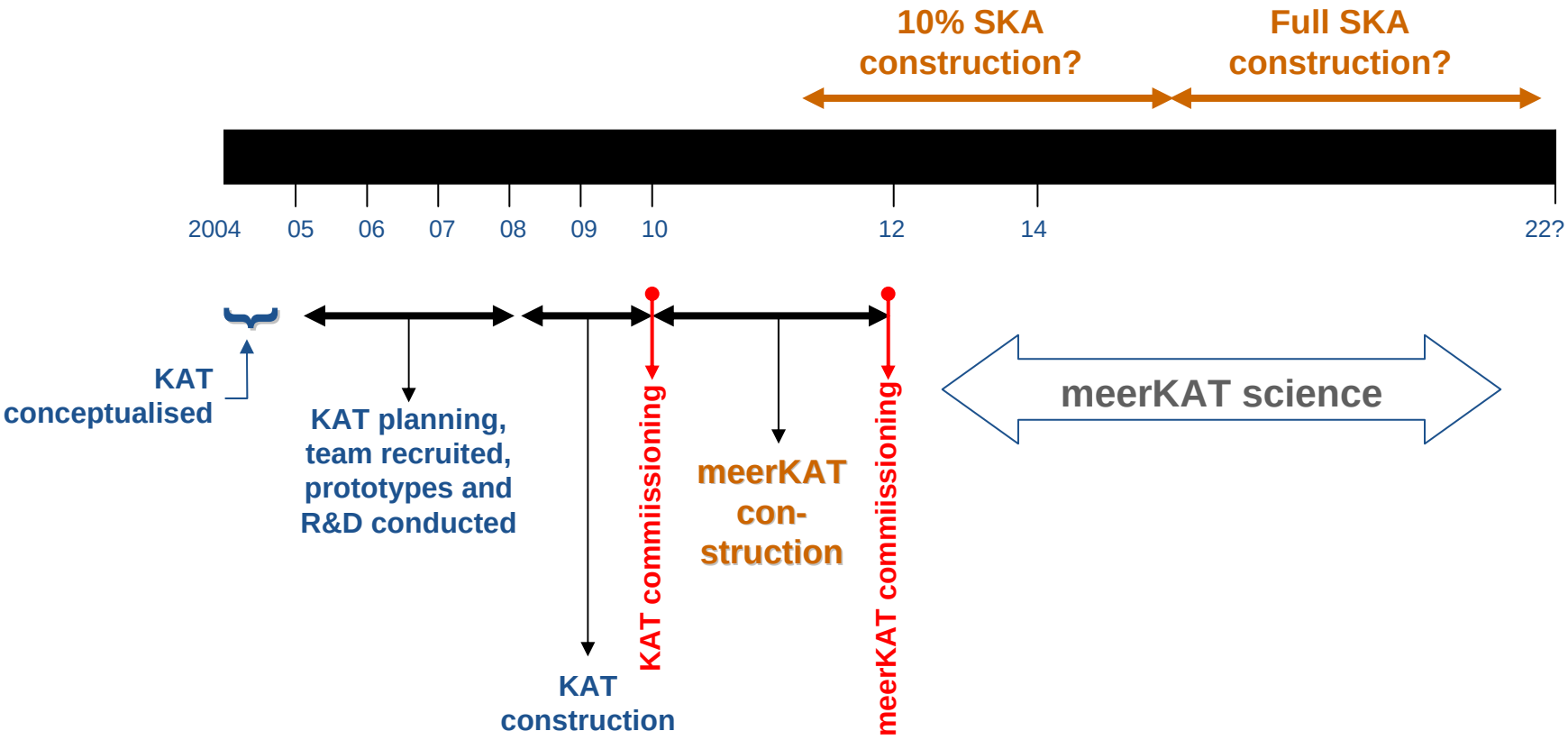
MeerKAT… work in progress

MeerKAT Team, Cape Town

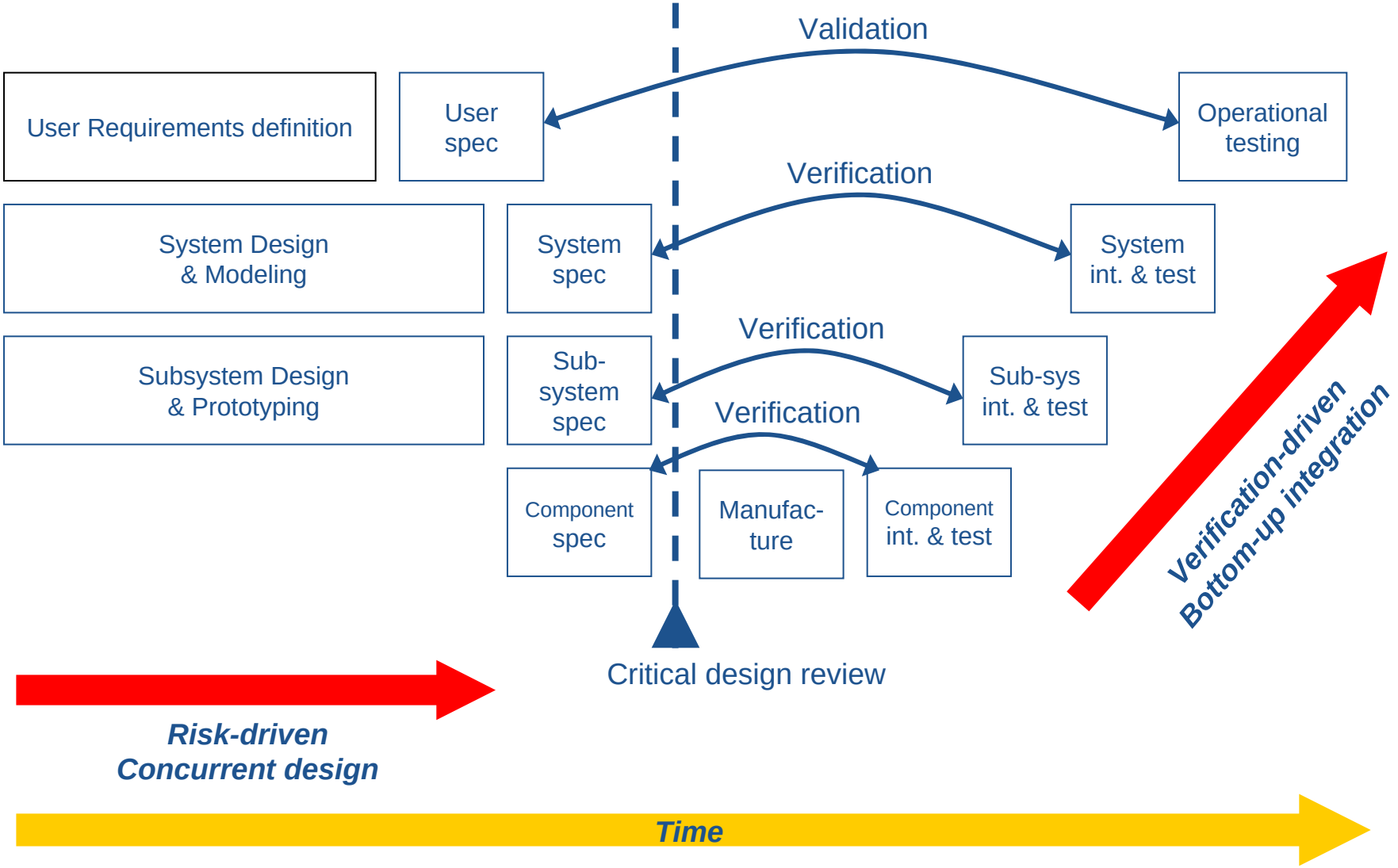
MeerKAT engineering team



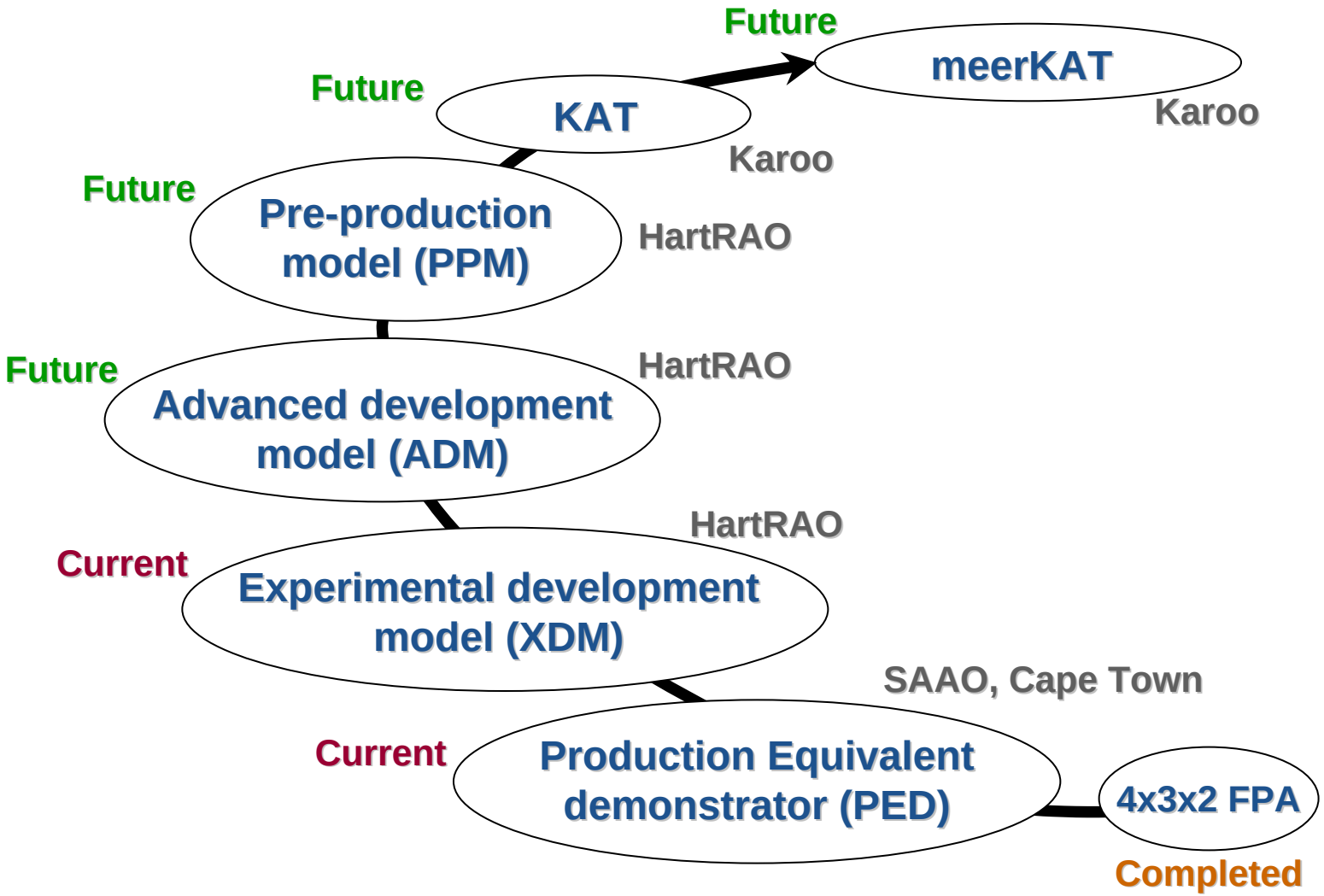
MeerKAT timescales



Making KAT happen – risk driven concurrent design approach



Making KAT happen – implementation through prototypes

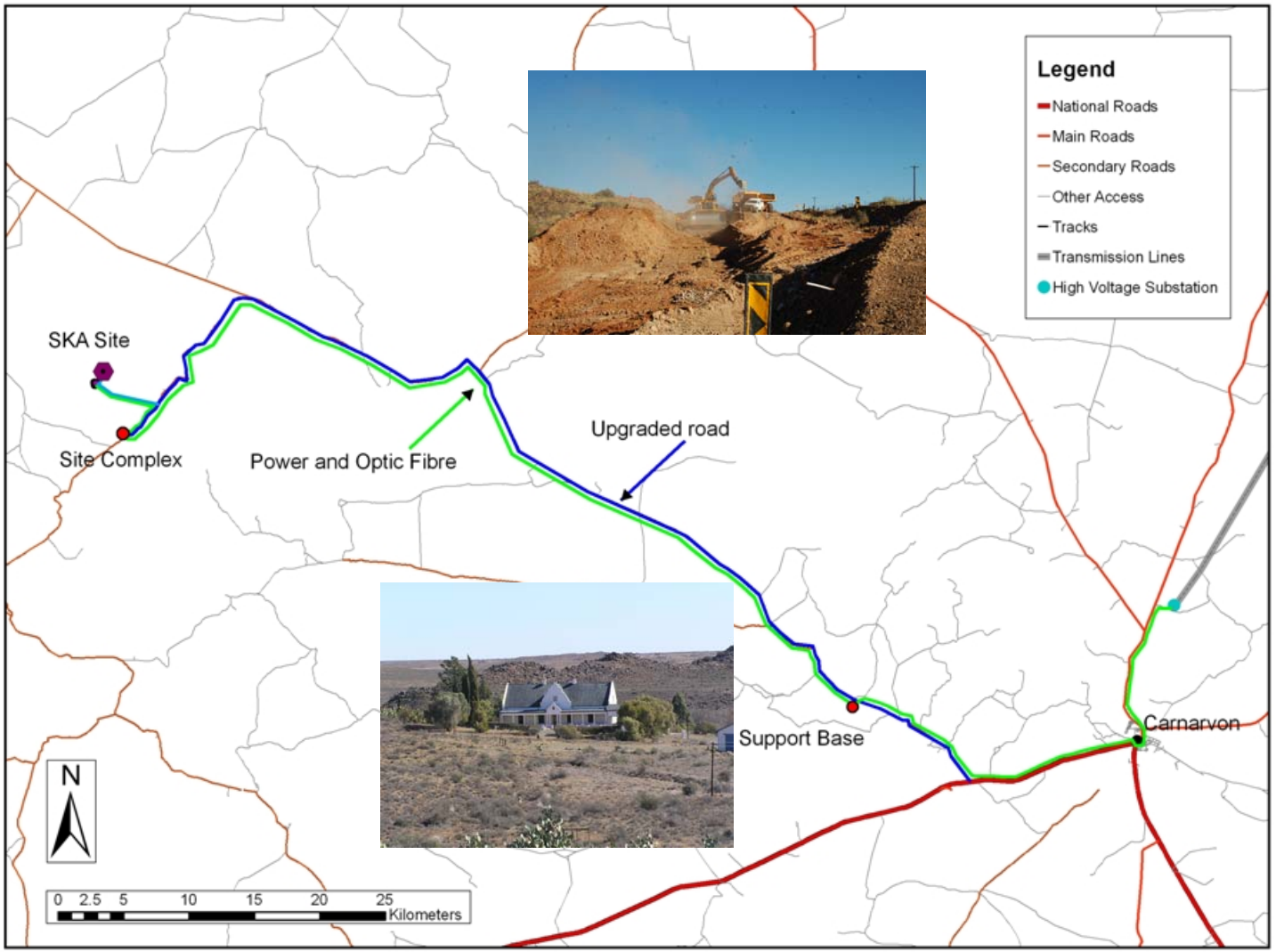


Challenges

- Geographical diversity
  - Teams based in Cape Town, Johannesburg and Grahamstown
- Very tight deadlines
  - 15 year project in 5 years, resulting in incomplete test and verification cycles
  - Over-engineered prototypes
- Experience in radio astronomy
  - Traditionally, radio telescopes built by scientists
  - Expertise held by scientists
  - Initial ‘incompatability’ between scientists and system engineers
- Future proofing
  - User requirements are ‘unknown’
- Highly skilled team members
  - High proportion of PhD’s and masters degrees

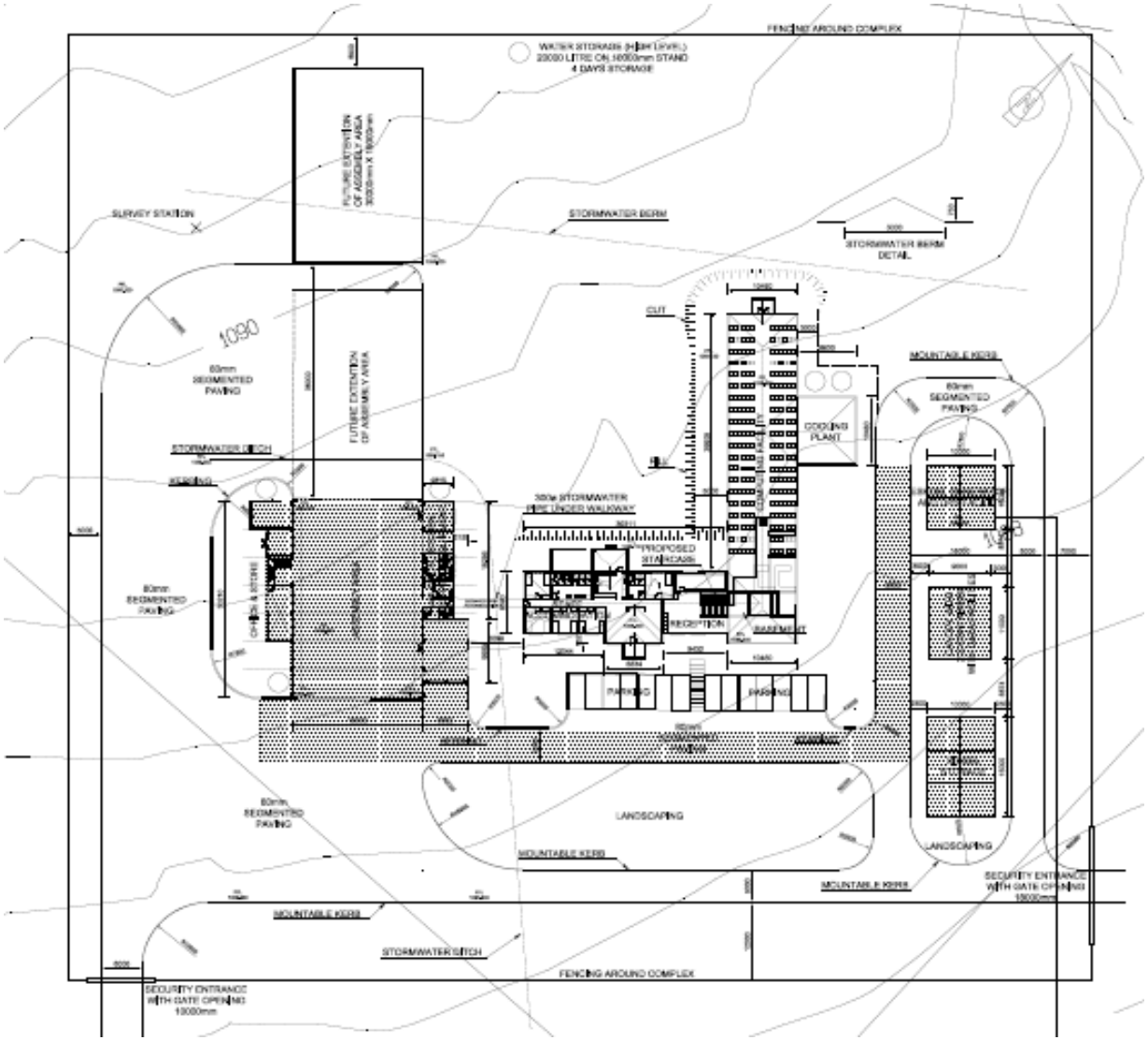
*Meer*KAT… work in progress

Roads and power



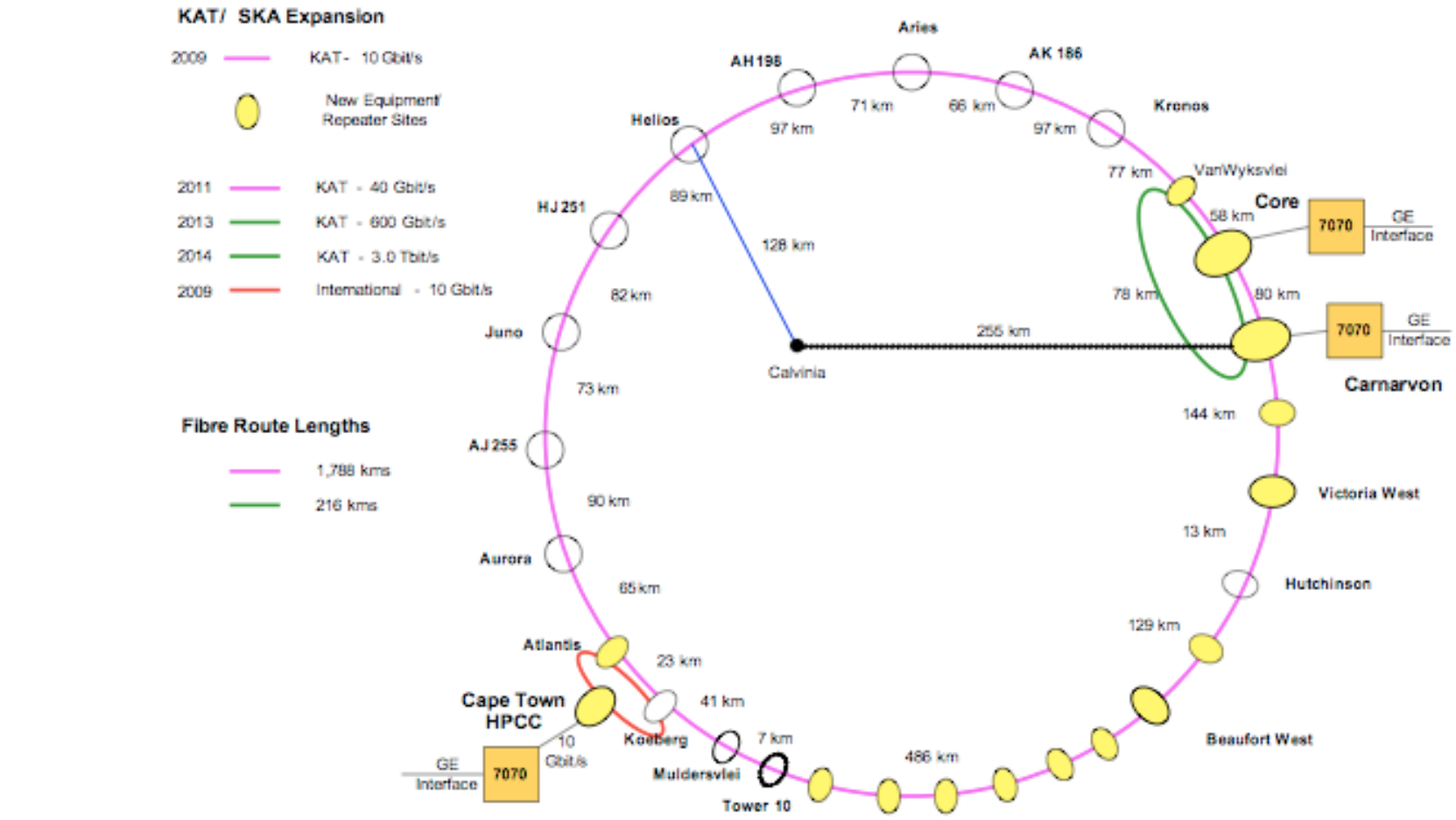
14 000 Ha of land purchased for MeerKAT

RFI-shielded on-site complex for MeerKAT to be built at Losberg



Support base for MeerKAT at Klerefontein, near Carnarvon

Data Transport

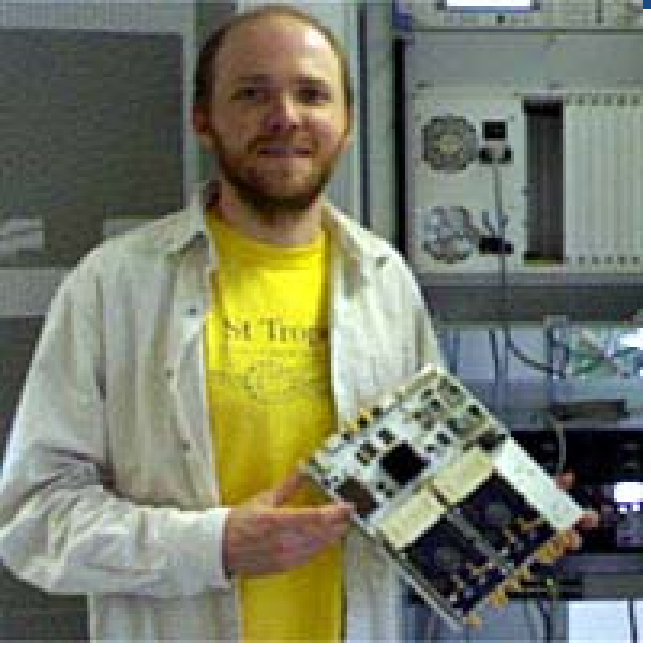


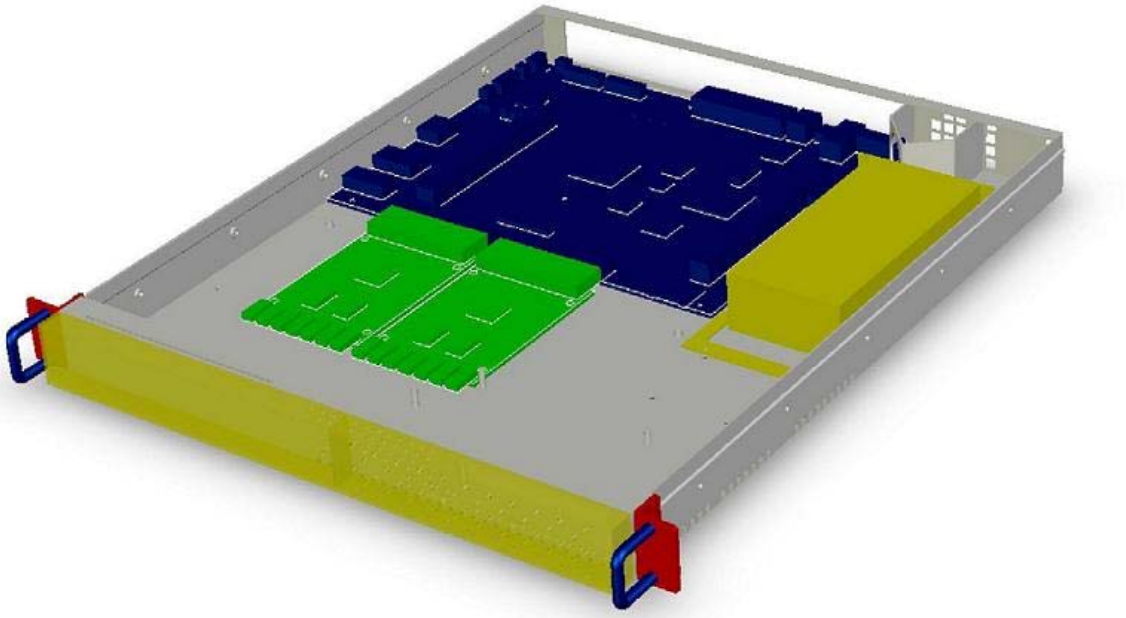
Site to be linked in to regional redundant loop

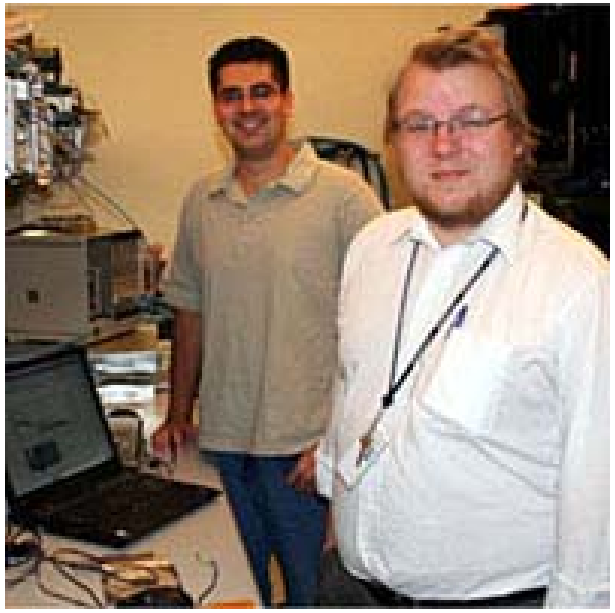
Direct link to SANREN and peer research networks

MeerKAT Collaborations

- South Africa is part of SKA Design Study (FP6 programme) and PrepSKA (FP7 programme)
- Participating in new technology receiver development (FPA) with UK SKADS group (Cambridge, Oxford, Manchester) and ASTRON
- Existing technology partnerships
  - CONRAD (www.conradsoftware.org)– South African/Australian collaboration to develop software for new generation radio astronomy array telescopes
  - CASPER(casper.berkeley.edu) – Collaboration to develop new generation, generic backend digital signal processing boards for astronomy facilities
- Other collaborations
  - Caltech/Jet Propulsion Labs (USA)
  - University of Illinois (USA)
  - University of Wisconsin
  - Cornell University
  - IBM







Collaboration with Berkeley University to develop ROACH

(digital back end for MeerKAT)

Human Capital Development

- Initiated in 2004 to leverage attraction of SKA and MeerKAT
- Raise interest of careers in science and technology and grow human capital in
  - radio astronomy, fundamental physics, radio frequency engineering, digital signal processing, software engineering, high-performance computing, rapid data transport and related subjects.
- Strategy to grow science, engineering and technology at school, undergraduate, post-graduate and senior research levels
  - The SA SKA senior researchers programme
  - The SA SKA postgraduate bursay programme
  - The SA SKA undergraduate bursary and development programme
  - The SA SKA astronomy and engineering schools programme
  - The SA SKA supplementary mathematics and science teaching programme
  - The SA SKA Youth into Science programme
- Dual supervision agreements for SA SKA/KAT bursars with Cambridge, Oxford, Manchester, Caltech, Illinois

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SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY

SKA
SQUARE KILOMETRE ARRAY

meerkat
karoo array telescope

HartRAO

science and technology
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