The Acquisition of KAT-7

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Objectives

To present KAT-7 as a case study

- Successful acquisition of a complex system using systems engineering principles
- Challenges
- Lessons learned

- Looking ahead: MeerKAT and the SKA

About SKA South Africa

The SKA SA project is funded by the Department of Science and Technology (DST), and is administered by the National Research Foundation (NRF).

Johannesburg office:

- Human Capital Development
- Infrastructure & Ancillaries Management Team
- Site Bid Team

Cape Town office:

- KAT-7 / MeerKAT Telescope Engineering Team
- African VLBI Network Engineering Team

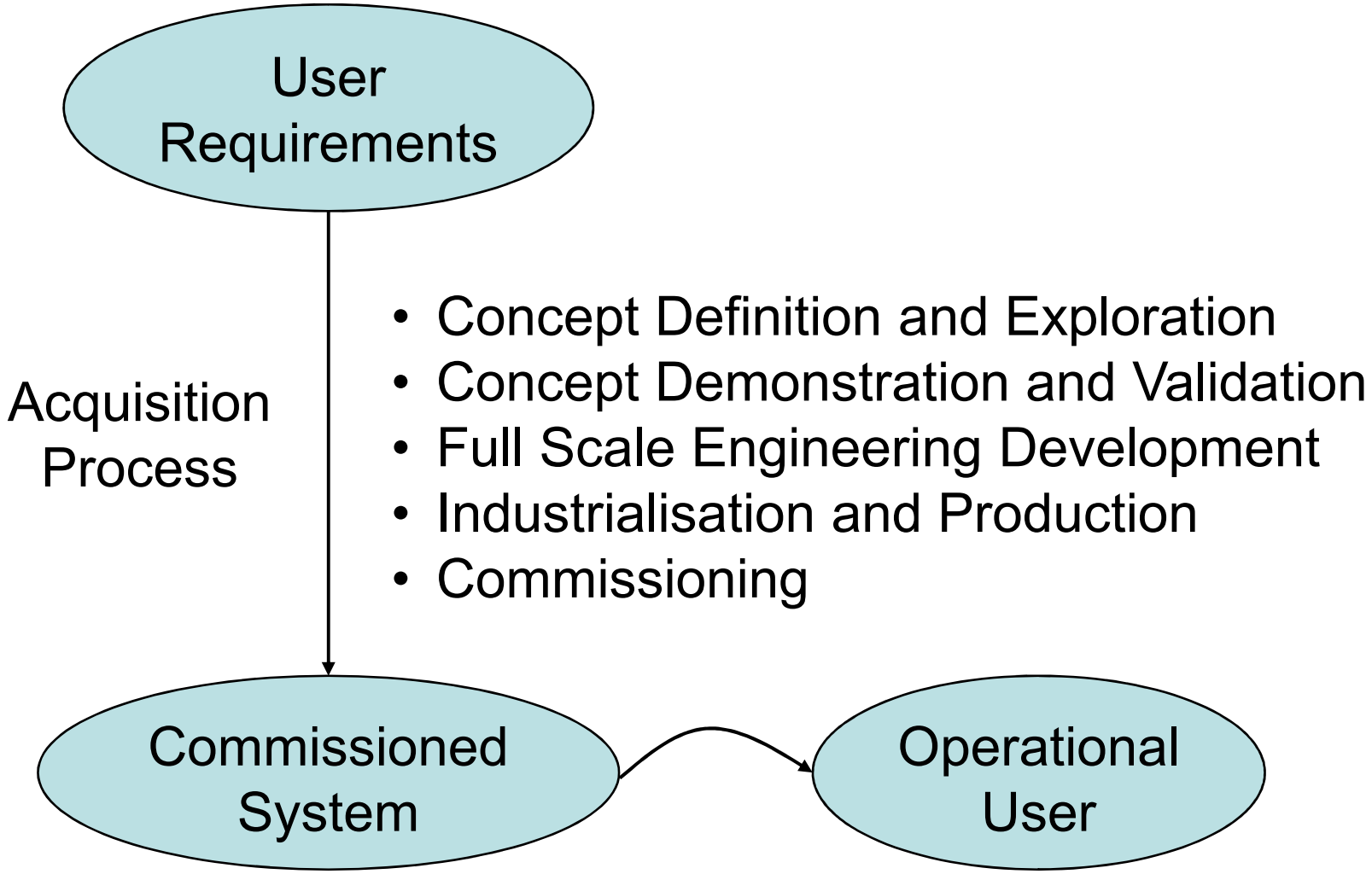
Klerefontein office (Support Base near Carnarvon):

- Site Operations and Maintenance Support Teams

Losberg (Site Complex about 80km NW of Carnarvon):

- On-site Infrastructure and Accommodation

The Acquisition Process



What is KAT-7?

- First *interferometric* radio telescope in Africa!
- Stepping stone towards MeerKAT
- System in its own right
- Engineering Development Model (EDM) for MeerKAT
  → Meant to qualify MeerKAT design
  → However, MeerKAT design has changed
- Aim: To implement an operational system in the Karoo to learn the lessons of how to operate and maintain a radio telescope on a remote site.

Challenges

- Ever-changing user requirements
- Astronomers and scientists getting involved with engineering solutions, instead of focussing on science requirements
- Geographically dispersed project team
- Challenging Karoo environment
- Lack of infrastructure in the Karoo
- Developing process maturity
- Lack of user domain experience
- Non-existence of enabling systems

Risk Reduction for MeerKAT

XDM
(1 Antenna)

KAT-7
(7 Antennas)

MeerKAT
(64 Antennas)

Artist's Impression

XDM Timeline

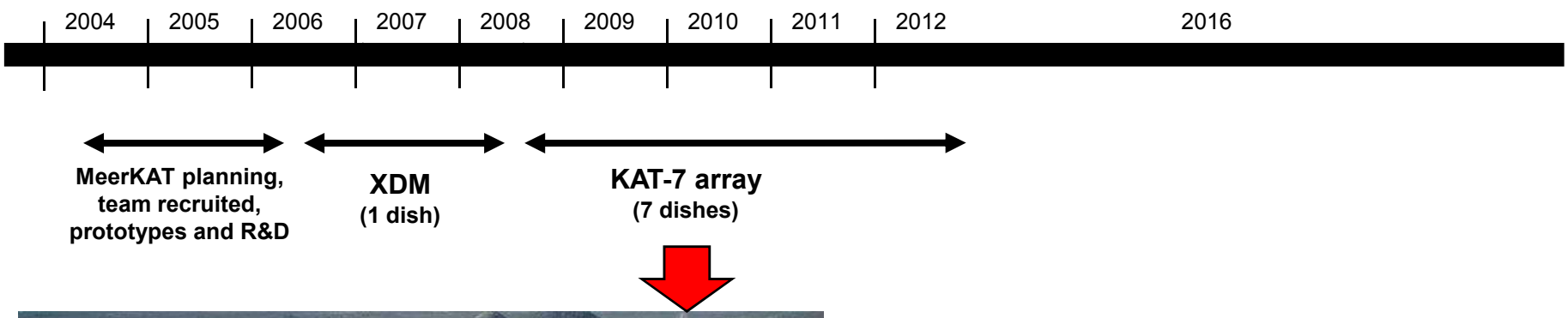
MeerKAT planning, team recruited, prototypes and R&D

XDM (1 dish)

- Build a coherent engineering team
- Address technical risks
- First single-dish radio telescope
- Aggressive timescale
  - 18 months from concept definition to acceptance testing completed on site

Key Specs	
Dish	15m Prime Focus
Frequency Range	1.4 – 1.7 GHz
Processed Bandwidth	256 MHz

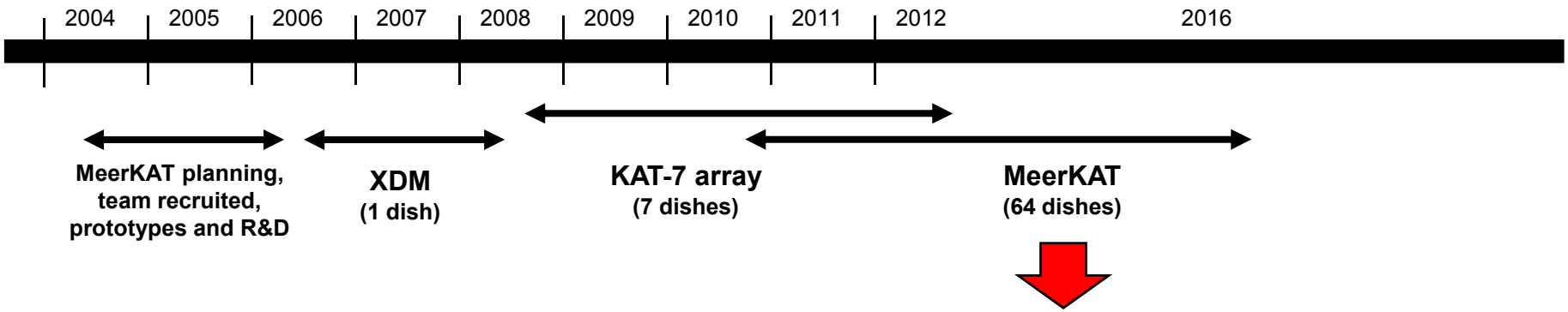
KAT-7 Timeline



- First array radio telescope
- Deployment and operation on a remote site

Key Specs	
Dish	12m Prime Focus
Frequency Range	1.2 – 1.95 GHz
Processed Bandwidth	256 MHz
Baseline max	185 m

MeerKAT Timeline



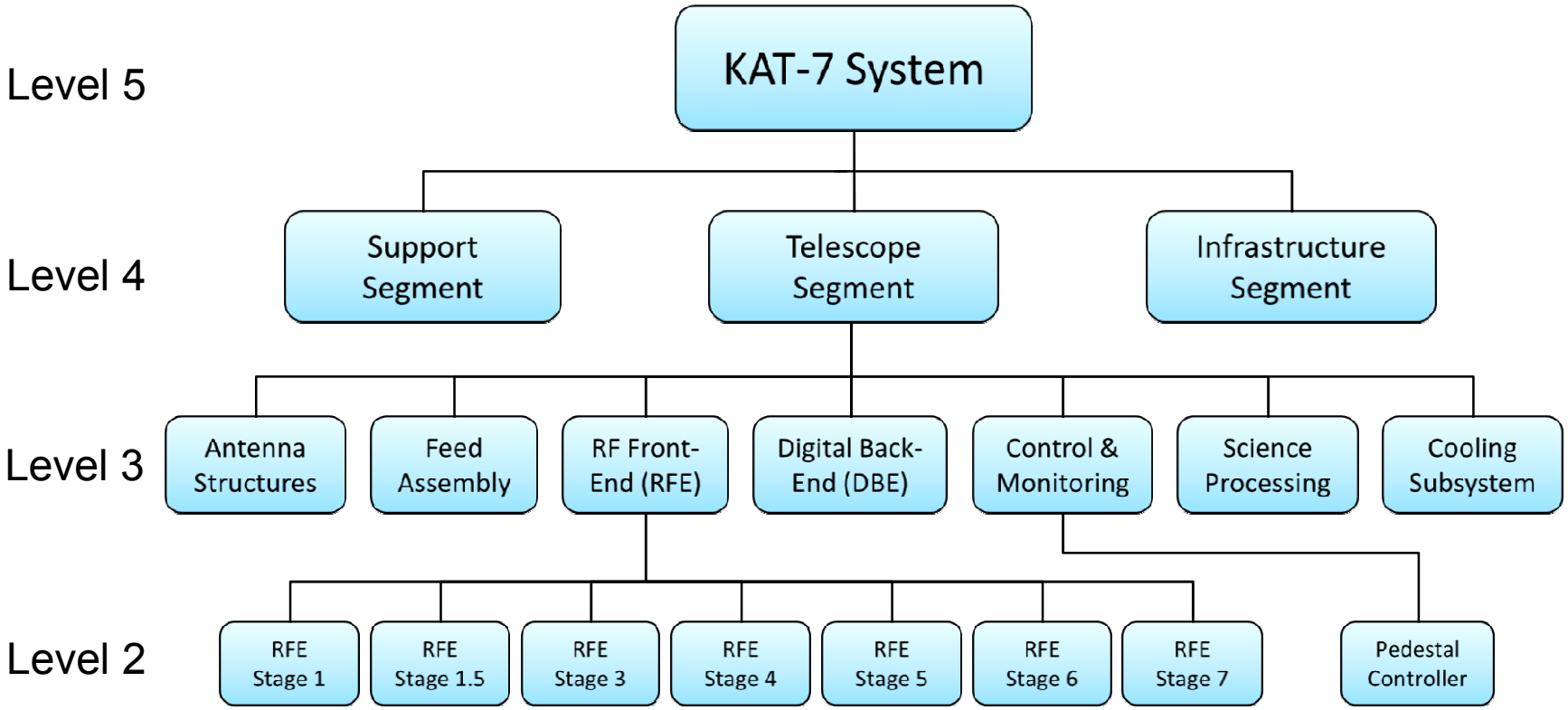
World-class operational radio telescope
SKA pre-cursor

Key Specs	Phase 1	Phase 2
Dish	13.5m Offset Gregorian	
Frequency Range (GHz)	0.9 – 1.67	0.58 – 1.015 0.9 – 1.67 8 – 14.5
Processed Bandwidth	770 MHz	2000 MHz (goal 4000 MHz)
Baseline max	8 km	20 km

Concept Definition and Exploration

- KAT-7 did not start with a formal URS
- In 2007 the scope and development strategy of MeerKAT were investigated
- Frequency band and array configuration (among other parameters) were limited, based on:
  - Scientific capability
  - Affordability
  - Technical feasibility
- It was recommended that KAT-7 should become the start of MeerKAT
- This did not materialise – scope of project has changed considerably, including timescales, budget and user requirements

KAT-7 System Breakdown Structure

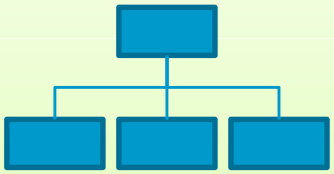


Concept Demonstration and Validation

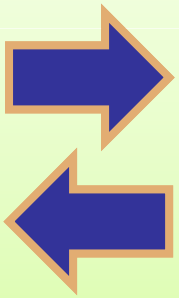
- Done by analysis and simulation
- In some aspects, the XDM can be seen as KAT-7's advanced development model, since it demonstrated that the required technology was obtainable
- 1040 system-level requirements recorded in CORE

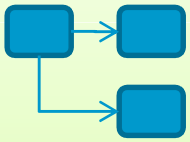
Architecture Design Process Overview

Architecture driving requirements



Physical decomposition

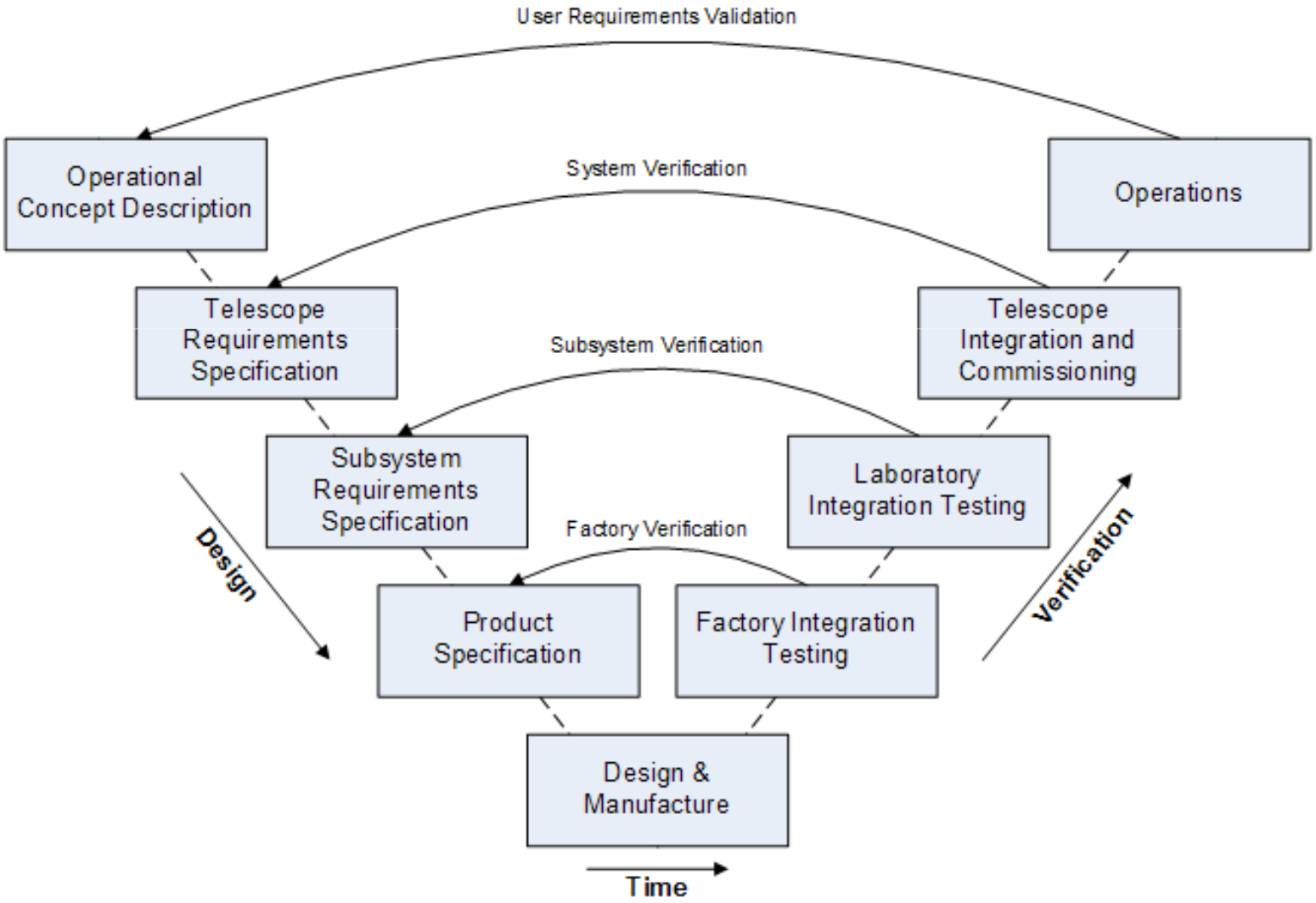




Functional analysis

List of requirements for each subsystem

Full Scale Engineering Development



Qualification and Acceptance Testing

- Qualification testing performed on *all* items
- Acceptance testing performed on all *production* items

- ~50 Factory ATPs
- ~30 Lab Inspection ATPs
- ~20 On-Site Installation ATPs
- 2 System-Level ATPs (Phase 1 and Phase 2)

Key Performance Indicators

Description	Requirement	Achieved
Frequency Range	1200 – 1950 MHz	1200 – 1950 MHz
Instantaneous Bandwidth	≥ 256 MHz	256 MHz
Wideband Channel Bandwidth	< 1 MHz	390.625 kHz
Spectral Line Channel Bandwidth	OH Search: ≤ 2.8 kHz OH Monitoring: ≤ 530 Hz	1.525879 kHz 381.4697 Hz
T_{sys}	≤ 35 K at zenith	~25 K at zenith ~30 K for θ_{ele} > 30°
Linear Polarisation Purity	≥ 25 dB	> 27 dB
Circular Polarisation Purity	≥ 30 dB	> 30 dB

Integration and Verification

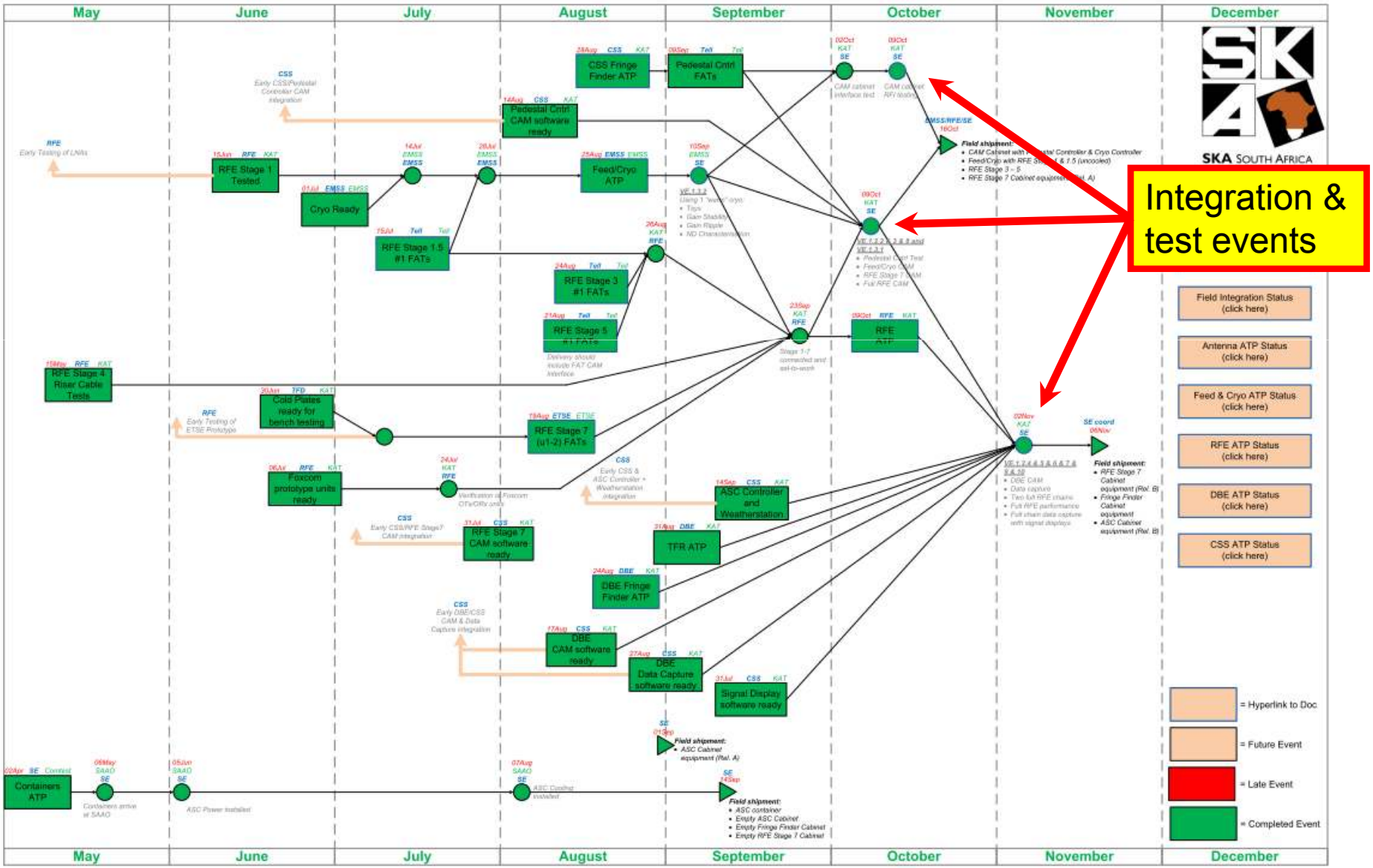
- Integration lab in Cape Town used extensively
- Integration test beds were not used, since number of production items was manageable
- Hardware simulators were used to qualify C&M system
- Final system-level ATP for Phase 1 conducted in 2011
- Final system-level ATP for Phase 2 due end of 2012

Iron laws of a system's life cycle*:

1) Problems downstream are symptoms of neglect upstream
2) Upstream problems can only be solved upstream

* Ad Sparrius

Integration Planning



Industrialisation and Production

Since KAT-7 is a one-off system, there was no production stage, and hence also no industrialisation stage.

Commissioning

Engineering Verification

- Verifies that the system meets the system requirements
- Qualification and acceptance testing performed on all system levels
- Seen as part of the Full Scale Engineering Development stage

Commissioning

- Involves the characterisation and calibration of the instrument
- Establishes the “user system”

User Verification

- Verifies that the system meets the requirements of the science user and the operational user

Utilisation, Support and Retirement

- KAT-7's utilisation was seen to be limited to a relatively short time period, and limited to engineering operations and some scientific operations
- This view is starting to change!
- Current emphasis is on Logistic Support Functions
- Retirement of KAT-7 has not yet been determined

Logistic Support Functions

Mission and Operations Functions

Logistic Support Functions

KAT-7 Telescope

Operators + Maintainers

Supplies

Facilities

Support-, Test- and Training Equipment

Data

Tools

Systems Engineering

- CORE from Vitech Corporation (http://www.vitechcorp.com)
- Capturing of requirements and verification requirements
- Requirements Traceability
- Functional Modelling

Configuration Management System

- enterprise Bridge (eB) (http://eb-director.software.informer.com)
- Controls as-built, as-maintained and as-operated information
- Contains history and latest revision of all documents, drawings, datasheets, manuals
- Manages waivers and engineering change proposals (ECPs)

Maintenance System

- RamLog.Net (http://www.ramlog.net)
- Manages all maintenance tasks
- Collects, consolidates and reports failure and repair data
- Creates, despatches and collects electronic work orders, job cards, item orders and delivery notes

Lessons Learned

- Ensure that the SEMP is tailored to the project, clearly written, and communicated to all subsystems.
- Ensure that the SE process is tailored for each subsystem.
- Ensure that each subsystem goes through the requirements review process and produces a requirement specification that has been formally reviewed.
- Ensure that each subsystem's or subcontractor's CDR is accompanied by a fully signed-off qualification test report, which verifies that the design meets the given requirements.
- Avoid granting waivers too easily, because problems downstream become more and more difficult to resolve.

Lessons Learned (continued)

- Ensure that subcontracted configuration items are not only acceptance tested at the factory, but also at the integration lab (where appropriate), as well as on-site after the installation process has been completed.
- Include logistic support analysis early in the process, as part of management plans, requirement specifications and contractual requirements.
- Collect design, manufacture and as-built information as part of the final acceptance of a delivered item, not later. This information needs to form part of contract milestones.
- Perform a physical configuration audit immediately after an item's final installation acceptance testing has been completed.
- Ensure that the Configuration Management System is always up to date, and that everybody in the organisation is using it correctly.

Acknowledgements

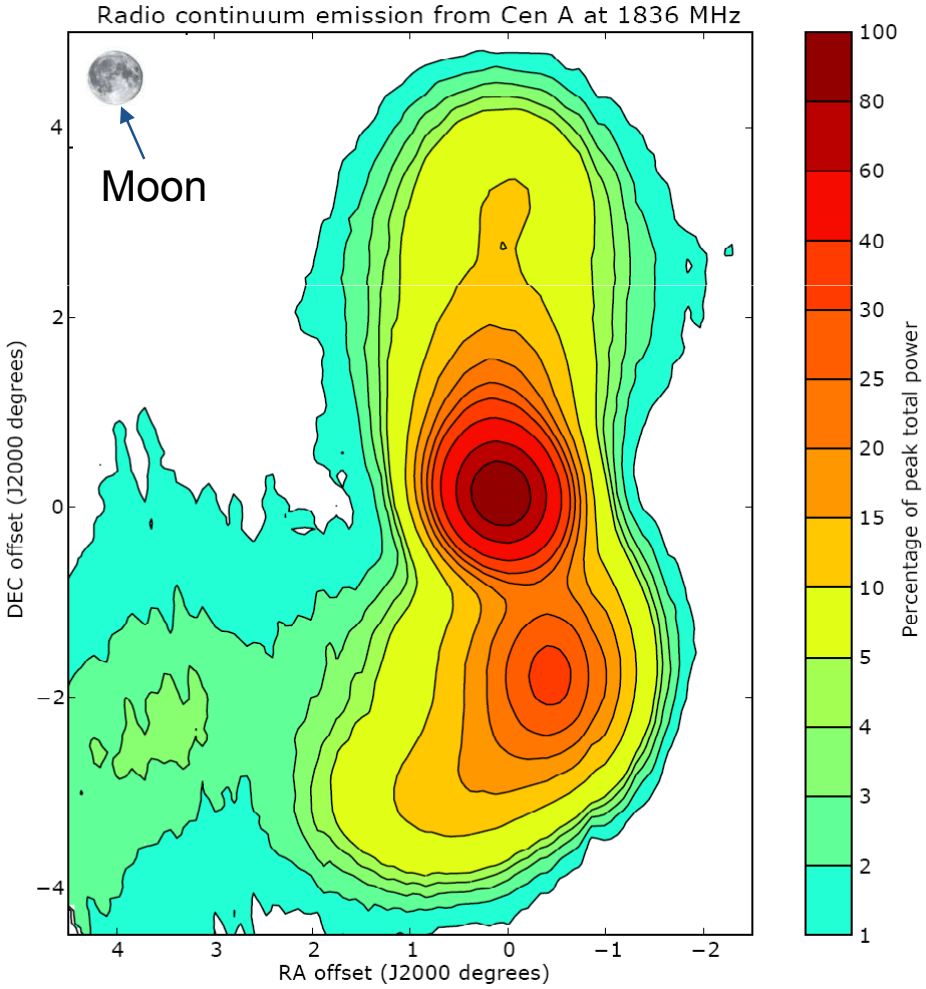
- Thomas Küsel
  → Lead systems engineer for MeerKAT
- Adriaan Peens-Hough
  → Responsible for performance-related issues
- Clifford Gumede
  → Interface manager
- Darrel Liebenberg
  → Senior logistic engineer
- Caxton Magozore
  → Integration support
- Pieter Kotzé
  → Managed final system-level ATP


KAT-7

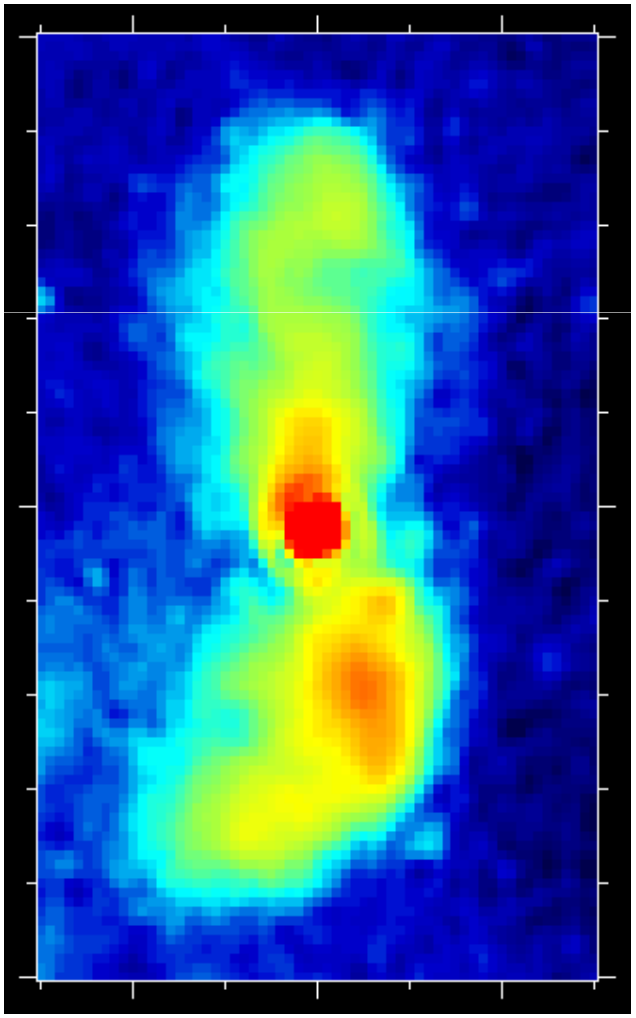
Operators and Commissioners in CPT

The First “Single Dish” Image

First KAT-7 image with Antenna 1 at 1836 MHz

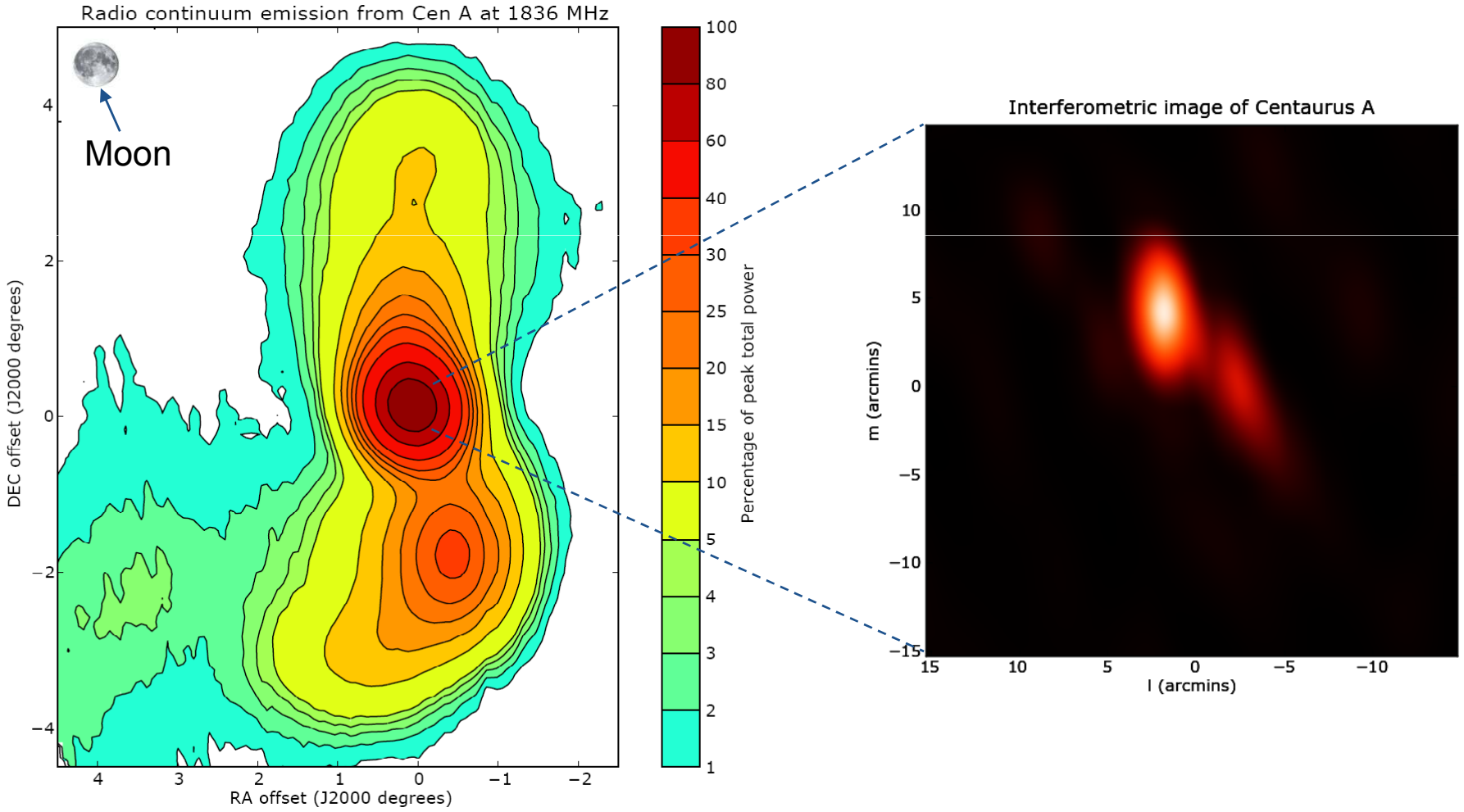


Rhodes/HartRAO 2326 MHz survey

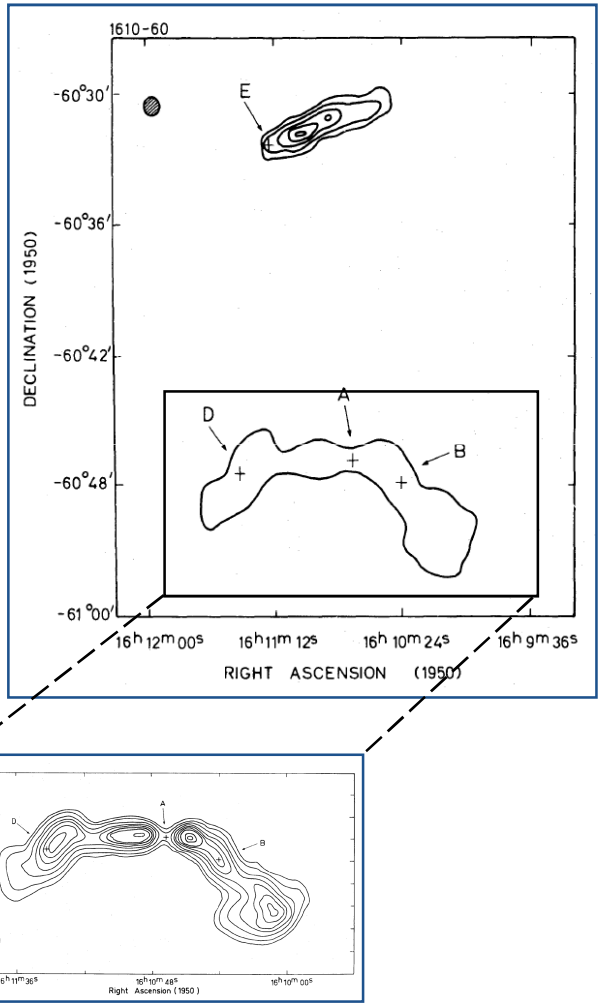


The First Interferometric Image

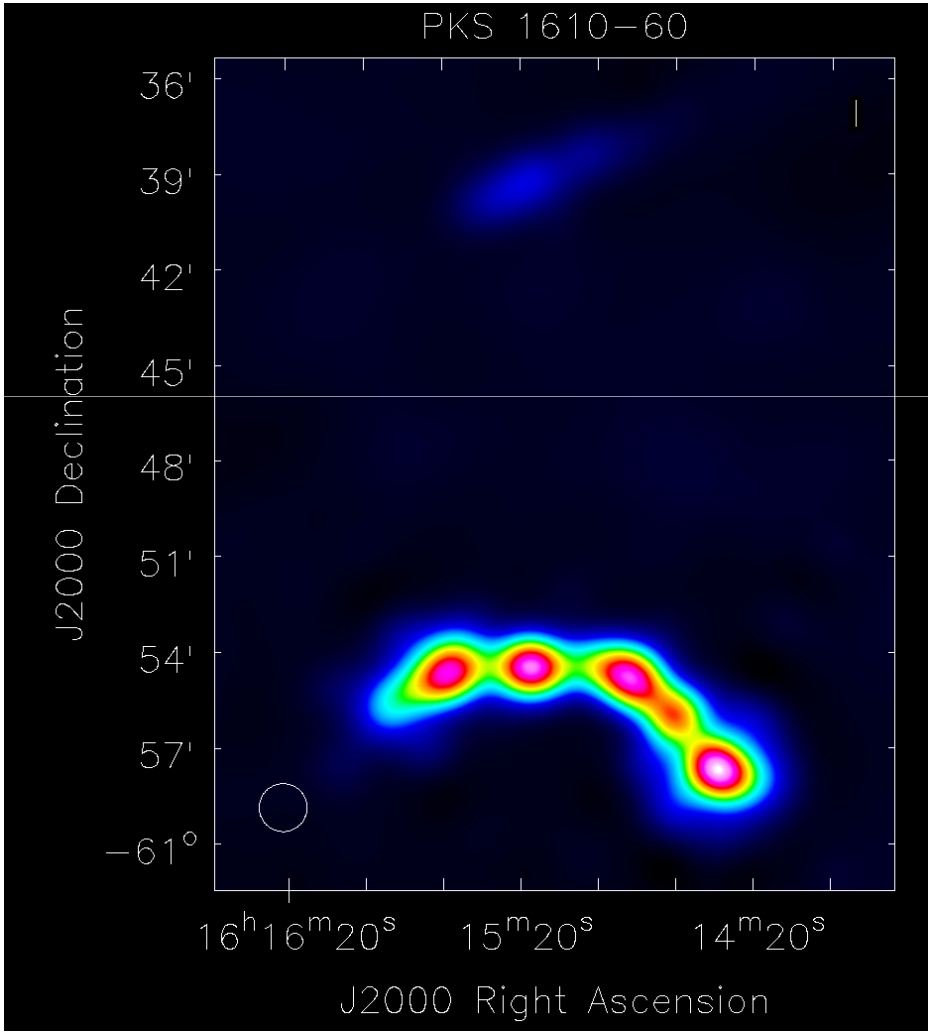
First KAT-7 image with 4 Antennas



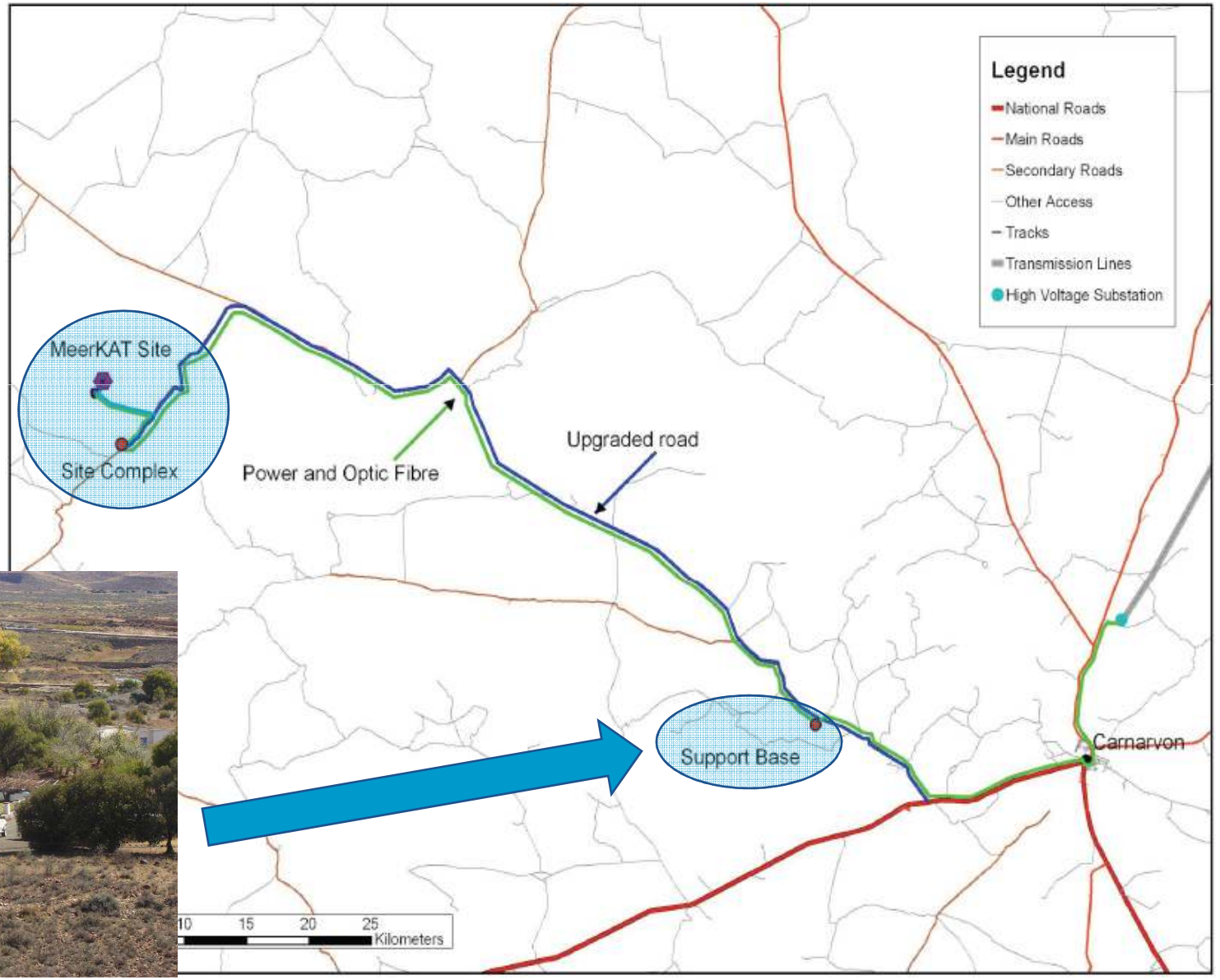
PKS 1610-60.8 observed with KAT-7



PKS 1610-60.8 at 1415 MHz
(Christiansen, et al. 1977)



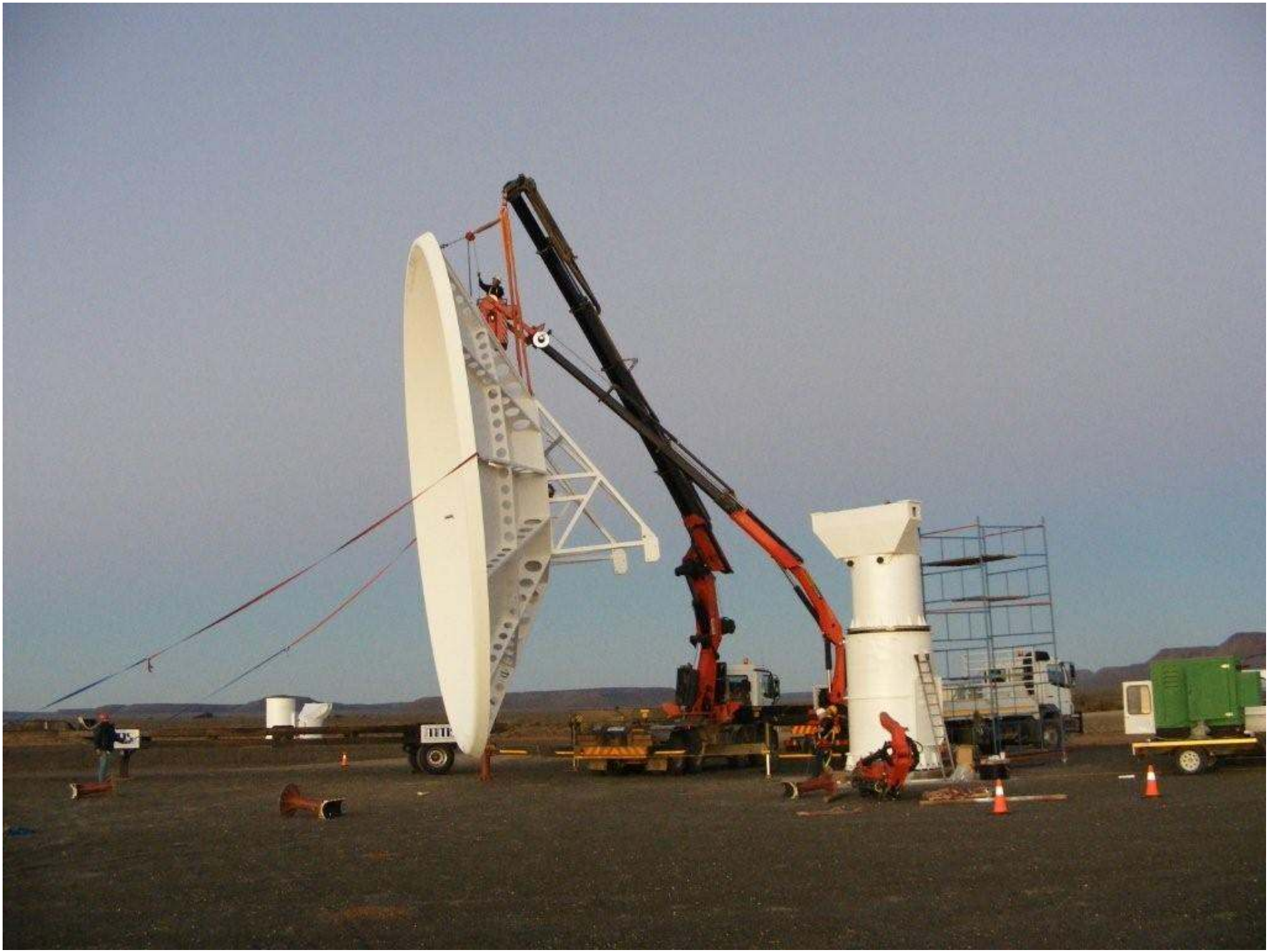
MeerKAT Site



Losberg (Site Complex)

Pedestals being transported to site

Completed Reflector



Why build MeerKAT?

MeerKAT Project Goals:

"*To be an inspiring flagship project for highlighting South African competence in technology and science, and enhancing South Africa's participation in the global knowledge economy*"

- Create a **world-class decimeter/cm wavelength telescope**
- **Attract and retain** scientists and engineers
- **Inspire** new generation of South Africans to pursue careers in science and high technology
- **Stimulate supporting industry**, particularly hi-tech industries
- Serve as engineering prototype and early science **pathfinder for SKA**

MeerKAT: Artist's Impression

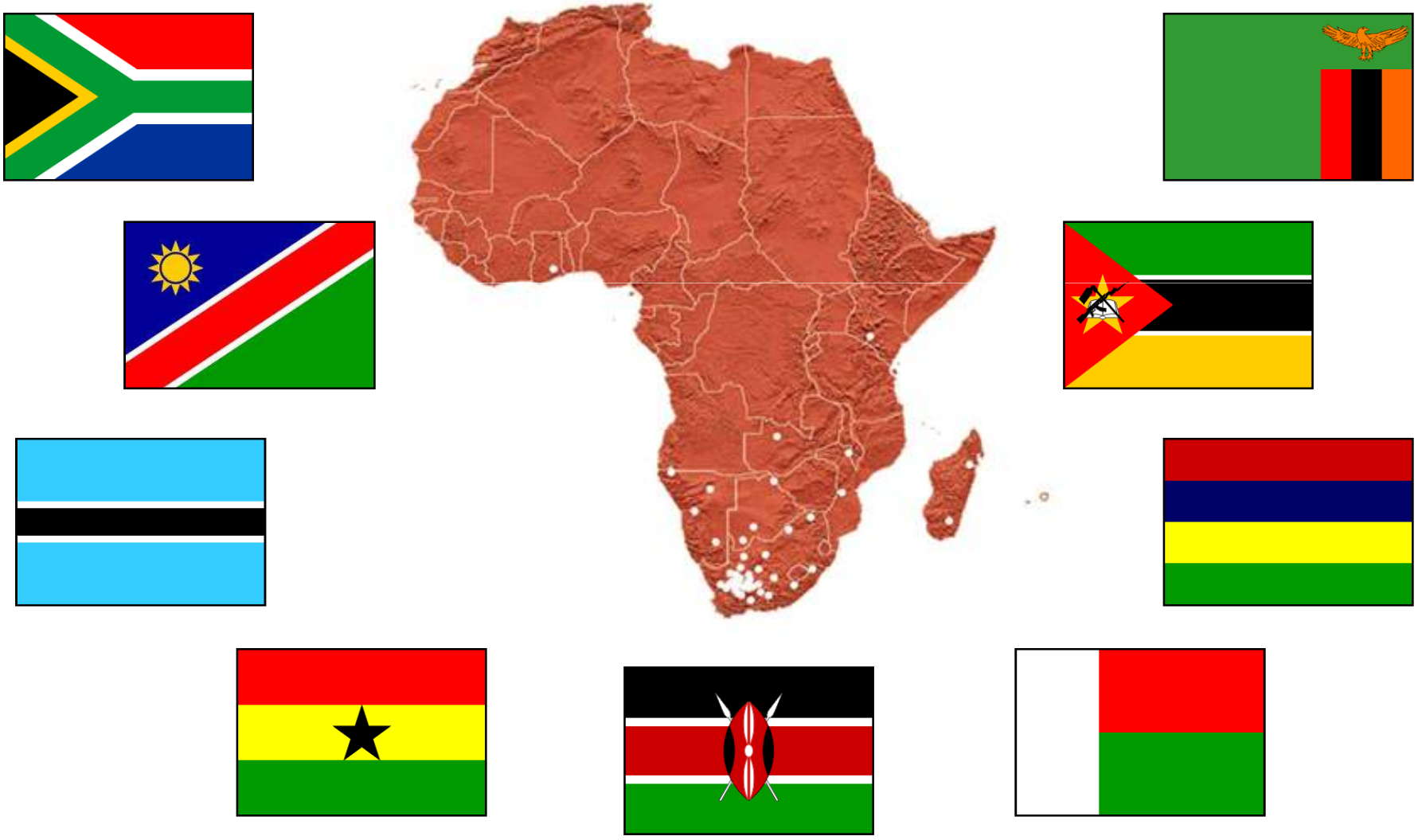
The International SKA Project

Three different kinds of receiving technologies:

1. **Mid-frequency dish array**
   Looks like big DSTV dishes, about 15m diameter
   Most well-known of the three receiver types
   Makes up the majority of the SKA
2. **Dense Aperture Array**
   Large, flat, disk-shaped receivers, about 60 m wide
   Operates at mid frequencies
3. **Sparse Aperture Array**
   Small upright radio receivers, about 1.5 m high
   Operates at low frequencies

SKA Stations in Africa

South Africa, Namibia, Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique and Zambia



Why build the SKA in Africa?

- Our superb radio-quiet environment is legally protected
- We offer the most affordable option and maximum return on investment
- We have excellent infrastructure already in place
- Our climate and altitude match the SKA requirements perfectly
- Our industries and expertise are world-class
- We've proven that we can do it. KAT-7 telescope already working
- Our cutting-edge pathfinder, the 64-dish MeerKAT, is under construction
- South Africa's government is totally committed to the SKA
- We have the full support of our African partners
- We have partners around the globe
- We are developing future capacity across the continent
- Our history of leading astronomy research goes back more than 200 years

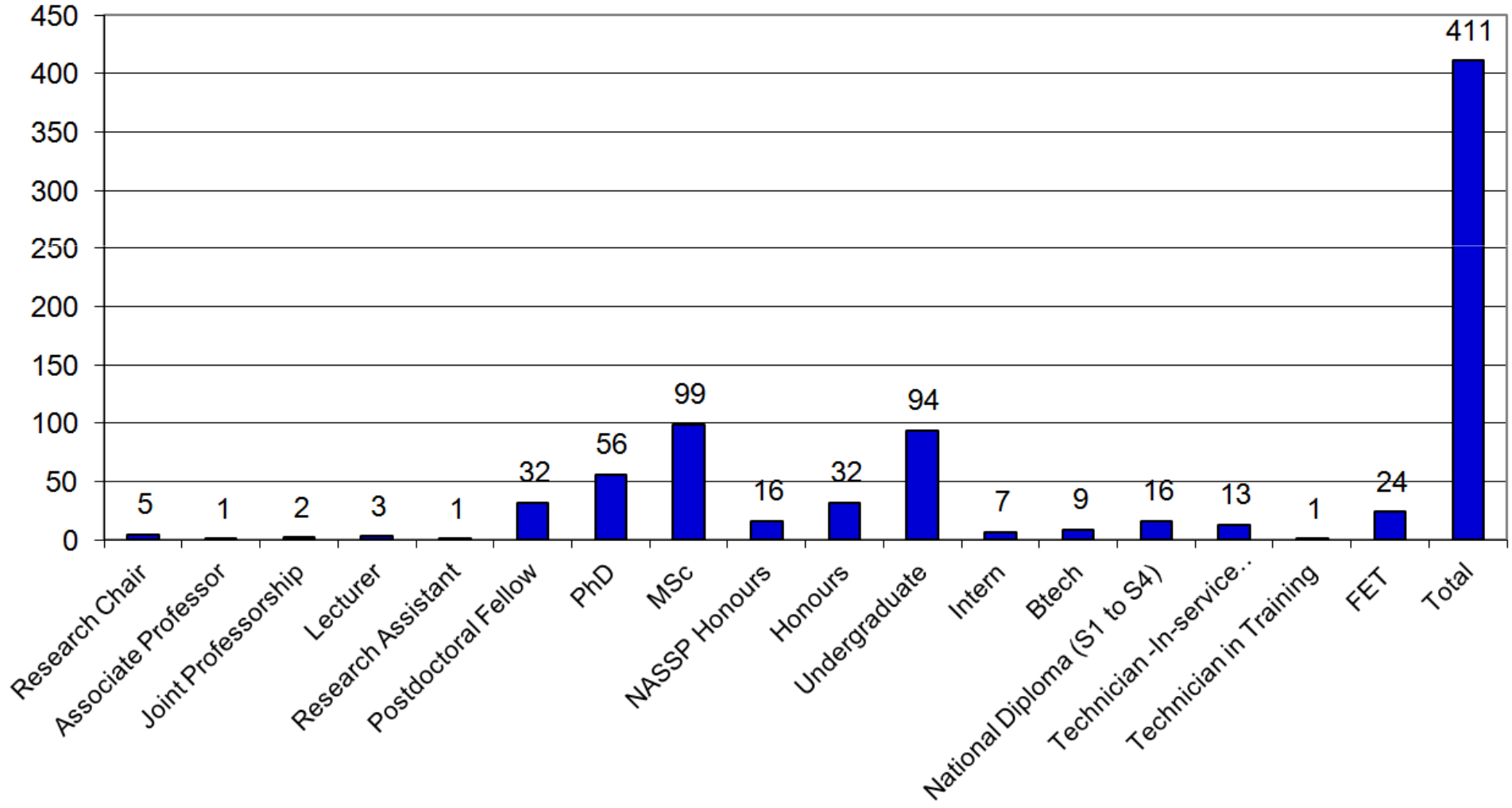
How does the SKA benefit South Africa?

- Technology spin-offs for more generic and commercial applications
- Research, job and study opportunities will be created
- Advances in high-performance computing to process large amounts of data
- Graduates exposure to the international arena
- Skills required to operate and maintain broadband optical fibre
- Motivate young people to go into engineering and the sciences

Generation of new knowledge and knowledge workers:
Young scientists and engineers
with cutting edge skills and expertise
in a wide range of scarce and innovative fields.

SKA SA Human Capital Development

Total number of grants, bursaries and postdoctoral fellowships awarded



Astronomy Outreach in SA

- SKA SA Website:
  http://www.ska.ac.za
- Astronomy Stars:
  http://www.southernscience.co.za/astronomystars/
- The Southern African Association of Science Centres:
  http://www.saastec.co.za/
- Southern African Astronomy Communication Network (AstroNet):
  http://mail.saasta.ac.za/mailman/listinfo/astronet
- IAU Office of Astronomy for Development:
  http://www.astronomyfordevelopment.org/

Thank You