SKA AFRICA
SQUARE KILOMETRE ARRAY

Building on what is there

Radio Astronomy
in Africa, the continent of opportunity

Hominids and modern humans originated in Africa
Technology and intellectual and abstract thought originated in Southern Africa
Karoo fossil record

Reaching our Potential

- Growth of an African middle class currently based on resource extraction - not indefinitely sustainable
- Even for South Africa, resources are still a very large % of exports
- Diversification essential – especially into the global knowledge and technology economies
- We must have a long-term vision

Reaching our Potential

- Africa as the next great business destination and the next great growth continent (see McKinsey, Boston Consulting, IMF etc.)
- How do we get there?
  - Infrastructure and logistics
  - Skills
  - Effective governance and administration
  - Education
  - Entrepreneurial growth
- Importance of high-level ICT and science skills
  - Construction, maintenance and use of infrastructure
  - Facilitating business development
  - Improving quality of government and administration
  - Capacity for innovation and participation in the global knowledge economy

Why Radio Astronomy?

- Astronomy has great public appeal
- Radio astronomy has historically led to major technology spin-offs especially in ICT
- Mega-projects (e.g. science research infrastructures) can be uniquely productive:
  - Raise profile, raise money and drag unrelated development along
- Astronomy and SKA, MeerKAT, African VLBI Network
  - Profile science and engineering as key development issues
  - Attract young people into SET training and careers especially ICT
  - Strengthen universities and teaching
  - Develop high level technical and scientific capacity for innovation
  - Develop high level problem technical and problem-solving skills to strengthen administration and governance

Deliberate and long-standing government policy

- White Paper – 1996
  - "Scientific endeavour is not purely utilitarian in its objectives and has important associated cultural and social values. **It is also important to maintain a basic competence in flagship sciences such as physics and astronomy for cultural reasons. Not to offer them would be to take a negative view of our future - the view that we are a second class nation, chained forever to the treadmill of feeding and clothing ourselves**"
- National R&D Strategy – 2002
  - "One way to achieve **national excellence** is to focus our basic science on areas **where we are most likely to succeed because of important natural or knowledge advantages. In South Africa, such areas include astronomy, human palaeontology and indigenous knowledge**"

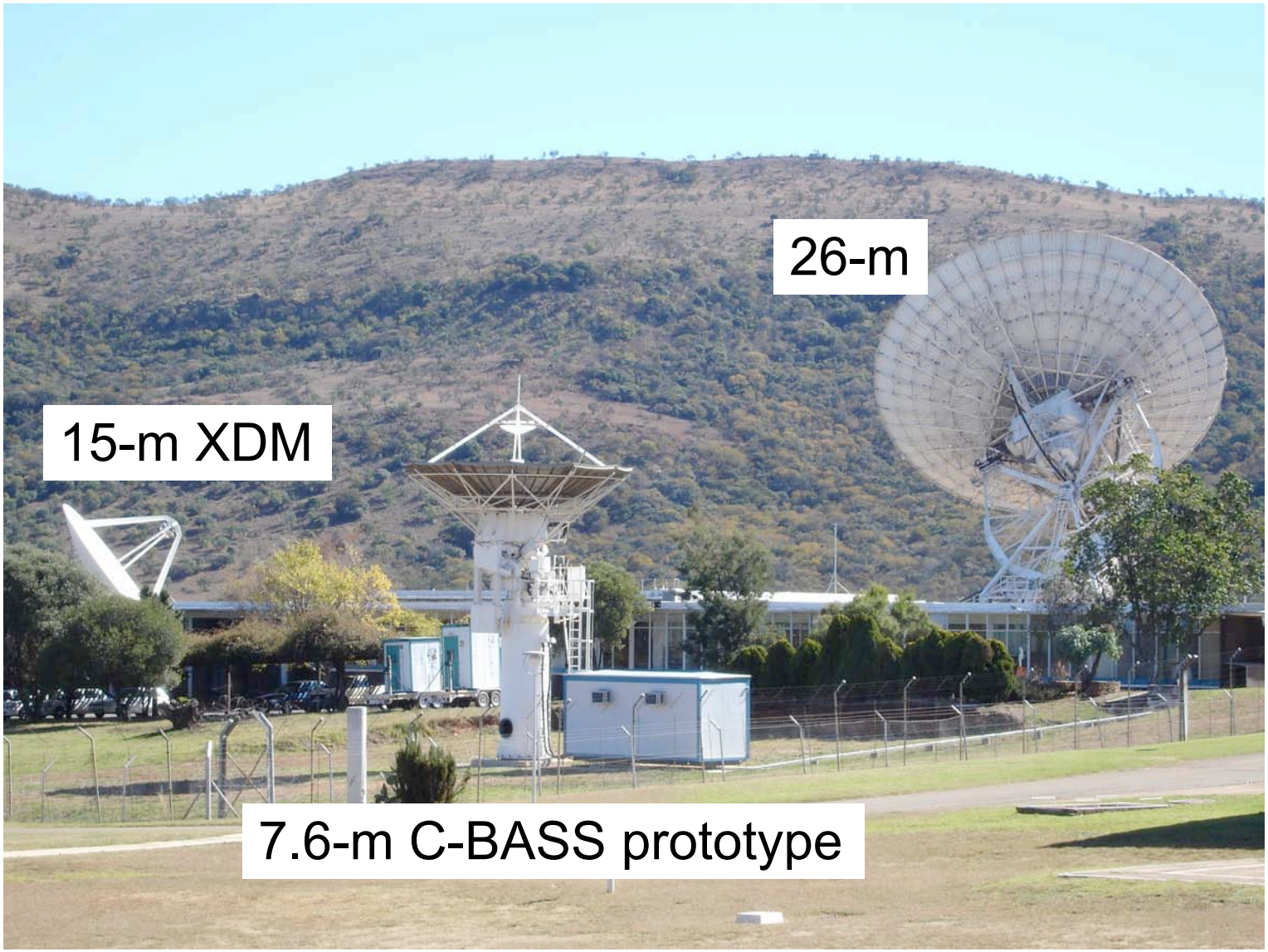
Partnership

- We have invested and have started to deliver
- We have close partnerships with many European research institutions and many European scientists have been awarded time to observe on MeerKAT and KAT 7.
- **With a partnership with the EU, we can do much more – create a focus for science and technology in European development policy**
- **It is time to build major global research infrastructure in Africa**
- We can really make a difference

Radio Astronomy in Africa

- 26m diameter dish at Hartebeesthoek Radio Astronomy Observatory near Pretoria – ex-NASA DSN
- New telescopes: South Africa
  - KAT 7 array, XDM dish, PAPER, C-BASS
- New telescopes: Africa
  - 25m diameter dish being built in Nigeria
  - 32m dish being converted in Ghana
- Build the SKA in Africa? African bid shortlisted 2006

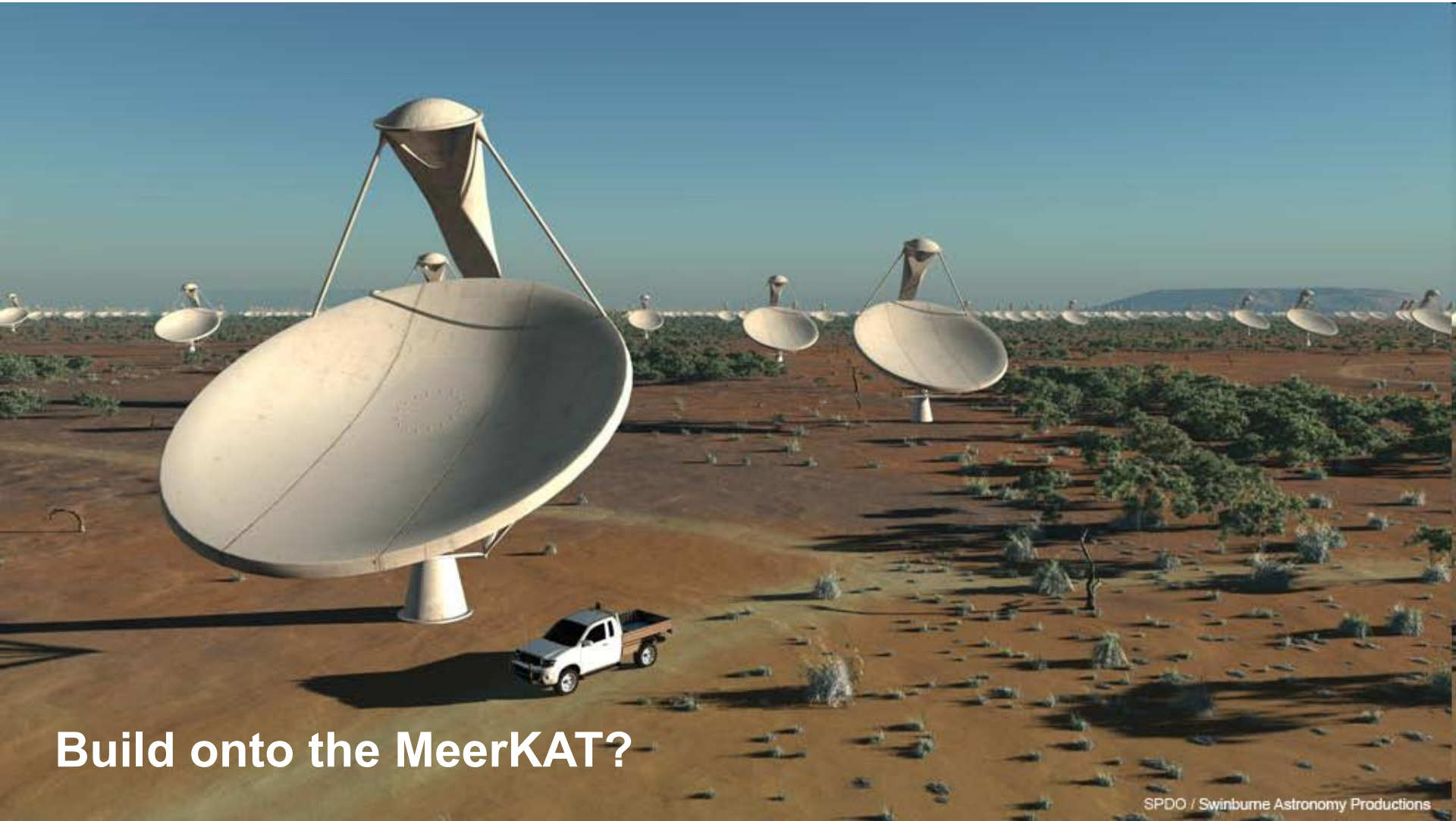
HartRAO today – 3 dishes



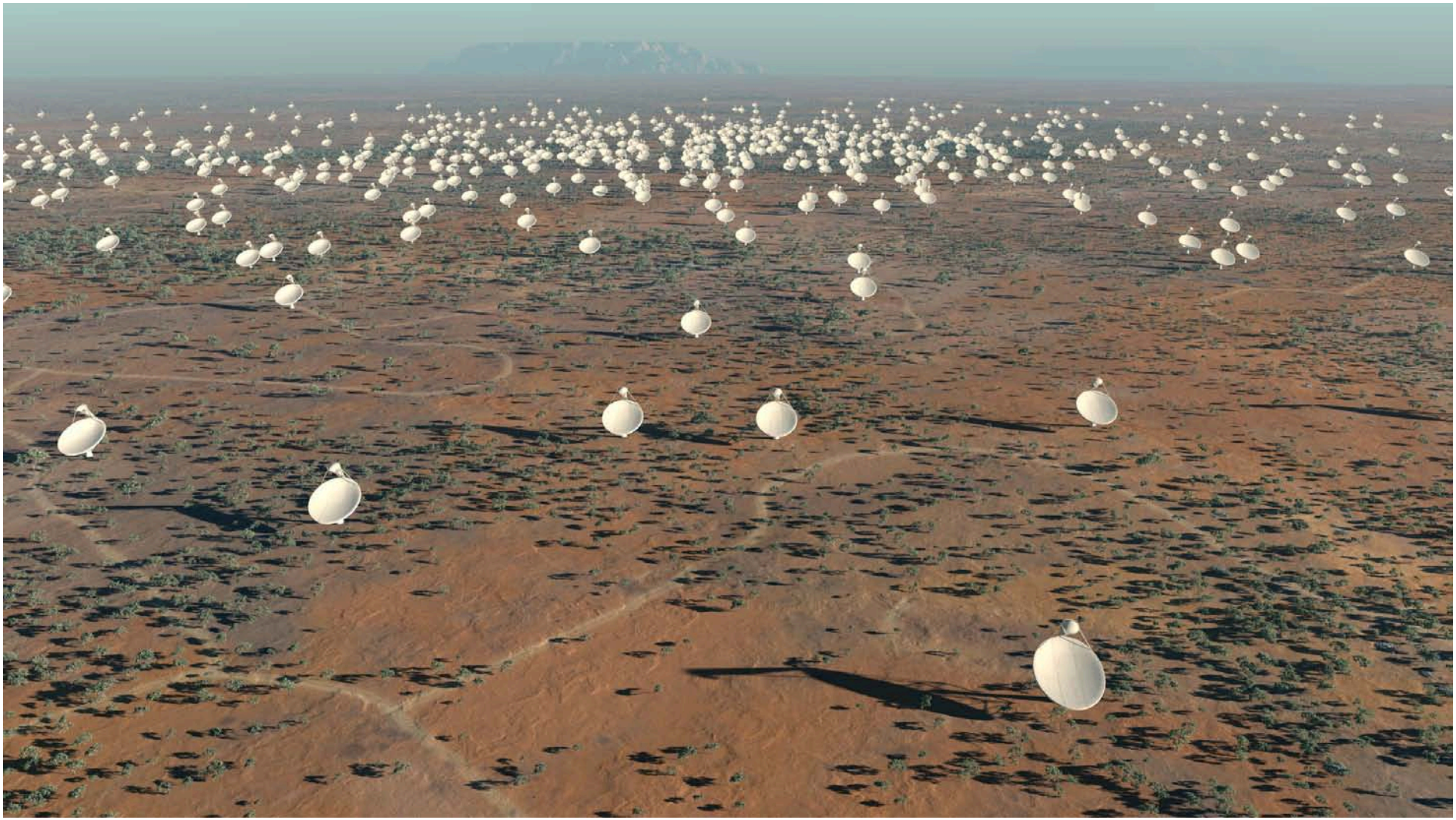
Square Kilometre Array (SKA)

- Global ‘mega-science’ project
  - World’s largest telescope - 50 times more sensitive
  - Nobel Prize science
    - Dark energy and dark matter; Gravitational waves; Proto-planets
  - Proposed construction cost €1.5 billion
  - Operations and maintenance estimated €150 - €200 million per year for 50 years
  - Operational < 2024
- Build in phases
    - Use existing infrastructure, especially in the core (first 180km)
    - Construction costs in RSA are low

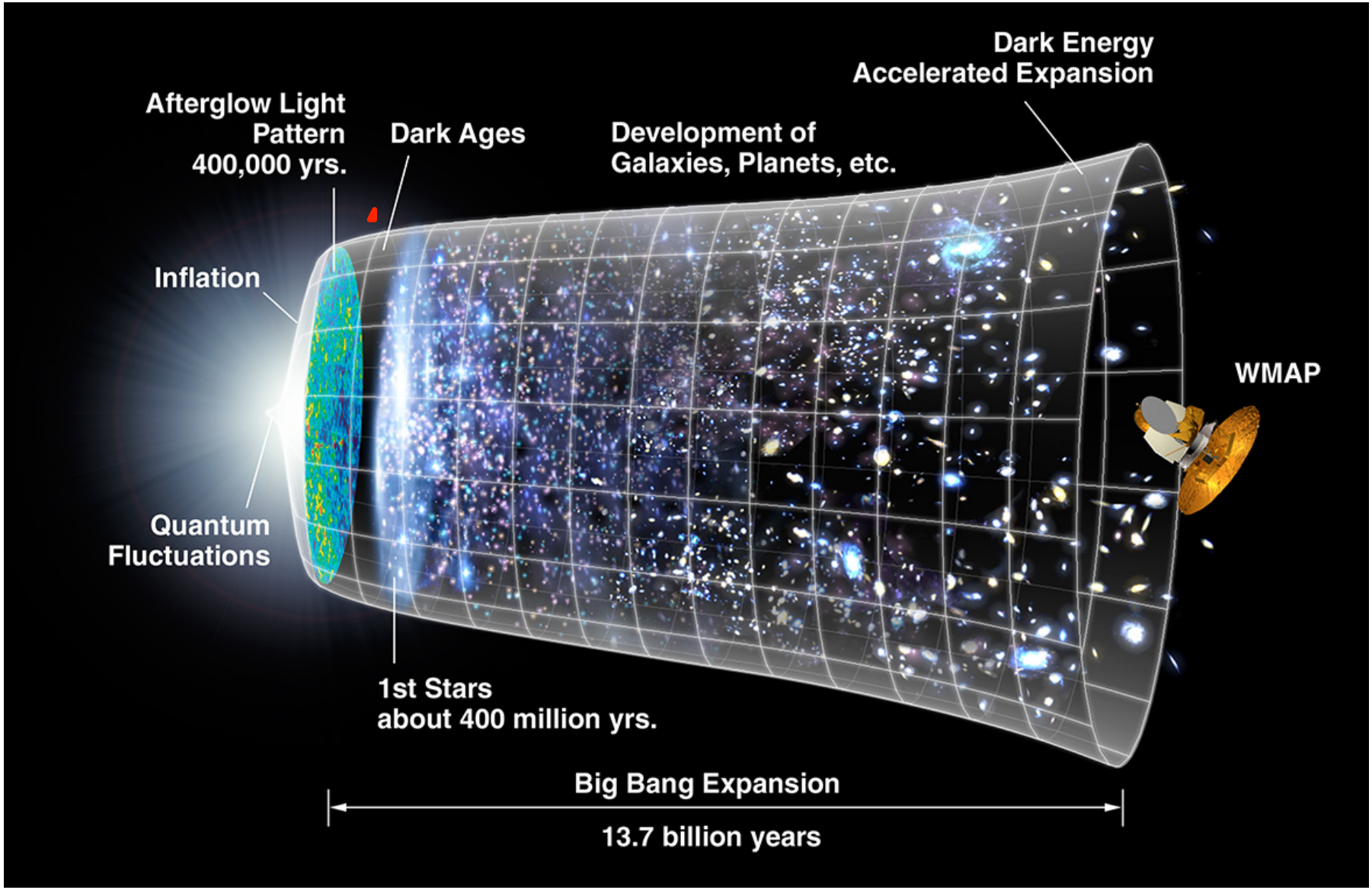
SKA Offset Dishes



SKA dishes in the “Core”



History of the Universe



Square Kilometre Array Technology

- Uses 100MW and >100Tb/s
- Pushes all technology to the limits
- Thousands of antennas combined – 1million sq m collecting area
- SKA central computer has the processing power of about 1 billion PCs - 1,000,000,000,000,000,000 operations per sec – exaflops (10E18)
- Enough optical fibre to wrap twice around the Earth
- SKA dishes will produce 10 times the global internet traffic
- SKA aperture arrays produce 100 times the global internet traffic
- Enough raw data to fill 15 million 64 GB iPods every day
- Sensitive enough to detect an airport radar on a planet 50 light years away

Radio astronomy in South Africa

- An integrated programme to advance scientific knowledge and contribute to Africa's future
- SKA in Africa – the site bid
- Greenfield protected site
- Building the MeerKAT array telescope – a world-class telescope and the SKA precursor closest to the concept and design of the SKA
- MeerKAT science
- Human capital development programme
- Mission-driven innovation
- African VLBI Network
- Contributing to the development of the SKA

Radio astronomy in Africa - return on investment

- More telescope per € - less cost for infrastructure and operation
- Outstanding site for revolutionary science
- Helping to fulfill Africa's potential as the next great economic growth and business destination
- Developing young people from Africa and the world

The SKA in Africa

Shape and location of the African continent allow flexibility in EW and NS baselines longer than the nominal 3 000 km SKA requirement

A United Africa for the SKA

- The African Union (AU) Heads of State July 2010 confirmed unanimous and continued support for the African SKA bid
- SADC Science Ministers unanimous support
- South Africa has an SKA Inter-Ministerial Committee
- SKA Africa Steering Committee and Working Group

DECISION TO SUPPORT THE SQUARE KILOMETRE ARRAY (SKA) PROJECT ON THE AFRICAN CONTINENT
Doc.EX.CL/584(XVII)

The Assembly,

1. **ENDORSES** the recommendation of the Executive Council with regard to the Square Kilometre Array (SKA) Project provided for in the Report of the Fourth Ordinary Session of the African Ministerial Conference on Science and Technology (AMCOST IV), held in Cairo, Egypt, from 8 to 11 March 2010;

2. **ACKNOWLEDGES** the importance of science, technology and innovation emanating from the SKA Project in development of our knowledge-based economies and driving human capital development programmes;

3. **APPRECIATES** the efforts of the Republic of South Africa in coordinating Africa's bid to promote space related science and technology matters on the continent;

4. **ENDORSES** the African bid to host the SKA on the African continent, thereby providing the world with the unique instrument for frontier research and discovery, cementing Africa's commitment to contribute to global scientific excellence and enterprise;

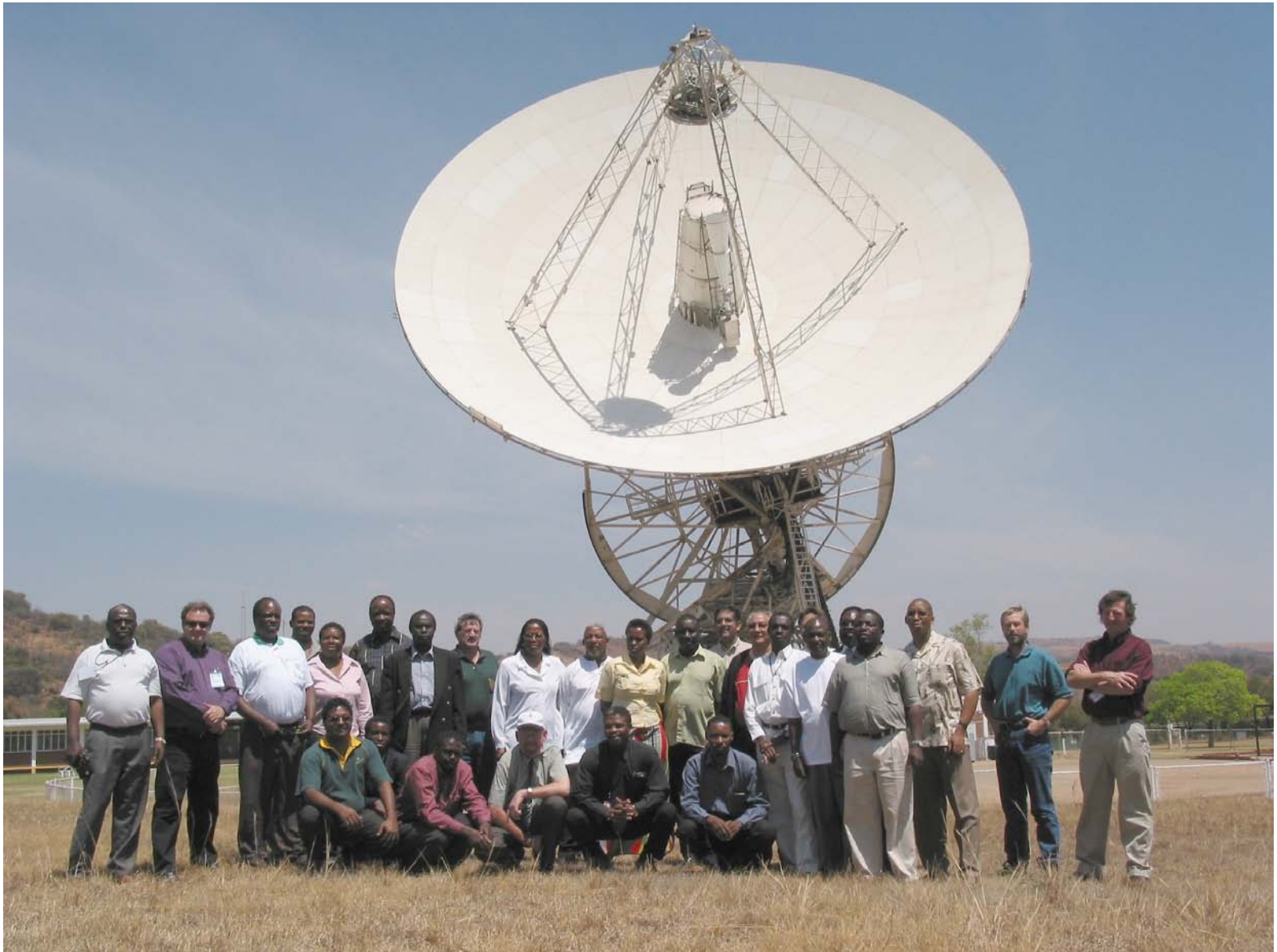
5. **ALSO ENDORSES** the Republic of South Africa's bid to host, in collaboration with Botswana, Ghana, Namibia, Madagascar, Mauritius, Mozambique, Kenya and Zambia the Square Kilometre Array (SKA) Project on the African continent;

6. **CALLS ON** Member States, the Commission and the Regional Economic Communities to fully cooperate with the Republic of South Africa on this project by providing the necessary support to this bid;

7. **ALSO CALLS ON** Africa's development partners and the global scientific community to support the African SKA bid, both directly and in all relevant forums where such support would promote the success of the bid.

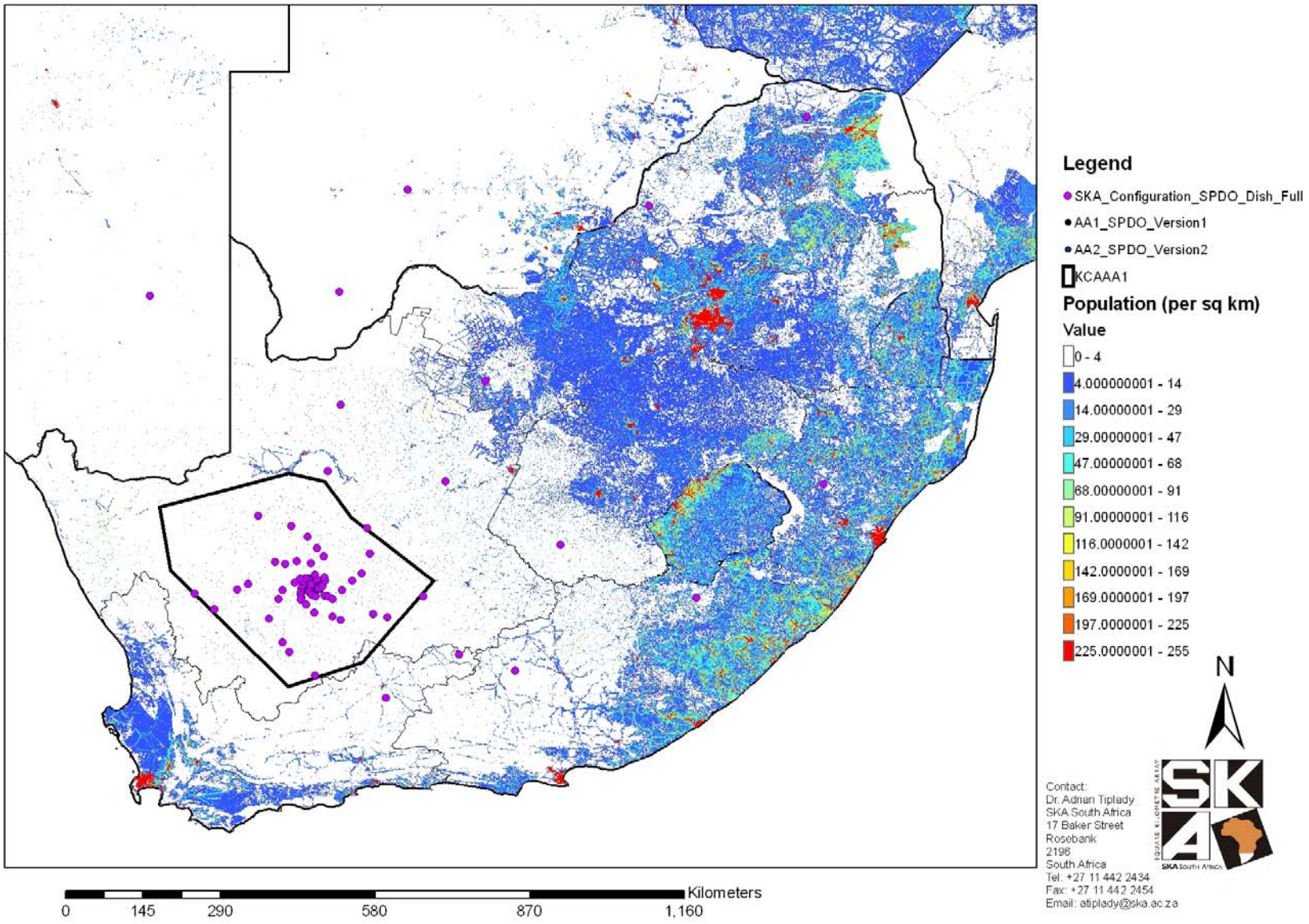
Calls on development partners

African Partners – first meeting 2003



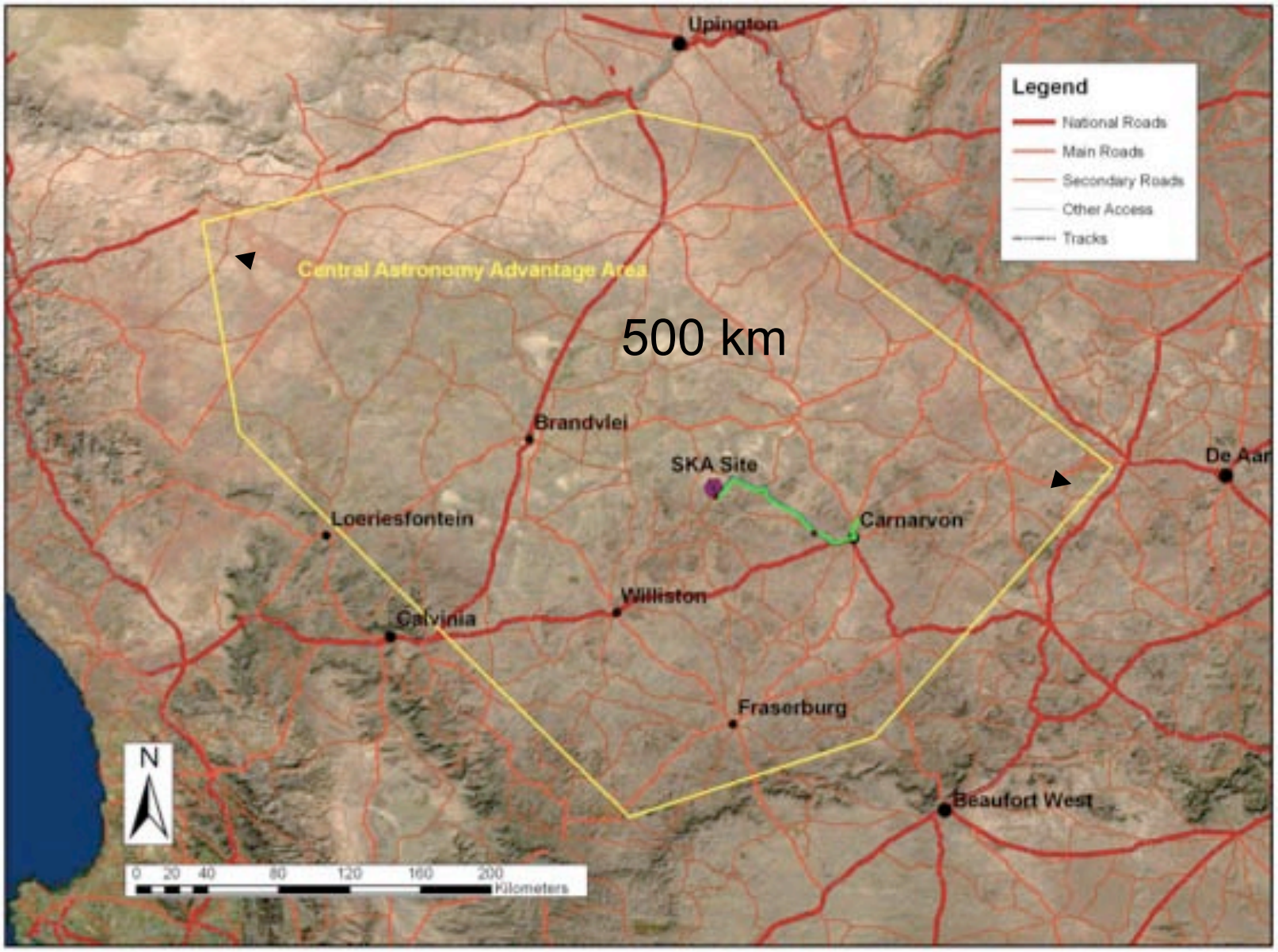
African Partners Steering Committee – Accra 2010

Population density in RSA



Karoo Site - before

Karoo Radio Astronomy Protected Reserve



Astronomy Geographic Advantage Act protects radio and optical (and other) astronomy

- Close cooperation with communities, regulator and broadcast and telecommunication operators
- Excellent support from Vodafone, MTN, Sentech etc.

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

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

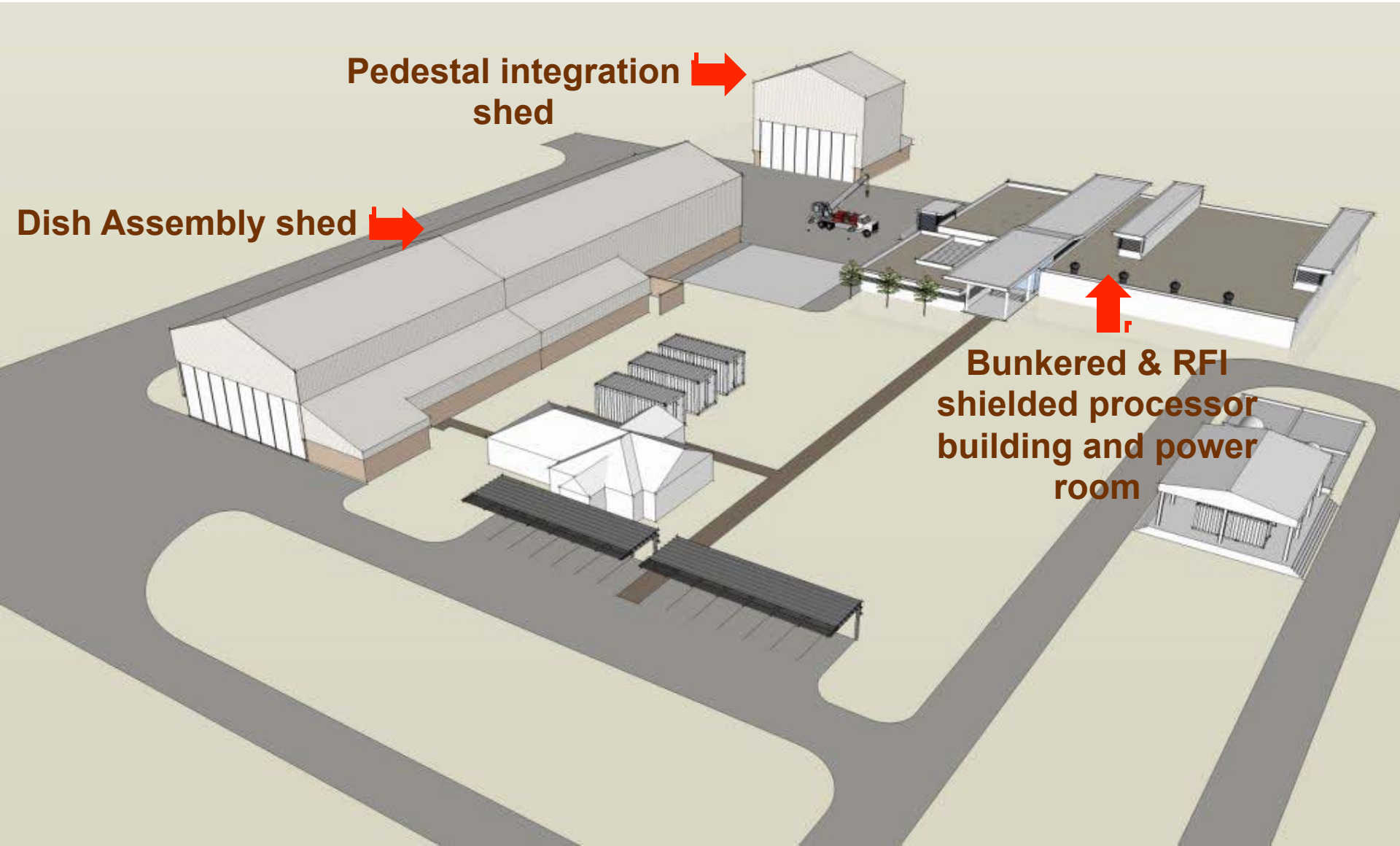
9 771682 584003 31157

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

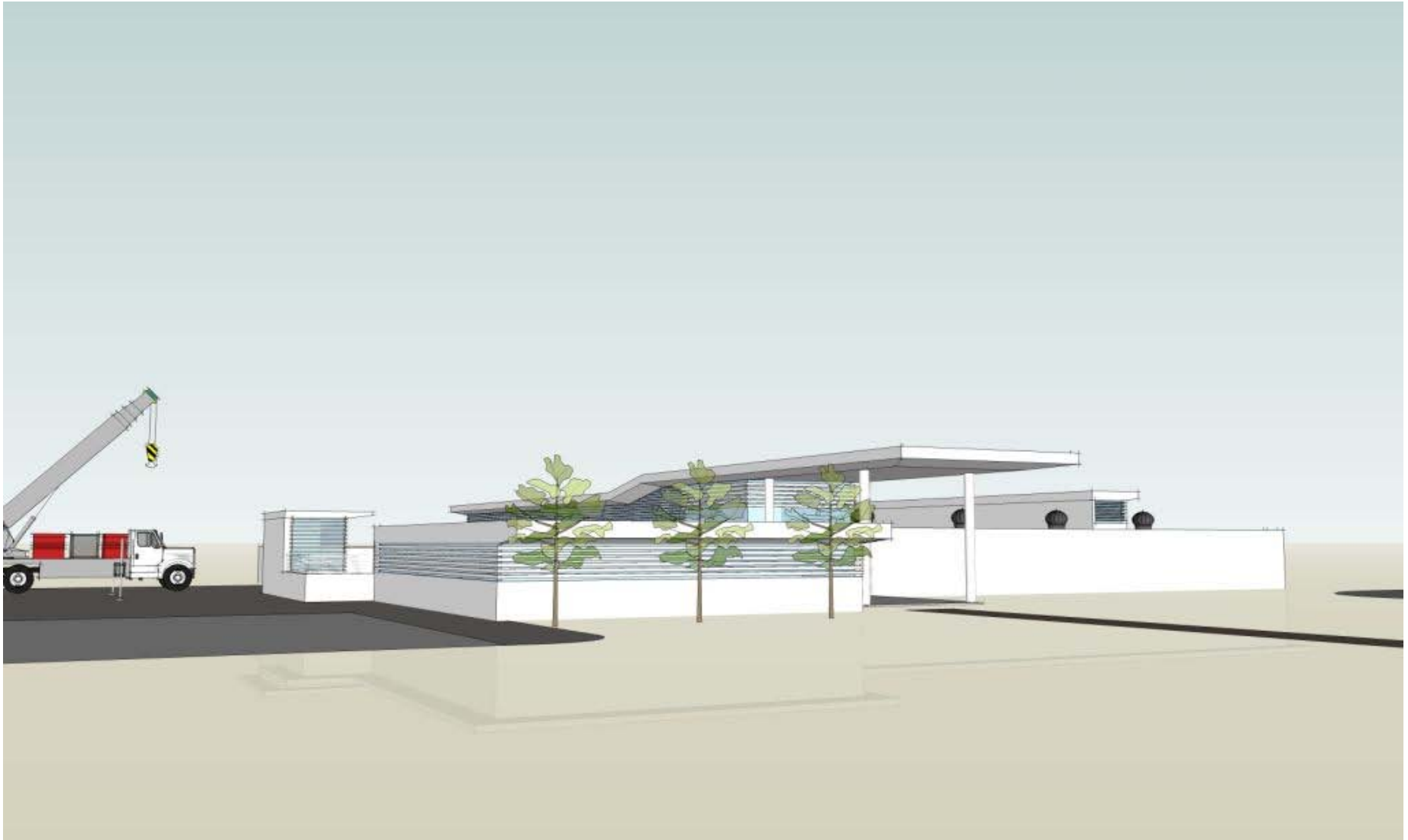
Klerefontein Support Base

Site Complex with dish assembly shed

Expansion of Site Complex for MeerKAT



Bunkered and RFI shielded Karoo Array processor building and power room



Infrastructure: Power

- Newly commissioned 33kV grid power line (including overhead optic fibre), with highly innovative design to ensure radio quietness
- Upgrade to Karoo substation from 5MVA to 10MVA by March 2012 - spare capacity for SKA Phase I
- Power Facility Bunker has been designed so that electrical infrastructure can be added in modules for SKA Phase I
- Plans completed for grid connection for SKA

On-Site Optical Fibre Cable

10 Gb/s from Cape Town to the heart of the Karoo

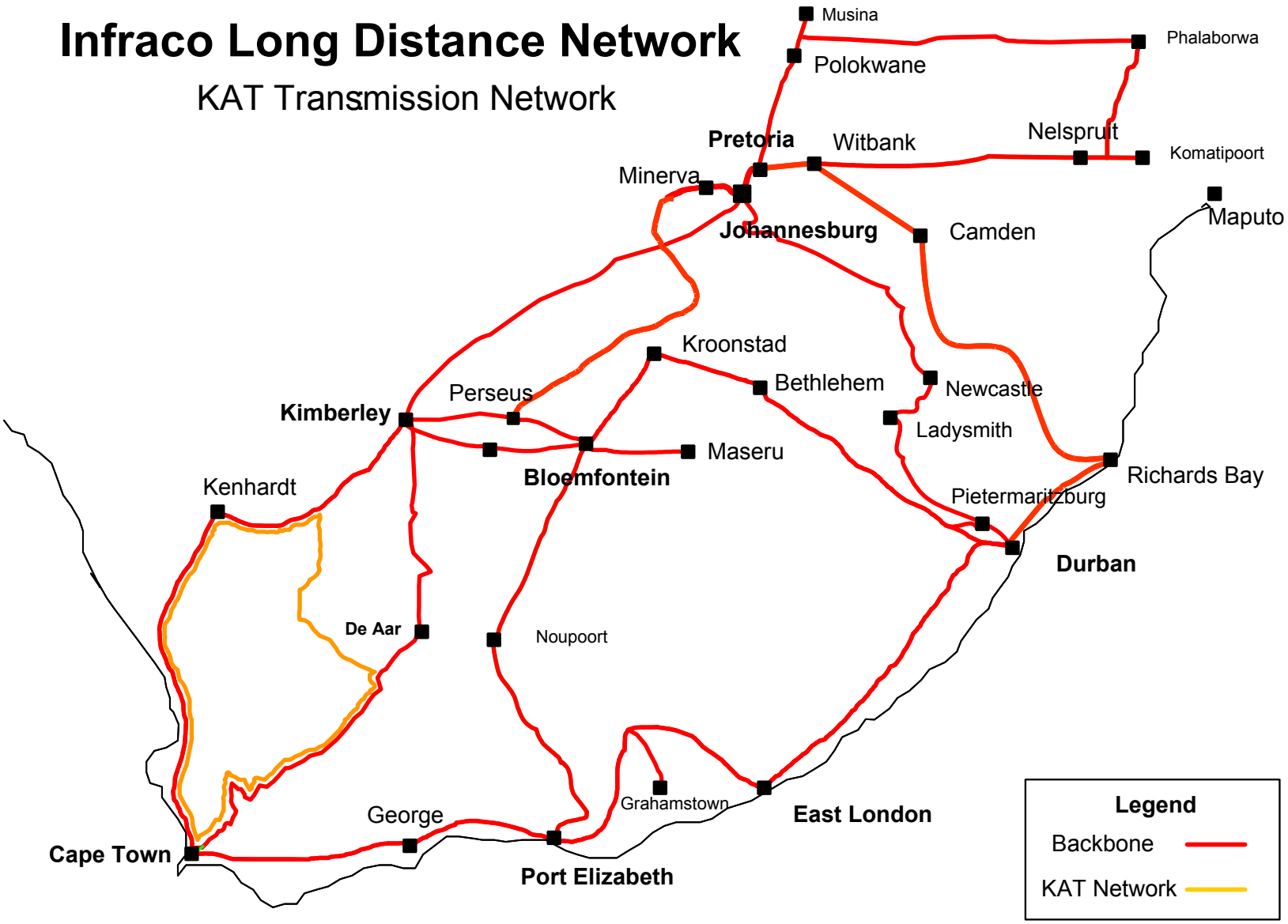
Broadband InfraCo container arrives at Carnarvon SKA POP Station

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

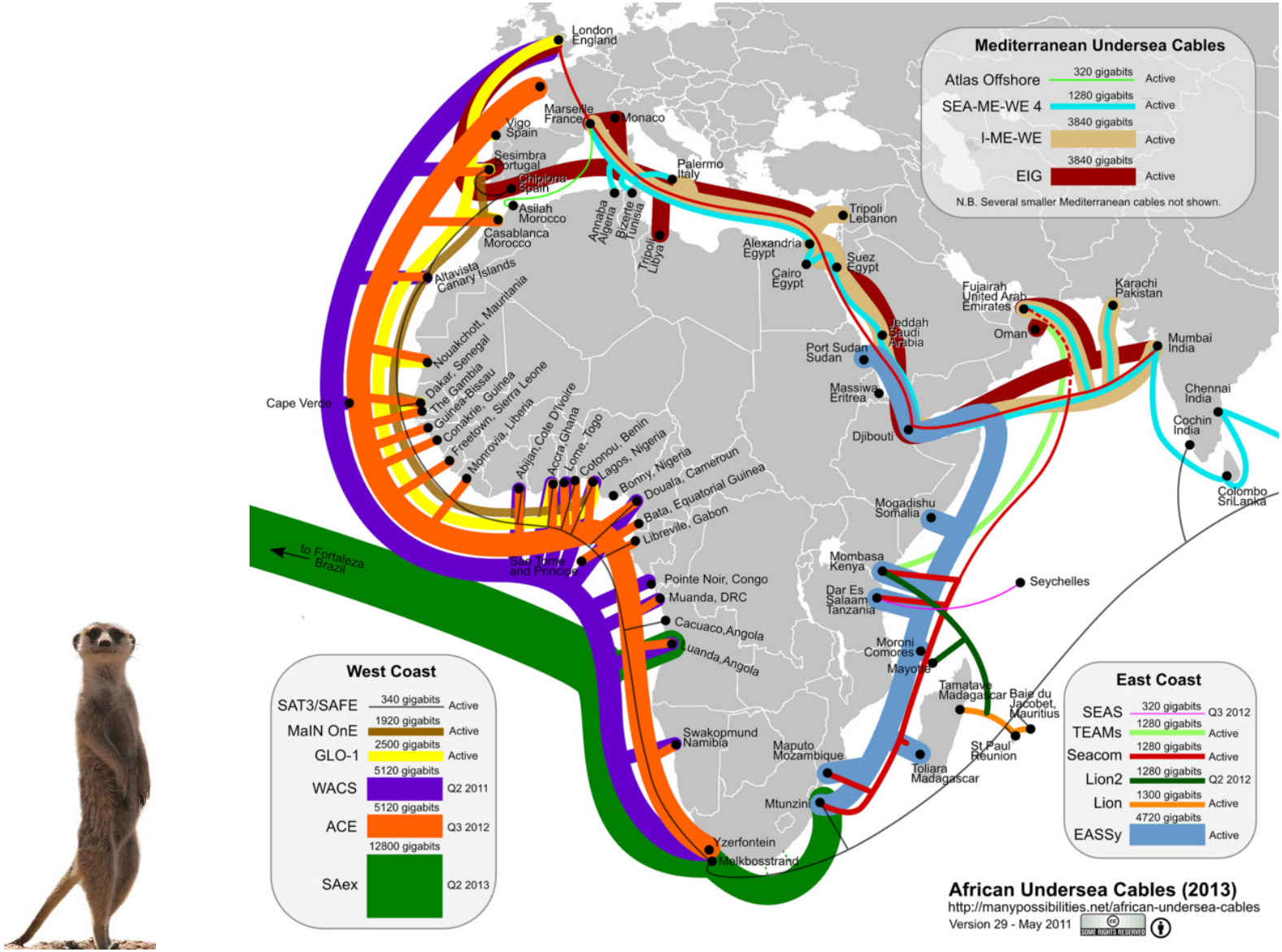
Infrastructure: Renewable energy

- Wheeled through grid or connected directly
- Base load supply through the grid, so no storage required
- > 14% renewables available through the national grid by 2030, increasing
- Huge solar parks to be constructed by private – public partnerships in the Northern Cape and available to SKA
- Feasibility study for 10MW demonstration solar PV plant for MeerKAT

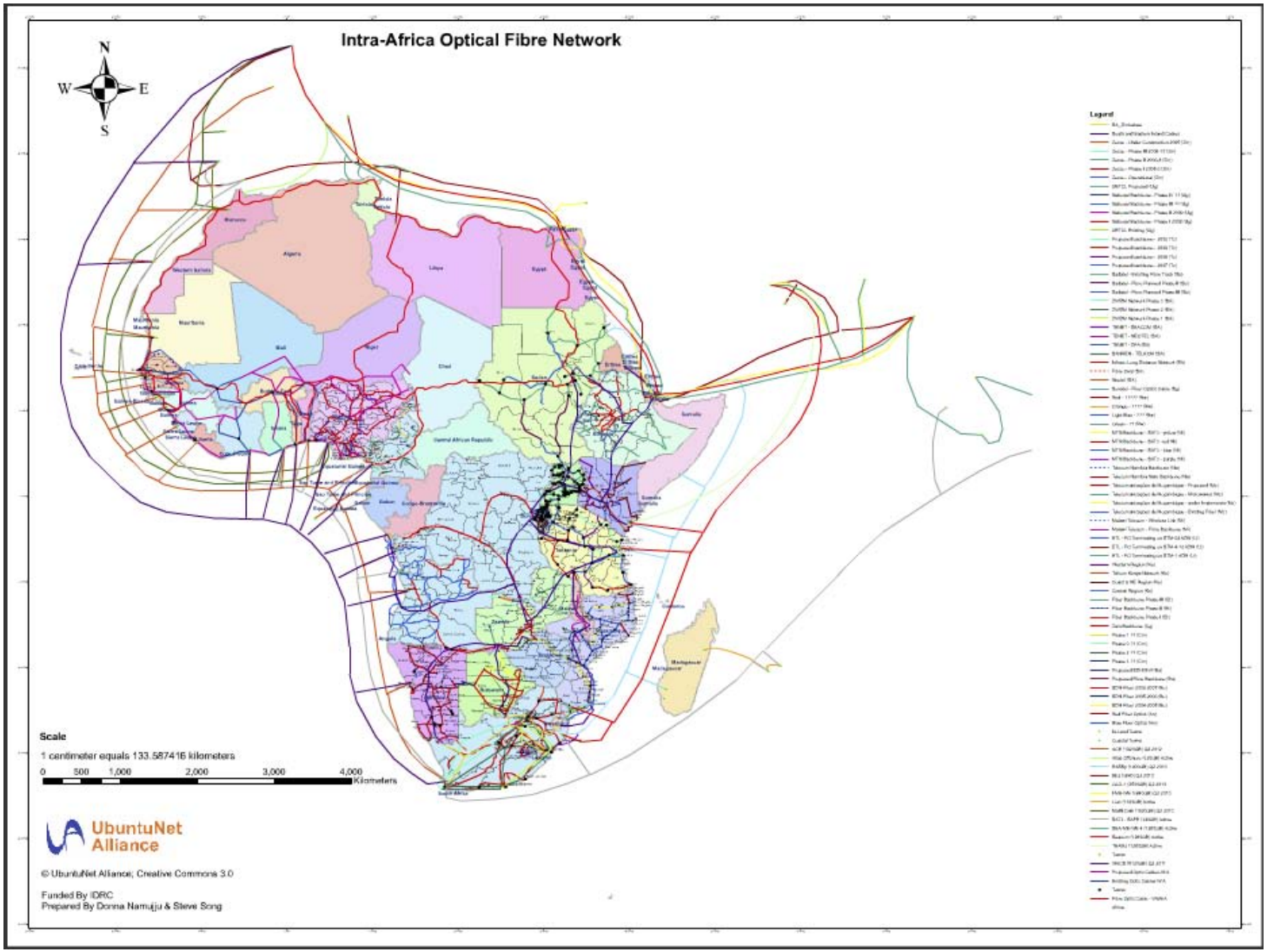
Data connectivity



African Submarine Cable Systems



Africa Terrestrial Cable Systems



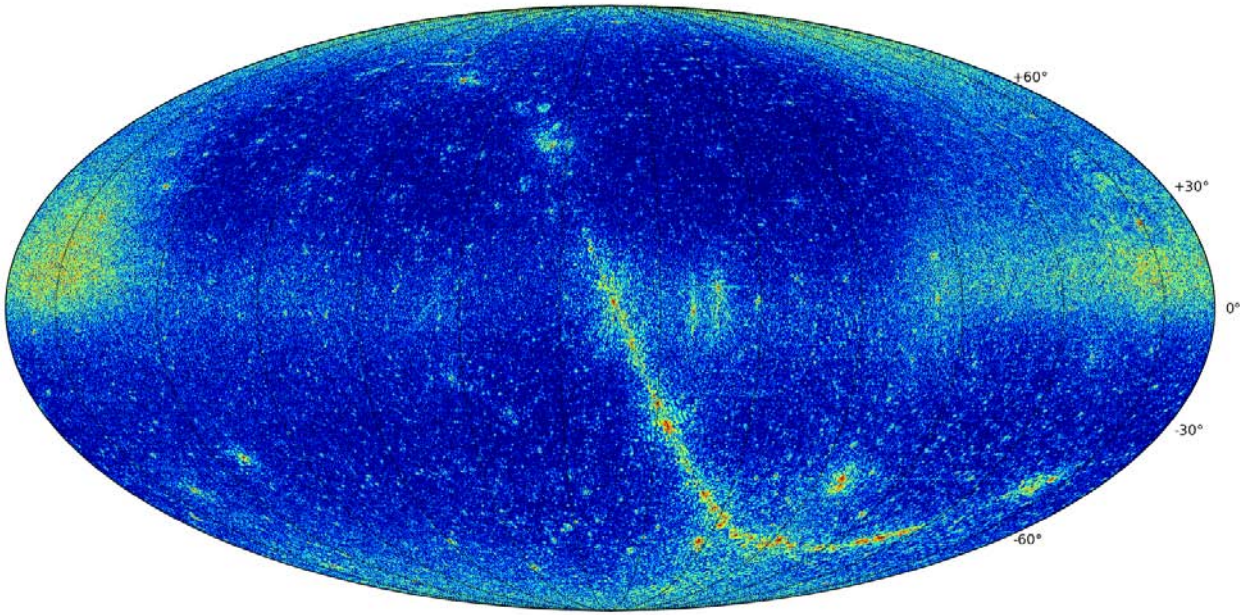
Radio Frequency Environment

- **Existing environment**
  - Karoo core site is exceptionally radio quiet
  - Global satellite signals dominate the L-band spectrum.
  - Very low economic activity (sparse sheep farming, no economically viable mineral deposits)
- **Protection and Improvement**
  - Protection through the Astronomy Geographic Advantage Act
  - 370,000 square km protected area (size of Germany) and can be extended
  - Protection levels are equal to or better than International Telecommunication Union recommendations
  - Unique - ensures protection of future radio frequency environment and improvement of **existing** environment, both enforceable by law
  - Regulations drafted with stakeholders and cover transmitters and all other activities and infrastructure, such as mining, wind turbines etc.

Demonstrating Radio Quietness with PAPER

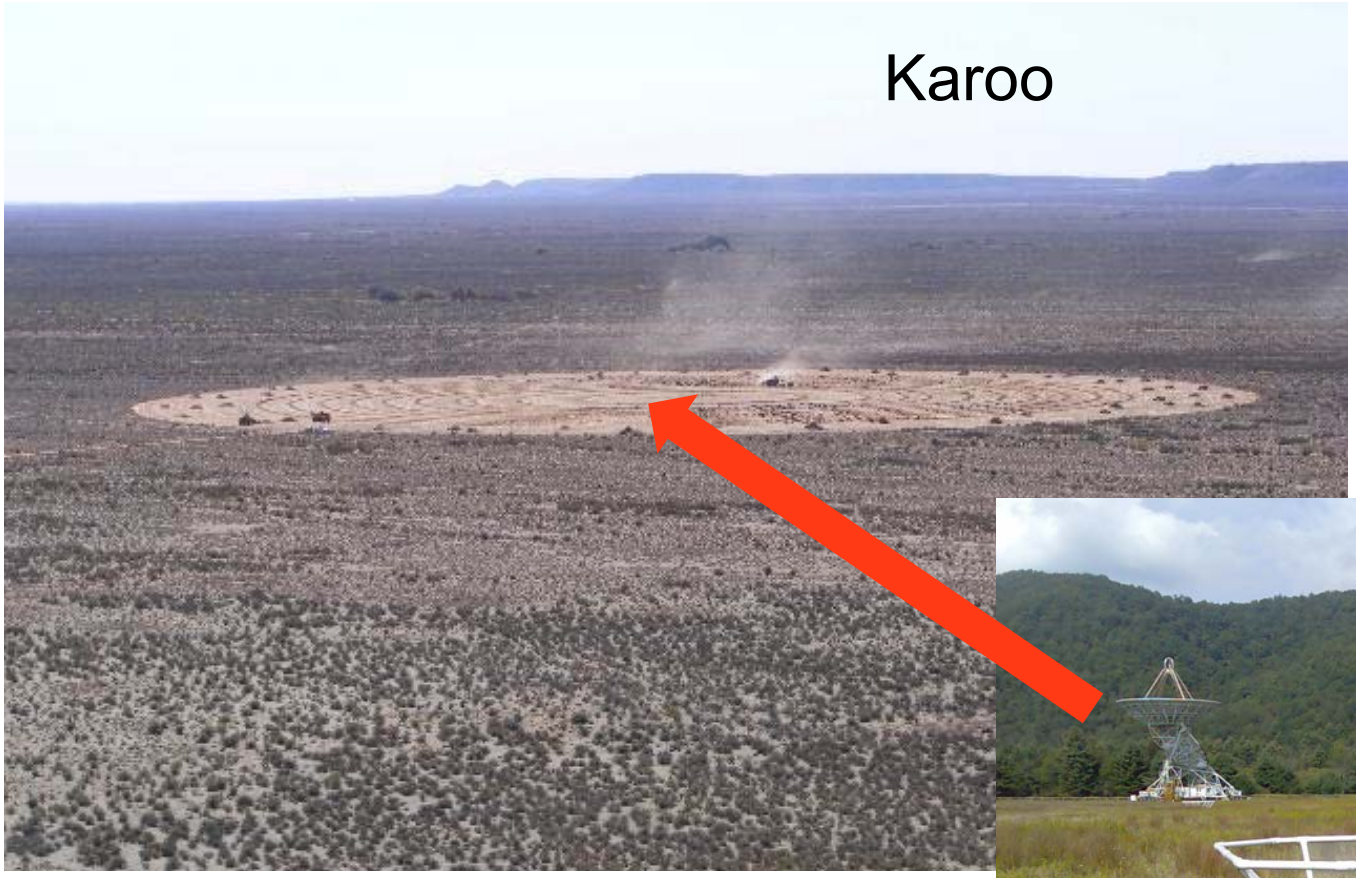
PAPER

- Low frequency array to detect the epoch of re-ionization relocated to South Africa
- 64 antennas currently being deployed on site, increasing to 128 in 2012
- Initial results show the Karoo site is exceptionally radio quiet
- Recently successful in NSF review



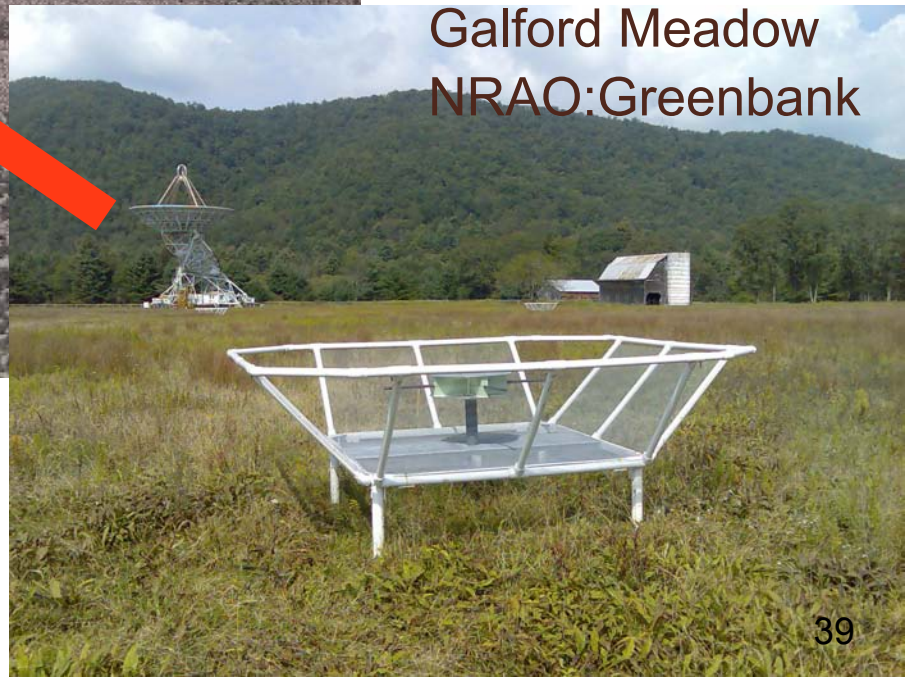
First map of whole sky using PAPER array in the Karoo and USA. Joint experiment with UC Berkeley, U. Penn. and NRAO

PAPER (Precision Array to Probe Epoch of Reionization)



Berkeley
UNIVERSITY OF CALIFORNIA

Penn
University of Pennsylvania



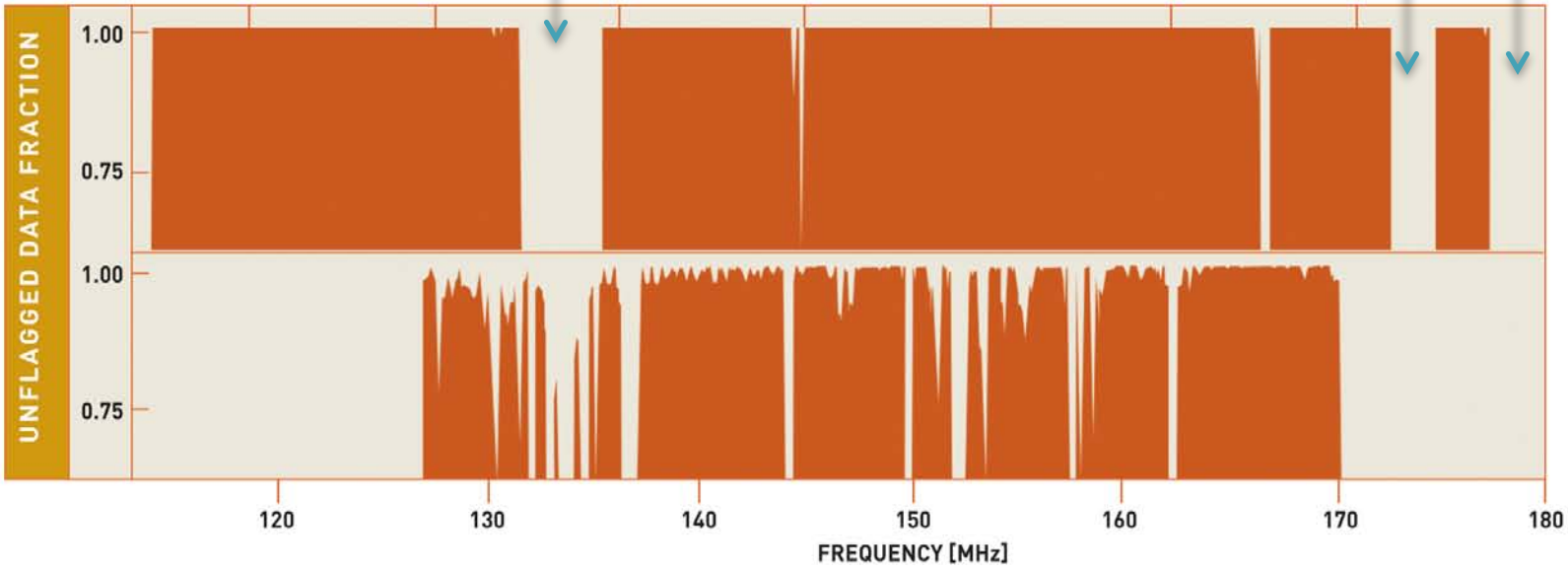
National Radio Astronomy Observatory
A facility of the National Science Foundation

PAPER - exploring the first stars & galaxies

Demonstrating Radio Quietness with PAPER

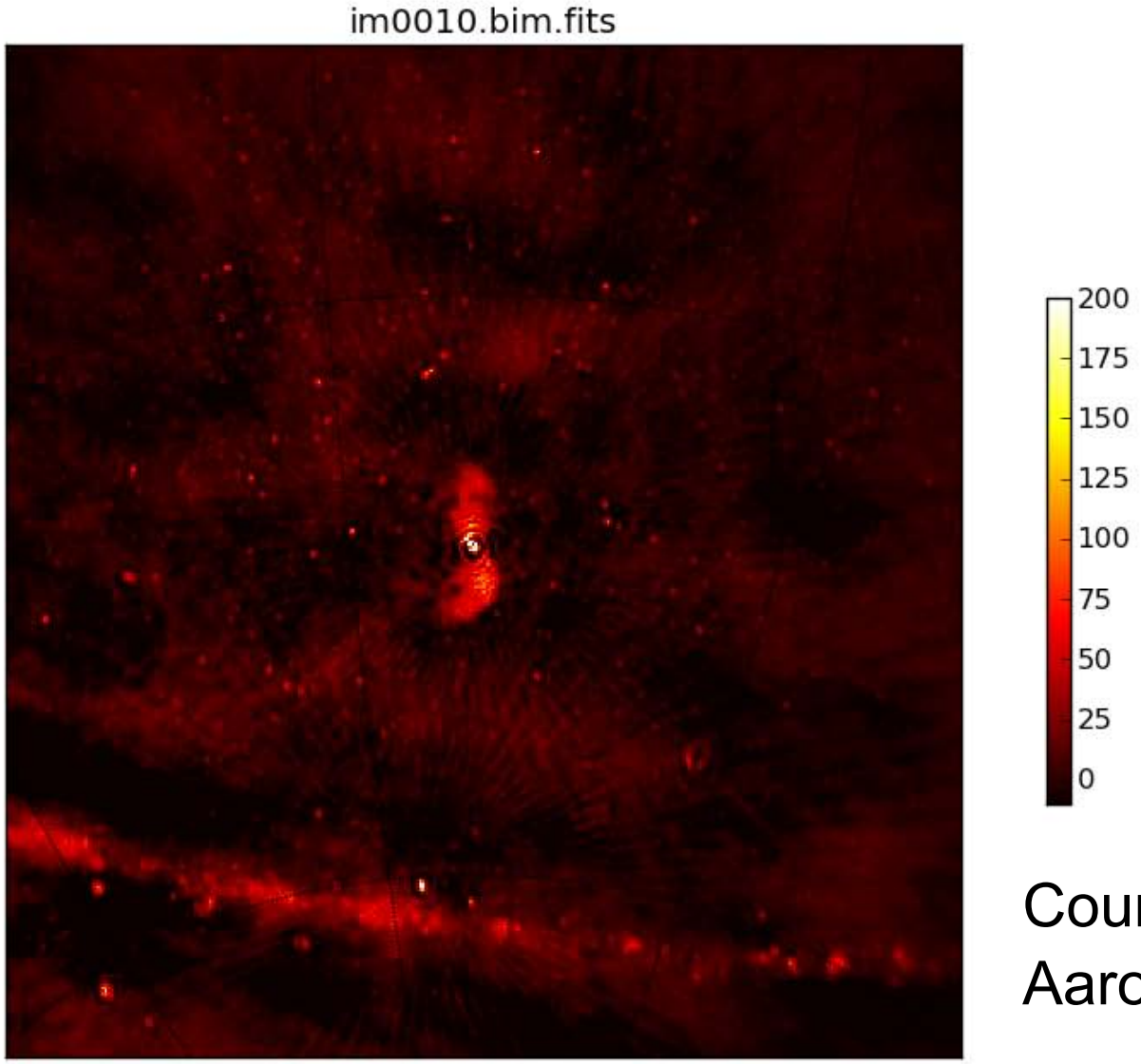
Global satellite band

VHF TV that will migrate to UHF digital



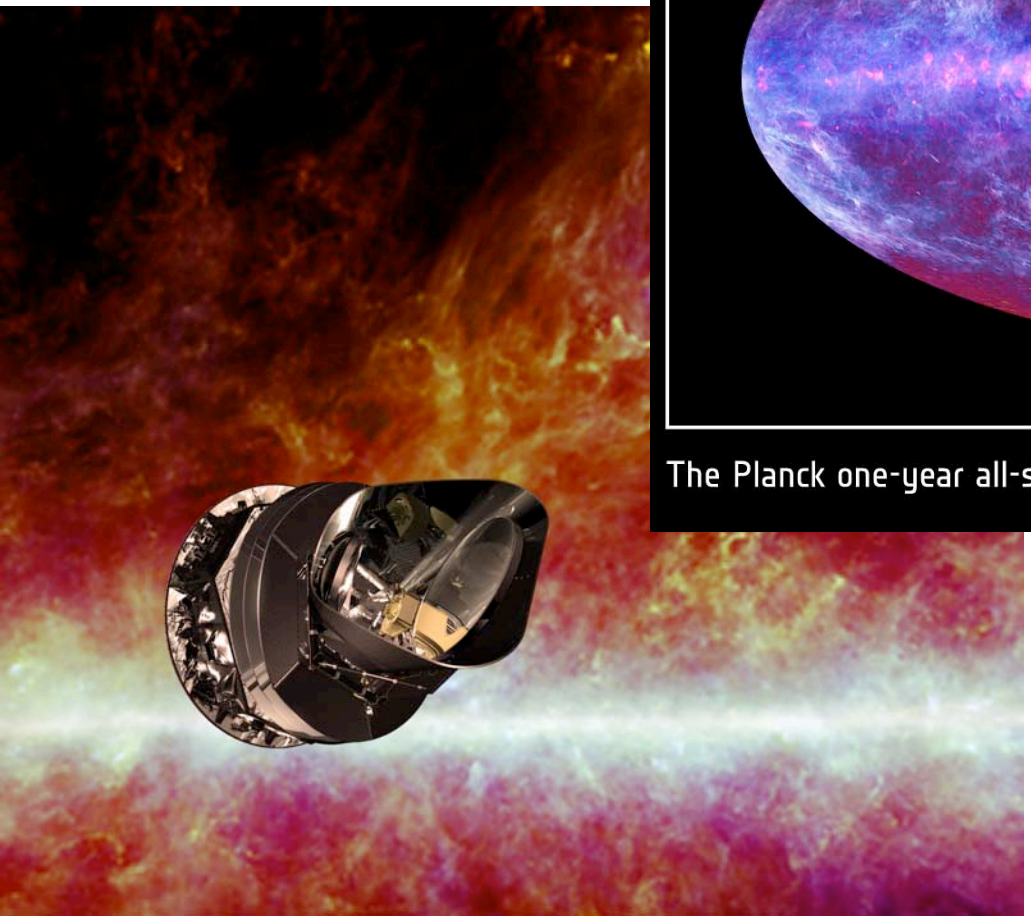
Spectrum availability of the Karoo site (top) compared to Green Bank (below), indicating that the Karoo RFI environment is orders of magnitude better than the premier USA site.

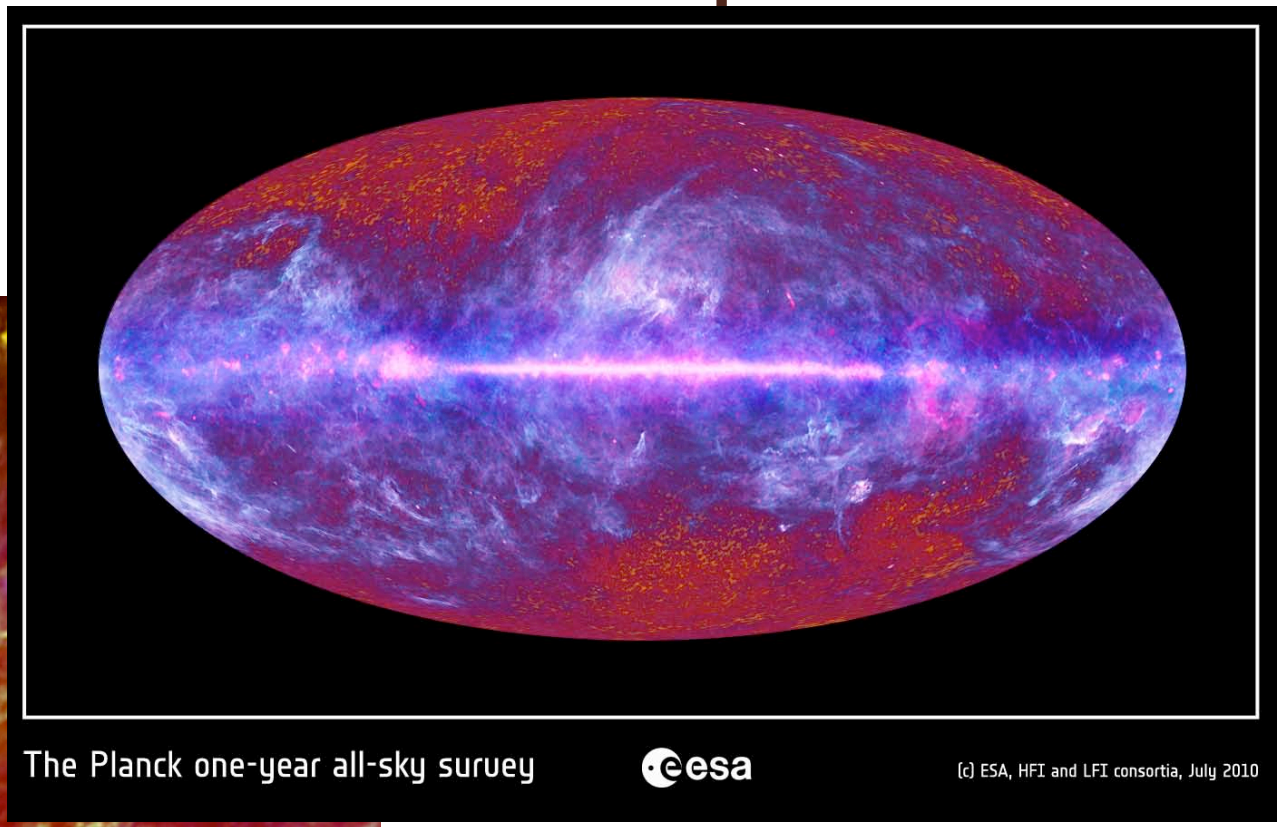
Cen A & Milky Way Galaxy



Courtesy:
Aaron Parsons

ESA Planck CMB Explorer





C-BASS at Klerefontein

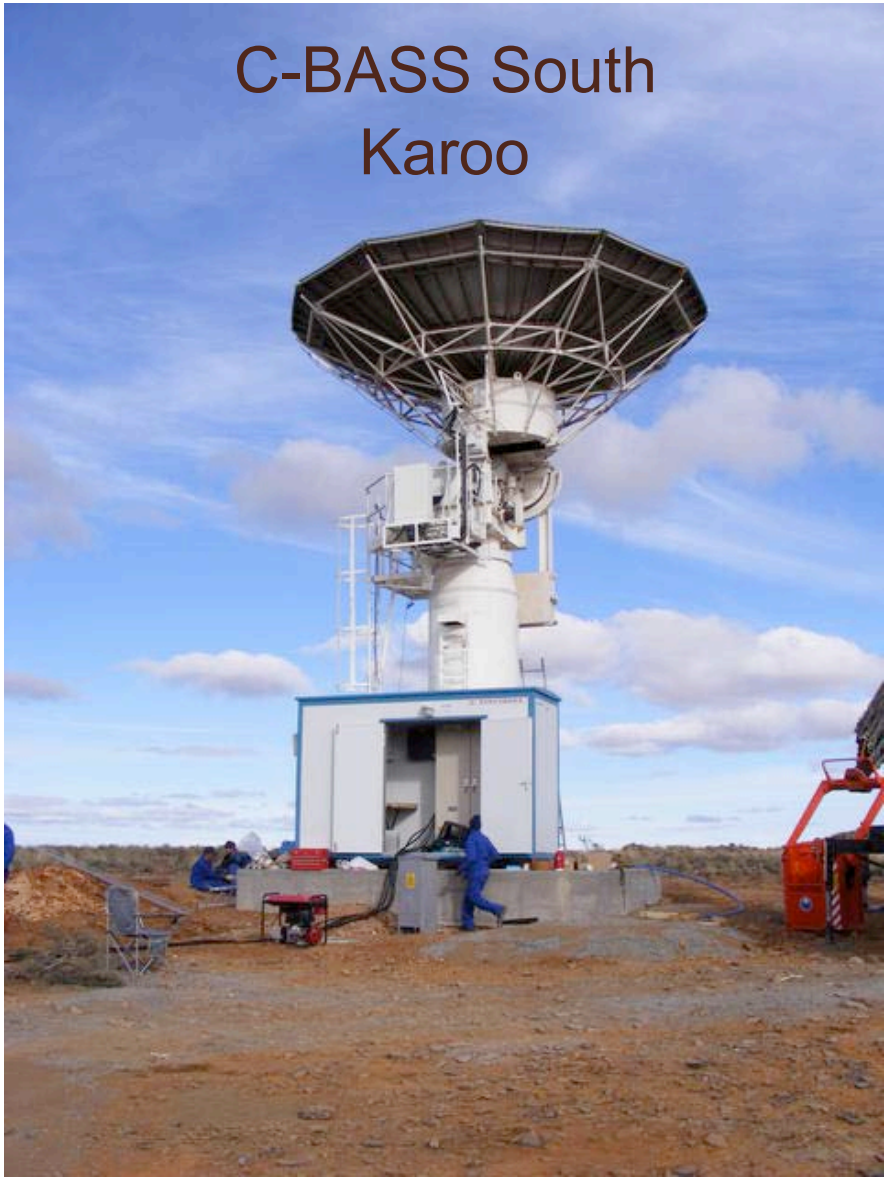
Oxford Physics

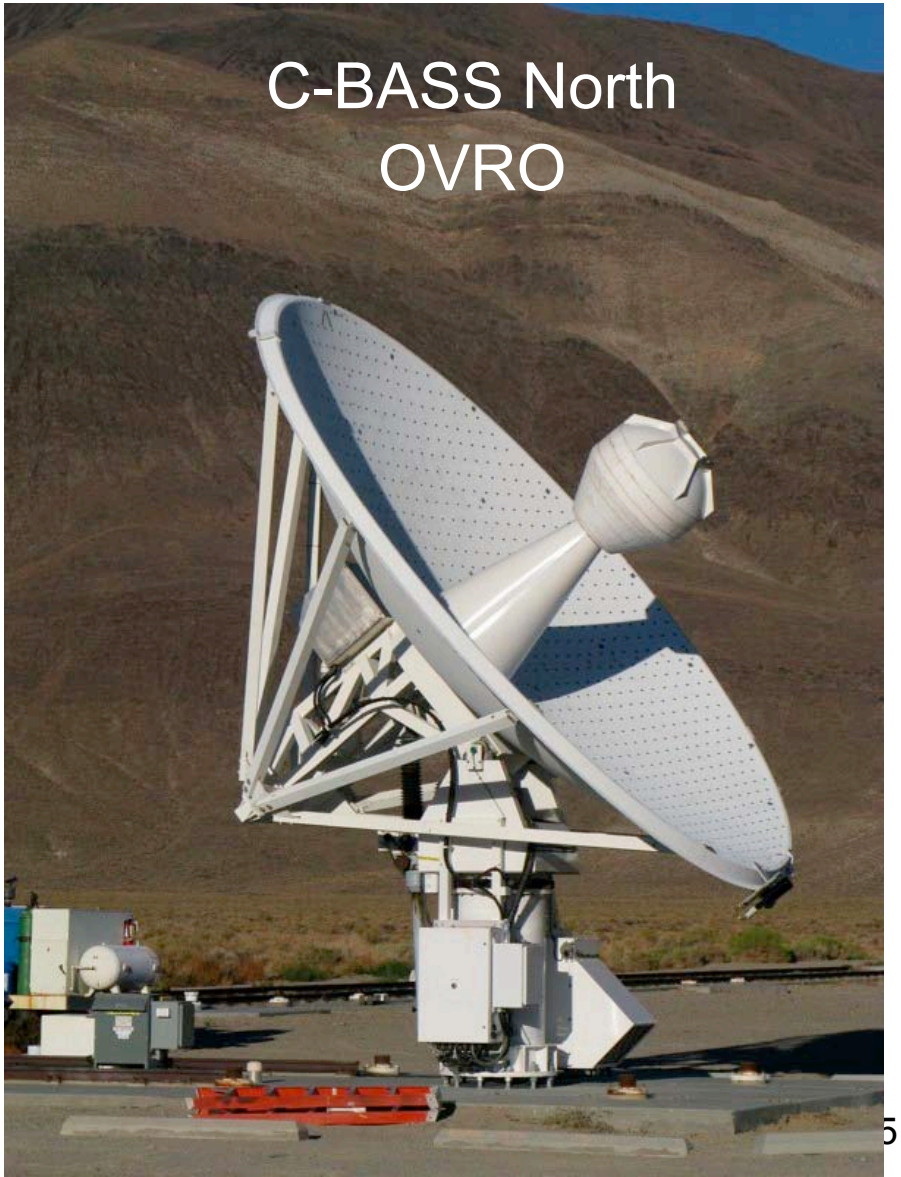
MANCHESTER 1824

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

JPL
Jet Propulsion Laboratory
California Institute of Technology

مدينة الملك عبدالعزيز للعلوم والتقنية KACST





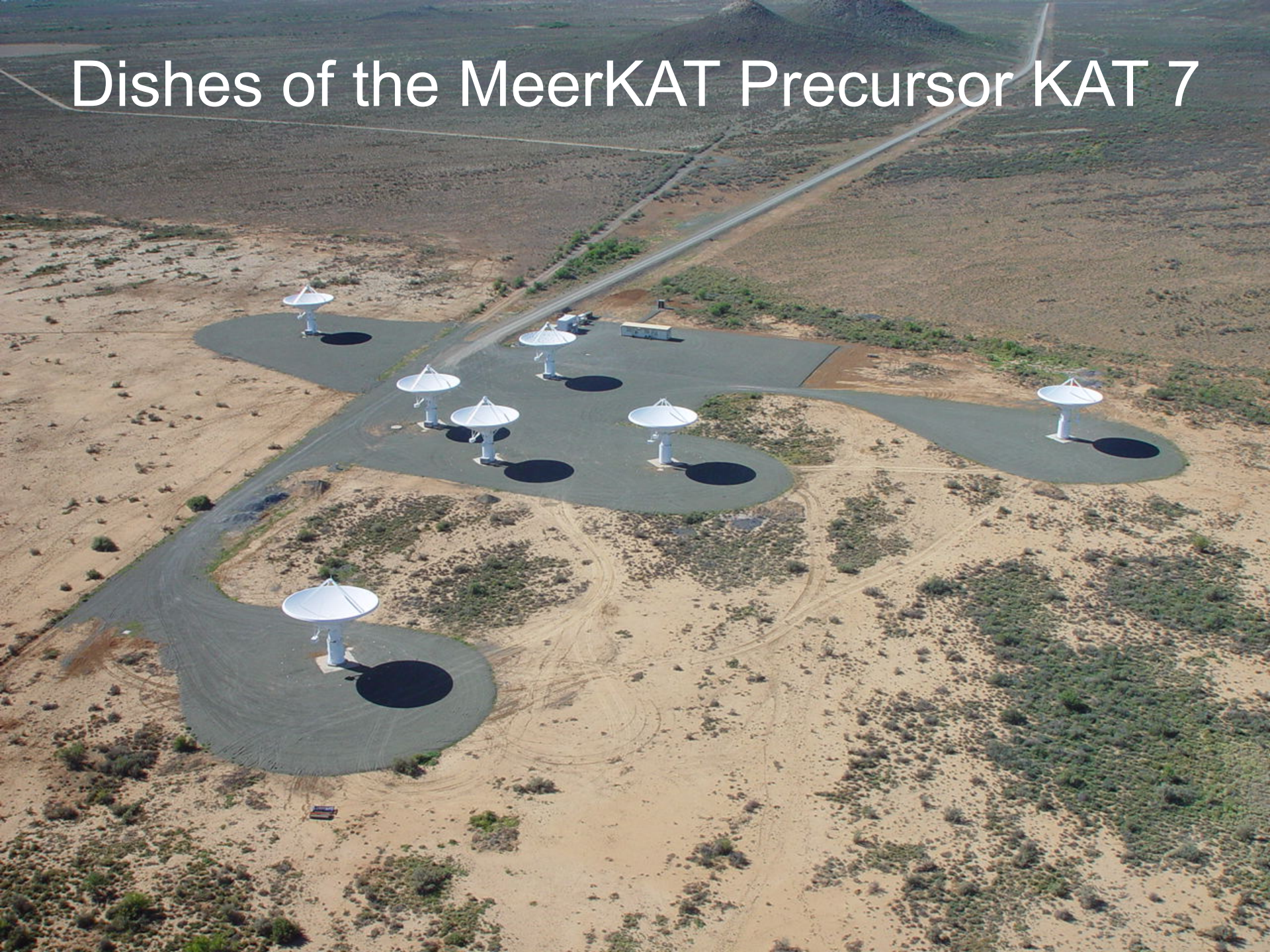
The MeerKAT Programme

- Africa will have a world-class 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
  - Largest radio telescope in southern hemisphere, one of largest in the world
  - Phased development: XDM, KAT-7, MeerKAT
  - Engaged local academia and industry

KAT 7 – MeerKAT prototype

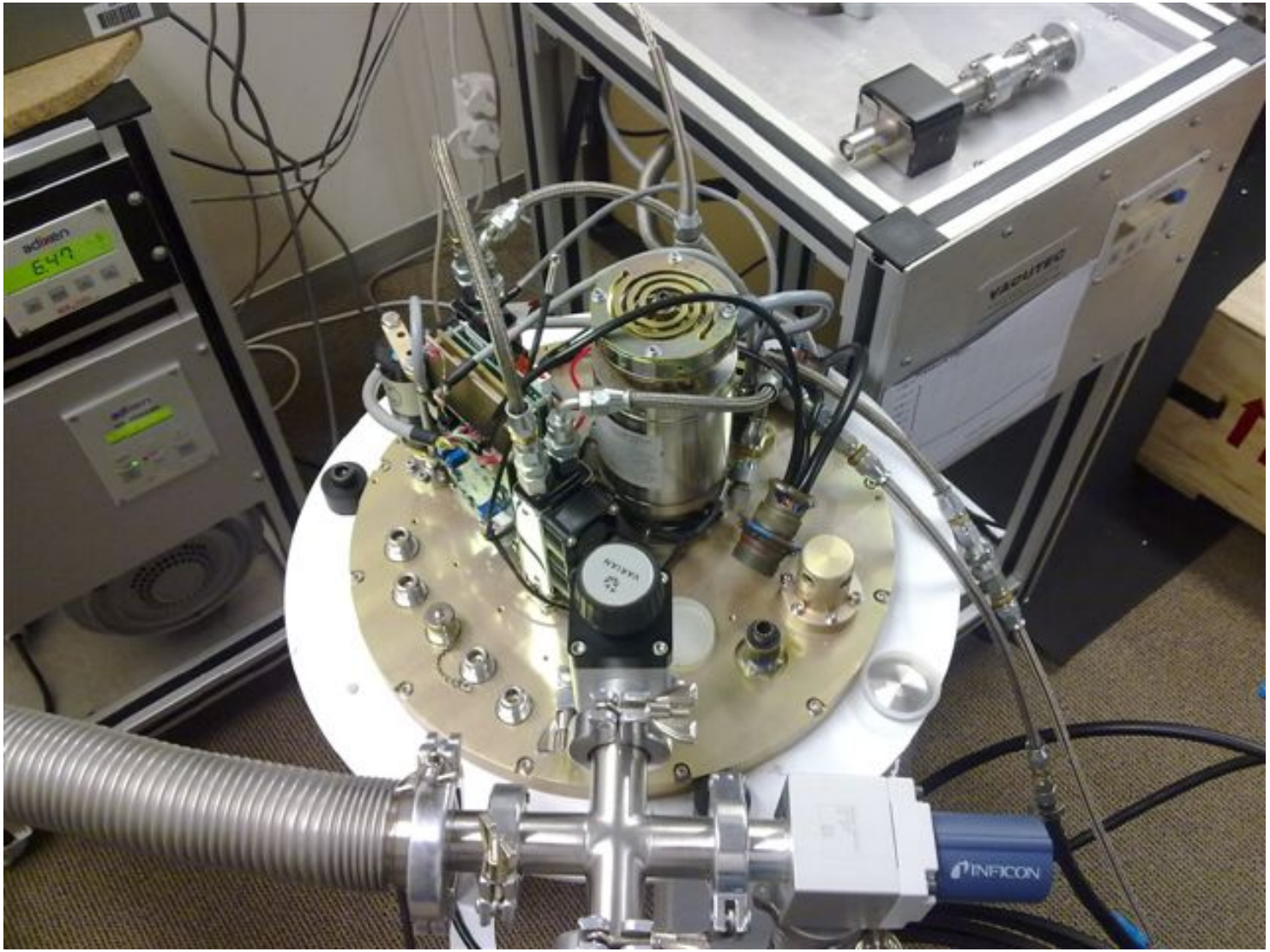
- Designed and built in South Africa
- Array of 7 antennas
  - Built and commissioned on time – and it works
- Component and system level prototyping
- Build experience in science and engineering teams
- Establish infrastructure in the Karoo
- Engage with local industry
- Produce publishable science
- “Build it and they will come”
  - Prof Steve Rawlings (Oxford), quote from *Field of Dreams*

Dishes of the MeerKAT Precursor KAT 7




MORRIS

Receiver Package



Reconfigurable Computing

CASPER / ROACH

ROACH correlator

Dan Wertheimer
UC Berkeley:

… special thanks for getting South Africa involved from early days. SA has become the principal CASPER contributor and driver, and is enabling instrumentation and science around the planet.

CASPER / ROACH

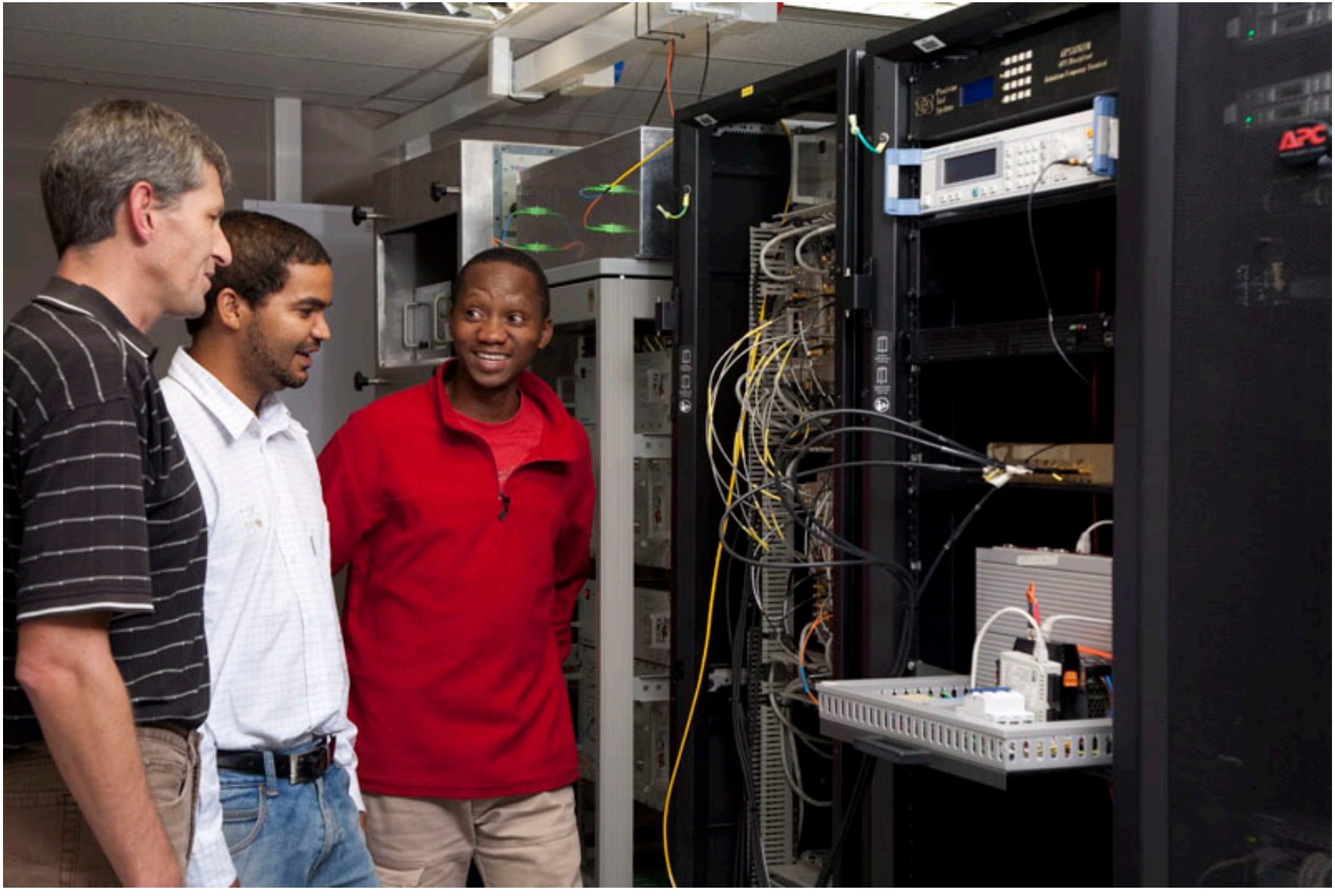
Technology and Science Collaborations

- **USA** : NRAO, UC Berkeley, Caltech, Illinois, Pennsylvania
- **Europe** : ASTRON, Oxford, Cambridge, Hertfordshire, Southampton, INAF, JIVE
- **India** : TIFRA
- South African universities
- **Examples**
  - **ASTRON**
    - Collaboration to model and understand the effect of beam-shapes in high precision imaging
  - **NRAO**
    - Collaboration in the further development of the CASA processing package for high performance computing, required by EVLA and MeerKAT
  - **GMRT**
    - Correlator development

International Industry Collaboration

- Mutual benefit R&D agreements with Nokia Siemens Networks, IBM, Intel, Oracle
- BAE Land Systems
- And others
- **Partnerships for pre-competitive research benefit us all**

KAT 7 integration lab

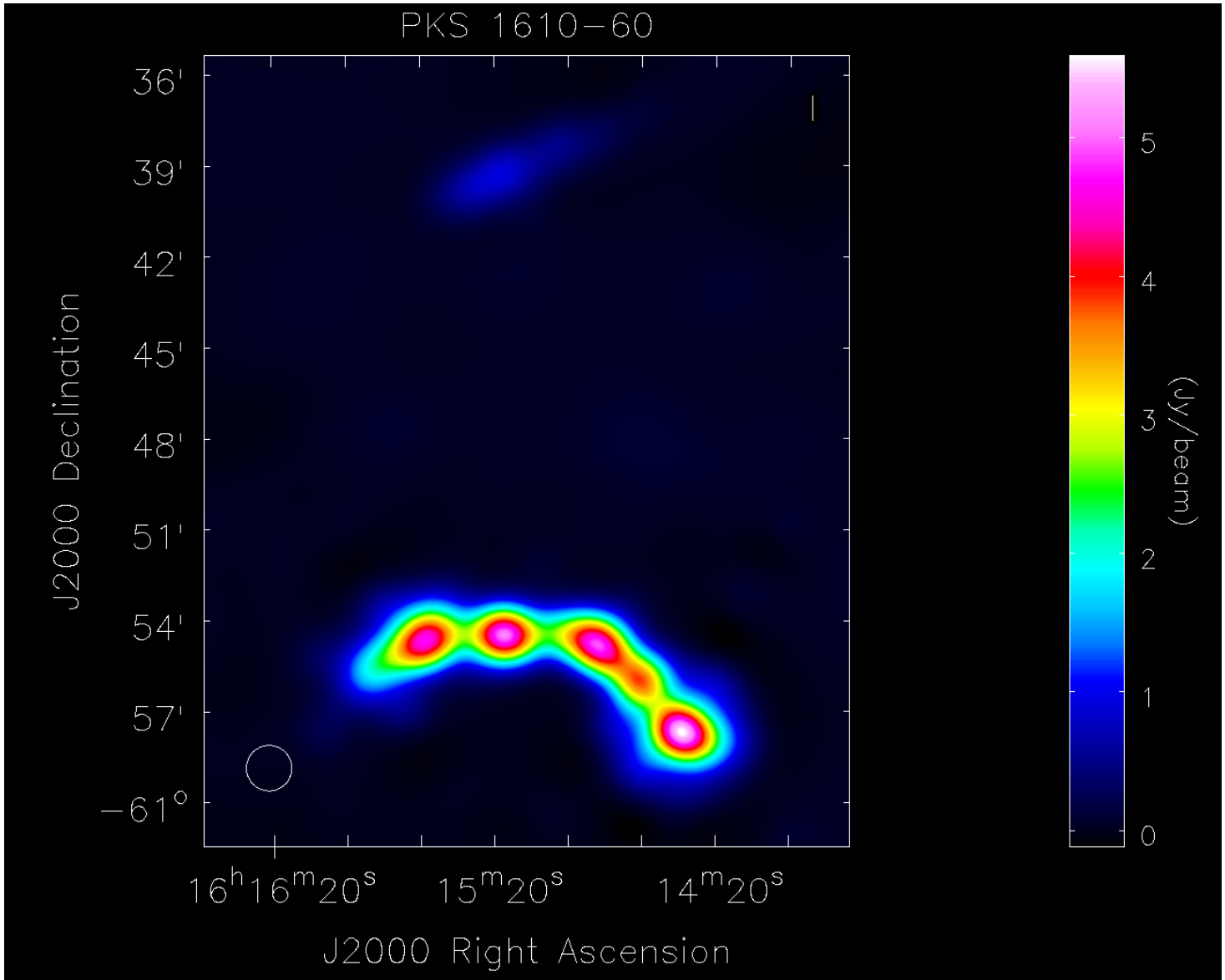


Cape Town KAT 7 Control Room

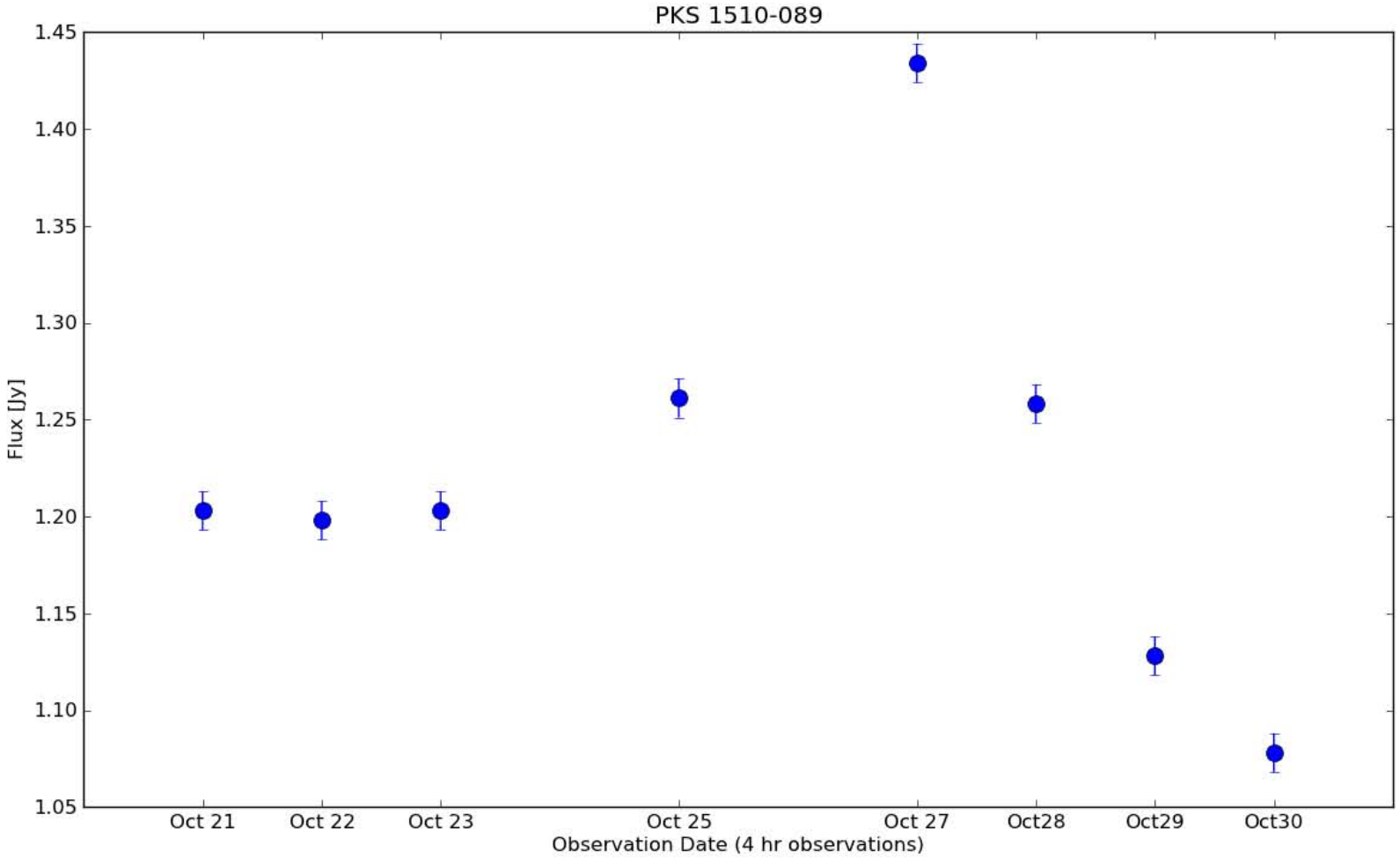
KAT 7 racks on site

Technicians on site

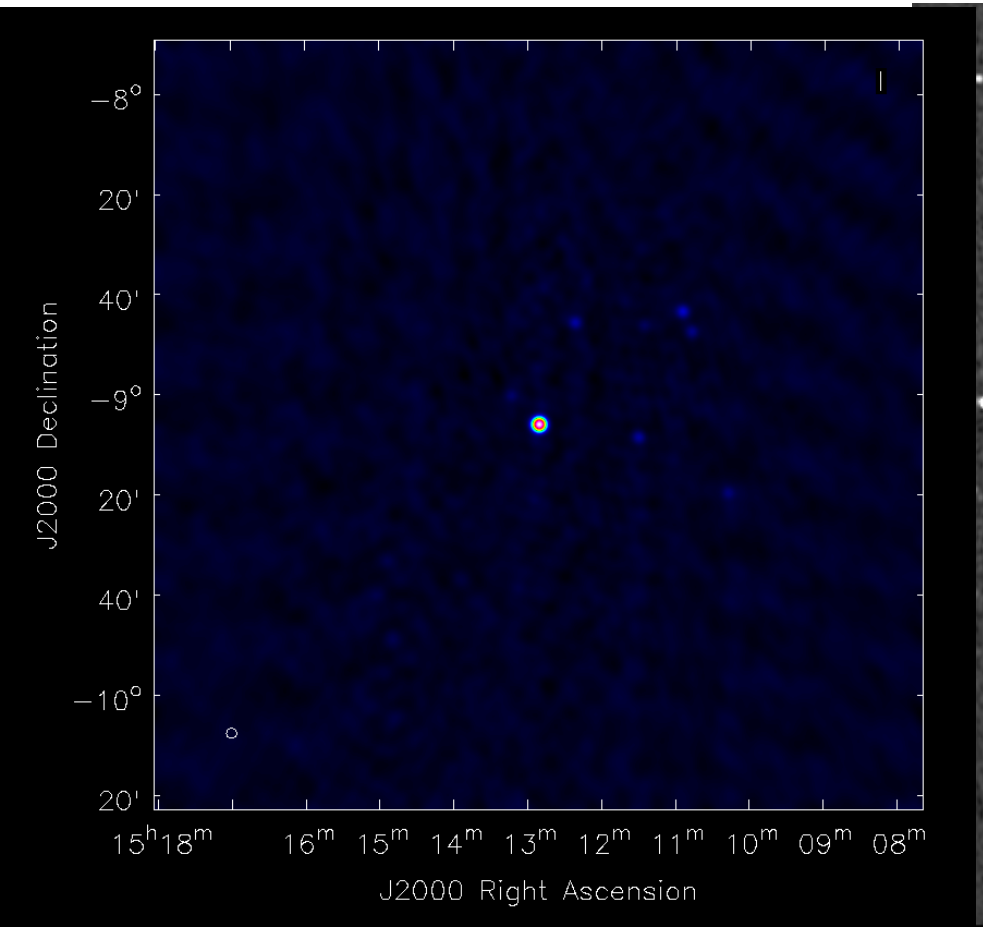
Radio galaxy observed with KAT 7

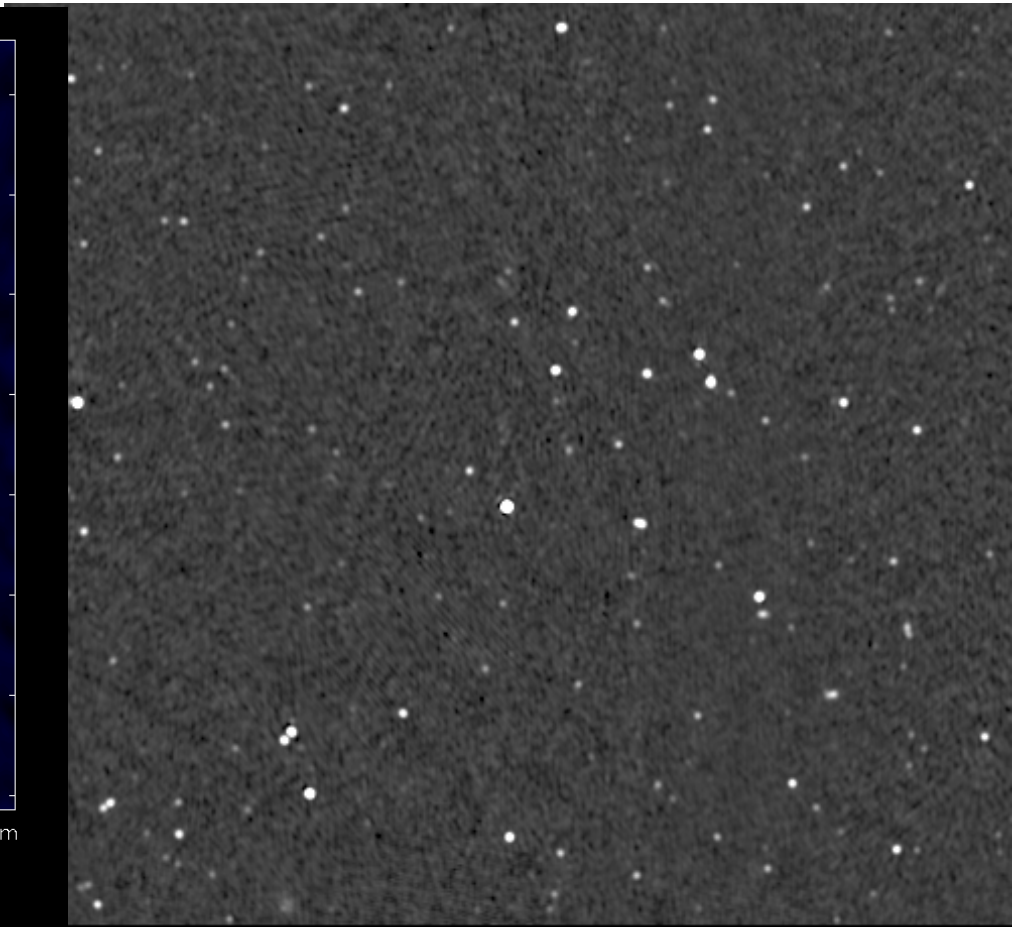


The first KAT 7 science: measurements of a gamma ray burster



KAT 7
2.5 Degree Field Compared to NVSS





MeerKAT – a world-leading telescope and SKA precursor

- Most sensitive radio telescope in the Southern Hemisphere until the SKA is completed in 2024
- MeerKAT design is aligned with SKA reference design for dishes
- Infrastructure and site establishment is SKA ready

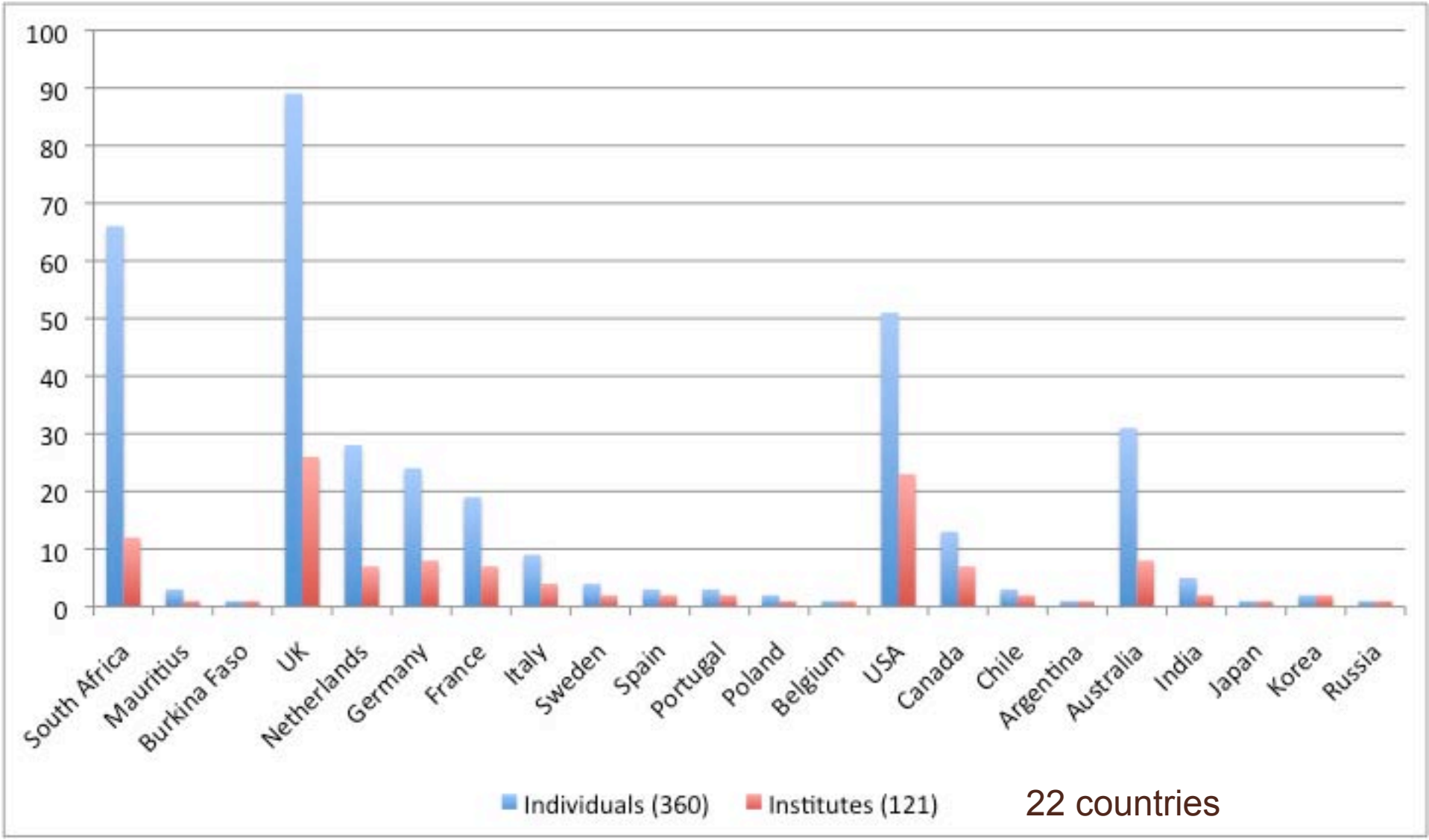
MeerKAT Large Surveys

- 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 VLBI Science

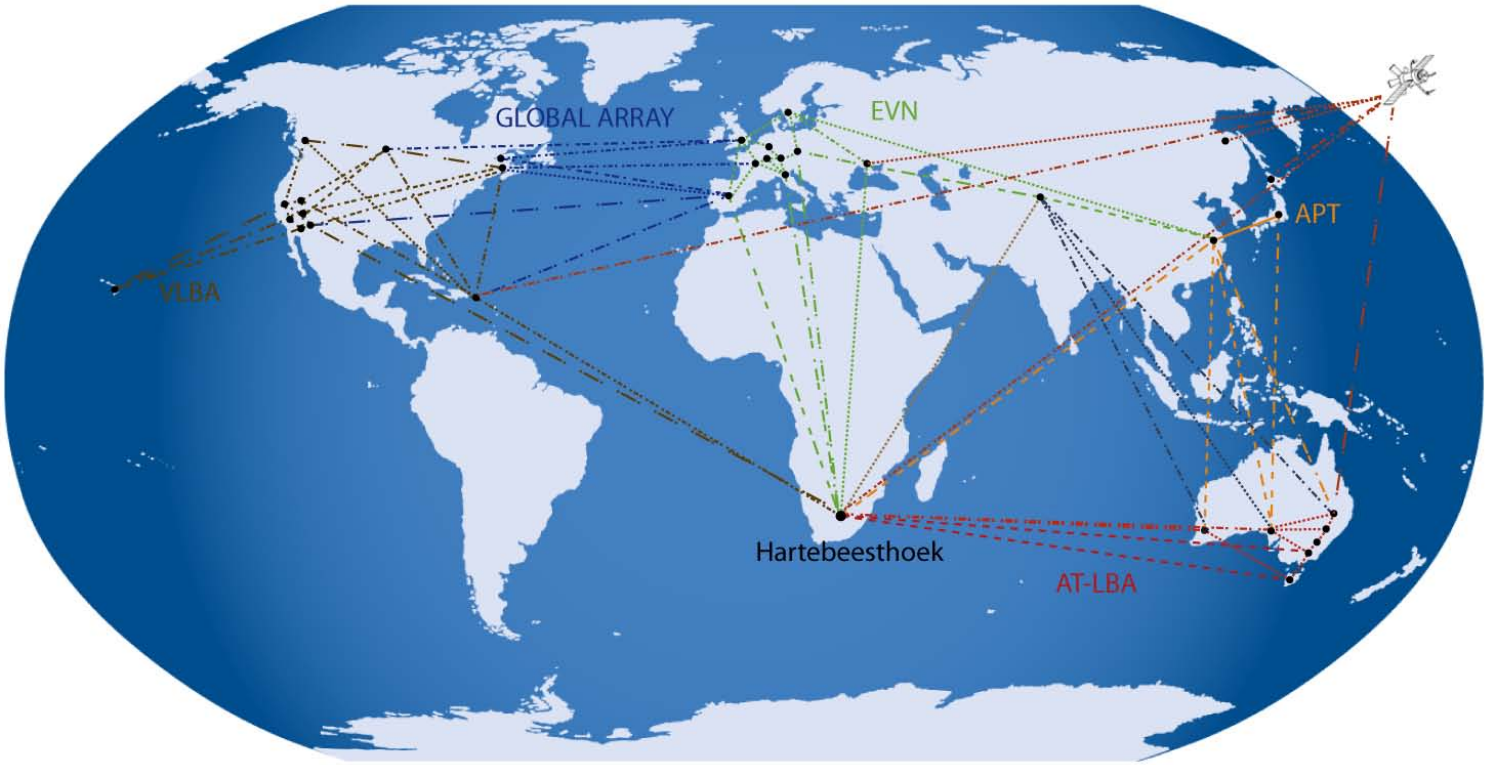
- MeerKAT will also participate in global VLBI operations with all major radio astronomy observatories around the world and will add considerably to the sensitivity of the global VLBI network, and enhance the southern VLBI arrays

MeerKAT Large Surveys: Time Awarded



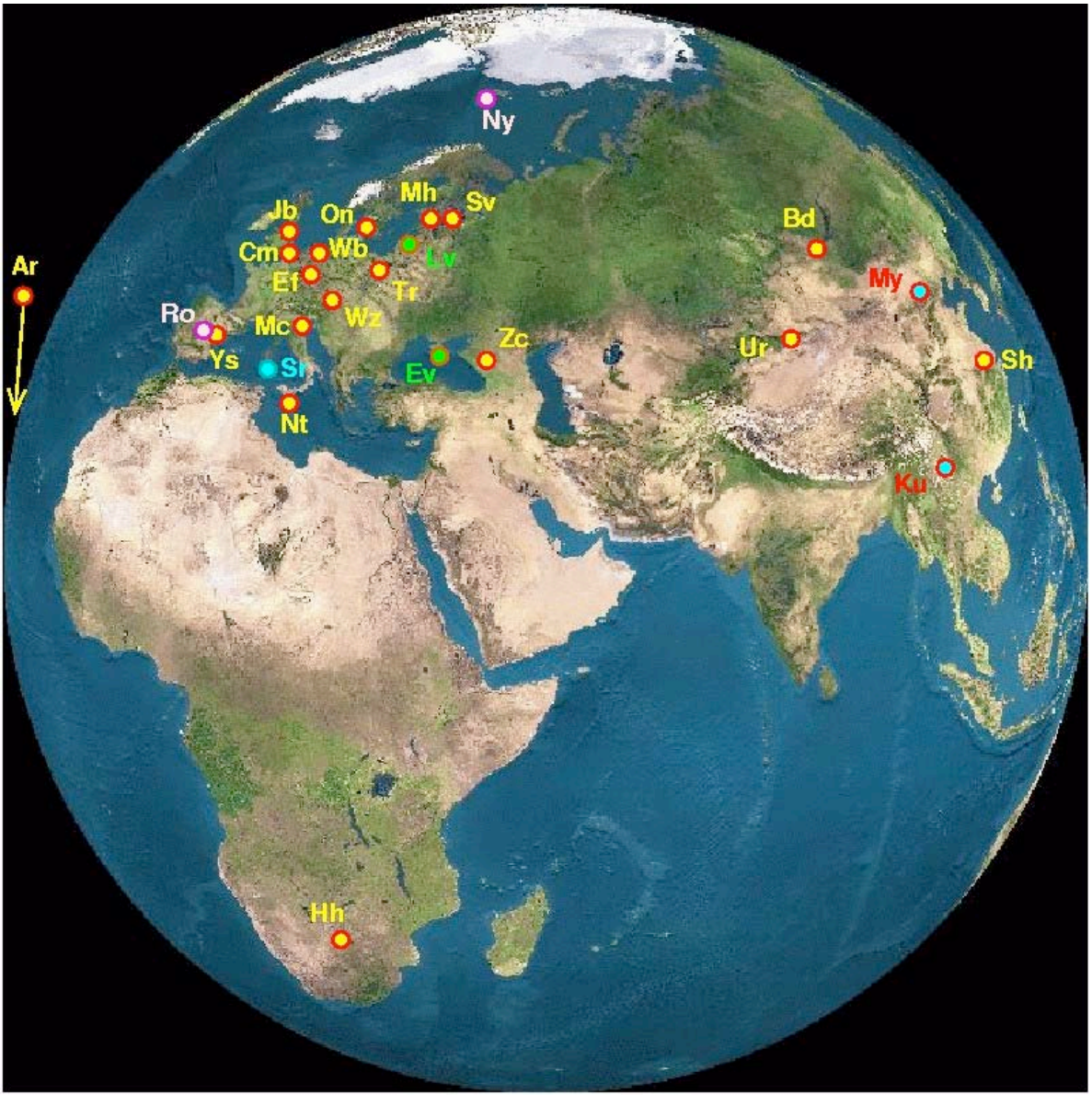
African VLBI Network

- Project launched to convert >20 obsolete 32m class satellite telecommunication dishes in Africa into radio astronomy facilities
- Result in the creation of VLBI network to complement the EVN and SKA and improve existing VLBI network UV coverage and performance

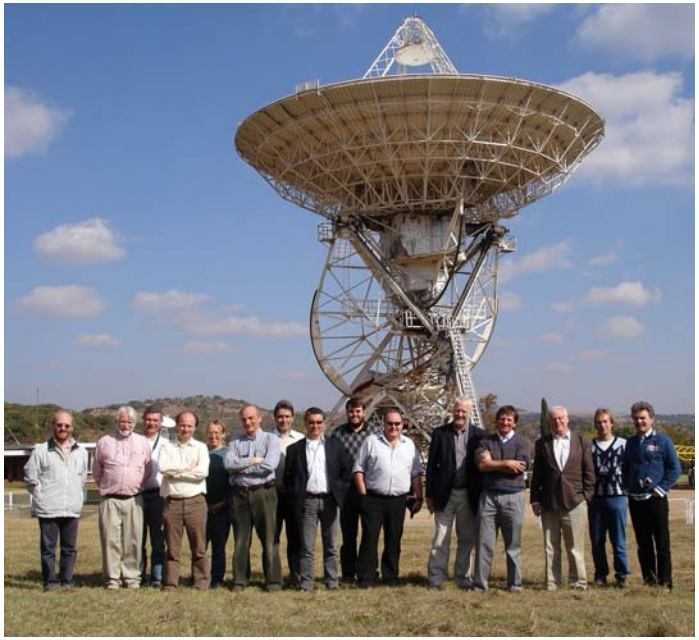


Existing VLBI Networks

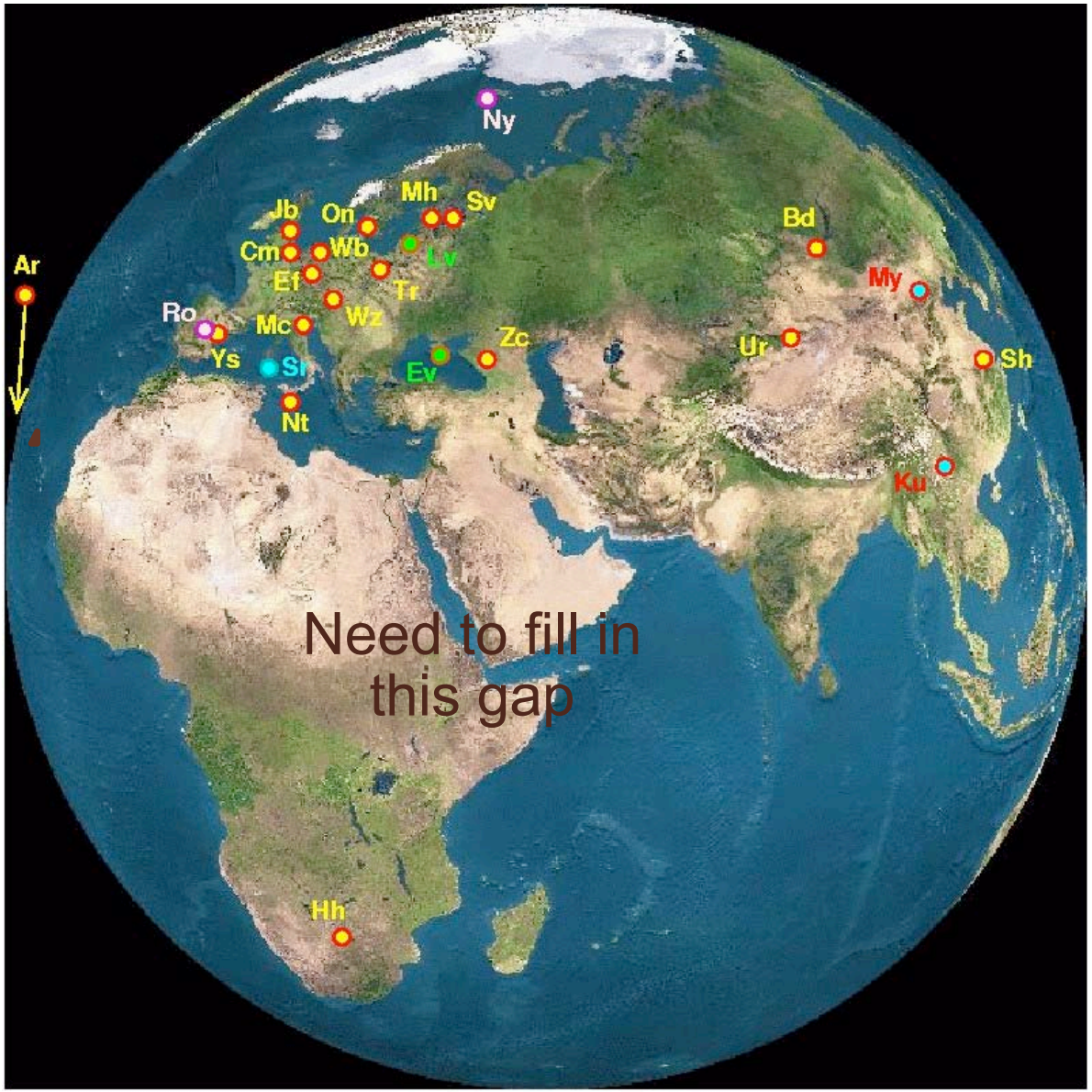
European VLBI Network



EUROPEAN vlbi NETWORK



Mind the Gap

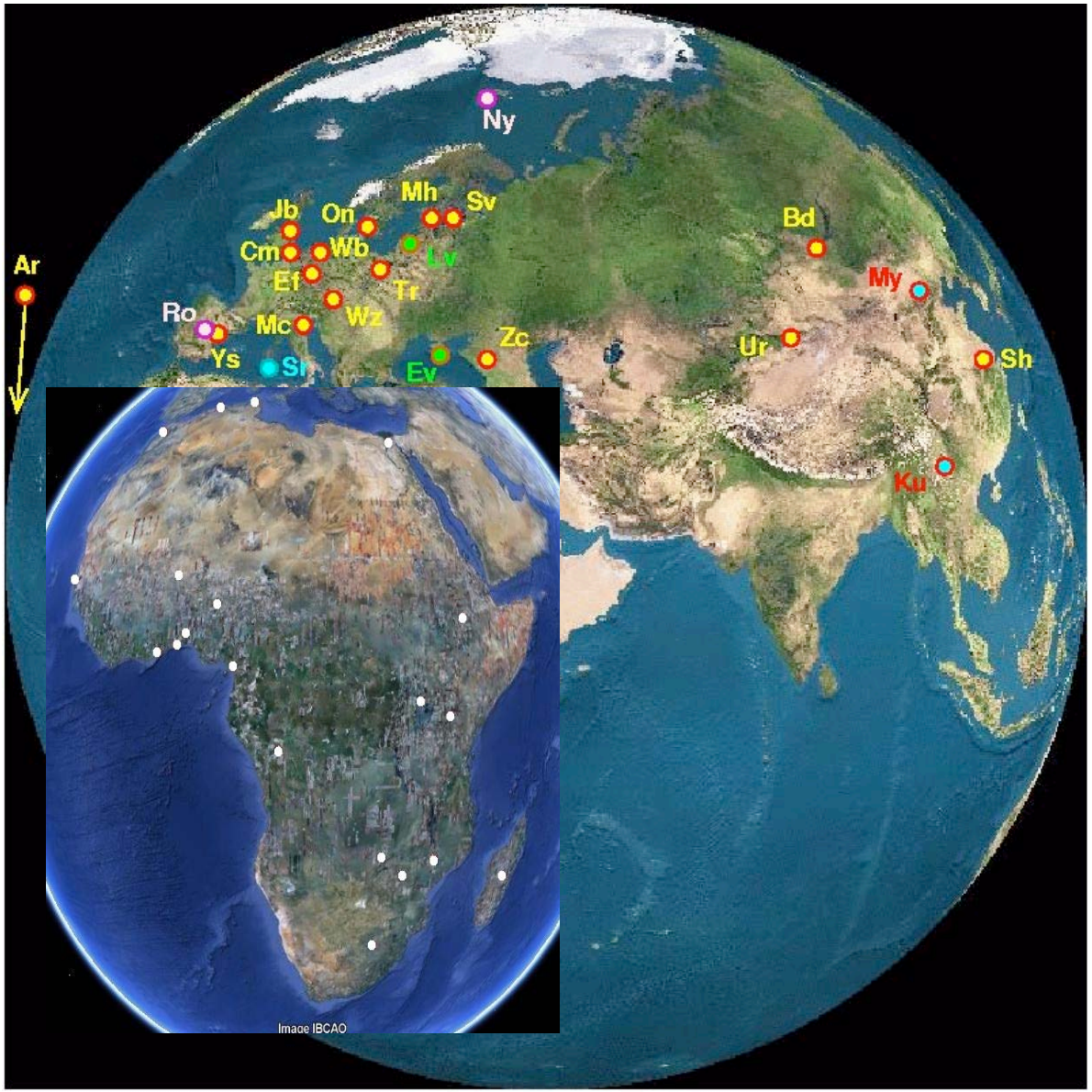

Ny
Jb
On
Mh
Sv
Cm
Wb
Lv
Ef
Tr
Ar
Ro
Mc
Wz
Ys
Sl
Ev
Zc
Nt
Bd
My
Ur
Sh
Ku
Hh
Need to fill in this gap

30-m class antennas in Africa

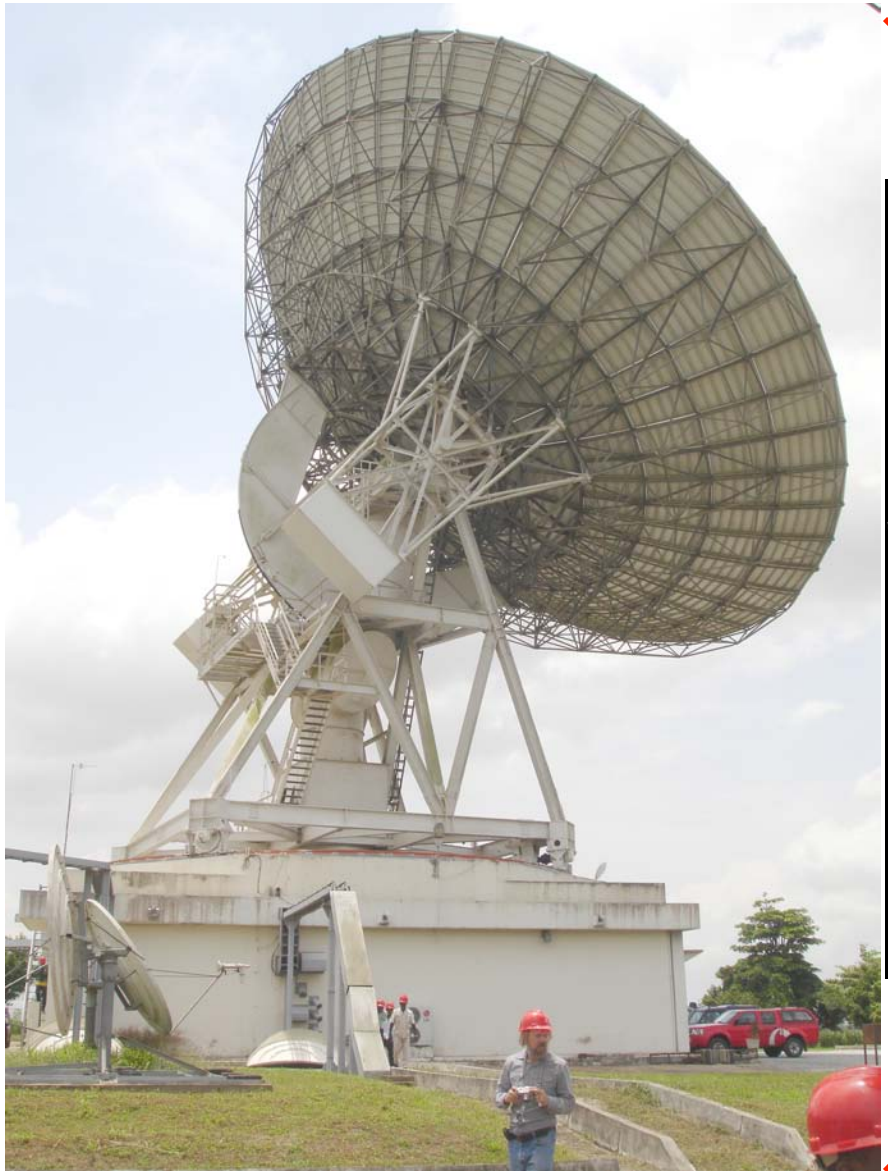
The African VLBI Network

- Convert existing communications antennas into radio astronomy facilities.
  - Maintain existing staff.
  - Install new receivers and instrumentation.
  - Create a VLBI array that will link with
    - MeerKAT
    - HartRAO
    - Europe, the USA and Australasia.

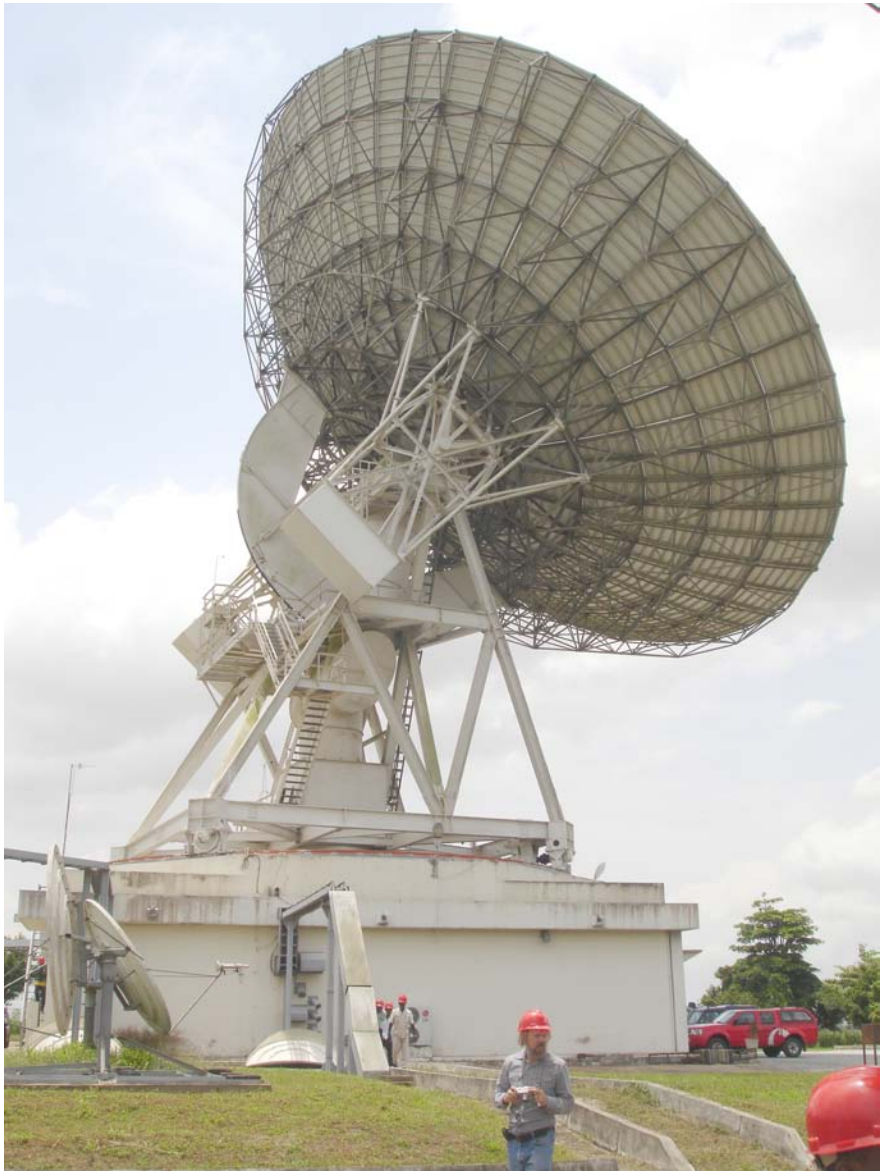
European + African VLBI Network



Nkutunse - Ghana



And its twin – Medicina, Italy



32m Vodafone dish at Nkutunse, Ghana

Ghanaian team inspecting dish. The team has already initiated work. First light by December 2012?

Nkutunse – last week

Youth into Science & Engineering

- Research chairs
- Visiting / joint professorships
- University grants – support or lecturers
- Postdoctoral fellowships
- Postgraduate bursaries
- Undergraduate bursaries
- Internships
- Technician training – national diplomas at universities of technology
- Artisan training
- Development of astrophysics and related engineering in Africa partner states
- Mobility grants

A focused and structured programme with a pipeline strategy

History of the HCD programme

- Started in 2005 with 9 grants awarded
- To date we have funded more than 300 student bursaries, postdoctoral fellowships, academic positions at SA universities, visiting professorships and research chairs.

Growth in student numbers

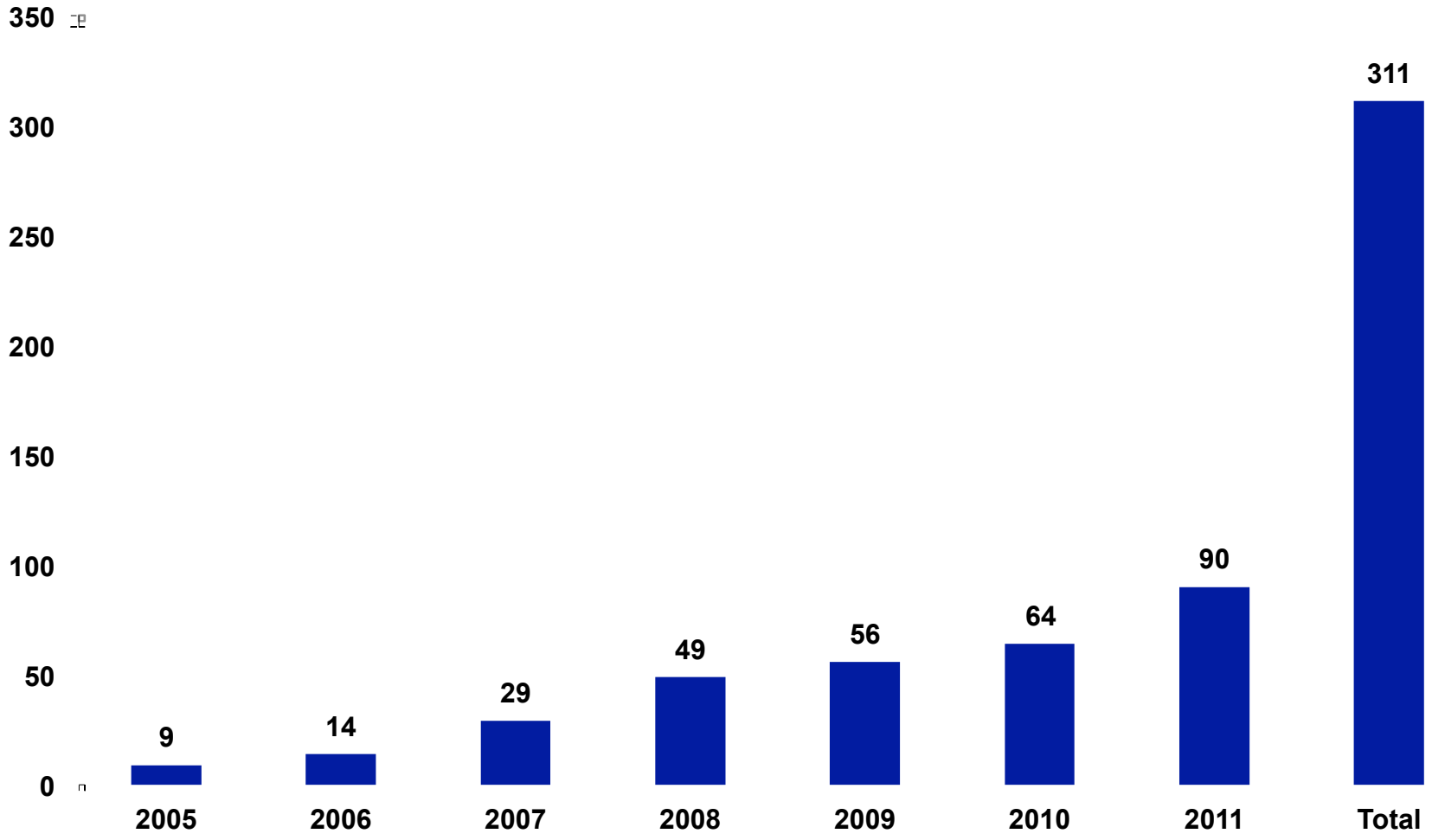
SKA PhD Student from Kenya

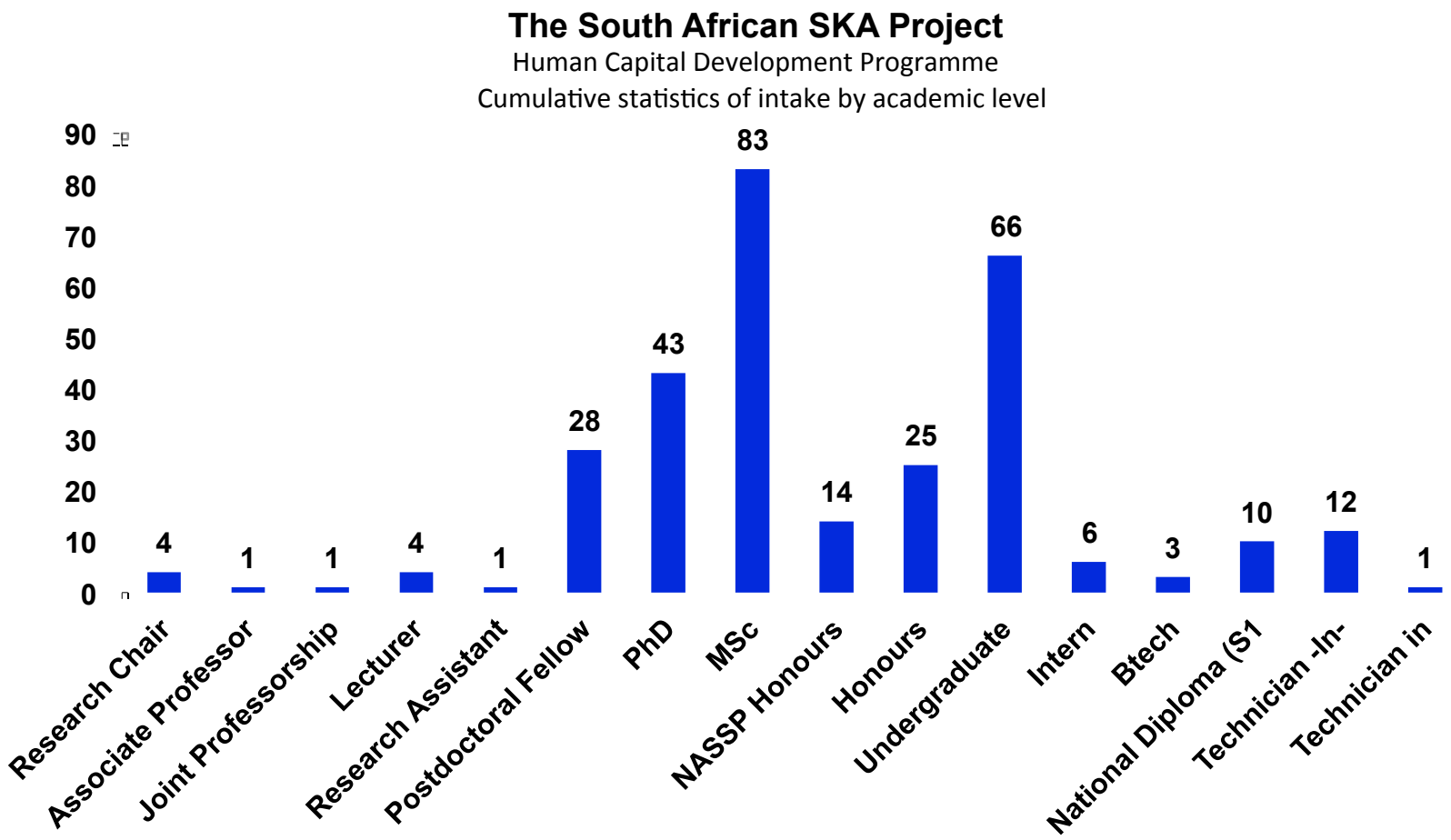
Members of the computational electromagnetics research group at Stellenbosch University

Africa HCD workshop at KAT 7 site (May 2011)

The South African SKA Project
Human Capital Development Programme

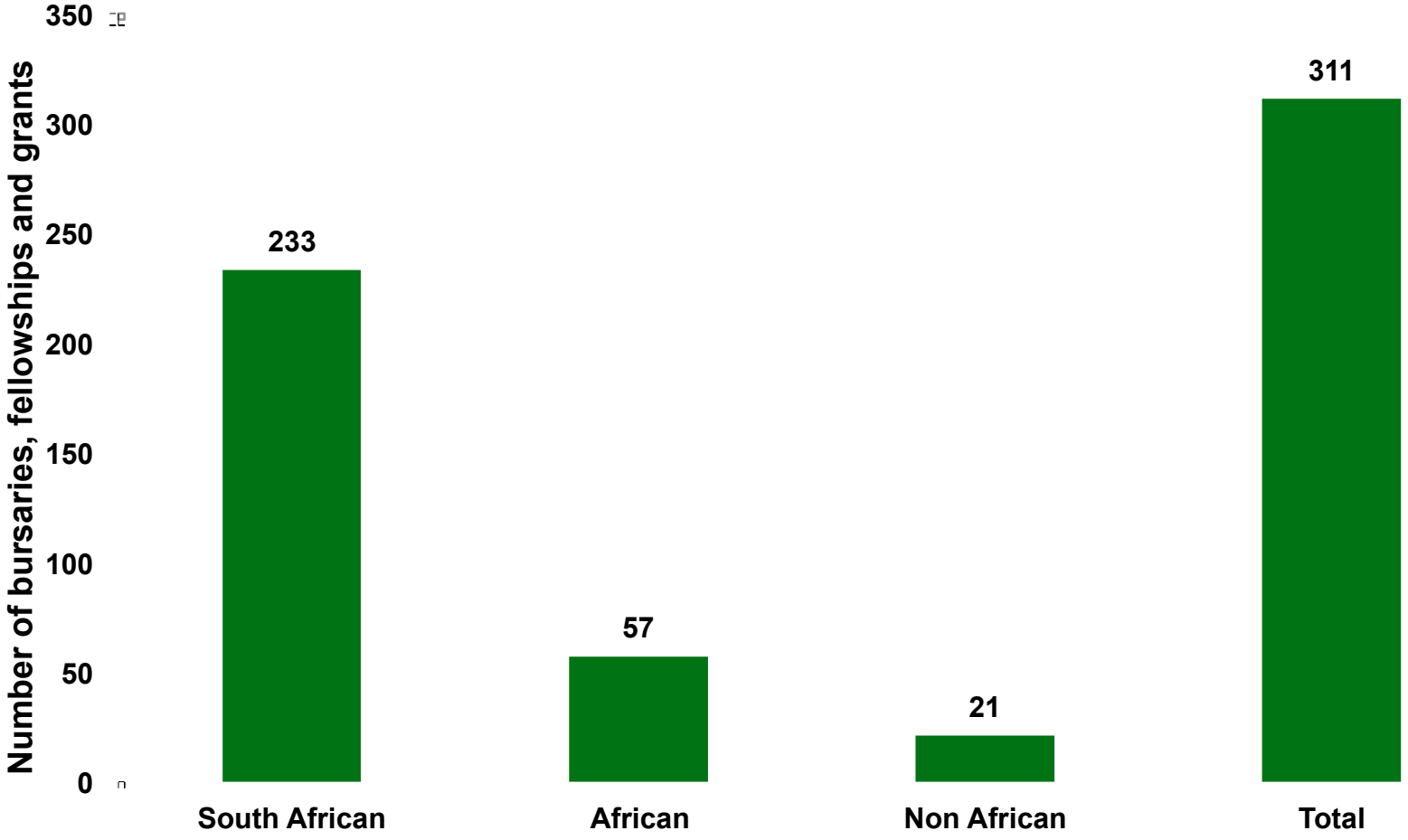
Intake by academic year



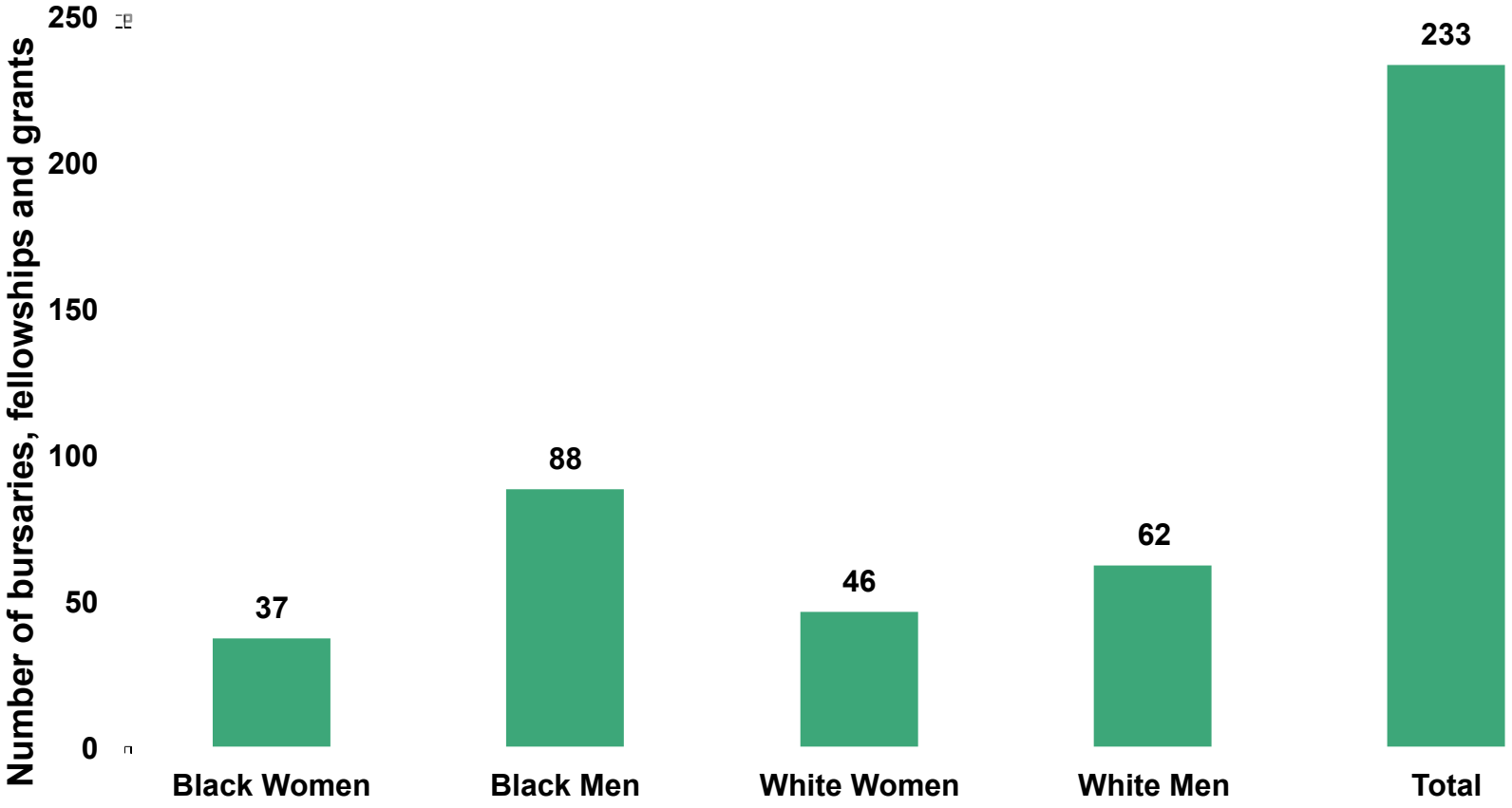

The South African SKA Project
Human Capital Development Programme
Cumulative statistics of intake by academic level
90
80
70
60
50
40
30
20
10
0
4
1
1
4
1
28
43
83
14
25
66
6
3
10
12
1
Research Chair
Associate Professor
Joint Professorship
Lecturer
Research Assistant
Postdoctoral Fellow
PhD
MSc
NASSP Honours
Honours
Undergraduate
Intern
Btech
National Diploma (S1
Technician -In-
Technician in

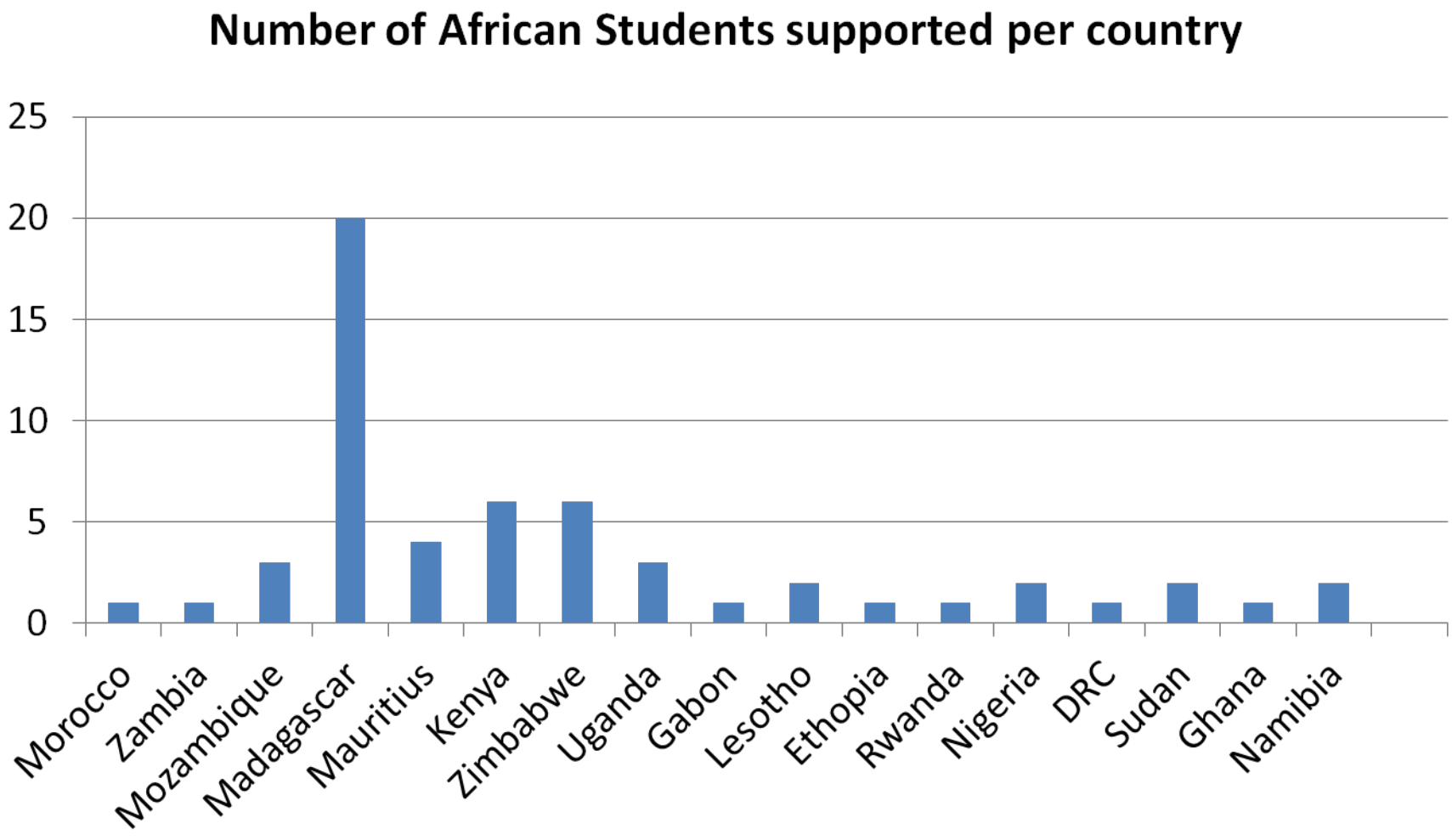
The South African SKA Project
Human Capital Development Programme

Cumulative statistics by nationality



The South African SKA Project
Human Capital Development Programme
Awards to South Africans




Number of African Students supported per country
25
20
15
10
5
0
Morocco
Zambia
Mozambique
Madagascar
Mauritius
Kenya
Zimbabwe
Uganda
Gabon
Lesotho
Ethopia
Rwanda
Nigeria
DRC
Sudan
Ghana
Namibia

African partners now teaching astronomy

Name	Current level of teaching	Status
Kenya	Undergraduate	Honours
Mozambique	Undergraduate	Honours
Mauritius	Postgraduate	MSc
Madagascar	Postgraduate	MSc
Zambia	Undergrad	In process
Botswana	Undergrad	In process
Ghana	Undergrad	In process

PhD bursaries awarded for 2012

- 6 South African
  - 2 Black men
  - 1 white woman
  - 3 white men
- 5 from other African countries
  - 2 Kenya
  - 2 Madagascar
  - 1 Burkina Faso

MSc bursaries awarded for 2012

- 6 South Africans
  - 1 Black woman
  - 1 Black man
  - 1 White woman
  - 3 White men
- 4 from other African countries
  - 2 Mauritius
  - 1 Madagascar
  - 1 DRC

PhD and MSc Bursary Programme

- 43 PhD bursaries awarded since 2005
- 24 graduated
- 83 MSc bursaries awarded since 2005
- 53 graduated

Launch of new labs at Carnarvon High

Visiting the Site