MEGA-SCIENCE PROJECTS: COMBINING SCIENCE AND DEVELOPMENT

BANGALORE
OCTOBER 2015

science & technology
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Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation

SKA AFRICA

SKA SQUARE KILOMETRE ARRAY Africa

THANKS

- To the organisers
- For the invitation
- For a really interesting and informative conference
- For the opportunity to share ideas

THIS TALK

- What is the SKA?
- SKA Science
- The South African SKA site, the MeerKAT, CBASS, HERA and HIRAX
- MeerKAT science
- Data challenges of the SKA and the Big Data Africa programme (including the African Big Data Research Cloud)
- SKA SA's Human Capital Development programme

South Africa must increase its participation the knowledge economy in order to grow and reduce inequality

SQUARE KILOMETRE ARRAY

- Truly a mega-project
- World's largest radio telescope
- World's largest science project
- Global participation
- Huge data rates
- Transformational science
- Two phases (SKA-1 and SKA-2) up to 2030
- The scale of the SKA represents a leap forward in both engineering and research and development.

SKA – A MEGA-PROJECT IN SCIENCE

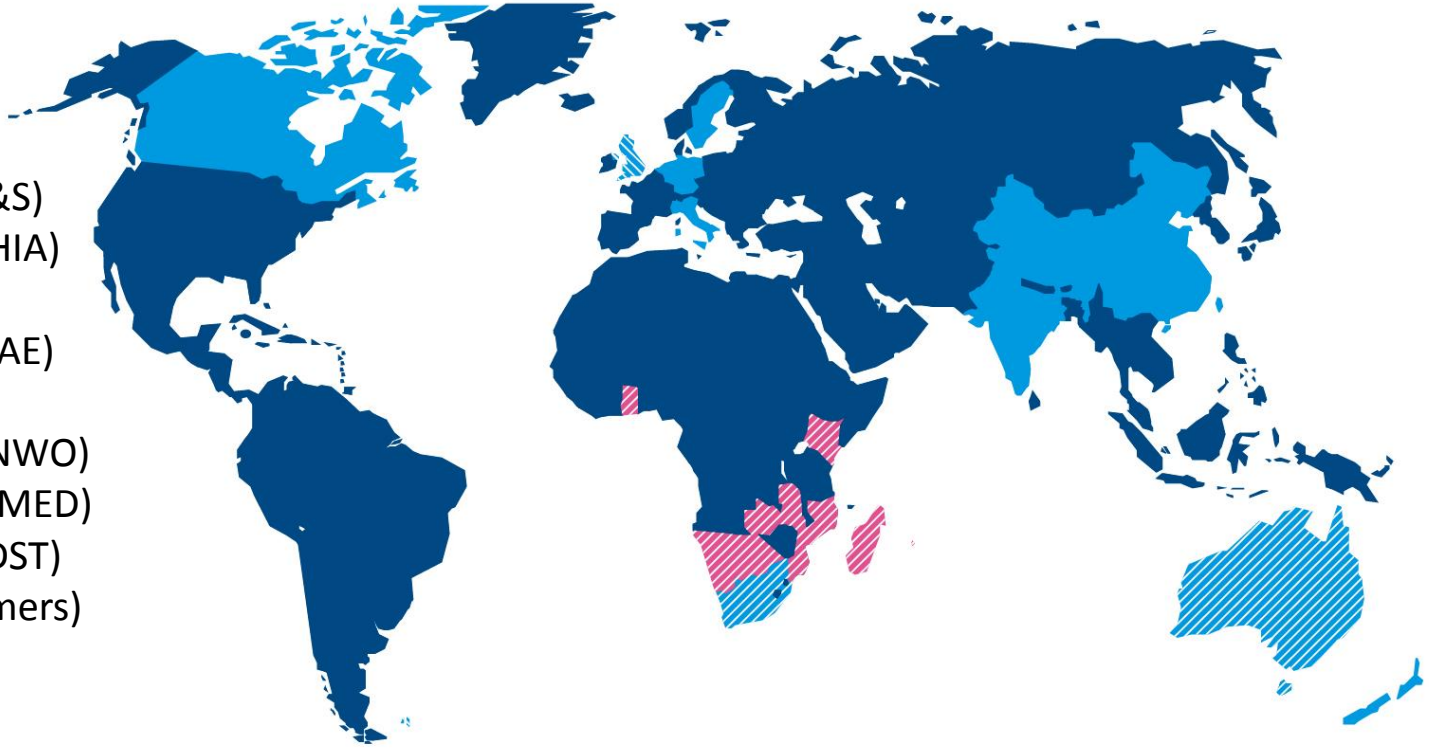
- High profile, so attracts attention to science and technology – very good public and political coverage
- Changes national and international perception of what we can do in South Africa – world-leading science and technology
- Attracts young people to study science and technology
- Unlocks public sector funding
- Attracts industry collaboration
- SKA Africa builds on all of these to maximize the development benefit as well as the science
- 240 people directly employed by SKA SA in three locations: Karoo; Cape Town; Johannesburg
- Many more in universities and industry working with us

THE SKA IS A GLOBAL PROJECT

- Ten countries are members of the SKA Organisation – Australia, Canada, China, Germany, India, Italy, New Zealand, South Africa, Sweden, The Netherlands and the United Kingdom.
- India now a full member of the SKA Organisation through the DAE
- The SKA Organisation is headquartered at the Jodrell Bank Observatory, near Manchester in the United Kingdom.
- Approximately 100 organisations and companies from 20 countries are participating in the design and development of the SKA
- India is fully involved, especially in the telescope manager software design consortium (consortium lead)

SKA Organisation: 10 countries, more to join

Australia (DoI&S)
Canada (NRC-HIA)
China (MOST)
India (NCRA/DAE)
Italy (INAF)
Netherlands (NWO)
New Zealand (MED)
South Africa (DST)
Sweden (Chalmers)
UK (STFC)



Full members
SKA Headquarters host country
SKA Phase 1 and Phase 2 host countries

African partner countries
(non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders

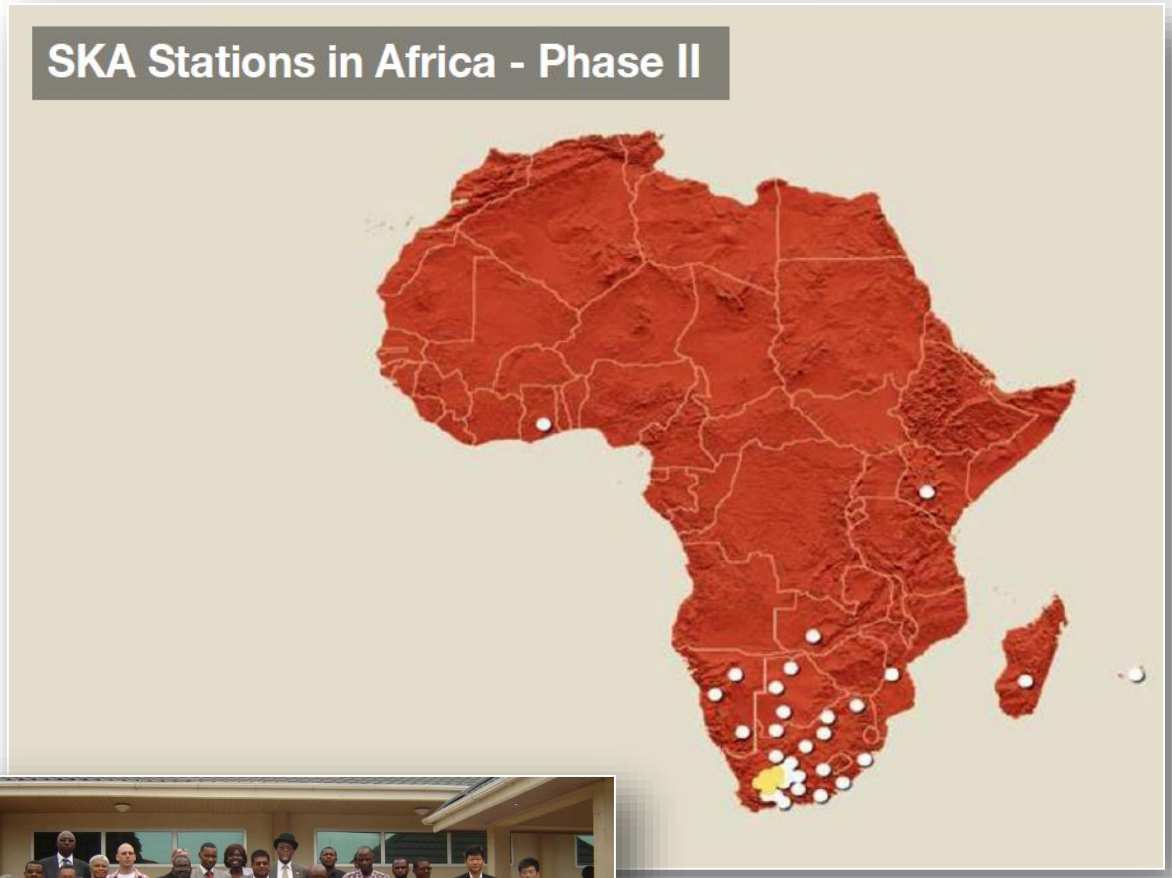
WHAT WILL THE SKA DO?

- The SKA will use thousands of dish antennas and up to a million dipole antennas that will enable astronomers to monitor the sky in unprecedented detail and survey the entire sky much faster than any system currently in existence

- This will give the SKA unrivalled scope in observations, exceeding the image resolution quality of the Hubble Space Telescope

- SKA will also image huge areas of sky with an unprecedented level of sensitivity

SKA IN AFRICA



Partner Countries:

- Botswana
- Ghana
- Kenya
- Madagascar
- Mauritius
- Mozambique
- Namibia
- Zambia
- Supported by African Union Heads of State

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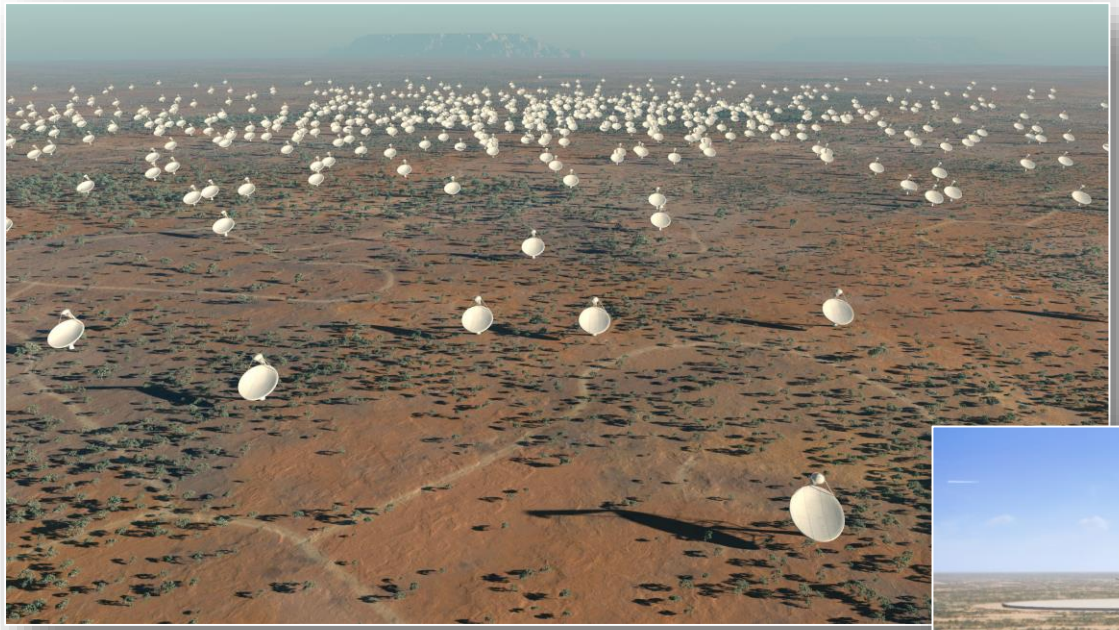
SKA SQUARE KILOMETRE ARRAY Africa

SKA CORE IN THE KAROO



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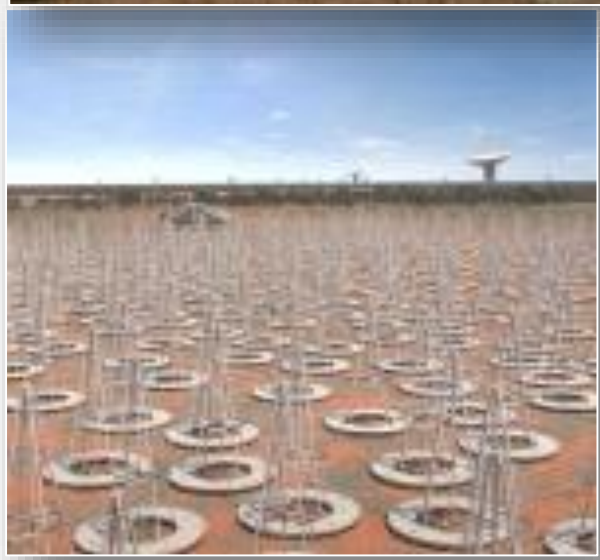
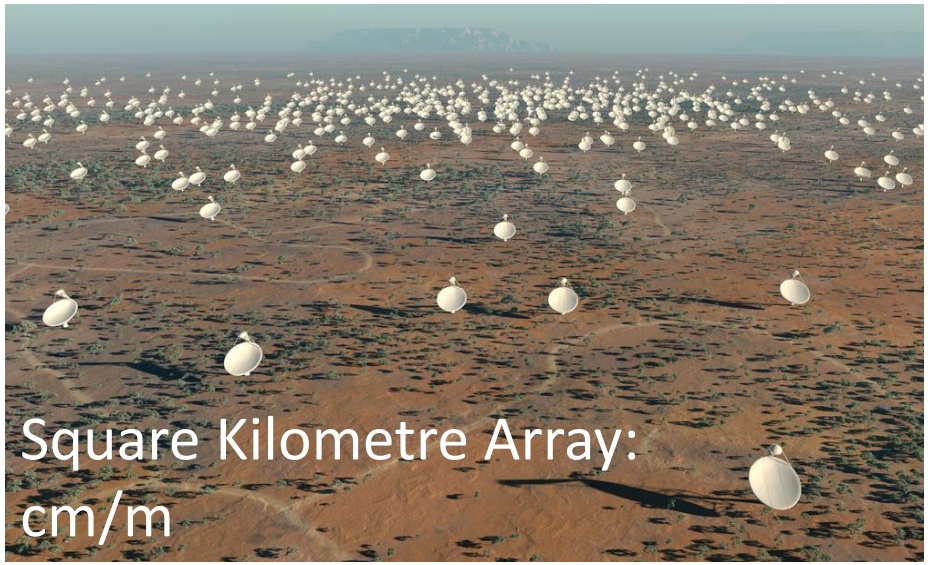
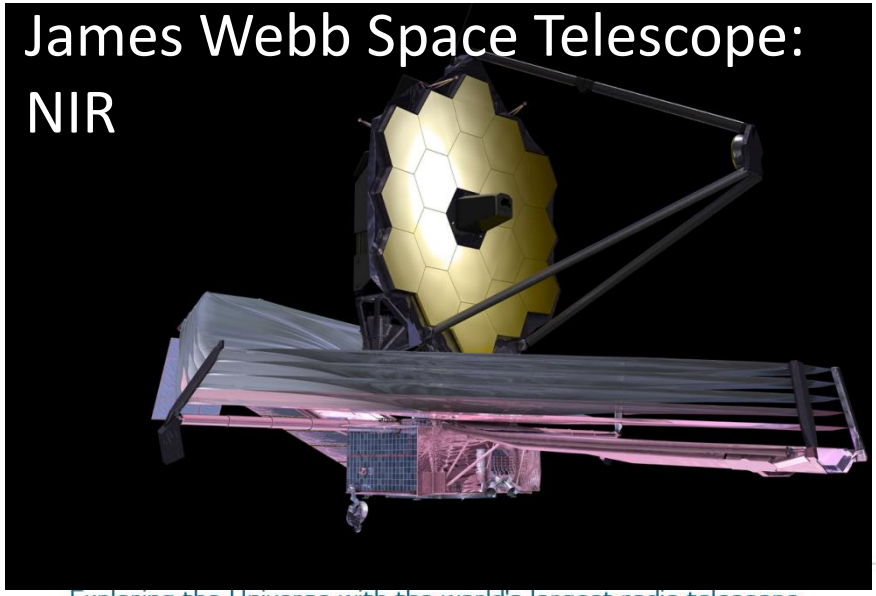
SKA CONSTRUCTION TIMETABLE

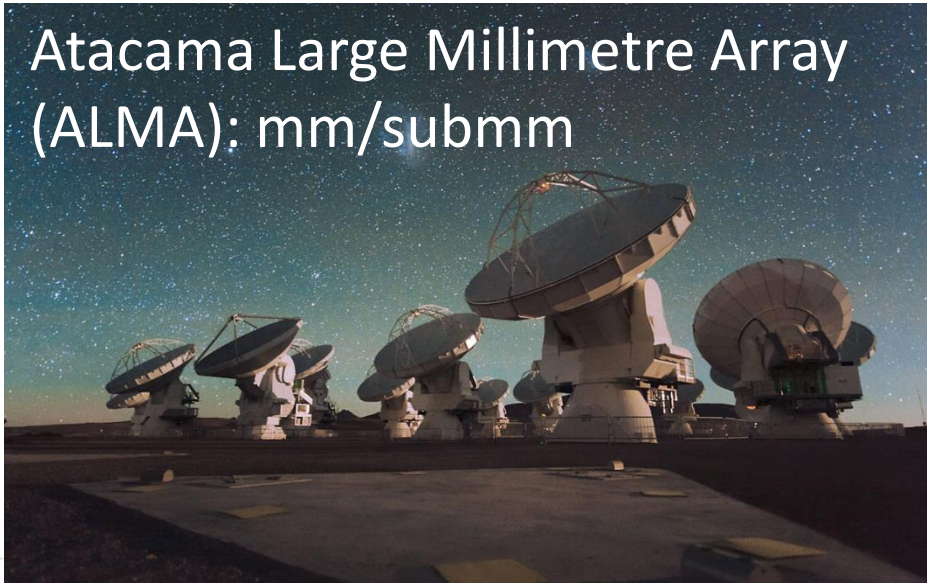
- MeerKAT - 64 x 13.5m diameter offset dishes over 8km
  - Completion 2017
- SKA1-MID –197 x 15m dishes over 150km
  - Design phase 2013-2016
  - Construction 2018 - 2022
- SKA2-MID – up to 2500 dishes over ~ 3000km
- SKA2-MFAA – mid-frequency aperture array
  - Design starts about 2019
  - Construction about 2023-2030
- In Western Australia
  - 125 000 low frequency antennas for SKA1-LOW
  - SKA2-LOW not yet clear



Great Observatories for the coming decades







WHY THE SKA?

SKA will be one of the great physics machines of 21st Century and one of the world's engineering marvels

The SKA will be able to conduct transformational science, breaking new ground in astronomical observations to investigate:

- Einstein's theory of relativity to the limits
- How the very first stars and galaxies formed just after the Big Bang
- The mysterious force known as dark energy, the discovery of which gained the 2011 Nobel prize for physics
- The powerful magnetic fields which permeate the cosmos
- Whether we are alone in the universe

SKA: driving innovation

Element	SKA1 scale	SKA2 scale
Dishes, feeds, receivers	~200	~2500
Aperture arrays	~130,000	~1,000,000
Signal transport	~1 Pb/s	~10 Pb/s
Signal processing	~exa-MACs	~exa-MACs
High performance computing	~100s tera-flops	~exa-flops
Data storage	Exa-byte capacity	Exa-byte
Power requirements	~10MW	~50MW

Key innovation: Software engineering and algorithm development

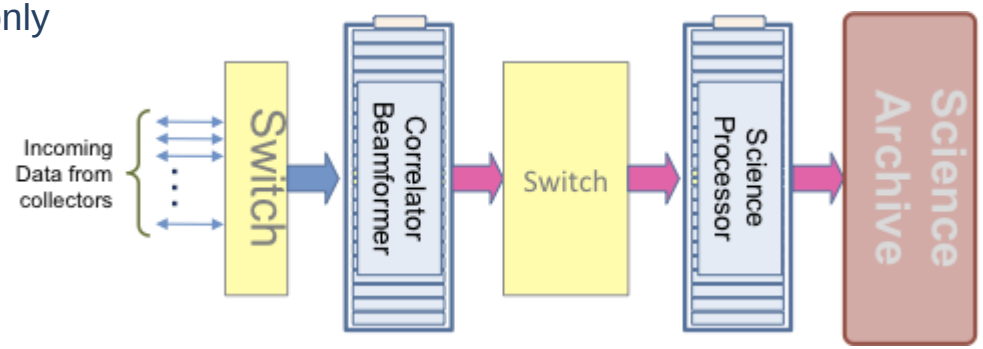
Exa = 10^{18}, or 1 followed by 18 zeroes;
increase in compute capability by factor 1000

EXTREME DATA CHALLENGE

	MeerKAT	SKA1-Mid	SKA2-Mid*
Into Correlator	2 Tbps	~20 Tbps	up to ~5 Pbps
Into Science Processor	700 Gbps	~3 Tbps	up to ~500 Tbps
Into Archive	20 Gbps**	~300+ Gbps	up to ~2 Tbps
Compute load	500 TFlops	~80+ PFlops	~3+ EFlops

* Data rates indicative only

** Sustained



HOW SENSITIVE WILL SKA BE?

- Current radio astronomy techniques can detect planets orbiting nearby stars.

- Phase 1 of the SKA will be able to detect the airport radar signals from these same planets, should any being be using such equipment

- Phase 2 of the SKA will be able to detect television broadcasts from the planets

BIG QUESTIONS IN COSMOLOGY

- Why is the expansion of the Universe accelerating? Is it Dark Energy? Is it modified gravity?
- What is the nature of the primordial Universe? Was there Inflation? Are the primordial perturbations non-Gaussian?
- Does Einstein's General Theory of Relativity really apply to cosmological scales, or does it needs modification?
- Is the Universe really isotropic and homogeneous? Is the Universe really flat?
- **SKA will not only measure cosmological parameters with more precision, but will answer fundamental questions in cosmology: this needs a balance between "precision cosmology" and "discovery cosmology"**

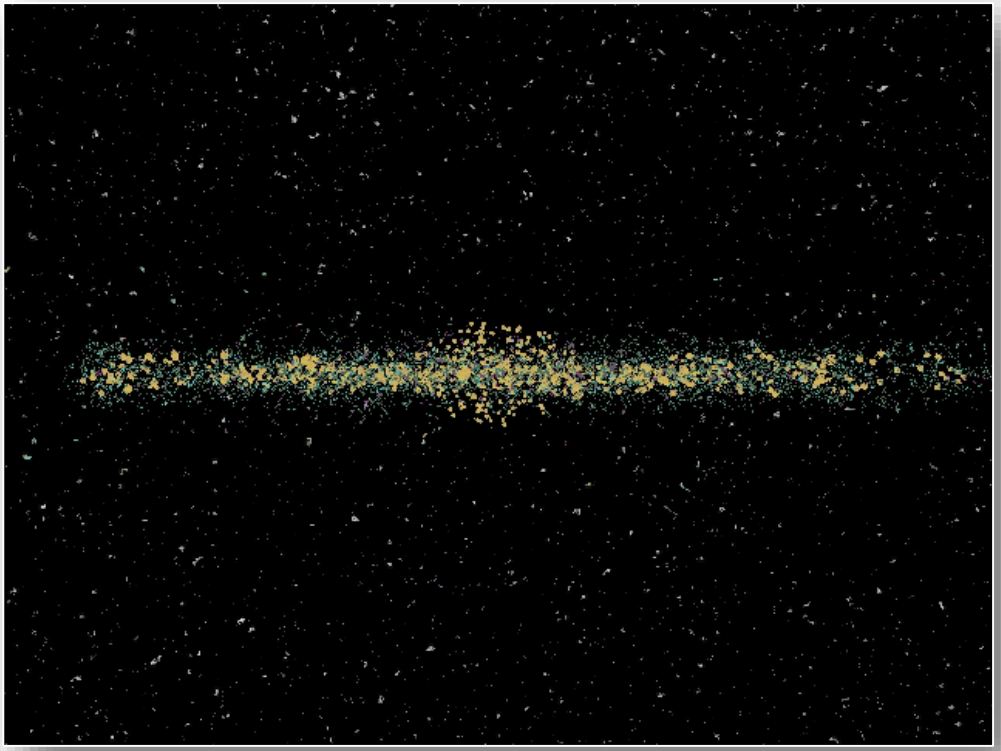
SKA SCIENCE REVIEW PANEL PRIORITY: COSMOLOGY

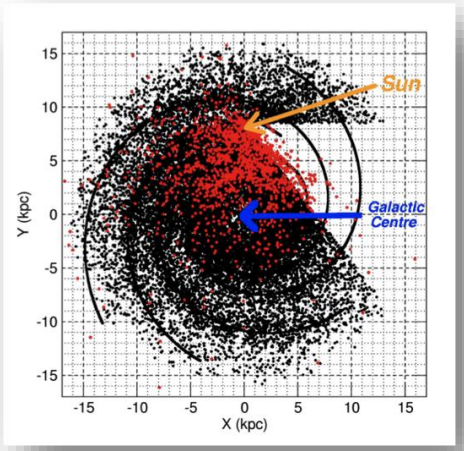
- "Map the 3D matter distribution on the largest scales and deepest redshifts ever - in order to obtain transformational constraints on primordial non-Gaussianity and to perform the first tests of gravity on super-horizon scales."
  - **Require a large HI intensity mapping survey on SKA1-Mid**
- "Probe the initial conditions and the global features of the Universe through non-Gaussianity and the dipole in the matter distribution using high precision measurements of the angular correlation functions."
  - **Require a large continuum survey on SKA1-Mid**
- Extra "headline" science: Map the distribution of HI on cosmological scales from z=20 to z=0 ("make a movie of the Universe!")
  - **Combine SKA1-Low with large HI intensity mapping survey on SKA1-Mid**

All of this science is transformational – and not possible without SKA

FINDING ALL THE PULSARS IN THE MILKY WAY

(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)





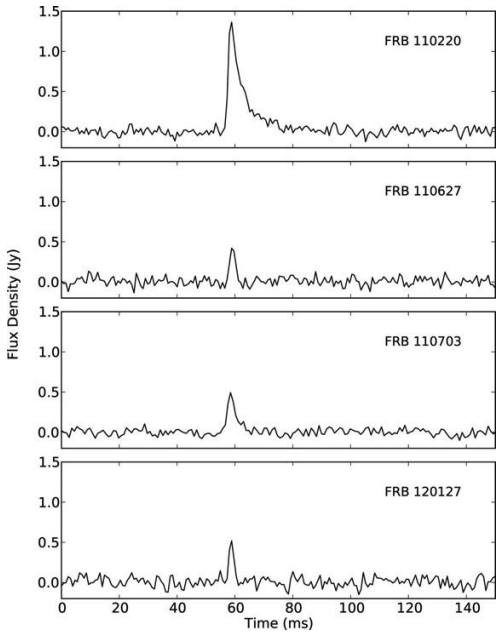
- ~40,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

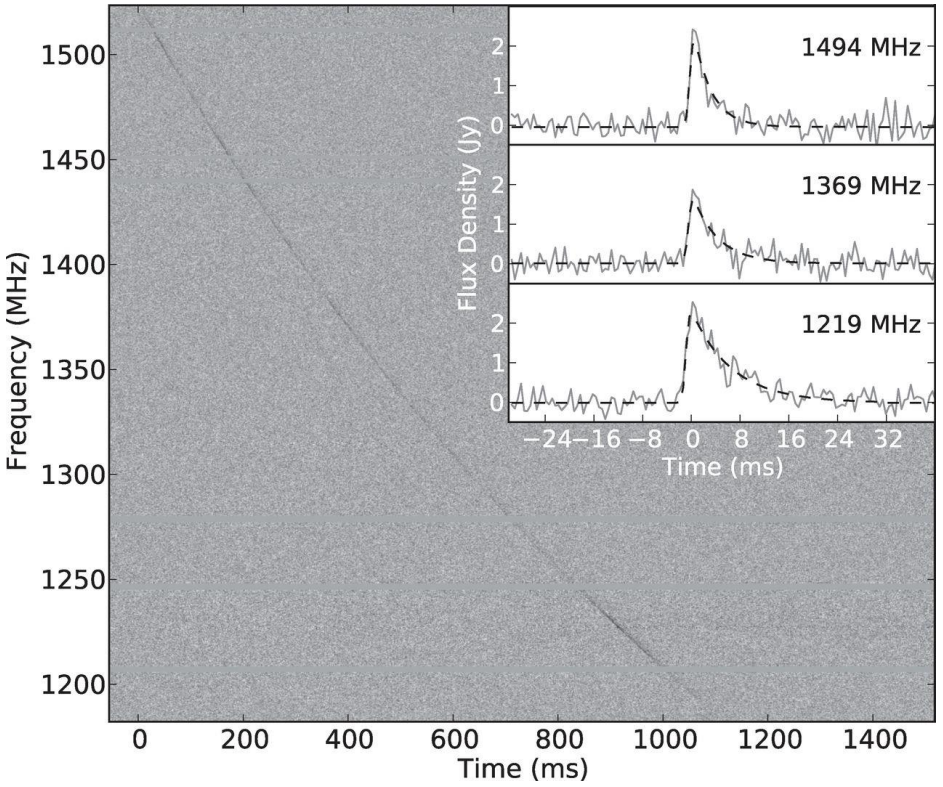
- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

THE TRANSIENT RADIO SKY

Science
AAAS

A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789





- Four celestial "FRB" events now detected (after first "Lorimer" burst):
  S = 0.5 – 1.3 Jy, Δt = 1 – 6 msec, DM = 550 – 1100 cm^{-3} pc
- Estimated event rate: $1x10^4$ sky^{-1} day^{-1}
- Completely unknown origin, possibly at cosmological distances

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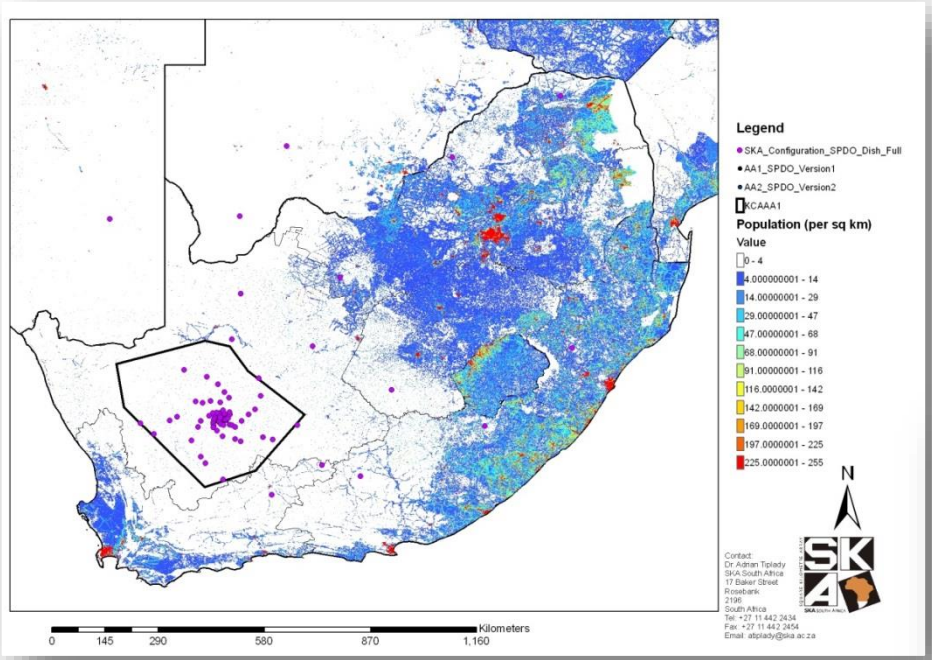
THE SKA SOUTH AFRICA PROGRAMME

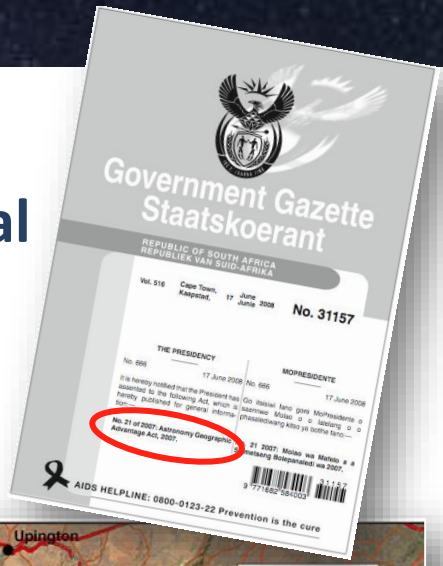
- Prepare and conduct the site bid
- Prepare the greenfield SKA site(s) and infrastructure
- Build the MeerKAT 64-dish array
- Protect the radio quieteness of the site
- Participate in the design and governance of the SKA
- Human Capital Development Programme
- Community development projects
- Outreach
- African Very Long Baseline Interferometry Network
- Host and collaborate on PAPER, HERA, C-BASS and possibly HIRAX telescopes

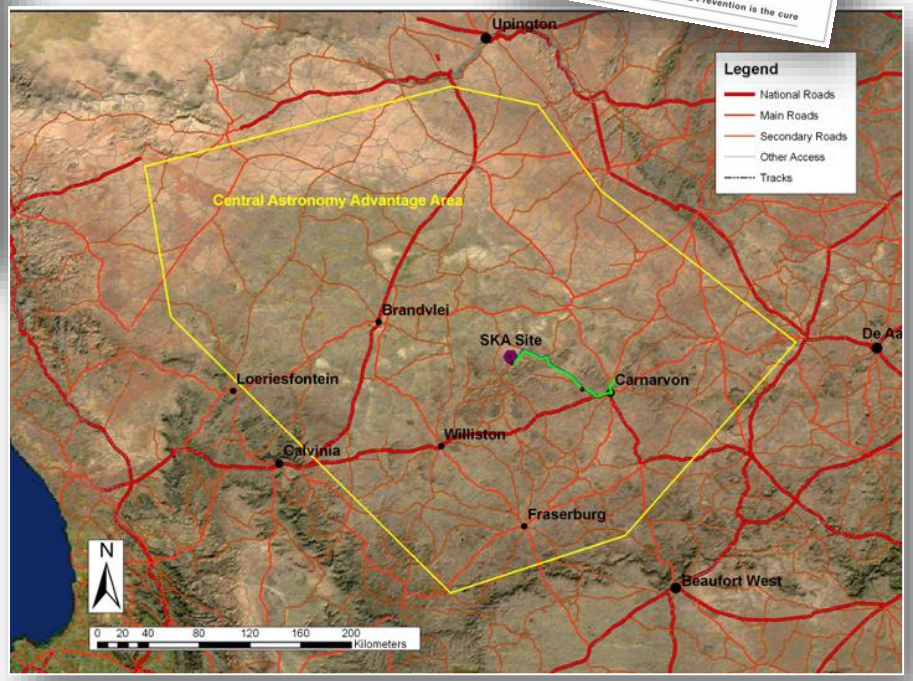
SKA SITE



Population density

Protected Central Astronomy Advantage Area (AGA Act)





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AVOIDING RADIO FREQUENCY INTERFERENCE

THE SITE IN 2003

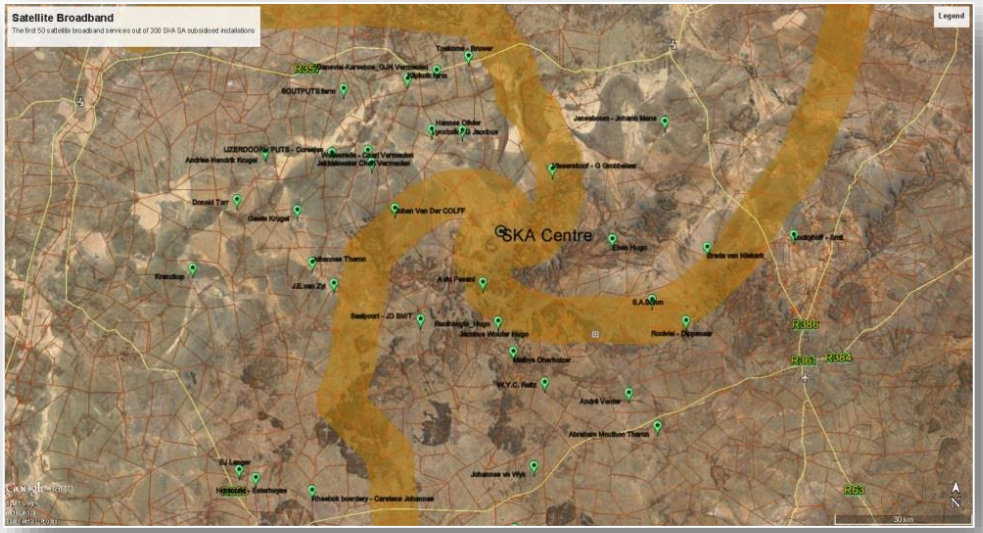
ALTERNATIVE COMMUNICATIONS

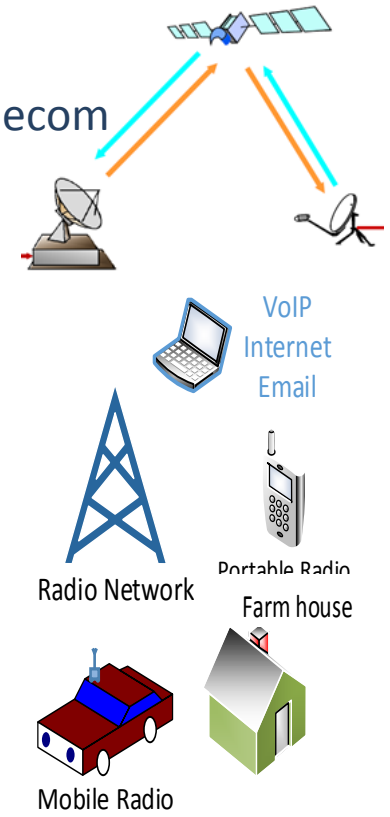
ENSURING ACCESS TO 'RADIO ASTRONOMY-FRIENDLY' TELECOMMUNICATIONS

Karoo telecommunications are poor

SKA expanding provision of radio astronomy friendly telecom services to public, municipal services, rural safety

– Vox satellite voice and data





– Mobile voice connectivity – establish radio astronomy friendly mobile network for area. Opportunities for local entrepreneurs to manage and operate network

THE PRESIDENT VISITS SIP16

- SKA & MeerKAT - Special Infrastructure Project 16
- Presidential Infrastructure Coordination Commission

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DEPUTY PRESIDENT AND MINISTER AT MeerKAT ANTENNA

Very good support - deliver what we promise, on time

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BRICS MINISTERS VISIT THE SITE IN 2014

ESTABLISHING THE KAROO SITE

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INFRASTRUCTURE

Long-haul fibre from site to Cape Town – 2010/2011

New 33 kV Power line with MASS fibre optic cable approaching Core Site

MKAT upgrade to SKA1_MID

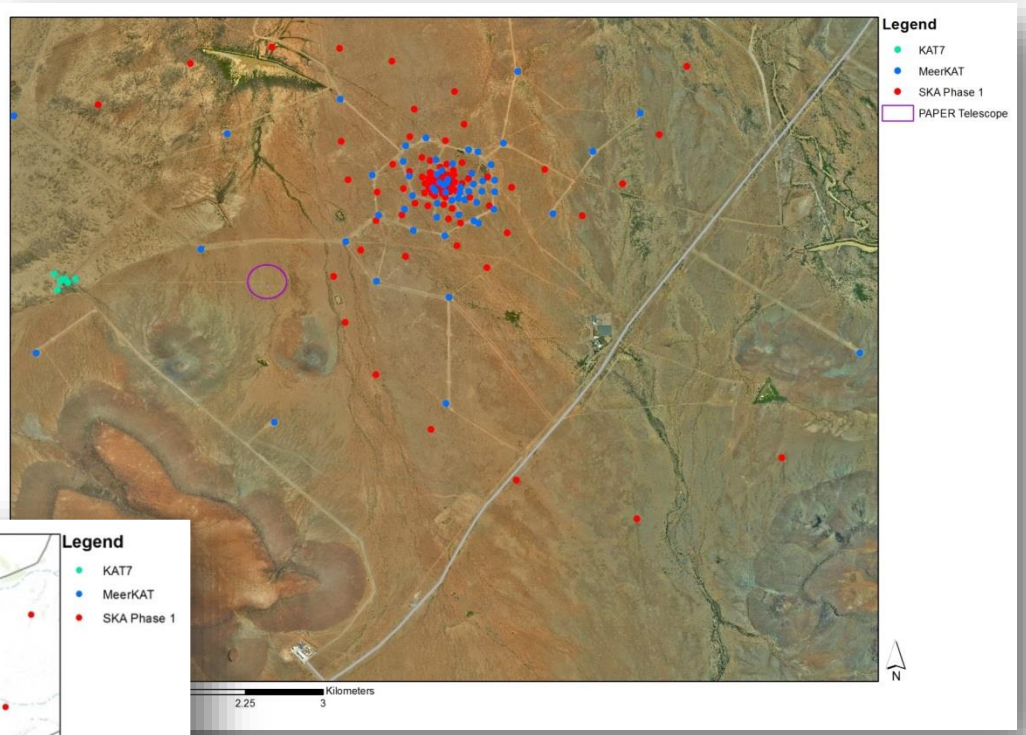
CARNARVON POP SITE

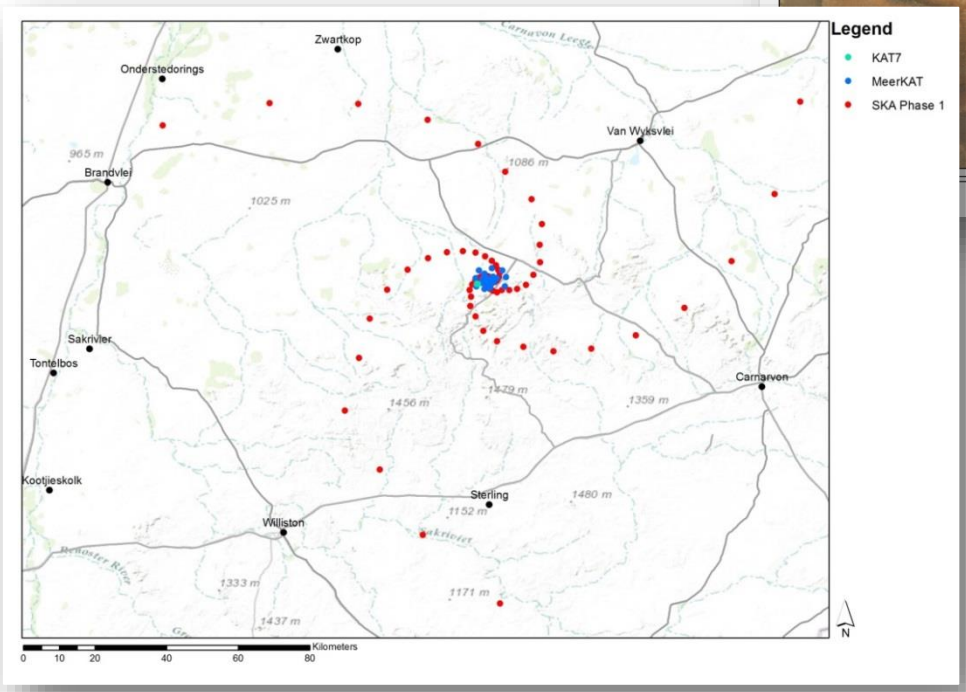
LOSBERG SITE 2014

KAT7

MeerKAT CORE

MeerKAT and SKA1-MID LAYOUT





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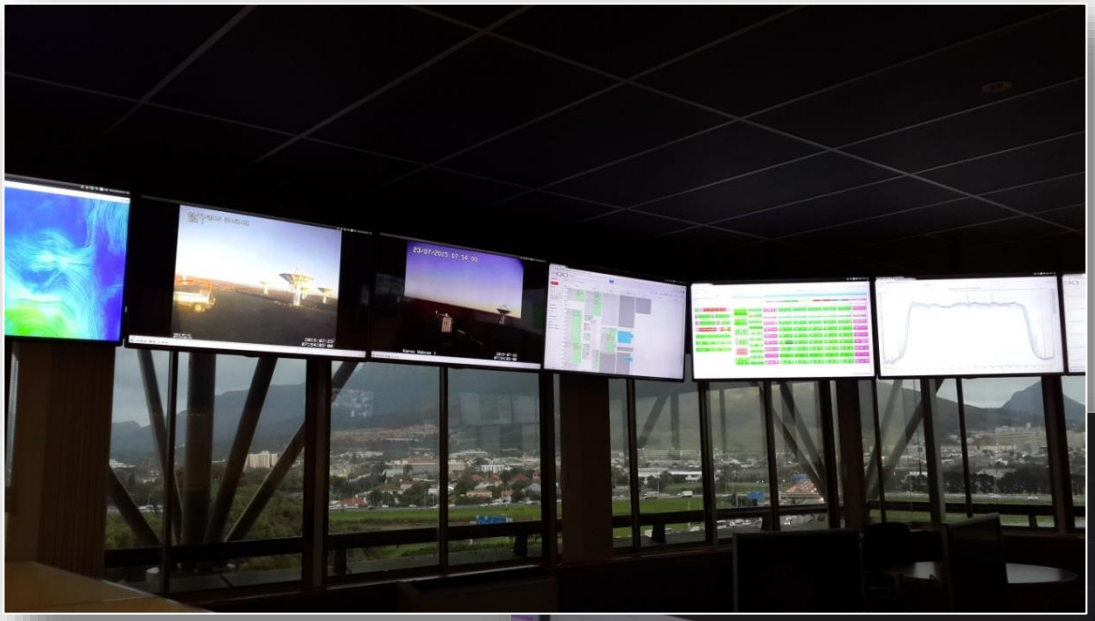
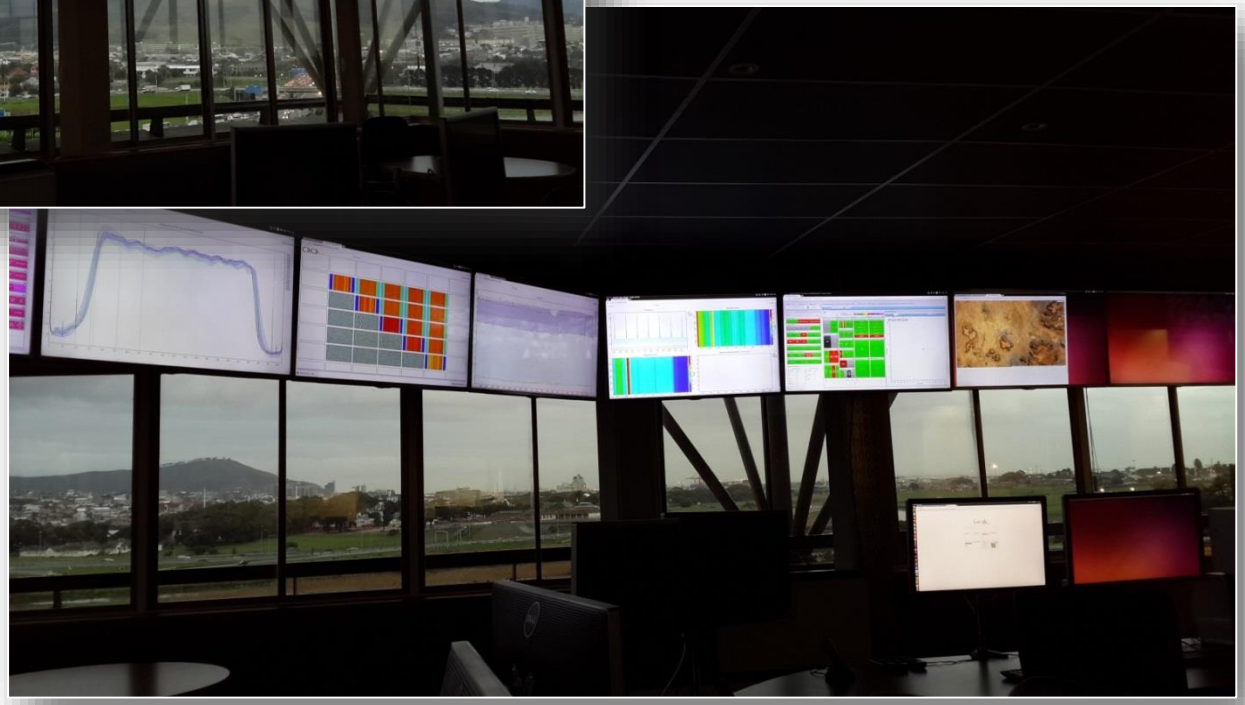
CONTROL ROOM IN PINELANDS

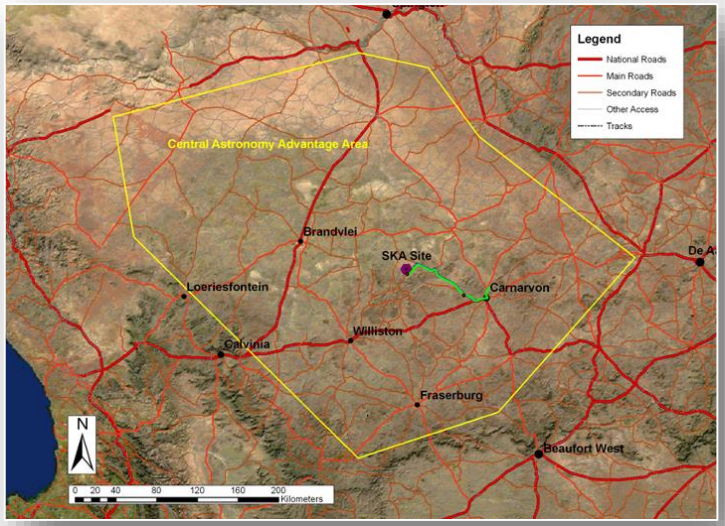




SITE INFRASTRUCTURE AT LOSBERG

RFI SHIELDED ROOM

RADIO INTERFERENCE : IS THE BIGGEST THREAT



THE MeerKAT TELESCOPE

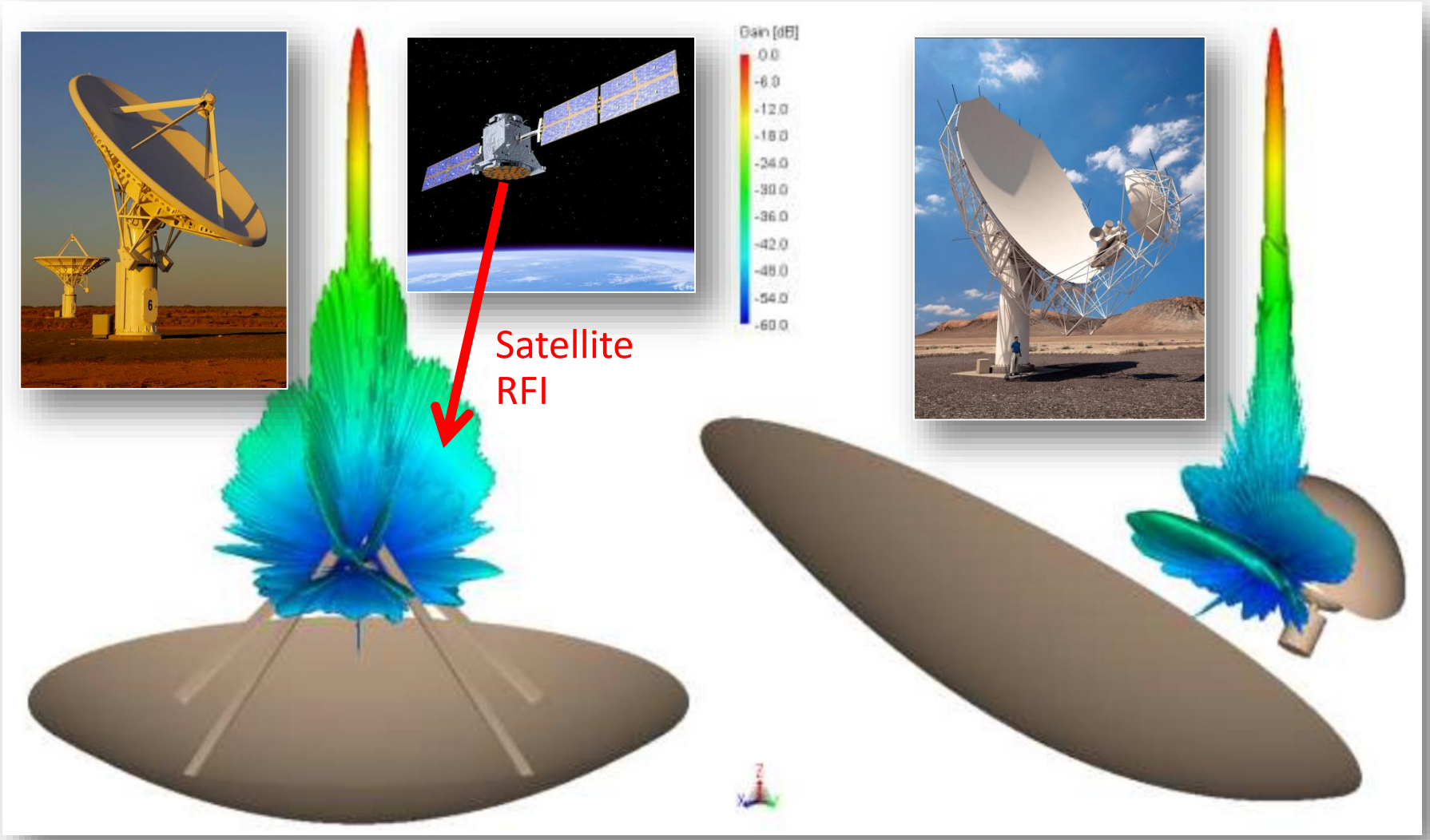
- South Africa's "precursor" instrument.
- It was initially intended to allow us to benefit from technology and science development and human capital development
- Designed, developed and built by SKA South Africa with industry
- Will be integrated into SKA-1 about 2022
- Experience in constructing MeerKAT is proving invaluable in SKA-1 design and technologies.

DESCRIPTION OF MeerKAT

- Designed to maximise sensitivity and dynamic range (so that we can use all the sensitivity)
- Array of 64 interlinked receptors (a receptor is the complete antenna structure, with the main reflector, sub-reflector and all receivers, digitisers and other electronics installed).
- The configuration (placement) of the receptors is determined by the science objectives of the telescope.
- 48 of the receptors are concentrated in the core area which is approximately 1 km in diameter. Good for pulsar observations and imaging of diffuse sources.
- The longest distance between any two receptors (the so-called maximum baseline) is 8 km
- Three sets of receivers: UHF; L-band; S-band

MeerKAT DISHES 1 & 2

COMPARISON OF BEAM PATTERNS



THE MeerKAT PROGRAMME

- MeerKAT is an SKA “precursor” - 25% of SKA1
  - Largest array radio telescope in the world before SKA
- Most sensitive cm-wavelength array in the world
- Very reliable and low operating cost
- Built using system engineering processes, including frequent international reviews
- Phased development
- 75% by value sourced in South Africa – two new factories
- Industrial methods not laboratory methods
- South African science and engineering team
  - 240 staff in project office
  - Others in universities and industry

MeerKAT HIGHLIGHTS

- Better than specified performance because of excellent optics and receivers
  - Confirmed by Canadian measurements – ”superb engineering” by EMSS (Stellenbosch)
- Nearly 4 times the advertised survey speed at no additional cost – much more telescope, no extra $
- Max Planck Institute (Bonn) investing €11m in S-band receivers and downstream capacity

MeerKAT SCHEDULE

- Q2 2015/16 - dish qualification achieved
  Q1 2016/17 - AR1
  Q3 2016/17 - AR2
  Q4 2016/17 - AR3
- Forming an image by the end of the calendar year (5 antennas and all downstream systems need to be commissioned).
- A working 16 antenna array (AR1) by end of June 2016 (which is aligned with the 21 installed antennas end of March 2016)

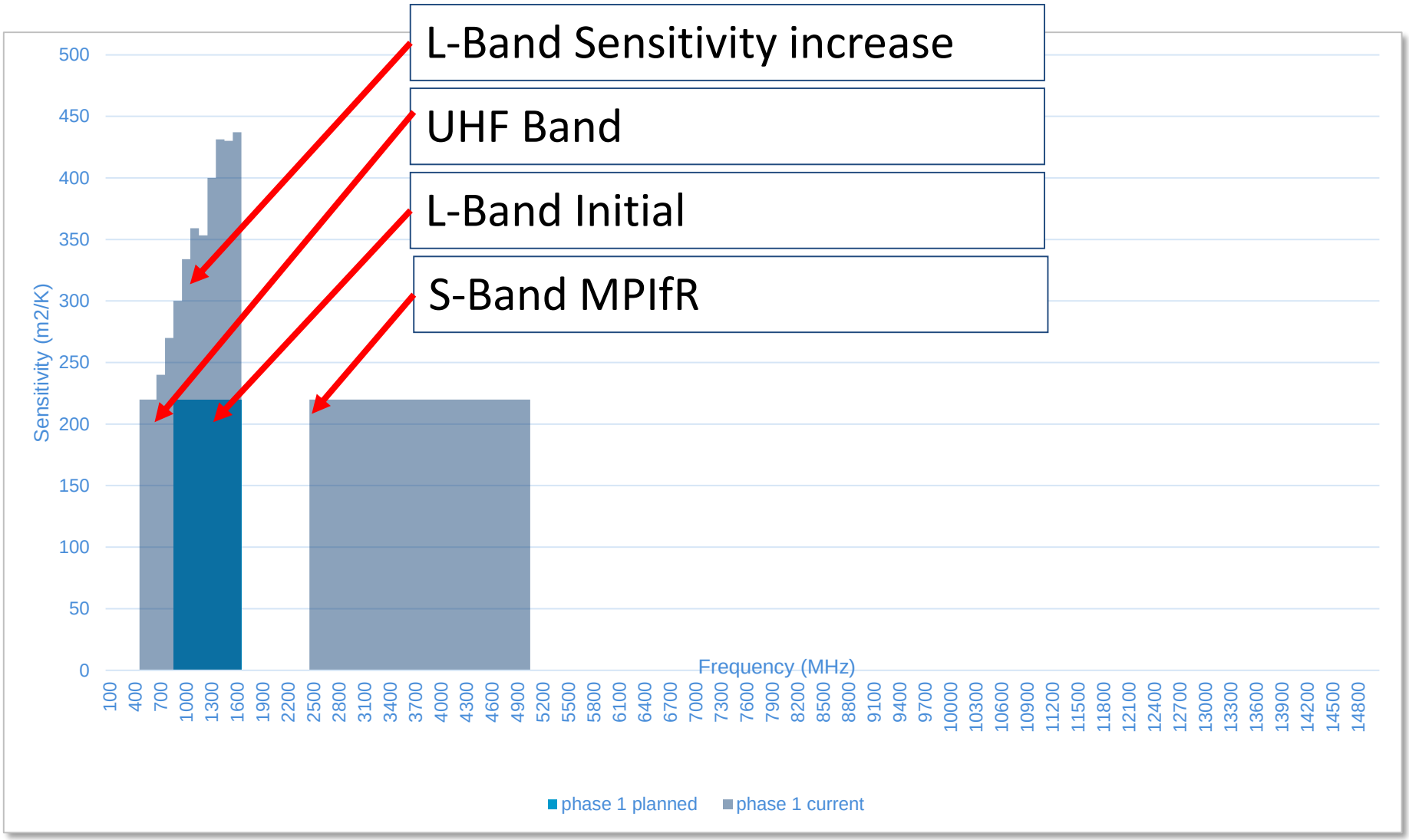
PERFORMANCE @ 1420 MHZ

	JVLA	MeerKAT RfP	MeerKAT 2013	MeerKAT 2014
N_{dish}	27	64	64	64
D_{dish}	25 m	13.5 m	13.5 m	13.5 m
T_{sys}/ε_a	47.3 K	44.1K	29.4 K	22.5 K
N_{beam}	1	1	1	1
BW	1 GHz	750 MHz	750 MHz	750 MHz
A_e/T_{sys}	1	0.74 (×1)	1.11 (×1.5)	1.45 (×1.96)
SS	1	1.88 (×1)	4.24 (×2.25)	7.24 (×3.84)

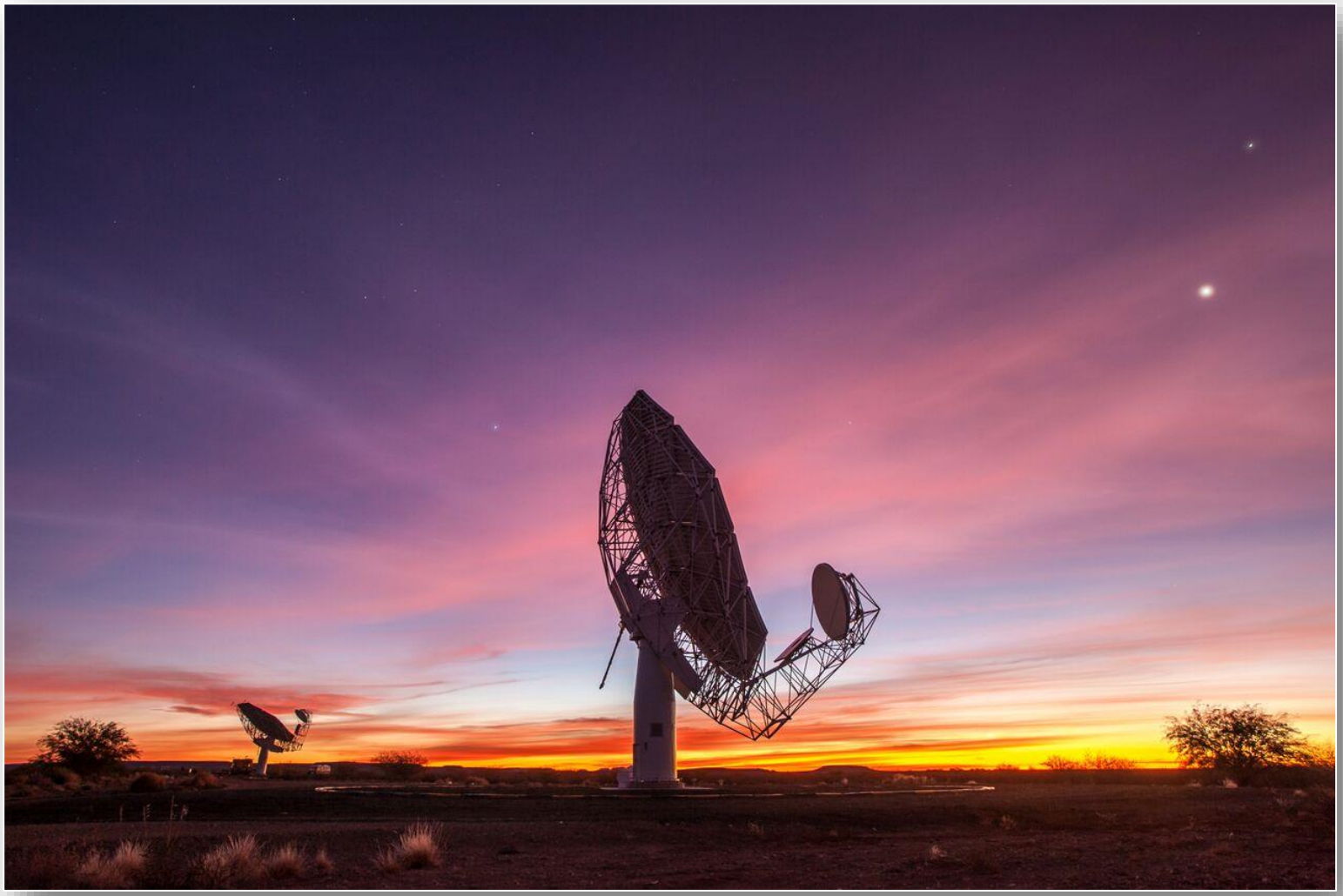
Survey Speed proportional to λ^2 for single-pixel receivers.

Much better instrument for the same $ through innovative RSA designed and built receivers and careful optical design

SCIENCE CAPABILITY



MeerKAT

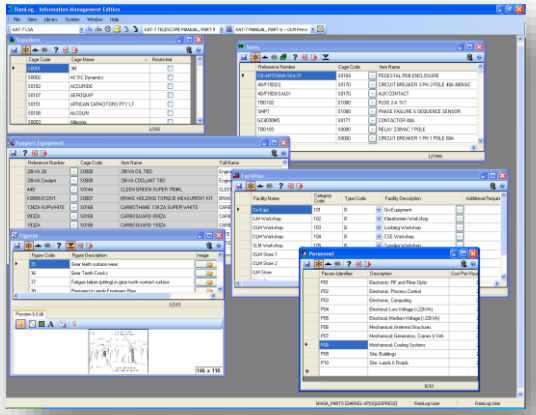


DISH TRANSPORTED

DISH LIFT

LOGISTICS

- Hasn't been done on telescopes in much detail – MeerKAT and SKA are on industrial scale, not laboratory scale
- MeerKAT requires very high availability at optimal cost
- World first – full integration of configuration management, logistic analysis, on-line technical manuals, life cycle cost simulations, operational transactional data, maintenance planning



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CORRELATOR BEAMFORMER

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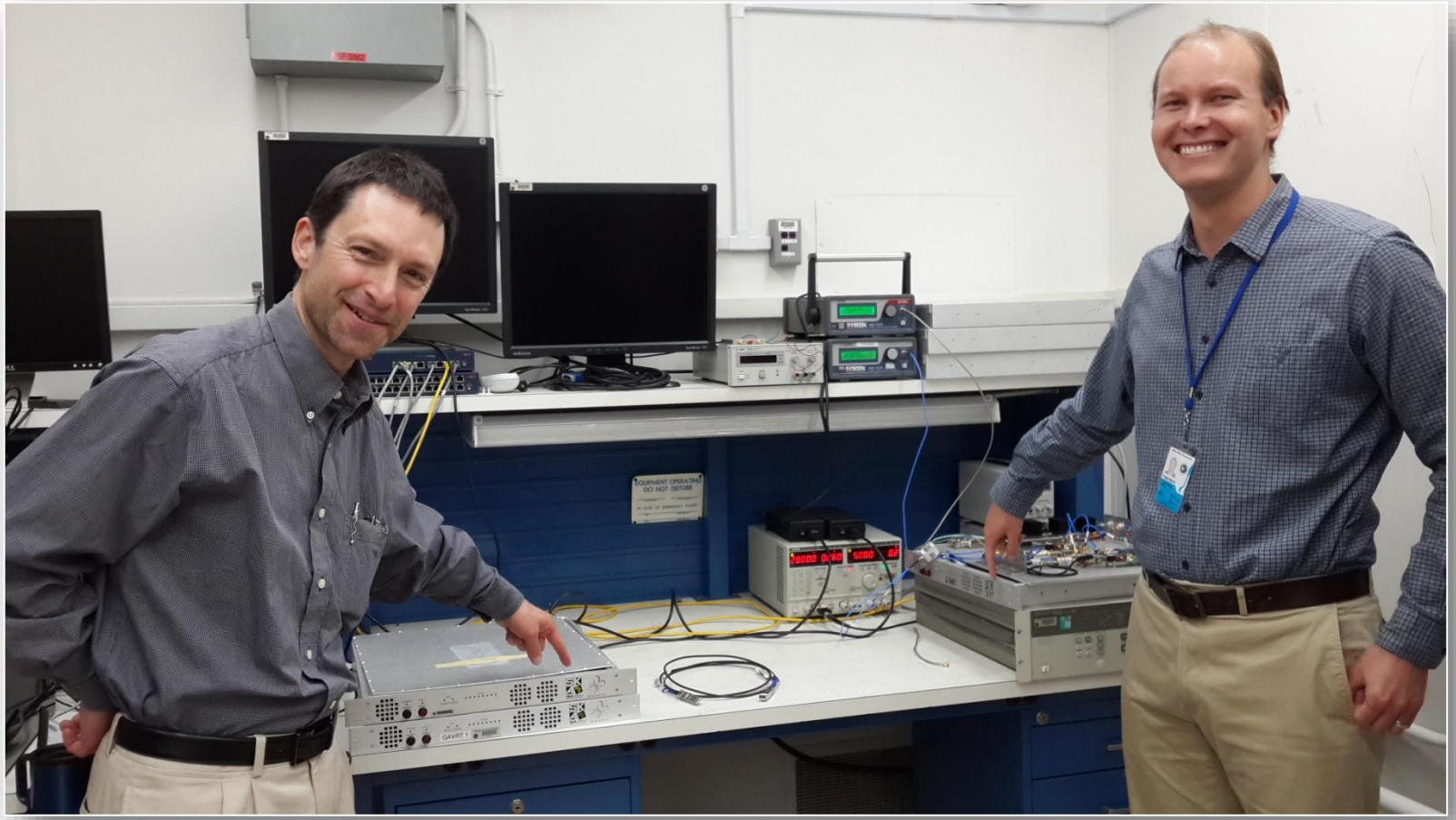
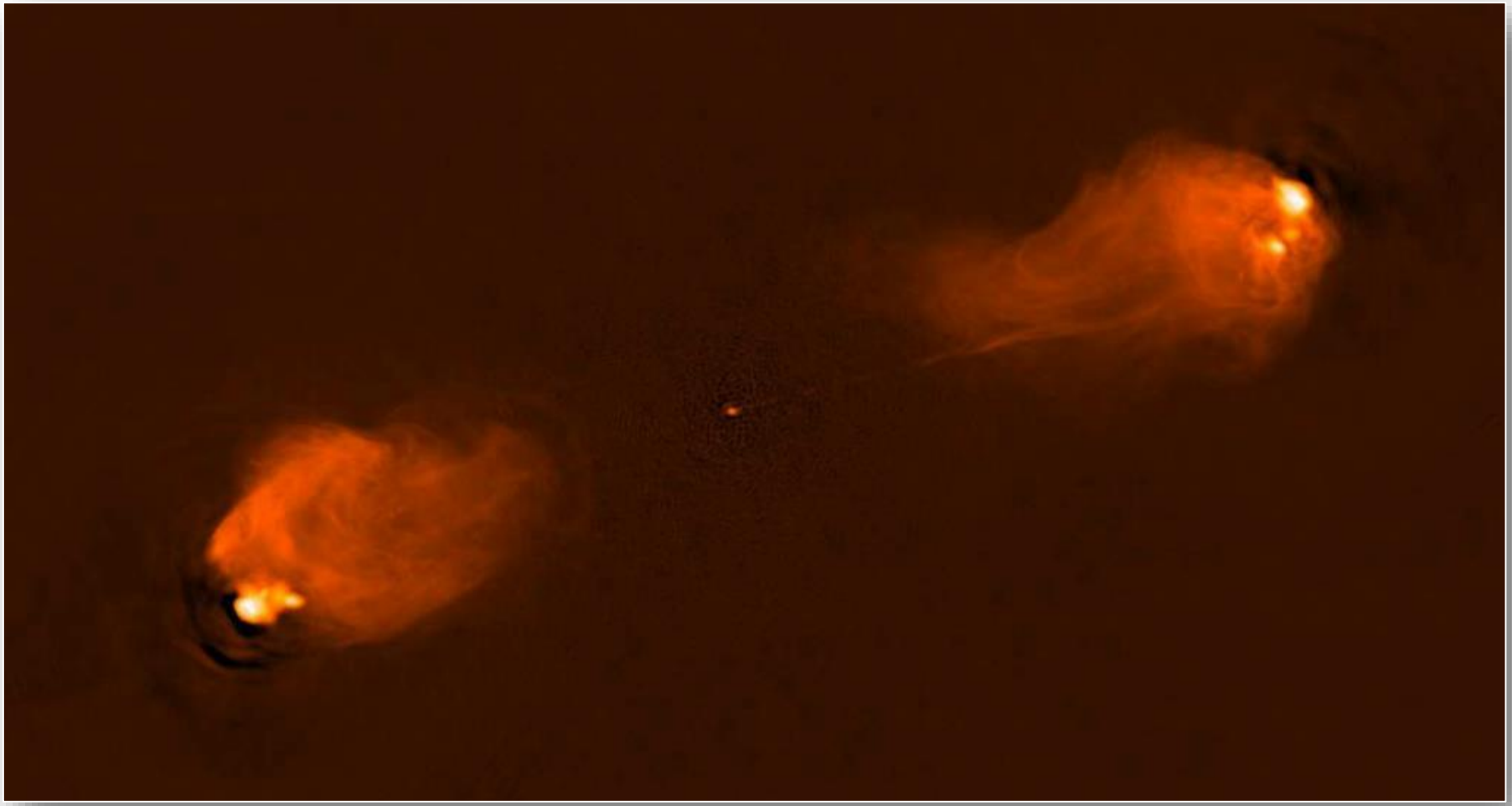
ROACH BOARDS IN USE AT NASA JPL



SMIRNOV & PERLEY CYGNUS A – WORK IN PROGRESS



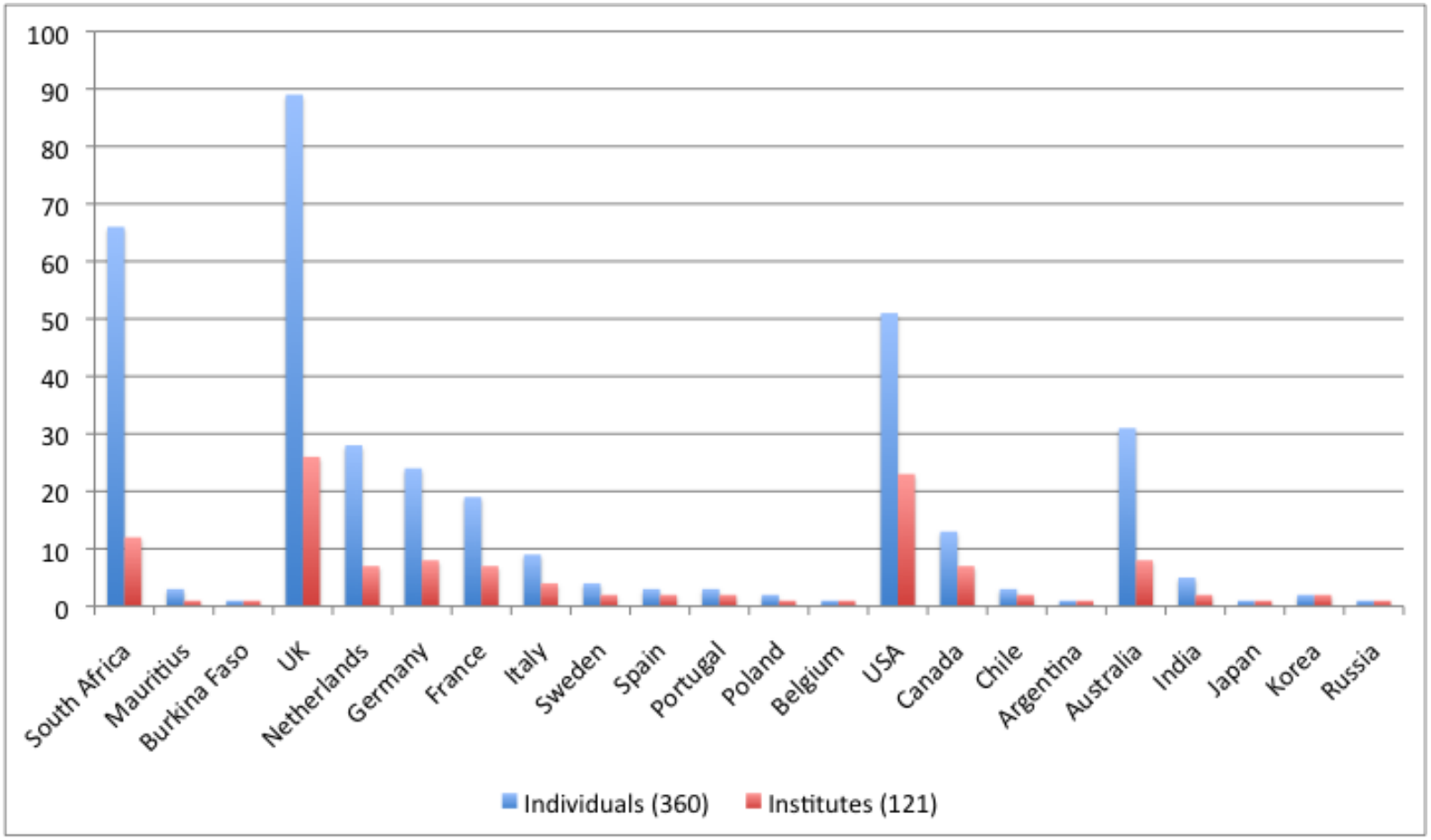
THIRD GENERATION CALIBRATION

- A new effort led by Arun Aniyan (SKA South Africa/DOME/RATT) aims to apply machine learning (ML) techniques to the problems.
- Complicated extended sources, of which Cygnus A is perhaps the most famous, present a very different challenge.
- Raw radio images are corrupted by a complicated point spread function due to gaps between telescopes. Correcting for this is known as 'deconvolution'.
- For point-like sources such as those in the 3C147 field, deconvolution is easily handled by the venerable CLEAN algorithm (dating from 1974), but this breaks down on complex sources such as Cygnus A.
- One very promising development is a new family of deconvolution algorithms based on compressive sensing (CS) theory. Quite a few CS algorithms have been published and discussed, but the first one "to market" in the sense of being released as public and fully functional software able to process real data, is a joint African/French effort.

BAYESIAN TECHNIQUES

- With 3GC becoming mainstream, there are more exciting developments to look forward to. In particular, Bayesian techniques will enable robust statistical inferences about the radio sky, as opposed to the historical "this image looks plausible so it must be true" approach. A new collaboration called Bayesian Inference for Radio Observations (BIRO) between UCT, RATT, AIMS and UCL (UK) is investigating the use of Bayesian techniques.

MeerKAT LARGE SURVEYS



MeerKAT PRIORITY 1 PROJECTS

- Pulsar timing
- Tiered HI surveys

MeerKAT PRIORITY 2 PROJECTS

Project Name	Project Description	Principal Investigators
MESMER (MeerKAT Search for Molecules in the Epoch of Re-ionisation)	MESMER will study the first luminous objects in the Universe by searching for emission from their carbon monoxide lines. It will make use of the X band (8-12 GHz) receivers of MeerKAT.	Dr Ian Heywood, CSIRO Astronomy & Space Science, Australia and Rhodes University, South Africa
MeerKAT Absorption Line Survey.	The MeerKAT telescope will survey for atomic hydrogen and OH lines in absorption against distant continuum sources (OH line ratios may give clues about changes in the fundamental constants in the early universe)	Dr Neeraj Gupta, ASTRON, The Netherlands; Dr Raghunathan Srianand, Inter-University Centre for Astronomy and Astrophysics, India.
MHONGOOSE (MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters)	**MHONGOOSE** will conduct investigations of different types of galaxies; dark matter and the cosmic web. Very deep observations of the gas in and around nearby galaxies. These observations will be used to study the distribution of dark matter in these galaxies, the relation between gas and star formation, and will investigate how galaxies acquire their gas from the cosmic web.	Prof Erwin de Blok, ASTRON, The Netherlands.

MeerKAT PRIORITY 2 PROJECTS

Project Name	Project Description	Principal Investigators
MIGHTEE (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey)	**MIGHTEE** will conduct deep continuum observations of the earliest radio galaxies.	Dr Kurt van der Heyden, University of Cape Town, South Africa; Professor Matt Jarvis, University of the Western Cape, South Africa and the Oxford University, UK
TRAPUM (Transients and Pulsars with MeerKAT)	The **TRAPUM** project will search for, and investigate new and exotic pulsars and also for fast radio bursts. These extreme objects will be used for studies of gravity and the baryon content of our Universe amongst other things.	Dr Benjamin Stappers, Jodrell Bank Centre for Astrophysics, University of Manchester, UK; Prof Michael Kramer, Max Planck Institute for Radio Astronomy, Germany
ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT)	Through commensal and pointed observations, the MeerKAT radio telescope will search for transient radio sources, e.g. gamma-ray bursts, X-ray binaries and tidal disruption events, novae and supernovae.	Prof Patrick Woudt, University of Cape Town, South Africa; Prof Rob Fender, Oxford University, UK
A MeerKAT HI Survey of the Fornax Cluster	Galaxy formation and evolution in the cluster environment.	Dr Paolo Serra, ASTRON, The Netherlands
MeerGAL (MeerKAT High Frequency Galactic Plane Survey)	Galactic structure and dynamics, distribution of ionised gas, recombination lines, interstellar molecular gas and masers.	Dr Mark Thompson, University of Hertfordshire, UK; Dr Sharmilla Goedhart, South African SKA Project

SKA Cosmology in the media…

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SKA – Cutting-edge Astronomy in SA

11 February 2015, 15:00 Share:

Scientists from around the world are lining up to participate in the world's biggest science experiment, South Africa's Square Kilometre Array. Hidden deep in the Karoo, SKA will enable us to look back to the origin of life and answer questions we haven't even thought o yet.

The massive Square Kilometre Array (SKA) telescope, to be built in a collaboration between Australia and South Africa, will allow scientists to look far back into the history of the cosmos and give more detail than ever before on how the universe has evolved and how stars and galaxies formed. It will also ultimately allow for the plotting of a 3D map of the universe.

CAPE TIMES

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SKA telescope poised to map history of the universe

January 21 2015 at 07:01am

Staff Writer

THE Square Kilometre Array (SKA) telescope in the

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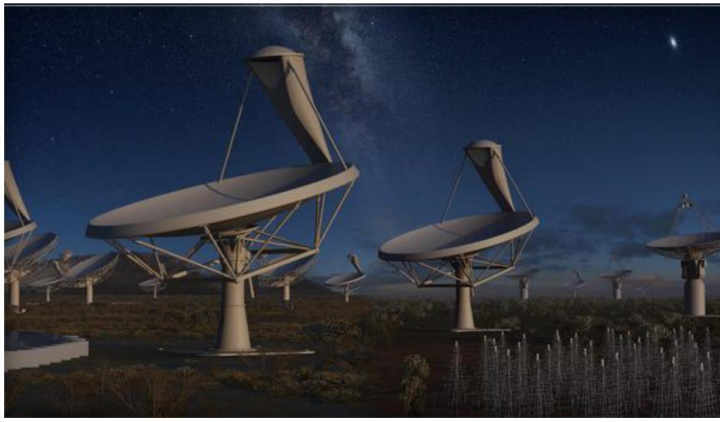
How South African scientists plan to map the universe, yes really

By MICHAEL CASEY / CBS NEWS / February 6, 2015, 12:06 PM

Team sets out to map universe, unraveling its mysteries along the way



An artist rendering of the Square Kilometer Array, which will be the largest telescope ever built and tasked with mapping the universe. / SKA ORGANISATION

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It is one thing to draw up a map of the United States or even Earth.

But the entire universe?

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NRAO

National Radio Astronomy Observatory

A facility of the National Science Foundation

NSF

University of the Western Cape

DUT Durban University of Technology

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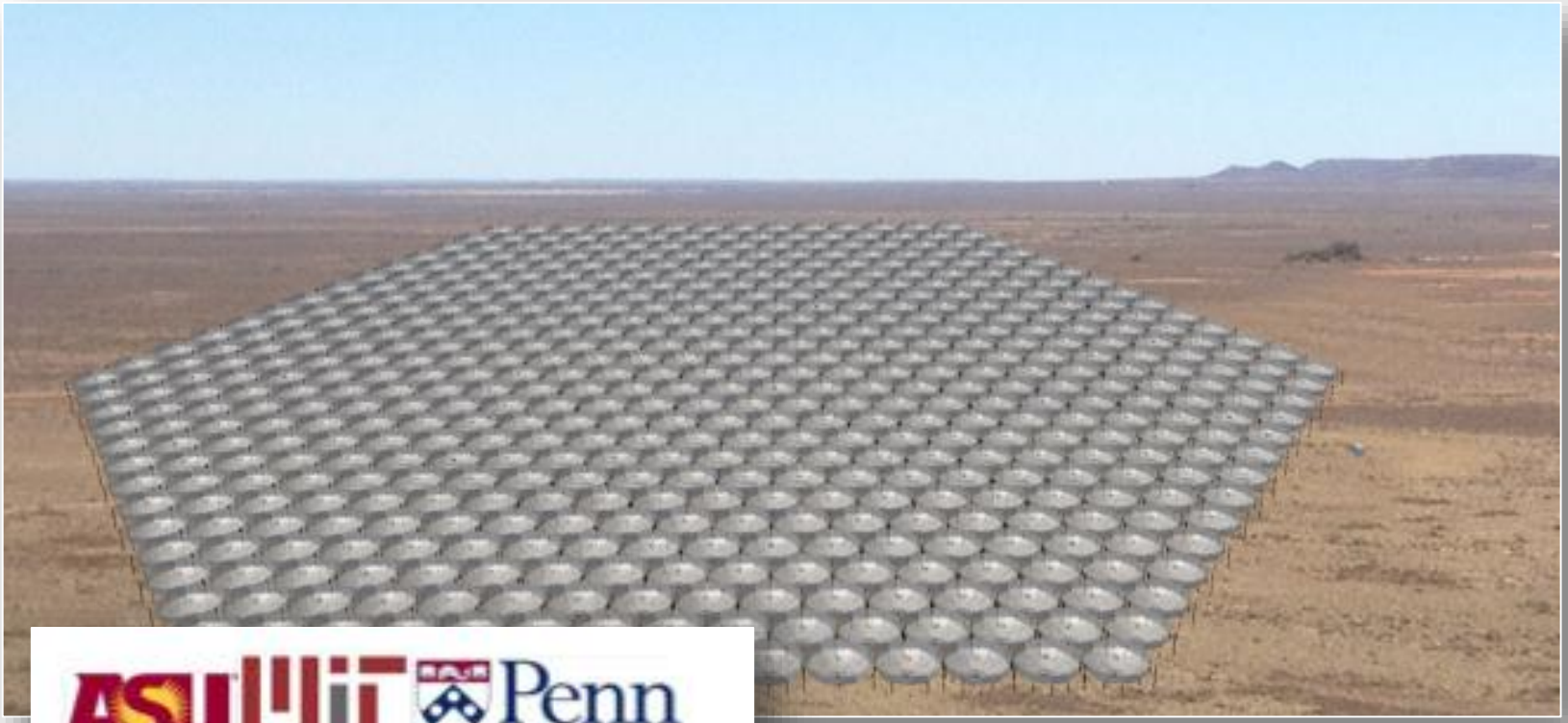
SKA Africa

SKA Square Kilometre Array Africa

HYDROGEN EPOCH OF REIONISATION ARRAY (HERA)



- Kavilan Moodley, UKZN on behalf of the SA HERA Collaboration

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C-BASS SOUTH

HIRAX

The Hydrogen Intensity & Real-time Analysis eXperiment

- Main goal: measure dark energy via 21cm intensity mapping.
- Natural design: smallish dishes (~5m) at z~1 (~700 MHz). Too high, no DE effects. Too low, no volume.
- BAO signal faint, need lots of elements to reach sensitivity.
- Plan is to piggyback on Canadian development of northern-hemisphere cylinder BAO experiment CHIME, digital electronics nearly identical.
- HIRAX supported by UKZN as part of NRF Institutional Engagement and Partnership Development. Official outcome of proposal expected soon.

DATA PROCESSING AND COLONIALISM

- It is not sufficient to collect the SKA data in SA and ship it off to overseas researchers, who then perform the fundamental research (with associated skills development and economic spin-offs) and collect the Nobel prizes.
- To derive the wider benefits of involvement in such projects and facilities, SA needs to be globally competitive itself in the knowledge economy of astronomy and as a catalyst for other knowledge-based cross-disciplinary activities.
- Big Data Africa programme launched by SKA South Africa with the Department of Science and Technology

BIG DATA AFRICA PROGRAMME

- The immediate focus of this programme is to service the data intensive astronomy needs of the telescopes.
- The ultimate aim is broader:
- Leverage the interest and appeal of the SKA in Africa to help establish a critical mass of big data skills and activities across multiple domains and sectors in SA and other African countries.
- South Africa to become a world leader in Big Data by 2020.
- Inter-University Centre for Data-Intensive Astronomy (IDIA) launched in September 2015. We will use it to connect universities in the eight SKA African partner countries to SA and Europe / UK
- IBM established research centre in Johannesburg in 2015 – SKA is one of three focus areas

AFRICA BIG DATA RESEARCH CLOUD

- Five-year pilot project to establish an African Big Data Research Cloud (ARC) for data intensive radio astronomy research as a distributed infrastructure among collaborating partners in South Africa and African Square Kilometre Array (SKA) partner countries.
- Pilot under construction by Inter-University Centre for Data-Intensive Astronomy (IDIA)
- Training programme for African astronomers and data scientists under Big Data Africa programme supported by the Newton Fund

BIG DATA AFRICA HIGHLIGHTS

- DST has recognized the importance of Big Data
- New IBM research lab in Johannesburg - major focus on SKA
- SKA SA and universities collaborate with ICT industry
  - *IBM and SKA SA especially on machine learning and micro-servers*
  - *Cisco and NRF / SKA SA jointly funding large optical data transport lab at NMMU*
  - *CISCO and Coriant collaboration with SKA SA*
- Inter-university Centre for Data-Intensive Astrophysics - funding from UCT, UWC and NWU of R50 million; other universities in South Africa and partners will join. Additional funding requested from NRF and EU.
- JEDI workshops- further support from DST and Newton Fund
- Advising W Cape Government on major data centre

MAJOR DATA PROCESSING DEVELOPMENT FOR SKA1

- Power efficient supercomputing
- Stream processing for huge data volumes
- Automated, high quality pipelines
- Remote post-processing and visualization
- Wide field calibration and imaging to extreme sensitivity
- Real-time processing of hundreds of beams
- New machine-assisted approaches to enhance serendipitous discovery

MAJOR DEVELOPMENT AREAS FOR SKA2

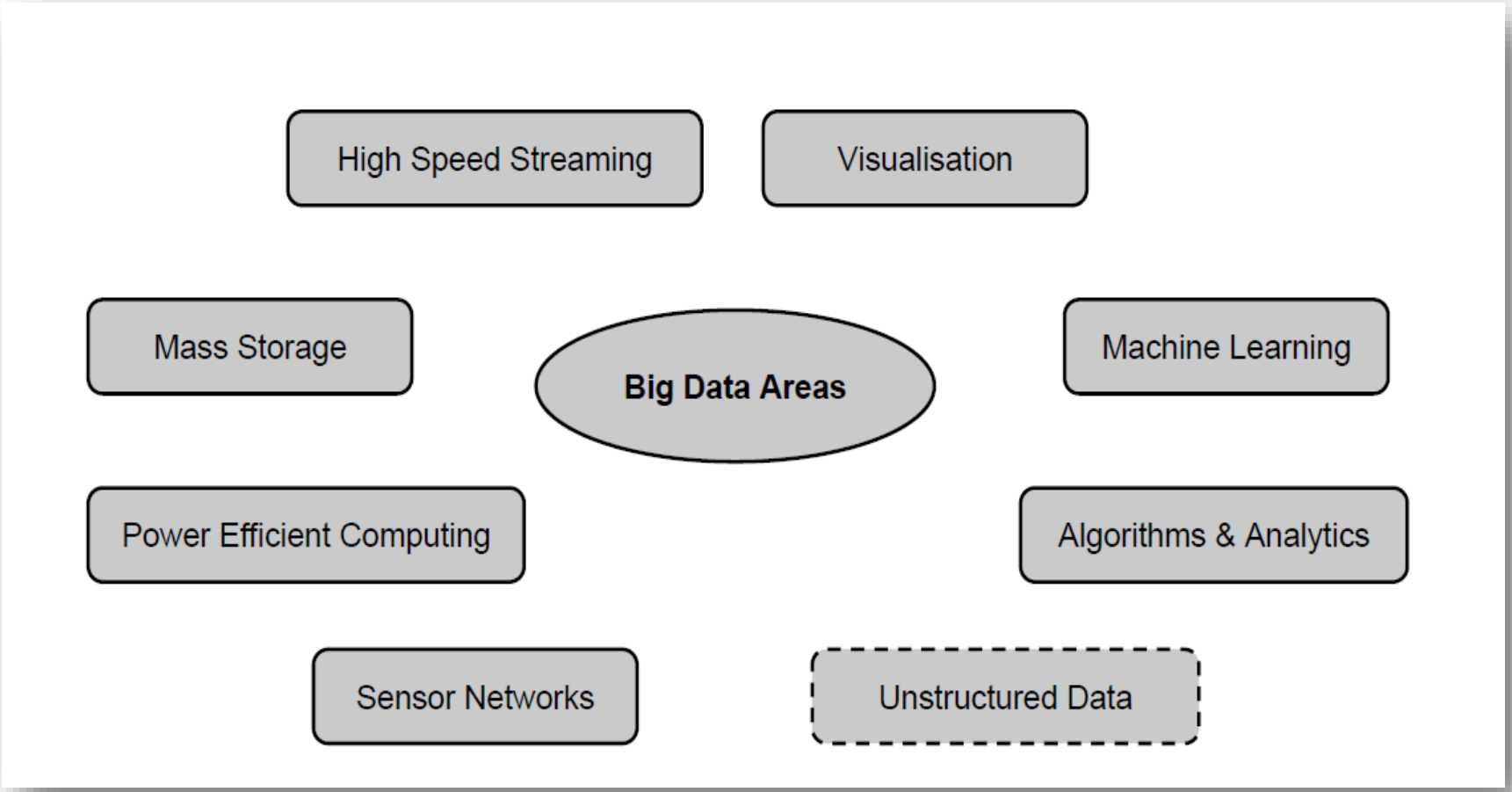
- Power efficient supercomputing
- Dealing with huge scale
- Dynamic resource allocation for compute and data system using e.g. machine learning
- Data scale implies humans largely out of the loop? Automation, machine learning
- Towards autonomous operations and serendipitous discovery

So working on SKA data processing is a good focus to build competence and capacity in Big Data.

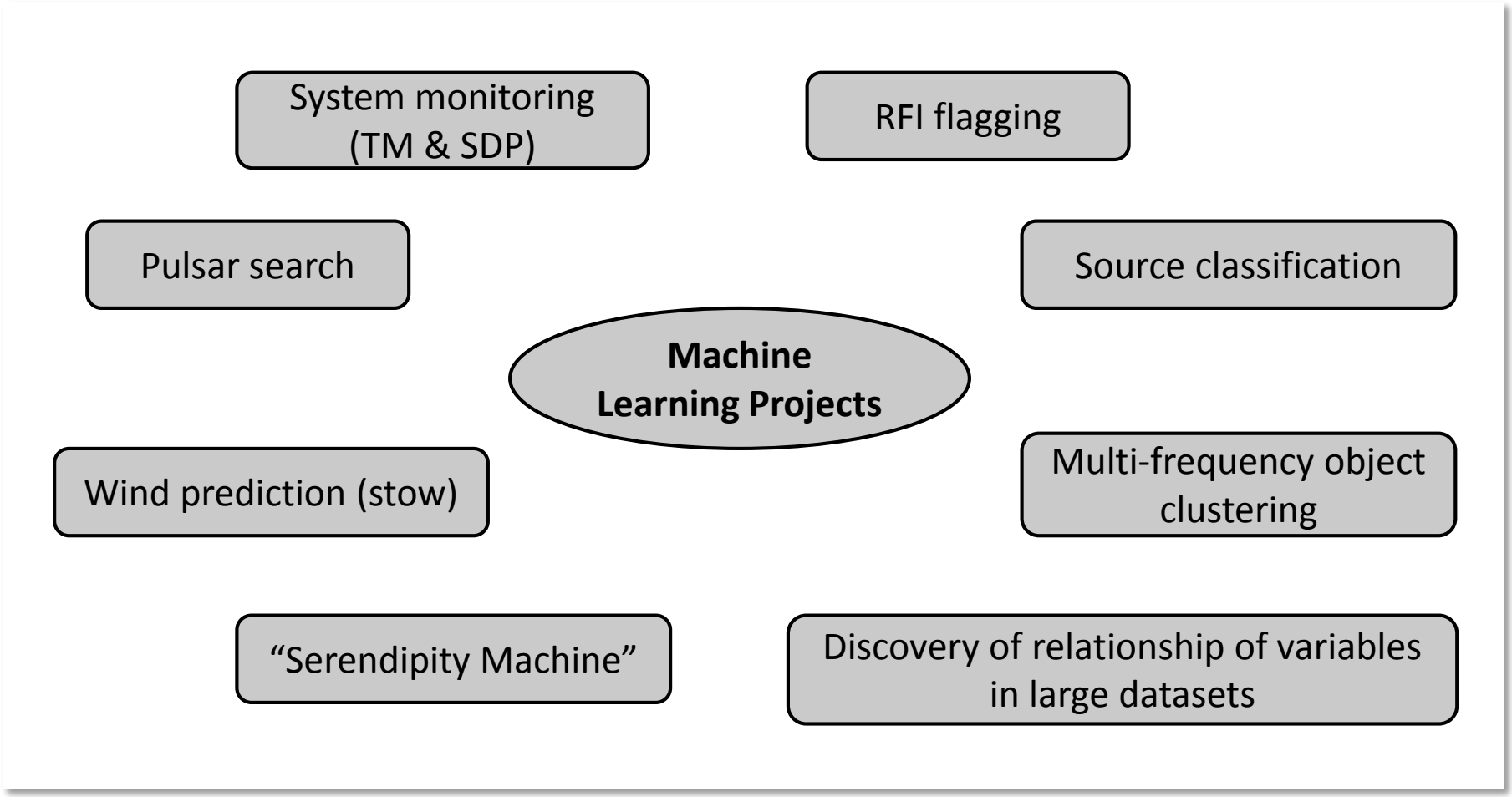
MeerKAT INNOVATIONS

- Power efficient microserver supercomputer imager
- Reconfigurable power efficient correlator / beamformer (SKARAB)
- Heterogeneous SDP and data flow architecture.
- Efficient deployment and updates using Docker-based technology in SDP
- Dynamic self-discovery TM with lots of sensors
- Support for sub-array modes and commensal observations
- IP switched architectures in CSP and SDP taking advantage of mainstream technology
- Machine learning explored in astronomy and operations domains
- Building models for predictive analysis for component failures

SKA SA BIG DATA FOCUS AREAS



SKA SOUTH AFRICA – MACHINE LEARNING (ML)



HUMAN CAPITAL DEVELOPMENT PROGRAMME

- Objective
  - Pipeline from school to tenured positions: train astronomers, engineers, technicians and artisans to build, operate, maintain and use the MeerKAT and the SKA (and win Nobel Prizes)
  - Use SKA and MeerKAT (and PAPER, CBASS, HERA, HIRAX etc.) to establish large, vibrant, world-class university research groups
  - Increase number of PhDs and MScs in South Africa
  - Train scientists and engineers from African partner countries
  - Reverse the brain drain
- Method
  - Create Research Chairs with a package of post docs, PhDs and MScs (plus travel etc.)
  - Post doctoral positions and bursaries for PhD, MSc, BSc, BSc Eng, BTech, National Diplomas
  - Very hands-on by SKA SA project office

ANNUAL SKA SA POST-GRADUATE BURSARY CONFERENCE

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GROWTH IN STUDENT NUMBERS

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YOUNG PROFESSIONALS PROGRAMME

Open day for candidates 2014

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LAUNCH OF THE NEWTON FUND PROGRAMME

LUSAKA (ZAMBIA) JUNE 2015

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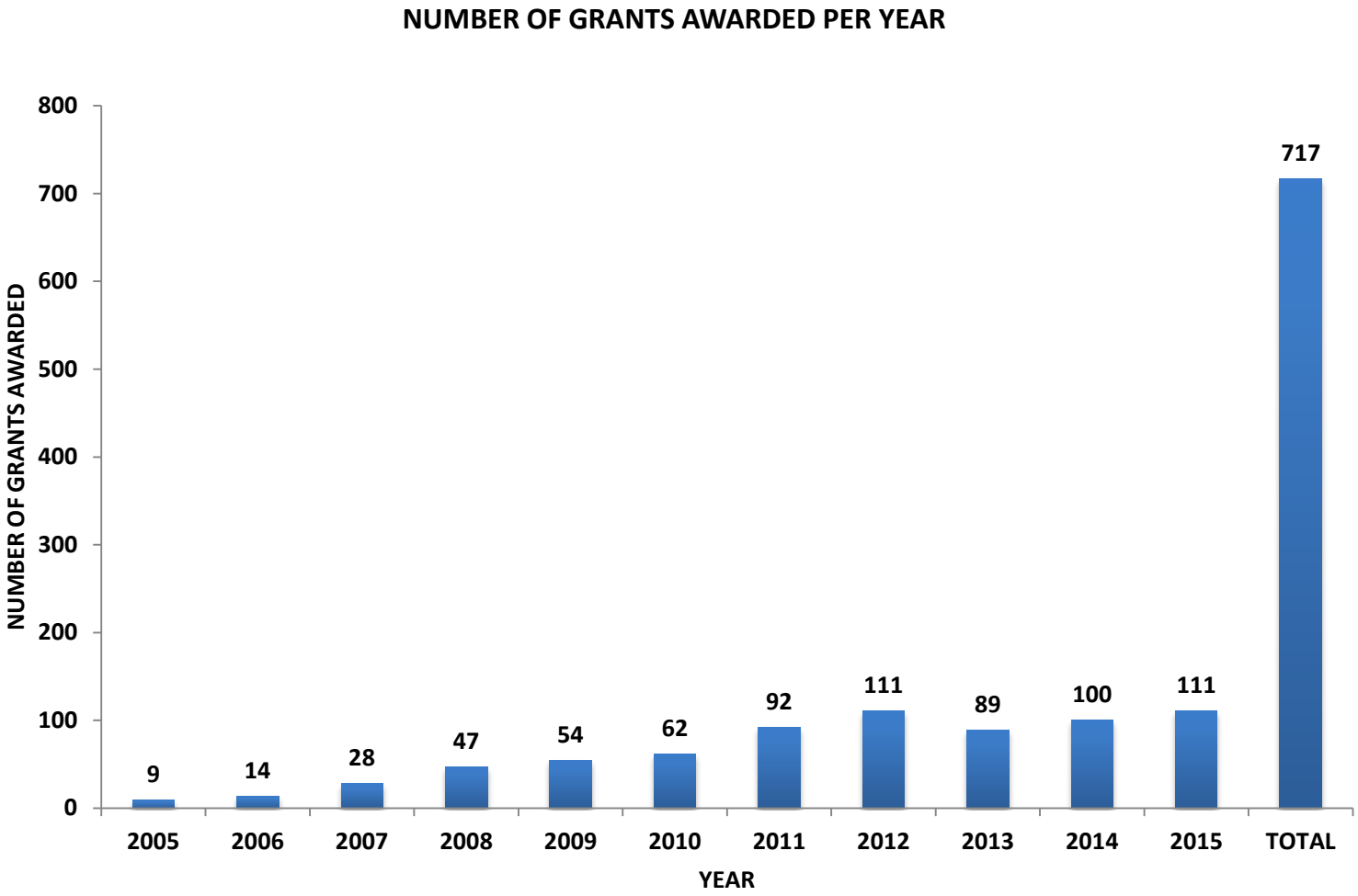
BIG DATA AFRICA ACTIVITIES

Kenya - Nairobi graduates who completed the JEDI workshop
(November 2013)

SKA SOUTH AFRICA HUMAN CAPITAL DEVELOPMENT PROGRAMME



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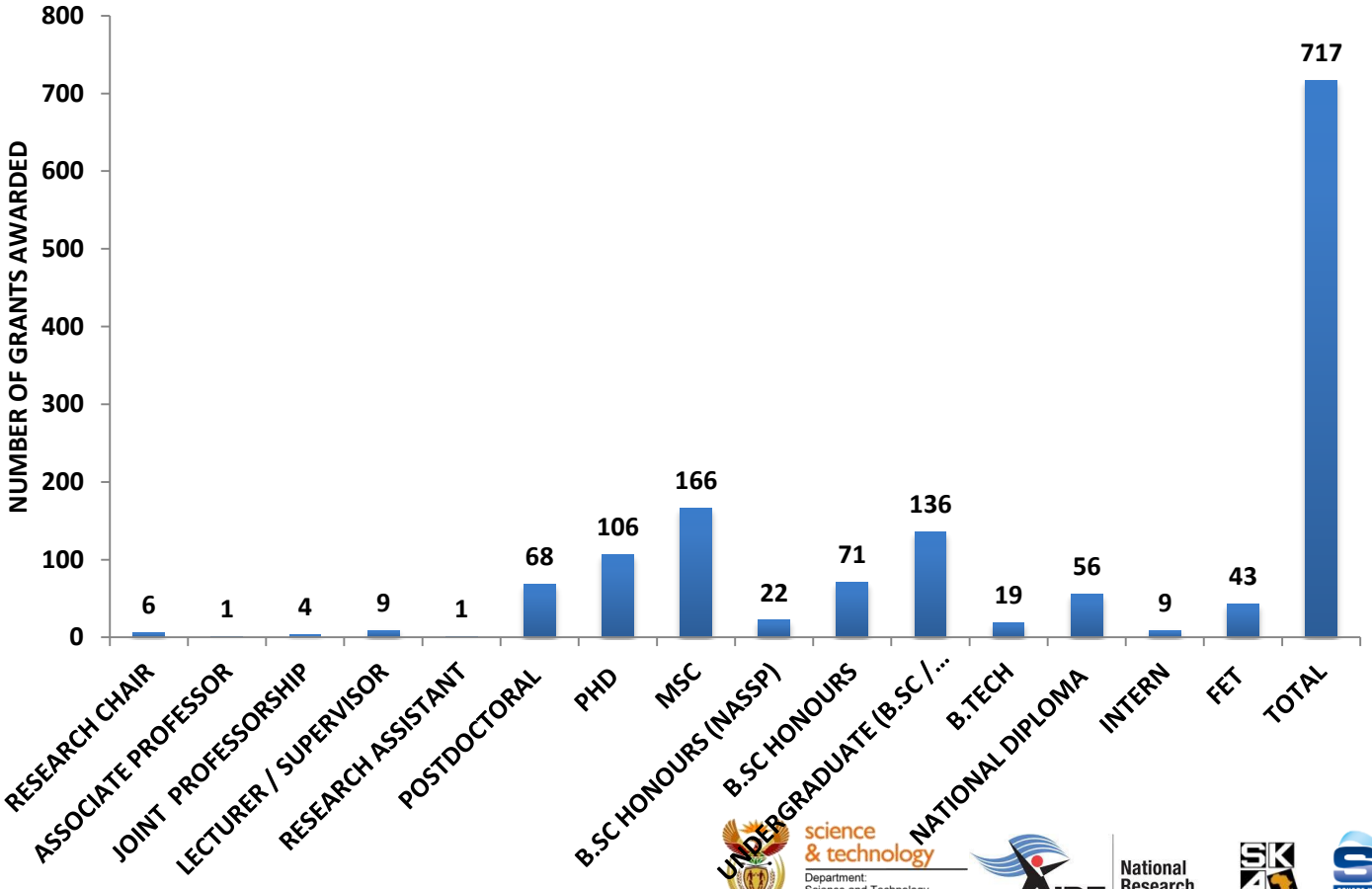
NUMBER OF SKA SA BURSARIES AND GRANTS AWARDED - BY ACADEMIC LEVEL



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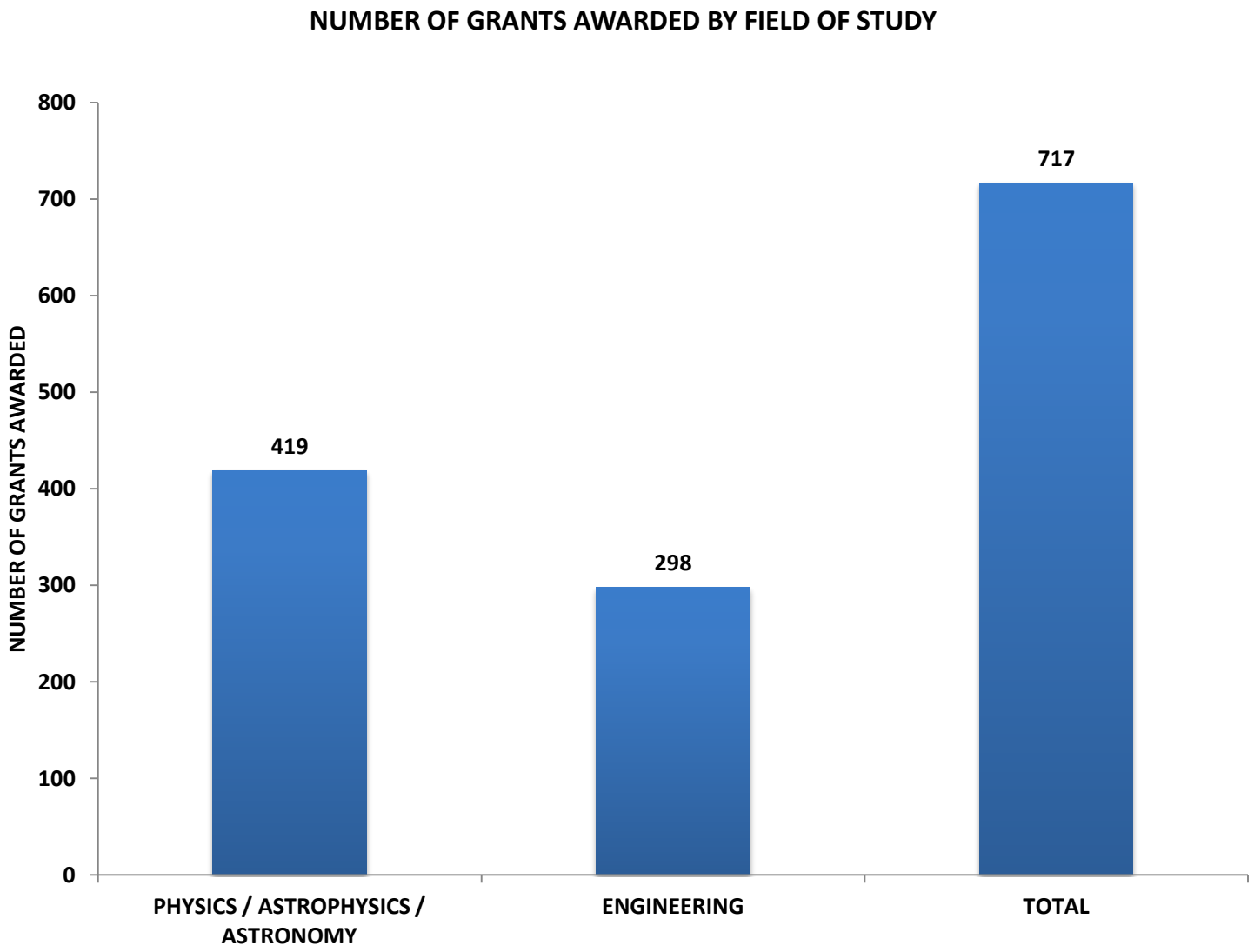

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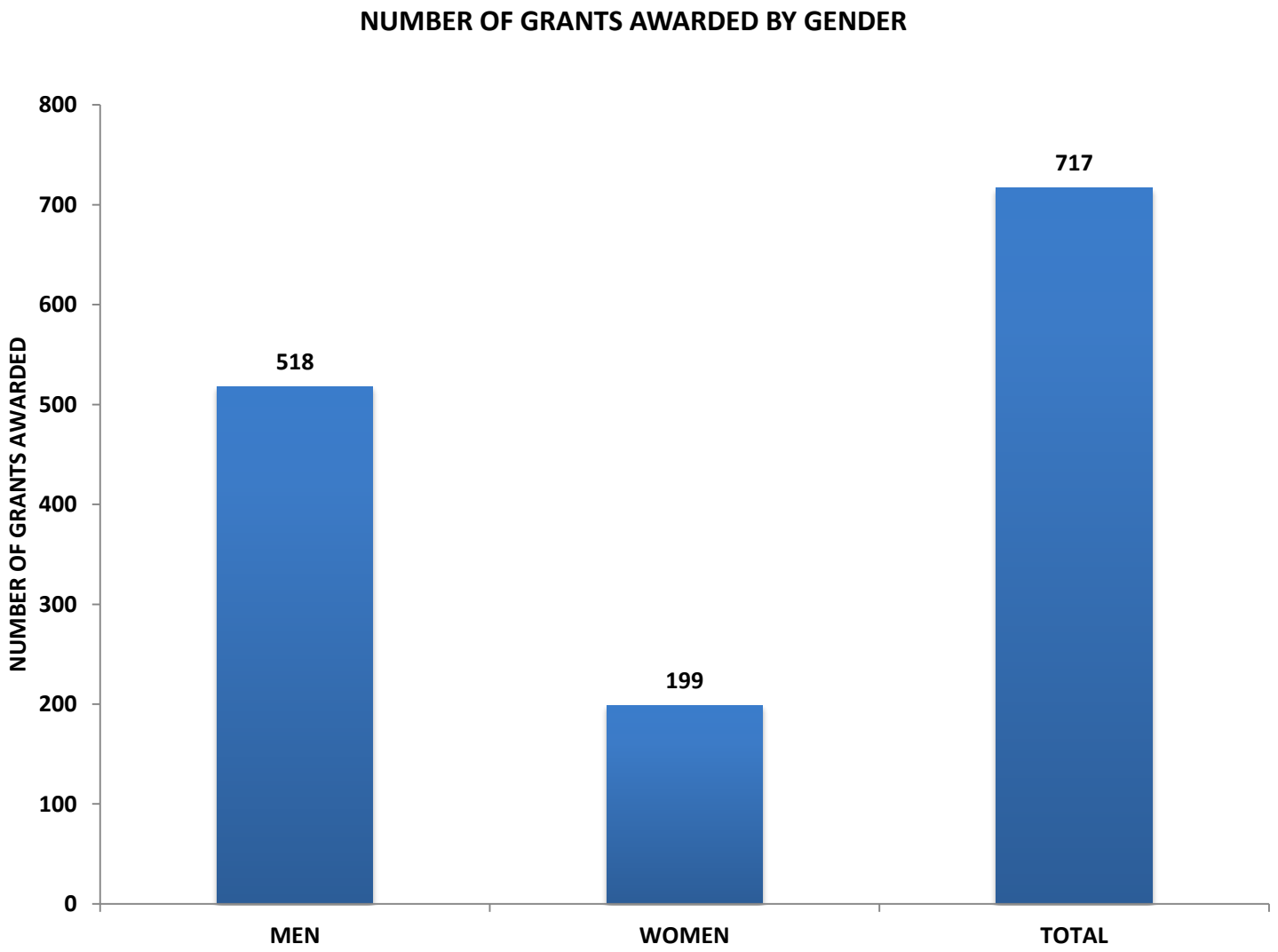

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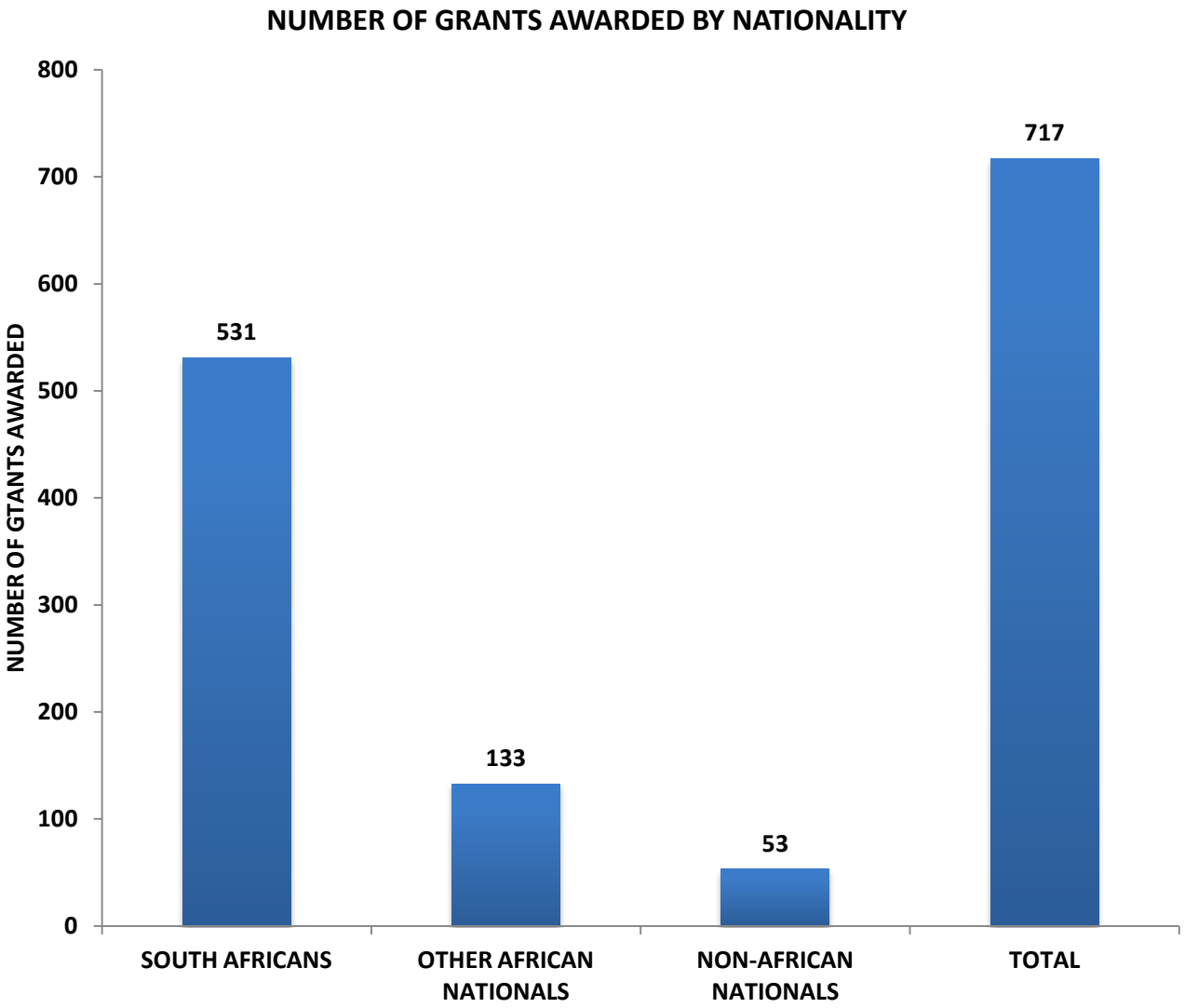

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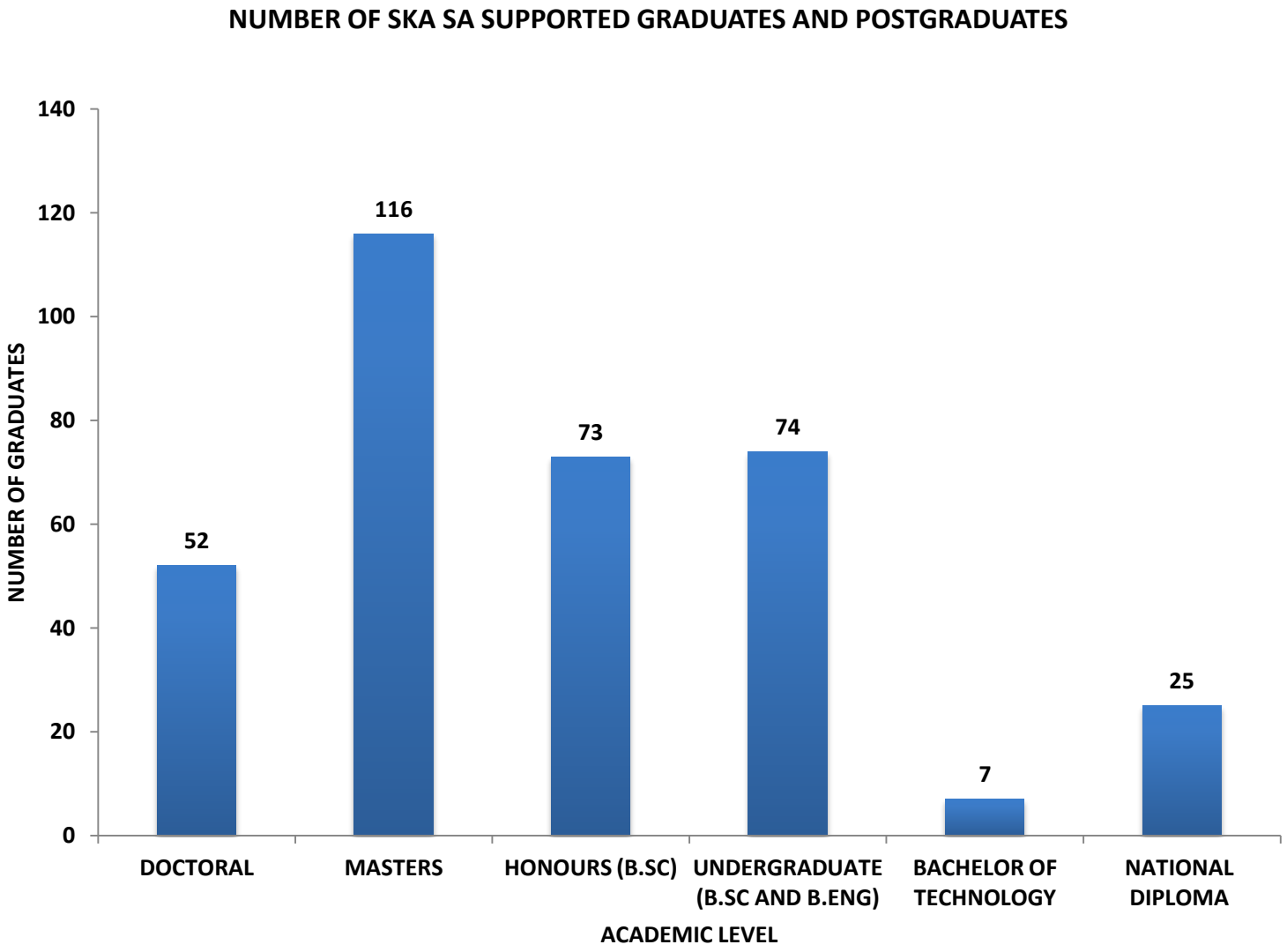
GRADUATED TO DATE FROM THE HUMAN CAPITAL DEVELOPMENT PROGRAMME



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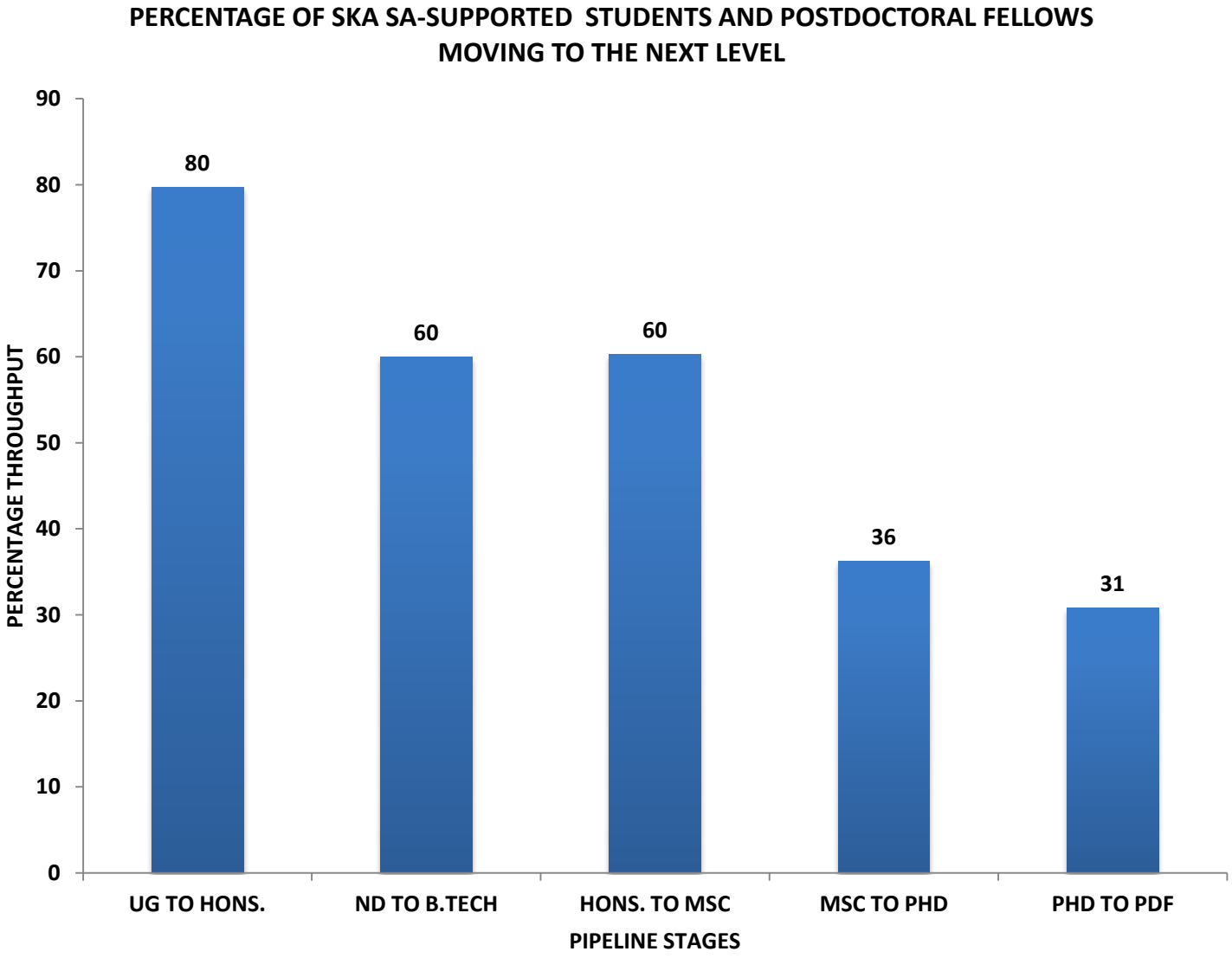

2016 CALL FOR APPLICATIONS

- Postdoctoral Fellowships – issue 1 July 2015 (5 available)
- PhD and MSc Bursaries – issue 1 July 2016 (10 of each available, 4 of each for students from SKA SA Partner Countries)
- Undergraduate / Honours Bursaries – issue 1 July 2015
- (15 bursaries available)
- Undergraduate Block Grants – issue 1 August 2015 (3 grants available, 2 for engineering programmes)
- National Diploma and Bachelor of Technology bursaries – issue 1 September 2015 – (15 bursaries – focus some on civil engineering for site)
- FET Bursaries – issue 1 September 2015 (10 bursaries available)

ON THE JOB TRAINING

KAROO TRAINING PROGRAMMES

- SKA SA initiated an Artisan Training Programme in 2011
  - Skills training opportunities for youth in the towns close to the SKA SA site
  - Attend FET colleges in Kimberley or Bloemfontein - 40 bursaries to date
  - Five of the students already employed by the project full time
  - Plan to employ up to 15 of the students completing FET training by 2017
  - Additional 10 bursaries in 2015
- Community Knowledge Centre
- Contractor training and new FET course
- E-learning and teacher development

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MATHS AND SCIENCE IN THE KAROO

- Brought in maths and science teachers in cooperation with Teach SA and Northern Cape Department of Education
- Competitive bursaries for children from surrounding towns to attend Carnarvon High School
- Cyber-labs and e-learning rolled out in schools in the area in cooperation with DoE, Department of Rural Development and industry partners
- Teacher training
- Local people trained to manage cyber-centres, community knowledge centre and e-learning equipment – thanks to Department of Rural Development

TECHNICIANS AND ARTISANS

- Artisan and technician training for people from the Karoo
- Employing many of them in SKA SA
- Role models for the communities around the SKA site

Artisan trainees in
the Hartebeesthoek
26m dish

AVN : GHANA AND KENYA

Also progress in Namibia, Botswana, Zambia, Mozambique, Mauritius

Ghanaian Essential Observatory Staff In Cape Town Training

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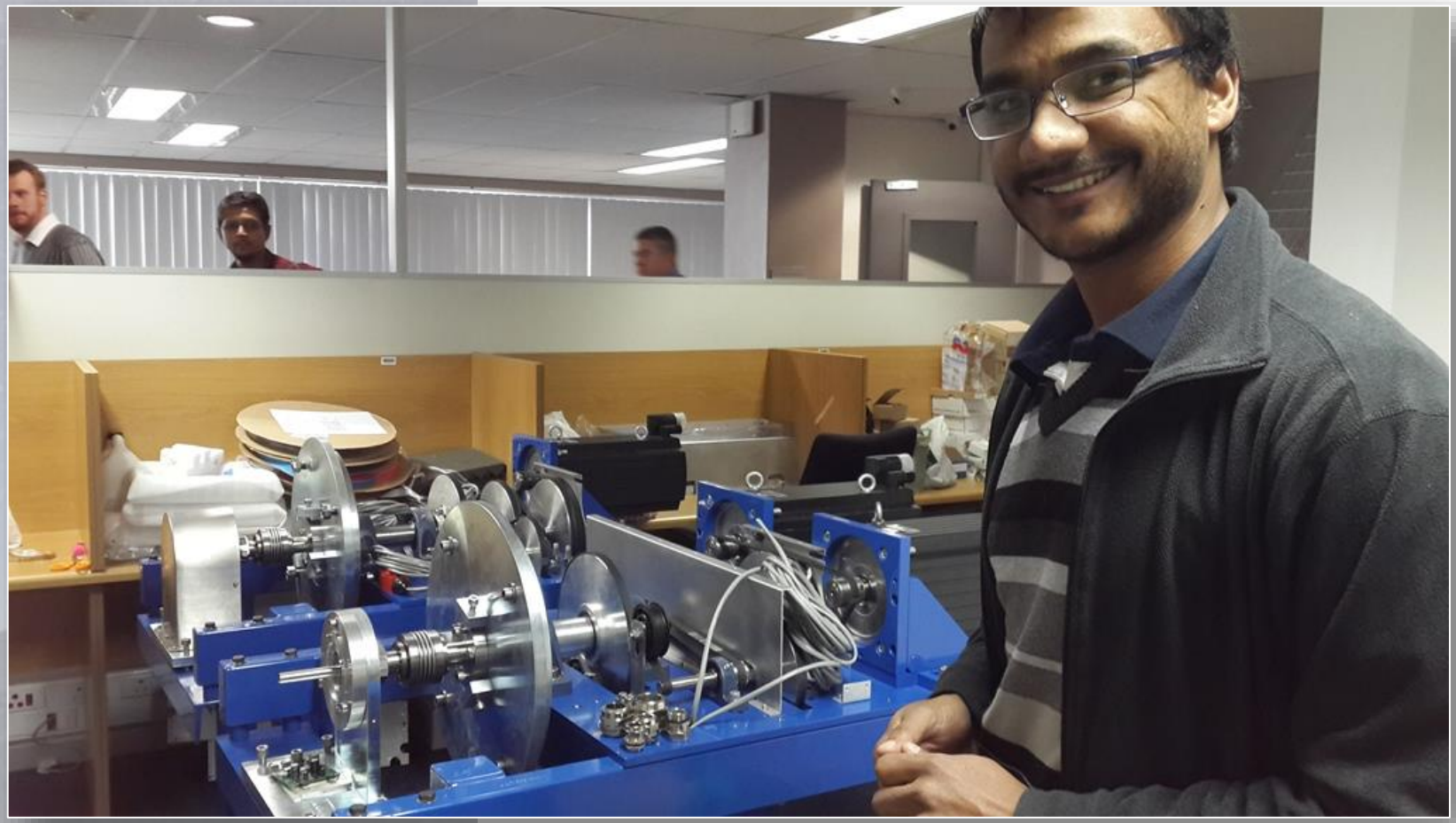
TECHNICIANS

TESTING NEW DRIVE MOTORS



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