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SKA AFRICA

SQUARE KILOMETRE ARRAY



Special Edition Newsletter - June/July 2011





"It is isolated and quiet, but also extremely well equipped with the required support infrastructure for science," says Anita Loots, associate director of the South African SKA project.

Location, location, location – South Africa’s SKA site is best of both worlds

The candidate SKA site in South Africa has the double advantage of being both remote and accessible for scientists and engineers.

"We are sufficiently far away to avoid urban disturbances, but close enough for material to be shipped into Cape Town and delivered to the site for assembly less than a day later. This will make a big difference to the cost and convenience of building the SKA, and then maintaining it."

The Karoo site is scientifically excellent and very accessible to the world-class academic

centres of Stellenbosch, Grahamstown and Cape Town.

Its geographic location relative to Europe is another significant advantage. Telescopes in the Karoo can see the same sky as their counterparts in Europe. This makes it ideal for very long baseline interferometry.

"Our site is also on the same time zone as the scientists and support staff at SKA headquarters in Europe," says Loots. "This will be extremely important during both the building phase, and when operations get underway."

More SKA in SA

With global science budgets under pressure, scientists are debating how they can get the most SKA for the available money.

Construction, operation and maintenance of infrastructure are world-class but relatively low cost in South Africa. The location of the proposed SKA site means the project could be delivered for considerably less than alternative sites.

"Our cost advantage means the full scope

of the SKA is more likely to be delivered in Africa, with significantly lower risk of delays and runaway costs. The less we spend on building the instrument, the more we can devote to the science we do on it."

Not only is a lot of the infrastructure already in place, but the site's connection to the power and optical fibre national grids means that power and data connectivity are available and at relatively low cost.



"You get more SKA in South Africa," says project director Dr Bernie Fanaroff.

Making the most of MeerKAT

South African infrastructure means first SKA phase is well underway

The response to MeerKAT by the international radio astronomy community is a signal of approval for South Africa's ability to host the biggest and most important science facilities.

"We called for proposals to use MeerKAT and those who responded are a who's who of the radio astronomy world," says Prof. Justin Jonas, associate director for science and engineering at the SKA South Africa Project. "We knew that if we created world-class radio astronomy facilities, then world-class



"MeerKAT can accelerate the development of the SKA," says Prof. Justin Jonas, associate director for science and engineering at the SKA South Africa Project.

researchers would come to use them. And that is what has happened."

Prof. Jonas says MeerKAT is more than just evidence of South African and African competence in the development of scientific infrastructure. "We've actually built what could be seen as a significant part of the SKA's first phase."

The MeerKAT and SKA teams were working separately when they set out to design the best possible telescope, but came to very similar conclusions about what was required.

"We designed MeerKAT as the best possible instrument for the next generation of radio astronomers, and were very pleased to see that the SKA team came up with something very similar," Jonas explains. "Now we should exploit that confluence of intelligent and appropriate design to save money and accelerate the development of the SKA."

Apart from the dishes, MeerKAT has a team of highly competent people, management systems, facilities and project infrastructure.

"The question for the SKA is really whether in a constrained economic environment we want to build on the excellence we already have, or start the whole expensive enterprise again from the beginning."



The MeerKAT is a true precursor for the SKA. The specifications and concept for the MeerKAT antenna systems closely match those of the SKA.

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It doesn't get much quieter than this

South Africa's proposed site for the SKA has been confirmed as one of the quietest places on Earth. Recent measurements of radio frequency interference, conducted by the international SKA consortium, confirmed the site's extremely low occurrence of radio frequency interference.

"South Africa was shortlisted in 2006 as an SKA host because our Karoo site already met the science, technology and infrastructure requirements determined by the international astronomy community," says SKA South Africa RFI and site characterisation manager Dr Adrian Tiplady. "The low level of radio frequency interference was a key factor in 2006, and we've made significant improvements since then."

Initial measurements showed the presence of some RFI from broadcasting and mobile phone infrastructure. These have been addressed

through a combination of political and legislative support for the SKA, cooperation with South African industry, and innovative technology and engineering.

The integrity of the South African SKA site is protected by the world's most progressive science-based legislation – the Astronomy Geographic Advantage Act – which ensures protection of the radio frequency environment for the future and regulates all future development in the area.

SKA South Africa has engaged with the broadcasting sector to develop plans that will establish an optimal radio frequency environment for the SKA, following the imminent migration to digital broadcasting in the Karoo region, thereby significantly increasing access to valuable spectrum for radio astronomy observations. New technology developed to support the African SKA site bid by telecommunication operator Vodacom (part of Vodafone), to be shared with other operators, will see a significant reduction in potential interference from GSM signals.

The availability of grid power on the SKA site is a key advantage for South Africa's bid. Detailed studies and design processes were carefully undertaken to design a transmission system that offered cheap and available power without compromising the site's RFI silence. Power cables have been routed through valleys, support and strain structures adapted, and key equipment buried underground. The lack of economically viable mineral deposits within 180 km of the SKA core site ensures that there is a very low risk of future mining developments, and hence sources of RFI.

Naturally occurring disturbances are virtually eliminated on the high and dry SKA site in the Karoo, where the stable and benign climate means radio astronomy is not disturbed by severe weather, atmospheric turbulence, hurricanes or floods.



"South Africa's SKA site will be as close to perfect as the community needs it to be when the SKA begins construction," says Dr Adrian Tiplady, RFI and site characterisation manager at the SKA South Africa Project.



The Central Astronomy Advantage Area in the Karoo region of South Africa's Northern Cape Province is legally protected.

C-BASS eye on the southern sky

The proposed SKA site in South Africa's Karoo desert is demonstrating its next-generation radio astronomy credentials as the location for the southern hemisphere component of the multinational C-BASS project.

C-BASS is the C-Band All Sky Survey, which will map the polarisation of galactic radio emissions from the Milky Way. A telescope is required in each hemisphere to map the entire sky.

Apart from its intellectual contribution, South Africa is hosting the southern hemisphere 7.2 m C-BASS dish at Klerefontein, close to the MeerKAT and proposed SKA sites in the Karoo.

A second C-BASS dish at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) was used to develop and test the receiver and other telescope systems. It will stay in use for education and public outreach.

The South African research partners on C-BASS are Rhodes University and HartRAO. They are working with Caltech in the US, the Universities of Oxford and Manchester in the UK, and Saudi Arabia's King Abdulaziz City for Science and Technology. Rhodes graduate Oliver King is designing part of C-BASS as a post-doc at Caltech.



The multinational C-BASS (C-Band All Sky Survey) project at South Africa's SKA site in the Karoo.

Taking Milky Way pollution out of the picture

Cosmic Microwave Background Radiation (CMBR) is the relic emission generated from the early universe some 300 000 years after the Big Bang. The CMBR provides the earliest picture of the universe a billion years before the first stars and galaxies were formed.

Scientists want to know what happened between the Big Bang and the CMBR epoch. They want to understand how primordial density ripples formed, and get a better understanding of the structure of time and space.

Einstein's Theory of Relativity and competing theories provide a number of different interpretations of how the universe expanded in its infancy. The popular inflation theory predicts that the universe experienced a short period of explosive expansion shortly after the Big Bang. This expansion would have left a distinctive imprint in the polarization of the CMBR, and hence the measurement of the CMBR polarization has become an important scientific challenge.

These measurements are extremely difficult to take and require very stable high-frequency receivers at high altitude on mountains, balloons and satellites. They are affected by foreground emission, such as the radio emissions from the Milky Way. C-BASS measurements of this Milky Way "pollution" enable their contaminating effect to be subtracted with great accuracy from high-frequency CMBR images such as those made by Planck.

Karoo infrastructure ready for the SKA

A powerful advantage from the grid

The Karoo doesn't just have the radio silence required to host the world's most ambitious radio astronomy telescope. It also has the infrastructure to power the SKA, analyse and deliver the data, support its scientists and enable world-class science at the lowest cost.

South Africa's SKA Africa site has reliable grid power, good access roads, and small towns capable of providing home comforts for a consort of international astronomers. Primarily developed for MeerKAT, the Karoo's radio astronomy infrastructure is also designed to be ready for the SKA and scalable where necessary.

"The grid connection gives us good quality of supply and cheap energy for what is a very

power-intensive scientific project," says SKA infrastructure manager Tracy Cheetham.

The SKA telescope and ancillaries (the computing and data processing back-end, the dishes and receivers etc.) are estimated to require a 105 MW power supply, with 65 MW for the antennae and 40 MW for the off-site super-computing centre. The newly-constructed 33 kV power line to site for MeerKAT is operational and planning is at an advanced stage for the provision of a new 132 kV power line to power the SKA. A rotary UPS system will be installed for MeerKAT to provide uninterrupted power supply to the radio telescope.



Taking charge of infrastructure developments at South Africa's Karoo SKA site is Tracy Cheetham, the architect on South Africa's SKA team

Data delivery

The SKA will produce vast amounts of data, requiring high-performance computing facilities and optical fibre to deliver it via Cape Town to the world's researchers, through submarine cables such as SEACOM and the West African Cable System (WACS).

The WACS cable, with a capacity in excess of five terabits and connections from South Africa along the West African coast to Portugal and the United Kingdom, has been laid and landed and is due for commercial launch in early 2012. SEACOM is already delivering broadband data services along the eastern and southern African coastline.

Construction of the 10 Gbps data fibre link for MeerKAT is currently underway and is expected to be completed by July 2011. This 10 Gbps data link has been provided by the South African National Research Network (SANReN) and includes the construction of the Cape Metro link and the long-haul fibre from Hutchinson to Carnarvon in the Northern Cape. SANReN is connecting more than 200

South African sites to 3 000 research and education organisations internationally.

The Northern Cape Province recently upgraded the main access road to the site and planning for the MeerKAT road network is expected to be completed in mid-July 2011. Existing buildings for KAT-7 include a dish manufacturing facility, accommodation and RFI-shielded computing containers. The project is currently in the detailed design phase for the provision of new buildings for MeerKAT, which includes extensions to the existing dish manufacturing facility, a new dish pedestal integration building, and a bunkered, temperature-controlled computing and power facility which is RFI-shielded.

Provision has been made in the design and in some cases the footprint of the new buildings to accommodate further expansion and growth in the future.

"South Africa has proved its capability to deliver world-class infrastructure which is affordable. We have a thriving engineering

and construction industry that delivers to globally competitive standards," Cheetham says. "This has been successfully demonstrated on our project and on other projects like the construction of the Gautrain rapid transit railway system and the FIFA World Cup stadiums.

"By the end of 2013 all the MeerKAT infrastructure will be in place and our site will be ready to host the SKA."



Artist's impression of new infrastructure at SKA South Africa's Karoo site



The existing site complex at Losberg in the Karoo, South Africa

PAPER demonstrates suitability of SA site

Further evidence of the Karoo's suitability for next-generation radio astronomy comes from the successful deployment of the PAPER project on the South African site selected as a candidate for the SKA.

PAPER – the Precision Array to Probe the Epoch of Re-ionization – is a radio interferometer, a system of radio telescopes linked to create one larger telescope. It is a pathfinder project for the low-frequency components of the SKA. It requires the extremely low radio interference characteristics of the Karoo while using new signal processing technology to detect the signatures of the first stars and galaxies.

Jointly led by the NRAO, the University of Virginia and the University of California at Berkeley, PAPER is another successful project to emerge from the SKA Africa project's collaboration with the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER). PAPER shares its digital signal processing architecture with KAT and so South Africa was a natural home for the array, close to the expertise in this critical area of the signal processing chain.

The PAPER project was initially intended for Australia's Murchison Desert (near their proposed SKA site) and a 4-antenna, single-polarization deployment of the PAPER experiment actually took place in Western Australia in 2007. However, the project was moved to South Africa and 2009 saw a large-scale deployment on the Karoo site. The primary drivers for this move were the excellent RFI-quiet environment and the proximity to ROACH expertise, on which PAPER is based.



"ROACH is like the Swiss Army knife of radio astronomy," says Jason Manley, digital signal processing specialist at South Africa's MeerKAT project.



The PAPER experiment is thriving on site in the Karoo, South Africa

The ROACH (Reconfigurable Open Architecture Computing Hardware) platform for PAPER was developed by MeerKAT engineers (designed and prototyped in the Cape Town office) together with CASPER collaborators. Jason Manley, digital signal processing specialist at SKA South Africa (photo right) built the correlator in the MeerKAT laboratories in Cape Town.

"ROACH is a single platform which can be reprogrammed to perform various signal processing operations," explains Jason.

The digital signal processing systems form the heart of interferometric arrays like PAPER.

"PAPER is operating extremely well on our SKA site," says Prof. Justin Jonas, associate director for science and engineering at SKA South Africa. "It is in South Africa for two reasons. We are recognised as having the ideal site, and we have the scientists and engineers to deliver our part of the project."

There are currently 40 antennas on site with regular, ongoing expansions. June 2011 will see another 24 deployed and in 2012 there will be 128 antennas on the current South African site. PAPER will eventually have thousands of antennas. "This is a big project; they need lots of collecting area to detect the incredibly faint, highly red-shifted hydrogen spectral line," says Jason.

All existing PAPER antennas and associated components were shipped from the United States to Cape Town and taken by road to the Karoo site for installation by local engineers. The correlator was built in South Africa. Investigations for possible local manufacturing of future antennas are underway and grid power



A ROACH-2 prototype

and fibre optic data links are currently being installed to the nearest KAT-7 infrastructure 2 km away.

There are several projects worldwide searching for the epoch of re-ionisation, which should eventually allow the first formation of the stars to be imaged. PAPER is one of the forerunners. The South African site, together with the northern-hemisphere site in Green Bank, West Virginia, has already produced a full sky map with thousands of detected sources. The South African site is their primary science site with the 32-antenna Green Bank being kept for array development and engineering tests.

Top astronomy talent lights up African SKA bid

Some of the world's most distinguished radio astronomers and cosmologists have taken up key academic posts dedicated to the African SKA project.

Four of the five new university SKA research chairs have been filled with professors from the UK, South Africa, Italy and Canada. The posts, supported by South Africa's Department of Science and Technology and the National Research Foundation, demonstrate the country's commitment to world-class science and to hosting the SKA.

"We have recruited the very best research talent," said Prof. Justin Jonas, the project's associate director for science and engineering. "We have substantially boosted an already strong South African academic base in astronomy and its associated disciplines such as engineering, mathematics and instrument science."

The SKA research chairs are worth R225 million over fifteen years, in addition to a R140 million bursary programme for young people to study

radio astronomy, physics and engineering related to the SKA and MeerKAT.

Prof. Jonas applauds South Africa's success in attracting such influential astronomers and cosmologists. "These are people with established records of excellence and who have been hand-picked not just for their own scientific pedigree, but also their ability to groom the next generation of radio astronomers and engineers."

"We aren't stuck in South Africa with a legacy of astronomy skills which may not be entirely appropriate or relevant to the SKA," notes Jonas. "When you make a fresh start you have the ability to design the system to follow the latest scientific trends, and that is as true for the people as it is for the technology."

"What we have in South Africa is a long history of radio astronomy, and a young dynamic team of agile people who are able to develop and exploit new ideas."

South Africa's SKA Research Chairs

Prof. Roy Maartens has been appointed as the SKA Research Chair in the Astrophysics Group at the University of the Western Cape (UWC). He returned home to South Africa from England, where he was director of one of the UK's top cosmology research groups.

His research will exploit data from the MeerKAT array and the SALT optical telescope to answer key questions about the universe.

Maartens is an expert in building theoretical models of dark energy and testing them against observations. Dark energy is the mysterious substance thought to be driving the acceleration of the Universe, causing galaxies to move away from each other at ever greater speeds.

His team will use high-precision data from MeerKAT, SKA and other telescopes to test various ideas about dark energy – including the possibility it doesn't exist and is instead a breakdown of Einstein's theory of gravity.

Of special interest is the period called the Dark Ages, when the universe was cool enough for hydrogen clouds to form and start condensing, but still too young for the formation of stars.

MeerKAT and SKA will probe further back in time than optical telescopes, and help map these hydrogen clouds as they evolve and give birth to the first generation stars that lit up the Universe and ended the Dark Ages.

UWC's winning of a SKA research chair builds on the university's strengths in astrophysics developed through the joint SKA/UWC appointment of Prof. Catherine Cress. Matt Jarvis has also been appointed to a professorship at UWC, which he will hold jointly with his position in Hertfordshire.

Maarten's research team will benefit from UWC expertise in radio data, statistical analysis and massive computer simulations of galaxies. The astrophysics group has been very successful in training MSc and PhD students, delivering astronomy courses in the Physics BSc, and taking astronomy to schools and the public. The new research team will help to strengthen these activities. Early-career scientists in Roy's research team will be trained to build models, analyse data and test their models against observations.



Keen to take on astronomy research challenges in South Africa – Prof. Roy Maartens was the first academic appointed to one of South Africa's five SKA Research Chairs.

Prof. Claude Carignan heads the new SKA research chair in Multi-Wavelength Extragalactic Astronomy at the University of Cape Town, which has the largest university astronomy group in Africa. He is an expert on galaxy dynamics and dark matter and is from the University of Montreal in Canada.

Prof. Carignan specialises in the study of mass distribution in galaxies, using both radio synthesis and optical Fabry-Perot interferometric techniques. He will continue this research with students using MeerKAT

for radio observations and the SALT optical telescope. Prof. Carignan is active in the development of next generation astronomical instrumentation, mainly photon counting cameras based on EMCCDs.

He has been very involved in the development of astronomy in Burkina Faso and in the setting up of the African Astronomical Society (AfAS). He intends to continue helping the development of astronomy in other African countries because "the involvement of the whole African continent increases South Africa's chances of winning the SKA bid."

Prof. David Davidson is the new SKA Research Chair in Electromagnetic Systems and EMI (Electromagnetic Interference) Mitigation at Stellenbosch University.

He currently heads the Computational Electromagnetics research group in the Department of Electrical and Electronic Engineering. He recently led the flagship high-performance computing project on electromagnetic simulation for MeerKAT and the SKA with the national Centre for High Performance Computing.

The 2nd edition of his textbook, Computational Electromagnetics for RF and Microwave Engineering, has just been published by Cambridge University Press.

David proposes to focus on radio astronomy instrumentation, specialising in EM systems and EMI mitigation on MeerKAT and the SKA. During his twenty-three years in academia, Prof. Davidson has enjoyed sabbaticals at academic institutions which are leaders in his field, including the University of Arizona, Trinity College Cambridge, and the Delft University of Technology.

“The SKA has already had a significant impact on science and engineering in South Africa,” says Prof. Davidson. The department has eight students and three post-docs working on MeerKAT and SKA, four of them from African SKA partner countries Kenya and Madagascar.

“Stellenbosch has a long tradition of excellence in training post-graduate students in electromagnetics, radio-frequency (RF) and microwave engineering. We have trained well over 200 post-graduate students since the 1980s and this chair will add crucial high-level capacity for integrating research activities in antennas, signal detection, and EM interference,” Davidson says.

“South Africa and Africa have long needed a high-profile science project to drive technology, attract a new generation of learners, nurture innovation and create new industries.

“MeerKAT and the SKA are fulfilling this need with diverse and very

challenging requirements in electrical and electronic engineering, computing and computer engineering, IT, mechanical and even civil engineering.

“Focussed spending in South Africa in the past has led to the emergence of new industries and the MeerKAT/SKA project is a wonderful investment in our technological future.”



Prof. Davidson (middle) with research students Dewald Schoeman (left) and Emmanuel Mukubwa (a Kenyan student).

Prof. Sergio Colafrancesco will take up his SKA research chair in Radio Astronomy at the University of the Witwatersrand in August 2011. He is currently a professor in Astrophysics at the University of Rome and senior scientist with the Italian Institute for Astrophysics (INAF).

Prof. Colafrancesco's research interests include observational and theoretical research in radio astronomy, and tackling challenges generated



by advances in cosmology, extragalactic astrophysics and astro-particle physics.

These include the nature of dark matter and dark energy, the exploration of the dark ages and the evolution of large scale structures in the universe. Colafrancesco is interested in galaxies and clusters of galaxies, as well as tests of general relativity and gravity, and the origin and evolution of cosmological magnetic fields, of cosmic rays in cosmic structures and of supermassive black holes.

He says his SKA research activities will support and reinforce the African SKA bid and help to position it at the centre of international research in radio astronomy, cosmology, extragalactic astrophysics and astro-particle physics.

“The SKA Chair offers me unique opportunities to address the most fundamental questions at the basis of our understanding of the structure and evolution of our Universe and of the cosmic structures it contains.”

“We will fully exploit the exceptional combination of astronomical data from SKA and its precursor MeerKAT, and from gamma-ray observatories like HESS in Namibia.”

The research chair will also provide the capability to build a multi-disciplinary research strategy linking radio and gamma-ray astronomy in South Africa with MeerKAT, the future SKA, the HESS facility and future CTA experiments. It will connect these facilities and their research with other world-class experiments such as PLANCK, OLIMPO, RADIOASTRON, Millimetron, CORe, NUSTAR, DUAL, Fermi, and CTA.

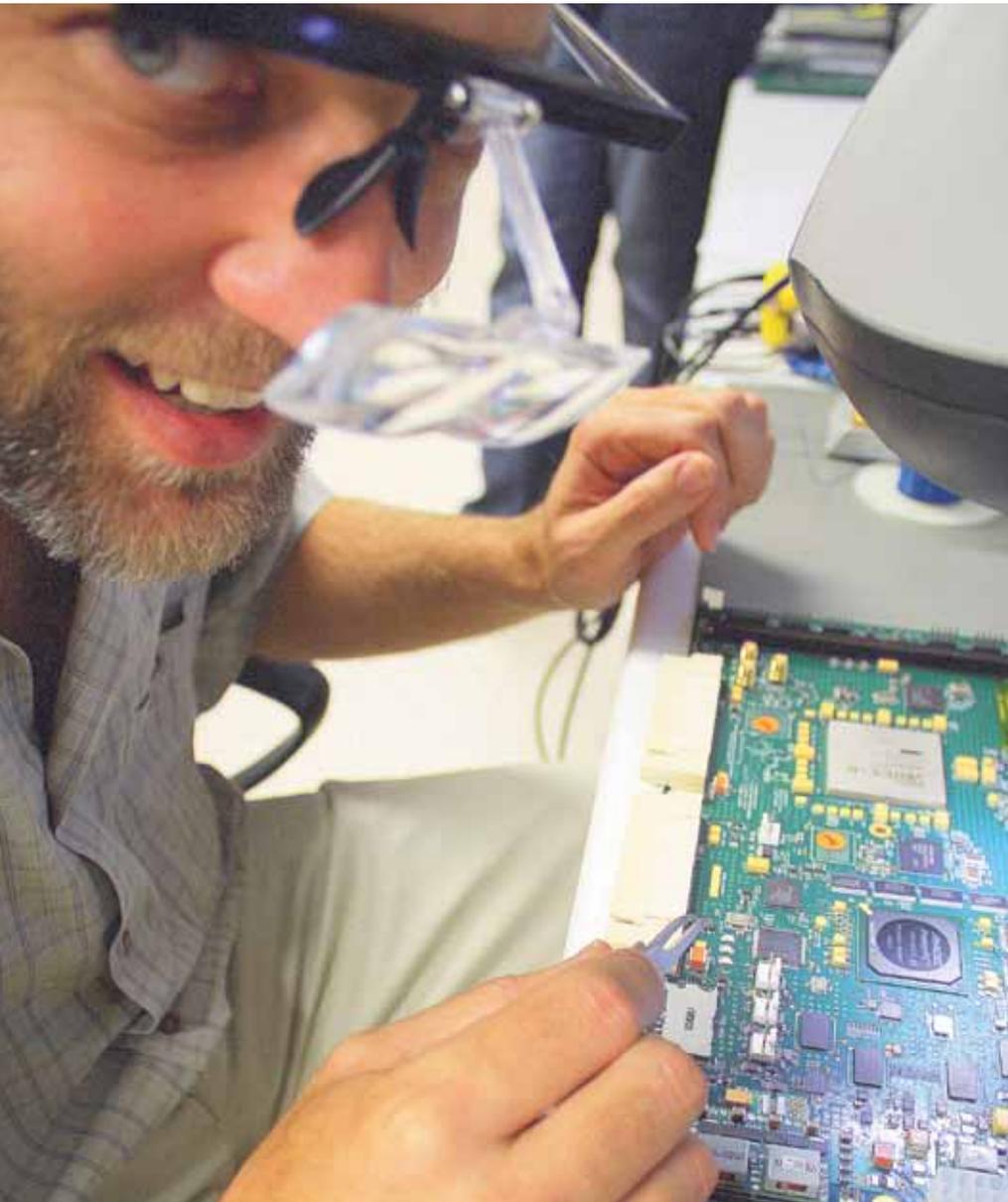
Prof. Colafrancesco's research will help to put South Africa's radio-gamma activities at the forefront of international research, and will build around them an inter-African scientific and cultural system to support the creation of a SA knowledge-based economy.

Taking up a research in South Africa soon – Prof. Sergio Colafrancesco at the Experimental Cosmology Laboratory, University of Rome.

Rhodes University Research Chair in Instrumentation: A top candidate has been identified and will take up the position in the near future.

Moore for less

Hot swapping ROACH boards means maintenance is an upgrade



"We are designing the PC of radio astronomy," says Francois Kapp about ROACH-1 to 6 and more... Kapp is the digital back-end systems manager at the MeerKAT project.

African electronic engineers from the MeerKAT and SKA projects are at the forefront of digital signal processing which drives the next-generation of radio telescopes.

The innovative ROACH board is an electronic building block which increases computing capacity while reducing costs, making it ubiquitous in new astronomy instrumentation.

Engineers at the Cape Town-based MeerKAT office of South Africa's SKA project were instrumental in the design of the first ROACH (reconfigurable open architecture computing hardware) and led the design of its more powerful successor ROACH-2 from concept to production. These boards were designed within the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) in conjunction with engineers and academics from leading institutions like the University of California, Berkeley; Caltech; the US National Radio Astronomy Observatory and the

University of Cape Town.

CASPER and its hardware have been very successful in this field and the boards are currently in use in over 30 institutions worldwide. They are the processing backbone of many major international astronomy projects. Over 300 ROACH boards have been produced in California and deployed at research facilities internationally. Fifty are destined for the local MeerKAT project and the others are in use by institutions such as Oxford, MIT, Stanford, UCLA, India's GMRT, and others.

ROACH-2 production facilities are being set up in South Africa. The ROACH-2 prototype used the latest advances in FPGA technology (field-programmable gate array), which reduces development costs as the board can be configured after production. ROACH-2 has five times the processing capacity of ROACH-1.

"We are designing the PC of radio astronomy, so we can track Moore's Law and

double our processing capacity every three years," says Francois Kapp, the digital back-end systems manager at the MeerKAT project. Kapp is already anticipating ROACH-6 driven by continued progress in FPGA development.

ROACH-1 is the board behind the KAT-7 telescope. MeerKAT was designed to be built on ROACH-2, but is now likely to use ROACH-3.

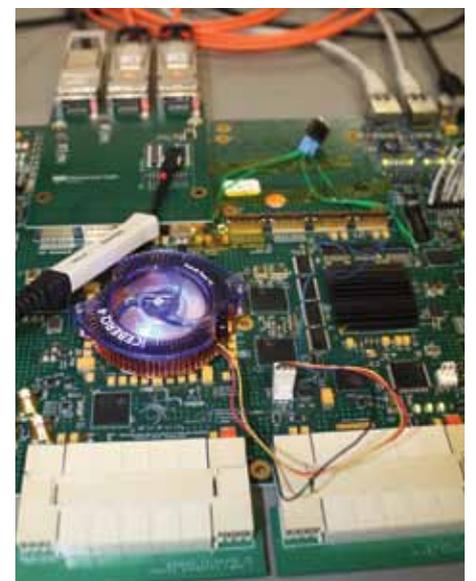
"This is the beauty of it," says Kapp. "We have a development process which lets us wait as long as possible and then put the very latest processing capacity into our telescopes," says Kapp. He notes that the money saved on MeerKAT by adopting ROACH-3 is more than the total cost of developing ROACH-3.

"This really is Moore's law in action, with added design intelligence. If you cleverly design the telescope around a board which is still under development, and stay as close as possible to the FPGA release cycle, you get the best possible processing power at a lower cost."

Because much of the ROACH board is unchanged between generations, each new version is compatible with its predecessor and shares many peripherals. "Let's look at MeerKAT," explains Kapp. "We will build it with two years' worth of spare ROACH boards. After that we will insert the next-generation board, which means simple maintenance is actually a phenomenal upgrade. And this upgrade is easy to do because we can hot-swap the boards on the live array, which is cheap and limits the amount of science downtime."

ROACH and its surrounding infrastructure are designed to operate remotely, with the whole design philosophy based around engineers not having to visit the site. This is useful and important on a project like MeerKAT, with its 64 dishes, "but on the SKA it is absolutely non-negotiable," says Kapp.

"It all adds up to practical maintenance. We had to design ROACH for remote access and redundancy, and that's exactly what we have done."



Each new generation ROACH board is compatible with its predecessors.

Researcher response to MeerKAT demonstrates SKA potential

The overwhelming response by researchers to MeerKAT has demonstrated South Africa's capacity to host and support world-class astronomy projects. "We knew that if we built it they would come," said Prof. Justin Jonas, the SKA Africa associate director for science and engineering. "And five years before MeerKAT is finished we have already allocated 43 000 hours of observing time."

The high demand by radio astronomers internationally is a tribute to the quality of research infrastructure available in South Africa's Karoo semi-desert, a candidate site for the SKA.

MeerKAT is South Africa's SKA precursor instrument and will consist of 64 dishes of 13.5 m in diameter. MeerKAT's own test bed of seven dishes, the KAT-7 array, is fully installed on the site.

More than 500 astronomers bid for time on MeerKAT, including 59 from Africa, with 21 proposals received. Among the criteria for selection was the unique science MeerKAT would enable.

Many of the approved MeerKAT science projects are aimed at discoveries which the SKA telescope is focused on. "This confirms MeerKAT's critical role as a precursor to the SKA," says Prof. Roy Booth, associate director of the SKA South Africa.

Until the SKA is completed, MeerKAT will be the largest and most sensitive radio telescope in the southern hemisphere, with sensitivity (A/T) of 220 m² per Kelvin. Its design and construction has enabled African scientists and engineers to take a leading role in the global design and technology effort for the SKA.

MeerKAT has already left a legacy of radio astronomy and engineering skills. Nearly 100 scientists and engineers are working on MeerKAT from the project office in Cape Town and on the remote Karoo site, in cooperation with South African industry and universities and researchers internationally. Many visitors



Excited about the super science they are going to be doing with MeerKAT are (ltr) Prof. Rob Fender (ThunderKAT), Prof. Mark Thompson (MeerGAL), Willem Esterhuysen (MeerKAT project manager), Prof. Ben Stappers (Trapum) and Prof. Matt Jarvis (Mightee). All MeerKAT PIs met with the project's engineers and other developers in Cape Town during April 2011.

have commented on the great enthusiasm and commitment of this young team and their world-class capabilities.

The MeerKAT designers independently arrived at an antenna model very close to that developed by the SKA design team. Among the innovations developed for the MeerKAT are a the South African-designed and built composite dishes, highly innovative signal processing back ends, receivers and feeds and algorithms.

The offset configuration of the dishes provides an unblocked aperture which doesn't compromise performance and sensitivity,

provides excellent imaging, and reduces radio frequency interference from satellites and terrestrial transmitters.

It also facilitates the installation of multiple receiver systems in the primary and secondary focal points, in line with the reference design for the mid-band SKA concept.

MeerKAT will support a wide range of observing modes, including deep continuum, polarisation and spectral line imaging, pulsar timing, and transient searches.

MeerKAT will be commissioned in 2014 and 2015, with the array coming on line fully for science operations in 2016. This phase will include all antennas, but only the first receiver will be fitted (< 1.0 – 1.75 GHz), and a processing bandwidth of 750 MHz will be available. For the second and third phases, the remaining two receivers (580 MHz – 1.015 GHz and 8 – 14.5 GHz) will be fitted and the processing bandwidth will be increased to at least 2 GHz, with a goal of 4 GHz.

The very low frequency band will enable the detection of atomic hydrogen at a red-shift of at least 1.4, the signals emitted when the universe was less than half its current age. The high frequency receiver will make it possible to detect carbon monoxide at a red shift of 7, close to the epoch of re-ionisation when material which cooled after the Big Bang began to combine to form galaxies.

Surveys of radio pulsars and hydrogen gas in the deep universe came top in the first round of allocating MeerKAT's observing time.



MeerKAT PI Dr Erwin de Blok, University of Cape Town, with PhD student Bradley Frank and MSc student Moses Mogotsi.

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A radio pulsar timing proposal to test Einstein's theory of gravity and investigate the physics of enigmatic neutron stars has been granted 8 000 hours on MeerKAT, with another 5 000 hours for an ultra-deep survey of neutral hydrogen gas in the early universe.

MeerKAT will also participate in global very long baseline interferometry (VLBI) operations with major radio astronomy observatories around the world. It will add considerably to the sensitivity of the global VLBI network, and enhance the southern VLBI arrays.

Other potential science objectives for MeerKAT are to participate in the search for extra-terrestrial intelligence, and collaborate with NASA on downloading information from space probes sent to other planets.

The radio astronomy research teams with successful MeerKAT proposals are working with the MeerKAT team throughout the design phase of the telescope.

MeerKAT science projects	Research leaders
Testing Einstein's theory of gravity and gravitational radiation – Investigating the physics of enigmatic neutron stars through observations of pulsars.	Prof. Matthew Bailes, Swinburne Centre for Astrophysics and Supercomputing, Australia
LADUMA (Looking at the Distant Universe with the MeerKAT Array) – An ultra-deep survey of neutral hydrogen gas in the early universe.	Dr Sarah Blyth, University of Cape Town in South Africa; Dr Benne Holwerda, European Space Agency, The Netherlands; Dr Andrew Baker, Rutgers University, United States Dr Ian Heywood, Oxford University, UK
MESMER (MeerKAT Search for Molecules in the Epoch of Re-ionisation) – Searching for CO at high red-shift ($z > 7$) to investigate the role of molecular hydrogen in the early universe.	
MeerKAT Absorption Line 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) – Investigations of different types of galaxies; dark matter and the cosmic web.	Prof. Erwin de Blok, University of Cape Town, South Africa
TRAPUM (Transients and Pulsars with MeerKAT) – Searching for and investigating new and exotic pulsars.	Dr Benjamin Stappers, Jodrell Bank Centre for Astrophysics, UK; Prof. Michael Kramer, Max Planck Institute for Radio Astronomy, Germany Dr Paolo Serra, ASTRON, The Netherlands
A MeerKAT HI Survey of the Fornax Cluster (Galaxy formation and evolution in the cluster environment).	
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
MIGHTEE (MeerKAT International GigaHertz Tiered Extragalactic Exploration Survey) – Deep continuum observations of the earliest radio galaxies	Prof. Matt Jarvis, University of the Western Cape, South Africa and the University of Hertfordshire, UK; Dr Kurt van der Heyden, University of Cape Town
ThunderKAT (The Hunt for Dynamic and Explosive Radio Transients with MeerKAT) – eg. gamma ray bursts, novae and supernovae, plus new types of transient radio sources.	Prof. Rob Fender, University of Southampton, UK; Prof. Patrick Woudt, University of Cape Town, South Africa

VLBI network to be deployed across Africa

An African radio telescope network would fill in a major gap in the global VLBI network and that is what South Africa and its SKA partner countries are working towards. Such a network will also boost engineering and science skills development across the continent.

There are at least 26 satellite ground segment dishes, possibly more, spread out over Africa which could become a part of this new VLBI network.

Where countries do not have existing antennae suitable for conversion, converted dishes from other parts of Africa could be "transplanted". In some cases, new dishes will

be built. "We are exploring options tailor-made for each partner country," explains Dr Bernie Fanaroff, director of SKA South Africa. "This is essentially a bottom-up project, where governments are talking to telecommunications operators to gain access to the redundant dishes".

The project will kick off with the conversion of a Vodafone 32-m satellite communications antenna at Kuntunse, Ghana. This project is already well underway with a dedicated team in Ghana driving it. At the same time, preparatory work to establish a dish in Mozambique has already begun.



The conversion of Ghana's 32-m satellite communications antenna as part of an African VLBI network will provide a model for similar dish conversions across the continent.



Conversion of the Vodafone 32-m satellite communications antenna in Ghana has already begun.

"We should be able to track an astronomical object within nine months," Fanaroff adds. "By December 2012, the dish in Ghana should demonstrate first light as part of a joint VLBI observation with the Hartebeesthoek Radio Astronomy Observatory in South Africa."

"An ambitious and challenging road map with many intermediate steps have been defined towards this goal", explains TL Venkatasubramani (aka "Venkat"), manager of the African VLBI Network project.

A new generation of astronomers emerges in Africa



Kim McAlpine is a PhD student at Rhodes University working on the calibration and analysis of data from the GMRT to produce wide-field, high dynamic range radio images. She is using these images to study the evolution of radio galaxies, a key science topic for the SKA. This work is being done in collaboration with Dr Matt Jarvis at the University of Hertfordshire. Kim has developed a deep understanding of the techniques of radio interferometry – her MSc project involved the analysis of VLBA data to study the circumstellar envelopes of late-type stars.



Tshakule Nemalili joined the MeerKAT engineering office in Cape Town in 2008 after studying maths and physics at the University of Johannesburg. He enjoys the challenges of the MeerKAT project and the experience he is gaining in cutting-edge software development and data analysis. "As we are moving into a more knowledge-based society, there is no better place to be working right now," he says.



"We have extraordinary talent in Africa, and our people are now firmly part of the global radio astronomy mainstream," says the project's human capital development manager Kim de Boer.

The South African SKA Project has awarded 293 grants and scholarships since its human capital development programme was started in 2005, substantially boosting Africa's capacity to design, build, operate and upgrade astronomy facilities, to carry out astronomy and instrumentation research and to participate in the SKA.

The grant holders have included 22 postdoctoral fellows, 43 PhD and 74 MSc students who are doing research aligned with the science and technology of the MeerKAT and SKA telescopes and the C-BASS and PAPER experiments. The project has also awarded 100 bursaries to undergraduate and honours students to create a pipeline of excellent students who can advance into postgraduate research.

The South African SKA Project was initiated in 2003 with South Africa's preliminary bid to host the Square Kilometre Array Radio Telescope (SKA). At that time there were twelve practicing radio astronomers in Southern Africa. Today there are more than sixty. In addition, there are close to 100 engineers and engineering organizations in South Africa working on radio telescope technology and in many cases leading international technology design efforts. Relevant departments in universities have also grown significantly and there is now a critical mass of relevant research across the continent. The universities in the SKA Africa partner states (Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia and Zambia) have all initiated undergraduate courses in astronomy and the University of Mauritius is now launching an MSc programme.

The quality of the research and the calibre of the students are winning the respect of international peers.

As well as radio astronomers, cosmologists, physicists and engineers, a cadre of technical skills are being developed at South Africa's technical universities, particularly in electronics, to work on the upgrade and maintenance of the radio telescopes and their various electronic components.



Breeding ground for African expertise and global collaborations – the 5th South African SKA postgraduate conference, December 2010, Stellenbosch, South Africa attracted 164 delegates from South Africa and other African countries including Madagascar, Mauritius, Namibia, Kenya and Botswana, as well as many international radio astronomers and engineers.

Karoo workshop boosts astronomy capacity in Africa



African and global collaboration in the training of future astronomers on the continent was the focus of a three-day workshop, held during May 2011 at South Africa's proposed SKA site in the country's Northern Cape Province. Having the workshop in the Karoo gave participants the opportunity to see the KAT-7 array and other scientific experiments that have already been installed in the area.

Academics from Botswana, Ghana, Kenya, Madagascar, Mauritius, Mozambique, Namibia and Zambia were joined by their South African counterparts and participants from the UK and US. The workshop was held under the auspices of the Africa Working Group of the South African SKA project.

Participants spent three days exploring collaboration in the training and supervision of students and worked on plans to share and exchange curricula, lectureships, postdoctoral fellowships and sabbaticals.

"While we facilitated this networking opportunity, it is now up to the academics to implement the collaborations," says Kim de Boer, manager of the SKA SA Human Capacity Development Programme. "We are very encouraged by the keen interest of African academics to grow astronomy education within their respective universities, and the willingness to share expertise and course materials."

Workshop delegates were also very keen to find out more about the proposed development of an Africa VLBI network that would see an array of telescopes being deployed across Africa. Dr TL Venkatasubramani (aka "Venkat"), South Africa's project manager for this African network, helped to build excitement around the potential of this project for Africa.

In addition to sharing their expertise in astrophysics education, the two participants from Oxford University, Prof. Pedro Ferreira and Dr Khalil Chamcham, made a significant contribution because of their ability to speak Portuguese and French, respectively.

"It was very impressive to see how much is already happening in our African partner countries and we are excited that these SKA partnerships are attracting so many young people at places such as the University of Nairobi," De Boer adds. "At the University of Madagascar and at Eduardo Mondlane University in Mozambique, new undergraduate courses have taken off and as a result we now have undergraduate courses in astronomy in all but one of our partner countries."

The 30 participants stayed over at guest houses in Carnarvon, while the workshop was offered at two local hotels. Despite the bite of winter, everyone enjoyed the Carnarvon hospitality.



Francis Kofi Ampong, senior lecturer in physics at the Kwame Nkrumah University of Science and Technology in Ghana, takes a closer look at one of the PAPER antennae at South Africa's SKA site.



Making plans to let astronomy training soar in Africa: Nchimunya Mwiinga (University of Zambia); Dr Kgagamatso Moloi (University of Botswana); Prof. John Awuor (Kenya Polytechnic University College); Gary van Vuuren (Durban University of Technology); Dr Charles McGruder (US National Society of Black Physicists) and (seated) Stuart Macpherson (Durban University of Technology).



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