The University of Cape Town's Research Centre in Astrophysics, Cosmology and Gravity



## Welcome messages Vice-chancellor, University of Cape Town, Dr Max Price

Established 182 years ago at the foot of the African continent, the University of Cape Town (UCT) in South Africa has created a proud legacy at the forefront of science and technology.

UCT is part of the great hub of activity in Southern Africa in the field of astronomy and related technologies, thanks to our country's Southern African Large Telescope (SALT) and Karoo Array Telescope, or MeerKAT. The latter is a demonstrator telescope in the country's arid Karoo alongside the core site of the proposed Square Kilometre Array (SKA), a  $\in$ 1.5 billion international project to build the world's most powerful radio telescope.

Indeed, South Africa is on the brink of a golden age in astronomy and cosmology.

Supporting South Africa's bid to become a premier destination for astronomy, the Department of Science and Technology has initiated the Astronomy Geographical Advantage Programme (AGAP). AGAP aims to attract international astronomy projects by promoting the excellent viewing conditions on the sub-continent and its wealth of engineering and scientific know-how. Winning the bid for SKA would be a major coup.

How are we at UCT placed to maximise these opportunities? Our Department of Astronomy is the largest university-based astronomy group in the country and has strong ties and joint positions with the South African Astronomical Observatory (SAAO) and the SKA office.

It is also closely associated with a number of other groups in various UCT departments, such as the Cosmology and Gravity Group of the Department of Mathematics and Applied Mathematics, the astro-particle group of the Department of Physics, and the Department of Electrical Engineering.

We have forged a new Astrophysics, Cosmology and Gravity Research Centre (ACGC), which



Dr Max Price.

hosts over 30 senior researchers, postgraduate research fellows and students in the fields of astronomy and cosmology, drawn from the astronomy department and the Cosmology and Gravity Group of the mathematics and applied mathematics department.

UCT has also been awarded two South African Research Chairs (SARChI): Professors Erwin de Blok and Claude Carignan, the incoming SKA SARChI Chair in Multi-wavelength Extragalactic Astronomy. De Blok's research specialities include dark matter in disk galaxies; low surface brightness galaxies; HI surveys; the interstellar medium in nearby galaxies; and the evolution of dark galaxies. Carignan, who has been instrumental in the development of astronomy in Burkina Faso, is an expert on galaxy dynamics and dark matter. He is also involved in the development of astronomical instrumentation on next-generation telescopes.

Four ACGC key science proposals from UCT have been listed among the ten successful international bids for the 43 000 hours of observing time on the MeerKAT telescope allocated to radio astronomers around the world.

## Director, South African SKA Project, Dr Bernie Fanaroff

The objectives of the SKA South Africa Human Capital Development Programme are to strengthen and expand the community of astronomers and instrumentalists in South Africa and our African partner countries, and to contribute to producing the high-level skills and capabilities which Africa needs to be able to fulfil its potential as the next great focus of economic growth.

It is gratifying to see how the programme has assisted the partner universities in building strong and vibrant groups in astrophysics and radio astronomy-related engineering.

In a relatively short time the University of Cape Town has established a group that is recognised as world-class, and which is one of the larger and more active groups working on galaxies in the local Universe.



Dr Bernie Fanaroff.

The university collaborates with the MeerKAT team and will lead several key MeerKAT large survey programmes. The strength and enthusiasm of their staff and students for the SKA South Africa programme bodes well for the future of science in South Africa and the African continent.

### ACGC co-directors, Profs Renée Kraan-Korteweg and Peter Dunsby

With the exciting opportunities offered by the world-class facilities SALT, MeerKAT and potentially the SKA, UCT is perfectly positioned to act as a national and international resource.

The university's Astrophysics, Cosmology and Gravity Centre (ACGC) is well placed to make maximum use of the opportunities presented by these new facilities and also provides a home for the National Astrophysics and Space Science Programme (NASSP), one of the primary drivers for capacity building in astrophysics and space science in South Africa.

The centre's goal is to become one of the leading research hubs in astrophysics and cosmology, leading the way in projects involving the new facilities SALT and MeerKAT, as well as being a resource for postgraduate students (South African, African and other international students),



Prof Renée Kraan-Korteweg.



Prof Peter Dunsby.

postdoctoral research fellows and visiting international scholars alike.



Animation of the MeerKAT array (source: http://www.ska.ac.za).

# The future of radio astronomy

#### The Square Kilometre Array

The Square Kilometre Array (SKA) represents a revolutionary step forward in radio astronomy. Combining new and innovative technology with groundbreaking science, the SKA will allow us to peer backwards in time to when the first stars and black holes were formed, to probe the evolution of galaxies and dark energy, and to test our understanding of strong-field gravity using pulsars and black holes.

With an equivalent collection area of one square kilometre (resulting in unrivalled sensitivity), spread out over hundreds of thousands of kilometres (giving incredible resolving power), the SKA employs a range of cutting-edge technologies to probe the fundamental laws of physics and address key science questions about the Universe we live in.

Scientists in the SKA community have defined five key science themes:

- Galaxy evolution, cosmology and dark energy. The evolution of the Universe and the structures contained within it appears to be driven by dark energy. The SKA will shed light on the dark side of the Universe (dark matter and dark energy) through observations of the evolution of galaxies and of the interaction between galaxies and the flow of gas in the cosmic web. It will also probe the earliest stages of the formation of galaxies, and observe how gas collects in dark-matter halos and begins to form stars.
- Strong-field tests of gravity using pulsars and black holes. Through observations of pulsars,

the SKA will study the effects of gravitational waves and test the workings of the theory of gravity in extreme environments.

- The origin and evolution of cosmic magnetism. By observing polarised radio emissions from millions of distant galaxies, the SKA will detect magnetic fields throughout the Universe. This will lead to new insights into the role that cosmic magnetism plays in regulating star formation processes.
- **Probing the Dark Ages.** With the enormous sensitivity of the SKA, it will be able to detect neutral hydrogen emissions from before galaxies were fully formed. It will be able to probe the period of the Universe's history which occurred soon after the Big Bang, when the first stars formed.
- The cradle of life. The SKA will be able to detect rare and exotic molecules in star-forming (and planet-forming) regions. It will help us to understand how planets form, and will scan stars in the Milky Way for artificial signals – possible signs of life from elsewhere in the galaxy.

The SKA design is based on new and developing technologies, including a range of multifrequency detectors, new-technology radio dishes (with higher dynamic range imaging), phased aperture arrays (giving a large field of view), and focal plane arrays (achieving a large field of view using radio dishes). Combining these features with real-time processing of incredibly fast and broad data streams through the most powerful of supercomputers, the SKA will survey the skies faster and deeper than ever before. All the technology developments for the SKA are currently being pioneered and developed through SKA pathfinder and SKA precursor telescope projects.

Given the superior sensitivity of the SKA, its enormous field-of-view, simultaneous wide frequency coverage and high-time resolution, we anticipate that it will open up the exploration of the unknown. As many of the fundamental discoveries in physics and astrophysics happened unexpectedly, we should expect the unexpected.

The proposed first phase of the SKA, dubbed 'SKAI', will consist of two components: a novel dish design operating in the midfrequency range, and a sparse aperture array operating at low frequencies. SKAI will enable two of the key science themes of the SKA to be addressed fully, namely galaxy evolution, cosmology and dark energy, and strong-field tests of gravity using pulsars and black holes.

The MeerKAT array currently under construction in South Africa is one of two SKAprecursor telescopes, and a pathfinder for the newly-designed dish component of SKA1. It is no surprise, therefore, that the two highest priority, key science projects planned for MeerKAT echo the SKA1 science drivers.

In 2010, ten large survey projects on Meer-KAT were allocated thousands of hours of telescope time over the first five years of MeerKAT's operation (from 2015 to 2019). Each of these projects explores aspects of the SKA's key science themes: the evolution of galaxies, the flow of gas into and out of galaxies, and the relationship between galaxies and other large-scale structures (the cosmic web), testing strong gravity through pulsar observations, the study of complex molecules in the Universe, studying the largescale structures of galaxies and the history of star formation over cosmological time, exploring the transient radio sky in real time, discovering new pulsars and keeping an (radio) eye out for new or as yet undiscovered phenomena in the Universe.

These projects will use SKA-precursor technologies and high-powered computational tools to explore the Universe, refine the science themes for the SKA, and further develop skills leading up to the construction of the SKA.



Four of the seven KAT-7 dishes in Carnavon at the MeerKAT site (source: http://www.ska.ac.za).

# **Astronomy in Southern Africa**

#### Strength in diversity

Building on a long and distinguished history of world-class astronomical observations from Southern Africa, the arrival of world-leading facilities in optical, infrared, radio and gamma-ray astronomy in the region at the beginning of the 21st century has ushered in a new era of multi-wavelength astronomy on the African continent.

#### SALT – The Southern African Large Telescope (South Africa)

The Southern African Large Telescope (SALT) is the largest single optical telescope in the Southern Hemisphere. It consists of 91 individual one-square-metre mirror segments creating a spherical primary mirror with an aperture of 11.1m x 9.8m. It operates at optical wavelengths; an upgrade is currently under development to extend the wavelength coverage of the main spectrograph to the near-infrared part of the electromagnetic spectrum. SALT's large aperture and sensitivity make it a fantastic facility for studying the distant Universe as well as high-time domain astrophysics, providing an excellent match at complementary wavelengths for the science themes of the SKA. SALT obtained first light in 2005.

#### HESS – The High Energy Stereoscopic System (Namibia)

The High Energy Stereoscopic System (HESS) in Namibia is

an array of Cherenkov atmospheric imaging telescopes operating at gamma-ray wavelengths. This part of the electromagnetic spectrum is the realm of high-energy astrophysics. Gamma-ray sources are associated with supernova remnants, pulsars and active galaxies (accreting supermassive black holes). Gamma-ray astronomy provides a natural link to the SKA and its precursor telescopes for studies of dark matter in the Universe, and for high-energy astrophysics studies (energetic explosions). The HESS telescopes have been in operation since December 2003.

#### MeerKAT – The SKA-precursor Karoo Array Telescope (South Africa)

The South African SKA-precursor Karoo Array Telescope (MeerKAT) will be the most sensitive radio telescope in the Southern Hemisphere, operating at centimetre wavelengths. It will consist of an array of 64 Gregorian offset radio dishes, each with an effective diameter of 13.5 metres. This dish design has been selected for the first phase of the SKA in order to provide the best possible image quality. An engineering and science-commissioning array of seven 12-metre radio dishes (KAT-7) has been constructed at the MeerKAT site in South Africa and has already produced interferometric images. Science observations with KAT-7 will commence in 2011.

South African support for the construction of a radio telescope in Mozambique highlights the commitment of the South African SKA project towards scientific and technological development in the African partner countries. In addition, there are advanced plans underway to transform decommissioned communication radio dishes in Africa into fully operational radio telescopes, providing essential baselines in the world's VLBI (Very Long Baseline Interferometry) network. A 30-metre dish has been made available by Vodafone in Ghana.

There are various centres of excellence in multi-wavelength astronomy throughout South Africa, at a wide range of universities



The Southern African Large Telescope (SALT) (source: http://www.salt. ac.za).

and national facilities. Gamma-ray astronomy has a natural home at North-West University in Potchefstroom; optical and near-infrared astronomy has a long history of excellence at the South African Astronomical Observatory (SAAO), the University of the Free State, the University of Johannesburg and UCT; whereas radio astronomy has been the focus at the Hartebeesthoek Radio Astronomy Observatory, Rhodes University and the University of South Africa, and over the past five years has grown rapidly at UCT. Theoretical cosmology has deep roots at UCT, with further worldclass centres of cosmology at the University of KwaZulu-Natal, the University of the Western Cape (UWC) and Rhodes University.

In the Western Cape (the Cape Town area) there are very strong inter-institutional links in astronomy and cosmology between scientists at UCT, UWC, the SAAO, the MeerKAT science operation centre and the African Institute for Mathematical Sciences (AIMS), creating a vibrant community of staff and students involved in multi-wavelength astronomy.

Through dedicated support at all levels (from sources including the Department of Science and Technology of South Africa, the National Research Foundation, the national facilities in astronomy and the universities) the community of astronomers, astrophysicists and cosmologists in South Africa has matched the exciting and explosive growth in astronomy, ensuring that Africa is ready to host the SKA and to embark on a journey of scientific discovery with it.



Astronomy and engineering undergraduate and postgraduate students at UCT. (From left, back) Tafadzwa Mukwashi, Sally Macfarlane, Teboho Makhabane and Riona Ramraj, (Front) Priscilla Chauke and Bradley Frank.

## Capacity development in astronomy

#### A home in Africa

For the better part of the past decade, two very successful initiatives have focused on African capacity development in astronomy: the National Astrophysics and Space Science Programme (NASSP) and the South African SKA project's Youth into Science and Engineering Programme. Both initiatives have attracted bright young Africans to astronomy and space science in general, and to radio astronomy in particular.

To date, over 200 students have achieved postgraduate degrees in astronomy and space science through NASSP (126 BSc Hons and 76 MSc degrees). Of these graduates, 42 have continued with PhDs in (radio) astronomy and space science, often supported by competitive bursaries offered by the South African SKA capacity development programme. The success of this dedicated effort is evident from the marked increase in the number of (South) Africans in postdoctoral and faculty positions in astronomy in South Africa, across the African continent and around the world.

NASSP began in 2003, in recognition of the need to train (South) African postgraduate students in astronomy and space science given the new opportunities for astronomy in Southern Africa. NASSP is a unique postgraduate programme in South Africa. Top academics from ten South African universities and three research facilities have formed an inter-academic consortium and have taken full responsibility for the expert teaching and supervision of future generations of astronomers, astrophysicists, space scientists and cosmologists in Southern Africa.

UCT is the academic host of NASSP, and provides facilities for students and guest lecturers during the BSc honours year and the first six months of the MSc degree (the coursework component). For the dissertation component of their MSc degree, NASSP students take up research positions under the supervision of academics at one of the 13 partner institutes.

The South African SKA project places a strong focus on capacity development through strategic support in terms of undergraduate and postgraduate bursaries in astrophysics and engineering, as well as supporting competitive postdoctoral fellowships and funding top-level university positions. In 2005, the SA SKA project initiated the Youth into Science and Engineering Programme to develop highly skilled young scientists and engineers.

At present, the South African SKA project has issued 292 grants and scholarships, which have supported 100 undergraduate and honours students, 117 postgraduate students (from South Africa and African SKA partner countries) and 22 postdoctoral researcher fellows. UCT has received around 25% of these bursaries across science and engineering (17 undergraduate bursaries, 68 postgraduate bursaries and seven postdoctoral research fellows). This highlights and emphasises the strong involvement of UCT in the SKA project, through high-quality teaching and supervision in both astronomy and engineering.

In addition to the dedicated postgraduate initiatives of the Department of Astronomy at UCT, since 2006 the department has also offered an undergraduate major in astrophysics. The number of students attending UCT to study astrophysics at undergraduate level has risen sharply since the introduction of the astrophysics major, and currently stands at 50 for the 2011



UCT electrical engineering students (from left) Jason Manley, Wesley New, Adam Barta and Shanly Rajan.

academic year. The students in this stream are fully representative of the diverse demographics of South Africa; typically, 75% of the astrophysics undergraduate students are black South Africans and around one-third is female.

In the astronomy department alone, at least four MSc students and two PhD students (on average) graduate each year, and compete successfully for international PhD and/or postdoctoral positions. Previous NASSP research students who have graduated at UCT currently hold postdoctoral fellowships in the US (Caltech and Yale) and Australia (the University of Western Australia). Starting in 2011, UCT is making funds available for a PhD scholarship in SKA-related science, in addition to a postdoctoral mobility grant.

The Department of Electrical Engineering at UCT has supervised and continues to supervise many of the younger members of the KAT engineering team in completing their postgraduate degrees. Importantly, from 2012 the department will also be able to fund MSc and PhD students, as well as postdoctoral research fellows. Their programme has trained a number of graduate students, two of whom are currently completing PhDs at Stanford and UC Berkeley in the US.

So, after nearly a decade of dedicated capacity building in astronomy in South Africa, UCT offers a vibrant undergraduate and postgraduate curriculum in (radio) astronomy and engineering, making an essential contribution to the education and mentoring of the next generation of African scientists, and to the development of astronomy on the African continent.



(From left) UCT's Dr Benne Holwerda, Prof Erwin de Blok, Dr Sarah Blyth, AlProf Patrick Woudt and Dr Kurt van der Heyden. Their MeerKAT Large Survey Projects are among ten successful bids for the 43 000 hours of observing time allocated to radio astronomers from around the world on South Africa's SKA-precursor telescope, MeerKAT.

# **Radio astronomy in South Africa**

#### Science and engineering at UCT

Astronomy and cosmology have a long and well-established history of research excellence at UCT. From this position of strength, both the Department of Astronomy and the Cosmology and Gravity Group in the Mathematics and Applied Mathematics Department have grown enormously since 2005. In anticipation of the exciting changes in the African astronomical landscape, they joined forces in 2009 to form the Astrophysics, Cosmology and Gravity Research Centre (ACGC), a research centre accredited by UCT.

Through a wide range of initiatives and with strategic support from UCT, the ACGC has built up a critical mass of observational astronomers, astrophysicists and theoretical cosmologists. At present the centre consists of 15 permanent academic staff, three emeritus professors (all internationally recognised world leaders in their respective fields), 17 postdoctoral research fellows and approximately 40 postgraduate research students (MSc and PhD).

The South African Research Chair Initiative (SARChI), established in 2006 by the South African Department of Science and Technology) specifically aims to enhance scientific research leadership and capacity in areas of research that are of strategic importance to South Africa; the SARChI Chair positions come with funding for student bursaries, research equipment, mobility grants and postdoctoral fellowships. Of the seven SARChI professors in the Faculty of Science at UCT, two are hosted by the ACGC: Prof Erwin de Blok, the SARChI professor in Astrophysics and Space Science since 2007; and Claude Carignan, the SARChI professor in Multiwavelength Extragalactic Astronomy since 2011. Both are experts in the study of neutral hydrogen in nearby galaxies, one of the key science themes for the SKA-precursor telescope, MeerKAT, and for SKA1.

The ACGC has strong links with the national facilities in astronomy; besides joint student supervision, there are two joint staff positions in collaboration with the South African Astronomical Observatory, and one South African SKA-funded lecturer.

Following the 2010 international call for Large Survey Proposals on the SKA-precursor telescope, MeerKAT, 21 proposals were received by the MeerKAT project, of which 10 were accepted after international peer review. Four of these 10 MeerKAT Large Survey Projects are led or co-led by researchers at the ACGC.

These are:

- LADUMA: Looking at the Distant Universe with the MeerKAT Array. Pls: Sarah Blyth (ACGC, UCT), Benne Holwerda (ESA), Andrew Baker (Rutgers University)
- MHONGOOSE: MeerKAT HI Observations of Nearby Galactic Objects: Observing Southern Emitters. PI: Erwin de Blok (ACGC, UCT)
- MIGHTEE: MeerKAT International Giga-Hertz Tiered Extragalactic Exploration. Pls: Kurt van der Heyden (ACGC, UCT), Matt Jarvis (UWC and University of Hertfordshire)
- **ThunderKAT:** The Hunt for Dynamic and Explosive Radio Transients with MeerKAT. Pls: **Patrick Woudt** (ACGC, UCT), **Rob Fender** (University of Southampton and ACGC, UCT)

Each of these Large Survey Projects covers key science themes in radio astronomy for the 21st century, ranging from the study of the distribution and evolution of neutral hydrogen gas in and around galaxies, to understanding the evolution of star-forming galaxies and galaxy clusters over cosmological time-scales, to the characterisation of the transient radio sky in real time.

Besides leading a number of the key science projects on MeerKAT, UCT has also played a leading role in the engineering developments for MeerKAT. The Department of Electrical Engineering at UCT recently received a grant from the MeerKAT project to develop next-generation signal-processing hardware. With funding mostly from UCT and the South African National Defence Force, a training platform was developed for the Software-Defined Radio Research Group, known as Rhino (www. rhinoplatform.org).



The Rhino board.

With the new MeerKAT funding, the electrical engineering department is extending the production of the Rhino board and training material and using this board as a training platform. They are also assembling a hybrid computer suitable for many signal-processing tasks. This machine consists of conventional multicore technology, FPGA interconnection and processing, and GPUs. They also fund visits by UCT personnel to collaborate with colleagues in Hong Kong and Stanford relating to the development of software tools for hybrid computing.

Through a dynamic scientific community involved in SKA-precursor science and engineering, SKAsupported postdoctoral research fellows, SKA visiting professors, and postgraduate research students involved in SKA science, UCT takes pride in creating a community of South African and African radio astronomers and engineers who are able to take a leading role in the exploration of the Universe through the Square Kilometre Array.

Key events in the ACGC/Department of Astronomy timeline:			
2006	_	Introduction of the undergraduate programme	
2007	_	First SARChI position	
2009	-	Accreditation of the Astrophysics, Cosmology and Gravity Research Centre	
2010	_	Four MeerKAT Large Survey Projects approved	
2011	_	Second SARChI position	
2011	-	Three SA SKA and three SARChI postdocs at ACGC	
Key events in the MeerKAT timeline:			
2006	_	Shortlisting of South Africa and Australia as	
		potential SKA sites	
2006-7	_	Design phase of KAT-7	
2008-10	_	Construction of KAT-7	
2010	_	Call for MeerKAT large survey projects	
		[10 projects allocated time]	
2011	_	Early science with KAT-7	
2012-13	_	Development of MeerKAT dish/commissioning	
2013-14	-	Construction of the MeerKAT array, commissioning, early science	
2015-19	-	Full science operations with MeerKAT	
Key events in the SKA1 timeline:			
2010-12	_	SKAI telescope design phase	
2012	_	Site decision for the SKA	

2012	<ul> <li>Site decision for the SKA</li> </ul>
2013-15	<ul> <li>SKA1 engineering and pre-construction</li> </ul>
2016-19	- Construction, commissioning and early science
2020	<ul> <li>Full SKA1 science operations</li> </ul>

For more information about astronomy and cosmology at the University of Cape Town please visit www.acgc.uct.ac.za