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SQUARE KILOMETRE ARRAY (SKA) SOUTH AFRICA

Update SKA SA & KAT

SKA South Africa

Evolution of the KAT Science Case

Prof Justin Jonas, SKA & KAT scientist.

While the engineers have been hard at work keeping to tight deadlines for sub-systems development, the KAT science case has been constantly evolving to take into account what the local astronomy community and the leading international astronomers have to say.

The system engineering process being followed by the project team has provided an interface between the science input and user requirement specification, with often inspirational moments of clarity coming from both sides due to the uniqueness of the system engineering process in astronomy.

As the KAT is an SKA demonstrator, and pre-dominantly a survey instrument, the KAT science case is aligned to that of the SKA, with an emphasis on long-term programs such as large scale HI and continuum surveys. However, with a multiplexed processing environment and remote operability, KAT will be able to cover a broad base of scientific objectives simultaneously, including fast and slow transients, pulsars and magnetism.

The development of the science case gathered momentum in September 2005 with the hosting of a two-day workshop within the confines of the white lion enclosure at the Johannesburg Zoo (lunch was an interesting experience, with delegates seated outside looking over the lions). International guests Lister Staveley-Smith (ATNF), Simon Johnston (xNTD) and Robert Braun (Westerbork) delivered wide ranging talks on the potential science impact of SKA demonstrators around the world, including KAT, xNTD and APERTIF.

As a follow-up to this meeting, a second workshop took place at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in May of this year. The two major areas that the construction of KAT will introduce into the astronomy community of South

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Building skills and networks for future astronomy

The South African Square Kilometre Array (SKA) project has a student bursary programme, the SKA/KAT Human Capital Development Programme, initiated to develop high-level skills and human capacity for the SKA, Karoo Array Telescope (KAT) and other multi - wavelength astronomy projects.

"We want to create a connected, interactive and engaged community of astronomers, engineers, academic supervisors and research students around the SKA and KAT", says Kim de Boer of the SKA office, who manages the bursary programme. "We need to build networks of astronomy and engineering students with the high-level skills that these projects will demand," she adds.

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Special points of interest:

- 14 - 25 August 2006 — XXVIth General Assembly of the International Astronomical Union (IAU)
- 21 August 2006 — Long Wavelength Astrophysics Joint Discussion 12 at the IAU General Assembly
- 28 - 30 August 2006 — ISSC

Evolution of the KAT Science Case

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Africa is the uses of an interferometric array, and low frequency astronomy (the lower frequency limit of HartRAO is 1665 MHz). With limited experience in these two areas, a strong drive is being made to involve international collaborations in the user requirement specifications. The Oxford science meeting in April, and follow-up discussions with collaborators at Oxford, Manchester and Cambridge, has served to solidify the science input into the systems engineering process. This input is based on the following long-term programs for KAT:

HI in the Universe
An all-sky survey HI survey with KAT has the potential to detect tens of thousands of low and intermediate redshift (0.01 < z < 1) galaxies in emission. This mapping allows the tracking of the large scale matter distribution as a function of time, along with precise measurements of fundamental cosmological parameters. Mooted experiments include the following:

- Wide field HI survey - Consisting of a 2000 square degree survey, in collaboration with a good optical survey, to study the interstellar medium in the local universe, and obtain the HI content. Taking approximately 200 days, the survey would detect a large number of objects, allowing for a statistical study to provide the total HI content as a function of galaxy type and environment.

Continuum and Magnetism
Faraday rotation is an important astronomical tool for the measurement of the interstellar magnetic field, which contributes significantly to the total pressure of the interstellar medium. An all-sky rotation measurement survey would provide a sufficiently sampled grid that can be used to study the generation and amplification of galactic fields, their coupling to the interstellar medium, the distribution of intra-cluster magnetic fields, the search for correlations between magnetic field and cluster properties and the generation of magnetic fields in cluster environments. Mooted experiments include the following:

- A polarised galactic foreground survey of 4 x 30 deg squared patches, providing support for CMB polarisation experiments such as CLOVER.

- A few hundred square degree survey in the galactic plane, which could piggy-back on an HI survey, to measure faraday rotation. In combination with a continuum polarisation measurement, this will allow a probe of magneto-hydro dynamic turbulence. Using HI as a tracer of velocity fields, tests of the origin of magnetic fields can be made.

Transients
Transients occur in a variety of different flavours, including gamma ray bursts, x-ray binaries, compact sources, transient pulsars, rotating radio transients (RRaTs), and of course the serendipitous. Although not exhaustive, this list necessitates the need for adaptable instrumentation to cover both short and long time scale events over a wide field of view. Current instrumentation plans allow for continuous real-time monitoring of short timescale (<2 secs) transient events, as well as a regular monitoring of long term variability.

Pulsars
Studies of pulsar phenomenology provide keys to the emission mechanisms, while the pulsar signal can be used to probe the structure of the interstellar medium, leading to insights into galactic electron density models, interstellar turbulence and scattering.

Although the computational demands of an all-sky pulsar survey could prove to be excessive, the transient detection system will be suitable to the job of discovering exotic objects, such as transient pulsars and giant pulses. A regular all-sky pulsar monitoring program will provide regular high precision timings, essential for detecting large scale correlations across a pulsar timing array.

JIVE Next Generation Correlator Workshop

Engineers from all over the world recently gathered in Groningen, Netherlands from 27 - 29 June 2006, to discuss the Next Generation Correlators for Radio Astronomy. They met at the Joint Institute for Very Long Baseline Interferometry in Europe, also known as JIVE.

Delegates included representatives from all major telescopes and associated research organisations, providing a great pool of expertise to thrash out next generation correlator technologies, as well as to review current designs.

According to Peter Dewdney from the National Research Council Canada (NRCC), the KAT is regarded as a small correlator. He adds, however, that "small correlators are much larger than they used to be".

Field Programmable Gate Arrays (FPGA) are the preferred technology for such systems, and the approach of general purpose FPGA boards linked together by high speed commodity switches is the suggested architecture for such small correlators. This is the approach led by the CASPER group at Berkeley and the approach fundamental to the KAT correlator.

A summary of the workshop is available for download at www.ska.ac.za/newsletter

KAT fact finding mission to the US

Dr Jasper Horrell of South Africa's KAT project standing in front of the north arm of the VLA.

During June of this year, two members of the KAT Computing Team (Jasper Horrell and Rudolph van der Merwe) visited the USA on a technical fact-finding trip.

Their visit kicked off at the 10th Summer Synthesis Imaging Workshop (SSIW) held at the University of New Mexico in Albuquerque, New Mexico. This workshop is a biennial event organised by the National Radio Astronomy Observatory (NRAO) in the USA, consisting of a week of lectures on aperture synthesis theory and related advanced signal processing techniques and algorithms. These mathematical techniques are used to turn the raw noisy data coming from a radio telescope array, such as the KAT, into high resolution, high-fidelity images of the radio sky. These in turn are used by astronomers to try and answer a multitude of questions on the nature, structure and evolution of stars, galaxies and the universe.

The workshop also included a day-long "hands on" tutorial on data collection, calibration, reduction and imaging, which was held at the NRAO's Array Operations Center in Soccoro, New Mexico.

A visit to the Very Large Array (VLA) followed. Situated on the plains of San Augustin, 80 km west of Socorro, the VLA is one of the world's premier radio astronomy observatories.

"Seeing the scale of operations at the VLA, and how things are done there, provided an invaluable perspective on the logistical challenges posed by the commissioning and operation of such a large scientific facility", said Rudolph van der Merwe, the calibration and imaging lead on the KAT Computing Team. "I think the design, construction and commissioning of KAT will benefit by leveraging the lessons that have been learned over the last couple of decades by successful facilities such as the VLA".

The last few days of the US visit were spent in California with the team from the Allen Telescope Array (ATA). The ATA is another world-class radio telescope being built at Hat Creek Observatory, northern California, by the Search for Extra-terrestrial Intelligence (SETI) Institute and the University of California, Berkeley. Upon completion, the ATA will consist of an array of 350 six meter dishes. The ATA will be used primarily for SETI observations, but with the ability to conduct a broader horizon of astronomical research.

The team met with Dr. Dave De Boer*, the ATA project leader and chief engineer, in Berkeley for technical discussions as well as a tour of some of the design and production facilities. A trip to the site allowed the team to see the array in action and meet the technical staff.

The visit provided many useful and highly relevant contacts. It was reassuring to confirm that current engineering choices being made for KAT are in line with future plans for other facilities, and that the KAT project is on track to leapfrog many of the current radio telescope technology implementations.

* *Dr. DeBoer is also on the technical review panel for the KAT prototype antennas.*

Convergent Radio Astronomy Demonstrator launched

July 2006 saw the launch of the South African - Australian radio astronomy computing collaboration. Known as CONRAD (Convergent Radio Astronomy Demonstrator), this collaboration aims at producing common parts of the KAT and xNTD computing systems.

"Although we have been holding regular discussions for many months with Tim Cornwell of the ATNF regarding KAT/XNTD computing requirements, the launch of CONRAD marks the start of a more focused joint effort to produce operational software for the new telescopes," said Jasper Horrell, the KAT Computing Subsystems manager.

CONRAD-compatible telescopes should be able to make use of the codebase to be developed over the next few years through this collaboration. KAT and xNTD will be the first CONRAD-compatible telescopes.

Concrete steps towards setting up CONRAD were made during a visit to the KAT Pinelands offices by Tim Cornwell, leader of the XNTD computing team in Australia, earlier this year. Tim was impressed by the progress made by the KAT Computing Team and, in particular, the work performed on the KAT "operating system" (monitor, control, etc) architecture. Discussions ensued with the proposal that South Africa and Australia not duplicate computing efforts, but rather make use of each other's strengths in joint development. The South African team has strengths in commercial software development, while the Australian team has specific experience in the design and operation of radio telescopes and in the back-end astronomical processing.

Tim Cornwell commented: "The collaboration aims to fuse the considerable talents and experience of both teams into one. This is important not only for KAT and xNTD, but also for future telescopes such as the Square Kilometre Array."

Building skills and networks for future astronomy

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According to Ms de Boer, a bursary from the SKA/KAT project will provide students with a unique opportunity to become part of a 'real-life' team that is developing a world-class astronomy instrument. They will benefit from vacation training at the KAT offices in Cape Town and regular seminars with KAT scientists and engineers.

The programme already has 24 students at Masters and PhD level and two post-docs. By 2009, Ms de Boer hopes to support 76 students and post-docs.

We need to build networks of astronomy and engineering students with the high-level skills that these projects will demand

"During August and September 2006 we will visit campuses around the country to present the bursary programme to students and supervisors" says Ms de Boer. "We have a list of research topics for students to choose from and we need more supervisors on board to support the increasing number of interested students."

"A bursary from this programme does not mean that a student will only be qualified to work on the SKA or KAT. We are looking to develop a broad range of cutting edge skills in astronomy and related engineering that will be relevant to a broad range of employers in industry".

A large component of the KAT development is research in the fields of high performance computing, challenging software development, large computer cluster systems, digital signal processing and radio frequency engineering.

The programme provides an opportunity for students and supervisors to acquire experience and skills in these scarce fields. During the campus visits, academic departments in astronomy and computer sciences will be targeted, as well as electrical and mechanical engineering.

University academics in relevant fields are welcome to contact Ms de Boer on kdeboer@ska.ac.za or call her on (011) 442-2434 to arrange a visit.

From mid-September 2006, students should look out for the list of research topics and the application forms on the SKA web site (www.ska.ac.za) and make sure to get their applications in by 31 October 2006.

The SKA/KAT Human Capital Development Programme fits within the overall strategy of the Department of Science and Technology to develop astronomy across all wavelengths in South Africa.

Kim de Boer is passionate about developing skills via the SKA/KAT Human Capital Development Programme.

SKA/ KAT Student Conference

Networking between current SKA/KAT bursars, their supervisors and South Africa's astronomy community will be the focus of the SKA/KAT Student Conference: Growing Southern African Multi - Wavelength Astronomy, to be held from 28 November to 1 December 2006 at the South African Astronomical Observatory in Cape Town.

At this conference, students will get an opportunity to present their work and listen to international and local scientists. This will be supplemented by high-level training seminars and ample time for interaction between research students and study leaders with SKA and KAT astronomers and engineers.

Join and participate!

- **KAT Science and Engineering wiki**

  Participate in discussions and collaboration with the KAT team and other developers and end users of the KAT by joining the "KAT Science and Engineering wiki" at www.kat.ac.za.

- **SKAnet**

  SKAnet is an email list which keeps subscribers updated on news and latest developments about the Square Kilometre Array South Africa project. Join the list at www.ska.ac.za.

Survivor astronomy style

If South Africa wants to host the world's biggest radio telescope, the Square Kilometre Array (SKA), we have to prove that a remote part of our country is "radio quiet" enough to allow this cutting-edge mega telescope to be built here.

In the same way that light pollution from big cities impairs optical astronomy, human settlements and communication networks produce radio waves that interfere with radio astronomy. The radio signals from outer space that astronomers measure can be a million times fainter than a cell phone signal. Therefore finding the best place to build a new radio telescope means getting far, far away from where people are.

Based on measurements over the last three years, South African scientists identified potential sites for hosting the SKA in the Northern Cape.

There is probably no site on earth 100% free from radio interference. The challenge is to find the best possible site with minimal radio interference and where it is also possible to mitigate the existing interference through measures such as providing local communities with alternative television and phone services, thereby getting rid of some of the sources of radio interference. The proposed SKA sites are also shielded against radio interference from the Cape metropolitan areas by a mountain range towards the south.

Engineers at the Hartebeesthoek Radio Astronomy Observatory (HartRAO) designed a unique RFI measuring system that could run unattended at the sites and do measurements across a wide range of radio frequencies. Components such as receiving antennas, low noise amplifiers and spectrum analyzers, as well as control and data storage systems, were all built into three robust trailers that could be parked on rugged terrain. Each unit had to be air-conditioned to protect the equipment against sub-zero winter temperatures and temperatures that soar to more than 40 degrees Celsius in summer. One of these trailers was dedicated to measurements at the core of the proposed site, while two mobile units moved between remote areas where outlying stations of the SKA could be located in other parts of South Africa, as well as Botswana, Namibia and Mozambique. The Independent Communications Authority of South Africa (ICASA) provided key people and expertise to make the RFI project possible.

The team spent months at a time in some of South Africa's harshest environments, where hours can go by without a single car passing on the narrow gravel roads. They had to cope with bad roads, and often no roads, to get to the designated coordinates.

"This was as tough as any Survivor series," says Gerhard Petrick, who worked for the SKA South Africa project at the time and spent months in the field for the on the RFI project.

The team was working around the clock to complete the RFI survey in time for a deadline set by the international SKA project. So, when the core site's RFI unit broke down, HartRAO immediately dispatched a rescue mission. They hoisted the cabin up into a tree just outside Carnavon, and fixed it on the spot.

The team enjoyed the cooperation of local farmers on whose land the measurements were done and especially the hospitality of the Louw family, who provided accommodation, meals and logistical support.

The radio frequency interference measurements at the proposed SKA site took place in some of the remotest parts of South Africa.

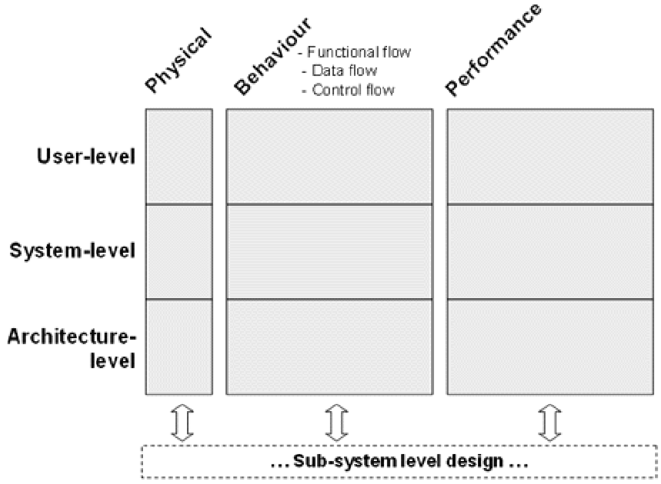
A mobile RFI measurement hoisted up in a tree in Carnavon for on-the-spot repairs.

South Africa is one of four countries shortlisted to host the SKA. A final decision on the host site is only expected in 2008. The RFI project has also helped to select an ideal location for the Karoo Array Telescope (KAT). The Department of Science and Technology (DST) supports both the SKA South Africa bid and the building of the KAT.

KAT Systems Engineering Update

On a project such as the Karoo Array Telescope, "systems engineering" must ensure that the technologies of all the sub-systems, such as the antenna, digital hardware and software, are integrated. Another responsibility is to look at the whole life cycle of the system (from conception to the end of its useful lifetime) and to consider key factors which influence the design of the system and subsystems.

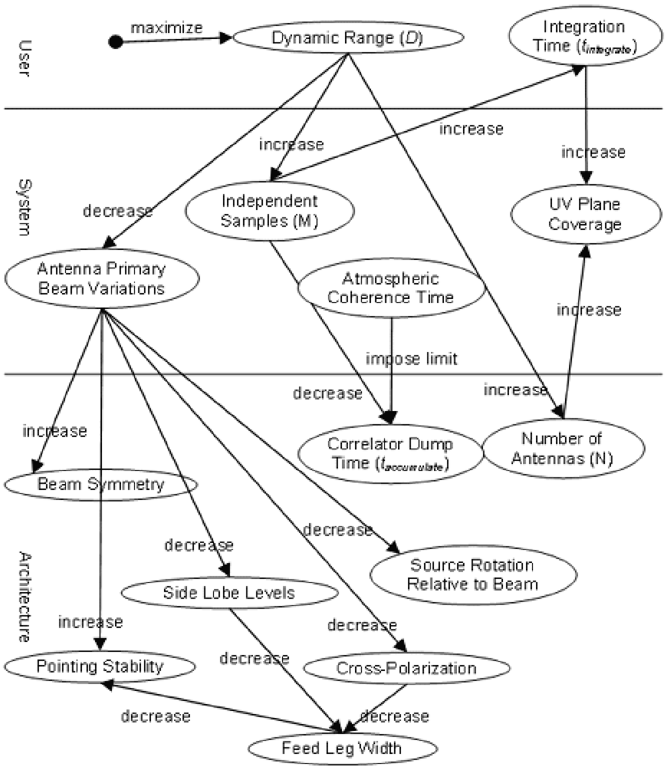
While the KAT is now being designed, there are many ongoing system engineering design activities, as shown in the following diagram:



The systems engineering team must consider the physical, functional and performance aspects of the system and must trace each of these aspects from the user-level (in this case astronomer level design) through to the architecture design that will form the basis for sub-system specifications.

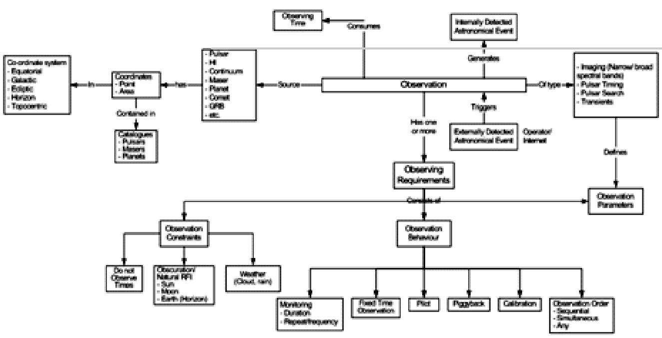
At the user-level, the systems engineering team is compiling models and design information on the astronomer's requirements for using the KAT. A first draft is currently under review. The diagram below shows some of the concepts being developed and the emerging structure for capturing the astronomer's requirements.

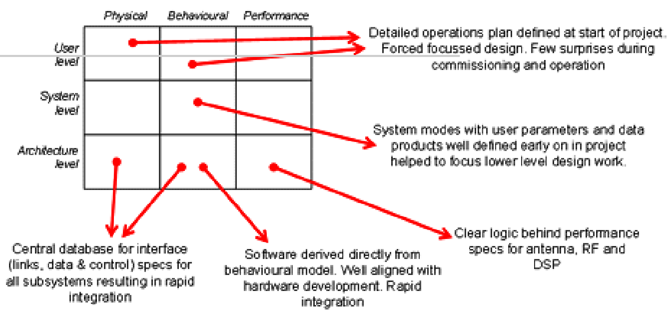
these performance measures are traced through the system design levels is shown in the following figure:



Current systems engineering activities on Prototypes

On the development of prototypes the systems engineering team has to play an integrative role on prototype design and testing. The "3x4 FPA" prototype project is currently in its final stages. This was a valuable test case to see how the systems engineering design work would integrate with subsystem design activities and how it adds value. Some of the highlights are shown in the figure below, indicating which aspects of the system design provided key value points.





At the system-level design the first concepts are emerging. This includes a high level description of proposal management; signal conditioning; signal processing required for all the observing modes; data management, instrument control; instrument monitoring and maintenance concepts.

In the performance management domain, good progress is being made on tracing the astronomer-level performance requirements down to subsystem performance specifications. An example of how

The next challenge for the systems engineering team is the Experimental Development Model (XDM) which will be a single-antenna system with full digital back-end receiver to test high-risk aspects of the KAT design. The scope of the project has been defined, based on a risk-driven strategy. Currently the XDM operations plan is being formulated which would be the major input for subsequent system design work.

Please note: Larger versions of the figures used in this article are available for viewing at www.ska.ac.za/newsletter.