

Position Paper on
A Decadal Strategy for
Human Capacity Development
in
Astronomy and Astrophysics in South Africa



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1. Executive Summary

1.1 Background

Astronomy in Southern Africa is on the threshold of one of the most exciting stages in its development: the first stages of the installation of the SKA pathfinder infrastructure has begun, SALT is due to be (fully) operational early in 2011, and exciting infrastructure investments are being planned by the international high energy gamma ray astronomy community. This is an appropriate time to review the state of astronomy in South Africa and to chart a way forward for a comprehensive human capacity development approach for astronomy.

The position expressed in this paper was arrived at after reviewing relevant documents generated over the last 5-10 years and the findings of various review panels during this period, as well as taking into account the views of a number of national (and two international) stakeholders whose opinions were canvassed on the state of astronomy in South Africa and on the development of skilled human resources in astronomy.

Two significant recent documents were the International Panel Review of the Astro-Geo-Science Facilities, 1999-2004¹, and the report that resulted from a series of meetings coordinated in 2005 by NRF with representatives from university groups (UCT, UKZN, UFS, UNISA and others), the National Facilities (SAAO, HartRAO), SKA SA and the Department of Science and Technology (The Astronomy Frontiers Programme (AFP)). The former recommended that radio-astronomy capabilities remain coordinated, integrated and working towards national priorities, with in particular HartRAO staff and resources being integrated fully into SKA activities and SKA project office, and the non-operational scientific, technical and administrative components of HartRAO being co-located at a common central site.

The AFP advocates a thematic approach to research, cross-cutting collaborations in science and technology, and a systematic capacity-driven programme that stimulates the growth of human capital to match the available physical infrastructure, with particular attention paid to expansion of black and female South African participation.

The key issues that need to be addressed in a decadal strategy for astronomy include

¹ A new review, covering the term 2005 to 2009, was performed since the first version of this document was drafted; it contains pertinent recent data and discussion.

1. Establishing a viable South African astronomy research and technology community critical to which are
 - i) Developing critical mass groups in universities and in regions
 - ii) Attracting new students to the field and retaining postgraduate students up to and beyond the PhD level
 - iii) Increasing significantly the representation of black South Africans in astronomy and astrophysics
 - iv) Increasing research supervisory capacity at universities and national facilities
 - v) Strengthening the university-national facility partnership in astronomy research, research planning and high-level skills development
2. Astronomy research to be prioritized around key science areas that will make optimal use of the new multi-wavelength facilities in South Africa
3. Establishing well-resourced technical support groups
4. Providing high performance internet connectivity
5. Establishing a new governance structure for astronomy in the SALT/MeerKAT Era

1.2 Recommendations

A summary of the recommendations for the development of South African human capacity in astronomy and astrophysics are presented here. More details of these recommendations can be found in Section 6.

1. Coherent governance structure:

The central requirement for the development and growth of astronomy in South Africa is a coherent governance structure for astronomy, which manages South African astronomical facilities in a coherent and holistic way, with astronomers playing a key part in this structure. More details can be found on page 34.

2. Substantially increase institutional capacity in astronomy:

The success of any human capacity development programme for South African astronomy is strongly dependent on the development of critical-mass capacity at several institutions across the country that are involved in astronomy research, teaching and outreach. More details can be found on page 35.

3. Develop human capacity in astronomy by substantially increasing the number of black astronomy students and astronomers:

Central to the long-term success of any human capacity development programme for South African astronomy is the training of many more black astronomy students. It is also vital to provide continuing support for these young astronomers through the various stages of their

career development so that they can ultimately take up posts as professional astronomers. More details can be found on page 37.

4. Supporting well-resourced astronomy technology groups:

There is a need to ensure that there are well-resourced technical groups in South Africa that are working on cutting-edge astronomical instrumentation, so that the South African astronomy community, in particular young and upcoming astronomers, remains internationally competitive by producing new and world-class science with these instruments. More details can be found on page 38.

5. Coordinated and well-resourced astronomy education, outreach and science awareness programme:

A well-coordinated and well-resourced astronomy education and outreach programme will play an invaluable role in creating awareness of astronomy among the public, in particular high-school learners, who could be attracted into studying astronomy at university and pursuing a career in astronomy. More details can be found on page 39.

6. A continuing decadal strategy for astronomy: prioritization of research themes:

A key strategy for the growth of human capacity in astronomy is to identify and focus on a prioritized set of research themes, taking into account the astronomical facilities available in South Africa, so that South African researchers can play a leading international role in these areas of research and thereby increase their international reputation. This in turn will inspire young and upcoming South African astronomers, and give them the necessary training and skills to succeed in a competitive international research arena. More details can be found on page 40.

7. Establishing collaborative structures:

Since the South African astronomy community is relatively small at present, significant benefit in developing human capacity can be gained by combining skills and resources through collaborative programmes between different South African institutions, and with institutions in Africa and further abroad. More details can be found on page 41.

8. Adequate resources to support astronomy research and teaching:

A basic platform of resources to support astronomy research and teaching is required to develop capacity in this area. More details can be found on page 42.

9. National centre for astronomy and astrophysics:

A national centre for astronomy and astrophysics is required to provide an environment in which people engaged in astronomy (including astronomers, educators, instrument scientists and engineers, and students) can interact and think about science with the

minimum administrative or formal teaching responsibilities. More details can be found on page 43.

2. Background and Mandate

The Department of Science and Technology (DST) has suggested that the various capacity development programmes in astronomy should be incorporated within an overarching strategy in AGAP – the Astronomy Geographic Advantage Programme. During its recent negotiations with the DST for funding for these programmes, the NRF agreed to coordinate a review on the state of astronomy in South Africa and to develop a national strategy, based on the findings of the review, to chart a way forward for a comprehensive human capacity development approach for astronomy.

In this context this position paper was commissioned by the National Research Foundation “to address:

- A strategic plan for astronomy
- Human capital requirements

covering the three existing funding areas

- National Astronomy and Space Science Programme (NASSP)
- Multi-wavelength Astronomy
- Radio-astronomy.”

The position paper was to be based on relevant documents generated over the last 10 years and the findings of various reviews during this period, such as the SETI Review of the National Facilities completed in 1998 and the NRF review of the SA Astro-Geosciences Facilities.

3. Issues identified in Reviews

Several issues pertinent to the current review were identified in the Institutional Review of the NRF and its National Facilities in 2004, and in the subsequent workshop of key role players in astronomy that was convened by the NRF in 2005, and which resulted in the development of the Astronomy Frontiers Programme. These issues are presented below.

3.1 Institutional Review of the NRF and its National Facilities 1999-2004²

The Institutional Review of the National Facilities made findings on a) cross cutting issues that were applicable to all the NFs, and b) issues relevant to NFs in a cluster.

The cross-cutting issues that were identified included the need

- i) to increase human resources within the National Facilities (NFs), and to accelerate transformation and diversity in the workforce
- ii) to replace/upgrade ageing equipment or acquire additional equipment for the NFs
- iii) for the NFs to play a major role in informing national policies in the area of their expertise
- iv) to continue to strengthen their role in developing human resources for the country
- v) to continue to strengthen and improve their outreach programmes
- vi) to pursue/strengthen, in varying degrees, their presence/visibility in the international arena through increasing publications in international peer review scientific journals, and
- vii) to strengthen national, regional and international collaborations

The major issue identified in the Astro-Geo Facilities Review was the re-positioning of HartRAO to participate in SKA pathfinder development (KAT & MeerKAT). The Review Panel recommended that

- i) HartRAO staff and resources be integrated fully into SKA activities, particularly the KAT/MeerKAT operations
- ii) Radio-astronomy capabilities remain coordinated, integrated and working towards national priorities, and
- iii) SKA Research and Technology Collaboration Centre (RTCC), SKA project office and the non-operational scientific, technical and administrative components of HartRAO be co-located at a common, central location
- iv) the NRF find ways of enhancing capacity-building in the HEIs – to take full advantage of SALT and the SKA pathfinder

3.2 The Astronomy Frontiers Programme

The Astronomy Frontiers Programme (AFP) was the result of a series of meetings coordinated in 2005 by the NRF of representatives from the Universities, SAAO, HartRAO, SA SKA and the DST. The AFP identified the main factors that would impact on the success of SALT and the SKA pathfinders as

- i) the quality of the scientific output

² A new review, covering the term 2005 to 2009, was performed since the first version of this document was drafted; it contains pertinent recent data and discussion.

- ii) the ability of technical staff to maintain the telescopes in optimal condition
- iii) the extent to which the telescopes can be upgraded with new technology and be kept competitive with other large telescopes
- iv) the training of scientists to PhD level and beyond to the best international standards
- v) linking SALT, HESS and KAT (and MeerKAT) with the rest of Africa
- vi) using SALT, HESS and KAT (and MeerKAT) as icons to generate public interest and attracting the young into scientific careers

The AFP advocates

- a thematic approach to research
- cross-cutting collaborations in science and technology
- a systematic capacity-driven programme that stimulates the growth of human capital to match the available physical infrastructure, with particular attention paid to expansion of black and female South African participation

To respond to these challenges, the AFP proposed the establishment of an Institute of Astronomy, a real and a virtual one centred in Cape Town and with nodes around the country, with the objective of providing an environment in which students will be able to interact with expert observers, theorists and instrument scientists from around the world, as well as with their peers from Africa. The IoA, as proposed, was to focus on support for PhD students, while Honours and MSc students would continue to receive support through NASSP.

4. Overview of Current Status

South Africa has distinct geographic advantages, which have the potential to make it a major global player in astronomy. In order to exploit these advantages the Department of Science and Technology (DST) has made huge investments in astronomy facilities and infrastructure that offer opportunities for international class research and collaborations, the development of highly skilled scientific and technical human resources, technology transfer and science education and outreach.

These investments include

- a) SALT: the Southern African Large Telescope, the largest single optical telescope in the southern hemisphere, an international undertaking in which South Africa is the major shareholder

- b) SKA Pathfinders KAT and MeerKAT

South Africa is one of the two remaining bidders to host the Square Kilometer Array (SKA) – a project to construct a radio telescope with a collecting area of one million meters. SKA is estimated to cost approx. US\$2 billion and will involve more than 34

institutions in 16 countries. Development work on the South Africa's SKA pathfinders KAT and MeerKAT are well underway and legislation has been enacted to protect the main site of the proposed SKA in the radio-quiet Northern Cape Province. Because of this legislation and the available hi-tech infrastructure the KAT/MeerKAT site is well positioned to become host to a range of international radio-astronomy experiments and has already attracted PAPER and C-BASS (see below)

- c) South Africa has a small share in the ultra-high energy gamma ray telescope, High Energy Stereoscopic System (HESS), in Namibia. DST/NRF support towards capital costs for HESS terminated in 2009. HESS II is expected to be fully operational by the end of 2011 and will also provide the necessary bridge in energy between NASA's Fermi LAT Space Telescope and HESS I. South Africa is expected to contribute towards the capital investment of HESS II
- d) There are a variety of small telescopes at Sutherland. The older, South African, common user telescopes and the newer international projects (mostly robotic) offer exciting possibilities for the local community in terms of student training and research. It is interesting to note the growth of automated telescopes at Sutherland over the past few years, all of which allow the SA community some sort of access to their data on variable stars, planets, transients etc. These are a testament to the quality of the site and the infrastructure at SAAO, but they also reflect an interesting paradigm shift in the way that small telescopes are used; they have moved from general purpose common-user instruments to dedicated automated telescopes, often though not always, focused on some particular problem

SALT is expected to be fully operational in 2011, construction of KAT and MeerKAT are well under way, and HESS is operational. South Africa, hence, has access to three major international astronomy instruments which are new, are in widely separated wavelength bands, and will produce new and exciting science for at least the next decade. South Africa's full participation in this science requires that the leaders, research students and the technical experts needed to operate, maintain and upgrade the facilities are available at the appropriate levels and in the requisite numbers. This section therefore gives brief overviews of

- the current situation in key areas at the astronomy related National Facilities/Projects and their funding allocations
- the current situation in astronomy programmes at universities
- Human Capacity Development (HCD) programmes, which lead on to the identification of key issues that need to be addressed in a decadal strategy for astronomy in South Africa.

4.1 Current situation at the National Facilities

4.1.1 SAAO/SALT

SAAO is the premier optical/infrared astronomy research facility on the African continent. Its headquarters are in Cape Town and house its research astronomers and technical staff, state-of-the-art IT centre, laboratories, workshops, library, auditorium and administration. SAAO's research telescopes are located 360km away in the Northern Cape on the Sutherland observing plateau, together with a lodge for visiting scientists, plus housing for site staff, workshops, visitor centre and recreation centre. (Since the inauguration of SALT, the Sutherland telescopes have been receiving over 12,000 visitors per year).

The Sutherland observing station is a key part of SA's strategic "geographic advantage" in astronomy. This advantage has resulted in SAAO hosting numerous international facilities, and the formation of collaborative relationships with a variety of overseas partners. Virtually all of these are new, i.e. started since 1994, and the majority of them are robotic in operation, opening up new regions of parameter space for astronomical research, particularly in the search for exo-planets and the study of the transient sky.

Over the years, SAAO has built a reputation for producing world class, cost-effective research and astronomical instrumentation, and has a significant fraction of the SA astronomy PhD contingent on its staff, including postdoctoral researchers and SALT astronomy operations personnel. The established small telescopes are being used to prepare for SALT programmes, and also to serve as training platforms for the next generation of astronomers. It is essential that, even when SALT is fully operational, the 1.9m and 1m telescopes at SAAO be upgraded and maintained appropriately. Both instruments play important roles in capacity development and supporting and complementing SALT operations.

SAAO contributes to HCD through training of scientists, engineers and technicians, in collaboration with a number of local and international tertiary educational institutions. The Observatory has spearheaded an initiative to produce large numbers of high quality PhDs on the African continent via NASSP (see later). SAAO also provides training to engineering students in its mechanical and electronic departments.

SAAO is also the primary institute responsible for maintaining Sutherland's AAA status (as an "Astronomy Advantage Area") within the ambit of the Astronomy Geographic Advantages (AGA) Act, which was passed in late 2007 and signed into law. SAAO plays a leading role in the promotion of science awareness and community development through a variety of

science outreach programmes delivered nation-wide by the SALT Collateral Benefits Division of SAAO. These activities are regarded as part of the core functions of SAAO, and are resourced accordingly. The overarching goal was to ensure that the maximum collateral benefits are derived from the SALT project to advance the economy, technology, and society of Africa.

The SCBP focuses on 3 areas: education in mathematics and Science, Engineering & Technology (SET) to supply the country and the continent with well-trained and motivated professionals in substantially increased numbers; science communication and awareness to effectively engage with the public in order to disseminate relevant information in the fields of astronomy and space science; and socio-economic development in order to contribute to a better quality of life for all people, especially the disadvantaged.

The Observatory has also been involved in the wider societal applications of space science and technology, in the sense that we all now live in an era of global space-based services and utilities. Astronomy may be seen as one of the basic space sciences that underpin applied space sciences. Since 2004, the Space Science and Technology Division has played a leading role in the development of the space arena in South Africa and all the developments that led to the establishment of the new South African Space Agency inaugurated in December 2010. SAAO hosts the Space Secretariat, which has played a leading role in coordinating inter-Departmental activities and discussions that have led up to the plans to establish a South African Space Agency. The Secretariat has organized national and international conferences and has taken the lead in the organisation of the International Astronautical Congress in Cape Town in 2011. The Secretariat has also been centrally involved in the development of the National Space Policy.

SALT

SAAO has the responsibility to operate the Southern African Large Telescope (SALT) on behalf of the SALT Foundation, in which South Africa is the largest single shareholder (1/3). SALT is equipped with state-of-the-art imaging, spectroscopic and polarimetric instruments, aspects of which provide unique, world-leading capabilities. SAAO has contributed to the development of the SALT instrumentation suite, in particular the detectors of SALTICAM and RSS.

With its much greater light-gathering power, SALT has brought new scientific investigations within reach of South African astronomers. SALT is a consortium of international partners from South Africa, USA, Germany, India, Poland, UK and New Zealand that funded its construction. This 10m-class telescope although very similar to the Hobby-Eberly Telescope (HET) in Texas, has a redesigned optical system, providing greater throughput, larger field-of-view and improved image quality. This South African redesign will soon be retrofitted to

HET by our Texas partners. SALT was inaugurated by President Mbeki in late 2005, shortly after completion of the initial construction phase, since when it has been undergoing testing and commissioning.

SALT is approx 4 years behind its original schedule, which is now recognised as having been highly unrealistic in the light of the major changes and improvements that were incorporated into its design compared to the HET prototype. This delay is due to two major problems: (i) the main spectrograph (RSS) was found to have extremely poor UV/blue performance, which was well below specification, and (ii) the telescope image quality (IQ) could not be maintained over more than a quarter of the intended field of view.

The first problem was identified as being due to a chemical reaction, which contaminated the lens coupling fluid, thereby changing its optical properties. Solution to this problem entailed removing RSS from the telescope, dismantling the optics and returning them to the US manufacturer for repair. The problem is now fully solved, the optics were returned in 2009, reinstalled, realigned and tested.

The SAAO Instrumentation Division led by Darragh O'Donoghue undertook an extensive set of IQ tests that allowed them to isolate the second problem as being in SALT's Spherical Aberration Corrector (SAC), showing that the mirrors in the SAC cannot be in their manufactured and (supposedly) sealed positions. The problem was dominated by the poor mechanical interface of the SAC with the telescope, which leads to severe mechanical and thermal stresses being propagated into the relatively weak SAC, thereby distorting and misaligning its sensitive optical components.

During 2008/9 O'Donoghue's team completely redesigned the mechanical mounting for the SAC; isolating it from any stresses occurring in the tracker. In April 2009, the SAC was removed from SALT and the telescope was stood down (it is inoperable without a SAC) in order to put this redesign into effect. Over the next 15 months the SAC was carefully dismantled and all the optical components tested, verifying their optical condition (all are excellent) and cleaning them where necessary. The SAC mirrors were all carefully realigned and finally tested. On-sky images under good conditions were obtained on August 28, 2010 and demonstrated clearly that the IQ problem was finally solved. Furthermore, this result demonstrated the considerable potential of the large spherical mirror HET/SALT design. HET itself is building a new, wide-field instrument (HETDEX), which incorporates a modified SAC closely based on the SALT design.

While these problems have been very frustrating to SAAO and SALT scientists, the remedial actions undertaken by the technical staff required an extensive checking of the telescope's entire optical system. Considerable effort has also been expended on optimising and characterising the CCD detectors, as well as improving the instrument software. This has

resulted in a much greater understanding of SALT and its sub-systems, and provides an excellent basis for future upgrades of SALT instruments.

Despite the above problems, SAAO and university researchers have still managed to undertake a commendable number of science programmes with SALTICAM together with the small telescopes, and achieved an impressive list of refereed publications during the past two calendar years (an average of 2 per scientist). This augurs well for the productivity that can be expected once SALT is finally fully commissioned.

4.1.2 Radio-Astronomy

At present the Hartebeesthoek Radio Astronomy Observatory (HartRAO) is the National Facility for Radio astronomy. It has responsibility for the operations of the telescopes at Hartebeesthoek, and has led research and research- and technical-capacity development particularly in VLBI (very long baseline interferometer) radio astronomy.

The main observational instrument at HartRAO has been the 26m antenna with both azimuthal and polar tracking capabilities. In addition to the spectroscopy undertaken as a stand-alone telescope, this instrument has been central to several VLBI astrophysical and geodetic applications in partnerships with several international observatories.

The astrophysical applications include

- i) serving as an important node in long N-S and E-W baselines in collaborations with European and Australian partners, respectively
- ii) serving as a partner in e-VLBI at 1.6 – 22GHz in real-time through the internet ,
- iii) coupling with radio telescopes orbiting the Earth, to provide baselines much longer than the Earth's diameter – the limit for terrestrial VLBI - and so higher angular resolution
- iv) maintaining and extending the International Celestial Reference Frame (ICRF) through astrometric and geodetic VLBI's managed by International VLBI Service (IVS). The ICRF is used to obtain the absolute positions of objects observed by telescopes and is crucial to multi-wavelength astronomy as it is used to align images obtained at different wavelengths

The 26m telescope has also been an important reference point for national and international geodetic surveys. These include

- i) Hartebeesthoek 94 datum – reference point for SA survey system
- ii) International Terrestrial Reference Frame (ITRF) fiducial point with co-located precise position measuring systems
- iii) Station location determination and change with time from plate tectonic motion - the Hart 26m telescope was used to make the first measurement of the

- present-day motion of the African Tectonic plate
- iv) Earth rotation and orientation parameter determination by the International Earth Rotation Service (IERS)
 - v) Absolute reference point for co-located NASA MOBLAS-6 Satellite Laser Ranging (SLR) that is operated by HartRAO on behalf of NASA and the International Laser Ranging Service (ILRS) through an inter-governmental agreement
 - vi) Absolute reference point for co-located base stations for Global Navigation Satellite Systems
 - vii) Absolute reference point for co-located DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite) (based at the adjacent CSIR Satellite Application Centre)

The telescope has also been in extensive use in the training of radio-astronomers skilled in VLBI, of KAT development teams and operations teams, and for BSc Hons, MSc and PhD projects.

The bearing failure on the telescope in October 2008 was a major setback for the above activities. The bearing was replaced and the telescope returned to service in July 2010 and is now working well.

The SKA Project

The international astronomy community is developing proposals for a major (US\$2 billion) investment in a new radio telescope called the Square Kilometre Array (SKA). A number of research and development projects are now underway around the world to develop the scope of the SKA and to demonstrate some of the technology the SKA could exploit.

South Africa and Australia have been shortlisted as potential host sites for the Square Kilometre Array Project. To lead the South African bid, the Department of Science and Technology set up the SKA SA Project in 2004, whose primary purpose is to demonstrate to the international SKA partners that, in addition to our obvious geographic advantages for observational astronomy, we have the scientific and technical competence necessary to successfully construct and operate a telescope of this calibre. The SKA SA project has four components:

1. The design and construction of a cost effective, competitive SKA precursor, which will demonstrate that South Africa has the competence, capacity, and the commitment, to handle a “Mega-Science” project of this nature.

The South African SKA pathfinder project includes the construction of the KAT-7 and MeerKAT radio telescopes in the Karoo. Once operating MeerKAT will be the one of

the largest radio telescopes in the Southern hemisphere, and will be able to produce breakthrough science. It has already attracted world-leading scientist and engineers in response to a call for Large Surveys Proposals, in which they will work with South African scientists and engineers.

2. The establishment of a radio-quiet astronomy reserve in the Karoo which will be the site for the MeerKAT telescope and possibly the SKA (when it is built) and for other experiments which require radio quietness, e.g. C-BASS, (a C-band All-Sky Survey, to measure Galactic foreground in order to correct the satellite-borne Cosmic Background surveys; for this work, South Africa has renovated a 7m Telkom antenna), PAPER (a low-frequency array with which to detect low-frequency radio emission in the Epoch of Re-ionisation), and possibly attracting NASA to locate a component of its Deep Space Array.
3. A Human Capital Development programme
 - i) To create the highly skilled individuals who will be candidates for the jobs created by the MeerKAT over the 30 to 50-year life of the project.
 - ii) To create a user community of post graduates students and researchers at Higher Education Facilities who will be able to use MeerKAT
 - iii) To contribute to the national objective of a knowledge based economy by increasing the number of quality PhDs created within Africa
 - iv) To increase the number of SET professionals on the continent as a whole.

4. Mission-driven innovation within the NSI

MeerKAT when fully operational would serve as an exemplary model of mission-driven innovation that has developed new skills and expertise, generated new scientific knowledge and intellectual property and contributed to building a critical mass of very high-level expertise in cutting-edge technologies which are generic (i.e. not limited to radio astronomy).

The technology development avenues offered by the SKA pathfinder projects include i) systems engineering, ii) antenna and feed design, iii) digital signal processing, iv) very fast computing, v) very fast data transport, v) protection against radio frequency interference, and vi) optical fibre networks and dark fibre technology.

A number of local companies have been involved with the project specifically working on the demonstrator antenna XDM, and KAT-7. The innovation produced by the companies has been effective and has placed them in a position to compete internationally on SKA contracts and in industry sectors, which require related expertise. At the same time, substantial expertise is being gained by SET researchers at universities, which will be available to industry.

The proposed core site to host the Square Kilometre Array is located close to the towns of Carnarvon and Williston in the Northern Cape. The construction of KAT-7 and MeerKAT will bring investment into the area through the establishment of infrastructure, which includes roads, grid power, an optic-fibre network and facilities for the operations and maintenance of the telescope. In addition to this, short to medium term jobs will be created through construction and long-term jobs for operations and maintenance. Other investments are being planned in associated facilities, such as a computer centre, an operations centre, a science centre and training facilities. The Astronomy Park will be a protected area in terms of the Astronomy Geographical Advantage Act.

Progress in existing and proposed assets in the South African SKA project are described below:

- i) **KAT-XDM**, a prototype/demonstrator for KAT, it consists of a 15m antenna located at HartRAO. Collected first light in 2007, operating at 1.4-1.6GHz but can potentially operate at 1-10GHz. It was tested at 12GHz, where efficiency is down to half that at long wavelengths owing to the surface roughness. Its KAT-related test programme completed in 2010 with the testing of a microwave holography receiver built by HartRAO for measuring the surface of KAT antennas. Thereafter it will be fitted with a dual-frequency cryogenic receiver being built by HartRAO to permit it to do geodetic VLBI to offload and back up the 26m telescope.
- ii) **KAT-7**, is an array of seven 12m antennas designed to operate at 1-2GHz, with 1mm rms surface accuracy. The array was constructed at a site near Carnarvon in the Northern Cape – installation of all seven dishes was completed in 2010. The antennas are under commissioning, cooled receivers are being installed and the array should be operational by mid 2012.
- iii) **MeerKAT** consist of 64 x 13.5m offset Gregorian antennas and the design at the time of writing involves the following frequency bands: 1.0 – 1.75 GHz, 0.58 – 1.0 Ghz and 8-14.5 GHz .The MeerKAT maximum baselines will be about 8 km; a suggestion to include a spur with longer baselines may prove too expensive, although several of the Large Survey Projects require the high resolution it will provide. The total collecting area as a tied array is equivalent to a 100m single-dish, and this, or a subset thereof will be available for use with the long baseline arrays for VLBI.

MeerKAT is designed to be a fully operational radio telescope and a prototype for SKA. It will be among the largest mid-range radio telescopes, with an area roughly 1% of SKA. First light is expected in late 2015.

iv) Square Kilometre Array (SKA)

The proposed Square Kilometer Array (SKA) telescope embodying new technologies under development is designed to provide orders of magnitude improvement in performance over existing radio telescopes and will be at least 50 times as sensitive as MeerKAT or the EVLA. Final site selection is on schedule for the end of 2012, although funding prospects may be impacted by the global financial crisis and new 50m-class optical telescopes being proposed. Construction could begin 10 years from now, assuming that the requisite technology demonstrations have been successful.

As stated above, up to now HartRAO has led radio-astronomy research, and research and technical capacity development for the operations of the telescopes at Hartebeesthoek. The latter includes XDM, the experimental KAT prototype test instrument. The South African SKA team, on the other hand, is tasked with technology research directed to the SKA antennas and the building of the telescopes and associated infrastructure for the SKA pathfinders, KAT and MeerKAT. If the technology issues of the medium/high frequency SKA components can be solved affordably and South Africa is selected as the host site, then SKA will have to be funded as the long-term new frontier radio astronomy instrument. However, it is not expected to become operational until some 20 years into the future. In the interim MeerKAT will be the telescope array with which most science will be done, although HartRAO is likely to remain important for some time to come because of its critical position within the VLBI network, its importance for geodesy and its location in Gauteng.

There is at present a good working relationship between HartRAO and the SKA teams, with two recently appointed (HartRAO) scientific operators located at the KAT operations site and working closely with the KAT technical team on antenna design considerations and related technical issues. However, attention needs to be given to the recommendation of the International Review Panel on the integration of HartRAO and SKA SA to create a long-term sustainable radio-astronomy programme, and the roles of the different components need to be clearly defined with respect to design and construction of the telescopes, undertaking the science, building capacity to operate and maintain the telescopes, and building research capacity.

4.1.3 HESS

Through the University of North West (Potchefstroom campus) South Africa has a small share in the high-energy gamma-ray astronomy facility HESS I (the first array of four High Energy Stereoscopic System telescopes) located in Namibia. HESS is part of the network of large research infrastructure of the ASPERA network (ASTroParticle ERAnet), a network of 17 agencies from 12 different European countries. Following the success of ASPERA-1, the European Commission launched ASPERA-2 on 7 July 2009. Its roadmap for the next two

decades defines the research needs and strategies, and in particular proposes seven large infrastructures (“Magnificent Seven”) designed to answer the seven fundamental questions of Astro-Particle Physics. One of the proposed large arrays consists of more than 80 HESS-type Cerenkov detector telescopes. Southern Africa is listed as a possible site for the Cerenkov Telescope Array (CTA). This opens opportunities for synergies to be developed in research programmes in astrophysics (optical, radio and gamma-ray astronomy) as well as in electronic engineering and software development with the SKA-MeerKAT team. We can then define three stages of participation

- HESS I: This was the very successful exploratory phase, which led to the HESS I Collaboration winning the Descartes Prize of the European Union (<http://ec.europa.eu/research/index.cfm?pg=newsalert&lg=en&year=2007&na=na-070307-2>). From South Africa only the NWU was involved in the HESS Project, the reason being its historical involvement in ground based gamma-ray astronomy since 1984. The DST/NRF contribution towards the capital funding (R200,000 p/a) ceased in 2009 and new funds must be secured for the future.
- HESS II: This 30-meter class telescope will lower the threshold energy of HESS to overlap NASA’s Fermi/Lat Space Telescope, but with greater sensitivity. The lack of intergalactic absorption at these energies (below 100 GeV) is also expected to increase the cosmological horizon for multi-wavelength radio, optical and gamma-ray studies. More South African parties outside NWU indicated their willingness to participate in the joint HESS I and II Collaboration.
- CTA as discussed above (at a cost equivalent to MeerKAT or more) is now in the FP7 PP (prep) phase. At the moment NWU is representing a number of South African universities, and SAAO is a signatory to this phase, until the time has arrived to write a more detailed MoU document. The sensitivity of CTA is expected to be at least ten times better than HESS I/II. One interesting spin-off of this gamma-ray telescope is the ability to do optical interferometry over a few km baseline with a high density of telescopes, which will allow us to resolve the surfaces of bright stars at the milliarc second level for the first time. This will be the “SKA” of gamma-ray astronomy. Apart from the interest to place this telescope in South Africa, there is also interest from Argentina to host CTA. For this purpose they have made a bid of 10 million Euros to have CTA in Argentina. Since South Africa is closer to the main body of the Collaboration (Europe), the spokesperson of CTA asked if DST/NRF is also interested in having CTA in the Karoo where conditions are favourable. This project and MeerKAT are expected to become operational at nearly the same time and should be excellent multi-wavelength partners, probing time variability simultaneously in sources if CTA is located in South Africa.

SALT, MeerKAT and HESS/CTA offer a unique triumvirate of international telescopes, all available in the one region of Southern Africa, allowing scientists to explore astrophysical phenomena over a very wide multi-wave length regime of the electromagnetic spectrum.

4.1.4 Funding Allocations

The DST funding allocations per financial year for the period 2005 – 2012 for the astronomy national facilities (SAAO and HartRAO), SALT and the SKA SA project are listed in Tables 1a, b and c, respectively. The figures for 2011/12 are projected, while those for earlier years are actual. Funding for the astronomy facilities, SALT and the SKA SA project is allocated in somewhat different ways, which means that a direct comparison of the numbers is not entirely straightforward.

The core Parliamentary-grant allocations, as per the MTEF, for HartRAO and SAAO are the primary income from government, but it is important to note that additional funding for these facilities is provided through NRF as ad-hoc and discretionary grants and allocations for capital projects.

Table 1a: MTEF allocations (in kR) for SAAO and HartRAO per financial year (FY).

Source/FY	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
a)SAAO	21 152	21 951	23 926	25 122	26 479	28 597	30 724	32 567
ΔF (%) ^(a)	-	3.78	9.00	5.00	5.32	8.00	7.44	6.0
b) HartRAO	11 864	12 631	13 768	15 011	17 345	18 733	19 886	21 079
ΔF (%) ^(a)	-	8.10	8.29	9.03	15.55	8.00	6.16	6.00

(a)Also presented in the table are the percentage increases over the previous FY allocations (ΔF (%)) for SAAO and HartRAO, which over a seven-year period averages to 6.36% and 8.73%, respectively; the mean CPI from 2005 to 2010 was 7.12%

Table 1b shows the operational costs of SALT, as paid by the international consortium that owns the telescope. The portion of the operations levy which is paid by DST through NRF as a contribution to these costs is shown as a separate line; it is approximately one third of the total as this is South Africa's share of the telescope.

Table 1b SALT operations (in kR).

	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
SALT Operations	9 784	12 340	14 052	16 342	17 664	21 260	23 000
NRF contribution	3 239	3 949	4 671	4 254	5 879	5 879	7 209

Table 1c reflects the total finance going into the SKA SA project, most of which comes directly from DST, although some comes, e.g. through the Innovation Fund. The major cost for the SKA SA Project is the construction of KAT-7 and MeerKAT. Thus its funding profile is very different from those of the national facilities where the MTEF allocation described above is largely for salaries and running costs.

At 31 March 2010, SKA SA had a rollover of R627 million. In order to remedy the surplus position, the project and the NRF worked with the DST to refine the SKA SA cash flow. It was also agreed that the project would not receive funds as committed for the 2011 and 2012 financial years.

This is reflected as per the *Estimates of National Expenditure* published in February 2011.

The following changes to the SKA SA funding commitments have been noted as follows:

1. The R508 million commitment for the 2011 financial year has been declared a cost saving and reprioritised.
2. The R546 million commitment in the 2012 financial year has been split and will be received in two tranches of R218 million and R328 million in the 2013 and 2014 financial years respectively.
3. The R508 million that was reprioritised in the current financial year will be returned to SKA SA in and out year (outside the current MTEF cycle).

Table 1c SKA SA finances (kR).

Year	2004/5	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
SKA	25 000	24 810	24 569	120 511	290 225	502 293	12 600	38 217

4.2 Current situation at Universities

By far the most active and vibrant of the universities involved in astronomy and astrophysics is the **University of Cape Town (UCT)** where the university's Research Office has recently approved the establishment of a *Research Centre for Astrophysics, Cosmology and Gravity* (ACGC) bringing together researchers from the Departments of Astronomy and Mathematics and Applied Mathematics. In September 2010 the ACGC had 17 academic staff, including three emeritus professors and one SARChI chair in radio astronomy (a second SARChI SKA chair has been allocated and will be filled in 2011). There are 13 postdocs, 15 PhD students (7 are South African and 2 of those are black) and 23 MSc students (supervised/co-supervised by ACGC staff not including NASSP coursework students; 14 are South Africans and 4 of those are black).

The University of Cape Town (UCT) is one of the two universities in South Africa offering undergraduate programmes in astrophysics; the other is the University of South Africa (UNISA). UCT students graduating with a major in astrophysics are optimally prepared for NASSP, and are generally among the top performers. In 2009 UCT had 42 undergraduates registered for astronomy (76% black, 38% female) and in 2010 the number was 45 (69% black, 36% female); all of these are South African. Note that many more students are taking courses in astronomy, the numbers above reflect only students taking astronomy as a major.

Research in the ACGC is organised around various themes (mass–transferring compact binaries, distance scale of the Universe, large–scale structures in the Universe, early universe physics, string theory and cosmology, non–linear problems in astrophysics and cosmology, modelling inhomogeneity, gravitational wave physics and observational cosmology). Motivated by the opening of SALT and construction of MeerKAT, new research areas have been initiated in galaxy evolution, relation between dark and visible matter in nearby galaxies, search for intermediate mass black holes, the evolution of the hydrogen content of the universe, the nature of dark energy and modified gravity. The strength of this group is illustrated by the fact that UCT astronomers lead four of the big international key projects that have been submitted to MeerKAT. The ACGC plays a leading role in the offering of the NASSP programme.

The NASSP extended honours programme (EHP – see below) is led from UCT’s Academic Development Programme (ADP) by a physicist, A/Prof Saalih Allie, who also is also supervising education-research students who are studying the effectiveness of the EHP itself.

The **Northwest University (NWU)** has just declared a new Centre of Excellence named *the Centre for Space Research* which involves both astrophysics and space physics research. Apart from the space physicists there are 5 permanent PhD astronomers at the Potchefstroom Campus (of whom one holds a SARChI Research Chair) and one at the Mafeking Campus. The distribution of research interests are as follows: High Energy Astrophysics (2), Star Formation (1), Galaxies (1), Stellar Structure (1), Computational Astrophysics (MHD) (1).

The staff are involved in research, teaching, and supervising honours, masters and PhD level. For example, at honours level there were 8 students enrolled for 2010, of which 4 are black. All students are South African citizens. There is also a 16-inch telescope with high optical quality and instrumentation for both training and research focussed on the cores of active galactic nuclei (Blazars) to complement the gamma-ray work. The training is of very high standard. For example, one PhD who finished in 2008 on pulsars (rotating neutron stars) was awarded the prestigious NASA Post-doctoral Award for 2010. Only a limited number of such awards are made available annually on a competitive basis.

The result of these successes prompted the NWU to create a new permanent full professor position in High Energy Astrophysics. Competitive applications from Europe and the USA were received.

The **University of Western Cape (UWC)** has seen rapid growth in astronomy since 2007 and now includes 8 staff with PhDs, including a SARChI professor who started on 1 October

2010. When four new postdoctoral researcher positions are filled the total will grow to 12 staff. In the last 3 years postgraduate enrolment has gone from 0 to 4 to 8, with 4 students graduating. Research is focused on galaxy evolution and cosmology, but also includes stellar evolution, and involves theory, simulations and observations. Exploitation of MeerKAT/SKA data is central to the new research chair's plans for the future.

An undergraduate programme has also been developed which allows students to enroll for formal courses in astronomy in their second and third years and to participate in an additional research-training programme. Enrolment in the 2nd year course reached 60 in 2010 (all black students). While students are enthusiastic about continuing in astronomy, the lack of an Honours programme in astronomy at UWC, means that students are likely to follow the Materials and Nuclear Science programme.

At the **University of KwaZulu-Natal**, the Astrophysics and Cosmology Research Unit (ACRU) was established in 2004. In October 2010 it had 5 academic staff and 3 postdoctoral researchers working in astrophysics, relativity and cosmology, including a SARCHI Chair in Gravitating Systems. There are currently 11 postgraduate students and 6 undergraduate students in astrophysics and cosmology at UKZN.

Research programmes in astrophysics/cosmology are also offered at the **Universities of South Africa, Free State, Johannesburg, Rhodes** and the **Witwatersrand**. The observational projects are undertaken in collaboration with scientists at the national research facilities.

In October 2010, there were 101 PhD astronomers in South Africa, distributed as shown in the table below (note that 66 of them are based in the Western Cape).

Table 2. Distribution of PhD astronomers in South Africa as on 1 October 2010

Institution	Number	Institution	Number
SAAO	25	HartRAO	7
UCT	29	Wits	4
KAT	6	UKZN	6
Rhodes	1	UJ	3
UWC	8	UFS	2
UNW	7	UNISA	1
UniZul	1		

Note that the numbers given above include theoretical cosmologists and particle cosmologists; they do not include people working in the closely related fields of relativity theory or space physics and who often work within the same school/department/research-group as astronomers.

4.3. Human Capacity Development Programmes

4.3.1 Outreach Programmes

Outreach programmes directed at communities, learners and educators in high schools and amongst undergraduate students at universities are vigorously pursued at all the national facilities (SAAO/SALT, HartRAO, HMO), and are proving quite attractive to the participants. The programmes include supervised visits to the national observatories. The programme at each facility is not facility specific, but, commendably, is inclusive of astronomy/astrophysics and space science.

The activities of the SAAO/SALT Collateral Benefits Programme, lead by a dedicated manager and team, is particularly impressive and provide a sound basis of a national outreach programme in astronomy. Their work led directly to SAAO being asked to host the IAU's Global Office of Astronomy for Development (GOAD). This, in turn, offers huge potential to South Africa to influence the global science development agenda and particularly the use of astronomy for development in Africa.

4.3.2 The National Astrophysics and Space Science Programme (NASSP)

The National Astrophysics and Space Science Programme (NASSP) is a joint venture of researchers from around South Africa and the national facilities. It was launched in 2003 with funding from the Ford and subsequently Mellon Foundations, and is now directly funded by the Department of Science and Technology.

NASSP is a cooperative, combined graduate programme aimed at addressing the research and technical human capacity needs of the astrophysics and space science research community. The programme is hosted at the University of Cape Town where South African students and students from around Africa and the rest of the world study under the guidance of some of South Africa's leading scientists. Two programmes are on offer, which lead to the following degrees:

- Honours in Astrophysics and Space Science
- Masters in Astrophysics and Space Science

Lectures are given by staff in the NASSP consortium and cover most areas of modern Astronomy, Astrophysics and Cosmology, and Space Physics. In addition to lecture courses, students take substantial practical components, which involve field trips to telescope facilities at SAAO/SALT in Cape Town and Sutherland, HartRAO, the Hermanus Magnetic Observatory and (on occasions) Boyden Observatory at the University of the FreeState, or

North West University at Potchefstroom. The Programme aims to equip graduating students with the necessary skills to undertake research at the cutting edge of Astrophysics and Space Science and have the broad science skills needed in any modern technological society.

Over 65% of the NASSP MSc students have gone on to do PhDs either in South Africa or abroad; of course some of these are in space physics rather than astrophysics or cosmology. PhD funding from NASSP for PhD studies is very limited and is provided only to students who have obtained a NASSP honours and/or Masters degree and who will register at a South African university (financed via the Ford Foundation). The majority of NASSP students going on to do a PhD are funded in other ways, e.g. scarce skills or SKA. This is a serious bottleneck; funds are available via the SA-SKA initiative for students doing radio astronomy, but it remains difficult to fund PhDs in other areas.

To increase the intake of black South Africans, an extended Honours programme was initiated in 2008. Intake into this programme is restricted to students from formerly disadvantaged institutions. In addition to introductory courses on astronomy and scientific literacy students are offered directed physics and mathematics courses and training in requisite computer skills in the 1st year, and then proceed to the full Honours programme in the 2nd year.

The programmes are fully funded by the DST, under a NASSP allocation for the Honours and MSc degree programmes, and partly supported under a Multi-Wavelength Astronomy (MWA) allocation for the PhD (and post-doctoral) programmes – although at a lower level than the SKA bursaries. The funds allocated for NASSP and MWL programmes for the financial years 2003 – 2011 are listed in Table 3a below.

Table 3a: NASSP /MWL Funding (in kR) as per source and Financial Year (FY)

Source/FY	2003	2004	2005	2006	2007	2008	2009	2010	2011
a) NASSP									
Ford Found.	700	700		400	500	500			
Mellon Found.			900	900					
UCT♠	440	479	301	284	285	109	426	539	
NRF (PD* –grant)				164	164	164	164	164	
DST					2000	3843	5 367	5 838	6 432
NASSP TOTAL	1 140	700	900	1464	2664	4 507	5 531	6 002	6 432
b) MWL (DST)				4 000	1 465	3 154	3 100	3 410	3 751
TOTAL	1 140	7 00	900	5 464	4 129	7 661	8 631	9 412	10 183

♠ these numbers are only the direct financial contribution and do not include, e.g., the overheads such as costs of space (lecture rooms, offices, computer lab etc), nor the salaries of the academics involved, including the Director.

* Peter Dunsby grant;

The student intake into the NASSP Honours and Masters programmes is presented in Table 3b below.

Year	2003	2004	2005	2006	2007	2008	2009	2010
Honours	13	14	12	19	13	11	17	20
Masters	5	15	9	8	12	15	15	18

Table 3b: BSc honours and masters students participating in NASSP

The number of applicants has increased dramatically in recent years, e.g. in 2009 and 2010 there were 50 and 83 applications, respectively, to do an MSc with NASSP. The number of South African students entering the programmes is also now increasing due in part to the introduction of Astronomy Undergraduate programmes at the University of Cape Town and probably the increased awareness of astronomy in the country through the various PR/outreach activities. The recent expansion of astronomy at UWC is expected to contribute in future.

Increasing the number of black South African graduates in astronomy has been recognised as one of the main challenges, and initiatives to address the situation include the Extended Honours Programme (EHP) mentioned above as well as winter schools targeted at students from the historically disadvantaged universities (HDUs), from which the students entering the EHP are selected. The first winter school was held in 2007 and in 2008 four students started the EHP of which three went into the main honours programme in 2009. Subsequent winter schools have accommodated 20 to 30 students with the aim of selecting 10 to start the EHP in the following year. In 2009, there were 7 students in the EHP who entered the full honours programme in 2010, while 9 new students entered the EHP that year.

More support is needed to continue to be able to cater for the increasing number of South African students while at the same time continue the involvement of students from elsewhere in Africa. It is particularly difficult to hold on to students from other African countries that have gone through NASSP, because such a small numbers can benefit from NRF grants.

There is general happiness with the course content of the NASSP programmes, although it is acknowledged that the programme is tough for students entering the programme without exposure to astrophysics/astronomy modules in their undergraduate degree.

Thanks to a grant from the Kellogg Foundation, the first African-American lecturers participated in NASSP in 2008 and the first African-American students in 2009. These will provide African students with important links to the large community of astronomers in the USA.

Some areas of unhappiness over NASSP related to the following:

- i) all students for the Honours degree are registered at UCT, which deprives their home institutions of much needed LE points; this raises the possibility that some HEIs may discourage students from the programme for fear of losing their good students and of losing income – which could ultimately lead to the loss of posts in the department.
- ii) the majority of students in the programme were non-South African students, but this situation has gradually changed (12 out of 19 honours students, financed by the DST grant, who started in 2010 were South Africans and 8 of these are black).
- iii) a pass in the NASSP Honours programme does not assure a student admission into the NASSP MSc programme.
- iv) the lack of accreditation for the organisation of the programme offered by the UCT Administration (Faculty Office).
- v) Lecturers from outside the Western Cape find it difficult to spend a whole semester in Cape Town if they also have teaching duties elsewhere in South Africa. The situation may, however, be better for Research Professors who have less teaching responsibilities and who are more mobile to travel around.

4.3.3 Capacity Development Programme within SKA SA

Since 2004, SKA SA has engaged in a vigorous capacity development initiative and offered bursaries to MSc (engineering and astronomy), PhD and Post-Doctoral Fellow (PDF) bursaries. In order to attract black and female students to Science, Engineering and Technology study at university the programme has introduced an undergraduate bursary scheme in 2008, and bursaries were awarded to 16 undergraduate physics and engineering students. Table 4 below lists statistics in terms of number of bursaries offered by academic year, by discipline, by gender, and in terms of SA demographics:

Table 4 a. Number of bursaries offered per year.

Year	Number
2005	9
2006	14

2007	29
2008	48
2009	45
TOTAL	145

Table 4 b. Number of bursaries awarded per academic year/level

Academic level/year	Number
Intern	5
1 st year undergrad	12
2 nd year undergrad	10
3 rd year undergrad	7
Hons	7
MSc	55
PhD	27
PDF	11
Lecturer	3

Table 4c. Demographics of South African Bursars

Black Female	Black Male	White Female	White Male
8	36	27	29

Of the 145 bursaries awarded, 96 have been to science/astronomy students and 49 to Engineering students (NB a large fraction of the 96 Science students are honours and masters students and most of those have come through NASSP).

Number of PhDs required

MeerKAT will be a large facility by international standards and the SKA SA team estimate that 40 - 60 PhD graduates will be required in order to utilise the facility to its full potential. Assuming that on average 50% of the South African science PhDs that qualify will either move abroad or move into other industries, suggests that it will be necessary to create 80 to 100 PhDs by 2012, i.e. 25-30 radio-astronomy PhDs per year over the next three years.

To this estimate we need to add 3-4 per year for SAAO/SALT science and 1-2 per year to utilise HESS.

Our current rate of PhD production is 4-5 per year; a vast improvement on the 1/year prior to 2005, but in clear need of further growth. Those returning from training outside the country will of course, augment this, although the numbers are still small there too.

The existing supervisory capacity, within South African universities and facilities, is a critical factor limiting the growth of PhD training within this country.

5. Issues to be addressed

5.1 Establishing a viable South African astronomy research and technology community

The main challenge facing astronomy in South Africa is the establishment of a viable South African astronomy research community, including the creation of significant human capacity in the fields of engineering and IT related to astronomy, in order to fully utilise the instruments mentioned above. Central to this are:

1. The development of critical mass groups in universities

The Western Cape is already developing a critical mass of astronomy scientists and technologist, between universities (UCT, UWC), industry and national facilities (SAAO, MeerKAT and the High Performance Computing Centre).

Gauteng could also develop a critical mass, particularly when the initiative to get astronomy started at Wits, in collaboration with HartRAO, really gets going; the repair and return to service of the 26m at HartRAO will impact positively on that. The activities at UKZN are to be encouraged, as they too have great potential to develop as a local centre.

Other universities that are supported must, together with extensive collaborations with the national facilities, be able to develop a critical mass in a fairly focused area of work.

2. Attracting new students to the field and retaining postgraduate students up to and beyond the PhD level. This requires an enthusiastic outreach programme, attractive bursaries at the undergraduate and postgraduate levels, career paths for graduates and postdoctoral fellows in research and related industries.

3. Increasing representation of black South Africans in Astronomy/ Astrophysics.

The under representation of black South Africans in the astronomy profession is a major challenge recognised by all, and which is shared by other sciences. A similar challenge faces astronomy in the USA where the AAS Committee on the Status of Ethnic Minorities in Astronomy, estimates that to achieve parity with the general population within one generation (~30 years), the number of underrepresented minorities earning graduate degrees in astronomy and astrophysics must increase in the coming decade by at least a factor of five. The Committee advocates vigorous

outreach programmes at schools and universities, and at the higher level recommends:

“...the profession must develop and invest in mechanisms to more effectively move individuals across critical educational junctures to the PhD and beyond. Early and continuous research engagement starting in the undergraduate years is critical to this vision, in which the federally funded research internship programmes (e.g. NSF REU, NASA GSRP) and national centres/observatories play a vital role. Regionally based partnerships with minority-serving institutions (MSIs) are crucial for tapping extant pools of minority talent, as are post-baccalaurate and/or masters degree “bridging” programmes that provide critical stepping stones to the PhD.”

Several HMU’s (Historically Minority Universities) in the USA have excellent bridging programmes in place in partnerships with national observatories – examples we could well emulate in South Africa.

Teachers are of vital importance to the development of science in South Africa in general, including the further education and career choices of the pupils they deal with. It is therefore important that the various astronomy programmes examine how best they can interact with and support teachers – as they train and later as they are in-service.

It is also important to pay attention to the broader educational aspects that underpin the main thrust of producing astronomers and astrophysicists. While many of the findings relating to the areas of teaching, learning and understanding of science in general, and physics in particular, are pertinent to astronomy it has become clear that a more focused approach is essential if substantial progress is to be made. Thus, Science Education Research that is specifically targeted at issues that relate to astronomy and astrophysics must be actively encouraged and supported. The Centre for Astronomy Education at the University of Arizona offers a large-scale example of how a research based approach to astronomy is used to drive several agendas including outreach and education and they are very interested in collaborating in similar investigations in South Africa. The establishment of a National Physics and Astronomy Education Research Unit is currently under consideration at UCT/SAAO, which could be the driver of directed bridging programmes in astronomy.

4. Increasing research supervisory capacity at Universities:

Supervisory capacity at universities is currently saturated due to the low numbers of supervisors in SA universities who are able to supervise astronomy and astronomy engineering research. For long-term sustainability, the universities should be able and committed to taking over the additional research students, which are subsidized

through human capacity development support packages of the national facilities and SKA SA. At present, the universities generally do not have funds to support new programmes, nor growth in staff. Most university posts have been frozen now for several years. This situation has to be changed if astronomy is to grow without prejudicing the other sciences.

5. Increasing University – National Facilities collaborations in research, research planning and research supervision

The university research groups should regard the national facilities as extensions of their research infrastructure, and play a large role in research and research infrastructure planning. This can be strengthened by joint appointments of key staff, appointment of NF staff to associate positions at the universities (as is already happening at SAAO, KAT and universities in the Western Cape), and the establishment of User and Programme Advisory Committees on which the university users are well represented. Good examples of these are the User Committee, Programme Advisory Committee and the Director's Advisory Council at iThemba LABS. Although it must be noted that the nature of the activities at the astronomy facilities demands international representation on such committees.

A focus of any capacity development programme must be the strengthening of research and research support capacity at the universities (including some universities in partner countries such as Madagascar, Mauritius, Mozambique, Namibia and Botswana). To create critical mass in a specific area, a university research group should if possible start with the minimal viable unit of three researchers. This could be a core group consisting of a professor (including for instance an NRF Research Chair) senior and junior postdoctoral fellows who can carry out limited teaching, assist in supervising postgraduate students and carry out research. This model ensures two essential elements for capacity development, dynamic leadership and the availability of supervision capacity, which can motivate both students and established researchers to become involved in globally competitive astronomy research.

This process has to be carefully managed, however. How do we decide to which universities additional resources should be directed? Those that are already successful at PhD training? The data on student intake and throughput in the NASSP programme presented above show that there is limited progress in opening access to post graduate studies in astronomy to South African black students. Should intervention focus on selected programmes at selected universities? The DST and the Department of Higher Education need to engage in discussions and arrive at an acceptable medium term strategy to address this issue. We are at risk of failing both

to fully utilise our investment in research infrastructure and university education as well as to fully exploit the role of such investment as a means of social advancement and mobility.

5.2 Organisation of Astronomy Research around Key Science Questions

Astronomy research in SA has up to now consisted in some cases of small isolated pockets of astronomers coming together in an ad hoc manner, carrying out research in areas limited in scope. (Some reviewees commented on a lack of research leadership!). The new leadership in the universities and national facilities must be able to identify the research questions which the South African facilities are best suited to tackle, so as to make significant advances in astrophysics that will be recognized as such by the international community. This process is well-established amongst the SALT partnership, as it must exploit its unique or enhanced capabilities.

The Astronomy Frontiers Programme also advocates the organisation of the astronomy research programme around 5 key research themes. Most relevant is the motivation for the building of the SKA, which lists the following **Fundamental Questions** in physics and astronomy which will guide the major part of the research effort:

- What are the basic properties of the fundamental particles and forces?
- What constitutes the missing mass of the universe?
- What is the origin of the Universe and the observed structure and how did it evolve?
- How do planetary systems form and evolve?
- Has life existed elsewhere in the Universe, and does it exist elsewhere now?

A national astronomy strategy must identify the key growth areas in which South Africa wants to be a major player. One way to push astronomy research in SA towards the most promising and exciting areas of research is to introduce a problem-based approach to research, which combines multi-wavelength observations to come up with answers. This approach also means that not everyone has to have access to a specific instrument. There is a large volume of important data accessible through international observatories and the virtual observatory.

It is essential to ensure that SA research groups work with international astronomers and technologists. This will greatly enhance the capacity and the reach of research in SA and will help us to overcome the lack of experience and expertise in many groups. It will also encourage the international exchange of researchers and get excellent researchers to come to work and live in SA.

5.3 Well-resourced technical support groups

Together with the necessity of establishing astronomy research groups of the requisite critical mass there is the need to ensure that there are well-resourced groups focused on the instruments whose objective is to ensure that the instruments produce the best possible results and remain cutting edge, competitive and capable of producing new science. The NRAO in the USA focuses on making the VLA and their other telescopes the best and most productive in the world. We need to have similar priorities. The instrument groups also need dynamic and forward-looking leaders and adequate support and resources from the NRF and the DST.

5.4 High performance internet connectivity

Significant capacity needs to be created in data management; in terms of storage capacity, data processing capacity, and transmission capacity. Multiple Gb/s connectivity to Europe and the rest of the world is required to enable international access to the expected large volumes of data from SALT and MeerKAT, to participate in international astronomy projects such as the eVLBI network and to make use of the huge amount of very useful and important data available through the Virtual Observatory.

The development of a South African Virtual Observatory was started with DST funding for multi-wavelength astronomy and has been continued at SAAO. This should be expanded particularly with a view to the future needs of the radio astronomers.

In addition, quick access to research literature via the Internet and Internet connectivity that is fast and reliable to download data, and to manipulate data on- and offline is among the basic level of academic infrastructure required at universities.

Hence the recent news of the completion of undersea optical cable terabyte/s internet connectivity to East Africa comes at an appropriate time, and offers the opportunity to exploit high performance dark fibre networking, i.e. installing extra capacity on existing networks that is not 'lit', but lit (by adding front end and back end components) as and when required.

(SANReN itself will consist to a large degree of dark fibre, since it is a high-performance network and needs to be able to provide on-demand capacity, which is essential for SALT and the large distributed array telescopes. This has begun as of 2010, but much remains to be done to make this available to the entire SA astronomical community).

5.5 A new governance structure for astronomy in the SALT/MeerKAT era

The issues identified in the reviews and documents generated over the past 5-6 years and the views expressed in the current interviews all point to the need for a new governance structure for astronomy under whose umbrella the entire spectrum of our astronomy and astrophysics activities (research, human capacity development, science awareness and outreach, strengthening of research capacity in the universities and national facilities, strengthening the technical support base) would be managed. A board that includes astronomers from SA universities and national facilities, as well as key international astronomy experts, would oversee the governance body.

As noted in the Frontiers Report and specifically in the KPMG/DST Report: A Review of the Current State of Astronomy in South Africa (Report 2 of 3):

“Strategic Management of Astronomy: Astronomy resides in a number of discrete institutions and universities, at present. Notwithstanding the goodwill within the community of astronomers, collaboration between institutions and wavelength specialities are, at best, episodal. Funding is similarly fragmented, as it flows through the institutions, or occurs ad-hoc, typically for research projects. Ownership is strong, but focused within the separate domains; no single body has been mandated to manage astronomy at a strategic level. Given the nature of the immediate future in astronomy, dominated by international collaborations on new instruments, multiple shareholders and large capital investments, the current absence of a mandated governance body for SA astronomy will be a major weakness. The requirement to build human capital in astronomy and related fields, to compete strategically for new flagship projects, to communicate a consistent message of strategic intent to stakeholders locally and abroad, and to contract with global partners on a major scale, all indicate the need for an integrated governance entity for astronomy. Decision-making pertaining to resource allocation, strategic initiatives, investment priorities, research direction and partnerships require an intimate understanding of astronomy, a greater degree of autonomy in financial resource allocation, and a high degree of governance maturity. “

In Australia, the Decadal Plan for Astronomy shows that significant investments in world-class research infrastructure in astronomy have been made since the 1960s. The investment in astronomy in Australia has increased dramatically in the last three years. This year, major investments have been made in establishing a Centre of Excellence for All-Sky Astrophysics (CAASTRO), with A\$ 28 million new funding for optical and radio astronomy. Spanning seventeen partner organisations, it aims to hire 25 scientific staff and nine support and administration staff in the first year, making CAASTRO a group of around 65 staff, plus students. The Australian government Super Science programme has also made significant investments of A\$ 80 million towards establishing an Australian Centre for SKA Science, hosting high-performance computing facilities. These programmes will lead to a significant increase in permanent staff and postdoctoral positions. For example, the Super Science

programmes want to hire over 33 new postdocs in SKA science over the next 5 years. The establishment of the International Centre for Radio Astronomy Research in Perth, a joint research centre of the University of Western Australia and Curtin University, also represents a A\$ 100 million investment over 5 years by the Western Australian State government as well as the Australian Federal government.

Significant investments in optical astronomy have also been made: the Australian government has awarded A\$ 88.4 million for Australia's participation in the construction phase of the international Giant Magellan Telescope (GMT) project. The new funding includes \$23 million for Australian infrastructure and instruments at the ANU's Mount Stromlo Observatory in Canberra, and \$65 million for construction of the telescope itself.

Another model of a centre to consider is offered by the Inter University Centre for Astronomy and Astrophysics (IUCAA) in India. IUCAA has a small complement of scientific staff (14), which includes the Director and two Deputy Directors who oversee the Core programmes and the Visitors Programmes of the Centre, 10 PDF positions and 24 funded Research Scholar positions. The Core Programmes include research, the PhD programme, and Advanced Research Workshops and Schools. The Visitors Programmes include i) international and national visitors on short term visits, ii) the Associateship Programme (for university academics to spend 6 months to 3 years at IUCAA), iii) refresher courses for university lecturers and school teachers – all aimed at nucleation and growth of astronomy and astrophysics at universities. All programmes are fully funded by IUCAA (and the University Grants Division).

6. Recommendations

In this section we present the recommendations for the development of South African human capacity in astronomy and astrophysics. While the recommendations presented here have been placed in different categories it should be understood that many of them are interlinked and should therefore be dealt with simultaneously.

Recommendation 1: Coherent governance structure for astronomy

The central requirement for the development and growth of astronomy in South Africa is a coherent governance structure for astronomy, with astronomers playing a key part in this structure. The *role* of the governance structure would be to

[R1-Role]

1. Manage SA astronomical facilities coherently and holistically
2. Provide input and guidance to bodies that are involved in the funding of astronomy research

3. Provide administrative and governance structures that strengthen and enhance international interest in South African astronomy
4. Make South African astronomy internationally competitive, so that South Africa becomes the destination of choice both for international projects and for international scientists and engineers

The **actions** that are required to establish an astronomy governance structure include [R1-Actions]

1. Establishment of an Astronomy Desk that will make key recommendations to government regarding the establishment of an astronomy governance structure. The Astronomy Desk should undertake a broad based investigation into international best practice for the governance structure, as well as consider the requirements of the South African astronomy community and other key role players
2. Implementation by government of recommendations for the astronomy governance structure made by the Astronomy Desk. Government should also take into consideration the recommendations made by other recent panels e.g., the reviews of the NRF and the Astronomy National Facilities, to deliver a coherent astronomy strategy

Once the astronomy governance structure is established this body should maintain ongoing consultation with astronomers, including key international partners, on matters that relate to the organization and governance of astronomy. A selection of local and international astronomers should serve as members of the astronomy governance structure and play a central role in this body.

Sufficient **funding** should be provided to establish and sustain the astronomy governance structure, as follows

[R1-Funding]

1. Interim funding of the Astronomy Desk
2. Full funding for the smooth functioning of the astronomy governance structure

Recommendation 2: Substantially increase institutional capacity in astronomy

The success of any human capacity development programme for South African astronomy is strongly dependent on the development of critical-mass capacity at several institutions across the country that are involved in astronomy research, teaching and outreach. The **goals** of the institutional capacity programme would be to

[R2-Goals]

1. Establish critical masses of astronomers in various regions across South Africa by focusing on institutions where interest and some capacity exist
2. Aim to achieve the minimum viable unit of 3 researchers in establishments that are currently below this staffing level as soon as possible
3. Develop astronomy research and teaching programmes at these institutions, incorporating a cutting-edge research programme, an undergraduate teaching programme, a postgraduate teaching programme, a postdoctoral fellowship programme, and an undergraduate research internship programme
4. Build these programmes, initially through support from intra-regional collaborations, with every effort made to support these regional collaborations
5. Provide a career path for astronomy by establishing faculty positions, initially targeted at junior faculty
6. Provide a mentoring system for postdoctoral fellows and junior faculty

These goals can be achieved through the following **actions**

[R2-Actions]

1. Develop a business model to motivate universities to buy into making faculty appointments, focused on junior faculty, so that critical mass groups in astronomy are established
2. Run a joint DST-DHET-University Executive Astronomy workshop to ratify business model and sign memoranda of understanding
3. Creation of astronomy faculty positions, in addition to current SARChI programme, and hiring of astronomers at SA universities where interest and capacity in astronomy exists
4. Critical mass astronomy groups to develop a growth plan for their astronomy undergraduate and postgraduate teaching and research programmes, and a mentoring system. To start implementing these plans and systems with support from the institution and DST via the astronomy governance structure
5. Facilitate local collaborations so that, e.g. students can attend maths and physics courses at their home institution, but attend astronomy courses at another institution, or register for UNISA astronomy courses

The following **funding instruments** should be established to ensure adequate financial support for these goals to be met

[R2-Funding]

1. Astronomy junior faculty programme
2. Programme of junior and senior long-term fellowships for astronomy faculty members
3. Mobility funding programme, especially for fledgling astronomy research groups
4. Visitors funding programme
5. Astronomy research chairs programme (as a continuation/extension of the SARChI)

programme)

6. Mentoring support programme for postdoctoral researchers and junior faculty

Recommendation 3: Develop human capacity in astronomy by substantially increasing the number of black astronomy students and astronomers

Central to the long-term success of any human capacity development programme for South African astronomy is the training of many more black astronomy students. It is also vital to provide continuing support for these young astronomers through the various stages of their career development so that they can ultimately take up posts as professional astronomers. The specific *goals* of such a focused programme would be to

[R3-Goals]

1. Significantly increase the number of black learners with academic potential that take up a first degree with astronomy
2. Establish support structures in critical mass astronomy groups, such as a mentoring system and a tutoring system, to ensure that students easily pass through critical junctures in their path to a PhD and into their postdoctoral research phase
3. Engage students in early and continuous research activities starting in their undergraduate years
4. Provide a mentoring system for undergraduate and postgraduate students
5. Increase the overall number of undergraduates, postgraduates and postdoctoral researchers in astronomy

These goals can be achieved through the following *actions*

[R3-Actions]

1. Develop and implement an intensive astronomy outreach and career popularization programme to focus on black learners at a large number of schools
2. Provide a sufficient number of undergraduate bursaries for black learners
3. Set up an intensive mentoring and academic support programme
4. Set up an undergraduate research internship programme for undergraduate and honours students that could be run during the academic semester and over university vacations
5. Ensure participation of undergraduates in national astronomy activities such as an annual national astronomy conference
6. Set up bridging programmes between HDUs and national facilities and/or critical-mass astronomy groups
7. Make available excellent bursaries for postgraduate students, including equipment funding, and travel funding for national and international exposure
8. Provide excellent support for early career phase postdoctoral researchers and academics in the form of research support – supplies and equipment, student

funding, conference travel; teaching and administration relief; mentorship; sabbatical and study visits for critical national and international exposure

To achieve the above goals and support the above actions the following **funding instruments** should be established

[R3-Funding]

1. An astronomy outreach programme with a focus on attracting black learners into astronomy
2. An undergraduate bursary programme with attractive levels of support, primarily targeted at black students (and recognising the need to compete with industrial and engineering programmes)
3. An undergraduate research internship programme
4. A mentoring support programme for undergraduate and postgraduate students
5. An astronomy bridging support programme
6. A postgraduate student funding programme with attractive levels of support
7. A postdoctoral funding programme for junior and senior postdoctoral researchers, including both short-term and long-term fellowships
8. A “Thuthuka-like” programme for astronomy that will support professional black astronomers

Recommendation 4: Supporting well-resourced astronomy technology groups

There is a need to ensure that there are well-resourced technical groups in South Africa that are working on cutting-edge astronomical instrumentation, so that the South African astronomy community, in particular young and upcoming astronomers, remains internationally competitive by producing new and world-class science with these instruments. A dedicated programme to fund astronomy technology development should be established with the **goal** to

[R4-Goals]

1. Develop new and cutting-edge astronomical instrumentation on an ongoing basis to remain internationally competitive
2. Grow active astronomy technology groups based at national facilities and connected with universities
3. Advertise the opportunities that astronomy offers for a very wide variety of engineers and people with technical skills

The **actions** required to drive the astronomy technology programme include

[R4-Actions]

1. New appointments of engineers and experimentalists to grow astronomy technology research groups

2. Regular astronomy technology reviews and strategic workshops
3. Development of courses to train students and young researchers in astronomy technology

The **funding instruments** required to make this a successful programme include

[R4-Funding]

1. An astronomy technology human capacity development programme to fund staff positions, postdoctoral fellowships and student bursaries
2. An astronomy technology resources funding programme to fund the resources required by cutting-edge instrumentation projects
3. Appropriate long-term investment in the national facilities' instrumentation groups which support and maintain existing equipment and are crucial in the identification, development and implementation of future state-of-the-art instruments in order to keep SA facilities at the forefront of astronomical research

Recommendation 5: Coordinated and well-resourced astronomy education, outreach and science awareness programme

A well-coordinated and well-resourced astronomy education and outreach programme will play an invaluable role in creating awareness of astronomy among the public, in particular high-school learners, who could be attracted into studying astronomy at university and pursuing a career in astronomy. The **goals** of the astronomy education and outreach programme would be to

[R5-Goals]

1. Strengthen the teaching of mathematics and physical science in schools, through the use of astronomy
2. Make science, engineering and technology careers, particularly those related to astronomy, attractive to young people
3. Improve public appreciation of government policy on science and technology and encourage support for international astronomy projects, such as SKA
4. Stimulate global citizenship and tolerance through an appreciation of our place in the universe
5. Set up intensive collaborations with the media to promote astronomy and develop media skills in astronomy, for example, through an astronomy journalism programme involving workshops, short courses, electronic courses
6. Set up and maintain an astronomy website portal for the media, schools and the general public. This website should take advantage of new technologies e.g. facebook and twitter to engage with the astronomy audience
7. Emphasise the fact that a PhD in astronomy provides highly desirable skills that expand career choices beyond astronomy jobs

The **actions** required to achieve these goals include

[R5-Actions]

1. Immediately engaging key role-players currently involved in astronomy outreach and astronomy education (e.g. SKA-SA programme, HartRAO programme, SAAO/SCB programmes, university groups, planetariums, science centres, SAASTA, IAU-GOAD) to develop a coherent and coordinated astronomy outreach, education and science awareness strategy. This strategy can initially be developed at a 1-day workshop, where a working group can also be established to develop goals, actions and instruments, which will expand on those listed here
2. Getting all role-players in astronomy outreach and education to work together to ensure maximum impact
3. Engaging extensively with school teachers and learners
4. Engaging extensively with the public via all forms of the media and activities at all astronomy outreach institutions
5. Making available university-level teaching materials, and coordinating astronomy-teaching resources
6. Working with the IAU-GOAD to bring in finance and expertise from outside the country
7. Involving amateur astronomers around the country through local astronomy amateur associations
8. Setting up a programme to inspire young children from underprivileged environments, e.g. UNawe
9. Supporting UNISA in developing courses that are specifically aimed at educators, and that build on that a network involving national observatories and amateur astronomers to support the practical tuition
10. Support viable bridging programmes at all levels, with emphasis given to improving access of high school students to university, particularly in remote areas

The optimal **funding instruments** required to support this programme would be best decided by an astronomy education and outreach programme working group, nevertheless it is clear that a free-standing astronomy outreach funding programme is required to ensure continued support of these important activities. [R5-Funding]

Recommendation 6: A continuing decadal strategy for astronomy: prioritization of research themes

A key strategy for the growth of human capacity in astronomy is to identify and focus on a prioritized set of research themes, taking into account the astronomical facilities available in

South Africa, so that South African researchers can play a leading international role in these areas of research and thereby increase their international reputation. This in turn will inspire young and upcoming South African astronomers, and give them the necessary training and skills to succeed in a competitive international research arena.

The **goals** of such a strategy would be to

[R6-Goals]

1. Identify a set of astronomy research themes in which South African astronomers can play a major role internationally, and regularly update these research themes, for example, every ten years with a possible interim review, by taking into account national capacity and resources, and international trends
2. Prioritize the allocation of astronomy resources, based on the decadal review, to support future observational, theoretical, and technological astronomy projects

The **actions** required to achieve these goals include

[R6-Actions]

1. Setting up a panel of local and international astronomers to develop a national astronomy science and technology strategy
2. Setting up a decadal review panel to regularly provide recommendations on South African astronomy research priorities

Funding should exist to support the decadal review and strategy programme, with the national astronomy research-funding programme being informed by the decadal strategy document. While the funding for major projects should be decided in this way, this should not prevent individuals and small collaborations doing research outside the priority areas.

[R6-Funding]

Recommendation 7: Establishing collaborative structures

Since the South African astronomy community is relatively small at present, significant benefit in developing human capacity can be gained by combining skills and resources through collaborative programmes between different South African institutions, and with institutions in Africa and further abroad.

The **goals** of such an initiative would be to

[R7-Goals]

1. Grow collaborations between national facilities and university groups on research projects, joint appointments, student and staff exchange, and joint supervision of students
2. Grow astronomy links with astronomers from other African countries, in particular exploiting the IAU-GOAD structure

3. Grow astronomy links with international research groups

These goals can be realised through the following **actions**

[R7-Actions]

1. Encouraging the Department of Higher Education to review the inherently competitive framework within which universities operate and which strongly inhibit teaching collaborations between universities, i.e. collaborations such as NASSP
2. If possible modify NASSP, after review, so that it facilitates growth in its partner universities and strengthens its collaborative character
3. Regular meetings of the South African astronomy community e.g., a national astronomy conference
4. Setting up an international visitors programme
5. Using virtual technology e.g., video-conferencing, to promote collaboration between physically separated astronomy groups
6. Setting up user and programme advisory committees at the national facilities

Support for these collaborative structures can exist through **funding instruments** such as

[R7-Funding]

1. A programme for joint university and university-national facility appointments
2. An international visitors funding programme
3. A national astronomy conference programme
4. A “virtual technology for research collaboration” programme that funds video-conferencing and other web-based conference technologies
5. A bursary programme and postdoctoral fellowship programme for students from African countries
6. Bilateral programmes with astronomers from African countries, and leading astronomy groups in other countries

Recommendation 8: Adequate resources to support astronomy research and teaching

A basic platform of resources to support astronomy research and teaching is required to develop capacity in this area. An astronomy resources programme should be set up to ensure these resources are available, with a **goal** to

[R8-Goals]

1. Provide mobility support for observing trips to telescope facilities and research visits to centres with significant astronomy resources
2. Ensure high-performance internet connectivity for all institutions engaged with astronomy research and teaching

3. Provide access to library resources including books and journal articles

These goals can be achieved through the following **actions**

[R8-Actions]

1. Establish an astronomy mobility programme
2. Complete the South African National Research Network (SANReN) as soon as possible and ensure that it is available to all astronomy groups across South Africa
3. Develop a framework for sharing library and other educational resources or set up a central structure where such resources can be accessed

The **funding** of these resources should be established through

[R8-Funding]

1. An astronomy mobility-funding programme
2. DST (through the Meraka Institute) funding of SANReN, in particular for the current SKA bid
3. An astronomy library and electronic resources programme

Recommendation 9: National centre for astronomy and astrophysics

A national centre for astronomy and astrophysics is required to provide an environment in which people engaged in astronomy (including astronomers, educators, instrument scientists and engineers, and students) can interact and think about science with the minimum administrative or formal teaching responsibilities. The **goals** of the national centre would be to

[R9-Goals]

1. Host South African astronomers for short or extended visits thereby supporting their research
2. Host international high profile visitors
3. Provide an environment where research collaboration can occur between South African and international astronomers
4. Provide an environment where multi-skilled and multi-disciplinary research collaboration can occur, for example, between observers and theorists, and between astronomers and biologists
5. Host national and international astronomy conferences and workshops

The national astronomy centre should have the necessary infrastructure to support these goals, for example, meeting rooms of various sizes including a lecture theatre, and low cost accommodation, and should provide an attractive environment so that it appeals to researchers to spend their time there. The national centre can take advantage of research

capacity in astronomy across South Africa by adopting a regional structure. Astronomers based at South African universities and national facilities should play a key role in the governance of the national astronomy centre.

The **actions** required to establish the national centre for astronomy and astrophysics include [R9-Actions]

1. Setting up a comprehensive business and operations plan for the national centre
2. Embarking on international fund raising efforts in collaboration with international partners

The **funding** required to set up the national centre will come primarily from non-government sources, with fund raising efforts able to start once a viable governance structure for South African multi-wavelength astronomy is established. [R9-Funding]

7. Acknowledgements

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Peter Dunsby and Patricia Whitelock for providing details of the NASSP and MWL programmes and their funding projections,

Patricia Whitelock for documents relating to the Astronomy Frontiers Programme,

Kim de Boer for details of the SKA SA Human Capacity Development Programme and its funding projection,

Mike Gaylard for a detailed report on activities at HartRAO, and

Renée Kraan-Korteweg for a comprehensive report on Astronomy at UCT.

List of Acronyms

AAA	Astronomy Advantage Area
AGAP	Astronomy Geographic Advantages Programme
CSIR	Council for Scientific and Industrial Research
CTA	Cerenkov Telescope Array
DHET	Department of Higher Education and Training
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
DST	Department of Science and Technology

EHP	Extended Honours Programme
HartRAO	Hartebeesthoek Radio Astronomy Observatory
HCD	Human Capacity Development
HDU	Historically Disadvantaged University
HEI	Higher Education Institution
HESS	High Energy Stereoscopic System
HMO	Hermanus Magnetic Observatory
IAU-GOAD	International Astronomical Union Global Office of Astronomy for Development
ICRF	International Celestial Reference Frame
IERS	International Earth Rotation Service
ILRS	International Laser Ranging Service
IT	Information Technology
ITRF	International Terrestrial Reference Frame
IUCAA	Inter-University Centre for Astronomy and Astrophysics
KAT	Karoo Array Telescope
KAT-XDM	Karoo Array Telescope-eXperimental Development Model
MTEF	Medium Term Expenditure Framework
NASA	National Aeronautics and Space Administration
NASSP	National Astrophysics and Space Science Programme
NF	National Facility
NRF	National Research Foundation
NWU	North West University
RSS	Robert Stobie Spectrograph
SAAO	South African Astronomical Observatory
SAASTA	South African Agency for Science and Technology Advancement
SAC	Spherical Aberration Corrector
SALT	Southern African Large Telescope
SALTICAM	SALT Imaging Camera
SANReN	South African Research Network
SCBP	SALT Collateral Benefits Programme
SET	Science, Engineering and Technology
SETI	Science, Engineering, Technology and Innovation
SKA	Square Kilometer Array
SLR	Satellite Laser Ranging
UCT	University of Cape Town
UFS	University of the Free State
UJ	University of Johannesburg
UNAWA	Universe Awareness for Young Children
UNISA	University of South Africa
UWC	University of the Western Cape

UKZN	University of KwaZulu Natal
VLBI	Very Long Baseline Interferometry
WITS	University of the Witwatersrand

Appendix: The Process

The process followed in arriving at this position paper was to review the relevant documents and reports that have been generated over the past few years. In addition, with the concurrence of the NRF CEO, the views of a number of stakeholders were canvassed on the state of astronomy in South Africa, on the development of skilled human resources in Astronomy.

The documents that were reviewed and the discussions that were held included those listed below.

a. Documents reviewed

The documents reviewed included

- i) SETI Reviews of National Facilities, 1998
- ii) International Panel Report on Future of Physics, 2004.
- iii) NRF Review of Astro-Geo-Sciences Facilities, 2004
- iv) Astronomy Frontiers Programme (P.A. Whitelock et al., 2004)
- v) KPMG report on Astronomy Strategy
- vi) SKA Report on State of Radio Astronomy (2008)
- vii) “New Horizons”: A Decadal Plan for Australian Astronomy, 2006– 2015
- viii) Michael Cherry, Star of the South, *Nature* 438 (2005) 18-19
- ix) Nature article on US Decadal Review of Astronomy
- x) AGAP: DST presentation to the Parliamentary Portfolio Committee on Science and Technology.
- xi) Astronomy Geographic Advantage Act (2009)
- xii) SA National Space Agency Act (2008)

b. Consultations

Consultations were held with a wide range of stakeholders from different institutions. These are listed below.

- i) SAAO: Phil Charles, Patricia Whitelock, Ramotholo Sefako, David Buckley, Peter Martinez and Kevin Govender,
- ii) HartRAO: Roy Booth, Michael Gaylard and Management team,
- iii) SKA: Bernie Fanaroff, Kim de Boer, Faranah Osman, Justin Jonas
- iv) HMO: Sandile Malinga
- v) UCT: Renee Kraan-Korteweg, Peter Dunsby, Thebe Medupe, Kurt van den Heyden
- vi) UWC: Catherine Cress, Chris Koen, Robbie Lindsay

- vii) UKZN: Sunil Maharaj and Kavilan Moodley
- viii) NWU: Okkie de Jager
- ix) Meraka Institute: Bruce Becker

Email inputs were received from Chris Engelbrecht (UJ), Patrick Woudt (UCT), Derck Smits (UNISA), Mike Gaylard (HartRAO), Joao Rodrigues (WITS). In addition, visits were made to and consultations held with Prof Naresh Dadhich, Director of the Inter University Centre for Astronomy and Astrophysics (IUCAA), India, and Prof Steve Rawlings, School of Astronomy, Oxford University, U.K.

The original version of this document was circulated to the astronomy community for comment in 2010. Their input and subsequent discussions were used to update and produce the final version of this document. The group responsible for that drafting comprised: Roy Booth (HartRAO, MeerKAT), Phil Charles (SAAO), Catherine Cress (UWC), Okkie de Jager (NWU), Peter Dunsby (UCT), Renée Kraan-Korteweg (UCT - chair), Mike Gaylard (HartRAO), Thebe Medupe (NWU), Kavilan Moodley (UKZN), Molapo Qhobela (DST), Derck Smits (UNISA) and Patricia Whitelock (SAAO, UCT).

There was practically unanimous support for a holistic astronomy strategy that encompassed the entire wavelength spectrum, from radio astronomy, to optical and x-ray astronomy, to high-energy gamma ray astronomy. It became apparent too that in order to fully exploit our geographic advantages for observational astronomy and astrophysics a new governance structure was required in which outreach and awareness programmes, the development of the scientific and technical human resources and world class research would be managed in a coordinated way.

The document presents brief overviews of the current status in astronomy at the national facilities and universities, of the NASSP and SKA capacity development programmes and of the funding allocations. This is followed by an outline of the key issues that need to be addressed, and finally by a set of recommendations that should form the basis of a decadal strategy for Astronomy in South Africa.