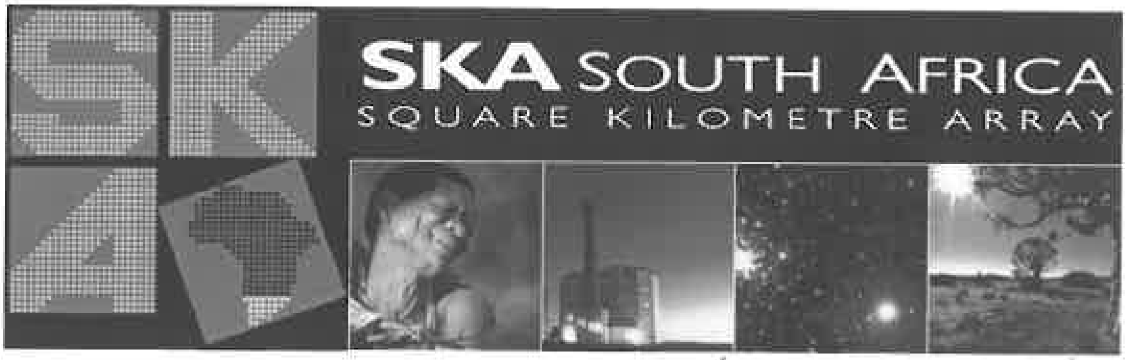

Support for Astronomy and the SKA facility

This SUMMARY report was commissioned by the

SKA Bid Committee

And developed by

Andrew Paterson, Glenda Kruss and Angelique Wildschut

Human Resources Development Research Programme
Human Sciences Research Council

September 2005

HSRC

Contents

Acknowledgements:
Thanks to Jane Hendry for her contribution through the production of tables on the key study fields referred to in this document and for her background knowledge of the HEMIS system.

Acronyms

CSIR	Council for Scientific and Industrial Research
DACST	Department of Arts Culture Science and Technology
DoC	Department of Communications
DST	Department of Science and Technology
DTI	Department of Trade and Industry
GDP	Gross Domestic Product
GIS	Geographical Information Systems
HartRAO	Hartebeesthoek Radio Astronomy Observatory
HEMIS	Higher Education Management Information System
HESS	High Energy Stereoscopic System
HMO	Hermanus Magnetic Observatory
ICT	Information and Communication Technologies
ISSA	Institute for Satellite and Software Applications
IF	Innovation Fund
IMS	Integrated Manufacturing Strategy
IT	Information technology
KAT	Karoo Array Telescope (Also referred to as 'Pathfinder')
NASSP	National Astrophysics and Space Science Programme
NRF	National Research Foundation
PUSET	Public Understanding of Science Engineering and Technology
R & D	Research and development
S & T	Science and technology
SADC	Southern African Development Community
SALT	Southern African Large Telescope
SKA	Square Kilometer Array
SMME	Small Medium and Micro Enterprises
THRIP	Technology and Human Resources for Industry Programme
VLBI	Very Long Baseline Interferometry

1 Aim and structure of this report

This report demonstrates South African support for astronomy and the SKA facility with specific reference to the national commitment to science and technology (S&T) activity and the availability of human resources in astronomy and other fields that would be required to support the SKA project.

Commitment to astronomy from highest levels of government

In his State of the Nation Address in 2004, President Mbeki emphasised the national commitment to growing capacity for Southern Africa to compete as a hub for global astronomy (Mbeki 2004). Astronomy is classified as one of the large scale, broad scope new technology platforms that will be directly coordinated and led by DST as a priority area into the future.

The Minister of Science and Technology recently highlighted the strategy of developing scientific capacity through international cooperative agreements to support and promote priority fields such as astronomy (Mangena 2005b). To this end, an Astronomy Geographical Advantage Programme (AGAP) is being established, to develop capacity to drive multi-wavelength astronomy observation facilities – radio waves, light rays and cosmic rays.

As part of its bid to win the opportunity to host the SKA, the South African government has committed to funding the construction of an SKA 'demonstrator' - henceforth the Karoo Array Telescope (KAT). The KAT will serve as a vehicle: to demonstrate that South Africa does indeed have the technological and scientific skills to host large projects such as the SKA, and to enable South Africa to become an important global role-player in the field of radio astronomy. The aim of the KAT is by 2008 to have an operational radio telescope that, unlike the European FP6, will not merely be a technology demonstrator but a working radio telescope which will be designed with the flexibility to be extended over time and which will complement and extend the current work of major radio telescopes across the globe (Frescura et al. 2005, 3).

These examples suggest that there is a strong commitment from highest levels of the South African government to astronomy as a focus of 'big science', and clear evidence of government's willingness to harness resources to support this aim.

Report structure

This account of the commitment of the South African government to supporting science and technology and of the capacity in South Africa to conduct large scale science projects will procede as follows.

First, attention is drawn to the emphasis on partnerships and cross-sectoral coordination in the South African national system of innovation.

Second, an overview of how South Africa ensures depth, responsiveness and continuity in the science and technology system is presented with reference to: generating public interest, improving the quality graduates from the schooling and higher education system, renewing the acacemic and scientific labour force and replenishing technology infrastructure.

Third, the report shows how innovation and technology transfer are facilitated through partnerships and linkages between higher education, science councils and the private sector. Three examples of big science projects arising out of this environment are given.

Fourth, this report examines the key institutions involved in astronomy activities, namely: the national astronomical observatories, research and teaching capacity in the higher education system and technology development capacity in the science councils.

Fifth, the report describes the range of academic and professional expertise that is available in South Africa that can develop and operation the SKA project.

2 Supportive science and technology policy environment

Partnerships and cross-sectoral coordination in the South African National System of Innovation

The policy environment which frames the South African National System of Innovation recognises the complex nature of research and innovation in the twenty-first century which requires cross-sectoral policy coordination.

The fundamental framing policy text in South Africa since 1994 is the 1996 *White Paper on Science and Technology: Preparing for the Twenty-First Century* (Department of Arts, Culture, Science and Technology [hereafter DACST] 1996). The primary aim of the White Paper is to set up a national system of innovation based on the core principles of partnerships, co-ordination, problem-solving, multi-disciplinary knowledge production, and a societal culture which privileges the advancement of knowledge and information in all its forms (DACST 1996: 3). The White Paper argues forcefully that new forms of knowledge production are emerging as a consequence of globalisation, and that

> traditional ways of producing knowledge within single disciplines and institutions are being supplemented by knowledge generated within various applied contexts. This is knowledge that is collaboratively created within multidisciplinary and trans-disciplinary research

> programmes directed to specific problems identified within social and economic systems (DACST 1996: 6).

In the new Science and Technology policy a key principle of the national system of innovation is 'cross-sectoral' state policy co-ordination. The White Paper (1996) argues:

> The promotion of a national system of innovation as a framework for social and economic policy maximises the possibilities for all parts of the system to interact with each other to the benefit of individual stakeholders or groupings of stakeholders and the advancement of national goals.... (DACST 1996: 5,6,18).

A cross-sectoral approach also informs the National Research and Development Strategy (2002), which provides strategic guidance for growing the Science and Technology system. The approach adopted is to learn from international experience, to adapt systems to local realities, and to mobilise the private sector, research organisations, venture capital and higher education to 'deliver innovation through the technology missions'.

The Research and Development (R&D) Strategy highlights four key thrusts. First, to identify new technology and innovation missions that can accelerate economic growth and wealth creation. Second to identify new technology platforms in line with global trends where, ICT and biotechnology have been prioritised. The third focus is:

> The use of earth observation (satellite and aerial) data to support government, industry and SADC in key areas such as: disaster prevention, monitoring and remediation, mapping and GIS services, agriculture services, land-use and urban development services, amongst others (2002: 45).

The fourth thrust emphasises ways in which a developing country with resource constraints like South Africa can position itself favourably. The principle adopted is that,

> with limited resources, our best chances of success will depend on our ability to focus on our potential strengths while staying well connected to international research (2002: 52).

Hence, it is important for South Africa to focus on scientific areas where there is some geographical or knowledge advantage. One geographical advantage that stands out is astronomy, given that South Africa is one of a few countries – such as Australia and Chile – which has access to the southern skies and a relatively well developed local engineering and big science capacity. One area of knowledge advantage identified is micro-satellite engineering, in which South Africa has a niche competence. Thus, fields of R&D that are cognate to the SKA have been identified by the South African government as priorities for focusing attempts to promote 'big science' on a globally competitive scale.

Within this commitment to a coordinated approach, government has committed itself to increasing R&D funding. South Africa's investment in R&D in 2003/4 stood at 0.81% of GDP, a slight increase from 0.76% in 2001/2, but low in comparison with the international average of 2.15% (DST 2005). There is strong commitment from the highest level to reach the target of 1% of GDP set by the R&D Strategy, by 2008.

3 Programmes ensuring depth, responsiveness and continuity in the science and technology system

Government recognises that a range of conditions must be met in order to ensure depth, responsiveness and continuity in the science and technology system. In moving to address these fundamentals, government has established an enabling environment for S&T projects such as the SKA.

Science in schools and public understanding of science

Education policy and Science and Technology policy stress the need to 'invest in people at all levels' (DACST 1996: 9) through new approaches to education and training. At the most basic level, there are concerted attempts to develop the educational foundations of the citizenry through improving the public understanding of science, engineering and technology (PUSET), and particularly, their preparedness for careers in science and technology. For instance, new curriculum policy proposes mathematics and science studies should be compulsory up to the first possible school exit level at Grade 9, and that mathematical literacy or mathematics should be a compulsory subject choice to Grade 12, the highest school leaving level.

In the space sector specifically, government has created a Space Science Portal (http://www.space.gov.za) by the National Working Group on Space Science and Technology, to disseminate developments and spark interest in this field on a wider basis. The related Space Resource Centre is a non-profit organisation that promotes public and industry awareness of space science and applications. Active participation in World Space Week is co-ordinated between the Departments of Science and Technology, Communications, Trade and Industry and Foreign Affairs. The general thrust of such initiatives is to demonstrate to ordinary South Africans, particularly the youth, ways in which space-related technologies are used in their daily lives, for sustainable development.

Restructuring the higher education system

Higher education institutions are critical to the reproduction of the professional scientific labour force at all levels. Driven by the Department of Education, a process of higher education transformation initiated by the *National Commission on Higher Education (1996)* centres on the need for increased participation by a diverse range of constituencies, greater responsiveness to economic and social needs, and increased cooperation with other social actors. The Department of Education proposed a *New Funding Framework (2003*) that aims to shape higher education in line with national human resources development needs, and ensure that there is dedicated funding for research. All of these processes are intended to improve the efficiency of the higher education system and increase the flow of skilled graduates and professionals from the higher education system, in a more equitable manner than in the past.

Renewing the R&D and academic labour forces

One of the core issues that *the National Research and Development Strategy* (2002) directly responded to is that the human resources for science, engineering and technology must be renewed continuously. To this end, it proposed increased funding and a number of interventions in a targeted, cross-cutting and integrated approach towards increasing research excellence.

In its most recent strategic plan, the NRF proposes to increase the scale and quality of the PhD degree as a key vehicle for enhancing the national system of innovation, to 'provide the bedrock for an innovative and entrepreneurial knowledge society' (National Research Foundation 2005: 6). The new 'seamless approach' adopted, aims to co-ordinate programmes from school level to the point of commercialisation of knowledge. Doctorates are recognised as the 'platform upon which transformation of our knowledge system can commence, so that it can make a real difference to the lives of ordinary South Africans' (National Research Foundation 2005:6). On this basis the NRF has dedicated itself to support internationally competitive 'big science' initiatives, such as the SKA.

Through the vehicle of the NRF, funding and capacity development programmes have been initiated to intervene by strengthening the academic and R&D labourforce at a number of different levels such as: development programmes, grant schemes, scarce skills scholarships, post-doctoral fellowships, and awards for excellence.

Enhancing the R&D institutional infrastructure

In terms of enhancing the research and development (R&D) labour force and R&D capacity in general, the NRF manages a number of programmes: the Centres of Excellence and the National Facilities.

Research excellence is to be enhanced by the creation of well-funded Centres of Excellence as a base for retaining skilled scientists as well as for attracting skilled scientists from other countries who can contribute to stimulating the system. For example, one of six Centres established in 2004 is the Centre of Excellence in Strong Materials, which studies materials such as hard metals, metal alloys and ceramics that retain their distinctive properties under extreme conditions. These have wide applications in the manufacturing and mining industries and may be of significance for the construction of SKA components (http://www.nrf.ac.za/centres/strong.html).

In addition, South Africa has a number of science councils, the most relevant to this overview being the Council for Scientific and Industrial Research (CSIR). There is a recent commitment to the re-capitalisation of basic research capacity at the CSIR, and to enhance its research capacity development programmes. Science councils are charged with expanding their international activities in areas of strategic importance, and to create internationally visible centres of excellence to open opportunities for international collaboration.

Equipment and technology infrastructure

A National Equipment Programme administered by the NRF (http://www.nrf.ac.za/equipment/) aims to provide funding to enhance the equipment infrastructure for research and technology development, informed by a *National Research and Technology Infrastructure Strategy* (2004). The strategy proposes a major intervention to fund the renewal of research infrastructure in higher education and science councils. Of particular significance to SKA, is a strategy to support the development of 'big expensive facilities'. Upon Cabinet approval such projects may be spearheaded by DST but funded by way of special grants from the parliamentary science vote, with management responsibility assigned to a specific agency.

Provision for a 'long range planning culture around research equipment' (DST 2004: 11) is thus a significant indication of future R&D capacity, particularly for 'big science' projects. Moreover, a strategic approach has been adopted to co-ordinate long-term re-capitalisation and funding of world-class equipment for national science missions based on geographical or knowledge advantage, and national technology missions – of which astronomy and space science is one key mission. As will be shown below, significant funding has been allocated for the 2007/8 financial year for science and technology infrastructure, including astronomy facilities.

International scientific collaboration

A key challenge identified by the DST in developing the science and technology system is to position South African capacity more effectively and advantageously in the international arena.

Modes of collaboration include exchange of experts and students from higher education and science councils, joint research projects, scientific and technical publications, seminars and conferences, usually in niche areas, and often to promote participation from disadvantaged groups (http://www.nrf.ac.za/funding/opportunities.stm).

Collaboration within Southern African is identified as a priority, to contribute to regional development. A framework for cooperation between researchers in the Southern African Development Community (SADC) was developed in 2000 (DACST 2000). Essentially, this is premised on supporting peer-to-peer interaction, in broad project areas, based in the respective Science Councils, with a view to leveraging additional donor funding. Based on extensive research, such a course of action was proposed to facilitate rapid and effective cooperation.

Technology missions

In accordance with international trends in the 1990s the DACST initiated a national technology foresight exercise to identify emerging generic technologies as early as possible, to target resources and to facilitate effective and timely development of these technologies. The National R&D strategy emphasises the significance of new technology missions aligned to quality of life goals, and economic and industrial strategies.

The *National Research and Technology Foresight Project* began in 1997 and culminated in a synthesis report in 1999 that identified three emerging technological bands requiring prioritisation: Biotechnology, Information and Communication Technologies (ICT) and New Materials development. A range of programmes targeting the development of capacity in the strategic scientific research areas on which these technologies depend have been initiated by government, industry and the higher education sector.

Government support to increase ICT driven economic activity also provides a facilitative policy environment for the SKA. The ICT sector is subject to direct government influence in a number of dimensions, including regulation of the telecommunications sector which provides infrastructure for electronic communication. Government departments and agencies including DST, DTI, Department of Telecommunications and the National Advisory Council on Innovation (NACI) have engaged in research and planning exercises with the intention of identifying, supporting and exploiting the economic, technological and social development potential in the ICT sector. Recent activities include:

- Studies on various sub-sectors of the ICT industry (eg: software development, security etc.) commissioned by the DTI in 2004
- The *ICT Roadmap* exercise initiated by the Department of Science and Technology in 2004, covering five key areas of potential expansion including: high-performance computing, the human computer interface, and web services and applications

Support for the astronomy and space science technology missions structured on similar lines, will be discussed below.

4 Enhancing technology transfer, innovation and networks

It is important to provide a perspective on how the South African government has created an environment that supports technology diffusion in industry, and that encourages R&D networking between higher education, science councils and industry. A national innovation environment which has these characteristics is likely to facilitate the kinds of innovative R&D work that must support the SKA project through its design to implementation.

Technology diffusion in industry

Central to technology diffusion is the presence of enterprises that are able to absorb new technologies, to optimise transfer of technological capacity, and to acquire and grow locally-based expertise. Government's role in technology diffusion - of both domestic and imported technologies – is identified as critical, particularly to stimulating diffusion in the small medium and micro enterprise sector (SMME).

The DTI has developed a new trade and industry policy with the Integrated Manufacturing Strategy(IMS) at the heart of the new approach. The DTI takes a lead role here, but there is considerable cross-sectoral work with DST. For instance, DST has prioritised collaboration with DTI to promote technology diffusion in SMMEs, in line with the 1995 White Paper on a Support Strategy for Small and Medium Scale Enterprises.

In partnership the DST and the DTI have established:

- the Godisa Incubation programme, which provides support to SMMEs, by enhancing capacity to apply and absorb technological innovation, particularly in relation to ICT and biotechnology
- The Tshumisano Technology Stations, a joint programme with the German government, entails the establishment of centres to facilitate technology transfer at technikons (since 2005, universities of technology), particularly with SMMEs
- The National Manufacturing Advisory Centre (NAMAC) which supports monitoring and evaluation activities at provincial Manufacturing Advisory Centres, focused on enhancing the competitiveness of SMMEs through technology diffusion

Funding research partnerships and networks

Linkages between higher education, business and science councils are identified as critical to the diffusion of best practice technology. Accordingly, government has put in place programmes to incentivise research partnerships through the NRF which provides support across the research-commercialization value chain, from the conception of an idea and its development, to the point of technology transfer and commercialization through two programmes: the Technology and Human Resources for Industry Programme (THRIP) and the Innovation Fund (IF).

These programmes demonstrate the commitment of government to provide incentives to grow the human resources and capacity required for a vibrant national system of innovation in South Africa that can support big science projects such as the SKA. In addition, some of the research projects that receive funding may themselves be relevant to the design, materials and technological needs of the SKA facility.

The Innovation Fund

The Innovation Fund, which aims to provide incentives for longer-term, large innovation research projects with cross-sectoral collaborative consortia composed of researchers from the higher education sector, government science councils, private sector or civil society (http://www.nrf.ac.za/innovationfund/). The aim is to encourage the key policy goals of competitiveness, quality of life, environmental sustainability and harnessing information technology.

Following an evaluation of its first rounds, the fund has defined its focus areas and themes in alignment with national socio-economic development priorities. In 2004 calls for proposals were in three broad clusters – protecting biodiversity, Missions in Technology (development of high risk, market driven enabling technology) and a Technology Advancement Programme (to support progress to prototype stage). A Commercialisation Office (IFCO) was established in 2003, to facilitate knowledge transfer and networking, by providing entrepeneurial skills that allow a prototype to develop into a license, or a business idea to develop into a spin-off company. Through such mechanisms, the IF aims to intervene in technology transfer value chain, in line with the vision of building a knowledge economy.

The Innovation Fund, has invested R650million to date, in 106 large-scale projects, allocating approximately an equal share between science councils, universities and private sector research agencies (Innovation Fund 2004). Investments in the manufacturing, environment and mining and minerals sectors average R65 million each, and about R4 million in the telecommunications sector.

There may be considerable scope for lateral migration of the technology developed on the basis of this research, for applications to support the implementation of the SKA. For example, the development of advanced titanium metal technology may provide innovative solutions for the construction of the SKA facility.

The Multi-sensor Micro-satellite imager (MSMI) project which is funded through the Innovation Fund stands out as an indication of the kind of knowledge and technology that can develop out of local capacity based in universities and science councils, drawing in international collaborators in universities and industry, and attracting interest from international space agencies (See Box 1 below).

Box 1. The Multi-sensor Micro-satellite imager research consortium
The Multi Sensor Microsatellite Imager (MSMI) research project is the first active project of the large, multi-agency, medium term ZASat programme. The ZASat programme is currently being driven by academics at the University of Stellenbosch, as part of the Stellenbosch Satellite Engineering Group (SSEG). It is an attempt to form a consortium that includes the Satellite Applications Centre at the CSIR, in collaboration with DST and the Department of Communications. Key players in government, user and technology organizations have agreed to work towards a common plan for a R200 million, 5 year programme for space technology in Southern Africa. A key strand in these attempts is the fledgling micro-satellite industry, of which the partners within this network are pioneers, having designed and built South Africa's first satellite, SunSat1.

In 1994 negotiations began with NASA, the USA space agency, for collaboration around the launch of the satellite being developed. SunSat was researched, developed and manufactured completely at Stellenbosch University in the ESL, by a local team of engineers including post-graduate students, and successfully launched from California in 1999 by NASA. The only external involvement at that stage was for the optics of the imager, through the CSIR. Some of the key innovations were the imager, the gravity gradient boom, the star camera and the software development. Clients and partners of SunSpace in the space industry internationally include the Australian Co-operative Research Centre for Satellite Systems, the Satellite Technology Research Center (SaTReC) established in 1989 and located within the Korea Advanced Institute of Science and Technology (KAIST) and National Aeronautics and Space Administration, NASA.

The MSMI project was formed in 2003 around the Innovation Fund consortium consisting of Stellenbosch University, SunSpace and Information Systems, the CSIR-Environmentek and the Agricultural Research Council-Institute for Soil, Climate and Water. The latter two partners are integrally involved in the technology design from an applications perspective, given their interest in applications of satellite images in the service of monitoring natural resources. An additional set of relationships are structured into the network in the form of a collaboration between the University of Stellenbosch and partner researchers at the Catholic University of Leuven, who are in turn partnered with Belgian industry, funded by the Flemish government. A second additional set of relationships are structured into the network through a sub-contracting relationship between SunSpace and Defencetek of the CSIR, specifically, the Optronics Research Group, responsible for the optics development and manufacture.

The micro-satellite sector is a high value-added business with a direct financial benefit, besides the spin-offs in other technology areas.

The Technology and Human Resources for Industry Programme

The DTI introduced the 'Technology and Human Resources for Industry Programme' (THRIP), which has a number of objectives. Firstly, it facilitates and funds the increased participation of higher education and science council researchers and students in industrial innovation, technological adaptation and commercialisation. Secondly, THRIP encourages the formation of stronger linkages between companies in undertaking joint R&D work. And lastly, THRIP promotes technological development in the SMME sector.

In this way, THRIP aims to address the challenge of supporting increased levels of science, engineering and technology performance, in the context of rising demands for its limited funds. This programme aims to foster a culture of strategic and applied research collaboration between academics in higher education and researchers based in industry.

The programme has been extremely successful in facilitating research partnerships between industry, higher education and science councils, with a growing number of research projects and expenditure rising from R202 million in 1999 to some R367million in 2003. The accumulative total funds spent on research, including industry's contribution, since 1995 is R1 818,9 million.

The largest industrial sector accessing THRIP funds is manufacturing, receiving over 50% of funding (Table 1). However, this is a cross-cutting sector and includes projects from a wide range of economic sectors. There are a number of significant examples of innovative research in the field of new materials development, which may have implications for the infrastructural requirements of the SKA. For instance, the development of a new composite cement material containing synthetic fibres instead of asbestos, by a team based at the Department of Civil Engineering at the University of Pretoria, supported by Grinaker-LTA. The project has expanded to include not only foamed concrete and mining applications of concrete, but also conventional pre-cast concrete used for infrastructure above ground (http://www.nrf.ac.za/thrip/AnnualReport/less_more.html).

Table 1. THRIP funds allocated by Industrial Sector in 2003/4 (ZAR million)

Sector	ZAR	%
Transport, storage & communication	18.5	7.0
Agriculture	22.2	8.4
Electricity, gas & water supply	24.3	9.2
Mining	26.2	10.0
Manufacturing	171.6	65.3
	262.8	99.9

Note: Total may not add up to 100 on account of rounding

An HSRC survey conducted in 2002 found that THRIP industry partners display a high degree of commitment to research partnerships (HSRC 2003). There was evidence of an appreciation of the benefits of research partnership and networks, which bodes well for future collaboration

It has also had successes in supporting research and innovation in areas cognate to the infrastructural, hardware and software requirements of SKA. One project which may have potential application to the infrastructure and software development required for the SKA related to a research network which focuses on measuring polarization mode distortion in optical fibre for higher levels of efficiency (Box 2).

Box 2. The Fibre Optic Cables network

The University of Port Elizabeth Department of Physics hosts a collaboration with a large local company, Aberdare Fibre Optic Cables, its American partner, Corning Optical Fibre, and Telkom to improve the quality of optical fibre and cabling. The partnership is based in the institution's Telkom Centre of Excellence, one of a number of such telecommunications research centres sponsored by Telkom to facilitate research collaboration between higher education institutions, and to promote human resources development through providing post-graduate bursaries and a national academic network.

5 'Big science' projects in South Africa

It is important to highlight that South Africa has a strong science environment that serves as a base for 'big science' projects, of which three examples are cited below. Of particular interest is the recent success of the SALT astronomy project.

The aim is to provide exemplars of 'big science' projects which demonstrate the capacity of the South African S&T community to engage in large scale, large budget, multi year multi-lateral projects. This element is very important for projects such as the SKA, which necessitates stable, efficient and sustainable collaborative international partnerships.

Pebble Bed Modular Reactor (PBMR)

The South African electricity utility, Eskom, has been investigating the PBMR since 1993 as part of its strategic planning process. The objective of these investigations was to establish whether such a system could form part of Eskom's expansion planning. Various geo-energy, spatial and supply factors prompted Eskom to contemplate small electricity generation plants that can be placed near to the points of demand. The PBMR concept, which has a short construction lead time, low operating cost and fast load-following characteristics, is such an option.

In 2000, a PBMR company was formed between Eskom, the Industrial Development Corporation of South Africa (IDC), British Nuclear Fuel (BNFL) and the US utility Exelon, to build and market PBMR-based power plants. The intention is to build and operate a single module to serve as a demonstration plant and a launch platform for local and international sales. Successful completion of the demonstration phase will be followed by commercialization, with Eskom likely to be the first customer (https://www.pbmr.co.za/).

Deep Mining

Over a long period, South Africa has gained international respect in deep and ultra deep level mining technologies (Mangena 2004). In 1996, the CSIR's mining technology division, Miningtek, and Wits University initiated "Deep Mine" - intended to identify new technologies that would sustain gold mining's competitiveness. Driven by industry needs, the programme was launched in 1998 based on collaboration from within the industry and on a joint funding commitment over four years of R70million. The programme produced a range of innovations and reports which led to the creation of a web-portal for dissemination of reports to mining companies globally.

The PBMR and DEEPMINE projects demonstrate that South Africa's science and technology community has the technical, innovative and management capacity to engage in large-scale multi-year and large-budget science projects with international partners.

South African Large Telescope (SALT)
The South African Large Telescope (SALT) is a good example of a successful and groundbreaking South African astronomy project. SALT is the largest optical telescope in the Southern Hemisphere. In its original concept it was modeled on the Hobby-Eberly Telescope in Texas which provided SALT's engineers the opportunity to make creative use of the 'lessons learned' from the only existing telescope of this type (SAAO 2005).

In September 2005, SALT's full array of mirrors (91 hexagonal mirror segments in a primary mirror array spanning 11 meters across) and its digital imager/camera (SALTICAM) built at the South African Astronomical Observatory, successfully became fully operational with the production of its first colour images (SAAO 2005).

Telescope and instrument commissioning as well as full optimization of SALT's systems are currently being completed. Nevertheless, it is important to recognise the overall success of the project. The team of local engineers and scientists in collaboration with eleven international institutional partners from six countries (including Germany, Poland, New Zealand, UK and USA) successfully built SALT to the tight five year timescale and in addition, achieved this within the original budget that was set at US$20 as early as 1998(SAAO 2005).

Furthermore, South African based institutions were successfully awarded about 60% of the tenders to construct SALT, which meant that many of the high-technology elements of the project – such as the robotic tracking system - were contracted to South African industry. As a result the R&D community in South Africa have acquired skills and capabilities that were previously not realized (SAAO 2005).

The SALT therefore presents a powerful example of the capacity of the science and R&D community in South Africa to develop and execute innovative high technology astronomy projects (The SALT project is discussed in more detail with reference to the SAAO).

6 National Astronomy Observatories

Having provided an overview of how government policy with reference to S&T has matured, the aim in this section of the report is to demonstrate the current science and technology capacity and activity in South Africa specific to astronomy and also in fields of research that are cognate to the SKA project. Hence, this section will provide an overview of current activities and capacities in the:

- national research facilities,
- the science councils, and the
- higher education institutions

National Facilities

The national facilities are grouped in clusters in relation to their domain of knowledge production: Astro/Space/Geo Sciences; Biodiversity/Conservation, and Nuclear Sciences. These clusters are aligned with the science themes identified as critical in the national Research and Development Strategy and central to the national research and innovation agenda (NRF 2005: 8).

The criteria for national facility status are stringent and in order for an institution to become a national facility it should fufill the following:

- They should have a unique position in South African knowledge production;
- Their core technologies, research methods, or data pools/collections should live up to international standards;
- Their goals should be well-aligned with the overall objectives of the national system of innovation, especially with regard to the diffusion of new knowledge;
- They should have critical mass of equipment, skills and users – these include researchers from the higher education sector, Science, Engineering and Technology Institutions (SETIs) and, where appropriate, from industry;
- They must have potential for networking and for attracting international collaboration to South Africa (NRF 2005: 37).

It is significant that three out of South Africa's seven national facilities operate in the field of astronomy. They are:

- the Hartebeesthoek Radio Astronomy Observatory (HartRAO),
- the Hermanus Magnetic Observatory (HMO), and
- the South African Astronomical Observatory (SAAO).

This demonstrates the importance given to astronomy in government's S&T strategy

Funding National Facilities

The South African Department of Science and Technology funds the national facilities through the National Research Foundation (NRF). The budget allocation for the seven national facilities from the NRF for 2005/6, is R129.742m (Table 2). Within the overall budget for national facilities, the share allocated to astronomy facilities is consistently in the region of 30%. This demonstrates the firm commitment of government to the expansion of knowledge and infrastructure, and the deepening of resources and research in astronomy.

Table 2: National Research Foundation budget allocation 2003/4 to 2005/6 (in ZAR million)

	2003/4	2004/5	2005/6
Total NRF allocation	377.263	409.276	518.873
Budget for seven National Facilities	109.565	122.876	129.742
Budget for astronomy based facilities	32.540	37.264	38.980
Astronomy share of budget	29.7%	30.3%	30.0%

Table 3 provides a breakdown of the total allocation to the astronomy related national facilities (HartRAO, HMO & SAAO), namely, an amount of R38.98m. This table does not represent the entire value of NRF allocations to national facilities, because certain initiatives or programmes may receive additional separate NRF funding, such as the Southern African Large Telescope (SALT) which will receive a separate allocation of R3 000 000 for 2005/6 from the NRF, even though it resides under the SAAO.

Table 3: Astronomy national facilities budget allocation 2003/4 to 2005/6 (in ZAR million)			
Facilities	**Total 2003/4**	**Total 2004/5**	**Total 2005/6**
HartRAO	10 751 000	11 864 000	12 631 000 (32.4%)
HMO	4 311 000	4 248 000	4 398 000 (11.3%)
SAAO	17 478 000	21 152 000	21 951 000 (56.3%)
Total	32 540 000	37 264 000	38 980 000 (100 %)

The report will discuss each of the three astronomy facilities in turn according to their respective share of the national facilities budget.

South African Astronomical Observatory (SAAO)

The South African Astronomical Observatory is the prime national research facility for optical/infrared astronomy in South Africa. It focuses on furthering fundamental research in astronomy and astrophysics at both the national and international levels. Its programmes are aimed to better understand the formation, structure and evolution of our galaxy. It plays an advocacy role in terms of furthering awareness and research of astronomy and astrophysics in the Southern Africa.

The NRF budget allocation from the Department of Science and Technology for 2005/6 is R21 951 000. This represents 16.9%, of the total NRF allocation to national facilities and 56.3%, of the allocation to astronomy facilities in 2005/6. If one were to judge government commitment solely on monetary terms, this facility would rank very highly in terms of its importance for the national research and development agenda. Over and above this budget allocation, an additional R 1 368 000 was spent in 2004 in improving the research infrastructure of the SAAO, showing firm commitment to increasing present instrumentation capacity.

The facility displays research excellence and is underpinned by strong technical competencies in clearly defined niche areas (SAAO 2004). SAAO's general areas of research include: 1) Galaxies and Quasars, 2) Magellanic Clouds, 3) Galactic Structure and 4) Stellar Astrophysics.

The capacity for maintaining international collaborative partnerships is an important aspect in judging the capability of a facility. There are six installations at SAAO Sutherland currently operated by foreign groups:

- the Birmingham Solar Oscillations Network (BiSON), a collaboration between SAAO and Birmingham university in the United Kingdom
- the Broad-band Seismograph (SUR), a collaboration with the university of California in the United States of America

- the Infrared Survey Facility (IRSF), a collaboration with Nagoya University in Japan
- the Monitoring Network of Telescopes (MONET), a collaboration with Georg-August-Universitat and the SA-German Geodynamic Observatory a collaboration with GeoForschungs-Zentrum in Germany
- South African Geodynamic Observatory (SAGOS), a co-operative agreement between the National Research Foundation (NRF), South Africa and the GeoForschungsZentrum Potsdam (GFZ), Germany.
- the Yonsei Survey Telescopes for Astronomical Research (YSTAR), a collaboration with Yonsei University in Korea (SAAO 2004).

This national facility's potential for international collaboration is further illustrated by the fact that many of its scientists hold office in the divisions and commissions of the International Astronomical Union (IAU) (NRF 2005: 55).

The flagship project of SAAO is the Southern African Large Telescope (SALT), that was highlighted earlier in this report as an example of the engineering, astronomy and management excellence which South Africa can bring to astronomy projects. The opportunity to build SALT arose out of consistently high quality work undertaken in projects within the SAAO. The quality of the science carried out by SAAO using various instruments, including the Automatic Photometric (Alan Cousins) Telescope, with good results presented a strong case for new investment in the construction of a top class telescope - SALT - in South Africa under the banner of SAAO (Box 3 below).

Box 3. The Southern African Large Telescope (SALT)
The Southern African Large Telescope was conceptualized as an African facility and initiated in 2000, at an estimated cost of some $30 million. The telescope and instrument commissioning as well as full optimization of SALT's systems are currently being completed. The Performance Verification phase of SALTICAM recently completed is has provided opportunities for broad participation in a large international consortium.

The SALT design is based on the Hobby-Eberly Telescope(HET) in Texas, but deviates in many ways to accommodate requirements specific to SALT and to take advantage of the opportunity to optimise aspects of the design where difficulties have been identified with the HET performance. SALT is in effect the largest single optical/infrared telescope in the southern hemisphere, with a hexagonal mirror array 11 metres across. The SALT Science Working Group has representatives from the partner institutions, and is responsible for determining the user requirements for the telescope.

SALT is an excellent example of South African capability in astronomy and space science, not only in the manufacture of parts necessary to assemble such a piece of equipment, but the capacity to manage and maintain large-scale international collaborations. About 60% of the parts necessary for the construction of the telescope have been contracted in South Africa, which partially addresses the goal of creating spin-off companies from this project. Black empowerment is ensured through the criteria set for the selection of participating companies. This also in part addresses the educational or skilling benefits to previously disadvantaged individuals through the practical experience received as a part of the construction team. The SALT project recognizes training, development and education in astronomy and cognate fields as a priority, nationally and internationally. This is illustrated by the SALT Collateral benefits plan, which aims to promote industrial empowerment, educational empowerment, public outreach and direct educational benefits. The SALT project has specific programmes aimed at addressing educational development of Africans, in the astronomy and space science fields.

The Rutgers SALT postgraduate fellowship provides funds for the training of black PhD South African students in astronomy, and the STARTEC initiative connects groups of science communicators/educators associated with large telescope facilities, with the aim of promoting public outreach and science education.

These elements clearly illustrate SALT's commitment to the principle of not only scientifically and financially beneficial, but also broadening developmental astronomy and space science practice. This example also clearly illustrates SAAO's capability and capacity to manage and successfully maintain similar astronomy projects on a scale such as the Square Kilometre Array (SKA) would necessitate.

SAAO is currently involved in the transitional period to the full operations phase of SALT:

- Recruitment of initial astronomy operations staff.
- Commissioning of Salticam, the SALT verification and acquisition instrument.
- Commissioning of the Acquisition Camera and Science Imager (ACSI) mode.
- Restructuring of SAAO for optimal operation in the SALT era.
- Reorientation of the operations of the small telescopes, which support SALT.
- Increased focus on building public-private partnerships, with the aim of constructing the Stargate visitor center, as well as capacity to operate the facility.

The operation of SALT represents a gateway to opportunities for expanding the astronomy science base in South Africa, greater employment opportunities, and more incentives undergraduate and graduate students to enter the field of astronomy.

Hartebeesthoek Radio Observatory (HartRAO)

HartRAO is the only major radio astronomy observatory in Africa (www.hartrao.ac.za/ summary). It focuses on research and training in radio astronomy and space geodesy in South Africa. It is further devoted to research into radio wavelengths and their mapping. It was originally built in 1961 by NASA, and during that time operated as a Deep Space Station. Like HMO, it was also previously administered by the CSIR until 1991. It is frequently used in very long baseline interferometry (VLBI) networks and is a member of the European VLBI network.

The NRF budget allocation for HartRAO from the DST for 2005/6 is R 12 631 000, which is 9.7% of the total allocation to national facilities and 32.4% of the allocation between the three astronomy national facilities. HartRAO has a staff of 55, indicating sizeable human capacity for astronomy research.

It has three main programmes. First, the SKA itself, where HartRAO forms a part of the team to develop the bid to host the SKA in Africa. Second, the Radio Astronomy Programme, which includes radiometry, spectroscopy, pulsar timing, and VLBI, as observing techniques for astronomy. HartRAO's Radio Astronomy Programme is restructuring in order to meet expectations and prerequisites of the SKA and greater university involvement.

Third, the Space Geodesy Programme, forming part of a global network, using applications of very long baseline interferometry (VLBI) and the global positioning system, in order to conduct research in geodesy. They are in possession of a satellite laser that provides data to NASA, together with the International Laser Ranging Service (ILRS) and the GPS base station network, which provides data to the International GPS service. It is one of the five permanent "fundamental space geodesy stations worldwide..." (NRF 2005: 40). Although geodesy is not astronomy, these examples clearly illustrate HartRAO's capacity and future capability to efficiently maintain international collaboration.

HartRAO's future plans related to the SKA include:

- Completion of SKA bidding process
- Development of the Research and Technology Collaboration Centre (RTCC)
- Groundwork of design and engineering requirements for the SKA
- Development and construction of the Pathfinder demonstrator (See 'Karoo Array Telescope' below) (NRF 2005: 41).

The Karoo Array Telescope (KAT)

As part of its bid to win the opportunity to host the SKA, the South African government has committed to funding the construction of an SKA 'demonstrator' - henceforth the Karoo Array Telescope (KAT). The KAT will serve as a vehicle: to demonstrate that South Africa does indeed have the technological and scientific skills to host large projects such as the SKA, and to enable South Africa to become an important global role-player in the field of radio astronomy. The aim of the KAT is by 2008 to have an operational radio telescope that, unlike the European FP6, will not merely be a technology demonstrator but a working radio telescope which will be designed with the flexibility to be extended over time and which will complement and extend the current work of major radio telescopes across the globe (Frescura et al. 2005, 3).

Construction of the KAT has already begun. The design and planning of prototype dishes for KAT is underway, but in the interim the 26 metre Hart RAO dish will be used to test new signal processing technologies. A single prototype antennae will be constructed at Hartebeesthoek which permits engineering tests at a location with full technical support. This phase will be followed by replication of the test dish array construction in the Northern Cape targeted for operation in 2009 (Gaylard,2005;Frescura et al,2005,4).

The core aim of the KAT is to test and demonstrate the new technologies needed for the SKA. Nevertheless, in its own right, KAT has the potential to be a valuable survey, monitoring and observing instrument which can be put to a variety of uses including: radio wavelength surveys of different types, and high impact survey of redshifted HI (Frescura et al 2005, 5)

Hermanus Magnetic Observatory (HMO)

As part of a worldwide network of magnetic observatories, the Hermanus Magnetic Observatory's (HMO) primary function is to monitor and model variations of the earth's magnetic field. It aims to be a center of excellence in geomagnetic field related research, information and services, which should stimulate collaboration with researchers and students from South Africa and other countries.

The NRF budget allocation for HMO from the DST for 2005/6 is R4 398 000. This figure makes up only 3.4% of the total allocation to national facilities and 11.3% of the allocation to the national astronomy facilities in 2005/6. It should be borne in mind though, that the HMO has only relatively recently been given national facility status (www.nrf.ac.za/facilities/hmo/)

HMO's broad research areas are firstly, space physics, involving research of the earth's magnetic field and the space environment, and secondly, geomagnetism, which monitors and models the geomagnetic field variations, as well as providing data, models and information. The work done by HMO on ionospheric propagation will be useful for the SKA. Thirdly, technology, providing controlled magnetic-field and sensor-related services and research to clients on a commercial basis. HMO also does education and science awareness, which develops and implements science awareness programmes aimed particularly, but not exclusively, at school children.

In terms of its capacity for international collaboration and partnerships, the HMO forms part of a worldwide collaboration network of magnetic observatories studying the variations of the earth's magnetic field. The HMO has entrenched partnerships related to the type of research it carries out, which have sustained the facility over the years. Box 4 provides an example of a flagship international collaborative research project, Inkaba ya Afrika, that is pertinent to SKA.

Box 4. Inkaba ye Afrika

This project was initiated in 2003/04 following concern expressed locally and internationally about the decrease in geomagnetic field in the southern Africa region. The initiative to study and explain this phenomenon is called Inkaba ye Afrika. Research activities will use both ground-based and satellite data. Funding for this ongoing project is shared between the South African government and German funders on a 1:2 basis.

This facility holds significance for the SKA, because the "characterization of ionospheric conditions above the proposed SKA sites is a key parameter requirement" (NRF 2005: 42). HMO's use of the global positioning system (GPS) signals, to provide a more accurate characterization of the total electron content (TEC) of the ionosphere, is of strategic importance. Radio telescopes' ability to accurately observe and record radio signals, the currently available method used to determine the condition of the ionosphere, are adversely affected by TEC. This is important for both the conceptualization, and the actual operation phases of the SKA. The importance of this facility for the SKA cannot be overstated, as the recording stations at HMO are the only "operational sources of ground-based geomagnetic field data south of the equator in Africa" (HMO 2002: 1).

In addition, HMO's participation in INTERMAGNET is important. INTERMAGNET is an international organization routinely collecting real-time data at central collection points via the internet. This data is available to be used internationally, meaning that the HMO has access to data from other magnetic observatories. HMO has a service contract with the Satellite Applications Centre (SAC) of CSIR. This is a good example of national collaboration capability between HMO and SAC, which increases its capacity. HartRAO also has INTERMAGNETstatus.

HMO's future plans for 2005/6 include:

- Consolidation of South Africa's ionospheric research activities, and also increasing the number of post-graduate students within this field. (Rhodes University is significant in this regard, see below).
- HMO's takeover of responsibility for the technical maintenance and development of the SHARE HF-radar facility from the University of KwaZulu Natal.
- Sustaining funding for the Inkaba ye Afrika project.

7 Astronomy research capacity and expertise in higher education

Six universities have significant research expertise in astronomy, three historically English medium universities, and three historically Afrikaans medium universities. All have associated observational sites, many have long well-established histories and reputations, and most have access to significant research equipment and/or observatories. Each university will be described in turn.

North-West University

The newly created North-West University (NWU) received an Innovation Fund award for the most progressive innovative university of 2004 in the National Innovation Competition, which reflects the institution's commitment to harness research in the service of innovation. The North West University was formed from the merger of the University of North West and the University of Potchefstroom.

The Unit for Space Physics is a long-standing astrophysics research group based in the School of Physics, at the Potchefstroom Campus (www.puk.ac.za/physics/). Its research is conducted in collaboration with national and international groups, in the following fields: Antarctica (South African National Antarctic Programme), gamma rays (Gamma Ray Group), star formation and radio astronomy (HartRAO, Sutherland, CTIO and Heinrich Hertz Telescope) and heliospheric physics (SANAE).

The USP has also been involved in radio astronomy from the beginning of 1990 with the assistance of the HartRAO telescope at Hartebeesthoek. Areas where star formation is taking place are studied by means of the maser radiation which is characteristic of such areas. (http://www.puk.ac.za/physics/Physics%20Web/Research/Research.htm).

From 2001, the unit has been involved as a partner in an international group involved in erecting a world-class gamma ray telescope in Namibia, the High Energy Stereoscopic System (HESS). The HESS project is based on an international collaborative partnership with a wide range of European universities and research institutes globally.

Commercialisation of locally designed apparatus has been taking place since 1998. North-West university and the SPU is also of interest in its promotion of commercialisation and the application of technology developed in space research to everyday uses in other fields (see Box 5 below).

Box 5. The commercialisation of space physics research
The School of Physics and the Unit for Space Physics have commercialised a spin-off from basic research in space physics, namely an effective ozone generator. The Unit for Space Physics has applied the technology it developed to make switched mode power supplies smaller, cooler and more effective. Ozone is a highly oxidising gas that destroys bacteria and viruses, that has been used to purify water and air and to increase the shelf life of foods. The new ozone generator can be applied to various social problems, such as the sterilisation of medical equipment in rural hospitals and the purification of water and air. The efficiency of the process opens new areas for research into possible applications of ozone, for example in the chemical and pharmaceutical industries. A company called Sterizone has signed a contract with the university to produce and market the new ozone generator, with venture capital supplied by HBD (Here Be Dragons), a company started by Mark Shuttleworth (http://www.puk.ac.za/opencms/export/PUK/html/fakulteite/natuur/fisika/komersialisering_e.html).

Rhodes University

Astronomy at Rhodes is housed in the Department of Physics and Electronics (http://www.rhodes.ac.za/academic/departments/physics/), with a research focus on: aeronomy, radio astronomy, luminescence and electronics. The Radio Astronomy group, headed by Prof. J. Jonas, uses the radio telescope at HartRAO as its prime instrument, and actively collaborates with radio astronomy institutes around the world. One of its projects which is is unique and well known in internationally has been to create a microwave map of cosmic radio emission from the southern sky.

The main research areas in electronics relate to the design of instrumentation and control systems to support other research areas. For example, a project was undertaken in collaboration with HartRAO as part of a post-graduate degree, that aimed to design a digital, micro-processor / FPGA-based timer to replace the current systems at the HartRAO Observatory.

University of Cape Town

The existence of a formal department of Astronomy is an indication of the considerable financial and infrastructural commitment to astronomy as a priority - and not only as a sub-field - over many years in this institution (http://mensa.ast.uct.ac.za/).

There is current commitment from the University to build up the group of astronomers in this productive department which has an Emeritus Professor, Prof Brian Warner working full time; one part time honorary Professor, two fulltime professors including Prof Kraan-Korteweg, who is Head of Department. The academic staff is well published in peer-reviewed publications and have international reputations. For instance, Professor Brian Warner, whose major focus is compact stars, was awarded a gold medal by the Academy of Science of South Africa in 2004, in recognition of science that benefits the public.

The Department will offer an undergraduate astronomy course from 2006 which means that UCT as a contact teaching institution joins UNISA - a distance education institution - in offering a full undergraduate programme. This is an important addition to the range of opportunities to study astronomy on a full-time undergraduate contact basis in South Africa.

The Department specialises in high speed photometry and spectroscopy of variable stars, in long period variable stars and Galactic Structure, and in large-scale structures of the Universe. Staff members are interested in: study Cataclysmic Variable stars (exploding stars such as novae) and pulsation white dwarf stars. There is also work on large-scale structures in the spatial distribution of galaxies are carried out. Particular emphasis is given to large-scale structures of galaxies heavily obscured by the foreground Milky Way. There are close research links between the Department and the SAAO and through it, with the SALT project.

Outside of the Astronomy department, the university has a significant research presence across two other units. First, in the department of Mathematics and Applied Mathematics, is the Relativity and Cosmology research group. This group is associated with Professor George Ellis, (now retired), who attained international recognition, being awarded the Templeton Prize for 2004. Current Programme Director of the National Astrophysics and Space Science Programme (NASSP) (discussed below) Prof Dunsby is based in the Department. Second, the Institute of Theoretical Physics and Astrophysics, an interdepartmental research unit is devoted to the promotion of interdisciplinary research in the areas of Astronomy & Astrophysics, Cosmology & General Relativity, and Theoretical Physics (Elementary Particle and Astroparticle Physics).

University of Johannesburg

The University of Johannesburg has in the last year committed itself to expanding activities in astronomy in the Department of Physics with support from that institution's Vice-Principal: Research. There are currently two full time staff members: Prof H Winckler whose research interest is in extra-glactic astronomy and Dr Chris Engelbrecht whose research interest is in theoretical astrophysics and data analysis. This group collaborates with an A-rated statistician in the university on data analysis aspects of pulsar research. Staff are involved in supervising post-graduate students in the fields of pulsar physics and astro-technology and participate in the Johannesburg pulsar research group which collaborates accross the university of Johannesburg, University of Witwatersrand and HartRao. This group intends to offer an astronomy elective module in selected topics in astrophysics in the near future (http://www.uj.ac.za/physics/index.asp)

Members of staff from University of Johannesburg and the University of Witwatersrand are responsible for organisation of a summer school in Astrophysics which will take place in January 2006. The school is the Chris Engelbrecht Summer School in Theoretical Physics, run annually, under the auspices of the Organisation of Theoretical Physicists, a specialist group of the SAIP. This year's school will be concentrating on current key issues in Astrophysics and their impact on KAT/SKA science.

University of KwaZulu-Natal

The School of Pure and Applied Physics at the newly created University of KwaZulu-Natal has two major research institutes in related fields, the Space Physics Research Institute and the Plasma Physics Research Institute, and a new centre the Astrophysics and Cosmology Research Unit (ACRU) under the leadership of Prof Sunil Maharaj.

The Space Physics Research Institute carries out research in magnetosphere and upper atmosphere physics, and has operated in collaboration with a number of national and international research programmes over the years, such as the British Antarctic Survey, Cambridge, the Royal Institute of Technology, Stockholm and the Applied Physics Laboratory, Johns Hopkins University, Baltimore.

The Astrophysics and Cosmology Research Unit (ACRU) is a new centre based at the University of KwaZulu-Natal (http://www.acru.ukzn.ac.za/unit.html). The broad goals of ACRU are to:

- Promote research in astrophysics and cosmology thereby advancing our understanding of the universe and the diverse range of structures that it contains
- Increase awareness of astrophysics and cosmology by informing the public of latest developments in these fields

Staff at the ACRU are involved in optimizing the proposed SKA layout taking key science drivers and the South African geography into account. They are also investigating new science that the SKA could potentially tackle e.g., dark energy clustering and gravitational lensing.
(http://www.acru.ukzn.ac.za/research/galaxies.html#ska_sci)

University of South Africa (UNISA)

The Department of Mathematical Sciences at this distance education university is large, with some 30 research staff members. Two members of staff undertake research that is focused specifically on astronomy (http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=222).

This UNISA Department's contribution to making astronomy accessible as an undergraduate field of study is critical because until 2005 it has been the only university department that offers a dedicated undergraduate astronomy programme.

Prof D Smits's research includes atomic modelling of low-density astronomical gases, and radio observations of astronomical masers. One application of his atomic models is the estimation of the amount of helium formed during the creation of the Universe by the Big Bang. Dr B Cunow's main research focus is internal absorption in spiral galaxies. She is also involved in the Munster Redshift Project, which comprises a galaxy catalogue as a source for studies in observational cosmology, specfiically providing photometric calibration sequences (http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=1675).

University of the Free State

Astronomy at the University of the Free State are based in the Department of Physics, which offers an undergraduate programme in astrophysics and physics where the courses in astrophysics are source based courses presented by the University of South Africa (UNISA). There are two active astronomers in the Department lead by Prof PJ Meintjies who also supervise senior post-graduate degrees.

Astronomy research at this university in the Department of Physics centres on surface science, and astrophysics. The UFS astrophysics group is conducts research in relativistic astrophysics and collaborates with astronomers at University of KZN as well as Pennsylvania. Current research projects focus mainly on the microlens planet detections and the gamma ray burst follow up projects for which the Department provides observational support. Most importantly, projects originating within the Department focus on: accretion driven phenomena in astrophysics like the theoretical and observational study of the cataclysmic variables, the X-ray binaries and micro quasars, as well as Active Galactic Nuclei.

Members of the Department are also external collaborators with the international HESS group, especially in the study of the multiwavelength properties of outbursts in the micro quasars and the High Energy gamma-ray blazars. Since this research involves the release of accretion power into radiation in the presence of supermassive black holes, this research can be categorized as relativistic astrophysics. As a result, the group is in collaboration with Prof Phil Charles, the new director of SAAO, who is a leading authority in the field of black hole astrophysics.

Astrophysics research will benefit from the Boyden Observatory near Bloemfontein as a high standard research facility which has good atmospheric and observation conditions, particularly in the winter, as well as being located at a latitude that makes its telescopes significant for many international astronomical projects. The 1.52m telescope is being refurbished in an international collaboration between the SAAO, Notre Dame University in

Indiana, USA and the Lawrence Livermore National Laboratory at the University of California.

University of Witwatersrand

The University of the Witwatersrand has three astronomers who are located in: the School of Physics, the School of Computational and Applied Mathematics and in the Johannesburg Planetarium. The fields of research interest of these astronomers are respectively: theoretical astrophysics, cosmic dust while the Director of the Planetarium was responsible for setting up the pulsar monitoring programme at HartRAO and works in the field of radio astronomy.

In the School of Physics, a module in Radio Astronomy is offered at the postgraduate Honours level, while advanced courses in experimental, theoretical and applied physics are offered at the Masters level (http://www.wits.ac.za/physics/). Masters and PhD students doing dissertations are supervised in both the School of Computational and Applied Mathematics (CAM) (http://www.cam.wits.ac.za/) and in the School of Physics. In the CAM, astronomy is one of five identified research programmes.

South African Institute of Astronomy

The imperative to fast-track the development of an effective indigenous university user-community for South Africa's world class astronomy facilities has been recognised within the local astronomy and broader science community.

Astronomers in South Africa have taken the initiative to address the challenge brought by the need to increase the critical mass of astronomy research capacity in the form of the proposed South African Institute of Astronomy (SAIoA).

The SAIoA concept was born following an intensive process of consultation within the astronomy community and with various stakeholders. The central objectives of the SAIoA are envisaged as:

- To attract and train future South African graduate students – especially PhD students - and provide an environment in which students can interact with top rate scientists
- To support the development of human resources which can maximize the scientific return from astronomy facilities, and to achieve scale with respect to exploiting the substantial research resources as they become available
- To engage in technology development through the establishment of an astronomy technology centre to exploit the expertise developed in the development and construction of SALT and SALTICAM, and a technology collaboration centre to encourage the formation of inter-institutional research groups that have sustainable critical mass

- To develop the SAIoA within the vision of NEPAD as a 'Centre of Excellence'
- To exploit the possibilities associated with the development of a virtual observatory
- To support the successful National Astrophysics and Space Science Programme (NASSP) in developing students in space physics and astronomy
- To encourage the growth of theoretical astronomy as well as to explore the social and historical aspects of astronomy in South Africa, and
- To engage strongly and consistently with society through programmes of education, outreach and public relations.

The SAIoA is slated to be located in Cape Town to exploit synergies with the SAAO and the NASSP programme which are based there.

Representatives of the astronomy and broader science community in South Africa who developed the SAIoA idea recently presented a full proposal to the Minister of the Department of Science and Technology. This is a positive sign that government is taking the prospect of creating the SAIoA seriously. Developments are pending the decision by the Department.

8 Science Council support

From a number of science councils in South Africa, there is one council which conducts research and development activity of relevance to the SKA – the Council for Scientific and Industrial Research (CSIR). The CSIR's main focus is to act as a technology bridge for the transfer of scientific and technological advances to South Africa and the wider Southern African Development Community (SADC). It further aims to funnel international technology and adapt it for African specific conditions, developing technology locally to meet South African needs.

The CSIR claims to be the largest, most comprehensive "community and industry directed scientific and technological research development and implementation organization in Africa, and currently undertakes approximately 10 per cent of all research and development work on the continent" (www.csir.co.za). It has a staff component of approximately 3 300 scientists, engineers, technologists, technicians, sociologists and support staff. It has very stable financial and technological capability, as well as longstanding international networking relationships and collaborations.

What is important to recognize in terms of CSIR's potential contribution to the SKA bid, is the vast capacity and expertise in the inter-related business units, and the capacity to manage partnerships with industry and higher education, in addition to international linkages (see for example, the discussion on Innovation Fund incentivised projects above). The CSIR's direct importance for the SKA bid stems more from its extensive technological and management capacity in space science applications and cognate fields, rather than astronomy directly.

There are three units in the CSIR which do work relevant to the SKA.

First, DefenseTek is involved in the development of the Karoo Array Telescope (KAT).

Second, the Satellite Applications Centre, is positioned "for ensuring greater stakeholder input on space science and earth observation, investment and business planning advise, as well as on performance in terms of science and technology excellence" (www.csir.co.za). Its ground station is at Hartebeesthoek, ideally situated for satellite operations, telemetry, tracking and command services, and data acquisition.

The third centre, Boutek, is the CSIR's Building and Construction Technology component. Its broad areas of expertise include:

- Development Management
- Facilities Planning and Management
- Construction Technologies and
- Materials

Its expertise in facilities development and construction may be significant for the SKA.

9 Academic and professional expertise to develop and operate the SKA project

Introduction

The SKA project will generate broad demand for human capital in the domain of high level S&T skills. The skills needed will include those applicable to:

- planning, development and installation of the physical facilities at the telescope sites
- design, prototyping and manufacturing of a the antennae for the telescope array as well as a wide range of artifacts, components, and materials related to the SKA infrastructure
- design, development and installation of various software systems, components and utilities
- supply of services associated with the ongoing operations and maintenance of the installation.
- Undertaking astronomy research at the frontiers of knowledge

The aim of this section is firstly, to describe the population of academics and professionals in astronomy and to indicate the likely expansion of this population with reference to numbers of graduate students and training facilities. The second aim is to consider the availability of the population of engineers and other technical personnel that would be required in the planning, construction and operation of the SKA facility

The analysis focuses on five disciplinary areas as follows:

- At the first level **astronomy** (more specifically astrophysics) is the core discipline
- At the second level are two disciplines that form the theoretical basis for understanding astronomy. They are **physics** as the fundamental discipline that students must have to do astronomy or to convert to astronomy later in their professional career. The **mathematical sciences** play an important role in contributing to the preparation of students for astronomy careers.
- At the third level are two disciplines that will supply the implementation of the SKA facility with reference to its supporting technologies (ie: designing and building the antennae, and designing and building the IT infrastructure). These disciplines are: **engineering** and **computer science.**

It is important to note that the reference to three levels is a device to show the range of skills that will be required and is not intended to oversimplify a research environment in which, for instance, some branches of astrophysics are closer to mathematics and some to engineering.

Each of the fields identified will be treated in turn.

Astronomy enrolments and graduations

Over the period, 1994 to 2003, a total of 40 undergraduate and 62 post-graduate students graduated in astronomy from South African universities (Table 4).

Table 4: Number of astronomy students graduated in universities and technikons, 1994 - 2003

	Undergraduate	Honours	Masters	PhD
Total	40.0	36.0	16.5	10.5

Source: HEMIS Database 2000-2003.

Between 2000 and 2003, 203 students were registered as undergraduates and 35 were registered as post-graduates (Table 5).

Table 5: Number of astronomy students enrolled in universities and technikons, 2000 - 2003

	Undergraduate	Honours	Masters	PhD
Total	203.7	8.0	10.0	17.0

Source: HEMIS Database 2000-2003

In addition to the number of students registered for degree programmes, the following occasional astronomy students were also registered at three institutions from 2000 to 2003 (Table 6). Occasional students are usually physics students who are registered in a university which has no astronomy department or faculty and by arrangement are able to register in a university which does offer astronomy courses. As can be seen, a large number of these students were registered for astronomy courses at UNISA which as a distance learning institution offers a convenient solution. Unisa as the only university still offering a BSc major in Astronomy has undergraduate courses that are used at some universities which do not offer courses in astronomy. Students register for a BSc (usually with physics as their major) at their home (residential) university and, in addition, register for astronomy modules at Unisa for non-degree purposes.

Any UNISA modules passed are given as credits towards the degree by the residential university. A number of students from Pretoria University, Wits and University of the Free State have done astronomy using this system. A residential university prepared to recognize the UNISA modules, could offer astronomy together with its own physics courses. Such an option would be more sustainable if there was at least one astronomer in residential university's department.

Table 6: Occasional astronomy enrolments by institution, 2000 - 2003

Year	University of Cape Town	University of South Africa (UNISA)	University of Witwatersrand	Total
2000	-	-	-	0
2001	4	35	1	40
2002	-	28	-	28
2003	-	42	-	42

Source: HEMIS Database 2000-2003

The enrolments indicated above are only available up to 2003 because this is the latest set of data made available by the Department of Education's Higher Education Management Information System. In order to give an indication of current and future progress in enrolments and graduations in astronomy at the post-graduate level, it is necessary to refer to the NASSP programme.

National Astrophysics and Space Science Programme (NASSP)

This collaborative iniative promises to create a significant network for the reproduction of human resources for astronomy and space science. It harnesses the expertise of the three national facilities, and seven universities in nine locations: University of Cape Town, University of KwaZulu Natal, University of the Free State, University of North West, University of Zululand, Rhodes University and UNISA (http://www.star.ac.za/about.php).

NASSP has funding from both the National Research Foundation, and international donor foundations: Ford Foundation, Andrew W Mellon Foundation and Canon Collins Educational Trust for Southern Africa. The cooperative, combined graduate programme is hosted at the University of Cape Town, with lecturers drawn from staff in the NASSP consortium.

Two degree programmes are on offer, an Honours and Masters in Astrophysics and Space Science, covering most areas of modern Astronomy, Astrophysics and Cosmology, with a substantial practical component based in the space science research facilities.

The numbers of students in the programme are given in Table 7 below.

Table 7: Graduates from the NASSP programme, 2003 - 2005

	Honours		Masters	
Year	Enrolments	Graduates	Enrolments	Graduates
2003	13	12	5	All passed coursework. 3 submitted thesis and graduated
2004	14	10	14	All passed coursework. Thesis submissions current
2005	12	Current	9	Current

Source: NASSP 2005

Projected numbers of students in astronomy programmes in the next five years

The data from the Higher Education Management Information System (HEMIS) shows that between 1994 and 2003, the average annual output of graduates in astronomy at the first-degree, honours, masters and doctoral levels was 4, 3.6, 1.7 and 1 per year. This is not a large output. However, following the successful launch of a number of relatively large astronomy projects involving the South African astronomy community such as the High Energy Stereoscopic System, Southern African Large Telescope and the Karoo Astronomical Telescope, two major programmes involving skills development in astronomy have evolved. The first is the NASSP programme which was established to bring student through from honours to masters degree levels. Masters students have already graduated from NASSP this year.

Secondly, the NRF Frontiers in Astronomy Research Programme is at an advanced stage of planning. The aim is to establish an Institute of Astronomy as a joint venture between the three National Facilities, nine local universities and also international partners (Whitelock et al,2005). Inter alia, the envisaged outcomes of the programme are to increase the number of physics and astrophysics graduates at all levels. The plan for this process takes into account the NASSP programme as well as the recruitment of students from South Africa and internationally into the programme. Table 8 reflects the envisaged flow-through of students over a five year period that may start in 2006. As can be seen, this is an ambitious projection, but it is supported by planning for a strong support base in the form of senior researchers and also post-doctoral researchers – for different types of supervision – as well as full time academic, administrative and support staff.

Table 8: Projected numbers of students by degree level						
	Level	Year 1	Year 2	Year 3	Year 4	Year 5
1	Undergraduate	10	15	20	25	30
2	NASSP Honours	18	23	30	40	52
3	NASSP Masters Semester 1	18	23	30	40	52
4	NASSP Masters Semesters 2 & 3	10	15	20	25	30
5	PhD Frontiers Programme	5	15	30	45	60

Source: Whitelock et al, 2005.

The size of the programmes indicated in Table 8 above is eminently achieveable, given that there appear to be sufficient numbers of students currently registered in and graduating from physics programmes (See Table 9 below) in South Africa. A critical factor will be the availability of the right mix of bursaries to attract and support students in astronomy programmes at different degree levels and with an appropriate balance between local and international opportunities.

The programmes associated with NASSP and PhD Frontiers have put in place the foundations for sustainable growth in the astronomy community. They also demonstrate clearly that interest in astronomy as an academic discipline in South Africa is on an upswing energised by important and successful projects such as the SALT and by the KAT Demonstrator.

Size of the community of professional astronomers in South Africa

The community of professional astronomers is located in eight universities, and at HartRAO and the SAAO. Although this research community, like any other, changes over time, it appears to be in a phase of growth with the approximate numbers per institution given in Table 9 below:

Table 9: Distribution of Professional astronomers in South Africa		
Institution	Field/Department/Project	Approximate number
Rhodes University	Physics, Electronics	3
University of Cape Town	Astronomy, Physics and Mathematics	10
University of the Free State	Astronomy	2
University of Johannesburg	Physics	2
University of Kwa-Zulu Natal	ACRU and Space Physics	7
University of North West	Astronomy, Space Physics, HESS	6
University of South Africa	Mathematics	3
University of Stellenbosch		1
University of Witwatersrand	Mathematics, Theoretical Physics	3
University of Zululand	Cosmology	1
HartRAO		5+
SAAO		15
Total		58+

Source: Adapted from personal communication with Dr P Whitelock, 24 June 2005

Physics graduates

The output of students with Physics from South African universities is sound, with over 1 500 graduations with first degrees between 1994 and 2003

(Table 10). It is also reassuring that relatively large numbers of students graduated with Honours (549) and Masters (297) degrees in the same period. This means that the output of physics graduates represents a pool that is sufficiently large from which to attract students into the field of astronomy. It is also important to acknowledge that the pool of undergraduate physics students itself represents a large reservoir from which many potential students could be attracted by institutions which elect to offer official undergraduate programmes in astronomy.

Table 10: Number of physics students graduated in universities and technikons, 1994 - 2003

Year	Undergraduate	Honours	Masters	PhD
1994	144.6	64.4	35.0	18.0
1995	167.5	60.2	18.0	12.0
1996	154.3	54.5	22.0	9.0
1997	190.4	50.6	31.4	21.0
1998	157.0	44.1	28.0	23.0
1999	146.6	50.6	29.5	19.0
2000	144.6	57.4	27.5	13.0
2001	183.9	43.3	37.0	24.0
2002	147.6	70.2	43.0	11.0
2003	138.4	54.5	26.3	16.0
Total	1574.9	549.8	297.8	166.0

Source: HEMIS Database 1994-2003

By the same token, the numbers of students enrolled in physics between 2000 and 2003 shows that there is no sign of a slow-down in enrolments, so that a bottle-neck in the supply of candidates for astronomy programmes is unlikely to occur (Table 11).

Table 11: Number of physics students enrolled in universities and technikons, 2000 - 2003

Year	Undergraduate	Honours	Masters	PhD
2000	2364.7	95.6	135.8	115.5
2001	2055.1	171.9	172.0	114.0
2002	2029.2	276.6	154.1	111.0
2003	2496.3	217.1	156.7	133.5
Total	8945.3	761.2	618.6	474.0

Source: HEMIS Database 1994-2003.
Note: For 1994 to 1999 enrolment data was not disaggregated below the broad Life Sciences and Physical Sciences CESM Category.

Mathematics graduates

The numbers of graduates with first degrees and honours degrees in mathematics is larger than that of physics, while the conversion to Masters and PhD levels is lower than physics. Nevertheless, the numbers of students graduating (Table 12) in mathematics can be considered sufficient to provide candidates who could be drawn into further study in astronomy.

Table 12: Number of Mathematical science graduates in universities and technikons, 2000 - 2003					
	2000	2001	2002	2003	Total
UG	876.7	945.4	937.8	1028.7	3788.6
PGHons	260.2	293.7	286.3	325.3	1165.4
PGM	47.0	41.9	52.1	77.6	218.6
PGPhD	24.0	27.0	23.0	20.0	94.0
TotalPG	331.2	362.6	361.3	422.9	1478.0

Source: HEMIS Database 2000-2003

Engineering graduates

The average annual output of engineers from South African higher education institutions between 2000 and 2003 was about 2149, 749, 401 and 74 at the first degree, honours, masters and doctoral levels respectively (Table 13). In gross terms, the numbers of engineers being produced is adequate in supplying the pool of expertise that may be required to participate in the SKA project. Further data on the current population of practicing engineers is presented below.

Table 13: Number of engineering graduates in universities and technikons, 2000 - 2003					
	2000	2001	2002	2003	Total
UG	2115.0	2172.0	2161.0	2148.0	8596.0
PGHons	564.4	741.2	799.2	891.4	2996.2
PGM	386.0	388.3	404.6	426.5	1605.3
PGPhD	58.0	66.0	79.5	74.0	297.5
TotalPG	1008.4	1215.4	1283.3	1391.9	4899.0

Source: HEMIS Database 2000-2003

Computer Science graduates

The average annual output of computer science graduates from South African higher education institutions between 2000 and 2003 was about 2789, 494, 48 and 5 at the first degree, honours, masters and doctoral levels respectively (415). Computer science qualifications tend to be strongly oriented towards business applications, with less emphasis on engineering and even lesser on science. Nevertheless, the numbers of computer scientists being produced seems adequate in supplying the pool of expertise that may be required to participate in the SKA project.

Table 14: Number of computer science graduates in universities and technikons, 2000 - 2003					
	2000	2001	2002	2003	Total
UG	2217.5	2321.9	3234.1	3382.3	11155.8
PGHons	260.2	424.3	611.4	678.3	1974.2
PGM	25.0	54.1	42.6	71.5	193.2
PGPhD	6.0	5.0	1.0	8.0	20.0
TotalPG	291.2	483.3	655.0	757.8	2187.3

Source: HEMIS Database 2000-2003

In addition to the above overview of graduate outputs, the Institute for Satellite and Software Applications (ISSA) provides a strong infrastructure and set of teaching programmes that can support the SKA. ISSA was established to develop high-level ICT skills, particularly geared towards the development of software solutions, and aimed at historically disadvantaged individuals (http://www.issa.org.za).

Size of the engineering Profession

Recent data on the population of engineers in South Africa shows that there are 64 874 people who have a higher education qualification and are practicing engineers and engineering technicians in the labour market (Table 15). This number has declined slightly in gross terms and as a proportion of the labour force, but can be assumed to be sufficiently large enough to meet the increased high skill labour demand implied in the SKA project.

Table 15: Employment of engineers as a percentage of the total labour force, 1994-2001

Year	Engineers employed	Total labour force	Percentage of labour force
2000	73 060	15 794 000	0.46
2001	73 750	16 077 000	0.46
2002	76 158	16 059 171	0.47
2003	68 165	16 370 486	0.42
2004	64 874	15 955 069	0.41

Source: Steyn and Daniels, 2003, p.563; Labour Force Survey 2002Sept, 2003Sept, 2004Sept

Table 16 below reflects that there are engineers and engineering technicians practicing in the South African workforce in fields related to SKA such as: electrical engineers (5870) and electronics and communications engineers (1309); electrical engineering technicians (6239) and electronics and communications technicians (13 775); and civil engineers (4249).

Table 16: Distribution of engineers and engineering technicians and related occupations in the workforce, Sept 2004	
Occupation	Total
Architects, town and traffic planners	7 230
Civil engineers	4 249
Electrical engineers	5 870
Electronics and communications engineers	1 309
Mechanical engineers	5 460
Chemical engineers	1 470
Mining engineers, metallurgists and related	1 059
Physical sciences technologists	6 395
Civil engineering technicians	1 418
Electrical engineering technicians	6 239
Electronics and communication technicians	13 775
Mechanical engineering technicians	2 132
Chemical engineering technicians	0
Mining and metallurgical technicians	2 958
Draughtsmen	1 943
Technicians not classified elsewhere	1 178
Total	62 685

Source: Labour Force Survey 2004Sept

References

Advanced Manufacturing Technology Strategy (AMTS) (2003) A National Advanced Manufacturing Technology Strategy for South Africa, Volume 1 and Volume 2. National Council on Innovation.

Department of Arts, Culture Science and Technology (DACST) (1996) *White Paper on Science and Technology: Preparing for the Twenty-First Century.* Pretoria: Government Printer.

Department of Science and Technology (DST)(1997) National Research and Technology Foresight Report: ICT Sector. <www.dst.gov.za/reports/foresight_reports/FORESIGHT%20ICT%20REPORT.doc>

Department of Arts, Culture, Science and Technology (DACST) (1998). *The System-wide Review of Public Sector Science, Engineering and Technology Institutions.* A Report Submitted to DACST June 1998.

Department of Arts, Culture, Science and Technology (DACST) (1999) Foresight summary report: *Dawn of the African Century: A nation at work through science and technology for a better future*. Pretoria DACST.

Department of Education (1997) *White Paper on Education and Training 3: A Programme for the Transformation of Higher Education.* Pretoria: Government Printer.

Department of Education & Department of Labour (2001) *Human resource development strategy for South Africa: A nation at work for a better life for all.* Pretoria: DoE and DoL

Department of Education (2001a) *National Plan for Higher Education*. Pretoria: DoE.

Department of Education (2001b) *The Restructuring of the Higher Education System in South Africa.* Report of the National Working Group to the Minister of Education. December. Pretoria: DoE.

Department of Education (2003*) Higher Education Act 101, 1997, Policy and Procedures for Measurement of Research output of Public Higher Education Institutions.* Pretoria: DoE.

Department of Science and Technology (2001) *A National Biotechnology Strategy for South Africa*. 20 August. Pretoria: DST.

Department of Science and Technology (2002) *South Africa's Research and Development Strategy.* Pretoria: DST.

Department of Science and Technology (2004a) *National survey of research and experimental development (2001/2 fiscal year).* High-level key results.

Department of Science and Technology (2004b) *A national key research and technology infrastructure strategy*. Abridged version. July. Pretoria: DST.

Department of Science and Technology (2004c) Developments in South Africa's Government Science and Technology System. Pretoria: DST.

Department of Science and Technology (2004d) ICT Roadmap Process. <http://www.ictroadmap.co.za>

Department of Science and Technology (2005) *National Survey of Research and Experimental Development (R&D) (2003/04 fiscal year). High-level key results*. Pretoria: DST.

Department of Trade & Industry (2002) *Accelerating growth and development: The contribution of an integrated manufacturing strategy*. Pretoria: DTI.

Gaylard, M. (2005) 'South African SKA demonstrator (SASKAD)' Appendix in: Frescura, F.A.M. et al. "Concept Paper: Radio Wavelength Observation" Astronomy Frontier Programme Unpublished Paper.

Hermanus Magnetic Observatory (2003) HMO *Annual Report 2001 –2002* Hermanus:HMO

Human Sciences Research Council (2003) *Government incentivisation of higher education-industry research partnerships in South Africa. An audit of THRIP and the Innovation Fund.* Cape Town: HSRC Publishers.

Innovation Fund (2004) *Annual Report 2003/4* NRF: Pretoria.

Innovation Fund (2004) Innovation Fund Annual Report 2003 Pretoria: NRF.

Kahn, M., Blankley, W., Maharaj, R., Pogue, T., Reddy, V., Cele, G. and Du Toit, M. (2004) *Flight of the Flamingoes. A study on the mobility of R&D workers*. A project by the Human Sciences Research Council in Partnership with the CSIR for the National Advisory Council on Innovation. Pretoria: HSRC publishers.

Kaplan, D (1999) On the literature of the economics of technological change. *South African Journal of Economics* 67(4) 473-491.

Kraak, A. (2000) *Changing modes. New knowledge production and its implications for higher education in South Africa*. Pretoria: Human Sciences Research Council.

Mangena, M. (2004) 'Evening of the Stars', Keynote address by the Minister of Science & Technology, Mr Mosibudi Mangena, to the 5th NRF Presidential Award ceremony 4 June 2004
<http://www.info.gov.za/speeches/2004/04060414451001.htm>

Mangena, M. (2005a) Budget vote address by the Honourable Minister of Science and Technology, Mosibudi Mangena. 7 April 2005.

Mangena, M. (2005b) Address by Minister Mosibudi Mangena, Minister of Science and Technology of the Republic of South Africa, at the International Space Conference "Space and Science" session. Brussels, Belgium 17 February.

Mbeki, T (2004) "State of the Nation address" Pretoria.

Naidu, E. (2005) National Space Agency will bid for cutting edge tenders. *Sunday Independent* 1 May 2005.

NASSP (2005) Report on Activities: 2003-2005 PostGraduate Studies South African National Astrophysics and Space Science Programme.

National Research Foundation (2001) A strategy (and conceptual framework) for research capacity development at historically Black Universities (HBUs). NRF Strategy Document for HBU RD support.

National Research Foundation (2003) Technikon Research Development Programme. *Programme Framework (2002 – 2007*). Pretoria, July.

National Research Foundation (2005) *Business plan 2005/6-2007/8* NRF: Pretoria.

Pandor, N. (2004) "Maths today and tomorrow" Speech by Naledi Pando, MP, Minister of Education, opening AMESA conference, 1 July 2004.<www.amesa.org.za>

RTCC (Research and Technology Collaboration Centre) (2003) "Development of an SKA Technology Roadmap" RTCC Roadmap Ver 1_4
Accessed at: http://www.ska.ac.za/techdev/docs/tech_roadmap_phase1.pdf Date:02/02/2005

SAITIS (South African Information Technology Industry Strategy). 2002. *ICT diffusion and ICT applications in usage sectors*
<http://www.milless.co.za/downloads/ICT%20Difussion%20%20Internationa l%20Scan.pdf >

South African Astronomical Observatory (2004) *SAAO Annual Report* 2003/4 Cape Town: SAAO.

South African Astronomical Observatory (2005) *'First Light' for Africa's Giant Eye: 1st Colour Images from SALT* Press Release 01/September/2005 Cape Town: SAAO.

SAOG (2001) "DEEPMINE: A South African ultra-deep level collaborative mining research programme"
<http://www.saoug.org.za/archive/2001/0110.pdf>

Statistics South Africa (2002) Labour Force Survey, September 2002.

Statistics South Africa (2003) Labour Force Survey, September 2003.

Statistics South Africa (2004) Labour Force Survey, September 2004

Steyn,G. and Daniels, R.Z. (2003) Engineers and technicians In: Human Sciences Research Council (ed) Human Resources Development Review 2003: Education, Employment and Skills in South Africa Cape Town, HSRC Press pp.554-583.

Technology and Human Resources for Industry Programme (THRIP) (2003) *Strategic Plan 2003-2007* Pretoria, THRIP.

Technology and Human Resources for Industry Programme (THRIP) (2004) *Annual Report 2003/4* NRF: Pretoria.

United Nations Office for Outer Space Affairs (2005) "United Nations' treaties and principles on outer space" Status of international agreements relating to activities in outer space as at 1 January 2005. UNOOSA

Whitelock, P. et al. (2005) Frontiers in Astronomy: A proposal for a South African Institute of Astronomy 31 May 2005 (Document prepared by: P Whitelock, J Jonas, O de Jager, P Dunsby, R Kraan-Korteweg, C Cress, P Meintjies, D Smits, F Frescura, A Beesham, T Madupe, and P Charles).

Wood, T. 1997 Breaking through depth barrier could shine gold up: ULTRA-DEEP MINING *Business Times* 05/04/1997
<http://www.btimes.co.za/97/0504/tech/tech2.htm>

