Non-astronomy benefits of the Square Kilometre Array (SKA) radio telescope

Artist's impression of the SKA dishes.
Credit: Swinburne Astronomy Productions

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Executive Summary

The Square Kilometre Array (SKA) will be a revolutionary new radio telescope and is an iconic project for global cooperation in many 'frontier' domains of the 21st century. To achieve the enormous potential that the SKA offers in terms of increasing our understanding of the Universe, exploring technologies for communication and innovation, and testing viable green energy supply, the SKA project requires support and funding commitment from its government and institutional benefactors.

This document classifies the major benefits that can result from the SKA and other large scale infrastructure research projects, in four key areas: Information and communication technology (ICT), renewable energy, global science-industry-government linkages and human capital development.

SKA: a major driver for innovation in ICT and sensor technology

The SKA represents more than a telescope; it is also a potential model for the future of global communication and information technology. If this unique opportunity to use the SKA as a development laboratory for worldwide communication infrastructure is exploited, the tangible benefits to industry and society will equal the astronomical discoveries.

Engineers for the SKA will challenge the ICT industry to innovate for efficiency and cost savings in high performance networks, power and capital investment. New software and hardware that will drive the SKA and make it smart will be developed, potentially setting global standards for ICT engineering and construction. The anticipated benefits involve not only signal processing, storage and computation, but also reliability and maintainability for remote SKA use, providing a backbone for development of remotely distributed ICT commercial services.

ICT innovations necessary for the SKA will also be useful for all other systems that process large volumes of data retrieved from around the globe, including activities essential to financial, commercial, environmental monitoring and communications industries.

SKA: a global model for 100% renewable energy

The Square Kilometre Array (SKA) infrastructure will have considerable energy needs in the order of 50-100 MW, with much of the demand concentrated in remote areas. The use of renewable energy for the SKA would pioneer remote power generation with low running costs that would be unaffected by fluctuations in global fuel prices. Such a renewable strategy would accelerate technology development in the areas of scalable energy generation and storage, distribution, efficiency and demand reduction and provide a launch pad for commercialisation of innovative green energy technologies.

SKA: a model for improved global-science-industry linkages

The SKA has the opportunity to lead in the development of new techniques for mega-project management and effective global research collaboration. The nature of the project will inspire individuals, research groups, industrial partners and governments to be part of a global fellowship that will endure beyond their involvement. Furthermore, the profit and benefits to all those involved will be realised over a long timescale and in the broadest sense, build capacity and kudos for those who engage.

Industry and academic engagement in the SKA project is maximised through the growth of contact networks and targeted events that provide clearly defined opportunities and timescales so that potential partners can decide on the level of engagement appropriate for their research or business.

SKA: impact on human capital development and employment

The SKA will allow a new generation of astronomers and astrophysicists to probe the cosmos and will provide employment opportunities in a wide range of associated fields. The SKA, by its scale and scope, has the potential to inspire generations of young people with science. It can do so not only because astronomy appeals to our natural curiosity but also because it is a stepping stone to many other fields of science and technology development including engineering, aerospace, mathematics and the natural sciences.

The SKA can provide long-standing benefits, proportional to the long-term investment it requires. The construction and operation of the SKA facilities will impact local and regional skills development in science, engineering, technology and in associated industries.

Introduction

Radio astronomy has produced some of the greatest discoveries of the last century and central to these discoveries have been innovations in technology. The SKA will continue this tradition of innovation by combining the skills of participating countries to develop, construct and operate this mega-science infrastructure project. The remote location, complexity and size of the SKA demands careful planning and will drive the technological innovation leading to capability development, as well as direct economic and indirect social benefits.

The SKA will be constructed from thousands of receptors linked together across an area the size of a continent. The total cosmic radio wave collecting area of all the SKA receptors combined will be approximately one square kilometre. This collecting area will comprise individual dishes, plus ground-level sparse and dense aperture arrays arranged in clusters along five spiral arms, extending from a central core to at least 3,000 km. Electronically combining the signals from the receptor will enable the SKA to function as a single giant telescope with spectacular angular resolution.

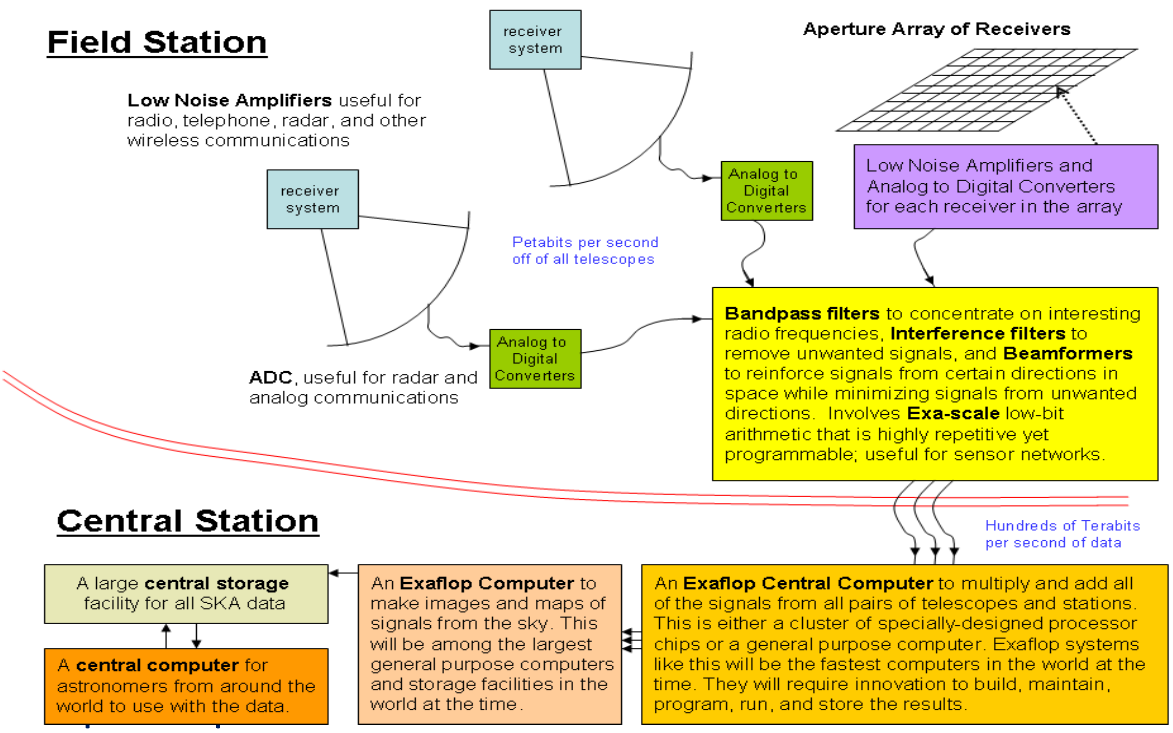
The radio Universe is as important as the optical Universe in terms of astronomy research. Radio telescopes provide alternative views of the Universe to those seen with optical telescopes and they can reveal areas of space that would otherwise be obscured by cosmic dust. The SKA will give astronomers insight into the formation and evolution of the first stars and galaxies after the Big Bang, the role of cosmic magnetism, the nature of gravity and possibly life beyond Earth.

The SKA will be the world's premier imaging and surveying telescope, able to observe at fifty times the sensitivity and ten thousand times the survey speed of any previous radio telescope. This combination of unprecedented versatility and sensitivity offers new opportunities in technology development and will open new windows of astronomical discovery.

SKA: a major driver for innovation in ICT and sensor technology

The SKA will comprise high frequency dish antennas, with radio receivers at the foci of the dish and two other types of antennas, sparse and dense aperture arrays. Each receiver has an amplifier and a digitiser, which represents the starting point of a long chain of signal processing. This includes filters to isolate the interesting frequency ranges and remove unwanted interference and beam-formers to sum and reinforce the signals. The central computers process, multiply and sum the signals from the field stations and the central core region. The data stream is reduced in size (mostly by time-averaging), and stored in forms useful to astronomers.

An overview of SKA components:



At the most fundamental level, the SKA is a giant network of sensors, digitisers and computers, like any other sensor field or civic recording network. The processed signals are relayed to central computers over optic fibres that extend for thousands of kilometres, offering a communications infrastructure that would almost certainly not otherwise be considered.

ICT is the backbone of the SKA. SKA engineers will challenge the ICT industry to innovate for maximum mega-scale construction efficiency and reduction of power consumption and capital costs. The requirements of the SKA will necessarily involve new collaborations with industry which has the experience to develop, manufacture, install and maintain SKA infrastructure.

Remote desert conditions pose problems to mechanical and electronic components which will require extremely low failure rates and the ability to predict and manage failures at the cutting edge of aerospace engineering.

Front end software will be used for monitoring, control, radio interference mitigation, basic calibration and simple arithmetic to form beams of sensitivity in the sky. At the back end, the correlator multiplies the signals from each pair of antennas or stations, sums these products on a grid that keeps track of the relative antenna positions and uses this grid to make maps of the sky in each frequency channel. Further software will be required for different astronomical and meta-analysis use of the telescope.

Benefits beyond the SKA

The SKA will pioneer our ability to pass high volumes of data at the Petabit/second rate through an interconnected network and intelligently reduce these data to a manageable size in real time. Software will be used to monitor system performance and the impact of component upgrades. Such innovative design engineering will be only partly specific to the SKA; much of it will also be useful to other geographically distributed sensor networks.

The SKA has serious potential for adjacent market opportunities in ICT, where hardware and software packages may either be adapted from commercial items or may produce new products. The SKA infrastructure, like any comparable ICT infrastructure in the financial, commercial, or government sectors, will have direct benefits to society through the training of technicians for development and operations and through the attraction of new talent to ICT in general.

The SKA will break new ground in ICT engineering and construction and this could influence international standards as well as standards for innovation in hardware and software. The SKA will also generate environmental applications with the ability to detect and analyse natural events in real time. Such applications will require smart, world-wide communications and the development of models, protocols and microelectronics to handle the enormous data traffic. The SKA will drive innovation in wireless communication through the development of extremely low noise amplifiers (LNAs) and analogue-to-digital converters (ADCs). These are important in virtually all types of digital electronics and communications technologies. As a giant sensor network and signal processor, the SKA will drive innovations in algorithms and software for on-the-fly data manipulation and compression, flagging of transients and other notable signals and enhanced processing of the selected data segments.

ICT developments will be useful for:

- Financial and retail markets that have to intelligently adjust to changing conditions in the world.
- Intelligent surveillance for the recognition of license plates or faces in a crowd.
- Weather and traffic monitoring followed by active response during anomalies.

- Security and military applications that must sense and respond to rapidly changing conditions in a large, interconnected area.
- Numerous other events and disturbances that require high speed detection and analysis to initiate the appropriate response.

Many other big science projects, some much bigger than the SKA, have had significant non-science benefits that were not anticipated at the start. NASA is a classic example of an organisation with a science and engineering mission that has many important spin-offs to society. The development at CERN of protocols that enabled the internet is another good example, as is the development at CSIRO of the algorithms that are necessary for modern wireless communications. Similarly, the LOFAR in the Netherlands is the first example of a nationwide research network for high speed data transmission that links together a range of environmental monitoring instruments from a single project, a low frequency radio telescope.

Conclusions

Clearly, the SKA represents more than a telescope; it is also a model for the future of global communication and information technology and the benefits to society from ICT innovations will precede the astronomical discoveries.

The SKA is an astronomy and engineering project for the next decade that has the potential to develop new methods for the detection, transport and analysis of enormous volumes of data. These new methods will span a wide range of SKA components, from hardware radio receivers and optical transmission lines, to processors and software for streaming data analysis, to storage and dissemination in the world wide community. With adequate resources and a mission that has worldwide perspective on ICT, the SKA research infrastructure can be a force for revolutionary technology improvements with great market potential. ICT innovations that are useful for the SKA will also be useful for all other activities that process large volumes of data retrieved from around the globe, including activities essential to the financial, commercial, communication and environmental monitoring industries.

SKA: a global model for renewable energy

Uncertainty regarding the cost and supply security of traditional fossil fuels, as well as concern over carbon dioxide emissions, makes maximum utilisation of sustainable, renewable energy desirable as an SKA power source.

The Square Kilometre Array (SKA) infrastructure will have considerable energy needs in the order of 50-100 MW, with much of the demand concentrated in remote desert areas. In the desert environment, solar power is usually abundant and is the natural renewable choice for the remote stations. This is highly desirable over expensive fossil fuels that require transportation and decanting infrastructures and differs from national power grids that rarely deliver energy over large distances to remote locations. The development of a sophisticated ICT network that runs on locally generated renewable energy demands significant innovation in scalable generation and storage technologies and would benefit communities and industry in remote locations across the globe.

A renewable energy solution for the SKA will drive innovation in the following areas:

- Development of passive cooling systems and smart load sequencing to minimise demand side energy requirements.
- Generation side radio frequency interference (RFI) shielding, interfacing with grid supplies and land use.
- Storage technologies, including charge/discharge capacities and back-ups.
- Distribution and reticulation design for price/reliability trade-offs.

Examples of Impact

Although a renewable energy solution for the SKA might prove initially costly and present a number of technological challenges, the benefits will be substantial. Today, concentrated solar thermal power (CSP) presents the advantage of easy energy storage in the form of heat (e.g. in salt or graphite), which allows for 24/7 operation. On the other hand, CSP has higher maintenance needs and might ultimately be more costly than photo-voltaic cells (PV) where the cost is reducing fast. For each doubling of globally installed PV power capacity, the cost of modules decreases by 20% and of systems by 15%. A system to support the SKA will add considerably to the global level of installed solar power and thereby contribute to falling prices.

Should a large proportion of the SKA energy supply rely on PV, large-scale electrical storage solutions will need to be developed. These might include water electrolysis to produce hydrogen that can generate electricity in fuel cells, Vanadium redox-flow batteries that store positive and negative charges separately from the central membrane unit where electricity is produced, or more conventional solutions like NaS batteries that can be up-scaled.

Other methods of generating CO_2 free electricity will also be considered based on local conditions e.g. geothermal energy, wind energy and possibly offset generation of green energy, such as ocean energy sources and hydro. In the short term, hybrid energy solutions utilising existing non-renewable power supplies may be considered but it is anticipated that viable renewable sources will mature during the course of the SKA development.

In addition to the technical issues, the financial consequences of renewable energy solutions are an important consideration. Whilst the capital costs are large, ongoing generation costs are very low. Despite the high set up costs, an important advantage of solar power, especially PV, is the minimal operational costs. The revenue possibilities derived from excess power production could also be explored and scalable systems will offer society an effective complementary adjunct to grid systems for the future.

Benefits beyond the SKA

The COP15 climate talks in Copenhagen did not fully succeed in reaching a global framework agreement on reducing CO_2 emissions through binding emission limits for each country. However, the way is open for governments, institutions and multi-nationals to show leadership by improving energy efficiency, by increasing the fraction of available electricity that is produced from renewable energy sources and by moving towards 100% renewable energy solutions. Such actions would not concentrate on limiting economic activities to reduce CO_2 emissions but rather use today's green technologies to benefit the environment, to generate jobs and to contribute to economic growth.

In adopting a renewable energy strategy, the SKA would set an important example and would benefit the community in the following ways:

- The SKA would play a global leadership role as an iconic scientific project aspiring to run on renewable energy 24/7. The SKA would create a launch pad for reliable green power generation in remote areas without grid connection and thus provide a global test bed.
- The SKA will drive innovative solutions in generation, distribution, efficiency and demand reduction in a remote, harsh environment.
- Employing renewable energy solutions will enable operational (public) money to be spent on science instead of increasing fuel costs.
- The SKA will act as a trailblazer in the implementation of multi-scale, reliable energy generation and storage solutions through early competitive evaluation.
- The SKA will provide employment and education opportunities in implementation of renewable energy and could deliver excess power to the local population.
- Spin-off research and technology developments will benefit societies, especially the 1.6 billion people currently without any access to electric power.
- The SKA will broaden societal awareness of renewable energy.

Innovations in the field of green energy solutions would open up markets for remote and local power generation, potentially accelerating important technological developments that are currently required globally, particularly in the developing world.

Conclusions

A renewable energy strategy for the SKA would provide a launch pad for commercialisation of innovative green energy technologies and would pioneer remote power generation with low running costs that would be unaffected by fluctuations in global fuel prices.

Solar thermal power currently has the advantage that heat can be more easily stored than electricity, however, battery technology is improving rapidly and the advantage of few moving parts may result in a largely PV solution. Possible RFI from electrical inverters will also require research and development into mitigation strategies.

The SKA will inspire and innovate;

- Development and cost-competitive evaluation of multi-scale renewable energy power storage solutions.
- Renewable energy generation and distribution free from radio frequency interference.
- Operation of multi-scale distributed renewable energy sources and storage solutions.

SKA: a model for improved global science-industry-government linkages

The global nature of the SKA offers participation and collaboration across international borders whilst respecting cultural differences, relative regional capacity and managing diversity amongst all project partners and stakeholders. The mega-scale of the project introduces both challenges and opportunities for dealing with research support, science-industry-government 'mega data' protocols, as well as systems integration - central to all mega-project challenges.

The project as a whole relies upon the building of trust and commitment. To realise this effectively requires the SKA to deliver clear and concise messages of a shared vision acceptable to all. The SKA can inspire individuals, research groups, industrial partners and governments to be part of a global fellowship which will last beyond their involvement. Furthermore, the profit and benefits to all those involved will be realised over a long timescale and in the broadest sense, build capacity and kudos for those who engage.

The SKA offers a massive leap forward in our understanding of the Universe and how it was formed. This has the potential to act as a strong motivator and a model for other global science/engineering mega-projects. It has the potential for individuals and nations to gain international recognition for their contributions. This necessitates leadership and strategic direction from all stakeholders and therefore raises the credibility of all those involved.

The benefits of the SKA extend beyond the science and can have much wider socio-economic impact which will underpin solutions for future global challenge areas including communication, computing and energy, as well as support scientific and engineering skills development.

Examples of Impact

The SKA Program Development Office (SPDO) will undertake a global mapping exercise of industrial capabilities on a national or regional basis. The results of this mapping will show where there are significant strengths and, of equal importance, show where there are currently capability gaps. A number of companies have already been involved in SKA Pathfinder projects, some of which have been given public sector support to develop a variety of early stage demonstrator technologies. A legacy outcome of the SKA project will be the retained capabilities, skills and tooling once the SKA is complete.

The SKA procurement strategy will identify and cultivate reliable, quality supply chains. The procurement style will be open, operate under clear policies and take a long-term view to be able to realise the maximum impact beyond the value of initial contracts. In other words, become more than a simple '*Juste retour*' model.

Industry and academic engagement in the SKA project is maximised through the growth of contact networks and targeted events that facilitate information exchange. With clearly defined opportunities and timescales, potential partners can decide on the level of engagement appropriate for their research or business. Some small scale public sector funding is initially required to promote the formation of industry groups (consortia of interested local and global companies). These quickly become self financing, through subscription and benefit from inter-company trading between members leading to increased trust and a willingness to work together.

Benefits beyond the SKA

The term 'science and industry linkage' covers the processes by which scientific knowledge, expertise and skilled people exchange information and develop relationships. The government aspect adds the dimension of contribution to economic competitiveness and the effectiveness of public services and policy.

The indirect benefits of science, industry and government linkages offer the following:

- Producing new scientific information for novel, commercial applications.
- Training skilled graduates.
- Supporting new scientific networks and stimulating interaction.
- Expanding the capacity for problem-solving.
- Producing new instrumentation and methodologies/techniques.
- Creating new firms and jobs.
- Providing social knowledge.
- Access to unique facilities.

Such benefits can be stimulated between academia and science institutions, government science facilities and laboratories and industrial research centres and industry. Research shows that such linkages undoubtedly offer benefits in terms of improved qualifications, increased productivity in research, the provision of additional resources, support and enhanced career opportunities, opportunities to apply research results to industrial problems and enhanced university prestige.

From industry's viewpoint, scientific affiliation is important for patent quality: in particular, the non-science related patents of firms with strong scientific linkages are more frequently, more broadly and more quickly cited than comparable patents of firms without these science linkages.

The SKA has the opportunity to lead in the development of a model for effective global research collaboration of use to future global science projects. One option could be the formation of a global version of European Research Infrastructures Consortia (ERIC). The creation of global agreement models necessary to ensure the success of the SKA will, in turn, create best practice models, frameworks and agreements for new collaborations, allowing future projects to move forward in shorter timescales. It will also require the development of international agreements on partnerships between industry and scientific research which can act as best practice.

Conclusions

The Square Kilometre Array, as a large scale global project at the forefront of science, necessitates international collaboration by scientists, industry and governments from the earliest stages. It can provide leadership for the development and growth of national and international industry clusters. The legal entity and procurement process may require unique arrangements and policies not necessarily compliant with generic rules e.g. the World Trade Organisation. The SKA has the opportunity to share experiences, as well as an understanding of risk, including technical, political and financial risks, with the broader community. From an industry perspective, the science involved in the SKA is compelling but the engineering solutions are forefront in industry thinking as they apply to future commercial outcomes.

The SKA has the potential to offer industry opportunities over and above the potential value of contracts to be placed. These opportunities include the value of global fellowship gained through collaboration, kudos and pride in being a part of a successful groundbreaking science project and use of core technology platforms to build new business opportunities in broader market sectors.

SKA: Human capital development

The Square Kilometre Array (SKA) is one of the largest earth-based science projects ever proposed and it is also one that involves many international partners. The SKA will employ thousands of people from a wide range of professions. Individuals are needed to design, build and operate the SKA as well as run the associated services. Builders, caterers and administrative staff, as well as scientists, engineers, IT specialists and communicators will be employed. In addition to these staff, a number of employment opportunities will arise around demand created by the existence of the facility. The tourism industry is expected to flourish nearby, offering numerous employment opportunities. Visitor centres and galleries, as well as educational institutions will require education professionals to develop material related to the SKA.

Examples of Impact

The potential of this major scientific facility to contribute to the development of human capital globally is one of its strongest positive impacts in times when 'blue-skies' research comes under increasing pressure to deliver economic justifications.

- Support and administrative staff: The SKA is an international project, with stakeholders from government agencies, the private sector and academia. Working in such an international environment at the interface of the stakeholder communities will provide the support and administrative staff in all international locations with a useful and transferable skill set.

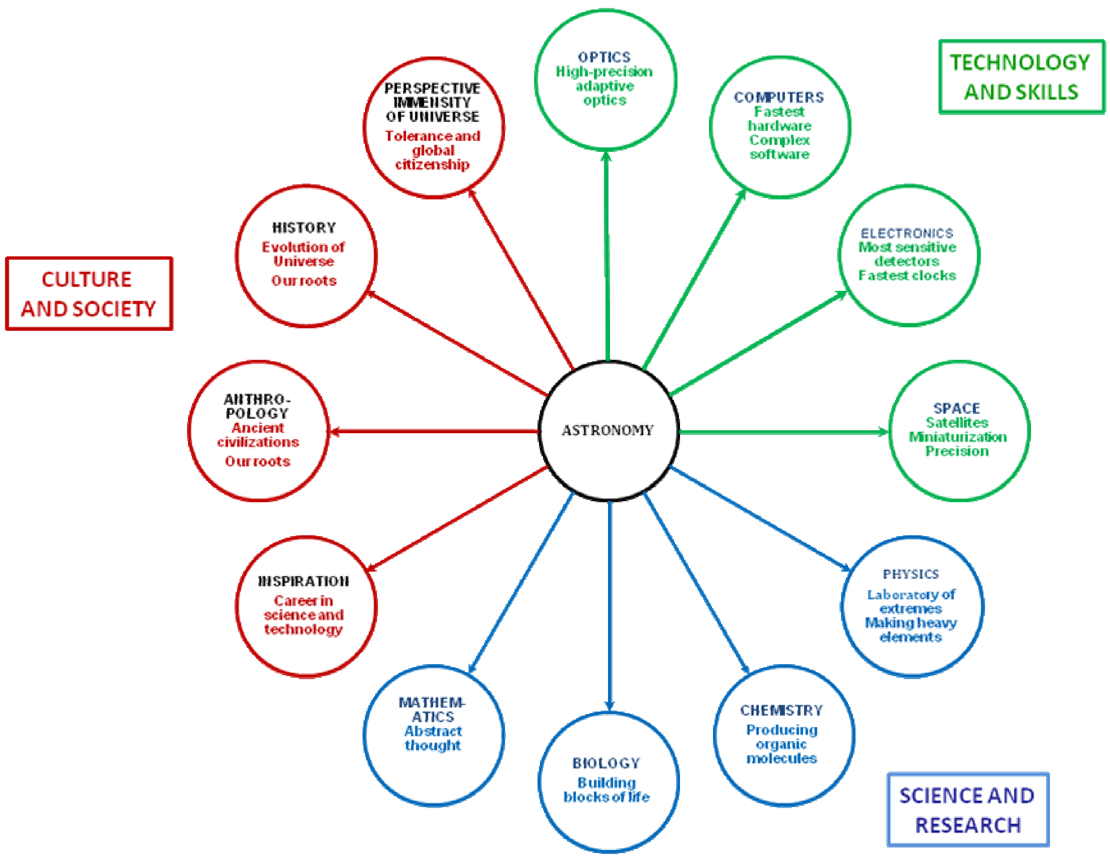
- Construction workforce and engineering disciplines: The construction of a high-tech facility will equip civil engineers and construction workers with valuable experience and skills for future employment. Communications and power engineers will benefit from the valuable experience of working on the installation of the ground breaking communications and power infrastructures required for the SKA.

- Tourism and other non-technology driven spin-offs: Visitor centres located near to SKA facilities could attract large numbers of visitors leading to business opportunities locally. Such opportunities will promote governance and business skills, as well as drive community development. When coupled with SKA outreach activities, business and community involvement will create a sense of ownership of the telescope and its astronomy. Where visitor centres are located close to the radio antennas themselves, the radio quiet zones will need to be protected. Other radio telescopes have shown that this is achievable (for example, the VLA in New Mexico and Jodrell Bank in the U.K.) where tourism within a radio quiet zone is suitably managed.

- Environmental Impact Awareness: During the construction phase opportunities will be taken to build the telescope and associated facilities in the most environmentally friendly way possible. Proper communication of this construction policy is expected to raise awareness of environmental issues in each of the countries concerned.

Benefits beyond the SKA

The SKA will allow a new generation of astronomers and astrophysicists to probe the cosmos and will provide employment opportunities in a wide range of associated fields. The SKA, by its scale and scope, has the potential to inspire generations of young people with science. It can do so not only because astronomical discoveries channel our imaginations but also because astronomy is a gateway to many other fields of science, including engineering, aerospace, mathematics, natural sciences and technology development. If, through astronomy, the SKA inspires young people to study science, it will help build the scientific communities in the disciplines shown below.



Conclusions

The SKA can provide long-standing benefits, consistent with the long-term investment it requires. The construction and operation of the SKA facilities will impact local and regional skills development in science, engineering and technology and in associated industries.

The nature of the SKA will excite the young and old alike about science and technology. By building on existing successes e.g. NASA and the Hubble Space Telescope, the SKA can become part of our culture, using its popularity to inspire the next generation of scientists and engineers.

This document was produced by the SKA Program Development Office (August 2010) with reference to the conclusions of the Strategic Workshop: Benefits of Research Infrastructures beyond Science: the example of the Square Kilometre Array (SKA), organised by COST in March 2010, Rome. This workshop attracted around 200 experts from the four subject areas as well as experienced members of the international astronomy community.

About COST

COST is an intergovernmental European framework for international cooperation between nationally funded research activities. COST creates scientific networks and enables scientists to collaborate in a wide spectrum of activities in research and technology. COST Activities are administered by the COST Office - www.cost.esf.org/

About the SKA

The Square Kilometre Array will be a revolutionary international radio telescope. The total collecting area will be approximately one square kilometre giving 50 times the sensitivity, and 10,000 times the survey speed, of the best current-day telescopes. With receptors extending to distances of more than 3,000 km from the centre of the telescope, the SKA will address fundamental unanswered questions about our Universe including how the first stars and galaxies formed after the Big Bang, how galaxies have evolved since then, the role of magnetism in the cosmos, the nature of gravity, and the search for life beyond Earth. More than 70 institutes in 20 countries, together with industry partners, are participating in the scientific and technical design of the SKA telescope which will be located in either Australia – New Zealand or Southern Africa extending to the Indian Ocean Islands. The target construction cost is €1,500 million and construction is scheduled to start in 2016.
For more information about the SKA: www.skatelescope.org