AERAP Framework Programme for Cooperation

A Vision for the Future of African-European Radio Astronomy Cooperation

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Executive Summary

The AERAP Framework Programme for Cooperation presents a comprehensive agenda for advancing the radio astronomy partnership between Africa and Europe. This document targets AERAP's key stakeholders in both continents in an effort to ultimately contribute significantly to the development of modern radio astronomy sites in Africa and the maximisation of the positive socio-economic side-effects.

The assets of African-European radio astronomy cooperation are explored through eight thematic priorities: Research infrastructures; Instrumentation, research and development; Support for global projects; Human Capital Development for radio astronomy; ICT and Big Data; Renewable energy for radio astronomy; Astronomy as a tool for science education and Public understanding.

These thematic priorities have been strategically selected to showcase recent technological advancements in radio astronomy and to position AERAP as a main actor in the development and implementation of future radio astronomy partnership between the EU and Africa. In addition to promoting AERAP and its role in the development of modern radio astronomy, this document addresses the major challenges facing the future of European-African radio astronomy cooperation. These challenges include obstacles to the implementation and communication of new technologies as well as ensuring the longevity of project operation.

The body of this framework programme is divided into seven sections to address these challenges. Each of the seven sections provides a detailed description of one thematic priority, its background significance and policy context, in addition to specifying key objectives and concrete actions that must be undertaken by AERAP to achieve each priority. The logic rooting these thematic priorities rests on the notion that scientific needs of modern astronomy—such as more sensible receivers and larger frequency coverage—drive innovation.

The eight thematic priorities laid out by AERAP in this programme are integral to the success of global radio astronomy cooperation between Africa and Europe. A majority of these priorities—including Research infrastructures; Instrumentation, research and development in addition to Astronomy as a tool for science education and Public outreach—call for publicity in the dissemination and exploitation of new science and technology ideas between European and African scientists, engineers, members of industry and policy makers.

Moreover, this paper presents AERAP's vision of a streamlined framework of communication between research and industry which can be monitored over time to exploit new technologies through collaborative projects in radio astronomy. For instance, in the sections on ICT and Big Data and Renewable energy for radio astronomy, the establishment of network and infrastructural foundations is required—before the implementation of new technologies—in other areas, such as transportation, energy and communication structures.

The AERAP Framework Programme also privileges the dynamic between the provision of adequate foundations for scientific knowledge dissemination and the promotion of socio-economic development as a value of science. In other words, radio astronomy collaboration cannot be understood solely in terms of advancing science and technology but also in terms of enhancing capacity building and infrastructure development within a developing society. This document promotes the enabling element of successful radio telescopes with regards to human capital development in Africa, which includes employment and economic development through technical training and education in radio astronomy.

The thematic priorities outlined in this document will be reinforced by concrete and holistic measures.

I. Introduction

The study of radio emissions from distant cosmological sources is crucial for a better comprehension of the universe. For this scientific purpose, radio astronomy facilities are set to grow significantly in the near future, especially in Africa because the continent provides optimal conditions for radio astronomical observations.[1] The existing and planned African radio astronomy facilities like KAT7[2], MeerKAT[3], the African VLBI Network or the Square Kilometre Array (SKA) will enable scientists to address a wide range of fundamental questions in physics, astrophysics, cosmology and astrobiology. They will be able to probe previously unexplored territories in the distant universe.

Radio astronomers from all over the world will use KAT 7 and MeerKAT to test Einstein's theory of gravity and gravitational radiation, to study the role of hydrogen in the early universe or to learn more about dark matter and the origin of the universe. There is also a strong case for MeerKAT and, eventually, the SKA to participate in the African VLBI network (AVN) and world-wide VLBI (very long baseline interferometry) observations.[4] VLBI is used for imaging distant cosmic radio sources, for spacecraft tracking and for applications in astrometry. It is also be used "in reverse" to perform Earth rotation studies, to map movements of tectonic plates very precisely and for other geodesy applications.

With its unprecedented sensitivity and frequency coverage, the SKA will complement and enrich the astronomical data provided by optical telescopes and artificial satellites, and will allow astronomers to study areas of space and cosmic phenomena that are now inaccessible. Astronomers will be able to locate over a billion new galaxies, measuring their mass and relative speed. The SKA will look back to the dark ages of the universe, a time between 150 and 800 million years after the big bang, and will help astronomers discover how the earliest black holes and stars were formed. Moreover, radio astronomy is the primary means for searching traces of extra-terrestrial life. The SKA will be able to detect even very weak extra-terrestrial signals and will scan the universe searching for the complex molecules that are the building blocks of life.

In addition to producing ground-breaking science, radio astronomy can also have a relevant and significant socio-economic impact in Africa. The operations and maintenance of radio astronomy

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[1] Southern Africa has a number of competitive advantages that make it an ideal location for astronomy observatories and related research facilities. Its geographical position offers wide coverage of the astronomically "rich" southern sky, and is the best location from which to study the Milky Way. It is and will remain a radio quiet zone, with exceptionally low levels of radio frequency interference. Areas in Southern Africa well suited for radio astronomy have very little light pollution but offer excellent infrastructure of roads, electricity and communication networks.

[2] Seven-dish MeerKAT precursor array that have been completed in December 2010.

[3] MeerKAT is a 64-dish radio telescope that will make up one quarter of the SKA Phase 1 mid-frequency array. It will be completed by 2016.

[4] VLBI is an observational technique which allows the combination of observations made by several observatories, achieving the same capacity as a theoretical telescope with the extension of the maximum distance between the dishes.

facilities requires highly qualified engineers, scientists and other technical staff. The skills required to participate in the global radio astronomy arena are in many ways generic and applicable to other industries where high-technology skills are necessary, such as the telecommunications industry, medical devices and technologies, agriculture and the like. Investment in radio astronomy on the African continent will therefore be a key enabler in unlocking the potential of the human capital on the continent by training a critical mass new generation of highly qualified scientists, engineers, technicians and professionals. Astronomy is a fascinating discipline that is also highly suitable to awake the interest of children and teenagers in science, mathematics and engineering.

Major projects like the Square Kilometre Array can also facilitate bulk civil engineering infrastructure development and promote growth in high technology, high added-value markets. Facilities to conduct radio astronomy typically require roads and other civil infrastructure, energy (in many cases off-grid energy solutions) and communication infrastructures (including high capacity data transfer networks). Because the equipment and facilities needed for radio astronomy requires cutting-edge technologies, the discipline drives innovation in several technological fields including supercomputing, information and communications technologies, advanced materials and renewable energy - both in Europe and Africa. Radio astronomy advances require collaborations that transcend national boundaries and constraints.

In addition to co-operation between research institutes, successful instrumentation R&D depends on the close interaction with relevant industries, which include the telecoms and avionics sectors, semiconductor manufacturers, and vendors of specialised electronics products. These companies (both European and African) will need to be closely involved in instrumentation R&D and support should be available to facilitate their involvement. This is particularly important for small-to-medium sized companies which often have the latest technology but do not have the resources to support R&D that is not immediately profitable.

A significant collateral benefit from radio astronomy facilities and its new enabling technologies on the continent will be the possibility to provide a significant number of Africans with access to reliable electricity and sources of knowledge and information through tools such as the internet. This has the potential to improve the quality of life of many through telemedicine, e-learning and data collection for climate studies and crop control and access to markets. New radio astronomy facilities and all necessary infrastructures should therefore be designed to meet the global scientific demands and to serve the local population in equal measure. These major projects require close collaboration between African and European partners and African ownership of the planned projects. The aim is to develop African projects with European cooperation, not European projects in Africa.

The African-European Radio Astronomy Platform (AERAP) wants to contribute significantly to the development of modern radio astronomy facilities in Africa and aims to maximise the positive socio-economic impact these could have. The present AERAP Framework Programme for Cooperation describes AERAP's vision for the future of African-European radio astronomy cooperation. This vision is shaped around seven thematic priorities: Research Infrastructures; Instrumentation, Research and Development; Support for Global Projects; Human Capital Development; ICT and Big Data; Renewable

Energy for Radio Astronomy and Astronomy as a Tool for Science Education and Public Understanding. The background and importance of each topic for the advancement of radio astronomy, AERAP's objectives as well as key actions for the implementation of the objectives will be outlined in the centrepiece of this document. Even though each thematic priority will be explored in a separate chapter, various links between the topics exist and will be pointed out. The last part of the documents describes the different supporting actions that will be necessary to achieve the goals of this Framework Programme; this includes political, financial and practical assistance. In all its actions, AERAP aims at building on existing infrastructures and projects like RadioNet[5], NEXPReS[6] or GO-SKA[7] to avoid duplication and use existing expertise. Projects that are focused on Europe should be extended to Africa and opened for African participants.

The African-European Radio Astronomy Platform is a stakeholder forum of industry, academia and the public sector established to define and implement priorities for radio astronomy cooperation between Africa and Europe. This framework will enable major research and technological advances that will drive socio-economic development and competitiveness in both Africa and Europe. AERAP is a response to the calls of the European Parliament, through the adoption of the Written Declaration 45/2011, and of the Heads of State of the African Union, through their decision "Assembly/AU/Dec.407 CXVIII", for radio astronomy to be a priority focus area for Africa—EU cooperation. The AERAP Framework Programme for Cooperation is AERAP's next step towards the implementation of the Written Declaration 45/2011.

[5] More information: http://www.radionet-eu.org/

[6] More information: http://www.nexpres.eu/

[7] More information: http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=12275437

II. Thematic Priorities for African-European Radio Astronomy Cooperation

I. Research Infrastructures

1.1. Background and Objectives

The radio astronomy research infrastructure projects that could benefit significantly from African-European partnerships include the African VLBI (very-long-baseline interferometry) Network project and a proposed network of high performance computing centres linked to high speed data transfer infrastructure on the continent. On a longer time scale the aim is to optimise the active and meaningful involvement of African teams in the full deployment and operations of the global Square Kilometre Array (SKA) radio telescope in African countries and all its global collaborations – for science as well as engineering.

The African VLBI Network (AVN) will be established through a combination of new-built antenna systems (25m or larger in diameter) as well as converted systems composed of satellite communication antenna systems that have become redundant (30m diameter or larger) due to advances in optical fibre data connectivity on and around the African continent. These antennas will be donated for scientific use and converted so that they can be used for radio astronomical research. The AVN is underpinned by a strong science case of global interest and will be used to study the evolution of galaxies through cosmic time and the role of Active Galaxy Nuclei in this. Particularly valuable will be the fact that the AVN has access to the same sky as the Atacama Large Millimeter/sub-millimeter Array (ALMA) in Chile and some of the most sensitive optical telescopes. Unique to the Southern hemisphere is the option to observe the inner galaxy where many star-forming regions are located. Through maser[8] studies these star-forming regions can also be used to map out the dynamic structure of our galaxy (the Milky Way). The galactic centre is a Target of Opportunity to "zoom in" on a nearby massive black hole and its immediate environment. Finally, the AVN will be able to make a fundamental contribution to the International Celestial Reference Frame[9], which is poorly defined in the South. The AVN will help to fill a major gap in the European VLBI Network (EVN), which lacks telescopes on the north-south axis extending into African continent. Furthermore, VLBI stations will be valuable platforms for co-locating other scientific instruments like metrological units or equipment for seismology.

Antenna conversions for the AVN have already begun in Ghana and are under investigation in Kenya; similar projects are foreseen in Zambia and eventually in Madagascar. Not all countries interested in participating in the AVN have large redundant telecommunication systems at their disposal. In some countries, like Botswana, Mauritius, Namibia and Mozambique, the construction of new radio telescopes is envisaged to expand the network. Countries that are not formally partners in the African SKA roll-out will be able to join the network in cases where the science case is strengthened through these additions. Additionally, the MeerKAT array, currently under construction at the proposed African SKA core site in South Africa, will become a very sensitive observational instrument in the VLBI global networks. At the same time it could be considered to dedicate antennas in Southern Europe (Azores,

[8] Microwave Amplification by Stimulated Emission of Radiation

[9] The International Celestial Reference Frame (ICRF) is a reference system for mapping equatorial coordinates of extragalactic radio sources observed in Very Long Baseline Interferometry (VLBI) programmes.

Canary Islands, Greece, and Turkey) whose inclusion in the EVN would improve the joint VLBI observation capacities and science output.

In the roll out of the AVN, it will be imperative to involve as much local participation as possible (i.e. involving institutions, individuals and industry from the African country on whose soil the instrument is built) will be aimed for in the roll-out of the AVN. This is expected to be challenging in countries with few radio astronomy practitioners and relevant engineering skills are available. A pilot training programme is planned for engineers and technicians to maintain and operate the telescope systems established in Africa to be cared for by their own professionals who can build bigger teams and transfer their skills and knowledge to enable full participation in subsequent SKA remote stations on the continent. Those goals can be easily achieved through strong collaboration with EU projects that are already funded, such as RadioNet[10]. Strong collaboration will result in an increase in scope and budget, allowing the participation of young African astronomers and engineers in the events. Thus, the AVN can make a significant contribution to the science capacity building for radio astronomy in Africa.

In order to build capacity in the skills required to collect, interpret and use large data sets generated by the AVN, a network of high performance computing facilities and data centres will be established and operated in SKA partner countries. These facilities will require fast broadband internet connectivity to move large volumes of data to central correlation facilities and to science teams around the globe. The chapter on ICT and Big Data provides more information on this challenge and how African-European partnerships can respond to it.

Besides the aforementioned VLBI collaboration, there are other options for joining forces on common research infrastructures in radio astronomy, even before the SKA is completed. A potential proposal would be the hosting of a telescope in Africa, capable of contributing to the global millimetre array. With the advent of ALMA, very exciting opportunities are emerging to probe the physics of the Galactic Centre at very short wavelengths. Such observations require high-precision telescopes which are located high above sea level, preferably in Western Africa, and capable of observations in short wavelengths.

Radio astronomy has a tradition of pioneering technology solutions applicable to many aspects of contemporary society, for example, telecommunications. This has been true not only for radio frequency applications but also for digital equipment. For example, the long-haul e-VLBI application uses innovative point-to-point streaming protocols. Moreover, radio astronomy is appealing to young engineers and scientist. The excitement of a local VLBI research infrastructure is important for involving the general public as well as professionals.

[10] RadioNet is a project supported by the European Commission under the 7th Framework Programme (FP7). It includes 27 partners operating world-class radio telescopes and/or performing cutting-edge Research & Development (R&D) in a wide range of technology fields important for radio astronomy. (www.radionet-eu.org)

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Development of cost effective solutions for the conversion of redundant antenna systems into VLBI capable radio telescopes;
- Establishment of an African voting board to drive African science programmes in radio astronomy (e.g. science cases for single dish observations for the AVN dishes);
- Integration of the AVN and the science community from Africa in global VLBI networks; Development a dynamic global network of collaborators who can assist with development and provision of instrumentation and technical support needed for science surveys and experiments of global interest;
- Support the participation of African individuals and teams in the International VLBI Service for geodesy and astrometry activities;
- Enabling local (African) engineers and technicians to convert or build new AVN telescope systems underpinned by extensive and holistic human capital development programmes;
    - Including the possibility of having AVN in the RadioNet TNA programme
    - Including the advantage of RadioNet3 NAs: ERATec, New Skills, Science Working Group, and also taking advantage of the Spectrum Management experiences
- Research the possibility to have a VLBI capable millimetre dish on the African continent.

1.2. Key Actions

- **Compatibility with global VLBI equipment**
  If the AVN telescope systems are to co-observe with the EVN and other VLBI networks, some backend (data recording and related instrumentation) equipment needs to be in place that ensures compatibility with the data formats of all the other VLBI telescopes. The EVN has a standing Technical Operations Group that works on the development of such equipment. Broadband internet connectivity to do real-time data streaming with modern VLBI telescopes (by optical fibre) should be considered for African VLBI telescope systems. This will require upgrades to the commissioning systems envisaged in Africa, including upgrades of data recording systems and back-ends and participating in the international process to develop data standards. A close collaboration with the EVN and RadioNet will be encouraged.
- **Integration of African facilities in multi-national science observations**
  Once initial telescope systems are built and set to work, scientists globally modify these systems during their operational lifetimes (typically 30 years or more) in line with global science requirements and research trends. The AVN systems will be no different and it is therefore envisaged that - after setting the commissioning telescope systems to work – these systems will be subject to frequent upgrades and modifications to remain relevant and important to the global research community. The European science community need to transfer critical skills and knowledge to the African teams on an on-going basis as is the case amongst the communities of practice in Europe.
- **Joint correlation of observational data**
  The VLBI instrument is complete only when all the telescope data are combined in a so-called correlator. Currently the Hartebeesthoek VLBI telescope system in South Africa subscribes to

the EVN correlator at JIVE in the Netherlands. This could be implemented for all the AVN telescopes. The telescope systems in Africa will also conduct single dish observations to other VLBI observations that are not part of the formal European network schedule. For this to be feasible, it will be important to establish capacity in Africa to correlate data at a central facility and for national teams to process large data sets as part of their national research programmes. This requires the establishment of a network of high performance computing facilities (preferably dedicated to radio astronomy research) and exchange of expertise in specific computational methods and complex software.

- **Scientific services**
  In line with an “open skies” policies of the international radio astronomy community, the VLBI network will be open to all scientists. As new entrants into this community, African radio astronomers will have to familiarise themselves with VLBI science data processing. Skills transfer to set up tools with which to do science proposals and subsequent scheduling of observations will be important to ensure optimal use of the telescopes. User support facilities will be required that introduce (new) users to the data repositories and the scientific processing thereof. Some specific training interventions and technical sessions will be required to achieve this.
- **Deployment of a high-frequency single-dish telescope**
  Such a telescope will be useful for the AVN and equipped with an array of receivers on a high-altitude African site or all-sky survey instruments to complement Northern hemisphere installations.

2. Instrumentation, Research and Development

2.1. Background and Objectives

Advanced instrumentation is a key enabler for successful radio telescopes and observatories. Such instrumentation includes uncooled and cryogenically cooled signal chains and receivers, signal conditioning electronics, recording and networking systems for synthesis arrays such as for (e-)VLBI, and signal- and data-processing for beamformers and correlators. For the long-term future of the AVN project it is essential to develop state-of-the-art instrumentation compatible with other VLBI Networks such as the European VLBI Network (EVN), the Australian Long Baseline Array (LBA) or the Very Long Baseline Array in the U.S. (VLBA).

Commonly used frequency bands at these networks include L-band (1-2 GHz) and C-band (4-8 GHz) while receivers at higher frequencies, e.g. the important K-band between 18 and 26 GHz, require new antenna systems located at suitable (preferably dry) sites at high altitudes. There is a general trend towards multi-octave receivers, contiguous frequency coverage and direct sampling techniques. Compared to the traditional octave bandwidth feeds, wide bandwidth feeds create the possibility of significantly larger instantaneous frequency coverage observations with existing radio telescopes, such as those used in the VLBI networks. Generally, this also results in a significantly improved operational performance at lower costs. A close integration of antenna and Low Noise Amplifiers (LNA) development is essential to achieve the best performance.

Increased sensitivity of a VLBI network by increasing the observing bandwidth requires new wide-band receivers and back-ends which can handle bandwidths of several GHz. Specifications for the receiving/backend system in future telescopes should be able to operate in a single broad band, ranging for example from 2 to 14 GHz observing in dual linear polarization. Such a wide input band is of great interest to astronomy because of the significant increase in sensitivity. Being able to process an entire 14 GHz wide piece of band could be a quantum leap in the digital radio astronomy data acquisition. This goal is very ambitious and its implementation in a radio astronomy backend would be a novelty.

With suitable R&D programmes, the AVN may be able to leap directly from its initial commissioning telescope systems to an advanced instrumentation suite comparable with the best in the world.

There are opportunities for other co-operative instrumentation developments between European and African institutes. These can include receivers that are multi-purpose (suitable for both VLBI and stand-alone observations), receivers for AVN antennas for stand-alone observations (not for VLBI) and new small-to-medium scale antennas and receivers, which develop particular scientific and technological areas (of which C-BASS[11] is a current example).

[11] The C-Band All Sky Survey (C-BASS) is a project to image the whole sky at a wavelength of six centimetres (a frequency of 5 GHz), measuring both the brightness and the polarization of the sky. (www.astro.caltech.edu/cbass/)

Other opportunities involve collaborations and focussed efforts to advance the concepts of

(i) very wideband receivers mentioned earlier and

(ii) advanced aperture arrays[12] in the so-called mid-frequency range due for construction in Southern Africa in SKA_2 and pioneered in Europe e.g. through the FP6 project "SKADS"[13]. The latter is the ultimate wide-field of view approach which opens up for new science to be done in the southern skies accessible from Africa. Technology development programmes like SKADS are particularly valuable as they allow the rapid deployment of new technology and act as a test-bed for new science and technology ideas for modern radio astronomy projects like SKA_2 (see also chapter 3 on "Support for Global Projects").

(iii) In support of all the new instrumental developments, the past decade has seen a number of theoretical breakthroughs in radio interferometric calibration, imaging and de-convolution algorithms. Some of the new ideas have already made their way into software tools (AW-projection in CASA[14] and the LOFAR imager, multi-scale de-convolution methods in CASA, etc.) Other ideas show considerable promise (compressive sensing, calibration filtering), but have not yet been implemented and/or validated with real data. It is also becoming clear that imaging remains one of the critical bottlenecks and risks in modern radio astronomy projects, both in terms of computational requirements, and achievable dynamic range. Urgent progress is therefore still required both on the algorithmic side -- developing the new ideas further -- and on the software side -- providing computationally efficient and highly parallel implementations of the new algorithms.

The expertise required to drive these developments is rare, particularly in South Africa, and scattered across various organisations and steps are required in support of developments for the wide-frequency bandwidth and wide field aperture array approaches mentioned in (i) and (ii). The expected outcome would be new techniques and software tools for calibration and imaging of MeerKAT, LOFAR and other SKA pathfinders that would scale to SKA_1 and beyond, as well as a new generation of young specialists trained to use and extend them.

The training of engineers and technicians throughout Africa in state-of-the-art hard- and software technologies is an important aspect of all projects in Africa, especially in view of the roll out of SKA. Both hands-on training and maintenance are required to reach this goal. The transfer and dissemination of the (newly) acquired and existing knowledge can be achieved through close cooperation between African and European institutions e.g. through dedicated workshops, symposia, staff exchange and radio science- and astro-technologies curricula in schools and university to train a new generation of graduate students. In addition to this knowledge transfer, there are other methods involved in the

[12] Aperture arrays are used in low and medium frequency ranges. In contrast to traditional telescopes they don't consist of a dish that deflects radio waves to a receiver but aperture arrays capture radio signals directly with receptors arranged on the ground.(http://www.skatelescope.org/the-technology/aperture-arrays/)

[13] The Square Kilometre Array Design Studies (SKADS) focused on the development of the Aperture Plane Phased Array which uses fast digital technology to make a flexible, multitasking telescope that can do many different astronomical observations all at the same time. (http://www.skads-eu.org/p/SKADSbrief.php)

[14] Common Astronomy Software Applications (CASA) package is a software package designed for the processing of interferometric and single dish data produced by modern radio astronomy facilities (http://casa.nrao.edu/)

effective training of technicians and engineers. For instance, South Africa has already become a global leader in some aspects of instrumentation development, e.g. FPGA processors, while various research collaborations already exist between European and (specifically) South Africa. It is also essential that there is full co-operation on the scientific goals of these instrumentation projects between Europe and Africa.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Investigating the procurement of the best set of receivers for the AVN including multi-use receivers for AVN;
- Corresponding high performing networks and centres, network management and data management aspects and synergies with existing VLBI networks;
- Involving Africa in advanced receiver systems such as multi-field aperture arrays ;
- Promoting programmes to foster scientific and R&D co-operation between Africa and Europe;
    - This could involve of African scientists and engineers in state-of-the-art instrumentation projects and include training local engineers and technicians to implement, operate and maintain state-of-the-art receiver systems and telescopes;
- Involvement of European and African industry in radio astronomy R&D and the promotion of open access;
- Developing synergies with MeerKAT e.g. of potential new receiver bands.

2.2. Key Actions

- Development of high sensitivity, very wide-band, multi-octave receiver technologies and backend systems;
- Research, design and evaluation for new technology Low Noise Amplifiers with focus on low power, wide bandwidth and very low noise temperatures;
- Implementation of an exchange programme for scientists, engineers and technicians (including students as potential new users and experienced trainers), to enhance exchange of the newly acquired and existing knowledge, and to promote innovative ideas in instrumentation and experiments.

3. Support for Global Projects

3.1. Background and Objectives

The most important new, collaborative radio astronomy project of the next decades is the Square Kilometre Array (SKA). The first phase of the project, SKA_1, is already well planned and will comprise of multiple Radio Astronomy elements in South Africa and Western Australia. This phase is underpinned by pathfinder projects such as LOFAR[15], PAPER[16], MeerKAT and ASKAP[17]. In the second phase of the project, SKA_2, Southern Africa will host both dishes and the mid-frequency aperture arrays, the latter of which is a novel technique providing astronomers with a wide field of view as well as flexibility, agility and rapid response capability not provided by the more conventional dishes. The mid-frequency aperture array (AA-mid) is being developed by a consortium led by ASTRON (Netherlands Institute for Radio Astronomy) as part of the SKA preconstruction work programme. Aperture arrays operating at higher frequencies were pioneered under the FP6 project SKADS (cf. chapter 2). Some limited preparatory activities (exchange of researchers) are part of the recently approved FP7-MarieCurie-IRSES project "MIDPREP".

The wideband receiver and dish developments mentioned in chapter 2 are also relevant for SKA_2 and might be extended to include new approaches to dish construction for SKA_2 e.g. serving as a demonstration project for high(er) frequency low-cost dishes building on experience for SKA1 dish developments.

Other global projects that are related to radio astronomy, like the Solar Orbiter (ESA), the extension of EGNOS[18] to Africa and the International VLBI Service for Geodesy & Astrometry, could also benefit from enhanced African-European cooperation.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Extending aperture arrays to higher frequencies above 1 GHz and to demonstrate its science capability and technology readiness at its intended location in South Africa;
- Applying new calibration and imaging tools and algorithms, data reduction techniques and archiving methods in support of steps toward the SKA;
- Reducing manufacturing and operating costs of aperture array technologies while maintaining performance and reliability;
- Establishing fast broadband data connections within Africa between participating countries and between Africa and Europe for dissemination of data products to/from science data centres in Africa and Europe;
- Developing science expertise in connection to (a) European and African science centre(s) and other users.

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[15] LOFAR = Low Frequency Array, see www.lofar.org

[16] PAPER = Precision Array for Probing the Epoch of Re-ionisation

[17] ASKAP = Australian SKA Pre-cursor

[18] EGNOS = The European Geostationary Navigation Overlay Service

3.2. Key Actions

- Development of a wide-band, mid-frequency aperture array demonstrator through African-European cooperation including scientific training which could support preparations for Africa's hosting of these components in the 2nd phase of the Square Kilometre Array. This includes synergies through integrated solar powered energies.
- Develop a cohesive program for new techniques and software tools for calibration and imaging of MeerKAT, LOFAR and other SKA pathfinders that would scale to SKA_1 and beyond installations.

4. Human Capital Development for Radio Astronomy

4.1. Background and Objectives

Radio astronomy investment in recent years has raised both the supply of and demand for a skilled, science, technology and engineering workforce. Because of this increase of human capital in African economies, it can contribute to the creation and growth of a high-knowledge skill-base across the African continent.

The International Astronomical Union has highlighted the effective role of astronomy in human capital and economic development in its Strategic Plan 2010-2020 "Astronomy for Development ". Astronomy has been an important driver behind the development of advanced technology, such as the most sensitive detectors of light and radio waves and the fastest computers. Radio astronomy is also embedded in one of the committees of the International Radio Science Union (URSI), which proves the relevance of synergies between (radio) science fields e.g. between radio astronomy imaging and medical imaging techniques. Moreover, unlike in most sciences, astronomers can participate in frontier astronomical research regardless of their geographic location. Many of the cutting-edge facilities, both on the ground and in space, developed for astronomy are available for use at no cost by scientists throughout the world.

With its potential to advance our fundamental understanding of the universe, radio astronomy has captured the imagination of young people and increased the number of students studying astronomy and space-related sciences at universities. Current radio astronomy projects, like MeerKAT, are already contributing to the development of astronomical and engineering skills across Africa. Since technologies being developed for these telescopes will be commercialised in the next 10-20 years, young Africans currently working on the project will be in high demand around the world. Embedded in the wider international perspective of the SKA, the building, commissioning and operation will significantly enhance their science and engineering experience.

To facilitate the involvement of students, scientists and engineers involved in radio astronomy projects all over Africa, communication and promotion material should be multilingual (mainly English and French) and language barriers should be taken into account for the organisation of events.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Increasing the number of Africans studying astronomy, physics, engineering and other astronomy related subjects;
- Increasing the number of post-graduate astronomy programmes;
- Supporting science and engineering tertiary education using tools and facilities from the astronomy field, e.g. data processing techniques, remote observing tutorials, virtual observatories, etc.;
- Facilitating the mobility of students and young researchers between Africa and Europe;
- Supporting projects that provide employment opportunities for highly skilled scientists and engineers in research and industry.

4.2. Key Actions

- Establish a network of African-European centres for radio astronomy education and training with potential for close links with industry. Such a programme can complement existing African education programmes like the South African National Astrophysics and Space Science Programme (NASSP);
- Develop post-graduate curricula and related teaching facilities and resources (lecturers) to grow the fields of radio astronomy and all its related disciplines in engineering and ICT;
- Develop a pilot training programme for engineers and technicians to maintain and operate the AVN telescope systems established in Africa including ICT applications
    - Use one antenna as a pilot/as a meeting point for African academics and scientists to develop on-sight capacities and work
    - Mobility grants and financial support for African astronomers, engineers technicians and other technical staff to participate in training events, like the RadioNet schools, scientific and training workshops
- Establish regular radio science and engineering schools and workshops in relevant areas for early researchers to interact with experienced researchers;
    - A particular example is the recent Calibration Workshop but could in general relate to system integration and commissioning
    - Other examples follow programmes from FP7 Marie Curie SKADS and RadioNet;
- Hosting of events related to the scientific unions (International Astronomical Union, International Union of Radio science etc.) and other (e.g. Institute of Electrical and Electronics Engineers);
    - Developing an African centre for these activities ensures improved interaction potential with these Unions such as is advancing with the International Astronomical Union
    - An ambition could be to host a general assembly of a scientific union in sub-Saharan Africa within a decade. Prior to that, a dedicated smaller event could be planned such as now done for the upcoming Africon-IEEE event hosting a specific Europe-Africa URSI meeting emphasizing radio astronomy and instrumentation
- Support and promote the access to the Virtual Observatory as a vehicle for multi-wavelength astronomy for research, education and outreach;
    - To facilitate access by the astronomical community to multi-wavelength astronomical data as well as tools for dealing with them;
    - To ensure that data are accessible to the international community in a manner that does not violate any ownership rights; and
    - To develop human capital through schools and workshops that introduces people to astronomy through the tools of the Virtual Observatory;

5. ICT and Big Data

5.1. Background and Objectives

ICT is the backbone of modern radio astronomy and will enable radio astronomers to reveal some of the most extreme events in the universe. Due to improving observation capacities (advances in technology and larger instruments), the amount of data that radio telescopes collect is increasing dramatically and will soon reach the Exabyte/year level. These recent developments require new infrastructures, technologies and software for the capturing, processing, transporting and storing of data.

Undoubtedly, future communication networks will marry the mobility offered by wireless connectivity to the high bandwidth provided by an optical distribution network. SKA, with its broadband connectivity requirements and its distributed antennae or radio cells, can also help to provide a vision for how this cross-fertilisation will work. It can explore how a fast optical data network infrastructure can benefit the future mobile wireless communications networks. It will help drive the development of cost-effective energy-efficient computing solutions which are likely to draw on technologies from the mobile devices markets and aid their transition into data centres and cloud computing.

The processing requirements for radio astronomy drive key aspects of the Big Data technology roadmap[19] in particular the analysis of "streaming data", "data analytics" as well as "exploration and visualisation" of very large-scale, but comparatively homogeneous data volumes. In the wider context, these technologies translate into areas which have broad commercial and social application. The underlying compute and storage components required to deliver the basis for these technologies will provide the infrastructural elements for the next generation of commercial data centres and distributed cloud computing. Likely applications of streaming Big Data technology include real-time analysis of large-numbers of related video streams for applications from automated safety or security screening to environmental monitoring to individually tailored video for entertainment. The data analytics technologies, coupled to streaming data, have application in remote medical screening and automated diagnosis. These are a new and emerging set of technologies in which Africa and Europe have the opportunity to drive both their development and uptake. Furthermore, Africans and Europeans can be at the forefront of creating a broad ecosystem of new businesses built on novel commercial exploitation of these developments.

The data production and transmission of up to the Exaflop regime from the radio astronomy facilities will require networking infrastructure from the African-based radio astronomy sites to the rest of the world. Additionally, access to these data from the African science teams will require regional High Performance Computing (HPC) and distributed cloud resources. The data network connectivity for radio astronomy between Africa and Europe is ensured by submarine cables such as SEACOM and the West African Cable System (WACS). The telescopes and data processing facilities have to be connected

[19] The Big Data technology roadmap relates to the plans of manufacturers for future generations of components and subsystems for High Performance Computing (HPC) and how these would relate to the applications necessary for streaming radio astronomy data.

to these major intercontinental links and significant high-speed, high capacity terrestrial data transfer networks will be required. For this purpose innovation on optical fibres and the cost effective production of them is necessary. Development of equipment for radio astronomy and related ICT infrastructure require careful attention to radio frequency interference (RFI) issues to ensure optimum efficiency of equipment and maximise the science output from the instruments.

These required infrastructures for radio astronomy will have a direct effect on the wider African economy. The regional High Performance Computing (HPC) and distributed cloud resources will help boost distributed storage and processing services that will benefit and cross-fertilise broader data-centre and cloud computing initiatives in Africa. This will enable citizen science projects to use databases constituted by radio astronomy projects and open market opportunities for information processing. This last aspect will provide a backbone for other concurring areas of science related applications like space navigation with Galileo, Global Monitoring and Earth Surveillance (GMES) for climate studies and crop control) and new businesses. Additionally, an increase in broadband connectivity may bring benefits in many areas which are critical for the future of Africa. It may support education with e-Learning that can bring schooling for everyone also in remote areas, and the deployment of streaming Big Data technologies and analytics could provide a valuable tool for remote medical diagnosis. A related great potential lies in the establishment of e-health services, which contribute to major improvements in maternal care and reduced child mortality rate, while improving the mother's welfare.

Full exploitation of this potential for economic impact and return requires an innovative and well-trained ICT skill-base. The need to develop a large skill-base in these technologies is a challenge common to Africa and the EU. In Big Data, both Africa and Europe are at similar levels of implementation capability, this is an area where we can provide mutual assistance for all our benefits.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Data processing, transport and storage solutions for radio astronomy projects and their broader applicability for economic return in Africa and the EU;Exploiting ICT developments for the benefit of the local population (collateral and direct economic benefit) and transfer these benefits to local markets. In particular, the technologies and techniques associated with Big Data are likely to provide the next wave of applications in government and business;
- Help to develop the skill base in Africa and the EU for the support and development of these emerging technologies using astronomy as a training platform;
- Identifying potential ICT partners in the EU and Africa with interest in radio astronomy projects;
- Developing technologies and techniques to minimise radio frequency emissions from ICT equipment or shield telescope equipment from radio frequency interference generated by ICT equipment.

5.2. Key Actions

- Development of the Big Data Africa programme[20] which seeks to establish a network of smaller, university linked centres with a focus on skills development in Big Data technologies and techniques;

- Development of high performance networking, data centres and processing technologies for the AVN (to bring ICT systems together);
- Establishment of a distributed laboratory across centres of excellence in Africa and the EU for "ExaScale Astronomy" as a primary vehicle for training to doctoral level of ICT professionals as well as providing a focus for Africa-EU research collaboration in the aspects of Big Data in relation to astronomy and linked to the Big Data Africa programme;
- Development of cloud-based techniques as applied to radio astronomy problems such as the search for pulsars and transients;
- Develop content delivery networks for global distribution system of science data and better data streaming;
- Development of solutions for internet of connected sensors:
  - Addressing large scale management, sensors and the related information
  - Correlation of science data with monitoring data;
- Develop European and African projects for extra ICT capability exploitation: e-Science, e-Learning, distributed remote sensing, remote medicine etc.;
- Develop the appropriate tools for data reduction, imaging, archiving, and data product distribution toward the SKA;

[20] Refer to annexe for details on the planned Big Data Africa programme.

6. Renewable Energy for Radio Astronomy

6.1. Background and Objectives

Due to the increased use of the broadcast spectrum (that portion of the electromagnetic spectrum that is ideal for telecommunication), more and more modern radio telescopes have to be built in remote (and often rural) areas, where there is limited broadcasting in the frequency domains relevant to radio astronomy. This requirement for “radio quiet zones,” coupled with the African geography, necessitates innovative thinking from the designers of radio astronomy infrastructure to ensure effective and efficient technologies for future energy production, distribution and storage, which generate as little radio interference as possible.

The radio telescopes envisaged in Africa will serve as a launch pad for reliable green power generation in remote areas without grid connection. This real need for autonomous modular power supply at remote observation sites is only one of several promising opportunities renewable energy presents for African-European radio astronomy. Furthermore, the high solar radiation of many African regions creates ideal conditions for solar power plants. Another positive factor is the dramatically falling material costs for solar power plants, which will reduce the financing cost and thus the risk associated with the investment. The use of renewable energy sources will make radio astronomy facilities independent from fossil fuels and thus from the rising prices and the finite availability of these fuels.

Green power plants that supply radio astronomy infrastructure with electricity may set a pioneering example for self-sustainable mega-science production and infrastructure operation, with an expected direct economic and indirect societal impact in the developing nations. The spin-off triggered by radio astronomy projects can have a positive impact on the quality of life of the local population by providing reliable power access. These people will benefit from the energy solutions and its early market introduction to be developed around the radio astronomy projects in Africa. The European Union has a direct interest in supporting a sustainable energy roadmap in Africa, for reasons that include environmental concerns (reducing global CO_2 emissions) as well as opening up new markets for its "green energy" industry.

Moreover, the development and construction of renewable power plants can create new local jobs and businesses, while new skills and knowledge can be transferred to the local population. Many of these opportunities will require higher levels of skills that might currently be available in the affected areas, stimulating interest in education into technical domains.

Nevertheless, some challenges need to be overcome before renewable energy projects for radio astronomy can be realised. These challenges concern mainly technical and financial issues. For example, the storage of energy (especially for solar energy) to assure around-the-clock power supply is a technological challenge that receives global attention. Adequate backup solutions for renewable energy systems will be necessary as well to prevent the loss of data and interruptions during astronomical surveys. This is a particularly challenging issue because several remote telescope stations will not have grid power connectivity.

The development of small-scale smart-grids, which can assess and match local power needs and power generation capabilities at a small cost, could also help overcoming this challenge. Smaller, but real-scale demonstration projects will provide hints on the best day observing regimes, what best observation strategies can be recommended under this extreme circumstances and how to reconcile peak energy production with peak use and thus peak science production.

Various SKA member countries (Netherlands, Germany) and others i.e. Portugal and Spain in Europe are presently engaged in "sustainable energy for science" initiatives. The planned telescopes in Africa together with partners form these countries, offer excellent opportunities for collaborative projects for furthering the Key Actions pointed out below.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Demonstration of the viability of solar power (voltaic, thermal or combinations) for radio astronomy;
- Exploration of the possibility to use biomass, wind energy and geothermal energy for radio astronomy;
- Identification of candidate renewable energy technologies according to requirements of the installations and local renewable energy resources;
- Development of technologies and techniques to avoid or shield radio frequency interference of power plants and equipment;
- Augmentation of the skill levels in local communities to participate in the operations and maintenance of any infrastructure deployed in their immediate vicinities;
- Design power plants and grids in a way that it benefits local communities;

6.2. Key Actions

- Conduct a study to characterise the power and energy requirements of radio astronomy installations;
- Develop impact analysis of renewable power scenarios on radio telescopes sites
    - This includes aspects of radio interference and potential for excess power
    - Identify R&D aspects for large scale implementation and use;
- Development of a joint training programme with industry and local communities for the design, the construction and maintenance of renewable energy plants that can be used to train engineers and technicians;
- Evaluate other types of energy to integrate the maximum energy supply over the long-term;
- Use the AVN as a potential test bed for renewable energy projects. A possible second test bed for this priority, similar to AVN, is the Cherenkov Telescope Array (CTA)[21], if it will be constructed in Africa.

[21] The Cherenkov Telescope Array (CTA) aims to build the next generation of ground-based and high energy gamma-ray instrument. Currently, the CTA international consortium is on track to be ready for a construction phase in 2015.South Africa is being considered as a possible site to host the CTA observatory.

7. Astronomy as a Tool for Science Education and Public Understanding

7.1. Background and Objectives

Modern astronomy, and thus radio astronomy, plays a key role as a tool for inspiring and educating young people. As one of the most approachable and fascinating sciences to for children, especially the very young, astronomy is an excellent vehicle for to introducing them to science and technology.

It is well known that good scientific research requires a good basis in science education from the earliest stages. It has distinct potential in facilitating education and capacity building throughout the world. Its ability to stimulate wonder in all audiences has the potential to bring together parents and their children and to make them work together on a common educational project. Such an impact on the Mathematics and Science education system as well as influencing the public perception of science and technology will also feed directly into the Human Capital Development programme, by supplying young enthusiastic school leavers into the tertiary education system. Astronomy is also a powerful tool for raising the awareness of companies and policy makers for the potential of science and innovation for socio-economic development.

Science education can also be interpreted as public understanding or integration of key scientific research and technology into the larger community. Public engagement, both in the scientific process underlining radio astronomy as well as the implications of the research in policy and community initiatives, requires the development of (media, policy, education, etc.) strategies that make radio astronomy accessible to a larger audience (e.g. citizen science tools and programmes). To ignite community involvement in a given project, it is important to encourage and train networks for amateur astronomers as conduits for astronomical awareness. It is equally important to inform and involve the local communities living in the vicinity of the radio astronomy sites. Public engagement also entails the identification of best-practices to involve the local population both in the technical implementation of radio astronomy projects in the development of research infrastructures. The aim of public engagement is, therefore, to ensure community acceptance of the radio astronomy projects as well as to promote a sense of “ownership” through conceptual understanding.

Although the topic of astronomy has so many applications in other areas of science and society, the aim of this thematic priority is to emphasise a particular form of collaboration and engagement with radio astronomy. In this context, the collaboration with science unions like the International Astronomical Union (IAU) would be very beneficial. The IAU, is an organisation that works to promote astronomical education and research in developing countries. One of its major projects is the Global Hands on Universe Training Programme and other programmes including Teaching for Astronomy Development (TAD), and on World Wide Development of Astronomy (WWDA). Another partner could be the International Union of Radio Science (URSI), which is a non-governmental organisation responsible for the coordination and initiation of studies, research, applications and international scientific exchange and communication in the field of radio science.

Due to its unique combination of science with inspiration and excitement, modern (radio) astronomy can be promoted through a wide spectrum of initiatives and actions on two different levels: projects (e.g. teacher and research training) and systematic change (e.g. curriculum and policy). These types of actions are outlined in the following list of objectives and key actions.

The objectives of AERAP in this thematic priority are to support cooperation related to:

- Increasing the number of schools using astronomy to enhance mathematics and science education;
- Developing astronomy-based educational materials for young children and teenagers to excite them about science in non-school based contexts, and to provide them with a practical view on how science will be done in the near future;
- Training of teachers on astronomy content and teaching methodology in order for them to use astronomy to enhance the teaching of mathematics and science;
- Raising the awareness of European and African citizens, companies and policy makers to the potential of radio astronomy for science education and development;
- Using the cultural links through indigenous knowledge of astronomy both in Europe and Africa to promote ownership of the science of astronomy and stimulate a culture of scientific thinking;
- Improving the uptake of science, mathematics and ICTs at schools and undergraduate levels at universities;
- Encouraging collaboration with relevant international projects such as RadioNet;
- Emphasising ICT related activities, necessarily linked to the new era that Radio Astronomy is entering, thus introducing students to e-Science tools, technologies and collaborative practices.

7.2. Key Actions

- **Curriculum design:** Work closely with the curriculum specialists within partner countries to identify ways in which the teaching of the existing local school curriculum could be enhanced through strategic topics relating to the fascination of astronomy, e.g. searching for exoplanets using real data, e-tools and mathematical methods. This project should be sensitive to the local curriculum needs and objectives and how astronomy can help to achieve that. There could be emphasis on the close connection between radio astronomy and e-Science. The long-term goal would be to incorporate astronomical topics strategically within the mathematics and science curricula in order to enhance the learning of these subjects. The success of this key action relies on teacher availability and motivation.
- **Teacher training:** Identify and work with facilitators in European and African countries who will be able to inject astronomy-related training into the teacher training systems within that country. The underlying principle will be to try to link the excitement of astronomy to the existing mathematics and science curricula. A bi-product of this action will, thusly, be the promotion of active participation of its members in science training programmes and initiatives. To maximise the output of this action, the teachers themselves must be trained in communication methods as well as the cultural background of the students they will be educating. By developing a community of teachers associated with the project, both in Europe and in Africa, there will be an exchange of ideas, materials and methodology to enhance teaching in both continents.

- **Educational Resources:** Facilitate the collation of existing educational resources; the development of new resources where necessary; and the dissemination of all these resources to schools and outreach organisations across Europe and Africa. Part of this action should entail the peer review and evaluation of resources such that there is an assurance of quality amongst astronomical resources being used within the educational communities. Such resources may also include larger projects such as Astro-buses, mobile planetaria and portable radio telescope instrumentation. All educational resources must be adapted (through translations and content) before used in educational outreach initiatives.
- **Inspiring the very young:** Develop training programmes and materials for facilitators in each partner country who deal with young children. These facilitators could be based at science centres, observatories, museums, schools, child care facilities, etc. The training and the materials would focus on conveying the beauty and scale of the universe to young children in order to inspire them to follow an education path that includes mathematics and science. It should also convey a sense of tolerance and global citizenship through the knowledge of the vastness of the universe e.g. children could be encouraged to work with other schools in "conferences" where they could collaborate with other students around the world.
- **Establish educational and outreach platforms** with primary and secondary schools and schools for higher (technical and other) education. Platforms could mean project related activities as part of the (local and/or regional) education for both pupils and teachers. Important aspects of such platforms would be to provide a modern image of science and scientists, promote careers in science and technology, transmit the importance to preserve and protect the world's cultural and natural heritage of dark skies, and to contribute to improving the gender-balanced representation of scientists in the future. Outreach training for researchers will be an additional focus for this key action.
- **Promote the use of e-tools for science education:** Develop innovative ways of teaching by means of e-Science technologies. e-Science tools will be of special interest for teachers, including how to access public astronomical archives, simple internet tools to work with astronomy data, use of collaborative tools (e.g. wikis, forums, shared whiteboards), all of them leveraging a wealth of open resources to both teachers and students, while promoting the use of the scientific method.
- **Institute a process of monitoring and evaluation**: trace the impact of these activities on the different target groups (local communities, general public, policy makers, media, etc.). This action also emphasises learning from past experiences and developing best practices (through workshops, meetings, etc.).
- **Policy design and proposals**: Defining policy options and ideas for specific projects to strategically target sources of funding. This option will require the development of communication and outreach strategies tailored to policy-makers and funding bodies. This action will involve the design and production of high-quality events (exhibitions, conferences, etc.) and distribution of outreach material for different audiences, with different formats and platforms in order to raise the awareness of radio astronomy and its technological, economic and social benefits.

III. Support for the Implementation of the Framework Programme

To successfully implement the actions outlined in the previous section, AERAP is poised to engage its European and African stakeholders in the collaborative process for radio astronomy as well as ensure that these stakeholders benefit from **political** and **public engagement** in addition to **financial** and **practical support**. These areas of support will facilitate and accelerate the implementation of the framework programme and the potential of African-European radio astronomy cooperation.

Political support will be a critical tool for the implementation and advancement of the seven thematic priorities mentioned in this document and, eventually, the resolution of a communication gap between the scientists, policy makers and the general public. The target audience for this support includes international policy-makers and diplomats (in both continents) as well as local policy-makers, who may be interested and/or strategically positioned to support radio astronomy projects on the ground.

Political support for Africa-EU radio astronomy collaboration can be identified on two distinct levels: ***raising*** awareness of radio astronomy amongst European and African policy-makers and ***informing*** current political discussions concerning scientific excellence in radio astronomy, technological innovation as well as proposed initiatives in science for development and capacity building in Africa. The first level of political support, “raising awareness,” seeks to translate the framework programme’s seven thematic priorities into a common language that is easily accessible for policy-makers and key stakeholders on an international level. The second level is expected to influence a **sound policy basis** for the development and promotion of radio astronomy cooperation in terms of research and development policy in the EU and Africa.

In launching this framework programme, a major goal is expanding awareness of socio-economic development aspects of radio astronomy which, currently, is quite limited. To maximise public support and acceptance of the framework programme, it will be necessary to explain the discipline as well as the potential for its positive socio-economic side effects. In light of Africa’s growing science capacity AERAP is especially committed to promoting the inherent added value of Africa-EU radio astronomy collaboration in development and science initiatives. For example, the South African KAT7 project can be appreciated by policy-makers for its contribution to the development of astronomical skills across Africa. KAT7 is an example of how awareness-raising initiatives can stir political support from lead policy-makers and legislators for Africa-EU radio astronomy cooperation.

These efforts will ensure that Africa-EU radio astronomy cooperation, especially those programmes which encourage socio-economic returns, can ***inform*** current policy discussions in both continents (e.g. human capital development, astronomy as a tool for science education as well as the UN Millennium Development Goals and ICT). For the framework programme to adequately inform policy related to Africa-EU radio astronomy cooperation in both continents, it is important to have a strong understanding of realistic policy and funding targets and ideas in the early stages of the programme’s implementation. For instance, AERAP can explore bases for securing funding from public bodies, philanthropic organisations and companies for radio astronomy projects. Political support for Africa-EU radio astronomy cooperation will also make sure that funding instruments and financial resources are adapted to benefit African-European radio astronomy partnerships. For this last point, it is critical that the eligibility of African countries as well as radio astronomy topics be taken into account (e.g. S&T and R&D, science for capacity building, HCD or education policy initiatives).

In addition to political and public engagement, the successful implementation of this framework programme relies on the identification and exploitation of a wide range of funding mechanisms. AERAP will be strategically positioned to facilitate the access to **financial support** for the implementation of African-European radio astronomy partnerships within this framework programme. Under the banner of Africa-EU radio astronomy cooperation, this financial support will involve working with industries, foundations and institutes to open up new and/or alternative financial sources for AERAP members. AERAP will develop a degree of expertise linking its members' activities and partnerships with specific funding instruments (e.g. the European Development Fund, "Pan-African Instrument" of the Development Cooperation Instrument) as well as other EU funding instruments geared towards development initiatives overseas. Based on the input of its members, AERAP will exhaust its networks to uncover new options for funding for specific projects and partnerships. Moreover, AERAP will help steer specific partnerships towards a wide array of public funding options by endorsing the development of communication and outreach strategies tailored to policy -makers and funding bodies in both continents.

Given the potential of radio astronomy collaboration, its possible benefits to astronomy and to science in general, a final factor in enhancing support for the framework programme is a strong **media presence** through multiple dissemination channels on an international scale (e.g. international and national news, science magazines and social media platforms, etc.). Through these channels, media coverage of radio astronomy projects will be *regular* and *targeted* towards a large and diverse audience. Media support, especially on a local level, will require other instruments to achieve this coverage, such as special events and the direct engagement between scientists and citizens. A strong media presence can also serve as a tool for promoting the involvement of local communities in support for radio astronomy and its technical, economic and social benefits.

AERAP will offer **technical** and **practical support** in implementing the framework programme. This support will serve as an umbrella extending over multiple short and long-term actions. These actions range from assisting in the preparation of tenders and match ideas through seminars, workshops, consortium building meetings. Moreover, AERAP Helpdesk will be at members' disposal to initiate partnerships with European entities as well as assist in proposal writing. In addition to providing its members with early information on funding opportunities and upcoming calls of research and development cooperation projects, the AERAP Helpdesk will promote communication amongst members as well as develop a list of best practices to be distributed amongst its members for future programmes.

Lastly, all the support actions for the implementation of this framework programme must be embedded within a comprehensive communications strategy supported by a regular evaluation to secure success.

Annexe

Big Data Africa - Programme Proposal (v1 - DRAFT)

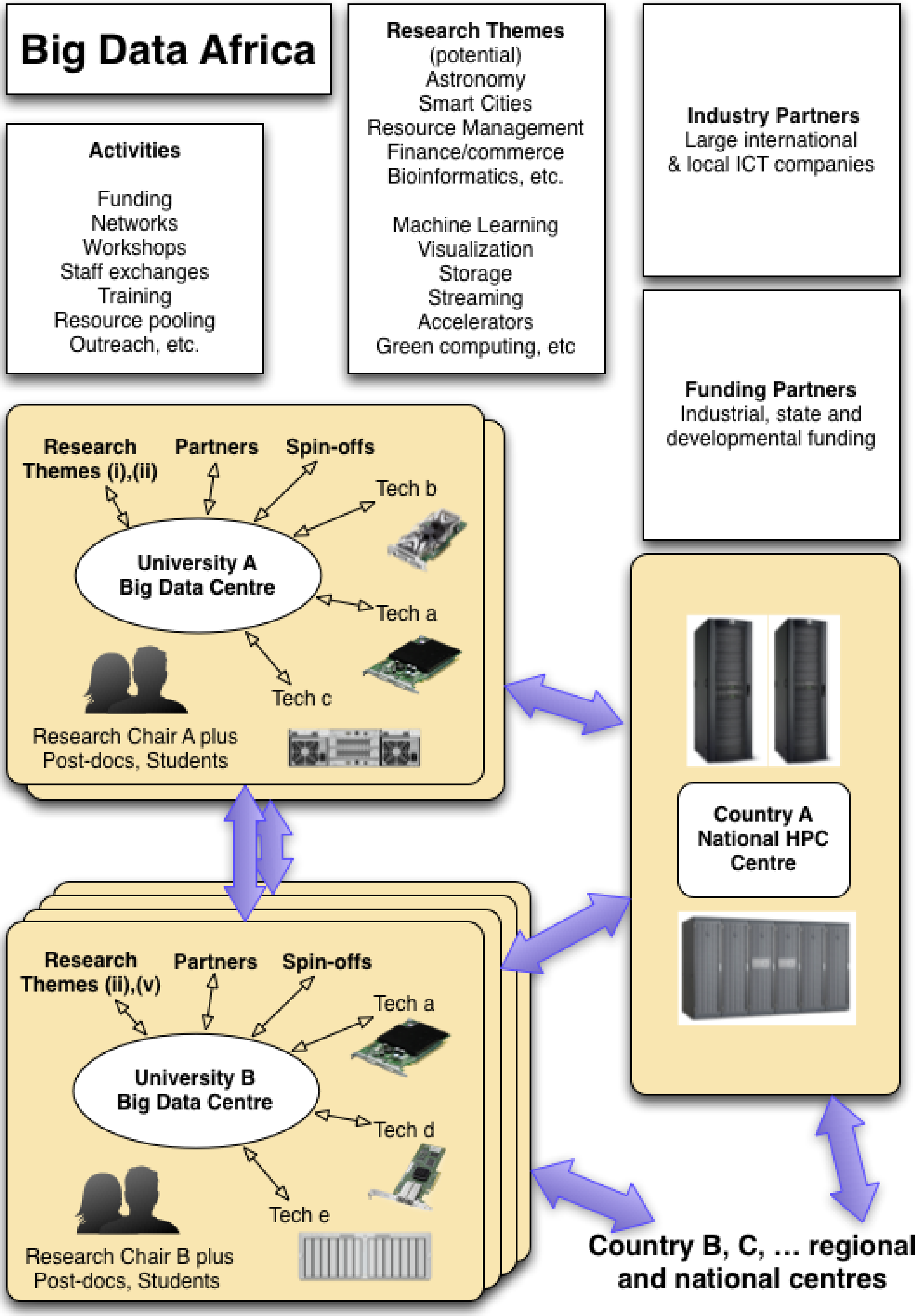
Jasper Horrell, SKA South Africa, 15 April 2013

Vision:
A network of high performance computing (HPC) centres spread throughout Africa with access to the latest technologies, active skills development programmes, touching government and business, comprised of smaller university-based regional centres linked to larger national facilities, strong involvement from leading ICT companies, mobilizing developmental funding for Africa, strong linkages between regional and national centres, strong linkages to leading international HPC centres, addressing the African situation and market with local skills and international expertise, a well-managed flagship programme for African high tech development, owned by Africa

Background:
The Square Kilometre Array (SKA) provides a Big Data focal point in Africa. The project has attracted the interest of most of the world's largest ICT companies and many of the governments. Many see the SKA as a natural entry point into Africa development and markets and are looking to leverage off the already substantial and growing presence of SKA in Africa. Big Data is the new buzz phrase with many seeing this as an emerging multibillion dollar industry, a new and critical skill to master for future government and industry.

We look to establish an African-wide programme, **Big Data Africa**, harnessing the interest around the SKA, but aiming more broadly than that. The programme is to be initiated in South Africa, but will aim to link in the SKA Africa partner countries as early as possible. The main focus and funding of the programme will be the development of skills in HPC technologies and techniques through the establishment of a number of university-linked regional centres in HPC technology focused primarily on HPC skills development and the application of HPC technology to local issues. Programmes and codes developed at the regional centres would be transferred to the national centres (e.g. CHPC in SA) to run at scale on large HPC hardware installations. The SKA SA funded programme, "HPC in Radio Astronomy", which has been running for the last couple of years, provides a good blueprint for this bigger, more ambitious Big Data programme.

The importance of the strong university links in the Big Data Africa Programme lies in the access to students for skills development in the latest technologies and application of such skills to local African problems and markets. We wish to see a steady stream of students, trained in such techniques, moving into a range of application domains within government and industry. A schematic of the Big Data Africa Programme is depicted below. Shown are several university-based regional centres and one national centre in a single country, but the intention is ultimately for multiple countries, each with a number of regional centres.


Big Data Africa
Activities
Funding
Networks
Workshops
Staff exchanges
Training
Resource pooling
Outreach, etc.
Research Themes
(potential)
Astronomy
Smart Cities
Resource Management
Finance/commerce
Bioinformatics, etc.
Machine Learning
Visualization
Storage
Streaming
Accelerators
Green computing, etc
Industry Partners
Large international
& local ICT companies
Funding Partners
Industrial, state and
developmental funding
Research Themes (i),(ii)
Partners
Spin-offs
Tech b
University A
Big Data Centre
Tech a
Tech c
Research Chair A plus
Post-docs, Students
Country A
National HPC
Centre
Research Themes (ii),(v)
Partners
Spin-offs
Tech a
University B
Big Data Centre
Tech d
Tech e
Research Chair B plus
Post-docs, Students
Country B, C, ... regional
and national centres

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