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The Square Kilometre Array and the SKA Design Studies

S.A. Torchinsky

Observatoire de Paris, 5, Place Jules Janssen, 92190 Meudon, France

Abstract. The Square Kilometre Array (SKA) is the future radio astronomy instrument which will deliver an order of magnitude improvement in sensitivity compared to current radio astronomy facilities. By taking maximum advantage of the latest digital technology, the SKA is particularly well suited to extremely large surveys, including a number of experiments targeted at understanding Dark Energy. The SKA project is described, with emphasis on the European contributions.

Résumé. Le grand radiotélescope du futur « SKA » est prévu d'être un réseau d'un kilometre carré (Square Kilometre Array). Ceci délivrerai un amélioration d'un ordre de grandeur par rapport aux radio télescopes existants. En profitant pleinement des avancés en technologie numérique, le SKA sera parfaitement adapté pour faire des très grands relevés, y compris des études particulièrement conçues pour éclairer le mystère de l'énergie sombre. Ici, on présente le projet SKA avec l'accent sur les contributions européens.

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1. Introduction

The Square Kilometre Array(SKA) will be an enormous radio astronomy facility with first-light of the completed array expected by 2020, and initial operations beginning in 2015. The SKA will be a massive array of many receiving elements, and it will thus have both exquisite sensitivity and angular resolution, as well as an ultra wide field of view. The fully sampled field-of-view, of the order of 200 square degrees, makes the SKA effectively a 10-gigapixel ultra wide field spectroscopic radio camera.

Survey science will especially benefit from this instrument. Understanding Large Scale Structure, and Dark Energy in particular, is a key science driver of the SKA. This is one of a number of Key Science projects which include the nature and origin of Cosmic Magnetism ; the detection and evolution of the first luminous objects during the Epoch of Reionisation ; testing Einstein's theory of General Relativity in the extreme field limit ; and tracing the processes which lead to life on Earth including planet formation, extra-solar planets, organic molecules, and perhaps indications of extra terrestrial intelligence (see Carilli & Rawlings(2004) for more details).

The SKA is a global collaboration, currently including 17 countries worldwide. There are two shortlisted sites for the instrument, both in radio quiet zones with very low population. These are the Karoo desert in South Africa, and the Mileura desert region in Western Australia. The final decision for the site will be made in 2010, with construction beginning soon thereafter.

2. Dark Energy Experiments

The spectroscopic capabilities in an ultra wide field of view allow the SKA to make a billion galaxy redshift survey out to z=2. An initial, all-sky survey ca be completed within a year, and will be used to detect Baryonic Acoustic Oscillations (BAO) in the galaxy distribution, leading directly to a measure of the Dark Energy equation of state parameter. The SKA has the great advantage of simultaneously mapping the galaxy sky positions and redshift, by detecting the λ21 cm electron spin-flip transition of neutral hydrogen. The simulaneous mapping and spectroscopy eliminates the systematic errors which limit the optical surveys using photometric redshift estimates in follow-up observations. A review of current and planned BAO experiments, as well as the relevance to Dark Energy has been done in this volume by Abdalla (Abdalla (2007), and see also Blake et al.(2004)).

A continuum survey complements the BAO spectroscopic survey, and will provide a large database for a statistical weak-lensing survey, with the goal of measuring Cosmic Shear (Zhang & Pen(2005), Zhang & Pen(2006)). Over 10 billion galaxies are expected to be catalogued Blake et al.(2004)), and large, clean, sample can be extracted. Galaxies with intrinsically stretched morphologies, for example due to starbursting, can be removed from the sample, while still retaining a very large sample, distributed throughout the sky. By further dividing the sample into redshift bins, the evolution of Cosmic Shear can be determined as a function of redshift (Blake et al.(2004)). Statistics on gravitational microlensing traces the intervening mass distribution, and the combination with redshift evolution adds the ability to measure the angular diameter distance contribution to the lens equation, effectively probing Dark Energy.

A programme of proper motion studies of galaxies will provide a precise measurement of the local Hubble constant H_0. With its high sensitivity, and angular resolution using baselines of up to 3000 km, the SKA will monitor proper motion of extragalactic maser sources over a period of years, and eventually decades. A large sample of sources over a moderate timescale of several years will already provide $\sim 1\%$ precision on H_0. Such precision provides a robust constraint on the estimation of the equation of state of Dark Energy (Blake et al.(2004)).

If it turns out that the accelerated expansion of the universe is due, at least partly, to a negative vacuum energy, and not entirely a purely geometrical factor in General Relativity (*ie.* the Cosmological Constant with $w \equiv 1$), then one can consider measuring the sound speed of Dark Energy (Torres-Rodríguez & Cress(2007)). Such an experiment is possible with the SKA, and can measure differences from a $w = 1$ model to the 10% level.

3. The Square Kilometre Array Design Studies

The Square Kilometre Array Design Studies (SKADS) is a European Community project funded by the EC Framework Programme 6. It was proposed in 2004, and formally began on 1 July, 2005 with a total duration of 4 years. SKADS brings together the science and technology development in the partner institutes with the overall aim of producing a designed and costed SKA which is well matched to the requirements of the SKA scientific goals. SKADS is funded at the level of 38M€ with nearly 11M€ provided by FP6, and the rest by the partner national funding agencies.

Much of the scientific interest in the SKA within Europe is related to science using very large surveys. On the technological side, this capability is best provided by the concept of the Aperture Plane Phased Array (Faulkner et al (2007)). Thus, SKADS focuses on the development of the Aperture Plane Phased Array which exploits fast digital technology to

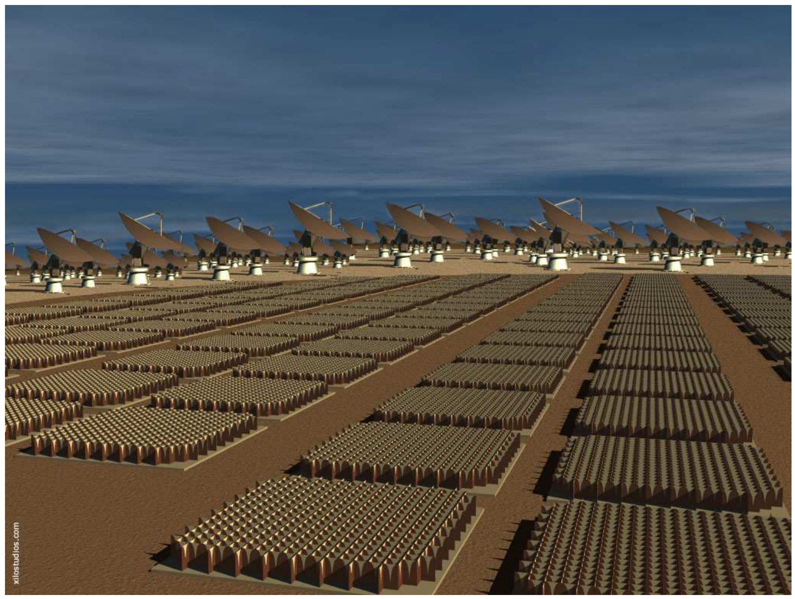

Figure 1.: *An artist's conception of a SKA station. The Aperture-Plane Phased-Array occupies a large area, with many small receiving elements viewing the sky directly. This technology provides a very large field of view, and digital technology permits are large number of synthesised beams to fully sample the field of view with high spatial resolution. (image by Xilostudios)*

make a flexible, ultra-wide field, multitasking telescope that can do many different astronomical observations all at the same time.

SKADS aims to prove the technical feasibility of the aperture array concept by building and testing prototypes. Three demonstrators are under construction : BEST, EMBRACE, and 2PAD.

The Basic Element for SKA Training (BEST) focuses on testing components and algorithms. The validity of some concepts that are at the heart of the SKA philosophy are being verified using a part of the large Northern Cross Radiotelescope in Medicina, Italy. The technique of multi-beaming must be proven, and this involves electronically creating multiple pixels in the field-of-view of a single parabolic receiver. Adaptive beam forming will also be studied which involves combining signals from separate receivers with the proper phase delay in order to create a given pointing direction. Finally, BEST is developing and testing algorithms for mitigating and possibly eliminating man-made radio frequency interference.

The Electronic Multi-Beam Radio Astronomy Concept (EMBRACE) is the demonstrator of the aperture-plane phased-array concept which is the main focus of SKADS technology development. The EMBRACE project is led by Parbhu Patel at ASTRON, and will have demonstrators built at Westerbork in the Netherlands, and at Nançay in France. EMBRACE will be a single-polarisation telescope covering a frequency range from 500-1500 MHz, with a $\pm 45°$ scan angle. There will be a total collecting area of 300 m^2 at the Westerbork site, and a further 100 m^2 at Nançay. The individual receiving structures in each 1 m^2 tile are Vivaldi antennas. Each tile has 64 elements placed in parallel rows, and a dual-polarisation tile is being developed which uses a novel method for mechanically interlocking the individual antenna elements.

The combination of signals from the 64 antenna elements is done in an integrated analog circuit called a beamformer chip. This is where the phase shift is applied in order to vary the scan range. Different implementations of the beamformer chip are under development at ASTRON and at Nançay.

The entire EMBRACE development maintains a focus on cost, as well as on performance. EMBRACE components are designed with emphasis on reproducability, and the ease of mass production. The SKA will be an instrument composed of tens of thousands of antennas and tiles, each with large numbers of the same components. Mass production is essential for making an affordable SKA.

The ultimate capability of an aperture-plane phased-array is realised with the development called 2PAD : the Dual Polarisation All Digital aperture array tile. This concept exploits digital technology to the fullest extent. The signal from the sky is digitised right after reception at the

Vivaldi antenna element, and from then on, only digital electronics are used. This concept promises unpredecented flexibility and performance for a telescope, limited only by the computer power and speed of data transfer. It remains to be demonstrated that low system noise level, power consumption, and feasible data transfer rates can all be achieved at an affordable cost, but the fully digital solution provides the maximum possibility for simultaneous observing, post-analysis of transient signals, and virtually instantaneous telescope repointing. The SKA based on 2PAD technology would truly be a software telescope, limited only by computer processing power.

The Science Simulations are at the heart of the effort in SKADS. Within this context, the science drivers of the SKA are modelled in detail and they ultimately provide the technical specifications for the instrument. The core activity is the pure sky simulation which feeds into the telescope and network simulators. These tasks, in turn, take input from the technical development as well as the measured behaviour from prototype components. The result is a virtual observation which is analysed to see if the science goals can be met. Requests for specific areas of improvement are passed-on to the technical development, and this process is iterated. In particular, the SKADS Design & Costing (Alexander et al. (2007)) effort is the focus of the science and technical interactions.

4. Acknowledgements

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