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Sweden and the Square Kilometre Array

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Summary

The Square Kilomtre Array, currently under construction in the South Africa and Australia, will be the largest radio telescope in the world. It is expected to have a major impact on nearly every aspect of astrophysics. In this talk we will highlight some of the scientific motivations, the technological challenges, as well as the Swedish contribution to the project.

1 Introduction

The Square Kilometre Array (SKA) is an ambitious international project to build the largest radio telescope in the world. In fact, the SKA will consist of two interferometers being built in South Africa and Australia. The project, whose inception began with the establishment of a working group by URSI in Sept 1993[1], and officially began construction on 5 Dec 2022, is aiming for first light with 4 dishes and 6 stations in 2024. The SKA Observatory (SKAO) is the intergovernmental organization coordinating the design, construction, and operations, which will ultimately oversee the two telescopes. Its current membership (full and associate members) consists of 16 countries, and 8 African partner countries coordinating the future expansion of the telescope.

The scientific motivation for building the SKA spans the full breadth of astronomical research from cosmology and the early Universe, through galaxy evolution, to stellar astrophysics and planet formation. It touches on fundamental physics of gravity and magnetism, through multi-disciplinary fields such as astrochemistry, and will be sensitive to events occurring on timescales from Gyr to submilliseconds. The extremes of these science cases provide system requirements for the telescopes for their collecting area, antenna distribution, wavelength coverage, and data dump rate. Swedish astronomers, engineers, and companies are actively contributing to the scientific and engineering design and work packages.

2 Science Motivation

A square kilometre of telescope is roughly the collecting area needed to detect the neutral atomic hydrogen (HI) content of a galaxy at a redshift of z=1 [1]. This corresponds to approximately the peak in the star formation activity in the Universe. However, scientific discoveries the last 30 years, and technological advances, demonstrate that the SKA will have a profound impact on nearly every aspect of astronomy, providing motivation from a wide range of disciplines. These include, but are not limited to: tracing the history of HI through the Epoch of Reionization ($6<z<25$), and the formation of the first galaxies through HI intensity mapping ($z<6$), to detailed understanding of the baryonic cycle in distant galaxies down to the Milky Way ($0<z<1$), connecting large scale perturbations of the early Universe to galaxy evolution today; testing theories of gravity and nuclear physics with extreme precision using pulsars and pulsar-blackhole binaries; understanding the role of magnetic fields in the evolution of cosmic objects; detecting complex molecules and cm-sized dust in star- and planet-forming systems, etc [2].

3 Telescope & Instrumentation

SKA-Low at the Inyarrimanha Ilgari Bundara, CSIRO Murchison Radio-astronomy Observatory in Western Australia will consist of 131,072 antennas spread between 512 stations with an maximum baseline of 70 km and operating between 50 to 350 MHz. SKA-Low will operate as an aperture array: the antennas observe the entire sky at once, but software which combines signal of antennas with a specific time delay is used to image specific parts of the sky and filter others. By forming multiple of "beams" on the sky, through multiple sets of time delays, the aperture array can simultaneously observe large areas of the sky, only limited by the signal processsing and computing capacity of the backend, with trade offs for sky area versus resolution.

SKA-Mid near Carnarvon in the Karoo, RSA will consist of 197 dishes (64x13.5m + 133x15m) with a maximum baseline of 150 km and operating between 350 MHz to 15.3 GHz over 5 bands. SKA-Mid will use off-axis parabolic dishes to focus incoming signal to one of five more traditional single-pixel feeds. The dishes will consist of light weight composite materials.

[1] https://www.skatelescope.org/history-of-the-skaproject/

The expected data rate is ~7-8 Tb/s for each of SKA-Mid and SKA-Low. Each remote SKA telescope site will host a Central Processing Facility where data is averaged and correlated. The visibilities (~5 Tb/s) will be calibrated (and imaged where appropriate) by the Science Data Processor–also hosted at the telescope sites–before being delivered to SKA Regional Centers (SRCs) for access by the scientific community.

4 Swedish Contributions to SKA

In past years, Swedish scientists have participated in defining the science cases for several key science goals, including exploring cosmic dawn, and extragalactic HI. Swedish scientists and companies have participated in international design consortia, and provided prototype SKA-Mid receivers. In addition, Sweden continues to actively participate in a number of ways:

SKA Pathfinders - Onsala Space Observatory (OSO) hosts an international LOFAR station: one of the SKA Pathfinder telescopes, and an important precursor to SKA-Low. The international baselines of LOFAR provide high resolution imaging at low frequencies, and provide an important test for developing data calibration and imaging algorithms in preparation for SKA.

Instrumentation - OSO has designed and prototyped the Band 1 receiver for SKA-Mid which covers the frequency range 0.35-1.05 GHz. Procurement is currently ongoing for a Swedish prime contractor who will deliver the production run of 133 copies of this innovative wide-band receiver. The Gothenburg-based, Low Noise Factory, a Chalmers spin-off company, has developed the room-temperature low noise amplifiers for SKA Band 1[2] and cryogenic low-noise amplifiers suitable for SKA Bands 2-5 (0.95–13.8 GHz)[3] all of which are fabricated at the Chalmers clean-room/Myfab nanofabrication infrastructure. Sweden, as coordinated by OSO, also has the overall responsibility for the delivery of all the digitizers for SKA-Mid including for the construction of the state of the art digitizers that serve receiver Bands 1 to 3. The Gothenburg Quamcom company [4] has been involved in the final design for production of these digitizers. Combining the industrial deliveries for Band 1, LNA's and Digitizers approximately 15 M€ of contracts will be delivered by Swedish companies for the construction of SKA.

SKA Regional Center - OSO in collaboration Chalmers e-Commons is developing the Swedish SRC node in the collaborative global network, SRCNet[5]. The SRCs will provide data access and platforms for advanced analysis and training. Current preparations use large survey data from SKA Precursors (MeerKAT and ASKAP telescopes) and Pathfinders (Apertif, LOFAR).

SKA Science Data Challenges - The SKAO has developed a series of Science Data Challenges (SDC) for the community in order to prepare users and encourage the development of advanced algorithms to be ready to exploit SKA data as soon as early science operations start. The first SDC covered continuum science [3]. SDC2 took place in January-July 2021, which aimed to develop and test extragalactic spectral line source finding algorithms from competing teams on a 1 TB simulated image cube. A multi-disciplinary team of researchers from OSO and Fraunhofer-Chalmers Centre (FCC), "FORSKA-Sweden", took second in the competition, using a combination of machine learning with convolution neural networks, open source software for characterizing galaxies, and in-house algorithms for calculating additional source properties. Further data challenges span the range of science cases, including modeling foregrounds of the Epoch of Reionization (EoR; SDC3a now underway)[6], measuring the EoR power spectrum, and the characterization polarized sources.

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References

[1] Blyth S., van der Hulst T. M., Verheijen M. A. W., Catinella B., Fraternali F., Haynes M. P., Hess K. M., et al., 2015, aska.conf, 128. doi:10.22323/1.215.0128

[2] Braun R., Bourke T., Green J. A., Keane E., Wagg J., 2015, aska.conf, 174. doi:10.22323/1.215.0174

[3] Bonaldi A., An T., Brüggen M., Burkutean S., Coelho B., Goodarzi H., Hartley P., et al., 2021, MNRAS, 500, 3821. doi:10.1093/mnras/staa3023

[2] https://lownoisefactory.com/library/10-k-room-temperature-lna-for-ska-band-1/
[3] https://lownoisefactory.com/library/cryogenic-lnas-for-ska-band-2-to-5/
[4] https://www.qamcom.com/square-kilometre-array/
[5] https://aussrc.org/wp-content/uploads/2021/05/SRC-White-Paper-v1.0-Final.pdf
[6] https://www.skao.int/en/science-users/160/skao-data-challenges