Spanish Involvement in Precursors and Pathfinders for the SKA.

The Editorial Board of the SKA Spanish White Book.

Abstract

In this contribution, we describe the main SKA precursors and pathfinders, focusing on those facilities in which Spanish astronomers are involved. SKA will benefit -scientifically, technically and operationally- from all previous experiences with these facilities. For the Spanish community, it will be very convenient a significant participation in these projects and their planned scientific key-projects to optimize the scientific exploitation of the SKA in the future.

1 Introduction

In 2008, and in order to protect the SKA project, the SKA Science and Engineering Committee (SSEC) established a clear definition of what constitutes a SKA Precursor and a SKA Pathfinder facility. The following designations were established:

- Precursor facility: A telescope on one of the two candidate sites. The Precursor telescopes are the South African MeerKAT, the Murchison Widefield Array (MWA) in Australia and the CSIROs Australian SKA Pathfinder (ASKAP).
- Pathfinder: SKA-related technology, science and operations activity. The Pathfinder telescopes and systems are spared around the world and are engaged in SKA related technology and science studies. The list of pathfinders in Europe includes, among others, the electronic European VLBI Network (eEVN), e-MERLIN, the Aperture Tile in Focus (APERTIF), the Electronic MultiBeam Radio Astronomy Concept (EMBRACE), NenuFar and the Low Frecuency Array (LOFAR).

To be officially designed as an SKA Contribution, the facility must contribute to the development of technologies, science, software and analytical techniques and/or operation modes, of interest for SKA, according to the following criteria: i) technology: it should contain new technical elements that are considered as part of the SKA Baseline design and that have not previously been tested on a large telescope; ii) science: observational tests will be carried out, both simulated and real, in order to explore new capabilities at flux density and dynamic range levels similar to or scalable to the full SKA; iii) operations: it provides robust tests of methods of scheduling and time allocation similar, or scalable to, what is needed for the SKA.

In the following, we briefly present the SKA precursors and the main european SKA pathfinders, making emphasis on those scientific projects in which the spanish community is participating.

2 SKA Precursors

2.1 ASKAP

ASKAP is the Australian SKA precursor. It comprises 36 antennas of 12-m diameter each. It is located in a radio quiet zone in Western Australia, where part of the SKA will be installed in the future. The ASKAP array is using Phased-Array Feeds (PAFs), which allow a 30-square-degree field-of-view. These PAFs are very efficient for the performance of surveys and searches for unidentified transients. However, they suffer from a loss of sensitivity (narrower total bandwidth and higher antenna temperature), compared with the new, very broadband feeds. In that sense, the use of both technologies -single-pixel feeds or phased-array feeds- is being pursued for cutting-edge observations and its use depends on the sicientifc application.

ASKAP will operate in the 0.7 - 1.8 GHz frecuency range and will provide a maximum angular resolution of $\sim$8 arcseconds. A 6-antenna test array (BETA) was completed in 2013 and is being used to test the phased-array feed (PAF) technology. ASKAP is primarily a survey instrument. During the first five years of observations, around 75% of its observing time will be dedicated to large survey science projects. For that purpose, ten projects[1] (needing more than 1500 hours each) have been selected based on their scientific merit. None of these projects are lead by a European PI. However, these programs comprise 363 investigators from 131 institutions with 28% of the Co-Is from Europe (33% from Australia, 30% from North America and 9% from the rest of the world).

Spanish Astronomers are involved in some of the legacy projects (VAST, "Variable and Slow Transients"; EMU, "Evolutionary Map of the Universe); GASKAP, "The Galactic ASKAP Spectral Line Survey").

2.2 MeerKAT

The MeerKAT interferometric array consists of 64 dishes of 13.5-m diameter each, and is currently under construction in South Africa (with a completion planned for 2016). It is located on the radio-quiet, future SKA South-Africa site. MeerKAT will have a dense inner core, with 70% of the dishes and with baselines ranging from 29 m to 1 km; the other 30%

[1]http://www.atnf.csiro.au/projects/askap/ssps.html

of the dishes, will provide baselines ranging from 2.5 km to 8 km (with a possibility of an extension up to 20 km with 7 additional antennas). The antennas have been designed to achieve high sensitivity -a large 4-GHz bandwidth- and high imaging dynamic range in several observing windows ranging from 0.6 to 15 GHz. The construction of the KAT-7 science prototype array was successfully completed in 2012, and several refereed scientific publications have already been published.

The first years of activity of MeerKAT will mainly be reserved for key science projects[2] (70% of the available observing time) following an international call for proposals in 2009. Ten large proposals have been selected1, each with a total observing time ranging from 1900 to 8000 hours. European PIs lead (or co-lead) a significant fraction (55%) of these large programs, whereas 27% of the proposals are led by South African PIs (18% are lead by the rest of the world).

Spanish Scientists are members of the initiative to incorporate MeerKAT to global VLBI operations with all major radio astronomy observatories around the world, improving the sensitivity and enhancing the southern VLBI arrays.

3 SKA Pathfinders

3.1 EVN

The European VLBI Network (EVN) is a collaboration of radio telescopes in Europe, with joint observing campaigns with telescopes in China, Russia, South Africa, and other single dishes in the world. Up to 20 telescopes participate in the array. With a frequency range from 327 MHz to 43 GHz, the EVN provides a unique resolving power: from a few milliarcseconds to sub-milliarcsecond scales. Due to its high angular resolution, high sensitivity and superb astrometric precision, the EVN has become a unique astronomical facility. The EVN covers many different research fields: i) the study of the inner regions of AGNe, blazars and radio galaxies; ii) the study of young radio supernovae, GRBs, pulsars and transients in general; iii) the study of circumstellar rings and the process of high-mass star formation, considering the gas dynamics, molecular excitation and the magnetic fields very close to the forming star; iv) the study of distant star-forming systems and the central regions of nearby galaxies; v) the astrometric capabilities of the VLBI arrays, providing very accurate determinations of the proper motions, parallaxes and distances to the star-forming regions within the Milky Way; vi) the extremely precise determination of state vectors of planetary probes.

Within the framework of the RadioNet program NEXPReS, the EVN has supported and developped real-time electronic VLBI operations. In fact, the EVN have routinely carried real-time science observations since 2006 for baselines up to 12000 km. In that sense, the eEVN is an SKA pathfinder in terms of data collection and transportation (with data rates > 1 Gbps), distribution of the clock signal and operations (quick response to external triggers).

Spanish Astronomers are frequent users of the (e-)EVN. Spain is one of the members

[2]http://public.ska.ac.za/meerkat/meerkat-large-survey-projects

of the EVN, contributing to it with the Yebes antenna, and also member of the recently approved JIVE-ERIC (European Research Infrastructure Consortium).

3.2 LOFAR

The Low-Frequency Array (LOFAR) is a next generation telescope based on phased-array technology, in which thousands of low-cost, stationary collecting elements are digitally combined in a central processor. The radio maps for a given region of the sky are reconstructed with innovative software. LOFAR offers two observing bands: low band, 10 - 90 MHz, and high band, 110 - 240 MHz. LOFAR was dessigned to address the Key Science Projects: i) Epoch of Reionization: understanding how the first stars and black holes ionized the Universe; ii) Extragalactic Surveys: probing the history of star formation and black hole growth with time; iii) Transients and Pulsars: exploring extreme and explosive astrophysical events; iv) Cosmic Rays: identifying the origin and energy distribution of the most energetic particles in the Universe; v) Solar Physics: mapping the solar wind, solar bursts, and their interaction with the Earth; vi) Cosmic Magnetism: mapping the large-scale magnetic field in the Universe.

LOFAR is the largest pathfinder on the road to SKA-Low. From a technical point of view, LOFAR provides a pathfinder scenario in terms of distributed operation, high bandwidth data links, massive correlation and post-processing, among others.

Furthermore, the LOFAR core and the LOFAR international telescopes are being used for a number of experiments intended to test challenging concepts in radio astronomy. The NenuFAR experiment at the Nanay station extends a station to the lowest frequencies at the ionospheric limit, with much greater collecting area. The ARTEMIS (Advanced Radio Transient Event Monitor and Identification System) experiment at Chilbolton does real-time beam forming and searches for very fast pulses such as Fast Radio Bursts, pulsar giant pulses, and possibly unknown phenomena. The AARTFAAC (Amsterdam-ASTRON Radio Transients Facility And Analysis Centre) and DRAGNET (Dynamic Radio Astronomy of Galactic Neutron Stars and Extragalactic Transients) experiments on the LOFAR core correlate the innermost sets of dipoles one-by-one, and search for fast transients in all-sky imaging and in beam formed signals, respectively.

Spain is not a member of the LOFAR collaboration, yet a number of Spanish astronomers participate at a personal level in some LOFAR projects.

3.3 eMERLIN

e-MERLIN is operated by the University of Manchester, as a national facility, through a contract with the Science and Technology Facilities Council (STFC). e-MERLIN consists of 7 telescopes distributed across the UK, with a maximum baseline of 217 km. eMERLIN provides sub-arcsecond imaging with very high (microJy) sensitivity. The telescopes are all connected to the central correlator via optical fibre. e-MERLIN is a uniquely sensitive instrument for imaging on milliarcsecond to arcsecond scales at centimetre wavelength. A number of approved legacy projects have been approved[3]. e-MERLIN achieves 50 to 150 milliarcsecond resolution, with sub-microJy sensitivity in deep observations, across relatively large fields-of-view. With this angular resolution, many astrophysical scenarios can be probed in a unique way such as the pebble-sized material in planet formation, the disc-jet zone (linear sizes of tens of AUs) in newly forming stars, the powerful jets of AGNe and X-ray transients and the star-forming regions in distant galaxies.

e-MERLIN has been considered as an SKA pathfinder in terms of high resolution science observations, long-distance data transport and phase transfer over optical fibre links.

Spanish scientists are involved in the commissioning and observations of some legacy projects (LIRGI, "Luminous Infrared Galaxy Inventory", with Miguel Ángel Pérez-Torres as one of the PIs; LEMMINGS, "Legacy e-MERLIN Multi-band Imaging of Nearby Galaxies Survey").

3.4 APERTIF

APERTIF (Aperture Tile in Focus) constitutes an operational demonstrator for the focal plane array technology, with the associated developments of algorithms and software to calibrate and process APERTIF data both in real time and off-line. With APERTIF, WSRT science will be driven full-time by large all-sky survey.

Several spanish astronomers are involved in some of the Apertif survey key-projects.

3.5 Other Pathfinders

We should mention other pathfinders outside Europe, in which the spanish astronomers regularly submit proposals and obtain observig time. This is the case of the:

- The Jansky Very Large Array (JVLA), located in New Mexico (USA), is composed of 27 antennas of 25-m diameter along a reconfigurable array providing a wide range of angular resolutions. It operates at frequencies from 1 to 50 GHz. The JVLA has just completed a very major upgrade with a large, 8-GHz broadband backend, making it the most sensitive radio telescope in the world for sources accessible from the Northern Hemisphere.

- The Giant Metre wave Radio Telescope (GMRT) consists of thirty antennas with a diameter of 45 m spread over distances of up to 25 km. It is located near Pune (India). It is a versatile telescope, with unique capabilities (high sensitivity and high resolution) in the metre wavelength range.

[3]http://www.e-merlin.ac.uk/legacy/projects/

4 Synergies with other Future Facilities

SKA surveys will be synergetic with current complementary multi-spectral-range facilities (e.g. ALMA, SDSS, Chandra) and other future projects like the LSST, Euclid, or eROSITA. Using synoptic observations from SKA, LSST, and Euclid, it will be possible to perform large scale structure and very high redshift cosmology (up to z 10 and beyond) studies. In the field of Galaxy Evolution, SKA will accurately determine the Star Formation history over cosmic time while LSST will provide redshifts and stellar masses. Moreover, it will be possible to trace the pathway from neutral gas (HI with SKA), to molecular gas (with ALMA) to star formation (with SKA radio continuum, probing galaxies with Star Formation Rates of up to 10 solar masses per year up to redshifts of around 3-4). Such synergies are discussed in the different chapters of this White Paper.