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The Spanish participation in the SKA

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Abstract

The Square Kilometre Array (SKA) will be a radio interferometer aiming to answer fundamental questions in Astrophysics, Fundamental Physics, and Astrobiology. It will be composed of thousands of antennas distributed over distances of more than 3000 kilometres on both Africa and Australia. The SKA has been recently identified as a Landmark Project in the European Strategy Forum on Research Infrastructures (ESFRI) roadmap. Spain has been participating in SKA-related activities since the 1990s, coordinated since 2011 by the Instituto de Astrofísica de Andalucía (IAA-CSIC). Up to now, 21 researchers participate in 7 out of the 11 main SKA Science Working Groups, and a total of 119 researchers from 40 Spanish centres have participated in the Spanish SKA White Book [2], published in 2015. From a technological point of view, more than 20 research centres and companies are contributing to the design of the SKA as part of 7 international consortia. The Spanish contribution was estimated in $\simeq$ 2M €(2014), officially recognized by the SKA Organisation Director General in a letter to the Spanish Ministry of Economy and Competitiveness. In addition, the Spanish Astronomy Infrastructures Network (RIA from its Spanish initials) issued a recommendation on the interest of the scientific community and industry that Spain explores the possibility to join the SKA project as Full Member before the construction phase starts. In December 2015, the Spanish Secretary of State of Research, Development and Innovation sent a letter to the SKA Organisation Director General proposing to establish a dialogue in order to explore scenarios for Spain to join the SKA, what constitutes a further motivation for the Spanish community to continue its efforts.

1 Introduction

The idea of building such an unique telescope like the SKA, which will be the largest scientific infrastructure on Earth when fully built, comes from the confluence of several open questions from Astrophysics, Fundamental Physics and Astrobiology. Among them are the formation of the first galaxies in a dark Universe dominated by atomic gas (HI), or the evolution of the HI till the current epoch. Strong field tests of gravity will be performed using pulsars and black holes, while the acceleration in the expansion of the Universe will be investigated. In a very

different area, a search for habitable extrasolar planets will be possible, approaching both from the study of proto-planetary disks and planet formation, or the search for biomarkers.

The SKA project is an international effort, with 100 participating organisations from 20 countries, including 10 Full Members (Australia, Canada, China, India, Italy, The Netherlands, New Zealand, South Africa and the United Kingdom). It has been qualified as high-priority in the European Strategy Forum on Research Infrastructures and ASTRONET roadmaps and was recently identified as an ESFRI Landmark Project in its 2016 roadmap. At the time of writing, the SKA Organisation (SKAO) coordinates the efforts to design such a big telescope and is running in parallel the negotiations between member countries to become an Intergovernmental Organisation. Spain is one of the countries invited to attend the SKA Board meetings as Observer.

The SKA will be developed in 2 phases. SKA Phase 1 (construction 2018-2023; cost 674M €, inflation adjusted) will already constitute the largest radiotelescope on Earth: Australia will host 130.000 low-frequency dipoles (SKA-low, covering a frequency range from 50 to 350MHz, with a maximum baseline of 65km), whilst South Africa will host 200 15-m dishes (SKA-mid, observing between 350MHz and 14GHz, with a maximum baseline of 150km). The second phase of SKA (SKA2) will be built between 2023 and 2030, when the Observatory will add 250 Dense Aperture Arrays (observing from 200 to 500 MHz), and will increase the number of dipoles in Australia (up to 500.000) and up to 2.000 antennas in Africa. A series of demonstrator telescopes (e.g. ASKAP[1], MeerKAT[2], MWA[3], JVLA[4], LOFAR[5], Arecibo, GMRT[6], etc.) are already operational or under development, paving the way for SKA technologies, with Spanish astronomers actively involved.

The SKA design started in 2013 divided into 11 work packages (WPs), each managed by an international consortium. In November 2014 SKA passed the Preliminary Design Review (PDR, Stage 1). The consortia are currently running the Stage 2 of the design, the Critical Design Review (CDR), to be completed in 2018, to be followed by construction. Both Spanish scientists and engineers participate in the current Design phase of SKA1, as detailed later.

In the following sections we will explain the Spanish involvement in the project. In section 2 we summarize the activities performed since 2011 to coordinate and promote the Spanish participation in the SKA. The following sections describe the involvement of the Spanish groups during the pre-construction phase in the SKA science (section 3), engineering (section 4) and outreach (section 5) activities. Section 6 contains the conclusions.

2 Organisation of SKA in Spain and coordination activities

The preparatory phase for the SKA took place between 2008 and 2013. In this Phase the Project Execution Plan (PEP) was defined, and the SKAO was born as a new legal entity.

[1]Australian Square Kilometre Array Pathfinder
[2]Originally the Karoo Array Telescope
[3]Murchison Widefield Array
[4]Jansky Very Large Array
[5]Low Frequency ARray
[6]Giant Metrewave Radio Telescope

The broad and strong scientific interest of Spanish researchers in the SKA was expressed in this stage during the RIA meeting "Science and technical opportunities in the SKA era", held in Madrid in May 2011. RIA stands for the Astronomy Infrastructures Network in Spanish, an advisory committee for the National General Administration about Singular Scientific-Technical Infrastructures related to Astronomy (http://www.riastronomia.es) to which SKA related activities and reports are regularly described via its Radioastronomy Working Group (G1). This interest also materialized in the creation of the "Spanish Network of SKA" (PI. J. C. Guirado, Universidad de Valencia) funded by the Ministry for Science and Innovation (MICINN, whose functions are developed nowadays by the Ministry of Economy and Competitiveness, hereafter MINECO), within the framework of the "Subprograma de Acciones Complementarias y Proyectos de Investigación no orientados" (2011-2014). Taking into account this interest of the scientific community, and that SKA received a "very high" prioritization in the MICINN roadmap on Spain's participation in ESFRI projects, becoming the second major astronomical facility after the E-ELT (ESO), the MICINN requested Observer status for Spain in the SKA Founding Board. This request was accepted, although it did not materialize due to the change in the scheme of the legal entity, the current SKA Organisation.

In November 2011 the MICINN approved the funding for the Feasibility study of the Spanish participation in SKA (VIA-SKA project, PI. L. Verdes-Montenegro, IAA-CSIC), through the "Subprograma de Infraestructuras Internacionales", with the participation of 7 research institutions and 8 Universities. The aim of this project was to identify technological and industrial interests and capacities in the SKA and to facilitate the incorporation of Spanish companies and centers into the international consortia that were to design the SKA.

The approval of VIA-SKA was very timely. In January 2012, the groups to prepare the Work Breakdown Structure (WBS) and the Statements of Work of the SKA were established. VIA-SKA started conversations with the SKA Project Office so that 9 VIA-SKA members were accepted in the WBS working groups. This provided visibility of the Spanish centers to the SKA Office, direct access to SKA information, project status, and processes, and resulted in direct interaction between VIA-SKA members and staff from the SKA Office. In May 2012 SKA issued a call for Expressions of Interest (EoIs) on the various elements and work packages for the Stage 1 of SKA. VIA-SKA distributed the information on the EoIs to potentially interested Spanish centers, and interacted with the involved partners, so that finally Spain participated in four EoIs (Dish, Aperture Arrays, Science Data Processor and Power). Spanish solar concentrating solutions aroused the interest of the SKAO and a visit was organized in 2012 to Abengoa Solar's facilities in Sanlúcar la Mayor, which was attended by representatives of MINECO, CDTI (Centro para el Desarrollo Tecnológico e Industrial), Instituto de Telecomunicaes Aveiro, ASTRON (Astronomy institute Netherlands Institute for Radio Astronomy), IAA-CSIC, CTAER (Centro Tecnológico Avanzado de Energías Renovables), and other companies.

The technological interest from Spanish academic groups and companies was confirmed in the workshop "SKA: Strategic Position and Future Opportunities for Spanish Industry" (held in November 2012) and reported to the G1 RIA Working Group in May 2013. In November 2013, eleven international consortia were established and started to work on the prelim-

inary design of the SKA. Currently 11 Spanish research centres and 12 Spanish companies have contributed to the SKA design efforts, participating in the following international design consortia: Central Signal Processor, Dish, Infrastructure Australia and South Africa, Signal and Data Transport, Science Data Processor and Telescope Manager. VIA-SKA worked as well for Spain to become a member of the SKA Communications and Outreach Network (hereafter SKACON) since its beginning in early 2013. This participation is coordinated by IAA-CSIC and performed in collaboration with the Observatorio de Valencia.

Since October 2013 a representative of MINECO is regularly invited to the SKA Board. In November 2013, the G1 working group of the RIA issued a recommendation about the interest of the Spanish scientific community and industry to explore the possibility to participate in the SKA as a full member prior to the beginning of the construction phase. In 2014, the board of the RIA endorsed that recommendation. The work performed during recent years by the Spanish scientific community, technological groups and industry led them to reach a strategic positioning at different levels. The Spanish in-kind participation has a value of $\simeq$ 2M €, officially acknowledged by the SKAO Director General in 2014, following the contact of MINECO in July 2013 with John Womersley (SKA Board Chair) stating the amount of Spanish participation.

In October 2014 the Spanish SKA Day took place at IAA-CSIC, gathering together for the first time Spanish astronomers, and engineers from academic centers and companies, showing the synergies that SKA had already generated among the Spanish community. The main purpose of the meeting was to present a scientific and technical overview of the SKA project, with a special emphasis on the Spanish participation. 18 institutions and 17 companies attended the meeting, facilitating the Spanish researchers to identify their niche among SKA scientific goals, presenting the status of the Spanish technological groups participation in the SKA design and informing industry on the potential areas for involvement.

The scientific and technological activities carried out in Spain so far led Spain to receive in May 2015 the survey distributed by SKAO to assess the interest of member states in the different work packages related to the Construction of SKA, called "Survey of SKA Member National Aspirations". In this questionnaire, Spain expressed the main areas of interest during construction.

As a result of these activities, in December 2015 the Spanish Secretary of State of Research, Development and Innovation sent a letter to the SKAO Director General to explore adhesion scenarios of Spain to the project and this process has already started. Soon after (February 2016), CDTI decided to organise the "Square Kilometre Array (SKA) Industry Day" at their headquarters in Madrid, in collaboration with IAA-CSIC and in close interaction with SKAO. The aim of this Industry Day was to inform about the SKA status to the representatives of Spanish companies and technological groups related to sectors such as renewable energy, telecommunications, computing, mechanical systems or electronics. It consisted of general plenary sessions and several parallel sessions aiming at different industrial sectors. It was attended by more than 80 participants from around 50 companies and research centers in Spain, including Phil Diamond, SKAO and the leaders of the Infrastructures South Africa and Australia Consortia. On the following day, the Solar Platform of Almería (PSA) organized, in collaboration with IAA-CSIC, a visit to their facilities for SKA Infrastructure

consortia leaders and engineers, SKAO engineers and MINECO representatives.

During the first semester of 2016, MINECO applied to the SKA project a methodology of Evaluation and Prioritization of International Research Infrastructures. This resulted in a report that seeks to provide complete and objective information during the decision-making process related to the positioning of Spain in the SKA. This report was submitted to the Spanish Secretary of State of Science, Technology and Innovation, with a positive outcome.

The here presented contribution is framed within the XII Biannual Scientific Meeting of the Spanish Society of Astronomy, which included, for the first time, a monographic plenary session focused on the SKA. This session was opened by the SKAO Director General Phil Diamond, who gave an overview of the project, by the first author of this article, on a summary of the Spanish participation, and by presentations from several main authors of the Spanish White Book, offering an overview of the science that SKA will enable. The session was complemented with panels explaining the Shared Sky exhibition panels at the main entrance of the hall, as an appetizer for the indigenous art exhibition organized by the SKAO (see Section 5).

3 Spanish contribution to the SKA science

The scientific interest of the Spanish community in the SKA has been demonstrated repeatedly since the beginning of the preparatory phase, e.g in the different workshops indicated in the previous section. Spanish researchers are involved in preparatory works for the SKA by their contribution to pathfinder and precursor radiotelescopes. In addition, strong synergies have been identified with other projects and installations with Spanish participation e.g. ALMA[7], CAHA[8], CAY[9], GTC[10], OAJ[11], IRAM[12], E-ELT[13], LSST[14], LIGO[15], XMM-Newton[16], CXO[17], the future Athena[18] or CTA[19] among others.

Likewise, Spanish researchers have participated in 14 out of the 135 chapters of the international book "Advancing Astrophysics with the Square Kilometre Array [3]", leading 3 of them. The goal of this publication is to document the scientific progress that the first stage of the SKA will enable, and also those related to the SKA when it is finished. This publication constitutes an update of the previous book published about the SKA science [1].

The interest of the Spanish scientific community was also shown in 2015 with the

[7]Atacama Large Millimeter/Submillimeter Array
[8]Centro Astronmico Hispano Alemn Almera
[9]Centro Astronmico de Yebes
[10]Gran Telescopio Canarias
[11]Observatorio Astronmico de Javalambre
[12]Instituto de Radio Astronoma Milimtrica
[13]European Extremely Large Telescope
[14]Large Synoptic Survey Telescope
[15]Laser Interferometer Gravitational-Wave Observatory
[16]X-ray Multi-Mirror Mission
[17]Chandra X-ray Observatory
[18]Advanced Telescope for High ENergy Astrophysics
[19]Cherenkov Telescope Array

publication of the Spanish SKA White Book [2], due to the coordinated effort of 119 Spanish astronomers from 40 research centres. The full book has 30 chapters, which cover the areas of Cosmology and Large-Scale Structure of the Universe, Galaxy Evolution, Magnetism in the Universe, The Craddle of Life and its Chemistry, Stellar Astrophysics, SKA Precursors, and Synergies with other Facilities.

The Spanish scientific community also participates in the SKA Science Working Groups (SWG). Currently a total of 21 scientists from 8 Spanish research centres participate in 7 out of the 11 SWG (in bold font we highlight the groups with Spanish participation): **Cosmic Magnetism**, **Cosmology**, Craddle of Life, **Epoch of Re-ionization**, **Extragalactic Continuum**, Extragalactic Spectral Line, Fundamental Physics with Pulsars, **HI Galaxy Science**, **Our Galaxy**, Solar and Heliospheric Physics and **Transients**.

As a continuation of these preparatory works, Spanish astronomers are involved in the definition of the proposals for SKA Key Science Projects (KSP). KSPs are large-scale collaborative projects expected to focus on key scientific goals with significant legacy value. It is important to remark that only the researchers from SKA member countries will be able to lead these KSPs, being this leadership distributed among the member countries proportionally to their economic contribution to the project. Likewise, the participation in the KSPs will also be distributed proportionally to their contribution. The participation of scientists from non-member countries will be limited to no-management roles which provide a clear benefit for the group. At the moment this contribution is being discussed, and by now it is limited to 10%.

4 Spanish contribution to the SKA design

The design of large-scale international science and engineering projects is complex and therefore SKA design has been divided into 11 consortia, bringing together more than five hundred engineers and scientists from around the world. Currently, SKA is immersed in the second phase of the design, which will culminate in early 2018 with the Critical Design Review (CDR) to ensure the maturity of the detailed design for each of the WPs.

Since its beginning, more than 20 Spanish research centres and companies have participated in 7 out of the 11 SKA design consortia. Below we provide a brief description of the SKA design consortia with involvement of the different Spanish research centres and companies, as well as the specific contribution of some companies and research centres.

The Infrastructure Consortia of Australia (AU) and South Africa (SA) are responsible for all the work needed to deploy and operate the SKA telescopes in both countries. All power-related activities were initially under the Infrastructure consortia, although some of the power supply solutions have now been centralized by the SKAO with the creation of a Power Supply Options Workgroup (PSOW). This group aims to address the challenge of the consumption and power distribution of the SKA and to reduce the environmental impact of the project. The group has 8 members and Spain is represented via the Plataforma Solar de Almería (PSA-CIEMAT).

The Dish Consortium includes all the necessary activities for the design of the SKA

dishes, including local monitoring and control of each individual antenna in pointing, other necessary electronics, local infrastructure, planning for manufacturing all components, etc. It consists of 17 institutions from 8 countries. Spain participates through the University of Cantabria and the National Geographic Institute by developing and testing LNA (Low Noise Amplifier) cryogenic systems for bands 4 and 5 of SKA-mid telescope (to be located in South Africa).

The Telescope Manager Consortium is responsible for managing all the necessary hardware and software to control the telescope and its associated infrastructures, including the coordination of all observatory-level systems and the software necessary for telescope operations planning. GTD System and Software Engineering have collaborated with this consortium in the management of software and telescope hardware required for astronomical observations, monitoring and control and protocols to communicate all parties involved in the observations.

The Signal and Data Transport (SaDT) Consortium includes all the necessary hardware and software for the transmission of data and information between the WPs of the SKA. It also includes data synchronization and the generation and distribution of frequency references and timestamps, necessary for the synchronization of local oscillators in Disks, and the accuracy in pulsar measurements. The University of Granada participates in SaDT since 2013 and leads the time distribution tasks of the SaDT subtask. The SaDT technological requirements are unique and extremely complex, with a quite demanding time synchronization requirement (10 ns). The Universitat Politécnica de Valencia has recently joined the consortium due to its expertise in radiocommunciations links, photonics systems, radar and microwaves systems.

The Central Signal Processor Consortium includes the hardware design and all the firmware/software required for visibility generation, sky surveys to find pulsar candidates, and pulsar timing for the different telescopes. It also comprises the distribution of data within the processor, diagnostic tools, etc. The Integrated Systems Laboratory (Universidad Politécnica de Madrid) is responsible for the design and implementation of advanced signal processing models, the evaluation of new solutions to improve energy efficiency in the SKA, and the design of quantization tools and synthesis of DSP (Digital Signal Processing) specifications at two different levels: architecture and high level specifications best suited for each processing module, and open source optimizing design tools targeting FPGA (Field-Programmable Gate Arrays) devices.

The Science Data Processor (SDP) Consortium designs the hardware platforms, software and algorithms needed to process the scientific data from the correlator to become scientific products. The data rate for the whole SKA telescope will reach the exascale, and meeting this challenge falls in large extent into the SDP. IAA-CSIC belongs to it and works to strengthen the efficient distribution of SKA data and metadata among the scientific community. To this end, it collaborates to characterize SKA processes and data, as well as design federated access to them, which exploits computing resources by minimizing latency time and power consumption. The Castilla y León Supercomputing Center Foundation (FCSCL) assesses the suitability of specific hardware configurations and infrastructures. It will also run a heterogeneous test benchmark with distributed resources and a 10GB lambda network between the remote centers, which will serve to analyze the performance of a federation of storage and distributed computing across networks with high bandwidth. The Barcelona

Supercomputing Center (BSC) contributes to this consortium applying its experience in operations with HPC (High Performance Computing) systems, HPC application tuning and parallel programming models to prototyping tasks.

The work carried out by the different groups involved in the pre-construction phase has opened a wide range of international opportunities to establish new collaborations and to access to new funding sources. The following list summarizes some of the most recent ones.

- ASTERISCS (Astronomy ESFRI and Research Infrastructure Cluster), an H2020 project to enhance performance and interoperate astronomy ESFRI facilities, like the SKA, CTA, KM3Net and the e-ELT, with participation from *Institut de Ciències de l'Espai*, *Instituto de Astrobiología*, Universidad de Granada, *Institut de Física d'Altes Energies*, *Institut d'Estudis Espacials de Catalunya* and *Universidad Complutense de Madrid*
- AstroCompute in the Cloud grant, with the participation of the University of Edimburgh and IAA-CSIC
- AENEAS (INFRASUPP-3-2016-2017), an H2020 grant to develop the concept and design of a European Science Data Centre network, where Spain participates through IAA-CSIC.

5 Spanish participation in the SKA Communications and Outreach Network (SKACON)

The SKA Communications and Outreach Network (SKACON) is the core of outreach nodes that are located in each of the project member countries. It deals with the dissemination and outreach activities of the SKA project. The training and dissemination strategy is aimed at the entire population and has significant development through the Internet and social networks.

Spain participates in SKACON through IAA-CSIC, in collaboration with the Astronomical Observatory of the University of Valencia, being member since its inception in 2013. The participation includes the development of the SKA's Strategic Communication Plan, the creation of press releases in Spanish, participation in radio/TV interviews, presentations to the general public, communication with other research institutes, event organisation etc. The objective is that everyone, with different degrees of specialisation, knows the SKA project, the involvement of Spain in it, as well as the importance of this project for the country. Dissemination about the project activities related to Spain is also performed using social media, via Twitter (#SpainSKA) and Facebook.

In this XII Biannual Scientific Meeting of the SEA a major upgrade of the Spanish SKA web (http://spain.skatelescope.org) has been presented, including a new set of Web pages describing the Spanish participation. Coordination activities are detailed, as well as scientific ones, e.g. membership into the SKA SWGs, or the Spanish White Book. The technological activities are also described, including the capacity map of the Spanish industry performed as part of VIA-SKA, or the contributions to the SKA design consortia. Besides, an outreach

area has been created providing access to content for general audiences. Finally a repository with all different kinds of talks and presentations can be found, with access to the PDF of the talk and the context.

6 Conclusions

As aforementioned, the SKA will lead to such an important scientific revolution that no mature scientific community should miss the opportunity to participate in the project. The challenges faced by such a project will become opportunities for Research, Development and Innovation in cutting edge technologies, such as communications, signal processing, Big Data/e-Science, energy supply and storage, etc., all of which are also areas of significant social impact. Besides, SKA will bring together a large number of the best scientists, engineers and managers in the world in order to ensure the project success. Therefore, participation in a project like SKA is a vehicle for the internationalisation of Spanish science and technology.

The activities carried out so far by the Spanish community of scientists and engineers from academic centers and companies place Spain in a privileged position for the scientific exploitation of the SKA. Spanish stakeholders have provided key contributions to the SKA design phase, and have large potential contributions in areas like mechanics, amplifiers, telescope management, time synchronization, advanced digital signal processing, data processing, e-Science, or renewable energies, among others. Becoming Full Member of the SKA well before the construction phase starts would culminate this effort and bring a large number of benefits. Among those benefits, the right to have two representatives in the SKA board, the possibility of leading SKA KSPs, get access to the construction Cost Book, and provide the Spanish industry the guarantee to access direct contracts and opportunities of in-kind contributions for construction.

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