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The high-frequency upgrade of the Sardinia Radio Telescope

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Abstract

We present the status of the Sardinia Radio Telescope (SRT) and its forthcoming update planned in the next few years. The post-process scenario of the upgraded infrastructure will allow the national and international scientific community to use the SRT for the study of the Universe at high radio frequencies (up to 116 GHz), both in single dish and in interferometric mode.

A telescope like SRT, operating at high frequencies, represents a unique resource for the scientific community. The telescope will be ideal for mapping quickly and with relatively high angular resolution extended radio emissions characterized by low surface brightness. It will also be essential for spectroscopic and polarimetric studies of both Galactic and extragalactic radio sources. With the use of the interferometric technique, SRT and the other Italian antennas (Medicina and Noto) will operate within the national and international radiotelescope network, allowing astronomers to obtain images of radio sources at very high angular resolution.

1 The Sardinia Radio Telescope

The Sardinia Radio Telescope (SRT) is an altazimuthal radio telescope of 64 m in diameter located in San Basilio, about 35 km north of Cagliari (Italy). The SRT optical system is based on a quasi-Gregorian profile with shaping applied to both the primary and the secondary surfaces. In addition to the primary and secondary reflectors, a complex system of reflecting surfaces provides different focal positions, allowing to equip on the SRT up to fifteen receivers that can be automatically selected through robotic systems. One of the most advanced technical features of the radio telescope is the active surface: the primary reflector is composed of about 1000 panels and the same number of precision mechanical actuators that are digitally controlled to compensate gravitational deformations of the reflector. The active surface allows to obtain a high efficiency of the radio telescope at high frequencies. Although SRT has been designed for the observation of the radio sky up to 116 GHz, at present its maximum observational frequency is 26.5 GHz. In its current first light configuration the instrument is equipped with a 7– beam receiver operating in K Band (18 – 26.5 GHz), with a single-band receiver in C_{high} Band (5.7 – 7.7 GHz), and with a dual frequency receiver in P/L Band

(305 – 410 MHz/1.3 – 1.8 GHz). Furthermore, two new S Band (3.0 – 4.5 GHz) and C_{low} Band (4.2 – 5.6 GHz) receivers are being finalized [1].
In addition to being an innovative tool for applications as a "single dish", SRT also operates in the Very Long Baseline Interferometry (VLBI) network. The VLBI is a technique that allows correlation between data collected by various antennas which simultaneously observe a radio source, combining them in order to obtain a high resolution image (the wider is the distance between the antennas of the network, the higher the resolution of the image will be). SRT, together with the other two italian radio telescopes of 32 m in diameter, located in Medicina (Bologna) and Noto (Siracusa), is part of the interferometric European VLBI Network (EVN; http://www.evlbi.org/) and the Italian VLBI network. Furthermore, SRT will contribute to the monitoring and tracking of space debris, to the observations of the European Geodynamics network, and on the base of agreements signed with the Italian Space Agency (ASI), it offers 20% of its time to near- and deep-space spacecraft tracking and to space radio science experiments.

SRT was officially inaugurated in 2013 at the end of the technical commissioning phase [2]. The technical commissioning was then followed by an astronomical validation phase [3], which confirmed the scientific capabilities of the telescope allowing SRT to be transformed from a purely technological project into a real research infrastructure. In 2016, with the phase called "Early Science Program" (ESP), the instrument started the scientific observations. In 2017, the regular phase of the astronomical observations was interrupted due to a further improvement of the infrastructure. This upgrade involved moving all the equipment to new buildings, that had been completed in the meantime at the SRT site, and the renewal of the active surface. This important upgrade has been successfully completed. Since February 2018 the EVN observations have regularly resumed, and since October 2018 the telescope entered in the regular call for proposals at the Italian radio telescopes (http://www.radiotelescopes.inaf.it/proposal_main.html). The high profile of the first scientific publications has unequivocally confirmed the entry of SRT in the international panorama demonstrating the capabilities of the instrument to operate for both single dish and interferometric observations (http://www.srt.inaf.it/astronomers/science_srt/).

2 SRT at high frequency

The National Institute of Astrophysics (INAF), has recently surveyed the interest of the Italian radio astronomical community for the use of existing and future front-end receivers installed at the national radio telescopes, with the aim of maximising the scientific return and harmonising the efforts and resources of the Institute. The result of this survey has clearly highlighted [4,5] the interest in the use of high frequency receivers (>20 GHz). This request can be met thanks to a PON (National Operational Program) funding, which the Italian Ministry of University and Research has recently assigned to INAF with the aim to upgrade the SRT to allow observations at high radio frequencies. The approved budget is equal to 18.700.000 Euro (15% of which can be outside to upgrade the radio telescopes of Medicina and Noto). One of the constraint of this funding is that the budget is not eligible to hire personnel and for internal R&D activities, but only to equipment purchase. Furthermore, the time-scale of the project is 32 months starting from June 2019 and finishing on February 2022. In particular, the PON project is organized into nine Work Packages (WP):

WP1 - Multi-beam cryogenic receiver in W Band for SRT
WP2 - Multi-beam cryogenic receiver in Q Band for SRT
WP3 - Millimetre camera for SRT
WP4 - Simultaneous microwave compact Triple-Band receiving system for the three Italian radio telescopes
WP5 - Metrology system for SRT
WP6 - Backends for SRT
WP7 - Supply of electronic and mechanical interfaces for the integration of new systems
WP8 - HPC and storage systems for the archival and use of SRT data
WP9 - Upgrade of laboratories for the development of microwave technologies.

2.1 New high-frequency receivers (WP1-WP4)

The SRT is currently equipped with radio astronomy receivers operating in the 305 MHz - 26.5 GHz frequency range. However, the telescope has been designed to operate with good efficiency up to a maximum frequency of 116 GHz. An instrument like SRT, operating at high frequency will be ideal for mapping quickly and with relatively high angular resolution (about 24 arcsec in Q Band and about 12 arcsec in W Band) extended radio emissions characterized by low surface brightness. It will also be essential for spectroscopic and polarimetric studies of both Galactic and extragalactic radio sources. In particular, our goal of the next few years is to acquire, install, and bringing in the operational phase new high frequency radio astronomical receivers:

- A multi-beam cryogenic receiver operating in the 70 – 116 GHz frequency band (W Band) for SRT, composed of 16 double linear polarization beams. This receiver is fundamental for the detection of complex organic molecules through polarimetric studies of galactic and extragalactic sources.

- A multi-beam cryogenic receiver operating in the 33 – 50 GHz frequency band (Q Band) for SRT, composed of 19 double circular polarization beams. This receiver is ideal for surveying large areas of the sky in radio continuum emission and in broadband spectro-polarimetry.

- A bolometric millimetre camera for SRT operating in the 77 – 103 GHz frequency band composed of an array of 408 detectors (pixels) that simultaneously sample a wide field of view. This will be suitable for the observation of extensive and diffused emission with low surface brightness.

- A simultaneous microwave compact Triple-Band receiving system to be installed on the three Italian radio telescopes (SRT, Medicina and Noto). The three cryogenic microwave receivers will operate simultaneously in the K / Q / W Bands (18 – 26 GHz, 34 – 50 GHz, 80 – 116 GHz). Having the same type of receiver in the three Italian antennas will allow us to strengthen the role of SRT in both the Italian and European VLBI networks.

In Table 1 and in Figure 1, we show the receivers currently installed at the SRT, the receiver under construction and those expected in the next future thanks to the PON project. Once all the planned receivers are installed, the SRT will be able to operate with great versatility and efficiency offering a frequency coverage from 305 MHz to 116 GHz.

Table 1. Receivers of the Sardinia Radio Telescope: current and future.

Receiver	Frequency range [GHz]	Beams x polarizations	Polarization type	Status
Dual frequency L-P band coaxial feed	0.305-0.410 1.3-1.8	1 x 2 1 x 2	H/V or L/R H/V or L/R	Operational Operational
C_{high} band	5.7-7.7	1 x 2	L/R	Operational
K band	18-26.5	7 x 2	L/R	Operational
S band	3.0-4.5	7 x 2	H/V	Under Construction
C_{low} band	4.2-5.6	1 x 2	L/R	Under Construction
Q band	33-50	19 x 2	L/R	PON WP2
W-band	70-116	16 x 2	H/V	PON WP1
Tri-band (K/Q/W)	18-26 / 34-50/ 80-116	1 x 2 (for each frequency band)	L/R	PON WP4
W-band KID detector bolometer	77-103	408	Polarization insensitive	PON WP3

2.2 Metrology system for SRT (WP5)

To reach a maximum frequency of 116 GHz, the radio telescope must have a pointing precision of about 1 arcsec and a surface quality of the primary mirror of about 150 μm (RMS, compared to the ideal profile) corresponding to about λ/20 in W Band. These goals can be achieved through a sophisticated measurement and control system of the active surface of the primary reflector and of the entire mechanical structure of the radio telescope. To this goal we intend to equip SRT with a metrological system for the optimization of the pointing and the gain of the antenna at all the elevations. In fact, the active surface of the primary reflector and the sub-reflector can be constantly adjusted in quasi real-time thanks to look-up tables (LUTs). The metrology system will provide a fine calibration of the LUTs allowing, on one hand, for the correction of systematic effects due to the gravity, on the other hand, to measure, model and compensate for the non-systematic effects due to thermal variations.

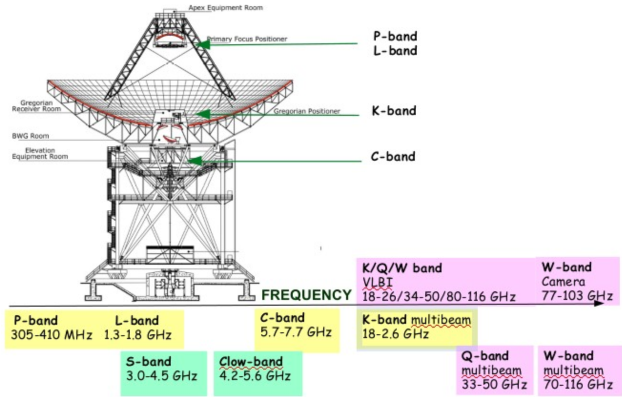

Figure 1. Receivers of the Sardinia Radio Telescope and their focal position: current (yellow), under construction (green) and those expected from the PON project (pink).

2.3 Backends for SRT (WP6)

In order to improve the scientific capabilities of the SRT, the high frequency receivers that will enhance the instrument must be complemented with an advanced radioastronomy signal processing system (also called "backend"). SRT is currently equipped with a variety of backends, each of which dedicated to a specific observing mode. The most capable of these backends is the SArdinia Roach2-based Digital Architecture for Radio Astronomy (SARDARA), which is composed of seven ROACH2 boards, and can analyse up to 14 signals of 2 GHz each [6]. A new complement of backends is thus necessary to cover the specific requirements (number of simultaneous signals, instantaneous bandwidth, available spectral and temporal resolution) needed for fully exploit the new receivers.

Three digital signal processing systems are being designed for this purpose as part of this project, and will gradually supreseed the current backends. The first uses 10 SKARAB (Square Kilometer Array Reconfigurable Application Board) boards, currently employed at the MeerKAT array, for a total of 40 processed signals. The second uses the Digital Base Band Converter 3, a platform developed specifically for VLBI. Finally, a platform based on the RFSoC (Radio Frequency System on Chip) technology uses 8 commercial boards form Abaco System, for up to 64 input channels. These new platforms will strongly enhance the data quality in terms of dynamic range, as data will be sampled with up to 14 bits for each sample instead of the 8 provided by SARDARA.

One of the major burdens concerns the overall instantaneous bandwidth provided by the multi-feed receivers: up to 38 signals with an aggregated bandwidth of up to 56 GHz has to be digitized and properly processed for many different scientific applications, among them wide-band high-frequency resolution spectroscopy. The high processing capabilities of the new generation FPGAs allow to achieve, for each feed, a spectral resolution up to a few hundred Hz even in the case of a bandwidth up to 1 GHz. A mixed FPGA-GPUs hybrid solution may be required for specific applications (for example real-time pulsar search). For this reason a high performance computing cluster of 5 GPU based nodes is also part of the system, connected to the acquisition backends and to the station computing centre by a high speed (40-100 Gb) network.

2.4 Supply of electronic and mechanical interfaces (WP7)

The set of acquired goods, that will include new receivers, new backends and the metrology system, will be integrated together through a "turnkey" supply of electronic and mechanical interfaces, allowing the radio telescope as a whole to operate at high frequencies, optimizing its frequency agility. The integration of these parts will include the transmission of the signal trough coaxial cables, the transmission through broadband fiber optic links, new servo systems to allow us to quickly switch the telescope optics and to be able to use all the installed receivers, and new mechanics for positioning the receivers in the primary focus.

2.5 HPC and storage systems (WP8)

We plan the provision, installation and startup of storage and high computing facilities, necessary for archiving and analysing the data obtained with SRT. Basically, this is made up of two clusters, both consisting of computational and storage nodes, distributed between the computing centre at the SRT site and the computing centre located at the INAF - Astronomical Observatory of Cagliari. The division into two parts is linked to the optimization of the activities. The computing centre at the SRT site will be necessary for the rapid analysis of the quality of data acquisition, and for the data preservation on the short period. The computing centre at the INAF - Astronomical Observatory of Cagliari will be dedicated to the full exploitation of data for scientific purposes and their optimized analysis, as well as their archiving.

2.6 Upgrade of laboratories (WP9)

We plan to acquire state of the art equipment for the electronic and mechanical laboratories located at the INAF - Astronomical Observatory of Cagliari and used for the Sardinia Radio Telescope. We will acquire some very performant and high frequency measuring instruments for the microwave laboratory and some CNC high precision milling and lathe machines.

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