SARDINIA DEEP SPACE ANTENNA:
CURRENT PROGRAM STATUS AND RESULTS

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The Sardinia Radio Telescope (SRT) is a fully steerable 64 m diameter parabolic radio telescope, capable of operating with high efficiency in the 0.3-116 GHz. The telescope is located about 35 Km north of the town of Cagliari, on the island of Sardinia, Italy. The infrastructures, and the operations relevant to the deep space communications and tracking activities performed at the SRT site are under the Sardinia Deep Space Antenna (SDSA) by the Italian Space Agency (ASI). The SDSA functionalities have been developed in order to achieve a national Deep Space Ground facility, able to contribute to the current and future interplanetary missions. In this paper we present an overview of the SDSA program status and the results of some activity performed in 2018, in particular the tracking of the Insight lander on Mars during the approach and descent phases and the track of the asteroid 2003-SD220 at the end of 2018.

I. INTRODUCTION

The Sardinia Radio Telescope [1,2] (SRT, Lat. 39°29’34’’ N - Long. 9°14’42’’ E) is a flexible instrument for Radio Astronomy studies and Space Science, either in single dish or VLBI (Very Long Baseline Interferometry) mode. SRT is a fully steerable, 64m diameter parabolic radio telescope capable of operating with high efficiency in a wide frequency range: from 300 MHz to 116 GHz.

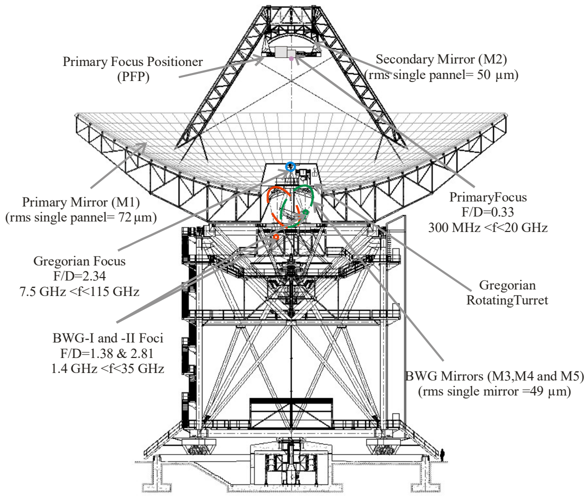

Fig. 1: Sketch of the Sardinia Radio Telescope. The picture shows all fundamental mechanical parts of the antenna and the reflecting surfaces.

The SRT optical configuration is a quasi-Gregorian system with a shaped parabolic primary mirror M1, a shaped elliptical mirror M2 and three other mirrors M3, M4 and M5, which compose the beam waveguide Layout I (BWG-I) and Layout II (BWG-II), see Figure 3. Particular attention has been dedicated to selecting the shape of the Primary and Secondary mirrors in order to minimize the spill-over and standing waves. Figure 2 shows a comparison between the aperture illumination for a classical Gregorian optics and for the shaped SRT. The energy shifts away from the blocked centre region of the primary mirror, enhancing the antenna illumination efficiency and reducing the M2 standing waves. Another benefit of this shaped design is the added taper at the main reflector edge, reducing noise contributions and side lobe levels at the same time.

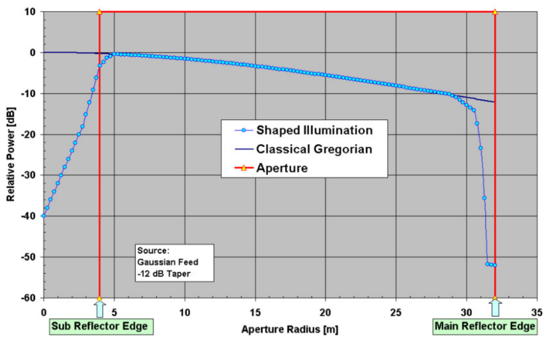

Fig. 2: Simulated Sardinia Antenna aperture illumination [3]

The main reflector (M1) consists of a back up structure which supports the quasi-parabolic active surface[4] composed by 1008 aluminum panels. The M2 is made of 49 aluminum panels are supported by a back up and a quadripod structure.

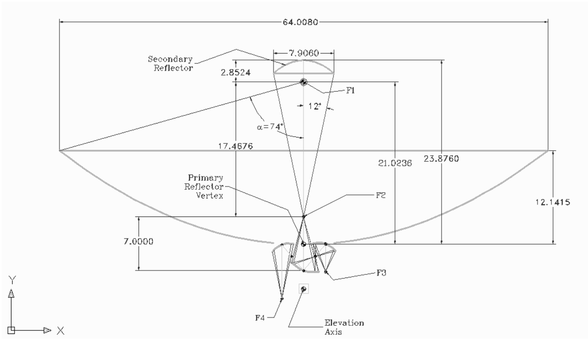

Fig. 3: Sardinia antenna geometry (dimensions are in meter).

The SRT has been designed to observe from six focal positions: Primary focus (F1), Gregorian focus (F2) and Beam-Wave Guide foci (F3-F5 and F4-F6), with focal length to diameter ratio (F/D) and frequency ranges respectively equal to 0.33 (0.3-20 GHz), 2.35 (7.5-115 GHz), and 1.37 & 2.84 (1.4- 35 GHz). A schematic view of the SRT with its optical configuration is reported in Figure 3. The combination of the available foci, in addition to the servo-assisted receiver assemblies, allows to install on the SRT up to 20 receivers (the so-called "frequency agility"). This means that the SRT is capable of switching between different receivers remotely and automatically .

The infrastructures and the operations relevant to the deep space communications and tracking activities performed at the SRT site, are under the project Sardinia Deep Space Antenna [5-6] (SDSA) by Italian Space Agency (ASI). The SRT was built thanks to the agreement between ASI and INAF. A specific ASI-NASA agreement states that the antenna, in the near future, will be employed for the tracking of several interplanetary missions in collaboration with the Jet Propulsion Laboratory (JPL).

The agreement between ASI and INAF states the exclusive assignment to the Agency of the scientific and technological research projects related to the deep space operations.

The SDSA's capacity has been extended and will continue to be increased in subsequent phases to offer a full Deep Space Ground Capability, increasing Italian role in the current and future interplanetary missions.

At the moment, in particular for space applications, the SDSA has the capacity to receive the signal in the standard X-band for deep space applications, 8.2-8.6 GHz. The signal is received with a cryogenic front-end installed in one of the beam wave guide foci with F/D equal to 2.81.

In this paper we will highlight the relevant aspects of the 2018 activity and therefore the future developments of the SDSA.

II. SDSA PROGRAM STATUS AND DEVELOPMENTS

The Sardinia Deep Space Antenna employs the SRT for all space operations. At the moment, the SRT has been developed to have the X-band reception capacity of the telemetry signal coming from the interplanetary probes. The scheme of the receiving system is shown in Figure 5.

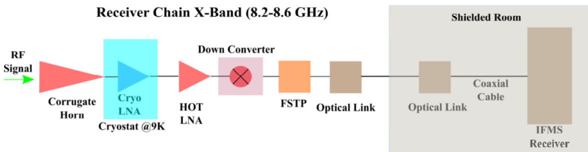

Fig.5 Simple block diagram of the receiving system of the SDSA.

It consists of a cryogenic front-end, operating in the X-band, that injects the signal to a down conversion system, which converts it from the sky frequency (8.2-8.6 GHz) to the operating frequency of the back-end installed in the shielded room. The central frequency of the down conversion system is at 70 MHz with a bandwidth of 28 MHz (54-84 MHz). The specific backend is called Intermediate Frequency Modem System (IFMS) [7], which demodulates and decodes the detected signal.

The signal coming from the antenna passes through the focus selector total power (FSTP) that checks the system noise level. Then, it is routed to an optical radiofrequency converter and transport up to the shielded room to reach a signal distributor (IF-Distributor). From the signal distributor, via a coaxial cable, the signal arrives at the IFMS to be demodulated and decoded.

The IFMS needs a precise reference of time and frequency, which specifically are 5 MHz, 1-pps and IRIG-B at 1 KHz. These signals are generated in the station by a time frequency laboratory at the state of the art.

The signal distributor (IF-Distributor) can split the signal to a real-time monitoring system (usually a spectrum analyzer) and/or to other digital back-ends.

The control room is also located at the SDSA, from which it is possible to set all the parameters to track the target, demodulate and decode the signal for the specific mission. The setting of the antenna and specific parameters is managed by the antenna control software (DISCOS) [8]. Other interfaces necessary for the SDSA activity are available, as, for example, the IFMS and the open-loop acquisition system.

Until the beginning of the autumn of 2018 the activity of the SDSA was mainly focused on tracking interplanetary probes and technical commissioning. From November to December the activities moved to the tracking of the landers and asteroids. In the next chapters, we will describe these activities.

III. SDSA ACTIVITIES

In the last months of 2018, two activities of the SDSA has been started: the tracking of the InSight lander during its EDL phase on the Martian soil and the tracking of the asteroid 2003-220D.

III.I InSight activity

One of the main activities of the SDSA includes the reception of the signal coming directly from landers present on the surfaces of celestial bodies.
In November2018 the SDSA was involved in the collaboration with the NASA-JPL for the acquisition of the real-time transmission of the signal coming from the InSight lander in its descent phase on the red planet.The activity was aimed at receiving the UHF carrier transmitted by InSight during the Entry Descent and Landing phases (EDL phases) on Mars, and real-time monitoring and display of the carrier. In addition the phase before the landing was also recorded. The goal was the measurement of the Doppler shift that is used to determine the EDL phase of probe. In figure 6 the theoretical variation of the predicted frequency is shown.

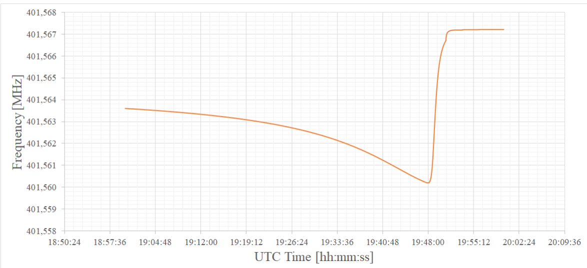

Figure 6. Frequency predict of the InSight lander.

During its descent through the Martian atmosphere, InSight transmitted a signal in the ultrahigh frequency (UHF) band. The signal was generated by a UHF transceiver on the lander. The MRO (Mars Reconnaissance Orbiter) listened for the UHF transmission from InSight during the critical minutes of entry, descent and landing. In this scenario, the SDSA listened to the signal directly from the lander without using the MRO spacecraft as a bridge for X-band communication. The acquisition of the InSight signal is particular because a non-standard acquisition system must be used unlike deep space applications. The SDSA, thanks to the collaboration with INAF, was able to receive the lander signal. For this particular activity a new receiver configuration of the RF signal was studied. The UHF signal transmitted from the Insight was around the frequency of 401.5 MHz, so we planned to receive in the radio astronomical band, allowed by SRT, called P-band.
The SRT P-band receiver is installed in the primary focus of the antenna. This receiver is a cryogenic dual-band coaxial-feed, that simultaneously covers the frequency range of 305-410 MHz (P-band) and 1.3-1.8 GHz (L-band) [10-11-12]. The signal from the P-band receiver was split by a RF distributor block and therefore, it is send in parallel to different digital back-ends and a spectrum analyzer used for a real-time carrier display. The implemented reception scheme is shown in figure 7.

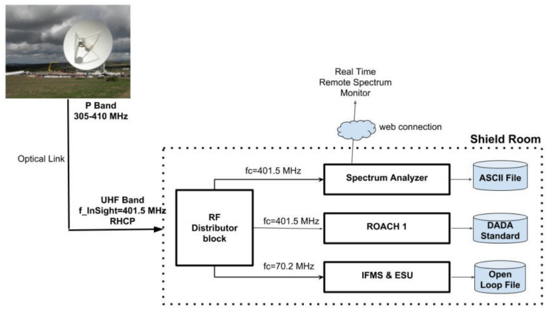

Fig.7 Block diagram of the receiving system used for tracking the InSight lander.

The section view and the photo of the P-Band receiver coaxial feed is shown in Fig. 8 [9].

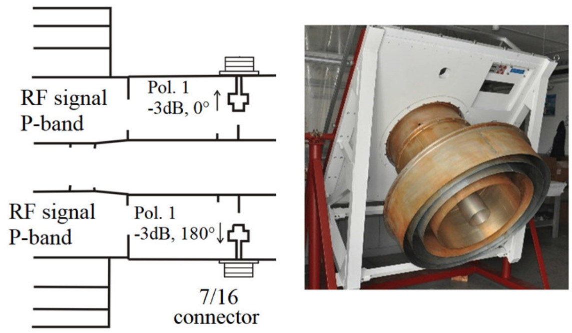

Fig.8 Section view and photo of the P-band feed.

The signal is received by the primary reflector of the radio telescope. The UHF receiving system installed in the primary focus amplifies the detected signal which is guided, through optical fiber, to the shielded room, wherein the radio frequency signal is recorded. In details, the IFMS in open loop configuration and a digital system based on FPGA were used. These two data formats, open loop and baseband (DADA), allow the processing of data not in real time and it is possible to perform a post processing analysis such as digital filtering, FFT processing, and so on. This block was

developed for this specific mission. Furthermore, the block down converts the RF signal to the 70.2 MHz.
The spectrum analyzer for the real-time carrier display, has been installed in the shielded room. It allowed us to monitor remotely the signal received from the lander and share the data with the colleagues from the JPL. A preliminary set of data (DATA files) analysed is shown in Fig. 9. It represents the carrier received before the lander entered the Martian atmosphere.

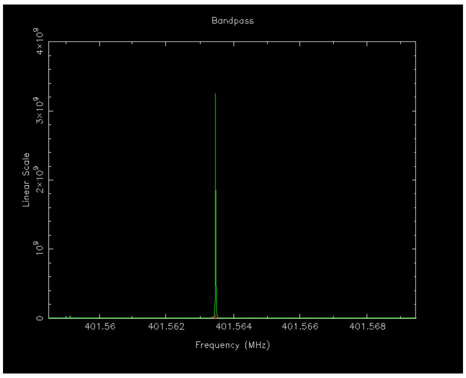

Fig.9 Frequency spectrum of the signal acquired before the lander entered into the Martian atmosphere, results of the DADA analysis

III.II Asteroid 2003-220D activity

In December 2018, another activity involved the SDSA: the monitoring of the asteroid 2003-220D.
The system studied for this type of observation was a bistatic radar. The transmitting antenna was DSS14 (Goldstone 70-m antenna) with CW transmission Left circular polarization (LCP) from 80KW of power. The receiving antenna was DSS64 (64-m SDSA antenna) with the X-band cryogenic system in right circular polarization (RCP). The acquisition section was composed by several backends, as shown in Fig. 10.
The connected backends were: the IFMS system, the ROACH1 and a spectrum analyzer.
The IFMS was configured to record the signal in open loop mode. The ROACH1 was configurated to record the signal in base-band mode with a very high spectrum resolution. Finally, a spectrum analyzer was also connected to show the signal in real-time, allowing us to check the quality of the observation.
All the parallelized backend systems present in the shielded room operates at the down-converted frequency of 70.2 MHz. The frequency of the tone transmitted by the DSS14 station was continuously corrected to compensate the Doppler respect to the SDSA station. Therefore, SDSA received a fixed frequency tone, i.e. at 8560 MHz. The signal received varied in amplitude because the cross section of the monitored asteroid varied over the time. The data analysis is currently in progress.

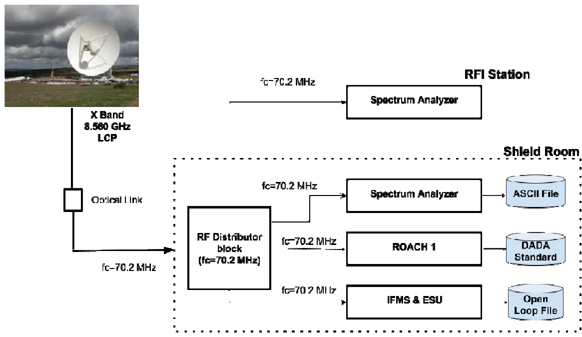

Fig.10 Block diagram of the receiving system used for tracking of the asteroid.

IV. CONCLUSIONS AND FUTURE ACTIVITIES

The two activities carried out at the end of 2018 proof the potential and versatility of the SDSA and the fruitful collaboration with the NASA-JPL and with the Astonomical Observatory of Cagliari (INAF). Future activities are aimed at optimizing the tracking of interplanetary probes and the radio science, updating the instrumentation owned by ASI. The goal is to extend the operations of the SDSA in the X band, in the K band, and in the Ka band.

V. ACKNOWLEDGEMENTS
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