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Solar radio emission surveillance by the Trieste Solar Radio System 2.0

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Abstract

In this paper we describe the Trieste Solar Radio System 2.0 (TSRS 2.0), a project for a new facility dedicated to the continuous surveillance of the solar radio emission in the range 1-19 GHz. It is presently under development at the INAF Astronomical Observatory of Trieste and will be installed at the Basovizza Observing Station. TSRS 2.0 will be constituted by a three-meter parabolic antenna with an LHCP and RHCP large-bandwidth feeder, a receiver with high resolution digitizer, a high dynamic detector, a fully-sky coverage, alt-az motorized mount and an imaging and control software with tracking options. In this paper we focus on the TSRS main operational features, its science goals, observation modes and data products. Thanks to its peculiar and unique operational capabilities, TSRS will be an interesting diagnostic tool and will play a fundamental role in the Solar Radio Weather framework, contributing to detection, monitoring, newcasting, forecasting, modelling and scientific investigation of radio solar emission and its effects on ground based infrastructures via radio interferences.

1 Relevance of Solar Radio Weather monitoring

The Sun is a broad band and non-directional source of radio waves. These solar radio emissions can increase by several orders of magnitude during severe outbursts and persist at high level for minutes to hours depending on the solar activity level. These sudden and intense outbursts from the Sun are called Solar Radio Bursts (SRBs) and are recognised as extreme Space Weather events ([1], [2], [3]). Their potential impacts on the technological world and all its applications relying on the use of radio waves are a matter of fact and they have been an important topic of research due to their strong relevance to Space Weather operations. Various research investigations ([4], [5], [6], [7]) have demonstrated, in fact, how several technologies can be easily affected, without any warnings, by these strong radio solar emissions, such as the satellite communication (SATCOM), the Global Navigation Satellite System (GNSS), the Wide Area Augmentation System (WAAS), Radar Systems and so on. In particular, a sudden outburst in the L band (1.1 - 1.6 GHz) from the Sun is recognized as a source of Radio Frequency Interference (RFI) that directly impacts the performance of the Global Navigation Satellite System (GNSS) receivers. The GNSS is a satellite-based positioning,navigation and timing system whose technology is now widely adopted in many fields such as industry, transportation, aviation, navigation etc. The U.S. Global Positioning System (GPS) is one of the globally operational GNSSs, consisting of a satellites constellation that emits right hand circular polarised (RHCP) L band signals at two frequencies, L1 (1575,42 MHz) and L2 (1227,6 MHz) respectively. The occurrence of an intense and RHCP SRB in the L band can influence the GPS signal reducing the carrier-to-noise power spectral density ratio (C/N) of all the receivers located in the sunlit hemisphere of the Earth, as reported in [8], [9], [11], [10]. Consequently this results into a degradation of the positioning and navigation accuracy. In the worst scenario, i.e.in the case of a significant reduction in C/N, a complete loss of lock of GNSS signals can occur and may persist also for a significant period of time, causing the complete loss of receiver tracking. These effects represent an important issue for a wide range of services and applications that rely on the use of GNSS and demand uninterrupted navigation satellite service with a certain level of position accuracy, both in civil and military frameworks, for example in the civil aviation field for the take-off and landing procedure or in the support of the military services. These considerations reinforce the need for diachronic observations of the Radio Sun, to be carried out by dedicated solar radio instruments that perform a continuous and near-real-time surveillance, deriving solar radio indices in specific bands, measuring radio flux density and polarisation, producing radio spectra and radio images time series in near-real-time. Only this approach allows to describe a comprehensive Solar Radio Weather scenario, defined by the identification of radio precursors and characterized by the impacts to radio communications and GNSS receivers, [12]. In this framework, the Trieste Solar Radio System will play a fundamental role not only in the Space Weather Science but also in the Space Weather operations. It is definitely a smaller and less refined instrument compared to other big radio telescopes, but it presents operational features that will make it unique with respect to most of the existing solar monitoring systems in Italy and in the world. In the present Space Weather operational scenario, in fact, it is the only instrument that can be considered an effective

Solar Radio Weather monitoring facility, while other instruments are not fully dedicated to the diachronic observations of the Radio Sun. For example the Italian INAF-ASI single dish antennas within the Sun Dish Project (32-m diameter Medicina Radio Telescope, 32-m diameter Noto Radio Telescope, and the 64-m diameter Sardinia Radio Telescope (SRT)) [14] which provide synoptic images and high resolution region mapping, present some operational limitations as an appropriate dedicated observation time must be requested. TSRS provides also accurate full circular polarisation information, while most of the instruments distributed around the world do not perform these measurements. The polarisation measurements are added value for twofold reason: (1) it provides diagnostic tools to Solar Radio Physics in interpreting the plasma characteristics at the radio emission source, radio emissions, radio emission mechanisms and propagation effects such as plasma structures, reflections, diffusive processes, Faraday rotation and so on. It is possible to trace the radiation that is measured on the ground up to the propagation site from the active region adopting reverse modeling techniques. (2) the polarisation information is fundamental for operations and monitoring purposes in the L-band (1.1 to 1.6 GHz), the band relevant to GNSS systems, the polarisation measurement allows to discriminate between RHCP and LHCP radio events and to identify the potential impact to aviation and GNSS-based services of a solar radio burst interference with proper polarisation type. In fact as the GPS system operates with right polarisation so that an entirely left-hand polarised solar radio signal does not influence the GPS signal while one with right polarisation causes a reduction of the noise signal,because it basically contributes to increase the noise of the receiver.

2 The Trieste Solar Radio System 2.0

The Trieste Solar Radio System 2.0 (TSTS 2.0) is the project for a new, state-of-the-art solar radio polarimeter primarily devoted to solar radio observations. TSRS will be part of the INAF Trieste Solar Radio Weather Centre (TSRWC), a center dedicated to the Radio Solar Physics and to the monitoring, modelling and newcasting /forecasting of radio events. In addition, it will be one of the observing nodes belonged to the future INAF National Space Weather Service Network (INAF NSWSN) consisting of several INAF observing assets involved into different space weather fields, whose development is in progress. Its consolidated architecture is currently under definition and the tool will be operated in the next months by the INAF - Astronomical Observatory of Trieste and installed at the Basovizza Observing Station. TSRS 2.0 is characterised by unique features (high time resolution, polarisation, calibration, extended observing bands, single frequency and spectral observing modes) that make it more advanced than the previous project, TSRS 1.0, which is no longer operational following a lightning strike that irreparably compromised its operations. TSRS 2.0 will be constituted by the following sub-systems: (a) a three-meter parabolic antenna with alt-az mounting, a fully-sky coverage, (b) a radiopolarimeter operating in selected frequency bands in the range 1 to 19 GHz such as the L, 2800 MHz, C and Ku-bands with an LHCP and RHCP large-bandwidth feeder; (c) a receiver with high resolution digitizer, (d) a high dynamic detector, (e) an imaging and control software with tracking options, (f) a digital data acquisition system, (g) a Solar Radio Archive directly accessed through the WWW via unified interfaces, (h) a radio data analysis system. We describe the data flow foreseen for the TSRS project. A scheme of the TSRS data flow is reported in Figure 1. Two observation modes are foreseen: (a)frequency scan and (b)spatial scan. In the TSRS architecture a scheduling system is foreseen in order to switch from one to the other observation mode and produce the raw data. In the frequency scan mode high time resolution 2.5D spectra are produced with the spectral coverage from 1 to 19 GHz and an instantaneous bandwidth of 4 GHz. In the other mode, high frequency 2D synoptic images are produced with full disk spatial resolution but very high time resolution to highlight active radio sources. They are made at the highest observation frequency, close to the SRT operational frequencies in order to operate in synergy with and compare the results with those obtained with a much more sophisticated instrument characterized by a greater spatial resolution. The synoptic images are useful to identify relevant radio sources which will be recorded into a catalogue in the Solar Radio Archive. From the raw spectra, full time resolution spectro-polarimetric time series at selected frequencies and bands will be produced. For nowcasting purposes, a trigger mechanism will allow to send an instantaneous alert. The TSRS will publish in near real time the relevant solar radio indices that are derived from the time series and provide near real time information on the status of the coronal plasma at different heights and representative of the solar coronal activity level. Such radio indices are suitable inputs to a variety of nowcasting and forecasting models in Space Weather prediction allowing the identification of radio precursors by applying deep learning techniques. All the raw and derived data will be stored (e.g. as FITS files) and indexed in the Solar Radio Archive using provenance linking to connect the various products and collections. Data and indices will be published on a dedicated web site together with a selection of quick-look graphs updated in near-real-time. Archive discovery, access and, in general, interfacing solutions will follow the current scenario for open science and FAIR-principles-driven interoperability adopting global technological standards and architectures.

3 Conclusions

The new TSRS system will provide radio diagnostics relevant to Space Weather applications by solar radio indices derivation, forecasting and publication tools in near real time. Thanks to its operational flexibility and diagnostic capabilities TSRS can play a fundamental role in Space Weather framework.

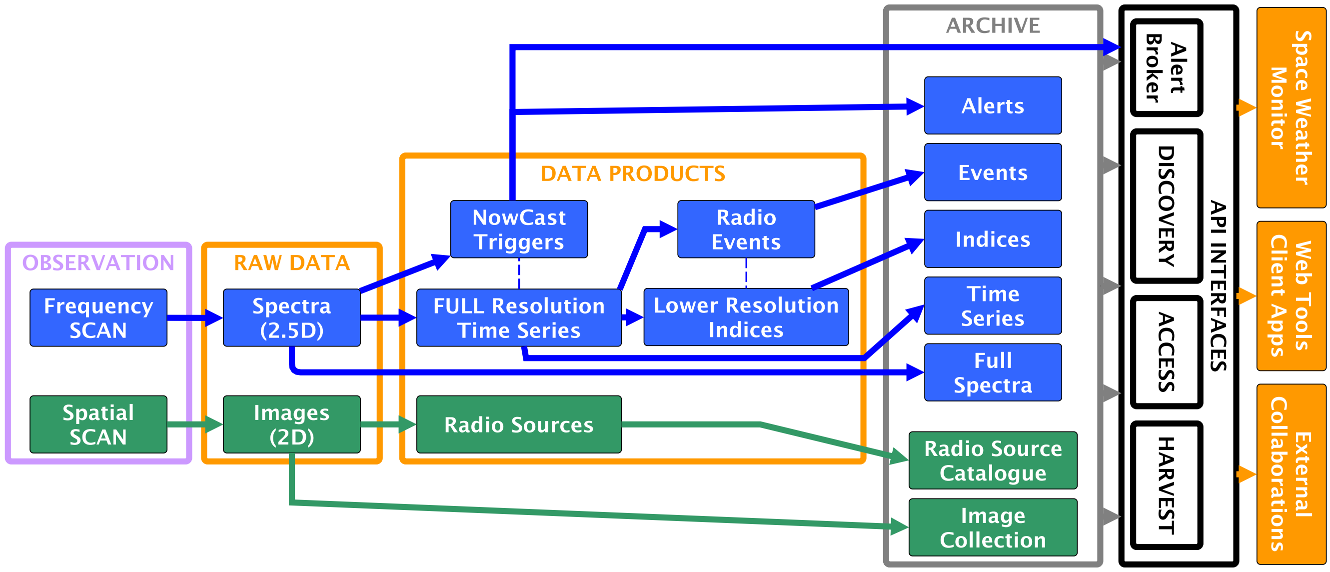

Figure 1. Data flow for the TSRS-2.0 radio polarimeter. Starting from the right the two expected observation modes will provide collections of raw data in the form of 2.5D spectra (records of the flux variations versus frequency and time) and images taken from spatial scans of the radio sun. The two raw collections will feed independent reduction pipelines. The spectral one will output full time resolution time series, then used to generate lower resolution indices (as aggregates of the former series) and identify radio events, as well as triggers for now-casting solar activity. The imaging observations will be used to identify radio sources. All of the data products will be stored in a dedicated archive that will also keep track of the connections existing among the various datasets (e.g. events will point to the relevant datasets of indices, series and spectra, but also, if possible, to the radio source). The archive will be provided with a set of API for programmatic discovery and access to the data collections contents, as well as harvesting interfaces to connect to external services and collaborations. An alert broker could also be used for direct broadcasting of the now-cast transient solar radio events. All the space weather monitoring interfaces, web applications, client tools, etc. will be set up as consumers of the archive's API.

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