Modernising discovery, access and interoperability for the Trieste Solar Radio System Heritage Archive

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ABSTRACT

The TSRS was a set of two multi-channel solar radio polarimeters which performed continuous surveillance of the decimetric and metric coronal radio emissions with high time resolution. TSRS was operational in Trieste (Italy) under the management of the INAF Astronomical Observatory of Trieste from 1969 to 2010 when a lightning stroke irreparably compromised its operations. Starting from that moment, all the services related to it, including the archive system, were abandoned due to lack of funds and resources. An Heritage Archive (TSRS-HA) has been preserved with the available digitised data and this contribution describes how it was planned to refurbish archive and service for such an heritage resource following current common FAIR principles adherence and new technologies.

Keywords: FAIR, Space Weather, heritage data collections

1. INTRODUCTION

The Trieste Solar Radio System (TSRS) was a dedicated instrument designed for the continuous monitoring of the solar radio corona in the meter and decimeter wavelength bands.[1] Operated by the Trieste Astronomical Observatory from 1969 to 2010, the TSRS provided valuable data on solar radio flux density with high-time resolution (millisecond scale) and circular polarisation information. The system consisted of two main subsystems:

1. **Metric Multichannel Solar Radio Polarimeter (mMSRP)**: This component utilized a 10-meter dish to observe the solar radio corona in the metric regime across four radio bands ranging from 200 to 800 MHz, see Fig. 1.

2. **Decimetric Multichannel Solar Radio Polarimeter (dmMSRP)**: Added in 1999, this subsystem employed a 3-meter dish to monitor the solar radio corona in the decimetric regime, covering two radio bands between 1 and 4 GHz, see Fig. 2.

Managed by the INAF Astronomical Observatory of Trieste, the system remained operational until 2010, when it was damaged by lightning. Subsequently, all associated services, including the archival systems, were discontinued due to financial and resource constraints. Despite this setback, the extensive TSRS dataset, spanning over four decades, remains a highly valuable repository for studies in solar radio physics, historical solar radio events and their implications for Space Weather and technological systems. The TSRS-HA archive, which stores the collected data from the TSRS system, has played an important role in various scientific discoveries and advancements. For instance, it has enabled the identification of fine structures in the coronal plasma, referred to as "fibers" and "zebras",[2] providing insight into the complex dynamics of the solar corona. Additionally, TSRS data has been crucial in establishing correlations between solar radio bursts and disruptions in the Global Navigation Satellite System (GNSS), which has significant implications for industries and sectors reliant on

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Figure 1. **Metric Multichannel Solar Radio Polarimeter: a multichannel radiopolarimeter with 4 receiving channels in the band 200-800 MHz (237, 327, 408, 610 MHz), 10 m parabolic reflector with equatorial mounting.**

Figure 2. **Decimetric Multichannel Solar Radio Polarimeter with 2 receiving channels in the band 1-4 GHz (1420 and 2695 MHz), 3 m parabolic reflector with alt-az mounting.**

satellite-based technologies.[3] The examination of previously unexplored data, coupled with high-temporal resolution and circular polarisation data as well as the refinement of interpretations of historical radio observations can lead to breakthroughs in solar radio physics, enhancing our understanding of fundamental processes within the solar corona. Furthermore, the TSRS-HA can significantly contribute to the improvement of Space Weather prediction models. By conducting post-event assessments and case study, researchers can develop robust criteria for evaluating the potential impact of solar activity on various technological systems, essential for developing

strategies to mitigate the adverse effects of space weather events.
The TSRS-HA's availability for international collaborations and cross-disciplinary research is also of great importance. Researchers can access the TSRS data to correlate it with complementary ground-based and space-borne observations, facilitating new insights and discoveries in solar physics and related disciplines. The TSRS archive also serves as a valuable resource for the development of advanced forecasting algorithms. Utilizing TSRS data, researchers can develop sophisticated Deep Learning algorithms capable of accurately forecasting multivariate solar radio time series.[4] These algorithms have the potential to revolutionize solar weather predictions, enabling automatic analysis and near-real-time nowcasting services. Additionally, TSRS data is crucial for understanding the effects of Solar Radio Bursts (SRBs) on the Global Navigation Satellite System (GNSS). By investigating disturbances in GNSS and radar signals, mobile communications and customizing alert levels based on historical solar radio events recorded by TSRS, researchers can develop strategies to minimize disruptions and enhance the resilience of critical technological infrastructure.

Recognizing the importance of the archive and its immense research potential, preserving and ensuring easy access to this data is essential. In response to these needs, a comprehensive refurbishment of the TSRS-HA and a data curation initiative have been launched. The primary goal is to modernize the archive infrastructure under FAIR (Findable, Accessible, Interoperable, and Usable) principles, ensuring that it remains current, relevant, and easily accessible to researchers. This upgrade aims to significantly improve the TSRS-HA's accessibility and usability, facilitating advancements in solar radio physics, post-event analyses and Space Weather research. Furthermore, this refurbishment will serve as a model for optimizing the forthcoming TSRS2.0 data infrastructure, ensuring that future solar radio observations continue contributing to our understanding of the Sun and its impact on our technological systems.

2. OLD TSRS ARCHIVE AND CURRENT DATA COLLECTION

The TSRS-HA data is currently preserved in both physical and digital formats. The digital component consists of approximately 2 TB of compressed data within the INAF-IA2 tape archive facility for long-term preservation. This collection includes a complete set of available digitised datasets, covering all time series from the 1999-2010 monitoring period. The Archive was structured into two primary sections: : the Radio Archive (RARC) and the SOLar Radio Archive (SOLRA).[5]

- **Radio Archive (RARC)**: It contains raw data in a proprietary binary format, including time series for both LHCP (Left-Hand Circular Polarization) and RHCP (Right-Hand Circular Polarization) at six distinct frequencies (237, 327, 408, 610, 1420, and 2695 MHz). It also includes quick-look images that represent the 10-minute average flux per frequency, as well as detailed metadata on polarization, gain, and atmospheric conditions.
- **SOLar Radio Archive (SOLRA)**: It contains calibrated radio polarimetric data formatted as FITS binary tables. These tables are organized into daily blocks that capture millisecond radio flux for each 10-minute interval. Additionally, this part includes solar indices derived from the maximum and average flux per second.

The data were made accessible through a dedicated web interface, allowing users to efficiently search and download data based on their specific requirements, as depicted in Fig. 3. Users could specify precise time ranges, select desired data types and opt for preferred output file formats, facilitating tailored searches of solar radio events.

The web interface exposed also the synoptic graph of the radio emission measured by the two radiopolarimeters. In Fig. 4, the upper panel displays the time evolution of the total (LHCP+RHCP) radio flux density for all receiving channels. The lower panel depicts the difference (LHCP-RHCP) between the left-hand and right-hand polarization channels for each frequency, indicating the circular polarization of the signal.

Furthermore, The TSRS-HA data products have also been seamlessly integrated into the European Space Agency's Space Weather European Network service (ESA SWENET) (`https://swe.ssa.esa.int/TECEES/swenet.html`), as depicted in Fig. 5.

Figure 3. **SOLRA TSRS Real-Time Solar Radio Archive Panel interface. Users can specify a time range, select specific data types, and choose output file formats, allowing for precise and customized searches of solar radio events. The user-friendly design facilitates efficient data retrieval and analysis for researchers.**
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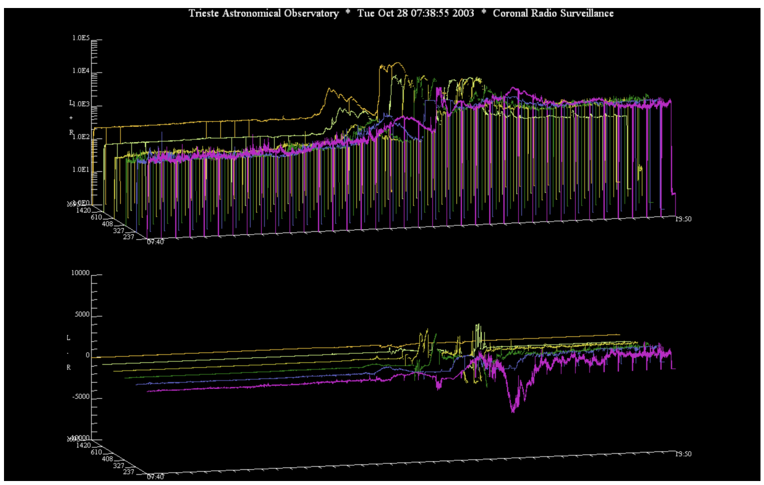

Figure 4. **Multi-channel synoptic graph of the radio emission of the perturbed corona. It was generated automatically with a 10-minute cadence. Upper panel: Total (LHCP+RHCP) Flux Density. Lower panel: Circular Polarization (LHCP-RHCP).)**

Aside from ESA SWENET, a curated catalogue of highly energetic radio events sourced from the TSRS-HA has been furnished to the HELIO project's Heliophysics Event Catalogue (http://hec.helio-vo.eu/hec/hec_gui.php), accompanied by comprehensive metadata providing details on relevant solar radio events (see Fig. 6).

3. TSRS-HA ARCHITECTURE

To update and maintain the TSRS-HA, a comprehensive digitization process will be carried out to transform all datasets into a unified and standardized digital format. This effort is part of a broader strategy to improve data management and enhance user experience through the application of advanced data preservation methods and the integration of FAIR (Findable, Accessible, Interoperable, and Reusable) principles within the archive's framework. This digitization process aims to improve directory structures and data models within the archive

Figure 5. **Portal of ESA/SWENET**

by implementing new standardized metadata. This will enhance the accessibility and usability of the archive for the scientific community. Key frameworks being considered include the Europlanet Network-TAP (EPN-TAP), Heliophysics Application Programming Interface (HAPI), and Space Physics Archive Search and Extract (SPASE) Metadata Model.

- Europlanet Network-TAP (EPN-TAP): Developed by the Europlanet Research Infrastructure, EPN-TAP[6] offers standardized interfaces based on the International Virtual Observatory Alliance (IVOA)[7] Table Access Protocol (TAP) standard[8] for efficient data discovery and retrieval in astronomy. Its implementation will streamline access to TSRS-HA data and enhance interoperability across various astronomical data repositories and services.
- Heliophysics Application Programming Interface (HAPI):[9] Similarly, it provides specialized functionalities for managing time series data. By leveraging HAPI, users will be able to query and retrieve time series data from the TSRS-HA in a standardized and efficient manner.
- Space Physics Archive Search and Extract (SPASE) Metadata Model:[10] This standardized approach for describing and organizing metadata related to heliophysics data can improve the consistency and interoperability of metadata across different heliophysics datasets. Its adoption will benefit from wide acceptance by institutions such as NASA and ESA.

The implementation of these frameworks will enable seamless collaboration and interoperability among research organizations, significantly enhancing the accessibility and usability of astrophysical data. Transitioning to standardized solutions will facilitate smooth data ingestion and the shift from bespoke data formats and proprietary software to standardized and open-source solutions, ensuring greater flexibility and compatibility with other scientific tools and platforms. A key component of this initiative is the development of a user-friendly, lightweight service, specifically tailored for the heliophysics community. This service will be based on a microservice architecture, deployed within an efficient and easily manageable containerized framework. This design will allow for

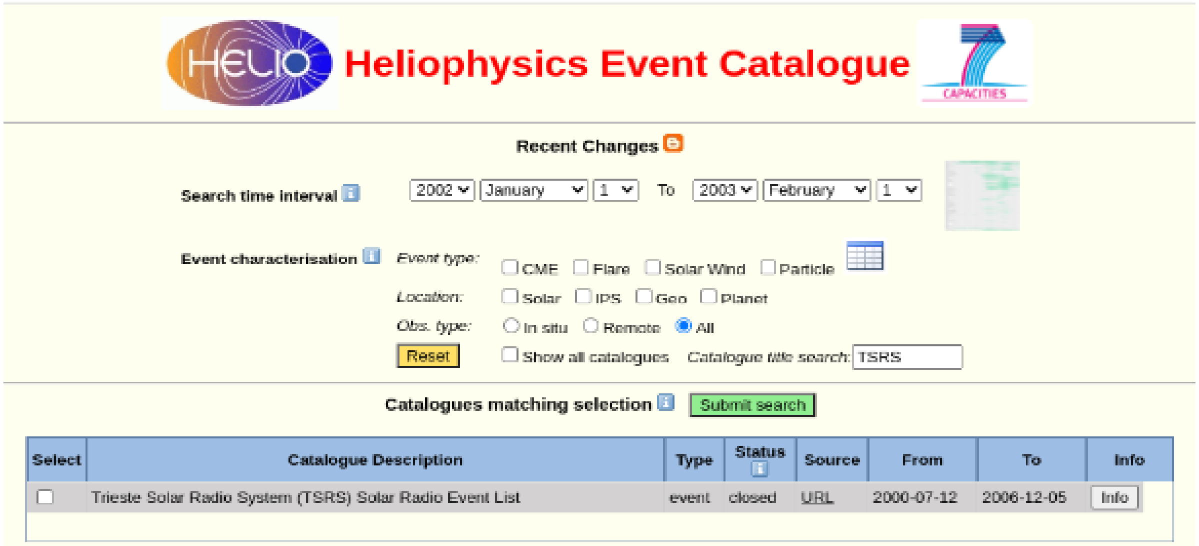

Figure 6. **Helio Heliophysics Event Catalogue portal**

seamless integration of various community standards and applications, such as the widely used Jupyter Notebook, thereby improving workflow efficiency. The service will be designed with modularity and scalability in mind to accommodate future enhancements based on user feedback and evolving research needs, ensuring the longevity and usability of the provided data services. By adopting a collaborative approach and incorporating the latest advancements in data management and analysis, the architecture will facilitate groundbreaking discoveries and advancements in the field, promoting international collaborations and cross-disciplinary research.

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