Mem. S.A.It. Vol. 94, 40

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Solar radio observations in Trieste contributed to avert a nuclear war in 1967

An ante-litteram Space Weather application

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Received: 19-11-2022; Accepted: 19-01-2022

Abstract. Solar Radio Astronomy was started in Trieste by Margherita Hack in the second half of the Sixties as an innovative and young field of research. After the declassification in 2016, the science community could learn that the solar radio astronomical observations at 239 MHz carried out in May 1967 at the Trieste Astronomical Observatory helped to avert a nuclear war. This was an ante litteram Space Weather application relevant to the importance of Solar Radio Weather monitoring to detect potential radio frequency interferences with radio communications. In this work, we describe the solar radio event that was about to start a nuclear war by emphasising the role played by the Trieste radio observations in contributing to the correct scientific interpretation of the strong radio interferences suffered by the US Ballistic Missile Early Warning System radars in 1967, i.e., that they were of natural origin and not due to a malicious action of an adversary. This event marked the beginning of Solar Radio Weather operations in Trieste thanks to the open mind of Margherita Hack, and made it possible for the solar radio emission monitoring in Trieste to gain the scientific and applied role recognised worldwide.

Key words. Sun: radio radiation – Sun: solar-terrestrial relations

1. Introduction

In 1964 Margherita Hack, first woman in Italy, won the position of Full Professor in Astronomy at the University of Trieste (Italy) and took on the role of Director of the Trieste Astronomical Observatory. She was interested in all innovative scientific observations. At that time, Solar Radio Astronomy was a quite new discipline, since radio emissions from the Sun had been discovered in 1942 during the Second World War (Hey 1946), and systematic scientific observations were started only in the second half of the Fifties.

Within this context, in 1966 solar radio emission monitoring was started in Trieste after the implementation of a solar radio telescope.

In 2016, after the canonical 50-year time limit of non-disclosure according to military regulations, an interesting event which occurred in 1967 was declassified and published in a scientific journal with the co-authoring of some of the key figures of the time (Knipp et al. 2016). The solar radio observations carried out in Trieste played a role in this event, which in this work is considered in the light of its contextualisation in the field of Space Weather.

This work is organised as follows. In Section 2, we briefly report about the discovery of solar radio emission. In Section 3, we summarise the current knowledge of the solar radio emission interference with radio communication systems. In Section 4, we consider the cultural background and interest of Margherita Hack for Radio Astronomy and Solar Radio Astronomy, and in Section 5 we briefly describe the role she played in founding solar radio astronomical observations and science at the Trieste Astronomical Observatory. In Section 6, we provide a concise Cold War scenario in the year 1967. The early warning about a nuclear attack issued in May 1967 which was due to the radio blinding of the US Ballistic Missile Early Warning System (BMEWS) is elaborated in Section 7, and the related back alarm due to the correct interpretation in terms of solar radio emission interferences is explained in Section 8. In Section 9, we present the optical and radio observations carried out in Trieste which supported the interpretation of the natural origin of the interference given by the USAF specialists. In Section 10, we provide the present and future scenarios of Solar Radio Astronomy at INAF and in Trieste. The conclusions are drawn in Section 11.

2. The discovery of solar radio emissions

During the Second World War, the British army was surveilling the Channel by means of a radar system to detect a possible landing of German troops. The officer and scientist James Stanley Hey was in charge of supervising this surveillance.

On 27 and 28 February 1942, the radar system was blinded by very strong radio signals: Was this an intentional jamming action by the German army, preparatory to the dreaded landing?

In practice, was this radio jamming an intentional action by the adversary or was another cause possible?

In 1942, the Sun was very active. As a scientist, James S. Hey correctly understood that the interfering radio signal was produced by the active Sun, and not by any adversary. Anyway, this information was kept as classified until the end of the conflict. In fact, James S. Hey could publish his discovery on the journal Nature only 4 years later, on 12 January 1946 (Hey 1946). The relevant article is reported in Fig. 1.

For the first time, natural and intentional radio jammings were discriminated according to the physical knowledge, which allowed Hey to ascribe strong radio emissions to the Sun. This event marked the birth of Solar Radio Astronomy, whose observational and theoretical basis were established in the ’50s and ’60s.

3. Effects of Solar Radio Weather

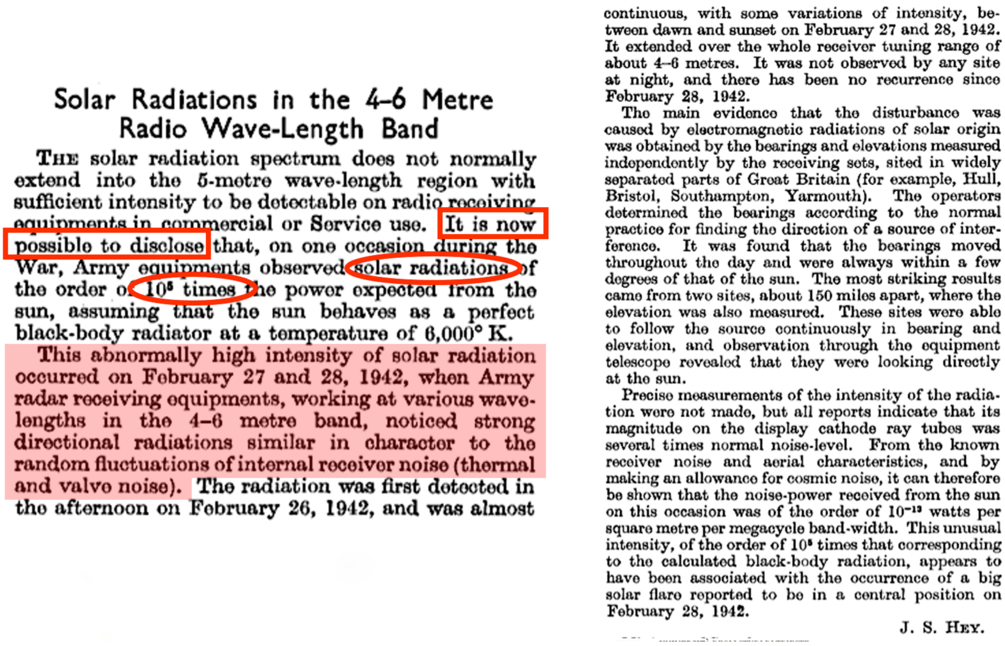
After decades of observations and modelling, it was known that the Sun is a broad- and narrowband source of radio emissions, originated by a variety of thermal and non-thermal physical processes, which occur locally in the plasma when it is not in local equilibrium due to different perturbations.

When the radio flux density of solar radio emissions exceeds a minimum threshold, they can interfere with radio communication systems (see. e.g., Messerotti (2016, 2018, 2019), and references therein). In fact, when the Sun is active, these radio emissions can intensify by orders of magnitude.

In this framework, Solar Radio Weather refers to the physical state of the Sun as a complex made up of radio sources. It is characterised by quiet conditions up to highly perturbed conditions according to the levels of the generated radio signal.

Solar radio emissions are detected in the whole sunlit Earth’s hemispheric region after 8.3 minutes.

Radio communication systems (e.g., satellite localisation, aviation systems, mobile communications) are directly interfered under specific geometric conditions (radio source to re-



Solar Radiations in the 4–6 Metre Radio Wave-Length Band

THE solar radiation spectrum does not normally extend into the 5-metre wave-length region with sufficient intensity to be detectable on radio receiving equipments in commercial or Service use. It is now possible to disclose that, on one occasion during the War, Army equipments observed solar radiations of the order of 10^5 times the power expected from the sun, assuming that the sun behaves as a perfect black-body radiator at a temperature of 6,000° K.

This abnormally high intensity of solar radiation occurred on February 27 and 28, 1942, when Army radar receiving equipments, working at various wave-lengths in the 4–6 metre band, noticed strong directional radiations similar in character to the random fluctuations of internal receiver noise (thermal and valve noise). The radiation was first detected in the afternoon on February 26, 1942, and was almost continuous, with some variations of intensity, between dawn and sunset on February 27 and 28, 1942. It extended over the whole receiver tuning range of about 4–6 metres. It was not observed by any site at night, and there has been no recurrence since February 28, 1942.

The main evidence that the disturbance was caused by electromagnetic radiations of solar origin was obtained by the bearings and elevations measured independently by the receiving sets, sited in widely separated parts of Great Britain (for example, Hull, Bristol, Southampton, Yarmouth). The operators determined the bearings according to the normal practice for finding the direction of a source of interference. It was found that the bearings moved throughout the day and were always within a few degrees of that of the sun. The most striking results came from two sites, about 150 miles apart, where the elevation was also measured. These sites were able to follow the source continuously in bearing and elevation, and observation through the equipment telescope revealed that they were looking directly at the sun.

Precise measurements of the intensity of the radiation were not made, but all reports indicate that its magnitude on the display cathode ray tubes was several times normal noise-level. From the known receiver noise and aerial characteristics, and by making an allowance for cosmic noise, it can therefore be shown that the noise-power received from the sun on this occasion was of the order of 10^{-13} watts per square metre per megacycle band-width. This unusual intensity, of the order of 10^5 times that corresponding to the calculated black-body radiation, appears to have been associated with the occurrence of a big solar flare reported to be in a central position on February 28, 1942.

J. S. HEY.

Fig. 1. The text of the article published in the journal Nature by J.S. Hey (1946), where the relevant points about solar radio emissions are highlighted in red colour.

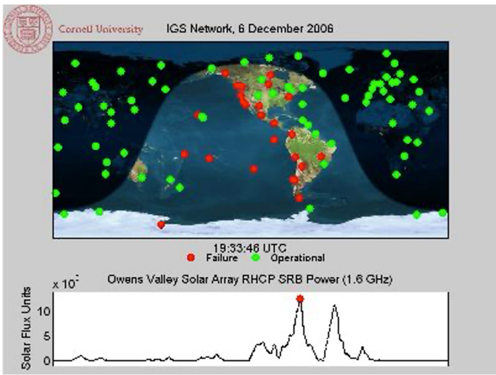


Fig. 2. Map of ground-based GPS (Global Positioning System) receivers, which lost the synchronisation with the GPS satellite constellation (upper panel, red colour) during the peak emission of an intense solar radio burst (lower panel). Courtesy of Cornell University.

ceiving antenna alignment) without any intermediate agent or process.

On the one hand, X-ray and EUV (Extreme UltraViolet) outbursts associated with flares can:

1. Increase the ionisation in the Earth's Ionosphere. This changes the conditions for the reflection and absorption of radio waves according to their frequency;
2. Increase the turbulence in the ionospheric plasma. This affects the propagation of radio waves and makes it difficult or impossible to receive them, e.g., the ones transmitted by GNSSs (Global Satellite Navigation System).

In turn, strong solar radio emissions can:

- Increase the receivers' background noise in the HF band (3-30 MHz);
- Interfere with the reception of GPS radio signals up to full disruption in the L band (1-3 GHz) as depicted in Fig. 2, and schematised in (Messerotti 2008);
- Interfere with cellular communications;

– Affect the reception of the original radar signal by overlapping to it in the 300 MHz-30 GHz bands.

The relevant impacts can be summarised as difficulties or failures of:

– HF communications among airplanes and ground control centres;
– HF communications at large distances by ionospheric reflection;
– Cellular communications due to loss of lock with cell repeaters;
– Reception of GPS satellite signals for geo-localisation;
– Use of Over-The-Horizon (OTH) radars;
– Use of surveillance radars in airports.

Hence, monitoring and forecasting Solar Radio Weather is a must for the mitigation of impacts to radio communication systems by interference.

4. Margherita Hack and Solar Radio Astronomy

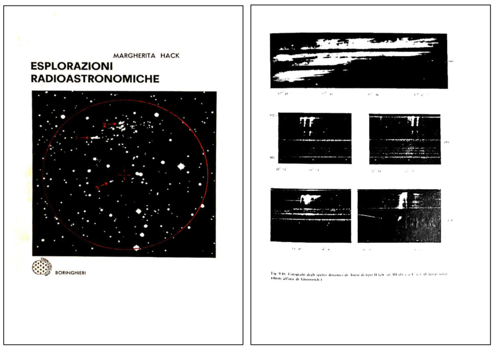


Fig. 3. Cover of the book "Esplorazioni radioastronomiche" written by M. Hack (1964) (left panel), and a page depicting solar radio spectra (right panel).

Radio Astronomy and Solar Radio Astronomy were top sciences in the '50s, '60s, and '70s, and Margherita Hack was very interested in all innovative observation techniques, even those that were not specifically related to her research field, stellar spectroscopy, as she was very open-minded.

Hence, in 1960 she wrote the book in Italian "La radioastronomia alla scoperta di un nuovo aspetto dell'Universo" (Radioastronomy for the discovery of a new view of the Universe) (Hack 1960).

In 1964, M. Hack held the full professorship of Astronomy at the University of Trieste, and the Directorship of the Astronomical Observatory of Trieste.

In the same year, her new book in Italian "Esplorazioni radioastronomiche" (Radioastronomical explorations) was published (Hack 1964) with a section on Solar Radio Astronomy (Fig. 3).

5. Solar Radio Astronomy in Trieste

In 1965, M. Hack promoted the creation of a Solar Radio Astronomy group at the Trieste Astronomical Observatory.

Prof. Alberto Abrami, permanent staff Astronomer and later professor of Radio Astronomy at the University of Trieste, formed a capable technical team with the aim to build a solar radio instrument.

With the support of the staff of the electronic and mechanical laboratories, Prof. Giorgio Sedmak designed and realised a tube solar radiometer to measure the solar radio flux at 239 MHz with a dihedral antenna and a strip chart recorder to analogically record its output.

The first location was in Prepotto, a small village on the Karst Plateau in the proximity of Trieste. In fact, in 1966, after the test phase, the instrument was moved and installed in Prepotto.

The first solar radio observation was made on 12 March 1966. Solar radio data were acquired in the time period of 2 hours before and 2 hours after the local meridian passage of the Sun.

On 26 March 1967, the solar radiometer was moved to the newly acquired Basovizza Observing Station on the Karst (Fig. 4).

In August 1967, two Brush strip chart recorders with fast response (10 and 21 ms) were added.

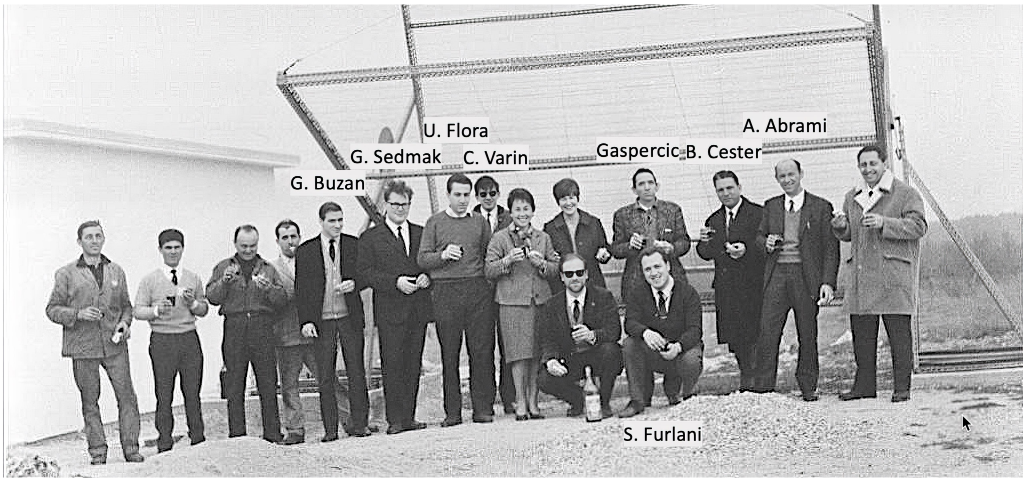


Fig. 4. First light of the solar radiometer with the dihedral antenna in the Basovizza Observing Station in 1967. Most staff members of the Trieste Astronomical Observatory participated in this event. Prof. Alberto Abrami is visible on the right and Prof. Giorgio Sedmak at the centre-left.

At that time, Margherita Hack signed a contract with the US Air Force for the provision of the solar radio data acquired by the Trieste observatory. In turn, USAF provided a significant funding that was used to acquire a state-of-the-art 10-m parabolic dish solar radio polarimeter to empower the monitoring capacities. This instrument was installed at the Basovizza Observing Station at a later time.

6. The Cold War in 1967

In May 1967, the Cold War was going on as well as the Vietnam War. The Non-Proliferation Treaty had not been signed yet. Both the Western and the Eastern blocks were competing for nuclear weapons procurement.

The situation was quite tense worldwide and the risk of a global nuclear war was quite high.

In U.S., a Ballistic Missile Early Warning System (BMWES) was operational. It was based on a series of high power and long range surveillance and tracking radar sets, among which a General Electric AN/FPS-50 radar set operating at 440 MHz that was located near Anderson in Alaska (Fig. 5). It was designed to detect a mass ballistic missile attack launched on northern approaches to the U.S. and Canada from the USSR. BMEWS could provide from 15 to 25 minutes warning time (McNamara 1961).

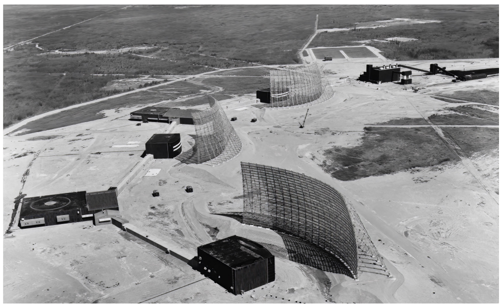


Fig. 5. The large radar antennas of the US BMWES located in Anderson (Alaska). (C. Henry, 5 July 1962, Photographic Services, Riverton, NJ, BMEWS, Public Domain; Library of Congress Prints and Photographs Division Washington, D.C. 20540 USA `http://hdl.loc.gov/loc.pnp/pp.print`)

7. A nuclear attack early warning in May 1967

On 23-25 May 1967, the BMEWS was blinded by strong radio signals that caused its inoperativeness, as reported in Knipp et al. (2016), who made a detailed reconstruction of the event both from military and scientific perspective after declassification of the relevant military information. In fact, this work is co-authored by the protagonists of the event, i.e., people retired from the USAF Air Force Air Weather Service (AWS) and from the Air Force Research Laboratory (AFRL).

The first interpretation by military analysts was of a nuclear attack from USSR. Hence, a nuclear attack early warning was issued and a nuclear counteroffensive was prepared by setting up bombers ready for take off.

The global nuclear conflict scenario was set.

8. Back alarm by USAF solar experts

As reported in Knipp et al. (2016), a back alarm was issued thanks to USAF solar experts who were trained on solar physics. In fact, they ascertained that:

- The Sun was very active;
- An extended sunspot group was present in the Photosphere, named AR 8818;
- AR 8818 was located in the proximity of the Central Meridian, a location with the best magnetic connection with the Earth;
- AR 8818 was very active and produced many intense solar flares associated with intense and long enduring radio emissions.

Therefore, the USAF experts concluded that the radio frequency interference with BMEWS was originated by the very intense solar radio emissions associated with AR 8818.

Similarly to the conclusion by J.S. Hey in 1942, also in this case the inoperativeness of BMEWS was determined by solar activity radio emissions, i.e., a natural phenomenon, and not by any adversary malicious action. The capability to discriminate between the former and the latter case proved to be fundamental in avoiding catastrophic evolutions (e.g., Messerotti (2017)).

These occurrences reinforced the interest in solar radio monitoring that underwent fast worldwide development in the second half of the '60s and in the '70s.

9. The contribution by Trieste solar radio observations

The solar radio observations carried out in Trieste during the warning days in May 1967 were relevant to the receiving frequency of 239 MHz. This frequency was the nearest to the 440 MHz frequency used by the BMEWS radars available at that time.

For this reason, the Trieste radio data were considered as a reference to support the interpretation about the Sun as the radio jamming source. In fact, (Knipp et al. 2016) state that "The Trieste Astronomical Observatory reported saturation of its 239 MHz radio system due to extreme solar flux at that frequency on 25 May 1967 [Abrami and Zlobec, 1968]".

In fact, at that time routine optical and radio observations were carried out at the Trieste Astronomical Observatory, and the relevant data were provided in near-real-time to the stakeholders such as USAF and were published on technical bulletins at a later time. A year later, the data relevant to the year 1967 were reported in Abrami & Zlobec (1968).

In particular, Figure 6 depicts the manual drawing of sunspots on 24 May 1967, where 15 sunspot groups were identified and a Wolf number of 219 was estimated. AR 8818 was very extended and constituted by 36 sunspots, which was indicative of magnetic complexity and high flaring potentiality.

The mean radio flux density for the year 1967 is depicted in Fig. 7. The whole year was very radio active, but the highest mean solar radio flux corresponds to the days in May when BMEWS was blinded.

The solar radio flux density measured on 25 May 1967 is depicted in Fig. 8, when it took values of many tens of thousands of solar flux units (sfu). These levels are typical of solar radio outbursts in the metre band, where the quiet Sun radio level is around 10 sfu: the experimental confirmation of the correctness of the USAF experts' interpretation.

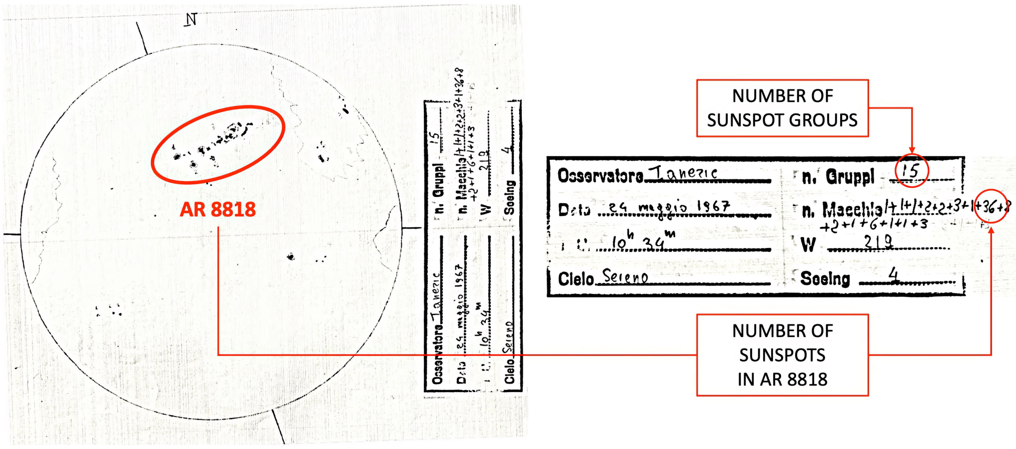


Fig. 6. Manual drawing of sunspots made at the Trieste Astronomical Observatory on 24 May 1967 (left panel). AR 8818 is encircled in red colour. Zoom of the drawing label with the sunspot and sunspot group numbers derived by the observer, Mr. Adriano Janezic (right panel) (INAF-Trieste, Solar Drawings Paper Archive).

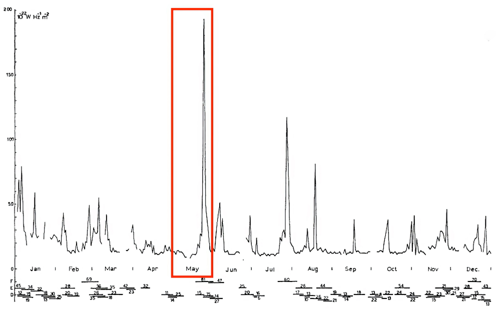


Fig. 7. The mean solar radio flux density in solar flux units (1 sfu = $10^{-22} W{\cdot}m^{-2}{\cdot}Hz^{-1}$) detected at 239 MHz in Trieste in the year 1967. The radio emission occurred in May 1967 with a high peak (195 sfu) is highlighted by the red rectangle (Abrami & Zlobec 1968).

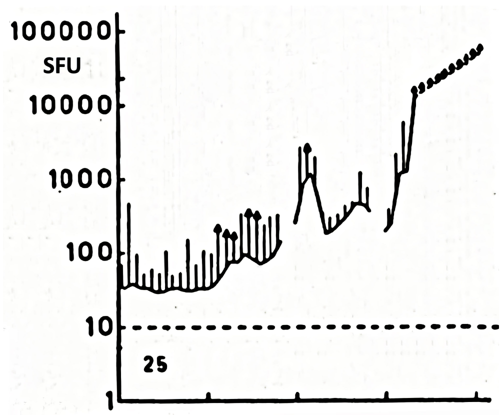


Fig. 8. Estimated solar radio flux density detected at 239 MHz in Trieste on 25 May 1967 (Abrami & Zlobec 1968).

10. Solar Radio Astronomy at INAF and INAF-Trieste

During the recent years, the ever increasing Space Weather effects awareness and the need to advance the preparedness for mitigating these effects (e.g., (Opgenoorth et al. 2019; Plainaki et al. 2020)) have led to a renewed interest in solar radio monitoring for nowcasting and forecasting possible interferences with radio communication and geo-localisation systems.

In this context, the Italian National Institute for Astrophysics (INAF) has been managing several radio astronomical stations in Italy for decades.

The map in Fig. 9 indicates the geographical location of the stations hosted by INAF Research Structures. As highlighted on the map, some of them are dedicated to solar ra-

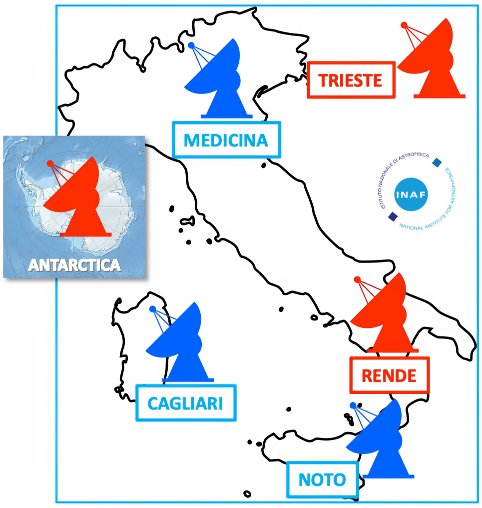


Fig. 9. Locations of radio astronomical stations managed by INAF in Italy and shortly in Antarctica. Sun-dedicated stations are coloured in red and are still under development, whereas non-dedicated ones are in blue colour.

Fig. 10. The new solar radio polarimeter (TSRS 2.0) at the Basovizza Observing Station in Trieste is visible in the foreground, and the older solar radio polarimeter (TSRS 1.0) in the background.

dio observations and others have been used for both non-solar and solar observations.

Solar radio observatories are located in Trieste and shortly at the Space Weather campus hosted by the University of Calabria (UniCal) in Rende (Cosenza), where an INAF Section has been active at the Department of Physics since 2019. The solar radio station in Rende will be managed in the framework of a MoU between INAF and UniCal. Both these new generation instruments are solar radio polarimetric spectrographs operating in the 1-18 GHz band and will be used for diachronic observations of solar radio emissions.

Both the 64m-dish Sardinia Radio Telescope (SRT) near Cagliari and the 32m-dish Medicina Radio Telescope near Bologna have been used for solar radio observations in the 18-26 GHz band (see, e.g., Pellizzoni et al. (2022)).

The 32m-dish Noto (Siracusa) Radio Telescope is undergoing upgrading and will be used for solar radio observations as well.

Furthermore, a new project is in progress for the installation of a solar radio telescope in Antarctica operating at 100 GHz.

All these radio stations will become nodes of the INAF National Space Weather Service Network (INAF NSWxSN) that will participate in the European and worldwide Space Weather monitoring and forecasting networks (Opgenoorth et al. 2019; Plainaki et al. 2020).

In particular, the Trieste Astronomical Observatory has a long tradition in solar radio observations, which started in 1966 under the directorship of Margherita Hack and, since the very beginning, had been used for an ante-litteram Space Weather activity as illustrated in the previous sections.

In the course of the following decades, two multi-channel radio polarimeters were set up: a 10m-dish multi-channel radio polarimetric system operating in the metre band and a 3m-dish multi-channel radio polarimetric system operating in the decimetre band. This set was named Trieste Solar Radio System (TSRS 1.0) and had been routinely used for Solar Radio Weather monitoring (e.g., (Messerotti 2008, 2016; Messerotti et al. 2010; Messerotti 2018, 2019)). In the year 2010, TSRS 1.0 was hit by a lightning stroke that destroyed its electronics and made it irreparably inoperative.

A few years ago, INAF funded the procurement of a new solar radio polarimeter with a 3.7m-dish antenna for solar radio monitoring as Trieste Solar Radio System (TSRS 2.0). Fig. 10 shows TSRS 2.0 in the foreground and the 10m-dish antenna of TSRS 1.0 in the background. The commissioning phase of TSRS 2.0 has not been completed at the time of writing. Shortly TSRS 2.0 will be used for solar radio emission surveillance on a routine basis (Jerse et al. 2020).

11. Conclusions

Solar Radio Weather can have significant societal impacts, as it can directly interfere with, e.g., satellite communications, geolocalisation by Global Navigation Satellite Systems like GPS, mobile communications, and High Frequency communications.

These impacts can be critical due to their relevancy for military and political equilibria, as proven by the 1967 event mentioned in this work.

Radio science plays a key role in helping discriminating between natural and intentional radio frequency interferences through awareness and preparedness.

To date, INAF-Trieste has been playing a fundamental role in this context thanks to the foresight of Margherita Hack who promoted an ante-litteram activity of operational Space Weather. This activity is expected to continue in the framework of the INAF National Space Weather Service Network, which is currently under development.

In fact, we are confident that the heritage and legacy of this activity in Trieste will be gathered by the new generation of scientists after decades of "dark ages" for Solar Radio Astronomy characterised by the absence of interest. Nowadays this attitude has changed and there is a renewed interest in this area owing to its importance for Space Weather applications, and also to the advent of new generation radio instruments like LOFAR (Low Frequency Array) and SKA (Square Kilometre Array) in the international framework.

Acknowledgements. We are grateful to the HACK100 Scientific Committee for having invited us to prepare this review work, and to an anonymous Referee whose suggestions significantly contributed to improve this work.

We acknowledge the original technical staff members of the Trieste Astronomical Observatory, in particular Mr. Luciano Perla, who participated in the technical development of solar radio observations in Basovizza since the very beginning in the sixties, as, notwithstanding being retired, they tirelessly and enthusiastically provided us with explanations and photos.

It is a pleasure to acknowledge the scientists who passed away with whom we had intensively collaborated, and from whom we have learnt during our career as staff solar radio astronomer like Margherita Hack, Alberto Abrami, and Paolo Zlobec.

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