European F10.7 and F30 Indexes Monitoring System *ROSIE*

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In our paper we describe basic goals and characteristics of the presently constructed European F10.7 and F30 Indexes Monitoring System *ROSIE*, which in the final configuration will be dedicated to regular and continuous measurements of the F10.7 and F30 solar radio indexes. The University of Wrocław and the ITTI Sp. z o.o. in Poznań prepare the system to order of the European Space Agency (ESA). The *ROSIE* will ensure an independence of the European Union from external providers of the F10.7/F30 solar indexes data and will improve a space awareness of the Union's institutions and agencies.

The monitoring station installed in the Astronomical Observatory in Białków near Wrocław will be equipped with the six-meter dish radio telescope and two fast digitisers/radiospectragraphs. Due to an uncomplicated scalability, the network of the observing stations of the fully-featured European F10.7 and F30 Indexes Monitoring System could be gradually extended to allow 24/7 observations.

1 Introduction

All quiet, active and eruptive solar phenomena, being manifestations of the so-called solar activity, comprise numerous interrelated physical processes of various spatial and time scales, which collectively cause substantial variations of a state of the solar atmosphere (from the photosphere up to the upper corona and even further to outskirs of the heliosphere), of an interplanetary plasma and, indirectly, of the Earth's magnetosphere and ionosphere. A momentary overall level of the solar activity, properties of the involved physical processes, their energy budgets, and their direct and indirect influences onto a cosmic environment of the Earth can be scrutinized and investigated only through recording of emitted radiations and/or through of in-situ measurements of plasma's and physical fields' parameters.

One of the most widely and lengthy applied indicator of the solar activity level and an indicator of separate active phenomena ongoing in the lower part of the solar atmosphere is the F10.7 solar index, being a momentary (or averaged) flux of the solar radio emission integrated over the whole disk and over the 100 MHz wide frequency band centered on 2800 MHz (or, equivalently on 10.7 cm wavelength). The 10.7 cm radio emission of the Sun can be easily recorded using relatively small, easy to maintain and service, and inexpensive dish antennas supplied with low-noise amplifiers, digital receivers, and automatic steering systems. Thanks to the excellent penetrability of these radio waves through the Earth's atmosphere, the observations in the 10.7 cm band are virtually undisturbed by actual weather conditions.

Regular observations of the solar emission in the 10.7 cm waveband started in 1947 in Ottawa, Canada. Up to now, the 10.7 cm flux is measured only with two small radio telescopes located at the Dominion Radio Astrophysical Observatory, Penticton, Canada (Tapping, 2013). No measurements of the F10.7 index are performed regularly in countries belonging to the European Union.

Basic physical mechanisms of the emission and statistical properties of the 10.7 cm solar radio flux have already been studied intensively (Schonfeld et al., 2015; Tapping & Detracey, 1990). The 10.7 cm radio emission is mostly thermal in origin and it is dominated by free-free processes in plasma (called the thermal bremsstrahlung). However, the emission in the 10.7 cm band has also a gyroresonance component, emitted at low harmonics of the electron gyro-frequencies of the coronal plasma, predominantly from the plasma volumes confined in strong magnetic fields over the sunspots in the active regions. Thus, the 10.7 cm radio emission is emitted mostly by plasma having properties typical for the low solar corona and the upper chromosphere, reflecting processes ongoing in layers crucial for all kinds of the solar active phenomena. Variations in time of the 10.7 cm solar radio flux can be sub-divided into three main components, namely: I) a fast component varying in time scales of seconds to minutes, having a form of easily distinguishable radio bursts, II) a slowly varying component alternating in time scales from hours to years, which is related to a compound emission of active regions present on the Sun at an actual phase of the activity cycle, and III) a background emission of the quiet Sun. The variations of the slowly varying component related to the solar cycle (marked II), are well reflected by changes of the F10.7 cm solar index. In a course of the eleven-years-long solar cycle, the solar emission in 10.7 cm band fluctuates between roughly 50 to 300 SFU ($1\ \mathrm{SFU} = 10^{-19}\ \mathrm{W\,m^{-2}\,Hz^{-1}}$).

Long and homogenous observational series of the F10.7 solar index are commonly applied in statistical and correlative investigations of various aspects of the solar activity and related phenomena of the space weather (thereafter SWE) (Bruevich et al., 2014; Du, 2020; Oh & Kim, 2013). Variations of the F10.7 index and simultaneous variations of various solar emissions and phenomena, like soft and hard X-ray fluxes, sunspot numbers, mean solar magnetic fields, UV integrated fluxes, total solar irradiance, full-disk CaII, and MgII fluxes, and other are highly correlated (Acebal & Sojka, 2011; Basu & Antia, 2019; Mendoza-Torres et al., 2014; Santos et al., 2017). For this reason, the 10.7 cm integrated solar flux is widely recognized as an easy to record supplement or, to some extent, even a replacement of more difficult to record proxies of the solar activity. The very high diagnostic potential of the F10.7 index is also broadly exploited in the forecasting of the solar activity, in predictions of the space weather phenomena, and even of selected geophysical processes. For example, the 10.7 cm solar flux represents a combined emission of the chromosphere, transition region, and corona modulated by solar active regions, which is deposited in the Earth's thermosphere (Del Zanna & Andretta, 2011; Dudok de Wit & Bruinsma, 2017; Svalgaard, 2016). The 10.7 cm flux can also be applied in global MHD simulations of the Earth's ionosphere as a surrogate for the measurements of the solar emission in the wavebands that cause photoionization and determine ionospheric ionization and conductivity (Bruinsma, 2015).

The F10.7 index is measured and widely applied in solar physics and related sciences for more than six full cycles of solar activity. The newest investigations of the statistical properties of the radio solar fluxes emitted in numerous other wavebands, for example in 30-cm (1 GHz) band show their very high diagnostic potential, and thus the radio monitoring of the solar activity will be extended onto these wavebands. The F30 index is related to numerous solar features, like plages, faculae, sunspot, and coronal loops.

2 The F10.7 and F30 Indexes Monitoring System and its objectives

The University of Wrocław and the ITTI Sp. z o.o. in Poznań prepare the *proof-of-the-concept* station of the European F10.7 and F30 Indexes Monitoring System, called *ROSIE* like Radio Observations of the Solar Indicative Emissions, to order of the European Space Agency (ESA). The system will monitor simultaneously fluxes and dynamic spectra of the solar radio emission in two bands: 1 GHz and 2.8 GHz, each band 100 MHz wide, with a high temporal resolution and with a high accuracy. Due to uncomplicated scalability, in final configuration a network of observing stations could collect measurements of the F10.7 and F30 solar radio indexes uninterruptedly (24/7), ensuring an independence of the European Union from external providers of the F10.7/F30 solar indexes data and will improve a space awareness of the Union's institutions and agencies. The secondary objective of the present project is a preparation of a semi-automatic and low-maintenance system of data collection (observations), data calibration and processing, and data storage.

Various products will be offered on-line as a service on a dedicated web-site (access rules will be set by the relevant EU authorities), like: F10.7 and F30 solar indexes measured with a selected/demanded time resolution (for example: 1/sec), radio-spectra of selected radio bursts in both radio bands, low time-resolution F10.7 and F30 solar indexes (average hourly, daily and so on). The data will be available as downloadable data-files and as a real-time incremental plots of the indexes and radio spectra on the dedicated www-page (upgraded every few minutes or so).

According to the project implementation schedule, the radio telescope will be installed at the Astronomical Observatory in Białków in August 2022. Routine measurements of both radio solar indexes will begin shortly thereafter.

3 Short description of the monitoring station at Białków Observatory

The *proof-of-concept* monitoring station is intended at the Astronomical Observatory of the University of Wroclaw in Białków, about 60 km from Wrocław, in a radio-quiet region. Mean spectral powers of electromagnetic background and relative coverage by interferences are equal to $P = -84.82$ dBm and 24.94 % in 0–1 GHz band, $P = -106$ dBm and 2.03 % in 1–2 GHz band, and $P = -103.6$ dBm and 1.6 % in 2–3 GHz band, respectively (Błaszkiewicz et al., 2021).

The 6-m dish of the radio telescope will be moved by an alt-azimuthal drive fitted for observations of the Sun and astrophysical targets and an universal 1–3 GHz front-end receiver (Fig. 1). Just after the front-end receiver a stabilised noise/load calibration unit (so called noise diode) will be coupled via 20 dB electronic coupler. The signal amplified with low-noise LNA can be splitted into three channels, but only two channels, both fitted with 100 MHz wide filters centered on 1 GHz and 2.8 GHz will be applied during standard monitoring of the F10.7 and F30 indexes. The third channel can be used, if necessary, with a filter of any width. Signals collected strictly simultaneously in both channels will be digitised and the spectra will

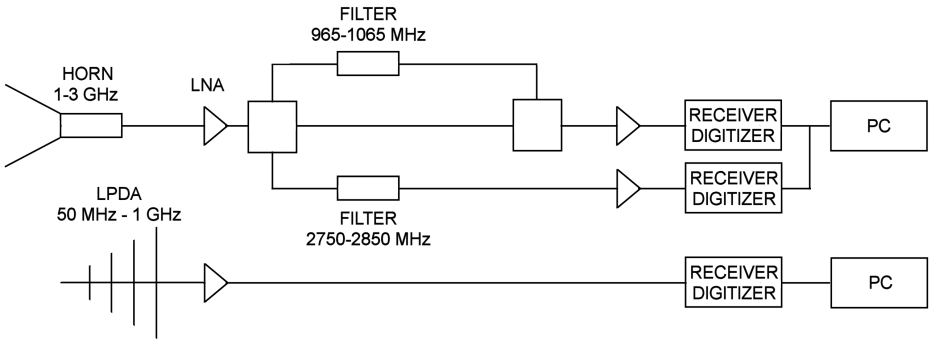

Fig. 1: Diagram of the radio telescope applied in the *ROSIE* programme.

be calculated using 24-bit end-receivers. The end-receiver will provide simultaneous measurements in 600 sub-channels of 100-MHz-wide frequency-bands (digitizer sampling rate: 2 gigasamples/sec). The data will be calibrated absolutely using the noise/load calibration unit and the astrophysical reference sources. Collected data will be shipped outside the Observatory using 200 Mbps upload and download link. Two receivers will be controlled by dedicated computer. Electronic devices of the radio telescope, data processing and data storage systems will be located in a dedicated, air-conditioned container installed close to the radio telescope.

The third, independent receiving system, dedicated mostly for educational purposes, will be mounted to the side of the dish (piggy-back drive). The system will collect data in the 50 MHz-1 GHz band, using a LDAP antenna, a LNA amplifier, and a digital receiver/digitizer identical as the digitizers applied in the monitoring system. The collected data will be presented in real-time in the Astronomical Education Centre hosted in a closest vicinity of the Observatory in Białków.

The sole obstacle limiting available length of a period of the daily observations with the monitoring system constitute trees surrounding the Observatory, which can limit the length of the daily observations to about 13 hours per day in summer and nearly 5 hours per day in winter.

All data will be collected and processed semi-automatically, with an assumed minimized participation of the University's staff in the routine daily operations, with remote initialization/supervision of the observations. The special measures will be taken to ensure long-term accuracy and stability of data calibration and data homogeneity.

In a case of regular measurements of the F10.7 cm and F30 cm solar indexes (fluxes) the time resolution will be 0.001 sec (1000 measurements per second and per channel), while in case of relevant radio spectra a very moderate one-second time resolution will be applied. Thus, an expected data flux will be equal to about 13 kB/s or 350 MB/d (assuming 4 B per single data). The relevant data will be transferred to the local coordination center and to the ESA servers in nearly real-time (limited by Internet only), where they will be processed "in-flight", stored, and presented/disseminated. Two kinds of the end-products: solar indexes in 2800 MHz and/or 1000 MHz wave-bands and radio-spectra of the selected events will be presented and available as convenient downloadable data-files and as real-time incremental plots on the dedicated WWW-page. Some methods/algorithms of a fully automatic or supervised data selection (e.g. automatic detection of the radio bursts) can be applied to mitigate archived data volume to a reasonable value. The same algorithms will trigger automatic radio burst's alerts.

Even a single observing station, namely proof-of-concept station installed in Białków will provide fully valuable measurements of the F10.7 and F30 solar indexes, having a great scientific and forecasting potential, applicable in the solar physics, space weather and geophysics. The procedures and processing methods developed during the proposed project can be applied in construction of a fully-featured monitoring network, having observing stations installed on various longitudes around the Earth's globe, selected to ensure uninterrupted and redundant observations of the Sun around the clock.

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