Prospects for Ground-Based Solar Radio Astronomy in Russia

V. M. Bogod

Special Astrophysical Observatory of the Russian Academy of Sciences,
vbog_spb@mail.ru

Abstract. The activity of the Sun –our nearest star is a natural laboratory for studying the manifestations of cosmic plasma using both ground-based observatories and instruments on spacecraft. At the same time, ground-based observations are significantly supplemented by information outside the absorption spectrum of the Earth's atmosphere EUV, X-ray and cosmic rays. The solar radio emission available to ground-based observations covers the multi-octave wavelength range from sub millimeters to the long-wave meter range. Small optical and radio telescopes are used to study the powerful activity of the Sun, while the study of faint and fine-structured formations requires the use of large radio telescopes. The efficiency of using various methods on small ground-based instruments is increasing to-day due to the growing relevance of studies of solar-terrestrial connections for forecasting space weather (SW), the state of which is caused by solar activity (SA). However, actual problems of the nature of solar radiation, which includes both weak structures (halo type), short pulse structures (jet type), and the nature of preflare plasma, requires the use of instruments with a large effective area, a wide multi-octave view with a high time and frequency resolution. The article gives a brief overview of topical problems in the study of the solar atmosphere and current trends in the use of the large radio telescope RATAN-600.

Keywords: Sun: radio radiation; techniques: radar astronomy
DOI:10.26119/978-5-6045062-0-2_2020_399

Instrumentation for Ground-Based Observations of Solar Activity

Currently in our country there are several observation places for solar activity study (radio telescopes, radiometers, spectrographs, etc.). The instruments at these stations are not unified, and require a rather deep modernization of both technical and methodological nature. The following organizations and tools can be distinguished.

Complexes of small telescopes:

- GAS GAO RAS — A set of telescopes at the Kislovodsk Mountain Station, providing synoptic measurements of the level of solar activity at different heights of the solar atmosphere.
- IZMIRAN — Radiometer at fixed frequencies (169, 204 and 3000 MHz), spectrograph (25–270 MHz).
- CRAO RAS — Radio telescopes RT-22, RT-3, RT-2 and RT-M, as well as measurements of magnetic fields of sunspots.
- UAFO RAS - Radio telescopes RT-2, RT-8 (600, 750 and 1000 MHz).

Large radio telescopes:

- SAO RAS — RATAN-600 radio telescope, operating in a wide wavelength range for forecasting solar flares and early forecasting of the appearance of active regions.
- ISTP SB RAS — Radioheliograph (5700 MHz), spectropolarimeters in the range of 4–8 GHz and 2–24 GHz.
- BSA (FIAN) (111 MHz for corona scintillation). To register coronal mass ejections (CME).

Two major instruments stand out from this list. The first large instrument RATAN-600 (range 1-30 GHz) is located in the SAO at st. Zelenchukskaya and has parameters that allow it to be used for detailed physical studies of solar plasma. The second major instrument, the SSRT (SRG) (3-24 GHz band) is currently undergoing modernization. It is planned to expand the dimensions, the range of overlapping frequencies on it, and it will be made in the form of small-sized radio telescopes arrays, creating a cross-shaped aperture of the radio interferometer. Its parameters have not yet been determined.

Finally, the third large instrument BSA (FIAN) (111 MHz band) is designed to track the movements of CME against the background of scintillations of galactic radio sources.

In the world, for comparison, the following instruments with high spatial resolution should be noted with an indication of their pros and cons:

- ALMA (submm range, spectrum, sensitivity), 1–2 arcsec (1.3mm). For tasks on the Sun, no more than 3% of the time is allocated, which limits them.
- E-OVSA (range 1–18 GHz, 3–53 arcsec). Has a small field of view.
- EVLA, (1–50 GHz band) (has high parameters, but there is a time limit of 1-3 days a year for solar study).

– LOFAR (Europe) (10–240 MHz band, solar time study limited).
– MUSER (CHINA), (meter, decimeter and centimeter ranges) does not work yet due to calibration problems.
– NRH Nancay (France) (150–430 MHz) angular resolution from $50''$ to $150''$, (for VHF bursts and Noise storms).

Thus, while unique tools are available, in general they are designed for objects other than E-OVSA, NRH and MUSER.

Below we will dwell on the transformations that are being carried out at the RATAN-600 radio telescope to adapt it to the actual problems of solar physics and highlight those of its parameters that can give priorities for a number of problems.

The methods of radio astronomy on large instruments make it possible to measure the main parameters of plasma: temperature, density, magnetic field, polarization, propagation and movement of plasma. Meanwhile, the high brightness temperature of the Sun worsens the parameters of the receiving equipment and makes it difficult to register fine and weak details. And to achieve high brightness temperature sensitivity, large receiving areas of radio telescopes are needed. Radio heliographs do not solve this problem, since in the pursuit of high spatial resolution interferometers increase their size, as a result, the brightness temperature sensitivity deteriorates squared. Meanwhile, the need for instruments with a solid surface continues to be both for registering weak background objects and for calibrating interferometers.

For the practical implementation of such observations in the radio range, high characteristics of the instrument are required in many parameters: in spatial resolution and width of the field of view, in coordinate accuracy and tracking accuracy, frequency resolution and width of the frequency range coverage, in sensitivity in terms of radiation flux and dynamic range, in terms of polarization accuracy and for measurements for both temporal resolution and coverage, etc. However, today there are no instruments that have a complete set of such parameters.

Obtaining data on physical conditions for a number of radio sources in active regions (AR) requires observations with a high sensitivity to the radiation flux. At the same time, it is important to obtain simultaneous information about active structures of different spatial scales, for which reflex radio telescopes with continuous filling of the UV plane of spatial frequencies are most effectively used. This circumstance severely limits the number of instruments capable of conducting such research. For example, the 100m radio telescope in Bonn was used in the early years to map the Sun at 8mm, but is now practically not used for solar study. The large radio telescope VLA and its new version JVLA are used for solar study once or twice a year for 3–4 days, which sharply limits its effectiveness due to the random coincidence of the observation time and the required type of AR. At the same time, a certain D-configuration of antennas is required to select wide structures, which is often difficult. An indirect acknowledgement of our observational success is the publication of American astronomers Wang et al. (2015). In this work, the authors simulate the spectral - polarization characteristics of AR radiation, trying, on the one hand, to demonstrate the capabilities of their modernized EOVSA instrument for measuring coronal magnetic fields, and, on the other hand, to explain some of the observed effects such as depression of radiation above the sunspot. As shown in Bogod (2011), to register such effects, increased surface brightness sensitivity is required, which is also related to the filling level of the UV plane. This fact, despite the high spatial resolution of EOVSA and taking into account the narrow field of view of this instrument, reduces the possibilities for measuring coronal magnetic fields.

Operating Receiving Complex RATAN-600

For complex observations of solar radio emission, the RATAN-600 radio telescope uses a broadband spectral complex that covers the frequency range from 3 GHz to 18 GHz with a frequency resolution of 100 MHz on 80 frequency channels with separate registration of the right and left polarization channels (Bogod 2011). The reflexivity of the instrument and the continuous filling of the UV-plane of spatial frequencies makes it possible to register the full flux of radio emission from the Sun in a wide frequency range and to study both large-scale spatial signals and extremely narrow radio sources with the dimensions equal to the dimensions of the horizontal diagram of the radio telescope. Work Storozhenko et al. (2020a) describes a new system for collecting multichannel data with a high readout rate of 10–50 μs.

Receiving Complex with Improved Parameters

Despite the presence in the world of new large instruments used for studies of radio emission from the Sun, the RATAN-600 radio telescope has a combination of a number of parameters that are difficult and sometimes impossible to obtain with other telescopes. Here, the presence of a large collecting area with the regularity of long-term observations, the coverage of a wide multi-octave frequency range with a high accuracy of polarization measurements, and the continuous filling of the UV plane of spatial frequencies are well combined.

There was a transition to new technological solutions for radiometric receiving. In March 2020, a new spectral complex was tested with continuous frequency coverage of the 1–3 GHz range with a frequency resolution $\frac{\Delta f}{f} = 10^{-3}$ and a time resolution of < 1 ms (Lebedev et al. 2020). At the same time, on the basis of the achieved parameters, an on-line industrial noise cleaning system is implemented.

Implementation of the Long-Term Tracking Regime

In 2020 the introduction into regular operation of the long-term support mode for 4–6 hours near local noon began (Storozhenko et al. 2020b). This mode uses the movement of the receiving mirror and the carriage along the arc rails at the selected positions of the main mirror of the Southern sector. To implement this mode, an automated control scheme was organized for the positioning subsystems of the carriage and the primary mirror-feed.

The Main Tasks for the Created Solar Complex RATAN-600

New technical capabilities, which are now underway, will expand the observation apparatus's both in terms of the slowly varying S-component in a wide multi-octave frequency range, and in terms of impulse and long-term changes in solar radio emission.

The following areas of research will be developed:

- *Active regions* (radio sources above and between spots, floccules, coronal holes, filaments, prominences, halo). AR magnetosphere and coronal magnetography, stereoscopic magnetography.
- *The nature of the solar atmosphere* (transition layer chromosphere-corona, transition layer from the S-component to the burst meter range, diagnostics of magnetic reconnections, heating of the corona, preflare heating in a wide altitude interval, the formation of sources of solar wind and noise storms).
- *The nature of fine microburst structures* based on multifrequency data (quasiperiodic pulsations, microbursts, zebra structures, jets, etc.).
- *Space weather forecast (SW)* (study of methods for forecasting solar activity).

The combination of new parameters of the receiving equipment and radio telescope modes leads to unique capabilities of the instrument for recording fast frequency and temporal changes of both strong (powerful bursts) objects and weak structures (microbursts) on the Sun and will open up new directions of research.

Acknowledgments. The work was performed within the SAO RAS state assignment in the part "Conducting Fundamental Science Research" and was supported in part by the Russian Foundation for Basic Research, projects no. 18-02-00045 and 18-52-34004.

Bibliography

Bogod, V. M. 2011, Astrophysical Bulletin, 66, 190

Lebedev, M., Ripak, A., & Bogod, V., 2020, in Proceedings of the All-Russian Conference "Ground-Based Astronomy in Russia. XXI century", ed. I. Romanyuk, I. Yakunin, A. Valeev, & D. Kudryavtsev, this issue

Storozhenko, A. A., Bogod, V. M., Shlenzin, S. V., et al. 2020, in Proceedings of the All-Russian Conference "Ground-Based Astronomy in Russia. XXI century", ed. I. Romanyuk, I. Yakunin, A. Valeev, & D. Kudryavtsev, this issue

Storozhenko, A. A., Lebedev, M. K., Ovchinnikova, N. E., et al. 2020, in Proceedings of the All-Russian Conference "Ground-Based Astronomy in Russia. XXI century", ed. I. Romanyuk, I. Yakunin, A. Valeev, & D. Kudryavtsev, this issue

Wang, Z., Gary, D. E., Fleishman, G. D., et al. 2015, ApJ, 805, 93