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Prospects for observing the near-limb zone of the Sun using the radio telescopes RT-32 IAA RAS

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Abstract. The report presents the first results of test observations conducted since April 2024 on the RT-32 radio telescope of the “Svetloe” observatory at a wavelength of 3.5 cm. The observations were carried out in the quasi—circular scanning mode, a variant of scanning when the telescope sequentially tracks a number of points located on a circle.
With the beam width of this instrument being 4 arcminutes, active regions and their sunspot components are easily identified in the entire limb zone, which is problematic, for example, for the RATAN-600 radio telescope. While not having high resolution, RT-32 successfully detects faint sources above the solar limb, which are poorly visible on the SRH radioheliograph. And the joint use of all three RT-32 radio telescopes makes it possible to monitor solar activity in the summer practically throughout the entire day.

Keywords: methods: observational; Sun: coronal mass ejections (CMEs), prominences

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1 Introduction

Observations carried out in the microwave range have shown that the chromosphere, transition region and lower corona contain a large number of non-stationary three-dimensional structures of various types and sizes. The brightness, size and relative position of individual structures are determined quite well by mapping the solar disk using modern radioheliographs (SRH, Nobeyama), interferometers (ALMA) and large variable-profile antennas (RATAN-600). But the study of the altitude structure of sources, necessary for their adequate modeling based on observations of the central regions of the solar disk, turns out to be difficult and very ambiguous. A natural solution here is to observe sources in the near-limb zone, especially in its behind-the-limb part, when the altitude structure of the source is displayed directly in the picture plane. However, observations in this region present significant difficulties due to the strong altitudinal brightness gradient of the solar atmosphere. At the same time, the raster mapping method usually employed in radio observations leads to large errors when identifying sources on the solar limb.

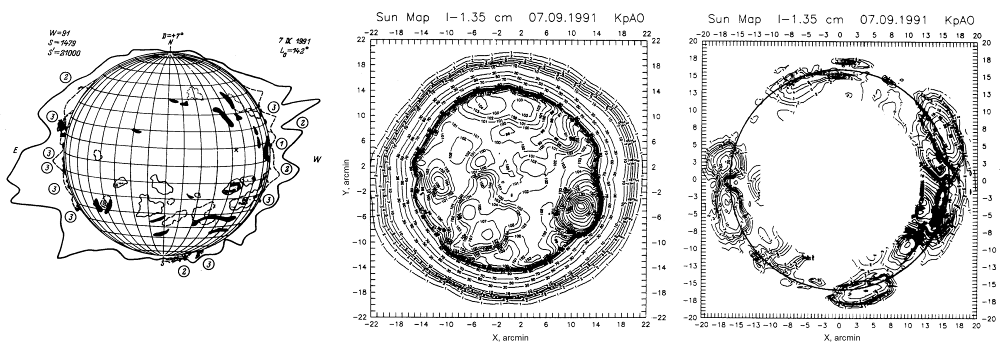

Fig. 1. An example of mapping the entire Sun at a wavelength of 1.35 cm in intensity (map in the center) and the results of identifying sources in the limb zone using circular scanning (right map). Isophotes are given as a percentage to the level of the quiet Sun. On the left are the sources visible in optics on the day of observation, according to the "Solar Data" Bulletin.

In the 80s, to improve the accuracy of near-limb observations on large full-circle antennas, a different method was proposed – circular scanning, when the telescope moves in a circle relative to the center of the solar disk. This and other developed methods were implemented on the RT-22 radio telescopes of the Lebedev Physical Institute and RT-22 of the CrAO. With their help, in the 80s–90s, observations of solar prominences behind the solar limb and filaments on the disk in the near-limb regions were carried out at waves of 8 mm and 1.35 cm. Accuracy estimates of intensity measurements were $\sim$1% of the level of the quiet Sun and 0.01% in circular polarization. Their position, dimensions along the limb and height were determined, and the magnetic field was measured. Cases of observations of the rise and decay of prominences, as well as coronal mass ejections (CMEs), have been noted. The radio radius of the Sun has been measured. Similar methods have also been used for many years to map the Sun on the RT-7.5 radio telescopes of Bauman MSTU on waves 3.4 and 2.5 mm (Topchilo et al. 2023).

A typical example of solar observations made at that time is shown in Fig. 1 in the form of a complete map of the Sun obtained using raster scanning, and a map of the near-limb zone of the Sun obtained using circular scanning with the background component removed.

Based on previous results, it was proposed to implement these methods on the RT-32 radio telescopes, which are part of the Quasar-KVO complex of the IAA RAS. Technically, they are similar to previous observations, but in a longer wavelength range (3.5–12 cm).

2 Methodology and examples of limb observations of the Sun on RT-32

Initially, the Quasar-KVO radio astronomy VLBI complex of the IAA RAS was intended to solve navigation problems. However, its technical characteristics turned out to be very suitable for conducting studies of microwave radiation from the Sun. Using these radio telescopes, we carried out episodic observations of solar eclipses during two 11–year cycles of solar activity (on average every 2 years during the period 1999–2022), and in two or three observatories simultaneously (Ivanov et al. 2023). The observation technique consisted of tracking selected objects on the solar disk during the period of their coverage/opening by the lunar disk, including the places of I and IV contacts. More complex observation modes mainly associated with scanning an object, were not used yet, since they were not implemented in the version of the Mark IV “Field System” software used on the telescopes.

In this situation, to implement the circular scanning required for full-scale solar observations of the near-limb zone, it was proposed to use its discrete version – the quasi-circular scanning – a variant of scanning when the telescope sequentially tracks a number of points located on a circle. Mathematically, this corresponds to replacing a continuous function with a small set of points. For a solar radius of $\sim\ 16'$ and a half power beam width (HPBW) of $\approx\ 4'$, the minimum number of tracking points is $\sim$50.

Figure 2 shows two examples of quasi-circular scanning. On the left is a variant with a large step following the angle along the limb and with long tracking of points. Large signal spikes are a consequence of the antenna quickly moving from the current point to the next point. The magnitude of signal fluctuations in the tracking areas is determined by the accuracy of the telescope tracking the Sun. The signal averaged over the tracking areas (red curve) shows good tracking accuracy (the red curve is smooth, without breaks). The figure on the right shows a working version of scan records for different scanning radii. The pitch of the dots along the angle approximately corresponds to half of HPBW; along the radius, it is 1/4. The recordings clearly show the presence of radiation sources associated with solar active regions.

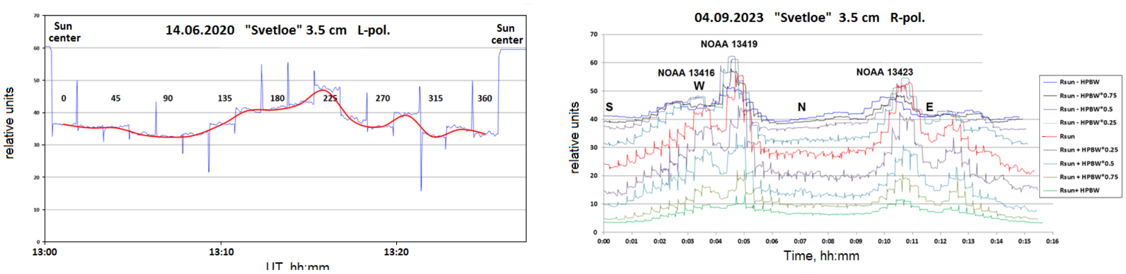

Fig. 2. Two examples of quasi-circular scanning on the RT-32 telescope of the IAA RAS at a wavelength of 3.5 cm with a step of 22.5° (left) and 7° (right). On the right, the AR numbers visible on quasi-circular scans are marked (scan radii are Rsun ± (0(red curve), 0.25, 0.5, 0.75, 1) × HPBW).

Figure 3 shows examples of quasi-circular scans obtained in March – May 2024 at the observatory "Svetloe" at a wavelength of 3.5 cm (right polarization). The scans are normalized to the level of the quiet Sun. From the above examples it is clear that noticeable activity is observed not only on the disk, but also far beyond the limb. Based on observations from April 5, 2024, a map of the Sun was constructed, similar to the central map from Fig. 1. But there the map was built using raster scans, and here, using an incomplete set of quasi-circular scans (hence the empty space in the center of the solar disk). In general, both maps are similar. Comparison with the SRH radioheliograph data (at 6 GHz) showed their agreement when corrected for different angular resolutions.

The last Fig. 4 shows maps of the near-limb zone of the Sun for May 3 and 6, 2024, obtained from a set of quasi-circular scans by subtracting the large-scale background component. The maps obtained on RT-32 at 3.5 cm are similar in nature to the map obtained on RT-22 at 1.35 cm, shown in Fig. 1 on the right, but the level

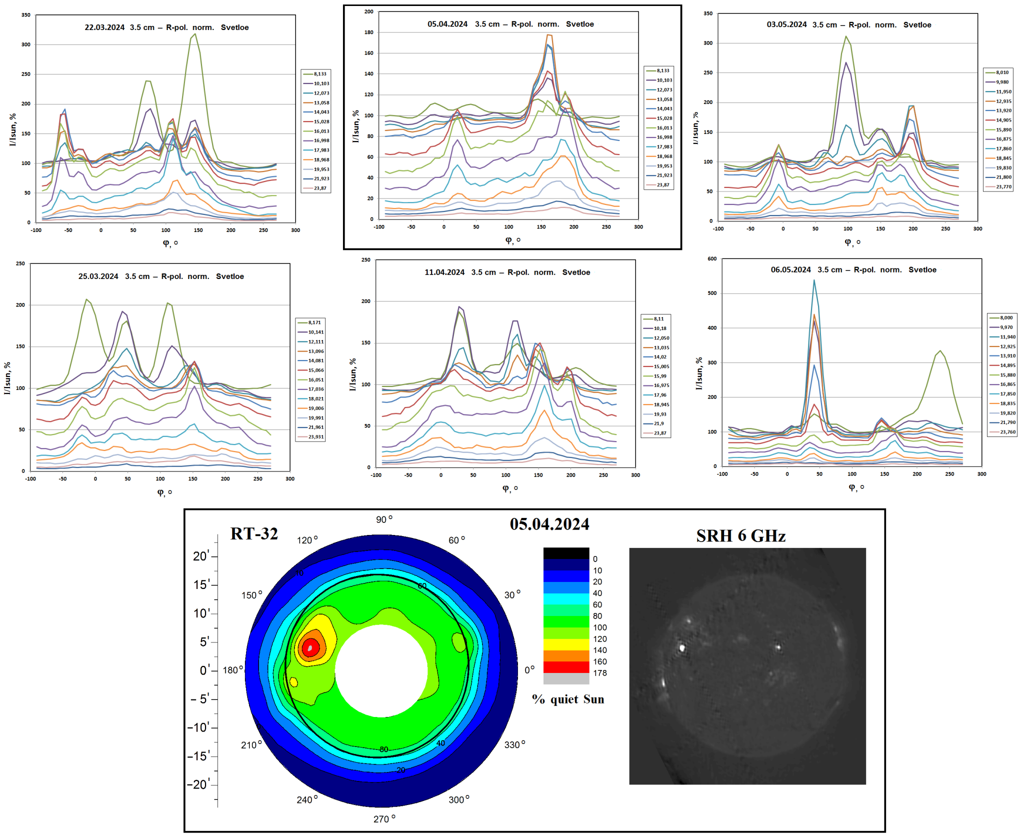

Fig. 3. Examples of circular scans in the range of radii 8–23 arcmin, obtained in April–May on RT-32 at the observatory "Svetloe", and a map for 04/05/2024 on RT-32 and the SRH radioheliograph at 6 GHz.

of solar activity on them is naturally much higher. Comparison with simultaneous observations in other frequency ranges showed the coincidence of individual structural details.

3 Summary

Observations using large single antennas such as RT-32 are certainly inferior in angular resolution to interferometric observations, but they also have their advantages, allowing:

1. direct measurement of the heights/dimensions of stationary coronal objects from observations of their position on the solar limb;

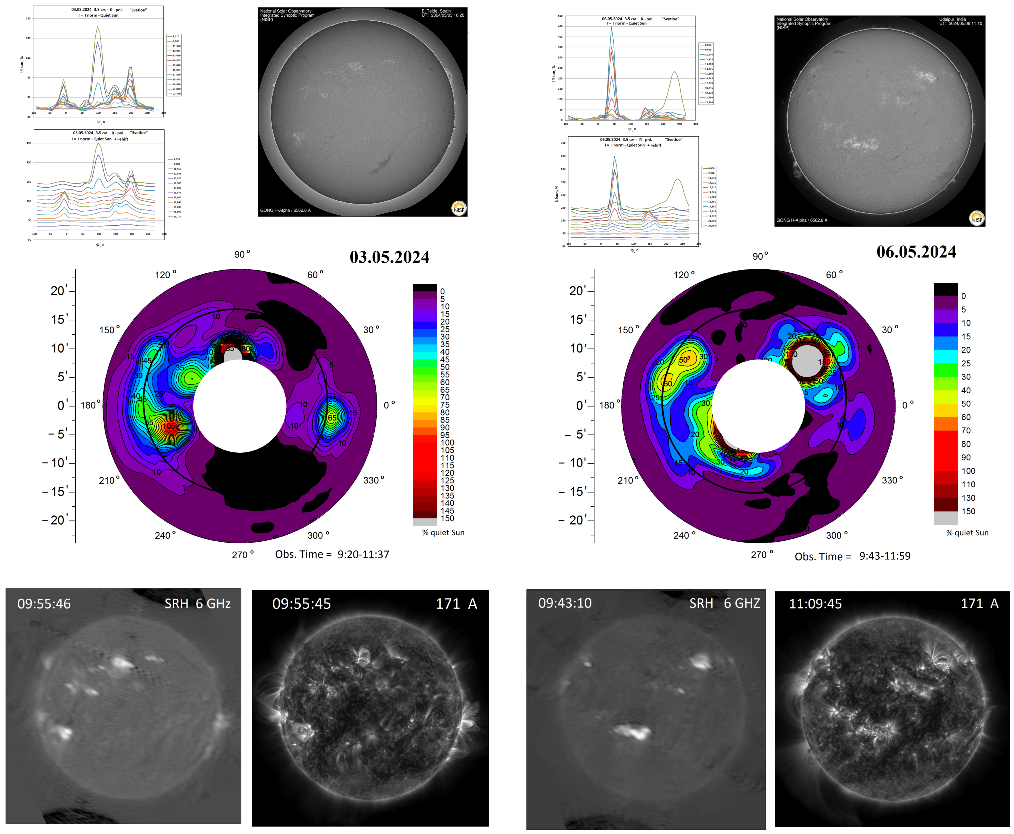

Fig. 4. Scans and maps of the near-limb zone with a removed background for 05/03/2024 and 05/06/2024 on RT-32 and comparison with observations in other wavelength ranges: on the SRH radioheliograph at 6 GHz, the space observatory SDO at 171 Å and H-alpha from NISP. The moments of observations at UT are marked in the corresponding pictures.

2. observation of prominences and measurement of their magnetic field (under development);
3. observations of the dynamics of the post-flare state of the region of the marginal or near-limb flare;
4. observation of CMEs in the lower corona, inaccessible to observations on LASCO;
5. regular measurements of the radio radius of the Sun.

References

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Topchilo N.A., Nagnibeda V.G., Peterova N.G., 2023, Transactions of IAA RAS, 65, p. 42