Instruments, techniques and some results of solar observations at the BMSTU Radio telescope at short millimeter waves

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In 80s, the program of observations and development the BMSTU Radio telescope included the study of interstellar matter and the Sun at short millimeter waves. A receiver for spectral observations at 3.4 mm was built and was used for mapping the HCN line emission of the Orion dark nebula. Later the receiver was cooled down to 15 K by closed-cycle refrigerator and 1024-channel acoustic-optical spectrometer were designed and constructed. Well-known financial problems of the Russia in early 90s resulted the break of the activity in spectral projects at the Radio telescope. But the plan of solar investigations was not reduced. On the contrary these researches were developed noticeably. These are presented here.

The main instruments now for observations are stationary radio telescope RT-7.5 and small movable radio telescope RT-0.6 for expeditionary observations of solar eclipses at wavelength of 3.4 mm. Both radio telescopes are equipped with heterodyne radiometers of 3-mm range having 0.1 K sensitivity at signal integration time of 1 s. The RT-7.5 antenna is irradiated from its primary focus. A flat mirror is used as the counter reflector in the RT-0.6 antenna. Rotation of the counter reflector results in conical scanning of the antenna beam.

At present the RT-7.5 dish of diameter about 8 m is the largest ratable antenna in the Russia which can be operated effectively at wavelengths down to 1 mm. It was used for regular mapping of the Sun at 3.4 mm wavelength with angular resolution of $2.5'$ since 1987. More than 2000 solar maps were obtained for today using various observation techniques. The main database contains maps drawn through rectilinear scanning. Radial scanning along various diameters was widely used as well. Minimum time for the mapping is of 40 – 45 minutes, so it is impossible to watch dynamics of many events at the Sun. Additionally stable meteorological conditions are required during observations. So circular scanning at fixed solar radius (usually of $16'$ – $18'$ from the Sun center) was used for observations of variability of solar limb emission. Period of the scanning the limb ring is about 6 minutes. A sequence of the ring scans reveals fast large-scale changes in brightness of the solar limb radio emission (Rozanov et al., 1994). A modification of the technique is circular scanning of the entire solar disk at equally distant circles of various radii. Rational arrangement of the scanning trajectories at the disk diminishes time per map down to 20 minutes. Typically all scanning modes are accompanied with calibrations. It allows to eliminate effects of atmospheric absorption variability in the course of registration. The most of solar maps obtained at the RT-7.5 was presented in highly convenient format fitting well to one used in the Metsähovi. A color presentation of brightness temperature levels is used sometimes in addition to maps of isothermal contours.

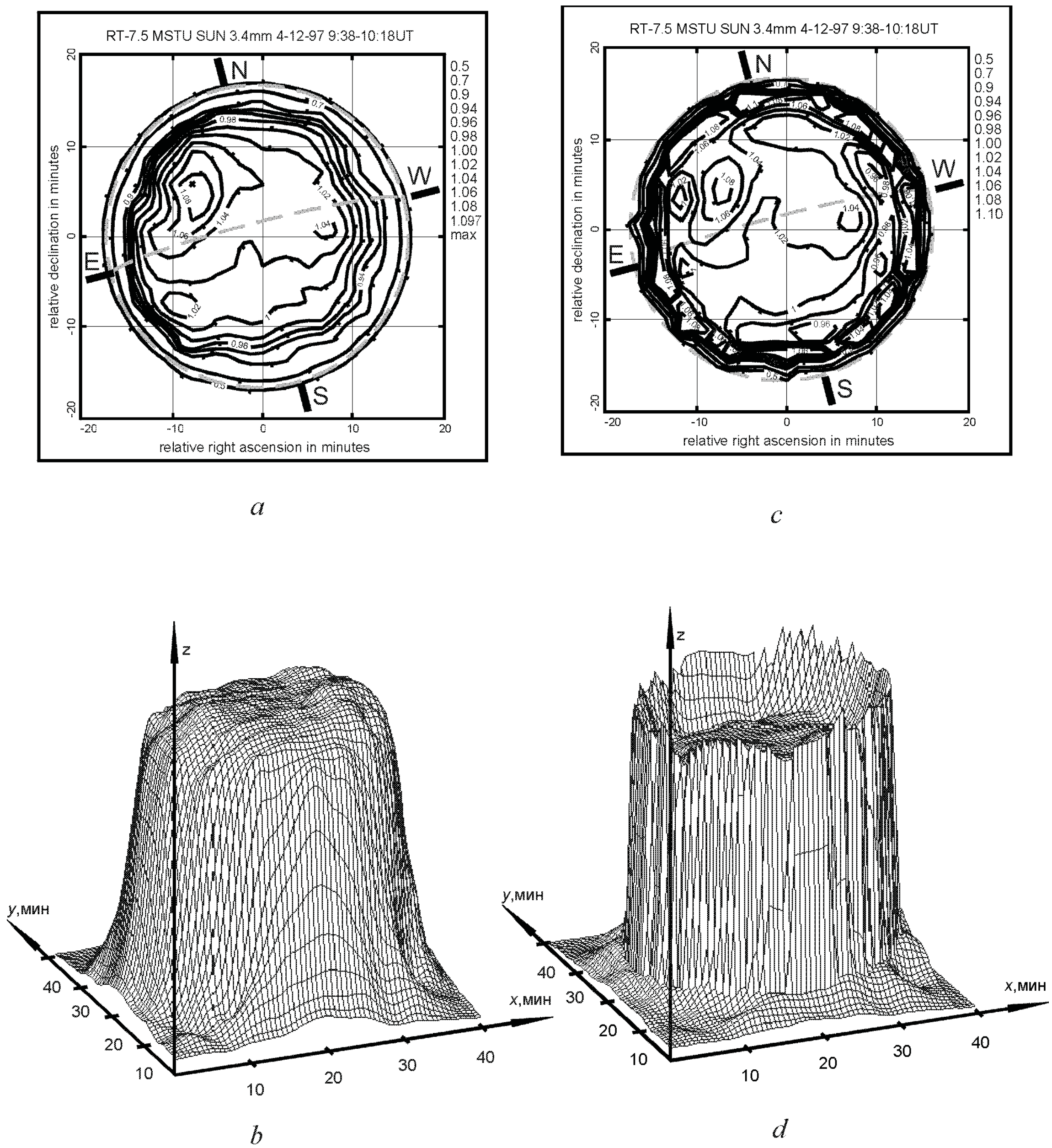
Equatorial mounting in design of the expeditionary radio telescope RT-0.6 simplified the device and provided 20-kg weight of the system. Since 1987 seven solar eclipses were observed in various points at the Earth, five of them being observed in centers of the eclipse zones. Three eclipses of five ones were occurred at favorable meteorological conditions so the transient brightness curves were measured. Fast (40 Hz) conical scanning of the antenna beam at radius of about $7'$ around the Sun center (the antenna pattern width was about $20'$) was used to eliminate strong influence of the atmospheric transparence variations on the eclipse curves and to increase contrast of the measurements. It is essential that the entire solar disk can be observed practically simultaneously at the scanning mode. From data processing the total solar flux vs. time was obtained. Additionally, synchronous detection of the signal at different phases of reference voltage generated synchronously to the beam scanning allowed obtain signals corresponding to differential fluxes from the opposite hemispheres of the Sun. The differential signals are not sensitive to large-scale atmospheric absorption fluctuations. Coordinates of sources observed could be estimated simultaneously. Comparison of antenna temperature values when pointing to the Sun, to sky at elevation of the Sun, and to a blackbody load at ambient temperature was used to obtain out of atmosphere absolute calibration of the RT-0.6 radio telescope antenna temperature. Mapping of the Sun by stationary radio telescope RT-7.5 with high spatial resolution was done for all the eclipses at the same time when observations by RT-0.6 telescope were carried out. So general picture of activity in different regions of the Sun was obtained for the eclipses (Rozanov et al., 1998).

The set of observational data acquired to the moment covers the 11-year cycle of solar activity and forms long and sufficiently homogenous series which may be extracted easily from the database. Only small part of the information was used up to now. Some effects observed are difficult for interpretation and comparison with data from other instruments. Recently the problem was simplified due to availability of UV and X-ray photographs of the Sun from space observatories SOHO and YOHKOH.

The most easily observed solar event is large-scale structure which is characterized by the ratio of radio emission radius to optical one and existence of latitude belts of activity (Nagnibeda et al., 1995). Data on profile of radio brightness of the solar disk edge are more contradictory. Spatial-temporal variations of the limb brightness with typical scales of 103 s and 106 km observed with circular scanning are under discussion.

Burst activity of the Sun was not a subject of special investigations but the bursts detected when mapping are well correlated to ones observed in UV range. Microflare activity of the Sun was surprisingly high. When solar eclipses were observed with the RT-0.6 radio telescope the microflare component formed main part of noise background which was the obstacle for recording of solar local sources cross sections by the Moon edge. Total intensity of the flare component during an eclipse was proportional to uncovered square of the solar disk (Rozanov et al., 1994). Spatial-temporal structure of the flare could be observed by watching godograph of the vector consisting of two differential signal components with orthogonal phases.

Situation with study of the emission of the internal corona at short millimeter wavelengths is unsatisfactory now. It was indicated due to the following (1) pulses of radiation at central phase of the total solar eclipses observed for all three cases of successful recording the eclipse curves and (2) reliable registration as sources of decreased of increased brightness of the most part of coronal holes observed in UV photographs.



Examples of 2D and 3D solar maps: before (*a,b*) and after (*c,d*) deconvolution

Further development of the solar observation program at the BMSTU Radio telescope depends considerably on improvements in instruments, techniques of observations and data proceeding. Upgrading of control system of the RT-7.5 radio telescope including replacement of control computer SM-4 to local network of IBM PCs was performed in 1998. Software is operated now under Windows 95/Windows NT. Dialogical interface, graphical displaying of the antenna beam relative to an object, and new possibilities for proceeding and presentation of data indicate essential broadened potentialities of the telescope.

At present software for deconvolution of the solar maps providing spatial superresolution of 1.5-2 times is being installed. Superresolution methods is limited however by inaccuracy of a priori knowledge of the radio telescope antenna pattern. So the first stage of the deconvolution is determination of the antenna pattern from observations of an object with sharp boundaries, and the Sun is used as the object. Accuracy of the measurements is estimated to be of 3 – 4 % (Pavlov, 1998). The next stage is elimination of smoothing by the antenna pattern from the solar map. The retrieval is done by method of maximum entropy using the antenna pattern determined at the previous stage. Figure illustrates efficiency of the method: after the retrieval an one-component source at the initial map became two-component one, area of the solar disk suitable for further analysis increased approximately twice, and effect of the limb brightening appeared sharply. A special test has shown that the brightening was not the artifact resulting from calculations.

Upgrading of the instruments is directed to building a dual-band receiver for measurments of the solar emission at wavelengths of 3.2 and 2.2 mm simultaneously. Receivers for both channels are performed already, they will be mounted at the secondary focus of the RT-7.5 dish and will be coupled to the antenna beam using a quasi-optical device based on frequency-selective surfaces. In prospect it is planned to add the dual-band receiver with the third channel of 1.4-mm wavelength and with polarizing beam-splitters for all channels.

References

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