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Quasi-tracking solar active regimes with radio telescope RATAN-600 and the construction of two-dimensional radio maps of the Sun(*)

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Summary. — We discuss the results of the radio telescope RATAN-600 by "zoned relay" using the conical secondary reflector. Such observations permit the evolution of the radio emission of local solar sources to be studied as well as the construction of the two-dimensional images of the Sun.

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1. – Introduction

The radio telescope RATAN-600 was designed as a transit telescope. This configuration [1] remains its principal mode of operation. The "relay" and "zoned relay" methods of observation, developed by Golubchina [2,3], allow long-period tracking of cosmic radio emission sources, *e.g.*, up to 15 hours of operation. In this paper we discuss the results of the first RATAN-600 observations of solar radio emission at wavelength $\lambda = 8.01$ cm solar radio emission with by "zoned relay" using a conical secondary reflector (Type-6) (fig. 1). This work was carried out using the following modifications: a new automatic control system, a modern narrow bandwidth 32-channel radiometer ($\Delta f = 1$ MHz), modern data acquisition and data processing systems, and a new antenna-setting calculation program.

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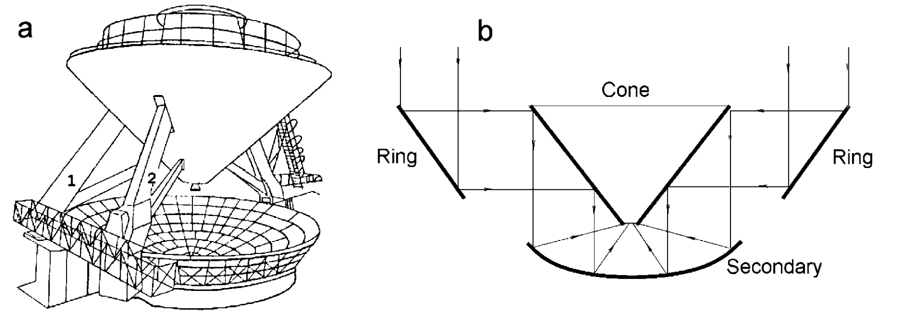

Fig. 1. – a) The Type-6 conical secondary reflector (1,2—the pilons of construction). b) Ray-tracing in system of three mirrors with conic and parabolic mirrors.

2. – Short description of method, facilities and data processing

The main antenna mirror of the radio telescope RATAN-600 consists of 895 separate reflecting elements (2.2 m × 7 m) that make up the ring, 600 m across. These panels have three degrees of freedom: 1 m radially, 0–6 degrees in azimuth, 0–53 degrees in elevation. These permit the reflecting surface of the main mirror to be brought into focus with respect to the coordinates of the observed cosmic radio emission source. The secondary mirror is situated in/or near the primary mirror focus. Coordinates of the reflecting elements of the primary mirror are calculated with respect to the fixed position of the secondary mirror in conjunction with the coordinates of the observed source. The position of the secondary one is a function of three principal parameters: the geometric area of the antenna, the horizontal angular resolution, and the radiometer bandwidth. Tracking of the radio source by the "relay with zoning" method is realized by the utilization of successive sectors of reflecting elements of the primary mirror as transitory active elements.

The observations of the solar radio emission on 20 October, 1999 employing the RATAN-600 at wavelength $\lambda = 8.01$ cm ($f = 3741$ MHz) were carried out by means of the "zoned relay" method. The surfaces of the active elements were zoned in order to enhance the effective area and thus to increase the antenna's horizontal angular resolution. For this purpose the radial coordinates of the active main mirror reflecting elements were adjusted by values proportional to a whole number (K) of the observation wavelength. The maximal whole number (K) is equivalent to $K_{\max} = 52$ for our observations. The central radiometer frequency is $f = 3741$ MHz. In this case, for the conservation of the space-time coherence, the maximal bandwidth of the radiometer must not exceed 9 MHz in accordance with the formula $\Delta f_{\max} = f/8 \times K_{\max}$. The bandwidth of each of the 32 radiometer channels used in these observations is 1 MHz, easily satisfying the requirement for space-time coherence conservation. The noise temperature of radiometer was equal to 80 K. Observations of the Sun were made initially with the secondary reflector in the special configuration shown in fig. 1 in which it was positioned at the center of the turntable or near to it.

The observations on 20 October, 1999 were carried out every 9 min for 6.5 h (0528 to 1200 UT). The azimuth of the Sun varied by approximately 2–3 degrees every 9 minutes of time. The elevation of the Sun during 6.5 hours of observation varied from 8.7 degrees to 29.8 degrees. The horizontal angular resolution varied from 1.3 to 1.8 arc-minutes;

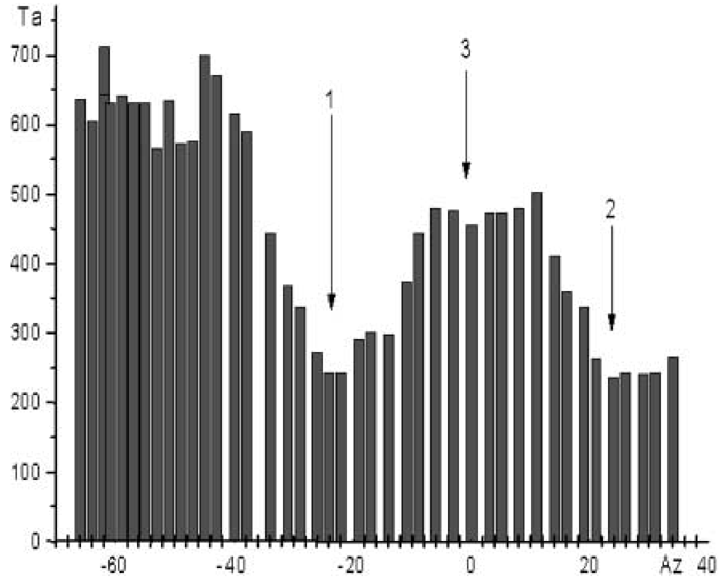

Fig. 2. – The distribution of the energy along the aperture of the antenna.

the vertical angular resolution was 19.7 arc-minutes, and the effective antenna geometric area was approximately (493–862) m^2. It was thus possible experimentally to produce a two-dimensional image of the Sun at 8.01 cm wavelength using an azimuth synthesis in the (u, v)-plane.

3. – Preliminary results from solar observations at $\lambda = 8.01$ cm on October 20, 1999

The local solar sources (LSs) in the record sources of the S-component solar radio emission were resolved by subtracting the conventional "quiet" Sun drawn through the regions free of local sources. The determination of the "quiet" Sun antenna temperatures and its variation with the azimuth (fig. 2) shows a complex energy distribution along the aperture obtained from observations employing the conical secondary mirror. The 1 and 2 minima were caused by a "shadow" cast by pylons 1, 2, the conical secondary reflector, as well as by "shadows" from the secondary reflectors (nos. 1, 2, 5) which were located in front of the conical secondary reflector during the observations.

The antenna temperature of the Sun decreased by 62–65% as a result of the 1,2 "shadow". The range 3 was caused by the "shadow" cast by the 1 reflector which was situated in front of the conical secondary reflector. The W-sector of the antenna surface was mostly unencumbered though it was partially shadowed by the reflectors 2,5, azimuth −60–66 degrees (see fig. 2). The cosmic radio source base references are usually required to distinguish the LSs solar radio fluxes derived from the observed LSs antenna temperatures. At present we have no such reference procedure in place, consequently, the total solar flux at $f = 3750$ MHz (NBYM) was used as a surrogate reference. This procedure allowed some preliminary quantitative estimations of physical parameters of the local solar sources to be made at $\lambda = 8.01$ cm for the 20 October, 1999 event. Scan numbers 1,44 for different parallactic angles are given on fig. 3 (see fig. 4).

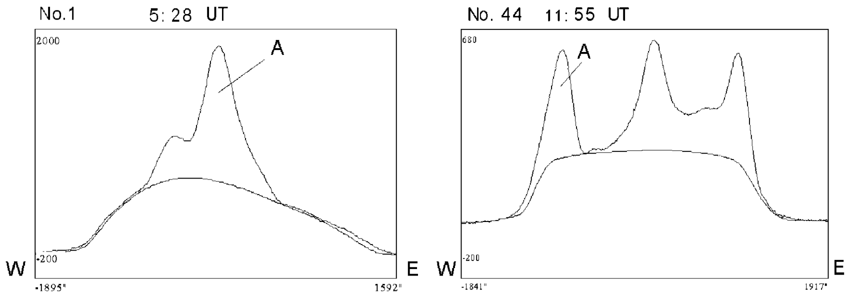

Fig. 3. – The scans of the solar radio emission at $\lambda = 8.01$ cm for the different parallactic angles on the moments: 5:28 and 11:55 UT.

The flux variation of the (A) local solar source (LSs) with respect to time is given on fig. 5. This variation with time may be attributed to the following:

1) "confusion" effect.

2) The absence of a common reference for the separate groups.

3) Ongoing activity of the LSs.

The "confusion" effect is caused by the simultaneous introduction of multiple LSs in the knife edge beam; however, this effect may be eliminated by the systematically changing antenna pattern resulting from the 24-hour cycle of the celestial sphere.

The (A) LSs flux reduction (see fig. 5) was caused mainly by the spatial resolution of the apparent LSs into three LSs (fig. 3). The elimination of the "confusion" effect is seen to be appreciable between the 19th and the 23th observations (fig. 5, 0810 to 0846 UT).

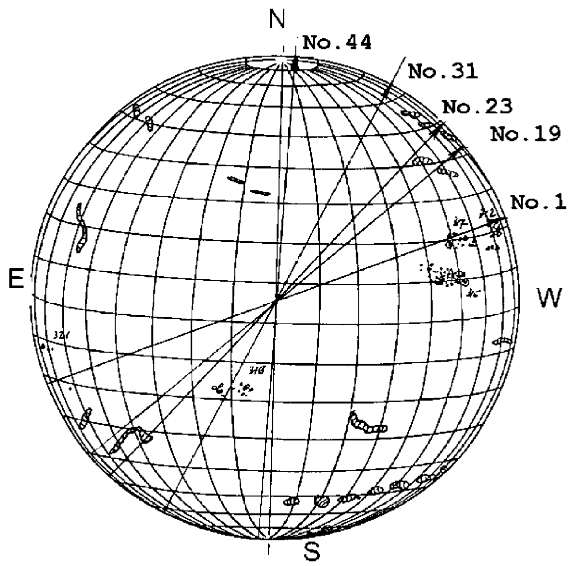

Fig. 4. – The heliographic schema of the Sun with the active regions, some axes and the positions of the antenna beam for nos. 1, 19, 23, 31, 44 observations.

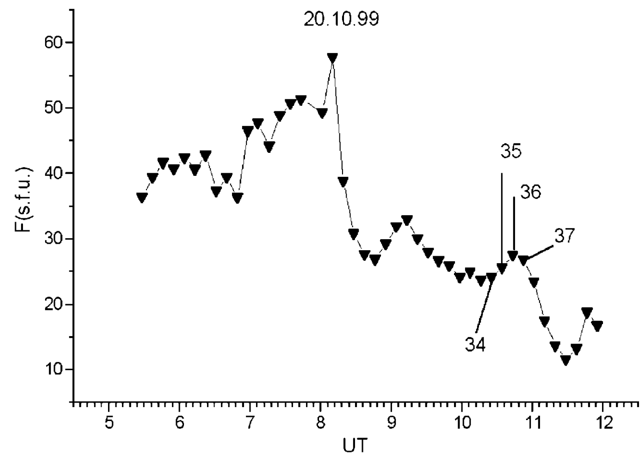

Fig. 5. – The change of (A) LSs flux with the time.

The parallactic angle for this time was decreased from $q_{19} = 22.4$ degrees to $q_{23} = 15.5$ degrees. The sum of the respective LSs fluxes results in a final reduction of the flux jump (fig. 6).

Using a common reference used for solar scans (34, 35, 36) involving different processed groups (fig. 6), resulted in the reduction of the flux jump of the (A) LSs (fig. 5). The elimination of the causes 1 and 2 permitted us to register the real flux change connected with the active solar processes. The following parameters of the LSs were observed: fluxes 2.5–55 s.f.u.; angular measure $\Omega = 3$–5.5 arc-minutes; and brightness temperature, $T_\mathrm{b} = 10^4$–10^6 K.

As noted we used the azimuthal synthesis to produce two-dimensional maps of the solar radio emission. The change in the Sun's azimuth for each 9 minute period was approximately 2–3 degrees. Therefore, the orientation of the main lobe of the knife-edge

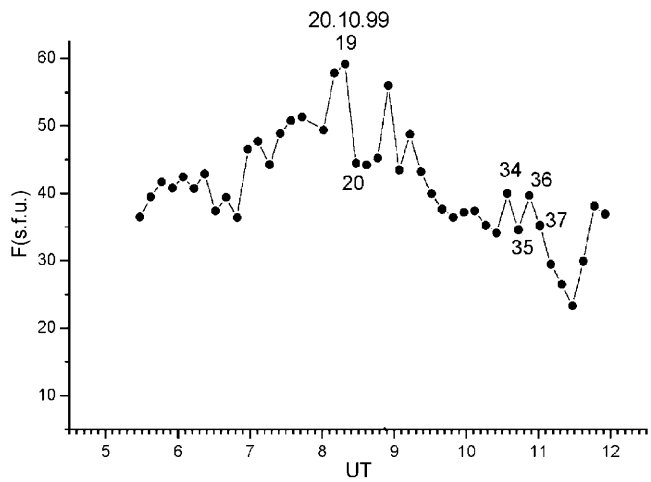

Fig. 6. – The change of the sum of three LSs flux with the time.

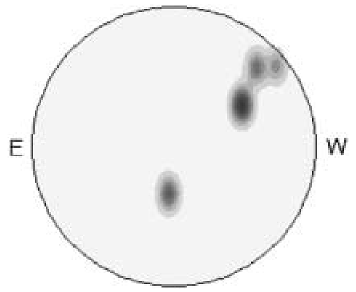

Fig. 7. – The experimental two-dimensional image of the Sun at the wavelength 8.01 cm.

antenna pattern (*i.e.* the position angle or parallactic angle q) relative to the declination circle, also changed. The sector of the position angles of these observations was equal to $2\Delta q = 2(q_{\text{no. }44} - q_{\text{no. }1}) = 135$ degrees (see fig. 4). This demonstrates a rather high filling of the angle sector Δq on the (U, V)-plane necessary for the construction of the two-dimensional maps of the Sun. Figure 7 contains an example of an experimental two-dimensional map of the Sun with the $47'' \times 168''$ space resolution so produced.

4. – Conclusions

1) The complex structure of the field distribution along the antenna aperture is revealed. A part of this structure is explained by the radio shadows cast by antenna pylons and by the secondary reflectors (nos. 1, 2, 5) which were located in front of the conical secondary reflector during the observations.

2) The sharp flux change with time (20 October, 1999) was caused by a combination of the "confusion" effect and the fact that no common reference was available for data processing the separate groups. Solar active processes may be investigated by this method in the case that these sources of interference are absent or can be eliminated.

3) The following physical parameters of the local solar sources were obtained at the radio emission wavelength $\lambda = 8.01$ cm: $F(\text{s.f.u.}) = 2.5$–55; $T_{\text{b}}(\text{K}) = 10^4$–$10^6$; $\Omega = 3$–5.5 (arc-minutes) are consistent with the generally accepted magnitudes of these parameters.

4) The capability of scanning of the Sun by the knife edge beam in the position angle sector $2\Delta q = 135$ degrees on the (U, V)-plane enables the construction of experimental two-dimension images of the Sun at $\lambda = 8.01$ cm.

The high-quality radio records obtained for all the scans confirm the efficacy of the antenna pattern reconstruction by this methodology. The derived physical parameters of the local solar sources at $\lambda = 8.01$ cm provide an additional measure of the validity of this method. These results also demonstrated that by using a conical secondary reflector in the described manner permitted the Sun to be observed without the azimuthal adjustments of the secondary reflectors for several hours. The latter procedure greatly simplified the observing technique as well as the analysis of the observations. The observations and procedures herein described introduced for the first time the possibility of producing two-dimensional maps of the Sun employing RATAN-600 observations. Finally, the efficacy of the conical secondary reflector for radio observations of the Sun using the " zoned relay" method is demonstrated.

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