Chapter 11
The Birth and Development of Radio Astronomy Studies of the Sun at the Siberian Institute of Terrestrial Magnetism, the Ionosphere and Radio-Wave Propagation

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Abstract The history of the organisation of the Department of Radio Astronomy at the Siberian Institute of Terrestrial Magnetism, the Ionosphere and Radio-Wave Propagation (SibIZMIRAN) is described, together with the principles behind the construction of the Siberian Solar Radio Telescope and the results of observations of the solar radio emission at decimetre wavelengths using this telescope.

11.1 Organisation of the Department of Radio Astronomy

Observations of the radio emission of the Sun using the Irkutsk Magneto-Ionospheric Station (IMIS) began in 1956 in connection with the *International Geophysical Year*. These observations were needed to remove the gap between the observations at the Ussuriisk and European observatories, as well as for the further development of geophysical research at Irkutsk.

In spite of the difficult conditions, the Laboratory for Solar Studies (supervised by G. Ya. Smol'kov) was organised relatively rapidly at IMIS. Regular observations of the solar radio emission began in 1958 at 209 MHz using a radiometer built at the Laboratory based on an STsR-637 radar station (Smol'kov, V. I. Burkov, N. K. Osipov and others).

Directly after this, the construction of a radio telescope operating at 10 cm wavelength began, as well as meteor radar facilities at 4 and 10 m wavelength. The radio telescope was introduced into operation in Noril'sk, and was first used for solar observations (in hopes of being able to obtain round-the-clock measurements), and then, more successfully, to record the radio noise produced by polar auroral layers of the Earth. The meteor studies were later transferred to Tomsk Polytechnical Institute in connection with the fact that the research themes of the Laboratory were restricted to solar physics.

With the transfer in 1959 of IMIS to the Siberian Division of the USSR Academy of Sciences, and the organisation on its basis of the Siberian Institute of Terrestrial Magnetism, the Ionosphere and Radio-Wave Propagation (SibIZMIRAN), in 1960 came the development and realisation of a programme for the creation of a new

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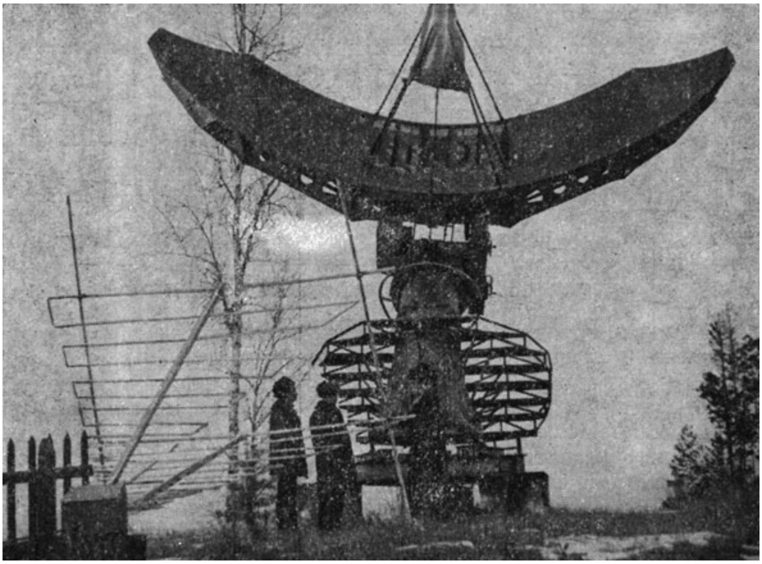

Fig. 11.1 Small-baseline radio interferometer (wavelength of 3.5 cm)

scientific complex at Irkutsk, which enabled modern studies of solar activity simultaneously using all ground-based methods available (Smol'kov, G. V. Kuklin, V. E. Stepanov, R. B. Teplitskaya, V. G. Banin, V. M. Grigor'ev, V. M. Skomorovskii, A. T. Altyntsev and others).

Many radio astronomy organisations (first and foremost, the Main Astronomical Observatory; Gorkii Radio Physical Institute; Lebedev Physical Institute; Institute of Terrestrial Magnetism, the Ionosphere and Radio-Wave Propagation; and the Institute of Applied Physics in Gorkii) helped us to master various methods and observing techniques and to prepare specialists. Collaborative studies are carried out with some of these organisations to this day.

Such collaborative efforts were facilitated in the first stage of the work of the new institute by the construction in Irkutsk of a radio polarimeter operating at 3.2 cm (Smol'kov, T. A. Traskov, V. P. Nefed'ev, L. E. Treskova, 1963) and a radio interferometer with a short baseline operating at 3.5 cm (V. G. Zankanov, Treskov, M. A. Khaitov, Smol'kov; Fig. 11.1). These formed the basis for studies of the polarisation and fluctuation properties of the solar radio emission (which became traditional at Irkutsk).

In recent years, the elucidation of the nature of active regions and of phenomena leading to the development of flares required studies of their structure and the dynamics of their development with high spatial resolution. It was expedient to carry out such studies at Irkutsk, since there were already well equipped optical observatories there, which were being used to conduct multi-faceted investigations of solar activity.

In this connection, SibIZMIRAN proposed in 1964 to erect a specialised solar radio telescope in Eastern Siberia, with a spatial resolution in both directions an order of magnitude higher than other solar radio telescopes in the world, making it possible to obtain radio images of the Sun in real time. This proposal was approved by the Radio-Astronomy Scientific Council of the USSR Academy of Sciences and the Presidium of the Siberian Division of the USSR Academy of Sciences.

The type and operational principles of the Siberian Solar Radio Telescope (SSRT) were chosen together with the Pulkovo (Main Astronomical Observatory) radio astronomers D. V. Korol'kov and G. B. Gel'freikh. Plans for the SSRT were confirmed in 1965. Corresponding member of the USSR Academy of Sciences A. A. Pistol'kors was appointed the scientific supervisor for the development of the technical design of the SSRT in 1967. The technical design composed by Pistol'kors, Smol'kov and Treskov was approved in 1969, and obtained high marks from the expert committee of the Siberian Division of the USSR Academy of Sciences, chaired by Academician A. L. Mints. The decision to construct the radio telescope was made in May 1972.

An operational model of the radio telescope—an eight-element radio interferometer—was assembled in 1974 at IMIS, as a means of verifying various design elements and testing certain nodes and systems of the SSRT. This facility was subsequently extended and transformed into a ten-antenna compound interferometer in 1979 (Smol'kov, N. N. Potapov, Treskov, B. B. Krissinel', V. A. Putilov and others). A second radio polarimeter working at the operational wavelength of the SSRT was also constructed in this same location in 1977 (Potapov and others).

With the beginning of the development of the SSRT project, the volume of radio-astronomy research carried out at SibIZMIRAN increased substantially. This led to the decision by the Presidium of the Siberian Division of the USSR Academy of Sciences to provide radio astronomers their own laboratory in 1965, which was reorganised into the Radio Astronomy Department in 1980 (in connection with the introduction into operation of the SSRT).

11.2 The Siberian Solar Radio Telescope

The Siberian Solar Radio Telescope is a so-called radio heliograph, intended for studies of the structure and dynamics of the development of active regions and flares in the solar atmosphere (Fig. 11.2). Strengths of the SSRT include its high resolution in both coordinates and the possibility of rapidly and frequently obtaining radio images of the solar corona facing the Earth (this is impossible at optical wavelengths due to the very high brightness of the solar disc).

Active regions in the solar corona can display very high contrasts at wavelengths of 5–6 cm, especially in polarised light. Based on this fact, and taking into account the operational wavelengths of radio heliographs that were already available or under development, the operational wavelength for the SSRT was chosen to be 5.2 cm. The field of view of the SSRT is $35 \times 35'$, which corresponds to the radio diameter of the Sun at this wavelength.

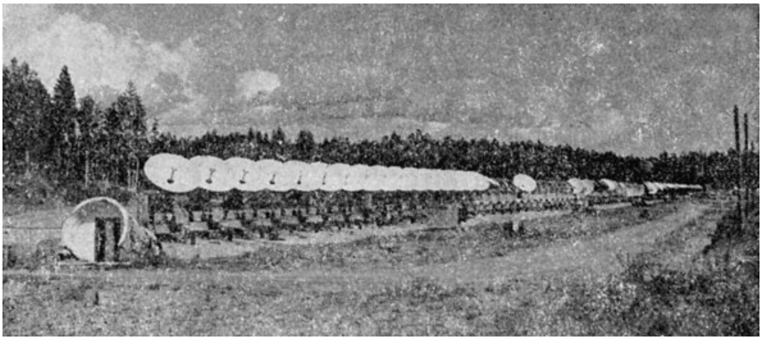

Fig. 11.2 Siberian Solar Radio Telescope (SSRT) in the Badara thicket (East–West line, comprised of 128 antennas with diameters of 2.5 m)

The high two-dimensional spatial resolution is achieved thanks to the large synthesised aperture of the antenna system—a 256-element radio interferometer forming a single large antenna with a diameter of 622 m. This radio interferometer consists of two mutually perpendicular rows of equidistant parabolic surfaces (128 in each row) oriented east–west and north–south.

The time required to obtain a radio image of the Sun is determined by the time for the Sun to pass through the diffractional maximum of the antenna beam, or 2.5–3.0 minutes. The possibility of obtaining hundreds (up to 300 in Summer) of radio images over the course of a day makes it possible to trace spatial and temporal properties of the development of events and processes occurring in active regions.

The antenna feed and receiver system distinguishes the total intensity and circularly polarised radio radiation of the Sun. Therefore, two-dimensional distributions of these two Stokes parameters are measured simultaneously.

Part of the antenna system (oriented East–West) is shown in Fig. 11.2, in 1981–1982, when it was being constructed.

The diameter of the surface of each antenna was 2.5 m; two schemes for mounting the antennas were foreseen: a symmetrical cross-like arrangement with resolution $20 \times 2''$, and a T-like arrangement with resolution $10 \times 20''$.

A method for processing radio images using *a priori* information was developed, based on the relationship between the structure of local sources of radio emission in the corona and groups of spots visible in unpolarised and polarised light. This processing makes it possible to appreciably increase the effective resolution of the SSRT.

An automatic tracking system enables the antennas to follow the Sun continuously from East to West at elevations of more than 10° above the horizon.

Test recordings of the radio emission of active regions on the Sun using the first group of antennas in the Western arm were begun in March–April 1981. Figure 11.3 shows a series of scans of the Sun obtained from 03^h25^m to 03^h50^m on August 26, 1981 in polarised emission (upper curve) together with a recording of a solar flare in intensity detected at this same wavelength using the radio polarimeter (lower curve).

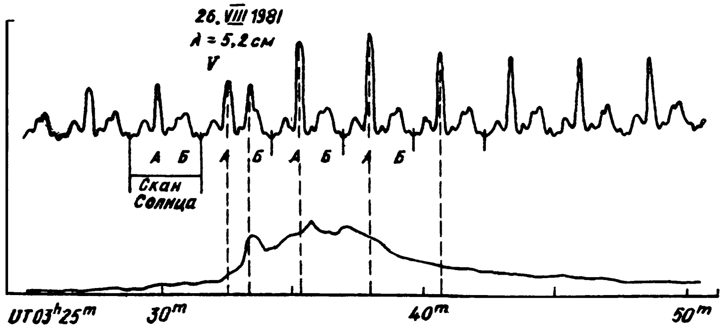

Fig. 11.3 Example of a scan across the solar disk at a wavelength of 5.2 cm (August 26, 1981): (1) using the first group of 16 antennas of the western beam of the SSRT and (2) using a single antenna. The *text below the first pair of letters on the left* "*A B*" reads "Scan of the Sun"

A solar radio eclipse was successfully observed at nine wavelengths using individual antennas of the SSRT on July 31, 1981, jointly by radio astronomers from the Main Astronomical Observatory, Special Astrophysical Observatory and the Leningrad Polytechnical Institute.

11.3 Research Directions

Three research directions were established and subsequently became traditional in the SibIZMIRAN Radio Astronomy Department.

(1) The development of new radio-astronomy equipment and radio telescopes, first and foremost the SSRT (Smol'kov, Treskov, Krissinel', Potapov, V. V. Kotovich, Putilov, V. V. Belosh, L. M. Risover, V. G. Zandanov and others).
(2) The measurement of characteristic physical processes and events occurring in the solar atmosphere using radio polarimeters, the short-baseline radio interferometer and multi-antenna radio interferometers (V. P. Nefel'ev, Zandanov, Treskov, Treskova, Potapov, Smol'kov, G. N. Zubkova), in close association with optical observations.
(3) Theoretical interpretation of observed processes and events, the eludication of mechanisms for their origin and development, the construction of physical models and diagnostics for fluxes of energetic particles (A. V. Stepanov, A. M. Uralov, V. G. Ledenev, B. I. Lubyshev, V. M. Bardakov).

The results of solar-physics research carried out by Irkutsk radio astronomers have now become well known both in our own country and abroad. They are systematically published in publications of SibIZMIRAN and in astronomy journals. In the 1983 monograph put out by the *Nauka* publishing house *Methods for the Construction and Processing of Solar Radio Images*, Irkutsk radio astronomers (S. D. Kremenetskii, Putilov, Risover and Smol'kov) develop in detail a variational theory for deriving the fine structure of solar radio images using radio telescopes with high spatial resolution, such as the SSRT of SibIZMIRAN. Much attention was paid to the specification of *a priori* astrophysical information about sources of radio emission on the Sun. The effectiveness of the methods developed by these authors is demonstrated using the processing of real data obtained on the Large Pulkovo Telescope and the RATAN-600 radio telescope as examples.