CORONAL LOOPS AND PROMINENCES AS OBSERVED WITH RATAN-600

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Abstract. This paper presents a short summary of observations of coronal structures at microwaves using an instrument with high spatial resolution and good wavelength coverage. The comparison of the RATAN-600 data with optical observations of coronal loops in the green line and with the Very Large Array maps at 21 cm has shown that the loops represent only a small part of coronal matter, although their role may be of great importance in the physics of the solar corona. Prominence (filament) associated sources, especially "peculiar" ones, are also reviewed.

Key words: Sun – Corona – Loops – Prominences - Radio Observations

1. Introduction

The important role of the radio observations in studying coronal structures, both of low and high temperatures, is widely accepted nowadays. One, however, should keep in mind that effective diagnostics of the parameters of the plasma and physical processes in the plasma structures essentially depend on the parameters of the radio telescopes used for the observations. We need both high spatial resolution and good spectral coverage and resolution, and reliable polarization measurements as well. These requirements are contradictory and are hardly met in a single antenna system.

The radio telescope RATAN-600 of the Russian Academy of Science is a reflector type telescope with an aperture of up to 600 meters in diameter and as such is used for detailed analysis of the spectra of different structures of the solar plasma (Pariysky et al, 1967). The main parameters of the instrument are given in Table I. Some ways of possible future development of the instrument for solar studies are also shown (Bogod, 1992, Gelfreikh, 1990, 1992). The main limitations (at present) are its moderate spatial resolution (about 15 arcsec at λ=1.7 cm in WE–direction), especially at decimeter wavelengths, and the transitional nature of the observations. The full coverage of the wavelength range 1.7-32 cm has been proven to be of great value, in particular when measuring coronal magnetic fields.

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TABLE I

Solar observations at RATAN-600

Wavelengths range	0.8-32 cm, more then 30 frequency channels
Polarization measurements	Circular (I and V or R and L, $\delta p < 0.5\%$)
Spatial resolution	One-dimensional, 17 arcsec at $\lambda = 2.0cm$
Time resolution	1 scan per 15 minutes, from 7:30 to 10:30 UT
Modernizations (planned)	Panoramic spectrograph with 80 frequency channels and 400 channels with frequency step 1.5 MHz
	Radioheliograph with 10 arcsec resolution at λ=2.0 cm

2. Active Region Observations

A typical well-developed active region (November 1980, SD548/1980) was studied at a number of radio wavelengths obtained with the RATAN-600. During disk passage we could see bright cyclotron sources above the main sunspots (strongly polarized) and an interspot component – rather weak at $\lambda < 4$ cm. When the region was on the limb (November 19) photographic observations made in the green coronal line at the Mountain Solar Kislovodsk Station have shown the loops reaching up to a height of about 100,000 km (see Fig.1). The radio sources observed with RATAN-600 have practically the same height above the photosphere. Their spectrum of fluxes is flat implying thermal bremsstrahlung as the most probable mechanism for the generation of the radio emission. The height of the cyclotron sources above the sunspots does not exceed a few thousands km and they are not seen on the radio scans of November 19, though clearly registered on the previous day. These may most probably be considered as the base of the above loops, seen in the corona in the green line.

We have used for this particuliar active region three methods of measuring magnetic fields developed in our group. They are based on the analysis of spectra and polarization of bremsstrahlung in magnetic fields (Bogod and Gelfreikh, 1980), the analysis of the spectra of the cyclotron emission (Akhmedov et al., 1982) and the interpretation of the observed inversion of the sign of circular polarization in a quasi–transversal magnetic field (Gelfreikh et al., 1987). Some parameters of this AR derived from these observations are summarized in Table II.

Fig. 2 illustrates another case (July 1982, SD228+SD229/1982). In the decimeter wavelength range the interspot component became a halo covering the whole AR (Akhmedov et al., 1987). We should note that the observations with higher spatial resolution of the region made with the VLA show the arc-type components but they are responsible only for a small fraction of the total flux at 20 cm. The physical nature of this decimeter halo is rather

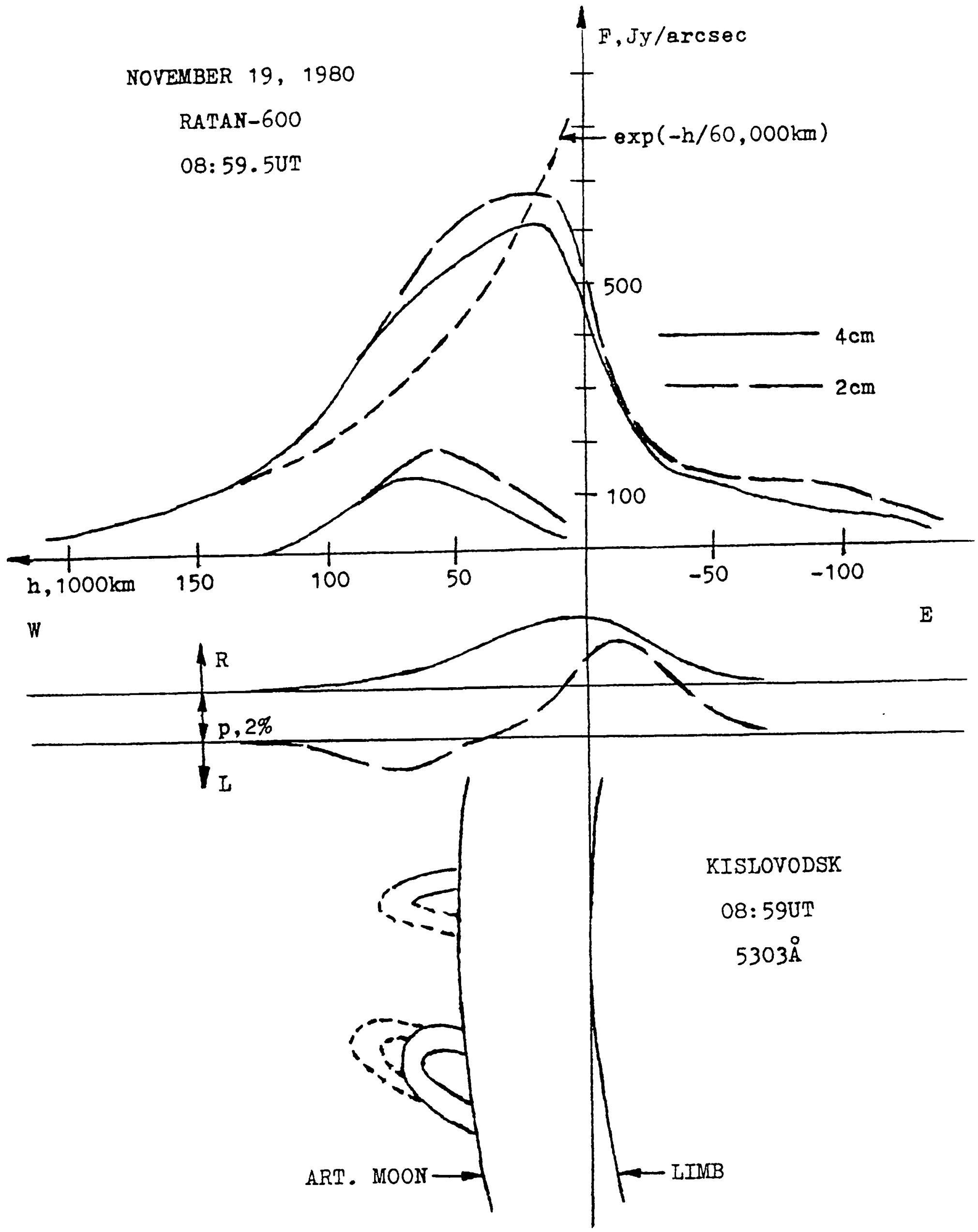

Fig. 1. Radio scans of an active region off the W-limb at the November 19, 1980, in total intensity (F) and circular polarization degree (p) at 2.0 and 4.0 cm wavelengths. The observations were made using the RATAN-600 at five short cm wavelengths (2.0, 2.3, 2.7, 3.2, 4.0 cm). Below is a sketch of optically observed coronal loops in the green coronal line made from coronograph spectroheliograms of Kislovodsk Solar Mountain Station.

enigmatic. The point is that the radio flux spectrum excludes the most natural interpretation in terms of thermal bremsstrahlung. So this component demonstrates a longlasting nonthermal process in coronal loops, like a high level of plasma turbulence and the presence of nonthermal particles.

TABLE II

Active region SD548/1980

1.	loops legs, H_{long} =50-80 G, N-polarity, $h = 4 - 8 \cdot 10^3$ km, (Nov 19,1980)
2.	loops top, H_{long} =15-25 G, S-polarity, $h = 75 \cdot 10^3$ km, (Nov 19,1980)
3.	QT-region, $\|H\| = 10 - 20$ G, $h = 75 \cdot 10^3$ km, (Nov 19,1980)
4.	above N-sunspot, $H = 2000$ G, N-polarity, $h = 1700$ km, (Nov18,1980) $h < 2000$ km, (Nov 19,1980)
5.	above S-sunspot, $H > 3000$ G, S-polarity, $h < 3000$ km, (Nov 14,1980)
6.	QT-region, $\|H\| = 20 - 30$ G, $h = 30 - 50 \cdot 10^3$ km, (Nov 16,1980)

3. Prominence Observations

The prominences at centimeter waves while observed off the limb have a brightness temperature comparable with its kinetic electron temperature of about 20,000 K. The position of this source corresponds to that of H_α observations. The measurements of weak polarization can be used to estimate the average longitudinal component of the magnetic field (tens of G, normally). While on the disk, prominences (filaments) are normally seen in microwaves as dark features with sizes often larger than optical ones. The origin of the above situation can be interpreted in terms of the bremsstrahlung mechanism for the generation of radio emission. The radio data supply additional and independent information on the temperature, gradients of temperature, and magnetic fields inside the prominence.

However, it is important that the filaments mark the neutral magnetic line – the line where the longitude component of the photospheric magnetic field becomes zero. Locally at this line the structure of magnetic fields becomes very complicated and even strong vertical currents have been found from the interpretation of magnetographic observations. Short cm wavelength observations reveal local bright sources with brightness temperatures up to 10^7 K and lasting for days (Akhmedov et al., 1986, 1987, 1989; Alissandrakis et al., 1993). The exceptionally high slope of the spectra leads to serious problems in the interpretation of their radiation (Korzhavin et al., 1989; Vatrushin and Korzhavin, 1989). An example of this type of peculiar sources is given in Figure 2 (source "d") and their typical parameters are summarized in Table III.

It is worth mentioning the general tendency to have brighter features in an active region near the neutral line, especially in the case of high gradients of the photospheric magnetic field. In this case the prominence become the locations of the highest brightness temperatures (at $\lambda = 3 - 6$ cm). Of course, strictly speaking it is not inside the prominence where the emission arises but rather in the surrounding magnetic loops of low height (of the order of

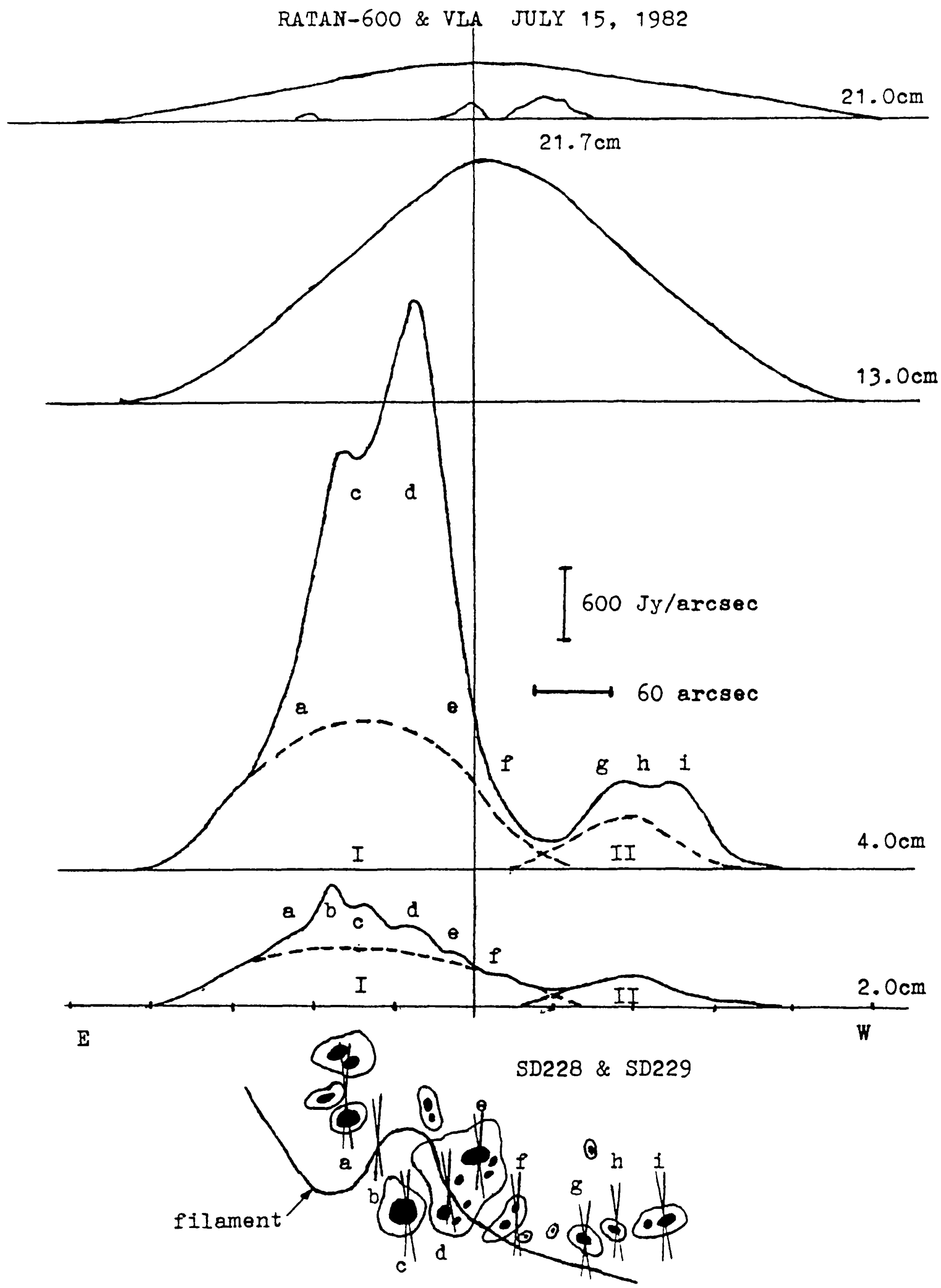

Fig. 2. Radio scans of the active region observed on July 15, 1982, near the center of the solar disk. The flux at $\lambda = 21.7$ cm from the loops observed on the VLA is shown below the upper curve (RATAN-600 scan at $\lambda = 21.0$ cm). At the bottom the optical structure of the sunspots and the H_α filament are presented. The position of the compact radio sources at microwaves from the RATAN-600 scans is shown (marked as a, b, c.....i).

15,000 km). However, their physical connection with the plasma-magnetic structures of the prominences cannot be ignored. These are certainly manifestations of local release of nonthermal energy in the solar atmosphere lasting for several days.

TABLE III

Peculiar sources

1.	Peak wavelength $\lambda = 3 - 4\,\mathrm{cm}$
2.	Steep spectrum index up to $n = 10$
3.	Max. brightness $T_B \approx 10^7$ K
4.	Life time (3 to 5 days) coincides with periods of proton flare activity
5.	Height and angular size $\approx 10^4$ km
6.	Location at neutral line of magnetic fields (filaments)
7.	Appear simultaneously with new magnetic flux, proton flares do not destroy them

4. Conclusions

In the conclusion we would like to emphasize that the most effective analysis of the above processes and structures of coronal loops and prominences can be achieved in cooperative observations is made the combination of radio telescopes of aperture synthesis with very high spatial resolution, and instruments like RATAN-600 with good wavelength coverage. Including in the program the modern solar crosses (Nobeyama, Irkutsk) may help in studying the development of the plasma structures. X-ray mapping from space is of special interest to measure temperatures and register acceleration processes independently from radio methods .

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