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Investigation of the polar coronal hole in the Sun with RATAN-600 in the centimeter radio range

O.A. Golubchina

Special Astrophysical Observatory of the Russian Academy of Sciences,
Pulkovskoe shosse 65, St. Petersburg, Russia

St. Petersburg Branch of Special Astrophysical Observatory of the Russian Academy of Sciences, St. Petersburg, Russia

E-mail: golubchina_olga@mail.ru

The article presents a brief overview of the main results of observations of the radio emission of a polar coronal hole (CH) on the Sun, obtained in a wide centimeter wavelength range (1.03-30.7) cm with the RATAN-600 radio telescope. The detected sharp decrease in the intensity of radio emission of the polar coronal hole at centimeter wavelengths ($\lambda \geq 6$ cm) near the optical disk of the Sun and its absence at short wavelengths of observation (λ = 1.03, 1.38, 2.7 cm) are analyzed. The identity of the temperature properties of the polar CH and large low-latitude CHs is discussed. During the discussion, a brief overview of some of the results of the study of the polar coronal hole in the Sun is given according to earlier observations, obtained with the radio telescopes LPRT, RATAN-600, RT-22 (CrAO), NoRH and others, as well as according to (EUV (SOHO) data and data from theoretical works.

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1. Introduction

The article presents the results of the observation of the maximum phase of the solar eclipse on March 29, 2006 in the "Relay race" mode on the northeast sector of the RATAN-600 radio telescope at wavelengths λ = (1.03, 1.38, 2.7, 6.2, 13.0, 30.7) cm [1]. Of particular interest is the study of the polar coronal hole (CH) located in the region of the North Pole of the Sun. Coronal holes (CHs) are characterized as areas of reduced temperature and density in the Sun's atmosphere. These are unipolar regions with an open magnetic field configuration. Polar coronal holes are always present at the poles of the Sun during the period of minimal solar activity. The main task of the study of the data obtained in the RATAN-600 observations of the March 29, 2006 solar eclipse was to determine the brightness temperature distribution of the Sun's radio emission in the centimeter wavelength range in the polar coronal hole region located in the northern hemisphere of the Sun, at a distance of (1.005-2.0) Rs from the center of the optical solar disk [1, 2]. The obtained characteristics were compared with the data found in the literature [3, 4, 5, 6, 7, 8].

2. Observation of the solar eclipse on March 29, 2006 with RATAN-600

The RATAN-600 radio telescope has a knife antenna pattern (AP). The spatial resolution of the RATAN-600 telescope is arc minutes: λ = (1.03, 30.7) cm; (ρ_h *x* ρ_v) arc min = (0.4 x 17.3), (13.4 x 84.4), where λ is the wavelength of observation, and (ρ_h) and (ρ_v) show the angular dimensions of the horizontal and vertical radiation patterns, correspondingly. At the time of the maximum phase of the solar eclipse (11:17 UT), 0.2% of the area of the optical disk of the Sun remained open. The center of the antenna pattern (AP) was shifted in height by +15 arc minutes north from the center of the optical disk of the Sun, so the central part of the AP was in the North Polar zone, where the polar Coronal Hole (CH) was located. A number of simplifications were introduced for modeling. The brightness temperatures of the model rings of the Sun (Moon) (T_b^S, T_b^M) were established either in accordance with the literature data [9, 10], or by correcting them by trial and error, or by solving the transfer equation, or by combining all the listed methods. The antenna temperatures of the model (T_a^S, T_a^M) were calculated according to the indicated (T_b^S, T_b^M), using the antenna smoothing equation according to the vertical AP:

$$T_a(\varphi^0) = \int_{\varphi_1}^{\varphi_2} T_b(\varphi)A(\varphi - \varphi^0)d\varphi$$

$A(\varphi - \varphi_0)$ is the normalized vertical antenna pattern, $(\varphi - \varphi_0)$ are the angle deviations from the center of the vertical AP. φ_2, φ_1 are the integration limits over AP. $T_b(\varphi)$ is the brightness temperature of the radio source, $T_a(\varphi_0)$ is the antenna temperature of the observed source [1, 2].

3. Comparison of model eclipse curves and real observations

The degree of coincidence of the antenna temperatures of the model and real observations of the radio emission of the Sun and Moon during the solar eclipse of March 29, 2006 is an assessment of the quality of the simulation. The close equality of the antenna temperatures obtained from real observations of the radio emission of the Sun and Moon during the observation of a solar eclipse with the model values means that a high-quality model has been obtained. Consequently, the brightness temperature distribution was obtained in a wide centimeter wavelength range (λ = 1.03, 1.38, 2.7, 6.2, 13.0, 30.7 cm) over the North Pole solar region stretching from the center of the Sun to distances of 2 R_s (R_s is the radius of the optical disk of the Sun) [2].

Low-latitude coronal holes can be organized by random convective motions in the photosphere, as well as reconnections of open magnetic field lines with closed field lines [5, 3]. The coincidence of the brightness temperatures of the polar coronal hole and large low-latitude coronal holes against the background of a quiet Sun at close wavelengths indicates the identity of the temperature properties of polar and low-latitude CHs. The identity of the physical conditions of CH in equatorial and polar regions was noted in the work [6] as a result of observations in the ultraviolet range and in white light. The above results of studies of the radio emission of polar and large low-latitude CHs with RATAN-600 revealed the same property of CHs in the microwave radio range. These results were demonstrated by observations with the Nobeyama radioheliograph (NoRH) and EUV (SOHO) images. Interspecular holes are located above the polar faculae, and the bright polar spots observed at λ = 1.76 cm are located close to the areas of the polar faculae [7, 8]. These models are in good agreement with the results of the RATAN-600 observations [2].

4. Conclusions

1. The observation of the solar eclipse on March 29, 2006 with RATAN-600 for the first time made it possible to determine the distribution of brightness temperatures over the North Pole of the Sun within the polar coronal hole in a wide range of centimeter wavelengths (λ = 1.03, 1.38, 2.7, 6.2, 13.0, 30.7 cm) at a distance of (1.005-2.0) *Rs* from the optical Sun.
2. A sharp decrease in the brightness temperatures of the radio emission of the polar coronal

hole at centimeter wavelengths ($\lambda \geq 6$ cm) near the solar limb was detected. This confirmed the real registration of a polar coronal hole over the North Pole region of the Sun.

3. The polar coronal hole is not visible at short centimeter wavelengths: λ = (1.03, 1.38, 2.7) cm

4. The coincidence of the brightness temperatures of the polar coronal hole and large low-latitude coronal holes against the background of a quiet Sun at close wavelengths in the Northern hemisphere indicates the identity of the temperature properties of the polar CH and large low-latitude CHs, regardless of their location on the Sun and, consequently, of the mechanism of their formation during the period of minimal solar activity

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