Coronal holes at microwaves observed with the RATAN-600

V.N. Borovik, V.G. Medar

Central Astronomical Observatory, Pulkovo, St.Petersburg, Russia

The observations of coronal holes in wide microwave range 2–32 cm with the RATAN-600 during the period of low solar activity in 1984–1985 showed that at wavelengths longer than 4 cm the coronal holes were clearly distinguished on solar strips as "darker" regions against the quiet Sun. For the first time, the brightness temperature spectra for four coronal holes and adjacent quiet regions have been obtained simultaneously using the same observations. On the basis of these radio data and taking EUV and optical observations of the Sun into account, the empirical homogeneous models of the upper layers of the quiet solar atmosphere and coronal holes have been constructed by the same method. The observed radio characteristics of coronal holes both in the center of the disk and at the limb (decrease in the radio radius and in limb brightening of the quiet Sun at decimeter wavelengths upon the emergence of a hole at the limb) were very consistent with an arch structure for the inner corona in the quiet solar atmosphere and with an absence of arches in the coronal holes (Borovik et al., 1990; 1993).

The analysis of the RATAN-600 data obtained during the 11-year sunspot cycle N 22 showed, that on the descending and ascending branches of the cycle (as well as at solar activity maximum) no brightness contrast of coronal holes and adjacent inactive regions was visible on one dimensional solar scans (Borovik et al., 1997). Therefore solar observations at microwaves carried out with the RATAN-600 at the last solar activity minimum (1995-1996) are very important for the coronal hole study.

As in the earlier sessions, in 1995–96 we have used in solar observations the southern sector of the RATAN-600 radio telescope in combination with a plane periscopic mirror. The total intensity and circular polarized component of the solar radio emission have been recorded daily simultaneously at 30–40 wavelengths in the range of 1.8–18 cm during the Sun passage through the fixed antenna beam at local noon (at $\approx 9^h$ UT). On some days the observations at 28–30 cm were available. The radio telescope provided resolution of $17'' \times 13'$ at 2.0 cm. The observations were carried out using panoramic spectrum analyser with a combined feed with a common phase centre (Bogod et al., 1993). The software for data reduction has been developed by Garaimov (1997).

The choice of the coronal holes to be investigated was determined by the goal: to compare the radio characteristics of the coronal holes and adjacent quiet regions, where no manifestations of activity were detected according to all optical data available. Seven equatorial isolated coronal holes have been considered. The times of their passage through the central meridian are given below according to H_α Synoptic Charts (Preliminary reports of Solar Geophysical Data, courtesy of V.N. Ishkov):

CH1 (17–18.06.95); CH2 (11–12.03.96); CH3 (26–27.08.96); CH4 (22–23.09.96, next revolution of CH3); CH5 (26–27.09.96); CH6 (23–24.10.96, next revolution of CH5); CH7 (12–13.10.96).

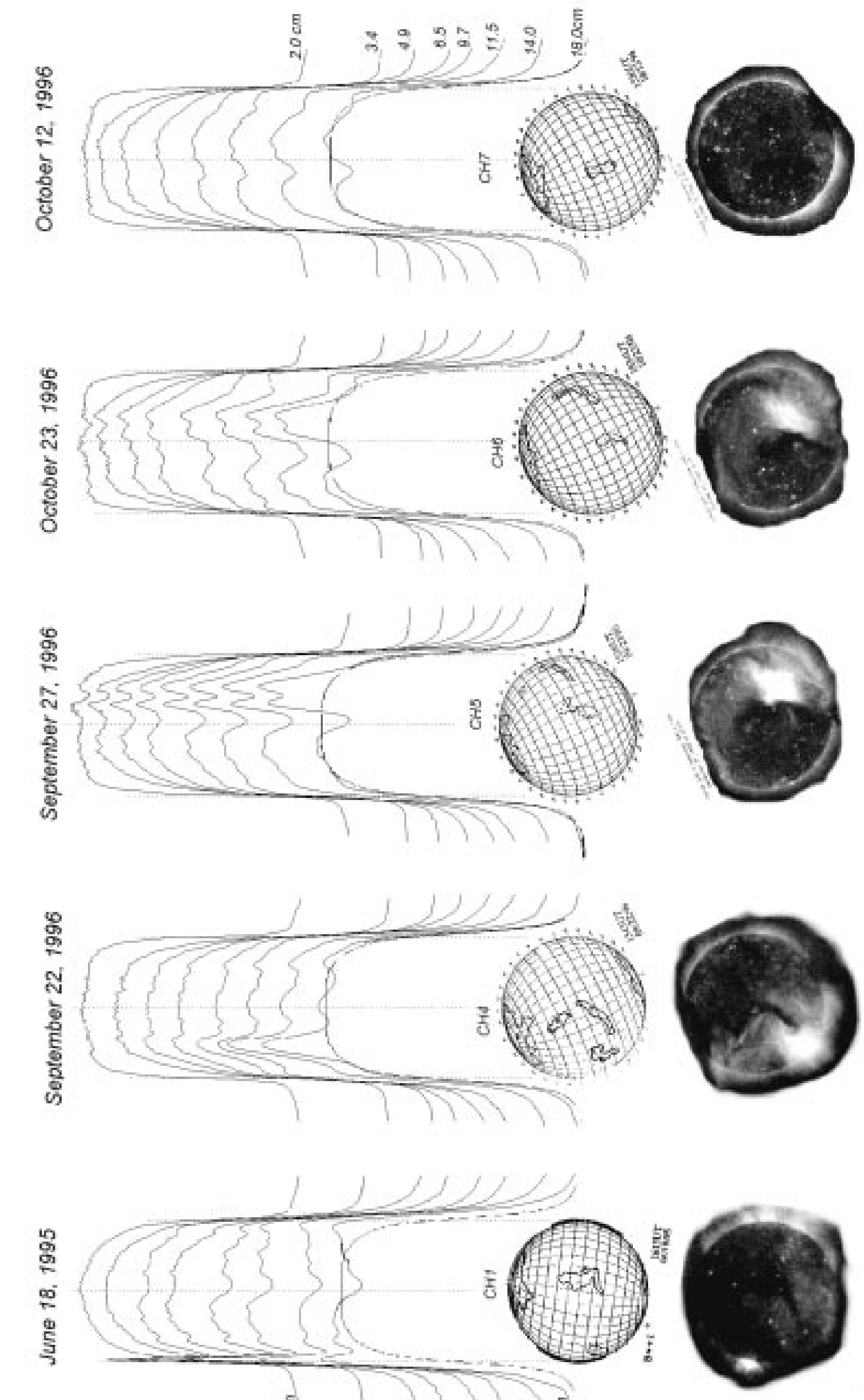

Fig. 1. The examples of visibility of the coronal holes on the solar scans obtained with the RATAN-600.

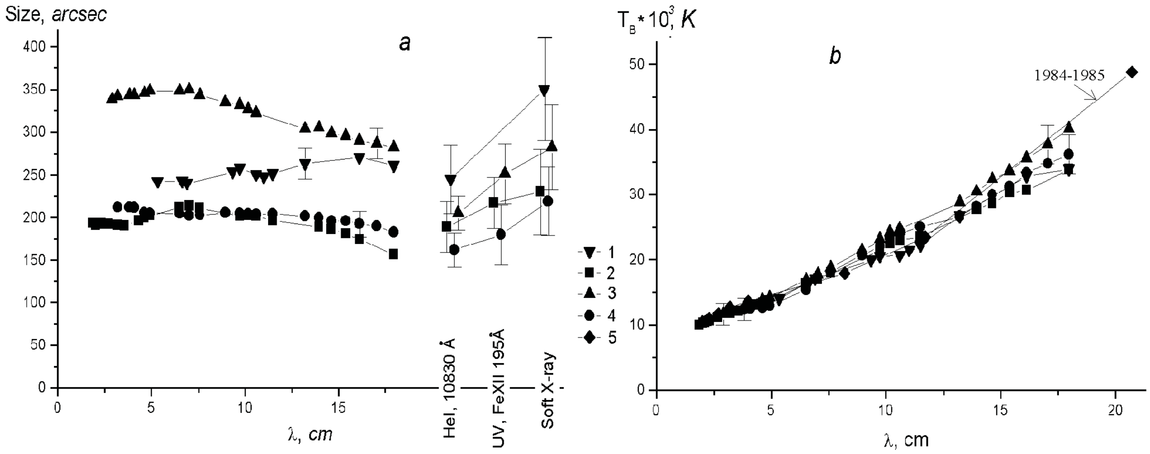

Figure 2: The effective radio sizes in the scanning direction (a) and brightness temperature spectra (b) of the following coronal holes: 1) CH1, June 18,1995; 2) CH5, September 27, 1996; 3) CH6, October 24, 1996; 4) CH7, October 12, 1996; 5) CHs in 1984-1985.

Some examples of the visibility of coronal holes on solar scans at different wavelengths in the range of 1.8-18 cm are given in Fig.1. Coronal Hole maps from National Solar Observatory (Kitt Peak) based on observations in HeI 10830 $\mathring{A}$ line and Yohkoh SXR telescope images are given below the scans. For example, the quiet Sun profiles are shown on the scans at 17.96 cm. They have been obtained statistically on the basis of RATAN-600 observations during 1995-1996, when the quiet Sun without active regions and coronal holes were observed. The total fluxes of the solar radio emission at microwaves (3.2, 8, 15 and 30 cm) measured at Nobeyama station and Penticton 10.7 cm data have been taken into account.

1. One can see in Fig.1 that the most of the coronal holes under consideration were well detectable on the scans against the quiet Sun as the regions of brightness depression at wavelengths longer than 4 cm. Only in two cases the coronal holes (CH5 and its next revolution CH6) were good distinguished as the regions of reduced radio brightness at short centimeter wavelengths 1.8–3.5 cm against the adjacent quiet Sun. It is interesting to note, that there was a bright active region with a bipolar magnetic configuration (the plage with the filament inside) quite near the coronal hole. A developed bipolar sunspot group was registered here in the previous revolution in August, 1996. Later, during three revolutions in September-November, this complex “coronal hole and plage” became very stable as it is seen on SXR images (Fig.1). Earlier RATAN-600 observations have shown that in most cases the coronal holes were undetectable on the solar scans at microwaves, if an active region was situated near the coronal hole. Such example one can see in Fig.1: CH4 on September 24, 1996. In the previous revolution this coronal hole CH3 was also undetectable.

2. The effective sizes of the regions of depressed radio emission associated with coronal holes in the scanning direction were determined with allowance for the smoothing effect of the beam pattern, assuming a Gaussian distribution of radio absorption in the coronal hole. The radio sizes of the coronal holes under consideration were in the range $200'' - 350''$

(Fig.2a). The sizes of coronal hole in the same direction according to HeI, SXR and EUV images are also given in Fig.2. It is seen that the radio sizes of coronal holes are practically constant in the range of 2–18 cm with the little decrease and increase with the wavelength for two coronal holes. We came to conclusion that the coronal holes at the last very deep sunspot minimum (1995–96) have the same sizes as in the previous cycle but they show the different dependence on the wavelength. For three of four coronal holes, which have been observed on RATAN-600 in 1984–85 in the range of 4–32 cm, we found an increase in the size with the wavelength (Borovik et al., 1990).

3. Although the contrasts of brightness temperature of coronal holes against the quiet Sun in 1995–1996 turned out to be lower than those in the previous cycle, the absolute values and spectra of brightness temperatures of coronal holes were the same for two cycles (Fig. 2b). It should be noted, that the intensities of the radio emission of the inactive regions adjacent to the coronal holes in 1984–1985 (at the end of the decay phase of 21th cycle) were higher than those were at the deep sunspot minimum in 1995–1996 (according to radio fluxes measured at World Solar Network stations and to RATAN-600 data).

4. The coincidence of calculated and observed effects detected by RATAN-600 during the rise of CH2 (March 3 to 9, 1996) confirmed the validity of the empirical homogeneous models of the coronal hole and quiet Sun atmospheres constructed on the basis of the RATAN-600 microwave data obtained in the previous cycle.

5. For the first time, the circular polarized radio emission associated with the isolated equatorial coronal hole (CH7) has been detected at microwaves on two revolutions in October - November, 1996. The strength of the longitudinal magnetic field of 7–10 G in the hole at coronal emitting layers at 9–30 cm has been estimated in the framework of bremsstrahlung (Borovik et al., 1999).

6. The RATAN-600 observations at short centimeter wavelengths 1.8–3.5 cm with high spatial resolution 10–30 arcsec have shown that there were no remarkable differences in the fine structure of radio emission in coronal holes and adjacent quiet regions.

This research was partially supported by "Astronomy" Program (grant 5.4.1.7) and by RFBR grant 99-02-16171.

References

Borovik V.N., Kurbanov M.Sh., Livshits M.A., Ryabov B.I., 1990. Astron.Zh., 67, 1038-1052

Borovik V.N., Kurbanov M.Sh., Livshits M.A., Ryabov B.I., 1993. Astron.Zh., 70, 403-414

Borovik V.N., Livshits M.A., Medar V.G., 1997. Astron. Zh., 74, 936-946

Bogod V.M., Abramov-Maksimov V.E., Dikii V.N., Vatrushin S.M.,Tsvetkov S.V., Preprint Spets. Astrofiz. Obs, St.Petersburg, 1993, 84

Garaimov V.I., Preprint Spets. Astrofiz. Obs,. Nizhnii Arhiz, 1997. N 127

Borovik V.N., Medar V.G., Korzhavin A.N., 1999. Pisma v Astron. Zh., 25, N 4, 299-307