INVESTIGATION OF CORONAL ROTATION BY THE SPECTROSCOPIC METHOD

V. E. STEPANOV and N. F. TJAGUN
Sibizmiran, Irkutsk, U.S.S.R.

Abstract. Coronal rotation is different in the northern and southern hemispheres of the Sun and varies with the cycle of solar activity. A sharp decrease in linear velocity by 0.4 km s^{-1} on the latitude and its relative constancy in the latitude interval $35° < \varphi < 50°$ are the most typical.

In the southern polar region an intensive stream of coronal gas directed oppositely to the solar rotation was detected during the time interval 1969–1972. In the greater part of the latitude range, on average, the corona rotates more slowly in comparison with the solar atmosphere at the photospheric level.

1. Introduction

In our earlier paper [1] the solar corona rotation rate was inferred using the Doppler shift of the Fe X 6374 Å line. In this paper there were used only 525 line profiles obtained at Sayn Mountain Observatory during the period March 1968 to September 1969. However, an analysis of errors showed that for more exact determination of the coronal rotation rate at higher latitudes more numerous observations are needed. Therefore, the program of observations has been enlarged and the results of this paper are based on the analysis of the 'gravity center' displacement of 4976 profiles of the Fe X 6374 Å line, obtained during the period 1969 to 1972.

The number of observed profiles used for determination of the rotation rate during different time intervals, is given in Table I. In 1971 and 1972 we paid special

TABLE I

Date		Number of profiles observed	Number of profiles for hemisphere N	Number of profiles for hemisphere S
Year	Month			
1969	6–9	215	79	136
1970	6, 7, 9	1624	902	722
1971	5–7	1191	550	641
1972	8, 9	1946	810	1136
Total number of profiles		4976	2341	2635

attention to the region of latitude within $20° < \varphi < 85°$. The same lines as in [1] were taken as standard lines. We used their wavelengths as determined in [2]. The coronal spectra were obtained with the help of a coronograph with an objective diameter of 53 cm using grating in the 2nd order as in [1]. The linear dispersion is equal to 1 Å mm^{-1}. Spectrogram measurements were performed with a step equal to 0°.9 of latitude. The processing of measured data and the computations were made on the computer BESM-4. The software of both automatic processing of spectra and

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computation of mean radial velocities for different heliographic latitudes is described in [3].

2. Observational Results

The Doppler velocities in the corona, which are averaged over the whole observational period as well as over 10° latitude interval and reduced to one quadrant, are presented in Figure 1.

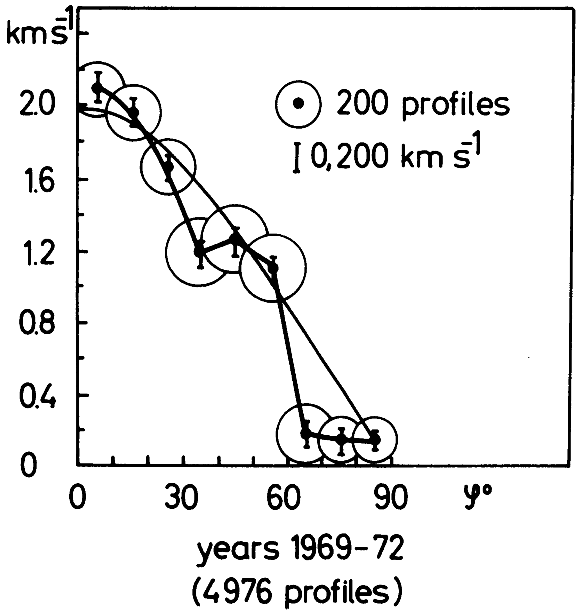

Fig. 1. The curve of coronal rotation, on the average, for the period from 1969 to 1972. The heavy full line is the rotation of the corona according to our determinations. The areas of circles correspond to the number of observations, the verticals correspond to the mean square error. The light line is the curve of the photosphere rotation from sunspots [4], extrapolated for higher latitudes.

Within the interval of heliographic latitudes from 0° to 15° the velocity of coronal rotation exceeds the rotation velocity inferred from sunspots by 100 m s^{-1}. Further, with the increase of latitude up to 35° the velocity decreases sharply.

At the latitude of 35° the coronal rotation velocity appears to be less than the photospheric rotation by 400 m s^{-1}. In the latitude interval from 35° to 55° the velocity remains constant. Then, a second new sharp decrease of velocity at the latitude of 65° takes place. At this latitude the coronal rotation rate is by 500 m s^{-1} less than that of the photospheric rotation rate obtained by extrapolating the Newton-Nunn curve [4] at higher latitudes. Within the latitude interval from 65° to 85° the velocity of coronal rotation remains constant.

Hence, the corona on the whole rotates a little slower than the photosphere; the difference of velocity rotation being most appreciable at the latitude of 35° and 65°.

We can distinguish three zones in the character of dependence of the coronal rotation velocity on heliographic latitudes.

The first one appears to be a zone of active latitudes where the angular momentum transfer to the equator occurs; the second zone contains the latitudes from 35° to 55° where an increase of angular velocity of rotation occurs, i.e. in the second zone the coronal rotation velocity is being restored up to the value of the photospheric rotation velocity. The third zone appears to be a zone at high latitudes, where the character of the motions, as we shall see below, is very complicated.

In Figure 2 the velocity curves are given for the northern (full line) and southern (dashed line) hemispheres. In general, the coronal rotation in different hemispheres looks like the pattern of the rotation for one quadrant.

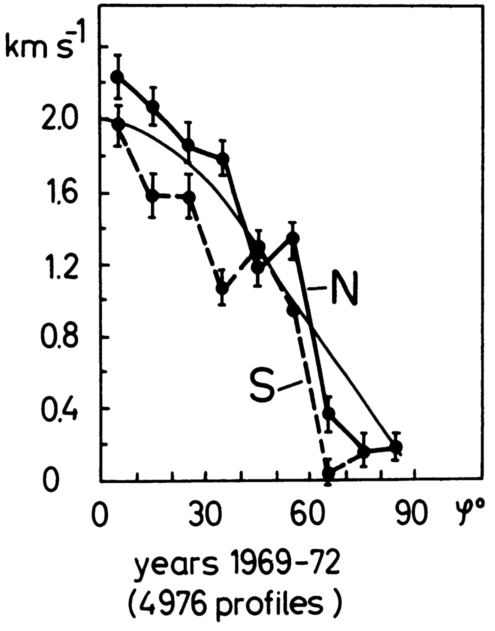

Fig. 2. Coronal rotation in different hemispheres for the period from 1969 to 1972. The heavy full line is for the northern hemisphere in the corona. The dashed line is the southern hemisphere. The light line is the rotation of the photosphere from sunspots [4].

However, the essential differences exist too. Firstly, during the whole observational period the corona in the southern hemisphere rotates, on average, slower than in the northern hemisphere. Secondly, a clear difference in the character of decrease of rotational velocity at the latitudes $\varphi > 25°$ takes place for both hemispheres – the relative minimum of velocity in the southern hemisphere occurs at the latitude of 35°, while in the northern hemisphere that minimum appears to be shifted 10° towards higher latitudes.

Finally, very low velocities are observed in the southern hemisphere at the latitude of 65°, that can be treated as the presence of a strong zonal motion along the direction opposite to that of the solar rotation.

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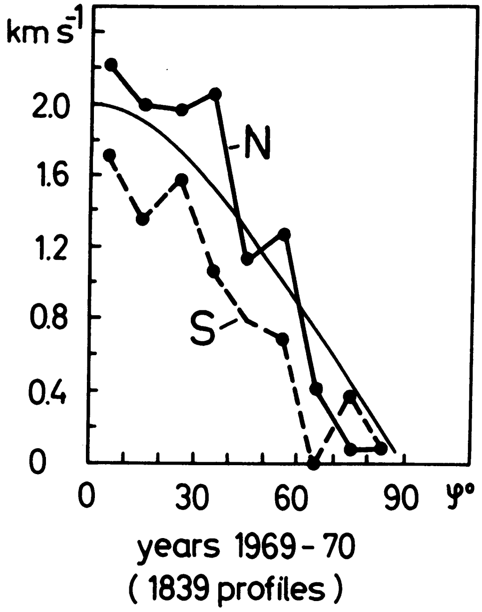

Fig. 3. Coronal rotation from 1969 to 1970. The heavy full line is the northern hemisphere in the corona. The dashed line is the southern hemisphere. The light line is the rotation of the photosphere from sunspots [4].

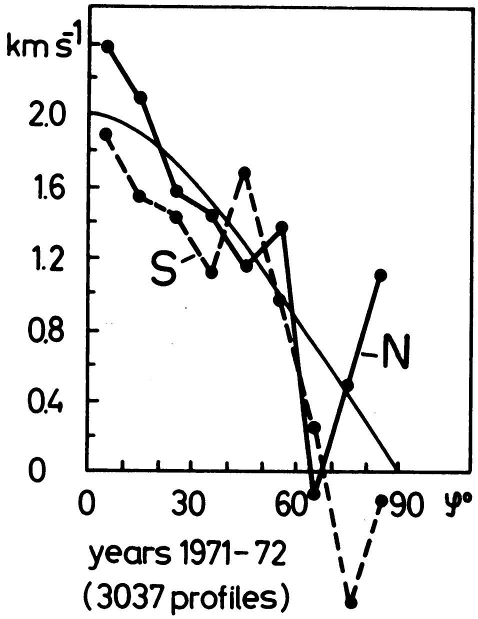

Fig. 4. Coronal rotation from 1971 to 1972. The heavy full line is for the northern hemisphere in the corona. The dashed line is the southern hemisphere. The light line is the rotation of the photosphere from sunspots [4].

In Figures 3 and 4, the velocity curves are given separately for the periods 1969 to 1970 and 1971 to 1972 accordingly. It is seen that the velocities in the first period of observations (1969–1970) are larger in the northern hemisphere than in the southern zone. In the second period (1971–1972) the character of coronal rotation has changed; at a latitude of 45° in the southern hemisphere the velocity is larger than in the northern hemisphere.

From Figures 3 and 4 we can draw the conclusion that the location of the stream, which moved oppositely to the direction of solar rotation, had shifted towards higher latitudes.

3. Discussion

Up to now the passage of typical coronal formations across the eastern and western limbs of the solar disk (the method of 'tracers' [5–15]) was used for investigation of coronal rotation rates. This method yields fairly high accuracy but it does not supply sufficiently comprehensive information on the variation of the rotation rate with the heliographic latitude. Besides, it can be applied only to the study of motions of distinctly visible coronal formations.

The method of the coronal rotation study by the Doppler shift of spectral lines allows, in principle, to obtain the rotation velocities of the bright formations as well as that of the diffuse background of the corona. However, the spectroscopic method has its disadvantage, which consists in summarizing emission along the line of sight. The structures with the different brightness contribute unequally to the formation of the spectral line. This circumstance causes a large dispersion of the observed velocities. Therefore, the determination of the coronal rotation velocities with the proper accuracy needs a large number of observations.

How can we explain the difference between the observational results obtained by the tracers method and our results? It is obvious that the lines with the largest equivalent width belong to the brightest coronal formations and that the lines with the small equivalent width belong to the quiet coronal background. Thus we must expect in accordance with the results of many authors [5–15] that the lines with largest equivalent widths should possess the largest velocities. Our investigations have shown that this regularity is not observed. The lines with large equivalent widths exhibit minimal velocities and give the smallest velocity dispersion [1].

The same lines have also the smallest line width [16]. Therefore, observations by using the method of tracers do not represent real gas motion in the corona. They give the displacement, a disturbed region, the position of which depends on the source of disturbance located at the deep level of the solar atmosphere.

The questions how to distinguish between rotation of a bright coronal object and coronal background as well as how to reveal the local motions in the vicinity of active regions will be considered by us in the future.

4. Conclusions

The results of this study are the following:

(1) The difference between rotation rates of corona and photosphere at almost all heliographic latitudes was found. The sharp decrease of the coronal rotation rate at latitudes of 35° and 65° appears to be the most remarkable peculiarity.

(2) The difference in coronal rotation rates for the northern and southern hemispheres was also found.

(3) In the southern polar region the intensive long-lived zonal streams were observed. These streams are directed oppositely to the solar rotation direction.

(4) The coronal rotation rate has been studied by us on the descending branch of the solar activity cycle. Nevertheless, using that material, one can conclude certainly that the character of coronal rotation varies with the phase of the solar cycle.

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