PRELIMINARY RESULTS OF SPECTROSCOPIC DETERMINATION OF THE CORONAL ROTATION

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Abstract. Coronal rotation is determined by means of the spectroscopic method. The mean value of the rotation rate vs. the heliographic latitude is found. At high latitudes the corona rotates much faster than the underlying photosphere. This fact confirms Waldmeier's and Billing's hypothesis that the high-latitude phenomena should depend on the magnetic fields of low latitudes and that the interchange of the matter between the active zone and polar coronal region along the field lines should take place.

1. Introduction

Determinations of the coronal rotation have been made for the first time from observations of single long-lived coronal regions. Waldmeier (1950) studied an emission (λ5303) region at 55°, which was identified by him for almost seven rotations; he determined its rotation rate from the successive observations. The values of this rate fit very closely the curve found by d'Azambuja (1948) from the rotation of filaments. The most extensive study of the coronal rotation from monochromatic observations was carried out by Trellis (1957). He also used successive east and west passages of bright λ5303 regions. The difference between the coronal rotation rate and the Carrington rate for latitudes from 0° to 70° was determined. He found that the corona rotates a little slower than the photosphere at latitudes below 35° and more rapidly at latitudes above 35°. The difference becoming significant at high latitudes.

Cooper and Billings (1962) from 29 successive rotations of an emission region at 65° have determined a rotation rate higher than the rotation found by Waldmeier (1950) and Trellis (1957). Hansen *et al.* (1969) from autocorrelation analyses of K-coronameter observations have established average yearly rotation rates of coronal features as a function of latitude. At low latitudes the corona was found to rotate at the same rate as sunspots but at higher latitudes it rotates much faster than the underlying photosphere. The white light corona in 1964–1967 rotated much faster than the green corona in 1943–1955 as reported by Trellis. Nevertheless the high rates found from the recurrence of two stable high latitude coronal regions (Waldmeier, 1950; Cooper and Billings, 1962) are confirmed by the results of Hansen *et al.* (1969). However the problem of the variations of coronal rotation with latitude cannot be solved only from observations of successive limb passages of bright emission regions. In addition there may be systematic differences between the rotation of the bright regions usually used for such studies and the rotation of the coronal matter.

In this paper we investigate the coronal rotation, using the Doppler displacements of the coronal emission line λ6374 Å.

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2. Data and Results

During the time interval from March 1968 until September 1969 a special program was undertaken with the 53 cm coronagraph of the Sajan Observatory (Siberia). The optical system of the coronagraph gives us a final solar disk image of 129 mm (Nikolsky, 1966) at the slit of the spectrograph.

The spectra of the corona used in this study were obtained in the wave length region of $\lambda\lambda$6350–6385 Å in second order at a dispersion of 1 mm per Å with a curved slit at height intervals of 20000–40000 km above the photosphere. The microphotometer of Sibizmir was used to obtain microphotometer traces. Altogether 600 traces were done along the dispersion. Line shifts of the line λ6374 Å due to coronal motion were measured relative to the Fraunhofer lines in the scattered light background. In Table I the wavelengths of the lines used, are given. The accuracy of the derived coronal rotation rates with the help of the spectroscopic method is limited by the presence of macroscopic motions within the corona, by the method of measurement of lineshifts, and by the width of the coronal emission line λ6374 Å. The measurement of the positions of the Fraunhofer lines at the disk center showed that it is necessary to make a correction which is equal to 0.0165 Å $\pm$ 0.0016 Å at the Sun's equator. The correction diminishes with increase of latitude according to the law of differential rotation. This displacement of the Fraunhofer lines in the background is caused by scattering of light in the instrument because of the solar limb close to which the coronal line is being photographed. The strong coronal line profiles differ very little from a Gaussian curve; most profiles of the weak lines are asymmetric. Most of those are distorted by film grain and by the presence of motions which are not randomly distributed. Furthermore, since the coronal lines are quite broad, a precise determination of the wavelength position of the intensity maxima is difficult. With this in mind we determined the position of the 'center of gravity' of the coronal lines and of the Fraunhofer lines in the scattered light background:

$$x_c = \frac{\int xI \, \mathrm{d}x}{\int I \, \mathrm{d}x}$$

were I is the intensity or depth of the lines. The height of the scanning aperture in the direction perpendicular to the dispersion was 8.″45 of arc; and the width was 0.05 Å. Traces were obtained at interval of 1°–2°, at the solar limb. In Table II the number of the positions for different latitudes at the east and west solar limb is given. To obtain a quantitative change of the rotation rate as a function of heliographic latitude, the northern and southern hemisphere and east and west limb coronal observations are analyzed together, and the average rotation rates were taken for each latitude.

Figure 1 (see Table III) shows the rotation rate in km/s as it depends on solar latitude. To compare the rates obtained from other solar traces including K-corona, regions of bright green coronal emission and photosphere, Figure 2 is given. At lower latitudes

TABLE I

Characteristics of the base Fraunhofer lines

Wave-length/Å	Equivalent width mÅ	Solar identi-fication	Low EP line	Note
6358.687 S	82	Fe I	0.86	reliable
6366.491 m	26	Ni I	4.17	unreliable
6371.355 m	35	Si II	8.12	unreliable
6378.256 S	27	Ni I	4.15	reliable
6380.750 S	40	Fe I	4.19	reliable

TABLE II

The number of contours for the east and west limb

$\varphi°$	0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90
East	74	65	54	26	15	14	21	27	12
West	54	61	34	16	11	2	10	19	9

our rates are much less than those found by Hansen and Loomis (1969) from analyses of K-coronameter observations, and within an uncertainty of 1% to 2% have the same rotation rate for latitudes up to about 25° as determined by Howard (1970) from observations of the photosphere Doppler shifts.

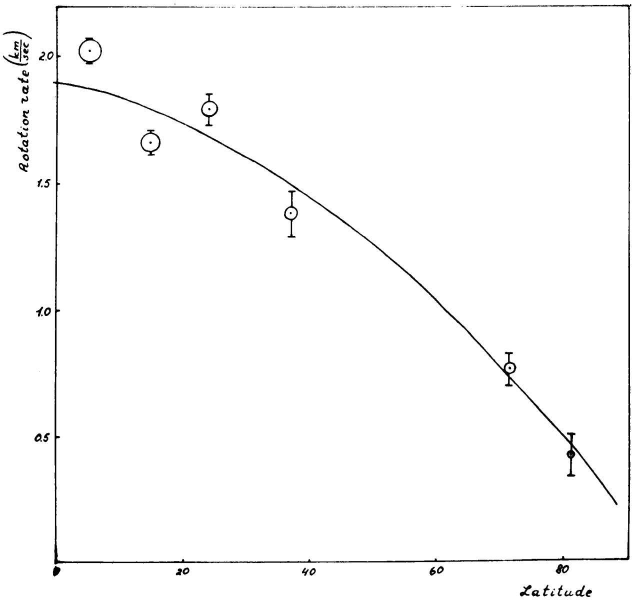

Fig. 1. Latitude dependence of coronal rotation rate, determined by the spectroscopic method. Dimensions of the open circles correspond to the number of data used for determination of the point. Relative errors are shown as vertical bars.

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TABLE III

Results presented in Figure 1

Heliographic latitude $\varphi°$	The number of points	Doppler displacements Å	Rotation rate km/s	Errors
5.4	139	0.043	2.02	± 0.193
14.9	113	0.035	1.66	± 0.198
23.9	91	0.038	1.79	± 0.236
38.3	78	0.029	1.38	± 0.287
71.5	56	0.016	0.763	± 0.264
81.2	31	0.009	0.424	± 0.344

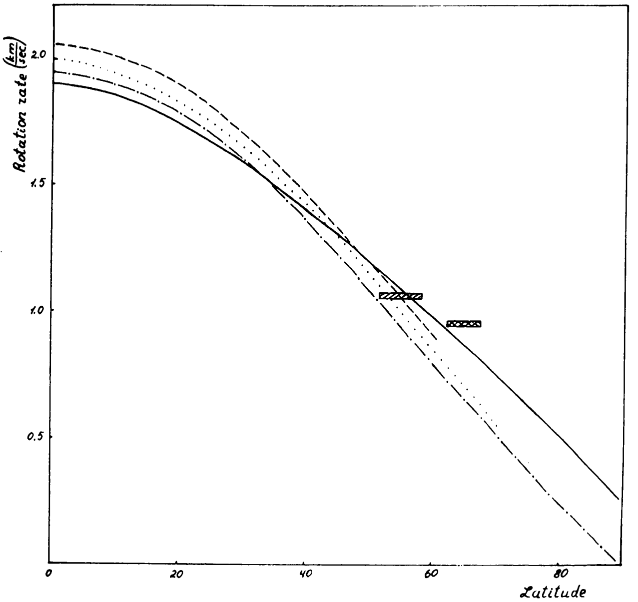

Fig. 2. Comparison of average rotation rate according to the spectroscopic method (solid curve) with those for the photosphere (dotted curve, Howard, 1970); K-corona at 1.125 Ro (dashed curve, Hansen *et al.*, 1969); Green Corona (points, Trellis, 1957); Waldmeier (shaded rectangle, 1959); Cooper and Billings, 1962 (blacked rectangle).

At high latitudes the corona rotates substantially faster than the underlying photosphere. Also our rates are generally faster than reported by Trellis for the green corona in 1945–1955 and for the K-corona (Hansen *et al.*, 1969). However the coronal rate at 30°–55° of the green corona (Trellis, 1957) of the K-corona (Hansen *et al.*, 1969) and the fast rate of the stable high latitude coronal regions are confirmed by our results.

At low latitudes the general agreement is remarkable on the one hand between the average photosphere and coronal rates determined through spectroscopic methods, and on the other hand between rates determined with the help of spots, filaments and coronal bright emission regions. At high latitudes however the difference between all measurements becomes great.

The differences are obviously due to systematic errors taking place when the measurements of rates are made at high latitudes. But there can be no doubt that at high latitudes the corona apparently rotates substantially faster than the underlying photosphere.

In earlier discussions of the difference between coronal rotation rates and polar faculae (Billings, 1966; Hansen *et al.*, 1969) suggested that high latitude phenomena should depend on magnetic fields at low latitudes and that the interchange of matter between the active zone and the polar coronal region along force-lines should take place. Our results prove this hypothesis.

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