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ON THE GREEN CORONA ROTATION

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Abstract. The solar emission corona rotation was determined using Fe XIV 530.3 nm coronal line measurements for the epoch 1947 – 1991 via the tracer method. The optimized correlation analysis has been applied together with a new reliability test for determination of rotation. Time-latitudinal dependence of the green corona rotation on the phase of the solar cycle shows nearly rigid latitudinal behaviour for few years before and during cycle minima and it is rapidly changing to a differential rotation just after the onsets of the solar cycle. This differential rotation profile prolongs up to the beginning of the descending phase of the cycle and then a slow return to the rigid profile follows. Large variations of green corona rotation between these two extremes lead to the conclusion that the overall latitudinal and temporal averages of coronal rotation are not physically correct.

Key words: corona - rotation - solar cycle

1. Introduction

The most extensively studied tracer of the solar emission corona rotation is intensity of the Fe XIV 530.3 nm green emission line. It was used by several authors dealing with data from different epochs, e.g., Trellis (1957), Sýkora (1971), Antonucci and Svalgaard (1974), Antonucci and Dodero (1977, 1979), Letfus and Sýkora (1982b), Sime et al. (1989) or Rybák (1994). It was found that the green corona rotates more rigidly than the photosphere - only a little faster on the equator but more rapidly at higher heliographic latitudes. The cycle dependence of this behaviour was also detected as a more differential at the beginnings of the solar cycles and during their maxima. This behaviour was found on the base of relatively low-precision green corona rotation results of low spatial and temporal resolution. Rybák et al. (1994) have shown that the existence of the sufficiently reliable tracers for the determination of rotation is not evident for the whole data set of green line measurements. This should be taken into account in more precise estimates of the overall rotation characteristics of the emission corona. Therefore, our aim was to determine coronal rotation exploiting all available green line measurements to cover time-latitude domain as large as possible and at the same time to estimate the precision of the obtained results in a natural way.

2. Data and methodology

'The Homogeneous Data Set of Coronal Green Line Intensities' (HDS) of Rybanský and Rušin (1992, 1994) represents at present the most extensive and detail source of Fe XIV 530.3 nm emission line intensities. The HDS has been compiled from all available green line intensity measurements from several coronal stations to a unified data set (Rybanský, 1975, Rybanský et al., 1994). The butterfly diagram of the green line intensity was detected clearly for each solar cycle (e.g., Letfus and Sýkora, 1982a, Bumba et al., 1990). For some cycles the double-peaked behaviour was found (Gnevyshev, 1963, Sýkora, 1994). Special data handling allowed to trace also the polar branches of the enhanced green line intensities (Leroy and Noens, 1983, Altrock, 1988, Minarovjech et al., 1997). The HDS allows to estimate rotation of the solar coronal features using the tracer method. The HDS data are available around the whole solar disk what allows to observe the green coronal tracers two times per solar rotation at their corresponding latitude. Limb data sets can be used strictly separated and rotation is derived then only from the tracer returns to the same limb.

It is needed to create sufficiently long 1D data segments of tracer's observations in the temporal direction at each latitudinal position. Only 1-dimensional temporal segments several months long lead to the sufficient statistics for the determination of the coronal rotation period. Temporal resolution of HDS enables to shift the data segments for few days only. Small shifts of the data segments offer a very helpful tool. Selection of the segments according to the tracer quality enables to pick up information on rotation of the green corona when tracers are more pronounced and the reliability of the results can be higher.

The data epoch was restricted to the range 1947 – 1991. The data segment length of 1 year has been selected with a partial overlapping of adjoining data segments with the temporal data segment shift of 1/10 year. Calculations have been performed with the latitudinal step of 5° only within the latitude range $\pm 80^\circ$. The computation procedure was applied strictly separately for the data sets from both limbs. Then the corresponding rotation results have been compared as a reliability check of the inferred limb results. This approach has enabled us to see clearly whether the assumption of the long-lived stationary tracer existence is valid and usable for each data segment.

The Spearman's rank-order correlation coefficient (CC) has been used for calculation of the autocorrelation function (ACF) (Press et al., 1986). The centroid position of the ACF rotation peak has been calculated from 7 points around the detected first ACF rotation maximum. This ACF rotation peak position has been used as the synodic rotation period of the green corona tracer, corresponding to the data segment center and to its latitude. Besides the rotation peak position results the corresponding CC values have been derived.

3. Results

In order to follow the coronal rotation using only the most pronounced and stable tracers results of the highest CC values were selected in each calendar year and latitude bin. The results were homogenized using an algorithm based on Hermite polynomials (Hill, 1982) for the recalculation of the rotation period and the CC values to the mid years.

The statistical effects of the selection and homogenization of the results were tested using distributions of the rotation period and CC results. A significant CC histogram centroid shift from the value of about 0.2 (original levels) to value at about 0.4 (selected and homog-

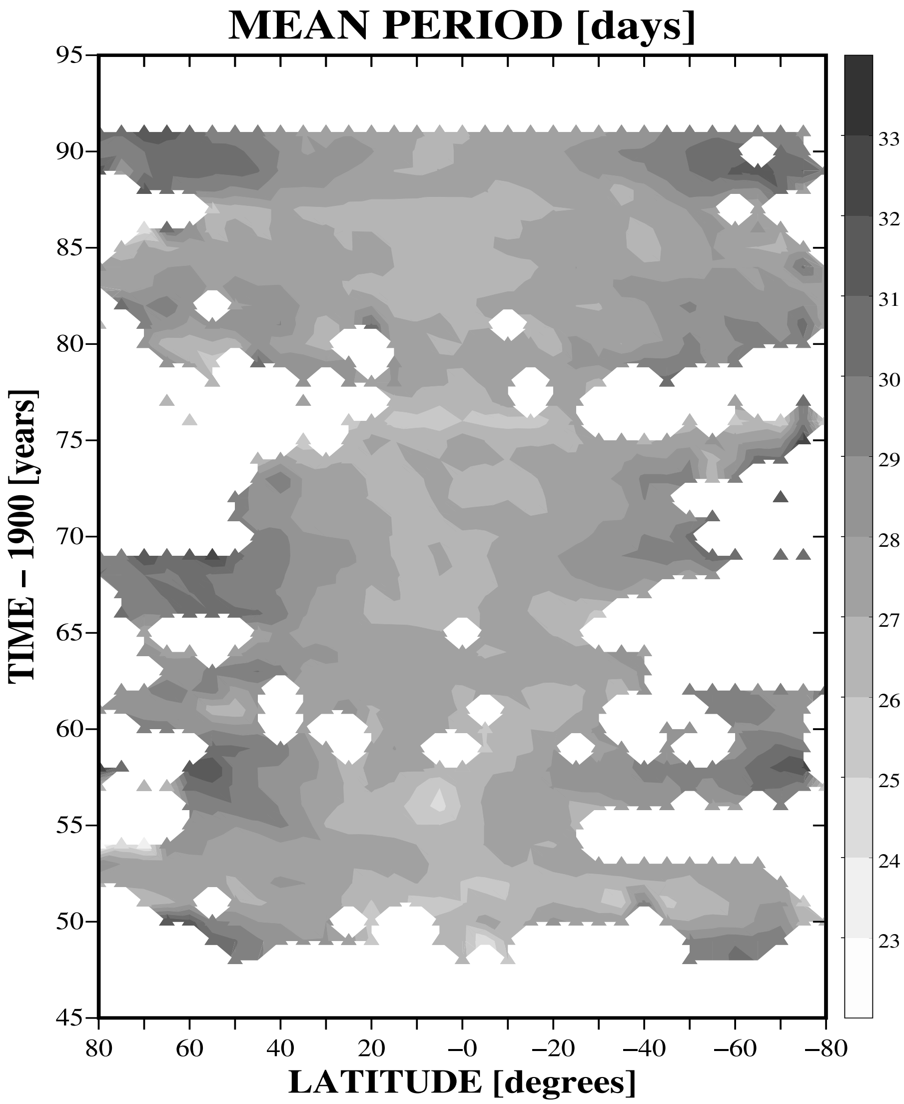

Figure 1: Time-latitude behaviour of the mean rotation period P_{mean} of the green corona. The CC limiting level of 0.2 was applied to results inferred from both limbs. Blank areas represent cases when at least at one limb the CC value is below this limit. The general dependence of the green corona rotation on the solar activity cycle can be seen together with some isolated deviations caused by the lower quality of the tracers.

enized levels) was found. A different effect was found for the rotation period distributions, where selection as well as homogenization of the results have not affected statistically the general behaviour of the rotation period histograms. Therefore, the results derived using the described process of selection and homogenization can be used for the determination of the rotation behaviour of the green corona.

The correlation coefficient of the first rotation ACF local maximum was used to rate the tracer quality. Its behaviour showed remarkable changes of the tracer quality. Although the selected method of the rotation determination is applicable over the whole time-latitude domain the inferred results should be considered relatively to the CC values omitting of all inaccurate results. Otherwise, the results would content also information which has been calculated numerically but the inevitable condition for the application of the method, selected for the determination of the rotation periods, has not been fulfilled adequately.

The time-latitude behaviour of the period difference $\triangle \mathrm{P} = \mathrm{P}_{east}$ - P_{west}, prepared from the results with the CC limit of 0.2 condition fulfilled on both limbs, shows that most of the results with CC values below this limit cover preferably higher latitudes in larger continuous areas and only few isolated areas at low latitudes. In fact, these areas would be covered dominantly with $\triangle$P differences of high values changing rapidly and randomly their sign. The largest $\triangle$P differences with CC values above the 0.2 limit are located mostly on the borders of the areas as a transition from the locations of more pronounced tracers with greater CC to the areas with the CC below 0.2.

The mean rotation period $\mathrm{P}_{mean} = (\mathrm{P}_{east} + \mathrm{P}_{west})/2$, calculated for each calendar year and latitude bin, with the CC_{east} and CC_{west} values above the limiting level of 0.2 (Fig.1) displays clearly the solar cycle dependence of the green corona rotation. During solar activity minima the green corona rotation is almost rigid up to high latitudes and the rotation period values are very close to the equatorial one at about 27 days. Contrary to this, an increase of the green corona rotation period for 3-5 days is detected in the medium latitudes with the onsets of new activity cycles. In fact, these longer periods extend above the sunspot latitudes upper limit $(40^\circ - 45^\circ)$ up to the latitudinal domain

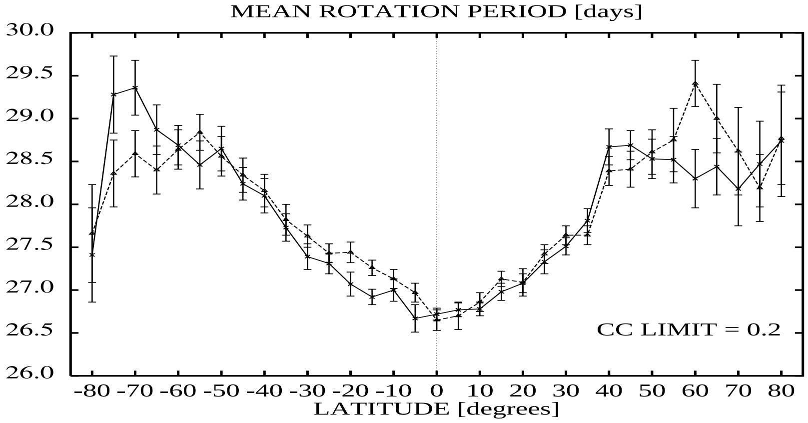

Figure 2: The overall latitudinal rotation profile averaged over the epoch 1947 – 91. East limb results (solid line) and west limb ones (dashed line) are plotted together with their corresponding standard deviations. The CC limiting level of 0.2 was applied.

border $\pm 80°$. The equatorial rotation period was found to be constant over the epoch within its uncertainty limits.

The overall latitudinal rotation profile averaged over the epoch 1947 – 91 (Fig.2) displays clearly differential behaviour of the green corona rotation. The difference of roughly 2.5 days (10%) is reached between the polar and the equatorial rotation periods. The standard deviations from the averaged values are in the range from 0.1 day for low latitudes up to 0.5 day for polar latitudes (0.3% and 2%, respectively).

The significant changes of the green coronal rotation period over the solar cycle (Fig.1) does not allow us in fact physically to interpret the mean latitudinal rotation profile. Typically, the fitting parameter B values are above 4.0 and below 1.0 when the latitudinal yearly profiles are fitted using the classical equation $P(\beta) = A + B.sin^2(\beta)$ for solar maxima and minima, respectively. Therefore, any detail discussion on the green coronal rotation should be performed using strictly actual results for different phases of the solar cycle avoiding the overall latitudinal profiles of the green corona rotation.

4. Conclusions

Our first finding is that in order to get reasonable results it is inevitable to perform a more detailed searching for reliable green coronal tracers. A strictly separate handling of the east and west limb green line data was exploited for estimation of the errors of the inferred rotation period. The reliable results clearly revealed the time-latitudinal dependence of the green corona rotation on the phase of solar cycle. An interesting feature is that while the green corona rotates almost rigidly few years before and during the cycle minima, this pattern is rapidly replaced by a differential one soon after the onset of a new solar cycle. This differential rotation profile extends up to the beginning of a descending phase of the cycle, when a slow return to the rigid profile was detected.

Large variations in the green corona rotation between the above-mentioned two extremes allow us to conclude that computations of overall latitudinal and temporal averages of the rotation is not a physically correct procedure. So, only rotation related to a specific point in the time-latitude domain, without any significant averaging, represents the large-scale rotation of the green solar corona.

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