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# Possible east side predominance of the optical emissions of the solar corona[☆]

V. Tritakis[a,1], H. Mavromichalaki[b,2], A.G. Paliatsos[c,1], B. Petropoulos[a,1], J.C. Noens[d,3]

[a]*Research Center for Astronomy and Applied Mathematics, Academy of Athens, Greece*
[b]*Department of Physics, Section of Nuclear and Particle Physics, University of Athens, Greece*
[c]*General Department of Mathematics, Technological and Education Institute of Piraeus, Greece*
[d]*Observatoire Midi-Pyrinee, Observatoire du Pic-du-Midi, 65200 Bagneres de Bigorre, France*

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**Abstract**

A long term analysis of the green and the red line intensities of the emitting solar corona as well as the polarization of the white corona, which have been compiled by the Pic-du-Midi, Kislovodsk, Irkutsk and Lomnisky Styt observatories, has led to some very interesting results. A prominent East-West asymmetry is obvious in most of the data while a very characteristic seasonal variation of this asymmetry with maxima close to December and minima in July–August is also present. All the errors involved in coronal optical measurements have been examined in a previous paper but none of them have been underlined as the possible cause of the east-west asymmetry. In such a case, the presence of this asymmetry should not be ignored while the reason for its existence should be studied, extensively. Two approximations to a possible explanation of the solar E–W asymmetries have been reported in the discussion section of this article. © 1997 Elsevier Science B.V.

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## 1. Introduction

The first reference to a possible east-west asymmetry of a solar configuration has been reported since the beginning of the 20th century when Maunder determined that 53% of the total spot area and 59% of the spot groups occur on the east half of the solar disk (Maunder, 1907). Some decades latter, the famous Dutch astronomer Professor Minnaert pointed out that Maunder's result was caused by a figurative rather than a physical effect. He explained that a positive radial gradient of the angular rotation in the sun causes the vertical axis of a sunspot to be titled westwards on the average by a half degree. The

[☆]Part of this article has been presented in the 30[th] COSPAR Scientific Assembly in Hamburg, 1994.
[1]E-mail: academy@isosun.ariadne-t.gr
[2]E-mail: emavromi@atlas.uoa.ariadne-t.gr
[3]E-mail: noens@DEC5000.bagn.obs-mip.fr

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tilt foreshortens the spots, thus systematically decreasing their apparent areas but more in the western than in the eastern half of the disk (Minnaert, 1946).

The subject of the east-west asymmetry arose again in the middle of our century when this effect was detected during optical observations of the solar corona in the Pic-du-Midi (Trellis, 1960, 1967) and the Lomnisky Styt (Link & Linkova, 1957; Pajdusakova, 1958, 1966) observatories.

Relatively recent reports concerning east-west asymmetries, which appear in the optical data of the solar corona, have been also presented by Sykora (1971); Leftus & Ruzickova-Topolova (1980); Rusin (1980); Tyagun & Rybansky (1981); Tyagun (1991); Tritakis et al. (1988); and Xanthakis et al. (1991), (1995).

In our effort to determine if these E–W asymmetries of the coronal optical emissions could be attributed to a physical phenomenon we have extensively analysed the Pic-du-Midi coronal data, which is the longest record of green and red line intensities, available as well as the polarization of the white light corona observations (Tritakis et al., 1988; Noens et al., 1994; Xanthakis et al., 1991, 1994; Mavromichalaki et al., 1994).

North-South asymmetries of solar features can be rather easily explained by a time difference in the solar activity development on both sides of the solar equator. In contrast, east-west asymmetries where the east or the west part of the solar disk appear brighter than the other, it is not understandable at all. Possible east-west asymmetry occurrences in solar configurations mainly imply that observational errors or wrong calculations have introduced this asymmetry. However, in the present case we have studied in detail all the possible errors which could introduce this sort of asymmetric emission around the solar disk, but we were not able to detect covariance between observational errors and E–W asymmetries (Noens et al., 1994; Tritakis et al., 1995). Consequently, either some unknown error induces or a physical phenomenon triggers these asymmetries.

In the present article, we summarize various evidence that the east part of the solar corona appears brighter than the west while we study seasonal and temporal variations of this asymmetry. Moreover we discuss some cases which could provide some explanation about the reason which introduces this sort of asymmetries.

## 2. Data reduction and processing

All the data we use in the present study belong to the following data sets:

1. Daily measurements of absolute intensities of the green and the red coronal emission lines which have been collected by the coronagraph of the Pic-du-Midi observatory and extend from 1944 to 1973.
2. Daily measurements of the polarization rate $\rho$B of the white corona expressed in $10^{-8} B_{\odot}$ collected by the polarimeter of the Pic-du-Midi observatory and extend from 1962 to 1978.
3. Daily measurements of absolute intensities of the green line intensity collected by the Kislovodsk observatory which extend from 1971 to 1991.
4. Daily measurements of absolute intensities of the red coronal emission line collected by the Irkutsk observatory. These data cover only a three year time span (9.8.1969 – 28.9.1972) and have been compiled for the solar sectors 140°–180° and 208°–285° around the solar disk. However, even this small sample of data has been proved very useful.
5. Finally, we have used the homogenized data of the Lomnisky Styt observatory from 1939 to 1992. This continuous time series contains daily green line intensities collected in various observatories which have been transformed to the Lomnisky Styt observatory photometric scale homogenizing in this way various data sets to a unified time series (Rybansky, 1975, 1979; Rybansky & Rusin, 1983).

All the data sets relating to the green and the red line intensities have been obtained by classic Lyot-type coronagraphs in a polar co-ordinate system, defined by the central meridian passage and the solar equator. Seventy two intensity values taken every 5°, around the solar disk are obtained every day, when observation is possible, starting from the solar north pole and moving to the east (anti-clockwise).

The absolute intensity of the green ($\lambda$5303) and the red ($\lambda$6374) coronal emission lines has been expressed in relation to the continuous photospheric spectrum, that is each value is expressed in terms of $10^{-6}$ times the intensity $B_{\odot}$ in the center of the solar disk within a band 1 Å wide at the same wavelength with the emission lines. The polarization rate $\rho$B of the white light is measured in units of $10^{-8}$ times of the total intensity $B_{\odot}$ of the solar disk.

Various errors of these observations which could introduce east-west asymmetries in the optical emissions of the solar corona have been studied in a previous extensive report (Tritakis et al., 1995).

Concerning the data processing, we have developed two techniques appropriate to both serial and seasonal studies, respectively. In the first of them, we have separated each data set in 27 time series which start from the 27 foremost dates of the records and contain measurements obtained every 27 days. In this way, each column contains dates which differ by one or more 27 day time lags. In this way every time series contains successive daily measurements with time lag 27 that is, data which correspond to the same more or less areas of the corona during successive solar rotations. In other words, all the dates from 1944 to 1973 have been tabulated in a two dimensional array of 27 columns and 30 years $\times$ 13.51 (27 days/year) $\approx$ 406 rows. This array has been filled by rows starting from the beginning of the first row and finishing at the end of the last. Empty places have been left for dates where observations are not available. In the following, we have calculated the asymmetry coefficient $A=(E-W)/(E+W)$, where $E$ and $W$ are the mean intensities within the latitudinal zone $\pm 60°$ on both sides of the solar equator of the east and the west solar limb, respectively. The asymmetry coefficient is a very convenient parameter for detecting which of the two hemispheres is brighter. In addition this way of processing helps to compare data which almost correspond to the same areas of the solar limbs during successive solar rotations enumerated in the Bartel's system.

In the second technique, we work with daily averages of the intensity values which have been calculated in the following way.

1. At the beginning, we separate the first twenty eight days of a certain data set in two successive blocks fourteen days each. In the following, we calculate the mean intensity $I_E$ of the east solar limb from $+60°$ to $-60°$ for the first fourteen day block. Further, we calculate the mean intensity $I_W$ of the west solar limb from $+60°$ to $-60°$ but for the second fourteen day block. We assume that the difference $I_E - I_W$ corresponds to the middle of the unified twenty eight days block, that is to the fifteenth day of the data set.

2. We slide the twenty eight day block one day further and we calculate in the above mentioned way another $I_E - I_W$ value which corresponds in the sixteenth day of the data set, and so on. If we continue this calculation all along the data set, we succeed to correspond to each date, except for fourteen dates at the beginning and thirteen dates at the end of the data series, an $I_E - I_W$ value which represents the difference between the brightness intensity in the east and the west limb during two successive fourteen days blocks. Features located on the east solar hemisphere pass to the west fourteen days latter the most. As a matter of fact, a $I_E - I_W$ value calculated in the way described above represents a comparison of the east side brightness between two successive fourteen day blocks.

It is very important to underline that, if we utilize this second technique of sliding two successive fourteen day blocks from the beginning to the end of the data set, we succeed to average and smooth irregularities introduced by the solar differential rotation as well as sudden changes of coronal brightness which occur due to the active center passages from the solar limbs, observing in this way the quiet component of the coronal emission. The $I_E$ and $I_W$ values, which have been calculated in the above mentioned way represent an objective and smooth parameter of the coronal brightness of the same solar hemisphere when it appears on the east or the west solar limb.

There are some limitations in the above mentioned calculations which should be mentioned before we discuss the processing of these data. It is necessary to keep in mind that the daily observations are less than the dates which construct the data set. As a matter of fact, we consider a fourteen day block empty if less than three observations exist in this block. Moreover, if two more blocks contain observations which have been obtained in the same dates we consider only one of these blocks because in the opposite case these observations would be overweighed.

3. After all, we form a new data set which starts on the fifteenth day of the source data set and terminates thirteen days earlier than it. This new data set contains $I_E - I_W$ values which express the difference between the averaged brightness intensity on the east and the west solar limb during successive blocks of fourteen days, respectively.

## 3. East-west asymmetries of the optical emissions of the solar corona

The application of the first data processing technique, we have described in the previous paragraph, has revealed that the East part of the solar corona appears brighter than the West in most of the cases.

Fig. 1 contains all the data available in the Pic-du-Midi observatory and represents all the cases where the east coronal part appears brighter ($I_E > I_W$) or fainter ($I_E < I_W$) than the west for the intensities of the green (upper), red (middle) and white light (lower) coronal emissions.

From this figure it is evident that the number of cases where the east part of the solar corona is brighter than the west ($I_E > I_W$) predominates in most of the cases in all the three panels of Fig. 1.

In Fig. 2 we present data obtained by the Kislovodsk observatory which concern to daily green line intensities from 1971 to 1991.

This data has been collected in the same way with the Pic-du-Midi observatory data and have been processed according to the first method described in the previous paragraph.

Since this data sample is rather small, minimum sample size criteria have been evaluated for statistical confidence reasons. At first, it is very important to examine if there is a sufficient number of observations in both the east and the west part of the solar corona. If we keep in mind that the effective part of the solar disk extends between ±60° on both sides of the equator and the observations are obtained every 5°, an ideal sample size of observations on each side of the solar corona should be 25 measurements per day.

After a serious consideration of observation losses and gaps, the minimum sample size criteria which have been inserted are consistent with ten measurements on each side of the solar corona at least as well as a sample size difference between the two sides not less than six. The purpose of this sample size limitation is to protect to some extent the confidence of our results from the induction of very unequal sample size effects between the east and the west solar corona. Sample sizes which finally participate in our calculations have been tabulated in Table 1. All the data which have been satisfied the above mentioned criteria, have been separated in 27 time series which start from the 27 foremost dates of the record and contain data every 27 days. In this way, each time series contains data with time lag of 27, that is data which correspond to more or less the same areas of the corona after successive solar rotations.

In Fig. 2 the number of cases for each of the 27 time series, where the east part of the solar corona appears brighter ($I_E > I_W$) or fainter ($I_E < I_W$) than the west, has been depicted. From this figure, it is evident that the number of cases where the east part is brighter than the west predominate by a factor of 3 to 4.

In Fig. 3 we present some data obtained by the Irkutsk observatory from 1969 to 1972 which concerns to daily measurements of the red line intensity. A feature of this data set is that it does not include full disk coverage of measurements but data within the solar sectors 140°–180° and 208°–285°. In addition the small size of the data sample makes the application of the analysis described in Section 2, impossible. For this reason we have calculated the average E–W asymmetry coefficient for only nine months which dispose sufficient data and they are spread out accidentally in the time span 1969–1973.

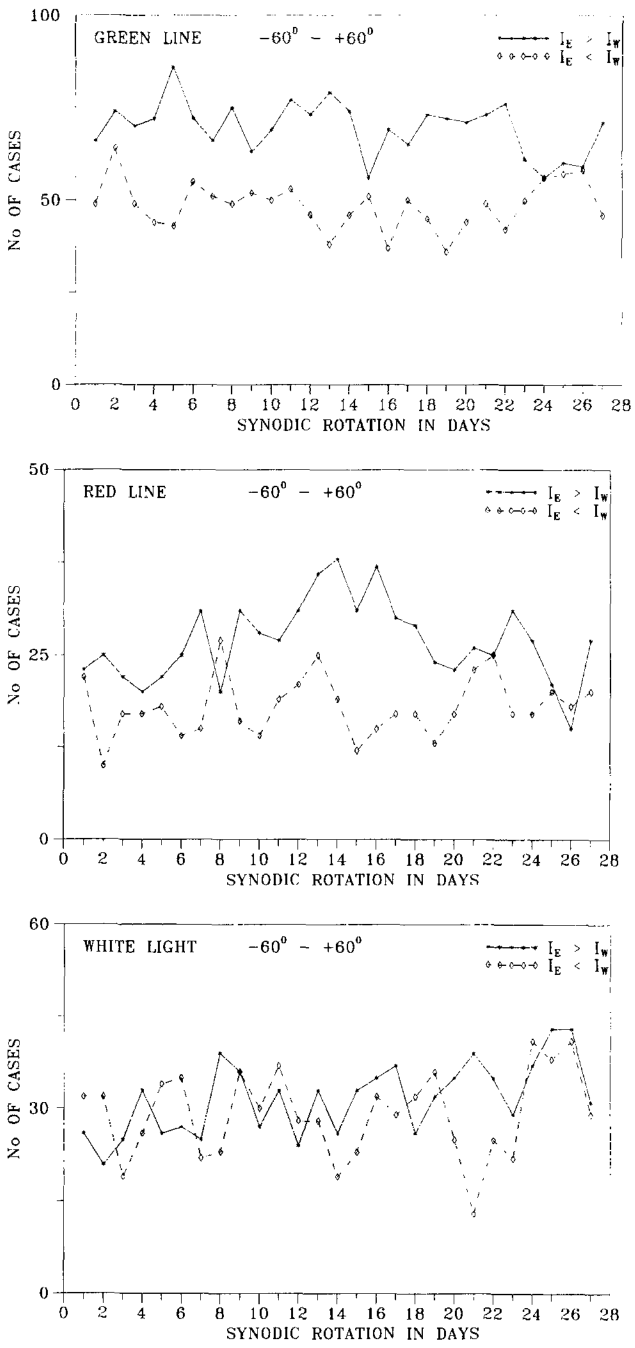


Fig. 1. Number of cases where the east part of the solar corona appears brighter ($I_E > I_W$) or fainter ($I_E < I_W$) than the west in the green and red spectral emissions as well as the polarization rate of the white-corona in the upper, middle and lower panel, respectively. Observations in all cases have been obtained within a ±60° latitude zone on both sides of the solar equator.

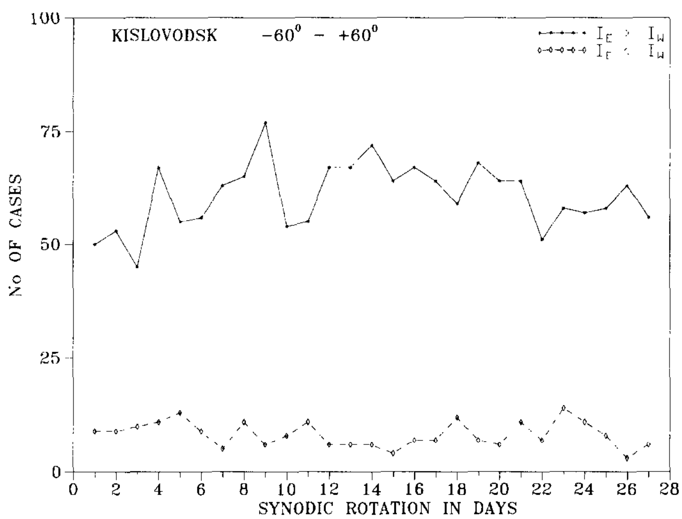


Fig. 2. Number of cases where the east part of the solar corona appears brighter ($I_E > I_W$) or fainter ($I_E < I_W$) than the west in the green spectral emission.

Nevertheless, even for this temporality and locally limited sample of data the inequality of the emission between the east and the west solar corona sector, where the east predominates ($I_E > I_W$), is obvious. Five of the nine values show a clear predominance of the East limb brightness against the west, two of them show the opposite and two are almost equal to zero, which manifests equal brightness on both solar limbs. The appearance of E–W asymmetries in the red line intensities of the Irkutsk observatory is very important given the nature of the coverage. The data were very few and isolated in two partly antidiametrical sectors south of the solar equator. Moreover, the red line intensity does not constitute the best indicator of E–W asymmetries. The asymmetry coefficient and the variation amplitude in this coronal spectral line are both very small so E–W asymmetries do not show up very clearly. Consequently, the east side predominance which appear in Fig. 3 gives strong support for the whole question of the coronal E–W asymmetries.

Table 1
Total number of daily observations obtained by Kislovodsk observatory that participate in our calculations

| Time span | Total number of daily observations | Number of observations that do not fulfill our criteria | Number of observations that participate in our calculations |
|---|---|---|---|
| 1971–1991 | 2265 | 378 | 1887 |

Finally, in Fig. 4 we present the east-west asymmetry coefficient which has been calculated by the green line intensities collected by the coronagraph of the Slovakian solar observatory, Lomnisky Styt.

The absence of a permanent east side predominance, because of the equality between cases where the intensity of the east or the west part of the solar corona predominates, is evident in Fig. 4. However, it is very interesting that the predominance of $I_E > I_W$ and $I_E < I_W$ cases do not vary randomly along the 27 day histogram. In the half of it ($3^d$–$16^{th}$ synodic day) the $I_E < I_W$ cases predominate while in the rest of it ($17^{th}$–$2^d$ synodic day) the opposite case ($I_E > I_W$) occurs. Perhaps we have to take in mind that the green line data of the Lomnisky Styt observatory present an essential peculiarity. They are not pure observations of a single observatory but a collection of various observatory measurements which have been homogenized and unified in a complete green

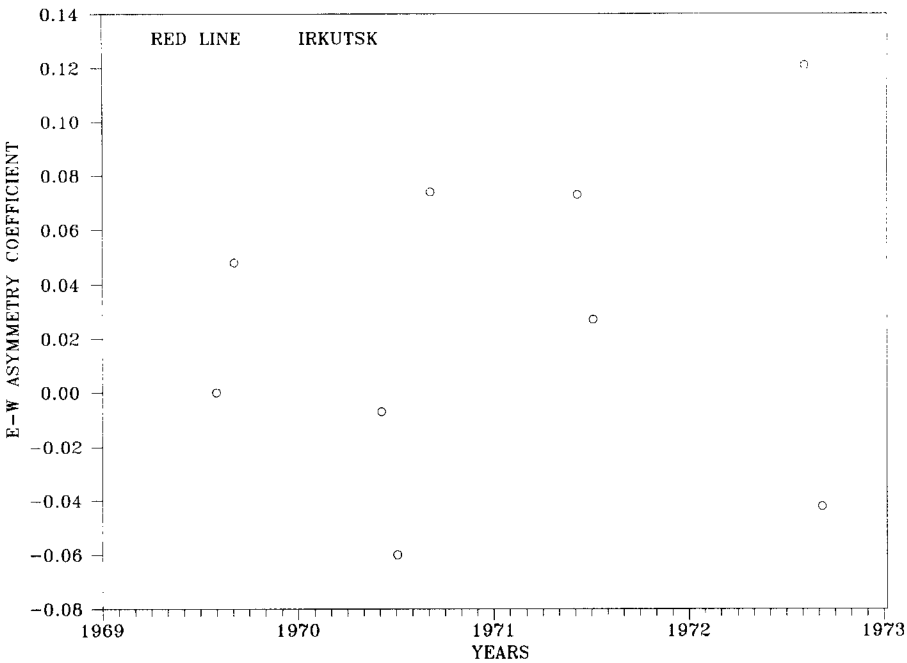


Fig. 3. Five positive cases ($I_E > I_W$) versus two negative ($I_E < I_W$) and two neutral ($I_E \approx I_W$) in the few red line intensity measurements of the Irkutsk observatory.

line intensity time series running from 1939 to the present. In addition, a large number of interpolated data have been included in the compilation of the final time series (Rybansky, 1975).

The partly negative result of the Lomnisky Styt data processing, where a permanent east side predominance is absent, is very positive because it can lead to useful derivations. We have already mentioned in previous papers that an east side predominance should be a small scale effect which does not extent further than a few millionth of the photospheric intensity in the center of the solar disk. Consequently, the homogeneization of a time series which contains data from various observatories suppresses small scale events like east-west asymmetries. The absence of an east-west asymmetry feature from Fig. 4 leads to the conclusion that pure raw observational data of a single observatory should be processed in order for this effect to be clear and prominent.

In Figs. 1–3, where the data complete this fulfillment, the presence of an east-west asymmetry feature is indisputable.

## 4. Discussion

Several papers published since the fifties have pointed out that optical emissions coming from the east part of the solar corona are more intensive on the average than those coming from the west, forming in this way an E–W asymmetry of the optical emissions of the solar corona. In general, E–W asymmetries of solar features are not easily understandable.

An exception applies only to solar emissions and ejections which could be driven by the interplanetary magnetic field or their radial trajectory could be curved by the solar rotation. We have already mentioned that a recent study of all the known errors which affect coronagraphic observations has failed to

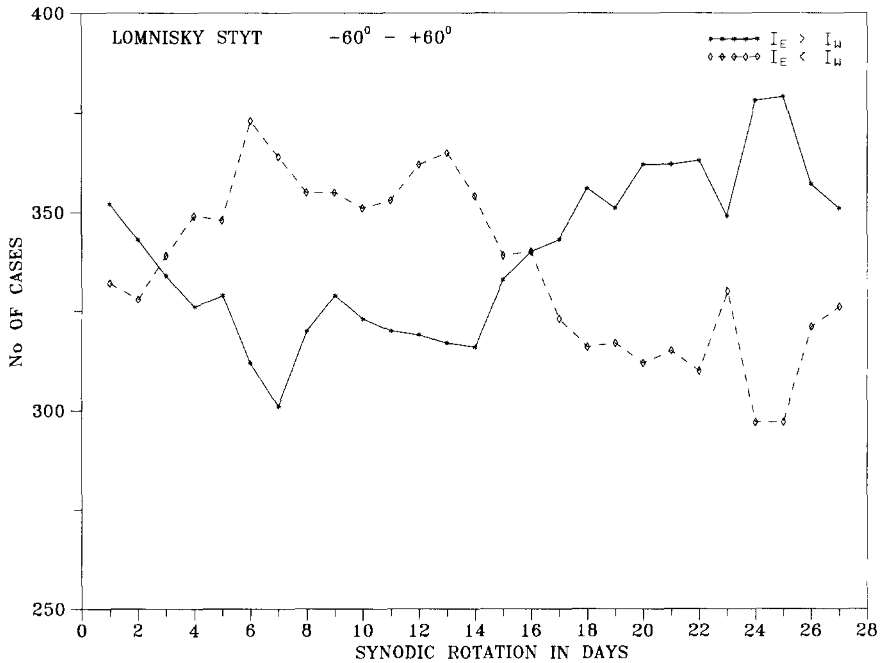


Fig. 4. Number of cases where the east part of the solar corona appears brighter ($I_E > I_W$) or fainter ($I_E < I_W$) than the west in the green line intensity homogenized time series of the Lomnisky Styt observatory.

attach some of them with the above mentioned E–W asymmetries (Tritakis et al., 1995).

Given the above, there are two possibilities, either to look for an unknown error which introduces E–W asymmetries or to accept this asymmetry as a physical phenomenon and seek a reasonable interpretation. The first possibility needs continued attention from observers and those dealing with instrumentation. Concerning the second possibility, the first possible attempt to interpret this event has been made by Trellis (1960) who attributed this phenomenon to external influences of the solar activity which have been created due to the motion of the planetary system towards the bright star Vega in the Lyrae constellation. The Sun itself moves to the point $\alpha = 18\,\mathrm{h}$, $\delta = 30°$ called Apex, with a velocity of about 20 km/sec. Trellis (1960), (1967) reported that the green coronal line is brighter in the solar region facing to the Apex while the red line in the same area is fainter. In addition, he mentioned that more active regions seemed to be born at heliocentric longitudes facing to the Apex as a consequence of asymmetry in the structure of the electromagnetic fields which occur due to the motion of the Sun towards the Apex.

Fig. 5 sketches the epochal location of the earth around the Sun, in relation to the Apex, while the Max and Min symbols denote areas of maximum and minimum E–W asymmetry values of the coronal green line intensity.

In case the solar motion to the Apex has really some influence on the formation of the solar activity, a seasonal variation of the E–W asymmetry should be expected. In Fig. 6, the above expectation looks to be well supported. This figure has been detached by a series of figures illustrating the seasonal variation of the E–W asymmetry, which is going to be included in a forthcoming paper and has been constructed by intensity values higher than the threshold of $T = 140 \times 10^{-6}\ B_{\odot}$, which have been

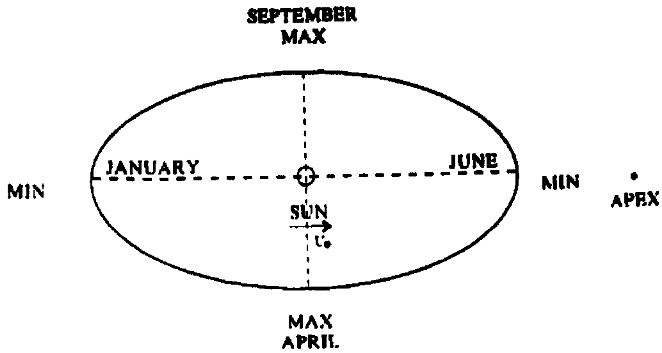


Fig. 5. Epochal location of the earth around the Sun, in relation to the apex point. Areas of maximum and minimum values of the east-west difference of the coronal spectral emission brightness are also depicted.

processed by the second technique described in Section 2. The prominent peaks around the equinoxes which are obvious in this figure imply clearly that a possible influence of the solar motion towards the Apex on the formation of the above mentioned E–W asymmetries predominates in high intensity emissions. In our case, green line intensities above a threshold of $140 \times 10^{-6} B_{\odot}$ make the seasonal variation effect of the E–W asymmetries very evident.

Another possible approach towards a reasonable

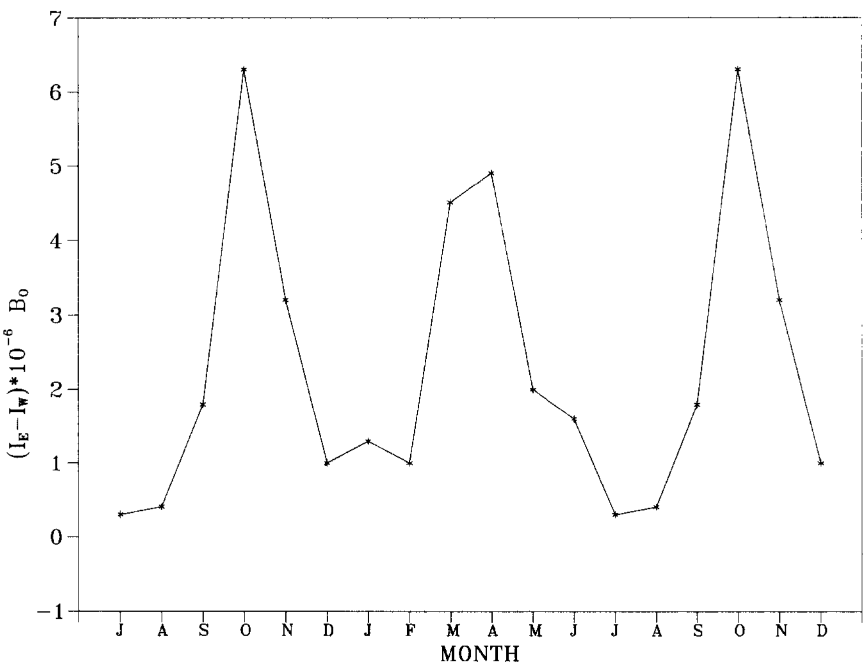


Fig. 6. Seasonal variation of the green line intensity differences between the east and the west part of the solar corona which exceeds the $140 \times 10^{-6} B_{\odot}$ threshold.

interpretation of E–W asymmetries is to consider the periodical brightness gradient differences between extreme west and east limb darkening profiles of the Sun which have been detected in high speed heliometric scans (Yerle, 1988). Clear brightness gradient differences between the east and the west limb darkening profiles are obvious in certain days of observation. If this effect is present in a long series of observations, a good background for further discussion in the direction of the interpretation of the E–W coronal optical emissions will have been built. However the most hopeful case for interpreting E–W asymmetries is a 3-D MHD model describing radial supersonic transalfvenic plasma thermal expansion. A main point of this model is the latitudinal and longitudinal velocity variation of the solar wind which increase with the heliocentric distance. These variations could be caused by magnetic field fluctuations created within 5–20 R heliocentric distance. Small latitudinal and/or longitudinal magnetic field variations of the order of 5% arising in the subalfenic region could create great latitudinal and/or longitudinal solar wind velocity variations in the superalfenic region (Pisanko, 1996).

Longitudinal magnetic field variations triggering longitudinal solar wind velocity variations which in turn create E–W asymmetries in the coronal optical emissions is an attractive subject which will be discussed in a future article.

## 5. Summary

The main point of the present article is the confirmation of E–W asymmetries in the optical emission intensities of the solar corona, which have been determined in the data of several observatories.

Two methods of processing applied mainly in the Pic-du-Midi observatory data sets, but in the Kislovodsk and Irkutsk observatories as well, have led to the conclusion that a prominent E–W asymmetry is present in all the data series of the above observatories. In contrast the absence of an E–W asymmetry from the homogenized data of the Lomnisky Styt observatory has underlined how weak is this effect. Raw data of single observatories must be used if we wish to find E–W asymmetries with certainty.

A very impressive seasonal variation in the green line E–W asymmetry measurements is also evident. Values higher than the threshold of $140 \times 10^{-6} B_{\odot}$ form a very characteristic variation with two maxima in the equinoxes and two deep minima in the solstices.

We have already mentioned that E–W asymmetry in any solar feature it is not easy to understand. However, some recent but also older studies have begun to shed light to the mystery.

For the present it is almost certain that none of the known observational errors is responsible for this sort of asymmetry (Tritakis et al., 1995). Consequently, the work of Yerle (1988) on the periodical brightness gradient differences between extreme east and west limb darkening profiles as well as the 3-D MHD model of the radial supersonic transalfenic plasma thermal expansion of Pisanko (1996), offer a significant physical background for further studies towards interpreting the formation of solar E–W asymmetries. Thus it is very likely that there already exists a simple kinematic and a more complicated 3D MHD model which can represent to some extent an east side predominance of the optical emissions of the solar corona. An integrated interpretation of this effect is anticipated in the near future.

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