THE EVOLUTION AND THE SECONDARY MAXIMUM OF THE GREEN LINE INTENSITY

J. XANTHAKIS and B. PETROPOULOS
Research Center for Astronomy and Applied Mathematics, Academy of Athens, Anagnóstopoulou 14, Athens, Greece

and

H. MAVROMICHALAKI
Cosmic Ray Group, University of Athens, Nuclear Physics Lab., Solonos 104, Athens 144, Greece

(Received 1 July, 1980; in final form 26 May, 1981)

Abstract. A new relation has been given in order to calculate the intensity of the green line of the solar corona at 5303 Å as a function of the number of proton events N_p and the $I_\alpha(R)$ index of solar activity. This relation is available for the 19th and 20th solar cycles. Moreover there is given a theoretical justification of this relationship taking into account as a new parameter the evolution of the coronal magnetic field during the solar cycle.

1. Introduction

The existence of two maxima in the sunspot activity during an 11-year solar cycle was first shown by Gnevyshev (1967) for the period 1954–1962. He also showed similar maxima in other indices of solar activity. In our days the study of different solar phenomena has confirmed the fact that the 5303 Å coronal line intensity, which reveals a basic feature of solar activity, has indeed two distincts maxima with different physical properties for every 11-year solar cycle (Gnevyshev and Antalová, 1965; Gnevyshev and Křivský, 1966; Gentilli *et al.*, 1966; Waldmeier, 1971; Cuperman and Sternlieb, 1972; Pathak, 1972; Antonucci and Svalgaard, 1974; Leroy and Trellis, 1974a; Rušín *et al.*, 1979; Rušín, 1980, etc.).

Many investigators have attempted to find relations between the coronal green line intensity and the classical indices of solar activity, i.e. the relative Wolf number (Leroy and Trellis, 1974a), areas index (Xanthakis, 1969), etc., in order to estimate the values of the coronal green line intensity when data of this intensity are not available.

Xanthakis (1969) has found the following empirical relationship between the coronal green line intensity I_{5303}, the areas index I_α and the number of proton flares N_{PF} for the time interval 1954–1964:

$$I_{5303} = I_0 + KI_\alpha(1+\sqrt{N_{PF}}) , \tag{1}$$

where $K = 0.165$ and I_0 is the intensity of the green line corresponding to the epoch of the quiet Sun ($I_0 = 14$). For this relationship three months data of the I_{5303} intensity of the Pic-du-Midi station have been used. The computed values

Solar Physics **76** (1982) 181–190. 0038–0938/82/0761–0181 $01.50.

of I_{5303} by this relation were close to the measured ones during the 19th solar cycle, as Xanthakis (1969) has shown.

Later, Leroy and Trellis (1974a) have established the following relation between the coronal green line intensity I_{5303} and the Wolf number R:

$$I_{5303} = \left(1 + \frac{R}{110}\right) 28 \times 10^{-8} I_{\odot}, \tag{2}$$

where I_{5303} is the integrated annual intensity of the coronal green line of the Pic-du-Midi observatory for the solar cycles 18, 19, and 20 and $I_{\odot}$ is the intensity of light of solar disk. The intensities computed with the relation (2) present significant deviations from the measured ones especially near the secondary maximum of I_{5303} intensity (see Figure 1).

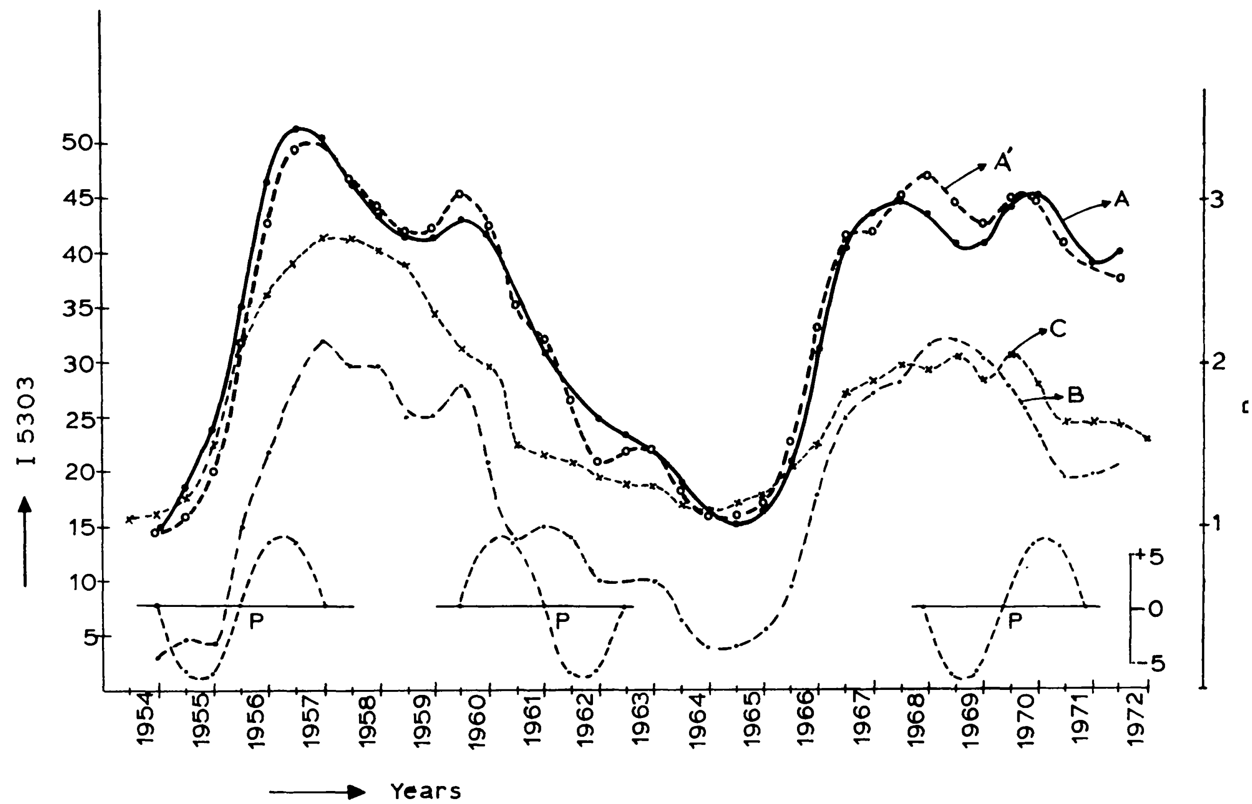

Fig. 1. Time dependence of the I_{5303} intensity in 19th and 20th solar cycles. The curve A (continuous line) gives the semiannual values of I_{5303} intensity measured at the Pic-du-Midi Observatory and the curve A' (dashed line) the semiannual values calculated by the relation (4) (smoothed values). The curve B presents the variation of the term $0.155(1+\sqrt{N_p})I_\alpha(R)$. The curve P presents the variation of the periodic term $P(t)$. The curve C gives the calculated by the Equation (2) values of the term $[1+(R/110)]$ (Leroy and Trellis, 1974a) (smoothed values).

In this work we propose a more correct formula for the intensity I_{5303}, the index $I_\alpha(R)$ (see Section 2) and the number of proton events N_P which can be applied for the time interval of 19th and 20th solar cycle, namely the years 1954–1972. Also a theoretical justification of this empirical relation is given taking into account the evolution of the coronal magnetic field during the solar cycle.

2. Data Analysis and Results

The coronal green line intensity data used in the present analysis have been obtained at the Pic-du-Midi station for the period 1954–1972. Also the number of the most important proton events, N_P, measured in polar caps (Shapley *et al.*, 1977, 1979) has been used for the same period.

It is noted that instead of the areas index I_α which Xanthakis (1969) had used in relation (1), we have used the index $I_\alpha(R)$ because data of the sunspots and faculae areas from the Greenwich Observatory are not available after the year 1966. So it was not possible to compute the index I_α for the time interval of 20th solar cycle. The new index $I_\alpha(R)$ is a successful approximation of the index I_α as Xanthakis and Poulakos (1978) have shown and can be computed by the following relation:

$$I_\alpha(R) = 56 - 3(18 - \sqrt{R}) \cos^2 \frac{\pi}{36} R, \tag{3}$$

where R is the relative number of Zürich.

Data of the index R are taken from the tables of the *IAU Quarterly Bulletin on Solar Activity*. Half-year values of the above-mentioned data over the whole period 1954–1972 are given in Table I.

Examining in detail all these data we give the following interesting relation for the two solar cycles, 19 and 20:

$$I_{5303} = C + 0.155(1 + \sqrt{N_P}) I_\alpha(R) + P(t) , \tag{4}$$

where $C_1 = 12$ for the years of the solar minimum 1954 and 1963(I)–1966(I) and $C_2 = 17$ for the other years 1955(I)–1962(II) and 1966(II)–1972(II).

$P(t)$ is a periodic term with a period of three years which has the same phase for the ascendant branches of solar activity and inverse phase for the descendant branches:

$$P(t) = \pm 7 \sin \frac{2\pi}{6} t \qquad (t = 0, 1, \ldots, 6) \tag{5}$$

$$- 1954(\mathrm{II})–1957(\mathrm{II})$$

$$+ 1960(\mathrm{I})–1963(\mathrm{I})$$

$$- 1968(\mathrm{II})–1971(\mathrm{II}).$$

The values of I_{5303} intensity computed by the relation (4) are given in Table I. The standard deviation between observed and calculated values of I_{5303} intensity is $\sigma = \pm 3.48$.

The values which are given in parentheses (Table I) are the I_{5303} values smoothed by the method $(n_{i-1} + 2n_i + n_{i+1})/4$. These data are presented in Figure 1. The good agreement betweeen the observed values (continuous line A) and those calculated by the relation (4) (dashed line A') is obvious. It is interesting to note that the

TABLE I

Semiannual values of the I_{5303} intensity measured (I_{5303}^{obs}) and calculated (I_{5303}^{cal}) by the relation (4) over the period 1954(I)–1972(II), the number of proton events N_P and the index $I_\alpha(R)$. The values in parentheses are the smoothed ones of I_{5303} intensity

Date	I_{5303}^{obs}	N_{PF}	$I_\alpha(R)$	I_{5303}^{cal}	Date	I_{5303}^{obs}	N_{PF}	$I_\alpha(R)$	I_{5303}^{cal}
1954 I	12.6		7.55	13.5	1964 I	18.9 (19.0)	1	16.82	17.2 (18.3)
II	12.6 (14.8)		11.81	13.8 (14.7)	II	15.1 (16.1)	0	12.88	14.0 (15.7)
1955 I	21.4 (18.4)	1	21.32	17.5 (15.7)	1965 I	15.4 (15.1)	1	17.96	17.6 (16.0)
II	18.2 (23.8)	0	19.97	14.0 (20.1)	II	14.6 (16.1)	0	18.36	14.8 (17.1)
1956 I	37.5 (35.2)	2	48.07	34.9 (31.7)	1966 I	19.7 (21.2)	1	29.24	21.0 (22.7)
II	47.6 (46.5)	2	53.37	43.1 (42.7)	II	30.6 (31.2)	4	36.43	33.9 (33.2)
1957 I	53.2 (51.3)	5	53.09	49.8 (49.5)	1967 I	43.9 (40.4)	9	43.69	44.1 (41.9)
II	51.3 (50.4)	12	55.15	55.1 (50.5)	II	43.0 (43.7)	9	45.64	45.3 (44.2)
1958 I	45.8 (48.5)	4	54.08	42.1 (46.7)	1968 I	44.8 (44.5)	6	47.22	42.2 (45.3)
II	43.1 (43.4)	7	54.18	47.6 (44.3)	II	45.2 (43.6)	14	46.75	51.3 (47.0)
1959 I	41.7 (41.3)	3	53.65	49.7 (42.0)	1969 I	39.1 (40.8)	11	48.36	43.3 (44.6)
II	38.7 (41.2)	4	51.36	40.9 (42.2)	II	39.7 (40.9)	10	45.94	40.6 (42.8)
1960 I	45.6 (43.0)	9	48.67	47.2 (45.5)	1970 I	45.1 (44.4)	9	48.21	46.9 (45.0)
II	42.2 (41.4)	5	47.13	46.8 (42.4)	II	47.7 (45.4)	5	45.26	45.8 (44.9)
1961 I	35.6 (36.2)	0	36.62	28.8 (35.4)	1971 I	41.1 (41.9)	5	35.84	41.1 (41.1)
II	31.5 (30.7)	8	34.04	37.2 (31.0)	II	37.6 (39.1)	4	41.71	36.4 (38.3)
1962 I	24.3 (26.7)	3	32.27	24.6 (26.4)	1972 I	40.1 (40.3)	6	41.27	39.1 (37.6)
II	26.7 (24.9)	1	26.74	19.2 (21.1)	II	43.6	5	37.51	35.8
1963 I	21.7 (23.3)	2	25.58	21.5 (21.7)					
II	23.2 (21.8)	5	25.17	24.6 (22.0)					

computed values of I_{5303} are very close to the measured ones, even in the region of the secondary maximum of solar activity. The standard deviation calculated by the smoothed data from Table I is ± 1.93. For comparison the smoothed result of the term $[1+(R/110)]$ of Equation (2) (Leroy and Trellis, 1974a) is also shown in Figure 1.

3. Theoretical Formulation of the Empirical Estimation of I_{5303} Intensity

The intensity of an emission line I_i of the solar corona spectrum is given by the following equation (Dollfus, 1971):

$$I_i = K_i T_e^{-1/2} e^{-W/KT_e} \frac{N_z}{N_0} N_e^{1+\alpha}, \tag{6}$$

where

N_e is the local electron density,
T_e the electron temperature,
N_0 the total number of the atoms of the element,
N_z the population of the upper level,
W the transition energy,
K the Boltzman constant,
K_i, α constants, and $0 \leq \alpha \leq 1$.

The coefficient α in the region of the corona has values between 0.5 and 1 (Dollfus, 1971). For the intensity of the coronal green line at 5303 Å Zirker (1971) estimated that the coefficient α had the value 0.62, while Fisher (1977) found that the coefficient α was 0.67. These values of α are found by the theory of Unsöld (1970) in which the variation of the coronal magnetic field with time is not considered.

According to Equation (6) the intensity of coronal green line for one observed line is given (Leroy and Trellis, 1974b; Leroy *et al.*, 1973) by the relation:

$$I_{5303} = \int_{-\infty}^{+\infty} A(T_e) N_e^{1+\alpha} \, \mathrm{d}x, \tag{7}$$

where $A(T_e)$ is a distribution function of the electron temperature which is estimated theoretically by Equation (6).

In order to express the intensity I_{5303} in terms of $I_\alpha(R)$ and N_P the following assumptions have been taken into account:

(1) The function $A(T_e)$ can be given by the following expression:

$$A(T_e) = I_\alpha(R) F(T_e), \tag{8}$$

where $F(T_e)$ is α function of the electron temperature that can be obtained by the relation (6).

This assumption is based on the fact that the mean yearly electron temperature of the corona has the same behaviour with the index of solar activity R (Trellis, 1957; Leroy and Trellis, 1974b). Moreover the better correlation which was found from our data analysis between I_{5303} and $I_\alpha(R)$ ($r_{19\ \text{cycle}} = 0.940$, $r_{20} = 0.911$) than that between I_{5303} and R ($r_{19} = 0.849$, $r_{20} = 0.890$) justifies the above assumption.

(2) The electron density of corona is proportional to the solar magnetic field. However, also the production of proton flares is proportional to the magnetic field so that the following relation can be adopted:

$$N_e = N_P N_e(t)$$

and

$$\Delta N_e = N_e - \bar{N}_e = N_P \Delta N_e(t)\,, \tag{9}$$

where $N_e(t)$ is a function of time, $\bar{N}_e$ is the electron density of the corona for a quiet Sun, and $\Delta N_e(t) \approx \bar{N}_e$.

The electron density of corona shows large condensations over the period of the second maximum of I_{5303} (Leroy and Trellis, 1974b), which corresponds for the second maximum in the number of proton flares (Gnevyshev, 1967, 1977), because the dynamic lines of the coronal magnetic field are closed (Yoshimura; 1977a, b, c) during that period. The electron density has also minimum values about the minima of I_{5303}, which corresponds to the observed 'coronal holes' at that time interval. Linear relations have been established between the area of the 'coronal holes' and the intensity I_{5303} (Nolte, 1976; Simon, 1979).

With the help of the relations (8) and (9) Equation (7) becomes

$$I_{5303} = \int_{-\infty}^{+\infty} I_\alpha(R) F(T_e) \bar{N}_e^{1+\alpha}\,(1 + N_P)^{1+\alpha}\,\mathrm{d}x \tag{10}$$

which is an analytical expression of I_{5303} with the indices N_P and $I_\alpha(R)$. If the binomial is developed in series, the variation of I_{5303} ($\Delta I_{5303} = I_{5303} - I_0$) is given by the sum of three terms:

$$I_{5303} = I_0 + (1+\alpha) I_\alpha(R)(1 + N_P^\alpha) \int_{-\infty}^{+\infty} \Delta F(T_e) \bar{N}_e^{1+\alpha}\,\mathrm{d}x\,-$$

$$-\alpha I_\alpha(R) \int_{-\infty}^{+\infty} \Delta F(T_e) \bar{N}_e^{1+\alpha}\,\mathrm{d}x\,, \tag{11}$$

where I_0 is the intensity of I_{5303} during the quiet Sun.

In this equation, for example, a value of coefficient $\alpha = 0.65$ is adopted that is the mean value of the two theoretical values calculated by Zirker (1971) and Fisher (1977). Also it is assumed that $N_P^\alpha \simeq N_P^{0.65} \simeq \sqrt{N_P}$ with a maximum error of 20%

for the maximum of $N_P = 14$ (Table I). So, by identifying this equation with the relation (1) it is found that

$$\int_{-\infty}^{+\infty} \Delta F(T_e)\bar{N}_e^{1+\alpha}\, \mathrm{d}x = 0.1 \tag{12}$$

and the last term of the relation (11) which has a coefficient 0.065 has been neglected.

4. Coronal Magnetic Field as Parameter

In order to give a more correct formula for the intensity of coronal green line I_{5303} it will be useful to take into account variations of the function $F(T_e)$ with the coronal magnetic field intensity.

It is known that the evolution of the magnetic field intensity does not change by Stark effect the profile of coronal green line intensity, but changes only the electron temperature and density of corona (Unsöld, 1970). So, the coronal magnetic field intensity can be used as a parameter for the study of the variations of I_{5303}. According to this the variation of the function $F(T_e)$ can be given by the relation

$$\Delta F(T_e) = F_1(T_e)F_2(T_e)\,, \tag{13}$$

where

$$F_1(T_e) = \left[\frac{\mathrm{d}F(T_e)}{\mathrm{d}B}\right] \quad \text{and} \quad F_2(T_e) = \int \frac{\mathrm{d}B}{\mathrm{d}T_e}\,\mathrm{d}T_e\,.$$

This assumption is based on the measurements by Dollfus (1971) who has found no displacement of the line 5303 Å for a long time of observations.

According to Yoshimura (1977c) the coronal magnetic field intensity B can be considered as the sum of two components: The toroidal component $B(\vartheta, \varphi)$ and the radial one B_r. The radial component can be developed into a series of Legendre polynomials, normal-modes (Stix, 1977):

$$B = B(\vartheta, \varphi) + B_r = B(\vartheta, \varphi) + \sum_{i=0}^{n} (A_i + S_i)\,, \tag{14}$$

where A_i are the axisymmetric and with respect to the equator antisymmetric parts of the field (E–W asymmetry) and S_i are also axisymmetric but symmetrics with respect to the equator (N–S asymmetry).

Taking into account the above assumption the relation (11) can be written as

$$\begin{aligned} I_{5303} = {} & I_0 + (1+\alpha)(1+\sqrt{N_P})I_\alpha(R)F^0(T_e) + \\ & + [(1+\alpha)(1+\sqrt{N_P}) - \alpha]I_\alpha(R)[\widetilde{A_1(0)} + \widetilde{S_1(0)} - \alpha F^0(T_e)] + \\ & + [(1+\alpha)(1+\sqrt{N_P}) - \alpha]I_\alpha(R)[\tilde{A}_2 + \tilde{S}_2]\,, \end{aligned} \tag{15}$$

where

$$F^0(T_e) = \int_{-\infty}^{+\infty} F_1(T_e)\bar{N}_e^{1+\alpha} B'(\vartheta, \varphi)\,\mathrm{d}x\,,$$

$$\widetilde{A_1(0)} = \int_{-\infty}^{+\infty} F_1(T_e)\bar{N}_e^{1+\alpha} A_0'\,\mathrm{d}x\,,$$

$$\widetilde{S_1(0)} = \int_{-\infty}^{+\infty} F_1(T_e)\bar{N}_e^{1+\alpha} S_0'\,\mathrm{d}x\,,$$

$$\tilde{A}_2 = \int_{-\infty}^{+\infty} F_1(T_e)\bar{N}_e^{1+\alpha} (A_1' + A_2' + \cdots)\,\mathrm{d}x\,,$$

$$\tilde{S}_2 = \int_{-\infty}^{+\infty} F_1(T_e)\bar{N}_e^{1+\alpha} (S_1' + S_2' + \cdots)\,\mathrm{d}x\,.$$

Comparing the empirical relation (4) with the theoretical formula (15) we find for $\alpha = 0.55$ (a value which is in agreement with the theoretical values given by Dollfus (1971)):

$$F^0(T_e) = 0.1\,,$$

$$C_{1,2} = I_0 + (1 + 1.55\sqrt{N_P})[\widetilde{A_1(0)} + \widetilde{S_1(0)} - 0.055]I_\alpha(R)\,,$$

and

$$P = (1 + 1.55\sqrt{N_P})[\tilde{A}_2 + \tilde{S}_2]I_\alpha(R)\,. \tag{16}$$

For the time interval when solar activity takes minimum values (1954(I), 1963(I)–1966(II)) we have calculated the mean value $\bar{C}_1 = 11.5$ by using the data of the Table I and taking into account that $(\widetilde{A_1(0)} + \widetilde{S_1(0)}) = 0$ (Yoshimura, 1977c). This value is very close to the value $C_1 = 12$ that has been calculated by the empirical relation (4). For the other time interval if it is taken $C_2 = 17$, it can be estimated an upper limit of $\widetilde{A_1(0)} + \widetilde{S_1(0)} = 0.01$. This value is in good agreement with the values computed by Stix (1977).

The normal modes $(A_1, A_2, \ldots S_1, S_2 \ldots)$, as Stix (1977) has shown, have significant values for the time interval 1960–1963 and 1969–1972. For these time intervals the function $P(t)$ has been calculated by using the values of N_P and $I_\alpha(R)$ of Table I and the A_i and S_i theoretical values given by Stix (1977). It is found that this function can be fitted by the expression $P(t) = \mp 7 \sin (2\pi/6)t$. It is interesting to note that for the same time intervals the E–W asymmetry of I_{5303} for the measured values of Pic-du-Midi is very small. This asymmetry is expressed in relation (15) by the normal modes $A_1, A_2, \ldots A_n$ which have also small values (Stix, 1977). On the other hand, the N–S asymmetry of I_{5303} has important values (Rušín, 1980) during these time periods and can be expressed by the $S_1, S_2, \ldots S_n$ normal modes (Stix, 1977). It is noteworthy that for these years the N–S asymmetry of I_{5303} and the term $(1+1.55\sqrt{N_P})\tilde{S}_2 I_\alpha(R)$ change phase simultaneously. It has been found that the N–S asymmetry changes polarity for the years 1956 and 1970 as $P(t)$ does in the empirical relation (4) (Fracastoro, 1978).

5. Conclusions

From all the above it is concluded that the new empirical relation (4) can successfully be used for computing the intensity of coronal line at 5303 Å. The calculated values from this relation are in good agreement to the measured ones during the 19th and 20th solar cycles even near the second maximum of them. This good agreement is obtained because we have taken into account not only the solar activity index $I_\alpha(R)$ but also the index N_P, that has two maxima for every solar cycle.

It is interesting to note that the two maxima of I_{5303} intensity can be interpreted by taking into account the evolution of the coronal magnetic field. The intensity of this field can be considered as the result of two components: One due to the poloidal field which exists on the solar surface without any direct relationship to the solar proton events and another due to the convection of the toroidal field into poloidal or radial fields through the formation of proton events and through subsequent penetration of the magnetic field into the corona. The first component is independent of the $\sqrt{N_P}$ in relation (15); the second one is dependent on this factor. In fact, superposition of the two fields can explain the two maxima of the coronal activity.

The empirical relationship (1) is an approximation of the relation (4) where the evolution of the magnetic field intensity is not taken into account. This relation can be used to compute the intensity of I_{5303} for a small time interval of one solar cycle (19th). This expression gives two maxima for this cycle, in spite of the relation (2) (Leroy and Trellis, 1974a) which gives only one maximum (the solar activity index R has only one maximum).

Summarising it is noted that the second part of the relation (4) is an index of coronal activity with two variables, N_P, which has two maxima, and $I_\alpha(R)$. Different solar and terrestrial phenomena that present two maxima for every solar cycle can be correlated with this solar index. Some of them are: The distribution of the chromospheric flares (Kopecký, 1973), the number of flares with radio emission II or IV (Dodge, 1975; Papagiannis *et al.*, 1972; Fritzová and Švestka, 1973), the Bartel index A_P (Gnevyshev, 1977; Simon, 1979), the frequency of the aurora lays (Pokorný, 1973), the intensity of the cosmic radiation (Křivský and Růžičková-Topolová, 1978), and the intensity of the interplanetary magnetic field (Simon, 1979).

Acknowledgements

Thanks are due to Prof. Rösch and Dr Leroy for their kindly supplying data of I_{5303} intensity of Pic-du-Midi Observatory. Also thanks are due to Miss N. Kalivioti of the Nuclear Physics of Athens University for technical assistance.

References

Antonucci, E. and Svalgaard, L.: 1974, *Solar Phys.* **34**, 3.
Cuperman, S. and Sternlieb, A.: 1972, *Solar Phys.* **25**, 493.
Dodge, J.: 1975, *Solar Phys.* **42**, 445.
Dollfus, A.: 1971, in C. J. Macris (ed.), *Physics of Solar Corona* **27**, 97.
Fisher, R. R.: 1977, *Solar Phys.* **55**, 135.
Fracastoro, M. G. and Marocchi, D.: 1978, *Solar Phys.* **60**, 171.
Fritzová-Švestková, L. and Švestka, Z.: 1973, *Solar Phys.* **29**, 417.
Gentilli di Giuseppe, M., Hugon, M., Leroy, J. L., Rosch, J., and Trellis, M.: 1966, *Ann. Astrophys.* **23**, 43.
Gnevyshev, M. N.: 1967, *Solar Phys.* **51**, 175.
Gnevyshev, M. N.: 1977, *Solar Phys.* **51**, 175.
Gnevyshev, M. N. and Antalová, H.: 1965, *Publ. Czech. Acad. Sci. Astron. Inst.* **51**, 47.
Gnevyshev, M. N. and Křivský, L.: 1966, *Astron. Zh.* **43**, 385.
Kopecký, M.: 1973, *Bull. Astron. Inst. Czech.* **24**, 113.
Křivský, L. and Růžičková-Topolová, B.: 1978, *Bull. Astron. Inst. Czech.* **29**, 30.
Leroy, J. L. and Trellis, M.: 1974a, *Astron. Astrophys.* **35**, 283.
Leroy, J. L. and Trellis, M.: 1974b, *Astron. Astrophys.* **35**, 289.
Leroy, J. L., Poulain, P., and Fort, B.: 1973, *Solar Phys.* **32**, 131.
Nolte, J. T., Krieger, A. S., Timothy, A. F., Gold, R. E., Roelof, E. C., Vaiana, G., Lazarus, A. J., Sullivan, J. D., and McIntosh, P. S.: 1976, *Solar Phys.* **46**, 303.
Papagiannis, M., Zerefos, Ch., and Repapis Ch.: 1972, *Solar Phys.* **27**, 208.
Pathak, P. N.: 1972, *Solar Phys.* **25**, 489.
Pokorný, Z.: 1973, *Bull. Astron. Inst. Czech.* **24**, 107.
Rušín, V.: 1980, *Bull. Astron. Inst. Czech.* **31**, 9.
Rušín, V., Rybanský, M., and Scheirich, L.: 1979, *Solar Phys.* **61**, 301.
Shapley, A. H. and Kroehl, H. N.: 1977, Solar-Terrestrial Phys. and Meteor. Working Document II.
Shapley, A. H., Ellyett, C. D., and Kroehl, H. N.: 1979, Solar-Terrestrial Phys. and Meteor. Working Document III.
Simon, A. P.: 1979, *Solar Phys.* **63**, 399.
Stix, M.: 1977, *Astron. Astrophys.* **59**, 53.
Trellis, M.: 1957, *Suppl. Ann. Astrophys.* **5**.
Unsöld, A.: 1970, *Astron. Astrophys.* **4**, 220.
Waldmeier, M.: 1971, *Solar Phys.* **20**, 332.
Xanthakis, J.: 1969, *Solar Phys.* **10**, 168.
Xanthakis, J. and Poulakos, C.: 1978, *Pracktica Acad. Athens* **53**, 286.
Yoshimura, H.: 1977a, *Solar Phys.* **47**, 581.
Yoshimura, H.: 1977b, *Solar Phys.* **52**, 41.
Yoshimura, H.: 1977c, *Solar Phys.* **54**, 229.
Zirker, J. B.: 1971, in C. J. Macris (ed.), *Physics of Solar Corona* **27**, 140.