ΑΣΤΡΟΝΟΜΙΑ.— **On a comparison between the predicted and the observed values of the different indices of solar activity for the 20th solar cycle,** *by C. Poulakos* *. Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἰωάννου Ξανθάκη.

Introduction.

Investigations carried out during the International Geophysical Year and during the International Quiet Sun Years have led to great advances in our knowledge and understanding of the Sun's activity and its influence on the atmosphere of the Earth as well as on interplanetary space. During the period 1964 - 1967 an attempt has been made to put all the obtained information to work by forecasting some aspects of solar activity and later on to correlate the different indices of solar activity with the terrestrial phenomena.

Sunspots, even today are used as an index of solar activity in the form of the sunspot relative numbers R, which was defined by Wolf of Zurich in 1849 as $R = K\,(10g + f)$, although, as it has been pointed out by Vitinskii (1965), this index is even today subjective and used to be far less reliable. Xanthakis (1969) after careful consideration, introduced a new index of solar activity i.e. the areas index I_α, defined by the relation $I_\alpha = \frac{1}{2}\left[\sqrt{A} + \sqrt{f}\right]$ (where A and f are the total areas of sunspots and faculae respectively corrected for foreshortening). This index can express better one principal characteristic of an active region and on the other hand goes back more than 90 years and have to be used by anyone attempting long-term prediction.

The advantages of the areas index I_α over the different other indices of solar activity and especially over the relative sunspot numbers are well described in the work of Poulakos and Tritakis (1972).

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* Κ. ΠΟΥΛΑΚΟΥ, Ἐπὶ μιᾶς συγκρίσεως μεταξὺ τῶν προβλεφθεισῶν καὶ τῶν παρατηρηθεισῶν τιμῶν τῶν διαφόρων δεικτῶν τῆς ἡλιακῆς δραστηριότητος διὰ τὸν 20ον ἡλιακὸν κύκλον.

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But it was after the invention of the spectroheliograph by Hale and independently by Deslandres that it was found using H_α for example, that the sunspots are surrounded by bright regions known as plages, and it is from these plage regions that solar flares develop. Flares are catastrophic events occuring on the Sun. Since 1947 more than 12 great flares have produced particles of even higher energies (above 1GeV) in the cosmic-ray range. The particle flux from the Sun in this energy range has been detected by ground-level stations, which record the secondary particles generated in the Earth's atmosphere by the primary solar radiation. It is this high-energy particle emission from the Sun which has increased the need for a better prediction of solar activity, since such a radiation on impact with the walls of a space vehicle would produce X-rays which might be lethal to the occupants.

Some accurate predictions of atmospheric density, the variations of which show high correlation with the variations in solar activity, several years in advance are essential for optimum orbital planning and spacecraft lifetime studies for several high-priority NASA-MSFC programs.

Solar activity prediction methods to date have primarily been based on an analysis of past data as α function of time, the prediction being an extrapolation of the statistical analysis to some future time.

In 1949 Lincoln and McNish developed the first method of solar activity prediction and Slutz et al (1971) the latest one. But a detailed investigation of the different methods used for solar prediction is, however, beyond the scope of this study since our aim is to compare the up to date forecasts of solar activity with the observed values of the different indices of solar activity for the 20th solar cycle.

The highest R^y_{max} as well as of the mean annual values of the wolf numbers and the time of rise for solar cycle No. 20.

Forecasts of the relative sunspot numbers for the 20th solar cycle have been given by many investigators.

Shove (1955) calculated that the maximum of the relative sunspot numbers R^y_{max} would be of the value of 120.

Minnis (1960) found for R^y_{max} the values $100 \div 160$ while Wertlieb

(1967) and Afanasjev (1967) found for the same quantity the values $125 \div 136$ and 148 respectively.

Halley and Gervaise (1963) have also developed a quite simple method of forecasting the maximum of the relative sunspot numbers and have found that R^y_{max} will occur in 1968.7 and will be of the order of $R^y_{max} = 114.2$.

King - Hele suggested in 1966 the relation (1)

$$(R_m - 16)\, T_R^2 - 10^{-5}\, (R_m - 100)^4 \simeq 1401 \qquad (1)$$

referred to the smoothed values of the relative sunspot numbers and by adopting the value $T_R = 3.4$ for the time of rise for cycle No. 20 concluded that the next maximum will be of the order of $R^y_{max} = 140$ and will occur in 1968.1 provided that the minimum of solar activity will be taken in 1964.7.

Figure 1 shows the prediction of the mean annual relative sunspot numbers for the 20th solar cycle given by Kukushkina et al (1968).

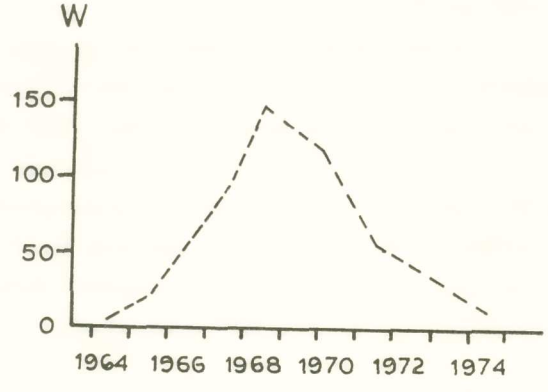

Fig. 1. The average forecast of cycle No. 20 given by Kukushkina et al.

Xanthakis (1966a, b) has adopted a new approach to the problem of the time of rise T_R and predicted among others the values of T_R for the forthcoming sunspot cycles. He particularly determined that T_R for the solar cycle No. 20 will probably not be less than 3.5 - 4 years. Therefore, taking into consideration that the minimum of cycle No. 20 occured in 1964.7, Xanthakis came to the conclusion that the next maximum of solar activity will happen not earlier than in 1968.2 - 1968.7.

Xanthakis (1967a) carried out a detailed study of the variation of solar activity using besides the smoothed also the observed values of the relative sunspot numbers the total areas of sunspots, the faculae and the prominences. He found that the main part of the variation of the mean annual values of all the above indices of solar activity within each sunspot cycle can be represented by the general relation (2)

$$[Z] = [Z_m] \cos^2 \frac{\pi}{2\Omega_{1,2}} t, \qquad t = 0, 1, 2 \ldots \tag{2}$$

where $\Omega_1 = T_R$ for the ascending branch and $\Omega_2 = 11 - T_R$ for the descending branch.

In the case of the relative sunspot numbers and on the basis of relation (2) Xanthakis (1967b) found for the sunspot cycle No. 20 the relations (3) and (4)

$$[R] = [R_m] \cos^2 \frac{\pi}{2\Omega_{1,2}} t + G_{1,2}(t) \tag{3}$$

where

$$[R_m] = 66.4 + 2\, T_O\, (T_O - T_R)^2 \tag{4}$$

On the basis of equations (3) and (4) Xanthakis (1967b) calculated the probable values of the mean annual relative sunspot numbers for values of T_R contained between $3.6 \leqslant T_R \leqslant 5.0$.

Table 1 gives the mean annual values of the relative sunspot numbers [R] for the time interval 1964 - 1974 corresponding to the values of the time of rise contained detween $3.6 \leqslant T_R \leqslant 5.0$.

Table 2 gives the observed mean annual values of [R] as well as the predicted values of this quantity computed with the help of equation (3) corresponding to the value of the time of rise $T_R = 3.8$ years.

An inspection of the differences $[R]^O - [R]^C$ given in Table 2 shows that equation (3) represents the observational data with a satisfactory approximation the accuracy being equal to 82 %.

This accuracy becomes equal to 86 % if we exclude the value of [R] corresponding to the year 1970 which as a matter of fact was an unexpected secondary maximum of the sunspot cycle No. 20.

The above results are better shown in Figure 2, where the continuous line represents the predicted values of [R] corresponding to the value of the time of rise $T_R = 3.8$ and the dashed line represents the

TABLE 1.

Predicted values of the mean annual relative sunspot numbers [R] for the successive years of the sunspot cycle No 20 corresponding to the values of the time of rise $3.6 \leqslant T_R \leqslant 5.0$.

Years \ T_R	3.6	3.8	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0
1964	3.6	0.8	0.0	0.1	0 6	1.1	1.8	2.5	1.6	0.8	0.3	0.1	0.0
5	16.1	19.7	23.0	24.5	25.8	27.1	28.3	2.5	3.4	4.3	5.2	6.1	6.9
6	61.1	62.3	62.5	62.4	62.2	61.9	61.6	29.3	30.2	31.0	31.9	32.6	33.3
7	106.7	100.9	95.2	92.5	89.9	87 4	85.1	61.2	60.8	60.3	59.9	59.6	59.3
8	**120.1**	**110.6**	**102.0**	**98.1**	**94.4**	**90.9**	**87.7**	82.9	80.8	78.8	77.2	75.6	74.2
9	106.7	97.3	88.8	85.0	81.4	77.9	74.7	**84.7**	**81.9**	**79.3**	**77.0**	**74.9**	**73.0**
1970	88.2	79.3	71.3	67.7	64.1	60.9	57.8	71.8	69.0	66.4	64.0	61.9	60.0
1	69.5	61.5	54.2	51.0	47.8	44.8	42.0	54.9	52.2	49.6	47.3	45.2	43.3
2	52.4	45.7	39.7	36.9	34.3	31.8	29.5	39.3	36.9	34.5	32.3	30.3	28.4
3	36.7	31.7	27.3	25.4	23.5	21.8	20.2	27.4	25.3	23.4	21.6	19.8	18.2
4	21.8	18.9	16.6	15.5	14.7	14.0	13.3	18.8	17.4	16.1	15.0	13.9	13.0
5	—	—	—	—	—	—	—	12.8	12.3	12.0	11.7	11.6	11.5

TABLE 2

The observed values of the mean annual relative sunspot numbers [R]^O as well as the values of this quantity computed from equation (3) [R]^C, and the differences O - C.

Year	[R]^O	[R]^C	O — C	Accuracy
1964	10.5	0.8	+ 9.7	$\left(1-\frac{\sigma}{[\bar{R}]}\right) 100 = 82\ \%$
5	15.0	19.7	— 4.7	
6	46.8	62.3	—15.5	
7	93.6	100.9	— 7.3	
8	105.8	110.6	— 4.8	
9	105.5	97.3	+ 8.2	
1970	104.6	79.3	+25.3	
1	66.6	61.5	+ 5.1	
2		45.7		
3		31.7		
4		18.9		

observed values of the same qauntity. Kukushkina's prediction has also been included in this figure for comparison purposes.

From Figure 2 we see that Xanthakis's prediction is not only a successful one, since his predicted values of [R] are very well closed to the corresponding observed ones (with the exception of 1970), but also much superior than the prediction given by Kukushkina et al. (1968).

Xanthakis (1967b) has also predicted the highest R^y_{max} and the lowest R^y_{min} of the monthly relative sunspot numbers by means of relations (5) and (6).

$$\left.\begin{aligned} R^y_{max} &= R_{max}\cos^2\frac{\pi}{2T_R}t + G_1 \quad \text{ascending branch} \\ R^y_{min} &= R_{min}\cos^2\frac{\pi}{2T_R}t + g_1 \quad \text{»} \quad \text{»} \end{aligned}\right\} \quad (5)$$

$$\left.\begin{aligned} R^y_{max} &= R_{max}\cos^2\frac{\pi}{2(11-T_R)}t + G_2 \quad \text{descending branch} \\ R^y_{min} &= R_{min}\cos^2\frac{\pi}{2(11-T_R)}t + g_2 \quad \text{»} \quad \text{»} \end{aligned}\right\} \quad (6)$$

The values of R^{y}_{max}, R^{y}_{min} computed by means of relations (5) and (6) for the successive years of sunspot cycle No. 20 corresponding to the value of the time of rise $T_R = 3.8$ are shown in Figure 3.

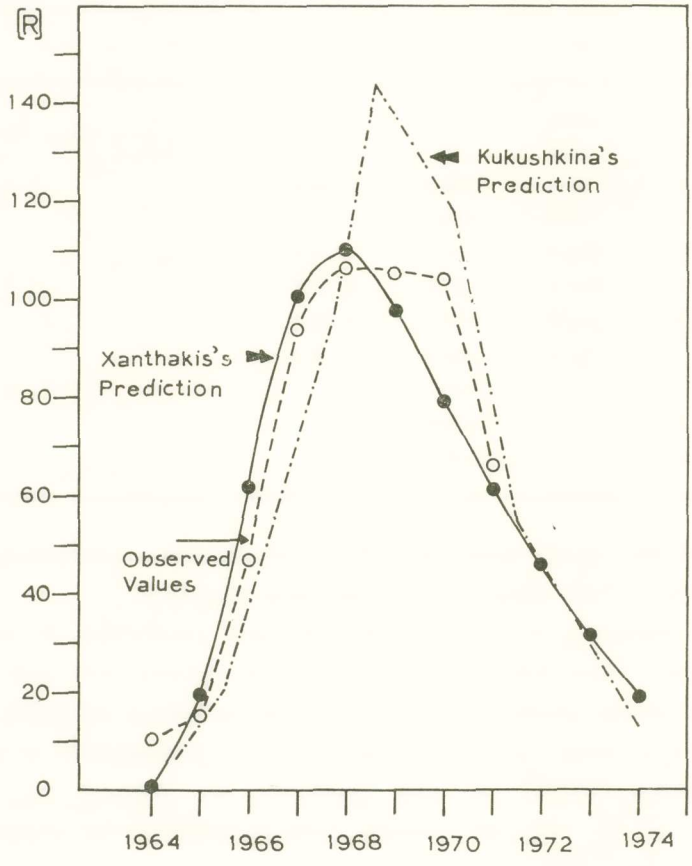

Fig. 2. The dashed line represents the observed mean annual values of the wolf numbers [R] and the continuous line represents the predicted values of [R] for the 20th solar cycle given by Xanthakis. The dashed-dotted line represents the prediction given by Kukushkina et al.

Xanthakis not been able to predict the exact month of each year during which the value of R^{y}_{max}, R^{y}_{min} will occur has plotted the values of these two quantities for the middle of the corresponding year, that is to say in June.

All the above discussed predictions are summarized in Figure 3 in which the observed mean monthly values of the relative sunspot numbers are represented by the dashed line. The small squares and circles represent the observed values of R^y_{min} and R^y_{max} respectively.

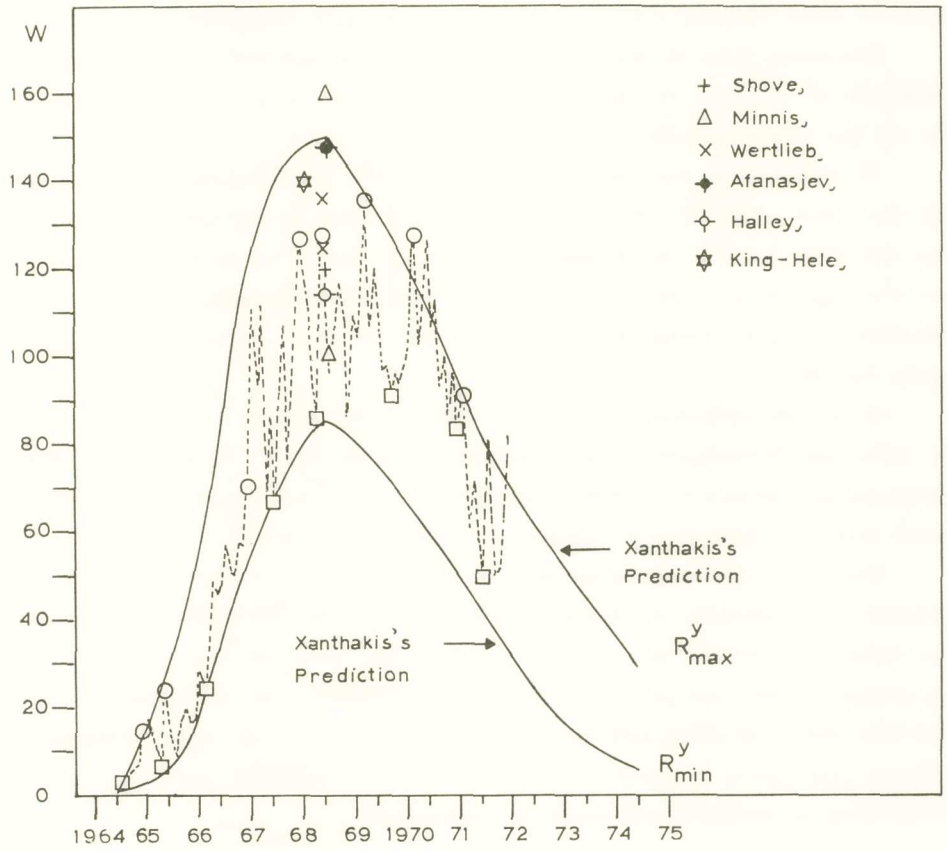

Fig. 3. The continuous lines represent the predicted values of R^y_{max} and R^y_{min} given by Xanthakis and the dashed line represents the observed values of these two quantities for the time interval 1964 to 1971. The predictions of R^y_{max} given by different authors have also been marked in this figure.

From this figure we see that with the exception of 1970 all the observed mean monthly values of the relative sunspot numbers for the time interval 1964-1971 are included between the two solid lines which represent the predicted values of R^y_{max} and R^y_{min} given by Xanthakis.

It is remarkable the fact that there exists a very close approximation between the observed extreme values of R^{y}_{max}, R^{y}_{min} and the corresponding predicted values of these two quantities as given by Xanthakis for the time intervals 1964.0 - 1969.0 and 1970.5 - 1972.0. Wertlieb's values, referred only to the highest values of R^{y}_{max} for the year of maximum of solar activity i.e. for 1968, are also quite satisfactory.

We would like to say at this point that the extreme high flat maximum which appears during the years 1968 - 1970 is a freak phenomenon for all the investigators.

In conclusion, we note that from all the predictions so far given for the solar cycle No. 20 Xanthakis's prediction is the most satisfactory one not only for the mean annual values of the Wolf numbers but also for the highest and the lowest values of the mean monthly values of the relative sunspot numbers corresponding to each year of the solar cycle No. 20.

It is also remarkable the fact that all the cited predictions given by different investigators for the maximum monthly value of the Wolf numbers are included between the limits of Xanthakis's prediction calculated with the help of the analytical relations (5) and (6).

However, it seems to me that forecast of solar activity is even at present quite chancy. So far no high satisfactory method of predicting the dates and intensities of future cycles has been developed. There is no accepted physical theory of solar distarbances and no agreement on the best index of solar activity. For these and various other reasons it follows that there is much to be done on solar activity prediction. But prediction is essential and must be attempted.

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ΠΕΡΙΛΗΨΙΣ

Ὡς γνωστόν, ἡ ἡλιακὴ δραστηριότης ἀποτελεῖ ἓν ἐξαιρετικῶς ἐνδιαφέρον φαινόμενον τῆς ἡλιακῆς φυσικῆς, διὰ τὸν λόγον δ' αὐτὸν ἐρευνᾶται ἀπὸ πολλῶν ἐτῶν ἐπισταμένως ὑπὸ τῶν ἀστρονόμων.

Ἡ σπουδαιότης ὅμως τοῦ φαινομένου τούτου ηὔξησε σημαντικῶς, ἀφ' ἧς ἀπεκαλύφθη ὑπὸ διαφόρων ἐρευνητῶν ἡ ἐπίδρασις τῆς ἡλιακῆς δραστηριότητος ἐπὶ διαφόρων φαινομένων τοῦ μεσοπλανητικοῦ διαστήματος, τῆς ἀνωτέρας γηίνης ἀτμοσφαίρας, τῆς ἰονοσφαίρας καὶ αὐτῆς ταύτης τῆς τροποσφαίρας, ὅπως ἔδειξαν πρόσφατοι ἔρευναι τοῦ ὁμιλοῦντος.

Ἐκ τῶν ἀνωτέρω συνάγεται ὅτι μία πιθανὴ πρόβλεψις τῆς ἡλιακῆς δραστηριότητος, παρέχει πολυτίμους ἐνδείξεις εἰς τοὺς ἐπιστήμονας διὰ μίαν ἐπίσης πιθανὴν πρόβλεψιν τῶν διαφόρων γηίνων φαινομένων.

Εἰς τὴν παροῦσαν ἐργασίαν, ὁ κ. Πουλάκος ἐξετάζει τὰς ὑπὸ διαφόρων ἐρευνητῶν γενομένας προβλέψεις διὰ τὸν 20ὸν ἡλιακὸν κύκλον τῆς ἡλιακῆς δραστηριότητος καὶ συγκρίνει ταύτας πρὸς τὰς τιμὰς τὰς ὁποίας ἔδωσαν αἱ παρατηρήσεις.

Αἱ ἐν λόγῳ προβλέψεις εἶναι δύο εἰδῶν, ἡ μία ἐξ αὐτῶν ἀναφέρεται εἰς τὰς μέσας ἐτησίας τιμὰς τῆς ἡλιακῆς δραστηριότητος εἰς ἀριθμοὺς WOLF. Ἡ δευτέρα ἀναφέρεται εἰς τὴν μεγίστην μηνιαῖαν τιμὴν τῆς ἡλιακῆς δραστηριότητος.

Εἰς τὴν πρώτην κατηγορίαν διετυπώθησαν μόνον δύο προβλέψεις, μία ὑπὸ μιᾶς ὁμάδος ἐκ τεσσάρων Ρώσων ἐρευνητῶν καὶ ἡ δευτέρα ὑπὸ τοῦ ὁμιλοῦντος.

Οὕτως εἰς τὴν εἰκόνα 2 ἡ συνεχὴς καὶ ἡ διακεκομμένη γραμμὴ παριστῶσιν

ἀντιστοίχως τὰς ὑπὸ τοῦ ὁμιλοῦντος καὶ τῆς ὁμάδος τῶν τεσσάρων Ρώσων ἐρευνητῶν γενομένας προβλέψεις τῶν ἐτησίων τιμῶν τῆς ἡλιακῆς δραστηριότητος κατὰ τὸν 20ὸν ἡλιακὸν κύκλον. Οἱ μικροὶ ἀνοικτοὶ κύκλοι παριστῶσι τὰς τιμὰς τὰς δοθείσας ὑπὸ τῶν παρατηρήσεων. Ἐκ τῆς εἰκόνος ταύτης ἐμφαίνεται ὅτι ἡ ὑπὸ τοῦ ὁμιλοῦντος δοθεῖσα πρόγνωσις παριστᾶ τὰ δεδομένα τῶν παρατηρήσεων μὲ ἀκρίβειαν 82 % ἥτις λαμβάνει τὴν τιμὴν 86 % ἐὰν παραλείψωμεν τὴν τιμὴν τὴν ἀντιστοιχοῦσαν εἰς τὸ ἔτος 1970.

Εἰς τὴν δευτέραν περίπτωσιν τῶν μεγίστων μηνιαίων τιμῶν διετυπώθησαν ὑπὸ διαφόρων ἐρευνητῶν 6 (ἓξ) ἐν συνόλῳ προβλέψεις.

Εἰς τὴν εἰκόνα 3 ἡ διακεκομμένη γραμμὴ παριστᾶ τὰς παρατηρηθείσας τιμὰς τῆς ἡλιακῆς δραστηριότητος ἐνῷ αἱ διὰ τῶν διαφόρων συμβόλων σημειούμεναι τιμαὶ παριστῶσι τὰς μεγίστας μηνιαίας τιμὰς τῶν ἀριθμῶν WOLF κατὰ τὸ ἔτος τοῦ μεγίστου τῆς ἡλιακῆς δραστηριότητος αἵτινες ἐδόθησαν παρὰ διαφόρων ἐρευνητῶν. Αἱ συνεχεῖς γραμμαὶ παριστῶσι τὰς μεγίστας καὶ ἐλαχίστας μηνιαίας τιμὰς τῶν ἀριθμῶν WOLF ἑκάστου ἔτους τοῦ 20οῦ ἡλιακοῦ κύκλου αἵτινες ἐδόθησαν ὑπὸ τῶν ἡμετέρων ἀναλυτικῶν σχέσεων.

Παρατηροῦμεν ὅτι ἅπασαι αἱ τιμαὶ αὗται εὑρίσκονται ἐντὸς τῶν ὁρίων τῆς προγνώσεως τῆς δοθείσης ὑπὸ τοῦ ὁμιλοῦντος.

Ἕτερον λίαν ἐνδιαφέρον ἐπίσης σημεῖον εἶναι ὅτι ἡ μεγίστη τιμὴ τῶν ἀριθμῶν WOLF ἡ ἀντιστοιχοῦσα εἰς τὸ ἔτος 1970 προκαλεῖ ἓν πεπλατυσμένον μέγιστον κατὰ τὴν ἐποχὴν τοῦ μεγίστου τῆς ἡλιακῆς δραστηριότητος.

Περισσότεραι λεπτομέρειαι εἰς τὰ Πρακτικὰ τῆς Ἀκαδημίας.