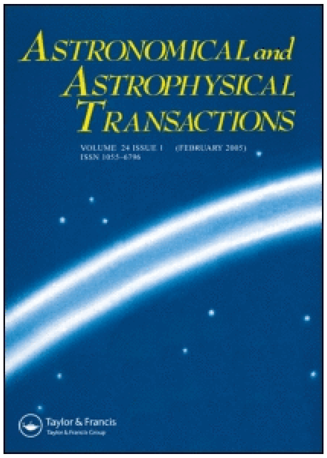

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N. E. Kurochkin [a]
[a] Sternberg State Astronomical Institute, Moscow, USSR

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THE SUN AS A VARIABLE STAR: ACTIVITY PERIODOGRAM AND FORECAST OF HIGH MAXIMA

N. E. KUROCHKIN

Sternberg State Astronomical Institute, Moscow 119899, USSR

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The Fourier spectrum (periodogram) of solar activity based on the Wolf numbers observed from 1749 to 1983 is constructed using a modified Deeming (1975) [3] method (see also Kurochkin, 1973 [4]). Some tens of peaks on the periodogram (more than 80%) have been identified with the periods of paired (sometimes triple) planetary configurations according to the formula $1/P_{ij} = 1/P_i + 1/P_j$ (see Table 1 and Fig. 1). The modulation of solar activity by the planetary motions should be considered as a firmly established fact. A decisive role is probably played by the resonances of planetary configurations with each other and/or with the rotation of the sun (or of its core), or otherwise, with its magnetic dynamo. The formulae for prediction of high maxima of solar activity have been obtained on the basis of mean curves for the Wolf numbers.

The observed chromospheric activity of dwarf stars (Wilson, 1978 [6]) probably exhibits periodicity with a characteristic time of 5–15 years, similar to the solar one. This can be considered as evidence for the existence of planets or substellar satellites near these stars.

KEY WORDS Sun, solar activity, Fourier spectrum.

Variations of solar activity exhibit a complex multicomponent character. Fourier analysis of Wolf numbers W reveals tens of significant peaks in the power spectrum (on the periodogram) (see Cohen, 1974, Verma, 1986). Most of the peaks are identified with the periods of paired, sometimes triple, planetary configurations according to the formula

$$1/P_{ij} = k_i/P_i \pm k_j/P_j \; (k_{i,j} = 0, 1, 2 \ldots) \qquad (1)$$

where P_i, P_j are the orbital periods of planets.

The results of periodogram analysis of Wolf numbers observed from 1749 to 1983 are presented in Table 1. They are compared with periods calculated from (1). The Deeming (1975) method with the modification of Kurochkin (1973) was used. The part of the table above the empty diagonal corresponds to the plus sign in (1), while the lower part corresponds to the minus sign. In each square of Table 1 the first number is the period calculated from (1), and the second number is the observed period derived from the periodogram together with its probable error.

Up to 83% of the peaks observed in the Fourier power spectrum coincide with precalculated planetary configurations. The influence of the planets on solar activity can be regarded as a well established and confirmed fact; however, its theoretical basis needs further study.

Table 1 Periods of paired configurations of planets compared with periods derived from Wolf numbers.

	$0\overset{\mathrm{a}}{.}24085$	0.61521	1.00004	1.88089	11.8622	29.4577	84.0153	164.788	247.697
	☿	♀	♁	♂	11.80 ♃	29.8 ♄	♅	♆	♇
					±. 8	.6			
		0.17310	0.1941	0.2135	0.2361	0.2389	0.2401	0.2405	0.2406
☿		0.1746	0.1950	0.2138	0.2368		0.2401		
		±. 2	. 2	. 2	. 3		. 4		
	0.3958		0.3809	0.4636	0.5849	0.6026	0.6107	0.6129	0.6137
♀	0.3950		0.379	0.4622	0.586	0.606	0.609		
	±. 7		. 8	. 12	. 2	. 2	. 2		
	0.3173	1.5987		0.6529	0.9223	0.9672	0.9883	0.9940	0.9960
♁	0.3150	1.585		0.649		0.971			
	±. 4	. 14		. 3		. 9			
	0.2702	0.9142	2.1354		1.6235	1.7680	1.8397	1.8597	1.8667
♂	0.270		2.135		1.64	1.77	1.835	1.85	
	±. 4		. 25		. 15	. 17	. 18	. 18	
	0.2458	0.6489	1.0921	2.2353		8.4568	10.3946	11.0657	11.3202
♃	0.2449:	0.647	1.091	2.26		8.45	10.56	11.11	
	± 4	. 25	. 7	. 28		. 40	.62	. 7	
	0.2428	0.6283	1.0352	2.0092	19.859/2		21.8102	24.9906	26.3269
♄	0.2431	0.622:	1.038	2.00	9.94		21.46	24.0	26.9
	±. 4	. 22	. 16	. 22	. 6		.26	.32	.40
	0.2415	0.6197	1.0121	1.9240	13.8125	45.364		55.645	62.735
♅		0.619		1.93	13.81			51.02	65.6
		±. 22		. 23	.11			2.46	2.72
	0.2412	0.6175	1.0062	1.9026	12.782	35.869	171.38		98.96
♆				1.89	12.89	34.8			(106.0)
				±. 2	. 9	.7			6.0
♇	0.2410	0.6167	1.0041	1.8953	12.4589	33.434	127.13	492.37	
							123:	500:	
							±8.4	13.7	

The main cycles of solar activity (the highest peaks on the periodogram) have periods $P_0 = 11\overset{\mathrm{a}}{.}11 \pm 0.07$ and $P_1 = 9\overset{\mathrm{a}}{.}94 \pm 0.05$. They correspond to the configurations Jupiter + Neptune ($P_{♃+♆} = 11\overset{\mathrm{a}}{.}06$) and Jupiter + Saturn (second harmonic in formula (1) with $k_{i,j} = 2$: $\frac{1}{2}P_{♃-♄} = 19.86/2 = 9\overset{\mathrm{a}}{.}93$). The variations of W with periods P_0 and P_1 have the largest amplitude. Why are these combinations of planetary movements the most prominent? First of all, they are connected with massive outer planets in combinations with Jupiter. But not all of these configurations are distinguished. This may be due to resonances between planetary configurations and internal fluctuations of solar activity (magnetic dynamo).

For periods P_0 and P_1 the mean curves of W variations were plotted as a function of phase, in a manner similar to that used in studies of variable stars (Figure 2a–d). Mean curves of W numbers are slightly asymmetric (asymmetry $\varepsilon_0 = \varphi_{\max} - \varphi_{\min} = 0\overset{\mathrm{p}}{.}42$; $\varepsilon_1 = 0\overset{\mathrm{p}}{.}43$). Depressions can be seen near the maxima of W curves; they may be significant (due to absorption or diffraction arising during alignment of planets with the Sun?). The mechanism of interaction of planets with the Sun remains unknown; perhaps it has an electromagnetic origin (interaction of magnetospheres).

The selected main periods are probably double ($2P_0 = 22\overset{\mathrm{a}}{.}22$, $2P_1 = 19\overset{\mathrm{a}}{.}88$). We

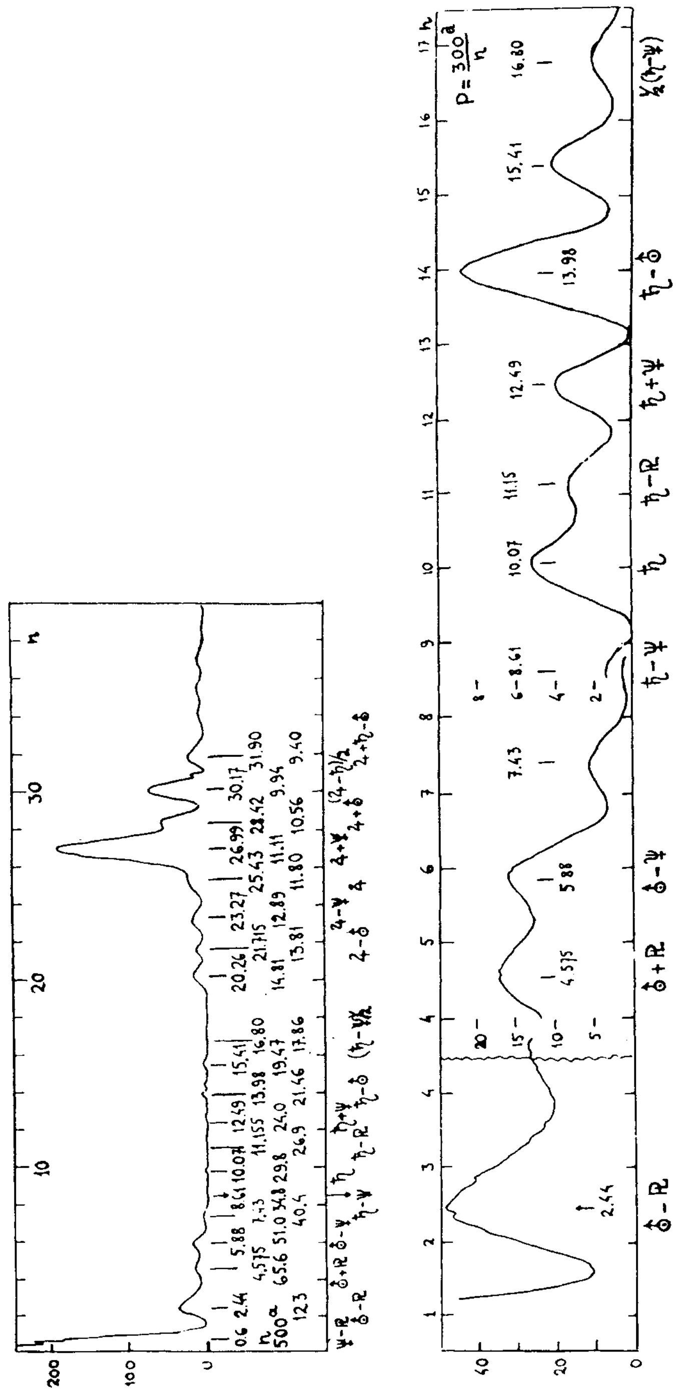

Figure 1 Characteristic parts of a Fourier periodogram of solar activity from Wolf numbers W for the years 1749–1983.

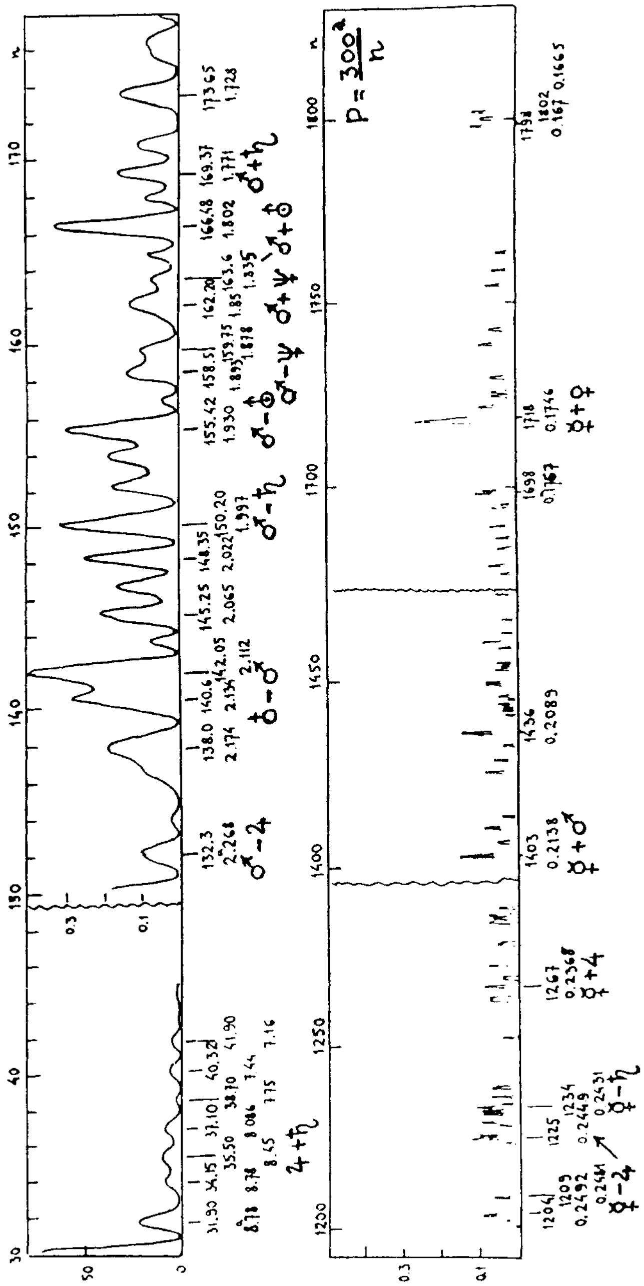

Figure 1 (*Continued*)

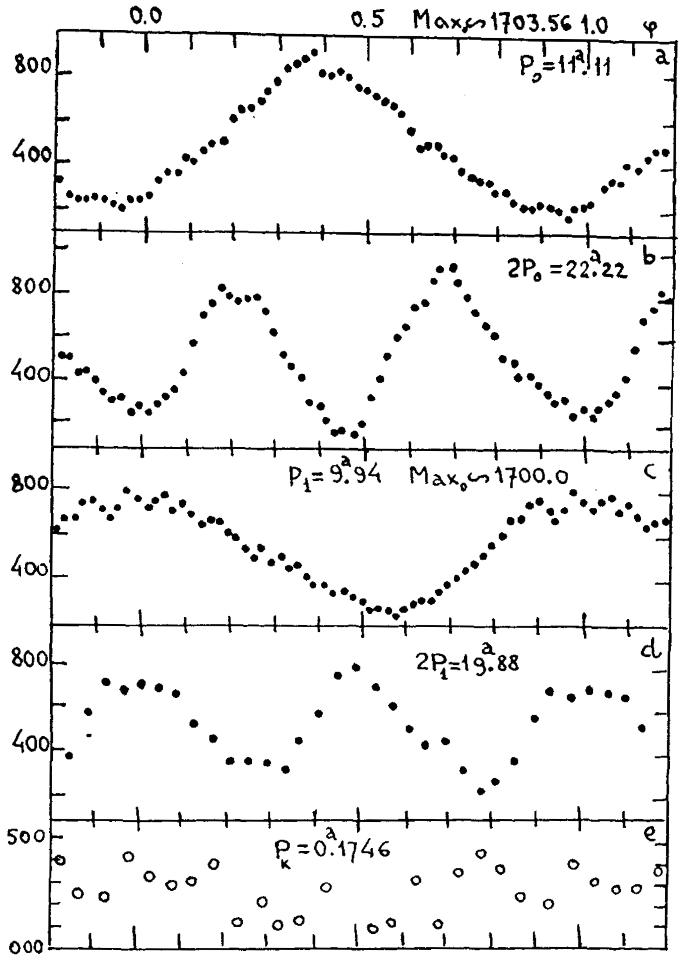

Figure 2 Mean curves for variations of Wolf numbers with periods $11^a.11$, $22^a.22$, $9^a.94$, $19^a.88$ and $0^a.1746$. The difference between even and odd cycles of double periods 22 and 19.9 years and depressions near maxima can be noticed.

should then consider the double wave (Figure 2b, d). The even and odd waves in double cycles have different shapes (one maximum is more sharp).

Our method of calculation allows tying the phases of mean curves to real time and obtaining a formula for computing activity maxima (for given selected oscillations):

$$\begin{aligned} T_0\,(\max) &= 1703.56 + 11^a.111 E_0 \qquad \text{Max: } 1982.4;\ 1993.5. \\ T_1\,(\max) &= 1700.00 + \ \ 9^a.944 E_1 \qquad \text{Max: } 1978.4;\ 1988.3. \end{aligned} \tag{2}$$

The last maxima, precalculated from (2), closely represent those observed during the last cycles of activity.

A comparison of the observed Wolf numbers curve for 1749–1987 with

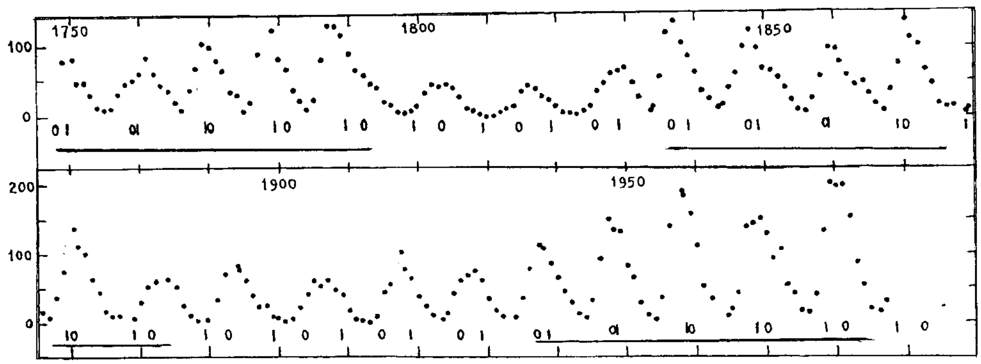

Figure 3 The Wolf numbers curve from 1749 to 1987. The dates of maxima, precalculated from (2) with periods $11^{\mathrm{a}}.11$ (0) and $9^{\mathrm{a}}.94$ (1) are marked below. It is evident that highest activity maxima (80–90 year cycles) occur when these two main periods interfere.

maxima, precalculated from the formula (2), is shown in Figure 3. This plot needs some comments. Maxima of oscillations with periods P_0 and P_1 coincide every 80–90 years. Maxima of both oscillations appear to be close during 3–4 solar cycles and should strengthen each other. The highest maxima of solar activity are observed at this time. This is the cause of centennial cycles of solar activity. Proceeding from formula (2), which is directly connected with planetary configurations, the highest maxima of Wolf numbers can be predicted, as we assume, in the range of ± 1000 years.

Outside of the regions of increased activity the maxima of one oscillation are near the minima of another (anticoincidence) and they should partly weaken each other. The exact shape of superposition is unknown; perhaps it is non-linear. However, variations of activity with smaller amplitudes remain. For more a accurate prediction we should take into account harmonics with smaller amplitudes and analysis of amplitude modulation. A sufficiently accurate forecast was given by Cohen *et al.* (1974) and Hill (1977), although they did not report the details of their decompositions. The possible connection between solar activity and planets was not mentioned in these works.

The configurations of inner planets with outer ones are sufficiently represented in the power spectrum (see Table 1). Configurations of the inner planets with each other are not so pronounced, but some cases are strikingly pronounced, apparently because of resonances. A part of the periodogram with peak $P_k = 0^{\mathrm{a}}.1746$ (significance level $\sim 6\sigma$ above the background) is shown in Figure 3. The peak corresponds to the configuration P (Mercury + Venus) $= 0^{\mathrm{a}}.1731$. More exactly: $P_{☿+♀-11.06} = 0^{\mathrm{a}}.1746$, i.e. because of resonance with the period of the main oscillation P_0 we obtain an exact coincidence with the precalculated period. The maxima of this oscillation can be derived from:

$$T_k\,(\max) = 1700.00 + 0^{\mathrm{a}}.1746 E_k; \qquad \mathrm{Max} = 1979.86.$$

The amplitude of this oscillation is small and it is not significant for prediction of solar phenomena. Nevertheless it is worth attempting a direct comparison between planetary configurations and observed manifestations of solar activity.

Many main-sequence G–M stars exhibit spot activity. The spot activity of some

BY Dra and RS CVn-type stars is known to be directly connected with the existence of massive satellites. We can assume that solar spot activity, modulated by planetary movements, belongs to the same class of phenomena. Long-time observations of chromospheric activity reveal that many G–M stars exhibit cyclic variability with characteristic times similar to solar ones (Wilson, 1978). We can assume that these observations indicate the existence of planetary systems around most of the solar-type stars. It is obvious that long-time observations of stellar chromospheric activity are vital for understanding these phenomena.

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