QUASI-PERIODIC VARIATION IN THE SOLAR NEUTRINO FLUX REVISITED

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(Received 20 December, 1994; in revised form 30 May, 1995)

Abstract. Neutrino capture rate data from the Homestake chlorine experiment (1970–1990) has been spectrally analysed. The data were smoothed by a 4-month equally-spaced sequence and by a cubic spline polynomial approximation. Fourier (FFT), maximum entropy spectrum analysis (MESA), and power spectrum analysis (PSA) employing the Blackman–Tukey window were used. The significant periodicities obtained are: 1 ± 0.1, 1.4 ± 0.2, 2.4 ± 0.2, 5 ± 0.2, and 11 ± 1.5 years. A possible correlation with similar coincident periods in other solar–terrestrial phenomena is discussed.

1. Introduction

Since the early thirties, and especially at the Solvay meeting on atomic nuclei in Brussels in October 1933, where Fermi (1934) developed his theory of beta decay and the inference about the rest mass of the neutrino (Pauli, 1934), great progress has been made on neutrino physics and astrophysics.

For the last 17 years it has been the conventional wisdom that there is a serious solar neutrino problem (although in the 1994 neutrino conference in Eilat, Israel, they preferred to speak of an 'anomaly'): the experimentally observed flux was much less than predicted by the theoretical Standard Solar Model (SSM) (Winter, 1991) and that new physics is required. The SSM follows the evolution of the Sun from its formation 4.6 billion years ago, from a protostar, to the present. Results from the Kamiokande, chlorine, and gallium experiments, which are in apparent disagreement, have been reviewed and found not to be significantly inconsistent, and moreover the theory (depending on which SSM model is chosen) and these experiments are not in significant disagreement (Morrison, 1992). Studies of oscillations of the Sun (helioseismology) give new information.

Nevertheless, while accumulated neutrino data over the past twenty-five years have sometimes led to conjectures about solar cycles or other phenomena, the observed rate has been consistently less than solar model prediction, ranging between 0.30–0.54 depending on the statistics in the experiment and theory (SSM model calculations).

Possible 'oscillations' between neutrino types may occur, where a beam cyclically changes its affinity as it travels along.

Problems with the SSM evoke several critical issues, the most critical being (i) opacity of the Sun, from the core via the intermediate zone to convection and

Solar Physics **161:** 29–47, 1995.

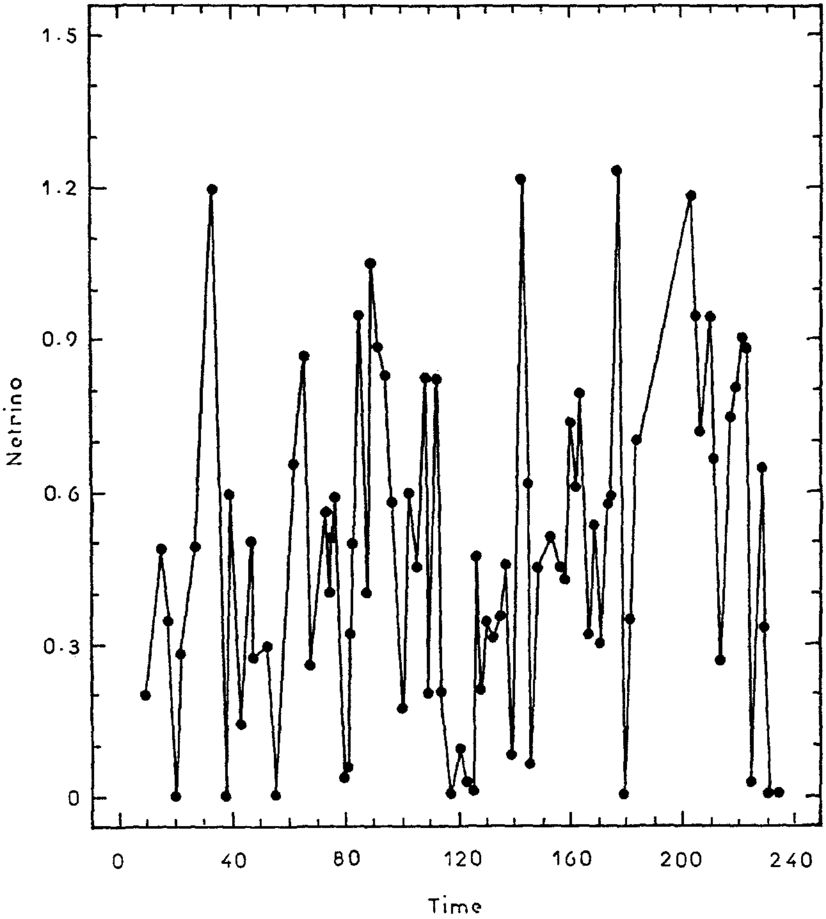

Fig. 1. Original neutrino data. Capture rate versus time (from Davis 1990; and Filippone and Vogel, 1990).

beyond, and abundance of elements, (ii) nuclear reaction cross sections, (iii) potential effects of neutrino (ν_e, ν_μ, ν_τ) oscillations (while many possible mechanisms are not ruled out, as vacuum oscillations and spin-flavour precession of solar neutrinos, and solar neutrino transitions induced by neutrino flavour changing neutral current interaction, the nonadiabatic MSW (Mikheyev–Smirnov–Wolfenstein) transitions provide an essentially attractive particle physics solution).

All tend to appreciably reduce the theoretical neutrino flux and increase the errors.

Noteworthy is the recent advancements in helioseismology, which give by inversion calculations a lower central temperature than the SSM.

Here an attempt is made to reappraise the available chlorine experiment neutrino flux data. With the chlorine experiment, in the reaction

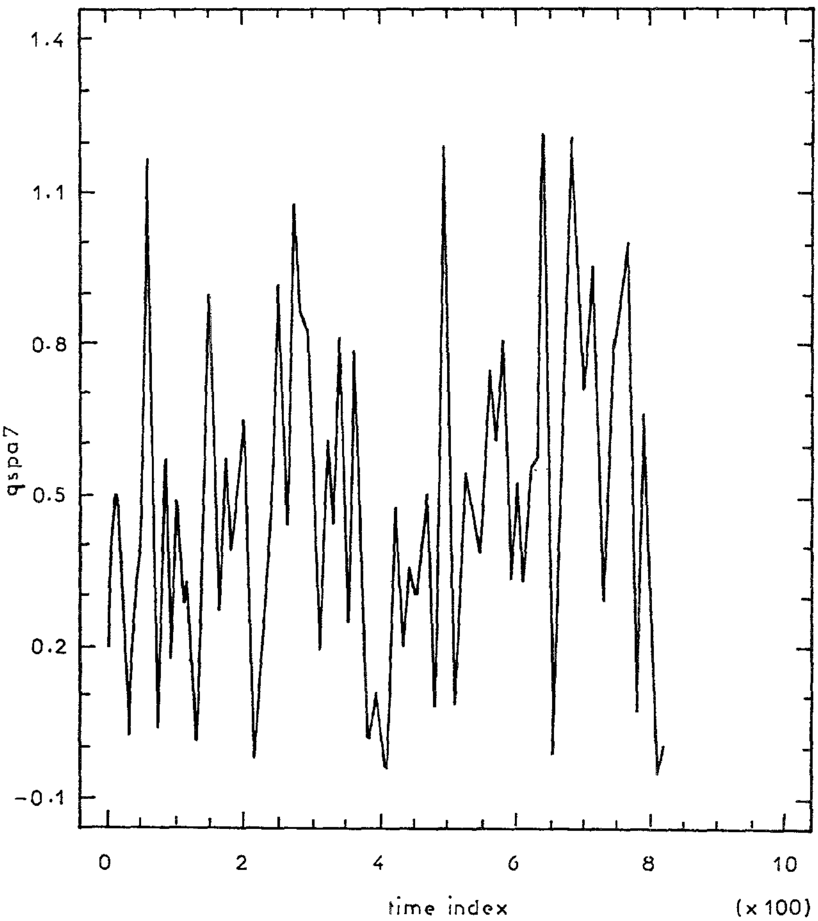

Fig. 2. Seven-term moving average, qspa7 (solid line) of cubic spline polynomial approximation neutrino flux series versus time. The time index consists of 821 data points or 821 × 8.9 days = 20 years.

$$\nu +^{37}\text{Cl} \Rightarrow e^- +^{37}\text{Ar}\,, \tag{1}$$

only the high-energy neutrinos can be detected, derived from less important fusion reactions, involving boron-8 and beryllium-7

$$(^7\text{Be}(\text{p},\,\gamma)^8\text{B},^8\text{B} \xrightarrow{+e} {}^8\,\text{Be} + \nu(\text{CE}))\,.$$

These come from rare processes that are peripheral to the main *pp* fusion reaction involving the light isotopes which give most of the solar neutrinos.

It is our goal to perform a detailed spectral analysis of these data avaraged over 4-months, a smoothing which removes possible outliers due to the decay half-life of the 35-day characteristic of ^{37}Ar, as well as other random or systematic errors, searching for and attributing possible periodic variation to interacting physical mechanisms.

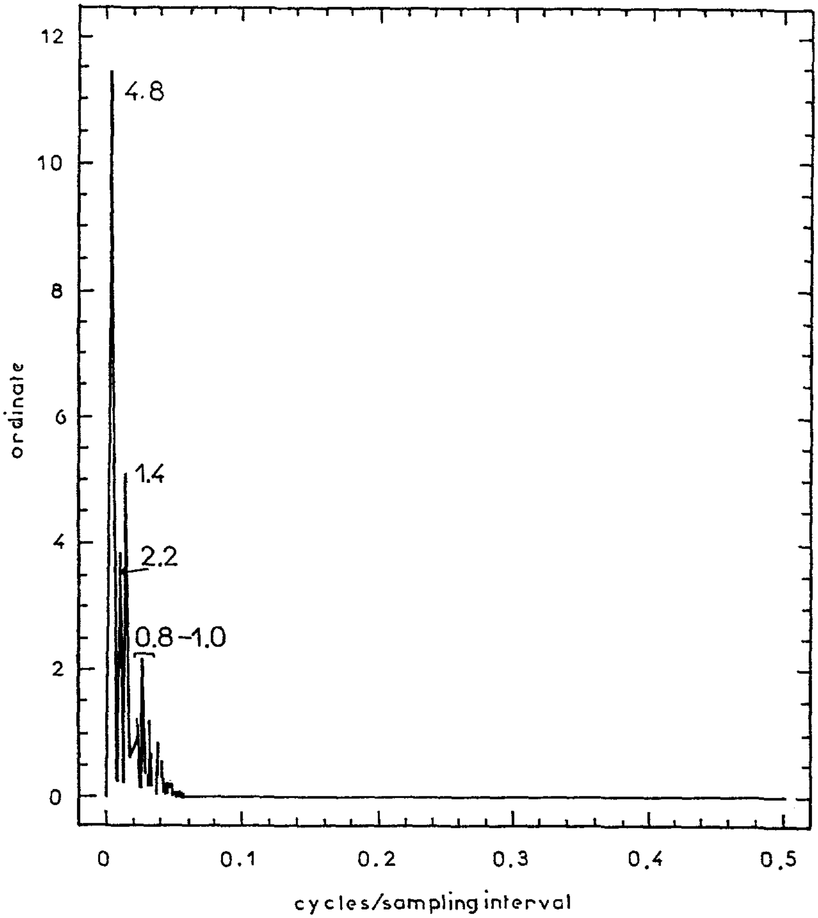

Fig. 3. FFT spectrum analysis of qspa7 detrended by subtraction of the mean value (frequency, f, against power density). Distinct periods of 4.8, 1.4, 2.2, and 0.8–1.0 years are noted. (T (yr) $= (1/f) \times 8.8$ days).

2. Previous Work on Neutrino Periodic Variation

In the search for neutrino periodic variation, the following main efforts have been made: (1) Sakurai (1980) has analyzed the neutrino flux for the period 1970–1978 as four months means and found a quasi-biennial (26-month period) variation; (2) two significant peaks at 1.6 and 2.1 years were found by Gavrin *et al.* (1982); (3) a quasi-biennial cycle has been reported by Raychaudhuri (1986a, b); (4) the 11-year solar period by Subramanian (1983); (5) a biennial cycle, associated with the cross of the solar equatorial plane and the ecliptic plane with an opening angle of $7°15'$ twice per year (Volishin, Vysotskii, and Okun, 1986); (6) a 4.7-yr period is reported by Filippone and Vogel (1990) as the best choice to satisfy an independent test for the significance of the correlation of production rates $P(t)$,

TABLE I

Test of randomness for qspa7 time-series after subtraction of the mean value, indicating the non-random nature of the time series (the confidence level, $Z = 0$ is well below 0.01, and the number for the runs test up and down show a total of 61 runs up and down which is significantly less than would be expected in a random sequence).

Tests for randomness

Median = 0.459233 based on 821 observations
Number of runs above and below median = 45
Expected number = 411.499
Large sample test statistic $Z = -25.5626$
Two-tailed probability of equaling or exceeding $Z = 0$

Number of runs up and down = 61
Expected number = 547
Large sample test statistic $Z = -40.2308$
Two tailed probability of equaling or exceeding $Z = 0$

Note: 0 adjacent values ignored.

with solar activity, assuming a best fit for the curve, while their analysis showed that the hypothesis of a time-independent ^{37}Cl neutrino capture rate is marginally rejected, having only a 2% probability. However, they were not able to find a simple hypothesis of time variation that would describe the data well. A capture rate anti-correlated with sunspot numbers had a probability of 6%; (7) Attolini *et al.* (1988) applied FFT on unequally spaced data and on Monte-Carlo simulations, as well as on a modified superposed epoch method. They report the biennial periodic variation (2–2.13 years) and the 1.6 years. On the whole, the highest spectral power ranged between 1–3.4 years.

Regarding the constant or random/periodic nature of the data, the following approaches are reported: (i) Bahcall, Field, and Press (1987) using the x^2 minimization approach have showed that the hypothesis of a constant capture rate was rejected for average errors but not rejected at all for upper errors; (ii) Fillipone and Vogel (1990) have applied the maximum likelihood technique to analyse the time dependence and found 2% probability only of a marginally rejected time-independent ^{37}Cl neutrino capture rate, considering a time series of experimental runs randomly scrambled; (iii) Attolini *et al.* (1988) have used the χ^2 statistic to test among the possible positions of the 4 points which represent a sinusoid, the largest deviation from a constant mean value, and rejected the H_0 hypothesis of a constant flux during the epoch and accepted the H_1 hypothesis of a sinusoidal type variation of period T.

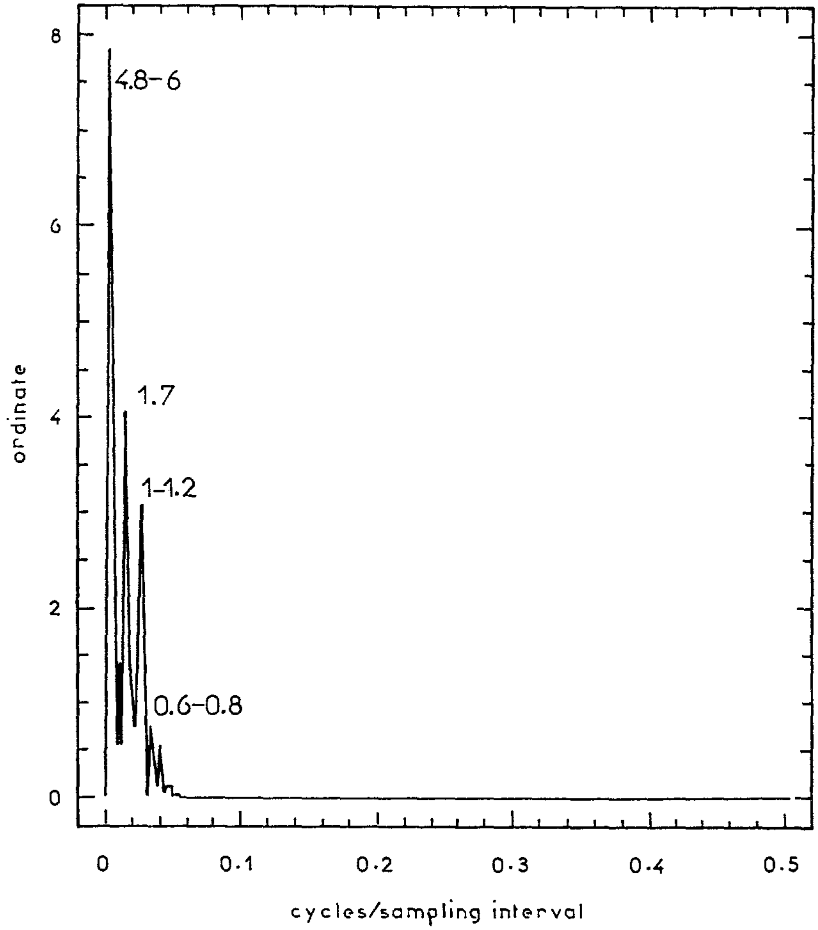

Fig. 4. FFT spectrum analysis of qspa7 detrended by subtraction of the mean value, for half of the record (1970–1980) (frequency against power density). Distinct periods between 0.8 to 4.8–6 years are noted.

In the present work, further sophisticated methods of spectrum analysis are applied, while the variability of the periods obtained are examined through truncated records (time evolution). Also, the periods obtained are quoted with their respective probable errors, due to (a) errors in the data set (counting itself plus counting time), (b) statistical processing of data (detrending, hypothetical tests), (c) smoothing and interpolation, and (d) peak shift due to the method applied.

3. Data Analysis

The solar neutrino flux has been inferred from the neutrino capture rate in ^{37}Cl, measured over the past two decades, in 83 separate runs. Since 1967, Davis and

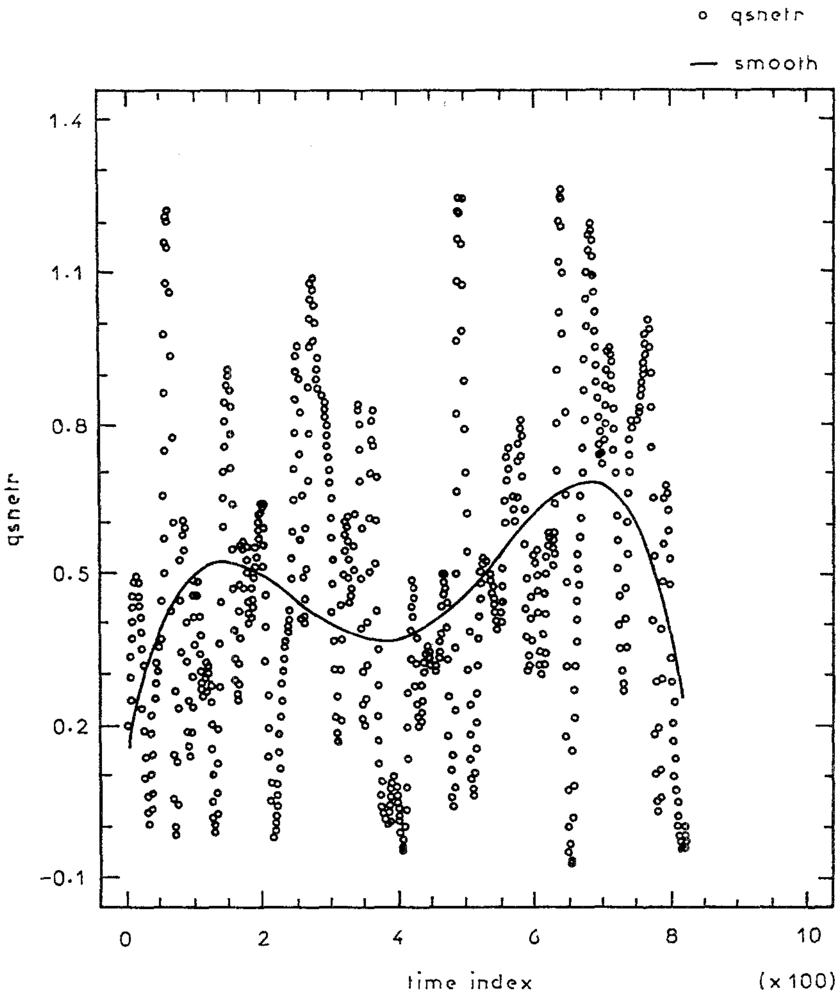

Fig. 5. Cubic spline polynomial approximation (dots) smoothed with a 4th-order polynomial (solid curve). The time index consists of 821 data points or 821 × 8.9 days = 20 years. The smooth curve exhibits a cyclic variation with peak-to-peak distance of 11–12 years.

co-workers performed experiments by extracting ^{37}Ar from a tank of 615 t of tetrachloroethelene C_2Cl_4, following the reaction (1) above. This contains ^{37}Cl quoted as 2.3×10^{30} atoms of ^{37}Cl. The ^{37}Ar decays by electron capture. The hole in the K-shell can give an Auger electron of 2.8 keV. The courter of 0.5 cm^3 volume is designed to measure this electron. The half-life of the decay is 35 days (Davis, 1990; Filippone and Vogel, 1990; Winter, 1991).

Our present work comprises a further statistical elaboration of these data aiming at the investigation of the time dependence of the neutrino capture rate for the period 1970–1990.

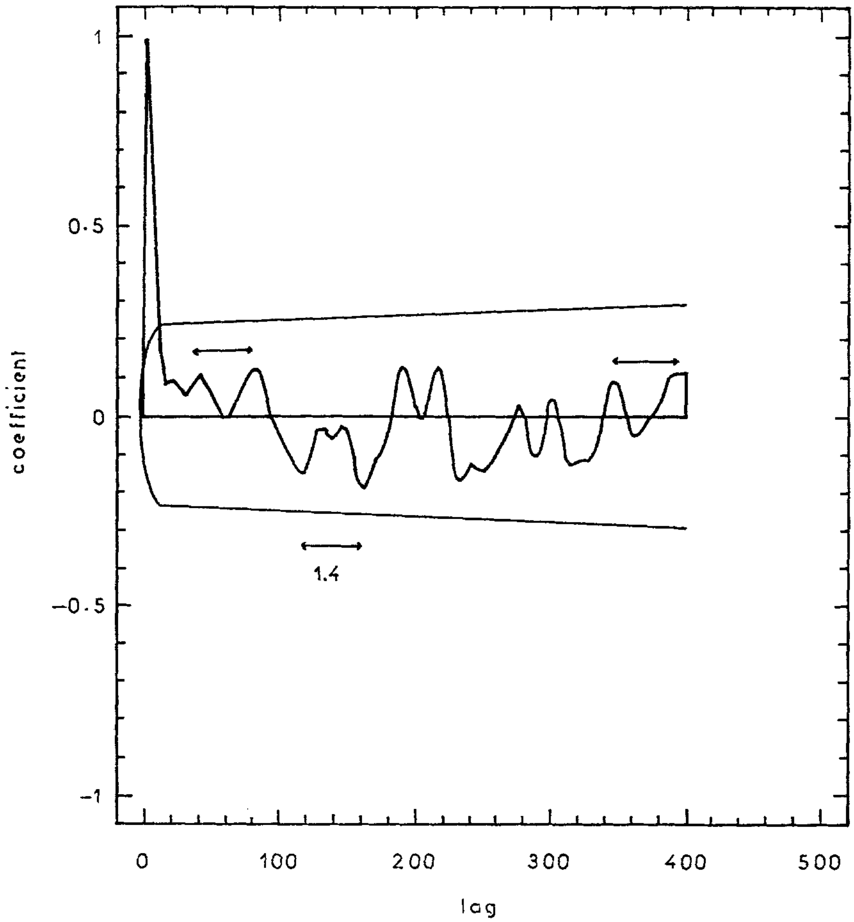

Fig. 6. Autocorrelation function of the qspa7 (autocorrelation coefficients, r, against lag). The 400 lags correspond to 400 data points or 400 × 8.9 = 3560 days = 9.8 years. The coefficient, r, exhibits a cyclic pattern with periods of 1.4–2.2 years.

Various smoothing and interpolation procedures were used and spectrum analysis methods (fast Fourier transform (FFT)), maximum entropy spectrum analysis (MESA), power-spectrum analysis (PSA) employing the Blackman–Tukey window) were applied (Liritzis, 1990, 1993).

The statistical significance of any results are dependent on the confidence levels assumed for the very low capture rate runs, thus assigning to any data elaboration a cautious consideration.

The original data as individual runs of unequal spaced data were treated (a) as an equally spaced sequence by a cubic spline polynomial approximation, and (b) as 4-month averages.

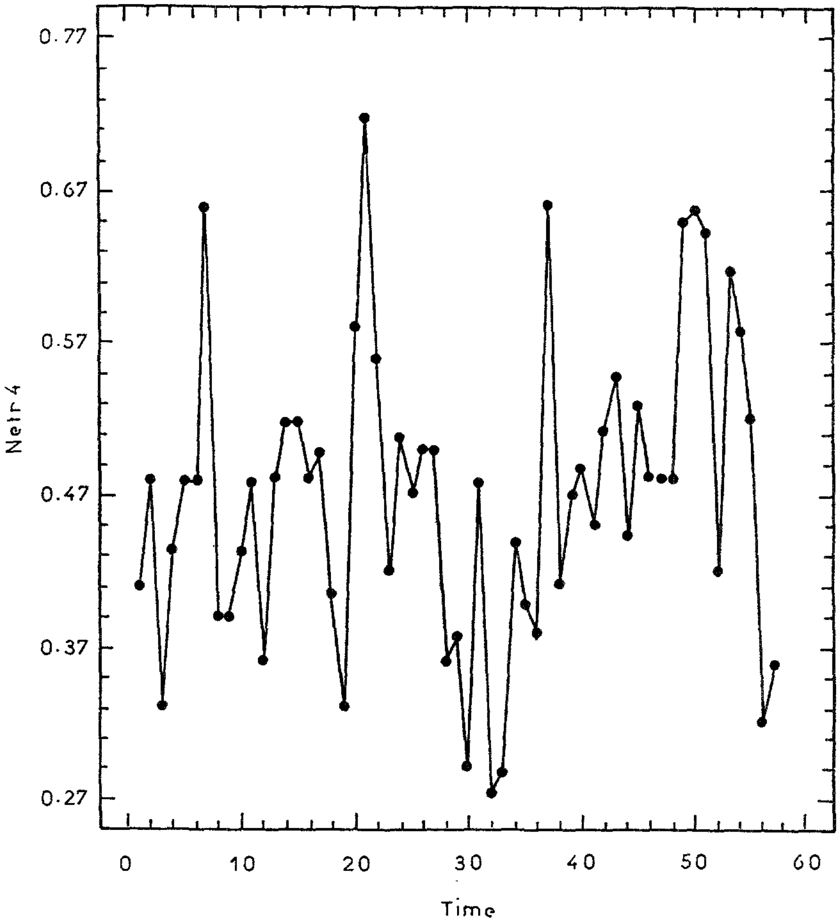

Fig. 7. Average neutrino capture rate per 4-months (NETR4) against time (1970–1990).

3.1. CUBIC-SPLINE APPROXIMATION OF UNEQUALLY SPACED DATA

Figure 1 shows the original neutrino data (sample size $N = 83$, average $= 0.476$, standard deviation $= 0.33$, standard error $= 0.036$, variance $= 0.108$).

These data were arranged by month, leaving blank months where no runs were made, thus making a total of 234 months ($\sim$ 65% blank entries).

A cubic spline polynomial approximation (abbreviated to qspa; a cubic spline is composed of piecewise cubic polynomials with continuity up to and including the second derivative) was applied, transforming the 83 data points to a new equally spaced time-series of a 7-term moving average, which consists of 821 points or 9.9 times more data points – about one data point per 8.9 days. The new average of 0.48 changed, compared to that of the raw data, by only 1%, while its standard deviation (± 0.257) changed by $\approx$ 22%.

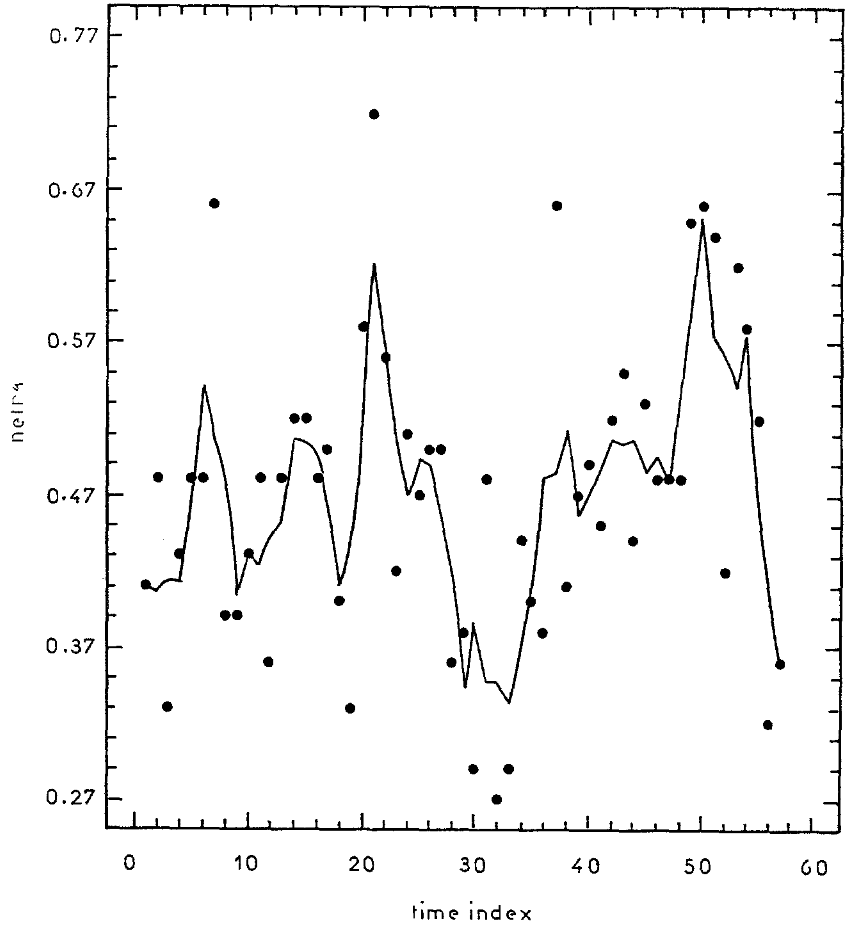

Fig. 8. Three-term moving average of Figure 7.

Spline functions yield smooth interpolating curves which are less likely to exhibit the large oscillations characteristic of high-degree polynomials (Elipe and Lanchares, 1988; Schoemberg, 1969), that is, they have the minimum norm property and the best approximation property.

Figure 1 shows the original data, and Figure 2 shows the qspa time-series with a moving average of 7-terms (abbreviated to qspa7). The 7-term moving average was chosen in order, first, to preserve the inherent periodic character and, secondly, to slightly smooth out some outliers.

In fact, a moving average of qspa time-series with 5, 10, 15, 21, 25 terms, as well as with 5 terms and five weights, in general, preserved the detailed structure of the spectrum shape, but with apparent variable smoothing of extreme points. The 7-term moving average was considered as a good compromise.

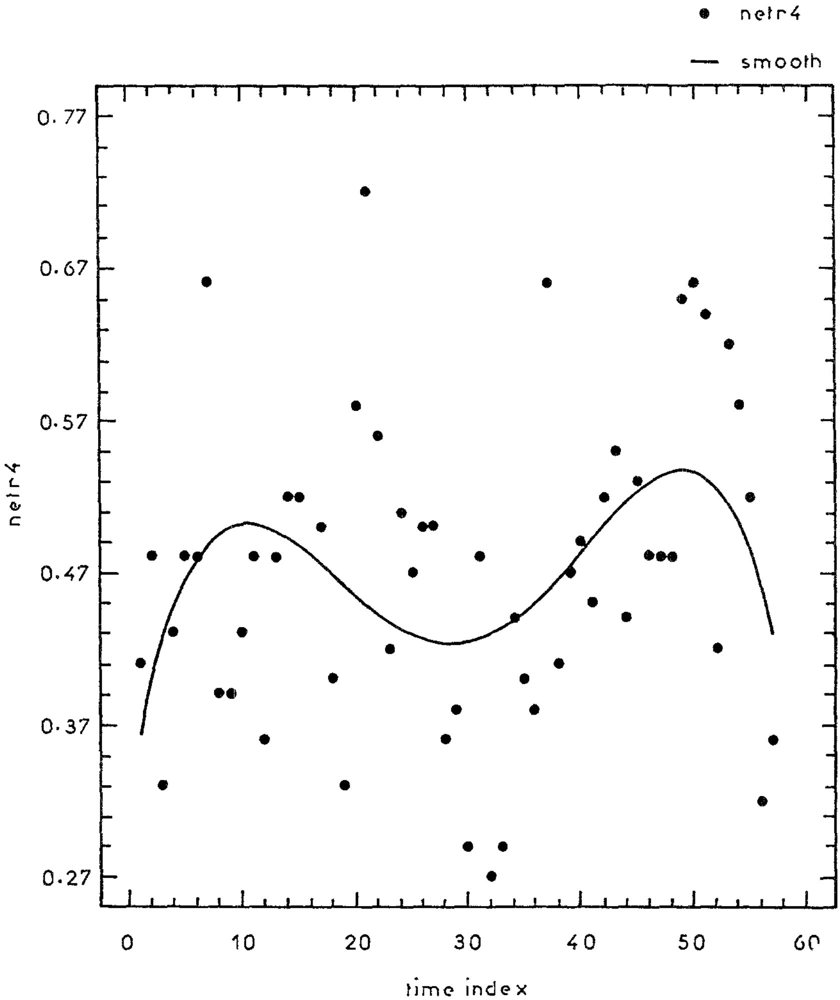

Fig. 9. Average neutrino flux per 4-months, smoothed with a 4th-order polynomial (NETR44).

An attempt was also made to recognise the distribution function of our time-series. The various distributions applied did not fit satisfactorily the neutrino time-series (Figure 1), the reason probably being due to either the large errors in individual runs, or due to more than one different neutrino source present in the measured neutrino capture rate.

The next step was to apply a test for randomness to the qspa7 data. The results assign a non-random variation to the analysed data (Table I).

Subsequently, FFT spectrum analysis of the qspa7 record, as well as of truncated sub-records from both ends of the series, was applied (Figure 3).

All high power-spectrum density (PSD) concentrated at low-frequency order of less than 0.06 cycles per sampling interval, with no alising (spectrum is zero as the

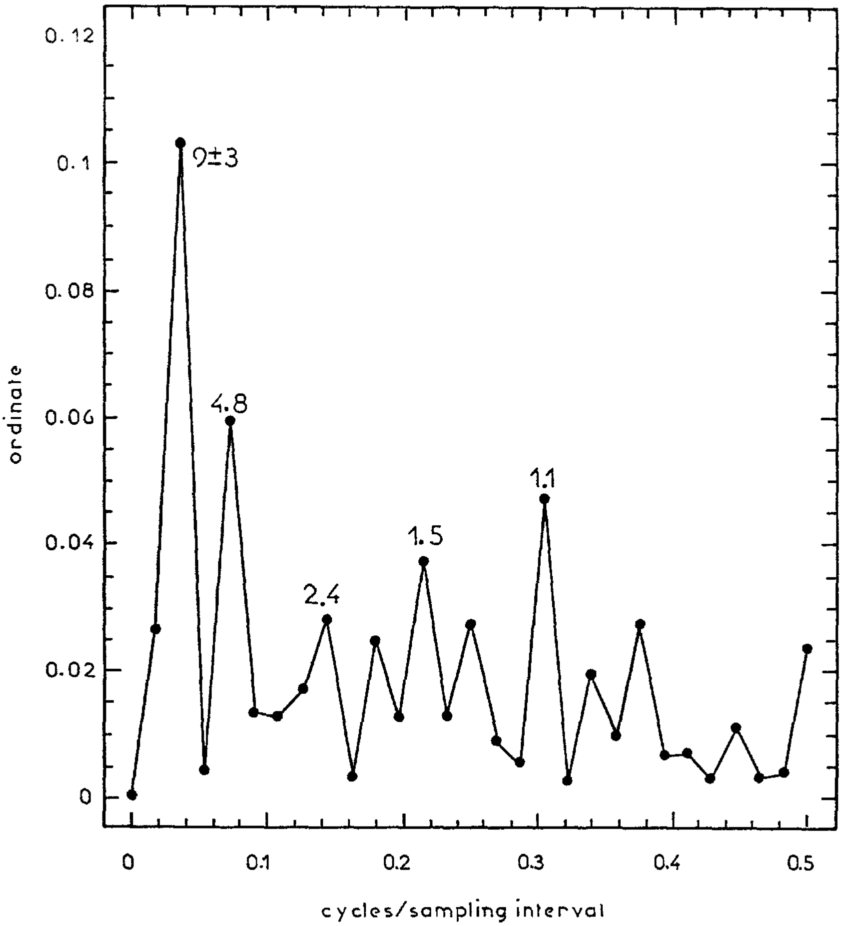

Fig. 10. FFT periodogram of NETR4 detrended by subtraction of the mean. Periods between 0.9–9 years are noted.

frequency approaches the Nyquist point). The PSD has a large peak at frequency 0.005 (4.8 years).

The quasi-periodicities obtained appear in discrete frequencies corresponding to 5 ± 1, 2.1 ± 0.1, 1.4 – 1.7, 0.9 ± 0.1, and 0.55 ± 0.05 years.

Similar peaks were obtained for sub-records from the right and left end of the series.

The second half of the total record does not show the 2.2 years, probably because of many missing values during this period (1985–1987) (Figure 4).

Table II shows the evolution of these peaks in different sub-records.

Finally, the qspa7 series was smoothed with a 4th-order polynomial (Figure 5). The sinusoid-like fit exhibits a peak-to-peak variation of ~ 12 years.

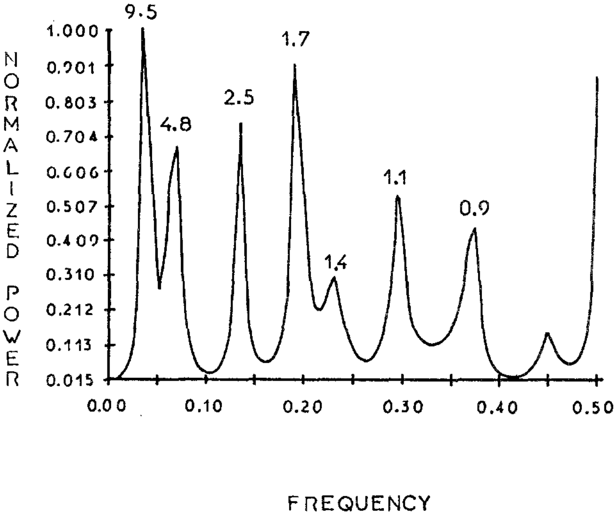

Fig. 11. MESA of NETR44. Distinct periodic terms between 0.9–9.5 years are noted.

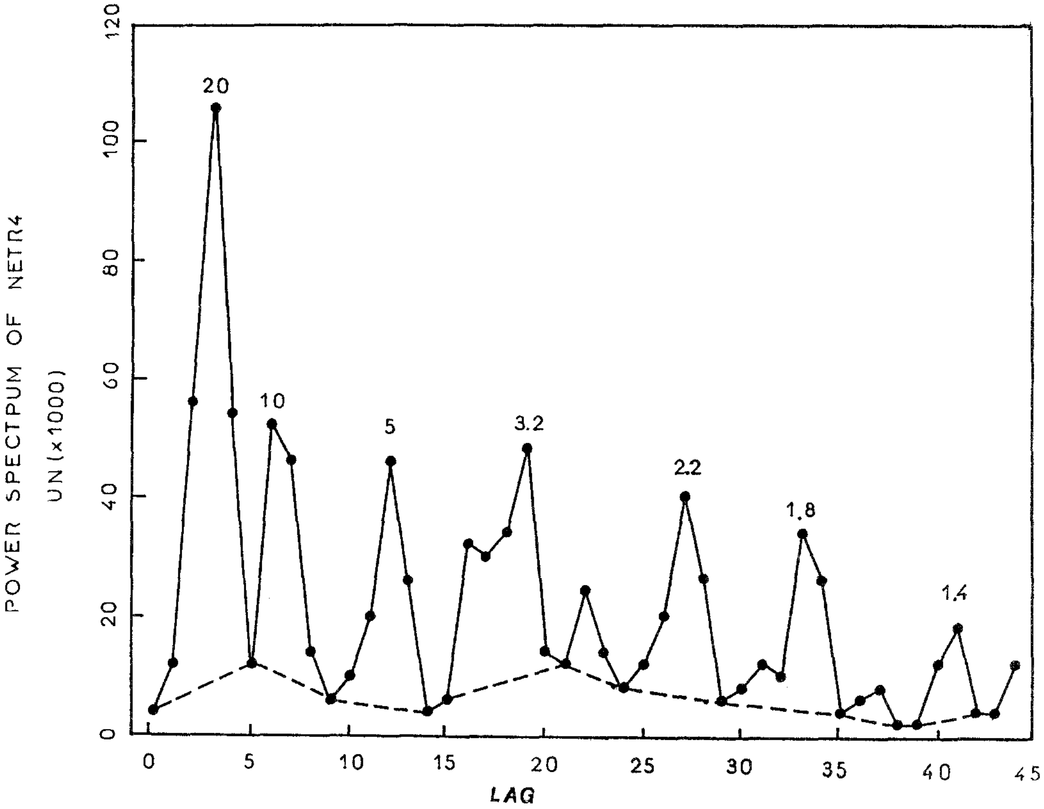

Fig. 12. PSA of NETR4. The solid curve indicates the power density of the periods and the dashed curve is the continuum. Periods in years are indicated above the significant periods. The lower raw curve is the lags.

TABLE II

FFT of qspa7 after subtraction of the mean for different subrecords. Total number of points is 821. Periods in years are grouped in successive bands, of 0–1 to 6–16 years.

Subset	Periodicity, years						
	6–12	5–6	4–5	3–4	2–3	1–2	0–1
0–821		5 ± 0.3			2.1 ± 0.1	1.4–1.7	0.9, 0.55
600–821	5–7				2		0.52
500–821	5–7					1.1, 1.7	0.55, 0.73
400–821		4.8–6			(2)	1, 1.7	0.75
300–821	>6				2.4	1.2, 1.5	0.8, 1.0
200–821		4.8–6			2.2	1.4	0.8–1.0
Average	6–12	5 ± 1			2.1 ± 0.1	1.4–1.7	1 ± 0.1 0.8 ± 0.1 0.5

Data points = 821 × 8.9 days = 7300 days or 20 years.

The estimated autocorrelation (Figure 6) for the truncated records, though it provided no significant autocorrelation coefficient, exhibits a cyclic variation for its coefficient, where the $\sim$ 1.4–2.2 years peaks are present.

3.2. FOUR-MONTH EQUALLY SPACED DATA

A new 4-month equally spaced time-series was constructed from average per 4-months windows (NETR4), replacing blank windows by the average of the real data of 0.476.

Noteworthy is the commensurability between the NETR4 and the monthly cosmic-ray intensity data variation from the neutron monitor Athens station (super NM-64, magnetic rigidity 8.72 GV) for the period 1970–1978 (Mavromichalaki, Belehaki, and Liritzis, 1989).

The new average of 0.471 was not different from the original. The same applies for the median too.

This 4-month window equally spaced time-series, consists of 57 data points or about 30% less than the individual runs.

Smoothing with a moving average of 3 terms was applied to these data (Figure 8).

A test of randomness of this smoothed record (netr4ma3) shows the non-random nature of this series ($Z = 0.00021$ or $Z \ll 0.05$). The low probability ($Z = 2.1\text{E-}4$) of equaling or exceeding Z (equal to the absolute value of 3.70) indicates the number of runs above and below the median is significantly below what would be expected if the NETR4MA3 neutron capture rate over time were random.

TABLE III

Periodicities in years obtained by the three methods of spectrum analysis: MESA, FFT, and PSA

MESA

F	Periodicities, years						
15	–	6.7	2.5	1.6	–	1.1	0.9
20	9.5	4.8	2.5	1.7	1.4	1.1	0.9
35	9.5	4.7	2.6	1.9	1.4	1.1	0.83
1st half	–	6.7 ± 1.5		1.8 ± 0.3	–	1.07 ± 0.05	
2nd half	–	5.1 ± 1.5		1.5 ± 0.3	–	0.95 ± 0.05	

FFT

Series	Periodicities, years						
	10–12	8–10	6–8	4–6	3–4	2–3	1–2
qspa7m				5 ± 1		2.1 ± 0.1	1.4–1.7 0.9 ± 0.1 0.55
4th-order polynom.	11–12						
NETR4 (mean, 4th order)	11 ± 2			4.8		2.4 ± 0.2	1.5 ± 0.2 1.3 ± 0.2 1 ± 0.1
NETR4 3-term mov. av.		9.5 ± 3 ($S > 95\%$)		4.8 ± 0.7 ($S > 95\%$)			

PSA

M		Periodicities, years ($S > 99\%$)						
30	20			5.7	3.3	2.2	1.8	1.46
45	20 ± 2	10		5	3.2	2.2	1.8	1.4
55	18 ± 4	10		5	3.2	2.2	1.8	1.5

The results for the runs test up and down show a total of 25 runs up and down, which is significantly less than would be expected in a random sequence. Since its significance level is well below 0.01, we can conclude that the NETR4MA3 series do not occur in a random order.

A similar result is reached for the qspa7 minus the mean time series, where the low probability is $Z = 0$ for $|Z| = 26.4$ and the number of runs up and down is 51.

A polynomial smoothing of 4th order (Figure 9) provides a similar picture to that of qspa7, giving an apparent periodic variation of 13 ± 2 years (peak-to-peak).

Also, the 3-term moving average smoothing of NETR4 preserved its spectral shape, as a similar smoothing of the original time series did.

This shared property reinforces our initial aim to preserve the spectral shape of the original unequally spaced series to an optimum degree (trend and seasonality), despite the albeit carefully applied interpolations and smoothing (spectrum preservation).

3.2.1. *FFT*

The periodicities obtained with the FFT analysis of the detrended NETR4 with a 4th-order polynomial (NETR44) are: 11 ± 2, 4.8 (a side lobe to the high period due to the kind of detrending of the high cycle with the 4th-order polynomial), 2.4 ± 0.2, 1.5 ± 0.2, 1.3 (1.4 ± 0.2), and 1 ± 0.1 years, with significance levels $<75\%$ according to Kolmogorov–Smirnov test.

Subtraction of the mean value gives the obtained PSD of FFT shown in Figure 10, with periodicities similar to the former, but with a distinct and high variance in the 4.8 and 9 year peak. The lower periods are closer to the Nyquist peak of 1 cycle/8 months.

Subtracting the 3-term moving average from the NETR4, the obtained periodicities and respective significance levels according to Kolmogorov–Smirnov test are: 4.8 ± 0.7 ($S > 95\%$) and 9.5 ± 3 ($S > 95\%$) years. That is, the moving average removed the small periodic terms ($T < 4$ years).

3.2.2. *MESA*

The MESA method of Ulrych and Bishop (1975) was applied to the NETR4, which was based on algorithms developed by Burg (1968), Anderson (1974), and Smylie, Clark, and Ulrych (1973). Use of Berryman's (1978) criterion for the best order of the autoregressive process (filter length, F), where $F = 2N/\ln 2N$, $N =$ number of data, as well as the Ulrych and Bishop (1975) ($N/3 < F < N/2$) and the Akaike's (1969) criterion (plot of prediction error filter against the autoregressive order) was made.

For $F = 20–35$ the obtained power spectrum density (PSD) is stable for the periods: 9.5 ± 0.2, 4.8 ± 0.1, 2.5 ± 0.2, 1.7 ± 0.1, 1.4 ± 0.2, 1.1 ± 0.1, and 0.9 ± 0.1 years (Figure 11).

The two halves (10 years of data) gave the following results; for 1970–1980: 6.7 ± 1.5, 1.8 ± 0.2, and 1.07 ± 0.5 years and for 1980–1990: 5.1 ± 1.5, 1.5 ± 0.3, 0.95 ± 0.05 years.

3.2.3. *PSA*

The PSA of the NETR4 gave the following results for three lags at 30, 45, and 55: 20 ± 2, 10, 5.5 ± 0.3, 3.2, 2.2, 1.8, and 1.4 years, with a high significance ($>99\%$) (Figure 12).

The NETR4 was normalized by subtraction of the mean ($= 0.4707$) from each data point and then dividing by the standard deviation ($= 0.101$).

The periodicity was obtained from the equation: period = (multiplier × 2 × lag/frequency = 180/frequency. If the spectrum represents a random sample from a normal population, the distribution of sample spectrum estimates at a given frequency is distributed about the corresponding population spectrum according to the distribution of chi-square divided by the number of equivalent degrees of freedom, $DF = [2N - (2\text{lag}/3)]\text{lag}$, lag = truncation length of the autocorrelation function and N = number of data points. The significance level at 1%, 5%, and 10% was estimated as the ratio of peak-to-background (continuum) height, which for lag = 45 of Figure 12 was 4.605, 2.996, and 2.302, respectively.

The limited length of the record does not allow reliable estimation of the periods higher than about 10 years; albeit the FFT and the PSA methods from their nature predict a high period at the extreme left end of the power spectrum. Otherwise, all three methods provide a multipeak power spectrum with large variance centered at 10 ± 1, 5 ± 0.2, 2.4 ± 0.2, 1.4 ± 0.3, and 1 ± 0.1 years. The attached deviation refers to slight differences of peak location in the three methods.

4. Discussion

4.1. PERIODS $T > 5$ YEARS

The higher quasi-periodicity of 10 ± 0.5 years resembles the well-known solar cycle of sunspots. The 5 ± 0.2 years is at present of unknown origin, even though it seems to form a subharmonic of the higher periodic term.

4.2. PERIODS $T < 5$ YEARS

The approximately 12-month peak is clearly related to the Earth's orbital motion and may,thus be expected to change only if some terrestrial parameter changes. The other two cycles of 2.4 and 1.4 years are discussed below.

4.2.1. *The 1.5 Years Peak*

The most intriguing and perhaps most interesting feature of the neutrino flux power spectrum is a peak at about 17 months or 1.5 years (Nyquist frequency = 8 months), which varies strongly with time.

It would be of interest to search for this periodic term in some solar-terrestrial phenomena. Thus, a similar cycle was found on a data set of Swedish visual auroras for the period 1721–1943, on a monthly basis, besides the anticipated 11 years, the annual and semi-annual cycles (Silverman and Shapiro, 1983). According to them, the 1.4-year peak in visual auroras showed a strong modulation of about 65 –68 years and an additional long-term trend of the order of centuries.

The origin of the auroral peak at 1.4 years at that time was unclear and puzzling. Perhaps, the excitation of oxygen and nitrogen molecules in the atmosphere by the particular solar energetic electron flux takes place in 1.4-year cycles associated with similar solar neutrino cycles, which produce the relevant electrons.

A peak at 1.4 years was also found in the power spectrum of the international magnetic index Ci, for the period 1884–1964, significant at the 5% level, but this could not be conclusively established, because of uncertainties as to the underlying continuum.

Analysis of the Mayaud (aa) magnetic indices in the same manner gave, at best, only a hint of such a peak around the turn of the century, but the significance level is extremely low.

Probably, the $\sim$ 1.5 years peak found here is modulated by the 11-year and/or the 4.8-year cycles. This can not be established before much more neutrino data runs are accumulated.

Coronal holes are large-scale structures of lower density and temperature in the solar corona and appear as large dark features in X-rays and radio images and as bright areas in infrared He I images of the Sun. The longest series of data comes from He I (10830 Å) observations within Hα synoptic charts.

The variation of coronal hole total area enclosed within a latitude band 10–50° S shows a 592 day periodic variation or 1.6 years throughout the 13-yr interval (McIntosh, Thompson, and Willock, 1992).

4.2.2. *The Other Periods*

Regarding the 2.3 $\pm$ 0.1 years, it may be related to solar energetic particles derived from solar flares, although closer examination discloses cycles of solar flares with mean periods of 9 years, 2.25 years, and 3.3 months (Ichimoto *et al.*, 1985).

The fundamental difficulty for the interpretation of this period is the restricted quantity and quality of neutrino flux data available for study.

Indications of two other periodicities include 0.42 years and 8.2 $\pm$ 1 years.

At present, it does not appear possible to find conclusive statistical evidence for any of the reported quasi-periodicities. The results of the various applied statistical methods of spectrum analysis, here and elsewhere, provide only 'hints' to the neutrino puzzle, and our result is an extract of the optimum information from these problematic data.

Nonetheless, with the present status of knowledge, the results obtained, combined with other solar-terrestrial phenomena, may contribute towards a better interpretation of the neutrino new physics.

5. Conclusion

Possible periodicities ranging between 1–12 years in the neutrino capture rate variation have been revealed, the prominent ones being the 1.4, 2.4 years and $\sim$ 5 and $\sim$ 10 years. The various spectrum analysis methods and statistical tests applied without destroying the spectrum information, support the conclusion of non-random variation of the neutrino data. Some of these periodicities obtained are in agreement with solar activity parameters as well as other solar-terrestrial indices.

Acknowledgement

I thank Prof. K. Winter for helpful correspondence.

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