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Correlative analyses for Homestake neutrino data(*)

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Summary. — We present results from linear correlative analyses between Homestake data and several solar-activity parameters in the period 1970-1992. Our findings support the hypothesis that the observed neutrino flux exhibits a significative correlation with some solar-activity parameters, particularly with those related with the heliomagnetic field.

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1. – Introduction

When in 1968 R. Davis and coworkers started the Chlorine experiment in the Homestake gold mine to measure the solar neutrino flux, they probably would have not thought to supply so much work to physicists. The Homestake measurements (fig. 1a) not only have revealed for the first time the reality of nuclear reactions in the solar core, but also gave rise to the existence of two "problems" (still widely studied and debated, see [1,2] for reviews on the matter):

i) A possible deficit in the observed neutrino flux average with respect to the theoretical prediction based on the Standard Solar Model (SSM), which has been confirmed later by the Kamiokande, Sage and Gallex neutrino experiments.

ii) A time variation of the neutrino flux (unexpected in the frame of the current knowledges of solar and particle physics) probably anticorrelated with the solar-activity cycle.

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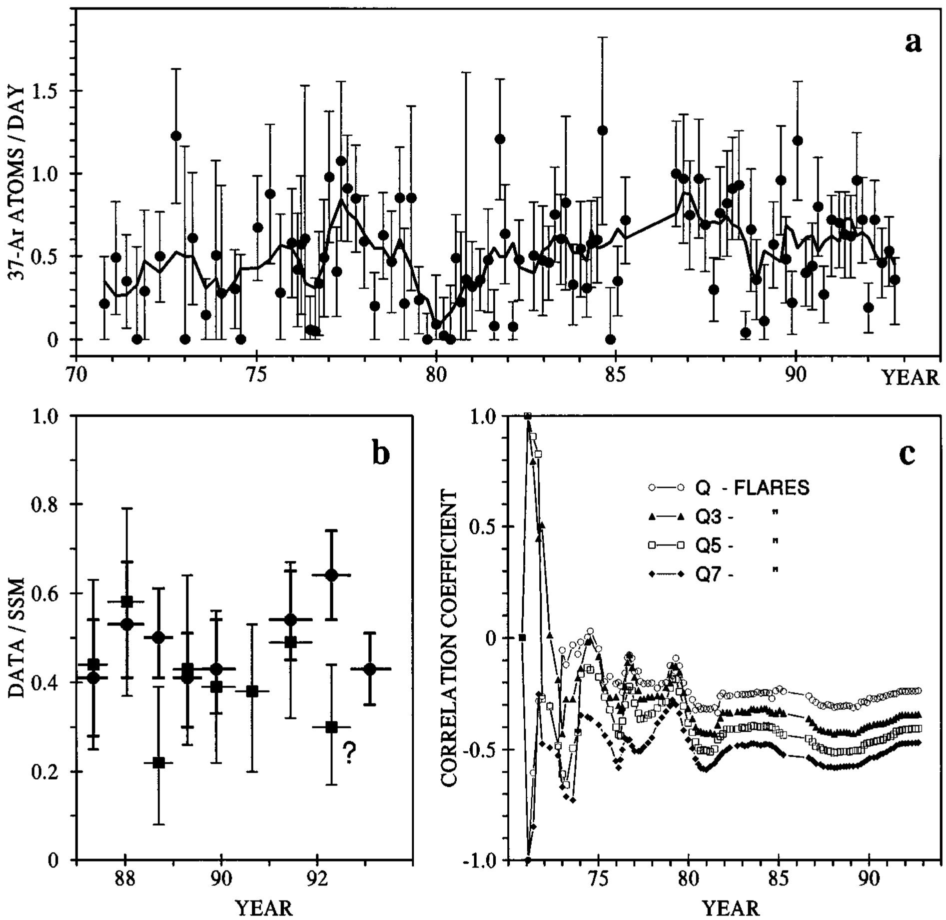

Fig. 1. – a) Homestake neutrino data with error bars, and 5-point running-averaged values (solid line): from run No. 18 to No. 126; b) comparison between Kamiokande (circles) and Homestake (squares) neutrino data averaged over the same time intervals: the last point of Homestake data (with a question mark) contains two runs that do not have still definitive values; c) time evolution of correlation coefficients of solar flares with 3-, 5- and 7-point running averages of Homestake neutrino data.

For the Homestake data, one possibility to solve the above problems could be to assume that the real solar neutrino flux is represented only by the highest values measured (being these values not far from the theoretical prediction [3, 4]) and then to suppose that there exists a mechanism able to deplete and to modulate the neutrino flux reaching the detector. The lack of a clear time variability in the Kamiokande data [5] is not sufficient alone to discard this effect because the period covered is still too short (6 years) to draw conclusions. Moreover, plotting the Homestake data in the same way as the Kamiokande ones (fig. 1b) we can observe that the two sets are in good agreement, in spite of the big differences between the detectors [1].

In this paper we have assumed that the time variations observed in the Homestake neutrino data have a physical meaning. Then we have looked for possible links with the long-term behaviour of the solar activity studying the time evolution of the linear correlation between the neutrino flux and several parameters connected to the solar cyclical variations. The present work extends, adding new neutrino data, and completes, with new parameters, a previous one [6] based on statistical analyses of the Homestake data.

2. – Data used and analysis

The following parameters are used:

- Neutrino data (Q): from run No. 18 to No. 126, as obtained from Bahcall [7] and updated until the end of 1992 by courtesy of R. Davis (private communication, 1994).
- Solar parameters [8]:

  i) sunspot number (SUNSPOTS),

  ii) solar-flare counts (FLARES),

  iii) solar radioemission (RADIOEMISSION) at 10.7 cm,

  iv) intensity of the green corona line (GREEN LINE: 530.3 nm), as derived on half-year basis [9].
- Solar-terrestrial parameters [8]:

  i) aa and Ap geomagnetic indices,

  ii) nucleonic intensity of galactic cosmic rays (CR), as obtained at Climax (average primary energy around 10 GeV).

All the parameters, but the neutrino one, are on monthly basis and averaged over the period covered by each neutrino run.

We have studied the Pearson correlation between the neutrino data and each of the other parameters as a function of time: we have repeated the regression analyses adding chronologically one pair of values at a time, and then plotting the obtained correlation coefficient (r) as a function of the mean exposure date of the last neutrino run considered (this technique is derived by an analogous one previously used in the solar-neutrino context by other authors [10]). The analyses have been done both forwards, from run No. 18 to No. 126, and backwards, from run No. 126 to No. 18: in this way, comparing the two trends we can draw conclusions also for the initial r values.

Since original Q data are very scattered, to illustrate better the long-term behaviour we have used also a set of 5-point running-average values ($Q5$). As an example, fig. 1c shows that other choices for the smoothing, for instance 3- or 7-point running averages, do not alter *qualitatively* the results. Figure 1c shows also that the correlation of the solar flare counts with neutrino data improves passing from Q to $Q3$, $Q5$ and $Q7$, suggesting the effectiveness of a long-term modulation.

Our results from regression analyses are reported in fig. 2.

3. – Discussion

From figs. 2a and 2b we notice that the flare counts and the intensity of the green coronal line are the parameters best (anti)correlated with neutrino data and not the sunspot numbers, as widely assumed in many works on the solar neutrino problems. By comparing the left and right upper panels of fig. 2 we observe a lack of correlation in the period

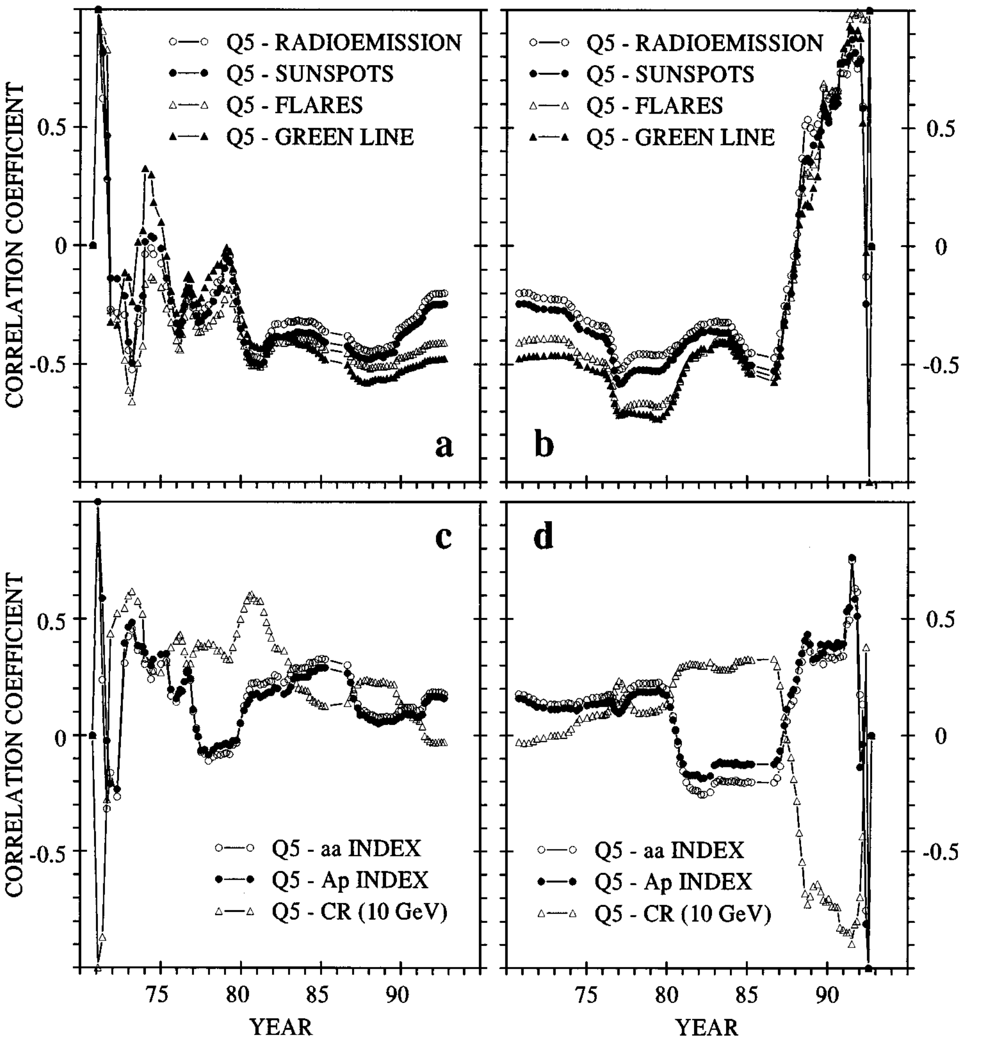

Fig. 2. – Time evolution of correlation coefficients of the 5-point running averages of the Homestake neutrino data with the parameters shown in the legends: a) and c) forwards from run No. 18 to No. 126; b) and d) backwards from run No. 126 to No. 18.

1970-1977 (particularly in the right panel) and in 1989-1992 (particularly in the left panel), *i.e.* during the descending phases of the even-numbered solar-activity cycles No. 20 and No. 22. Hence, whereas the anticorrelation for the whole period considered (1970 to 1992) of $Q5$ with FLARES and GREEN LINE has values around -0.45 ± 0.08, in the period 1977 to 1989 it reaches values up to -0.80 ± 0.10 (see the correlation plot between neutrino data and FLARES reported in fig. 3a). The reality of the neutrino link with these solar parameters can also be checked by considering that in both the forwards and backwards analyses, the correlations reach significative values already after 8–10 years, when the two data subsets are completely independent; we recall that data sets extend for about 23 years.

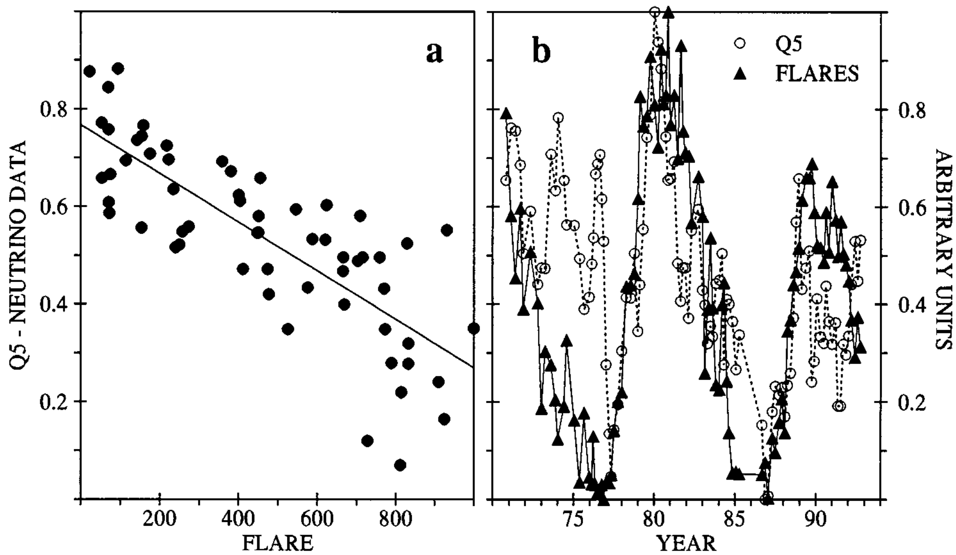

Fig. 3. – a) Scatter plot of solar flares counts *vs.* 5-point running averages of Homestake neutrino values in the period 1977 to 1989 ($r = -0.8 \pm 0.1$); b) the above data sets plotted as a function of time in the period 1970 to 1992: the neutrino data are reported with an inverted scale and both data sets are normalized in a way that minimum = 0 and maximum = 1.

A direct comparison between Homestake data and solar flares confirms that it is quite difficult to ascribe the existing analogies only to a mere chance (see fig. 3b, where the two data sets are normalized in a way that minimum = 0 and maximum = 1).

From figs. 2c and 2d it emerges that geomagnetic parameters and cosmic-ray intensities do not correlate with neutrino data on long-term basis. However, cosmic rays show a noticeable correlation from 1972 to 1982 (see fig. 2c), and this explains the positive result obtained in a past work [11]. An inverse behaviour, although with less significance, is followed by the geomagnetic indices due to the opposite response to solar activity phenomena.

4. – Conclusions

We found that the Homestake data:

i) Exhibit a clear modulation of the neutrino signal, almost on the long term (fig. 1c), confirming the results previously obtained by other authors with a smaller database [12, 13].

ii) Are badly correlated with geomagnetic indices (figs. 2c and 2d), supporting the hypothesis that the source of the modulation is on the Sun.

iii) Are correlated with cosmic-rays intensity only in the period 1970-1982, whereas over the total period the correlation is near zero (figs. 2c and 2d).

iv) Are well correlated with the green line intensity (figs. 2a and 2b). We notice that an increasing low cut-off level in the interplanetary magnetic-field intensity has been found in relation to an increasing green line intensity [14], which is surely connected with the global heliomagnetic field.

v) Are better correlated with flare counts than with sunspot numbers. We recall that flare phenomena are intimately related to the toroidal component of the heliomagnetic field. The best correlated period (1977-1989) corresponds to that characterized by a re-inforcement of the interplanetary magnetic-field intensity [15, 16], suggesting again an enhancement of the global heliomagnetic field.

Our findings could be explained by the 22-year modulation of the heliomagnetic field variability [17, 18] or, perhaps, by a pulsating character of the neutrino production inside the solar core [19, 20].

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