# Cosmic rays, solar activity, and neutrino flux from the sun

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(Submitted 12 February 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 6, 273–275 (20 March 1982)

An important correlation is found between the neutrino flux $\nu$ in Davis' apparatus, solar activity, and cosmic rays. It follows from this correlation that in 1981–1982 a small $\nu$ flux, increasing in subsequent years, should be observed. In October 1981, an increase in the $\nu$ flux, resulting from an intense burst of cosmic rays from the sun, could be observed.

PACS numbers: 96.60.Kx, 96.60.Vg

1. More than ten years have passed since the time that Davis began his experiment on detecting the $\nu$ flux from the sun.[1,2] The average, over this period, rate of formation of $^{37}$Ar atoms per day [as a result of the reaction $^{37}\mathrm{Cl}(\nu, e^-)\,^{37}\mathrm{Ar}$] is equal to $Q = 0.40 \pm 0.06$, which is approximately three times lower than that predicted by calculations using standard models of the sun.[2]

The values of $Q$ for 1970–1980 are presented in Refs. 1 and 2. It is interesting to examine the large-scale changes in this quantity over time and its possible relation to solar activity and cosmic rays. The number of groups of sun spots ($\eta$) and the cosmic ray flux at the maximum of the absorption curve in the stratosphere ($N_m$) were chosen as the parameters of solar activity and cosmic-ray intensity.[3,4] The average annual values of $Q$, $\eta$, and $N_m$ are shown in Fig. 1. The values of $Q$ were found from the equation $Q = \Sigma_i Q_i t_i / \Sigma_i t_i$, where $Q_i$ is the value of $Q$ in the $i$th session according to Refs. 1 and 2, and $t_i$ is the duration of the session. It is evident that the temporal behavior of these quanti-

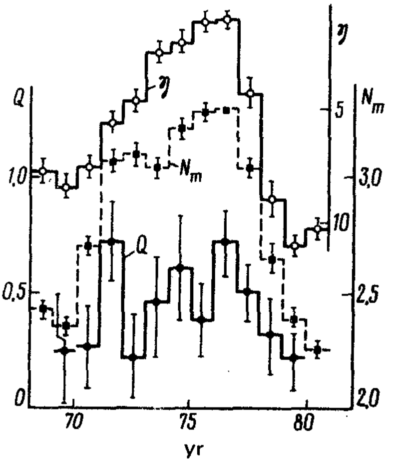

FIG. 1. The temporal behavior of the annual values of the rates of formation of $^{37}$Ar atoms per day, $Q$ (solid circles); average daily number of sun spot groups, $\eta$ (open circles, inverted scale); average daily flux of galactic cosmic rays, $N_m$ (squares); the errors are the mean-square values.

ties is similar. In order to reveal the relation between $Q$, $\eta$, and $N_m$, we calculated the mutual correlation coefficients $r$ between the annual average values of these quantities; in addition, the data block for $Q$ was taken for the period 1970-1980, while the $\eta$ and $N_m$ data blocks correlated with it were shifted in time. Figures 2a and b show the computed values of $r$ as a function of the magnitude of the time shift. The maximum values of $r$ are as follows: $r(Q, \eta) = -0.65 \pm 0.17$ with the temporal changes in $Q$ delayed relative to $\eta$ by $\Delta T = 0.5$-$1$ yr (Fig. 2a); $r(Q, N_m) = 0.67 \pm 0.17$ for $\Delta T = 0$ (Fig. 2b); $r(N_m, \eta) = -0.75 \pm 0.13$ with the temporal changes in $N_m$ delayed relative to $\eta$ by $\Delta T = 0.5$-$1$ yr.

If the increase in the $\nu$ flux from the sun with decreasing solar activity can somehow be related to processes occurring within the sun, then the relation between the quantity $Q$ and the flux of cosmic rays $N_m$ is difficult to understand, since atmospheric $\nu$ are clearly not sufficient to form the number of $^{37}$Ar atoms measured experimentally. According to Ref. 5, the average number of muons, formed in the entire atmosphere at a latitude with geomagnetic cutoff threshold $R_k = 2.5$ GV, is equal to 3.6 cm$^{-2}$ s$^{-1}$. Their average energy is $\bar{E}_\mu \simeq 470$ MeV. Hence, the $\nu$ flux ($\bar{E}_\nu \simeq 200$ MeV), passing through

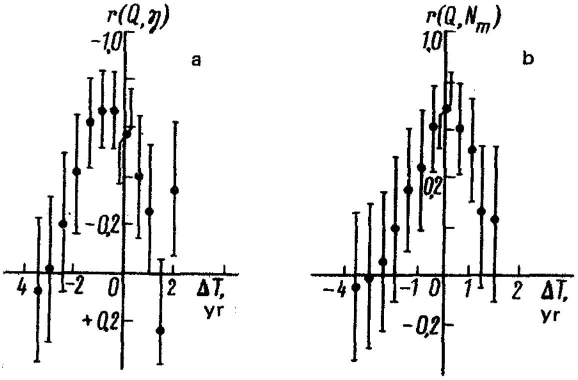

FIG. 2. The correlation coefficient $r$ between $Q$ and $\eta$ (a) and between $Q$ and $N_m$ (b) as a function of the time shift between the data blocks.

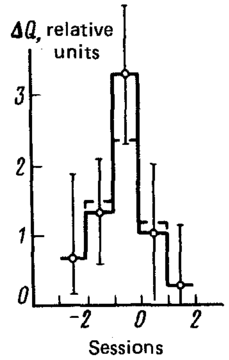

FIG. 3. The increase in the solar neutrino flux during powerful solar flares. The dashed line shows the result of eliminating session No. 27, which gave the greatest increase over 1970–1976.

Davis' apparatus, is $\phi_\nu = 4\pi \times 3.6 = 45.2$ cm$^{-2}$ s$^{-1}$. Even if the increase in the cross section $\sigma(\nu, n)$ as $E_\nu^2$ is taken into account, the contribution to the quantity $Q$ from atmospheric neutrinos must be 1.5–2 orders of magnitude smaller than from solar $\nu$.

2. In order to reveal the effect of solar flares on the $\nu$ flux, the experimental values of $Q$ were smoothed with a five-session moving average. Deviations from the smoothed values were analyzed by the method of superposition of epochs. Sessions No. 19, 21, 27, 30, 42, 51, 52, 54, and 55 (the enumeration follows Refs. 1 and 2), during which powerful flares generating protons with $E_p \gtrsim 500$ MeV occurred on the sun, were taken as the zero interval. The histogram illustrated in Fig. 3 has a peak, occurring at the zero interval, which includes the burst of solar cosmic rays.

This result indicates that the $\nu$ flux from the sun can increase during generation of particles in powerful chromospheric flares and their interaction with solar matter.

3. Conclusions: a) the $\nu$ flux changes oppositely in phase to the solar activity cycle and lags behind the latter by 0.5–1 yr; b) powerful bursts of cosmic rays on the sun increase the detected $\nu$ flux; c) a synchronous correlation is observed between the $\nu$ flux and the integral flux of primary cosmic rays ($E_p \simeq 1$ GeV), which is difficult to explain at the present time; d) according to the characteristics established in 1981, the quantity $Q$ must be small, $Q \simeq 0.2$–$0.3$ $^{37}$Ar atoms/day, since solar activity was high; in subsequent years, a drop should be observed in solar activity and the flux of cosmic rays and solar $\nu$ should increase; e) the quantity $Q$ in October 1981 may be increased, since in October 1981 a powerful burst of cosmic rays, generating protons with $E_p \gtrsim 1.5$ GeV, occurred on the sun.

We are deeply grateful to I. M. Zheleznykh, G. T. Zatsepin, S. I. Nikol'skiĭ, and A. E. Chudakov for useful discussions of this work.

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Translated by M. E. Alferieff
Edited by S. J. Amoretty