VARIATIONS IN THE SOLAR NEUTRINO FLUX

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Abstract

Observations are reported from the chlorine solar neutrino detector in the Homestake Gold Mine, South Dakota, USA. They extend from 1970 to 1985 and yield an average neutrino capture rate of 2.1±0.3 SNU. The results from 1977-1985 show an anti-correlation with the solar activity cycle, and an apparent increased rate during large solar flares.

1. Introduction. A solar neutrino detector based on the neutrino capture reaction on chlorine, $^{37}Cl(\nu,e^-)^{37}Ar$, has been in operation since 1967. In 1970 the sensitivity of the detector was increased by employing pulse rise-time measurements to improve the discrimination of the ^{37}Ar-like pulses from those produced by background beta and gamma radiations. The experimental procedures and various tests of the detector efficiency have been described in earlier reports 1). We report here results obtained between October 1970 and May 1985. Observations were terminated in May 1985 by the failure of the liquid circulation pumps. One pump has been replaced, and observations were resumed in October 1986. We plan to continue monitoring the solar flux in the future. The observed ^{37}Ar production rates for the period October 1970-January 1984 are listed in reference 2). Additional data are now available through May 1985.

We will discuss this set of data (Runs 18-88) in relation to solar model calculations, neutrino oscillation phenomena, and solar activity.

2. Averaged Results, Solar Models, and Neutrino Physics. The average ^{37}Ar production rate for the set of 68 individual experimental runs is 0.472±0.036 ^{37}Ar atoms per day in 615 m-tons of C_2Cl_4 (2.19×10^{30} atoms ^{37}Cl). From this we subtract an estimated production of ^{37}Ar from background processes, in particular those from cosmic ray muons, equal to 0.08±0.03 ^{37}Ar atoms/day 3). A new measurement of the muon background effect is in progress, using the radiochemical method of Fireman 4), based on the photonuclear interactions of muons with ^{39}K to yield ^{37}Ar. Subtracting this background rate leaves a net rate of 0.392±0.047 ^{37}Ar atoms/day that could be ascribed to the solar neutrino flux. The rate corresponds to 2.07±0.25 SNU where SNU stands for a solar neutrino unit, defined as 10^{-36} captures/target atom/second.

The results of the chlorine experiment can be compared to results predicted using theoretical models of the sun. (See references 5) & 7) for discussion.) The predicted neutrino capture rate in ^{37}Cl is 6 to 8 SNU 7).

According to the standard model, approximately 75% of the calculated rate would be attributed to the low flux of neutrinos from ^{8}B decay in the Sun. Only these neutrinos (E=0-15 Mev) have sufficient energy to feed the analog state in ^{37}Ar, a super-allowed transition with a neutrino capture cross section 3 to 4 orders of magnitude greater than that for other neutrino sources in the Sun (PeP, ^{7}Be, ^{13}N and ^{15}O) 6). The production of ^{8}B in the Sun is very sensitive to the internal temperatures. A number of solar models have been devised to accommodate the low rate observed by the ^{37}Cl experiment. These models invoke conditions that would lower internal temperatures, i.e., mixing, diffusion, reduced heavy element abundances, magnetic fields, and internal roation 8). They predict neutrino capture rates in ^{37}Cl from 1.5 to 2.5 SNU, in good agreement with experimental results.

It was suggested very recently, by Mikheyev and Smirnov 9) that electron-type neutrinos could be converted to muon or tauon type neutrinos in their passage through the dense interior of the Sun. The conversion, $\nu_e \rightarrow \nu_\mu$, is a resonance phenomenon ($\nu_e = \nu_\mu$ or ν_τ) resulting from a difference in the respective scattering cross sections with electrons. The process

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depends on the difference in masses between the neutrino types, and on the mixing angle. The electron neutrino must be the lightest of the neutrinos and at least one other neutrino must have a mass close to that of the electron neutrino. This phenomenon could result in a distortion of the normal ^8B neutrino spectrum and account for the low observed neutrino capture rate in ^{37}Cl[10]. For certain values of the neutrino mass differences ($10^{-4} eV^2 \geqslant \Delta m^2 \geqslant 10^{-6} eV^2$) and mixing angles ($0.086 \leqslant \sin\theta \leqslant 0.52$) a day-night effect may be observable with the ^{37}Cl solar neutrino detector[11]. The University of Pennsylvania is planning to search for a day-night effect with this detector. It can be accomplished by increasing the helium gas purging rate so that an ^{37}Ar sample can be recovered in 4 to 5 hours.

It was suggested by Okun, Voloshin, and Vysotsky[12] that if the neutrino is a massive Dirac particle with a magnetic or electric dipole moment, its spin could be flipped in passing through the magnetic fields in the Sun. In this case, the neutrino would not be detectable. This mechanism could account for variations in the ^{37}Ar production rate with solar activity. This process would be important if the neutrino had a magnetic moment of the order of 10^{-10} Bohr magnetons for magnetic fields of a few thousand gauss.

We now address the question of the constancy of the ^{37}Ar production rates observed in the chlorine detector. There are strong indications that the rate varies with the solar activity cycle, and that large solar flares produce sudden increases in the rate. These matters must be understood before one can interpret the results fom the chlorine detector in terms of the solar model, solar structure, and neutrino interactions.

3. Solar Flare Enhancements. It was pointed out by Bazilevskaya et al.[13] that three large solar flares (August 4, 1972; September 19, 1977, October 10, 1981) correlate in time with high ^{37}Ar production rates in the chlorine detector during runs#27,#51, and#71 (1.23±.41 ^{37}Ar/day; 0.85±.33 ^{37}Ar/day; 1.21±.37 ^{37}Ar/day, respectively). They compared the observed ^{37}Ar production rate with solar flare proton intensities (≥150Mev) measured at the top of the atmosphere. In addition, the largest flare observed by the solar maximum mission occurred on August 5, 1984, during the exposure interval of run#86 (1.26±.57 ^{37}Ar/day).[15] Monte Carlo simulations of the experimental data, assuming a steady neutrino source with an average production rate of 0.47 ^{37}Ar/day, show that one may expect to observe an average of one run with an ^{37}Ar production rate of 1.2 atoms/day in a set of 68 measurements. The three events that were observed are not inconsistent with expectation. However, when one considers that during the three highest runs observed in 68 measurements (#27, 71, 86)there occurred very large solar flares, and that these flares were the largest ones observed in that period, the chance of correlation is very unlikely. The flares which correlate with high ^{37}Ar production rates are flares in which gamma rays and neutrons were observed (October 10, 1981, and August 5, 1984).

Observing the neutrino flux and energy spectra from flares can give important information on acceleration mechanisms. Large scintillation and Cerenkov neutrino detectors are now capable of observing time-correlated neutrino bursts[16]. One may look forward to testing the indicated correlations of ^{37}Ar enhancements from the chlorine detector.

4. Correlation with Solar Activity. A number of authors have analyzed the observed ^{37}Ar production rate for periodicities[17], and for correlations with solar activity[13,18]. Figure 1 shows a plot of the 5-point running averages of the ^{37}Ar production rate, compared to the smoothed sunspot numbers. Note that the ^{37}Ar production rate drops from 0.8±0.15 atoms/day to 0.1±0.1 atoms/day with the onset of solar cycle #21. From 1977 to the end of our observations in 1985, the ^{37}Ar production rate anti-correlates with sunspot numbers in a systematic and organized way. Figure 2 shows the systematic anti-correlation for this period. Prior to 1977, the ^{37}Ar production rate is constant and consistent with the errors. The linear correlation coefficient for the period 1977-1984 is 0.80, using all experimental points.

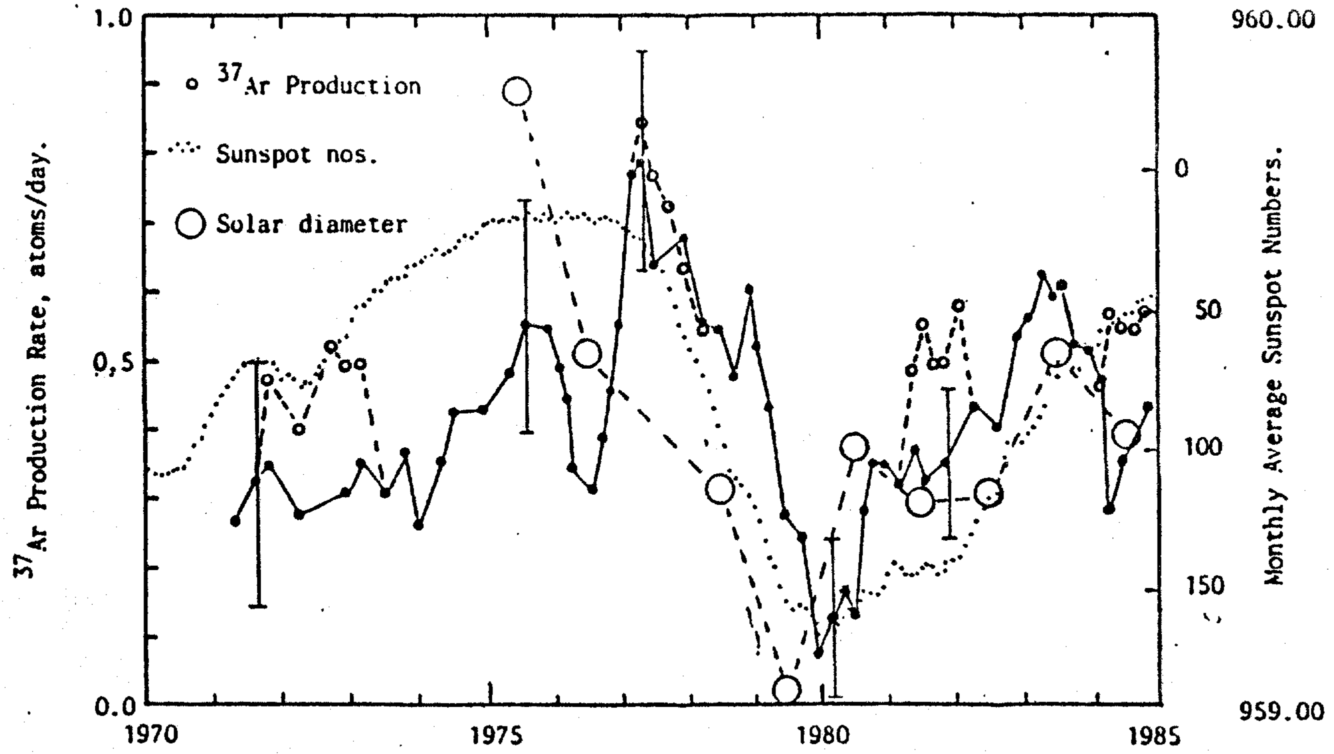

Figure 1. Comparison of 5-point running averages of ^{37}Ar production rates with sunspot numbers and solar diameter measurements. Solid points do not include runs associated with solar flares. Open points include flare associated runs.

It is difficult to explain this variation by the usual views on solar structure or conceivable cosmic ray neutrino or muon processes. There are changes in the solar diameter during 1975-1984 that correlate well with sunspot numbers and the ^{37}Ar production rates.As mentioned earlier, Okun et al.[12] suggested that the variations in ^{37}Ar production rates could be explained by a neutrino magnetic moment.

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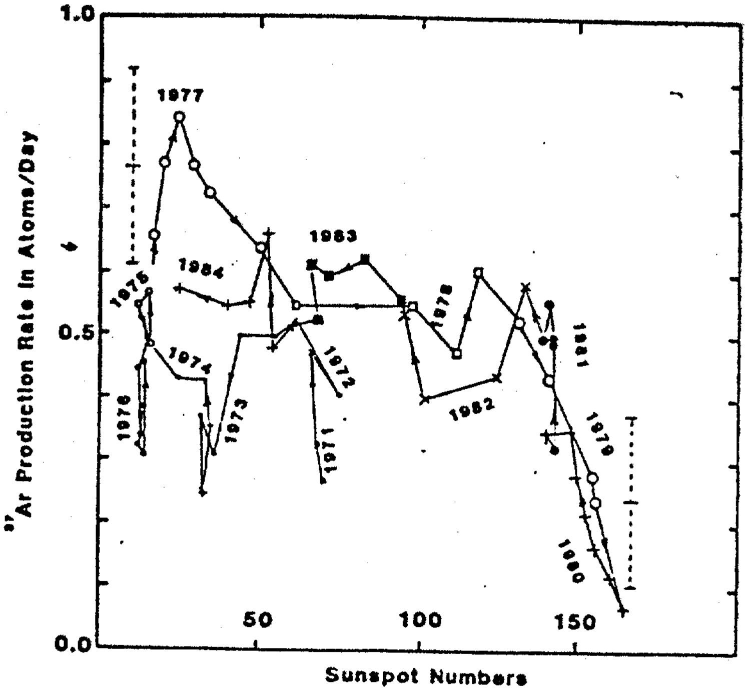

Figure 2. Correlation of ^{37}Ar production rate with sunspot numbers.

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