The Argument for a Low Energy Steady State Solar Neutron Flux

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Abstract: Recent experiments have suggested that there is a low energy solar neutron flux. Findings from the DANSON solar neutron detector experiment, which took data from October of 2016 to March of 2017, are revisited to provide a context for this suggested solar neutron flux. The fraction of neutrons arriving at 1 au (astronomical unit) has been calculated and used to determine the possible neutrino flux from the beta decay of the low energy solar neutron flux. Because there has been solar flare data reported during the time of this experiment, solar events cannot be ruled out as the source of this flux. Here we present an analysis that indicates the need for a comparison of data from an earth-based neutrino detector and for more experiments with real-time neutrino detectors and real-time neutron spectroscopy in low Earth orbit.

Keywords: Helio astronomy, solar neutrons, neutron decay

1. INTRODUCTION

Several experiments, e.g. MESSENGER [1,2] and DANSON [3], have now suggested that there is a low energy solar neutron flux, though this is not without controversy [4]. MESSENGER experienced higher than expected neutron counts from low energy neutrons during solar flare events, suggesting a low energy neutron flux from the sun [1,2]. The Comptel detector [5], although primarily a gamma ray detector, also detected significant neutrons but only above 8 MeV, which is higher than the neutron energies from the MESSENGER [1,2] and DANSON [3] detectors. The Comptel detector did detect solar neutrons but observed solar neutrons only in bursts associated with solar flares [6-12]. Though there is evidence for a low energy solar neutron flux, it is uncertain whether such neutrons are steady state (uniform over time) or associated with shorter bursts.

A multi-layer neutron detector designed to act as a neutron calorimeter, the DANSON detector [3], was launched and deployed aboard the International Space Station, collecting data over $8x10^6$ seconds. Effectively, the DANSON detector was a passive neutron calorimeter or spectrometer, so as to roughly determine the possible low-energy solar neutron flux and approximate mean energy of neutrons below 10 MeV [3].

The high energy solar neutron flux is produced by solar flares and other events that have been documented [8-25] and understood. The origin of the observed low energy solar neutron flux, observed by DANSON and MESSENGER [1-3] is, however, not known. So learning whether observed low energy solar neutron flux (less than 10 MeV) is steady state resulting from solar nucleosynthetic processes or associated with solar coronal mass discharge events will aid in the study of the phenomenon.

2. THE MEAN ENERGY FOR THE LOW ENERGY SOLAR NEUTRON FLUX

While the MESSENGER experiment placed the low energy neutron flux between 1 and 10 MeV, DANSON refined the low energy neutron flux to be in the region of 2 to 4 MeV. To further refine this estimate, the data collected during DANSON's operation was compared to the expected neutron energy distribution among the layers determined by Monte Carlo simulation provided previously to model DANSON [3]. It is realistic to expect that cosmic ray created neutrons and backscattered neutron would enter the DANSON detector from the earth facing (nadir side) of the detector. Such neutrons, not of solar origin, could contribute counts at the DANSON detector layer where solar neutrons would exit the detector. These additional non-solar neutron counts were not part of the Monte Carlo simulation [3] and there is some indication in the DANSON data of "extra" neutrons entering the DANSON detector from the nadir side. Accordingly, the data from the nadir side of the detector, in the data reported for DANSON [3], was excluded from the fit to reduce complications from backscattered neutrons that might not be part of the direct low energy solar neutron flux. For each incident energy in Figure 1, the squares of the difference between the expected capture at each layer and actual capture at each detector layer, each as fractions of the maximum value of each curve, were totaled for each incident energy. The lowest value for the difference between expected data and the data collected shows the incident energy for the neutrons, which was found to be about 2 MeV.

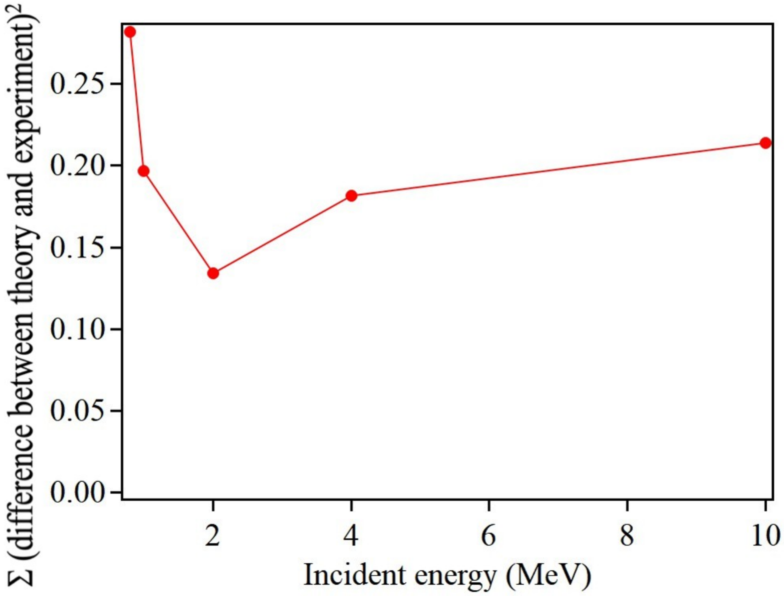

Figure 1: The experimental layer by layer detector response is compared to the simulation for DANSON detector response at that neutron energy. The sum of the square of the difference between experimental measurement of neutron intensity from DANSON data and the expected value of neutron intensity determined by Monte Carlo simulation [3], as a fraction of total counts.

Knowing the energy, the time it takes for neutrons to get to Earth can be calculated. This calculation can be used to determine the fraction of neutrons that arrive at 1 au based on standard neutron decay time which lies between 879.6±0.8 [26,27] and 885.7 ± 0.8 [28] seconds. This detectable fraction of solar neutrons at low energy, at 1 au, is a very small fraction of the initial neutron flux. At a neutron energy of 2 MeV, the fraction of neutrons arriving at the detector is 1.705×10^{-4}. The decay of most solar neutrons of low kinetic energy, at 1 au, means an increase in the solar neutrino flux, since the neutrons of 2 MeV mean energy, detected by the DANSON experiment, will have mostly decayed into a proton, an electron, and an electron antineutrino. This is caused by the conversion of the negatively charged (−1/3 e) down quark to the positively charged (+2/3 e) up quark by emission of a weak force W^- boson which decays into an electron and an electron antineutrino, i.e. $n \rightarrow p + e^- + \bar{\nu}_e$. The fraction of neutrons that arrive at 1 au also determines the fraction that have decayed before 1 au.

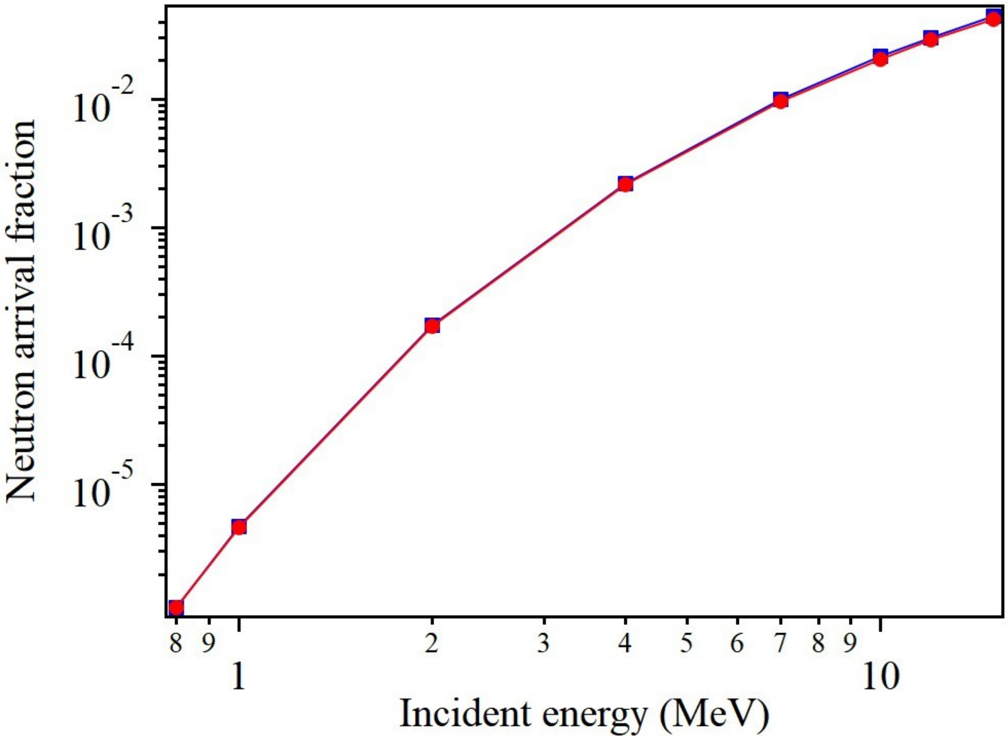

Figure 2: The calculated fraction of solar neutrons arriving at 1 au using the expected neutron decay lifetime (red) and using the decay lifetime with relativistic correction (blue).The relativistic correction to the decay lifetime for low-energy neutrons are small, becoming relevant only at higher neutron energies.

3. NEUTRINO FLUX FROM LOW-ENERGY SOLAR NEUTRONS

Since it was determined [3] that 250-375 neutrons$\cdot$cm^{-2}s^{-1} arrive at 1 au, the number of antineutrinos generated by the neutron decay can be calculated. Over a period of 8x10^{6} seconds, the total number of neutrinos will be roughly 3.4x10^{12} as a result of the decay of the vast majority low energy solar neutrons that do not reach 1 au. If this additional neutrino flux was divided into two or three short bursts over that length of time, each short burst would contain 10^{11} to 10^{12} neutrinos$\cdot$cm^{-2}s^{-1}. Not all of these electron antineutrinos will arrive at an earth-based neutrino detector; additionally, the generated neutrinos will not necessarily move in the direction of the neutron flux. The neutrino flux, generated by the beta decay of the low kinetic energy solar neutron flux, may still be large enough that a short burst of neutrinos would be detected by one or more of the current neutrino detectors.

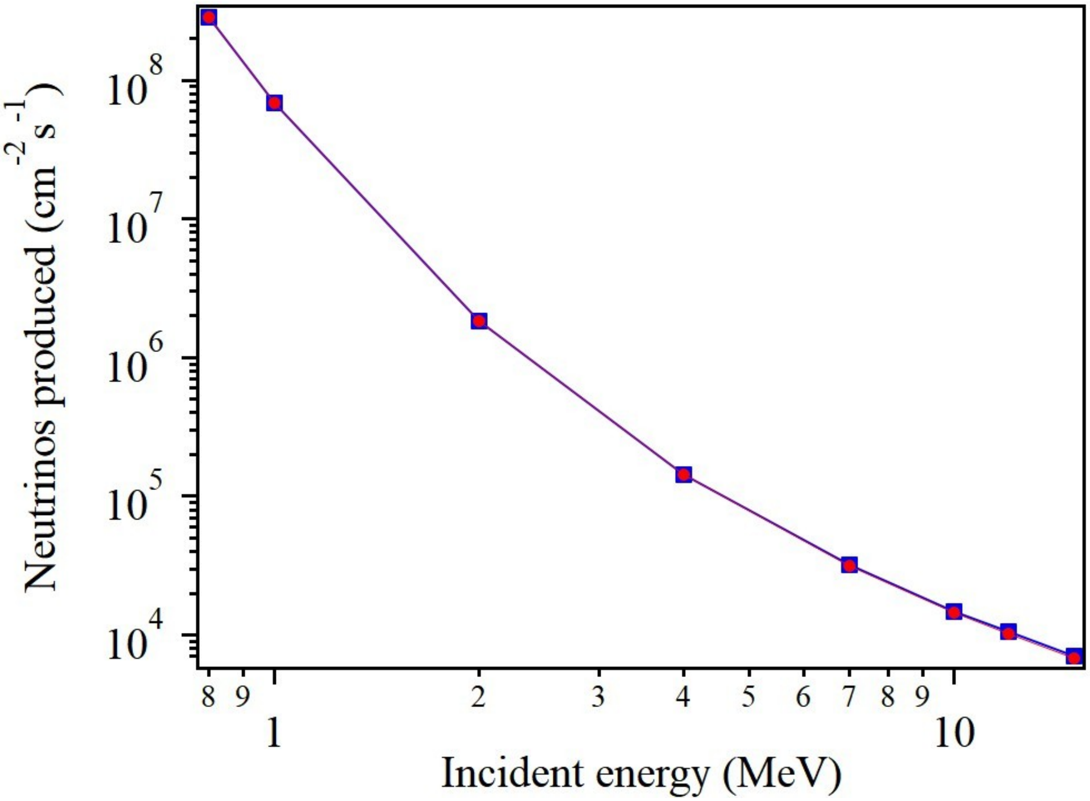

Figure 3: The expected neutrino flux from solar neutron decay (see text) calculated from Figure 2 both with (red) and without (blue) relativistic correction.

4. DISCUSSION

In order to assess the likelihood of a steady state solar neutron flux of around 2 MeV mean energy, it must be known whether there was solar activity recorded during the time of DANSON's operation. NOAA recorded some solar activity during that time from late 2016 to early 2017 [26]. This has to be a serious consideration because solar flare events between October 23, 2016 to March 17, 2017 would coincide with the period of neutron data collection by DANSON [3]. Because there was solar activity, it must be considered that DANSON's neutron capture signal may include neutrons from these solar flare events. In the case that solar flares contributed to this neutron count, it is important to note that the flares would have to be of significantly low energy, around 1 to 4 MeV, as compared to more familiar high energy flares of energies around 75 MeV [8,9,11-13,15,16,18-20,23], because of the low-energy acceptance window of the DANSON detector [3].

The relation of these known solar flare events [29] to DANSON's neutron capture count could be established by comparison with real-time neutrino detectors to see if there was an increase in neutrinos associated with the decay 2 to 4 MeV energy solar neutrons at the times of solar flares. The main contribution to the solar neutrino flux comes from the proton-proton reaction, with a peak flux above 10^{11} neutrinos $cm^{-2}*sec^{-1}$ at 1 au, and these neutrinos have a low energy, up to 400 keV [20-33], thus would overlap with the antineutrino flux resulting from neutron beta decay, which would also be at energies below 1 MeV. There are many neutrino detectors, including Sanford Underground Research Facility (SURF), Borexino, San Grasso, Super Kamiokande, Sudbury, and still others [30,31]. Each of these detectors has a different sensitivity to the neutrino that can be detected. Not all are sensitive to electron antineutrinos and furthermore, previous experiments sensitive to low energy neutrinos (SAGE, Gallex, GNO) did not measure the individual fluxes [31], unlike Borexino [34]. In this regard, the Borexino neutrino detector is of interest for comparison because this is one of the few neutrino detectors that is sensitive to the inverse beta decay reaction channel, and hence electron antineutrinos [35], with some detection sensitivity to neutrino energies below 1 MeV [32,34,36].

A neutrino flux that occurs from the decay of steady state neutron flux would be difficult to detect over the solar neutrino background produced by the proton-proton solar neutrino production mechanism, since the added neutrino flux would be orders of magnitude below this solar neutrino flux of solar origin which, as noted above, is in the region of 10^{11} neutrinos $cm^{-2}*sec^{-1}$ at 1 au). In contrast, if the neutrons came in two or three short bursts over the data collection period of the DANSON detector, then the neutrino flux measured by Borexino and other neutrino detectors might experience a significant, noticeable increase during the solar flare events, since only then would the neutrino production, from the decay of neutrons, be in bursts on or above the order of magnitude of the solar background produced by the proton-proton neutrino signal.

Detection of a possible neutrino flux, generated by the beta decay of the low kinetic energy solar neutron flux, will be complicated by the fact that while such neutrinos would be low-energy, neutrinos created from the decay of low kinetic energy solar neutron will be spread over a significant energy window. The significant energy window of the neutrino energy is required because the kinetic energy distribution of beta particles, resulting from beta decay, are diffuse, or roughly continuous [37-39], although decreasing in intensity up to 1 MeV. Such neutrinos will thus have an energy spectrum difficult to distinguish from the neutrinos created by the proton-proton mechanism.

If no neutrino bursts of energy less than 1 MeV have been reported or detected by the Borexino Collaboration or any other neutrino detector project, this would diminish the likelihood that the 1 to 4 MeV low energy solar neutron flux arrives in bursts. Yet an absence of detected neutrino bursts at energies below 1 MeV, correlated with solar flare events, does not exclude the possibility of antineutrino bursts resulting from the decay of episodic low energy solar neutrons, as detected by DANSON [3].

5. CONCLUSION

There is now a need to compare the recorded solar activity, specifically the solar flare events between October 23, 2016 to March 17, 2017, to any sudden influx of neutrinos captured by a real-time neutrino detector like Borexino, at neutrino energies below 1 MeV. Alternatively, a real time neutron detector with greater sensitivity to neutrons at lower energies could also be used to clarify the origin of low-energy solar neutrons. Such a real time neutron detector would provide the capability to compare the solar neutron flux to solar flare events. With real time data, the solar neutron flux could be monitored to measure for bursts or steady state flux and more accurately measure the energy of the flux. Determining the nature of the solar neutron flux, whether it is steady state or not, would lead to answers about the origin of these low-energy neutrons. If the neutrino detector efficiencies are improved sufficiently, such a neutron detector would also permit a comparison of the low energy neutron flux and the solar neutrino flux in real time.

If the production of the low energy solar neutron flux is largely steady state, then long sought measurements of the quadrupolar moment of the sun may be possible [40-43]. This latter measurement could be significant because an accurate determination of the quadrupolar moment of the sun could providing new insights into the cosmological constant [43-45].

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