

The Need to Measure Low-Energy Antineutrinos ($E_{\bar{\nu}} < 0.782 \text{ MeV}$) from the Sun*

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Abstract—Measurements are needed of low-energy antineutrinos generated by possible neutron decay at the core of the Sun. The measurement will test the validity of a proposal that solar luminosity, solar neutrinos, and the outpouring of H^+ ions from the solar surface are the products of a chain of reactions triggered by neutron emission from the solar core. Inverse β decay of 87-d ^{35}S , induced by capture of low-energy antineutrinos on ^{35}Cl , is a likely candidate for this measurement. © 2004 MAIK “Nauka/Interperiodica”.

Fresh debris of a supernova (SN) formed the Solar System. This is the conclusion to numerous measurements since 1960 [1]. The SN exploded about 5 Gyr ago [2]. The Sun formed on the collapsed SN core, Fe-rich material around the SN core formed iron meteorites and cores of the inner planets, and material from the outer SN layers formed the giant Jovian planets from light elements like H, He, and C [3, 4]. This sequence of events is shown in Fig. 1.

When first proposed in the mid-1970s [3, 4], the scene in Fig. 1 appeared to contradict several widely held opinions:

1. Supernovae always explode symmetrically.
2. SN debris cannot form planets surrounding the collapsed SN core.
3. Poorly mixed SN debris is inconsistent with uniform atomic weights and isotopic abundances assumed throughout the Solar System.
4. The Sun is mostly hydrogen; it could not be formed in this manner.
5. Abundant solar hydrogen is required to explain solar luminosity.

This paper suggests a measurement to test the validity of the fifth assumption. The other objections have been resolved.

Problems with the first assumption were exposed when the Hubble telescope found that asymmetric SN explosions are commonplace, for example, the explosion of SN1987A [5]. The validity of the second assumption was brought into question with the finding of two rocky, Earth-like planets and one Moon-like object orbiting a neutron star, PSR1257+12 [6].

Decay products of nuclides even shorter lived than ^{129}I and ^{244}Pu [7, 8] and linked elemental and isotopic variations in meteorites and planets [9–14] ruled out the third assumption.

The fourth assumption, that the interior of the Sun is hydrogen-filled like its surface, was invalidated by the finding that mass separation inside the Sun enriches lighter elements and the lighter isotopes of each element at the solar surface [15]. After correcting for mass fractionation, the most abundant elements in the interior of the Sun [15] were shown to be the same elements that Harkins [16] found to comprise 99% of ordinary meteorites, i.e., Fe, O, Ni, Si, Mg, S, and Ca. These elements are produced in the deep interior of highly evolved stars [17], as expected from the events in Fig. 1.

SN debris is not the only possible source for some short-lived nuclides and isotopic anomalies observed in meteorites and planets [9–14]. However, rapid neutron capture in a SN is the only viable mechanism to produce extinct ^{244}Pu [2, 8]. The validity of Fig. 1 was strengthened when Kuroda and Myers [2] combined age dating techniques based on ^{238}U , ^{235}U , and ^{244}Pu to show that a SN explosion produced these actinide nuclides at the birth of the Solar System, about 5 Gyr ago. Their results are in Fig. 2.

The present paper concerns the need for measurements to test a proposed source for luminosity in an iron-rich Sun, i.e., to test the validity of the fifth objection to events shown in Fig. 1. In layman’s terms, “How can the Sun shine if it is made mostly of iron?” The answer requires the use of reduced variables, like those in van der Waals’ equation of corresponding states, to look for sources of energy in properties of

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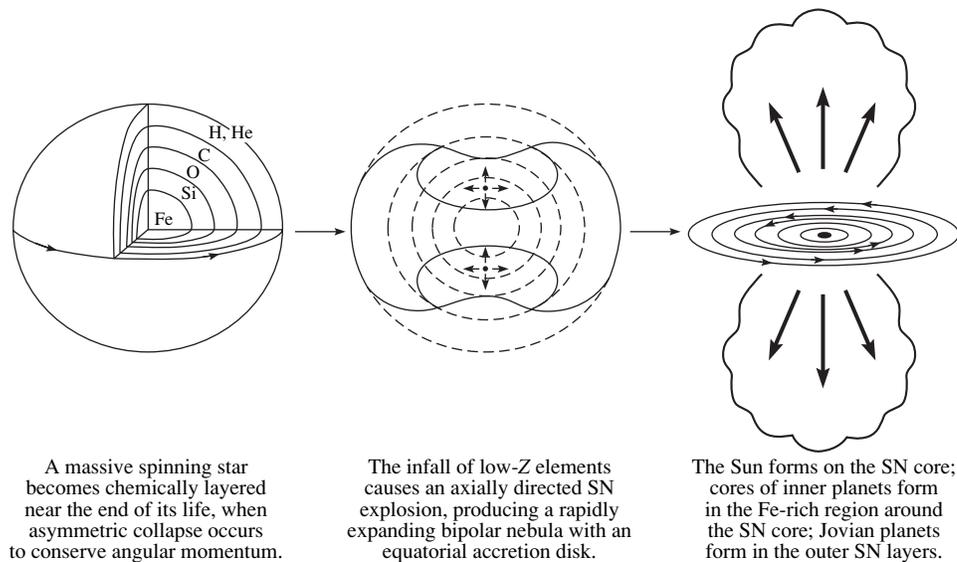


Fig. 1. Formation of the Solar System from the chemically and isotopically heterogeneous debris of a spinning supernova [3, 4]. The Sun formed on the collapsed supernova core; Fe-rich material formed iron meteorites and cores of the inner planets; and H, He, and C-rich material from the outer layers formed giant planets like Saturn and Jupiter.

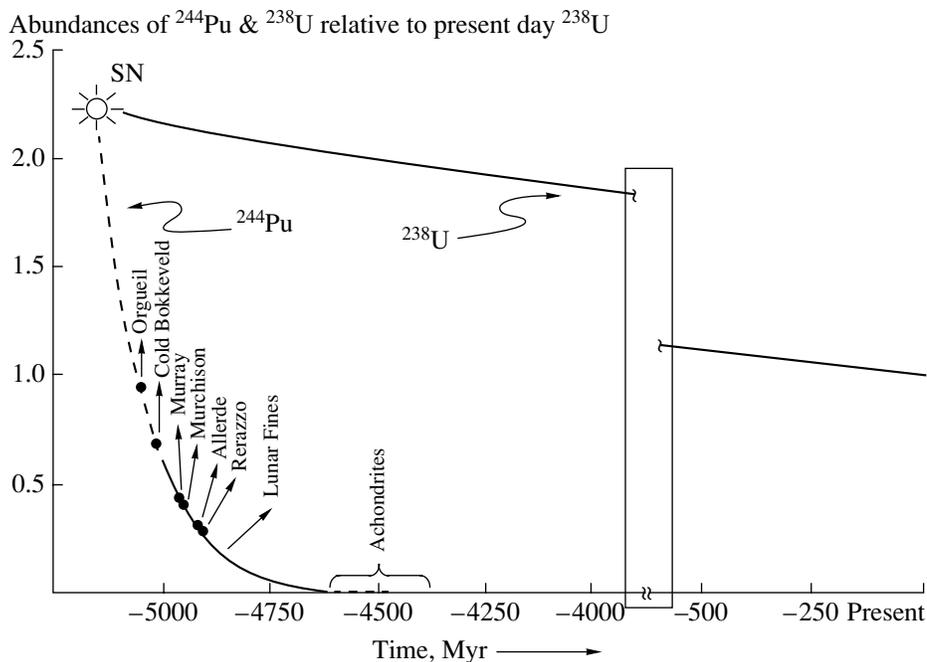


Fig. 2. Combined U–Pb and Pu–Xe age dating of the supernova explosion that occurred at the birth of the Solar System, about 5 Gyr ago [2].

the 2850 nuclides tabulated in the latest report from the National Nuclear Data Center [18].

The results are shown in Fig. 3, where data for ground states of 2850 known nuclides [18] are displayed on a three-dimensional graph of Z/A , charge per nucleon, versus M/A , mass or total potential energy per nucleon, versus A , mass number. All

nuclides lie within the limits of $0 \leq Z/A \leq 1$ and $0.998 \leq M/A \leq 1.010$, and the data [18] define a cradle shaped like a trough or valley. The more stable nuclides lie along the valley, and the lowest point is ^{56}Fe .

Cross sections through Fig. 3 at any fixed value of A reveal the familiar “mass parabola.” An example

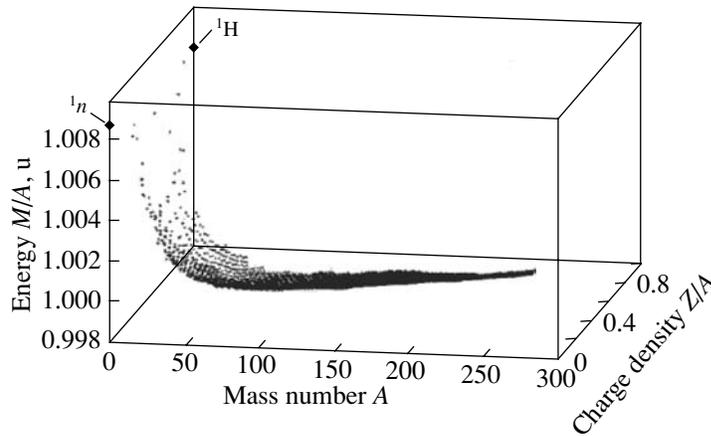


Fig. 3. The “cradle of the nuclides,” a three-dimensional plot of reduced nuclear variables, Z/A (charge per nucleon) vs. M/A (mass per nucleon) vs. A (mass number) for the ground states of 2850 known nuclides [18]. The cradle provides new insight into possible sources of nuclear energy [19].

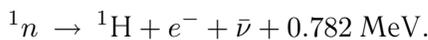
is shown in Fig. 4 at $A = 27$. Data points are also shown in Fig. 4 for unbound nucleons, 1n on the left at $Z/A = 0$ and 1H on the right at $Z/A = 1.0$. The mass parabola in Fig. 4 is defined by masses of ground-state nuclides at ${}^{27}F$, ${}^{27}Ne$, ${}^{27}Na$, ${}^{27}Mg$, ${}^{27}Al$, ${}^{27}Si$, ${}^{27}P$, and ${}^{27}S$ [18]. At $Z/A = 0$, the empirical parabola yields a value of $M/A = M({}^1n) + \sim 10 \text{ MeV}$.

The results shown in Fig. 4 are typical of values indicated at $Z/A = 0$ from mass parabolas at each mass number A , where $A > 1$. Together, these mass parabolas [18] at all values of A suggest a driving force of $\sim 10\text{--}22 \text{ MeV}$ for neutron emission from a neutron star [19]. This energy source and the following sequence of reactions thus offer a possible explanation for solar luminosity (SL), the fifth objection to the scene shown in Fig. 1:

Neutron emission from the solar core ($>57\%$ SL):



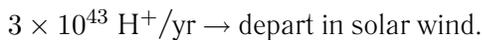
Neutron decay or capture ($<5\%$ SL):



Fusion and upward migration of H^+ ($<38\%$ SL):



Escape of excess H^+ in solar wind (100% SW):



Thus, neutron emission from a collapsed SN core in the center of the Sun, as shown in Fig. 1, may start a chain of reactions that explain luminosity, as well as the observed outflow of solar neutrinos and H^+ ions from the surface of an iron-rich Sun [19].

In the first step, neutron emission may release 1.1–2.4% of the nuclear rest mass as energy. In the third step, hydrogen fusion releases about 0.7% of the rest mass as energy.

However, this paper is most concerned with the need to measure low-energy antineutrinos emitted in the second step. This measurement may confirm or deny the occurrence of the above reactions in the Sun and the historical validity of the events shown in Fig. 1.

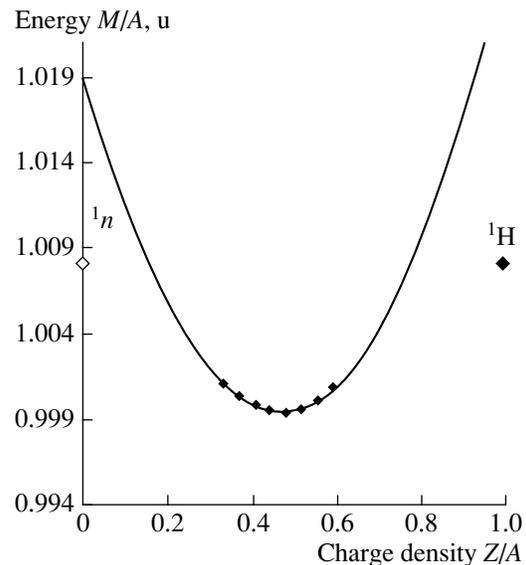


Fig. 4. A cross-sectional cut through the “cradle of the nuclides” (Fig. 3) at $A = 27$. The mass parabola is defined by masses of ground-state nuclides at ${}^{27}F$, ${}^{27}Ne$, ${}^{27}Na$, ${}^{27}Mg$, ${}^{27}Al$, ${}^{27}Si$, ${}^{27}P$, and ${}^{27}S$. For comparison, reference values are shown for unbound nucleons, 1n on the left at $Z/A = 0$ and 1H on the right at $Z/A = 1.0$.

Specifically, it is proposed to look for inverse β decay induced by low-energy antineutrinos coming from the Sun, e.g., ${}^3\text{He} \rightarrow {}^3\text{H}$, ${}^{14}\text{N} \rightarrow {}^{14}\text{C}$, or ${}^{35}\text{Cl} \rightarrow {}^{35}\text{S}$. The latter reaction in the Homestake mine [20] might produce measurable levels of 87-d ${}^{35}\text{S}$. Alternatively, ${}^{35}\text{S}$ might be extracted from underground deposits of salt (NaCl) and detected by counting or by AMS (accelerator mass spectrometry) measurements.

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