

IS THERE A DEFICIT OF SOLAR NEUTRINOS?

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Abstract. Measurements on the isotopic and elemental compositions of meteorites, planets, lunar samples, the solar wind, and solar flares since 1960 suggest that the standard solar model may be in error. A new solar model suggests that the observed number of solar neutrinos represents at least 87% of the number generated: There is little if any deficit of solar neutrinos.

In 1936 Francis William Aston, who developed the mass spectrograph for accurate determination of atomic weights and expressed his results in terms of nuclear packing fraction, visited Japan to view a solar eclipse. He presented a special lecture that sparked an unusually talented, 19-year old student's interest in nuclear and solar studies, Kazuo Kuroda¹. Kuroda joined the faculty at the University of Tokyo eight years later, moved to the US after the end of WWII, acquired "Paul" as a first name¹, and correctly predicted natural, self-sustaining, uranium fission reactors in the early history of the Earth² and the presence of ²⁴⁴Pu at the birth of the solar system³.

In 1956 John Reynolds reported the development of a new, high-sensitivity mass spectrometer for noble gases⁴, a significant advancement over earlier instruments. Then in 1960, Reynolds reported two astonishing discoveries with his new mass spectrometer:

- Meteorites contain radiogenic ¹²⁹Xe from the *in situ* decay⁵ of extinct ¹²⁹I.
- The abundance pattern of the other eight stable isotopes of primordial xenon in meteorites is unlike that of terrestrial xenon⁶.

The first author (om), a new graduate student in 1960, was called to the office of Professor Kuroda, shown Reynolds' startling results^{5,6}, and persuaded to use isotopic analyses of noble gases in meteorites as the subject of his PhD research. Manuel went to Reynolds' lab to learn this instrument first hand, but before an instrument could be set up for his graduate work, Fowler et al.⁷ concluded that the extinct ¹²⁹I in meteorites⁵ might have been produced here in the early solar nebula, together with D, Li, Be and B.

Over 40 years of isotope measurements on meteorites, planets, lunar samples, the solar wind, and solar flares since 1960, and advances in understanding systematic trends in values of Aston's packing fraction for the 2,850 nuclides currently known⁸ suggest the following modifications to the earlier conclusion of Fowler et al.⁷:

- Local element synthesis may have produced, not just the rare isotopes suggested by Fowler et al.⁷, but also bulk material of the solar system and imprinted it with a record of linked chemical and isotopic variations across planetary distances⁹.
- Lighter mass elements and the lighter mass isotopes of each element may be enriched at the solar surface. When the photosphere is corrected for this empirical fractionation, the seven most abundant elements in the interior of the Sun seem to be the same ones that comprise 99% of the material in ordinary meteorites. The probability is $< 2 \times 10^{-33}$ that this agreement is fortuitous⁹.
- Combined Pu/Xe and U,Th/Pb age dating shows our actinide elements were made in a supernova (SN) explosion at the birth of the solar system, about 5 Ga ago¹⁰.
- Neutron emission from the collapsed SN remnant at the solar core produces ¹H at the Sun's surface, ¹H in the solar wind, and $>57\%$ of the Sun's energy¹¹. Solar fusion of this neutron decay product generates $<38\%$ of its energy¹¹.

Table 1 compares the standard solar model¹² (ssm) with the new solar model¹¹.

Table 1. Two Models of the Sun

Properties	Std. Solar Model ¹²	New Solar Model ¹¹
Origin	The sun formed instantly as a homogeneous body from an interstellar cloud with no mass accretion or mass loss.	The sun formed in a timely manner by accretion of fresh SN debris on the collapsed core of a supernova.
Main source of luminosity	Hydrogen-fusion in the core	Energy from a SN core
Main nuclear reactions	Hydrogen fusion: $4 \text{ } ^1\text{H} + 2 \text{ e}^- \rightarrow$ $\text{}^4\text{He} + 2 \text{ } \nu + 27 \text{ MeV}$	a) Neutron emission: $\langle \text{}^1\text{n} \rangle \rightarrow \text{}^1\text{n} + 10 \text{ MeV}$ b) Neutron decay: $\text{}^1\text{n} \rightarrow \text{}^1\text{H} +$ anti- $\nu + 0.8 \text{ MeV}$ c) Hydrogen fusion: $4 \text{ } ^1\text{H} + 2 \text{ e}^- \rightarrow$ $\text{}^4\text{He} + 2 \text{ } \nu + 27 \text{ MeV}$
Energy from H-fusion	$\approx 100 \%$	$< 38 \%$
Solar neutrino flux observed/predicted, excluding oscillations	$\approx 33 \%$	$> 87 \%$
Observable by-products of solar luminosity	Neutrinos from decay of fusion products in the core.	a) Anti-neutrinos from decay of neutrons near the core. b) Neutrinos from fusion product decay near the core. c) H^+ ions escape from the surface in the solar wind.
Major elements	Hydrogen, helium, carbon	Iron, nickel, oxygen, silicon
Comparable meteorites	None. Only about 0.1 % of the sun has the composition of carbonaceous chondrites.	Most. The Sun and ordinary meteorites consist mostly of Fe, O, Si, Ni, S, Mg and Ca.
Comparable planets	Gaseous planets, far from sun	Rocky planets, close to sun

If the ssm is correct, there is a clear deficit of solar neutrinos and the neutral current observed in the SNO experiment¹³ likely originates in the Sun. If the new solar model is correct, the solar neutrinos detected seem to represent the bulk (> 87%) of those produced in the Sun and the neutral current observed in the SNO experiment¹³ is likely of non-solar origin.

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