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THE SUN'S ORIGIN AND COMPOSITION: IMPLICATIONS FROM METEORITE STUDIES

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ABSTRACT

In the 1970s meteorite studies indicated the Sun might be a supernova remnant. Decay products of short-lived nuclides, nucleogenetic isotopic anomalies in meteorites, and evidence of mass separation in the Sun confirmed that iron is the Sun's most abundant element.

1. INTRODUCTION

In 1960 the decay product of extinct ^{129}I and an unusual abundance pattern for the other, non-radiogenic xenon isotopes were found in meteorites [1,2]. Noting that ^{129}I exceeded that expected if the solar system formed from an interstellar cloud, Fowler *et al.* [3] suggested that D, Li, Be, B and extinct ^{129}I and ^{107}Pd might have been produced locally, here in the early Solar System.

In 1972 two major types of xenon were identified in meteorites: "Normal" xenon (Xe-1) or some fractionated form of Xe-1 on the dashed line in the lower left of Fig. 1 and "strange" xenon (Xe-2), enriched in the lightest and heaviest xenon isotopes, ^{124}Xe and ^{136}Xe, at the upper right of Fig. 1 [4]. Initially, primordial helium accompanied only Xe-2, not Xe-1 [5,6].

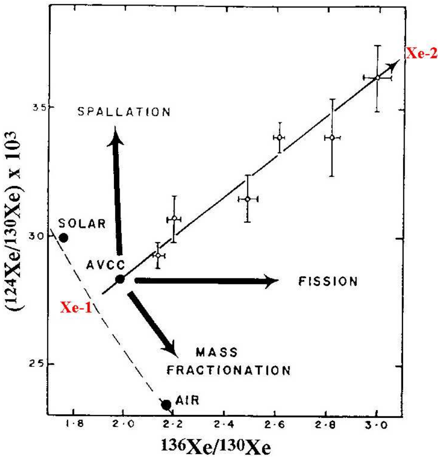
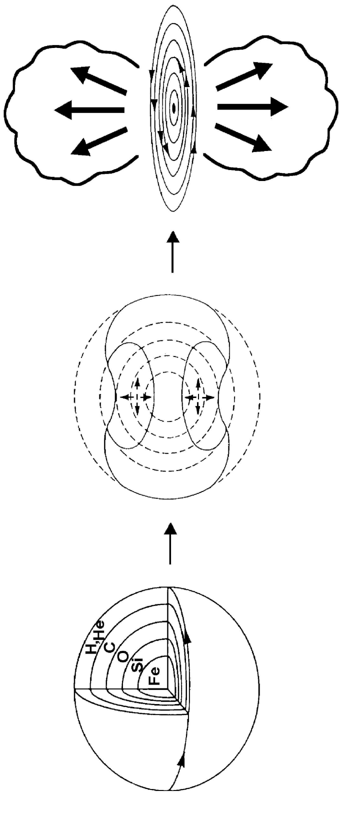


Fig. 1. "Normal" Xe-1 and "Strange" Xe-2

In the mid-1970s it was suggested that the link of all primordial helium with Xe-2 at the birth of the Solar System [5,6] might indicate an even more drastic form of local element synthesis than imagined earlier [3]: The solar system may have formed from the debris of a single, local supernova (SN), with the Sun forming on the collapsed SN core, the iron cores of inner planets forming in the central, iron-rich region surrounding the SN core, and the giant Jovian planets forming primarily from elements in the outer SN layers [5,6].



The sun forms on the SN core; cores of inner planets form in the Fe-rich region around the SN core; Jovian planets form from the outer SN layers.

Asymmetric collapse occurs to conserve angular momentum, and the infall of low-Z elements causes an axially directed explosion.

A massive spinning star becomes chemically layered near the end of its life.

Fig. 2. The Solar System From A Supernova

The scenario illustrated in Fig. 2 predicts that:

a) **Other heavy elements trapped with Xe-2 will display "strange" isotope ratios.**
b) **The link of Xe-2 with helium and of Xe-1 with iron extends across planetary distances.**
c) **The Sun must contain Xe-1 and abundant iron, with little helium or hydrogen.**
d) **Nuclear fusion depleted light elements from the region where inner planets formed.**

2. POST-1975 RESULTS

Super-heavy element fission was a popular interpretation of Xe-2 until the early 1980s [7]. Xe-2 and "strange" isotope ratios of other elements with Xe-2 are now ascribed to relic interstellar grains in meteorites [8], despite the link of primordial helium with Xe-2 and the absence of evidence that the grains are older than their meteorite host or were irradiated with cosmic rays before being embedded in the meteorite.

2.1 Meteorites and Planets

Meteorites studies confirmed links of a) "strange" tellurium with Xe-2 [9-12] and b) Xe-2 with primordial He in meteorites [13,14] and in He-rich Jupiter [15,16].

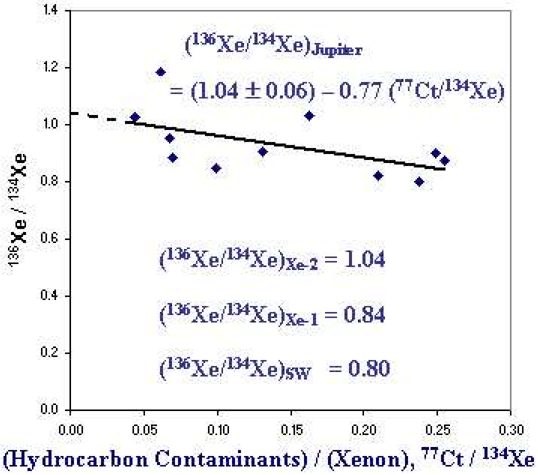


Fig. 3. "Strange" Xe-2 in Jupiter

In Fig. 3, hydrocarbon counts at 77 amu are shown as ^{77}Ct; the counts at 134 and 136 amu are mostly xenon with a trace of hydrocarbon contamination. Hydrocarbons increased as the probe descended into Jupiter's atmosphere (left to right in Fig. 3). Measurements ceased when the *Galileo* probe reached a depth where it was crushed by high atmospheric pressure. In the solar wind, in Xe-1, in Xe-2 and in Jupiter, $(^{136}Xe/^{134}Xe)$ = 0.80, 0.84, 1.04, and 1.04 ± 0.06, respectively.

Other studies further confirmed b) the link of Xe-1 with iron, in troilite (FeS) grains of meteorites and in the Fe,S-rich planets - - - Earth and Mars [17-21].

2.2 The Solar Wind and Solar Flares

The solar wind contains Xe-1, as predicted in c), but its light (L) isotopes are enriched relative to the heavy (H) ones by about 3.5%/amu [22]. As shown in Fig. 4, light isotopes of He, Ne, Ar, Kr and Xe in the solar wind all follow a common mass-dependent fractionation power law, where the fractionation factor, f, is

$$\log(f) = 4.56 \log(H/L) \qquad (1)$$

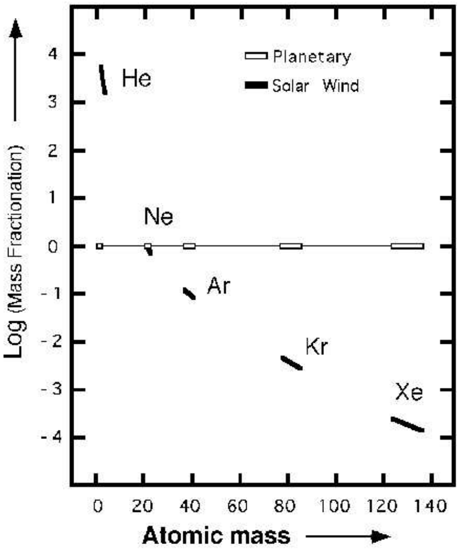


Fig. 4. Excess Light Isotopes in the Solar Wind

Light isotopes are less abundant in solar flares, as if flares by-pass 3.4 stages of mass fractionation [23]. The *Wind* spacecraft also observed large systematic enrichments of heavy elements in material ejected from the Sun's interior by impulsive solar flares [24].

Table 1. He, Ne, Mg, and Ar in solar wind and flares

Isotopic Ratios	Solar Wind	Solar Flares	SW/SF	Expected**
$^{3}He/^{4}He$	0.00041	0.00026	1.58	1.63
$^{20}Ne/^{22}Ne$	13.6	11.6	1.17	1.18
$^{24}Mg/^{26}Mg$	7.0	6.0	1.17	1.15
$^{36}Ar/^{38}Ar$	5.3	4.8	1.10	1.10

**If solar flares by-pass 3.4 stages of fractionation

Application of Eq (1) to the photosphere further confirms prediction c): Iron (Fe), nickel (Ni), oxygen (O), silicon (Si), sulfur (S), magnesium (Mg), and calcium (Ca) are the Sun's most abundant elements [22]. These are even numbered elements that are made inside supernovae; the same elements Harkins found to comprise 99% of ordinary meteorites [25].

The probability is low ($P < 2 \times 10^{-33}$) that Eq. (1) by chance selects from the solar atmosphere seven trace elements that a) all have even atomic numbers, b) are made deep in supernovae, and c) are the same elements that comprise 99% of ordinary meteorites [25].

Fractionated isotopes were noted [26-29] in lunar and meteorite samples long before this was recognized as a solar process [22], e.g., fractionation plus spallation explain all alphabetical types of neon found by 1980:

Ne-A, Ne-B, etc. [29]. The dashed fractionation line on the lower left of Fig. 1 [4] and the diagonal line between Xe-1 (lower left) and Xe-2 (upper right) of Fig. 1 forcast the finding of FUN (Fractionation and Unknown Nuclear) isotopic anomalies at Cal Tech [30].

3. CONCLUSIONS AND FUTURE TESTS

The link of Xe-1 with iron extends even to the Sun: Iron is its most abundant element. Its similarity to the composition of the inner planets confirms d) fusion, rather than gas loss, depleted their light elements.

Hoyle and many other astronomers [31] believed "*… the Sun was made mostly of iron …*" (p. 153) until the end of World War II. H-fusion research during the war [32] and the need to explain solar luminosity likely aided adoption of the hydrogen-filled model of the Sun. This standard solar model assumes [33] no mass accretion (i.e., instantaneous formation) of the Sun as a 1.99×10^{33} g, homogeneous protostar. By comparison, Fig. 2 shows a mechanism that explains the observations presented here and the iron Sun's origin.

3.1 Source of Solar Luminosity

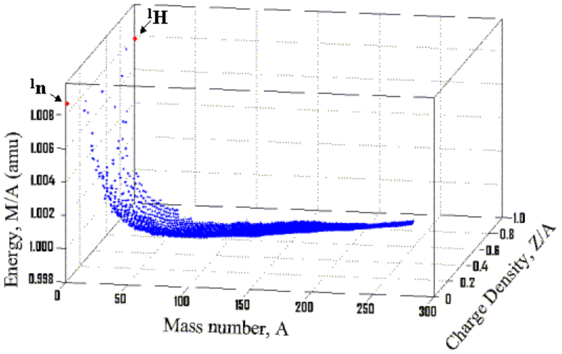


Fig. 5. The Cradle of the Nuclides

Systematic properties of the 2,850 known nuclides (Fig. 5) reveal an inherent instability in assemblages of neutrons relative to neutron emission. This may explain luminosity [34-36] of the iron Sun (Fig. 2). Neutrons emitted from its collapsed SN core initiate a chain of reactions producing luminosity, neutrinos, and a solar wind outpour of 3×10^{43} H^+ per year.

- Escape of neutrons from the collapsed solar core
  $< {}_{0}^{1}n > \longrightarrow {}_{0}^{1}n + \sim 10\text{-}22$ MeV
- Neutron decay or capture by other nuclides
  ${}_{0}^{1}n \longrightarrow {}_{1}^{1}H^{+} + e^{-} + \text{anti-}\nu + 1$ MeV
- Fusion and upward migration of H^+
  $4\ {}_{1}^{1}H^{+} + 2\ e^{-} \longrightarrow {}_{2}^{4}He^{++} + 2\ \nu + 27$ MeV
- Escape of excess H^+ in the solar wind
  3×10^{43} H^+/year depart in the solar wind

Although these observations provide no information on other stars, a hydrogen-filled universe might result from such outflow of protons, even if other stars had the composition concluded here for the Sun.

3.2 Future Tests

The following measurements can test the iron Sun:

1. Measure anti-neutrinos (3×10^{38} s^{-1}, E < 0.782 MeV) from neutron decay at the solar core. Low E targets for inverse β-decay are the Homestake Mine $^{35}Cl \rightarrow {}^{35}S$ reaction [37], the $^{14}N \rightarrow {}^{14}C$ or $^{3}He \rightarrow {}^{3}H$ reactions (may need Time Projection Chambers [38]).
2. Measure neutrinos from reactions that increased the $^{15}N/^{14}N$ ratio [39] and produced excess ^{6}Li and ^{10}Be in the outer layers of the Sun [40,41].
3. Measure microwave background radiation [42] from the supernova explosion here 5 Gy ago [43].
4. Measure magnetic fields, circular polarized light [44], or quadrupole moment from the dense, compact object (about 10 km) at the solar core.
5. Measure other properties that constrain mass segregation in the Sun and other stars [23, 45-50].
6. The *Genesis* mission may see enhancement of heavy elements in fast-moving SW from the Sun's poles.

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