Isotopes Tell Sun's Origin and Operation

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Measurements of isotope abundances and masses offer these conclusions on the Sun. **Abundances:** The Sun and its planets formed out of highly radioactive, poorly mixed debris of a supernova that exploded 5 Gy ago. This conclusion is based on measurements of a) the decay products of actinide elements (^{235,238}U, ^{244}Pu) [1] and short-lived isotopes in meteorites and in the Earth [2,3], b) residual excesses in meteorites of stable isotopes made by the α-, r-, p- and s-processes of stellar nucleosynthesis [4], c) excess ^{16}O [5] and excess ^{136}Xe [6] in the Sun itself, and d) linked chemical and isotopic heterogeneities preserved in meteorites and planets [4]. Measurements on 22 atoms in the solar wind [7] and 72 s-products in the photosphere [8] show that the Sun acts as a huge plasma diffuser that selectively moves lightweight elements and isotopes of each element to its surface. Iron is the most abundant element in the Sun, in rocky planets and in ordinary meteorites. **Masses:** Fusion cannot be the main source of luminosity in the Sun and Sun-like stars. The most abundant isotope of iron, ^{56}Fe, has tightly bound nucleons, and abundances of other elements in the Sun correlate with nuclear stability [9]. The discovery of rocky planets orbiting pulsar, PSR 1257+12 [10], and systematic properties in the rest masses of the 2,850 known nuclides [11] suggest that neutron repulsion drives solar luminosity, solar mass separation, solar neutrinos, and the H-rich solar wind leaving the surface of an Fe-rich object that formed on the collapsed core of a supernova [12]:

- Neutron emission from the solar core: $\langle n \rangle \rightarrow n + 10\text{-}22$ MeV
- Neutron decay: $n \rightarrow H^+ + e^- + \text{anti-}\nu + 0.782$ MeV
- H^+ upward migration and fusion: $4\,{}_1^1H^+ + 2\,e^- \rightarrow {}_2^4He^{++} + 2\,\nu + 27$ MeV
- H^+ that reaches the surface: $2.7 \times 10^{43}\ H^+/\text{yr} \rightarrow$ Departs in the solar wind

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"ISOTOPES TELL SUN'S ORIGIN AND OPERATION"

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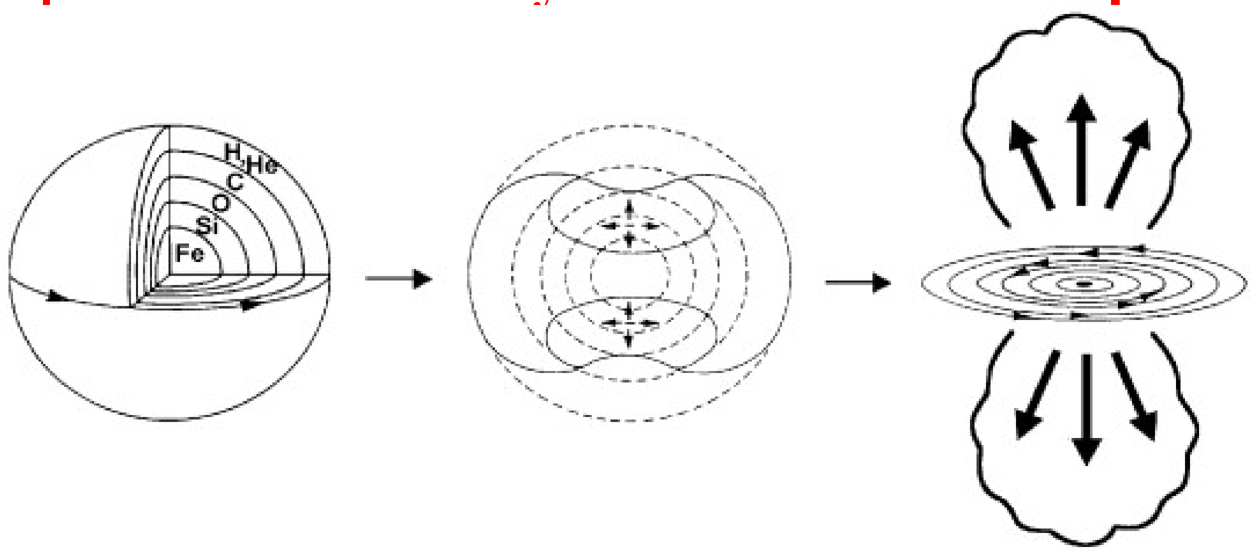
The Record in Meteorites

Aston's mass spectrometer [1] allowed us to see isotopes sorted by mass [2], *in situ* decay of short-lived nuclides, linked chemical/isotopic variations [3-5] from the Solar System's birth in a supernova

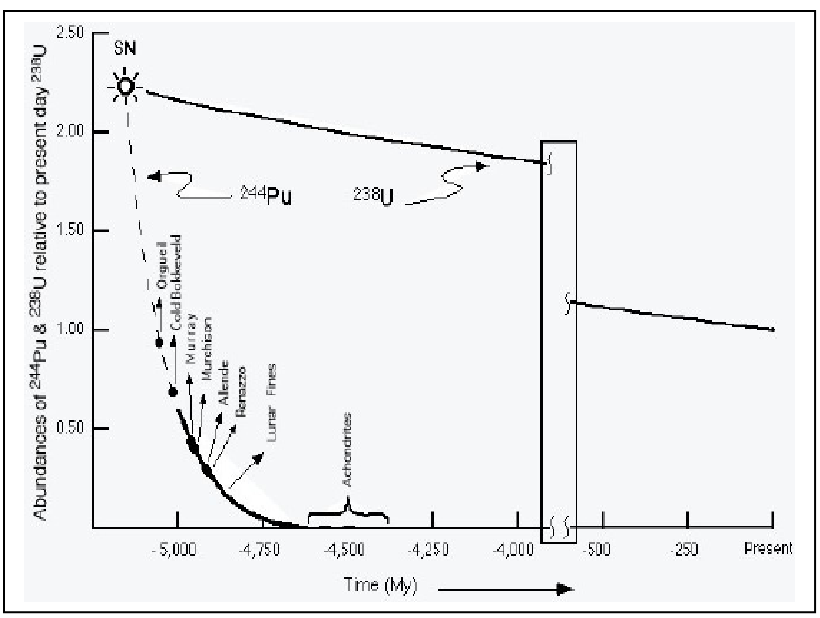


A massive spinning star becomes chemically layered near the end of its life, when asymmetric collapse occurs to conserve angular momentum.

The infall of low-Z elements causes an axially directed super-nova explosion, producing a rapidly expanding bipolar nebula with an equatorial accretion disk.

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

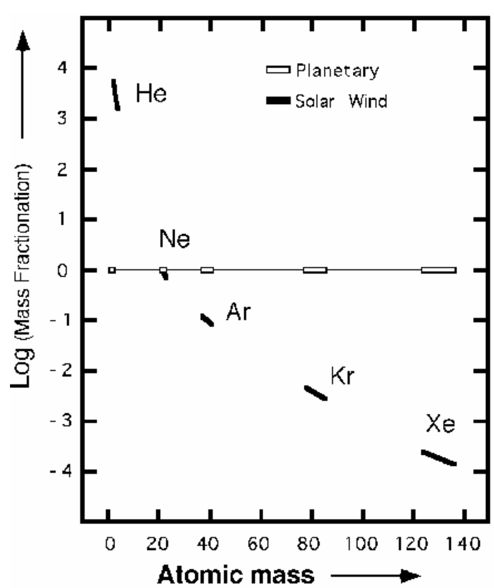
that made our ^{244}Pu, ^{238}U, and ^{235}U ≈ 5 Gy ago [6].



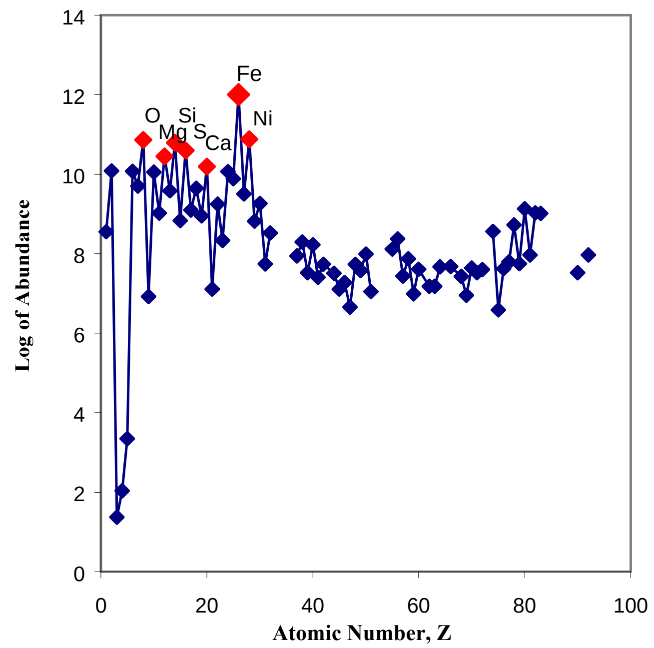
The Record in the Solar Wind

Light (L) isotopes are enriched relative to heavy (H) isotopes in the solar wind by 9-stages of mass fractionation, $f = (H/L)^{4.56}$ [7].

Mass Separation [7] of Isotopes in Elements Emitted from the Solar Surface



Composition of the Sun after Correction for Mass Fractionation

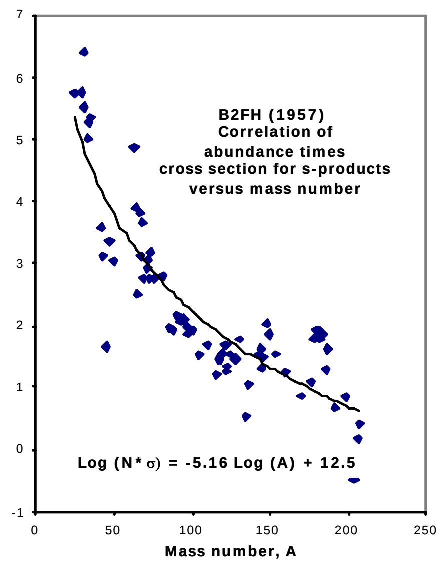


When elemental abundances in the photosphere are corrected for this mass separation, the most abundant elements inside the Sun are Fe, Ni, O, Si, S, Mg and Ca - the elements Harkins [8] found to comprise ≈99% of ordinary meteorites !

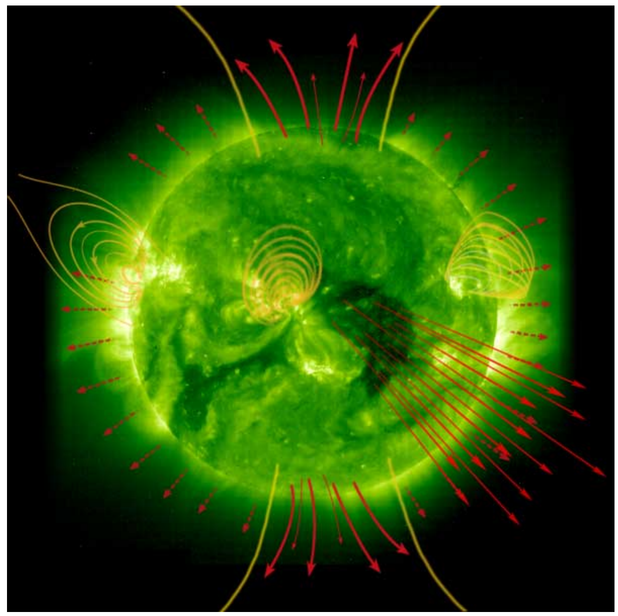
Photosphere Record of Mass Sorting

Light s-products (25 - 207 amu) [9] enriched in photosphere by 10-stages of mass fractionation.

Mass Fractionation Enriches Lightweight s-Products [9] in the Sun's Photosphere ⇓



Material from coronal holes (*long, red arrows from open magnetic fields*) moves faster and is less mass fractionated than material that leaves in the slow solar wind (*short , red arrows from closed magnetic loops* ⇓)



Deep magnetic fields from the collapsed SN core bring H^+ to the surface [10] with more heavy isotopes [11] and heavy elements [12] in the open magnetic fields of solar flares than in the closed field loops of the quiet solar wind [13].

Isotope Ratios	Solar Wind	Solar Flares	SW/SF	Expected**
$^{3}He/^{4}He$	4.1×10^{-4}	2.6×10^{-4}	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

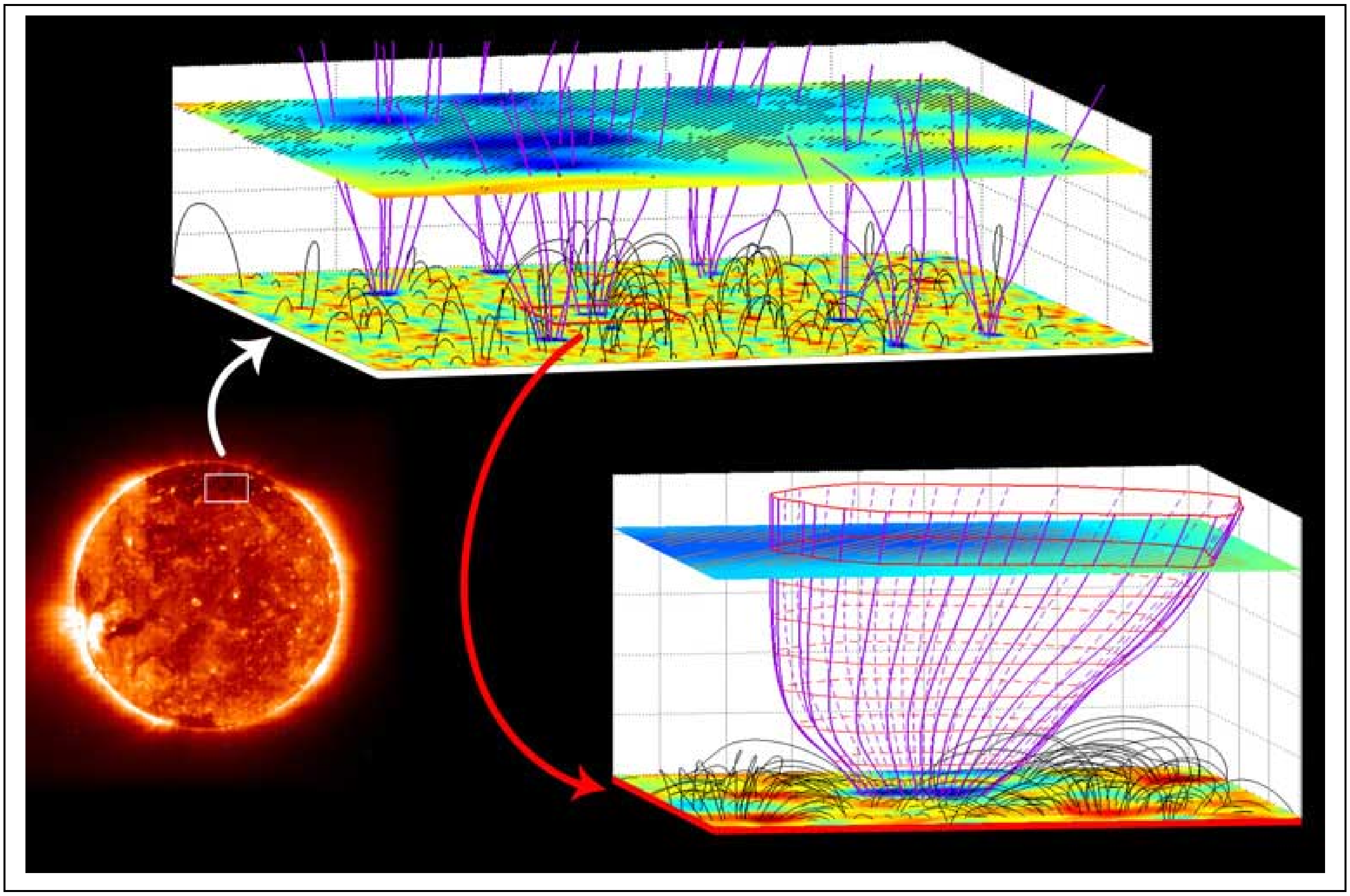
Expected if solar flares by-pass 3-stages of mass fractionation [11].

Record of Fractionation Changes

Deep magnetic fields from the collapsed super-nova core in the Sun bring H^+ [10] to the solar surface, causing mass-fractionation to differ in:

a.) Different parts of the Sun's surface [13, 14]

b.) Stars in magnetic "Maunder" minimum [15]



Stars with planets wobble and mix elements.

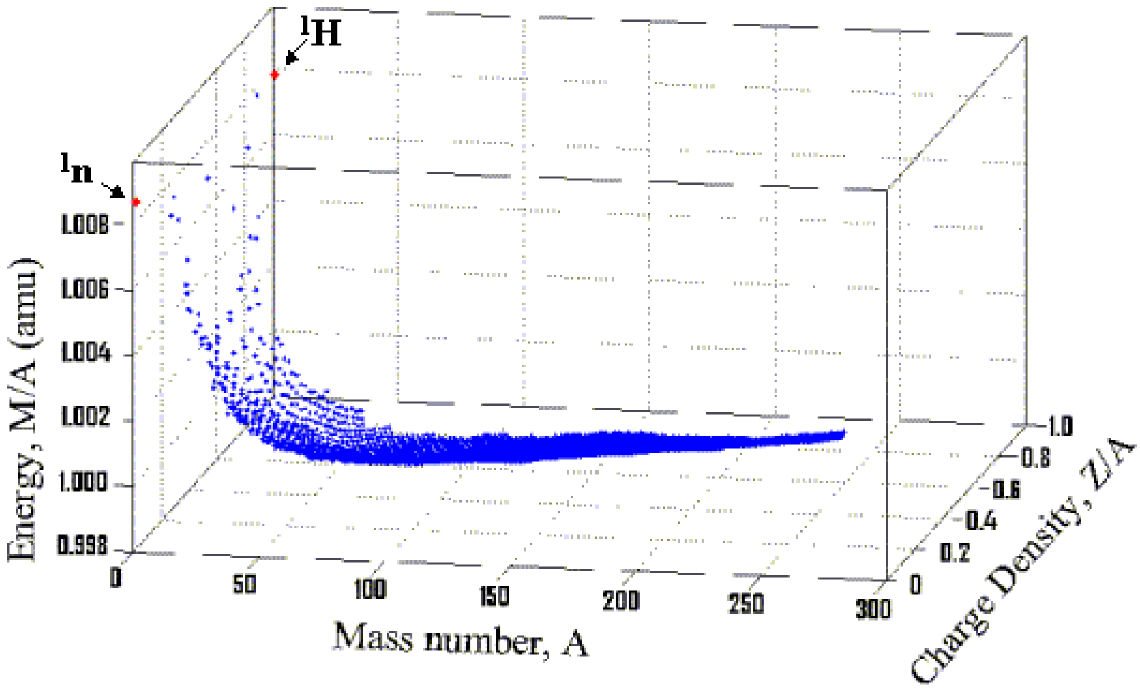
Recent surveys of stars reported high surface iron abundances when:

a.) Magnetic activity decreases, like the Sun's period of low sun-spot activity during the Maunder minimum from 1645 until 1714 [15]

b.) Planets orbit the star, inducing a center-of-mass wobble [16].

How Do Iron-Rich Stars Shine?

Aston's mass spectrometer [1] shows the nuclear properties that cause luminosity



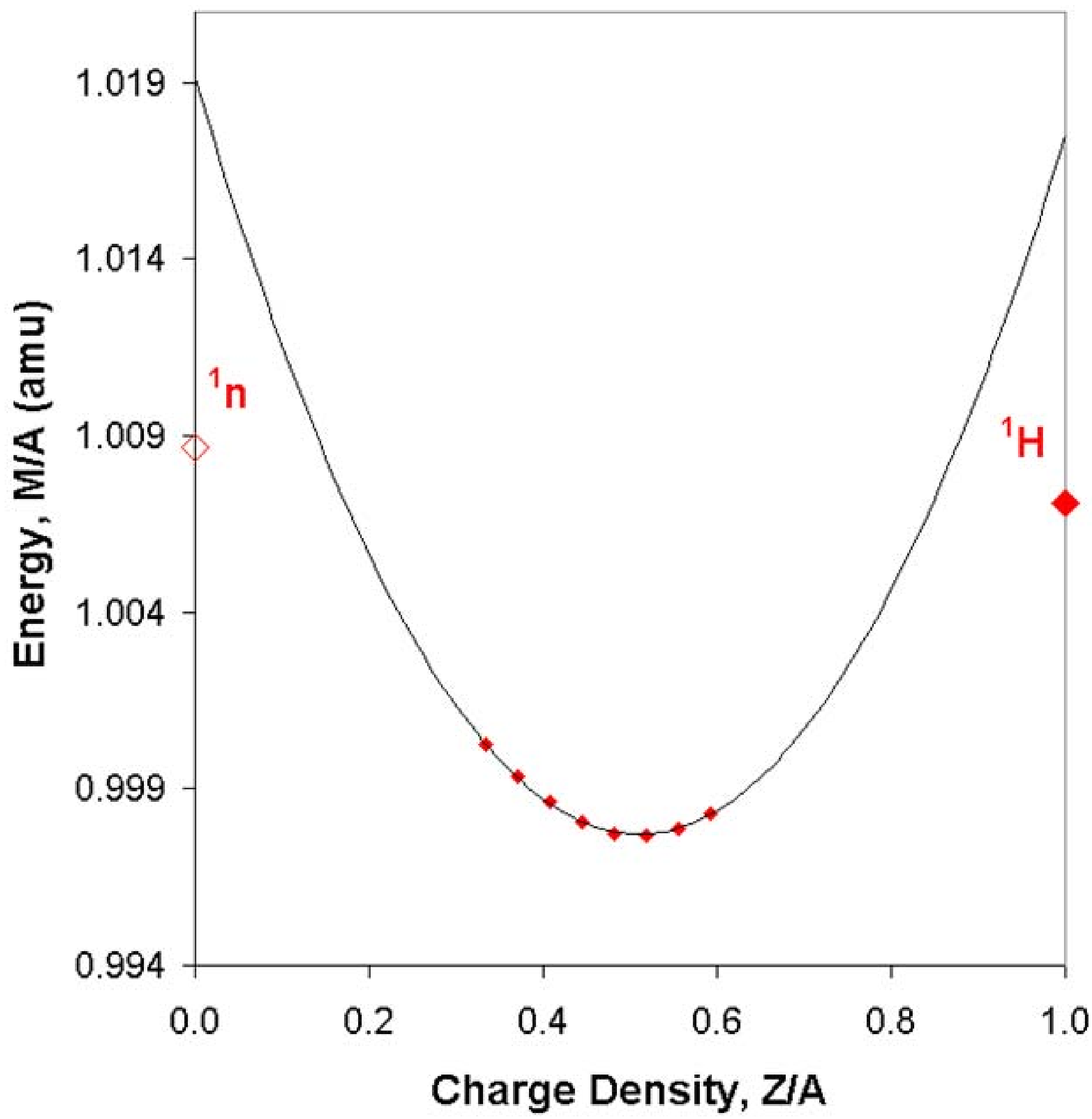
The Cradle of the Nuclides*

At every mass number > 1, repulsive interactions between neutrons increases M/A to M/A = M ($^1{}_0$n) + 10-22 MeV at Z/A = 0

* Data points are from [17], Nuclear wallet cards, 6th edition (2000) National Nuclear Data Center, Brookhaven National Lab., 96 pp.

Neutron-Repulsion at A = 27

At A = 27 the mass parabola yields
$M/A = M({}_0^1n) + 10$ MeV at $Z/A = 0$

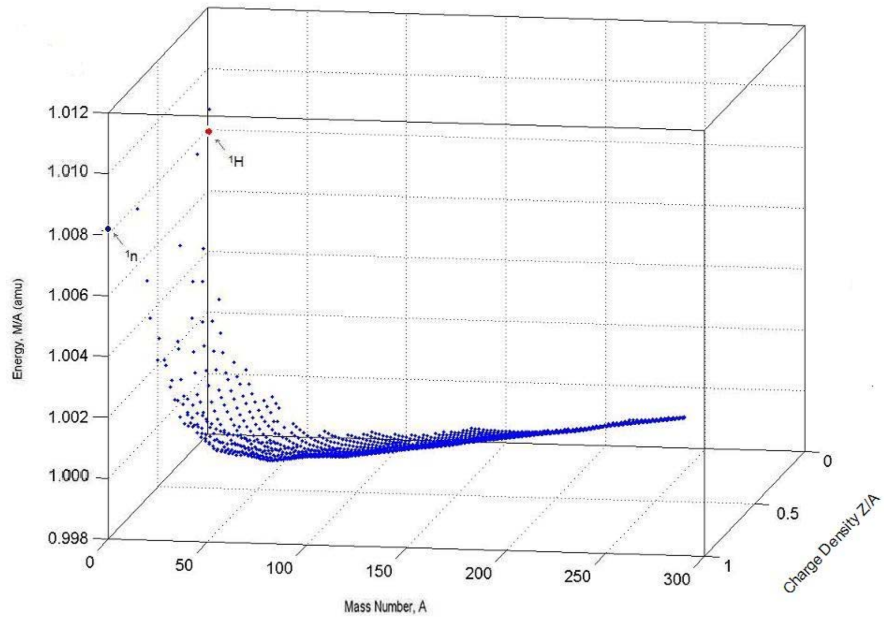


After subtracting Coulomb energy, the mass parabola has a minimum at
Z = 13.5 At Z = 13 or 14 there are
182 attractive n-p interactions but only 169 repulsive n-n & p-p interactions [18]

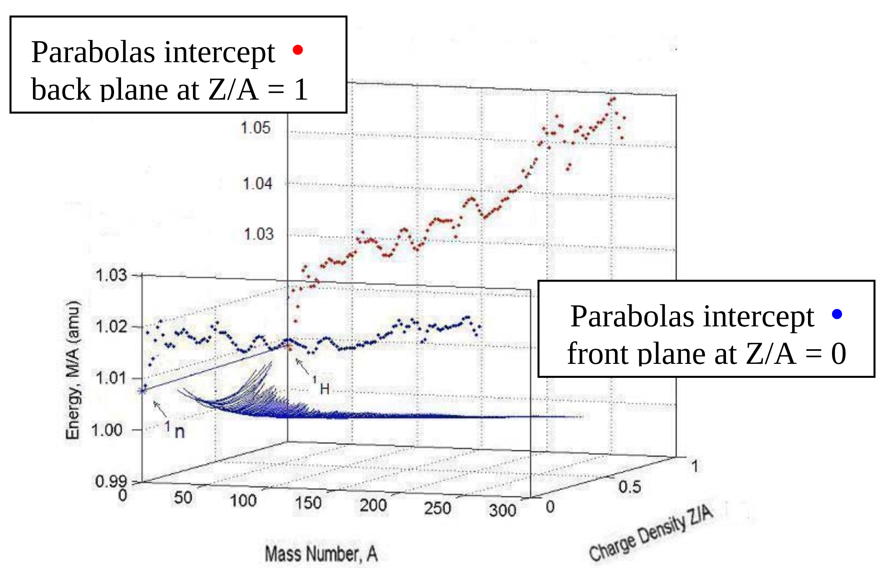
Nuclear Sources of Stellar Luminosity

What releases more energy than $^{1}H \rightarrow {}^{4}He \rightarrow {}^{56}Fe$?

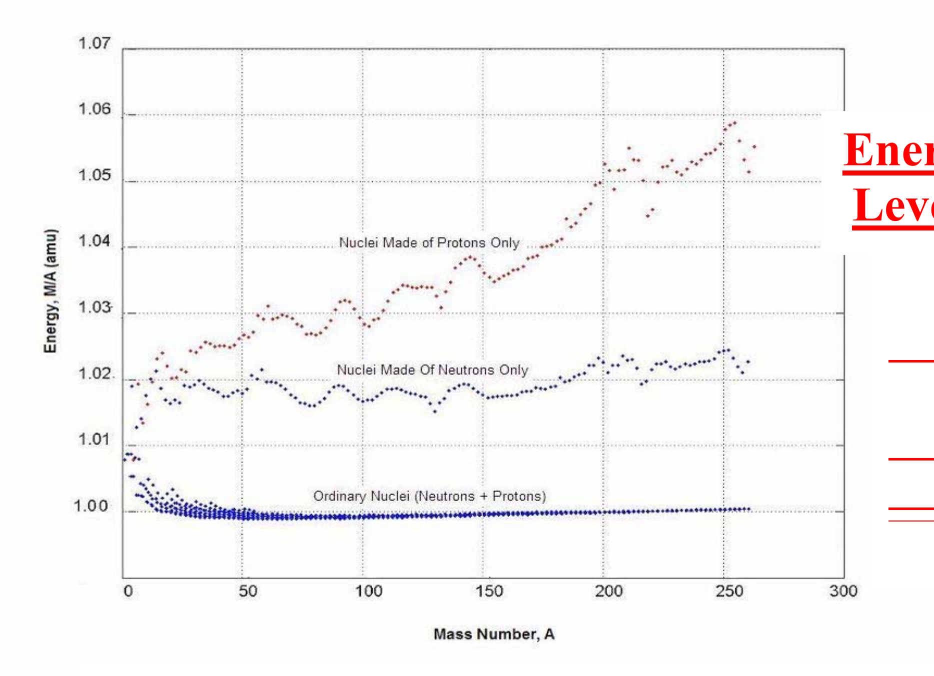
This compares potential energy of the neutron (•), proton (•) and all other 2,850 known nuclides. Among stable nuclides, ^{56}Fe has least and ^{1}H has greatest potential energy.



The data define mass parabolas at each value of A > 1.0 Each parabola inter-cepts the front plane at Z/A = 0 with M/A > M_n This repulsive interaction of neutrons is the main source of solar energy.



Ordinary Nuclear Matter and Nuclear Matter at Z/A = 0 and Z/A = 1.0



Energy Levels

Neutron emission from a neutron star generates ≈ 2 times the energy released in $^{1}H \rightarrow {}^{4}He \rightarrow {}^{56}Fe$

Sources of Solar Energy (SE) [19, 20]:

- Neutron emission from the solar core (>57% SE)

  $<{}_0^1n> \rightarrow {}_0^1n + \sim$ 10-22 MeV
- Neutron decay or capture (<5% SE)

  ${}_0^1n \rightarrow {}_1^1H^+ + e^- +$ anti-ν + 0.782 MeV
- Fusion and upward migration of H^+ (<38% SE)

  $4\ {}_1^1H^+ + 2\ e^- \rightarrow {}_2^4He^{++} + 2\ \nu$ + 27 MeV
- Escape of excess H^+ in the solar wind (100% SW)

  Each year 3×10^{43} $H^+ \rightarrow$ Depart in the solar wind

Neutron-emission releases **1.1% - 2.4%** of the nuclear rest mass as energy. Hydrogen-fusion releases **0.7%** if the end product is helium, and fission releases **0.1%** of the rest mass as energy [20].

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