Neutrinos & Supernova Nucleosynthesis

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Type Ia SNe

core-collapse SNe (mostly Type II)
Some of the Biggest Questions Connecting Quarks and the Cosmos

Board on Physics and Astronomy
US National Academy of Sciences

- What are the masses of the neutrinos, and how have they shaped the evolution of the universe?
- How were the elements from iron to uranium made?
Big Bang:
75% H + 25% He (by mass)

Sun:
70.7% H + 27.4% He + 1.9% “Metals”

“p” → “n” + e^+ + ν_ε
How to Become a Star

Virial theorem for a contracting gas cloud

\[
T_c + \frac{\hbar^2}{2m_e d^2} \sim \frac{GMm_p}{R}
\]

\[
\left( \frac{M}{m_p} \right) d^3 \sim R^3 \Rightarrow
\]

\[
T_c \sim \frac{GMm_p}{R} - \frac{\hbar^2}{2m_e} \left( \frac{M}{m_p} \right)^{2/3} \frac{1}{R^2}
\]

\[
\Rightarrow T_{c,\text{max}} \propto M^{4/3}
\]
The Beginning of the End
$M \sim 8-11 \, M_\odot$
$M > 11 M_{\odot}$
Stars as Nuclear Reactors

nuclear fusion in stars:
- elements up to Fe
- slow & rapid n capture:
- elements beyond Fe

O → Si → Fe
Arise from the Ashes

Relative Abundance of the Chemical Elements in the Solar System
The Energy from Radioactivity in SN1987A

- Early Light Curve Dominated by $^{56}\text{Ni}$ and $^{57}\text{Co}$ Radioactivity (Gamma-Ray Lines Detected by SMM and OSSE, respectively)
- Late Light Curve Power Source Unknown: $\sim 10^{-4} M_\odot$ of $^{44}\text{Ti}$? Pulsar?
- Detection by INTEGRAL Possible, if $^{44}\text{Ti}$ Source
Tominaga et al. (2007)

**normal SNe**

$M \sim 12-25 \, M_{\odot}$

**HNe**

$M \sim 25-50 \, M_{\odot}$

**faint SNe**

$M \sim 25-50 \, M_{\odot}$
low-mass & normal SNe: neutrino-driven

HNe: strong jets

faint SNe: weak jets