

Explosive Nucleosynthesis: Supernovae



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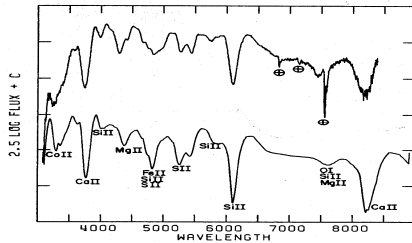




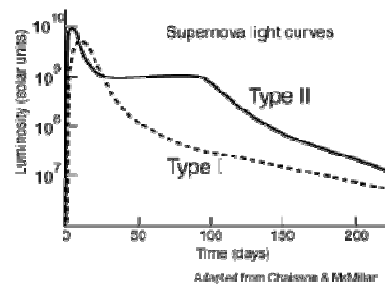
Distinctive Features



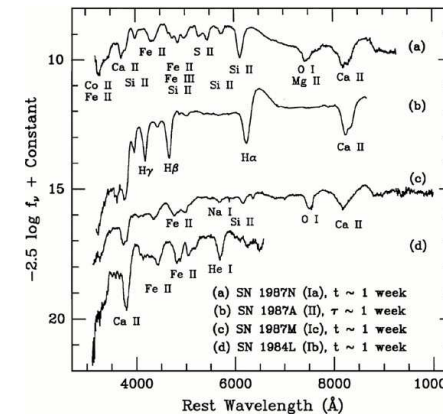
- SNIa
- Uniform spectral and luminosity class.



- $M_V(\text{max}) = -19.4$
- $E_{\text{kin}} \sim 10^{51}$ ergs
- Averaged rate of 0.005 sn/yr
- Present in all Galaxy types
- SNIa: **Biggest Iron factory in the universe.**



- SNIi
- Inhomogeneous spectral and luminosity class.



- $M_V > -18$
- $E_{\text{kin}} \sim 10^{51}$ ergs
- Averaged rate of 0.02 sn/yr
- Preferred site: spiral galaxies
- SNIi: **Biggest factory of Intermediate-Mass Elements**

Presupernova Structures

- SNIa

Massive White dwarf

($M \sim 1.4 M_{\text{sun}}$) in a compact binary system.

$^{12}\text{C} + ^{16}\text{O} + ^{22}\text{Ne}$ (~1-2%)

Available energy (nuclear):

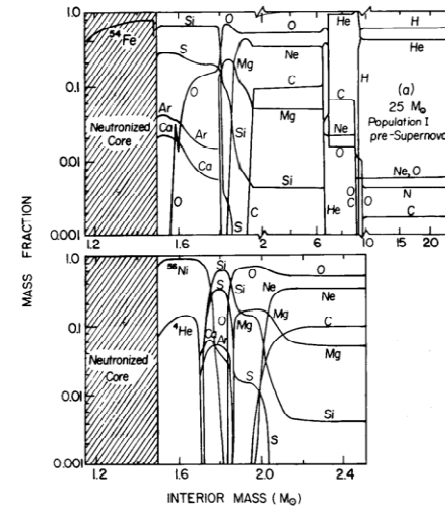
$\sim 2 \cdot 10^{51}$ ergs



SNIa thermonuclear bombs

- SNII

Massive Star $M > 8-9 M_{\text{sun}}$



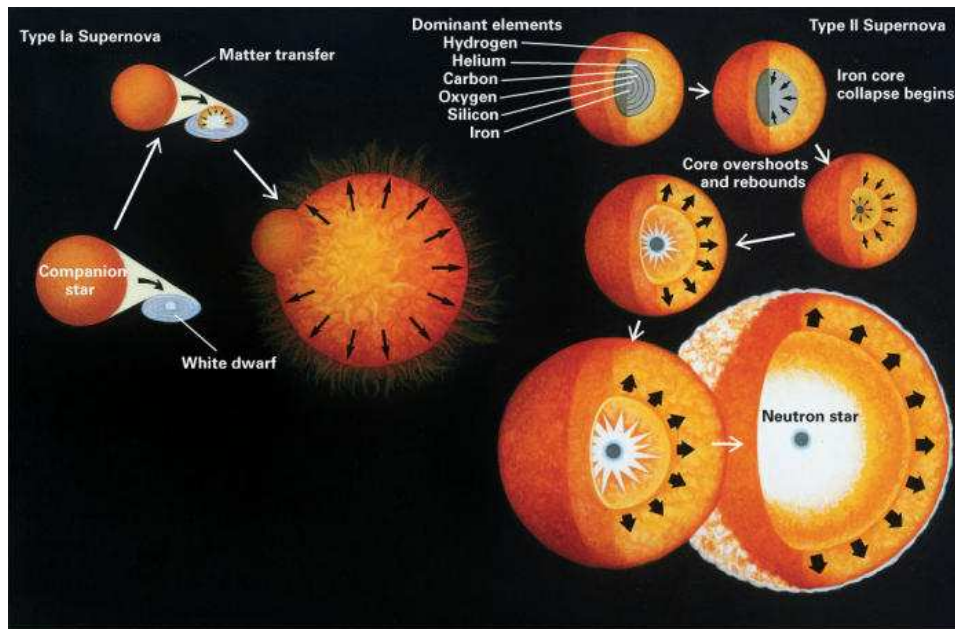
Available energy (gravitational):

$$U_{\text{NS}} - U_{\text{core}} \sim GM_{\text{Ch}}^2/R_{\text{NS}} \equiv 4 \cdot 10^{53} \text{ ergs}$$

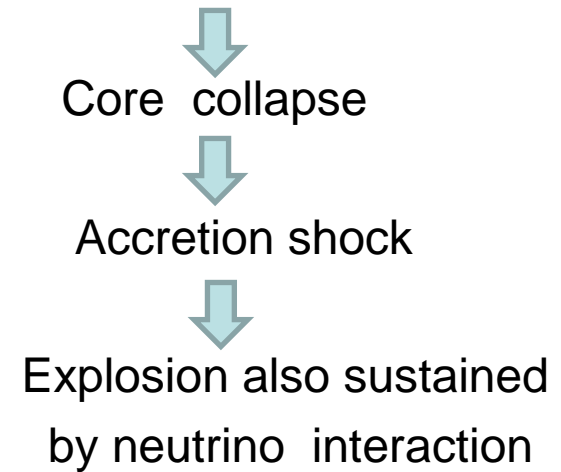
SNII Neutrino bombs

Explosion Issues

- **SN Ia** (complete disruption)
- **SN II** (explosion+remnant)
- Physical basic mechanism:
- Core instability: electron captures + iron fotodisintegration
- Combustion of $^{12}\text{C}+^{16}\text{O}$ in degenerate conditions.



Courtesy of Encyclopaedia Britannica, Inc.; from the 1989 Britannica Yearbook of Science and the Future; illustration by Jane Meredith



Nuclear Processes

- SNIa
- Explosive synthesis linked to the combustion propagation mode.

Combustion diagram

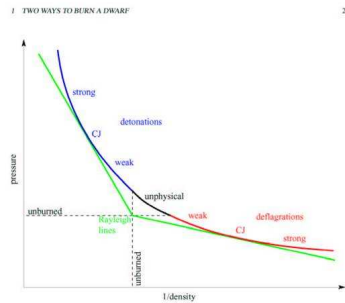


Figure 1: Hugoniot curve and Rayleigh lines, of [1].

Deflagrations versus detonations

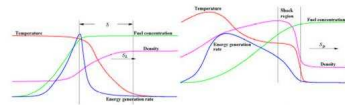
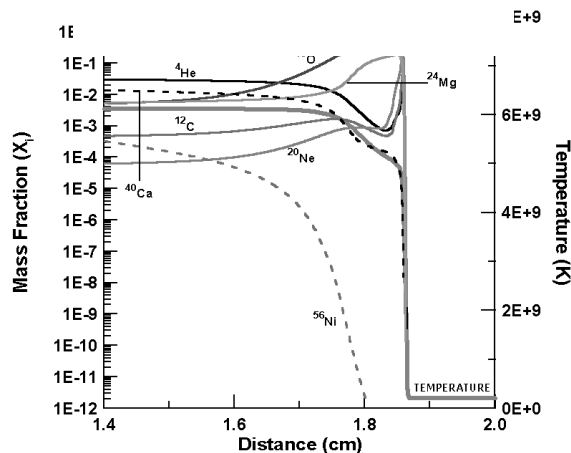


Figure 2: Profile of a deflagration.

Figure 3: Profile of a detonation.

Subsonic flame in SNIa



- SNII
- Nucleosynthesis mix of hydrostatic combustion (preSN)+ explosive synthesis.

$$T_{\text{peak}} \propto (E_{\text{kin}})^{1/4} R^{-3/4}$$

- Hydrostatic and explosive silicon burning products ($T_9 \sim 5$).

Si --- Fe

- Hydrostatic and explosive oxygen burning products.

IME (Si, S, Ar ..)

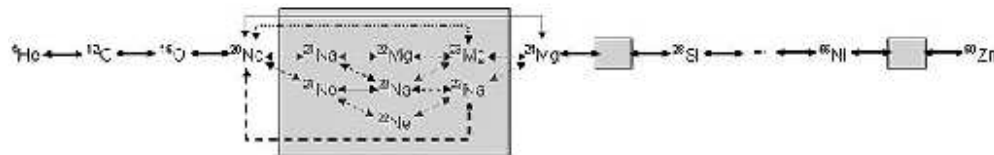
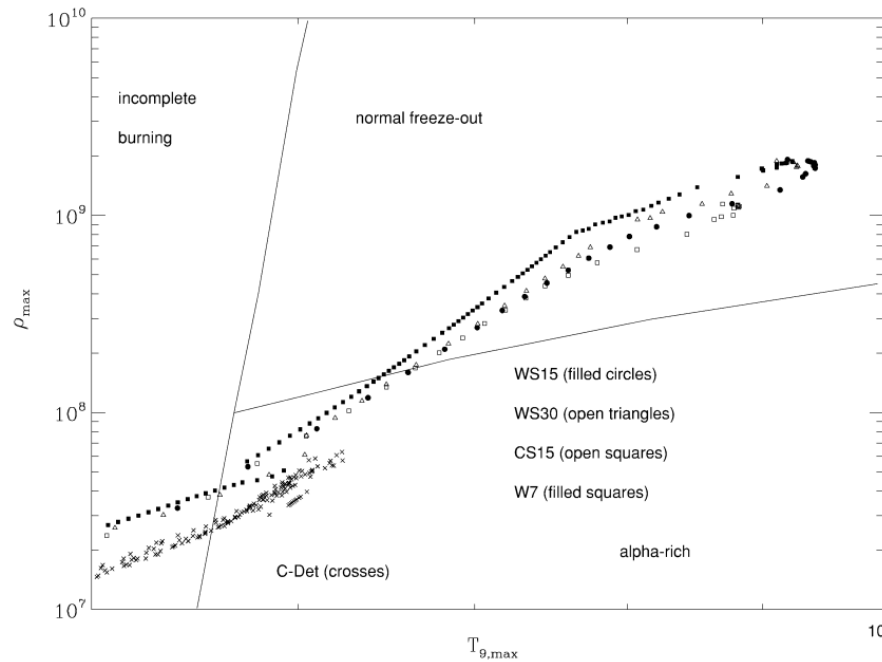
- Hydrostatic and explosive neon and carbon products ($T_9 \sim 2-3$)

Mg, Al, Ne

(but also some ^{60}Fe)

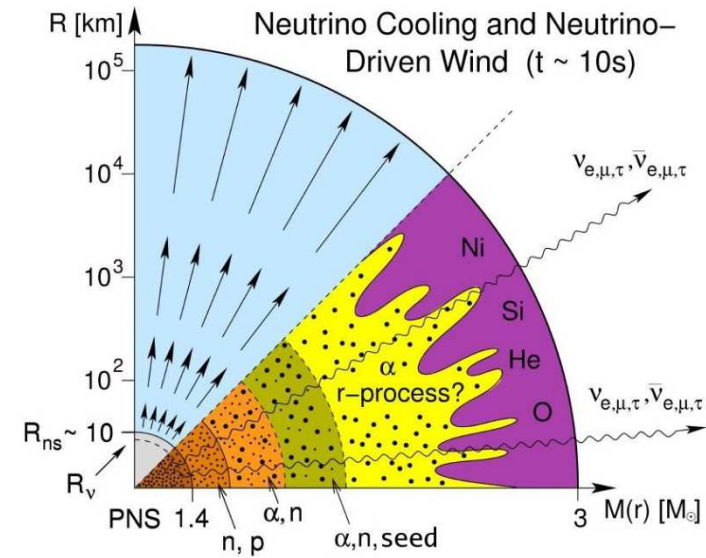
Nuclear Processes: (NSE-QNSE and α -rich freeze out)

- SNIa:



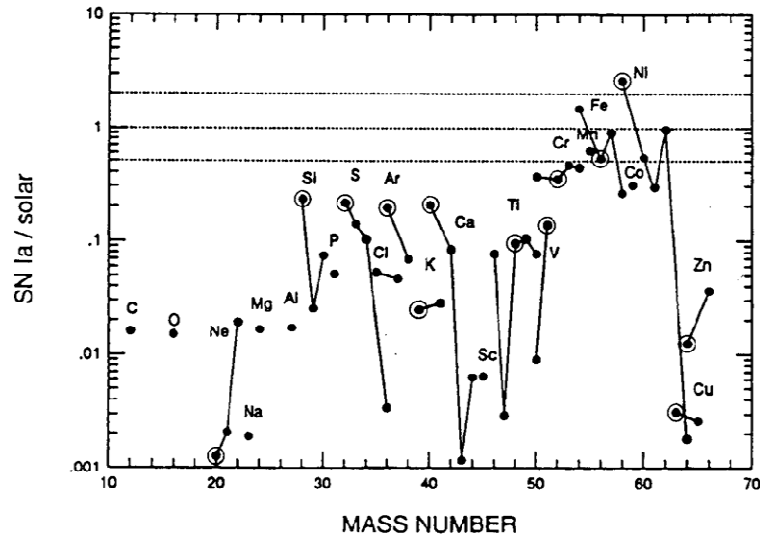
- SNIi

Innermost explosive synthesis:
the role of neutrinos

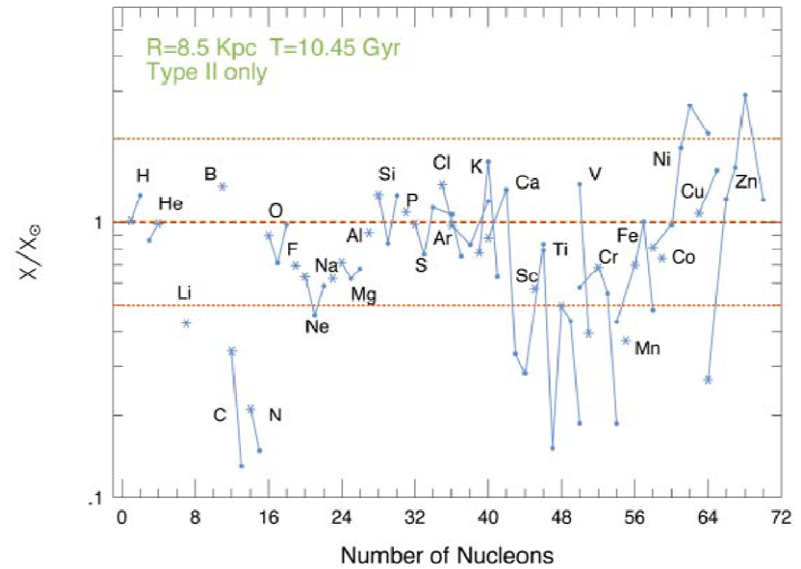


Abundance Patterns

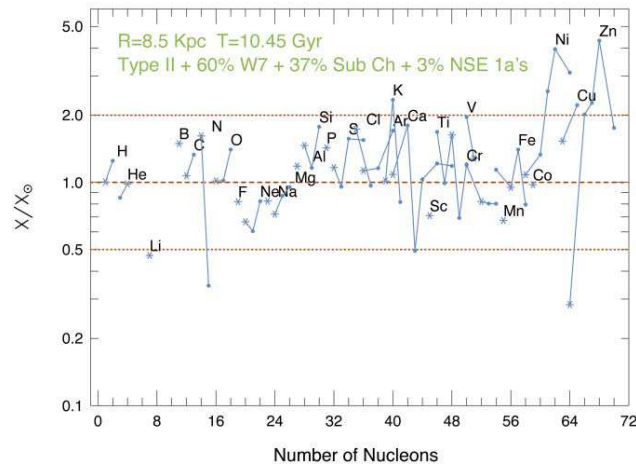
- SNIa



- * SNIi



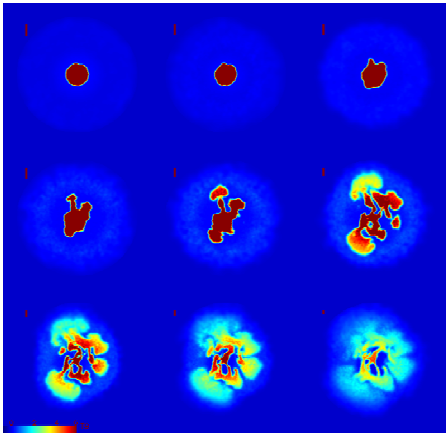
- Combination



Difficulties I (astrophysical)

- SNIa

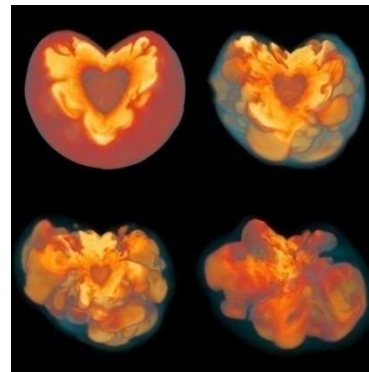
- Multi-D effects important



- Explosion mechanism not found yet.
- Detailed nucleosynthesis needs postprocessing

- SNIi

- Multi-D effects important.
- Physics not well understood



- Not unambiguous successful model for explosion.
- Detailed nucleosynthesis needs postprocessing

Difficulties (nuclear physics)

- SNIa

- Gross features of nuclear processes well understood.
- Errors in individual reactions smoothed during NSE and QNSE regimes.
- Individual (α, p) , (α, n) on IME important during the freeze-out.

- SNII

- Synthesis complicated inside the neutrinosphere (r-process?).
- Unclear location of the mass cut separating the protoNS from the ejecta.
- Role played by $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ in the pre-SN structure.
- Detected radioactive nuclei do not completely match predictions:
 ^{44}Ti , ^{60}Fe , ^{26}Al