Nuclear masses for explosiove nucleosynthesis

The νp-process and the r-process

Gabriel Martínez Pinedo

October 20, 2006

Outline

Outline

1. Introduction
   - Nucleosynthesis light p-nuclei
   - Metal poor stars
2. Early supernova ejecta (proton rich)
   - Role of weak interactions
   - The νp-process
3. Late supernova ejecta (r-process)
   - r-process needs
   - Fission in the r-process
4. Conclusions

Outline

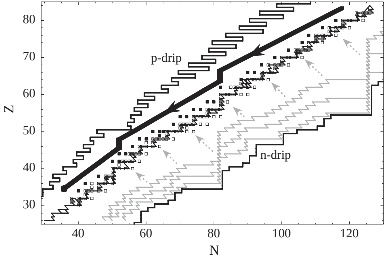
1. Introduction
   - Nucleosynthesis light p-nuclei
   - Metal poor stars
2. Early supernova ejecta (proton rich)
   - Role of weak interactions
   - The νp-process
3. Late supernova ejecta (r-process)
   - r-process needs
   - Fission in the r-process
4. Conclusions

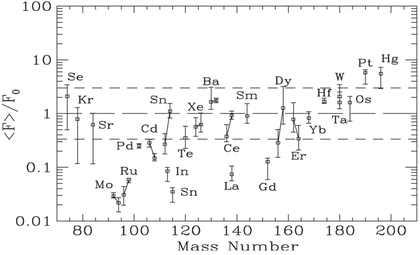
Outline

1. Introduction
   - Nucleosynthesis light p-nuclei
   - Metal poor stars
2. Early supernova ejecta (proton rich)
   - Role of weak interactions
   - The νp-process
3. Late supernova ejecta (r-process)
   - r-process needs
   - Fission in the r-process
4. Conclusions

Production light p-nuclei

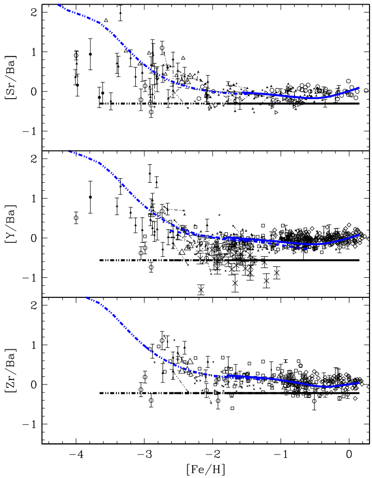
p-process fails to explain the solar abundances of ^{92,94}Mo and ^{96,98}Ru.





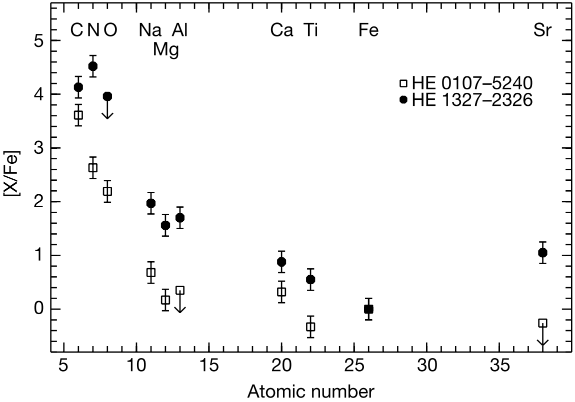
Galactic chemical evolution

- Travaglio *et al.*, ApJ **601**, 864 (2004), suggest a *lighter element primary process* to explain evolution abundances Sr, Y, Zr.
- Ge abundance is proportional to the Fe abundance [Cowan & Sneden, Nature **440**, 1151 (2006)]



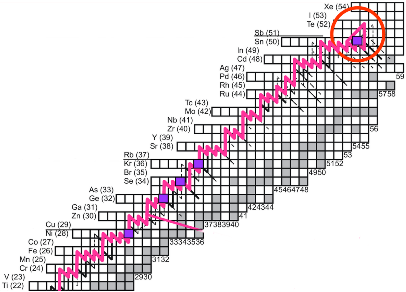
Ultrametal poor star

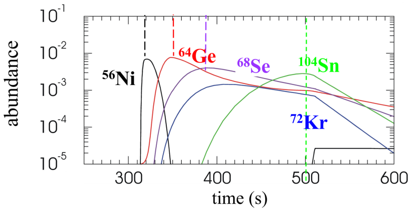
Recent observation star [Fe/H] = -5.4 ± 0.2
Frebel *et al.*, Nature **434**, 871 (2005)



rp-process

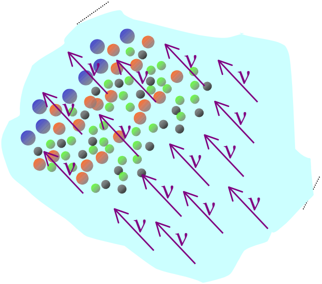
(From H. Schatz)





- Where else can we have proton rich ejecta? (Supernovae)
- How to speed up the matter flow? Nucleosynthesis time in supernova outflows ~ 10 s

Effect of weak interactions



Main processes:

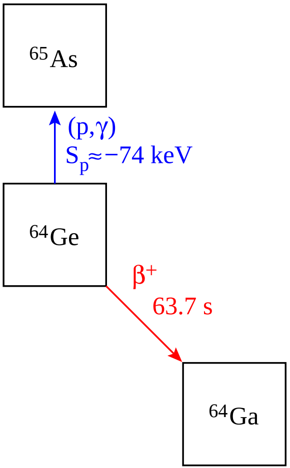
$$\nu_e + n \rightleftarrows p + e^-$$
$$\bar{\nu}_e + p \rightleftarrows n + e^+$$

- Current simulations show that early ejecta (1 s) is proton-rich
- This occurs whenever: $\epsilon_{\bar{\nu}} - \epsilon_{\nu} < 4(m_n - m_p)$.
- Proton-rich ejecta could be the mayor contributors to ^{45}Sc, ^{49}Ti, and ^{64}Zn.
- Neutrinos are responsible for the production of nuclei with $A > 64$ (νp-process).
- Later ejecta becomes neutron rich (r-process)

Proton-rich ejecta: The νp-process

- Proton-rich ejecta could be the major contributor of ^{45}Sc, ^{49}Ti and ^{64}Zn (Pruet *et al.* 2005, Fröhlich *et al.* 2006)
- Can proton-rich ejecta be the site of a kind of rp-process in supernovae?
- Problem with the short time scales for explosive nucleosynthesis in supernovae ($\sim$ seconds).
- Antineutrino absorption can speed up matter flow.

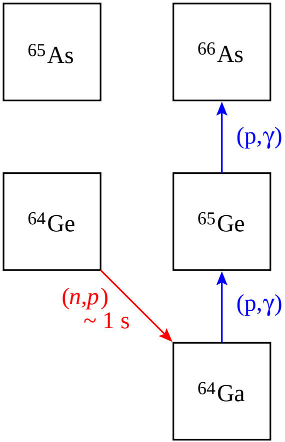
$$\bar{\nu}_e + p \rightarrow e^+ + n \quad (\text{time} \sim \text{seconds})$$



Proton-rich ejecta: The νp-process

- Proton-rich ejecta could be the major contributor of ^{45}Sc, ^{49}Ti and ^{64}Zn (Pruet *et al.* 2005, Fröhlich *et al.* 2006)
- Can proton-rich ejecta be the site of a kind of rp-process in supernovae?
- Problem with the short time scales for explosive nucleosynthesis in supernovae ($\sim$ seconds).
- Antineutrino absorption can speed up matter flow.

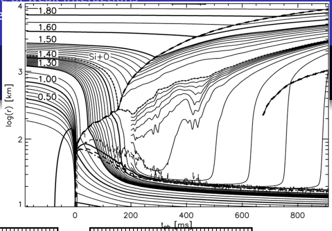
$$\bar{\nu}_e + p \rightarrow e^+ + n \quad (\text{time} \sim \text{seconds})$$

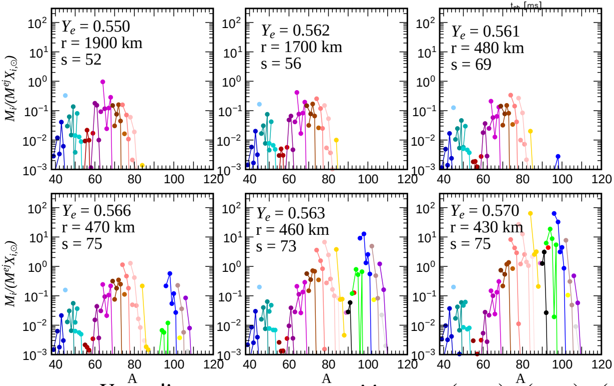


The νp-process
C. Fröhlich, *et al.*, PRL **96**, 142502 (2006)

Nucleosynthesis variability

Trajectories from Garching group
[Pruet *et al.*, ApJ **644**, 1028 (2006)]



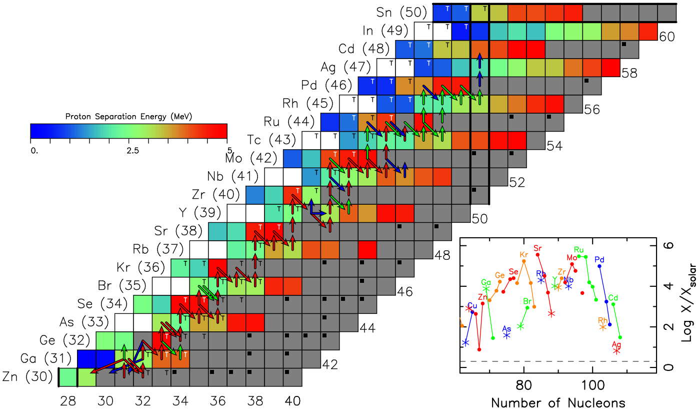


Sensitivity entropy, Y_e, radius.

Masses, (p,γ), (n,p), (n,γ), neutrino spallation.

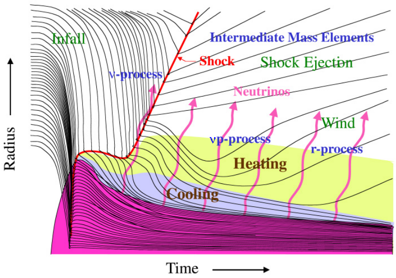
Nucleosynthesis fluxes

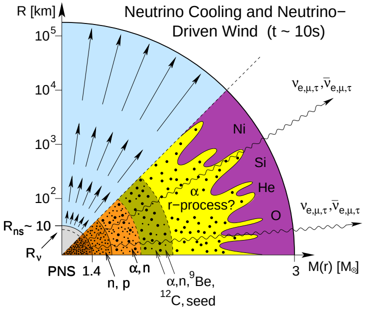
Figure from Pruet *et al*, ApJ **644**, 1028 (2006)



Production of ^{92}Mo is sensitive to the masses (and proton capture rates) in the region of ^{92}Pd.

Composition in neutrino heated ejecta

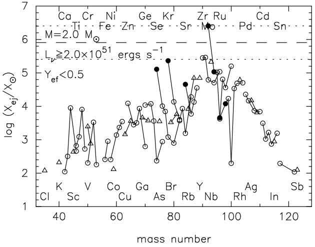


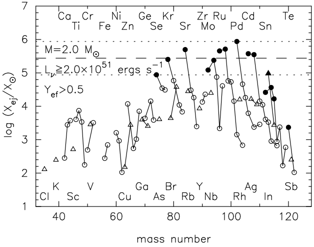


- Early ejecta proton-rich: νp-process
- Later ejecta neutron rich: r-process.
- Nucleosynthesis sentsitive to proton to seed ratio (νp-process) and neutron to seed ratio (r-process).

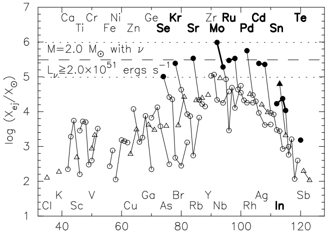
Production of light p nuclei

S. Wanajo, astro-ph/0602488





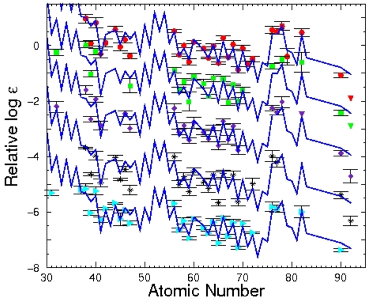
- ^{92}Mo is produced in slightly neutron rich ejecta, $Y_e \approx 0.47$–0.49 (Fuller & Meyer 1995, Hoffman *et al.* 1996).
- The rest is produced in proton-rich ejecta.



r-process needs

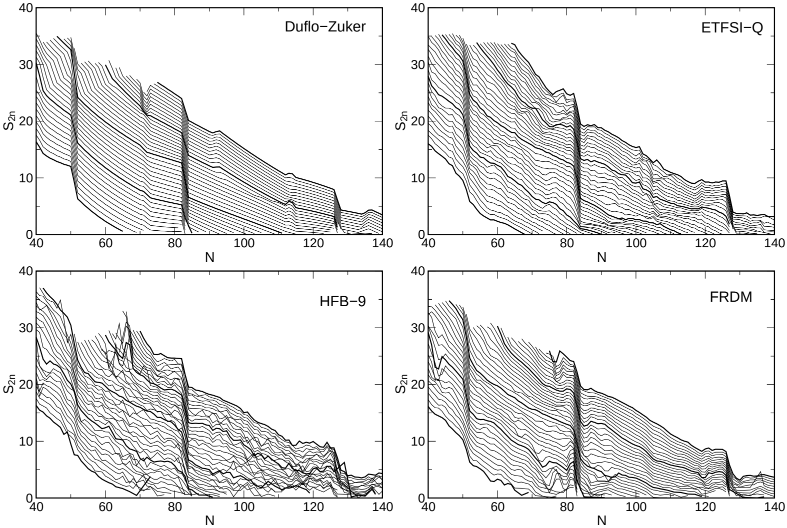
The r-process is responsible for the synthesis of half the nuclei with $A > 60$ including U, Th and maybe the super-heavies.
The r-process requires the knowledge and the evolution with neutron excess of:

- Nuclear masses.
- Beta-decay rates (beta-delayed neutron emission)
- Neutron capture rates (sensitivity to dipole strength)
- Fission (neutron induced, beta-delayed fission, spontaneous fission).
- Neutrinos (neutrino absorption rates, fission).

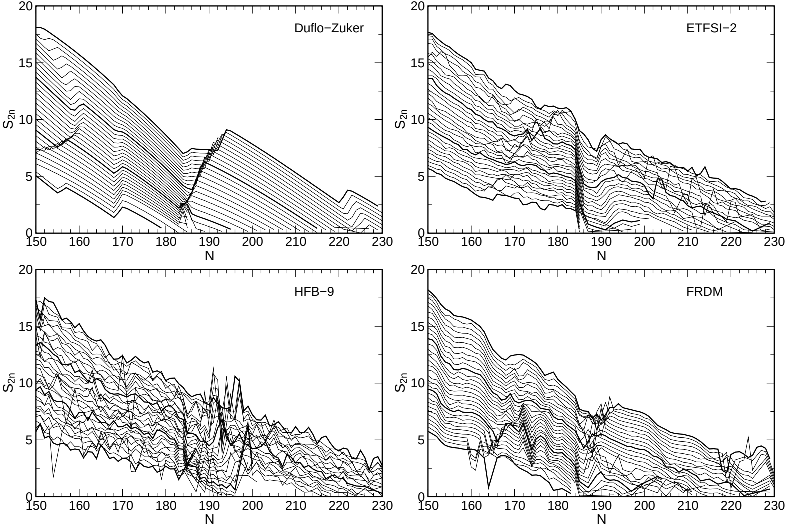


Cowan & Sneden, Nature **440**, 1151 (2006)

N=82 and N=126 Two-Neutron separation energies

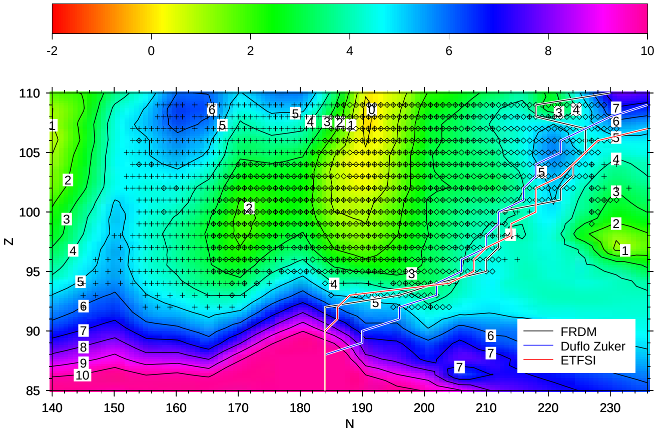


N=184 Two-Neutron separation energies

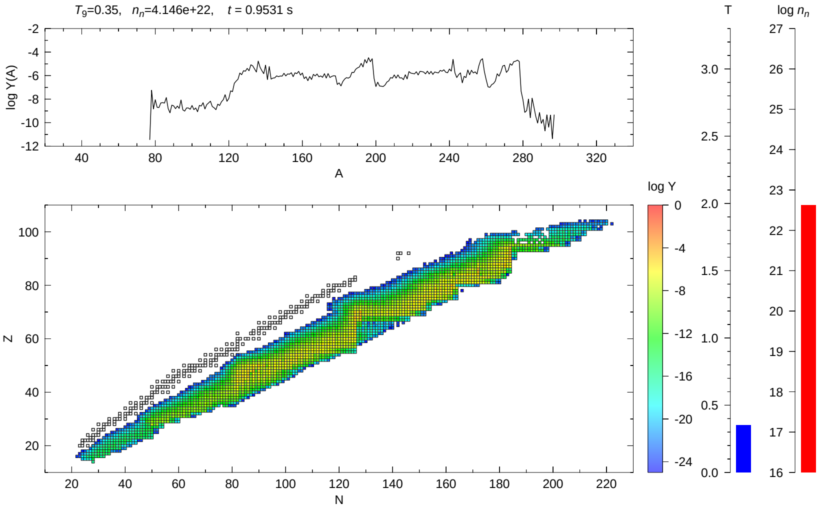


Where does fission occur?

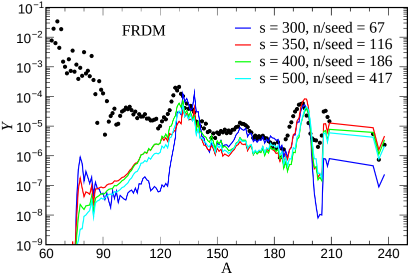
Myers & Swiatecki Barriers

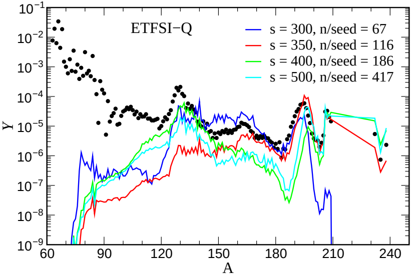


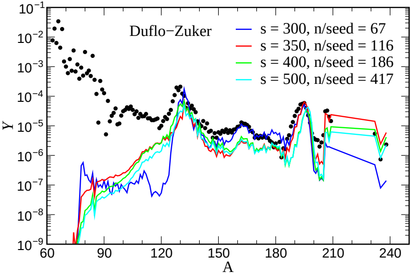
Snapshot



Comparison of abundances







Differences are due to different shell structure at $N = 82$

Conclusions

- A combination of proton-rich material (νp-process) and slightly neutron-rich material ($Y_e \sim 0.48$) could explain the solar abundances of light p-nuclei (^{92,94}Mo, ^{96,98}Ru).
- The masses in the region around ^{92}Pd are needed.
- The strength of the $N = 82$ plays a very important role in determining the role of fission.
- Mass models with strong shell effects are able to produce a consistent and robust r-process patters as soon as the neutron to seed ratio is large enough to induce fissions.