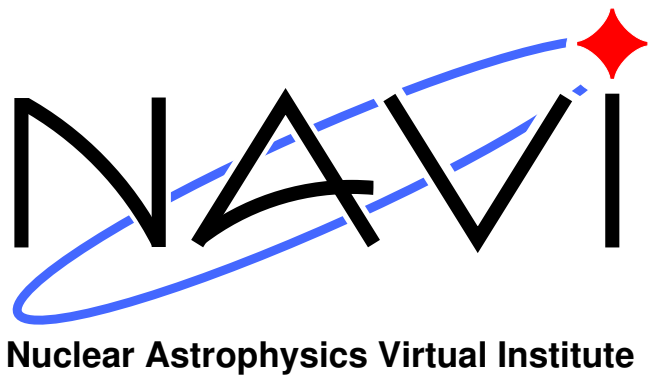
Equation of State/Weak Interaction/r-process

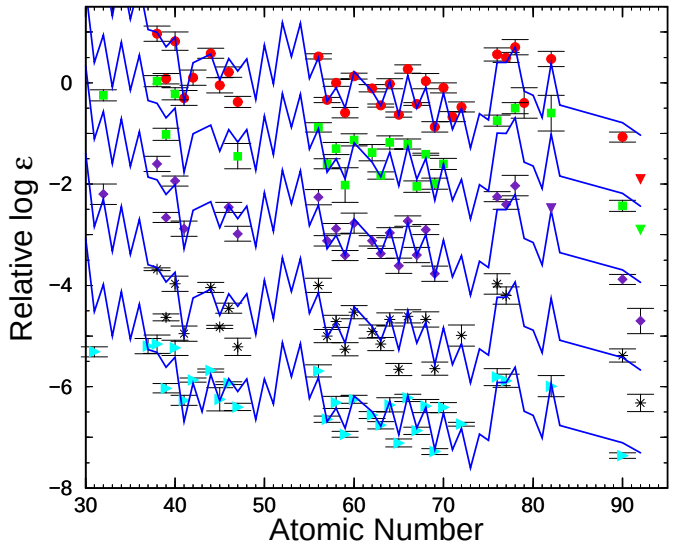
NAVI-JINA mini workshop



November 12, 2012

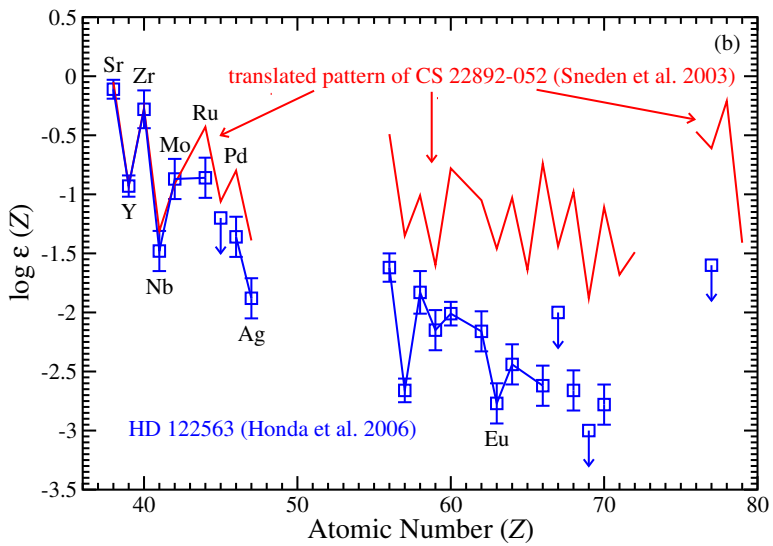
Heavy elements and metal-poor stars

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



- Stars rich in heavy r-process elements ($Z > 52$) and poor in iron (r-II stars, $[Eu/Fe] > 1.0$).
- Robust abundance patter for $Z > 52$, consistent with solar r-process abundance.
- These abundances seem the result of events that do not produce iron. [Qian & Wasserburg, Phys. Rept. **442**, 237 (2007)]
- Possible Astrophysical Scenario: Neutron star mergers.

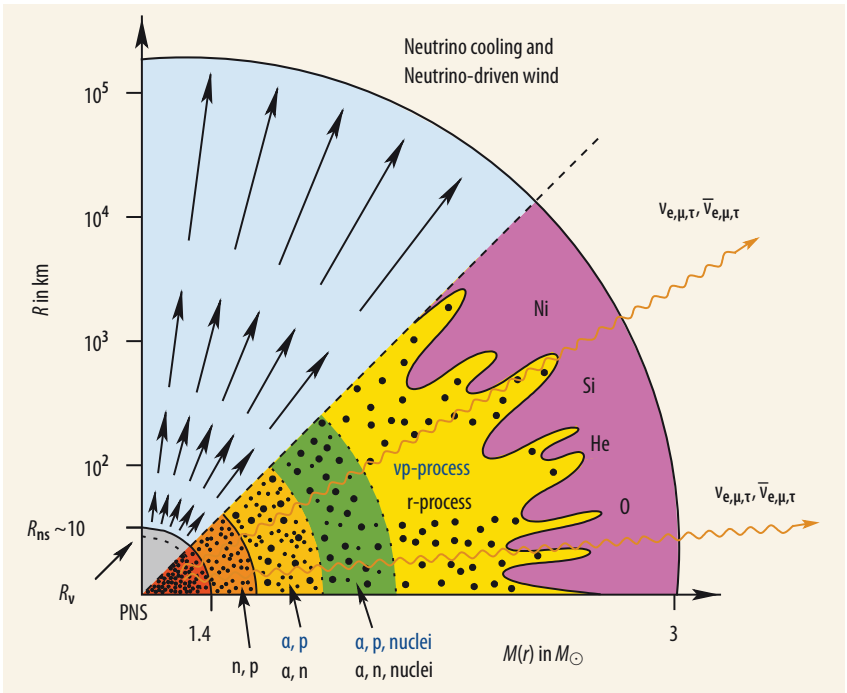
- Stars poor in heavy r-process elements but with large abundances of light r-process elements (Sr, Y, Zr)
- Production of light and heavy r-process elements is decoupled.
- Astrophysical scenario: neutrino-driven winds from core-collapse supernova



Honda *et al*, ApJ **643**, 1180 (2006)

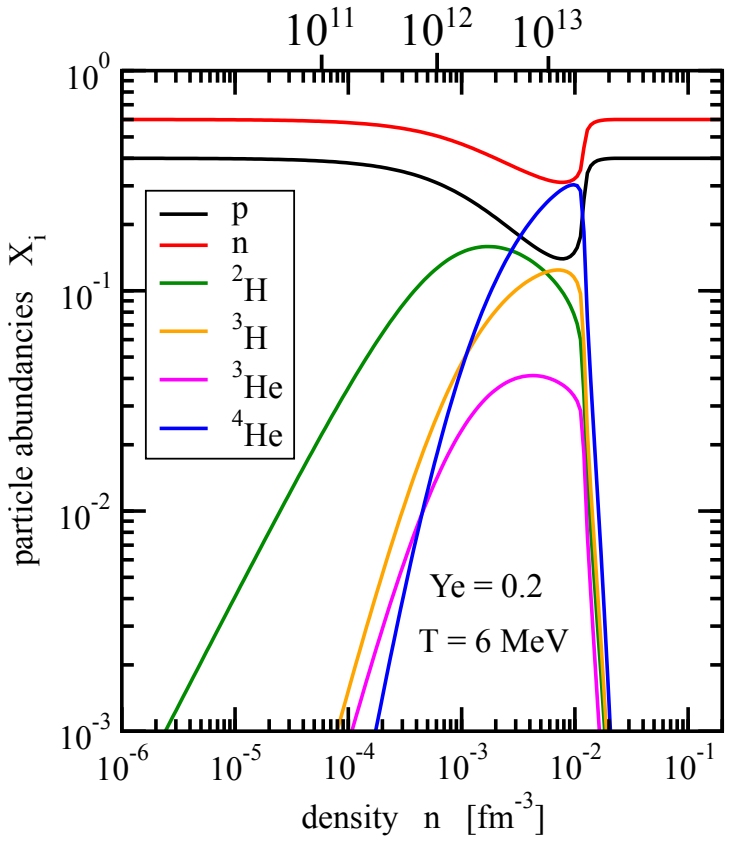
Nucleosynthesis in neutrino-driven winds

- EoS: How well do we know the properties of matter at the relevant density and temperature range? $\rho = 10^{11}$–10^{14} g cm^{-3}, $T \sim 5$ MeV, $Y_e \sim 0.05$.
- Neutrino-interactions: How well and how accurate do we need to know the rates?
- Transport codes: How accurate are they?
- Nuclear input: How can we constrain both experimentally and theoretically the necessary properties?
- Can we identify key quantities necessary for nucleosynthesis?



Dependence of composition on density

- We need Equations of State that provide detailed information about composition.
- It will be also desirable that the Equation of State provides a consistent description of neutrino opacities.



S. Typel *et al.*, PRC **81**, 015803 (2010)

Neutrino opacities and transport

- The main processes are:

Main processes:

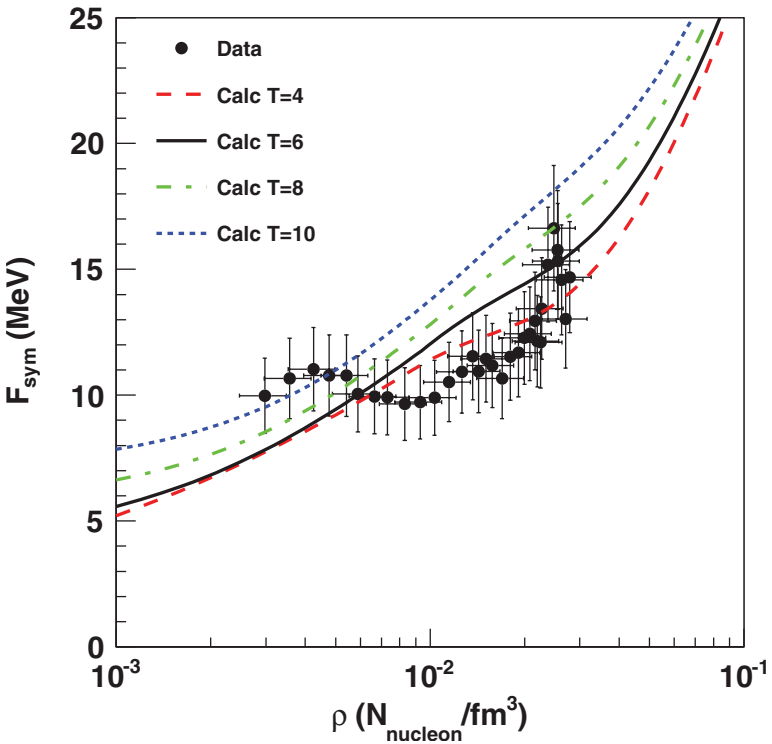
$$\nu_e + n \rightleftarrows p + e^-$$
$$\bar{\nu}_e + p \rightleftarrows n + e^+$$

- How important are correlations? It is enough to describe them at the RPA level?
- How to implement the relevant opacities in transport codes?
- How accurate are these codes? Can we do comparisons?
- Is convection important?

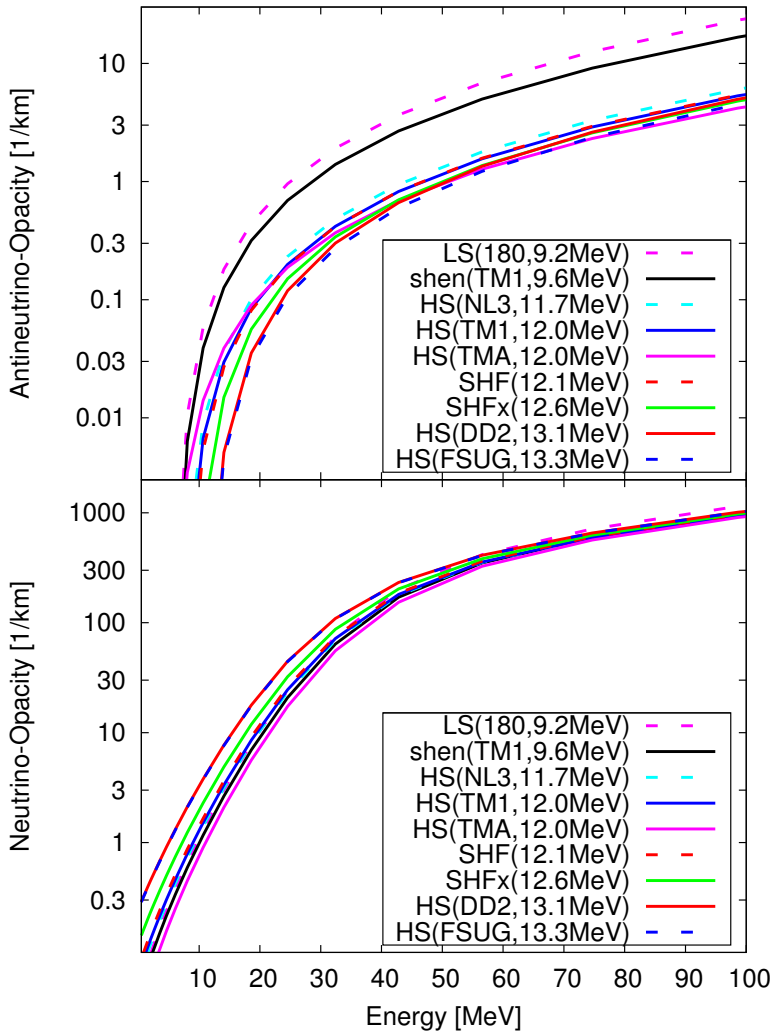
Sensitivity to nuclear symmetry energy

$$\rho = 2.1 \times 10^{13}\ \mathrm{g\ cm^{-3}}, T = 7.4\ \mathrm{MeV}, Y_e = 0.035$$

- Strong sensitivity of opacities to nuclear symmetry energy

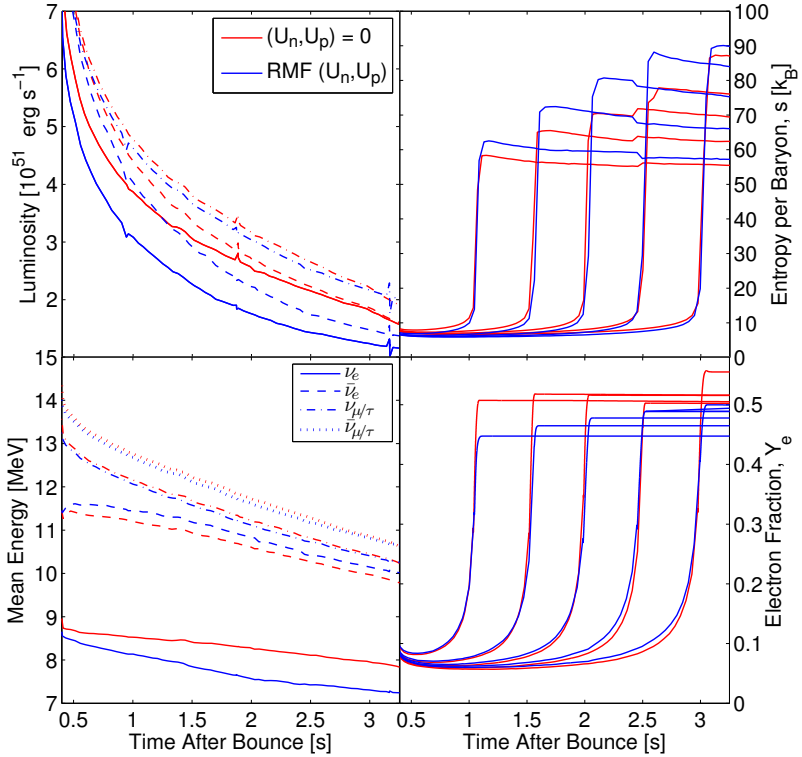


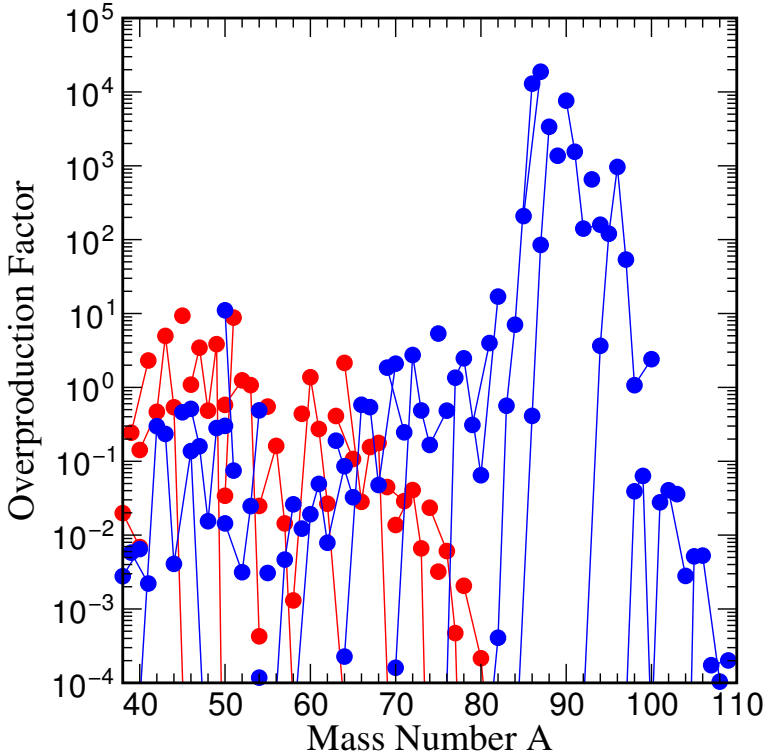
Wada *et al*, PRC **85**, 064618 (2012)



Impact neutrino mean energies and Y_e

Simulations for a 15 $M_\odot$ star (GMP, Fischer, Lohs, Huther, arXiv:1205.2793)





- Neutron-rich ejecta are possible in neutrino-driven winds.
- Neutron-richness sensitive to nuclear symmetry energy (see also Roberts & Reddy, arXiv:1205.4066)
- No substantial production of nuclei heavier than $A \sim 120$ ($Z \sim 50$).