Nucleosynthesis in core-collapse supernovae

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HELMHOLTZ GEMEINSCHAFT

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Points for discussion

- Impact of neutrinos: What are the relevant processes? How well do we need to know them? What is the role of neutrino oscillations?
- Impact of the explosion (multidimensional effects, different mechanisms) on nucleosynthesis: exposure to neutrino fluxes, changes in thermodynamical history, distribution of ejected material.
- Role of nuclear reactions: given a particular astrophysical model how sensitive are the yields to nuclear physics variations? How reproducible are the results?

Nucleosynthesis in neutrino driven winds

Neutrino interactions determine Y_e

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

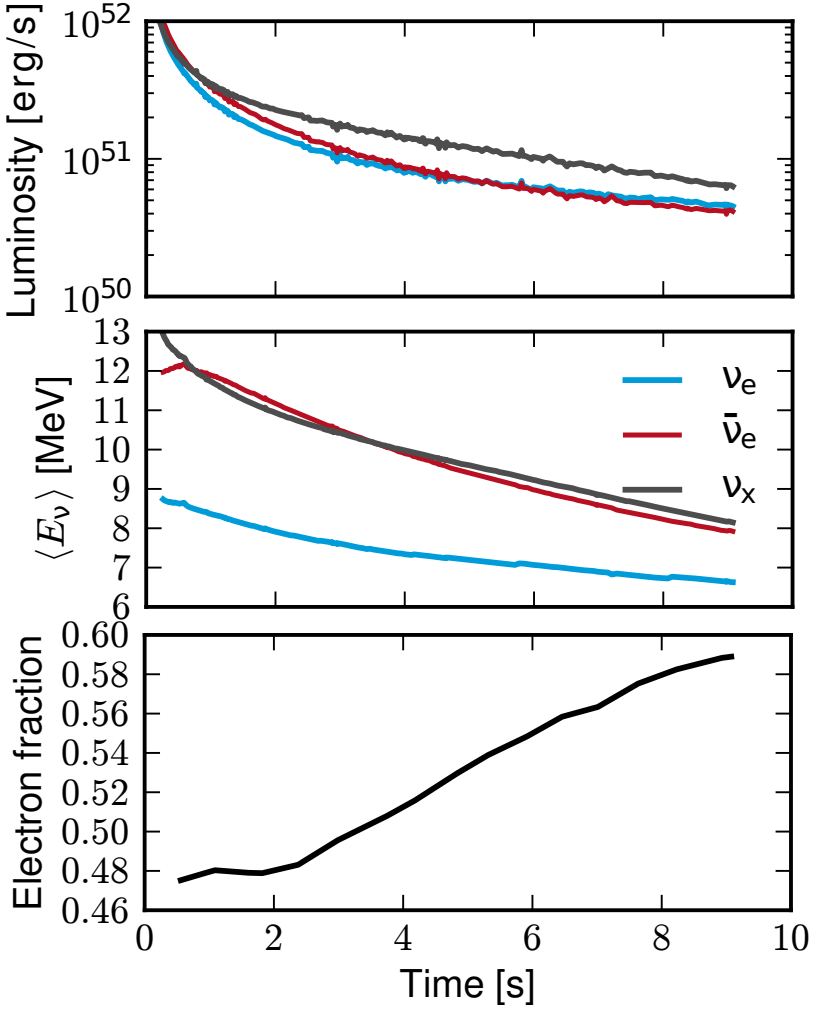
Neutron-rich ejecta:

$$\langle E_{\bar{\nu}_e} \rangle - \langle E_{\nu_e} \rangle > 4\Delta_{np} - \left[\frac{L_{\bar{\nu}_e}}{L_{\nu_e}} - 1\right]\left[\langle E_{\bar{\nu}_e} \rangle - 2\Delta_{np}\right]$$

- neutron-rich ejecta: weak r-process
- proton-rich ejecta: νp-process

Energy difference related to symmetry energy (GMP+ 2012, Roberts+ 2012)

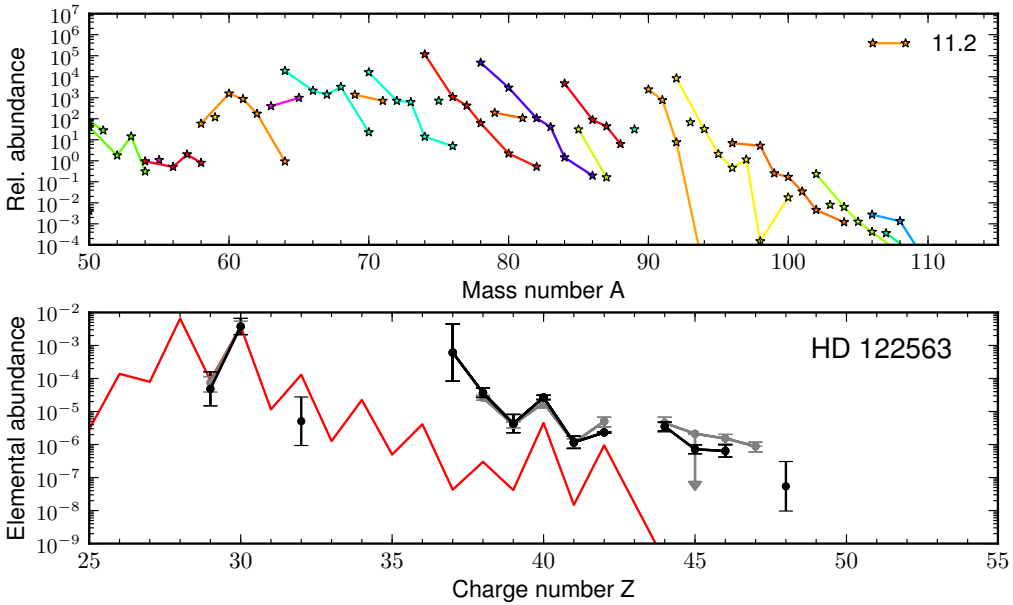
1D Boltzmann transport simulation (DD2 EoS)



GMP+ 2013

Nucleosynthesis

Neutron-deficient isotopes of elements between Zn and Mo

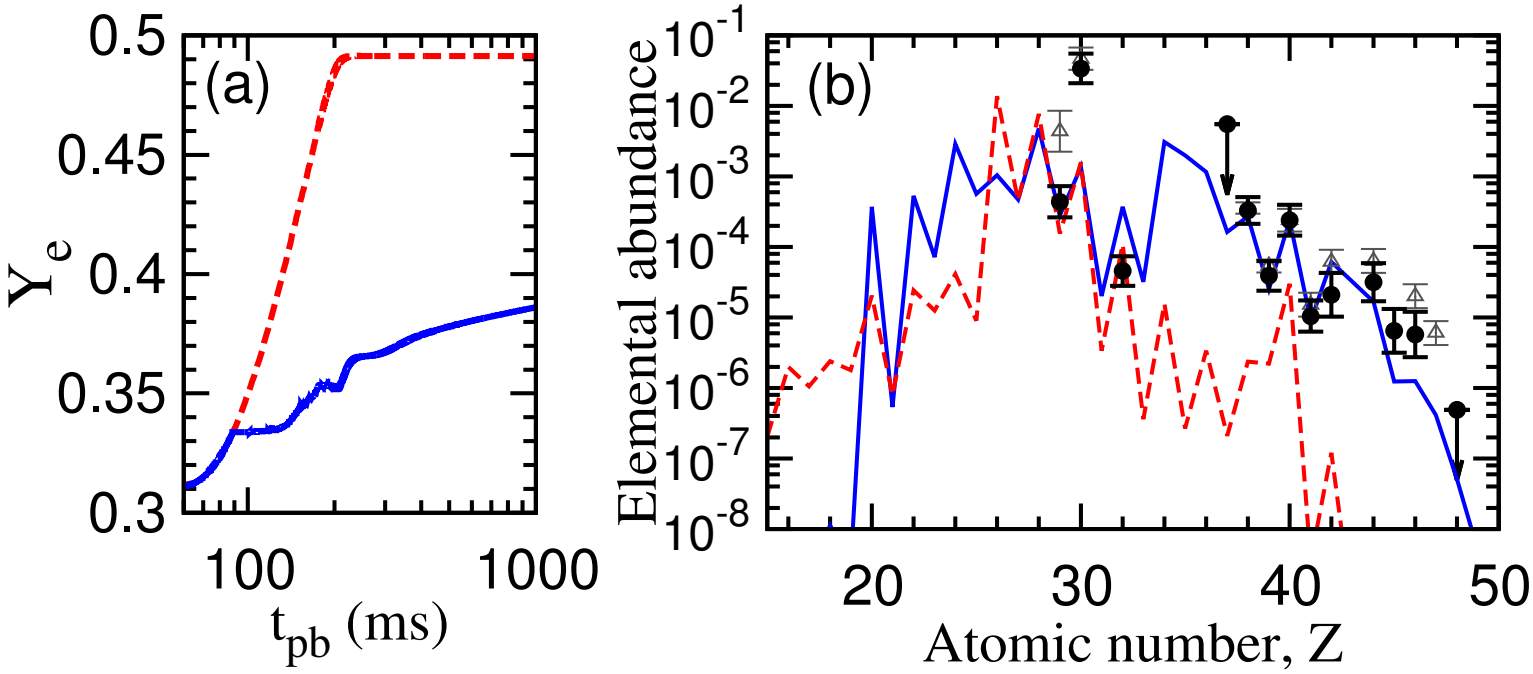


Uncertainties:

- Multidimensional effects (Wanajo+ 2011)
- Oscillations:
  - Collective: minor impact (Wu+ 2015)? But ...
  - Active-sterile: important impact on nucleosynthesis, detrimental for the explosion (Wu+ 2013)
- Sensitivity to neutrino opacities?

Active-sterile neutrino conversion and nucleosynthesis

M.-R. Wu, T. Fischer, GMP, Y.-Z. Qian, arXiv:1305.2382 [astro-ph.HE]



- Active-sterile flavor conversion increases the neutron richness of the ejected material
- This allows for the production of elements between Sr and Cd in agreement with metal-poor star observations.

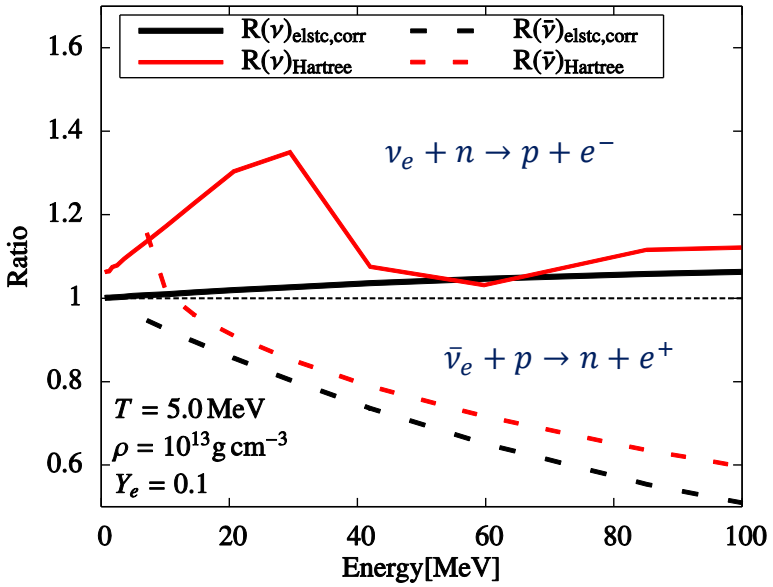
Improvements of neutrino opacities

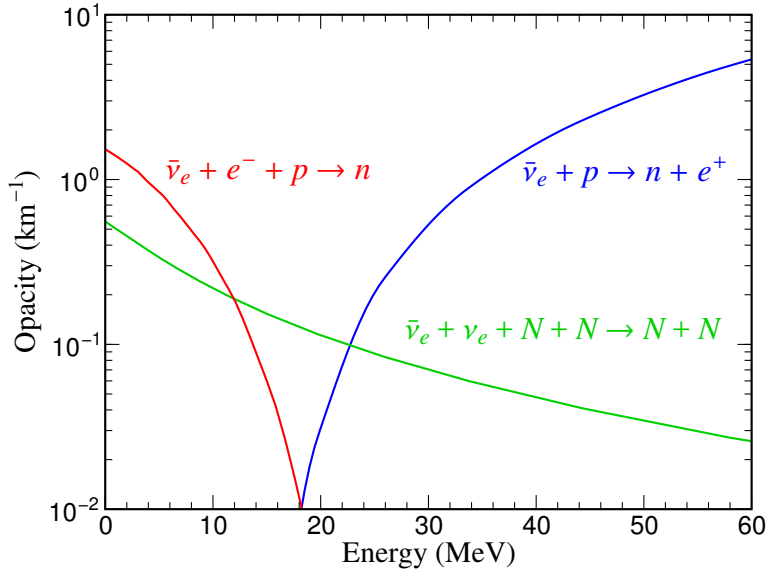
Most calculations assume elastic approximation (Bruenn 1985).
Improvements:

- Weak magnetism (Horowitz 2002)
- Inelastic contributions (Reddy+ 1998)
- Additional opacity channels for $\bar{\nu}_e$ (Direct URCA, Lattimer+ 1991)

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

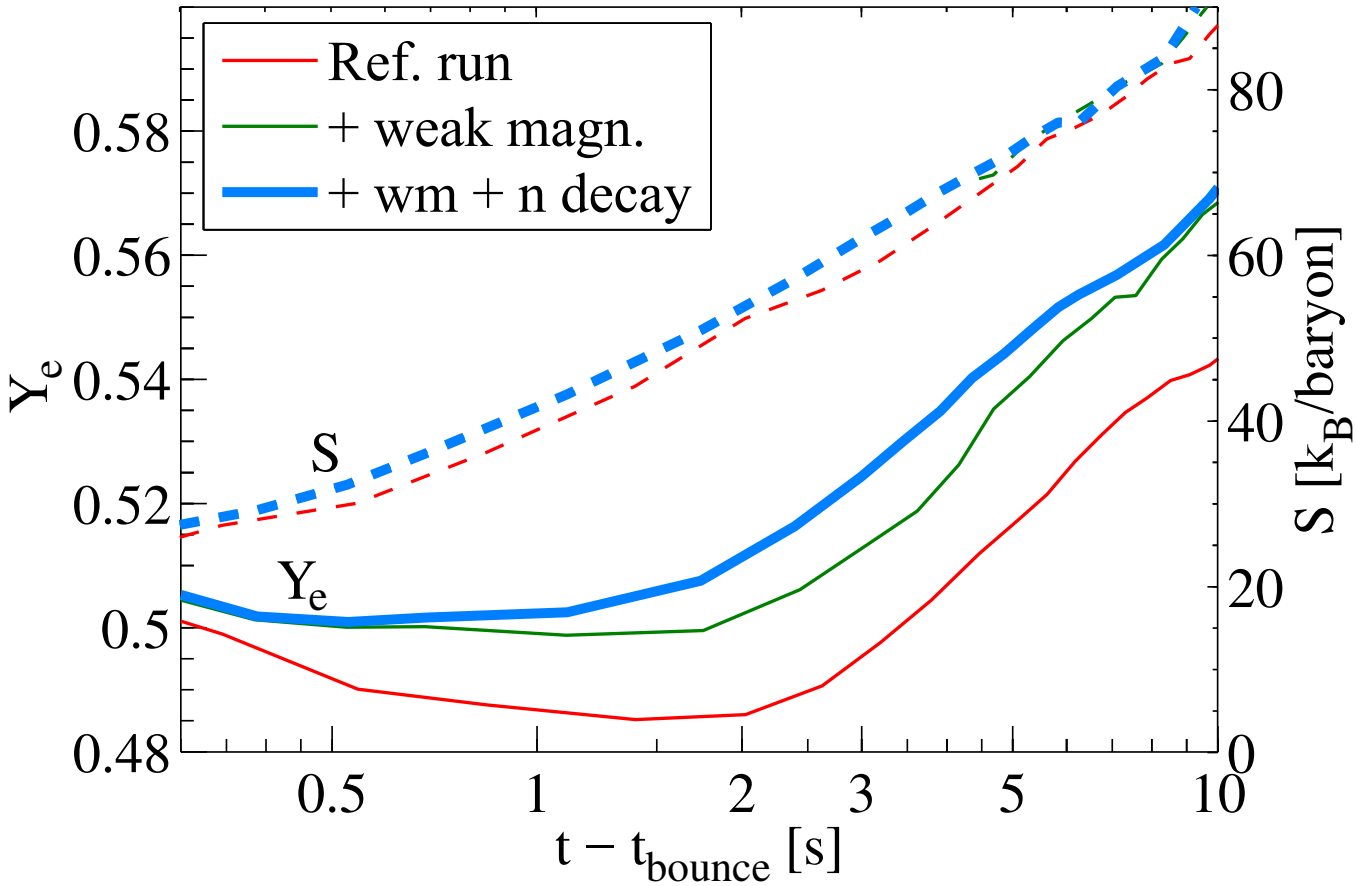
A. Lohs





Influence in Y_e

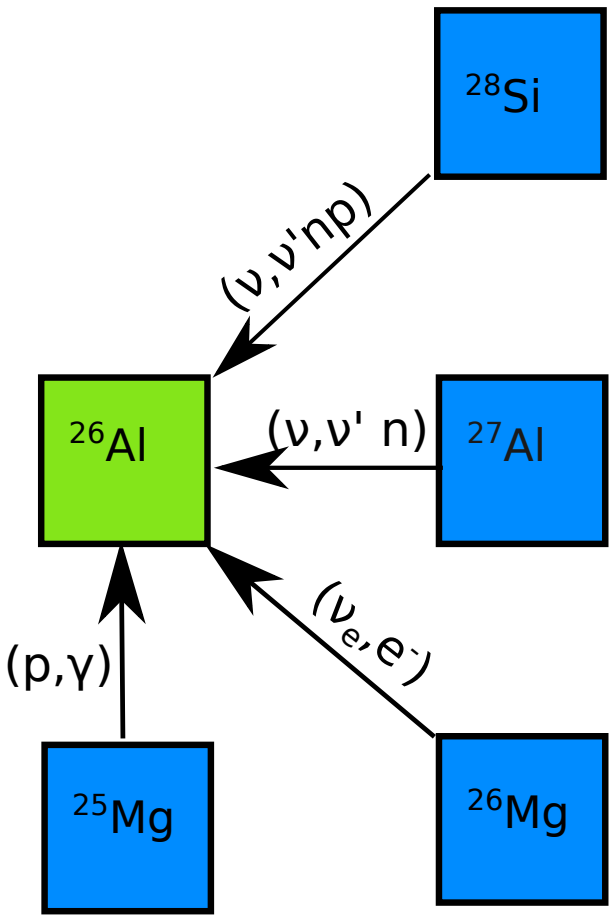
Fischer, GMP, Wu, Lohs, Qian, in preparation



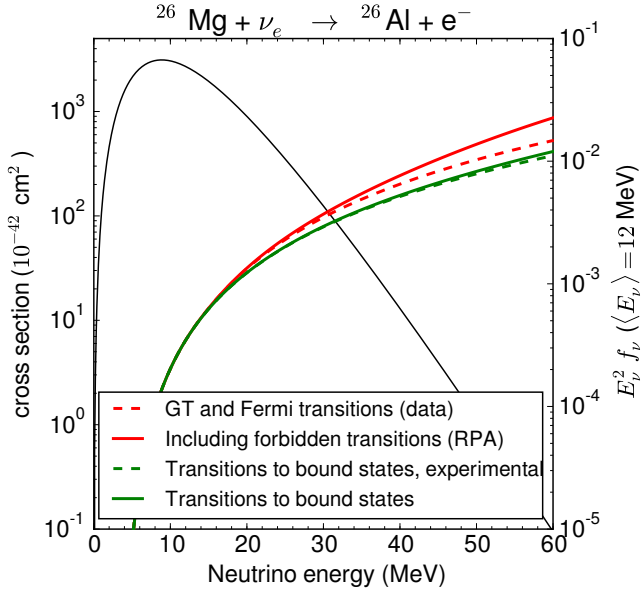
Ejecta are always proton rich: *νp*-process

Neutrino nucleosynthesis of ^{26}Al

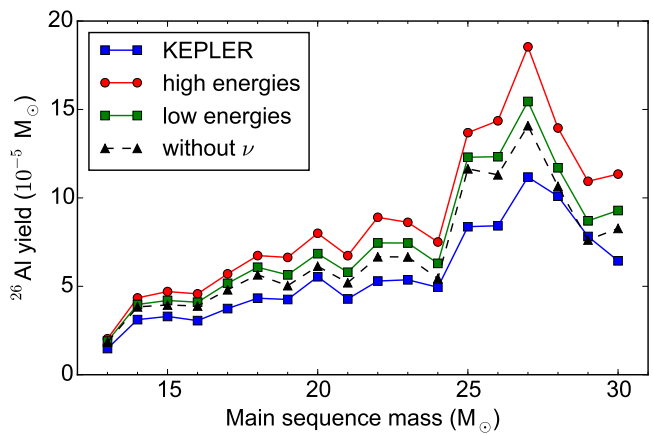
Having accurate neutrino spectra is also important for the production of several nuclei (^{7}Li, ^{11}B, ^{19}F, including ^{26}Al).



GT: (^{3}He, t), Zegers+ 2006; Forbidden: RPA



low: $\langle E_{\nu_e} \rangle = 8.8$ MeV, $\langle E_{\bar{\nu}_e} \rangle = \langle E_{\nu_{\mu,\tau}} \rangle = 12.6$ MeV
high: $\langle E_{\nu_e} \rangle = \langle E_{\bar{\nu}_e} \rangle = 12.6$ MeV, $\langle E_{\nu_{\mu,\tau}} \rangle = 18.9$ MeV



A. Sieverding

Update of reactions in Kepler

Preliminary results showing the impact of new JINA reaclib implementation in KEPLER.