Supernova neutrino-nucleus reactions

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- supernova neutrinos due to electron captures
- inelastic neutrino-nucleus scattering
- consequences for observation of neutrino-burst
- neutrino nucleosynthesis
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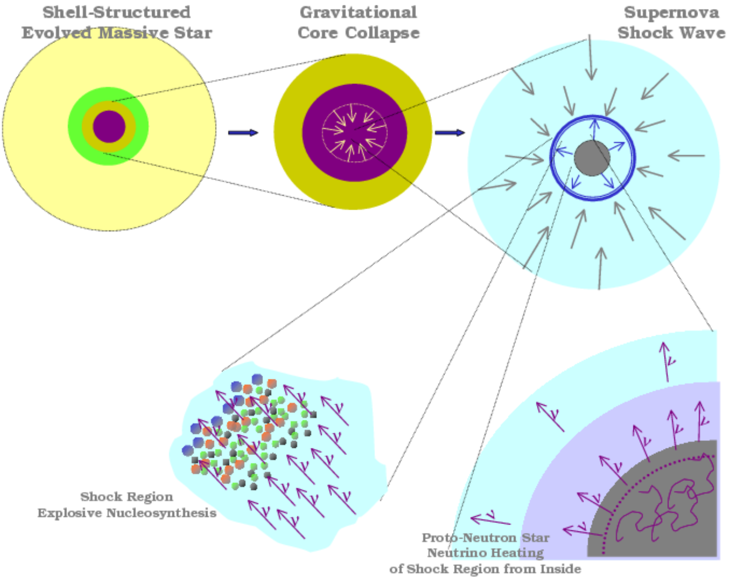
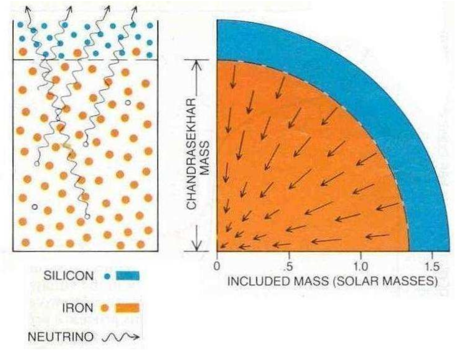
Core-collapse supernova.



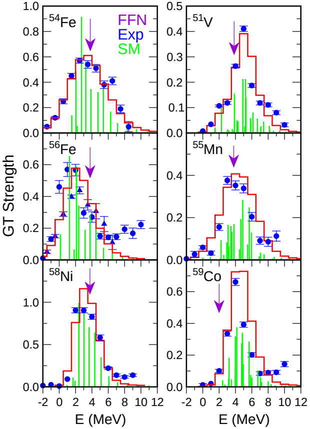
Electron captures in core collapse.



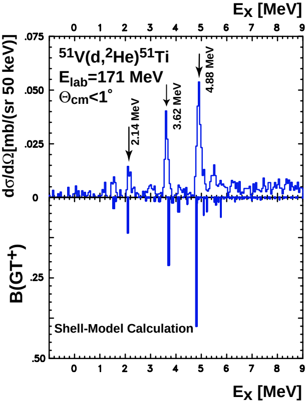
- $T = 0.5$–2.0 MeV, $\rho = 10^8$–10^{13} g cm^{-3}.
- The dynamical time scale set by electron captures: $e^- + (N, Z) \to (N+1, Z-1) + \nu_e$
- Evolution decreases number of electrons (Y_e) and Chandrasekhar mass ($M_{Ch} \approx 1.4(2Y_e)^2$ M$_\odot$)

- Capture rates on individual nuclei computed by:
  - Shell Model ($A < 65$)
  - Shell Model Monte Carlo ($A > 65$)
  - RPA with parametrized occupation numbers ($A > 115$)

(n,p) experiments, TRIUMF



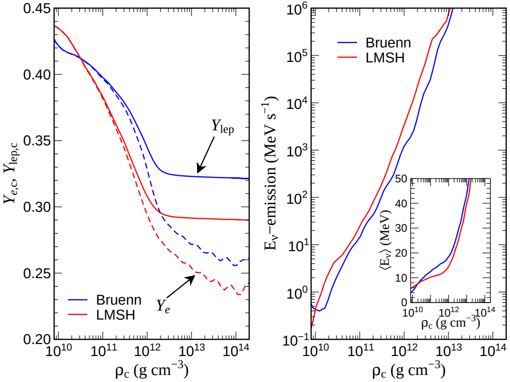
(d,^{2}He) experiments, KVI Groningen



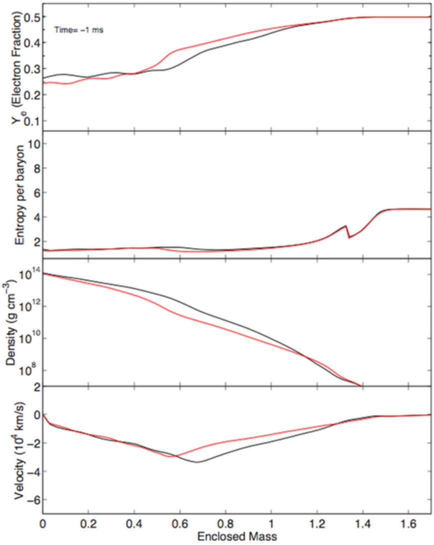
shell model results agree after overall quenching by $(0.77)^2$

Effect on improved rates on collapse simulations

With Rampp & Janka (General Relativistic model)
15 $M_\odot$ presupernova model from A. Heger & S. Woosley



Bounce and shock wave evolution



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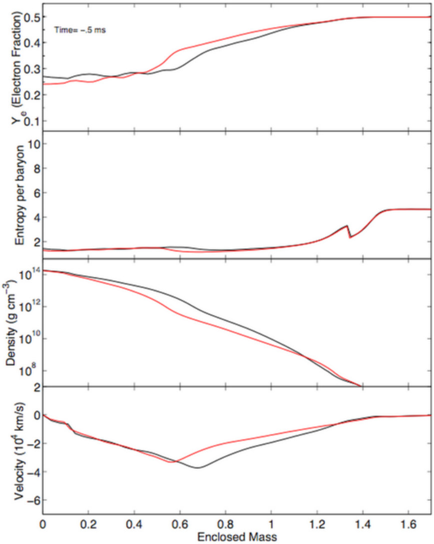

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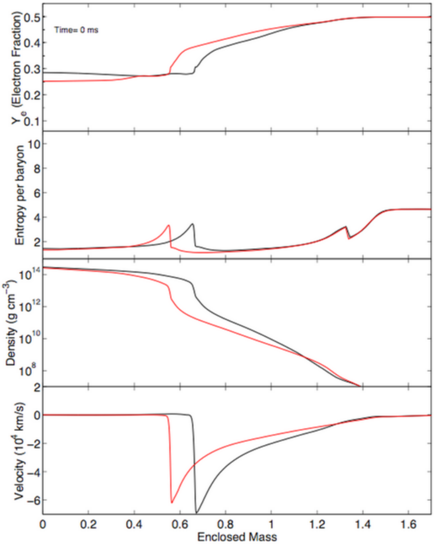

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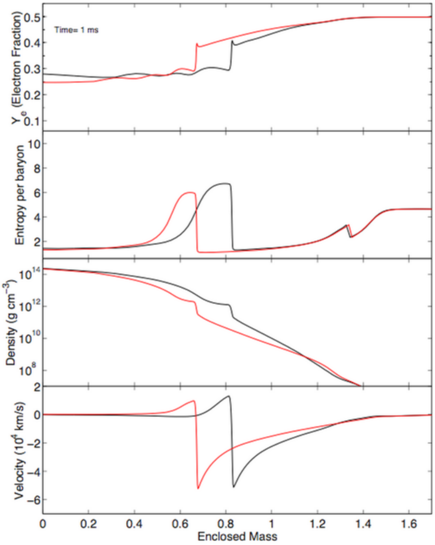

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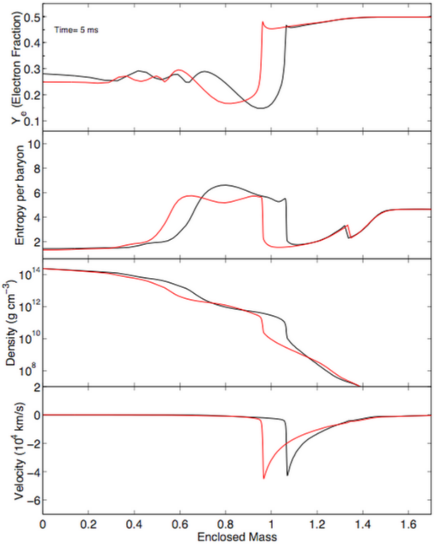

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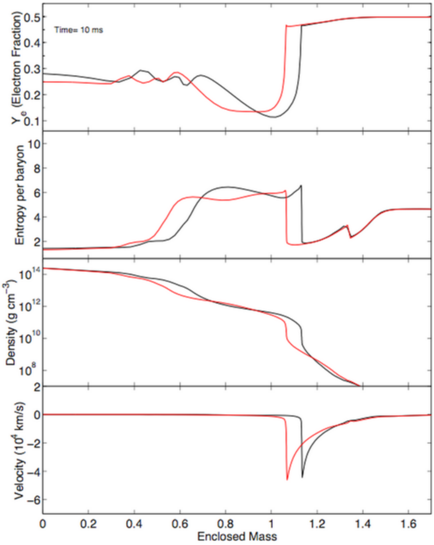

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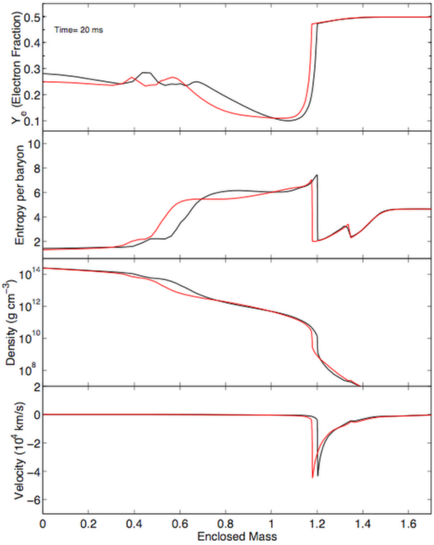

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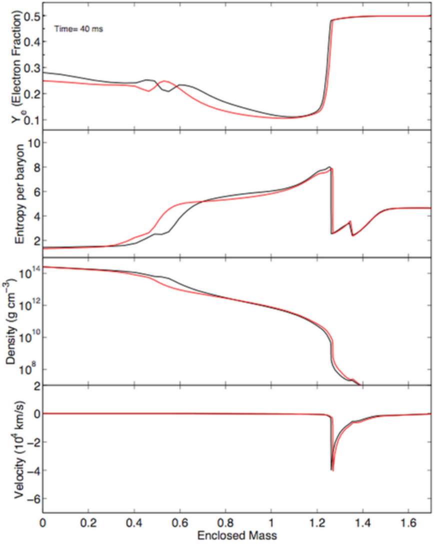
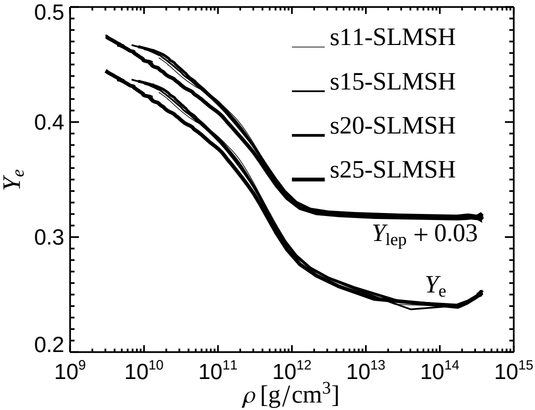
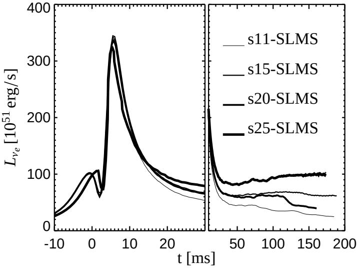


'Standard' core trajectory at bounce



Electron captures on nuclei and protons are self-regulating leading to the same trajectories at bounce for different stellar masses (H.Th. Janka, A. Marek, G. Martinez-Pinedo)

'Standard' neutrino burst

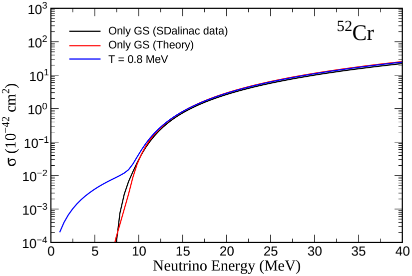


- shock dissociates matter into free protons and neutrons
- fast electron captures on free protons create ν_e neutrino burst
- 'standard' ν_e bursts
- future observation by supernova neutrino detectors
- 'standard neutrino candles'?

Inelastic ν-nucleus scattering in supernovae

Potential consequences:

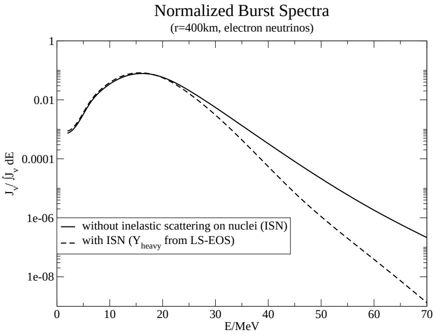
- thermalization of neutrinos during collapse
- preheating of matter before passing of shock
- nucleosynthesis, νp-process
- supernova neutrino signal



- neutrino cross sections from (e, e') data
- validation of shell model
- G.Martinez-Pinedo, P. v. Neumann-Cosel, A. Richter

Supernova neutrino signal

inelastic ν-nucleus scattering adds to the opacity for high-energy neutrinos



B. Müller, H.-Th. Janka, G. Martinez-Pinedo, A. Juodagalvis, J. Sampaio

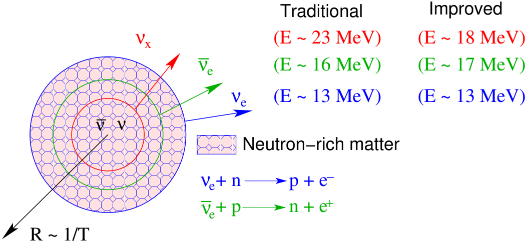
Consequences for supernova neutrino detectors

Detector	Material	$\langle\sigma\rangle$ (10^{-42} cm^2) With $A(\nu,\nu')A^\star$	Without $A(\nu,\nu')A^\star$	Change
SNO	d	5.92	7.08	16%
MiniBoone	^{12}C	0.098	0.17	43%
	^{12}C (N_{gs})	0.089	0.15	41%
S-Kamiokande	^{16}O	0.013	0.031	58%
Icarus	^{40}Ar	17.1	21.5	20%
Minos	^{56}Fe	8.8	12.0	27%
OMNIS	^{208}Pb	147.2	201.2	27%

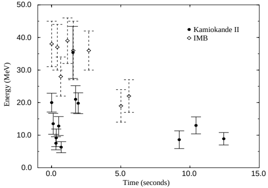
Change in supernova neutrino spectra reduce detection rates!

Neutrinos from supernovae

Raffelt *et al.*, astro-ph/0303226

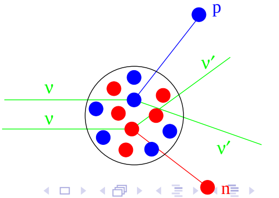


neutrino detection (SN1987A)



Neutrino nucleosynthesis

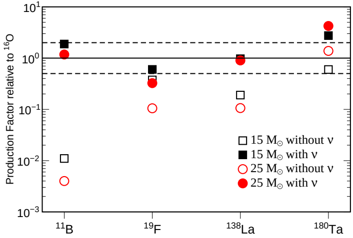
$^{12}\mathrm{C}(\nu,\nu' p)^{11}\mathrm{B}$ $^{12}\mathrm{C}(\nu,\nu' n)^{11}\mathrm{C}$

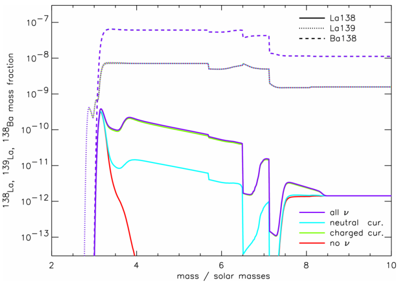


Neutrino nucleosynthesis

A. Heger *et al*, PLB 606 (2005) 258

Product	Parent	Reaction
^{11}B	^{12}C	$(\nu,\nu' n),(\nu,\nu' p)$
^{19}F	^{20}Ne	$(\nu,\nu' n),(\nu,\nu' p)$
^{138}La	^{138}Ba	(ν_e,e^-)
	^{139}La	$(\nu,\nu' n)$
^{180}Ta	^{180}Hf	(ν_e,e^-)
	^{181}Ta	$(\nu,\nu' n)$



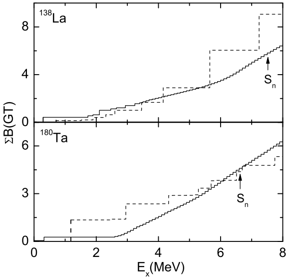


Importance of ^{138}La and ^{180}Ta nucleosynthesis

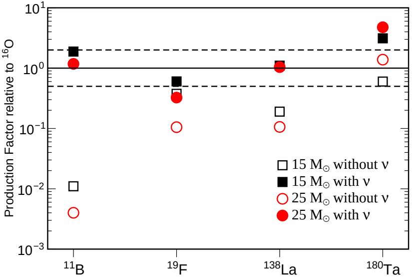
- ^{11}B and ^{19}F are produced by neutral-current reactions induced by ν_μ and ν_τ neutrinos and anti-neutrinos
- $\bar{\nu}_e$ neutrinos observed from SN1987a
- ^{138}La and ^{180}Ta are produced by charged-current reactions induced by ν_e neutrinos on ^{138}Ba and ^{180}Hf
- In summary, one has a sensitivity to ALL different neutrino spectra

However, neutrino cross sections based on theoretical models (RPA)

Measurement of GT strength for ^{138}Ba and ^{180}Hf



RCNP Osaka/ Darmstadt (A. Byelikov *et al.*)



Summary

Improved nuclear ingredients for supernova simulations

- Electron capture rates on nuclei change collapse trajectory
- Neutrino-nucleus cross sections have impact on neutrino-burst signal
- Neutrino-nucleosynthesis might serve as neutrino thermometer