Nucleosynthesis in Neutrino Driven Winds

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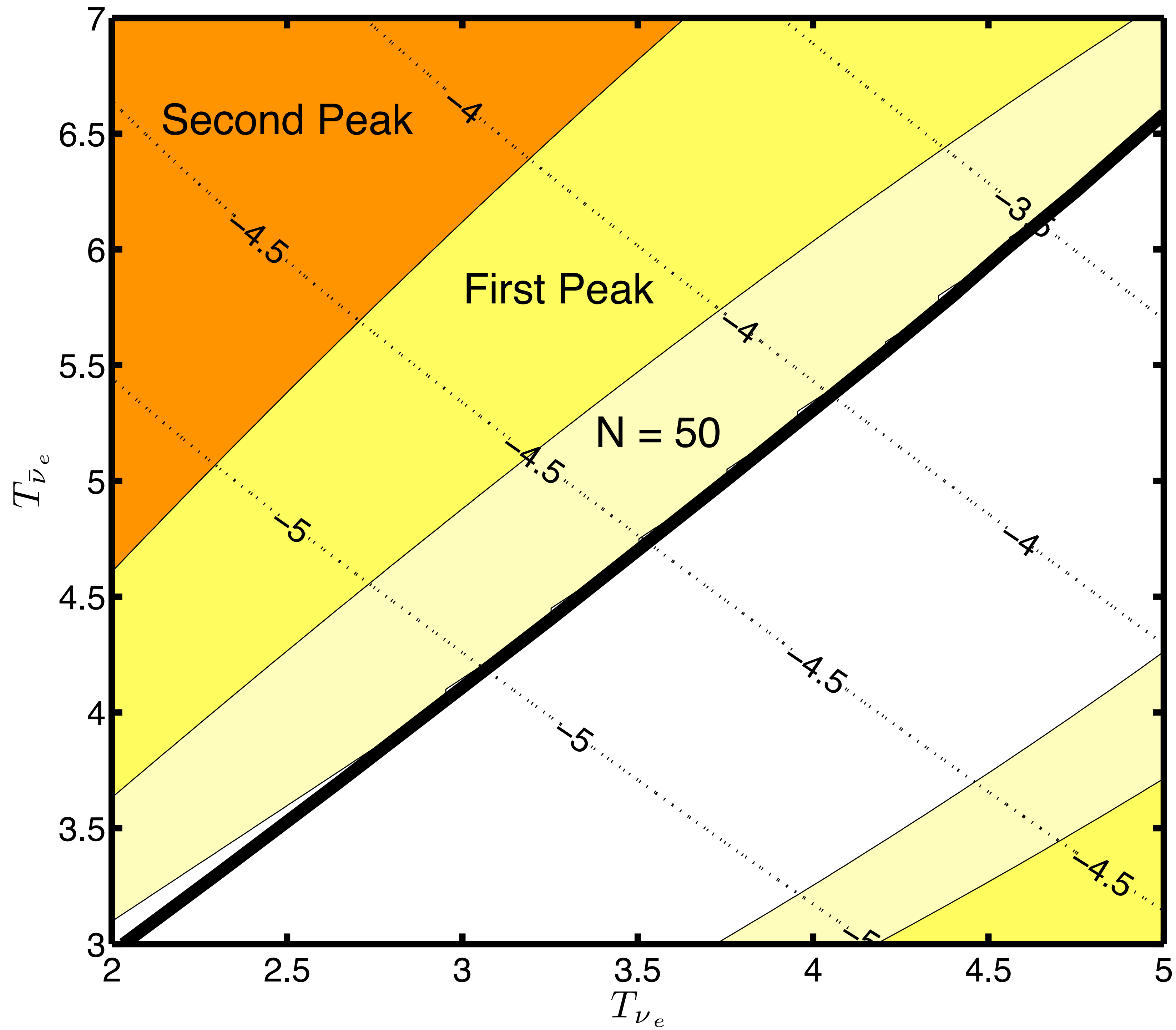
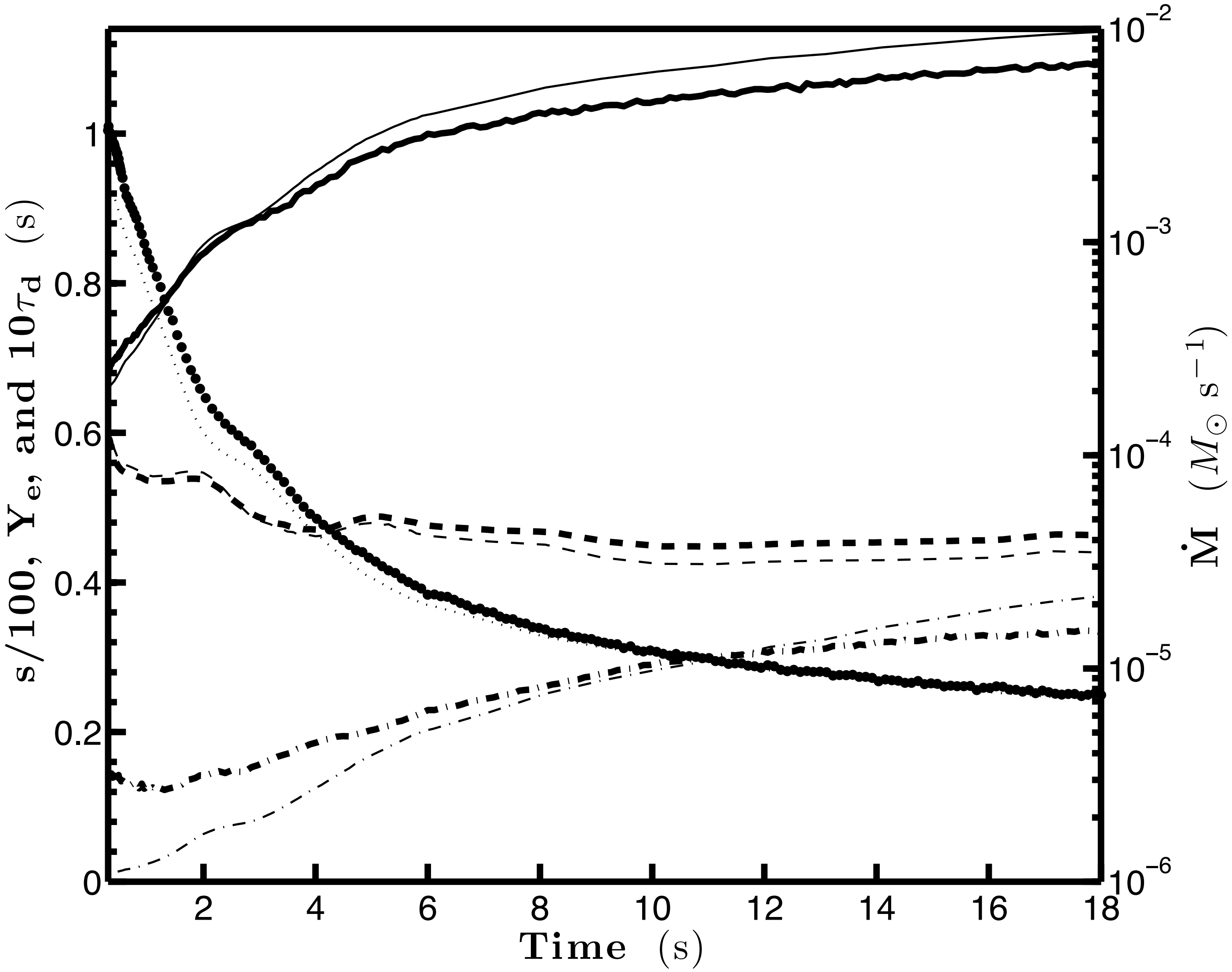
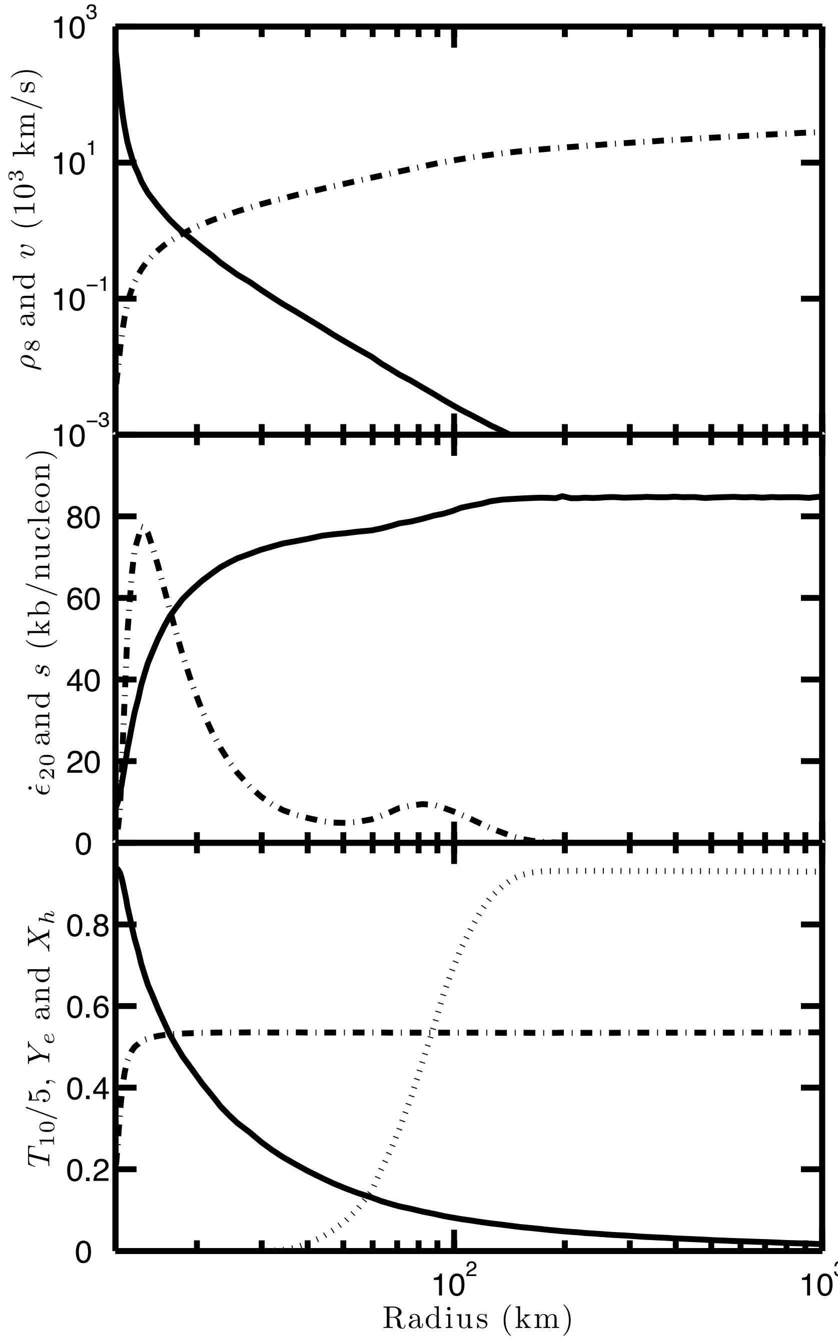
- Neutrino driven winds have been considered a potential site for both r-process and p-process nucleosynthesis
- Transonic winds driven by neutrino interactions near the surface of a newly born neutron star
- We model the winds dynamics and nucleosynthesis using the 1-D implicit hydrodynamics code Kepler

Analytic NDW Nucleosynthesis Predictions

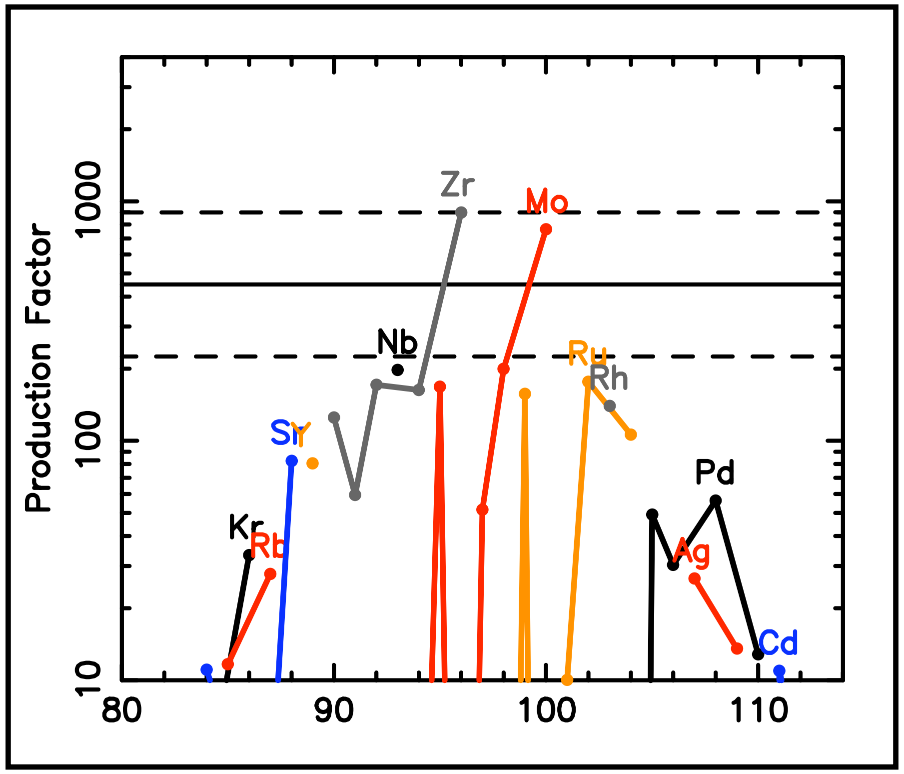


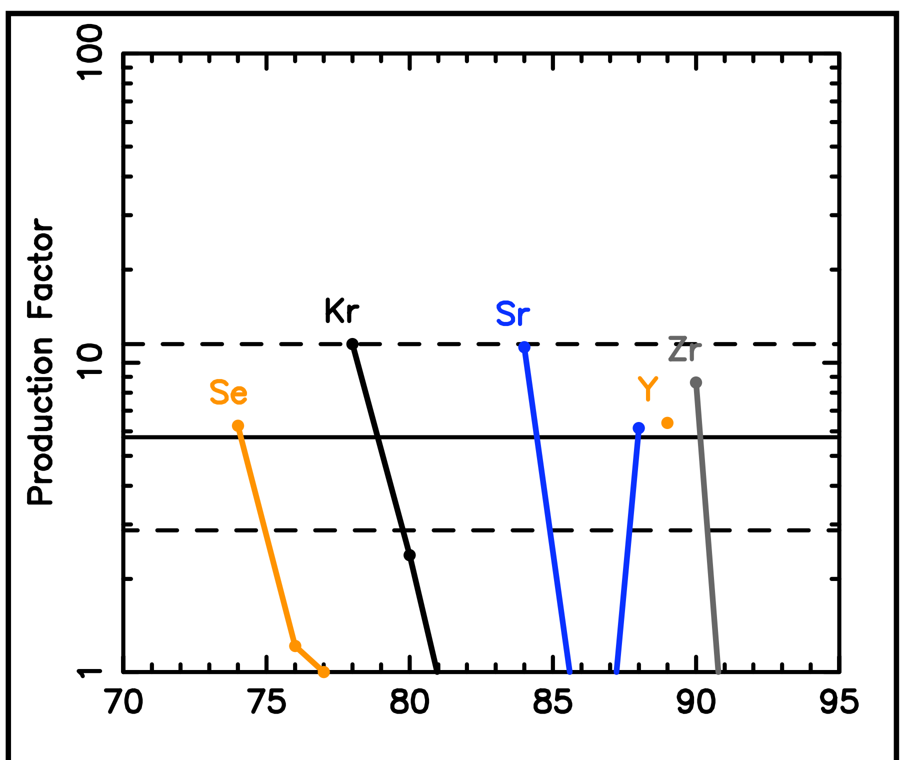
Numerical Wind Properties: 20 Msun

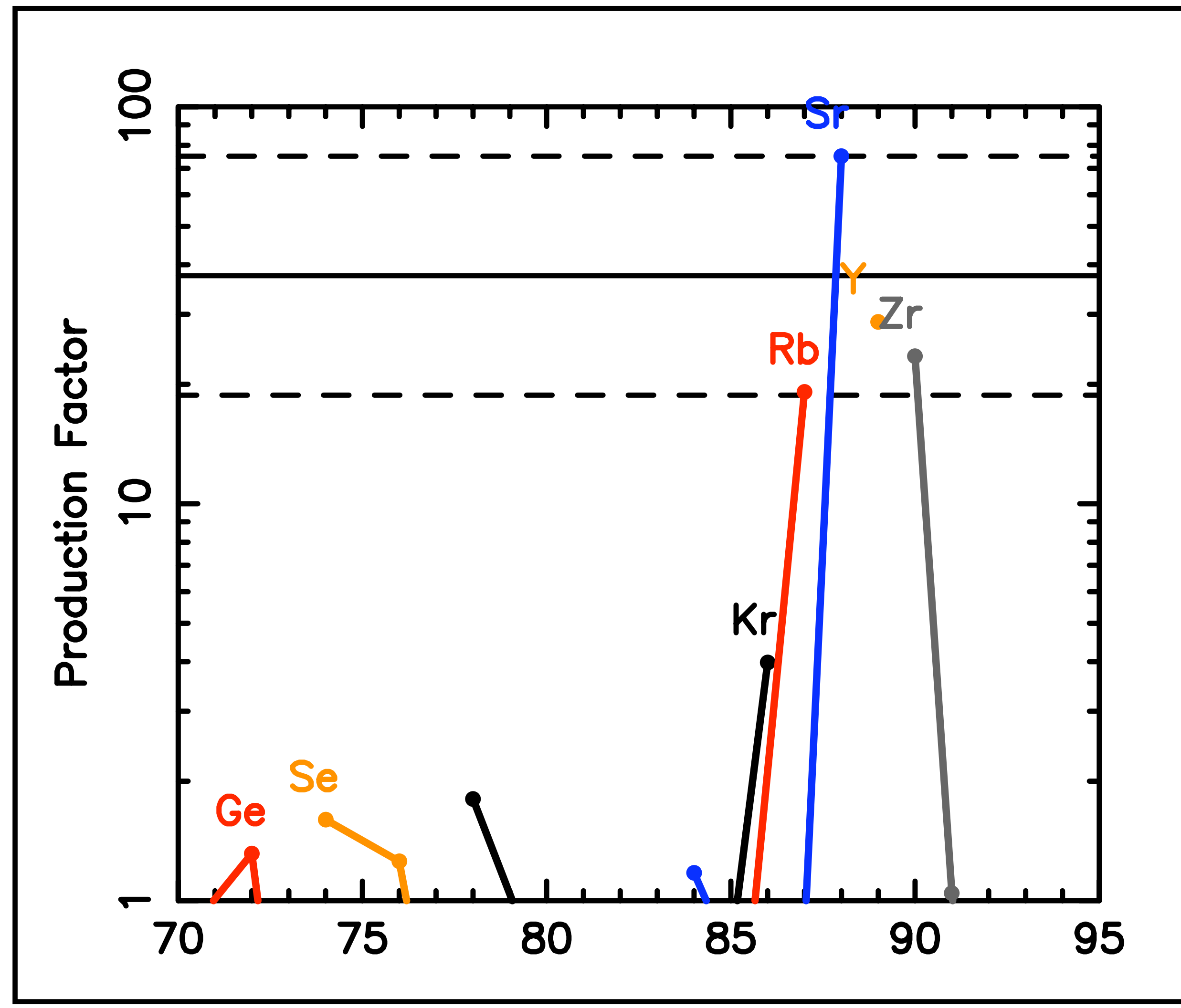




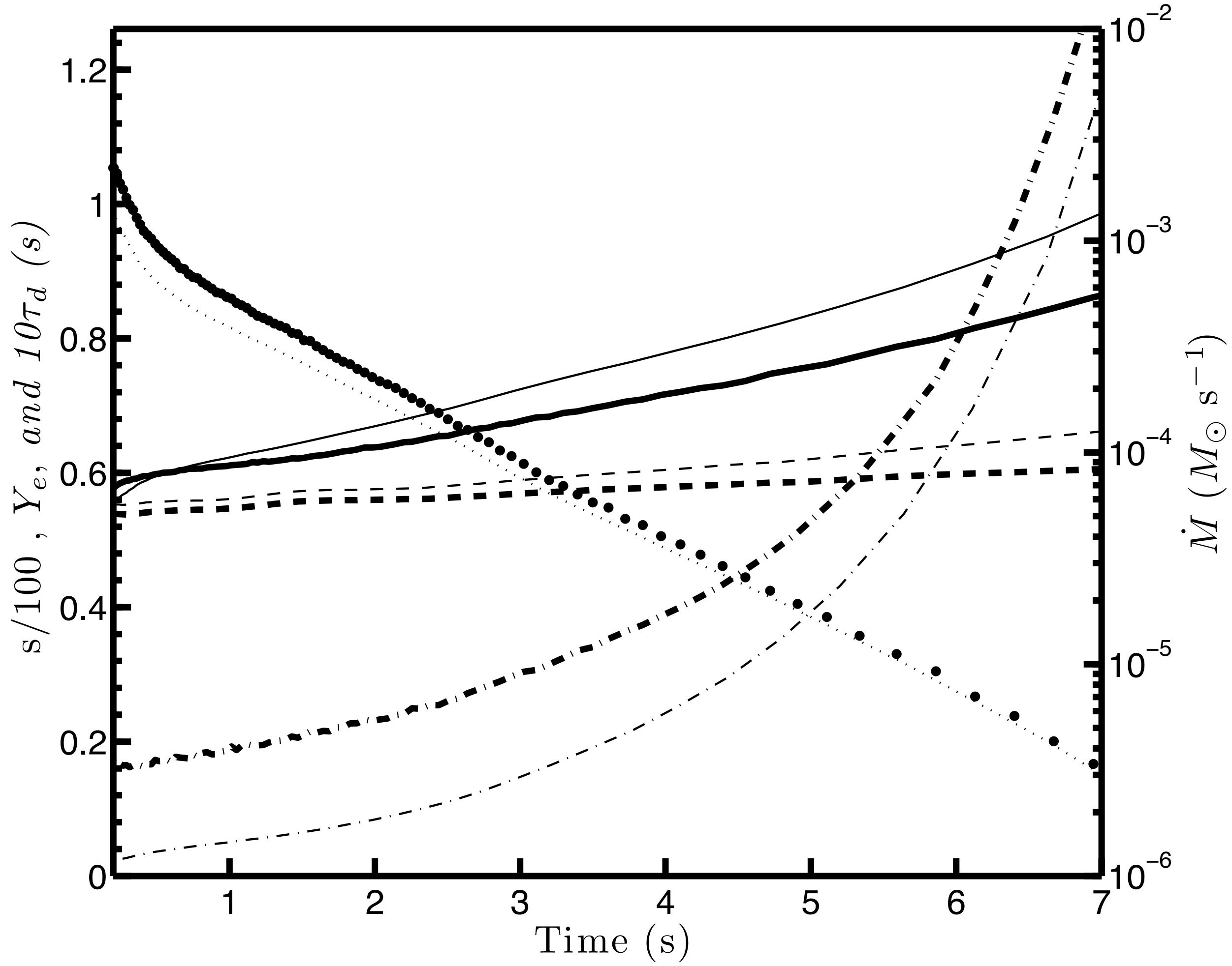
Integrated Wind Nucleosynthesis: 20 Msun

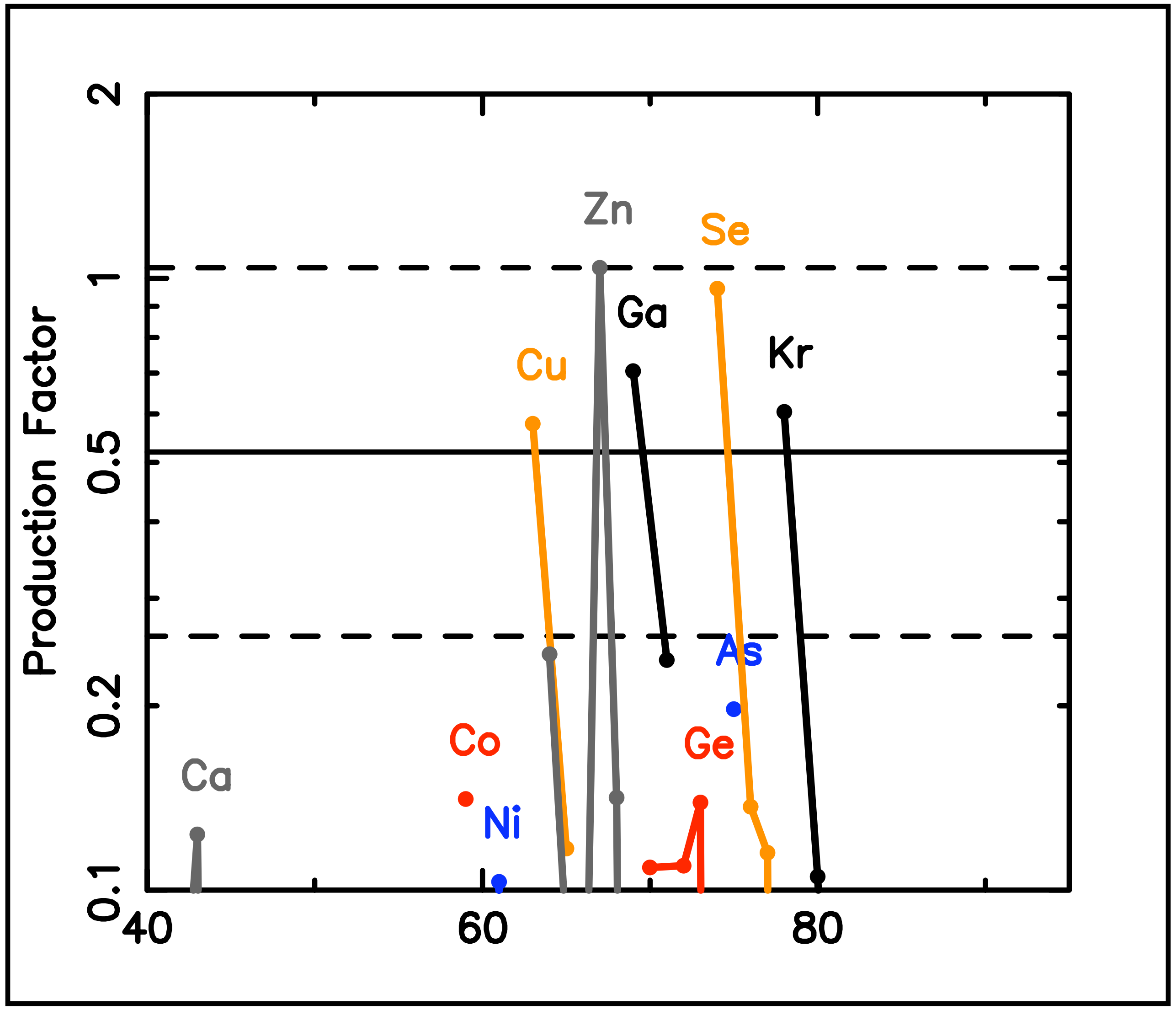






8.8 Msun Model





- For more details see arXiv:1004.4916
- Future work:
  - Different neutrino histories
  - Effect of PNS oscillations
  - Effect of more detailed transport

Proto Neutron Star Cooling

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Protoneutron Star KH Cooling Code:

TOV Equations:

$$\frac{dr}{da} = \frac{\Gamma}{4\pi r^2 n_B}$$

$$\frac{dm}{da} = \Gamma \frac{\rho}{n_B}$$

$$\frac{dP}{da} = -(\rho + P)\frac{m + 4\pi r^3 P}{\Gamma 4\pi r^4 n_B}$$

$$\frac{d\phi}{da} = \frac{m + 4\pi r^3 P}{\Gamma 4\pi r^4 n_B}$$

GR FLD Transport Equations:

$$\frac{dY_\nu}{dt} + \frac{\partial\left(4\pi r^2 e^\phi \left[F_\nu + F_{\nu,c}\right]\right)}{\partial a} = e^\phi S_n$$

$$\frac{dY_e}{dt} + \frac{\partial\left(4\pi r^2 e^\phi F_{e,c}\right)}{\partial a} = -e^\phi S_n$$

$$\frac{dE}{dt} - \frac{p}{n_b^2}\frac{dn_b}{dt} + e^{-\phi}\frac{\partial\left(4\pi r^2 e^{2\phi}\left[H_\nu + H_c\right]\right)}{\partial a} = 0$$

$$F_\nu = -\frac{\Gamma e^{-\phi} T^2}{6\pi^2}\left[D_3 \frac{\partial T e^\phi}{\partial r} + D_3 T e^\phi \frac{\partial \eta}{\partial r}\right]$$

Fully Implicit Transport, Predictor-Corrector between transport and structure modules

Convection included through MLT prescription

Relativistic Mean Field Equation of State from Steiner et al. 2005:

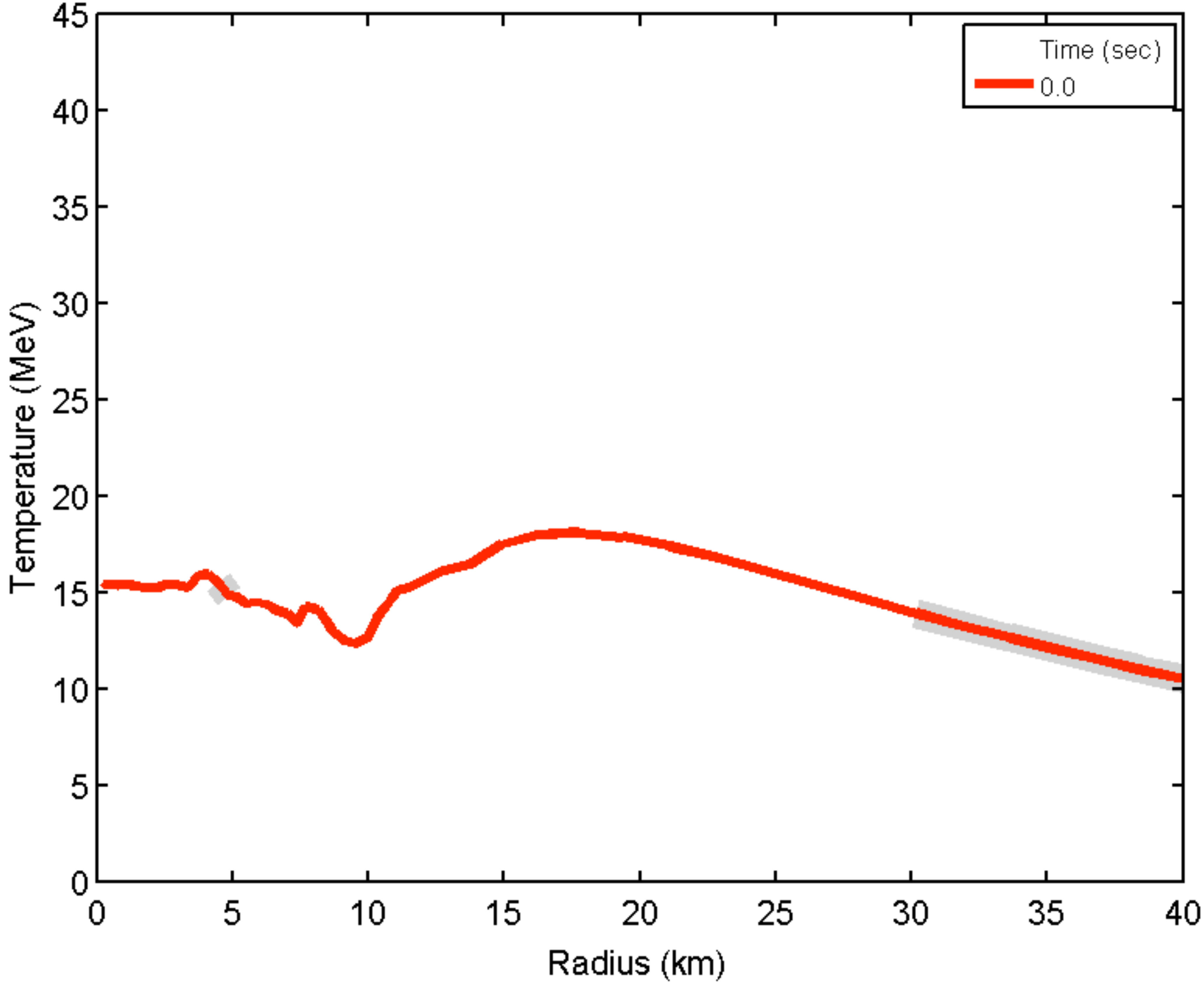
$$
\begin{aligned}
\mathcal{L} \;=\; & \sum_B \bar{\Psi}_B(-i\gamma^\mu\partial_\mu - M_B + g_\sigma\sigma - g_\omega\gamma^\mu\omega_\mu - g_\rho\gamma^\mu\vec{\rho}_\mu\cdot\vec{\tau})\Psi_B + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu + \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu \\
& -\frac{1}{4}W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}R_{\mu\nu}R^{\mu\nu} + \frac{\zeta}{24}g_\omega^4\omega^4 + \frac{\xi}{24}g_\rho^4\rho^4 + g_\rho^2 f(\sigma,\omega^2)\rho^2 \\
& -\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - U(\sigma)
\end{aligned}
$$

Potential terms fitted to the microscopic APR equation of state

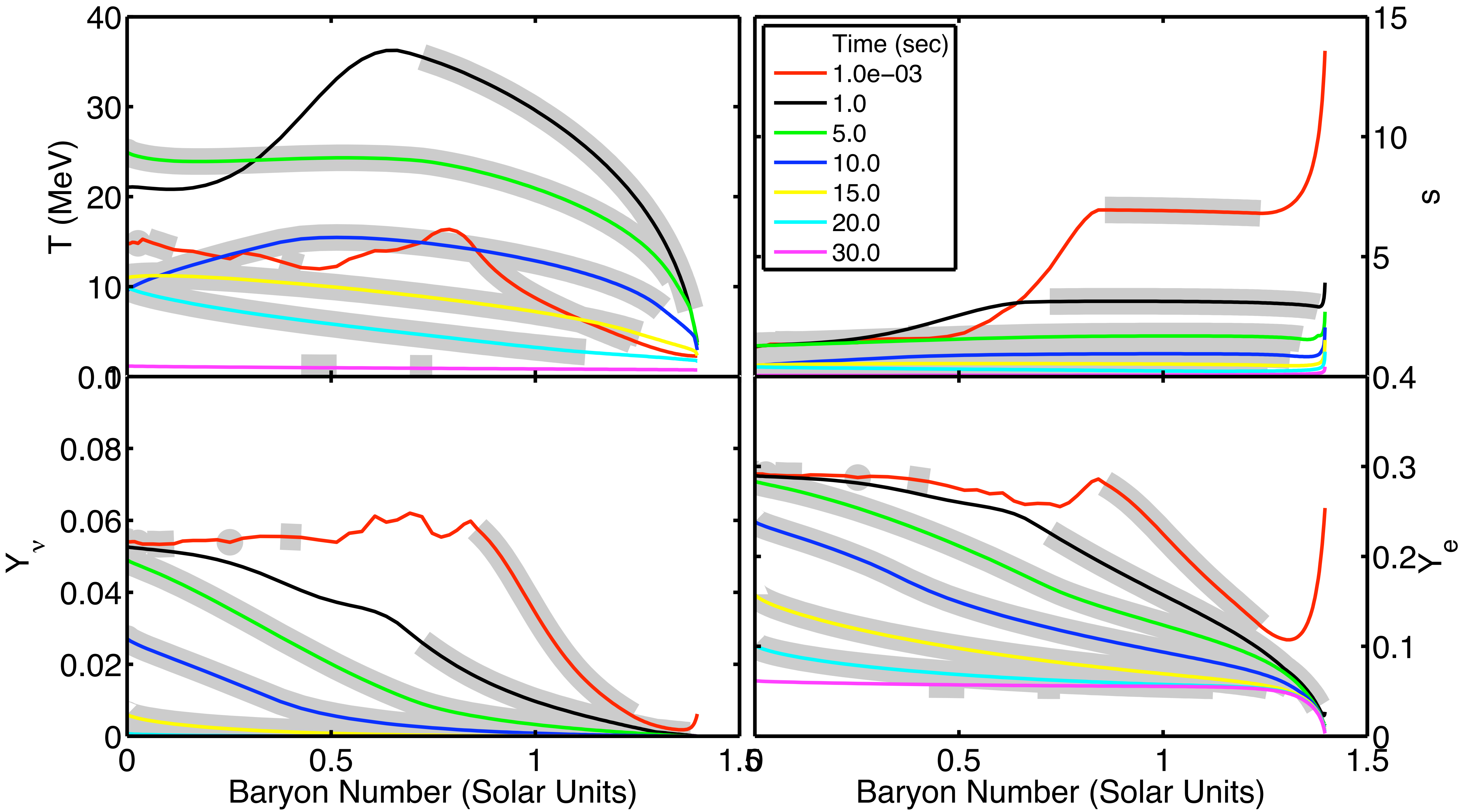
Neutrino Opacities:

- Nucleon and electron interactions
- In-medium effects at mean field level
- Approximately account for effect of correlations using

$$\kappa = \frac{\kappa_0}{1 + 1.3\,(n/n_0)^{1/3}}$$

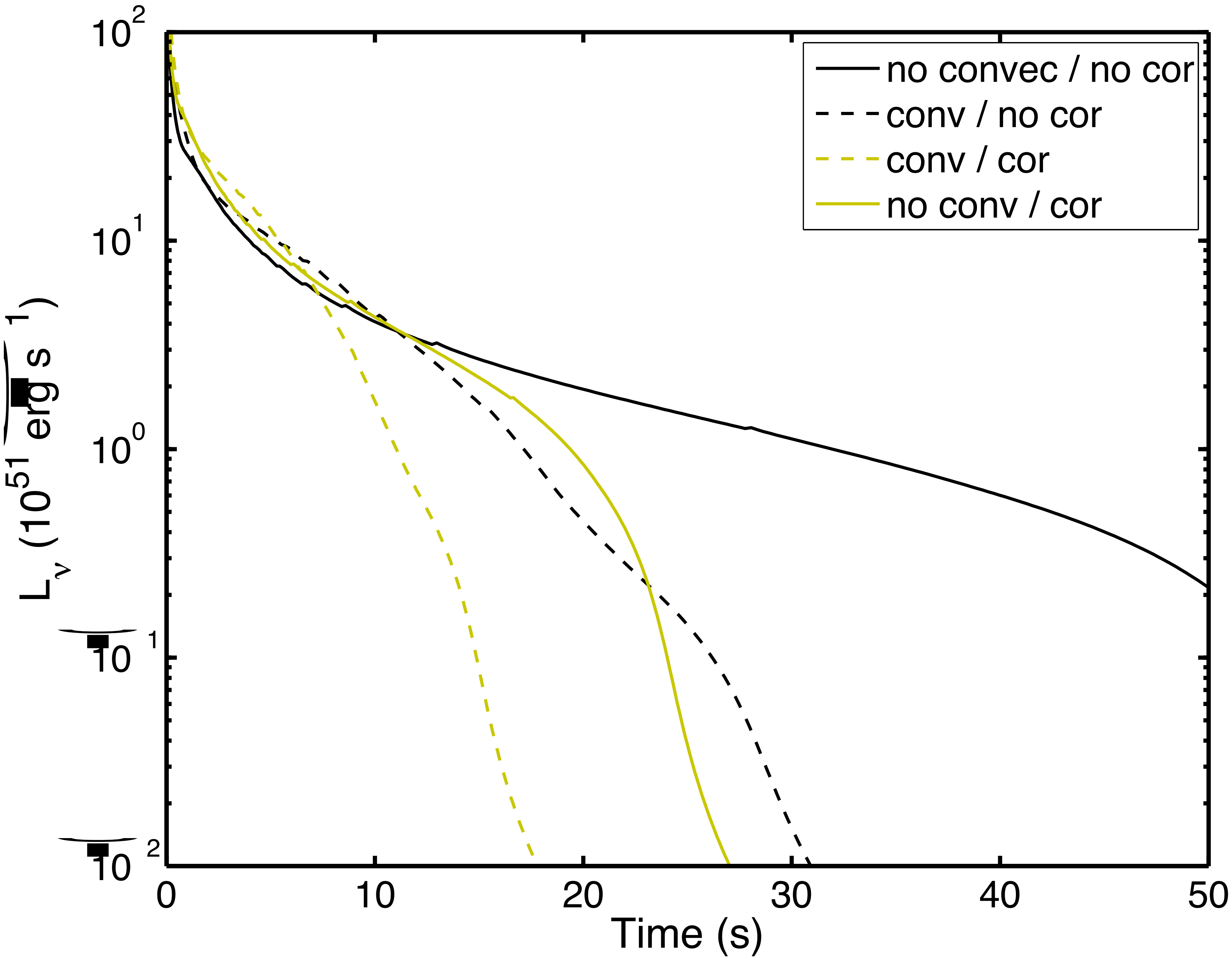

Time (sec)
0.0
Temperature (MeV)
Radius (km)
0
5
10
15
20
25
30
35
40
45

Evolution with Convection



Steiner et al. RMF EOS, 1.4 Msun PNS

Total Neutrino Luminosity



- Future work:
  - Test validity of convection implementation
  - Compare RMF EoS to tabular EoSs
  - Full transport in atmosphere to obtain spectra (for NDW models)
  - Determine late time neutrino observables that are sensitive to employed microphysics
  - Implement three flavor transport to study the effect of possible FCNCs
- Needs:
  - Post bounce initial conditions
  - New equations of state

Total Neutrino Luminosity