Charged-current interactions for muon neutrinos in supernova*

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A core collapse supernova is emitting most of it's energy, up to 10^{53} erg in form of neutrinos of all flavours. The microphysics of neutrino transport is therefore an important ingredient to understand this astrophysical scenario. Present supernova simulations do not include charged current weak interaction for muon type neutrinos. These reactions are considered to be suppressed due to the large Q-value of the muon mass. As a consequence the spectra of muon and tau-type neutrinos is the same. Also the difference between ν_μ and $\bar{\nu}_\mu$ is minor. However, in the interior of a proto-neutron star chemical potentials and temperatures are large enough in the first seconds to allow for production of muons. Using conditions that were taken from 1D hydrodamical supernova simulations with full Boltzmann neutrino transport [1], we have derived and calculated the following reactions:

$$\nu_\mu + n \to p + \mu^- \qquad \nu_\mu + e^- \to \nu_e + \mu^-$$
$$\nu_\mu + \bar{\nu}_e + e^- \to \mu^- \qquad \bar{\nu}_e + e^- \to \bar{\nu}_\mu + \mu^-$$

The ν_μ-absorption on neutrons is calculated in analogy to absorption of electron-neutrinos [2, 3]. The three leptonic processes are derived similar to neutrino scattering on electrons [4, 5, 6]. We find that especially the absorption of ν_μ on neutrons and on electrons is a significant opacity source in the region where the neutrinos decouple energetically from the matter, at densities above 10^{13} g/cm^3.

We argue that charged current opacities for ν_μ will probably change the respective neutrino spectrum so it might differ significantly from the other heavy-neutrino flavours.

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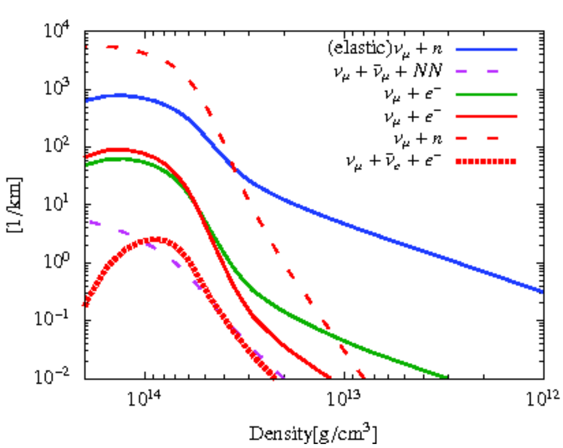

Figure 1: Spectraly averaged inverse mean free path of ν_μ

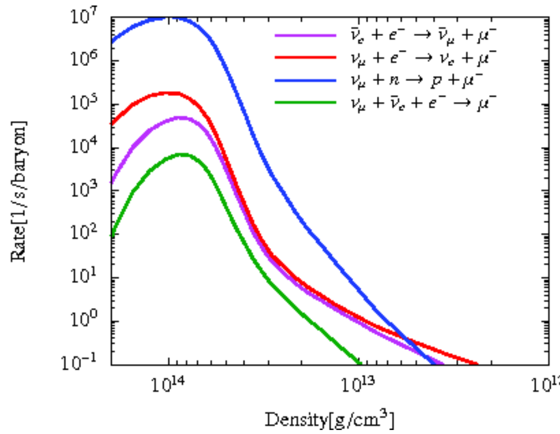

Figure 2: Rate of μ^--production per baryon per second

We also find that the production timescale of muons is comparably fast to the dynamical timescale. Muons will be in chemical equilibrium already at bounce. This should lead to the production of a positive net muon number in the core of the PNS. Also, once muons are present the charged current reactions contribute significantly to the equilibration of ν_μ of all energies. Eventually this might affect the deleptonization timescale of the PNS. The changes in the spectra could further be important for neutrino oscillations especially since the oscillations are sensitive to spectral differences. Finally we suggest that muonic charged current reactions should be implemented in future dynamical simulations of core collapse supernova to study their effects and to achieve an improved understanding of ν_μ spectra formation.

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