Neutrino properties in the light of Supernovae Typ II

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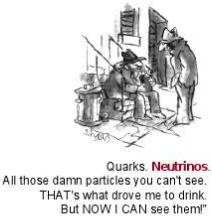
July 24, 2008

Particle Physics



outline

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- introduction supernova process
- neutrino oscillation in matter
- constrains on neutrino propagation in matter
- resonance behavior on supernova dynamics
- conclusion

The neutrino transport model for supernova blow-off from collapsing stars has enjoyed mixed fortune in recent years. Although, at present, core dynamics appears to be dominated by essentially hydrodynamic processes, neutrinos still play important roles in fixing the kinetics and equation of state of the collapsing matter and in the shock wave structure. Difficult problems coupling neutrino transport and hydrodynamics remain to be addressed before the supernova mechanism can be completely understood and the emergent neutrino pulse can be predicted.

Lichtenstadt et. al. 1979

Supernova Dimensions

energy released: 10^{53} erg $\approx 10^{61}\, eV$

energy released by neutrinos: $\geq$ 90%

explosion time: 1s ($t_{sb} = 50ms$)

initial size of core: $R = 300km$ (Fe-core)

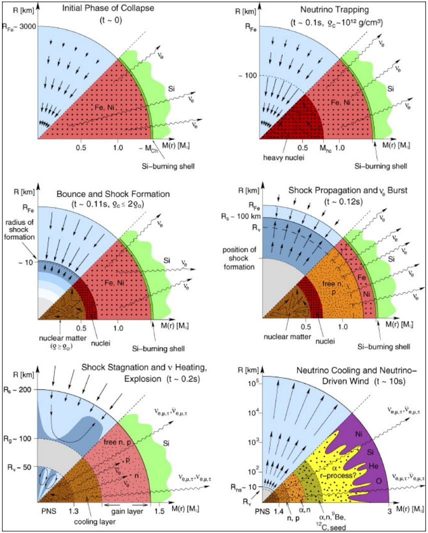
initial central density:

size of PNS: $R_{PNS} = 100km$

central temperature $\lesssim$ 100 MeV

comparism: solar radius $R_{\odot} \sim 7 \cdot 10^5$ km

(figure taken from [2])



vacuum oscillation

- propability of transistion: $P(\nu_l \to \nu_{l'}) = | \ \langle \nu_{l'}(t) | \nu_l \rangle \ |^2$
- calculating $|\nu_{l'}(t)\rangle = U_{\text{lept}} \, |\nu_i(t)\rangle$:

$$
\begin{aligned}
i\partial_t \, |\nu_{l'}(t)\rangle &= H^\alpha \, |\nu_{l'}(t)\rangle \\
H^\alpha &= U_{\text{lept}} H^i U^+_{\text{lept}} = \frac{1}{2p} \begin{pmatrix} m^2_{ee} & m^2_{e\mu} \\ m^2_{e\mu} & m^2_{\mu\mu} \end{pmatrix} \\
H^i_{ij} &= \frac{m_i^2}{2p} \delta_{ij}
\end{aligned}
$$

restricting to the two flavor case (e and μ), therefore no CP-violating phase δ

$$
H^\alpha = \frac{1}{4p} \left[(m_1^2 + m_2^2) \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \delta m^2 \begin{pmatrix} \cos 2\theta & \sin 2\theta \\ -\sin 2\theta & \cos 2\theta \end{pmatrix} \right]
$$

Note that every term cancels exept the mixing matrix while shifting into a constant phase!

$$
\begin{aligned}
P(\nu_e \to \nu_\mu; t) &= \sin^2(2\theta) \sin^2 \frac{\delta m^2 t}{4E} \\
P(\nu_e \to \nu_\mu; L) &= \sin^2(2\theta) \sin^2 \frac{\pi L}{L_{\text{osz}}} \\
P(\nu_e \to \nu_e; L) &= 1 - P(\nu_e \to \nu_\nu)
\end{aligned}
$$

Estimation: $L_{\text{osz}}(E_\nu = 20 MeV, \delta m^2 \approx 2.3 \cdot 10^{-3} eV^2) \approx 10^4 km$

matter effects

- ansatz: adding a matter contibution into the hamiltonian

$$
\begin{aligned}
H^{\alpha} &= H^{\alpha}_{\text{vac}} + H^{\alpha}_{\text{matter}} \\
H^{\alpha}_{\text{matter}} &= \begin{pmatrix} V_{\text{CC}}(n_e) & 0 \\ 0 & 0 \end{pmatrix} \\
A_{\text{CC}}(n_e) &= 2E \cdot V_{\text{CC}} = 2E\sqrt{2}G_F n_e \\
P(\nu_e \rightarrow \nu_\mu; t) &= \sin^2 \theta^m \sin^2 \left(\sqrt{\left[\left(\frac{\delta m^2}{4E} \cos 2\theta_0 - \sqrt{2}2G_F n_e \right)^2 + \left(\frac{\delta m^2}{4E} \right)^2 \sin^2 2\theta_0 \right]} t \right) \\
P(\nu_e \rightarrow \nu_\mu; L) &= \sin^2 2\theta^m \sin^2 (\pi \frac{L}{L^m_{\text{osc}}}) \\
L^m_{\text{osc}} &= \frac{4\pi E}{\delta m^2} = \frac{L_{\text{osc}}}{\sqrt{(\cos 2\theta_0 - \frac{A_{\text{CC}}}{\delta m^2})^2}} \\
\sin^2(2\theta^m) &= \frac{(\delta m^2 \sin(2\theta_0))^2}{(A_{\text{CC}} - \delta m^2 \cos(2\theta_0))^2 + (\delta m^2 \sin(2\theta_0))^2}
\end{aligned}
$$

- ***M**ikheyev-**S**mirnov-**W**olfenstein* effect, Neutral Current does not contribute to the mixing but CCs
- in case of a non-zero electron density this leads to a non-zero forward scattering amplitude
- by optical theorem this results in an effectiv electron-neutrino mass: increase of $\delta m_{\text{effectiv}}$
- but the effectiv electron density is relevant $N^*_e = N_e - \sum_{f \neq e} N_f$

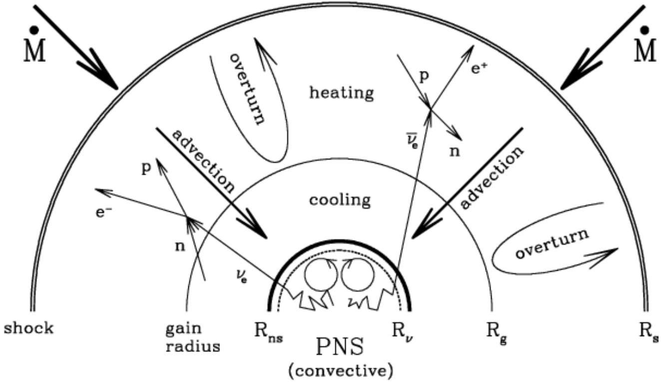
MSW resonance

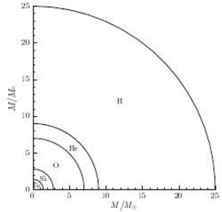
Parameter	Best fit	2σ	3σ
δm^2_{21} $[10^{-5} eV^2]$	7.6	$7.3 - 8.1$	$7.1 - 8 - 3$
$\left\| \delta m^2_{31} \right\| [10^{-3} eV^2]$	2.4	$2.1 - 2.7$	$2.0 - 2.8$
$sin^2\theta_{12}$	0.32	$0.28 - 0.37$	$0.26 - 0.40$
$sin^2\theta_{23}$	0.50	$0.38 - 0.63$	$0.34 - 0.67$
$sin^2\theta_{13}$	0.007	≤ 0.033	≤ 0.050

Table: Best-fit values for 3-flavor neutrinooscillation in a 2σ and 3σ intervall from different experiments (KamLAND, CHOOZ, K2K and MINOS) taken from [3]

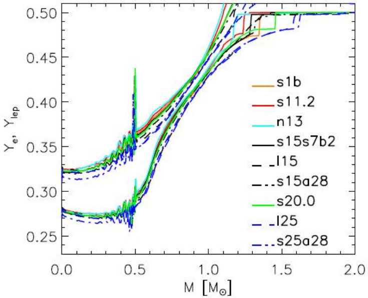
- Calculating the resonance densities: $A = \delta m^2 \cos(2\theta_0) \rightarrow \sin^2(2\theta_m) = 1.$
- assuming $Y_e = 0.5$ at neutrino energy $E_\nu = 20 MeV$
- case $1 \rightarrow 2$: $n_m \approx 2.5 \cdot 10^{-14} \text{fm}^{-3} \sim 1.5 \cdot 10^{-13} n_0$
- case $1 \rightarrow 3$: $n_m \approx 9.5 \cdot 10^{-13} \text{fm}^{-3}$
- note: $n_m \sim \frac{1}{E_\nu}$
- core collapse supernova central densities: $\sim 0.01 \ldots 0.1 n_0$ (simulation result)

- the neutrinosphere is given by the mean free path (MFP)
- MFP (neutral particals): $\lambda_{\text{MFP}} = \frac{1}{n\sigma}$
- $\sigma(\nu_e e)\ 10^{-44} \cdot E_{\text{MeV}} cm^2$

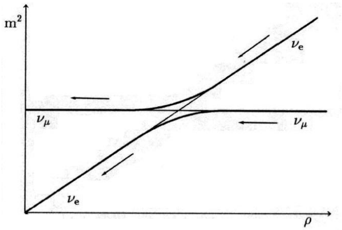




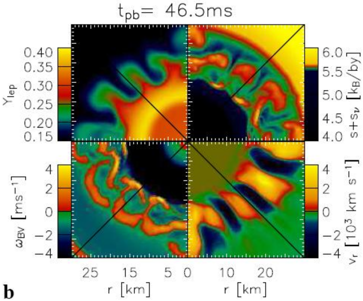
H
He
O
Si
Fe
$M/M_\odot$
$M/M_\odot$



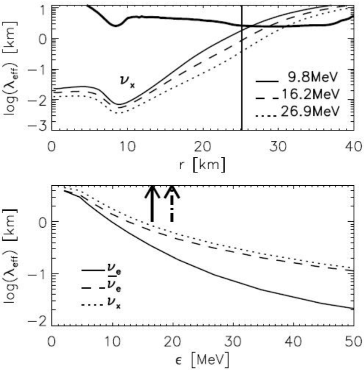
Y_e, Y_{lep}
M [$M_\odot$]
s1b
s11.2
n13
s15s7b2
l15
s15a28
s20.0
l25
s25a28



m^2
ν_e
ν_μ
ν_μ
ν_e
ρ



t_{pb}= 46.5ms
Y_{lep}
$s+s_\nu$ [k_B/by]
ω_{BV} [ms^{-1}]
v_r [10^3 km s^{-1}]
r [km]
r [km]
b



- mean free path as function of radii and influence of convective layers
- at a fixed position for different energies

central density after bounce

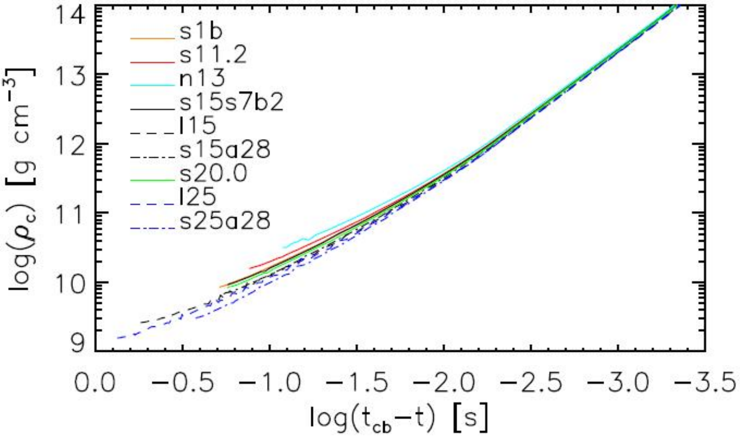


Figure: density change during collapse in the center taken from [1]

lepton fraction during shock and temperature

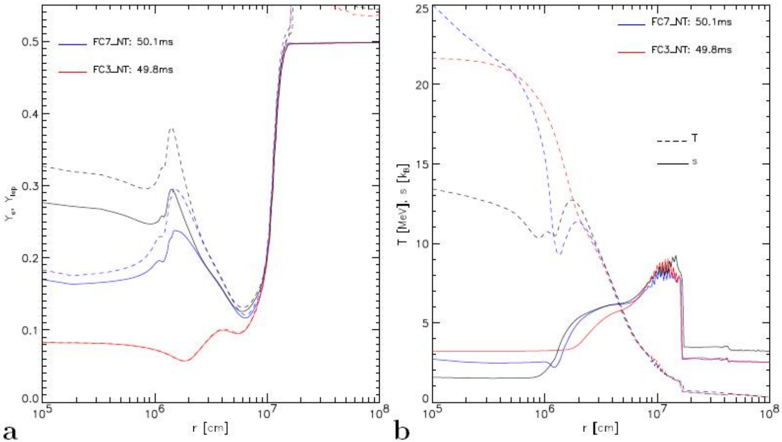


Figure: lepton fraction and temperature during collapse taken from [1]

resonance behavior during collapse

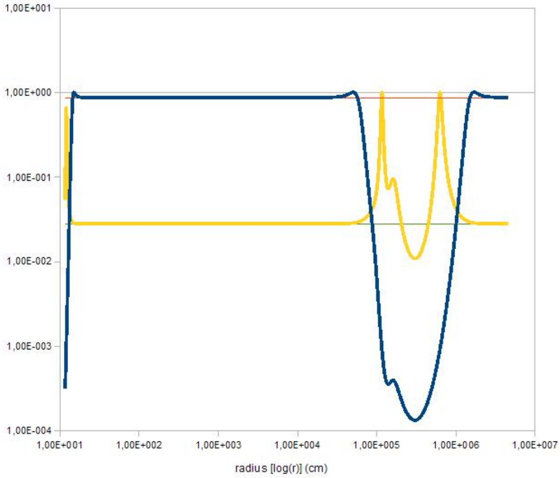


Figure: resonance occure only during shock wave (preliminary result)

mfp during collapse

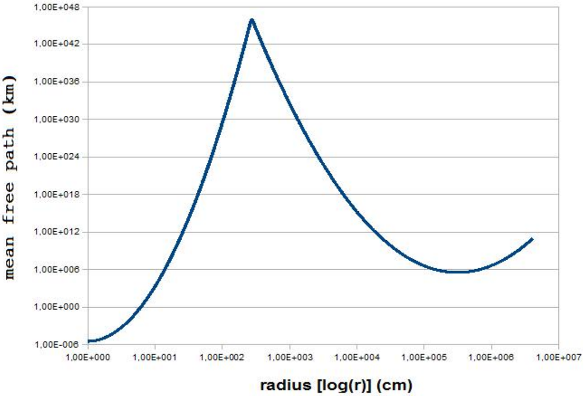
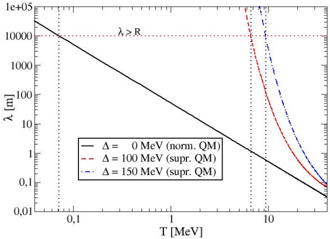


Figure: the mfp is only weakly changed in shock wave region. (preliminary result)

matter interaction in quark phase

- constraints to neutrinossphere depends on matter - EoS
- as an example the mean free path in quark matter



[1]

[1] J. Berdermann, diploma thesis (2004)

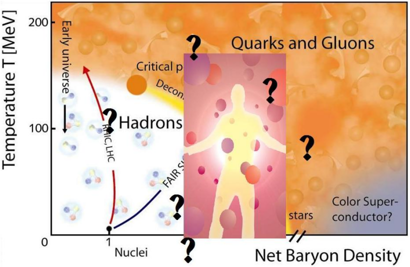
Conclusion - Problems

Conclusion:

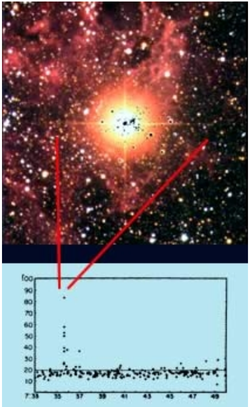
- the complex dynamics of the collapse can influence the oscillation behavior
- heating mechanism due to neutrinos can be enhanced

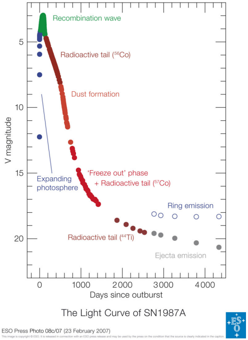
Problems:

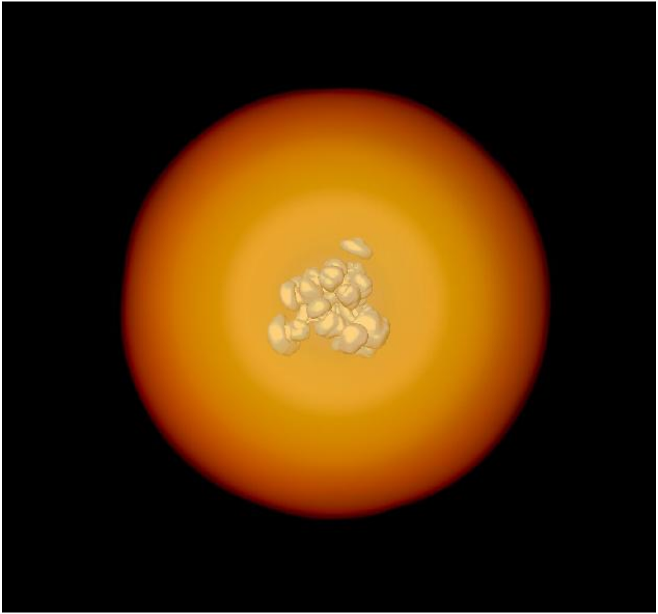
- equation of state including phase transistions
- density - pressure relation for hydrodynamical simulations
- how does density, pressure and temprature influence the lepton fraction

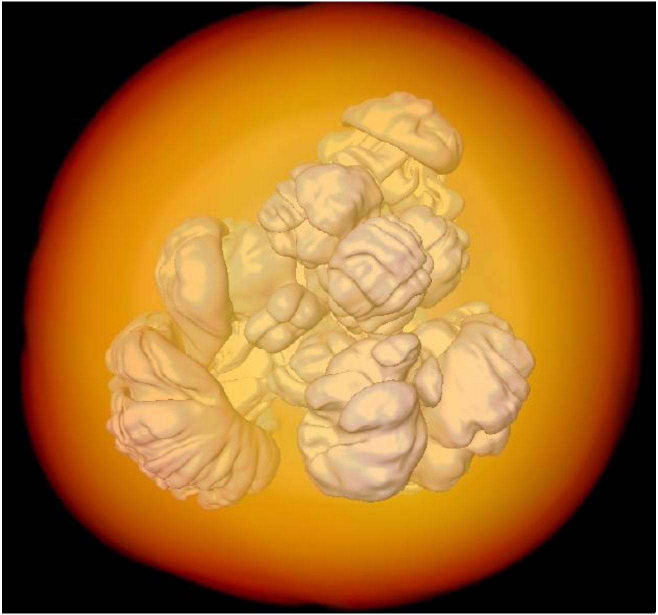


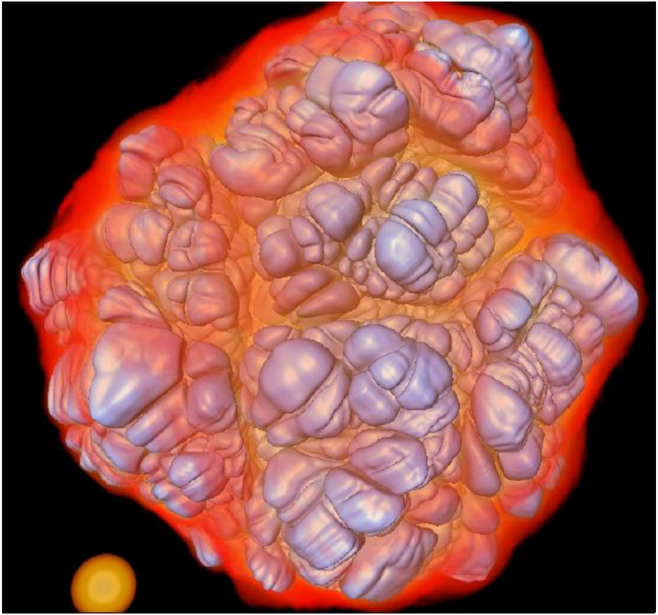
the only Signal ..... up to now!











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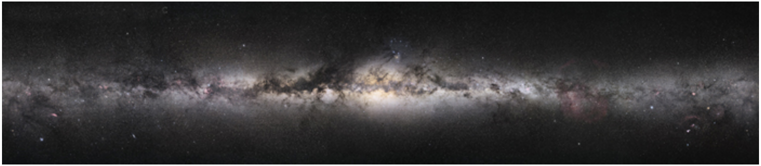

Figure: Milkyway panorama view

References:

[1] R. Buras et al. arxiv.org/astro-ph/0512189v2, Two dimensional hydrodynamic core-collapse supernovae

[2] Th. Janka et al. arxiv.org/astro-ph/0612072v1, Theory of core-collapse supernovae

[3] T. Schwetz arxiv.org/hep-ph/071027, Neutrino Oscillation: present status and outlook