Effects of random density fluctuations on Supernovae and solar neutrinos

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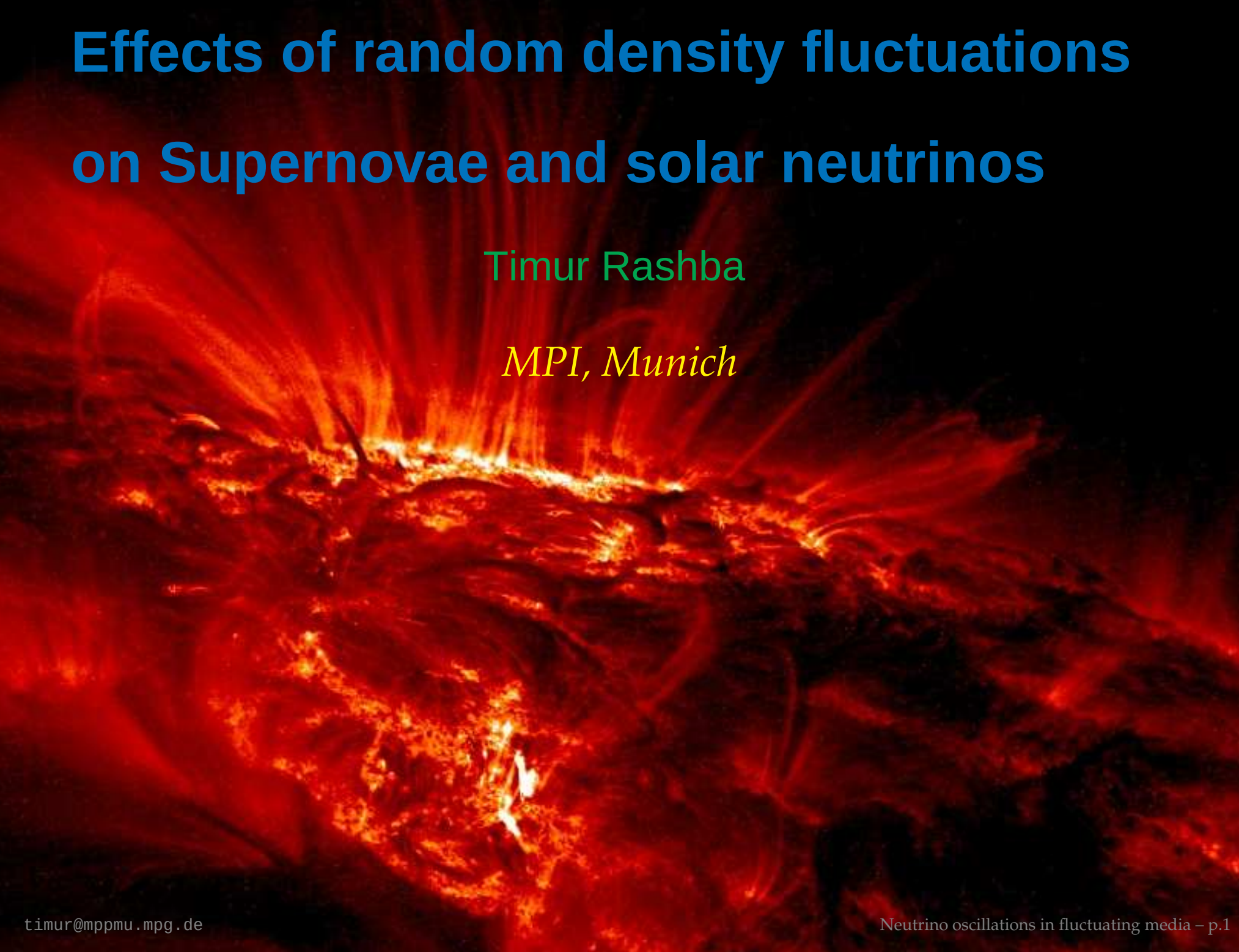

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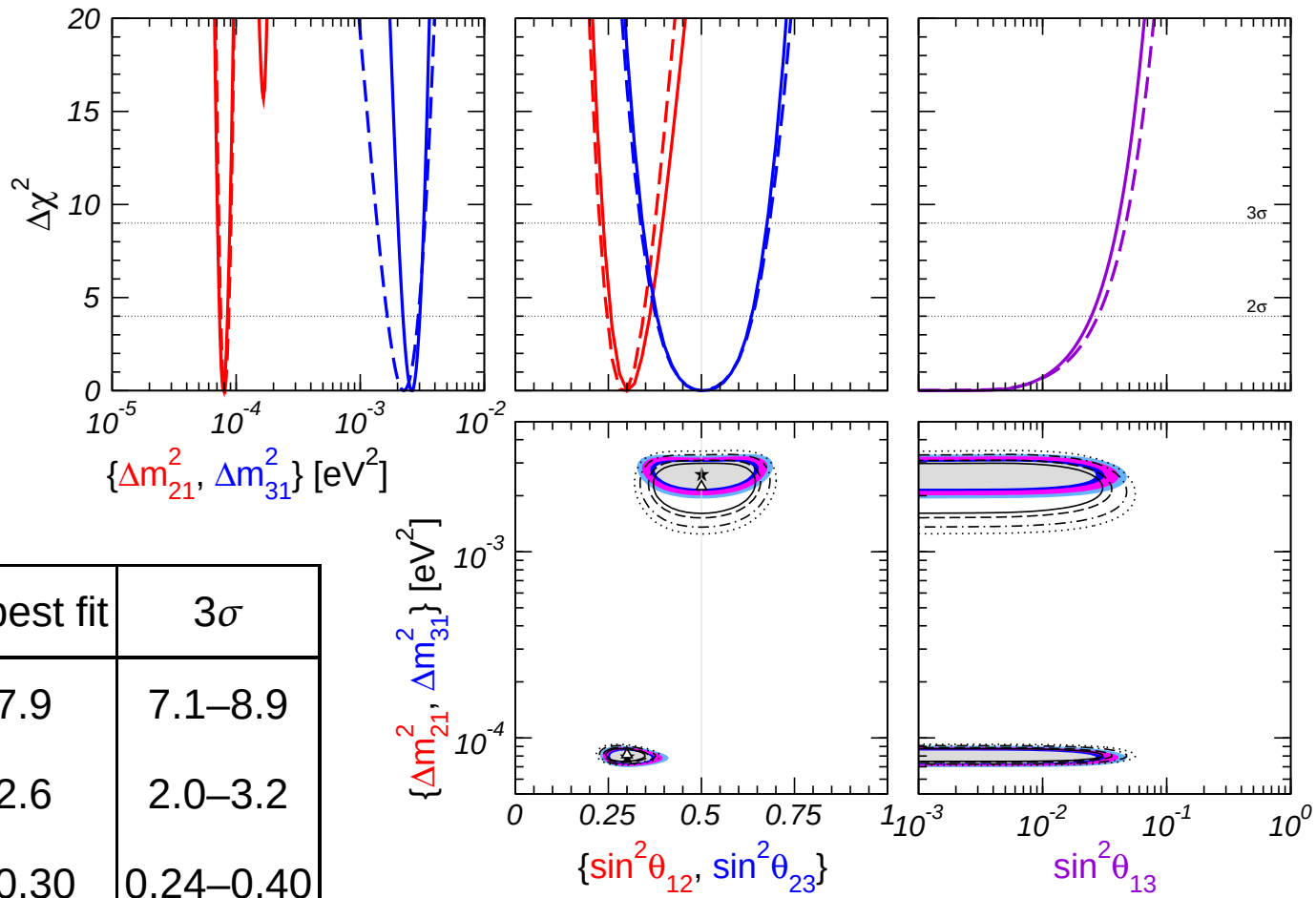
Outline

- Solar neutrinos and matter density noise
- Different models of fluctuating media
- Supernovae shock-waves
- Supernovae turbulence
- Summary

Neutrino oscillations



parameter	best fit	3σ
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.9	7.1–8.9
Δm^2_{31} $[10^{-3}\text{eV}^2]$	2.6	2.0–3.2
$\sin^2\theta_{12}$	0.30	0.24–0.40
$\sin^2\theta_{23}$	0.50	0.34–0.68
$\sin^2\theta_{13}$	0.000	$\leq$ 0.040

Maltoni et al., hep-ph/0405172v5 (2006)

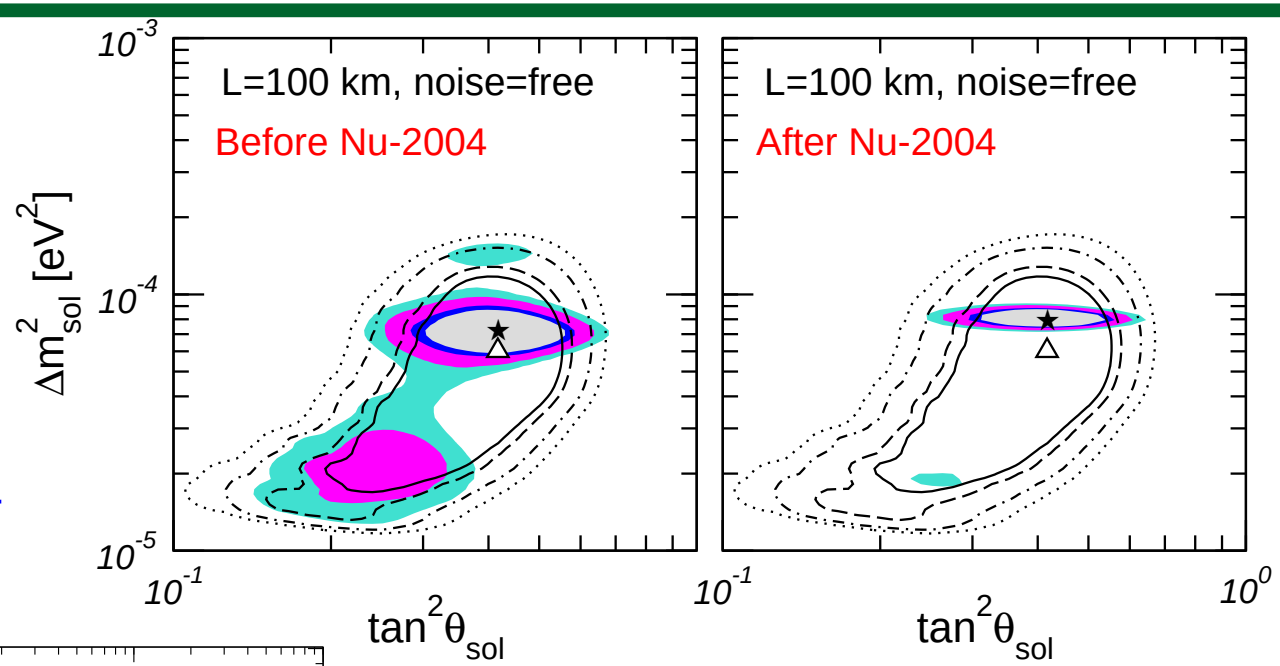
Importance of density fluctuations

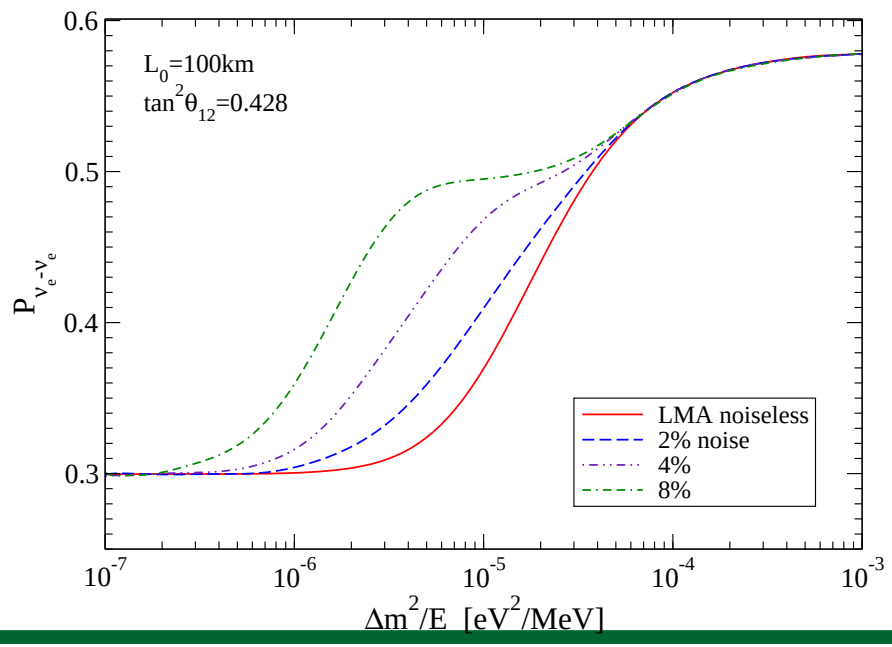
Burgess et al.,04

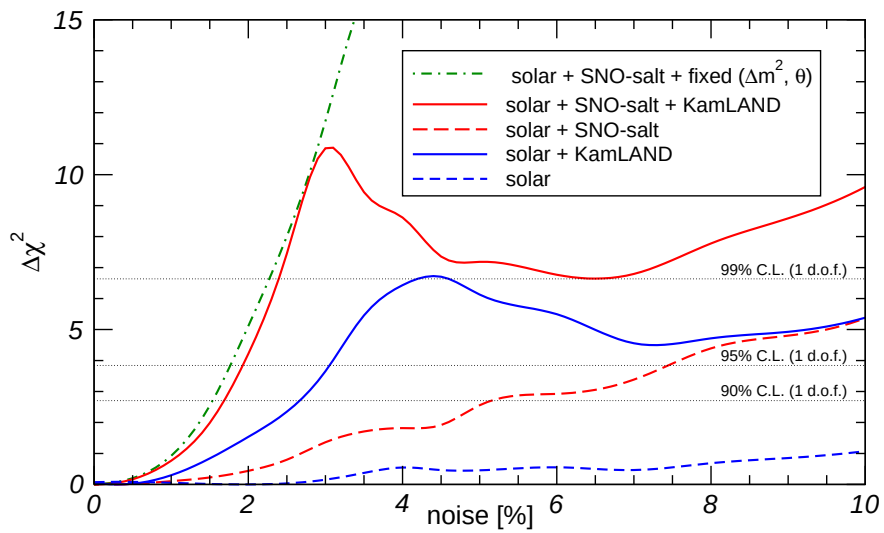
see also

Guzzo et al.,03

Balantekin&Yuksel,04







Fluctuating matter models

- Delta-correlated noise, valid if $L_0 \ll L_{osc}$

$$\langle \delta\rho(x_1)\delta\rho(x_2)\rangle = \xi^2\,\rho(x_1)^2\,L_0\,\delta(x_1 - x_2)$$

Nicolaidis (1991) (magnetic), Balantekin and Loreti (1994), and others

- Cell model

$$\langle \delta\rho(x_1)\delta\rho(x_2)\rangle = \xi^2\rho(x_1)\rho(x_2) \qquad \text{if } |x_1 - x_2| \leq L_0$$
$$\langle \delta\rho(x_1)\delta\rho(x_2)\rangle = 0 \qquad \text{if } |x_1 - x_2| > L_0$$

Burgess and Michaud (1997), Burgess et al (2003)

- Turbulent (Kolmogorov) models

$$\int dx_2 \left\langle \delta\rho(x_1)\delta\rho(x_2)e^{-ik(x_1-x_2)}\right\rangle = C\,k^{-5/3}$$

Miranda et al (2004) (magnetic), Friedland and Gruzinov (2006)

Magnetic case as an example

2ν spin-flavor precession in random field,
$\Delta = \Delta m^2/4E = 2\pi L_{osc}$

$$P(\nu_e \to \nu_\mu \to \bar{\nu}_e) \sim \frac{\mu^2}{2} \int_0^L dx_1 \int_0^L dx_2 [b(x_1)b(x_2)] e^{-2i\Delta(x_1 - x_2)}$$

Linear approximation, Small fluctuations

- δ-corr noise: $P_\delta \sim b^2 L L_0, \quad L_0 \ll L_{osc}$
- Cell-model: $P_{cell} \sim b^2 L_{osc}^2 \frac{L}{L_0} \sin^2(\frac{L_0}{L_{osc}}), \quad$ any L_0
- Turbulent model: $P_{turb} \sim b_{turb}^2 L L_{osc}, \quad b_{turb}$ at L_{osc},
  in the inertial scale of turbulence $b_{turb}(l) \sim l^{1/3}$

Two limits: $L_0 \ll L_{osc}$ and $L_0 \approx L_{osc}$

$L_0 \ll L_{osc}$

- δ-corr: $P_\delta \sim b^2 L L_0$
- cell: $P_{cell} \sim b^2 L_{osc}^2 \frac{L}{L_0} \sin^2(\frac{L_0}{L_{osc}}) \rightarrow b^2 L L_0$

$L_0 \approx L_{osc}$

- cell: $P_{cell} \sim b^2 L_{osc}^2 \frac{L}{L_0} \sin^2(\frac{L_0}{L_{osc}}) \rightarrow b^2 L L_{osc}$
- turbulence: $P_{turb} \sim b_{turb}^2 L L_{osc}$

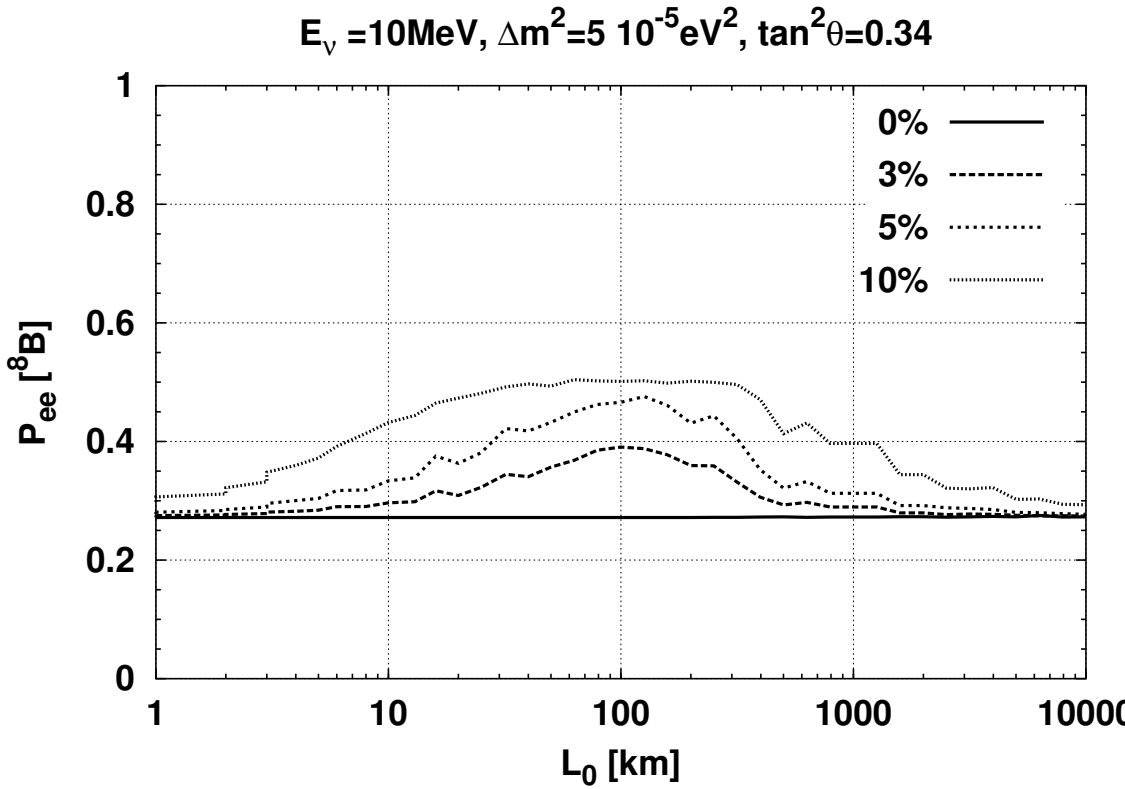
Comment: cell model gives good description of turbulent case for monochromatic neutrino if correlation scale chosen as $L_0 = L_{osc}$, but still turbulent model is needed!

Note: δ-corr: wrong limit, but $P_\delta \sim b^2 L L_0 \rightarrow b^2 L L_{osc}$

Matter density fluctuations

Parametric resonance at $L_0 \approx L_{osc}$ "seen" in the cell model

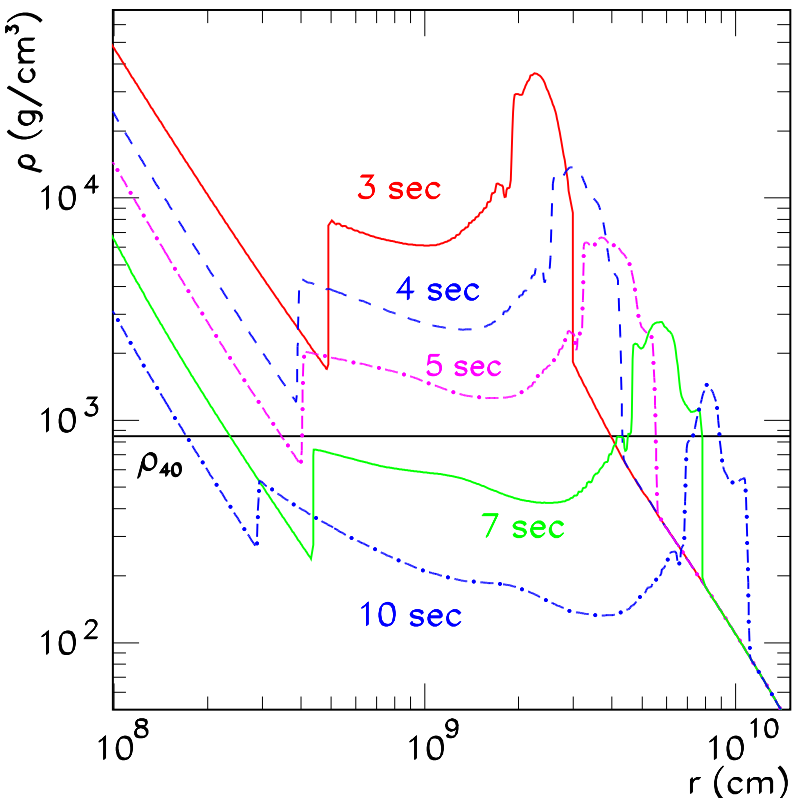
$$P_{cell} \sim L_{osc}^2 \frac{L}{L_0} \sin^2\left(\frac{L_0}{L_{osc}}\right)$$

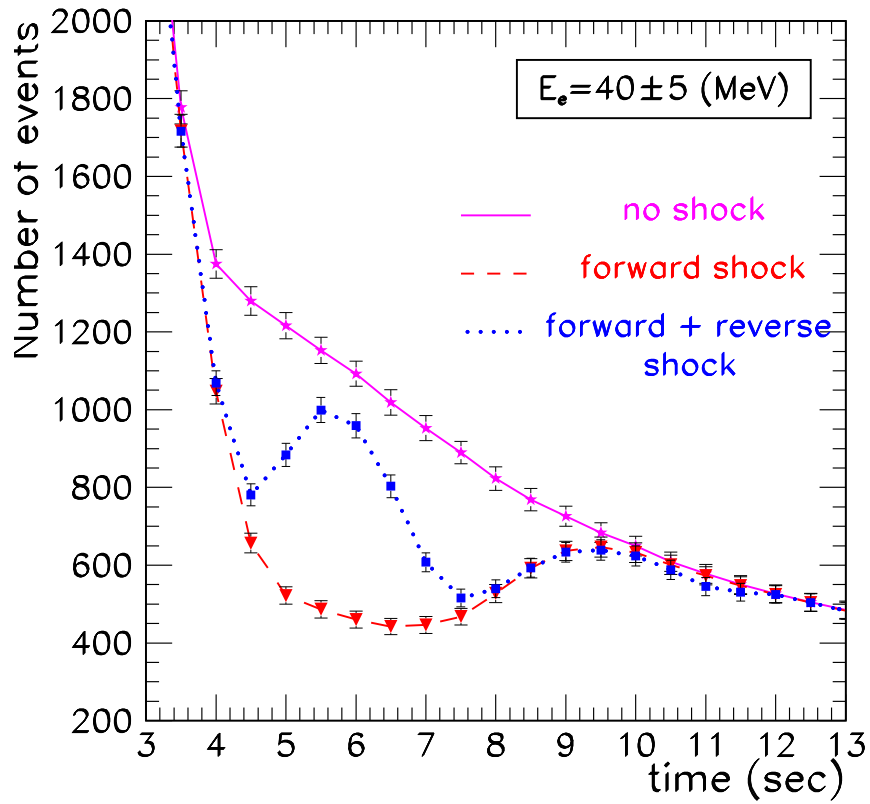


δ-correlations describes only the left side of the graph.

Supernovae shock propagation

Tomas et al, astro-ph/0407132



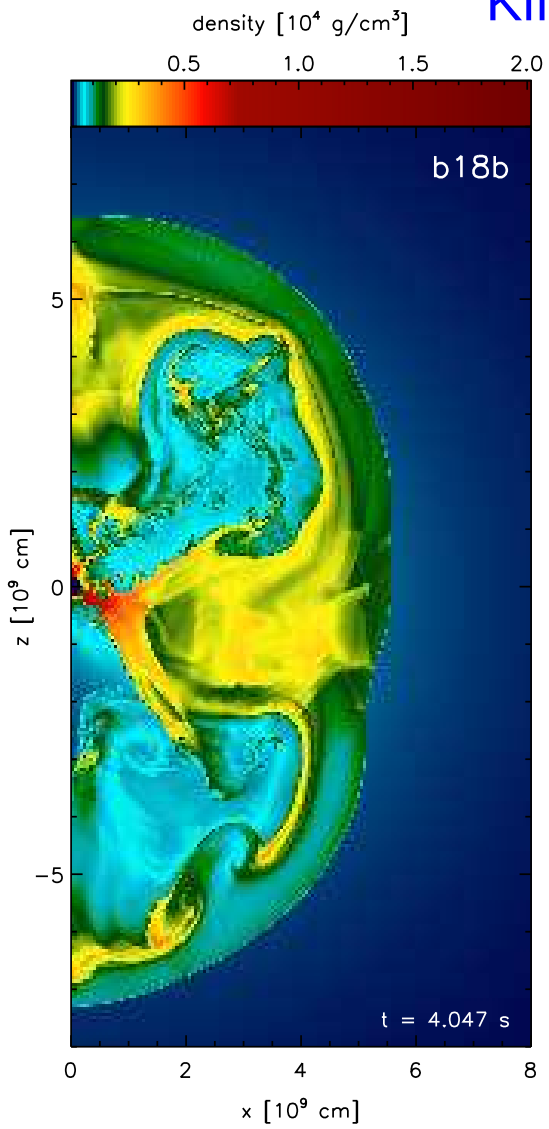


No matter density fluctuations

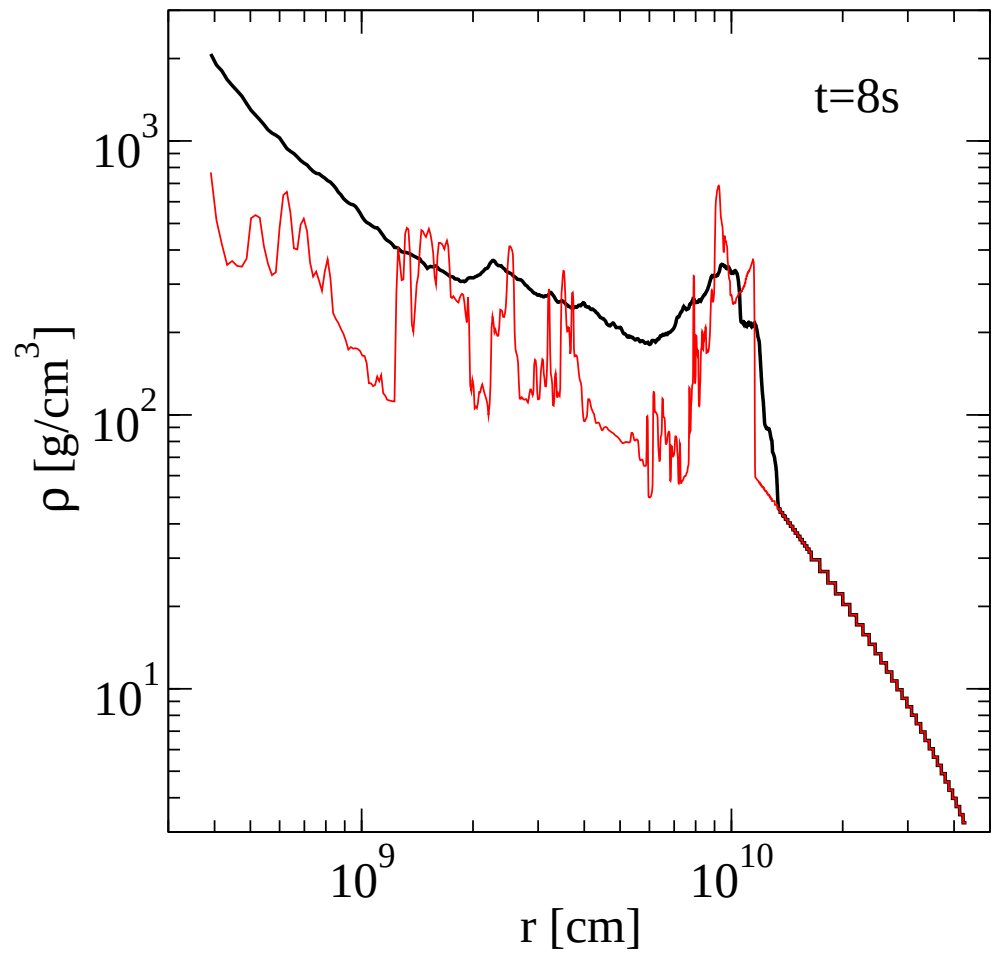
also Fogli et al, 2003, 2004, and other refs

Supernovae turbulence

Kifonidis et al, astro-ph/0511369



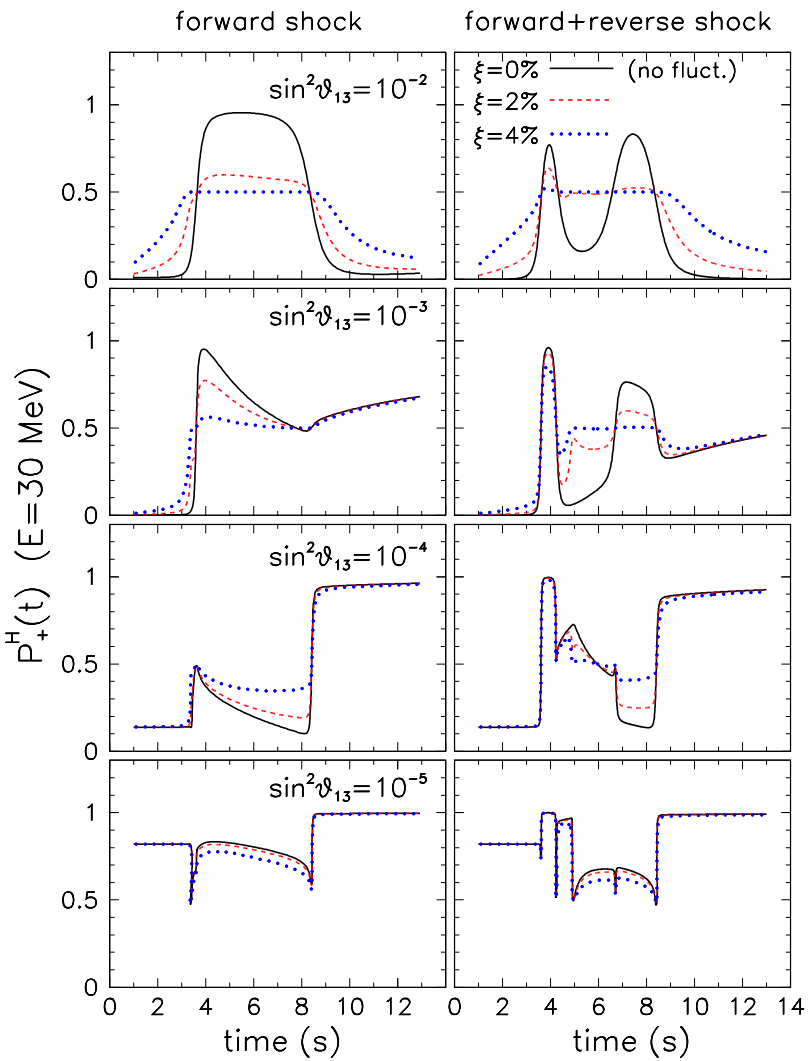
Sample from Janka and Kifonidis

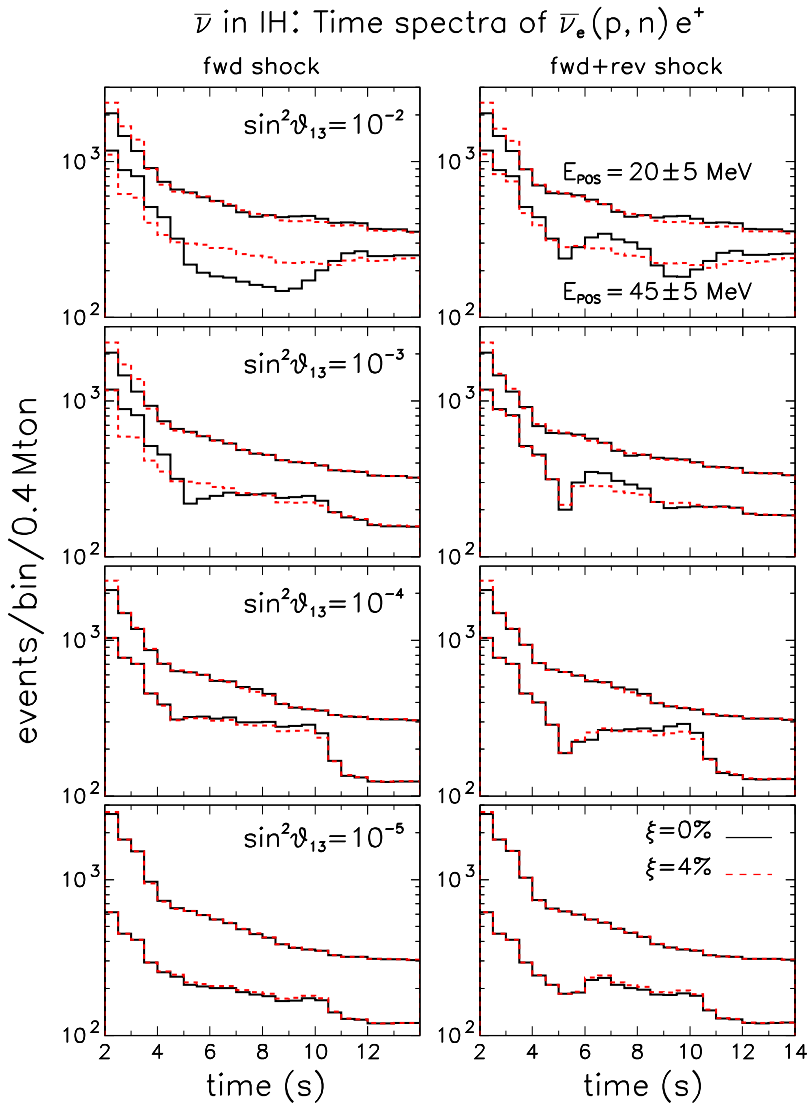


Shock-waves with fluctuations

Fogli et al, hep-ph/0603033

δ-correlated noise



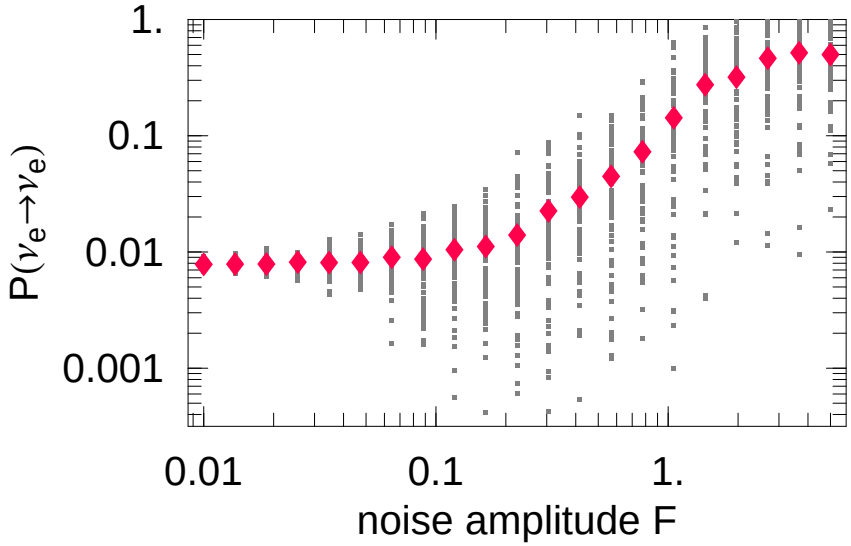


See Alessandro Mirizzi talk on Friday!

Kolmogorov turbulence

First attempt to estimate the Kolmogorov turbulence effects in Supernovae

Friedland and Gruzinov, hep-ph/0607244



$$C(k) \equiv \int dx \langle \delta n(0) \delta n(x) \rangle e^{-ikx} = C_0 k^{\alpha}.$$

$$P^{Kolm} \simeq 0.84 G_F C_0 (2\Delta \sin 2\theta_{13})^{-2/3} / \sqrt{2} |n_0'|, \quad \alpha = -5/3$$

Summary

- There is a clear and confirmed understanding that density fluctuations developed during the Supernovae explosion may alter significantly neutrino flavor transitions and therefore the observed signal.
- For quantifying of the phenomena the calculations of neutrino flavor oscillations in turbulent environment are needed.
- 3D simulations and better spatial resolution calculations of the Supernovae explosion are of the great importance for understanding of the neutrino signal from the future Supernovae.