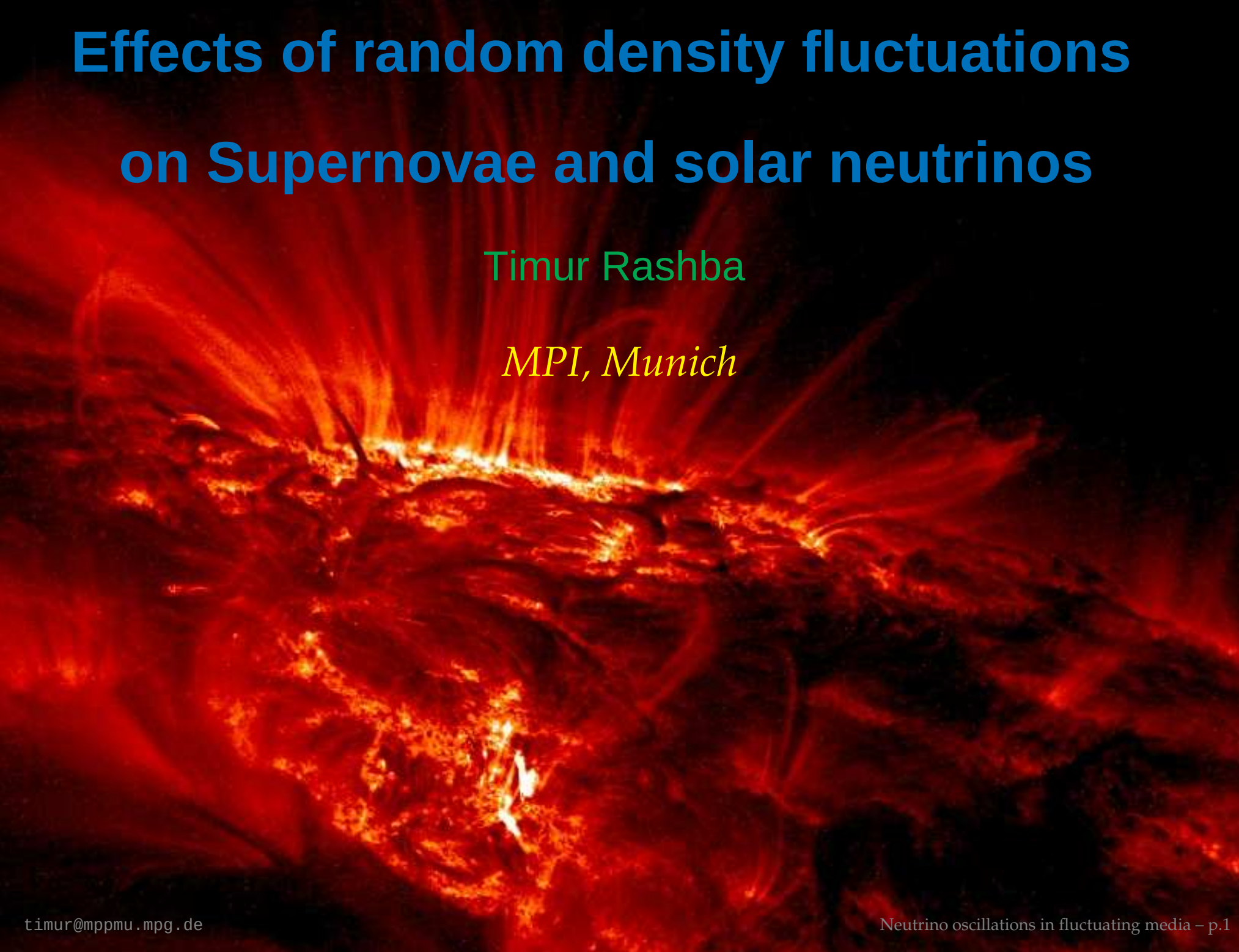
Effects of random density fluctuations on Supernovae and solar neutrinos

Timur Rashba

MPI, Munich

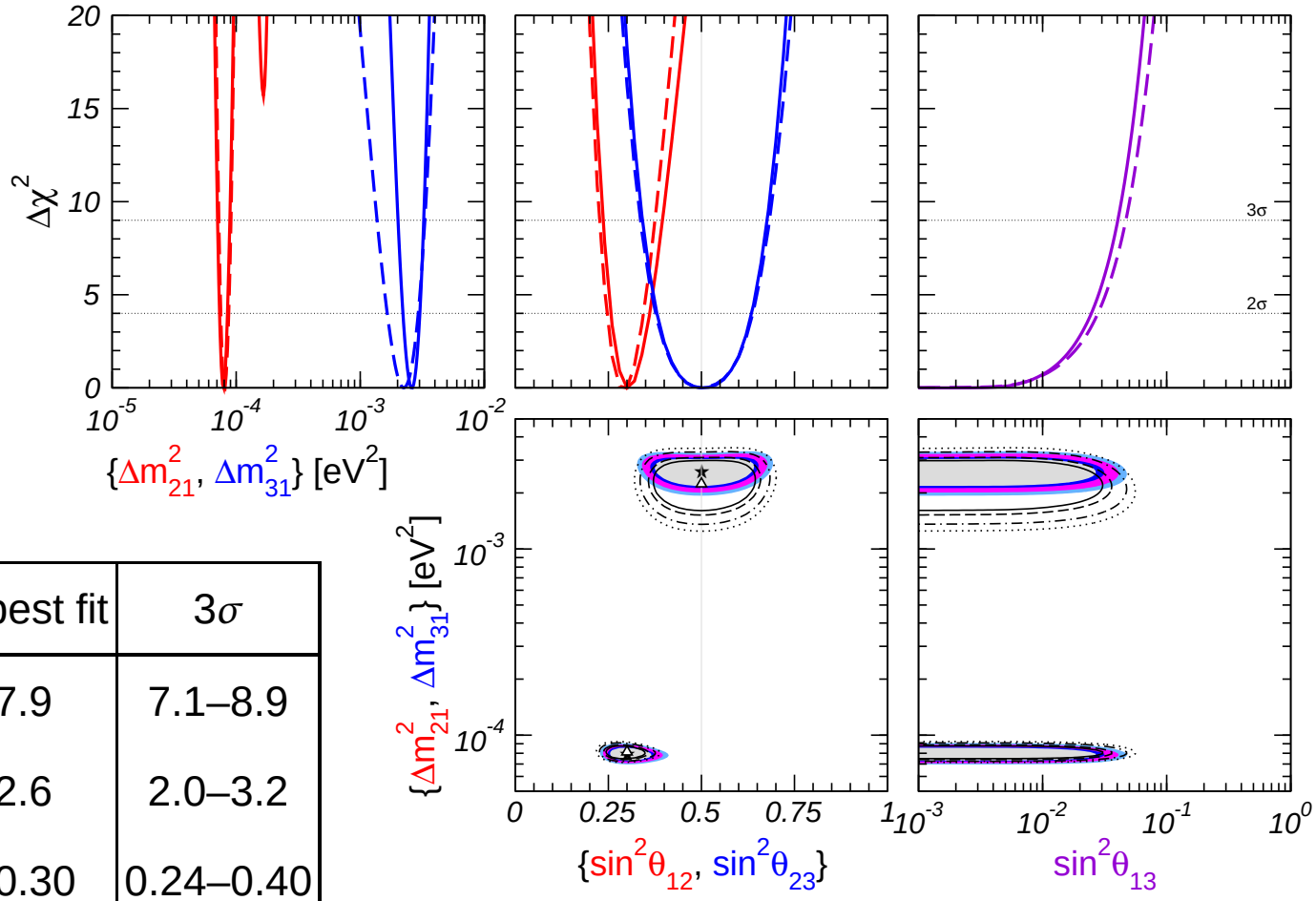


timur@mppmu.mpg.de

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	≤ 0.040

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

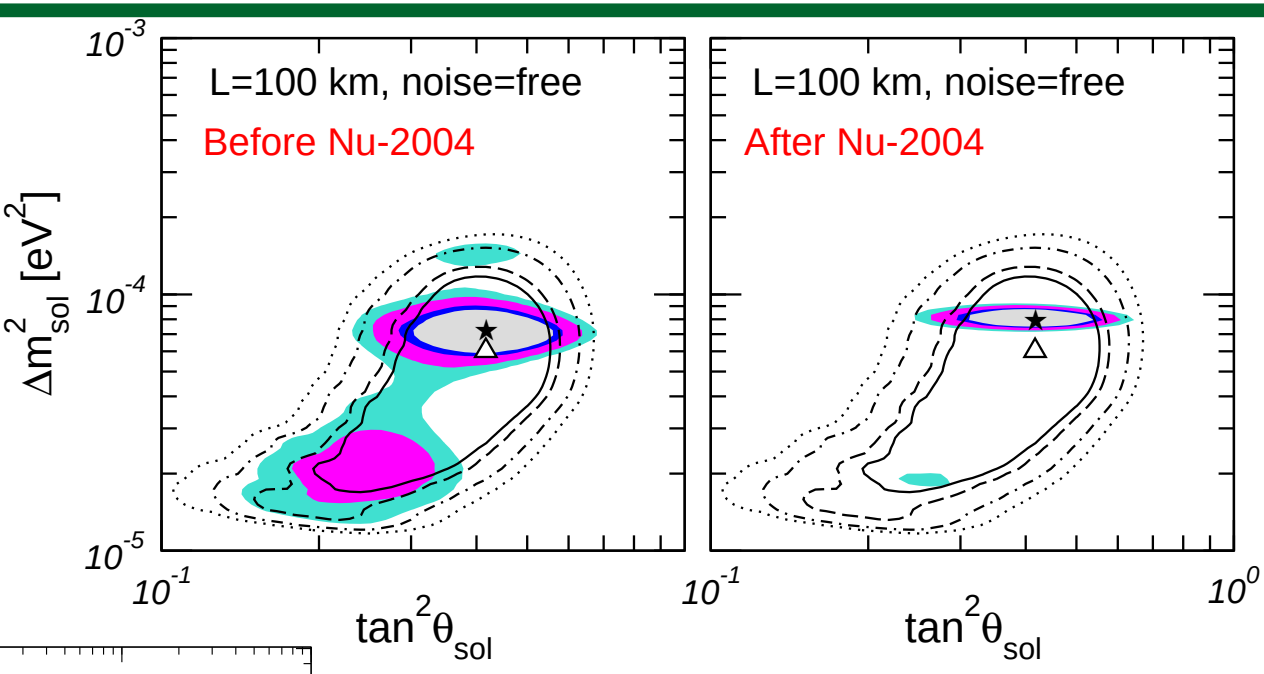
Importance of density fluctuations

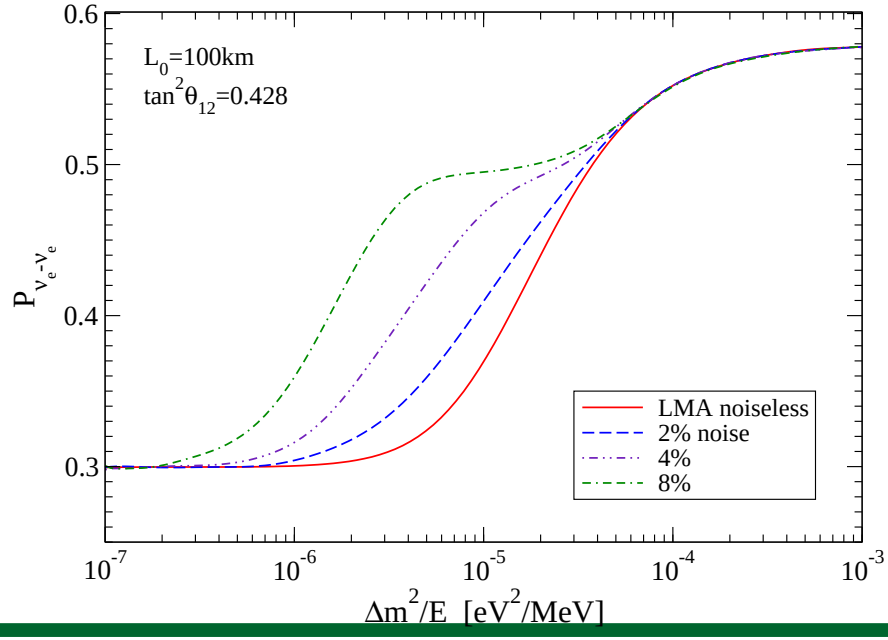
Burgess et al.,04

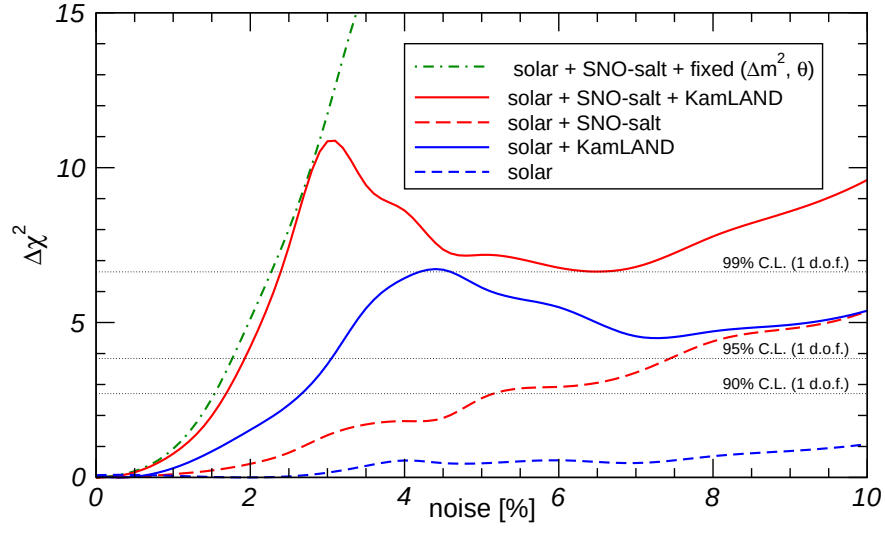
see also

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'91 (magn), Balantekin and Loreti'94, and other refs

- Cell model

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

Burgess and Michaud'97, Bykov et al'98 (magn), Burgess et al'03

- Turbulent (Kolmogorov) models

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

Miranda et al'04 (magn), Friedland'05 (magn),
Friedland and Gruzinov'06

Magnetic case as an example

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

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

Neutrino as a fourier-analyser

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 Kolmogorov 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: $P_{cell} \sim b^2 L_{osc}^2 \frac{L}{L_0} \sin^2(\frac{L_0}{L_{osc}}) \to b^2 L L_0$

$L_0 \approx L_{osc}$

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

Comments:

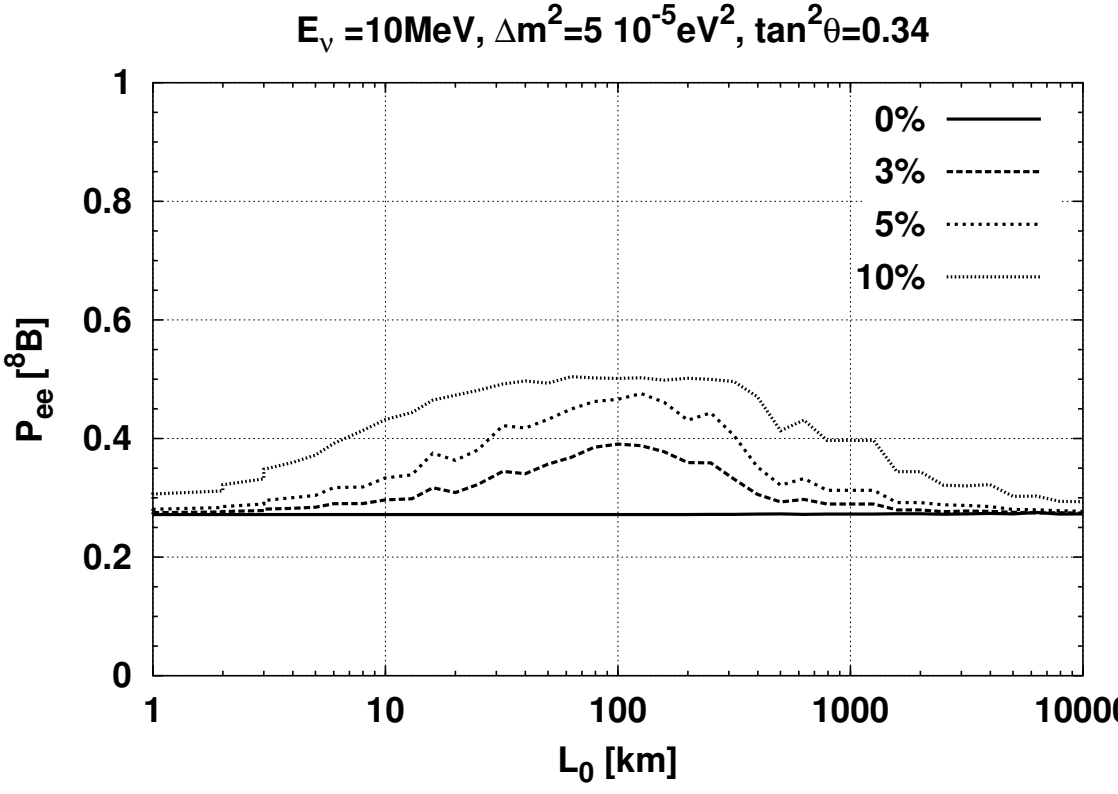
- cell model gives good description of turbulent case if correlation scale chosen as $L_0 \sim L_{osc}$, but still turbulent model is needed to account for real situation with many fluctuation scales.
- δ-corr: wrong limit, but $P_\delta \sim b^2 L L_0 \to b^2 L L_{osc}$

Parametric resonance

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

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

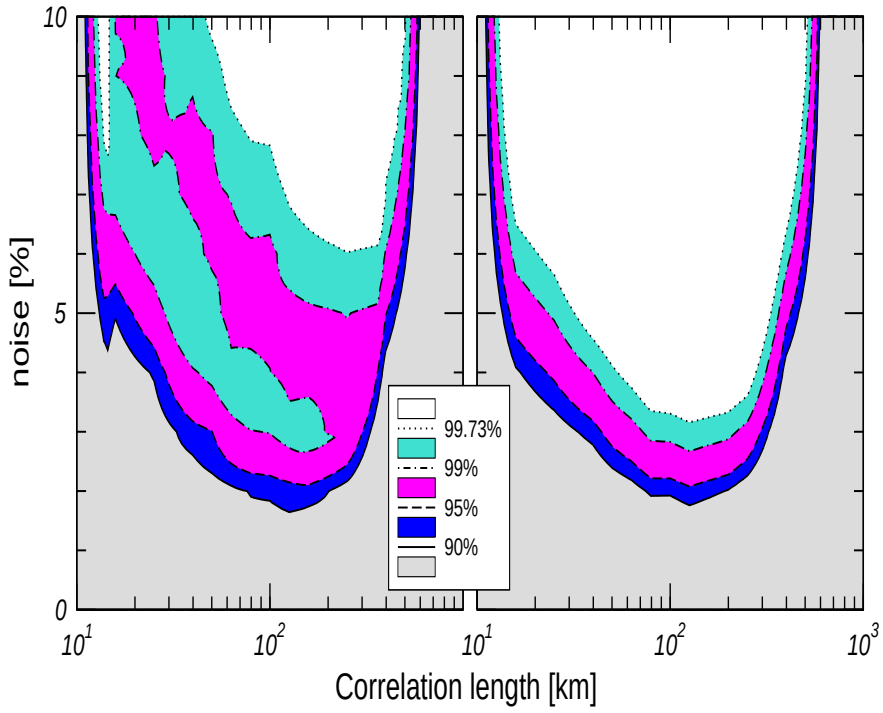
and numerically:

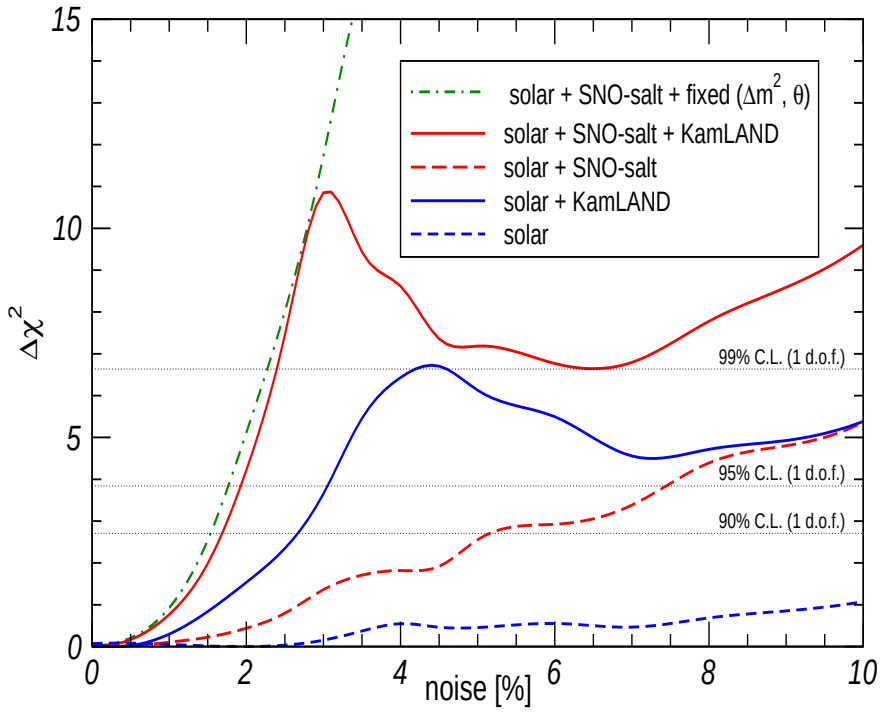


δ-correlations describes only the left side of the graph.

Probing solar noise with neutrinos

Burgess et al.'03

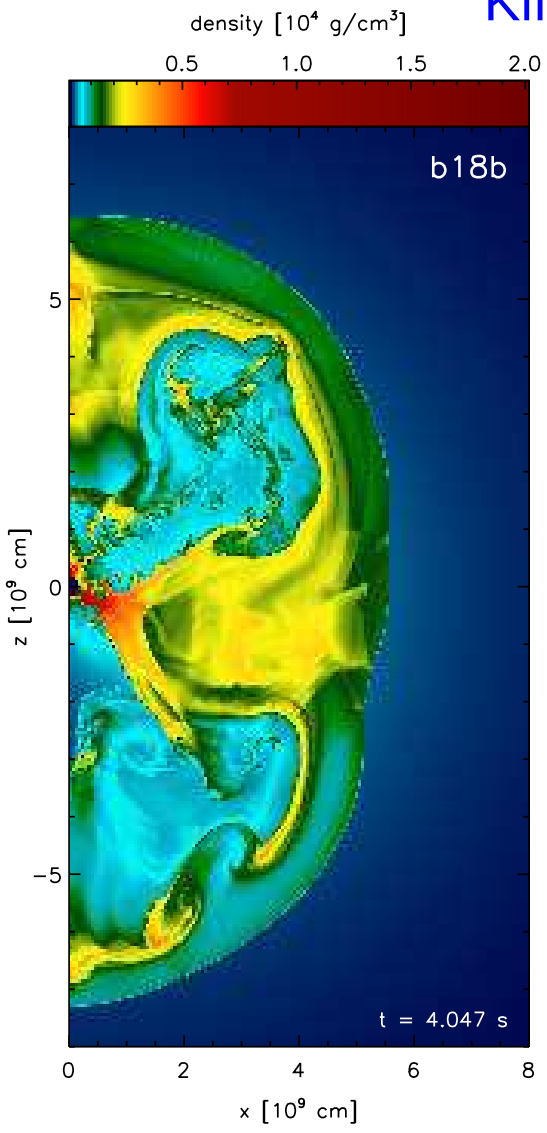




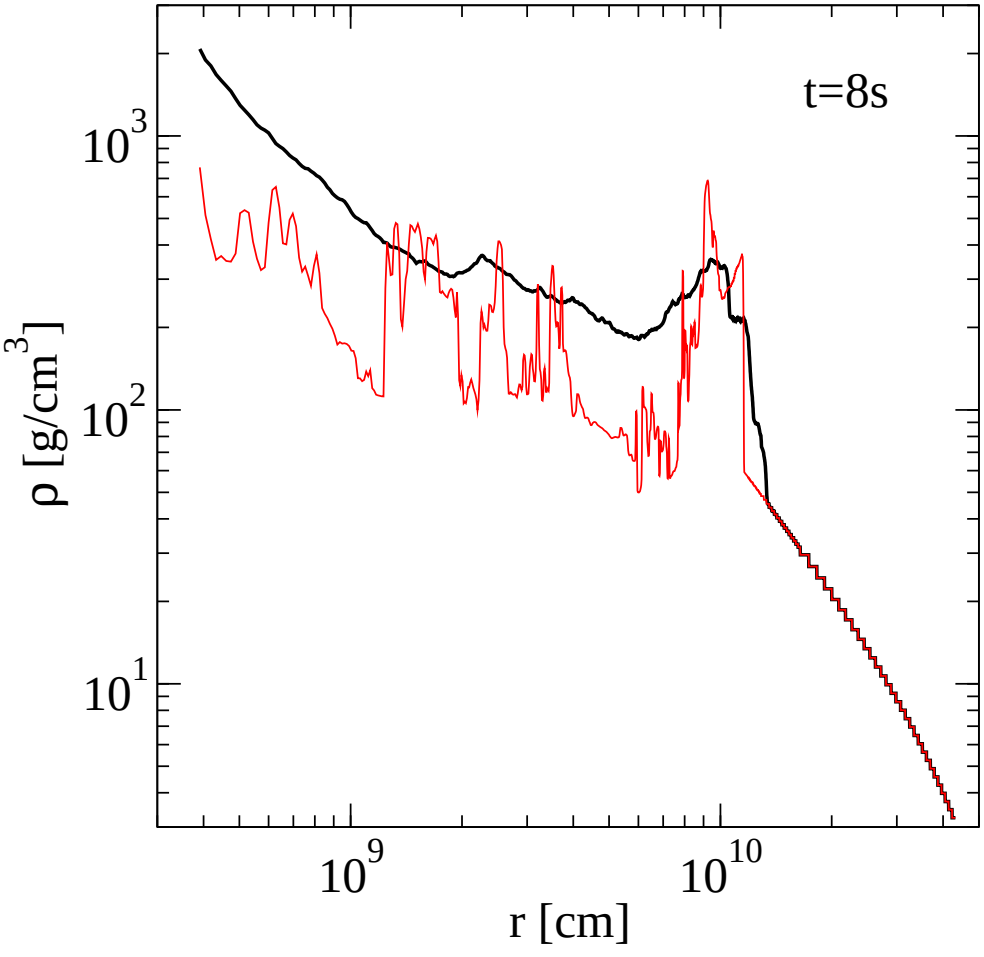
- Only neutrinos probe scales ~ 100 km, helioseismology bounds noise $< 0.1\%$ but at the scales > 1000 km!
- Future solar neutrino experiments like Hyper-K, UNO, LENA etc will have much better sensitivity to solar small-scale fluctuations.

SN matter density fluctuations

Kifonidis et al, astro-ph/0511369

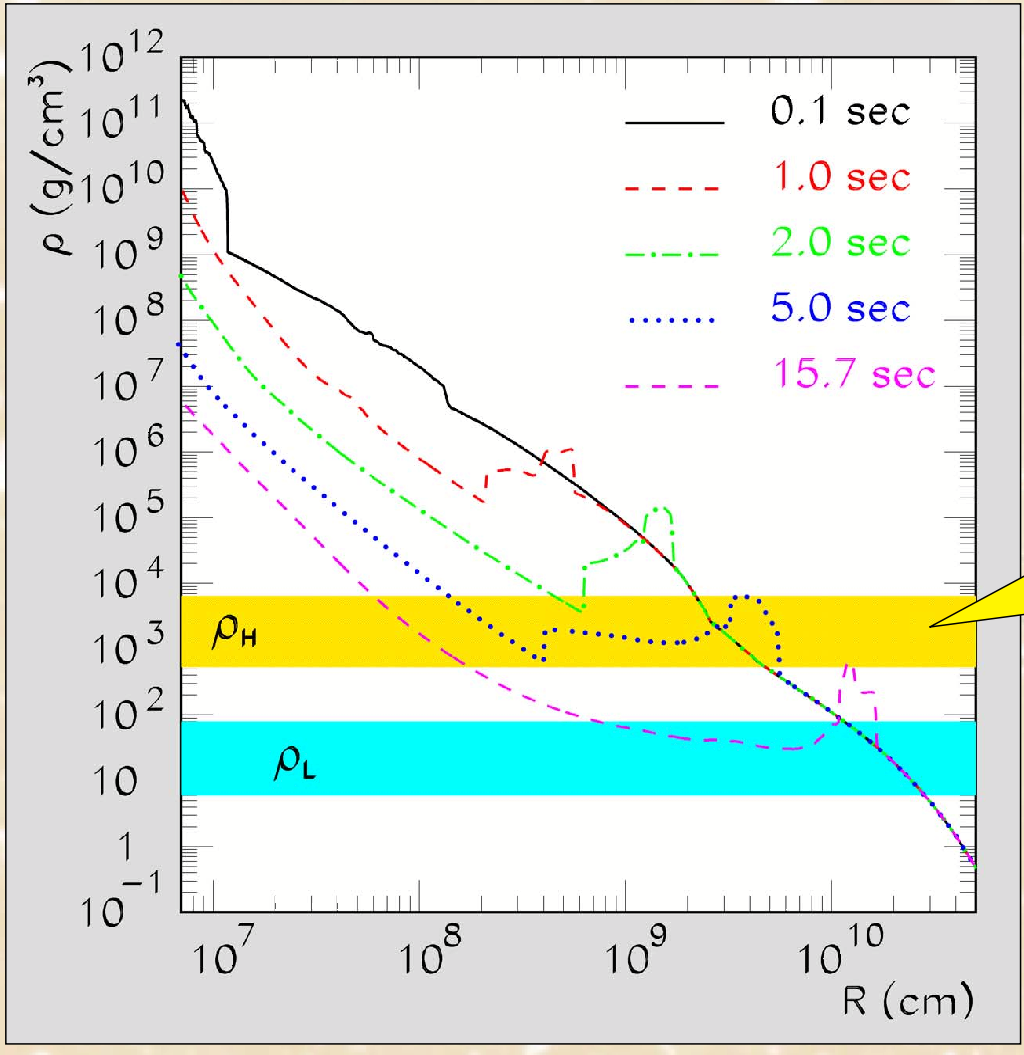


Sample from Janka and Kifonidis



SN shock-waves and neutrinos

Supernova Shock Propagation and Neutrino Oscillations



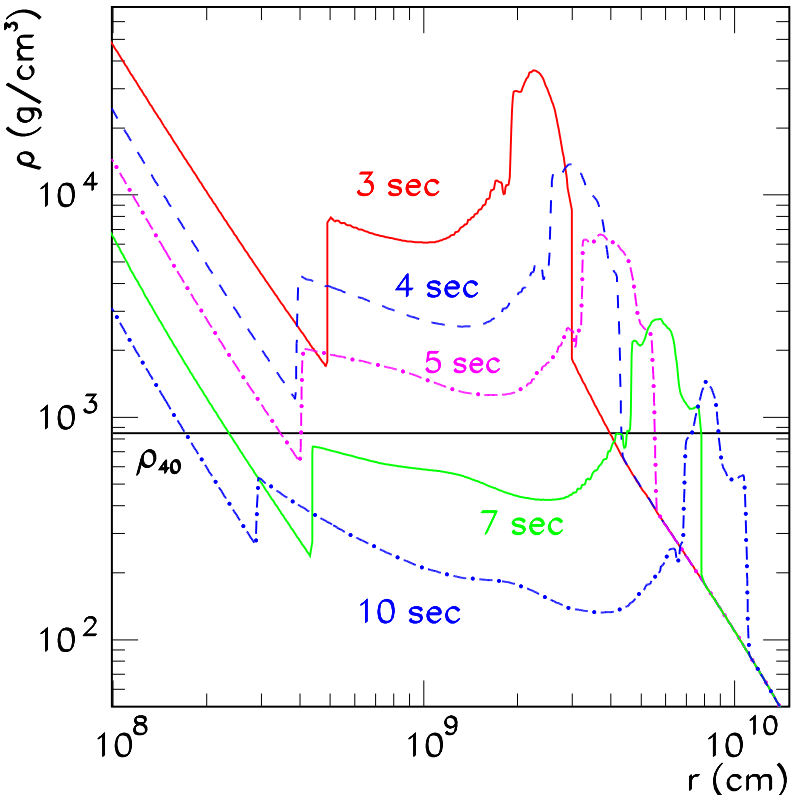
Schirato & Fuller: Connection between supernova shocks, flavor transformation, and the neutrino signal [astro-ph/0205390]

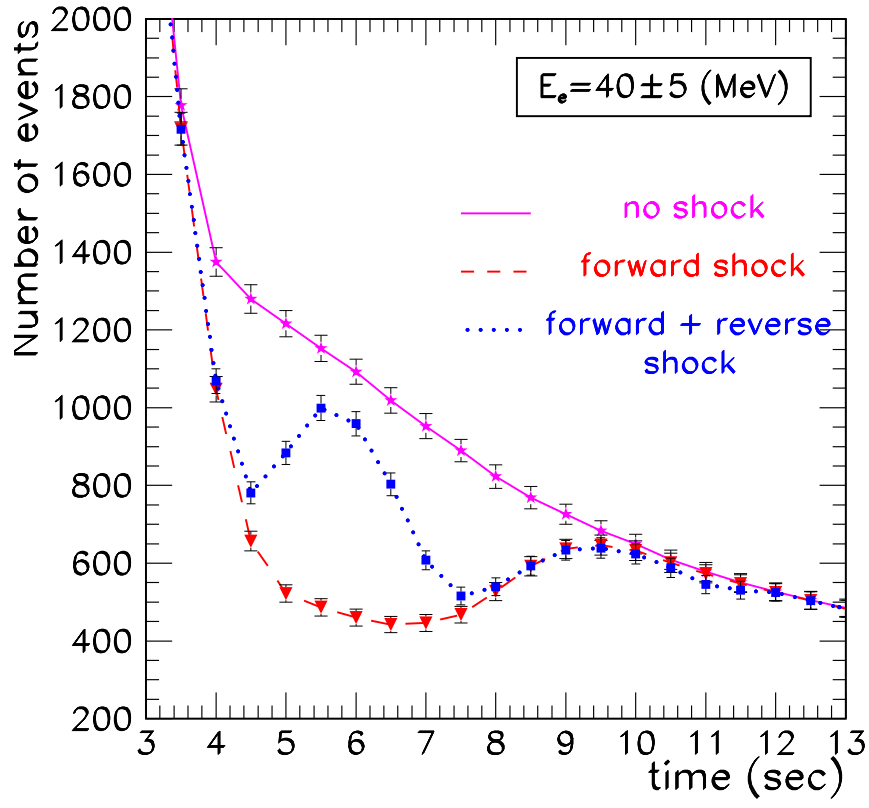
Resonance density for Δm^2_{atm}

R. Tomàs, M. Kachelriess, G. Raffelt, A. Dighe, H.-T. Janka & L. Scheck: Neutrino signatures of supernova forward and reverse shock propagation [astro-ph/0407132]

Supernovae shock propagation

Tomas et al, astro-ph/0407132





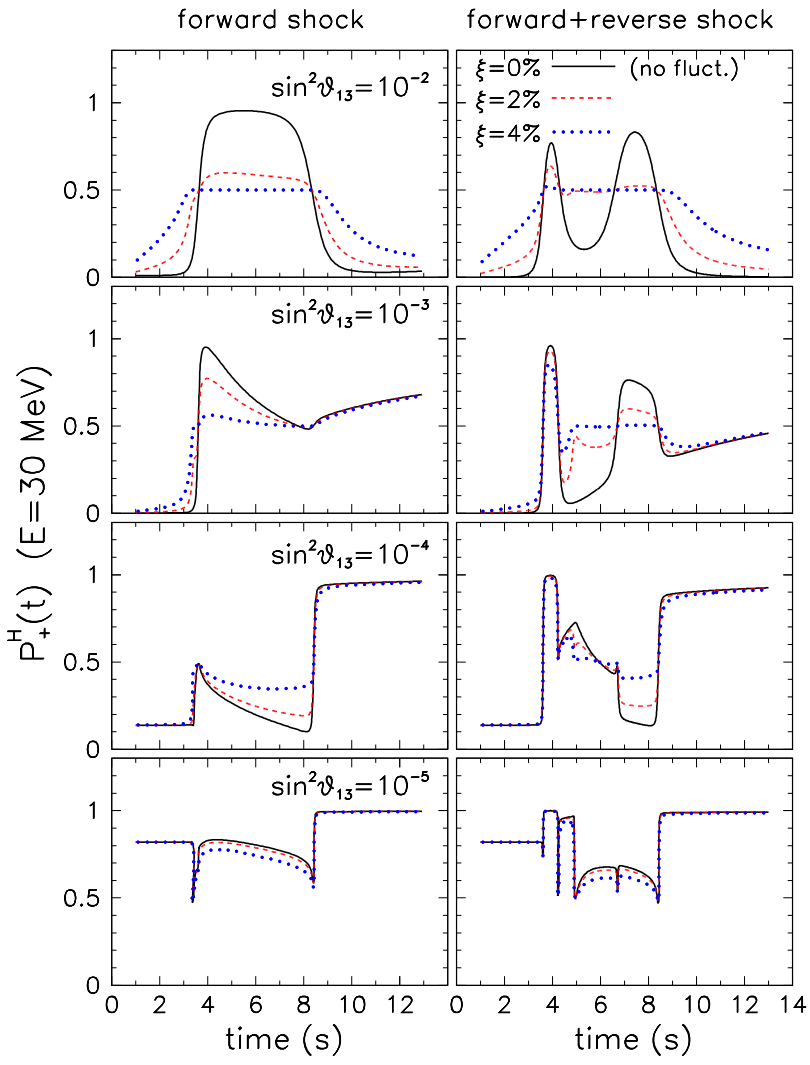
No matter density fluctuations

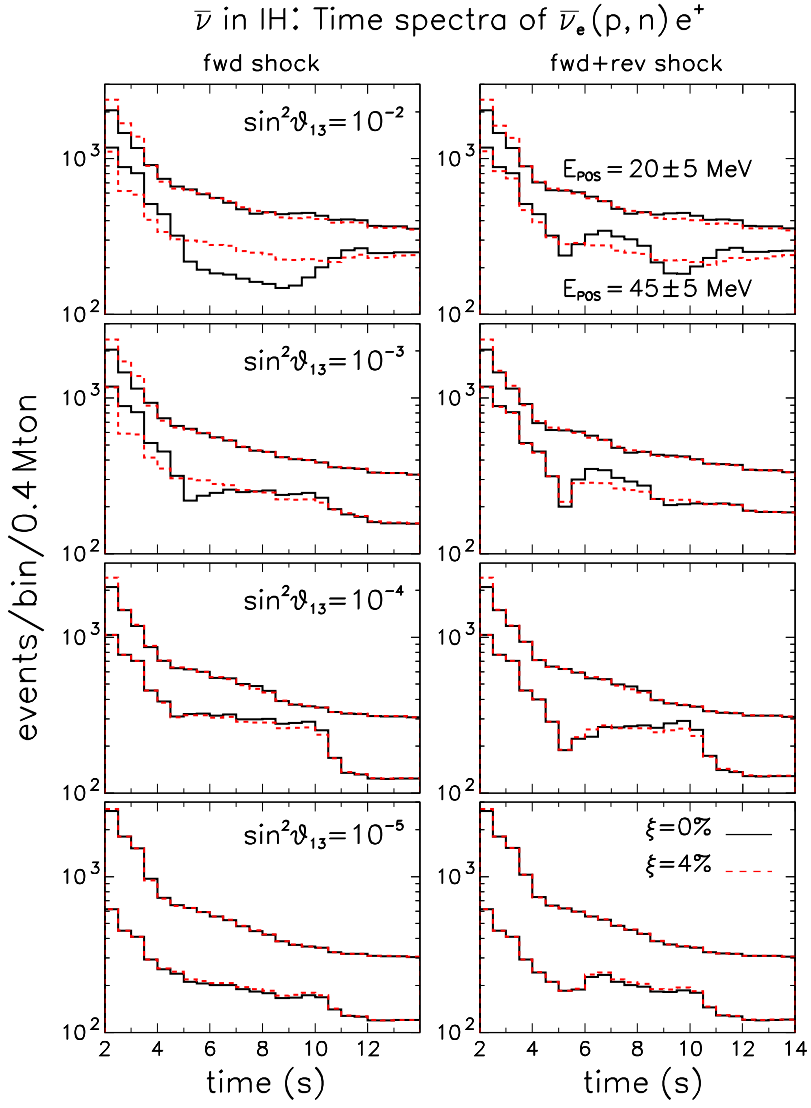
also Fogli et al, 2003, 2004, and other refs

Shock-waves with fluctuations

Fogli et al, hep-ph/0603033

δ-correlated noise





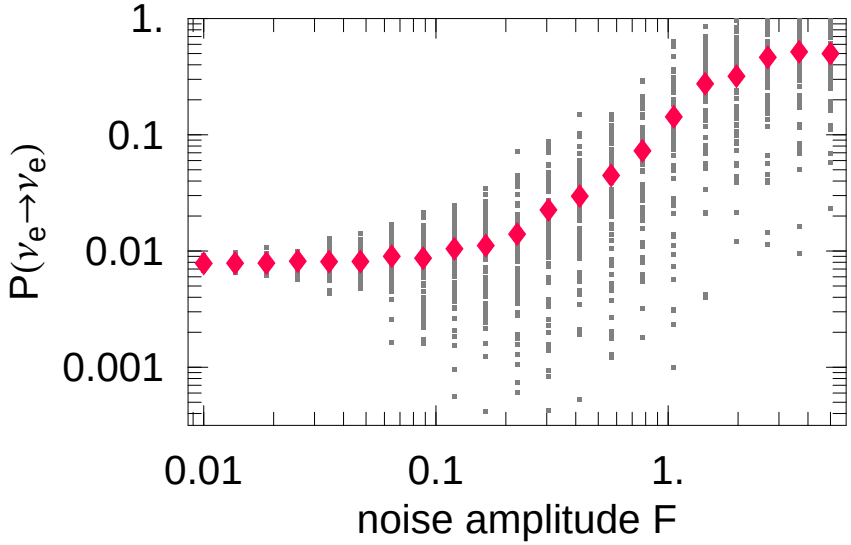
SN turbulence: opened questions

- How do turbulent fluctuations affect neutrinos?
- Is it Kolmogorov-like turbulence or not?
- Can one get some information from present 2D simulations?
- How large are the perturbations?
- Are the time scales long enough to develope a steady state turbulence?

How do turbulence affect neutrinos

First estimate of the influence of turbulence on neutrinos in Supernovae

Friedland and Gruzinov, hep-ph/0607244



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

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

Is it Kolmogorov-like turbulence?

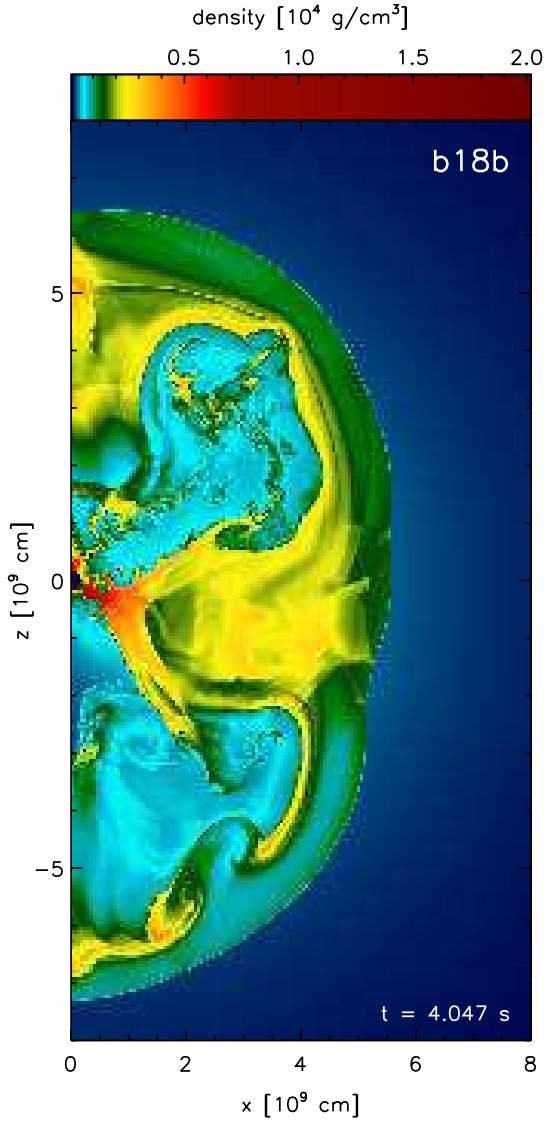
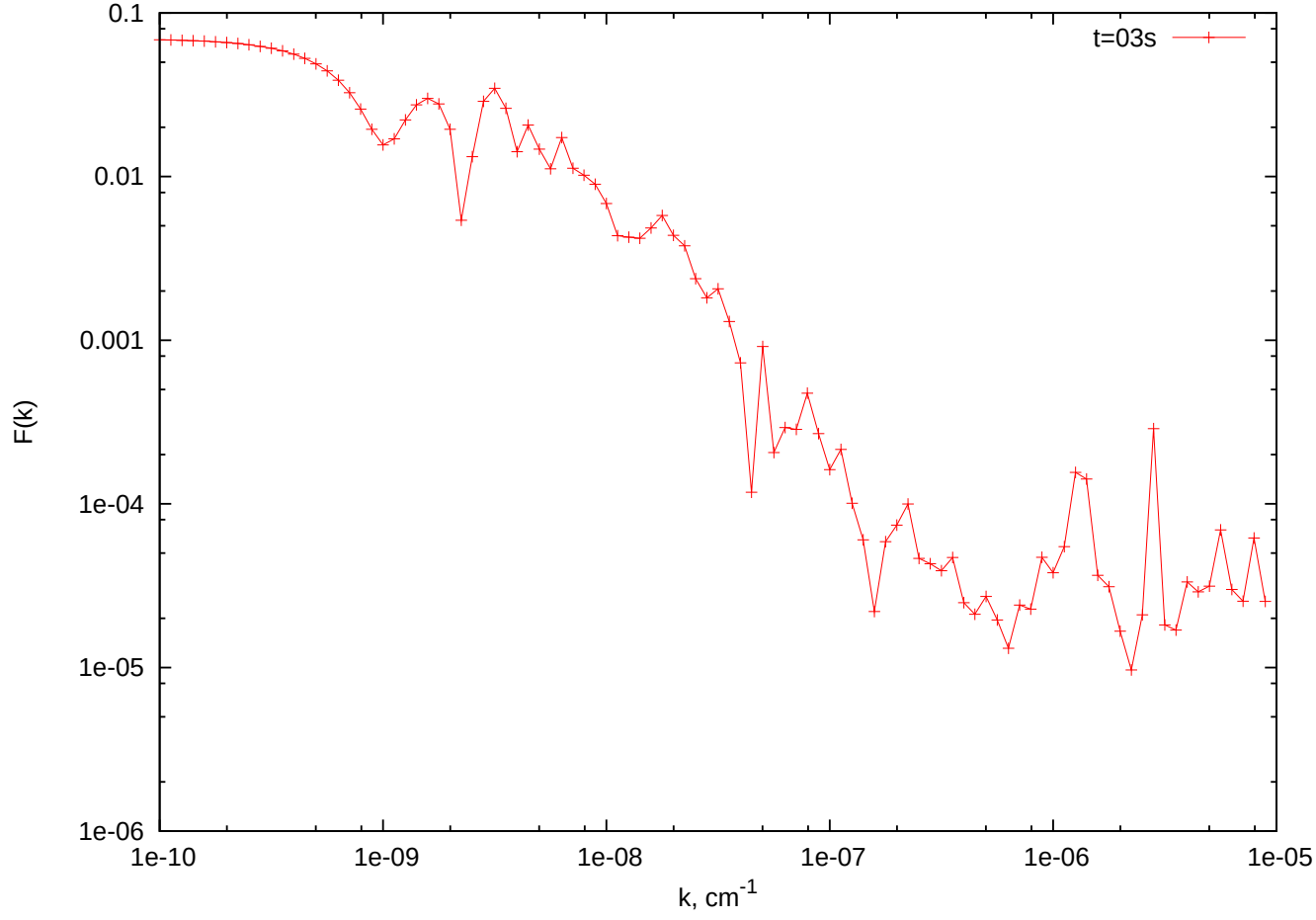


Illustration of noise power spectrum
from 2D simulations made by Janka and Kifonidis

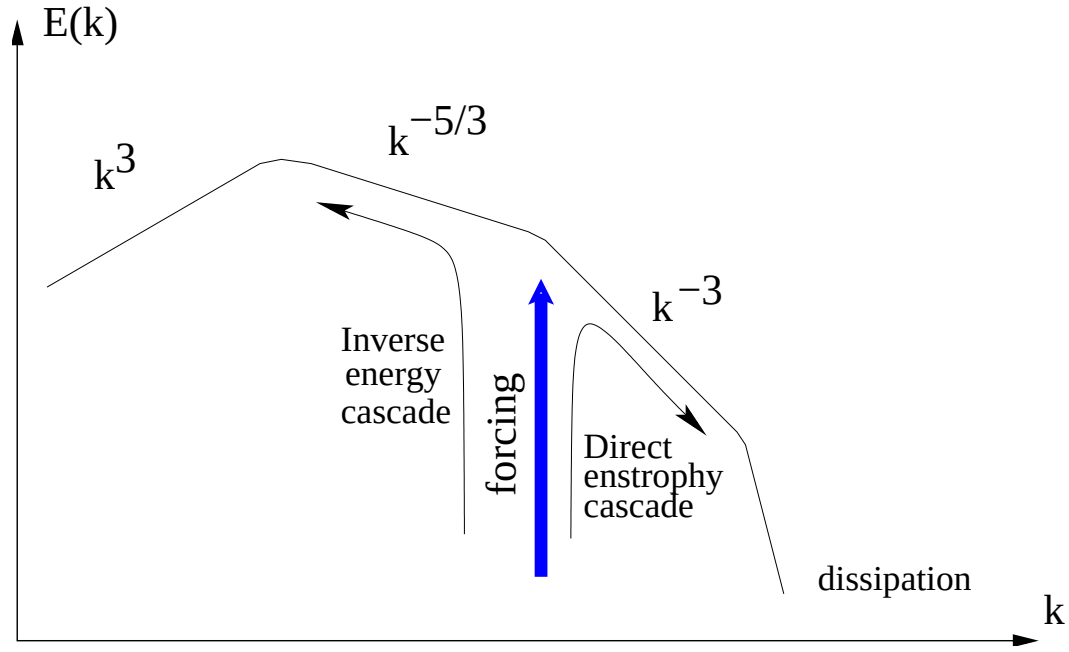


Two dimensional turbulence

Can one get some information from 2D simulations?

2D turbulence, classical picture

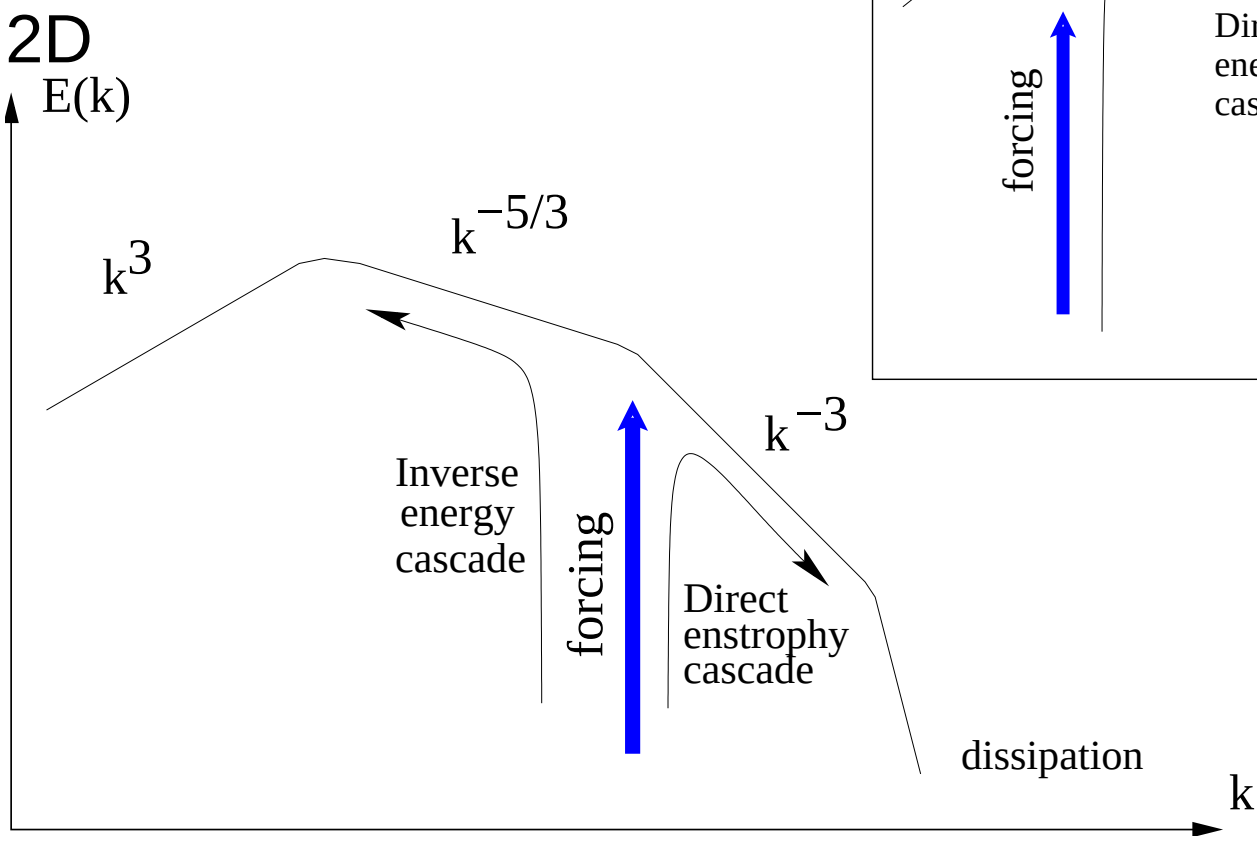
Kraichnan'67, Leith'68, Batchelor'69



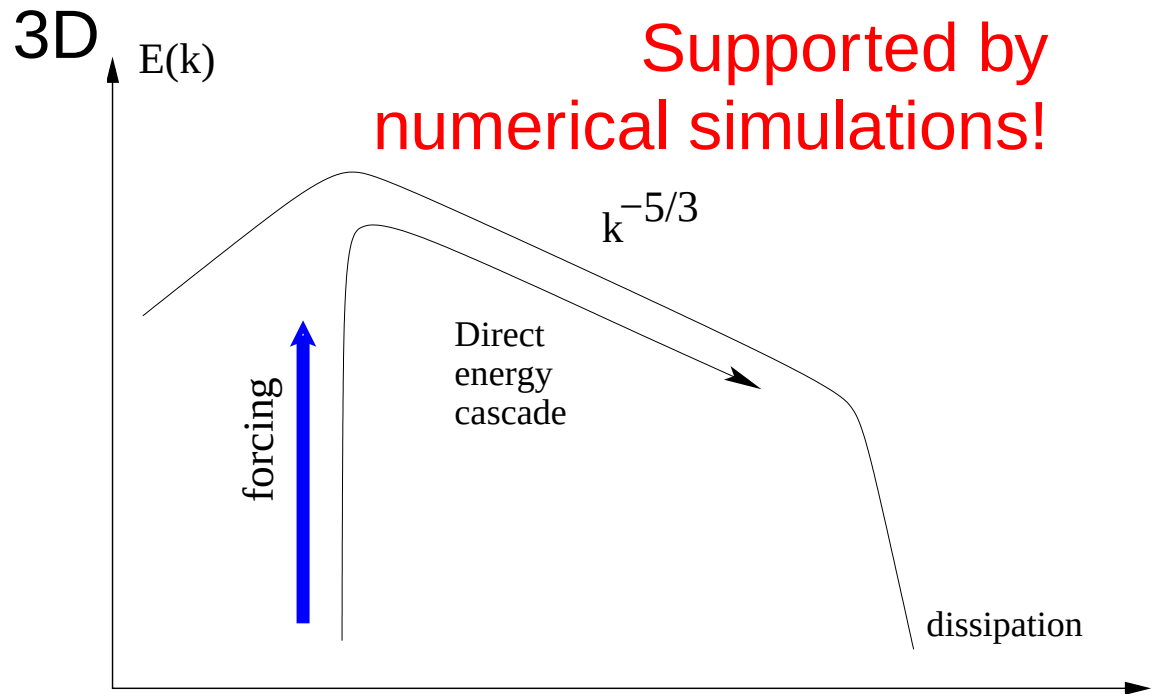
Problems come when finite time scale and size of the system are taken into account $\longrightarrow$ several contradictory scenarios in literature.

2D *vs* 3D turbulence

Classical picture



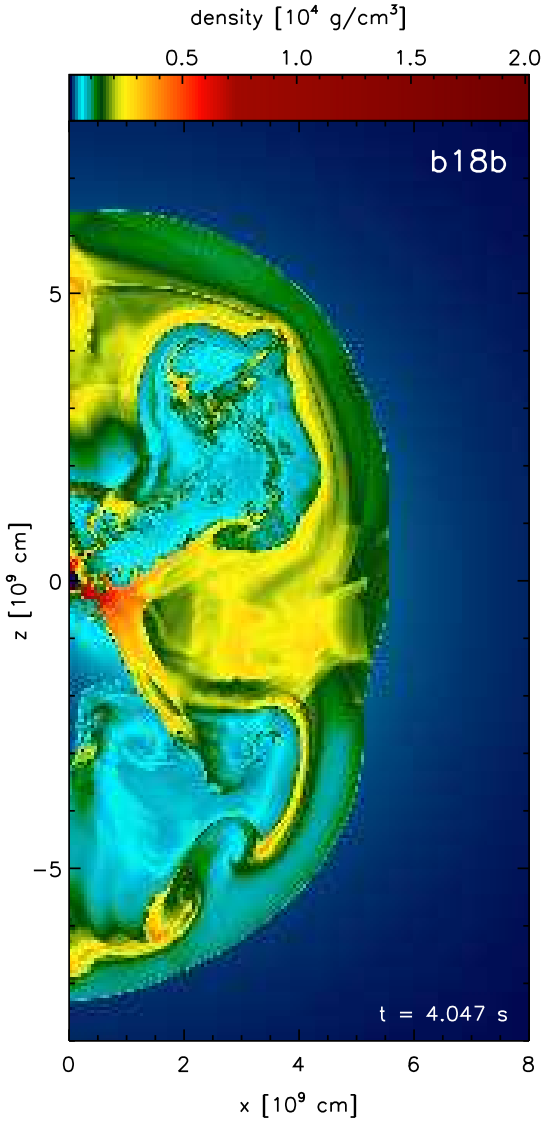
Kraichnan'67, Leith'68, Batchelor'69



Supported by numerical simulations!

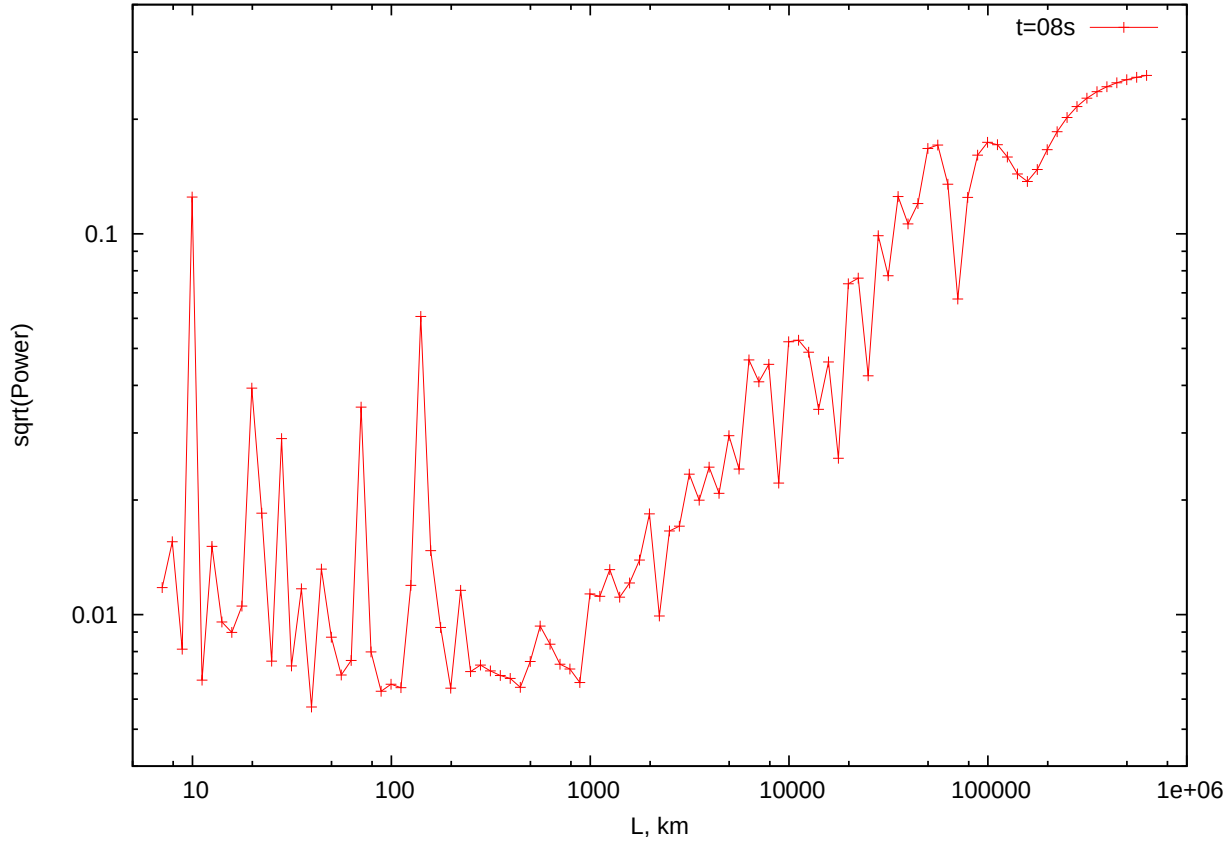
Kolmogorov'41

How large are the perturbations?



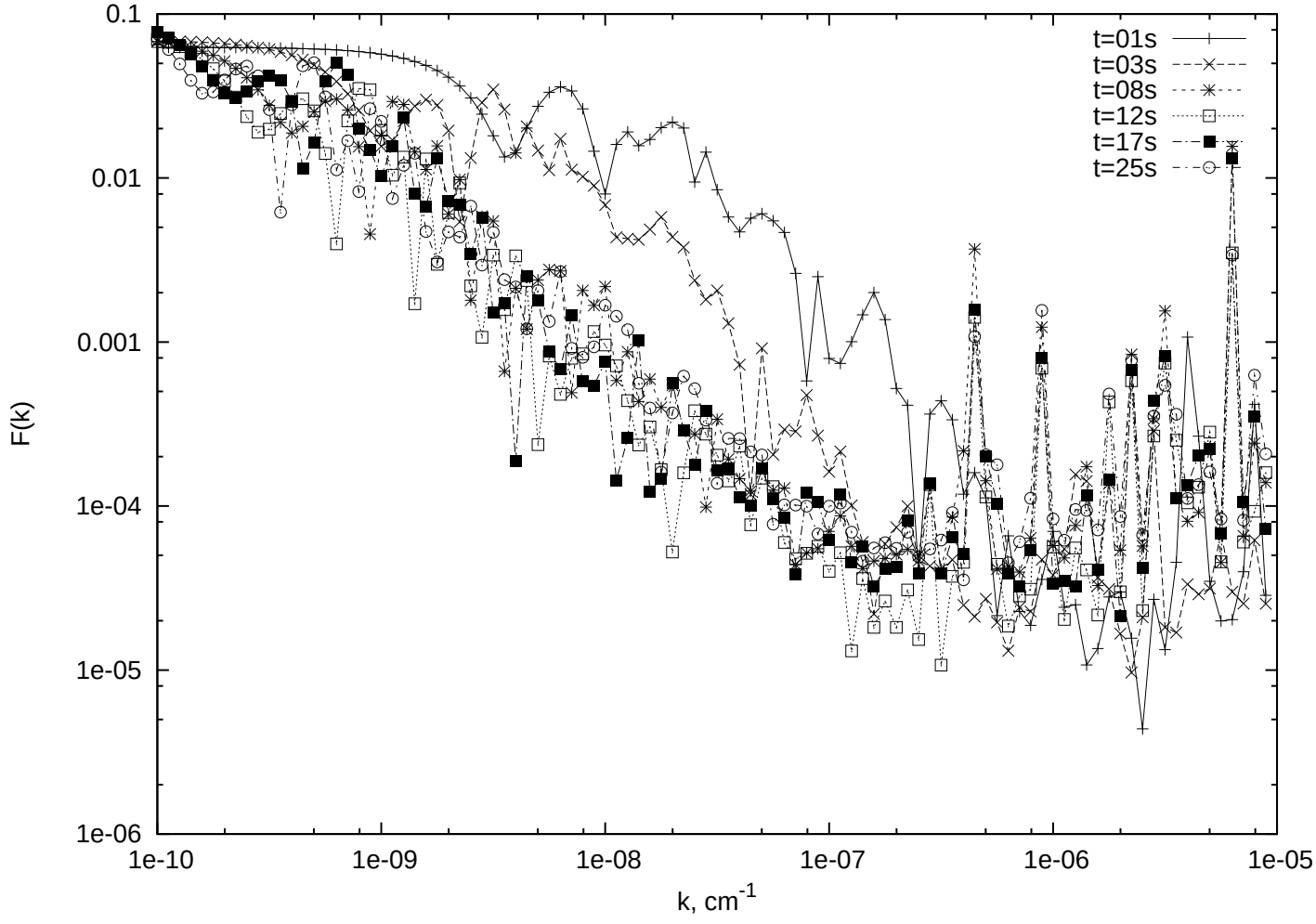
Estimate of strength

. from 2D simulations made by Janka and Kifonidis



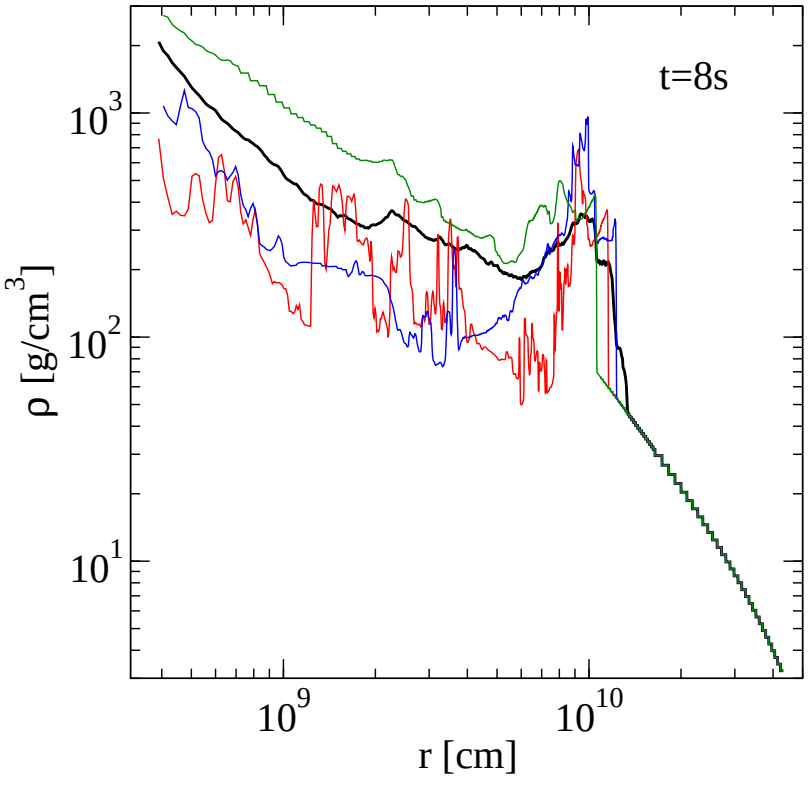
Developed turbulence?

Estimations of spectra from 2D simulations by Janka and Kifonidis



More opened questions

- No unique prediction of SN neutrino spectra



Sample, Janka & Kifonidis

- Neutrino self interactions near neutrinosphere may alter significantly initial neutrino spectra

[Duan, Fuller, Qian, astro-ph/0511275] and also [Duan et al'06, Hannestad et al'06]

Summary

- The SN matter density perturbations generated by shock waves and by HD and MHD instabilities may alter significantly neutrino flavor transitions.
- For quantifying of this phenomenon numerical calculations of neutrino flavor oscillations in SN turbulent environment are needed.
- 3D simulations with fine spacial resolution are of great importance for predicting and understanding the neutrino signal from future Supernovae.
- Still far from clear prediction of SN neutrino signal.

Thank you.