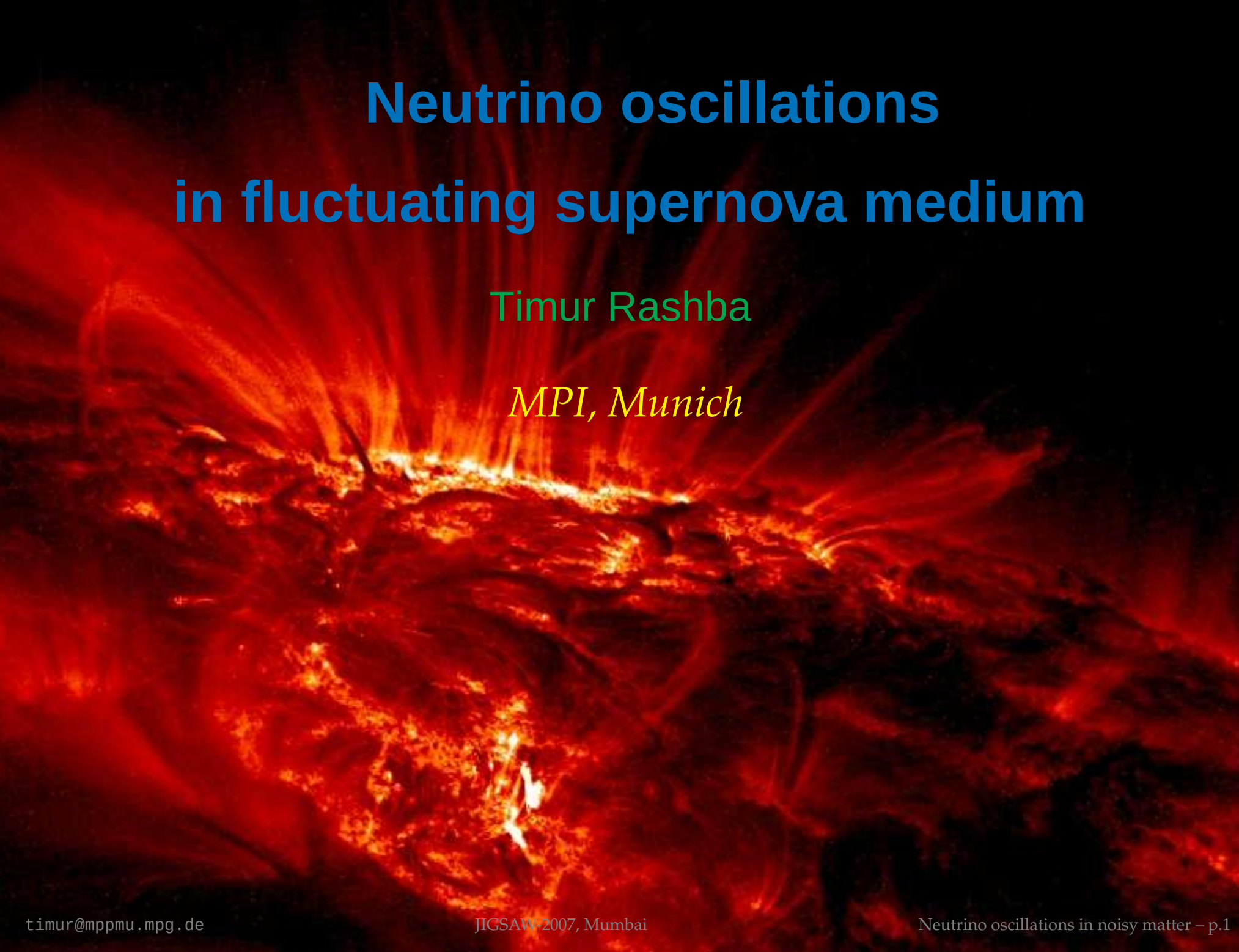


Neutrino oscillations in fluctuating supernova medium

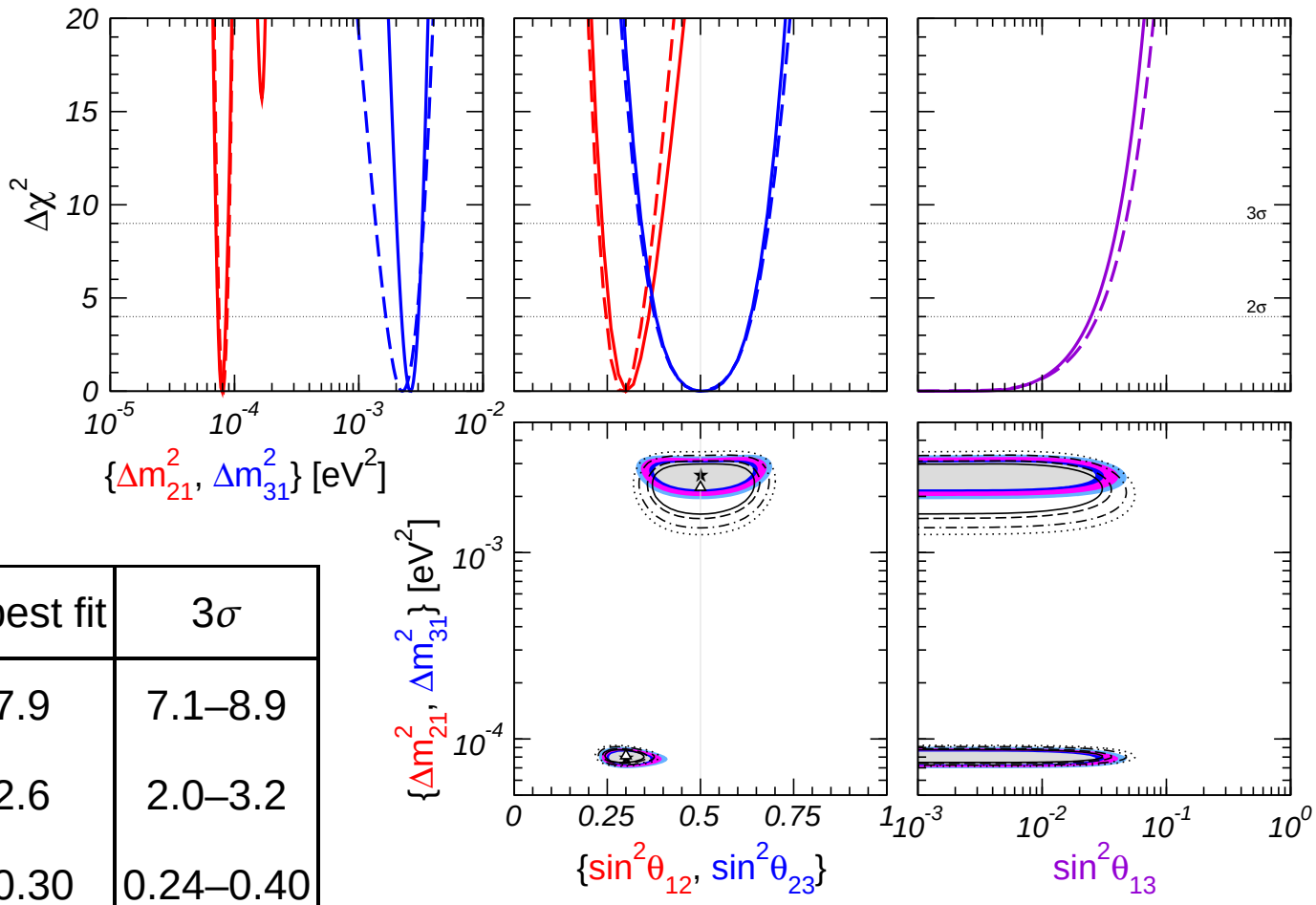
Timur Rashba

MPI, Munich

Outline

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

Neutrino oscillations



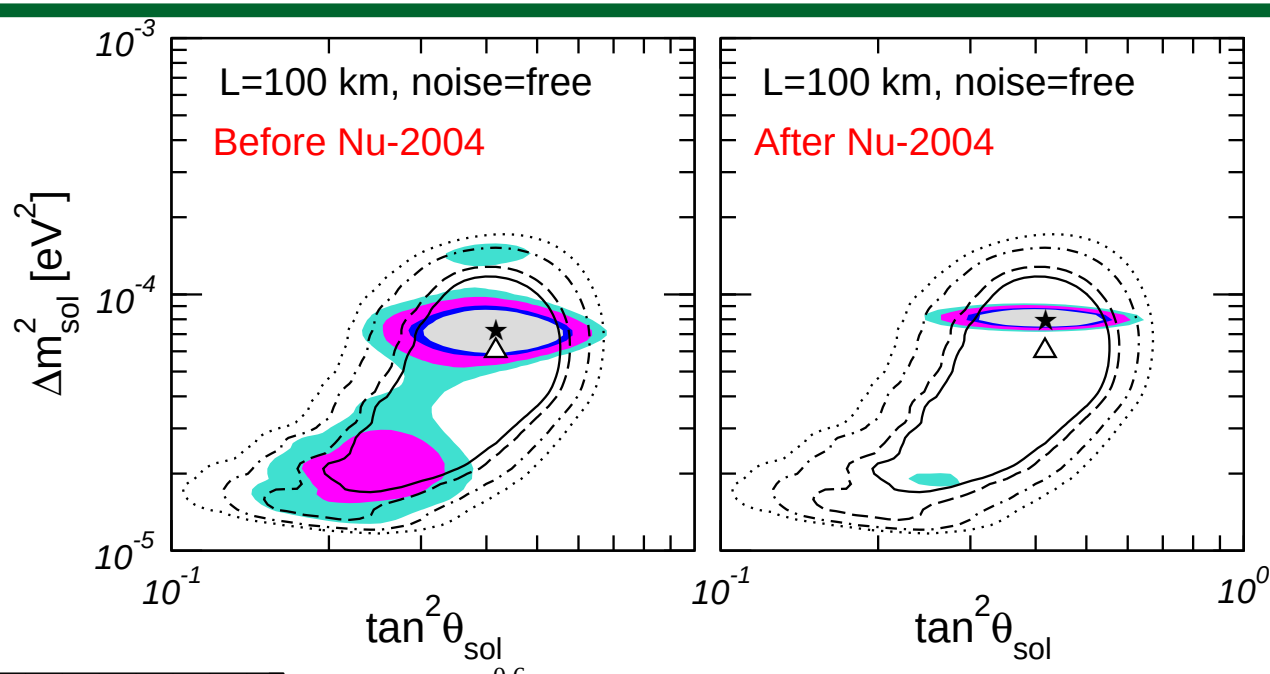
parameter	best fit	3σ
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.9	7.1–8.9
Δm^2_{31} $[10^{-3}\text{eV}^2]$	2.6	2.0–3.2
$\sin^2\theta_{12}$	0.30	0.24–0.40
$\sin^2\theta_{23}$	0.50	0.34–0.68
$\sin^2\theta_{13}$	0.000	≤ 0.040

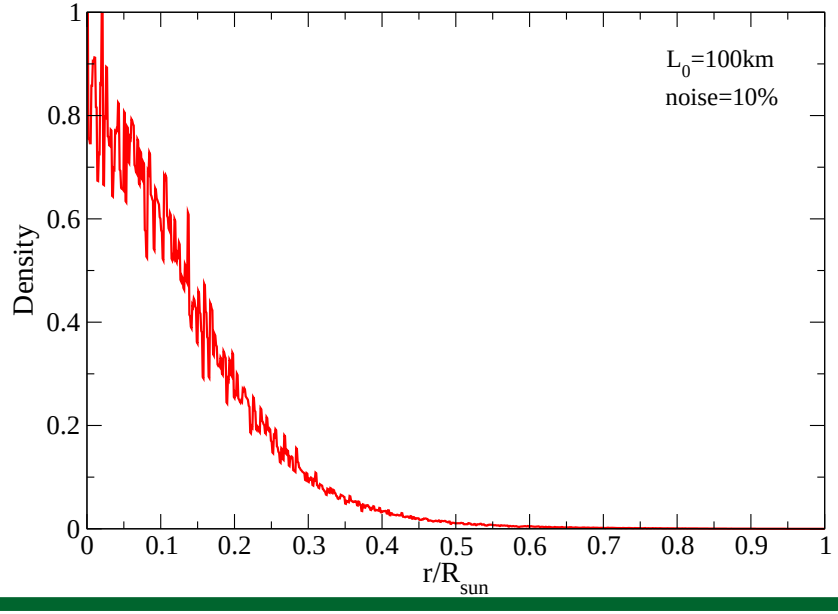
Maltoni et al., hep-ph/0405172v5 (2006)

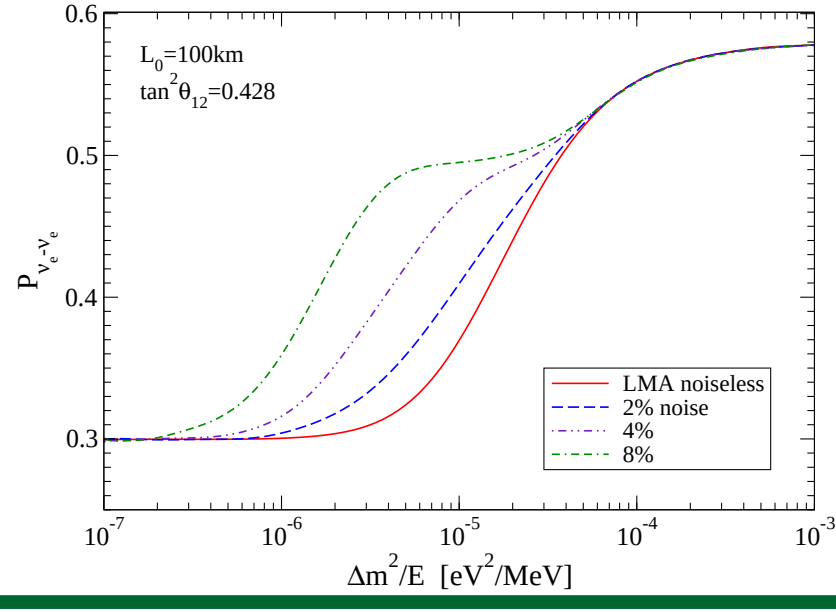
Importance of density fluctuations

Burgess, Dzhalilov,
Maltoni, TR,
Semikoz, Tortola,
Valle ’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, Dzhalilov, Maltoni, TR, Semikoz, Tortola and Valle'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, TR, Rez and Valle'04 (magn), Friedland'05 (magn),
Friedland and Gruzinov'06

Magnetic case as an example

2ν spin-flavor precession in random field,

$\Delta = \Delta m^2/4E = \pi/L_{osc}$ Miranda, TR, Rez and Valle '03, '04

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

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},

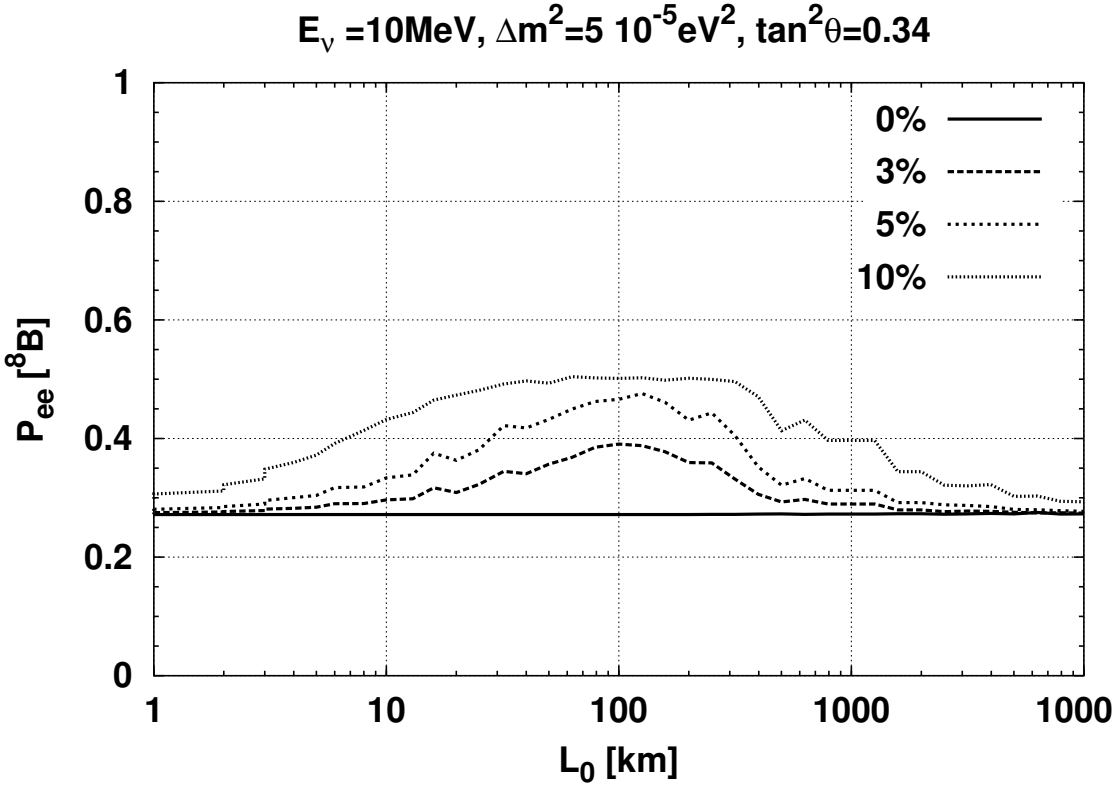
  in the inertial scale of Kolmogorov turbulence $b_{turb}(l) \sim l^{1/3}$

Parametric resonance

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

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

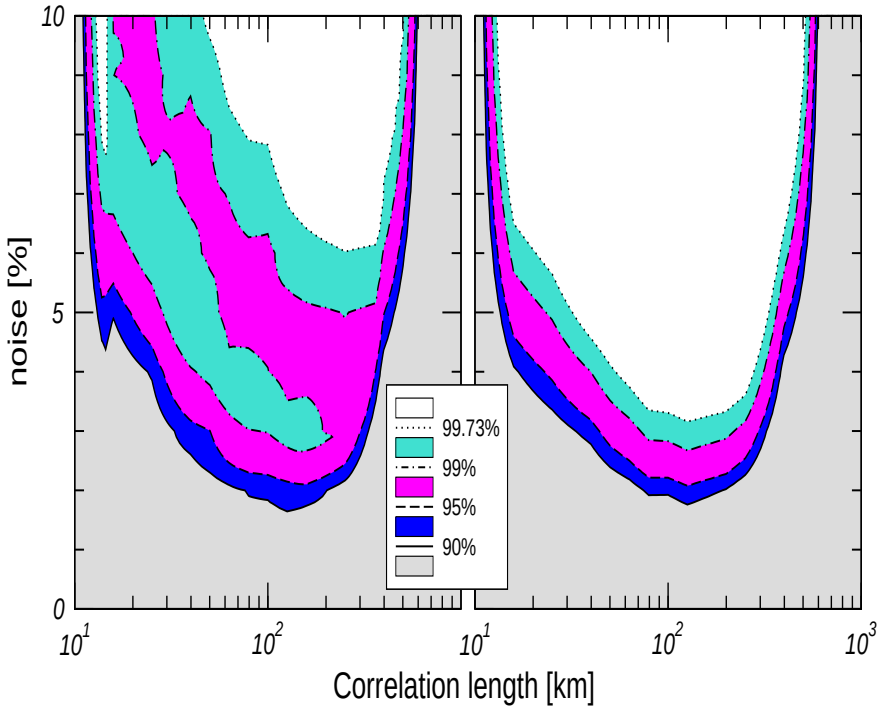
and numerically:

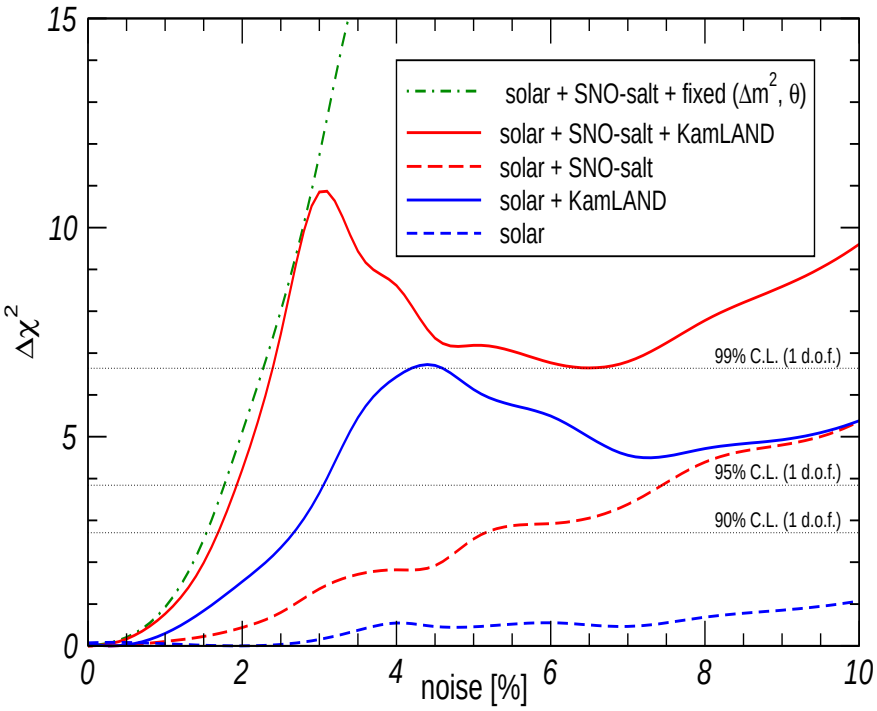


δ-correlations describes only the left side of the graph.

Probing solar noise with neutrinos

Burgess, Dzhalilov, Maltoni, TR, Semikoz, Tortola and Valle '03

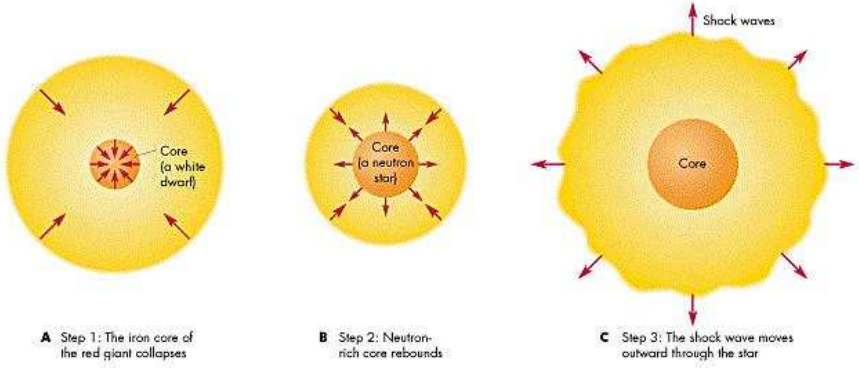


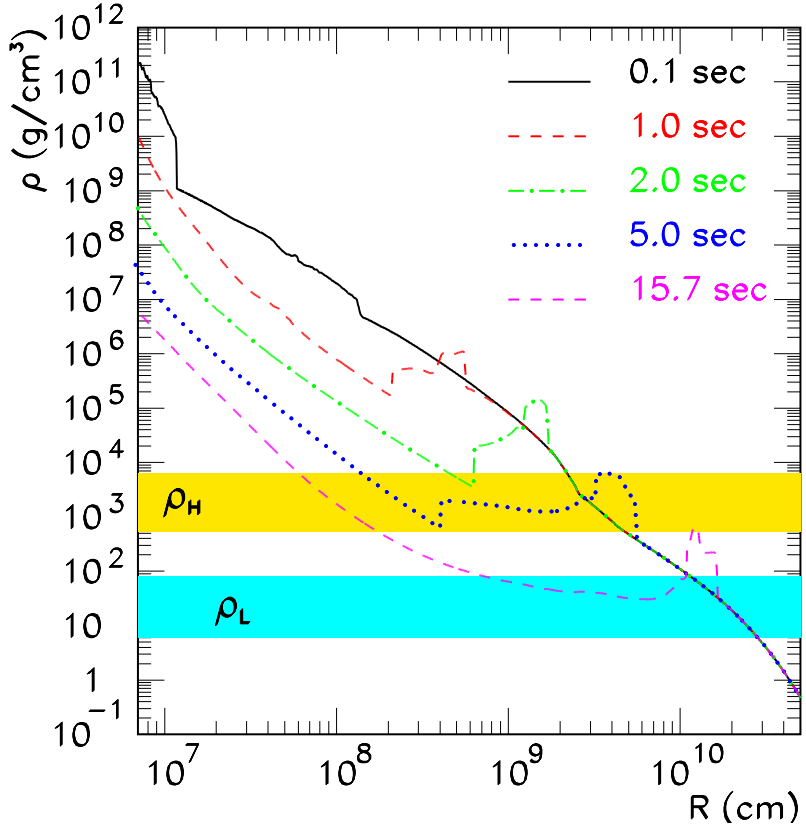


- Only neutrinos probe scales ~ 100 km, helioseismology bounds noise $< 0.1\%$ but at the scales > 1000 km!
- Future solar neutrino experiments like Hyper-K, UNO, LENA etc will have much better sensitivity to solar small-scale fluctuations.

Supernovae neutrinos

Tomas et al, astro-ph/0407132

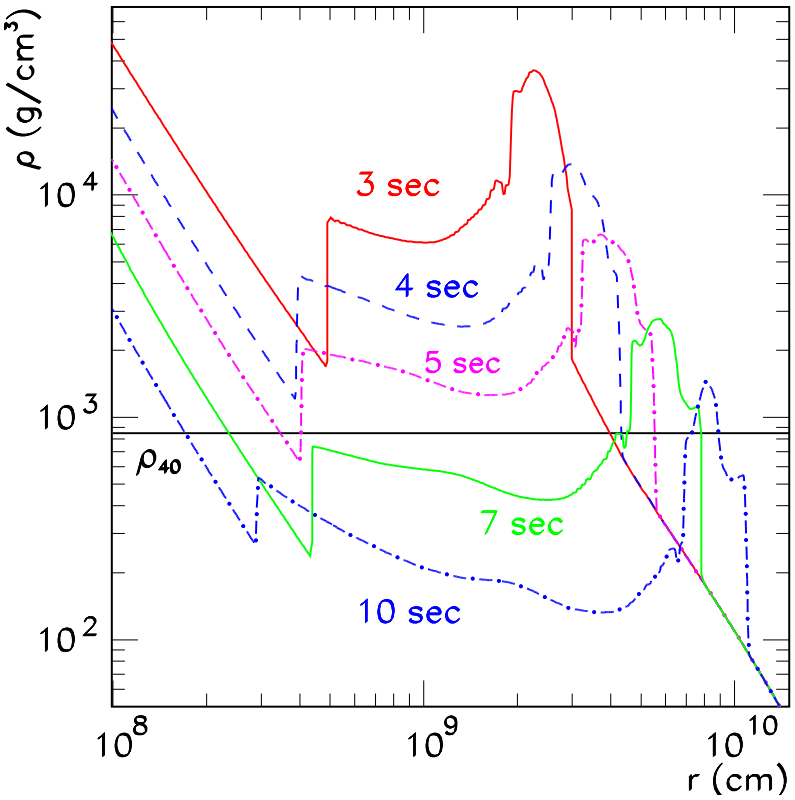


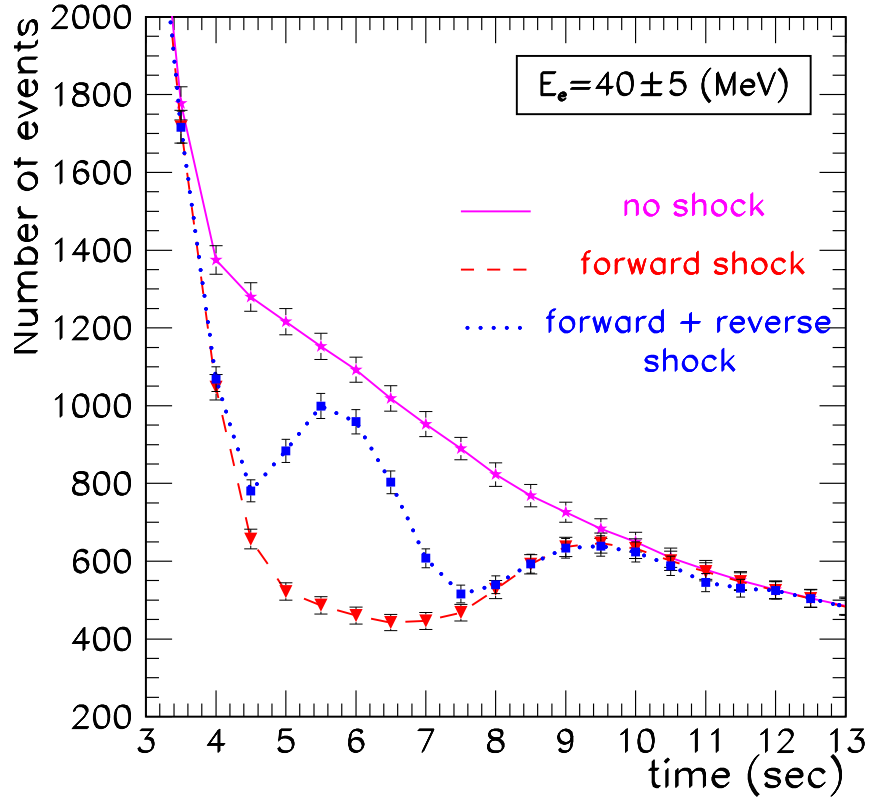


till now, only SN1987a ν-s were detected (Kamiokande, IMB and Baksan)

Supernovae shock propagation

Tomas et al, astro-ph/0407132

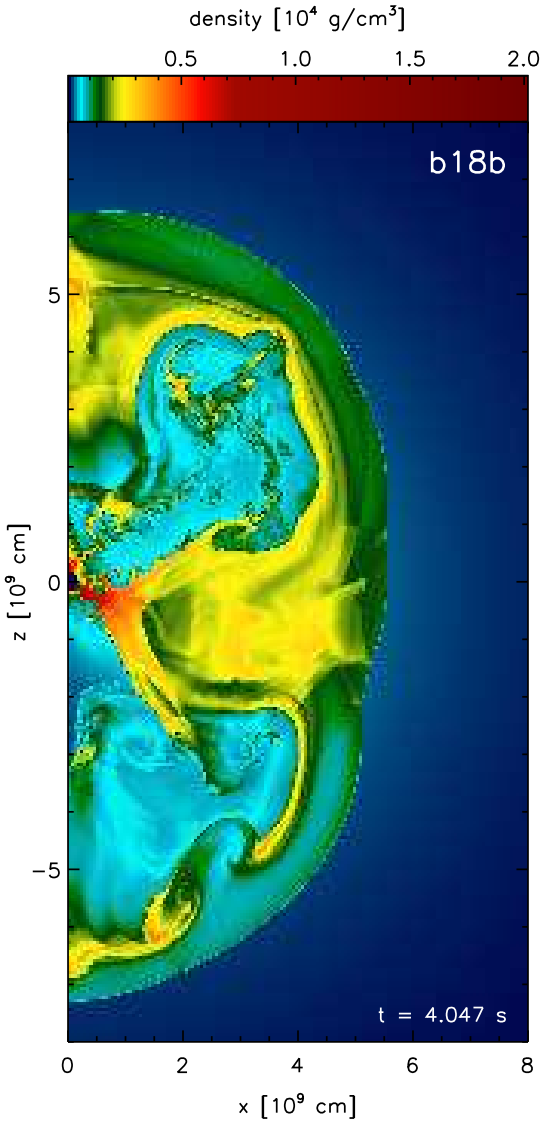




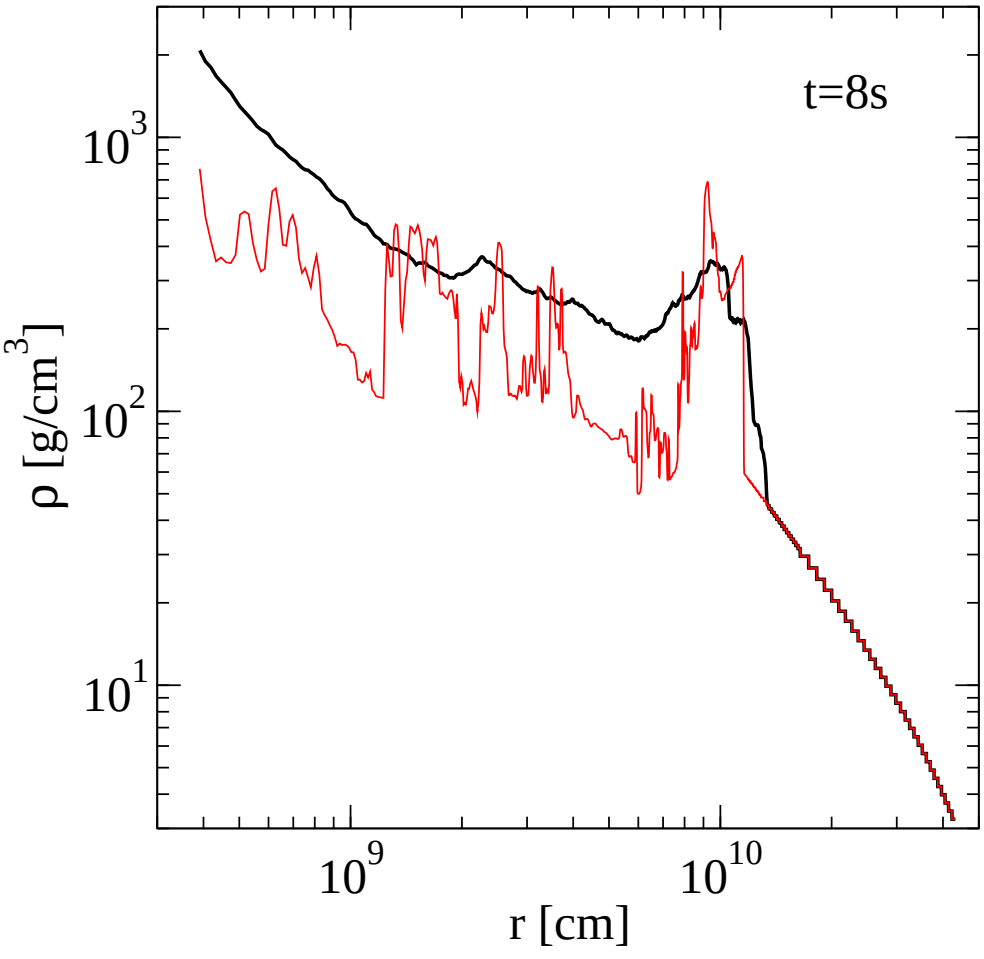
No matter density fluctuations

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

Supernovae density fluctuations



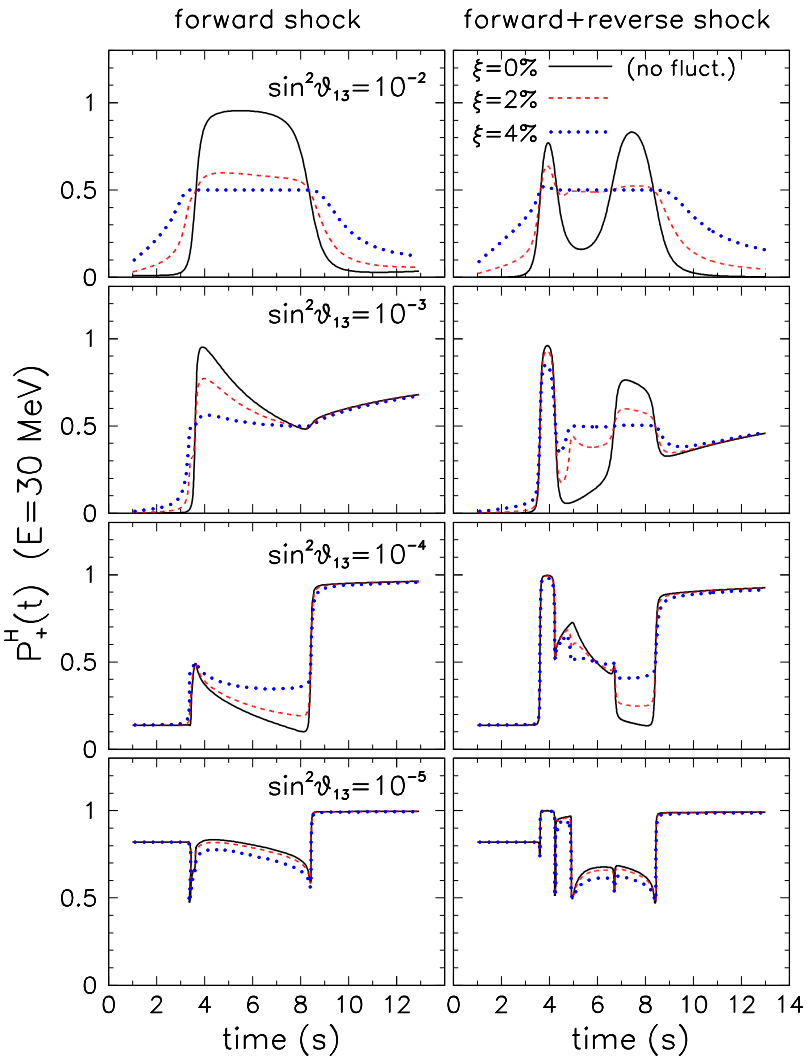
Kifonidis et al, astro-ph/0511369 (Garching)

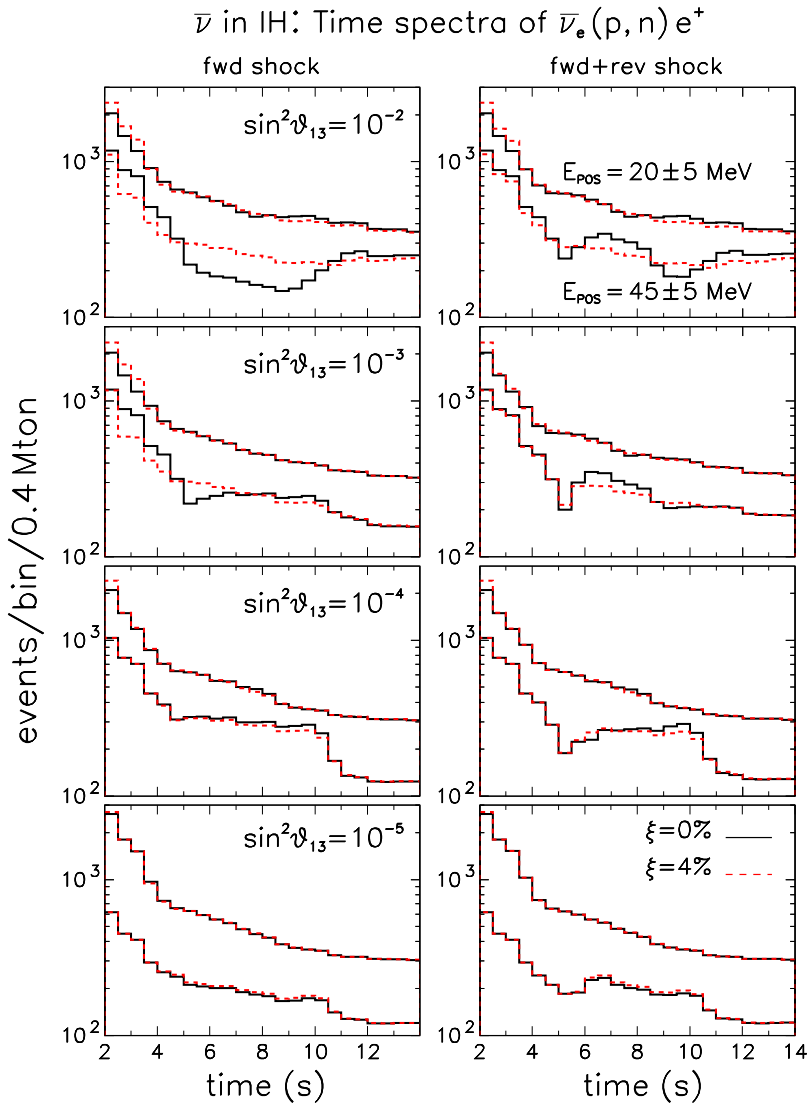


Shock-waves with fluctuations

Fogli et al, hep-ph/0603033

δ-correlated noise





SN turbulence: questions

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

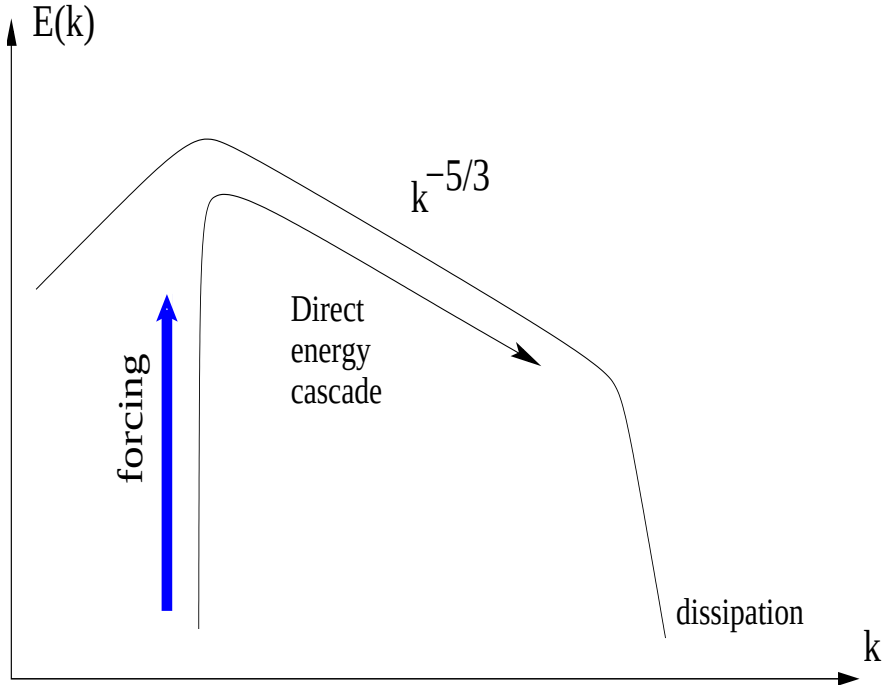
What is turbulence?

- Development of small scale structure from large scale motion
- Described by Navier-Stokes equations:

$$\frac{\partial \vec{v}}{\partial t} + \vec{v}\nabla\vec{v} = -\nabla p + \eta\nabla^2\vec{v} + \vec{f}, \quad \nabla v = 0$$

- Dimension analysis and concept of inertial range [Kolmogorov'41]

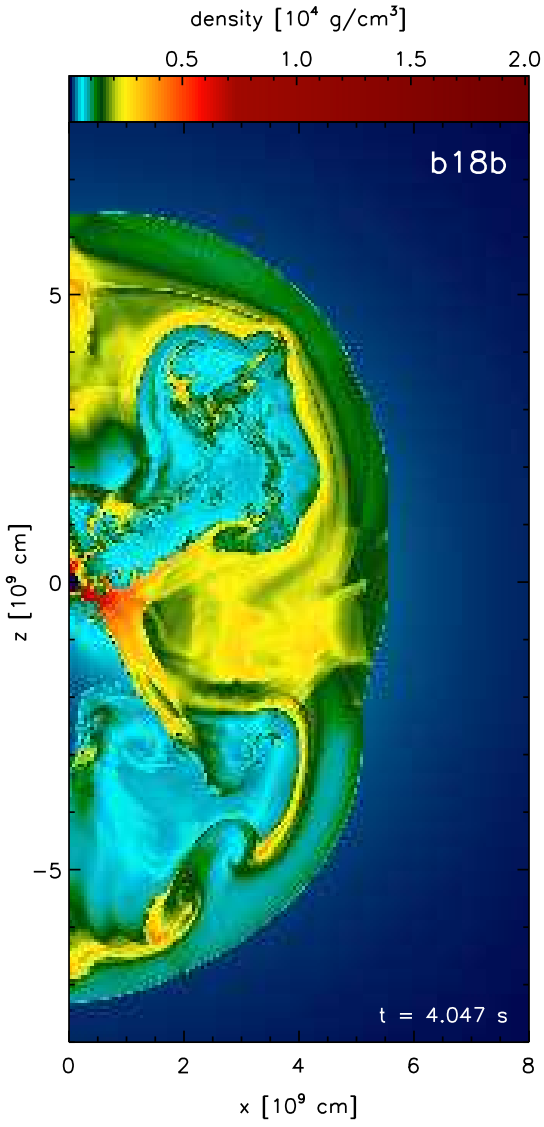
$$E(k) = C\epsilon^{3/2}k^{-5/3}$$



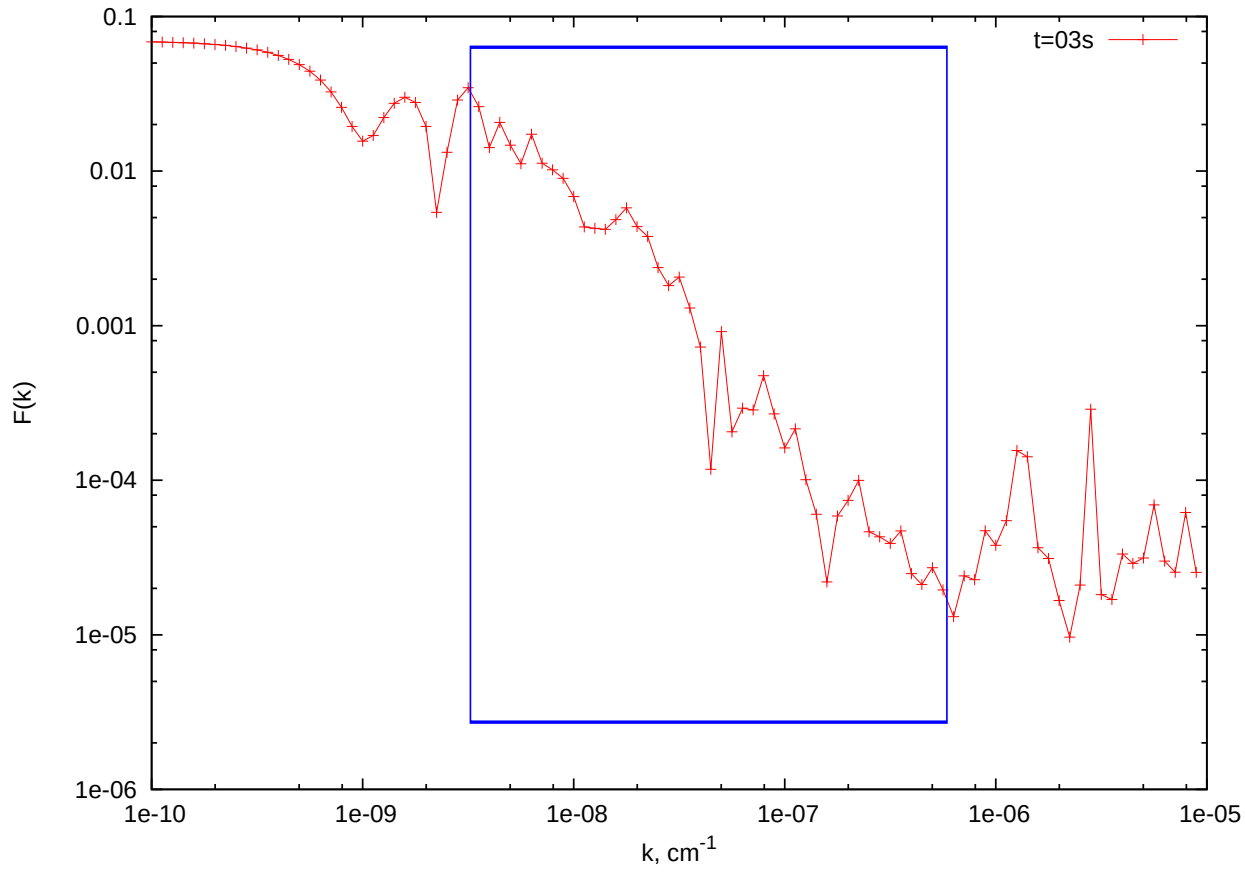
Leonardo Da Vinci

Is it Kolmogorov-like turbulence?

Garching group



Noise power spectrum from 2D simulations



Answer: it is close to power-law spectrum

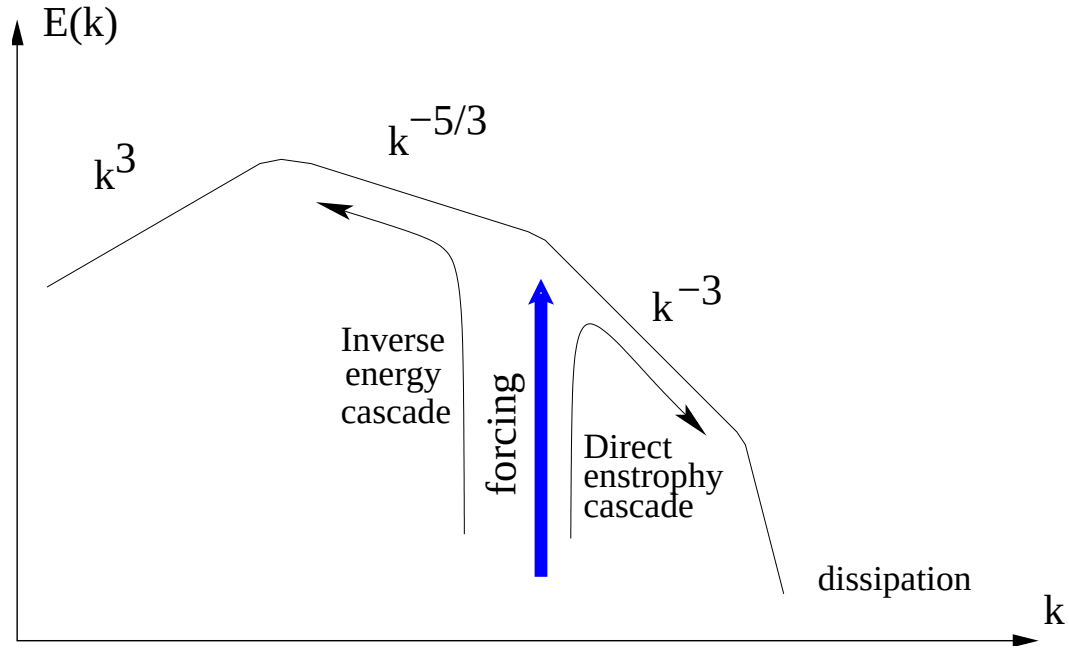
Two dimensional turbulence

Can one get some information from 2D simulations?

2D turbulence,
classical picture

Kraichnan'67, Leith'68,

Batchelor'69

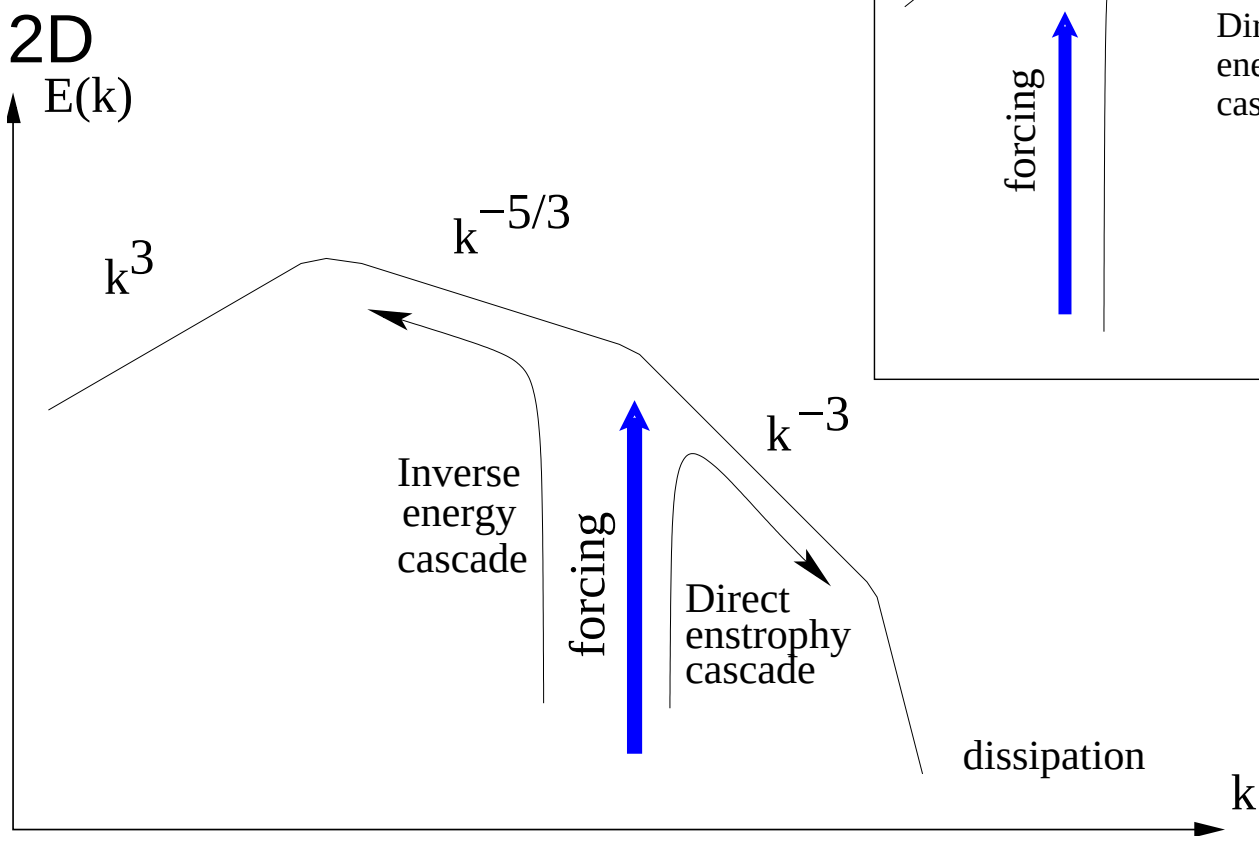


Problems come when finite time scale and size of the system are taken into account $\rightarrow$ several contradictory scenarios in literature.

Answer: mostly qualitative information is expected from 2D.

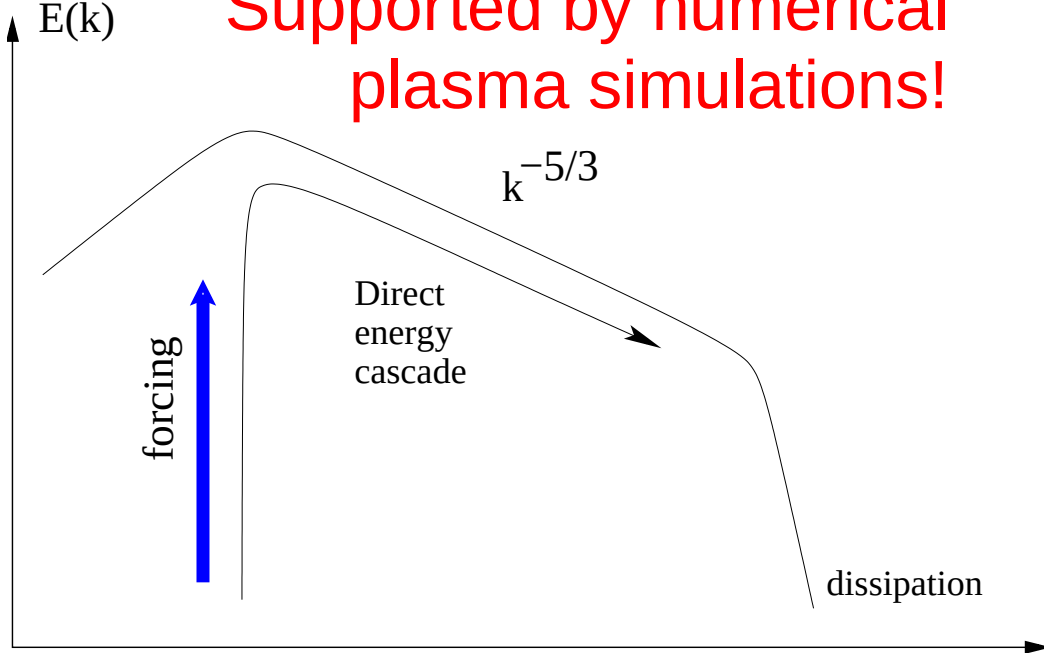
2D *vs* 3D turbulence

Classical picture



Kraichnan'67, Leith'68, Batchelor'69

3D

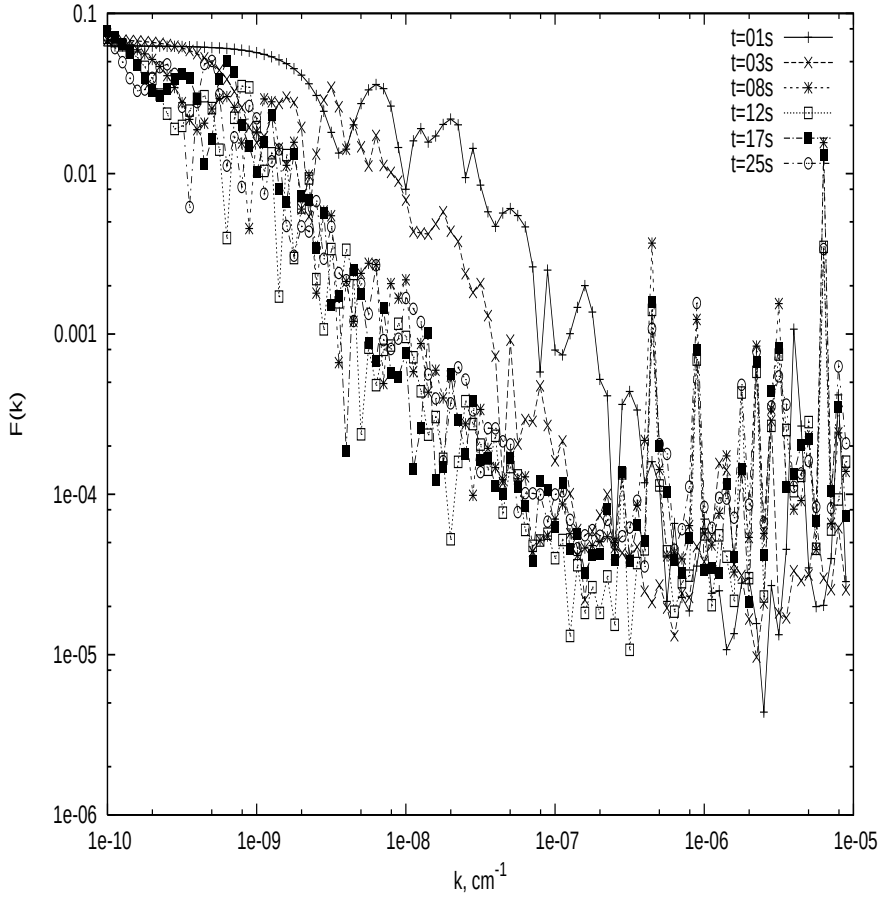


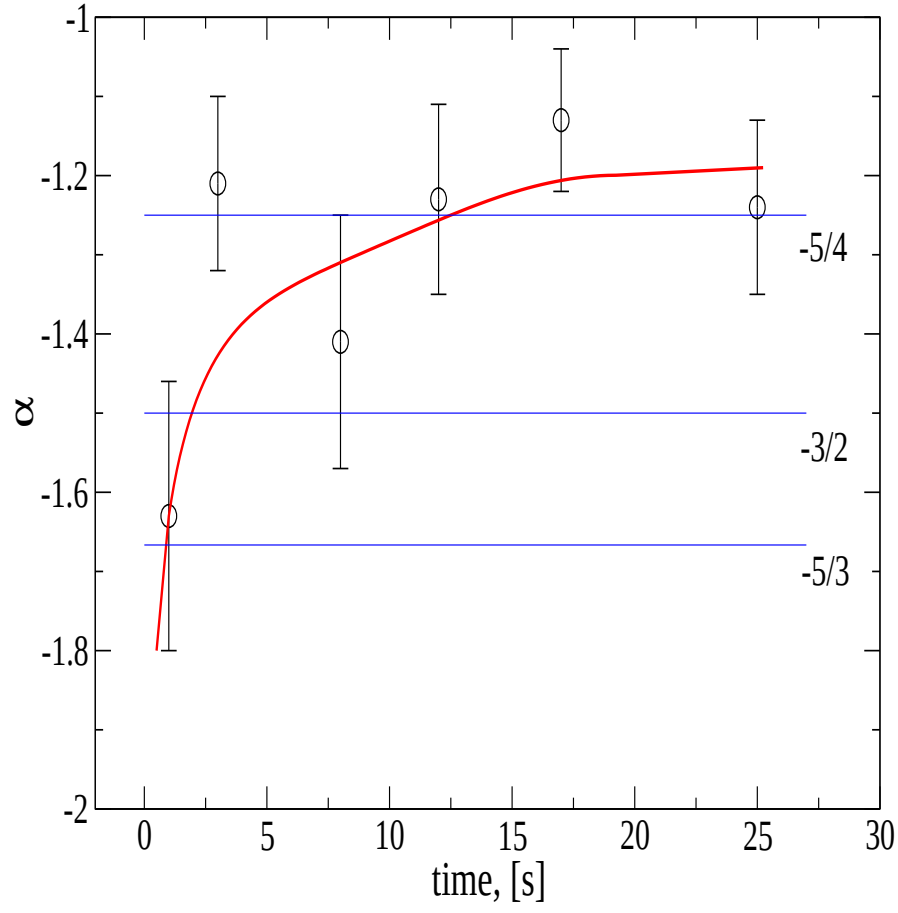
Supported by numerical plasma simulations!

Kolmogorov'41

Developed turbulence?

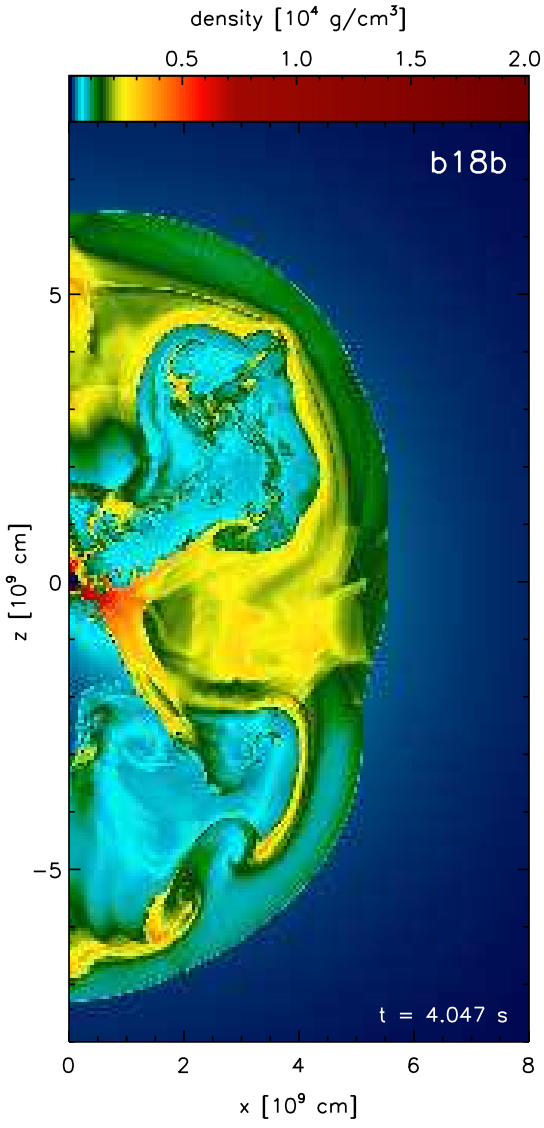
Time evolution of noise spectra from 2D simulations by Garching group





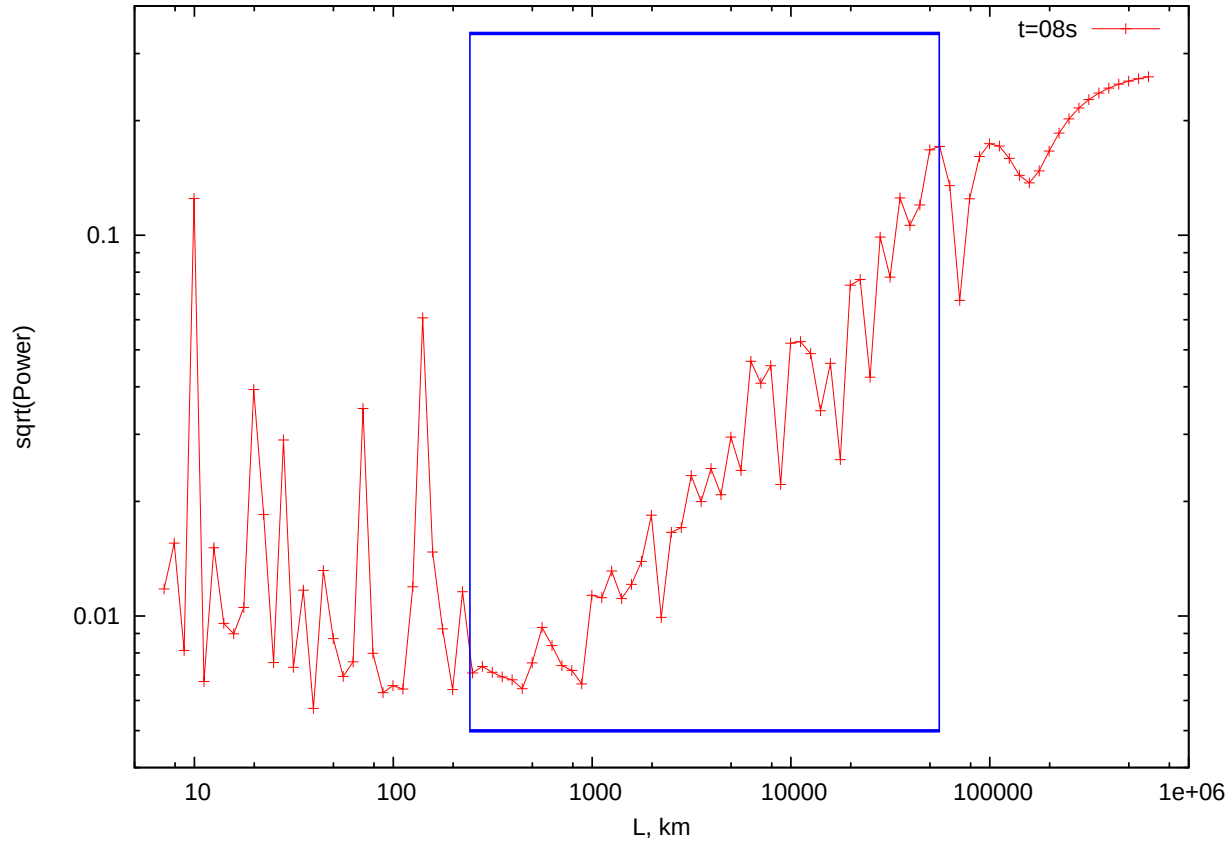
Answer: first few seconds - probably not,
after 10 seconds - probably yes.

How large are the perturbations?



Estimate of noise strength

. from 2D simulations made by Janka and Kifonidis



Can be 10% and more!

How does turbulence affect ν-s

First estimate of the influence of turbulence on neutrinos in Supernovae

Friedland and Gruzinov, hep-ph/0607244

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

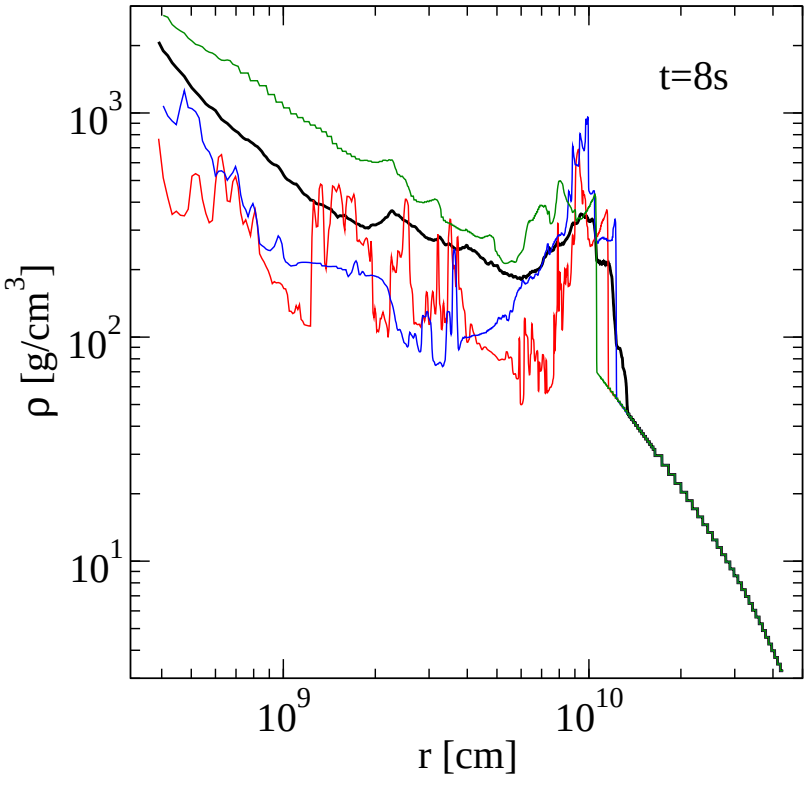
$$P^{Kolm} \simeq 0.84 G_F C_0 (2\Delta \sin 2\theta_{13})^{-2/3} / \sqrt{2} |n_0'|, \quad \alpha = -5/3$$

Full depolarization of neutrino states if

$$\frac{\delta n}{n} > 0.1\, \theta_{13}^{1/3}$$

More open questions

- No unique prediction of SN neutrino spectra



Garching group

- Neutrino selfinteractions near neutrinosphere may alter significantly initial neutrino spectra

Samuel'93

. . .

Pastor et al'01, '02

Duan et al'05, '06

Hannestad et al'06

Summary

- Fluctuating medium modifies neutrino spectra.
- Sun:
  density fluctuations at small spatial scales are constrained by neutrino data only.
- Supernova:
  density fluctuations are expected to be strong and therefore they significantly affect neutrino flavor spectra.
  Numerical calculations are coming soon.
- No unique prediction of Supernovae neutrino signal is possible.

Thank you.