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MATTER SUPPRESSION OF COLLECTIVE SN NEUTRINO OSCILLATIONS

Alessandro MIRIZZI
(Hamburg University)

Based on works in collaboration with: S.Chakraborty, T.Fischer, N. Saviano, R.Tomas, arXiv: 1104.4031, 1105.1130

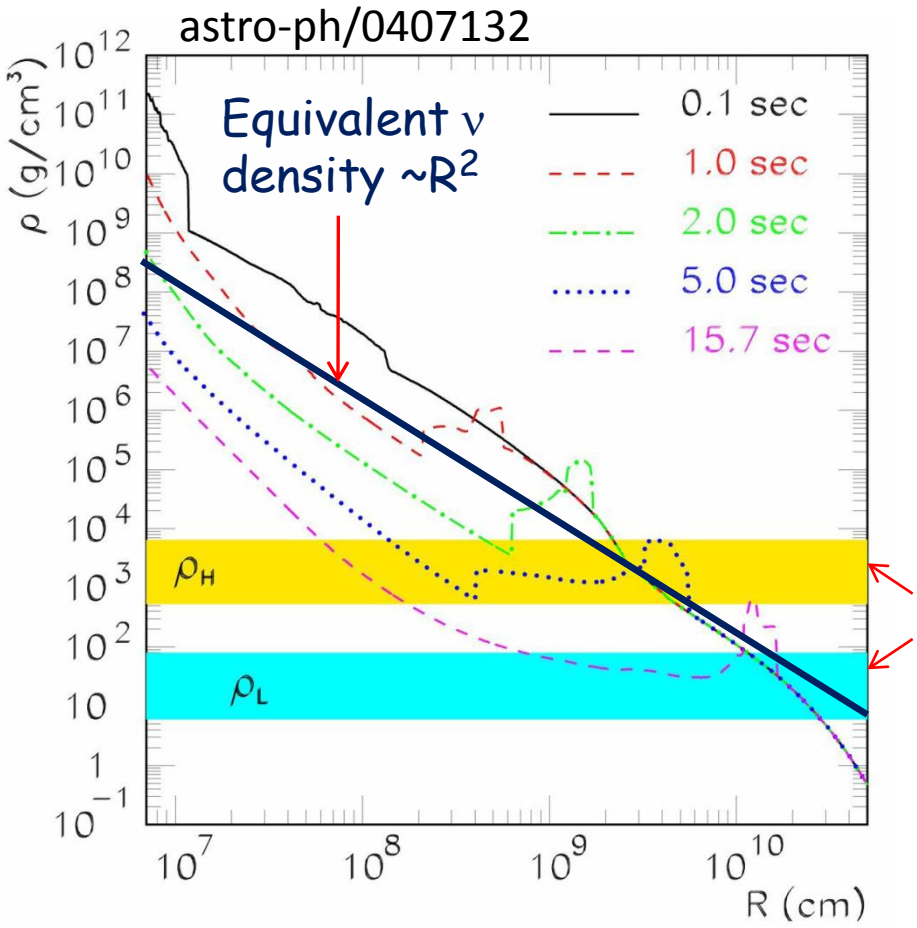
OUTLINE

I will follow the scheme proposed by the father of the scientific method Francis Bacon (1561-1626) in the *Novum Organum:*

- IDOLA (prejudice, false belief): Matter does not matter in collective oscillations in SNe
- PARS DESTRUENS: Matter suppression of collective oscillations during the accretion phase
- PARS COSTRUENS: Mass hierarchy determination at large θ_{13}

IDOLUM: Matter deos not matter

SNAP-SHOTS OF SN DENSITY PROFILES



- Matter bkg potential

$$\lambda = \sqrt{2} G_F N_e \quad \sim R^{-3}$$

- ν–ν interaction

$$\mu = \sqrt{2} G_F n_\nu \quad \sim R^{-2}$$

- Vacuum oscillation frequencies

$$\omega = \frac{\Delta m^2}{2E}$$

When $\mu >> \lambda$, SN ν oscillations dominated by ν-ν interactions

→ Collective flavor transitions at low-radii [O (10^2 – 10^3 km)]

[see Duan et al, arXiv:1001.2799 [hep-ph] for a review]

PRECESSION EQUATIONS OF MOTION

Decompose (anti)neutrino density matrix over Pauli matrices to get the "**polarization**" (Bloch) vector **P**. Survival probability P_{ee} related to $\mathbf{P}_Z$.

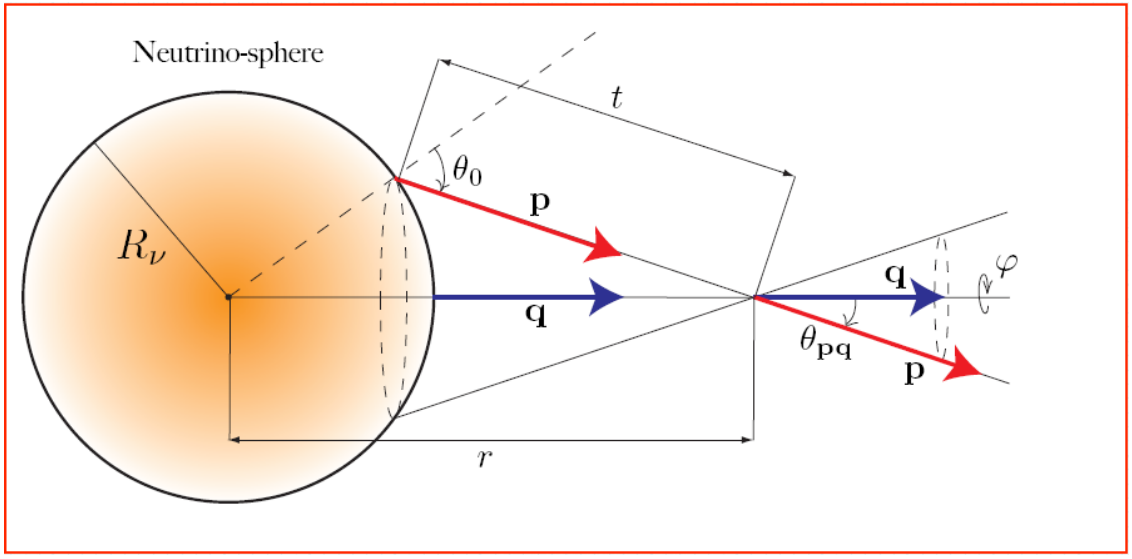
Neutrinos streaming from a SN core, evolution along the radial direction

Liouville operator

$$(\vec{v}\cdot\vec{\nabla})\vec{P}_{\omega,v} = H[\omega,\lambda,\mu,\vec{P}_{\omega,v'}]\times\vec{P}_{\omega,v}$$

$v = \cos\theta_r$ ⟶ v radial velocity

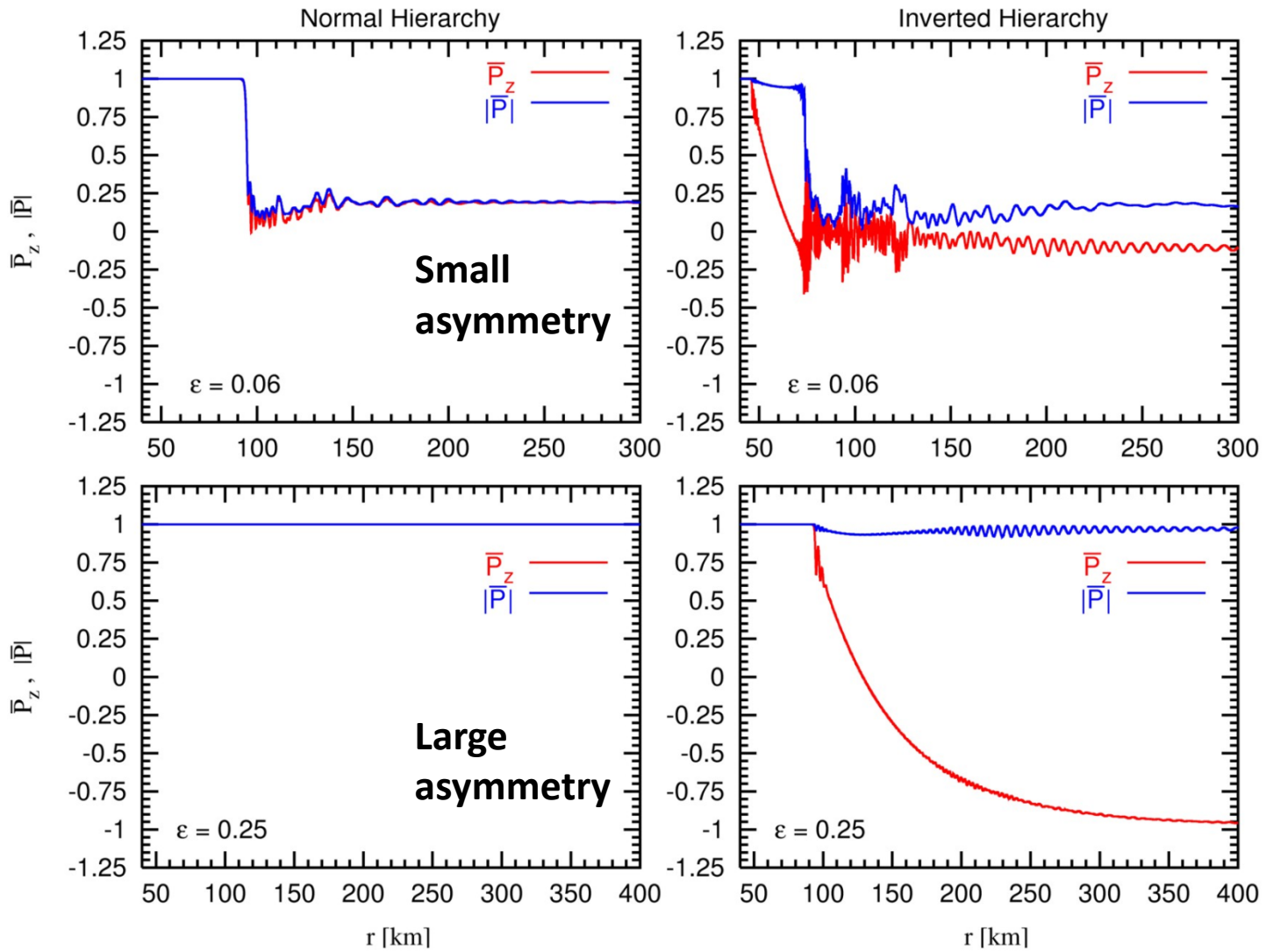
"Multi-angle" effects: $\mu \to \mu(1-\cos\theta_{vv'})$



Possible decoherence of collective effects
[*see Esteban-Pretel et al., arXiv:0706.2498 [astro-ph]*]

MULTI-ANGLE DECOHERENCE FOR SN NEUTRINOS

[*Esteban-Pretel et al., arXiv:0706.2498 [astro-ph]*]

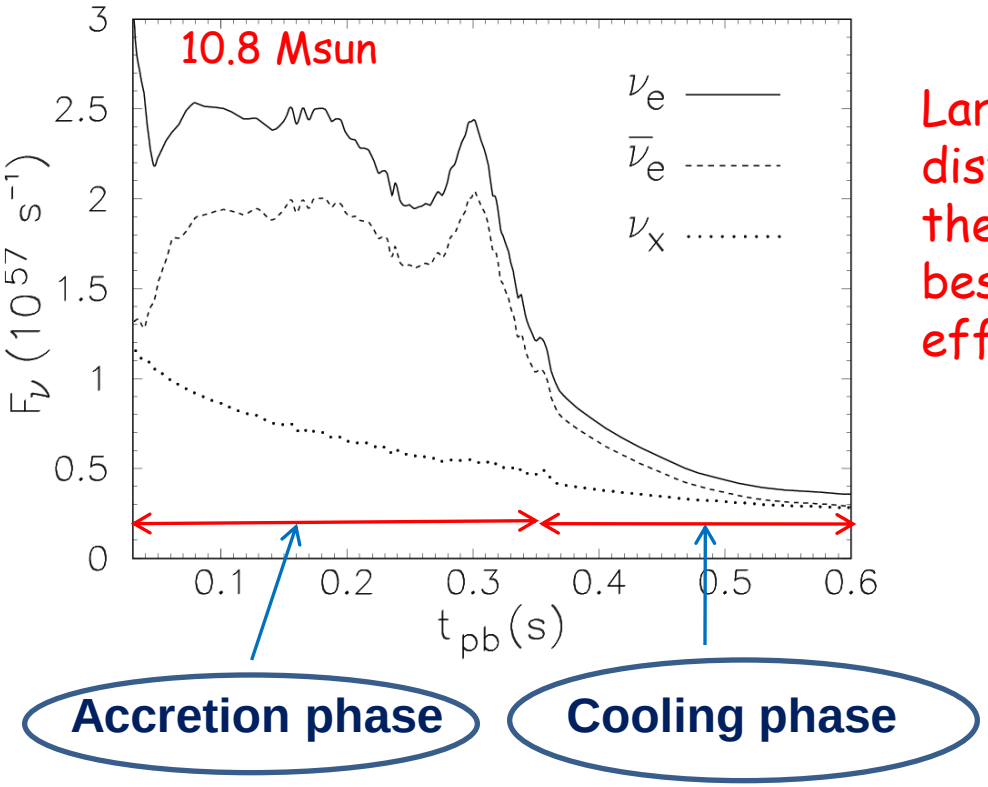


Large $\nu_e\overline{\nu}_e$ asymmetry required to suppress multi-angle decoherence

NEUTRINO FLUX NUMBERS

New long-term SN simulations [*Fischer et al. (Basel group), arXiv:0908.1871*]

- Spherically symmetric with Boltzmann neutrino transport
- Explosion manually triggered by enhanced CC interaction rate



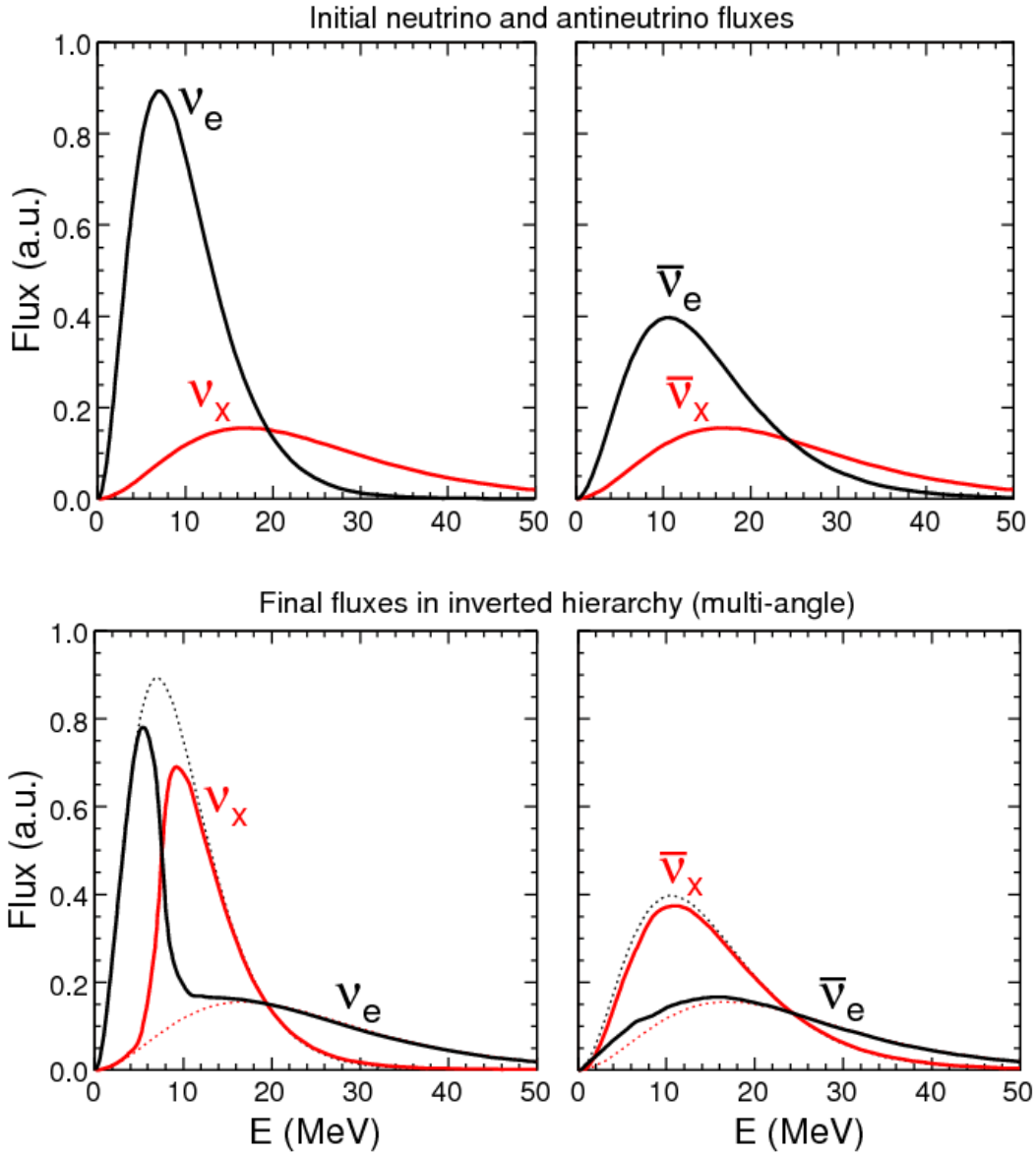
Large neutrino fluxes with distinct flavor hierarchy during the accretion phase offer the best opportunity to detect effects from ν flavor oscillations.

Excess of ν_e over ν_x due to core deleponization

Moderate flavor hierarchy

COLLECTIVE EFFECTS IN THE ACCRETION PHASE

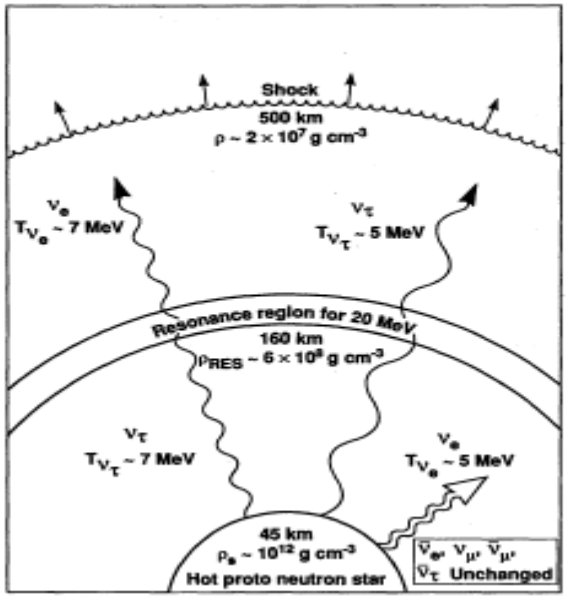
[*Fogli, Lisi, Marrone, A.M. , arXiV: 0707.1998 [hep-ph]*]



For $\lambda \ll \mu$

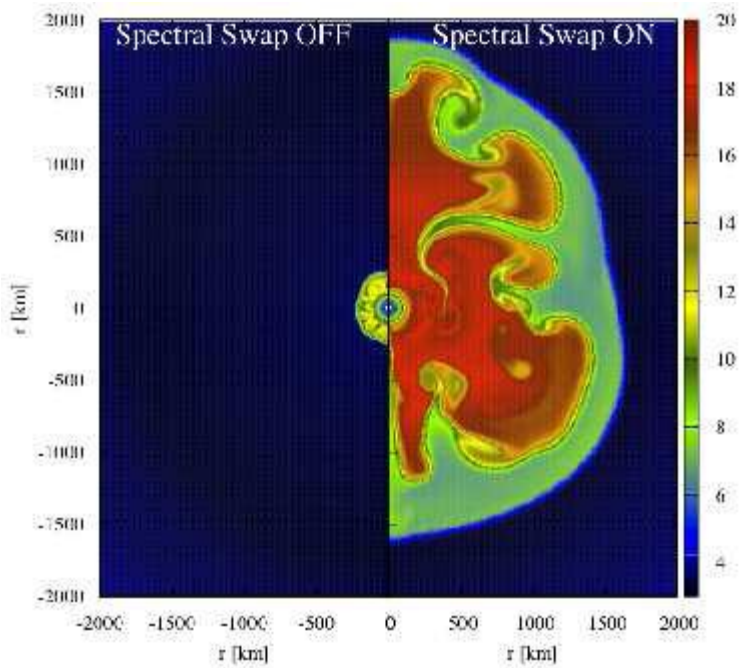
- Collective effects in inverted mass hierarchy (atm. $\Delta m^2 < 0$)
- Spectral splits and swaps
- Multi-angle effects subleadings ("quasi-single angle" behavior)
- Possible probe of the mass hierarchy at $\theta_{13} \longrightarrow 0$
  [see, e.g., Duan et al., arXiv:0707.0290, Dasgupta et al., arXiv:0802.1481]

POSSIBLE EFFECTS ON THE SHOCK REHEATING?



Flavor conversions btw ν_e and ν_x in the region btw the neutrinosphere and the shock front would increase the heating rate behind the shock via ν_e and $\bar{\nu}_e$ CC absorptions, since $\langle E_x \rangle > \langle E_e \rangle$.

[see Fuller et al., ApJ 389, 517 (1992)]



Can self-induced $\nu_e\bar{\nu}_e \rightarrow \nu_x\bar{\nu}_x$ revitalize the shock wave?

Putting manually a spectral swap before the shock front, strong SN explosions have been obtained for no exploding models. [see Suwa et al., arXiv:1106.5487]

HOWEVER….THERE IS NO FREE LUNCH!

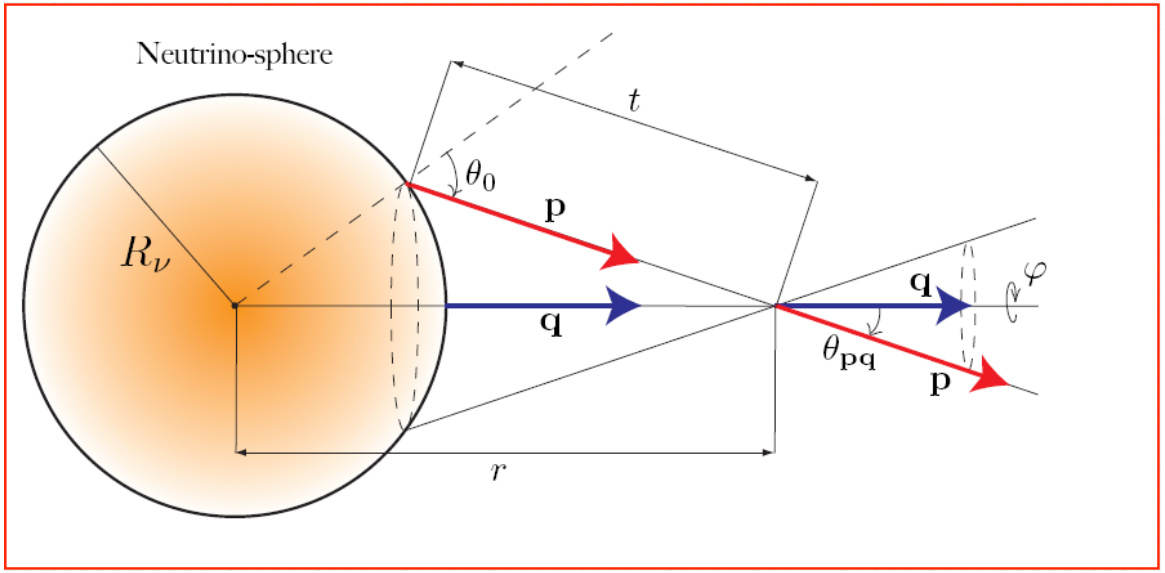
IL CONVITATO DI PIETRA

Will take his revenge!

MATTER INDUCED MULTI-ANGLE EFFECTS

[*Esteban-Pretel, A.M., Pastor, Tomas, Raffelt, Serpico & Sigl, arxiv: 0807.0659*]

- Spherical stream

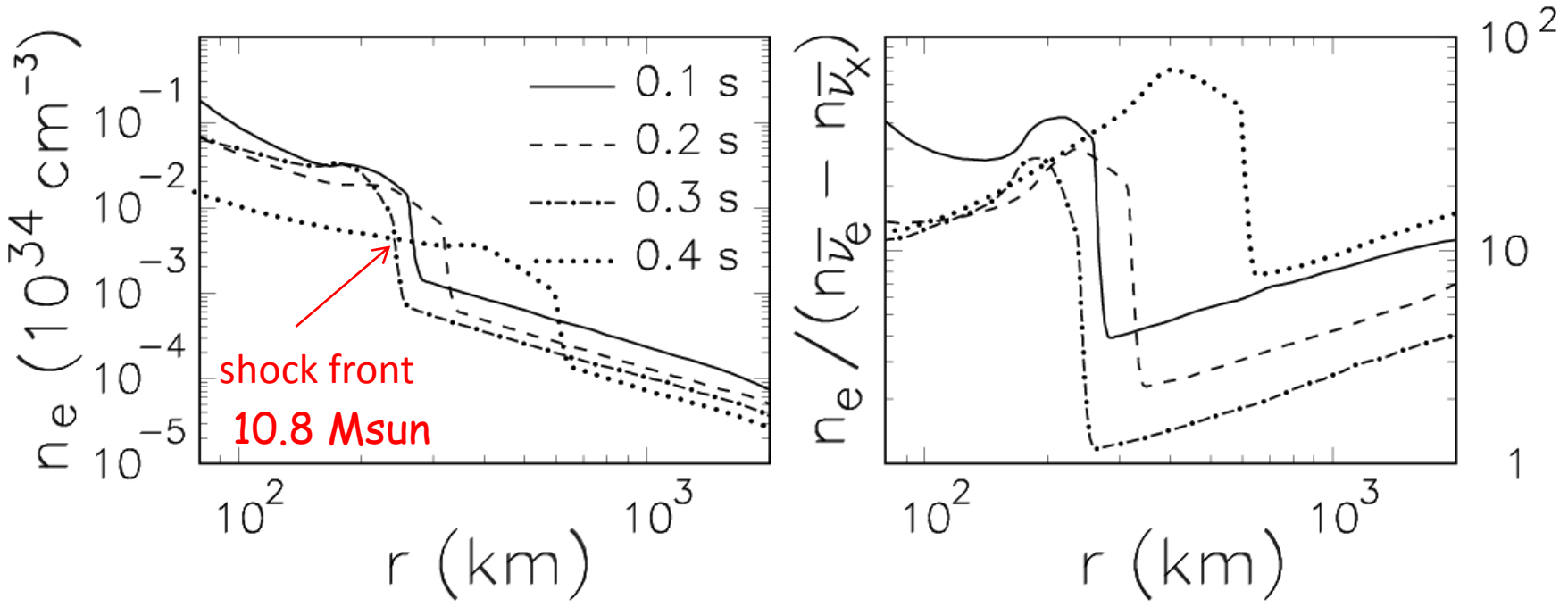


- Neutrinos emitted from a spherical source acquire different phases at a given radius r, having travelled on different trajectories.
- Matter effect is not the same for all the modes.
- It would introduce trajectory-dependent multi-angle effects.

Matter effect can suppress collective conversion unless $N_\nu \gtrsim N_e$

MATTER EFFECTS DURING THE ACCRETION PHASE

[*Chakraborthy, Fischer, A.M., Saviano & Tomas, 1104.4031, 1105.1130*]



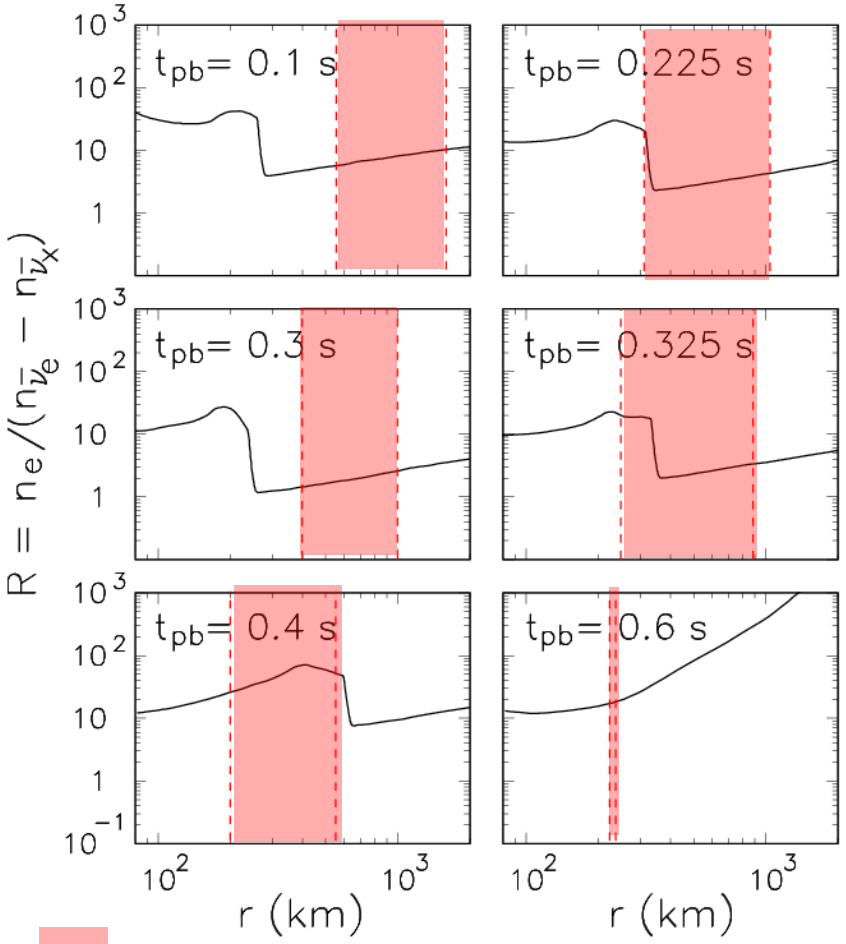
$$R = \frac{n_e}{n_\nu} > 1$$

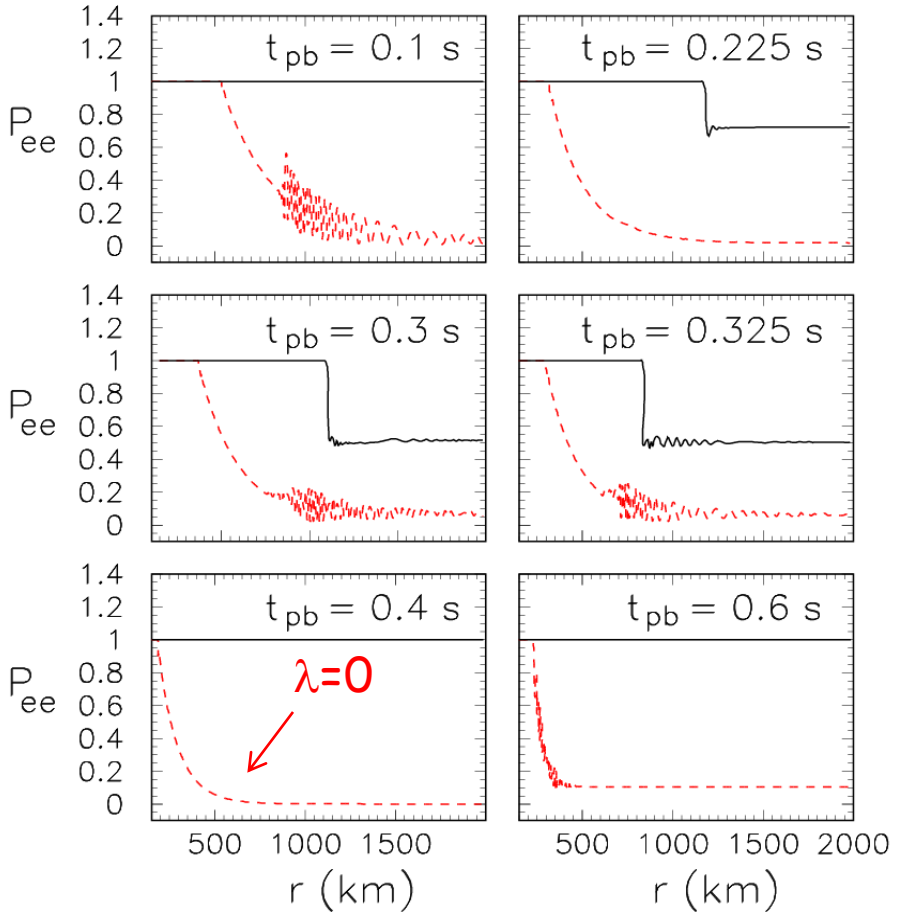
Matter effects cannot be neglected during the accretion phase!

PARS DESTRUENS: Matter suppression of collective oscillations during the accretion phase

MATTER SUPPRESSION OF COLLECTIVE OSCILLATIONS

Schematic single-energy (E=15 MeV) multi-angle treatment

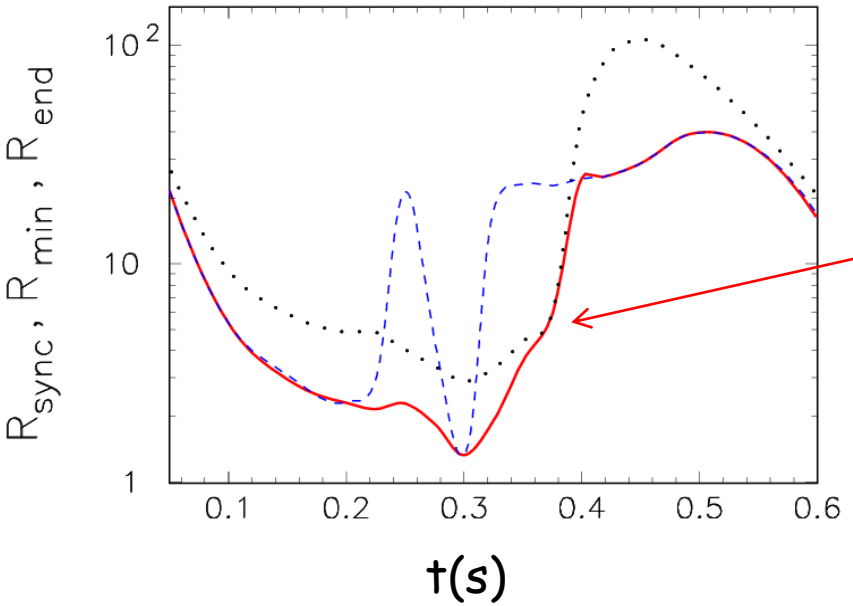




= collective range (λ=0)

- R>> 1 ⟹ Complete suppression (P_{ee}=1)
- R~ 1 ⟹ Decoherence (P_{ee}=1/2)

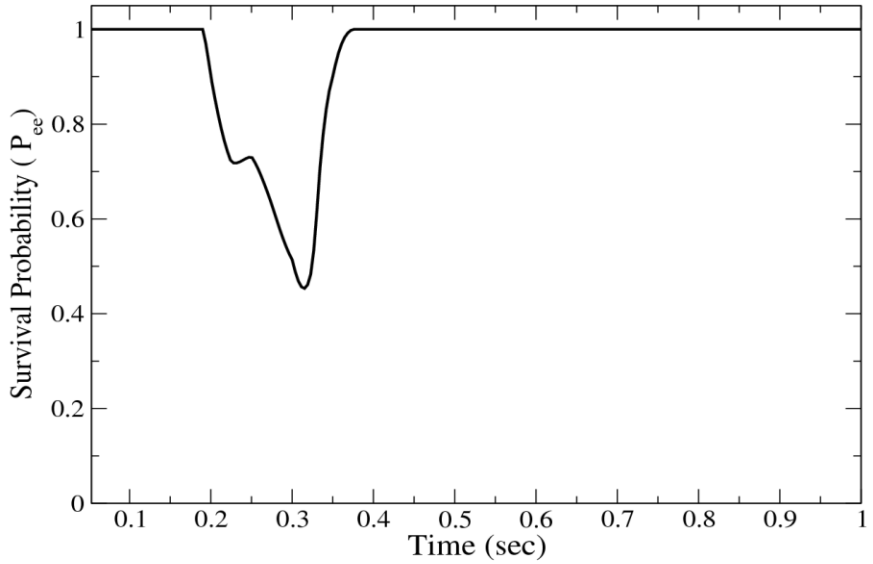
TIME DEPENDENCE OF MATTER SUPPRESSION



Our figure of merit

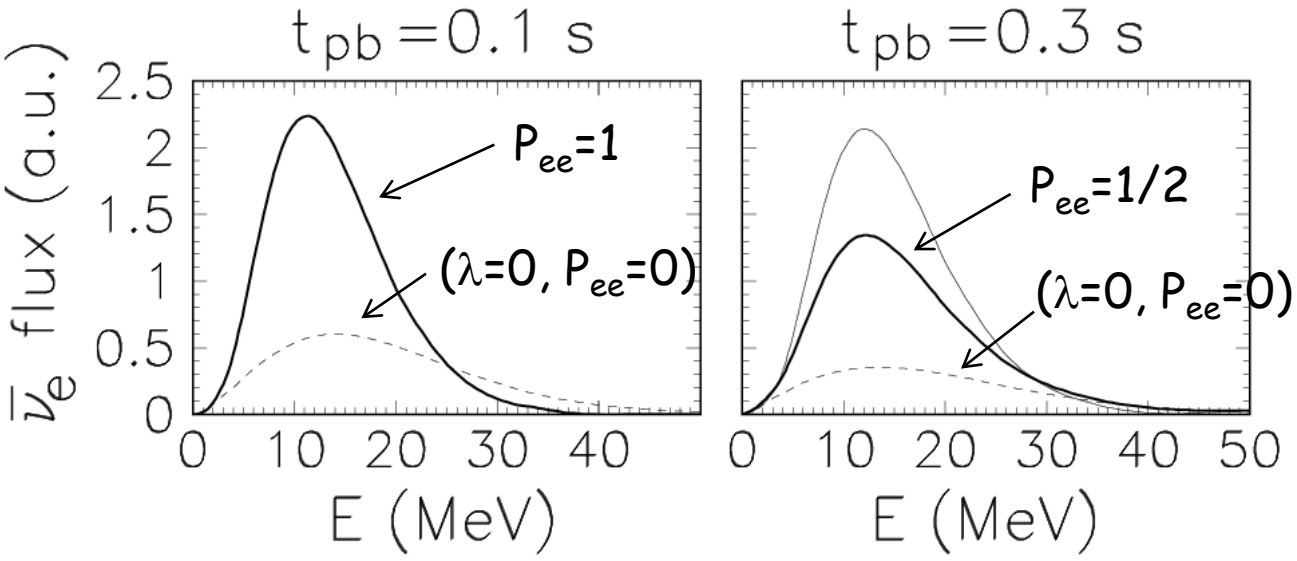
Time evolution of $R = n_e/n_\nu$ at its minimum in the possible range of conversions

The dip in R corresponds to the onset of the explosion



In the first second post-bounce, the matter suppression is complete, except for $0.2 < t < 0.4$ s

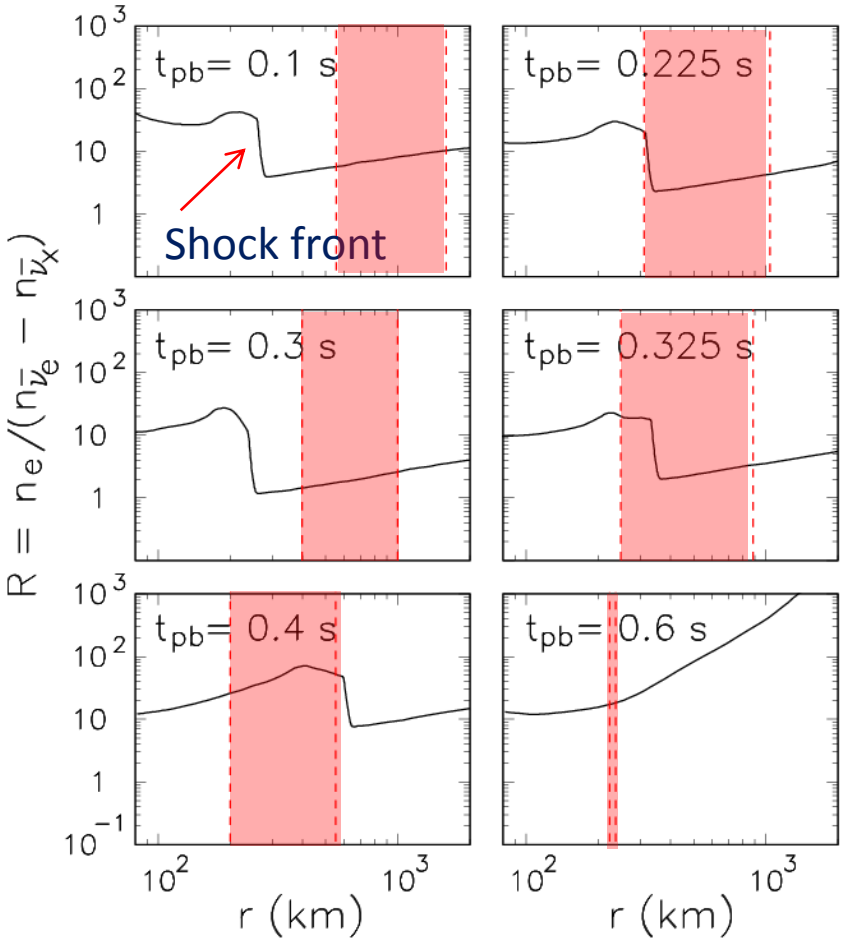
OSCILLATED SN NEUTRINO FLUXES

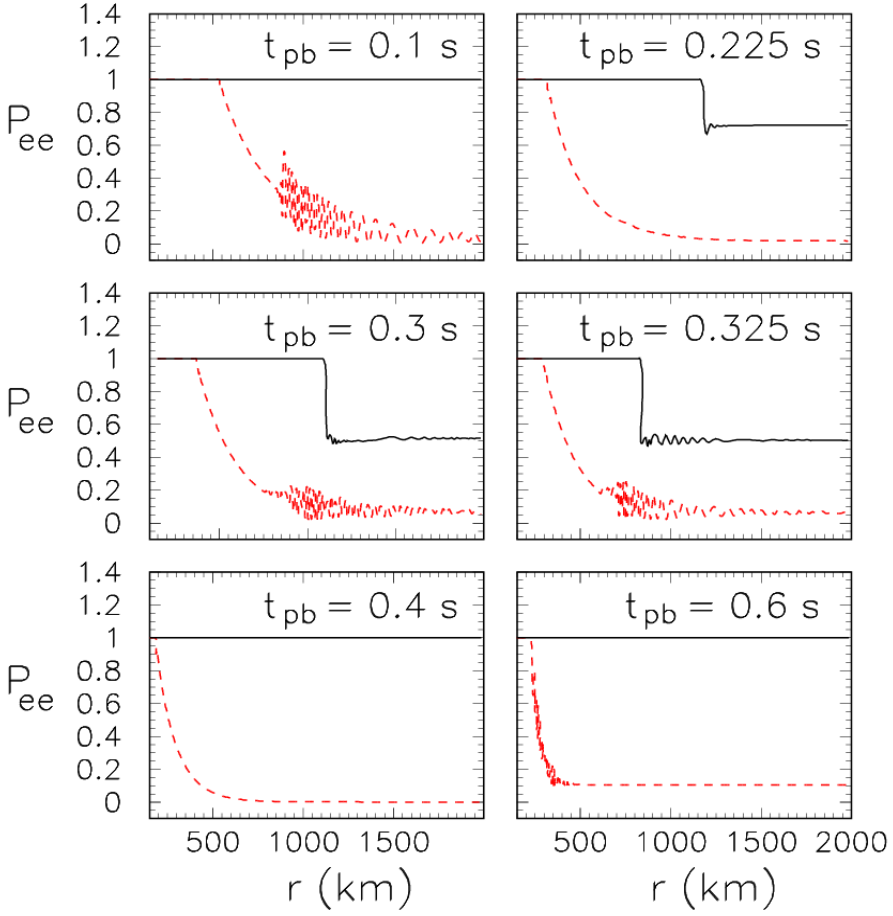


Striking difference btw the no matter/matter cases

The interpretation of the SN ν signal during the accretion phase changes once more

NO OSCILLATION EFFECT ON SHOCK REVIVAL





Matter suppression implies no oscillation effect on shock-reheating.
Note: already for λ=0 the oscillation range at t < 0.3 s would be at r> r_{shock}

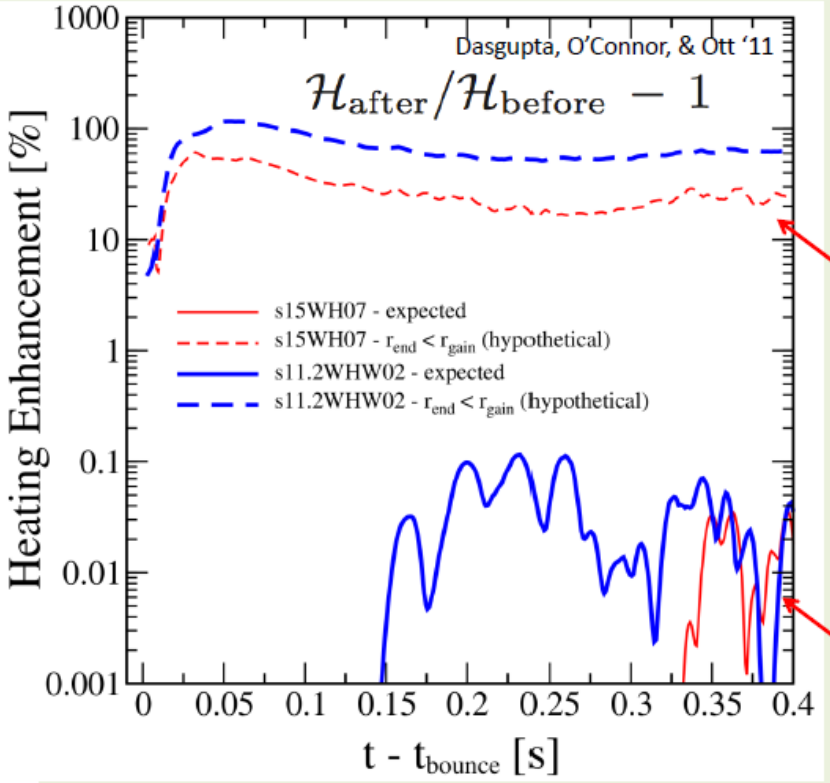
COMPARISON WITH OTHER PAPERS

Slide from C.Ott's talk

Heating Enhancement

[work with Basudeb Dasgupta and Evan O'Connor, arXiv:1106.1167]

Progenitors:
11.2 M_{Sun}
15 M_{Sun}
Woosley et al. '02



most optimistic guess

Not really reliable. (approach by Suwa at al., 11)

Single-angle results from actual calculations

Matter suppression would presumably reduce even more the effect.

See also
Suwa et al. '11

C. D. Ott @ Hanse 2011, 2011/07/20 46

WARNING: 1) Don't put the swaps by hand!
2) Be careful when using single-angle. Useful only to support a null result

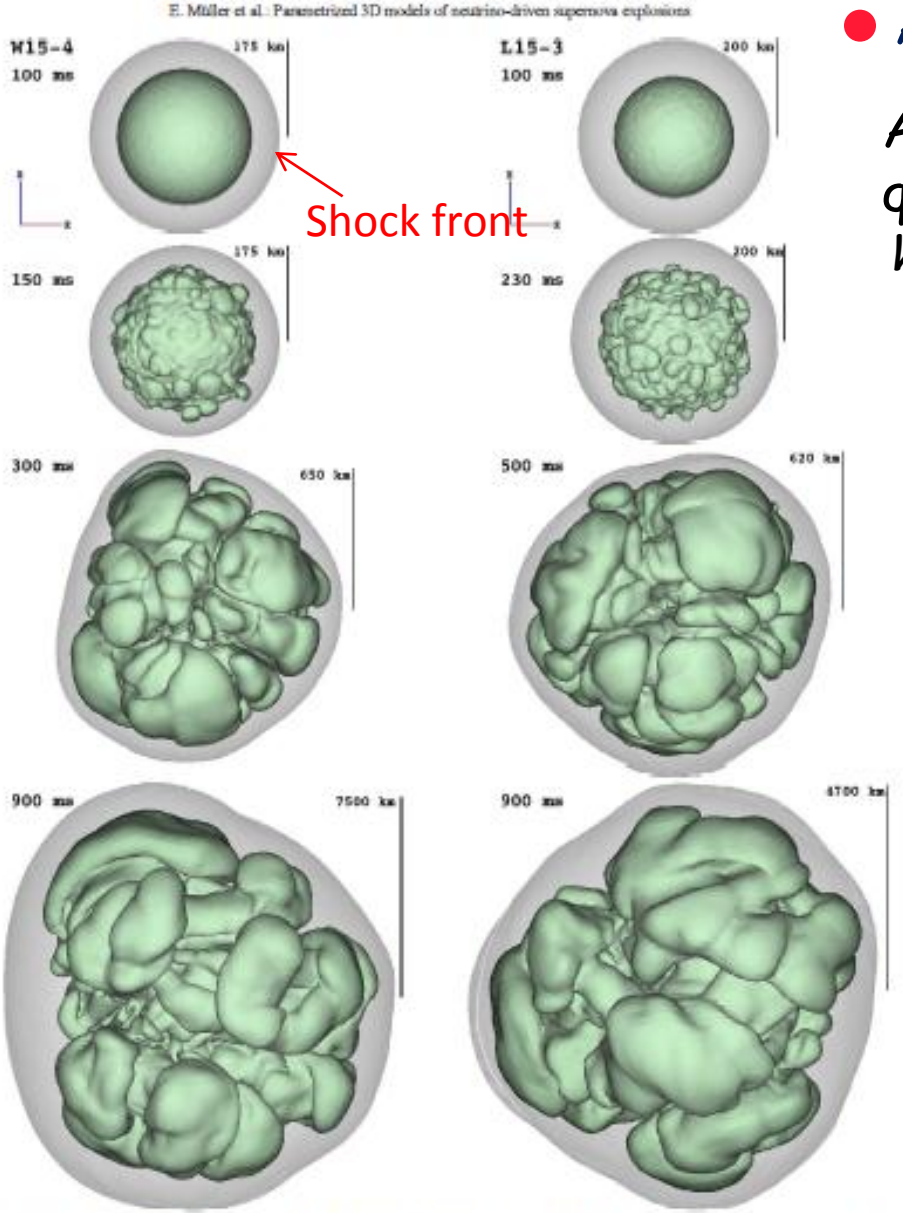


Fig. 3. Snapshots of models W15-4 (left) and L15-3 (right) illustrating the four phases characterizing the evolution of our 3D models (see text for details). Each snapshot shows two surfaces of constant entropy marking the position of the shock wave (grey) and depicting the growth of non-radial structures (greenish). The time and linear scale are indicated for each snapshot.

5

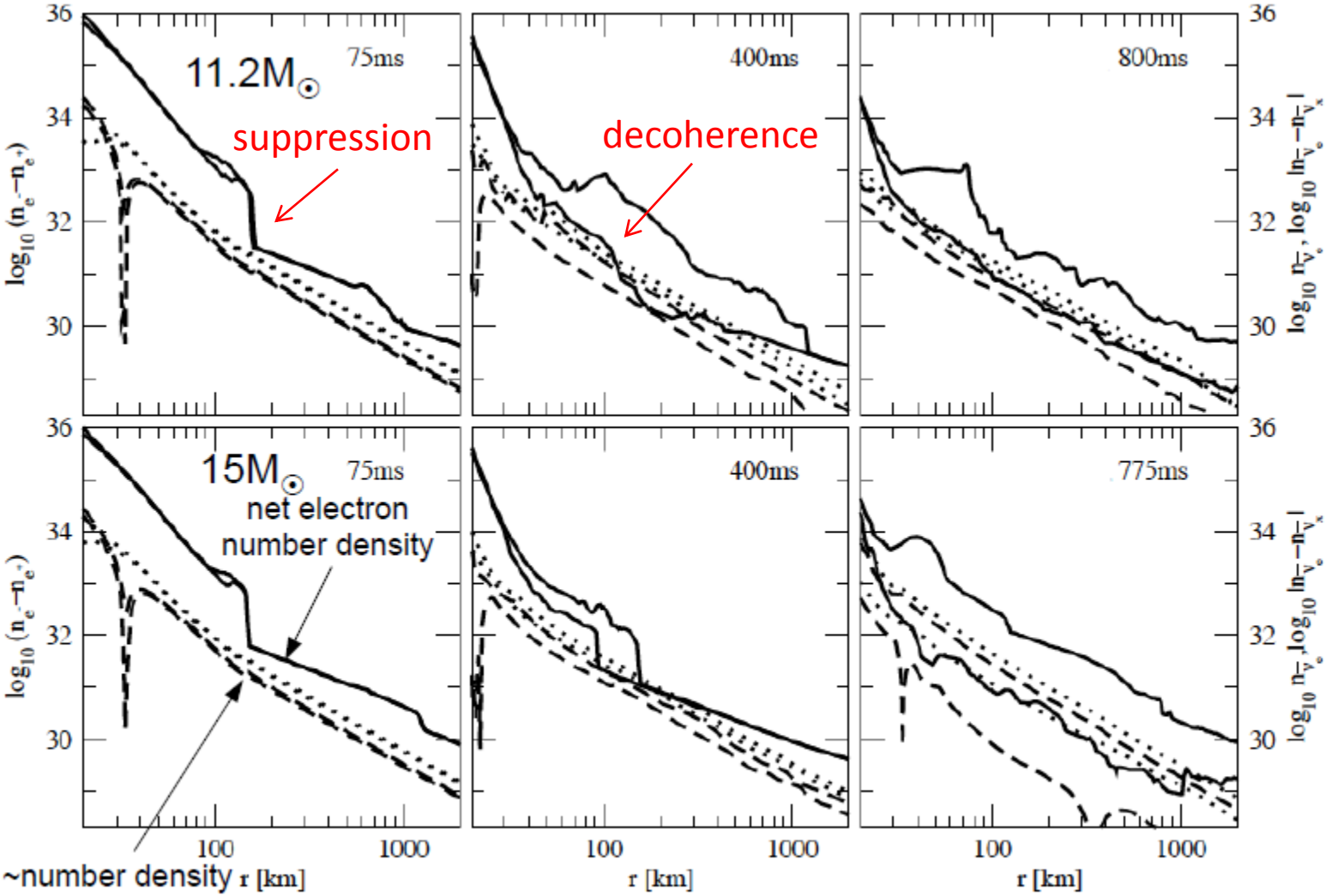
- Are multi-D effects important?

At t < 200 ms, also 3 D models are quasi-spherical *[see Muller, Janka and Wongwathanarat, arXiv.1106.6301]*

That's good: till now spherical symmetry has been never removed in the numerical simulations of flavor evolution.

Matter suppression still remains in 2D

Slide from B. Mueller's talk



Accretion phase similar to Dasgupta et al. (2011), early post-explosion phase appears post promising

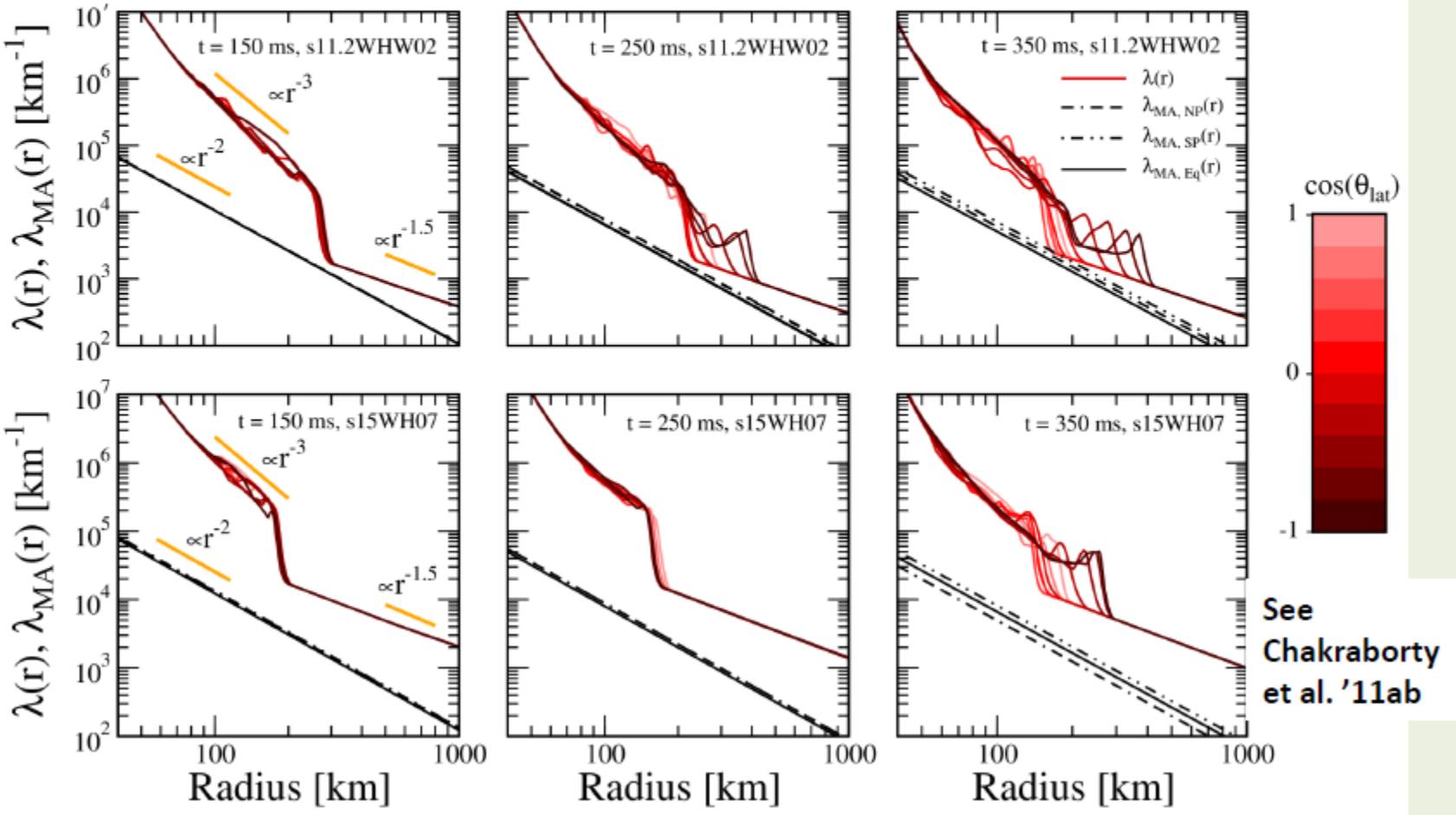
Slide from C.Ott's talk

Multi-Angle Effects: "Matter Suppression"

[work with Basudeb Dasgupta and Evan O'Connor, arXiv:1106.1167]

$$\lambda(r) = \sqrt{2} G_F \left[n_e(r) - n_{e^+}(r) \right] \lambda_{\rm MA} = 2\sqrt{2} G_F \Phi_{\nu,\bar{\nu}} (R^2_{\nu_e}/r^2) \mathcal{F}_-$$

Expect suppression of collective oscillations where λ(r) >> λ_{MA}



See Chakraborty et al. '11ab

PARS COSTRUENS: Mass hierarchy determination at large θ_{13}

SUPERNOVA NEUTRINO FLUX AT EARTH

Taking into account the matter suppression, one can evaluate the oscillated SN neutrino fluxes at Earth

- Normal mass hierarchy

$$F^{D}_{\bar{\nu}_e} = \cos^2\theta_{12} F_{\bar{\nu}_e} + \sin^2\theta_{12} F_{\bar{\nu}_x}$$

- Inverted mass hierarchy
  - $\sin^2\theta_{13} \geq 10^{-3}$

$$F^{D}_{\bar{\nu}_e} = F_{\bar{\nu}_x}$$

  - $\sin^2\theta_{13} \leq 10^{-5}$

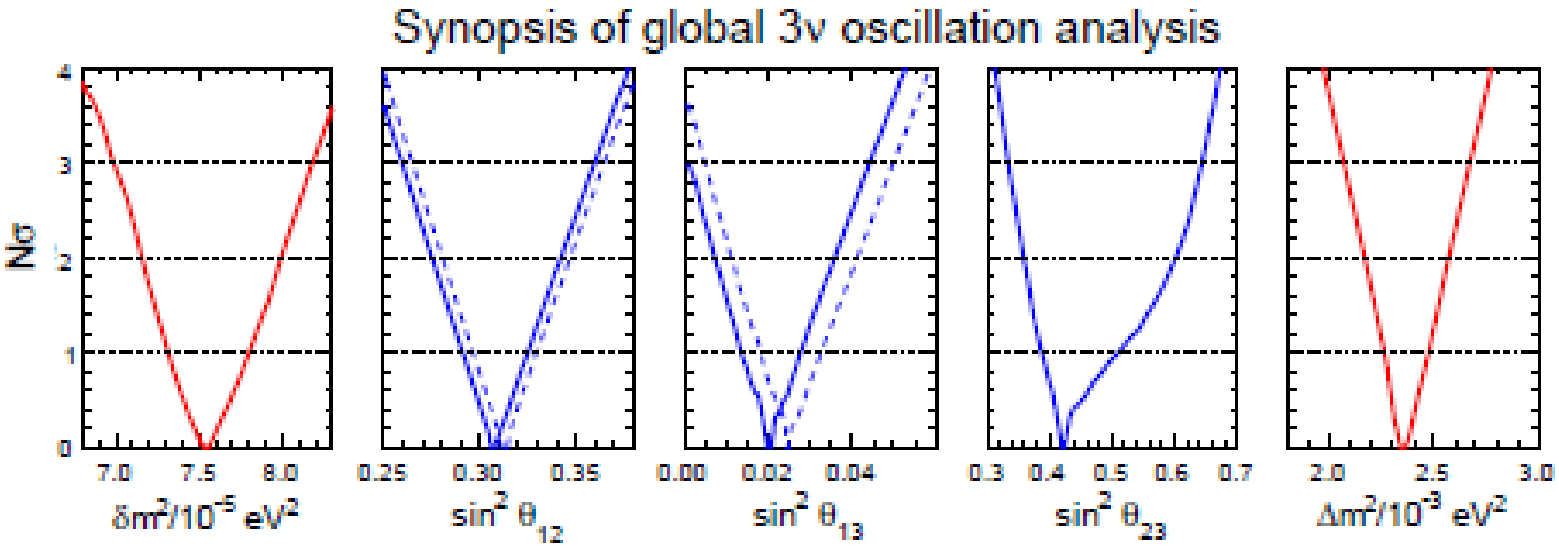
$$F^{D}_{\bar{\nu}_e} = \cos^2\theta_{12} F_{\bar{\nu}_e} + \sin^2\theta_{12} F_{\bar{\nu}_x}$$

Possible mass hierarchy discrimination at large θ_{13}.
Study of observable signatures in progress. Stay tuned!

EVIDENCE OF LARGE θ_{13}

[see Fogli, Lisi, Marrone, Palazzo, Rotunno, arxiv:1106.6028]

See talk by Fogli



Due to the matter suppression of collective oscillations during the accretion phase, the next galactic SN neutrino burst could become crucial to determine the neutrino mass hierarchy.

CONCLUSIONS

The perspectives for the detection of signatures of self-induced flavor conversions in SNe change once more.

- Multi-angle effects associated to the dense matter do suppress collective ν oscillations during the accretion phase.

- No impact of ν flavor conversions on the SN shock revival.

- Possible determination of the neutrino mass hierarchy at large θ_{13} from the SN ν burst during the accretion phase.