Fast Flavor Conversions & Collisions

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Neutrino Quantum Kinetics in Dense Environments

NBIA-LANL

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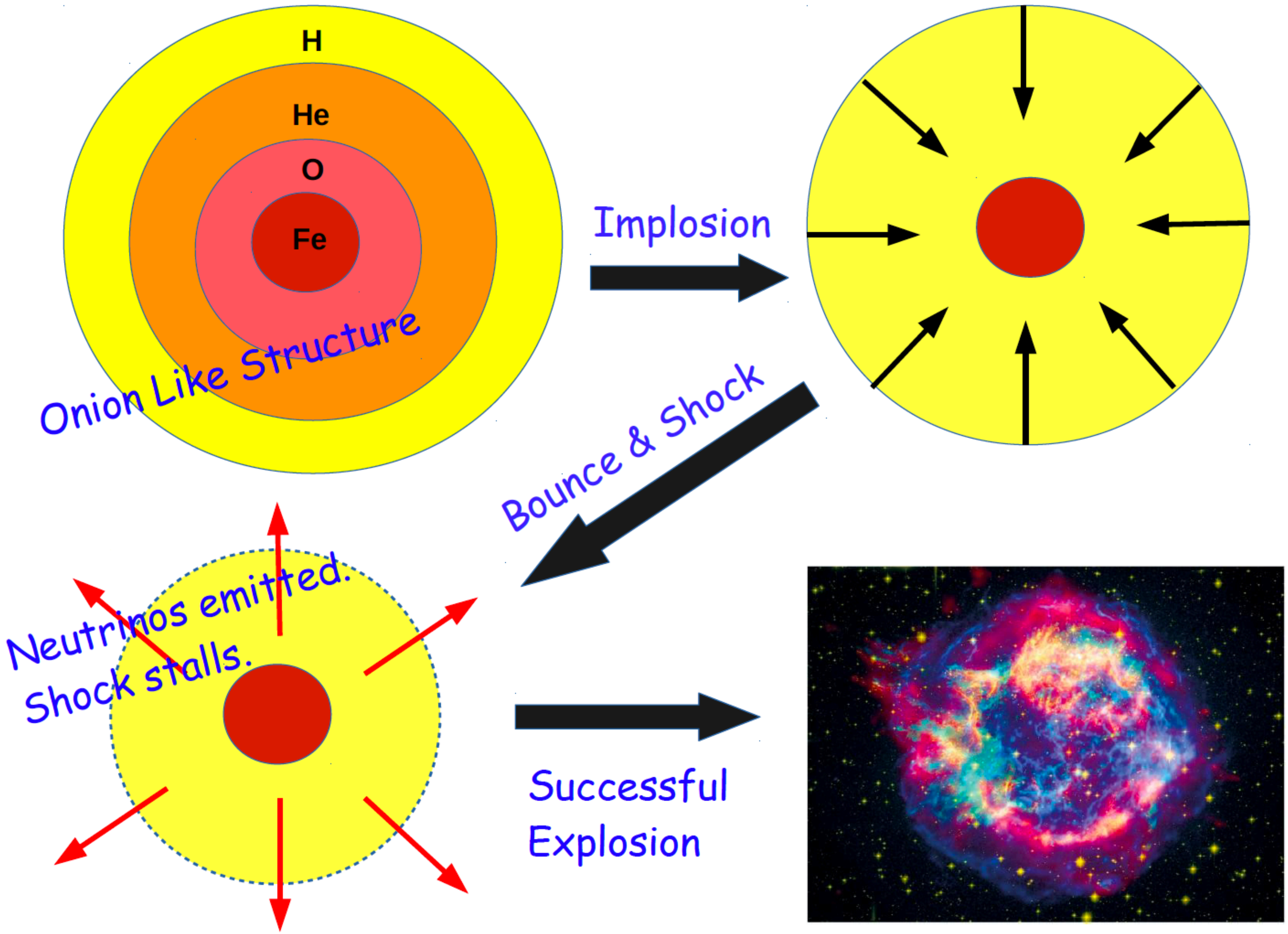
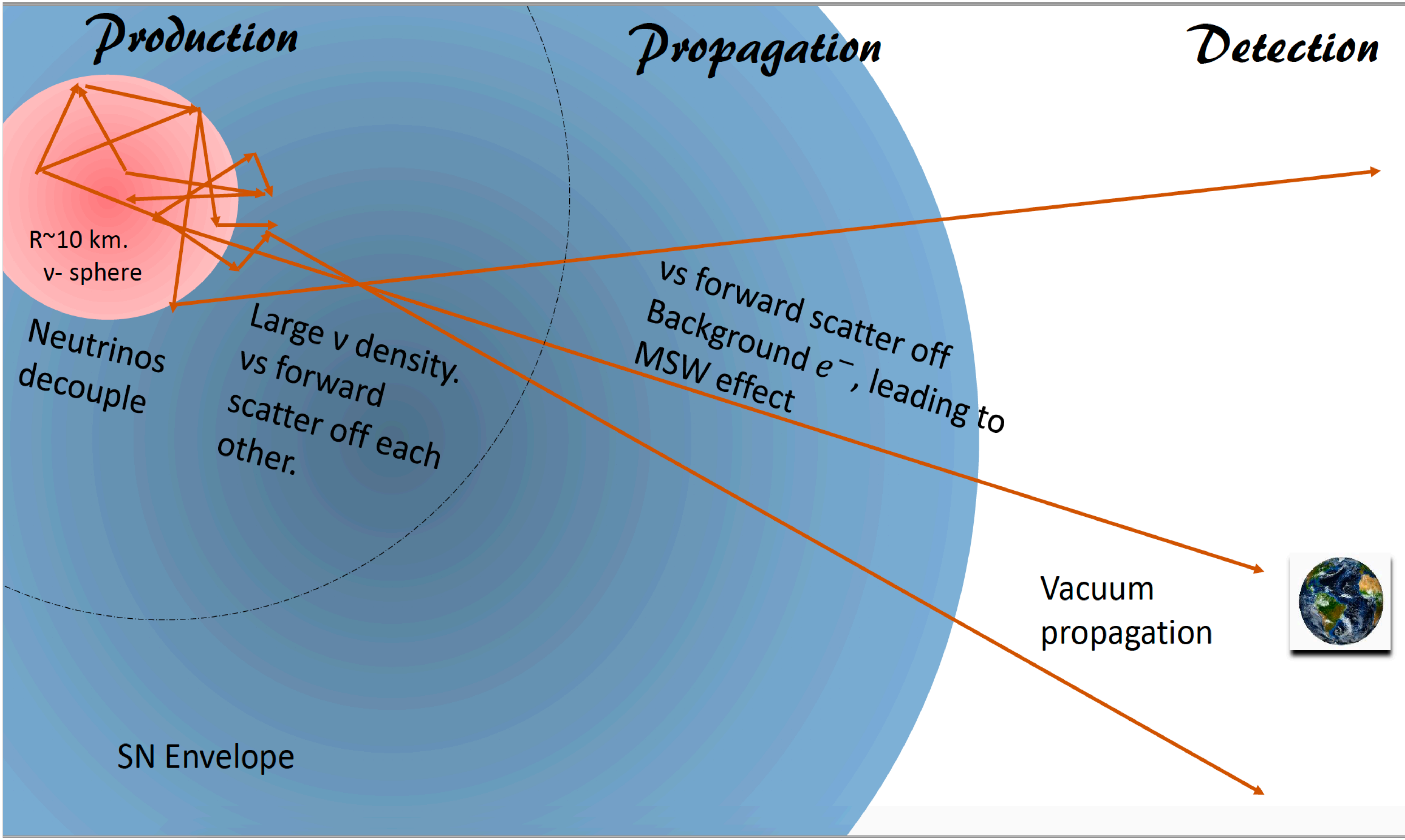
CCSN Odyssey



In a nutshell...



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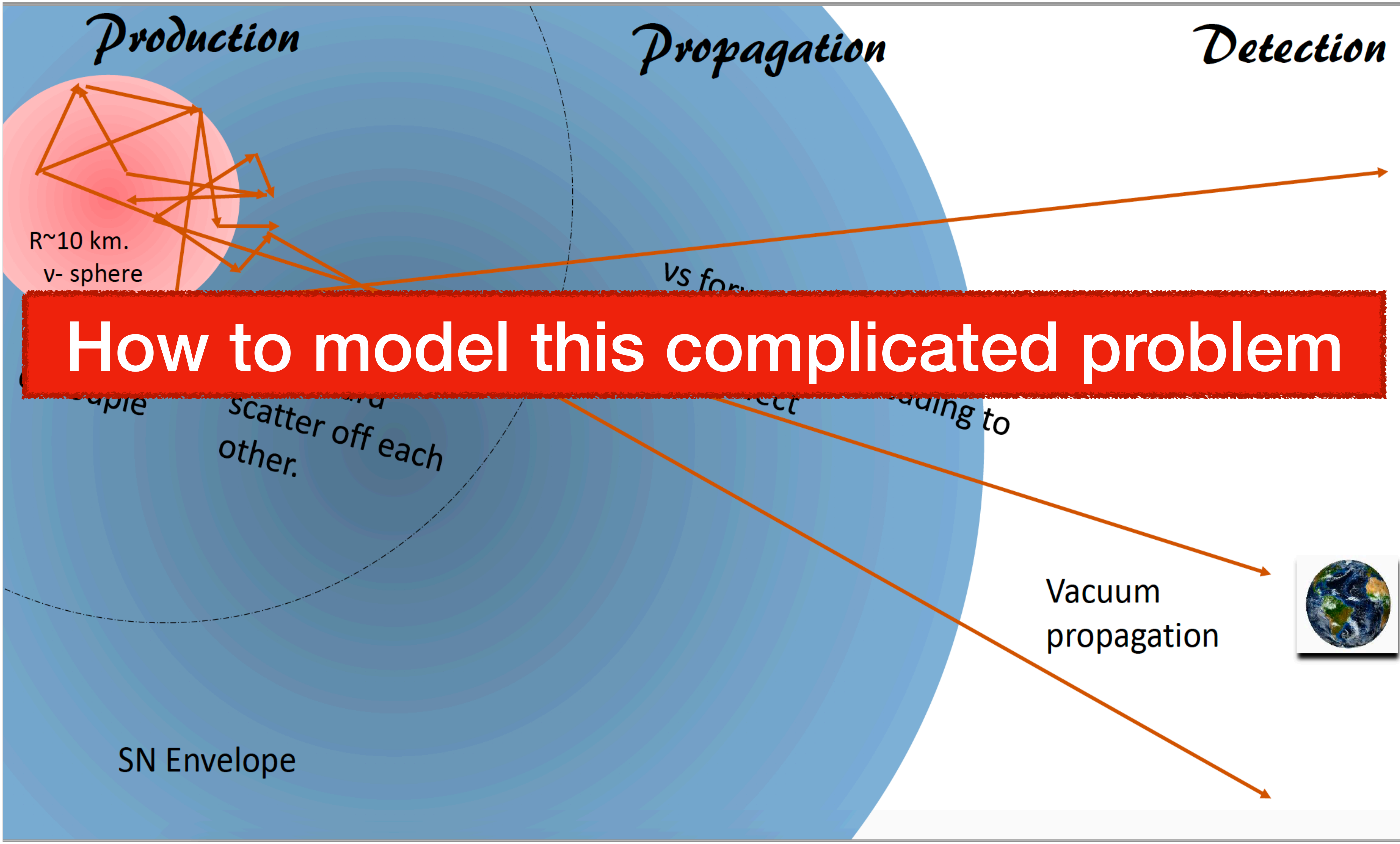


How to model this complicated problem

The matrix of densities (3+3+1)

$$\varrho = \begin{bmatrix} \langle \nu_e | \nu_e \rangle & \langle \nu_e | \nu_x \rangle \\ \langle \nu_x | \nu_e \rangle & \langle \nu_x | \nu_x \rangle \end{bmatrix}$$

EoM: $$d_t \varrho_p(r, p, t) = -i[H_p, \varrho_p] + C[\varrho_p]$$

$$H_p = \omega_p \quad + \quad \lambda \quad + \quad \mu \int d\Gamma' (1 - v_p \cdot v_{p'}) \varrho_{p'}$$

ω_p → $\frac{\mathrm{M}^2}{2\mathrm{E_p}}$

λ → Matter (MSW) term ∝ $\sqrt{2} G_F n_e$

$\mu \int \ldots$ → $\nu - \nu$ interaction term ∝ n_ν

Wolfenstein (PRD1978,1979)
Mikheyev and Smirnov (SJNP1985)
Pantaleone (PRD 1992)
Duan, Fuller, Carlson and Qian (PRD 2006,2007)
Hannestad, Raffelt, Sigland Wong (2006)

$$\mu \sim \lambda \gg \omega$$

What are fast flavor conversions?

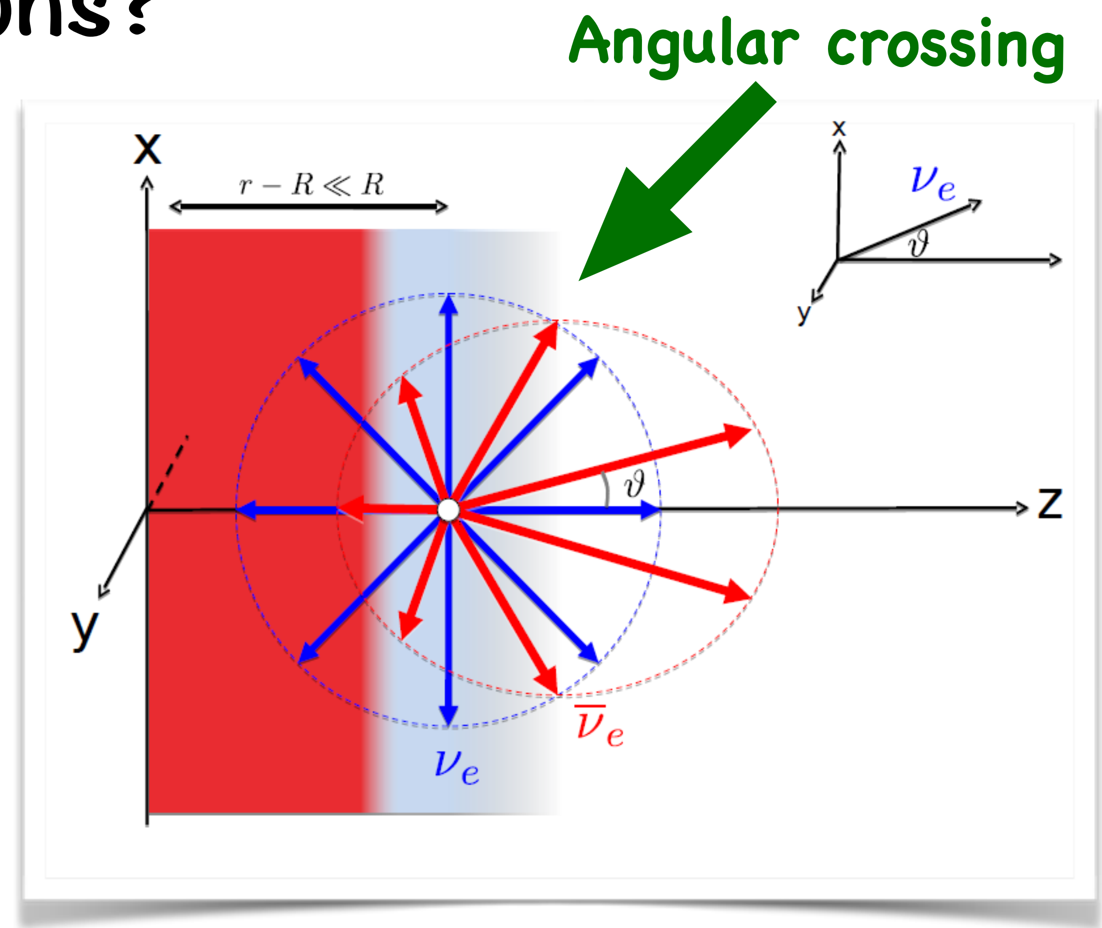
- New instability, growing at a rate proportional to the neutrino density of the medium.

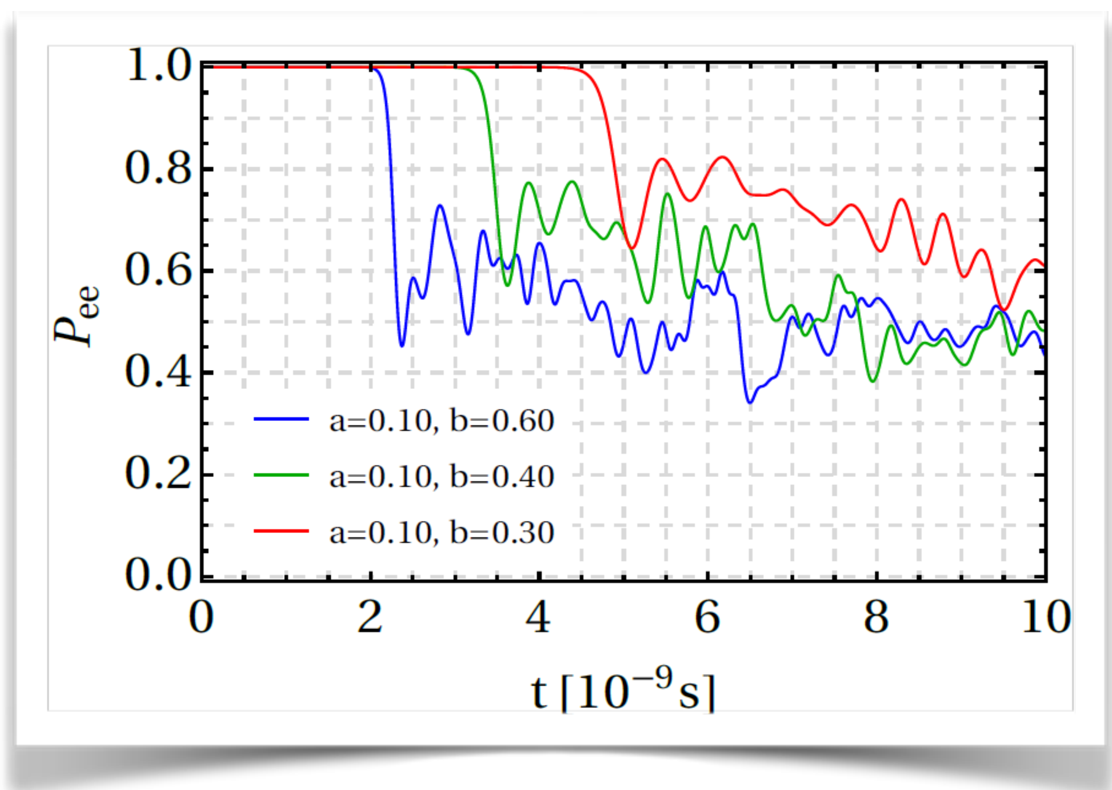
- Large flavor conversions, with a rate $\mu \sim 10^5 \omega$.

- Different radii of decoupling of νs due to different rates of interaction. Leads to crossing in angular spectra.

- Such crossings are *believed* to be essential for these conversions.

- Occurs almost above the neutrinosphere.





Sawyer (PRD 2005,2009, PRL 2016)
Chakraborty, Hansen, Izaguirre, Raffelt (JCAP 2016)
Dasgupta, Mirizzi, Sen (JCAP 2017, PRD 2018)
Izaguirre, Raffelt, Tamborra (PRL 2017)
Abbar, Volpe (Phys.Lett. 2019)

Why can this play a crucial role?

- Flavor conversions in the deepest region influence heating behind the stalled shockwave, helping a SN explode.

- Large flavor conversions can affect the heating rate, by converting energetic ν_μ to ν_e .

- Alters the n/p ratio through

$$\nu_e\, p \to n\, e^+$$
$$\bar{\nu}_e n \to p e^-$$

  This can have effects on r-process nucleosynthesis.

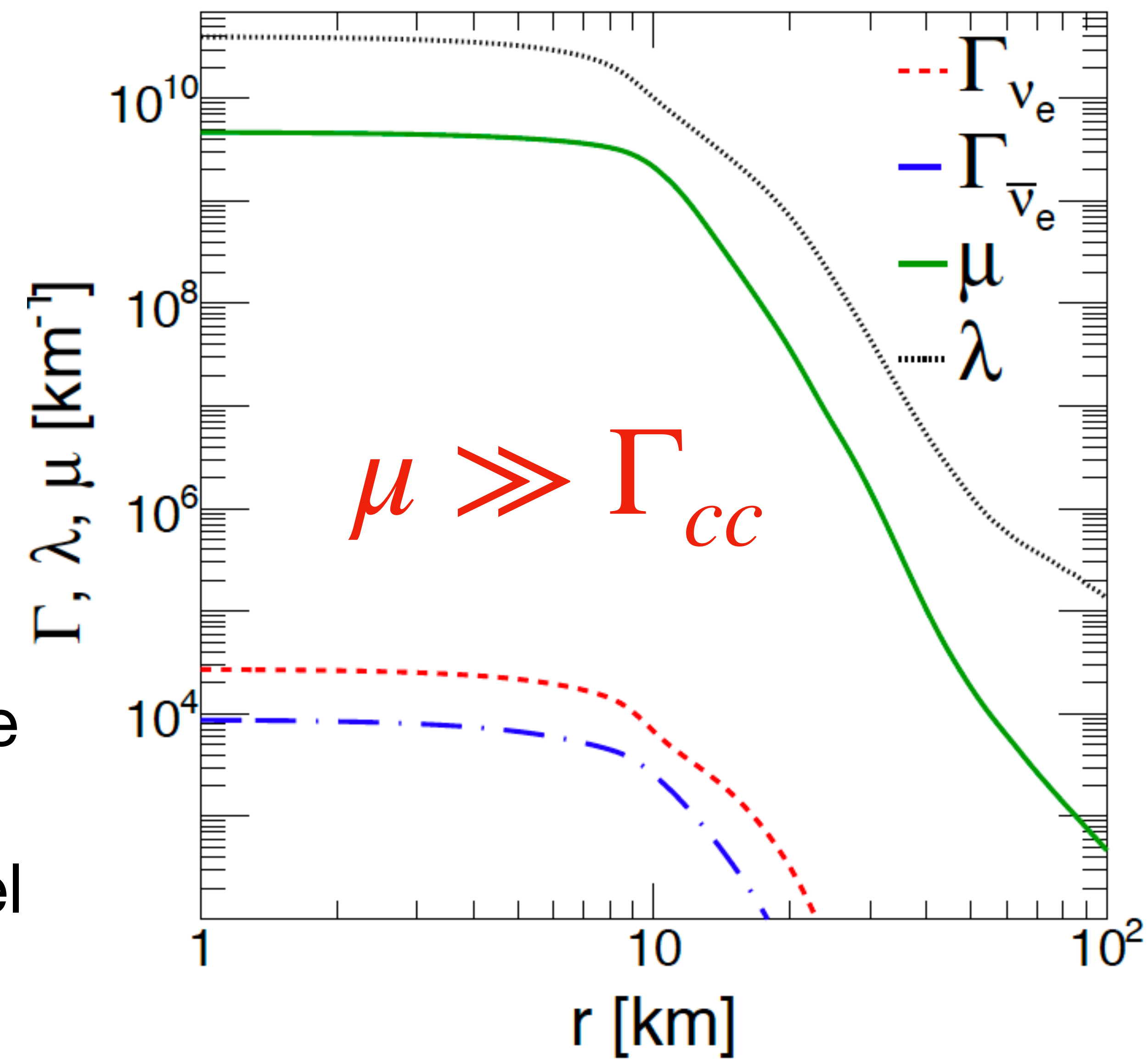
- All further flavor information *could* be washed-out. Crucial to predict observable SN ν_e signal.

- However, can collisions play a spoilsport?

What role does collision play?

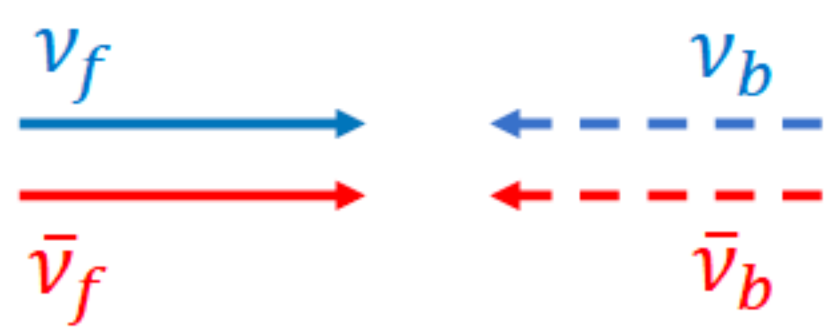
- Fast conversions require a crossing in the $\nu_e - \overline{\nu}_e$ spectra.
- This requires to ν_e and $\overline{\nu}_e$ to have different collisional rates.
- Question: collisions are important to create the conditions for fast conversions, but do they damp these oscillations?
  Are collisional and free-streaming wel separated?
- $C[\varrho] = \{\Gamma_p, \varrho^{\text{eq}} - \varrho_p\}$

Capozzi, Dasgupta, Mirizzi, Sen, Sigl (PRL 2018)

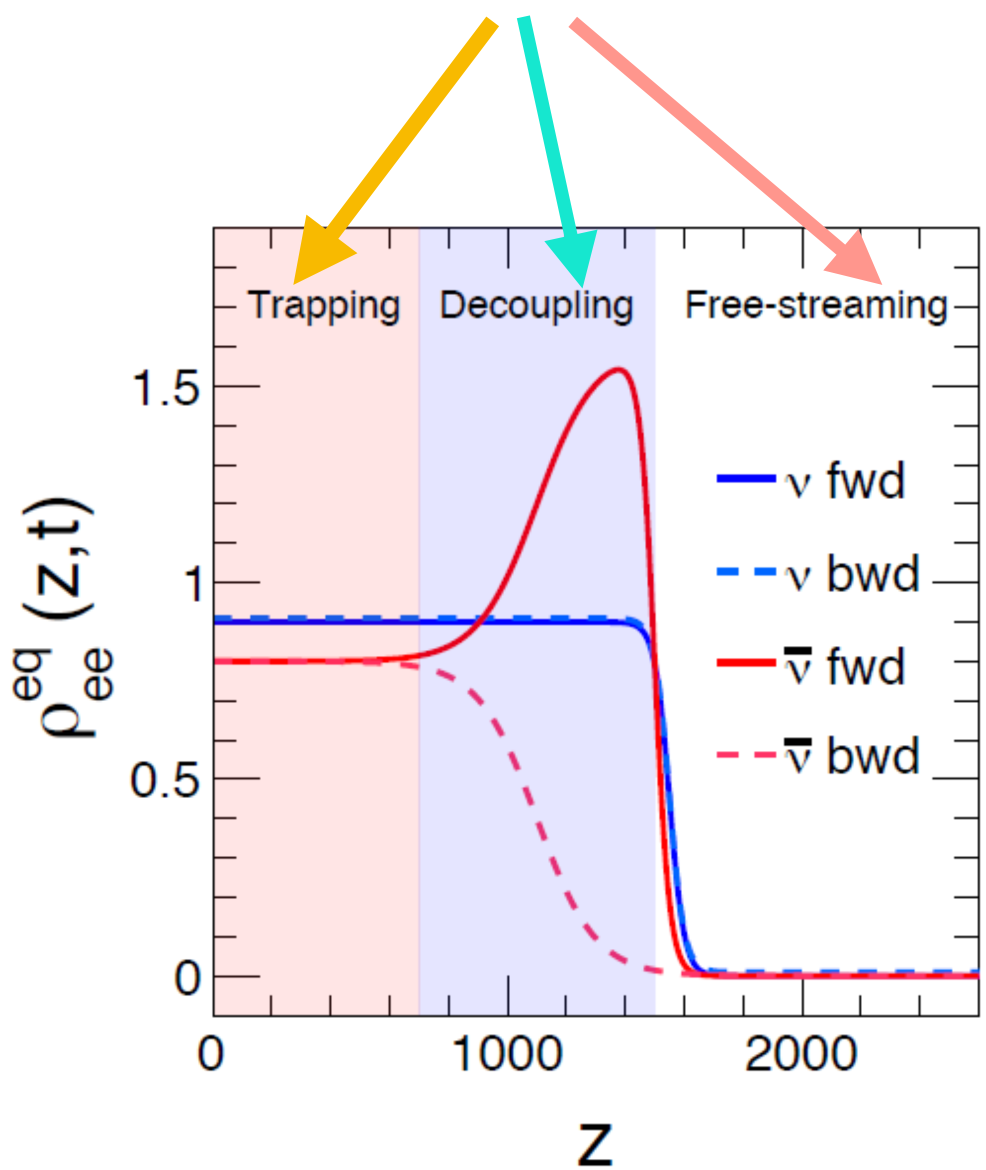


Tamborra, Hudepohl, Raffelt, Janka (Astr. 2017)

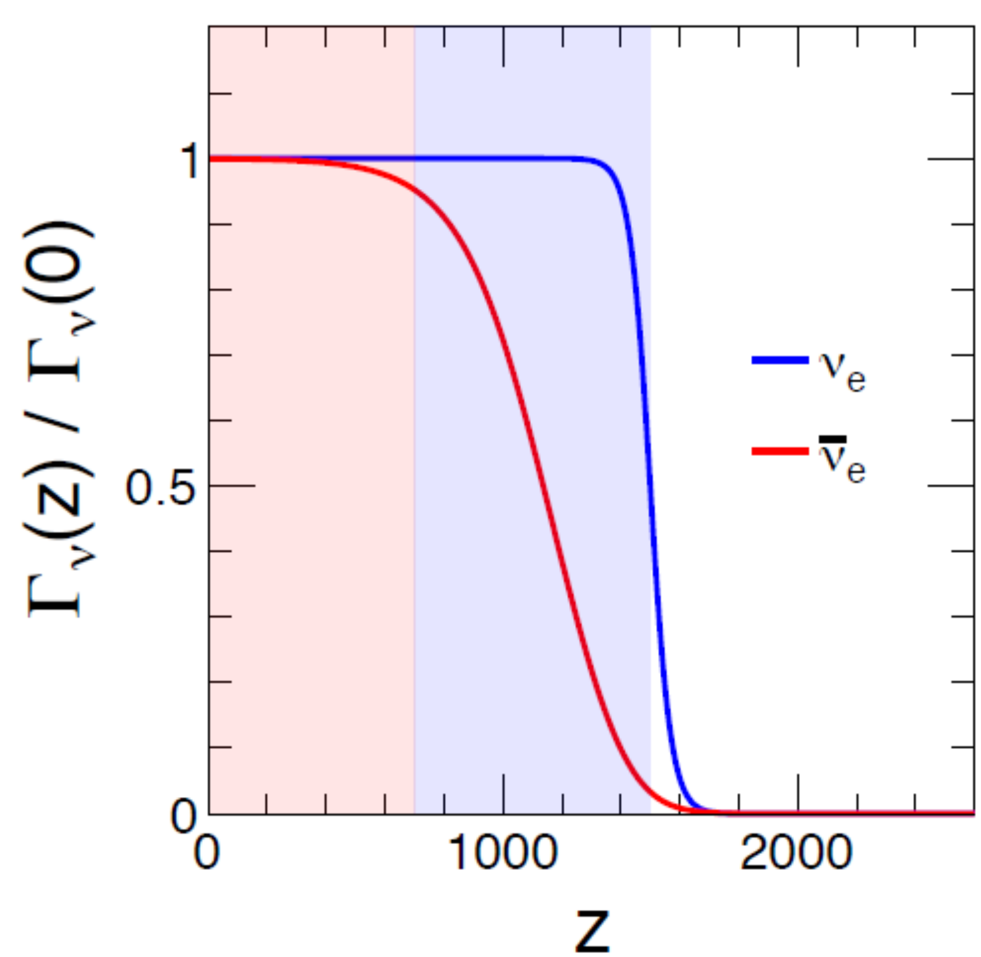
Toy model: the 2 beam



Divide the SN envelope in 3 regions



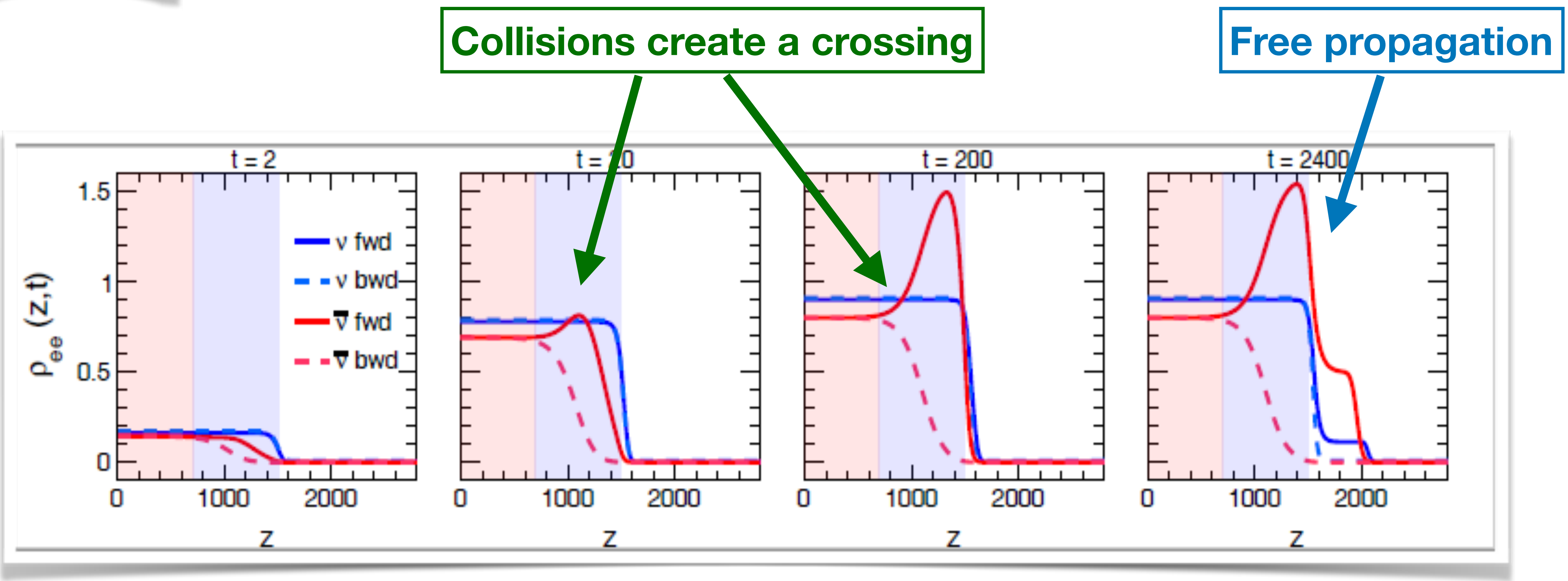
Normalized collision rates



Collisions and Oscillations: 101

$$\Gamma_{\nu_e} = \Gamma_{\bar{\nu}_e} = 0.1\,\mu_{\nu \mathrm{sph}}$$

$$\mu = 0$$



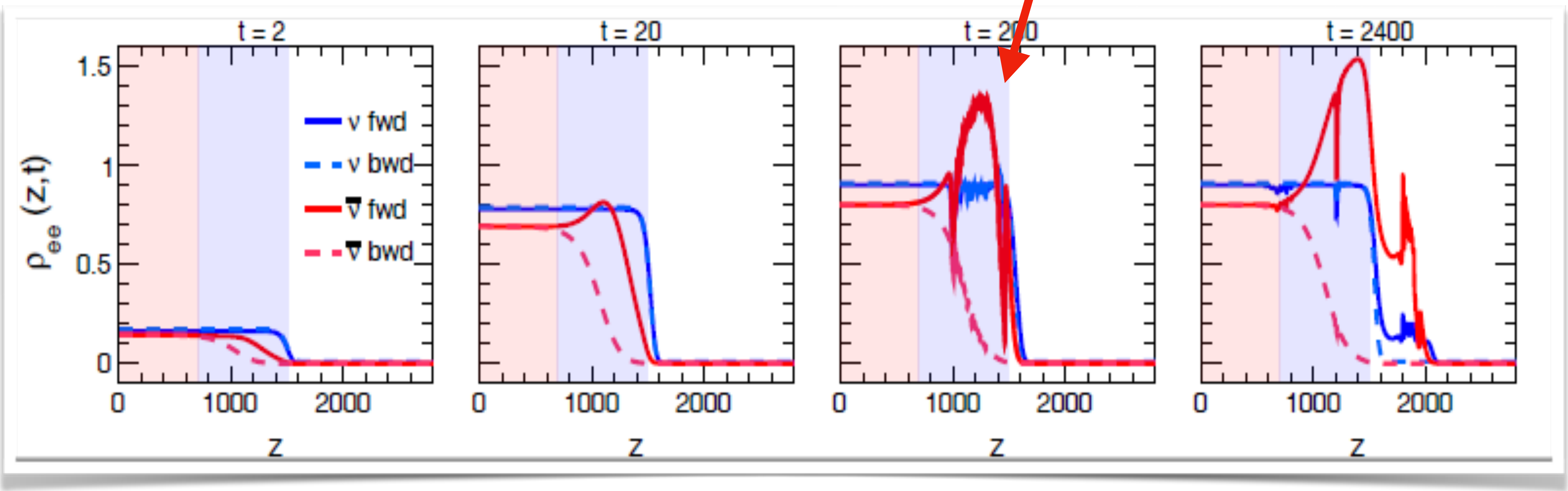
All modes reach equilibrium values. No Oscillations.

Collisions and Oscillations: 201

$$\Gamma_{\nu_e} = \Gamma_{\bar{\nu}_e} = 0.1\,\mu_{\nu\mathrm{sph}}$$

$$\mu = \mu_{\nu\mathrm{sph}}$$

Crossings lead to fast conversions

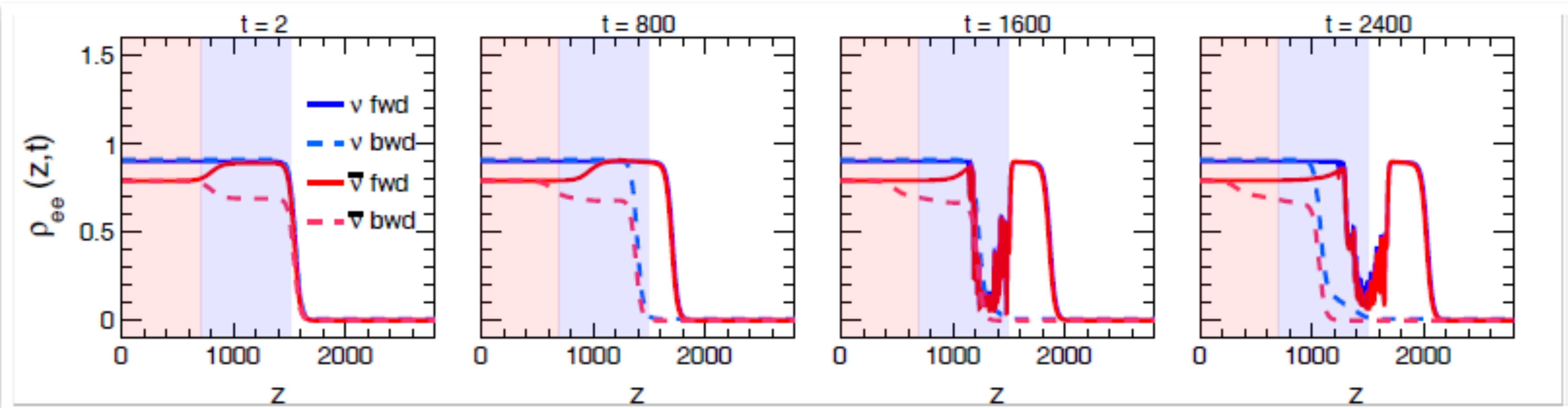


Fast oscillations develop, but system quickly equilibriates.

Collisions and Oscillations: 301

$\Gamma_{\nu_e} = \Gamma_{\bar{\nu}_e} = 10^{-4}\, \mu_{\nu \mathrm{sph}}$

$\mu = \mu_{\nu \mathrm{sph}}$



Fast conversions are sustained. Gradually reach the free-streaming zone.

Collisions can trigger fast conversions, by creating a difference between ν and $\bar{\nu}$ s.
However, they are too tiny to damp oscillations.

Summarizing

- Fast flavor conversions could cause a paradigm shift in our understanding of neutrino flavor evolution inside a SN.
- Rapid flavor mixing might alleviate the need to incorporate neutrino quantum kinetics in the simulation.
- However, neutrino scatterings might change the picture.
- Simple toy models suggest that collisions might be inefficient in suppressing these oscillations.
- However, more rigorous analysis is required to come to a conclusive picture.

Thank you!