Self-induced flavour conversion of supernova neutrinos

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Supernova neutrinos

SN neutrinos are affected by a strong potential due to self-interactions

$$H = H_{\rm vac} + H_{\rm matter} + H_{\nu\nu}$$

vacuum oscillations

ν_e, $\overline{\nu}_e$ - CC interactions with e^+, e^-

neutrino self-interaction

$$H_{\rm matter} \propto \sqrt{2} G_F N_e = V_{CC}$$

$$H_{\nu\nu} \propto \sqrt{2} G_F N_\nu = \mu$$

Self-interactions lock together the oscillation modes.
Collective phenomena take place.

Collective effects with the bulb model

BULB MODEL

First calculations were done assuming neutrino emission to be: uniform, half isotropical, azimuthal symmetric and stationary.

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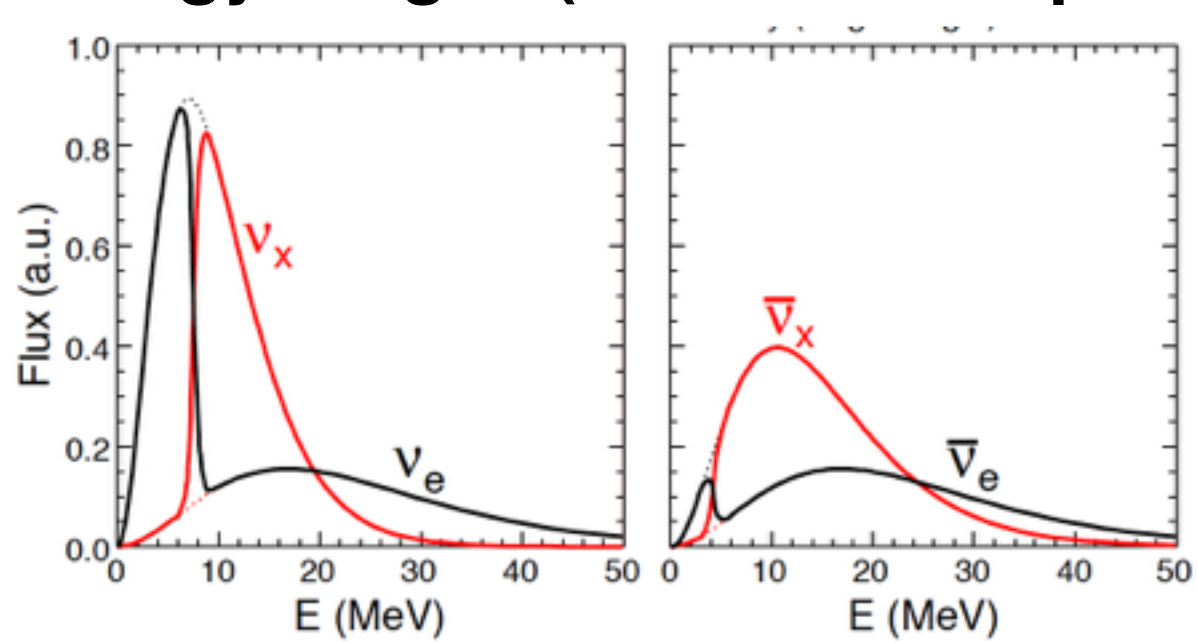
Synchronized oscillations: all neutrinos oscillate with the same frequency

Bipolar oscillations: Coherent $\nu_e\bar{\nu}_e \leftrightarrow \nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}$ oscillations even for extremely small mixing angle (only for inverted hierarchy)

Spectral splits: ν_e and $\nu_{\mu,\tau}$ ($\bar{\nu}_e$ and $\bar{\nu}_{\mu,\tau}$) spectra interchange completely only within certain energy ranges (because of lepton number conservation)



New developments

Recently, it was shown that:

translation symmetries in time and space are not stable

tiny space inhomogeneities may lead to new flavor instabilities which can develop even at small distances from the SN core (large μ) where are expected small flavour conversions (synchronized oscillations)

To large μ usually corresponds large V_{CC} that suppresses both homogeneous and inhomogeneous instabilities. The current understanding is that neutrinos cannot change their flavour if $V_{CC} >> \mu$

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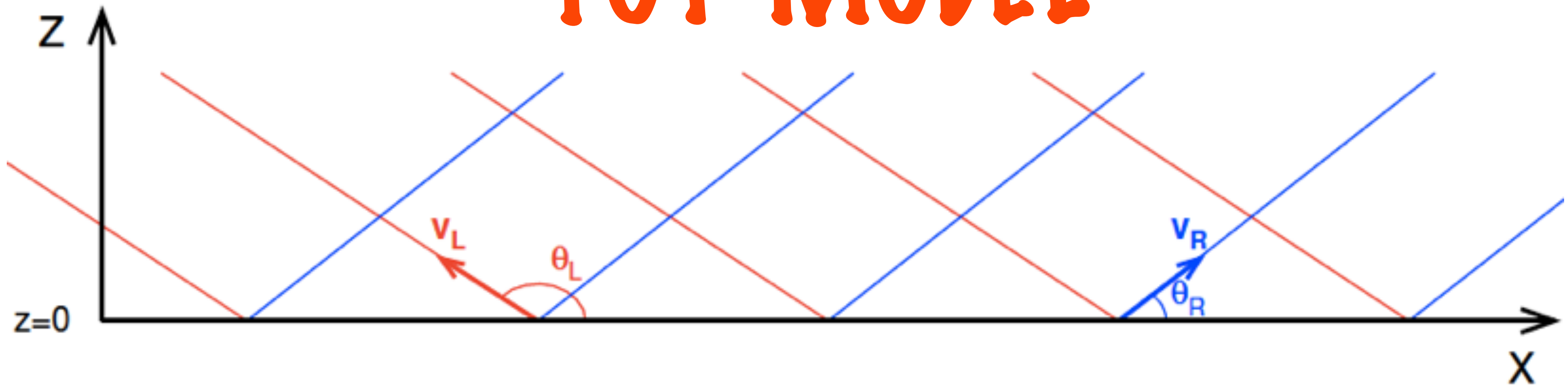
Not a complete understanding of flavour conversions.
Need to solve complete partial differential equation problem.

TOY MODEL



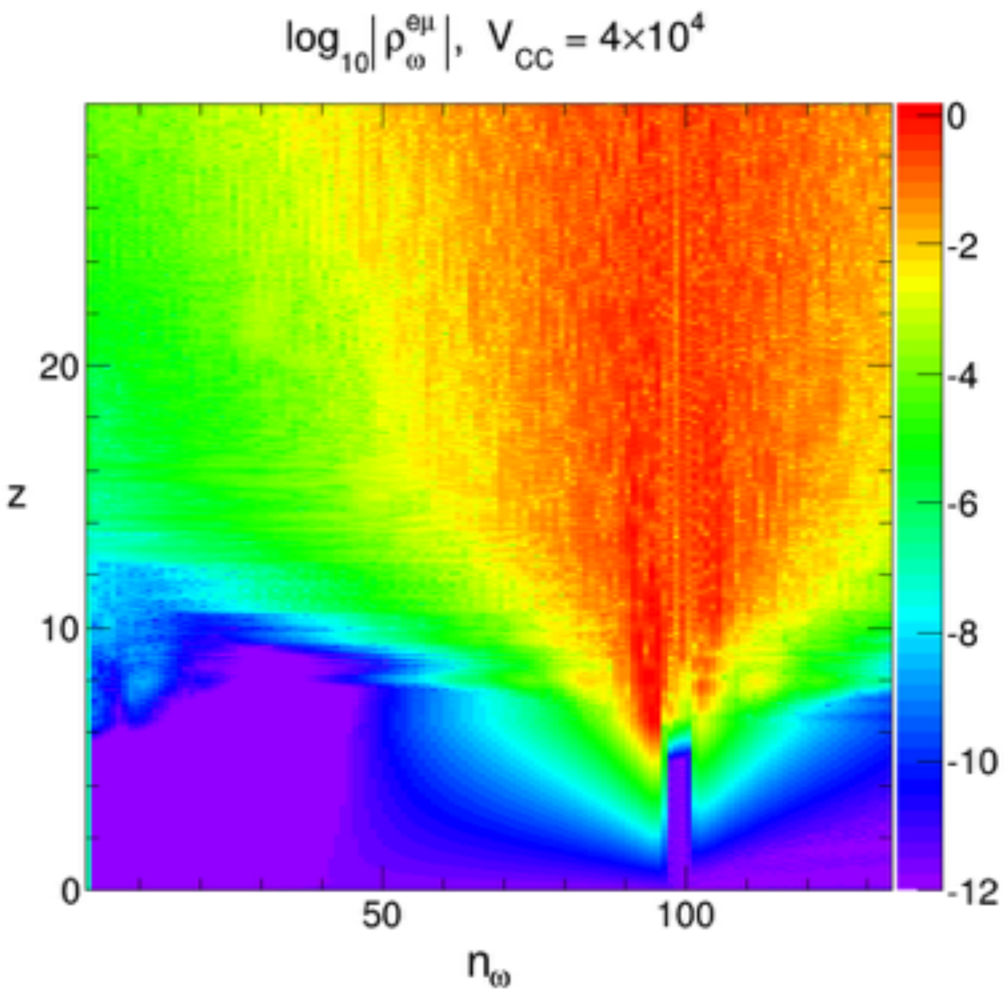
ν_e and ν_e emitted by an infinite boundary (x-axis) at z=0, in only two directions (L,R). Excess of ν_e over $\overline{\nu}_e$. We relax the uniform and stationary emission hypotheses. We work in the Fourier space:

$$\varrho_{L(R),k,\omega}(z) = \int dx\, dt\, \varrho_{L(R),\mathbf{x}}\, e^{-\imath k x - i\omega t}$$

where ω is the temporal pulsation of the mode $\rho_{L(R),k,\omega}$ and k is the wavevector of spatial inhomogeneities. $\omega = n_\omega V_{CC}/100$, n_ω=1,2,3,…

no flavour conversion for ω=0, since $V_{CC} \gg \mu$, but …

Results



$\rho^{e\mu}{}_{\omega}$=Amplitude of non stationary flavour conversions

If $V_{CC}=\omega$ (n_ω=90-100), the non-stationary modes compensate the phase dispersion due to matter effects, allowing for instabilities to grow.

FLAVOUR CONVERSION CAN OCCUR AT HIGH V_{CC}

Flavour conversion at high V_{CC} can:

- **influence supernova dynamics**
- **affect nucleosynthesis processes**
- **modify event spectra detected on Earth**

⟹ **TEST THIS NEW PARADIGM IN REAL SUPERNOVA CASE**