UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

Sapere Aude

Neutrino Flavor Conversions in Compact Astrophysical Objects

Ian Padilla-Gay – *Niels Bohr Institute, University of Copenhagen*

1. Neutrinos in compact objects

Flavor conversions of neutrinos can dramatically affect the inner workings of compact astrophysical objects (e.g. core-collapse supernovae and compact binary mergers) as well as the synthesis of the heavy elements. Notably, fast pairwise neutrino conversions are thought to be triggered in the core of compact objects, as a consequence of the high neutrino densities and the shape of the angular distributions of (anti)neutrinos, possibly leading to flavor decoherence.

Here, we present the first sophisticated numerical solution of neutrino flavor conversions and show that neutrino advection may hinder the development of fast conversions in compact astrophysical objects.

2. Quantum Kinetic Equations

The flavor evolution of neutrinos and antineutrinos is determined by the Quantum Kinetic Equations (QKE) in terms of the density matrices, ρ and $\bar{\rho}$, respectively:

$$i\left(\frac{\partial}{\partial t}+\vec{v}\cdot\vec{\nabla}\right)\rho(\vec{x},\theta,t)=[H(\theta),\rho(\vec{x},\theta,t)]\ , \quad (1)$$

$$i\left(\frac{\partial}{\partial t}+\vec{v}\cdot\vec{\nabla}\right)\bar{\rho}(\vec{x},\theta,t)=[\bar{H}(\theta),\bar{\rho}(\vec{x},\theta,t)]\ . \quad (2)$$

* Advective term $\vec{v}\cdot\vec{\nabla}\rho(\vec{x},\theta,t)$ included for the first time!

* The Hamiltonian in the QKE is defined as:

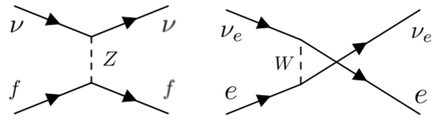
$$H(\theta)=\frac{\omega}{2}\begin{pmatrix}-\cos 2\theta_V & \sin 2\theta_V\\ \sin 2\theta_V & \cos 2\theta_V\end{pmatrix} + \mu\int d\theta'\,[\rho(\vec{x},\theta',t)-\bar{\rho}(\vec{x},\theta',t)]\,[1-\cos(\theta-\theta')]\ , \quad (3)$$

where $H(\theta)$ takes into account:

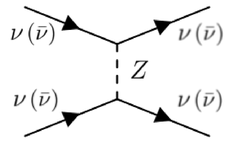
1) The vacuum term ω: vacuum flavor oscillations.

2) The neutrino self-interaction term μ: neutrino *fast* flavor oscillations may develop in a collective fashion (e.g pairwise $\nu\bar{\nu}$).

* As neutrinos propagate through the medium, they experience a refractive index due to coherent forward scattering with background fermions e.g $f = p, n, e$.



* Notably, neutrinos can also constitute a significant background to other neutrinos: non-linear feedback!



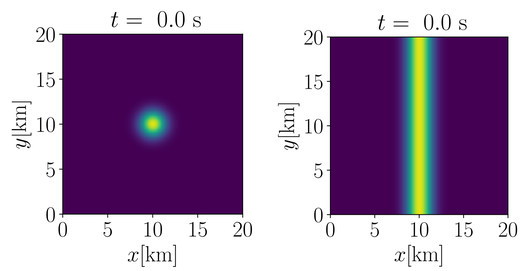
* *Fast* pairwise neutrino conversions depend on μ and can occur even for $\omega = 0$ if the angular distributions of ν_e and $\bar{\nu}_e$ cross each other → Electron Lepton Number (ELN) crossing.

3. Our results

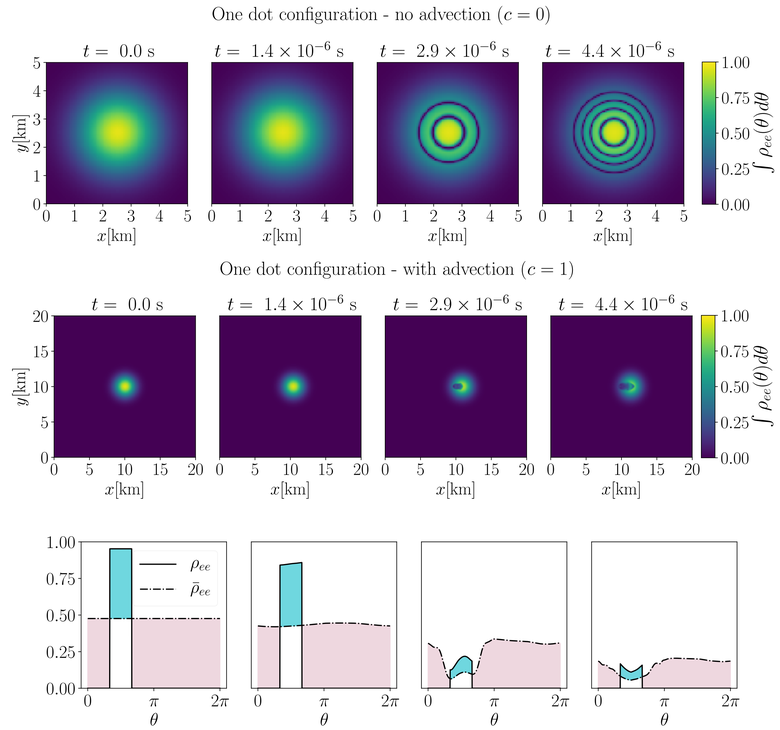
* Ours is the first sophisticated numerical solution of the evolution of neutrino flavor conversions including neutrino advection, two spatial coordinates and one neutrino emission angle.

* Our model resembles configurations similar to the ones that could occur in compact astrophysical objects.

* We explore two initial neutrino distributions: **1)** A dot: localized excess of ELN. **2)** A stripe: ELN localized in an extended region mimicking a scenario like LESA (Lepton-number Emission Self-sustained Asymmetry).



! Our results show that neutrino advection hinders the development of fast pairwise conversions as it erases the ELN crossings.



In summary:
1 The advective term in the QKE hinders the growth of flavor instabilities unless the ELN crossings are self-sustained in time.
2 Significant flavor evolution due to fast pairwise conversions can occur in the presence of the LESA instability (e.g. a stripe with a self-sustained mechanism for ELN crossings), but would not be significant for a localized ELN excess (e.g. a dot resembling stochastic hydrodynamical fluctuations).

References

* See our Animated Results to learn more.

* S. Shalgar, I. Padilla-Gay, I. Tamborra, *JCAP 2020 in press.* arXiv:1911.09110 [astro-ph.HE] .