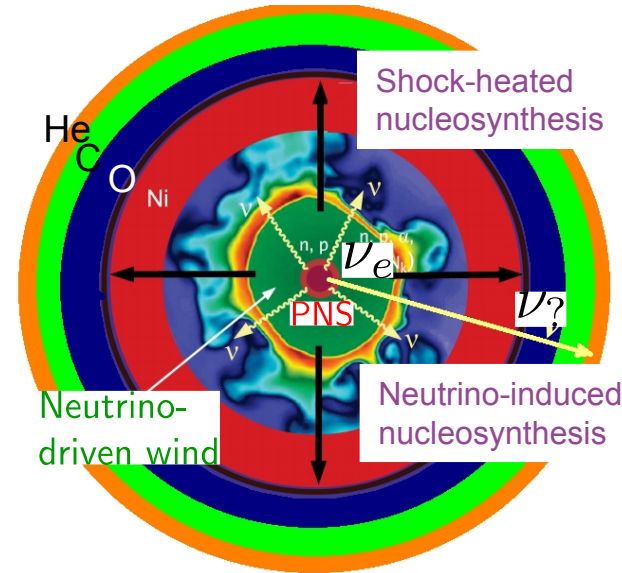


Neutrino oscillations in supernovae and neutron star mergers

[Modified from Janka+, PTEP 01A309, 2012]

- Neutrinos play important roles in both supernova explosion and nucleosynthesis of elements. However, typical treatments of neutrinos in hydrodynamic simulations do not include neutrino flavor mixings.
- Studies of the impact of neutrino flavor oscillations in supernovae and mergers were done by assuming:
 - neutrinos kinematically decouple at the “neutrinosphere”.
 - flavor evolution preserves the symmetries of the neutrino emission and astrophysical environment.
 - only lowest order of the correlation functions (mean-field), $\langle \hat{a}_p^\dagger \hat{a}_p \rangle$ contributes.
- Those studies indicated:
 - no impact on explosion (unless sterile ν exists). [e.g., Chakraborty+ 2011, Wu+ 2015]
 - potentially large effects on nucleosynthesis. [e.g. Duan+ 2011, Malkus+ 2012]



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- However, recent studies suggest that flavor evolution does not preserve the symmetries of neutrino emission and the astrophysical environments.
[e.g., Raffelt+ 2013, Duan+ 2015, Mirizzi+ 2015]
→ a fully multi-dimensional model is needed.
- Neutrino oscillations can potentially occur around the decoupling region,
[e.g., Dasgupta+ 2015, Sawyer+ 2015]
→ neutrino transport equations need to account for the flavor oscillations.
- The role of terms which are “beyond-the-mean-field” is still unclear.
[e.g., Volpe+ 2013, Vlasenko+ 2013]
- Scattered neutrinos far outside the “neutrinosphere” (neutrino halo) may also be important. [e.g., Cherry+ 2012]
- The role of neutrinos in supernovae and mergers may remain elusive until we have a full understanding of their flavor evolution.
- Can the detection of future Galactic supernova neutrinos help to understand how flavor oscillations happen deep inside the star?