Supernovae neutrino-pasta interaction

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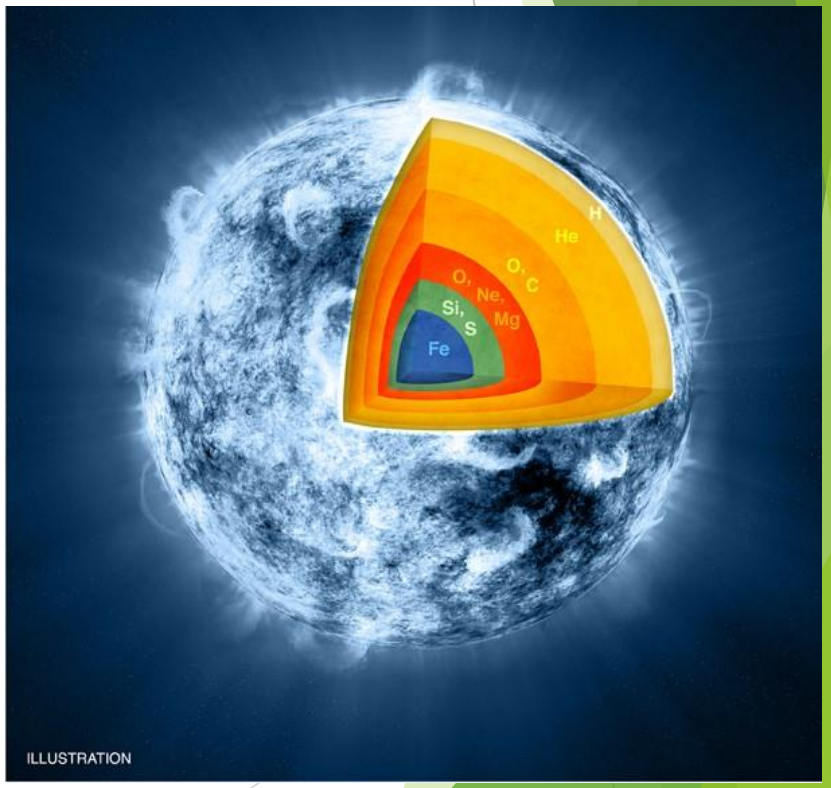
For JINA nuclear astrophysics winter school

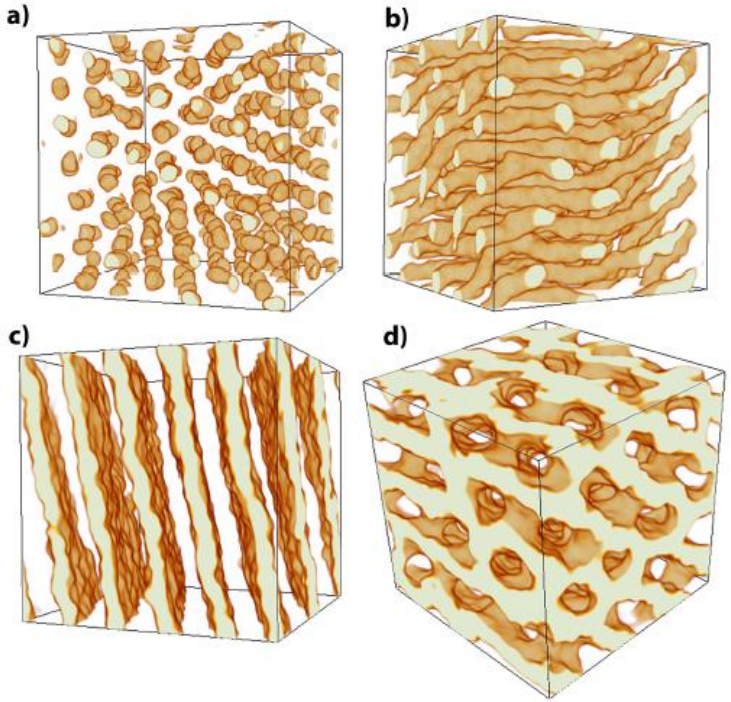
Pasta

Supernovae

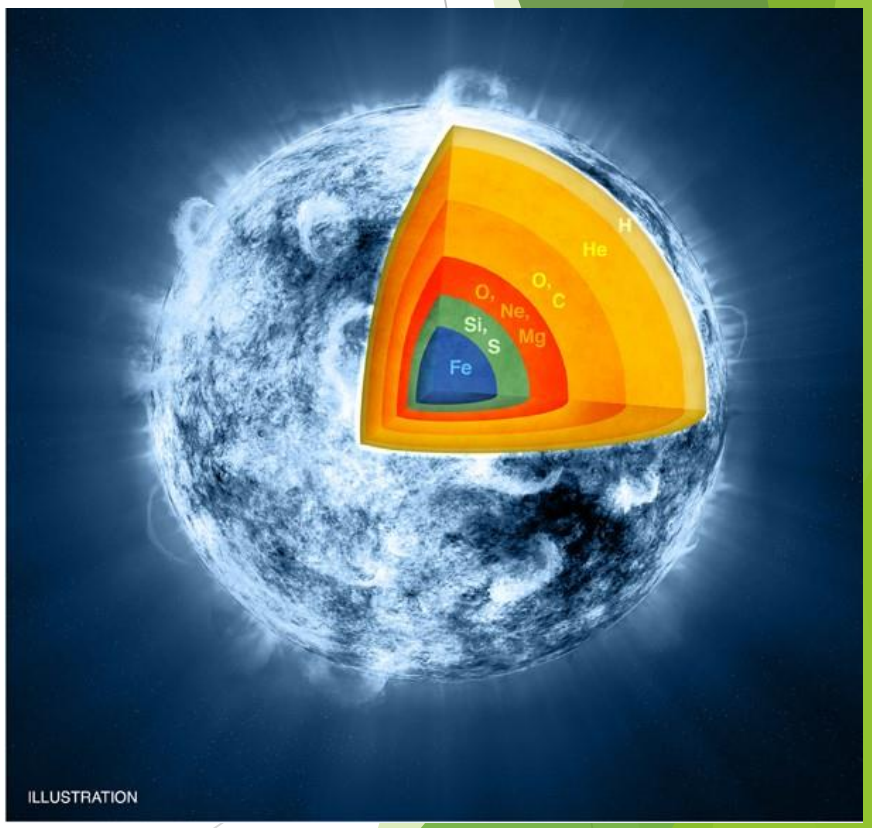
Inside



Pasta



Supernovae



Inside

Density: 0.1 to 0.01 fm^{-3} (sub nuclear density)
Temperature: in the order of several MeV
Result from competition between nuclear attraction and Coulomb repulsion

Neutrino-Pasta interaction

The free-space cross section for neutrino-nucleon elastic scattering is given by

$$\frac{d\sigma}{d\Omega} = \frac{G_F^2 E_\upsilon^2}{4\pi^2}\left[C_a^2(3 - cos\theta) + C_\upsilon^2(1 + cos\theta)\right] \qquad (1)$$

only the contribution from the vector current is coherent. The strong spin and isospin dependence of the axial vector current reduces the coherence. Therefore, in this work we only focus on the **coherence effect of the vector part** and the cross section per neutron can be expressed as

$$\frac{1}{N}\frac{d\sigma}{d\Omega} = S(q)\frac{G_F^2 E_\upsilon^2}{16\pi^2}\,(1 + cos\theta) \qquad (2)$$

$$S(q)$$

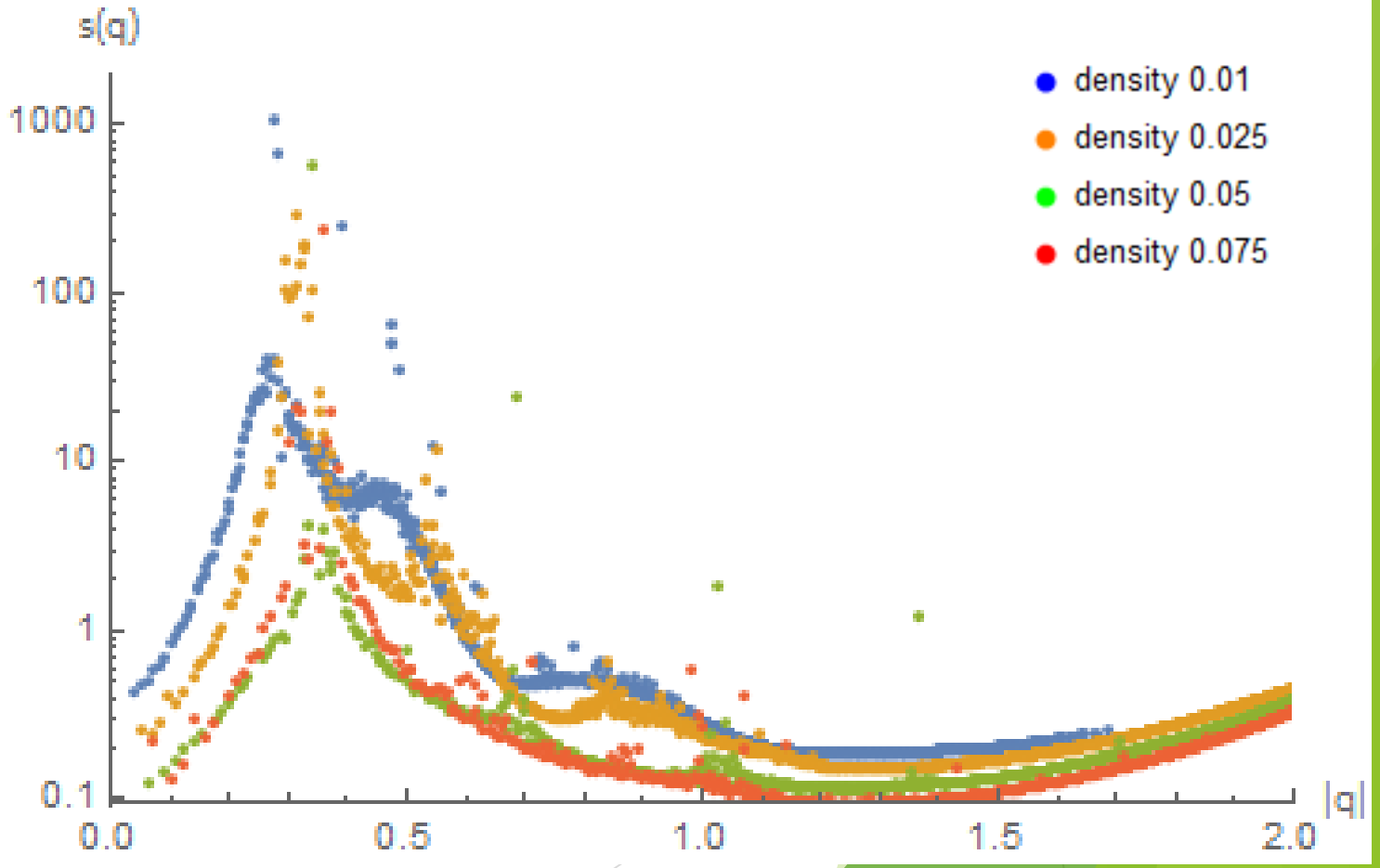
Classical Molecular Dynamics simulation for nuclear Pasta at different densities and temperatures

Static Structure factor S(q) for pasta at different densities and at temperature 1 MeV

$$S(\boldsymbol{q}) = \frac{1}{N}\int_0^\infty S(\boldsymbol{q}, w)dw = \frac{1}{N}\langle 0|\hat{\rho}^+\hat{\rho}|0\rangle \quad (3)$$

$$\rho(\mathbf{q}) = \sum_{i=1}^{N} \exp(i\mathbf{q}\cdot\mathbf{r}_i) \quad (4)$$

Results from MD simulations of 51,200 nucleons running for at least 180,000,000 fm/c, with time step 2 fm/c

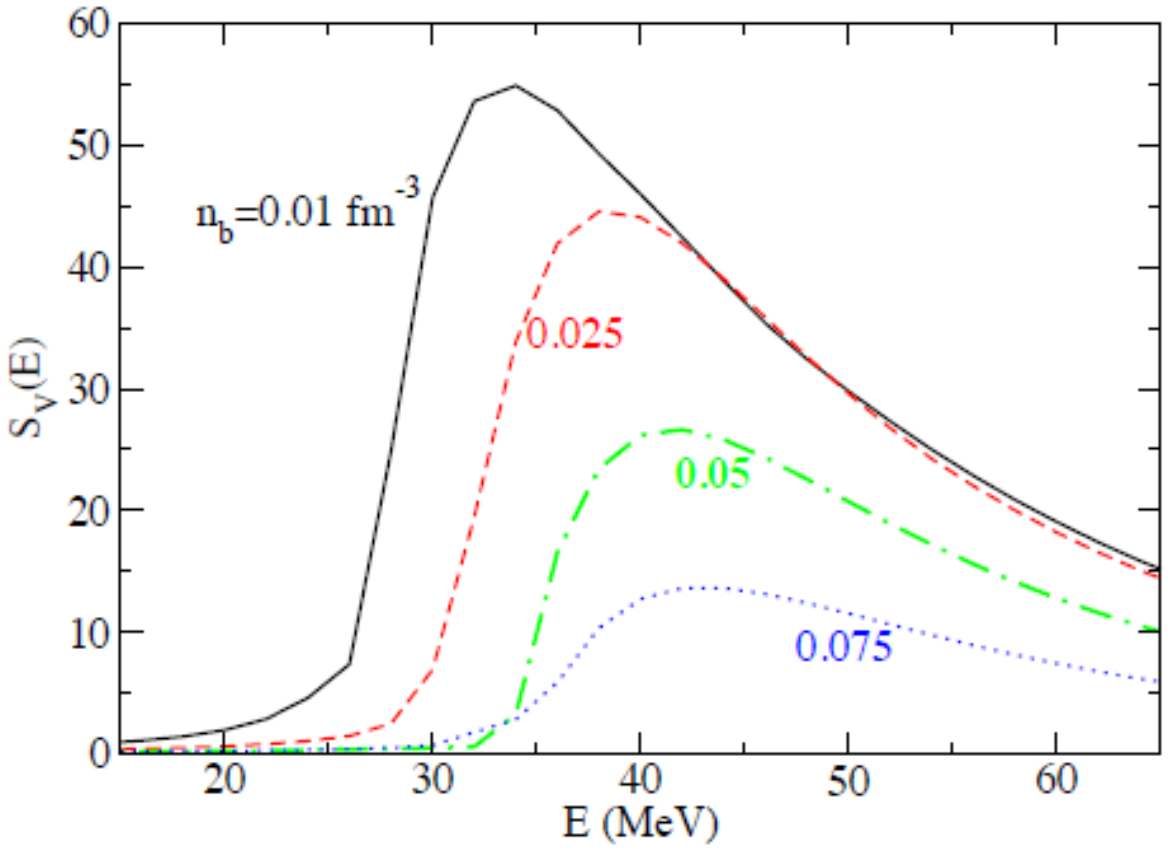


Static Structure factor S(E) for pasta at different densities and at temperature 1 MeV

$$\langle S(E_\nu)\rangle \equiv \frac{3}{4}\int_{-1}^{1} dx(1-x^2)S\big(q(x,E_\nu)\big)$$

(5)

Results from bigger pasta simulations will be discussed in our next paper coming soon next year!



Pasta at higher temperatures

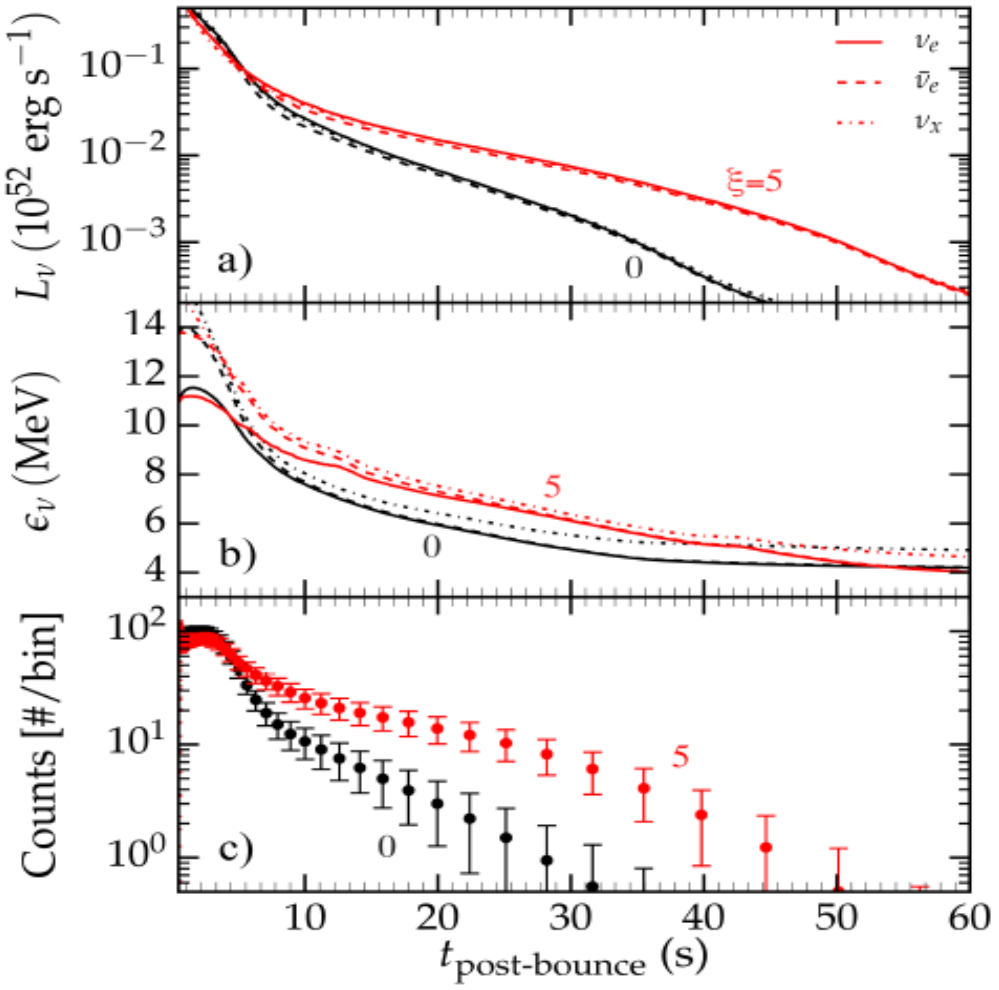
- Classical MD Simulation: Unfortunately this model is likely most accurate at low temperatures and high proton fractions. At temperatures significantly higher than 1 MeV, the classical heat capacity seems to be too large.

- Full quantum simulations for “Spherical pasta phases”: At Yp = 0.3, we find pasta phases for n_b = 0.03 to 0.11 fm^{-3} and up to a maximum T = 11 MeV. This region slightly decreases with decreasing Yp. For Yp = 0.1,pasta is present for n_b = 0.04 to 0.09 fm^{-3} and up to T = 7 MeV.

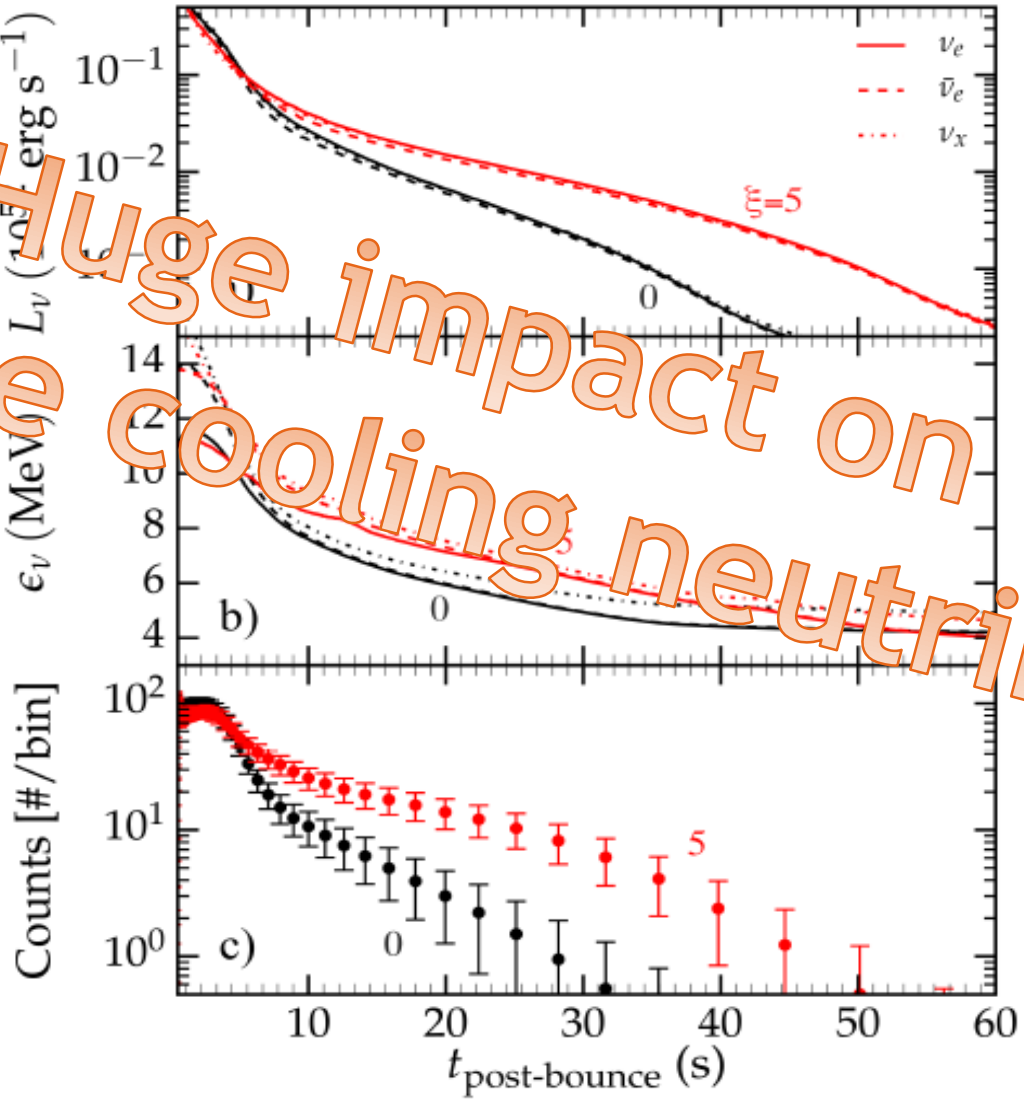
Pasta impact on supernovae simulations during the infall phase

- The pasta is located well inside the electron neutrino decoupling radius and since these neutrinos make up the bulk of the neutrino energy density at this time, we see no dynamic or thermodynamic effect of the presence of pasta.

Pasta impact on supernovae simulations during the late time cooling phase



Pasta impact on supernovae simulations during the late time cooling phase



Huge impact on the late time cooling neutrino signal!

Collaborators:

- C. J. Horowitz
- D. K. Berry
- M. E. Caplan
- T. Fischer
- W. G. Newton
- Evan O'connor
- Luke Roberts

Thank You !

A letter discussing this work in detail is now available on the arxiv:1611.10226 [astro-ph.HE]