Effects of Input Nuclear Physics on Core Collapse Supernova Simulations

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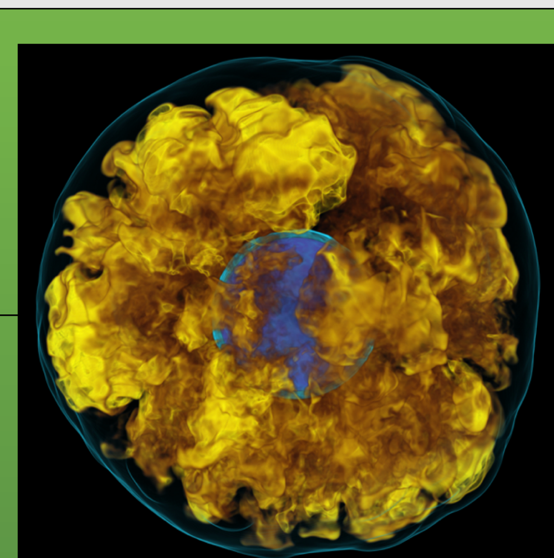
Motivation

In the proto-neutron star (PNS) formed during a core collapse supernova (CCSN), densities can reach several times nuclear density. Due to **uncertainties in nuclear physics**, there are several different physical models for the equation of state (EOS) at the densities present in the CCSN environment. The **outcomes of CCSN simulations can depend sensitively on the EOS**. 1D CCSN simulations are key in predictions of the outcome of stellar evolution, neutron star mass distribution, nucleosynthesis, and ultimately, galactic evolution. However, uncertainties in nuclear physics causes changes in these results: **simulations using different EOS tables can lead to entirely different predictions**. We explore the **sensitivity of CCSNe to variations in input nuclear physics**. A quantitative understanding of how different EOS tables affect the outcome of core collapse is crucial to our ability to make predictions.

Nuclear Physics



Explosion?

NS Mass Distribution?

Element Formation?

Methods

Progenitors
- 138 progenitor stars
- Masses ranging from 9 to 120 solar masses

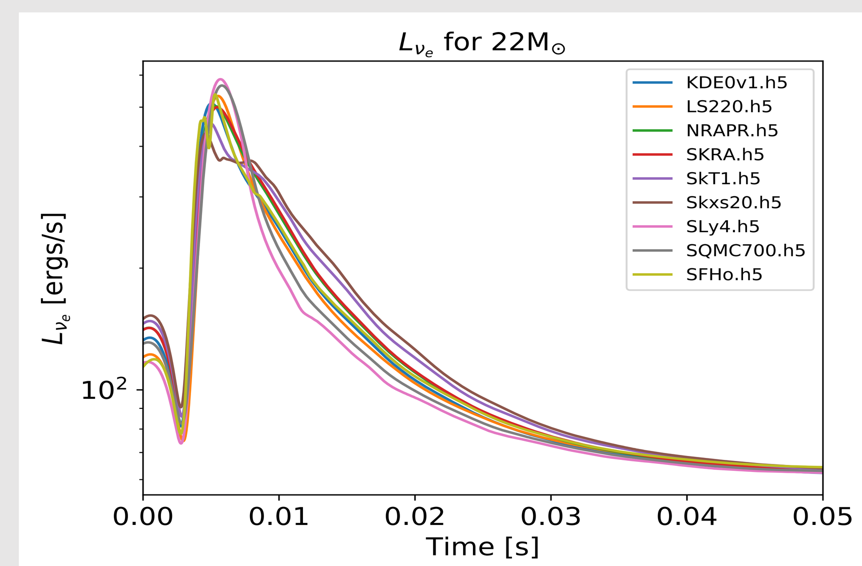
EOS
- 9 open source EOS tables [1]

Simulations
- 1242 1D simulations on MSU's HPCC computing resource
- We used a version of the FLASH code suitable for high fidelity supernova simulations which includes effects of turbulence

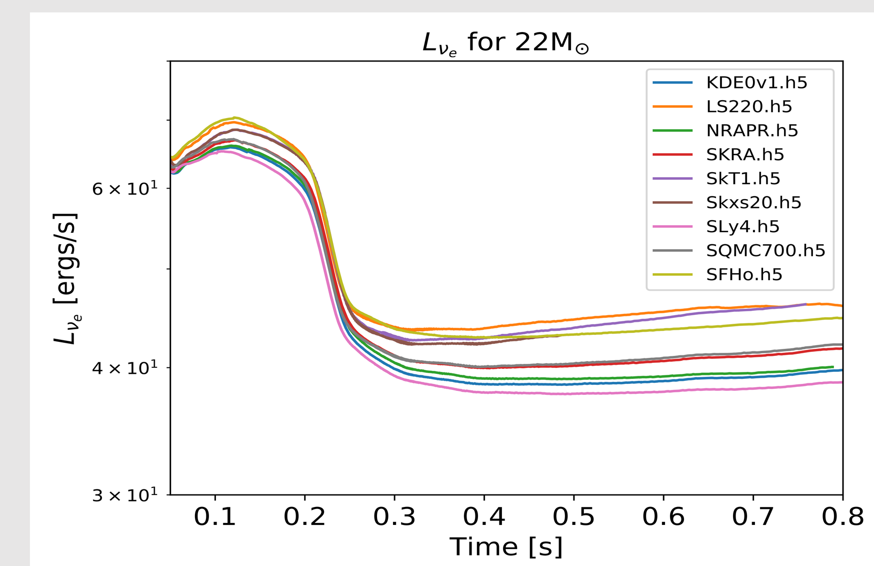
Compare
- Results compared across all progenitors and EOS's

Results

Neutrino Luminosity Bounce Signal

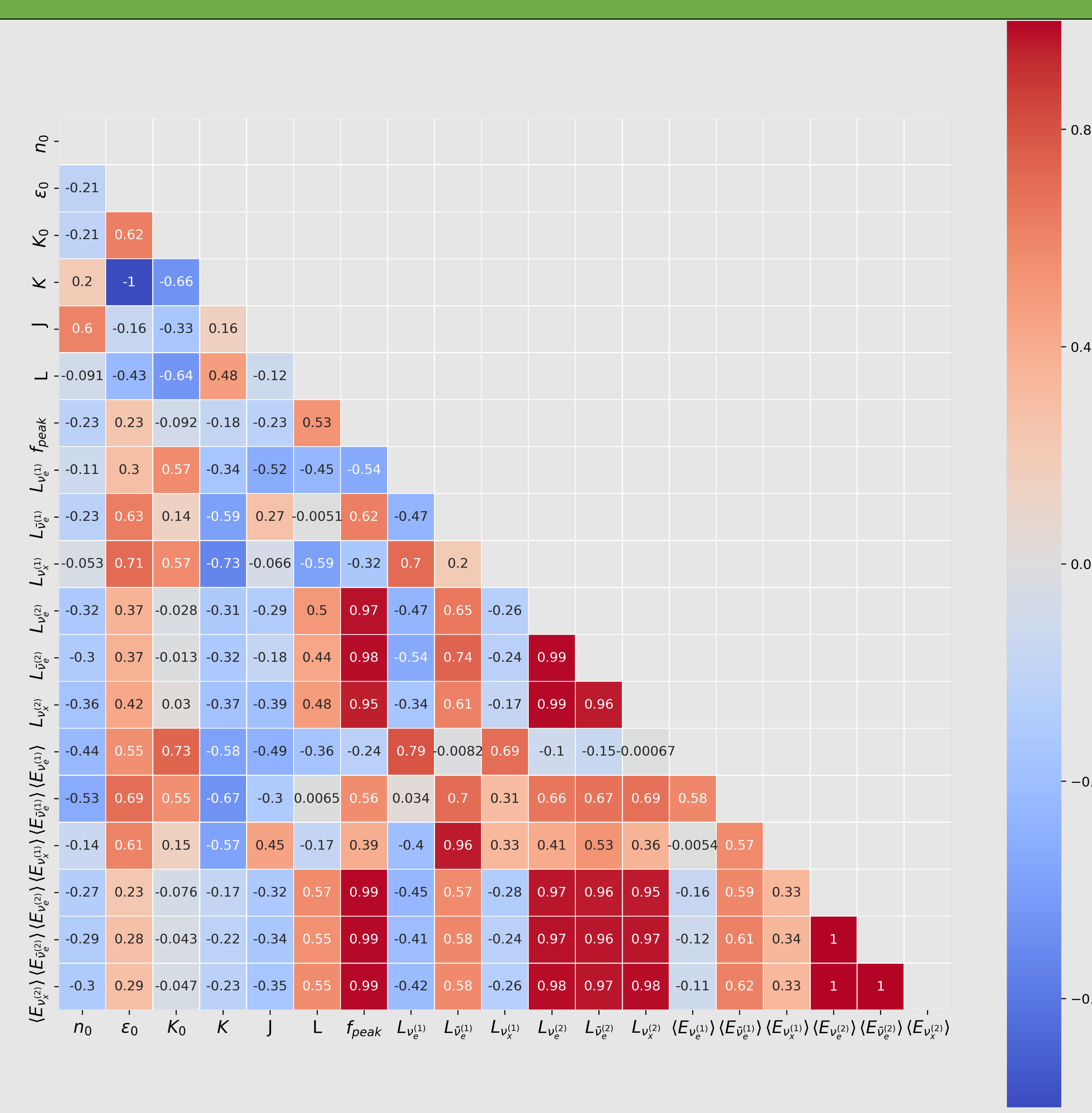


Neutrino Luminosity Signal



The above plots represent the differences in electron neutrino luminosities (L_{ν_e}) across 9 EOS's for a 22 solar mass progenitor.

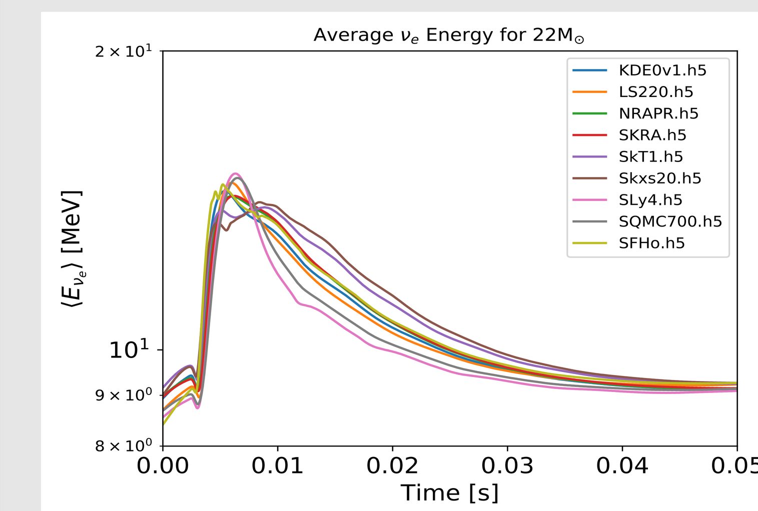
Correlation Matrix



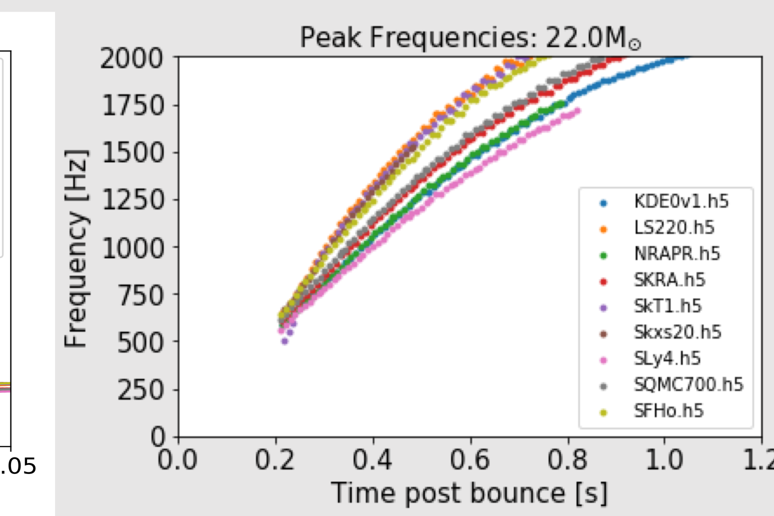
The above figure shows **correlations** between six EOS parameters, peak gravitational wave frequency at 0.48s post bounce, and neutrino luminosities and average energies. The EOS parameters are n_0 the saturation density of symmetric nuclear matter (SNM), ε_0 the binding energy of SNM at saturation density, incompressibility K_0, skewness K`, and energy symmetry parameters J and L. Additionally, the neutrino quantities are taken at two points: at the peak of the burst (1) and at 0.2s (2).

Results

Neutrino Energy



Peak GW Frequencies



(Left) Average electron neutrino energy for a 22 solar mass progenitor during the neutrino burst. (right) Peak GW frequencies produced by the PNS of a 22 solar mass progenitor.

Conclusions

We found that the equation of state non-trivially affects the outcomes of the CCSN. These effects manifested in differences in observables such as neutrino luminosities and peak gravitational wave frequencies. Moreover, we found significant correlations between EOS parameters, particularly binding energy, and these observables. Further work is necessary to better understand the statistical differences in these quantities and how the nuclear physics affects other outcomes of the explosion.

Future Work

1
- Run the simulations to further times and compare the results of the explosions

2
- Incorporate results from parameter study
- Redo the comparisons with more accurate physics

3
- Perform analysis of the differences in neutrino signals
- Explore effects on detected light curves

References and Acknowledgements

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- [1] Schneider, A., Roberts, L., and Ott, C. arXiv:1707.01527