Asymmetry in vp-process Nucleosynthesis

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Introduction

Core–Collapse Supernova (CC SNe) are the energetic death of massive stars where heavy elements are made.

(A) Massive stars burn their H into He. The star contracts and begins burning He to C. This contraction/burning cycle continues burning C → Ne, Ne → O, Si, O → Si, Si → Fe.

(B) Once Fe is reached the core contracts again, contraction becomes collapse since the burning of Fe is not energetically favorable.

(C) The core matter bounces outward and meets the collapsing material to create a shock.

(D) Due to various effects, this shock becomes unstable and blasts outward, tearing apart the star in an explosion and nucleosynthesis can occur.

(E) Matter and energy are ejected, and the explosion leaves behind a neutron star. These explosions spread the elements throughout the universe for new stars, new planets, and new life to be born.

The vp-process

CC SNe result in strong neutrino emission from the cooling proto–neutron star (PNS). The v winds from the PNS energize the matter between the shock and PNS. The main reactions occurring in the winds are ν + n → p + e⁻ and ν̅ + p → n + e⁺.

The reactions determine the ratio of p to n and will become proton rich due to the smaller mass of the proton.

Once p rich, the matter expands and cools to form nuclei that lie near N=Z, such as 54Ni. Nuclei cannot proceed beyond 64Ge, because the β decay half–life is much longer than the time of expansion. ν interactions on p creates free n in this p rich environment. The n are then captured by the n deficient nuclei. This allows for nucleosynthesis beyond A=64, defining the vp process.

Research Goals

Due to the lack of successful SNe II simulations, we do not have an accurate description of the conditions at the innermost ejecta layers. For the first time ever, 2D hydrodynamic simulations with accurate neutrino transport will be available for nucleosynthesis processing. However, 2D simulations are computationally expensive, and do not allow for nucleosynthesis study on many models.

The overall goals of this project are:
- study the vp process in 1D and 2D
- study the differences between 1D and 2D simulations
- find a way to connect the 1D to the 2D, to allow for more accurate 1D nucleosynthesis that is similar to the more physically accurate 2D simulations

This part of the project focuses on the 1D hydrodynamic simulations, with different parameters for the blast strength in 1D

Comparison of Hydrodynamic Models

We study two different types of hydrodynamic models, a push model and an absorption model. The absorption model creates an artificial explosion by adding extra energy to explosion by strengthening the reactions νe + p → e + ν, and ν̅e + n → ν + e⁻. The push model adds energy to the mu and tau flavor neutrinos, which adds energy to the shock. I compare one absorption model and three different strengths for the push model. I compare mass–zones ejected 2.8s post–bounce.

Each of these models are similar, however, the absorption model yields a much larger Y_e, resulting in a stronger vp process.

We can compare the 1D models with 2D models to determine the amount of extra energy needed in push or absorption. We can use these 1D models instead of 2D models for detailed nucleosynthesis of many models.

New Nucleosynthesis Path?

Comparing the different hydrodynamic models by looking at the strength of the reactions at a specific temperature shows the absorption model to have a stronger vp–process.

In analyzing different mass–zones, a set of reaction pathways that has not been seen before in this regime was found. It does not produce the (n,p) and (p,y) reactions, but instead is dominated by (n,p) and (p,y) reactions.

This pathway only shows up in the absorption model, so comparing to a mass–zone of a different model ejected at the same time shows it has a much lower Y_e, which is why we do not see a vp–process.

Future Work

The next steps are to further quantify the differences between the stair–step path we discovered to understand its origins. We also plan to analyze other hydrodynamic models. In doing so, we should have enough 1D to begin comparing to the 2D models being produced at ORNL, which we will process for nucleosynthesis purposes.

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References

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