

THE BIG QUESTION

What can polar axisymmetric models of the deaths of massive stars as Core-Collapse Supernovae tell us about the galactic chemical evolution since the birth of the universe via the Big Bang?

ABSTRACT

A Core-Collapse Supernova (CCSN) explosion occurs when nuclear fusion stops in the core of a massive star. Without a source of energy supplying enough pressure to balance gravity, the core becomes unstable and collapses to form a neutron star. Beyond the neutron star, a shockwave forms which moves outward through the star, causing heavier elements to be created through nuclear fusion.

We have been studying the elements that are ejected from a Core-Collapse Supernova using a nuclear code network called XNet, which follows the thermonuclear kinetics. We use the results from a code called Chimera, which explores the mechanism of Core-Collapse Supernova. We are exploring the composition of the newly-made elements that are ejected by the explosion. Here, we discuss how well extrapolations from earlier times fit the final result. If the extrapolations fit the final result well, it may be possible to shorten the simulation in order to save on computing costs while still maintaining accurate predictions.

SIMULATING SUPERNOVAE WITH CHIMERA

The Three “Heads” of Chimera

- **Spectral Neutrino Transport**
MGFLD-TRANS (Bruenn 1985)
- **Shock-Capturing Hydrodynamics**
Modified VH-1 hydrodynamics code (Hawley et al 2012)
- **Thermonuclear Kinetics**
XNet nuclear network code with 14-species α -network (Hix & Thielemann 1999)
- In addition, CHIMERA is supplemented by realistic equations of state, a limited approach to General Relativity, and up-to-date neutrino interactions.

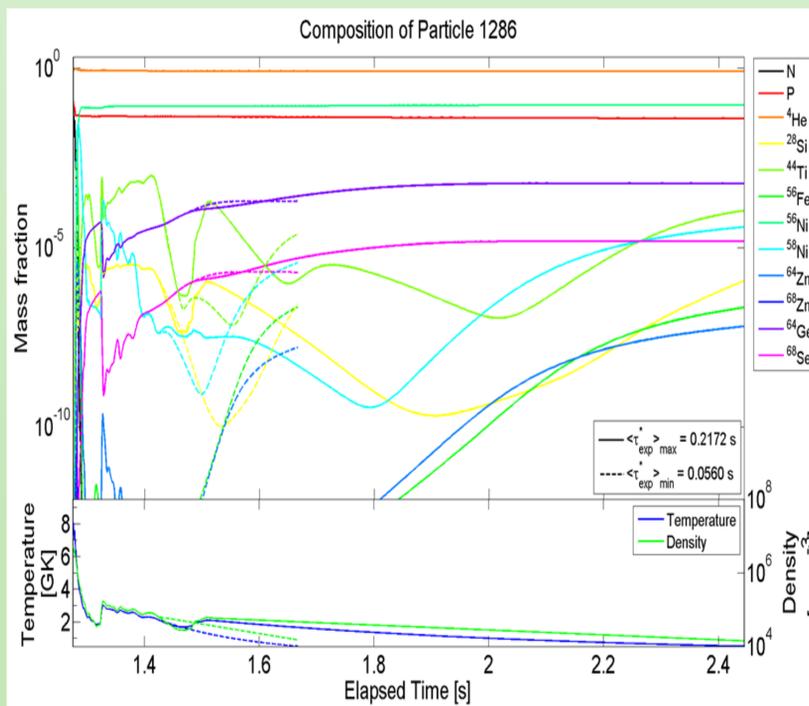
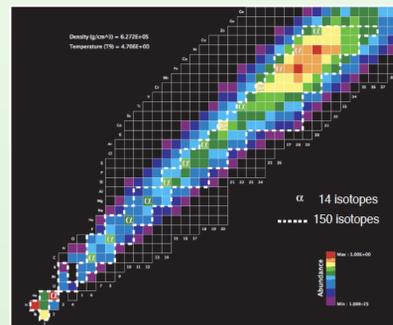


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POST-PROCESSING NUCLEOSYNTHESIS

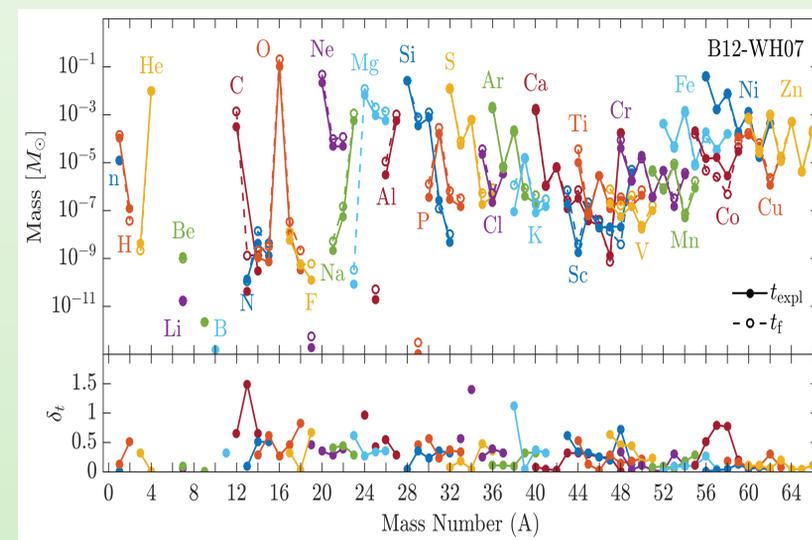
- Tracer particles record the temporal evolution of parcels of matter within the simulation (Lee 2008). We use these thermodynamic histories to analyze the nucleosynthesis in detail via post-processing.
- CCSN produce far more than the 14 species considered within CHIMERA, hence we post-process with a nuclear reaction network containing 1160 species (Fröhlich, et al 2006).
- While post-processing allows us to consider much more realistic nuclear networks, it also introduces additional sources of uncertainty.
- One significant uncertainty is the potential need to extrapolate the thermodynamic history beyond the end of the simulation. The figure below illustrates how this can affect the prediction of the nuclear composition of a single thermodynamic trajectory.



- As seen above, for a single tracer particle, extrapolating from an earlier time can significantly affect the final mass fraction of species that are still evolving at late times, for example, ^{44}Ti and ^{58}Ni , as a result of the effects on the temperature and density evolution. In contrast, species whose masses are set earlier, e.g., ^4He and ^{56}Ni , are much less impacted.
- This is also true for the total final mass of species from all of the particles.

RESULTS

The point at which the simulation is stopped has a great impact on the extent to which we need to extrapolate the thermodynamic histories in time. The figure below compares the total nucleosynthesis of the model extrapolated from 600 ms after the neutron star forms (t_{expl}) and 1400 ms from this time (t_f). The effects are quite significant, indicating that 600 ms is far too early to stop the model.



The top panel of the figure shows the total mass of each species at t_{expl} and t_f . The bottom panel is plot of the relative deviation of each species, $\delta_i = |\log_{10}(M_i(t_f) / M_i(t_{\text{expl}}))|$. As shown, some species are affected by more than an order of magnitude by the extrapolation at 600 ms, while others show minimal effects.

LOOKING AHEAD

The next steps will be to run the post-process again, but this time begin the extrapolations at different times: 700 ms, 800 ms, 900 ms, etc. to determine the earliest stopping time for the simulation which still provides accurate nucleosynthesis.

In addition, we will begin using the most recent version of CHIMERA with newly updated neutrino interactions.

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