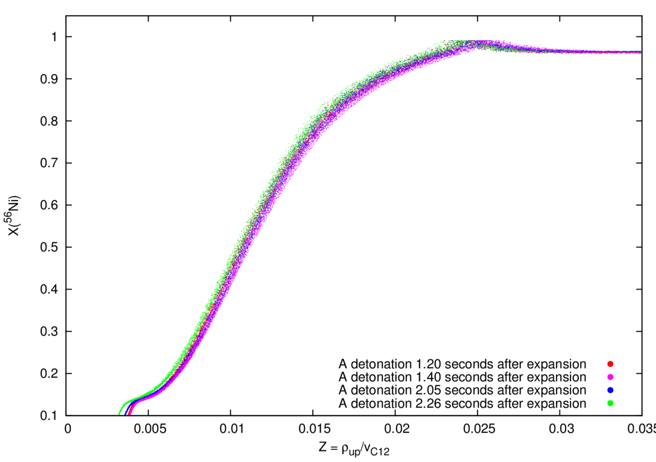
Joint Institute for Nuclear Astrophysics

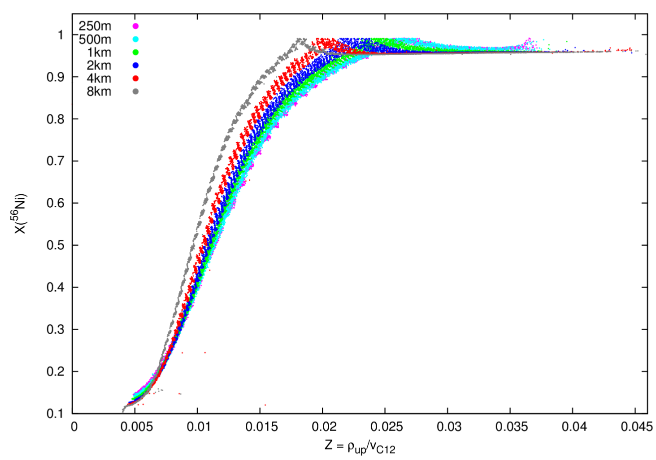
J I N A

Nucleosynthesis of ^{56}Ni in Type Ia Supernova

We have performed one-dimensional, spherically symmetric simulations for six different resolutions (250m, 500m, 1km, 2km, 4km, and 8km). For 500m resolution, we have studied the detonation mechanism for four different ignition conditions. These four conditions differ in the velocity profile of the star at the time of detonation. We obtained different velocity profiles by pulsating the star to mock up the stellar motion during the deflagration phase and then detonating the star at different times. We have found that the mass fraction of ^{56}Ni is very tightly related to an empirical variable $Z = \rho_{up} / v_{12C}$, where ρ_{up} is the mass density immediately upstream of the detonation wave and v_{12C} is the velocity at the end of carbon burning. These fluid variables were obtained from Lagrangian tracer particles that were embedded in the simulations. The mass fraction of ^{56}Ni was obtained from the post-process nucleosynthesis using the temperature and density histories recorded by the tracer particles. Above Z ~ 0.005 which corresponds to the temperature of about 4.5 x 10^9 K, this relation between ^{56}Ni mass fraction and the empirical variable also appears to be robust for all four different simulations (See left figure). This indicates that in one-dimensional, detonating supernova models, one can predict the final yields of ^{56}Ni without performing post-process nucleosynthesis if both the upstream density and the velocity at the end of carbon burning are known. Likewise, we find the relation between the ^{56}Ni yields and the empirical variable converges as the resolution increases (See right figure). However, the physical descriptions during the supernova explosion are now understood to be more complicated as the new observations show the explosions occur in non-spherically symmetric forms. Therefore, the verification of this relation in the two- and three-dimensional simulations is imperative. If the behavior of ^{56}Ni yields with the empirical variable, Z, is also valid in the higher-dimensional settings, this would represent a major breakthrough. With this empirical indication, we would be able to estimate the mass fraction of ^{56}Ni with an accuracy of ~ 10% or less without post-processing the thermodynamic trajectories by the tracer particles to calculate nucleosynthetic yields, which is computationally expensive. Additionally, we would be able to effectively push the resolution of the current multidimensional simulated ^{56}Ni yields from 4km down to 500m. The physical interpretation of the variable Z and the possibility that other variables other than the mass density and the velocity might be involved are under investigation. It is also conceivable to extend the scaling relation to the intermediate mass elements, the products of the incomplete nuclear burning, such as ^{28}Si, ^{32}S, ^{36}Ar, and etc.



Mass fraction of ^{56}Ni as a function of the ratio of mass density immediately upstream of the detonation wave and the velocity at the end of carbon burning for different initial conditions. A detonation was initiated at different times after the star was led to expand: 1.20, 1.40, 2.05, and 2.26 seconds.



Mass fraction of ^{56}Ni as a function of the ratio of mass density immediately upstream of the detonation wave and the velocity at the end of carbon burning for six different resolutions: 250m, 500m, 1km, 2km, 4km, and 8km. The initial velocity profile is the same for all resolution runs.

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