Fe-peak Nucleosynthesis in Surface Detonation Type Ia Supernovae

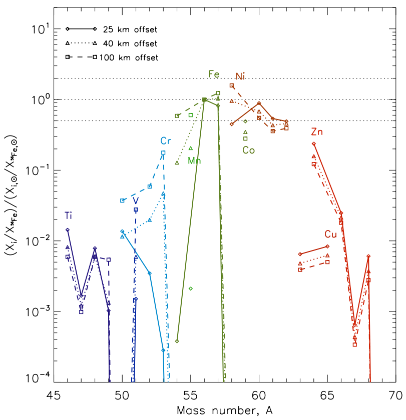

Fig. 1: Final nucleosynthetic yields of Fe-peak isotopes relative to solar values and normalized to ^{56}Fe. Shown are three models which span the degree of pre-expansion and neutronization in our suite of simulations.

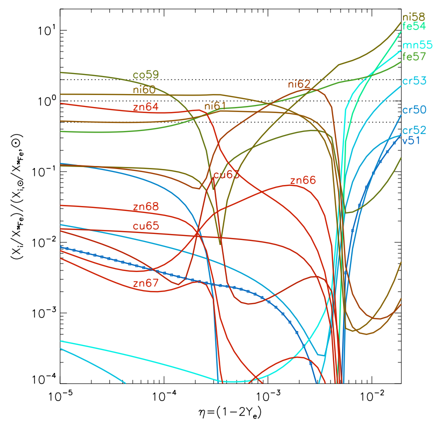

Fig. 2: Graphical rendering of the lookup table corresponding to the freeze out mass fractions of nuclear reaction network integrations along analytic trajectories (Fig. 4) parameterized by values along the black line of Fig. 3.

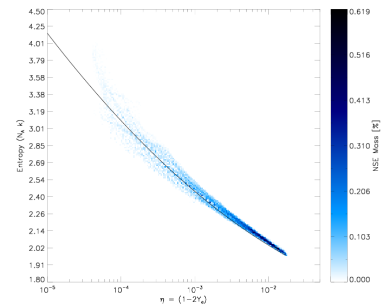

Fig. 3: Final entropy of tracer particles as a function of final neutron excess. The black line is the curve along which the look-up table (Fig. 2) was calculated.

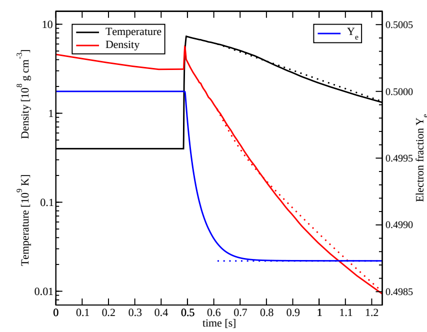

Fig. 4: Representative thermodynamic trajectory of a Lagrangian tracer particle (solid). The dotted line shows the analytic exponential temperature fit. The density is constructed at every time step using constant entropy while Y_e is kept constant at the asymptotic value.

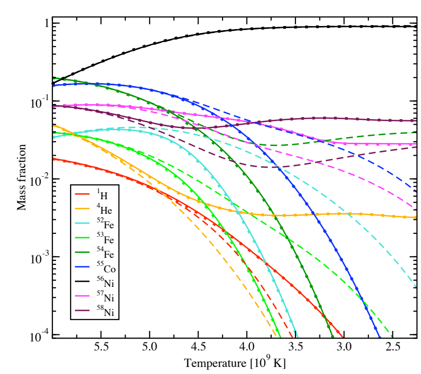

Fig. 5: Time evolution of mass fractions of Fe-peak nuclei. Network integration along the tracer particle (solid) agrees with integration along the analytic trajectory (dotted). NSE (dashed) shown for comparison differs significantly.

Type Ia supernovae (SNe Ia) are believed to be thermonuclear explosions of accreting C/O white dwarfs near the Chandrasekhar limit, powered by the energy released in burning the initial composition to Nuclear Statistical Equilibrium (NSE). They rank among the most important contributing sites to the production of Fe-peak elements and can be used distance indicators to probe the cosmology of the universe. In spite of being standardizable candles, SNe Ia exhibit large variations of their peak luminosity and spectral properties. Even though the explosion mechanism(s) of SNe Ia are still unknown and hotly debated, it is foreseeable that a large number of simulations will be required to explain the observed diversity. The expected large number of simulations makes an efficient method for calculating nucleosynthetic yields very desirable.

We have developed a computationally very efficient method to calculate the Fe-peak yields of SNe Ia that explode via detonations ignited near the surface, and we have applied this method to a suite of 2D axisymmetric SNe Ia models (Fig. 1). The method uses a look-up table (Fig. 2), which assigns Fe-peak yields as a function of neutron excess η. The construction of the table relies on a tight correlation of the final entropy and η that arises in the detonation (Fig. 3). The table is constructed by integrating a nuclear reaction network along analytic trajectories (Fig. 4) adiabatically at fixed electron fraction $Y_e = (1 - \eta)/2$ for a grid of Y_e and the corresponding entropies (black line in Fig. 3). The yields obtained by integrating along the analytic trajectories compare very well yields obtained from post-processing Lagrangian tracer particles, whereas NSE based freeze out estimates give a poor estimate of Fe-peak yields for all but ^{56}Ni (Fig. 5).

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