A Comparison of Type Ia Supernovae with C-O and Hybrid C-O-Ne White Dwarf Progenitors

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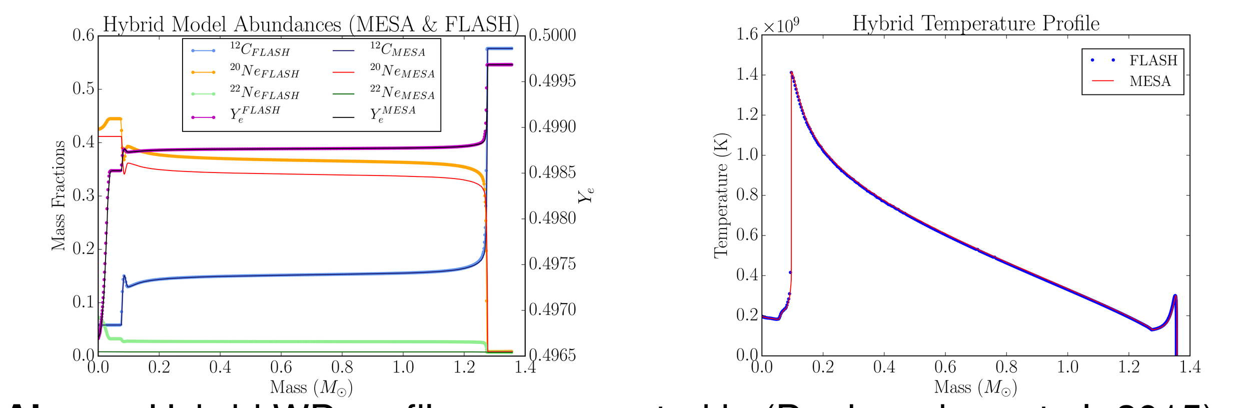
Abstract

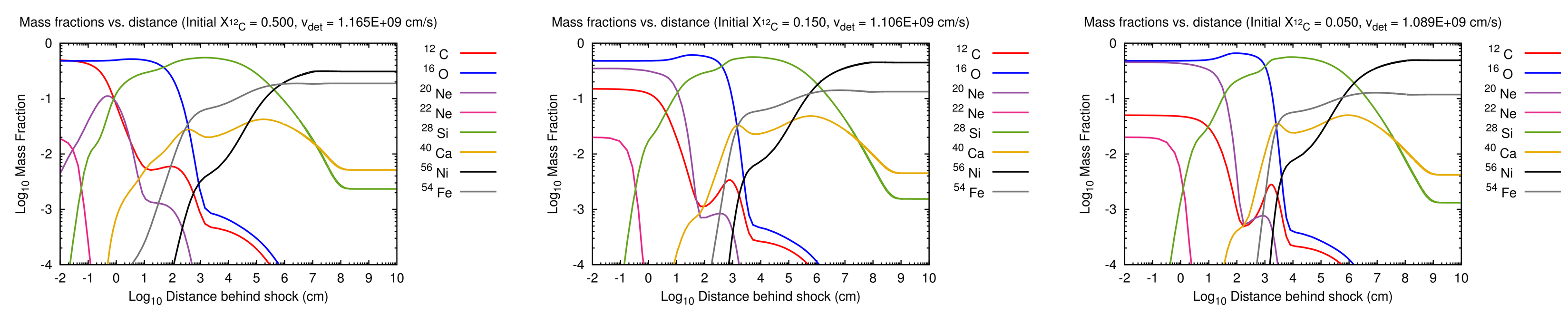
Motivated by recent results in stellar evolution that predict the existence of hybrid white dwarf (WD) stars with a C-O core inside an O-Ne shell, we simulate thermonuclear (Type Ia) supernovae from these hybrid progenitors. We perform 2-D simulations in the deflagration to detonation transition (DDT) paradigm of Type Ia Supernovae from hybrid C-O-Ne progenitors produced with the MESA stellar evolution code (Denissenkov, et al. 2015). We compare the results from these hybrid progenitors to previous results from C-O white dwarfs (Krueger, et al. 2012). We find that despite significant variability within each suite, trends distinguishing the explosions are apparent in their ^{56}Ni yields and the kinetic properties of the ejecta.

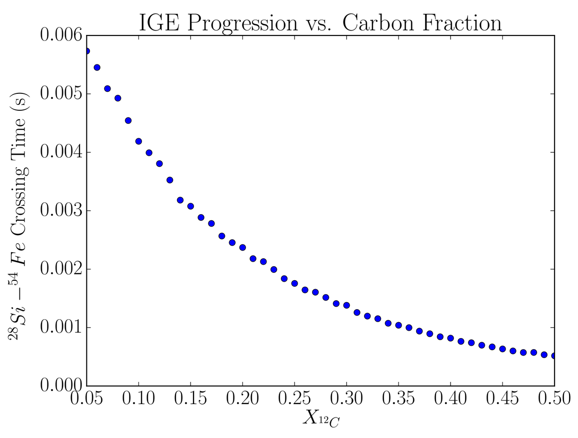
Hybrid Type Ia Supernovae Progenitor Profile



Above: Hybrid WD profiles as computed in (Denissenkov, et al. 2015).

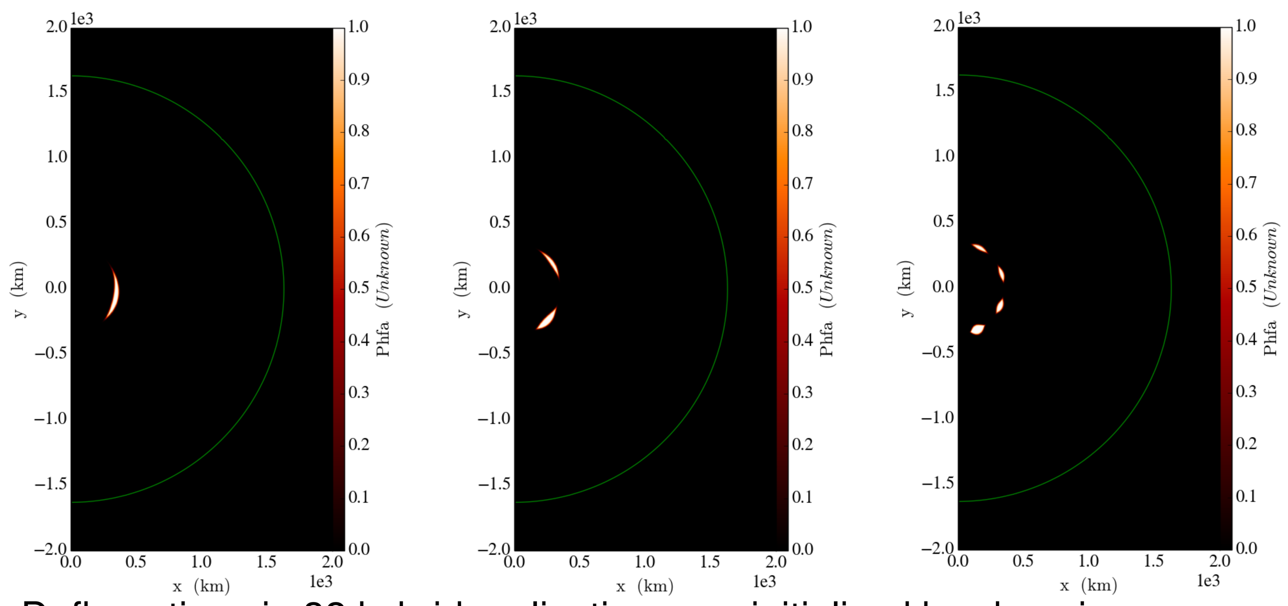
ZND Detonations for C-O-Ne Fuel





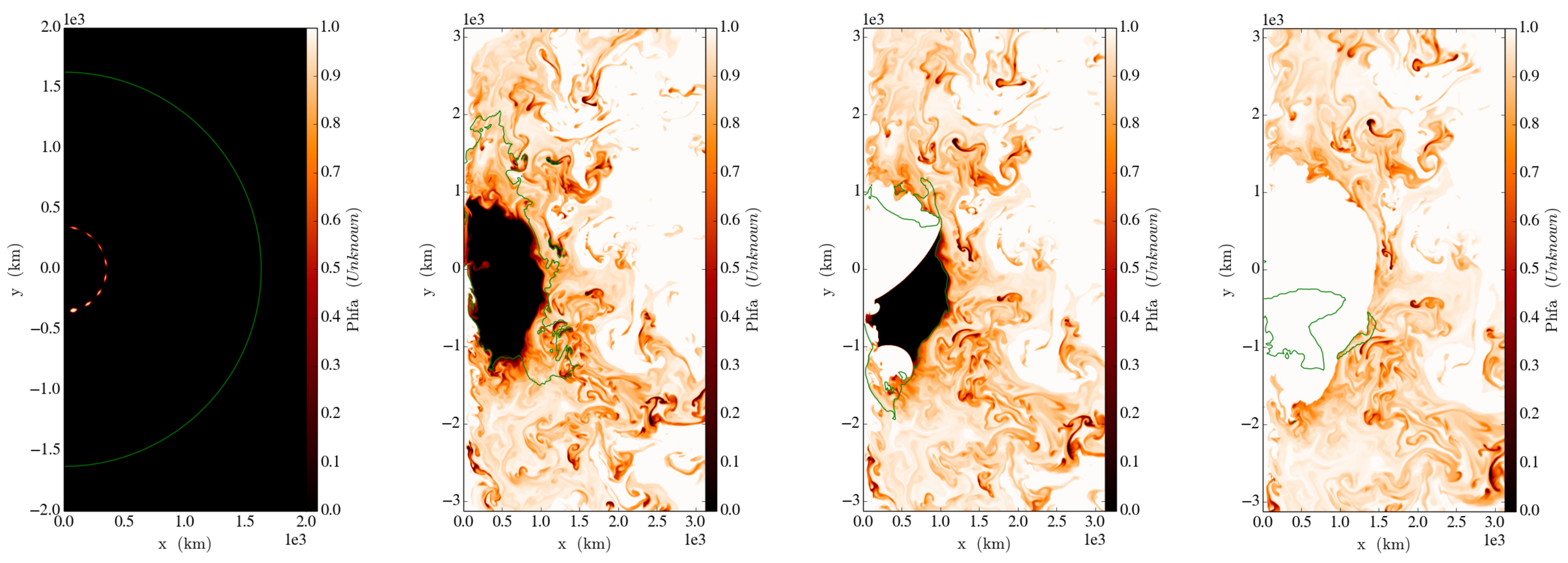
Above: Mass fraction evolution with distance behind shock for carbon fractions of 0.5, 0.15, & 0.05. **Right:** ^{28}Si - ^{54}Fe crossing time for $X_{^{12}C} = 0.05 - 0.50$.

Initialization of the Deflagration



Deflagrations in 32 hybrid realizations are initialized by choosing different numbers and sizes of ignition regions placed at the temperature peak at the base of the convective zone. In 26 C-O realizations, deflagrations are initialized by igniting a sphere with a randomly perturbed surface as in (Krueger, et al. 2012).

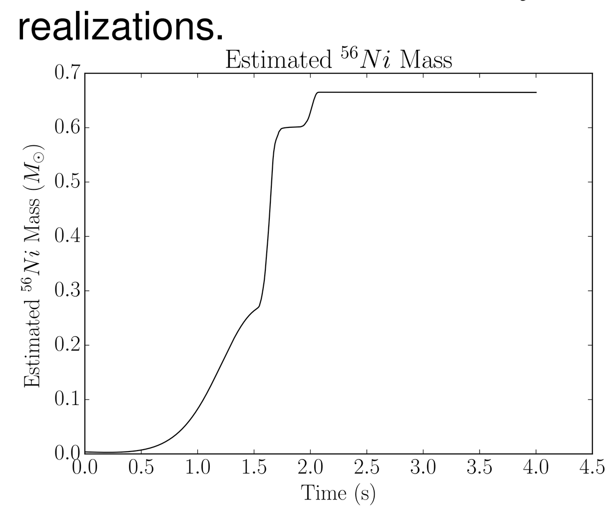
Delayed Core Detonation For Some Hybrid Realizations



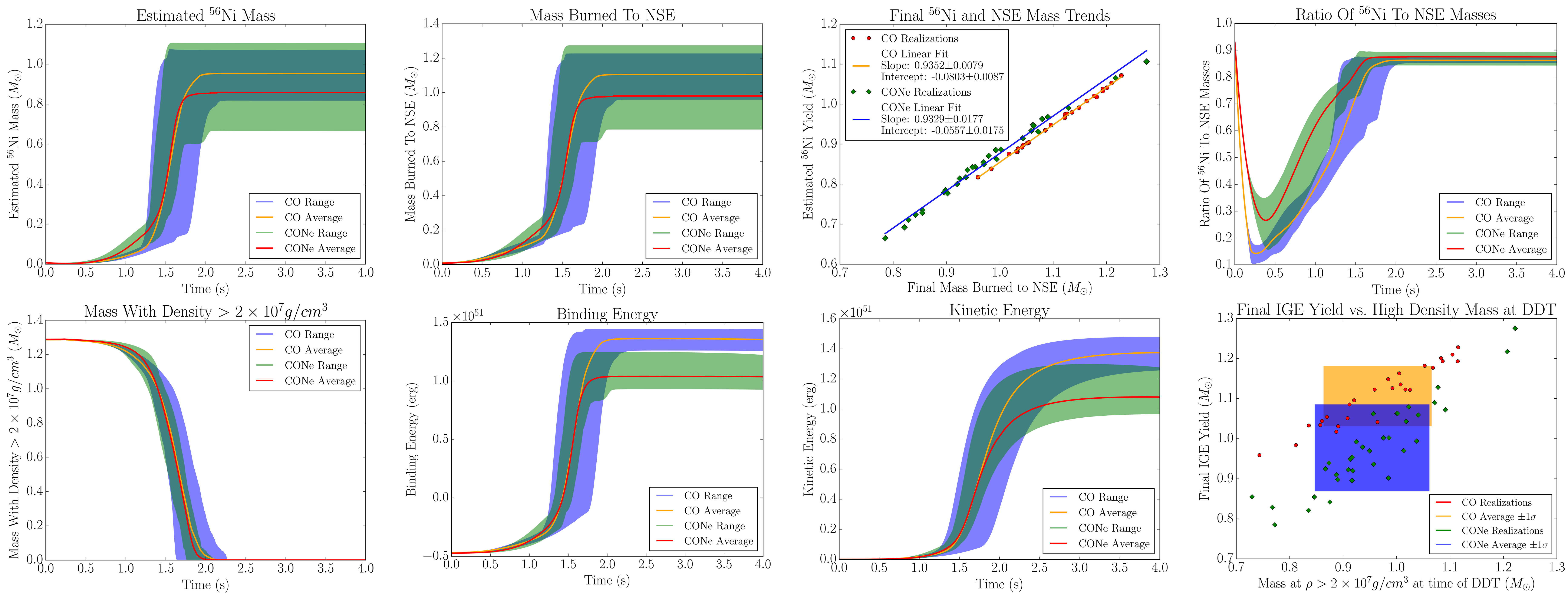
$t = 0s$ | $t = 1.90s$ | $t = 2.00s$ | $t = 2.10s$

Above: Ignition region and delayed progression of the detonation front through the core until after having consumed the remainder of the star as occurs in 6 of the 32 hybrid realizations. The green contour in plots such as these indicates the DDT density ($10^{7.2}$ g/cm^3).

Below: Estimated ^{56}Ni mass over time, showing a secondary plateau near 2.0s indicative of the delayed core burning as characteristic of 6 of the 32 hybrid realizations.



Integral Quantities (e.g. ^{56}Ni Mass) With Shading Showing the Range of Results Given By The Hybrid and CO Suites of Simulations



Conclusions

- Type Ia Supernovae from hybrid white dwarf progenitors yield on average $0.1 M_\odot$ less ^{56}Ni than from C-O progenitors, suggesting they will be correspondingly dimmer. Exceptions may occur, however, given the large spread in possible ^{56}Ni production among our hybrid realizations.
- Hybrid progenitors deposit an average of 21% less kinetic energy in their ejecta than C-O progenitors, indicating slower expansion velocities of the ejecta.
- We attribute lower average ^{56}Ni production from hybrid progenitors to the lower binding energy released when burning ^{20}Ne-enriched fuel compared to pure C-O fuel. Based on the comparable average mass remaining at high ($> 2 \times 10^7 g/cm^3$) density at the DDT time for C-O and hybrid models, we conclude that the degree to which fuel is burned to Fe-group elements is not caused by differences in stellar expansion during the deflagration stage.

References

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