Understanding Properties of Type Ia Supernova Flames

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INTRODUCTION

A white dwarf is a remnant of stellar evolution for progenitor stars not more massive than about 9-10 solar masses. If the white dwarf is located in a binary star system, it has the potential to accrete material from its companion star. Eventually, this process can result in the white dwarf reaching a critical mass, known as the Chandrasekhar limit, which leads to a Type Ia supernova.

Type Ia supernovae are explosive events we believe occur within binary star systems where one of the stars is a white dwarf. These explosions release an enormous amount of energy, briefly outshining entire galaxies and emitting a significant amount of radiation across the electromagnetic spectrum, including X-rays and gamma rays. Type Ia supernovae have a consistent and predictable peak brightness, making them useful as standard candles for cosmological studies such as measuring the universe's expansion rate and the nature of dark energy.

Despite our general understanding of the physical mechanism behind Type Ia supernovae, there is still some uncertainty about the exact nature of the progenitor systems, the ignition mechanism, and the role of asymmetries in the explosion.

AIMS

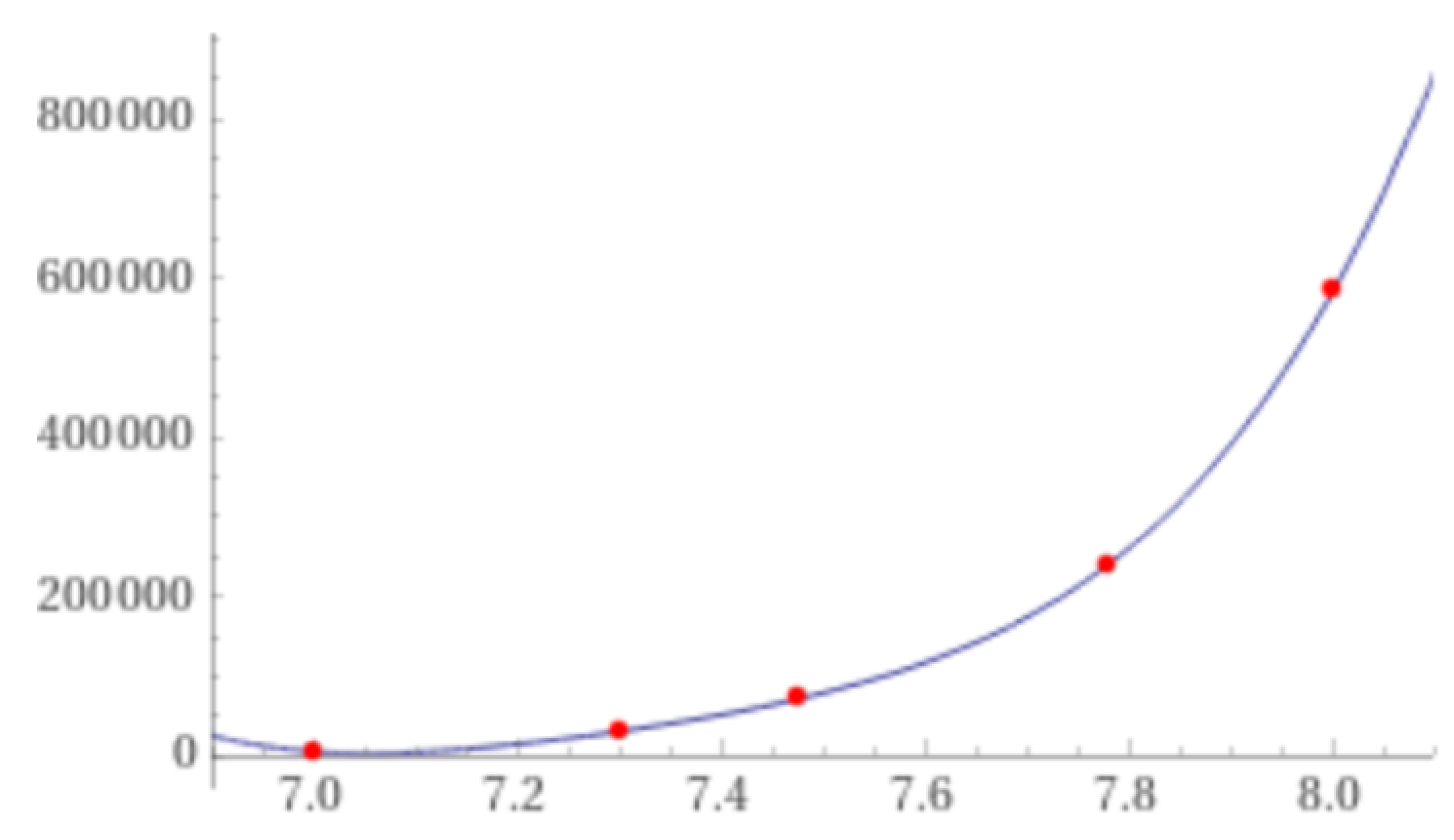
We aim to understand flame properties of Type Ia supernovae progenitors by creating an approximate flame speed formula through MESA simulations. Our results show strong dependencies of flame parameters. Six individuals are working to reduce the difference between approximate and true solutions. We seek to contribute to the advancement of our understanding of these astronomical events.

METHODS

The Advection-Diffusion-Reaction (ADR) equation is used to simulate the evolution of stars and their internal structures through computer code like MESA (Modules for Experiments in Stellar Astrophysics). In our research, we are using MESA to simulate a laminar flame evolution inside a white dwarf during the supernova explosion process. In this project, I modeled flames for densities in the range 1×10^7 - 1×10^8 g/cm^3. Additionally, we are guided by previous works such as TW92 and SFT20.

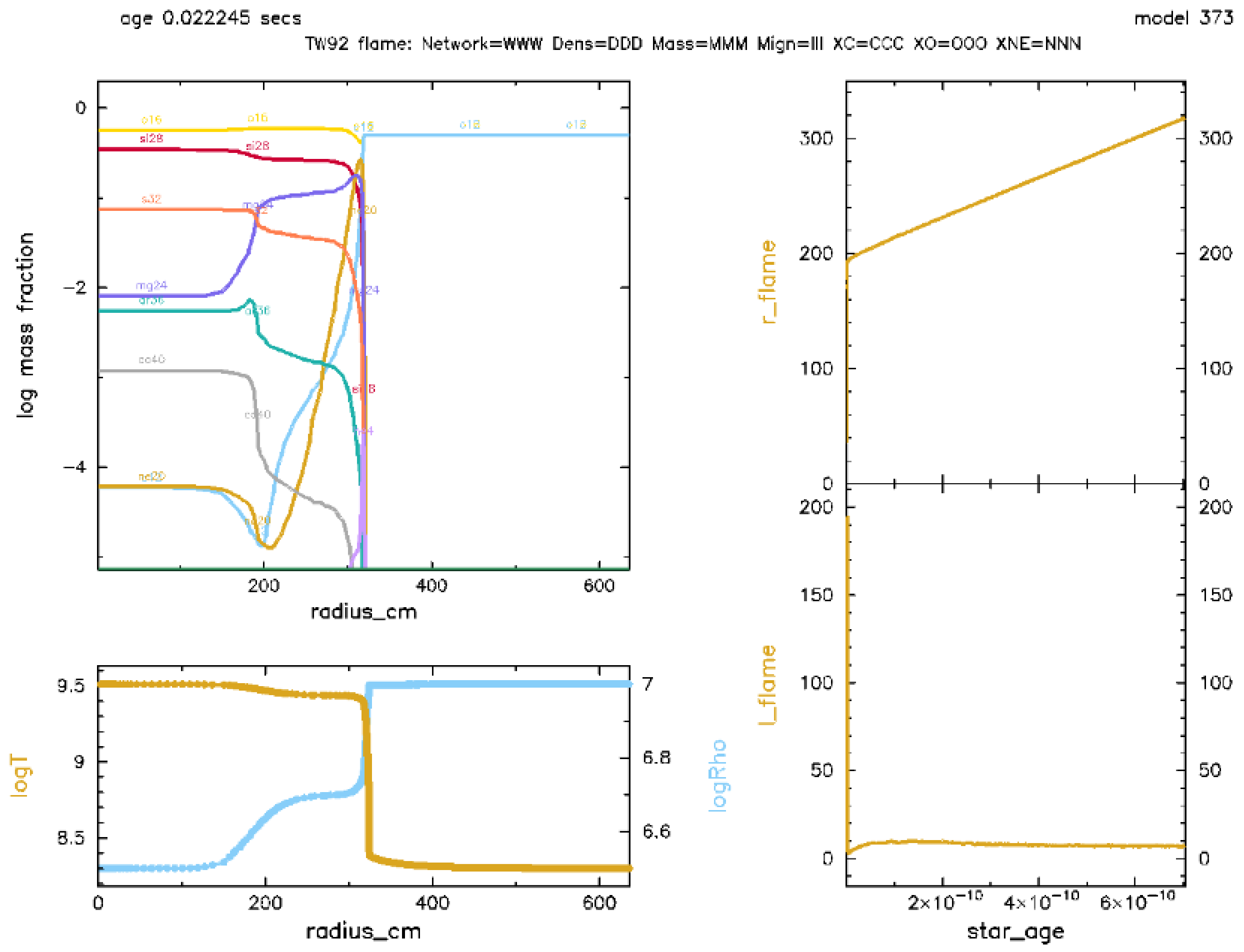
RESULTS

$$1.31917\times10^{6}\,x^{4}-3.85288\times10^{7}\,x^{3}+4.22205\times10^{8}\,x^{2}-2.05713\times10^{9}\,x+3.75992\times10^{9}$$



Flame Velocity as a function of log progenitor density.

Our ongoing goal is to create an approximate function that can describe the flame parameters, such as speed and thickness, as a function of fuel properties, including density and composition. To do this, we will need to sample a problem's parameter space and fit a model using collected data. For each density range, we want to have a number of points, or simulations, with varying density. Specifically, we want five points within each interval logarithmically spaced. Initially, we have focused on a fuel composition of C/O/Ne with a ratio of 50/50/0. After we established our initial simulations, we extracted information from output files, specifically about the thickness and speed of the flame. Next, we will expand our simulations to include fuel compositions of C/O/Ne with a ratio of 100/0/0 and a pure oxygen model of C/O/Ne with a ratio of 0/100/0.



1x10^{7} Progenitor Flame Evolution.

The top-left graph shows the composition of the progenitor during the explosion process. On the bottom-left graph, the log temperature and log density profile of the progenitor can be seen. The top-right graph displays the flame radius in kilometers, while the bottom-right graph shows the flame speed in kilometers per second.

DISCUSSION

We are still working on the project, and our immediate next step is to determine the error of the "fit" function in comparison to our collected data. Compared to the data presented in TW92, our data is relatively consistent, within magnitudes of 10. Note that we adopted different physics.

CONCLUSION

Flame properties change in a consistent and continuous manner in response to changes in the conditions of the flame, as seen with varied densities. Moving forward, we suggest utilizing larger nuclear networks for our simulations, as our current model utilizes a relatively simple network containing only 21 isotopes. Other improvements include a better physics model and higher numerical resolution.

We have encountered some difficulties throughout the research process, including learning how to operate MESA and Linux, comprehending the complex physics involved, and troubleshooting issues that arose during the simulations.

REFERENCES

- Paxton, B., Bildsten, L., Dotter, A., Herwig, F., Lesaffre, P., & Timmes, F. (2010). *The Astrophysical Journal Supplement Series*, *192*(1), 3. https://doi.org/10.1088/0067-0049/192/1/3
- Schwab, J., Farmer, R., & Timmes, F. X. (2020). *The Astrophysical Journal*, *891*(1), 5. https://doi.org/10.3847/1538-4357/ab6f03
- Timmes, F. X., & Woosley, S. E. (1992). *The Astrophysical Journal*, *396*, 649. https://doi.org/10.1086/171746