University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Master of Science

of

DAVID STEPHENS

BSc (University of Waterloo, 2017)

"3D1D Modeling of the Convective-Reactive Mixing in Rapidly Accreting White Dwarfs"

Department of Physics and Astronomy

Monday December 9, 2019
1:00 P.M
Elliott Building
Room 160

Supervisory Committee:
Dr. Falk Herwig, Department of Physics and Astronomy, University of Victoria (Supervisor)
Dr. Arif Babul, Department of Physics and Astronomy, UVic (Member)

External Examiner:
Dr. Peter Oshkai, Department of Mechanical Engineering, UVic

Chair of Oral Examination:
Dr. Terri Lacourse, Department of Biology, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

1D stellar evolution and nucleosynthesis simulations have traditionally modeled the mixing within convection zones as a diffusive process. The fluids within a convection zone are advecting and do not diffuse. However the diffusive approximation is valid when the burning timescale of an exothermic reaction is longer than the convective turn over timescale to which the mixing of those species is approximated over. Since it is 1D, it also assumes that the material is isotropically distributed within the convection zone. In the He-flash convection zones of rapidly accreting white dwarfs (RAWD) H is ingested and burned well within the convective turn over time of 38 minutes. The H is burned through the exothermic $^{12}\mathrm{C}(p,\gamma)^{13}\mathrm{N}$ reaction, $\mathrm{Q} = 1.944$ MeV, and then the unstable $^{13}\mathrm{N}$, with a half-life of 9.6 minutes, will decay to $^{13}\mathrm{C}$ which will undergo the $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$ reaction releasing neutrons. The neutron densities, depending on the H-ingestion rates and mixing details, reach $N_n \approx 10^{13} - 10^{15}$ cm^{-3} which starts the i-process within the convection zone. The H burning provides energy to the flow leading to the dynamic details of the flow being important for the mixing of the H and thus the i-process nucleosynthesis. This is a convective-reactive environment. The isotropic, well mixed over many convective turn over timescales, and long burning timescale assumptions for H in the diffusive approximation are broken in the convective-reactive environment of a He-shell flash convection zone in a RAWD.

To more accurately model convective-reactive mixing environments, a 1D two stream advective mixing model is formulated. A downstream advects H-rich material from the top of the convection zone down to the H-burning region while the upstream advects H-poor material back up to the upper convective boundary. The mixing model includes a horizontal mass flux, γ, which describes the efficiency to which mass is mixed between the two streams. This predominately causes the homogenization of the material between the two streams. The radial mass flux, α, and the horizontal mass flux, γ, are calibrated from 3D hydrodynamic simulations of the RAWD in order to model the mixing within the He-flash shell convection zone.

The downsampled 3D cartesian data output, the *briquette* data, from the 3D hydrodynamic simulations is used to compute γ. This required using numerical tools to interpolate quantities onto spherical shells from 3D cartesian data and to decompose the radial velocity field into its

spherical harmonic modes. Trilinear interpolation is the simplest 3D interpolation method that was tested and it was the interpolation method of choice due to the constraints it has on the interpolating function. The validity of using higher order methods on the *briquette* data was studied in detail but was determined to not be usable due to the computational effort and constraints of the methods.

The two stream model post-processing of the H burning within the 3D hydrodynamic simulations of the RAWD showed excellent agreement in the metrics of the total mass of H burned, the burning rate and burning location of H. This includes two models which undergo dramatic H-ingestion and burning events caused by a GOSH, Global Oscillations of Shell H-ingestion. By adding a network containing 1000's of species to the 1D advective mixing model, the i-process from the RAWD is simulated and compared with a traditional 1D diffusive mixing model. The resulting neutron densities between the two models are comparable however the efficiency to which each produce the heaviest stable elements are different. To reproduce the elemental abundance distribution of the CEMP-r/s star CS31062-050, the diffusive model is run for 15 days of stellar time while the advective model is run for 20 days. The H-ingestion into the He-shell as predicted by the stellar evolution calculations lasts 30 days. The i-process material within the RAWD can be removed from it and participate in the galactic chemical evolution of the galaxy that it resides in. This is due to the RAWD possibly reaching the Chandrasekhar mass and from the loss of material through stellar winds and common envelope interactions with its nearby companion star.