Notice of the Final Oral Examination for the Degree of Doctor of Philosophy of

ONDREA CLARKSON

BSc (University of Illinois at Chicago, 2014)

“The First Stars and the Convective-Reactive Regime”

Department of Physics and Astronomy

Monday, December 14, 2020
10:00 A.M.
Conducted Remotely

Supervisory Committee:
Dr. Falk Herwig, Department of Physics and Astronomy, University of Victoria (Supervisor)
Dr. Kim Venn, Department of Physics and Astronomy, UVic (Member)
Dr. Jay Cullen, School of Earth and Ocean Sciences, UVic (Outside Member)

External Examiner:
Dr. Catherine Lovekin, Department of Physics, Mount Allison University

Chair of Oral Examination:
Dr. Simon Devereaux, Department of History, UVic

Dr. Stephen Evans, Acting Dean, Faculty of Graduate Studies
Abstract

Due to their initially metal-free composition, the first stars in the Universe, the so-called Population III (Pop III) stars were fundamentally different than later generations of stars. As of now, we have yet to observe a truly metal-free star although much effort has been placed on this task and that of finding the second generation of stars. Given they were the first stars, Pop III stars are expected to have made the first contributions to elements heavier than those produced during the Big Bang. For decades significant mixing between H and He burning layers has been reported in simulations of massive Pop III stars. In this thesis I investigate this poorly understood phenomenon and I posit that interactions between hydrogen and helium-burning layers in Pop III stars may have had a profound impact on their nucleosynthetic contribution to the early universe, and second generation of stars.

First, I examined a single massive Pop III star. This was done using a combination of stellar evolution and single-zone nucleosynthesis calculations. For this project I investigated whether the abundances in the most iron-poor stars observed at the time of publication, were reproducible by an interaction between H and He-burning layers. Here it was found that the $i$ process may operate under such conditions. The neutrons are able to fill in odd elements such as Na, creating what is sometimes called the ‘light-element [abundance] signature’ in observed CEMP stars. I also present an additional finding, which is that it is possible to produce elements heavier than iron from the $i$ process operating in massive Pop III stars.

I then describe a parameter study I conducted on H-He interactions in a grid of 22/26 MESA stellar evolution simulations. I found that these interactions are described in four categories based on the core-contraction phase they occur in, and the convective stability of the helium-burning layer. I also examine in detail the hydrogen-burning conditions within massive Pop III stars and the behaviour of the CN cycle during H-He interactions. The latter is compared to observed CN ratios in CEMP stars.

Finally, I describe the first ever $4\pi$ 3D hydrodynamic simulations of H-He shells in Pop III stars. I also examine the challenges in modelling such configurations and demonstrate the contributions I have made in modelling Pop III H and He shell systems in the PPMStar hydrodynamics code. My contributions apply to other stellar modelling applications as well.