Onset of Convection on a Pre-Runaway White Dwarf

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Abstract. Observed novae abundances and explosion energies estimated from observations indicate that there must be significant mixing of the heavier material of the white dwarf (C+O) into the lighter accreted material (H+He). Accordingly, nova models must incorporate a mechanism that will dredge up the heavier white dwarf material, and fluid motions from an early convection phase is one proposed mechanism.

We present results from two-dimensional simulations of classical nova precursor models that demonstrate the beginning of a convective phase during the ‘simmering’ of a Nova precursor. We use a new hydrostatic equilibrium hydrodynamics module recently developed for the adaptive-mesh code FLASH. The two-dimensional models are based on the one-dimensional models of Ami Glasner[1], and were evolved with FLASH from a pre-convective state to the onset of convection.

INTRODUCTION

As a classical nova precursor accretes material from its neighbor, it heats up; by the time its peak temperature becomes roughly $4 \times 10^7$ K – well before the final stages of runaway – the accreted atmosphere becomes convectively unstable. The resulting convective motions may be important for the process of dredging up white dwarf material into the accreted atmosphere.

In this paper, we examine the turn-on of convective motions in a white dwarf atmosphere based on one-dimensional early-time models provided to us by Ami Glasner. This initial model is the same used in other multidimensional studies [1, 2], but taken at an earlier time – at the last timestep before the onset of convection in the 1-d model code. We map this model into the multidimensional FLASH code [3] using techniques developed in [4], and perturb the models to investigate the onset of convective motions.

SIMULATIONS

Figure 1 represents early convective motions in the atmosphere. The temperature in a 5 km × 5km region at the hottest (and least convectively unstable) point in the atmosphere is initially increased by 5%. Sound waves are emitted, and a convective roll
begins. This is shown in Figure 1, through approximately one rollover time, at times $t = 0, 0.2, 0.4, 0.6, 0.8, \text{ and } 1.0$ s after the perturbation is imposed. Note that the velocity field extends to the C+O interface.

The dynamics of the rolls depend on the initial amplitude of the perturbation. Shown in Figure 2 are the motions in the atmosphere at time $t = 1.2$ s with temperature perturbations of 2%, 5%, and 10%, respectively. The velocity vectors in the plots are scaled so that the kinetic energy of the motions are scaled to the thermal energy of the perturbation; note that the sound waves have very similar amplitudes in these plots. Even with these scalings, the 10% perturbation generates considerably more motion.

We can quantitatively see the effects of perturbation size on convective motions above. Shown, in Figure 3 are the kinetic energy as a fraction of the initial thermal energy perturbation, and the average of the interfacial shear velocities over the course of the simulation. Larger perturbations produce motions at the interface much more efficiently.

**DIRECTION OF FUTURE WORK**

Using what we are learning about shear and gravity-wave driven mixing [5], we can hope to model the unresolved mixing due to the interfacial shear generated by these motions. Shown in Figure 4 is a logarithmic plot of metallicity in the atmosphere at time $t = 0.89$ s, where the only source of C+O in the simulation is modelled mixing driven by
FIGURE 2. Early convective motions as in Figure 1 at time $t = 1.2s$ after perturbation, for perturbations in the temperature of 2%, 5%, and 10%. Velocity arrows are scaled to the amount of thermal energy in the perturbation.

FIGURE 3. On the left, kinetic energy in the atmosphere measured in units of the original thermal perturbation energy for the three perturbation amplitudes; on the right, the absolute values of the interface velocities at time $t = 1.2s$ for the three amplitudes. Large perturbations more efficiently cause motions, and the interfacial velocities rise monotonically with the perturbation size.

the velocities at the interface between the white dwarf and the atmosphere. The sub-grid model we have used here is preliminary, based on early results of observed mixing fluxes in small-scale simulations run by A. Alexakis and A. C. Calder described in this volume. As our understanding of the convective motions and the shear-driven mixing improves, we hope to see if this provides a robust dredge-up mechanism. We will incorporate our improved subgrid model into both one-dimensional and multi-dimensional simulations, and test our model results with respect to the typical observed levels of enrichment of
nova envelopes.

FIGURE 4. A metallicity plot at time $t = 0.89$ s of a simulation similar to that shown in Figure 1, but with the C+O white dwarf removed from the simulation domain; all metallicity is either from the accreted material, or from the preliminarily sub-grid model which represents the results of mixing simulations presented elsewhere in this volume.

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