THE CORE HELIUM FLASH

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ABSTRACT

The role of convection in the core helium flash is simulated by two-dimensional eddies interacting with the thermonuclear runaway. These eddies are followed by the explicit solution of the 2D conservation laws with a 2D finite difference hydrodynamics code. Thus, no phenomenological theory of convection such as the local mixing length theory is required.

Our core helium flash is violent, producing a deflagration wave. This differs from the detonation wave (and subsequent disruption of the entire star) produced in previous spherically symmetric violent core helium flashes as the second dimension provides a degree of relief which allows the expansion wave to decouple itself from the burning front. Our results predict that a considerable amount of helium in the core will be burned before the horizontal branch is reached and that some envelope mass loss is likely.

There have been to our knowledge four previous hydrodynamic calculations of the core helium flash. All have assumed spherical symmetry and some form of the local mixing length theory (MLT) for convective energy transport (and, interestingly, all were Ph.D. theses). Convection is important as it is the only mechanism that could even possibly carry away the energy released by nuclear burning on a sufficiently short time scale. In Table I we list the four previous hydrodynamic calculations, their treatment of convection, and their result. While there are many other differences between these calculations, this summary suggests that convection, most specifically the assumptions made about its time dependent response to the thermonuclear runaway, is exceedingly important.

The requirements for an approach to convection are thus formidable: 1) its time dependent response to nuclear activity must not be *a priori* imposed, 2) it must successfully operate in a nonlinear environment, 3) it must account for the effects of very strongly temperature-dependent

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nuclear energy burning rates on the buoyancy, and 4) it must be sufficiently tractable to mesh with realistic physical input and to perform adequately over the time scale of the problem.

Table I: Previous Hydrodynamic Treatments

Author	Treatment of Convection	Hydrodynamic Results
Edwards (1969)	Time dependent MLT	Complete disruption likely
Zimmermann (1970)	Instantaneous adjustment, adiabatic	Essentially hydrostatic
Villere (1976)	Instantaneous adjustment, non-adiabatic	Essentially hydrostatic
Wickett (1977)	Time dependent MLT	Complete disruption

The efforts to formulate a "good theory of time dependent convection" in stellar problems are numerous, and it seems to us naive and unrealistic to expect the appearance of such a theory satisfactory in all respects in the near to intermediate term, as seems to be advocated elsewhere in this volume. It is our opinion that the approach currently best suited for the core helium flash is that outlined by Deupree (1976, 1977a). This approach has been applied in several contexts and no evident observational disagreements have been found (Deupree 1977b, c, 1980; Deupree and Varner 1980). Furthermore, changes produced by variation of uncertain parameters are small (Deupree and Cole 1980). These features and the fact that the approach is explicitly designed for hydrodynamic events govern our choice.

Specific details are published in Cole (1980) and Cole and Deupree (1980, 1981), so that we merely summarize the results here. After an initial thermal readjustment, which spreads out the temperature discontinuity between the neutrino cooled core and the site of the runaway produced by hydrostatic local convection theory models, the flash becomes violent. The flash is nonspherical because the runaway first occurs in the rising eddies. The initial vertical impulse is reduced by horizontal expansion, so that our velocities are low compared to Wickett's although our peak temperatures are comparable. This horizontal expansion spreads the heating and thermonuclear ignition of the inner core over about five seconds, much longer than would be the case in a detonation. During this time, the outer core is expanding subsonically ($v \sim 200$ km/s), after having been heated only slightly. The ignition of the inner core sends out a second subsonic expansion wave ($v \sim 2000$ km/s). We regard it as likely, but unproven, that this second wave will lead to mass loss in the envelope.

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By the end of our calculation, about half of the helium interior to the hydrogen shell has been nuclearly processed. The final elemental abundances cannot be determined by our crude treatment of subsequent α captures on ^{12}C, ^{16}O, ^{20}Ne, etc. If the entire core out to, but not including, the hydrogen shell is then mixed, one can expect the horizontal branch lifetime to be roughly halved. The resulting evolutionary state is not clear if this mixing does not occur.

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DISCUSSION

SPARKS: How much time is involved in the first helium flash?

DEUPREE: About one day. It's not a steady phenomenon. The zone that is running away becomes very superadiabatic. Suddenly, the energy starts funneling to the nearest zones, and the superadiabatic excess beats down the temperature inversion.

SPARKS: Does convection extend all the way to the surface of the star?

DEUPREE: No. We only have the inner core modelled out to not quite the hydrogen burning shell. There are computational reasons for this limitation. The convection zone tails off slowly and does not stop suddenly as in mixing length theory. Convection does extend several zones interior to the temperature maximum and outward to a little beyond the formal boundary of the inner convective region at this phase. We do not include the outer convective envelope.

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