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Note

Stellar Hydrodynamics with Glaister's Riemann Solver: An Approach to the Stellar Collapse

In a previous paper [1], Glaister presented an approximate Riemann solver for the solution of the Euler equations of gas dynamics in one dimension. We have implemented this Riemann solver into a Lagrangian hydrodynamical code and applied it to the spherically symmetric stellar collapse.

The initial data are those corresponding to a like-white dwarf configuration (see [2] for details). The equation of state (EOS) is a γ-law one such that γ varies with density according to Van Riper's prescription [3]:

$$\gamma = \gamma_{\min} + S(\log \rho - \log \rho_b) \tag{1}$$

with: $S = 0$ if $\rho < \rho_b$ and $S > 0$ otherwise.

The parameters $\gamma_{\min}$, S, and ρ_b take values, typically, $\frac{4}{3}$, 1, and 2.7×10^{14} gcm^{-3}, respectively. Calculations with more realistic EOS for supernova matter are in progress.

We have advanced the cell-averaged values of our variables in time and used cell reconstruction with parabolic precision.

For the sake of comparison, we have run our hydrodynamical code by using Godunov's Riemann solver proposed by Godunov for an ideal gas [4] and applied it by considering that each point of the "pressure-density" plane is fitted by an ideal gas corresponding to the particular value of γ obtained from (1).

Our results can be summarized: Glaister's Riemann solver allows us to treat strong shocks, produced in the stellar collapse (see Fig. 1), in an efficient way. No artificial viscosity is needed. By comparing with Godunov's Riemann solver, Glaister's is 20% less time consuming.

In order to accent the discrepancies relative to the ideal gas and, therefore, to Godunov's method, we have taken an arbitrarily high value of S ($S = 10$). Figures 2 and 3 show, respectively, the density and velocity profiles of a model having a central density $\rho_c > \rho_b$. As these figures display, we can see some spurious oscillations, when we use Godunov's method, which do not appear in Glaister's. These oscillations appear just where the EOS is far from the ideal gas. Let us point out that the boundary conditions and the central cells are treated identically in both methods.

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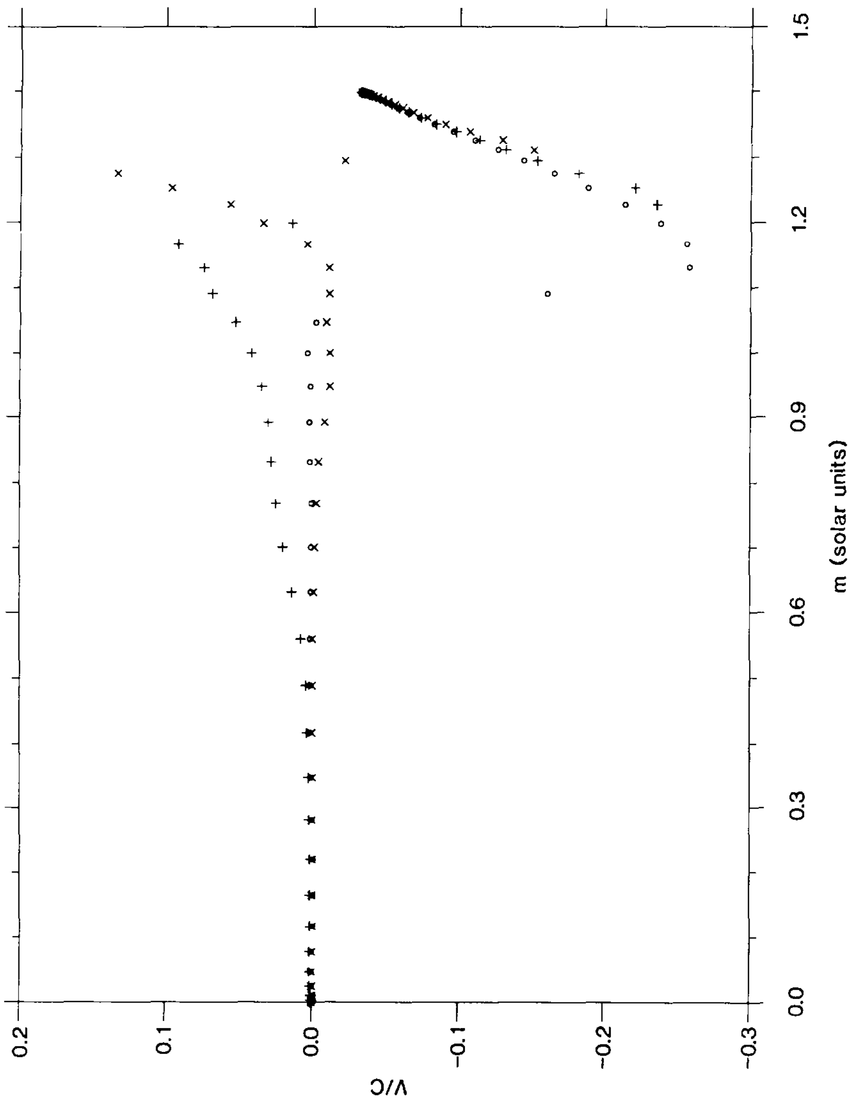

FIG. 1. Velocity (in units of light velocity) versus mass coordinate (in solar mass) at three epochs after bounce ($S = 2$, $\gamma_{\min} = 1.32$, $\rho_b = 2.7 \times 10^{14}$ gcm^{-3}).

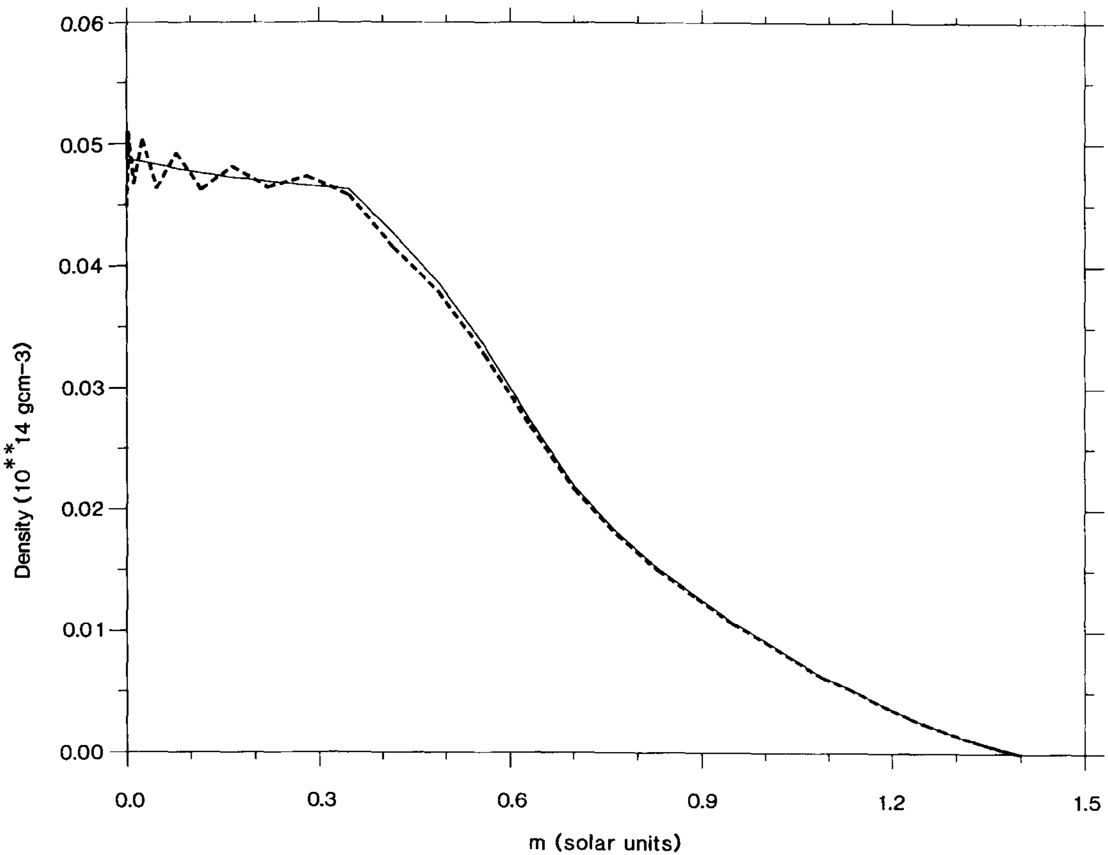

FIG. 2. Density (in units of 10^{14} gcm^{-3}) as a function of mass coordinate (in solar mass) for a model having a central density *greater than* ρ_b. Continous (dashed) line has been obtained by using Glaister's (Godunov) Riemann solver ($S = 10$, $\gamma_{min} = 1.3367$, $\rho_b = 4.6 \times 10^{12}$ gcm^{-3}).

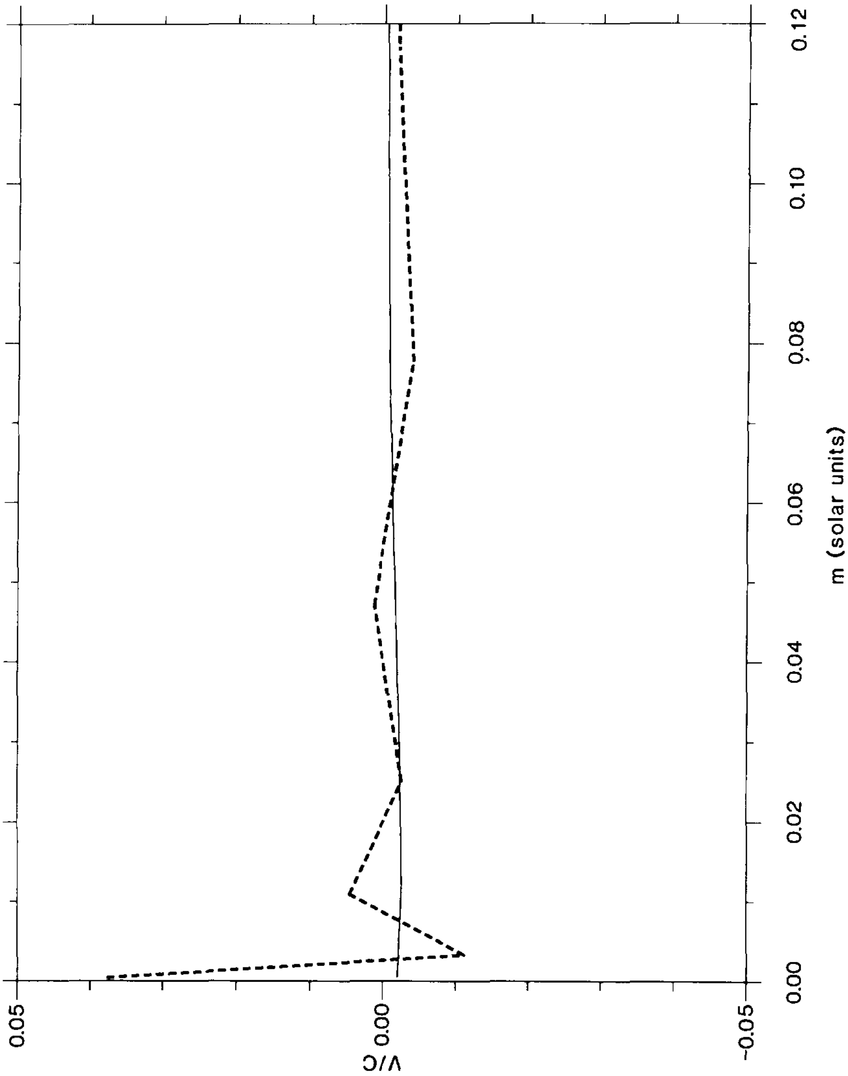

FIG. 3. Velocity (in units of light velocity) as a function of mass coordinate (in solar mass) for a model having a central density greater than ρ_h. Continous (dashed) line has been obtained by using Glaister's (Godunov) Riemann solver ($S = 10$, $\gamma_{min} = 1.3367$, $\rho_h = 4.6 \times 10^{12}$ gcm^{-3}).

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