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SIMULATIONS OF CORE COLLAPSE SUPERNOVAE IN ONE AND TWO DIMENSIONS USING MULTIGROUP NEUTRINO TRANSPORT

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SIMULATIONS OF CORE COLLAPSE SUPERNOVAE IN ONE AND TWO DIMENSIONS USING MULTIGROUP NEUTRINO TRANSPORT

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In one dimension, we present results from comparisons of stationary state multigroup flux-limited diffusion and Boltzmann neutrino transport, focusing on quantities central to the postbounce shock reheating. In two dimensions, we present results from simulations that couple one-dimensional multigroup flux-limited diffusion to two-dimensional (PPM) hydrodynamics.

1 Introduction

Current supernova modeling revolves around the idea that the stalled supernova shock is reenergized by absorption of electron neutrinos and antineutrinos on the shock-liberated nucleons behind it.[1] Key to this process is the neutrino transport in the critical semitransparent region encompassing the neutrinospheres. Potentially aiding this process is convection below the neutrinospheres and the shock,[2,3,4,9] although the verdict has been mixed.[2,4,5,6,8]

In semitransparent regions, neutrino transport approximations such as multigroup flux-limited diffusion (MGFLD) break down. Moreover, neutrino shock reheating/revival depends sensitively on the emergent neutrinosphere luminosities and spectra, and on the neutrino inverse flux factors between the neutrinospheres and the shock. At the very least, computation of these quantities by approximate transport methods have to be checked against exact methods, i.e., against Boltzmann neutrino transport.

We present results from one- and two-dimensional supernova simulations. In one dimension, beginning from postbounce slices obtained from Bruenn's MGFLD simulations, which are subsequently thermally and hydrodynamically frozen, we compute stationary state neutrino distributions with MGFLD and Boltzmann neutrino transport. From these, we compute and compare the neutrino luminosities, RMS energies, and inverse flux factors, and the net neutrino heating rate, between the neutrinospheres and the shock. In two dimensions, beginning with the same postbounce profiles, we couple one-dimensional MGFLD to two-dimensional PPM hydrodynamics to investigate "prompt" convection below the neutrinospheres and "neutrino-driven" convection below the shock. At the expense of dimensionality, we implement neutrino transport

that is multigroup and that computes with sufficient realism transport through opaque, semitransparent, and transparent regions.

2 Prompt Convection

Without neutrino transport, prompt convection develops and dissipates in ~15 ms in both our 15 and 25 $M_\odot$ models. When transport is included, there is no significant convective transport of entropy or leptons in either model. Neutrino transport *locally* equilibrates a convecting fluid element with its surroundings, reducing the convection growth rate and asymptotic convection velocities by factors of 4–250 between $\rho = 10^{11-12}$ g/cm^3, respectively.[5] Our transport neglects the finite time it takes for neutrinos to traverse a convecting fluid element; consequently, our equilibration rates are too rapid, and transport's effect on prompt convection is overestimated. Nonetheless, it is difficult to see how prompt convection will lead to significant convective transport when these effects are taken into account.

3 Neutrino-Driven Convection

In our 15 $M_\odot$ model, large-scale semiturbulent convection is evident below the shock and is most vigorous at $t = 225$ ms after bounce (we began our run at 106 ms after bounce when a well-developed gain region was present.) At this time, the maximum angle-averaged entropy is 13.5, and the angle-averaged radial convection velocities exceed 10^9 cm/sec, becoming supersonic just below the shock. Despite this, at $t = 506$ ms after bounce our shock has receded, the convection below it has become more turbulent, and there is no evidence of an explosion or of a developing explosion.[6]

Different outcomes obtained by the various groups are mainly attributable to differences in the neutrino transport approximations, which determine the postbounce initial models and the neutrino luminosities, RMS energies, and inverse flux factors, which in turn define the postshock neutrino heating rates. Most notable are dramatic differences in the RMS energies.[6] For example, for $\eta_{\nu_e} = 2$ and $T_{\nu_e} = T(\tau_{\nu_e} = 2/3)$, which is implemented by Burrows et al. (1995),[2] the electron neutrino RMS energy and matter temperature are related by $< E^2_{\nu_e} >^{1/2} = 3.6T$, whereas our MGFLD calculations give $< E^2_{\nu_e} >^{1/2} = 3.0T$. Because the neutrino heating rates depend on the square of the RMS energies, the Burrows et al. rates would effectively be 40–50% higher. In the Herant et al. (1994)[3] calculations, at 100 ms after bounce $< E_{\nu_e} > \sim 13$ to 14 MeV and $< E_{\bar{\nu}_e} > \sim 20$ MeV, whereas we obtain the significantly lower values, 10 and 13 MeV, respectively.

4 Boltzmann Neutrino Transport

Although differences in the MGFLD and Boltzmann transport luminosities and RMS energies between the neutrinospheres and the shock were seen, the inverse flux factors differed most. The fractional difference relative to MGFLD rose to $\sim$ 20–25% just below the shock. The net heating rate showed an even more pronounced difference, with the Boltzmann rate being 2–3 times higher just above the gain radius.[7] (Small differences in the heating rates lead to large differences in the net heating rate near the gain radii, where heating and cooling balance.) These results have two ramifications: (1) It may be possible to obtain explosions in spherical symmetry in the absence of convection. (2) Improved transport in two and three dimensions will give rise to more neutrino heating and may give rise to more vigorous neutrino-driven convection. Simulations in both spherical and axi- symmetry with one-dimensional Boltzmann transport are planned. We are also developing realistic multidimensional, multigroup transport.

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