THE INTERPLAY BETWEEN PROTO–NEUTRON STAR CONVECTION AND NEUTRINO TRANSPORT IN CORE-COLLAPSE SUPERNOVAE[1]

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We couple two-dimensional hydrodynamics to realistic one-dimensional multigroup flux-limited diffusion neutrino transport to investigate proto–neutron star convection in core-collapse supernovae, and more specifically, the interplay between its development and neutrino transport. Our initial conditions, time-dependent boundary conditions, and neutrino distributions for computing neutrino heating, cooling, and deleptonization rates are obtained from one-dimensional simulations that implement multigroup flux-limited diffusion and one-dimensional hydrodynamics.

The development and evolution of proto–neutron star convection are investigated for both 15 and 25 $M_\odot$ models, representative of the two classes of stars with compact and extended iron cores, respectively. For both models, in the absence of neutrino transport, the angle-averaged radial and angular convection velocities in the initial Ledoux unstable region below the shock after bounce achieve their peak values in $\approx$20 ms, after which they decrease as the convection in this region dissipates. The dissipation occurs as the gradients are smoothed out by convection. This initial proto–neutron star convection episode seeds additional convectively unstable regions farther out beneath the shock. The additional proto–neutron star convection is driven by successive negative entropy gradients that develop as the shock, in propagating out after core bounce, is successively strengthened and weakened by the oscillating inner core. The convection beneath the shock distorts its sphericity, but on the average the shock radius is not boosted significantly relative to its radius in our corresponding one-dimensional models.

In the presence of neutrino transport, proto–neutron star convection velocities are too small relative to bulk inflow velocities to result in any significant convective transport of entropy and leptons. This is evident in our two-dimensional entropy snapshots, which in this case appear spherically symmetric. The peak angle-averaged radial and angular convection velocities are orders of magnitude smaller than they are in the corresponding "hydrodynamics-only" models.

A simple analytical model supports our numerical results, indicating that the inclusion of neutrino transport reduces the entropy-driven (lepton-driven) convection growth rates and asymptotic velocities by a factor $\sim$3 (50) at the neutrinosphere and a factor $\sim$250 (1000) at ρ = 10^{12} g cm^{-3}, for both our 15 and 25 $M_\odot$ models. Moreover, when transport is included, the initial postbounce entropy gradient is smoothed out by neutrino diffusion, whereas the initial lepton gradient is maintained by electron capture and neutrino escape near the neutrinosphere. Despite the maintenance of the lepton gradient, proto–neutron star convection does not develop over the 100 ms duration typical of all our simulations, except in the instance where "low-test" initial conditions are used, which are generated by core-collapse and bounce simulations that neglect neutrino–electron scattering and ion–ion screening corrections to neutrino–nucleus elastic scattering.

Models favoring the development of proto–neutron star convection either by starting with more favorable, albeit artificial (low-test), initial conditions or by including transport

corrections that were ignored in our “fiducial” models were considered. Our conclusions nonetheless remained the same. Evidence of proto–neutron star convection in our two-dimensional entropy snapshots was minimal, and, as in our fiducial models, the angle-averaged convective velocities when neutrino transport was included remained orders of magnitude smaller than their counterparts in the corresponding hydrodynamics-only models.

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