NEUTRINOS IN CORE-COLLAPSE SUPERNOVAE

Abstract

by

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Despite over half a century of dedicated work, the explosion mechanism of core-collapse supernovae remains one of the most prominent unexplained phenomena in astrophysics. As models include more detailed nuclear and neutrino physics and higher dimensionality, it has continued to be difficult to generate successful explosions and the key to the explosion mechanism has remained unresolved.

Although it remains unclear what *the* supernova explosion mechanism is, it is becoming evident that there are likely many contributing factors. Multidimensional hydrodynamic effects, neutrino phenomena, and details of the nuclear equation of state will all contribute to the evolution of the system and thus have a direct impact on the success or failure of core-collapse supernovae. The goal of this thesis is to contribute to the understanding of the nuclear and neutrino physics that is relevant to the collapse of massive stars and the success or failure of the supernova mechanism.

Oscillations between a right-handed sterile neutrino species and active neutrinos provide an additional energy transport mechanism in the protoneutron star. Considering a range of mixing angles and sterile neutrino masses, including those consistent with sterile neutrinos as a dark matter candidate, I have examined whether such oscillations can impact the core bounce and shock reheating in supernovae. The optimum ranges of mixing angles and masses are identified that can dramatically enhance the supernova explosion. These oscillations efficiently transport energy from

electron antineutrinos from the core to behind the shock, where they provide additional heating leading to much larger explosion kinetic energies. This effect can cause stars to explode that otherwise would have collapsed. I have also found that an interesting periodicity in the neutrino luminosity develops due to a cycle of depletion of the neutrino density by conversion to sterile neutrinos that shuts off the conversion, followed by a replenished neutrino density as neutrinos transport through the core.

The Notre Dame-Livermore Equation of State, aspects of which were developed and implemented as part of this thesis, is a general purpose equation of state for use in neutron star and core-collapse supernova simulations. This equation of state is built upon the framework of the Bowers & Wilson EoS, but with many updates, including a reformulation to a Density Functional Theory approach, the incorporation of 3-body forces at high densities, an improved treatment of the transition to heavy nuclei at high densities, and the possibility of a first-order or crossover transition to a deconfined quark phase at densities above nuclear matter density. I have helped to develop and numerically implement several aspect of this code, including the "pasta" phases of heavy nuclei and the phase transition to quark gluon plasma. Additionally, I have explored in this thesis the impact of the equation of state on the supernova explosion energies and neutrino luminosities.

Finally, this thesis will address relativistic hydrodynamic simulations of black hole formation via rapid accretion onto a neutron star. The associated X-ray emission is analyzed as a means to identify such events. It has been proposed that such collapse may contribute to the precursor X-ray emission from long gamma-ray bursts. In this paradigm, the black hole forms after Bondi-Hoyle accretion onto a neutron star as it is engulfed by the expanding supernova envelope. I have found that the accretion process itself does not does not provide sufficient X-ray luminosity to explain the observed gamma ray burst X-ray precursor.