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Neutrinos and Neutrino Physics: Still Center Stage in Core Collapse Supernovae

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Ascertaining the core collapse supernova mechanism and understanding all of the phenomena associated with such stellar explosions, such as their element synthesis and gravitational wave signatures, neutron star kicks, the spin of pulsars at birth, etc., will require three-dimensional precision models that include realistic neutrino transport, stellar core fluid instabilities, rotation, magnetic fields, a realistic stellar core equation of state for both sub- and super-nuclear densities, and realistic weak interactions. Only in the last decade has supernova modeling broken free from the confines of spherical symmetry. I will review the current state of the art. Even the most fundamental questions remain: How do core collapse supernovae explode? What role do the neutrinos play? While a recent emphasis has been placed on the role of magnetic fields in generating core collapse supernova explosions, the neutrinos still occupy center stage. Moreover, in light of the now experimentally determined fact that neutrinos have mass, neutrino transport in core collapse supernovae takes on a whole new complexity. Previously, neutrino transport was well described by Boltzmann kinetic theory, but now more faithful modeling will require quantum kinetics. The role of neutrino mixing in the core collapse supernova mechanism remains virtually unexplored, with the potential for significant surprises. It is, as I will discuss, one of the frontiers in core collapse supernova theory. Finally, the development of precision three-dimensional supernova models will provide yet another scientific opportunity beyond the chance to ascertain how stars die and produce the elements necessary for life. Together with detailed observations, especially of the neutrino and gravitational wave emissions in the event of a Galactic supernova, detailed supernova models will allow us to use core collapse supernovae as laboratories for fundamental physics. I will discuss some of the possibilities.