TIFR Scientists successfully model Neutrino Oscillations near Supernova Cores

Supernovae are spectacular explosions of super-massive stars, believed to be responsible for a variety of important phenomena ranging from the shaping of galaxies, the birth of neutron stars and black holes, to the creation of vital chemicals — the oxygen in our lungs, the calcium in our bones, and the iron in our blood. The observation of a nearby supernova in 1987 established Colgate and White's longstanding prediction that these stellar explosions are actually powered by neutrinos. However, a detailed understanding is still awaited, because of the enormous challenges in calculating the behavior of neutrinos inside a supernova. The inherent numerical challenges in this are so complex that despite the use of powerful supercomputers to perform these calculations, neutrinos continue to be treated in a highly approximate manner. Theoretical physicists at TIFR, in collaboration with colleagues from Germany and Italy, have made an important advance in modeling neutrinos inside supernovae — including both collisions and fast collective oscillations in their computations for the first time.

Optical image of the supernova SN1987A that was first observed on 23rd February 1987 in the Large Magellanic Cloud. (Credit: NASA/ESA HST)

Neutrinos interact very weakly with matter — they can pass through light-years of lead before an appreciable number of them are stopped. However, a supernova produces more than 10^{57} neutrinos, which carry away 99% of the energy of the supernova within 10 seconds. About 1% of them are expected to be stopped inside the star, and they deposit enough energy to cause a successful supernova explosion. However, neutrinos, unlike photons, have tiny masses and undergo flavor oscillations, constantly flitting between being an electron-type neutrino to muon-type and back — a discovery that was rewarded with the 2015 Nobel Prize. Deep inside the supernovae, where neutrino densities are themselves very large, these oscillations can be very fast and occur over a few centimeters. On the other hand, neutrinos experience collisions much less frequently, and the star itself is much larger. Accurately representing this dynamic range, with enough detail, within a computer simulation has so far remained impossible.

Limiting their calculation to a small region of the star, around the region where neutrinos undergo collisions and oscillations at comparable rates, this team of theoretical physicists was able to show that collisions are crucial to creating the right conditions for fast oscillations of the neutrinos. Once oscillations start, collisions become less important. Their results are expected to allow significant simplifications to the modeling of these complicated systems. More detailed calculations, exploring further exciting connections between neutrinos and supernovae, are expected to lead to a deeper understanding of how stars explode, shape the universe around us, and create the chemical ingredients for life.

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