Sterile Neutrino Oscillations in Core-Collapse Supernova Simulations

WARREN, MacKenzie L., MEIXNER, Matt, MATHEWS, Grant J.
(University of Notre Dame)

HIDAKA, Jun
(Meisei University)

KAJINO, Toshitaka
(NAOJ/University of Tokyo)

Despite recent developments in computational methods and better understanding of the relevant micro-physics and hydrodynamics [1], the detailed explosion mechanism for core-collapse supernovae is still not known. Nevertheless, whatever the explosion mechanism is, it is clear the neutrinos play a very important role even if new neutrino physics may ultimately required to drive the explosion.

In our paper [2] we have explored a new way by which even non-exploding spherical supernova models can be made to explode. In this case the explosion occurs via the introduction of new neutrino physics during the explosion. Specifically, we consider the possible resonant mixing [3,4] between a sterile neutrino and an electron neutrino (or anti-neutrino). A sterile neutrino is a postulated right-handed neutrino that does not interact with normal matter except by vacuum oscillations [2].

We have made core-collapse supernova simulations [2] that allow oscillations between electron neutrinos (or their anti particles) with right-handed sterile neutrinos. We have considered a range of mixing angles and sterile neutrino masses including those consistent with sterile neutrinos as a dark matter candidate. We then examined whether such oscillations can impact the core bounce and shock reheating in supernovae. We identified the optimum ranges of mixing angles and masses that dramatically enhance the supernova explosion by efficiently transporting electron anti-neutrinos from the core to behind the shock where they provide additional heating. We show that an interesting oscillation 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.

We found that, for a broad range of sterile neutrino masses and mixing angles, an efficient transport of anti-neutrino flux can occur by the resonant conversion of electron anti-neutrinos into sterile neutrinos in the core followed by the reverse process behind the shock. This is illustrated in Figure 1 from put paper which shows that a substantial enhancement in the explosion energy can occur by this efficient transfer of energy out of the core by the conversion of electron anti-neutrinos to sterile neutrinos. In particular, sterile neutrino masses consistent with a dark matter candidate can lead to an explosion.

Thus, we can solve both the supernova explosion problem and dark matter problem with a single solution. We have also shown [2] that this process could lead to a unique neutrino luminosity evolution that may be detectable with a future detector like Hyper-Kamiokande.

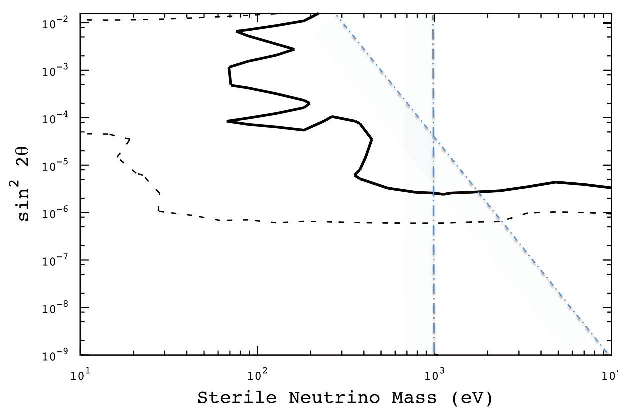

Figure 1: Contours from [2] showing the enhancement in the supernova kinetic energy, relative to an explosion without a sterile neutrino present. The dashed line encloses the region of a factor of 1.5× enhancement to the kinetic energy and the solid line encloses the region of a factor of 10× enhancement. The region of the parameter space that characterizes dark matter candidates is below the intersection of the two shaded lines of the figure.

References

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