Impact of Sterile Neutrino Dark Matter on Core-collapse Supernova Explosion

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The nature of dark matter remains one of the biggest open questions in physics. One viable dark matter candidate is a sterile neutrino. Sterile neutrino dark matter is an electroweak singlet that does not participate in the strong, weak, or electromagnetic interaction.

We have re-analyzed [1] the impact of sterile neutrino dark matter on core-collapse supernova explosions. We considered sterile neutrino masses and mixing angles that are consistent with sterile neutrino dark matter candidates as indicated by recent X-ray flux measurements [2]. We found that the interpretation of the observed 3.5 keV X-ray excess as due to a decaying 7 keV sterile neutrino that comprises 100 % of the dark matter would have almost no observable effect on supernova explosions. However, in the more realistic case in which the decaying sterile neutrino comprises only a small fraction of the total dark matter density due to the presence of other sterile neutrino flavors, WIMPs, etc., a larger mixing angle is allowed. In this case a 7 keV sterile neutrino could have a significant impact on core-collapse supernovae.

Figure 1 from [1] shows the electron neutrino luminosity versus time post-bounce, both with and without a sterile neutrino present. The neutrino luminosities of all neutrino and antineutrino flavors are enhanced from about 0.2 s to 0.4 s post-bounce. This increase in the neutrino luminosities increases the neutrino reheating behind the stalled shock, and thus enhances the explosion energy. The timescale of the increase of the neutrino luminosities corresponds to the time post-bounce when the explosion energy becomes enhanced.

A striking feature is the appearance of episodic neutrino bursts with a period of 40–50 ms in the luminosity and flux with a 7keV sterile neutrino. This is due to the fact that the neutrino photospheric luminosity is fixed by the ratio of the total internal energy to the neutrino diffusion time. When the neutrino chemical potential falls above the resonance energy, those neutrinos in the energy groups corresponding to the resonance energy and width immediately have a diffusion time scale drastically shortened by the free streaming of the sterile neutrinos to just below the neutrinosphere [3,4]. However, once a significant fraction of available neutrinos is depleted, the process is shut off and the luminosity actually decreases until neutrinos can diffuse back into the depleted energy and spatial groups. The amplitude and period of the luminosity spikes scale roughly linearly with neutrino mass. Hence, should an oscillation of the type shown here be detected in a next generation neutrino detector such as Hyper-kamiokande, its amplitude and period could be used to infer the mass of the oscillating sterile neutrino.

Thus, a multi-component model is required to accommodate a sterile neutrino mass and mixing angle that leads to an enhanced explosion. if the decaying sterile neutrino makes up (< 1 %) of the dark matter density, a shorter decay lifetime is allowed corresponding to the larger mixing angle needed to impact the explosion.

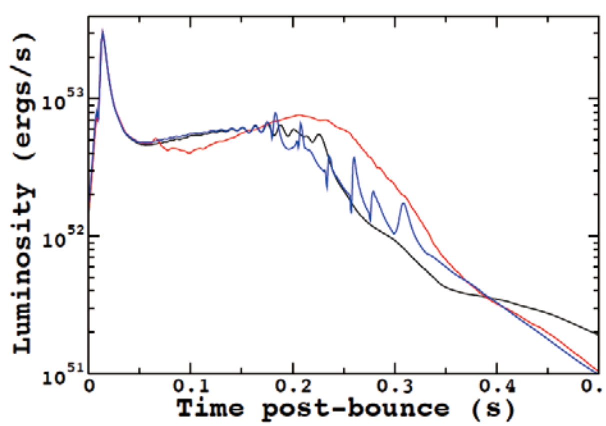

Figure 1: Neutrino luminosity versus time post-bounce. The black line is for a simulation without a sterile neutrino, the red line is for a sterile neutrino with mass m_s = 1 keV and mixing angle $\sin^2 2\theta_s = 10^{-5}$, and the blue line is for a sterile neutrino with mass m_s = 7 keV and mixing angle $\sin^2 2\theta_s = 10^{-5}$.

References

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[2] Boyarsky, A., et al.: 2014, *Phys. Rev. Lett.*, **113**, 251301.
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[4] Hidaka, J., Fuller, G. M.: 2006, *Phys. Rev. D*, **74**, 125015.