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Thermal enhancement of nuclear (anti)neutrino emission during pre-supernova stage

Accurate estimates of (anti)neutrino spectra and luminosities are essential for assessing the possibility of detecting neutrinos from pre-supernova stars. Using the thermal quasiparticle random-phase approximation (TQRPA) method, we studied the effects of nuclear temperature on pre-supernova (anti)neutrino emission. Comparing the ν_e and $\bar{\nu}_e$ spectra produced in neutral- and charged-current weak reactions involving cold and thermally excited (hot) nuclei, we conclude that energy transfer from hot nuclei not only enhances (anti)neutrino emission but also hardens the spectrum.

Using the MESA stellar evolution code, we generated density, temperature, and chemical composition profiles for a $14\,M_{\odot}$ pre-supernova model. From these results, we calculated the time evolution of luminosities and spectra for (anti)neutrinos emitted via thermal and nuclear processes. We find that the luminosity of ν_e from electron capture on hot nuclei exceeds that from e^+e^--pair annihilation by an order of magnitude even one day before collapse. Moreover, we show that for $\bar{\nu}_e$ production, neutrino-antineutrino pair emission via nuclear de-excitation (ND) is at least as significant as pair annihilation. We also demonstrate that flavor oscillations amplify the high-energy component of the ND process in the $\bar{\nu}_e$ flux. This effect could be crucial for the detection of pre-supernova $\bar{\nu}_e$ by terrestrial detectors.

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