COMPETITION OF ELECTRON-CAPTURE AND BETA-DECAY RATES IN SUPERNOVA COLLAPSE

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Weak interaction processes play a decisive role in the early stage of the core collapse of a massive star.[2,3] First, electron capture on nuclei in the iron mass region, starting after the core mass exceeds the appropriate Chandrasekhar mass limit, reduces the electron pressure, thus accelerating the collapse and lowering the electron-to-baryon ratio, Y_e, thus shifting the distribution of nuclei present in the core to more neutron-rich material. Second, many of the nuclei present can also β-decay. While this process is quite unimportant compared to electron capture for initial Y_e values around 0.5, it becomes increasingly competitive for neutron-rich nuclei due to an increase in phase space related to larger Q_β values. However, β decay on nuclei with masses $A > 60$ have not yet been considered in core collapse studies.[4] This is surprising since Brown pointed out nearly a decade ago[5] that certain nuclei heavier than $A = 60$ (e.g. ^{63}Co and ^{64}Co) have very strong β-decay matrix elements, making it conceivable that they can actually compete with electron capture. Brown argued that this might have quite interesting consequences for the collapse. During this early stage of the collapse, neutrinos produced in both electron capture and β decay still leave the star. Therefore, a strong β-decay rate will cool the star without lowering the Y_e value. As a consequence, the Y_e value at the formation of the homologous core (after neutrino trapping) might be larger than assumed. This results in a smaller envelope, and less energy is required for the shock to travel through the material.

In this study we are calculating supernova electron capture and β-decay rates for various pf-shell nuclei using large-scale shell-model techniques. We show that the centroid of the Gamow-Teller strength distribution has been systematically misplaced in previous rate estimates. Our total electron capture rates are significantly smaller than currently adopted in core collapse calculations, while the total β-decay rates change less. Our calculation indicates that for electron-to-baryon ratios $Y_e = 0.42$-0.46, β-decay rates are larger than the competing electron capture rates.

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