On Stellar Evolution in a Neutrino Hertzsprung–Russell Diagram

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Abstract

We explore the evolution of a select grid of solar metallicity stellar models from their pre-main-sequence phase to near their final fates in a neutrino Hertzsprung–Russell diagram, where the neutrino luminosity replaces the traditional photon luminosity. Using a calibrated MESA solar model for the solar neutrino luminosity \( L_{\nu,\odot} = 0.02398 \times 10^{31} \text{ erg s}^{-1} \) as a normalization, we identify \( \approx 0.3 \text{ MeV} \) electron neutrino emission from helium burning during the helium flash (peak \( L_{\nu}/L_{\nu,\odot} \approx 10^{4} \), flux \( \Phi_{\nu,\text{He flash}} \approx 170 \) (10 pc/d)^2 cm^{-2} s^{-1} for a star located at a distance of 10 parsec, timescale \( \approx 3 \) days) and the thermal pulse (peak \( L_{\nu}/L_{\nu,\odot} \approx 10^{9} \), flux \( \Phi_{\nu,\text{TP}} \approx 1.7 \times 10^{7} \) (10 pc/d)^2 cm^{-2} s^{-1}, timescale \( \approx 0.1 \) yr) phases of evolution in low-mass stars as potential probes for stellar neutrino astronomy. We also delineate the contribution of neutrinos from nuclear reactions and thermal processes to the total neutrino loss along the stellar tracks in a neutrino Hertzsprung–Russell diagram. We find, broadly but with exceptions, that neutrinos from nuclear reactions dominate whenever hydrogen and helium burn, and that neutrinos from thermal processes dominate otherwise.

Unified Astronomy Thesaurus concepts: Stellar physics (1621); Stellar evolution (1599); Stellar evolutionary tracks (1600); Hertzsprung Russell diagram (725); Neutrino astronomy (1100)
Stellar Neutrinos

Stars radiate energy by releasing photons from the stellar surface and neutrinos from the stellar interior.

\[ \sigma_\nu \sim \left( \frac{E_\nu}{m_e c^2} \right)^2 \cdot 10^{-44} \text{ cm}^2 \]

\[ \sigma_\gamma = \frac{8\pi}{3} \left( \frac{\alpha \hbar c}{m_e c^2} \right)^2 \sim 10^{-24} \text{ cm}^2 \]

\[ \lambda_\nu = \frac{m_u}{\rho \cdot \sigma_\nu} \bigg|_{\odot} \sim 3 \cdot 10^{19} \text{ cm} \sim 10 \text{ pc} \sim 4 \cdot 10^9 R_\odot \]

\[ \tau_\nu \sim R_\odot / c \sim 2 \text{ s} \]
Neutrino Targets for Current and Future Detectors

Pre-Supernova Stars

\[ \Phi_{\nu, \text{TP}} \approx 1.7 \times 10^7 \left( \frac{10 \text{ pc/d}}{d} \right)^2 \text{ cm}^{-2} \text{ s}^{-1} \]

Detection of Thermal Pulses

Detection of He Flash

\[ \Phi_{\nu, \text{He flash}} \approx 170 \left( \frac{10 \text{ pc/d}}{d} \right)^2 \text{ cm}^{-2} \text{ s}^{-1} \]

\[ L_{\nu, \odot} = 0.02398 \cdot L_{\gamma, \odot} = 9.1795 \times 10^{31} \text{ ergs}^{-1} \]
Future Work

• Multidimensional Effects

• larger range of nuclear reaction rates

• Larger Range or Finer Grid of Stellar Models

• Metallicity effects on Peak Neutrino Luminosities

• Not Previously Measured Neutrino Processes (BSM Physics)

• Determination of The Cosmic Neutrino Background Flux
Questions?