On Stellar Evolution in a Neutrino Hertzsprung-Russell Diagram

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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 ($L_{\nu,\odot} = 0.02398 \cdot L_{\gamma,\odot} = 9.1795 \times 10^{31}$ erg s^{-1}) as a normalization, we identify ≃0.3 MeV electron neutrino emission from helium burning during the helium flash (peak $L_\nu/L_{\nu,\odot} \simeq 10^4$, flux $\Phi_{\nu,\mathrm{He\ flash}} \simeq 170\ (10\ \mathrm{pc}/d)^2$ cm^{-2} s^{-1} for a star located at a distance of d parsec, timescale ≃3 days) and the thermal pulse (peak $L_\nu/L_{\nu,\odot} \simeq 10^9$, flux $\Phi_{\nu,\mathrm{TP}} \simeq 1.7 \times 10^7\ (10\ \mathrm{pc}/d)^2$ cm^{-2} s^{-1}, timescale ≃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

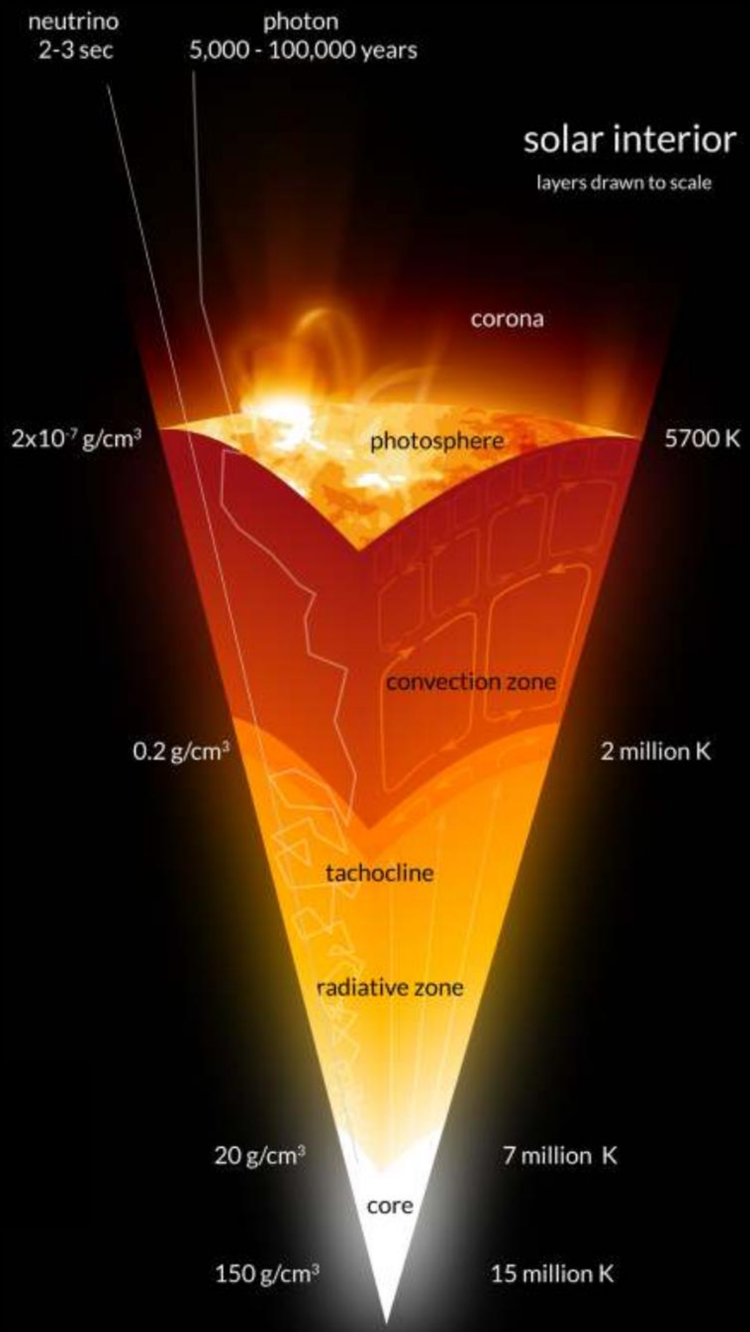
Stars radiate energy by releasing photons from the stellar surface and neutrinos from the stellar interior.

$$\sigma_\nu \simeq (E_\nu/m_e c^2)^2 \cdot 10^{-44}\ \text{cm}^2$$

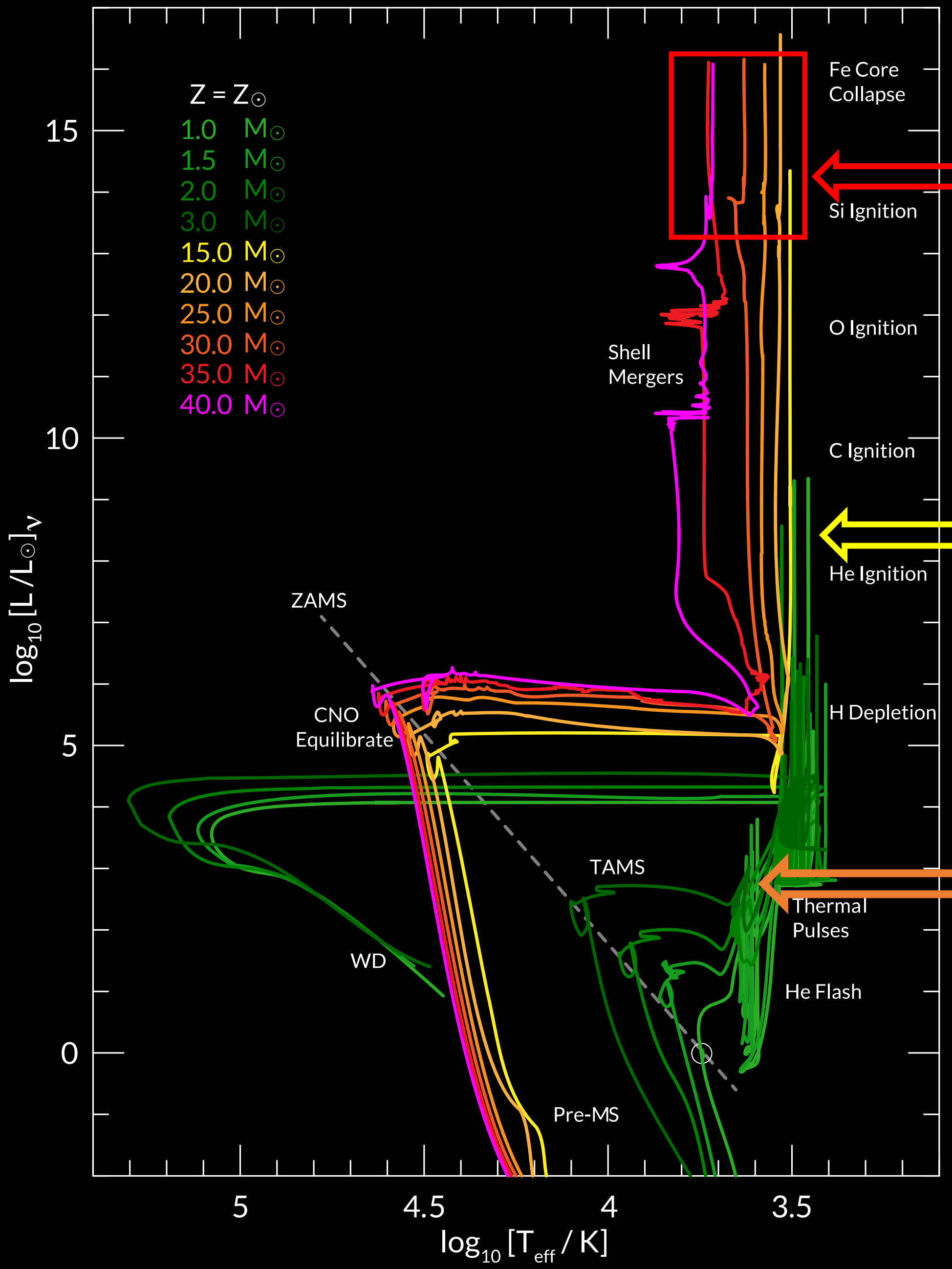
$$\sigma_\gamma = \frac{8\pi}{3}\left(\frac{\alpha\hbar c}{m_e c^2}\right)^2 \simeq 10^{-24}\ \text{cm}^2$$

$$\lambda_\nu = \left.\frac{\mathrm{m_u}}{\rho \cdot \sigma_\nu}\right|_\odot \simeq 3 \cdot 10^{19}\text{cm} \simeq 10\text{pc} \simeq 4 \cdot 10^9 R_\odot$$

$$\tau_\nu \simeq R_\odot / c \simeq 2\ \text{s}$$



Neutrino Targets for Current and Future Detectors



Pre-Supernova Stars

$\sim$ 10 hr before Fe core collapse, $>$ 200 events could be detected for a 15–30 solar mass star at 200 pc. Detectability within 600 pc is possible with the improved sensitivity of Super-Kamiokande with Gadolinium.

Detection of Thermal Pulses

$$\Phi_{\nu,\mathrm{TP}} \simeq 1.7 \times 10^7 (10\mathrm{pc}/d)^2 \ \mathrm{cm}^{-2} \ \mathrm{s}^{-1}$$

Detection of He Flash

$$\Phi_{\nu,\ \mathrm{He\ flash}} \simeq 170 (10\mathrm{pc}/d)^2 \mathrm{cm}^{-2} \mathrm{s}^{-1}$$

$$L_{\nu,\odot} = 0.02398 \cdot L_{\gamma,\odot} = 9.1795 \times 10^{31} \mathrm{ergs}^{-1}$$

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?