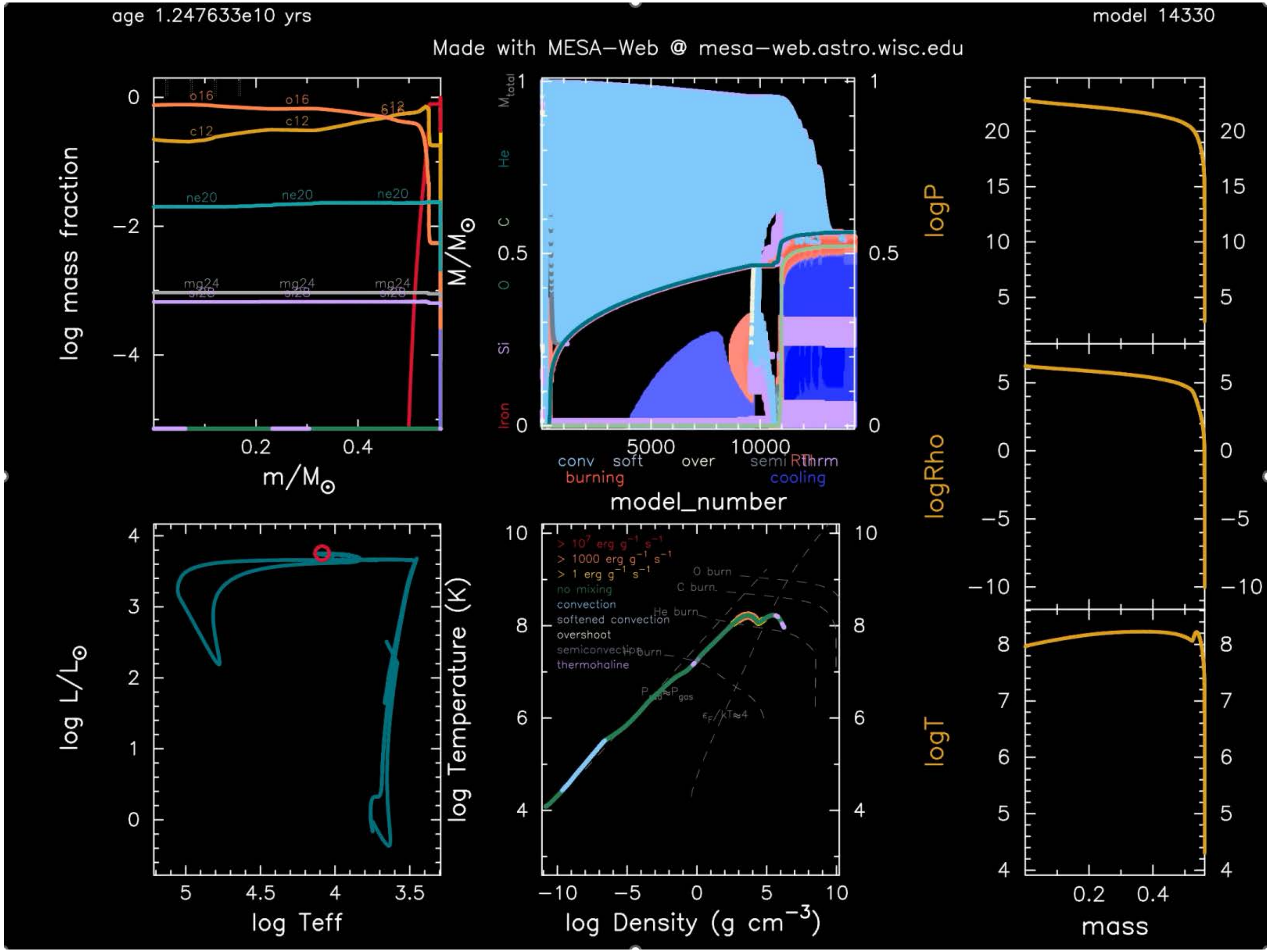
Today in Astronomy 241: later stellar evolution

- Ascent of the red giant branch: fully convective stars
- The horizontal branch
- The asymptotic giant branch
- Death of low-mass stars
- **Reading**: C&O chapter 13, pp. 457-470

No recitation tomorrow



[MESA](#) model of the Sun, through age 12.476 Gyr.

Late stages of stellar evolution

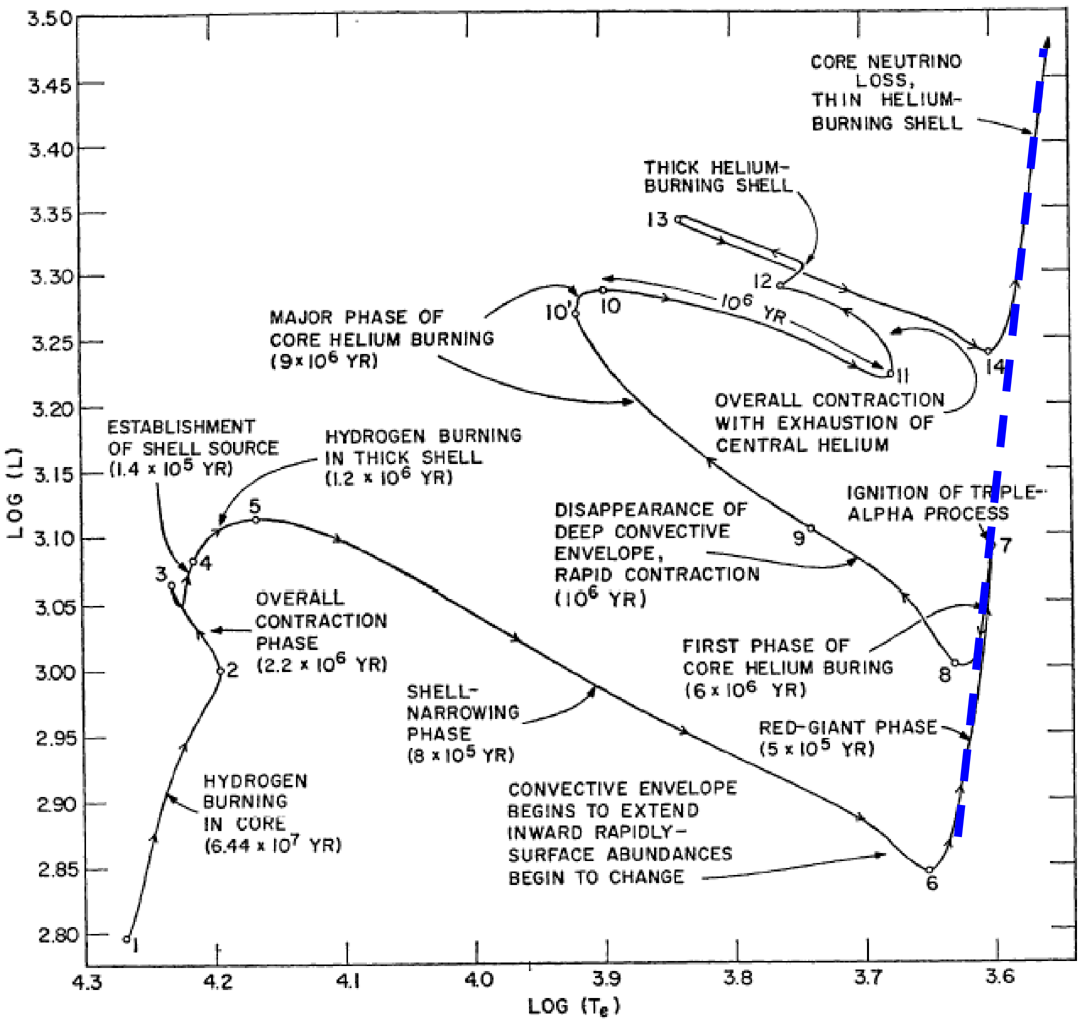
After the main sequence and the subgiant phase:

- **Red giant** phase
  - Core collapse and heating
  - Convection zone extends inward (**dredge-up**); eventually star becomes fully convective
  - Extreme expansion of envelope of star
  - Core temperature reaches 10^8 K, and triple-α begins burning helium efficiently, with a notable **helium flash** marking the onset in stars with $M > 2M_\odot$
- **Horizontal branch:** the helium-burning main sequence
  - Core helium burning, shell hydrogen burning
  - About half of the victims of ASTR 142 will have made special note of this phase in their observations

Late stages of stellar evolution (continued)

- **Asymptotic giant branch**
  - Further dredge-up; heavier fusion products transported to the surface
  - Shell helium hydrogen burning, carbon-oxygen core
  - Occasional **helium shell flashes**, from ignition of helium passed downwards by the hydrogen-burning shell
  - Mechanical instabilities, thermal pulses, pulsations, and mass loss
- Further evolution of stars with $M < 8\ M_\odot$
  - Low-mass end: ejection of stellar envelope, leaving degenerate helium or carbon-oxygen core; planetary nebula and white dwarf remnant
  - High-mass end: Type I supernova?

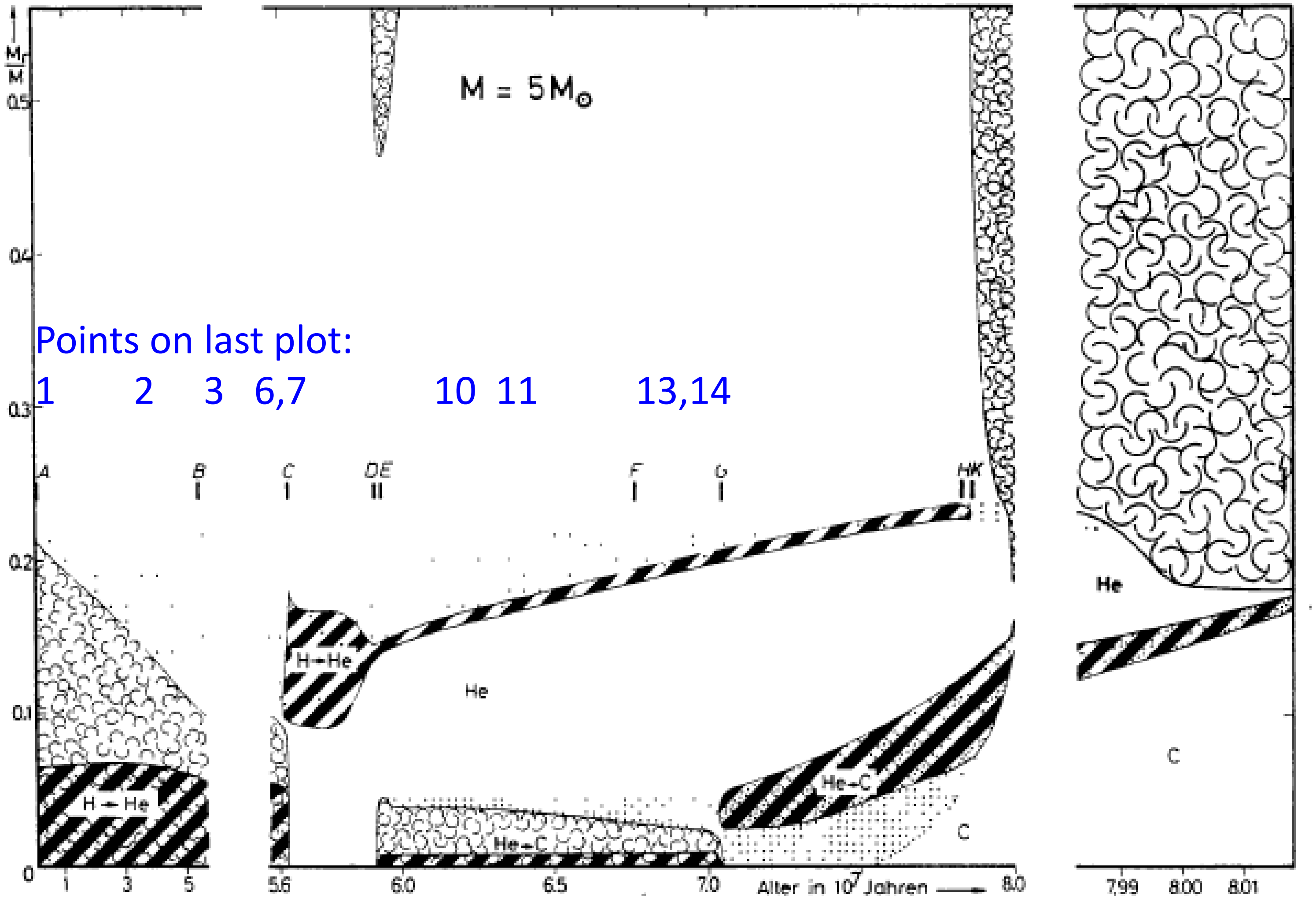
Post-main-sequence stellar evolution



Post-main-sequence development of a 5 $M_\odot$ star (Iben 1967)

– – **Giant branches**: star mostly convective and expanding; almost the reverse of the Hayashi track.

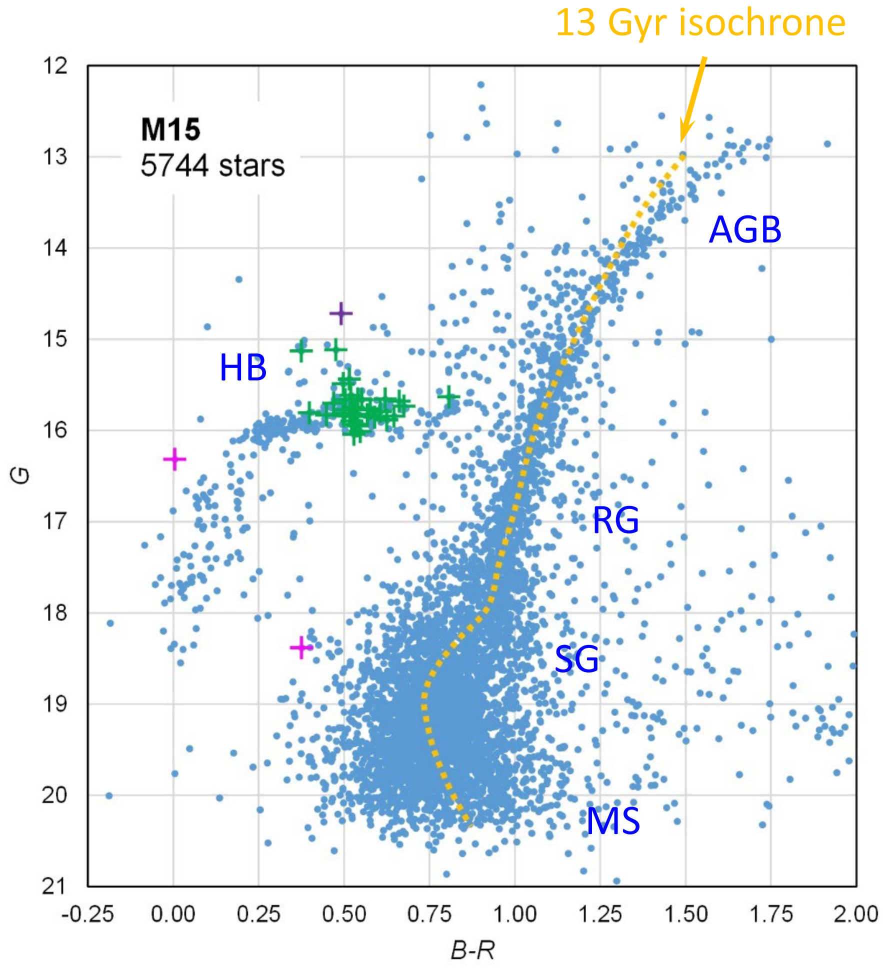
Post-main-sequence stellar evolution (continued)



[Kippenhahn, Thomas and Weigert 1965]

Snapshot of an evolved population

M 15 is nearly as old as the Galaxy and has low metallicity, like most Galactic globular clusters. Data from Mees.



Today's in-class problems

A. Recall that, for a stellar atmosphere, the optical depth to the photosphere is

$$\tau = -\int_{\infty}^{R} \kappa\rho dr = \overline{\kappa}\int_{R}^{\infty} \rho dr = \frac{2}{3} \quad .$$

Use this, along with the equation of hydrostatic equilibrium, to show that the pressure at the photosphere is

$$P_O(R) = \frac{GM}{R^2}\frac{2}{3}\frac{1}{\overline{\kappa}} \quad .$$

Here $\overline{\kappa}$ is the Rosseland mean opacity in the photosphere, generally very different from that deep in the interior.

Today's in-class problems (continued)

B. **The Hayashi track, or the red giant branch**. Suppose a stellar interior (I) is fully convective with ideal-gas pressure:

$$P_I = K' T_I^{\gamma/\gamma-1} = K' T_I^{5/3} \quad .$$

Suppose further that its atmospheric opacity is dominated by H^- bound-free transitions, for which the mean opacity can be (very crudely) approximated by

$$\overline{\kappa} = \kappa_0 P T^3 = \kappa_0 P_O T_e^3 \text{ at the photosphere.}$$

Find a relationship between luminosity and effective temperature for stars of this type, by setting the pressure and temperature in the interior equal to those at the photosphere (O, e).

Today’s in-class problems (continued)

C. Sketch your result from Part B, in the form of a plot of log L vs. log T_e. Sketch also, on the same plot, the hydrogen-burning main sequence. Comment on the comparison between the two, and on the nature of the star’s interior on the Hayashi track or the red giant branch.

Hints for the previous set of in-class problems

1. Eliminate T, solve for P:

$$P_{\text{gas}} = \frac{\rho kT}{\mu m_{\text{H}}} = (1-\beta)P \quad \Rightarrow \quad T = \frac{(1-\beta)\mu m_{\text{H}} P}{\rho kT}$$

$$P_{\text{rad}} = \frac{4\sigma}{3c}T^4 = \beta P \quad \Rightarrow \quad \frac{4\sigma}{3c}\left[\frac{(1-\beta)\mu m_{\text{H}} P}{\rho kT}\right]^4 = \beta P$$

$$\Rightarrow \quad P = \left[\frac{3c}{4\sigma}\left(\frac{k}{\mu m_{\text{H}}}\right)^4 \frac{\beta}{(1-\beta)^4}\right]\rho^{4/3} = K\rho^{4/3}$$

which is a polytrope with $n = 3$.

2. C&O 13.3.