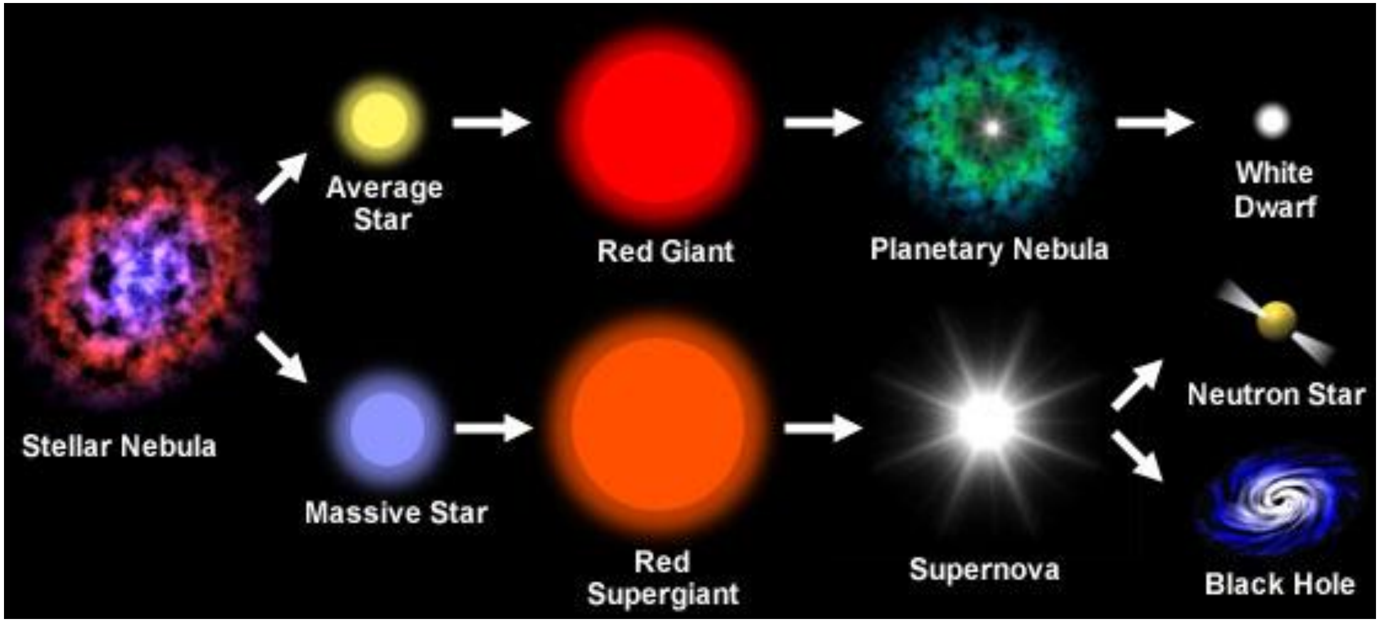
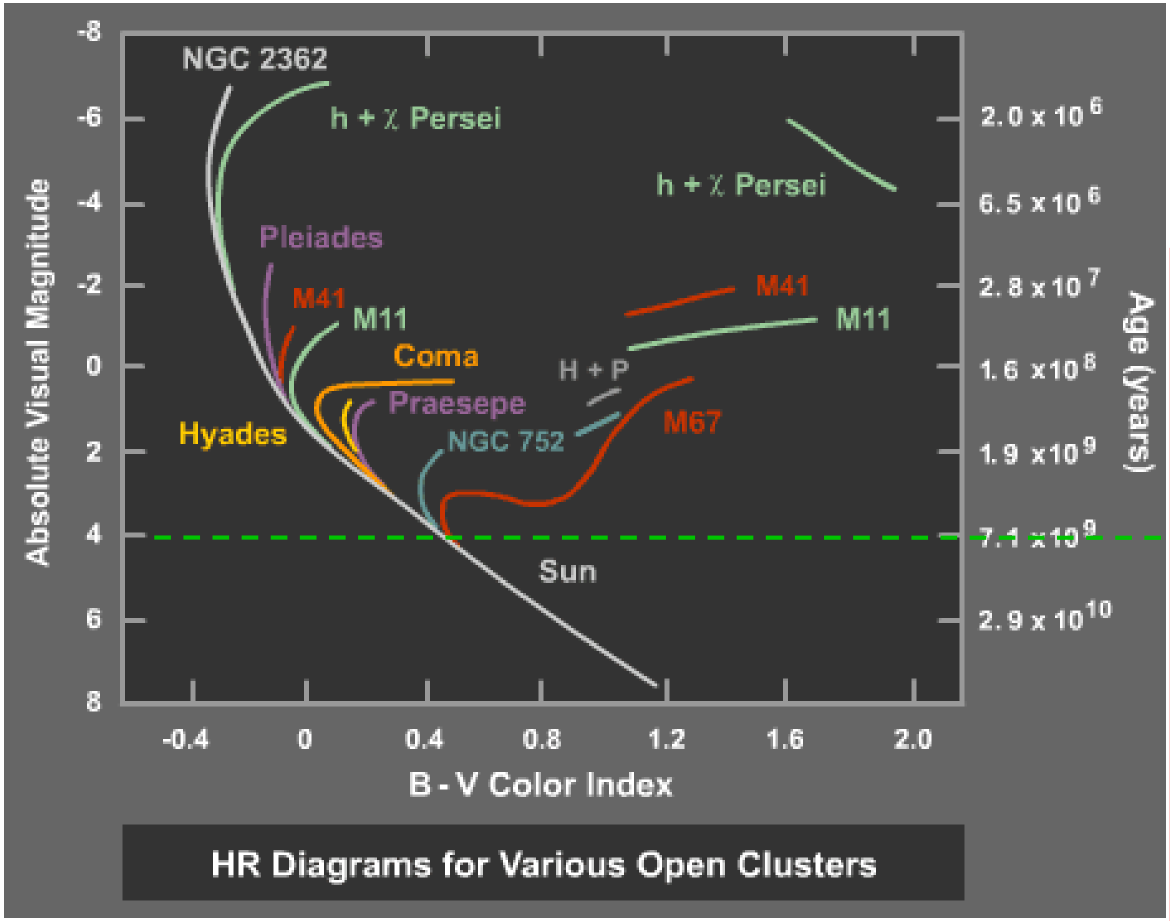
Bol 4: Evolución

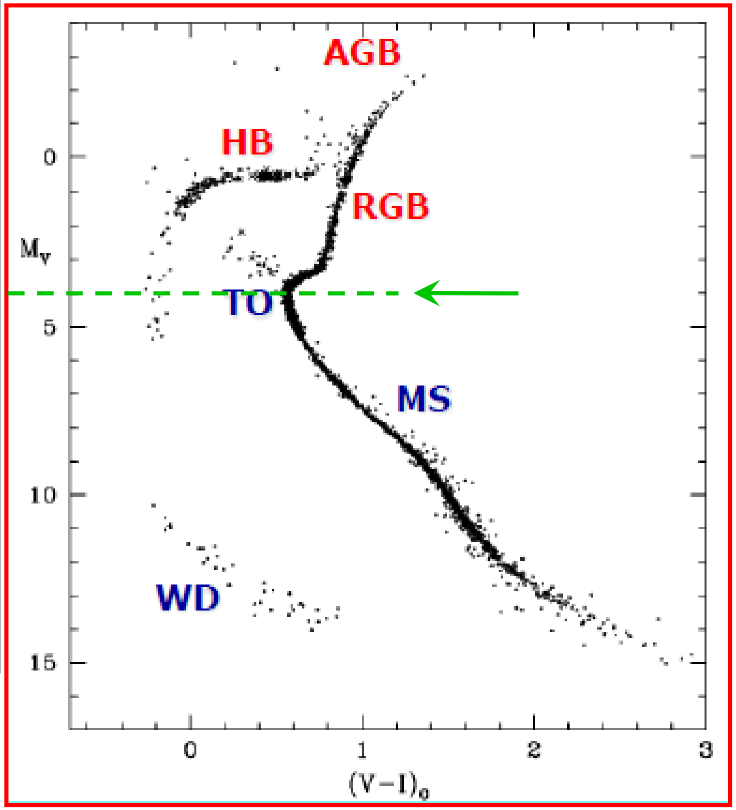


Natural science is distinguished from pure mathematics by the crucial role played by experiments and observations. This is why progress is slower in science than in mathematics. There are many self-consistent, logical structures, but most of these give a wrong description of the actual universe, not because they are illogical, but simply because nature does not happen to work that way. Without experiments and observations to guide it, the human mind would err and err again in trying to decipher the riddles of the actual universe.

***Frank Shu**:*
"The Physical Universe:
An Introduction to Astronomy"

Diagramas color-magnitud (DCM): características en relación al comportamiento evolutivo observable en cúmulos abiertos y globulares





Australia Telescope Outreach and Education
Credit: Mike Guidry, University of Tennessee

Teoría básica de evolución estelar

Los *diagramas HR de cúmulos abiertos y globulares, y de estrellas en los alrededores del Sol*, muestran que existe evolución estelar. El objetivo de la *teoría de evolución* estelar es explicar tales diagramas y lograr reproducirlos.

-Consideramos estrellas con *simetría esférica y en equilibrio hidrostático.* Se requieren 4 ecuaciones diferenciales que describen las estructura de la estrella en función del radio:

$\frac{d\mathcal{M}}{dR}, \frac{dL}{dR}, \frac{dT}{dR}, \frac{dP}{dR}$ y la ecuación de estado del gas.

La estructura de la estrella queda determinada por su *masa y comp. química*.

Es necesario comparar el ***diag HR observado "color-M_V" con el teórico "T-M_{bol}".***

Sobre la Secuencia Principal las estrellas son *escencialmente químicamente homogéneas y queman $H \rightarrow He$ en sus núcleos:*

Si $\mathcal{M}$

- **<** $1.5 - 2\,\mathcal{M}_\odot$: ciclo p-p
- **>** $1.5 - 2\,\mathcal{M}_\odot$: ciclo CNO

Diagrama color-magnitud de un cúmulo globular

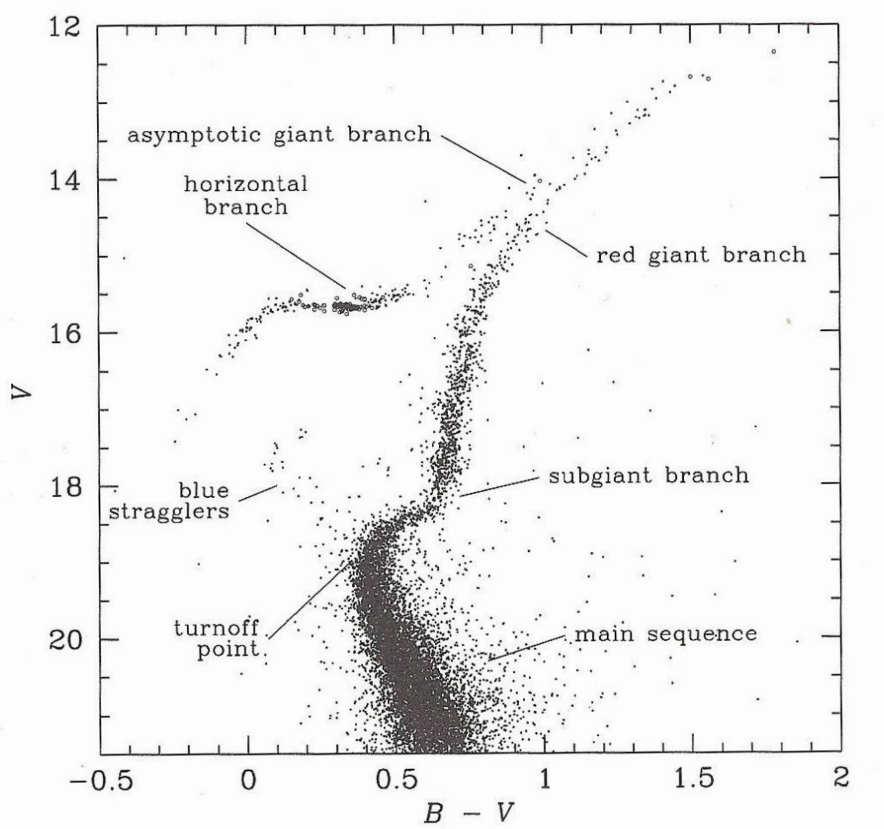


Figure 6.2 The color-magnitude diagram for the globular cluster M3. Known variable stars are shown as open circles, and the principal sequences are annotated. [From data published in Buonanno *et al.* (1994)]

Población estelar simple (SSP): es un conj. de estrellas de igual edad, que nacieron en un brote de formación estelar de duración despreciable y con igual composición química.

¿Por qué tiene ese aspecto este DCM?

No muestra una "trayectoria evolutiva" sino una "isocrona"

Cúmulo globular: la mejor *aproximación* a una SSP

"Galactic Astronomy"
Binney & Merrifield

Comparación de las Trayectorias (o "*tracks*") evolutivos a partir de la Secuencia Principal:

estrellas de 1 a 15 $\mathcal{M}_\odot$

- **Se muestra sólo *parte* de cada trayectoria**

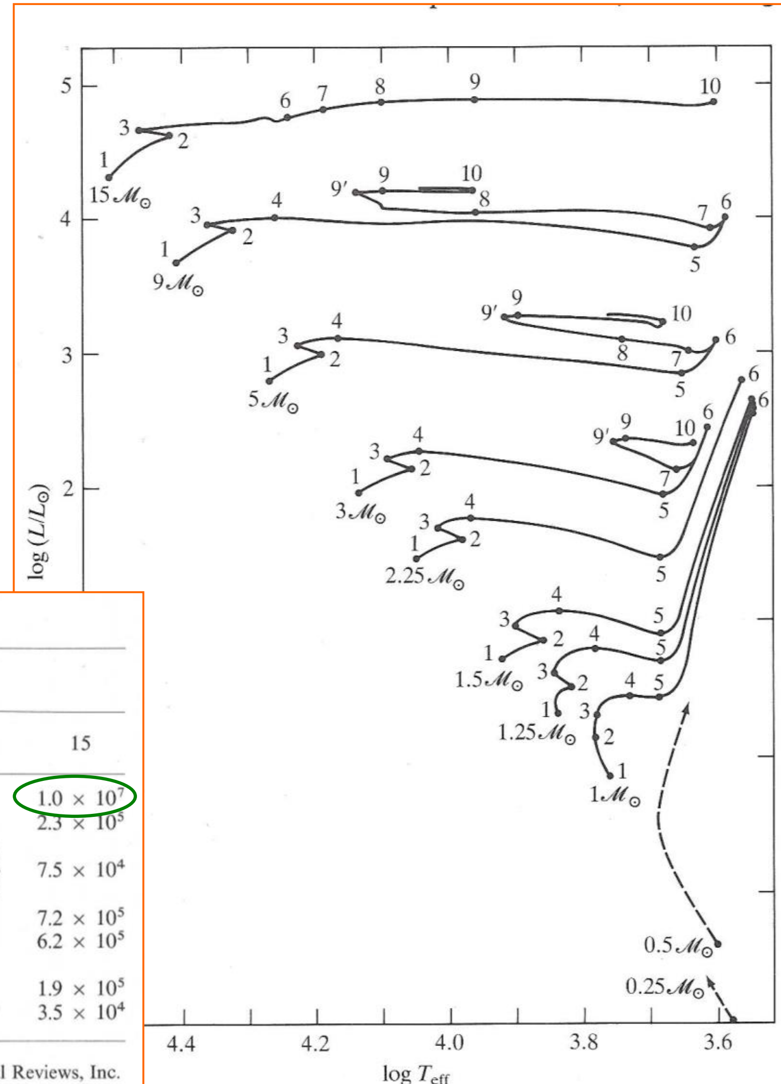


Table 3-9. Stellar-Evolution Times (Years)

Evolution-track interval	Mass ($\mathcal{M}_\odot$)							
	1.0	1.25	1.5	2.25	3	5	9	15
1–2	7×10^9	2.8×10^9	1.5×10^9	4.8×10^8	2.2×10^8	6.5×10^7	2.1×10^7	1.0×10^7
2–3	2×10^9	1.8×10^8	8.1×10^7	1.6×10^7	1.0×10^7	2.2×10^6	6.1×10^5	2.3×10^5
3–4	1.2×10^9	1.0×10^9	3.5×10^8	3.7×10^7	1.0×10^7	1.4×10^6	9.1×10^4	
4–5	1.6×10^8	1.5×10^8	1.0×10^8	1.3×10^7	4.5×10^6	7.5×10^5	1.5×10^5	7.5×10^4
5–6	$\geq 10^9$	$\geq 4 \times 10^8$	$\geq 2 \times 10^8$	3.8×10^7	4.2×10^6	4.9×10^5	6.6×10^4	
6–7	–	–	–	–	2.5×10^7	6.1×10^6	4.9×10^5	7.2×10^5
7–8	–	–	–	–		1.0×10^6	9.5×10^4	6.2×10^5
					4.1×10^7			
8–9	–	–	–	–		9.0×10^6	3.3×10^6	1.9×10^5
9–10	–	–	–	–	6.0×10^6	9.3×10^5	1.6×10^5	3.5×10^4

SOURCE: (**I3**). Reproduced, with permission, from the *Annual Review of Astronomy and Astrophysics*, Volume 5. © 1967 by Annual Reviews, Inc.

Figure 3-17. Post-main-sequence evolution tracks for stars with $0.25\ \mathcal{M}_\odot \leq \mathcal{M} \leq 15\ \mathcal{M}_\odot$. Ages at the labeled points are given in Table 3-9. For $\mathcal{M} \leq 2.25\ \mathcal{M}_\odot$, the tracks are terminated at the point of core helium ignition. For $\mathcal{M} \geq 3\mathcal{M}_\odot$, the tracks are terminated shortly before helium-core exhaustion. [Reproduced with permission from the *Annual Review of Astronomy and Astrophysics*, Volume 5. Copyright © 1967 by Annual Reviews, Inc.]

"Galactic Astronomy"
Mihalas & Binney

Trayectorias evolutivas de estrellas de baja masa

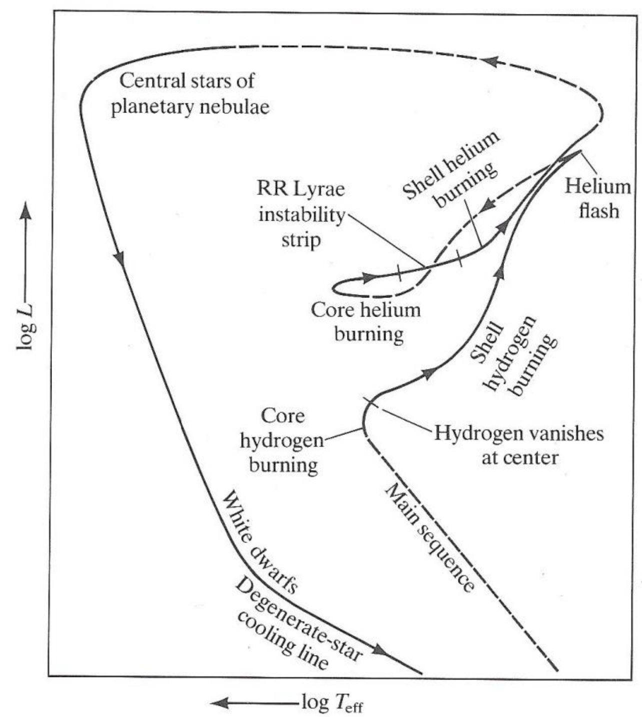


Figure 3-18. Schematic evolution track for a representative low-mass, globular-cluster star from the main sequence to its ultimate demise as a white dwarf. The major energy sources are indicated at several key phases. Dashed lines indicate episodes of very rapid evolution, during which details of the structure of the star are, at present, not too well known. Compare this figure with Figure 3-13.

"Galactic Astronomy"
Mihalas & Binney

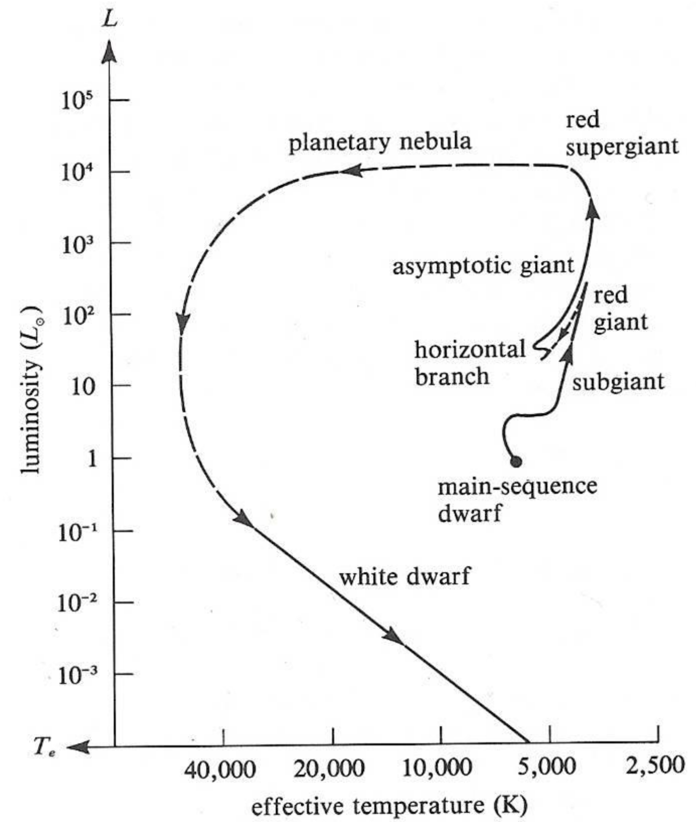


Figure 8.10. The complete evolution of a low-mass star from the main sequence to a white dwarf. The track from the asymptotic giant branch to a white dwarf (via a planetary nebula) is uncertain and is shown as a dashed curve.

"The Physical Universe: An Introduction to Astronomy"
Shu

Evolución de estrellas de baja masa: secuencia principal y rama de subgigantes

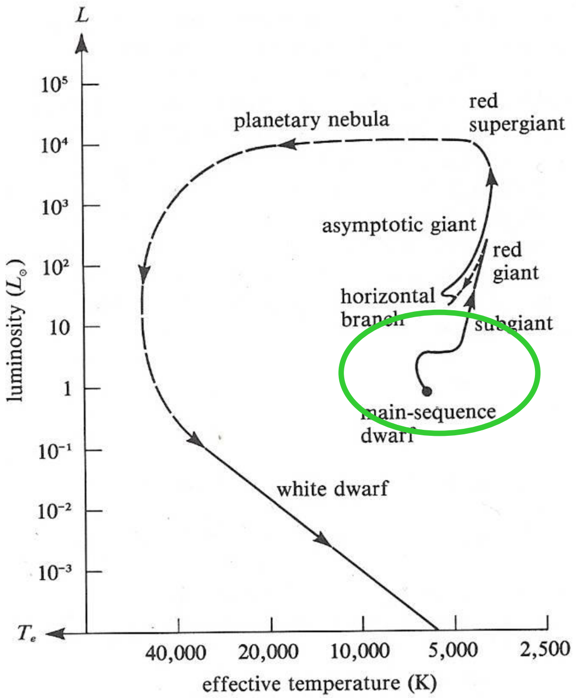


Figure 8.10. The complete evolution of a low-mass star from the main sequence to a white dwarf. The track from the asymptotic giant branch to a white dwarf (via a planetary nebula) is uncertain and is shown as a dashed curve.

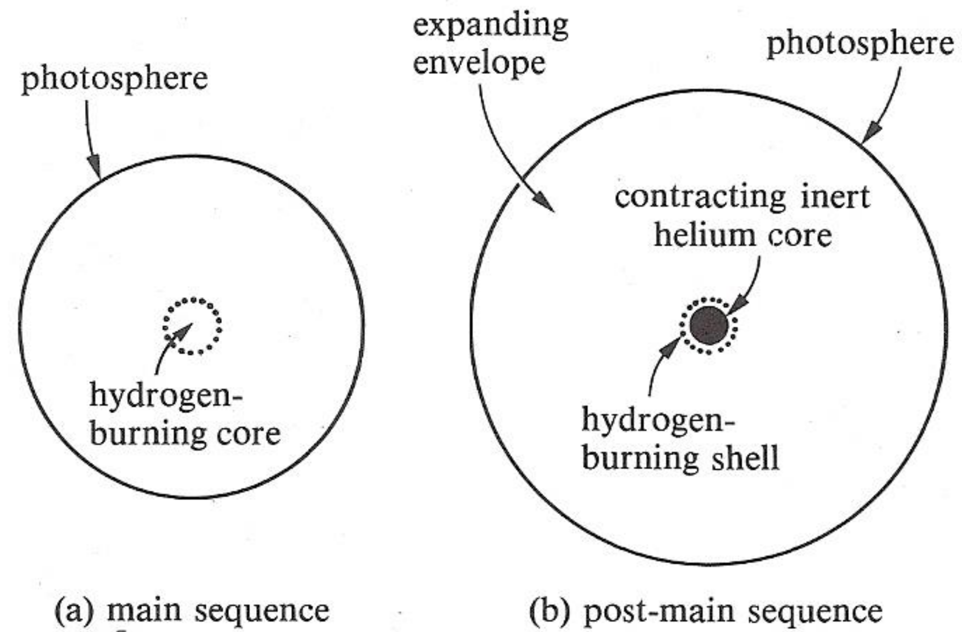


Figure 8.3. The structure of a star (a) on the main sequence and (b) as it begins to leave the main sequence because of core-hydrogen exhaustion.

"The Physical Universe: An Introduction to Astronomy"
Shu

Evolución de estrellas de baja masa: rama de gigantes rojas

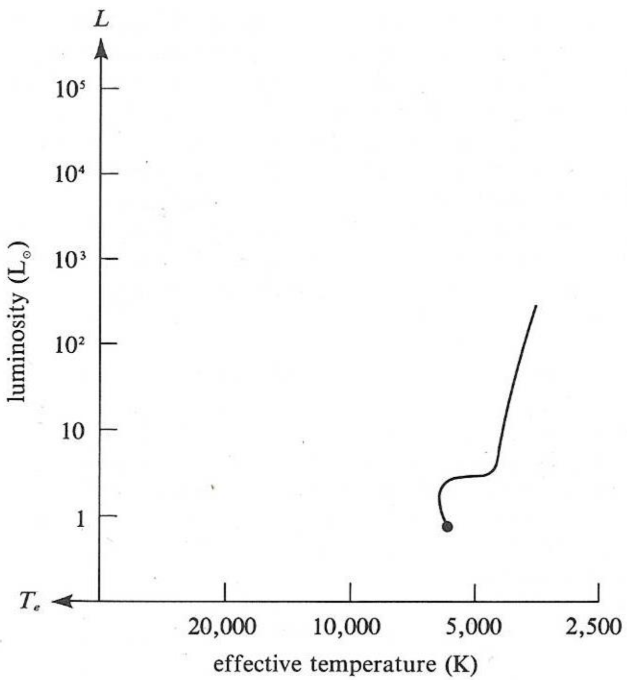


Figure 8.4. Ascent of a low-mass star to the red-giant branch. (Adapted from Icko Iben, *Ann. Rev. Astr. Ap.*, **5**, 1967, 571.)

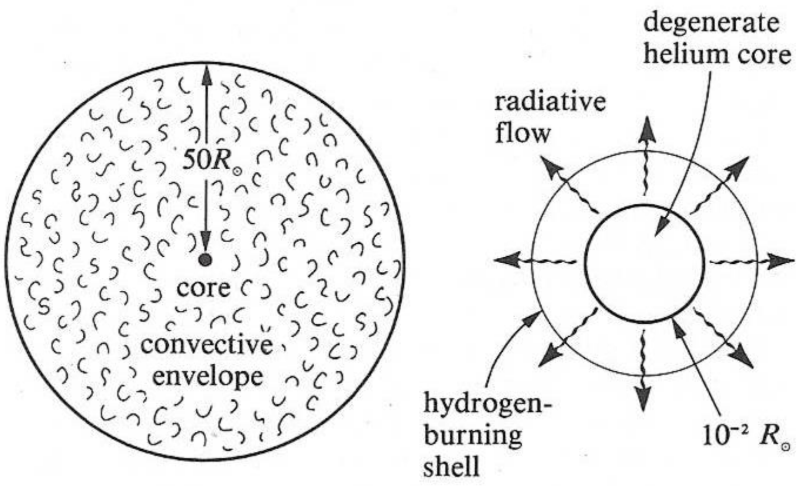


Figure 8.5. The structure of a red giant. The left figure shows the entire star from core to photosphere. The right figure shows an enlarged picture of the region near the core. Notice that the core, which may contain about half the total mass of a low-mass star at this point, occupies only one ten-billionth of the total volume.

"The Physical Universe : An Introduction to Astronomy"
Shu

Evolución de estrellas de baja masa: rama horizontal

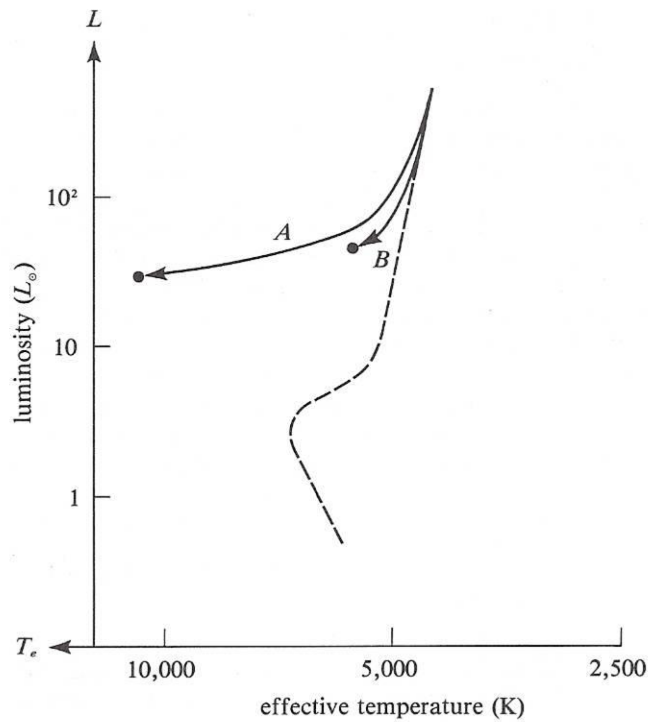


Figure 8.6. Descent of a low-mass star with poor heavy-element abundances (Population II star) from the tip of the red-giant branch to the horizontal branch. Track *A* corresponds to a star which suffered a relatively large loss of mass during the red-giant phase of stellar evolution. Track *B* corresponds to a star which suffered relatively little loss of mass. (Adapted from Icko Iben, *Ann. Rev. Astr. Ap.*, **5**, 1967, 571.)

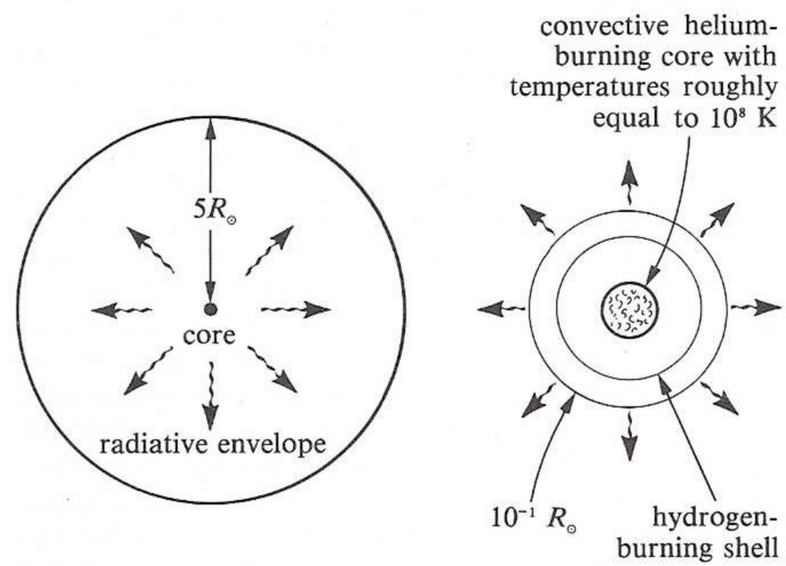


Figure 8.7. The structure of a horizontal-branch star. The left figure shows the entire star from core to photosphere. The right figure shows an enlarged picture of the region near the core.

"The Physical Universe : An Introduction to Astronomy"
Shu

Evolución de estrellas de baja masa: rama de gigantes asintótica

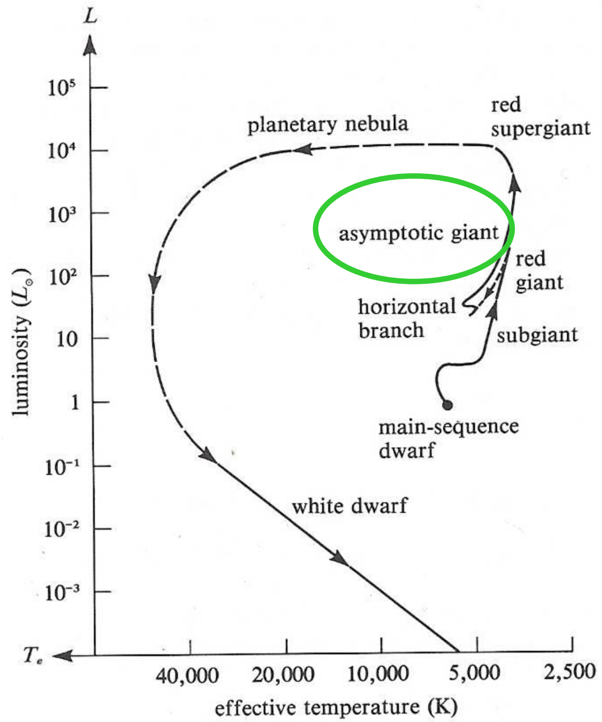


Figure 8.10. The complete evolution of a low-mass star from the main sequence to a white dwarf. The track from the asymptotic giant branch to a white dwarf (via a planetary nebula) is uncertain and is shown as a dashed curve.

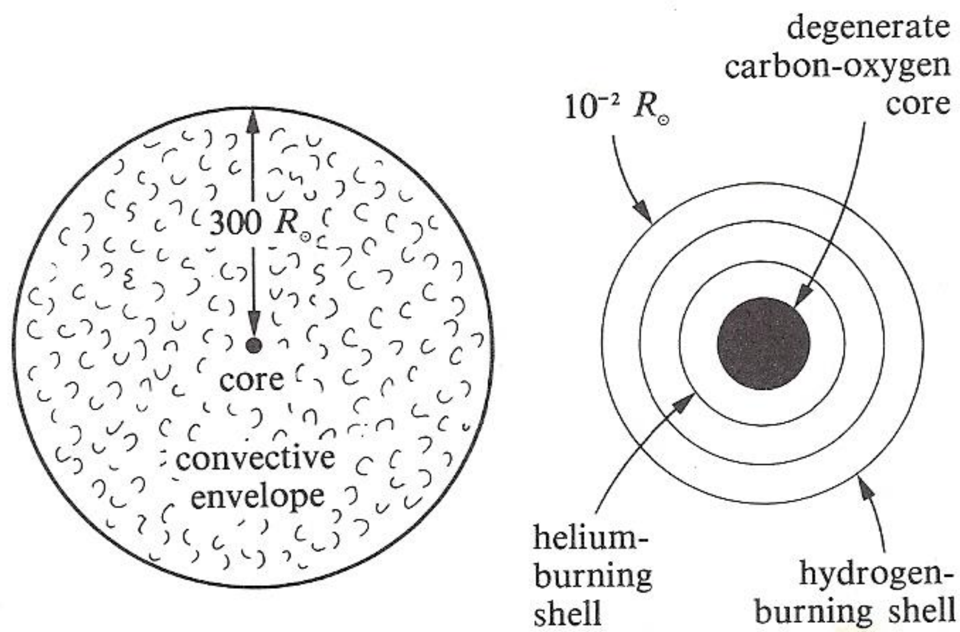


Figure 8.8. The structure of an asymptotic giant. The figure on the left shows the entire star from core to photosphere. The figure on the right shows an enlarged picture of the region near the core.

“The Physical Universe : An Introduction to Astronomy”
Shu

Trayectorias evolutivas de estrellas de alta masa: 9 y 25 $\mathcal{M}_{\odot}$

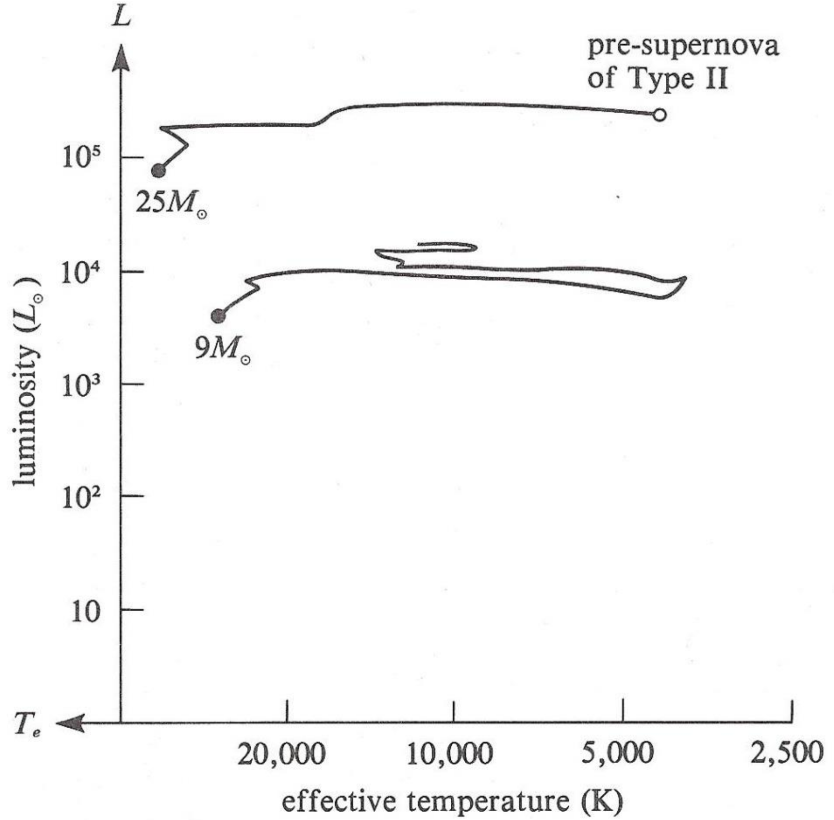


Figure 8.11. Evolution of a high-mass and a very-high-mass star in the Hertzsprung-Russell diagram. (Adapted from Icko Iben and from Weaver and Woosley, *Ninth Texas Symp. Rel. Ap.*, *Ann. N.Y. Acad. Sci.*, **336**, 1980, 335.)

"The Physical Universe : An Introduction to Astronomy"
Shu

Estrella evolucionada de alta masa: pre-supernova tipo II

Evolution of High-Mass Stars 155

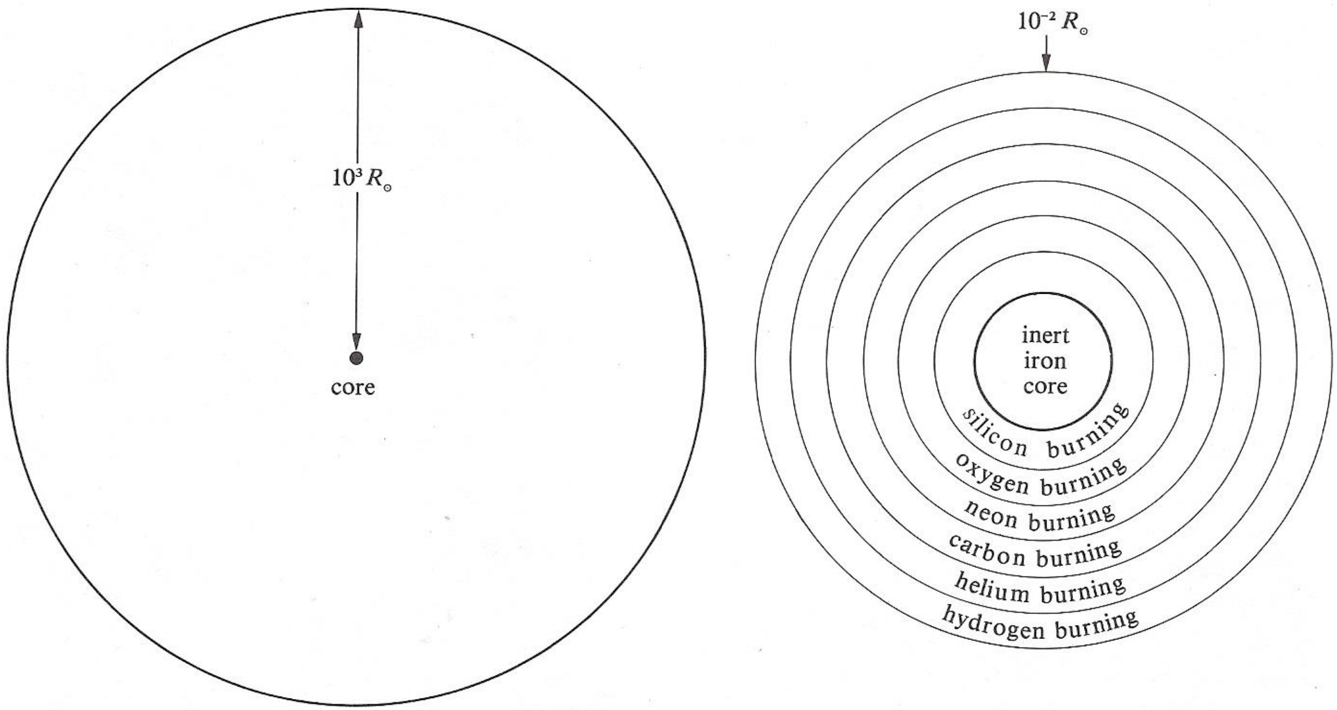


Figure 8.13. The onion-ring structure of a pre-supernova star (a very evolved star of high mass). The diagram on the left shows the dimensions of the entire star, a red supergiant, from core to photosphere. The diagram on the right shows the nuclear-burning regions near the inert iron core.

Bibliog. recomendada para Evolución Estelar: “The Physical Universe” Shu

“The Physical Universe : An Introduction to Astronomy” Shu