Midterm 2 Highlight Tour

Emphasize on understanding concepts over memorizing details

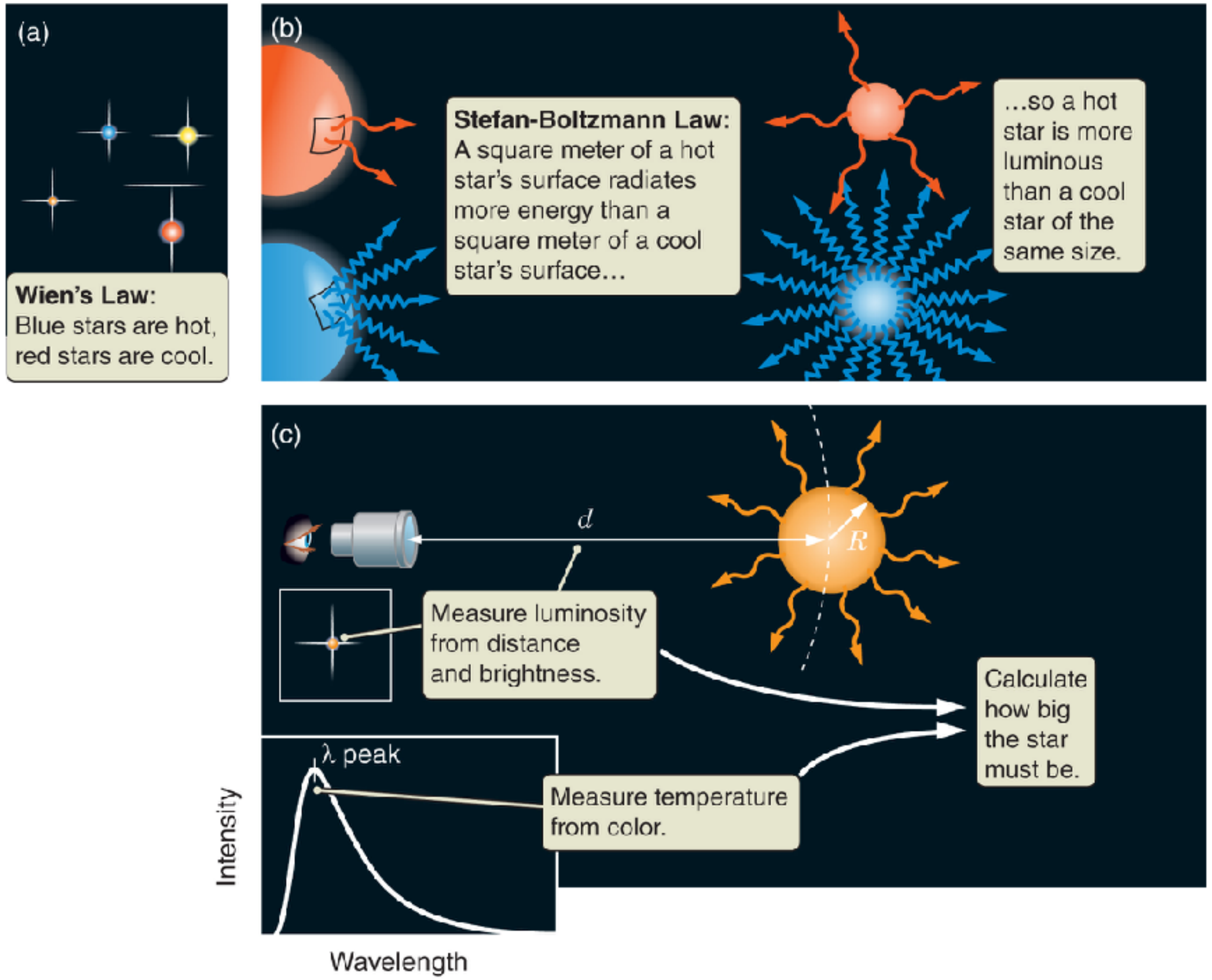
But, need to know what terms mean

Example:
Should know the inputs and outputs of the p-p chain, but not necessary to know the details of each step

25 multiple choice questions (3 pts each), similar to last time
Several short answer questions (more this time, but still 25 pts total)

TA-led reviews in office hours this afternoon and tomorrow

Luminosity depends on Temperature AND Size



Wien's Law: Blue stars are hot, red stars are cool.

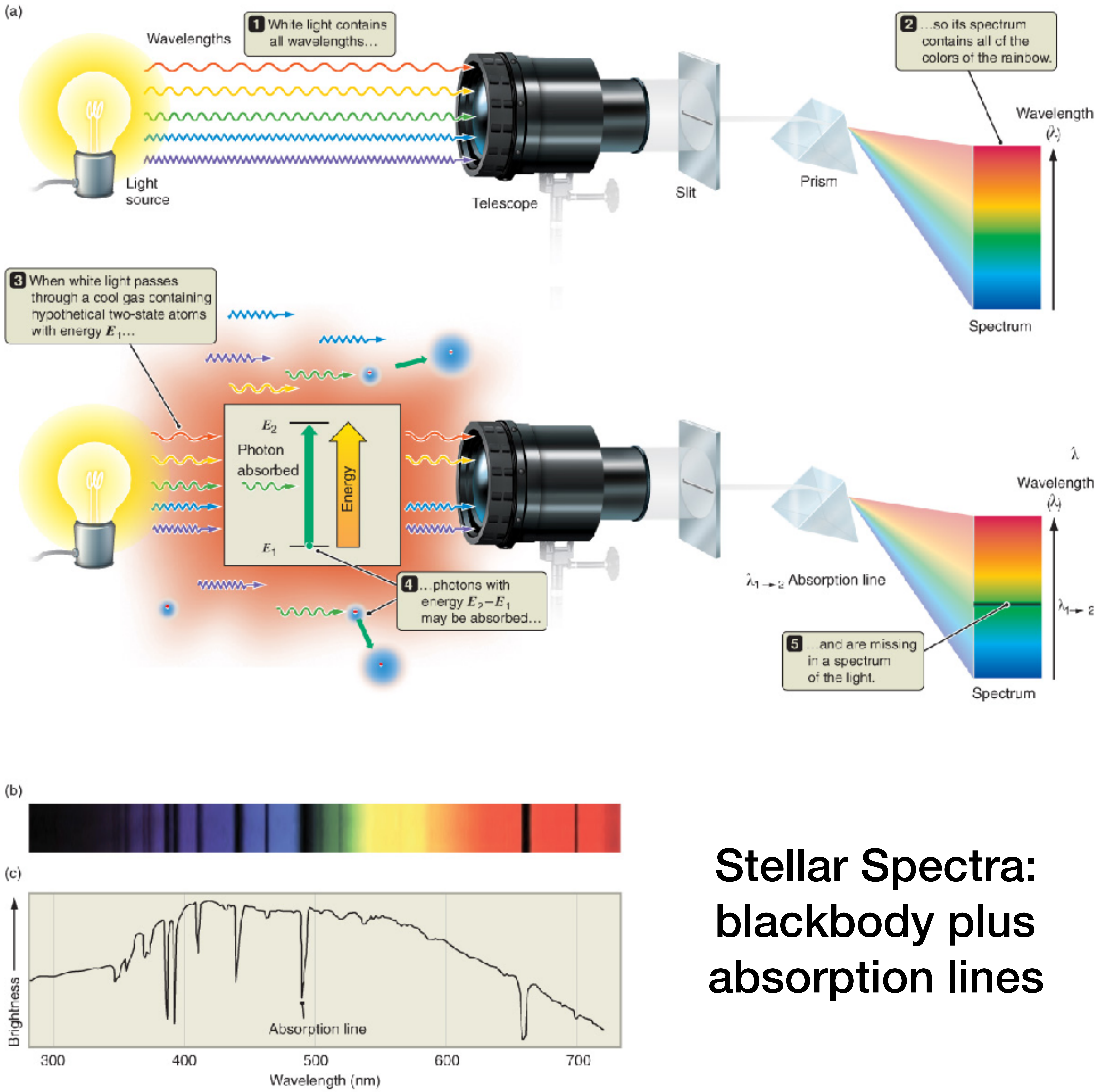
Stefan-Boltzmann Law: A square meter of a hot star's surface radiates more energy than a square meter of a cool star's surface…

…so a hot star is more luminous than a cool star of the same size.

Measure luminosity from distance and brightness.

Measure temperature from color.

Calculate how big the star must be.



1 White light contains all wavelengths…

2 …so its spectrum contains all of the colors of the rainbow.

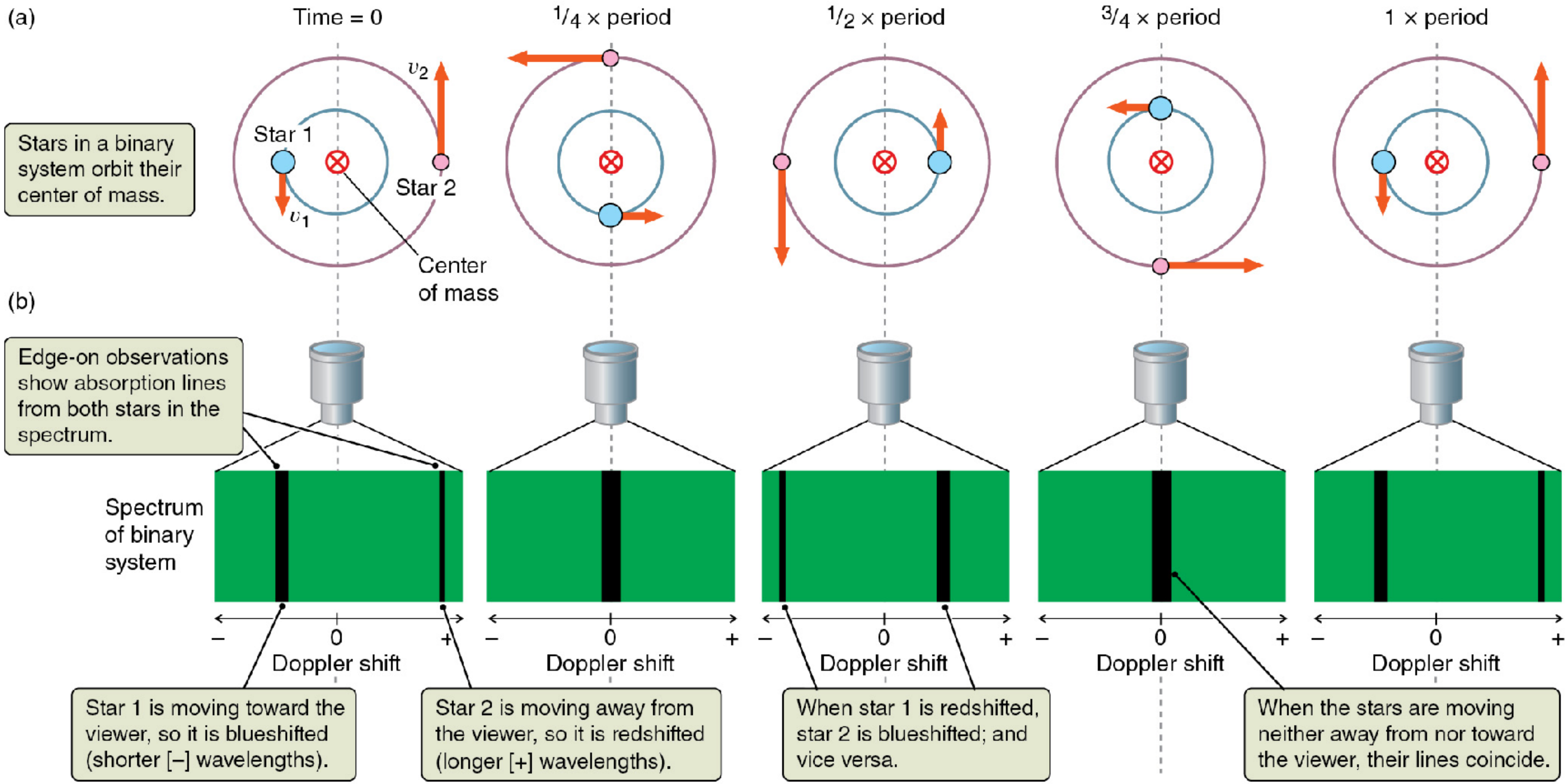
3 When white light passes through a cool gas containing hypothetical two-state atoms with energy E_1…

4 …photons with energy E_2-E_1 may be absorbed…

5 …and are missing in a spectrum of the light.

Stellar Spectra: blackbody plus absorption lines

Binary Stars: Doppler shift proportional to velocity, inversely proportional to relative mass



Stars in a binary system orbit their center of mass.

Edge-on observations show absorption lines from both stars in the spectrum.

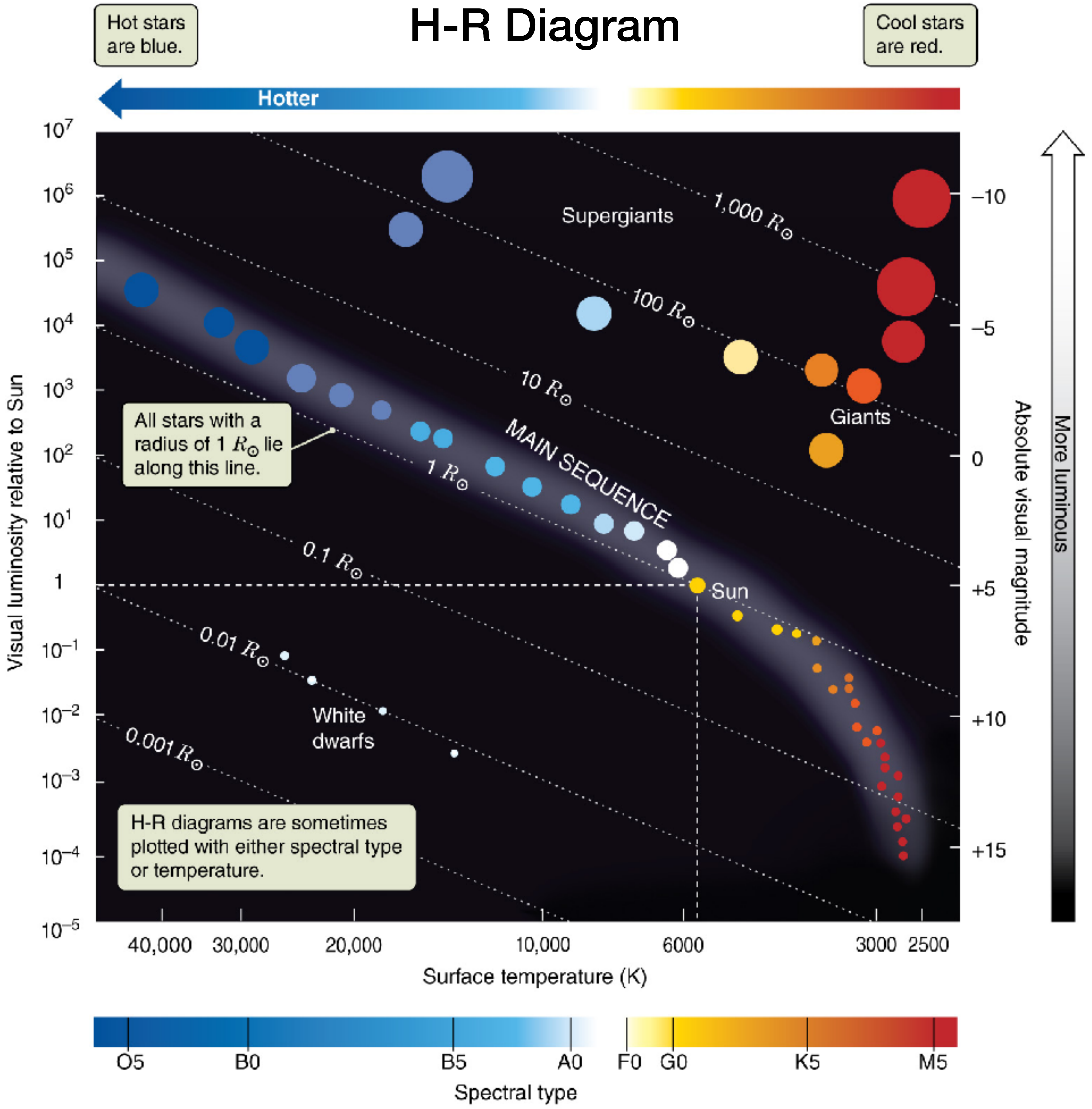
Star 1 is moving toward the viewer, so it is blueshifted (shorter [–] wavelengths).

Star 2 is moving away from the viewer, so it is redshifted (longer [+] wavelengths).

When star 1 is redshifted, star 2 is blueshifted; and vice versa.

When the stars are moving neither away from nor toward the viewer, their lines coincide.

H-R Diagram

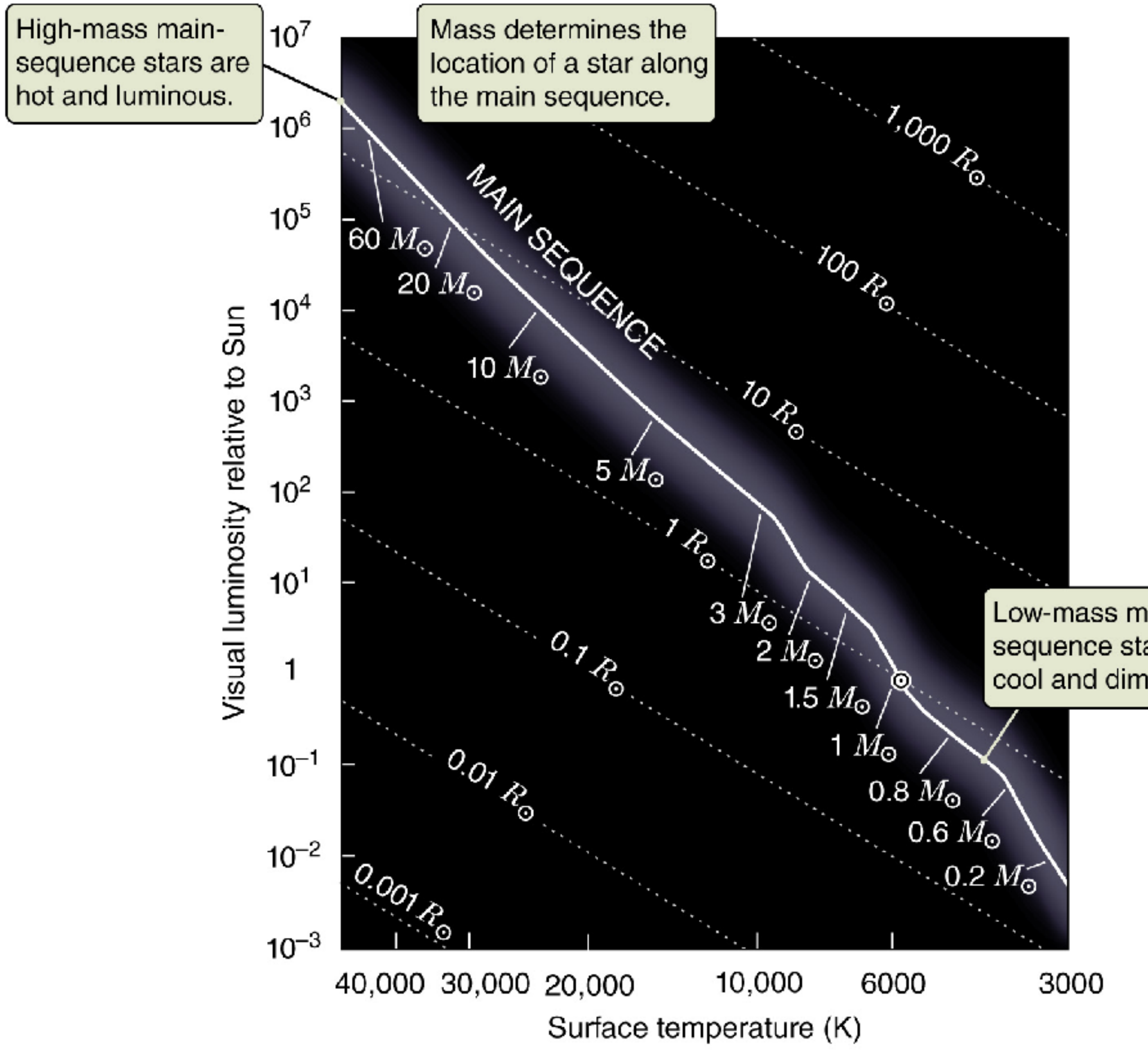


Hot stars are blue.

Cool stars are red.

All stars with a radius of 1 $R_\odot$ lie along this line.

H-R diagrams are sometimes plotted with either spectral type or temperature.

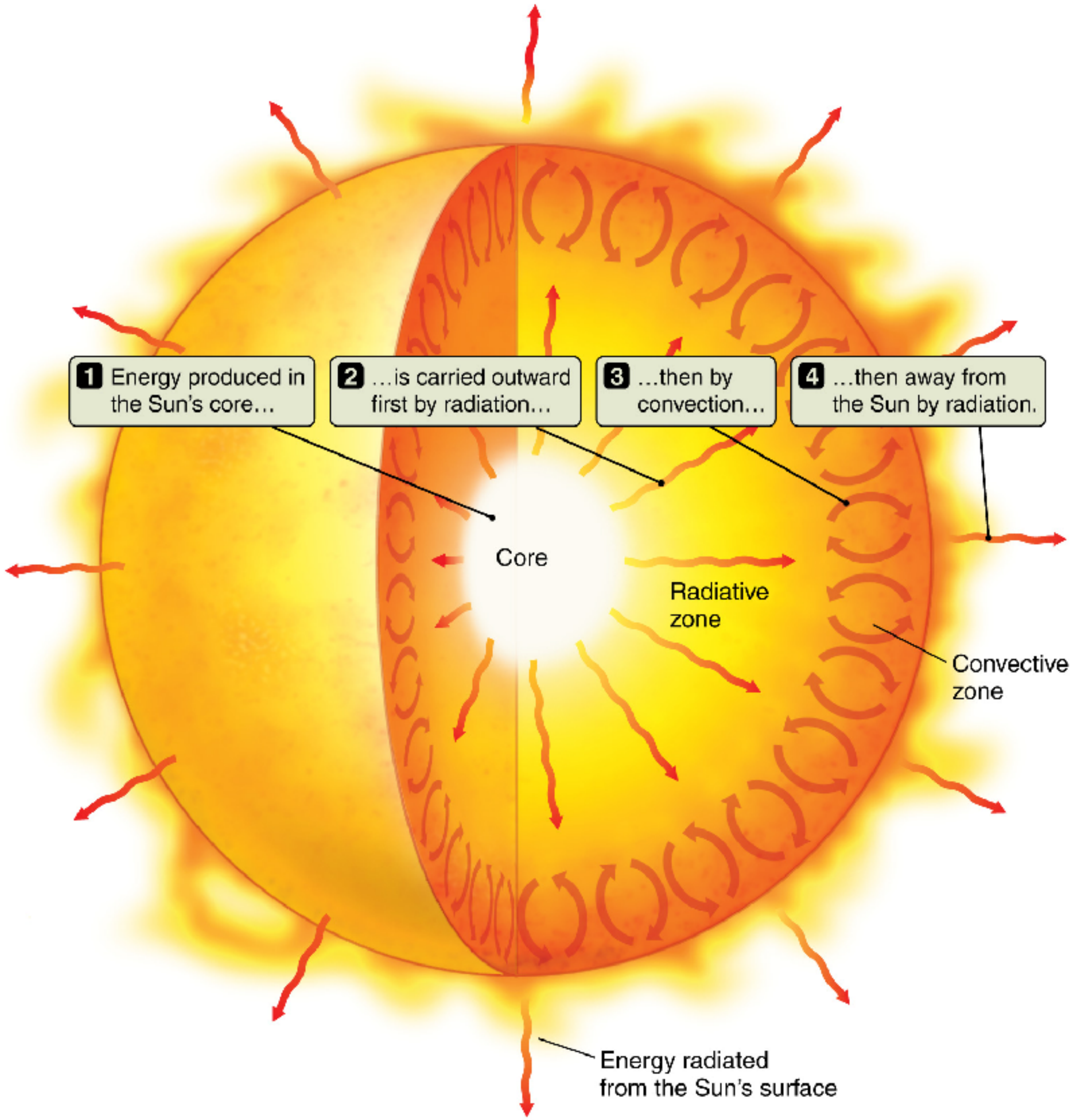


High-mass main-sequence stars are hot and luminous.

Mass determines the location of a star along the main sequence.

Low-mass m
sequence sta
cool and dim

Sun has distinct zones,
half way through its 10 billion year lifespan



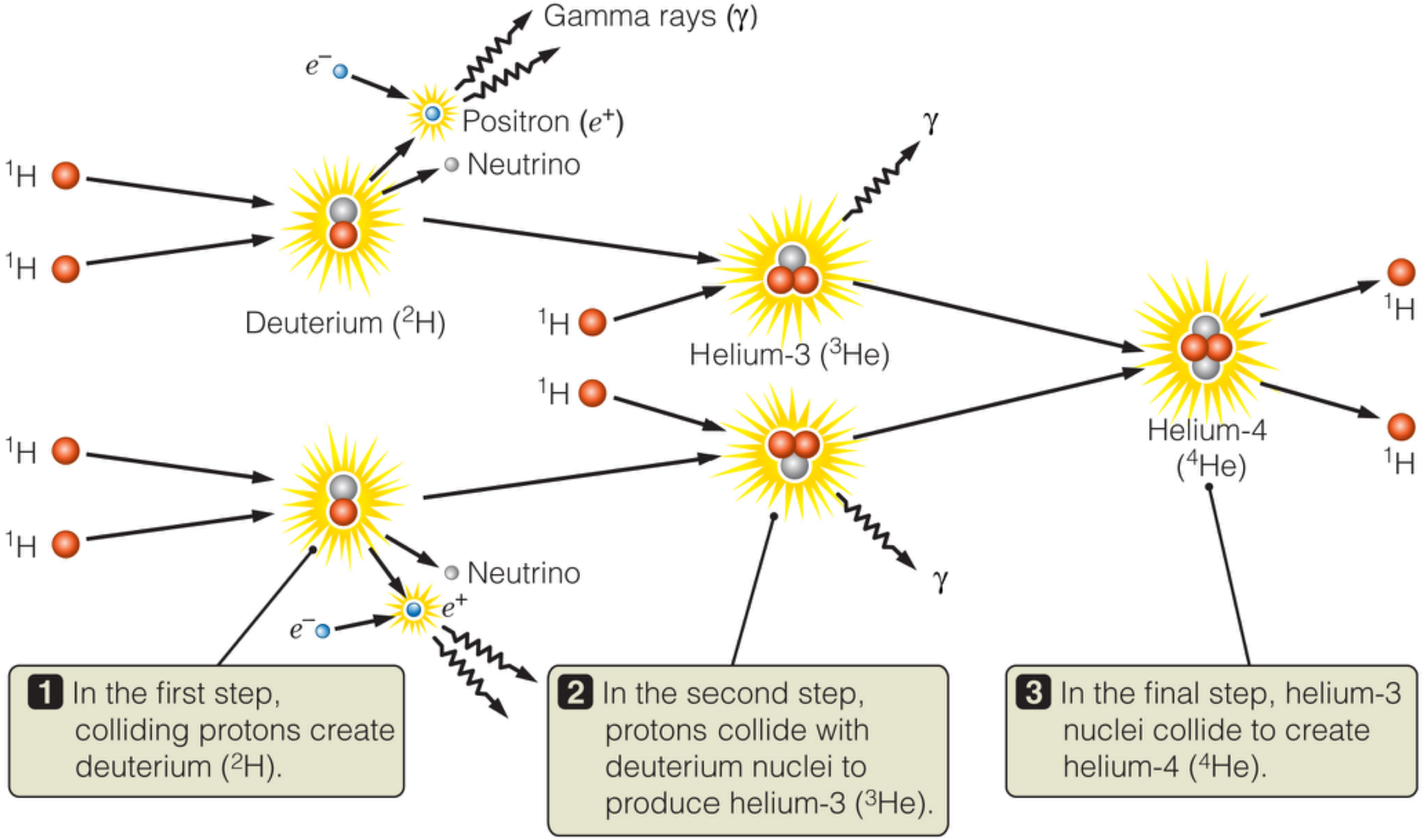
1 Energy produced in the Sun's core…

2 …is carried outward first by radiation…

3 …then by convection…

4 …then away from the Sun by radiation.

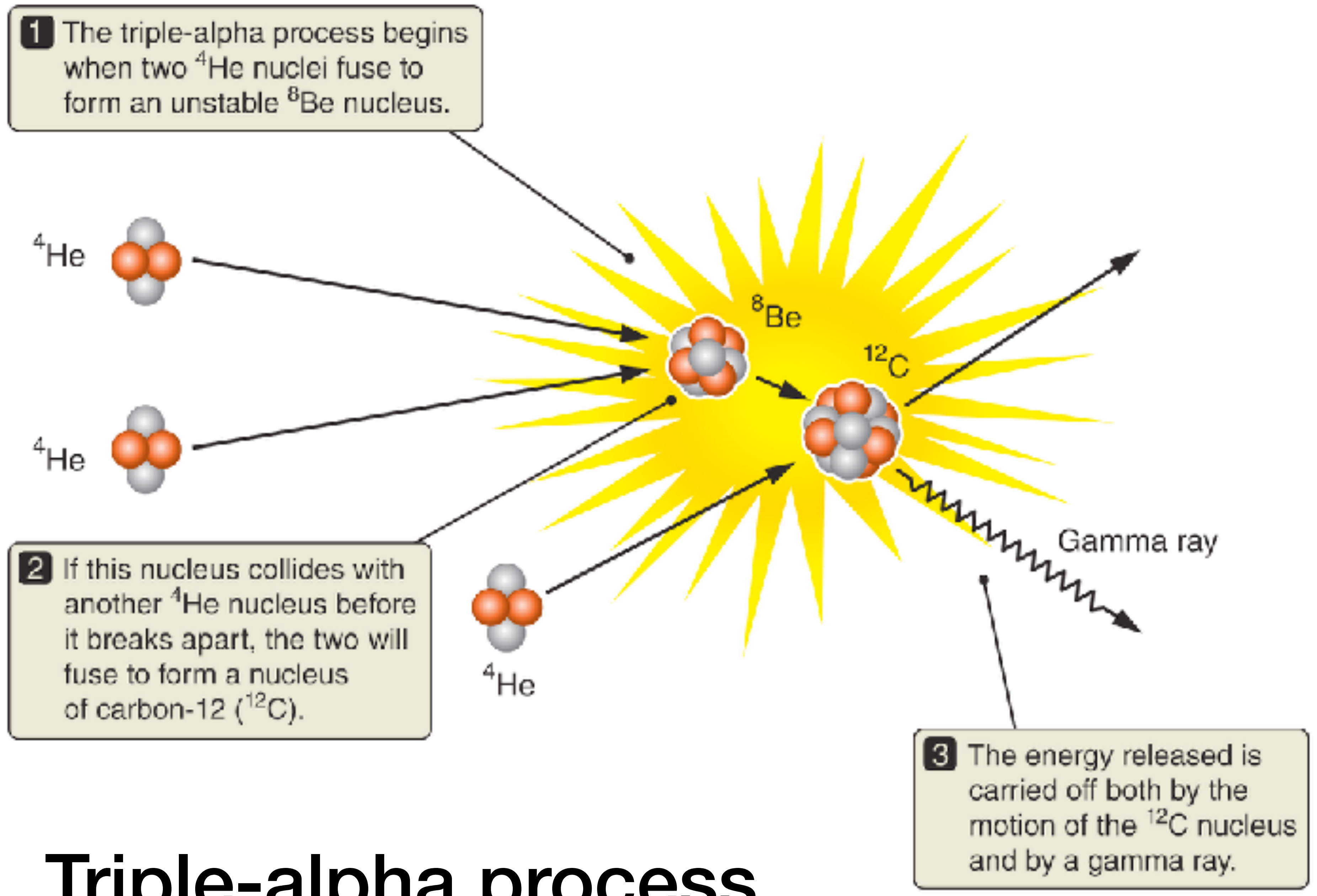
proton-proton chain burns H —> He, releasing neutrinos and positrons (gamma rays)



1 In the first step, colliding protons create deuterium (^2H).

2 In the second step, protons collide with deuterium nuclei to produce helium-3 (^3He).

3 In the final step, helium-3 nuclei collide to create helium-4 (^4He).

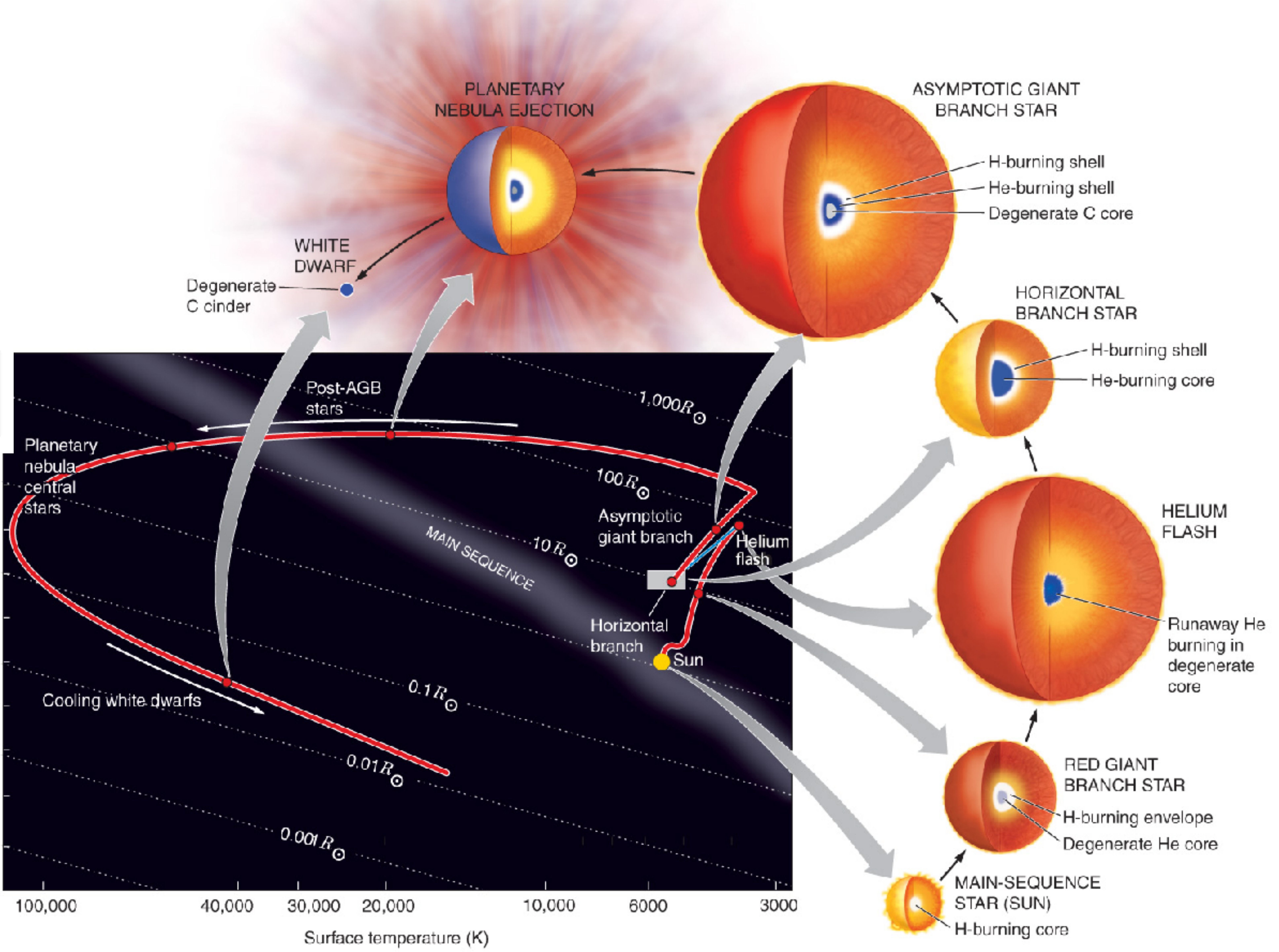


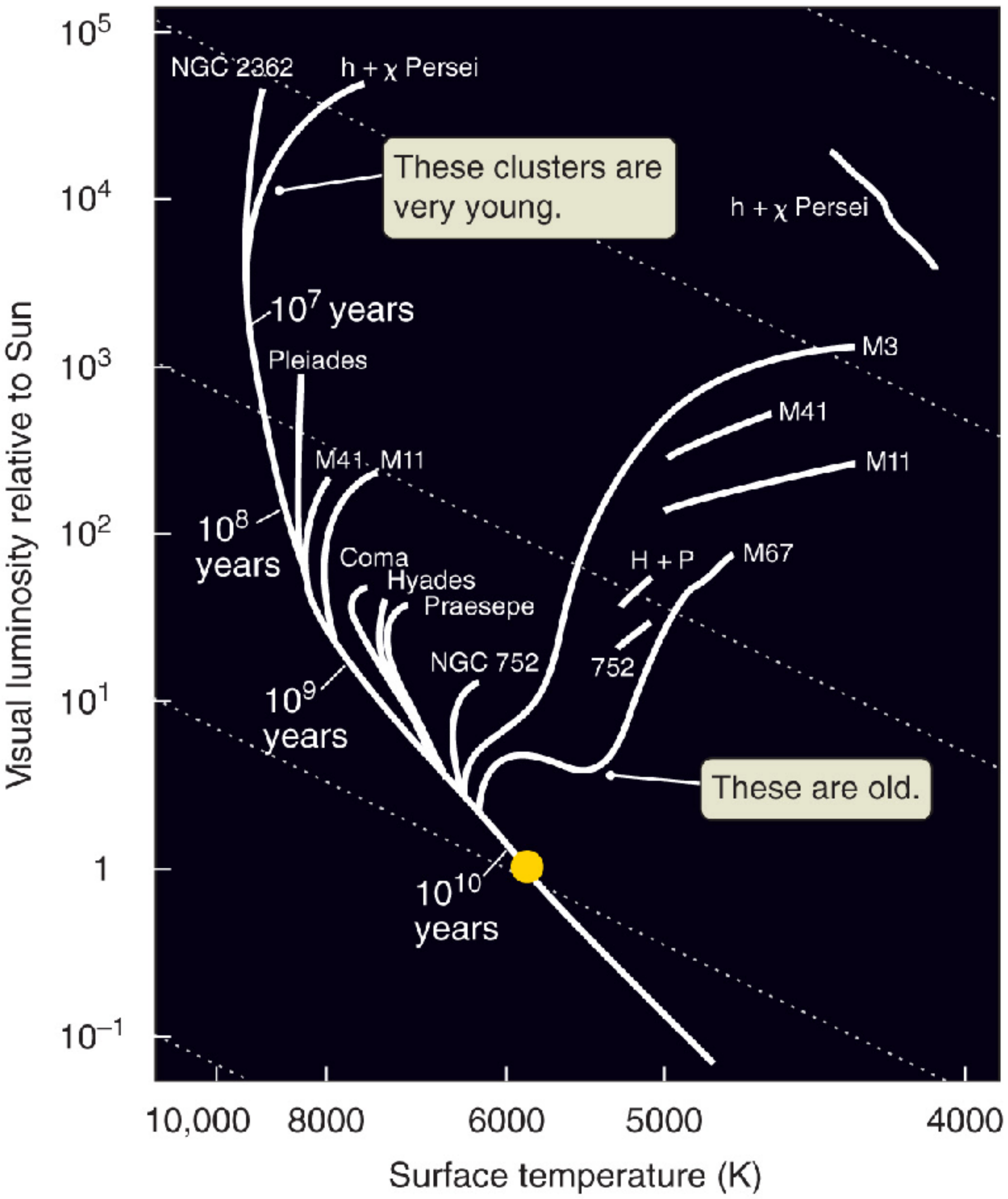
1 The triple-alpha process begins when two ^{4}He nuclei fuse to form an unstable ^{8}Be nucleus.

2 If this nucleus collides with another ^{4}He nucleus before it breaks apart, the two will fuse to form a nucleus of carbon-12 (^{12}C).

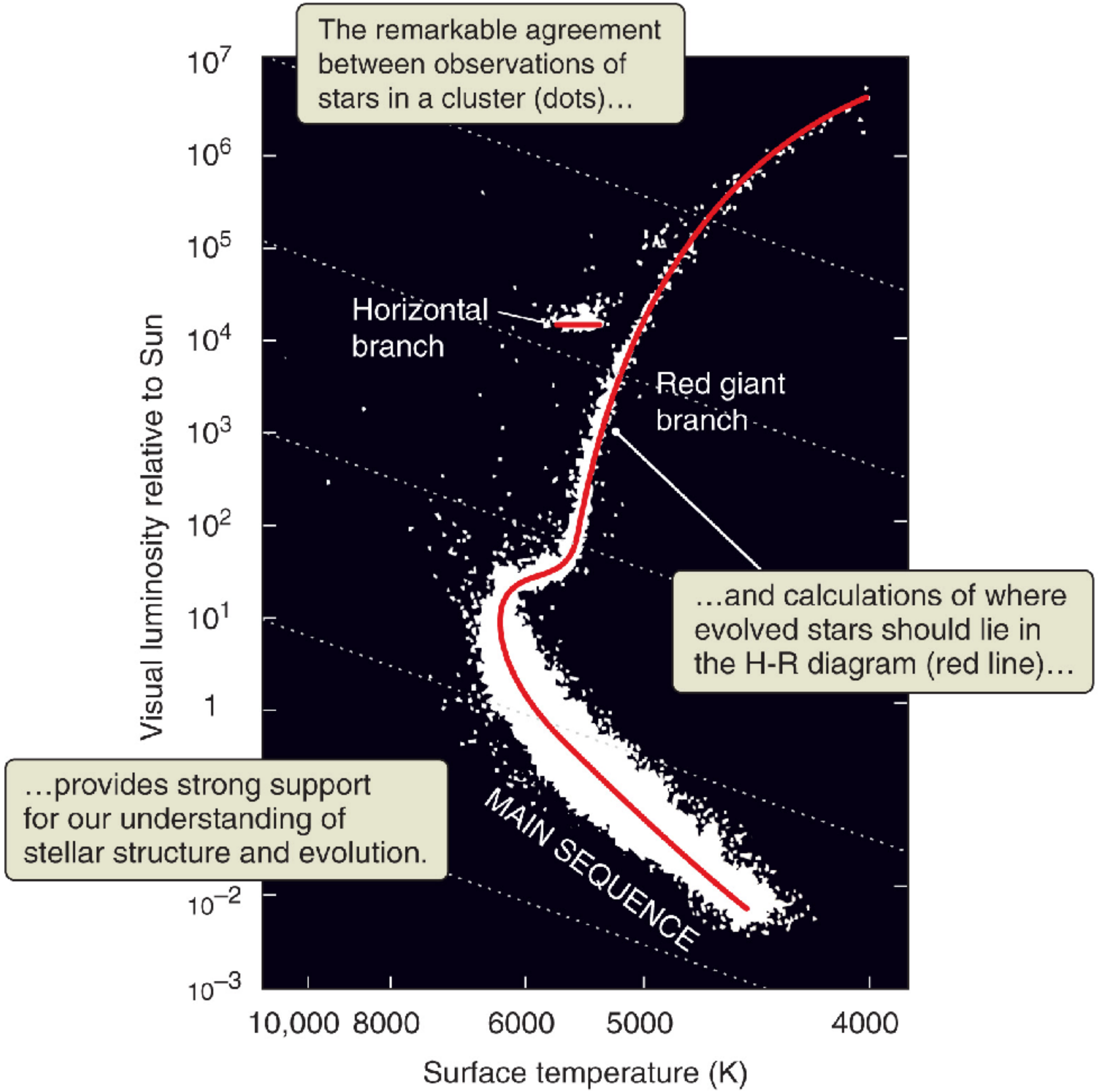
3 The energy released is carried off both by the motion of the ^{12}C nucleus and by a gamma ray.

Triple-alpha process, burns He —> C in Horizontal Branch phase




These clusters are very young.

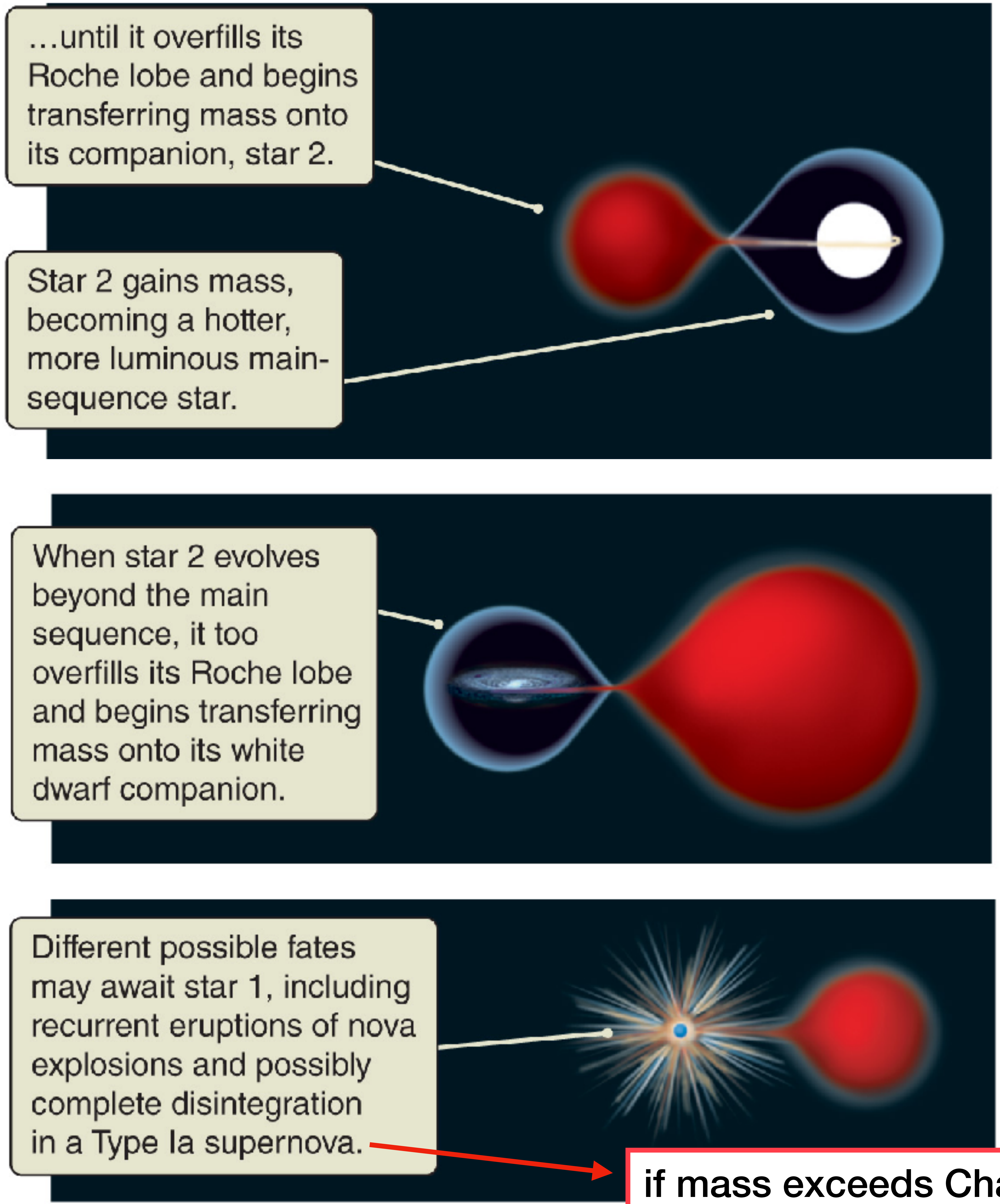
These are old.


The remarkable agreement between observations of stars in a cluster (dots)…

…and calculations of where evolved stars should lie in the H-R diagram (red line)…

…provides strong support for our understanding of stellar structure and evolution.

White Dwarf <—> electron degeneracy pressure



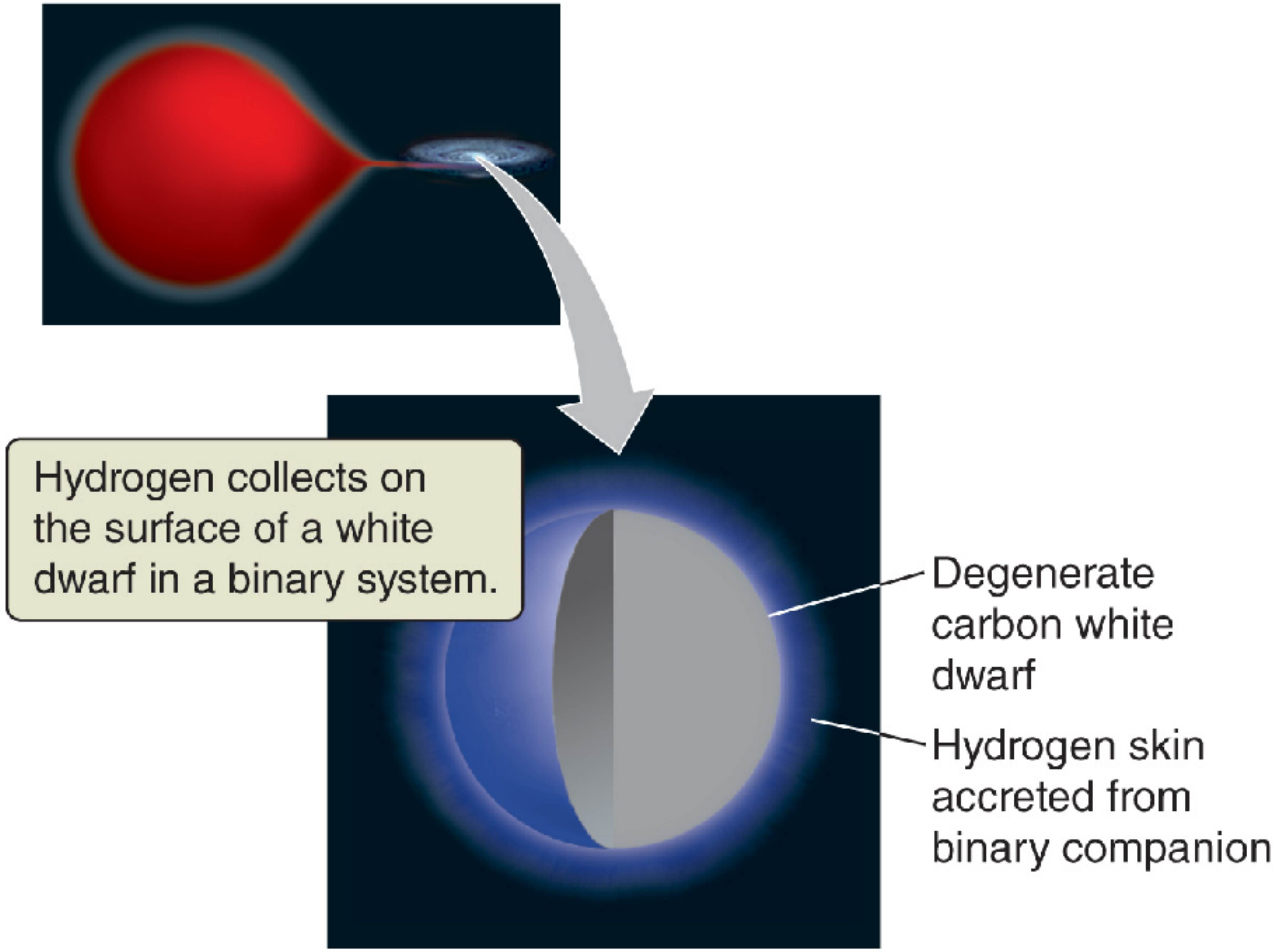
…until it overfills its Roche lobe and begins transferring mass onto its companion, star 2.

Star 2 gains mass, becoming a hotter, more luminous main-sequence star.

When star 2 evolves beyond the main sequence, it too overfills its Roche lobe and begins transferring mass onto its white dwarf companion.

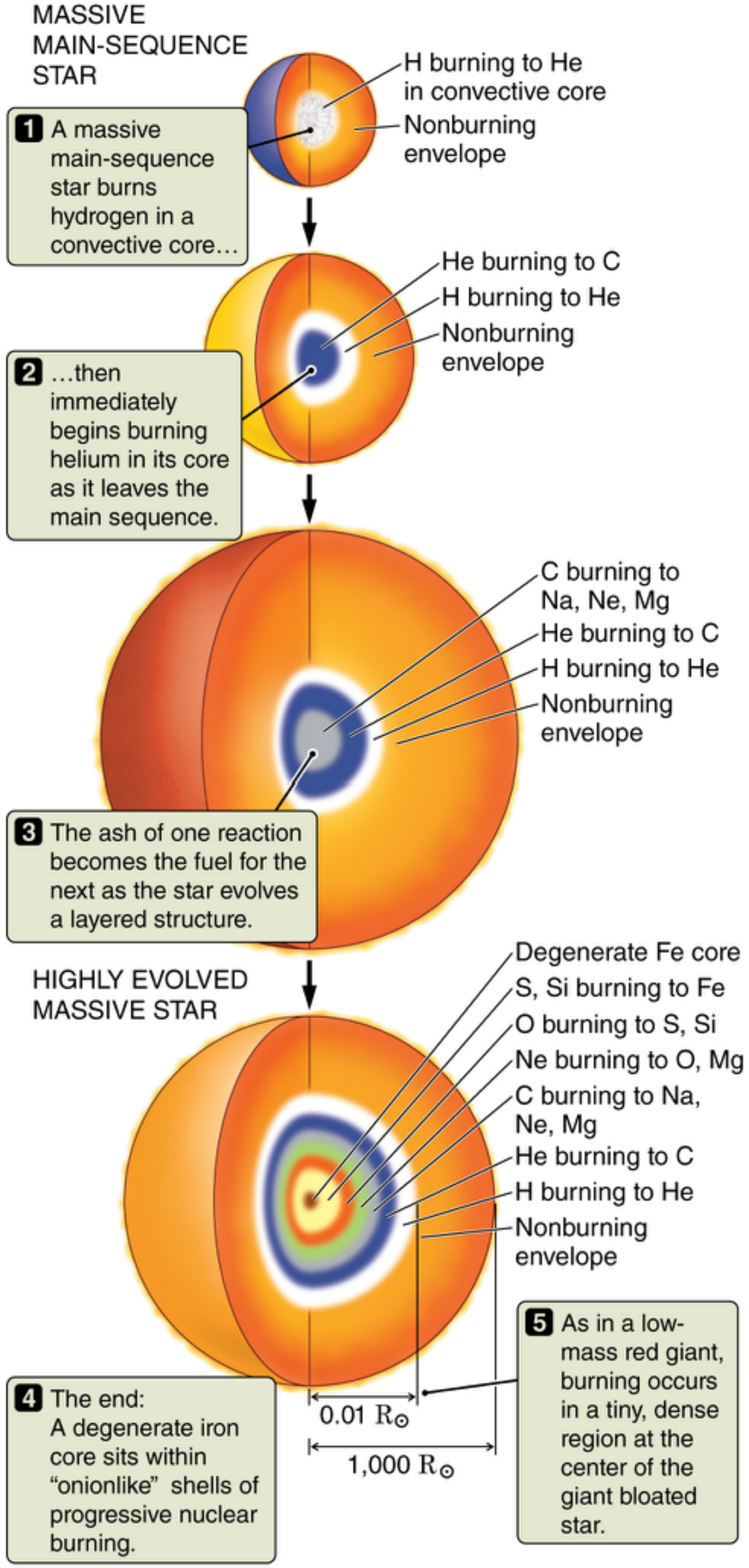
Different possible fates may await star 1, including recurrent eruptions of nova explosions and possibly complete disintegration in a Type Ia supernova.

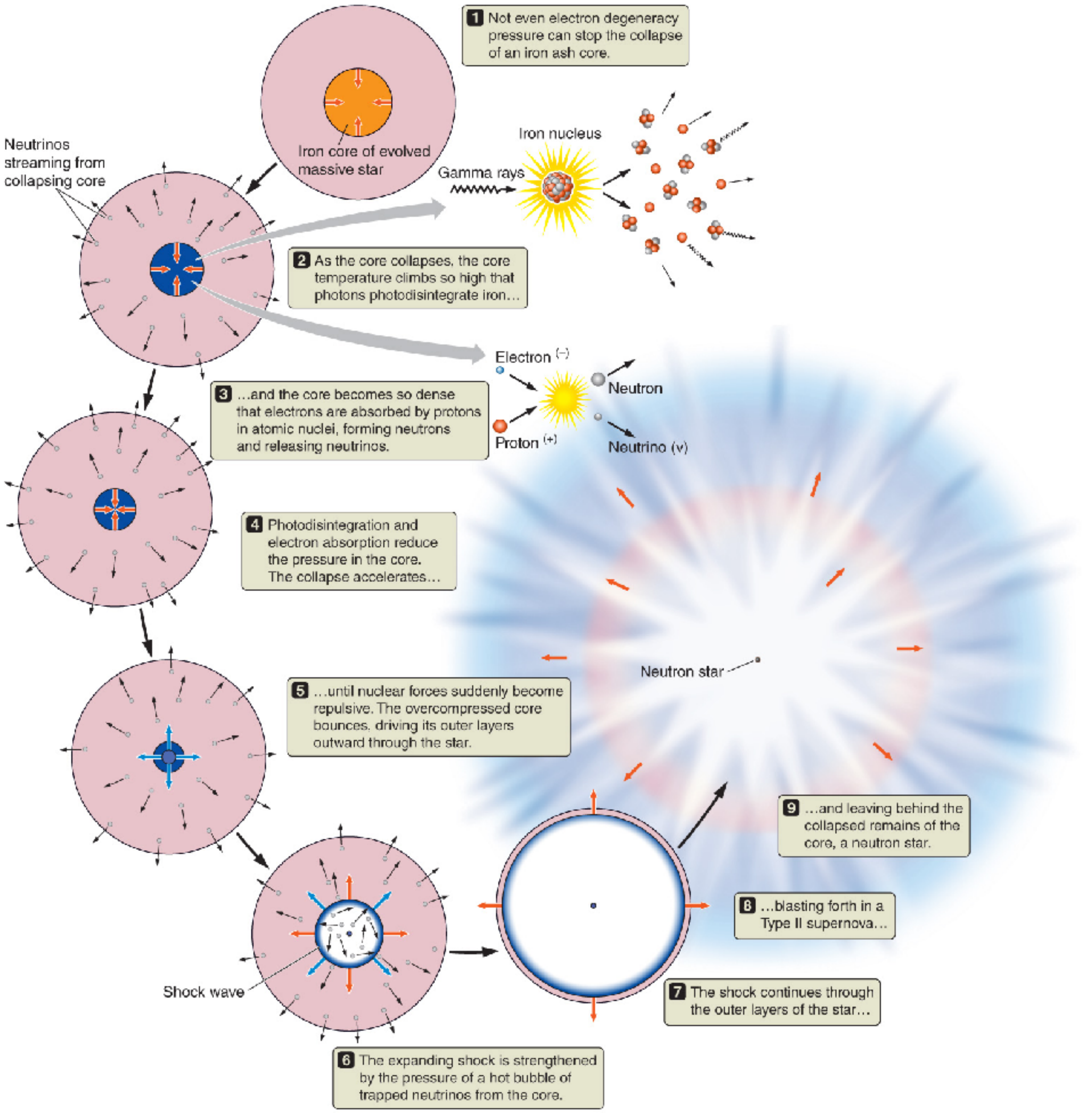
if mass exceeds Chandrasekhar limit (1.4 M_{sun})



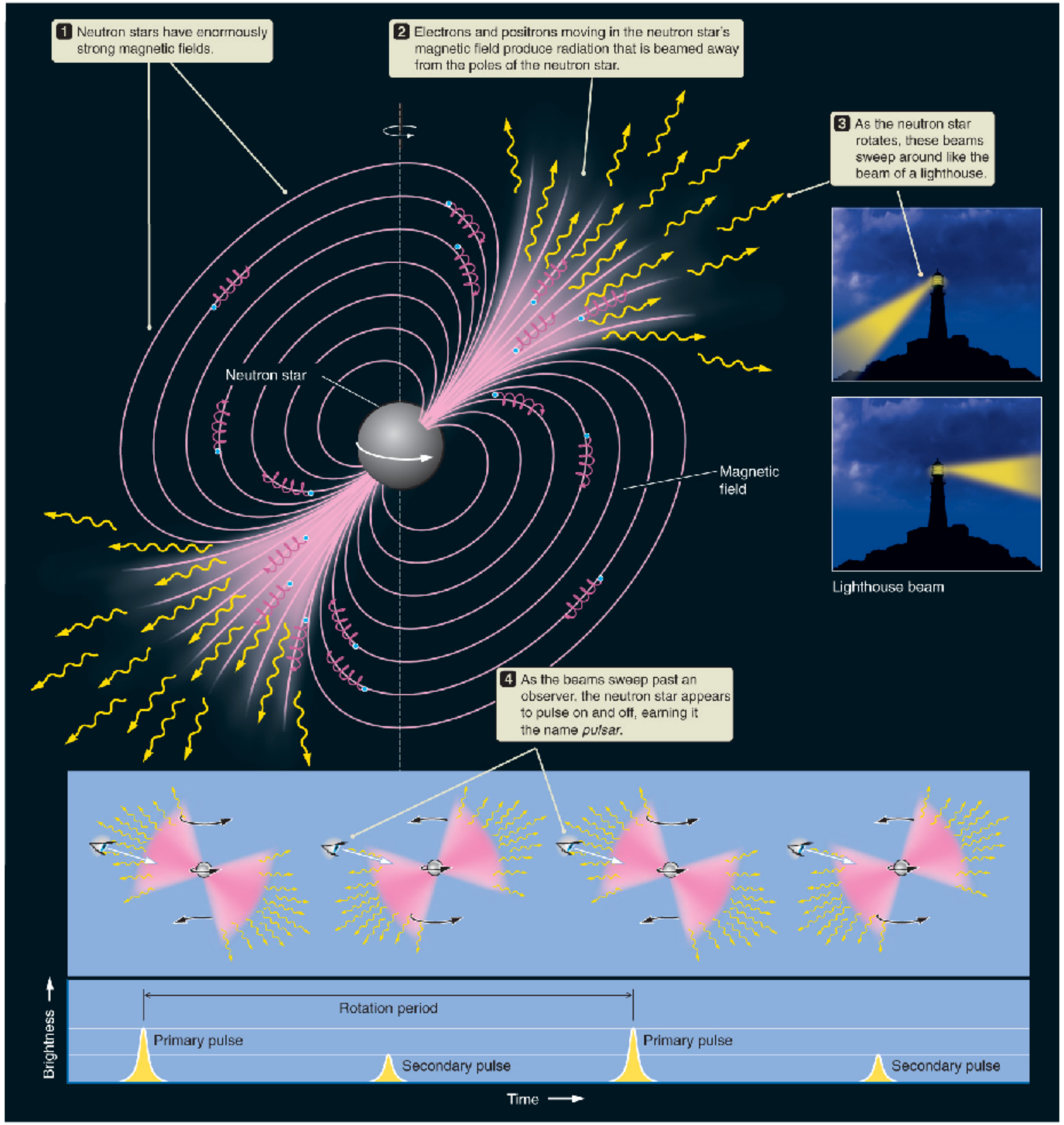
Hydrogen collects on the surface of a white dwarf in a binary system.

Massive stars burn up to Fe (iron) in its core, then go supernovae (Type II)



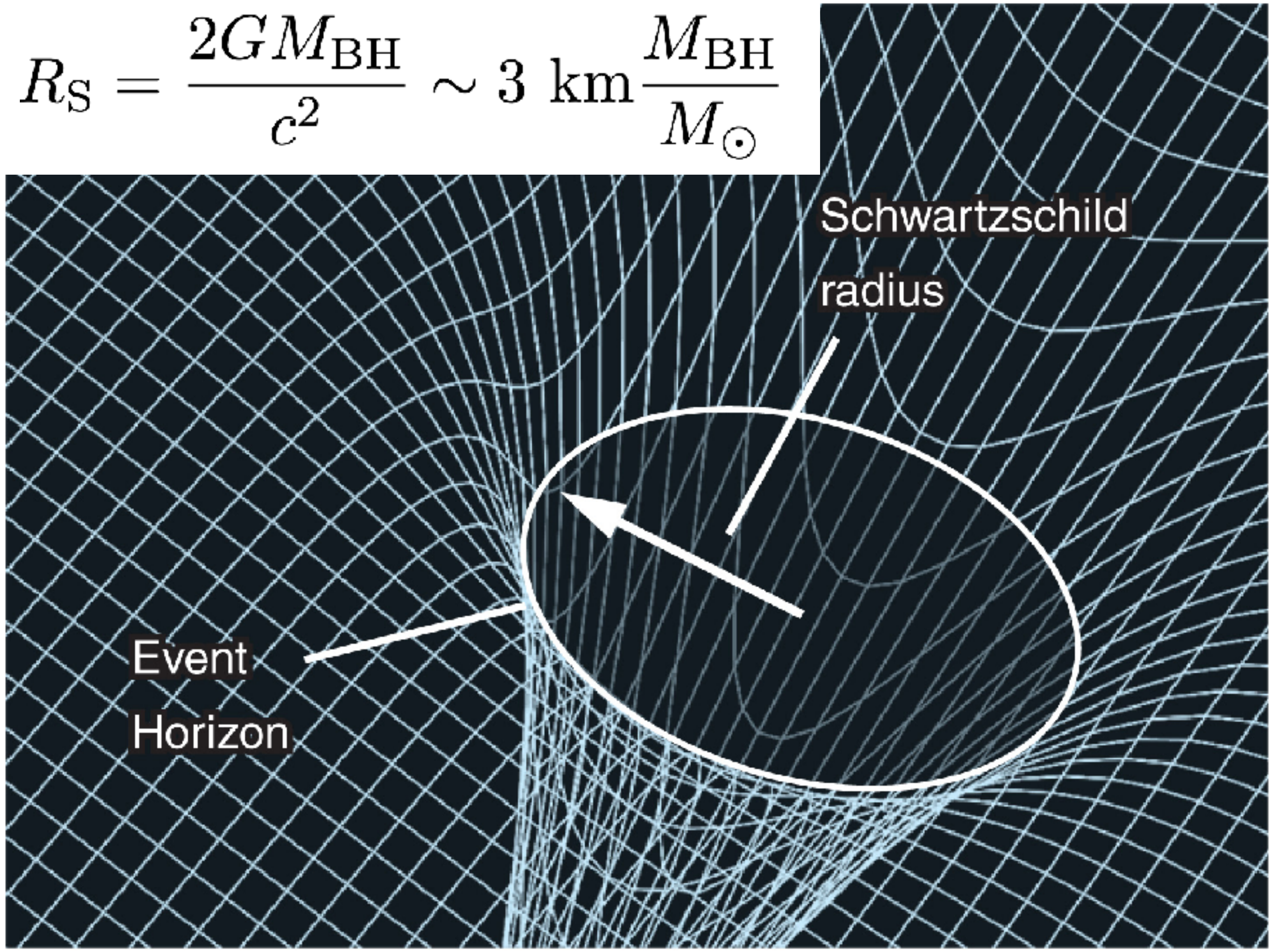


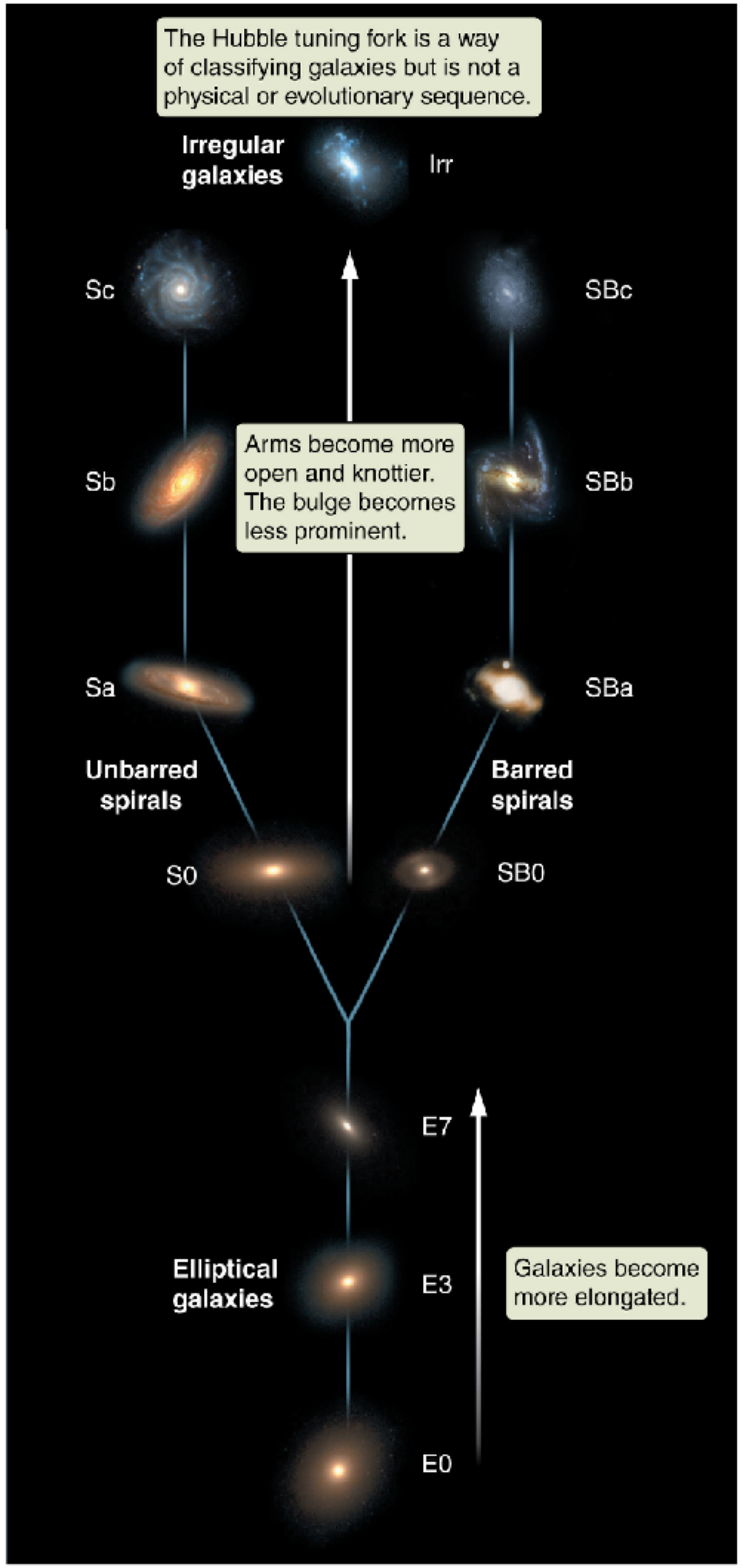
Neutron Stars



Black Holes

$$R_{\rm S} = \frac{2GM_{\rm BH}}{c^2} \sim 3\ {\rm km}\,\frac{M_{\rm BH}}{M_\odot}$$

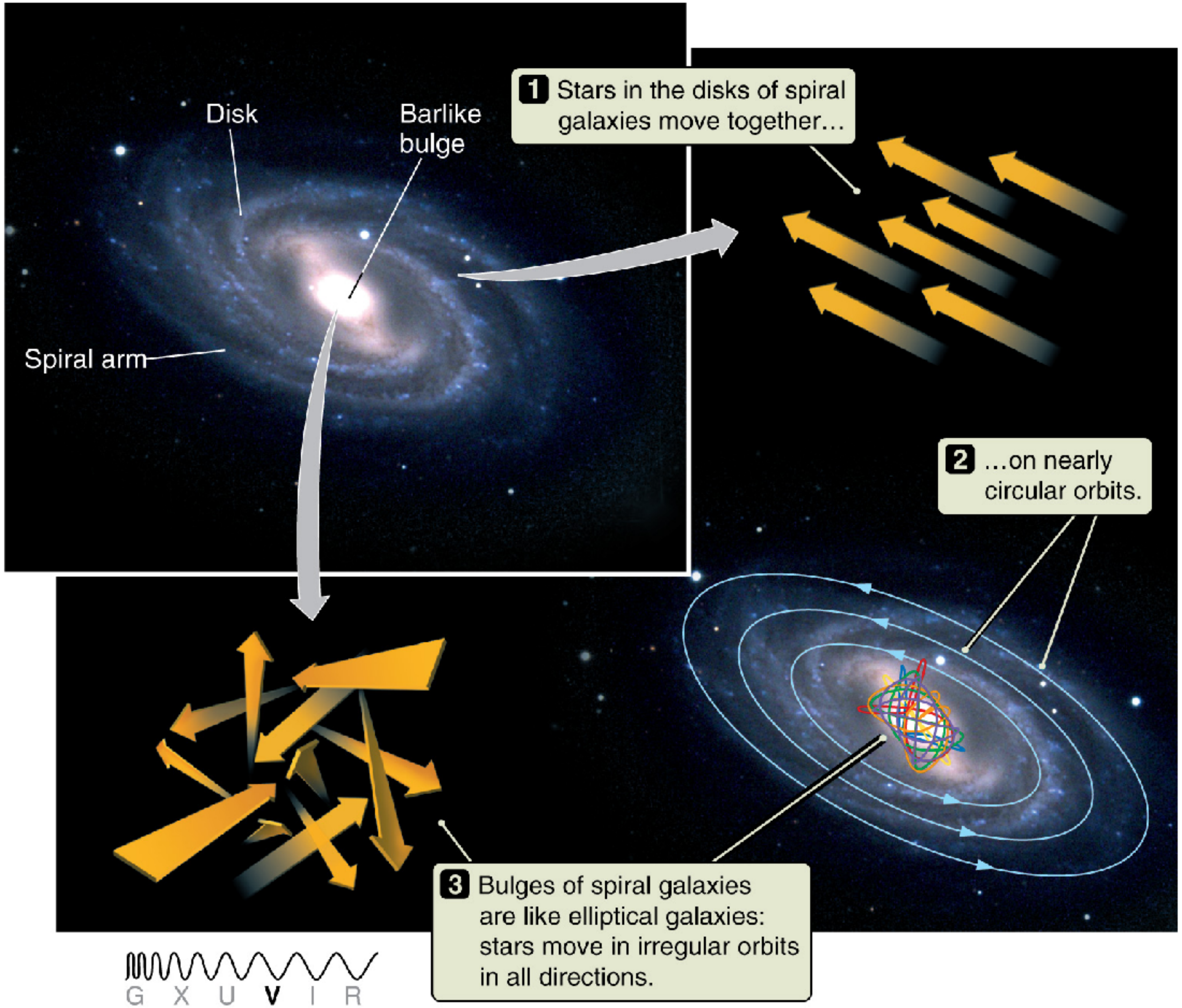




The Hubble tuning fork is a way of classifying galaxies but is not a physical or evolutionary sequence.

Arms become more open and knottier. The bulge becomes less prominent.

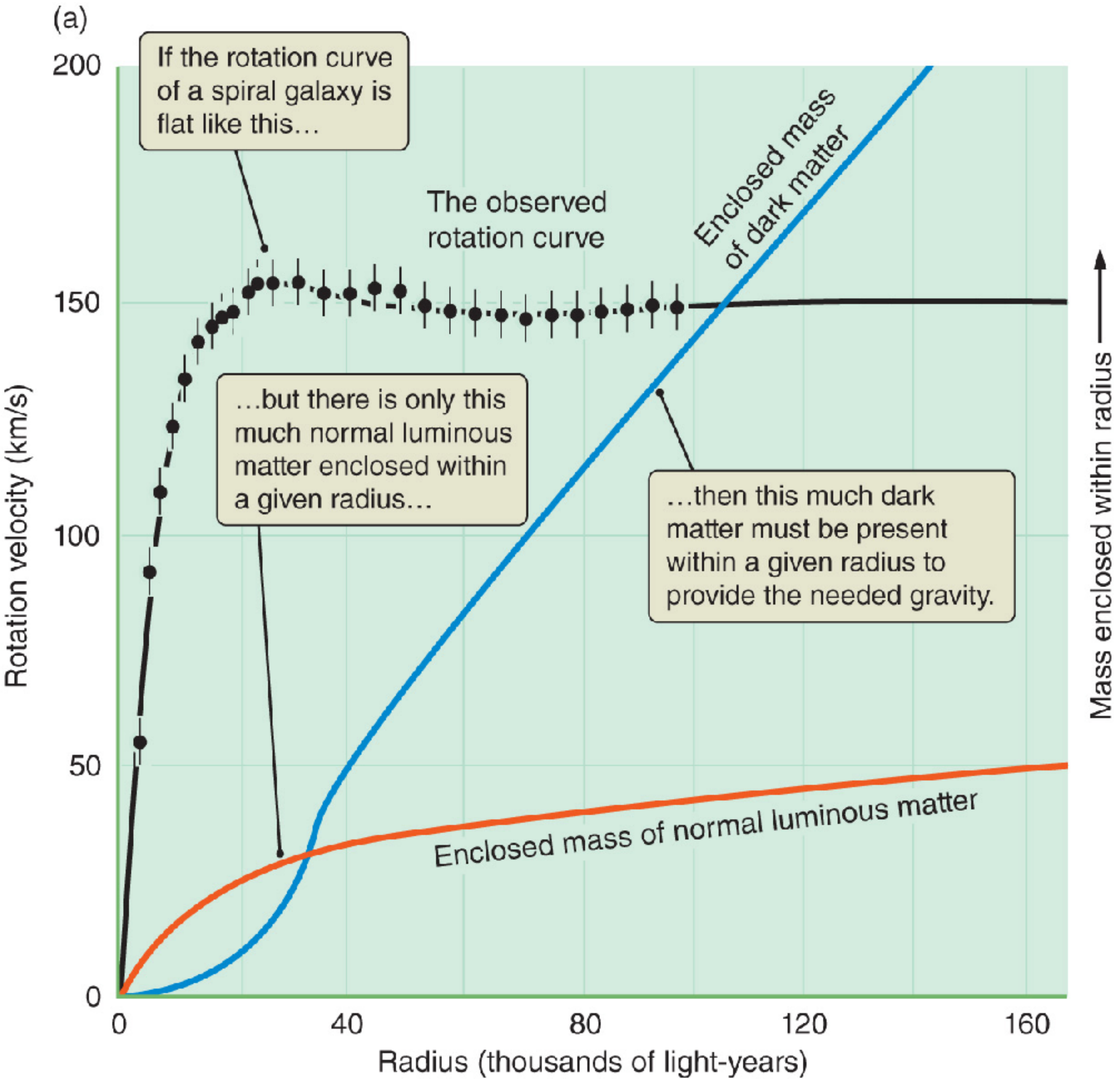
Galaxies become more elongated.



1 Stars in the disks of spiral galaxies move together…

2 …on nearly circular orbits.

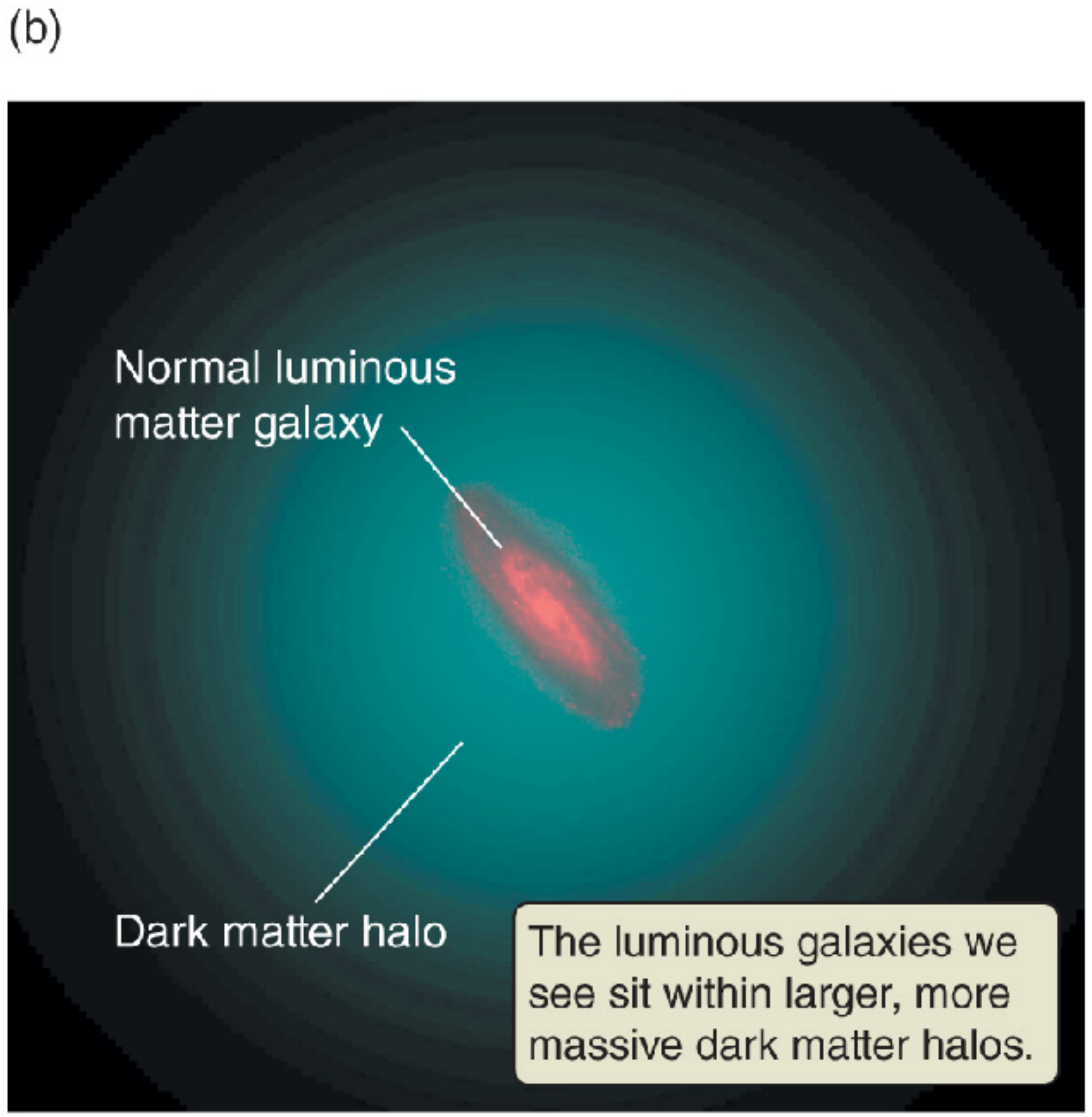
3 Bulges of spiral galaxies are like elliptical galaxies: stars move in irregular orbits in all directions.



If the rotation curve of a spiral galaxy is flat like this…

…but there is only this much normal luminous matter enclosed within a given radius…

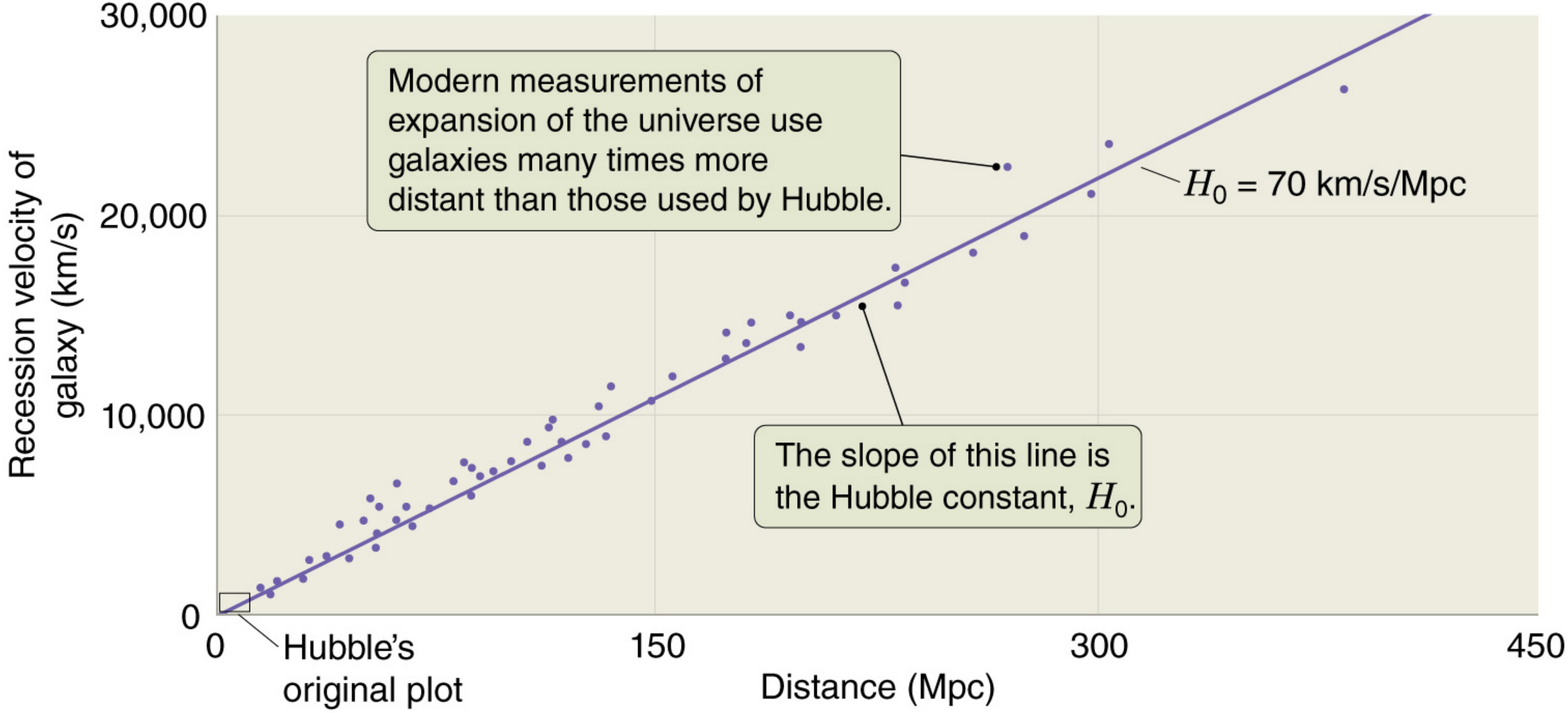
…then this much dark matter must be present within a given radius to provide the needed gravity.



The luminous galaxies we see sit within larger, more massive dark matter halos.

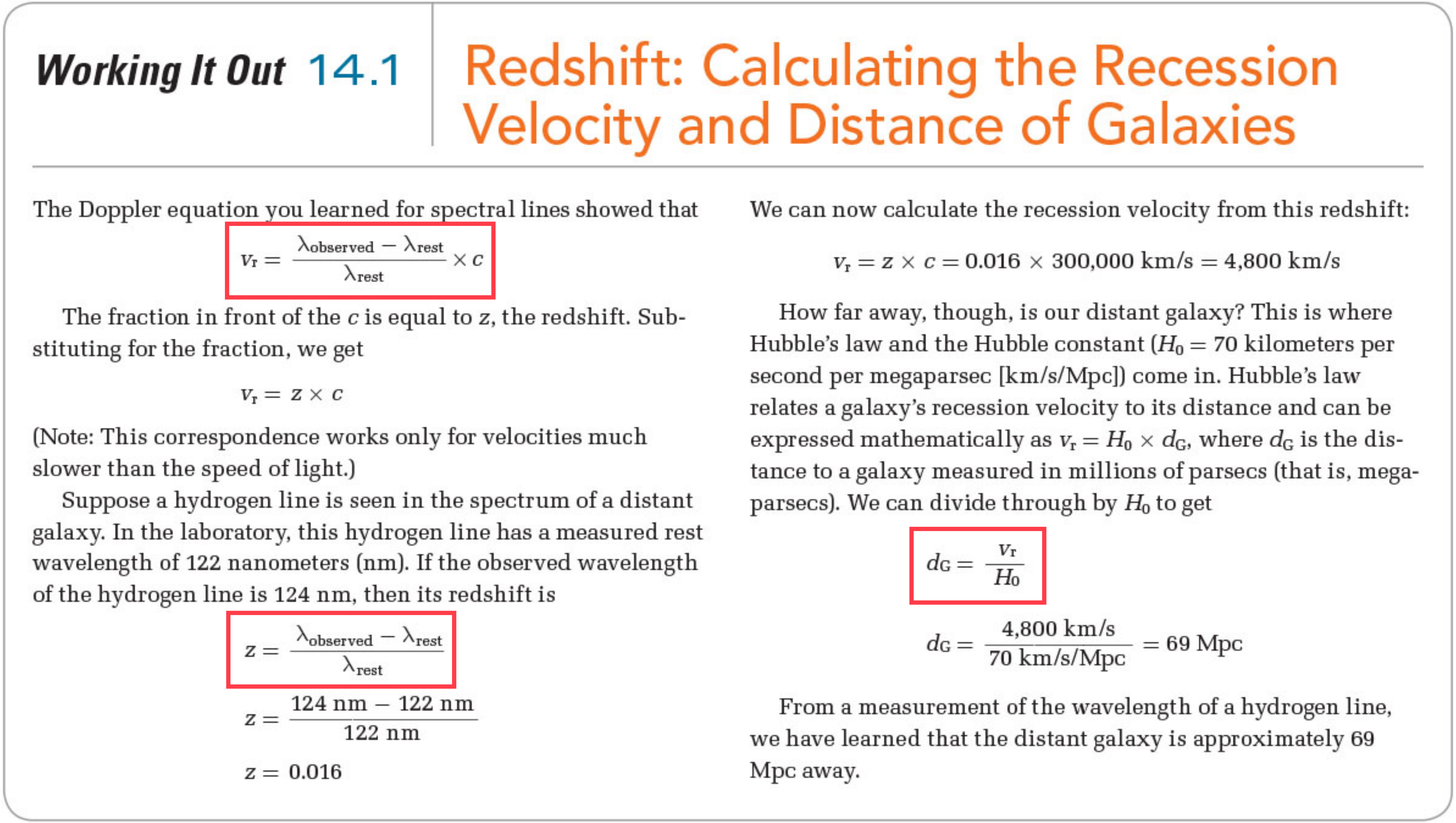
Galaxies seem to have more mass than we can see —> dark matter

Hubble's law demonstrates that the universe is expanding



Modern measurements of expansion of the universe use galaxies many times more distant than those used by Hubble.

The slope of this line is the Hubble constant, H_0.



Working It Out 14.1

Redshift: Calculating the Recession Velocity and Distance of Galaxies

The Doppler equation you learned for spectral lines showed that

$$\boxed{v_r = \frac{\lambda_{\text{observed}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}} \times c}$$

The fraction in front of the *c* is equal to *z*, the redshift. Substituting for the fraction, we get

$$v_r = z \times c$$

(Note: This correspondence works only for velocities much slower than the speed of light.)

Suppose a hydrogen line is seen in the spectrum of a distant galaxy. In the laboratory, this hydrogen line has a measured rest wavelength of 122 nanometers (nm). If the observed wavelength of the hydrogen line is 124 nm, then its redshift is

$$\boxed{z = \frac{\lambda_{\text{observed}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}}}$$

$$z = \frac{124\text{ nm} - 122\text{ nm}}{122\text{ nm}}$$

$$z = 0.016$$

We can now calculate the recession velocity from this redshift:

$$v_r = z \times c = 0.016 \times 300{,}000\text{ km/s} = 4{,}800\text{ km/s}$$

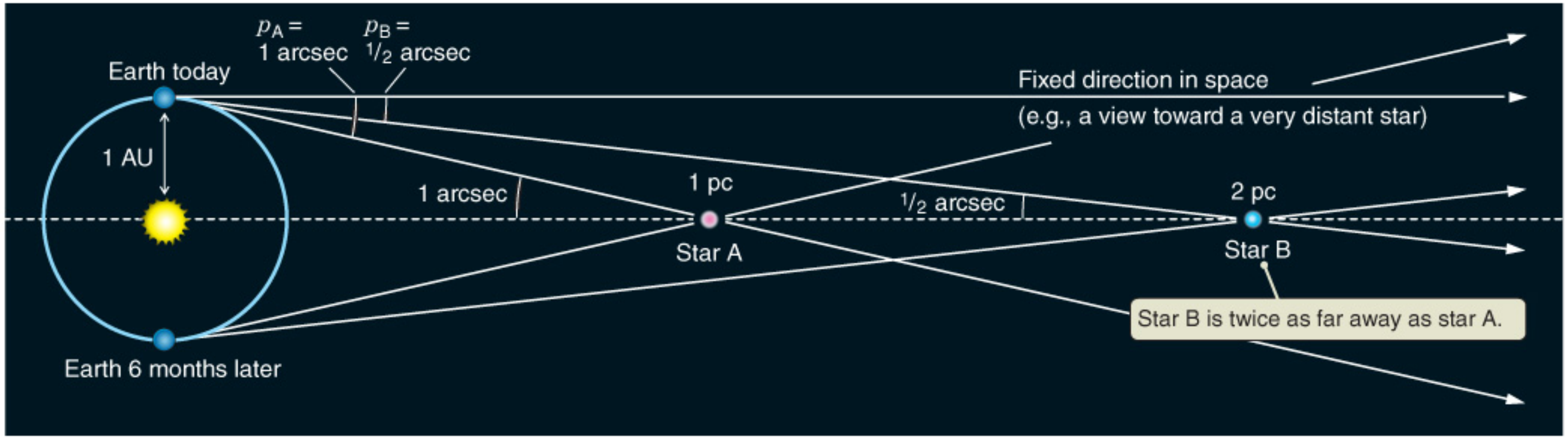
How far away, though, is our distant galaxy? This is where Hubble's law and the Hubble constant ($H_0 = 70$ kilometers per second per megaparsec [km/s/Mpc]) come in. Hubble's law relates a galaxy's recession velocity to its distance and can be expressed mathematically as $v_r = H_0 \times d_G$, where d_G is the distance to a galaxy measured in millions of parsecs (that is, megaparsecs). We can divide through by H_0 to get

$$\boxed{d_G = \frac{v_r}{H_0}}$$

$$d_G = \frac{4{,}800\text{ km/s}}{70\text{ km/s/Mpc}} = 69\text{ Mpc}$$

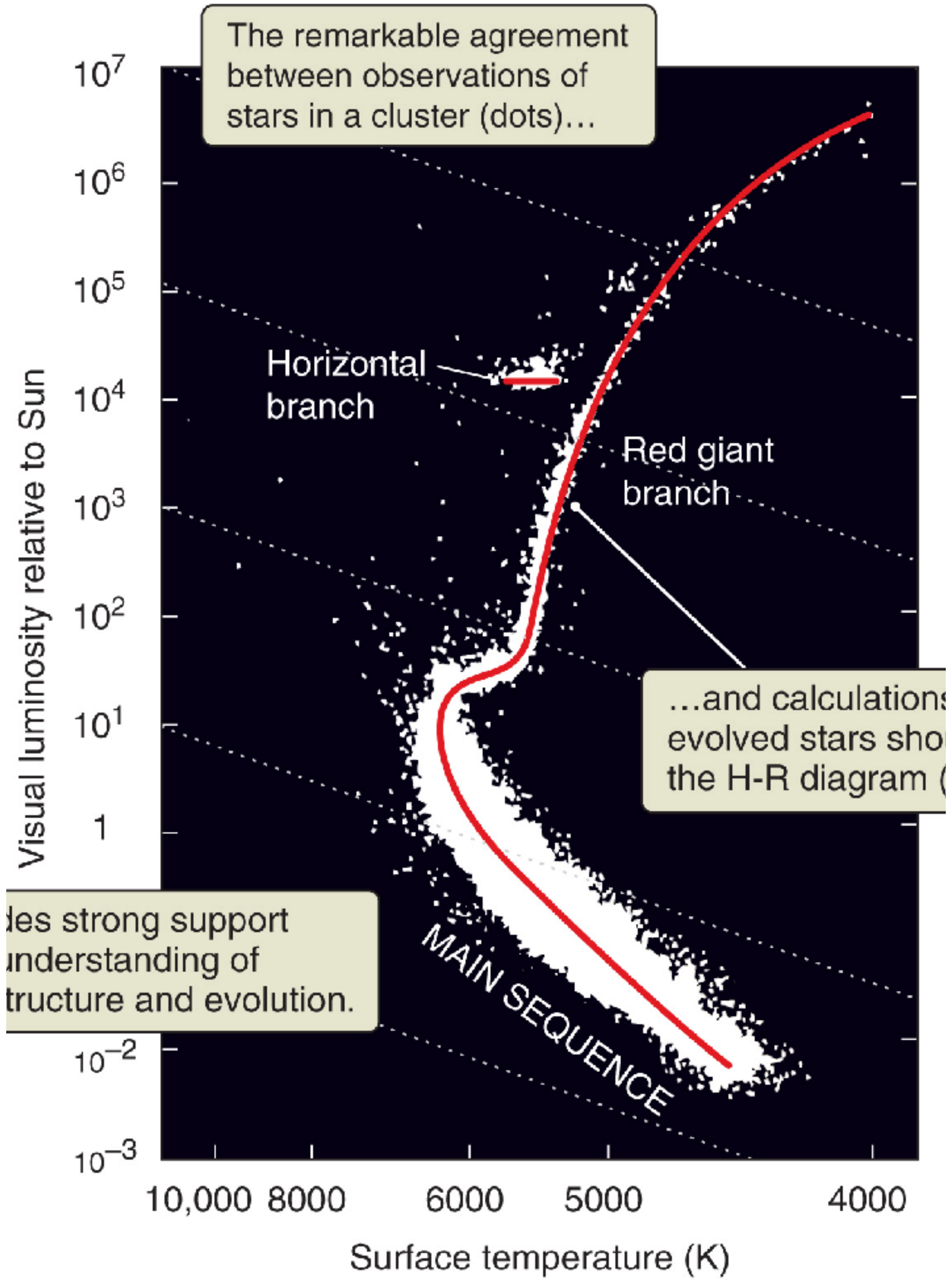
From a measurement of the wavelength of a hydrogen line, we have learned that the distant galaxy is approximately 69 Mpc away.

Parallax



Star B is twice as far away as star A.

Spectroscopic Parallax



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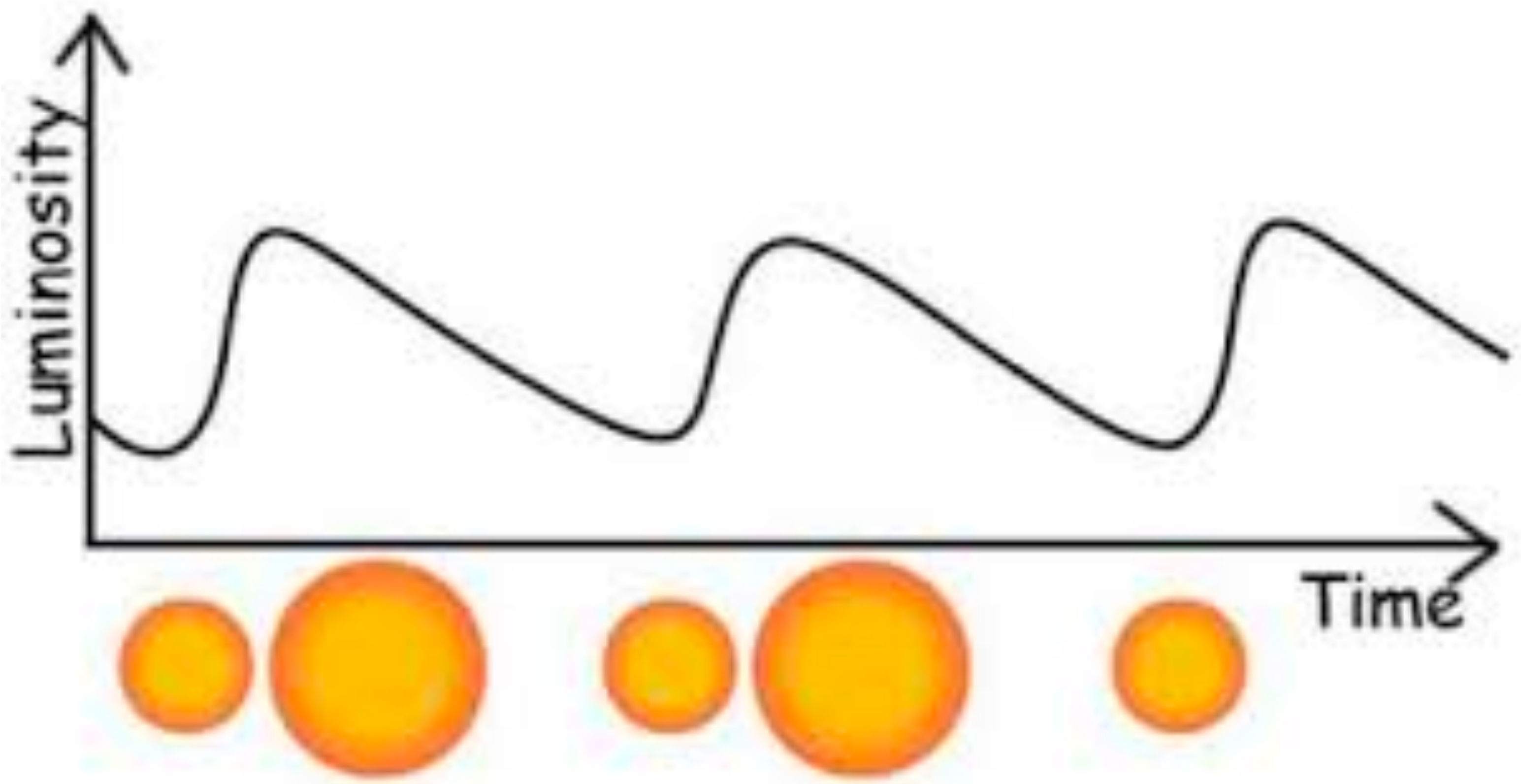
Cepheid Variables



Type Ia SNe