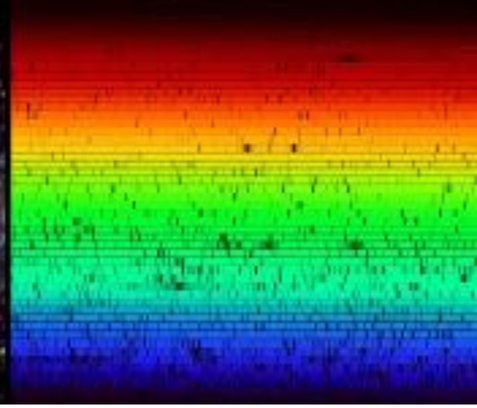


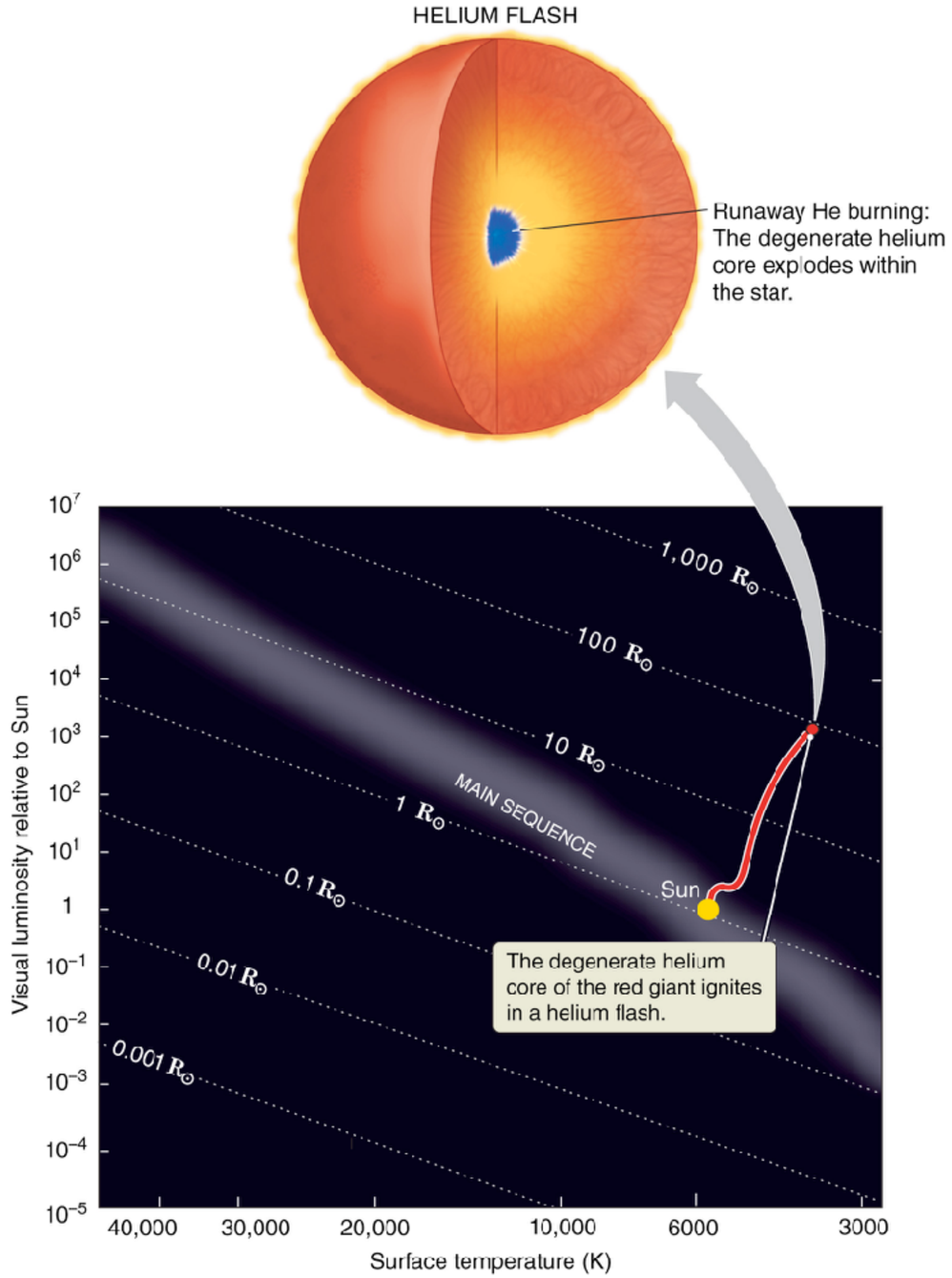
ASTR/PHYS 2500: Foundations Astronomy

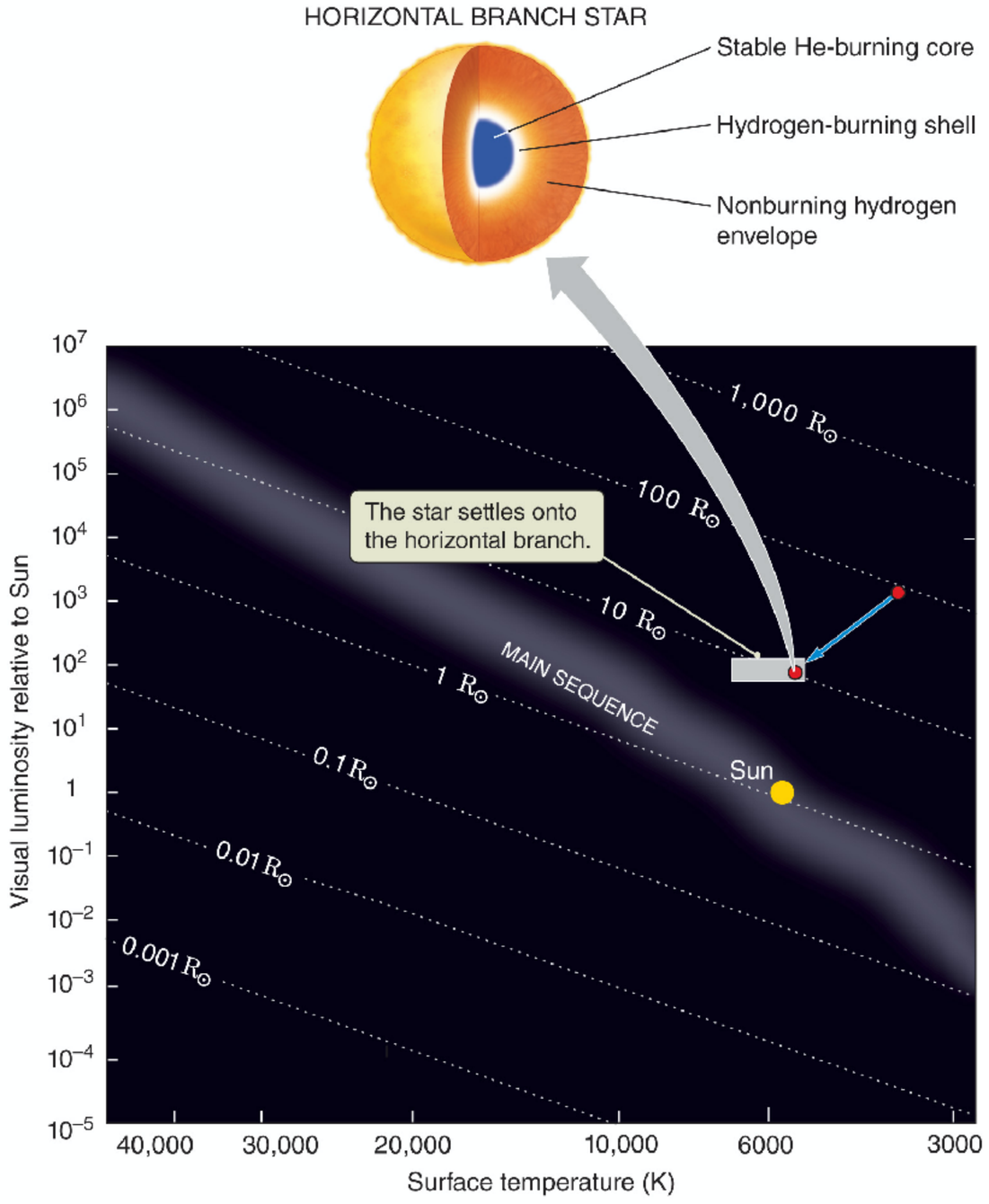
Week 9: Stellar Evolution / ISM

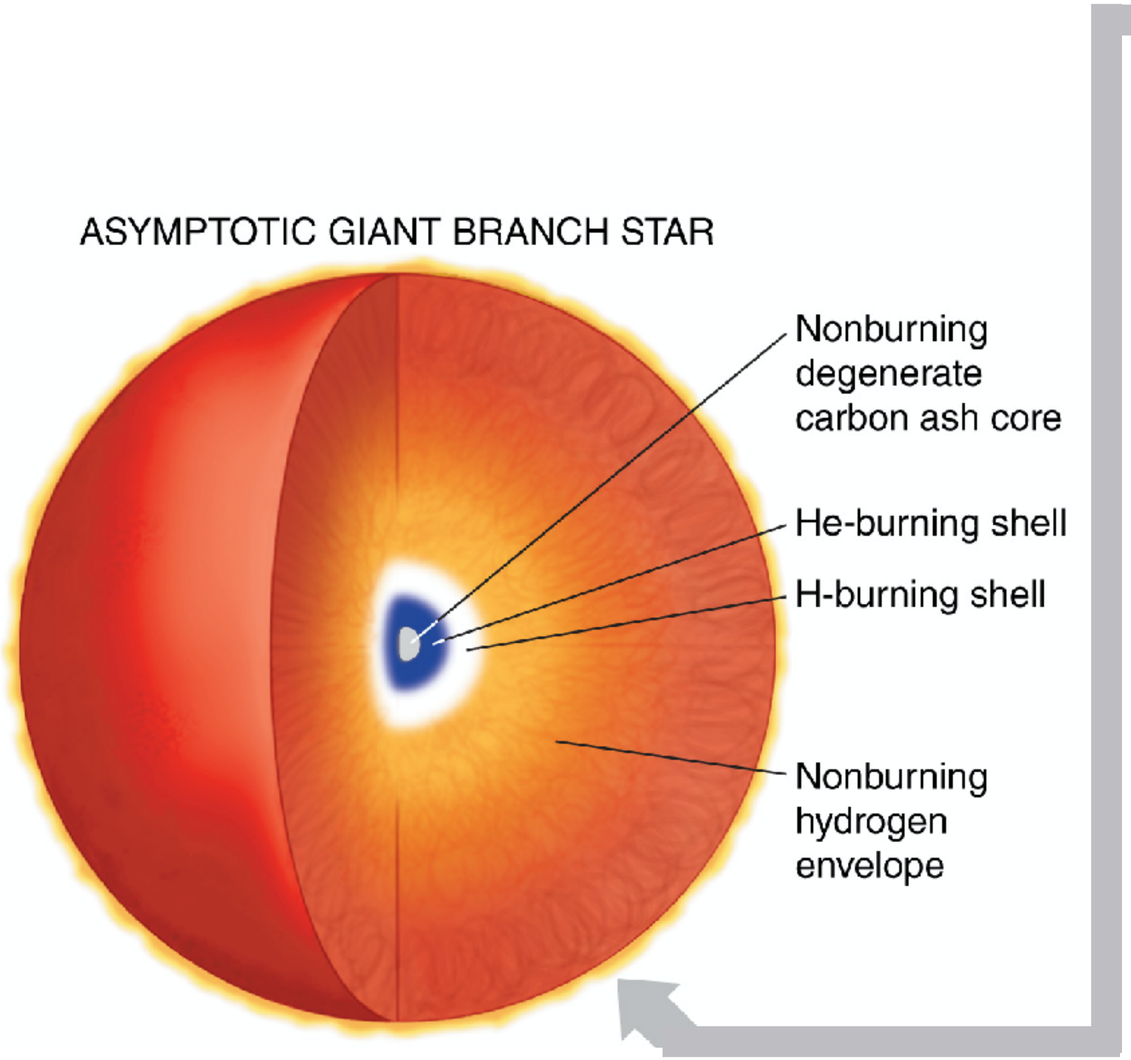
HW7 due now (OK to turn in Friday - just send me an email)

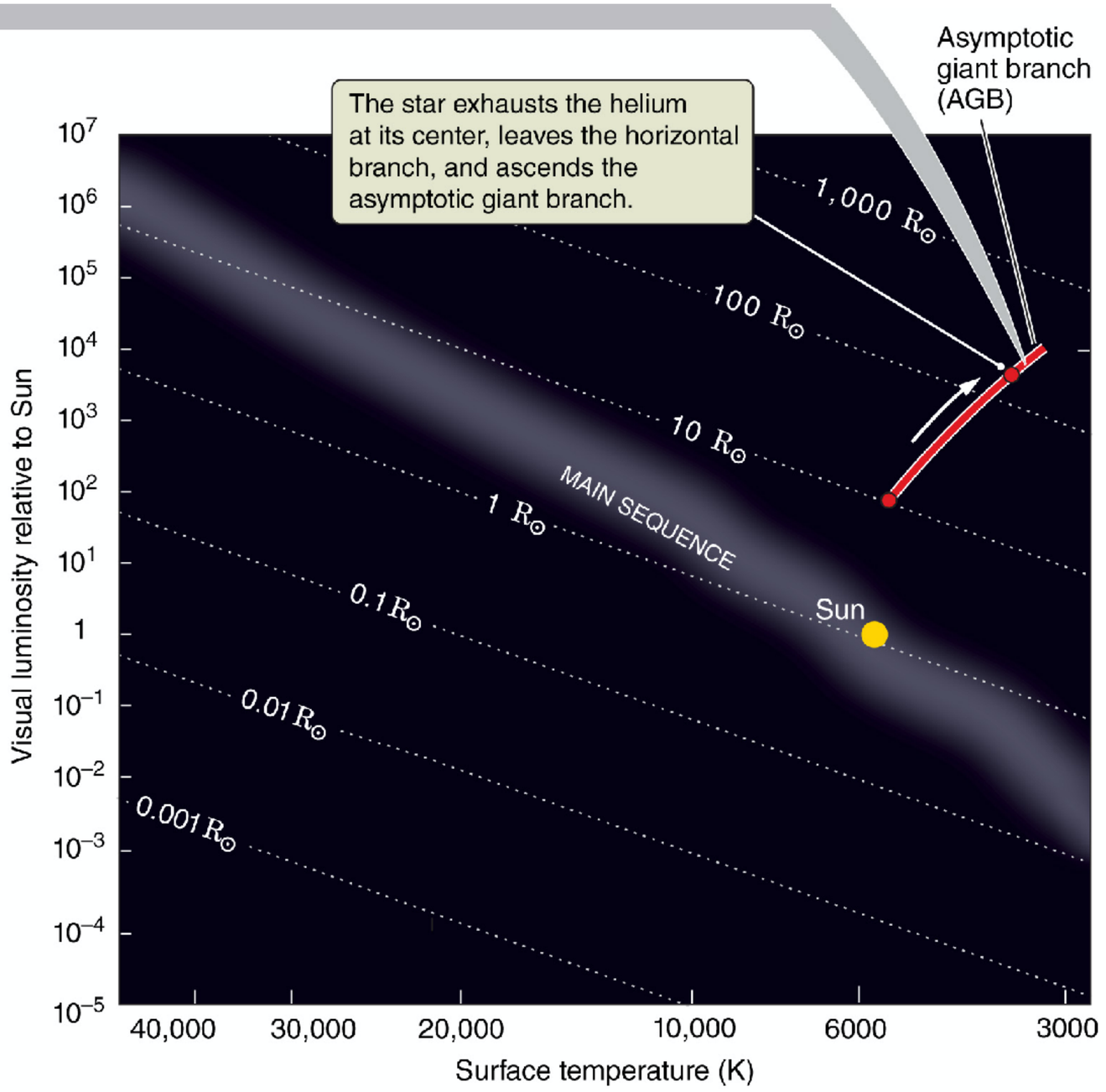
HW8 available now (only 4 HWs left!)

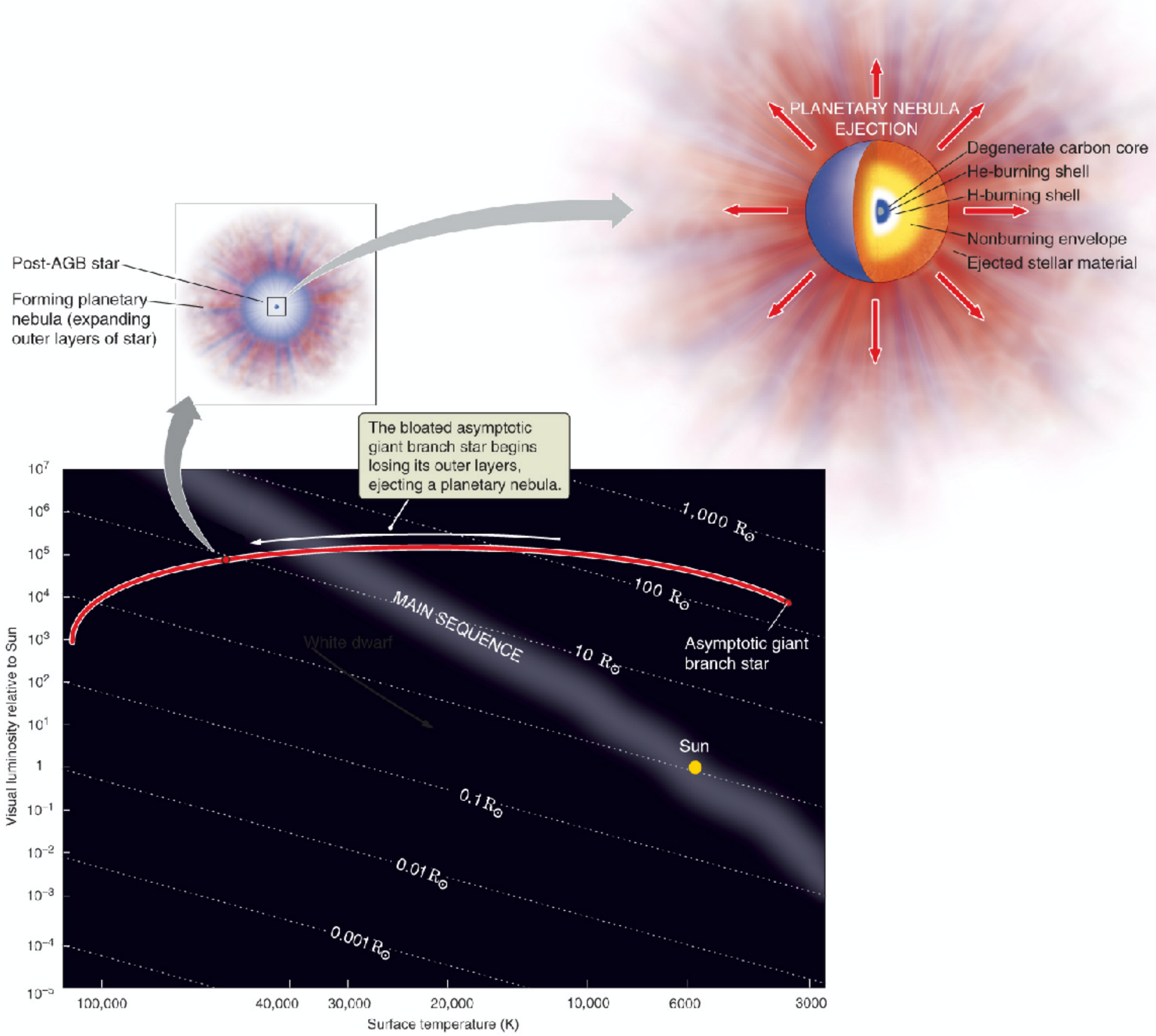
Read Ch. 18 for next week

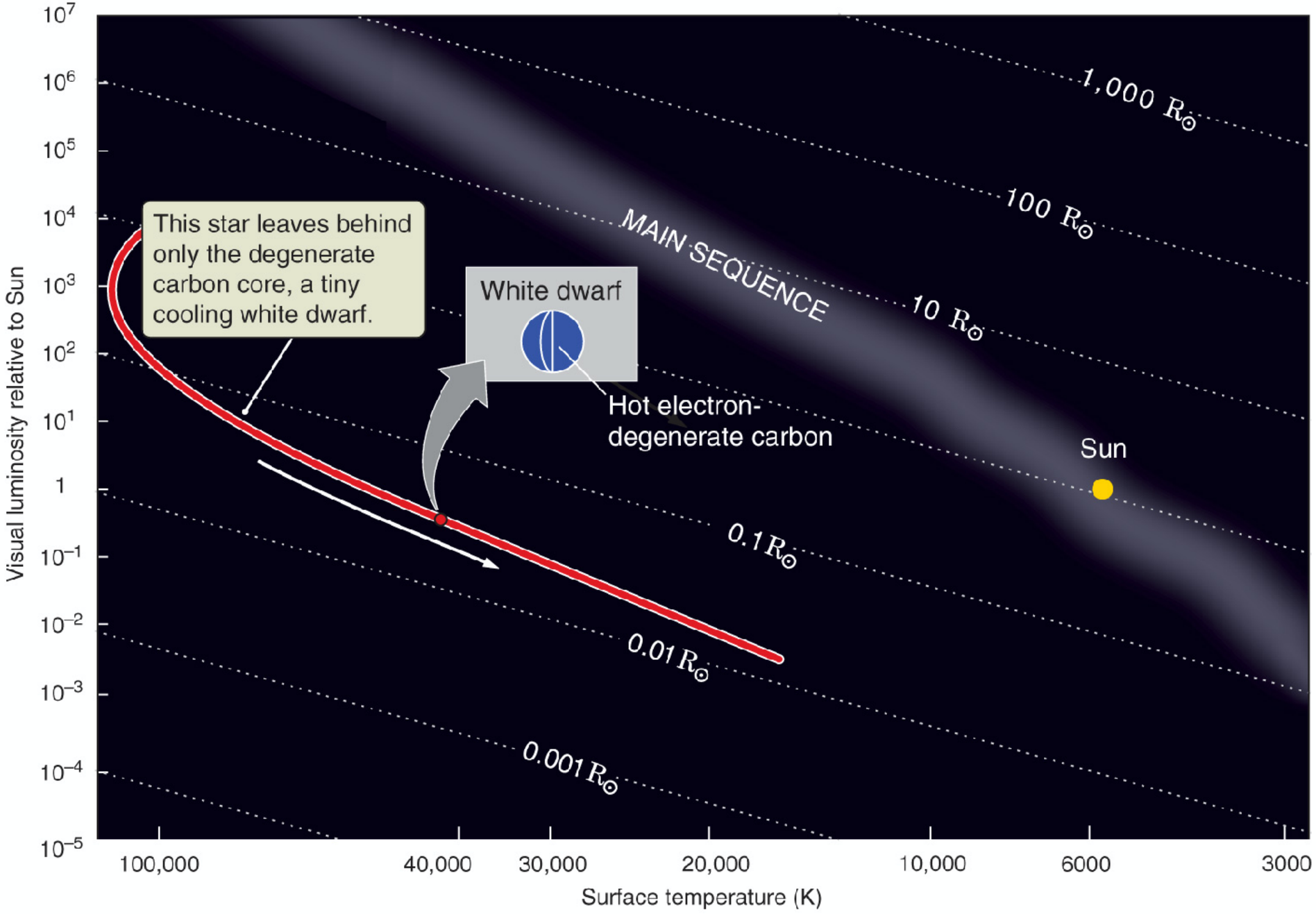

HELIUM FLASH
Runaway He burning: The degenerate helium core explodes within the star.
1,000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
The degenerate helium core of the red giant ignites in a helium flash.
Visual luminosity relative to Sun
Surface temperature (K)
40,000
30,000
20,000
10,000
6000
3000


HORIZONTAL BRANCH STAR
Stable He-burning core
Hydrogen-burning shell
Nonburning hydrogen envelope
1,000 R⊙
100 R⊙
The star settles onto the horizontal branch.
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
Visual luminosity relative to Sun
Surface temperature (K)
40,000
30,000
20,000
10,000
6000
3000


ASYMPTOTIC GIANT BRANCH STAR
Nonburning degenerate carbon ash core
He-burning shell
H-burning shell
Nonburning hydrogen envelope

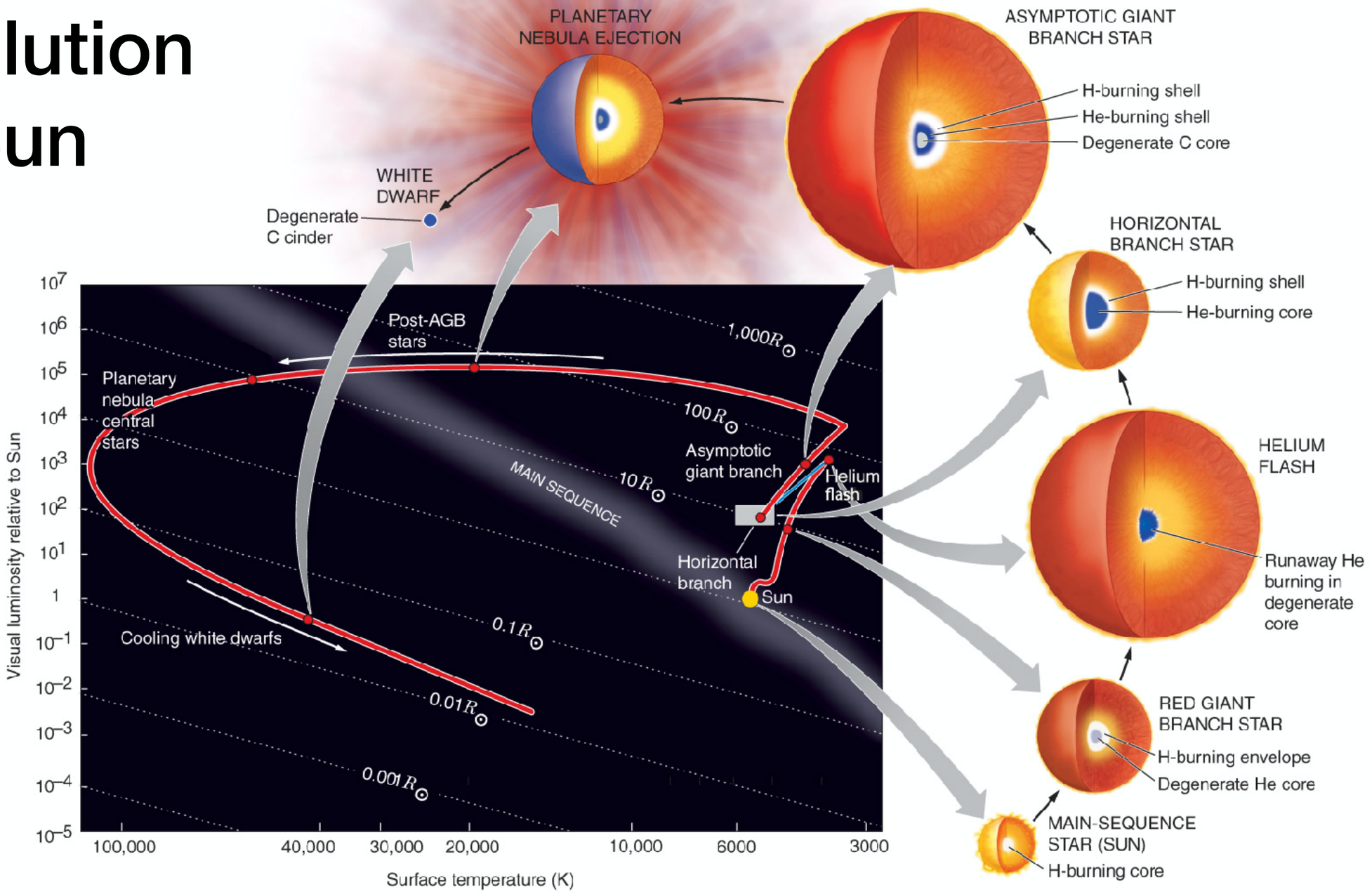

Asymptotic giant branch (AGB)
The star exhausts the helium at its center, leaves the horizontal branch, and ascends the asymptotic giant branch.
1,000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
Visual luminosity relative to Sun
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^-1
10^-2
10^-3
10^-4
10^-5
40,000
30,000
20,000
10,000
6000
3000
Surface temperature (K)


PLANETARY NEBULA EJECTION
Degenerate carbon core
He-burning shell
H-burning shell
Nonburning envelope
Ejected stellar material
Post-AGB star
Forming planetary nebula (expanding outer layers of star)
The bloated asymptotic giant branch star begins losing its outer layers, ejecting a planetary nebula.
1,000 R⊙
100 R⊙
10 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
White dwarf
Asymptotic giant branch star
Sun
Visual luminosity relative to Sun
Surface temperature (K)
100,000
40,000
30,000
20,000
10,000
6000
3000


Visual luminosity relative to Sun
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
MAIN SEQUENCE
This star leaves behind only the degenerate carbon core, a tiny cooling white dwarf.
White dwarf
Hot electron-degenerate carbon
Sun
100,000
40,000
30,000
20,000
10,000
6000
3000
Surface temperature (K)

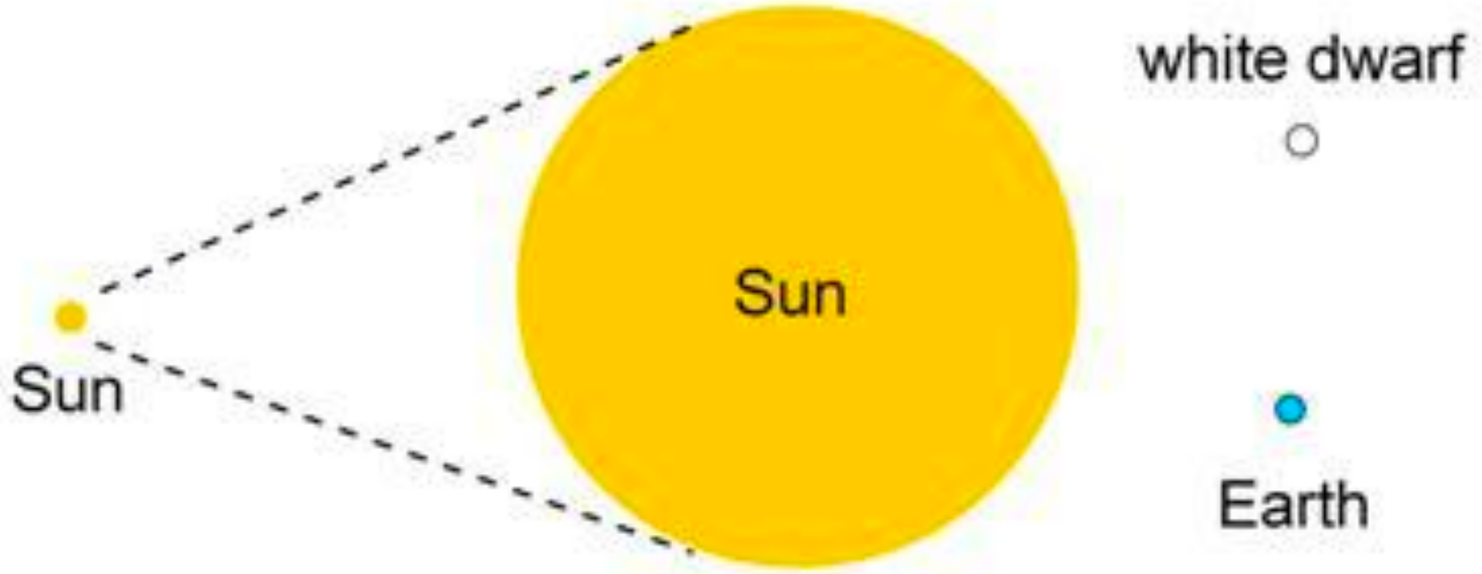
Future Evolution of the Sun

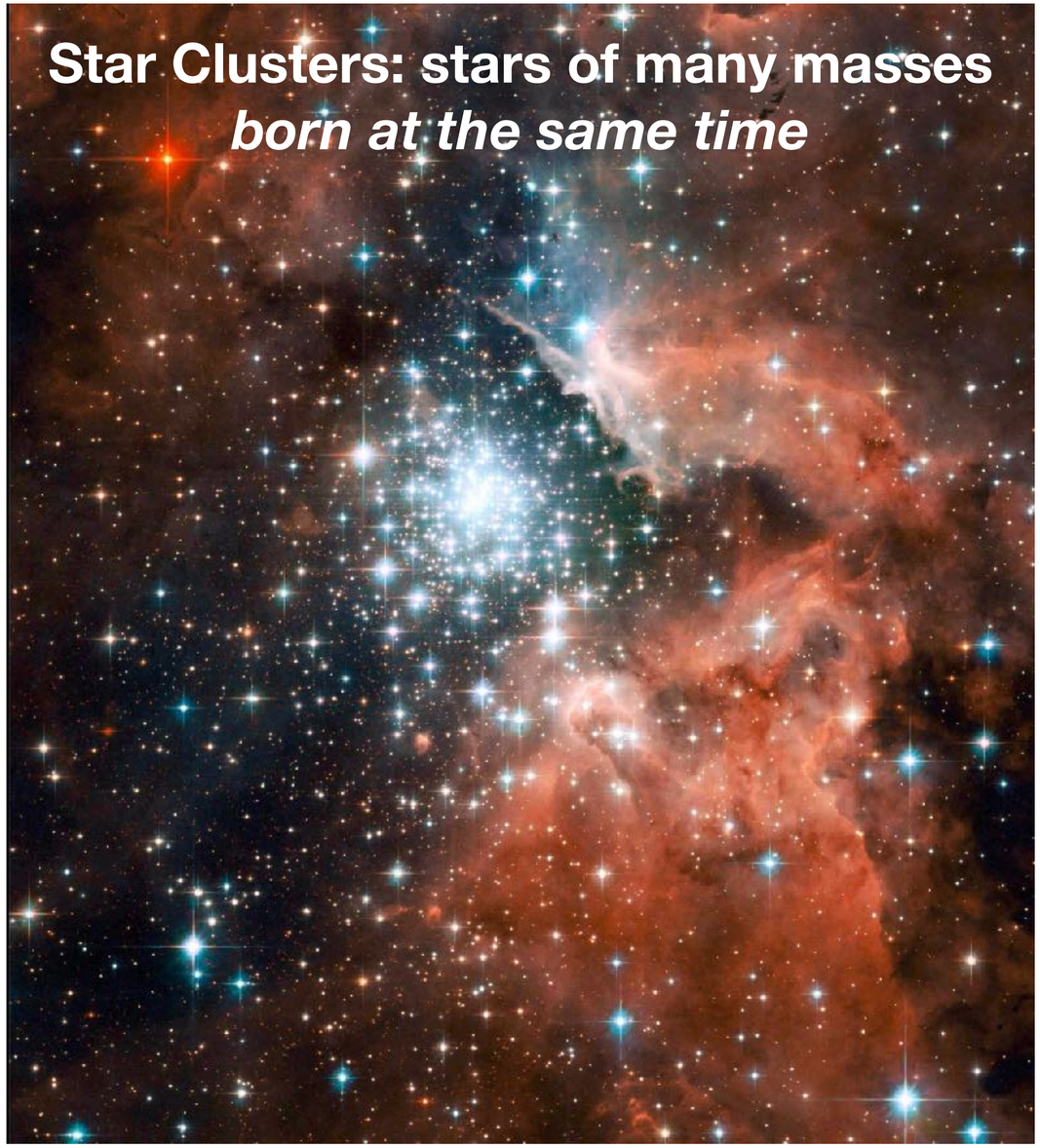
Again, this time with feeling!

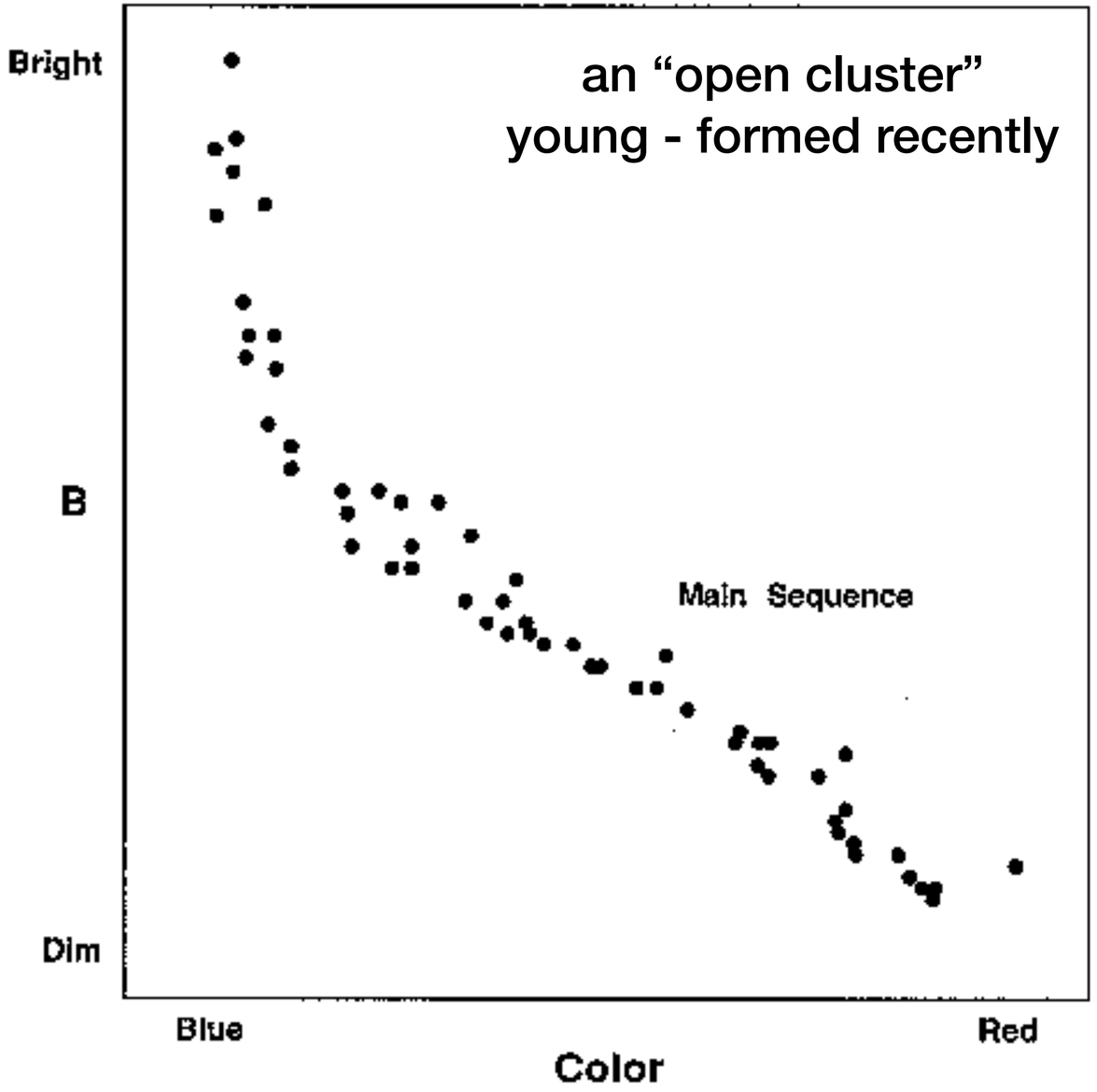


Size changes along with temperature

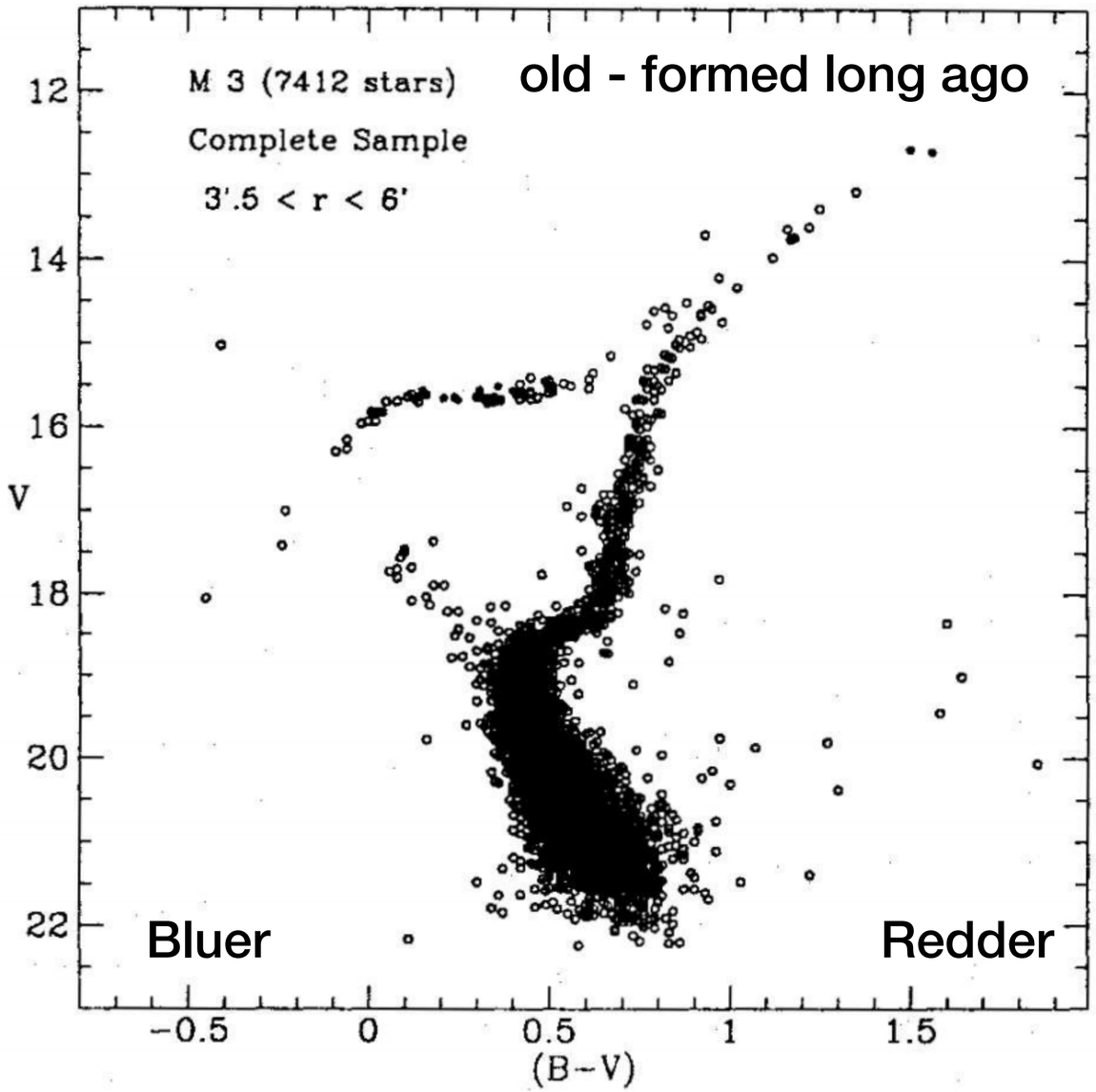
red giant



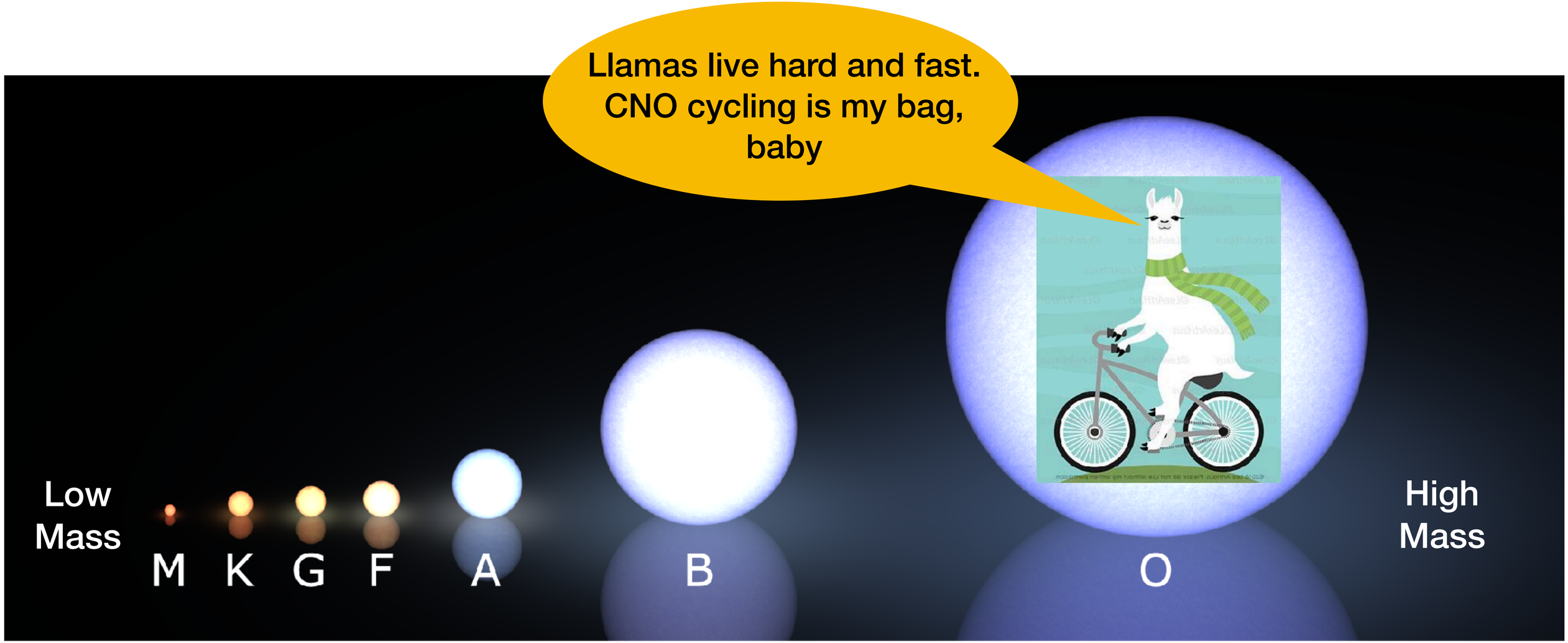

Star Clusters: stars of many masses
born at the same time


an “open cluster”
young - formed recently
Bright
B
Dim
Main Sequence
Blue
Red
Color

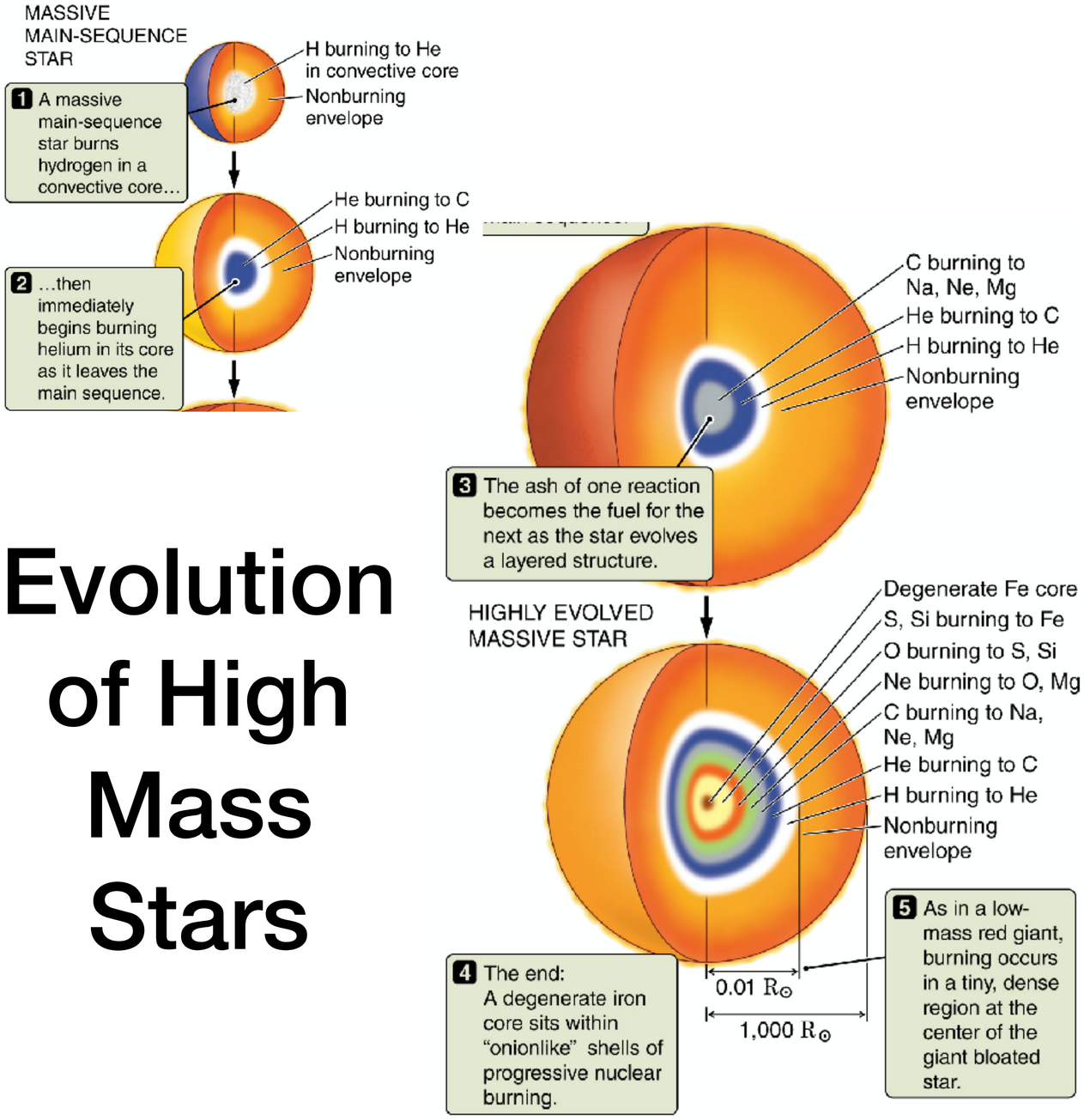
Globular Cluster Color-Magnitude Diagram

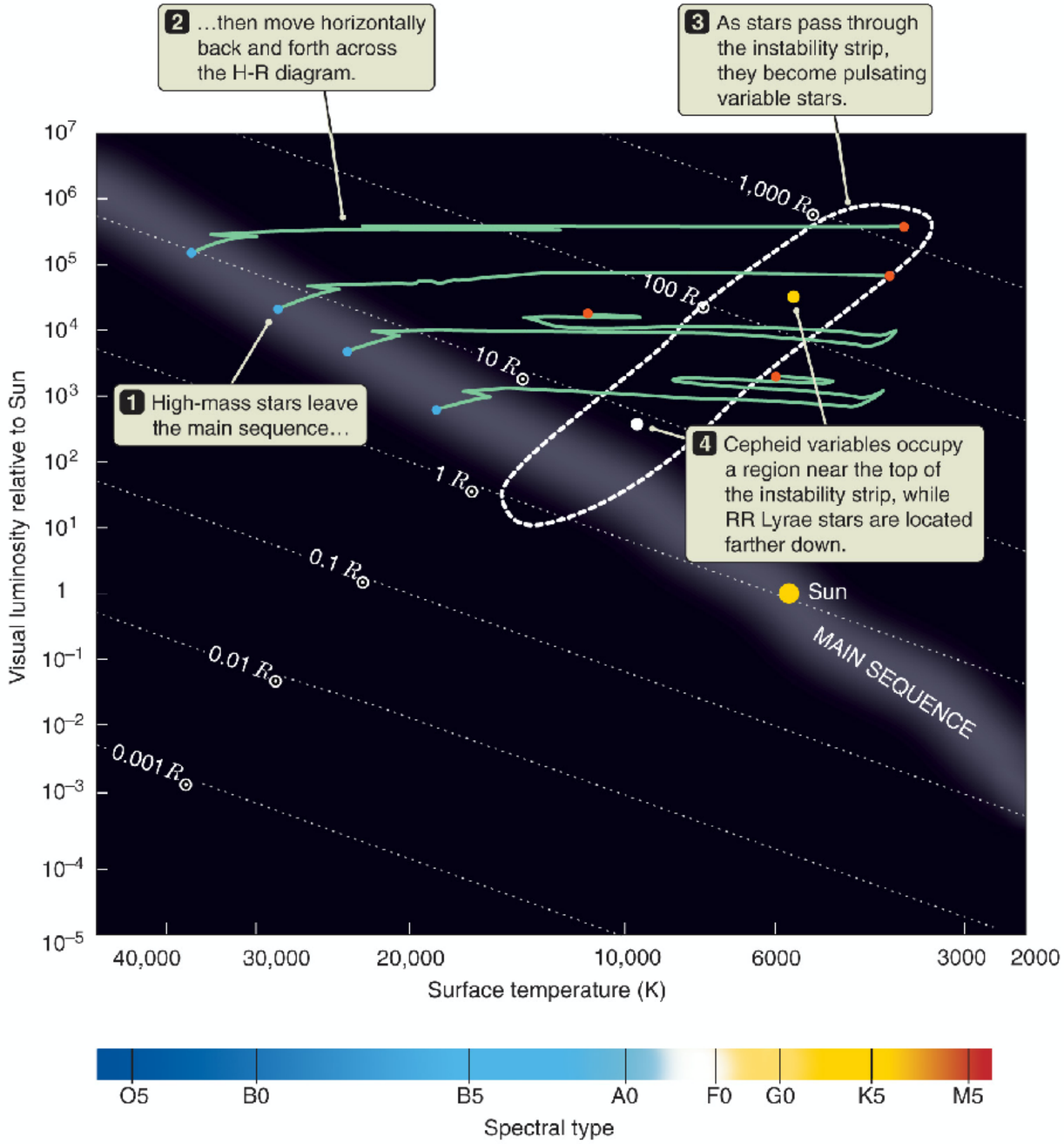


High Mass Stars = High Core Temps = CNO

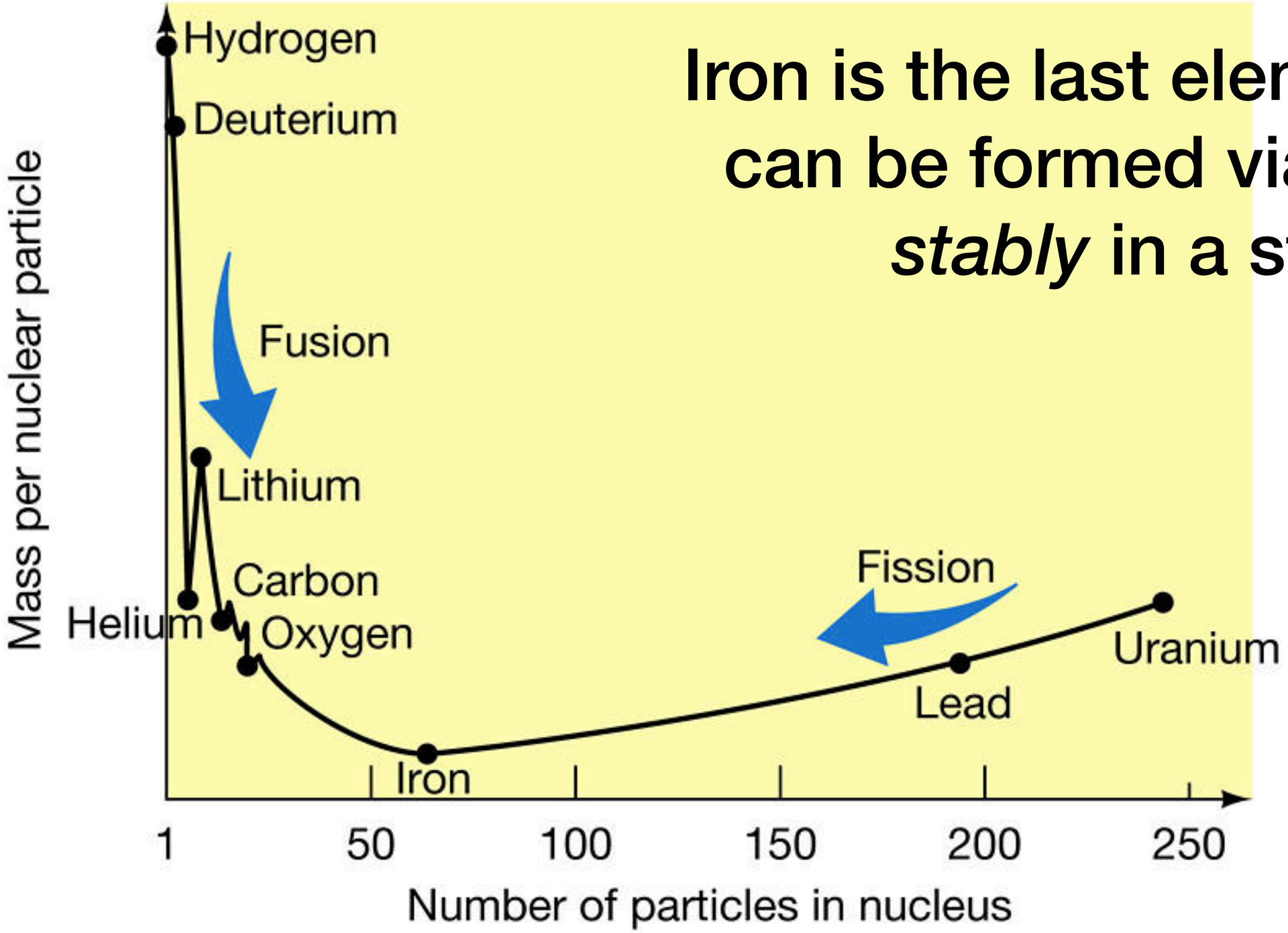


Evolution of High Mass Stars

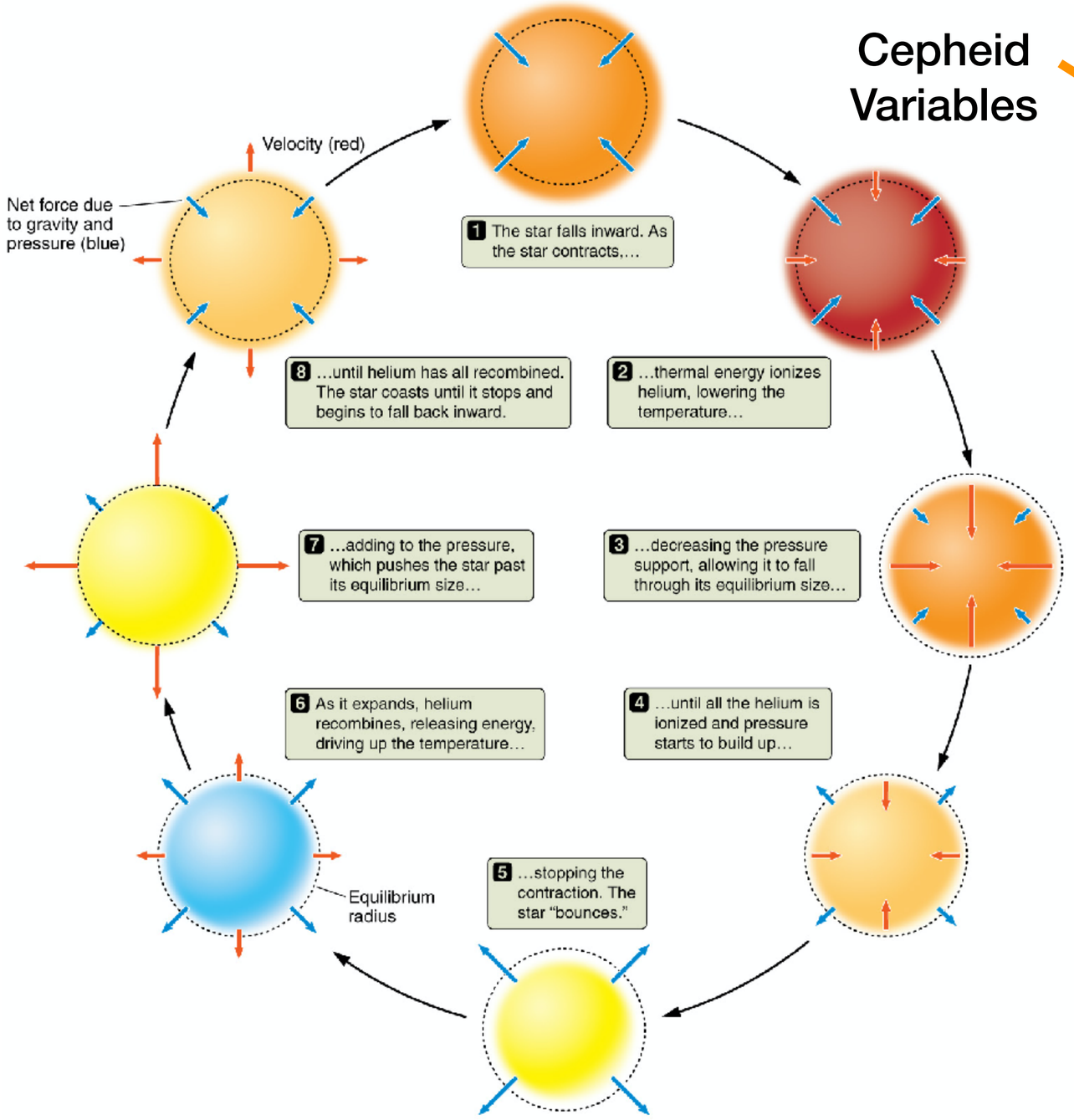


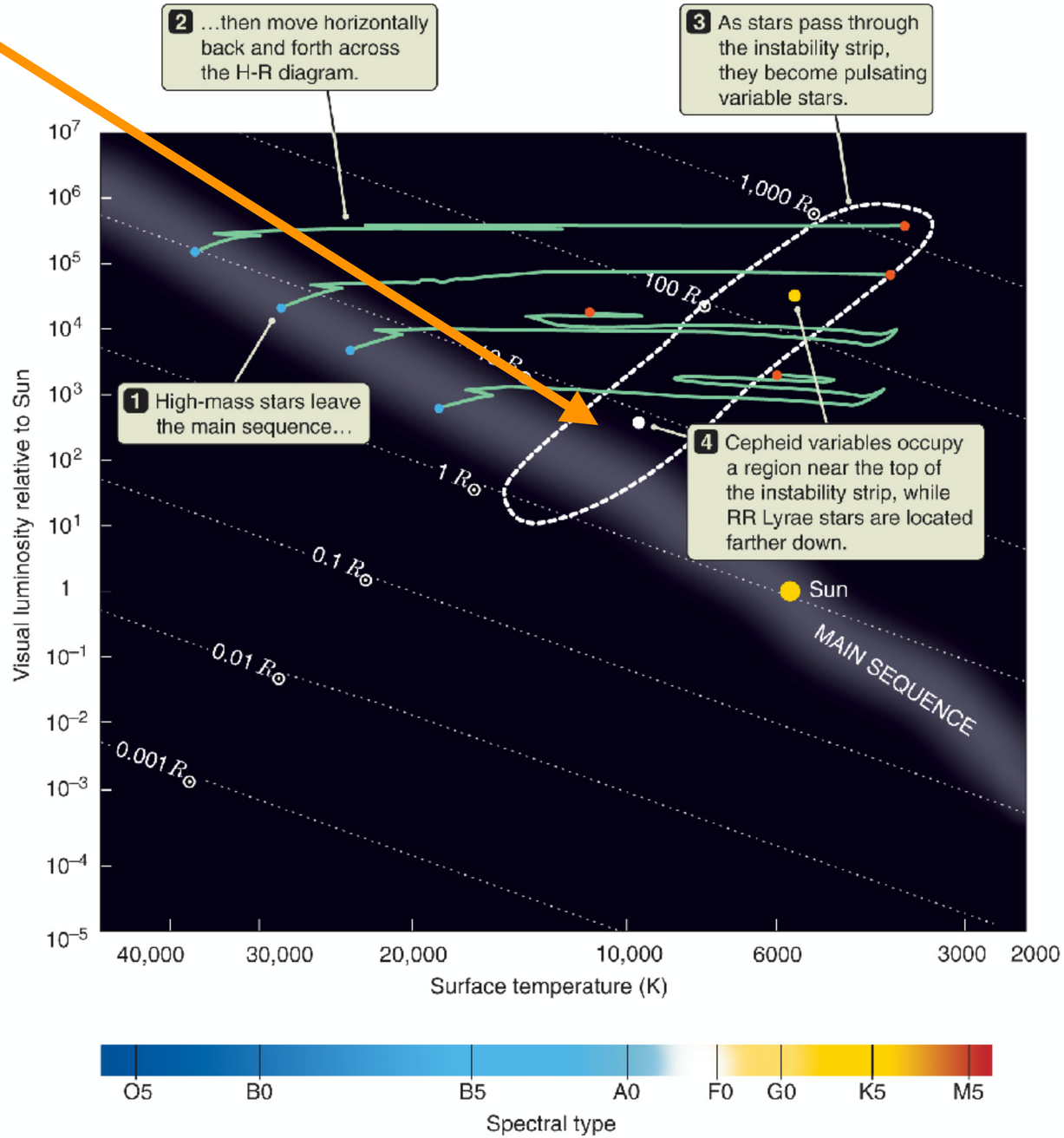


Iron is the last element that can be formed via fusion *stably* in a star

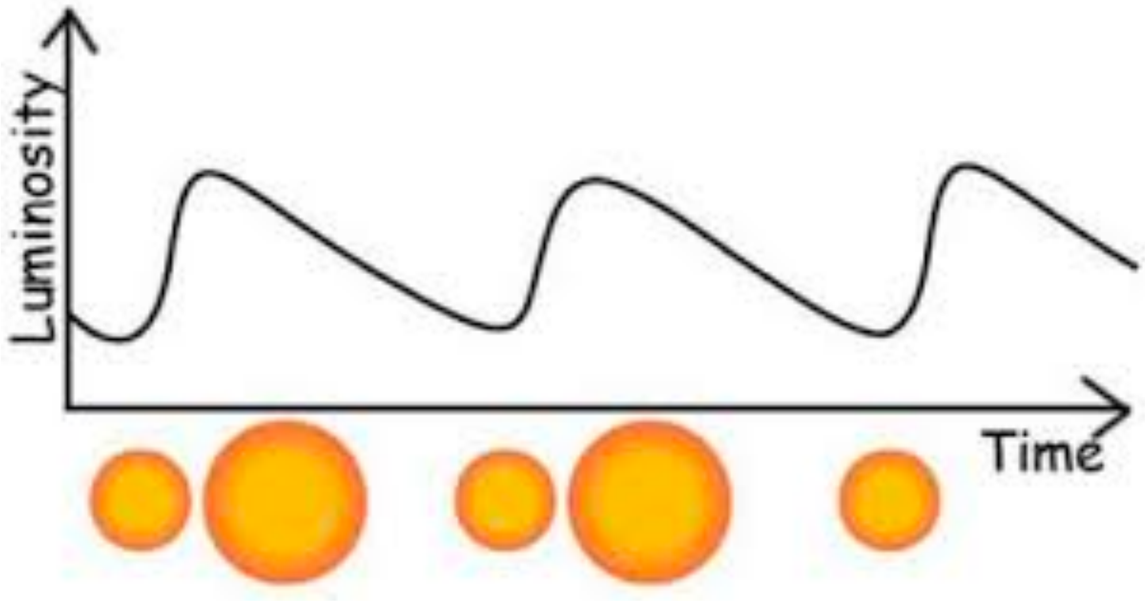


Cepheid Variables





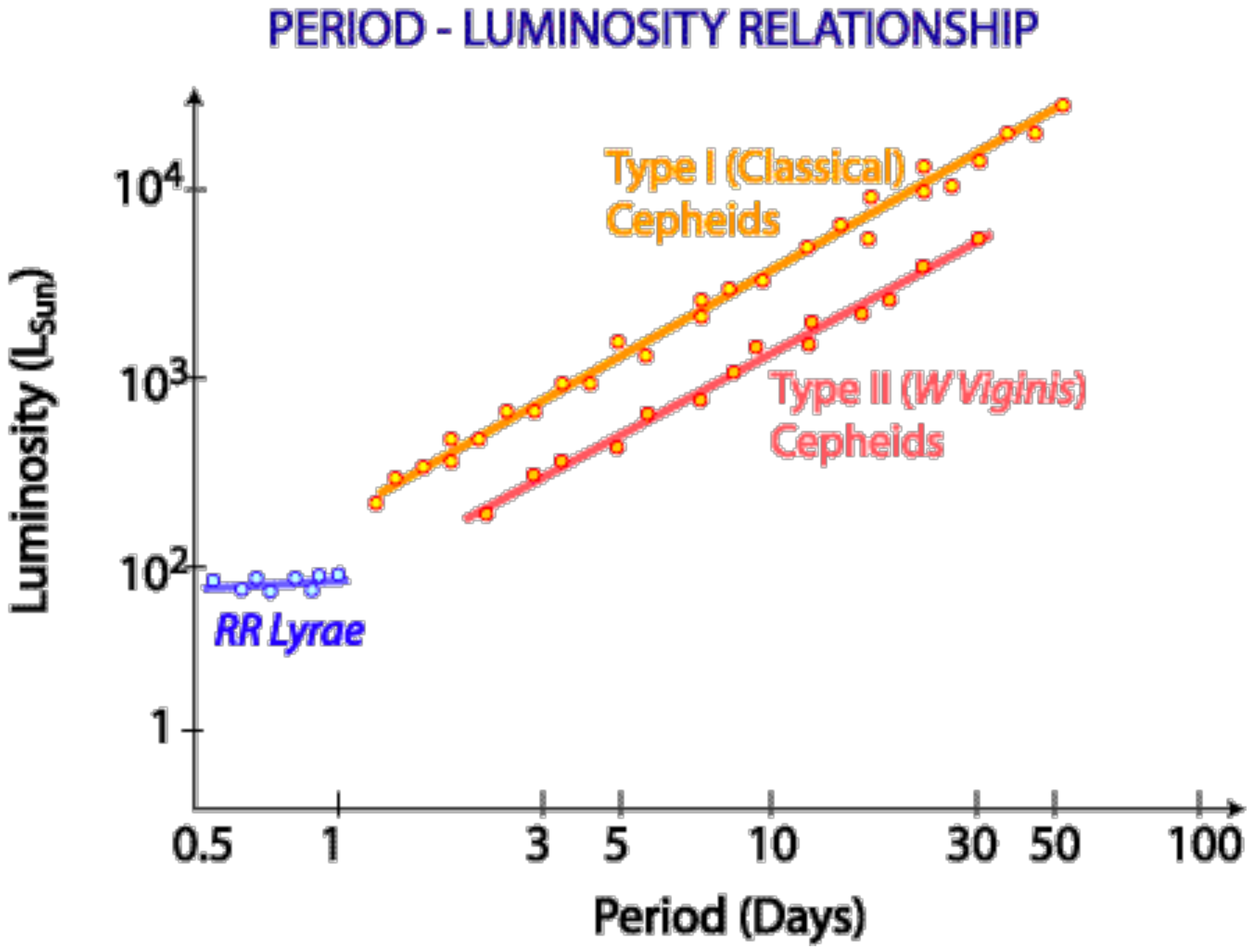
A Cepheid's luminosity can be inferred



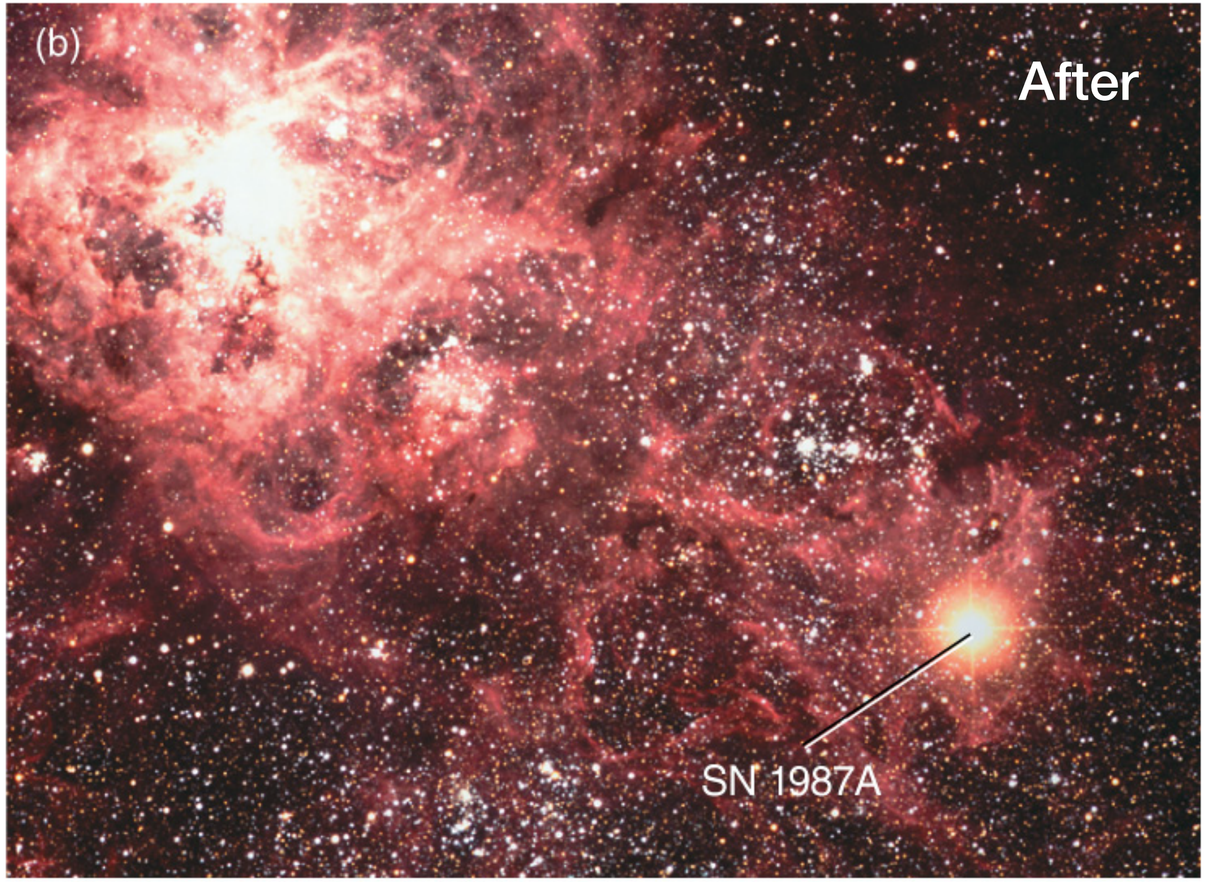
Empirically discovered by Henrietta Leavitt in 1912

$$\overline{M}_V = -2.76 \log(P/10 \text{ days}) - 4.16$$

$$\log(d/10 \text{ pc}) = 0.2(\overline{m}_V - \overline{M}_V)$$



Type II Supernovae



Betelgeuse: Future Supernova

… were a supernova to go off within about 30 light-years of us, that would lead to major effects on the Earth, possibly mass extinctions. X-rays and more energetic gamma-rays from the supernova could destroy the ozone layer that protects us from solar ultraviolet rays. It also could ionize nitrogen and oxygen in the atmosphere, leading to the formation of large amounts of smog-like nitrous oxide in the atmosphere.

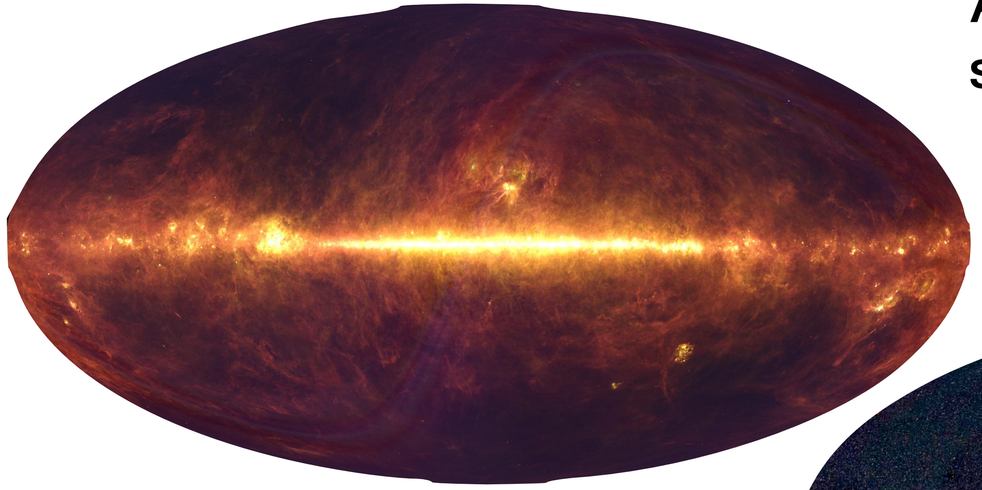
- Mark Reid, Harvard-Smithsonian CfA

430 light-years away (safe distance, unless it explodes as a gamma ray burst pointed at us)

May appear as bright as the full moon, visible during the day!

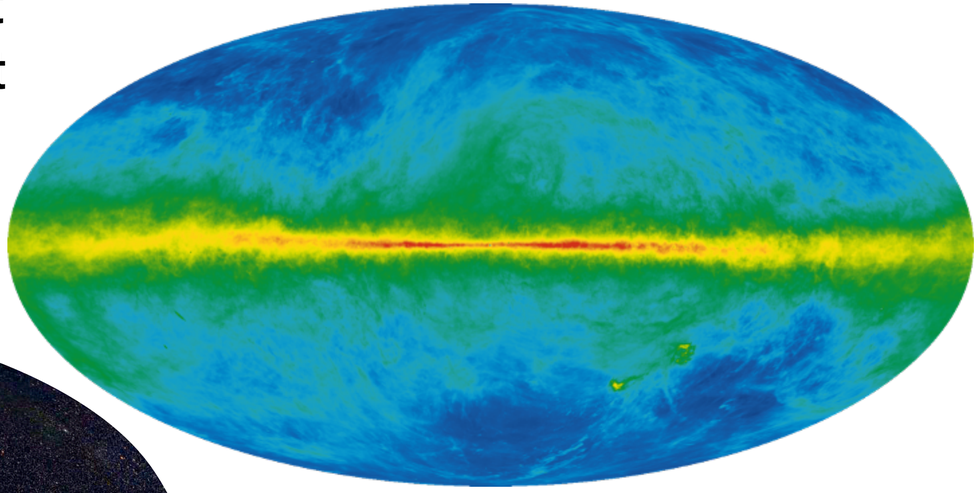
Interstellar Medium (ISM)

Hot Dust (far IR)

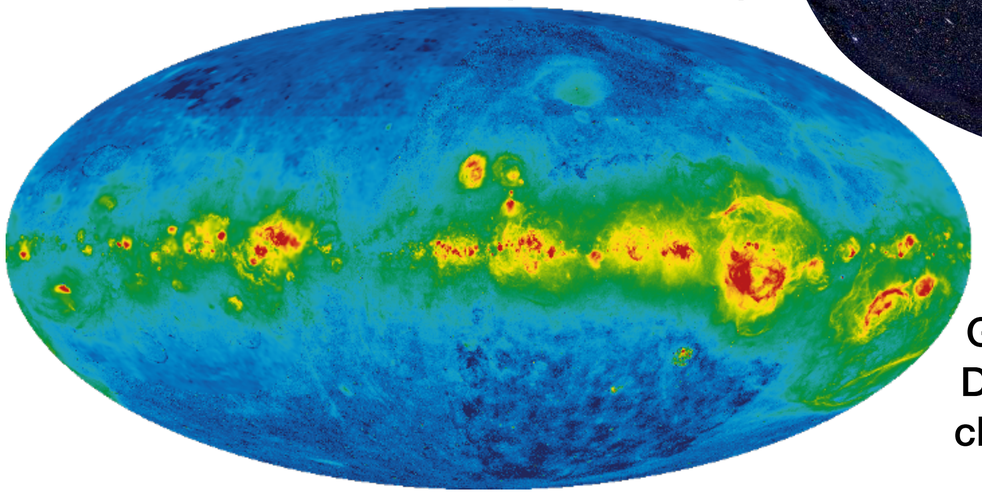


All the diffuse stuff in b/t stars and other compact objects in the MW

Neutral H (21cm; radio)

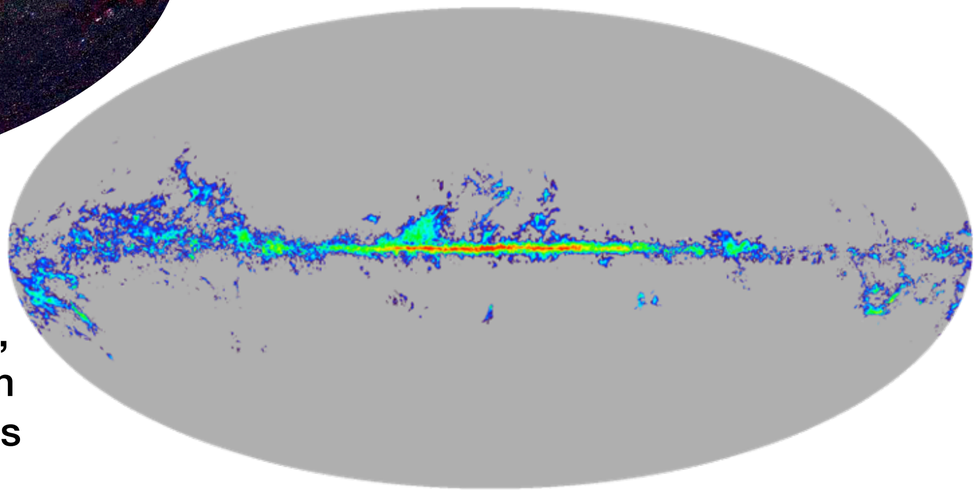


Balmer line n=3->2 (656.3 nm)



Stars (visible)

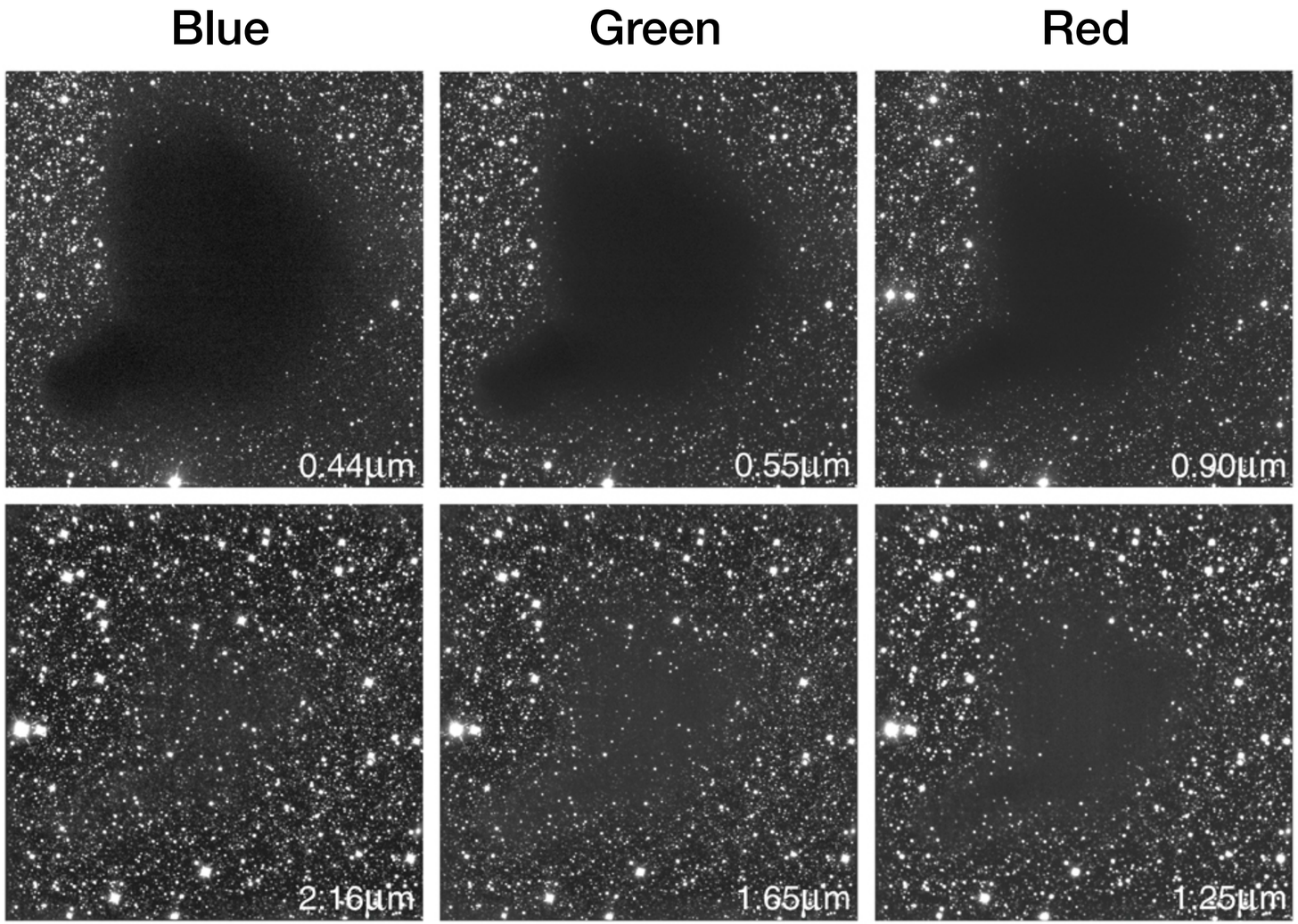
CO (2.6 mm; microwave)



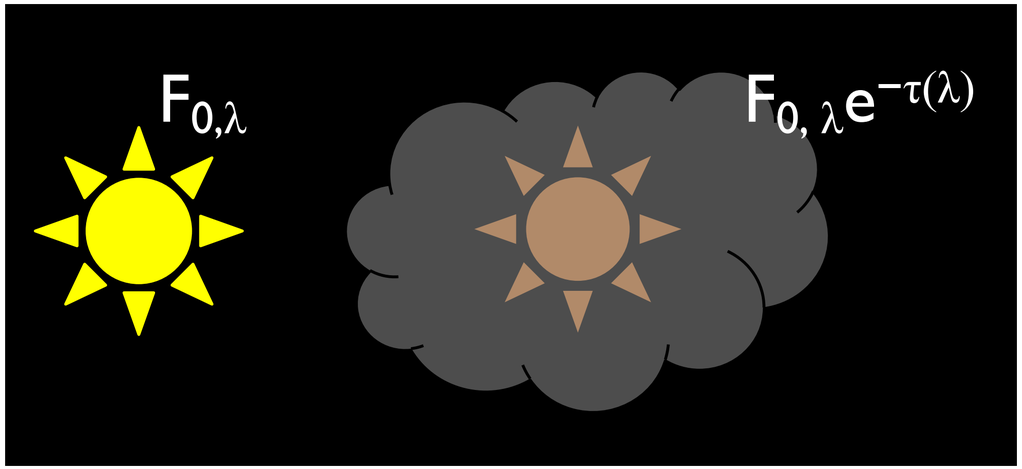
Gas (ionized, neutral, molecules), Dust (large molecules, singly or in clumps), & relativistic components (magnetic fields, cosmic rays)

Dust blocks starlight: Extinction

Barnard 68



Extinction messes up magnitudes AND colors



$$F_\lambda = F_{0,\lambda} e^{-\tau} = F_{0,\lambda} e^{-n\sigma r}$$

$$\begin{aligned} m_{\rm obs} &= C - 2.5\log(F) \\ &= C - 2.5\log(F_0) - 2.5\log(e^{-\tau}) \\ &= m_0 + 2.5\tau\log e \\ &= m_0 + 1.086\tau \end{aligned}$$

Correcting Magnitudes

$$m_{\rm obs}(\lambda) = m_0(\lambda) + A(\lambda)$$

$$\begin{aligned} \text{e.g., } m_{V,\rm obs} &= m_V + A_V \\ &= V_0 + A_V \end{aligned}$$

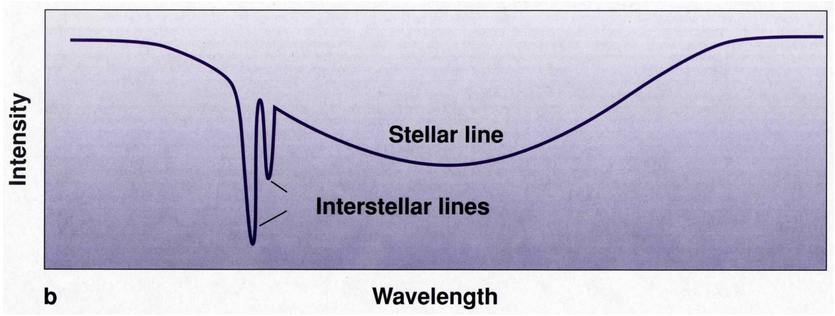
Correcting Colors

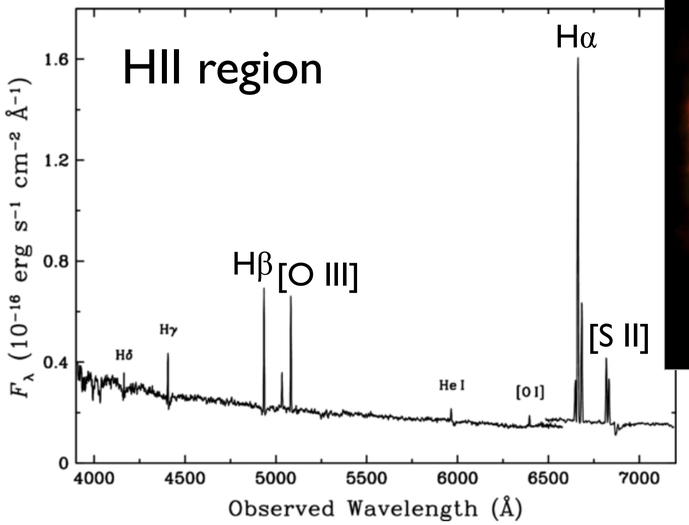
$$\begin{aligned} (B-V)_{\rm obs} &= (B-V)_0 + (A_B + A_V) \\ &= (B-V)_0 + E(B-V) \end{aligned}$$

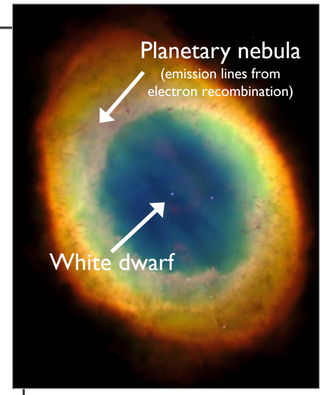
$$R \equiv \frac{A_V}{E(B-V)} \approx 3.1$$

Detection of gas is generally more direct

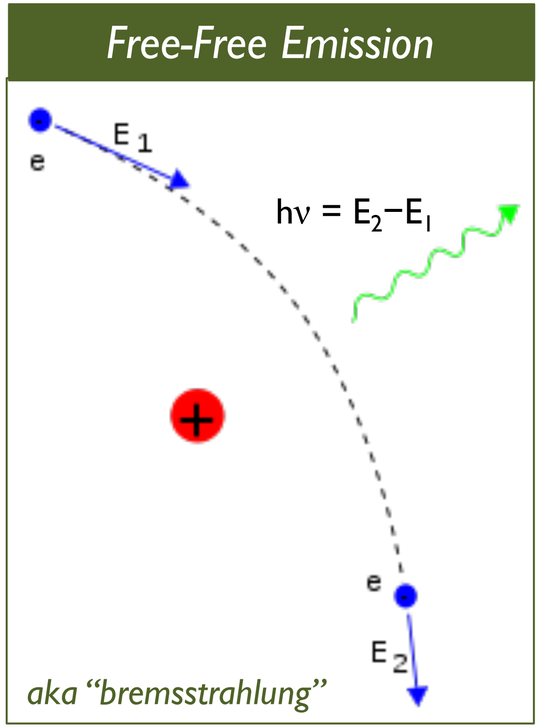
Absorption & Emission Lines (Kirchoff's laws)



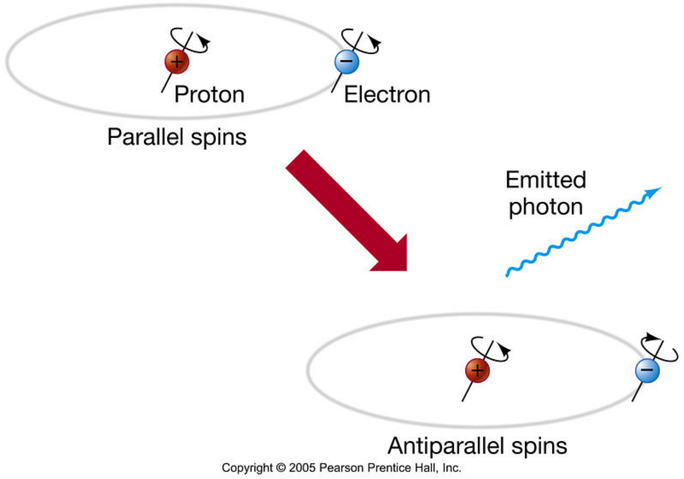




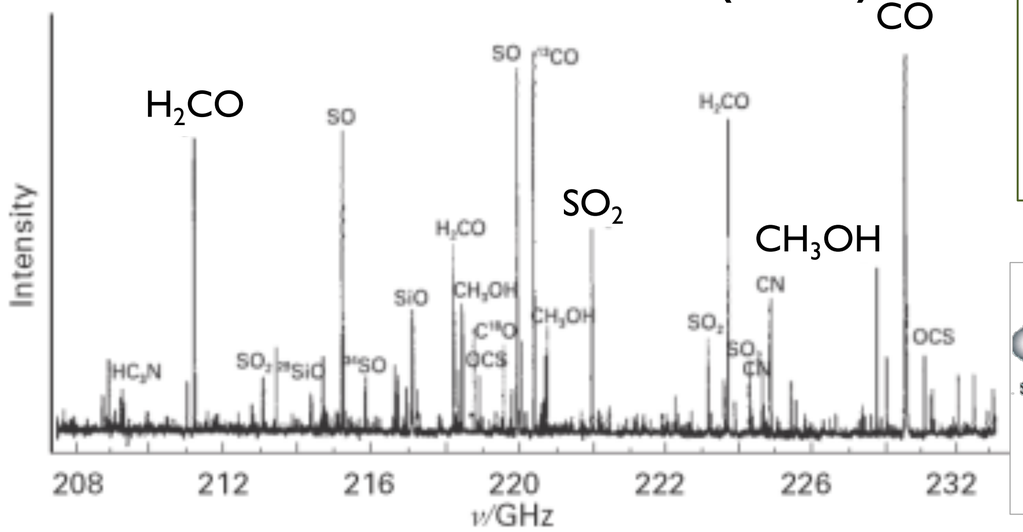
Radio continuum

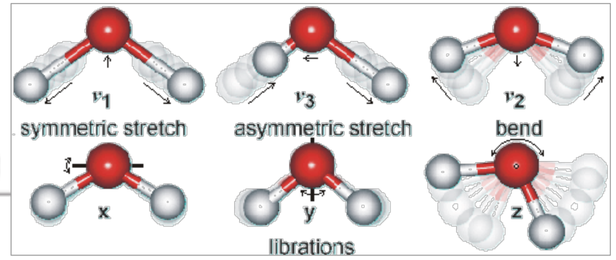


Neutral H "spin-flip": 21cm emission line



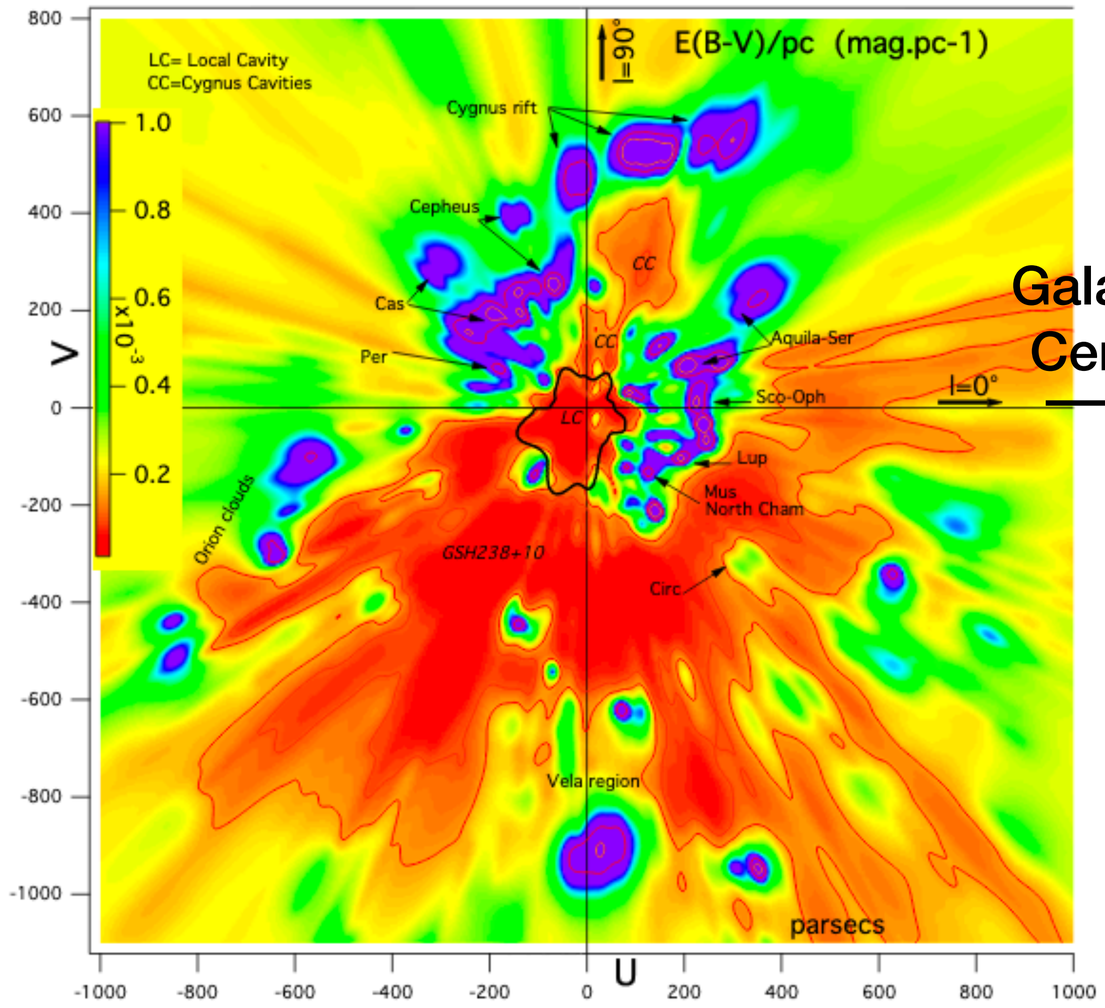
Molecule excitations (radio)





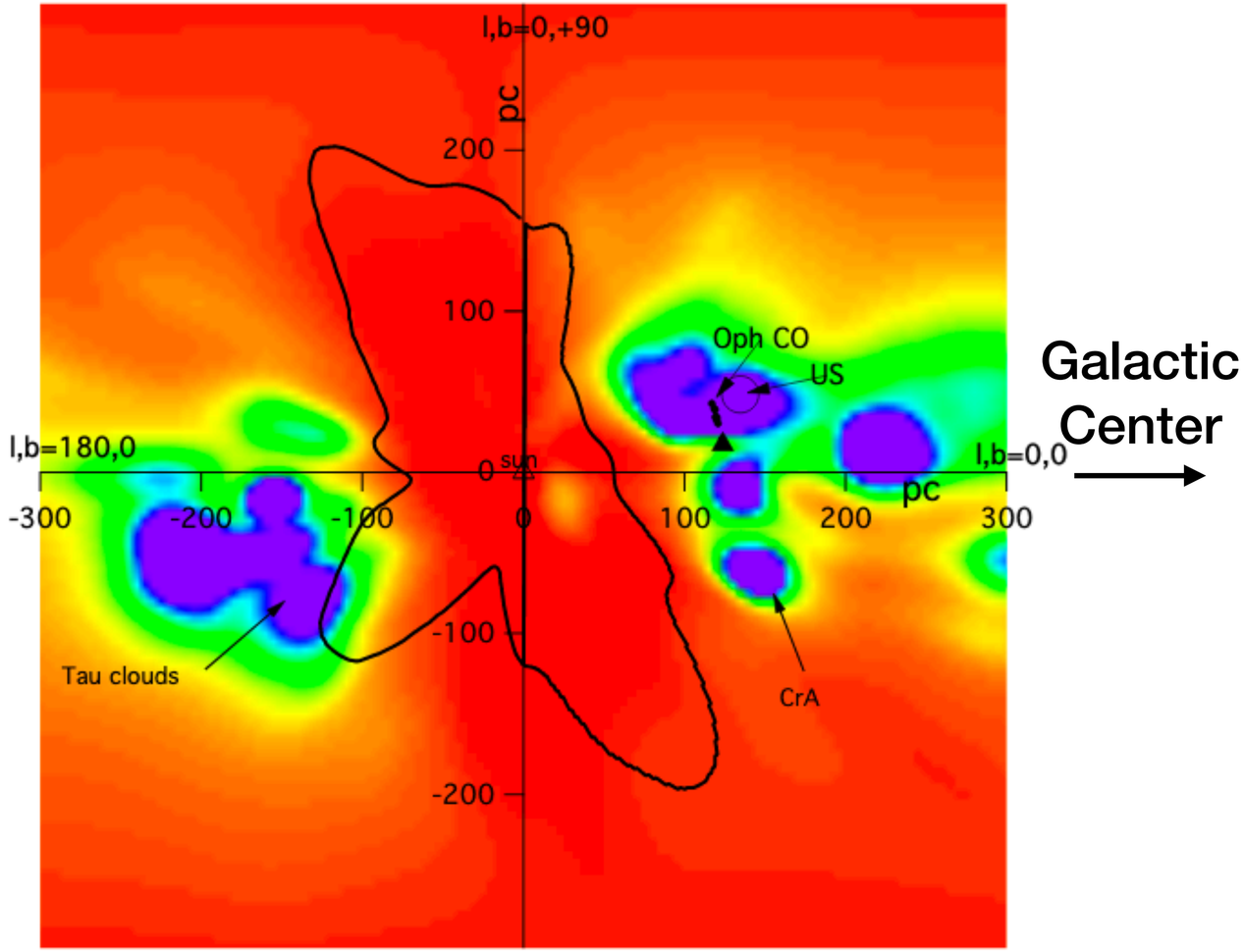
ISM also contains very hot gas heated by SNe

Face-on disk view



Galactic Center

Edge-on disk view



Galactic Center

All these gas “phases” are in pressure equilibrium

Cold Molecular Clouds:
$T \sim 10$ K, $n \sim 10^9$ m^{-3}
Cold Neutral Medium:
$T \sim 100$ K, $n \sim 10^8$ m^{-3}
Warm Neutral Medium:
$T \sim 7000$ K, $n \sim 10^5$ m^{-3}
Warm Ionized Medium:
$T \sim 10{,}000$ K, $n \sim 10^6$ m^{-3}
Hot Ionized Medium:
$T \sim 1{,}000{,}000$ K, $n \sim 10^4$ m^{-3}

$P \sim nkT \sim$ const.