the Stars

I. Position and Motion
Parallax, Proper Motion, Redshift

II. Size
Dwarfs, Giants, Stefan-Boltzman

III. Brightness
Magnitude, flux, distance

IV. Color & Temperature
B-*V* index, Spectral Type

V. H-R diagrams
Luminosity Classes

	The student will be able to:	HW:
1	Define and apply stellar parallax and the unit of the parsec.	1 – 3
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15	Explain and illustrate how the H-R diagram is used to help classify and understand different types of stars such as main sequence stars, red giants, blue giants, supergiants, red dwarfs, and white dwarfs.	
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17	Describe and apply the method of spectroscopic parallax and explain the importance of luminosity class to this method.	
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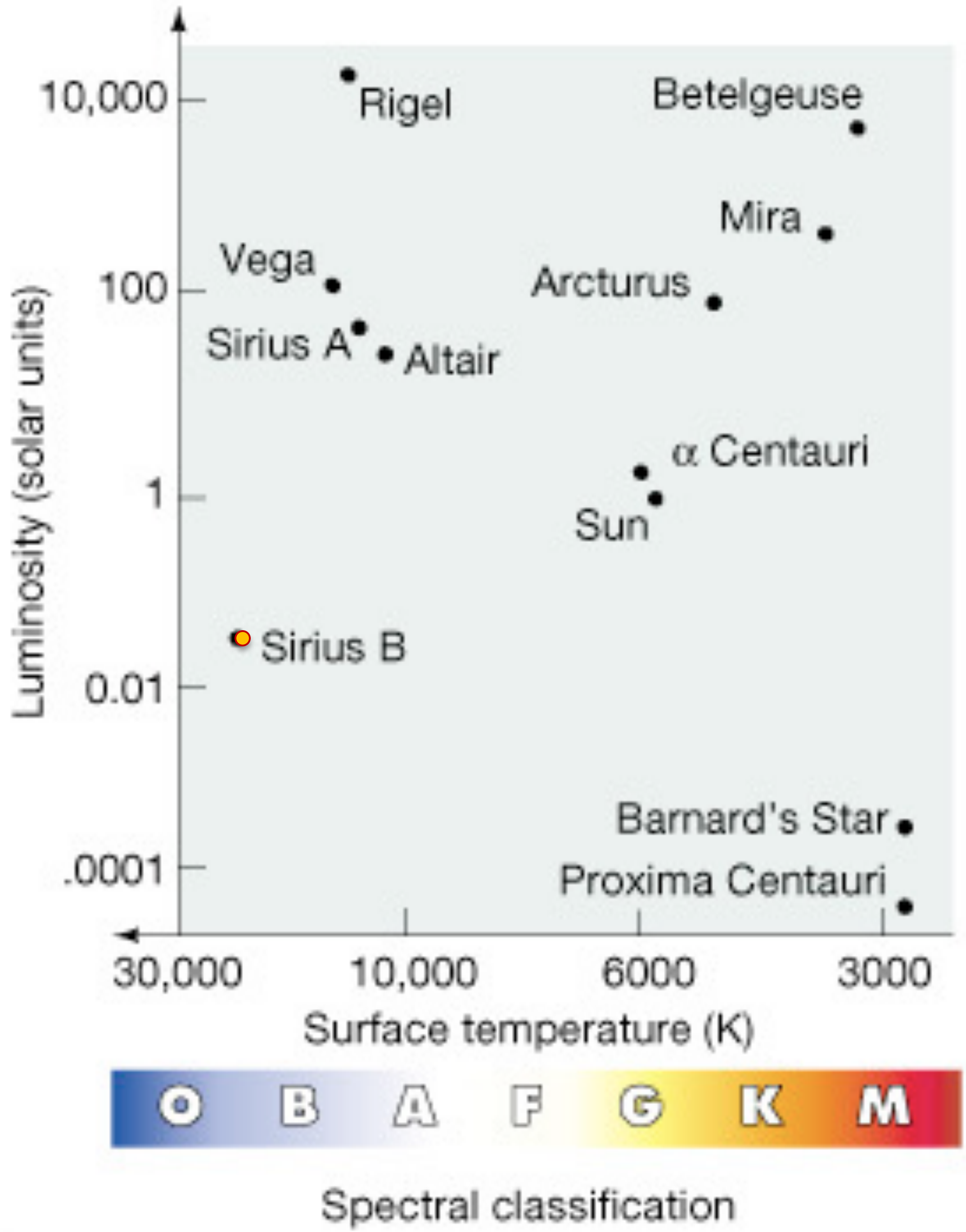
20	Describe properties and significance of open clusters and globular clusters.	

Hertzsprung-Russell Diagram

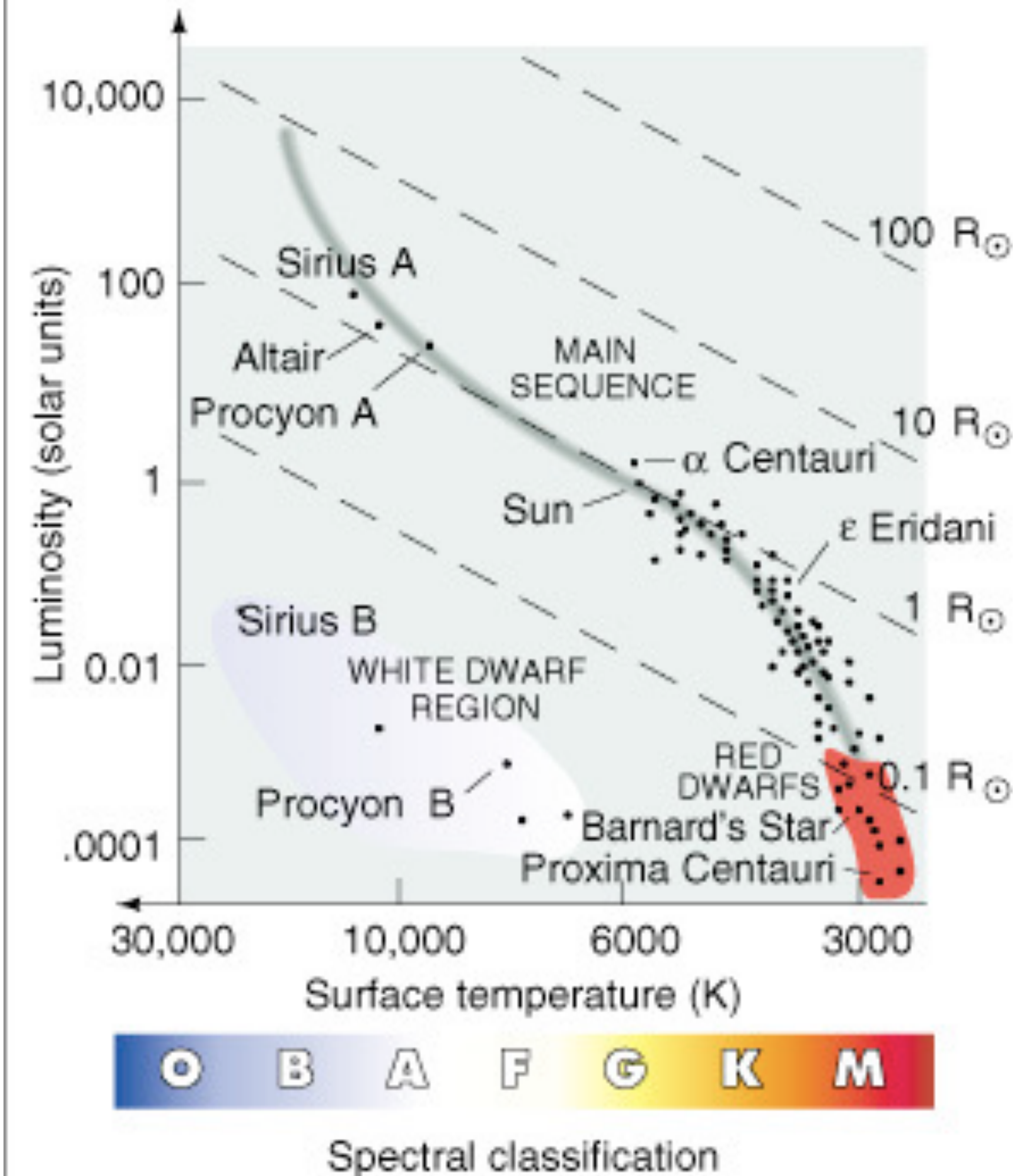
Putting It All Together

H-R Diagrams

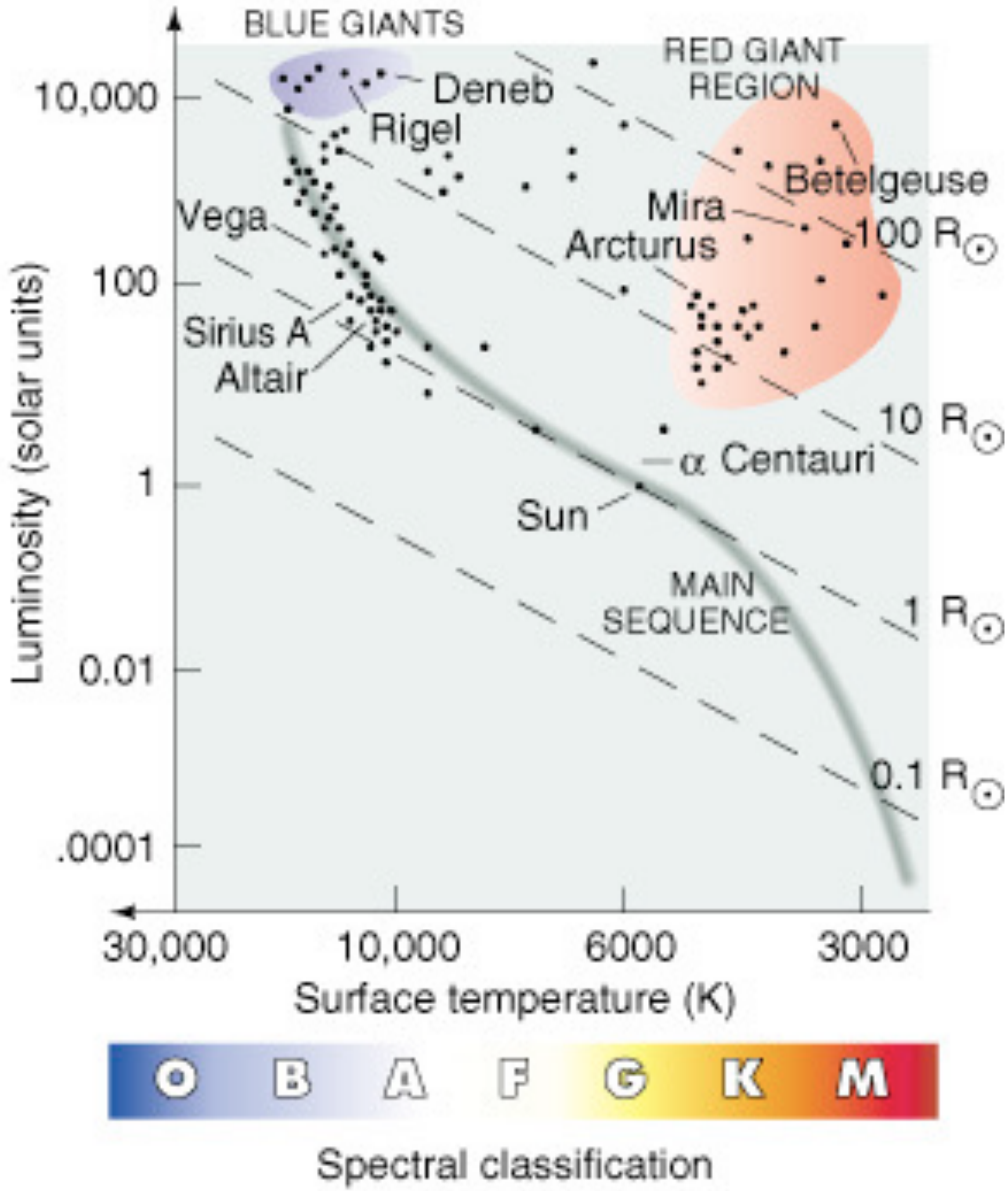
- Stars are found to come in a wide variety of sizes, temperatures, luminosities, etc.
- A Hertzsprung-Russell Diagram is a graph that plots some measure of brightness versus some measure of temperature.
- This type of diagram has helped astronomers to understand stars by revealing various patterns.

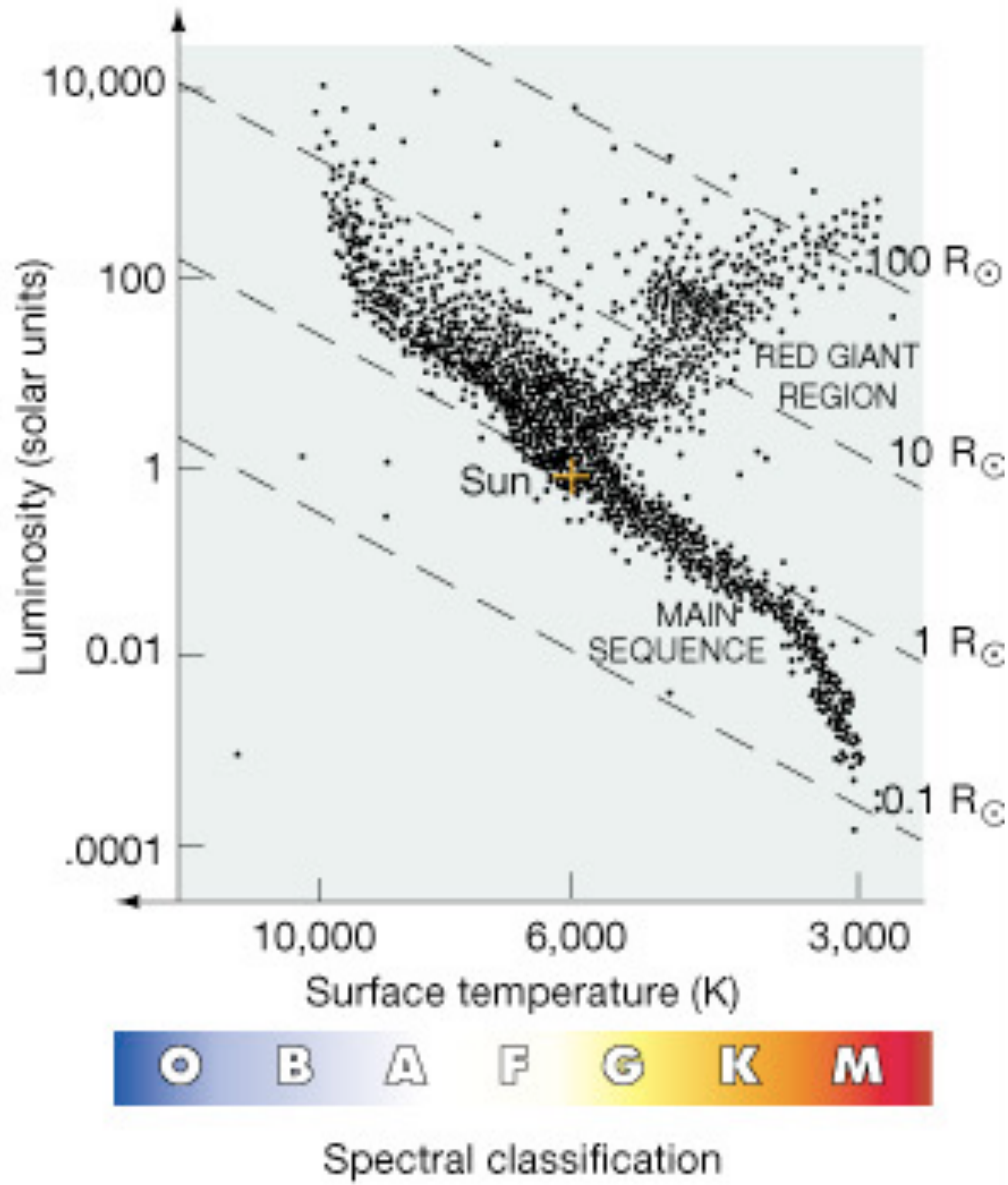


Luminosity (solar units)
10,000
100
1
0.01
.0001
Rigel
Betelgeuse
Mira
Vega
Arcturus
Sirius A
Altair
α Centauri
Sun
Sirius B
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification



10,000
100
1
0.01
.0001
Luminosity (solar units)
100 R☉
10 R☉
1 R☉
0.1 R☉
Sirius A
Altair
Procyon A
MAIN SEQUENCE
α Centauri
Sun
ε Eridani
Sirius B
WHITE DWARF REGION
Procyon B
RED DWARFS
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification


BLUE GIANTS
RED GIANT REGION
Deneb
Rigel
Betelgeuse
Mira
Vega
Arcturus
100 $R_\odot$
Sirius A
Altair
10 $R_\odot$
α Centauri
Sun
MAIN SEQUENCE
1 $R_\odot$
0.1 $R_\odot$
Luminosity (solar units)
10,000
100
1
0.01
.0001
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification


10,000
100
1
0.01
.0001
Luminosity (solar units)
100 R☉
10 R☉
1 R☉
0.1 R☉
RED GIANT
REGION
Sun
MAIN
SEQUENCE
10,000
6,000
3,000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

Conclusions About Stars

- The majority of stars are found to reside on the main sequence (about 90%).
- Stars on the main sequence are powered by fusion of hydrogen, similar to the Sun.
- Of the stars on the main sequence, the vast majority are type M red dwarfs (about 80% of all stars in universe).
- At the other extreme, types O and B are very rare – about 1 in 10000.

Main Sequence Stars

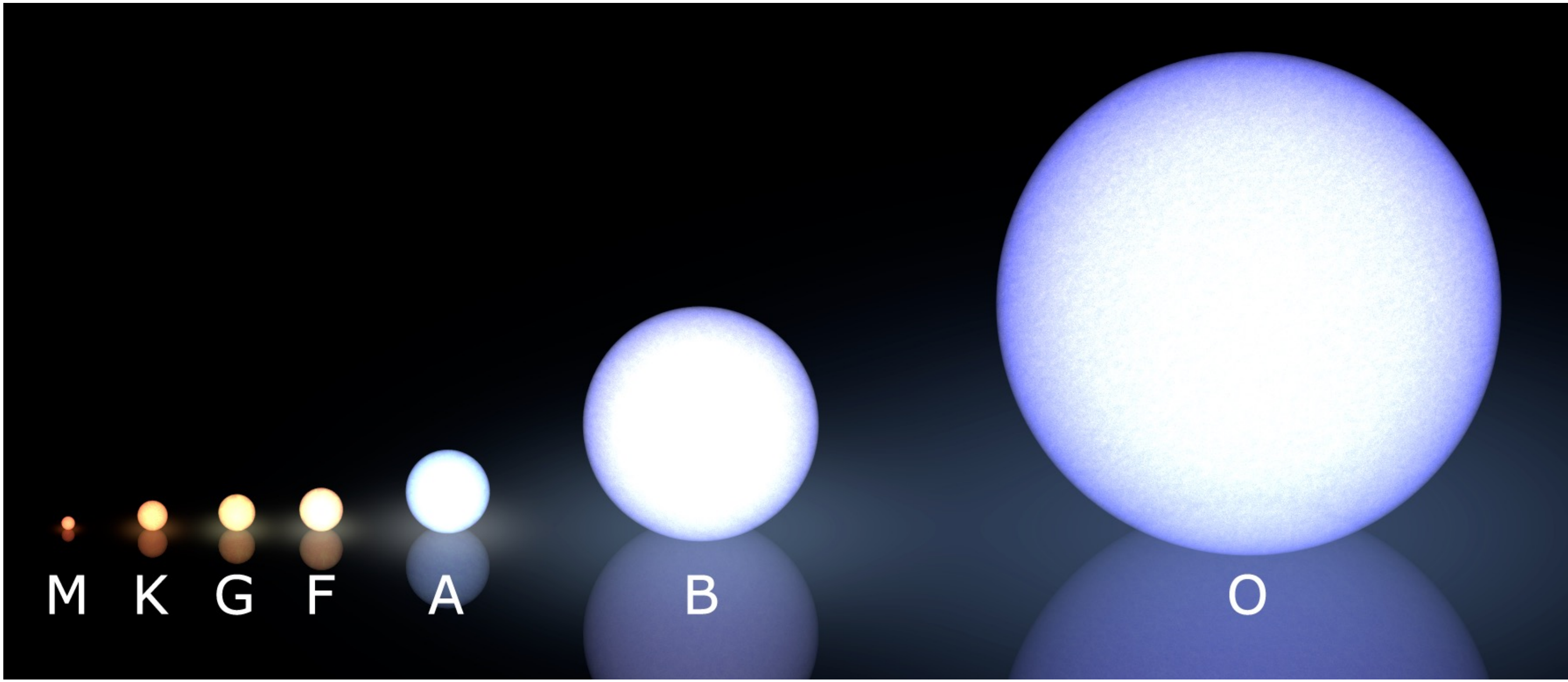


image credit: Wikimedia Commons

Conclusions About Stars

- The bulk of a star's lifetime is spent on the main sequence.
- Stars that are not on the main sequence are in a process of change, either "being born" or "getting old and dying".
- Stars in the red giant region are "running out of fuel" and have different fusion reactions occurring.
- Stars in the white dwarf region are the remains of a star that is "out of fuel".

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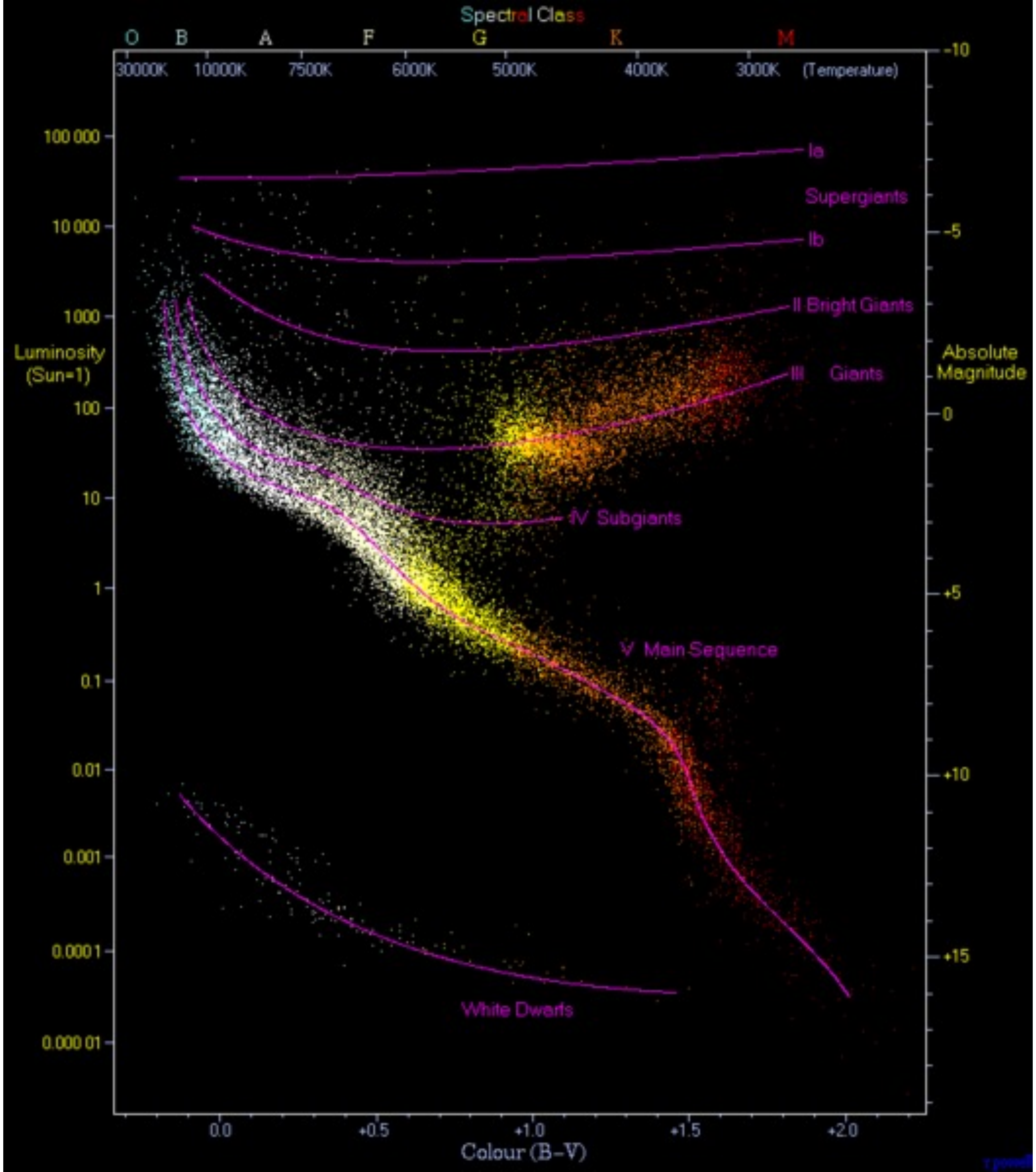
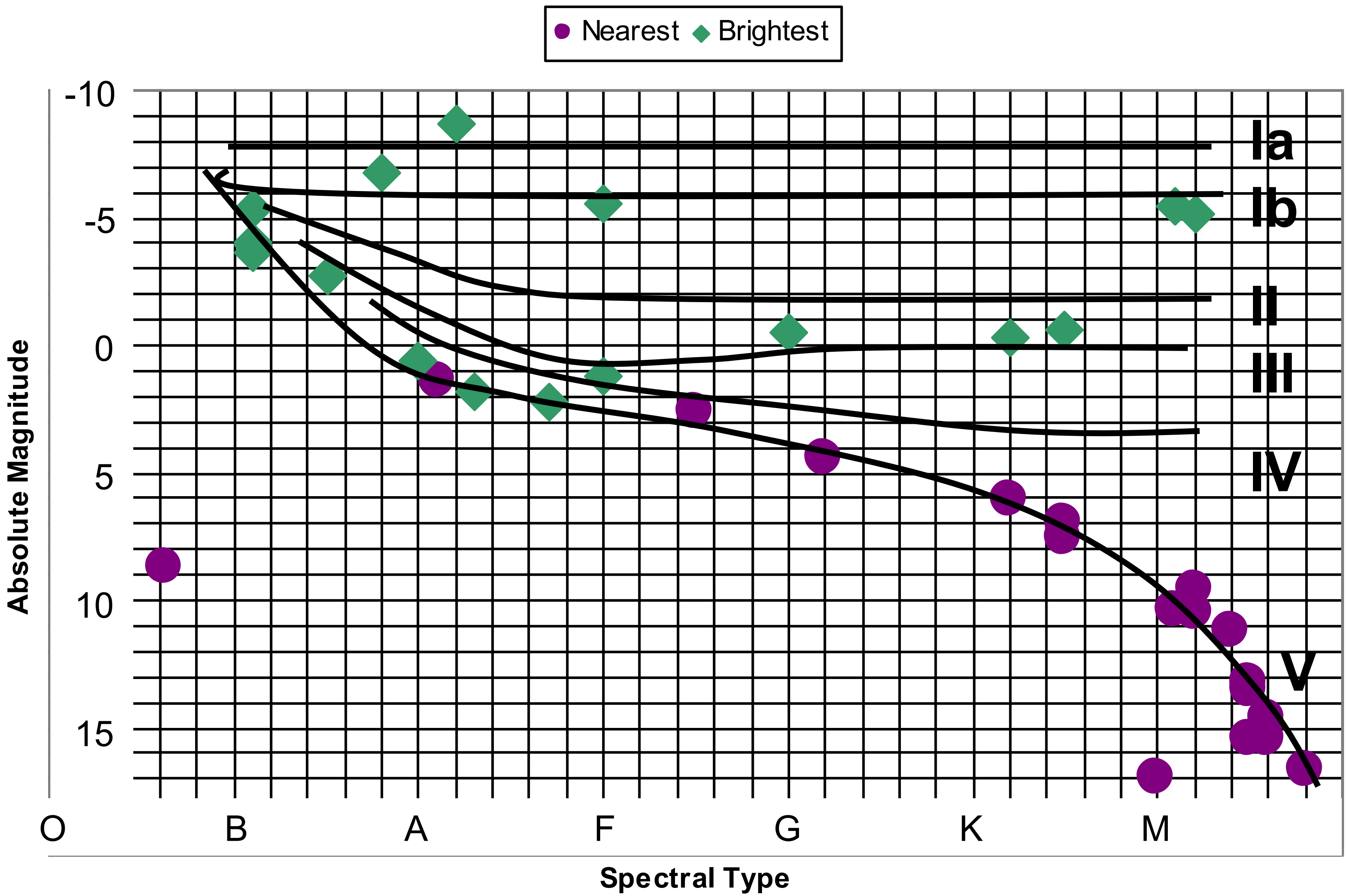
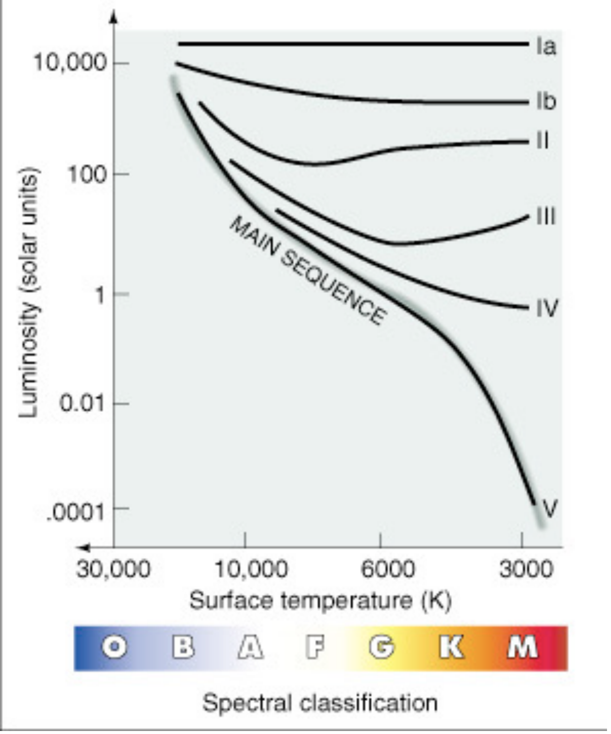

Spectral Class
O
B
A
F
G
K
M
30000K
10000K
7500K
6000K
5000K
4000K
3000K
(Temperature)
Luminosity (Sun=1)
100 000
10 000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.000 01
Absolute Magnitude
-10
-5
0
+5
+10
+15
Ia
Supergiants
Ib
II Bright Giants
III Giants
IV Subgiants
V Main Sequence
White Dwarfs
0.0
+0.5
+1.0
+1.5
+2.0
Colour (B-V)

Luminosity Class





Stellar Luminosity Classes	
Ia	Bright Supergiants
Ib	Supergiants
II	Bright Giants
III	Giants
IV	Subgiants
V	Main-Sequence / dwarfs

Luminosity Classes are determined by the width of the star's spectral lines. The wider the line the less luminous is the star. The luminosity classes are in order of line width.

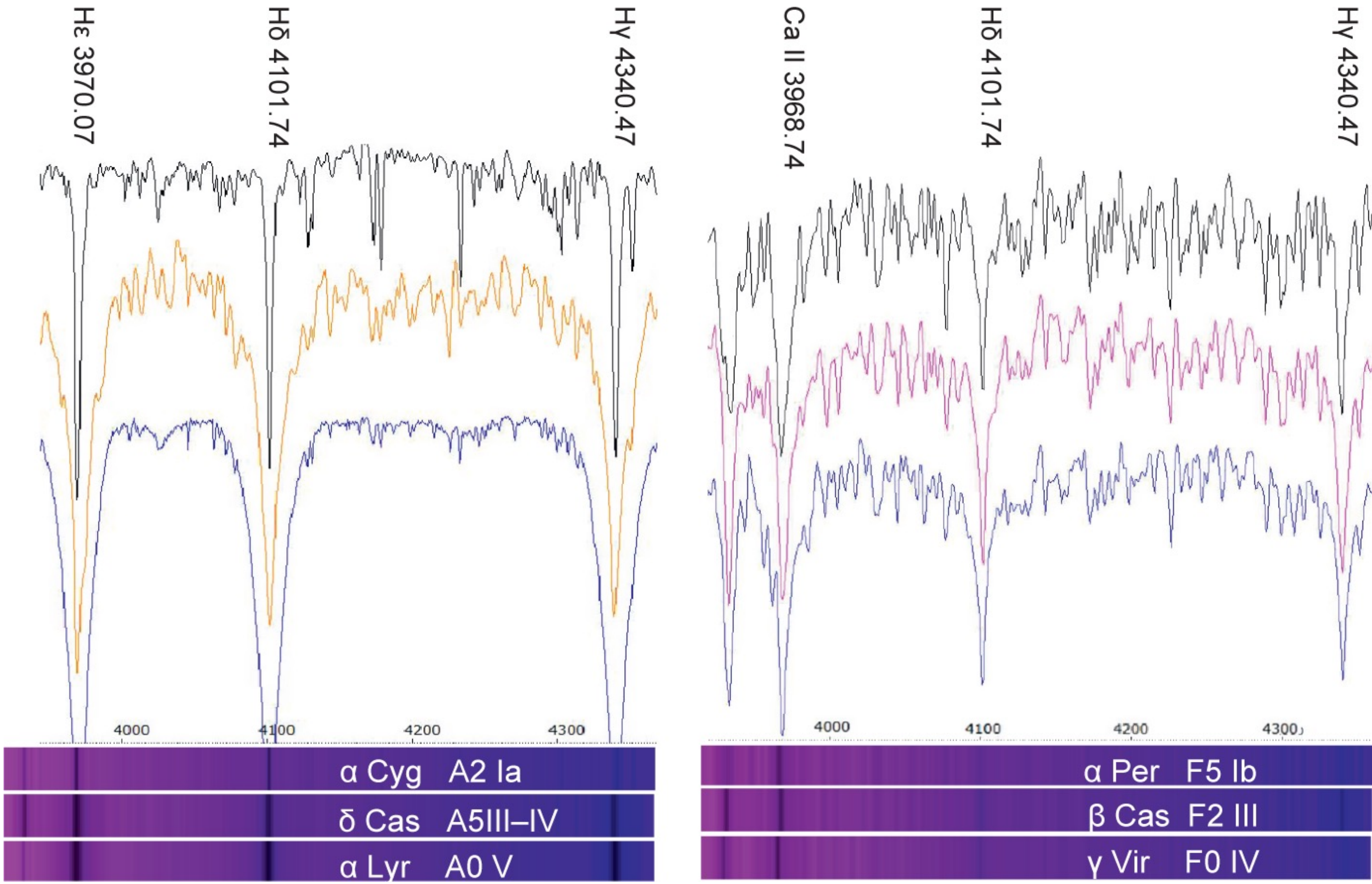
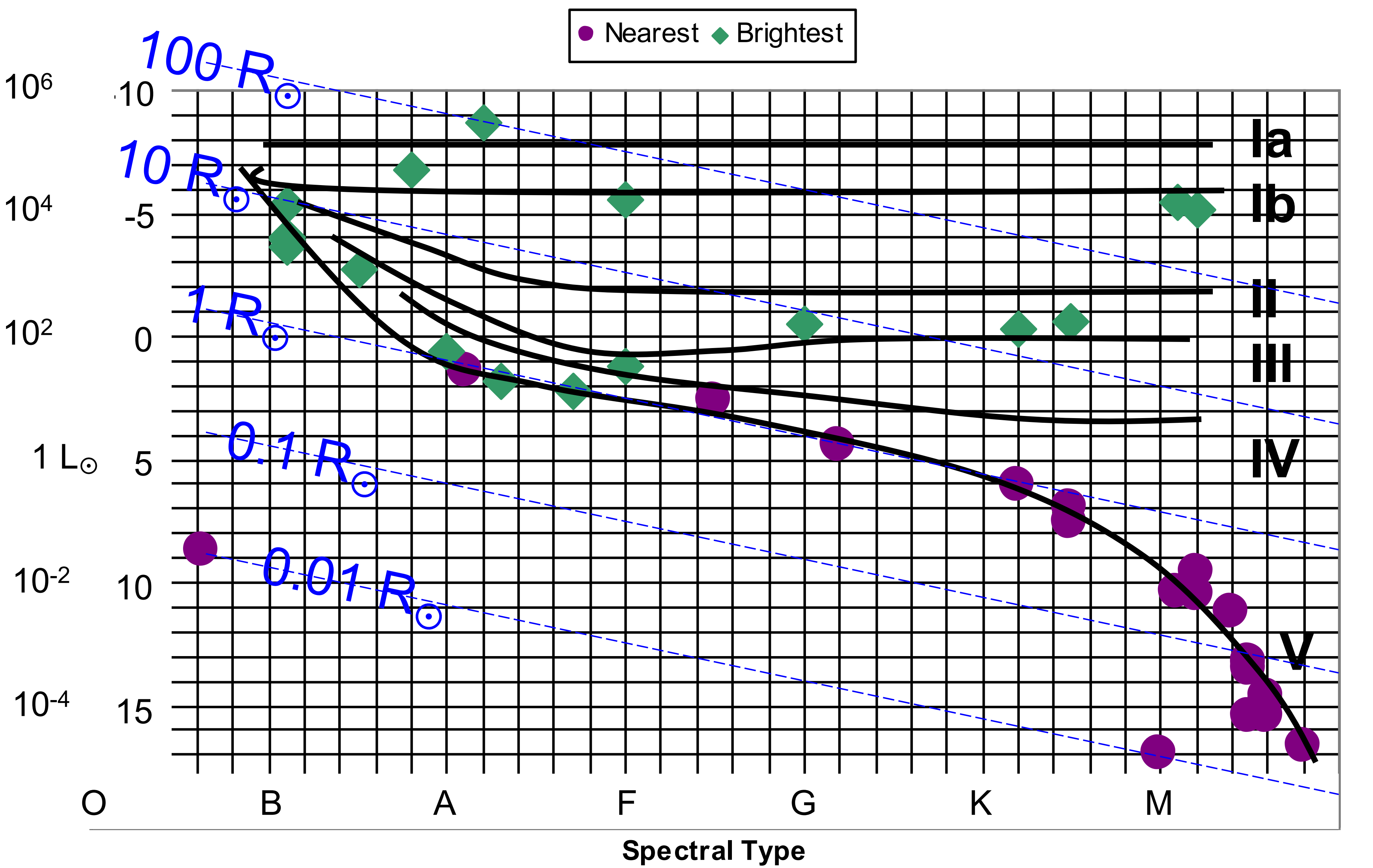


image credit: cambridge.org



Nearest
Brightest
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
10^6
10^4
10^2
1 L⊙
10^-2
10^-4
-10
-5
0
5
10
15
Ia
Ib
II
III
IV
V
O
B
A
F
G
K
M
Spectral Type

Variation in Luminosity Class

Temperature (K)	Luminosity ($L_\odot$)	Radius ($R_\odot$)	Type & Class	Example
5000	0.3	0.8	K2 V	ε Eridani
5000	120	23	K2 III	Arcturus
5000	5000	150	K2 Ib	ε Pegasi

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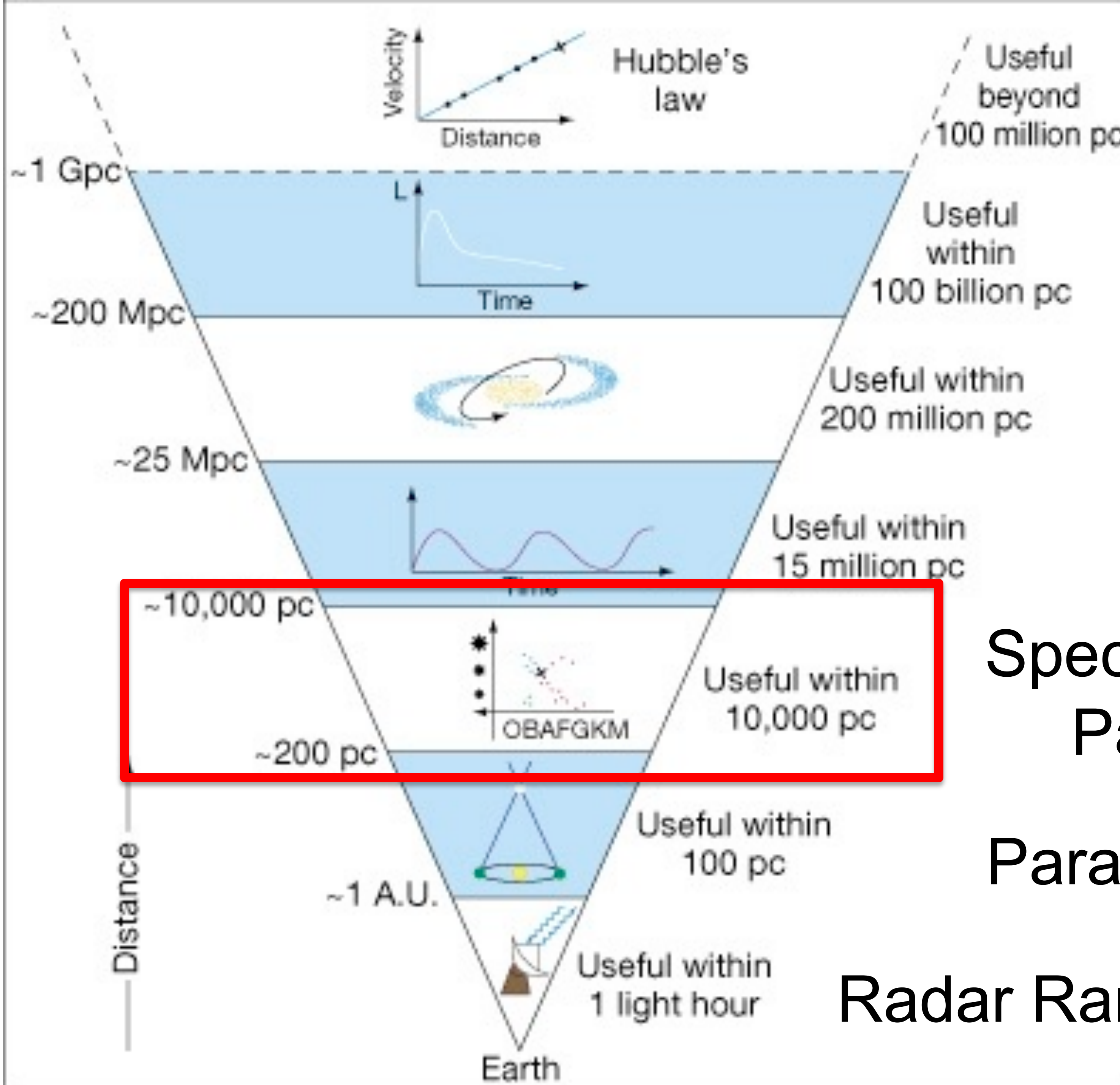


Spectroscopic Parallax

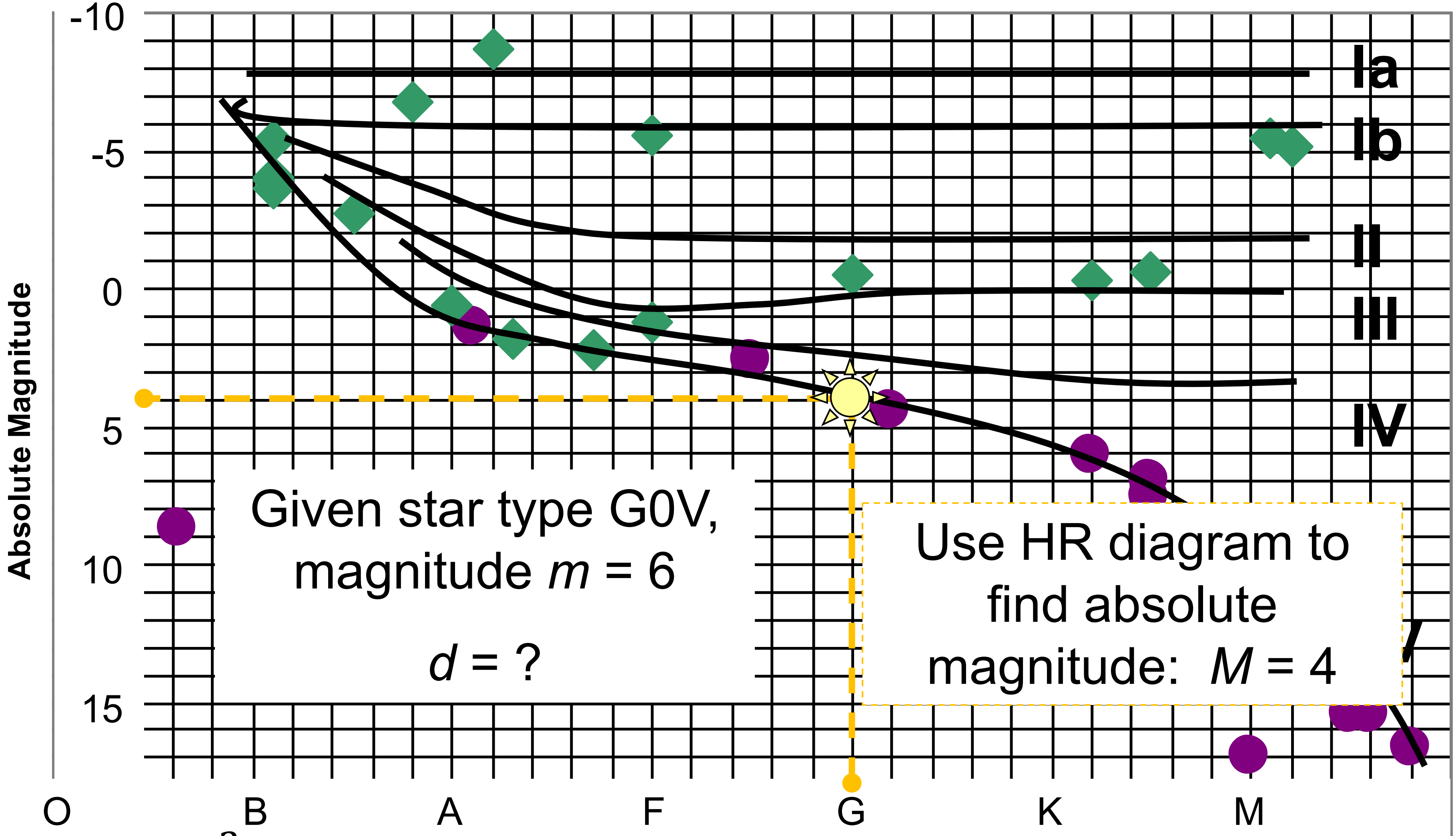
Parallax

Radar Ranging

Spectroscopic Parallax

- The HR diagram, combined with spectroscopy allows astronomers to find the distance to stars that have no measurable parallax.
- This method is called spectroscopic parallax.
- A star's spectral type and luminosity class can be used to determine its absolute magnitude.
- Then the absolute magnitude and apparent magnitude are used to find the distance.
- This method is useful out to distances of around 10000 pc.

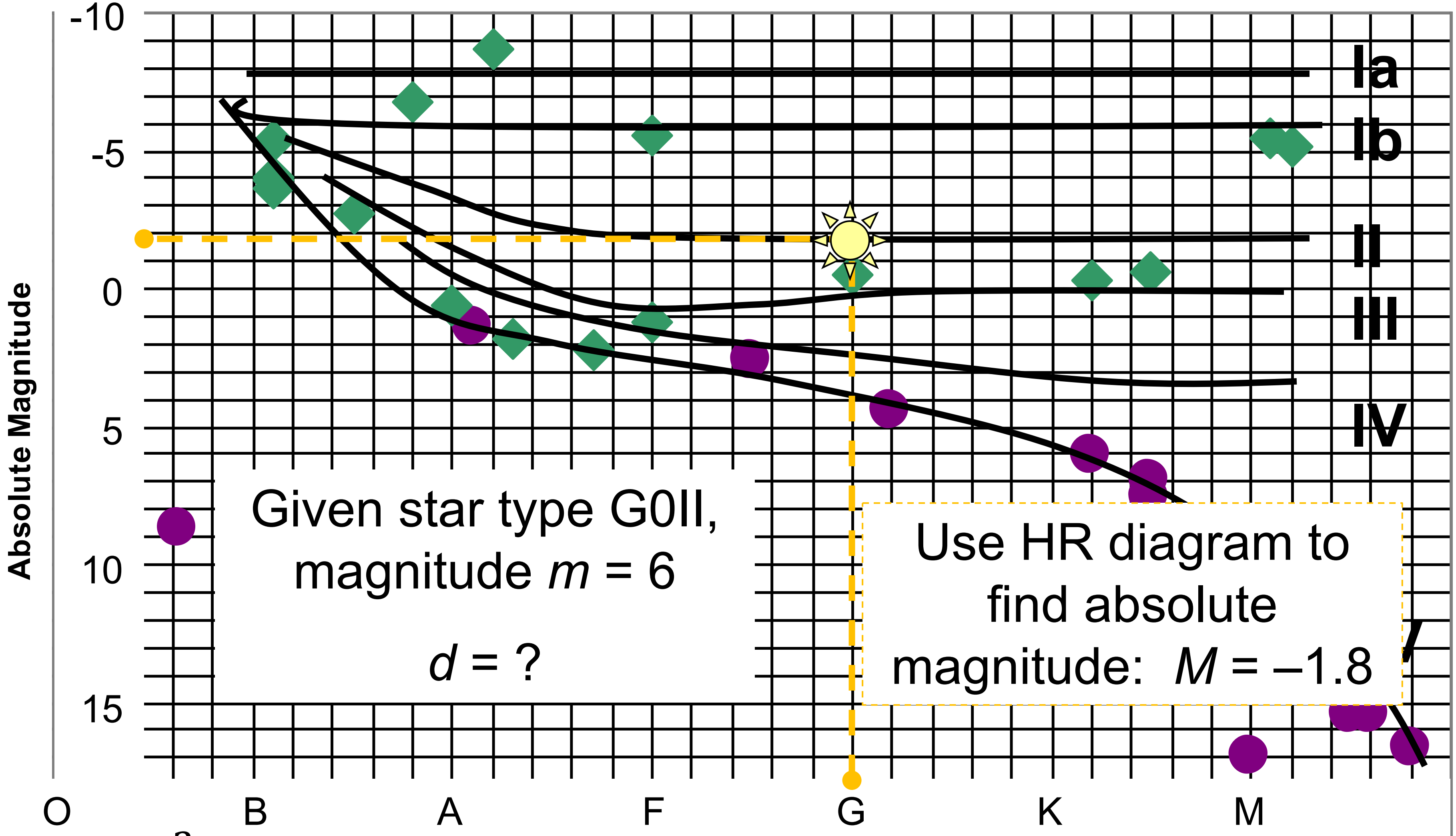
Spectroscopic Parallax Examples



$$\left(\frac{d}{10}\right)^2 = 2.512^{(6-4)}$$

Solve for distance *d* = 25 pc

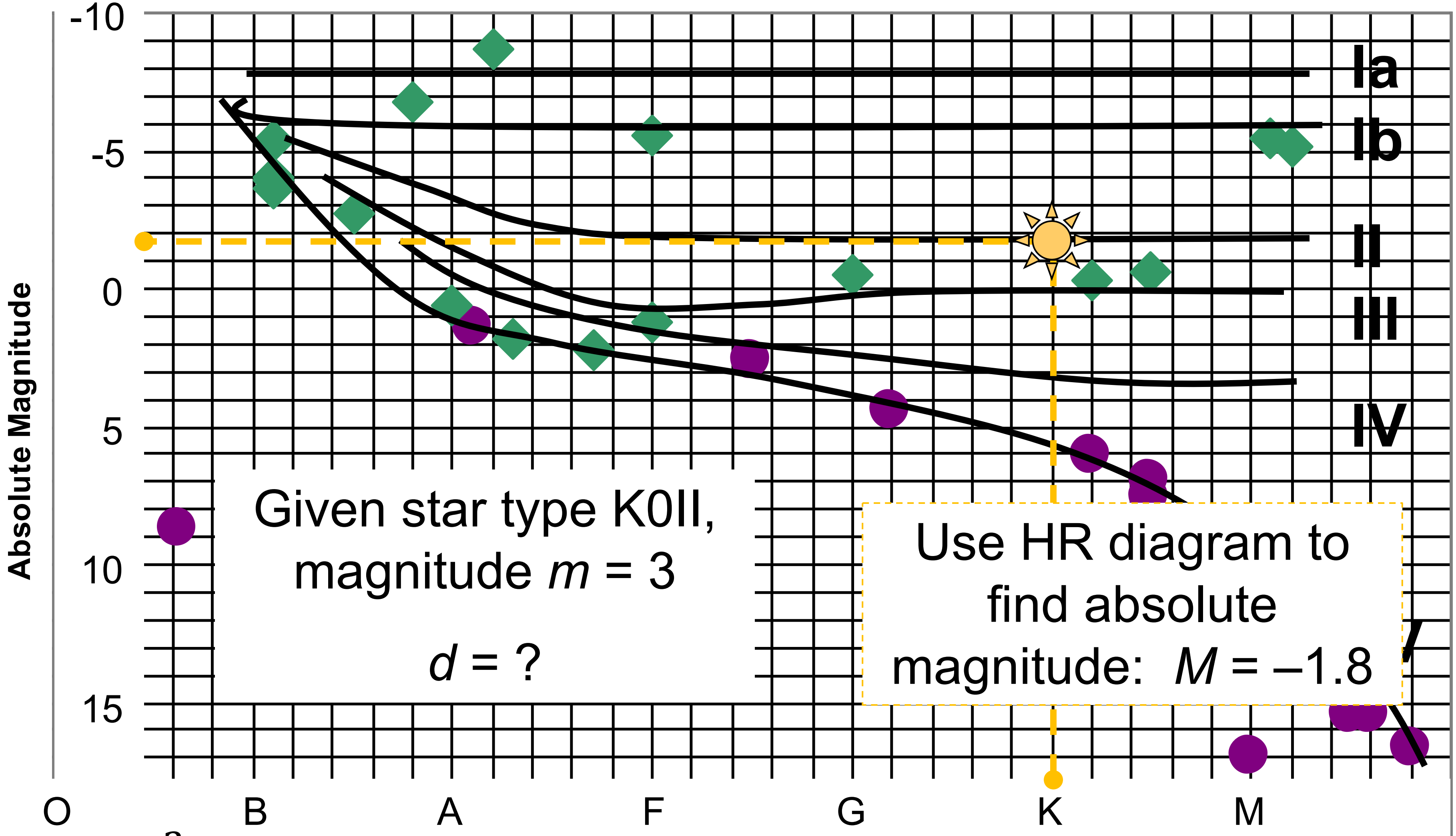
Spectroscopic Parallax Examples



$$\left(\frac{d}{10}\right)^2 = 2.512^{(6-(-1.8))}$$

Solve for distance *d* = 360 pc

Spectroscopic Parallax Examples



Given star type K0II, magnitude m = 3

d = ?

Use HR diagram to find absolute magnitude: M = –1.8

$$\left(\frac{d}{10}\right)^2 = 2.512^{(3-(-1.8))}$$

Solve for distance d = 91 pc

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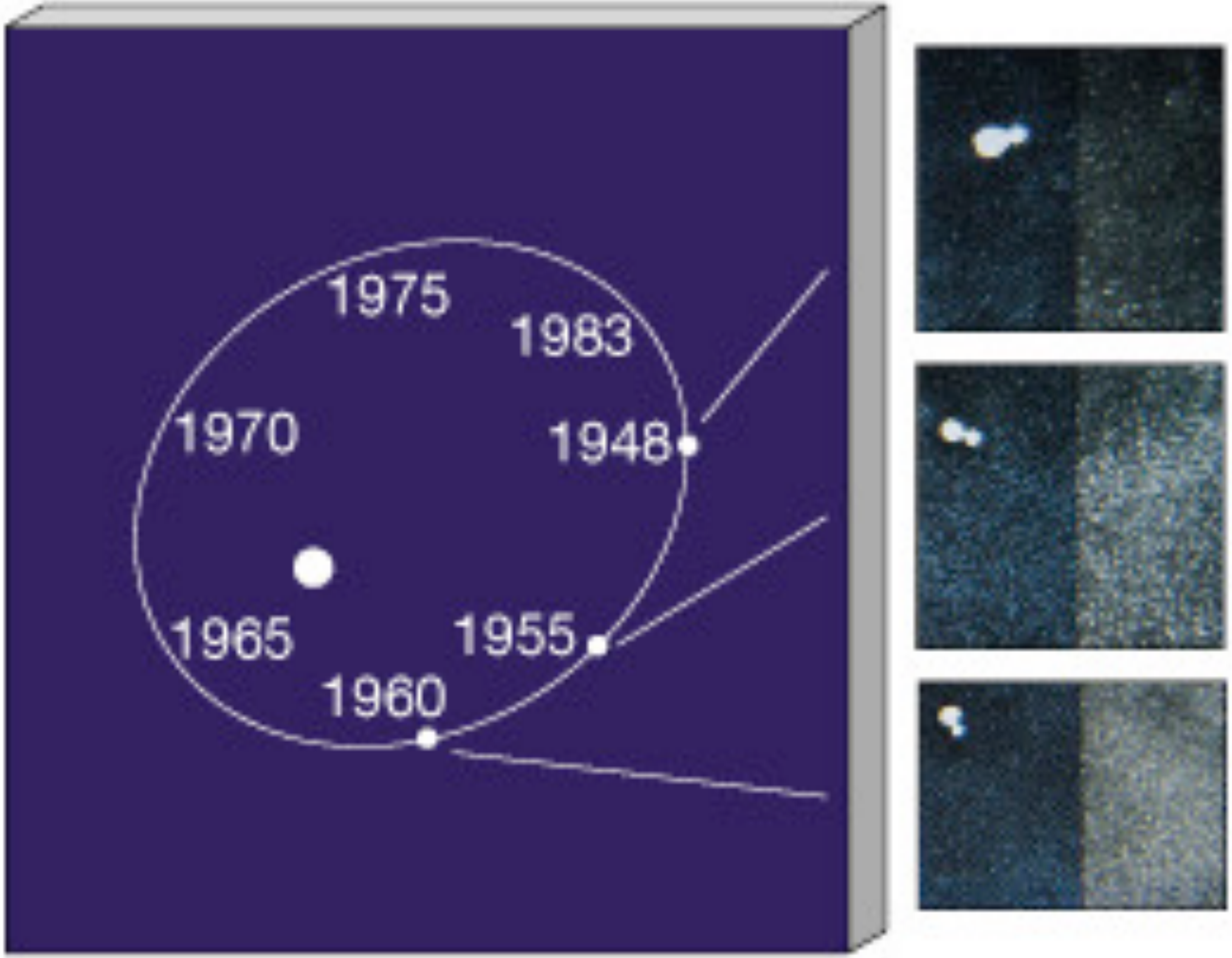
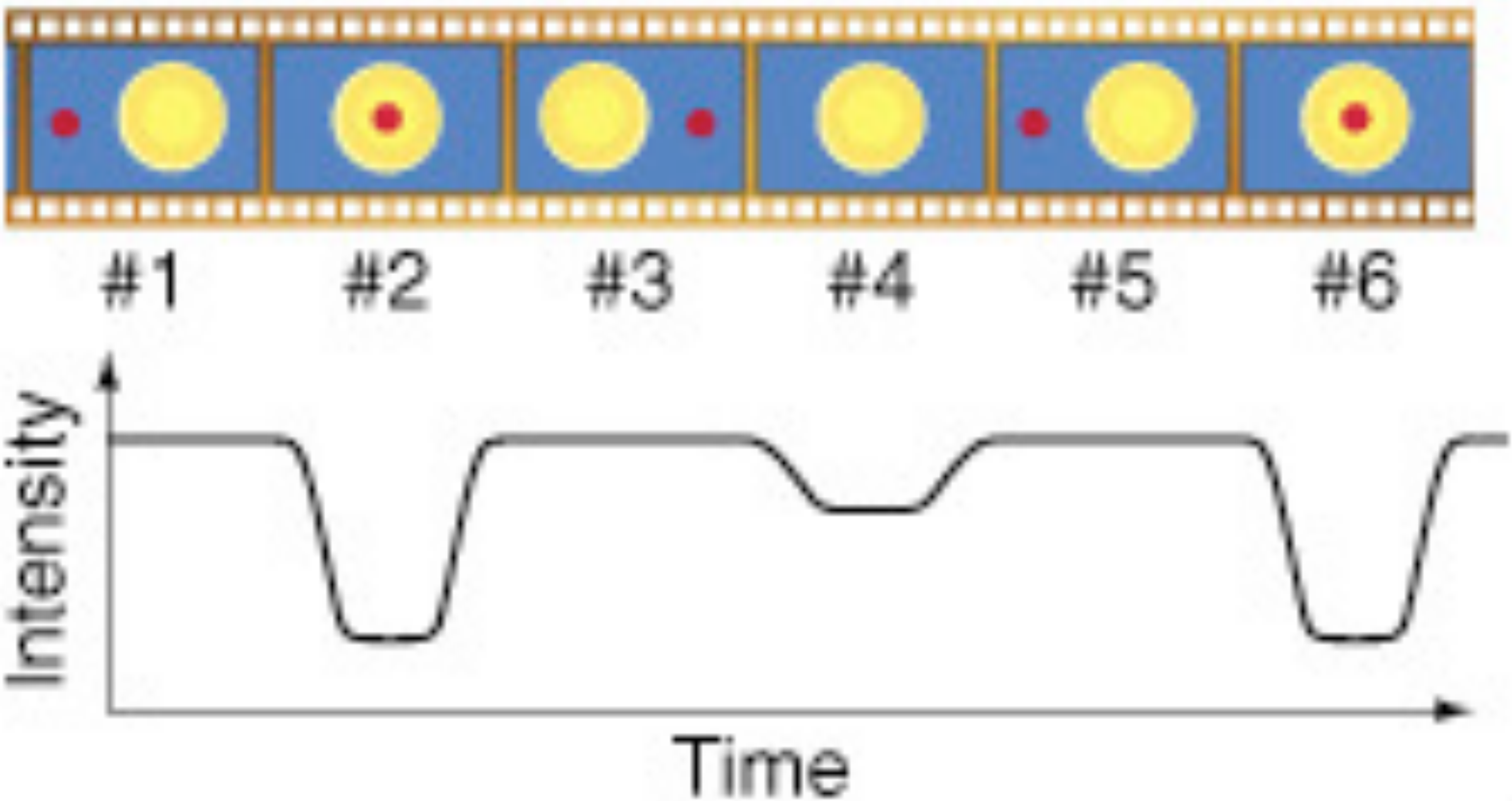
Stellar Mass

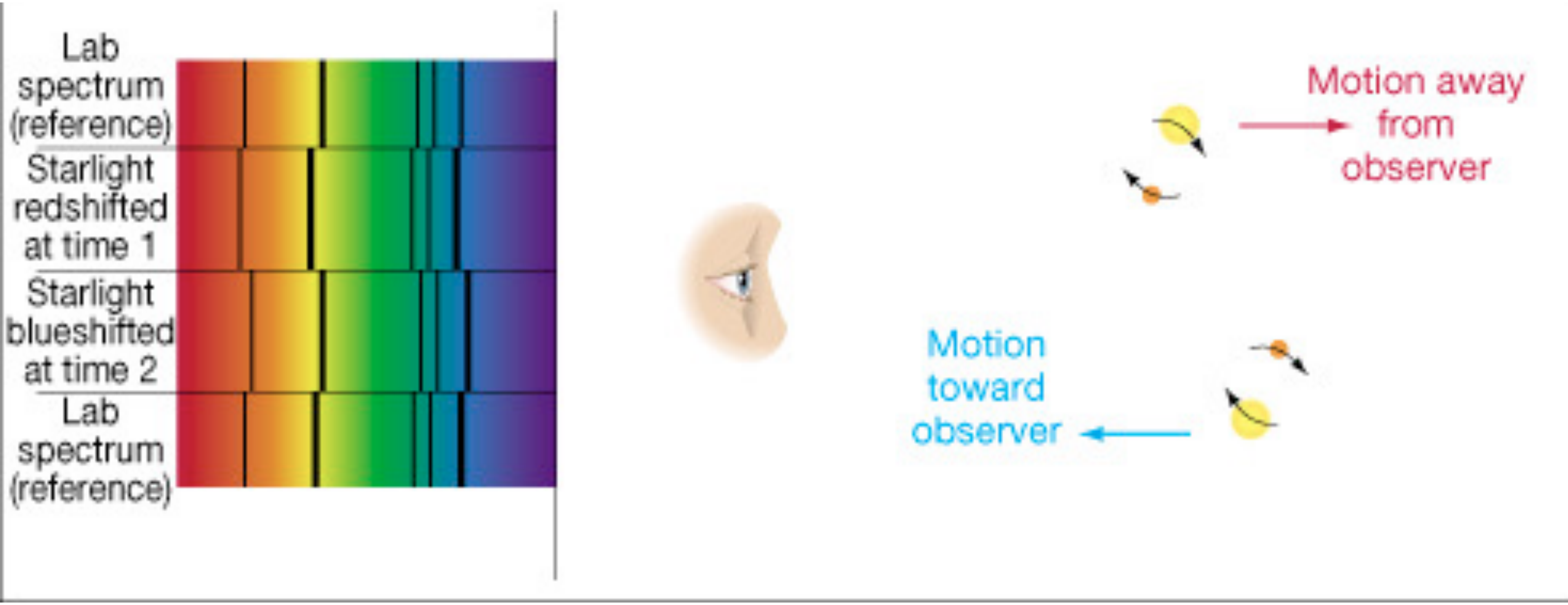
- The mass of a star can be determined based on Newton's Law of Universal Gravitation, but only if an observable object orbits the star.
- The orbiting object is most often another star – *i.e.* a binary star system.
- There are three types of binaries: visual, eclipsing, and spectroscopic.
- To determine mass it is necessary to measure the period of the orbit.


1975
1983
1970
1948
1965
1955
1960



#1
#2
#3
#4
#5
#6
Intensity
Time

Spectroscopic Binary

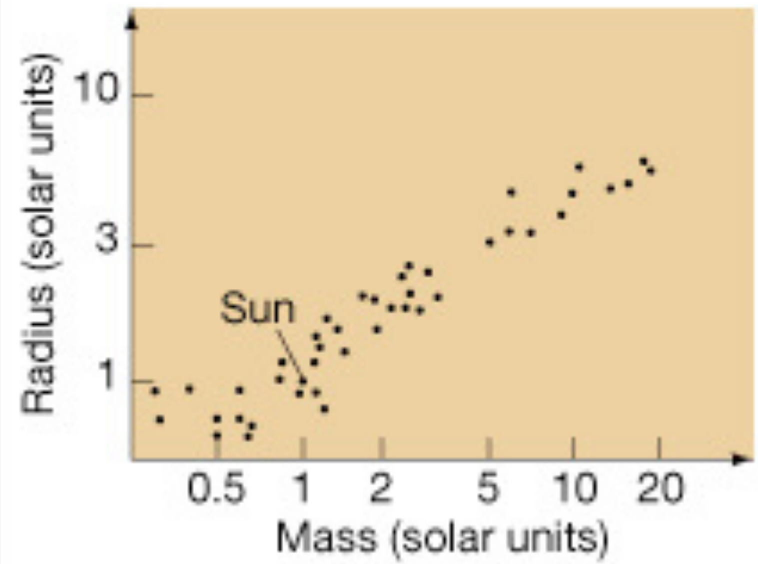


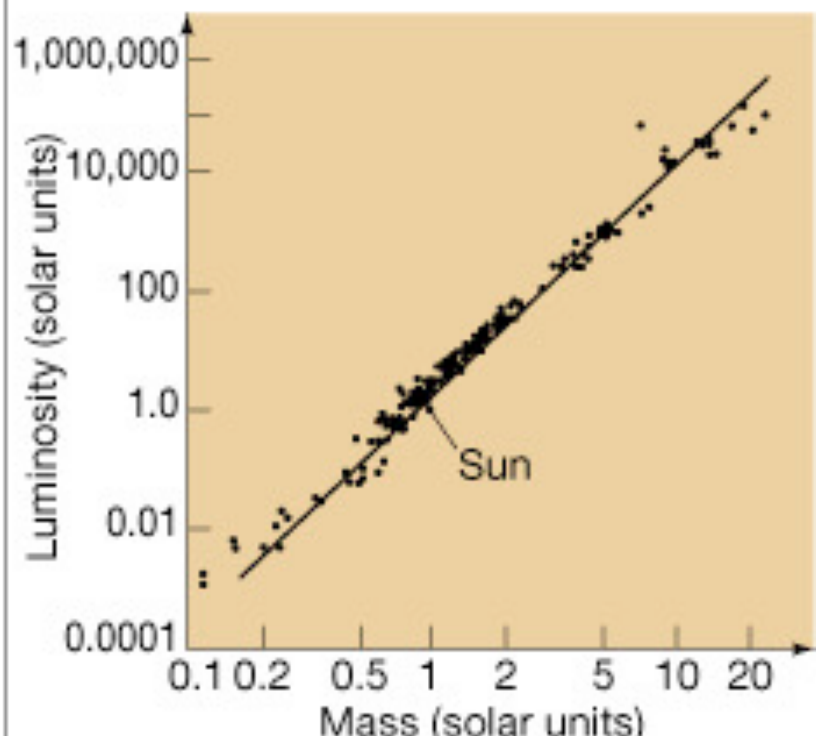
If a binary is not visual or eclipsing it may still be observable by the Doppler effect on its spectral lines.

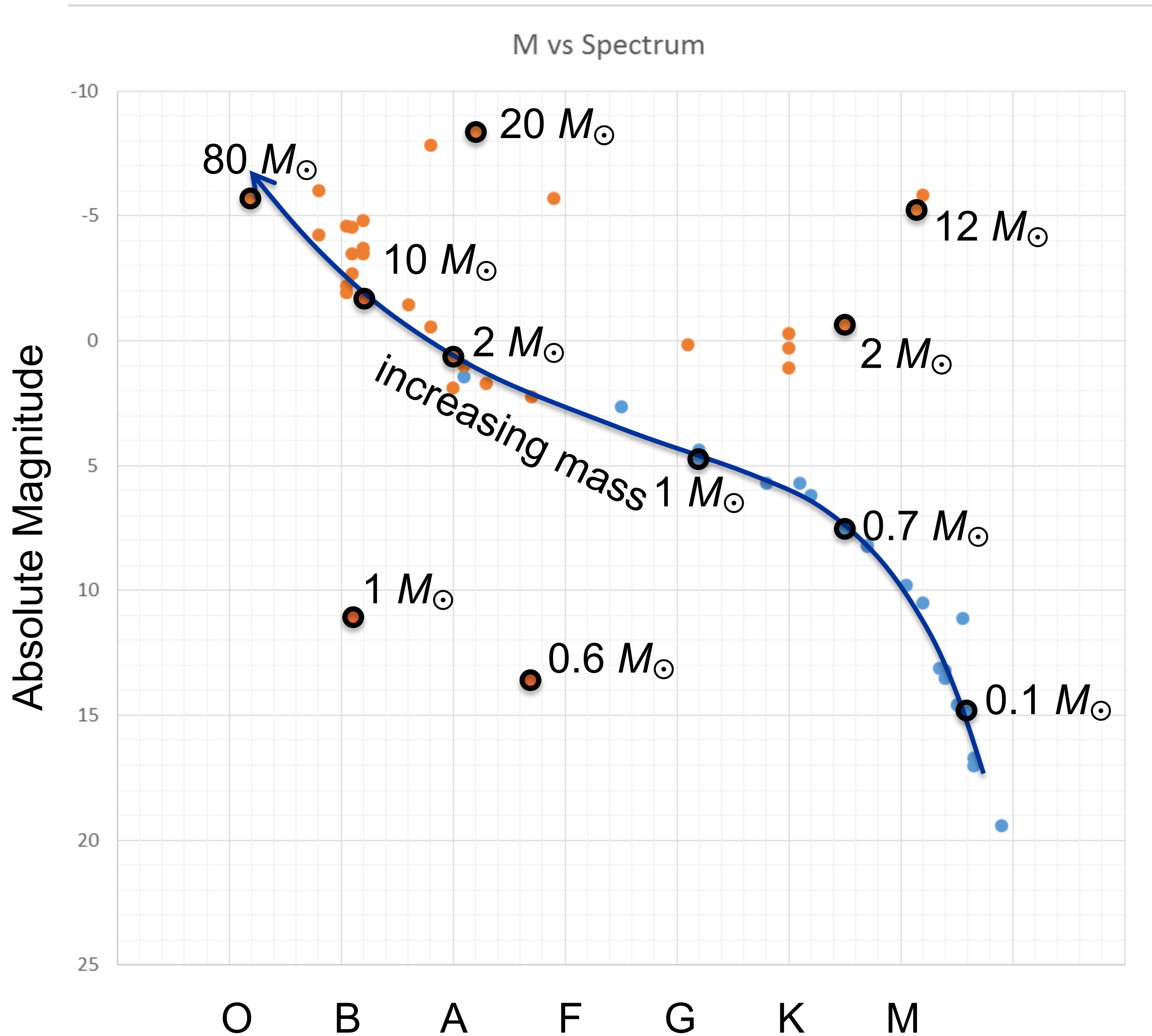
Stellar Mass

- The mass of a star governs its diameter and its temperature and thus its location on the main sequence when it reaches a steady state of nuclear fusion.
- The mass also determines the ultimate fate of the star and its lifetime.
- The time that it spends on the main sequence is proportional to its mass divided by its luminosity.

The radius and luminosity of a star can be related to its mass . . .






M vs Spectrum
Absolute Magnitude
-10
-5
0
5
10
15
20
25
O
B
A
F
G
K
M
80 $M_\odot$
20 $M_\odot$
10 $M_\odot$
12 $M_\odot$
2 $M_\odot$
2 $M_\odot$
increasing mass
1 $M_\odot$
0.7 $M_\odot$
1 $M_\odot$
0.6 $M_\odot$
0.1 $M_\odot$

Stellar Lifetimes

- Because luminosity is proportional to mass raised to the 4th power, a more massive star actually has a shorter lifetime even though it has more "fuel".
- Stars with high mass have extremely high luminosities and relatively short lifetimes.
- Stars with low mass have extremely low luminosities and relatively long lifetimes.

$$t \approx \frac{m}{L}$$

$$t \approx \frac{1}{m^3}$$

where: t = time on main sequence
m = mass of star
L = luminosity of star

Note: all values relative to the Sun

	Type	Mass ($M_\odot$)	Central Temp. (10^6 K)	Luminosity ($L_\odot$)	Lifetime (10^9 yr)
Spica B	B2 V	6.8	25	500	
Vega	A0 V	2.6	21	55	
Sirius	A1 V	2.1	20	23	
α Cent.	G2 V	1.1	17	1.4	
Sun	G2 V	1.0	15	1.0	10
Prox. C.	M5 V	0.1	0.6	0.00006	

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α Cent.	G2 V	1.1	17	1.4	8
Sun	G2 V	1.0	15	1.0	10
Prox. C.	M5 V	0.1	0.6	0.00006	16000

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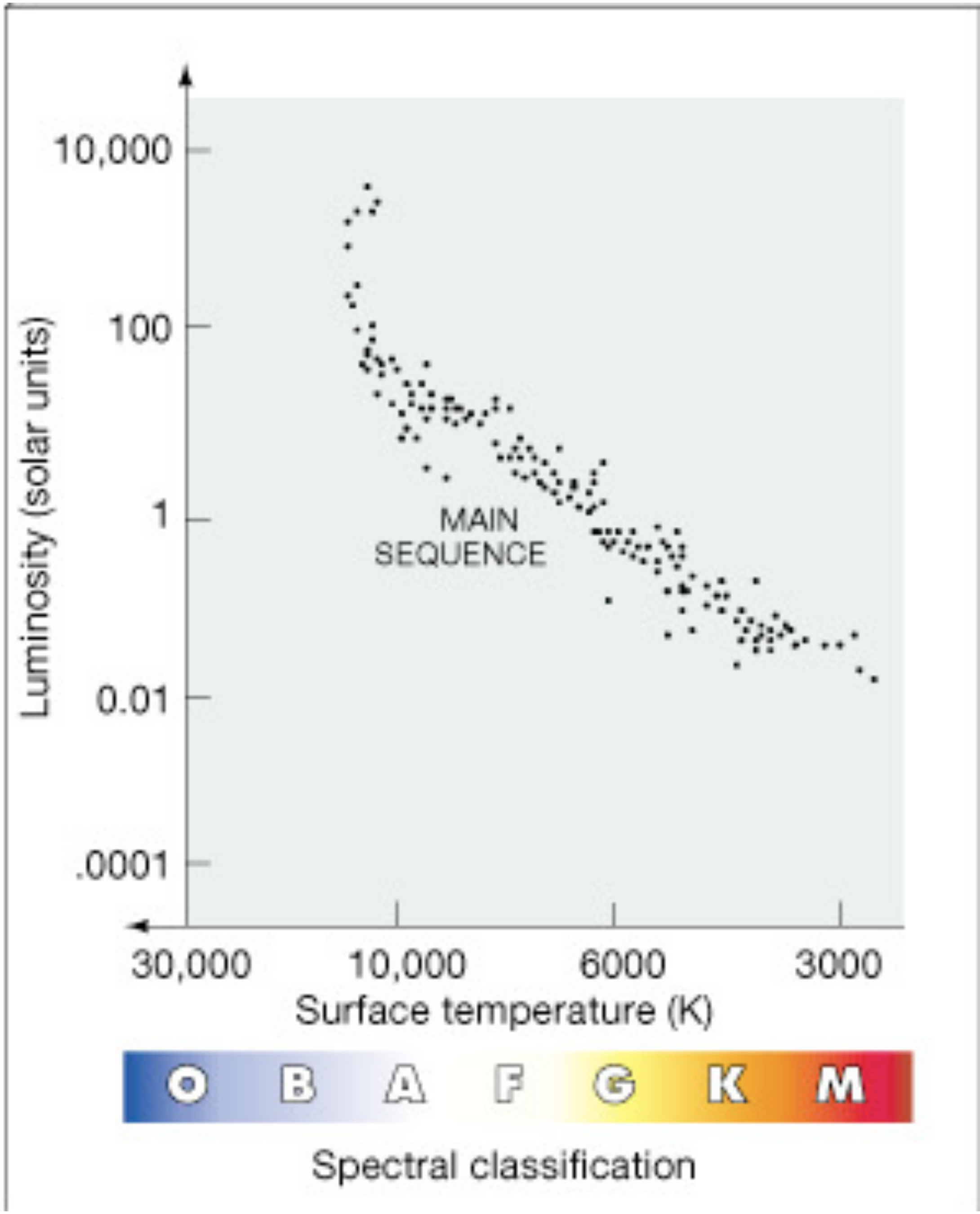
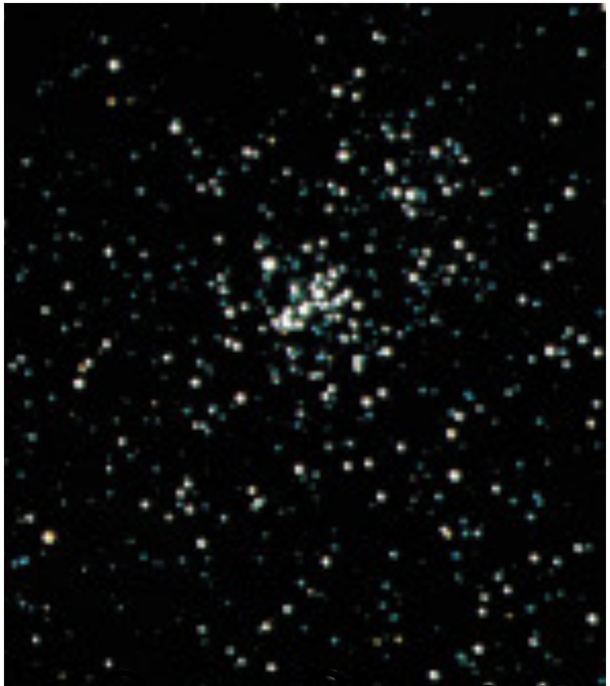
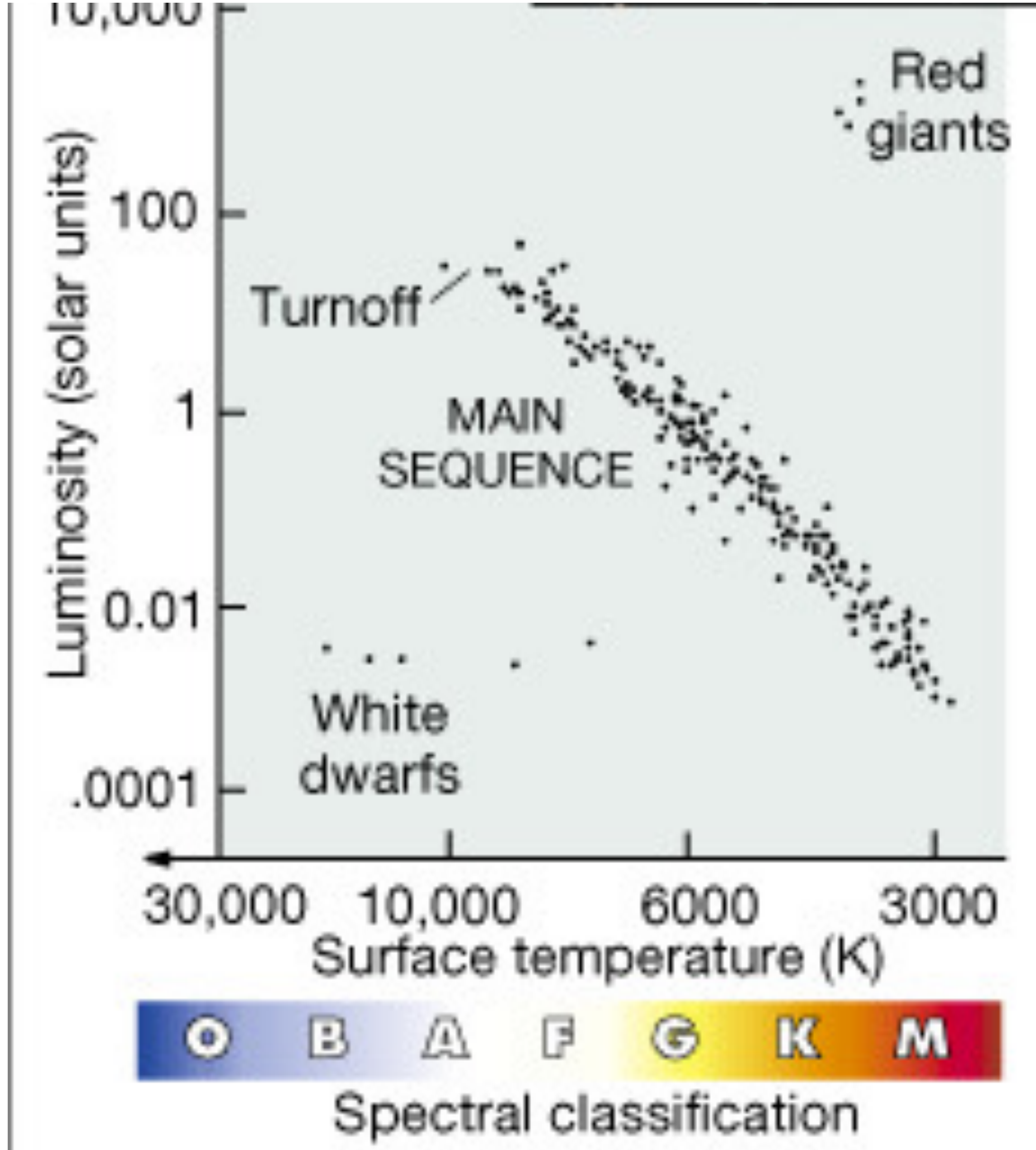
Open Cluster:
the Pleiades

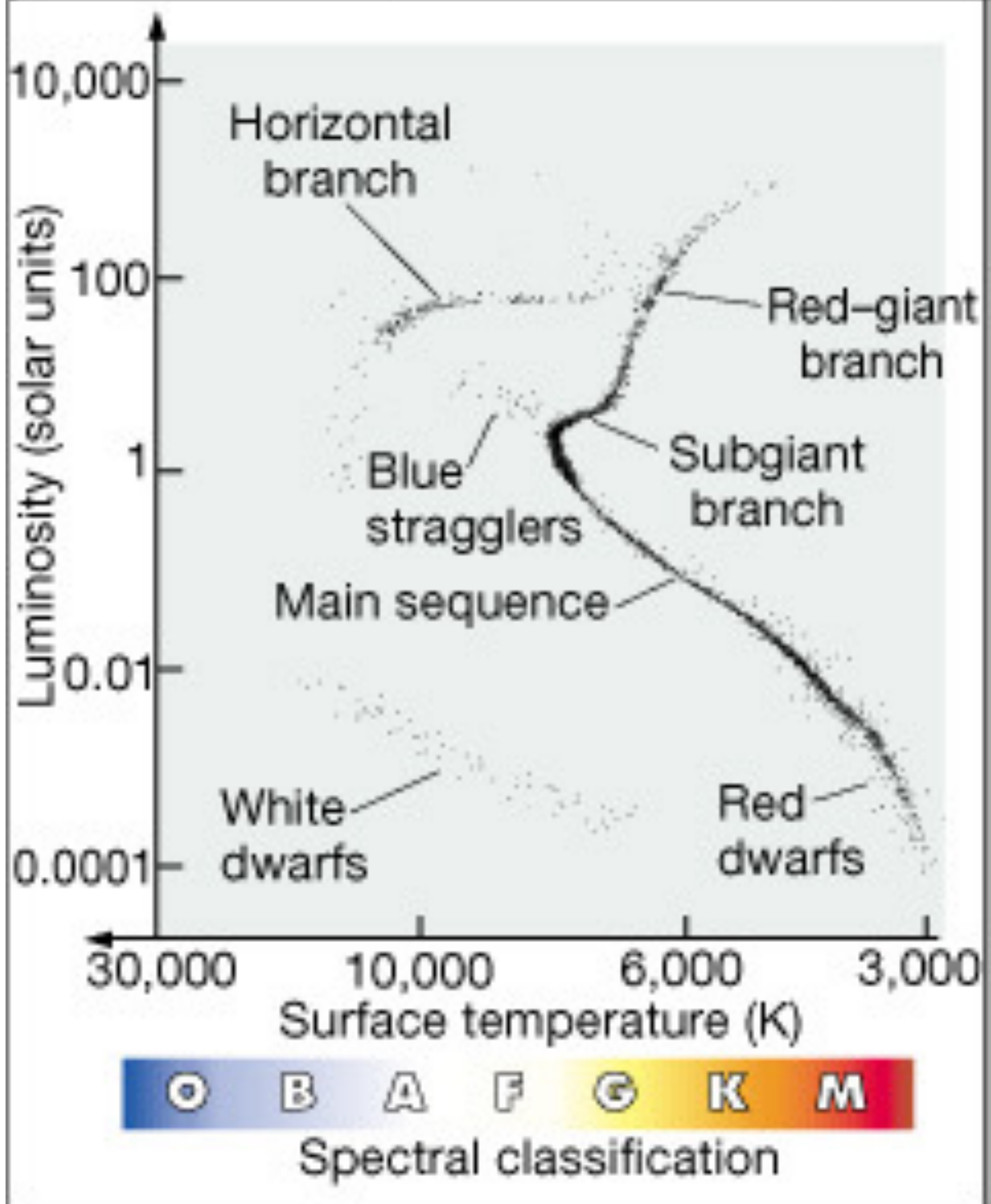




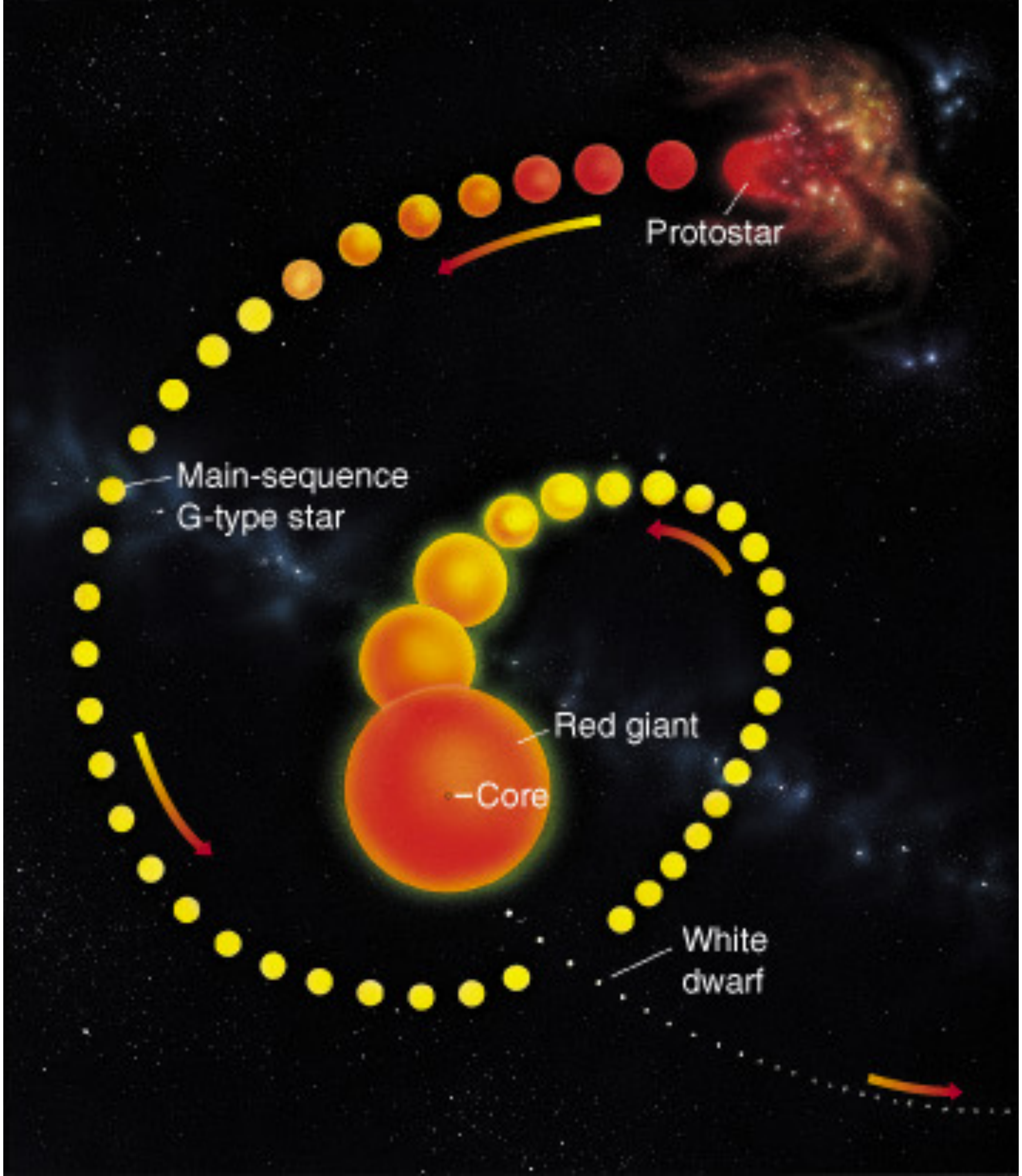
Open Cluster:
the Hyades

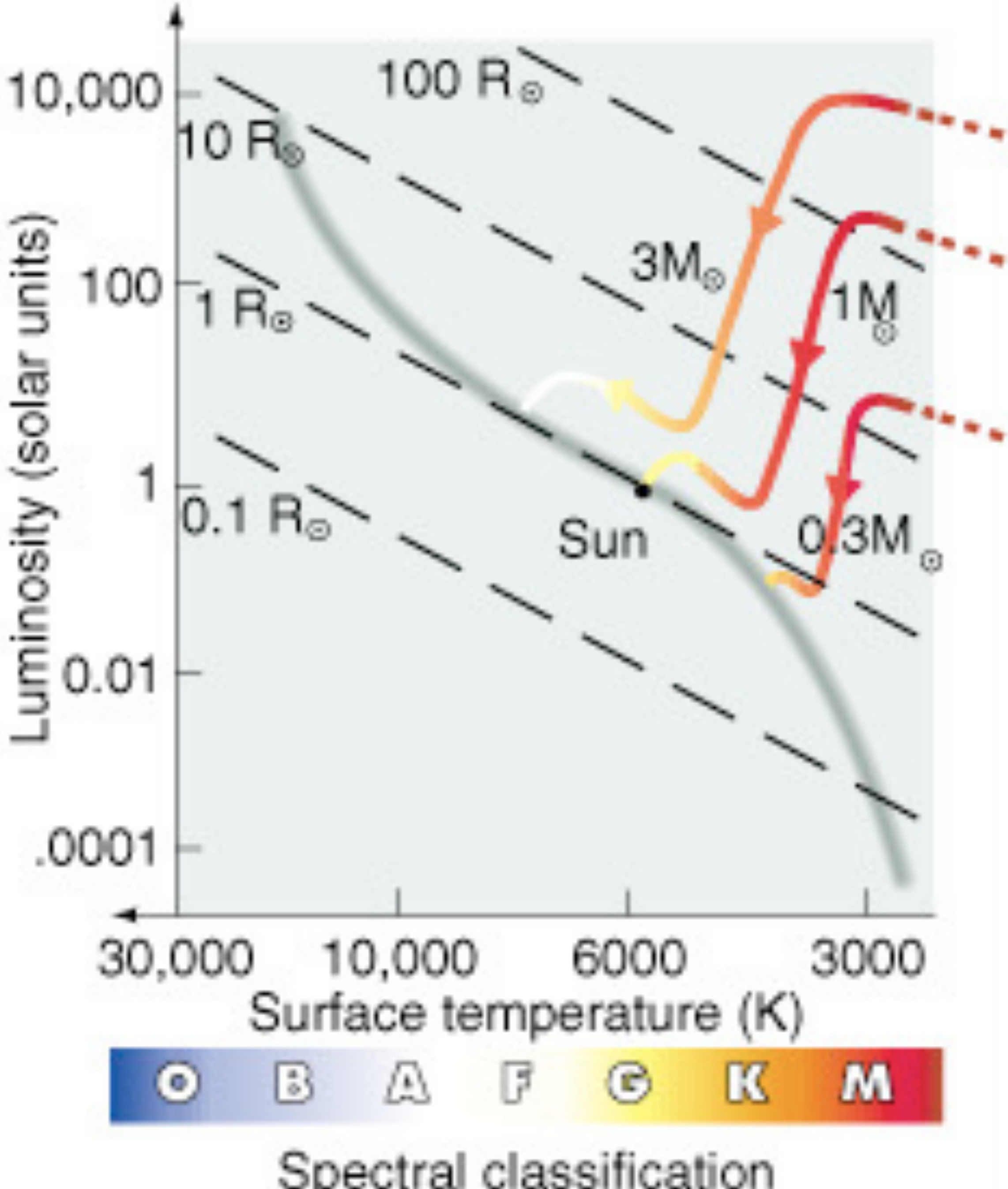


Globular Cluster

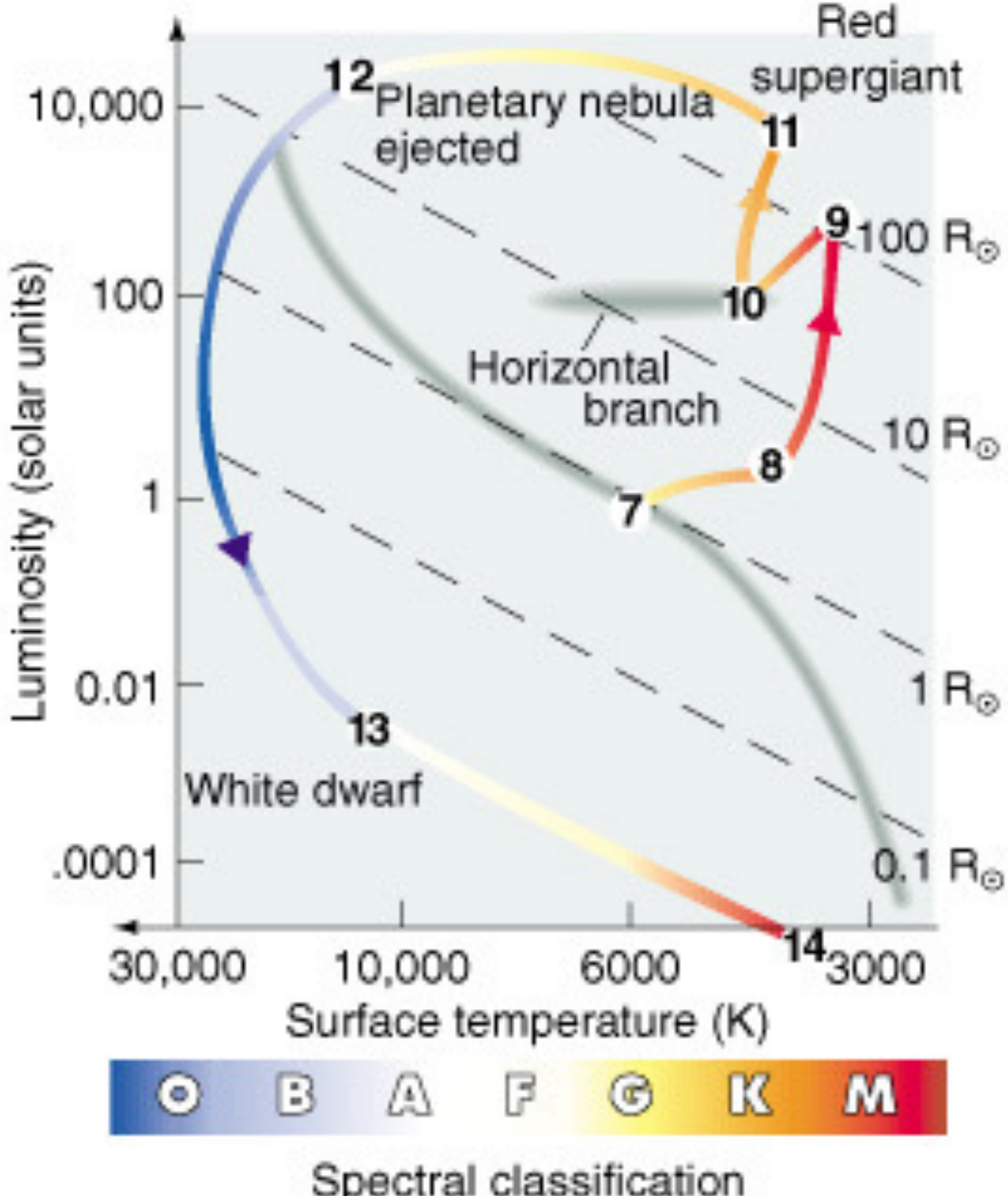


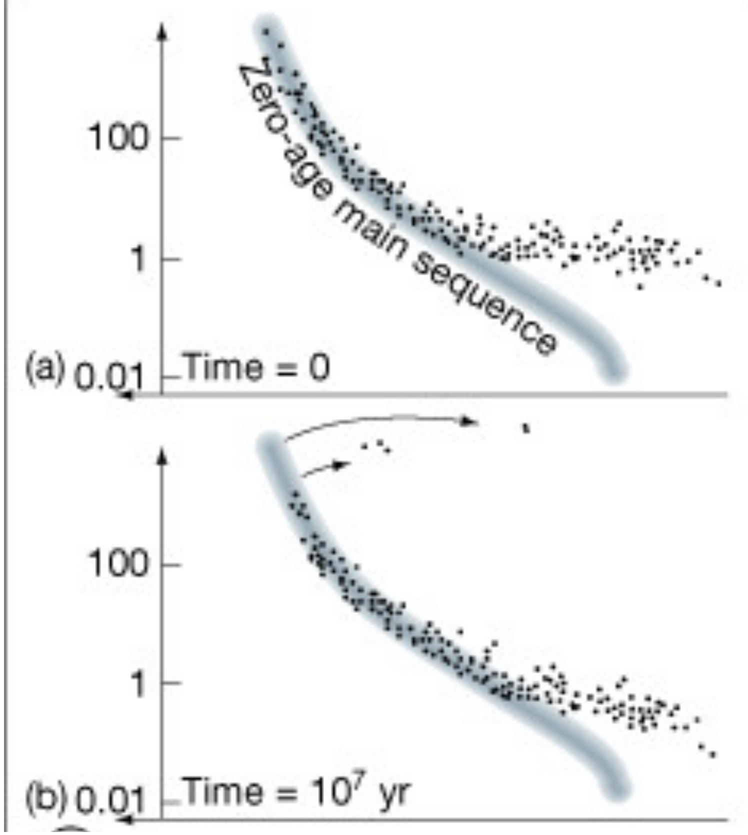
1. Stars in a cluster are located in the same region of space (i.e. they are relatively close to one another). It is believed that all of the stars within a given cluster are the same age – why does this make sense? What would have to happen for this not to be true?
2. When a star “becomes a star” it will be on the main sequence – why?
3. The length of the main sequence in a cluster’s HR diagram indicates what about the cluster? The longer it is…? The shorter it is…?
4. What can be concluded about stars that are not on the main sequence within a cluster?


Protostar
Main-sequence
G-type star
Red giant
Core
White
dwarf

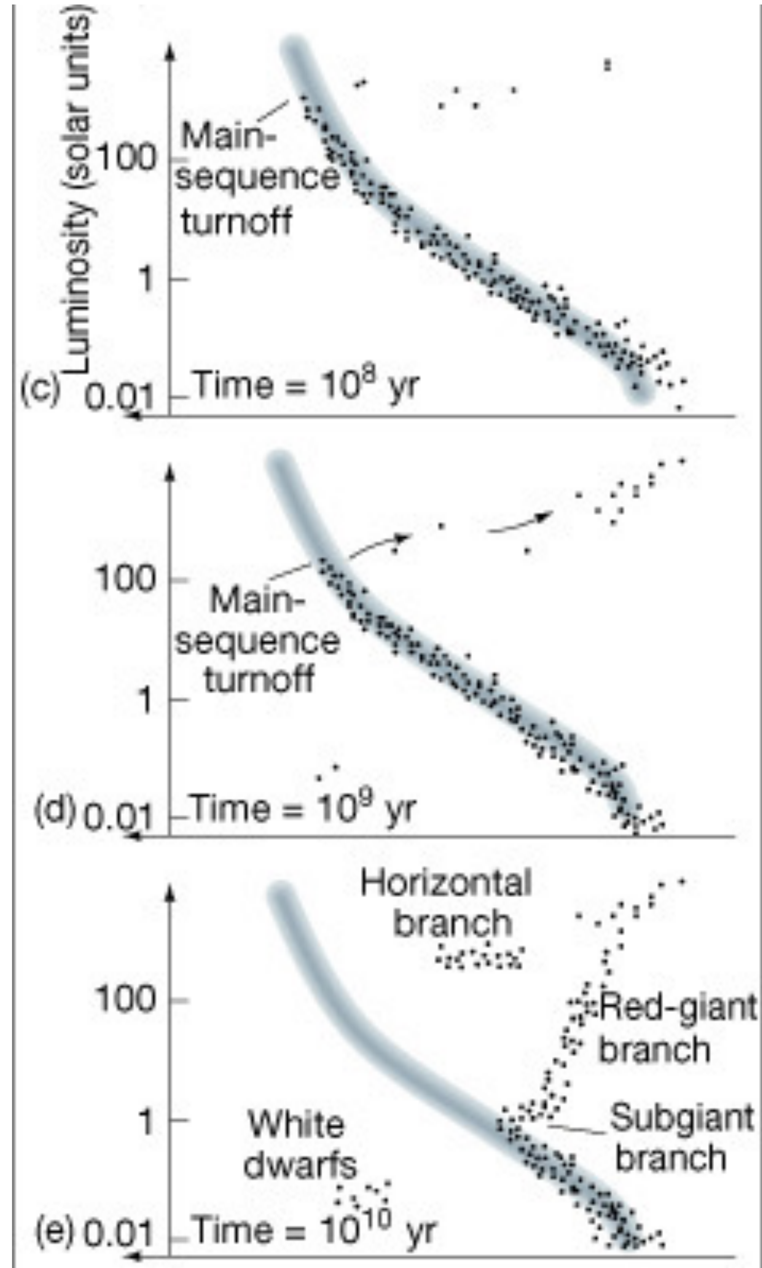


Luminosity (solar units)
10,000
100
1
0.01
.0001
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
3M⊙
1M⊙
0.3M⊙
Sun
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

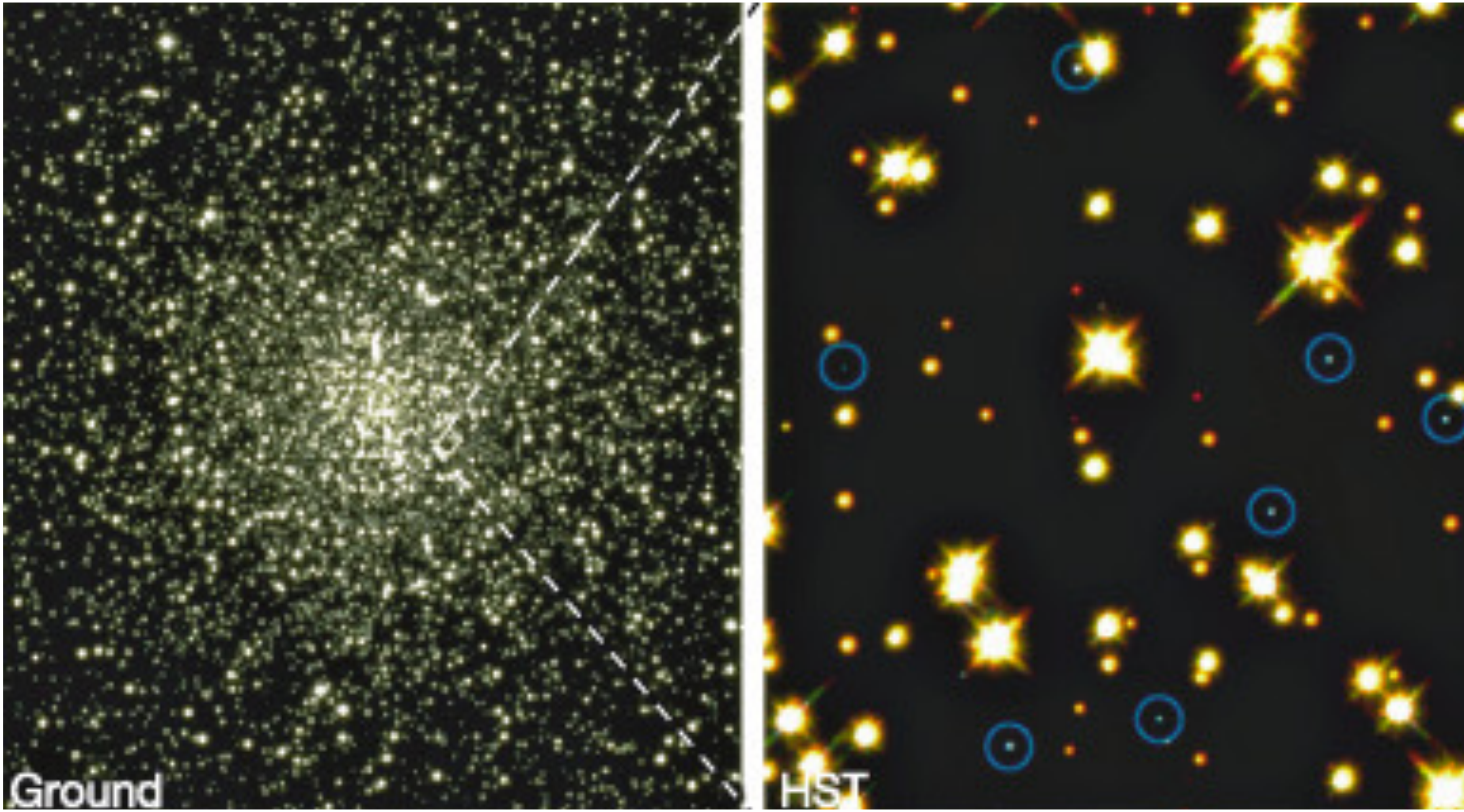

Red supergiant
12
Planetary nebula ejected
11
9
100 R⊙
10,000
100
10
Horizontal branch
10 R⊙
8
1
7
Luminosity (solar units)
1 R⊙
0.01
13
White dwarf
.0001
0.1 R⊙
14
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

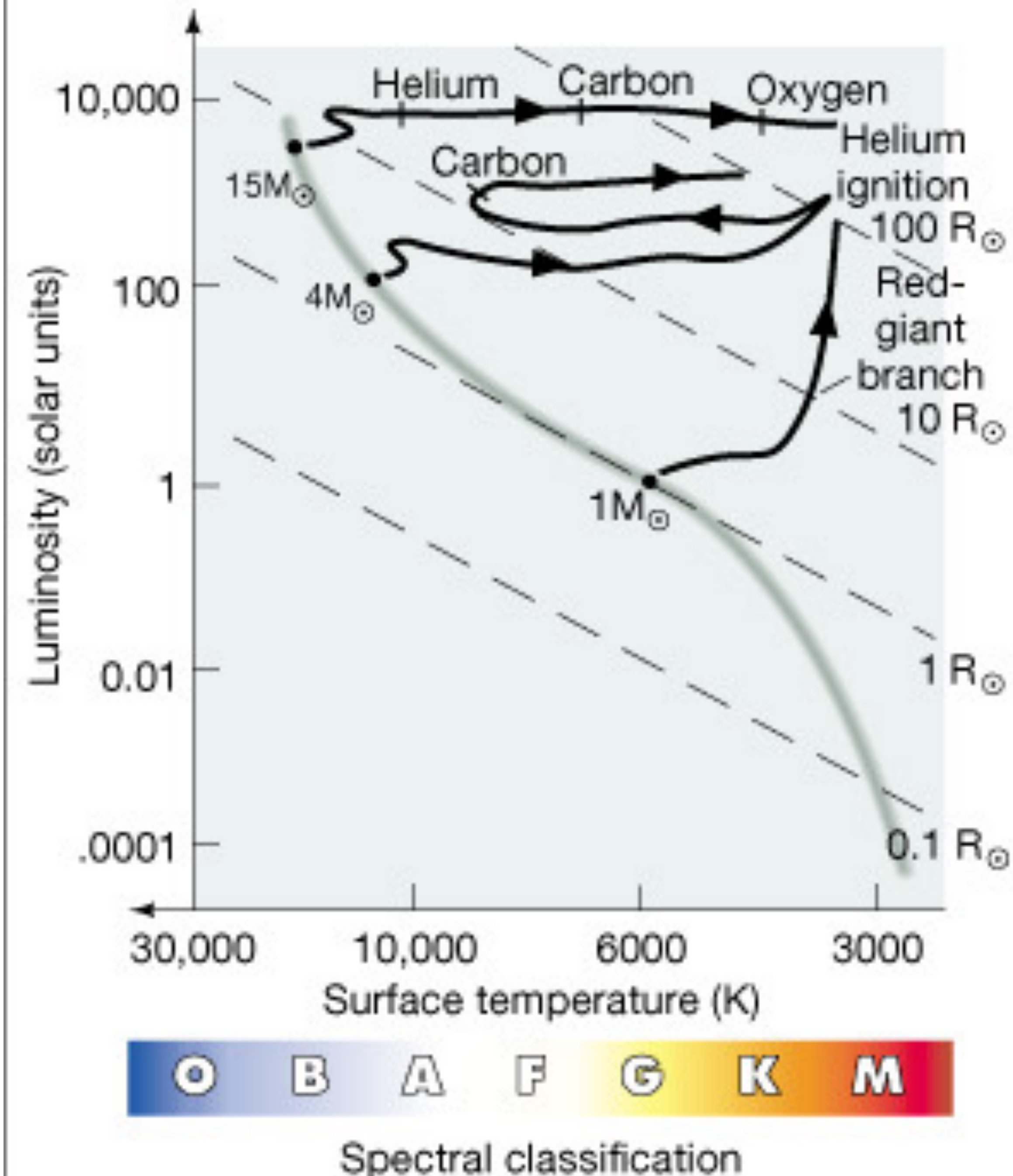


100
1
0.01
Zero-age main sequence
(a)
Time = 0
100
1
0.01
(b)
Time = 10⁷ yr

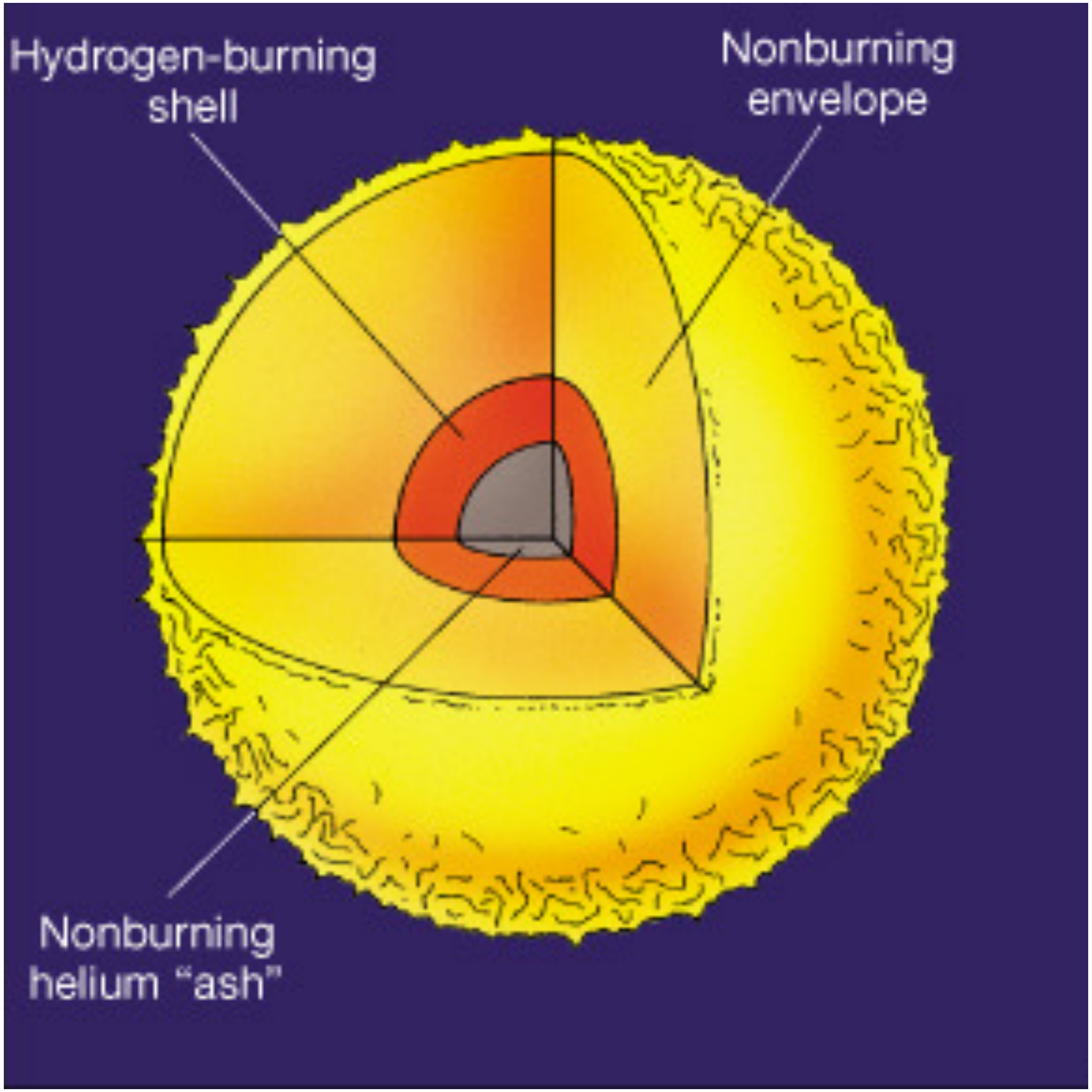


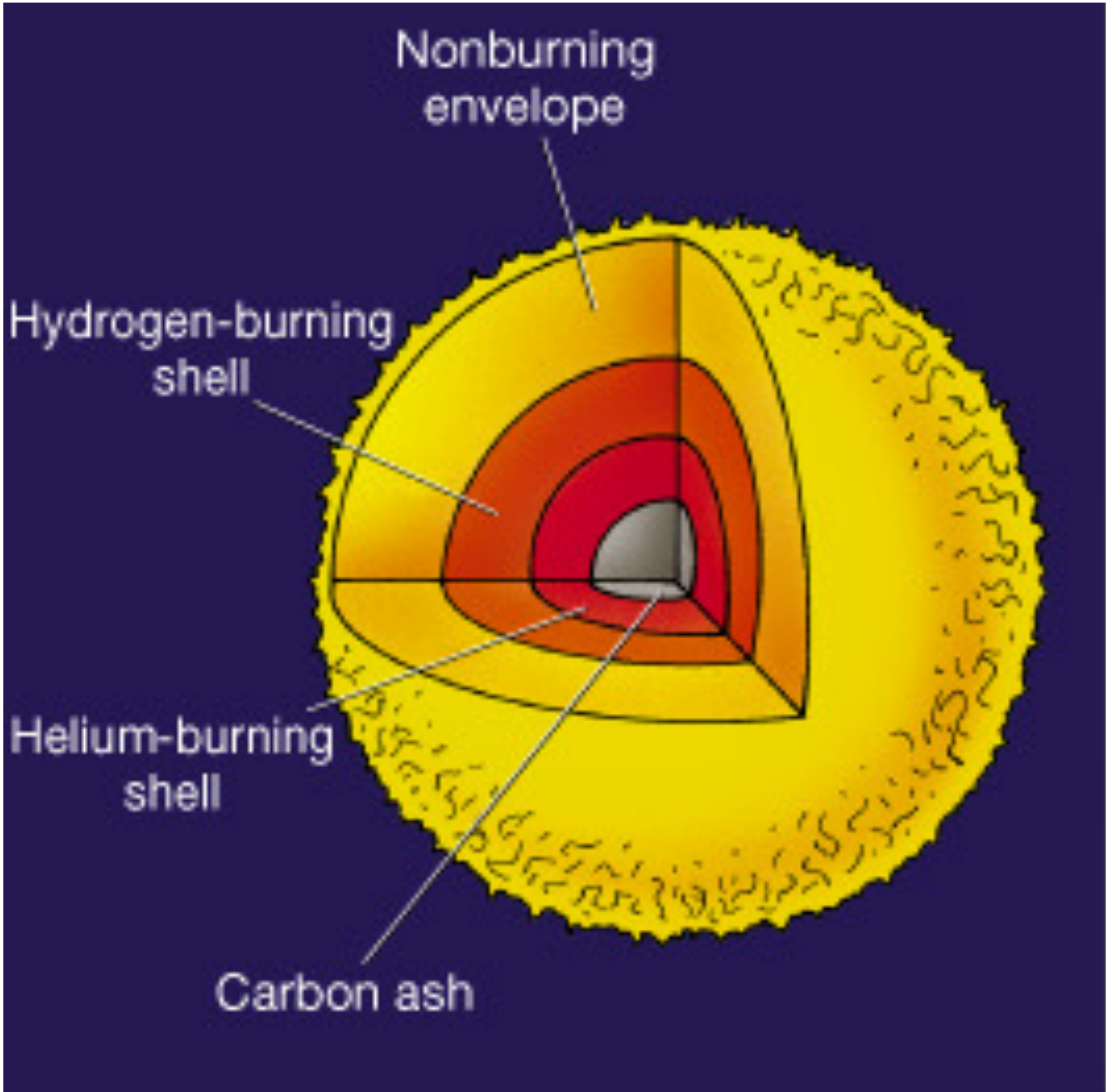
Luminosity (solar units)
100
1
0.01
Main-
sequence
turnoff
(c)
Time = 10⁸ yr
100
1
0.01
Main-
sequence
turnoff
(d)
Time = 10⁹ yr
Horizontal
branch
100
Red-giant
branch
1
White
dwarfs
Subgiant
branch
(e) 0.01
Time = 10¹⁰ yr

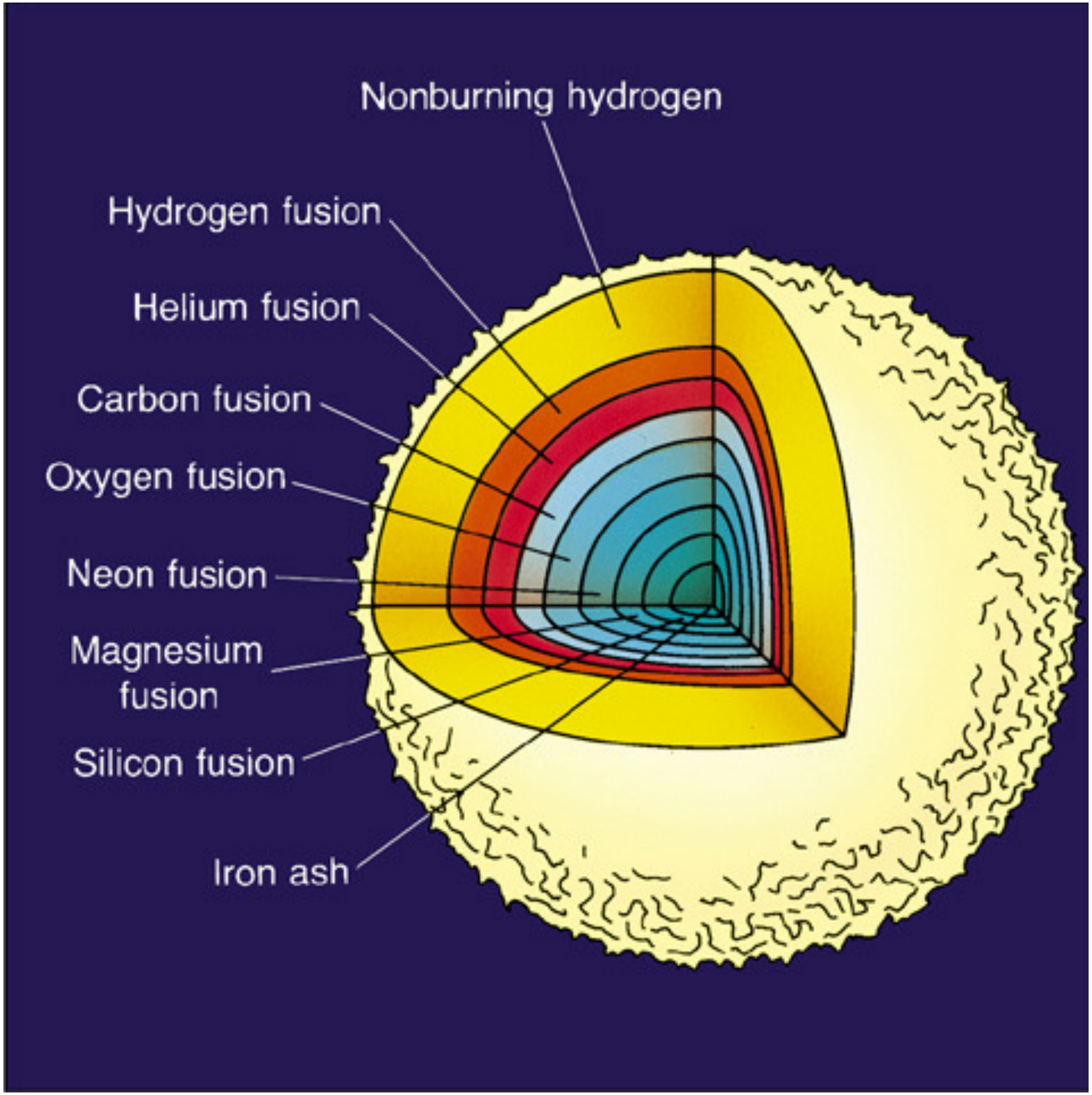

Ground
HST



Helium
Carbon
Oxygen
Helium ignition
Carbon
15M☉
4M☉
1M☉
100 R☉
Red-giant branch
10 R☉
1 R☉
0.1 R☉
10,000
100
1
0.01
.0001
Luminosity (solar units)
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification


Hydrogen-burning
shell
Nonburning
envelope
Nonburning
helium "ash"


Nonburning envelope
Hydrogen-burning shell
Helium-burning shell
Carbon ash


Nonburning hydrogen
Hydrogen fusion
Helium fusion
Carbon fusion
Oxygen fusion
Neon fusion
Magnesium fusion
Silicon fusion
Iron ash

Endpoints of Stellar Evolution

Initial Mass ($M_{\odot}$)	Final State
less than 0.08	Brown Dwarf
0.08 to 0.25	Helium White Dwarf
0.25 to 8	Carbon-Oxygen White Dwarf
8 to 12	Neon-Oxygen White Dwarf
greater than 12	Supernova