ASTR20A: Introduction to Astrophysics I

Dr. Devontae Baxter

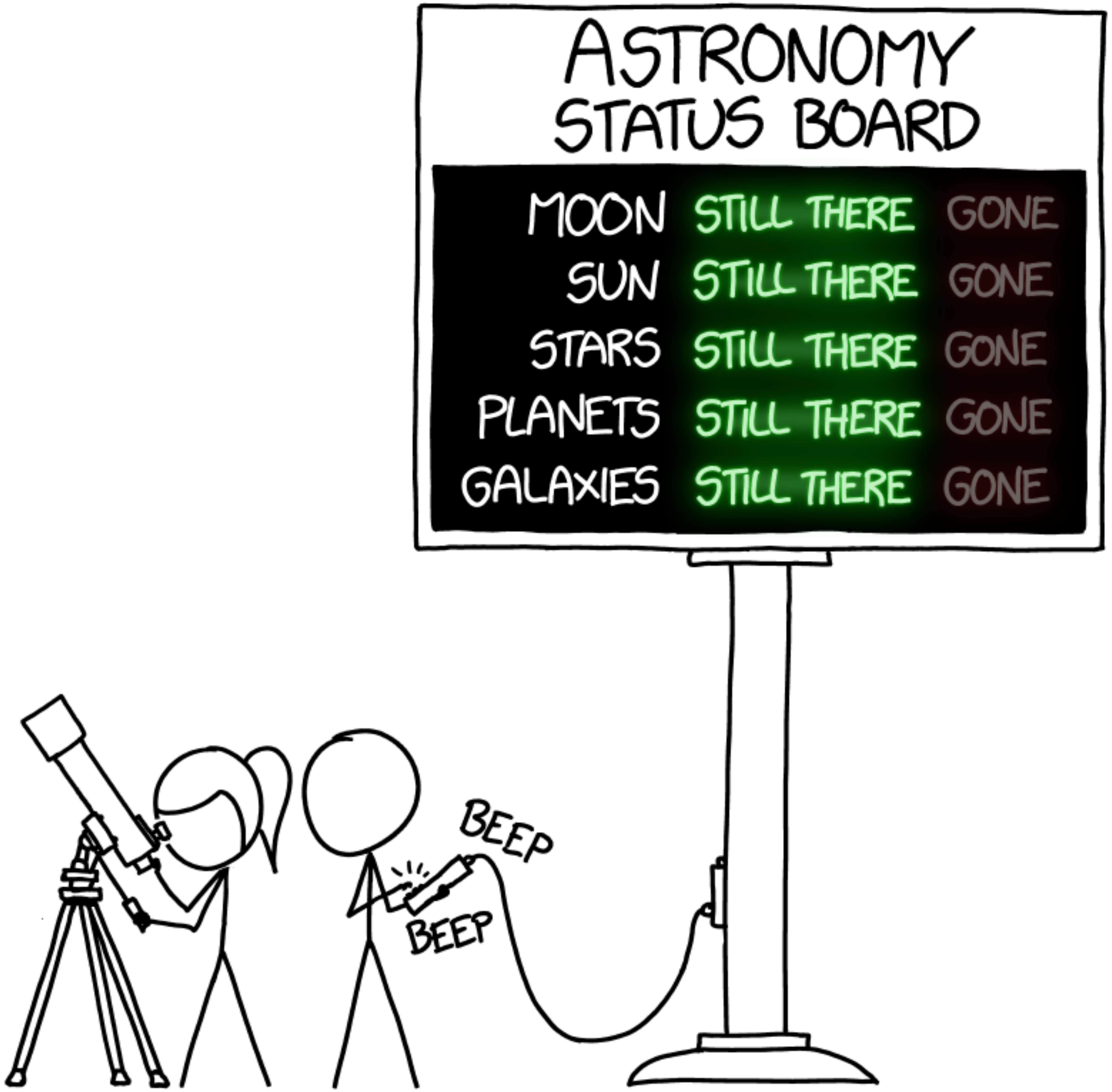
Lecture 16 | Stellar Atmospheres

Tuesday, December 02, 2025

Announcements

- HW #8 will be due **Thursday, 12/04 by 11:59 pm.**

- Final Exam is **Thursday, 12/11 from 3:00pm-5:59pm.**



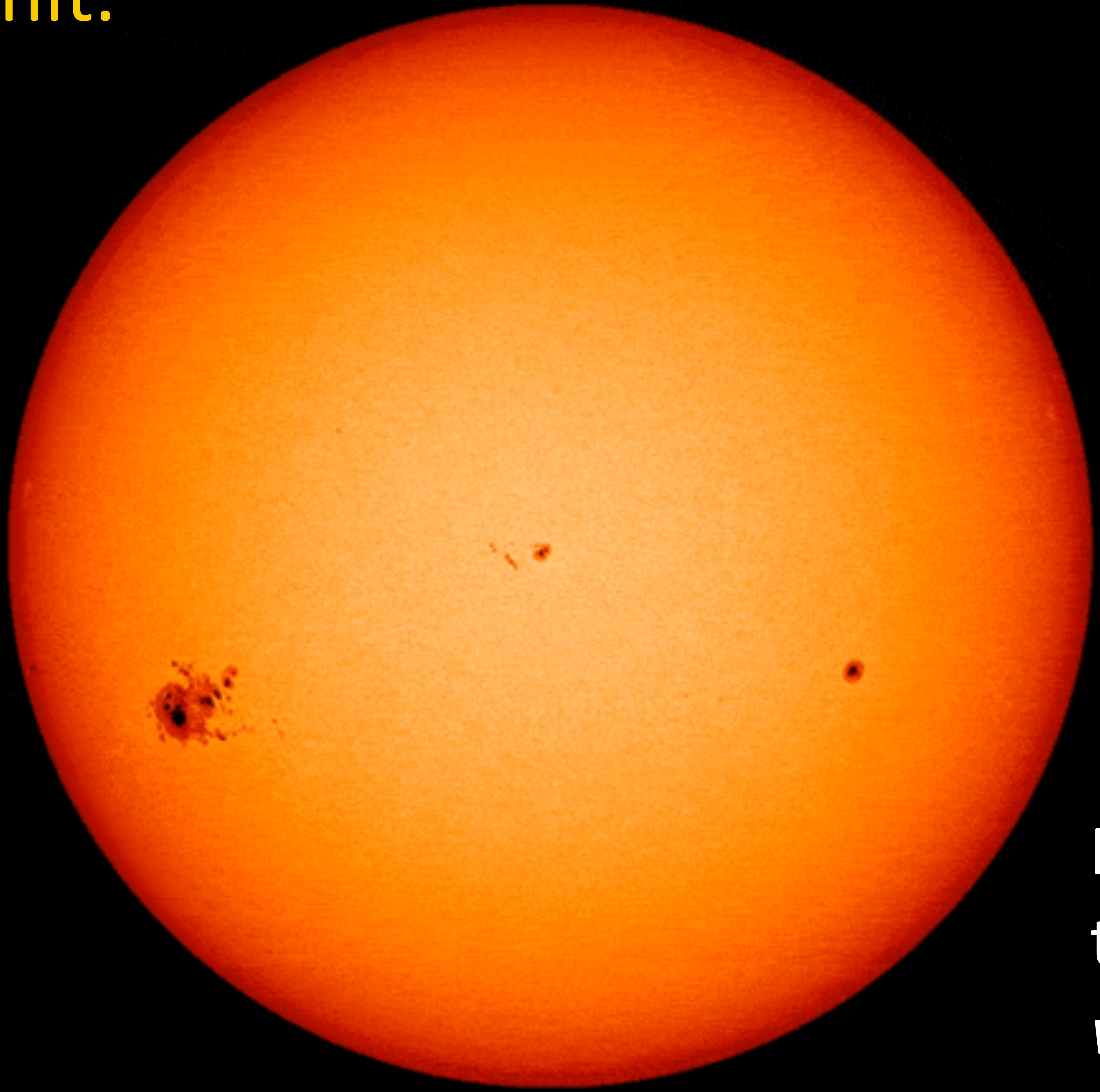
Learning Objectives

By the end of today's lecture you will be able to:

- Explain how the metallicity of a star is defined.
- Describe how *spectral types* and *spectral subtypes* are defined.
- Arrange stars by temperature based on their spectrum.
- Describe how luminosity classes are defined.
- Describe the four main opacity mechanisms that prevent photons from escaping from a star's interior.
- Describe how the H-R diagram is constructed.
- Explain why stars move off the "main-sequence".

Everything that we know about stars other than the Sun comes from collecting the photons that they emit.

However, photons only tell us what is happening in a star's *photosphere.*



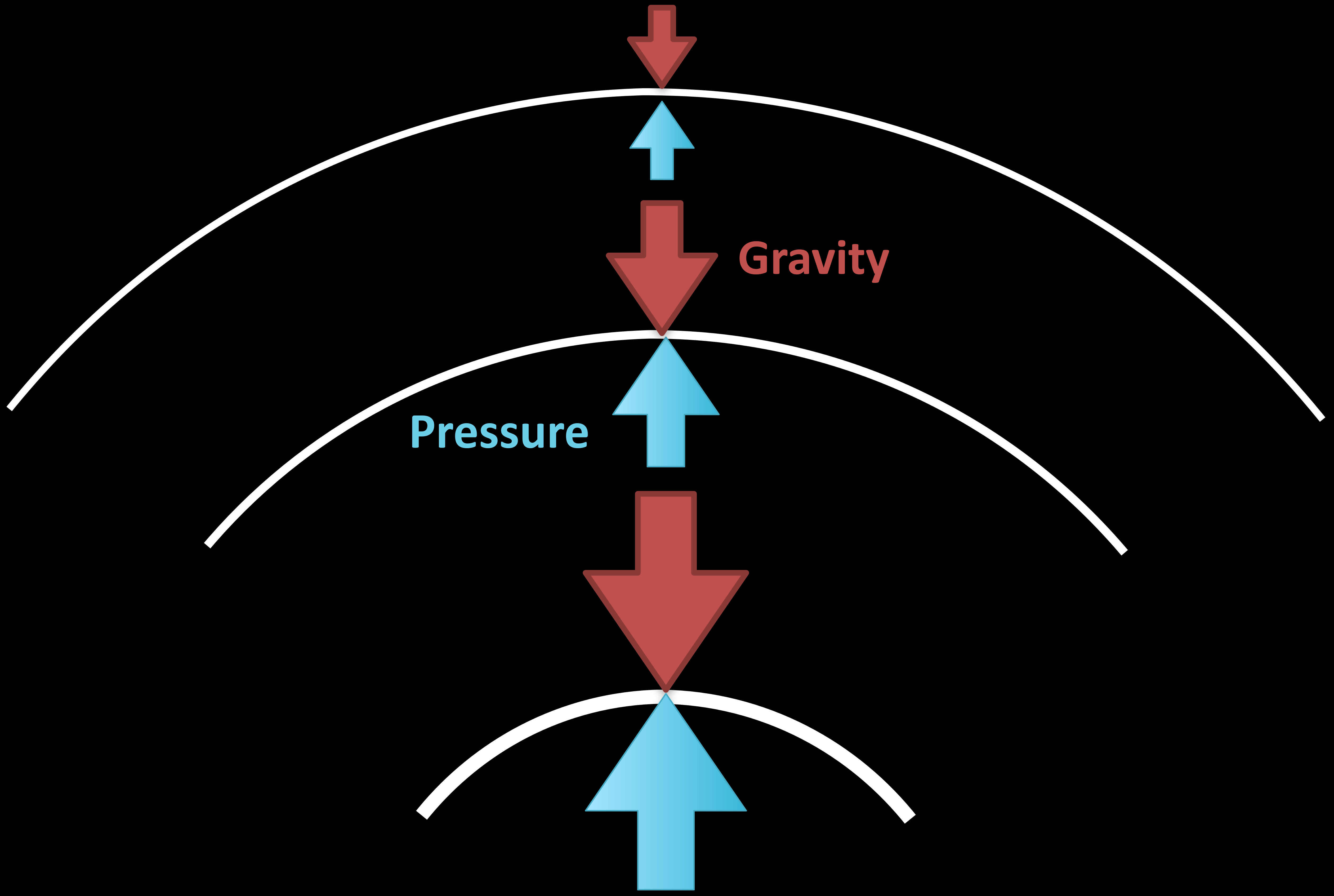
Review: The photosphere is the *relatively thin layer from which visible photons escape.*

Thus, to understand the basic properties of stars, such as how their spectra are produced, requires understanding the physics of stellar atmospheres.

Hydrostatic Equilibrium Review

Similar to the Earth, the Sun exerts a gravitational force on the gas of which it is composed.

This gas is stabilized against gravitational collapse by a **balance between the gravitational force and the differential gas pressure.**



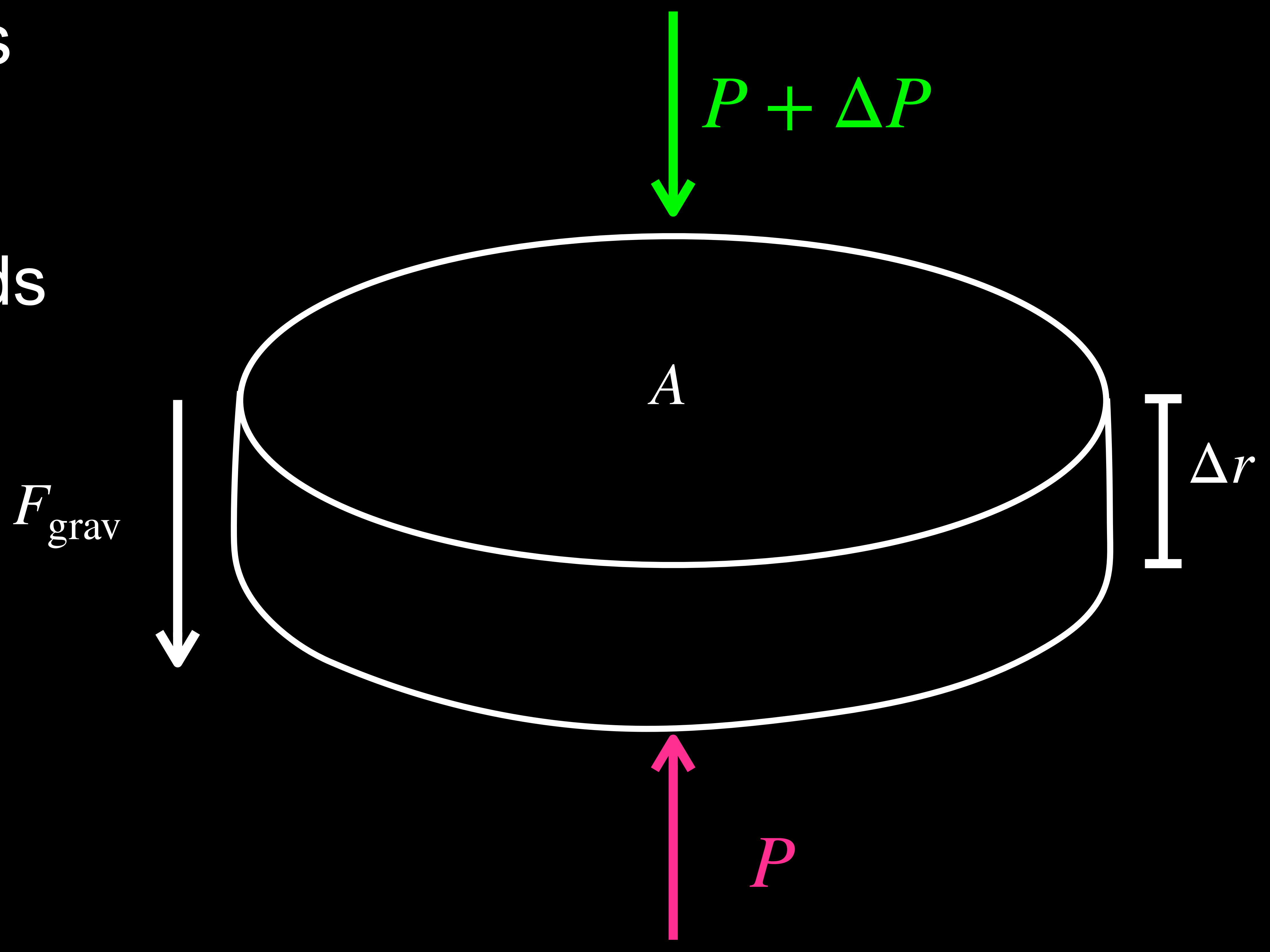
Hydrostatic Equilibrium

Hydrostatic Equilibrium Review

Consider the forces acting on an infinitesimally thick cylindrical volume of gas.

Gas pressure pushes on the bottom and top faces of the cylinder:

- P is the pressure pushing the bottom face upwards
- $P + \Delta P$ is the pressure pushing the top face downwards.



The net force on the volume element in the vertical direction is:

$$F_{\text{pres}} = A[P - (P + \Delta P)]$$

Note: The sign convention is chosen such that a **positive force is acting upwards.**

Hydrostatic Equilibrium Review

The gravitational force acing on the volume element is:

$$F_{\text{grav}} = -\frac{GM(r)\rho A\Delta r}{r^2}$$

$M(r)$ is the mass enclosed within a sphere of radius r centered on the center of the Sun.

In equilibrium, the atmosphere is neither expanding or contracting downward, meaning the sum of differential pressure and gravitational force is zero.

$$F_{\text{pres}} + F_{\text{grav}} = A[P - (P + \Delta P)] - \frac{GM(r)\rho A\Delta r}{r^2} = 0$$

Solving for the differential pressure:

$$\Rightarrow \qquad \Delta P = -\frac{GM(r)\rho}{r^2}\Delta r$$

Hydrostatic Equilibrium Review

In the limit that the cylinder becomes infinitesimally thin ($\Delta r \to 0$), this becomes the differential equation:

$$\frac{dP}{dr} = -\frac{GM(r)\rho}{r^2}$$ (equation of hydrostatic equilibrium)

Hydrostatic Equilibrium Review

The pressure at any point inside the star is well approximated by the ideal gas law

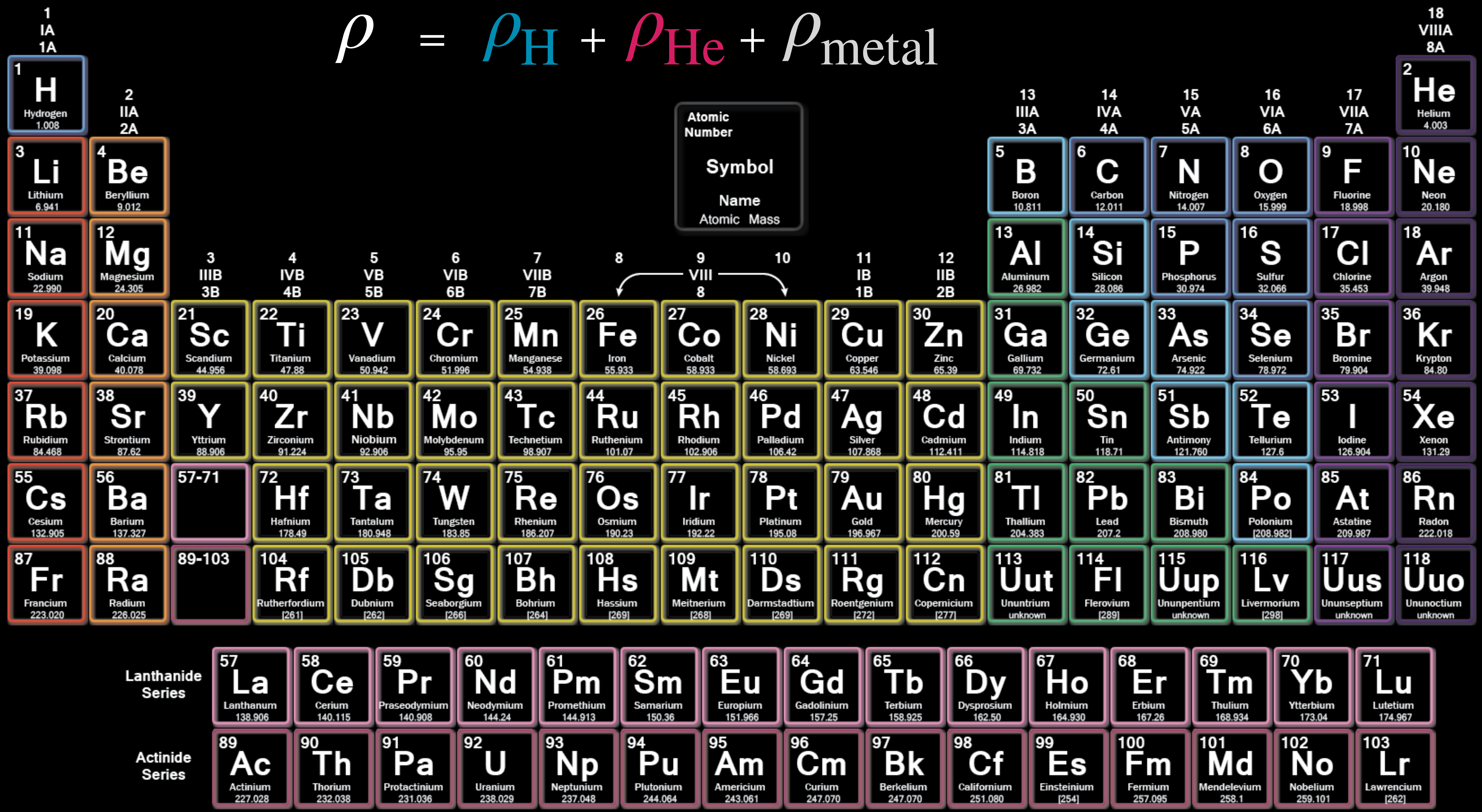
$$P = nkT = \frac{\rho k T}{\mu m_p}, \qquad \text{(Ideal Gas Law)}$$

where ρ is the mass density, m_p is the mass of a proton, and μ is the mean molecular mass that depends on the mix of elements present as well as the degree of ionization.

Metals

Astronomers split the total mass density ρ into three components based on the *atomic number* of the atom.

$$\rho = \rho_{\mathrm{H}} + \rho_{\mathrm{He}} + \rho_{\mathrm{metal}}$$



Metals

Therefore, for any given star, we can define the quantities X, Y, and Z that respectively represent the mass fractions of Hydrogen, Helium, and Metals.

$$\rho = \rho_{\mathrm{H}} + \rho_{\mathrm{He}} + \rho_{\mathrm{metal}}$$

The hydrogen mass fraction $\rightarrow X \equiv \dfrac{\rho_{\mathrm{H}}}{\rho}$

The helium mass fraction $\rightarrow Y \equiv \dfrac{\rho_{\mathrm{He}}}{\rho}$

The "metal" mass fraction $\rightarrow Z \equiv \dfrac{\rho_{\mathrm{metal}}}{\rho} = 1 - X - Y$

The relative mass fractions of the Sun's photosphere are

Hydrogen: $X_{\odot} = 0.734$

Helium: $Y_{\odot} = 0.250$

Metals: $Z_{\odot} = 0.016$

Metals

The "**metallicity**" of a star is measured *relative* to the Sun in log-space.

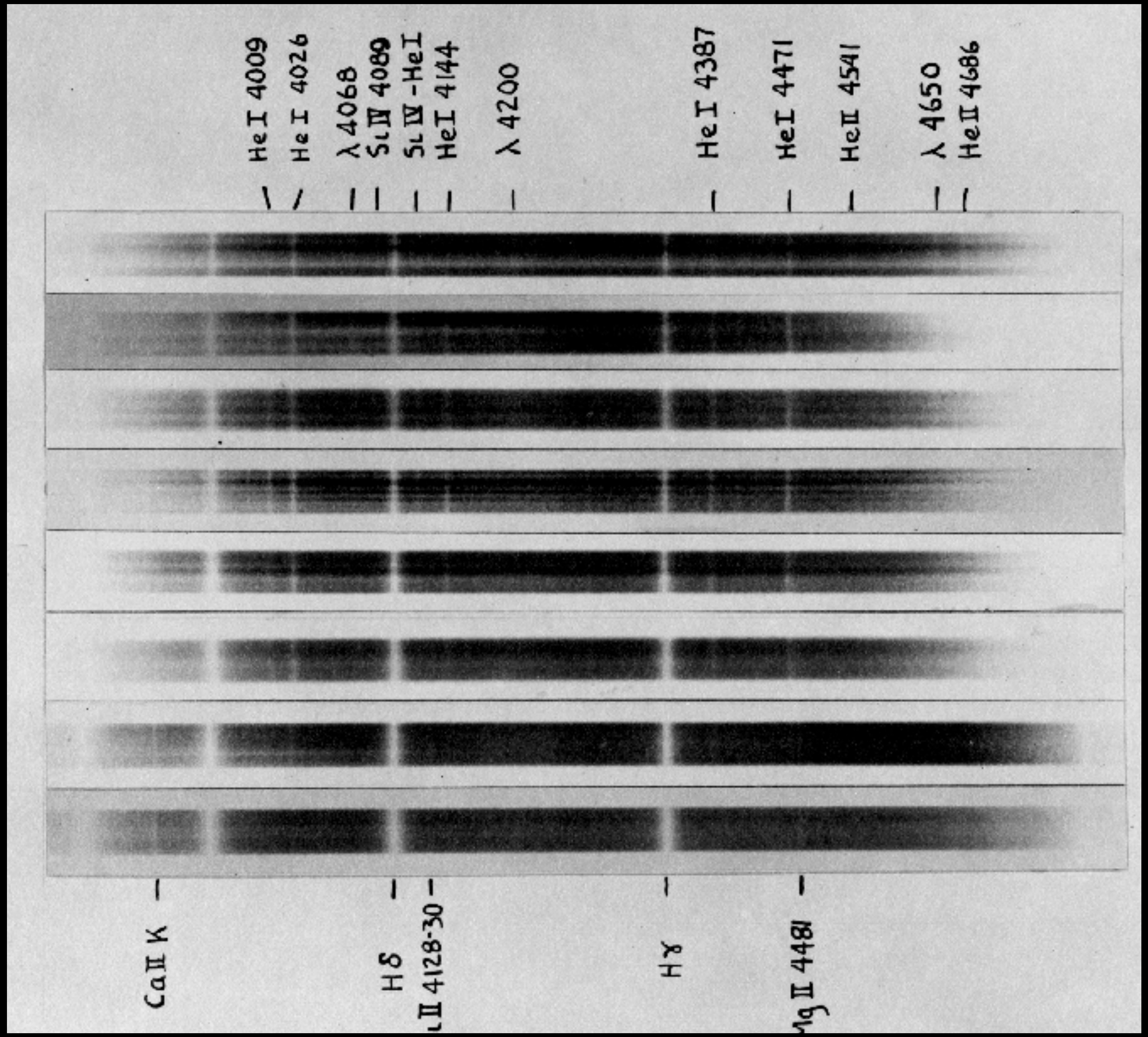
We typically measure the ratio of metals to hydrogen, and compare that to the Sun. A common tracer used is iron (Fe):

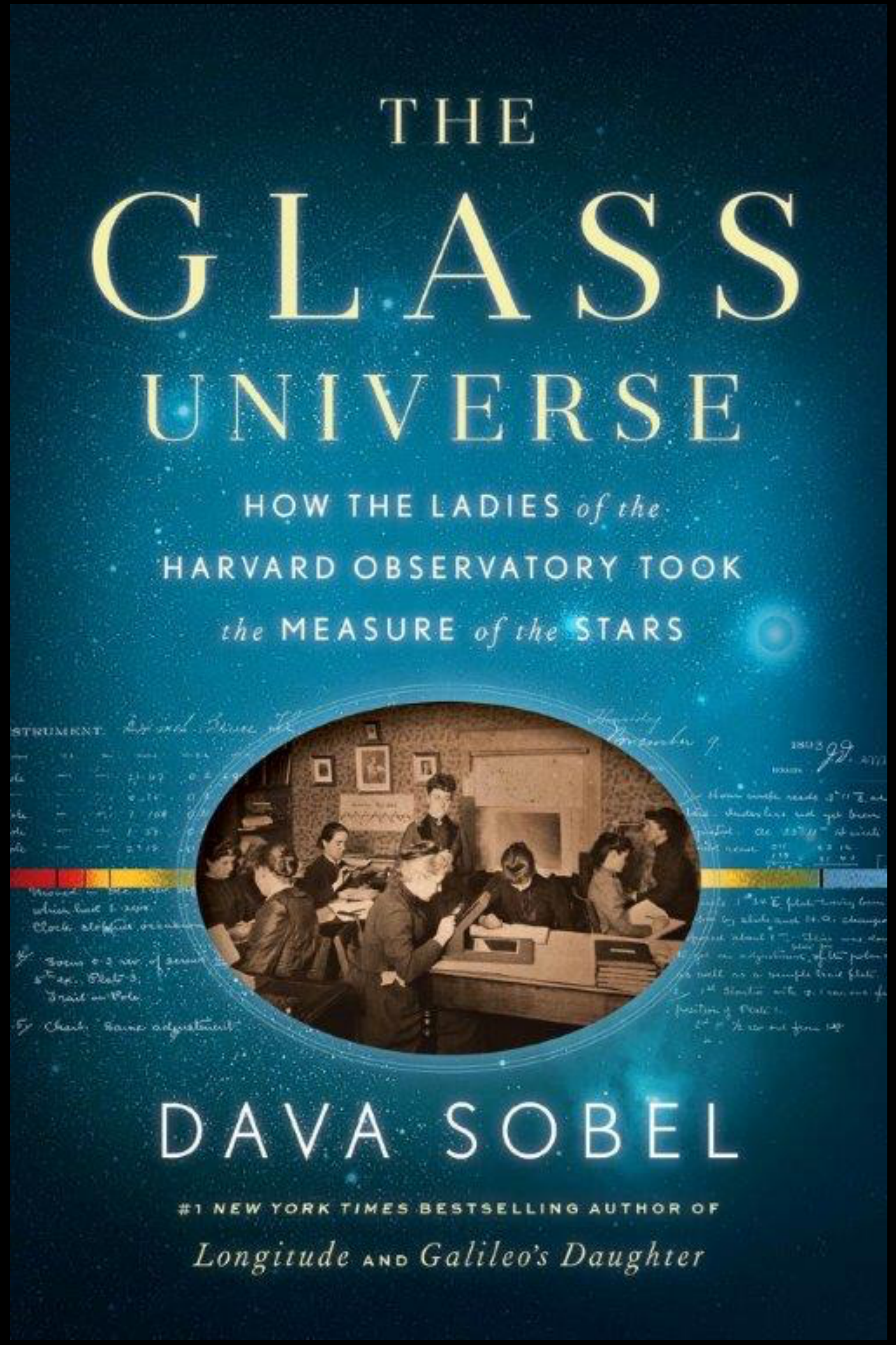
$$\left[\frac{\mathrm{Fe}}{\mathrm{H}}\right] \equiv \log_{10}\left(\frac{\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}}}{\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\odot}}\right)$$

When we say "metal poor" and "metal rich" we are always talking about in relation to the Sun.

Spectral Types

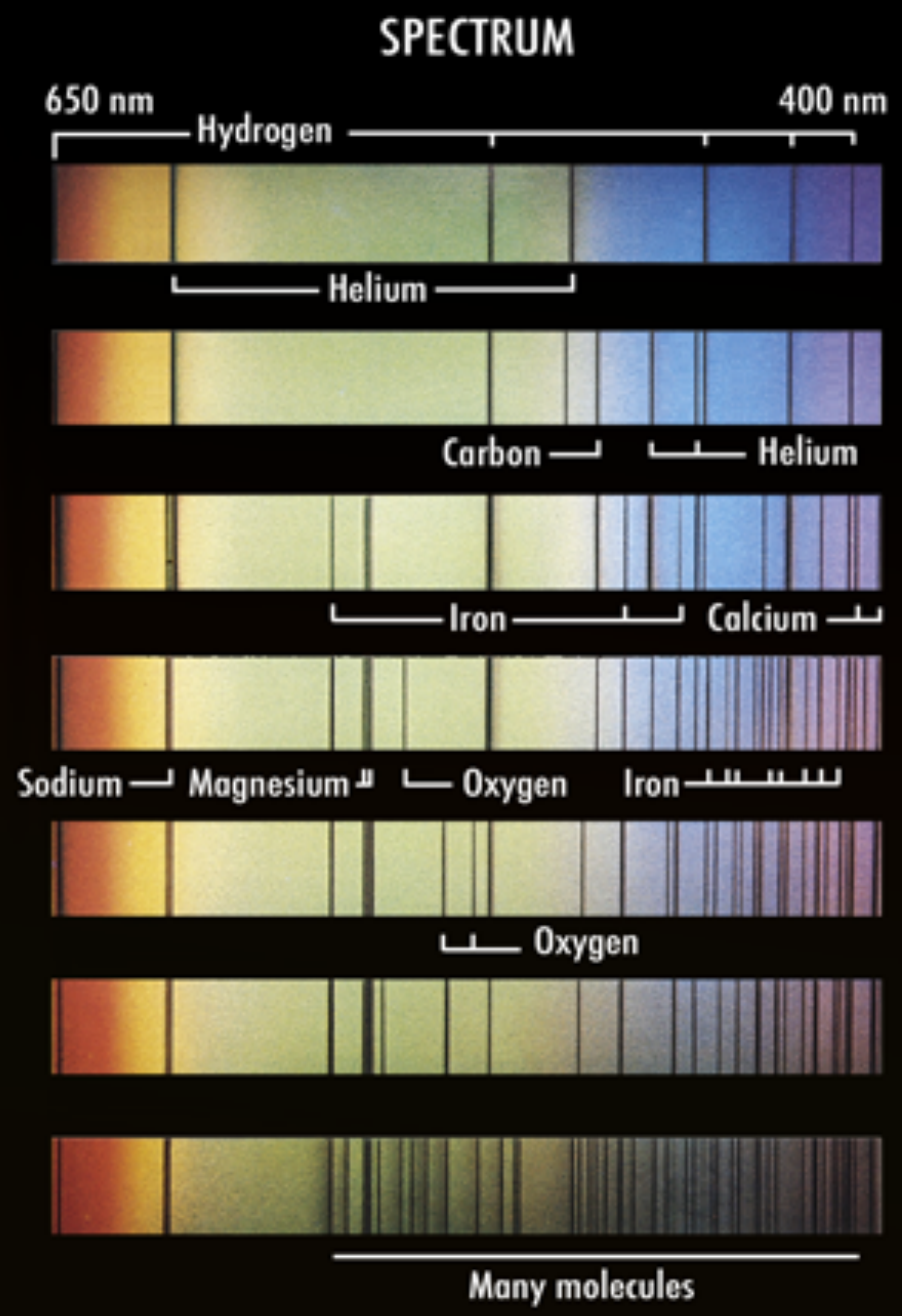
In the 1800s, the director of Harvard's Observatory, Edward Pickering, began a spectroscopic survey of stars in the sky. He employed a team of women to classify these spectra, dubbed the "Harvard Computers." They grouped stars based off features they saw in the spectra, laying the foundation for the modern stellar classification system.





Spectral Types

The original classification was based on the strength of the **Balmer lines** of hydrogen ($n = 2 \rightarrow n > 2$; absorption).



CLASS	COLOR	TEMP. (C°)	HYDROGEN	SIZE(SOLAR R)	% OF ALL
O		>30,000	WEAK	>6.6	~0.00003%
B		9,700 - 30,000	MEDIUM	1.8 - 6.6	0.13%
A		7,200 - 9,700	STRONG	1.4 - 1.8	0.6%
F		5,700 - 7,200	MEDIUM	1.1 - 1.4	3%
G		4,900 - 5,700	WEAK	.9 - 1.1	7.6%
K		3,400 - 4,900	VERY WEAK	.7 - .9	12.1%
M		2,100 - 3,400	VERY WEAK	<.7	76.5%


O6.5
B0
B6
A1
A5
F0
F5
G0
G5
K0
K5
M0
M5

Which of the following spectrum corresponds to the **hottest** star?

A

B

C

D

Which of the following spectrum corresponds to the hottest star?

 0%

 0%

 0%

 0%

Which of the following spectrum corresponds to the hottest star?

21

Which of the following spectrum corresponds to the coolest star?

Which of the following spectrum corresponds to the *coolest* star?

 0%

 0%

 0%

 0%

Which of the following spectrum corresponds to the *coolest* star?

Spectral Types

Annie Jump Cannon brought order to the spectral typing sequence, ordering stars by temperature instead of line strengths.

She removed redundant types that were too similar.

She also created **spectral subtypes** (e.g., G1, A2), where 0=hottest and 9=coldest.

Spectral Types

The current spectral type scheme extends to the coldest brown dwarfs (T type objects).

Sequences are separated by:

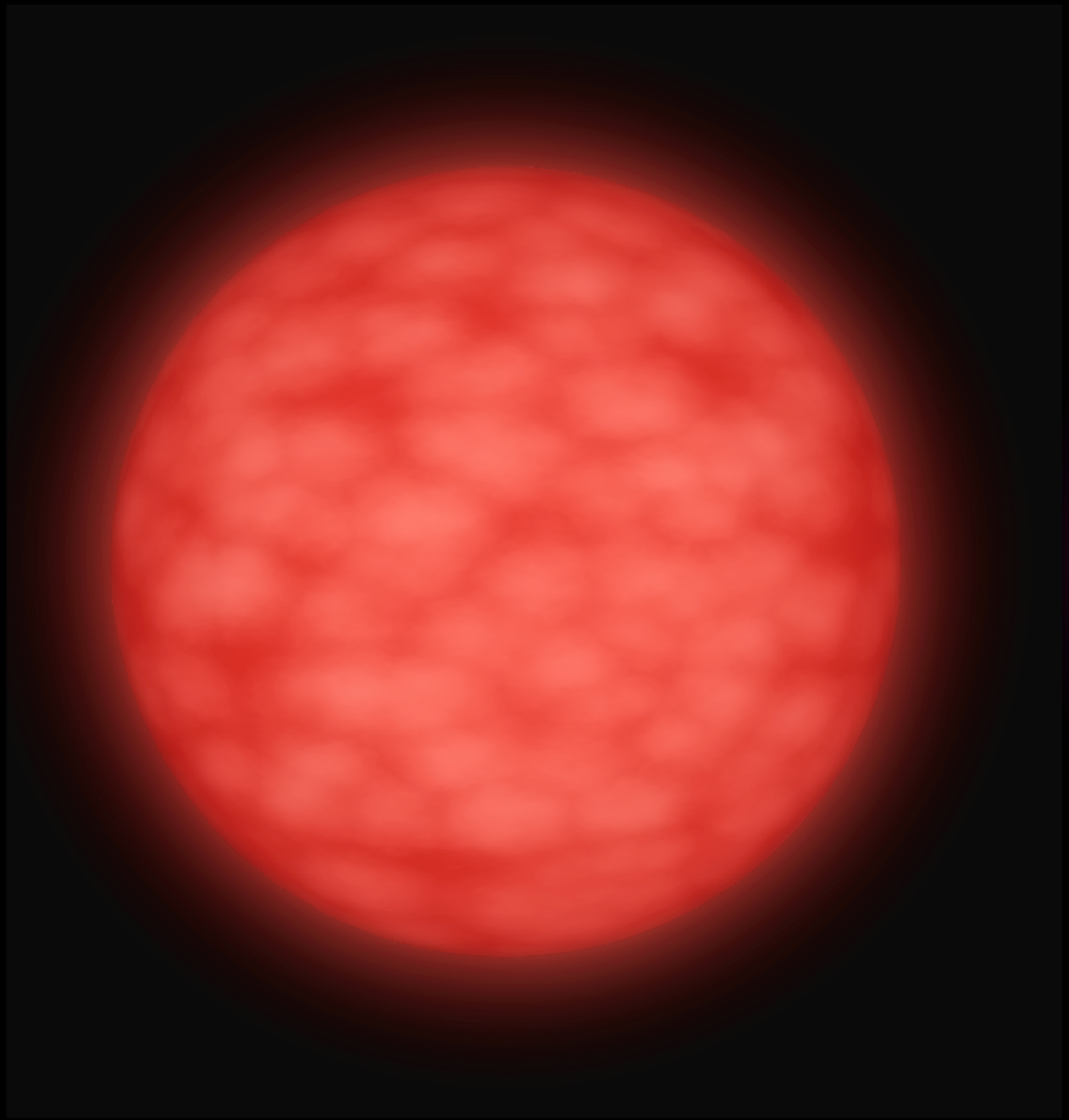
1.) The **strength of spectral lines.**

2.) and and the **appearance of new lines/molecules.**

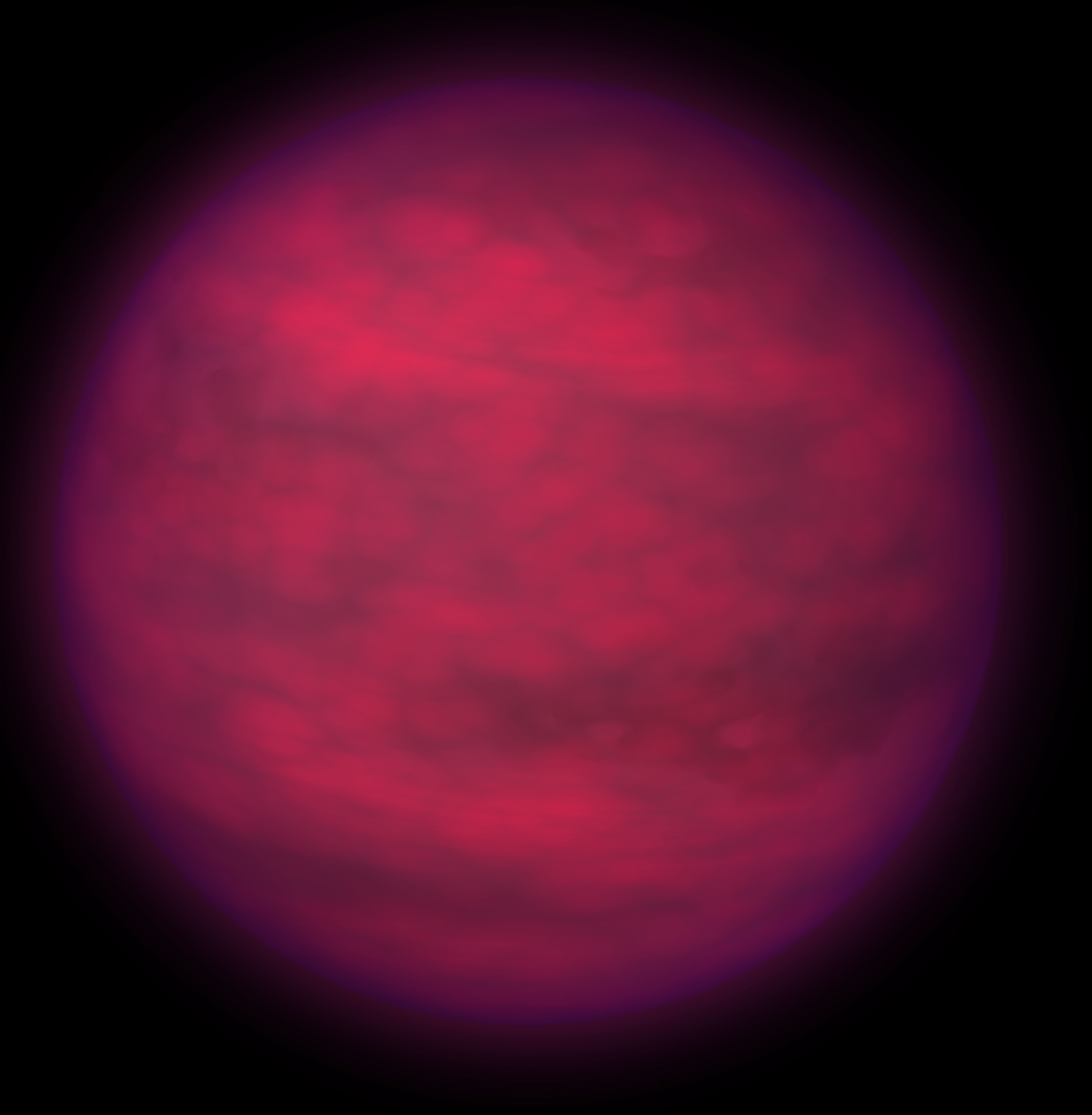
For example, the M sequence represents when molecules are the **dominating absorption feature** (primarily TiO and VO).

Spectral Type	Temperature
O	40,000 K
B	20,000 K
A	9000 K
F	7000 K
G	5500 K
K	4500 K
M	3000 K
L	2000 K
T	$<$ 1300 K

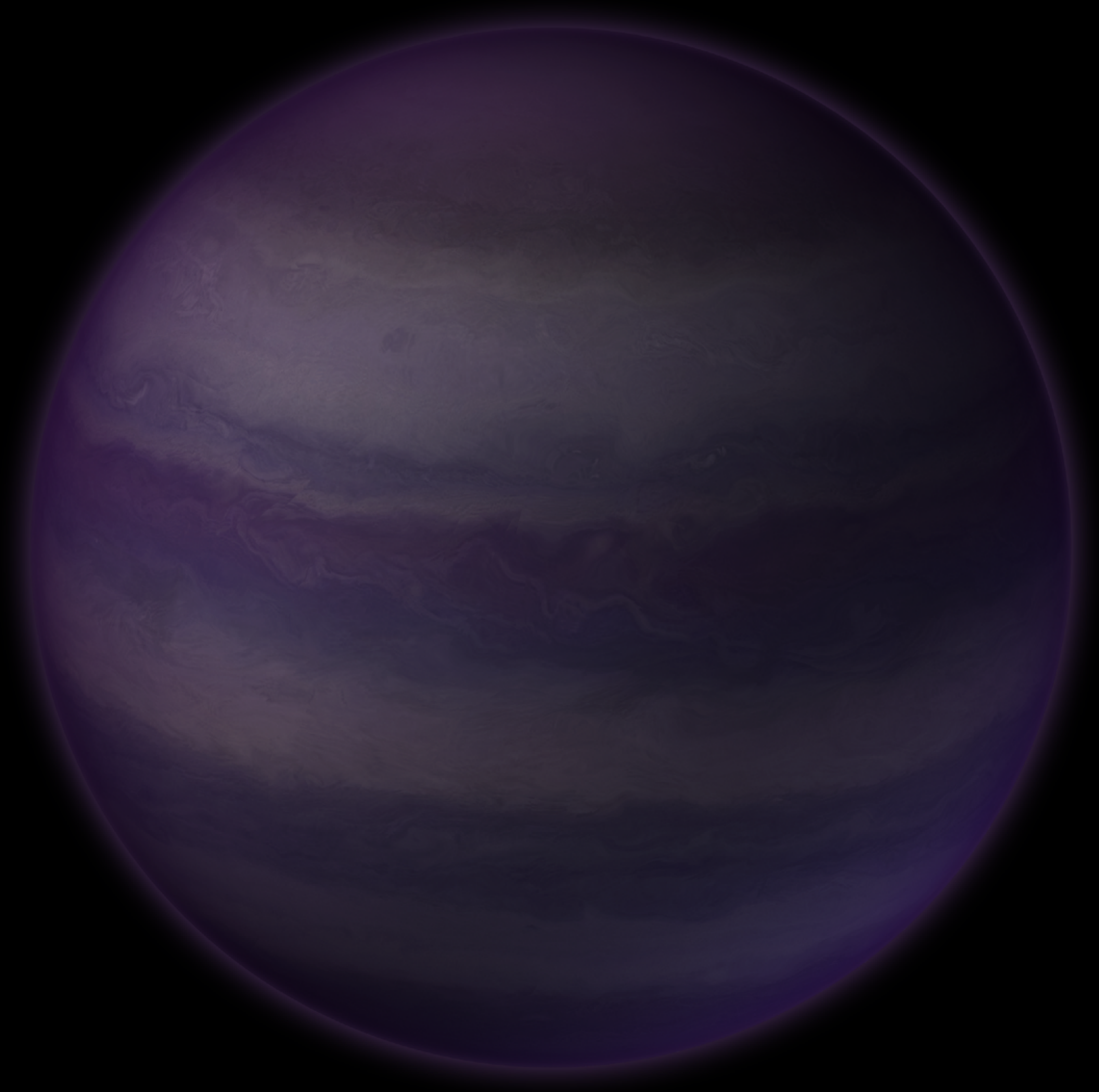
Spectral Types (Brown Dwarfs)



L Dwarf



T Dwarf



Y Dwarf

Brain Break – Think-pair-share

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Nobody has responded yet.

Hang tight! Responses are coming in.

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Oh Boy, A Fine Guy/Girl Kissed Me. Lowkey, Thank You.

6 0

Oh Boy A Fricking Giant Kangaroo Might Leap To You

4 0

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Only big-armed frogs grow kind mice, lemme tell ya

3 0

oh boy a freaky green kite might lie to you

2 0

Operation Bad Apple Keeps Giving Kids Measles Losing Their Youth

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Operation Bad Apple Keeps Giving Kids Measles Losing Their Youth

2 0

Omnidirectional Barracudas Attack Family Gathering Killing Many Little Tiny Yaks

1 0

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Oh Bats Are Freaking Gross Keep Me Leg Thank You (A pirate who's afraid of bats)

1 0

oh be a fine guy/girl kiss my leg thank you

1 0

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Operas beat all film genres. Kyphosis+monocle that's yield!

0 0

Only bananas allowed for Greg, knowing my loyal tortoise, yeah?

0 0

When poll is active respond at PollEv.com/busygalaxy520

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Over Bearing Alpacas Fight Game Knowledge Maybe Let Them Yell

0 0

Oh Boy An F Gonna Kill Me Like The Years (physics be like)

0 0

When poll is active respond at **PollEv.com/busygalaxy520**

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

Oh Boy, a fun guy knows more languages than you

0 0

insert a good mnemonic here

0 0

When poll is active respond at PollEv.com/busygalaxy520

Create a modern mnemonic to remember the spectral sequence: O B A F G K M L T Y

insert a good mnemonic here

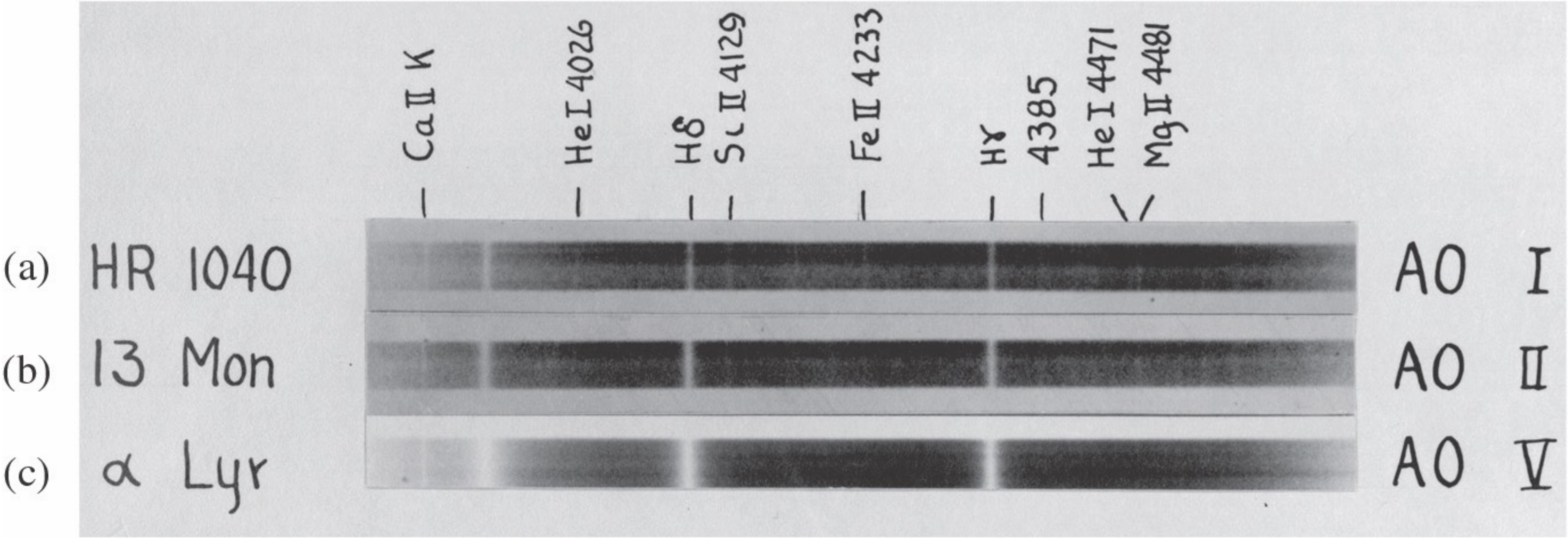
0 0

Otters Be All For Grooming Kindred Mates Like Thanksgiving Yams

0 0

Luminosity Classes

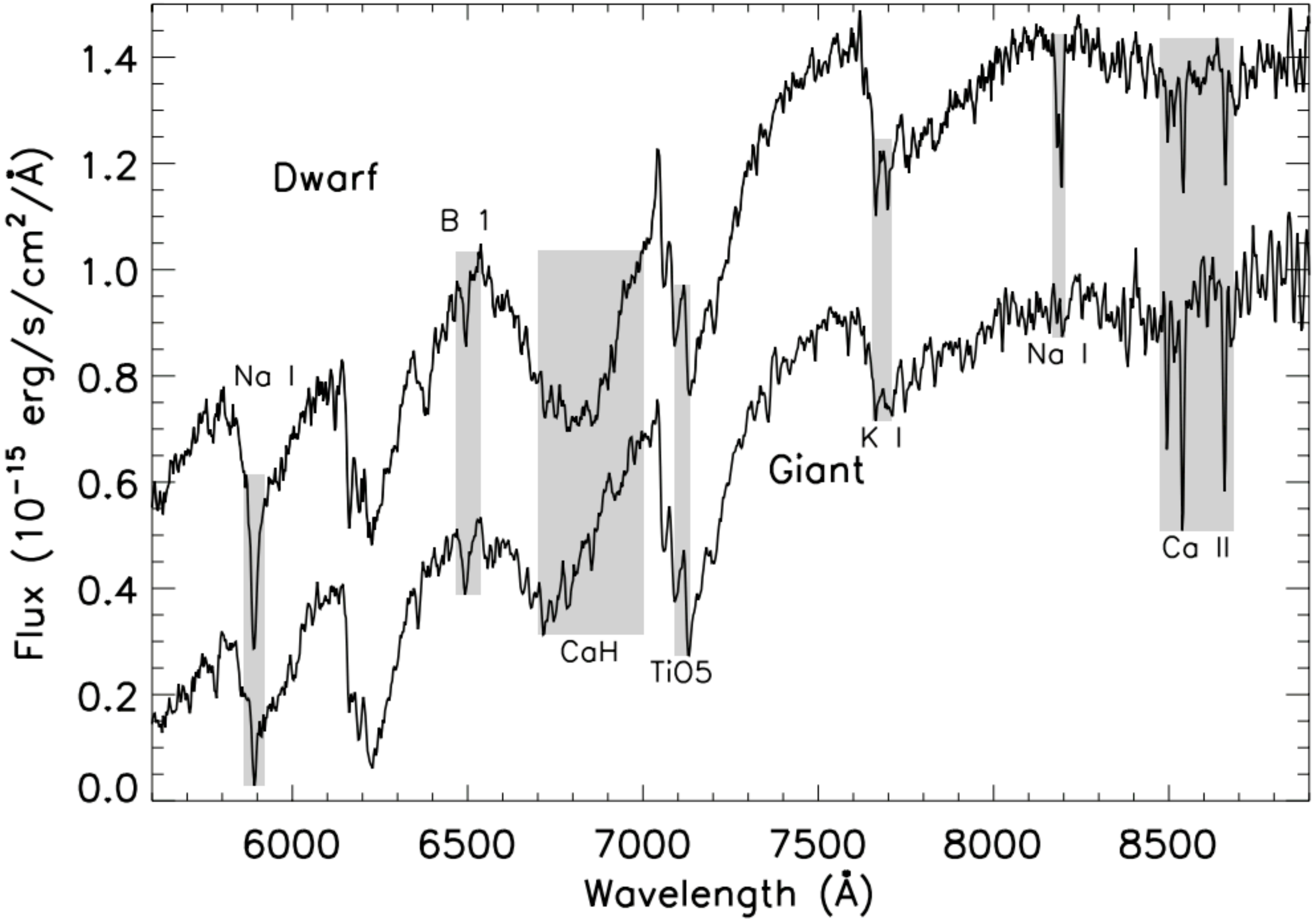
Stars with the **same spectral type** (or surface temperature) can have **different absorption line widths.**

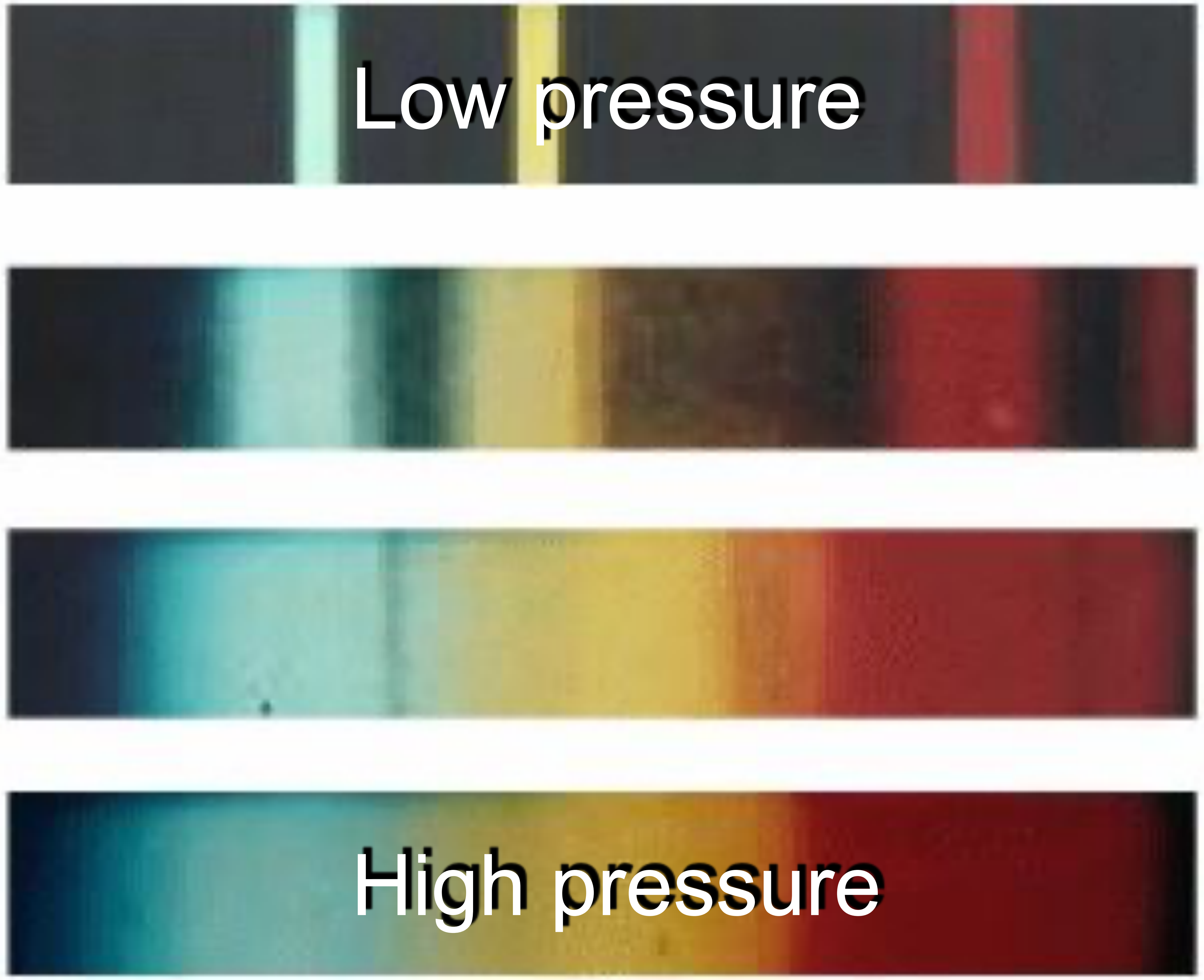


Despite being of spectral type A0, alpha Lyra (or Vega) has much broader absorption lines than HR 1040 13 Mon…. But why?

Luminosity Classes

Due to *pressure broadening (or increase in atomic collision in a high pressure gas)*, larger stars exhibit narrower absorption lines.





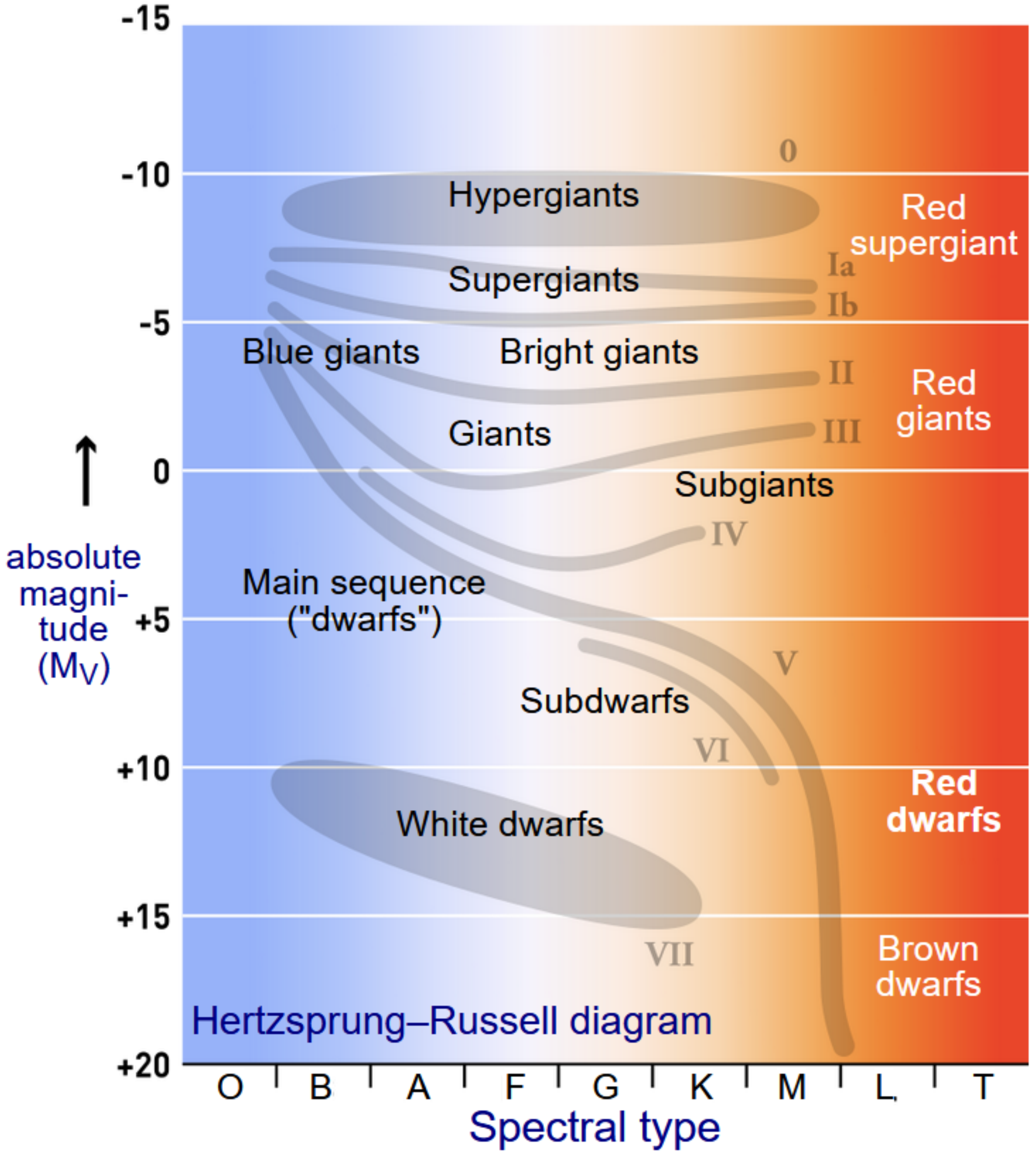
Luminosity Classes

Stars with the **same spectral type** (or surface temperature) can have **different absolute brightnesses**.

We append a Roman numeral to a star's **spectral type** to designate its **luminosity class:**

There are six luminosity classes and they correspond to stars of different radii:

Luminosity Class	Star Size
I	supergiant
II	bright giant
III	giant
IV	subgiant
V	dwarf (main sequence)
VI	subdwarf

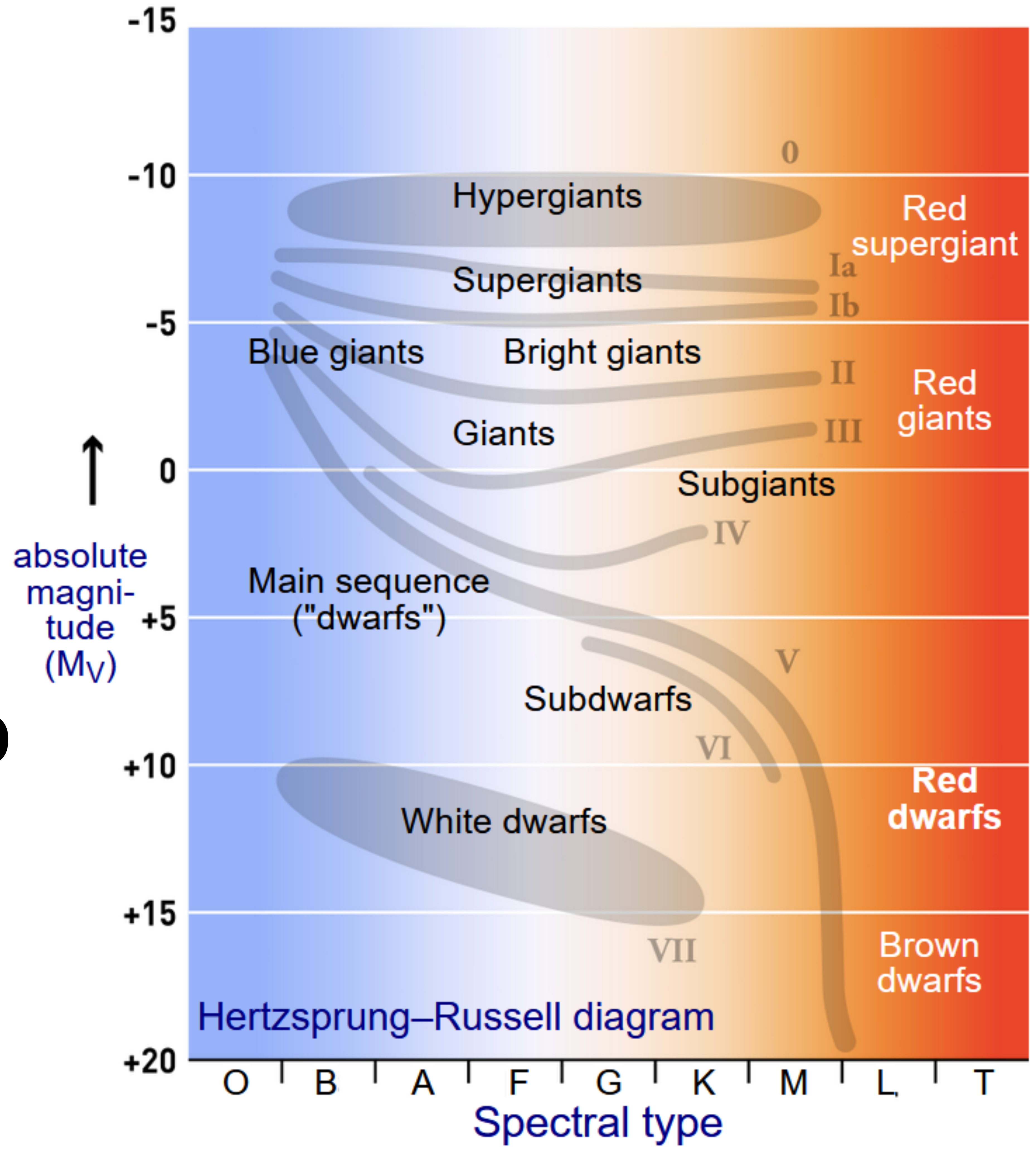


Hertzsprung-Russell Diagrams

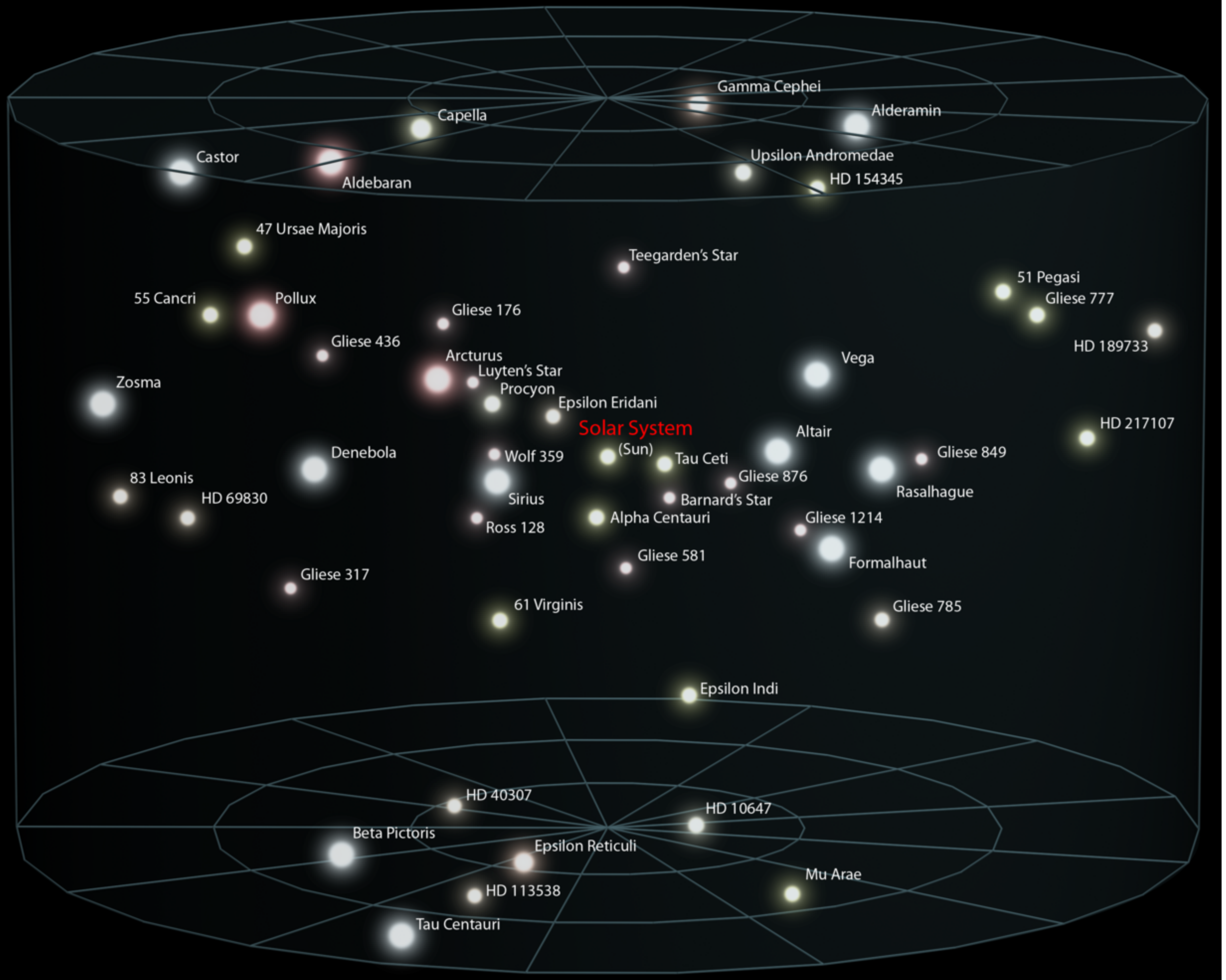
The **main sequence** is defined by stars with luminosity class **V**.

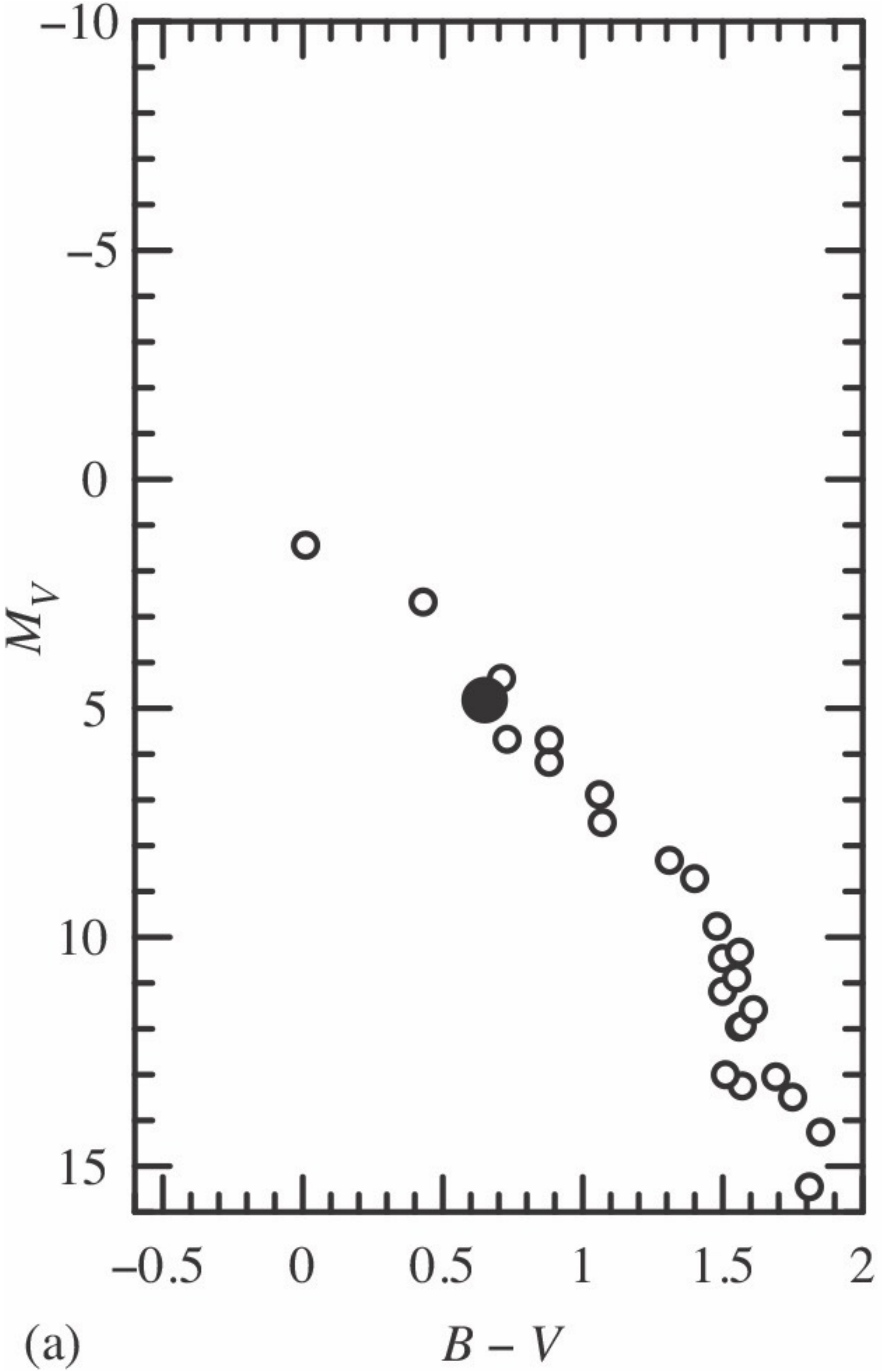
These stars are *relatively* dense, often referred to as *dwarfs* (yes, even the big ones).

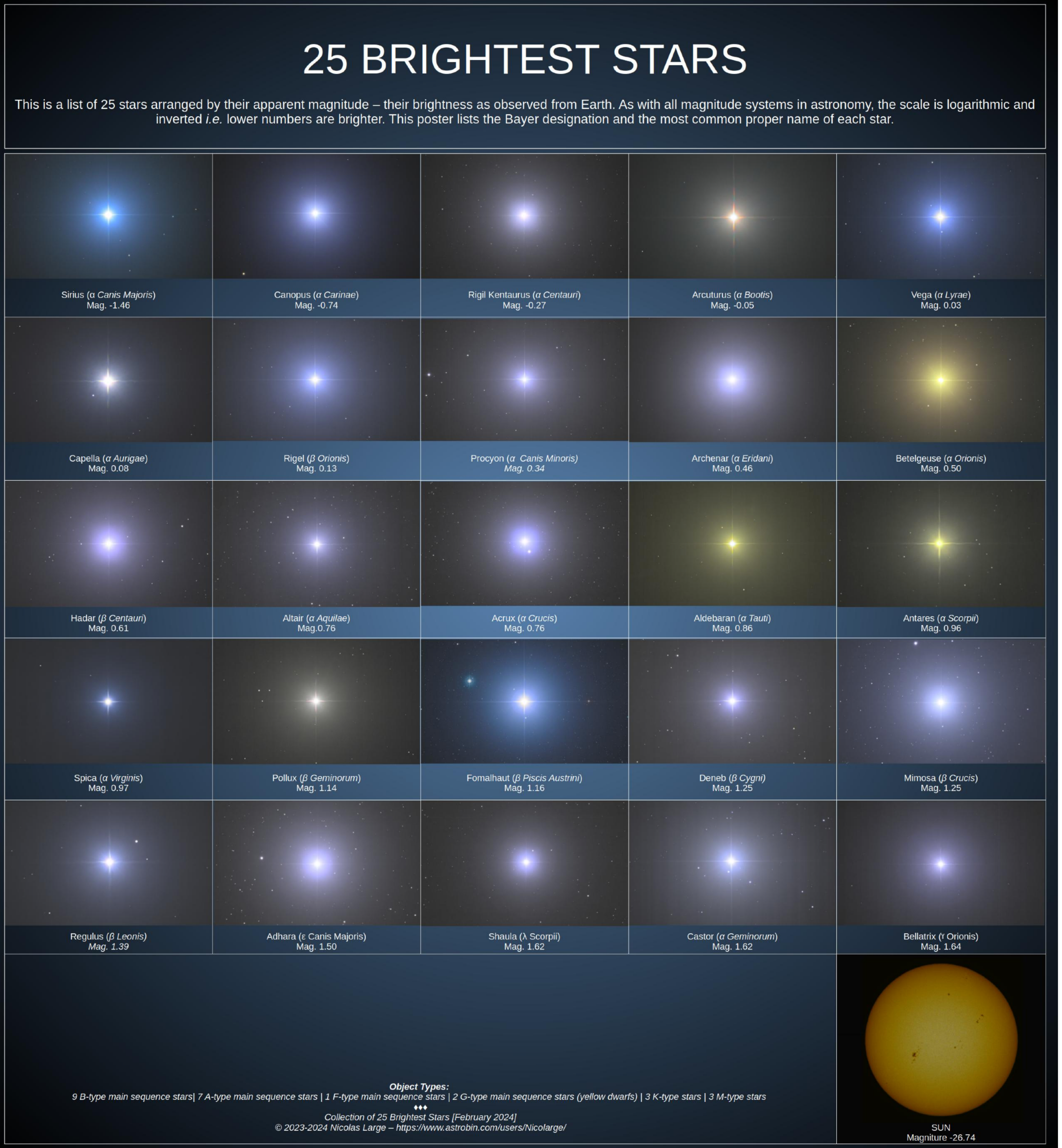
This is where stars fusing hydrogen into helium reside.

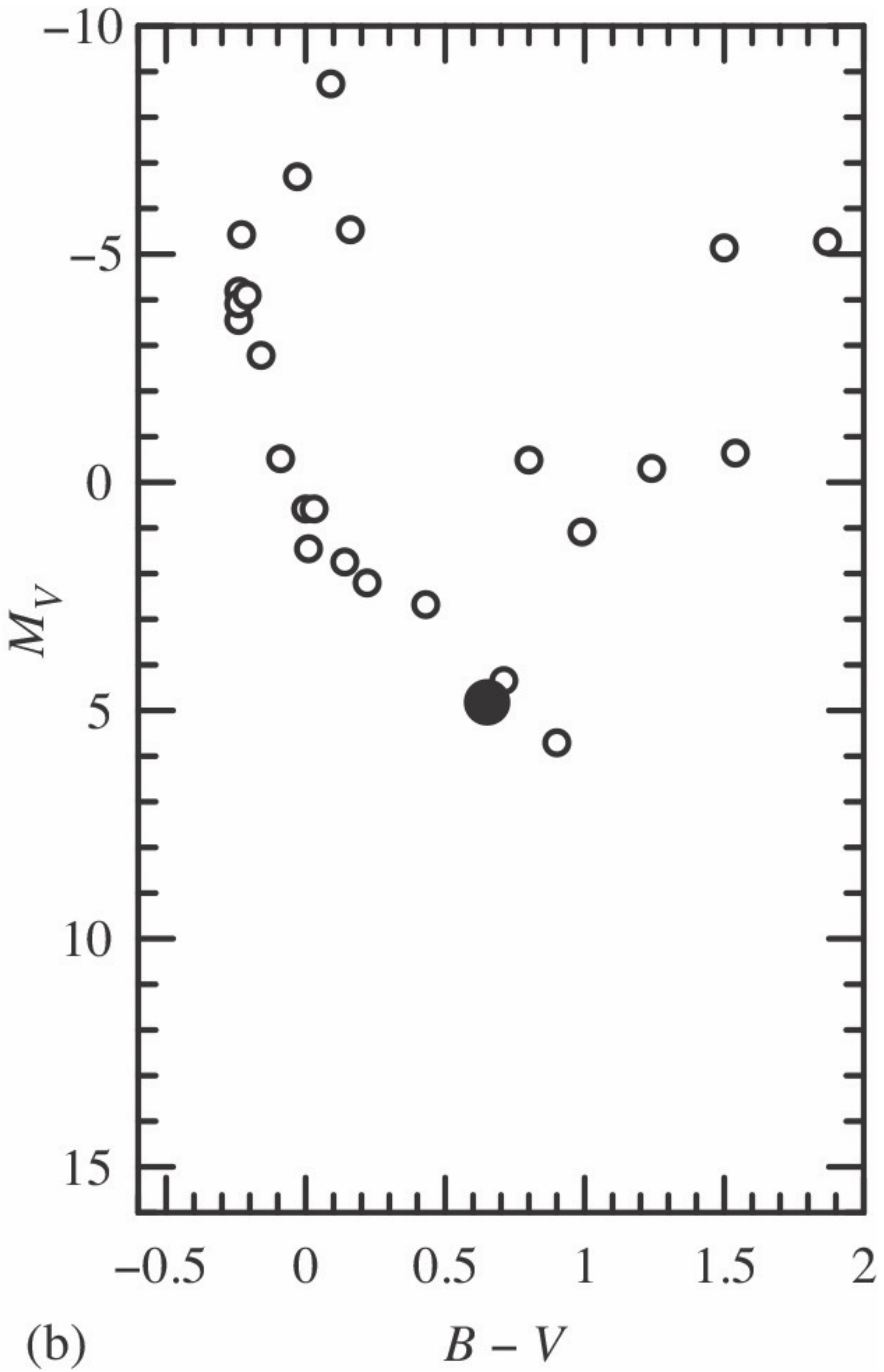


INTERSTELLAR NEIGHBORHOOD






25 BRIGHTEST STARS
This is a list of 25 stars arranged by their apparent magnitude – their brightness as observed from Earth. As with all magnitude systems in astronomy, the scale is logarithmic and inverted i.e. lower numbers are brighter. This poster lists the Bayer designation and the most common proper name of each star.
Sirius (α Canis Majoris) Mag. -1.46
Canopus (α Carinae) Mag. -0.74
Rigil Kentaurus (α Centauri) Mag. -0.27
Arcuturus (α Bootis) Mag. -0.05
Vega (α Lyrae) Mag. 0.03
Capella (α Aurigae) Mag. 0.08
Rigel (β Orionis) Mag. 0.13
Procyon (α Canis Minoris) Mag. 0.34
Archenar (α Eridani) Mag. 0.46
Betelgeuse (α Orionis) Mag. 0.50
Hadar (β Centauri) Mag. 0.61
Altair (α Aquilae) Mag.0.76
Acrux (α Crucis) Mag. 0.76
Aldebaran (α Tauti) Mag. 0.86
Antares (α Scorpii) Mag. 0.96
Spica (α Virginis) Mag. 0.97
Pollux (β Geminorum) Mag. 1.14
Fomalhaut (β Piscis Austrini) Mag. 1.16
Deneb (β Cygni) Mag. 1.25
Mimosa (β Crucis) Mag. 1.25
Regulus (β Leonis) Mag. 1.39
Adhara (ε Canis Majoris) Mag. 1.50
Shaula (λ Scorpii) Mag. 1.62
Castor (α Geminorum) Mag. 1.62
Bellatrix (γ Orionis) Mag. 1.64
SUN Magniture -26.74
Object Types:
9 B-type main sequence stars| 7 A-type main sequence stars | 1 F-type main sequence stars | 2 G-type main sequence stars (yellow dwarfs) | 3 K-type stars | 3 M-type stars
♦♦♦
Collection of 25 Brightest Stars [February 2024]
© 2023-2024 Nicolas Large – https://www.astrobin.com/users/Nicolarge/


−10
−5
0
5
10
15
M_V
−0.5
0
0.5
1
1.5
2
(b)
$B - V$

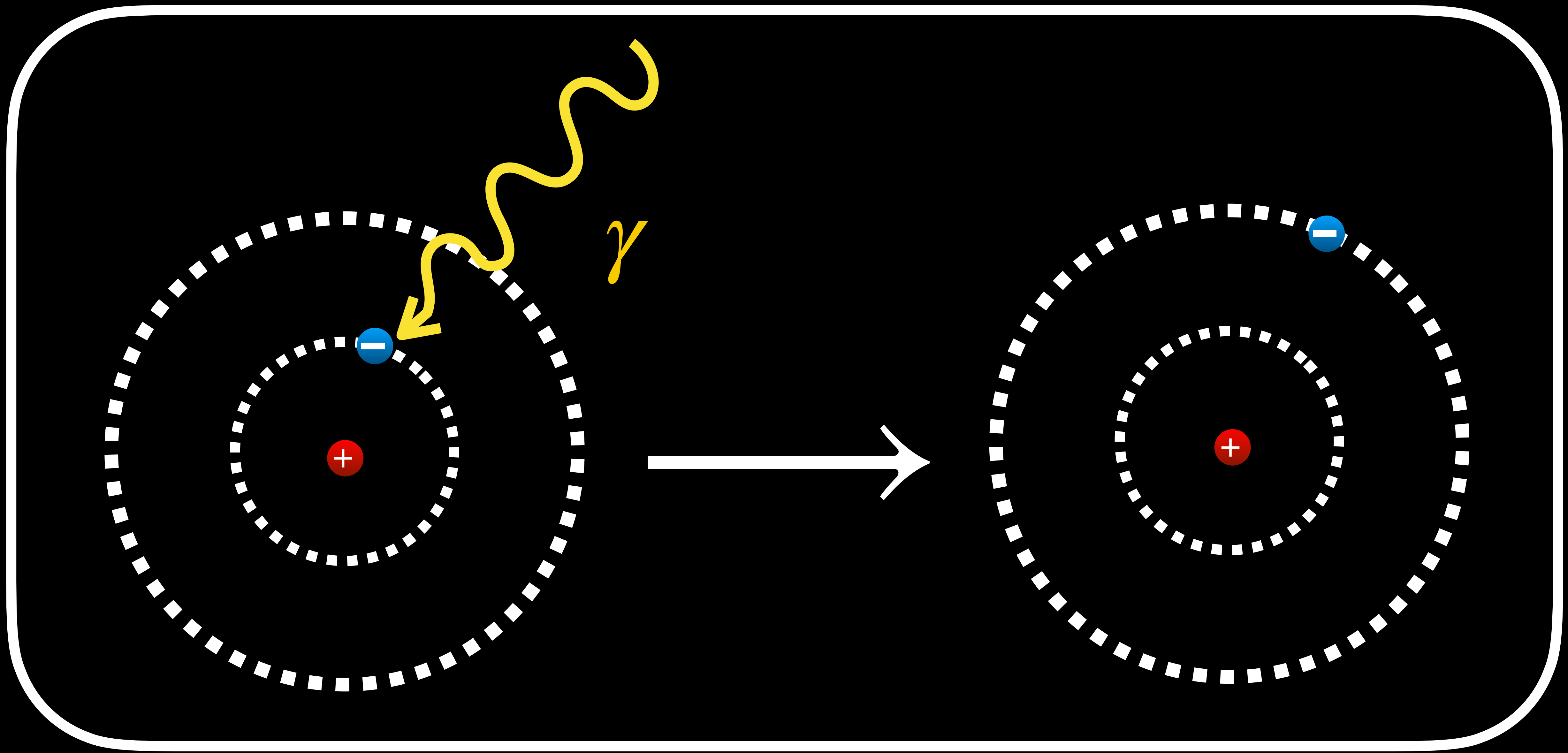
Opacity

(or why a photon doesn't make it out)

When a photon is emitted from the center of a star, it has to make a long journey to exit to space and arrive at Earth. Along the way, many things can happen.

Bound-bound transition:

An electron moves between two bound energy levels in an atom, absorbing or emitting a photon (γ) in the process.



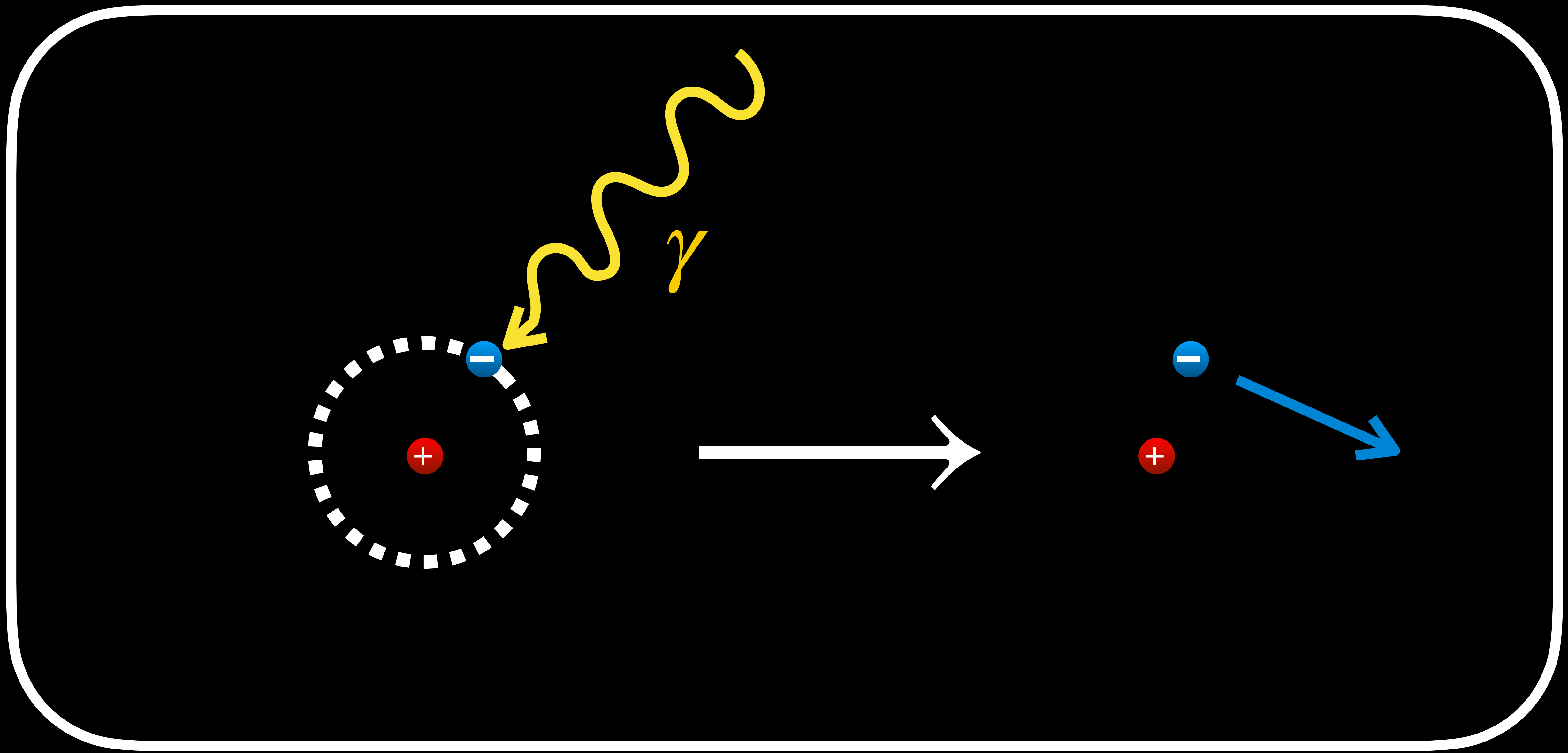
Opacity

(or why a photon doesn't make it out)

When a photon is emitted from the center of a star, it has to make a long journey to exit to space and arrive at Earth. Along the way, many things can happen.

Bound-free transition:

An atom absorbs a photon and has enough energy to ionize (or kick out an electron).

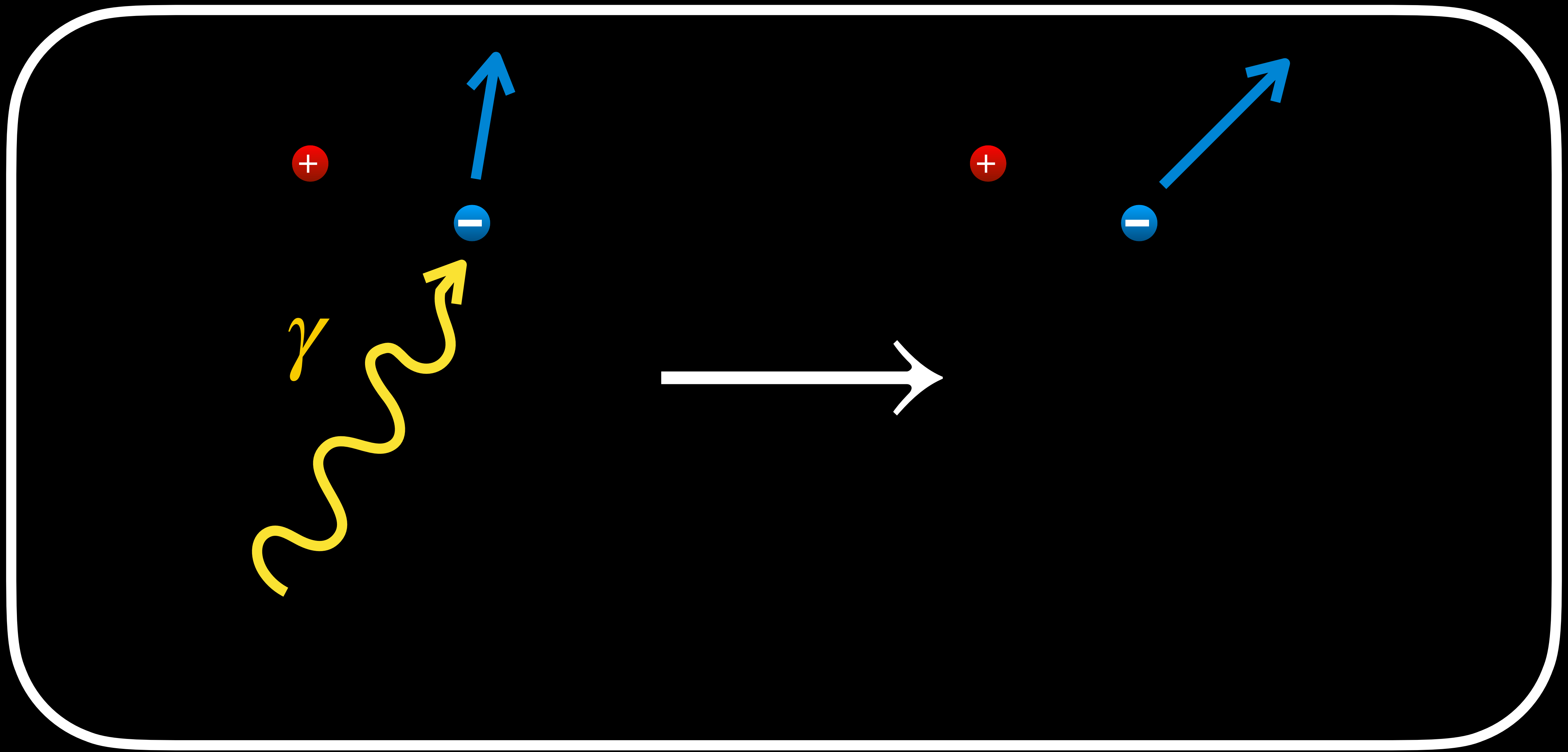


Opacity
(or why a photon doesn't make it out)

When a photon is emitted from the center of a star, it has to make a long journey to exit to space and arrive at Earth. Along the way, many things can happen.

Free-free transition:

An electron absorbs a photon and gains kinetic energy.



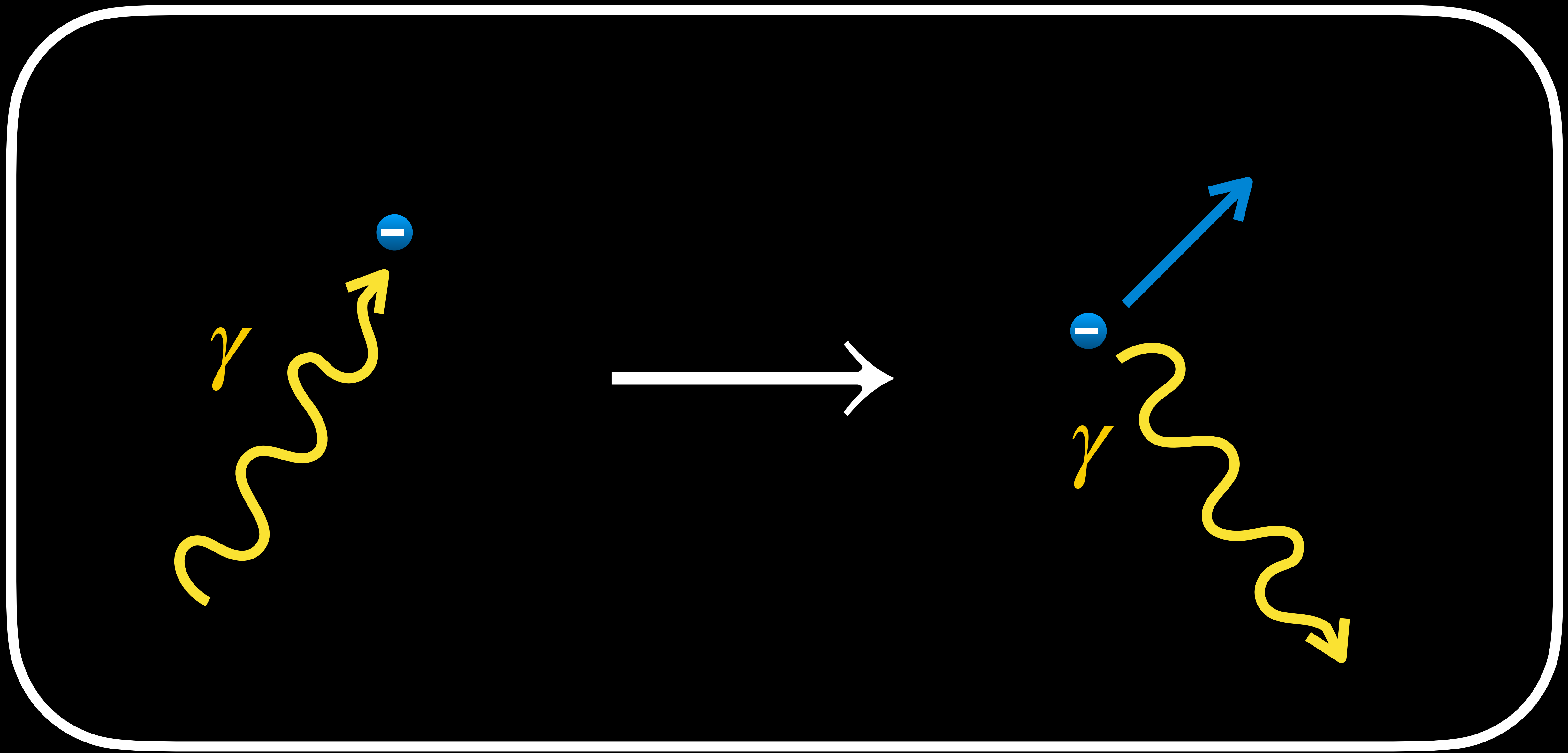
Opacity

(or why a photon doesn't make it out)

When a photon is emitted from the center of a star, it has to make a long journey to exit to space and arrive at Earth. Along the way, many things can happen.

Electron Scattering:

A low-energy photon scatters off a free or weakly bound electron, changing the photon's direction (and possibly energy).

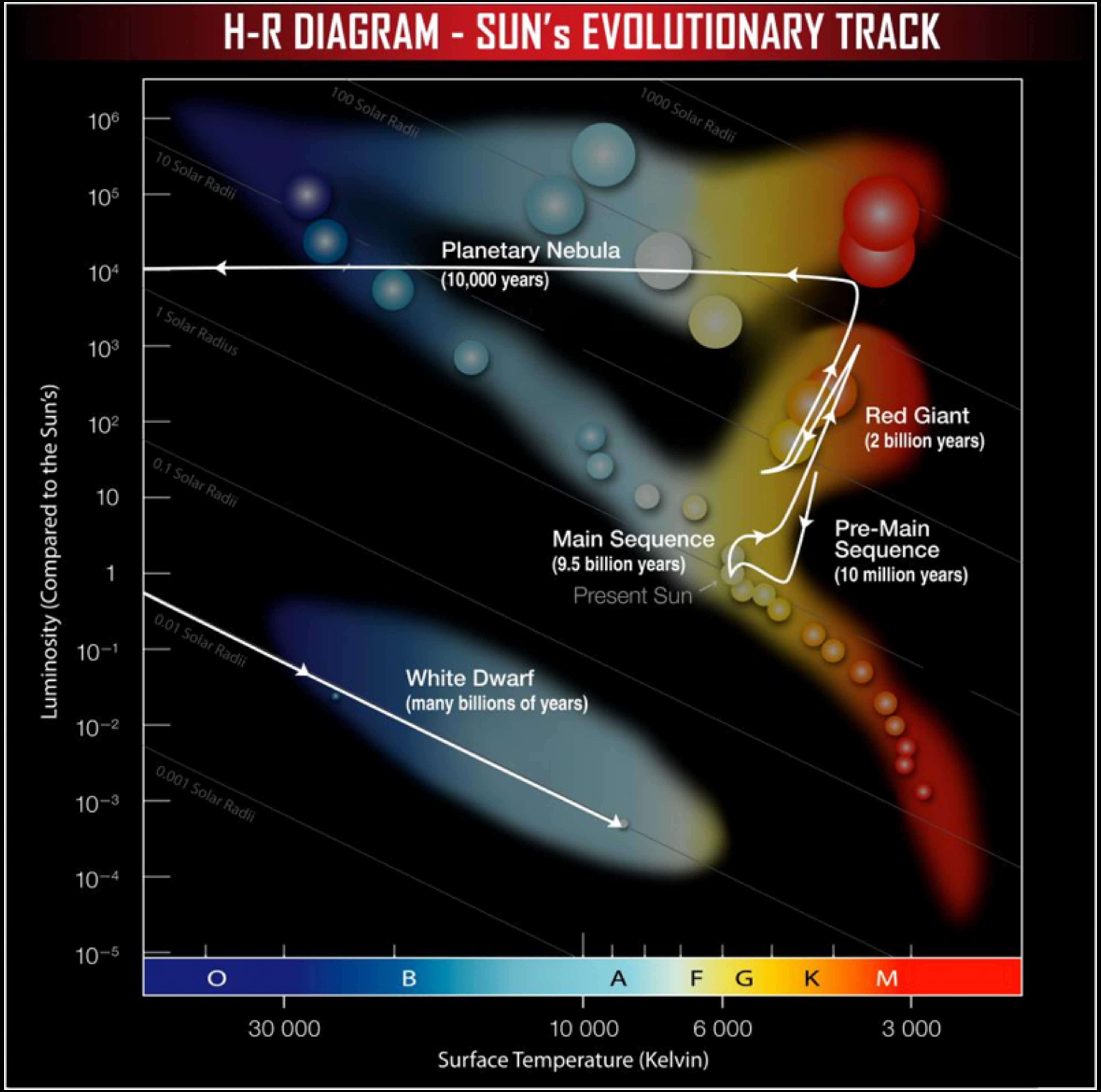


Lifecycle of the Sun

Stars move off the main sequence after they have fused a sufficient amount of Hydrogen into Helium in their cores and there is **not enough gas pressure to support against gravitational collapse.**

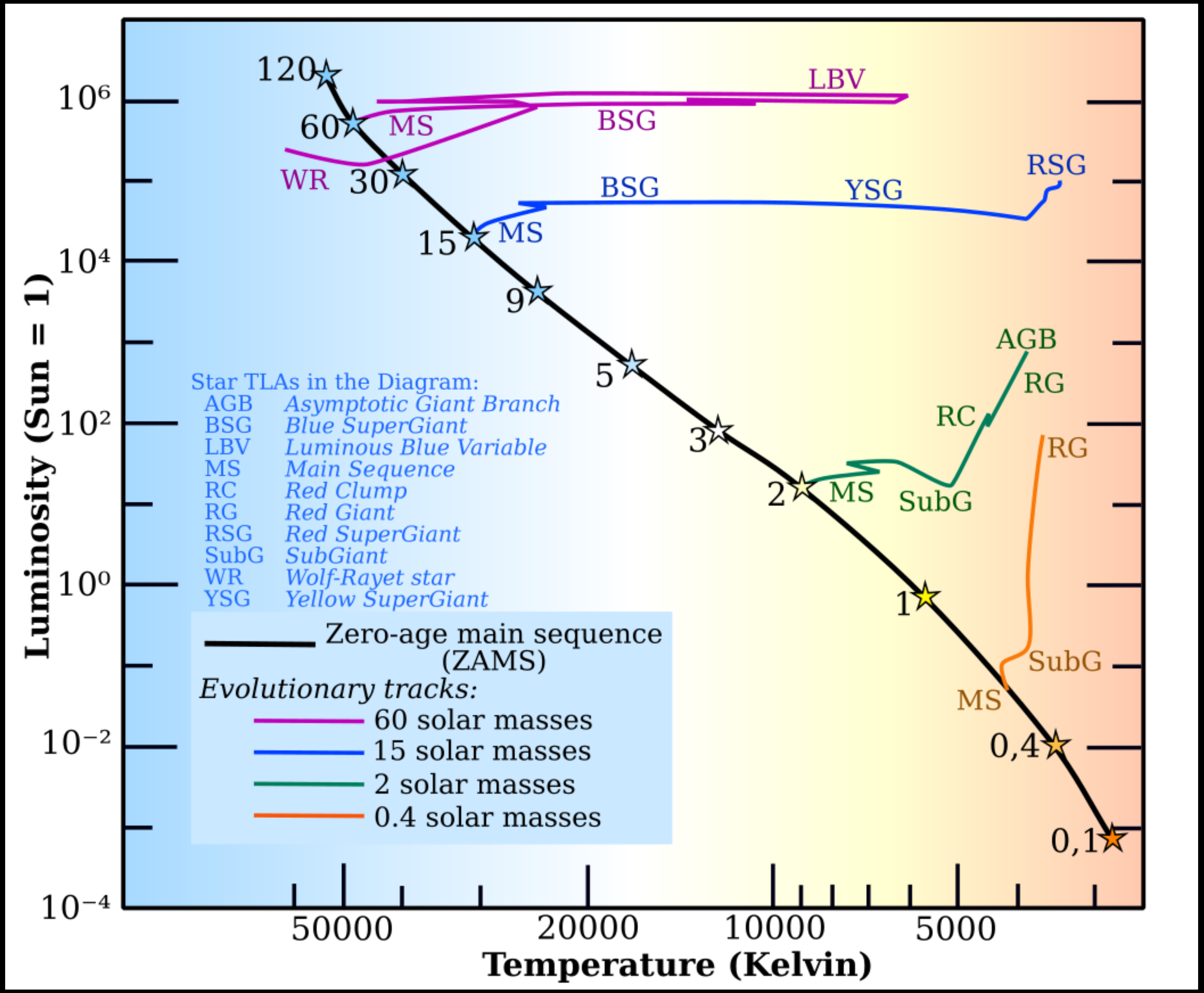
Main sequence stars of different masses follow different evolutionary tracks….

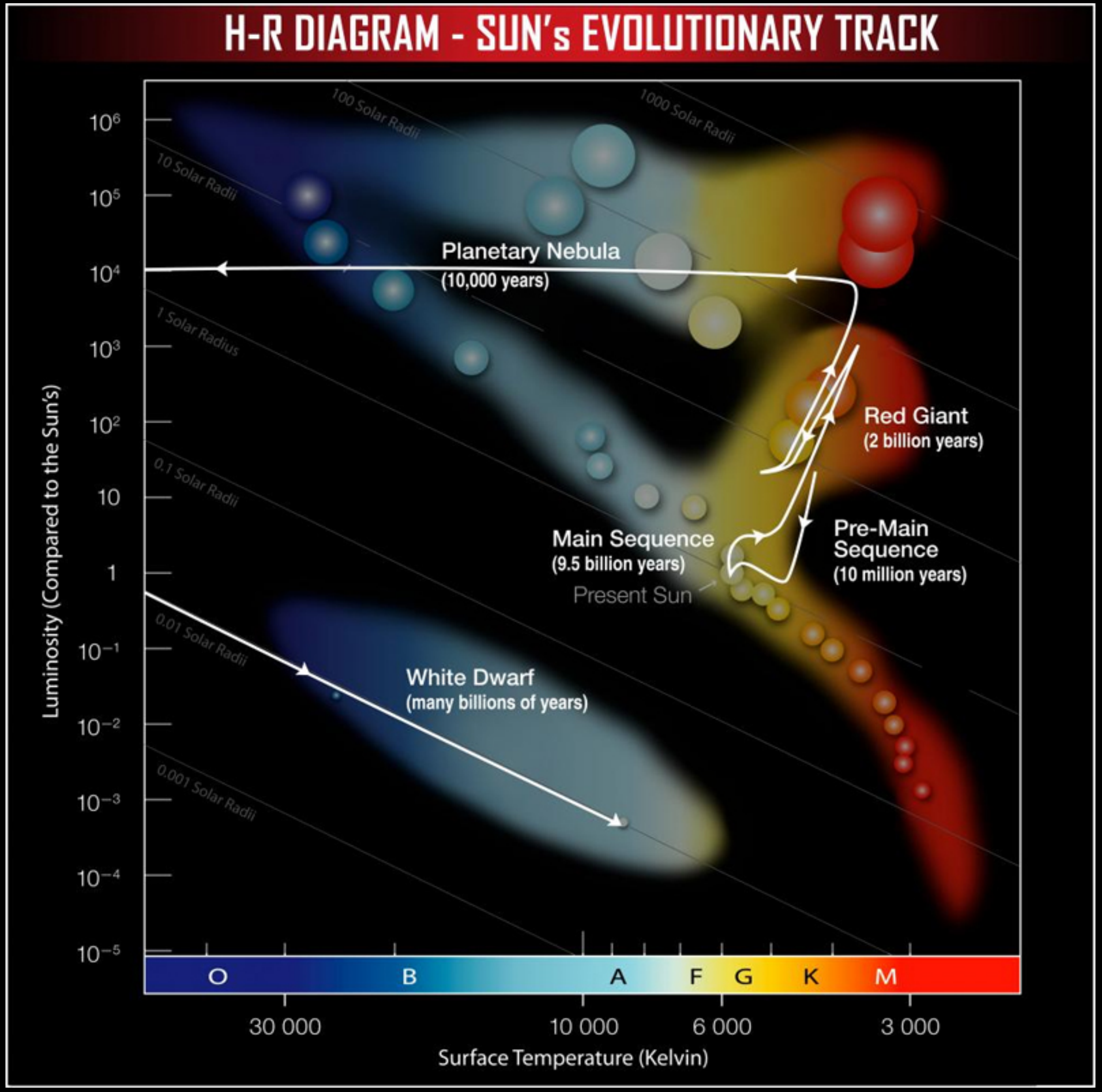
To be continued in 20B!



Stars <u>don't</u> evolve along the main sequence!

One important point to remember is that although the Sun will evolve across the H–R diagram over its lifetime, it does **not** move upward along the main sequence.





Student Evaluation of Teaching (SET)

- The Student Evaluation of Teaching Survey is available until **Saturday, December 6 at 8:00 AM.**

- Please provide comments and constructive feedback before the deadline.

- Your response are *anonymous*
  - *I can only see the percentage of students who have completed it.*

Reminders

- **HW #8 will be due Thursday, 12/04 by 11:59 pm.**
- **Final Exam is Thursday, 12/11 from 3:00pm-5:59pm.**
- Log into canvas and submit your answer to the discussion question by the end of the day to receive participation credit.