Chapter 10: Measuring Stars

Chapter 10 Reading Assignment due today at 10:45am

Chapter 11 Reading Assignment due Tuesday, October 1st

Are your grades in Canvas correct???

Planetarium Extra Credit Opportunity!
(see the syllabus)

Sept. 26th or 28th at 6:45 pm for the “Night Vision” show at the Clark Planetarium

Free tickets available from me, $2 otherwise

What's easy to measure for stars?

- Their positions on the celestial sphere
- Their spectra (brightness as a function of wavelength)

- ~Changes in position and spectrum~

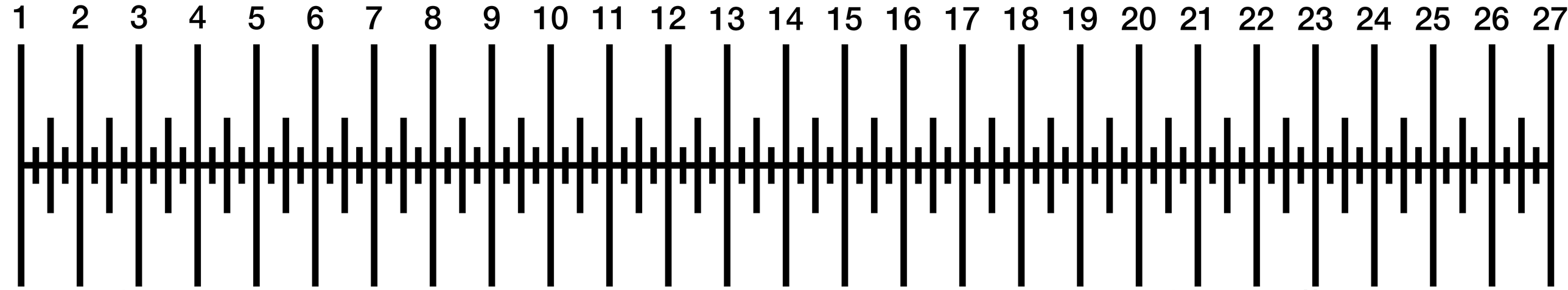
What's hard to measure for stars?

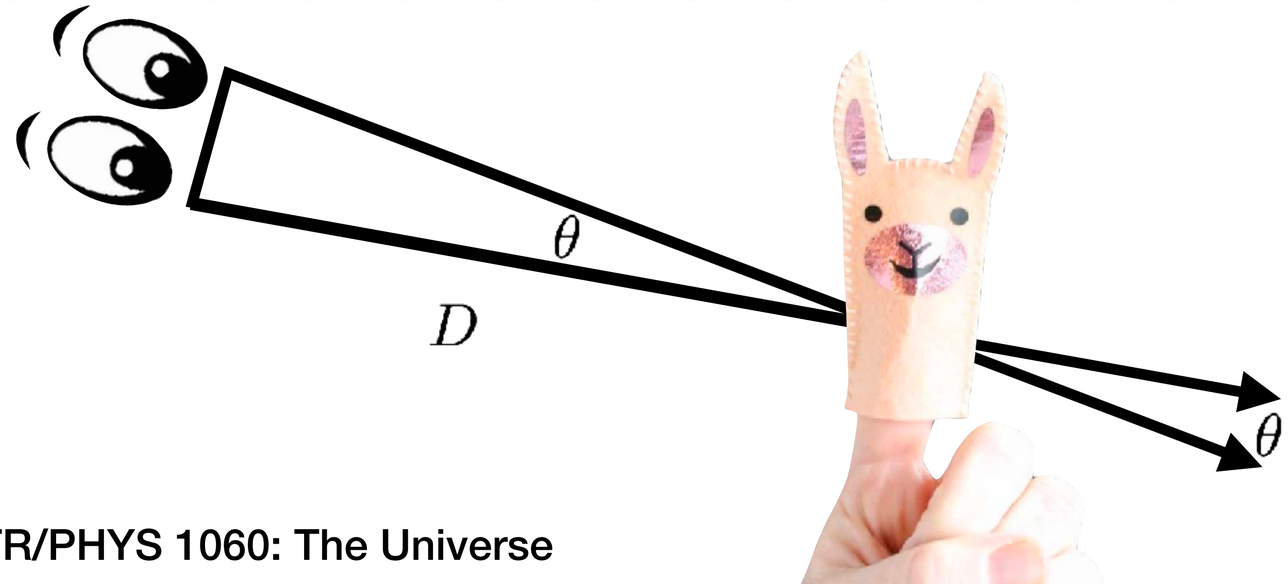
- Their distance
- Their size (resolving them)
- Their mass

How do we measure distances on the Earth?

Parallax

1) Calibration: hold your pinky finger at arm's length, close one eye, and measure its width (this is about 1 degree in angle)

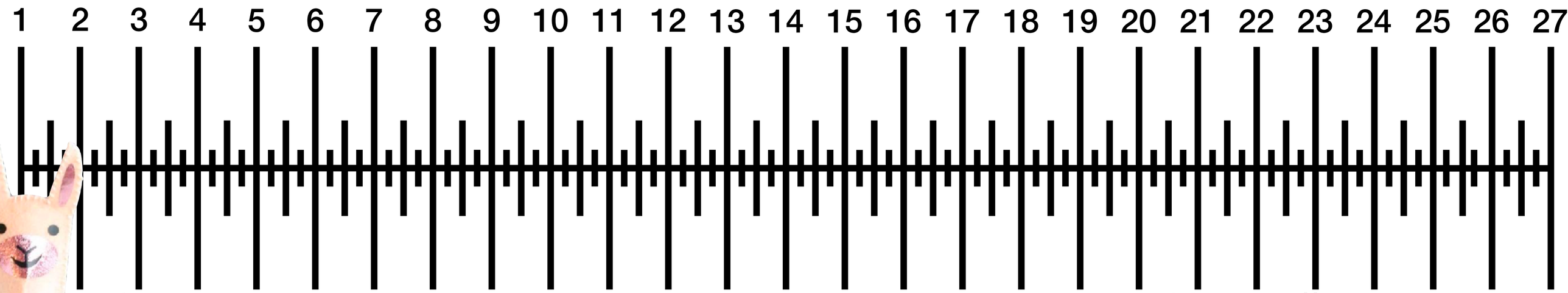


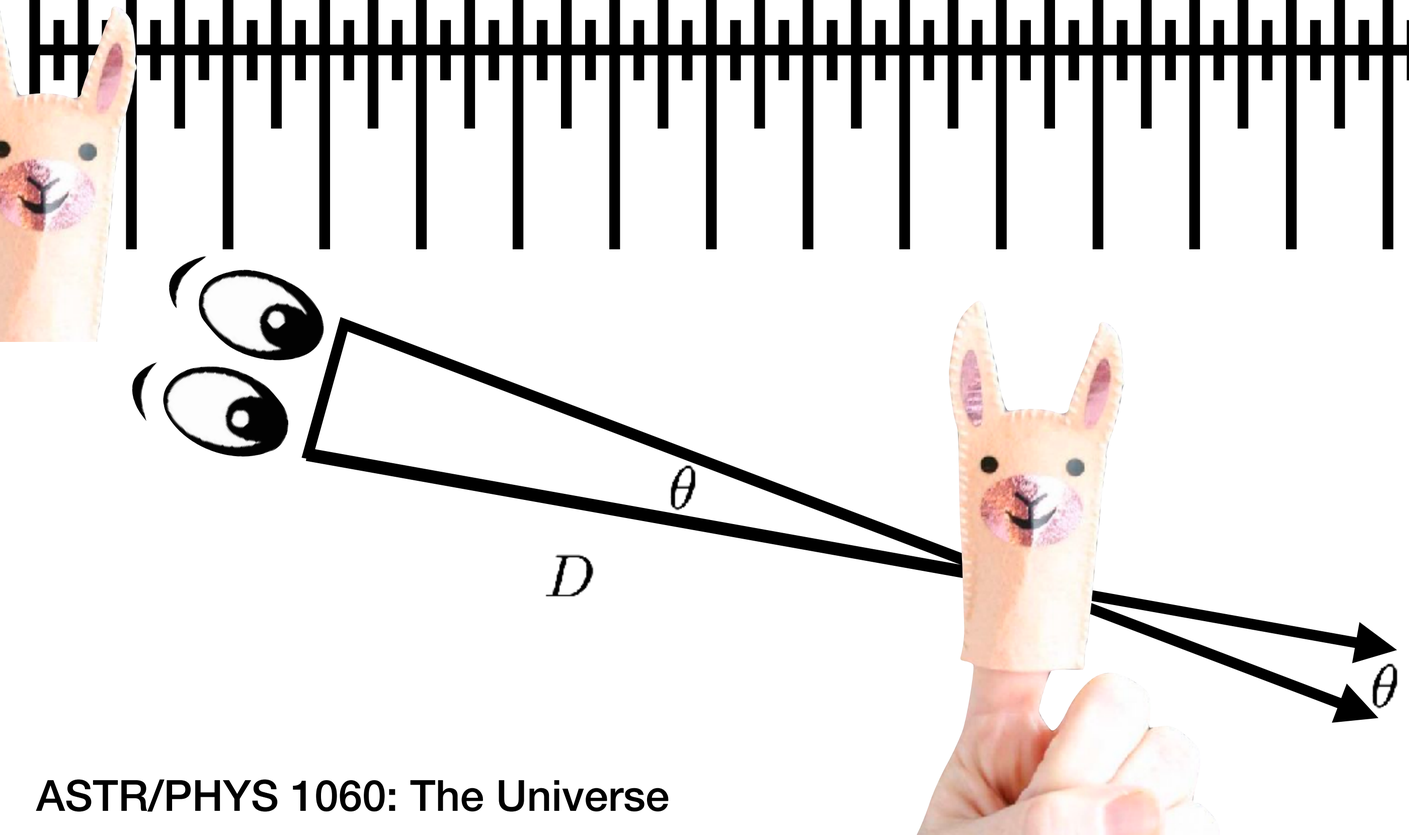


Example: Cuzco is about 1.5 units long

Parallax

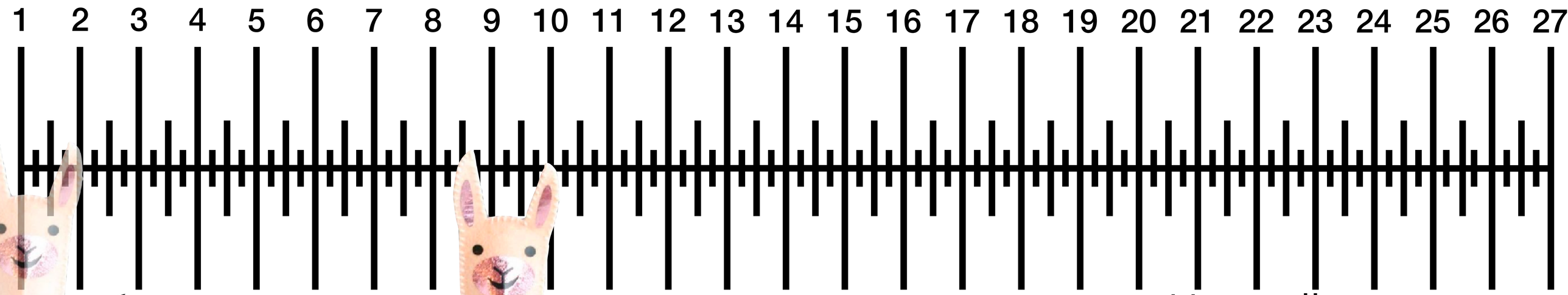
2) Close your left eye and center a finger or pen on the “1” line

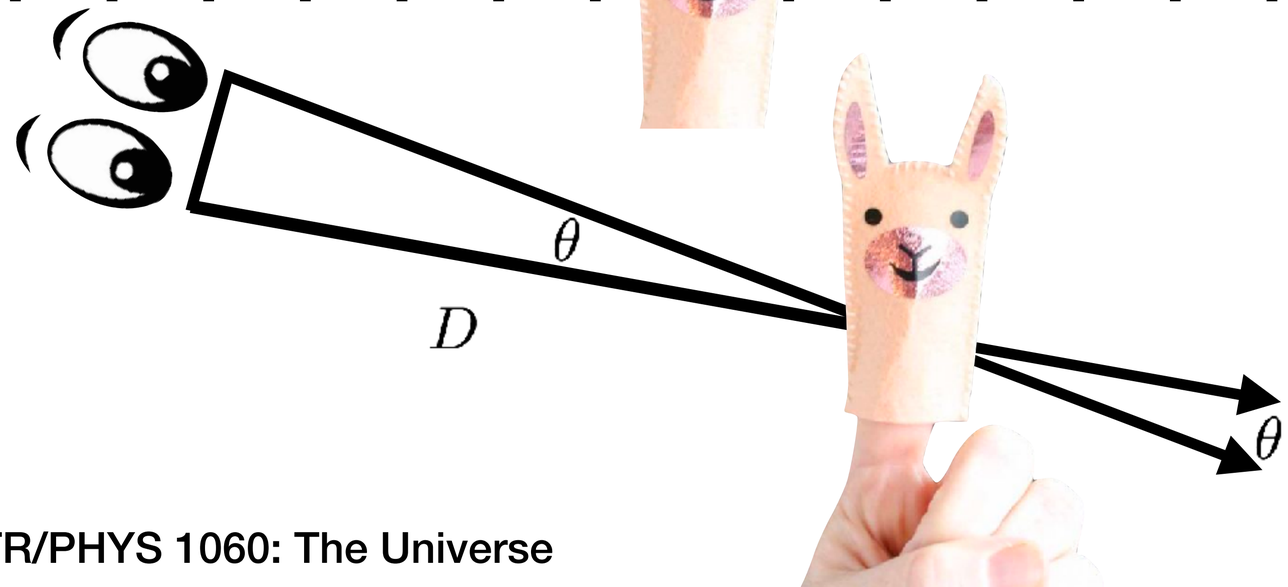




Parallax

3) Open your left eye, close your right eye, and measure how far your finger moved

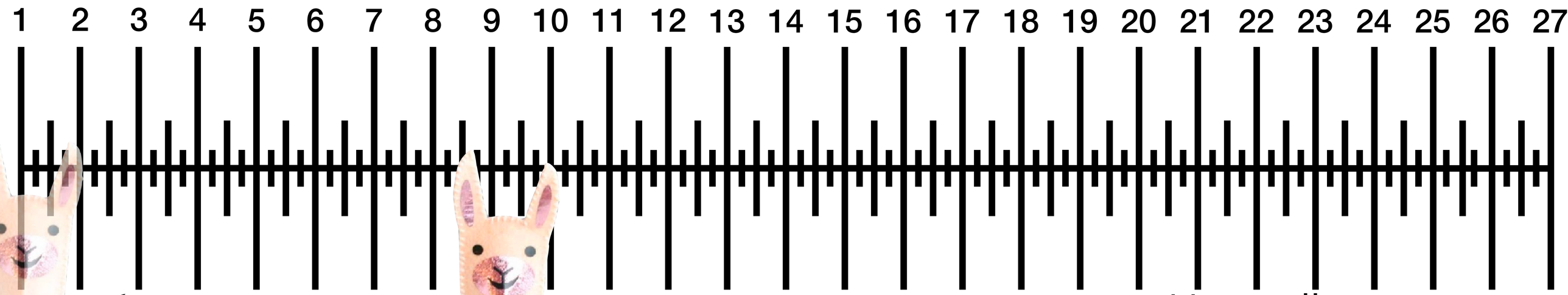


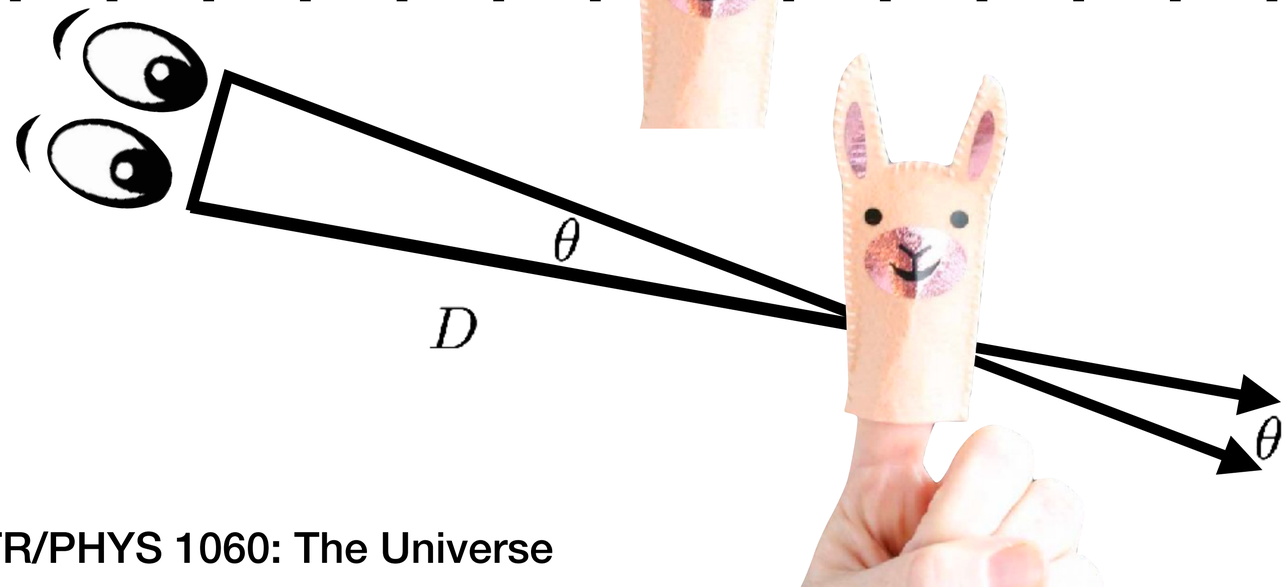


Example: Cuzco appeared to move 9.25 units

Parallax

4) Divide the apparent movement by the width of your pinky to get the angle in degrees

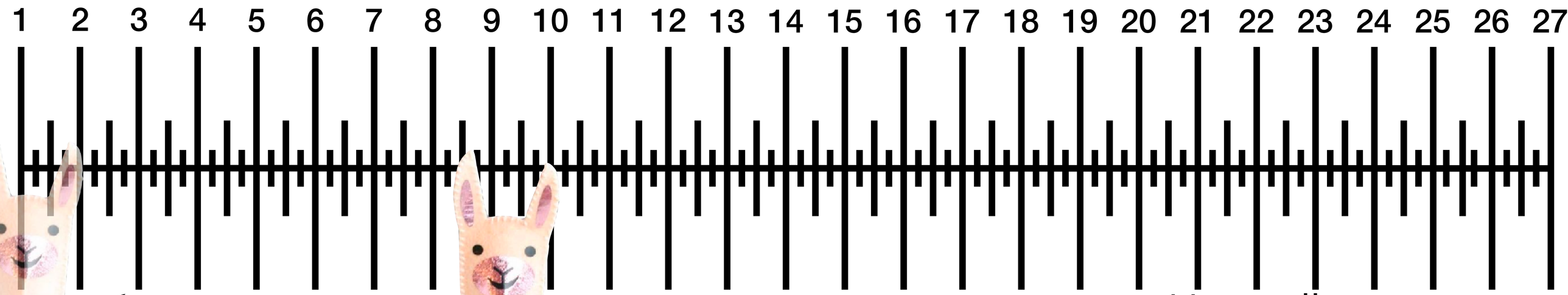


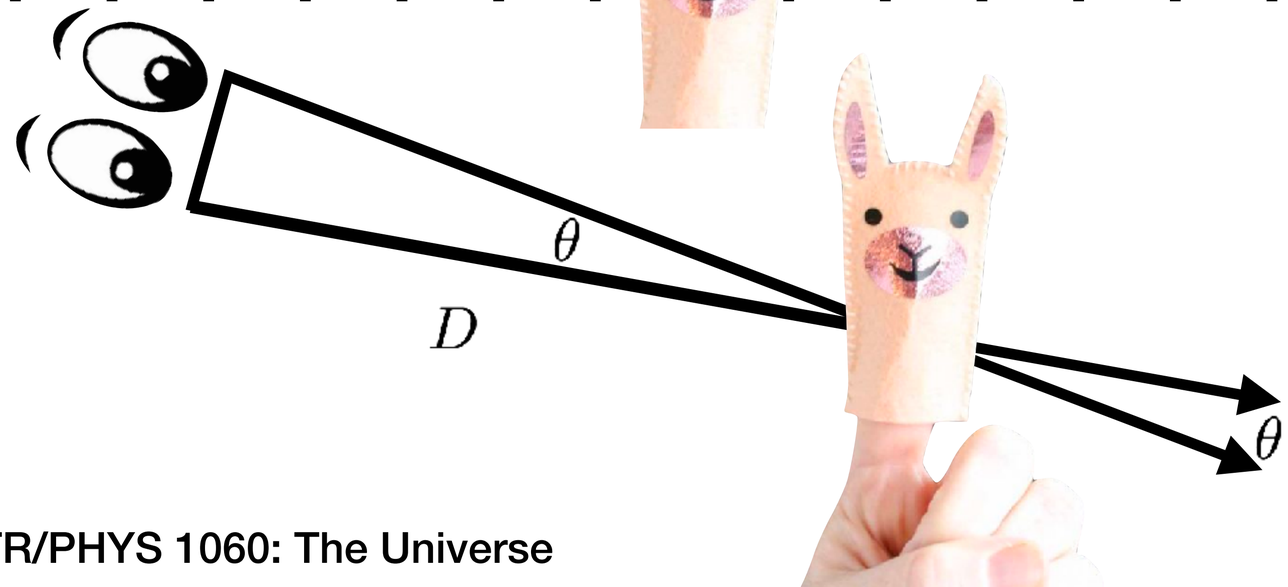


Example: 9.25 / 1.5 = 6.2 degrees

Parallax

5) Divide 110 inches by the number of degrees to get the distance to your finger!

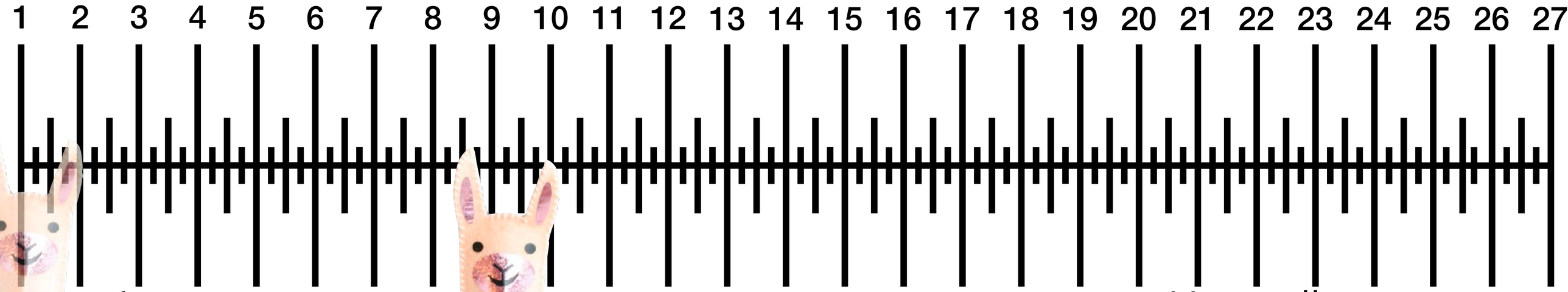


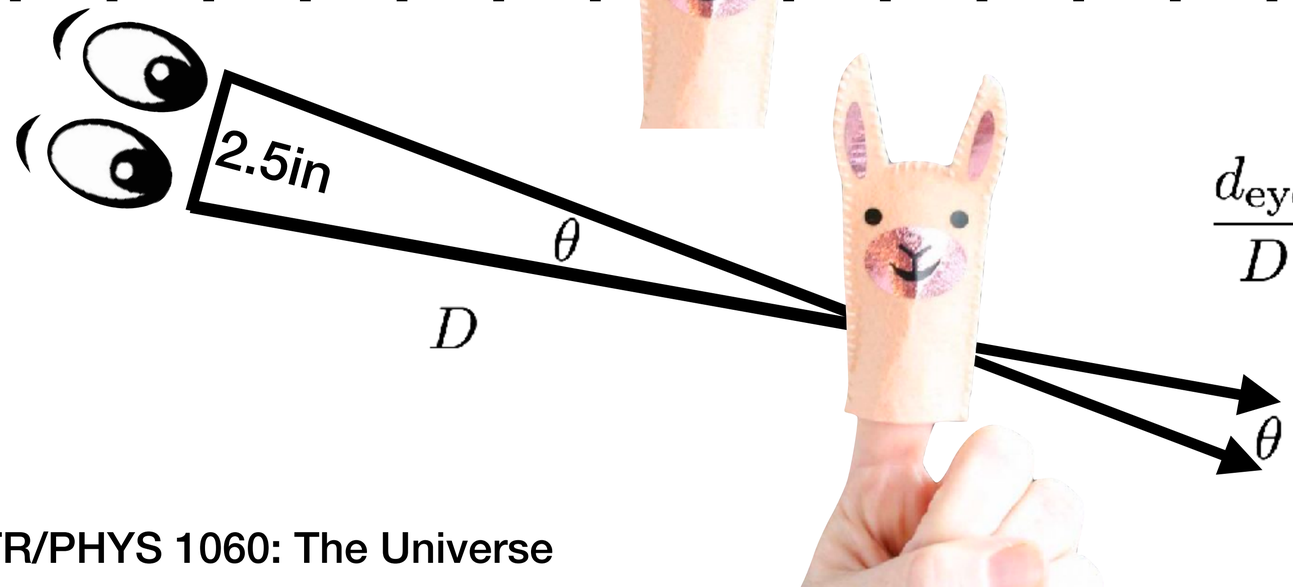


Example: 110 inches / 6.2 degrees ~ 18 inches

Parallax

5) Divide 110 inches by the number of degrees to get the distance to your finger!



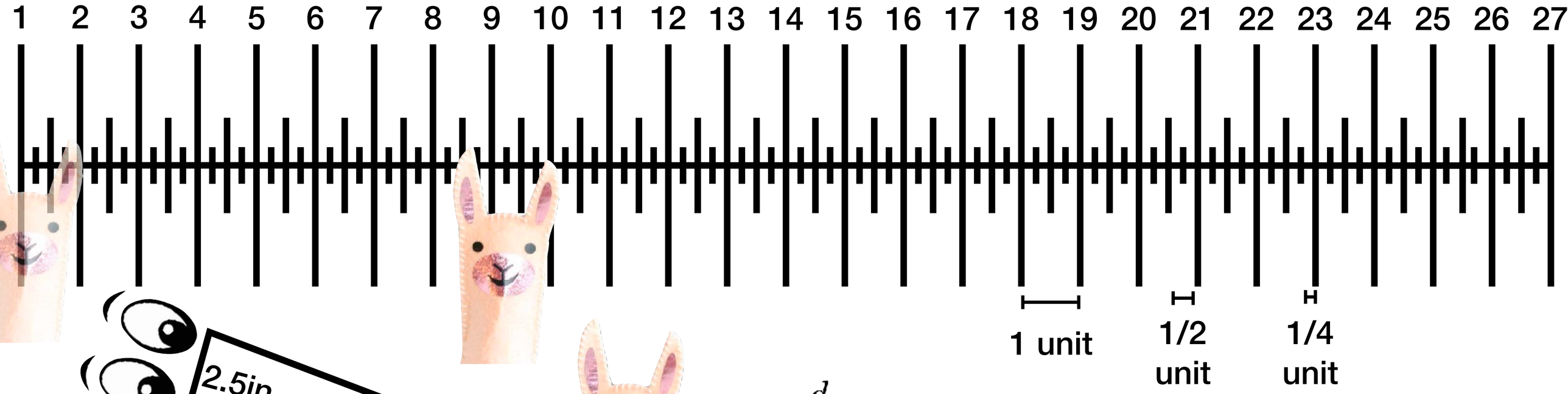


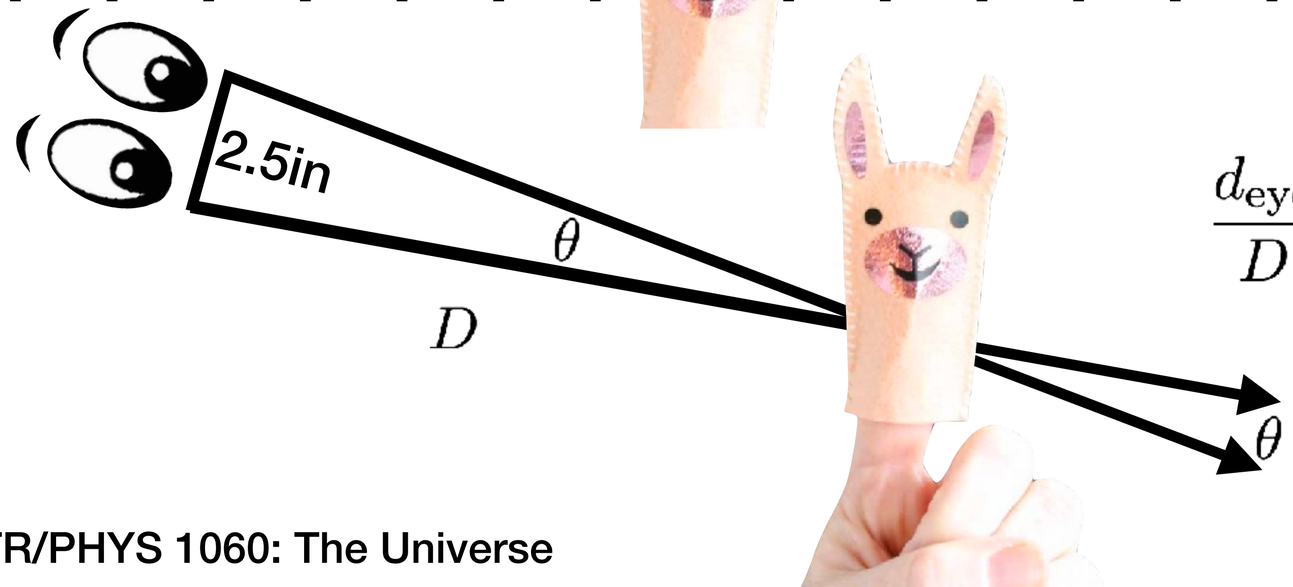
$$\frac{d_{\rm eye}}{D} = \theta({\rm radians})$$

$$D = \frac{2.5 \text{ inches}}{\theta(\text{degrees}) \times (\pi/180°)} \approx \frac{110 \text{ inches}}{\theta(\text{degrees})}$$

Parallax

Place your finger about 1 foot away and repeat the test. What distance did you get?





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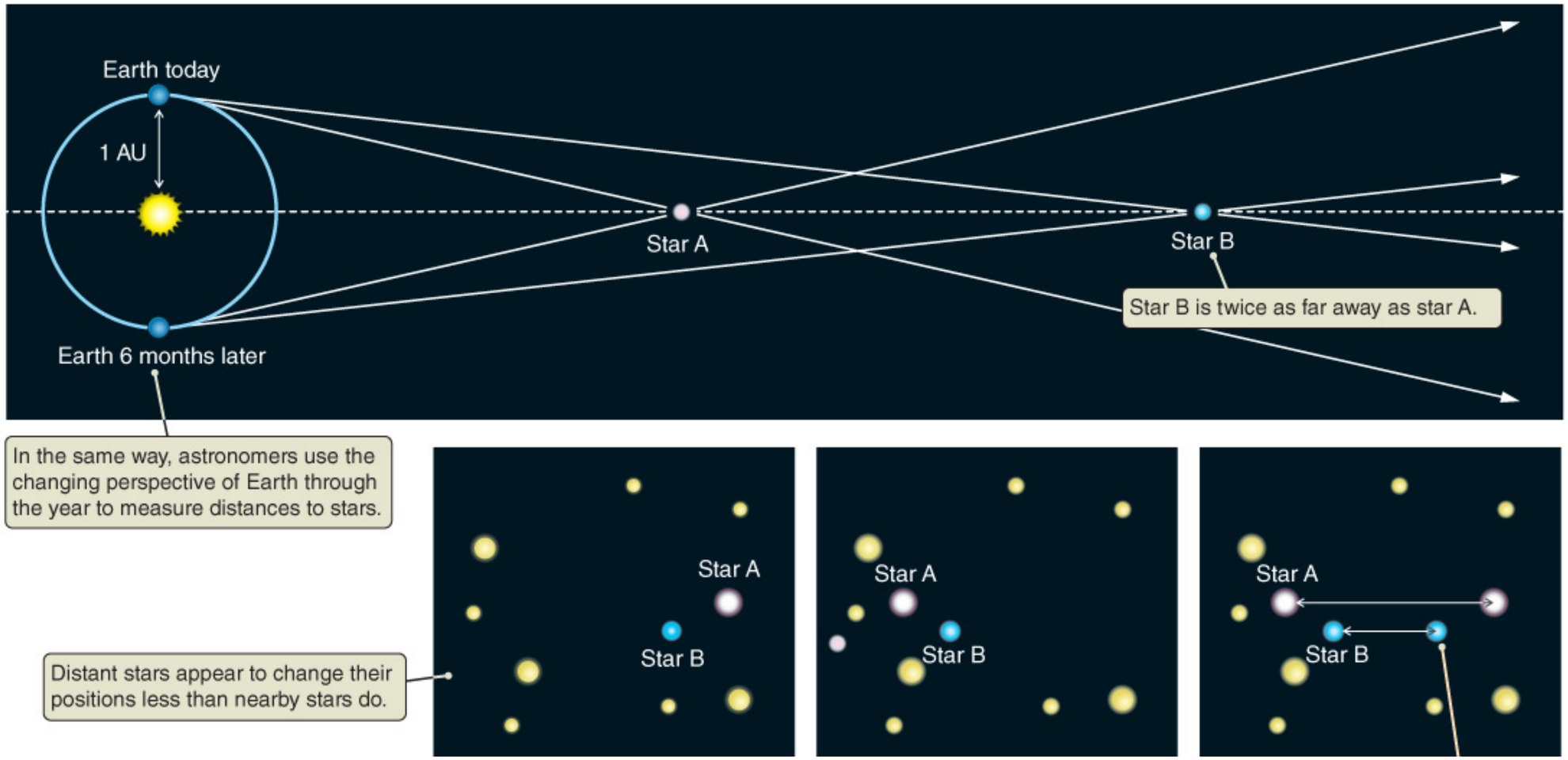
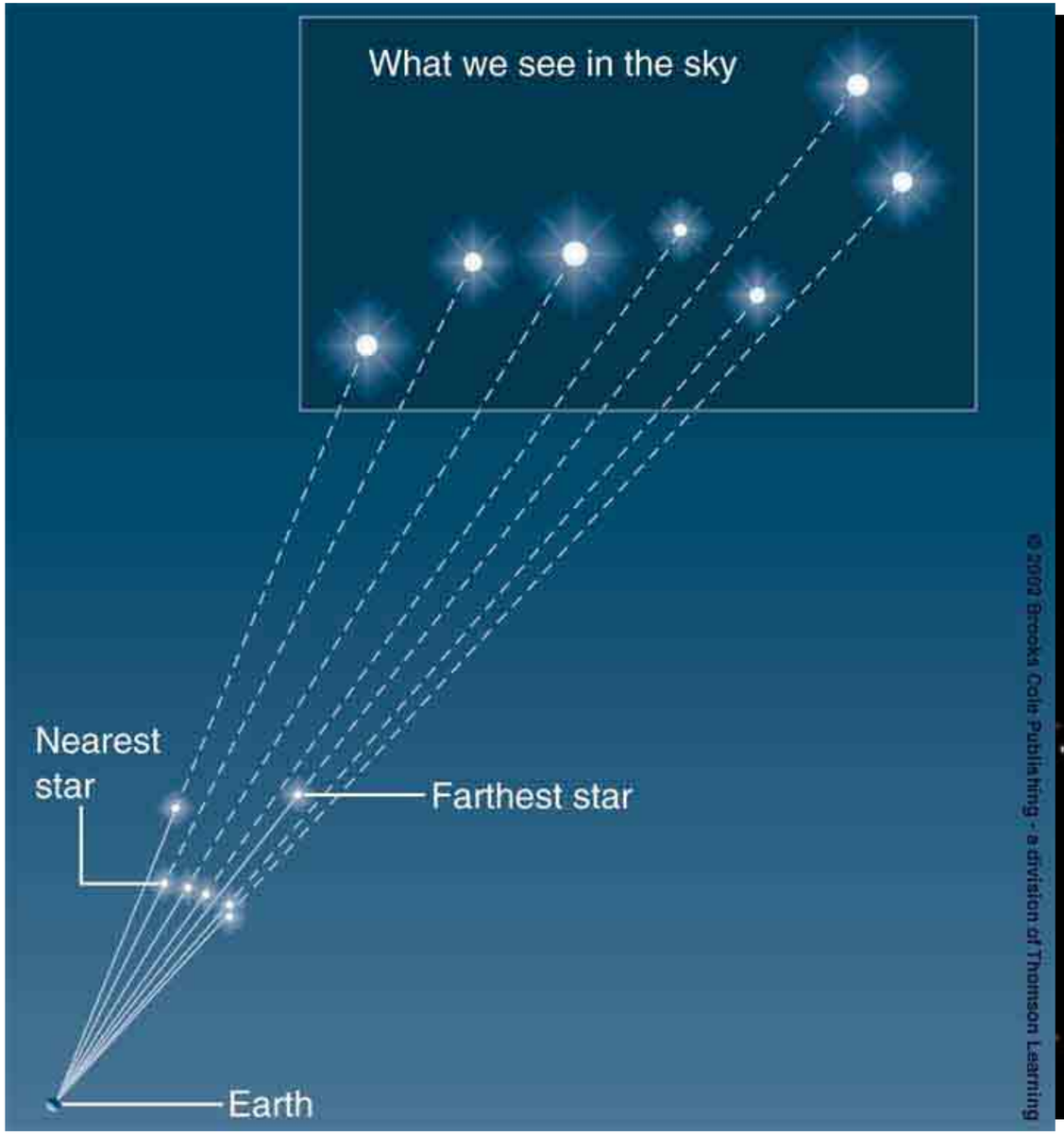
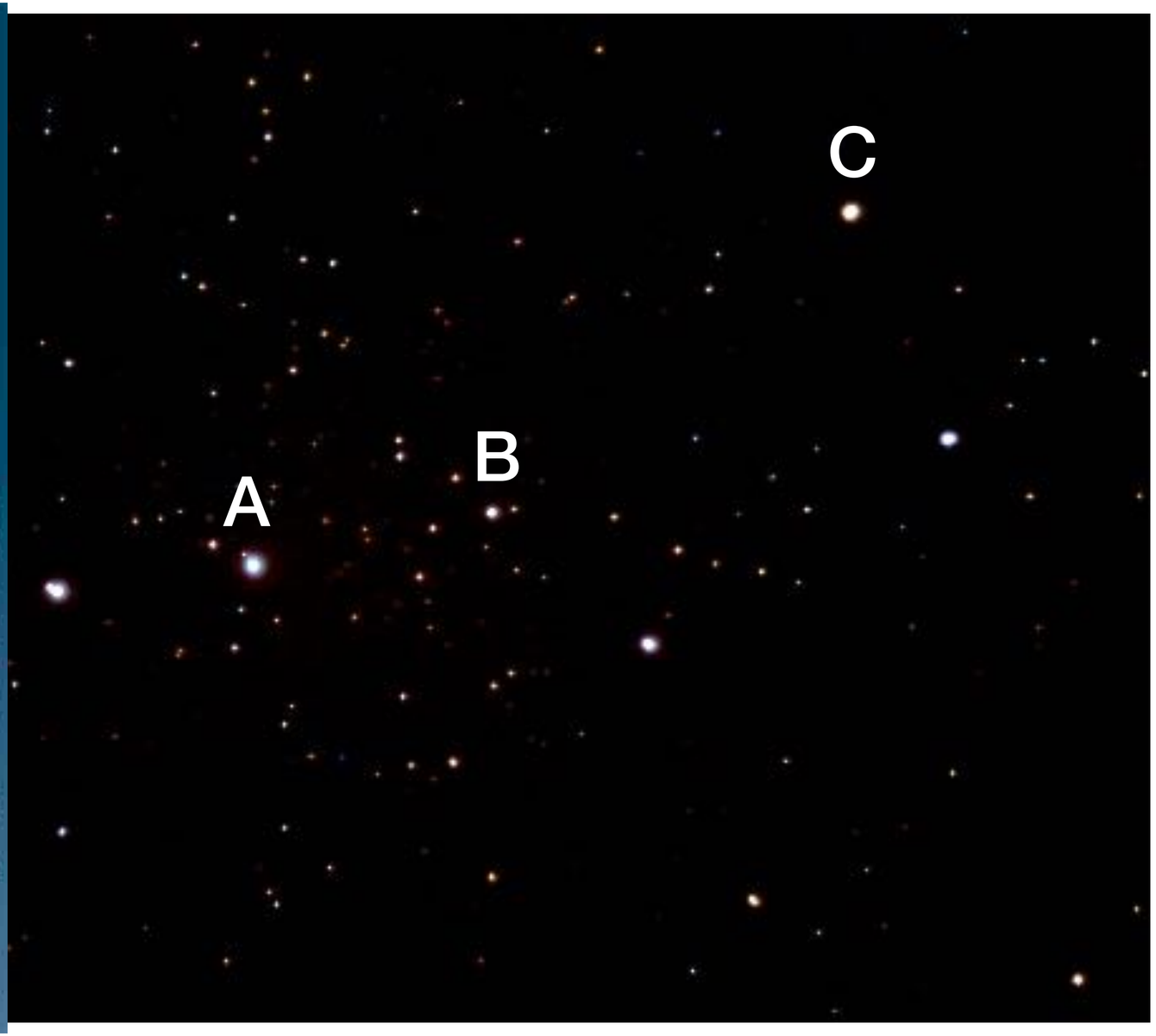
Parallax



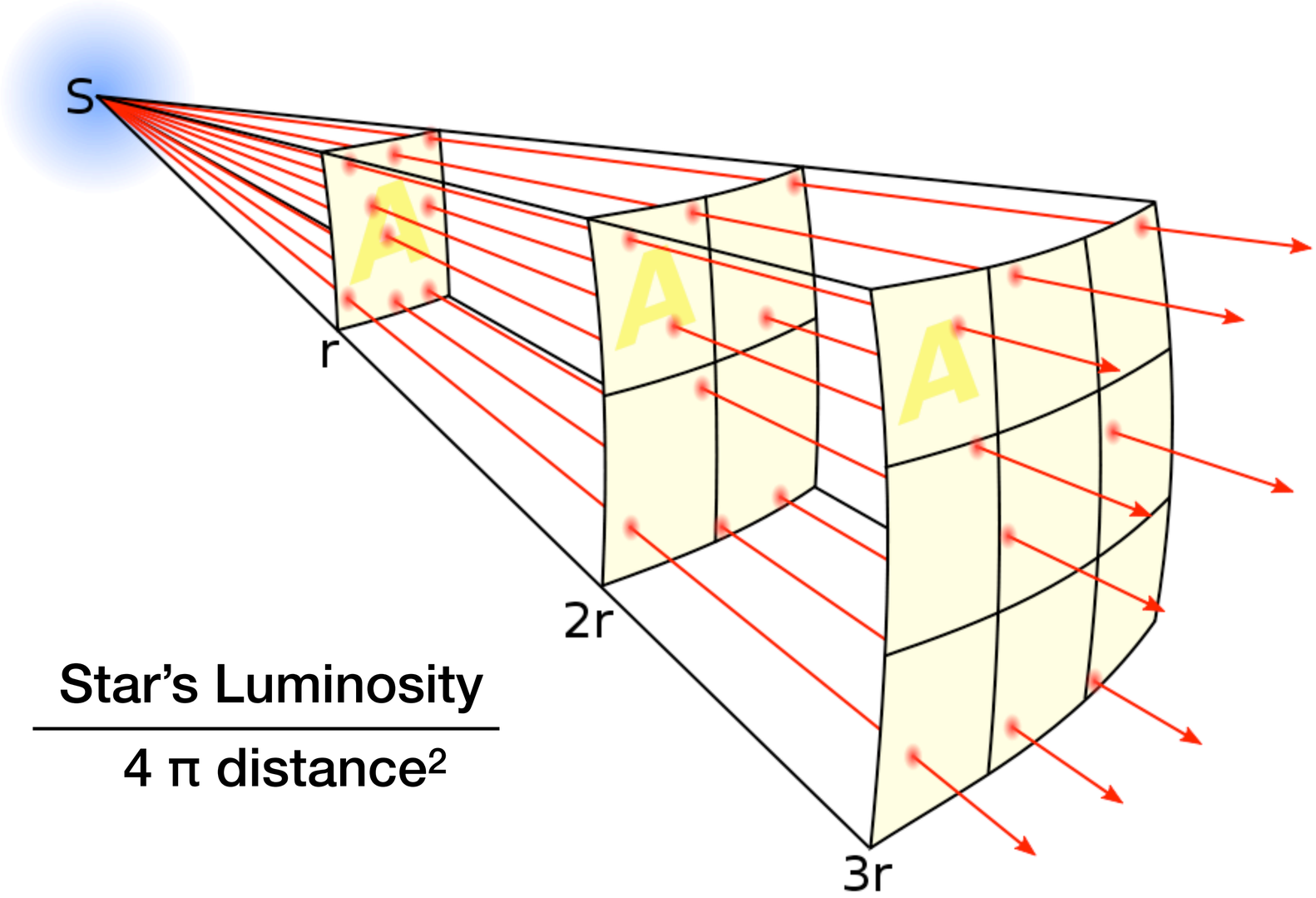
$$D = \frac{1\ \text{AU}}{\theta(\text{arcsec}) \times (\pi/180°) \times (1°/3600\ \text{arcsec})} \approx \frac{206,265\ \text{AU}}{\theta(\text{arcsec})} \approx \frac{3.26\ \text{ly}}{\theta(\text{arcsec})} \equiv \frac{1\ \text{parsec}}{\theta(\text{arcsec})}$$

Which star is the most luminous?

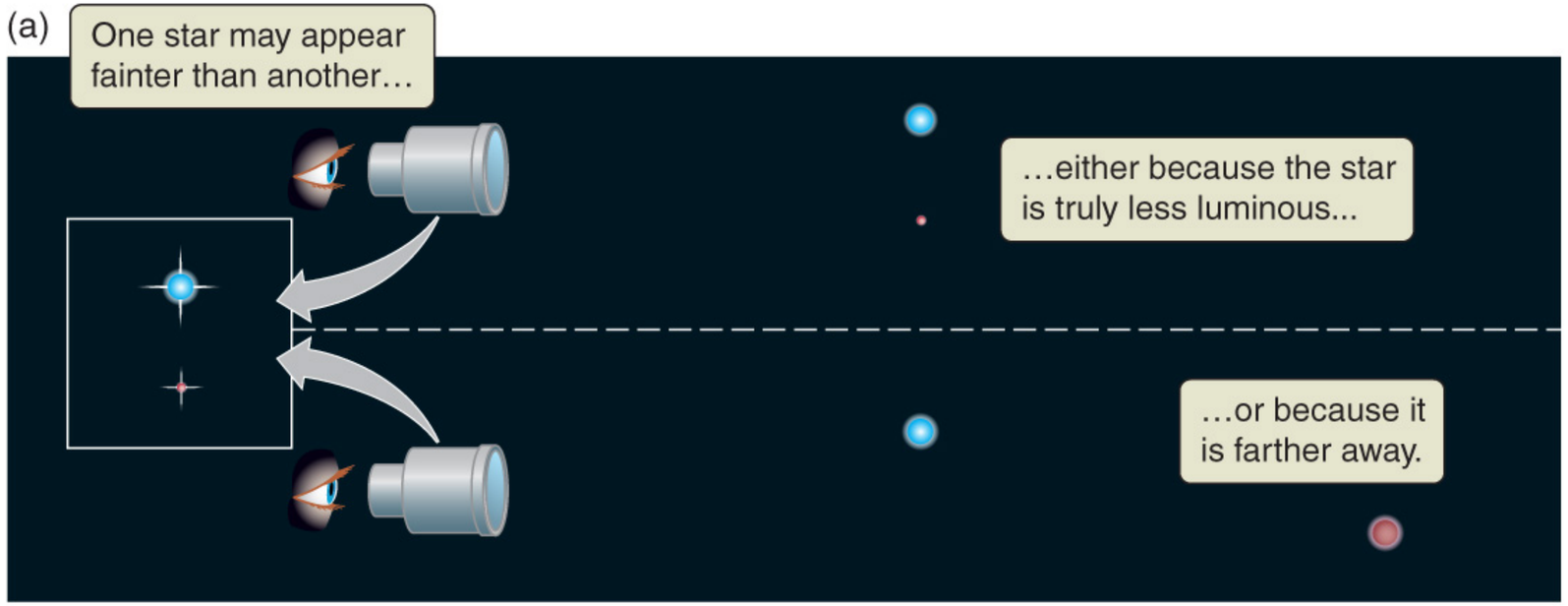




Distance and Brightness gives Luminosity



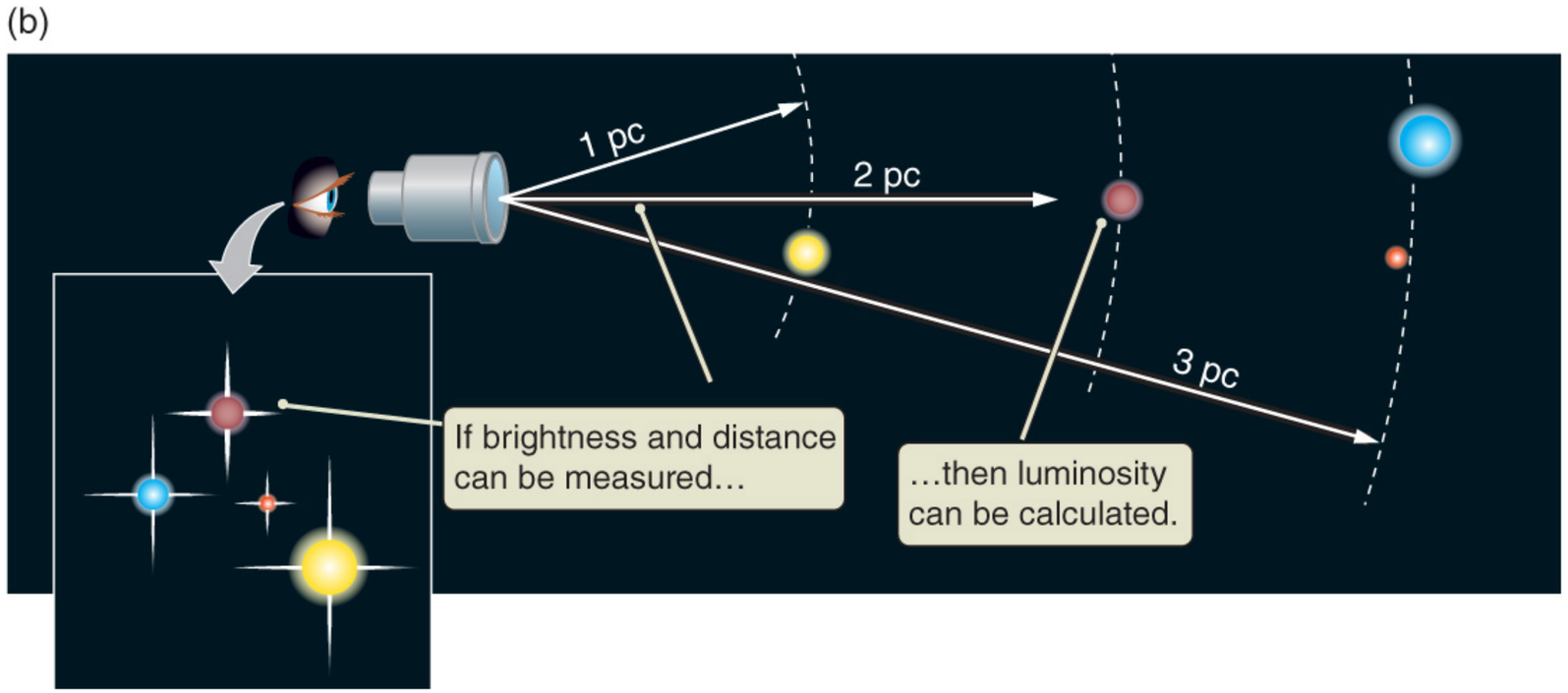
$$\text{Star's Brightness} = \frac{\text{Star's Luminosity}}{4\,\pi\,\text{distance}^2}$$



A

B

Which case for the red star would have the larger parallax?



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What's hard to measure for stars?

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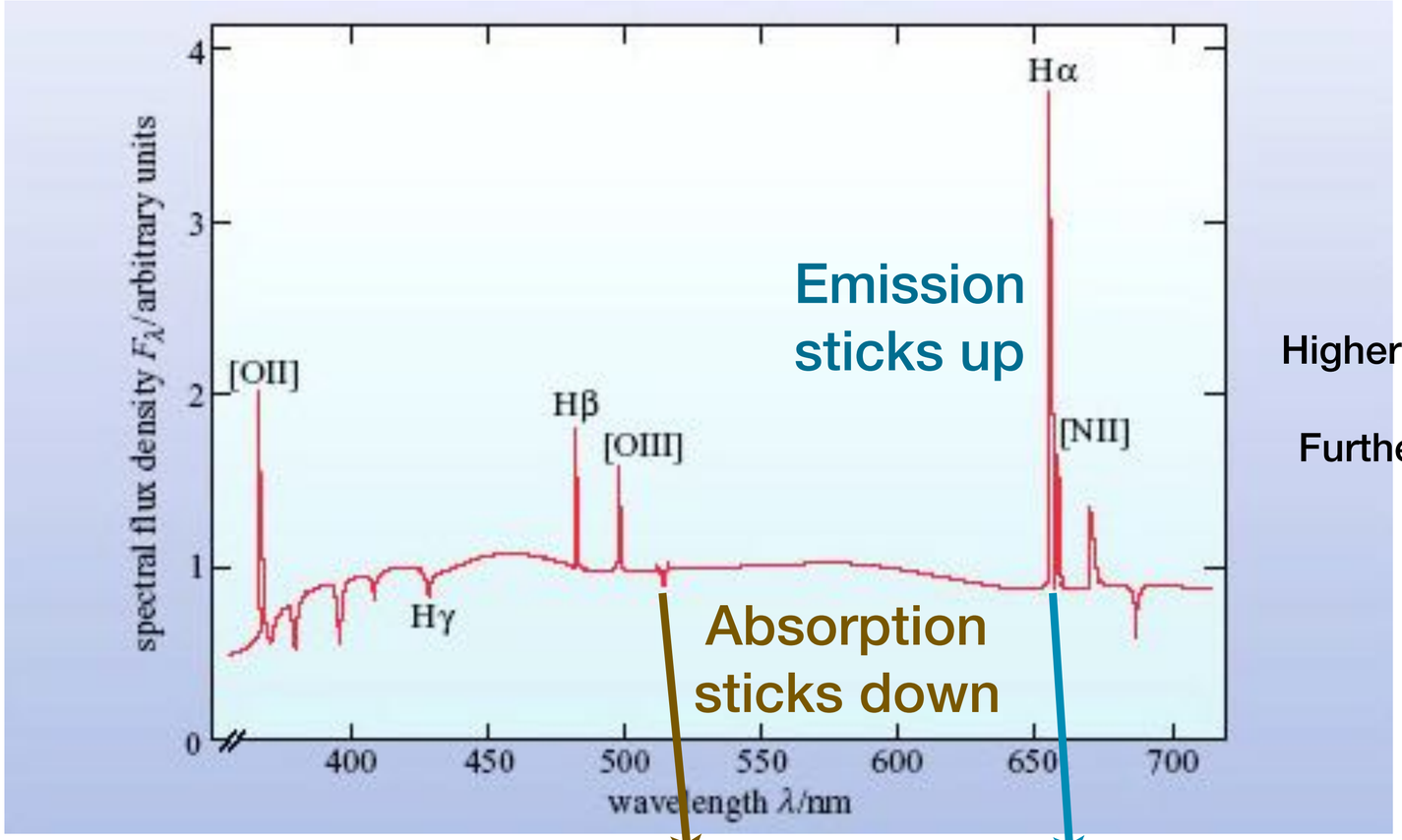
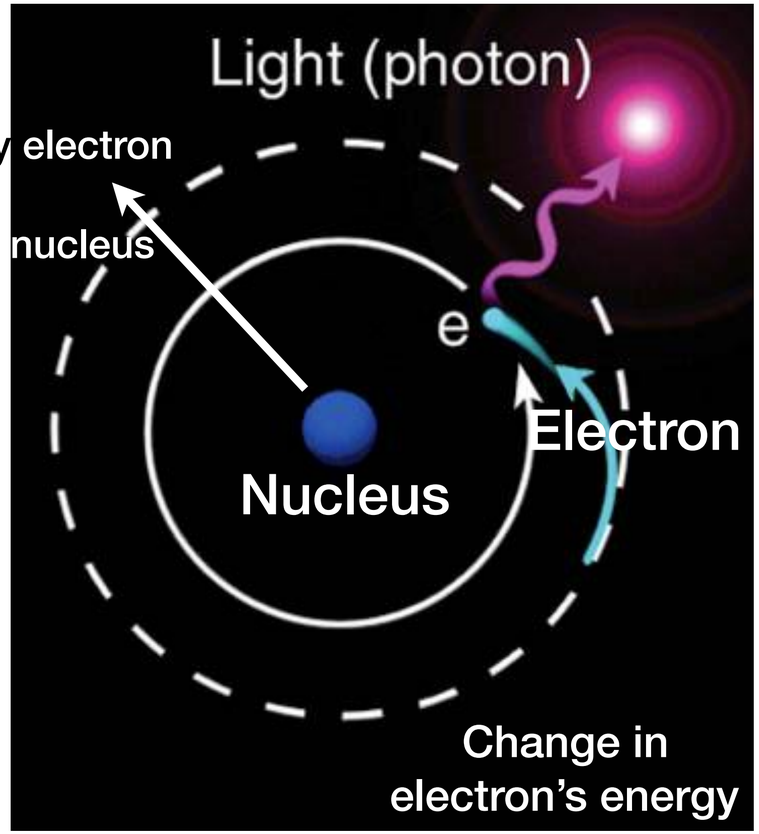
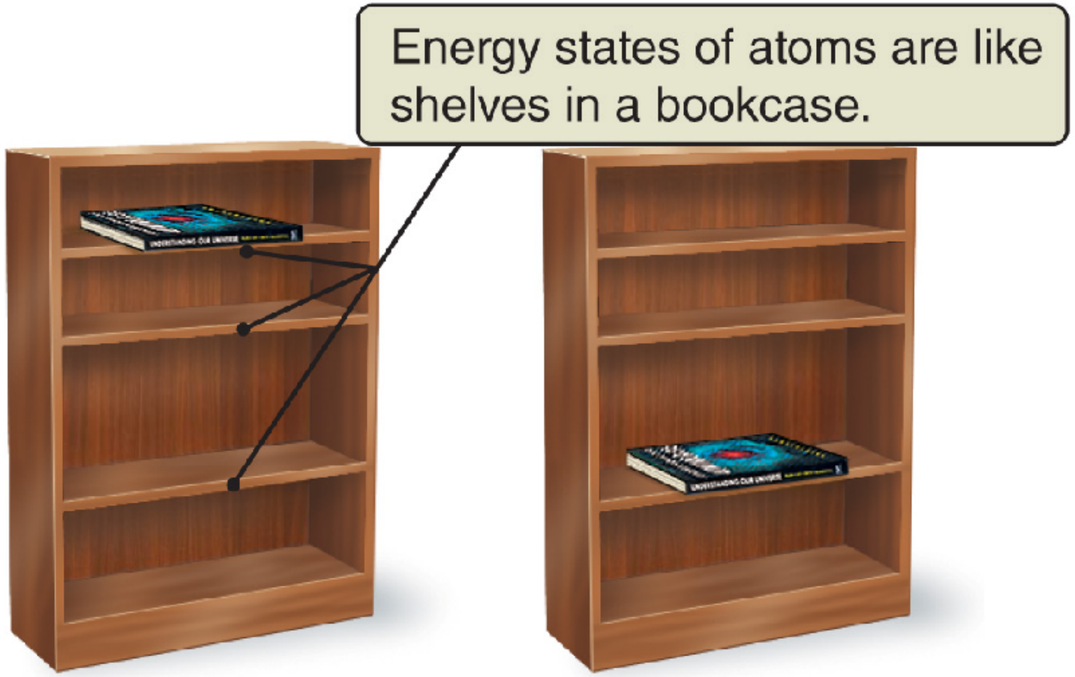
Emission and Absorption Lines



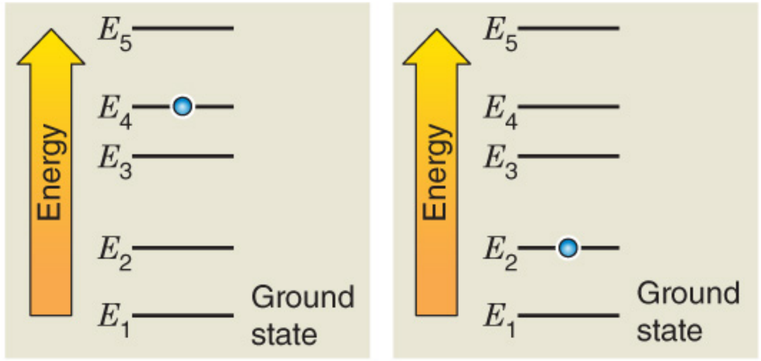
Electrons and Emission



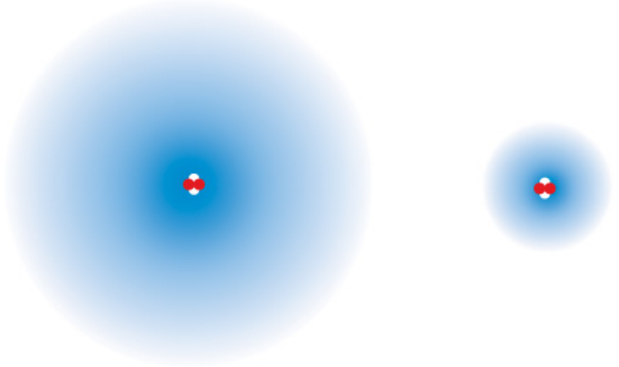
Each atom has a unique set of energy levels



You can find a book on one shelf or another, but not in between.



We use energy level diagrams to represent the allowed energy states of an atom.

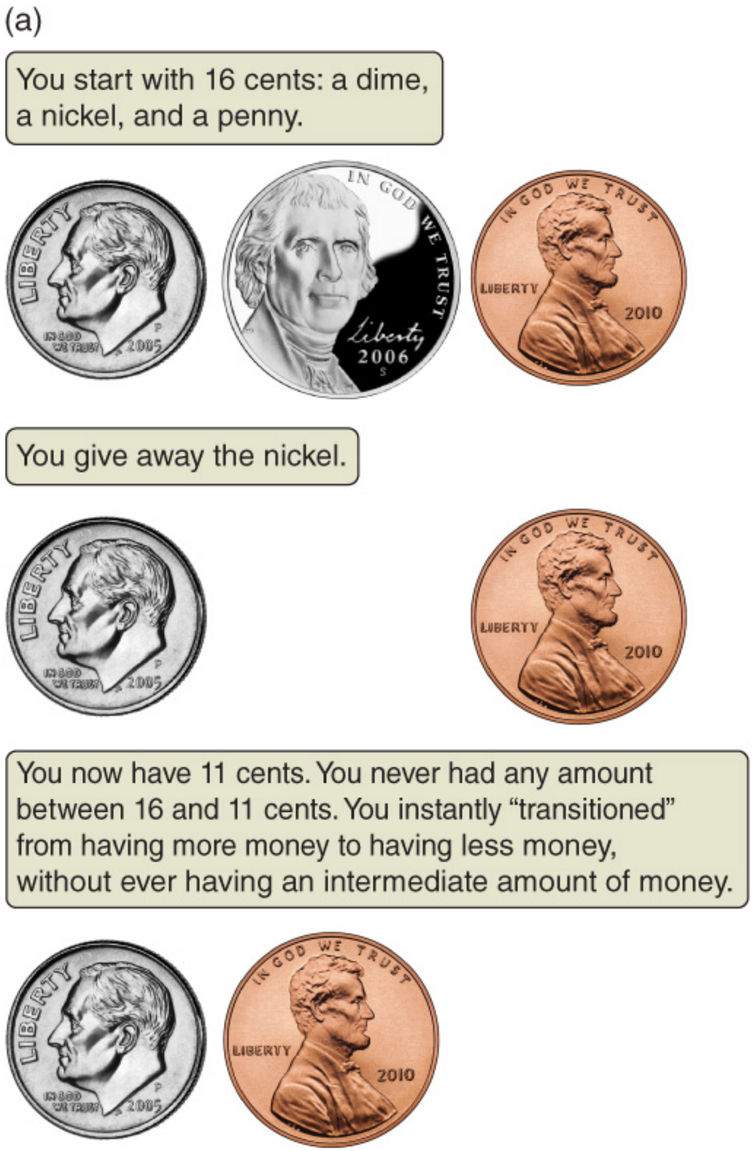


Atom in E_4 energy state

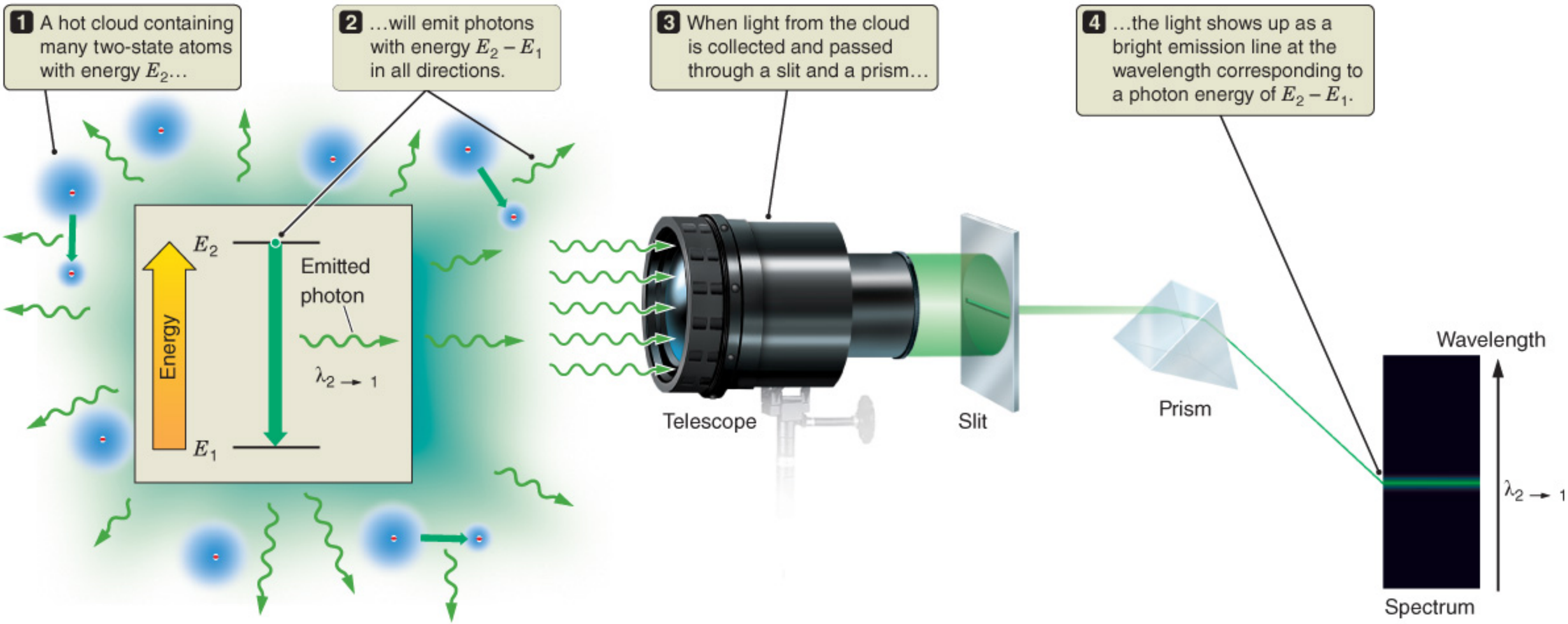
Atom in E_2 energy state

Analogously, atoms exist in one allowed energy state or another, but never in between.

Remember: Light is "Quantized"



Spectra Lab: Emission Tubes



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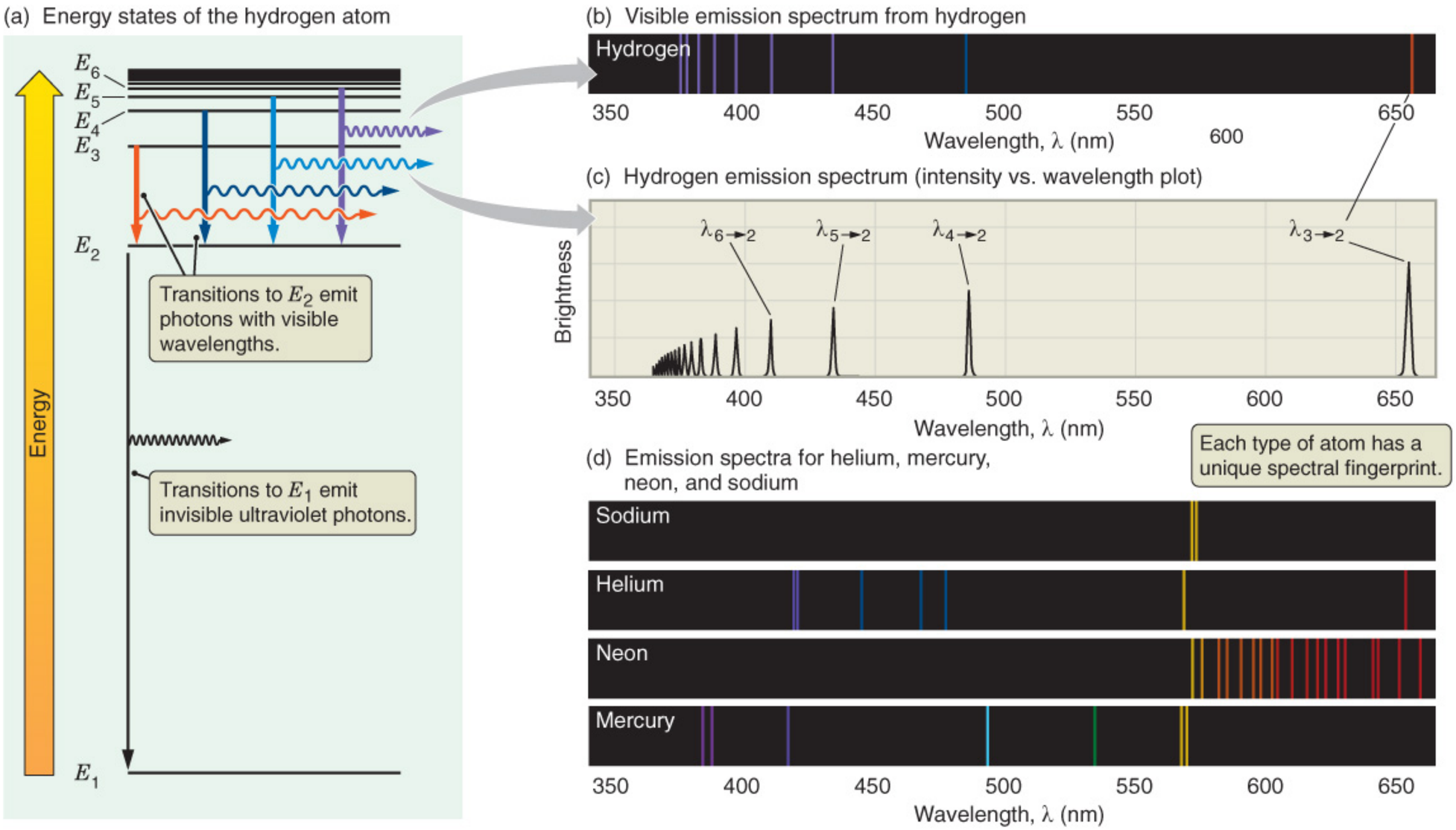
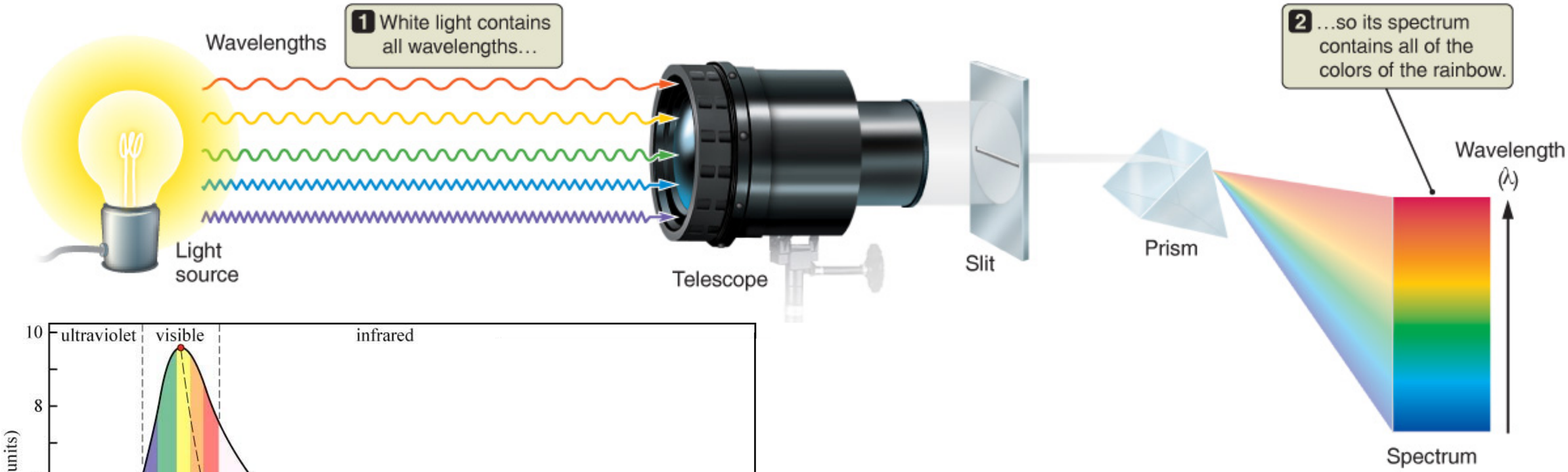
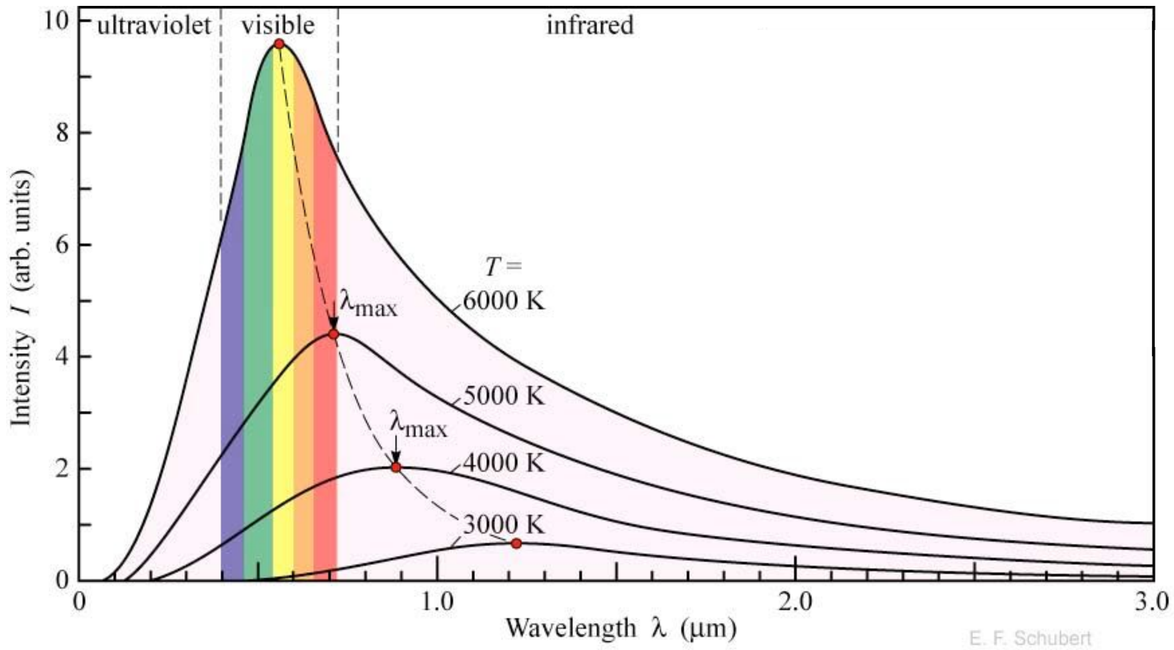


Spectra Lab: Blackbody Emission





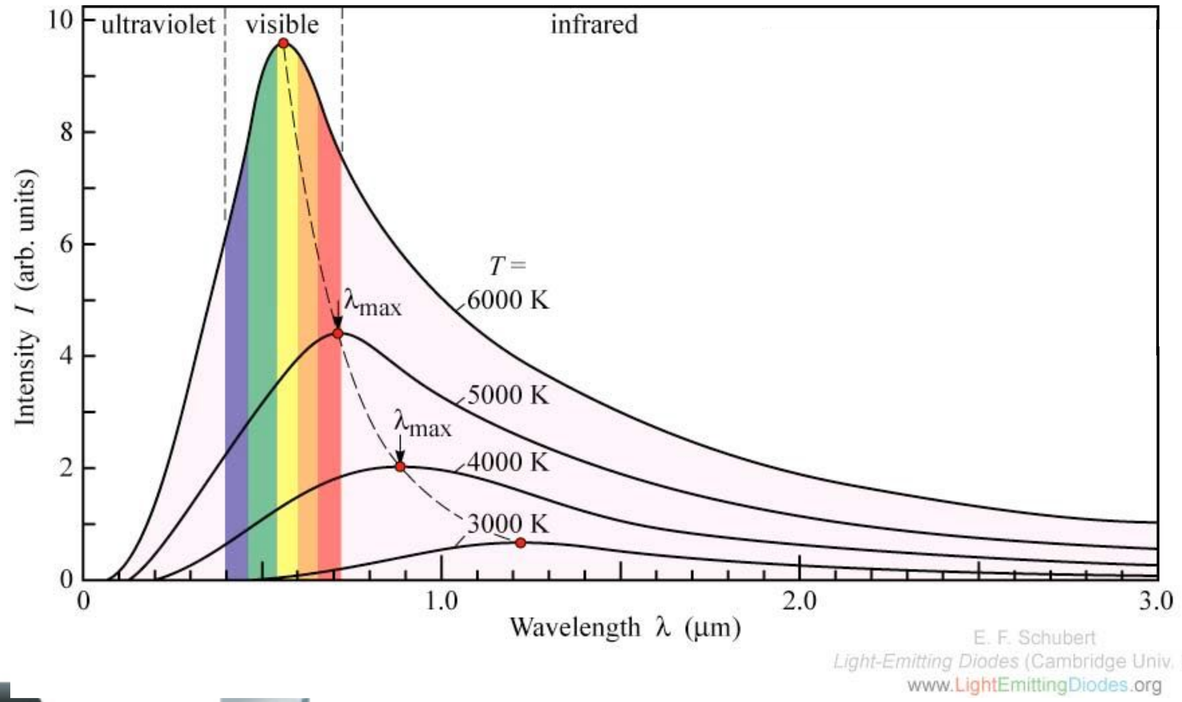
E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

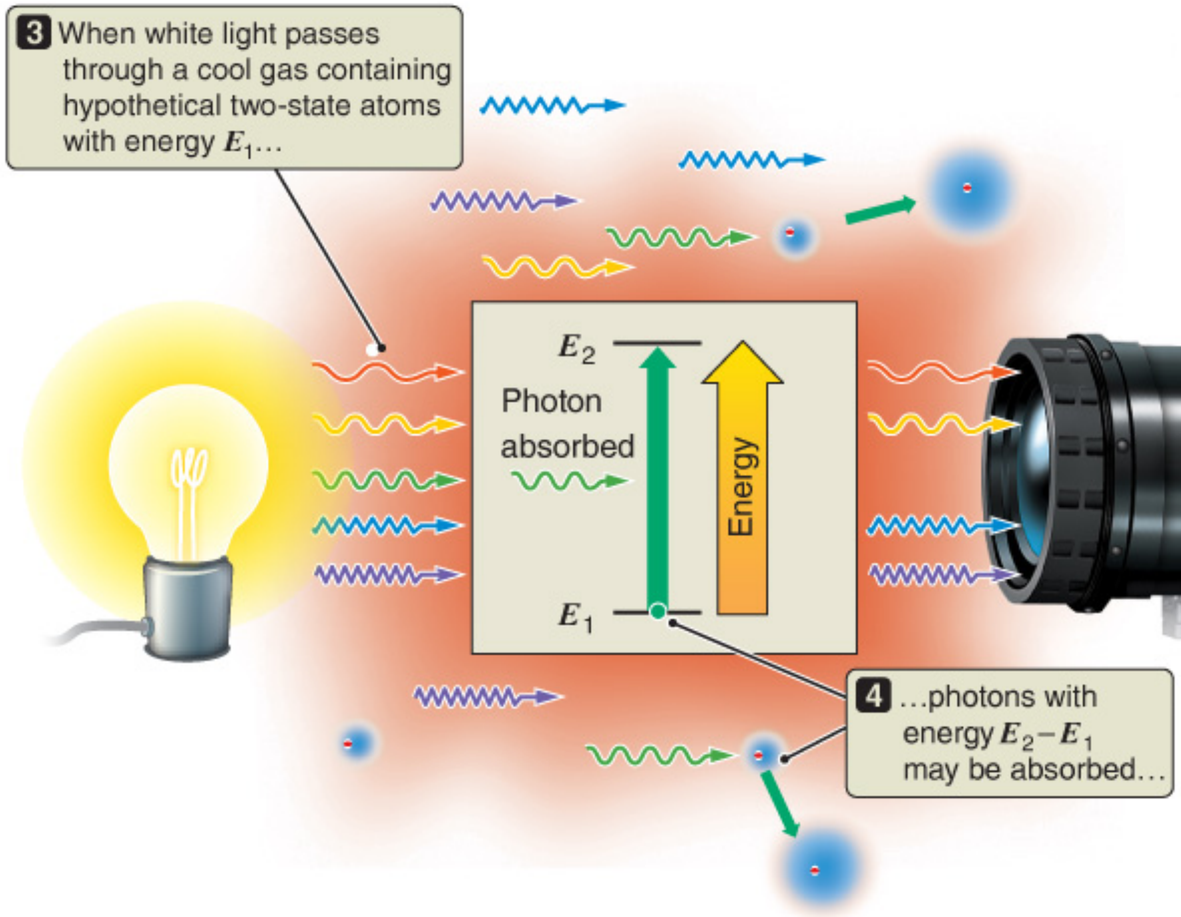
In small groups, discuss this question and your reasoning:

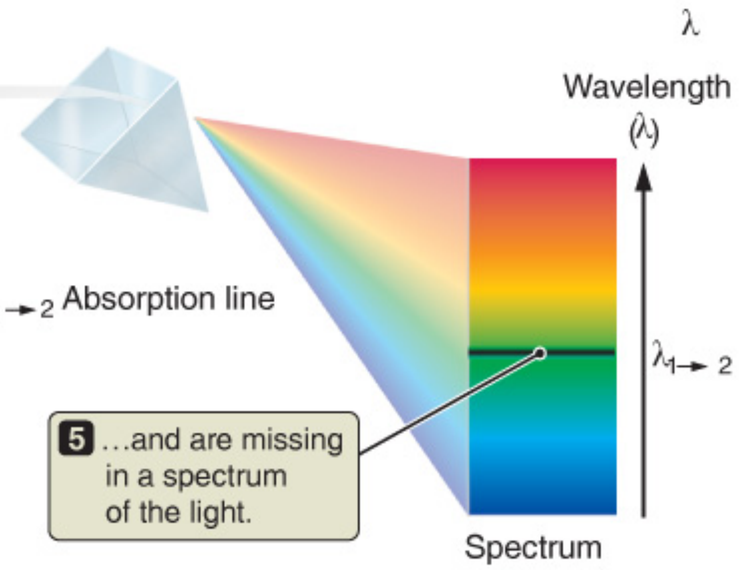
If you see a star bluer than the sun, would you expect it to have a lower or higher luminosity?

If a star is very faint, what color would you expect it to be?

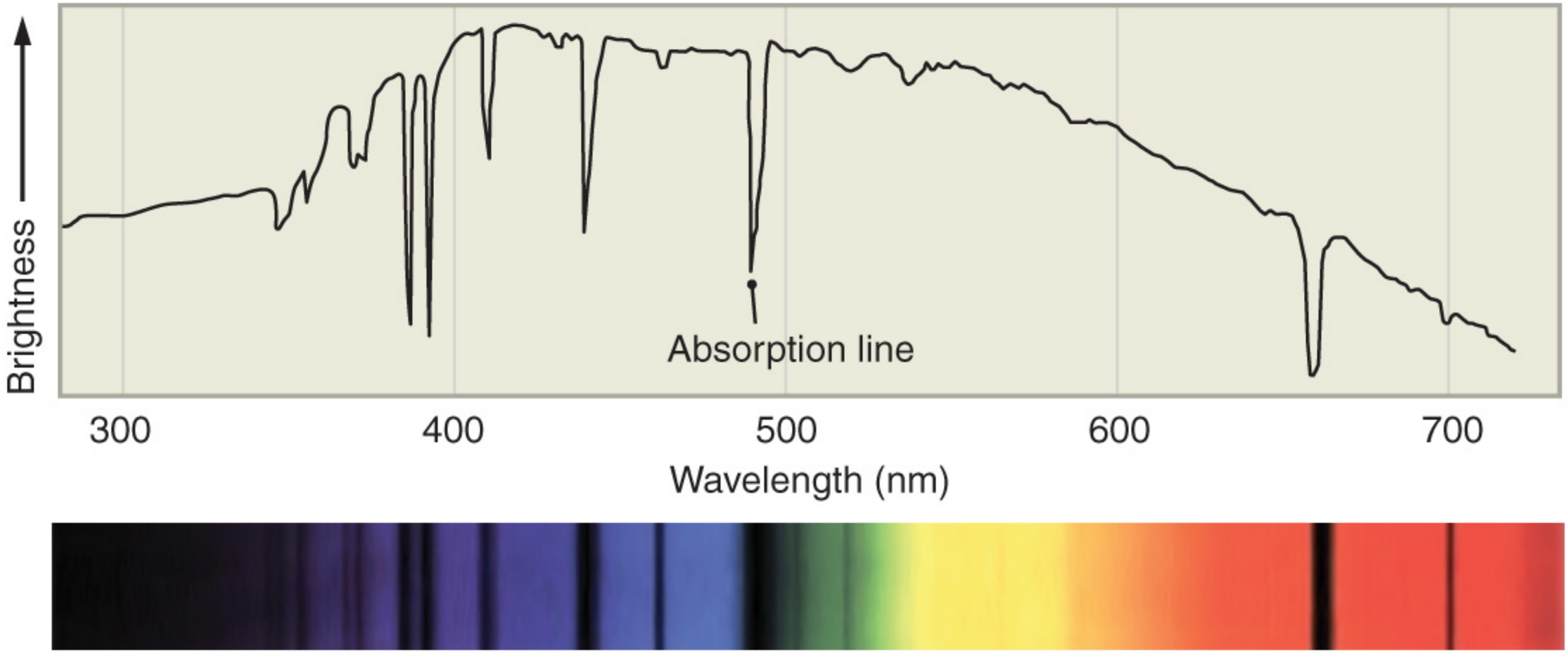
Spectra Lab: Blackbody Emission







Typical stellar spectrum has many absorption lines, which we graph



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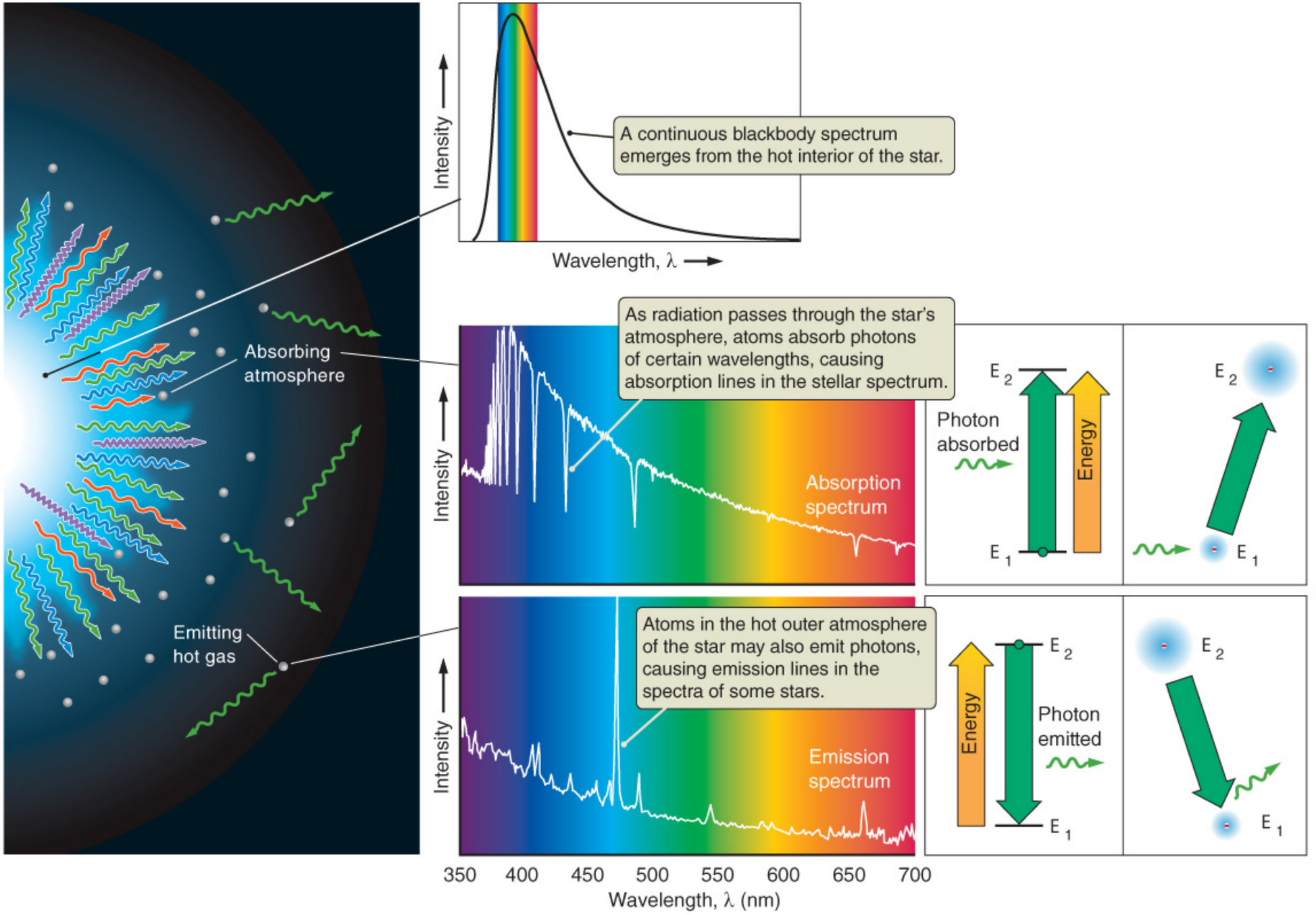

Intensity
A continuous blackbody spectrum emerges from the hot interior of the star.
Wavelength, λ
Absorbing atmosphere
As radiation passes through the star's atmosphere, atoms absorb photons of certain wavelengths, causing absorption lines in the stellar spectrum.
Absorption spectrum
Photon absorbed
Energy
E 2
E 1
Emitting hot gas
Atoms in the hot outer atmosphere of the star may also emit photons, causing emission lines in the spectra of some stars.
Emission spectrum
Photon emitted
350 400 450 500 550 600 650 700
Wavelength, λ (nm)

What kind of spectrum does the Moon have?

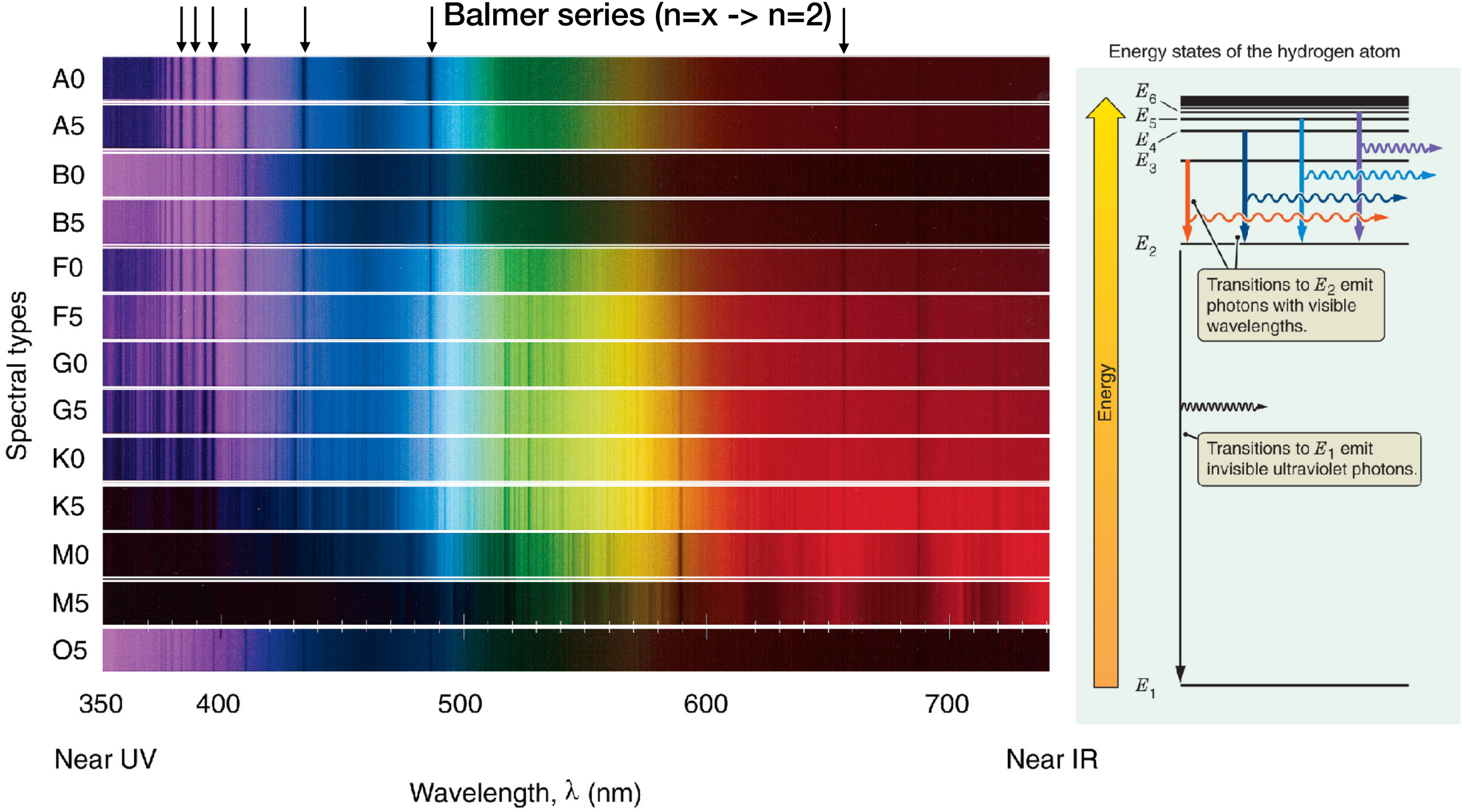
A) Emission Line

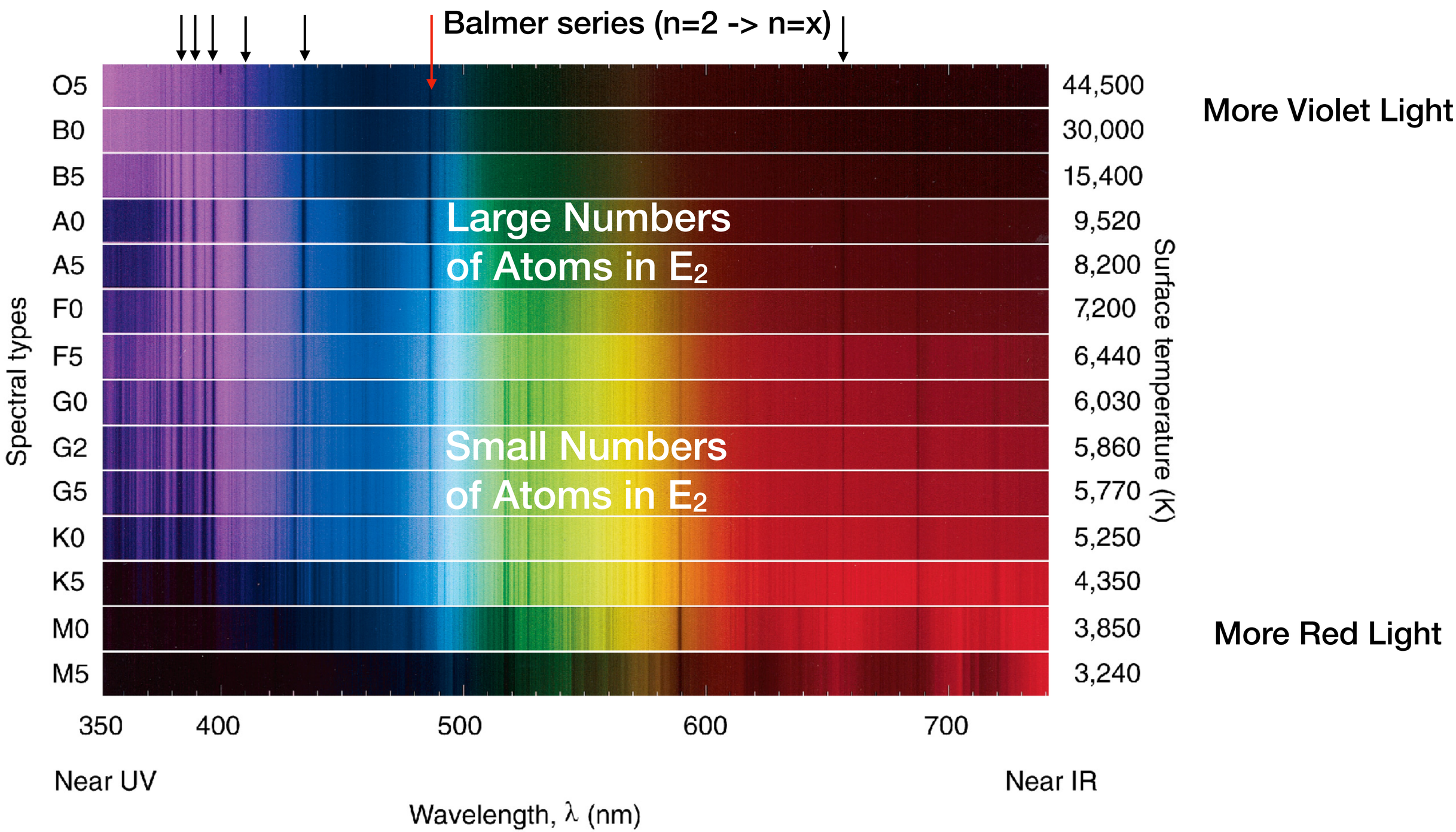
B) Blackbody

C) Absorption Line

Annie Jump Cannon Classifies the Stars

- one of “Pickering’s Women,” a Harvard “Calculator”
- part of the effort to catalog every star in the sky down to 9th magnitude
- defined the classification scheme for stellar spectra
- manually classified over 350,000 stars
- realized stellar types correlated with temperature (but not in the original order)


Balmer series (n=x -> n=2)
A0
A5
B0
B5
F0
F5
G0
G5
K0
K5
M0
M5
O5
Spectral types
350
400
500
600
700
Near UV
Near IR
Wavelength, λ (nm)
Energy states of the hydrogen atom
E_6
E_5
E_4
E_3
E_2
E_1
Energy
Transitions to E_2 emit photons with visible wavelengths.
Transitions to E_1 emit invisible ultraviolet photons.


Balmer series (n=2 -> n=x)
O5
B0
B5
A0
A5
F0
F5
G0
G2
G5
K0
K5
M0
M5
44,500
30,000
15,400
9,520
8,200
7,200
6,440
6,030
5,860
5,770
5,250
4,350
3,850
3,240
Spectral types
Surface temperature (K)
Large Numbers
of Atoms in E_2
Small Numbers
of Atoms in E_2
More Violet Light
More Red Light
350
400
500
600
700
Near UV
Near IR
Wavelength, λ (nm)

If temperature is what we want, why use spectra?

Dust preferentially absorbs bluer light (uniformly), so a star's color will change (but the relative strengths of its lines will not)

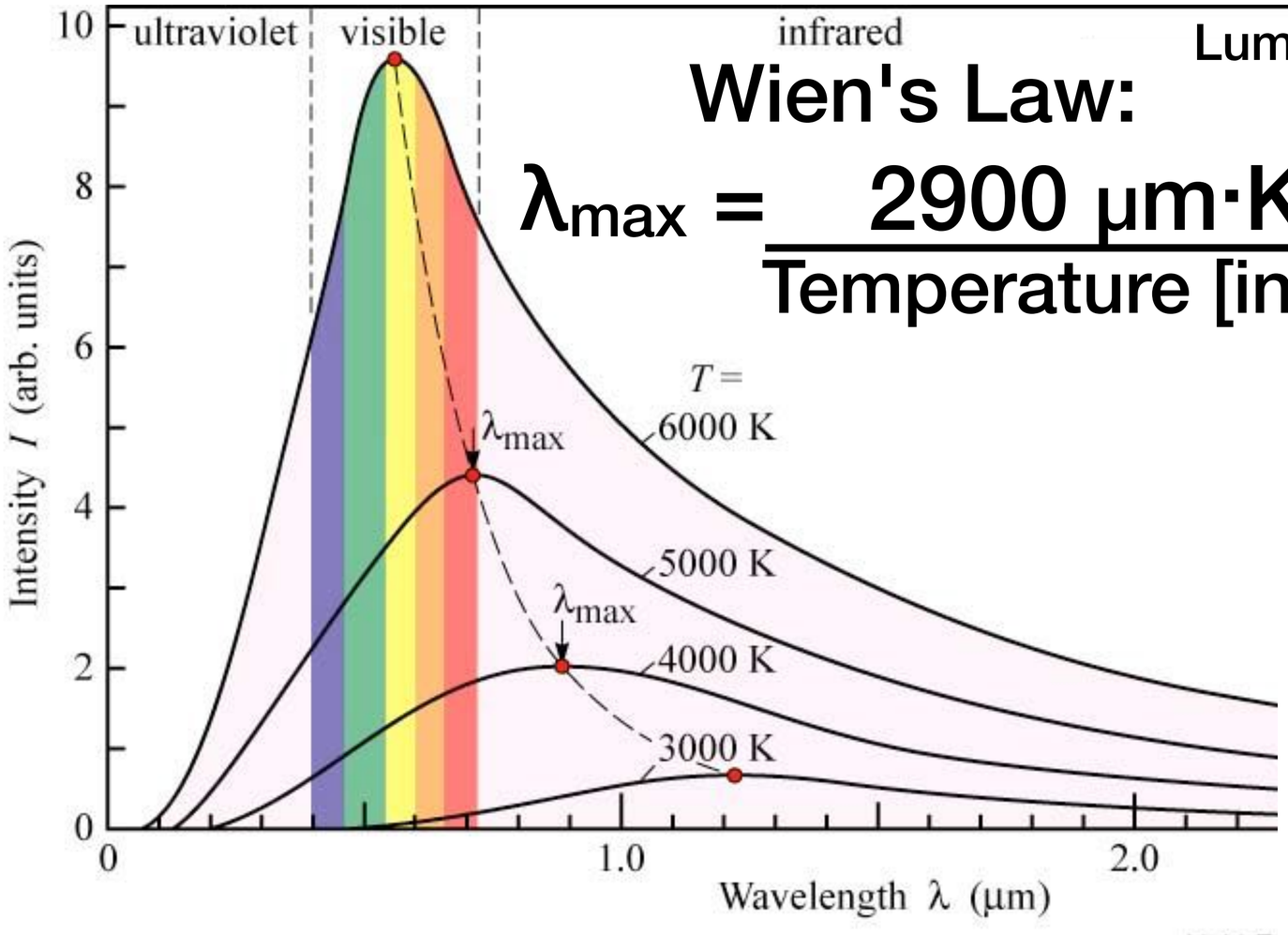
Color and temperature are connected

Stefan-Boltzmann Law:

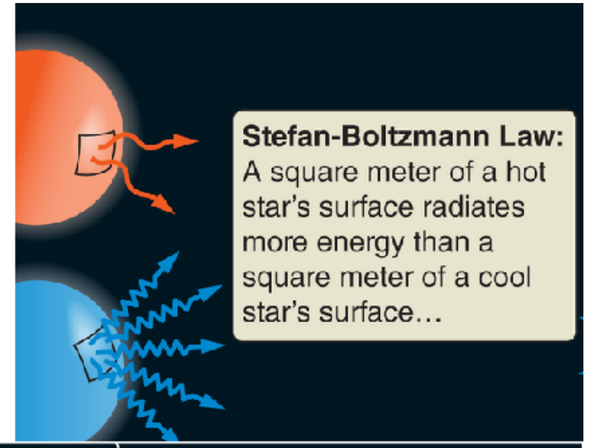
Luminosity per unit area = constant × Temperature^4

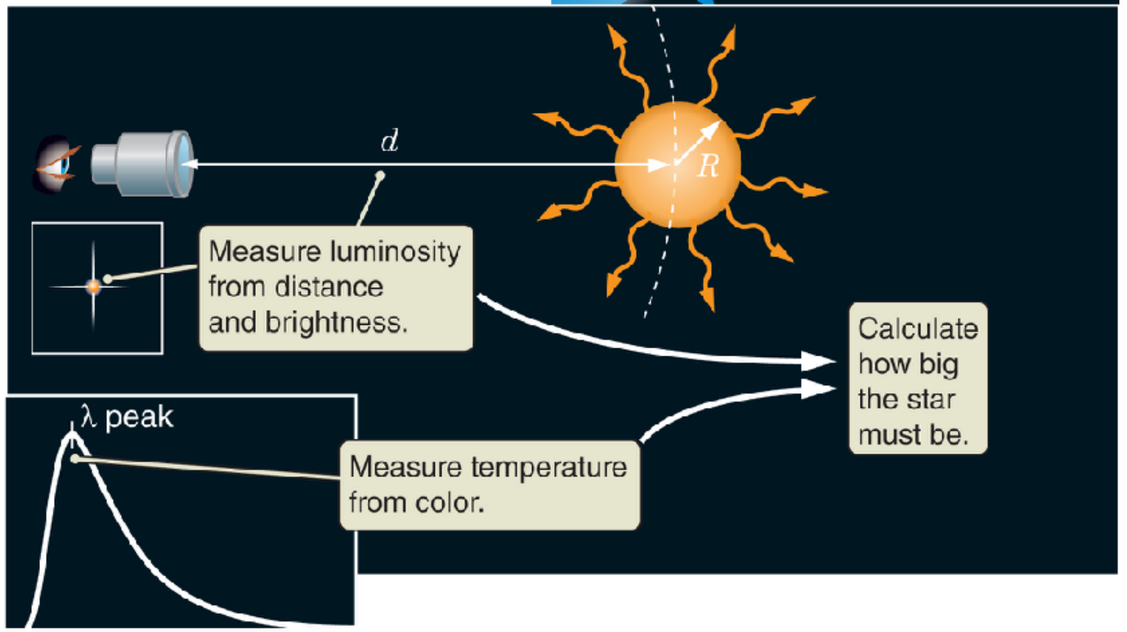
Wien's Law:

$$\lambda_{max} = \frac{2900\ \mu m \cdot K}{\text{Temperature [in K]}}$$

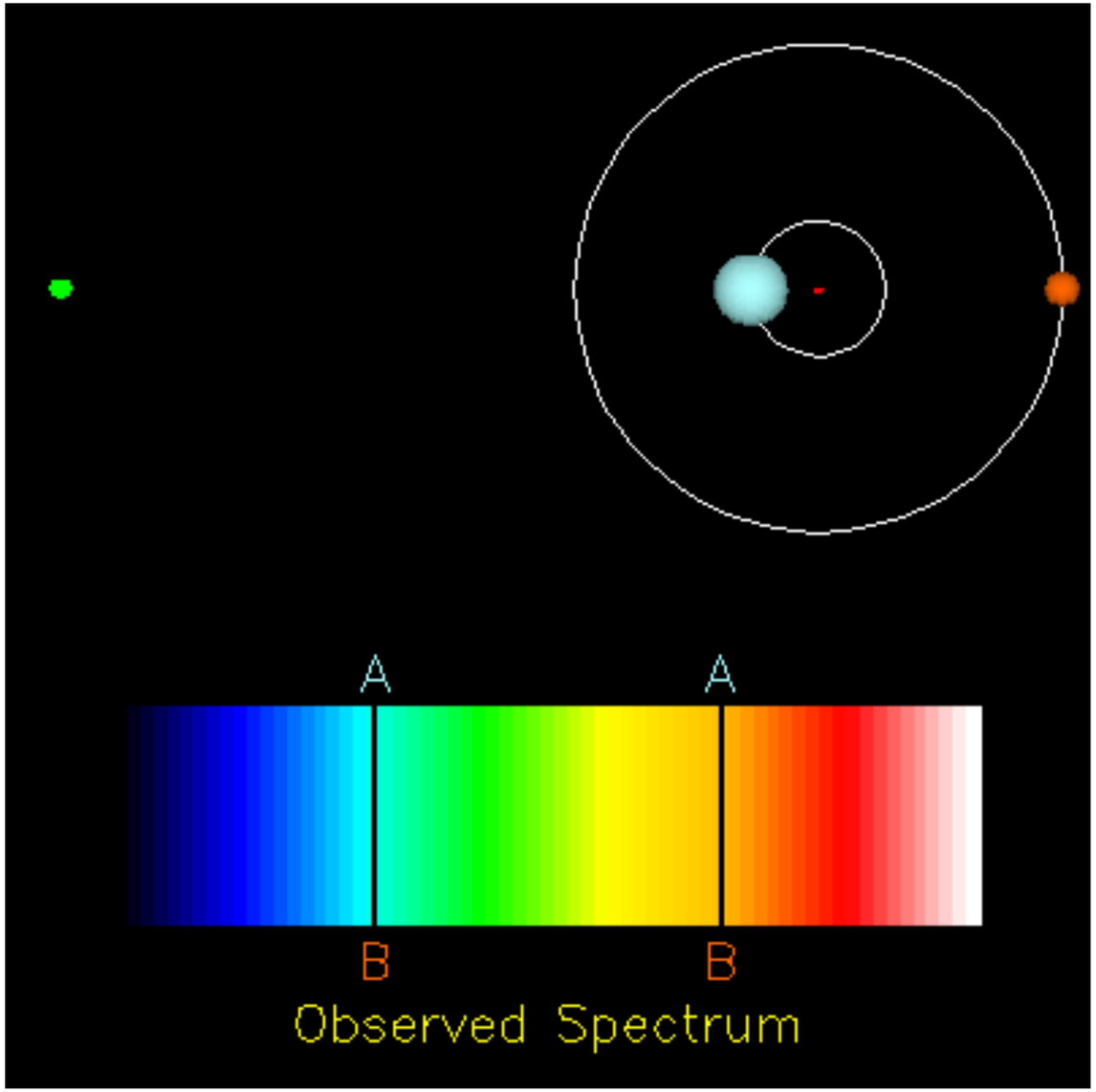


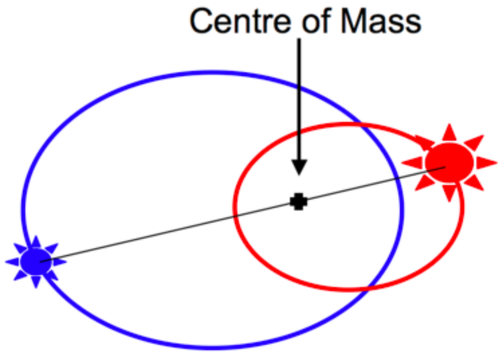
1 μm = 1000 nm





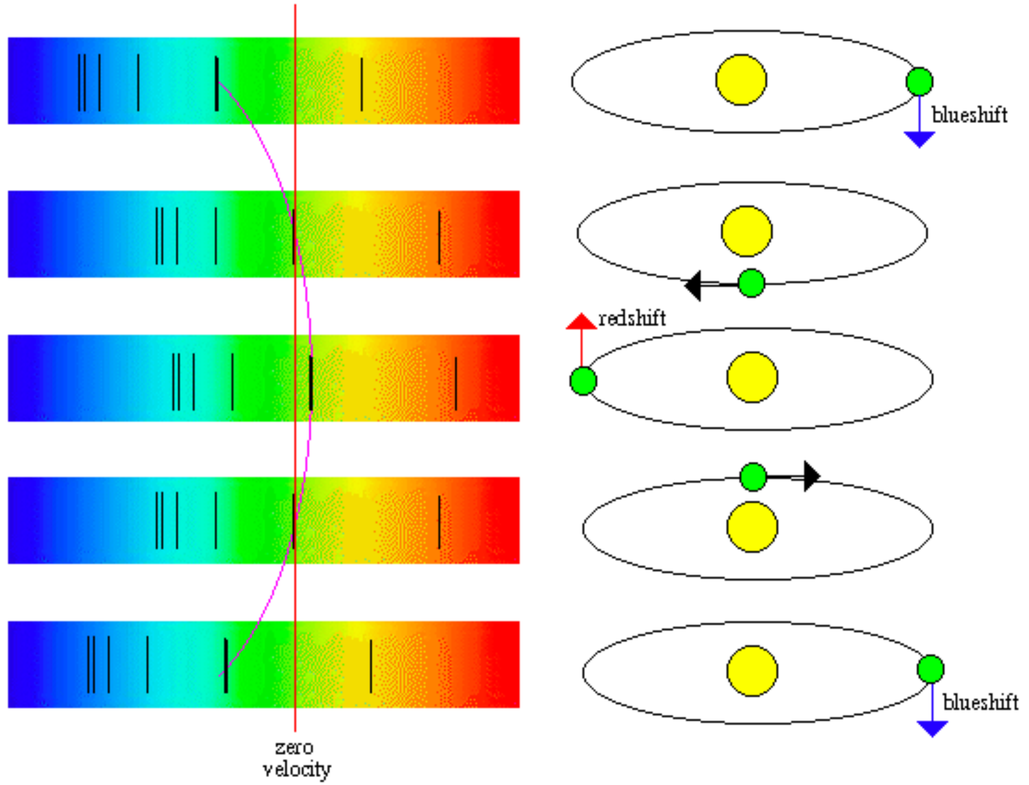
Binary Stars



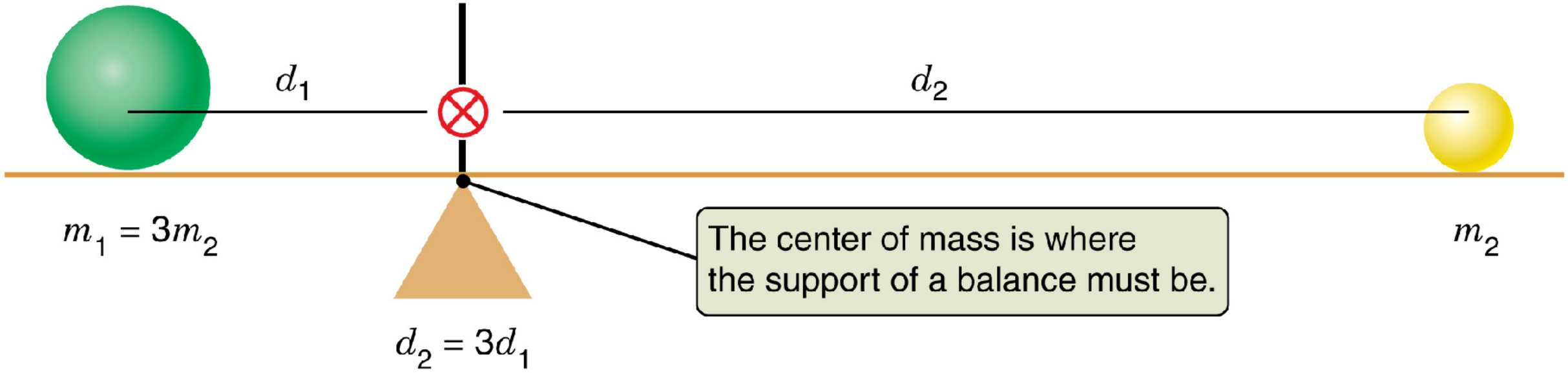


Spectroscopic Binary

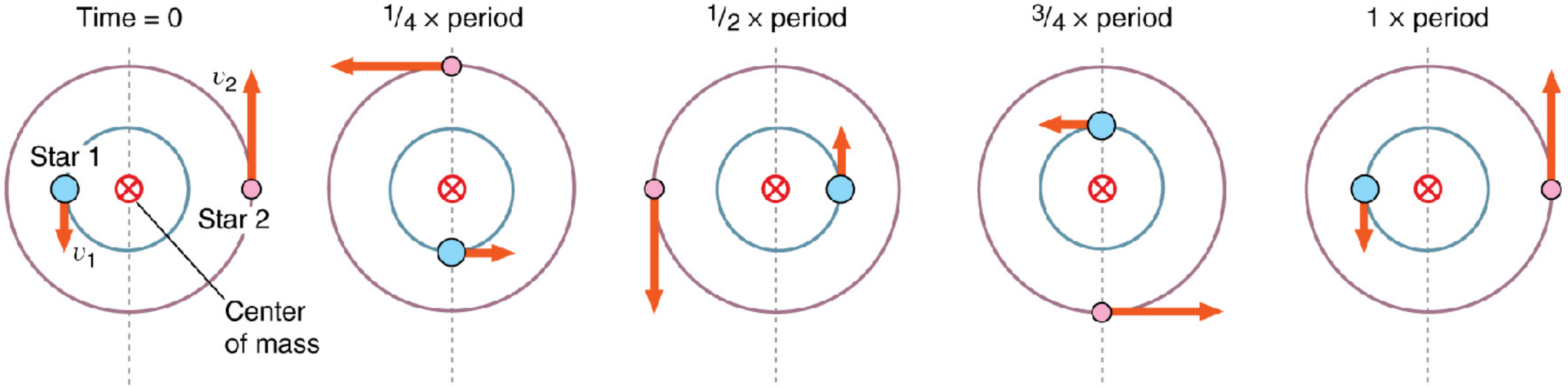
A spectroscopic binary is where there is evidence of orbital motion in the spectral features due to the Doppler effect



Weighing stars in a Binary



Stars in a binary system orbit their center of mass.



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- ~Changes in position and spectrum~

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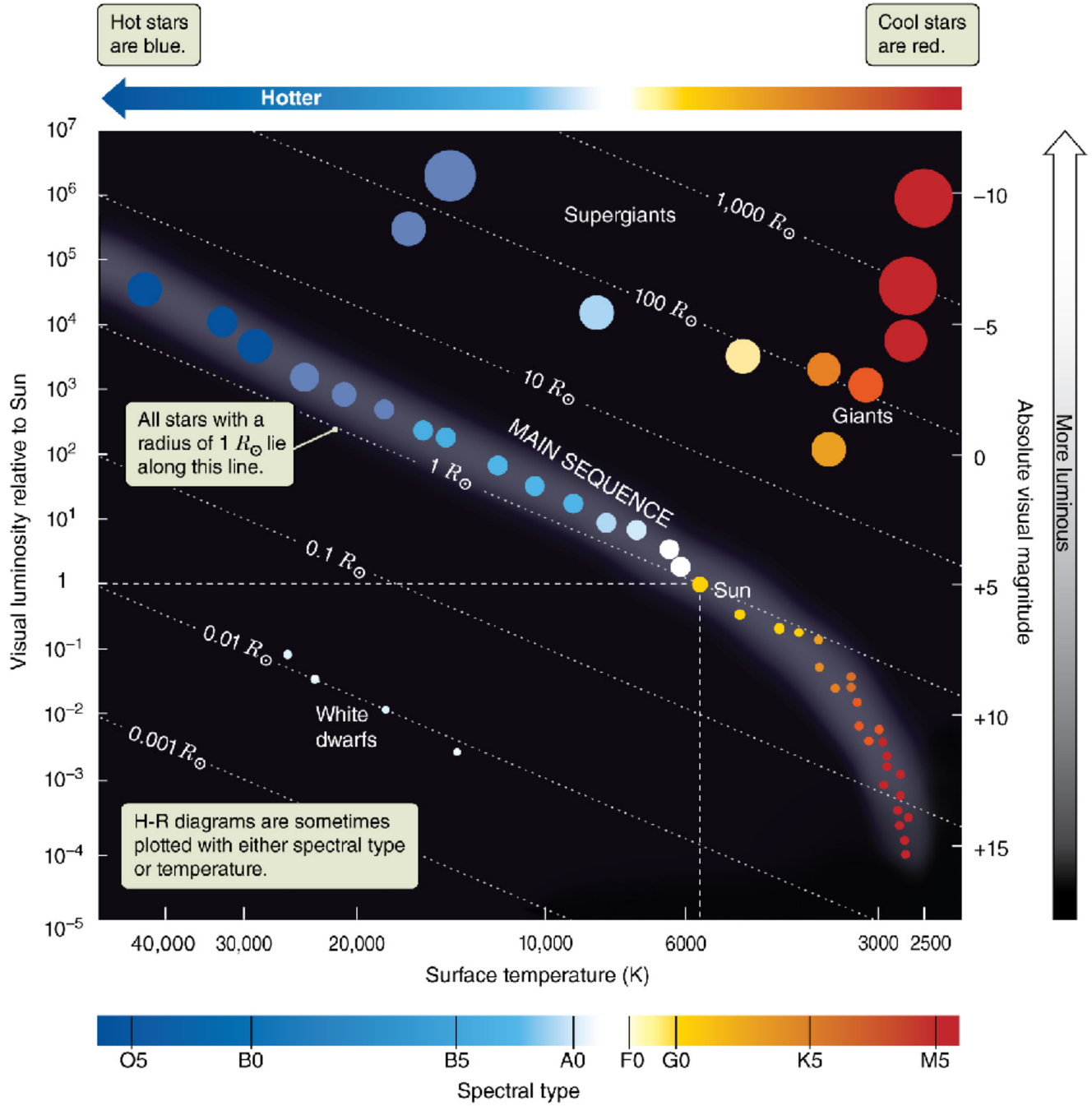
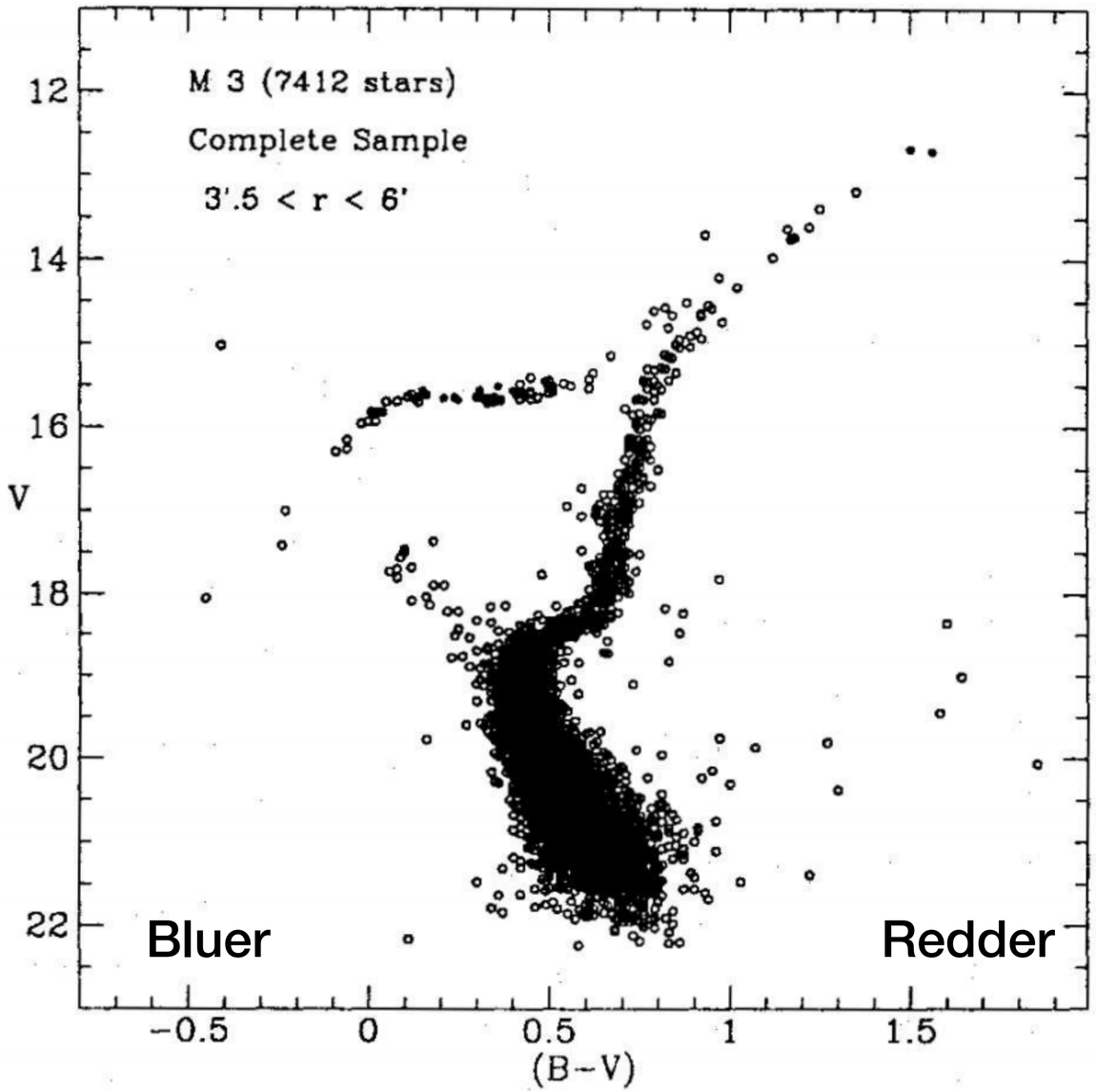
Hertzsprung-Russell (HR) Diagram

Luminosity (intrinsic brightness) on the y-axis

Spectral Type, Color, **Temperature** on the x-axis



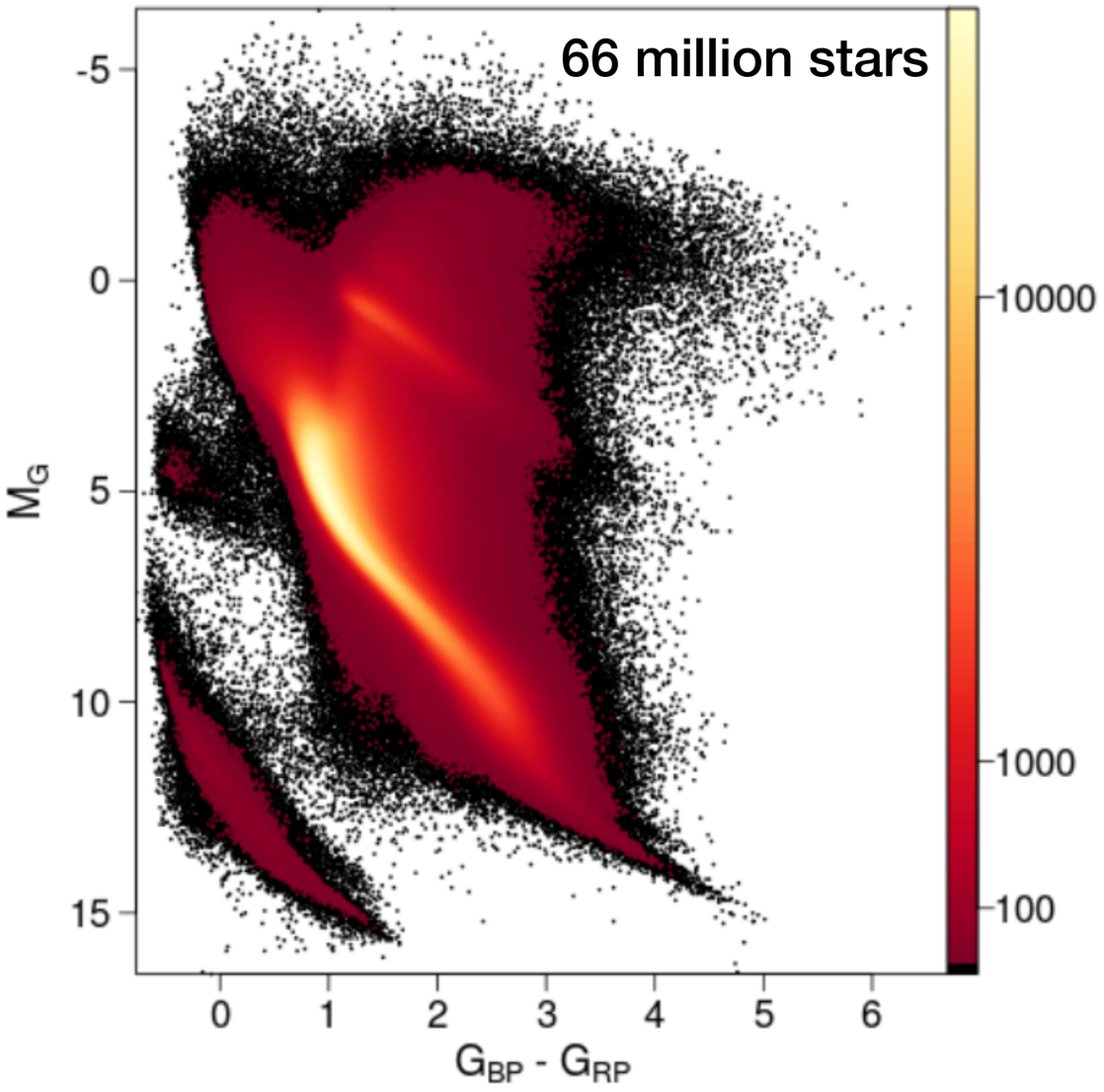
Globular Cluster Color-Magnitude Diagram

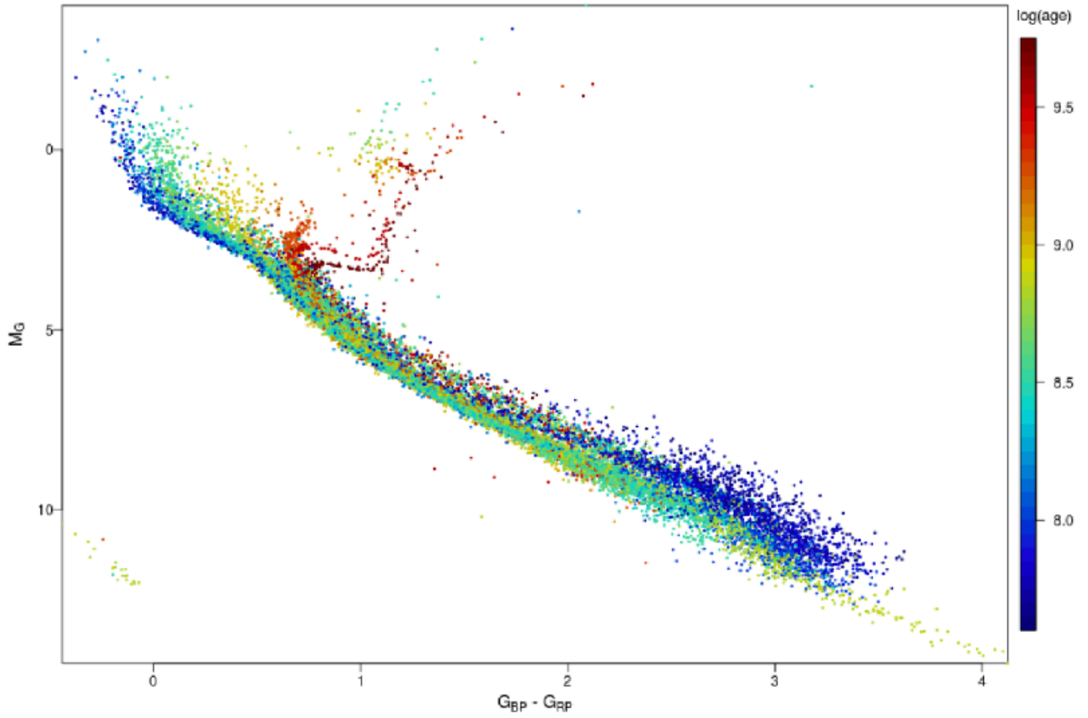


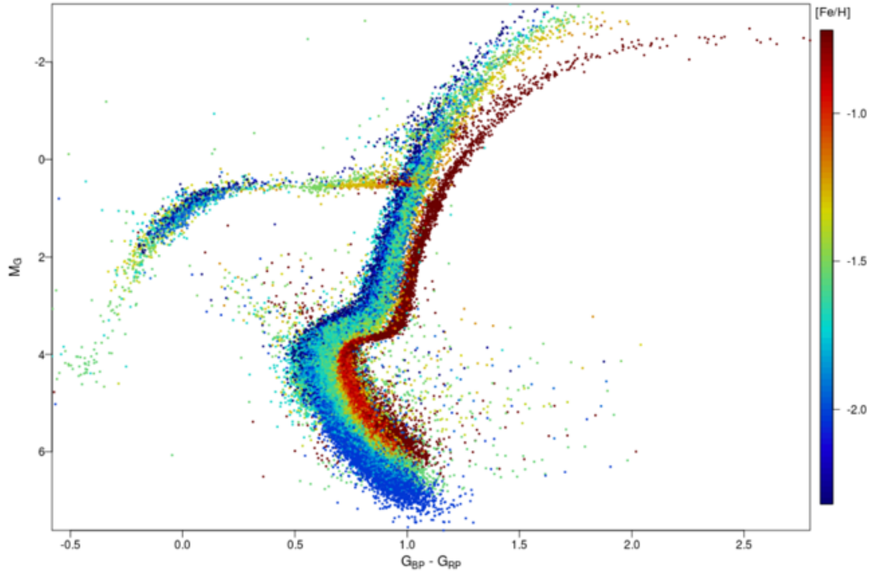
Brighter

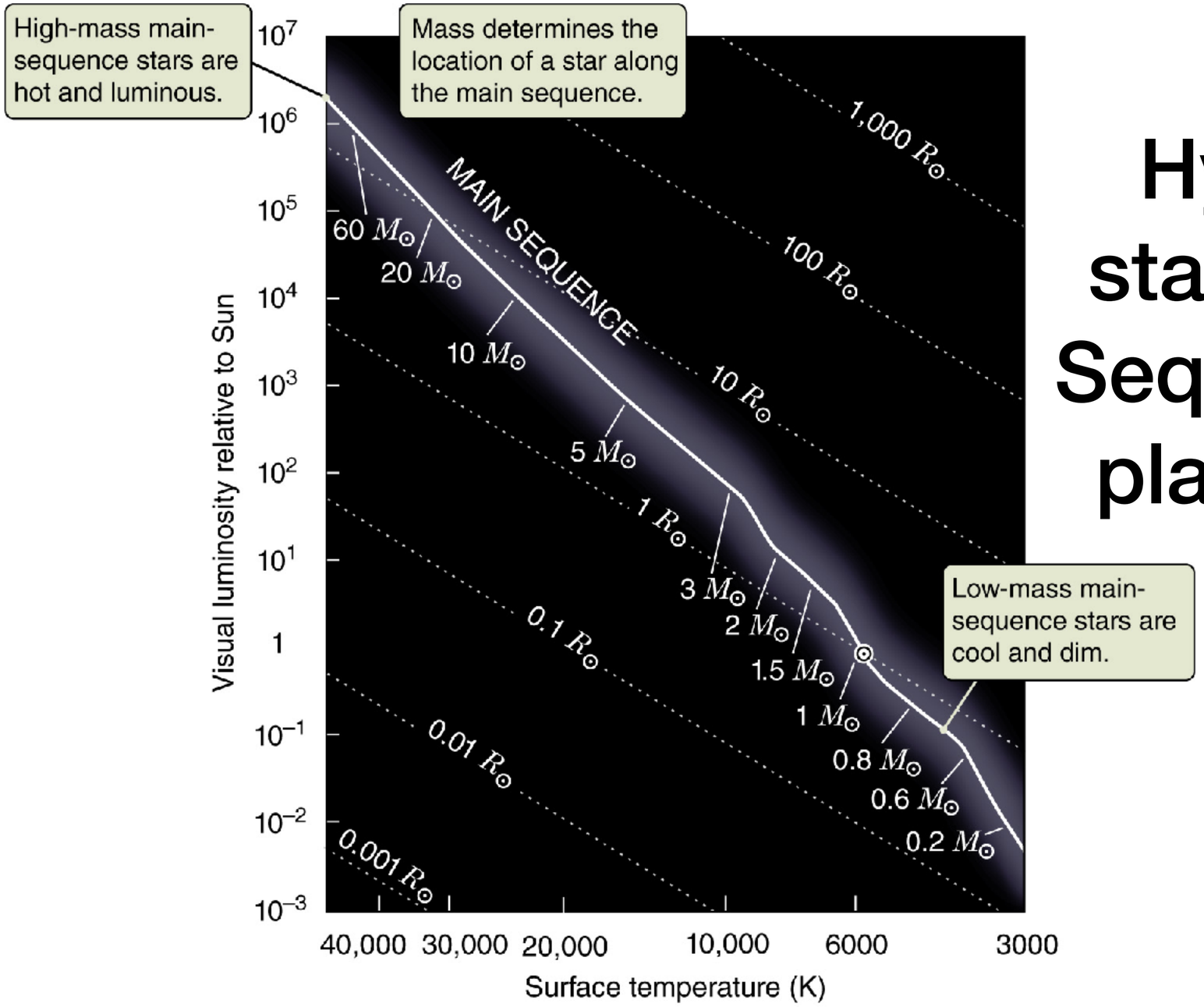
Fainter

Gaia CMDs

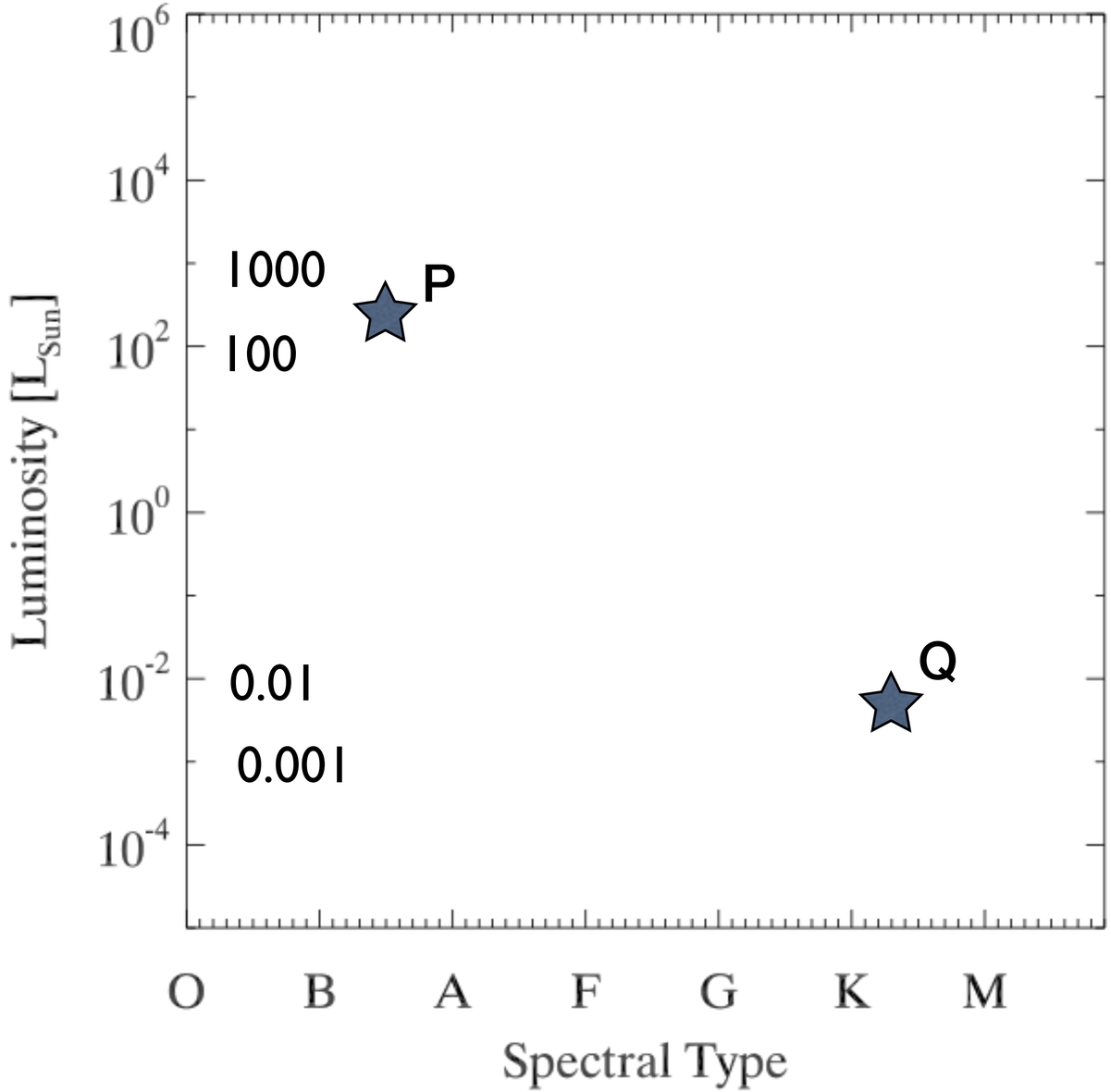

66 million stars
M_G
G_{BP} - G_{RP}
10000
1000
100


log(age)
M_G
G_{BP} - G_{RP}


[Fe/H]
M_G
G_{BP} - G_{RP}



Hydrogen-burning stars fall on the Main Sequence in a specific place determined by their mass



Star P:
Spectral Type: B5
Luminosity: 300 L_{sun}

Star Q:
Spectral Type: K3
Luminosity: 0.008 L_{sun}