Astro100 Lecture 13, March 25

Temperature, Mass and Size of Stars

http://www.astro.umass.edu/~myun/teaching/a100/longlecture13.html

Also, http://www.astro.columbia.edu/~archung/labs/spring2002/spring2002.html (Lab 1, 2, 3)

Goal: To learn how to measure various properties of stars

✓ **What properties of stars can astronomers learn from stellar spectra?**
➔ Chemical composition, surface temperature

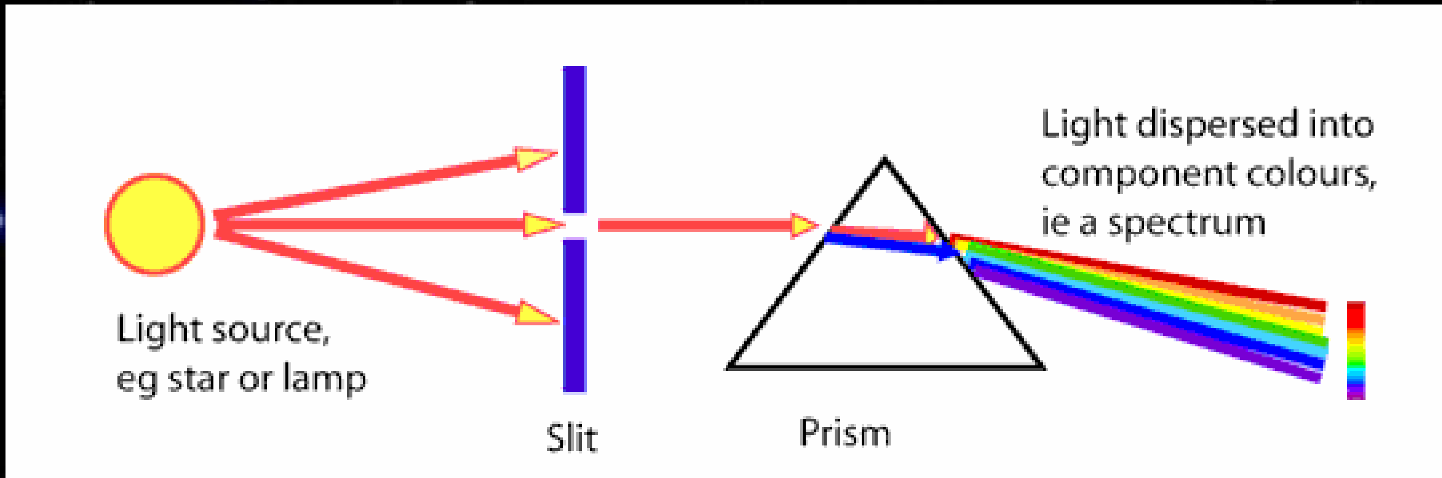
✓ **How useful are binary stars for astronomers?**
➔ Mass

✓ **What is Stefan-Boltzmann Law?**
➔ Luminosity, size, temperature

✓ **What is the Hertzsprung-Russell Diagram?**
➔ Distance and Age

Stellar Spectra

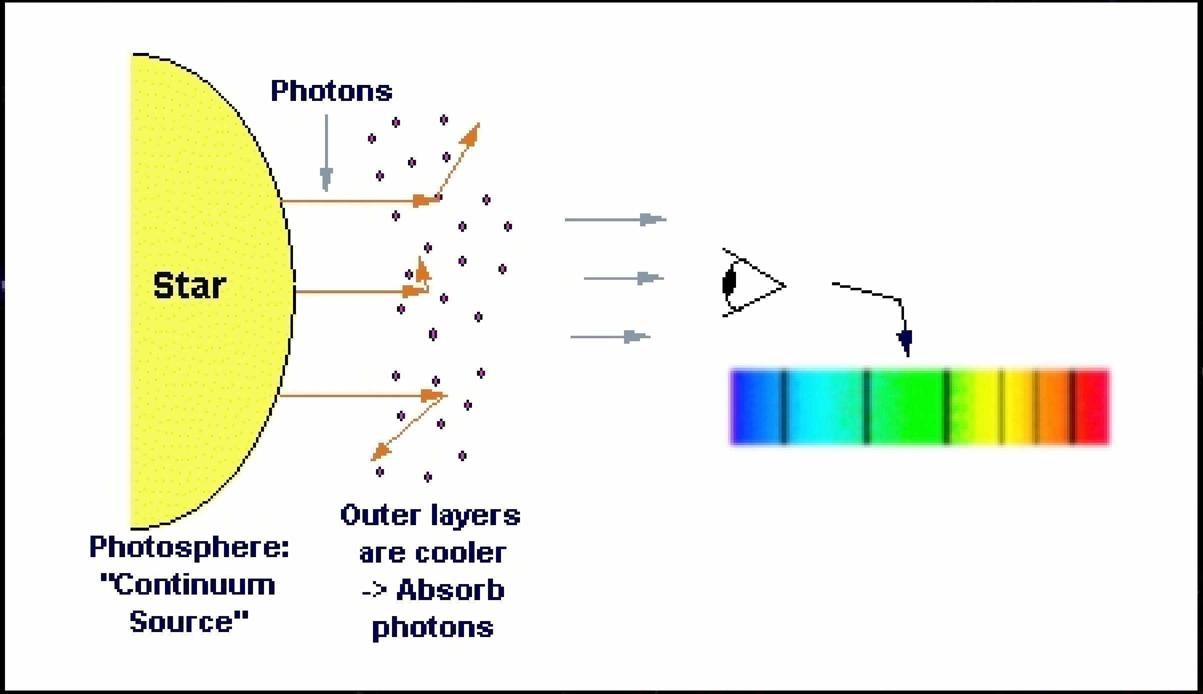
Spectrum: light separated and spread out by wavelength using a prism or a grating



Dispersion of light through a prism

BUT! Stellar spectra are not continuous…

Stellar Spectra

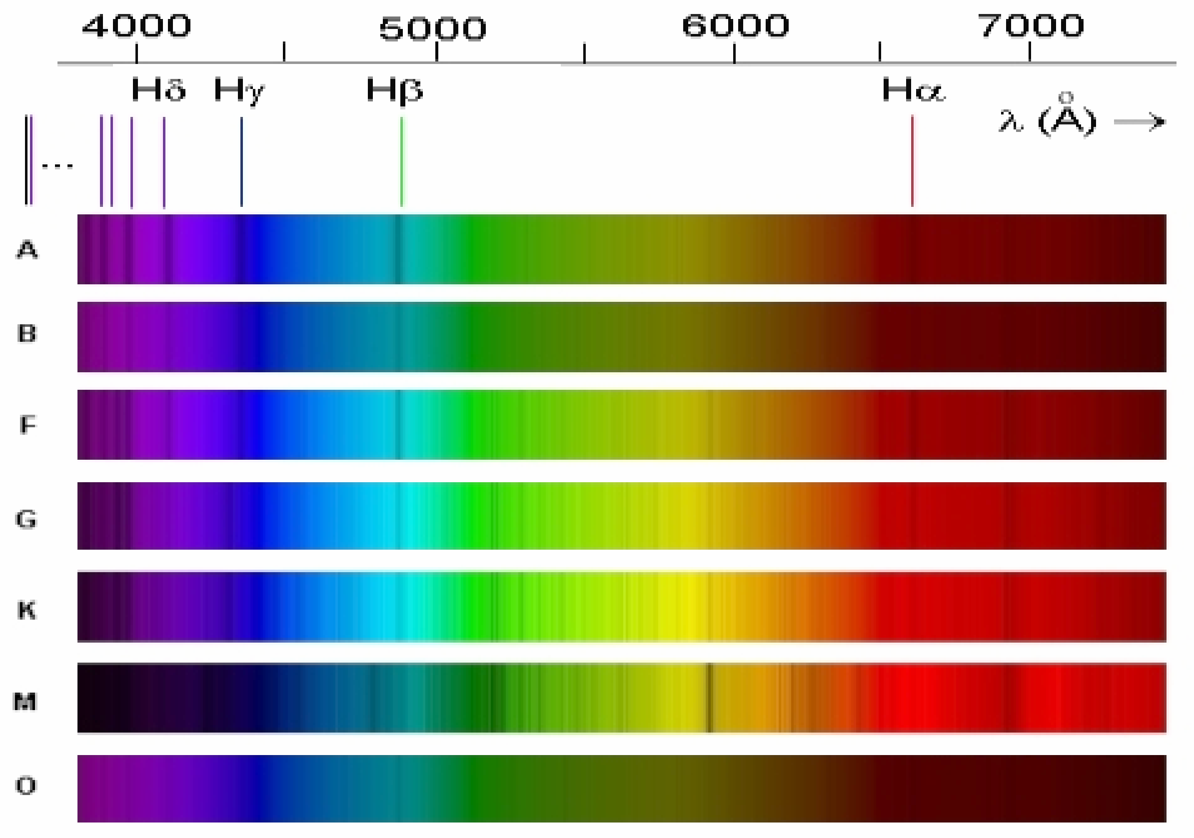


Photons from inside of higher temperature get absorbed by the cool stellar atmosphere, resulting in *"absorption lines"*

At which wavelengths we see these lines depends on the chemical composition and physical state of the gas

Stellar Spectra

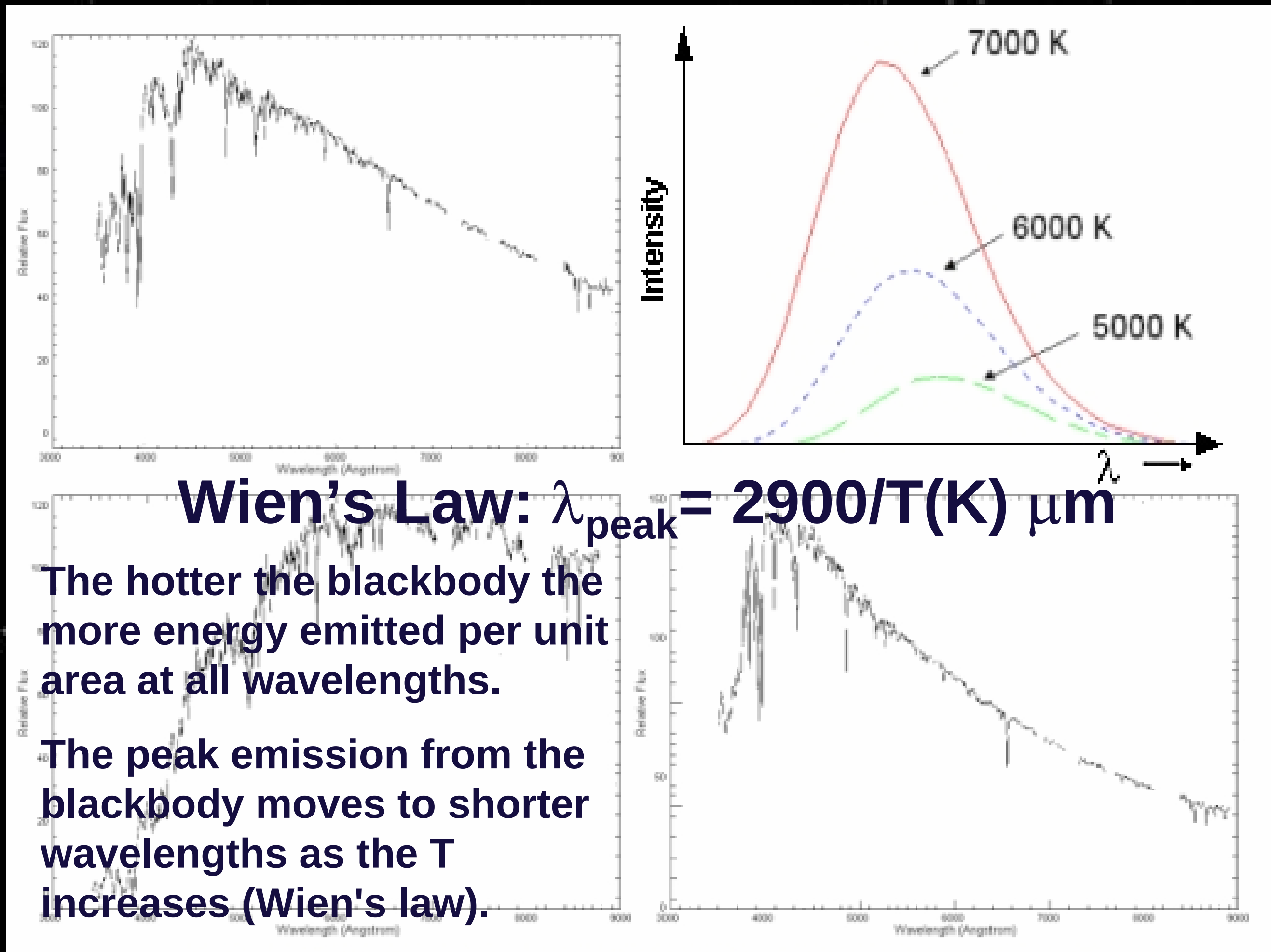
Using the most prominent absorption line (hydrogen),



The hydrogen Balmer spectrum is visible for most stars. And astronomers catagorized stars according to the strength of the hydrogen absorption lines in the spectrum in the late 19th century.

Stellar Spectra

Measuring the intensities at different wavelength,



Wien's Law: $\lambda_{peak} = 2900/T(K)\ \mu m$

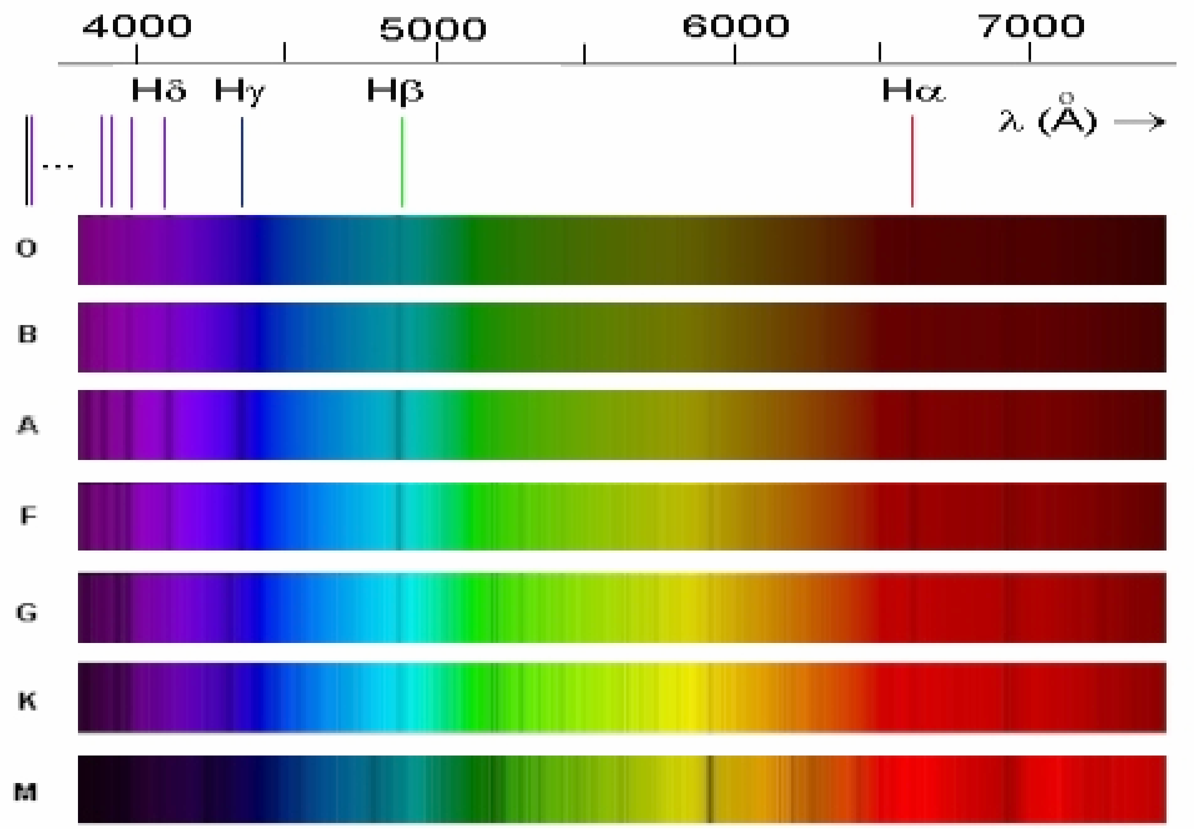
The hotter the blackbody the more energy emitted per unit area at all wavelengths.

The peak emission from the blackbody moves to shorter wavelengths as the T increases (Wien's law).

Scorpius Constellation

Stellar Spectra

Re-ordering the stellar spectra with the temperature



The spectral sequence is:
O, B, A, F, G, K, M
Hotter to cooler
(A temperature sequence)

Stellar Spectra

From stellar spectra…

Surface temperature (Wien's Law), also chemical composition in the stellar atmosphere

Class	Spectrum	Color	Temperature
O	Ionized and neutral helium, weakened hydrogen	Bluish	> 31,000 K
B	Neutral helium, stronger hydrogen	Blue-white	9750-31,000 K
A	Stronger hydrogen, ionized metals	White	7100-9750 K
F	Weaker hydrogen, ionized metals	Yellow-white	5950-7100 K
G	Weak hydrogen, ionized and neutral metals	Yellowish	5250-5950 K
K	Weak hydrogen, neutral metals	Orange	3950-5250 K
M	Little or no hydrogen, neutral metals, molecules	Reddish	2000-3950 K

Stellar Mass

Recalling the Newton's version of Kepler's Law,

$$M_{starA}+M_{starB}=a^3/P^2$$

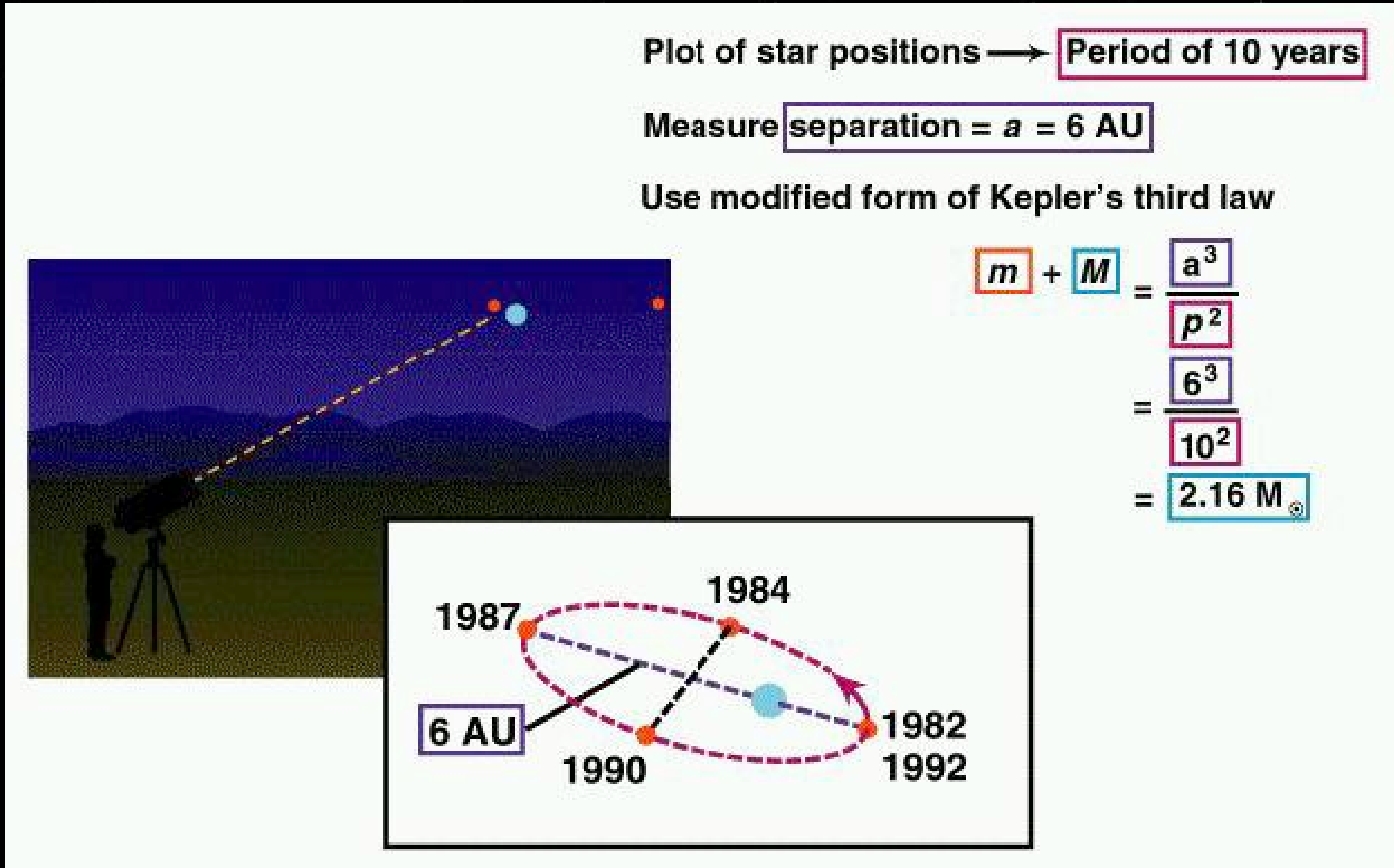
i.e. in a binary system where two stars are orbiting each other, we can determine $M_{starA}+M_{starB}$ by observing "a" and "P", the size of the orbit and the period

Depending on how we can measure "a" and "P"

- Visual binary: we can see a pair of stars orbiting each other
- Spectroscopic Binary: Doppler shift of stellar absorption lines
- Eclipsing Binary: periodic variation in brightness due to shadowing

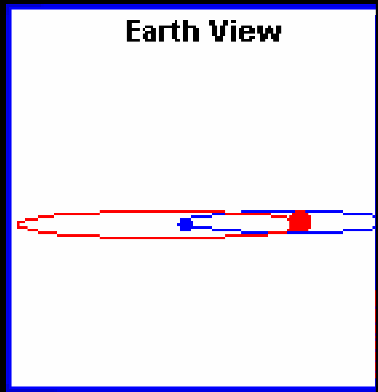
Stellar Mass

Visual Binary



Stellar Mass

Spectroscopic Binary



✓period (P) and line-of-sight velocity ($V = V_1+V_2$) is measured directly

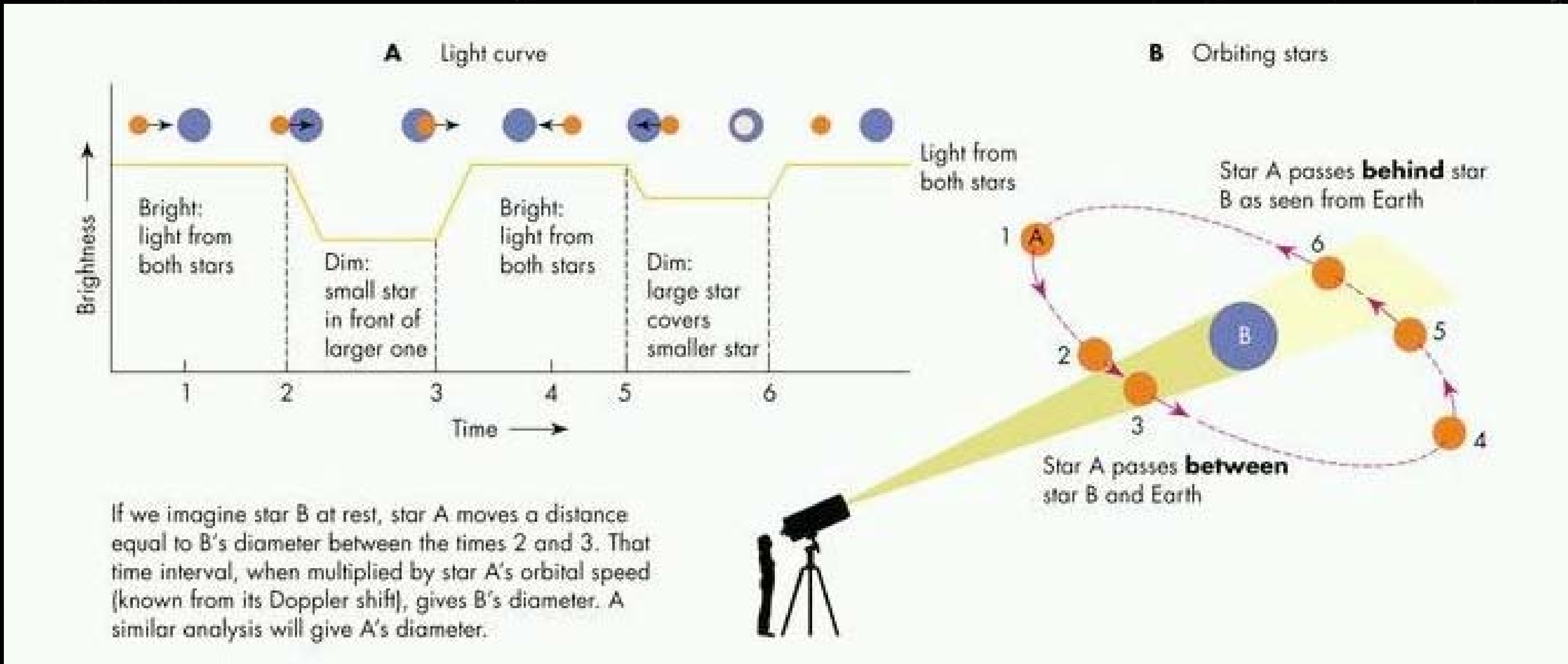
✓semi-major axis (R) = (VP/2π) sin(i)

✓mass ($M = m_1+m_2$) = R^3/P^2 (if R in AU and P in years as before)

Stellar Mass

Eclipsing Binary

When the orbital plane almost coincides with our line-of-sight



We may observe the variation in the brightness due to the geometrical changes in the total light emitting regions

Stellar Mass

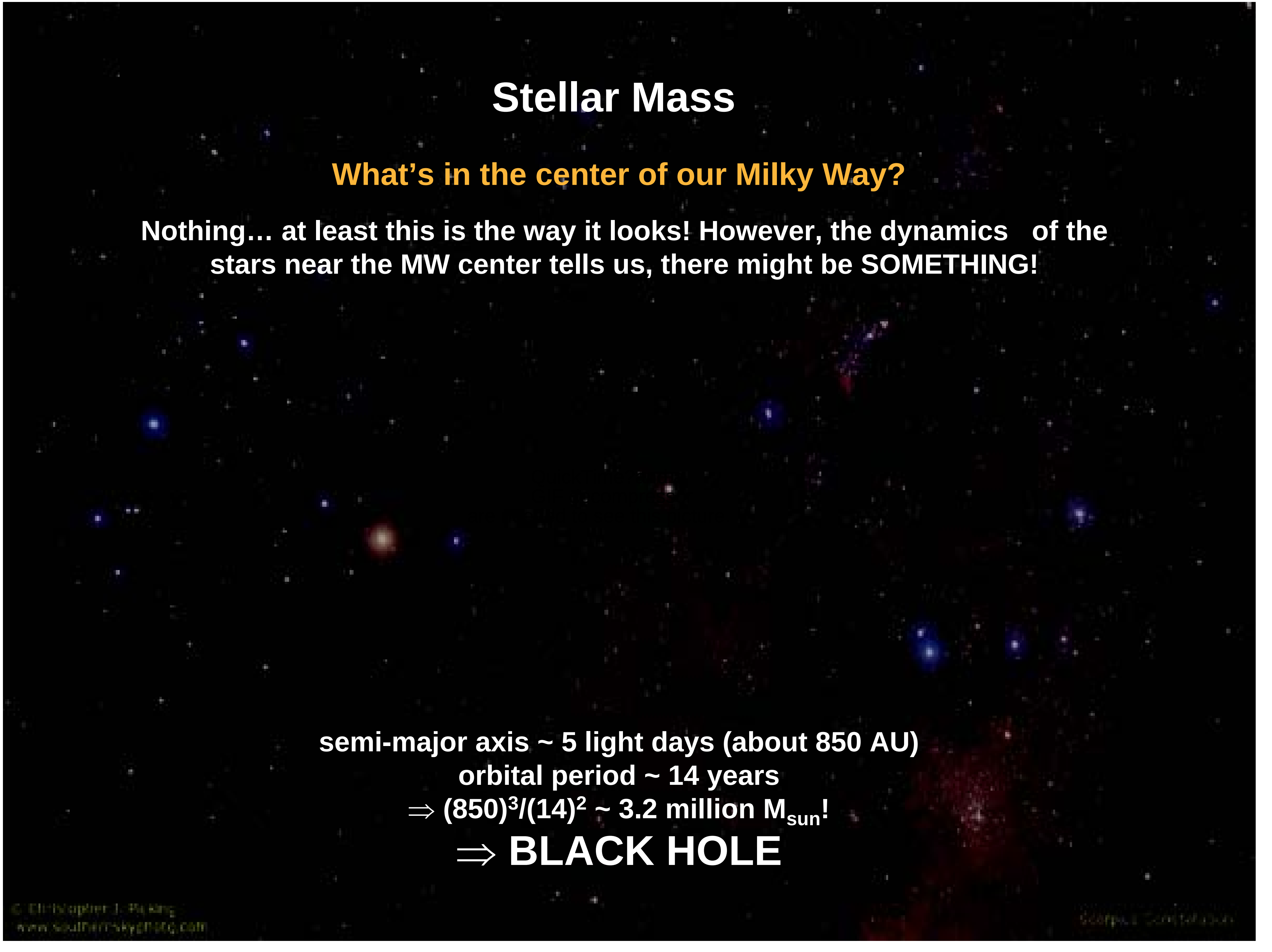
Quiz 13A

The binary stars A and B are seen orbiting each other with a period of 30 years. If the semi-major axis of their orbit is 10 AU, what is the combined mass of the two stars?

1. 0.5 solar mass
2. 1.1 solar mass
3. 1.9 solar mass
4. 10 solar mass
5. 15 solar mass

$$M_A + M_B \text{ in } M_{sun} = a^3\,(AU)/P^2\,(years)$$
$$= 10^3/30^2$$
$$\sim 1.1\ M_{sun}$$

Stellar Mass

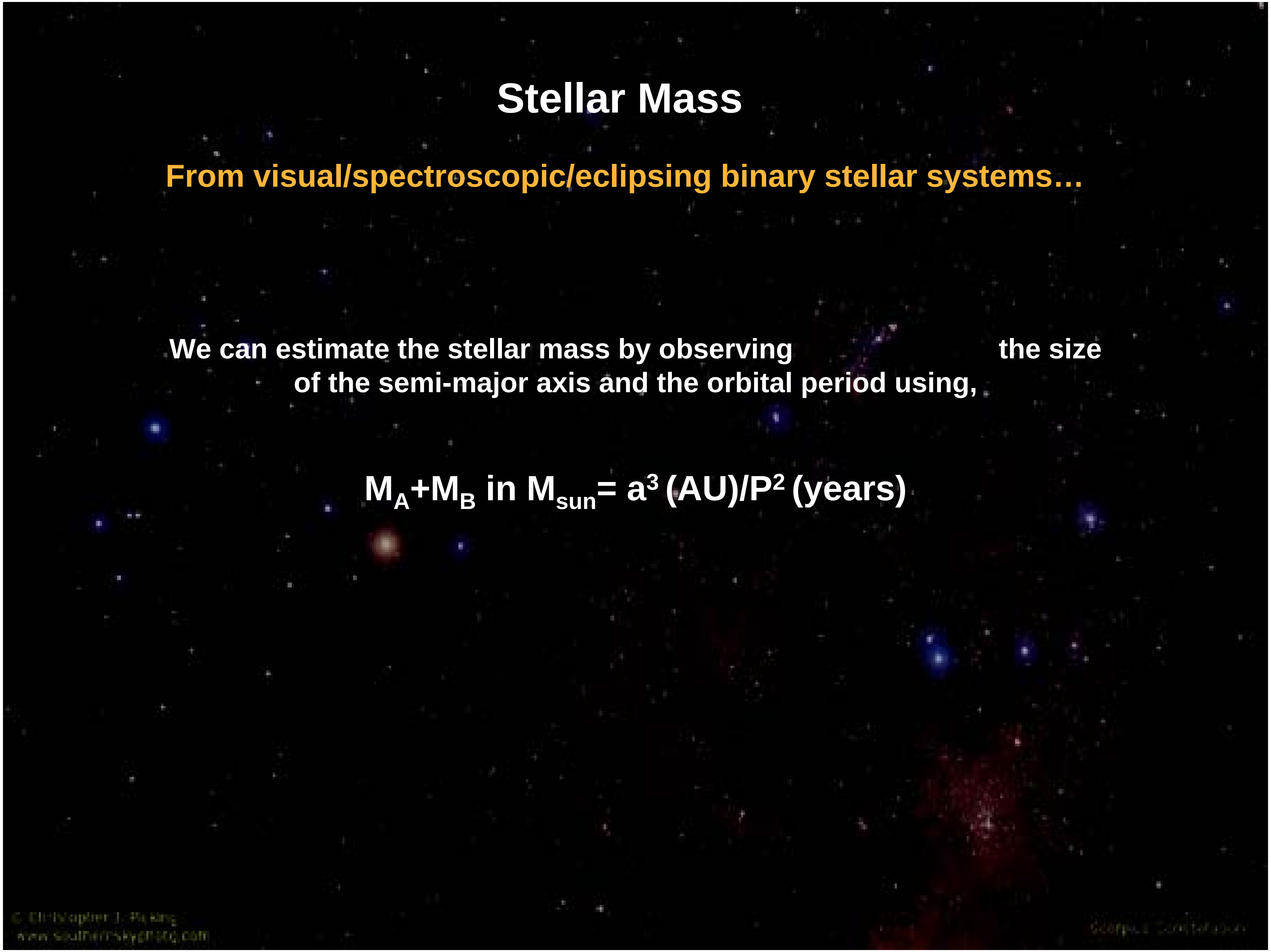


What’s in the center of our Milky Way?

Nothing… at least this is the way it looks! However, the dynamics of the stars near the MW center tells us, there might be SOMETHING!

semi-major axis ~ 5 light days (about 850 AU)
orbital period ~ 14 years
$\Rightarrow (850)^3/(14)^2 \sim 3.2$ million M_{sun}!

$\Rightarrow$ BLACK HOLE



Stellar Mass

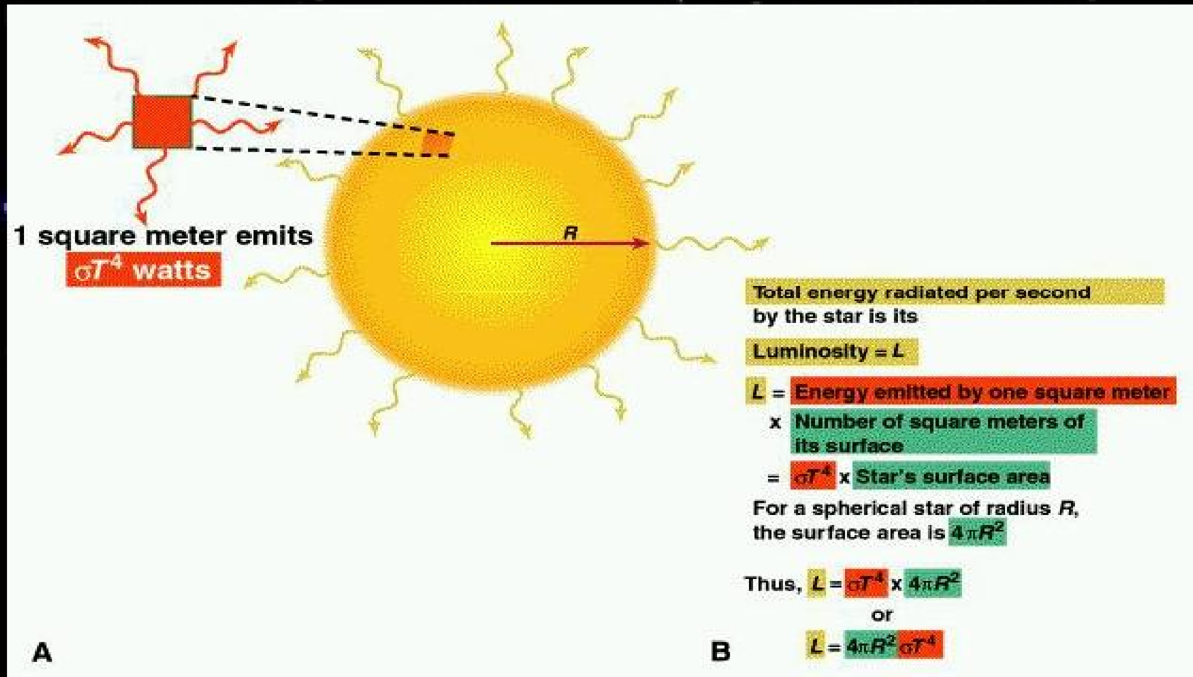
From visual/spectroscopic/eclipsing binary stellar systems…

We can estimate the stellar mass by observing the size of the semi-major axis and the orbital period using,

$$M_A + M_B \text{ in } M_{sun} = a^3\,(AU)/P^2\,(years)$$

Stellar Radius

What determines the total energy radiated from a star?



Stefan-Boltzmann Law: $L = 4\pi R^2 \sigma T^4$

*** Making T larger makes each square meter of the star brighter**
*** Making R larger increases the number of square meters**

We can determine R from the L & T

Stellar Radius

Quiz 13B

The Sun (6000 K) will become a red giant when it nears the end of its life (in about 5 billion years). Its temperature will drop to about 3000 K (thus "red") while the diameter of the Sun will become about 100 times larger (thus "giant"). How would its luminosity compare with the present luminosity?

1. 16 times smaller
2. 100 times smaller
3. 100 times larger
4. 625 times larger
5. 3000 times larger

$$L_{RG}/L_{now} = (R_{RG}/R_{now})^2 \times (T_{RG}/T_{now})^4$$
$$= 100^2 \times 0.5^4$$
$$= 625$$

Stellar Radius

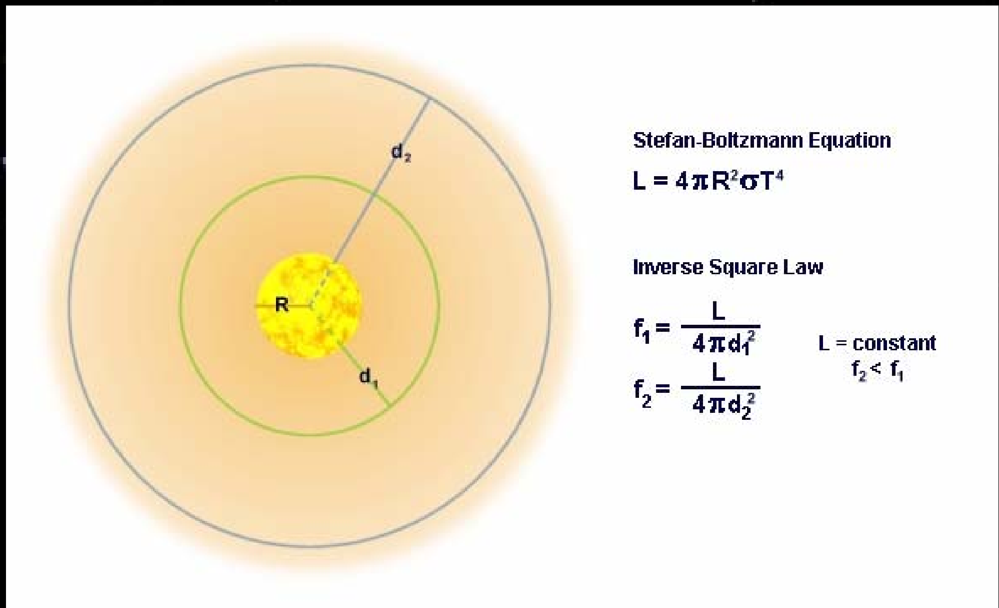
From Stefan-Boltzmann Law

(the relation between the total energy radiated, radius and the surface temperature of the star),

$$L=4\pi R^2 \sigma T^4$$

We can determine the size of the star!

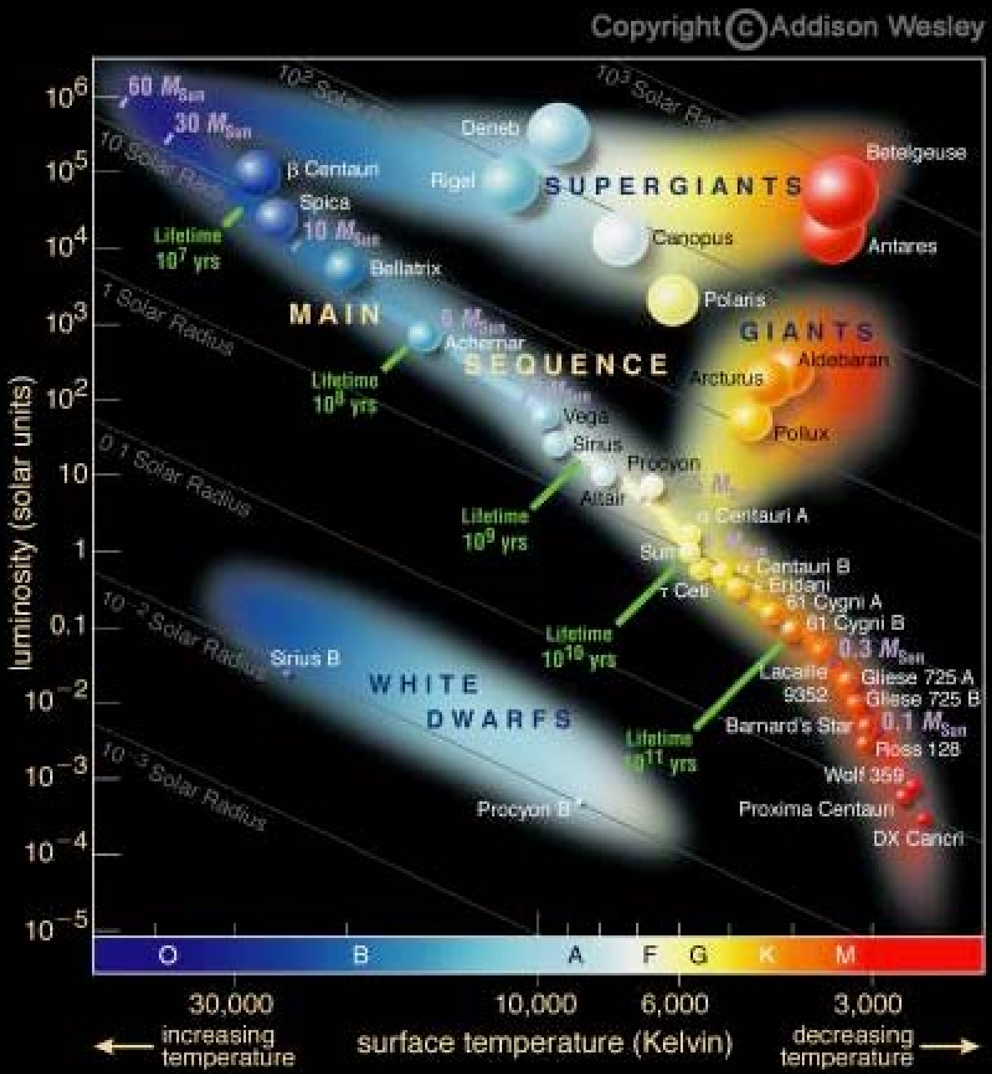
HOWEVER, measuring "L" is not trivial (inverse square law)



We can directly measure the luminosity mostly for a limited number of nearby stars whose distances are known

Hertzsprung-Russell Diagram (HRD)

Luminosity vs. Temperature of Stars (in Solar neighborhood)



$$L=4\pi R^2\sigma T^4$$

Main Sequence
- * most nearby stars (85%) & the sun
- * hydrogen-burning stars
- * 3000-30,000 K
- * 0.1 to 10 R(sun)

Giants and Supergiants
- * Brighter stars for the same T as MS
- * 3000-30,000 K
- * 10 to 1000 R(sun)
- * example: Betelgeuse

White Dwarfs
- * faint stars for the same T as MS
- * 5000-30,000 K
- * 0.01 R(sun)

Stellar Radius

Quiz 13C

A yellow supergiant star X has the same color as the Sun, and it has 10000 times larger luminosity. From this, you would conclude that

1. **Star X is hotter than the Sun.**
2. **Star X is colder than the Sun.**
3. **Star X has a larger diameter than the Sun.**
4. **Star X has a smaller diameter than the Sun.**
5. **Star X is powered by a black hole.**

Same color = Same surface temperature

According to Stefan-Boltzmann Law,

$$L=4\pi R^2\sigma T^4$$

star X should have a larger diameter (~factor 100) than the Sun!

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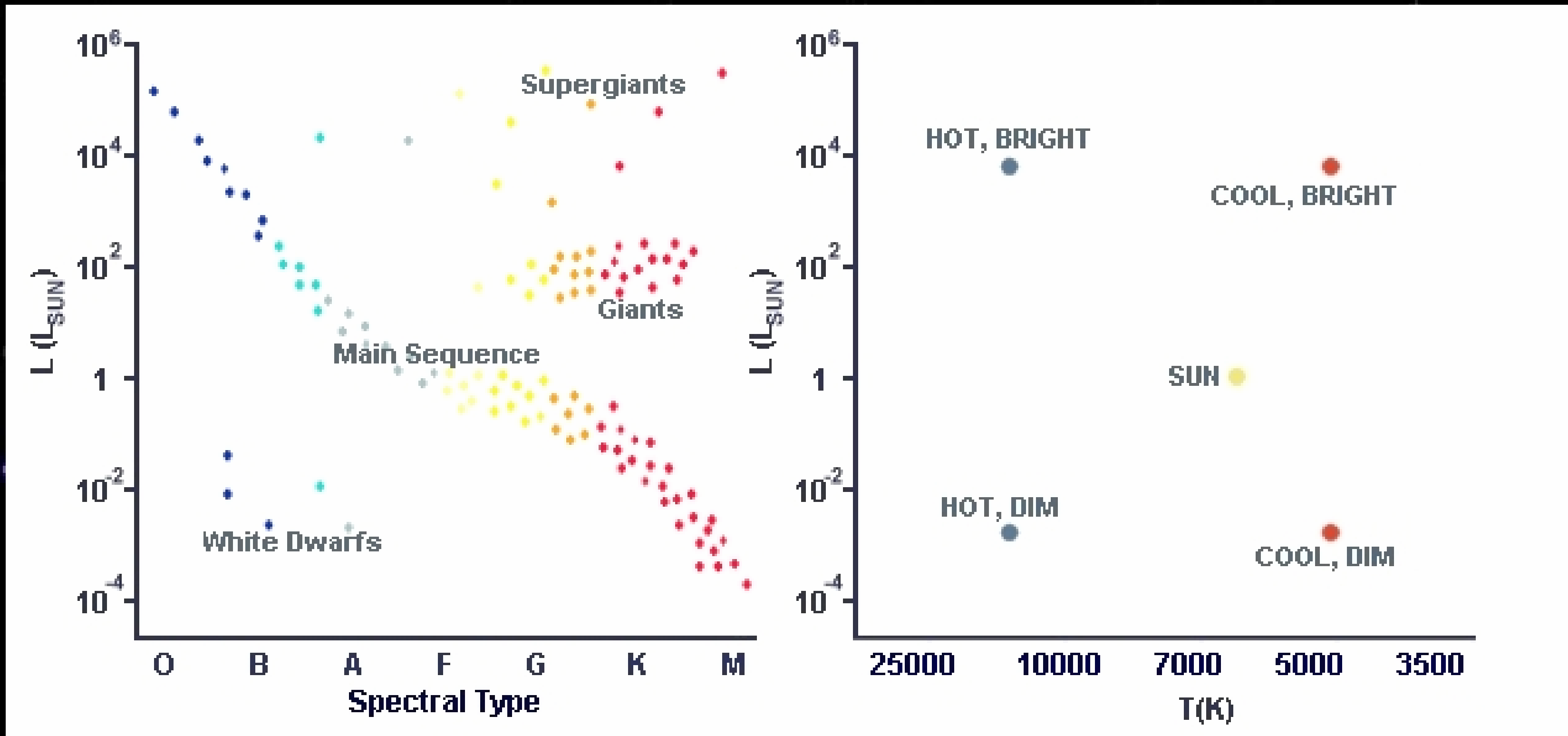
Hertzsprung-Russell Diagram (HRD)

Luminosity vs. Temperature of Stars



HRD can be used to determine the age and the distance to stellar clusters, where we can assume the same birth epoch and the unique distance for the entire members… (next lecture)

Summary: How to measure various properties of stars

✓ **What properties of stars can astronomers learn from stellar spectra?**

➔ **Surface T from Wien's Law, chemical composition from absorption lines**

✓ **How useful are binary stars for astronomers?**

➔ **Mass can be determined by observing the size and the period of the orbit (the Newton version of the Kepler's Law, M_1+M_2 (in M_{sun})=a^3 [AU]/p^2 [year])**

✓ **What is Stefan-Boltzmann Law?**

➔ **Luminosity, size, temperature: $L=4\pi R^2\sigma T^4$**

✓ **What is the Hertzsprung-Russell Diagram?**

➔ **Luminosity vs. Temperature of stars: ~85% of stars including our Sun reside along the trail called "Main Sequence" where cool stars are small and hot stars are big; as stars evolve stars can become cool but large (giants/supergiants) or hot but small (white dwarfs)**

➔ **HRD can be very useful to determine the age of distance to stellar clusters (next lecture)**

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