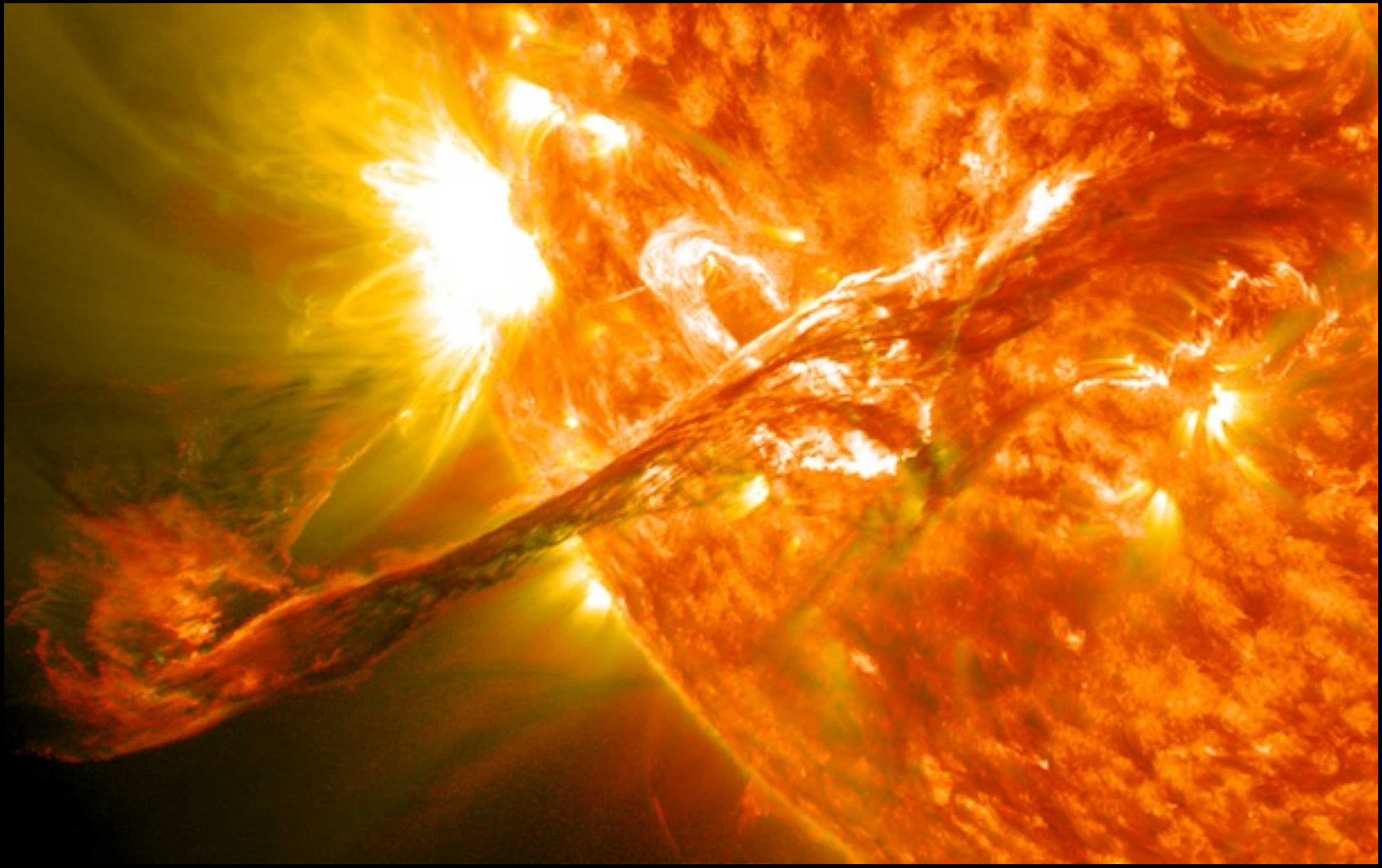
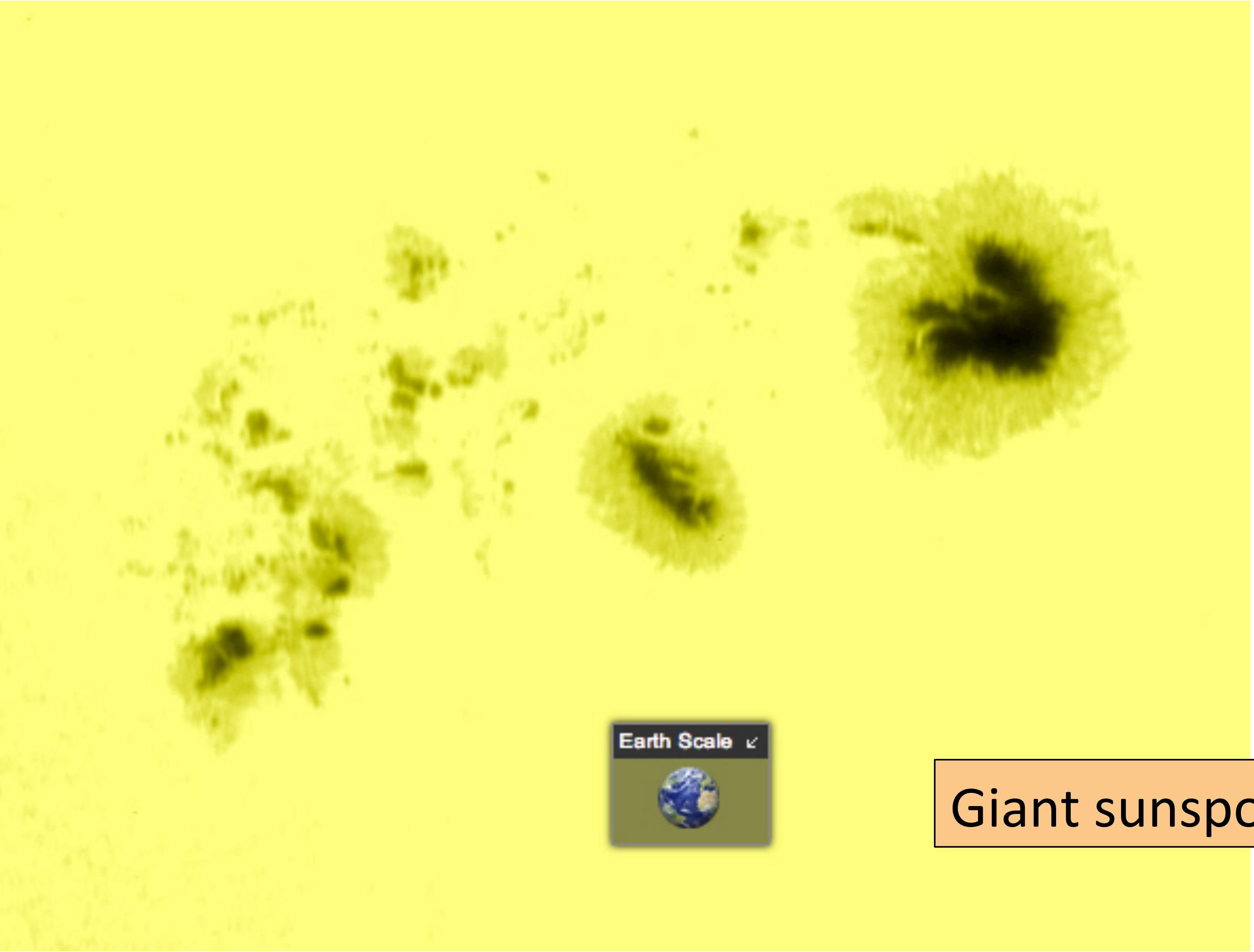
Announcements

- **Quiz 6** due Monday – this covers stars, Chapter 10
- Practice problems: **Problem sets 6A and 6B**
- Upcoming schedule: we'll finish Chapter 10 on Friday or Monday, start Chapter 11 on Monday

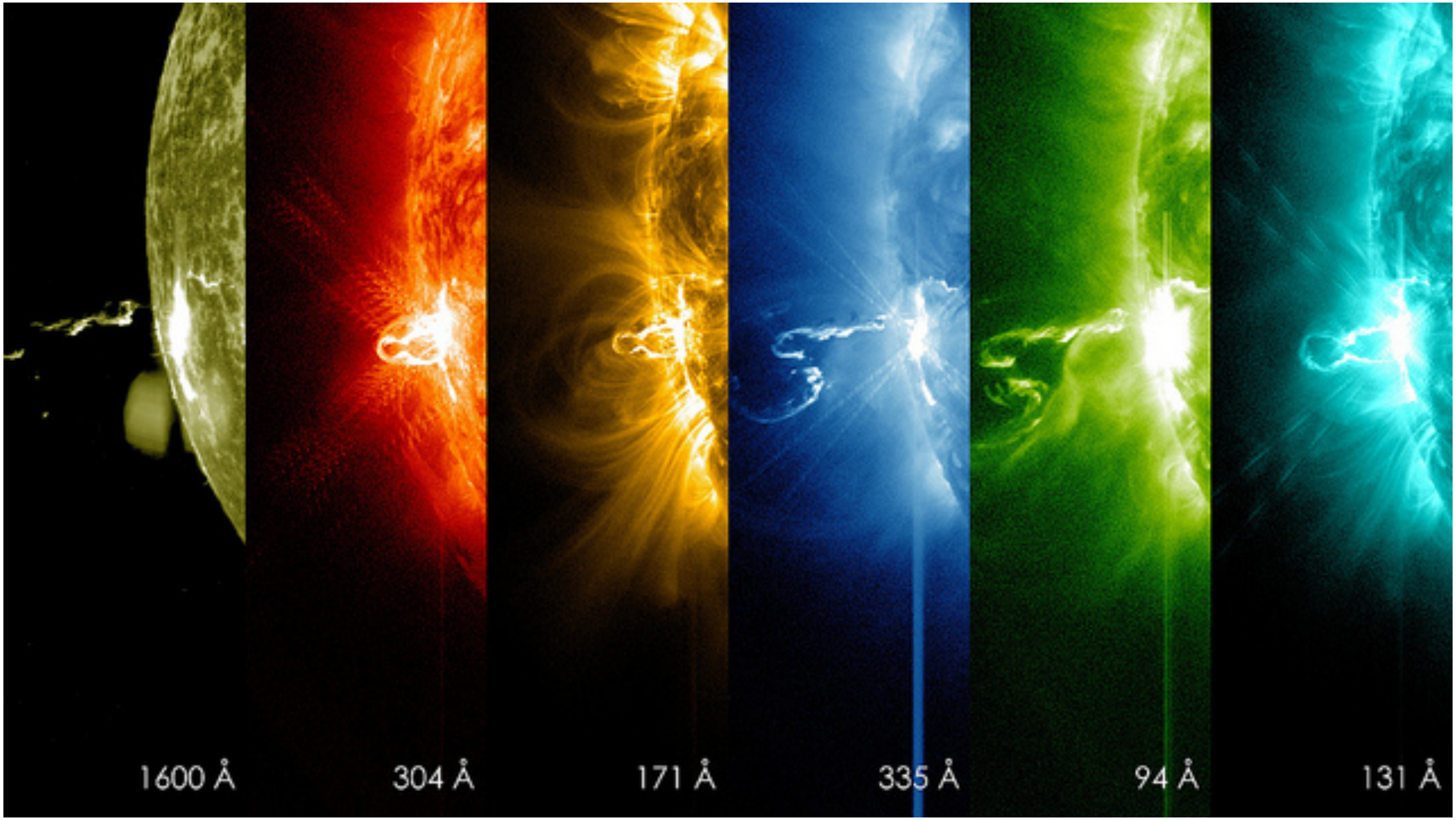
The Sun



What's the Sun doing today?



Giant sunspots!



Monday February 24, 7:25 pm EST

NASA's Solar Dynamics Observatory records giant solar flare

The Sun

- Powered by **nuclear fusion**: conversion of mass into energy as light elements fuse into heavier ones
- The Sun fuses hydrogen into helium
- 4 hydrogen atoms fuse into 1 He-4 atom, and 0.7% of the mass of the hydrogen is converted into energy

$$E=mc^2$$

Fusion in the Sun:
the proton-proton chain

https://www.youtube.com/watch?v=LpUB8iMbNw0

Astronomy 103

The Stars

Please read Chapter 10

Stars

We know a lot about stars and how they work!

- How big are they? **Mass** and **Size**
- How **bright** are they?
- How do they shine? We know this already, at least for the Sun – are other stars the same?

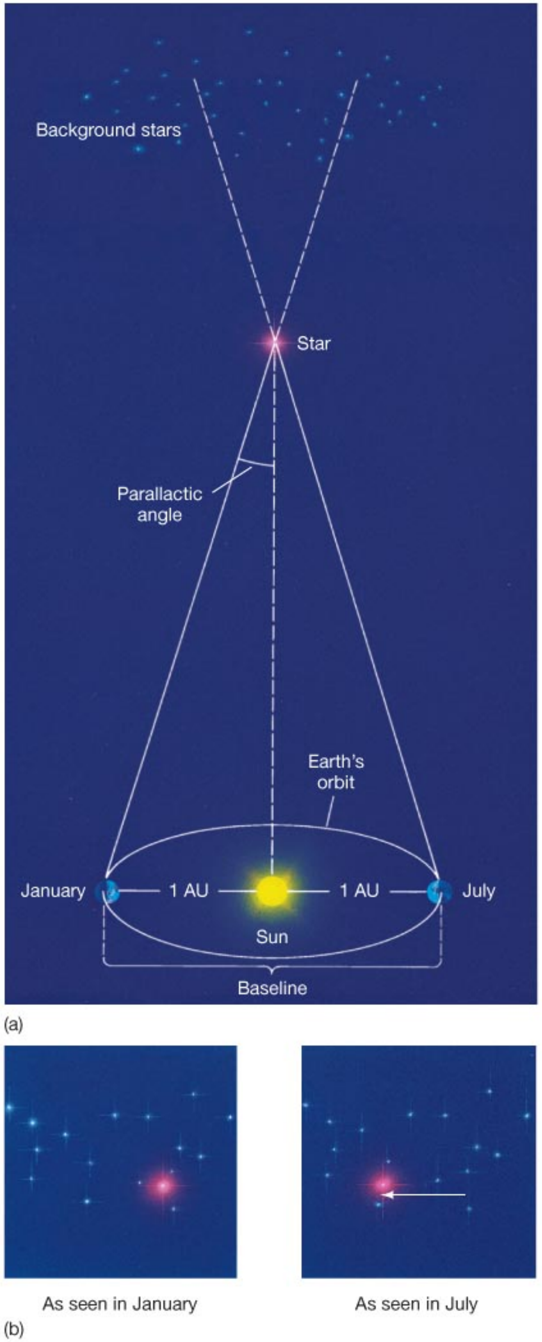
To tackle these questions, we must first know how far away they are. How do you measure the distances to the stars?

Method 1: **Stellar Parallax**

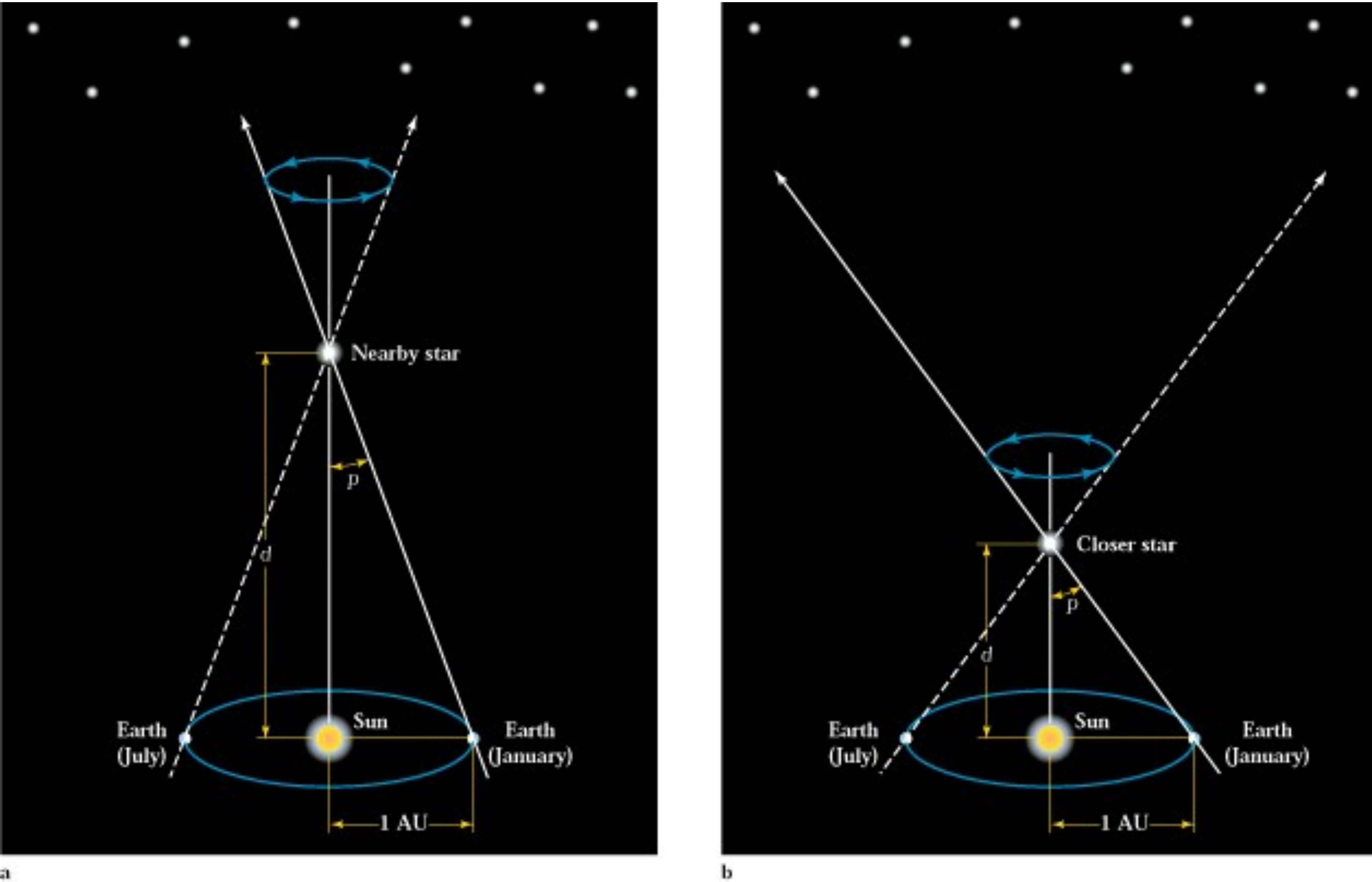
For the very closest stars we can measure how much they shift against more distant stars over the course of six months – the time it takes for the earth to move from one side of its orbit to another.

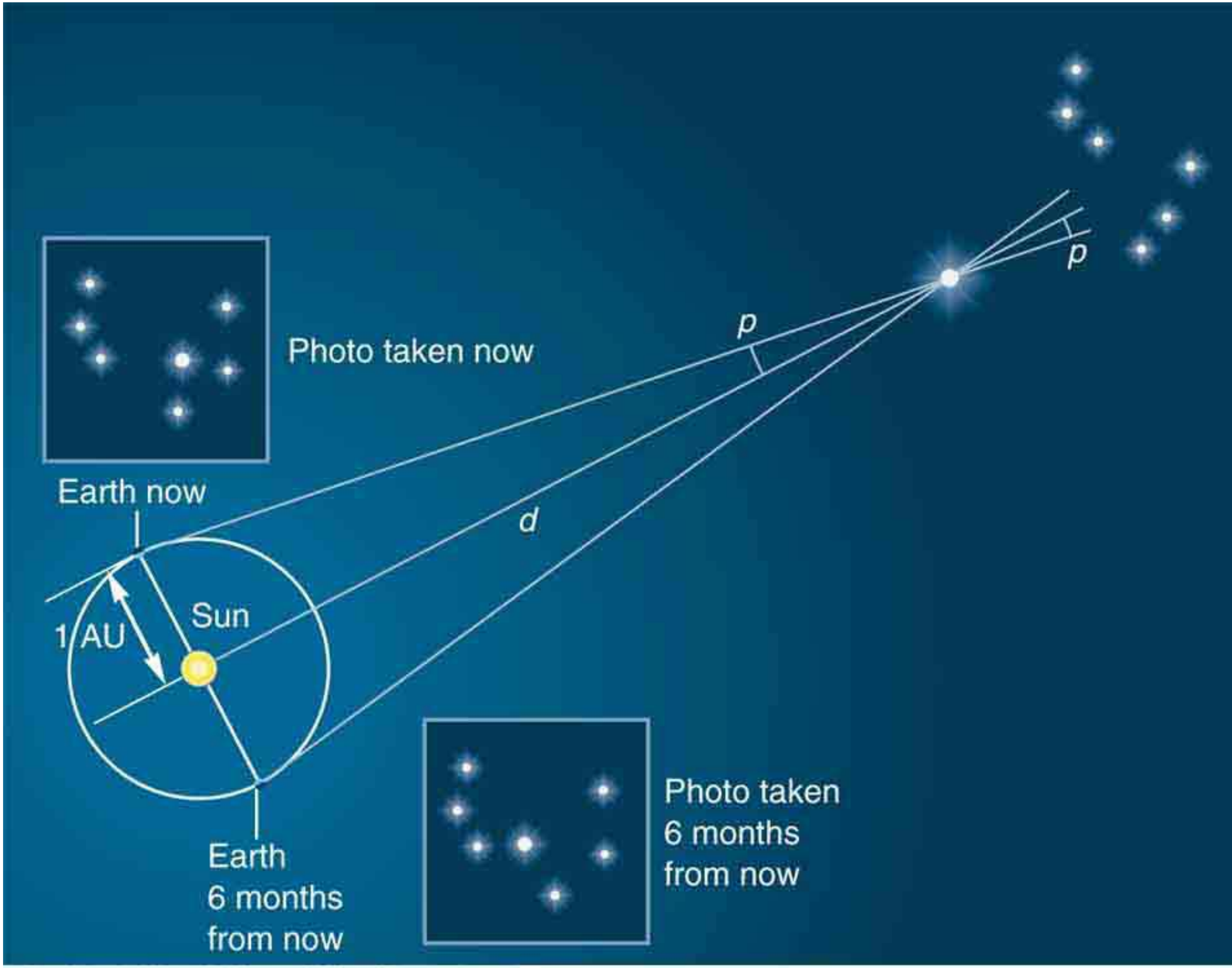
That tiny shift can tell us the distance to that star. So tiny that no one saw it until 1838.

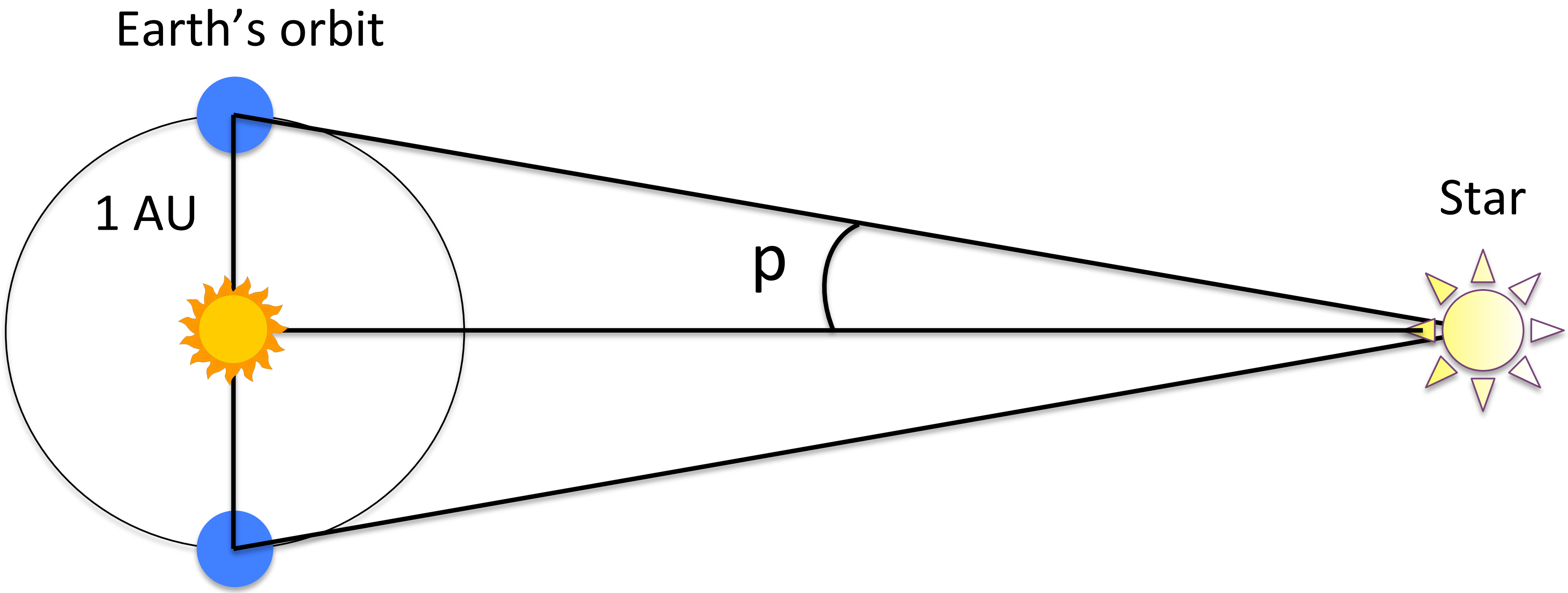
- Shift is about 1/3600 of a degree or 1 arcsecond.



Stellar Parallax




p
p
Photo taken now
Earth now
d
Sun
1 AU
Earth
6 months
from now
Photo taken
6 months
from now



- The **parallax angle** *p* of a star is the angle formed by the star and the radius of the Earth's orbit. (i.e. the angle subtended at a star by the radius of the Earth's orbit is the parallax angle, p, of the star)
- This is the apparent shift in the star's position due to the Earth's motion about the Sun.
- When the angle is 1", the star's distance is 210,000AU or 3.26 ly.
- This distance is called one **parsec** (for parallax second), or pc for short: 1 pc = 3.26 ly = 3.09 x10^{13} km

Method 2: **Spectroscopic Parallax**

If you know how bright something is, you can tell how far away it is by looking at how bright it seems.

Method 2: Spectroscopic Parallax

How bright something seems depends on its distance

$$\text{apparent brightness} = \text{luminosity}/(4\pi\, d^2)$$

How bright it seems

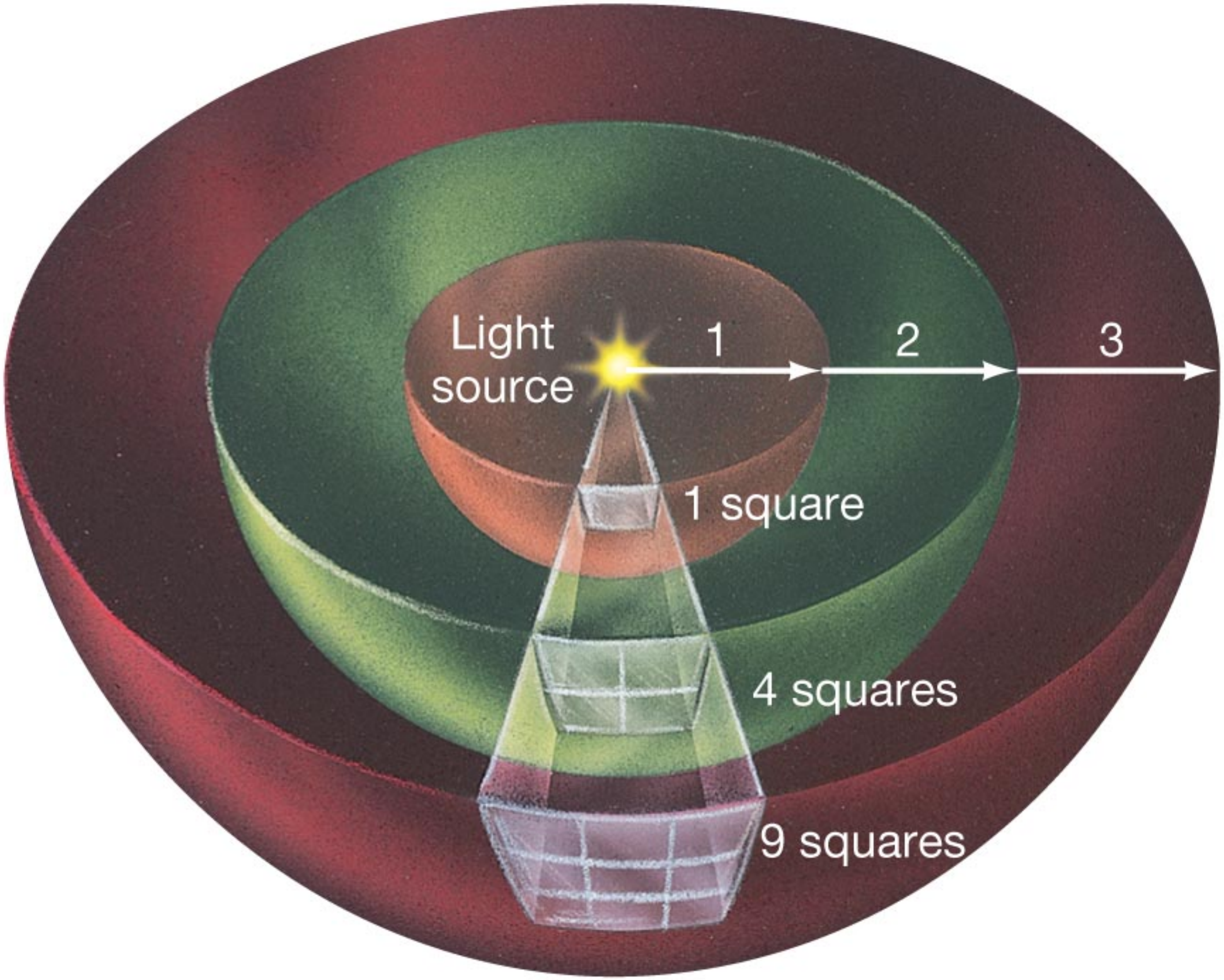
How bright it is

How far away it is

Some quiz problems will use the fact that apparent brightness is proportional to $1/(\text{distance})^2$

There is a very good reason for this!

As light moves away from a star (or light bulb) its energy is spread out over a larger area. That area is proportion to d^2



B proportional to $1/d^2$

or

$$B_2 = B_1 \times \frac{d_1^2}{d_2^2}$$

- Example: The brightness of sunlight at the Earth is 1400 watts/meter^2. What is the brightness of sunlight at Saturn, 10 AU from the Sun?

- Example: The brightness of sunlight at the Earth is 1400 watts/meter^2. What is the brightness of sunlight at Saturn, 10 AU from the Sun?

$$B \text{ proportional to } 1/\mathrm{d}^2$$

- Saturn is 10 times farther away from the Sun than the Earth, so sunlight is $1/10^2 = 1/100$ times brighter.
- The brightness of sunlight on Saturn is $1400/100 = 14$ watts/meter^2. This is why the outer planets are cold!

A few more examples:

1. What is the brightness of the sun at 40 A.U. if it is 1400 watts/m^2 at 1 A.U?

$$B_2 = B_1 \times \frac{d_1^2}{d_2^2}$$

$$= 1400 \times \frac{1^2}{40^2} = 0.875 \text{ watts/m}^2$$

A few more examples:

1. What is the brightness of the sun at 40 A.U. if it is 1400 watt/m^2 at 1 A.U?

2. How about at 100 A.U.?

$$B_2 = B_1 \times \frac{d_1^2}{d_2^2}$$

$$= 1400 \times \frac{1^2}{100^2} = 0.14 \text{ watts/m}^2$$

Another example: If the Sun has an apparent brightness of 0.0014 watts/m^2, how far away is it?

$$B_2 = B_1 \times \frac{d_1^2}{d_2^2}, \text{ so}$$

$$d_2^2 = d_1^2 \times \frac{B_1}{B_2}$$

$$= (1 \text{ A.U.})^2 \times \frac{1400}{0.0014} = 10^6 \text{ A.U.}^2 \text{ and}$$

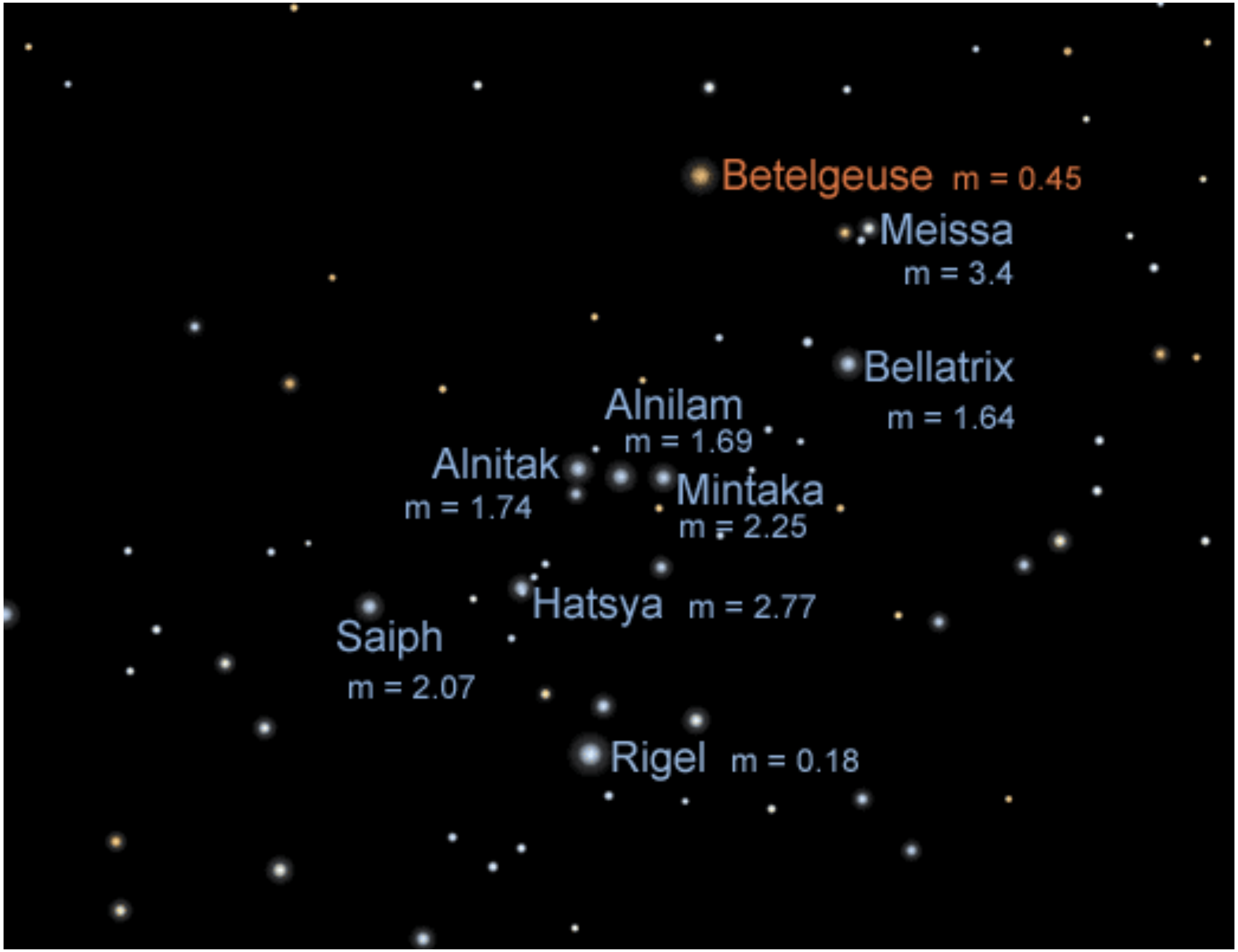
$$d_2 = \sqrt{10^6} = 1000 \text{ A.U.}$$

Apparent brightness of stars is measured in units of watts/meter^2.

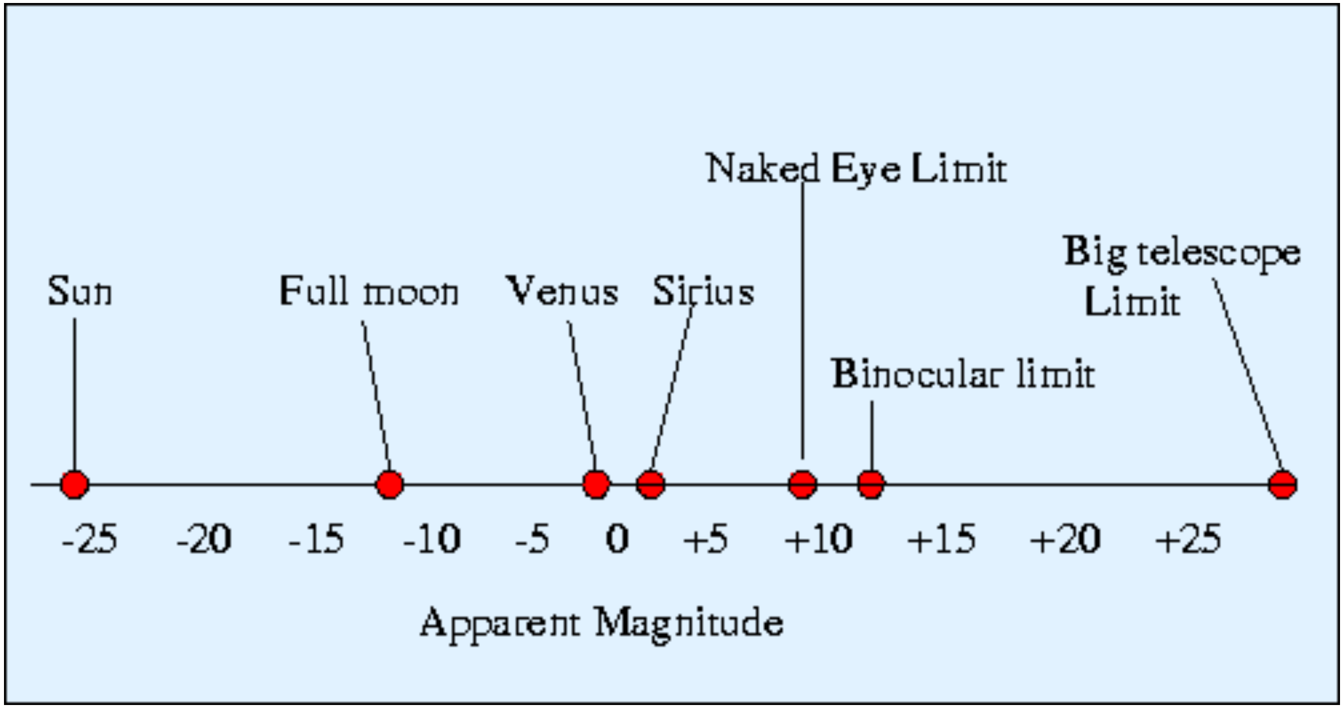
There is a much older scale, invented by the Greek astronomer Hipparchus after whom the Hipparcos satellite was named. (You should remember him from his discovery of the precession of the equinoxes.)

Hipparchus ranked the stars by apparent brightness, with the brightest stars assigned **magnitude** 1, the dimmest magnitude 6.

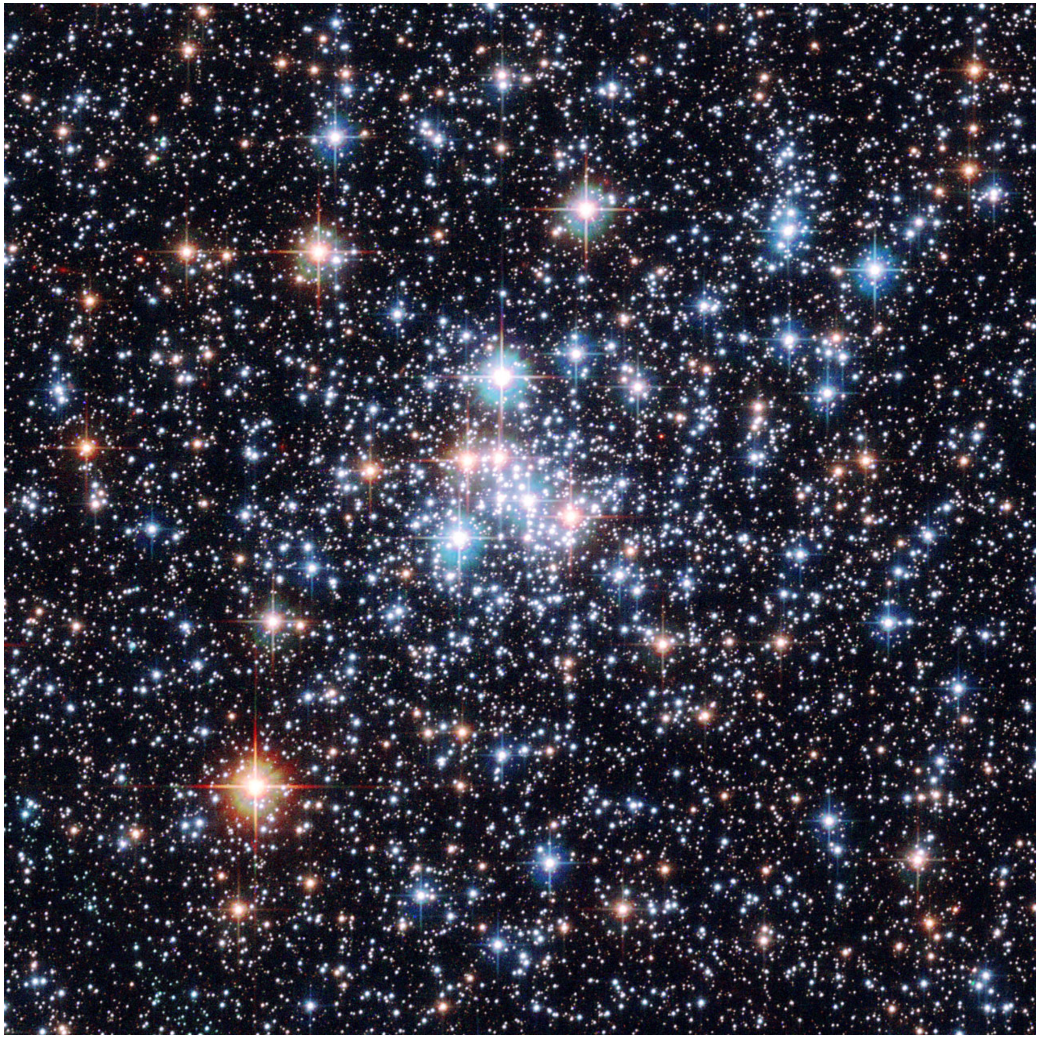
Magnitude 1 stars are about 100 times brighter than magnitude 6 stars (as seen from Earth).



The brightest stars have magnitudes around 0.
The faintest you can see are around 6.



Magnitudes are commonly used by astronomers today. A decrease in magnitude by 5 multiplies the apparent brightness by 100. The most sensitive telescopes can see stars 25 magnitudes larger (fainter) than you can see with the naked eye: stars whose apparent brightness is 10^{10} times smaller than the dimmest stars you can see.



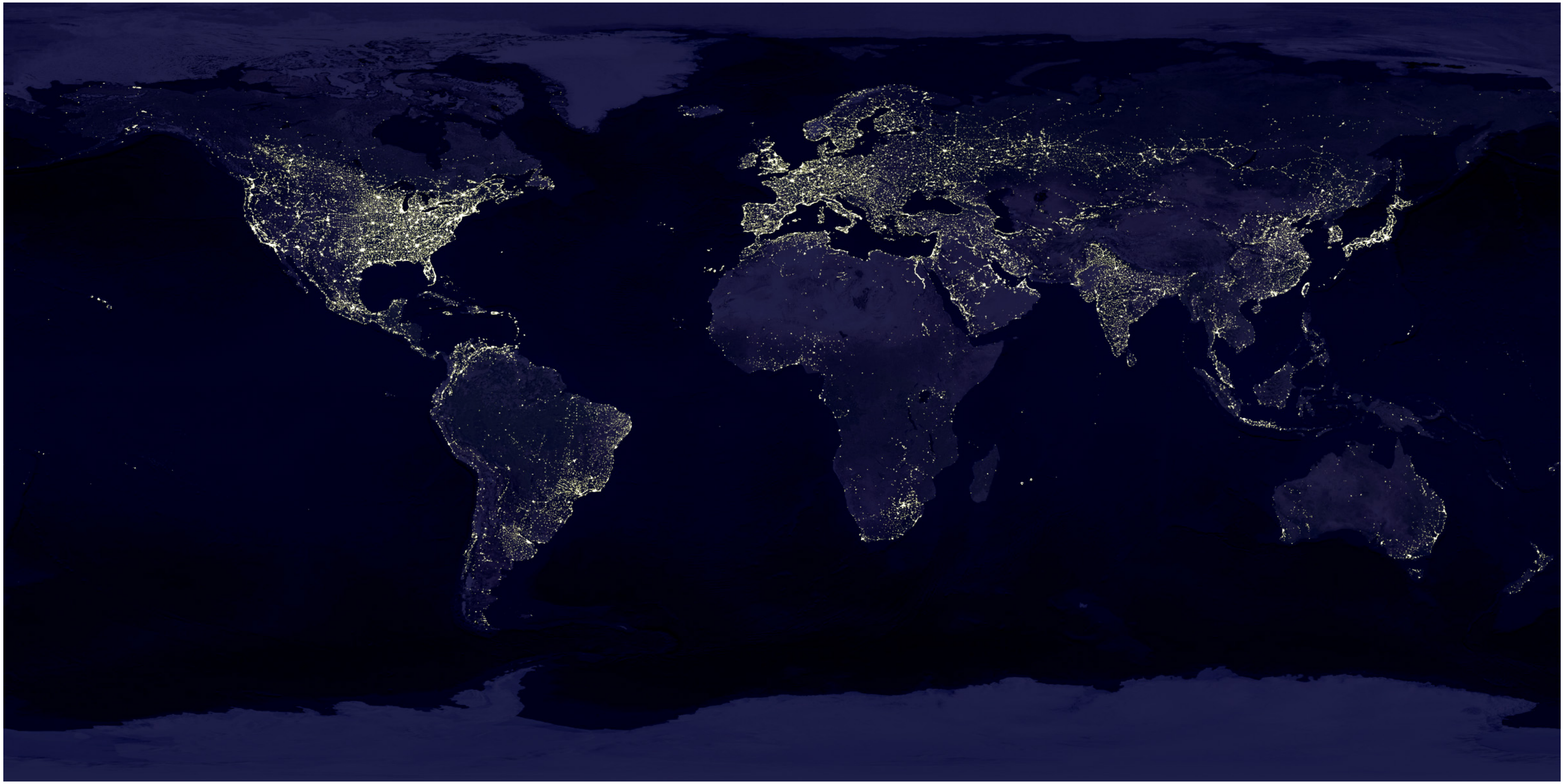
If every star were like the Sun, measuring distances would be easy – we would just measure the apparent brightness of a star, and then we could tell how far away it is.

But unfortunately they are not all like the Sun, as we can tell from pictures of star clusters. So we need to know more about the stars.

How bright are the stars, really?

How bright something *actually* is depends on:

1. How much light per unit area it is putting out
2. How big it is



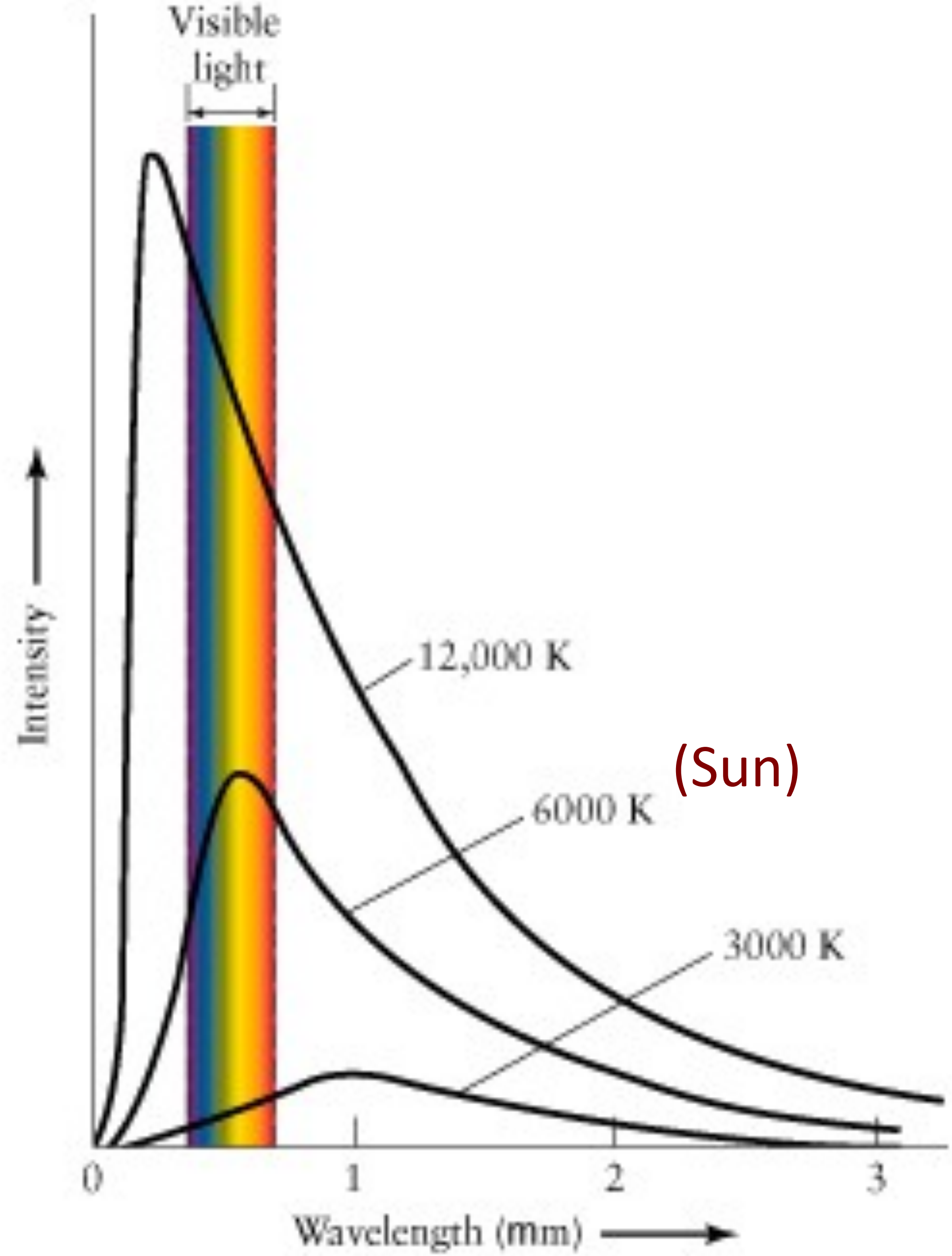
How do we do this for stars?
How can we tell how bright they are?
How can we tell how big they are?

Remember this?

The peak intensity of light emitted by a star (or other hot object) depends on the temperature of the star.

Hotter objects are brighter and have shorter peak wavelengths.

So the key is the **temperature** of a star



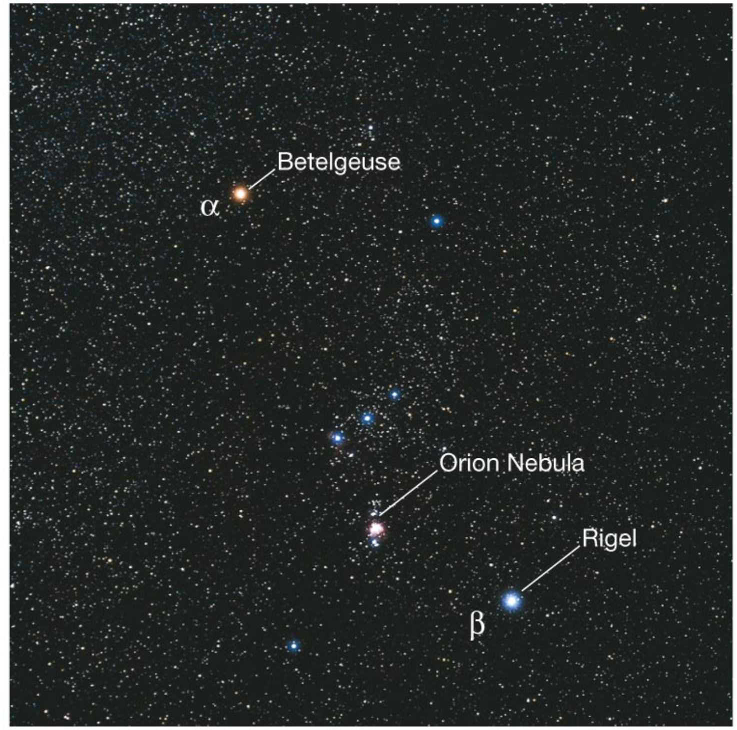
Stellar Temperatures

We now need the relation between temperature and color: The hotter the surface of a star, the shorter the average wavelength of the light it emits. Blue stars have hotter surfaces than red stars and stars whose peak wavelength is in the ultraviolet have still hotter surfaces.

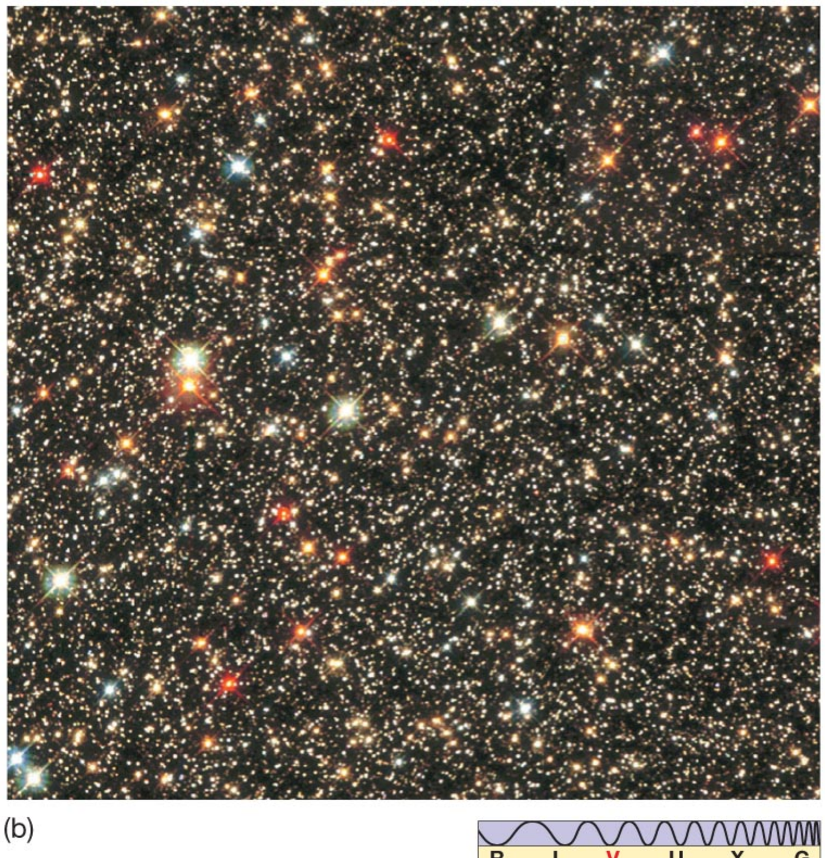
1) The relation is, again, $\lambda = \frac{.29}{T}\ \text{cm} = \frac{2.9}{T} \times 10^6\ \text{nm}$

2) Hotter stars also emit more energy per square meter of their surface.

The first relation lets us measure the temperature of stars. The second fact is the way we find the size of stars and their distances (!)



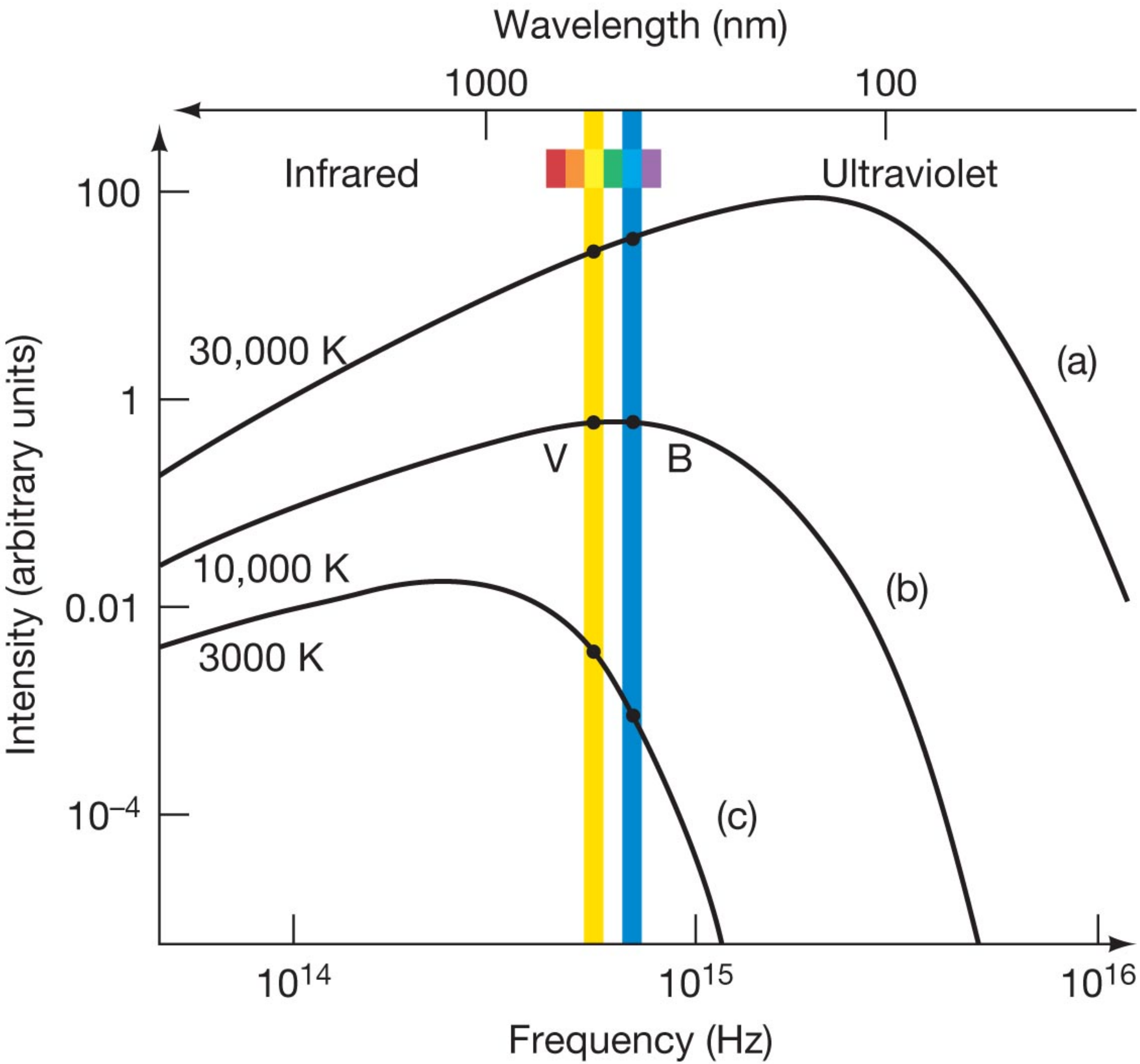
(a)



(b)

TABLE 10.1 Stellar Colors and Temperatures

Surface Temperature (K)	Color	Familiar Examples
30,000	electric blue	Mintaka (δ Orionis)
20,000	blue	Rigel
10,000	white	Vega, Sirius
7,000	yellow-white	Canopus
6,000	yellow	Sun, Alpha Centauri
4,000	orange	Arcturus, Aldebaran
3,000	red	Betelgeuse, Barnard's Star


Wavelength (nm)
1000
100
Infrared
Ultraviolet
100
1
0.01
10−4
Intensity (arbitrary units)
30,000 K
10,000 K
3000 K
V
B
(a)
(b)
(c)
10^14
10^15
10^16
Frequency (Hz)

We will return to the brightness and distances of stars, but first we need to talk about how we classify them

Stellar Spectra and Classification

William Wollaston in England, and Joseph Fraunhofer in Bavaria developed the spectroscope in the early 1800's.

Wollaston was the first to see dark lines in the spectrum of the Sun and by 1863, it was known that these dark lines were identical to patterns of spectral lines from particular elements found on the Earth.

(One set of lines failed to match the spectrum of any known element. The conclusion was that we were seeing an element on the Sun that had not been seen on Earth, and it was given the name **helium** after the Greek Sun god Helios.)

A great variety of stellar spectra are observed for different stars, but the differences do not reflect large differences in composition, i.e. in what elements are present (this was realized by Cecilia Payne-Gaposchkin in 1925, in her PhD thesis at Harvard).

Edward Pickering at Harvard University started to create a catalog of stars.

He supposedly became frustrated with his male assistants and famously declared that his maid could do a better job.

He was right. He hired his maid, Williamina Fleming, and later a bunch of other women around 1881.

They were known as the Harvard Computers and developed the classification system used for stars today (while being paid less than the secretaries at the university).

The most famous of them was **Annie Jump Cannon.**

Annie Jump Cannon, during the early part of the 20th century, classified almost 200,000 stellar spectra.

She consolidated an earlier classification by William Pickering that had been arranged alphabetically according to the strength of their hydrogen absorption lines.

A – strongest H lines, B – weaker . . . Down to “P”

Annie Jump Cannon classified the spectra of over 200,000 stars, early in the 20th century

The classification of a star is its **spectral type**.

- Ordered from hottest to coolest, the spectral types are:

O, B, A, F, G, K, M

(Use the mnemonic *Oh, Be A Fine Guy/Girl Kiss Me*, or make up your own!)

- O stars are hottest with surface temperature > 25,000 K.

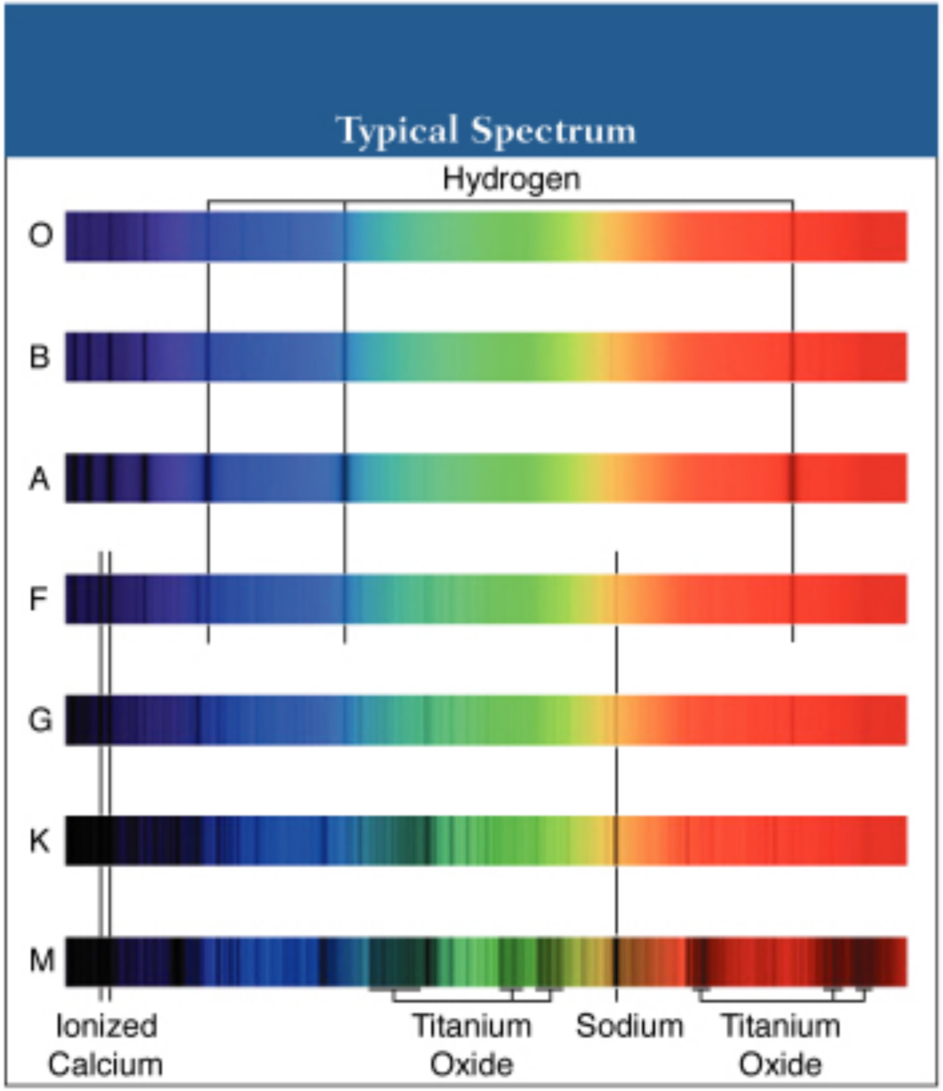
- G stars (like the Sun) have surface temperature of approximately 6000 K.

- M stars are coolest (Betelgeuse for example) with surface temperatures approximately 3000 K.

As one increases the temperature of a star from 3,000 to 10,000 K or so, a higher percentage of the light can excite hydrogen atoms, and the hydrogen lines are stronger (darker).

But if that's true, why do the hottest stars, types O and B, have weaker hydrogen lines (B is later in the alphabet than A, and O later than any of the other types)?

The answer is that in the hottest stars, hydrogen is ionized: Because the electrons are free of the protons, there are no hydrogen atoms and so no hydrogen lines.



O stars are the hottest and have few spectral lines

M stars are the coolest and have many spectral lines

Stellar Sizes

So if you know the spectral type, you know the temperature.
How do you know how luminous a star is?

The relation between temperature and luminosity is:

$$L = 4\pi\sigma T^4 R_*^2$$

Some constants we won't worry about

Temperature

Radius (size) of star

This relationship is for continuous, blackbody radiation.

So hot stars are (much!) brighter, and larger stars are also brighter.

$$L = 4\pi\sigma T^4 R_*^2$$

Some constants we won't worry about

Temperature

Radius (size) of star

This means that you can find the size of a star if you know its luminosity and its temperature.

1) Temperature you know by spectral type – O,B,A,F,G,K,M (you tell this by taking a spectrum of the star)

2) Luminosity if you know its distance – We will return to this later.

$$L = 4\pi\sigma T^4 R_*^2$$

Two ways stars can be luminous:

1. Either very high temperature – big T
2. Or very big – big R