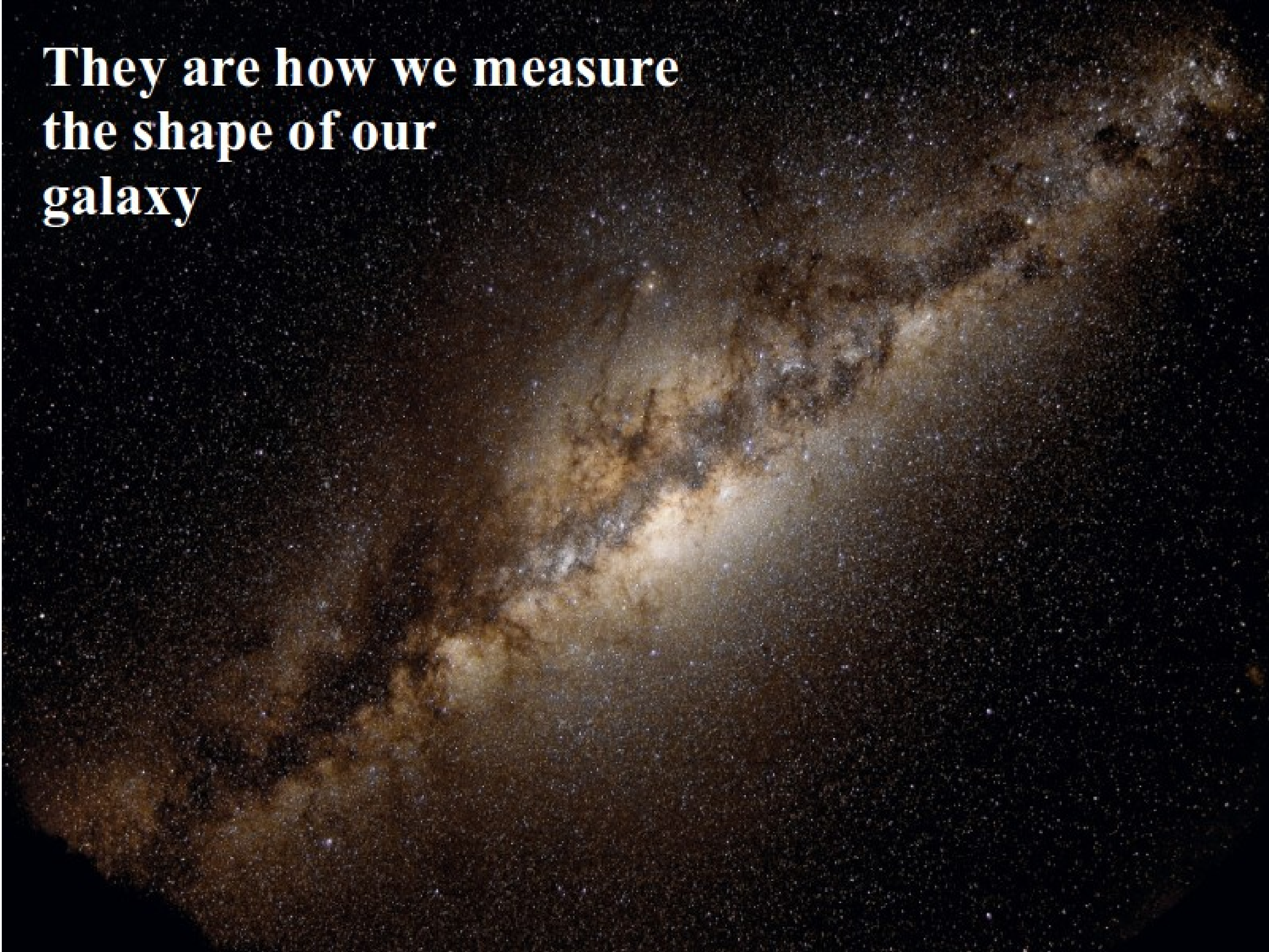
"The avalanche has already begun. It is too late for the pebbles to vote."

Kosh, Babylon 5

Any make-up tests no later than Wednesday before class.

Stars are the most visible part of our Universe.

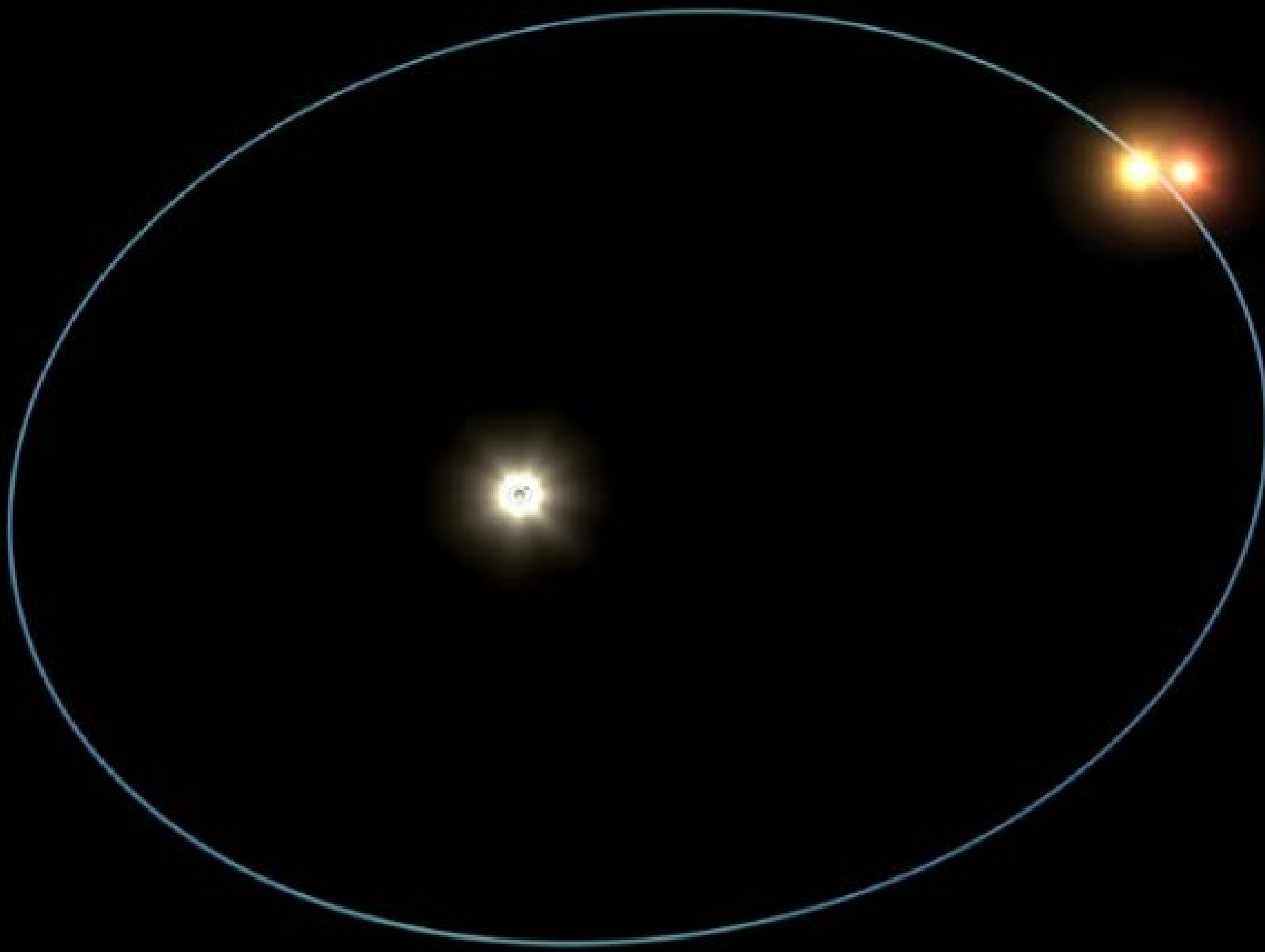

They are what we see when we look up
at night.

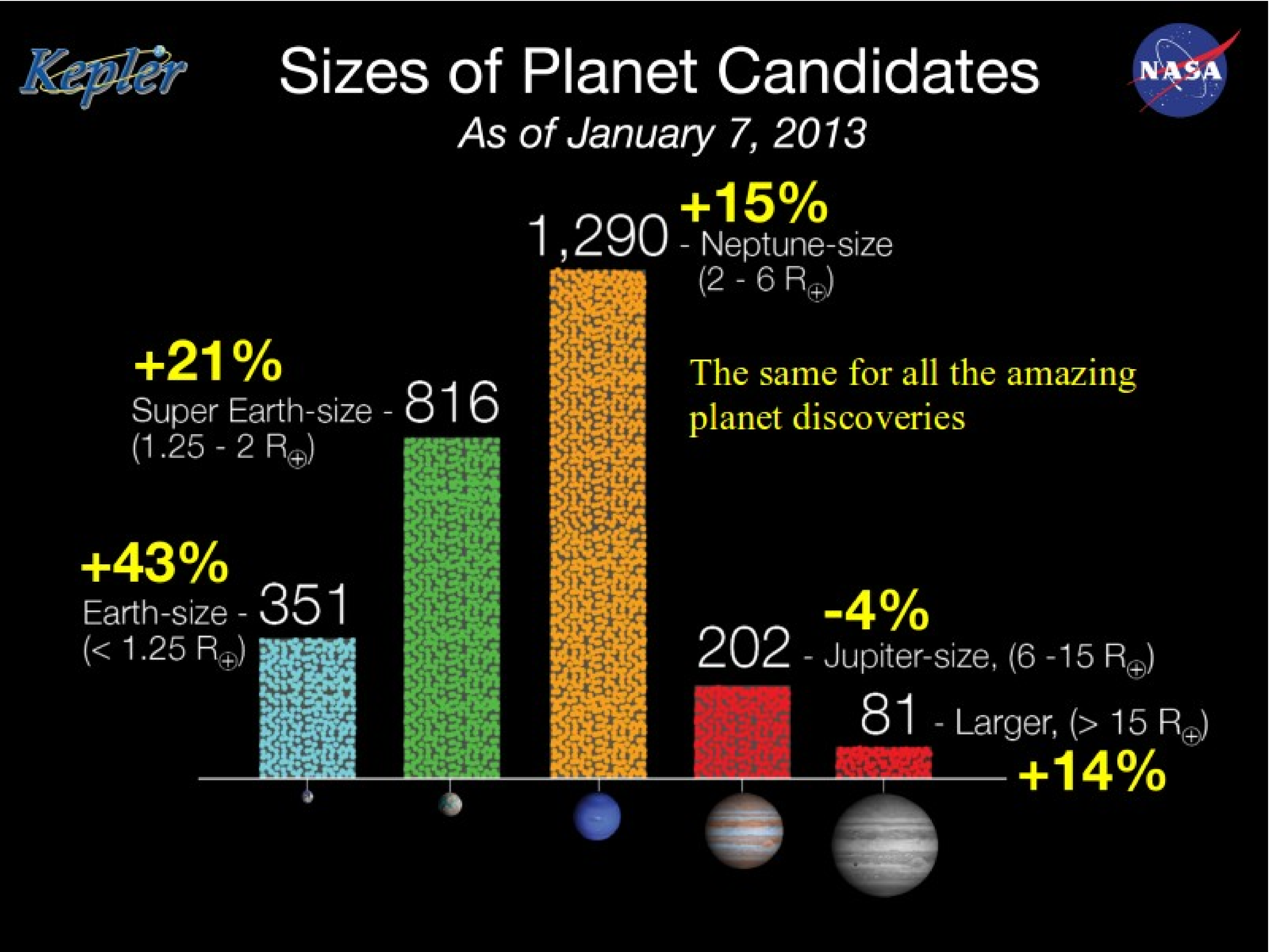

They are how we measure
the shape of our
galaxy

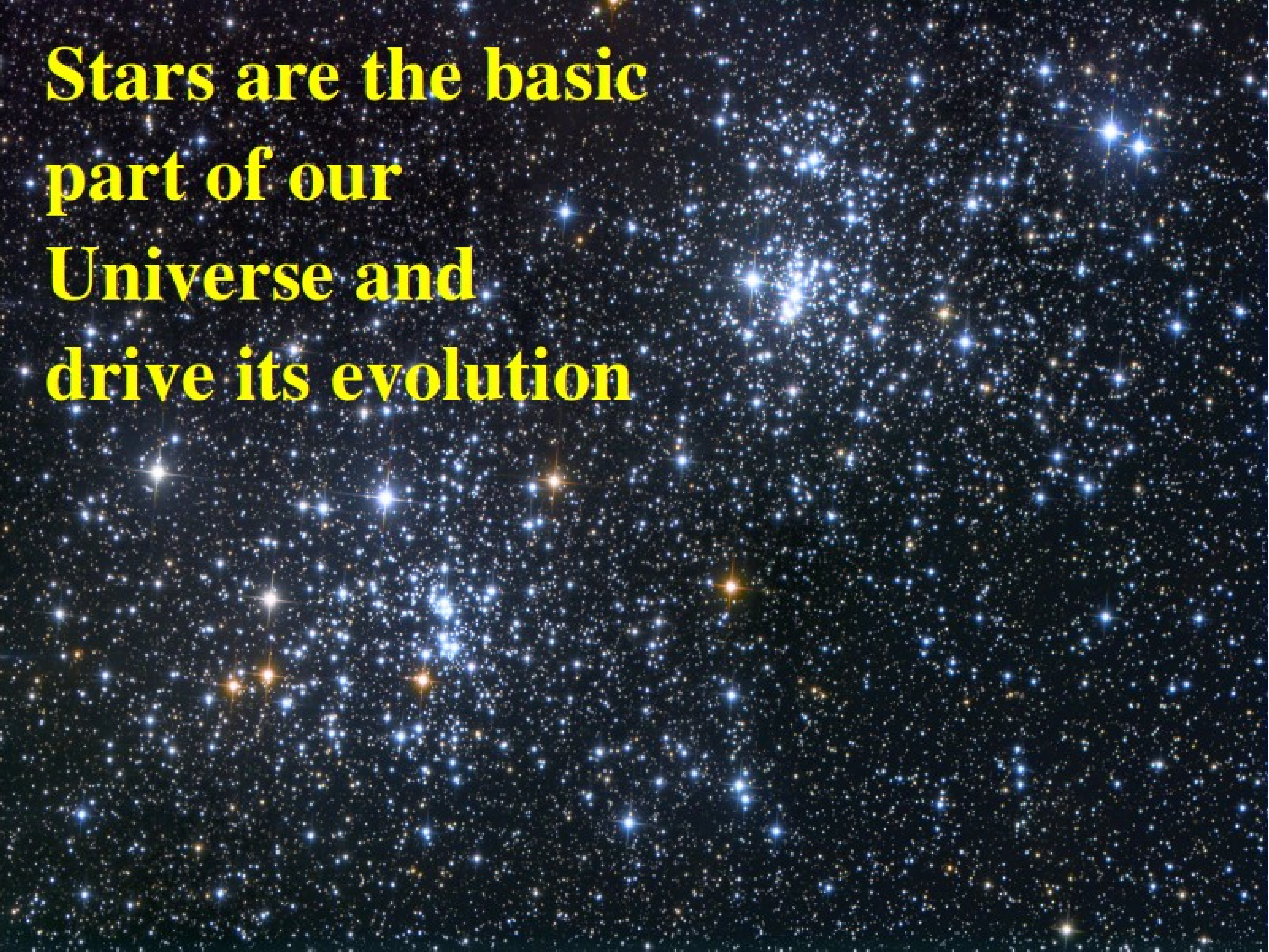

and what we see when we look
at other galaxies.

We use them to determine distances

masses



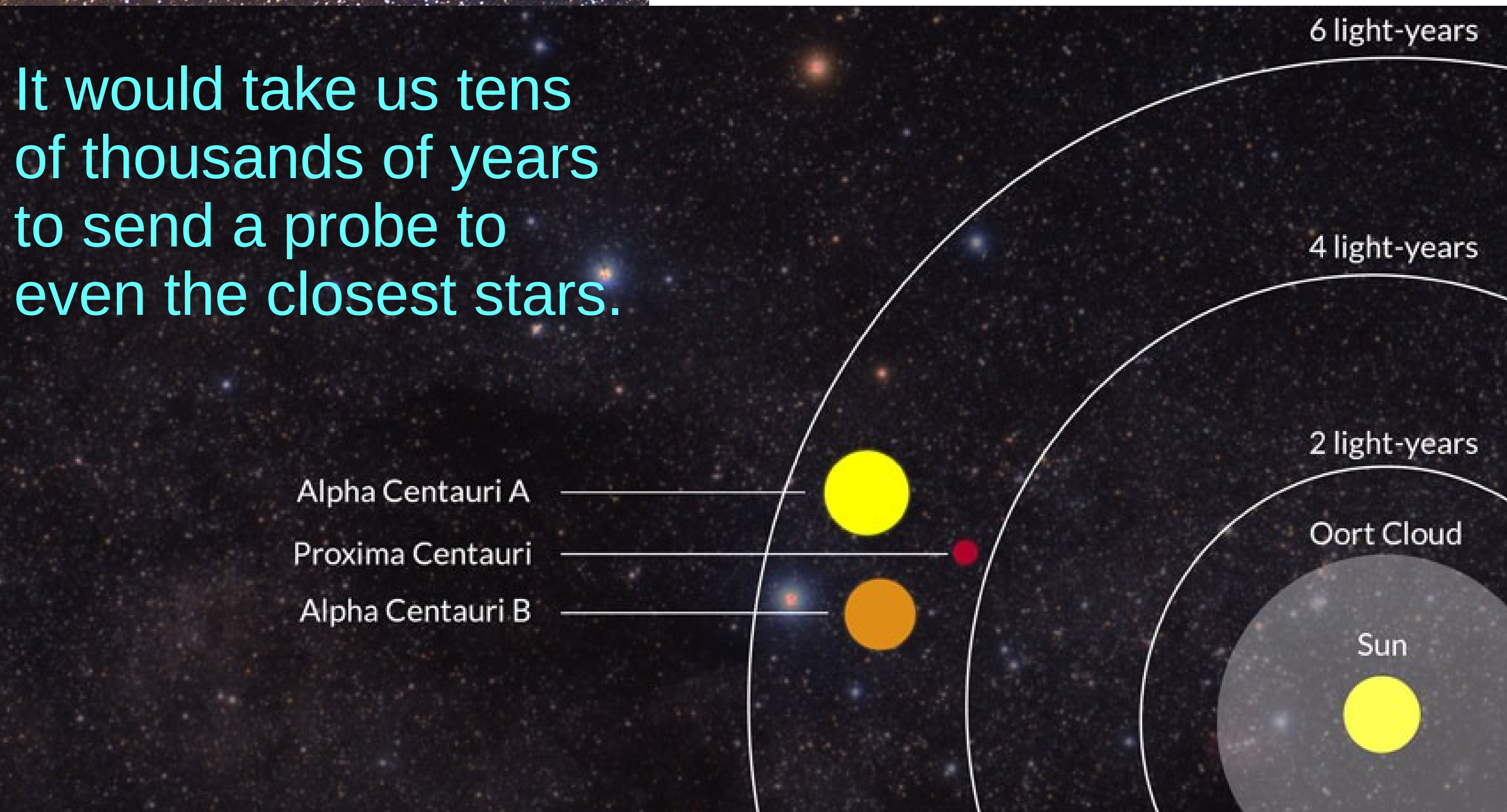

Kepler
Sizes of Planet Candidates
As of January 7, 2013
NASA
+43%
Earth-size - 351
(< 1.25 $R_\oplus$)
+21%
Super Earth-size - 816
(1.25 - 2 $R_\oplus$)
+15%
1,290 - Neptune-size
(2 - 6 $R_\oplus$)
The same for all the amazing planet discoveries
-4%
202 - Jupiter-size, (6 -15 $R_\oplus$)
81 - Larger, (> 15 $R_\oplus$)
+14%


Stars are the basic part of our Universe and drive its evolution

We want to know:

- How hot are stars?
- How BIG are stars (size)?
- How massive are stars?
- What are stars made of?
- How far away are stars?
- Are they in motion?
- How much energy do stars emit?
- Where does that energy come from?

It would take us tens of thousands of years to send a probe to even the closest stars.



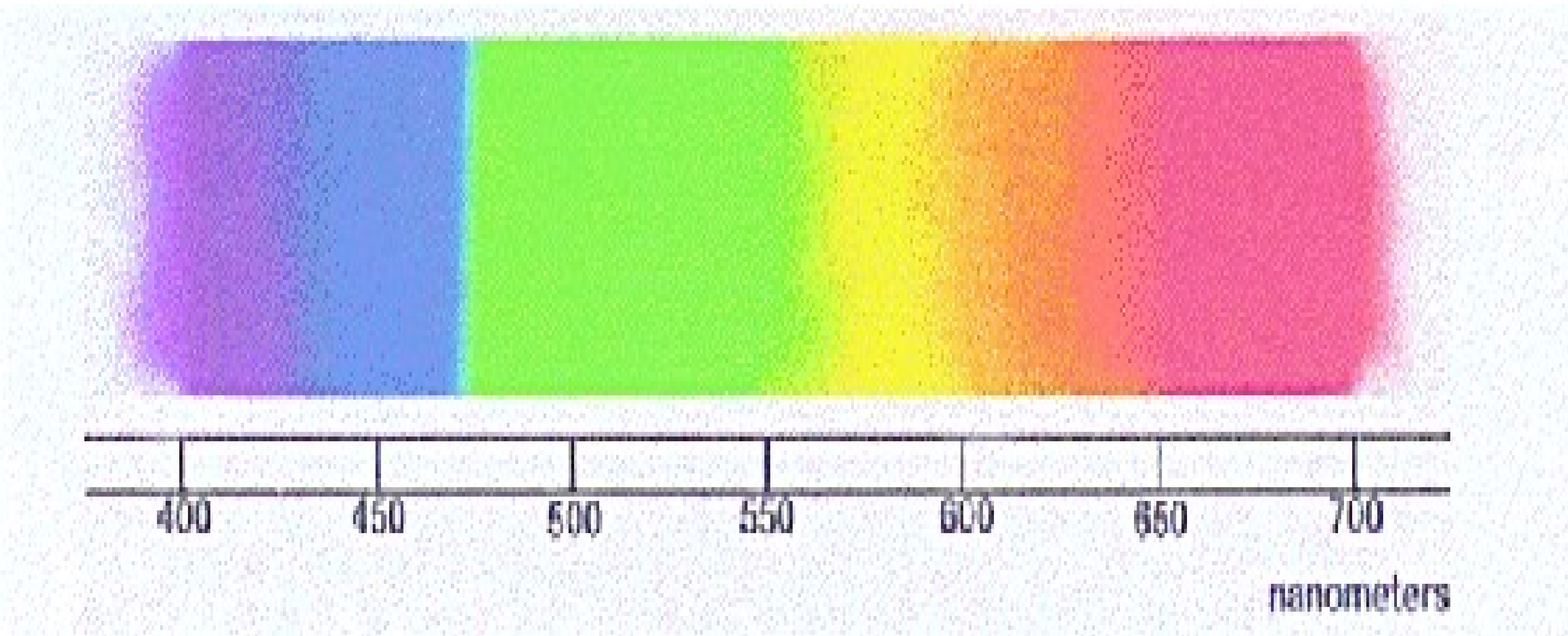

All we have
to work
with, is
light.

Quiz 6: What fraction of stars have planets?

A) few (<10)%
B) 25%
C) 50%
D) 75%
E) Nearly all of them (90+)%

Wavelength and energy

Since E = hc/λ,
if λ gets bigger, E gets smaller
if λ gets smaller, E gets bigger



400 nm | 700 nm

more energy | less energy

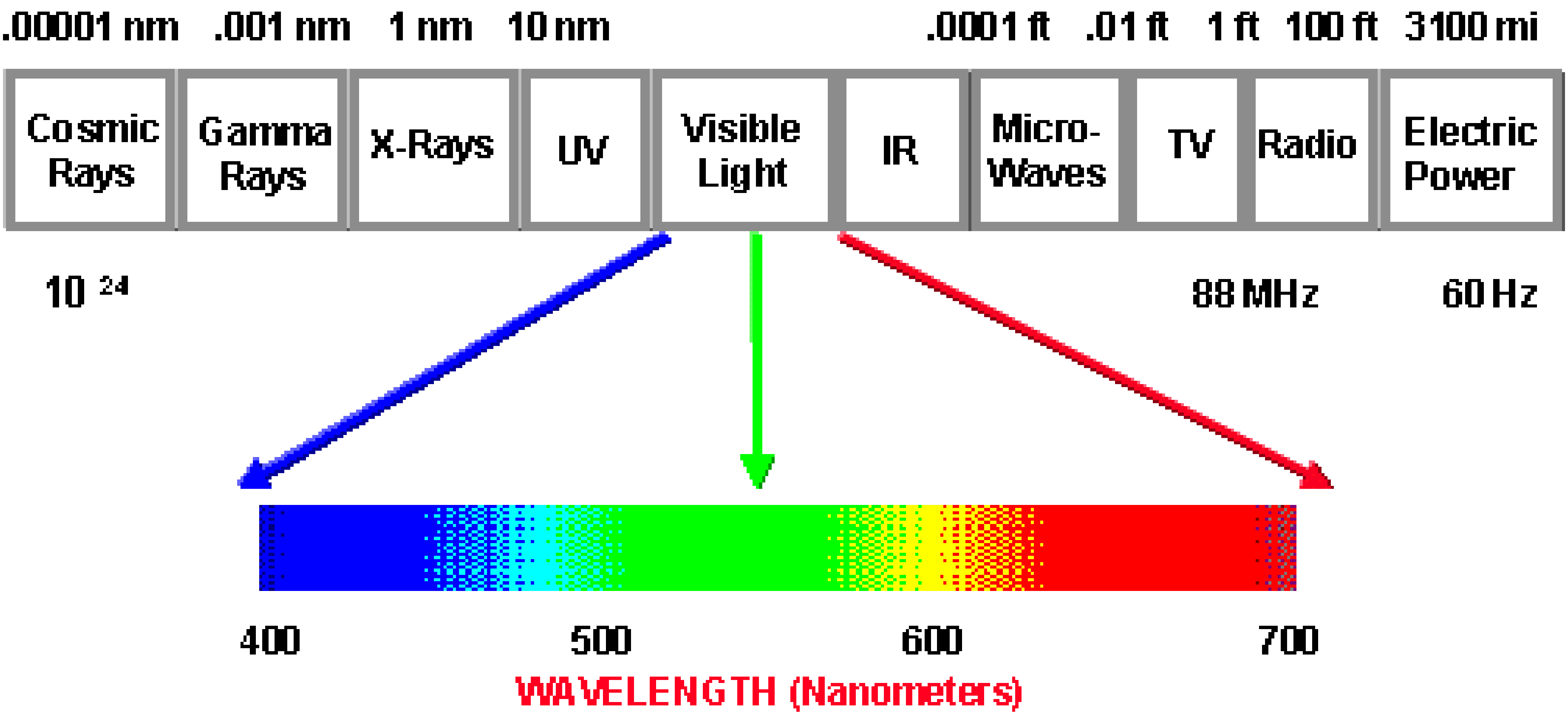
if 🍃 gets bigger, E gets smaller

if 🍃 gets smaller, E gets bigger

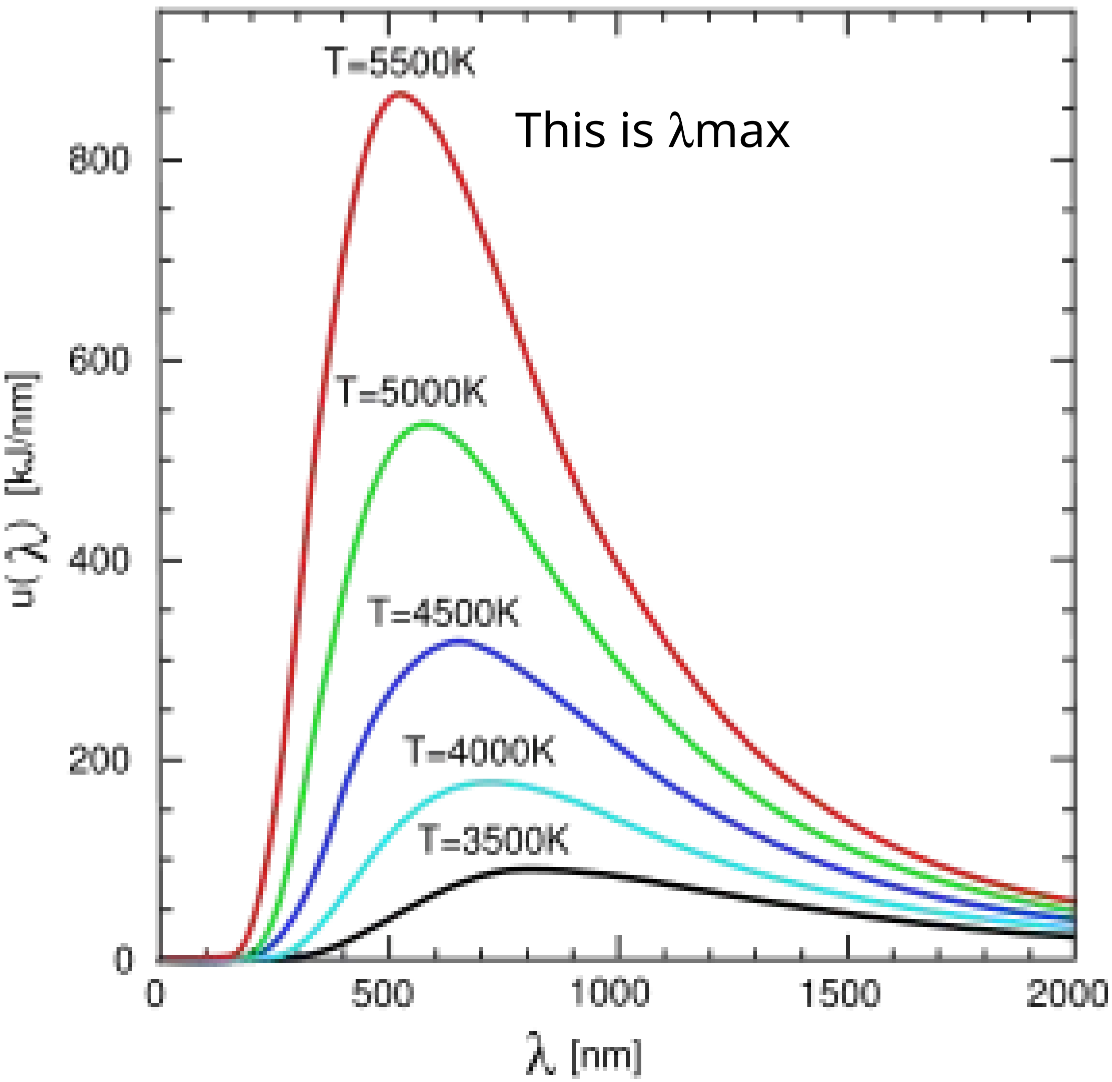
Blue light has more energy (is hotter) than red light.

UV has is hotter than blue light.

electromagnetic spectrum



Temperatures given in Kelvins $T=2.9x10^6/\lambda_{max}$ for λ in nm.



Shorter wavelengths = hotter object.

Objects glowing blue are hotter then objects glowing red.

For Wien’s law objects (most things)

Color = temperature = energy

“bluer” = shorter wavelength = hotter

“redder” = longer wavelength = cooler

Stefan-Boltzmann Law

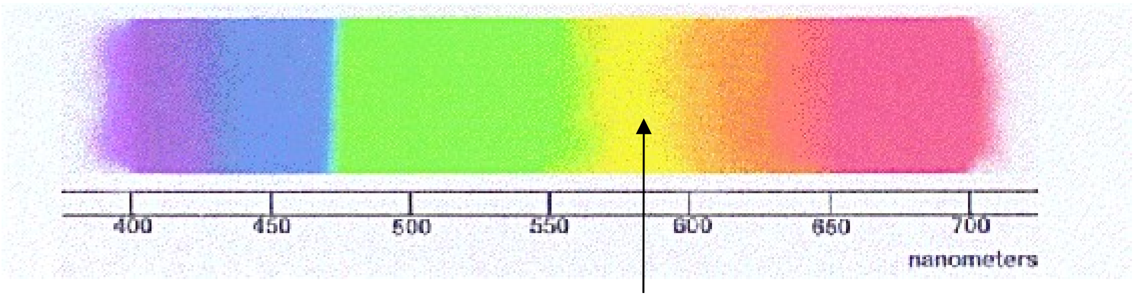
- Can determine energy per square meter from the temperature.
- $E/m^2 = \sigma T^4$
- Where $\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$ so

$E/m^2 = (5.67 \times 10^{-8}) T^4$


Example: You can determine
how hot the Sun is?

Example:

Our Sun looks yellow. So from the chart below, let's assume the peak of the continuous spectrum is at 575nm. What are the temperature and energy per square meter of our Sun?



400 575 700 nm

$$T = 2.9\times10^{6}/\lambda = ?$$

Example: our Sun

First find the temperature:

$T=2.9x10^6/$🍃 $= ?$

🍃$=575$

Example: our Sun

First find the temperature:

$T=2.9x10^6/ = 5043$

$=575$

Now find the energy associated with that temperature.

$E/m^2 = T^4=(5.67x10^{-8})(T^4)=?$

Example: our Sun

First find the temperature:

$T = 2.9 \times 10^6 / \lambda = 2.9 \times 10^6 / 575 = 5043K$

Now find the energy associated with that temperature.

$E/m^2 = \sigma T^4 = \sigma (5043^4) =$

$(5.67 \times 10^{-8})(6.47 \times 10^{14})$

$= 3.7 \times 10^7\ W/m^2$

That's 37 million watts for each square meter at the surface of the Sun!

Example: our Sun

$T = 2.9 \times 10^6 / \lambda = 2.9 \times 10^6 / 575 = 5043K$

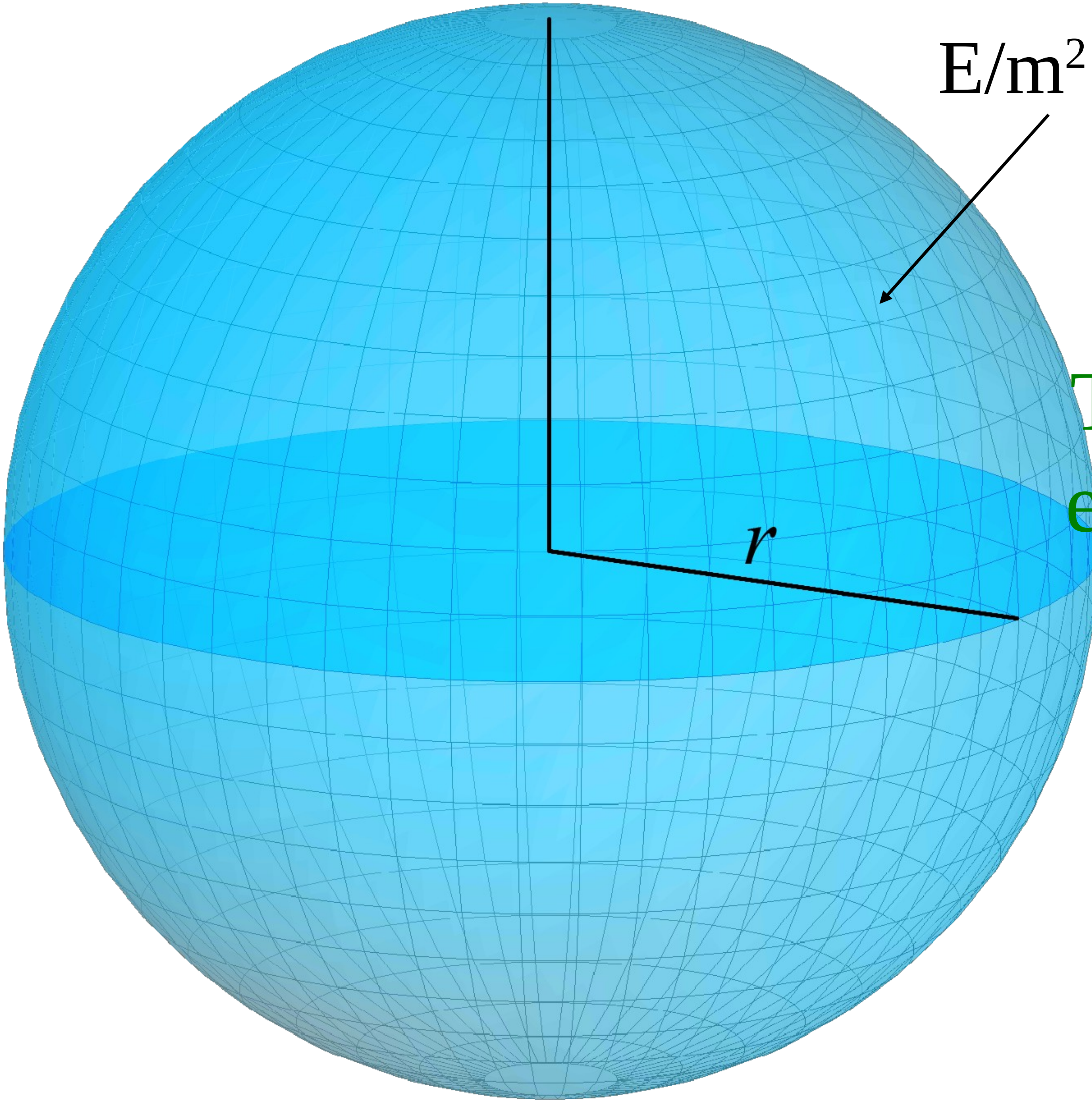
$E/m^2 = \sigma T^4 = \sigma (5043^4) = 3.7 \times 10^7 \ W/m^2$

That's 37 million watts for each square meter at the surface of the Sun!

But it's not the total energy of the Sun.

How do we find the total energy of the Sun?

$E/m^2 = 3.7 x 10^7 W/m^2$



To get the total energy, multiply by the surface area: $A = 4\pi R^2$

Example: our Sun

$T=2.9x10^6/$ $= 2.9x10^6/575 = 5043K$

$E =$ $T^4=$ $(5043^4)=3.7x10^7 \ W/m^2$

That's 37 million watts for each square meter at the surface of the Sun!

To get the total energy, multiply by the surface area of the Sun: $A=4\pi R^2$ where R is the radius of the Sun: $6.96x10^8$m.

$E = (3.7x10^7)4\pi(6.96x10^8)^2$

Example: our Sun

$$E = (3.7x10^7)4\pi(6.96x10^8)^2$$

I would rearrange this to do the hardest part first:

$$E = (6.96x10^8)^2 4\pi(3.7x10^7)$$

Example: our Sun

$T = 2.9 x 10^6 / \lambda = 2.9 x 10^6 / 575 = 5043 K$

$E = \sigma T^4 = \sigma (5043^4) = 3.7 x 10^7 W/m^2$

To get the total energy, multiply by the surface area of the Sun: $A = 4\pi R^2$ where R is the radius of the Sun: $6.96 x 10^8 m$.

$E_{tot} = 2.25 x 10^{26}$ watts.

This energy has a special name: Luminosity

Luminosity:

The total energy emitted by a star:

$L=4\pi R^2$📅T^4

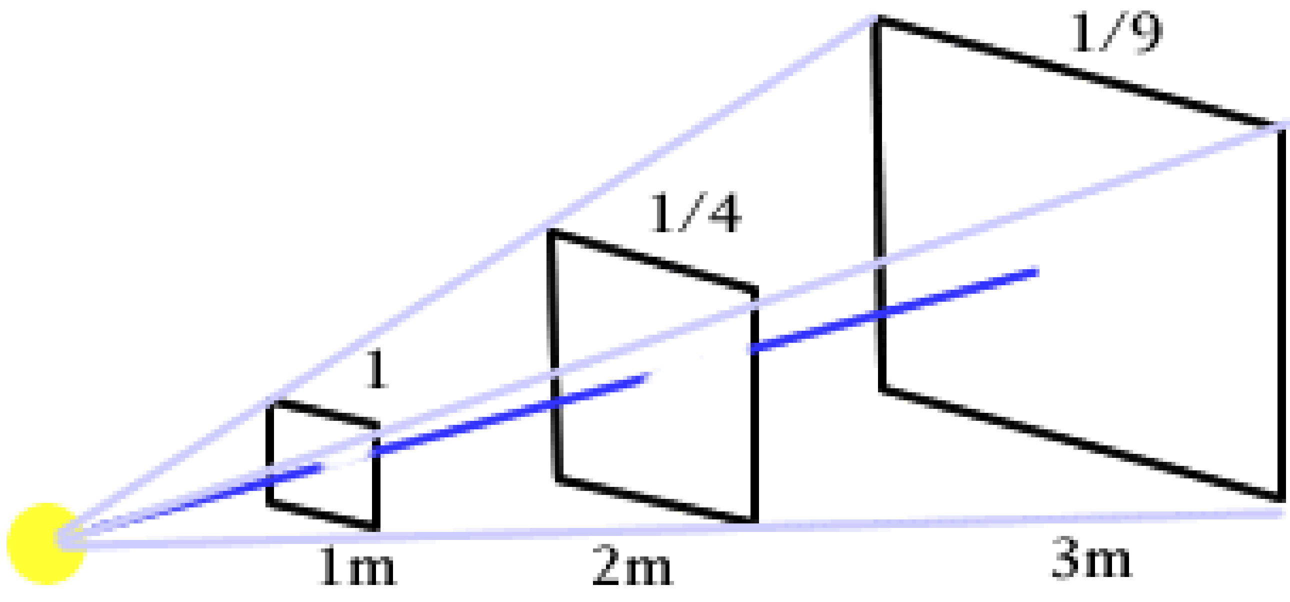
We want to know:

- How hot are stars? ✓
- How BIG are stars (size)?
- How massive are stars?
- What are stars made of?
- How much energy do stars emit ✓
- Where does that energy come from?
- How far away are stars?
- Are they in motion?

INVERSE SQUARE LAW

Light drops off as the square of the distance ($1/d^2$)

The light received at 2m is ¼ the light received at 1m. The light received at 3m is 1/9 the light received at 1m and so on. This is called the apparent luminosity (L_{ap}). So L_{ap} at 3m is 1/9L.



Put it all together:
Apparent Luminosity

Include distance into the calculation.

$L_{ap}=R^2$📅T^4/d^2

This is how bright stars appear to us when we look up into the sky at night.

Units: Temperature must be in Kelvin, size and distance must be in meters.

How to make a star brighter

- Make it hotter: $E \sim T^4$
- Make it bigger: $E \sim R^2$
- Make it closer: $E \sim 1/d^2$

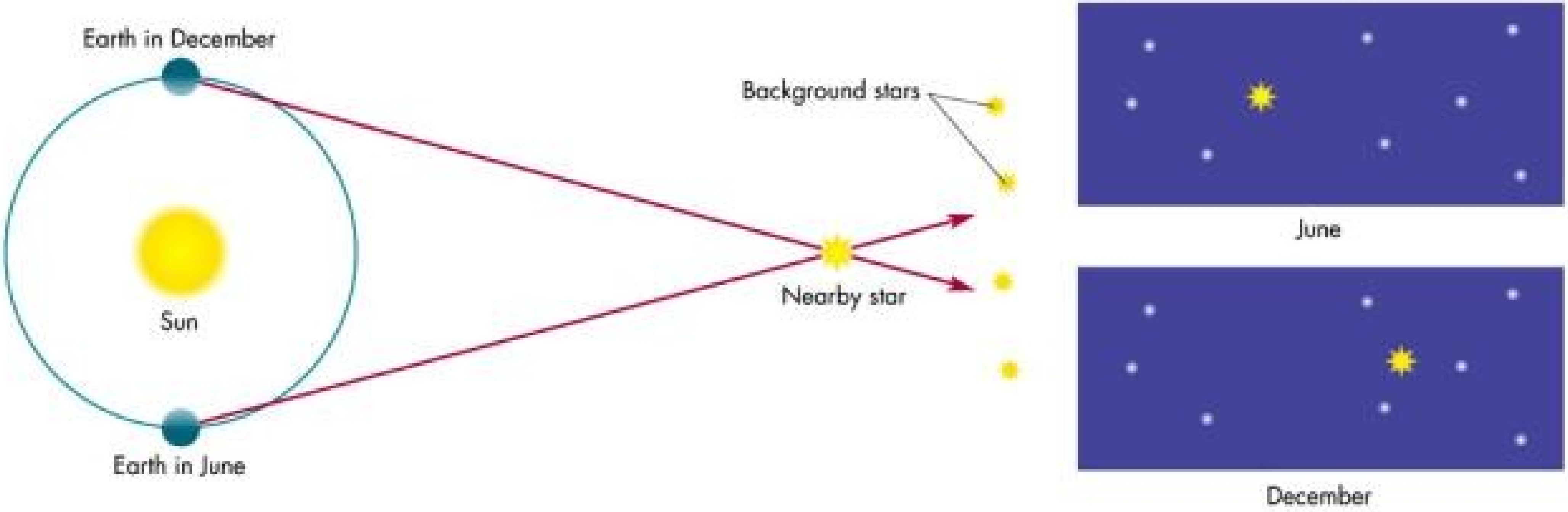
Hotter is most powerful.

The motions of stars.

Parallax

Parallax

The Parallax of a Nearby Star



Parallax

From parallax we can determine distances to nearby stars. This is the first step in determining the distances in our Universe.

This method is only good for nearby stars.

Parallax

From parallax we can determine distances to nearby stars.

This method is only good for nearby stars.

The closest star to us is 4 light years away (~250,000 AU)

Most stars we see are tens to thousands of light years away.

We want to know:

- How hot are stars? 
- How BIG are stars (size)?
- How massive are stars?
- What are stars made of?
- How much energy do stars emit 
- Where does that energy come from?
- How far away are stars 
- Are they in motion?

Sizes

- And from this formula $L_{ap}=R^2 T^4/d^2$, if we know d (from parallax), T (from a spectrum) and L_{ap} is just the brightness we ‘see’, then we can determine R. So for nearby stars, we can determine how big they are!

Parallax is due to the motion of Earth around the Sun.

But stars are in motion too!

(everything in the Universe is)

The motions of stars.

"What are you talking about, Mike?! The constellations have been the same over all of recorded history."

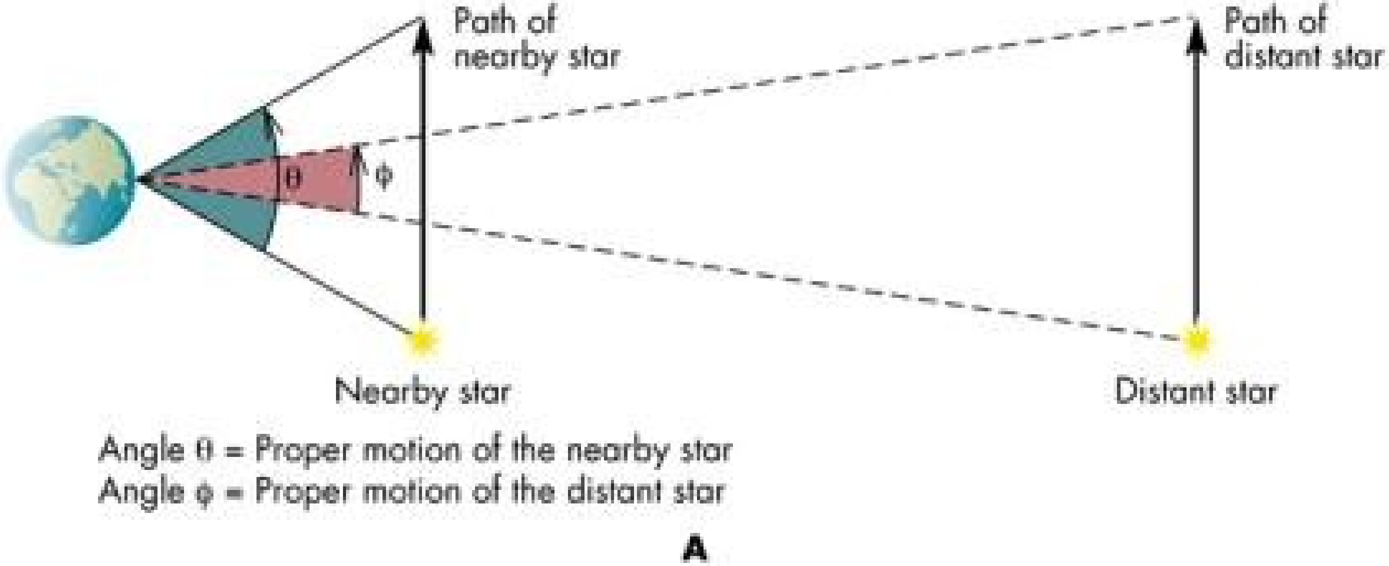
You will see, everything is moving!

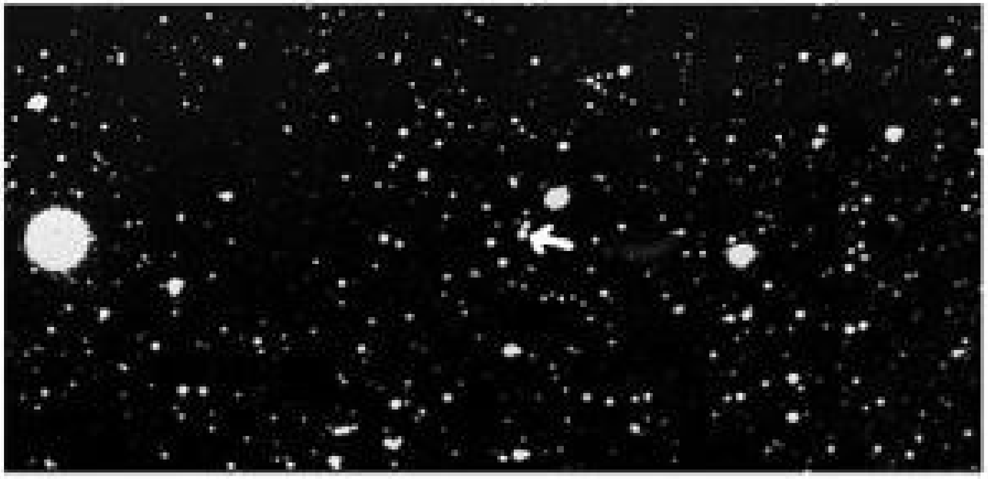
If you stand next to a highway, cars seem to go zooming by, whereas an airplane, far off in the sky, seems to go very slowly.

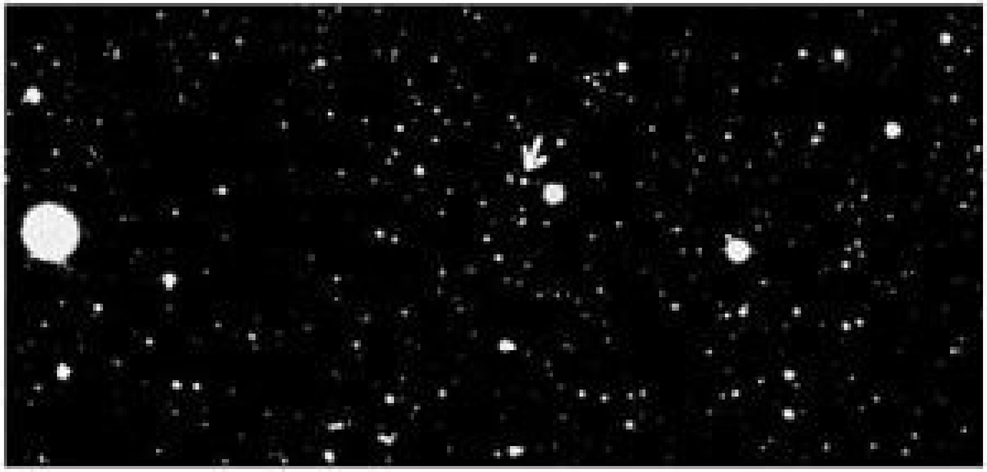
You know the plane is going much faster, it just appears slower because it is so far away.

The same is true for stars: They are going really, really, really fast, but they are very, very, very far away.

The Proper Motions of a Nearby and Distant Stars

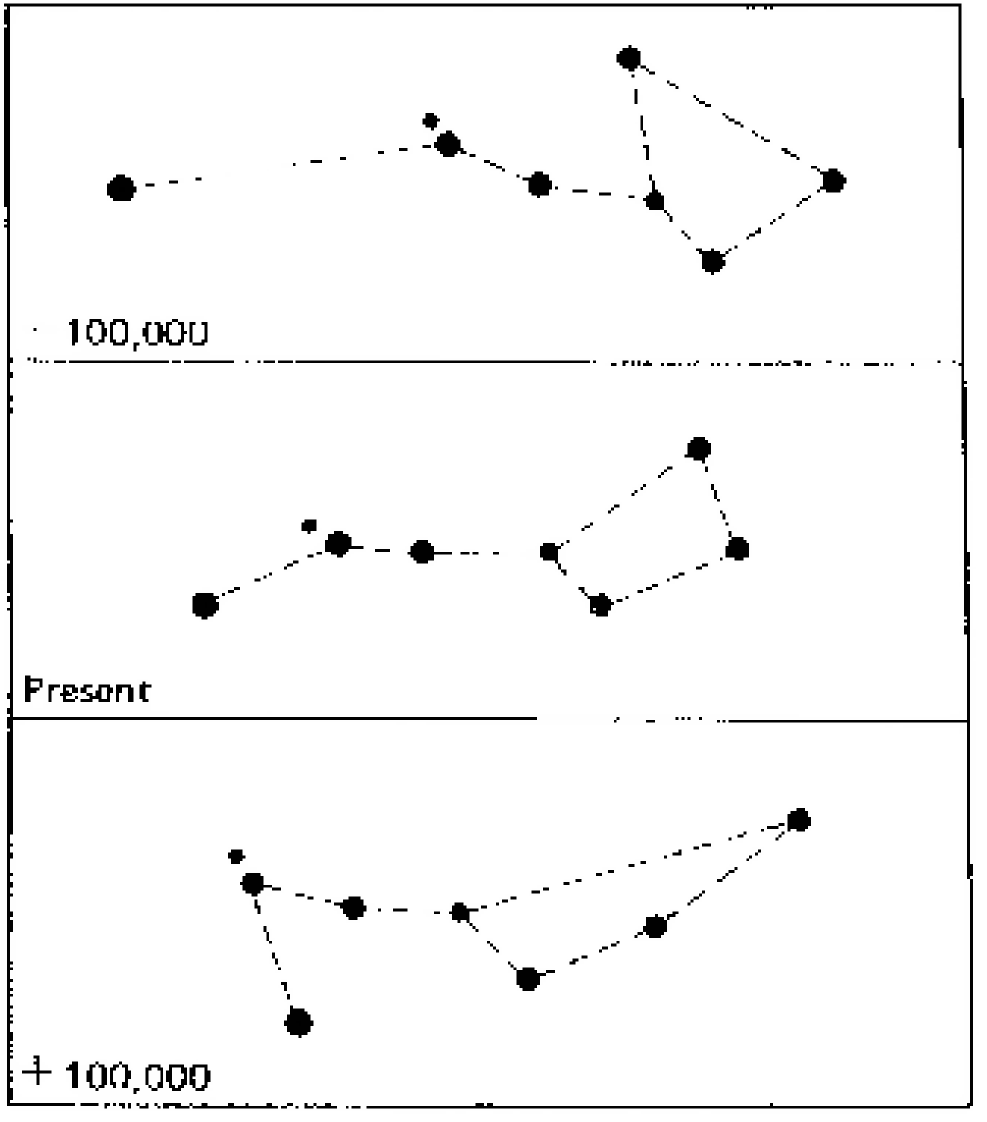






Even the big dipper will change, given enough time.

This shows the stars in the big dipper 100,000 years ago, today, and 100,000 years from now.



Parallax is due to the motion of Earth around the Sun.

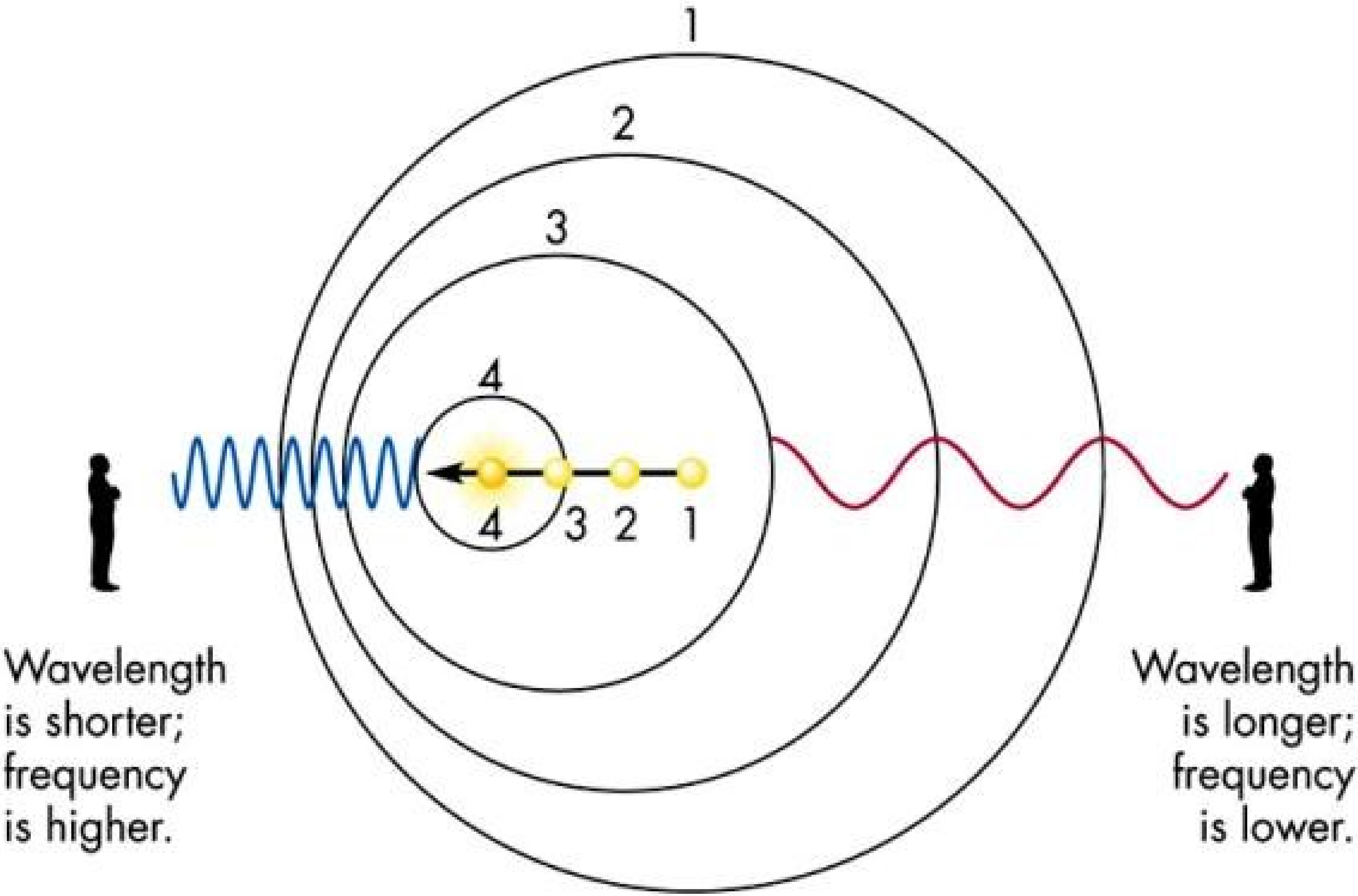
Proper motion is a stars motion *across* the sky. (not towards or away from us)

Again, closer stars will have larger proper motion, and faster stars will have larger proper motion.

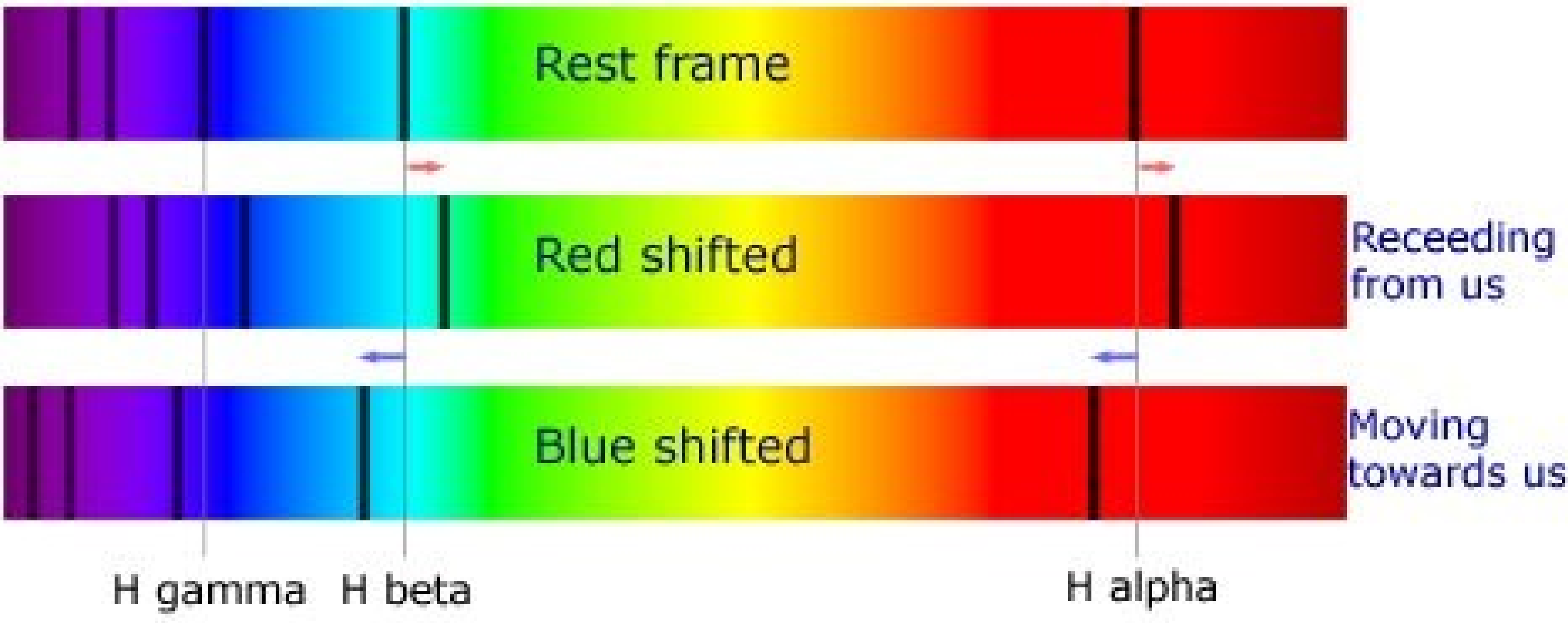
Radial velocity

But stars are also moving towards and away from us. To measure this motion, we use the Doppler shift.

The Doppler Effect



With light, we use lines in a spectrum to measure Doppler shift. From the shift, we determine the actual speed.

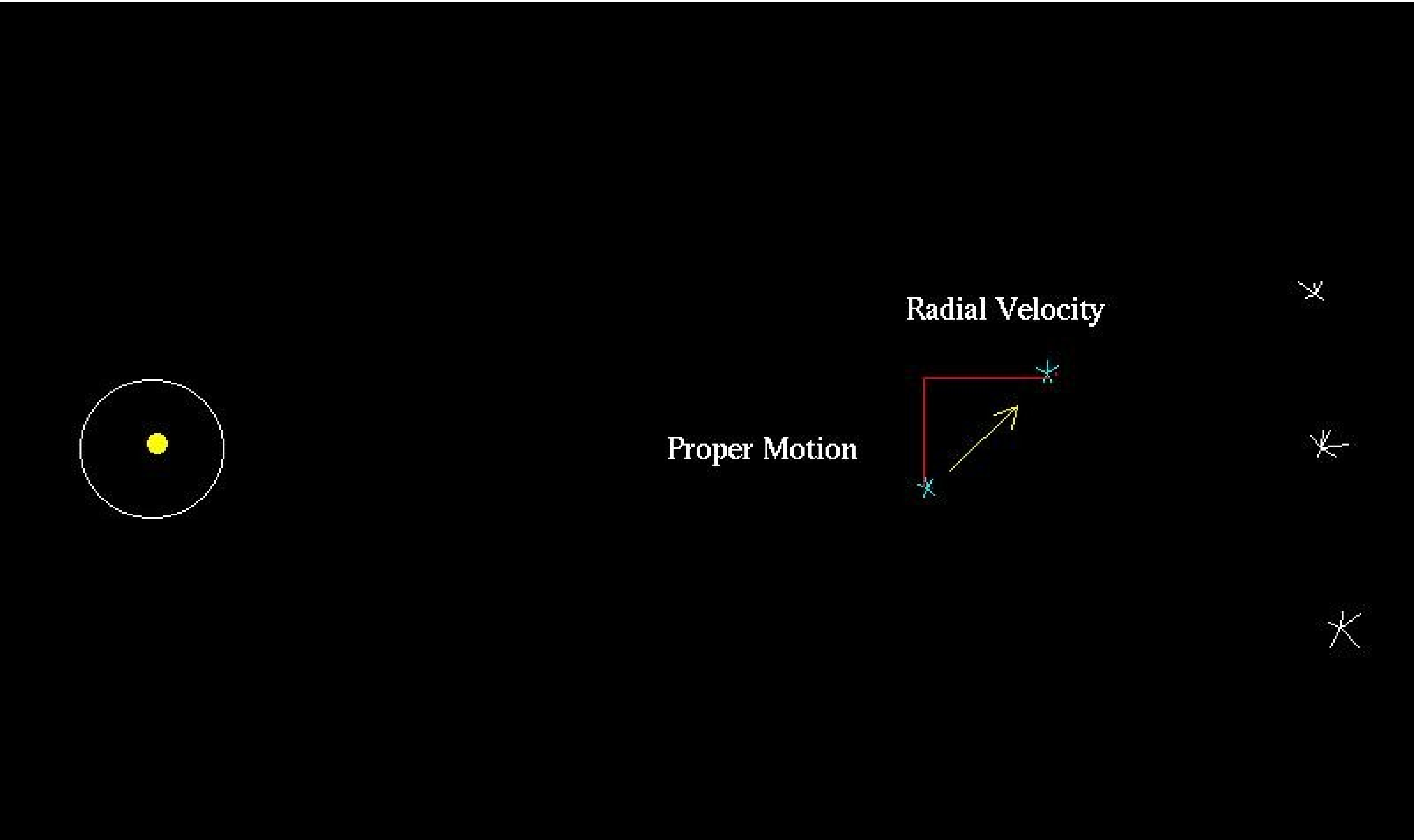


Parallax is due to the motion of Earth around the Sun.

Proper motion is a stars motion *across* the sky. (not towards or away from us)

Radial velocity uses the Doppler shift to measure a star's motion towards or away from us.

The complete picture.
Arrow shows true motion of star



We want to know:

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- How BIG are stars (size)?
- How massive are stars?
- What are stars made of?
- How much energy do stars emit
- Where does that energy come from?
- How far away are stars
- Are they in motion? Yes