"I bet a fun thing would be to go way back in time to where there was going to be an eclipse and tell the cave men, "If I have come to destroy you, may the sun be blotted out from the sky." Just then the eclipse would start, and they'd probably try to kill you or something, but then you could explain about the rotation of the moon and all, and everyone would get a good laugh."
Jack Handy quotes

You will want to have a calculator handy for the remainder of this course.


Exoplanets:
90% of all
stars have
planets!

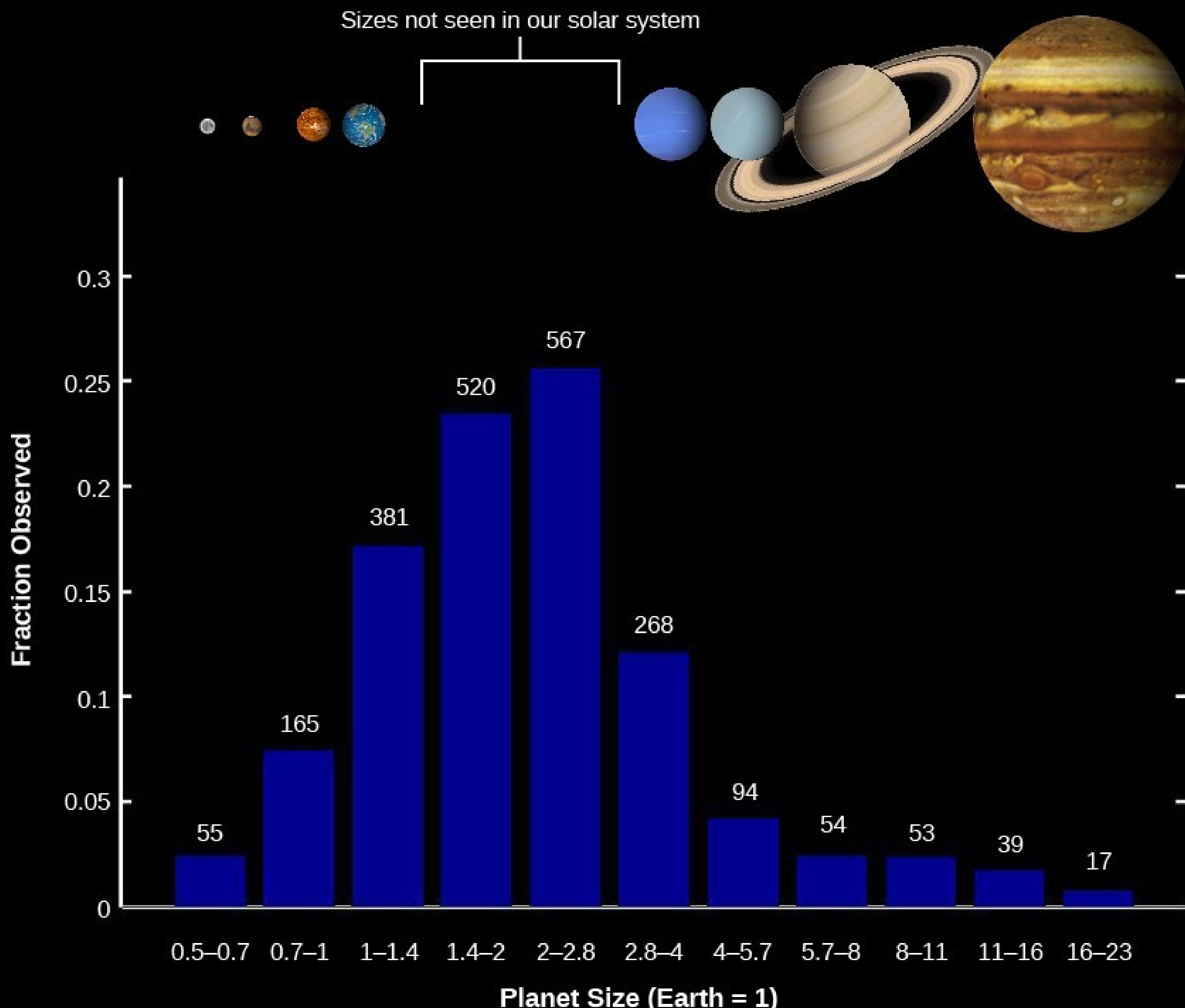
Finding exoplanets: 4 methods.

1) Doppler (radial velocity) wobble

2) Transits: far and away have found the most!

3) Microlensing

4) Direct imaging



Sizes not seen in our solar system
Fraction Observed
0.3
0.25
0.2
0.15
0.1
0.05
0
55
165
381
520
567
268
94
54
53
39
17
0.5–0.7
0.7–1
1–1.4
1.4–2
2–2.8
2.8–4
4–5.7
5.7–8
8–11
11–16
16–23
Planet Size (Earth = 1)

We only need 2 (or 3) for our solar system (Terrestrial and Gas Giant), but exoplanets need more

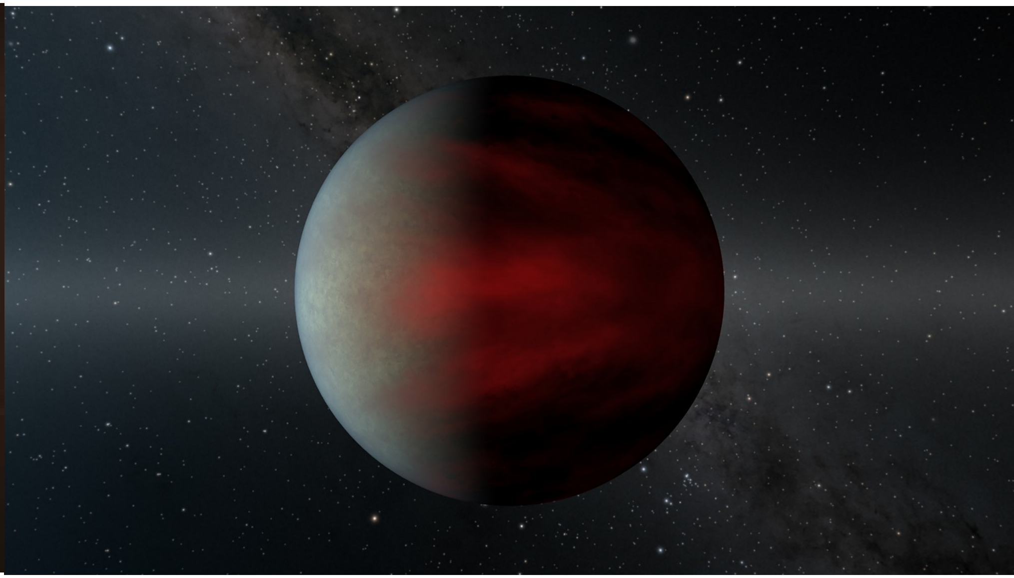
Hot/warm Jupiters
Hot/warm Neptunes
SuperEarths
Mini-Neptunes

How do other solar systems stack up to the theory of how our solar system formed?

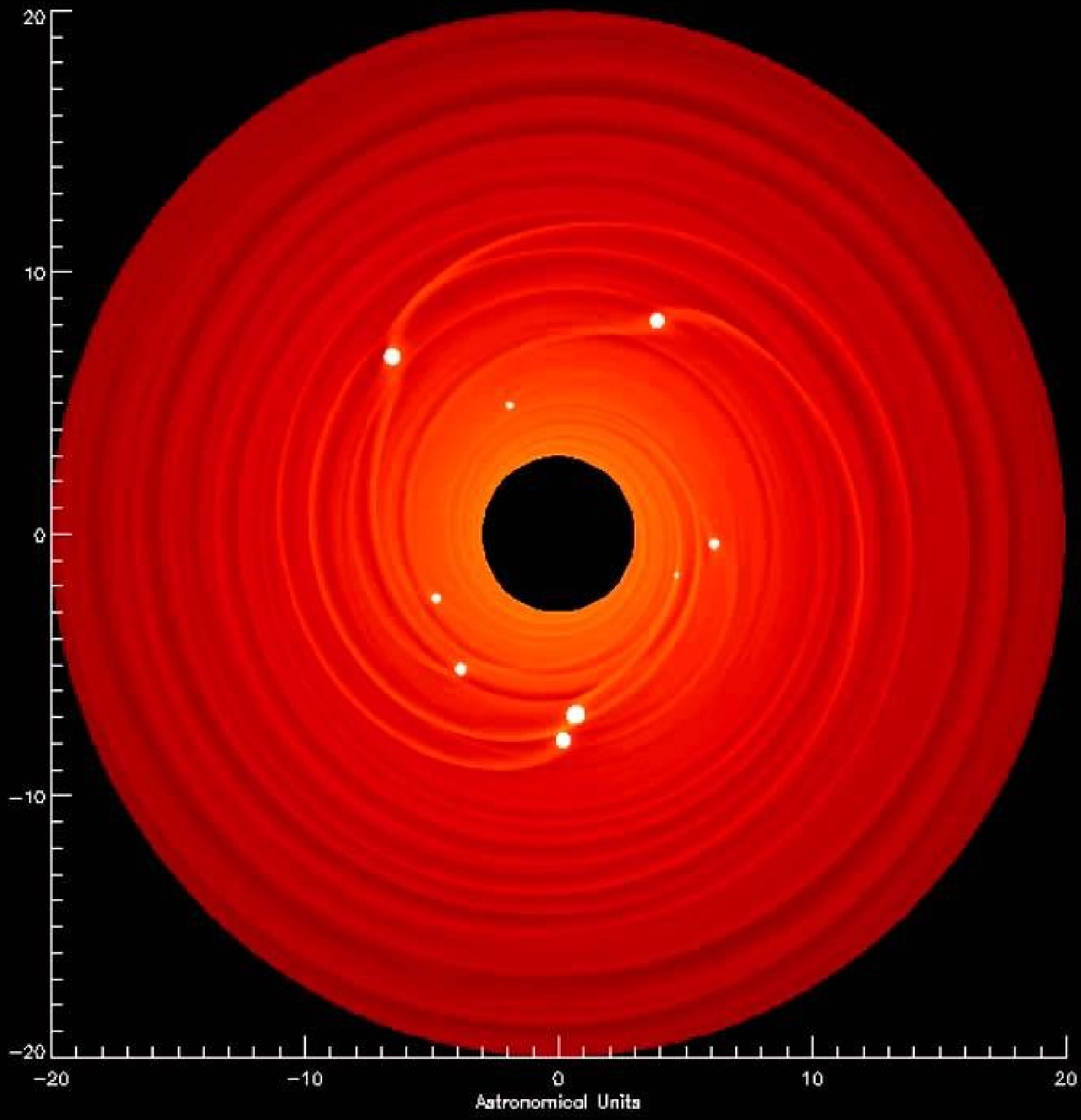
We really have not seen a solar system like ours, yet.

But ours is very hard to detect with our current technology.

If there are Jupiter-like planets in short orbits, well within the ice line, how did they form?

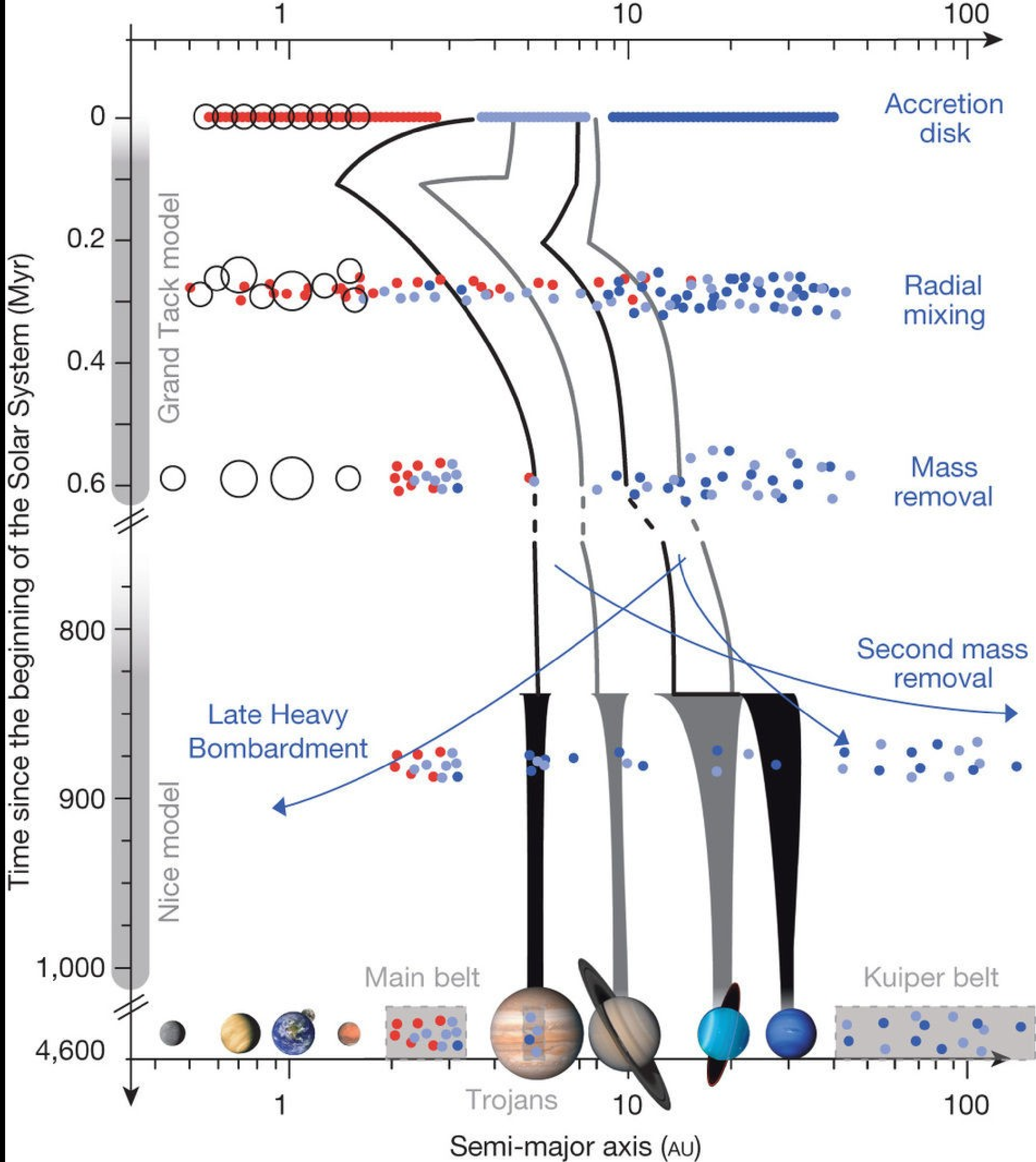



Planetary migration



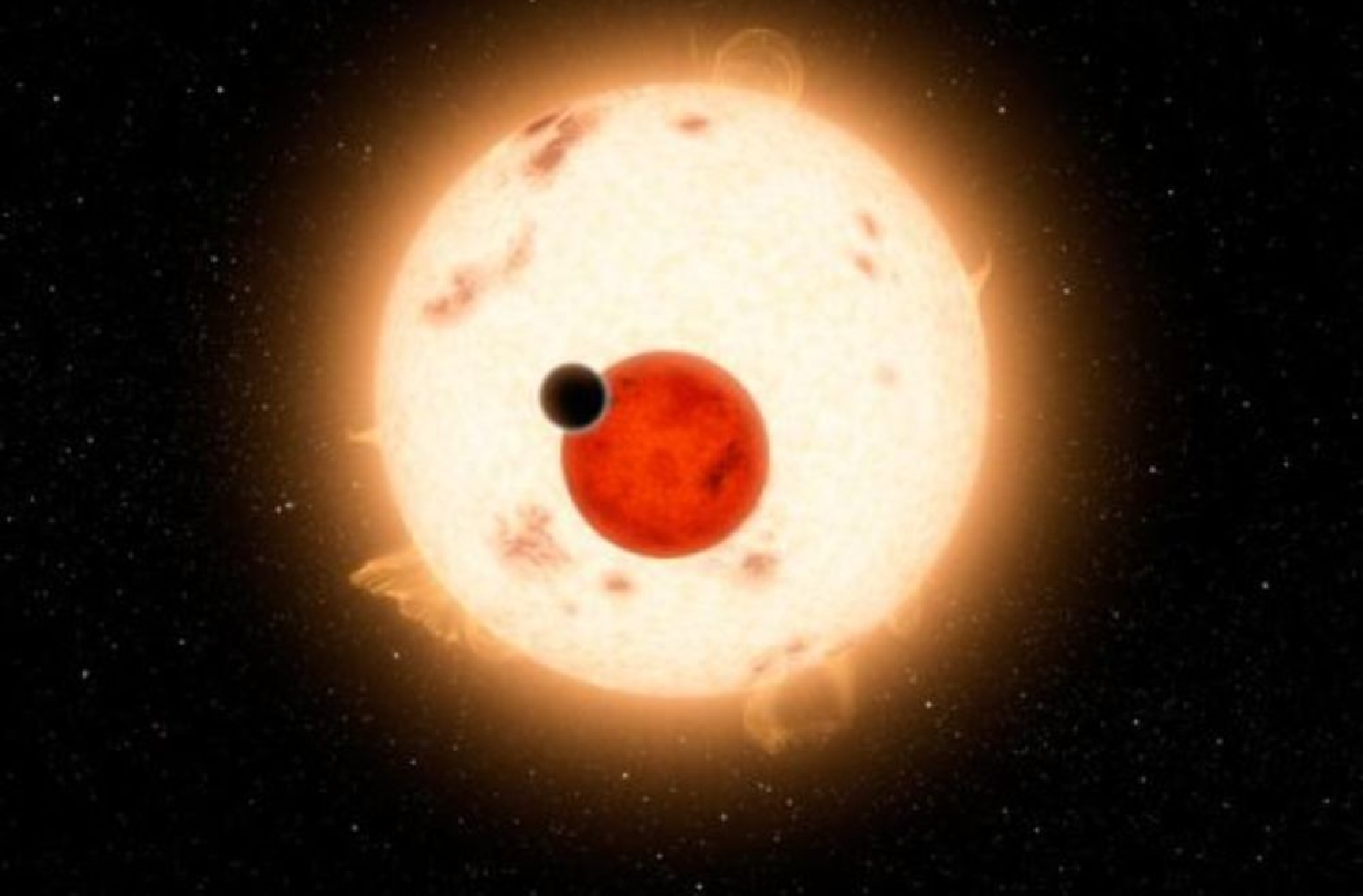
Planetary migration:

Occurred in our solar system too.



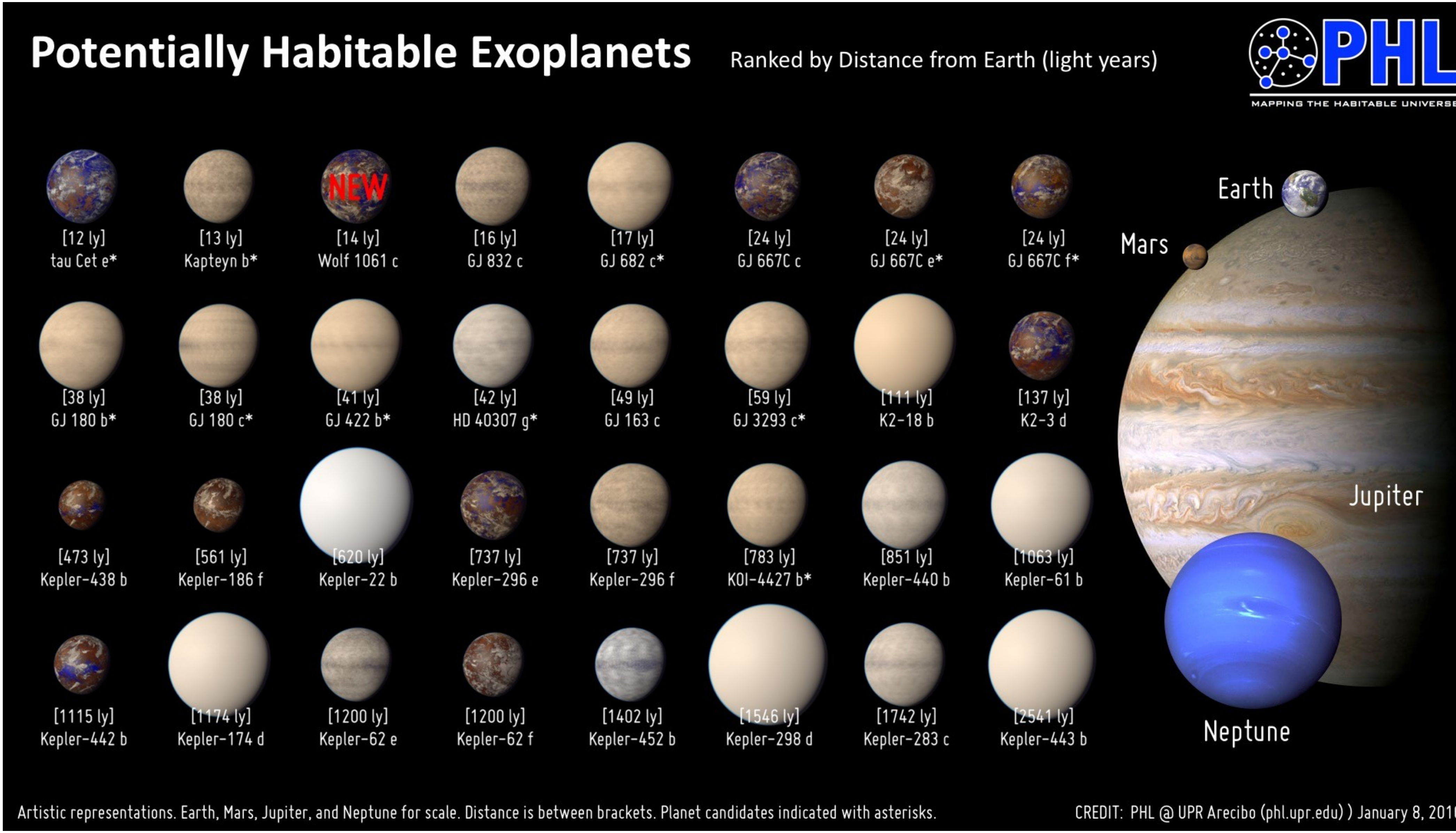
A planet orbiting 2 stars.
(Artists conception. They all are!)

2 stars, but the planet only orbits one.



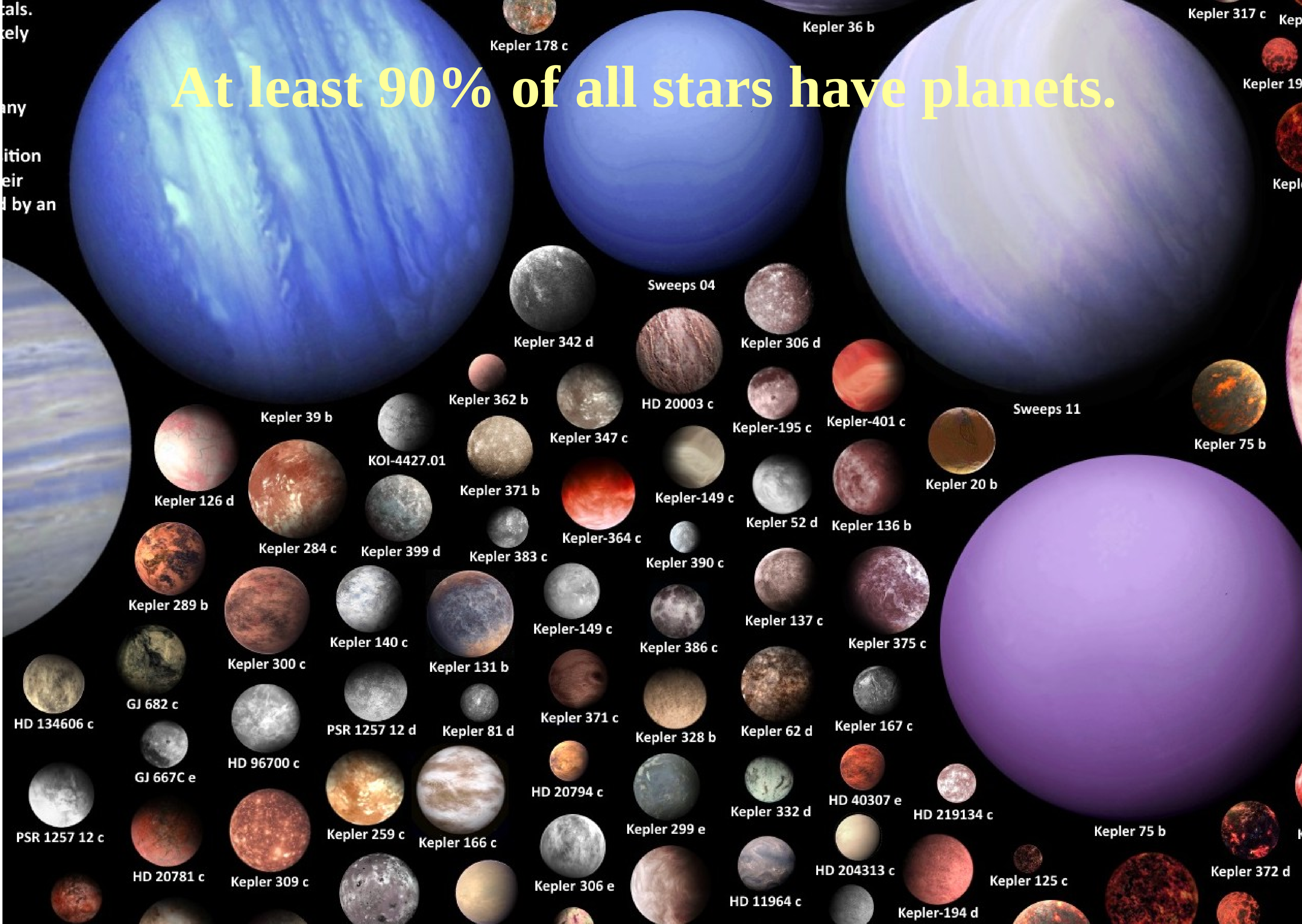
A planet orbiting 1 star, which itself orbits 2 other stars.

Four stars!



Potentially Habitable Exoplanets
Ranked by Distance from Earth (light years)
PHL
MAPPING THE HABITABLE UNIVERSE
NEW
[12 ly] tau Cet e*
[13 ly] Kapteyn b*
[14 ly] Wolf 1061 c
[16 ly] GJ 832 c
[17 ly] GJ 682 c*
[24 ly] GJ 667C c
[24 ly] GJ 667C e*
[24 ly] GJ 667C f*
[38 ly] GJ 180 b*
[38 ly] GJ 180 c*
[41 ly] GJ 422 b*
[42 ly] HD 40307 g*
[49 ly] GJ 163 c
[59 ly] GJ 3293 c*
[111 ly] K2-18 b
[137 ly] K2-3 d
[473 ly] Kepler-438 b
[561 ly] Kepler-186 f
[620 ly] Kepler-22 b
[737 ly] Kepler-296 e
[737 ly] Kepler-296 f
[783 ly] KOI-4427 b*
[851 ly] Kepler-440 b
[1063 ly] Kepler-61 b
[1115 ly] Kepler-442 b
[1174 ly] Kepler-174 d
[1200 ly] Kepler-62 e
[1200 ly] Kepler-62 f
[1402 ly] Kepler-452 b
[1546 ly] Kepler-298 d
[1742 ly] Kepler-283 c
[2541 ly] Kepler-443 b
Earth
Mars
Jupiter
Neptune
Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance is between brackets. Planet candidates indicated with asterisks.
CREDIT: PHL @ UPR Arecibo (phl.upr.edu)) January 8, 2016

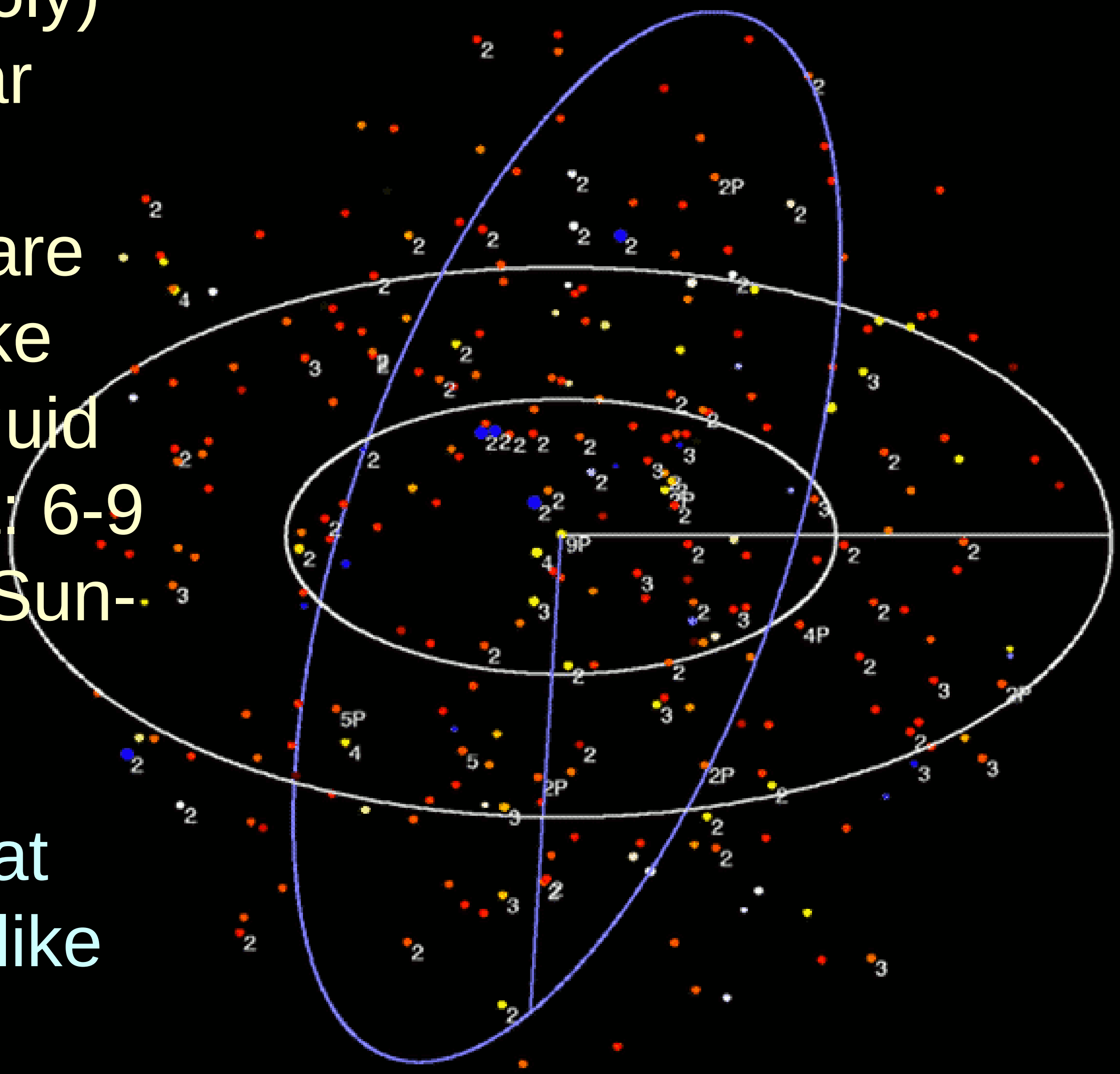
At least 90% of all stars have planets.



It is estimated there are 67-134 **million** Earth-like planets in our galaxy alone.

There are over 100 billion galaxies in our Universe.

Within 10pc (33.6ly) there are 259 star systems. It is estimated there are 132-160 Earth-like planets where liquid water could exist: 6-9 of these around Sun-like stars.



It is estimated that ~11% of all Sun-like stars have such planets.

Take aways

* Most stars have planets. Planets outnumber stars.
* Most planets are between Earth and Neptune in size- we have no such planets in our solar system.
* Most planets detected orbit closer to their stars than in our solar system. BUT we are BEST at finding this type.
* Why are they so close? We think they migrated (slowly moved) there after forming farther out.
* Only the ‘direct imaging’ method sees the planets, the rest only see the effect of planets on stars.
* Planets are in systems we never imagined they would be. Planets have a LOT more variety then we thought.
* No solar systems like ours yet, but ability to detect them is an issue.

How do you think you did on the test?

A)

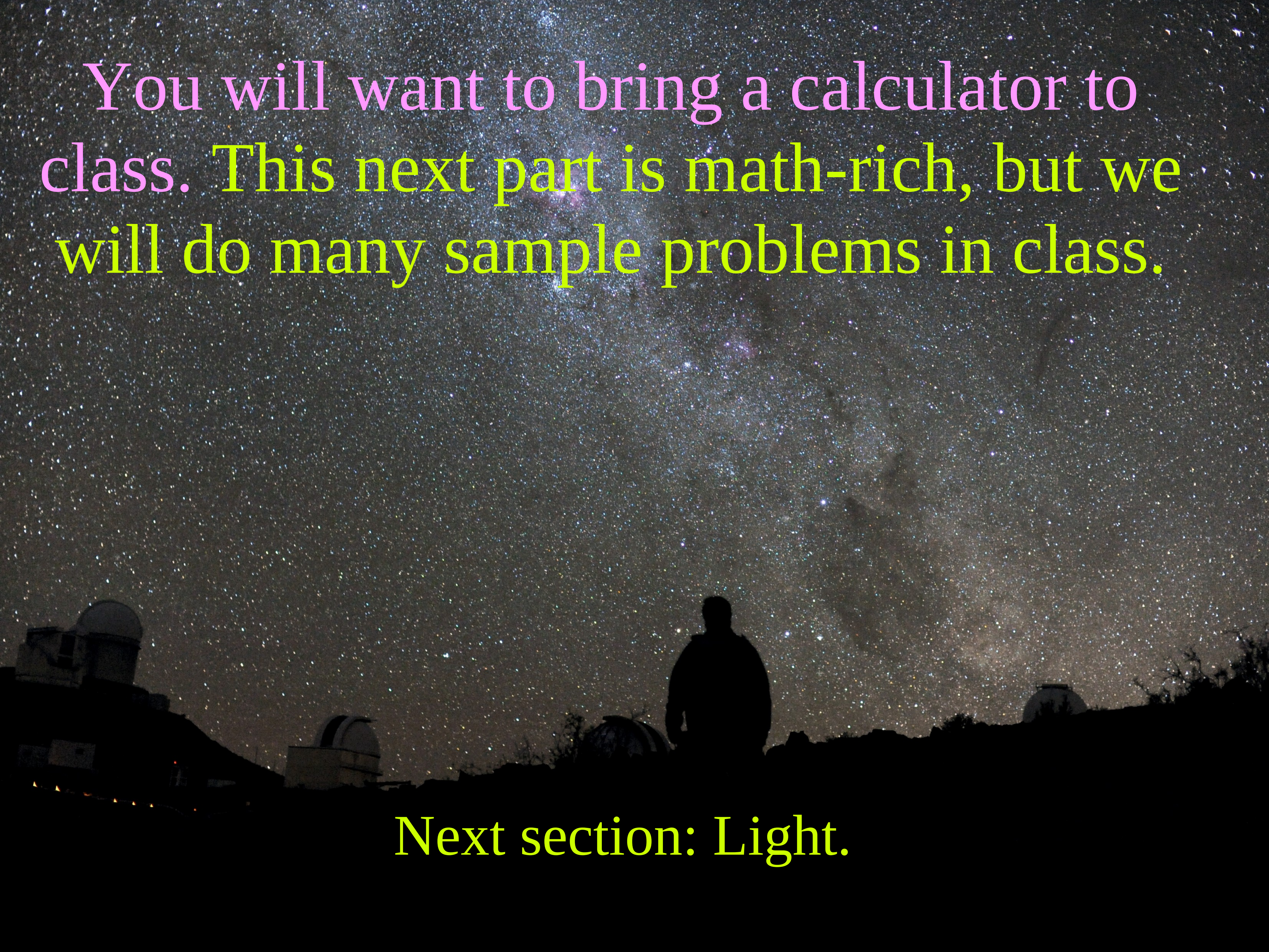
B)

C)

D)

E) No idea at all.

F)

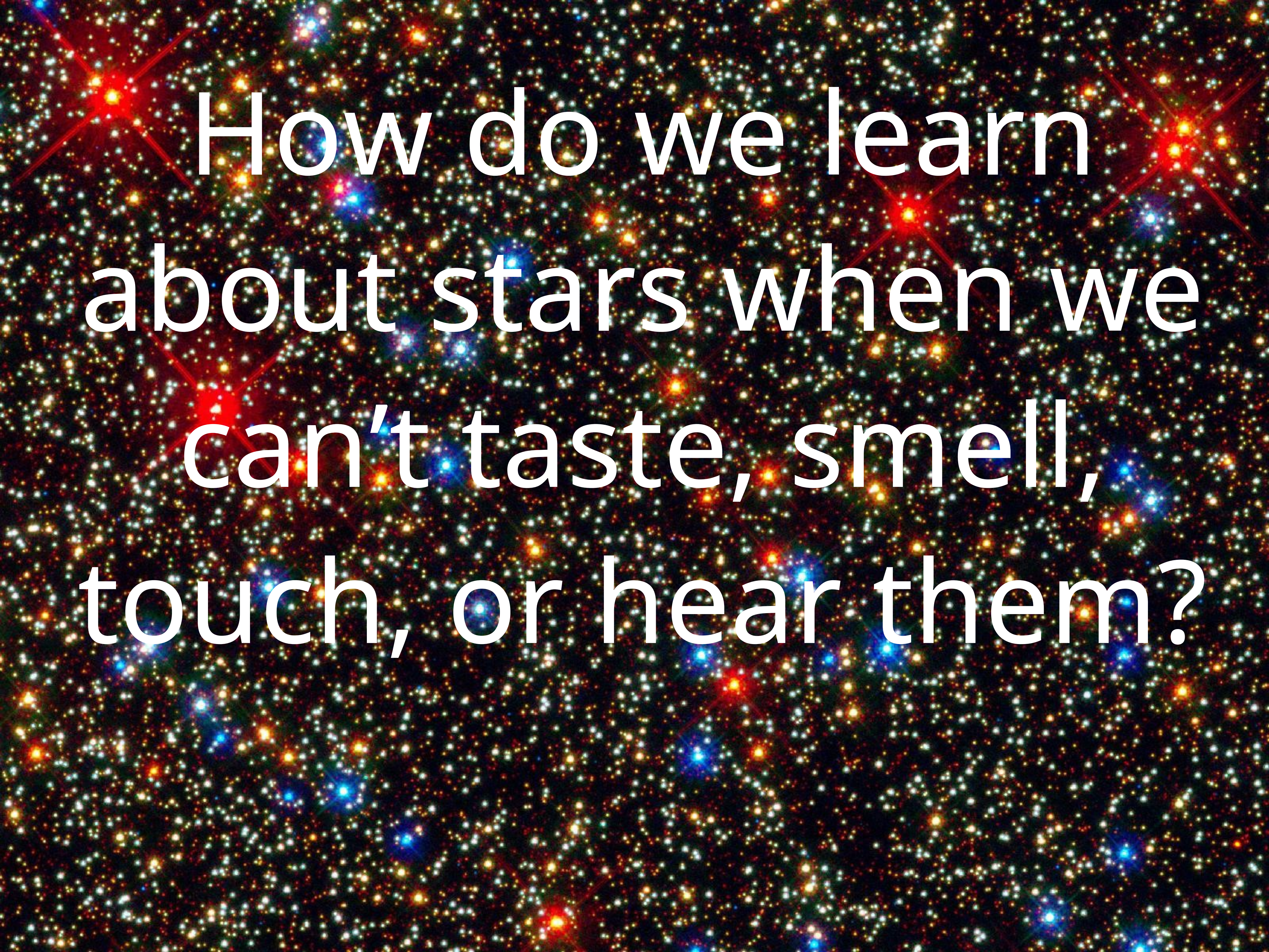

You will want to bring a calculator to class. This next part is math-rich, but we will do many sample problems in class.
Next section: Light.

Time for a completely new topic, Stars!

Stars do not all appear the same

We want to know:

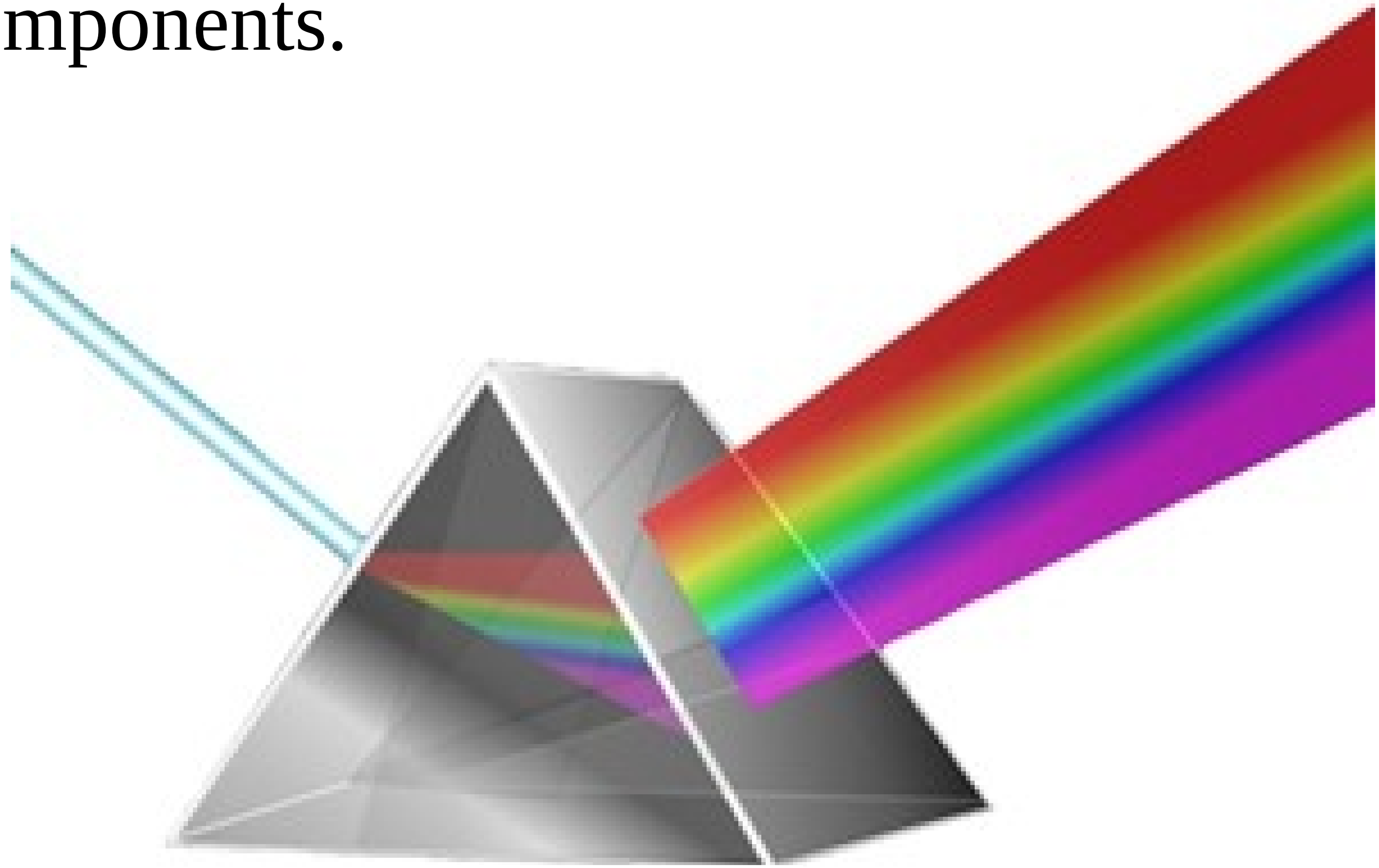
- How hot are stars?
- How BIG are stars (size)?
- How massive are stars?
- What are stars made of?
- How far away are stars?
- Are they in motion?
- How much energy do stars emit?
- Where does that energy come from?



How do we learn about stars when we can’t taste, smell, touch, or hear them?

Spectrum: spreading light out into a rainbow.

A ***spectrum*** is light spread out into its constituent components.

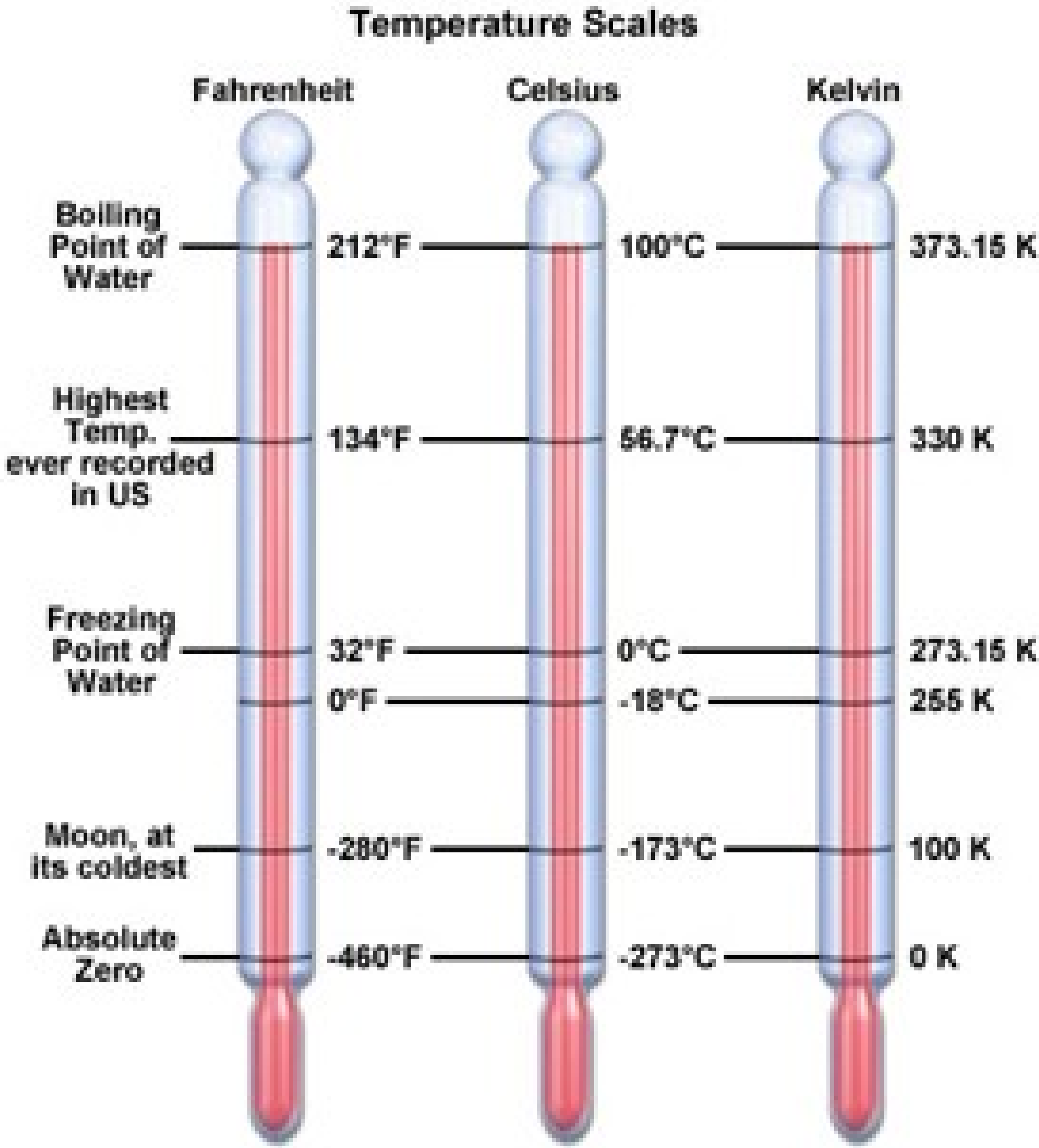


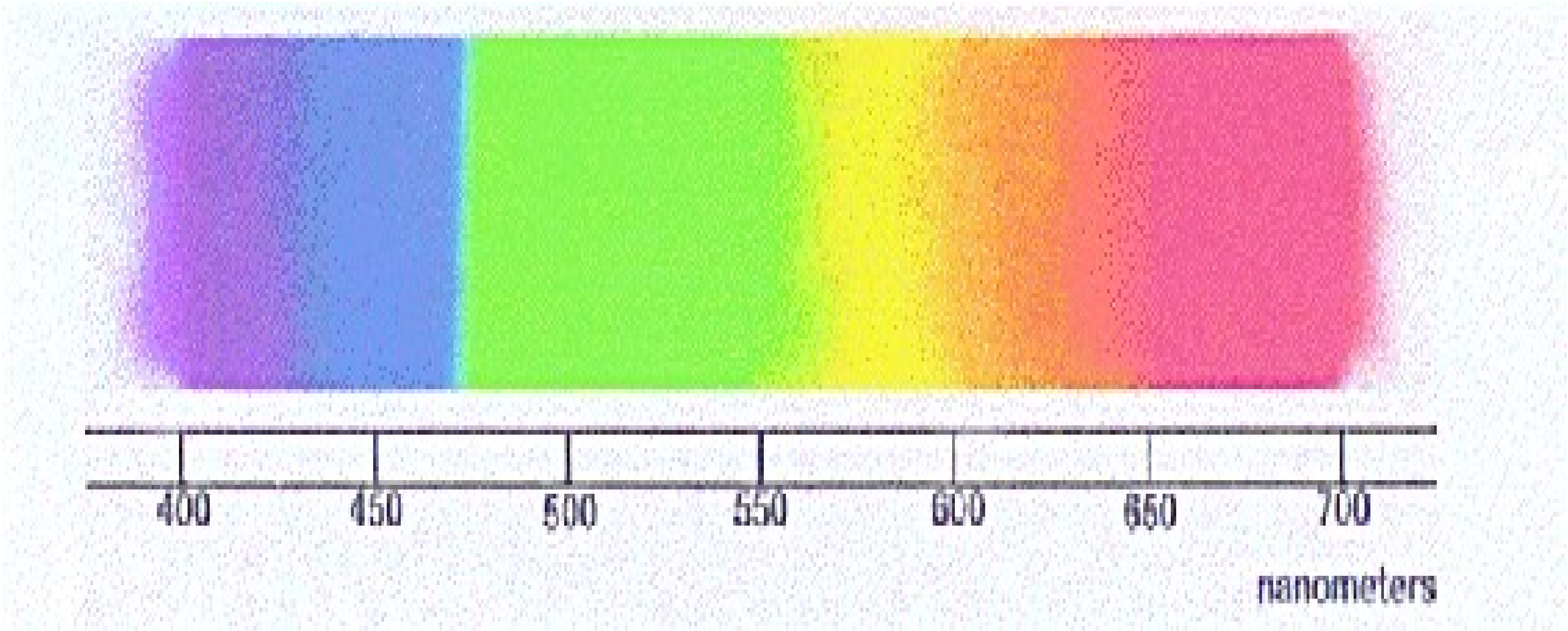
The nature of light: it is both a particle and a wave!

The wavelength tells us the *energy* that each photon (piece of light) has.

$E = 1240/\lambda$ (λ in nm)

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


Temperature Scales
Fahrenheit
Celsius
Kelvin
Boiling Point of Water
212°F
100°C
373.15 K
Highest Temp. ever recorded in US
134°F
56.7°C
330 K
Freezing Point of Water
32°F
0°C
273.15 K
0°F
-18°C
255 K
Moon, at its coldest
-280°F
-173°C
100 K
Absolute Zero
-460°F
-273°C
0 K



400 nm

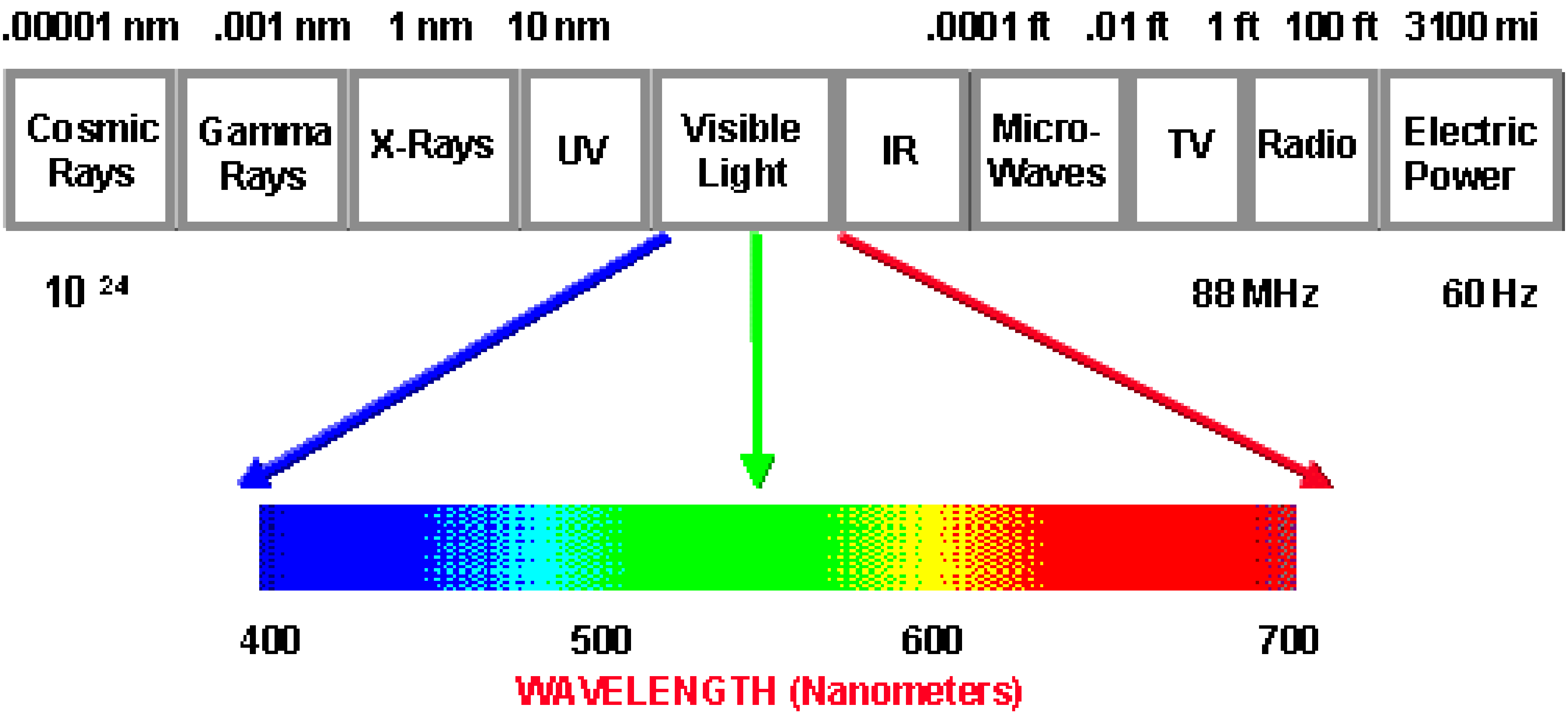
700 nm

more energy

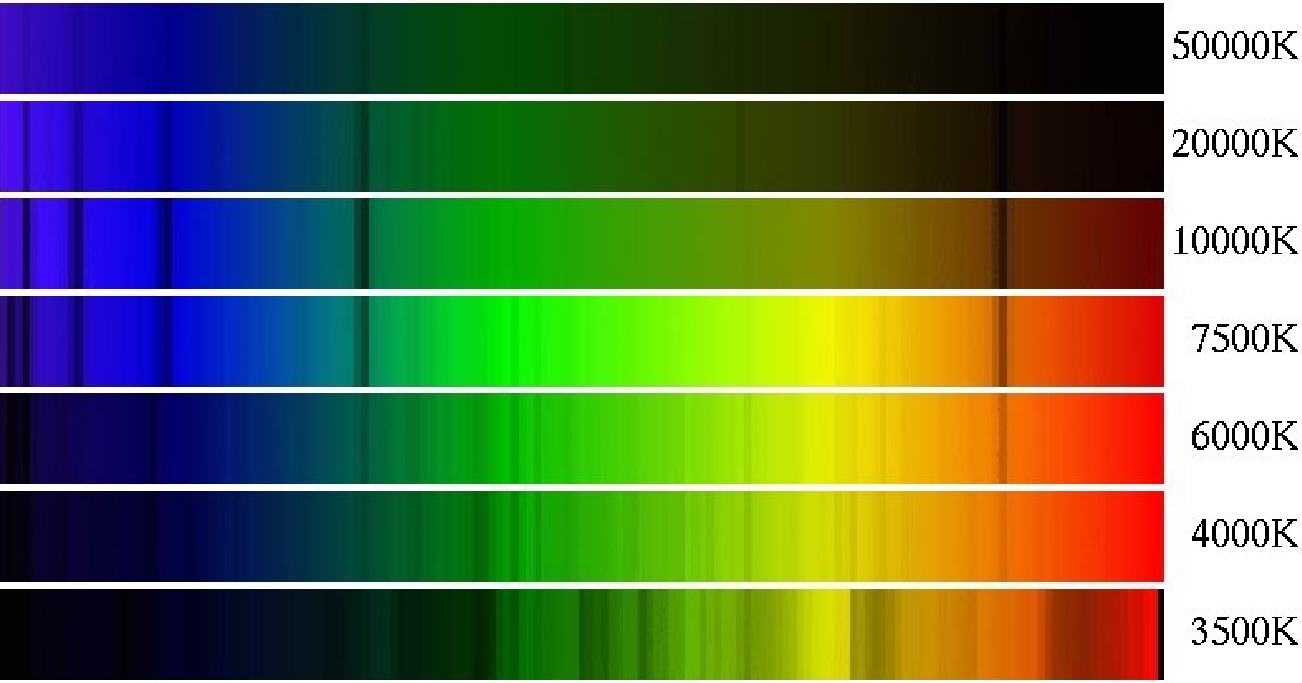
$$E = 1240/ \lambda$$

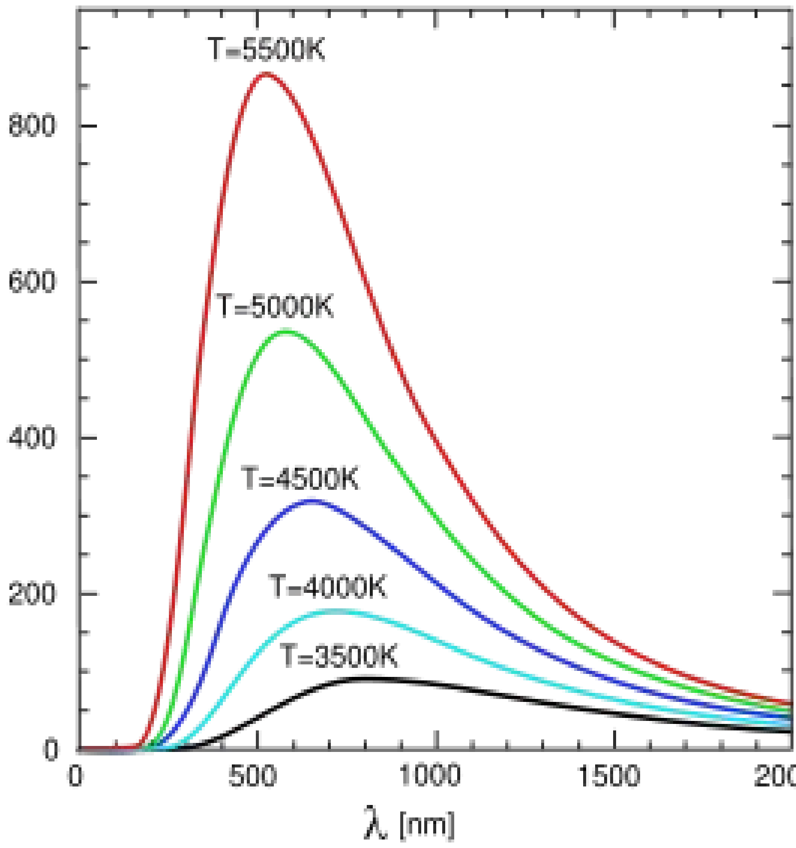
less energy

electromagnetic spectrum

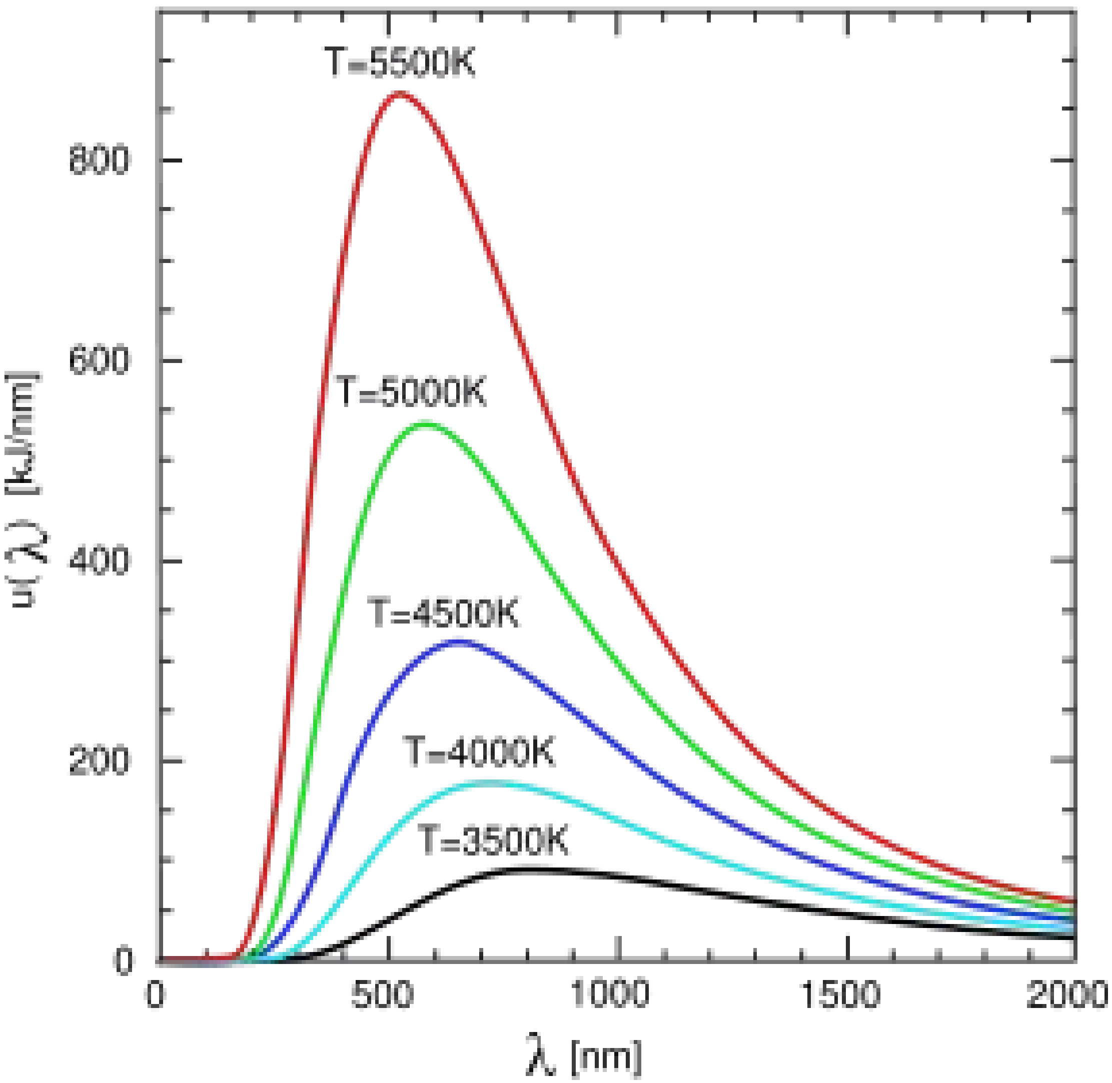


Take a spectrum (left) and measure the intensity (brightness) at each wavelength, and then make a graph (right)





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



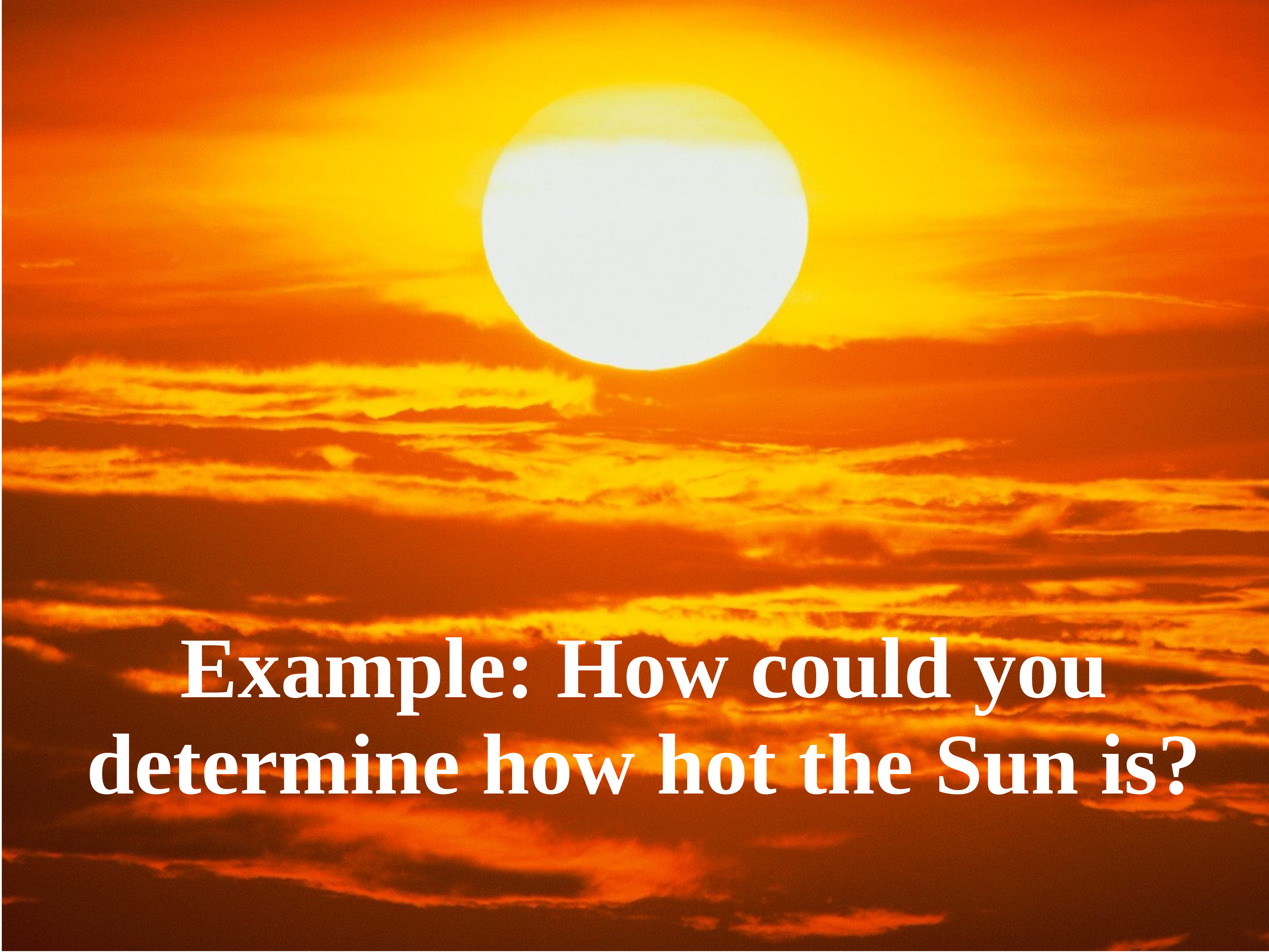
Shorter wavelengths = hotter object.

Objects glowing blue are hotter then objects glowing red.

Wien's Law

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: How could you determine how hot the Sun is?