Announcements

- **Final exam is Wednesday, December 14, in LR 1 VAN at 9:45 am.**
- Astronomy tutorial: Tuesday 3-5, 7-9 pm in 310 VAN
- Office hours: Tuesday 1–3 pm, Wednesday 10-11 am, or by appointment in 702 VAN
- There will be no homework #12.
- Scores for exam #3 are on ICON.

The final will be based on the homework, the clicker questions, and the review questions at the end of each lecture. The best way to study for the test is to review those and the lecture notes. If you feel you need more help with the material, then read the book or come to astronomy tutorial or office hours.

Equation Sheet

Some useful numbers:

Radius	Distance
Moon = 1.7×10^6 m	Earth-Moon = 3.8×10^8 m
Earth = 6.4×10^6 m	Sun-Earth = 1.5×10^{11} m
Sun = 7.0×10^8 m	Sun-Alpha Centauri = 4.1×10^{16} m

1 light-year = 9.5×10^{15} m 1 parsec = 3.26 light-years = 3.086×10^{16} m

Parallax formula: $d = 1/p$ for d in pc, p in arcseconds

Small angle formula $S=\dfrac{\alpha\cdot d}{206265}$ for S, d in meters and α in arcseconds

Schwarzschild radius = 3 km (M/M_{Sun}) Hubble law $v = H_0 d$ where $H_0 = 71$ km/s/Mpc

$$\frac{\text{Flux}_A}{\text{Flux}_B}=\frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

$$\frac{L_A}{L_B}=\frac{R_A^2 T_A^4}{R_B^2 T_B^4}$$

Scientific Method

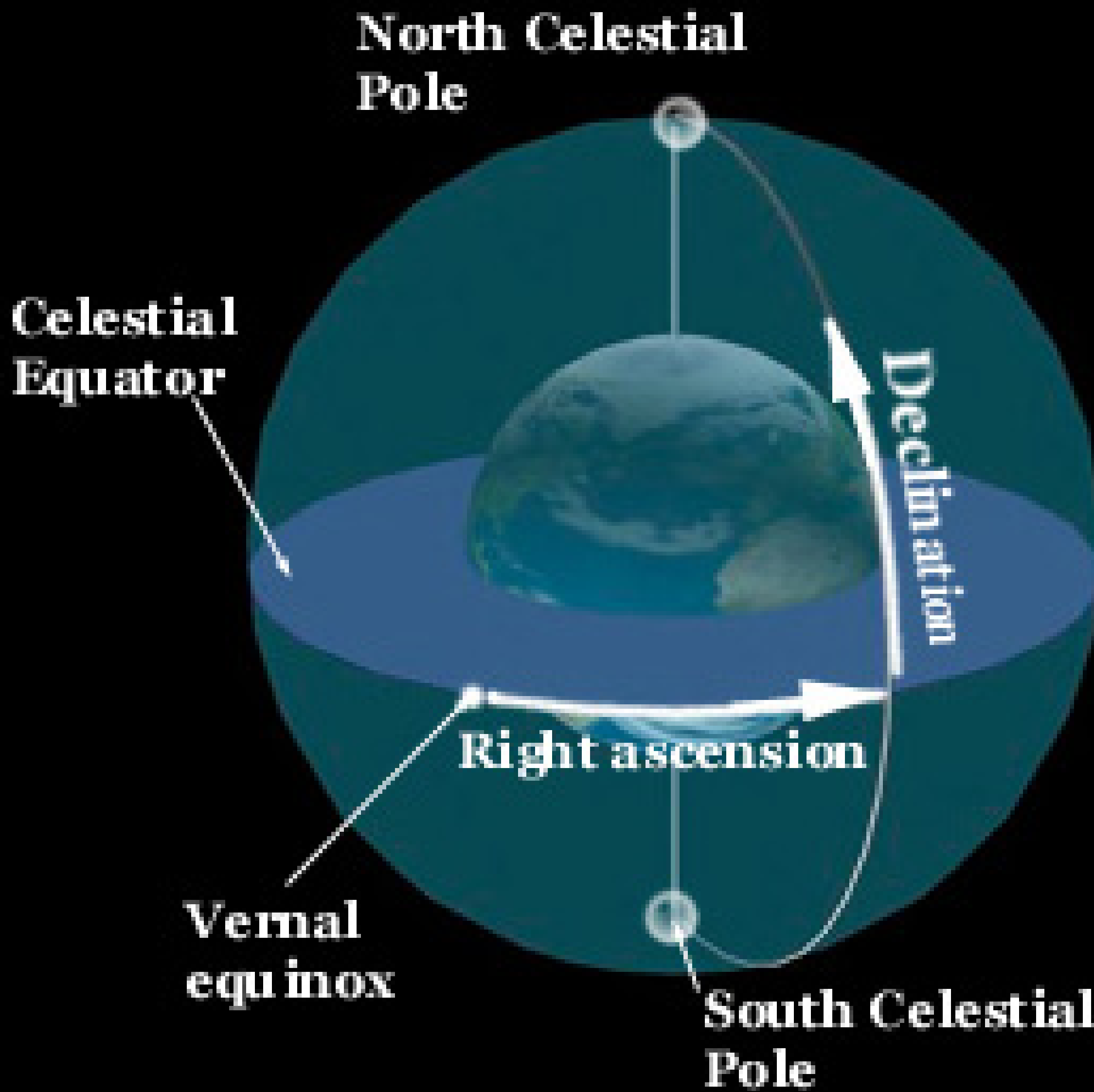
- A scientific hypothesis or theory must be falsifiable: it must make predictions about future observations that can be confirmed or refuted
- We choose between scientific theories based on which makes the most correct predictions. For equally correct theories, we prefer the simpler one.
- Theories tend to focus on one or a few aspects of a phenomenon or system, the "essential variables", e.g. a theory of planetary motion might consider only the position and speed of planets and ignore their size, composition, etc.
- Hypotheses or theories can take many forms: equations, scale models, maps, diagrams. Anything that can be used to make predictions is OK.

Scale Model

- A scale model is a representation of a real object or set of objects in which all of the different parts of the model have sizes in the correct proportions to the real thing.
- For scale factor *s*, if the real object has a dimension *D*, then the corresponding dimension in the model will be $d = sD$.
- Imagine you want to draw the Sun/Earth/Moon system to scale on a piece of paper (0.2 m across). How big will the Earth be?
  - A) 10^{-12} m
  - B) 10^{-8} m
  - C) 10^{-5} m
  - D) 10^{-3} m

Night Sky, Motion of Stars

- Locations on the sky can be described in terms of two coordinates (declination and right ascension) or in terms of constellations.
- Stars move on the sky due to the rotation of the Earth making one full circle in (a little less than) 24 hours.
- The stars visible at night during different times of year change because the Earth orbits around the Sun.



Coordinates are:

Declination = degrees North or South of the equator.

Right ascension = degrees East of the "Vernal equinox".

Vernal equinox is defined as the position of the Sun on the first day of spring. Note it is a point on the sky, not the earth.

How long was the exposure for this photograph?

A) 2 hours

B) 4 hours

C) 6 hours

D) 8 hours

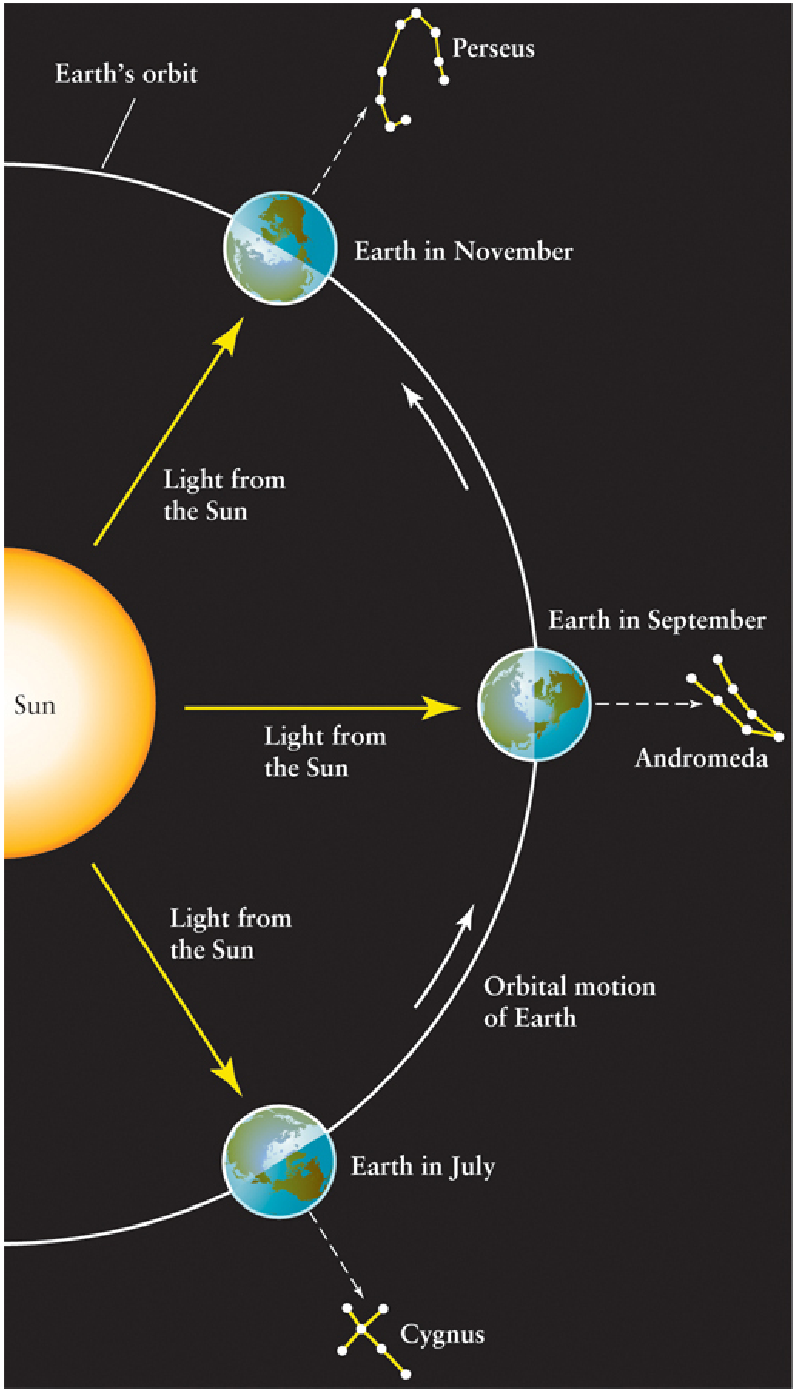
When is Andromeda directly overhead in September?

A) Noon

B) Sunset

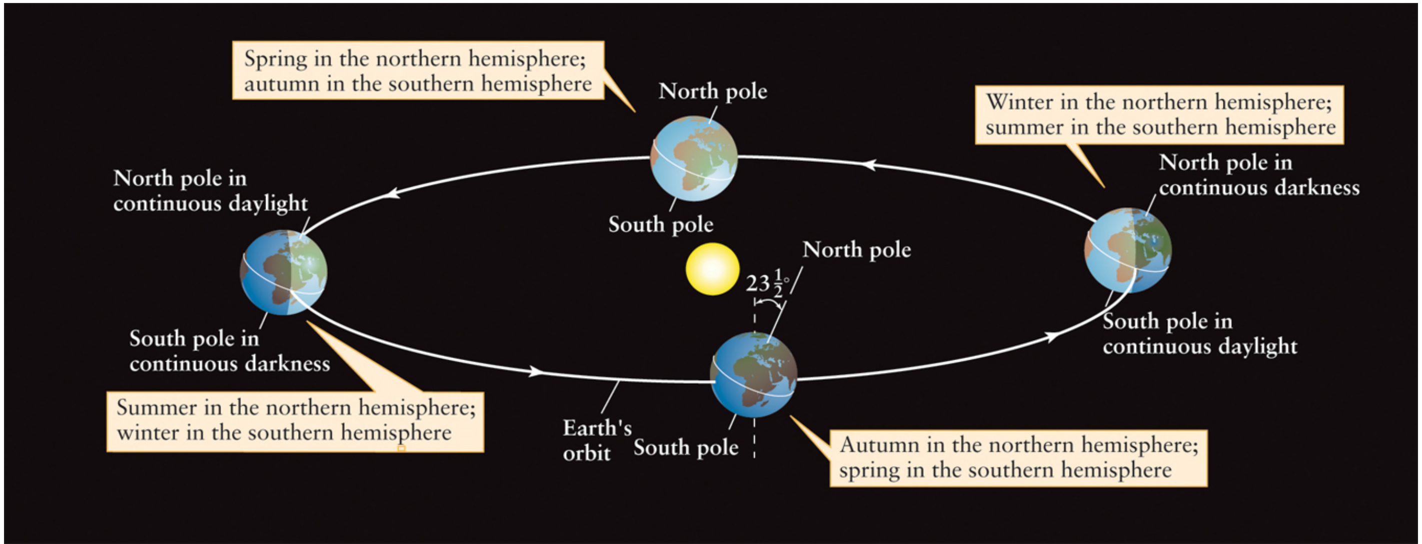
C) Midnight

D) Sunrise



Seasons

- The rotation axis of the Earth (a line running between the North and South poles) is tilted relative to its orbit around the Sun.
- When the North pole is tilted towards the Sun, the northern hemisphere intercepts more sunlight and the Sun is up for more than 12 hours each day. Thus, the northern hemisphere warms and has summer.
- Six months later the North pole is tilted away from the Sun and the northern hemisphere has winter.

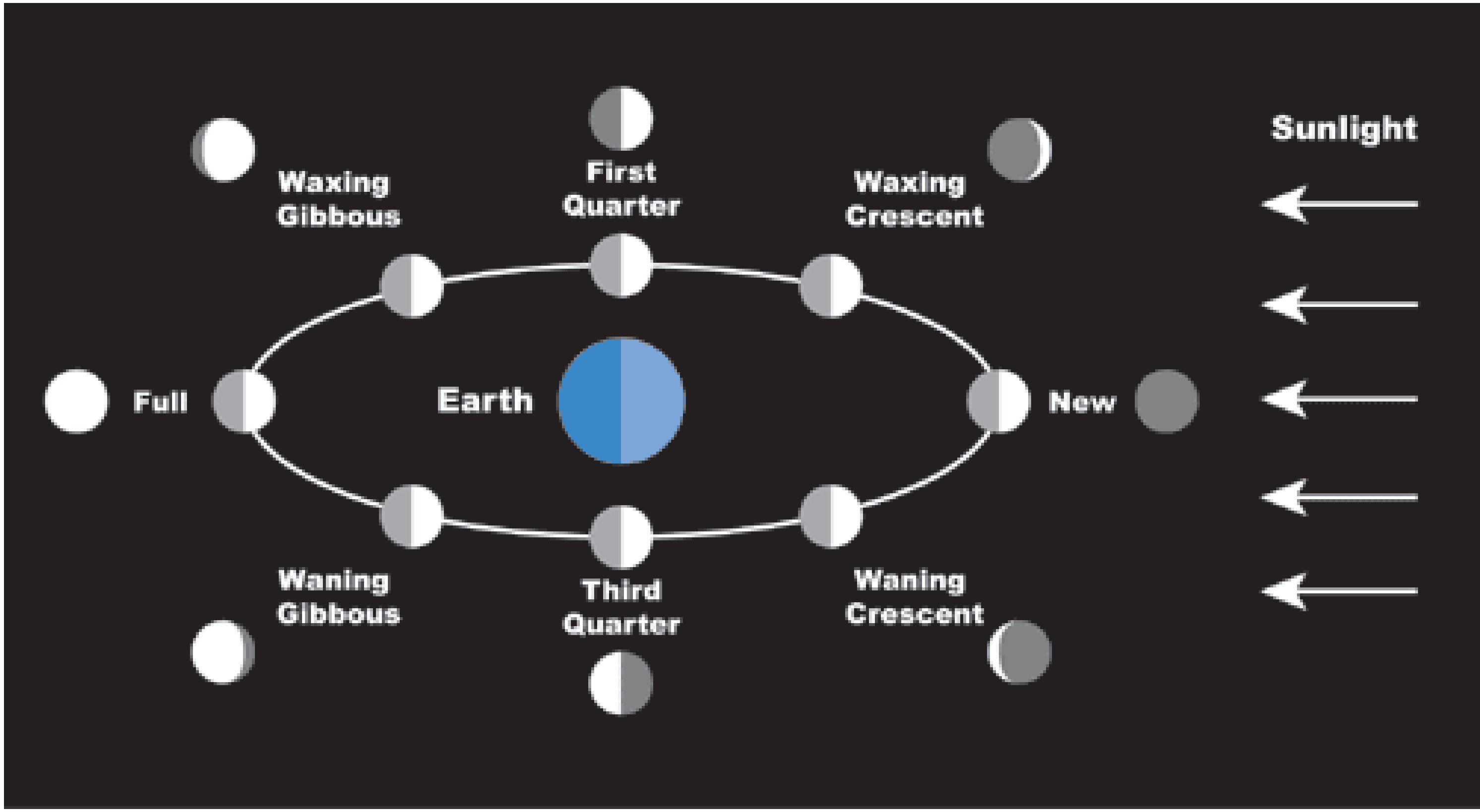


Phases of the Moon

- The Moon orbits the Earth and is illuminated by the Sun.
- The phase of the Moon are caused by the relative positions of the Earth, Moon, and Sun.
- Solar eclipses occur when the Moon blocks light from the Sun from reaching (parts of) the Earth.
- Lunar eclipses occur when the Earth blocks light from the Sun from reaching (all or parts of) the Moon.
- Remember **to draw a picture** and that (almost) everything in the solar system rotates in the same direction.

At approximately what time is the first quarter moon directly overhead?

A) Sunset
B) Midnight
C) Sunrise
D) Noon
E) No clue

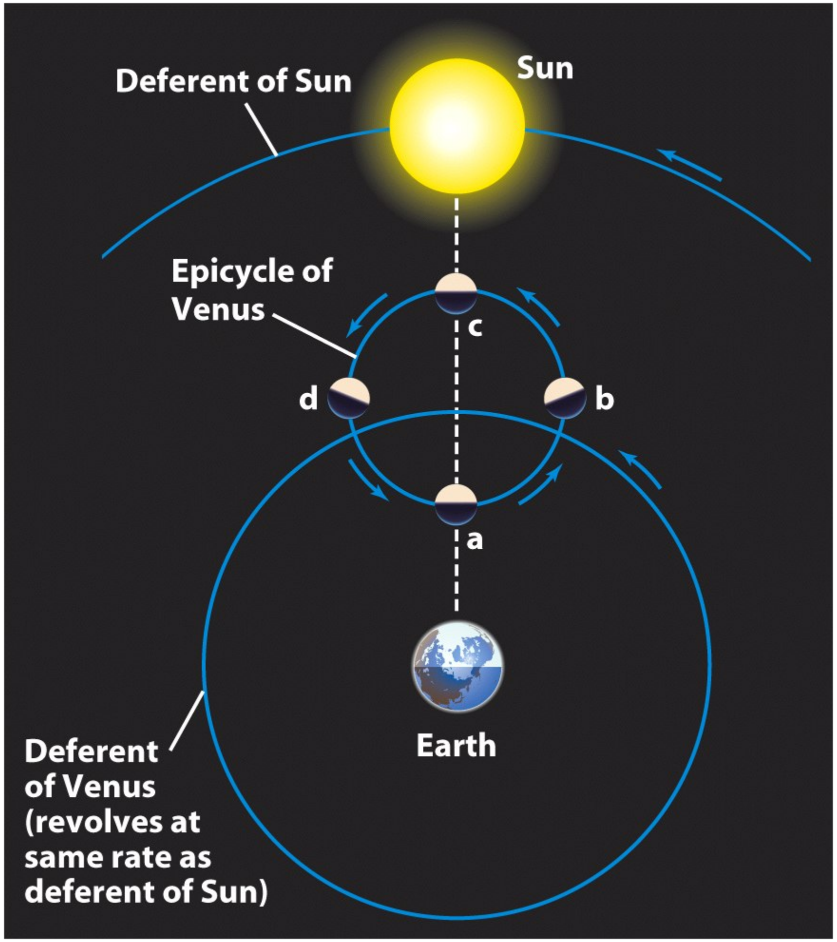


Earth versus Sun Centered Models

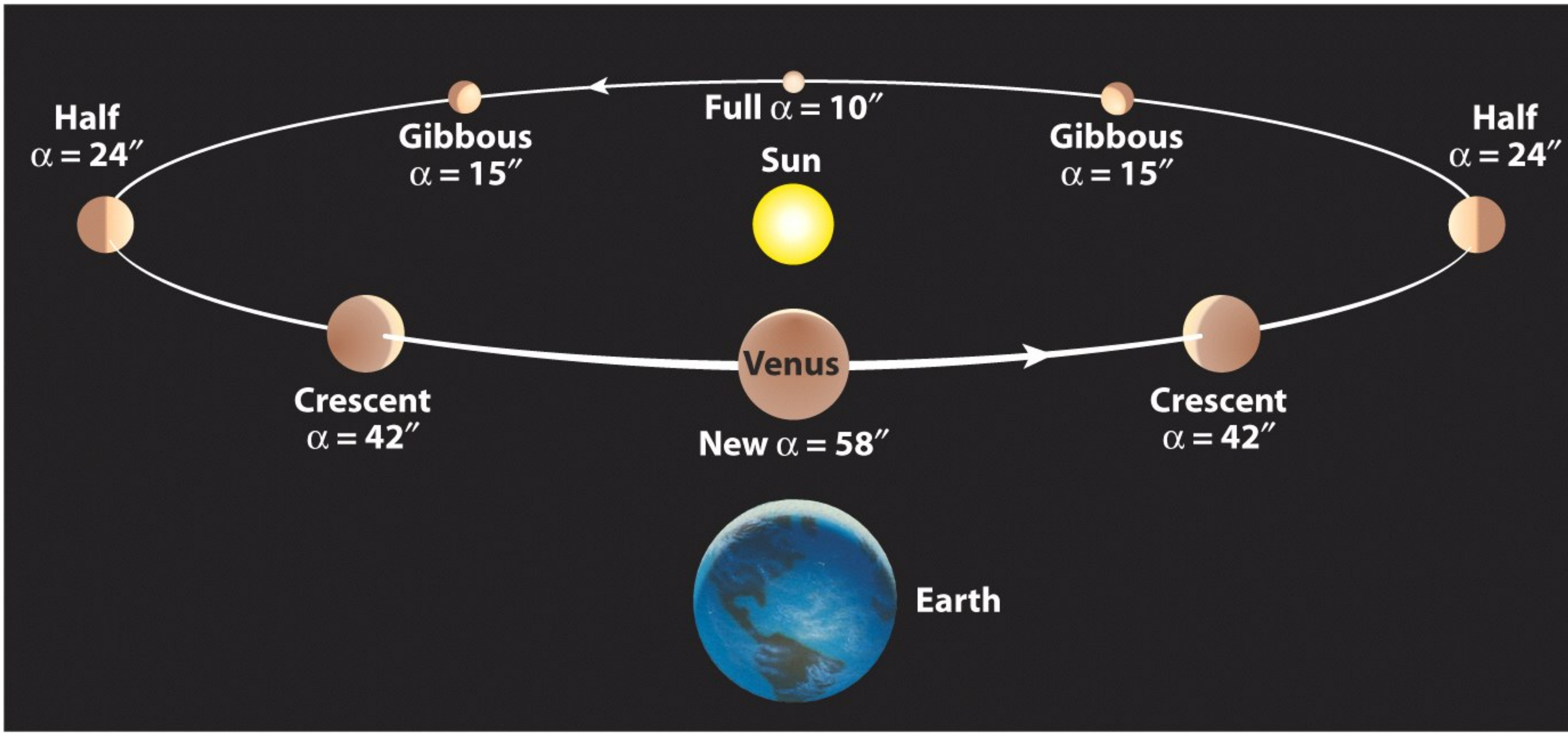
- The planets wander about the sky, mostly moving eastward, but sometimes moving westward (retrograde motion).
- In an Earth-centered model, this motion can be explained using “epicycles”: a small circle superimposed on a larger circle.
- In a Sun-centered model, this motion can be explained by the relative positions of the planet and Earth as both move in their orbits around the Sun.
- In the Earth-centered model, Venus is always between the Earth and Sun, therefore we should never see Venus at full phase, only new and cresent phases. In a Sun-centered model, all phases are allowed for Venus.
- Galileo observed that Venus shows all phases, thus disproving the Earth-centered model.
- It was this extra prediction of phases, not the original essential variables of planet positions on the sky that provided the decisive test to distinguish between the two theories.

Earth-Centered Model

- Venus is never seen very far from the Sun.
- In Ptolemy's model, Venus and the Sun must move together with the epicycle of Venus centered on a line between the Earth and the Sun
- Then, Venus can never be the opposite side of the Sun from the Earth, so it can never have gibbous phases – no "full Venus".



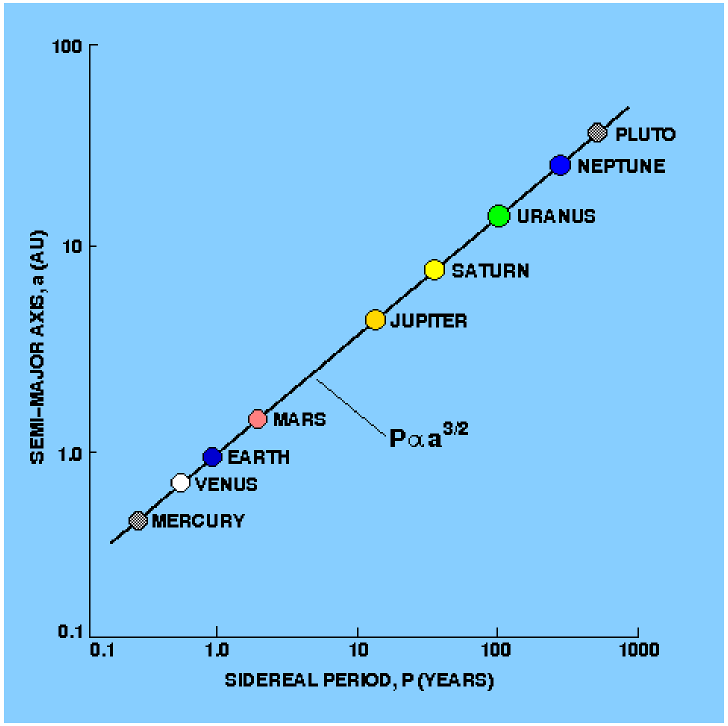
Sun-Centered Model



- In a Sun centered model, Venus can show all phases – as Galileo observed.

Planetary Motion

- The orbits are ellipses.
- Planets move faster when closer to the Sun and slower when farther away.
- Planets farther from the Sun take longer to orbit.



- These laws can be deduced from Newton's laws of gravity and motion.
- Planets move faster when closer to the Sun because the Sun's gravity is stronger when closer to the Sun.
- The orbital speed of Mercury is higher than that of Neptune, because Mercury is closer to the Sun, experiences a strong gravitation force, and needs a higher velocity to balance it.

Kepler's laws of planetary motion

Planets farther from the Sun take longer to orbit.

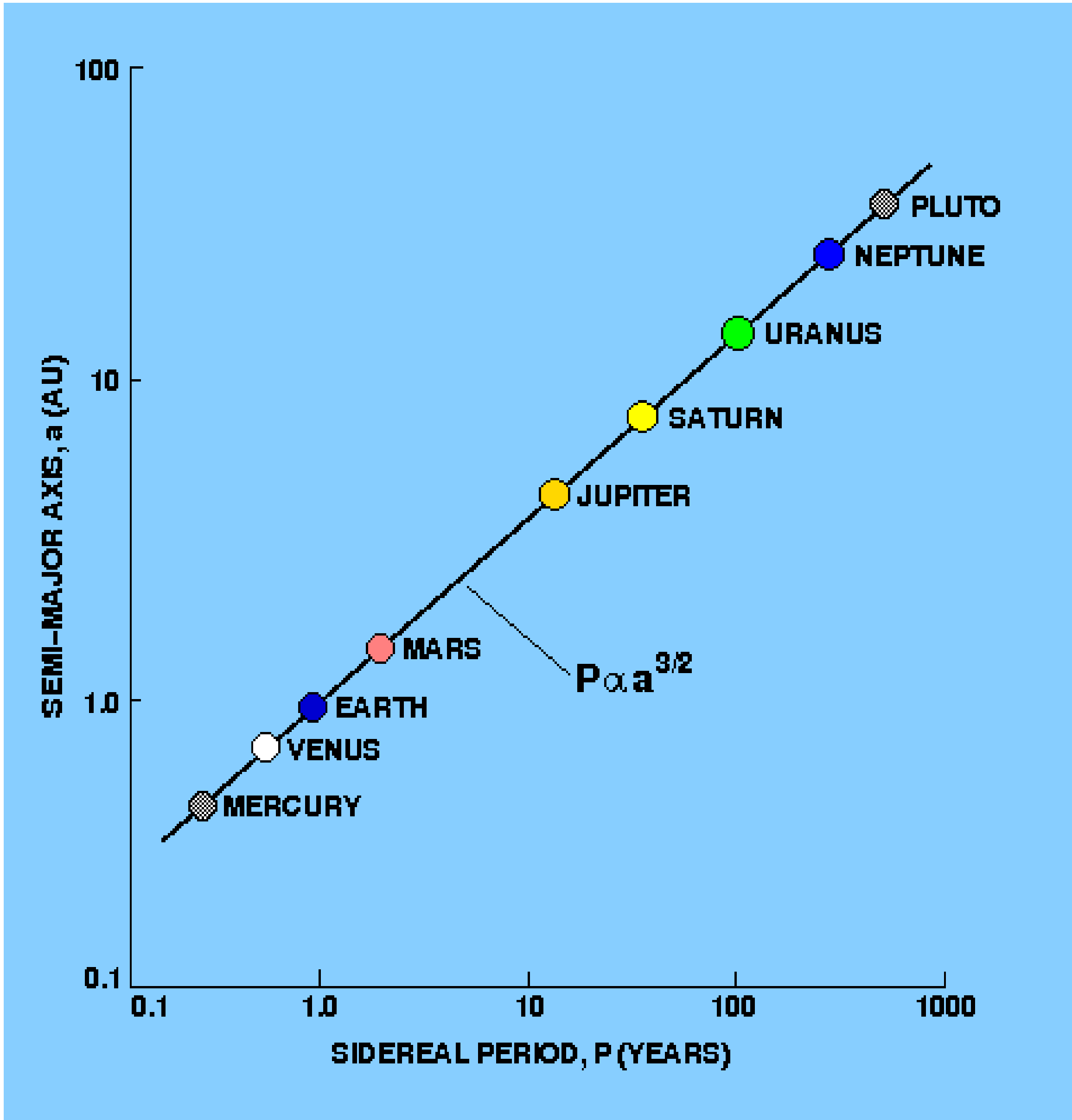
Can read relation from graph.

Where would a planet with an orbital period of 30 years lie on the horizontal axis?

A) 3/10ths of the way from 10 to 100 years

B)1/2 of the way from 10 to 100 years

C) 2/3 of the way from 10 to 100 years



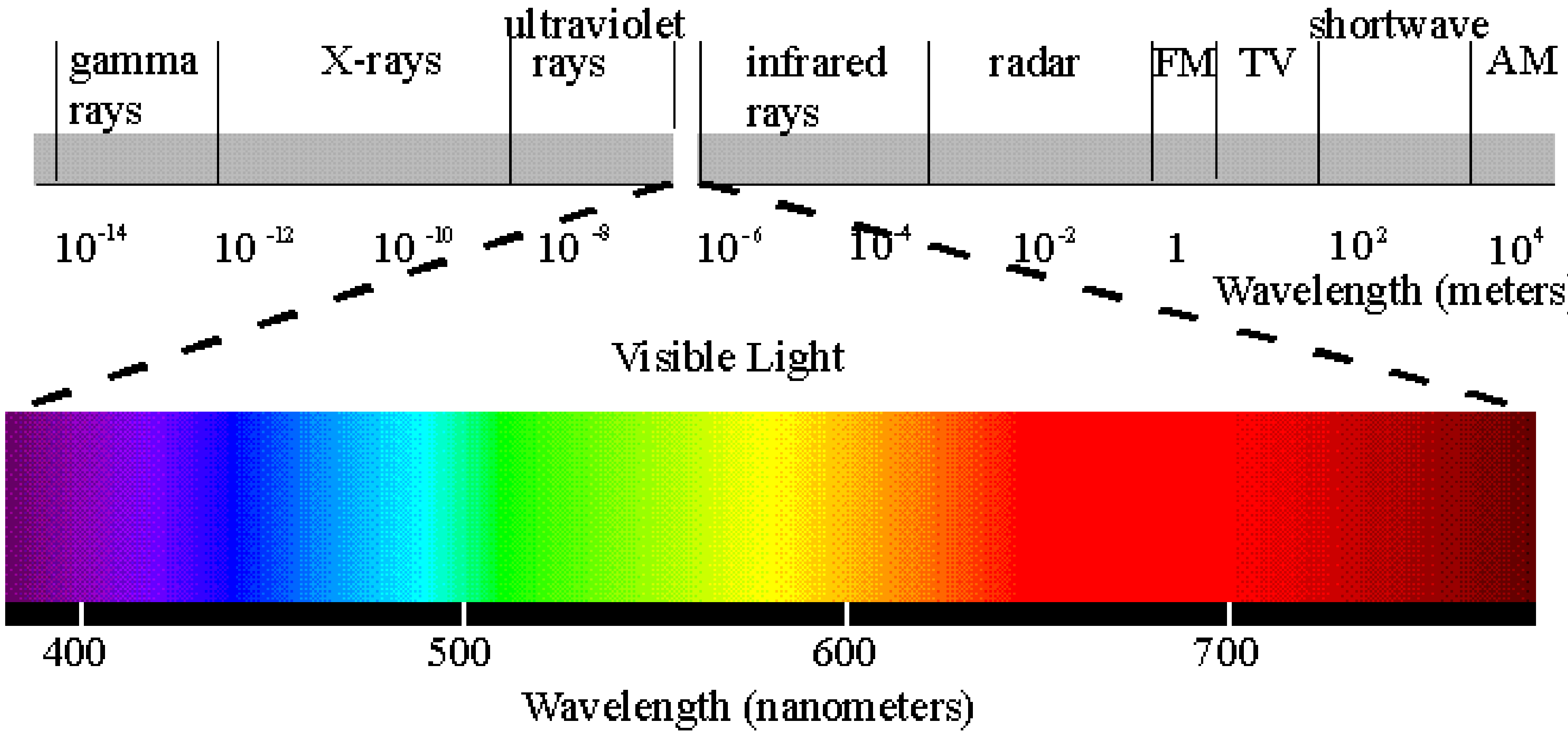
Light and Atoms

- Electromagnetic spectrum, photons
- Atomic structure
- Spectral lines from atoms
- Doppler effect
- Flux and luminosity
- Temperature versus color
- Luminosity, temperature, and radius

Light

- Light is electromagnetic radiation and travels at a constant speed.
- Light can be described as waves, in terms of wavelength.
- Light comes in packets, called photons. The energy of a photon is set by its wavelength.
- The electromagnetic spectrum runs over a range of wavelengths, in order from longest wavelength and lowest energy to shortest wavelength and highest energy the spectrum is: **radio, infrared, visible (red to blue/violet), ultraviolet, X-ray, gamma-ray**.

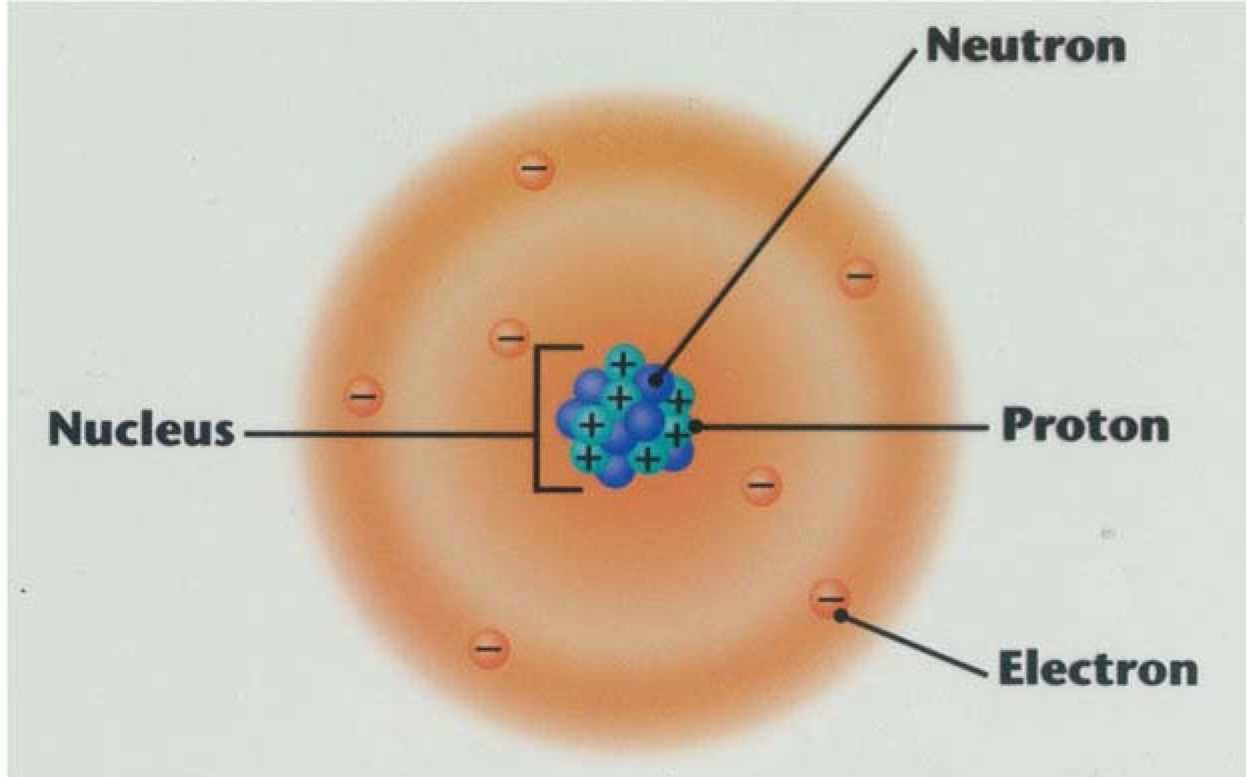
Electromagnetic spectrum



The color of light corresponds to its wavelength:

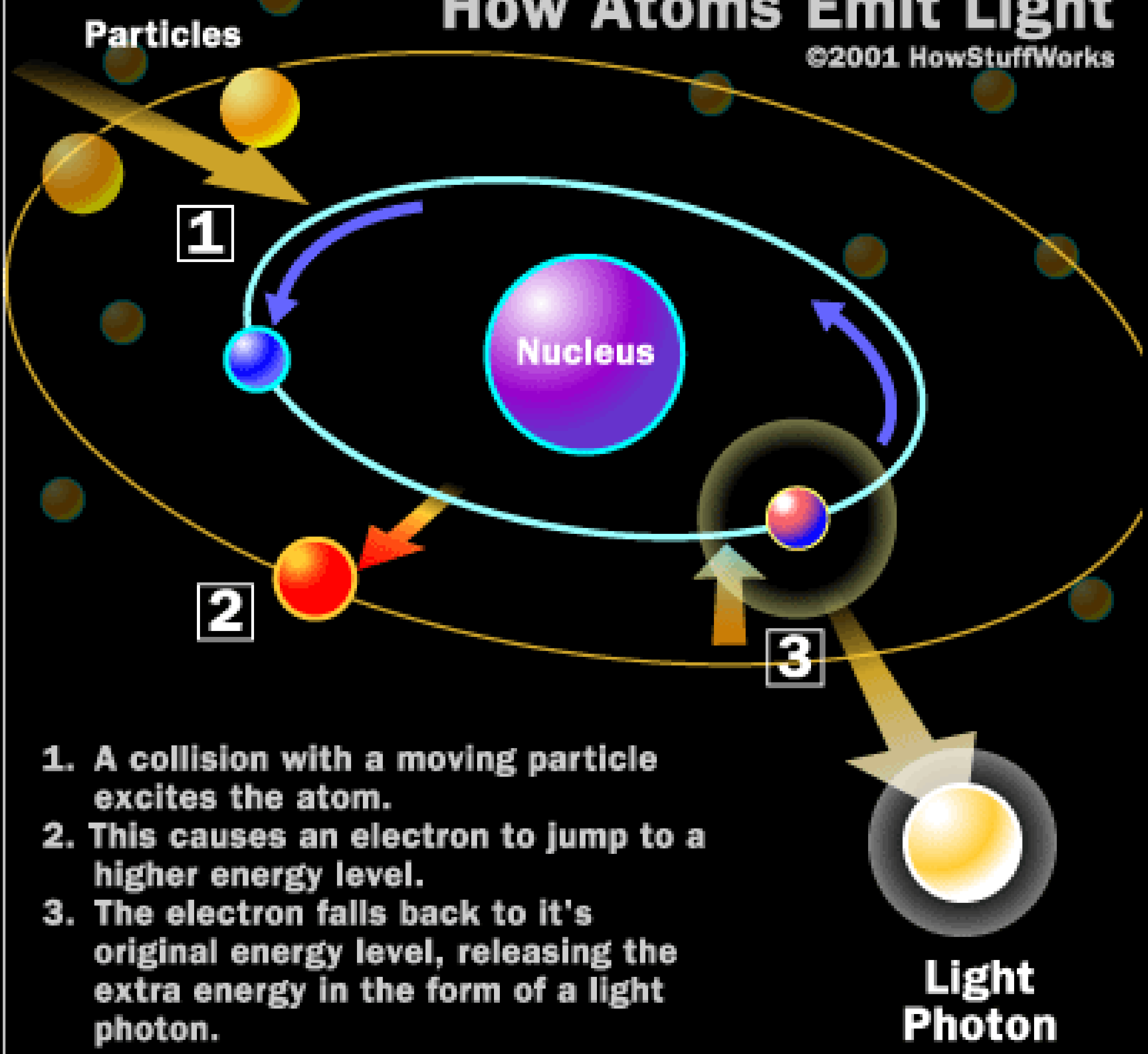
Red = long wavelength, Blue = short wavelength

Atomic structure

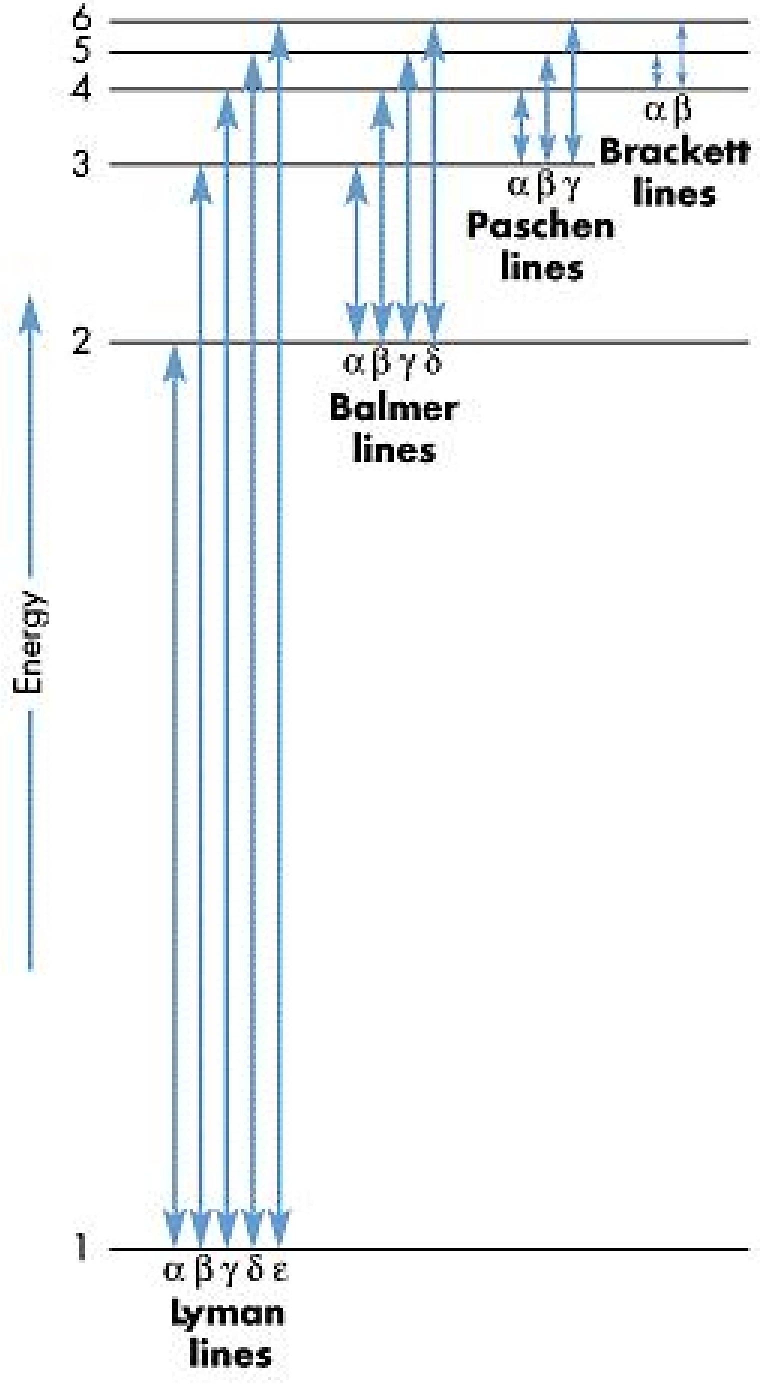


- Nucleus at center contains protons and neutrons
- Electrons orbit around nucleus
- Atom held together by electric force between positive charge on protons and negative charge on electrons
- Nucleus held together by nuclear (or “strong) force between protons and neutrons

How Atoms Emit Light



1. A collision with a moving particle excites the atom.
2. This causes an electron to jump to a higher energy level.
3. The electron falls back to it's original energy level, releasing the extra energy in the form of a light photon.



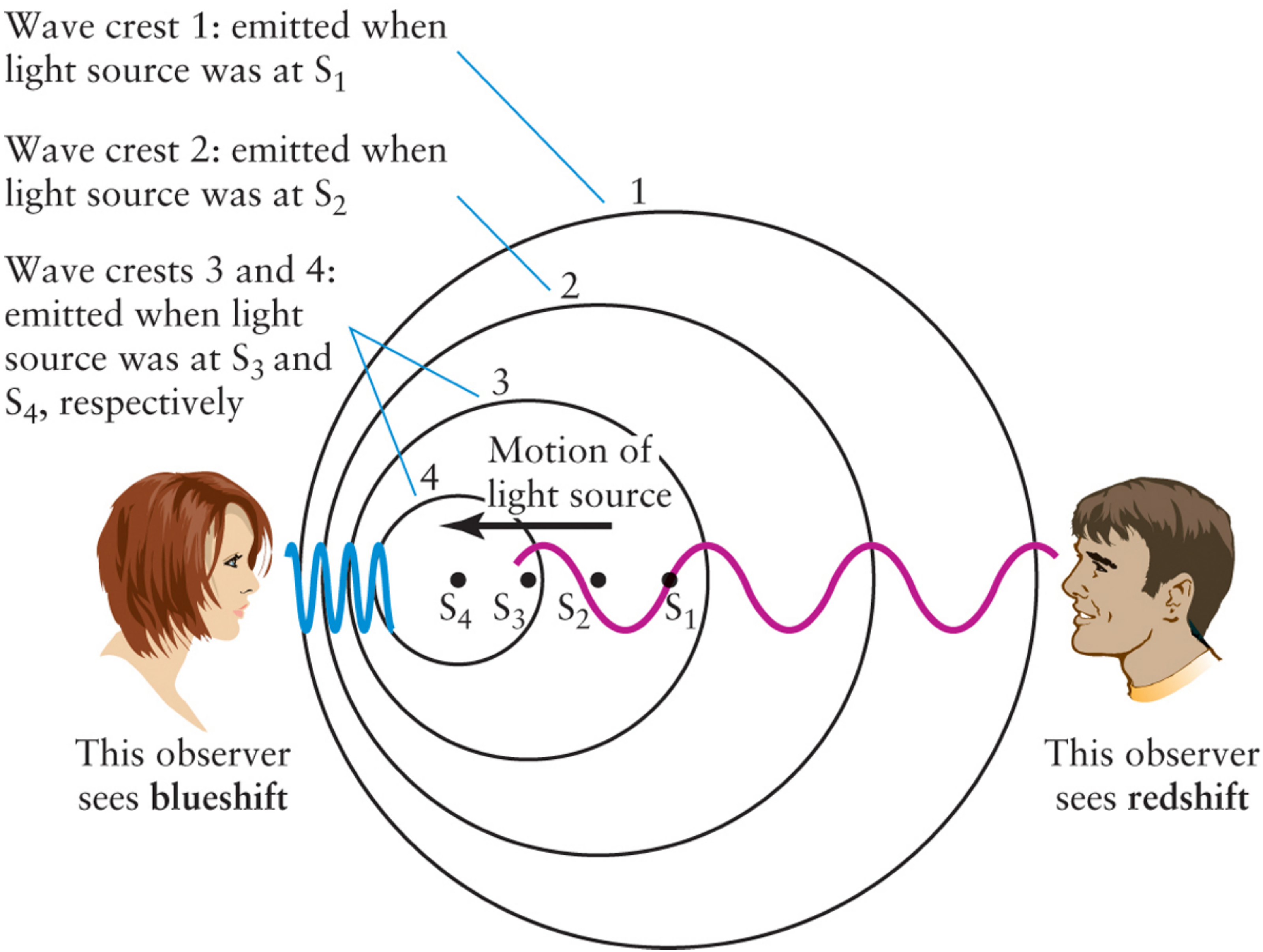
Spectral lines of atoms

- An atom will emit and absorb photons with energies equal to the differences between its energy levels. This sets of set of "spectral lines" of the atom.

- Different atoms have different energy levels and therefore different sets of spectral lines.

- Measurements of spectral lines can be used to determine the different types of atoms in a star.

Doppler effect

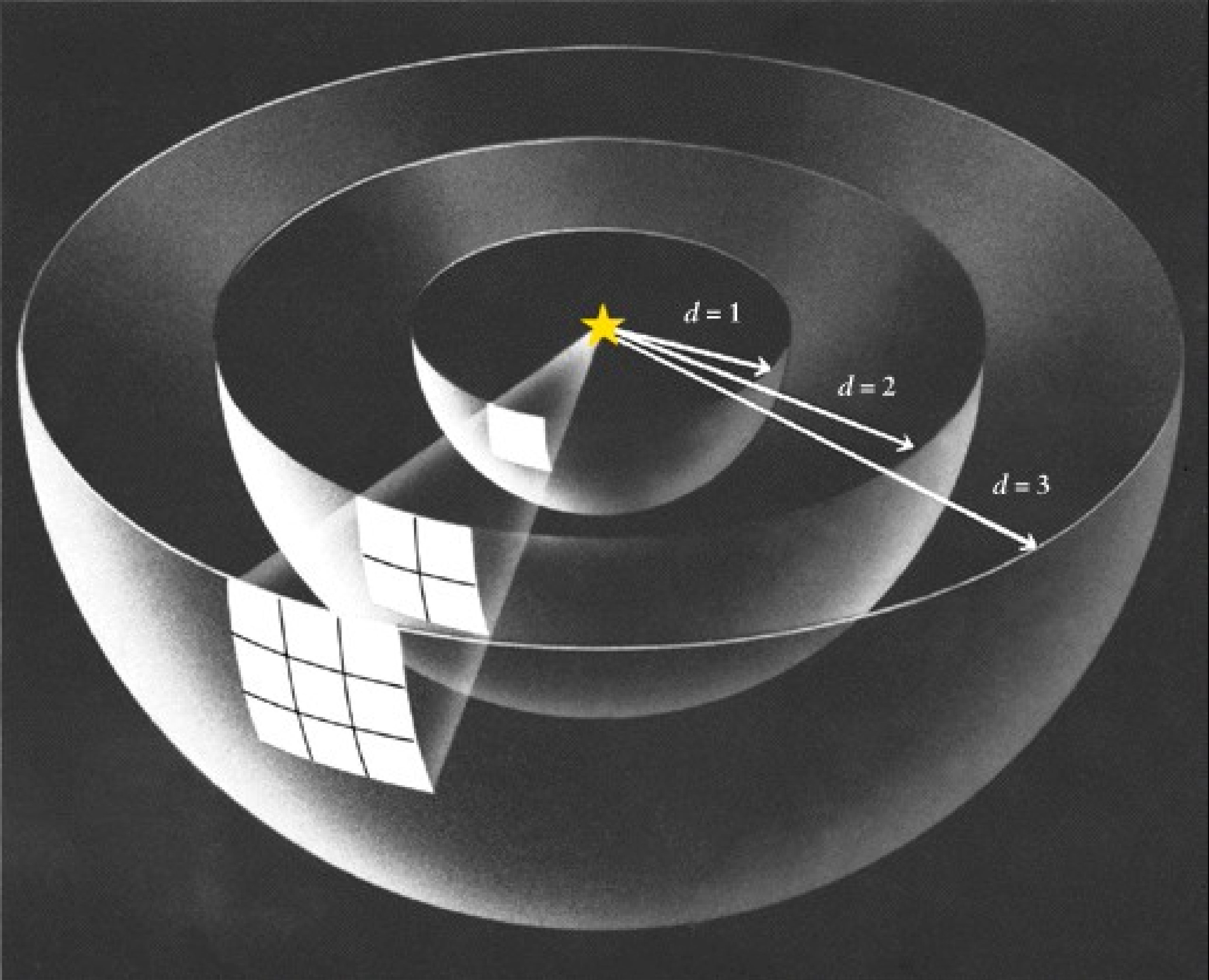


When an object is moving towards you, the light it emits is shifted

A) to lower energies
B) to higher energies
C) the energy is unaffected

Flux and luminosity

- **Luminosity** - A star produces light – the total amount of energy that a star puts out as light each second is called its Luminosity.
- **Flux** - If we have a light detector (eye, camera, telescope) we can measure the light produced by the star – the total amount of energy intercepted by the detector divided by the area of the detector is called the Flux.

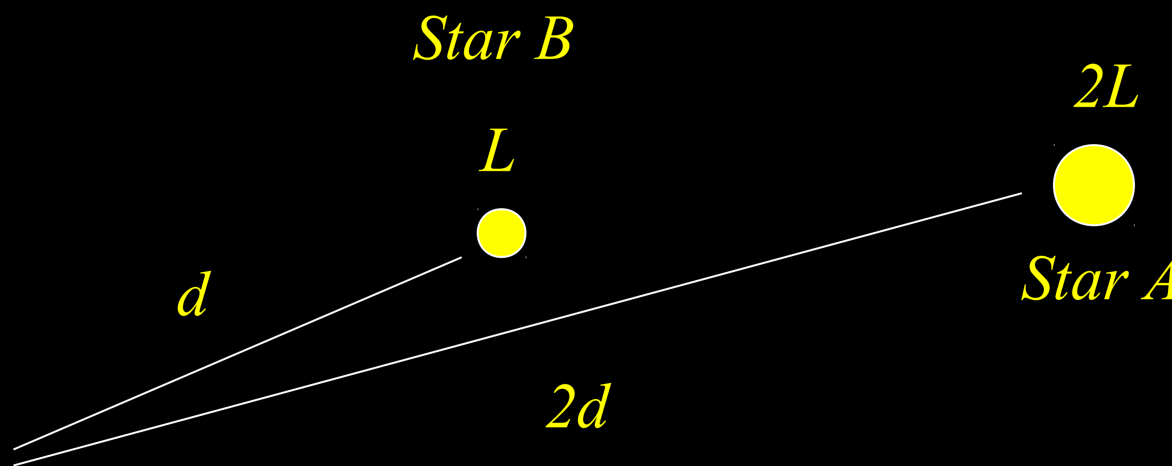

$d = 1$
$d = 2$
$d = 3$

Flux and luminosity

- Flux decreases as we get farther from the star
  – like 1/distance^2
- Mathematically, if we have two stars A and B

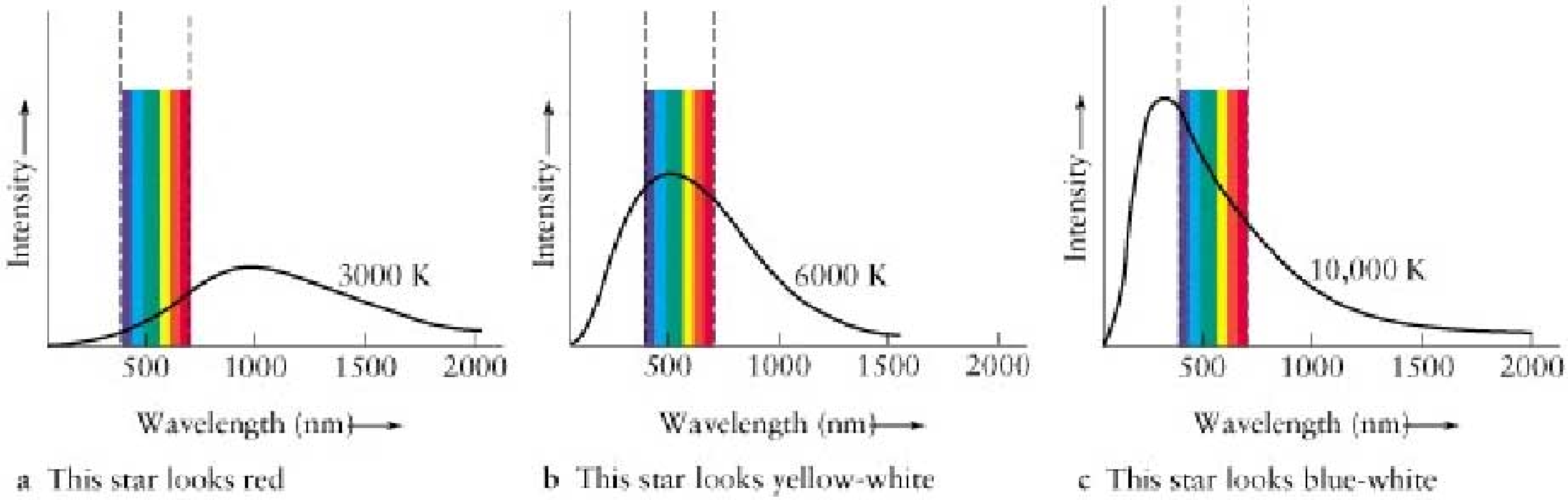
$$\frac{\text{Flux}_A}{\text{Flux}_B} = \frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

Distance-Luminosity relation: What is the flux of star A relative to star B? ($Flux_A/Flux_B$ = ?)



A) ¼
B) ½
C) 1
D) 2
E) 4

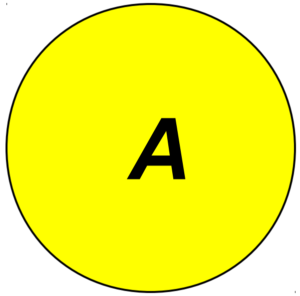
Cool stars are red, hot stars are blue.



Which object is hottest?

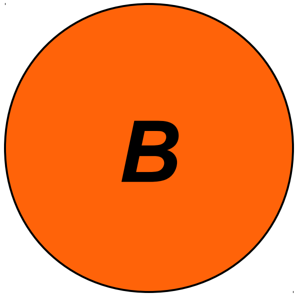
A) spectrum peaks in the blue
B) spectrum peaks in the radio
C) spectrum peaks in the ultraviolet
D) spectrum peaks in the infrared
E) spectrum peaks in the X-ray

Luminosity versus radius and temperature



$R = 0.5R_{\text{Sun}}$

$T = 4T_{\text{Sun}}$



$R = R_{\text{Sun}}$

$T = T_{\text{Sun}}$

How much more luminous is star A?

A) 4x, B) 8x, C) 16x, D) 32x, E) 64x

Angular Size and Parallax

- Angular size and the small angle formula

Small angle formula for *S*, *d* in meters, α in arcseconds:

$S = \alpha d/206265$

On exam, might need to solve for d or α or go find the numbers.

1° = 1 degree = 60 arc-minutes = 60' = 3600 arc-seconds = 3600”

- Parallax, parsecs

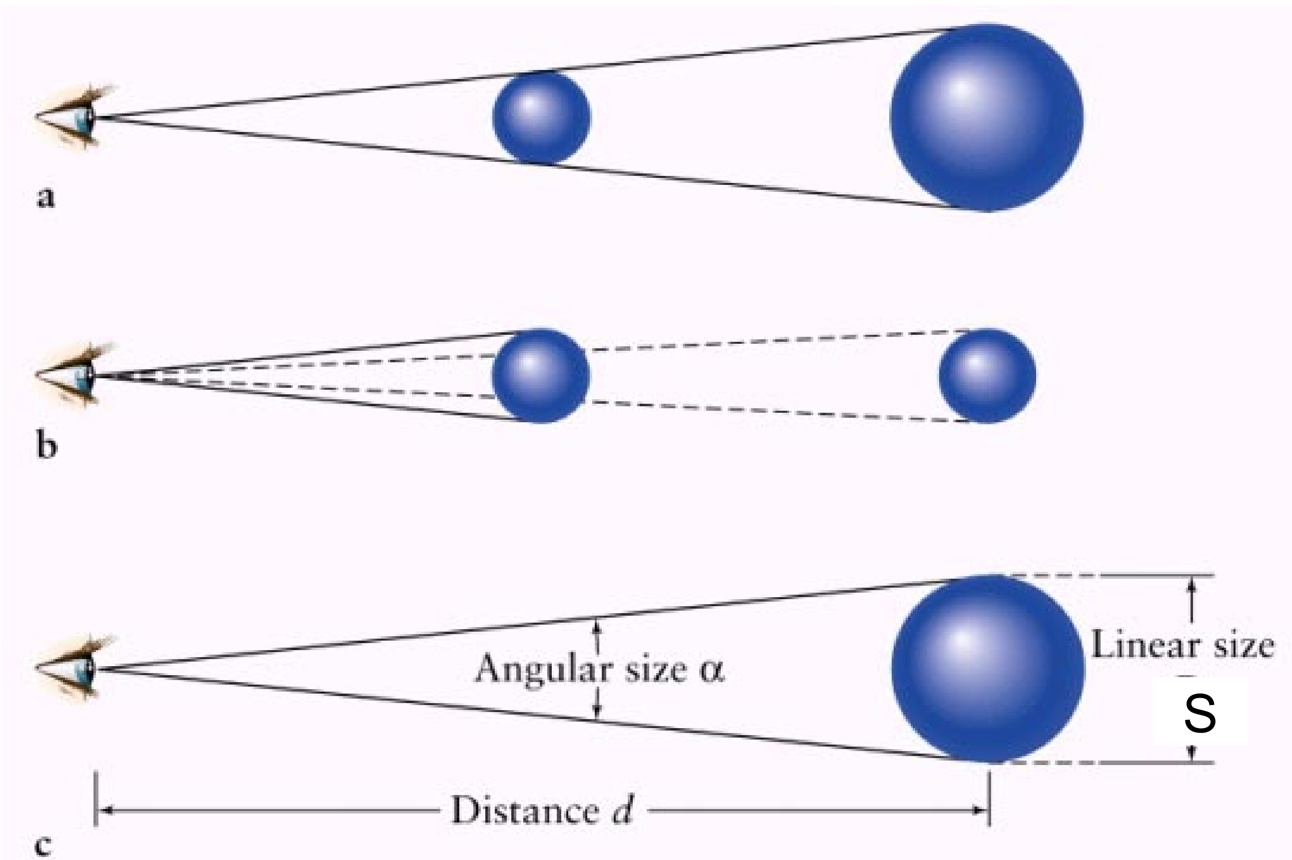
The Small-Angle Formula

$$S = \frac{\alpha \cdot d}{206265}$$

S = linear size of object

α = angular size of object (**in arcseconds**)

d = distance to the object



When an object moves 4 times farther away, its angular size

A) Increases by a factor of 16
B) Increases by a factor of 4
C) Stays the same
D) Decreases by a factor of 4
E) Decreases by a factor of 16

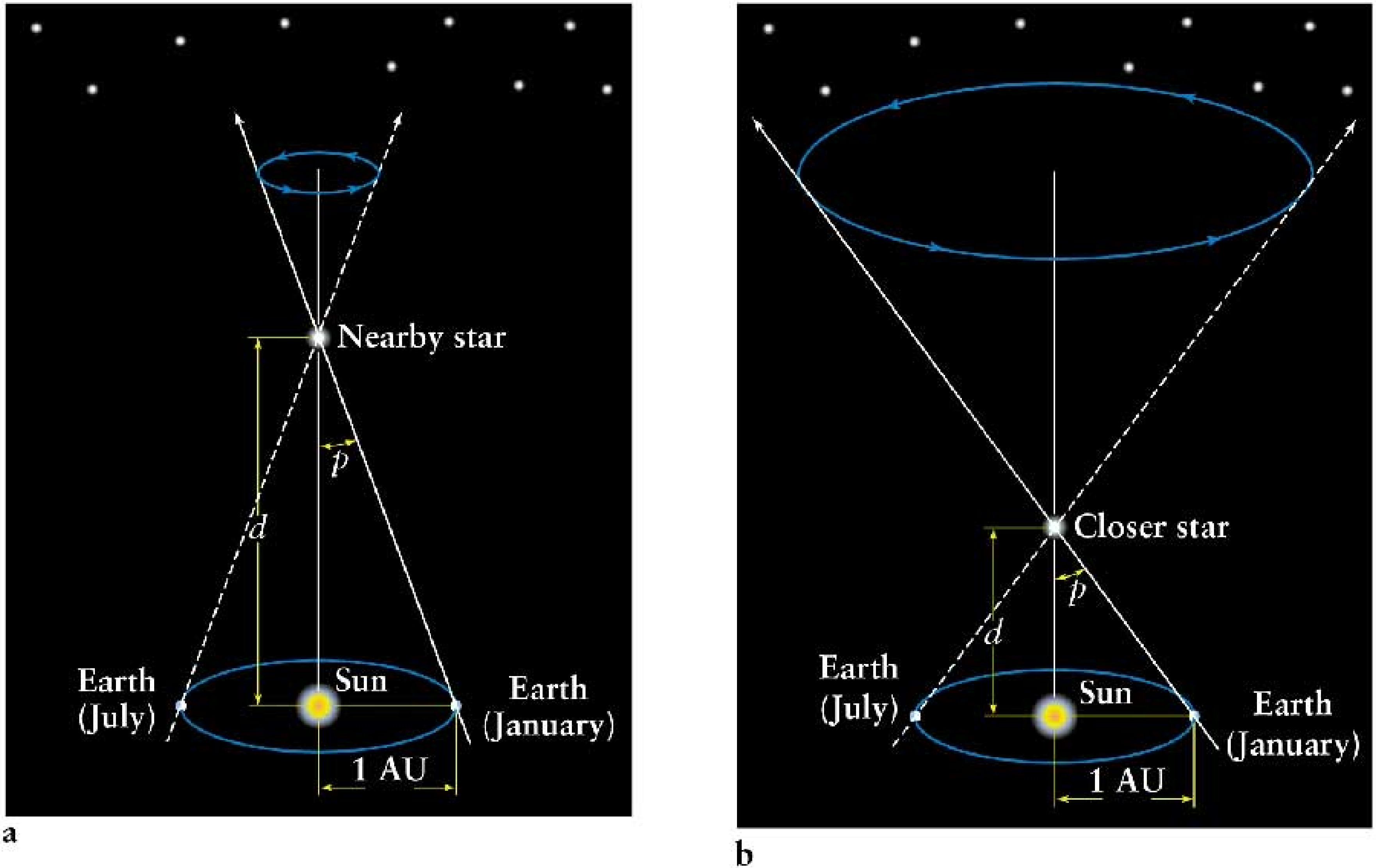
An object is 200,000 m away and has an angular size of 1”. How big is it?

A) Size of a grain of salt (10^{-4} m)

B) Size of finger nail on your pinky (10^{-2} m)

C) Height of a person (1 m)

D) Length of a football field (100 m)



Farther star – smaller parallax   Closer star – larger parallax

d = 1/*p* where *d* = distance to star in parsecs and *p* = parallax angle of star in arcseconds

By what factor would the parallax of a star change if an observer moved from 1 parsec away from the star to 10 parsecs away from the star?

A) Increase by a factor of 100
B) Increase by a factor of 10
C) Stay the same
D) Decrease by a factor of 10
E) Decrease by a factor of 100

By what factor would the observed brightness of a star change if an observer moved from 1 parsec away from the star to 10 parsecs away from the star?

A) Increase by a factor of 100
B) Increase by a factor of 10
C) Stay the same
D) Decrease by a factor of 10
E) Decrease by a factor of 100

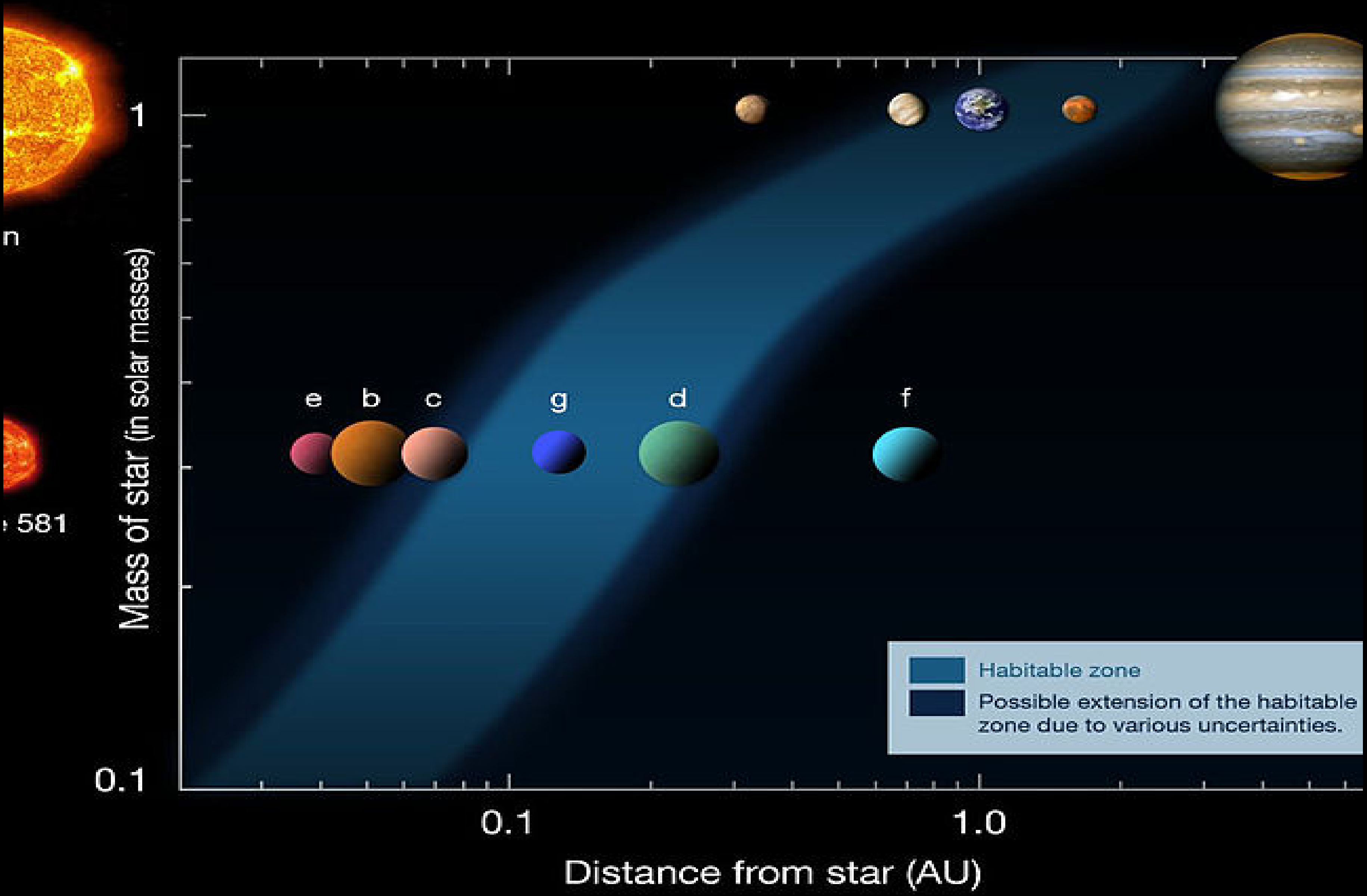
Extrasolar Planets

- Have been imaged directly, but only in a few cases and for young stars.
- Planets include a wobble in the motion of their parent star, this wobble produces a Doppler shift in the light emitted by the star. Most confirmed extrasolar planets have been discovered this way and are gas giants. Earth-mass planets make their star wobble only a tiny bit are hard to find this way.
- Planets can also eclipse the light from their parent star, but only if their orbit lies along our line of sight so that the planet sometimes passes between us and the star.
- NASA's Kepler mission is searching for eclipses due to planets around 100,000 stars. Hopes to find planets around about 1,000 stars including some with close to Earth's mass.

Life on Earth

- Life on Earth is based on complex molecules containing carbon atoms.
- Carbon atoms are important because each can form four chemical bonds, which makes complex molecules possible.
- Experiments have demonstrated that the molecules used in living organisms, amino acids, can be formed from chemicals that likely were present in the young Earth's atmosphere.
- Life on Earth appears to require water because liquid water allows other molecules to dissolve, move around, and interact with each other.
- The temperature of planet is controlled mainly by its distance from its star and the luminosity of the star. The range of orbits leading to temperatures with liquid water is the 'habitable zone'.

Habitable Zone



Carbon is a good building block for life because

A) It forms four strong bonds with other atoms.

B) It is abundant in the universe.

C) Carbon-based molecules can combine to form long complex chains.

D) All of the above

The Sun

- The Sun is powered by nuclear burning in which four protons combine into one helium nucleus, also some neutrinos and some photons are emitted.
- The mass of the helium nucleus is less than the mass of the four protons.
- The extra mass is converted into energy via $E = mc^2$.
- This happens in the core of the Sun where the temperature and density are very high.
- Neutrinos have been detected from the Sun and provide proof of nuclear burning.

The Sun

- The gas in the Sun is in “hydrostatic equilibrium” in which the inward pull of gravity is balanced by the outward push of gas pressure due to thermal motion of the gas atoms.
- Energy released in the core is transported as radiation through the inner layers. This takes about 200,000 years.
- Energy is the outer layers is moved by convection, like the motion of water in a boiling pot.
- The surface of the Sun has a temperature of about 6,000 K.
- The surface of the Sun is mottled with convective cells.
- Sunspots are regions of high magnetic field on the Sun's surface. They are cooler than the rest of the surface because the magnetic field inhibits convection.
- Sunspots can be used to measure the Sun's rotation, which is once every 25 days at the equator and slower at the poles.

The Sun

- The layers of the Sun's atmosphere are the chromosphere and the corona.
- Solar flares, solar prominences, and coronal mass ejections are eruptions of charged particles from the solar surface.
- These particles can reach the Earth where they cause the aurorae and can affect satellites.