Announcements

First midterm is this Wednesday, Oct 1st, in class

- Will cover Lectures 1-8 + beginning of 9,
  Textbook through Chapter 2
- Problems will be similar to those on quizzes
- 45 problems
- Problems on material through Chapter 2 – includes parts of quiz 4
- **No book, notes or calculator**
- Sheet of formulas will be given
- Calculations will be doable without a calculator
- **Bring a #2 pencil (and an extra!)**

The following information will be provided:

You may find the following information helpful:

- 1 AU $= 3 \times 10^8$ km
- speed of light $c = 3 \times 10^5$ km/s
- Kepler's 3rd law:

  $$a^3 = P^2$$

  with the period P in years and semi-major axis a in AU.
- Newton's law of gravity:

  $$F = \frac{GMm}{r^2}$$
- Peak wavelength and temperature of blackbody radiation:

  $$\lambda = \frac{3 \times 10^6}{T} \text{ nm}$$

  with wavelength λ in nm (1 nm = 10^{-9} m) and temperature T in Kelvin.
- Relationship between frequency f and wavelength λ of light:

  $$\lambda = \frac{c}{f}$$

Astronomy 103

Review for Midterm 1

Outline

- Scientific notation and powers of ten
- Units, scale of the Universe
- The celestial sphere
  - Motions of the stars
  - The seasons
  - Precession
  - The phases of the Moon
- Eclipses: lunar and solar
- The scientific method

Outline II

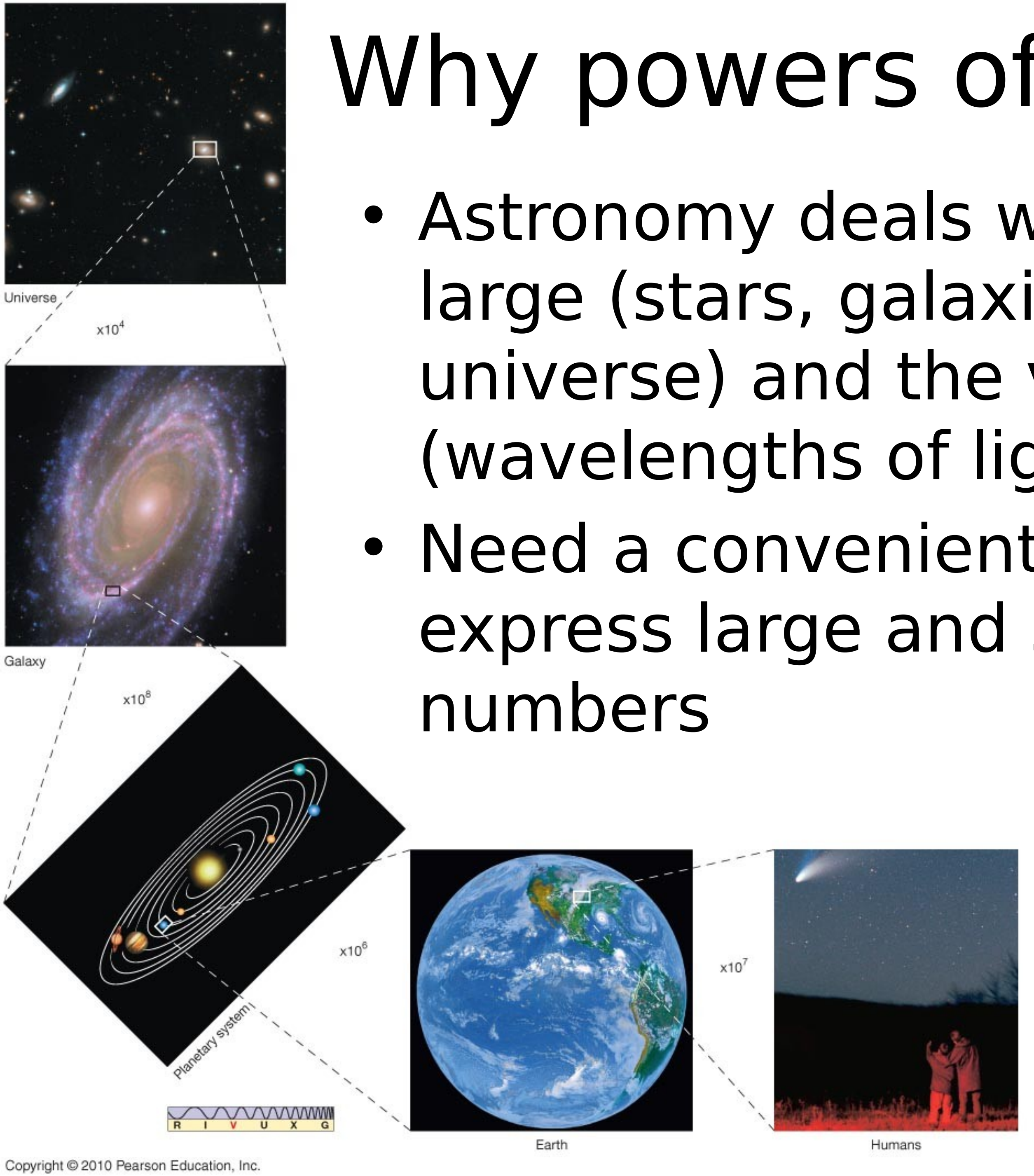
- Ancient astronomy and the motion of the planets
  - Retrograde motion of the planets
  - Ptolemaic model of the solar system
- Copernicus, Copernican model of solar system
- Tycho Brahe
- Kepler: Kepler’s three laws of Motion
- Galileo: observations and experiments
- Newton
  - Three laws of motion
  - Circular motion
  - Law of gravity

Outline III

- Light and electromagnetic waves
  - Frequency and wavelength
  - The electromagnetic spectrum
  - Temperature
  - Thermal or blackbody radiation
    - Relation between wavelength and temperature
- Atoms: electrons and energy levels
  - Absorption and emission lines
- Doppler shift

Why powers of 10?

- Astronomy deals with the very large (stars, galaxies, the universe) and the very small (wavelengths of light)
- Need a convenient way to express large and small numbers



Powers of 10

$10^1 = 10$

$10^2 = 10 \times 10 = 100$

$10^3 = 10 \times 10 \times 10 = 1000$

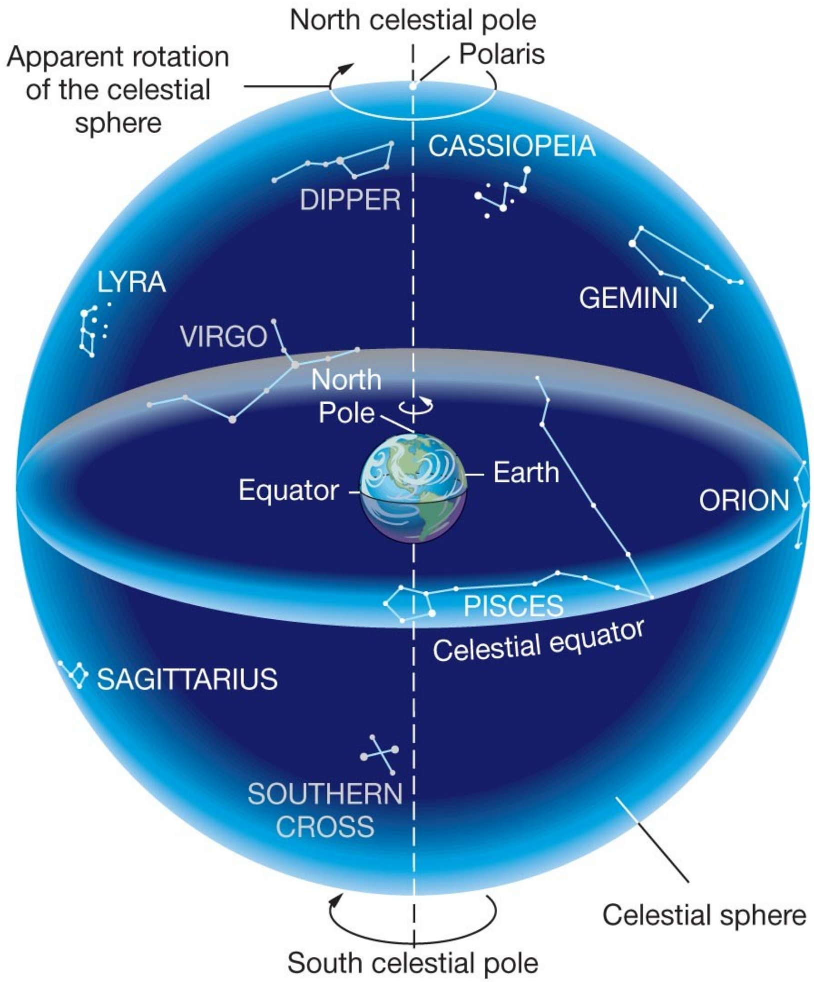
…

$10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1000000$

GEOGRAPHY OF THE UNIVERSE

	km	ly		
	10^{-2}		10m = 1/100 km FRONT OF LECTURE HALL	
x100	1		UWM CAMPUS	
x100	10^{2}		SOUTHEAST WISCONSIN	
x100	10^{4}		DIAMETER OF EARTH	($1.3\text{x}10^{4}$km)
x100	10^{6}		DIAMETER OF MOON'S ORBIT	($.8 \text{ x}10^{6}$km)
x100	10^{8}		DISTANCE FROM SUN TO EARTH	($1.5\text{x}10^{8}$km)
x100	10^{10}		DIAMETER OF SOLAR SYSTEM	($1.2\text{x}10^{10}$km)
	(10^{12})			
x1000	10^{13}km =	1 ly	DISTANCE TO PROXIMA CENTAURI	(4 ly)
x100		10^{2} ly	DISTANCE TO TYPICAL CLUSTER OF STARS	
x100		10^{4} ly	DISTANCE TO CENTER OF MILKY WAY	($3\text{x}10^{4}$ly)
x100		10^{6} ly	DISTANCE TO NEARBY GALAXIES	
x100		10^{8} ly	DISTANCE TO LARGE CLUSTERS OF GALAXIES	
x100		10^{10} ly	SIZE OF VISIBLE UNIVERSE	

The celestial sphere



- The sky has the appearance of a sphere, and at night it looks like the sphere rotates, with all of the stars moving as if the sphere were rotating. The name given to this imaginary sphere is the **celestial sphere**
- The celestial sphere appears to rotate once a day from east to west (counterclockwise looking up at the north celestial pole). **This is because the Earth really rotates once a day from west to east: counterclockwise, looking down at the north pole.**

The ***North Celestial Pole*** and ***South Celestial Pole*** are the points on the celestial sphere directly over the Earth's North and South poles.

From northern hemisphere, stars, Sun, Moon and planets appear to move from east to west in a circle around North Celestial Pole: Polaris, the North Star

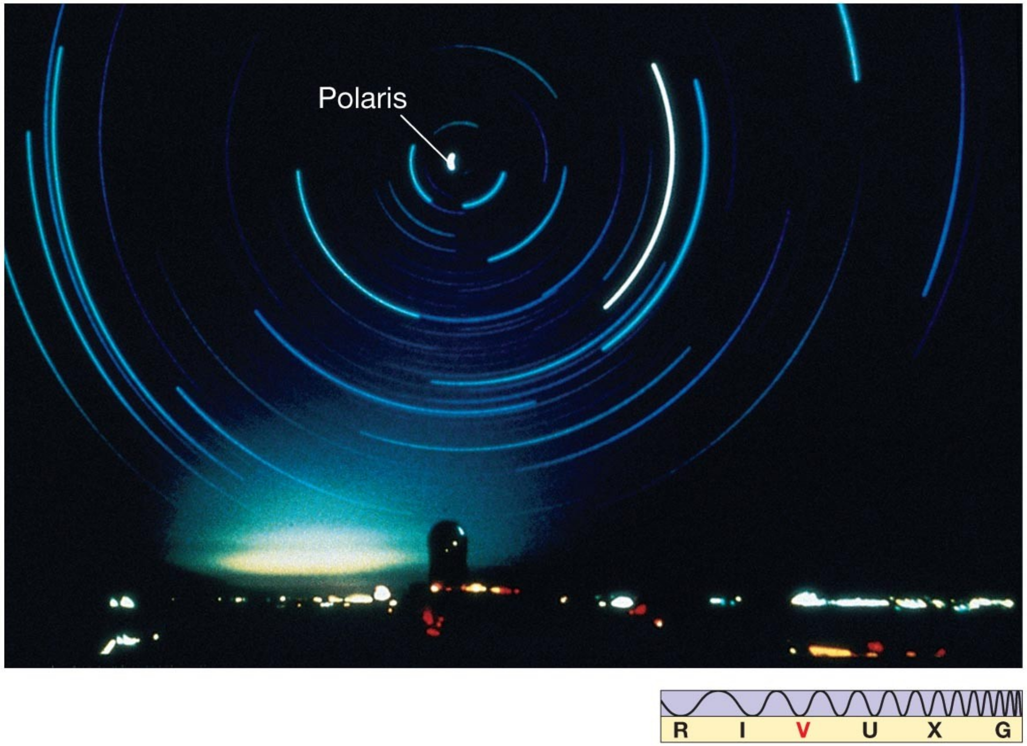
In a day, celestial sphere appears to rotate once
→ rotates 360° in 24 hours, so each hour rotates 360° / 24 = 15°
→ stars appear to move 15° per hour east to west

What you see at night depends on where you are standing

You can see only half the sky: The Earth blocks light from stars that are below the horizon. As the Earth rotates, stars rise along the east half of the horizon, move in circles centered about the NCP, and set along the west half of the horizon.

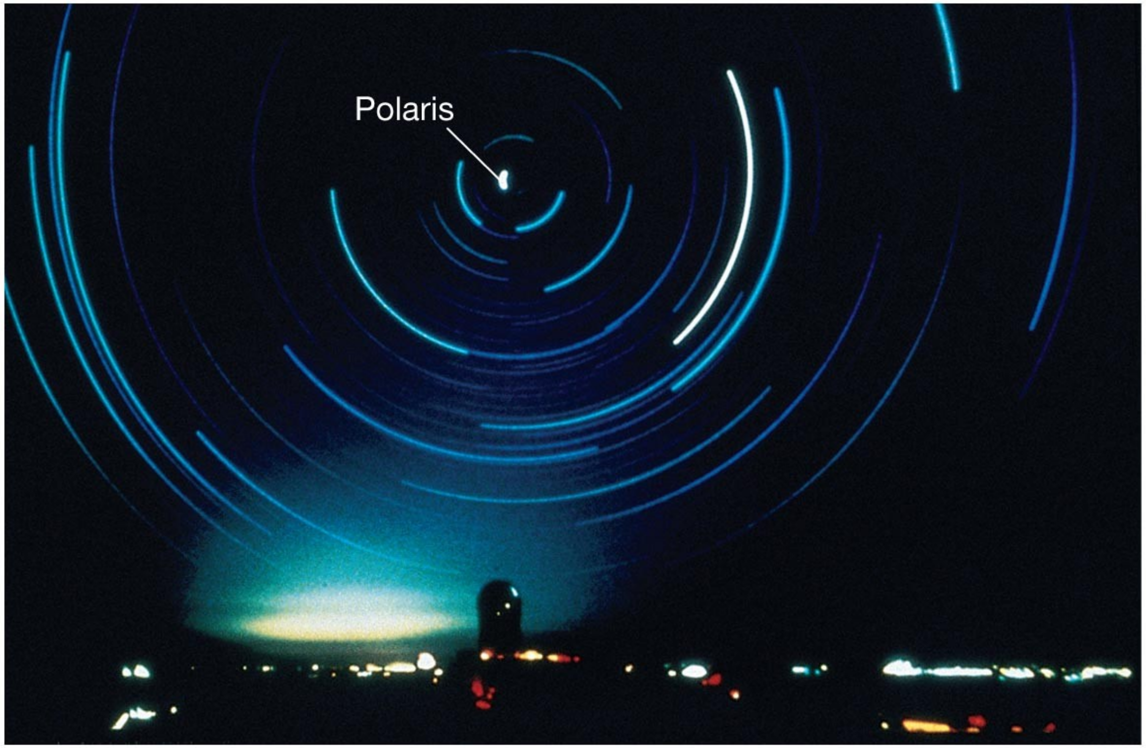
The star *Polaris* (North Star) is close to the NCP. Stars appear to move in circles about Polaris.

Some stars close enough to Polaris on the celestial sphere never rise or set and are called **circumpolar**



Seafaring Polynesians, Babylonians, and Libyans knew from sailing that as you move north, the NCP appears higher in the sky. (The Greeks finally understood the reason —that the Earth is round).

- As seen from the equator, Polaris is at the horizon. If you travel 1° north from the equator, Polaris will be 1° above your horizon.
- By the time you reach the North Pole, 90° N, Polaris is directly overhead, 90° above the horizon. In general:
- The altitude of Polaris = your latitude
- Because Milwaukee is 43 degrees north of the equator, Polaris is 43 degrees above our horizon. From south of equator, Polaris is below the horizon, never visible.
- There is no southern pole star

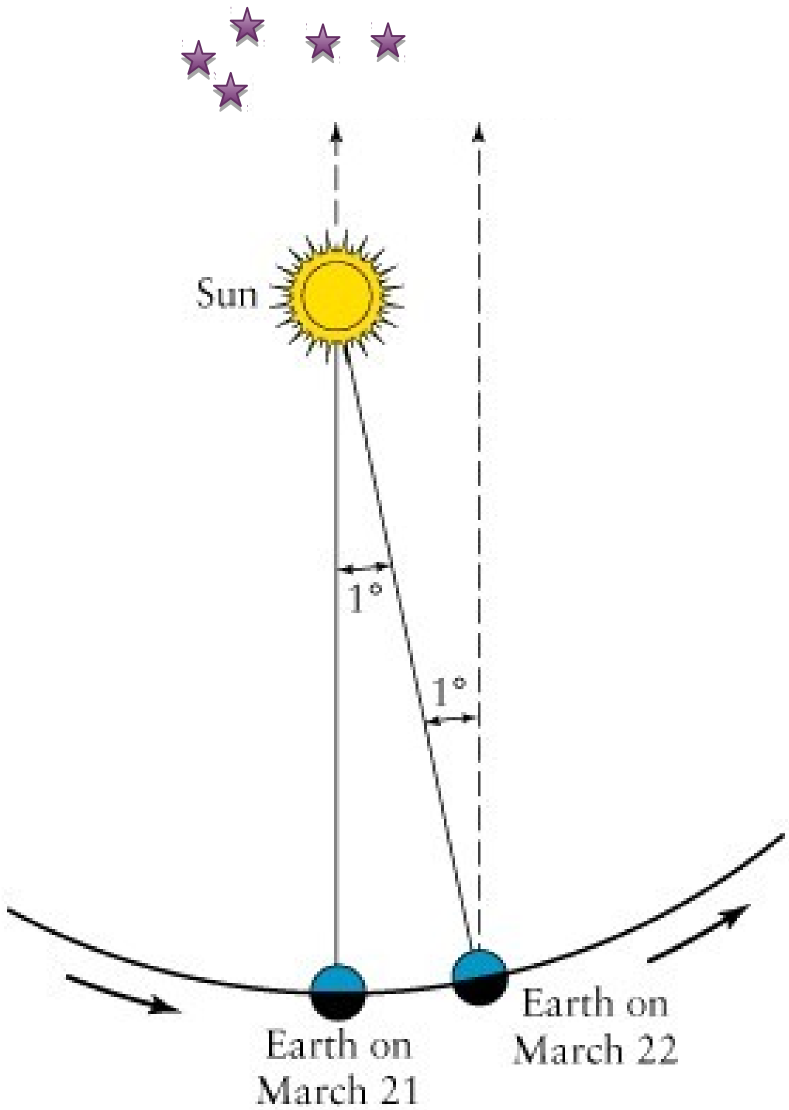


Celestial navigation: Altitude of Polaris = latitude!

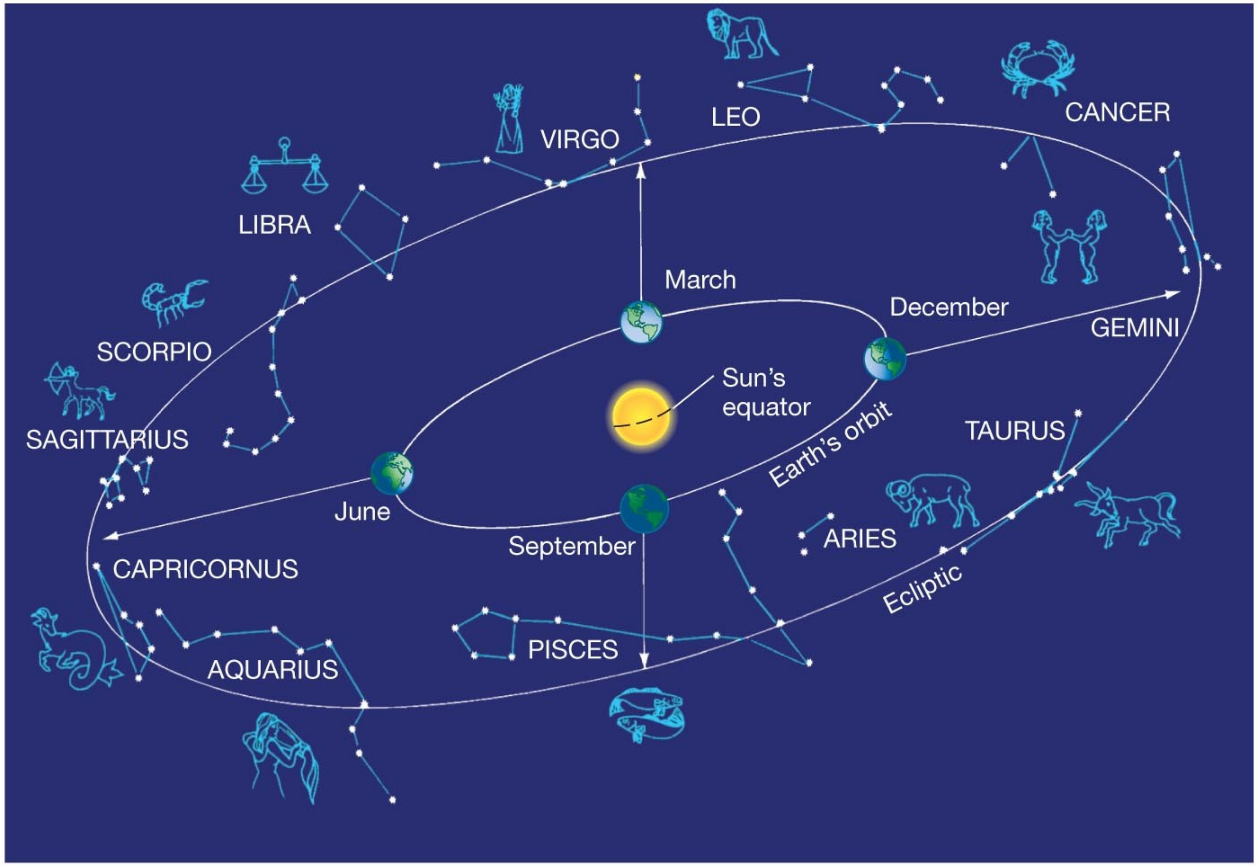
Earth's Orbital Motion: Seasonal Changes

In a year the Earth moves 360 degrees about the Sun, so each day it moves about 1°.

The Sun appears to move against the background stars. As the Earth moves 1° from west to east, the Sun appears to move 1° from east to west.



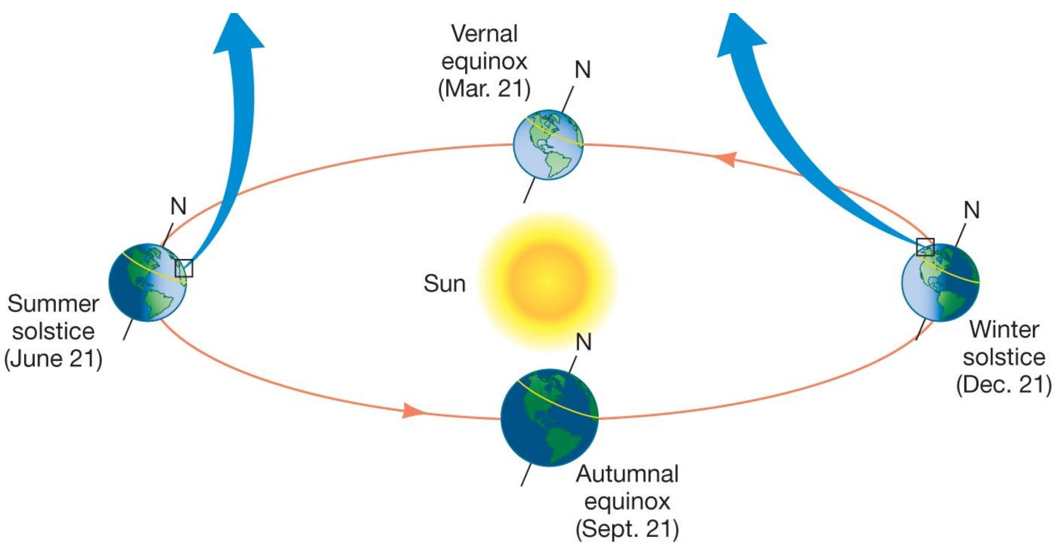
The stars that the sun appears to move over are the constellations of the **Zodiac** – If we could see the stars in the day when the Sun is out (and we can in fact see them during a total eclipse of the Sun) we would see the Sun move through these constellations during the course of the year.



The path the Sun sweeps out against the background of stars is called the ***ecliptic***.

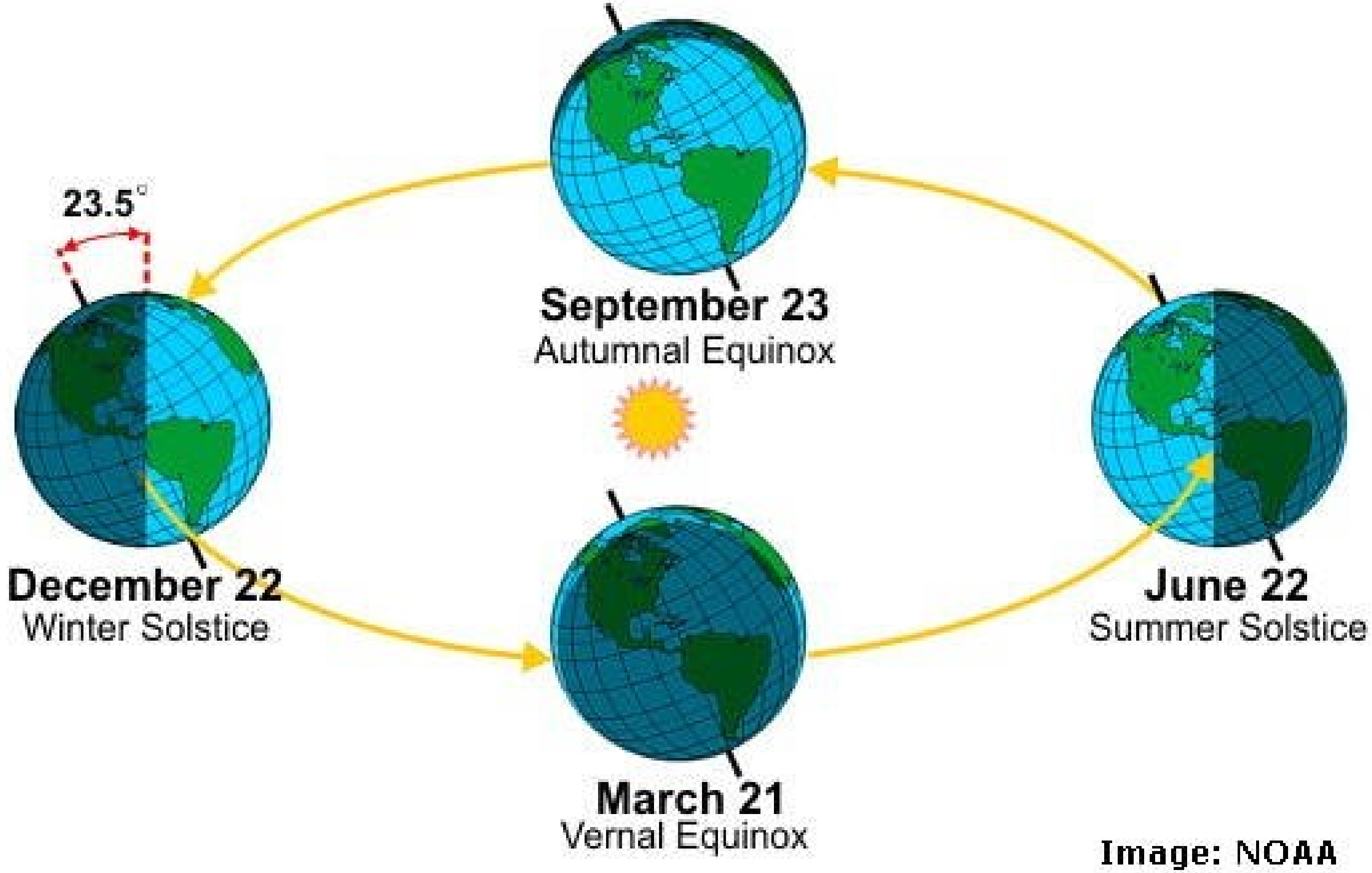
The seasons and the tilt of the Earth

The Earth’s axis of rotation is not perpendicular to the plane of the Earth’s orbit about the Sun:
The Earth's rotation axis is tilted by 23.5 degrees away from perpendicular to its orbit— the plane of the equator is 23.5 degrees from the plane of the orbit.



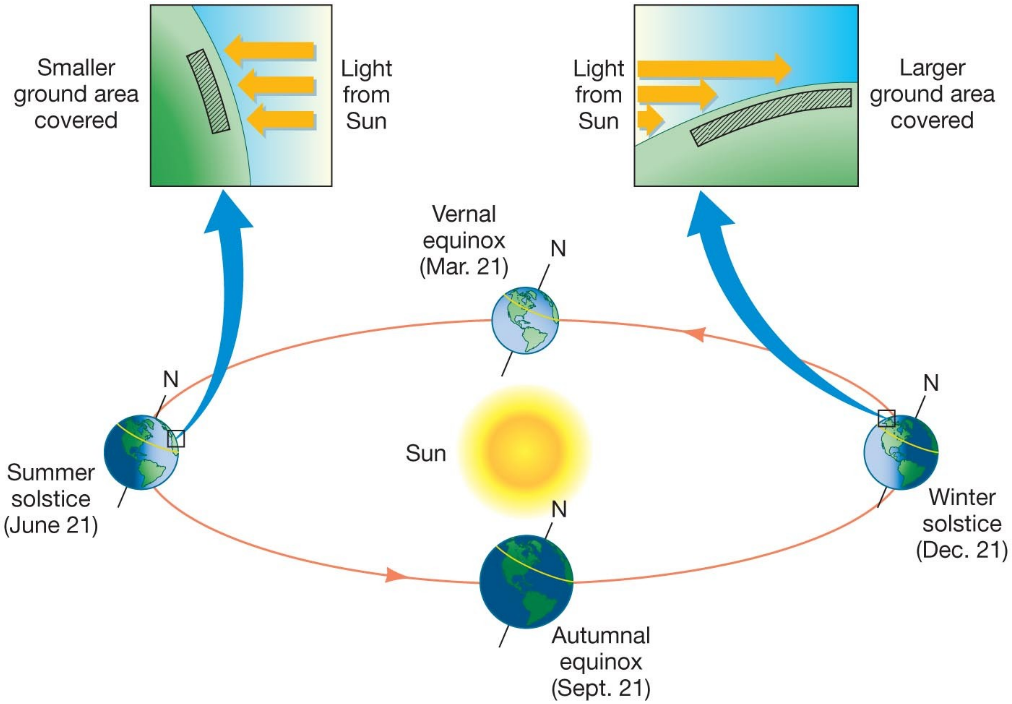
On the summer solstice, when the axis is most directly tilted toward the Sun, the Sun is directly over a point 23.5 degrees north of the equator. On the winter solstice, with the north part of the axis tilted away from the Sun, the Sun is over a point 23.5 degrees south of the equator.

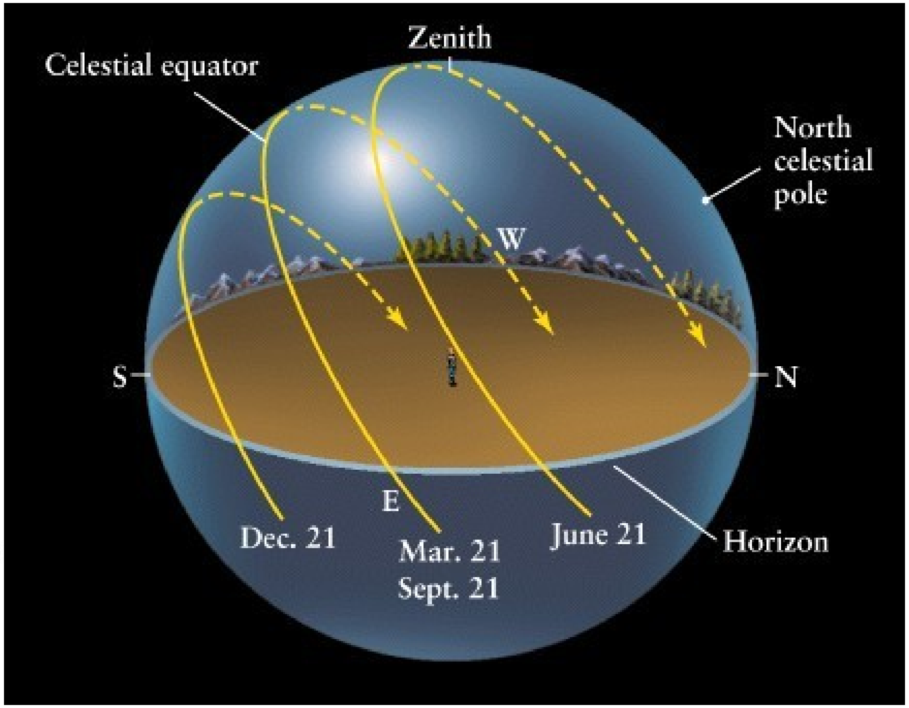
The Sun is directly over the equator on the **Vernal Equinox** (spring) and the **Autumnal Equinox** (fall). These are the two points where the ecliptic intersects the celestial equator.



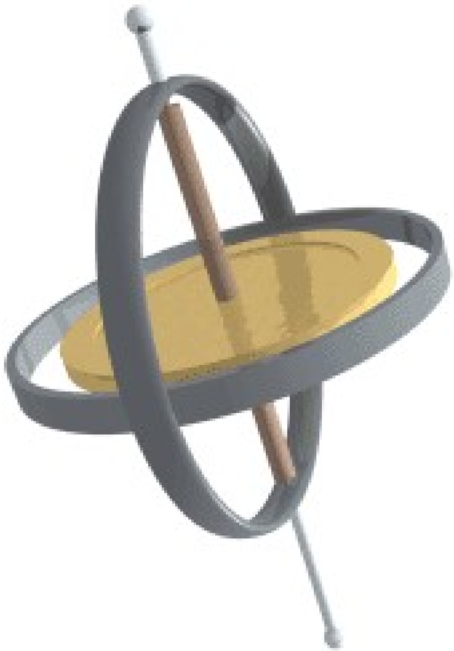
The seasons are caused by the tilt of the Earth's axis. The tilt has two effects:

1. Sunlight is more direct in the summer. In our summer, the northern hemisphere is tilted toward the Sun, in winter it is tilted away from the Sun.
2. The Sun is up longer in summer than in winter.



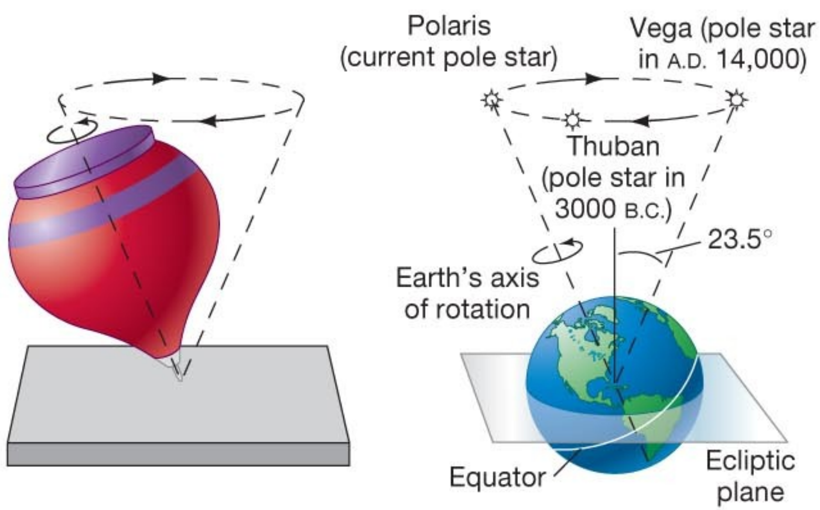


Precession

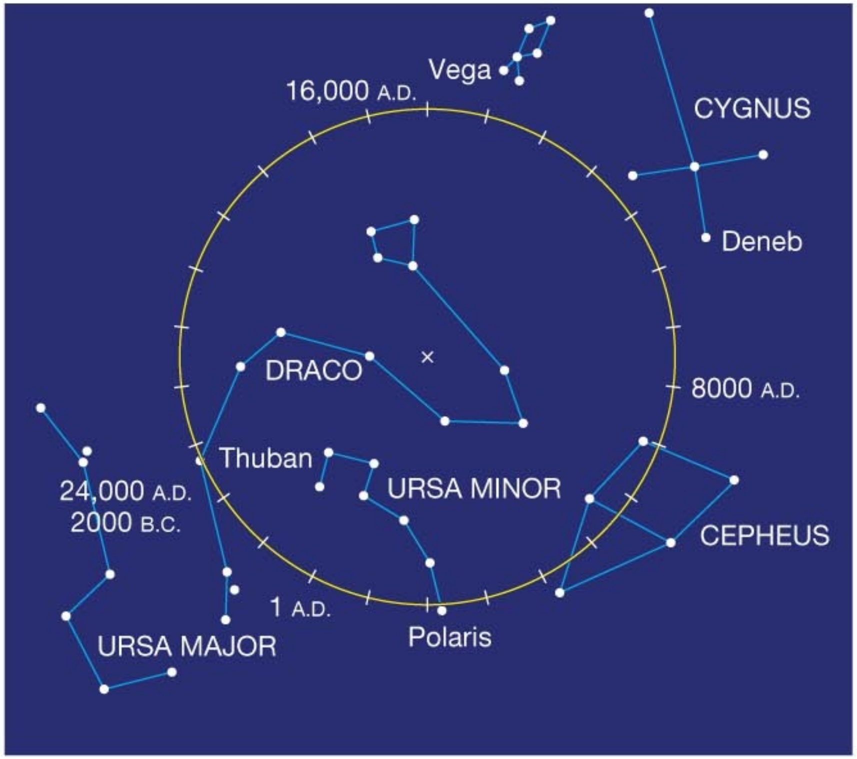


- Precession: **change in the orientation of the rotational axis** of a rotating body
- Direction of axis of Earth’s rotation changes on 26,000 year cycle: **precession of the equinoxes**

Earth's axis of rotation precesses with a 26,000 year period: In 13,000 years, what are now winter stars will be summer stars, and vice-versa. In 13,000 years, Vega, not Polaris will serve as our north star. In 26,000 years, the Earth's axis will again point in the direction it now points, and Polaris will again be the North Star.



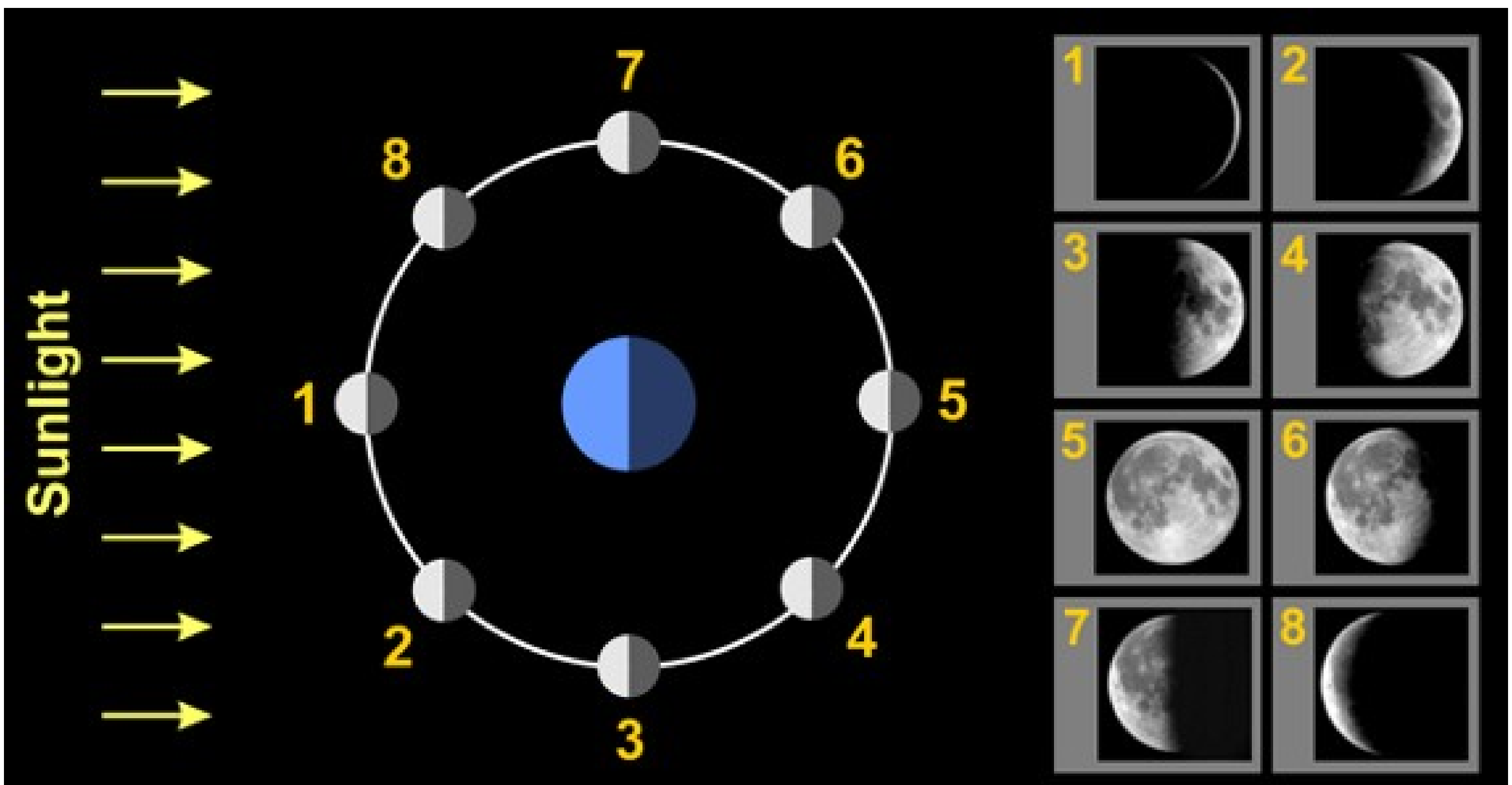
(a)



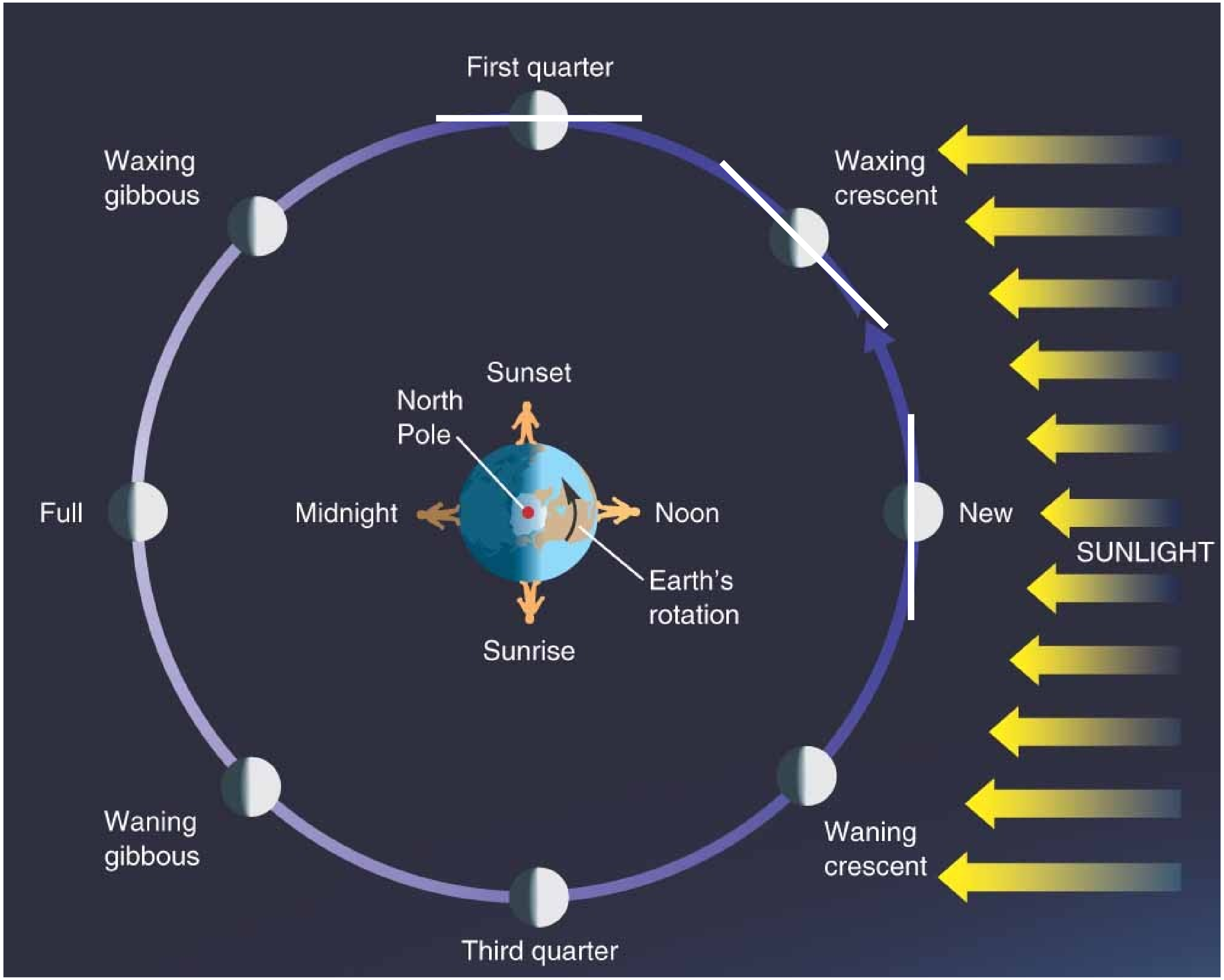
(b)

Phases of the Moon

- Why does the Moon shine? Reflected sunlight
  - The side of the Moon facing the Sun is lighted
  - The side facing away from the Sun is dark
- Moon orbits Earth in 1 month (29 days)

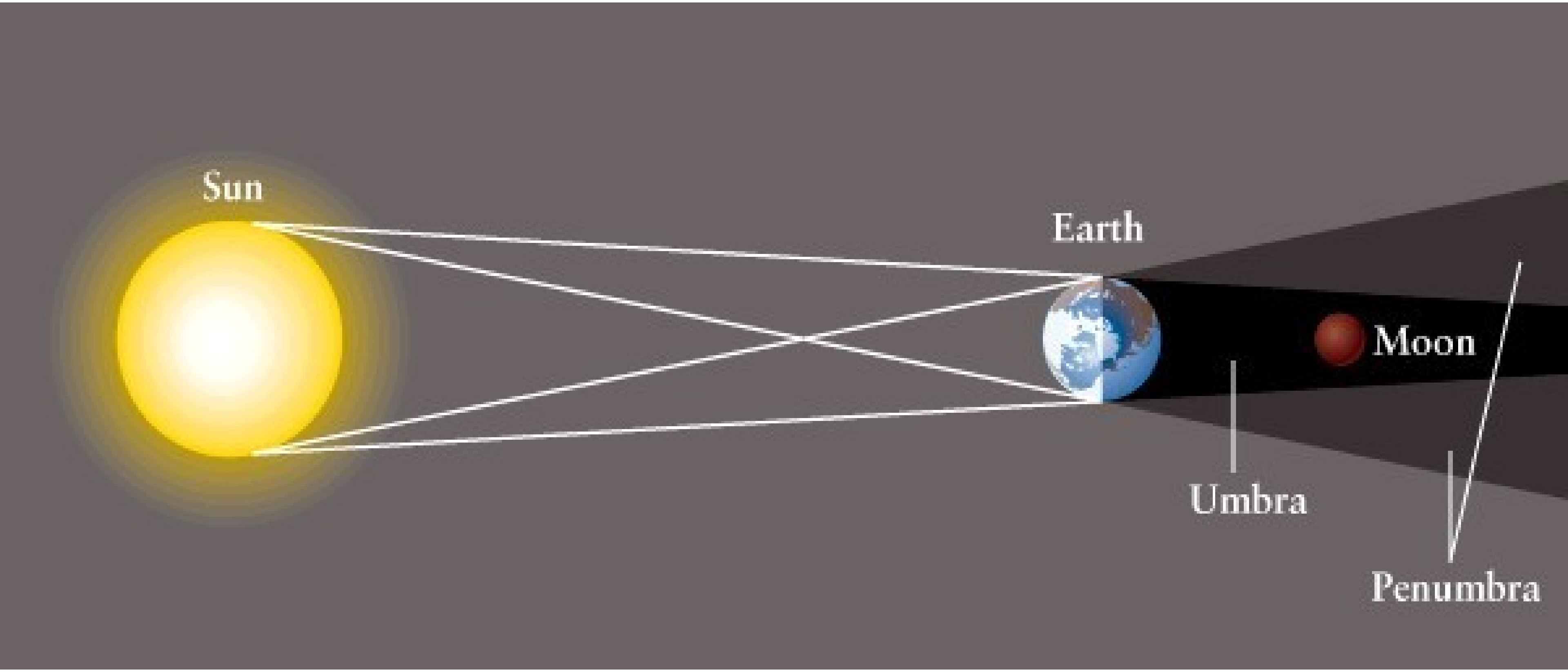


Phases of the Moon – as seen from Earth



Here's the picture again, with lines drawn to show which part of the Moon faces the Earth.

Total eclipse of the Moon: Shadow of the Earth covers the Moon

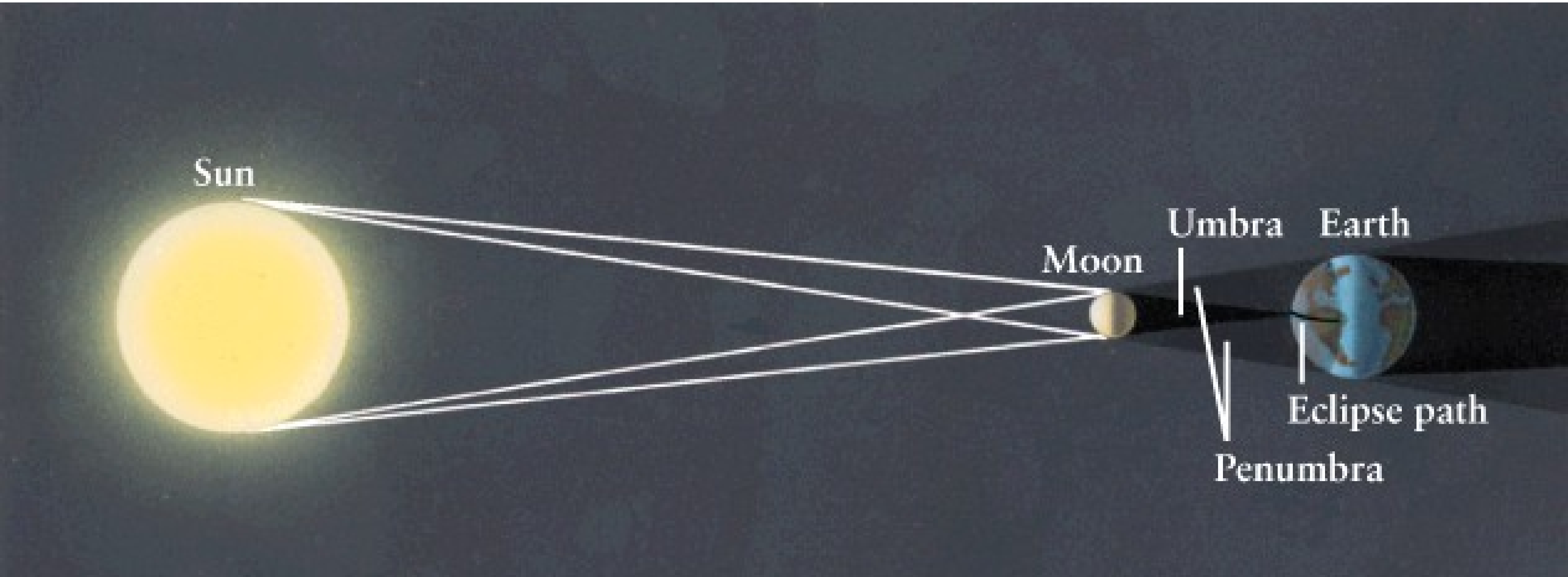


Visible simultaneously from everywhere on night side of Earth

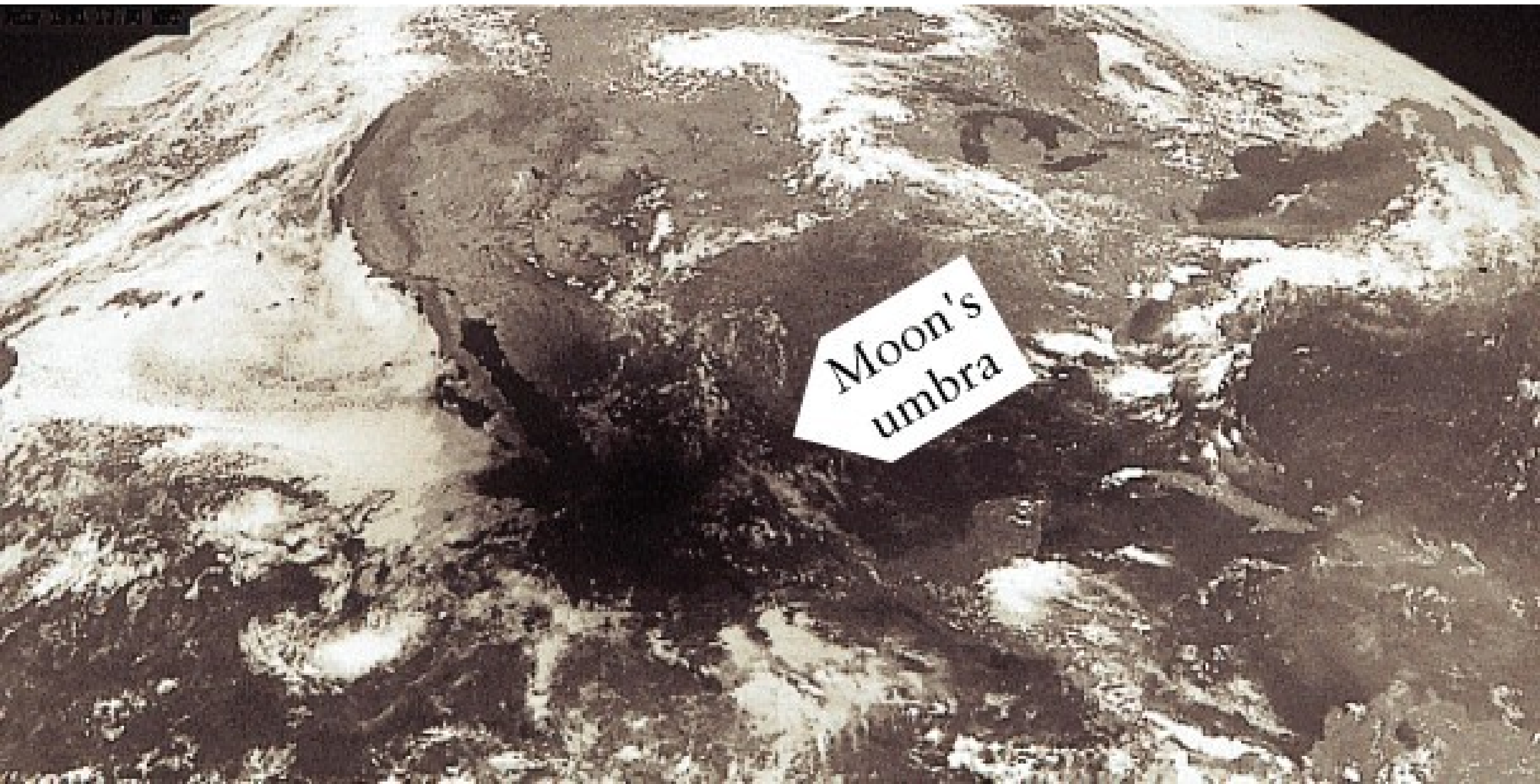
Eclipse of the Sun

Total: umbra of Sun's shadow falls on the Earth (Moon blocks all of Sun)

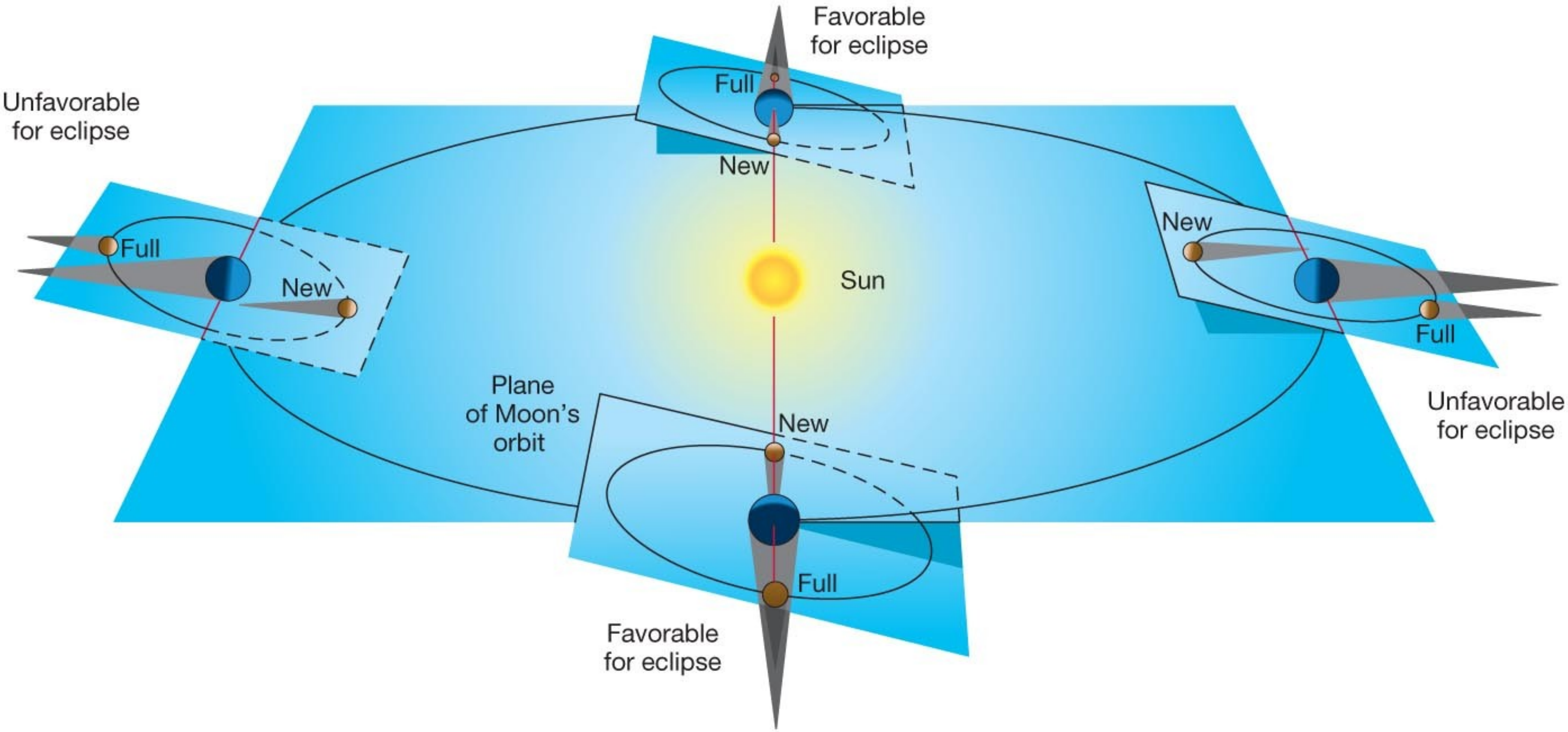
Partial: penumbra of Sun's shadow falls on Earth (Moon blocks part of Sun)



You can see an eclipse of the Sun only if you are on the path of the Moon's shadow.



About once every 6 months, the line from Sun to Earth lies in the plane of the Moon's orbit. Eclipses of Moon and Sun occur at these eclipse seasons



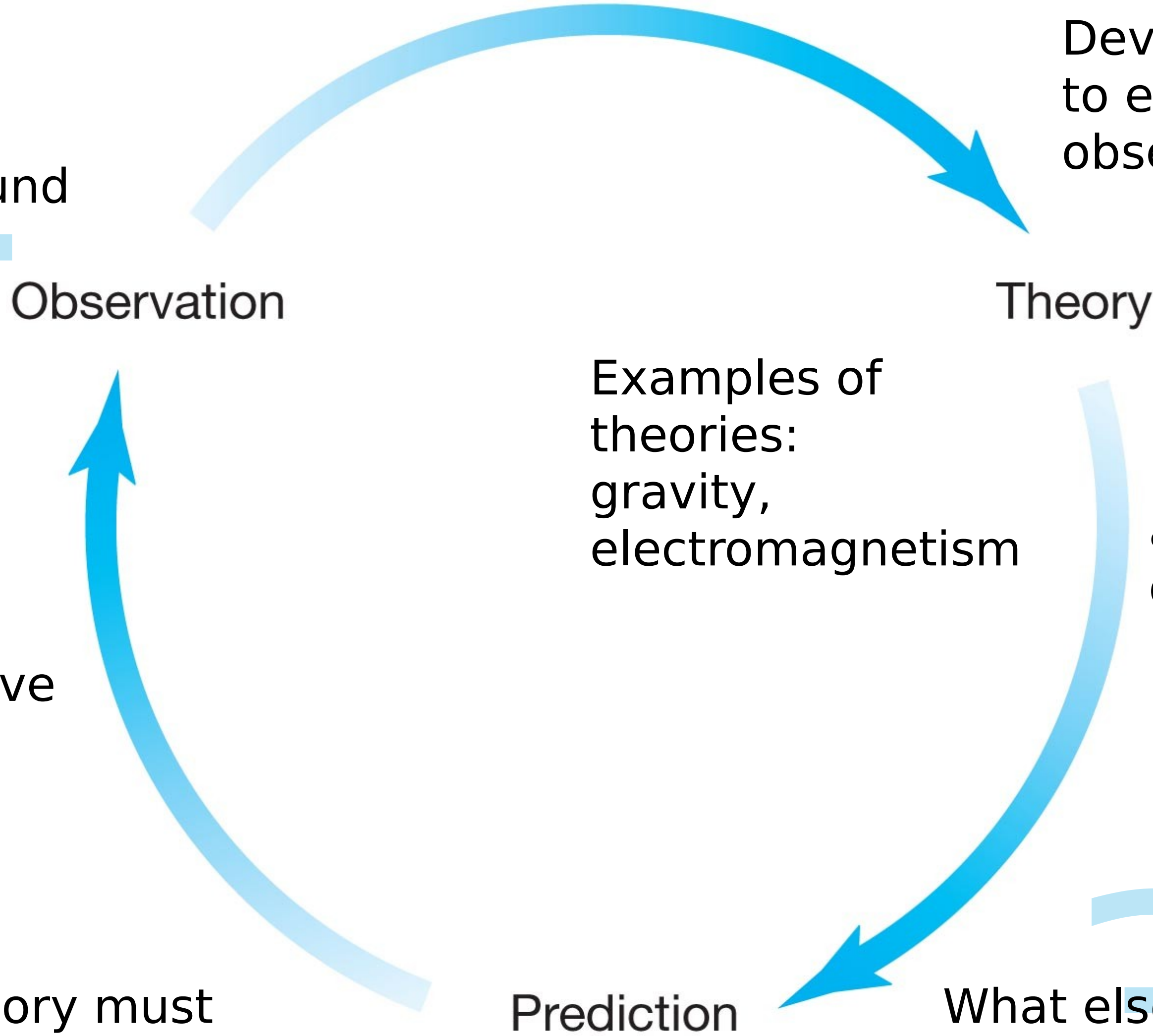
The scientific method

1

Study the world around us

2

Develop a theory to explain our observations



Examples of theories: gravity, electromagnetism

5

Revise theory to account for new observations

4

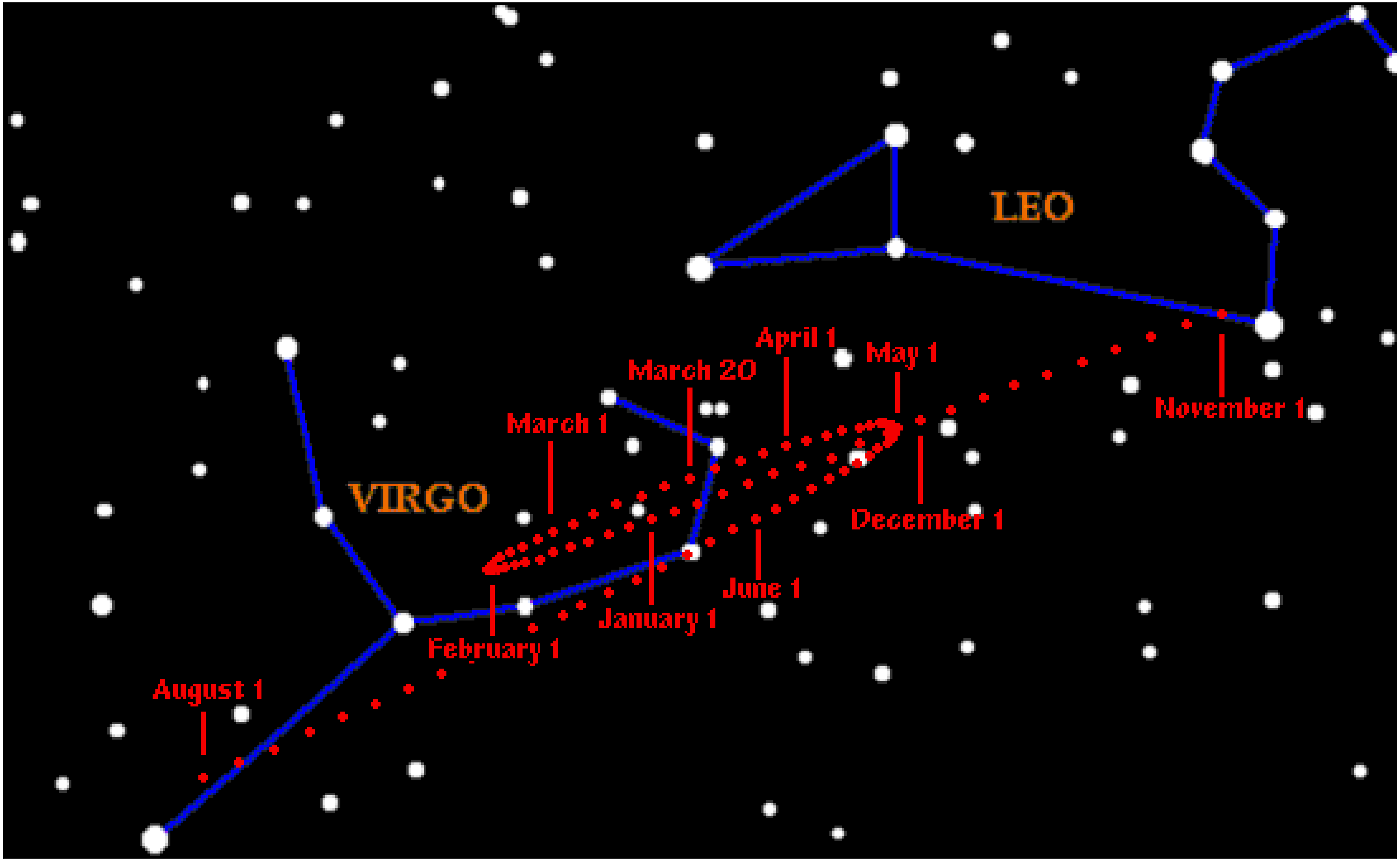
Do we observe what we predicted?

3

What else does the theory predict we should observe?

A theory must make testable predictions!

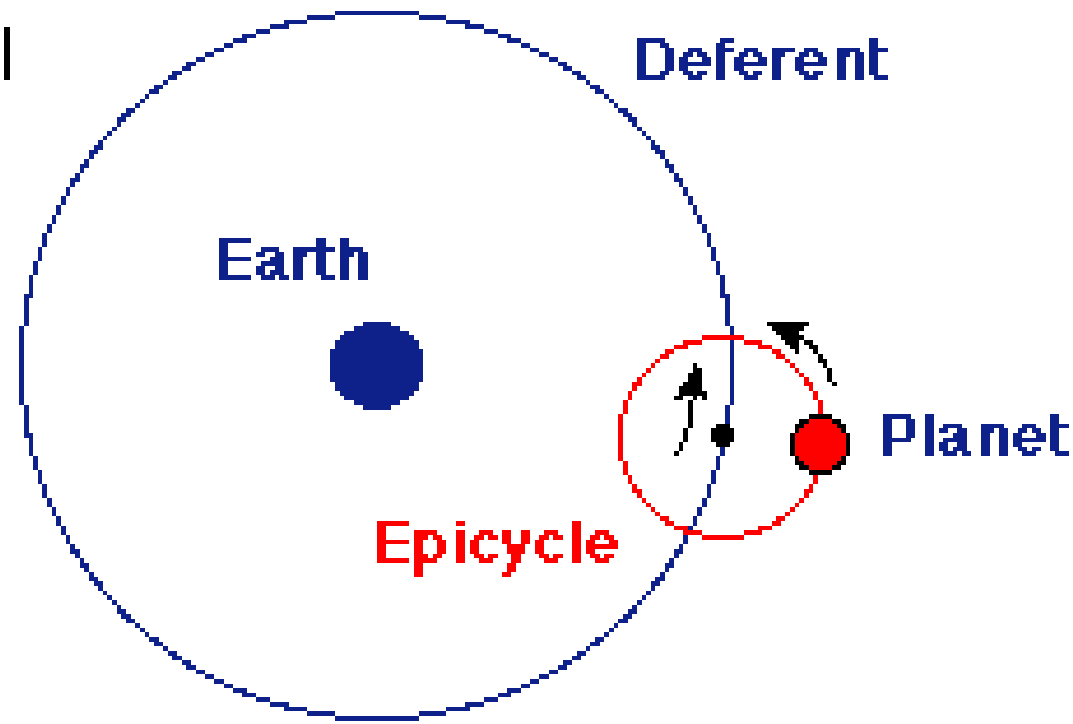
Apparent motion of the planets across the sky



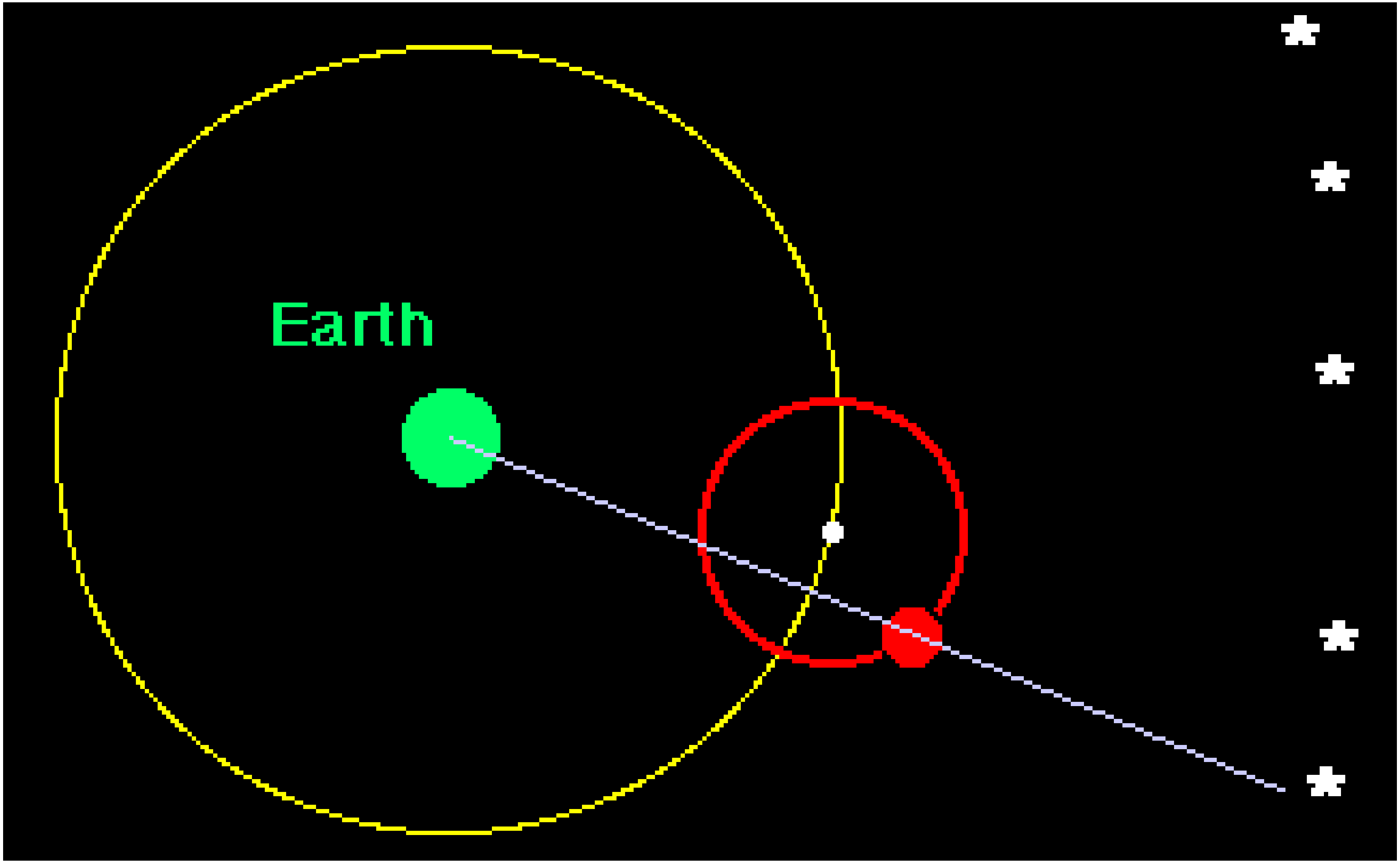
The backward motion is called *retrograde motion.*

Ancient astronomy: Ptolemaic model of the solar system

Each planet moves on a small circle (called an epicycle) while the center of the epicycle moves around the Earth in a larger circle known as the deferent. This produces overall west-to-east motion of each planet, while the looping motion is reproduced in the model by the motion of each planet along its epicycle – the planet moves backwards when it is at the part of the epicycle closest to the earth.

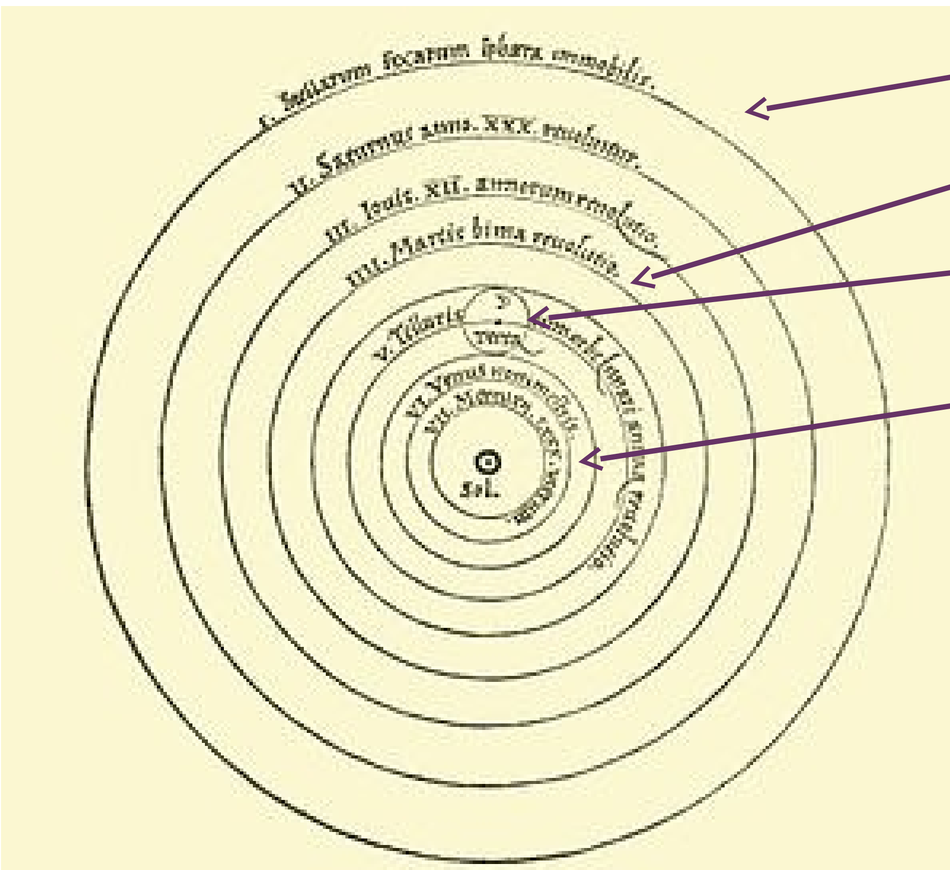


How do you get retrograde motion in the Ptolemaic model?



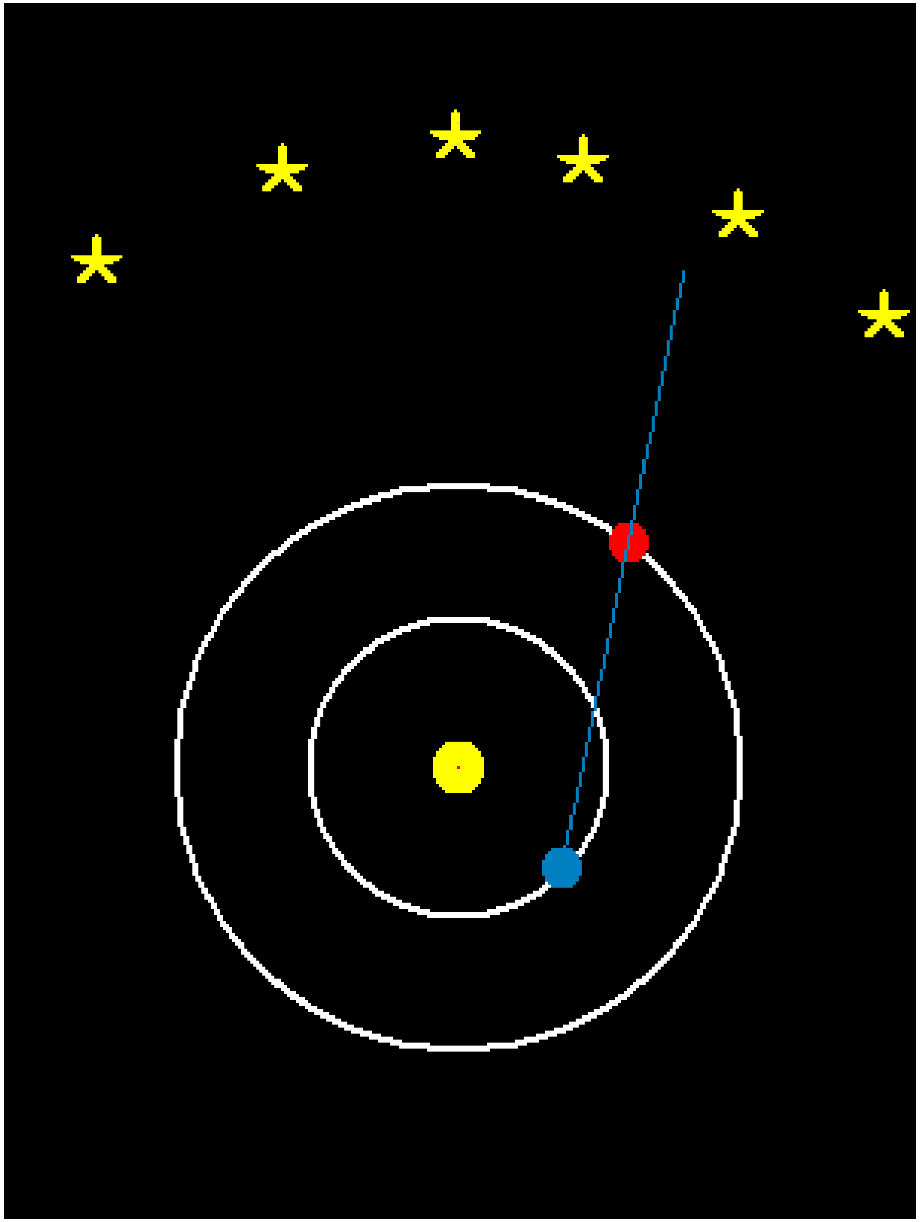
The Copernican model of the solar system

- Circular orbits
- Sun at center
- Planets closer to the Sun move faster



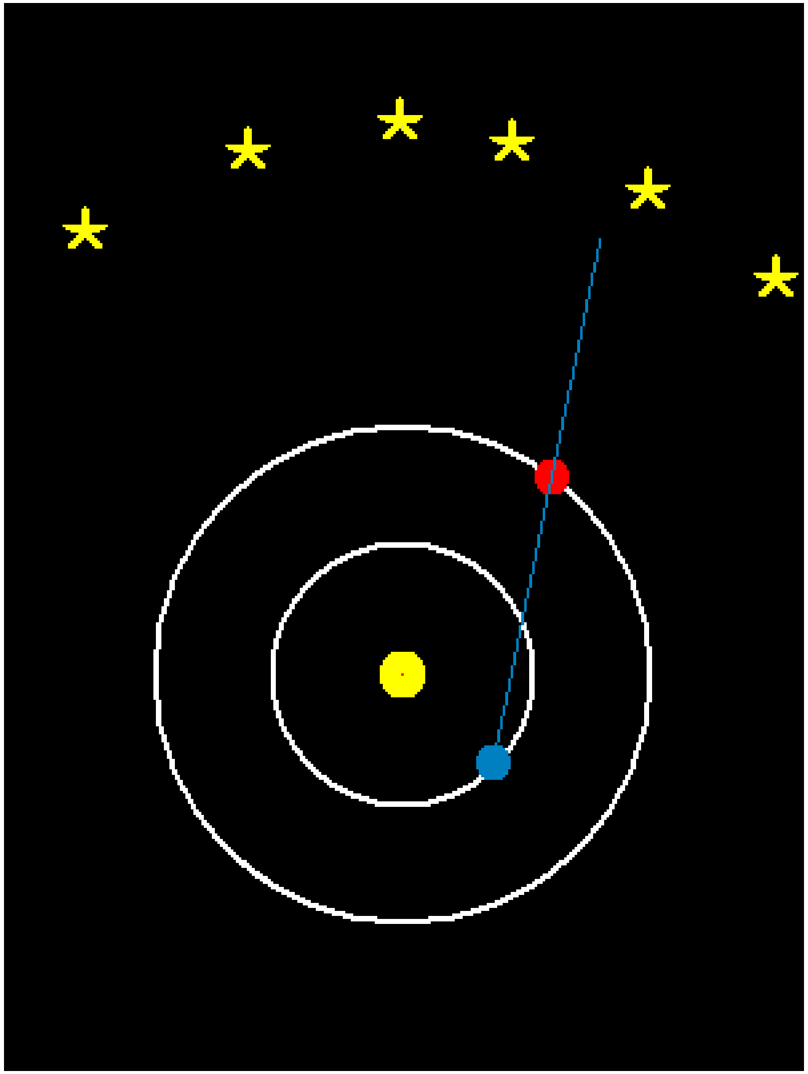
From Copernicus' original manuscript

Ok - how does this give us retrograde motion?

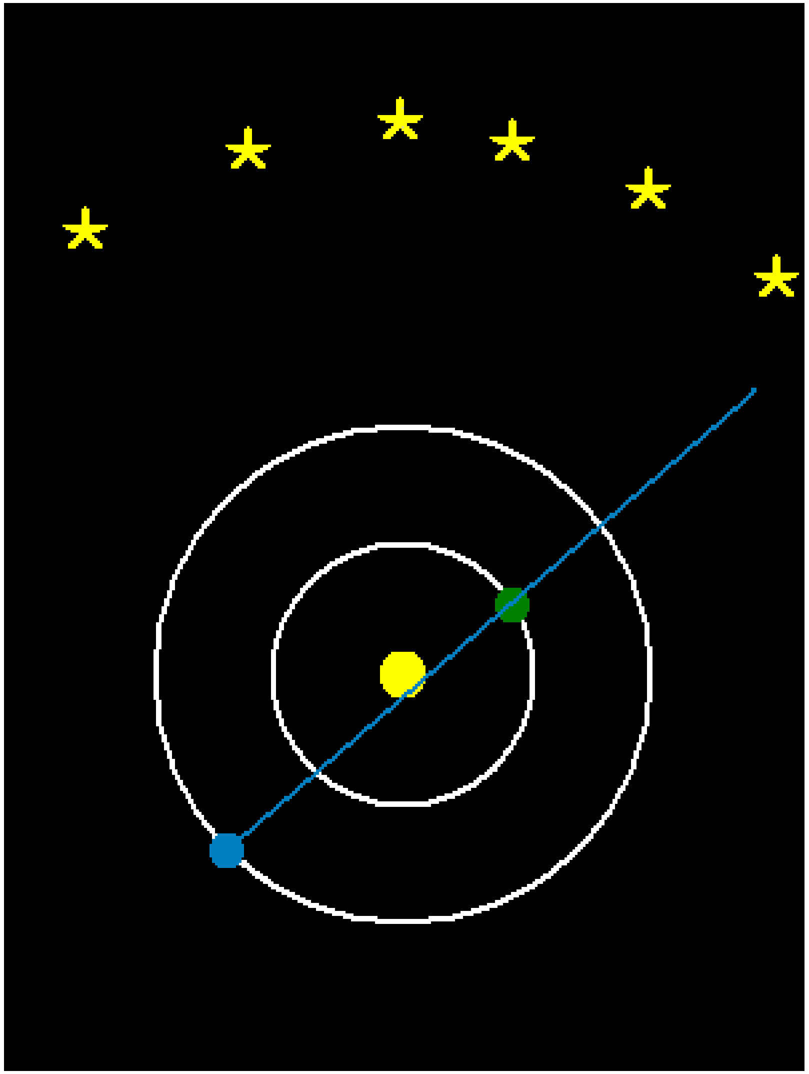


When the Earth passes an outer planet, that outer planet appears to move backwards relative to the background stars. It is the same effect you see when you pass a car on a highway. If you watch that car, you see it appear to move backwards relative to the background trees, even though both you and the other car are moving in the same direction.

By adjusting the different speeds of the orbits, you can get different amounts of retrograde motion. Similar to Ptolemic model, where the speed of the deferent and epicycles were adjustable.



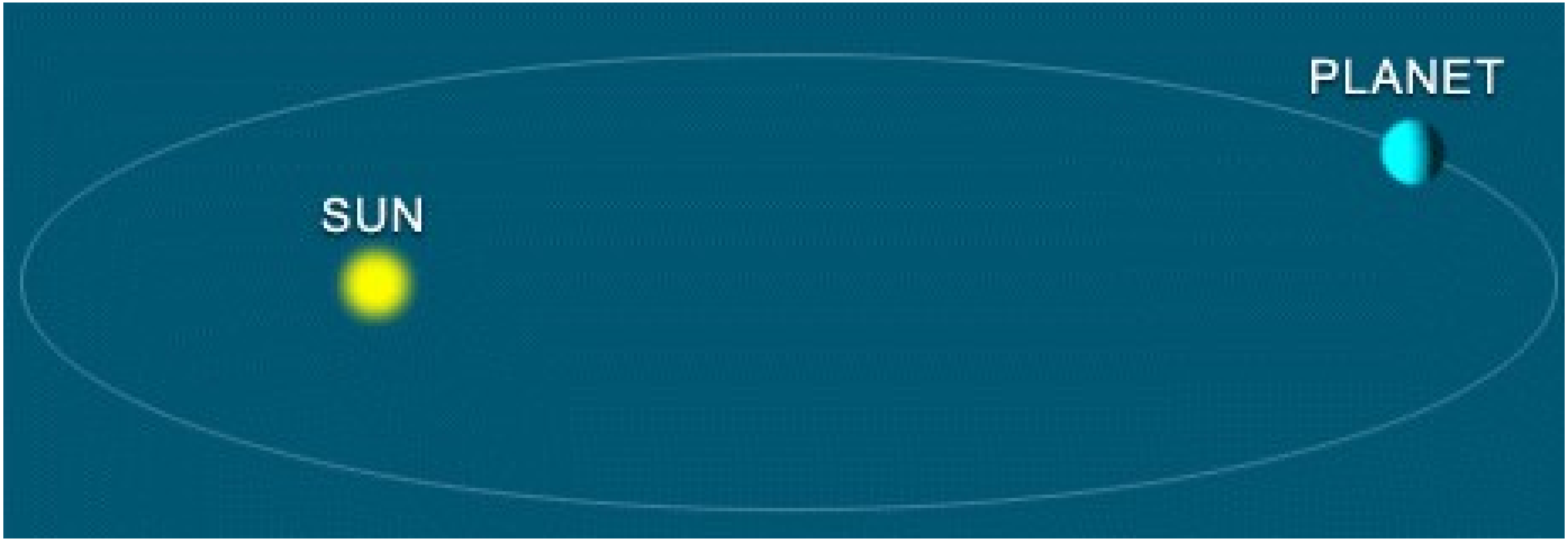
Mars



Venus

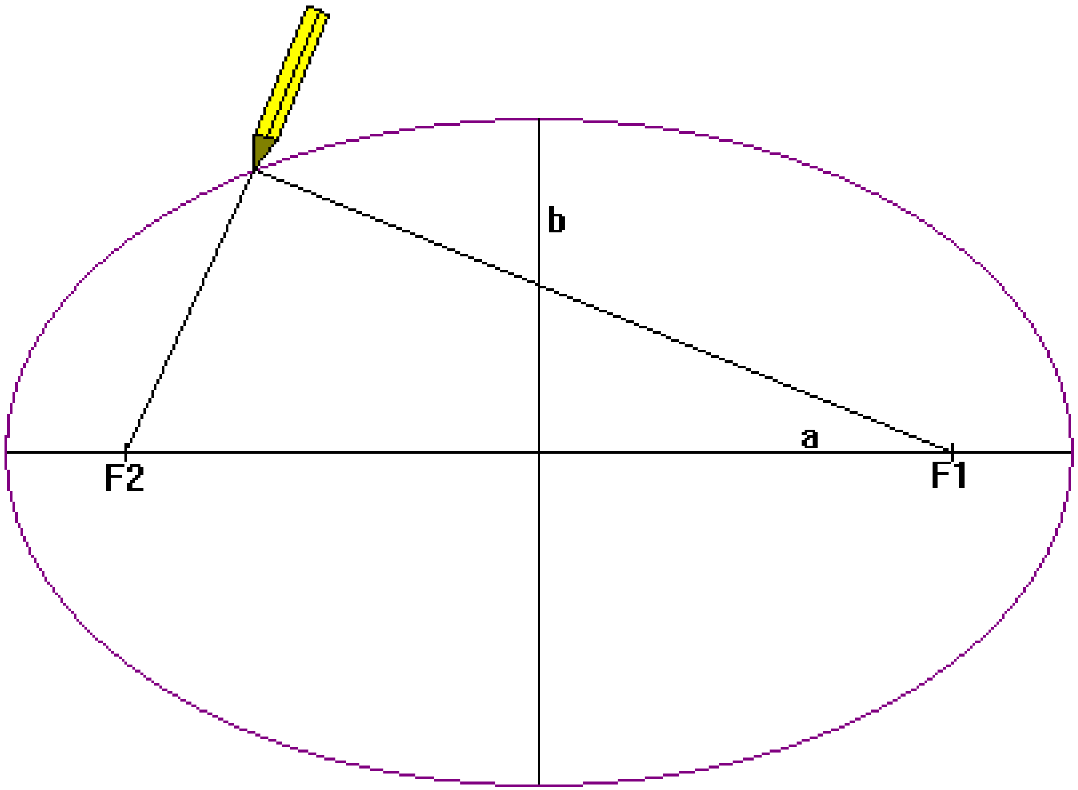
Kepler's First Law

Planets moves in ellipses with the Sun at one focus



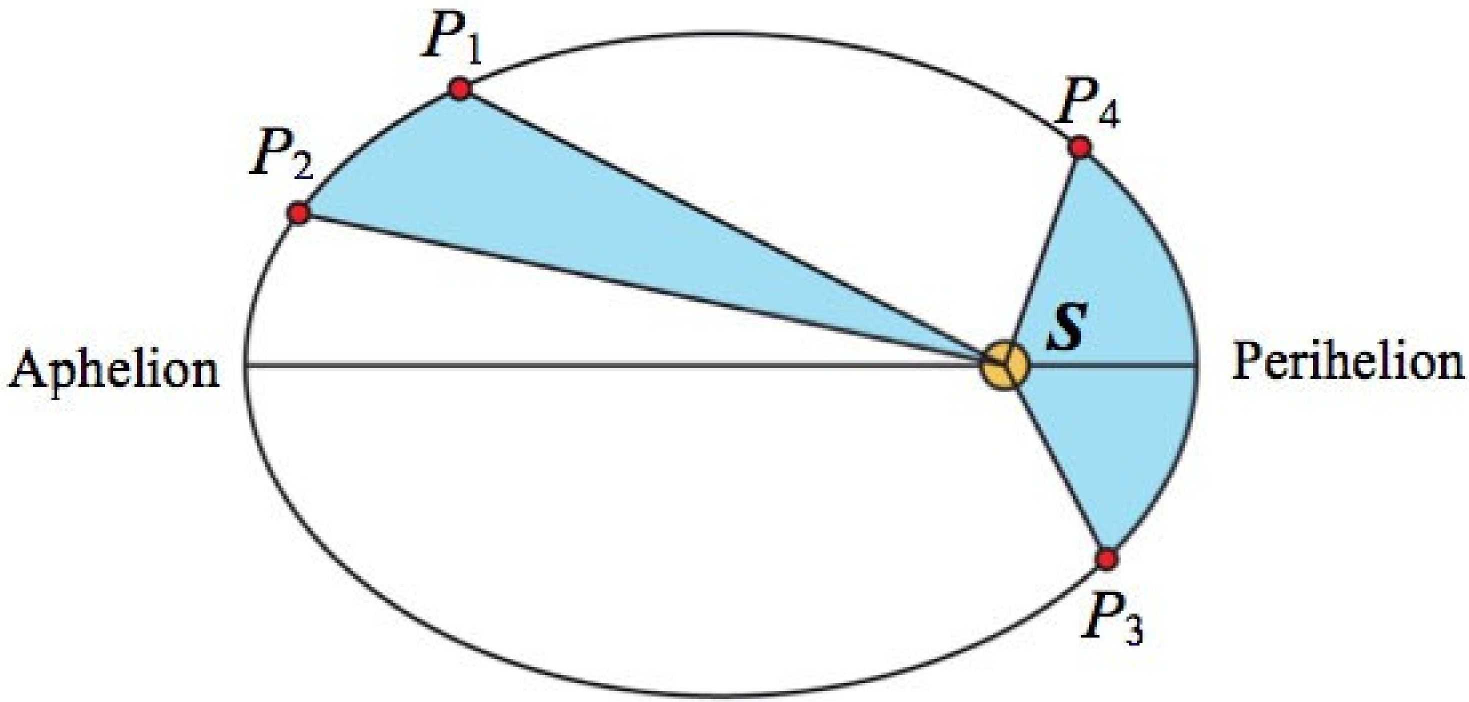
Kepler's First Law:

Planets moves in *ellipses* with the Sun at one focus



Kepler's Second Law:

The line from the Sun to a planet sweeps out equal areas in equal intervals of time.



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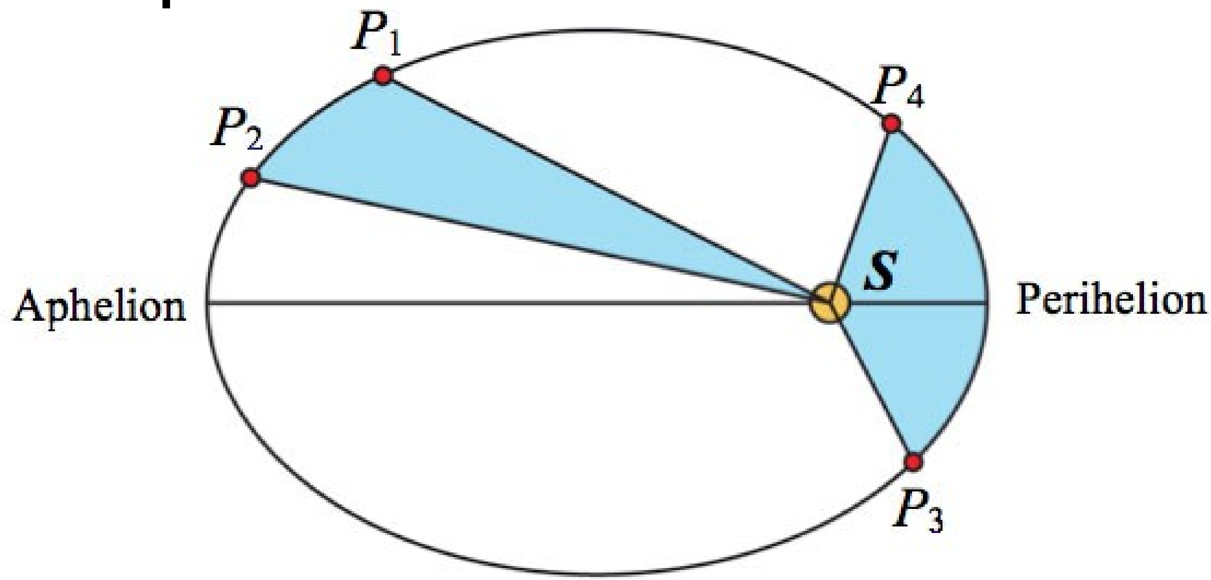
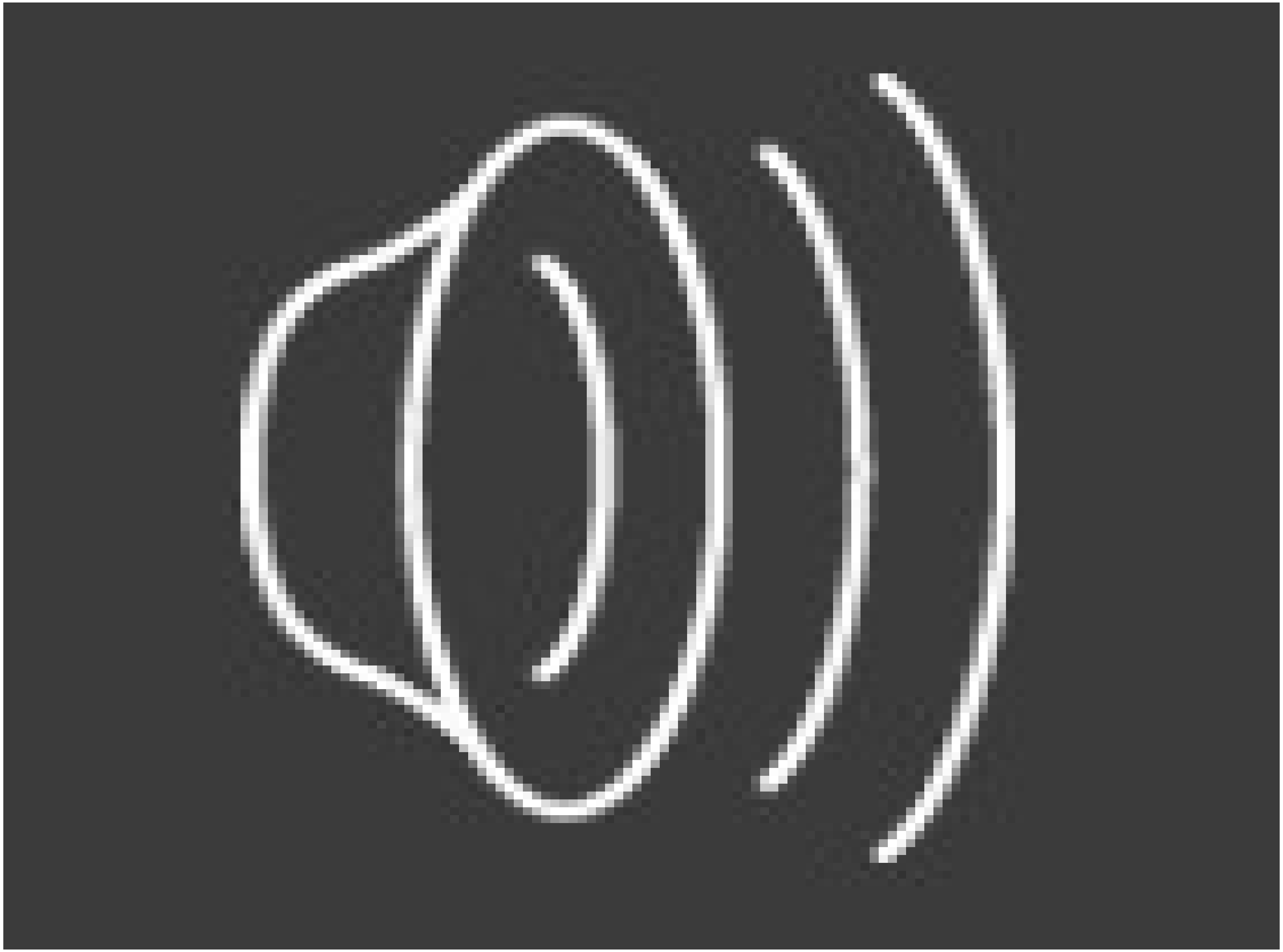


This means the planet moves **fastest when it’s closest to the Sun** (perihelion) and **slowest when it’s farthest from the Sun** (aphelion).

Kepler’s Second Law:



Kepler’s Third Law:

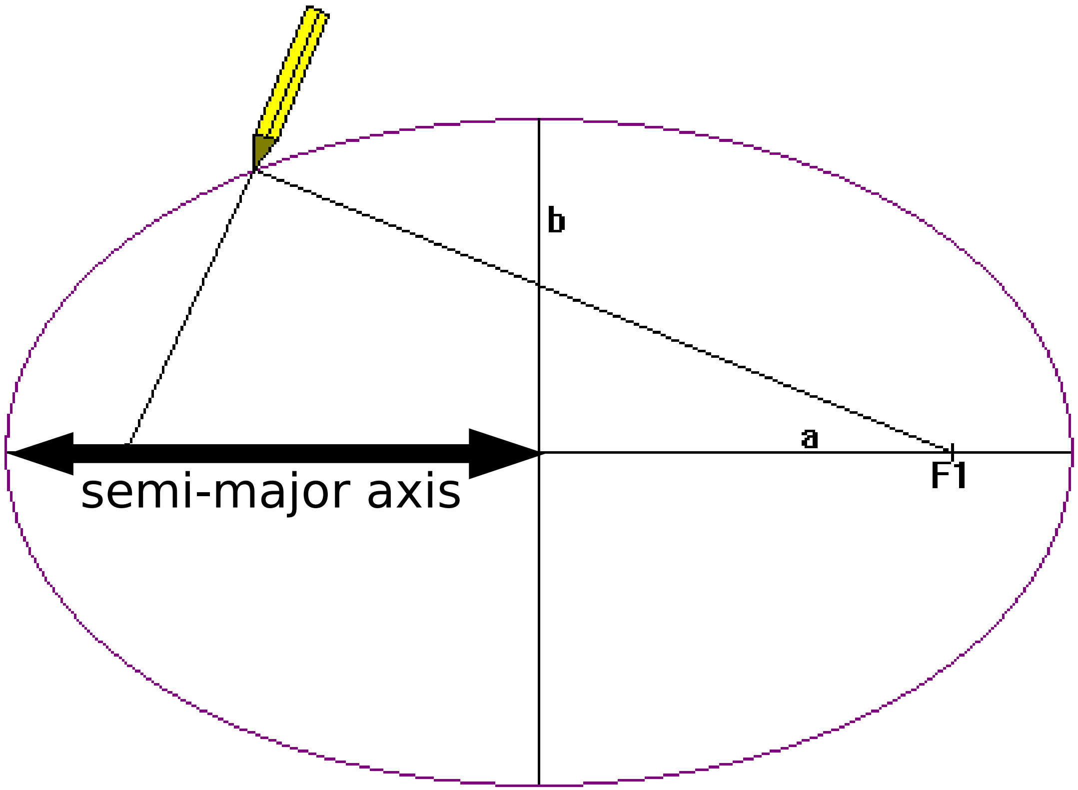
The period of each planet is related to its average distance from the Sun by the formula

$$a^3 = P^2$$

a = planet’s average distance from Sun (semimajor axis of ellipse) in AU

P = planet’s period in years

Reminder: semi-major axis



Galileo’s important astronomical observations:

- Phases of Venus, agreeing with Copernican model, but NOT the Ptolemaic model
- Craters on the Moon
- 4 moons of Jupiter, following Kepler's laws
- The Milky Way seen as a vast collection of stars
- Sunspots, whose motion showed that the Sun rotates slowly
- Rings of Saturn
  (he couldn’t see them well enough to know they were rings)

But Galileo also made essential contributions to physics, the nature of motion, and gravity (close to the earth) in particular

Newton’s First Law of Motion

An object at rest will stay at rest unless acted upon by a force. A moving object will continue to move forever in a straight line at constant speed, unless acted upon by a force.

Sometimes called the **law of inertia**: **Inertia** is the tendency of an object to keep moving at the same speed and in the same direction unless acted upon by a force

Massive objects have more inertia: it takes more force to change their motion

Newton’s Second Law of Motion

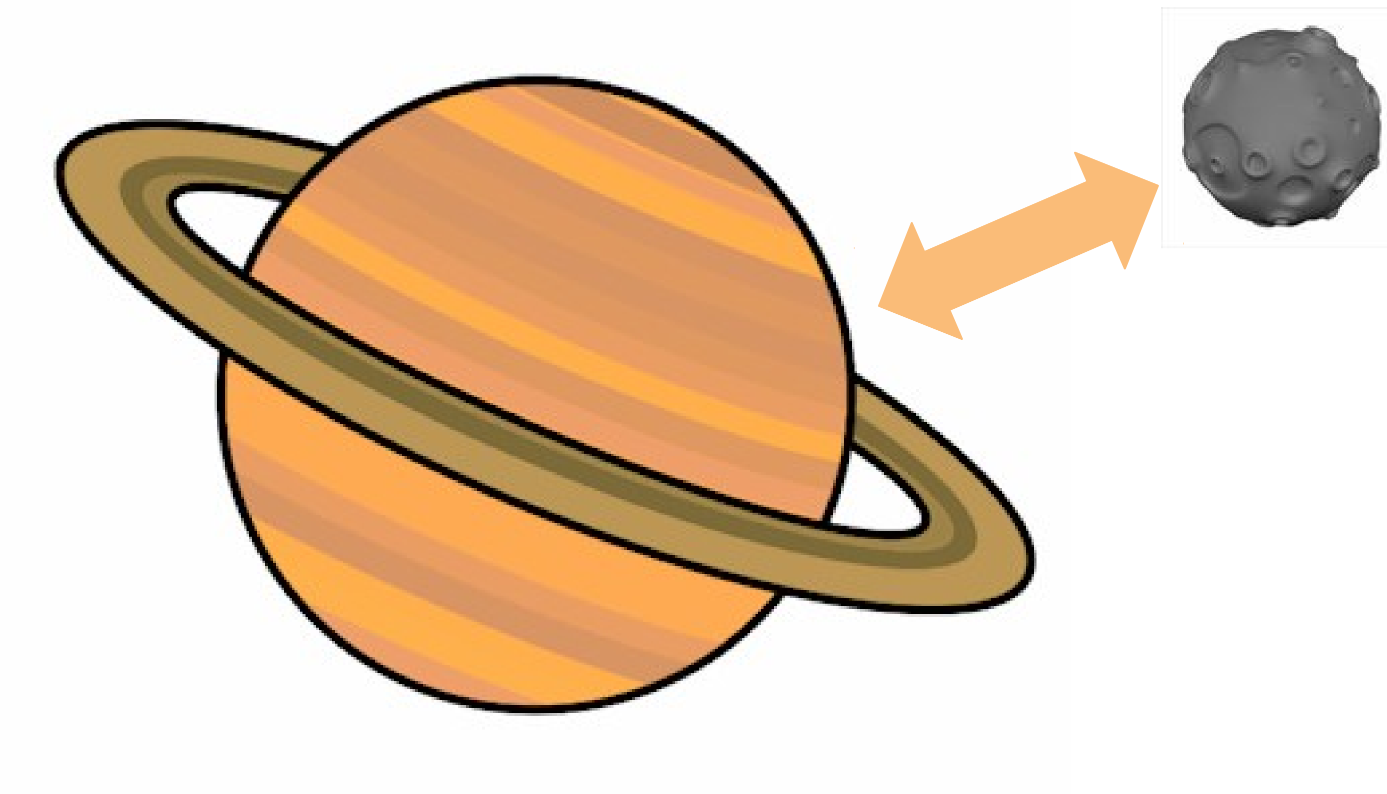
The acceleration of an object is directly proportional to the force applied, and inversely proportional to the object’s mass.

$$\underbrace{F}_{\text{force}} = \underbrace{m}_{\text{mass}}\ \underbrace{a}_{\text{acceleration}}$$

The same force will make an object with a small mass accelerate more than an object with a larger mass.

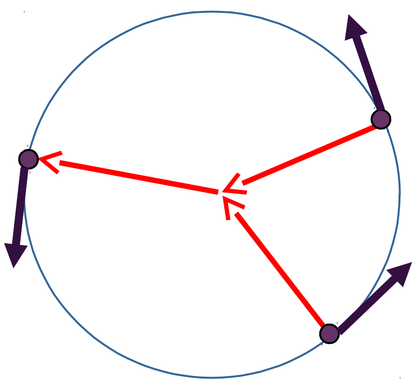
Newton's Third Law of Motion

For every action there is an equal and opposite reaction: if body A exerts a force on body B, then body B exerts a force on body A that is equal in magnitude but oppositely directed.

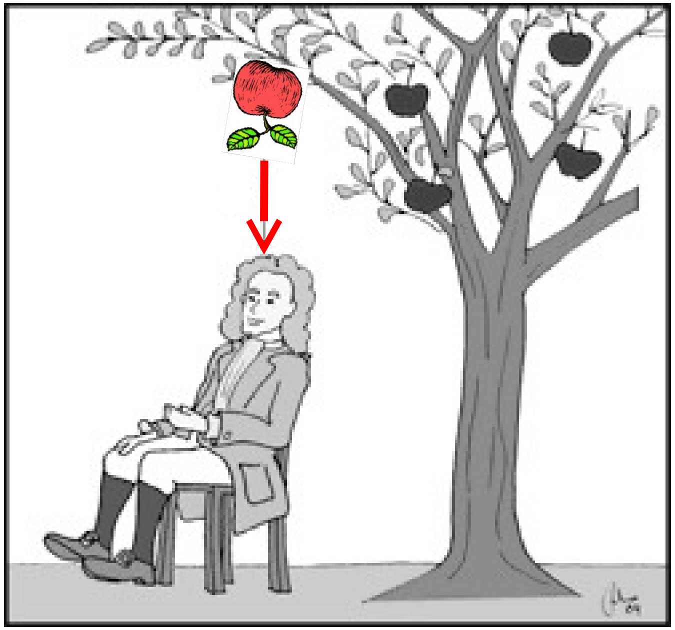


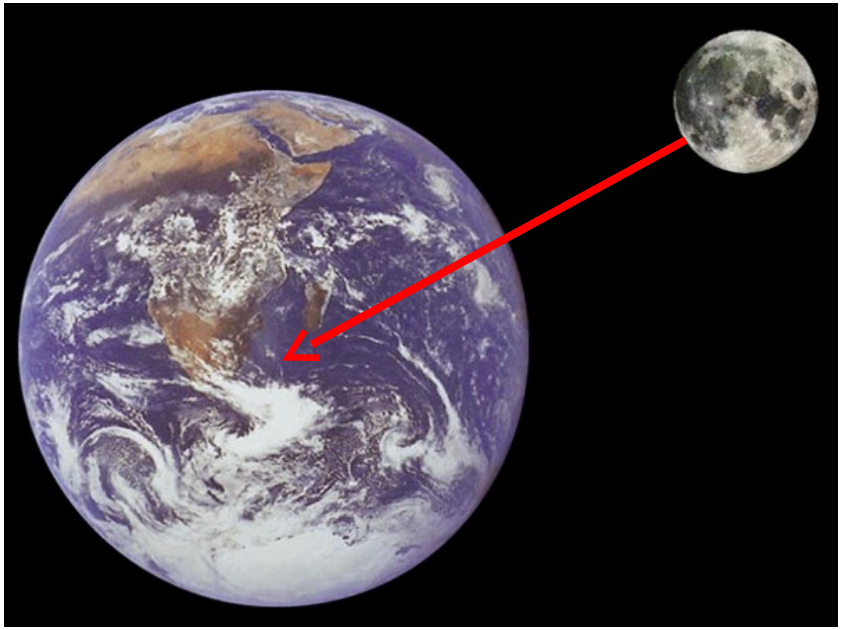
In what direction is the force on an object that moves at constant speed in a circle?

Toward the center of the circle:
This is the force of a cord on a ball you swing around in a circle



Gravity





The force on the apple and the force on the Moon both point toward the center of the Earth

Gravity is always attractive, never repulsive!

Newton’s law of gravity:

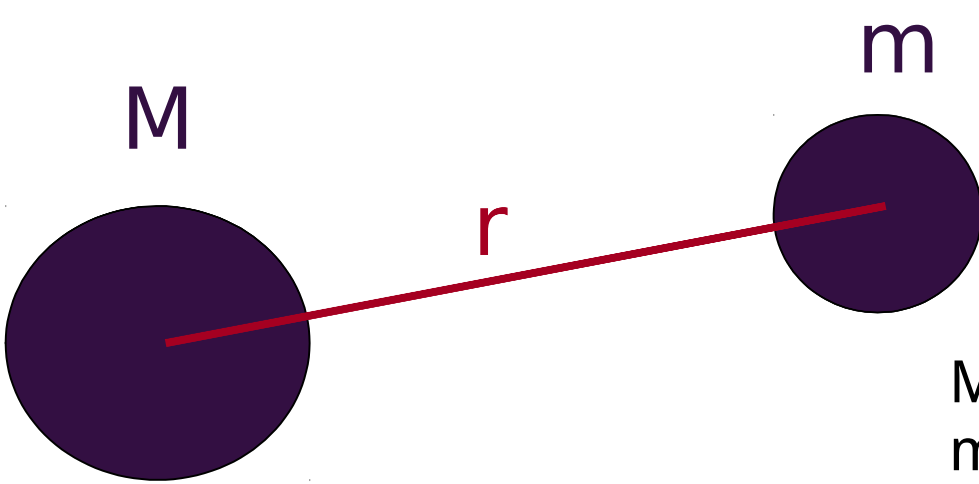
Any two objects in the universe attract each other with a force given by

$$F = G\frac{M\,m}{r^2}$$

With
r in meters
m in kg

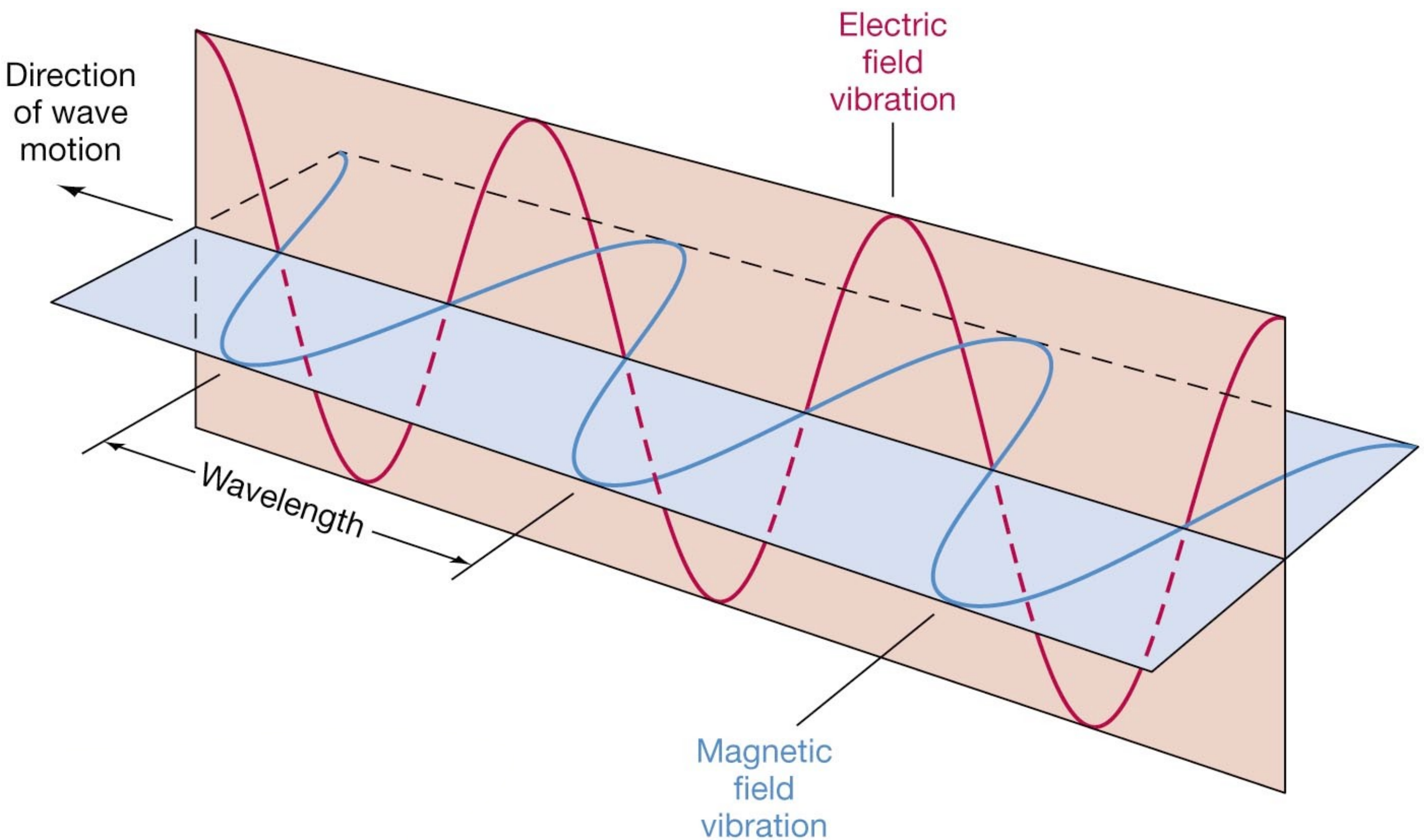
F in Newtons, where
1 Newton = 4.5 lb

G: Newton's gravitational constant
$G = 7\text{x}10^{-11}$



M: mass of object 1
m: mass of object 2
r: distance between the objects

Light is a wave in the electric field (there is also a magnetic field), and the wave travels at the speed of light.



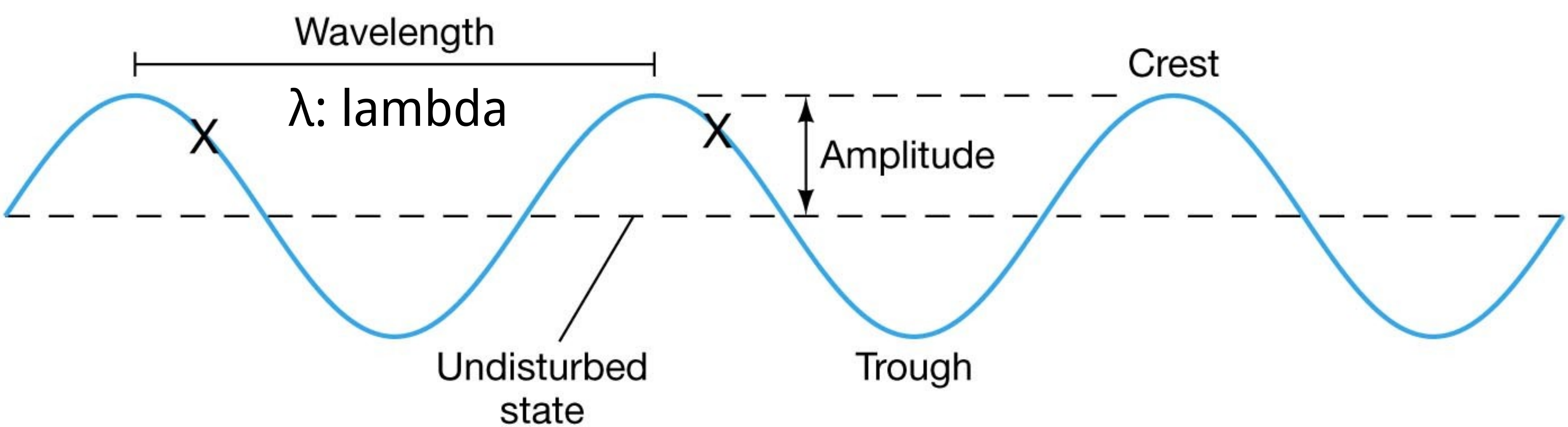
Light is also called **electromagnetic radiation**

Light characteristics

So light is a wave. There are two important characteristics about waves:

Frequency – number of waves that pass a point per second – units of Hertz or Hz

Wavelength – distance between wave crests



Relation between wavelength and frequency

For a frequency of f crests per second, you can see that the time between crests is $T = 1/f$.

The distance between crests is then given by distance = speed x time: i.e. $\lambda = c\,T$ or

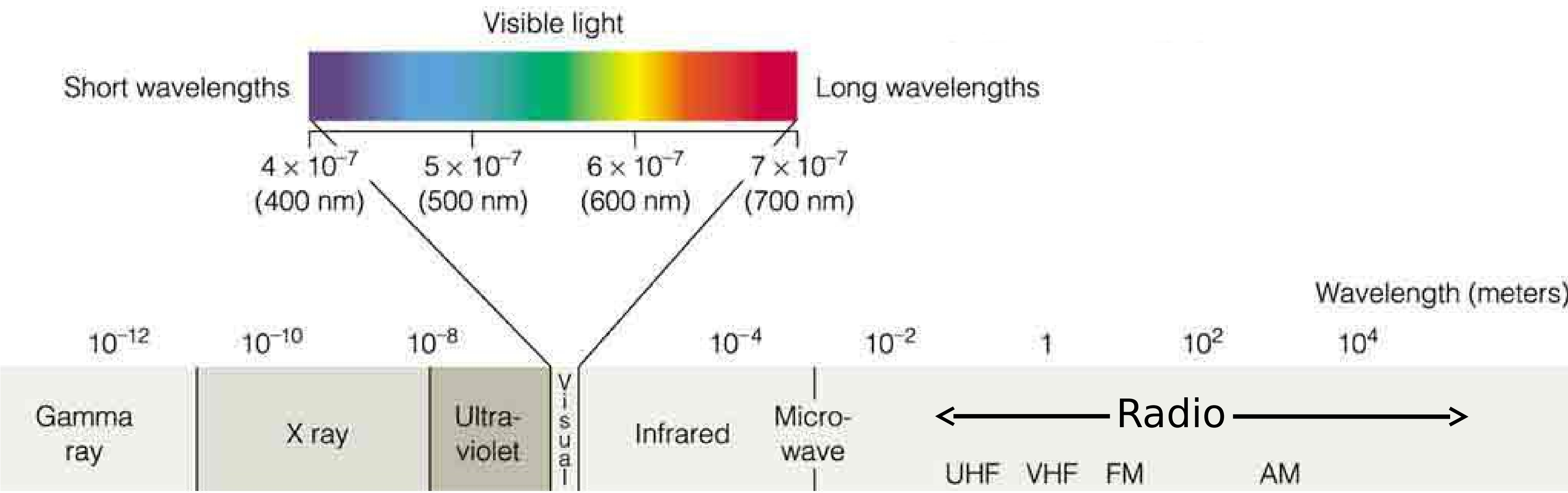
$$\lambda = \frac{c}{f}$$

We can also reverse the relation to solve for the frequency

$$f = \frac{c}{\lambda}$$

The complete spectrum of light

- Visible light is only a narrow part of the full spectrum of electromagnetic radiation.
- Visible wavelengths have wavelengths between 400 nm (violet) and 700 nm (red)
  1 nm = 1 nanometer = 10^{-9} m.
- There is stuff at longer and shorter wavelengths.



Temperature

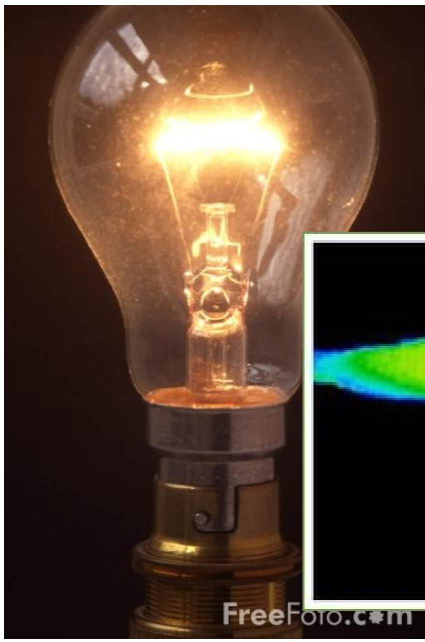
Temperature is a measure of how fast atoms or molecules are moving.

- Hot – atoms moving fast
- Cold – atoms moving slowly
- When atoms stop moving – lowest possible temperature.

This lowest temperature is called absolute zero, which is -273°C (-459°F).

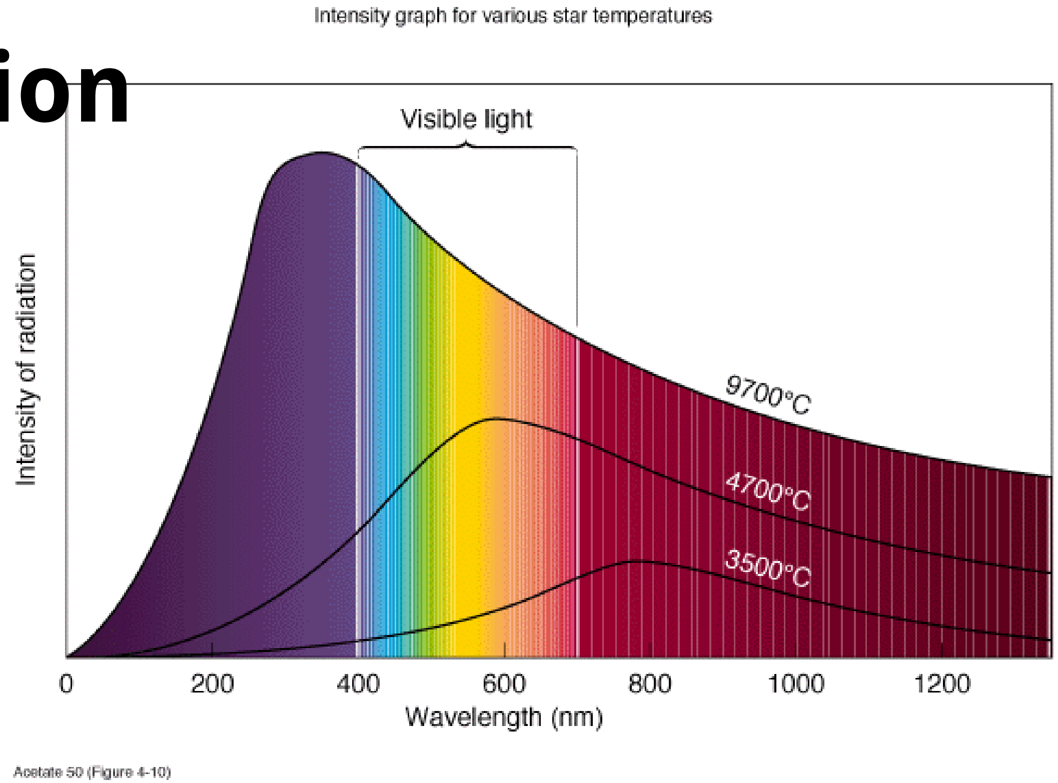
Thermal radiation:
The continuous blackbody spectrum

All objects with some temperature emit electromagnetic (EM) radiation – light



If you break up this radiation, you find some radiation at all wavelengths – it is continuous. So this is called a **continuous spectrum**

Blackbody radiation



The radiation that something emits because of its temperature is called **thermal or blackbody radiation**, and we can use the peak wavelength of the blackbody curve to determine the temperature of an object.

Nothing radiates as a perfect blackbody, but stars come close!

So **hotter stars emit more radiation, and the radiation peaks at a shorter wavelength.**

With wavelength λ measured in nanometers and **T in degrees Kelvin**, the relation between the average wavelength of light emitted by a hot object and the temperature of the object is

$$\lambda = \frac{3\times10^6}{T}\ \mathrm{nm}$$

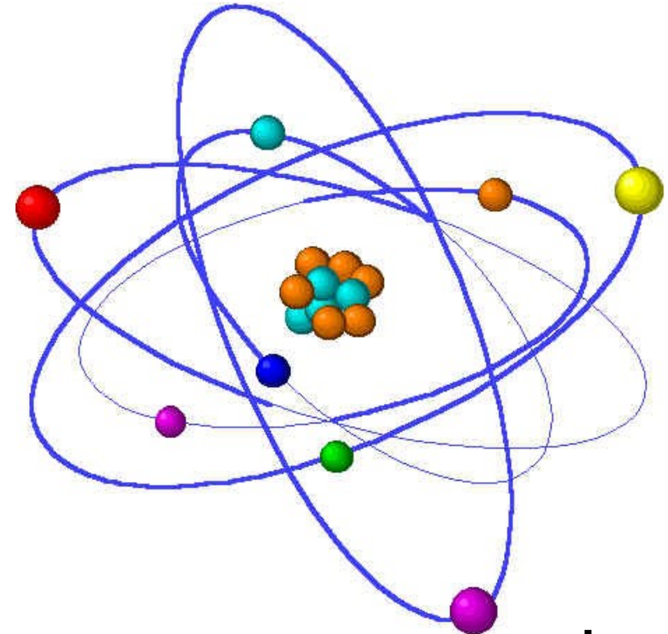
To 2 decimal-place accuracy and with λ measured in cm

$$\lambda = \frac{0.29}{T}\ \mathrm{cm}$$

Example: Milwaukee at 170 C = 290 K

Peak wavelength is 10,000 nm: infrared

Crash course : Atomic Physics in 10 slides



- All things are made of atoms.
- Atoms are about 1/10 nm (about 10^{-10} m) in diameter.
- Atoms are collections of neutrons, protons and electrons. The neutrons and protons form a very small, very dense nucleus. The electrons orbit the nucleus, bound by electric attraction to the protons.

  Opposite charges attract: electrons are negatively charged, and protons are positively charged. Neutrons have no charge.
- An atom is about 100,000 times larger than its nucleus

Spectra of isolated atoms

When light hits an electron in an atom, it can kick the electron outward to a more energetic orbit, called an excited state. An excited electron will spontaneously fall back down to a closer orbit, and the electron then emits light of a fixed wavelength that depends only on the difference in energy between the two orbits. Longer wavelength light corresponds to a smaller energy difference.

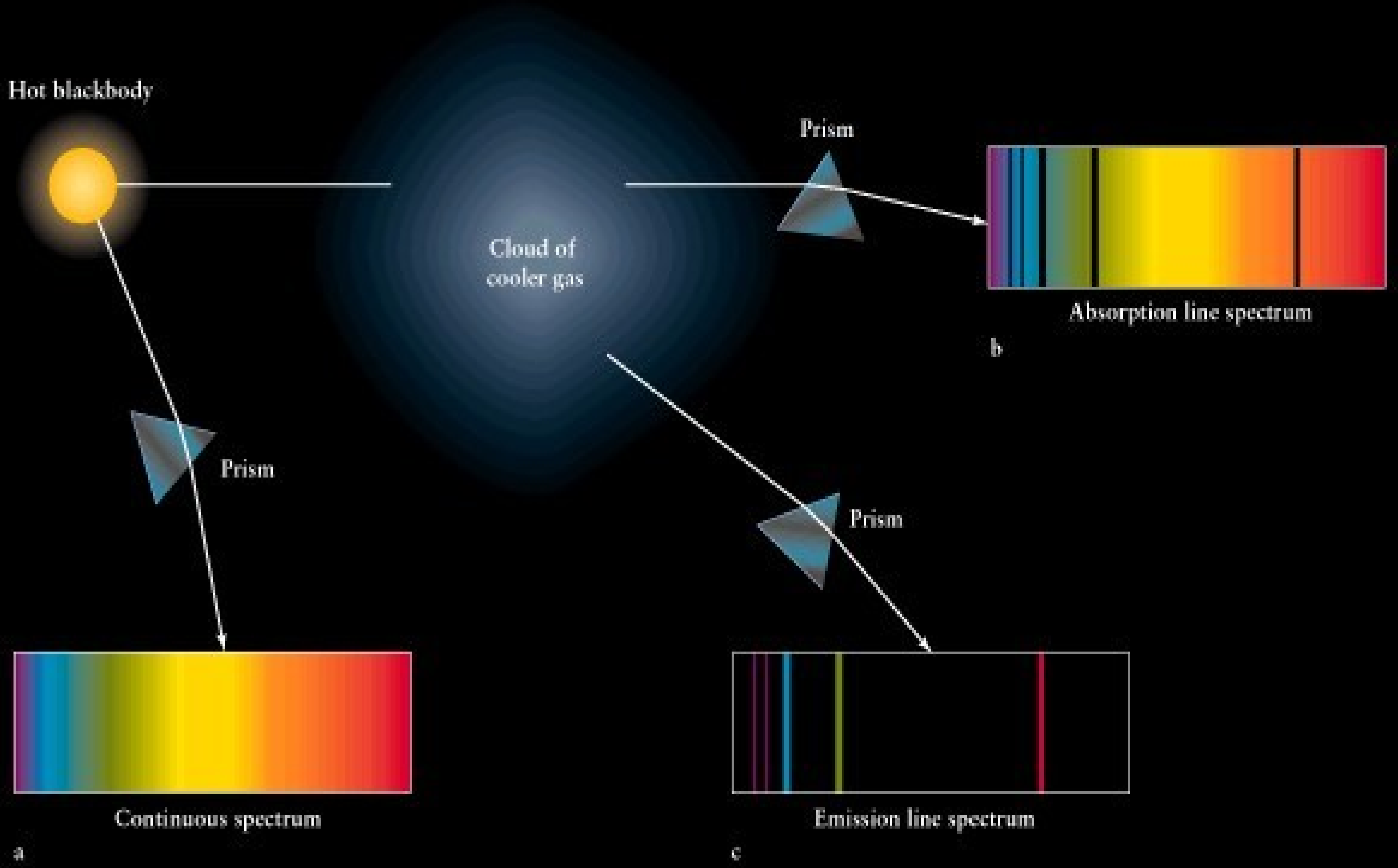
- **When an electron absorbs light, it moves from a closer to a more distant orbit.**
- **When an electron moves from a more distant to a closer orbit, it emits light.**

Spectra of isolated atoms

Atoms emit and absorb only those wavelengths of light that can correspond to the energy differences between orbits.

The light emitted or absorbed by isolated atoms is called a **discrete spectrum** because **only discrete wavelengths are emitted and absorbed**: one sees the spectrum as a set of distinct lines. Each type of atom (each element) has a different set of energy levels and therefore a different set of spectral lines.

- Each element can be identified by its discrete spectrum.
- The spectral lines (wavelengths) that an atom emits are the same as the spectral lines it absorbs



Hot blackbody
Cloud of cooler gas
Prism
Absorption line spectrum
b
Prism
Prism
Continuous spectrum
a
Emission line spectrum
c

Doppler Shift

- When a source of light (or sound) is moving away from you, its wavelength, seen by you, is longer.
- When a source moves toward you, its wavelength, seen by you, is shorter.