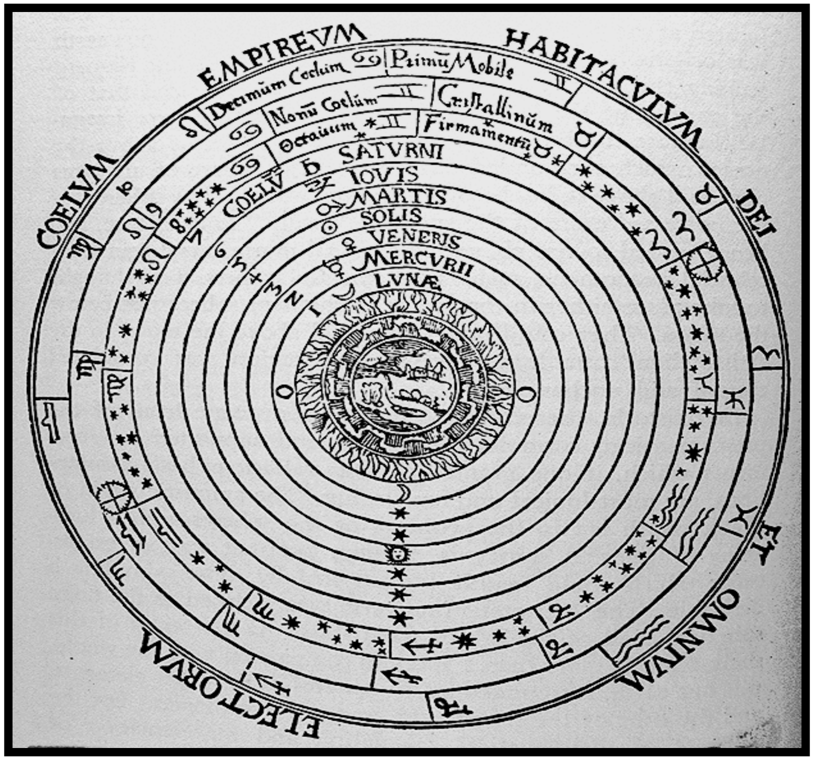
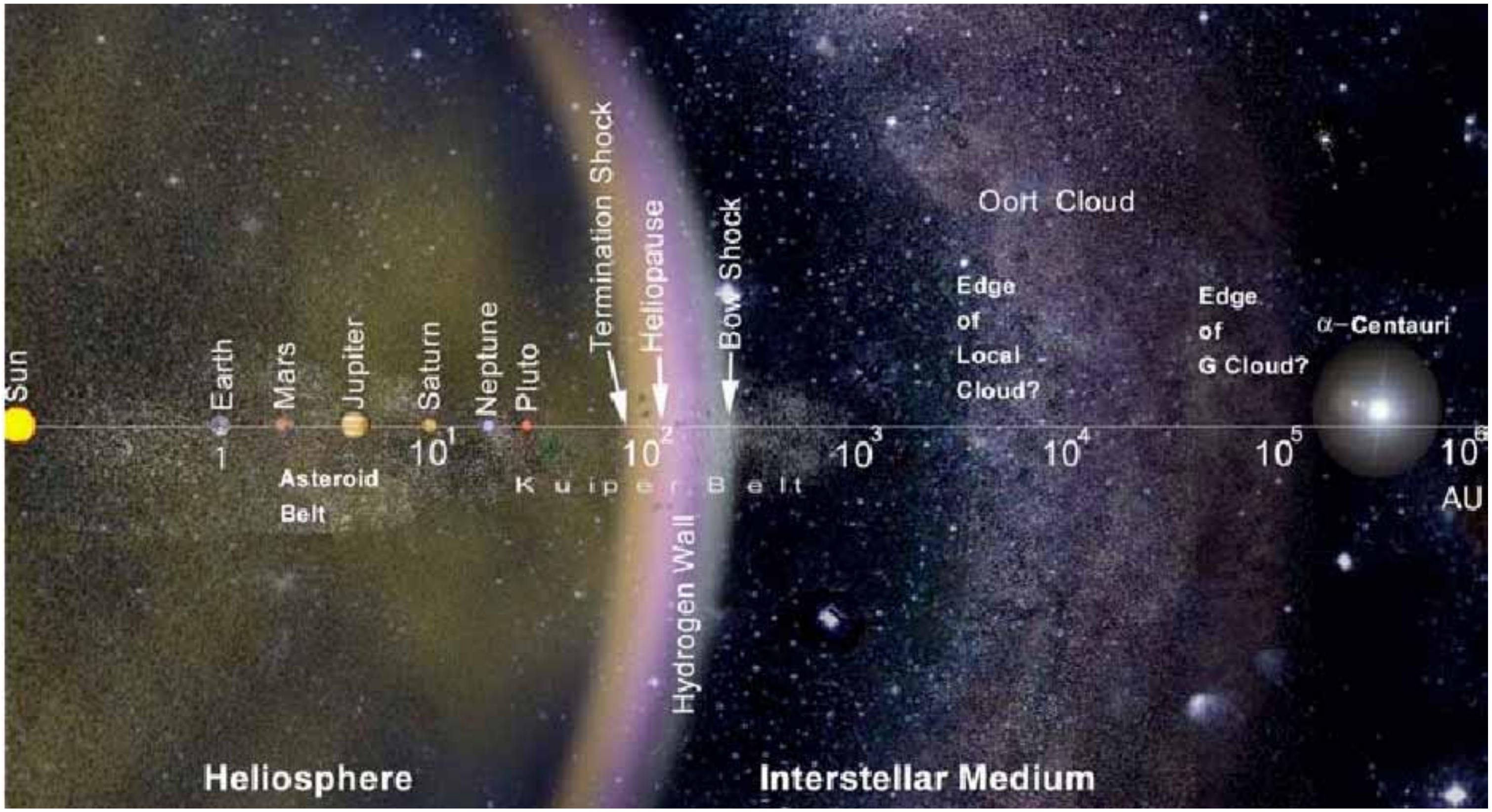
Planetary Motion:



The Heliopause:

- The location where the Solar wind stands off with the ISM is called the heliopause.
- Beyond this point, the influence of the solar wind is not felt.



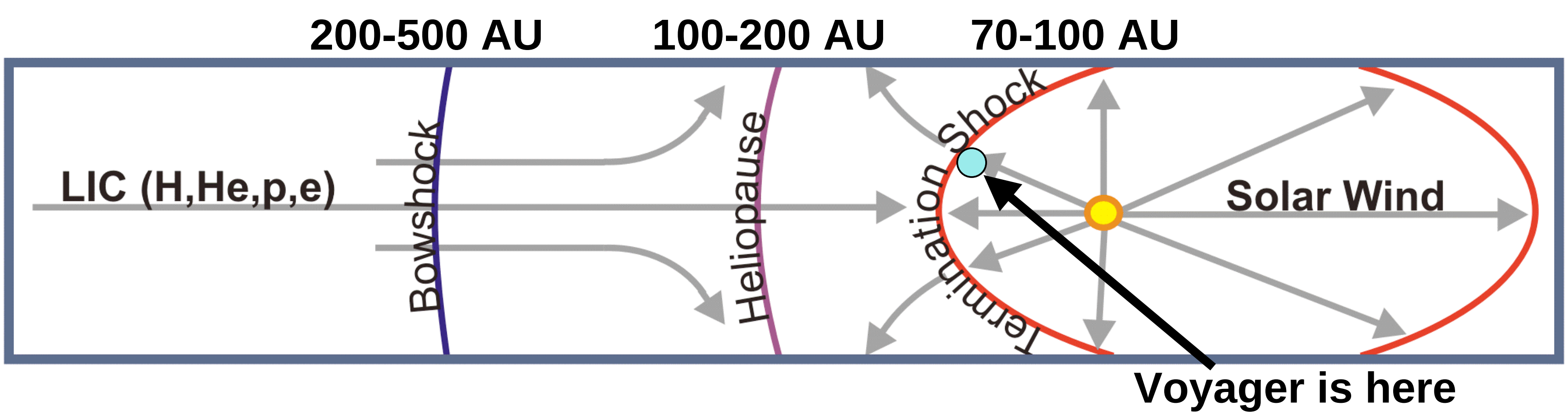
The Heliopause:

- The heliopause is actually a wide region extending over a distance more than 2x the size of the orbit of Pluto.

1) The ***Termination Shock*** is the region where the solar wind slows down in advance of the heliopause.

2) The ***Heliopause*** is the actual boundary between the SW and ISM.

3) The ***Bowshock*** is the region where the ISM begins to slow down in its approach to the heliopause.

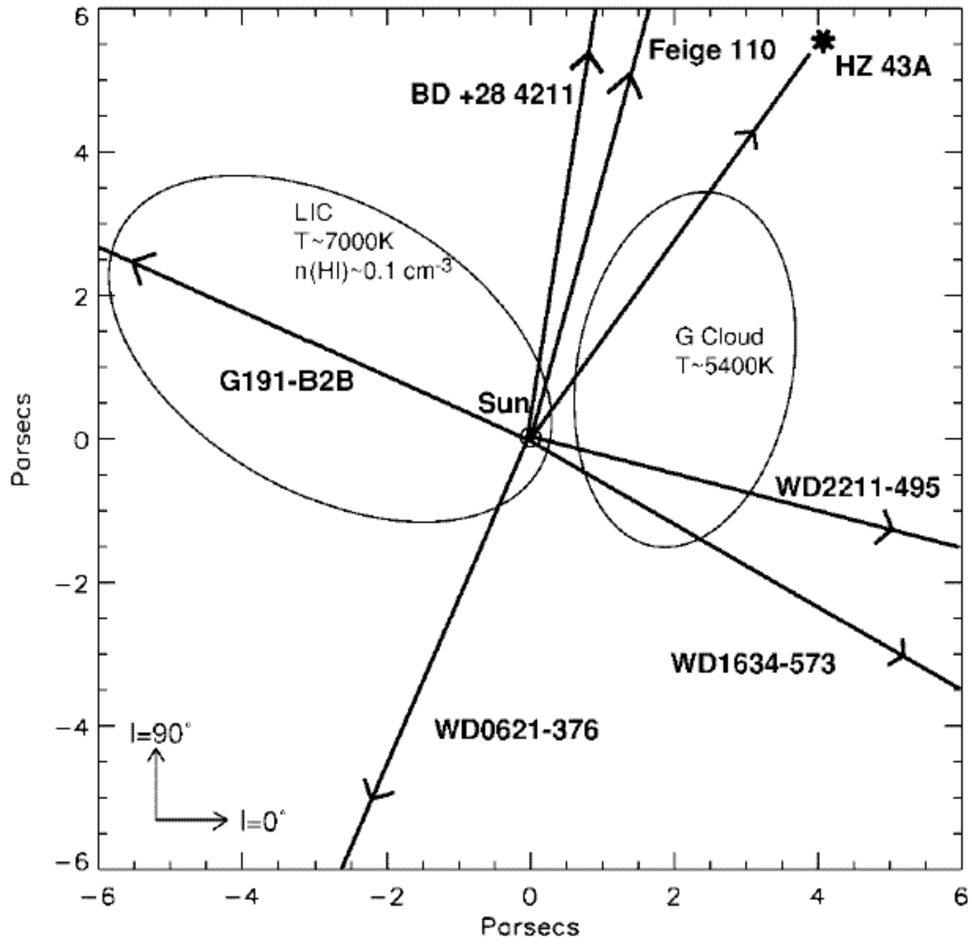


The Heliopause:

- Note that the heliopause only prevents the *ions and electrons* in the ISM from penetrating the solar system. The neutral component enters largely unaffected.

- The penetrating neutral component of the ISM is what we use to study the space just beyond the solar system.

- We also look at absorption of light from nearby stars to map the wider properties of the ISM.

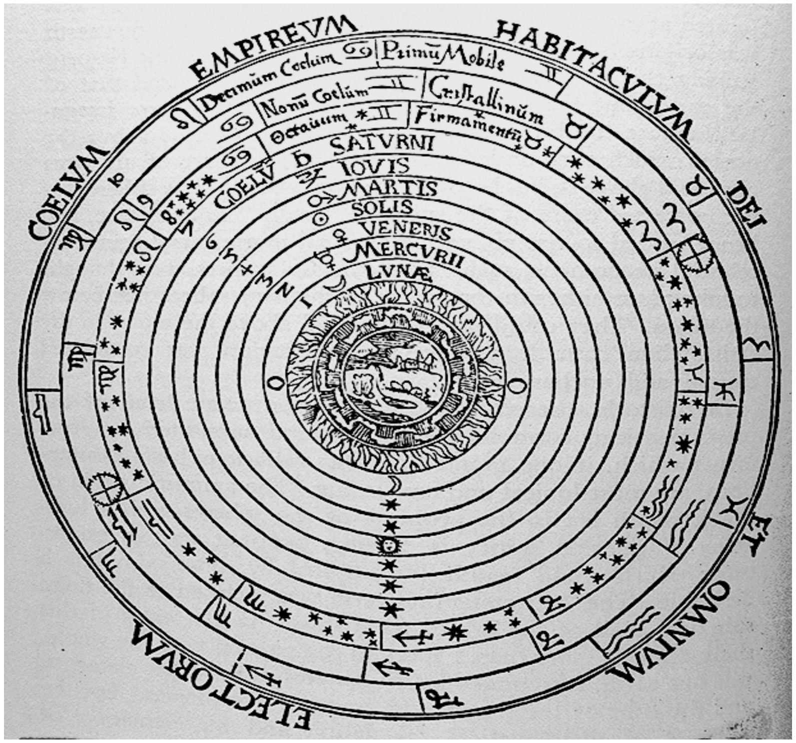


Planetary Motions:

- We think of the organization of the planets as obvious, but the truth is that this was a great mystery.

- The word *__planet__* is derived from the Greek root meaning ‘wanderer’. The ancient world knew of 7 planets.

- The planets, Moon, and Sun were the only objects to exhibit motion against the ‘fixed’ stars.



- The mathematician Ptolemy developed a model for planetary motion that assumed the Earth at the center of the universe with everything else moving around it.

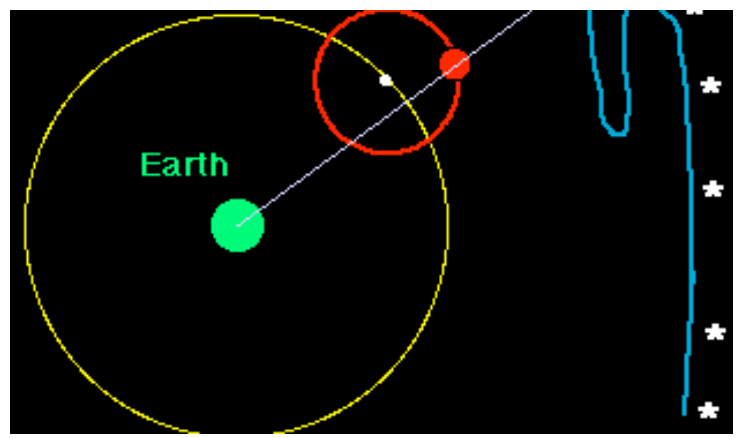
Planetary Motions:

- The theory had some problems, but was accepted for ~1500 years.

- A big problem was ‘retrograde motion’, where a planet would stop, reverse its motion, stop again, and resume its original course.

- Ptolemy solved this by invoking the *epicycle*.

- The epicycle could explain retrograde motion, but neither the Moon nor Sun appeared to need one.



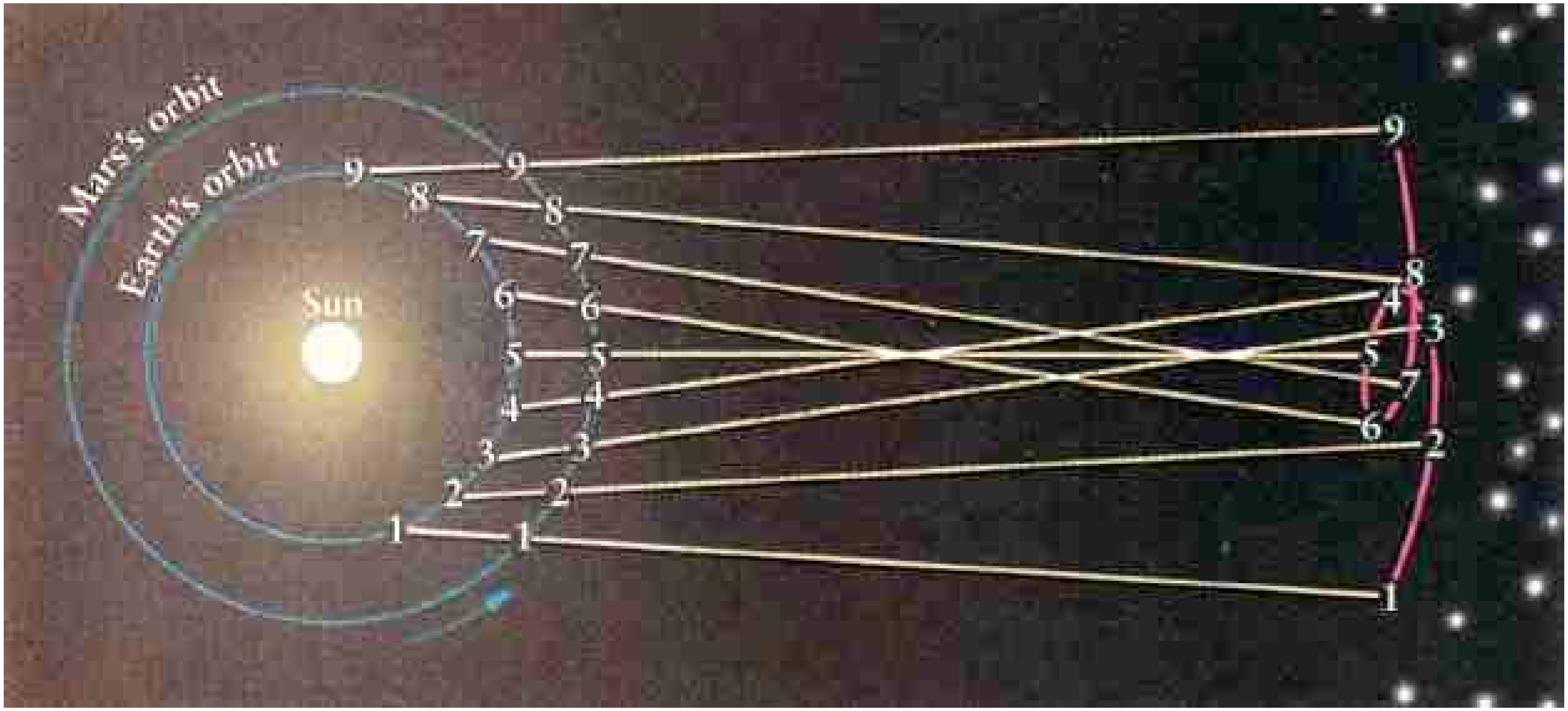
A Theory Questioned:

- Mikolaj Kopernik (1514) writes a pamphlet ("Little Commentary") that outlines 7 axioms conflicting with Ptolemy.

1) There is NO center to the Universe
2) The Earth is not at the center of the Solar System
3) The center is near the Sun.
4) The Sun-Earth distance is small compared to the Earth-Stars dist.
5) Movement of the Stars and Sun is from the Earth's *rotation*.
6) The annual movement of the Sun on the sky is from Earth's *orbit*.
7) Retrograde motion comes from motion of Earth relative to planets.

- This work was eventually published under his *latin* name (***Nicholas Copernicus***) in 1543 (after his death) as ***De Revolutionibus***.

Retrograde Motion from Copernicus:



Tycho Brahe:

- Tycho Brahe (Danish Astronomer) was probably the most accurate astronomer of the pre-telescope era.

- He precisely mapped the positions of the planets.

- Observed a comet and used *parallax* to prove that it was further than the Moon.

- He also used parallax to show that the stars were truly fixed in the sky. This meant that either….

  1) The stars are tremendously far away.

  2) The Earth was the center of the Universe.

- Tycho chose the second option (his big mistake).

Johann Kepler:

- Tycho Brahe fell out of favor with the King of Denmark and moved to Prague in 1588. There he met and hired Johann Kepler.

Kepler

- Kepler was very smart, but believed Copernicus was right, *not* Tycho. Tycho responded to this slight by giving Kepler his hardest data set, Mars.

- Mars could not be fit by a perfect circle, which all ancient cosmology assumed for motion.

- Kepler was left with two options by Mars…

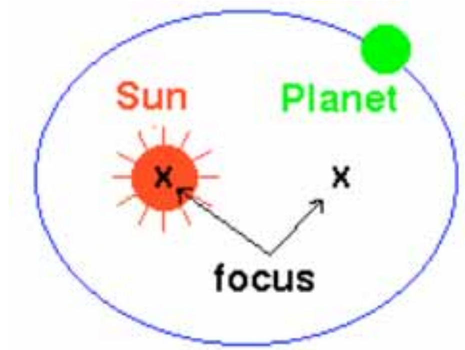
    1) Tycho Brahe's data had errors.

    2) Planets don't *have* to move in circles.

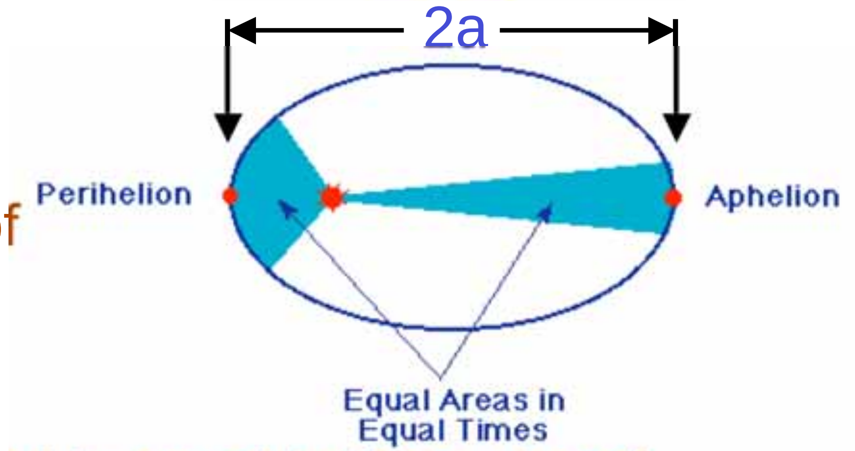
- He chose option 2 (his big success!).

Kepler's Three Laws:

- Tycho's Mars data gave Kepler the crucial clue to how planets move. He summed it up in 3 laws.



- The planets move in ellipses around the Sun, with the Sun at one focus.



- Planetary motion sweeps out equal areas of the ellipse in equal amounts of time.

- The square of a planet's orbital period is equal to the cube of semi-major (long) axis of the ellipse.

$$P^2 = a^3$$

Kepler's Third Law (Implications):

- Using Kepler's third law, we can determine how far the planets are knowing only their orbital periods.

Planet	Period	Distance
Mercury	0.24	?
Venus	0.62	
Earth	**1.00**	
Mars	1.88	
Jupiter	11.85	
Saturn	29.46	
Uranus	84.07	
Neptune	164.82	
Pluto	248.6	

Kepler's Third Law (Implications):

- Using Kepler's third law, we can determine how far the planets are knowing only their orbital periods.

Planet	Period	Distance
Mercury	0.24	0.38
Venus	0.62	0.72
Earth	**1.00**	**1.00**
Mars	1.88	1.52
Jupiter	11.85	5.20
Saturn	29.46	9.54
Uranus	84.07	19.18
Neptune	164.82	30.06
Pluto	248.6	39.44

- Everything is determined relative to the Earth-Sun distance (AU) and the length of a year!

Newton's Addition:

- Isaac Newton's discovery of Gravity changed our interpretation of Kepler's Laws.

- Newton showed that the strength of gravity fell off with the ***inverse square*** of the distance to a source.

$$G \propto R^{-2}$$

- Using this understanding you find that the planets are moving under the influence of gravity and that Kepler's Laws are simply an observational consequence of that fact!

- Moreover, you can re-write Kepler's third law to include an (invisible to Kepler) term!

$$P^2 = a^3 \times M^{-1}$$

Kepler's (more interesting) Third Law:

$$P^2 = a^3 \times M^{-1}$$

- What is M? The ***<u>Mass of the Sun</u>***!

- Because Newton's law of Gravity applies to every object in the Universe, this law must work for every orbiting body.

- Therefore, if you know:

  1) The distance between an object and the object it is orbiting (in Astronomical -Earth to Sun- Units).

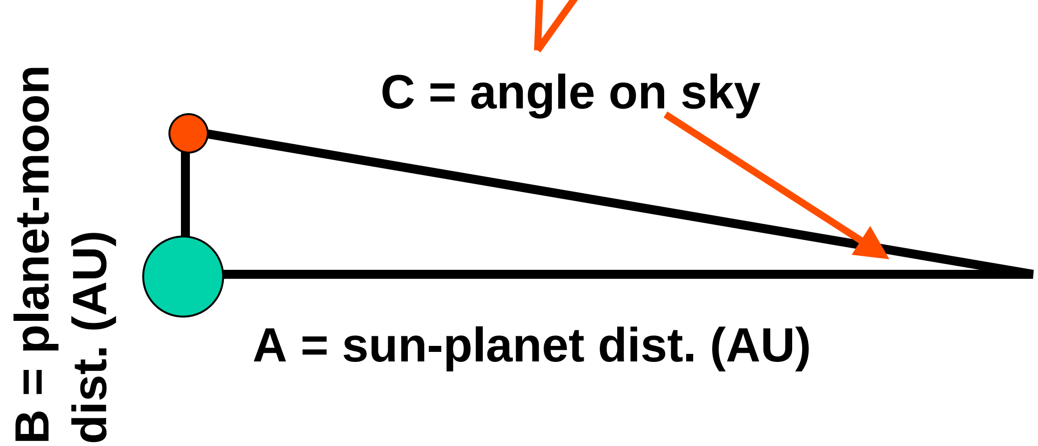
  2) The period of the orbit (in years).

- You can calculate the mass of the system in ***<u>solar masses</u>***.

What’s a Moon Good For?

- This new equation means that we can find out exactly how big all the planets are relative to the Sun!
- How? Using their ***moons***!
- Galileo had discovered that some planets had moons that appeared to orbit them, just like our moon.
- Thus, we could use the period of these orbits to get the masses of the planets!

B = A x TAN(C)



What's a Moon Good For?

- This new equation means that we can find out exactly how big all the planets are relative to the Sun!

Planet	Moon	Period (yr)	Dist. (AU)	Mass (Sun)
Earth	Luna	0.074	.0026	3×10^{-6}
Mars	Phobos	8.2×10^{-4}	6×10^{-5}	3.2×10^{-7}
Jupiter	Io	.005	.0028	9×10^{-4}
Saturn	Titan	.044	.008	2.6×10^{-4}
Uranus	Ariel	.007	.0013	4.1×10^{-5}
Neptune	Triton	.016	.0023	4.9×10^{-5}
Pluto	Charon	.017	.00013	8×10^{-9}

- We are missing something though….

What is an Astronomical Unit?

- This isn't as easy as it sounds to figure out. How far away IS the Sun?

- The modern way to do it is to use radar:

- The time between sending the radar and the return gives the distance between the objects.

- One Astronomical Unit = **$1.5x10^8$ km**