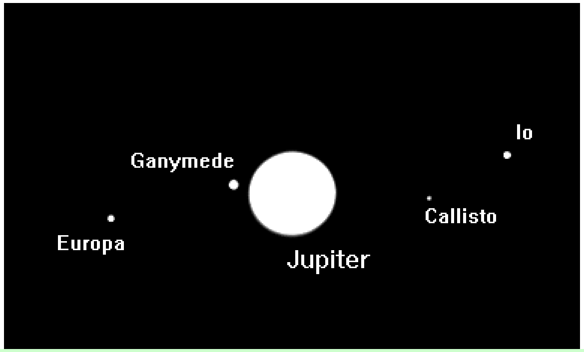
Galileo – Telescope - 1610

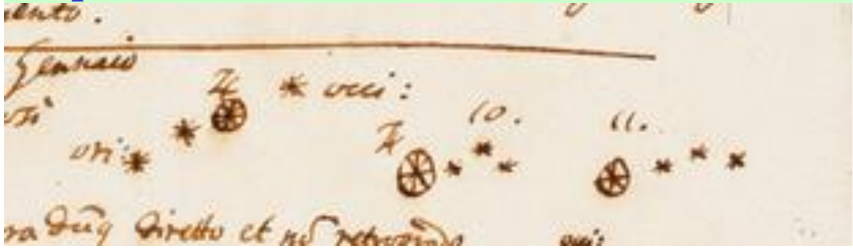
- Galileo first person to use telescope for astronomy. Clearly showed planets moving around the Sun.
- Jupiter had at least 4 moons which circled it (something besides Earth could be the center of motion); there were many more stars (saw 89 in Orion compared to 9 by eye), mountains on moon → Book ***Sidereus Nuncius (***Starry Messenger) 1610
- Venus had definite phases and clearly orbiting Sun
- Observed sunspots (patches on Sun). Sun revolved on own axis. Wasn't "perfect"
- Observed Saturn's rings but was confused as to what they were
- In response Catholic Inquisition 1616 decree (Earth at center and unmoving), bans parts of Copernicus. Galileo nominally agrees to abide but states *"I do not feel obliged to believe that the same God who has endowed us with sense, reason, and intellect has intended us to forgo their use."*
- Wrote book on Copernican vs Ptolemaic models in 1632, nominally with Church's permission. Dialogue Concerning the Two Chief World Systems. In Italian so everyone could read. Simplicio is character that defended Church's position

→ trial in 1633. Galileo old, sick, and concerned with torture, recants. Lives out life in house arrest (not prison) due to having powerful friends. Catholic church said his work contrary to scriptures……Church admits its error in 1992

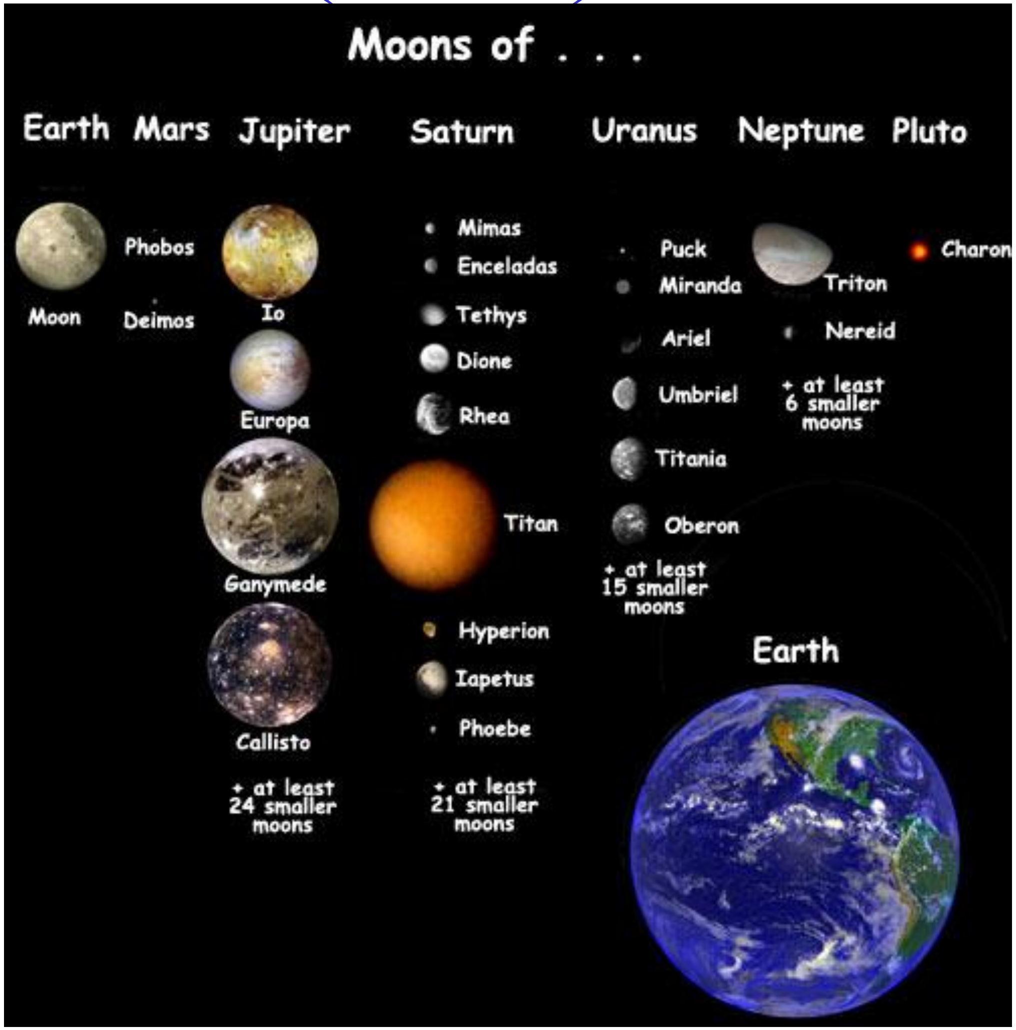
Jupiter's Moons (1610)



Jupiter's 4 largest moons can be seen with a small telescope. Change position with time → how long it takes to go around vs distance from Jupiter



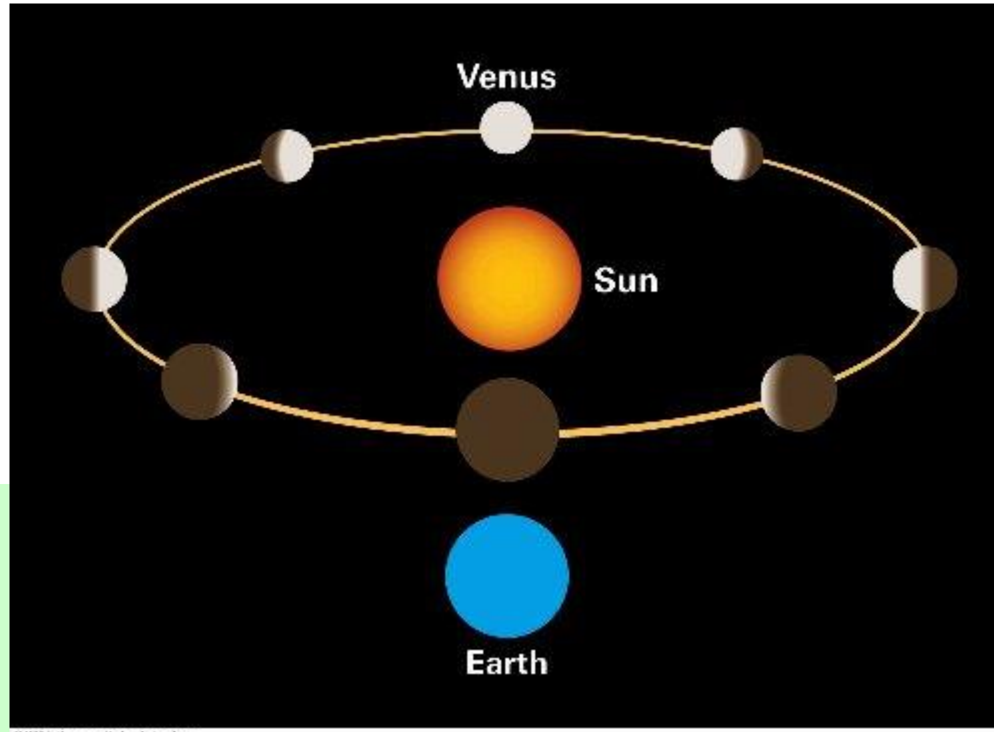
From Galileo's notebook, clearly something besides Earth was the center of motion. Circled object is Jupiter, smaller * are moons



More discovered: Pluto now has 4 moons

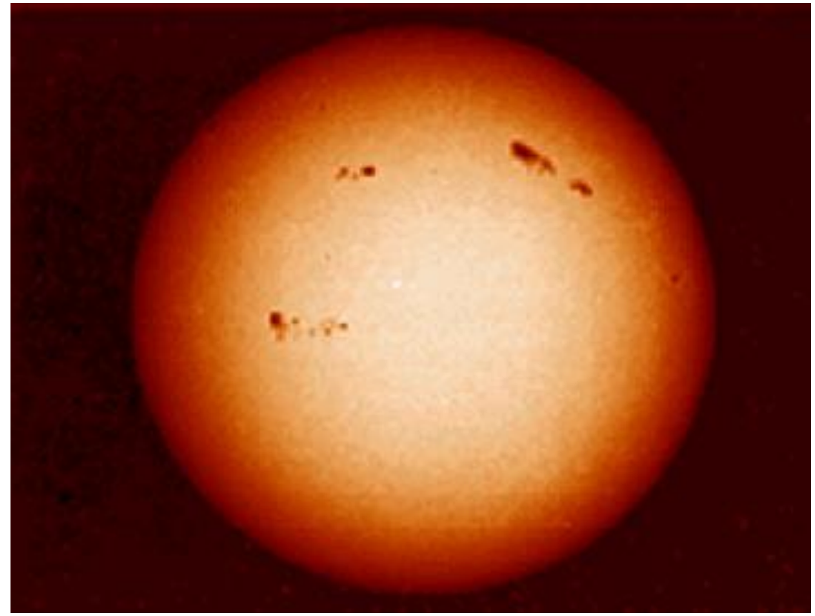
Phases of Venus (1610)

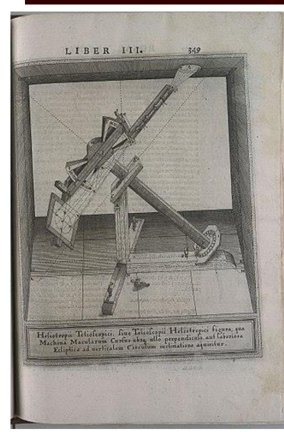
Venus has phases like the Moon which are easily explained by having it orbit the Sun and impossible to explain if the Earth was at the center of the Solar System



Sunspots

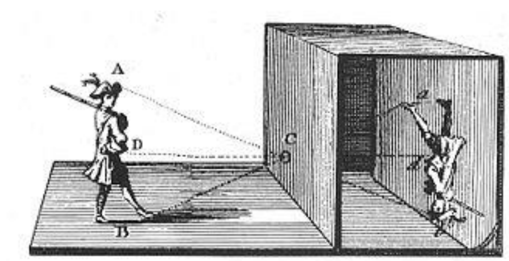
Sunspots are now known to be magnetic storms. Allows the rotation of the Sun to be readily observed. Seen without telescopes by Chinese in ~300 BC. Galileo, Harriot, and Fabricus father/son observed in telescopes. Galileo observations were of higher quality and showed Sun's 25 day rotation. Often used "pinhole" effect or helioscope to look at projected image





Helioscope

pinhole camera



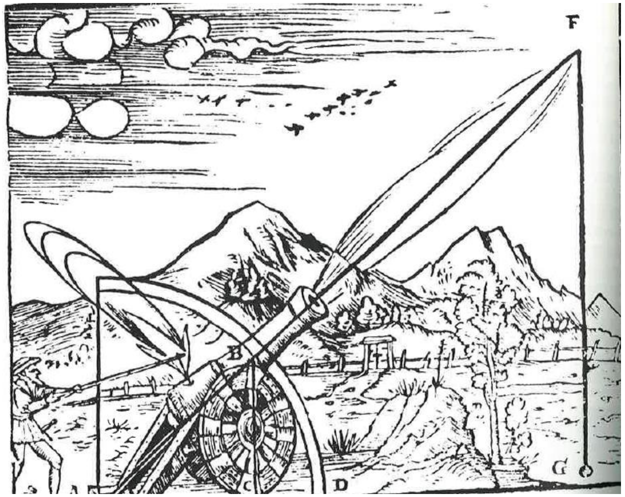
→ Sun isn't "perfect", unpredictable, and rotates like Earth

Galileo and the physics of motion

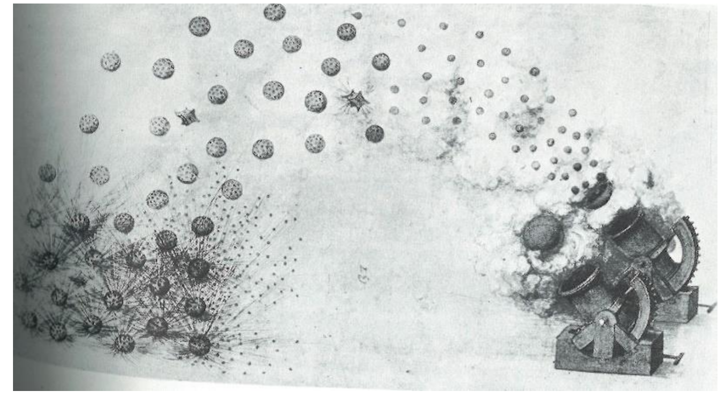
Studies of motion important: planetary orbits, cannonball accuracy, basic physics. Galileo among first to make careful observations, develop concepts

- velocity, acceleration, effects of friction
- pendulums, try to use as clock (Galileo observed swinging of objects during 3 hour long masses and noticed period depended on length, he was not successful at designing a practical clock)
- rate at which objects fall do not depend on their mass (ignoring friction)
- acceleration of falling bodies is a constant

Cannonball motion



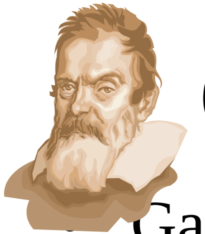
~1480 gunner's manual. Only straight lines.



Leonardo da Vinci sketch ~1500

Cannons started being used in the 1400s in Europe and accuracy was critical. The physics of the day, from Aristotle, said objects on Earth move in straight line, in the "heavens" move in circles. Soon that was clearly seen to be wrong (they did not play baseball or golf in ancient Greece or Renaissance Italy). Trying to understand this was part of why Galileo studied motion

Niccolo Tartaglia analysis 1551, close to correct

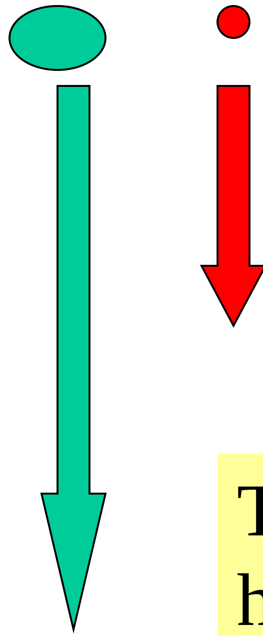


Galileo and Motion and Gravity

- Galileo and many of his contemporaries developed the concept of motion
  - velocity and acceleration
  - importance of friction
- Galileo used inclined planes (Florence museum) to reduce friction
- and (perhaps) the Leaning Tower in Pisa

186 ft high, 296 steps. Tower is "curved" to try and account for ground shift

Speed vs Mass



according to Aristotle, heavier objects fall faster then light objects

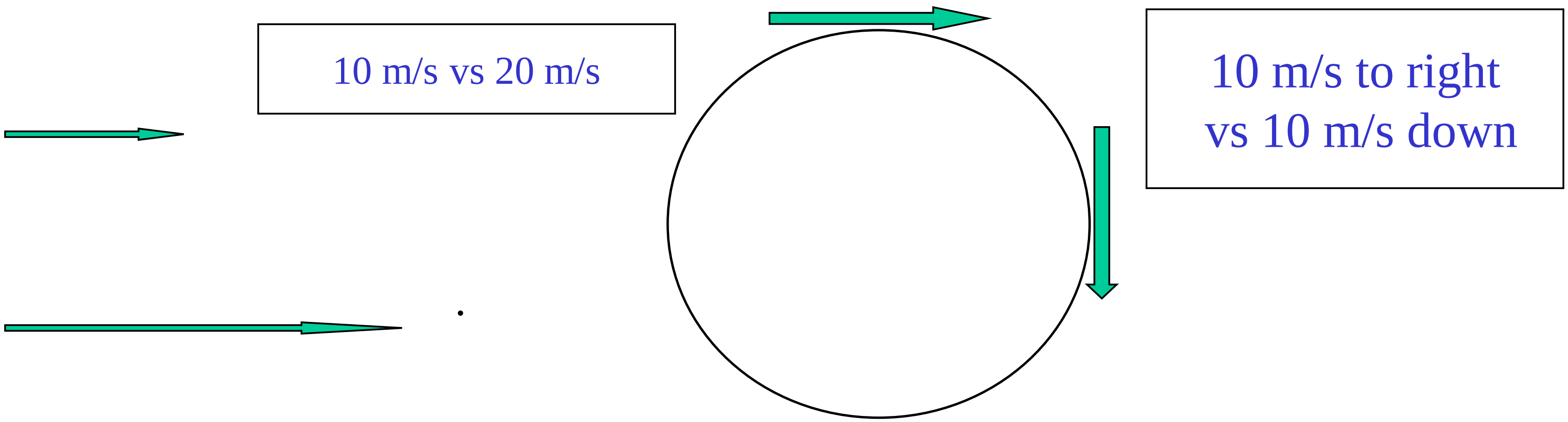
The heavier (green) ball will hit the ground before the lighter (red) ball

Experiments showed Aristotle was wrong.
"Pure thought" not the best way to do science

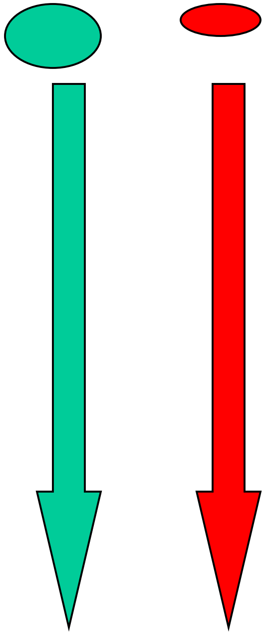
Motion: velocity and acceleration

MOTION: concepts

- acceleration = change in velocity either speed or direction. acceleration = dv/dt change in velocity per unit time. Accelerate in your car from stopped to 30 miles per hour
- Change in velocity depends on forces exerted. Cause acceleration. Gravity causes downward acceleration



Speed vs Mass vs Acceleration



Experiments done by Galileo and others showed that the heavier (green) ball and the lighter (red) ball hit the ground at the same time if you minimize the “slowing up” due to resistance from air

Galileo also showed that the gravitational acceleration was a constant 32 ft/sec/sec

Theories based on experimental observations are best way to do science. http://nicadd.niu.edu/~hedin/Galileo.htm - pretend news story

Hammer+feather on moon fall at same rate
https://er.jsc.nasa.gov/seh/feather.html

Newton 1642-1727 : Motion and Gravity

- Started from earlier concepts and measurements of motion
  - Kepler's Laws on planetary motion
  - Galileo determination that acceleration at Earth's surface was a constant independent of mass
- Developed calculus and so provided mathematical tool to relate acceleration to velocity to position.
- Developed his 3 law's of motion to relate acceleration to the applied force
- Developed form for gravitational force. Demonstrated it was universal (same everywhere)

Newton's Laws of Motion

1. Body continues at rest in uniform motion in a straight line unless a force is imposed on it. (Inertia)
2. Change of motion is proportional to the force and is made in the same direction.

   F = ma Force = mass x acceleration

   acceleration= change in velocity per time

- If F=0 than a=0 and velocity (and direction) stay the same

3. To every action there is an equal and opposite reaction (action depends on mass and velocity and is related to momentum)

→ For this course be able to apply 1 and 2 to Kepler's Laws

Forces in Nature

- Gravity
- Electromagnetism
- Strong Nuclear Force
- Weak Nuclear Force

Gravity (Newton)

- the first force to be understood was gravity
  - There is a force between any two bodies 1 and 2

$$F = G\, m_1 m_2/r^2$$

with m_1 and m_2 being the masses and r being the distance between 1 and 2. G = constant

  - Always attractive
  - Depends on the masses of the two bodies
  - Decreases as the distance increases
  - Is the same force everywhere in the Universe
  - Weakest force but dominates at large distances

Gravity Examples

- Body A on surface of Earth with mass m_A

$$F_A = G\, m_A\, m_{Earth}/r^2_{Earth}$$

- If object B has a mass 10 times that of object A, the Force of gravity is 10 times larger on B
- But F = ma or acceleration = Force/mass so the acceleration due to gravity is $= G\, m_{Earth} \,/\, r^2_{Earth}$
- Does not depend on mass so all objects have same acceleration (as shown by Galileo). Does depend on mass, radius of Earth
- G is universal constant

Surface Gravity

- Acceleration due to gravity at the surface of any planet is

$$g = G\ m_{planet}/r^2_{planet}$$

- different planets → different surface gravity
- Mars: mass = 0.11 mass(Earth) and radius = 0.53 radius(Earth)
- so g(mars) = $.11/.53^2$ g(Earth) or about 40% that of Earth
- Impacts escape velocity (how fast you need to go to escape gravitational field) from given planet (or moon) and what type of atmosphere planets have

Planetary Orbits

- Gravitational force between Sun and planets causes orbits with D being the planet's distance from the Sun

$$\text{Force} = G\, m_{Sun} m_{planet} / D^2_{orbit}$$

- as $a = F/m = G\, m_{Sun}/D^2$ does not depend on the planet's mass, all objects the same distance from the Sun will have the same orbits.
- Also true for orbits around other objects (Earth, Jupiter) - means satellites around Earth can have similar orbits even if different masses

Kepler's Laws

- Kepler's Laws can all be derived from Newton's laws of motion and force of gravity Junior-level physics class
- gravity causes elliptical orbits where planet moves faster when closer to the Sun as force of gravity is larger there
- Third Law actually

$D^3 = (\text{Msun} + \text{Mplanet}) \times P^2$ D=distance from Sun and P=period → weaker force further away gives longer period

- As mass Sun much larger can mostly ignore mass of planet (but Sun does move slightly due to planet's pull).
- Relationship between distance and period depends on Sun's mass, and measuring them can be used to determine the mass of the Sun.

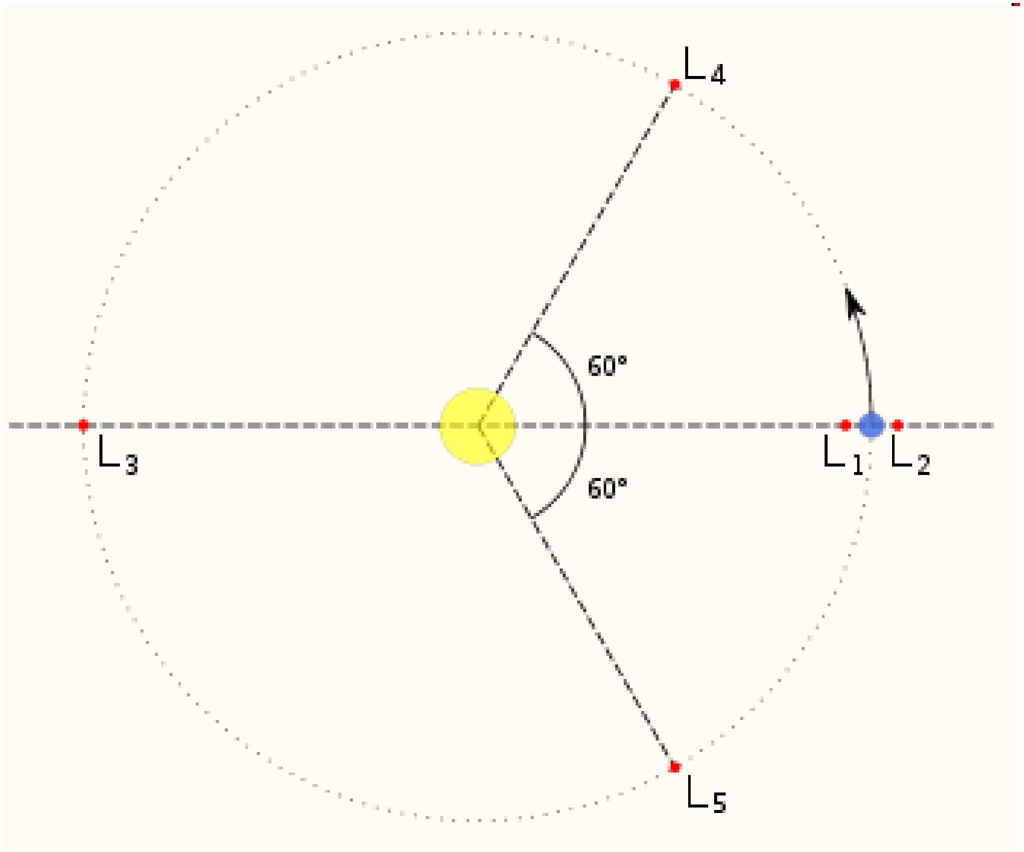
Orbital Periods

- Study orbital preriods → determine masses
  - planets around Sun → Sun's mass
  - Jupiter's moons around Jupiter → Jupiter's mass
- Also used for stars (more on this later)
  - two nearby stars orbiting each other → their masses
  - an exoplanet orbiting a star will cause the star to wobble a bit → can give mass of exoplanet
- see some animations at (from wikipedia) http://nicadd.niu.edu/~hedin/162/Center.html

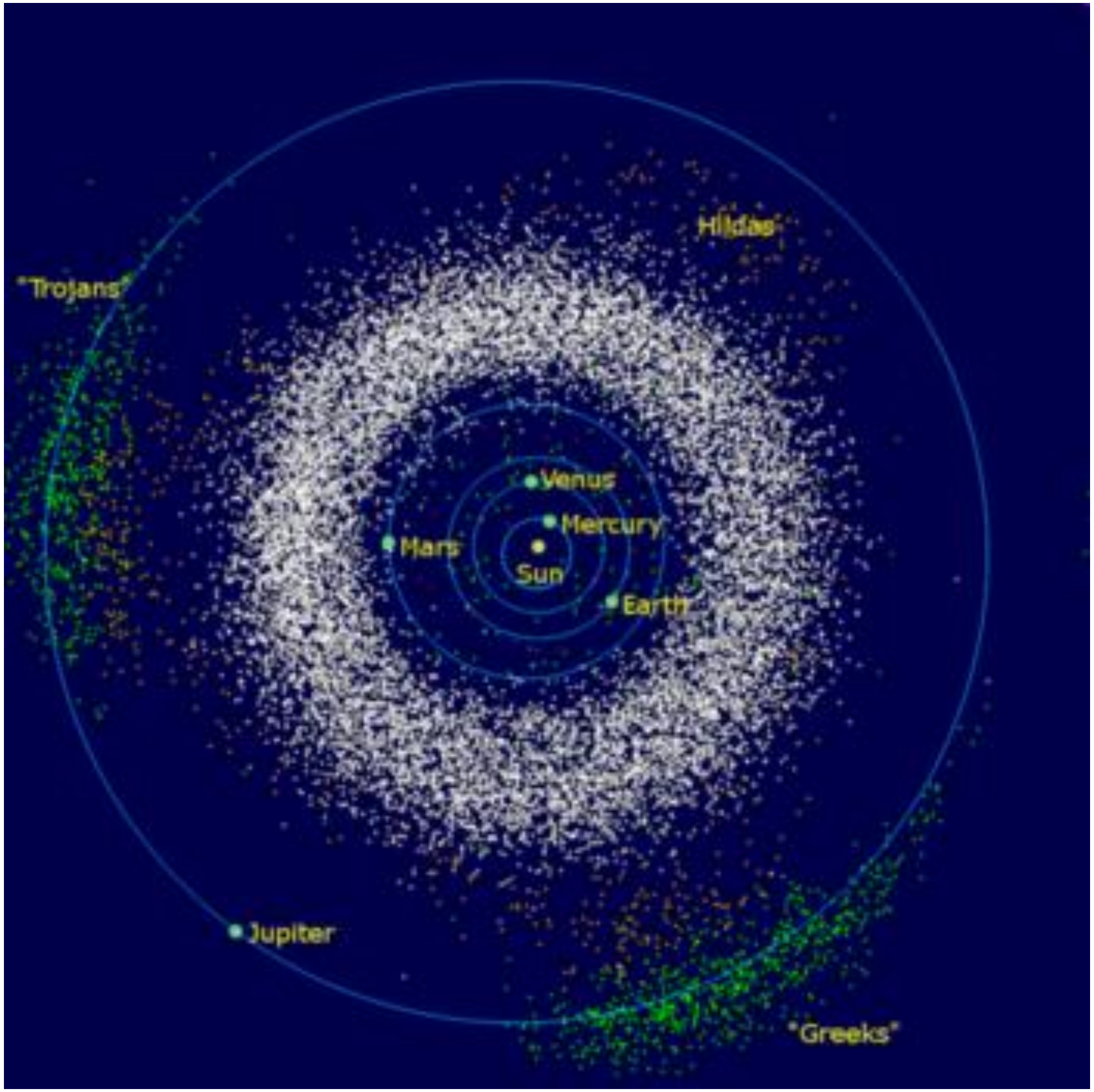
Extra Slides

Planetary Orbits – Trojan points

- have stable points in planetary orbits - also called Lagrange points – where the “tug” of gravity from the Sun and planet balance out. Objects there tend to stay there



Trojan points of Jupiter



Asteroids get trapped along Jupiter's orbit

- One asteroid found at Earth's Trojan point. See 162 webpage