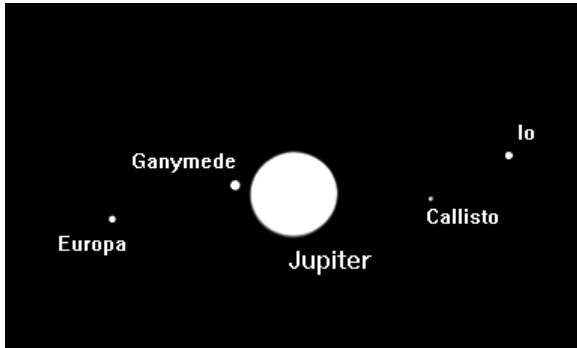


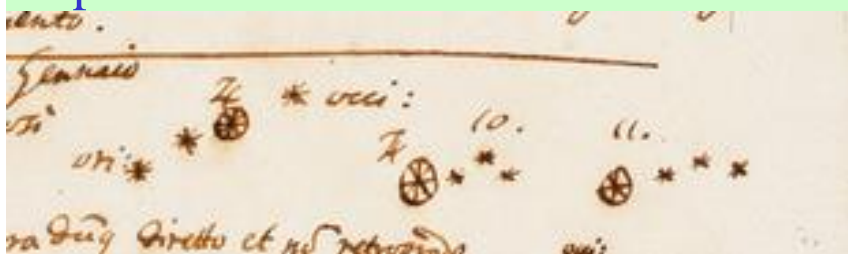
Galileo – Telescope - 1610

- 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

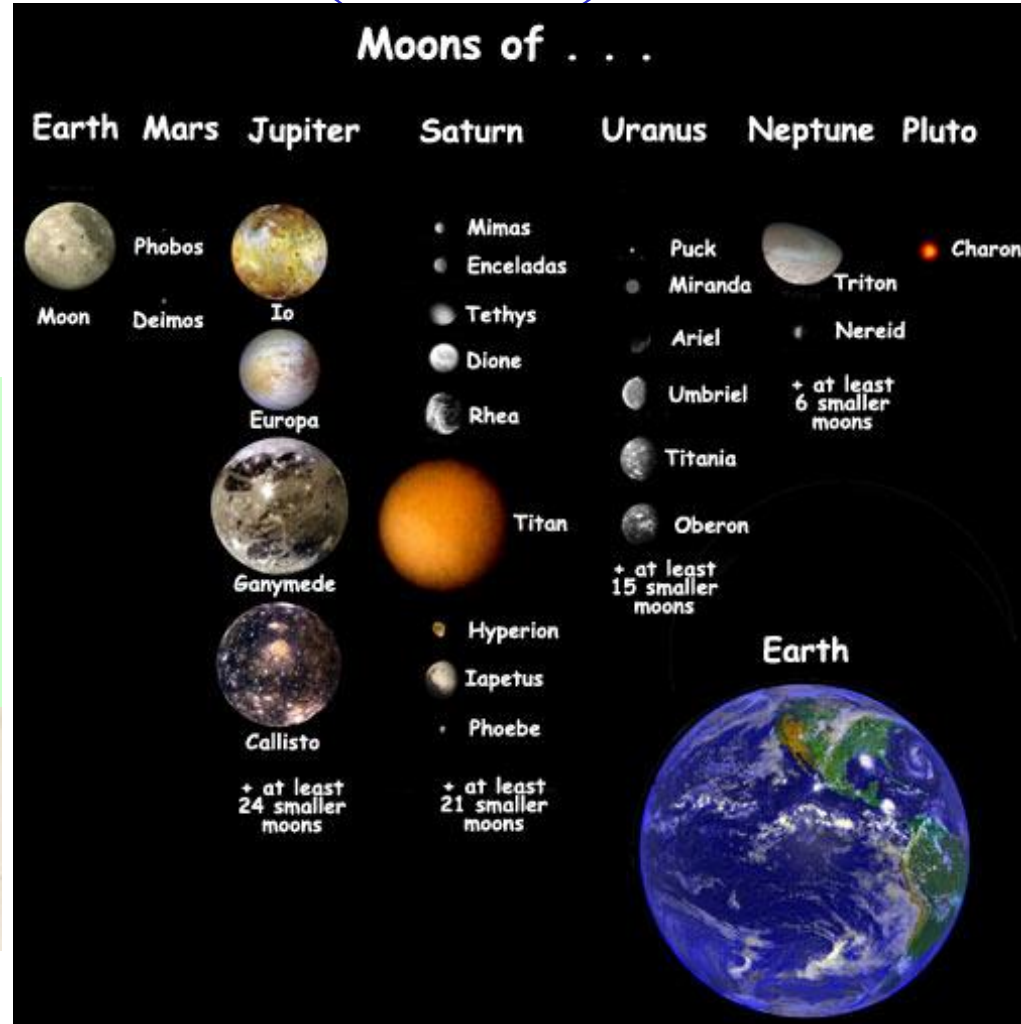
Jupiter's Moons (1610)



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



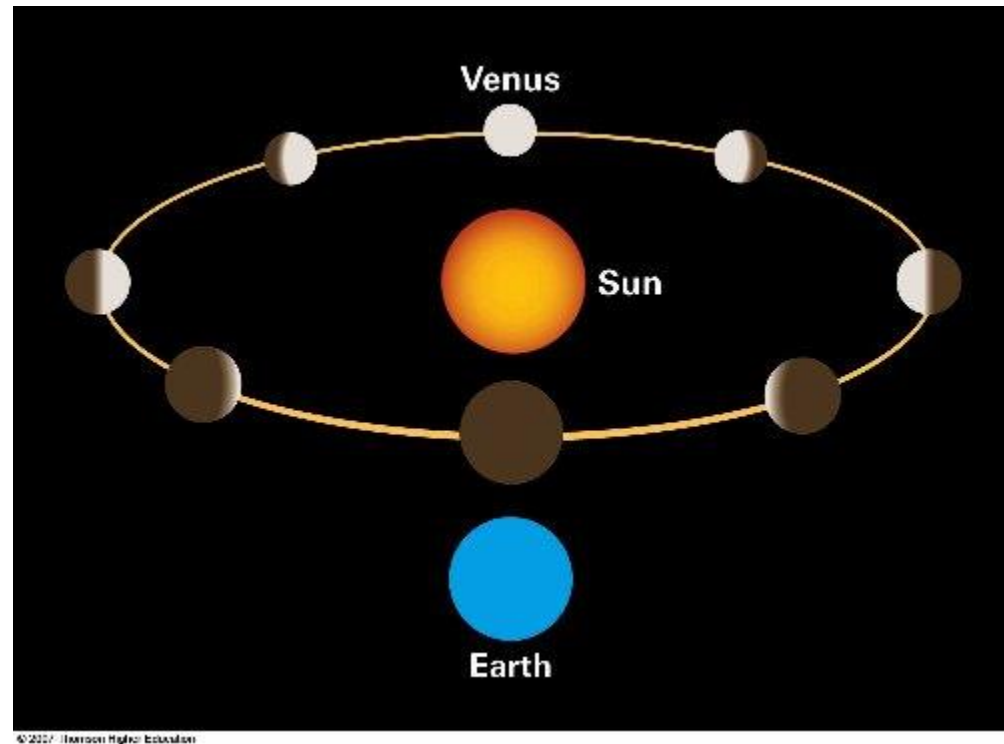
More discovered: Pluto now has 4 moons
 Saturn 83, Jupiter 80, Uranus 27, Neptune 14
 - confirmed, a few more are provisional

Quasi-satellites of Earth

The Earth may have more than one moon (!!). Five quasi-satellites have been observed recently which may or may not have stable orbits about the Earth. They are either captured asteroids or chunks of the Moon thrown out when an asteroid hit the Moon's surface. Best known is Kamo'oalewa discovered in 2016 at telescope on Maui which may be a moon fragment; it is 41 meters in diameter. See Wikipedia or Science News December 18, 2021.



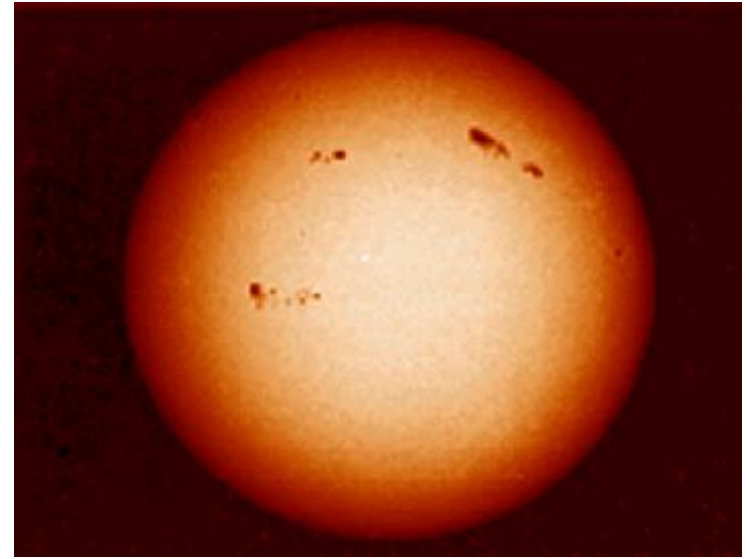
Phases of Venus (1610)



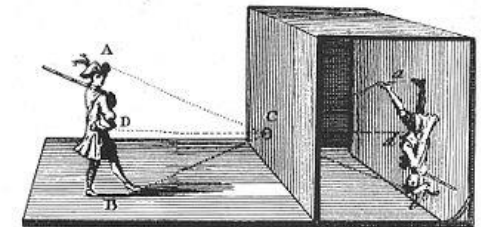
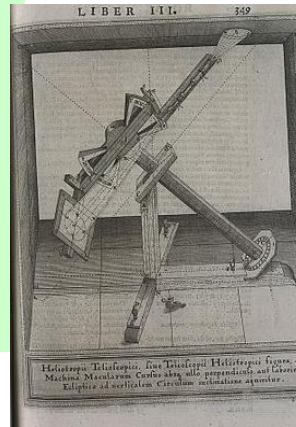
Venus has phases like the Moon which are easily explained by having it orbit the Sun and impossible to explain if the Earth was at the center of the Solar System

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 Fabricius 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. Note in lecture 1 slide 25 is a helioscope used in eclipse pinhole camera



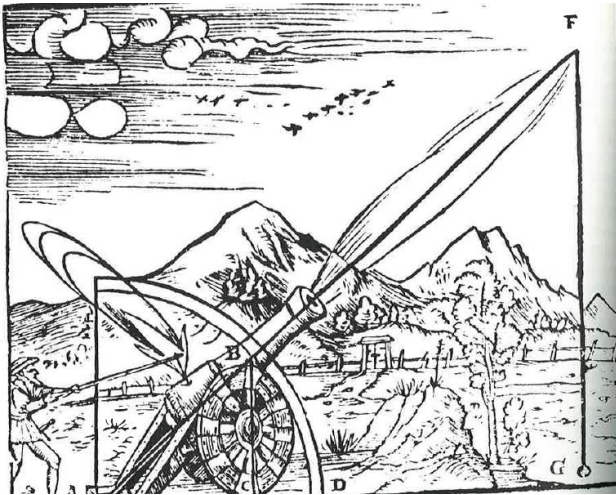
→ Sun isn't "perfect", unpredictable, and rotates like Earth

Galileo and the physics of motion

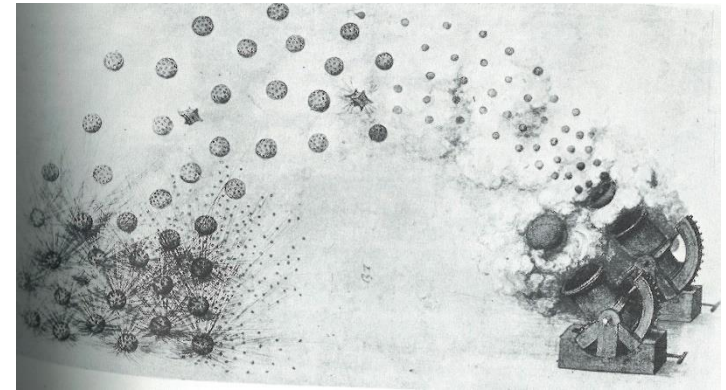
Studies of motion important: planetary orbits, cannonball accuracy, basic physics. Galileo among first to make careful observations, develop concepts

- velocity, acceleration, effects of friction
- pendulums, try to use as clock (Galileo observed swinging of objects during 3 hour long Catholic 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

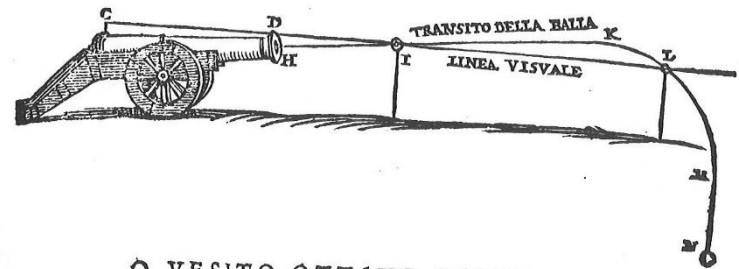


~1480
gunner's
manual.
Only
straight
lines.



Leonardo da Vinci sketch ~1500

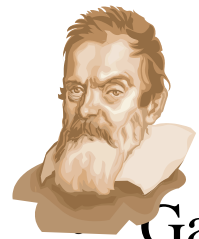
Cannons started being used in the 1300s in Europe and accuracy was critical. The physics of the day, from Aristotle, said objects on Earth move in straight line, in the “heavens” move in circles. Soon that was clearly seen to be wrong (they did not play baseball or golf in ancient Greece or Renaissance Italy). Trying to understand this was part of why Galileo studied motion



Q VESITO OTTAVO FATTO DAL
medesimo. S. Prior di Barletta.

PRIORE. Hor seguitamo la materia de hierfera. N. Hierfera (se ben mi ar
cordo) fu detto tutti gli effetti, ouer botte che puo occorrere, quando che per la
molta cortexza, ouer bassezza della mira denanti rispetto à quella de drio, la nostra

Niccolo Tartaglia analysis 1551, close to correct



Galileo and Motion and Gravity

Galileo and many of his contemporaries developed the concept of motion

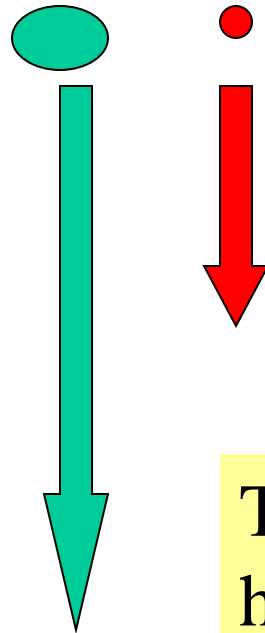
- velocity and acceleration
- importance of friction

- Galileo used inclined planes (Florence museum) to reduce friction placing bells along the device
- 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 than light objects

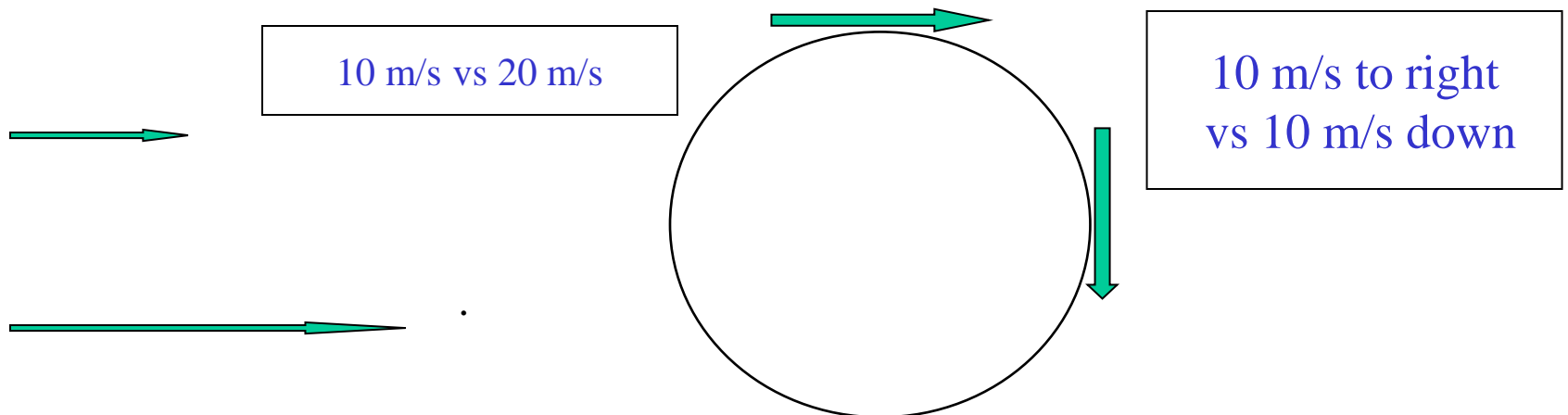
The heavier (green) ball will hit the ground before the lighter (red) ball

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

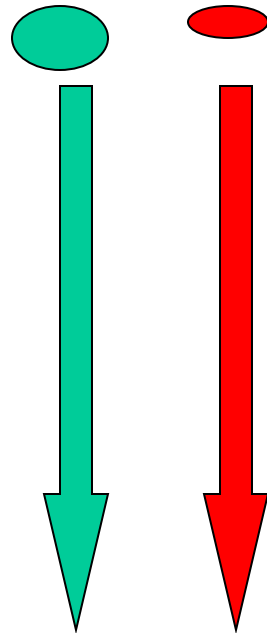
Motion: velocity and acceleration

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 fall at same rate on moon <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 laws 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.

$$F = ma \quad \text{Force} = \text{mass} \times \text{acceleration}$$

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)

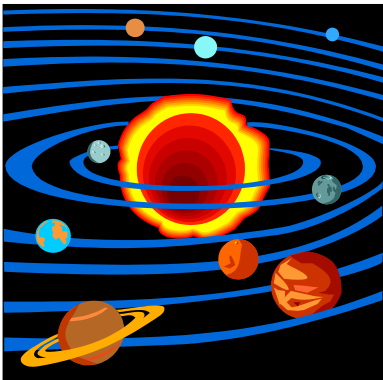
→ For this course be able to apply to Kepler's Laws

Forces in Nature

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

Gravity

- the first force to be understood was gravity
- Newton used results from Galileo, Kepler and others on motion on Earth's surface and orbits of the planets
- gave simple relationship for gravitational force between 2 objects separated by distance R



$$F = G \frac{mass_1 mass_2}{R^2}$$



Gravity (Newton)

- 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

- 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

$$F_A = G m_A m_{\text{Earth}} / r_{\text{Earth}}^2$$

- 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 $= G m_{\text{Earth}} / r_{\text{Earth}}^2$
- 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

$$g = G \frac{m_{\text{planet}}}{r_{\text{planet}}^2}$$

- different planets → different surface gravity
- Mars: mass = 0.11 mass(Earth) and radius = 0.53 radius(Earth)
- so $g(\text{mars}) = .11/.53^2 g(\text{Earth})$ 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

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

- as $a = F/m = G m_{\text{Sun}} / D^2$ 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

$D^3 = (M_{\text{sun}} + M_{\text{planet}}) \times P^2$ 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 periods → 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>

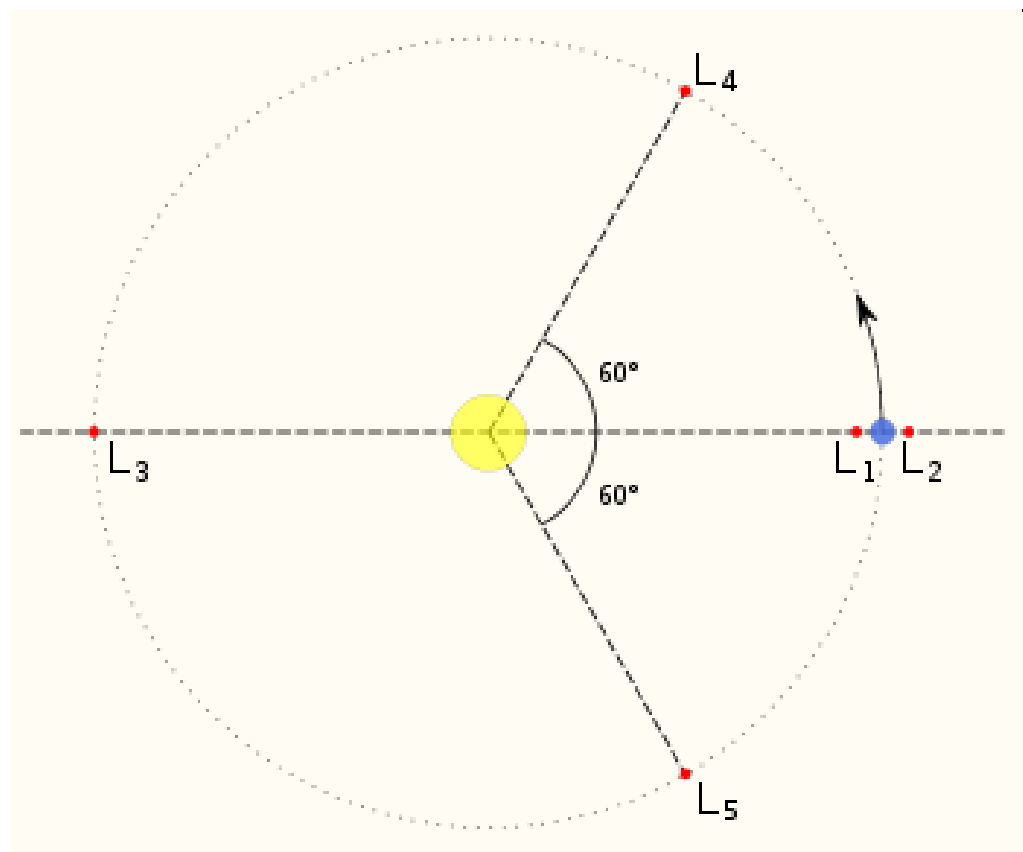
Lecture Feedback

E-mail me a few sentences describing one topic you learned from this set of presentations. Please also include the phrase “Galileo observed that objects of different masses fall at the same rate which was then proven by Newton’s theories.” after your mini-report but do not use that as your “one topic”.

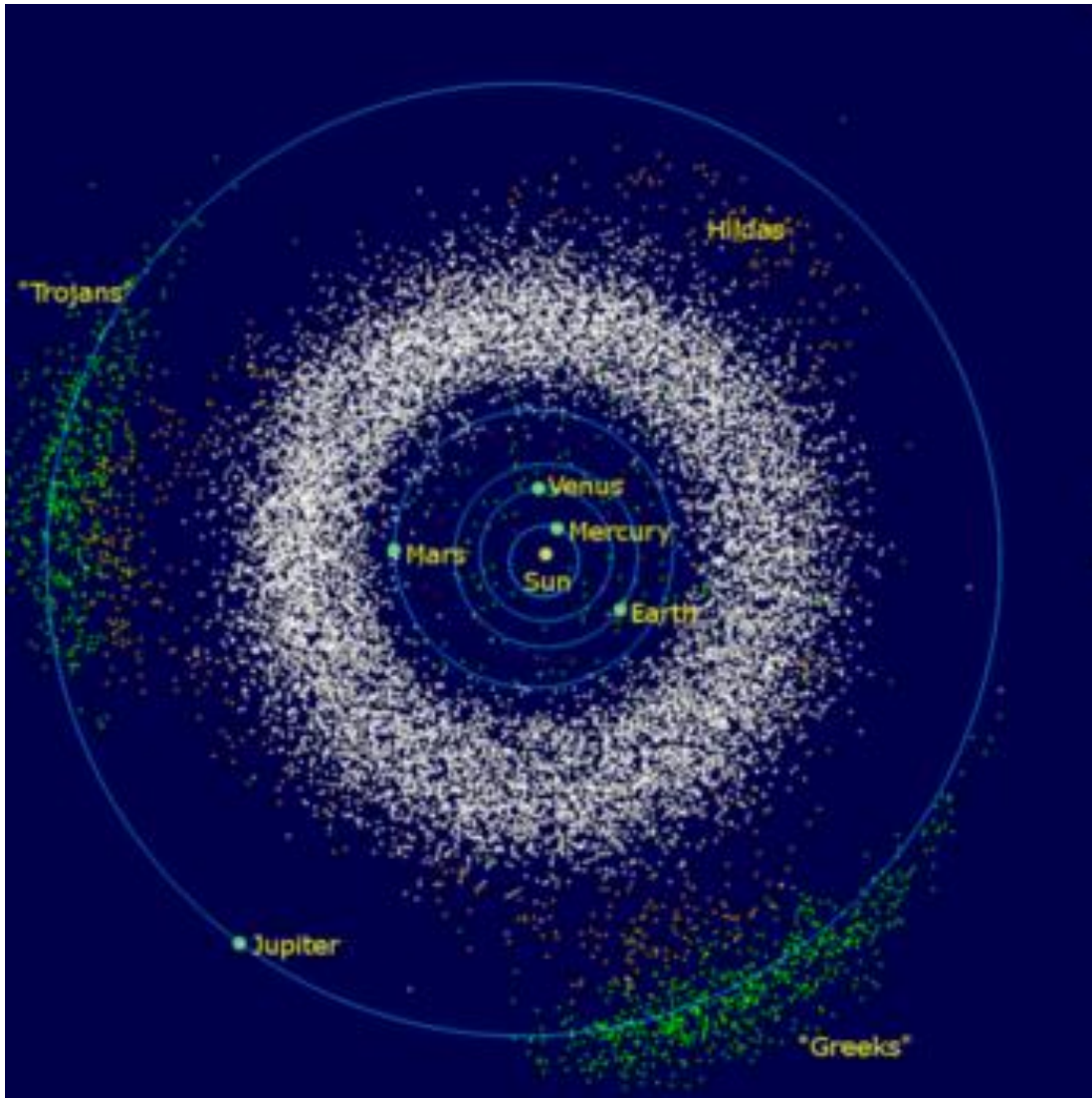
Extra Slides

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

At least 2 asteroids found at Earth's L4 Trojan point. Few km in size and will stay in that orbit for at least a few thousand years.