Kepler → Galileo and Newton

- Kepler: determined the motion of the planets.
- Understanding this motion was determined by physicists like Galileo and Newton and many others.
- Needed to develop Physics as a science: understand motion, forces, and gravity

Reminder: Kepler Three Laws

- 1: Planets orbit the Sun in ellipses with the Sun at one focus
- 2:The orbit of the planets sweep out eual area in equal time → move faster when closer to the Sun
- 3:The square of a planet's period is proportional to the cube of the length of the orbit's semimajor axis, T^2/a^3 = constant. Example: Mars. A=1.524 AU and T=1.881 years. (1.881*1.881) = 3.5 = (1.524*1.524*1.534)

The constant for 3: is the same for all objects orbiting the Sun → same process determines all planets' motions

Galileo 1564-1642

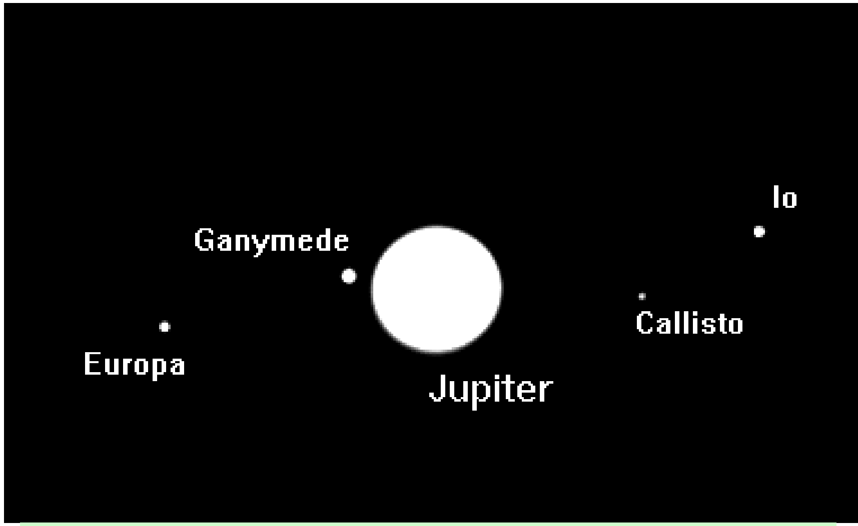
- Professor of art, mathematics, natural philosophy, astronomy in Florence, Pisa, Padua with occasional "contract" work for various Dukes, etc
- Very strong proponent of the scientific method – use of observations to test theories
- Early work:motion, and practical elements like hydrostatics
- 1609: first person to use a telescope for astronomy → became the most famous scientist/celebrity in Europe
- Last 25 years of life was often in trouble with the Catholic Church. His celebrity helped to save him

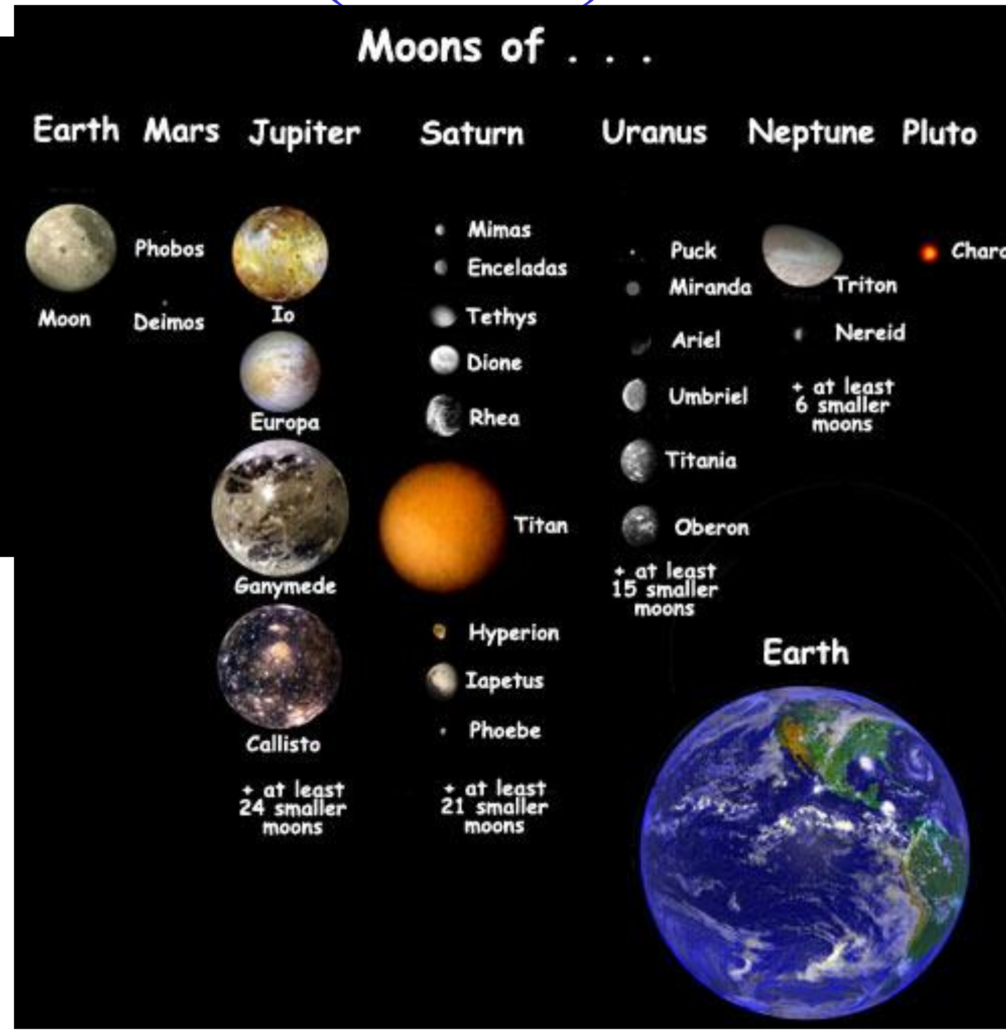
Galileo – Telescope - 1610

- Jupiter had at least 4 moons which circled it (something besides Earth could be the center of motion); there were many more stars, mountains on moon → Book Starry Messenger
- Venus had definite phases and clearly orbiting Sun
- Observed sunspots (patches on Sun). Sun revolved on own axis. Wasn't "perfect" and changes in unpredictable manner
- Observed Saturn's rings but was confused as to what they were
- Wrote book on Copernican vs Ptolemaic models in 1632, nominally with Church's permission. But it offended Church. Dialogue Concerning the Two Chief World Systems. In Italian. Character in book Simplicio defended Church's position

→ spent last 10 years of his life in house arrest. Catholic church said contrary to scriptures……Church admits in error in 1992

Jupiter's Moons (1610)



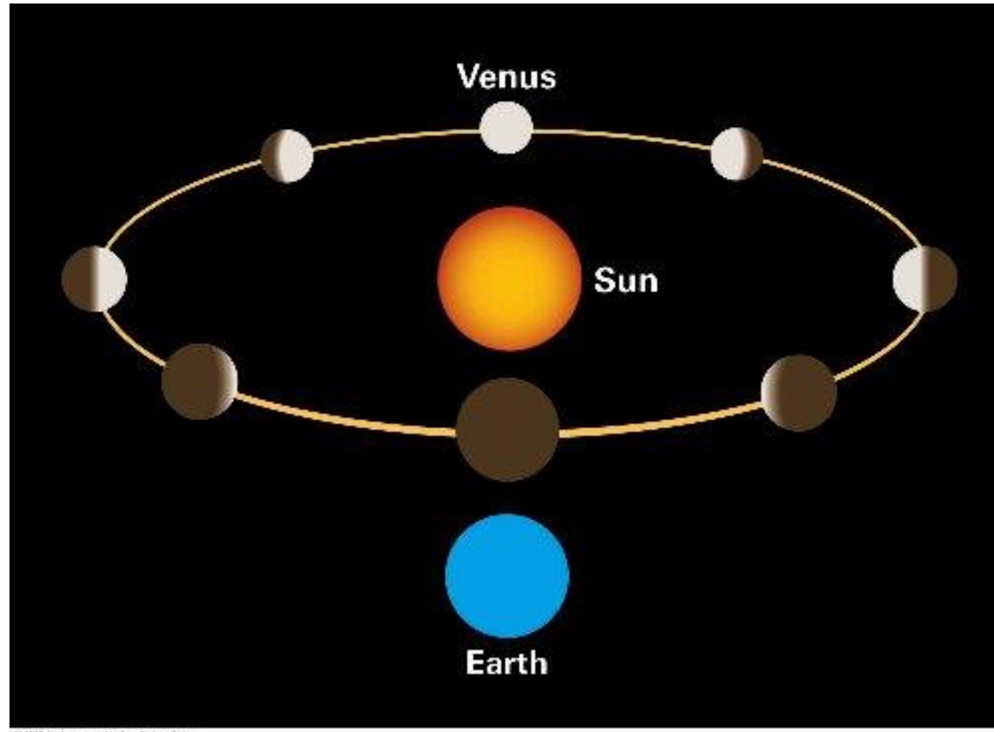


4 moons can be seen with a small telescope. Change position with time → how long it takes to go around vs distance from Jupiter

Clearly something besides the Earth was the center of motion

More discovered: Pluto now has 4 moons

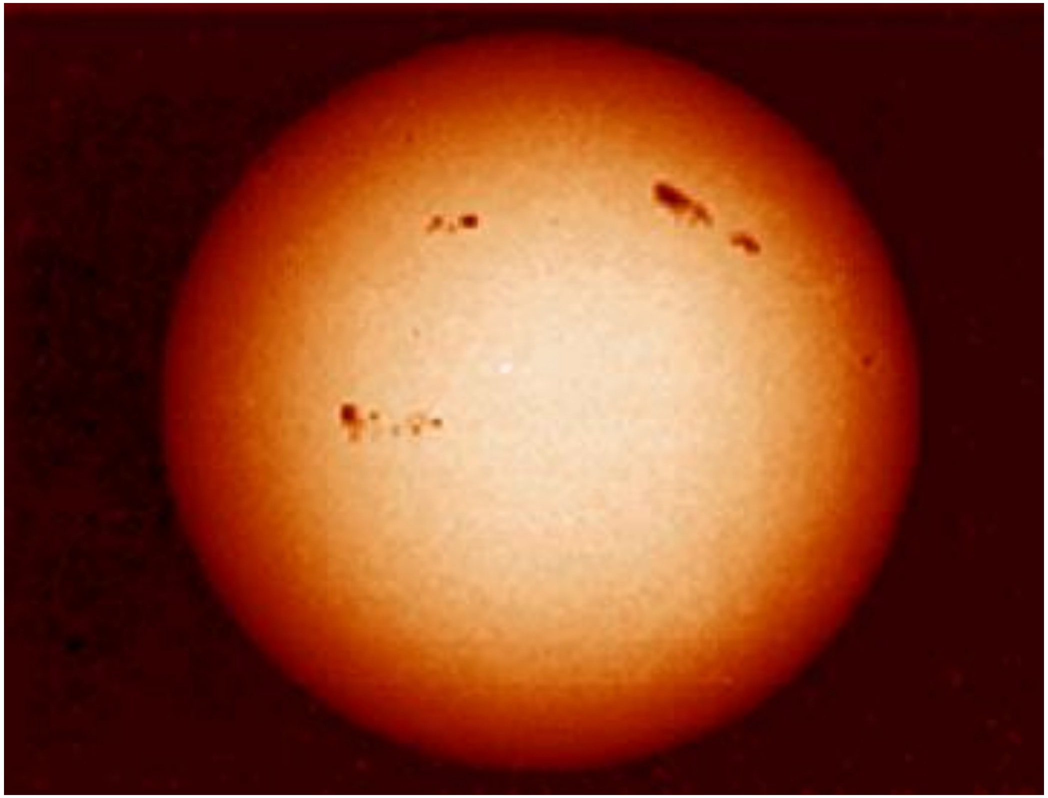
Phases of Venus (1610)



Venus has phases like the Moon easily explained if orbits Sun impossible to explain if Earth at center of the Solar System

Sunspots

Sunspots now known to be magnetic storms. Allows rotation of Sun to be observed. Seen without telescopes before Galileo but his observations were of higher quality and showed Sun's 25 day rotation



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

Galileo and the physics of motion

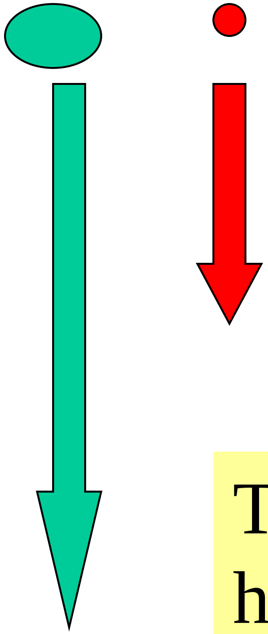
Studies of motion important : planetary orbits, cannonball accuracy, basic physics. Galileo among first to make careful observations, develop concepts

- velocity, acceleration, effects of friction
- pendulums, use as clock
- rate at which objects fall do not depend on their mass (ignoring friction)
- acceleration of falling bodies is a constant

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
- and (perhaps) the Leaning Tower in Pisa

Speed vs Mass



according to Aristotle, heavier objects fall faster then light objects

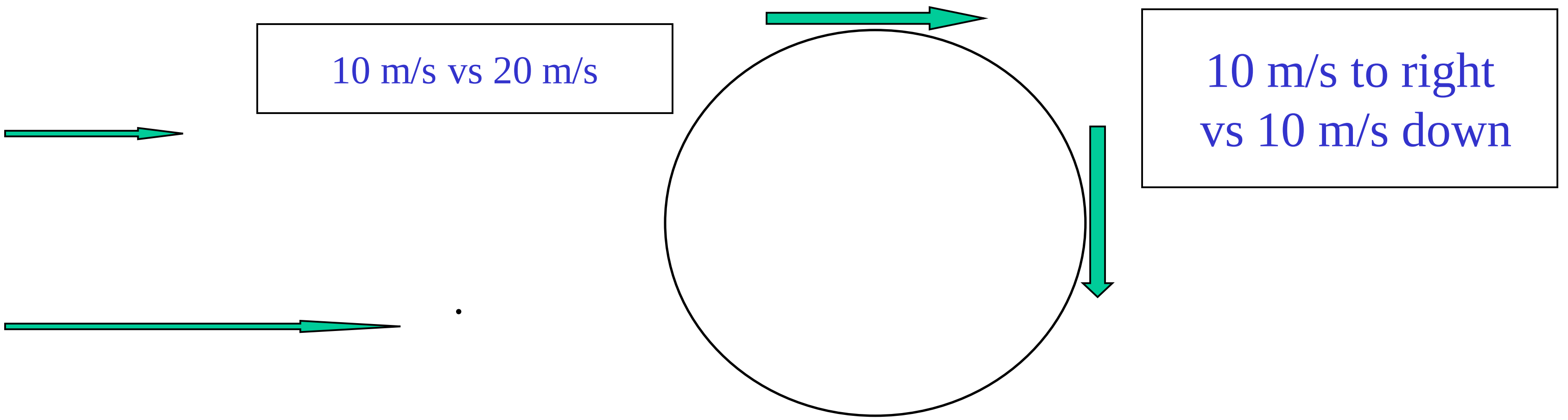
The heavier (green) ball will hit the ground before the lighter (red) ball

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

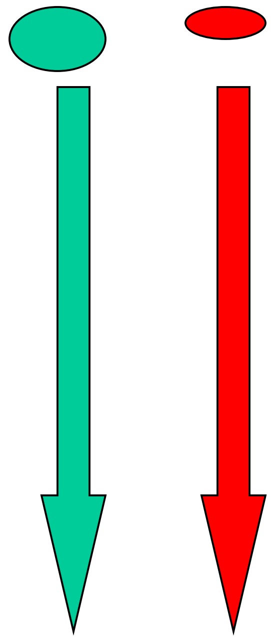
Motion: velocity and acceleration

MOTION: concepts

- acceleration = change in velocity either speed or direction. acc = dv/dt change in velocity per unit time
- 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

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

Theories based on experimental observations are best way to do science.

see http://nicadd.niu.edu/~hedin/Galileo.htm for a fake news story and some background on the history

Physics of Motion before Newton

- Galileo, Kepler, and other had started the investigation of motion
- Looked at velocity, acceleration, effects of friction
- rate at which objects fall do not depend on their mass (ignoring friction)
- found that acceleration of falling bodies is a constant
- Kepler's 3 Laws of planetary motion

Newton 1642-1727 : Motion and Gravity

MOTION: concepts and tools

- Calculus: mathematical tool to relate acceleration to velocity to position
- 3 law's of motion to relate acceleration to the applied force
- form for gravitational force

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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)

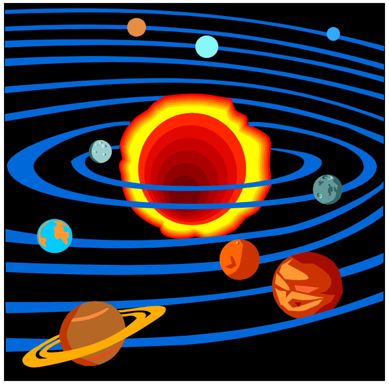
→ For this course be able to apply to Kepler's Laws

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)

- 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 distance increases
- Is 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 → all objects have same acceleration (Galileo). Does depend on mass, radius of Earth
- G is universal constant

Surface Gravity

- Acceleration due to gravity at the surface of planet

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

- 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 from given planet (or moon) and what type of atmosphere planets have

Planetary Orbits

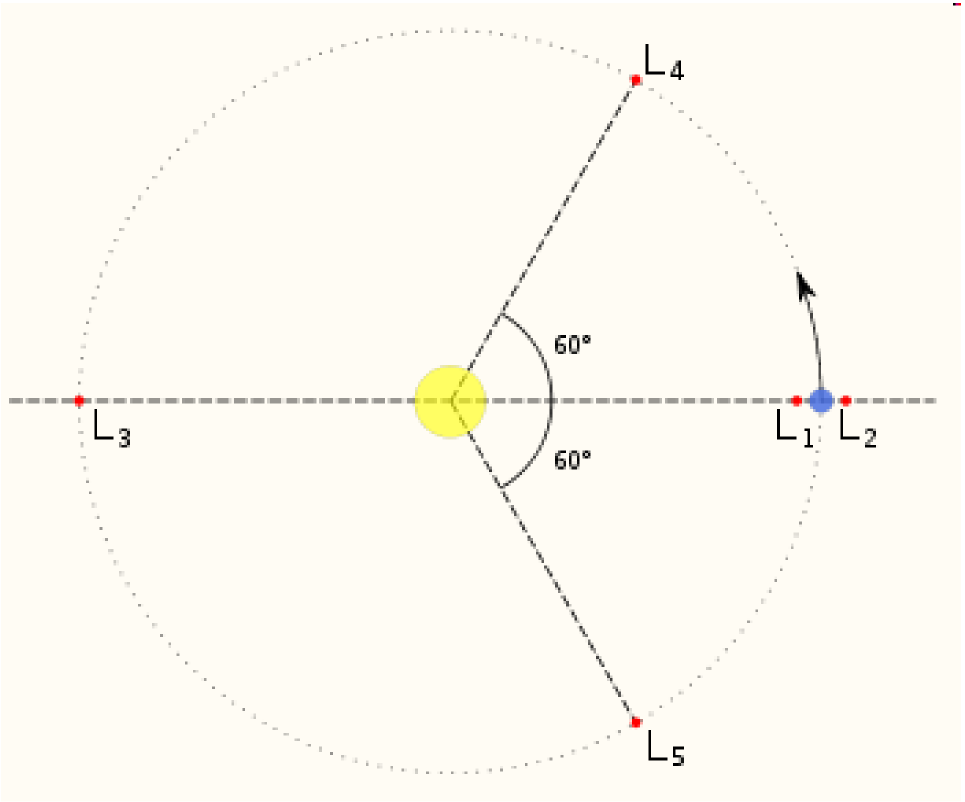
- Gravitational force between Sun and planets causes orbits with D being the planet's distance from the Sun

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

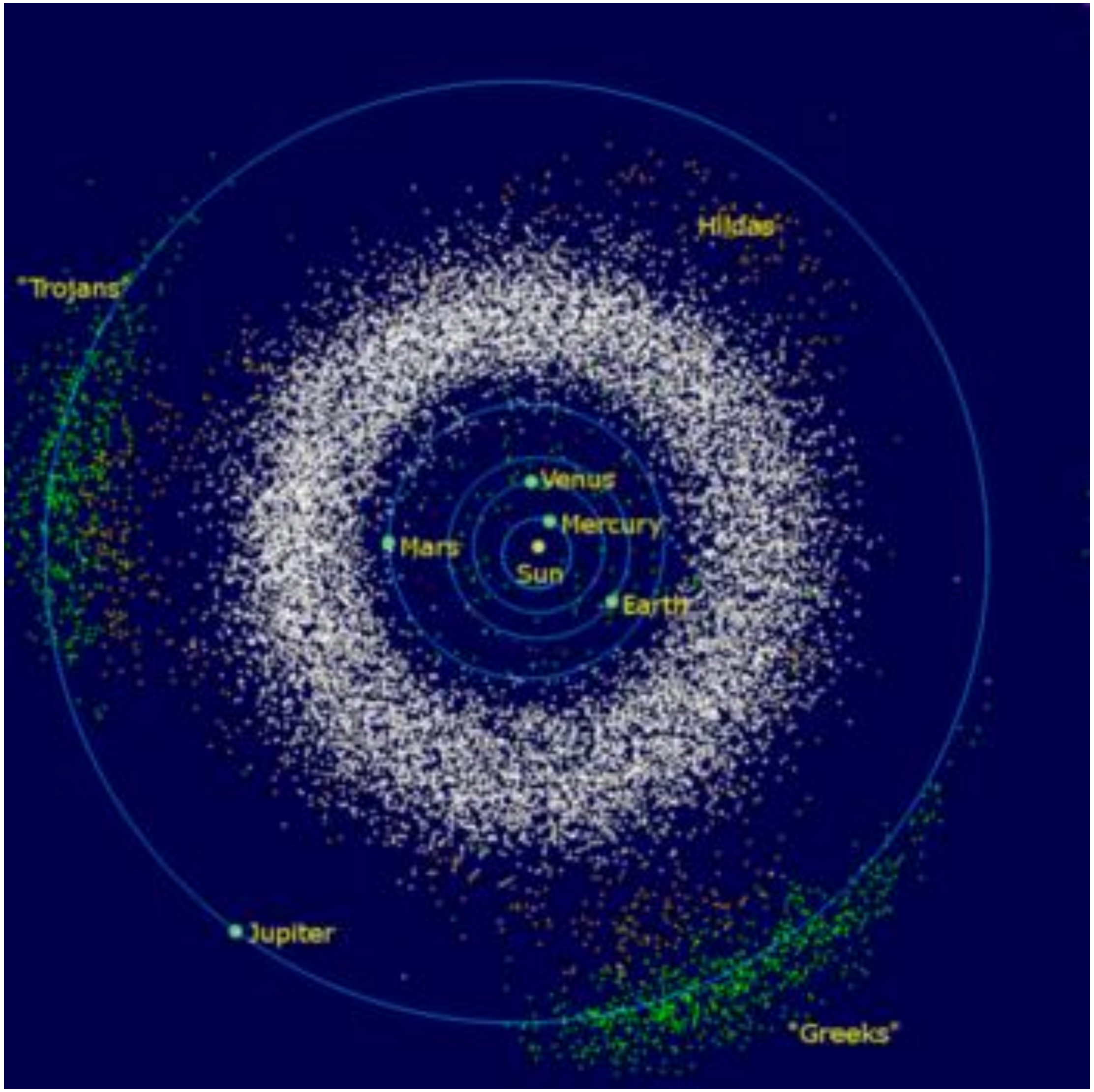
- as $a = F/m = G\, m_{Sun}/D^2$ does not depend on the planet's mass, all objects the same distance from the Sun will have the same orbits
- Also true for orbits around other objects (Earth, Jupiter) - means satellites around Earth can have similar orbits even if different masses

Planetary Orbits – Trojan points

- have stable points in planetary orbits - also called Lagrange points



Trojan points of Jupiter



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

Kepler's Laws

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

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

D=distance from Sun and P=period

→ weaker force further away gives longer period

- As mass Sun much larger can mostly ignore mass planet (but Sun does move slightly due to planet's pull)

Orbital Periods

- Study orbital preriods → get 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