Review: Movie – Cosmic Voyage

Looks at the Universe

→ First: increasing distance scales. to billions of light-years

→ Second: decreasing distance scales. to subnuclear scales

Looks at time evolution of the Universe over billions of years

→ Telescopes which look out very far away are looking back in time

→ Particle accelerators like Fermilab are reproducing how the Universe looked in the first moments after creation

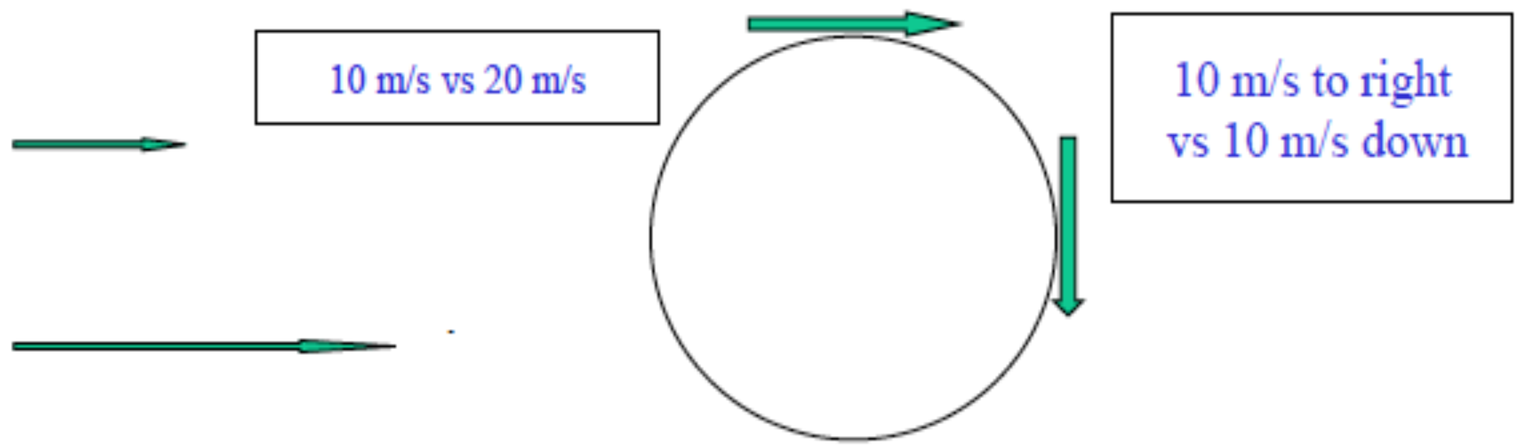
Review

- Retrograde motion of planets…
- Geocentric and heliocentric models … what were the main features
- What is parallax
- Copernicus
- Kepler's laws
- What phases of the moon are
- What the motion of the moon is around the Earth
- What the motion of the Earth is around the Sun, and its rotation around its own axis AND what is the orientation of that axis to the ecliptic (plane of the Earths' orbit around the Sun).
- Look at conic sections

Motion: velocity, speed 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



Third Law Example

- $(\text{Distance})^3$ = constant X $(\text{Period})^2$ such that

  $D1^3/T1^2 = D2^3/T2^2$ If one of the planets is Earth,

  D1 = 1 AU T1 = 1 year than constant =
- Jupiter compared to Earth
- If we measure that it takes Jupiter 11.9 years to orbit the Sun then:

distance ^{3}(Jupiter-Sun) = period^2

distance = period$^{2/3}$

distance = $(11.9*11.9)^{1/3}$

distance = $(142)^{1/3}$ = 5.2 AU

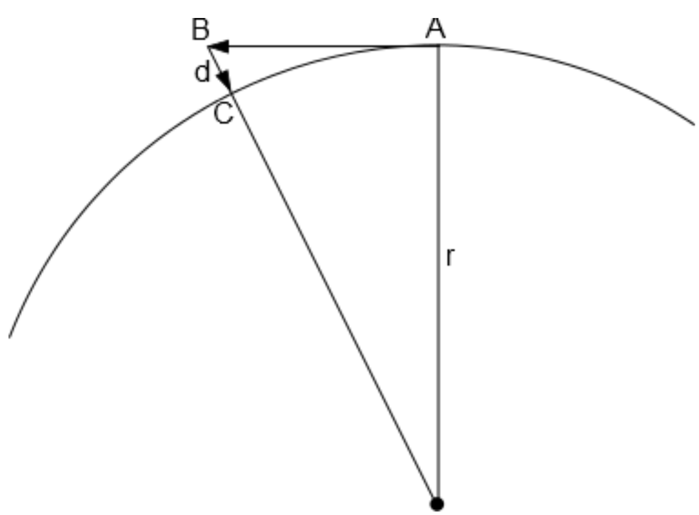
Newton and Kepler (2)…

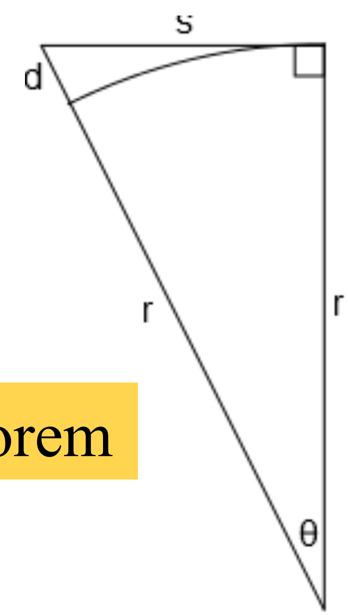
- When you combine Newton's gravitation and circular acceleration, which must balance in order for the object to remain in orbit, you get a nice relation between the period, distance, and mass of the central body.
  - $F_{grav} = F_{cent}$ → equate gravitational force to centripetal force
  - $F_{grav} = G\, m_1\, m_2 / r^2$
  - $F_{cent} = m_2\, V^2 / r$
- Let the Earth be m_1 and the Moon be m_2. For **circular motion** the distance r is the semi-major axis A.
  - $V = 2\, \pi\, A / T$ → T = period of moon → $\mathbf{G\, m_1\, m_2 / A^2 = m_2\, V^2 / A}$
  - $G\, m_1 / A^2 = ((2\, \pi\, A)^2 / T^2) / A$ → note that m_2's cancel!
- Rearrange to place all the A terms on the right and all the T terms on the left:
  - $G\, m_1 / (4\, \pi^2)\, T^2 = A^3$ Looks just like **Kepler's Third Law**!
- To use A and P to solve for mass:
  - $m_1 = A^3\, (4\, \pi^2 / G) / T^2$

Basic Physics: Centripetal Acceleration

For uniform, circular motion…

- **Direction:** Symmetry arguments. If the acceleration pointed in any direction other than perpendicular (left or right) then the body would speed up or slow down. It doesn't.
- **Magnitude:** Newton saw that in circular motion, there are two simultaneous, superimposed motions: (1) A straight-line motion, and(2) an accelerating motion toward the center.





Pythagorean theorem

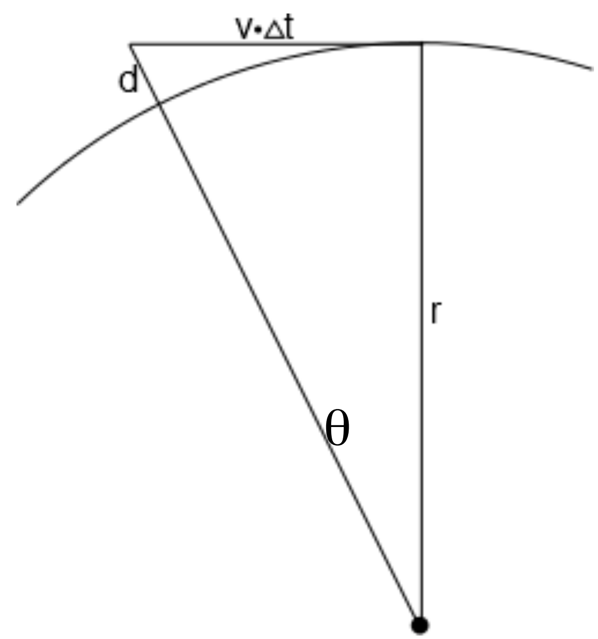
- **Small angle:** $r^2+s^2=(r+d)^2=r^2+2rd+d^2$

Centripetal Acceleration (con't)

For uniform, circular motion…

- **Solve for d:** $d=s^2/2r - d^2/2r$
- **Here is a bit of calculus:** Newton and Leibnitz developed calculus separately, basically infinitesimal is NOT = zero! (M.A.C.'s view)

$$\frac{\lim}{\theta \to 0} d = \frac{s^2}{2r}$$



- **From kinematics:** $d = \frac{1}{2}\,\mathbf{a}\,(\Delta t)^2$
- **From geometry:** $d = s^2/2r = (v*\Delta t)^2/2r$

  $d = \frac{1}{2}\,(\mathbf{v^2/r})\,(\Delta t)^2$

$$\rightarrow \quad a = \frac{v^2}{r}$$

Kepler → Galileo and Newton

- Kepler correctly determined the motion of the planets.
- Did not address WHY. Simply what curve best matched orbits and some arithmetical relationships
- The WHY was determined by physicists like Galileo and Newton and many others.
- Needed to develop Physics as a science: understand motion, forces, and gravity

Galileo 1564-1642

First person to really use a telescope (roughly 30 power) for astronomical purposes. Confirmed Sun at center of Solar system

- Jupiter had at least 4 moons which circled it (something besides Earth could be the center of motion)
- There were many more stars
- 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

→ spent last 10 years of his life in house arrest for stating Sun was at center (Catholic church said contrary to scriptures)

Galileo 1564-1642 (con't)

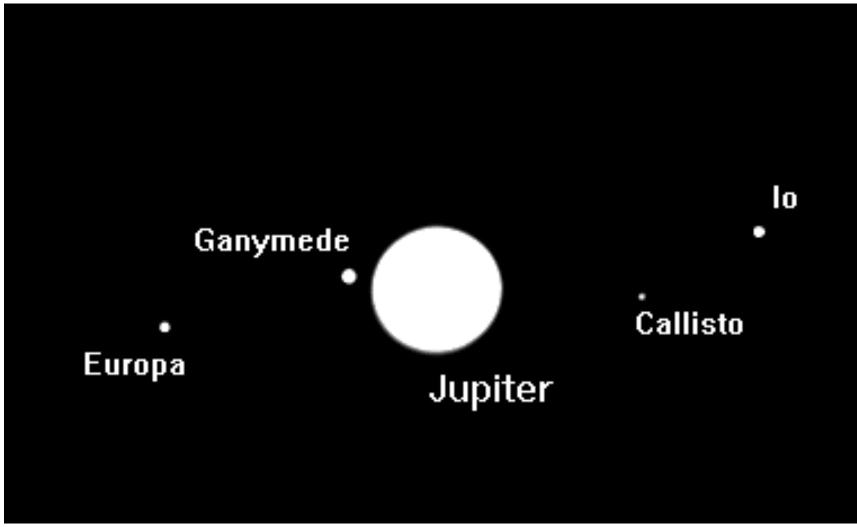
- Was professor of art, mathematics, natural philosophy and astronomy in Florence, Pisa and Padua.
- Very strong proponent of the scientific method – use of observations to test theories.
- Early work was on motion, and practical elements like hydrostatics
- In 1609 was the first one to use a telescope for astronomy => became the most famous scientist/celebrity in Europe
- Last 30 years of his life was often in trouble with the Catholic Church. His celebrity helped to save him.

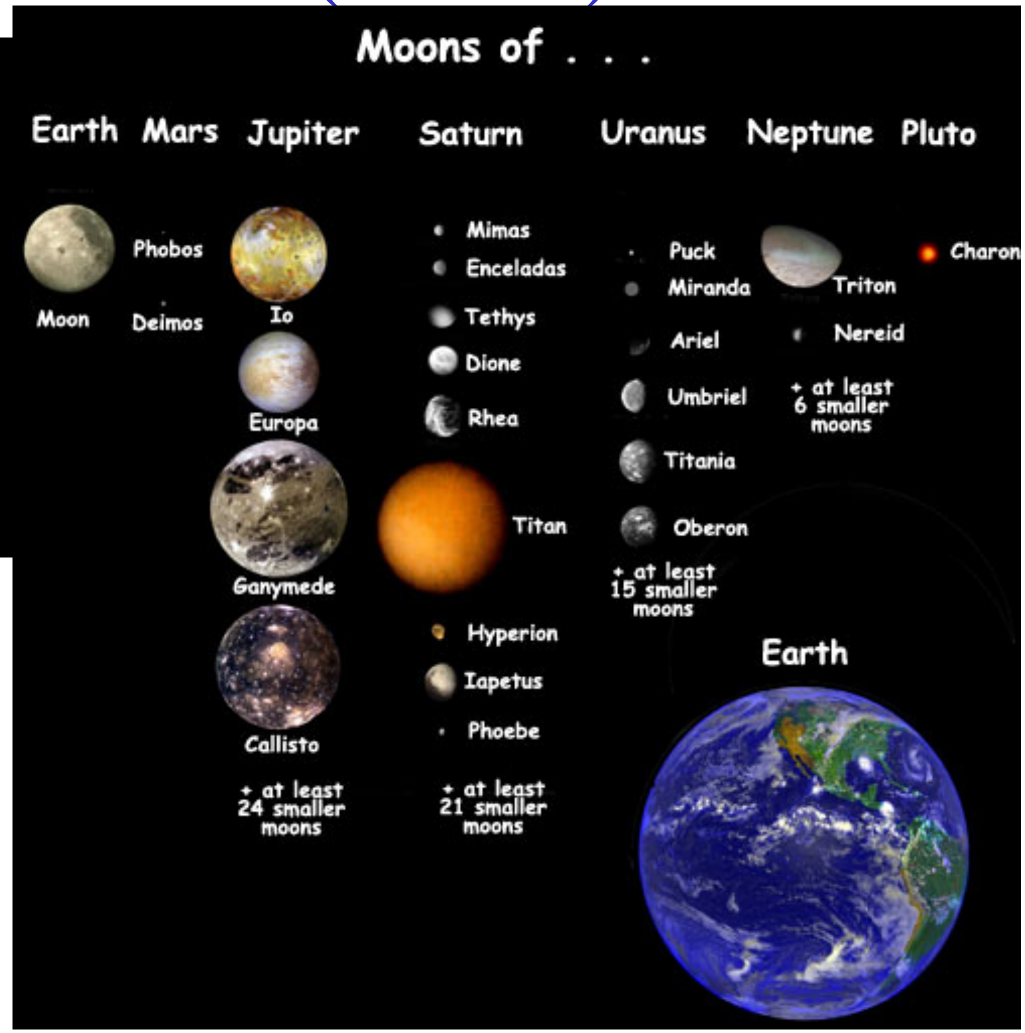
Galileo and the Telescope

- Jupiter had at least 4 moons which circled around it (something besides Earth could be at the center of motion)
- There were many more stars
- Venus had definite phases and was clearly orbiting the
- Observed Saturn's rings, but didn't understand what they were
- Observed sunspots on the sun, that the sun revolved on its own axis – wasn't "perfect" and changed in unpredictable ways
- Wrote book on Copernican vs. Ptolemaic models in 1632, nominally with the Church's permission. But it offended the Church (Simplicio was the Church's defender).

Spent last years of his under house arrest for stating that the Sun was at the center of the "universe" (solar system) CONTRARY to Scriptures

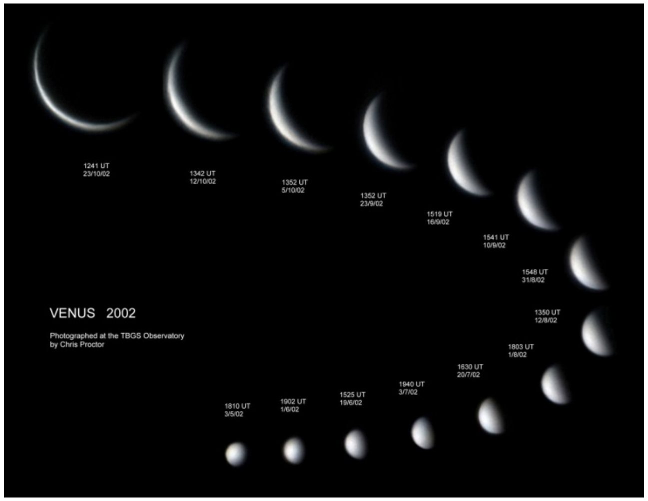
Jupiter's Moons (1610)

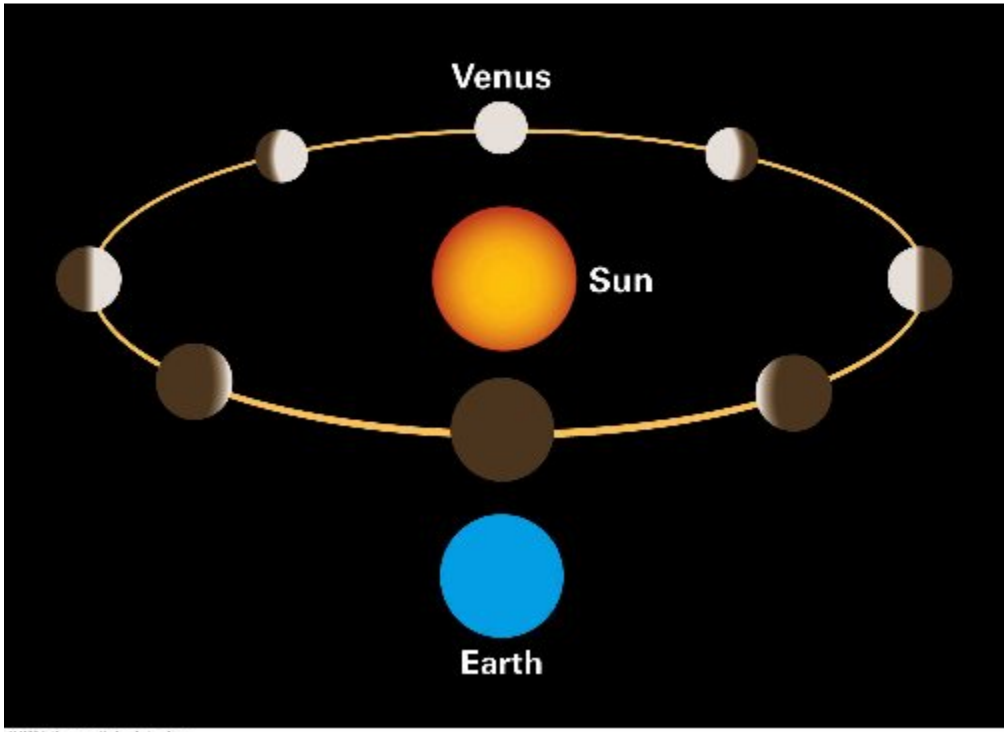




4 moons can be seen with a small telescope. Change position with time → how long it takes to go around vs distance from Jupiter

Phases of Venus (1610)

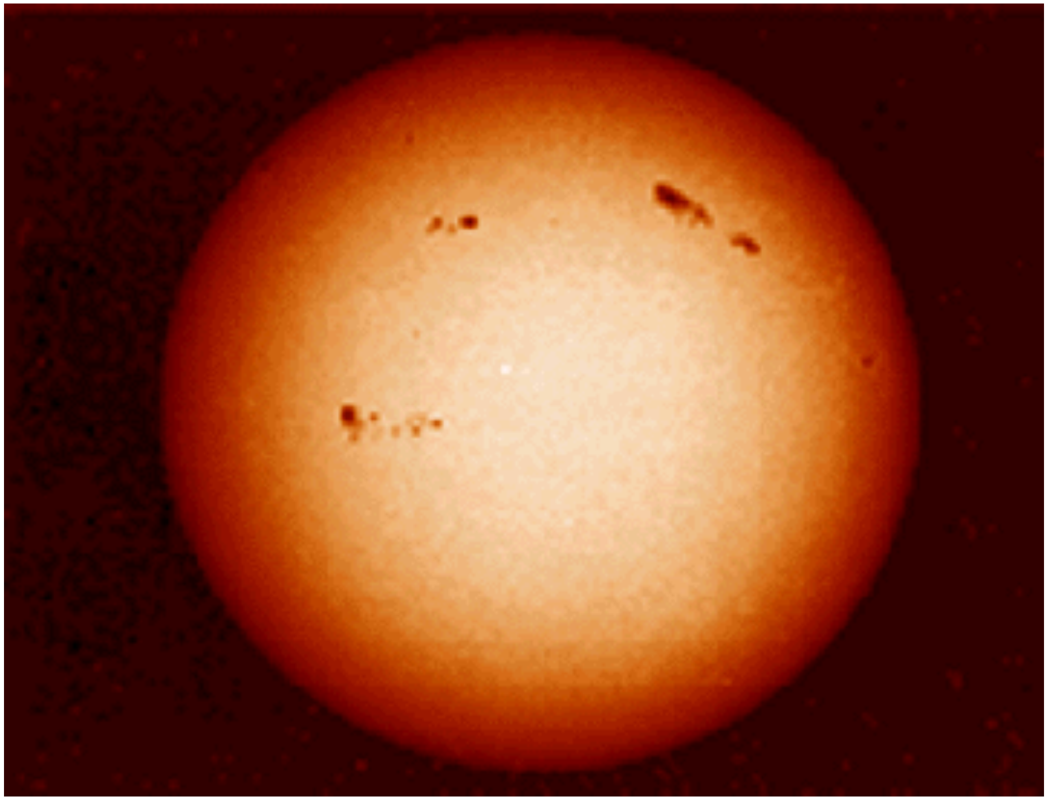




Venus has phases like the Moon which are easily explained by having it orbit the Sun and impossible to explain if the Earth was at the center of the Solar System

Sunspots

Sunspots are now known to be magnetic storms. Allows the rotation of the Sun to be readily observed.



Galileo and the physics of motion

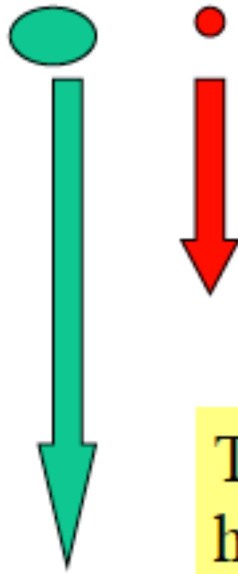
Studies of motion important : planetary orbits, cannonball accuracy, basic physics. Galileo among first to make careful observations, develop concepts

- Looked at velocity, acceleration, effects of friction
- studies pendulums, use as clock
- rate at which objects fall do not depend on their mass (ignoring friction)
- found that 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

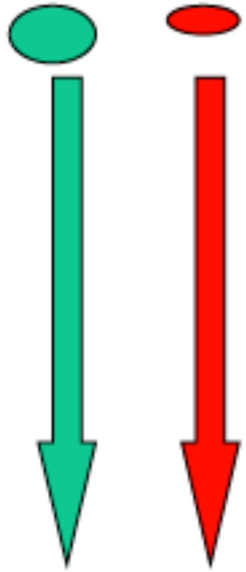


according to Aristotle, heavier objects fall faster then light objects

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

Speed vs Mass vs Acceleration



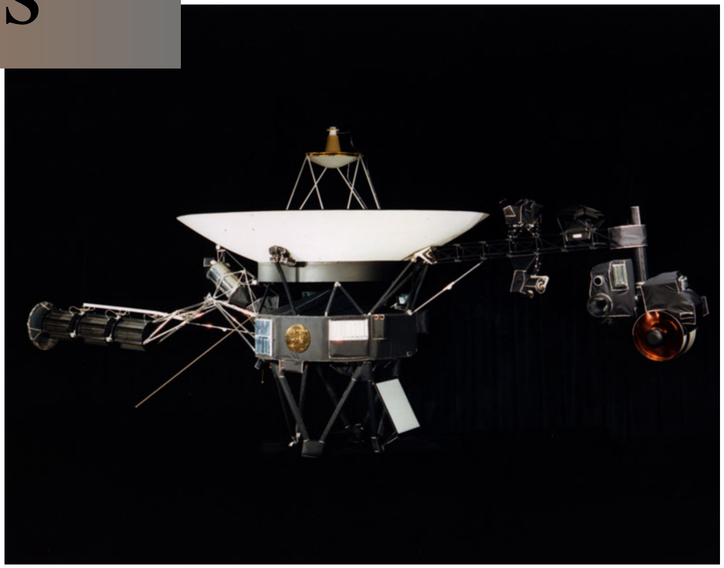
Experiments done by Galileo and others showed that the heavier (green) ball and the lighter (red) ball hit the ground at the same time

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

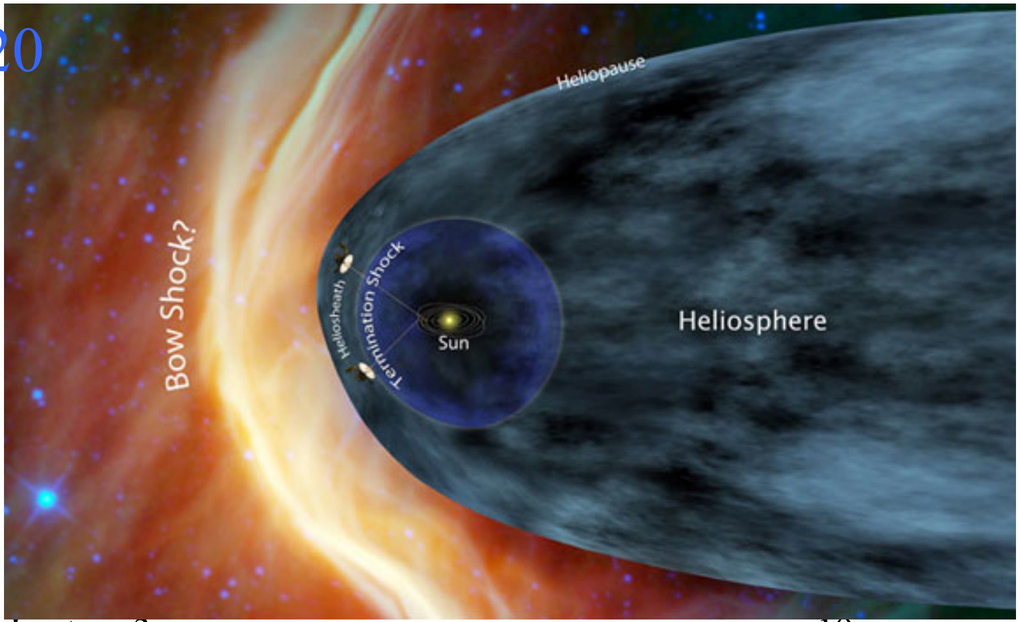
Theories based on experimental observations are best way to do science.

Go to http://nicadd.niu.edu/~macc/Galileo.htm for a fake news story, and some historical background.

Voyager Recent Updates

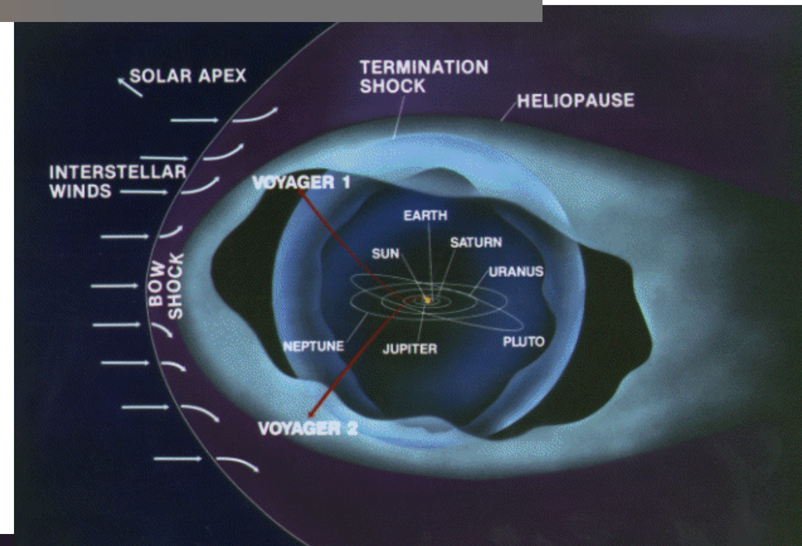


- Is leaving the solar system..
  - What does that mean?
  - What is the heliosphere?
- Launched 35 years ago…
  - 30 years more than originally planned
  - Will be able to run until 2020
- Costs
  - $845 Million
- Earth Info (Golden Disks)
  - Greetings in 55 languages
  - Music
  - Human DNA

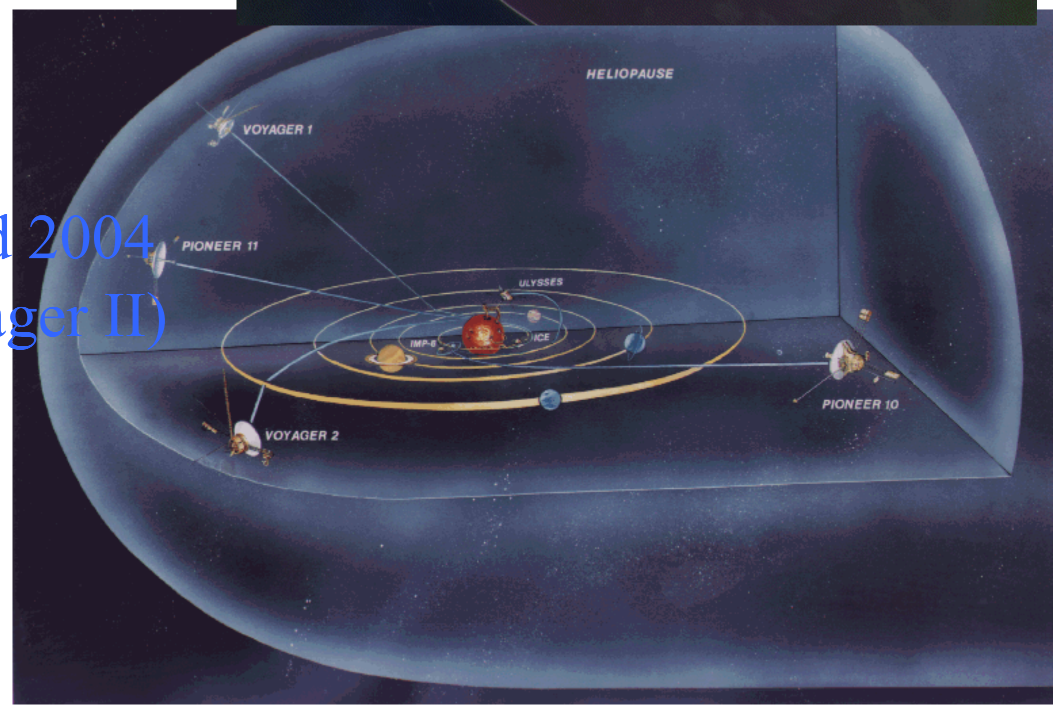


Voyager Interstellar Mission

- First Voyager mission completed in 1989
  - Voyager I: Jupiter, Saturn fly-bys
  - Voyager II: Jupiter, Saturn, Uranus, Neptune fly-bys

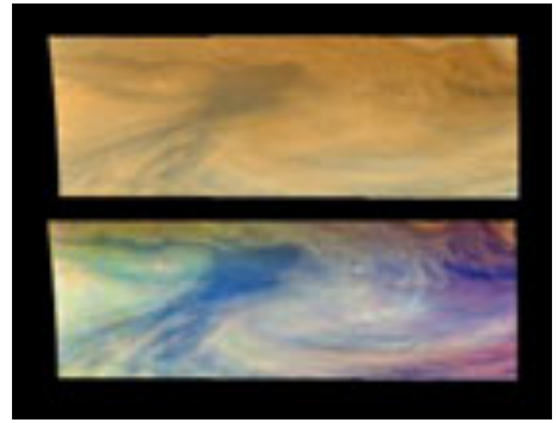


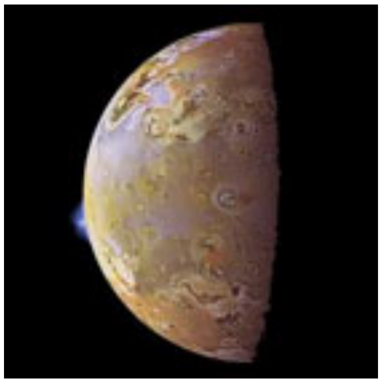
- Three Phases
  - Termination shock (ended 2004 Voyager I and 2007 Voyager II)
  - Heliosheath exploration
  - Interstellar



Galileo Mission

- Launch date: Oct 18 1989
- Ended Sept 21 2003 (plunged into Jupiter)
- 34 Orbits around Jupiter

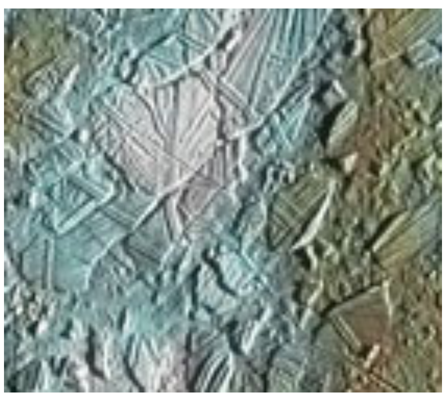




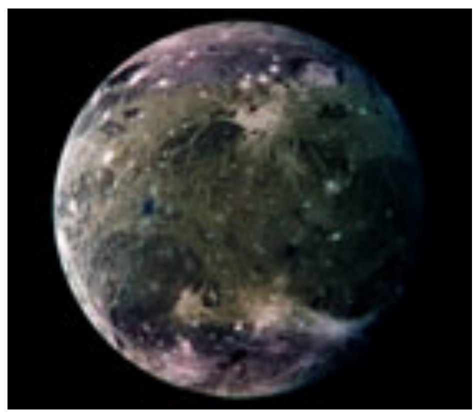
Io’s volcanos…

(hotter than Earth’s)

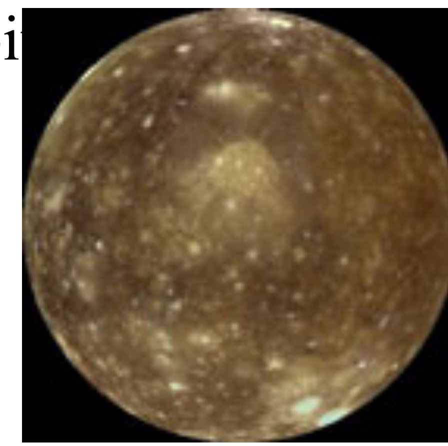
Jupi s…



A Possible Ocean on Europa



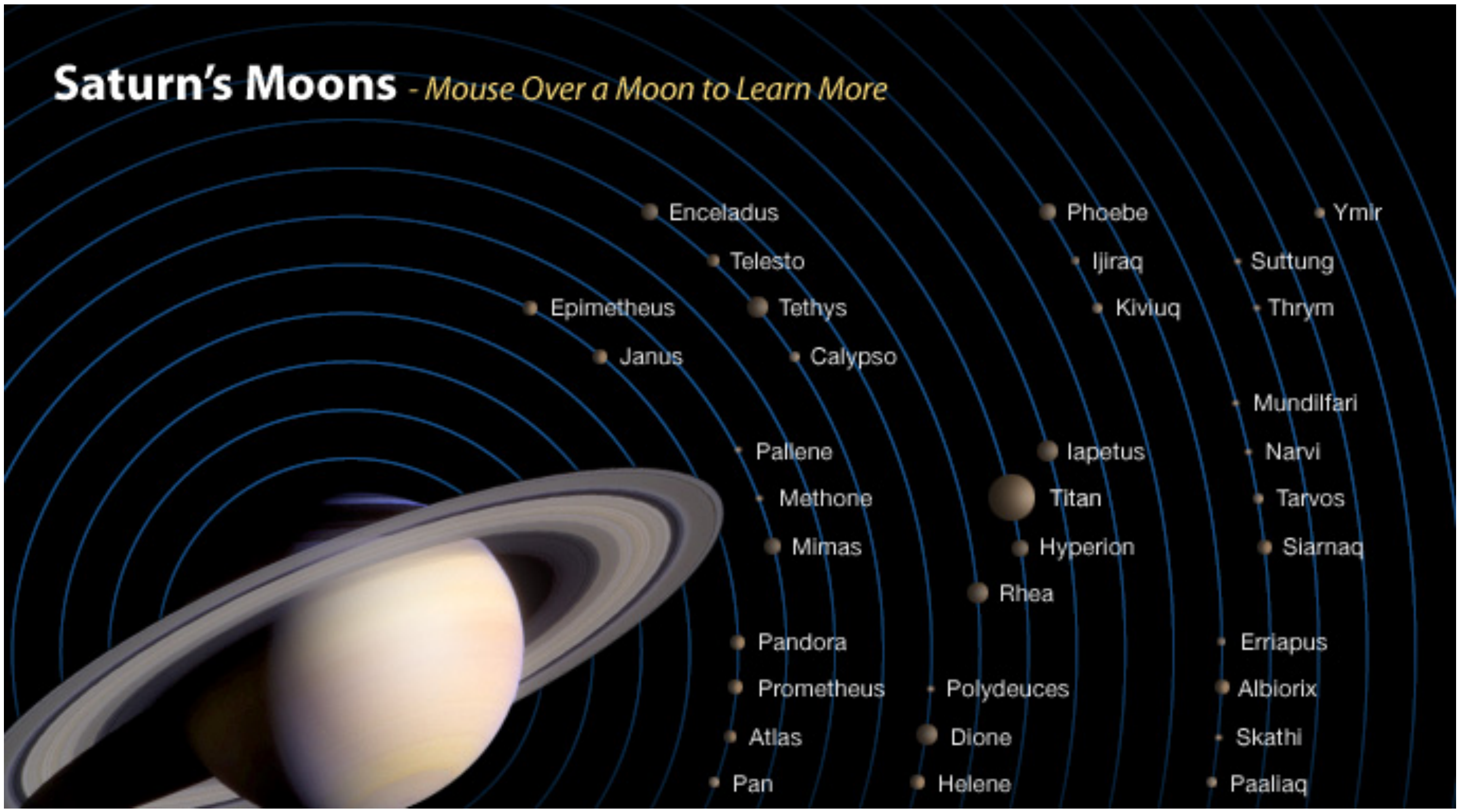
Ganymede’s own Magnetic field



An Ocean Beneath Callisto's Surface?

Cassini Mission

- **Cassini** Saturn Orbiter and **Huygens** Titan Lander
- Launch date: October 15, 1997
- Entered Saturn orbit: ~ July 1, 2004
- Duration: Still current, Cassini Solstice Mission → 2017



- http://www.nasa.gov/mission_pages/cassini/main