Astronomy 210

Section 1– MWF 1500-1550

134 Astronomy Building

This Class (Lecture 5):

Cosmic Revolution

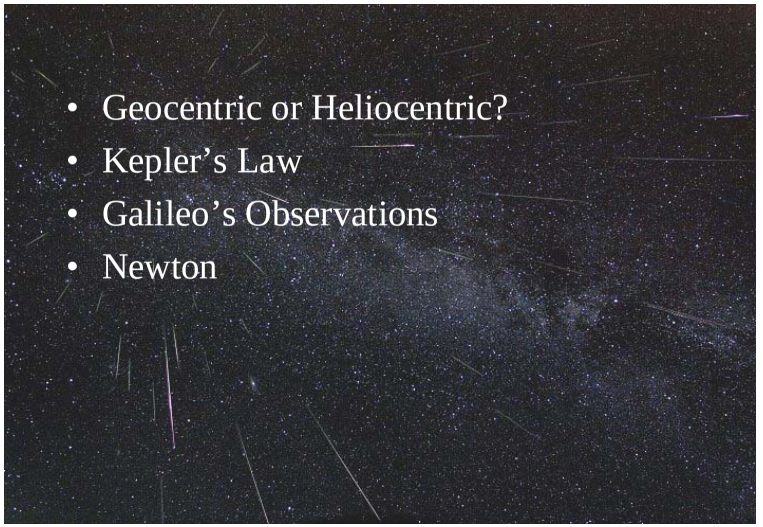
HW #1 Due Today!

Next Class:

Laws of Motion

Music: *Unemployed in Summertime* – Emiliana Torrini

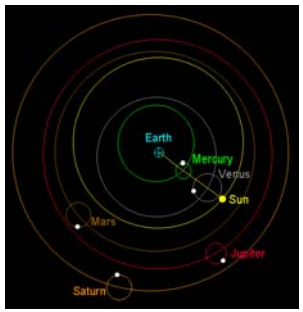
Outline



- Geocentric or Heliocentric?
- Kepler's Law
- Galileo's Observations
- Newton

Ptolemy (140 AD)

- Created a geocentric model with uniform circular motion that explained retrograde motion and inferior planets
- The Ptolemaic system

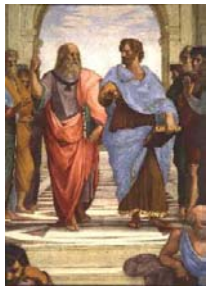


Ptolemaic Problems

- There was no universal rule governing planetary motion
  - Just mathematical constructs to fit the data
  - No reason **why**
- Nonetheless, for a 1000 years this model ruled western astronomical thought
- By the late middle-ages, a search began for a system with simpler underlying principles
  - Ptolemy's system too complex
  - Predictions only accurate for a century or so

Lessons: Were the Greeks Stupid?

- Not at all!
  Developed sophisticated, successful model
- But built in prejudices about the world
  not just geocentric but egocentric



What about scientists today?
Still can fool ourselves! (And have!)
But: *scientific method* is tool:

- To keep from fooling yourself
- To correct yourself when you have

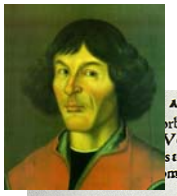
My guess:

80% of the material in this course will stand the test of time

- Compare baseball: 30% success good
- but also: 20% of course is wrong/incomplete!
  - Which 20%? Don't know! Would fix it if we knew! So…
  - You have to learn all of it!

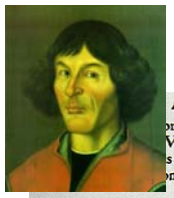
Nicholas Copernicus (ca. 1540)

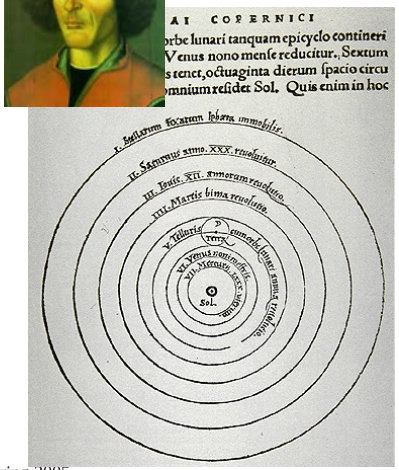
- Resurrected the heliocentric model
- This was dangerous
  - The geocentric system had become dogma
- Copernicus did not publish his work until the year he died.
- Still held onto the idea of perfect circular motion



Nicholas Copernicus (ca. 1540)

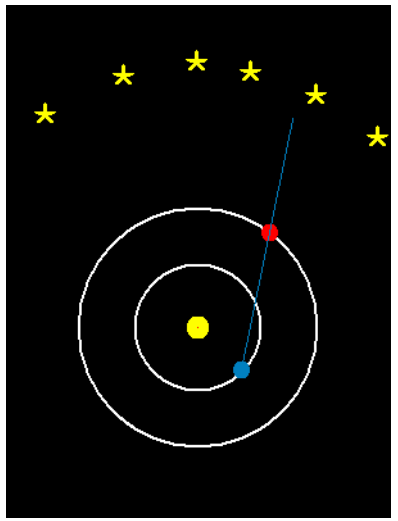
- Data problems:
  - Earth doesn't feel like it's moving.
  - Can something so heavy move so fast?
  - Wouldn't we get flung off?
  - The stars have no measurable movement.





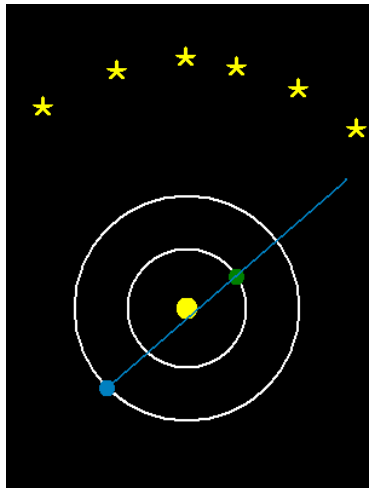
Copernicus Explains Retrograde Motion

- Inner planets move faster than outer planets
- Retrograde motion occurs when Earth overtakes and passes (or is passed by) another planet.
- Retrograde motion is a natural consequence of planetary motions



Copernicus Explains Inferior Planets

- Inferior planets have orbits closer to the Sun than the Earth.
- Always appear close to the Sun as seen from Earth.

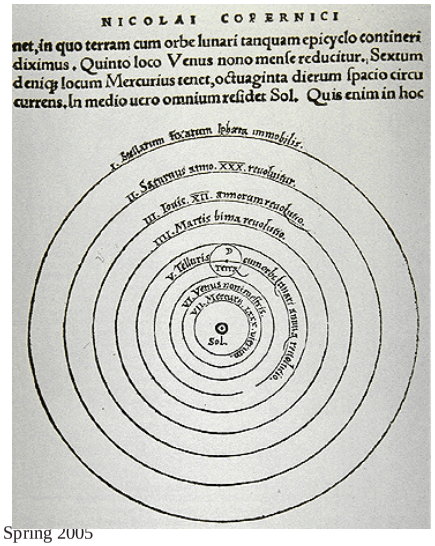


Copernicus (1540) Heliocentric Model

BUT, keep in mind that the geocentric model was still valid at the time. Both models explained the observed motion.

Heliocentric is NOT obvious!

IT was determined a philosophical argument for 50 years! New observations were required to determine which is correct.



Copernican Problems

- Clung to the idea of perfect circles.
  - Still needed epicycles to explain irregularities in planetary motion.
- Both Copernican and Ptolemaic models explained the observed planetary motions.
  - The Copernican model gave a simpler explanation of retrograde motion and inferior planets.
  - But, mathematically, it gave *worse* predictions of planet positions!

Significance

- Despite the problems with Copernicus' model, it marked a turning point in the history of science
- It began a major philosophical shift in the culture of science

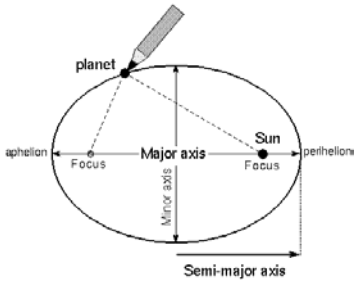
Tycho Brahe (ca. 1580)

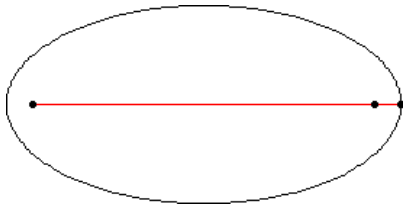
- Carefully observed stars and planets using a "state-of-the -art" observatory
  - Uraniborg – "Castle of the Heavens"
- Accurate to about 1 arcminute (1/15th the size of the moon)
  - ***No telescopes!***

Johannes Kepler (ca. 1600)

- Inherited a set of very accurate observations of the planets when Brahe (his boss) died
- Used the data to guide the creation of a new heliocentric theory
- Data could not be fit by circular orbits
- Considered an *ellipse*

Kepler's First Law



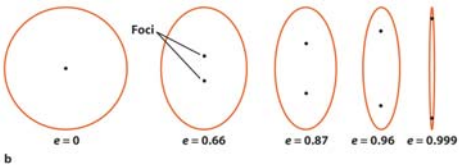


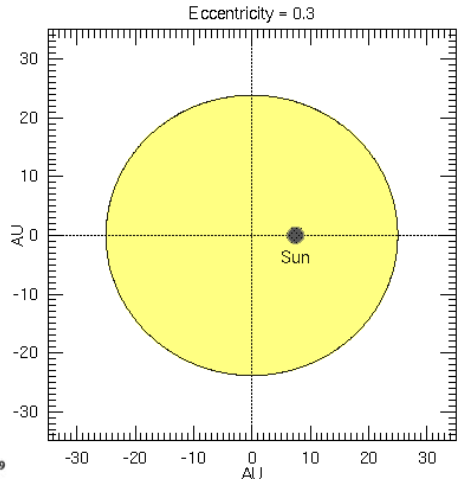
The orbits of the planets are ellipses with the Sun at one focus.

The heavens do not move in perfect circles!

Orbits of planets are ellipses with the Sun at one focus

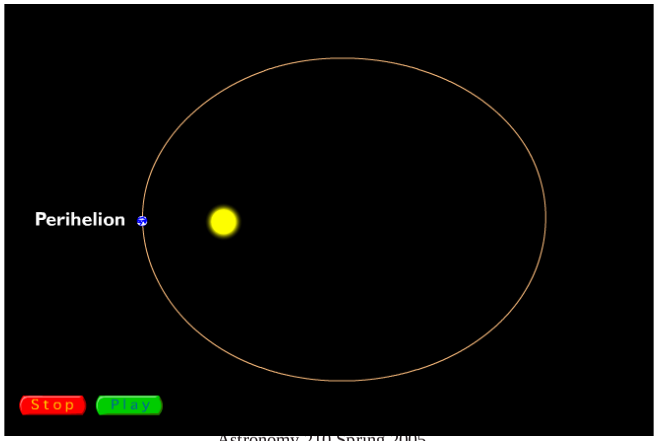
New Twist– even the Sun isn't at the center of the solar system now. How does that change our view of the Universe and our place in it?





Kepler's Second Law

The line that connects the planet to the Sun sweeps out equal areas in equal time



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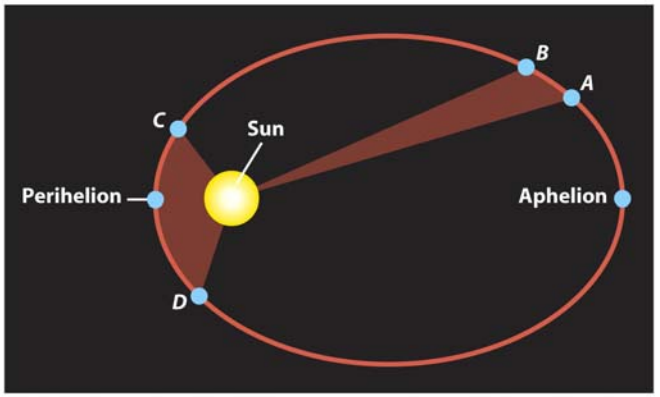


Inequality of the Seasons

- Planets move faster when closer to the Sun
  - Fastest at perihelion (closest to the Sun)
  - Slowest at aphelion (farthest from the Sun)
- Effect witnessed as the *inequality of the seasons*
  - Northern spring & summer have 93 days
  - Northern autumn has 90 days
  - Northern winter has 89 days
  - Why? Perihelion is on Jan 5th, Earth moves fastest in its orbit during our winter

Sidetrack: Meter Stick

- Average Distance from Earth to the Sun = 1.5×10^8 km (or 93 million miles).
- Too lazy for all that…
- So, astronomers defined a new unit
  - Average distance from Earth to the Sun = 1 Astronomical Unit (AU)
  - Useful for measuring distances in the Solar System

Kepler's Third Law

A planet's orbital period (P) in years, squared, equals the semimajor axis of its orbit (a) in AUs, cubed

$$P^2 = a^3$$

years — AUs (astronomical units)

Planetary Orbits

- The farther away from the Sun, the longer it takes for the planet to orbit AND the slower it's average orbital speed

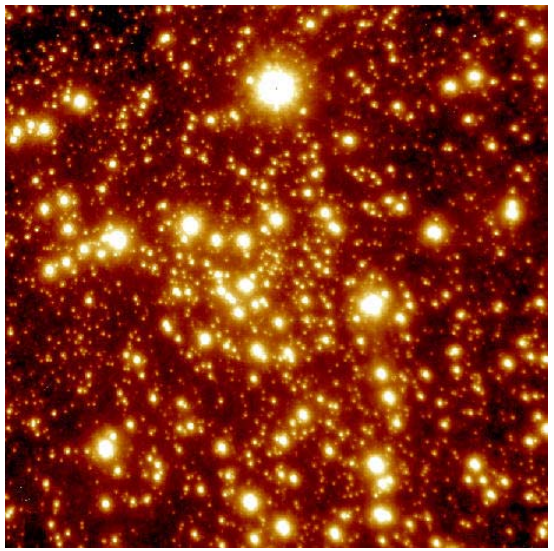
Planet	P (yr)	a (AU)	P^2	a^3
Mercury	0.24	0.39	0.06	0.06
Venus	0.61	0.72	0.37	0.37
Earth	1.00	1.00	1.00	1.00
Mars	1.88	1.52	3.5	3.5
Jupiter	11.86	5.20	141	141
Saturn	29.46	9.54	868	868

Java Fun with Kepler

http://csep10.phys.utk.edu/astr162/lect/binaries/visual/keplerold frame.html

Kepler's Laws: A Black Hole

A group in Munich is effectively using Kepler's Laws to determine the mass of the black hole in the center of our galaxy using deep near-infrared observations.

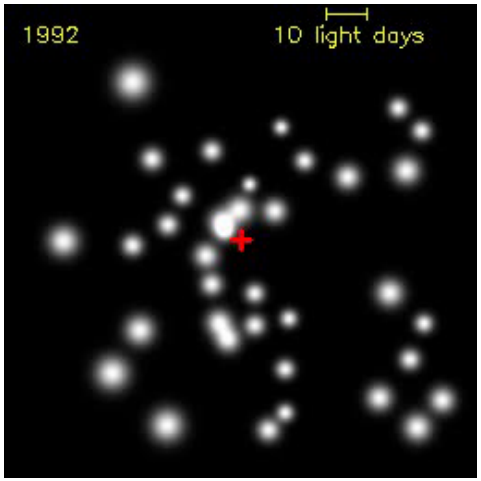


http://www.mpe.mpg.de/www_ir/GC/intro.html

Application of Kepler's Laws

By using the deepest images of stars toward the Galactic Center, they have been able to detected a full orbit of a star with a period of 15.2 years and Semi-major axis of 950 AU.

From Kepler's law, we can calculate the mass of the black hole is about 2.6 million solar masses!!!



Physics of the Ancients

- Heavens considered fixed, unchanging
  - Made of different stuff than we are (aether)
  - Follow different rules than things on Earth
  - Natural state of motion: circular orbits
- On Earth
  - Natural state of motion: rest
  - Objects have to be constantly "pushed" in order to move
  - Special exceptions for "violent motion"

Galileo Galilei (1564-1642)

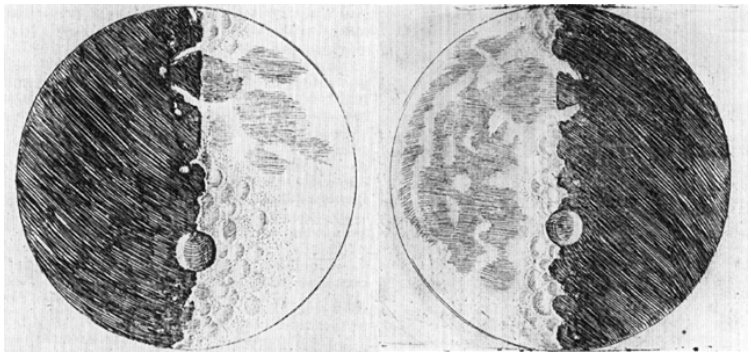
- Mathematics chair at Pisa & Padua
- Conducted experiments in mechanics
- Invented the compass & microscope
- Improved on existing telescope designs

Galileo the Astronomer

- The first to systematically use a telescope to observe the heavens
- And record the results of his observations!

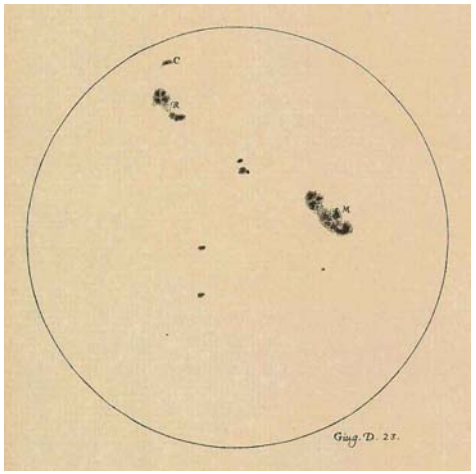
Mountains on the Moon

- Galileo observed mountains on the Moon.
- The Moon is **not** a perfect sphere!



Sunspots

- Galileo projected the Sun onto a screen with his telescope
- He saw dark spots, and they moved!
- The Sun is imperfect…
- And it rotates!



"Elongated" Saturn

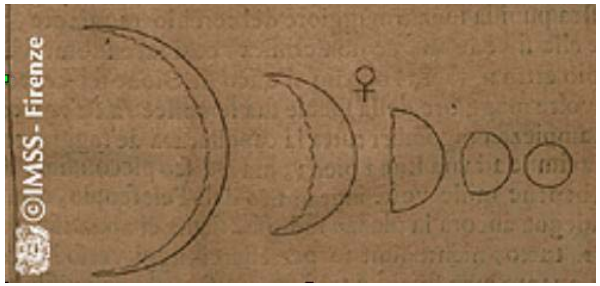
- When Galileo observed Saturn, he saw that the planet looked elongated
- Galileo described it as "composed of three"
- His telescope wasn't powerful enough to resolve the rings we see today

The Milky Way

- "Whichever direction one chooses for the telescope, immediately a very large number of stars can be seen"
- The Milky Way is made of faint stars!

Phases of Venus

- When Galileo looked at Venus, he saw that Venus has phases, like the Moon!
- The planets must reflect light from the Sun!
- Also, Venus changes size dramatically



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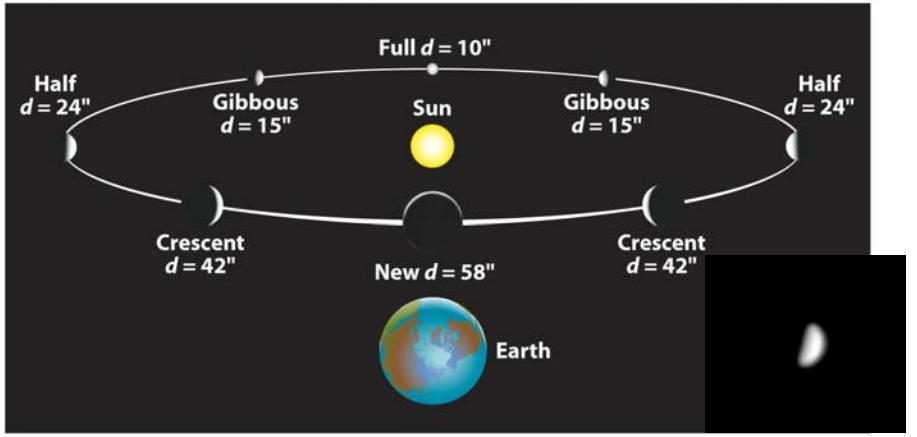
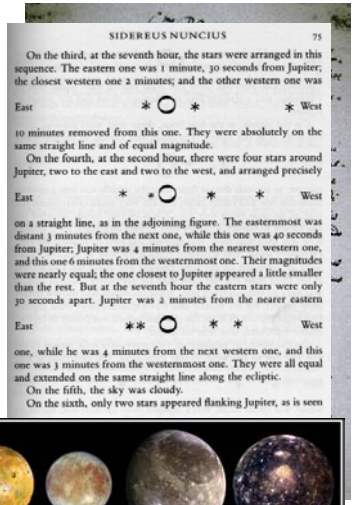


http://www.calvin.edu/academic/phys/observatory/images/venus/venusb.html

The Moons of Jupiter


SIDEREUS NUNCIUS 75

On the third, at the seventh hour, the stars were arranged in this sequence. The eastern one was 1 minute, 30 seconds from Jupiter; the closest western one 2 minutes; and the other western one was

East * ○ * * West

10 minutes removed from this one. They were absolutely on the same straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around Jupiter, two to the east and two to the west, and arranged precisely

East * * ○ * * West

on a straight line, as in the adjoining figure. The easternmost was distant 3 minutes from the next one, while this one was 40 seconds from Jupiter; Jupiter was 4 minutes from the nearest western one, and this one 6 minutes from the westernmost one. Their magnitudes were nearly equal; the one closest to Jupiter appeared a little smaller than the rest. But at the seventh hour the eastern stars were only 30 seconds apart. Jupiter was 2 minutes from the nearer eastern

East ** ○ * * West

one, while he was 4 minutes from the next western one, and this one was 3 minutes from the westernmost one. They were all equal and extended on the same straight line along the ecliptic.

On the fifth, the sky was cloudy.

On the sixth, only two stars appeared flanking Jupiter, as is seen

- Galileo found that Jupiter had 4 moons
- Orbited Jupiter, not the Earth!
- These moons are now called the Galilean Moons

Galileo, Superstar

- Galileo's discoveries made him famous
- Everyone wanted to see the "Medicean Stars"
  - Galileo named the moons of Jupiter in honor of his financial backers
- In 1610, he was named court mathematician to the Grand Duke of Tusancy
- But…


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.

Galileo, Troublemaker

- Galileo directly challenged the geocentric view held by the authorities of the day
  - Everything does **not** orbit the Earth
  - The heavens are **not** perfect spheres
- Published *"Dialogue Concerning the Two Chief World Systems"* in 1632
  - Compared the Copernican system with the Ptolemaic system
- In 1633, Galileo was brought before the Inquisition
  - He was forced to recant his support of the Copernican system
  - Placed under house arrest until his death in 1642

Data: Venus

Compare the Heliocentric to Geocentric models to explain the phases of Venus.

http://www.astro.ubc.ca/~scharein/a310/SolSysEx/phases/Phases.html

After Kepler's Laws

Kepler discovered these patterns in nature by using the data that Tycho collected, BUT the world had to wait until someone could understand the Natural Law that predicts Kepler's Laws.

The real problem: On Earth we're use to things that move but always come quickly to rest. Why don't the planets stop?

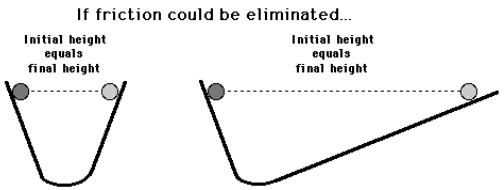
Galileo started the ball rolling here too.

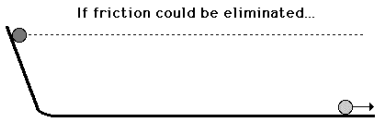
Galileo: Physicist

- Disproved Ptolemaic system
- Rome bullied him into recanting (cleared in 1992)
- Now we understand the motions and the fact that the solar system MUST be Heliocentric, but now we need a reason why?
- "Paradigm shift" – radical change in outlook/conceptual framework

Galileo: Physicist

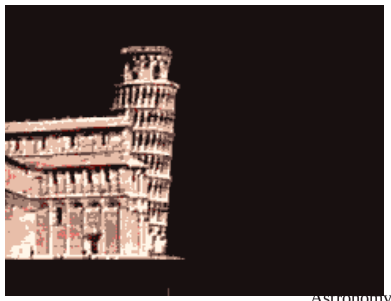
- Thought about problems with experimental techniques.
- First true experimental physicist.
- Developed concept of inertia: the resistance an object has to a change in its state of motion.





Free Fall

- Gravity is a force, producing acceleration
- Independent of mass!
- On the surface of the Earth, the acceleration due to gravity is 9.8 meters per second per second
- Drop a ball off the leaning tower of Pisa:



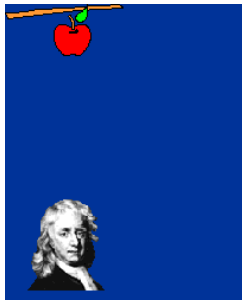
Time (seconds)	Velocity (m/s)	Accel. (m/s^2)
0	0	9.8
1	9.8	9.8
2	19.6	9.8
3	29.4	9.8

$a = g = 9.8\ m/s^2$

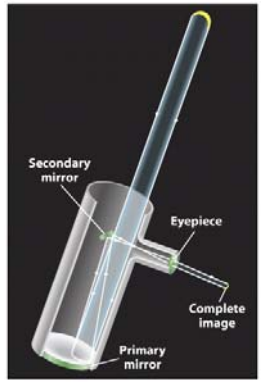
A Feather and a Hammer

http://www.hq.nasa.gov/office/pao/History/alsj/a15/a15v_1672206.mpg

Isaac Newton (1642-1727)



$$\int_a^x f(t)\,dt$$



Isaac Newton (1642-1727)

- Developed fundamental laws of nature
- Gave us a reason why the heliocentric system works – **GRAVITY**
- Designed the reflecting telescope
- Discovered that white light is a mix of all colors
- Also invented calculus

Isaac Newton (1642-1727)

He's our friend. Gave us the gift of vectors.

position : $\vec{r} = (x, y, z)$

velocity : $\vec{v} = \frac{d\vec{r}}{dt} = \dot{\vec{r}} = (\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt})$

acceleration :

The Laws of Motion

- Until the mid-17th century, scientists worked *empirically*
  - Building a mathematical formula that fit the data
  - No reason *why* the Universe worked
- Newton found fundamental laws that govern the motion of bodies
  - Both on Earth and in the heavens
  - Another blow to Aristotle's physics