Greece to Galileo

SE   S   SW   W

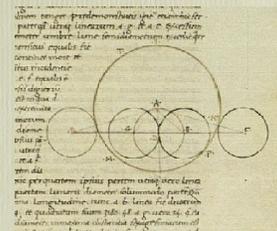E   SE   S   SW   W

n 01m 18.40s Dec:– 45° 22' 41.3"   LMT 09:18:08 PM Wed   May 4, 2011   Ottawa   75° 42' 00.0" W 45° 24' 00.0" N

Ptolemy ~140 AD

- All of these ideas came together in the Almagest (13 Volumes on Astronomy)
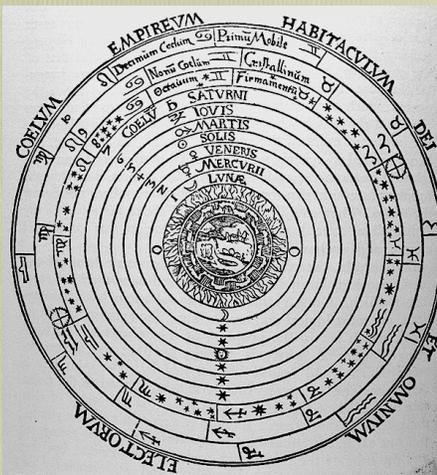
- First real model of the universe

- Ptolemaic model

Geocentric: Earth at the centre

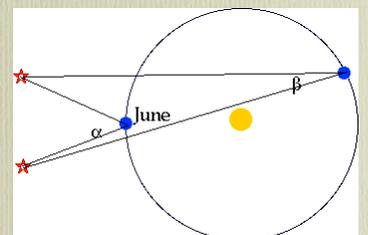Moon, Venus, Mercury, the Sun, Mars, Jupiter, and Saturn in circular orbits

Stars and crystal sphere beyond

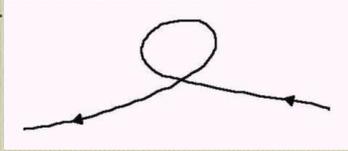## Why the earth must be stationary:

- Suppose that the earth revolved around the sun.

- In observing two distant stars, angle between them would change during year

- Separation doesn't change, so earth must be stationary.

But

- Mercury and Venus never get far from sun.

- Retrograde Motion.

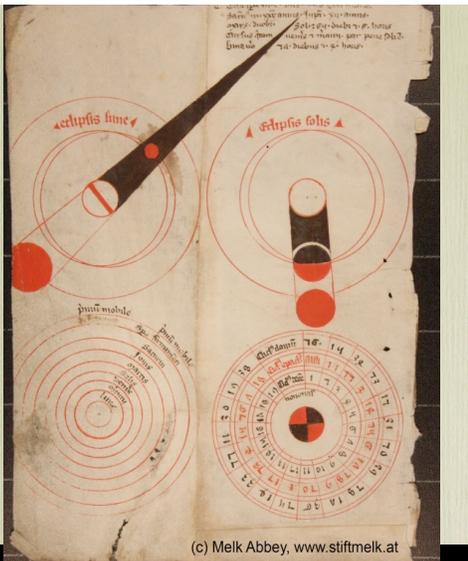- Changing brightness of planets during year: always brightest when south at midnight

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- Orbits of Mercury and Venus are locked to sun.

- All planets get epicyclic orbits: they orbit about a point, which revolves about the deferent - or orbital path about the earth.
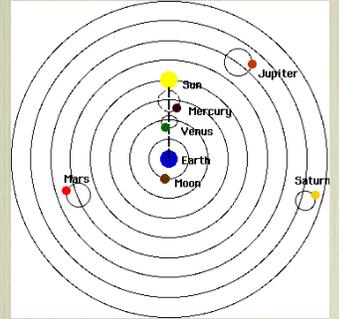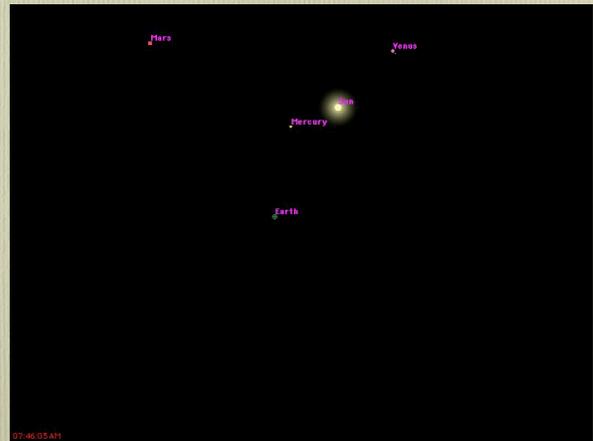
- Finally, the earth is removed slightly to off-centre

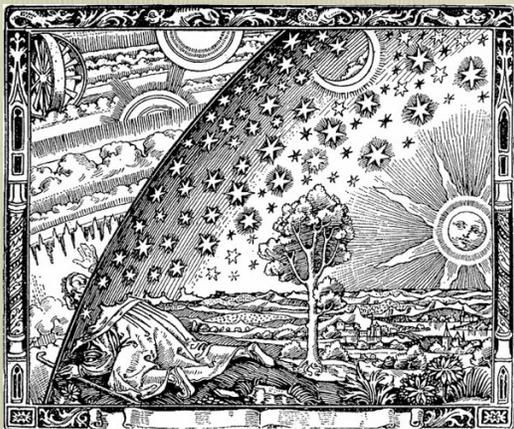- A medieval fragment (1490)

(c) Melk Abbey, www.stiftmelk.at

- And we can even get it to work!

- Flammarion engraving (1888)
- (artist and origin unknown: probably combination of several old woodcuts/ drawings
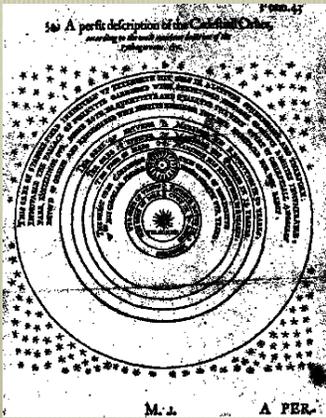

COPERNIKUS (1473-1543)

- Ptolemy's model now required 40 epicycles to work

Slide 1

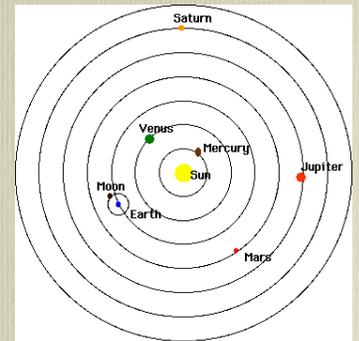*De revolutionibus orbium coelestium*
The Book No One Read

- A Heliocentric solar system.

- Still uses circular orbits, so still needs epicycles.

Slide 2

- Il sole no si muove (The sun does not move) Leonardo da Vinci

- Motion of Mercury & Venus "unlocked" from sun.

- No parallax because fixed stars are very far away

- So why did people at the time believe in Copernicus?

Slide 3

Reasons for asserting the earth is motionless:

1. David in Psalm 89: God has founded the earth and it shall not be moved.

2. Joshua bade the sun stand still-which would not be notable were it already at rest.

3. The earth is the heaviest element, therefore it more probably needs rest.

4. Everything loose on the earth seeks its rest on the earth, why should not the whole earth itself be at rest?

Slide 4

4. We always see half of the heavens and the fixed stars also in a great half circle, which we could not see if the earth moved, and especially if it declined to the north and south...

5. A stone or an arrow shot straight up falls straight down. But if the earth turned under it, from west to east, it must fall west of its starting point.

6. In such revolutions houses and towers would fall in heaps.

7. High and low tide could not exist; the flying of birds and the swimming of fish would be hindered and all would be in a state of dizziness.

Slide 5

Reasons for the belief that the earth is moved:

1. The sun, the most excellent, the greatest and the midmost star, rightly stands still like a king while all the other stars with the earth swing round it.

2. That you believe that the heavens revolve is due to ocular deception similar to that of a man on a ship leaving shore.

3. That Joshua bade the sun stand still Moses wrote for the people in accordance with the popular misconception

Slide 6

1. As the planets are each a special created thing in the heavens, so the earth is a similar creation and similarly revolves.

2. The sun fitly rests at the center as the heart does in the middle of the human body.

3. Since the earth has is itself its especial centrum, a stone or an arrow falls freely out of the air again to its own centrum as do all earthly things.

4. The earth can move five miles in a second more readily than the sun can go forty miles in the same time.

Voight (1667). Der Kurstgunstein Einfalt Mathematischer Raritaten Erstes Hundert.

Tycho Brahe 1546-1601

- Note the tin nose ...

Ruler of island of Hveen, off coast of Denmark.

Constructed Uraniborg to measure position of planets and stars

---

"Now it is quite clear to me that there are no solid spheres in the heavens, and those devised by the authors to save the appearances exist only in the imaginations for the purpose of permitting the mind to conceive the motion which the heavenly bodies trace in their courses."
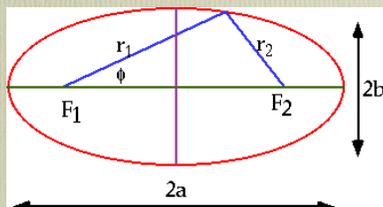

Kepler 1571-1627

- Corresponded with Brahe and "acquired" records after his death.

- (i.e. refused to give them up to his heirs)

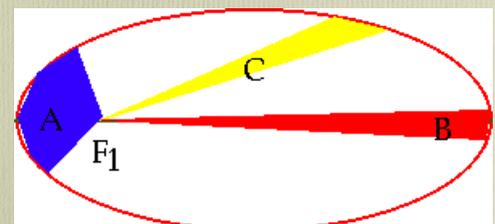- Planets move in ellipses, with one focus at the sun

Planet

$\vec{r}$
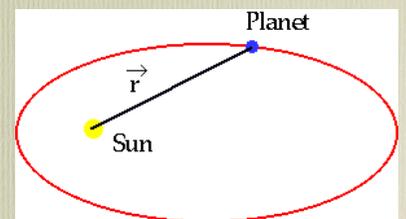
Sun

- A circle is a point moving so that its distance from one point is constant.

- An ellipse is a point which moves so that the sum of its distance from two points is constant

r_1 r_2 ϕ F_1 F_2 $2b$ $2a$

Keplers Second Law

- A line drawn from the planet to the sun will sweep out equal areas in equal times

C   A   B F_1

Third Law

- The period and the radius of orbit are related by

- (Period)^2 ~ (radius)^3

- i.e.: planet that is 4 times further away from sun takes 8 times longer to orbit

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And the solar system becomes so simple

But why?

GALILEO (1564-1642)
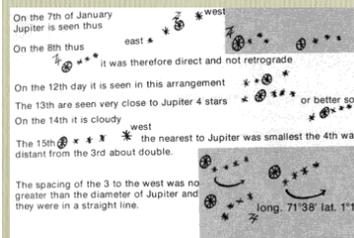
- Lived in Pisa

- Exploited (but didn't invent) telescope

- Moons of Jupiter: Jan 8th 1608

This is his original notebook

- and this is a translation.

- moons also discovered by a German astronomer, Marius (or Mayr). He gave them their names Io, Europa, Ganymede and Callisto.

Slide 1

- The final nail in the coffin of Ptolemaic model

- The phases of Venus

Slide 2
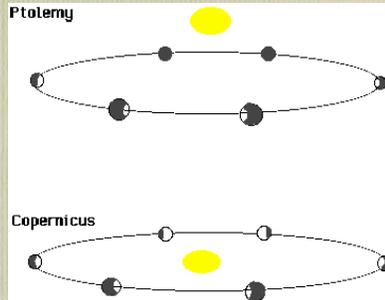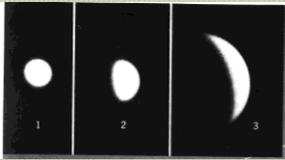
Except he wanted to keep it a secret!

- "Haec immatura a me iam frustra leguntur o.y."

- "These are at present too young to be read by me"

- "Cynthiae figuras aemulatur mater amorum"

- "The mother of love (Venus) imitates the shape of Cynthia (the Moon)"
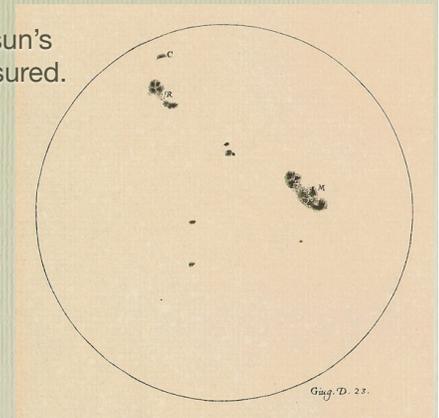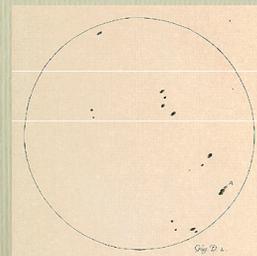
Slide 3

Mountains of Moon.

- Showed heavenly bodies "Imperfect":

- can see shadows changing on edge of crater
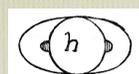

Slide 4
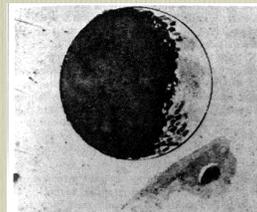
Sunspots 1612

- Allowed period of sun's rotation to be measured.

- ~ 29 days

Slide 5

Rings of Saturn

- He also saw these, but he could never figure out what they were! He thought that the planet had "handles".

Slide 6

- The greatest discovery Galileo never made

- For a week in 1612, Neptune was in the field of his telescope when he was observing Jupiter, and he even notes that it seemed to be a moving star

● But then it got cloudy!
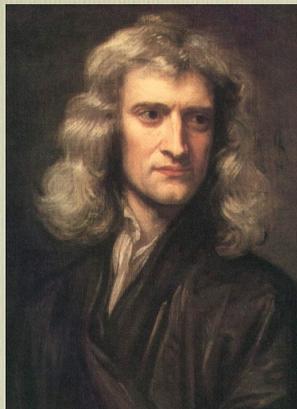
● And it took 250 years to find Neptune!

A final note: the most famous quote
Epur si muove
And yet it does move
was almost certainly made by Giardano Bruno before he was burnt at the stake in 1600

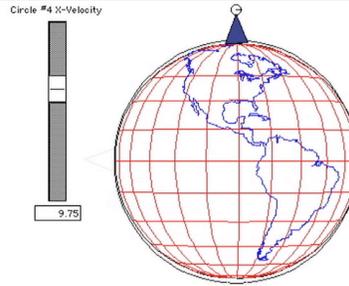## So the Ptolemaic model was **A Failure**

But a failure that lasted 1400 years!

Newton

• 1642-1727

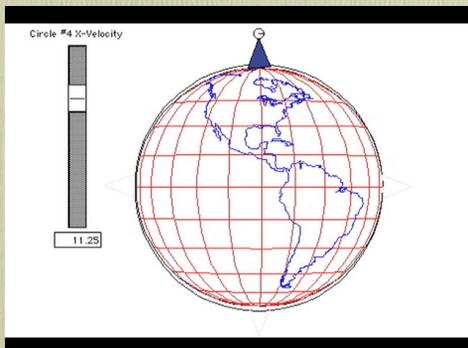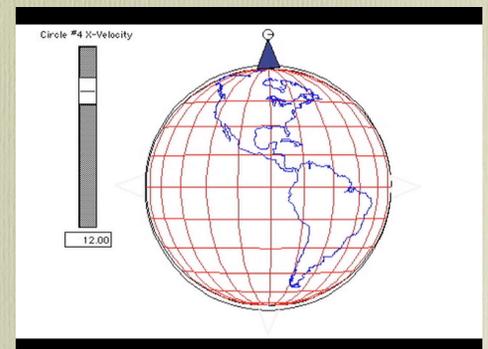• Born the day of Galileo's death

Universal Gravitation

• How does the moon stay up?

• By falling!
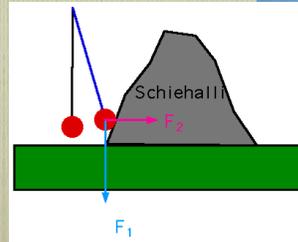
● Faster

● and faster

Warning: this slide contains an equation

- The extra step is to realise that any two bodies in the universe attract each other

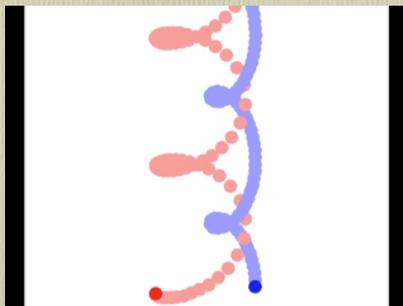- If they are mass M and mass m, separated by a distance r

$$F = -\frac{GMm}{|r|^2}$$

Even mountains!
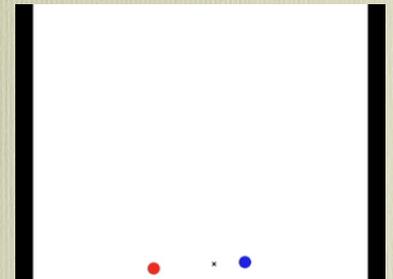
- First measurement was done with Schiehallion
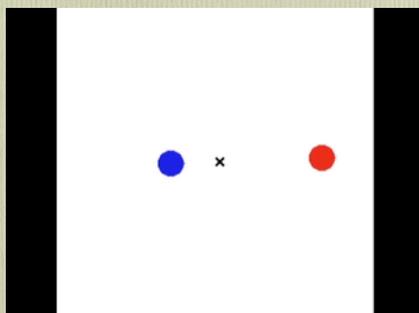

Things can get complicated when we have two bodies

But Newton gave us the tools to handle this

- Split the motion up into

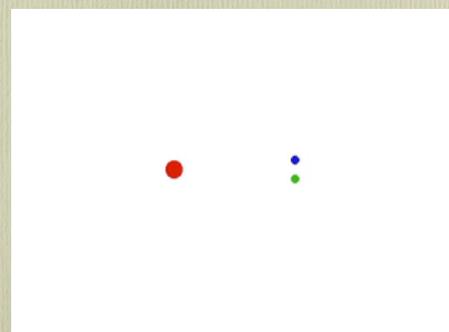- Motion of the whole system (doesn't change)

- Relative Motion

- And the we can get rid of the system motion and it gets simpler
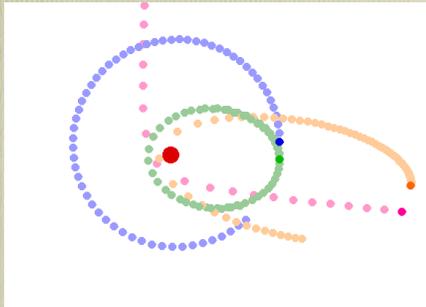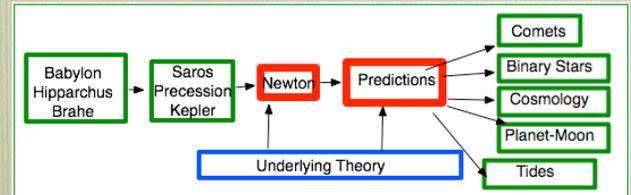

Lets us understand Kepler's laws

Slide 1

In fact Newton predicts

- Circles
- Ellipses
- Parabolas
- Hyperbolas

Slide 2

Observations → Patterns → Model → Predictions → Experiment / New Experiment ← Underlying Theory

Babylon Hipparchus Brahe → Saros Precession Kepler → Newton → Predictions → Comets, Binary Stars, Cosmology, Planet-Moon, Tides ← Underlying Theory

Slide 3
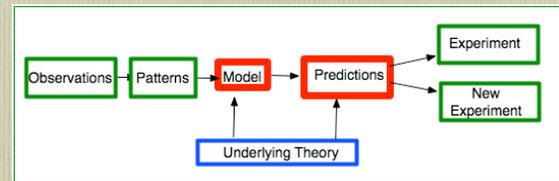
Newton' other contribution: understanding light

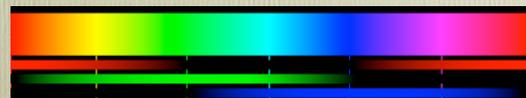Objective Mirror
Secondary Mirror
Eyepiece
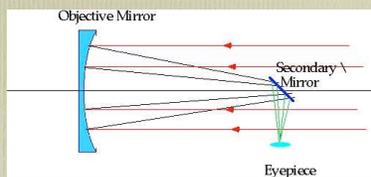
- the reflecting telescope
- precursor of all modern telescopes

Slide 4

and splitting up light into it's constituent colours

- Red (wavelength of 800 nanometres = 0.8 microns)
- Green ~520 nm
- Blue ~400 nm

Slide 5

Not popular with his contemporaries

Pray God us keep
From Single vision & Newton's sleep!
Blake
Philosophy will clip an Angel's wings,
Conquer all mysteries by rule and line
Empty the haunted air, and gnomed min
Unweave a rainbow, as it erewhile made

Keats

The atoms of Democritus
And Newton's particles of light
Are sands upon the Red Sea shore,
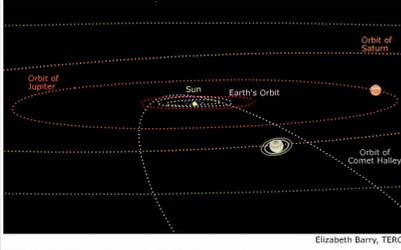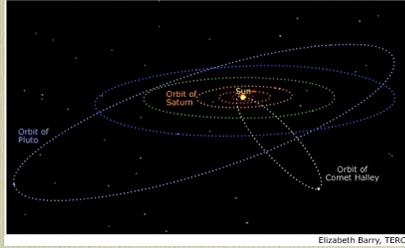Where Israel's tents do shine so bright.

Slide 6

Edmund Halley

- comet which had appeared in 1682,
- had appeared in 1531 (observed by Petrus Apianus)
- and 1607 (observed by Johannes Kepler).
- he predicted its return for 1758
- i.e comets work the same way as planets!

Slide 1

i.e comets work the same way as planets!

Elizabeth Barry, TERC

Elizabeth Barry, TERC

Slide 2

Acknowledgements

- • Astronomy Picture of the Day (APOD)

- • Anthony Ayiomitas

- • Simulations: Voyager (Carina software)

EXPLORING EARTH
HOME

Next;
Leaving Earth Behind