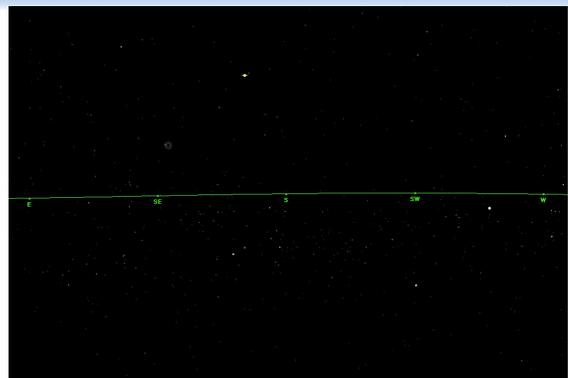
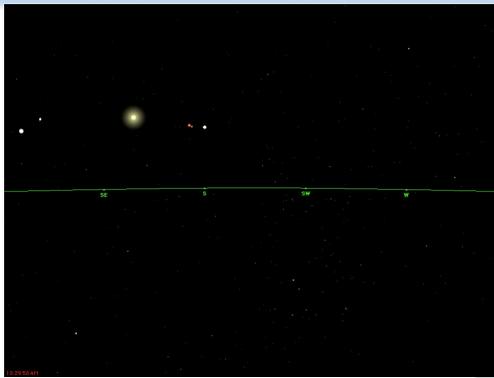


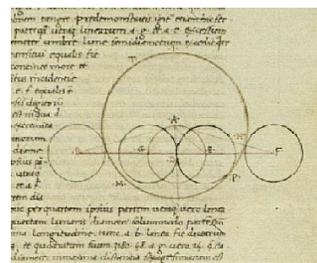


Greece to Galileo: the End of Astrology



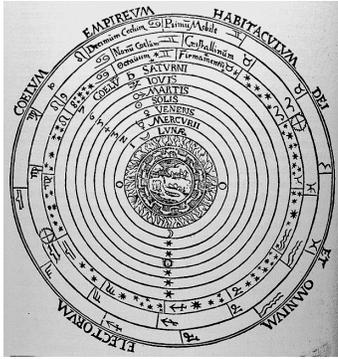
- Three questions:
- (Easy) Why do you believe the earth is not flat?
- Why do you believe the earth rotates?
- (Very hard) Why do you believe the earth orbits the sun?

Ptolemy ~140 AD



All of these ideas came together in the Almagest (13 Volumes on Astronomy)

First real model of the universe
Ptolemaic model

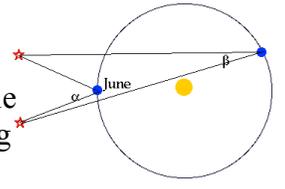


Geocentric: Earth at the centre
Moon, Venus, Mercury, the Sun, Mars, Jupiter, and Saturn in circular orbits
Stars and crystal sphere beyond



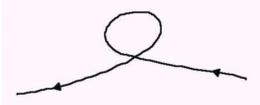
Why the earth must be stationary:

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.

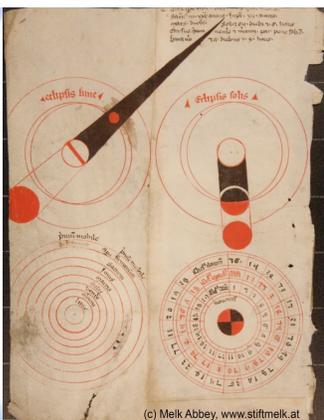
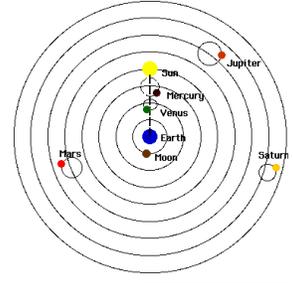


But

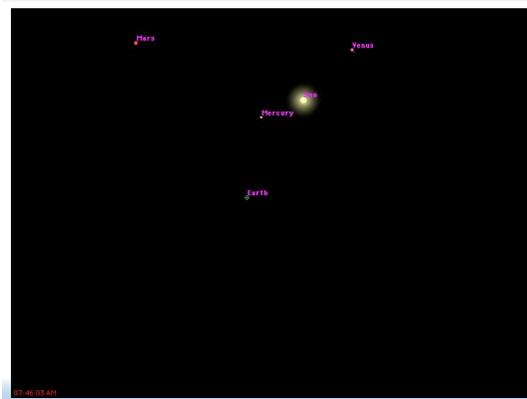
- Mercury and Venus never get far from sun.
- Retrograde Motion.
- Changing brightness of planets during year: always brightest when south at midnight



- 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)



And we can even get it to work!

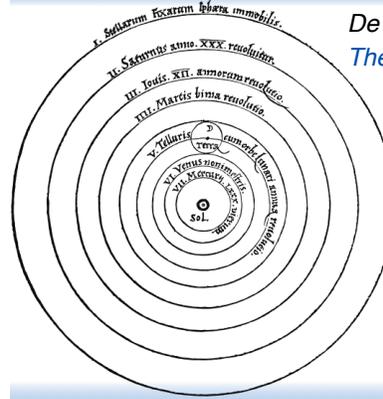


COPERNIKUS (1473-1543)

- Ptolemy's model now required 40 epicycles to work



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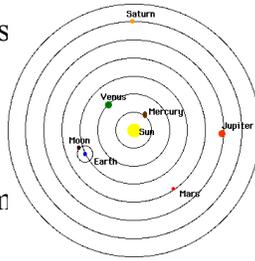
De revolutionibus orbium coelestium
The Book No One Read

A Heliocentric solar system
Still uses circular orbits, so
still needs epicycles.

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• 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?



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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?

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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.

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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

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4. As the planets are each a special created thing in the heavens, so the earth is a similar creation and similarly revolves.
5. The sun fitly rests at the centre as the heart does in the middle of the human body.
6. Since the earth has in 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.
7. 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 Raritäten erstes Hundert.*

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Tycho Brahe 1546-1601

- Note the tin nose ...



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Ruler of island of Hveen, off coast of Denmark.
Constructed Uraniborg to measure position of planets and stars

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Kepler 1571-1627

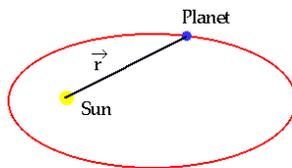
Corresponded with Brahe and “acquired” records after his death.
(i.e. refused to give them up to his heirs)



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Laws

- Planets move in ellipses, with one focus at the sun
- planets move fastest when they are closest to sun
- planet that is 4 times further away from sun takes 8 times longer to orbit



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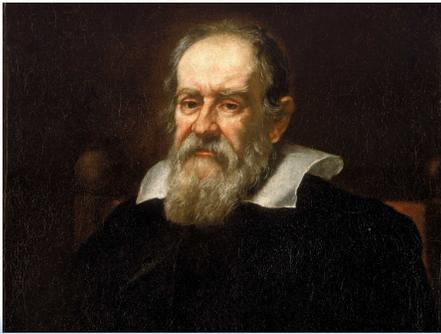
And the solar system becomes so simple



But why?

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GALILEO (1564-1642)



Lived in Pisa



- Exploited (but didn't invent) telescope



Moons of Jupiter: Jan 8th 1608



This is his original notebook

On the 7th of January Jupiter is seen thus

On the 8th thus

it was therefore direct and not retrograde

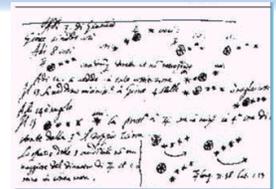
On the 12th day it is seen in this arrangement

On the 13th are seen very close to Jupiter 4 stars or better so

On the 14th it is cloudy

On the 15th the nearest to Jupiter was smallest the 4th was distant from the 3rd about double.

The spacing of the 3 to the west was no greater than the diameter of Jupiter and they were in a straight line.

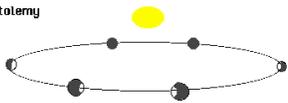


and this is a translation.

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



Ptolemy

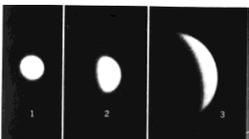


The final nail in the coffin of Ptolemaic model

Copernicus



The phases of Venus

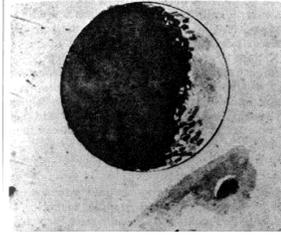
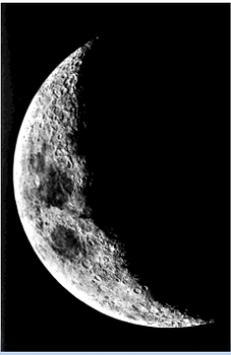


Except he wanted to keep it a secret!

- "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)"



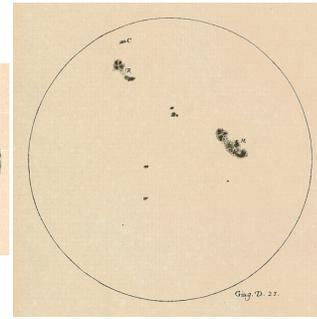
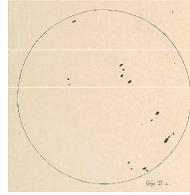
Mountains of Moon.



Showed heavenly bodies "Imperfect":
can see shadows changing on edge of
craters

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Sunspots 1612



Allowed period
of sun's rotation
to be measured.
~ 29 days

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Rings of Saturn

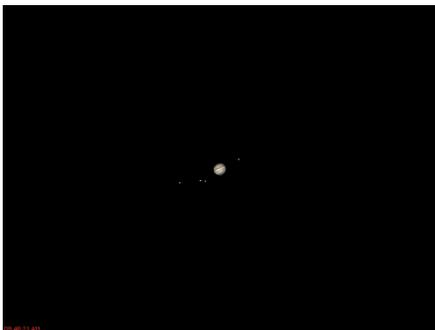
- He also saw these, but he could never figure out what they were! He thought that the planet had "handles".



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- 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

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

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So the Ptolemaic model was **A Failure**

But a failure that lasted 1400 years!

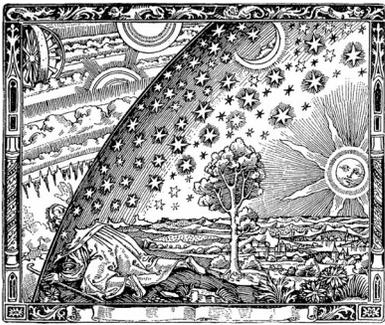
A final note: the most famous quote

Epur si muove

And yet it does move

was almost certainly made by Giordano Bruno
before he was burnt at the stake in 1600

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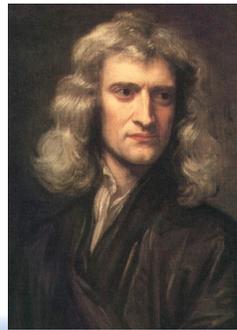


Flammarion engraving (1888)
(artist and origin unknown: probably combination of several old woodcuts/drawings)

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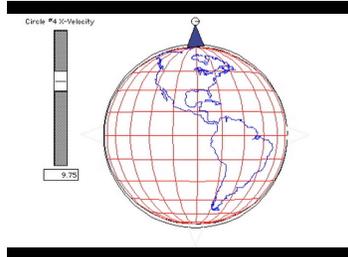
Newton

- 1642-1727
- Born (almost) the day of Galileo's death



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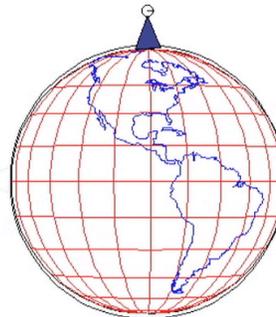
Universal Gravitation



- How does the moon stay up?
- By falling!

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Circle #4 X-Velocity



Faster

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Circle #4 X-Velocity



- and faster

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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

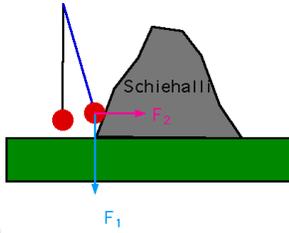
$$F = -\frac{GMm}{|r|^2}$$

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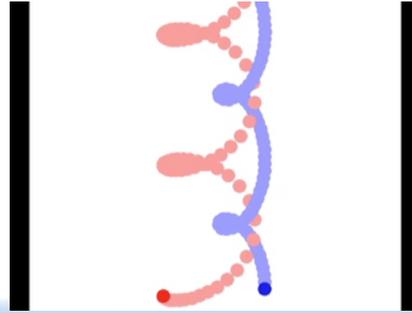
Even mountains!

First measurement was done with Schiehallion



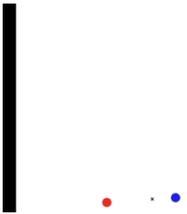
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Things can get complicated when we have two bodies



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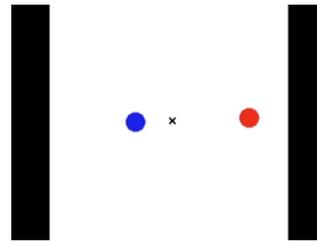
But Newton gave us the tools to handle this



Split the motion up into
Motion of the whole system
(doesn't change)
Relative Motion

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



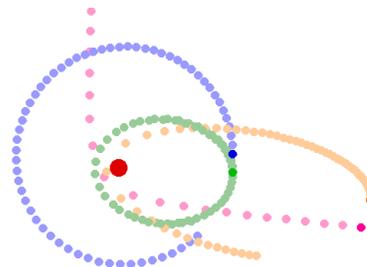
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Lets us understand Kepler's laws



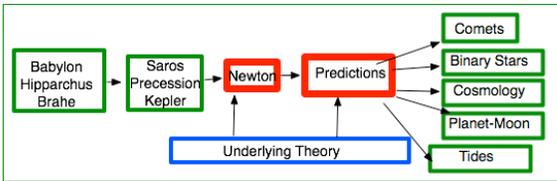
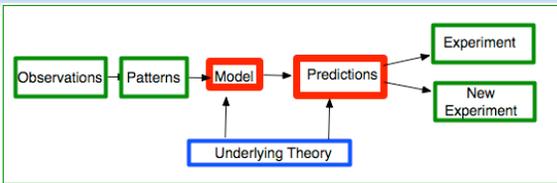
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In fact Newton predicts

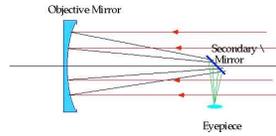


- Circles
- Ellipses
- Parabolas
- Hyperbolas

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Newton's other contribution: understanding light



the reflecting telescope precursor of all modern telescopes

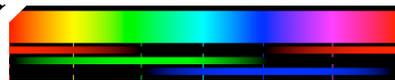
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and splitting up light into constituent colours



Almost all our information about the universe comes from light

Wavelength of 800 nm
(= 0.8 microns)
Visible light range: ~400 nm to ~700 nm



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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 mine
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.



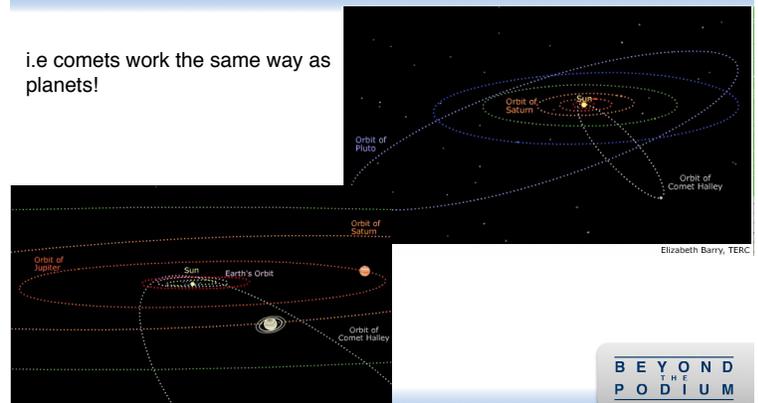
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Edmund Halley

- 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!

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i.e comets work the same way as planets!



Elizabeth Barry, TERC

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Acknowledgements

- Astronomy Picture of the Day (APOD)



Notes

- <http://people.physics.carleton.ca/~watson/Physics/Other.html>



Next: Fast forward to 1960
and Farewell to Earth

