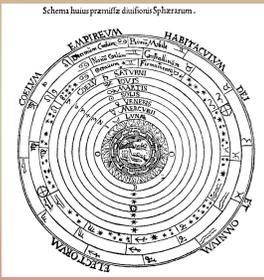


# A Wider Cast on the Copernican Revolution

Altrincham and District Astronomical Society  
April 2021

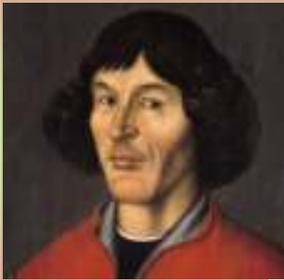
# What was the Copernican Revolution ?

## Ptolemy



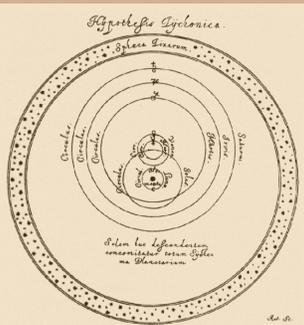
The diagram shows a geocentric model with Earth at the center. Concentric circles represent the orbits of the Moon, the Sun, and the planets. The outermost circle is labeled 'EMPIREVA' and 'HABITACIUM'.

## Copernicus



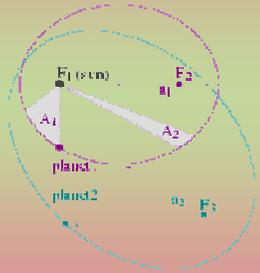
The diagram shows a heliocentric model with the Sun at the center. Concentric circles represent the orbits of the planets around the Sun.

## Tycho Brahe



The diagram shows a geocentric model with Earth at the center. The Moon orbits Earth. The Sun and planets orbit the Sun, which in turn orbits Earth. The diagram is titled 'Hypotesis Tyconica'.

## Johannes Kepler

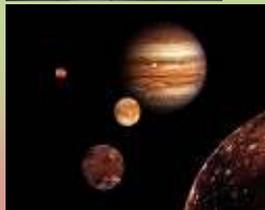


The diagram shows two overlapping elliptical orbits. The foci are labeled  $F_1$  and  $F_2$ . Points on the orbits are labeled  $A_1$ ,  $A_2$ ,  $A_3$ ,  $A_4$ ,  $A_5$ ,  $A_6$ ,  $A_7$ ,  $A_8$ ,  $A_9$ ,  $A_{10}$ . The orbits are labeled 'planct1' and 'planct2'.

### Galileo Galilei



er



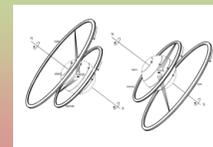
### Isaac Newton



### Time to take stock

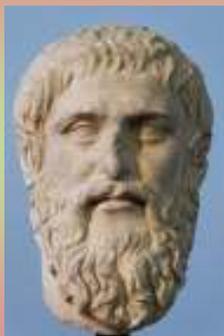
### Anaximander

- 610 – 546 BC



### Plato

- C 425 – 347 BC
- Uniform Circular Motion



### Aristotle

- 384 – 322 BC



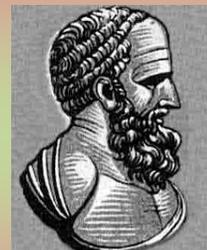
### Eudoxus

- 390 – 337 BC



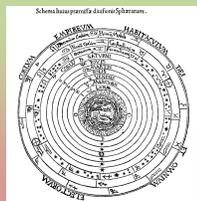
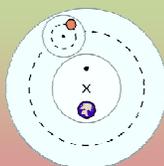
### Hipparchus

- c 190 – 120 BC
- Noted positions of stars with great accuracy.



### Ptolemy

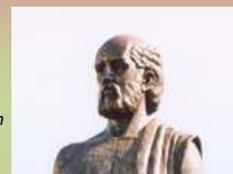
- 100 – 170 AD



### Aristarchus

310 – 230 BC

*“But Aristarchus has brought out a book ..... the fixed stars and the sun remain unmoved, that the earth revolves about the sun on the circumference of a circle, the sun lying in the middle of the orbit”*

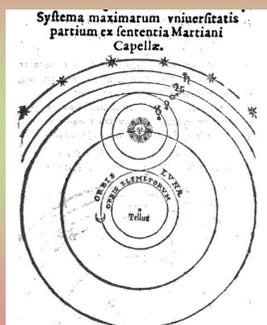


Believed stars to be so far away that no motion observed

Supported by Seleucus 190 – 150 BC

### Martianus Capella

- Active around 420 AD in what is now Algeria.
- Mercury and Venus revolve around Sun.



### Aryabhata

- 476 – 550 AD, India
- Acknowledged Earth to rotate.
- Otherwise geocentric model.



### John Scotus Eriugena

815 – 877 Ireland

Proposed that Mercury, Venus, Mars and Jupiter orbited the Sun.

Suffered unfortunate fate



### Al-Battani

- 858 – 929 lived in what is now Turkey. Later based in Syria.
- Distance between Earth and Sun varying. Axis of aphelion varying.



### Nur ad-Din al-Bitruji

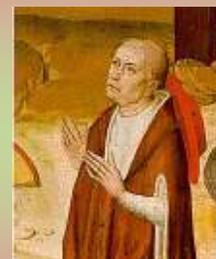
- d 1204 Spain
- System of rotating spheres.
- Other colleagues – rotation of Earth

### Cardinal Nicholas of Cusa

1401 – 1464. Holy Roman Empire

Does there HAVE to be a centre ?

"Thus the fabric of the world (*machina mundi*) will *quasi* have its center everywhere and circumference nowhere,"



### Georg von Peurbach

- 1423 – 1461 Vienna
- Expressed doubts on Ptolmaic System



### Johannes Muller von Konigsberg

- Also known as Regiomontanus
- 1436 to 1476
- Student of von Peurbach
- Wrote about the Aristarchus system
- Observed Eclipses and found discrepancies

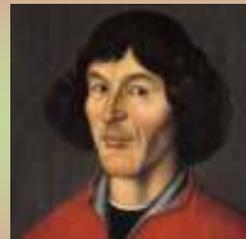


### Domenico Maria Novara de Ferrara

- 1454 – 1504
- Professor at Bologna
- Student of Regiomontanus but later mentor to Copernicus

### Nicolaus Copernicus

- 1473 – 1543
- Poland
- Published Heliocentric theory late in his life.
- Persuaded to publish by student Georg Rheticus

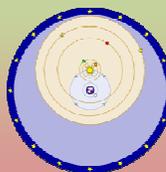


### Georg Joachim Rheticus

- 1514 – 1574 Austria
- Visited Copernicus 1539 to 1541
- *I heard of the fame of Master [Nicolaus Copernicus](#) in the northern lands, and although the University of Wittenberg had made me a Public Professor in those arts, nonetheless, I did not think that I should be content until I had learned something more through the instruction of that man..... there came a great reward for these troubles, namely, that I, a rather daring young man compelled this venerable man to share his ideas sooner in this discipline with the whole world.*

### Tycho Brahe

- 1546 – 1601
- Best pre-telescopic observations
- Hybrid theory



### Michael Mastlin

- 1550 – 1631
- Baden-Wurtemberg, Germany
- Supporter and publiciser of Copernican System



### Johannes Kepler

- 1571 – 1630
- Studied under Mastlin and later worked for Brahe
- Laws of planetary motion
  - Ellipses
  - Area
  - Periods



### Pierre Gassendi

- 1592 – 1655
- France
- Philosopher, Priest, Mathematician and Astronomer
- Used Kepler's Laws to predict and observe transit of Mercury in 1631.



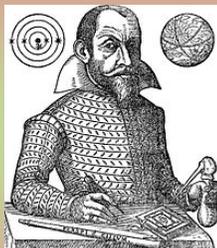
### Hans Lipperhey

- 1570 – 1619
- German, moved to Netherlands
- Attempted to patent the telescope
- Rival claim Jacob Metius 1571-1624/31



### Simon Marius

- 1573 – 1625
- Ansbach, Germany
- Visited Padua, dispute with Galileo
- Observed and catalogued the Moons of Jupiter.

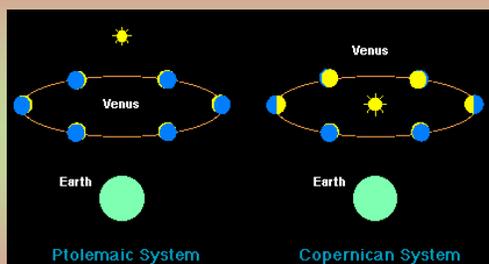


### Galileo Galilei

- 1564 – 1642
- Pisa, Padua, Italy
- Early observations with telescope
- Moons of Jupiter
- Phases of Venus
- Sun, Moon, Saturn



### The Phases of Venus



### Giordano Bruno

- 1548-1600
- Naples. Travelled a lot. Then Rome.
- Took Copernican principle further.
  - Stars were distant Suns
  - With their own planets
  - With life .....
- A sad conclusion



- And it gets sadder every week even now.

### Giovanni Battista Zupi

- 1590 – 1650
- 1631 Discovered phases for Mercury behaving like phases of Venus.

### Christiaan Huygens

- 1629 – 1695
- The Hague
- Discovered Titan, Moon of Saturn



### Three missing ingredients

- WHY does it work this way ?
- Does the Earth really rotate ?
- If the Earth is moving, why do we not see the stars move position ?

### It works – but WHY ?

- WHY did Kepler's Laws Apply
- Are they always going to work ?

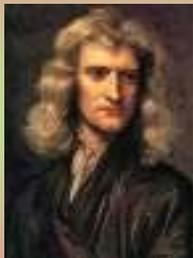
### Isaac Barrow

- 1630 – 1677
- London, Cambridge
- Looked for a solution involving maths.
- Inspired his student ...



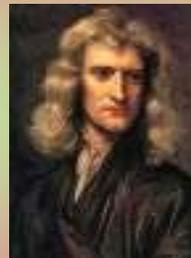
### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.

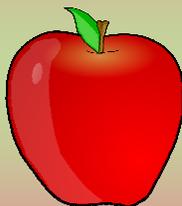


### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.
- Needed inspiration



### Inspiration



### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.
- Needed to invent new maths



### Calculus

- Branch of maths necessary to show Kepler's Laws came from inverse-square force.
- Invented by Isaac Newton

### Calculus

- Branch of maths necessary to show Kepler's Laws came from inverse-square force.
- Invented by Isaac Newton
- .... or was it ?

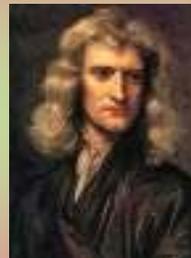
### Gottfried Leibnitz

- 1646 – 1716
- Germany
- Also credited with introducing calculus



### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.
- Needed to be persuaded to publish his results.



### Edmond Halley

- 1656 – 1764
- London
- Backed Newton and persuaded him to publish.



### Edmond Halley

- 1656 – 1764
- London
- Noted that positions of Sirius, Arcturus and Aldebaran had moved slightly from Hipparchus values.



### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.
- Royal Society had no funds to pay to publish



### Historia Piscium



### The History of Fishes



### Isaac Newton

- 1643 – 1727
- Lincolnshire, Cambridge
- Addressed issue but had to overcome some problems.
  
- Published. Showed that Kepler's Laws come from an inverse-square force.



### It is all solved

- Or is it ?

### Giovanni Domenico Cassini and Jean Richer

- 1626-1712 and 1630-1696
- Stationed in Paris and in Cayenne, French Guyana, 1672
- Measured and compared positions of Mars and hence found distance to Mars.

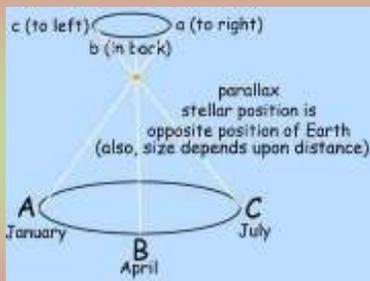
### A longer baseline ??

### James Bradley

- 1693 – 1762
- Gloucestershire
- 1727 : observed changes in the position of Gamma Draconis.



### Parallax ??



### Parallax ??

- Suggested that star gamma Draconis was at a distance of 0.16 light years.



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- Suggested that star gamma Draconis was at a distance of 0.16 light years.
- Subsequently ALL stars discovered to have a distance of 0.16 ly.

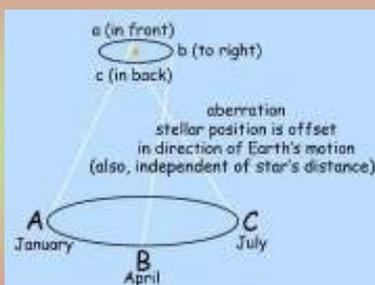


### Parallax ??

- Suggested that star gamma Draconis was at a distance of 0.16 light years.
- Subsequently ALL stars discovered to have a distance of 0.16 ly.
- Implications ?



### Or aberation ?



### Aberation of light



### Aberration of light

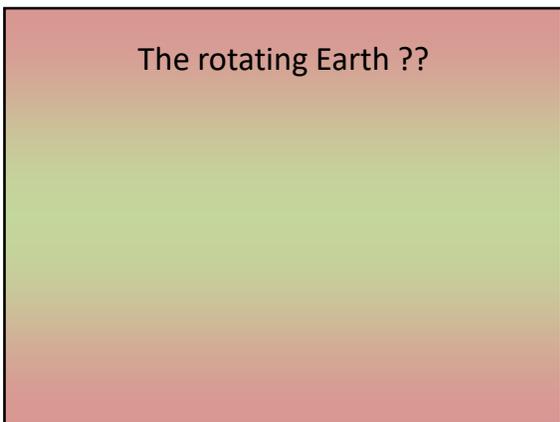


Not the effect looked for but gave an improved value for the speed of light.

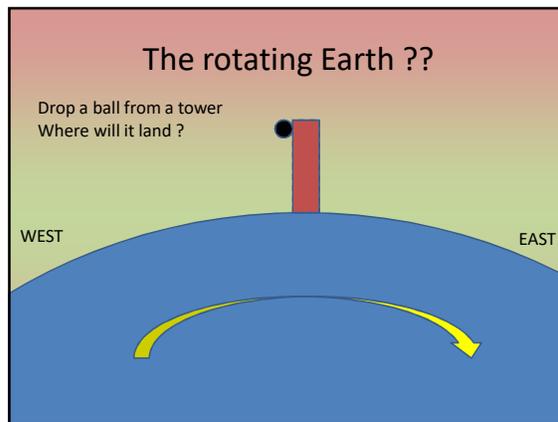
### How do we know we are rotating ?

- Some early models had contained flexibility about whether or not the Earth was rotating.
- Later models had the rotation of the Earth as standard.
- But why do we not feel the Earth rotating.
- The only evidence is that the sky appears to rotate.

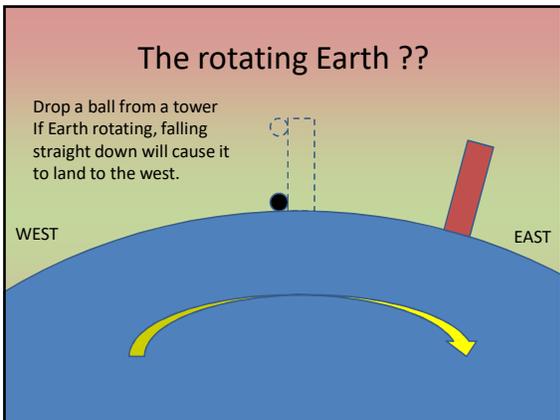
### The rotating Earth ??



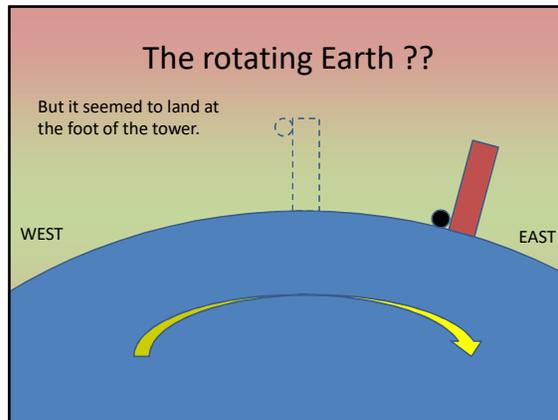
### The rotating Earth ??



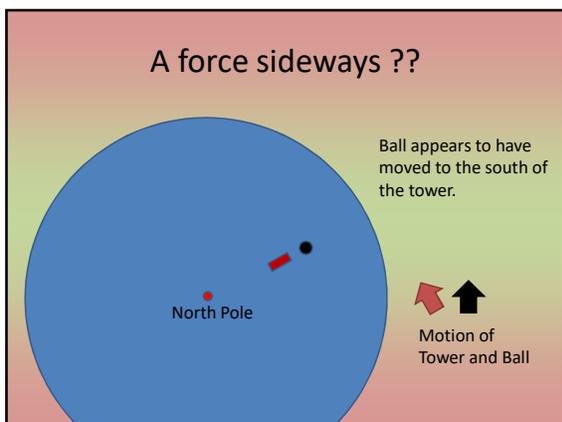
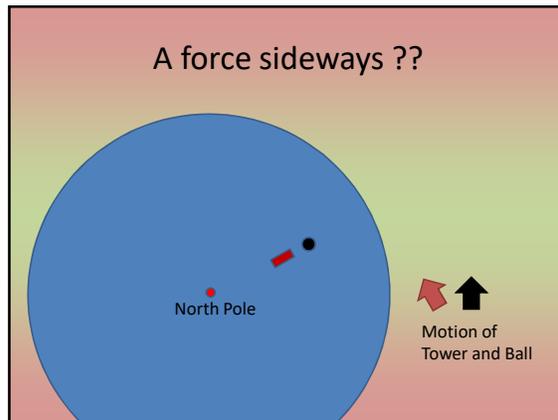
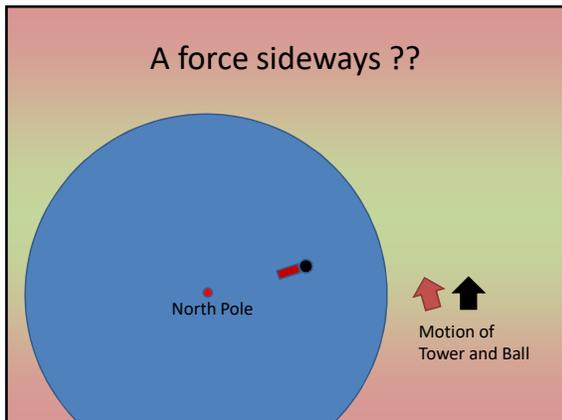
### The rotating Earth ??



### The rotating Earth ??

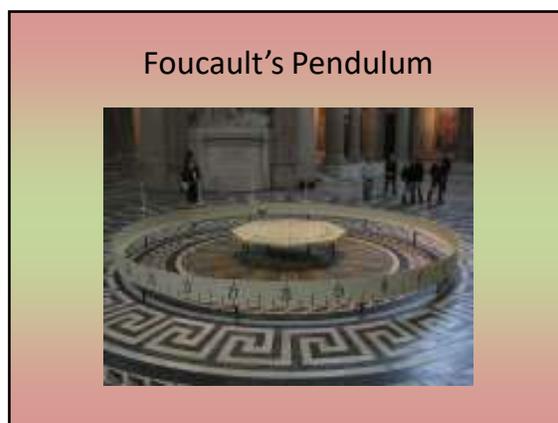






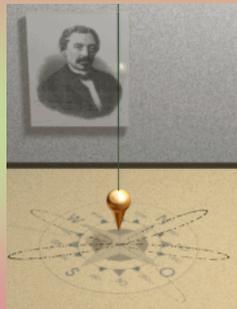
The Coriolis Force

- A force which, on a rotating planet, causes moving objects, in the northern hemisphere, to move to the right.



### Foucault's Pendulum

- If Earth rotating, plane of pendulum swing will change. Move to the right.



### But there is still a problem

- Why do we not see the stars move ?
- Observational Techniques are improving – surely we should be able to see results.

### Parallax

- Many observations submitted. But there was always a problem.
  - Tycho Brahe
  - Robert Hooke
  - John Flamsteed
  - Ole Romer
  - James Bradley
  - William and Caroline Herschel

- Guiseppe Piazzi
- Guiseppe Calendrelli
- Francois Arago
- Claude-Louis Mathieu
- Johann Schroter

### Thomas Henderson

- 1798 – 1844
- Sent to Cape Observatory 1832 and carried out observations including Alpha Centauri



### Manuel Johnson

- 1805 – 1859
- Travelled widely
- 1828 – 1835, operated observatory on St Helena.
- Noted high proper motion of Alpha Centauri
- Communicated to Henderson

### Thomas Henderson

- 1798 – 1844
- Sent to Cape Observatory 1832 and carried out observations including Alpha Centauri
- Received word from Johnson and made decision.



### Frederich Georg Wilhelm von Struve

- 1793 - 1864
- Germany, Russia
- Would really have liked a double star.
- Settled on Vega. Unrelated star 43 seconds away



### Frederich Bessel

- 1784 – 1846
- Germany, Prussia
- Interested in 61 Cygni



- What was Bessel's observing technique ?

- What was Bessel's observing technique ?
- He cut the main telescope lens in half.

### The heliometer

- Split-lens
- Allows two different targets to be observed and positions compared.
- October 1837 – October 1838 many observations of 61 Cygni



### December 1838

- Astronomische Nachrichten
- "Determination of the distance to the 61<sup>st</sup> star of the Swan"
- By FW Bessel
- 0.314 seconds – 10.4 ly. (Modern value 11.4)

### February 1839

- Thomas Henderson
- Distance to Alpha Centauri is 3.25 light years.
- Modern Figure 4.3

### Late 1839

- Struve : distance to Vega 12.5 light years. Modern value significantly higher.

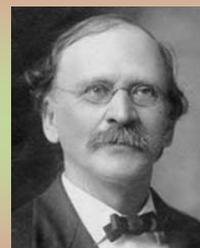
### Distances to the stars

- Finally, the distances to (some of) the stars were established.
- The loose ends of the Copernican Revolution were tied up.

### The Year 1838

- -60 degrees in Yakutsk
- Floods in Hungary
- Dickens writes Nicholas Nickleby
- Coronation of Queen Victoria
- First polytechnics open
- Federation of Central America is dissolved
- William Steele is born in Linlithgow
- Bombay Times and Journal of Commerce is founded
- The Pastry War
- Bessel measures distance to 61 Cygni
- The Timperley Tithe map is produced.

### This man was born



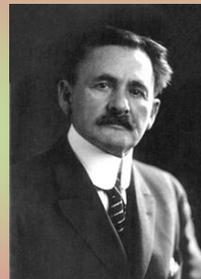
### Edward Morley

- 1838-1923
- USA



### Albert Michelson

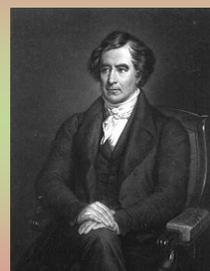
- 1852 – 1931
- Prussia, USA



- The Michelson-Morley experiment

### Francois Arago

- 1786 – 1853
- France
- Noted irregularities in orbit of Mercury.



### Urbain Jean Joseph Le Verrier

- 1811 – 1877
- France
- Conducted and orchestrated searches for planet inside orbit of Mercury.



### Edmond Modeste Lescarbault

- 1814 – 1894
- Rural France
- Recorded a 'transit' of object across the face of the Sun.

- What was the real reason for the irregularities in Mercury's Orbit ?

1838

- The final piece in the jigsaw of the Copernican Revolution was complete.

1838

- The final piece in the jigsaw of the Copernican Revolution was complete.
- The cast was assembling for the SECOND scientific revolution.

- If the first scientific revolution ended around 1838, when did/will the second scientific revolution end ?