

# The Universe Does Not Revolve Around You Week 2

**Capilano University Campus  
Jan 27th, Feb 3rd, Feb 10th**

**Presented by Michael Bradley**

[www.sunmoonstars.ca/eldercollege](http://www.sunmoonstars.ca/eldercollege)

# The Universe does not revolve around You

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## ▶ Week 1

- Opening Discussion
- Cosmologies of the Ancient World
- Greek Philosophers and the "Crystal Sphere"
- The spread of the Aristotelian "*geocentric*" view
- Video – "*Earth Views*"
- Video – "*No! You are not the centre of the Universe*"

## ▶ Week 2

- The Abrahamic faiths
- Copernicus and the "*heliocentric*" view
- Medieval & Renaissance society
- Galileo and the Vatican
- Video – "*Our Solar System*"
- Video – "*Venus Transit*"

## ▶ Week 3

- The Newtonian Universe
- The "Enlightenment" – 17,18 cent.
- The "Modern" Period
- Today
- Tomorrow

# Review of Week 1

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- ▶ Last week we saw how early cosmologies were developed to meet immediate local challenges and needs.
- ▶ We also saw how application of *Reason* and *Logic* advanced the thinking about the structure of the universe.
- ▶ The Aristotelian universe, as exemplified by the “Crystal Sphere” idea was starting to spread, aided in part by the reputation of its author and in part because it accurately described most of what people could experience for themselves.

# Review of Week 1

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- ▶ The view of earth as being *flat* changed to it being *spherical*.
- ▶ The "Aristotelian" view:
  - Universe is eternal and perfect
  - Universe consists of a series of concentric spheres
  - Earth lies in centre and is stationary (**geocentric**)
  - Earth is imperfect and therefore finite (sub-lunar)
  - Stars and planets are composed of a unique non-earthly substance - **quintessence** (supra-lunar)
  - Elements always return to their original positions

# The Universe does not revolve around You – Week 2

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- ▶ We'll see how the "Aristotelian" view of a geocentric Universe proved very resistant to alternative views.
- ▶ We'll see how the "Aristotelian" cosmological view was reconciled with the Christian Biblical view.
- ▶ We'll see how the belief that "everything has its naturally defined position" reinforces social mores.
- ▶ By the end of Week 2, earth is no longer at the centre of our Universe, the sun is. The "Crystal Spheres" have been shattered.
- ▶ Dogma's being questioned, Revolution is in the air!

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# **“Abrahamic Universe”**

# Abrahamic Universe

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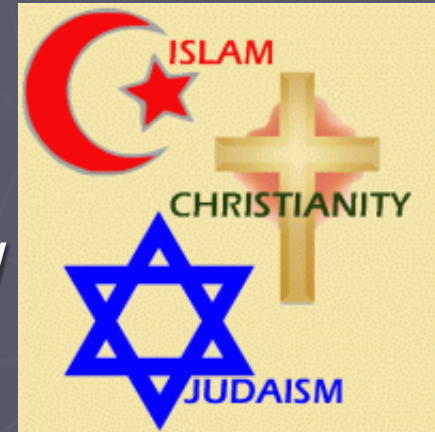
- ▶ Muslim, Christian and Hebrew scholars recognised that the Aristotelian view was inconsistent with their religions.
- ▶ The inconsistency that was most troubling was its *eternal* nature. There was no concern about the geocentrism.
- ▶ These scholars proposed versions of a *finite* universe, it had a beginning & end, more consistent with their faiths.



# Abrahamic Universe (6<sup>th</sup> century and beyond)

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- ▶ The Christian philosopher, John Philoponus of Alexandria, was one of the first to challenge the dominant view of an **eternal** universe.
- ▶ Later, in 9<sup>th</sup> and 11<sup>th</sup> century the Muslim theologians Al-Kindi and Al-Ghazali offered their own logical arguments favouring the **finite** view.
- ▶ In 10<sup>th</sup> century the Jewish philosopher Saadi Gaon argued for the **finite** view too.



# John Philoponus of Alexandria (490-570 CE)

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- ▶ John Philoponus was the most serious critic of the Aristotelian view of the universe. (He also challenged his thinking in many other areas too).
- ▶ He tried to develop a “scientific” view of cosmology with the Christian view of creation.
- ▶ He very successfully identified many of the weaknesses in the Aristotelian view.
- ▶ He was perhaps the first “creationist” critic of science!



# John Philoponus of Alexandria (490-570 CE)

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## ► John of Philoponus cosmology:

- Universe is the creation of a single God and is not eternal
- The heavens are composed of the same material as the earth
- Stars and planets are not different from earthly materials and can change
- Objects can move, even in a "void", and have a property of "impetus", a property rather like what later became known as "inertia".

# John Philoponus of Alexandria (490-570 CE)

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- ▶ Why was his understanding of the creation and function of the universe not adopted elsewhere?
  - John's reputation as a theologian was damaged by an posthumous accusation of heresy. He was unable to defend himself of course.
  - Copies of his work did circulate in Greek and Latin texts however.
  - Arabic scholars knew of him and referred to him respectfully as "John the Grammarian".

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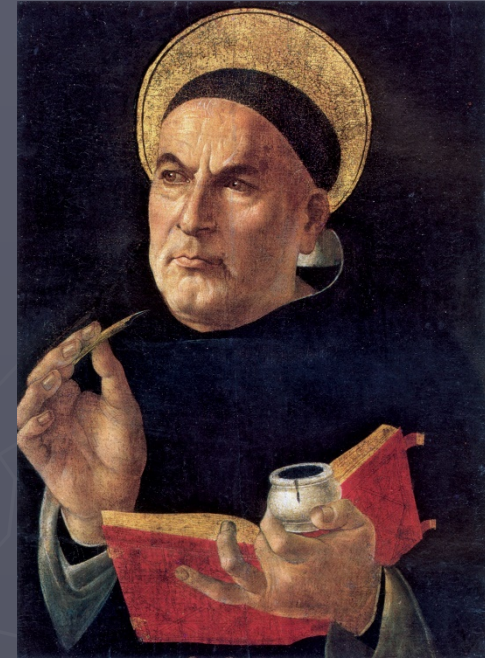
**“St. Thomas Aquinas”**



# St. Thomas Aquinas (1225-1274 CE)

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- ▶ A hermit had told his parents he would become a wise Friar.
- ▶ Educated by Benedictine Monks in Italy from age 5-18. His studies included the works of Aristotle.
- ▶ Favouring a life of *service* rather than *contemplation*, he joined the Dominican order.
- ▶ Parents kidnapped him and imprisoned him in an attempt to "de-program" him for over a year.



# St. Thomas Aquinas (1225-1274 CE)

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- ▶ Brilliant philosophical and theological mind.
- ▶ Developed a synthesis between Aristotle's metaphysics and Christian theology by reasoning that a "*beginning*" was not the same as an "*origin*".
- ▶ "*God is the uncaused cause of the world*"
- ▶ Aristotle's Prime Mover/First Cause argument was now central to the Christian view of the world.
- ▶ This became the basis of Aquinas's "Five Ways into exploring the existence of God".

# St. Thomas Aquinas (1225-1274 CE)

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- ▶ The universe exists
- ▶ Everything that exists has a cause
- ▶ Causes precede their effects
- ▶ The chain of cause & effect cannot go back in time indefinitely (*an infinite regress*)
- ▶ Therefore, there must be a 'first cause' that is not itself an effect (*ie. it has no prior cause*)
- ▶ Since everything has a cause, this first cause must be the cause of itself (*ie. it must necessarily exist*)
- ▶ This self-caused first cause is God
- ▶ Therefore, God exists

# St. Thomas Aquinas (1225 -1274 CE)

- ▶ Heavens were perfect spheres with Earth at centre.
- ▶ Aristotle – imperfect Earth  
Aquinas – “original sin”
- ▶ Beyond the celestial sphere was the realm of God and angels. God’s love moved the heavens like a vast machine.
- ▶ This “Summa Theologica” became Catholic dogma and set back science for 500 years.



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# **“The Great Chain of Being”**



# "The Great Chain of Being"

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- ▶ The Medieval view was of a biological chain of **immutable** lifeforms, forms decreed by God.
- ▶ The chain linked the living world to God & the angels and the celestial sphere. It secured for human beings a central position in the Universe.
- ▶ It reinforced the hierarchical structure throughout society.
- ▶ It supported "**plenitude**", the view of the Abrahamic faiths that a benevolent God gave man dominion over earth.

# Divine Rights of Kings (and Church)

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- ▶ In Medieval Europe everything had its place, a place ordained by God. The serf was a serf by Gods will, the king was the king because God had selected him personally.
- ▶ In the Aristotelian/Aquinas synthesis, everything had its natural place, including people.
- ▶ The church justified its own hierarchy as the divinely ordained continuation of this cosmic hierarchy.
- ▶ Challenging the Aristotelian cosmos would have repercussions far beyond the stars and planets.

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The background features a dark gray map of the world with white contour lines. A compass rose is visible on the left side, with the letter 'N' at the top and 'S' at the bottom. The word "Islam" is written in a bold, white, sans-serif font with a slight drop shadow.

**"Islam"**

# The Islamic Contributions

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- ▶ After the fall of the Roman Empire (ca 5<sup>th</sup> cent. CE), much classical learning was lost to Europe, but remained and was developed in the Islamic world.
- ▶ When Vikings were rampaging around Northern Europe:
  - the Persian mathematician al-Khwarizmi was solving quadratic equations.
  - al-Razi was differentiating between measles and smallpox and practicing vaccination.
  - al-Kindi was introducing Indian numerals into mathematics.
- ▶ Smallpox, Algebra, Mathematics - major advances already made by the end of the 9<sup>th</sup> Century!

# Our language

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- ▶ Common Star names: Aldebaran, Altair, Betelgeuse, Caph, Deneb etc
- ▶ Terms: azimuth, zenith, atlas, sine, almanac
- ▶ Do you remember the quadratic equation solver - al-Khwarizmi ? We remember him today when we refer to *Algorithm* - the Latin form of his name.

# Pre-Islamic period (before 700 CE)

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- ▶ Their observations were **empirical**, knowledge was gained by observation, i.e. of the stars rising etc.
- ▶ This approach even had a name "*anwa*". Dallal (1999)
- ▶ The Koranic obligation to determine prayer times and place (Qibla) gave rise to a more advanced study of astronomical topics. King (2005), "Call of the Muezzin"
- ▶ In their science, the empirical approach started to give way to the search for an understanding of **why** things happened.

# Astronomy in the Koran

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- ▶ The Koran itself makes many references to star patterns and astronomical aspects:
  - Planets “swim in their own orbits”
  - Heavens and Earth “were once one”
  - The universe is steadily expanding!
- ▶ The Muslim faith requires believers to pray 5 times a day at specific positions of the sun.
  - 1<sup>st</sup> daybreak
  - 2<sup>nd</sup> noon
  - 3<sup>rd</sup> when length of shadow doubles
  - 4<sup>th</sup> at sunset
  - 5<sup>th</sup> after sunset before dusk
- ▶ Muslims must face Mecca when praying, so celestial observation used to create tables for cities/times.

# Islamic Astronomy (7<sup>th</sup>-8<sup>th</sup> cent)

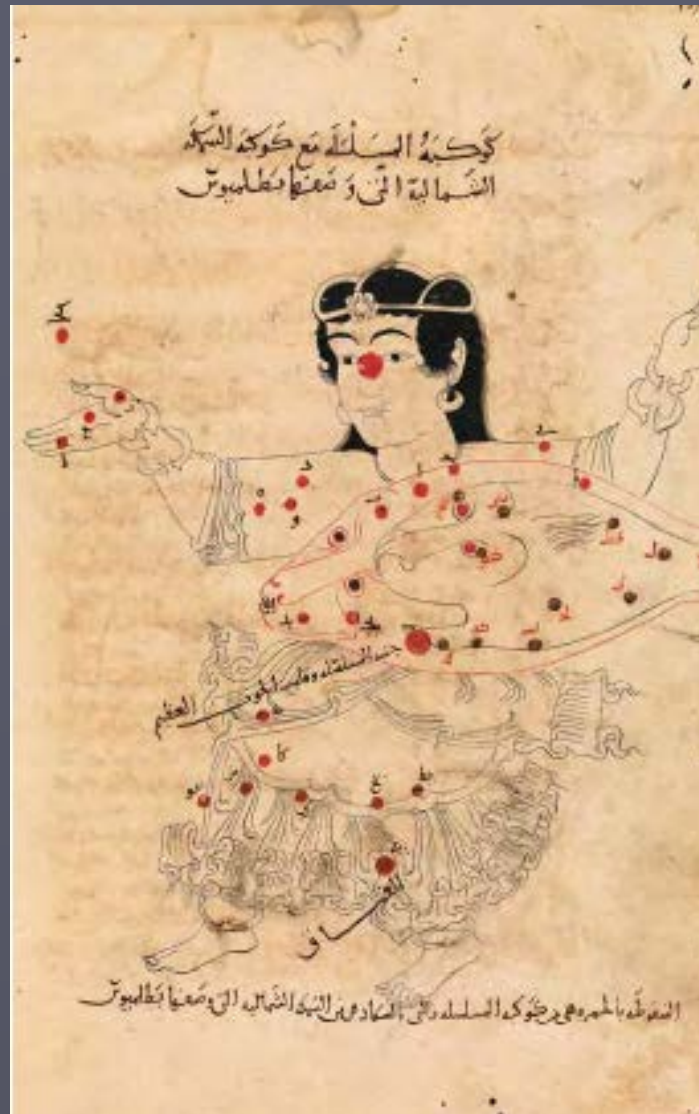
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- ▶ During the European “Dark Ages” scientific exploration largely took place in the Islamic world.
- ▶ Documents from elsewhere (Greece, Alexandria, India, China) were collected and translated.
- ▶ As the Islamic world spread into N.Africa and Spain these documents became available to European scholars. Many early works would have been lost forever if not for the work of these Islamic scholars.
- ▶ Observatories were built, sextants and astrolabes developed. The observatory in Samarkand catalogued >1000 stars, the most accurate survey.

# Islamic Astronomy (7<sup>th</sup>-8<sup>th</sup> cent)

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- ▶ The first major Muslim work of astronomy was *Zij al-Sindh* by al-Khwarizmi in 830.
- ▶ The work contains tables for the movements of the sun, the moon and the known planets. The work is highly significant as it introduced Ptolemaic concepts into Islamic sciences.
- ▶ Prior to this work Muslim astronomers had been translating works of others, not originating ideas.
- ▶ Al-Khwarizmi's work marked the beginning of nontraditional methods of study and calculations.



## Astronomers from the "Golden Age"

# al-Battani (850-929 CE)

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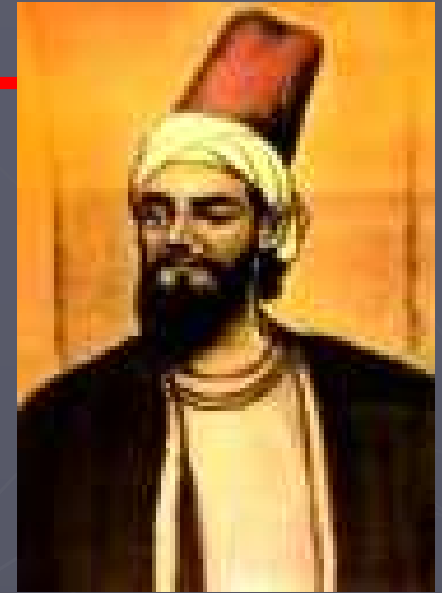


- ▶ al-Battani astronomer and mathematician. Corrected some of Ptolemy's observations and developed a method for calculating planetary positions.
- ▶ He started a process of developing alternate models that his fellow astronomers subsequently took up. They were all variants on the geocentric one though.

# Umar Kyayyam, (1048 -1131)

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- ▶ Umar Kyayyam, astronomer, philosopher, mathematician, poet. He made important contributions to geometry and corrected the calendar then in use.
- ▶ He calculated the year to be 365.24219858156 days long, a value accurate to the 6<sup>th</sup> decimal.
- ▶ His work on geometry was one of the sources built upon later by Rene Descartes in developing the Cartesian coordinate system and analytic geometry.



# Umar Kyayyam, (1048 -1131)

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*The Moving Finger writes: and, having writ,  
Moves on: nor all thy Piety nor Wit  
Shall lure it back to cancel half a Line,  
Nor all thy Tears wash out a Word of it."*



# Natural Philosophy and Religion

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- ▶ “Scientific enquiry” before the Renaissance was NOT like science in our own times at all. It is perhaps best described as “**Natural Philosophy**”.
- ▶ There were many points of contact between natural philosophy and religion. They were often part of the same discipline and often practiced by the same people.

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# **“European Renaissance”** (14<sup>th</sup>-17<sup>th</sup> cent)

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# The Printing Press

The background features a dark gray color with a faint, light gray outline of a map of the United States. In the lower-left quadrant, there is a faint compass rose with a dollar sign (\$) and the letter 'N' visible.

# Books in Medieval Europe

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- ▶ Europe, late 14<sup>th</sup> Century:
  - cheap paper
  - invention of spectacles
  - slow spread of vernacular literacy
- ▶ Paper and printing were not European technologies
  - Around 200 B.C.: paper developed in China
  - 7th century: spread to Middle East
  - 12th century: first paper mill in Europe

# Books in Medieval Europe

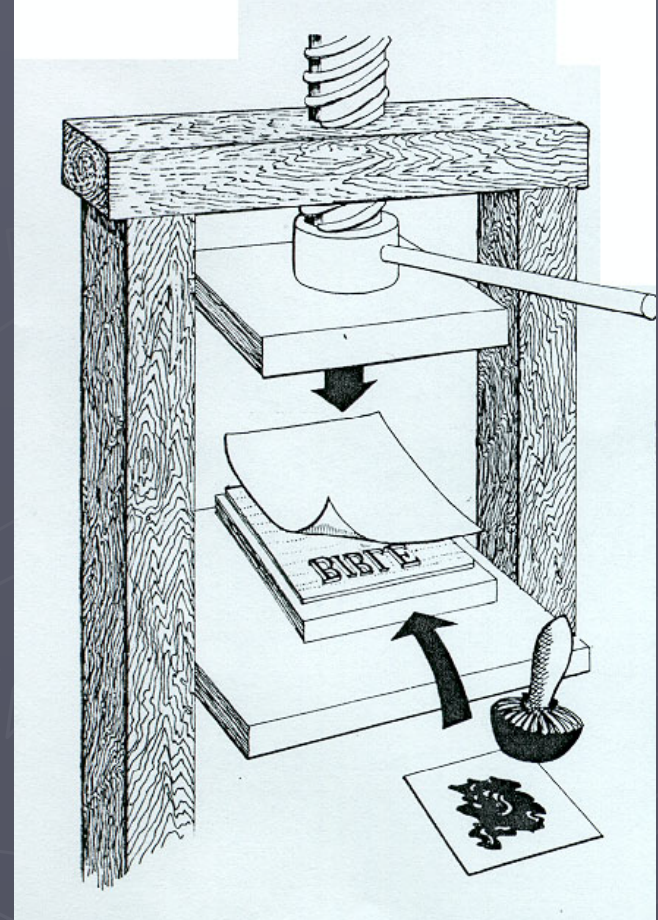
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- ▶ Text was scarce in medieval Europe. Books were expensive to produce. If a book was to survive, it had to be copied over and over, for every generation.
- ▶ Before the printing press in 1450, books were written out by hand, mainly by monks in monasteries.
- ▶ It could take one person six months or longer to write out a book, word for word and page by page.



# Gutenberg & the Printing Press (ca1450 CE)

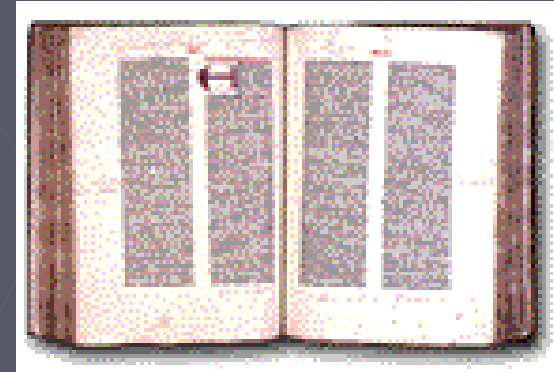
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# Social & political impact of Printing Press

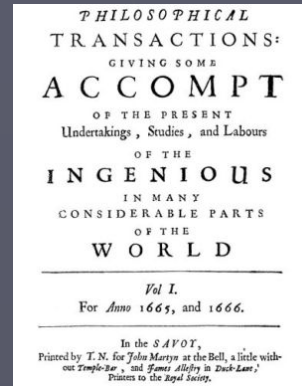
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- ▶ Accessible publications
- ▶ Imagine what the knowledge meant to the common people.
- ▶ Emergence of new, text-based communities and ideas (Protestant Reformation, liberal and Parliamentary political movements, etc.)
- ▶ Instead of having to take the church's or the king's word on something, they could learn to read and form their own opinions.

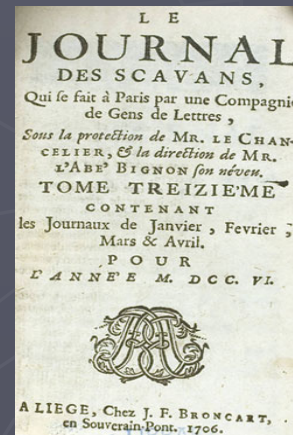


# Scientific impact of Printing Press

- ▶ The printing press also permitted the reproduction and distribution of scientific works to a wide audience. Previously only the rich and privileged had this access.
- ▶ It was a factor in the establishment of a community of scientists who could easily communicate their ideas through widely disseminated scholarly journals, helping to accelerate the scientific revolution of the Renaissance. "Virtual Communities"?



Pub. 1665



Pub. 1665

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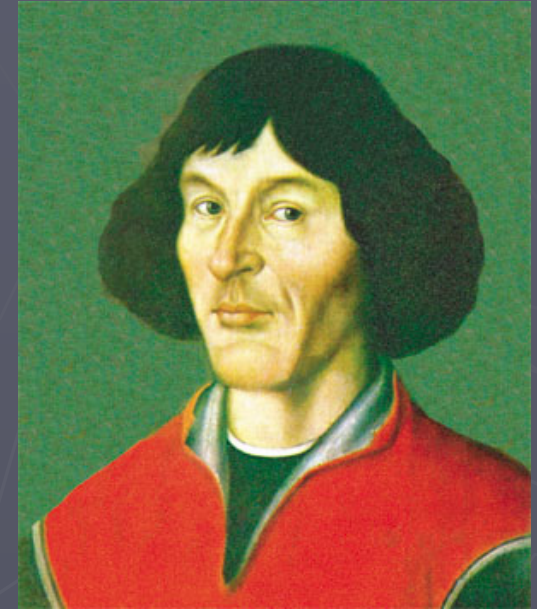
# Nicolaus Copernicus



# Copernicus (1473-1543, Poland)

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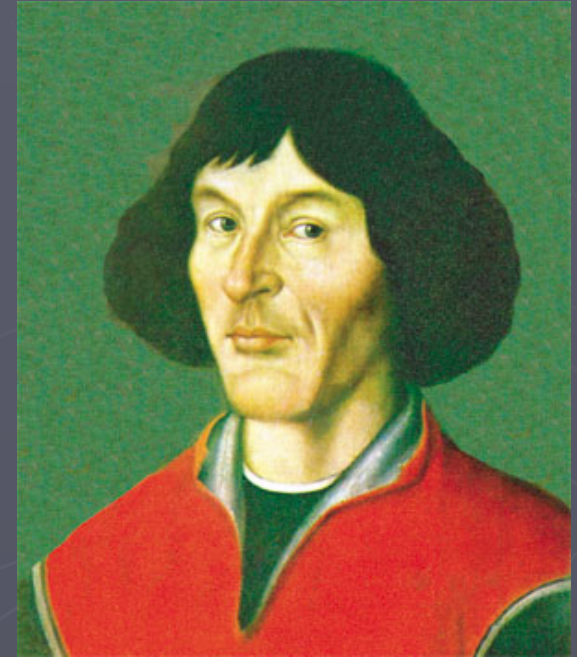
- ▶ Nicolaus Copernicus was born 1473 in Torun, Poland.
- ▶ Nicolaus's father died when Copernicus was ten, cared for by uncle who was a canon.
- ▶ He studied Latin, mathematics, astronomy, geography, philosophy, and astrology at Univ. Krakow, leaving without a degree



# Copernicus (1473-1543, Poland)

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- ▶ First person to widely promote a sun-centred or “heliocentric” model of the universe
- ▶ Earth now moves around the Sun.
- ▶ Unfortunately the Vatican had adopted Aristotle’s model – it was now a capital crime to express different ideas.
- ▶ He published *Des Revolutionibus* in 1543 (on his deathbed)





# The Copernican model of the Universe

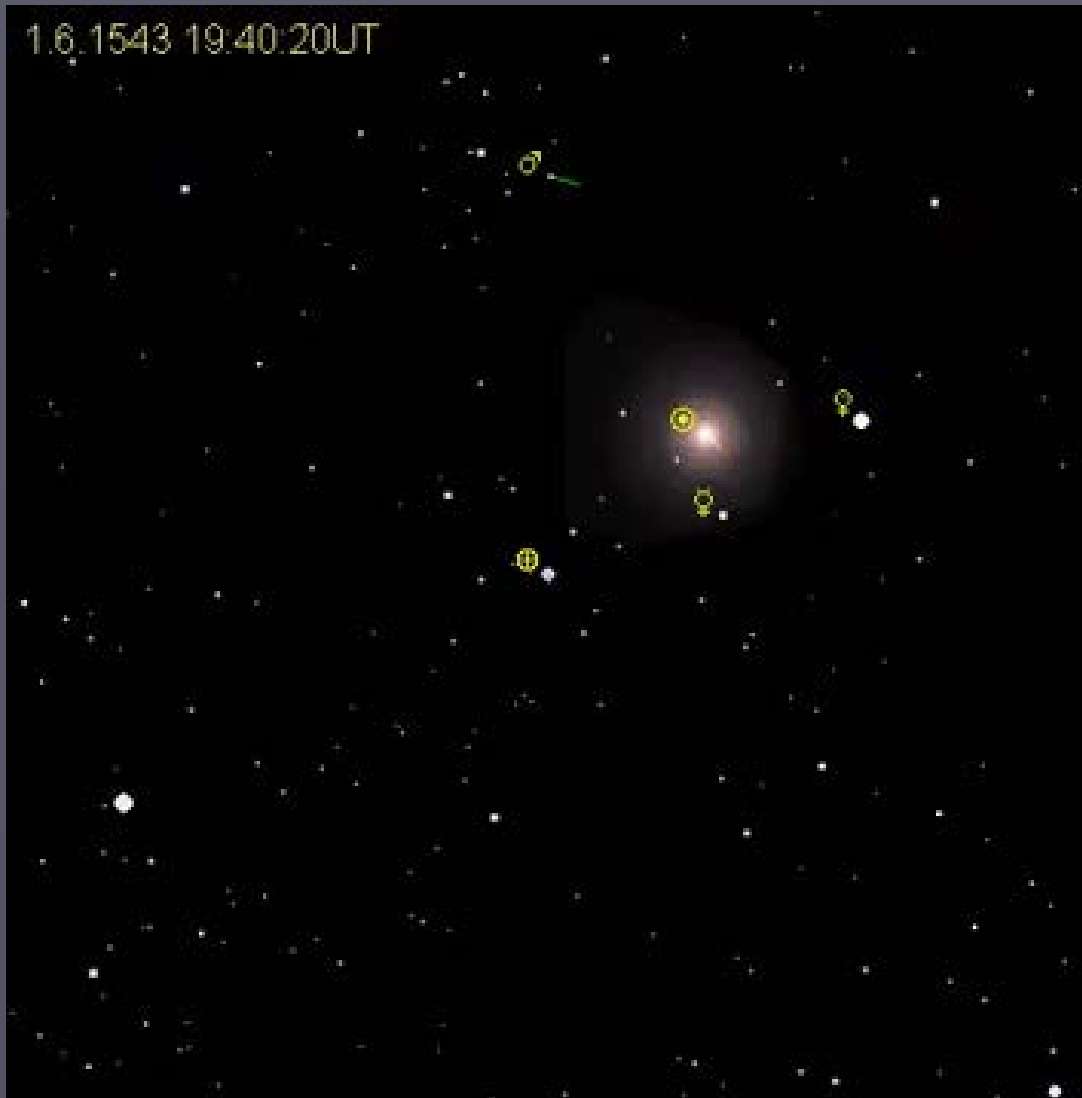
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## ▶ Retrograde Motion was explained again...

(remember Pythagoras!)

- In a heliocentric model, retrograde motion is simply an *apparent motion*...
  - e.g. the apparent backward motion of the car next to you when you go around a long curve on the inside lane and pass the other car.
- ▶ But Earth now had to rotate on its own axis, the orbits were perfect circles though.

# The Ptolemaic and Copernican models



**Ptolemy:** Paths of Sun and Mars as seen from Earth. Then the looping paths of Venus and Mercury are added.

**Copernicus:** we trace out the orbits of the 4 inner planets (Mercury, Venus, Earth, Mars) during one Martian year.

**Zoom:** shows two of the naked eye planets, Jupiter, Saturn.

# Advantages of the Copernican Model

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- ▶ It correctly ordered the planets.
- ▶ It correctly calculated time for planets to orbit the Sun.
- ▶ Explained the apparent motion of stars and Sun using Earth's rotation and orbit.
- ▶ Explained why Mercury and Venus are always seen near the Sun.
- ▶ But it still needed to "tweak" the results to fit actual observations.
- ▶ Martin Luther commented: "*this fool wants to overturn the whole science of astronomy*"

# Frontispiece from Luther's "Biblia: (1534)

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# Martin Luther's view

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- ▶ *"Scripture simply says that the moon, the sun, and the stars were placed in the firmament of the heaven, below and above which heaven are the waters... "*
- ▶ *"We Christians must be different from philosophers in the way we think about the causes of things. If some are beyond our comprehension like those before us concerning the waters above the heavens, we must believe them rather than wickedly deny them or presumptuously interpret them in conformity with our understanding."*

# Why leave the publication until his death bed?

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- ▶ At this time the established doctrine was the Thomas Aquinas dogma describing a geocentric universe with a stationary, central earth.
- ▶ Copernicus didn't only have earth moving, but it did so in two dimensions, once around the sun, and around its own axis – he thought dangerously!
- ▶ Knowing his ideas would be controversial at best, possibly even dangerous, he deferred publication until the year of his death.

# Why leave the publication until his death bed?

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- ▶ Theology: 'And the sun stood still, and the moon stayed' (Joshua, 10:12-13)
- ▶ Council of Trent (1545-1563)
- ▶ Protestant Reformation sweeping across Europe.
- ▶ Not a good time to upset Religious authorities!



# Why leave the publication until his death bed?

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- ▶ A well intentioned proof reader added a caveat to the manuscript explaining that placing the sun at the centre was merely a mathematical device to **make the calculations easier**.
- ▶ Copernicus was unaware of the caveat that had been added. Knowing his ideas would be controversial at best, possibly even dangerous, he deferred publication until the year of his death.
- ▶ As expected, *Des Revolutionibus* was controversial but being quite academic in nature it did circulate widely and was a big influence on thinking.

# Recognition by Google!

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## Birthday of Copernicus



Video by [simonrueger.de](http://simonrueger.de)

A vibrant, multi-colored galaxy with a central yellow-white core and blue, orange, and red outer regions. The galaxy is set against a dark, star-filled background. The word "Break!" is overlaid in the center in a bold, yellow font.

**Break!**

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# Tycho Brahe

# Tycho Brahe (1546-1601, Denmark)

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- ▶ One of the best *observers* in the history of astronomy
- ▶ Lost his nose in a duel over mathematics...
- ▶ The Danish "Court Astronomer"
- ▶ Home/castle/observatory in Uraniborg. This was the last major observatory that did not have a telescope as its main instrument!
- ▶ Not a nice guy to work for!



# Tycho Brahe cont'd.

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- ▶ Moved to Prague and became the "Court Astronomer" of Emperor Rudolf.
- ▶ He continued his practice of measuring the positions of objects throughout their entire paths, not just at quadrants as others had done.
- ▶ He was a mentor to Johannes Kepler.



# Tycho's Contributions

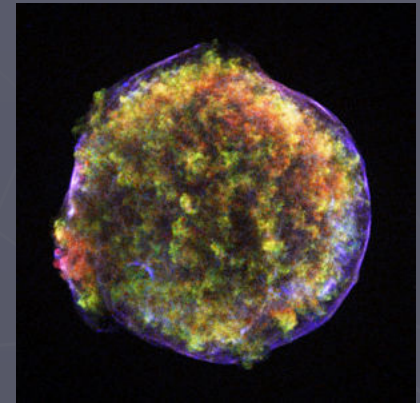
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- ▶ In 1572 Brahe observed a supernova. In 1577 he observed a comet. Current theory was that both were disturbances in the atmosphere but his precise measurements revealed differently.
- ▶ He proposed his own model of the Universe, earth was in the middle – stationary. The sun rotated around the earth, the planets rotated around the sun.
- ▶ On his death, he left a huge catalogue of highly accurate and detailed observations and measurements.

# SN 1572 – “Tycho’s Supernova”

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- ▶ The detailed measurements he made on the supernova of 1572 were among the most important in the history of astronomy.
- ▶ Its appearance challenged the Aristotelian view of the “*immutability*” of the “*crystal sphere*”.
- ▶ The appearance of the “new star” was widely reported and helped to revise ancient models of the heavens.



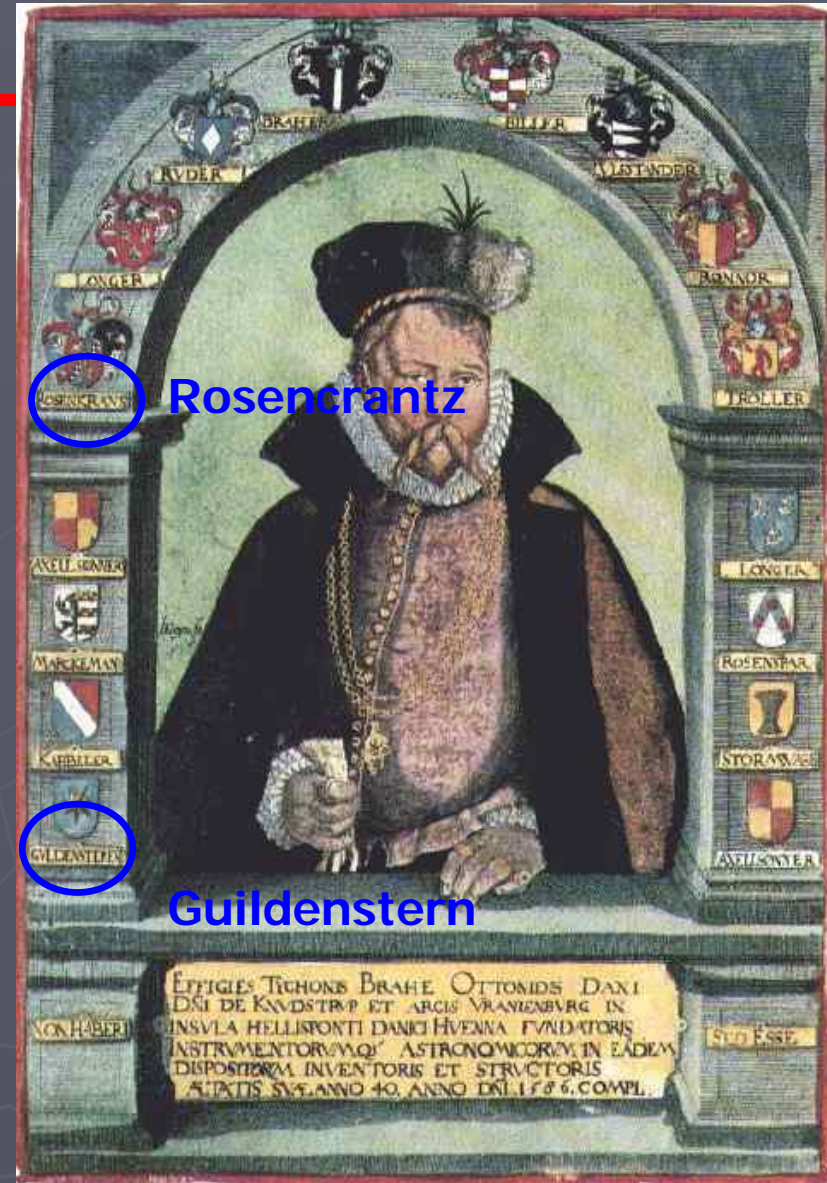
Remnant of SN 1572 as seen in [X-ray](#) light from the [Chandra X-ray Observatory](#)

# Tycho Brahe cont'd.

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Tycho Brahe published a widely read book on astronomy, it included his lineage (seen here).

He lived at his observatory on the Danish island of Hven, within sight of Kronborg Castle – immortalised as Elsinore in "Hamlet – Prince of Denmark".



# Tycho Brahe and Hamlet

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- ▶ Astronomer Peter Usher argues that Hamlet can be read as an allegory of competing cosmological world views!
- ▶ The evil Claudius represents Claudius Ptolemy, while Rosencrantz and Guildenstern represent Brahe, and Prince Hamlet is Thomas Digges – an English astronomer rival to Brahe.
- ▶ When Hamlet envisions himself as *“a king of infinite space”*, could Shakespeare be alluding to the new, infinite universe described – for the first time – by his countryman, Digges?

# Tycho Brahe and Hamlet

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- ▶ Donald Olson (Texas State Univ.) has argued that the star observed by Prince Hamlet shining *“westward from the pole”* was inspired by Shakespeare’s boyhood memory of Tycho’s star.
- ▶ Shakespeare has been described as having a “scientific sensibility” and was “surprisingly alert to, and interested in, the ‘scientific naturalism’ of his time”.

Stephen Greenblatt, Harvard.



Tycho’s “new star”

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**Thomas Digges** (1546-1595 CE)

**Giordano Bruno** (1548-1600 CE)

# Digges and Bruno

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- ▶ Thomas Digges extended Copernican thinking to include a multitude of stars, beyond the crystal sphere.
- ▶ Giordano Bruno went further by suggesting that even the Solar System isn't at the centre of the universe but rather an insignificant star system among a multitude of others.
- ▶ Bruno was burned at the stake for proposing a universe where God would be further away and other planets possible.

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# Johannes Kepler



# Johannes Kepler (1571-1630, Germany)

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- ▶ More a theorist & mathematician than an astronomer.
- ▶ A student of Brahe, he inherited his detailed observations and instruments at age 30.
- ▶ Appointed as “Imperial Mathematician” in Prague.
- ▶ It was these detailed and precise observations that led him to understand that orbits were elliptical and not circular.
- ▶ Finally he could calculate exact planetary positions!



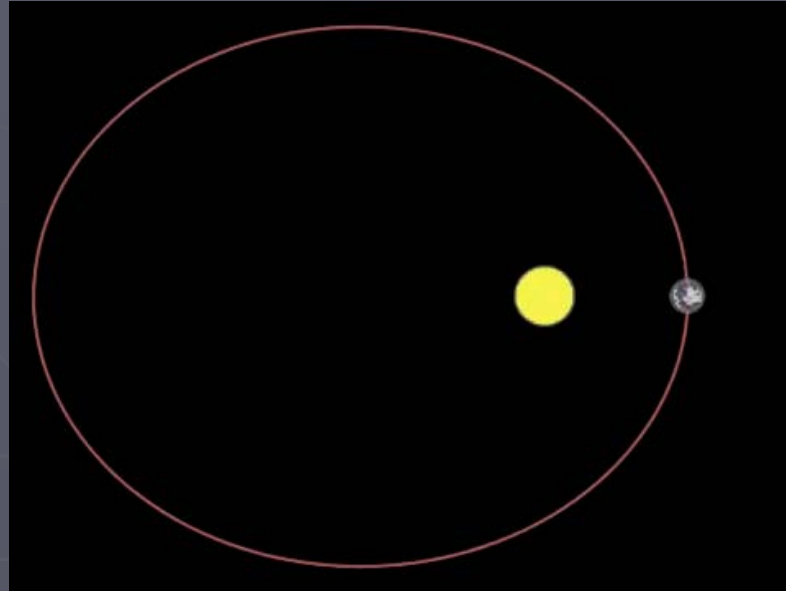
# Kepler's Laws of Planetary Motion (1609)

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- ▶ First Law: The orbit of a planet is an **ellipse**, with the Sun at one focus.
- ▶ Second Law: When a planet is nearer the Sun in its orbit (perihelion), it moves faster. When it is farther from the Sun (aphelion), it moves more slowly.
- ▶ Third Law: The larger the planet's orbit, the longer it takes to complete.

# Kepler's Second Law

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- ▶ This animation illustrates Kepler's Second Law (essentially the conservation of angular momentum)
- ▶ It shows a planet sweeping out equal areas in equal times as it moves along its elliptical orbit.

# JOHANNES KEPLER'S UPHILL BATTLE



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# Astrology

# Astrology

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- ▶ Astrology dates back as far as 20,000 years
  - Carvings on bones that are indicative of an interest in the motion of the moon
  - Mayans had an elaborate astrology involving time and the phases of Venus
- ▶ Astrology Today
  - Esoteric – but quite popular still
  - Dates back 4,000 years to around 1792 bc. in Mesopotamia—modern day Iraq

# Babylonian Astrology

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- ▶ Babylonian study of the cosmos had always been to predict the future. They didn't see the stars as gods. Nor did they try to understand why the and planets behaved as they did.
- ▶ Typically the predictions made were for whole societies or their rulers, rather than individuals.
- ▶ The ability to influence the decisions of rulers was seductive and portentous predictions were often censored (or invented) as required!



# Greek Astrology

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- ▶ Most Greek philosophers studied the cosmos in the pursuit of pure knowledge.
- ▶ There were a few who focused on study of planets to determine their impact on human destiny.
- ▶ By the time of Aristotle very few Greek astronomical thinkers were pursuing astrology.

# Hellenistic Astrology

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- ▶ Alexander's conquests united East & West, mixing Greek philosophy & math with Babylonian astrology (333-323 BCE).
- ▶ This led to astrology for individuals.
- ▶ The astrology practiced today is Greek with virtually no changes.



# Astrological Signs

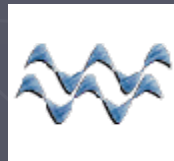
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Aries, Leo, Sagittarius



Taurus, Virgo, Capricorn



Gemini, Libra, Aquarius



Cancer, Scorpio, Pisces

# Astrology or Astronomy?

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- ▶ Throughout most of its history, **astrology** had been considered a scholarly tradition, connected with others, ie astronomy, alchemy, meteorology and medicine.
- ▶ Kepler, Ptolemy and many others astronomers dabbled in astrology. The developing cosmological ideas were quickly adopted by both disciplines.
- ▶ By the end of the 17th century, new scientific concepts in astronomy and physics called the very idea of astrology into question. Astrology thus lost its academic and theoretical standing.

# Astrology or Astronomy?

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- ▶ The attempt to relate how the pattern of stars or the distance to the planets is somehow reflected in us or on the earth, leads to the “metaphysical art” of astrology.
- ▶ A search for the fundamental principles which govern our world and the universe, leads to the science of astronomy.
- ▶ In the 18th century this difference had become clear and most serious astronomers were no longer also astrologers.

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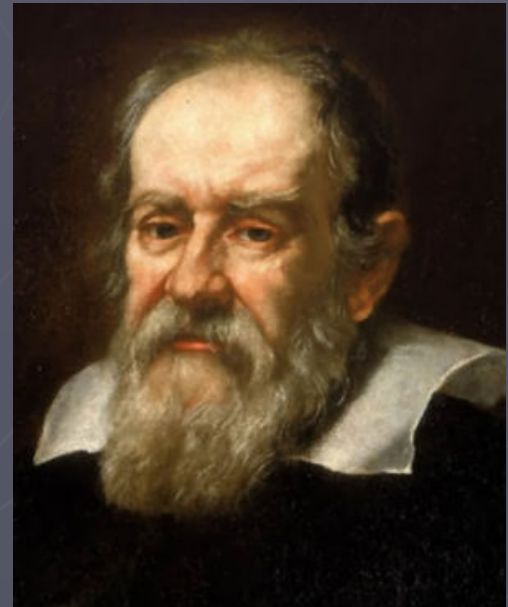
# Galileo Galilei

The background features a dark gray color with a faint, light gray topographic map overlay. In the lower-left corner, there is a faint compass rose with a needle pointing towards the top-left. The text 'Galileo Galilei' is prominently displayed in the lower-left area in a bold, white, sans-serif font.

# Galileo Galilei (1564–1642, Italy)

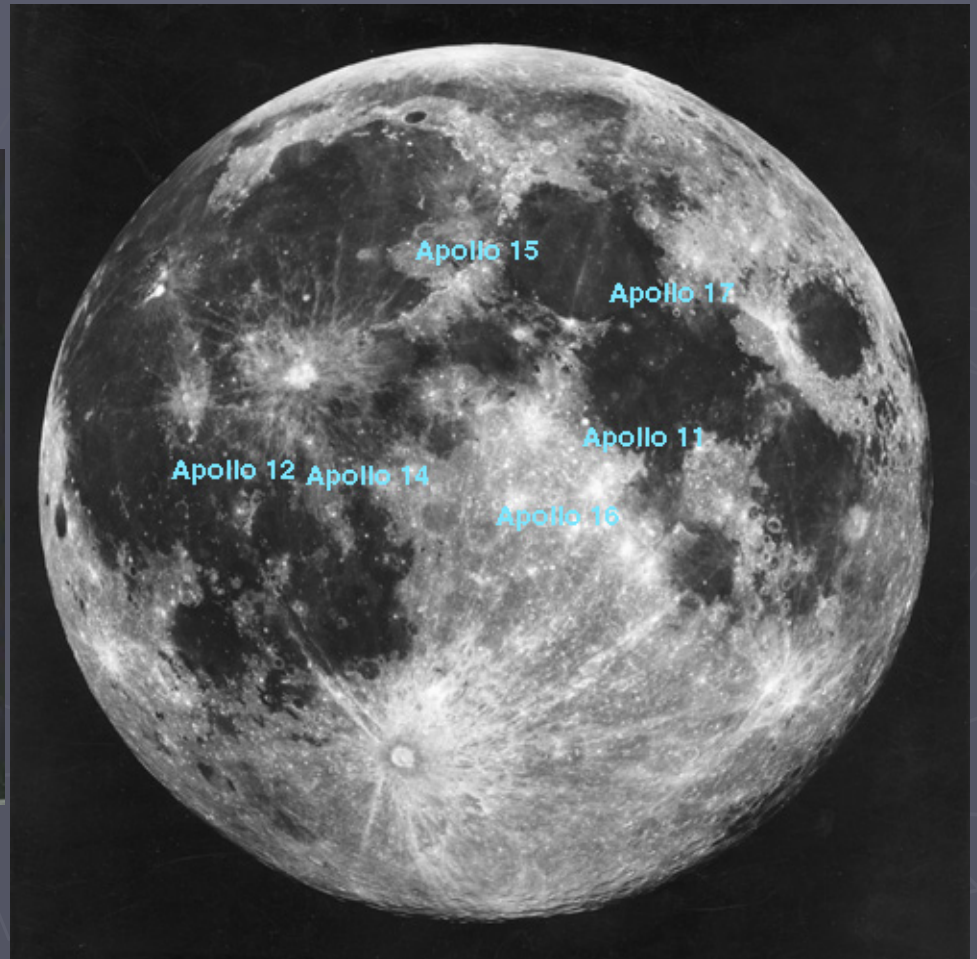
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- ▶ The first modern experimenter, well known for his ball drop from the Tower of Pisa
- ▶ Distinguished between **weight** and **mass**
- ▶ Many astronomical accomplishments...



# Jumping forward: Apollo 15, August 1971, landed at the Hadley rille on the moon

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# Galileo's Astronomical Accomplishments

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- ▶ First to use the newly invented "telescope" to look at sky (only 14X magnification)
- ▶ Saw stars visible only with a telescope, not with naked eye (500 in Orion alone!)



# His telescopes

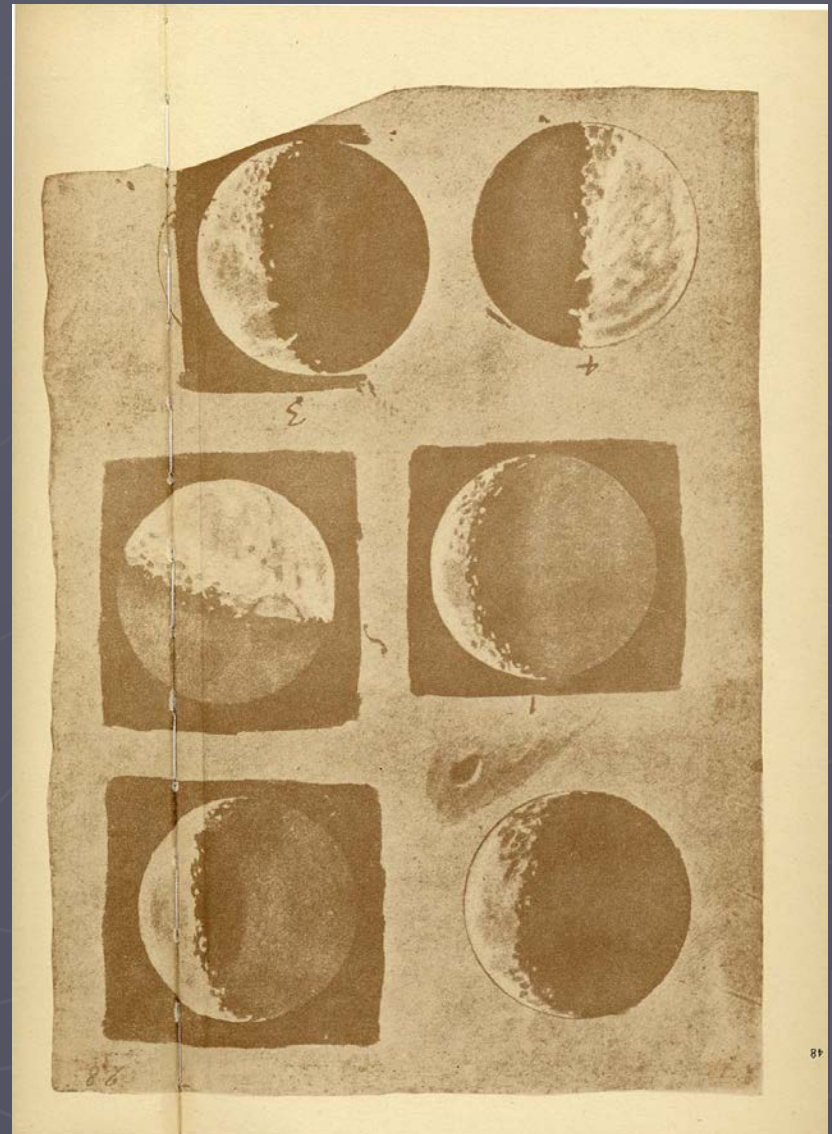
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- ▶ By the standards of today these early telescopes were fairly basic. They suffered from severe chromatic aberration.
- ▶ Modifications that Galileo invented improved the magnification and resolving power of his telescopes however.
- ▶ What he observed with these simple devices had a very profound effect on Renaissance Europe.

# More Galileo

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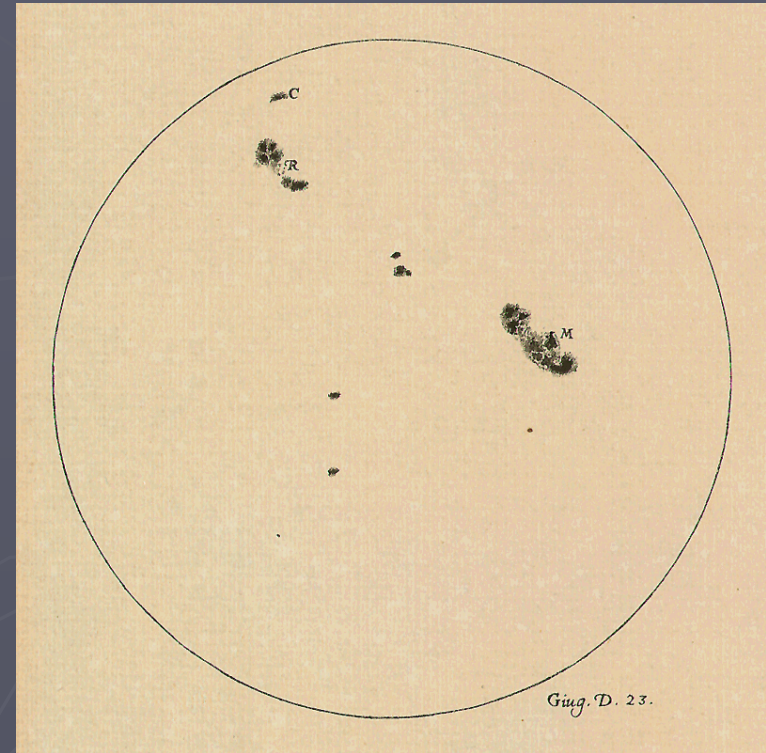
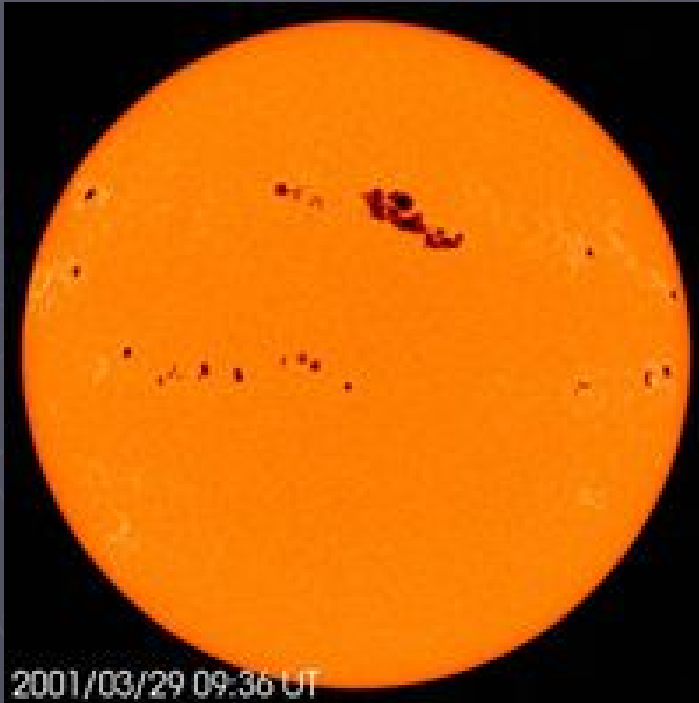
- ▶ He discovered mountains, craters, and plains on the Moon
- ▶ He discovered that Venus had phases, like the Moon.



# And More Galileo

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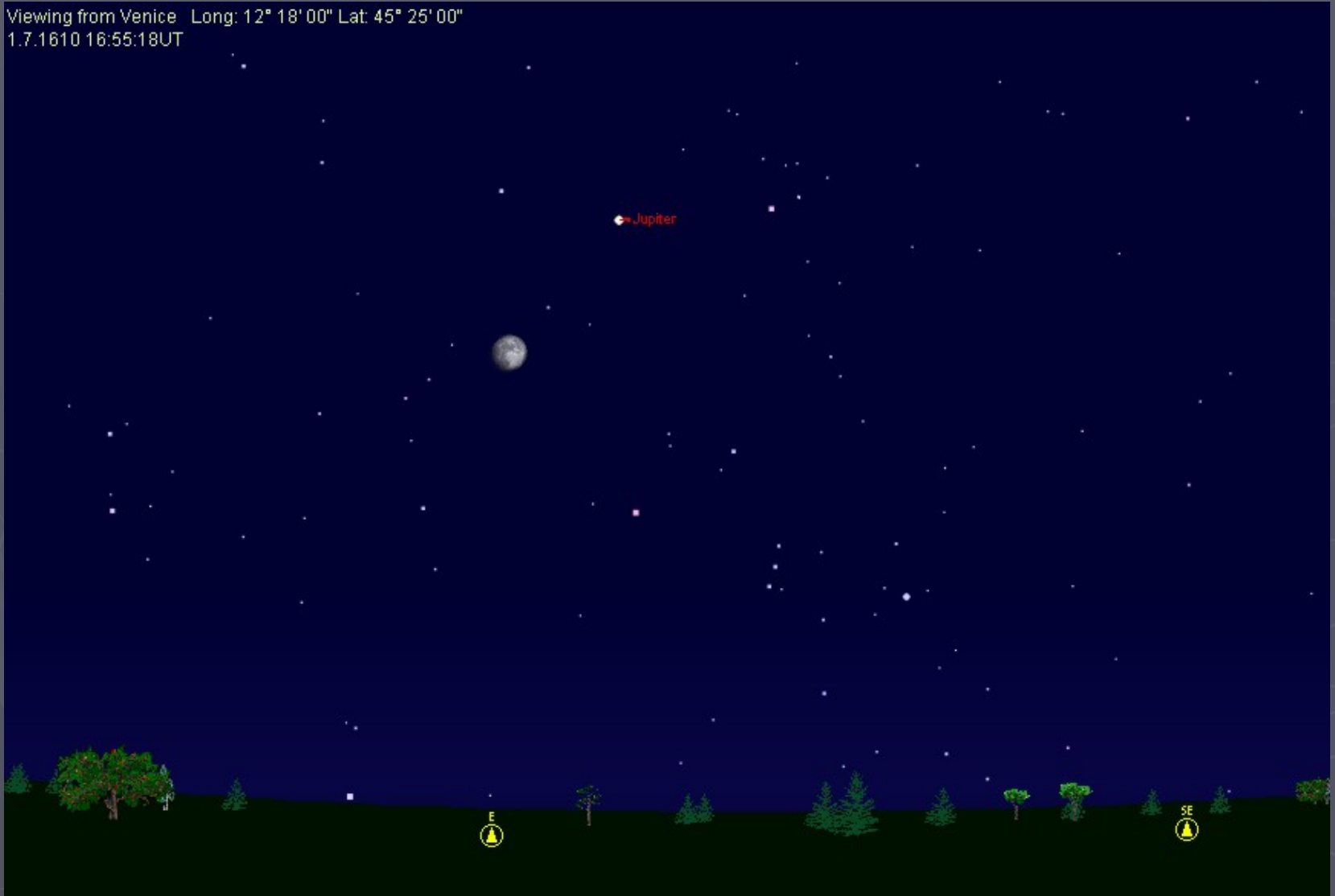
- ▶ He discovered sunspots on the Sun



# The night sky on January 7<sup>th</sup>, 1610

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Viewing from Venice Long: 12° 18' 00" Lat: 45° 25' 00"  
1.7.1610 16:55:18UT



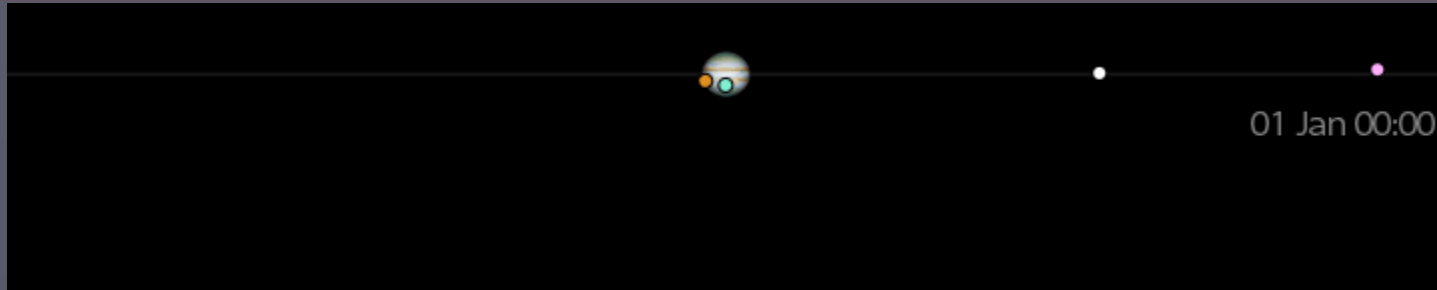
# Moons of Jupiter

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- ▶ On January 7th 1610 Galileo turned his telescope towards Jupiter.
- ▶ He observed the planet close to what he thought were 3 previously unseen “stars”. He mentioned what he saw in a letter to a friend.
- ▶ Next night he was surprised to see that instead of 2 “stars” being to the east and one to the west of the planet, now all 3 were to the west.
- ▶ Could Jupiter have moved eastwards when all expectations were for it to have moved westward?

# March 1613

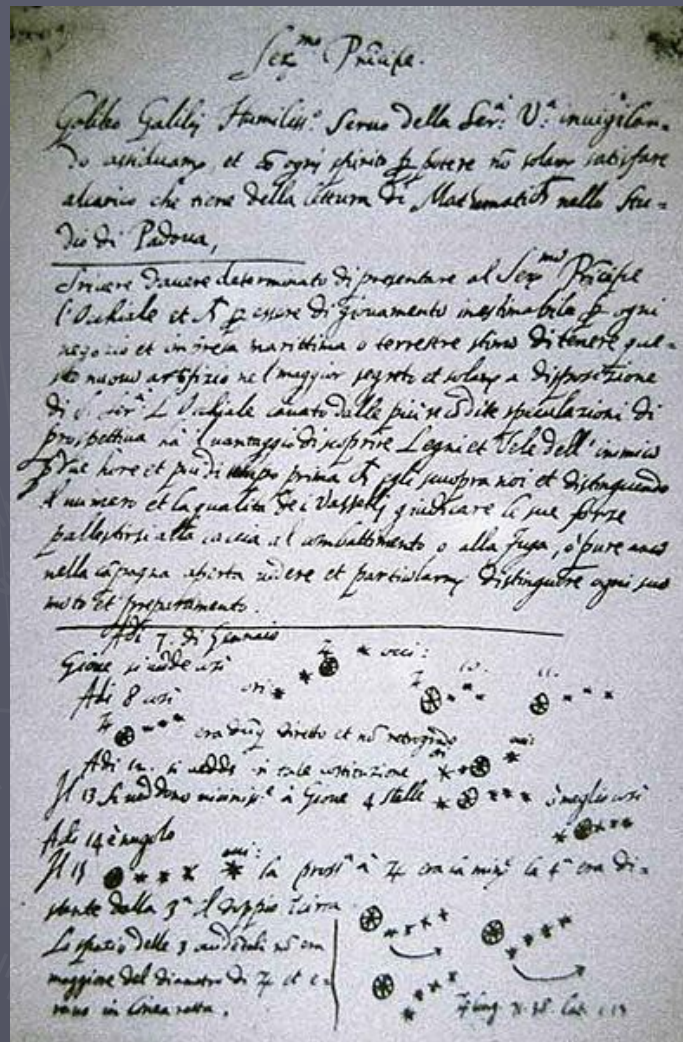
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Over the eight weeks from January 7 to March 2, 1610, Galileo sketched 64 observations of the positions of these four moons relative to Jupiter.

Look for the first night that Galileo realized the moons weren't stars, the night he first saw four moons, not just three, and the only night he drew a moon that wasn't there.

# Letter to Prince of Venice (January 1610)



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

The 13th are seen very close to Jupiter 4 stars

or better so

On the 14th it is cloudy

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.

♃ long 71°38' lat. 1°13'

# Moons of Jupiter

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- ▶ Over the next several days he observed the same mysterious movement, sometimes with Jupiter seeming to obscure one or more of the “stars”.
- ▶ On January 13<sup>th</sup> a fourth “star” joined the others.
- ▶ Gradually he began to realise that the “stars” may actually be moons and he started recording the times of his observations. He also started reporting them in scholarly Latin rather than vulgate Italian.
- ▶ On March 13<sup>th</sup> he published a document reporting his observations – Earth was not the only body to have moons.

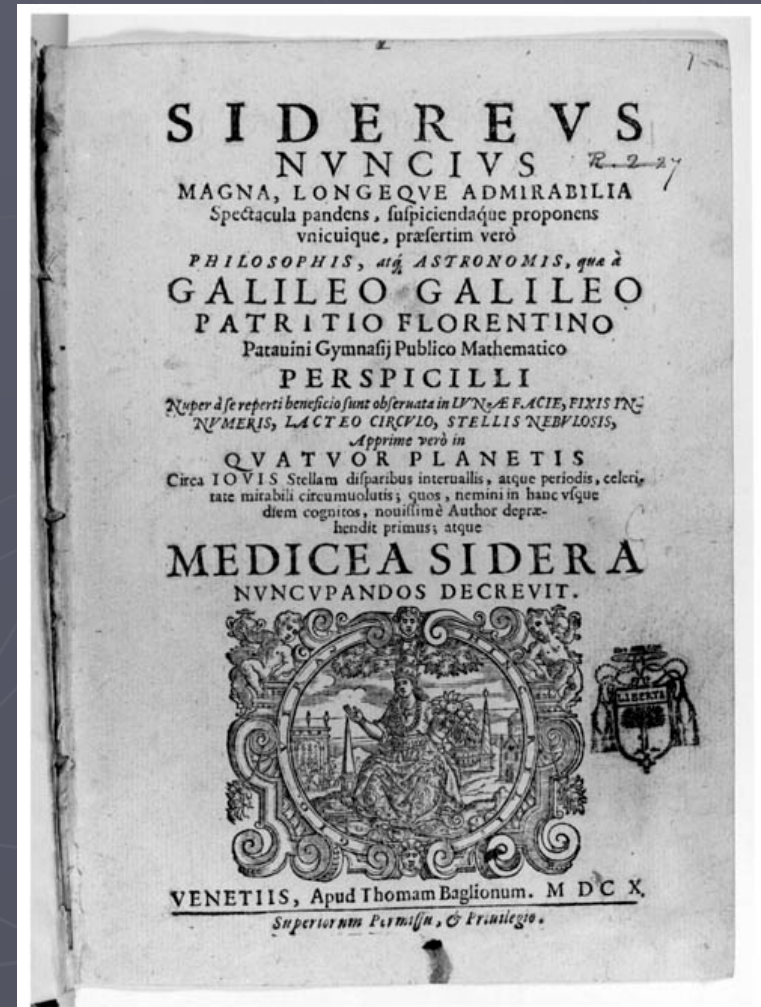
# Sidereus Nuncius (Starry Messenger)

The book created an immediate Sensation, its 500 copies sold out immediately.

The Pope, the King of England, philosophers, poets..., everyone was fascinated by the news:

*"Me thinkes my diligent Galileus hath done more in his three fold discoverie than Magellane in openinge the streightes to the South Sea"*

William Lower, British philosopher



# Making enemies

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- ▶ By presenting powerful arguments in support of the heliocentric view, Galileo made enemies within the church
- ▶ While many Catholic mathematicians accepted that Galileo's logic was correct, others argued that it contradicted biblical teaching.
- ▶ Galileo accepted that the bible could not be wrong, suggesting that instead the interpretations could be in error. He went so far as to offer his own interpretations of key biblical verses, stepping on the toes of the theologians
- ▶ He was accused of heresy and although found not guilty he had to promise not to teach the heliocentric view
- ▶ He remained silent, but actively thinking, for the next 16 years.
- ▶ Then....

# Dialogue concerning the two Chief World Systems: Ptolemaic and Copernican

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- ▶ Published in 1632 as *“Dialogue concerning the two chief world systems: Ptolemaic and Copernican”*
- ▶ Galileo laid out a series of powerful, logical arguments that convincingly undermined both the physics and cosmology of Aristotle. Publication was approved by the censors.
- ▶ The style was to present the arguments in the form of a Platonic dialogue between 3 characters, not a scientific paper
  - Salviati - An intellectual who seems to speak for Galileo
  - Sagredo - A wealthy nobleman who is seeking truth
  - Simplicio - An Aristotelian philosopher who puts up ineffectual arguments for Salviati to knock down

(Simplicio is a thinly disguised representation of the church hierarchy)

# The Inquisition

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- ▶ The book was a best seller, but not so popular with the Vatican.
- ▶ Under pressure from clerics, Pope Urban VIII ordered Galileo to appear before the Inquisition for the crime of teaching the heliocentric theory, despite having been ordered not to.
- ▶ *"a downright roguish attempt to comply with this order in appearance and yet in fact to disregard it. Unfortunately, it turned out that the Holy Inquisition was unable to appreciate adequately such subtle humor." Albert Einstein*



# The Inquisition

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- ▶ Threatened with torture, 68 years old and unwell, he publicly acknowledged that he had been wrong about the heliocentric view.

However after his confession he is rumoured to have whispered "and yet it moves"

- ▶ Galileo was placed under house arrest and the "Dialogue" was quickly added to Index of Forbidden Books.



# Galileo and the Church

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- ▶ He wasn't excommunicated, & remained a Catholic.
- ▶ He believed that Nature followed a Divine order.
- ▶ Just as the Bible represented the dictated word of God, so the natural world embodied God's work.

The persistent observer could decipher its hidden patterns, on earth and in the heavens.

*"how to go to heaven, not how the heavens go"*

- ▶ He argued that both "books" could be studied to find the mind and will of God; indeed, the "Book of Nature" could be used to help us interpret the Holy Bible.

# Progress – but at great personal cost

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- ▶ Single-handedly he showed that some objects don't orbit Earth, that Moon and Sun are not "perfect", that there are many more stars than Aristotle allowed for. Aristotles' ideas were refuted.
- ▶ Placed under house arrest by the Catholic Church and made to confess "vainglorious ambition" and mistakes of "pure ignorance".
- ▶ Not only religious conflicts: some political and personal rivalries, too.
- ▶ Worked on laws of motion and falling bodies until his death, 8 yrs later. Newton born that same year.

# Dynamics

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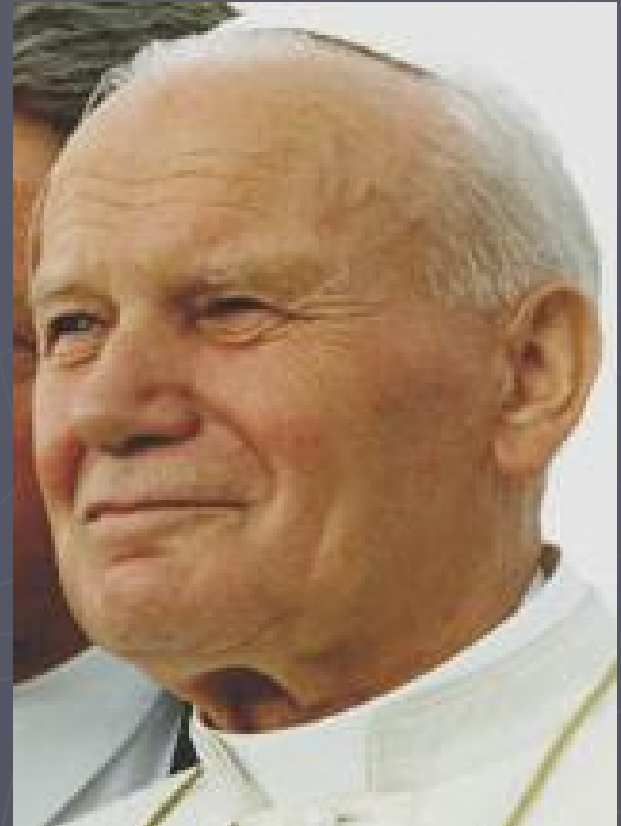
- ▶ Galileo made important contributions to the understanding of the motion of bodies and gravity.
- ▶ In particular he developed the idea that a body in motion possesses "inertia".
- ▶ This eventually became the first of Isaac Newton's Laws of Motion.
- ▶ Newton built on Galileo's work to show that the laws of motion on earth & the cosmos were the same.
- ▶ Einstein called him *"the father of modern physics – indeed, of modern science altogether."*

# Galileo and the Church

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- ▶ Galileo died in 1642. Newton was born the same year.
- ▶ *The Dialogue* was dropped from the Index of Prohibited Books in 1835.
- ▶ The Catholic Church acknowledged the injustice done to Galileo in 1979. Pope John Paul II speaking to scientists at an event commemorate the centenary of Einstein's birth:

*"Collaboration between religion and modern science is to the advantage of both, and in no way violates the autonomy of either."*



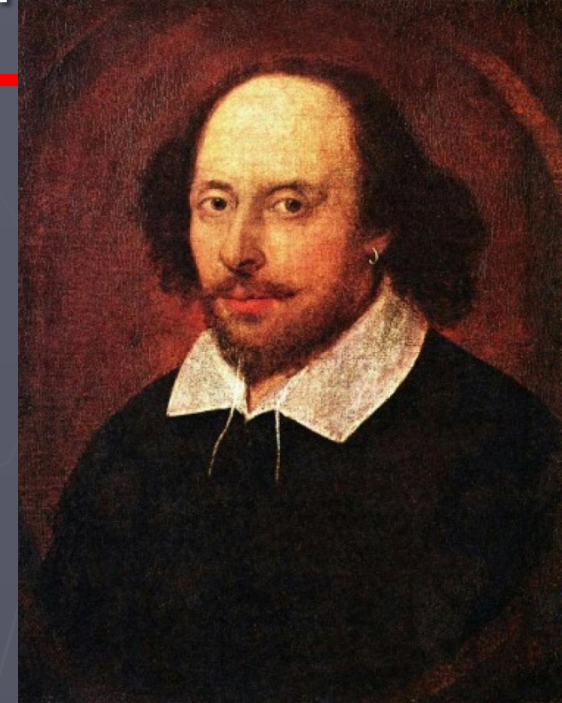
**"I do not feel obliged to believe that the same God who has endowed us with sense, reason, and intellect has intended us to forgo their use."**

**Galileo Galilei**

# William Shakespeare again

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- ▶ Galileo discovered the 4 moons of Jupiter in January 1610.
- ▶ William Shakespeare wrote Cymbeline the same year.
- ▶ In Cymbeline the god Jupiter is summoned to earth and when he arrives he is accompanied by four ghosts.
- ▶ Were these the newly discovered moons? Many academics think they were.



# An Ideological Revolution

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- ▶ Copernicus introduced the heliocentric model, displacing earth from the centre, but it was still only a theory, albeit an aesthetically superior one.
- ▶ Galileo's observations with his telescope gave the first convincing **evidence** that the earth was not at the centre of the Universe.
- ▶ At a stroke, this toppled the hierarchical structure of the Universe, as then understood.
- ▶ The human universe whose hierarchies were always assumed to reflect God's cosmic design started to crumble too.

**Thank You!**



# Additional Credits

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- ▶ Some material included in this presentation was taken from online sources. Particular credit to:
  - The View from the Center of the Universe, J Primack, N.Abrams, Riverhead Books
  - Theories of Matter in Greek Philosophy, <https://elementsunearthed.files.wordpress.com>
  - Andrew Liddle, Univ. Sussex
  - RASC Canada
  - Syney Harris Cartoons, <http://www.sciencecartoonsplus.com/index.php>
  - BC Knowledge Network, <https://www.knowledge.ca/program/space-suite>



**Thank You!**



"IF WE CAN MAKE THEM SMALL ENOUGH, WE  
CAN WEAR THEM ON OUR WRISTS."

So you created everything. Yes.



Including black holes. Yes.



Which will eventually swallow up everything. Yes.



Including you.



I'm working on that.

