Astronomy Through the Ages: 2 Middle ages through Renaissance

ASTR 101

10/1/2018

Watch the movie "Galileo's Battle for the Heavens"

can be viewed online at:

http://www.pbs.org/wgbh/nova/ancient/galileo-battle-for-the-heavens.html or https://www.youtube.com/watch?v=XCxkdR092c4

(no commercial breaks)

Arabic Astronomy

- While science and astronomy were in the decline in Europe, they flourished in the Arabic world during the Islamic golden age (9-13 century).
- Scientific pursuits were strongly supported by the ruling nobility and endowed the work with formal prestige.
- 'House of Wisdom' in Baghdad (founded in 830), sponsored by Abbasids caliphs became the main intellectual center of the world.
 - They translated many texts from Greek, Sanskrit and Persian into Arabic.
 - Many Greek texts otherwise would have been lost were saved in Arabic (ex: Almagest)
 - That knowledge was diffused throughout the vast Islamic empire and assimilated to their knowledge and developed further.





Scholars at an Abbasid library 13th C. Illustration en.wikipedia.org/wiki/House_of_Wisdom

المركاب ، يد وآلة البخوم والمسلكاب ومات

المواضع الم صابين والخطامعنال

Islamic astronomers placed far greater emphasis on observations than the Greeks and built superior astronomical instruments with improvements.



11th century Arabic astrolabe (Metropolitan Museum of Art. NY) www.metmuseum.org/collection/the-collection-online/search/444408





Arabic astronomers observing, (a 16th century painting).

Pages from the 10th century Star catalog by the Persian astronomer Abdurrahman Al Sufi, who was also the first to mention about the large Magellanic cloud and the Andromeda galaxy. Arabic names of stars now in use are from catalogs and maps produced during this era. ⁴



Medieval Arabic manuscript (by Qutb al-Shirazi) depicting an epicyclical planetary model.



en.wikipedia.org/wiki/Astronomy in the medieval Islamic world

- Their improved accurate observations of planets and stars with superior instruments began to revel the shortcomings of the Ptolemaic model of planetary motion.
- Many Islamic astronomers suggested improvements to the Ptolemaic geocentric model, but they did not take the step to put Sun at the center.

Indian Astronomy

There were many Indian astronomers who made many contributions during middle ages.



Their work influenced the Islamic astronomers. Most notable of them was Aryabhatta (476–550 CE).

- A mathematician and an astronomer, he was a pioneer of algebra and trigonometry. He had used a number system with zero (which later became the 'Arabic' number system we use today).
- Aryabhata correctly explained that the earth rotates about its axis and the apparent motion of celestial objects in the sky, as mentioned in one of his books: "In the same way that someone in a boat going forward sees an unmoving objects going backward, so someone on earth sees the unmoving stars going uniformly westward..."
- There are claims that he had introduced a heliocentric model of the universe with planets orbiting in elliptical orbits around the sun.
 - But none of those writing has survived. His work is known only though references by other Indian and Arabic astronomers.
- Just as for Aristarchus, his ideas were ahead of his time and were not followed up by others.



Chinese Astronomy

Su Song's star map 1092 CE



Crab nebula at the location where Chinese astronomers reported an appearance of an extremely bright star (supernova).

- Chinese astronomy predates astronomical work by all other civilizations, first records dating back to 3000BCE. Like in other cultures primary motivation was timekeeping and astrology.
- Early Chinese astronomy was evolved independent of western influence, and thus based on different principles (e.g. they had different constellations, used circumpolar stars as reference instead of horizon or ecliptic...)
- Ancient Chinese astronomers recorded celestial events like comets, solar and lunar eclipses. Over centuries of persistent observations Chinese astronomers became very adept at predicting eclipses.
- The first human record of an eclipse was in 21century BCE, a story about execution of two royal astronomers who failed to predict a solar eclipse.(2136 or 2159 BC)
- One of the famous observations made by Chinese astronomers was that of a supernova in the year 1054.

Western astronomy in the middle ages

- After the fall of the western Roman empire west suffered recurring political and social upheavals and instability.
 - with declining economy, continual warfare and disease populations fell and literacy declined.
 - Without strong urban centers and wealthy patrons, science was in the decline.
- Strongest cultural institution in the middle ages was the church.
 - Christianity had a model of the cosmos with a divine creation and order.
 - Nature of the universe and underlying reality seemed to be more of a province of theology.
- Astronomy still had a place in the education, and was one of the subjects in the 'quadrivium' (arithmetic, geometry, music, and astronomy), the preparatory work for the serious study of philosophy and theology.
 - Astronomy fulfilled many mundane and practical necessities, like determining the time, astrological forecasts.
 - Besides astronomy was considered as learning and investigation of God's creation.



en.wikipedia.org/wiki/Bible_moralis

God designing the universe from the Bible Moralisee, ca. 1225, Paris

<u>Medieval Cosmo</u>s

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From L'Image du monde by Gossuin de Metz 13th-century (Bibliothèque nationale de France)

http://expositions.bnf.fr/ciel/grand/t1-08.htm





Angels cranking the celestial sphere. c. late 14th century

- Christian scholars assimilated concepts of Aristotle's physics and cosmology to its doctrine supplemented with features in conciliation with accounts in the Genesis.
 - 7 planetary spheres going outward from the Earth: Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn.
 - Above this was the sphere of fixed stars (*firmament*), beyond that were the regions of heaven, angels and the God (*empyrean*).
- Thus Aristotelian physics and astronomy became intertwined with Christian theology. Challenging them was regarded as questioning the Church's authority.



From NOVA "Galileo's Battle for the Heavens" www.pbs.org/wgbh/nova/ancient/galileo-battle-for-the-heavens

Western astronomy in the middle ages



Book writing/copying in middle ages by Monks.

- By 12th century Europe was emerging from the dark ages, large monasteries developed libraries and schools. Which eventually evolved to universities (Bologna, Paris, Oxford).
- Through capture of the Islamic Spain, and by Crusades in the 11th century Europeans gradually became aware of the rich cultural legacy in the Islamic world, and the lost work of classical Greek and Rome.
 - In the 12th century most major work in Arabic was translated to Latin.
 Translations of the Greek and Islamic texts spread rapidly throughout Europe.
- There were many critics of the validity of Ptolemaic and Aristotelian views during this time, and even of suggestions for a heliocentric model (Roger Bacon (13th C), Leonardo Da Vinci (15th C...).
 - But the geocentric view of the cosmos continued to prevail.

Nicholas Copernicus (1473-1543CE)

 Copernicus was born in Poland. (Mikolaj Kopernik -Latinized as Nicholas Copernicus)



- Copernicus studied mathematics, astronomy, medicine, law and economics in addition to theology at various universities, first in Poland then at Italian universities Bologna, Ferrara, and Padua, until he was 30.
- Returned to Poland in 1503, and worked as a church administrator.
- While in Bologna Copernicus had learned about the wok of ancient Greek astronomers (including Aristarchus').
 - and exposed to the views of others who thought that Ptolemy's model of the universe was too complicated to be real.
- Copernicus believed that he could come up with a simpler solution by putting the Sun at the center of the solar system.



- But still believing in Platonic/Aristotelian ideas of the perfectness of the heavens as a manifestation of divine order, he wanted to keep orbits of the planets circular.
- His model of heliocentric universe with the Earth and other planets moving in circular orbits around the Sun did not fit well with observations.
- To resolve this he put each planet on an epicycle
 - each planet moves around on an epicycle, while the center of the epicycle moves around the Sun in an off centered circular orbit.
- So the Copernican model did not get rid of epicycles.
 - In fact it was neither simpler than the Ptolemy's model nor more observationally accurate.

• But it placed the Sun at the center of the universe.

On the Revolutions of the Heavenly Spheres

- Copernicus wrote an overview of his model in 1514 CE, which was well received (even by high church officials).
 - But Copernicus resisted openly publishing his views, not wishing 'to risk the scorn and ridicule' of his ideas, as he claimed.
- Finally under persuasion and pressure from his colleagues, the book was published in 1543, shortly before his death.
- Copernicus dedicated the book to Pope Paul III (1534-49) (who was interested in astrology). There was no major controversy on Copernican model immediately after the publication of *`On the Revolutions'* in 1543.
 - Many contemporaries saw it as a mathematical aid offering more accurate prediction of planetary positions.
 - While there were some accepted the heliocentric theory as the true nature of the universe.



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Title page of the 2nd edition, 1566

From NOVA "Galileo's Battle for the Heavens" www.pbs.org/wgbh/nova/ancient/galileo-battle-for-the-heavens.html

Tycho Brahe (1546-1601CE)





- A Danish Nobleman, made the most precise observations that had been made before the telescope.
- He disagreed with Copernicus, that the Earth moves around the Sun, on both religious and physical grounds (no observed parallax).
- He came up with his own model, which had planets orbiting the Sun, while the Sun moves around the Earth.
- He was an avid observer, and did the most accurate pre telescopic astronomical observations.

Supernova of 1572



What Tycho Brahe had observed in 1572 was a supernova, an exploding star. Remains of the 1572 supernova explosion as seen though a X-ray telescope today.



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position (I) of the bright star of 1572 shown in a star map by Brahe

- In 1572 a very bright star, suddenly appeared in the constellation Cassiopeia.
 - Initially it was brighter than Venus, was bright enough to be visible during daytime, and gradually faded from view over 18 months.
- According to the prevailing view of the time, heavens were permanent and unchanging.
 - All changing, transitionary phenomena occurred closer to earth, below the moon sphere.
 - So the bright object could not be a star, it had to be something closer to the Earth.
- To confirm this Brahe tried to measure its parallax, but failed to observe any.
- So the new star had to be far away, farther than the Moon, and among the stars.

Great comet of 1577



he maker life

Brahe's notes on the comet of 1577. He noticed that the comet's tail faced away from the Sun

- In 1577 a bright comet appeared, again Tycho set off to measure its parallax, and showed that it had to be farther away than the Moon.
- Those observations were the first clear evidence against the Aristotelian view of unchanging and permanent nature of the realm of stars.
- But Brahe's major contribution to astronomy was precision measurement of the positions of stars and planets over two decades.
 - He did his observations with unpreceded precision with better equipment and observatories he built.
 - He cataloged 777 stars and planets down to 1 arc minute precision (Resolution of the human eye is about 1 arc minute).
 - A tenfold improvement in accuracy over his predecessors.





Tycho Brahe's Stjerneborg ('Star Castle') observatory. Equipment's were located below the ground level to avoid disturbances from wind

Sketch of a Tycho's quadrant

- His expensive observational endeavors were initially funded by his inheritance and later by the Danish king Frederick II and the Emperor Rudolph II.
- Tyco wanted to use the vast amount of precision observational data he collected over the years to test his model of the universe.
- But he lacked necessary mathematical skills.
- In 1600, he hired Johannes Kepler, a talented mathematician to work with him, probably expecting Kepler would find evidence supporting his model of the universe.
- But soon after, in 1601 Tycho died.

Johannes Kepler (1571-1630CE)

- Johannes Kepler was form an impoverished German noble family, near present day Stuttgart.
- He became aware of the Copernican work while he was • studying philosophy and theology at the University of Tubingen.
 - He had been a firm supporter of the Copernican model since then.



- He first worked as a teacher of mathematics in Austria, then in 1600 joined Tycho Brahe as an assistant.
 - Tycho wanted someone with mathematical skills to compile the astronomical data he had collected and support his model of the geocentric universe.
 - In particularly understand the orbit of Mars Tycho had been struggling with.
 - Kepler wanted to access to Tycho's data to verify his ideas on the Copernican theory.
- Before anything materialized Tycho died in 1601.
- Kepler succeeded his title, 'the Imperial Mathematician to the emperor Rudolf • II', and also inherited (snatched) Tycho's data.
 - His primary obligation was to provide astrological advice to the emperor.
 - He was also given the task of preparing new planetary tables, again for the purpose of astrology. 20

- Kepler continued tackling the problem of the orbit of Mars.
 - Tycho had collected a vast amount of observations on Mars than any other planet.
 - But the Mars positions Tycho had recorded did not fit well with any of the models, Ptolemy's, Copernicus' or Tycho's.
 - The best match of Mars data to a Copernican orbit left him with an discrepancy of 8 arc minutes.
 - It was larger than the accuracy of Tycho's data (which was of the order 1arc minute)
 - After struggling over six years, Kepler finally realized that the orbit of Mars was not a combination of circles, as demanded by Plato and Aristotle and implicitly assumed by all after him (including Copernicus).
 - It has to be an ellipse.



A page from Astronomia nova

 Thus, Kepler abolished the 2000 year old dogma, that planets could only have uniform circular motions.

Kepler's Laws of planetary motion.



- Kepler published his findings in books 'Astronomia nova' (the New Astronomy 1609) and in 'Harmonices Mundi' (Harmony of the World, 1619)
- His findings on planetary orbits were in the form of three laws.

Kepler's Laws of planetary motion:

- 1. The orbit of a planet is an ellipse with the Sun at one of the foci.
- 2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.
- 3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.

The Ellipse:

- Ellipse is a generalized version of a circle,
 - On the other hand, a circle is a special case of an ellipse.



Defining property of a circle: distance from its center to any point on it is a constant. So for any point P on the circle: CP = a constant = radius A circle can be specified by giving the location of its center and radius



An ellipse has two centers, called foci (singular focus) Sum of the distance from each focus to a point on the ellipse is a constant.

So for an ellipse with foci located at A and B, for any point 'P' on the ellipse:

AP+BP= a constant





This property can be used to draw an ellipse

- push two pins at the foci points
- put a loop of string around them
- place a pencil so the loop form a triangle with pins and pencil tip at the corners
- draw a shape by moving the pencil about the pins while keeping the string taut.
- String keep the sum of the distances from pencil to foci at a constant value, hence drawing an ellipse.





	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Mean distance from the Sun (AU)	0.39	0.72	1	1.52	5.20	9.54	19.18	30.06
orbital eccentricity	0.2056	0.0068	0.0167	0.0934	0.0483	0.0560	0.0461	0.0097

 note the high eccentricity of the Mars orbit Which caused all the troubles to astronomers before Kepler who tried to fit it with circles.

(even though Mercury has the highest eccentricity Mercury is hard to observe, there wasn't much observation data available for a detailed study of its orbit)

Kepler's Second Law:

Says how the speed of the planet changes as it orbit around the Sun.

 In a given time interval (few hours, a day, few days) a line segment joining a planet and the Sun sweeps out an equal area



area proportional to \approx length of arc \times radius

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- So when the planet comes closer to the Sun to sweep the same area it has to move a longer distance along the orbit in a given time ⇒ moves faster
- When the planet is farther away from the Sun it has to move only a shorter distance to sweep same area in a given time ⇒ moves slower.

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www.phy.olemiss.edu/~perera/animations/kep2.html

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- A planet moves fastest at the **perihelion** point on orbit closest to the Sun
- A planet moves slowest at the **aphelion** point on orbit farthest to the Sun

Kepler's Third Law:

A relation between distance to a planet from Sun to its orbital period.

- The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit (i.e. size of the orbit, or its distance to Sun).
 - If P = orbital period (in years) a = length of semi major axis (in Astronomical Units) then $P^2 = a^3$

Example: Mean distance from Mars to earth is 1.52 AU. How long does Mars take to complete one orbit.

here a = 1.52from Kepler's 3rd law $P^2 = a^3$ $\Rightarrow P^2 = (1.52)^3 = 3.51$ $P = \sqrt{3.51} = 1.87$ years $= 1.87 \times 365 = 684$ days (ac

(actual value 687 days.)

Review Questions

- What were the reasons Ptolemy's model of the universe accepted over a millennium unchallenged?
- Which scholars preserved and further developed classical Greek knowledge during middle ages?
- What was the most significant contribution by Tycho Brahe to astronomy?
- Why do most stars have Arabic names?
- What other important observations (measurements) Brahe did that challenged the prevailing view of the universe (heavens) ?
- Why did astronomers since the time of ancient Greeks tried to explain movements of planets exclusively in terms of circular motions?
- Why did Copernicus heliocentric model was not any better in predicting positions of planets than Ptolemy's geocentric model?
- Who was the first astronomer to think that the Sun was at the center of the solar system (universe)?
- What made Kepler realize that the orbits of planets were ellipses rather than circles?
- According to Kepler's laws when does a planet move fastest on its orbit?
- What are the defining properties of an ellipse?