

History of Astronomy

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1 Introduction



- ❑ The history of astronomy is vast and complex and can not be summarized in a single talk. Therefore, we present only a few topics:
- ❑ the heliocentric concept of the universe
- ❑ some astronomical knowledge from several great cultures and civilizations of the past

2 Astronomy from the ancient Greeks

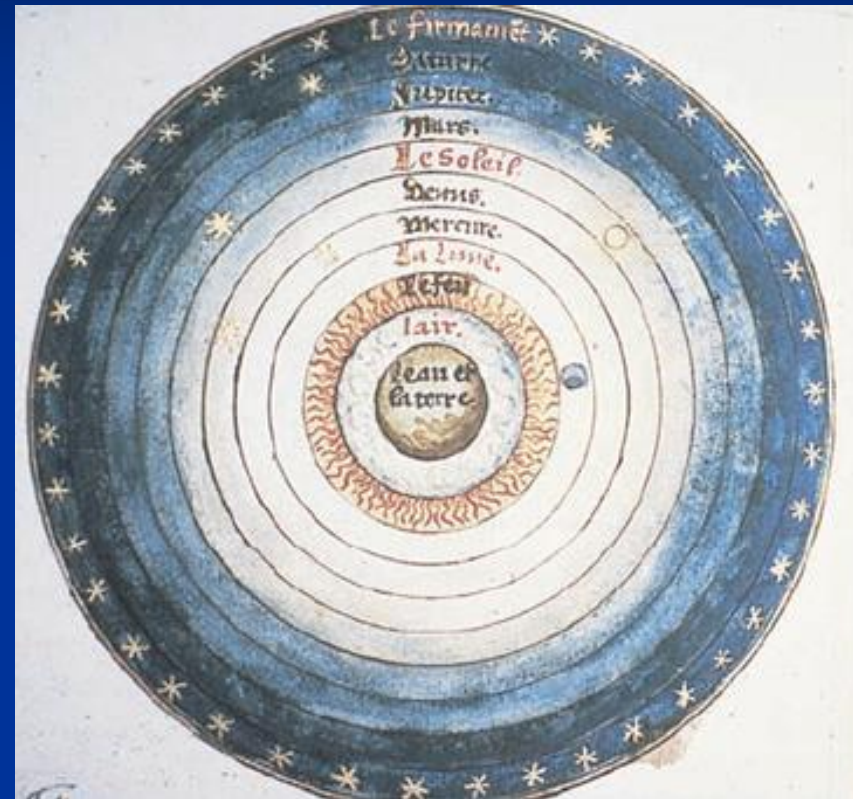
- ❑ The planets appear to move slowly in one direction (from West to East) with respect to the background stars: direct movement.
- ❑ But sometimes, a planet moves in the opposite direction (from East to West) with respect to the stars: retrograde motion

Simulation with the Zeiss ZNP3/B planetarium projector of Williams College's Hopkins Observatory by Jay M. Pasachoff, Yairiv Pierce, and Megan Bruck.



2 Astronomy from the ancient Greeks

- ❑ The ancient Greeks made theoretical models of the universe in order to explain the movement of the planets.
- ❑ To compare the duration of the retrograde motion of the planets, they ordered the celestial bodies with regards to distance.



2 Astronomy from the ancient Greeks



- ❑ Aristotle (350 BC) thought the Earth was definitely the center of the universe, and the planets, the Sun, and the stars revolved around Earth.
- ❑ According to Aristotle, the universe consisted of a set of 55 celestial spheres that are fitted one inside the other.

2 Astronomy from the ancient Greeks



- ❑ The natural movement of each sphere was the rotation. The planets moved in some of the spheres and the movement of each sphere affect the other. Retrograde motion could be explained in this way.
- ❑ The outermost sphere corresponds to fixed stars. Outside this sphere, it was "the primary mechanism" causes the rotation of the stars.
- ❑ Aristotle's theory dominated scientific thought for 1800 years, up to the Renaissance, and prevented that scientific work would consider new models.



2 Astronomy from the ancient Greeks

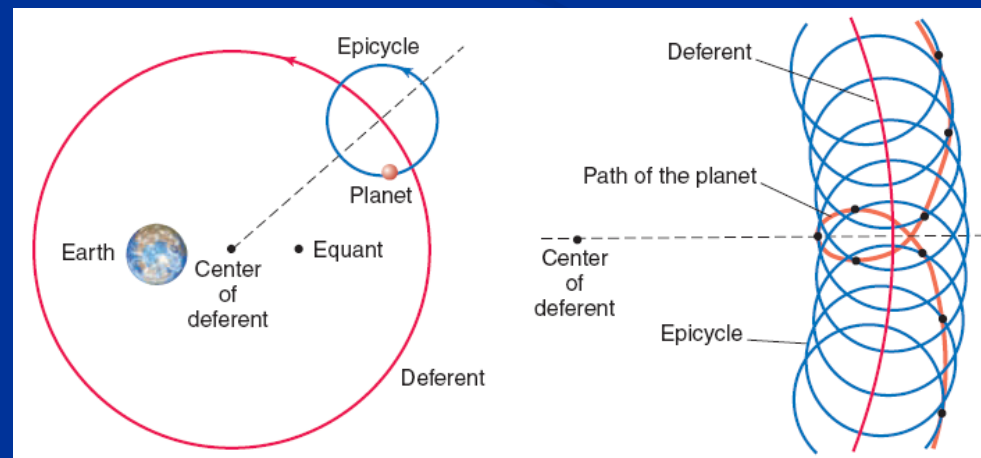
- Around 140 A.D., the Greek scientist Claudio Ptolomy of Alexandria presented a detailed theory of the universe that explained the retrograde movement.
- Ptolemy's model was geocentric (Earth in the Center), as was Aristotle's. To explain the retrograde motion of the planets, he conceived the planets traveling along small circles that move about larger circles of general orbits of planets.



Biblioteca Nazionale Marciana, Venice

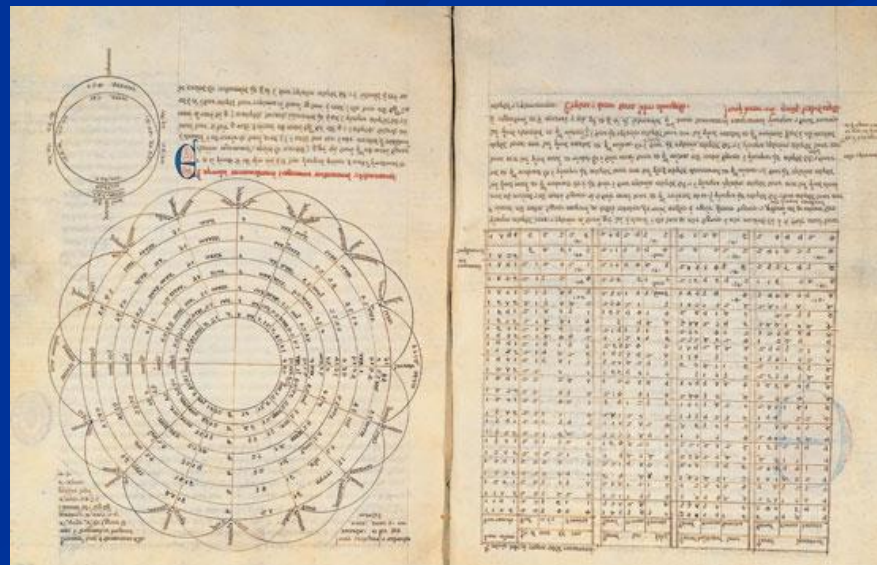
2 Astronomy from the ancient Greeks

- ❑ To explain the retrograde movement, Ptolemy proposed that the planets traveled in small circles called epicycles; the larger circles are called deferents.
- ❑ The center of an epicycle moves with a constant angular velocity relative to the point called the Equant.
- ❑ As it was believed that the circles were perfect forms, it seemed logical that planets should follow circles in their movements.



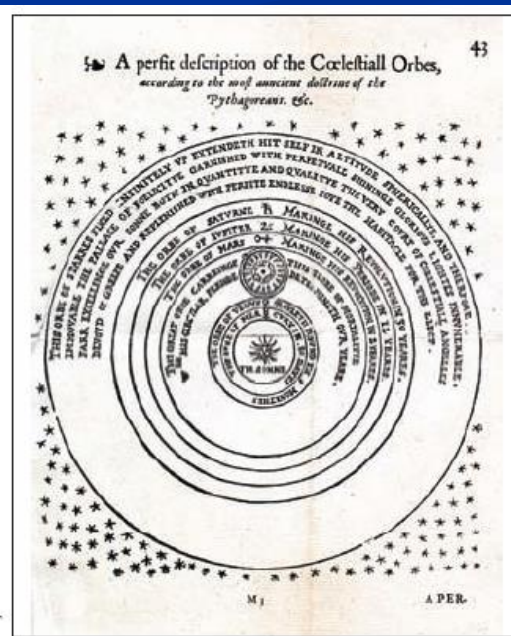
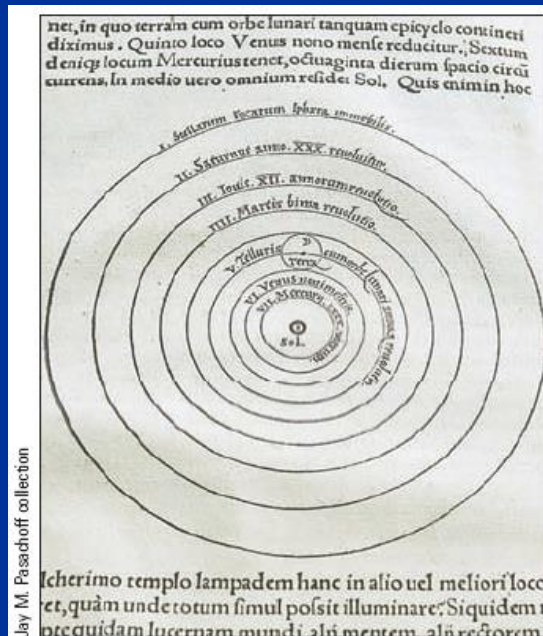
2 Astronomy from the ancient Greeks

- ❑ Ptolemy's most important work *the Almagest* (translation: the greatest) were accepted for nearly 15 centuries, and contained not only his ideas but also a summary of the ideas of his predecessors
- ❑ His tables of planetary movements were reasonably accurate considering the era.



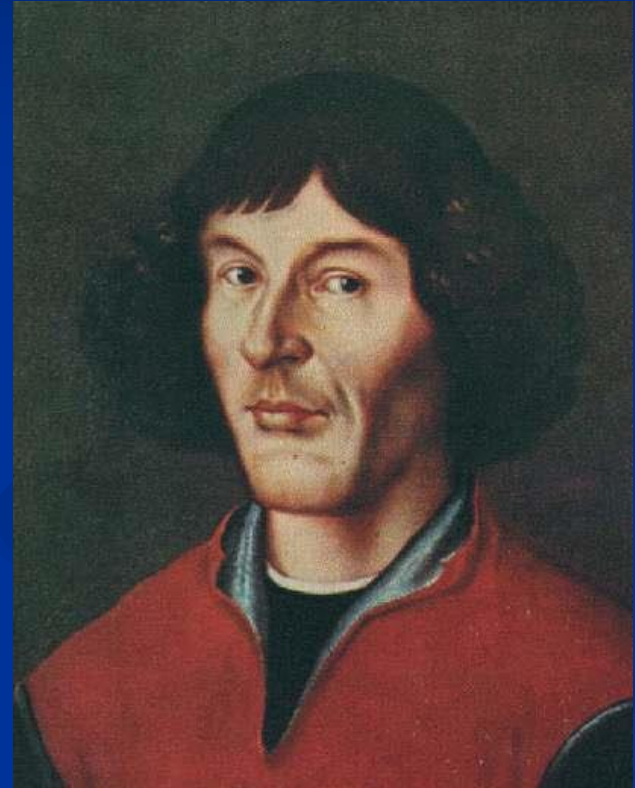
3 The sun-centered universe

- In the 16th century Nicolás Copernicus, a Polish astronomer, suggested a heliocentric theory (with the Sun in the Center)
- Aristarcus of Samos, a Greek scientist, suggested the heliocentric theory 18 centuries before Copernicus. We do not know, however, that early theory in detail.



3 The Sun-centered universe

- ❑ Copernicus assumes that the planets move in circles, though the circles were not exactly focused on the Sun.
- ❑ Copernicus used some epicycles in order that their predictions were better consistent with observations (and eliminated the equant.)

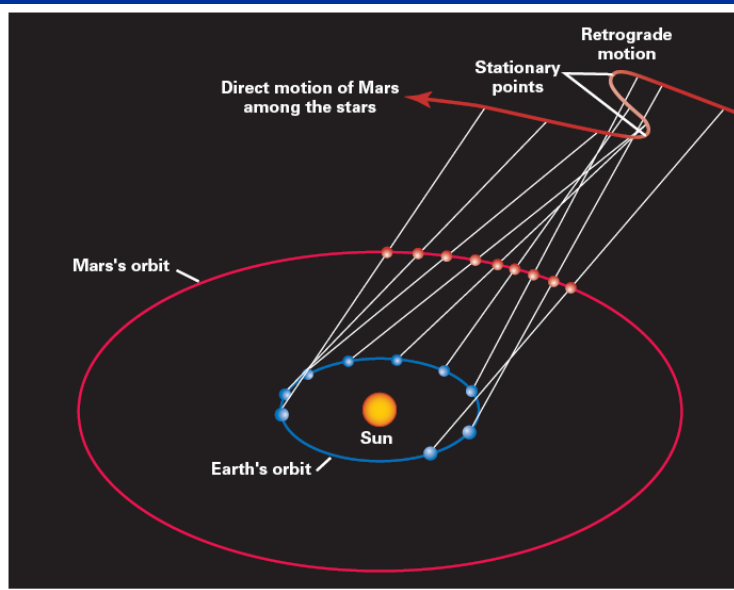


3 The Sun-centered universe

□ This model explained the retrograde motion of the outer planets (as Mars) by projection effect:

■ As Earth overtakes Mars, the projection of the line joining the Earth and Mars, shows an apparent movement of recoil among the stars, contrary to the actual direction of movement.

■ Then, as Earth and Mars are still moving in its orbit, the projection of the line that joins the two planets seems to move again in the real sense of the movement.



3 The sun-centered universe

- ❑ With the idea that the Sun was approximately in the center of the Solar system, Copernicus:
 - ❑ Computed the relative distances of the planets scaled to Earth-Sun distance.
 - ❑ Inferred the time for each planet to orbit the Sun from observations.



4 The sharp eyes of Tycho Brahe



In the latter part of the 16th century, not long after the death of Copernicus, Tycho Brahe, a Danish nobleman began to observe Mars and other celestial bodies to improve their predictions of the positions from his observatory Uraniborg



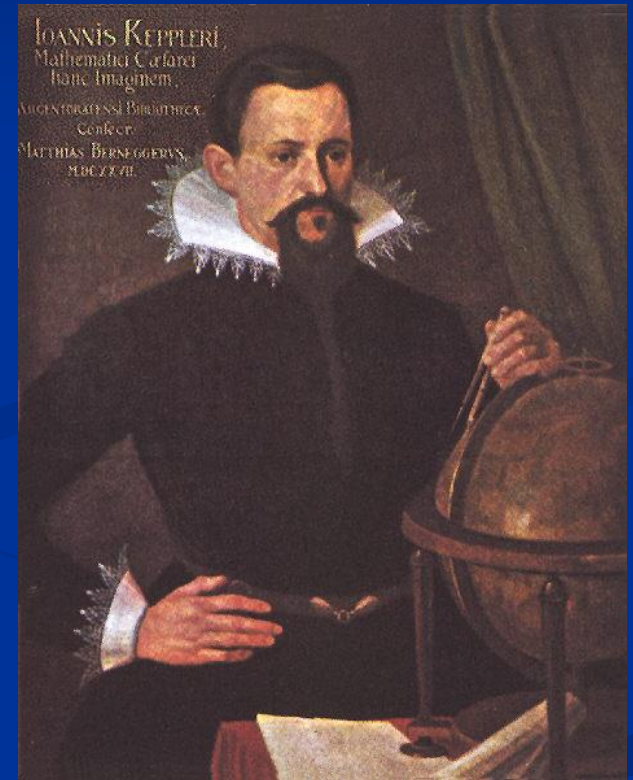
4 The sharp eyes of Tycho Brahe

- ❑ Since the telescope not had yet been invented, Tycho used giant observing instruments that had no precedent in terms of accuracy.
- ❑ Following Tycho's death in 1601, after some battles to access them, Johannes Kepler obtained the data.



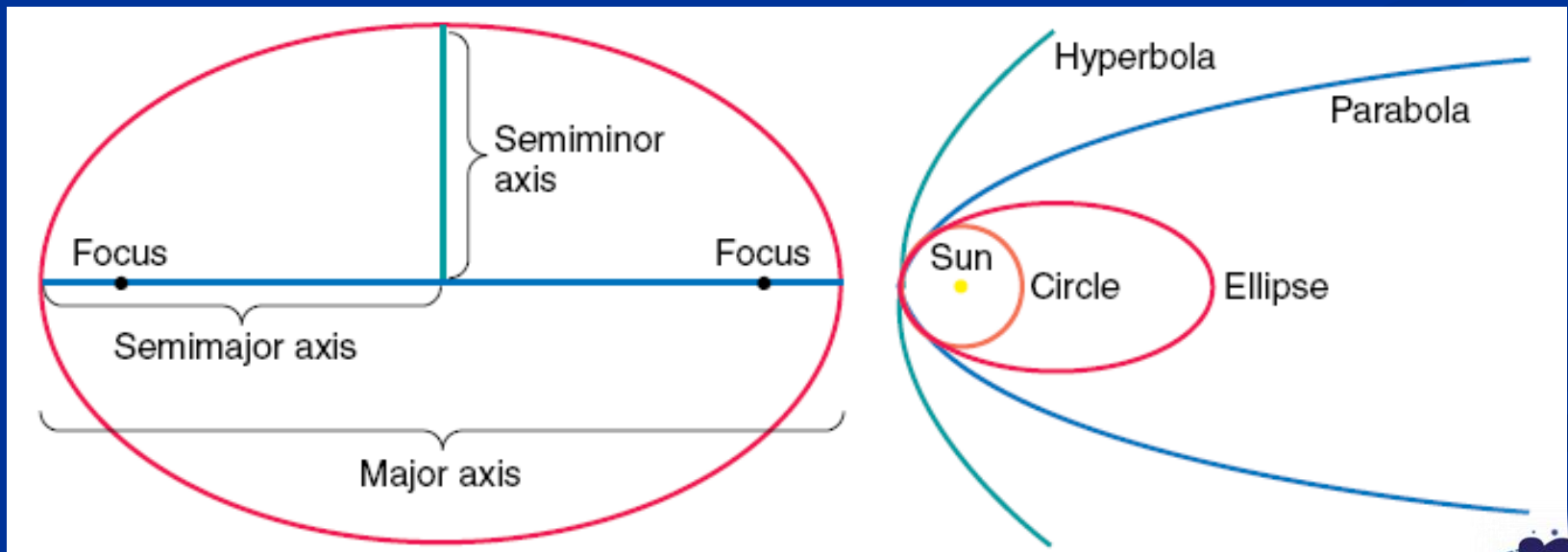
5 Johannes Kepler and his Laws

- ❑ The new, more reliable and precise observations of Tycho showed that the tables of the positions of the planets, in use at that time, were not very accurate.
- ❑ Tycho hired Kepler in 1600 to do detailed calculations to explain the planetary positions.
- ❑ First, Kepler tried to explain the orbit of Mars using circles, then other shapes, before he found the answer.



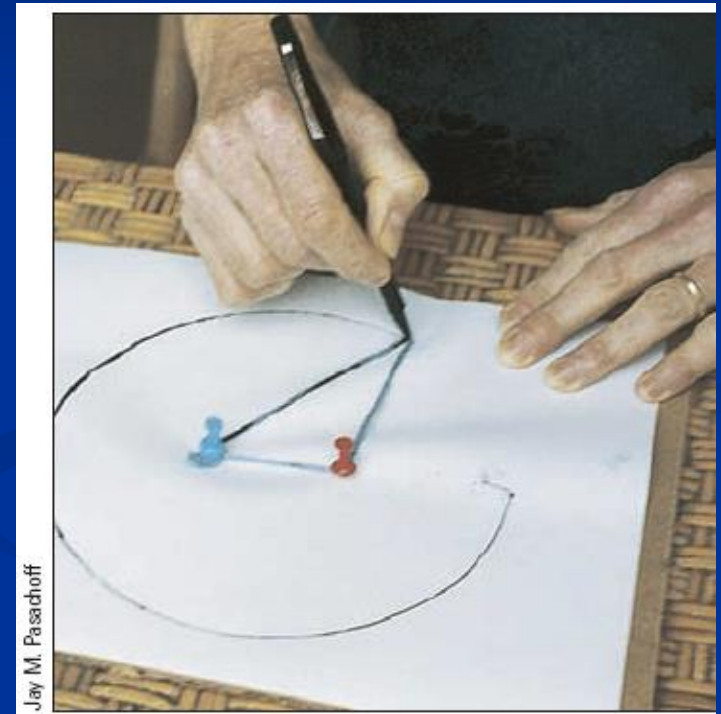
5a Kepler's First Law

- The Kepler's first law, published in 1609, says that the planets orbit around the Sun in ellipses, with the Sun at one focus.



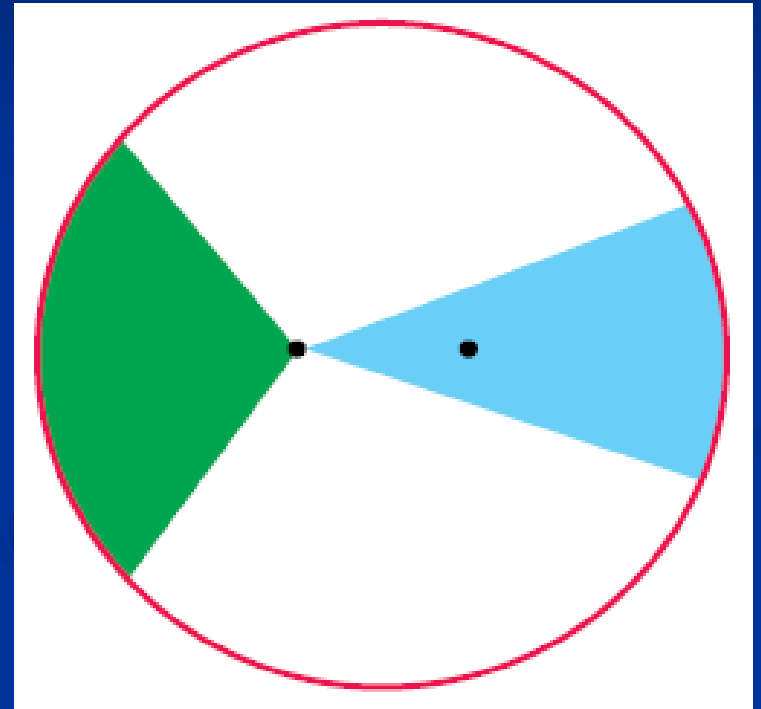
5a Kepler's First Law

- ❑ The separation between the foci and a given length of string defines an ellipse.
- ❑ The shape of the ellipse can be changed if you change the length of the string or the distance between the foci.



5b Kepler's Second Law

- Describes the speed with which the planets travel in their orbits:
 - a line joining a planet with the Sun describes equal areas in equal times.
 - This is also known as the law of equal areas.



5b Kepler's Second Law

- ❑ Kepler's second law is especially useful for the comets, which present highly eccentric elliptical orbits (i.e., flattened).
- ❑ For example, he showed that the Comet Halley is moving much more slowly when it is far away from the Sun, since the line that joins it to the Sun is very long.



5c Kepler's Third Law

- ❑ Kepler's third law relates the period with a measure of the distance of the planet to the Sun.
- ❑ Specifically, says that the square of the period of revolution is proportional to the cube of the semi-major axis of the ellipse:

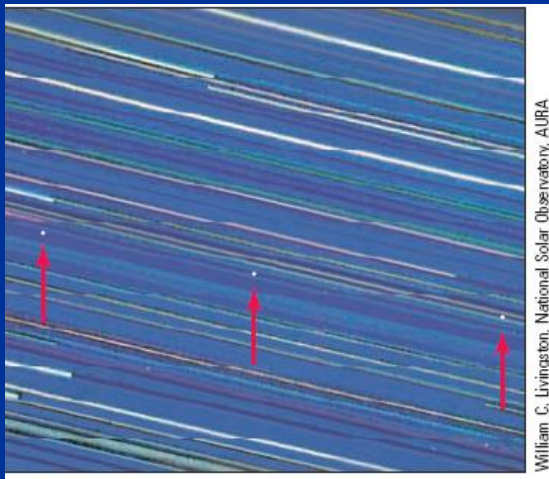
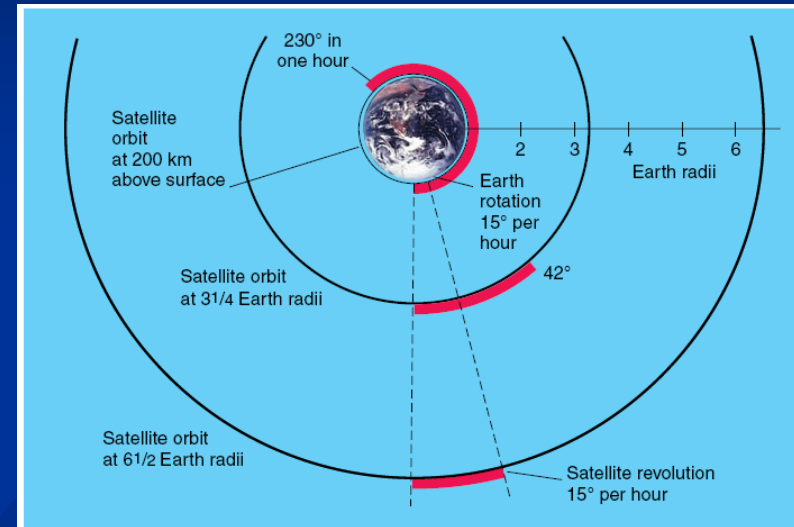
$$P^2 = kR^3, \text{ where } k \text{ is a constant}$$

- ❑ That is, if the cube of the semi-major axis of the ellipse increases, the square of the period increases by the same factor.



5c Kepler's Third Law

- A terrestrial application of Kepler's third law is in "geostationary satellites" which are at a distance where their orbital period is same as Earth's rotational period. They remain always above the same longitude on Earth.



William C. Livingston, National Solar Observatory, AURA

- They seem that they float above the Equator (see picture, left), and they are used to relay signals for TV and telephone.



6 The fall of the Ptolemaic model:

7 Galileo Galilei

- ❑ In late 1609 Galileo was the first to use a telescope for systematic astronomical studies.



Jay M. Pasachoff



Jay M. Pasachoff

6 The fall of the Ptolemaic model: Galileo Galilei

- ❑ In 1610, he published observations from his telescope: many more stars than one could see with the unaided eye.
- ❑ The Milky Way contained numerous individual stars.
- ❑ Mountains, craters and dark lunar "seas" on the Moon
- ❑ 4 small bodies that orbit Jupiter (this proved that not all the bodies revolve around the Earth)
- ❑ In addition, the 4 moons were not "left behind" while Jupiter moved, suggesting that Earth should behave in a similar fashion without leaving objects behind it.

Att. 7. Di Gennaio

*Giorno 7. uide asi **

*Att. 8. asi **

*Att. 13. Le uide asi **

*Att. 14. è rugolo **

*Att. 15. **

spande dalla 3^a di gruppo l'ora

*La spazi a delle 3. uide asi **

maggior del diametro di 7. et c.

raio in linea retta.

4 long. 71.38 lat. 1.13

On the 7th of January Jupiter is seen thus

On the 8th thus

On the 12th day it is seen in this arrangement

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

On the 14th it is cloudy

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

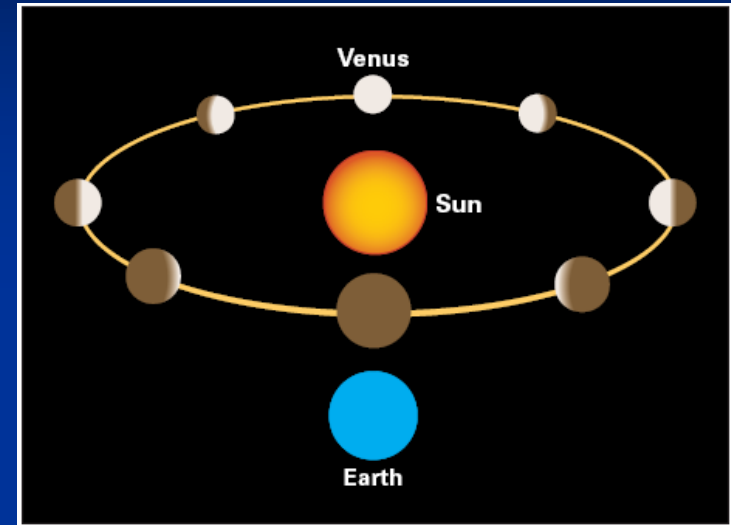
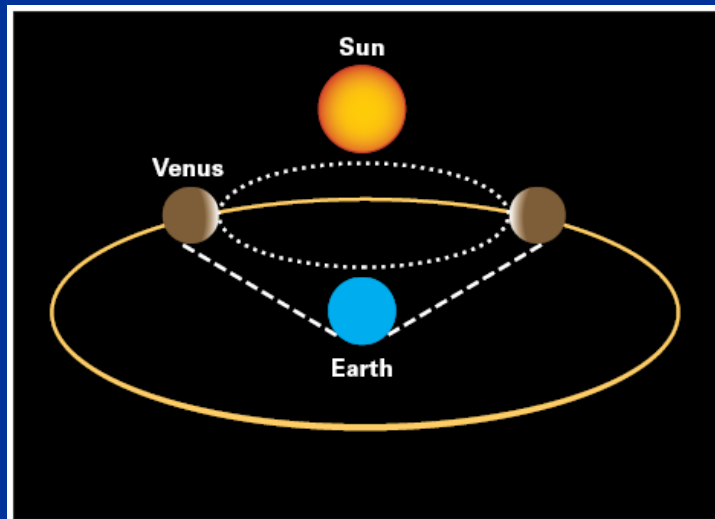
The spacing of the 3 to the west was no greater than the diameter of Jupiter and they were in a straight line.

long. 71°38' lat. 1°13'



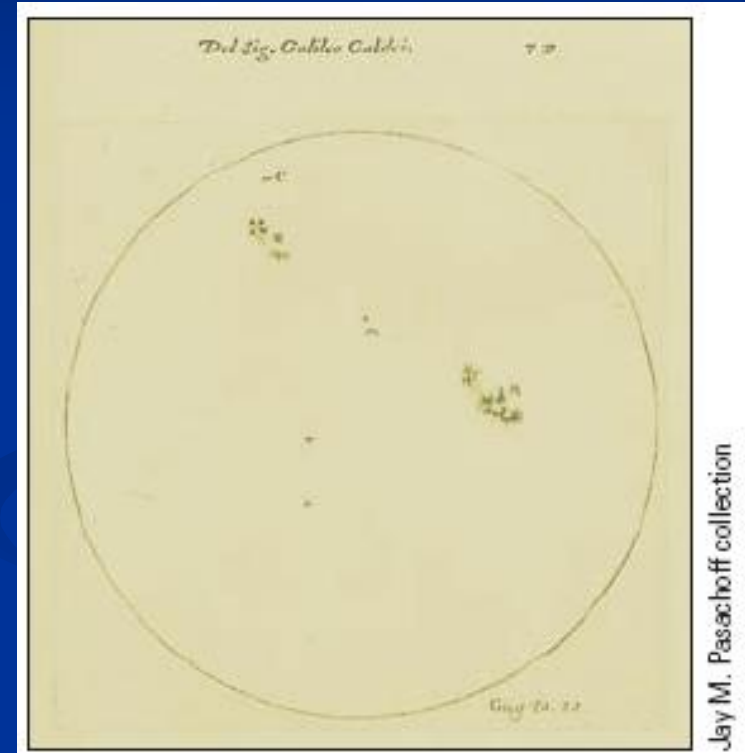
6 The fall of the Ptolemaic model: Galileo Galilei

- Galileo also discovered that Venus presented a complete set of phases; this was not explained with the Ptolemaic system



6 The fall of the Ptolemaic model: Galileo Galilei

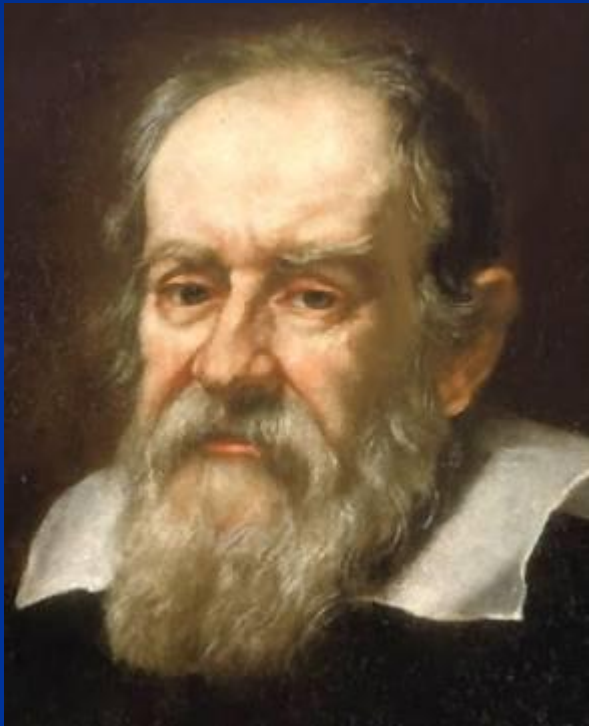
- In 1612 he described sunspots, (evidence that celestial objects were not perfect) showing that they move together across the surface of the Sun



Jay M. Pasachoff collection



6 The fall of the Ptolemaic model: Galileo Galilei



❑ In our era, about four hundred years after Galileo made his discoveries and more than four hundred years since his contemporary Giordano Bruno was burned at the stake in part by his vision of other worlds beyond our solar system, there prevails a peace between the Church and the scientists. For example, the Vatican maintains a modern Observatory staffed by several respected astronomers.



7 On Shoulders of Giants: Isaac Newton

- ❑ Only with the work of Isaac Newton 60 years later do we understand the physics behind the empirical laws by Kepler.
- ❑ Newton was born in England in 1642, the year in which Galileo died.
- ❑ It was the greatest scientist of his time:
 - ❑ He worked in optics.
 - ❑ He invented the reflecting telescope
 - ❑ He discovered the decomposition of visible light into a spectrum of colors.
 - ❑ But even more important was his work on motion and gravitation (for which he had to invent calculus)



7 On Shoulders of Giants: Isaac Newton

- ❑ *The Principia* contains Newton's three laws of motion.
- ❑ The first law states that bodies in motion tend to stay in motion in a straight line at constant speed unless an external force acts upon them.

This is the law of inertia, which was actually discovered by Galileo.

- ❑ The second law concerns the force associated with its effect on the acceleration (increase of speed) of a mass.

A larger force will make that the same mass is accelerate more ($F = ma$, where F is the force, m is the mass, and a is the acceleration).



7 On Shoulders of Giants: Isaac Newton

- The third law is often enunciated as "For every action, there is an equal and opposite reaction."

Rocket motion is only one of many processes explained by this law.

- *The Principia* also includes the Law of Gravity.

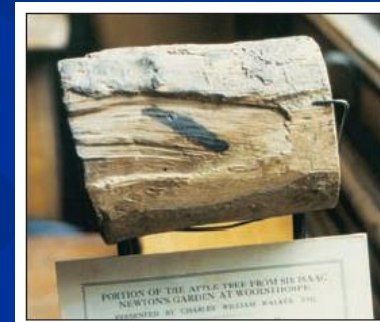
One application of Newton's Law of Gravity is the concept of weight.



7 On Shoulders of Giants: Isaac Newton

One of the most famous stories of science is that an apple fell on Newton's head, leading to his discovery of the concept of gravity

Although no apple fell on Newton's head, the story that Newton himself told, years later, is that he saw an apple fall and realized that just as the apple falls to Earth, the Moon is falling toward Earth, and keeps moving away from us. (In any short interval of time, the distance that the Earth's Moon travels toward the distance is compensated by the Moon's motion forward, the result over several such intervals is a stable orbit, rather than a collision with Earth.)

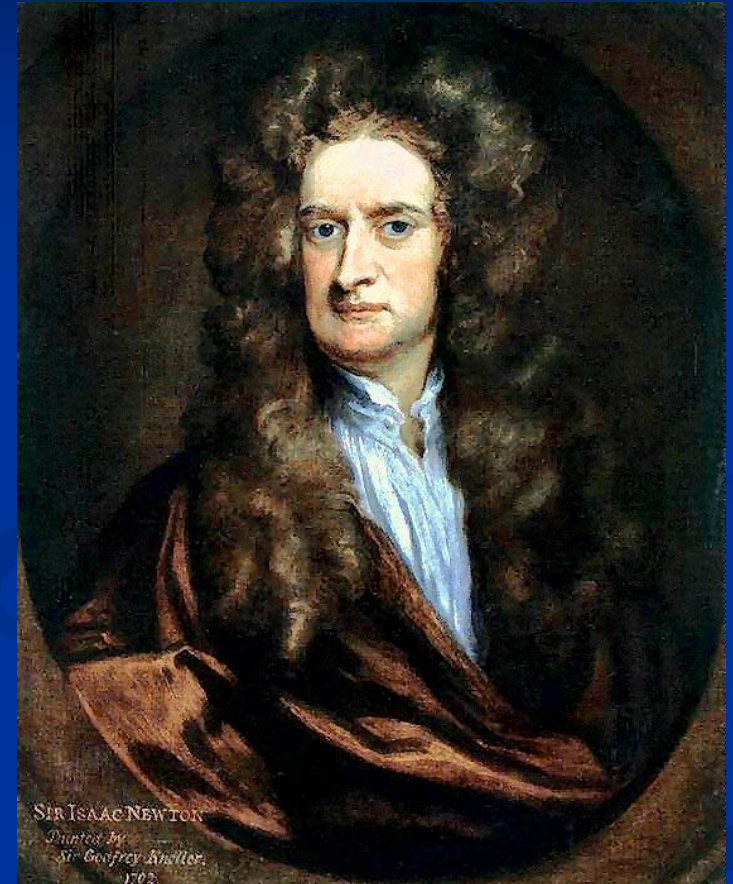


Jay M. Pasachoff



7 On Shoulders of Giants: Isaac Newton

- One famous phrase from Newton is, “If I have seen further it is by standing on the shoulders of Giants.”



Optional slides



8 The roots of Astronomy : BABYLON

The roots of occidental Astronomy are in Caldea. The Caldeans used the sexagesimal system of positional notation (similar to the actual decimal system, but with base 60), this facilitated the development of algebra and arithmetic. From this ancient system, we have the division of the circle in 360 degrees, or the division of one hour in 60 minutes, and these into 60 seconds.

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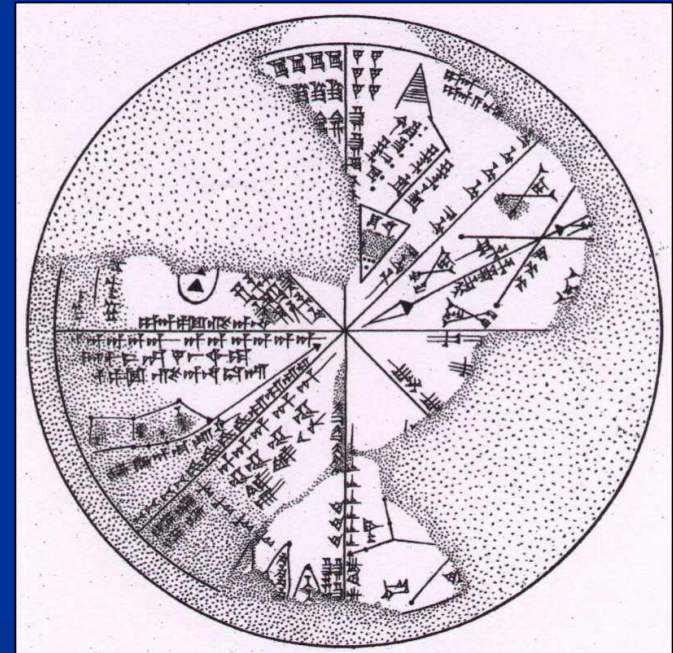


8 The roots of Astronomy : BABYLON

The Caldeans observed lunar eclipses and proposed the *Saros* series to predict the phenomena. Although they used the series only for lunar eclipses, it can be used to predict solar ones.



Letter to the king Asurbanipal where is detailed a lunar eclipse.



Planisphere, Ninive Library of Asurbanipal (800 BC)

8 The roots of Astronomy : BABYLON

Five planets known by Caldeans

Codex of Amurabi



Name	Meaning	Planet
Neberu	The pivot	Jupiter
Delebat	Which proclaims	Venus
Sithu, Ishtar	The jumper	Mercury
Kayamanu	The constant	Saturn
Salbatanu	The reddened	Mars

8 The roots of Astronomy : EGYPT

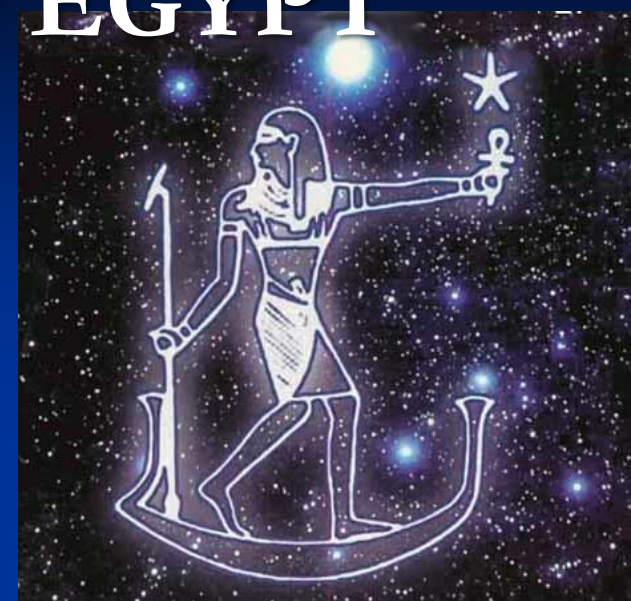


The sky-goddess
Nut covers Geb,
the Earth-god.

Nut forms the
limit between
Earth and
Heaven, the dead
world.

8 The roots of Astronomy : EGYPT

The Egyptians noted that when Sirius (called Sotis) rose just before the Sun (heliac) this was coincident with the river Nile's overflow. The desert became fertile, and for this reason, Sirius is connected with the goddess of fertility, Isis.



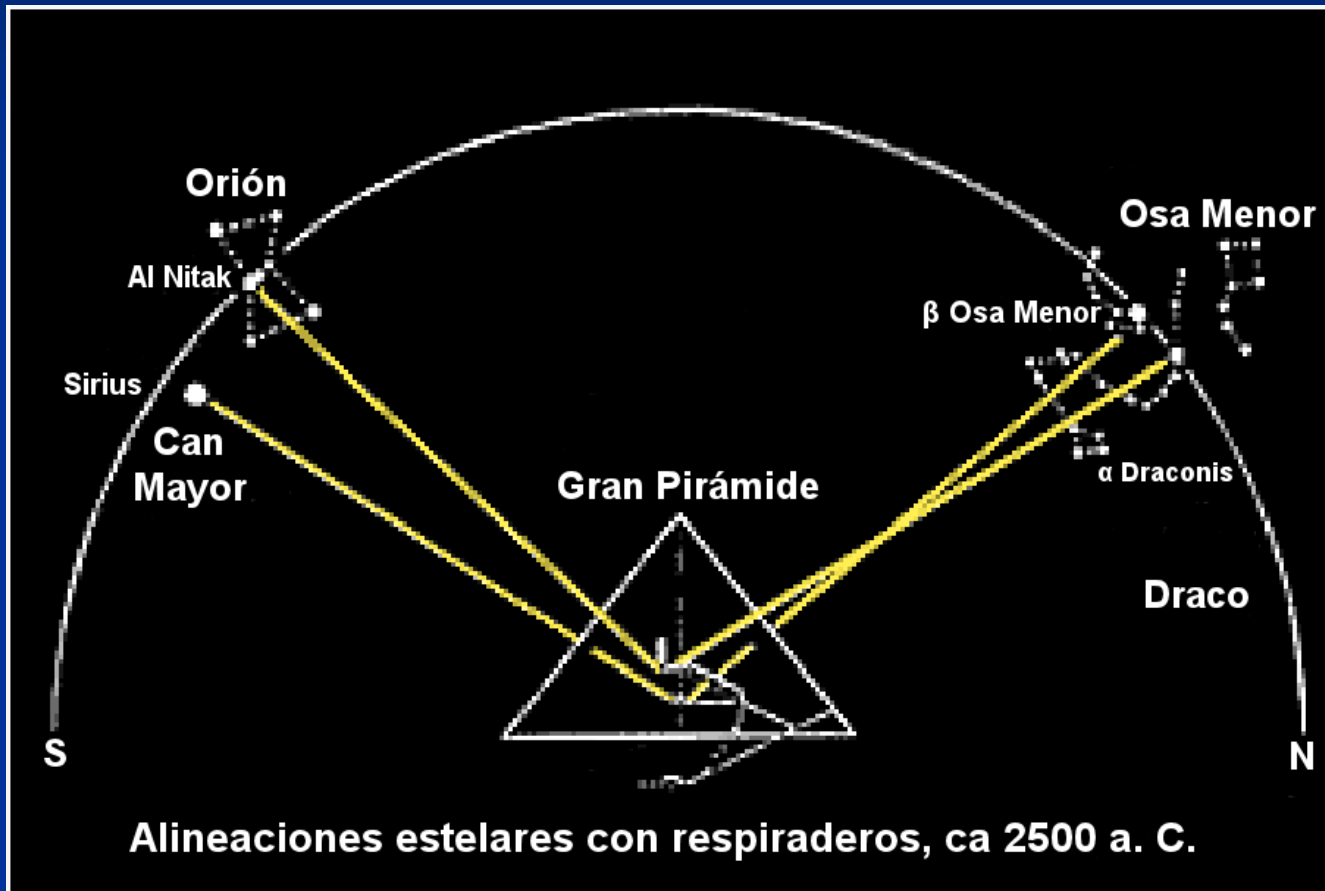
8 The roots of Astronomy : EGYPT



The Egyptian constellations of the Hellenic period are on the roof of Hathor Temple in Denderah.

The majority have disappeared, such as the crocodile and hippopotamus.

8 The roots of Astronomy : EGYPT



The buildings were oriented according to special positions of the Sun and the stars.

8 The roots of Astronomy: ÍNDIA

The first textual mention of astronomical content is given in the religious literature of India (second millennium BC)

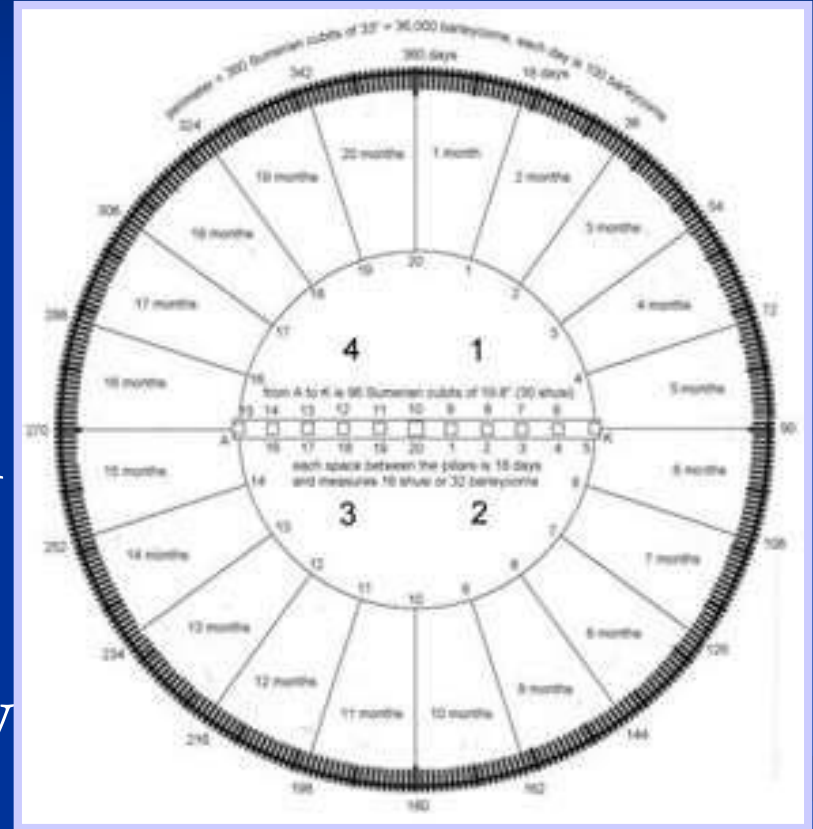
During the following centuries a number of Indian astronomers studied various astronomical aspects.



8 The roots of Astronomy: ÍNDIA

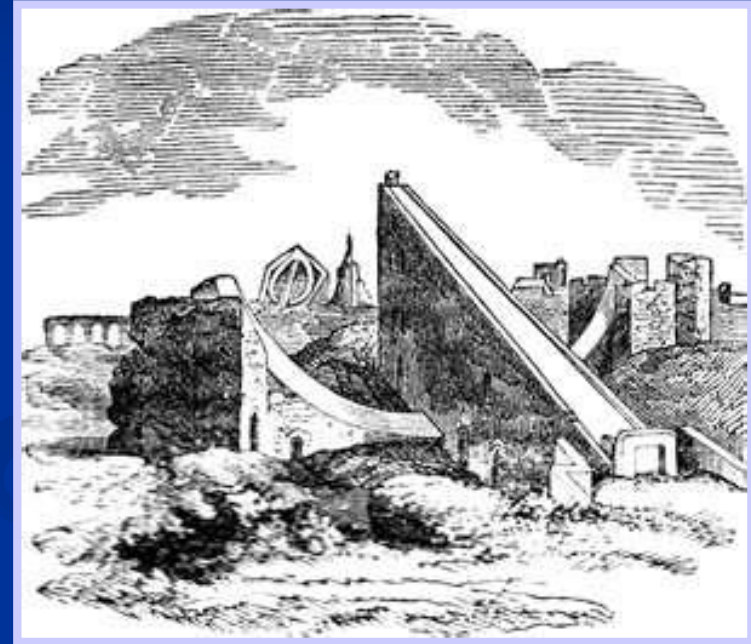
The Hindu calendar used in ancient times has undergone many changes in the process of regionalization, and today there are several regional Indian calendars, as well as an Indian national calendar.

In the Hindu calendar, the day begins with sunrise. Assigned to five "properties" calls *angas*.

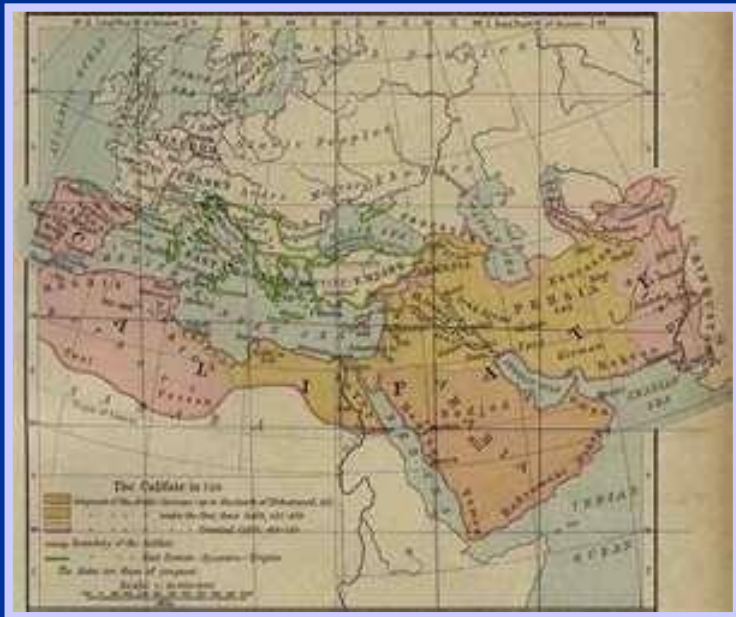


8 The roots of Astronomy : ÍNDIA

The ecliptic is divided into 27 nakshatras which are variously called lunar houses or asterisms. These reflect the moon's cycle against the fixed stars, from 27 to 27 $\frac{3}{4}$ hours, the fractional part being compensated by an intercalary 28th nakshatra. Nakshatra computation appears to have been well known at the time of the Rig Veda (second - first millennium BC.).



8 The roots of Astronomy : ARABIA



Astronomical developments made in the Islamic world, particularly during the Islamic Golden Age (eighth – fifteenth centuries), and written in Arabic

Most were developed in the Middle East, Central Asia, Al-Andalus, North Africa, and later in Southeast Asia and India.

8 The roots of Astronomy : ARABIA

The first systematic observations in Islam took place under the patronage of Al-Mamun (786-833) in many observatories from Damascus to Baghdad:

- measured the degrees of longitude,
- established solar parameters,
- made detailed observations of the Sun, Moon and the planets



8 The roots of Astronomy : ARABIA



A large number of stars in the sky (e.g., Aldebaran and Altair) and astronomical terms (e.g., alidade, azimuth, almucantar) are still cited by their Arabic names

Tools

- Celestial globes
- Armillary spheres
- Astrolabes
- Sundials
- Quadrants

8 The roots of Astronomy : MAYA

The Maya were very interested in the zenithal passages, the time when the sun passes directly overhead.

The latitude of most of their cities is below the Tropic of Cancer, these zenithal passages would occur twice a year equidistant from the solstice.

To represent this position of the sun directly overhead, the Maya had a god called "Diving God".



8 The roots of Astronomy : MAYA

Venus was the most important astronomical object for the Maya, even more than the Sun.

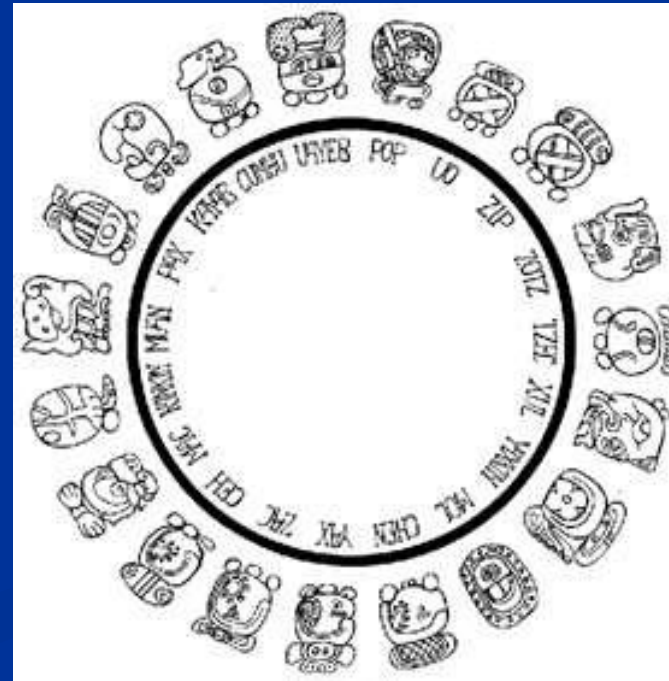
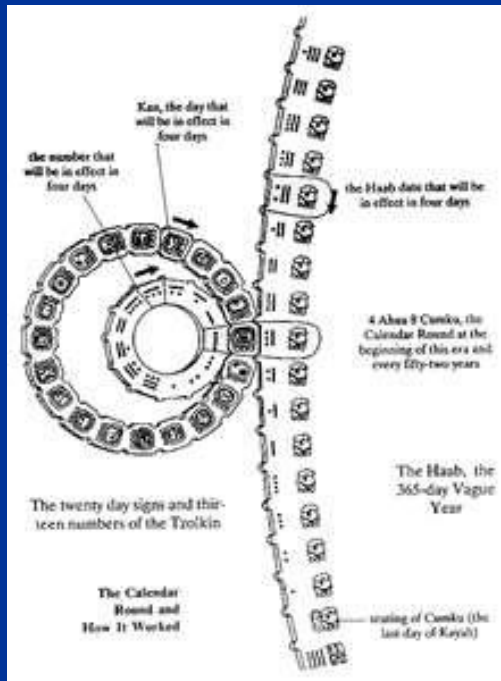


The Maya civilization seems to be the only pre-telescopic that demonstrates knowledge of the Orion Nebula as a diffused, i.e., not a stellar point.



8 The roots of Astronomy : MAYA

The Maya calendar is a system of calendars and almanacs used in the pre-Columbian Maya civilization, and in some modern Maya communities in the highlands of Guatemala and Oaxaca, Mexico.



8 The roots of Astronomy : MAYA

Although the Mesoamerican calendar did not originate with the Maya, their subsequent extensions and improvements of it were the most sophisticated.

Together with those of the Aztecs, the Maya calendars are the best documented and most comprehensive.



8 The roots of Astronomy : AZTECAS

From the thirteenth century the Valley of Mexico was the heart of Aztec civilization



They were ethnic groups of central Mexico, particularly those groups who spoke the Nahuatl language dominated much of Mesoamerica in the fourteenth, fifteenth and sixteenth centuries, a period known as the last post-classic period in Mesoamerican chronology.



8 The roots of astronomy : AZTECAS

The Aztec calendar is the oldest monolith that remains of pre-Hispanic culture. (approx. 1479).



The calendar is circular with four concentric circles. In the center stands the face of Tonatiuh (Sun God) holding a knife in his mouth. The four suns or earlier eras are represented by square-shaped figures flanking the central sun. The outer circle consists of 20 areas representing the days of each of the 18 months that comprised the Aztec calendar. To complete the 365 days of the solar year, the Aztecs incorporated five fateful days or nemontemi



8 The roots of Astronomy : AZTECA



The Aztecs grouped bright stars into constellations :

Mamalhuaztli (Orion's belt),

Tianquiztli (the Pleiades),

Citlaltlachtli (Gemini),

Citlalcolotl (Scorpion) and

Xonecuilli (The Little Dipper or the Southern Cross for others), etc.

Comets were called "the stars that smoke."



8 The roots of Astronomy : INCAS

The Inca civilization is a pre-Columbian Andean Group. It starts at the beginning of the thirteenth century in the basin of Cuzco in Peru and then extends along the Pacific Ocean and the Andes, covering the western part of South America.



At its peak, it extends from Colombia to Argentina and Chile, through Ecuador, Peru and Bolivia.



8 The roots of Astronomy : INCAS

The Incas used a solar calendar for agriculture and other of moon to religious holidays .



According to the chronicles of the Spanish conquistadors, on the outskirts of Cuzco was a large public calendar consists of 12 pillars of 5 meters, which could be seen from very far. With it, people could establish the date.

They celebrated two major parties, the Inti Raymi and Capac Raymi, the summer solstice and winter respectively.



8 The roots of Astronomy : INCAS



The Incas considered their King, Sapa Inca, the "son of the Sun".

Major cities were drawn following celestial alignments using cardinal points.

They identified various dark areas or dark nebulae in the Milky Way as animals, "dark constellations," and associated their appearance with the seasonal rains.



8 The roots of Astronomy : INCAS

The constellations, Yutu, one of the dark constellations, and the Flame of Heaven, were used by the Incas to keep pace with the seasons and events to mark the sacred events.



For example: In ancient Peru, sacrifices and black colored fires were scheduled for April and October, when the 'eyes of the Flame of Heaven' "Alpha and Beta Centauri" were opposed to and close to the Sun.



8 The roots of Astronomy : CHINA

The Chinese could be considered as the most persistent and accurate observers of celestial phenomena before the Arabs.



Detailed records of astronomical observations began during the 4th century BC. Elements of Indian astronomy reached China with the expansion of Buddhism during the dynasty of Later Han (25-220 AD), but more detailed incorporation of Indian astronomical thinking occurred during the dynasty of Tang (618-907)

8 The roots of Astronomy : CHINA

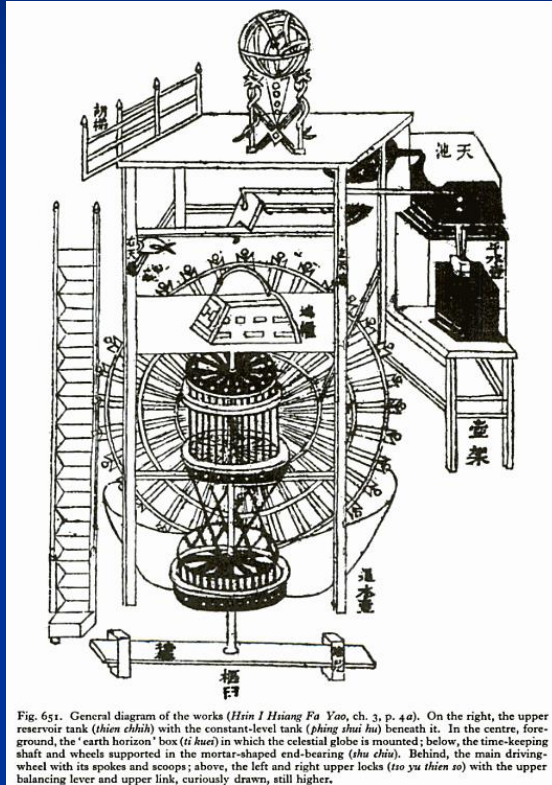


Fig. 651. General diagram of the works (*Hsin I Hsiang Fa Yao*, ch. 3, p. 4a). On the right, the upper reservoir tank (*shien chih*) with the constant-level tank (*ping shui hu*) beneath it. In the centre, foreground, the 'earth horizon' box (*ti kuei*) in which the celestial globe is mounted; below, the time-keeping shaft and wheels supported in the mortar-shaped end-bearing (*shu chiu*). Behind, the main driving wheel with its spokes and scoops; above, the left and right upper locks (*tsu yu thien so*) with the upper balancing lever and upper link, curiously drawn, still higher.

Astronomy was revitalized under the stimulus of cosmology and Western technology after the Jesuits established their missions in the 16th century.

Tools

Armillary sphere

Celestial globe

Sphere of hydraulic fittings

Celestial globe tower

The telescope was introduced in the seventeenth century.



8 The roots of Astronomy : CHINA



Chinese scientist Shen Kuo (1031-1095) was the first to:

- describe the magnetic compass needle

- make an accurate measurement of the distance between the pole star and true north to be used in navigation

8 The roots of Astronomy : CHINA



Shen Kuo and Wei Pu established a nighttime astronomical project in a period of five consecutive years, a job that could rival the observations of Tycho Brahe. For this project also drew the exact coordinates of the planets in a star map and created theories of planetary motion, including retrograde motion.



8 The roots of Astronomy : CHINA

Chinese astronomy focused on observation.

They had data from the year 4000 BC, including the explosion of supernovas, eclipses and the appearance of comets.

- at 2,100 B.C. they recorded a solar eclipse
- at 1,200 B.C. they described sunspots, calling them "*dark spots*" in the Sun.
- at 532 B.C. They noted the appearance of a *supernova* in the constellation Aquila
- at 240 and 164 B.C. observed Comet Halley



8 The roots of Astronomy : CHINA

Other observations:

- determined the *precession* of the *equinoxes* in one degree every 50 years
- they observed that comet tails always point in the opposite direction to the sun's position



- in 1006 A.D. they noted the appearance of a supernova so bright that you could see at day
- in 1054, they observed the explosion of a supernova, which later gave rise to the *Crab Nebula*



**Many Thanks
for your attention!**