

Cosmos to Chaos

A tour of cosmology through cultures,
people and history.

Spiral Galaxy NGC 5033
Hubble Telescope by
Adam Block, University of Arizona

Greek Beginnings

OLLI Spring 2024
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COSMOS [from Greek, *kosmos*, order, harmony, ornament, hence the world as an orderly system] the universe as an embodiment of order and harmony.

CHAOS [from Latin and Greek, *chaos*, empty space; abyss] confusion, formless matter, infinite space, an unordered universe.

COSMOGONY [from Greek, *kosmogonia*, the creation or origin of the world] the generation or origin of the universe; a theory or account for this.

COSMOGRAPHY a general description of the world; the science dealing with the structure of the universe as whole and its related parts.

COSMETOLOGY and **COSMEDICS** [from Greek, *kosmet*, decorate or adorn] the study of cosmetics and the techniques of their use.

COSMOLOGY [from Greek, *kosmos*, universe, and *-logia*, to speak] the theory or philosophy of the nature and principles of the universe.

From Webster's New Universal Unabridged
Dictionary, Second Edition, 1955

Cosmology – what is it?

- Cosmology attempts to discover, describe and perhaps understand the origin, the evolution, and the fate of our universe.
- Cosmology is really the oldest science – it was called “natural philosophy”. Cosmology has gone from a philosophical view of our existence to a science.
- The science of cosmology attempts to explain the state, principles, and mechanisms of how the universe works.
- Understanding the cosmos helps to satisfy the universal human need to discerning our “place” in the universe, assigning meaning to our existence, and grasping the significance of it all.

Cosmology attempts to answer the Big Questions.

This often raises more questions than can be answered.

Theory versus Observation, Experience, and Experiment

- Is there a difference?
- “Everyday” experience helps explain the world we live in.
- Experiments are controlled experience.
- Any model or theory must lead to common observational experience.
- Is it science?
- Is it religion?
- Is it an opinion or wishful thinking?

Science

- Science is based on observations. The tools available for observing our world continue to evolve and allow “better” observations.
- Observations allow scientists to formulate theories that explain the observed events.
- Theories generalize observations and predict unseen relationships, unexpected behavior, even future events.
- Theories – and predictions - must be “falsifiable.” The theory must allow for a test that can prove the theory wrong.
- In general, the theory will be stated in the language of physics – a mathematical equation.

Religion

- Religion is a set of assumptions and beliefs that seeks to place man in the grand scheme of the universe. Normally this assumes a divine power.
- These beliefs define the cause, nature and purpose of the universe.
- God – a supernatural power – is assumed to influence, judge, and forgive human behavior and eventually control human destiny.
- Historically, any observation that could not be readily explained by the science of the day was simply ascribed as occurring because “God wanted that to happen.”
- Cosmology does not attempt to prove or disprove the existence or activity of any supernatural being or God. The two disciplines are seeking answers to independent, separate questions.

Opinion or Wishful Thinking

I don't believe ice cream has any calories. Have you ever seen a calorie?
Is this a theory? Opinion? Or simply wishful thinking?

Let's review how ancient cultures viewed the creation of earth, heavens
and humans. The Big Bang of 2,000 B. C. E.

Sumerian and Babylonian Science

- These civilizations were quite advanced in many respects but predated classical Greek civilization by as much as 2,000 years.
- We tend to combine Sumerian and Babylonian civilizations but they were quite distinct, even though the Babylonians inherited much from the Sumerians.
- They may have developed some geometric methods similar to the concepts of the calculus – which was not fully developed in the West until the 1700's, independently, by Isaac Newton and Gottfried Leibniz.
- These geometric techniques allowed them to accurately calculate the motions of the sun, moon, and planets.
- Calendars were important in ancient societies for planting crops, setting the dates of religious ceremonies and civic festivals.

Sumerian and Babylonian Science

- The celestial motions as calculated by the Babylonians using these abstract concepts were also much simpler than the cycles and epicycles that the Greeks used several centuries later.
- The Babylonians used a number system based on 60 (sexagesimal) giving us 60 seconds per minute and 60 minutes per hour.
- 24 hour days came from the Egyptians and was based on the rising of certain star groups at twilight. Eventually this led to defining the year as 360 days.
- The grid we mark the earth with is also based on 60 – 60 seconds per degree and 360 degrees in a circle.



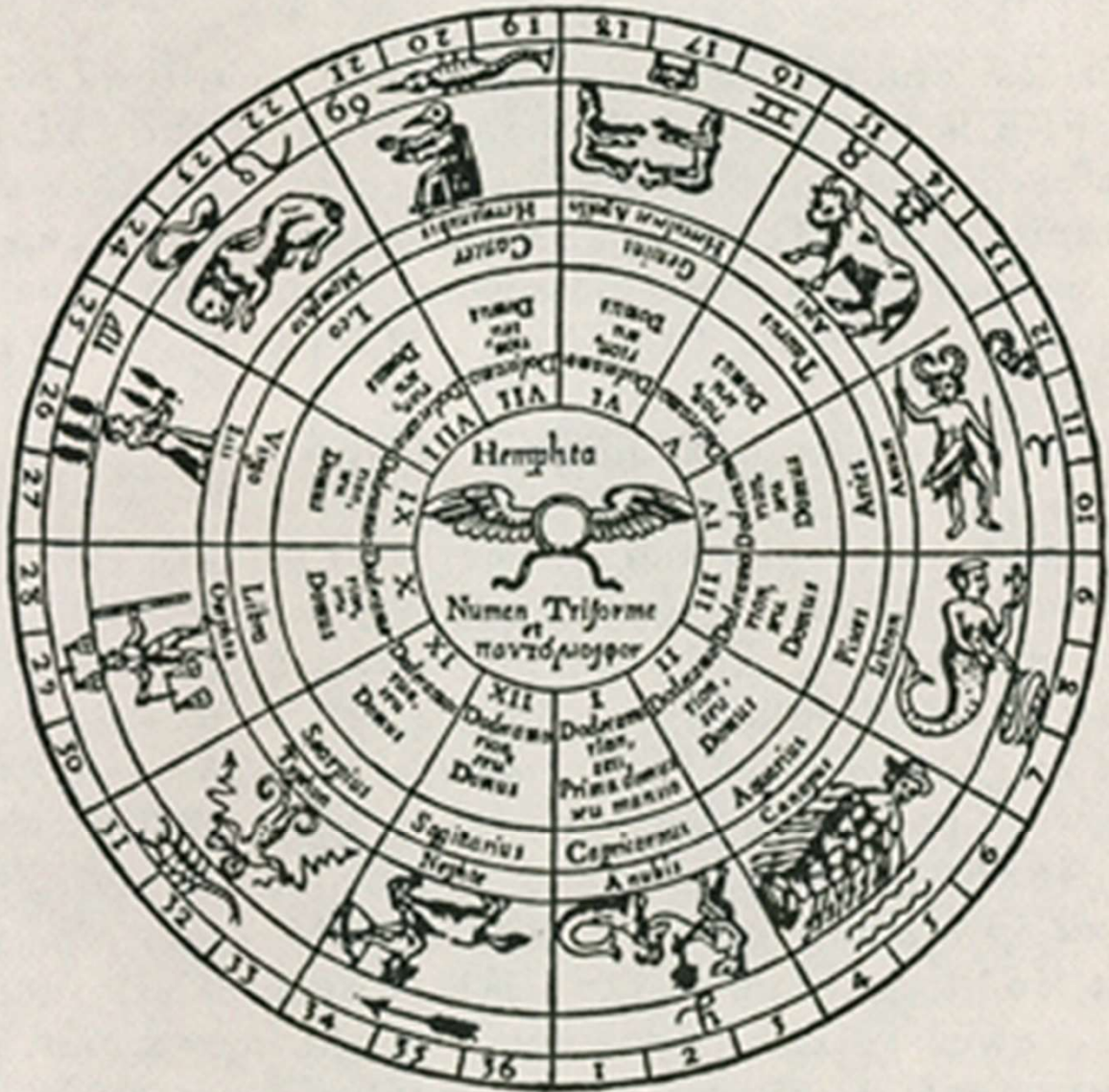
The 'Enuma Elish' epic of creation, describes the 'Half fish God' Eanna coming from the water following the 'great deluge' to bring knowledge to the Sumerians. This is probably predated by the creation epic "Gilgamesh" which was one of the earliest of these myths.

The relief of the Half Fish God may be from the British Museum. The stele is from the Louvre.

Sumerian and Babylonian Science

- The Sumerians began serious study of the heavens, called astronomy, over 1,000 years before the Greeks.
- They obviously knew about the planets and drawings suggest they understood that the planets – and the earth? – circled the sun.
- They celebrated the phases of the moon and may have understood why the moon had phases.
- Their tablets spoke of the heavenly sphere where the stars resided.
- Their creation story was similar to others of that era – man was created to serve the gods. It had a lot to do with water, mud and sex.

This Sumerian zodiacal map was used for practical mathematical and observational purposes. The Zodiac of Sumer, definitely complete by the time of Babylon, was adopted by the Greeks much later. Babylonians and the Chinese were using the 19 year Sun-Moon cycle in their calculations by the 6th Century BC. Today it is called the 'Metonic' cycle after a Greek who wrote of it a few hundred years after it was completed.

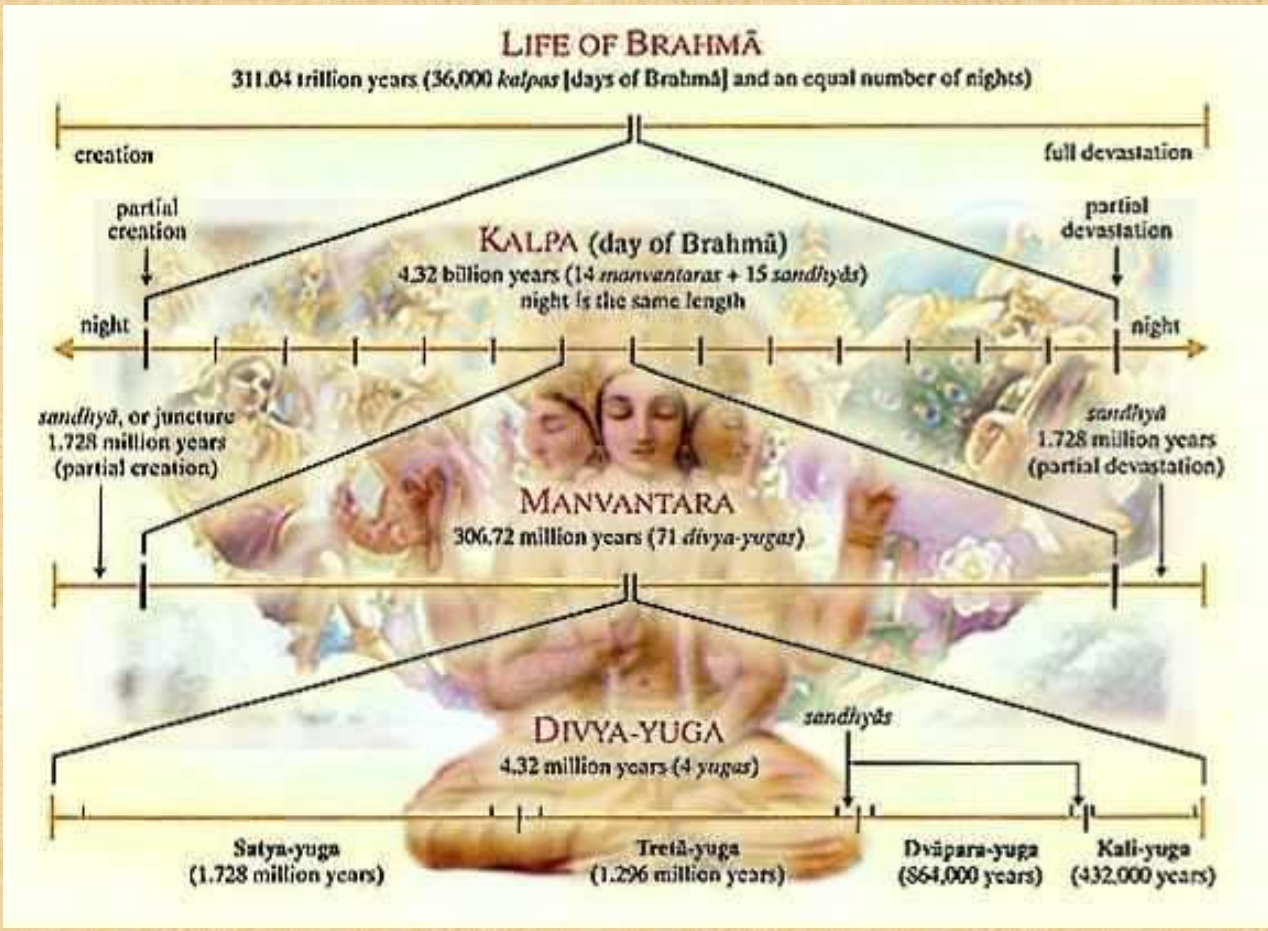


The Greeks Inherit Mesopotamia Concepts

- It is often said that the Mesopotamia culture did not have a cosmology. But it surely did.
- Babylonian astronomy concepts greatly influenced Greek cosmology.
- Greeks had a very finely developed (and rigid) concept of reality based on “perfection.”
- Music, architecture, human form, the heavens – there was a concept of perfection for everything.
- Things that fell short of the Greek concept of perfection were rejected or destroyed.
- Thus, some of the Sumerian/Babylonian concepts were rejected implicitly by Aristotle and most other Greek philosophers.
- This bias also led the Greek philosophers to assume that physical reality was based on geometry.

Indian Science and Cosmology

- In Hindu cosmology the world – all of the universe – is cyclically created and destroyed. Rebirth is fundamental.
- Time is much more complicated in Hindu cosmology. There is no start or end to time. It is also created and destroyed in cycles.
- Hindu cosmology postulates multiple universes that are created from chaos, evolve, and die back to into chaos.
- There are seven layers in each universe – earth, water, fire, air, sky, the total energy, and false ego.
- In the local sense, everything comes and goes; in the larger sense, through rebirth, everything is infinite, forward and backwards.
- Science was based on internal logic rather than observation and experiments.



Hindu cosmology embodies the idea that creation is timeless, having no beginning in time. Each creation is preceded by dissolution and each dissolution is followed by creation. The whole cosmos exists in two states - the unmanifested (chaotic) state and the manifested (cosmos) state. This has been going on eternally. There are many universes - all follow the same rhythm, creation and dissolution. Creation and dissolution recur over a period of 4.32 billion years.

Chinese Science and Cosmology

- Chinese science was practical; it was designed to serve the emperor.
- Thus, Chinese science, particularly technology, became highly developed.
- For many years China was isolated from the West so most Chinese science concepts were developed independently.
- Chinese astronomers made very accurate observations of the heavens in order to create a new calendar for each new dynasty.
- Most Chinese cosmology envisioned either a hemispherical or spherical dome where the stars resided. Similar to the later Greeks.
- At least one school taught that the heavens were infinite – based on the observation that celestial bodies moved across the sky at different speeds.
- The Chinese sky was divided into 28 “mansions” (or constellations), however it was the moon that moved through these houses. This was the basis for divining the future – astrology.



The Chinese cosmos as a dome. From about 1200 BC

The Chinese cosmos as an egg. From about 25 AD.



The Chinese cosmos as empty space. From about 200 AD

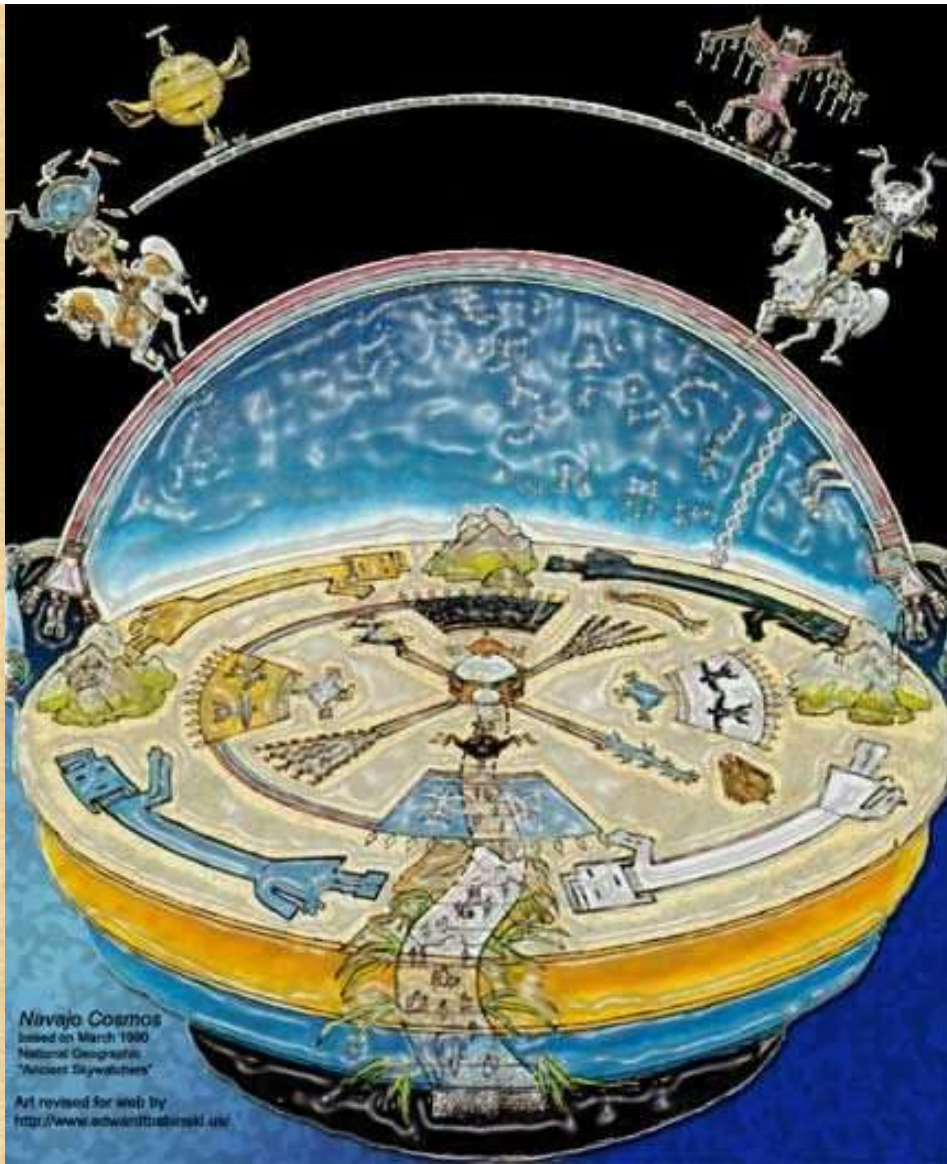


Native American Cosmology

- Everyone surely recalls that the Mayan calendar predicted the “end of the world” on December 21, 2012. This date marked the end of a 5,000-year cycle in the Mayan calendar. As well as the winter solstice. In the Gregorian calendar.
- Pre-Columbian America tended to be focused understanding and explaining the spiritual world rather than the physical one.
- As with many other cultures around the world, indigenous people in the Americas watched the sky in order to create a calendar.
- The Mayan calendar used two periods of about 400 years and 8,000 years.
- Most ceremonies were apparently not based on celestial events. Some were based on lunar cycles.

Native American Cosmology

- There were Seven Sacred Directions in most cultures: the four cardinal directions (north, east, south and west) along with The Above, The Below, and The Center of All Things (which was mother earth).
- Rather than spirits or gods, the Seven Sacred Directions were usually viewed as Guardians or Spirit Keepers. The Great Spirit was at the Center.
- The Seven Sacred Directions were associated with colors: white, red, yellow, black for the cardinal directions. Above is Blue while Below is Green. The Center is represented by Purple (sometimes Blue-Green).
- Most aboriginal cultures assumed that the universe was flat and four-cornered. Time was cyclical.
- Many Pre-Columbian cultures' creation stories, like most other cultures' creation stories, includes a flood that wiped out much of the world.



The Navajo universe was a dome. It included the four cardinal directions plus The Above, The Below, and The Center. Most other Native American cultures recognized these seven sacred directions.

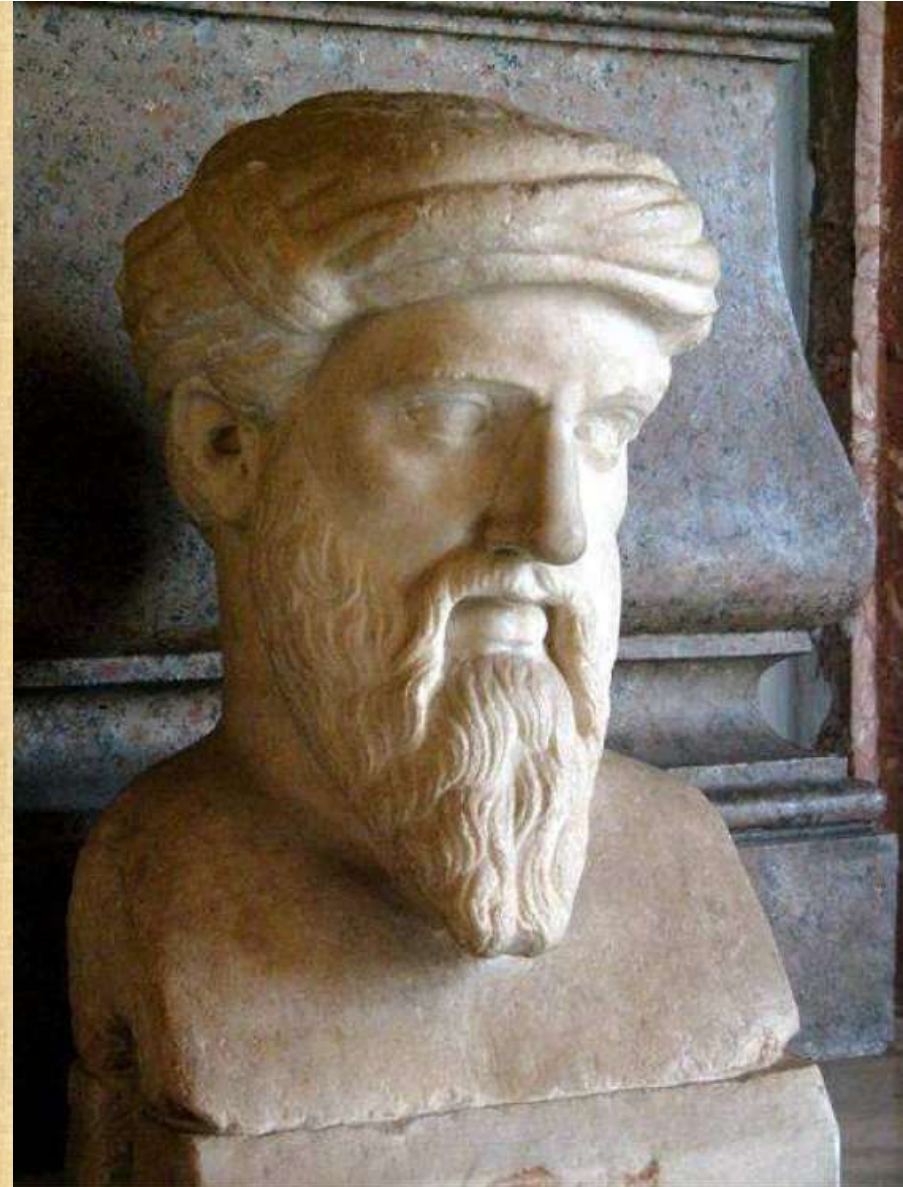
Common Cosmology

- There is a certain similarity to all the ancient world views and creation tales.
- As the centuries passed the gods got more involved in creation and development of the earth and man.
- Further, the structure of the universe got more detailed and complicated.
- Do the common elements of the creation stories imply a common source somewhere in the past?
- For example, essentially all cultures' creation stories include a worldwide flood that implied all of mankind came from a small number of progenies. A worldwide flood? Or a common source?

Greek Science

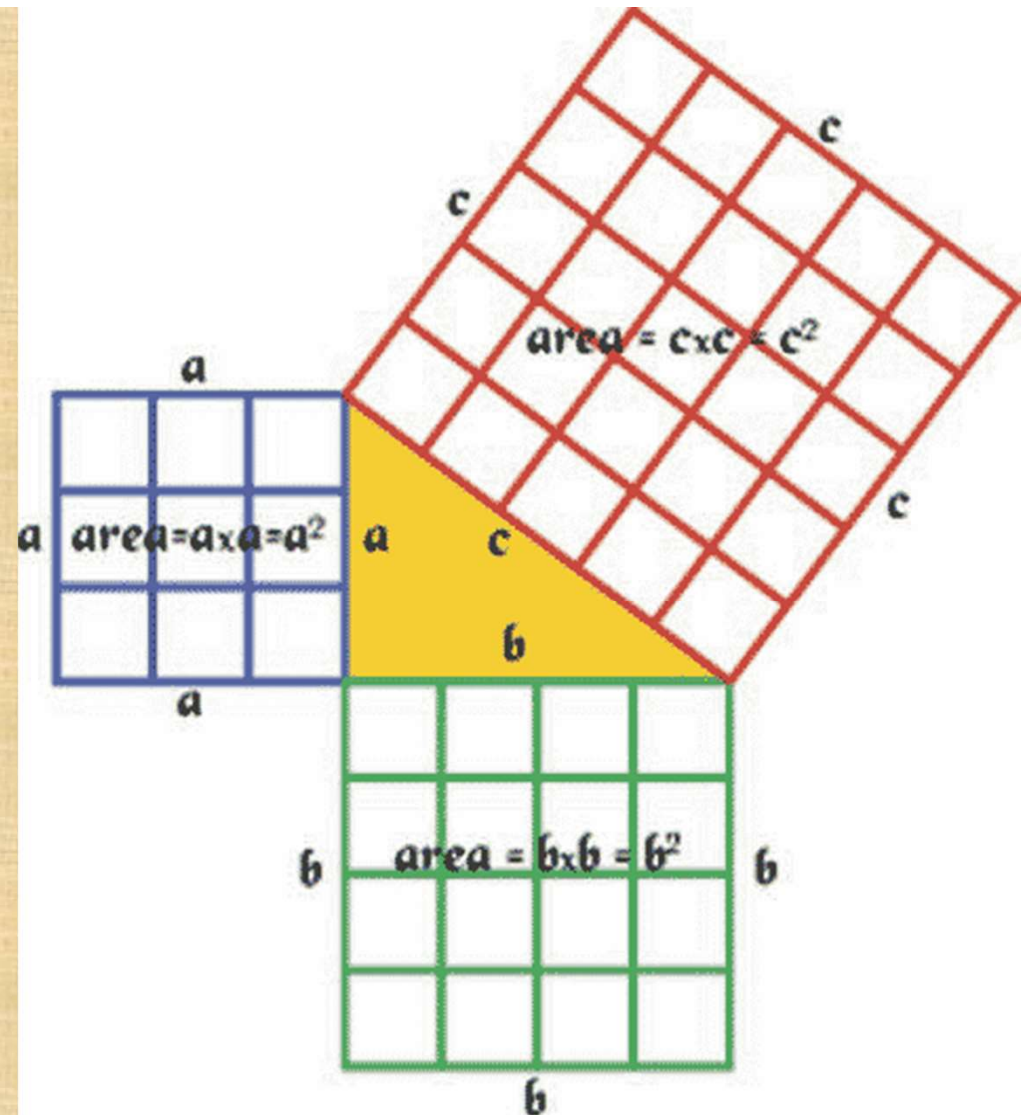
- The Greeks postulated some theories which could be tested.
- The most famous of these theories came in the form of geometrical statements and some algebraic formulas.
- Remember $a^2 + b^2 = c^2$? The theorem – it became an equation somewhat later – is attributed to Pythagoras (or his Academy) around 500 BC because of the proofs they developed.
- There is evidence that Babylonian, Indian, and Chinese mathematicians developed the same concept independently but did not state it as such.
- How is this theorem testable? Falsifiable?

Pythagoras was born in 570 BC and died in 495 BC (75 years). He lived and had his academy on the Greek island of Samos, near the coast of Turkey. This bust of Pythagoras is a Roman copy of the Greek original and resides in the Capitoline Museums in Rome. Pythagoras is always shown as a majestic and wise thinking person. Perhaps he was.



Was Pythagoras Right?

- Testable?
 - Yes, simply measure any triangle with the proper angles (the theorem only applies to triangles that include a right angle) and see if the area is correct.
- Falsifiable?
 - Yes, simply find a triangle where it is not true.
 - Or use a mathematical technique to show a conflicting result. Induction perhaps.



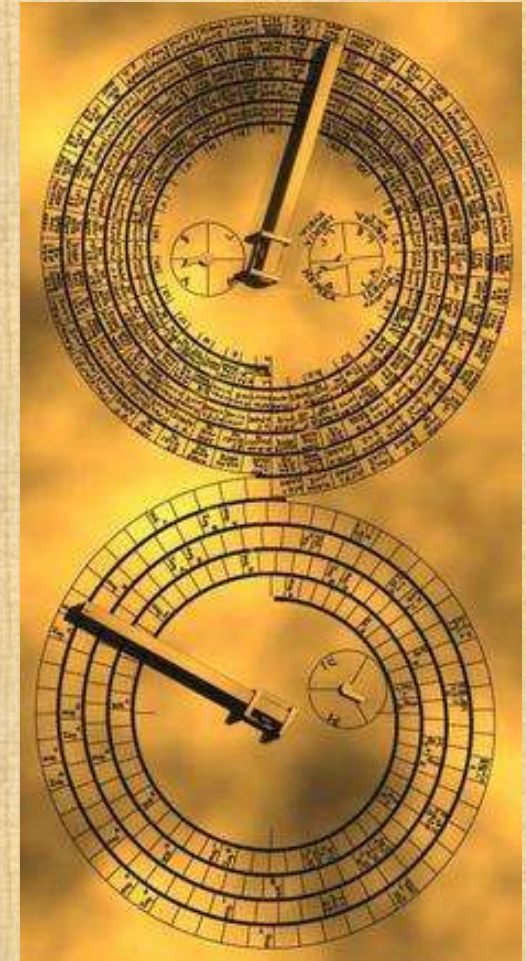
Pythagorean Theorem: $c^2 = a^2 + b^2$

The Greeks

- Ancient Greece slowly became a civilization starting around the 12th century BC.
- Classical Greek civilization flourished from about 480 BC (the Persian invasion) until 323 BC (the death of Alexander the Great) – about 250 years.
- The Romans appropriated much of Greek philosophy and these principles of civilization got exported around the Mediterranean Basin and to Europe as the Roman Empire expanded.
- Greek principles of civilization, government, and logical thought still form the basis of western society today.
- Greek philosophy, natural philosophy (science), and technology also flourished during the Classical Period.
- The Antikythera Mechanism is an example of this technology. It was an analog computer used to predict celestial events and eclipses for the calendar.



This was the condition of the Antikythera Mechanism when, in 1901, it was pulled from an ancient shipwreck off the island of Antikythera (called the island of Aigila in antiquity). It is an analog computer used (apparently) to predict the movement of celestial objects and eclipses. It contained at least 37 gears and was probably built around 100 BC.



These are some modern recreations of the Antikythera Mechanism. The actual Mechanism is displayed in the National Archaeological Museum in Athens. It has been somewhat cleaned but has not been “restored”.

The Famous Greeks

- Pythagoras of Samos was born in 570 BC and died in 495 BC. (75 years).
- Plato (about 428-348 BC) was a student of Socrates and founder of the first Academy. We believe that Plato's writings have survived intact. 2,400 years!
- Aristarchus of Samos lived between 310 BC and 230 BC. (80 years).
- Aristotle was born in northern Greece in 384 BC and died in 322 BC. (62 years). He was a student at Plato's academy.
- Claudius Ptolemy was a Greek who lived in the Egyptian city of Alexandria from about 100 AD to 170 AD.
- There were many others –at least as famous; ever heard of Homer? – but these are particularly associated with astronomy and cosmology.

Aristotle

- Aristotle was a Greek philosopher, born in northern Greece, and lived between 384 and 322 BC (62 years).
- He studied at Plato's Academy in Athens for about 20 years.
- He wrote the second – Plato was probably first but his was certainly the most comprehensive - system of what we now call Western philosophy.
- He wrote on a huge range of subjects: physics, biology, zoology, logic, ethics, music, theater, rhetoric, politics, government and languages. He also wrote poetry.
- We have at least 32 of his original works and know of many more by reference.
- When Plato died, Aristotle became the tutor for Alexander the Great (before he was Great) which gave him access to people, resources, and support otherwise not available.

This bust of Aristotle is a Roman copy in marble of a Greek bronze bust crafted by Lysipus around 330 BC. The alabaster mantle was added in the modern era. As always Aristotle is shown as wise, majestic, mostly perfect. As with other Greek statues, I remain jealous of his hair, not to mention his beard. This figure is in the Museo Nazionale Romano, Rome.





This is the famous painting of Aristotle contemplating a bust of Homer. It was painted in 1653 by Rembrandt for the well-known Sicilian art collector Antonio Ruffo and was purchased by the Metropolitan Museum of Art in New York in 1961.

The heavy gold chain hanging from Aristotle's shoulder holds a medallion paying homage to Alexander the Great. Aristotle is of course, dressed as a medieval aristocrat, not a Greek citizen.



This is site of the Lyceum that Aristotle established in Athens about 335 BC after he returned from Macedonia where he was tutoring Alexander.

Aristotle

- Aristotle set up his *Lyceum* in Athens in 335 BC and is thought to have composed most of his books there.
- Many of his dialogues were obviously flawed but revered due to the high respect he was accorded.
- Eventually he became estranged from Alexander (after he was Great). Not good. But Alexander died shortly after. Connection?
- As did most men of his social stature, Alexander had a wife, Pythias, a lover (mistress?), Herpyllis who bore him a son (his only?), and an eromenos, Palaephatus of Abydus.
- Unlike Socrates, he died a natural death, the year after Alexander.
- He left a will that requested he be buried next to his wife and appointed one of his students as executor.

Aristotle's Natural Philosophy

- Aristotle wrote a book on about everything but some of his most influential works were dealt with physics, astronomy, and cosmology.
- Empedocles had postulated that there four fundamental elements:
 - Earth – cold and dry. The concept of a solid.
 - Water – cold and wet. This is the concept of a liquid.
 - Air – which is hot and wet, a gas.
 - Fire – hot and dry. This became the modern idea of heat or energy.
- Aristotle accepted those and added
 - Aether – which is a divine substance that makes up all the heavenly spheres and heavenly bodies (stars and planets.)
- The concept of “perfection” was very important to the Greeks and to Aristotle. There was a perfect form for everything.

Aristotle's Natural Philosophy

- Aristotle was clear that “order” was the fundamental goal of nature or natural philosophy.
 - “nature is everywhere the cause of order.”
 - Aristotle, *Physics* VIII. 1
- Total Perfection was demanded by nature but was not achievable on earth.
- “Terrestrial spheres” were where humans lived (on earth) and were “corruptible.”
- “Celestial spheres” were the heavens and were moving but unchanging and perfect.
- Heavenly bodies were made of aether, weightless, and unchanging.

Aristotle's Natural Philosophy

- Terrestrial bodies were made up of varying proportions of the other four basic elements.
- Heavy materials such as rock or iron were mostly earth with small portions of the other three elements.
- Light substances were composed of mostly air with a very small portion of earth.
- The terrestrial sphere was made up of mostly water and earth and occupied the center of the universe.
- There were seven heavenly spheres – the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn.
- Beyond the heavenly spheres were the firmament of fixed stars (actually the eighth sphere.)

Aristotle's Cosmology

- The earth resided at the center of a static, unchanging, infinite universe.
- Heavenly bodies were perfect crystalline spheres made of luminous, unchanging and indestructible aether.
- All heavenly bodies occupied crystalline spheres and orbited the earth in perfect circles.
- The earth was also a sphere but made mostly of earth instead of aether.
- Much later, an additional sphere was added that contained the “Prime Mover” or God.
- All objects have a “natural place” toward which they move. The natural place of heavy objects is the center of the universe (the earth).
- The natural place of air is above the earth (but below the celestial spheres.)

Aristotle's Cosmology

- Aristotle's cosmology was adopted by early Christians, then enshrined in the doctrine of the Roman Church.
- This meant that Aristotle's ideas became *political* doctrine as well.
- It would be over a thousand years before anyone would seriously and publicly challenge Aristotle's description of the universe.
- Copernicus was the first to actually publish an alternative to the geocentric assumption in 1543.
- It was Galileo's observation of the moons of Jupiter in 1610 that opened the doors to re-evaluating Aristotle's cosmos.
- It was not until 1851 that Jean Bernard Léon Foucault directly demonstrated the rotation of the earth by using a pendulum.



This was the night sky in Ancient Greece. The orange dotted line is the path of the sun through the Zodiac. Ursula Minor (Little Dipper or Little Bear in this image) includes the North Star at the end of its handle. The Big Dipper comprises the four brightest stars in Ursula Major in the upper right.

Eratosthenes

- Eratosthenes was a Greek scientist who followed Aristotle.
- He lived in Cyrene, Libya, from about 276 until 194 BC.
- He was the first person (known) to have actually measured the size of the spherical earth, which was assumed to be the case. He got pretty close.
- He knew that the sun illuminated the bottom of a well near Syene (now Aswan) in Egypt (southeast of Alexandria) on the summer solstice (June 21st on the Gregorian calendar.)
- This meant that the sun was directly overhead at that time.
- Aaahhh! Eratosthenes knew the distance to Syene was about 500 miles. He measured the angle of a shadow at Alexandria at about 7.2° or $1/50^{\text{th}}$ of a full circle. So the circumference of the earth is 50×500 or 25,000 miles. More or less.

Eratosthenes is also credited with inventing (developing? building?) the armillary sphere in the West. An armillary sphere is a model of objects in the sky or the celestial sphere, consisting of a spherical framework of rings, centered on the earth or the Sun. Other astronomically important features such as the ecliptic are often included.

I believe this armillary is a modern construction and may be displayed in the Museum of Science History in Cambridge.



Claudius Ptolemaeus

- Ptolemy lived in the Greek province of Egypt from about 90 to 168 AD. He was of Greek descent and lived in the city of Alexandria.
- Ptolemy was quite the polymath (yes, a Greek word) and wrote on astronomy, math, geography, and harmonics (music).
- His book now known as the *Almagest* (this word is a hybrid of Arabic and Greek) sought to present empirical arguments for Aristotle's cosmology.
- He assumes that all the apparently irregular movements of the celestial bodies are still based on regular, uniform circular motion.
- Each planet is moved by two spheres: one is an epicycle. The other is its deferent (a circle whose center is slightly off from the center of the earth.)
- The combination of these two spheres allowed Ptolemy to refine the older Greek system and better predict celestial motion.

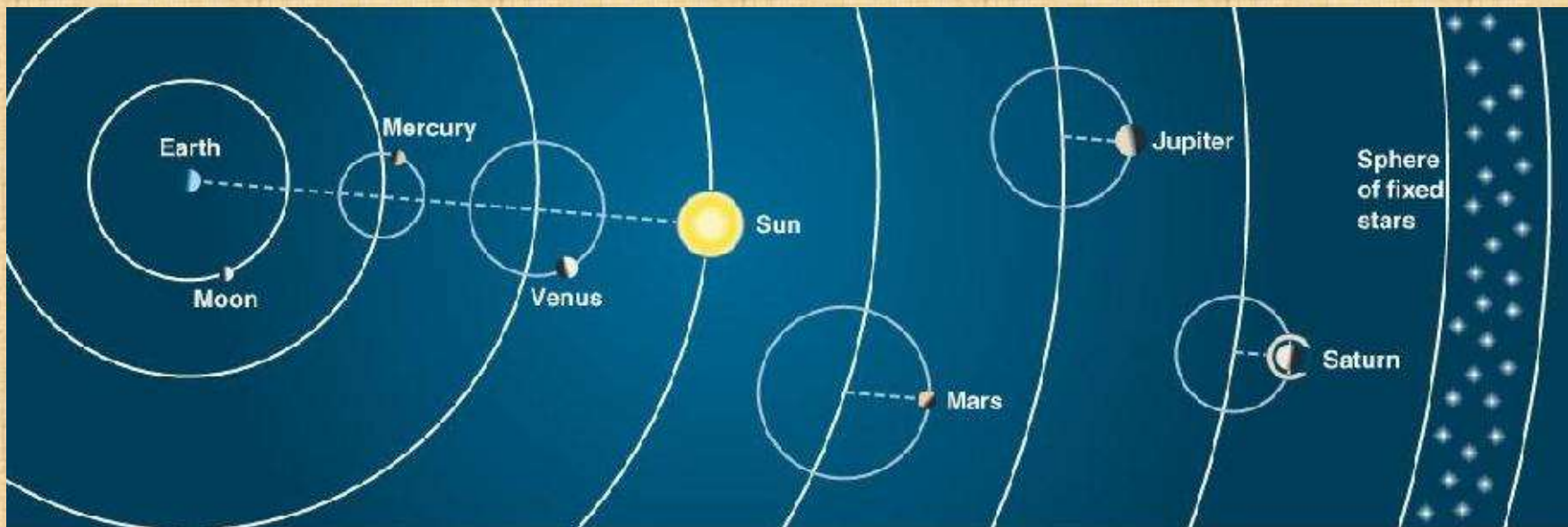


This sketch of Ptolemy obviously dates from the Middle Ages in central Europe. The publication of Copernicus' heliocentric theory and Galileo's observations of the celestial objects were not known before the moons of Jupiter stimulated increased interest in all the ancient Greek manuscripts. Some of these documents were preserved in monasteries and many others were translated from the Arabic while the Moors controlled parts of Europe (from about 711 until 1492.)

Claudius Ptolemaeus

Ptolemy's work (and Aristotle's) became the accepted cosmological theory by "science" and the Church for over a thousand years.

- Ptolemy was highly regarded in the Islamic world partly because of his work *Astrological Influences* which declared astrology to be legitimate and attempted to place astrology on a sound, "scientific" basis.
- This book described the physical effects of the position of the heavenly bodies on life on earth. He tried to reconcile the practice of astrology with the concepts of Aristotle.
- Ptolemy's works come to us through Arab references and recreations.



This is a close-up of the heavenly bodies and their epicycles. Note the sphere of fixed stars outside the orbit of Saturn. The size of the orbits and the size of the epicycles are not to scale.

Greek Cosmology

- Recall that the Greeks did very few experiments and so two principles informed the Greek view of the world and the universe we live in.
- The first was perfection. If it was in the realm of the gods, it had to be perfect. And there was no possibility of corruption or decay.
- The second was order. Nature provided an orderly universe, and this was one of the reasons experiments were not needed. Disorder was imperfection.
- When it was all thought out, the heavens were perfect and perfectly ordered.