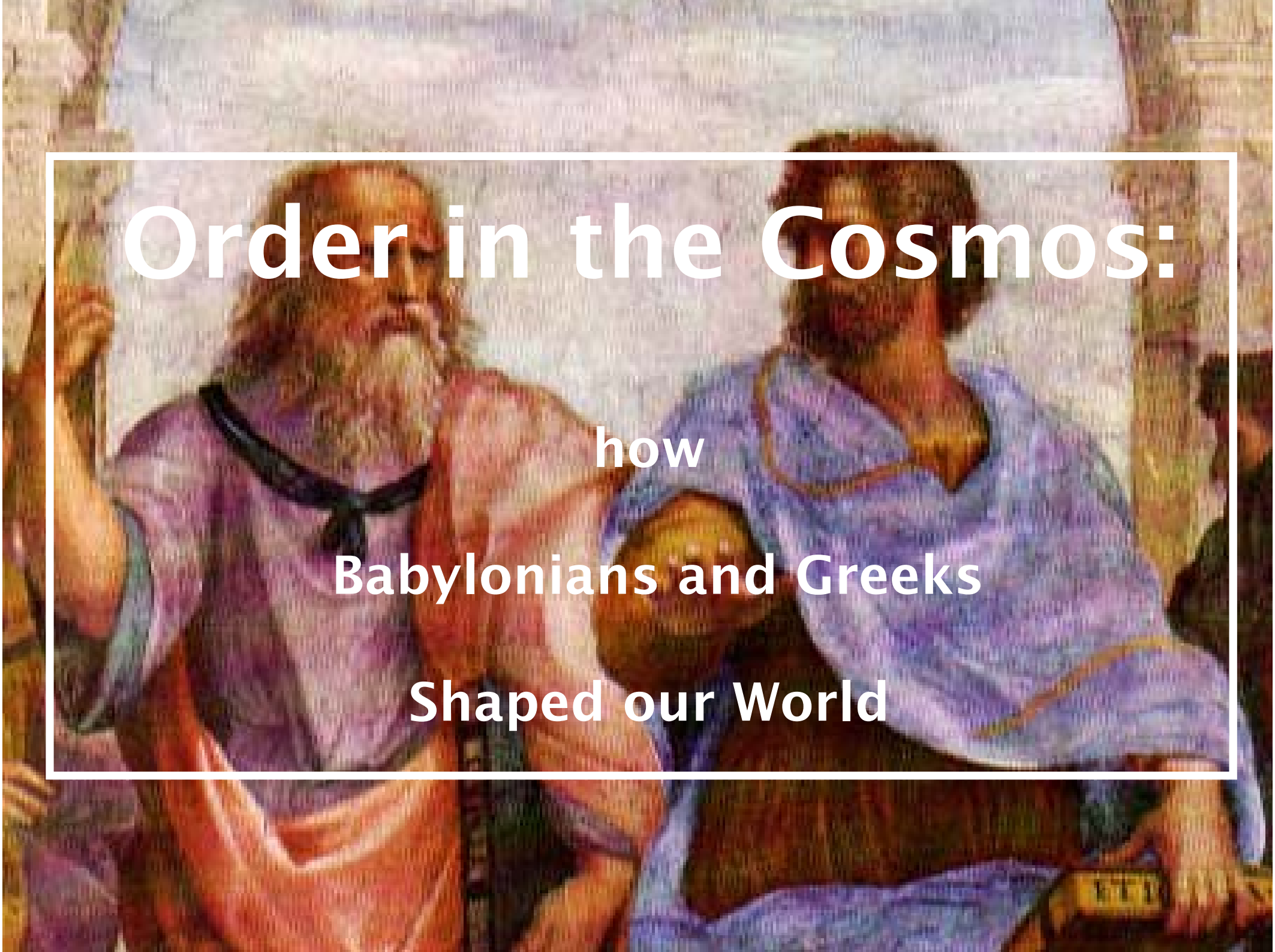
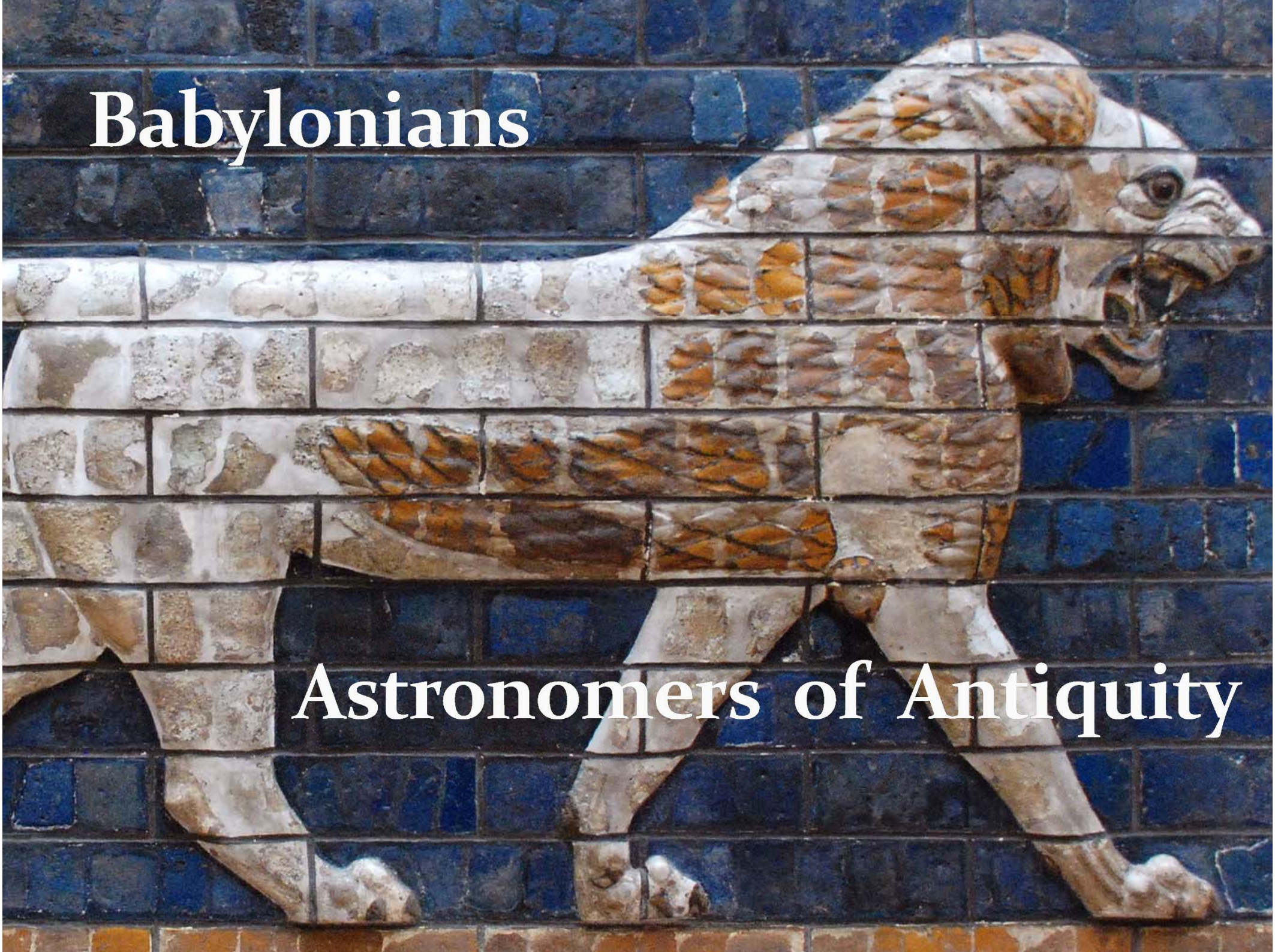


Order in the Cosmos:

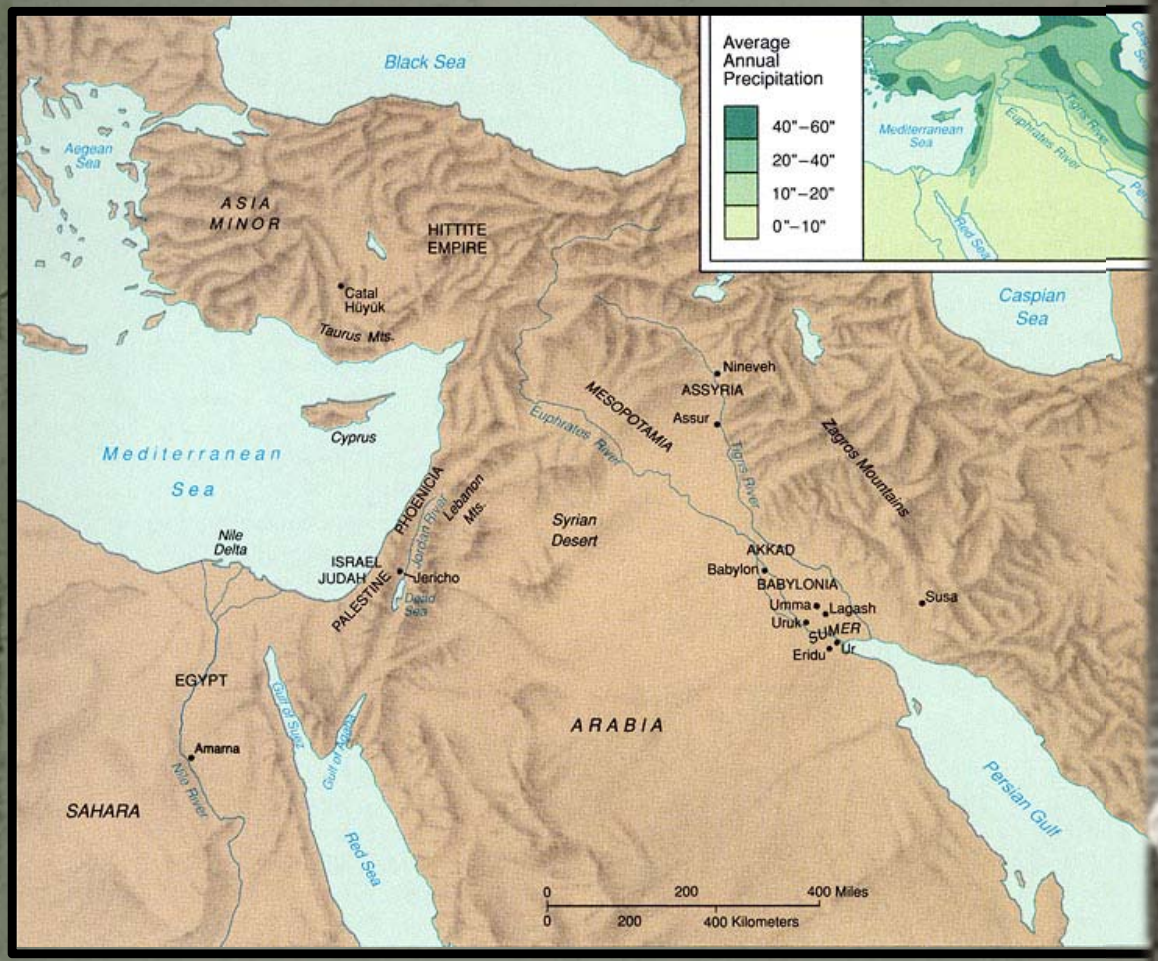
how

Babylonians and Greeks

Shaped our World


Babylonians
Astronomers of Antiquity

Babylonian Astronomy



Mesopotamia = "land of two rivers"

land between the rivers Euphrates & Tigris

Babylonian Astronomy

Two distinct periods of flowering:

- **Old Babylonian astronomy:**
  during and after
  First Babylonian dynasty (Hammurabi) 1830-1531 BCE

- **New Babylonian/Chaldean astronomy:**

Neo-Babylonian	(Nebuchadnezzar)	626-539 BCE
Medo-Persian		539-331 BCE
Seleucid		335-141 BCE
Parthian		129 BCE-224 AD

Babylonian Astronomy

timeline
Babylonian astronomy

Evans 1998

DATE	ASTRONOMY	GENERAL HISTORY
Old Babylonian Period		Reign of Hammurapi
1700 BC		
		Enuma Elish
1600	Venus observations	
Kassite Dynasty		
1500		
1400		
	Enuma Anu Enlil	
1300		
1200		
Six Dynasties		
1100	Oldest rectangular astrolabe	
1000		
900		
800		
	Eclipse records	Reign of Nabonassar
700 Assyrian Rule		
	MUL.APIN	Reign of Ashurbanipal
600 Chaldacan Dynasty	Oldest astronomical diaries	
Persian Rule		
500	Equal-sign zodiac	
	Regularization of calendar	
400		
		Alexander takes Babylon
Seleucid Dynasty		
300	Planetary theory	
200 BC		
100 Parthian Rule		

Babylonian Astronomy

Babylonian Astronomers:

- most consistent, systematic and thorough astronomical observers of antiquity
- First to recognize periodicity astronomical phenomena (e.g. eclipses !), and apply mathematical techniques for predictions
- Systematically observed and recorded the heavens:
  - Records spanning many centuries (> millennium)
  - Archives of cuneiform tablets
  - Famous Examples:

Enuma Anu Enlil	68-70 tablets	Kassite period (1650-1150)
	tablet 63:	Venus tablet of Ammisaduga
MUL.APIN		700 BCE
		oldest copy: 686 BCE

Astronomical Texts

- Several types of astronomical texts in Babylonian astronomy.

- Four principal types:

  1) astronomical diaries
  2) goal year texts
  3) ephemerides
  4) procedure texts

- Ephemerides:
  - listing of positions of planets and their meaning (eg. extreme points retrograde path)
  - predictive: positions based on calculations (based on scheme)
  - ephemerides for Moon
  - ephemerides for planets

- Procedure texts:
  description of procedure(s) to calculate ephemerides

ENUMA ANU ENLIL

Old text, probably Kassite period
(1595-1157 BCE)

- A major series of 68 or 70 tablets
- dealing with Babylonian astrology.

- bulk is a substantial collection of omens, estimated to number between 6500 and 7000,

- interpreting a wide variety of celestial and atmospheric phenomena in terms relevant to the king and state

ENUMA ANU ENLIL

2. If with it a cloudbank lies on the right of the sun: the trade in barley and straw will expand.

3. If with it a cloudbank lies to the left of the sun: misfortune

4. If with it a cloudbank lies in front of the sun: the king of Elam [will die]

5. If with it a cloudbank lies behind the sun: the king of the Gutians [will die]

6. If in Pit babi the sun is surrounded by a halo in the morning: there will be a severe heat in the country and the Lamashtu-demon will attack the country.

7. If with it a cloudbank lies to the right of the sun: the king of Eshnunna will die.

8. If with it a cloudbank lies to the left of the sun: the king of Subartu will die and his dynasty will come to an end.

9. If with it a cloudbank lies in front of the sun: the rains from heaven (and) the floods from the depths will dry up.

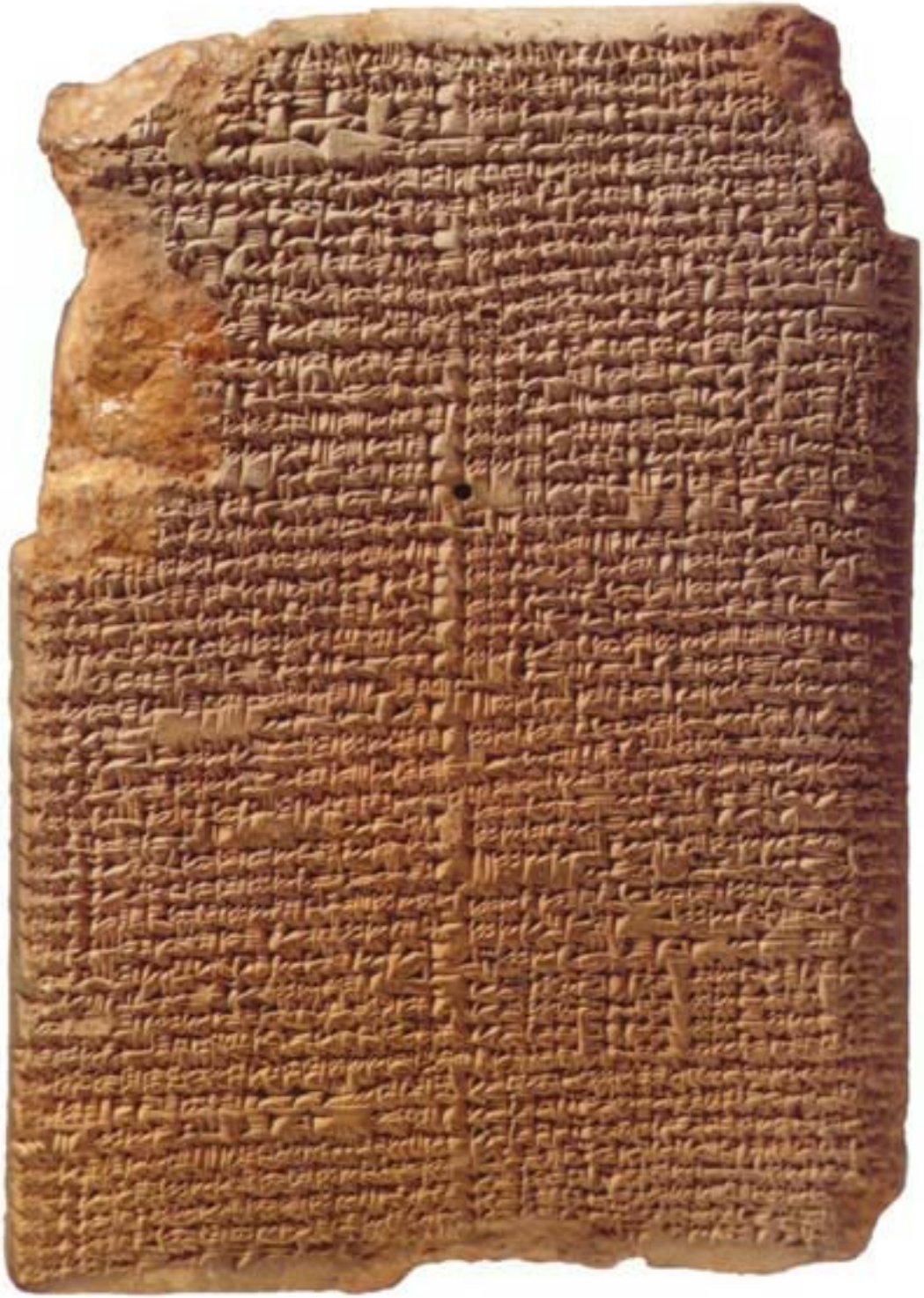
10. If with it a cloudbank lies behind the sun: the harvest of the land will not be brought in.

MUL.APIN

Around 700 BCE,
after king Nabonassar

- summary of astronomical knowledge (Neugebauer)
- Parapegma (Evans)

- **Catalogue of stars & constellations**
- **Schemes**
  heliacal risings/settings planets
- **Measurements lengths daylight**
- **66 stars**



Chaldean Astronomy

- Most Chaldean astronomers strictly concerned with ephemerides, not with theoretical models
- Predictive planetary models empirical, usually sophisticated arithmetical/numerical schemes
- Models do not involve geometry & cosmology (that's the Greeks !)
- Discovery (lunar & solar) eclipse cycles & Saros period

Babylonian Astronomy

Lasting Astronomical Influence:

- Constellation Names
- Zodiac
- Degree - unit angle
- Sexagesimal number system:
  circle: 360 degrees
  degree: 60 minutes

  place value number system
  (crucial for Greek science !)
- Eclipse Observations & Periods
- Synodic, Siderial, Draconic, Anomalistic months
- and ...

Magi: Chaldean Astronomers

Babylonian Astronomy

Transmission:

- Transfer of Babylonian astronomical knowledge essential for Hellenistic astronomy

- Alexander the Great:

orders translation astronomical records, under supervision Callisthenes of Olynthus,

to be sent to his uncle Aristoteles

- Direct Contacts:
  e.g. Hipparchus

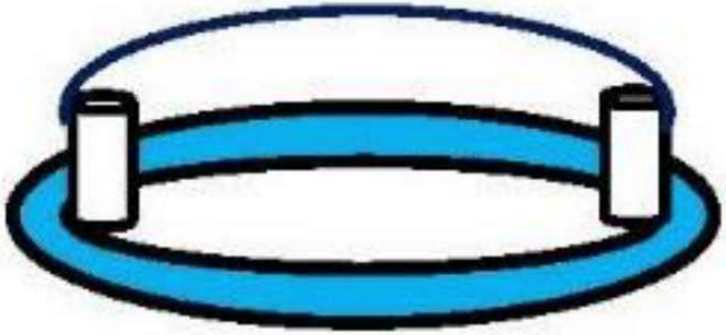
Reason & the Cosmos

Greek Cosmology

Timeline & Overview

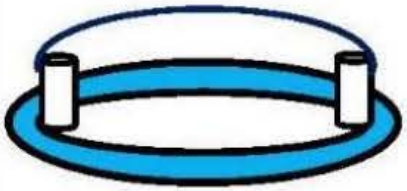
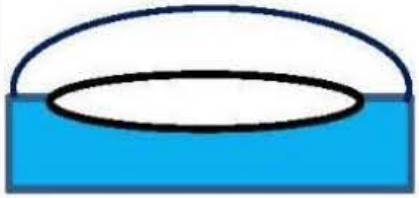
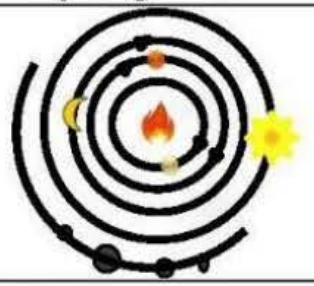
Greek Cosmology

8th Century BCE: mythical cosmology

8e eeuw v.Chr.
Mythische cosmologie
Homerus & Hesiodus
Wereldbeeld 
• Aarde platte schijf • Omringd door rivier • Hemel op pilaren

Homerus and guide
W-A Bouguereau

6th Century BCE:
Pre-Socratic Ionian Natural Philosophers

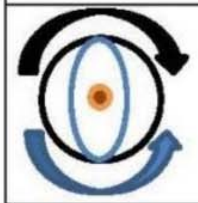
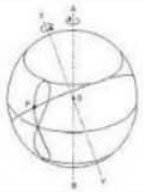
8e eeuw v.Chr.	6e eeuw v.Chr. Natuurfilosofen		
Mythische cosmologie			
Homerus & Hesiodus	**Thales**	**Anaximander**	**Pythagoras**
Wereldbeeld 			
• Aarde platte schijf • Omringd door rivier • Hemel op pilaren	• Aarde platte schijf • Rust volledig op water • Oerelement water	• Aarde platte schijf • Vrijhangend, geometrisch • Lucht, mist, vuur • Oerelement grenzeloos	• Aarde bol • Centraal vuur, aarde, anti-aarde, planeten • Oerelement getallen

5th Century BCE: Pre-Socratic Natural Philosophers

8e eeuw v.Chr.	6e eeuw v.Chr. Natuurfilosofen			5e eeuw v.Chr.		
Mythische cosmologie						
Homerus & Hesiodus	**Thales**	**Anaximander**	**Pythagoras**	**Anaxagoras**	**Empedokles**	**Leukippos & Demokritos**
Wereldbeeld 						
•Aarde platte schijf •Omringd door rivier •Hemel op pilaren	•Aarde platte schijf •Rust volledig op water •Oerelement water	•Aarde platte schijf •Vrijhangend, geometrisch •Lucht, mist, vuur •Oerelement grenzeloos	•Aarde bol •Centraal vuur, aarde, anti-aarde, planeten •Oerelement getallen	•Geen oerelementen •Alles bevat een deel van al het andere •Hemellichamen niet goddelijk	•4 oerelementen: aarde, lucht, vuur, water •2 eigenschappen: warm, koud •Alles bestaat uit verhouding van elementen met de 2 eigenschappen (4^2= 16 mogelijkheden)	•Alles bestaat uit atomen •Atomen zijn ondeelbaar en onveranderlijk, maar verschillen in vorm en grootte

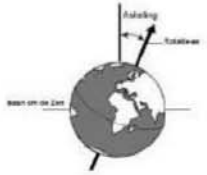
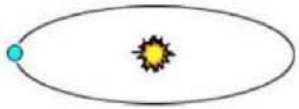
4th Century BCE: from Plato to Aristoteles

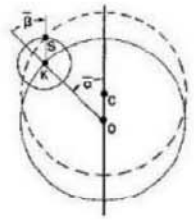
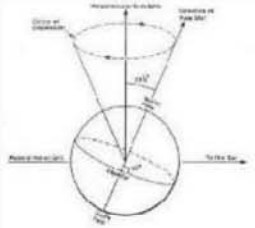
8e eeuw v.Chr.	6e eeuw v.Chr.		
	Natuurfilosofen		
Mythische cosmologie			
Homerus & Hesiodus	**Thales**	**Anaximander**	**Pythagoras**
Wereldbeeld				
•Aarde platte schijf •Omringd door rivier •Hemel op pilaren	•Aarde platte schijf •Rust volledig op water •Oerelement water	•Aarde platte schijf •Vrijhangend, geometrisch •Lucht, mist, vuur •Oerelement grenzeloos	•Aarde bol •Centraal vuur, aarde, anti-aarde, planeten •Oerelement getallen •geoexcentrisch wereldbeeld

4e eeuw v.Chr.			
Plato	**Eudoxos**	**Callippus**	**Aristoteles**
			
Geometrisch wereldbeeld			Mechanisch wereldbeeld
•Armillarium •Planeten niet in model opgenomen	•Hippopede •Planeten bewegen volgens combinatie van cirkels	•Calliptische cyclus •verbetering model Eudoxos door extra ringen	•4 elementen van Empedokles en voegde 5e toe: aether

5e eeuw v.Chr.		
Anaxagoras	**Empedokles**	**Leukippos & Demokritos**
•Geen oerelementen •Alles bevat een deel van al het andere •Hemellichamen niet goddelijk	•4 oerelementen: aarde, lucht, vuur, water •2 eigenschappen: warm, koud •Alles bestaat uit verhouding van elementen met de 2 eigenschappen	•Alles bestaat uit atomen •Atomen zijn ondeelbaar en onveranderlijk, maar verschillen in vorm en grootte

3rd Century BCE – 1st Century AD: the Hellenistic Scientific Revolution

4e eeuw v.Chr.	3e eeuw v.Chr.		2e eeuw v.Chr.	2e – 1e eeuw v.Chr.
Aristoteles	**Heracleides**	**Aristarchus**	**Seleucus**	
				
Mechanisch wereldbeeld	• Aarde draait om as • Venus en Mercurius draaien om de zon	Heliocentrisme	• Verdedigt als enige heliocentrisme	

Erastothenes	Appolonius van Perga	Hipparchus	Posidonius	Apollonius van Myndos
				
• berekening omtrek aarde	• Deferent –epicyclus • Excentrisch • Maan-theorie	• Precessie • Excentrische theorieën	• berekening afstand zon-aarde • maakte machine die bewegingen zon, maan en planeten weergaf	•Kometen in excentrische baan rond de aarde

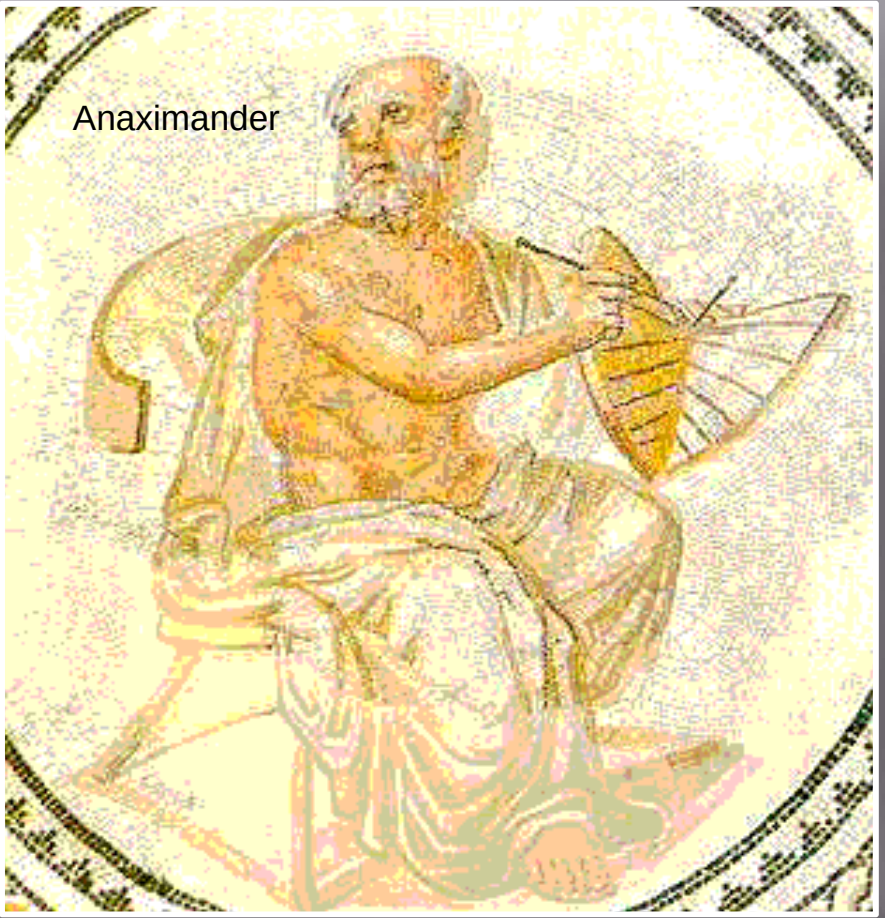
Ionia

Natural Philosophers

Ionia, 6th century B.C.

Phase transition in human history: the mythical world obsolete

… the Ionian coast, 6th century B.C., *regularities and symmetries* in nature recognized as keys to the cosmos …



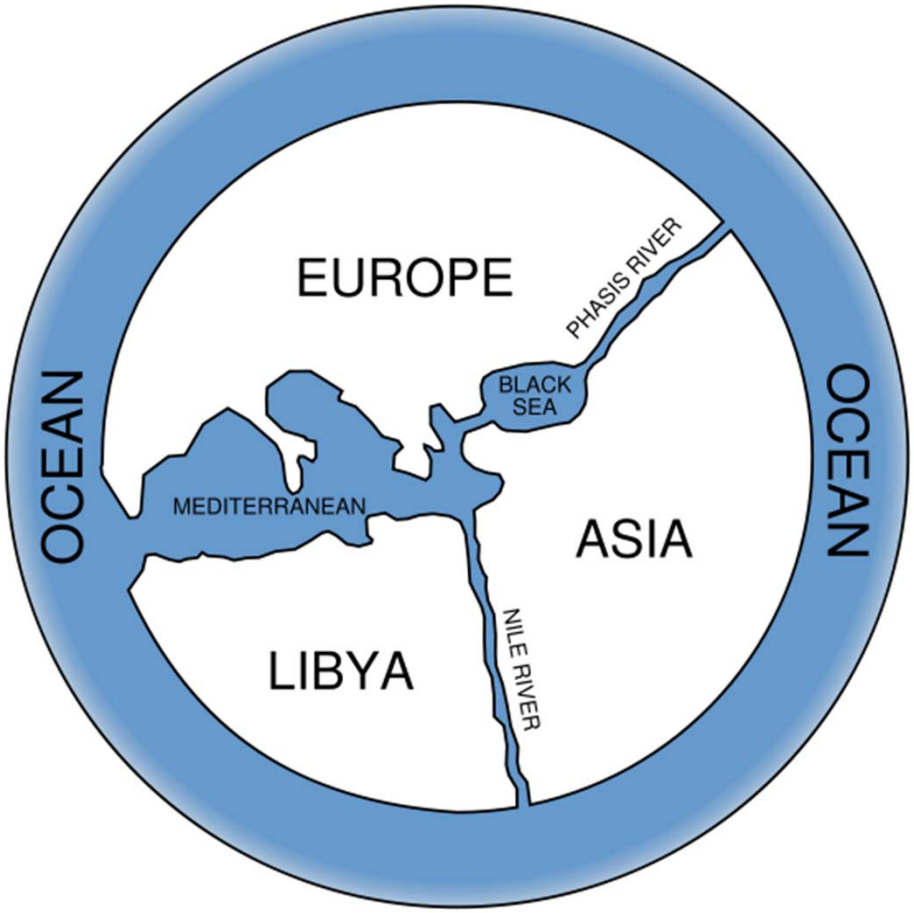
Mathematics as natural language of cosmos

➔ Physical cosmos modelled after *ideal form*, encrypted in concepts of *geometry*

… Anaximander of Miletus: the Apeiron
Pythagoras of Samos: music of spheres
Plato: Platonic solids

Anaximander

the First Cosmologist (Miletus, 610-546 BCE)



Cartography of Anaximander

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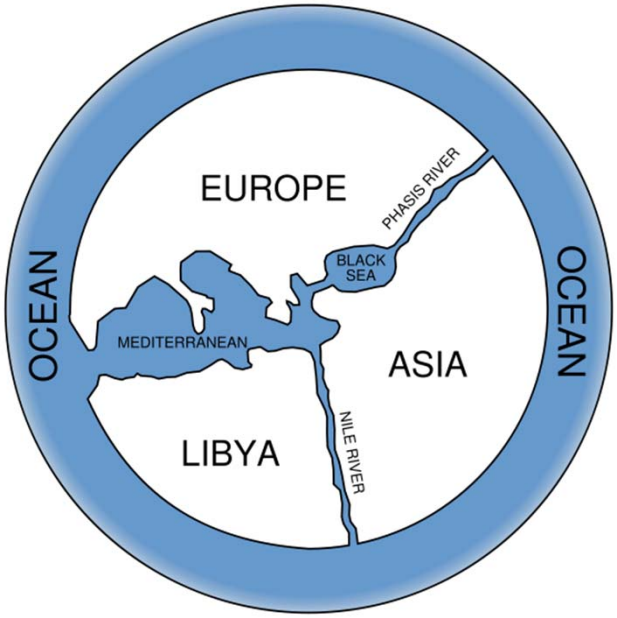
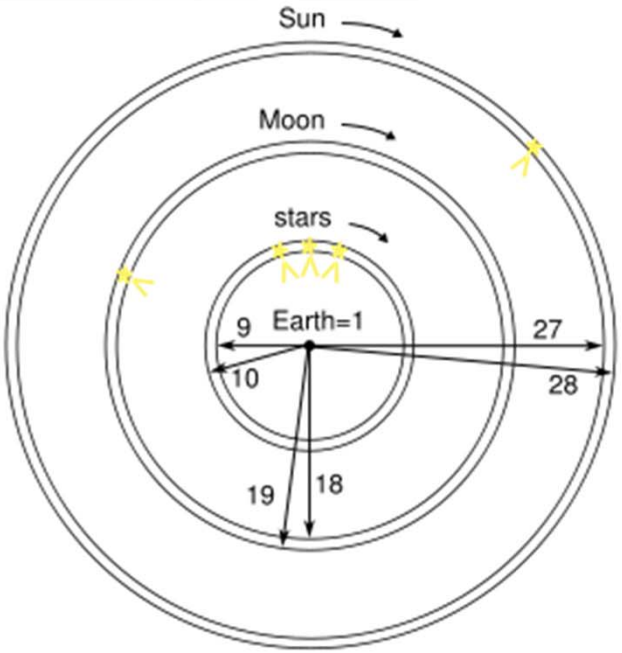


Cosmology of Anaximander:

- Earth floats free without falling
- Karl Popper:
  "one of the most boldest, most revolutionary, and most portentous ideas in the whole history of human thinking"

Anaximander

founder scientific Astronomy and Cosmology (Miletus, 610-546 BCE)



Cosmology Anaximander

- heavenly sphere is a ring of fire
- invisible, surrounded by fog
- Heavenly bodies part of ring, visible through openings through fog.
- ring for the Moon
- ring for the Sun

Anaximander

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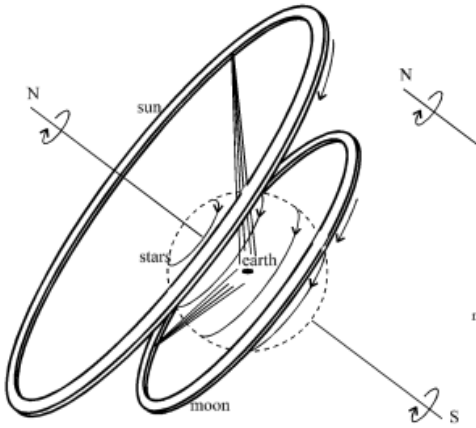
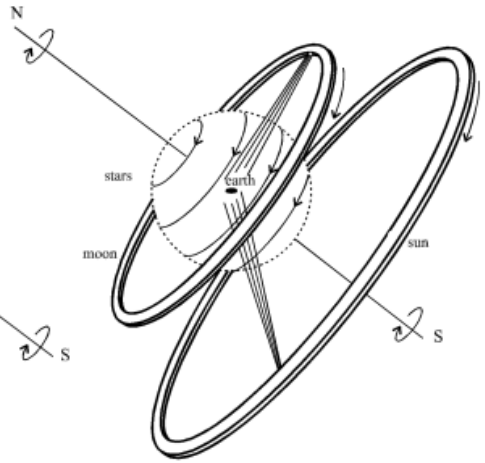


Daytime in summer



Nighttime in winter

Cosmology Anaximander

- Ring model could not explain all observations
- Anaximander preferred symmetry & number 3
- diameter Sun ring = 27 x diameter Earth
- diameter Moon ring = 18 x diameter Earth
- diameter stellar ring = 9 x diameter Earth

Anaximander

founder scientific Astronomy and Cosmology (Miletus, 610-546 BCE)

"The Apeiron, from which the elements [are formed], is something that is different"

The idea of Apeiron, the "infinite" or "limitless" out of which the world emerged, is suggested to be close to our current idea of vacuum energy

Classical Greek Cosmology

Plato & Aristoteles

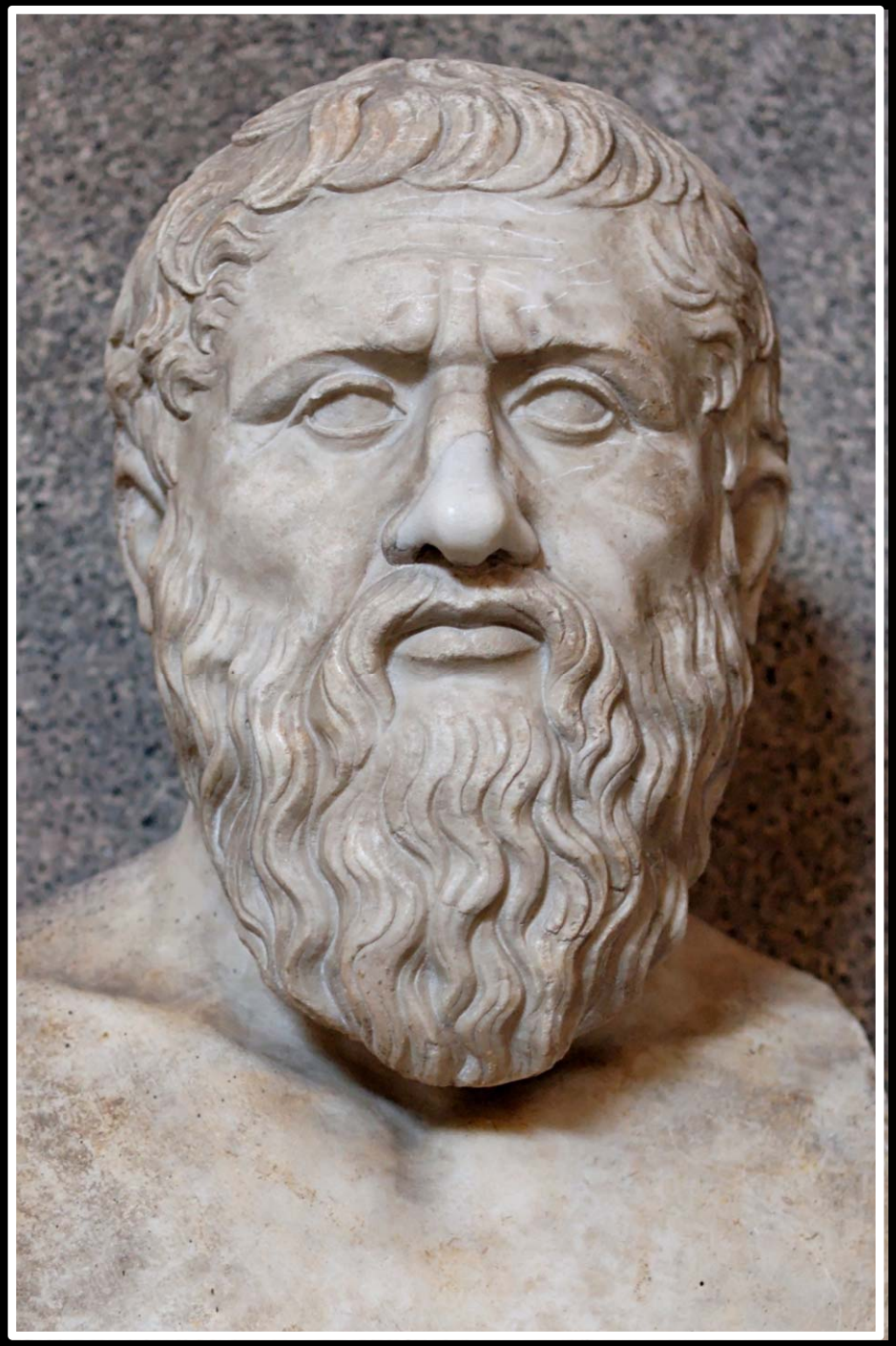
Plato

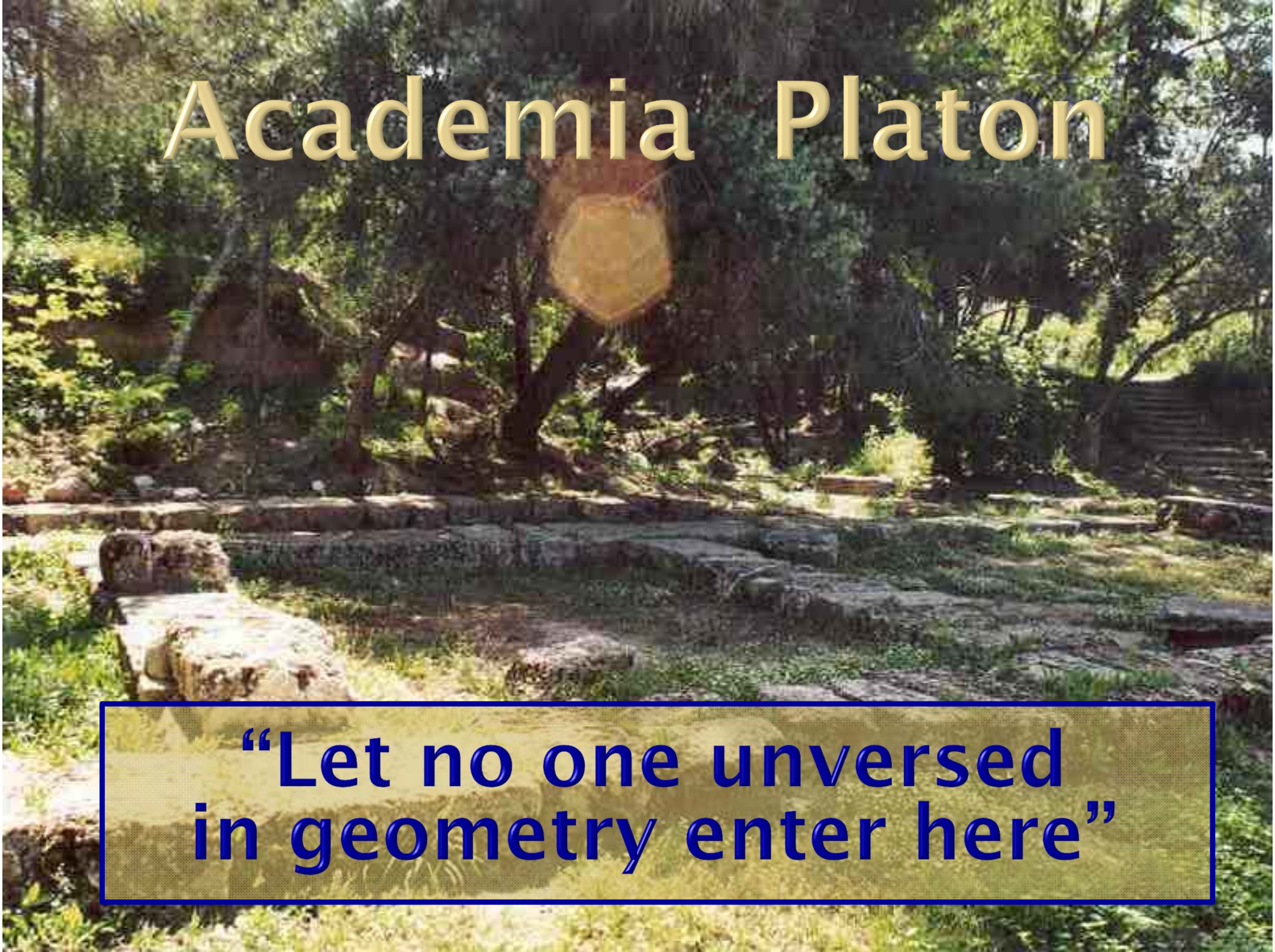
(Athens,
428-348 BCE)

Geometry as organizing principle of the world

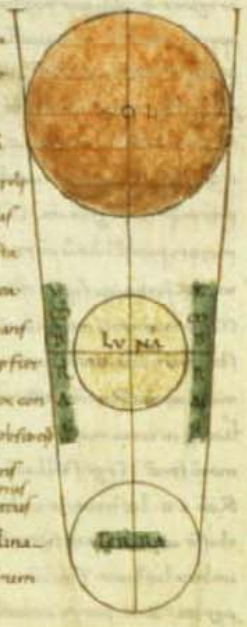
Founded Academy, Athens

- **Philosophy**
- **Mathematics**
- **Philosophical Dialogues**




Academia Platon
"Let no one unversed
in geometry enter here"

Timaeus: Plato's Cosmology



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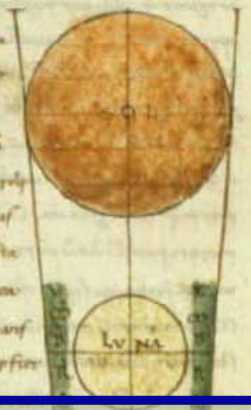


Plato's Cosmic Scheme:

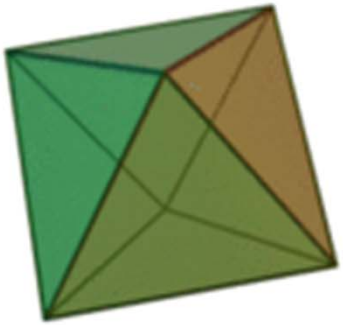
- ***Demiurge*, divine craftsman, *is a mathematician:***
- ***Universe constructed according to geometric principles***

Platonic Solids

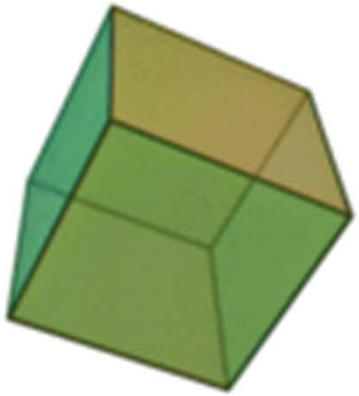
the Five Platonic solids

- there are only five convex regular polyhedra !
- Plato identified them with the cosmos and its constituents

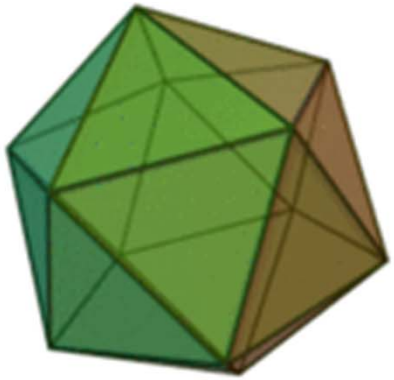
Tetrahedron:
fire



Octahedron:
air



Cube:
earth



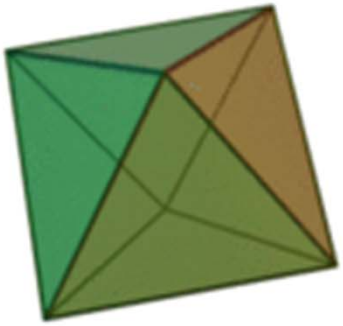
Icosahedron:
water

Platonic Solids

Dodecahedron ⟷ Quintessence

of which the Cosmos itself is made:
"the stuff for embroidering
the constellations on the heavens"

Tetrahedron:
fire



Octahedron:
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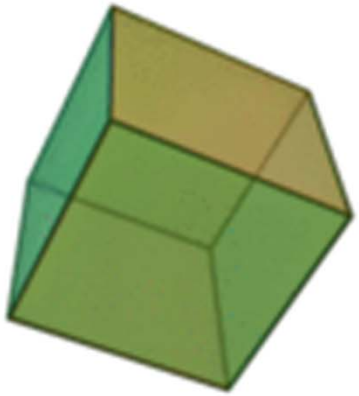
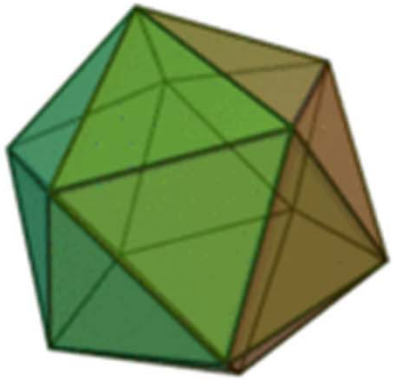


Cube:
earth



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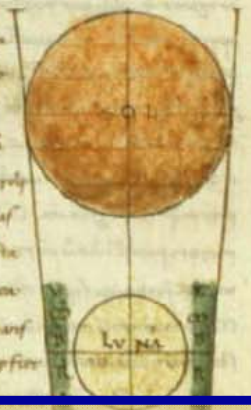
Timaeus: Plato's Cosmology



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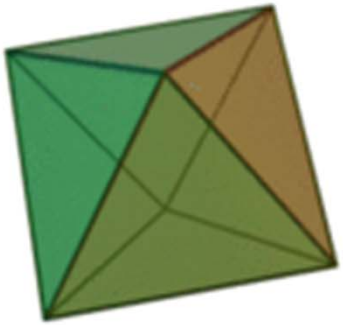
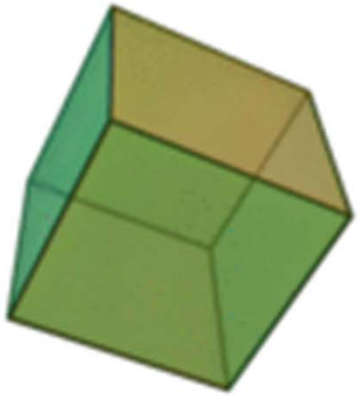
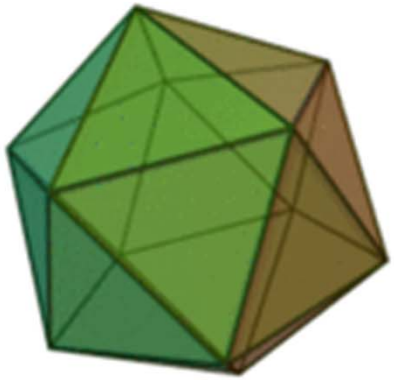


Octahedron:
air



Cube:
earth



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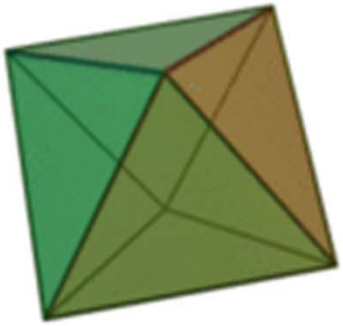
Platonic Solids

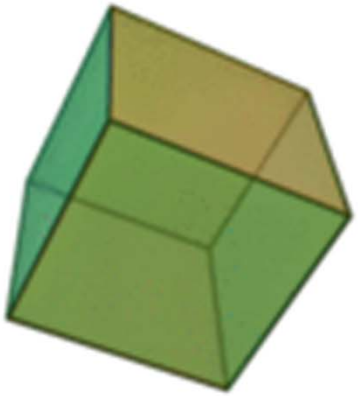
Dodecahedron ⟷ Quintessence

of which the Cosmos itself is made:
"the stuff for embroidering
the constellations on the heavens"

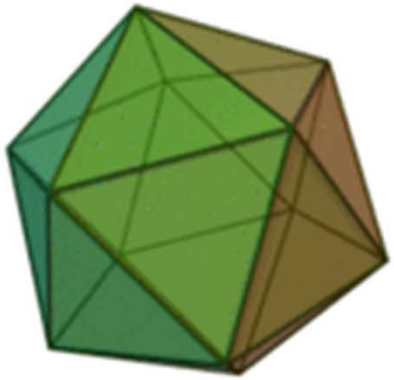
Tetrahedron:
fire



Octahedron:
air



Cube:
earth



Icosahedron:
water

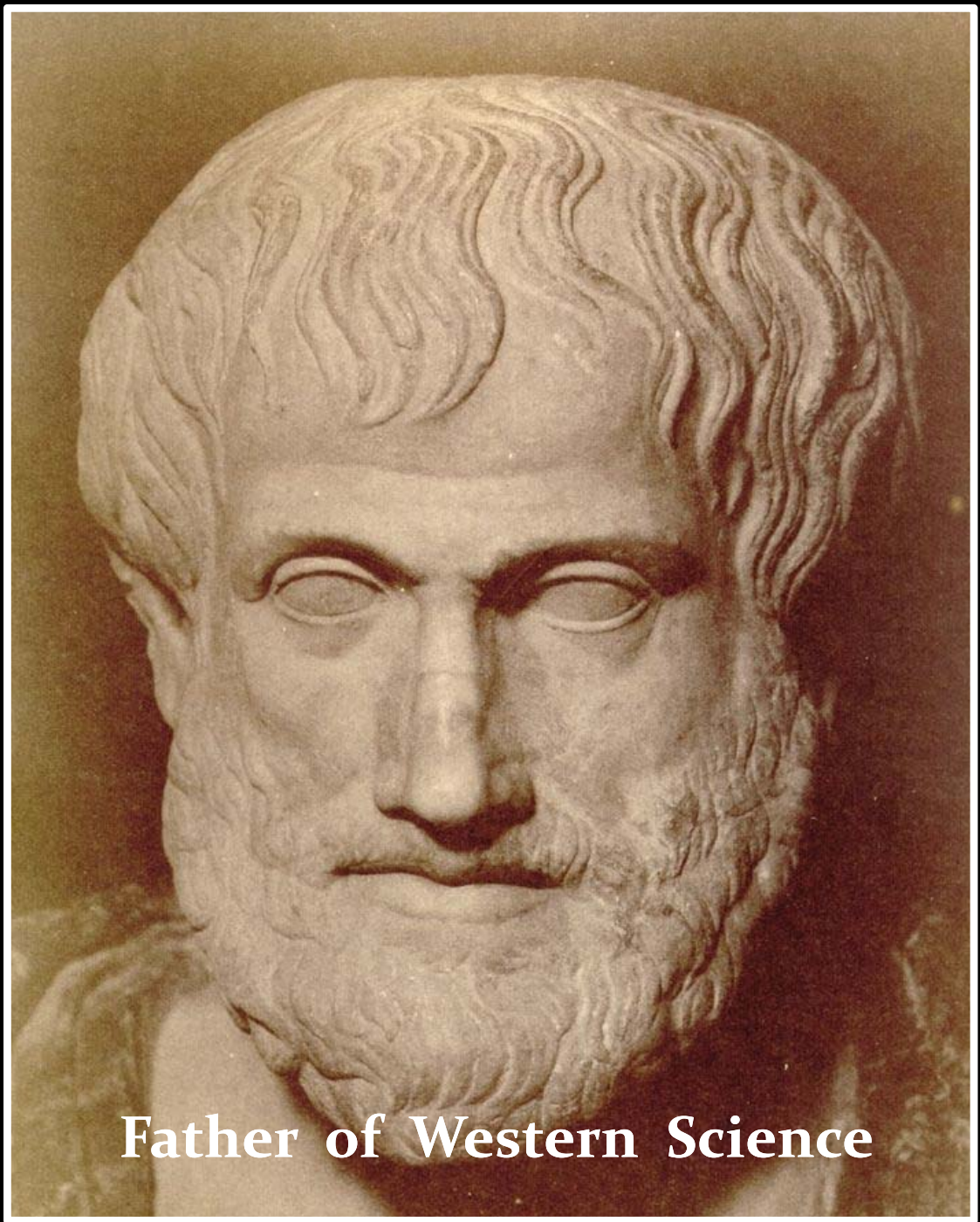
Aristoteles

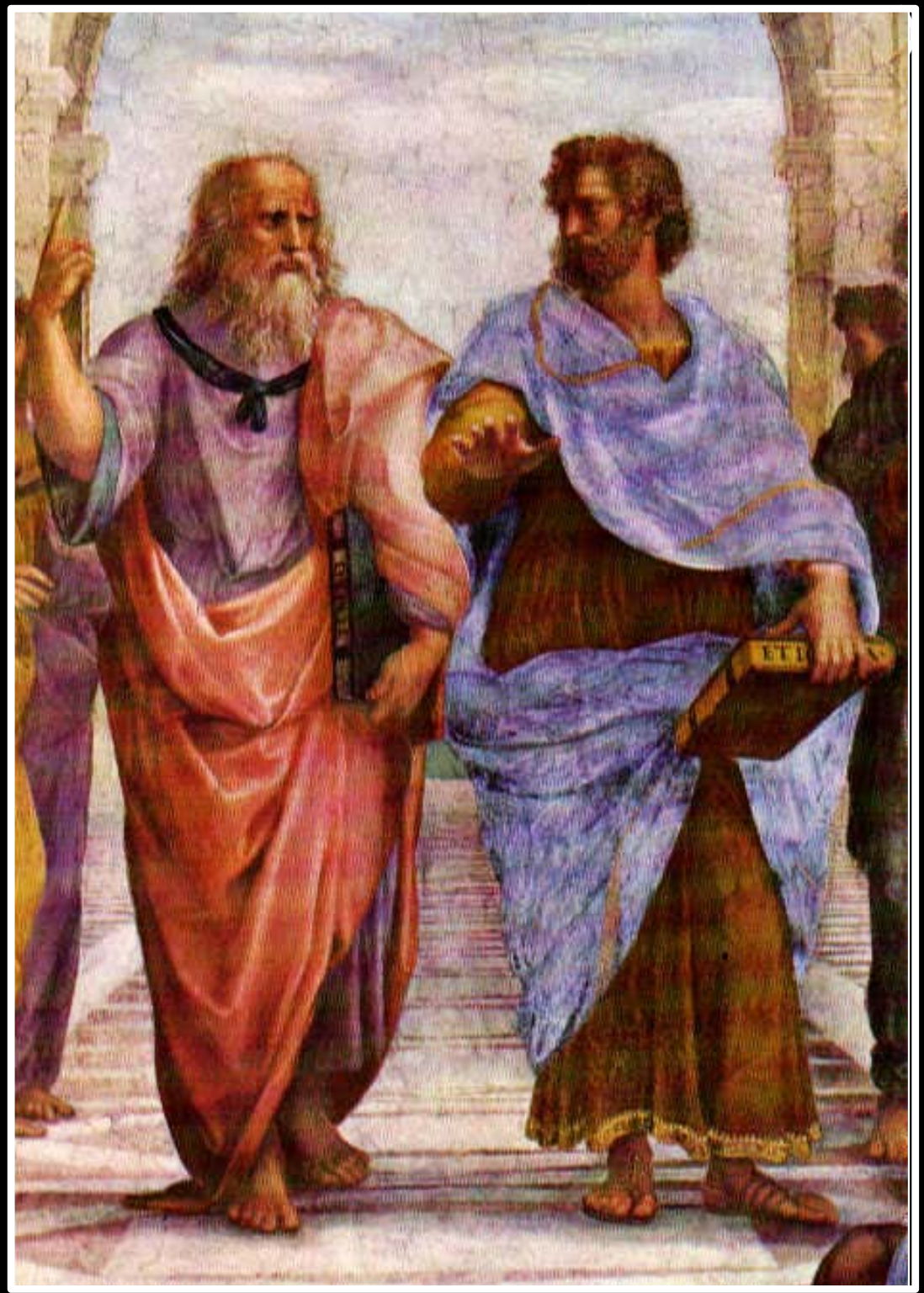
(Chalcidice-Athens, 384-322 BCE)

- "Aristotle was the first genuine scientist in history ... every scientist is in his debt"

Physics, Metaphysics,Astronomy,
Poetry, Theater, Music,
Logic, Rhetoric, Ethics,
Politics, Government,
Geology, Biology, Zoology

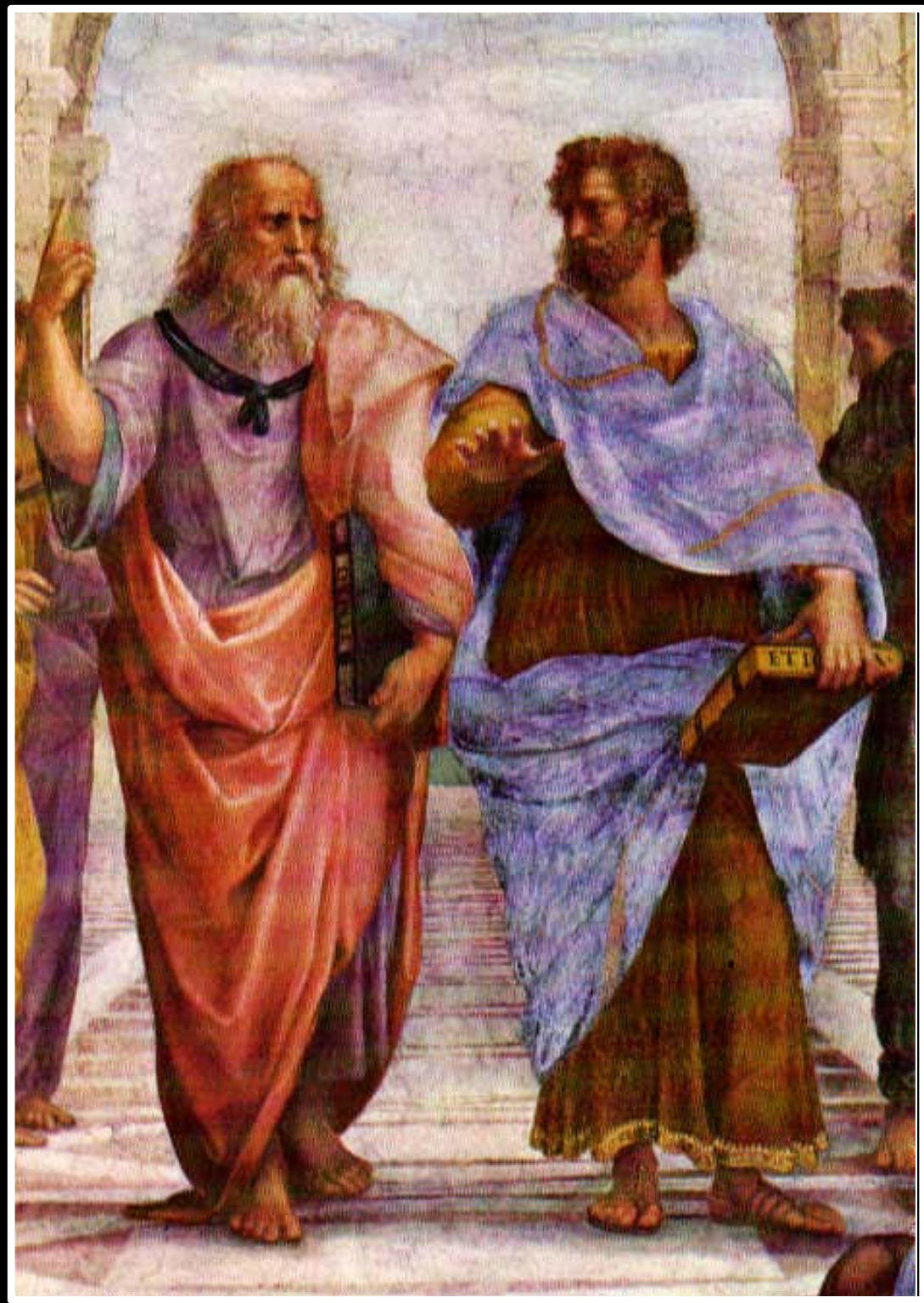
- Student Plato
- teacher Alexander the Great
- literary style:
  "River of Gold" (Cicero)
- founded Lyceum, Athens
- Dominant influence for over 1800 years
  both in Christian philosophy & theology
  and in Muslim intellectual history





I saw the Master there of those who know, Amid the philosophic family,
By all admired,
and by all reverenced;
There Plato too I saw, and Socrates,
Who stood beside him closer than the rest.

Dante, Divina Commedia
(1st level hell)



On the Heavens

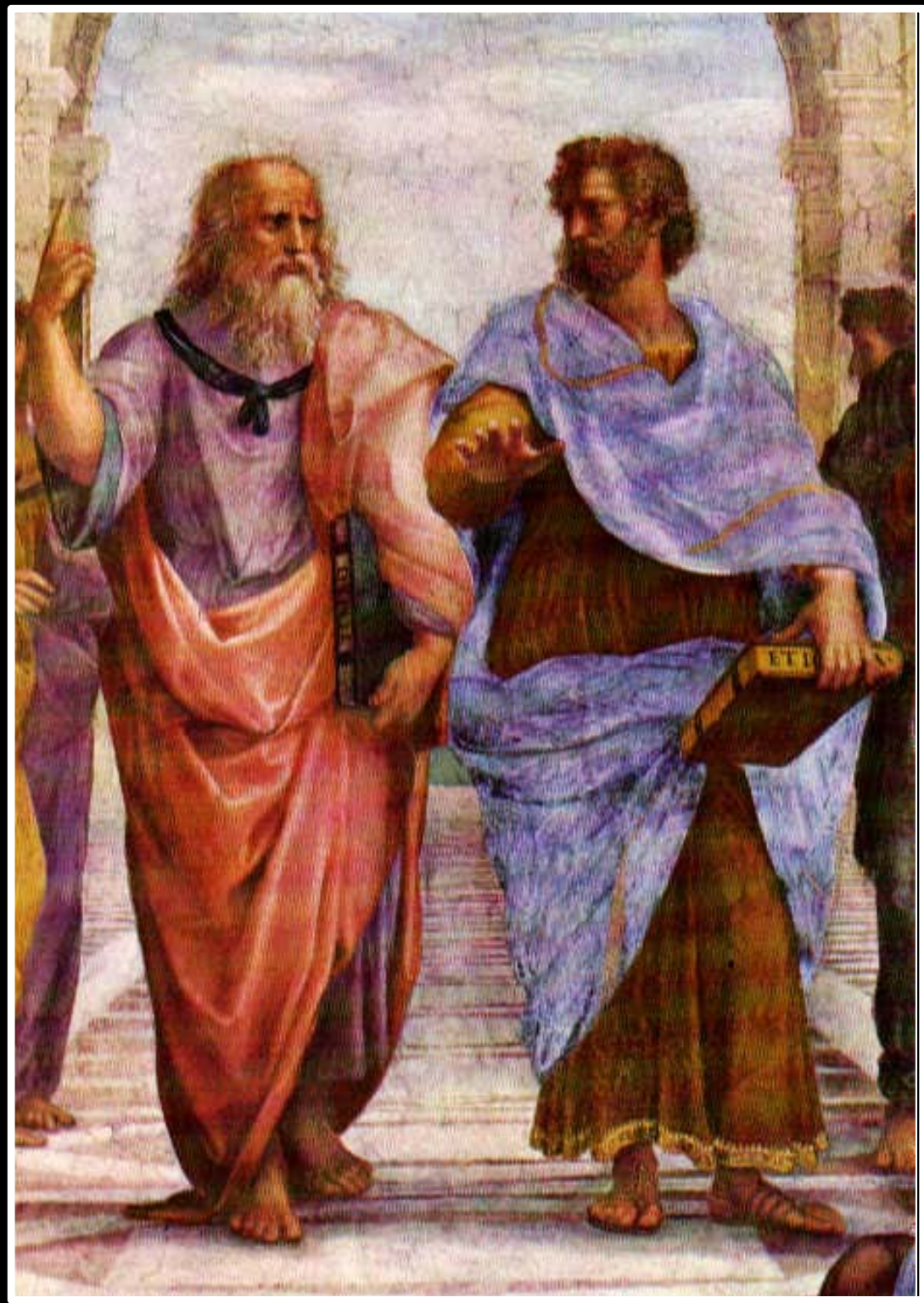
- **Aristotle's cosmological work**

- the most influential treatise of its kind in the history of humanity.

  It was accepted for more that 18 centuries from its inception (around 350 B.C.) until the works of Copernicus in the early 1500s.

- **Key aspects of Aristotle's Cosmology:**

  1) **Earth is at the centre of the Universe**
  2) **the Universe is finite**
  3) **the Universe is eternal and unchanged**
  4) **the motion of the heavenly bodies are uniform and circular**

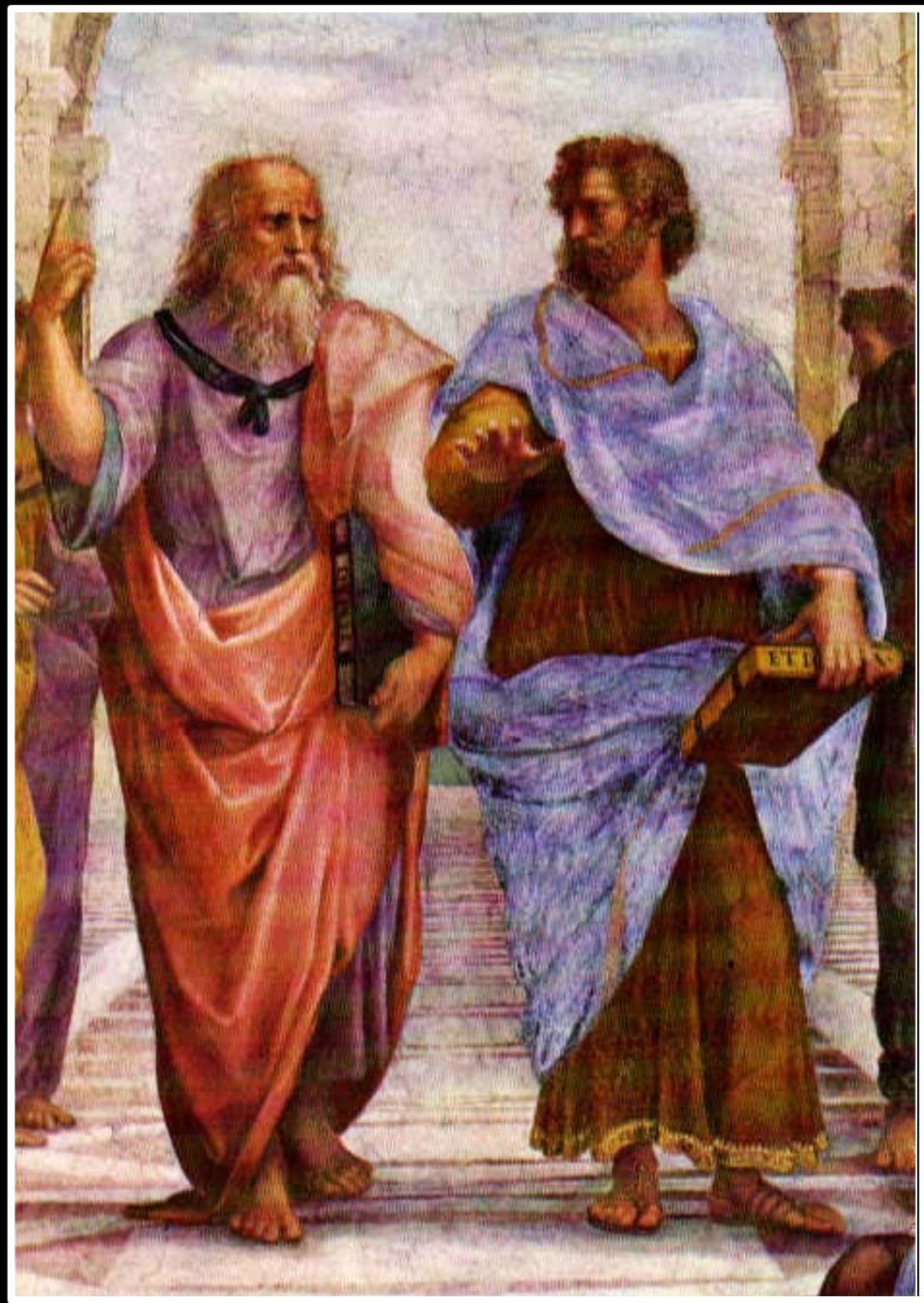


On the Heavens

- **Four causes**

Aristotle suggested that the reason for anything coming about can be attributed to four different types of simultaneously active causal factors:

1) **Material cause** - the material out of which something is composed.
2) **Formal cause** - its form, i.e., the arrangement of that matter.
3) **Efficient cause** - "the primary source", or that from which the change under consideration proceeds. This is akin to the modern concept of cause.
4) Final cause - its purpose, or that for the sake of which a thing exists or is done. This covers modern ideas of motivating causes, such as volition, need, desire, ethics, or spiritual beliefs.



On the Heavens

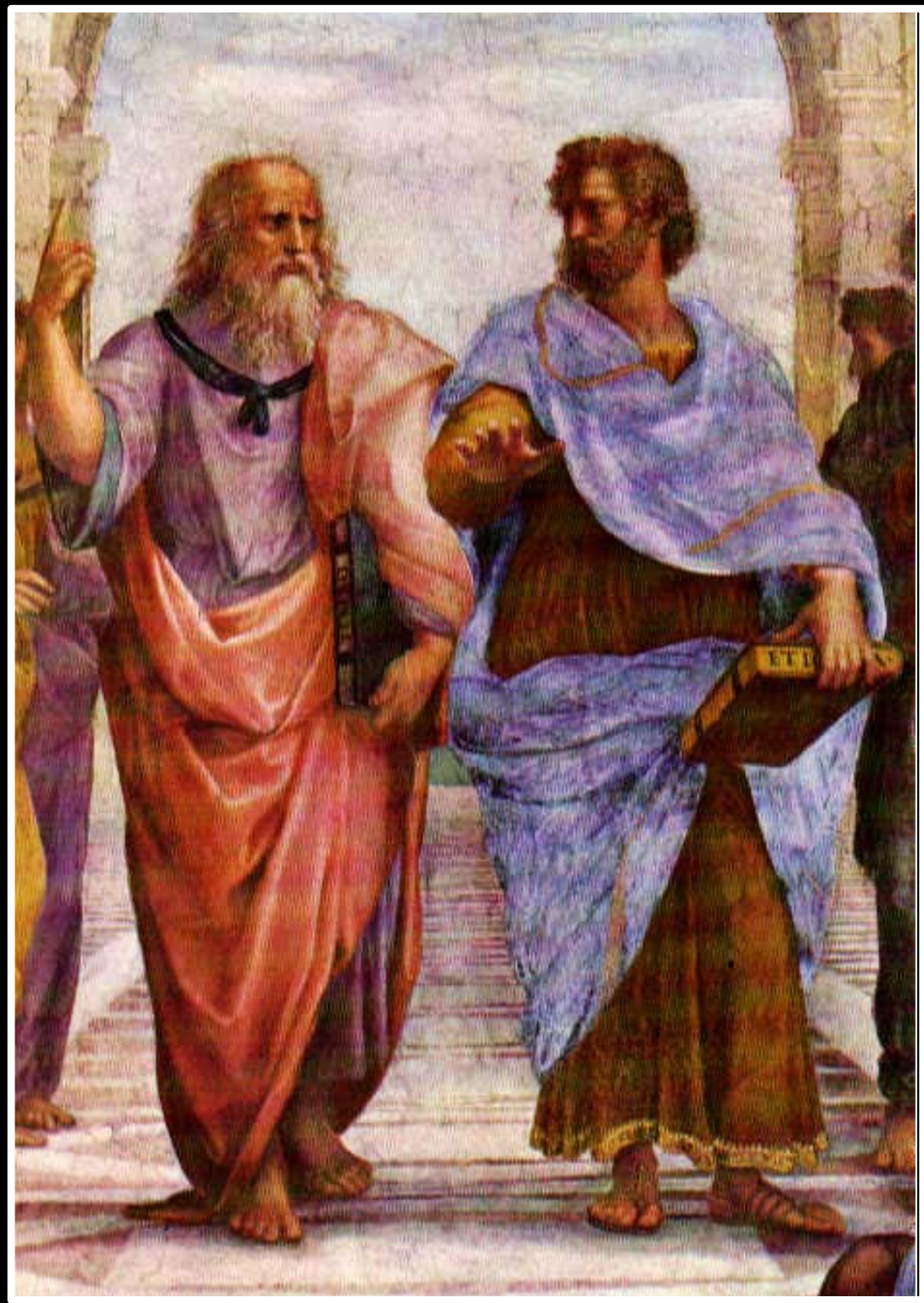
- **Elements - composition**

4 elements (Empedokles)

1) **Earth**	cold and dry	- modern idea solid.
2) **Water**	cold and wet	- modern idea liquid
3) **Air**	hot and wet	- modern idea of a gas.
4) **Fire**	hot and dry	- modern ideas of plasma

in addition,a 5th element

5) **Aether** divine substance making up the spheres and heavenly bodies (stars and planets)



On the Heavens

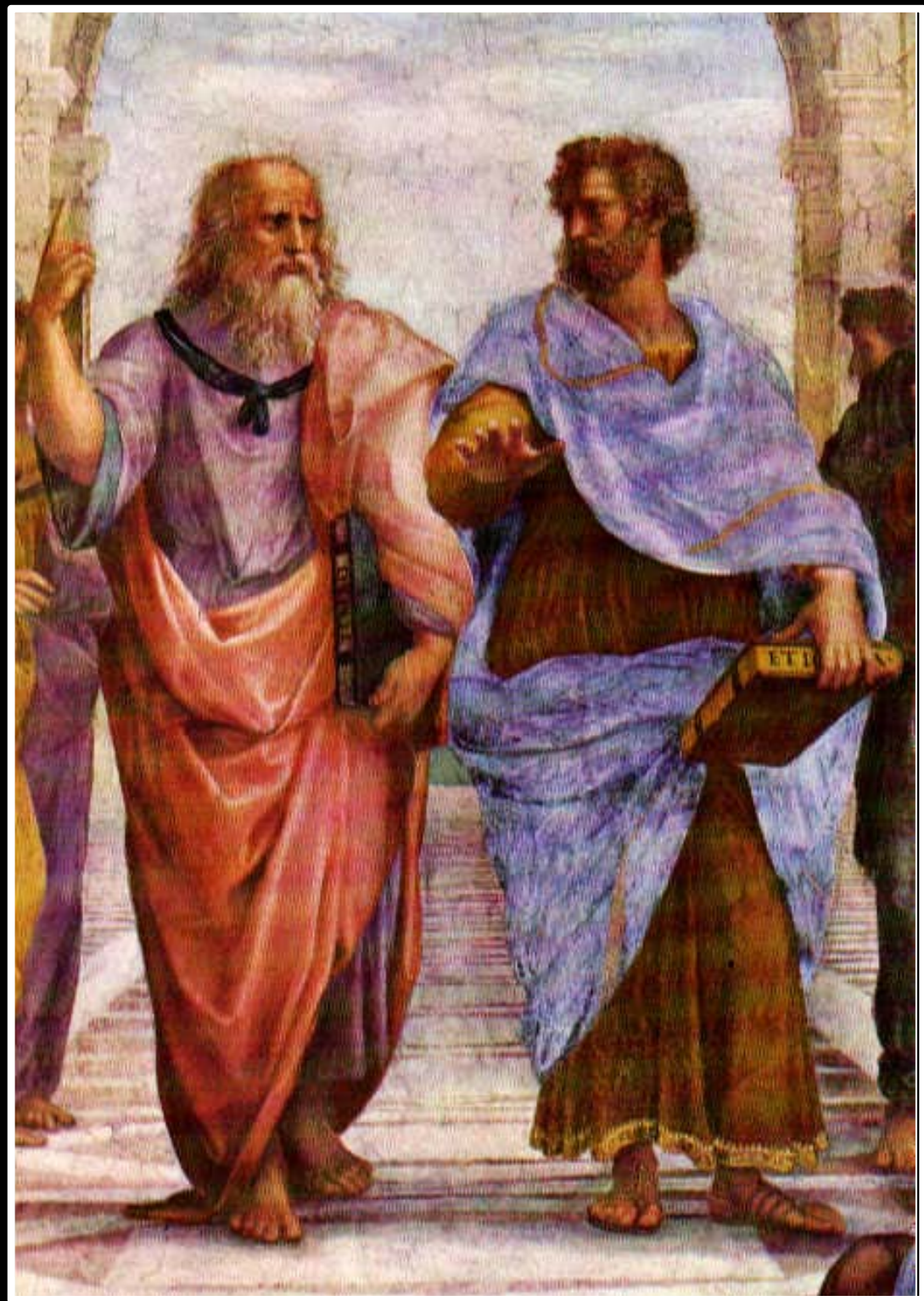
- **Movement of bodies**

  - **a**ll bodies, *by their very nature*, have a natural way of moving.
  - Movement is *not*, he states, the result of the influence of one body on another

- - Some bodies naturally move in straight lines
  - others naturally stay put.
  - Yet another natural movement: the circular motion.

- Since to each motion there must correspond a substance, there ought to be some things that naturally move in circles:

  the heavenly bodies
  (made of a more exalted and perfect substance than all earthly objects).



On the Heavens

- **Aristotle's Cosmos**

- **Aristotle's Cosmos** made of

  a central earth (which he accepted as spherical)

  surrounded by
  - the moon,
  - the sun
  - stars all moving in circles around it.

  This conglomerate he called ``the world''.

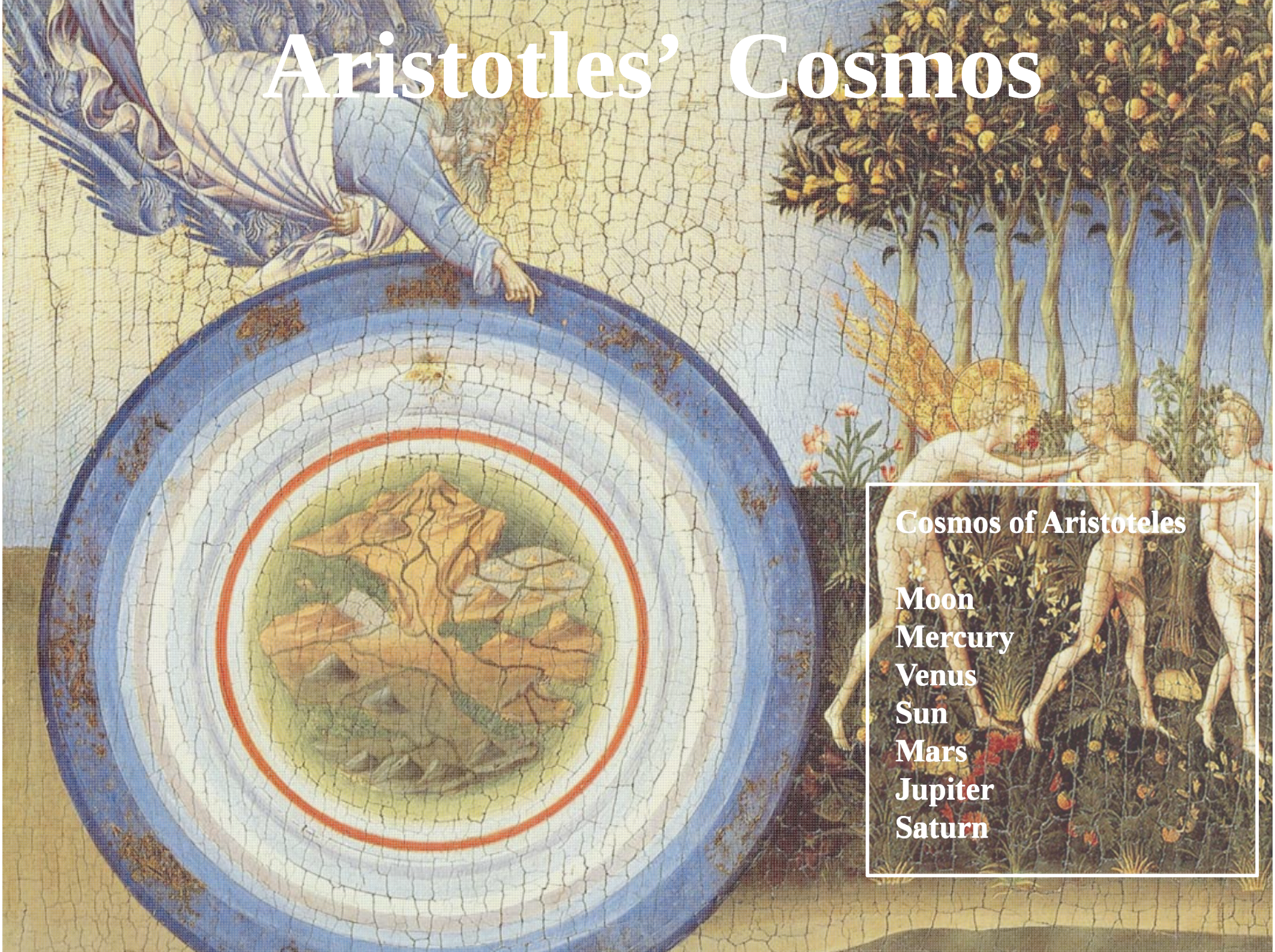
- Note the strange idea that all celestial bodies are perfect, yet they must circle the imperfect Earth.

  The initial motion of these spheres was caused by the action of a ``prime mover'' which (who?) acts on the outermost sphere of the fixed stars;

  the motion then trickles down to the other spheres through a dragging force.

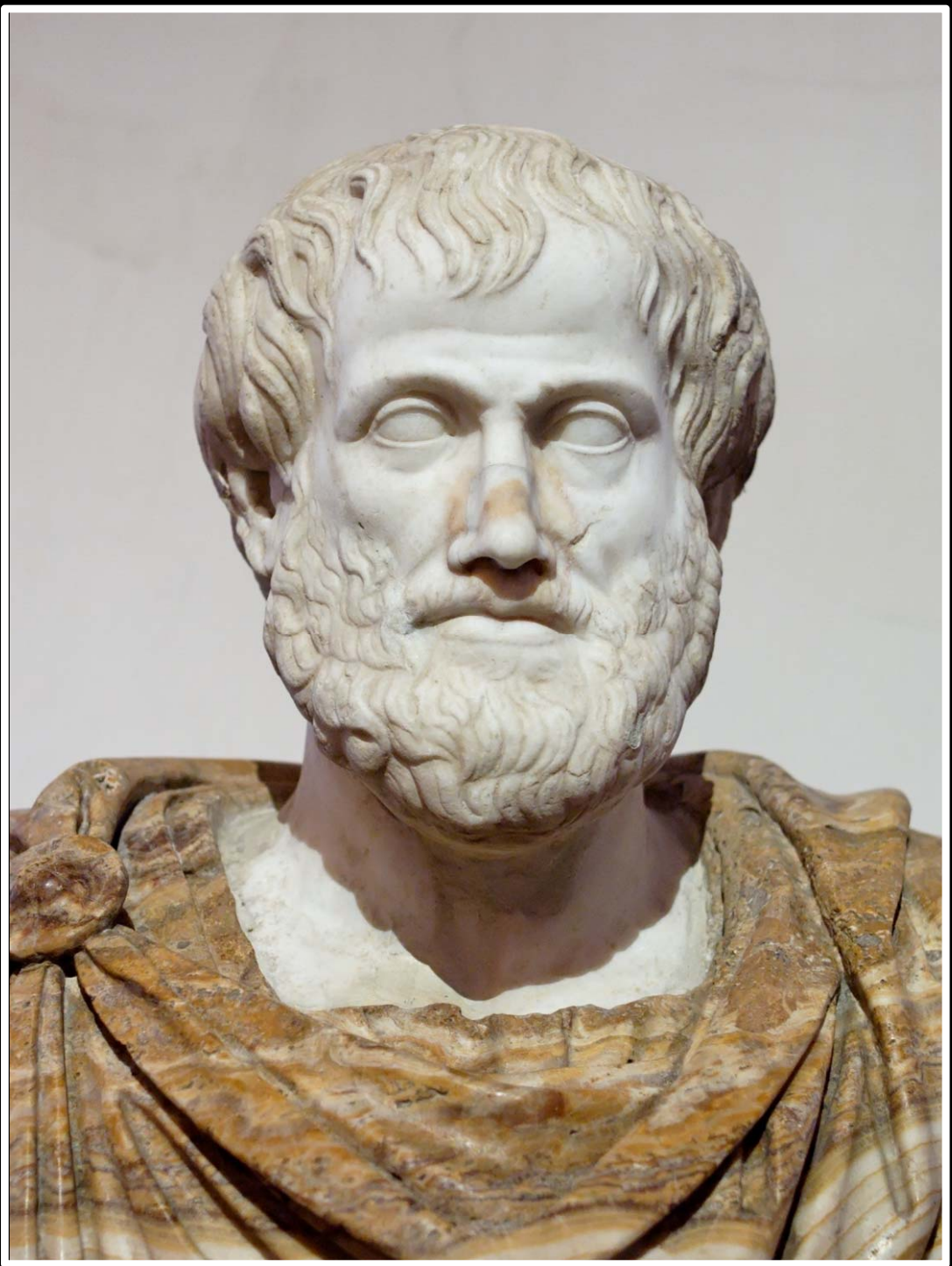
- Heavens consisted of a complex system of 55 spheres !
  - could explain and predict the motions of stars and planets
  - a real scientific theory

Aristotles' Cosmos



Cosmos of Aristoteles

Moon
Mercury
Venus
Sun
Mars
Jupiter
Saturn



On the Heavens

- **Aristotle's cosmology**

- **this world is unique.**

- the argument goes as follows:
  - earth (the substance) moves naturally to the center
  - if the world is not unique there ought to be at least two centers
  - but then, how can earth know to which of the two centers to go?
  - since ``earthy'' objects have no trouble deciding how to move, there can only be one center (the Earth) circled endlessly by all heavenly bodies.

- Note:
  - this cosmological tenet turned out to be completely wrong with the discovery of the moons of Jupiter

On the Heavens

- **Existence**

- **the world did not come into being at one time**

- **The world has existed, unchanged for all eternity**
  - it had to be that way since it was ``perfect'';
  - the universe is in a kind of ``steady state scenario''.

- Still, since he believed that the sphere was the most perfect of the geometrical shapes,
- the universe did have a center (the Earth)
- and its ``material'' part had an edge,
- which was ``gradual''
  - starting in the lunar and
  - ending in the fixed star sphere.
- Beyond the sphere of the stars the universe continued into the spiritual realm where material things cannot be

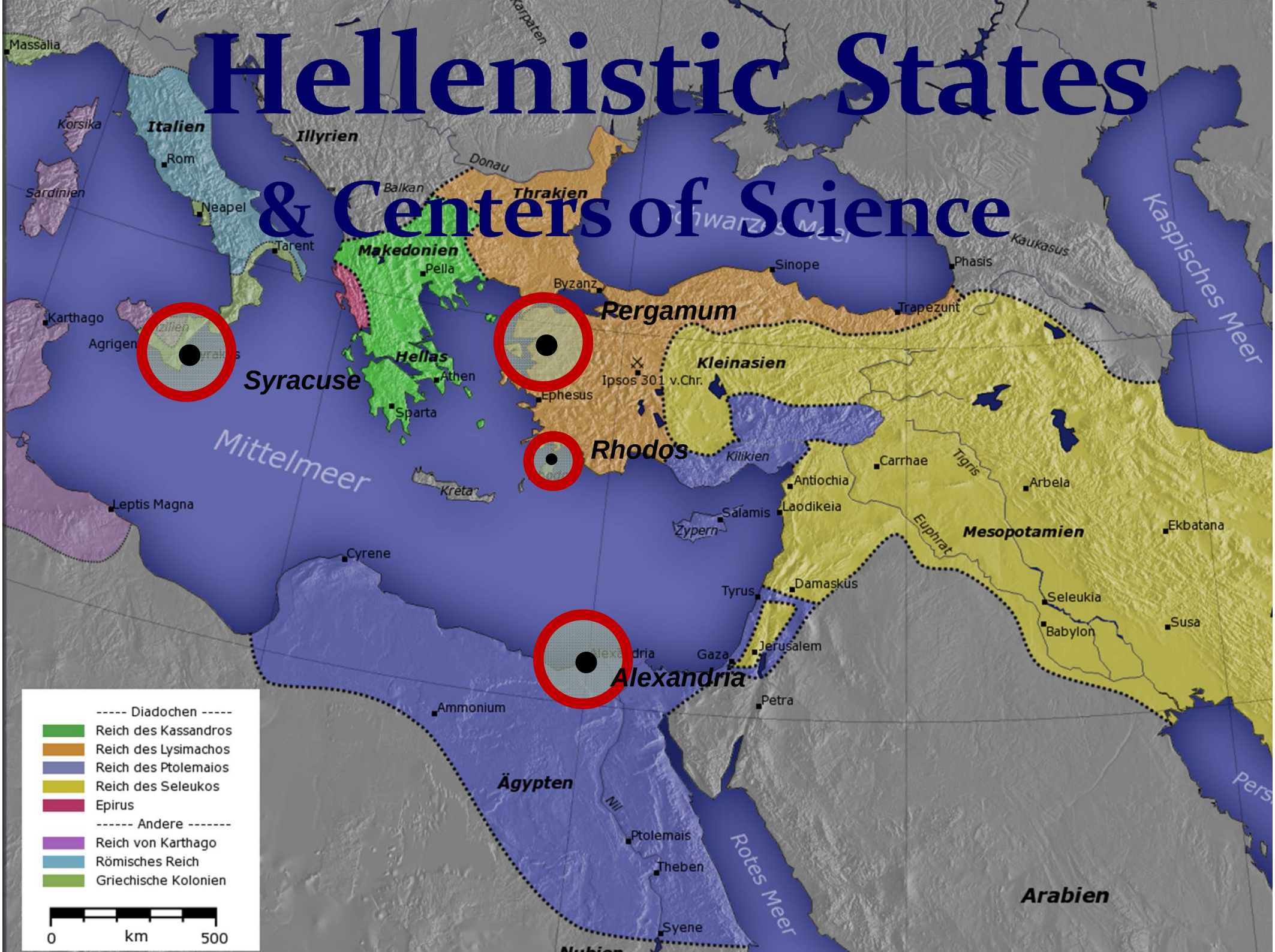
- This is in direct conflict with the Biblical description of creation, and an enormous amount of effort was spent by the medieval philosophers in trying to reconcile these views.

Pictorial view
Aristotelian view of the Cosmos

Hellenistic Cosmology:

the first Scientific Revolution

First Scientific Revolution: Hellenistic World


Hellenistic States
& Centers of Science
Massalia
Korsika
Italien
Rom
Sardinien
Neapel
Illyrien
Donau
Balkan
Thrakien
Tarent
Makedonien
Pella
Byzanz
Sinope
Phasis
Kaukasus
Kaspisches Meer
Schwarzes Meer
Karthago
Agrigent
Syracuse
Pergamum
Trapezunt
Hellas
Athen
Sparta
Ephesus
Ipsos 301 v.Chr.
Kleinasien
Rhodos
Mittelmeer
Kilikien
Carrhae
Tigris
Antiochia
Arbela
Leptis Magna
Kreta
Salamis
Laodikeia
Zypern
Euphrat
Mesopotamien
Ekbatana
Cyrene
Tyrus
Damaskus
Seleukia
Susa
Babylon
Jerusalem
Gaza
Alexandria
Petra
Ammonium
Ägypten
Nil
Ptolemais
Theben
Rotes Meer
Arabien
Syene
----- Diadochen -----
Reich des Kassandros
Reich des Lysimachos
Reich des Ptolemaios
Reich des Seleukos
Epirus
------ Andere -------
Reich von Karthago
Römisches Reich
Griechische Kolonien
0
km
500

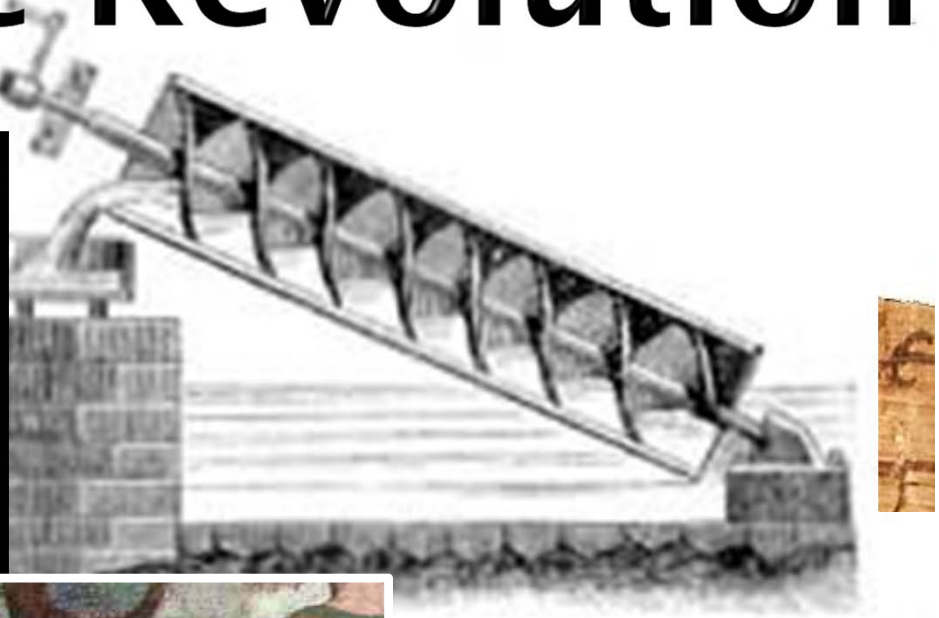
Massalia
Korsika
Italien
Illyrien
Rom
Sardinien
Balkan
Neapel
Tarent
Makedonien
Pella
Karthago
Sizilien
Agrigent
Syrakus
Hellas
Sparta
Mittelmeer
Leptis Magna
Cyrene
Tyrus
Damaskus
Seleukia
Babylon
Susa
Alexandria
Gaza
Jerusalem
Petra
Ammonium
Ägypten
Nil
Ptolemais
Theben
Syene
Rotes Meer
Arabien
Pers

----- Diadochen -----
Reich des Kassandros
Reich des Lysimachos
Reich des Ptolemaios
Reich des Seleukos
Epirus
------ Andere -------
Reich von Karthago
Römisches Reich
Griechische Kolonien

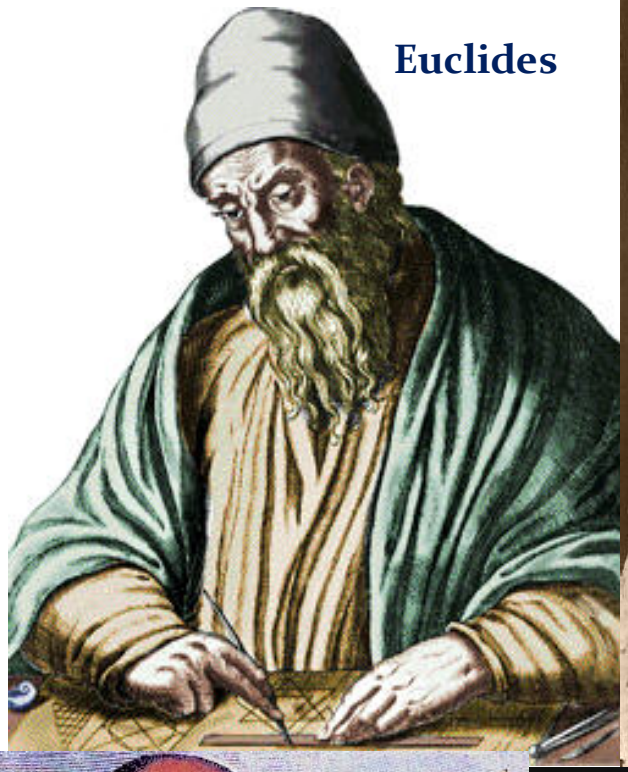
0 km 500

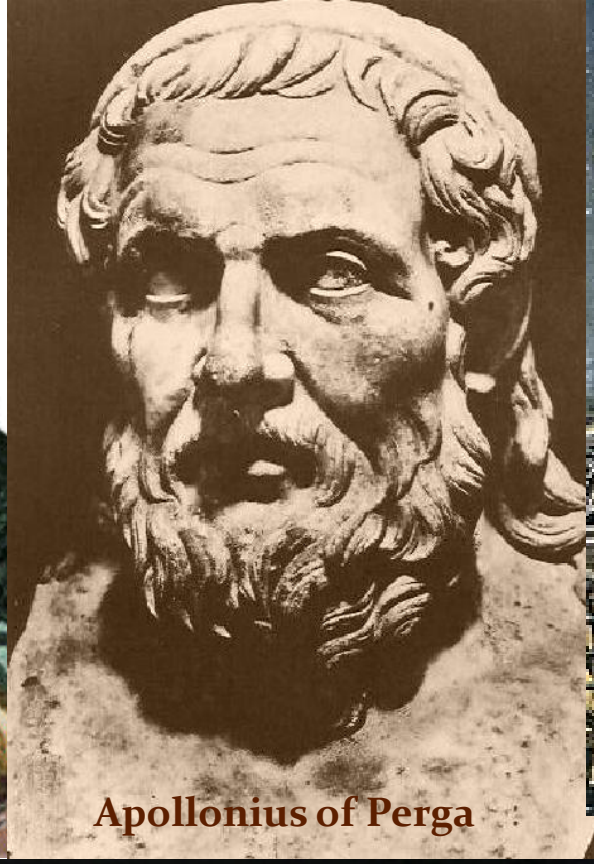
Alexandria

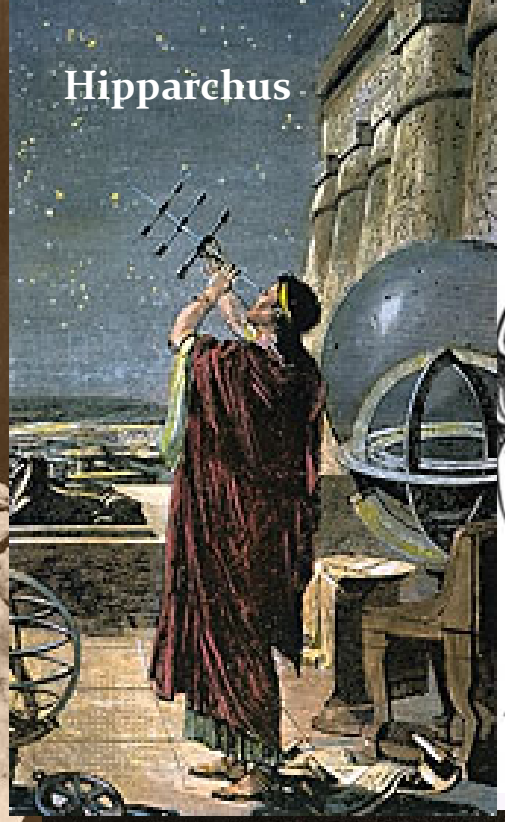
First Scientific Revolution




Euclides
Herophilus
Aristarchus
Ctesibius
Archimedes
Eratosthenes
Apollonius
Hipparchus
Heron of Alexandria
Ptolemaeus

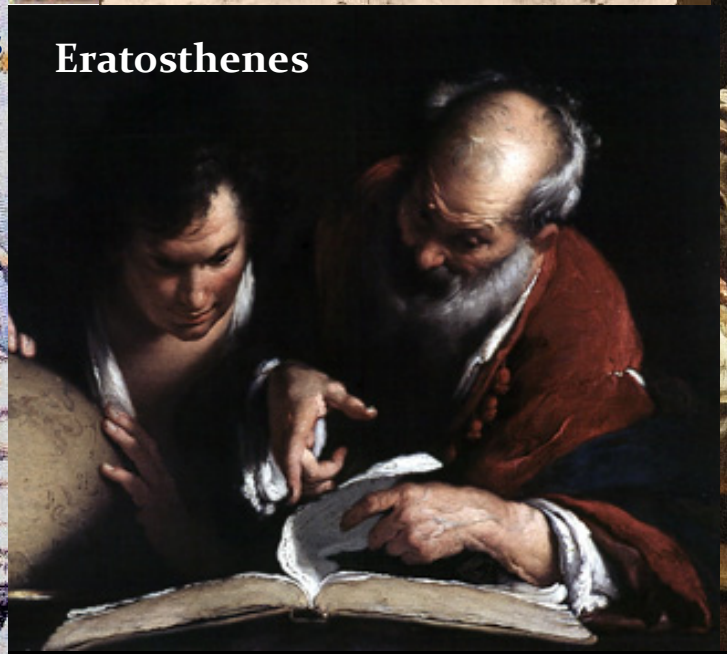

Euclides

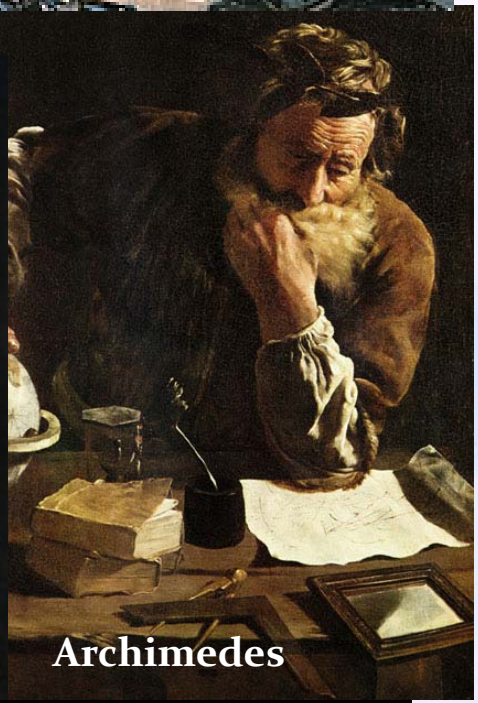

Apollonius of Perga


Hipparchus


Heron


Ptolemaeus


Eratosthenes


Archimedes


Aristarchus


Euclides (~ 300 BC)
Herophilus (335-280 BC)
Aristarchus of Samos (310-230 BC)
Ctesibius (285-222 BC)
Archimedes (287-212 BC)
Eratosthenes (276-194 BC)
Apollonius of Perga (262-190 BC)
Hipparchus of Samos (190-120 BC)
Heron of Alexandria (10-70 AD)
Ptolemaeus (83-168 AD)

Hellenistic Astronomers

Various astronomers made significant, even amazing, contributions. Noteworthy examples:

- **Aristarchus of Samos** - **Heliocentric Universe**
  - **distance Moon & Sun**
  - **size Sun**
- **Archimedes** - **Planisphere/Planetarium ?**
- **Eratosthenes** - **Diameter Earth**
- **Hipparchus** - **multitude essential contributions**

Problematic is the loss of nearly all, except for a few, of the books and works they have written ...

Aristarchus of Samos
Ἀρίσταρχος

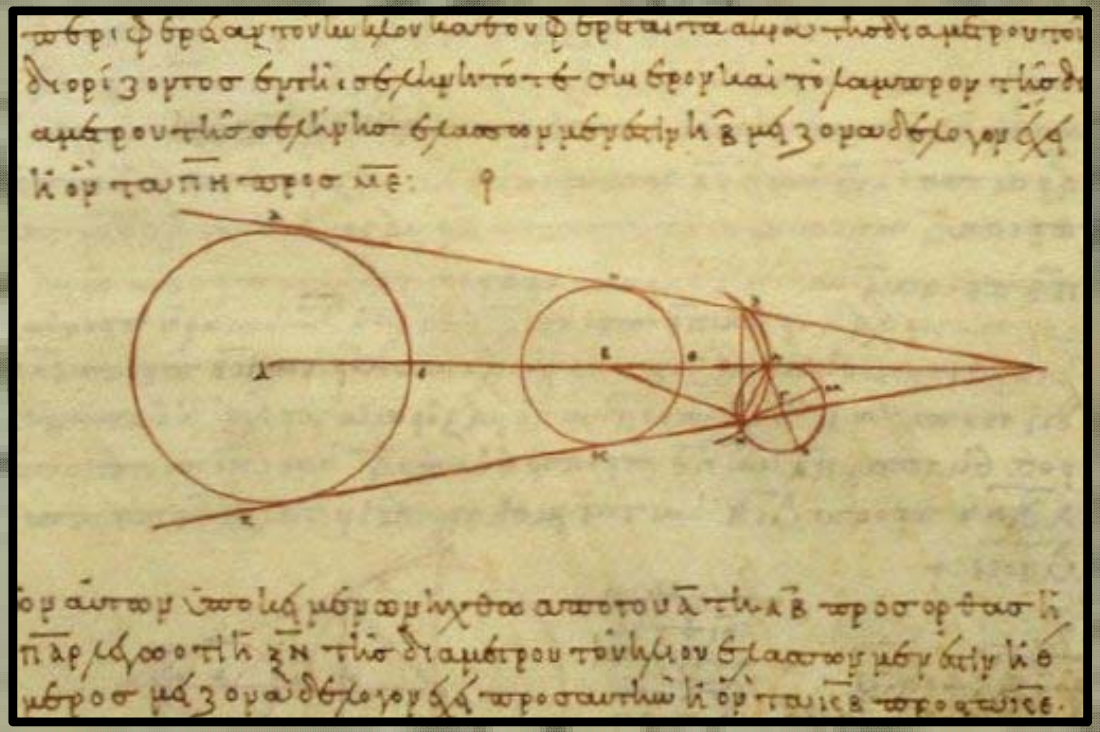
310-230 BCE

Aristarchus of Samos

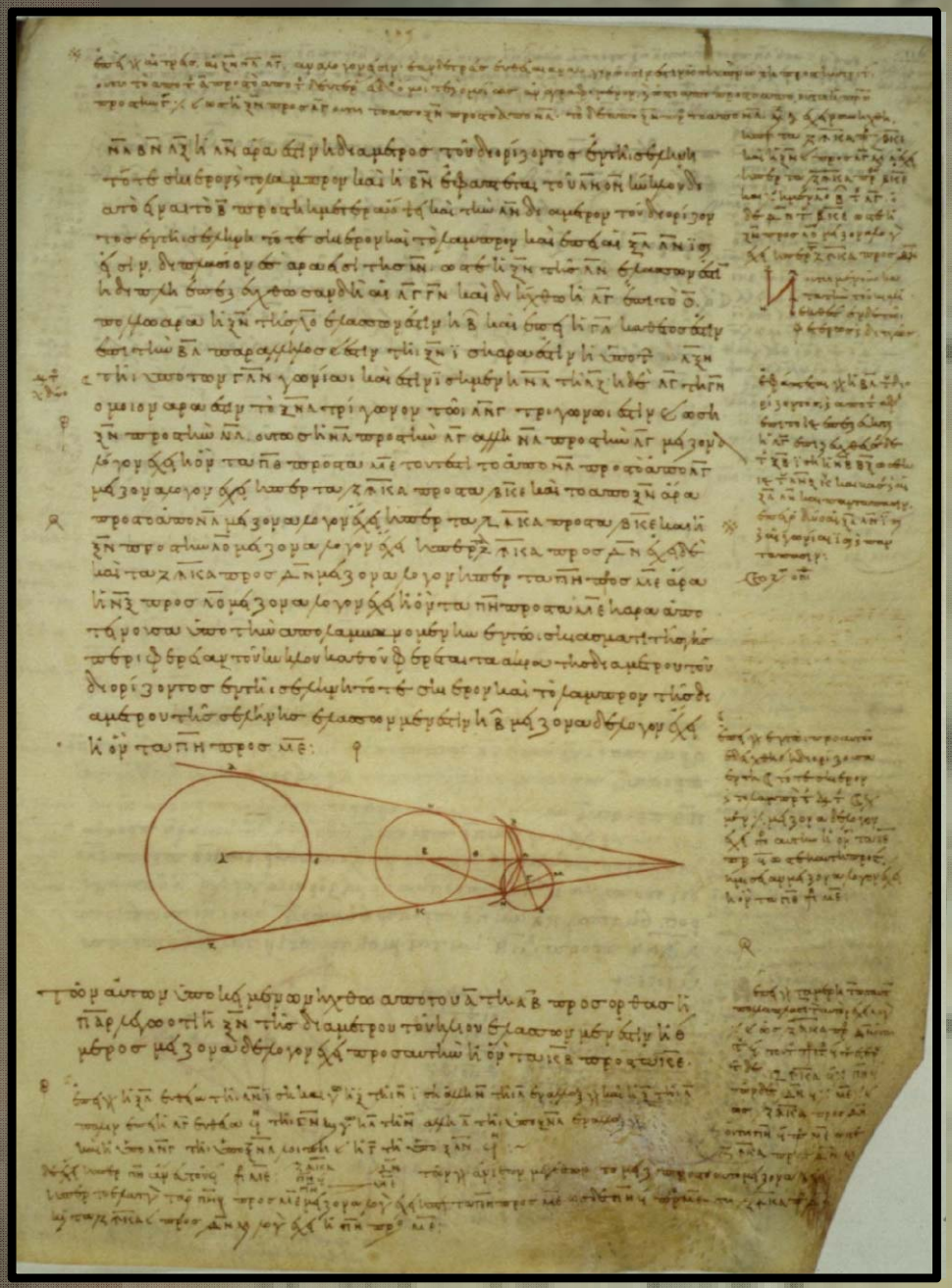
(Samos, 310-230 BCE)

the ancient Copernicus

"On the Sizes & Distances of the Sun and Moon ":



On the Sizes and Distances



Only one work of Aristarchus survives:

On the Sizes and the Distances of the Sun and Moon

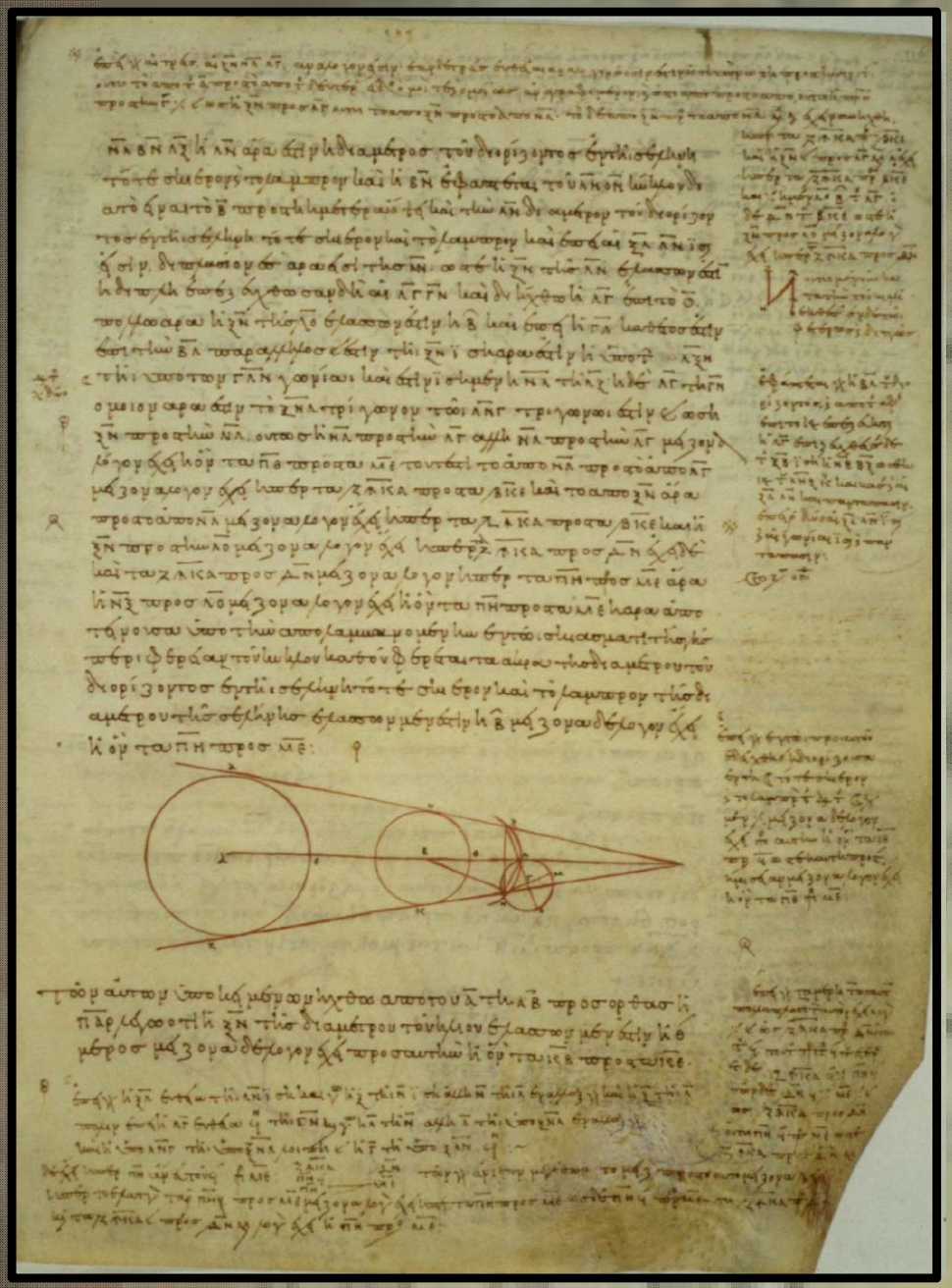
First mathematically based attempt to measure distance Earth-Sun, thus

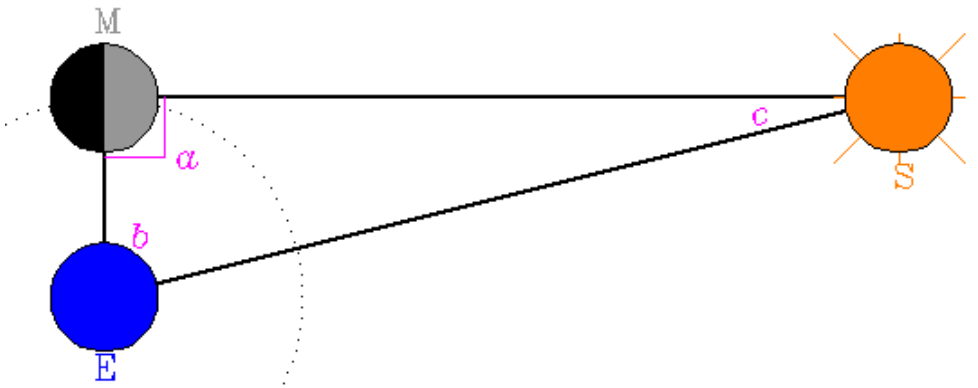
First attempt to measure scale Universe

Based upon geocentric view of Universe

On the Sizes and the Distances
Greek copy 10th century

On the Sizes and Distances





Aristarchus' geometric construction used to estimate the distance to the Sun.
Earth (E) –Sun (S)-Moon (M) triangle and sizes are not drawn to scale.

Measure angle b:

c = 90°-b EM/ES = sin(c)

Aristarchus:

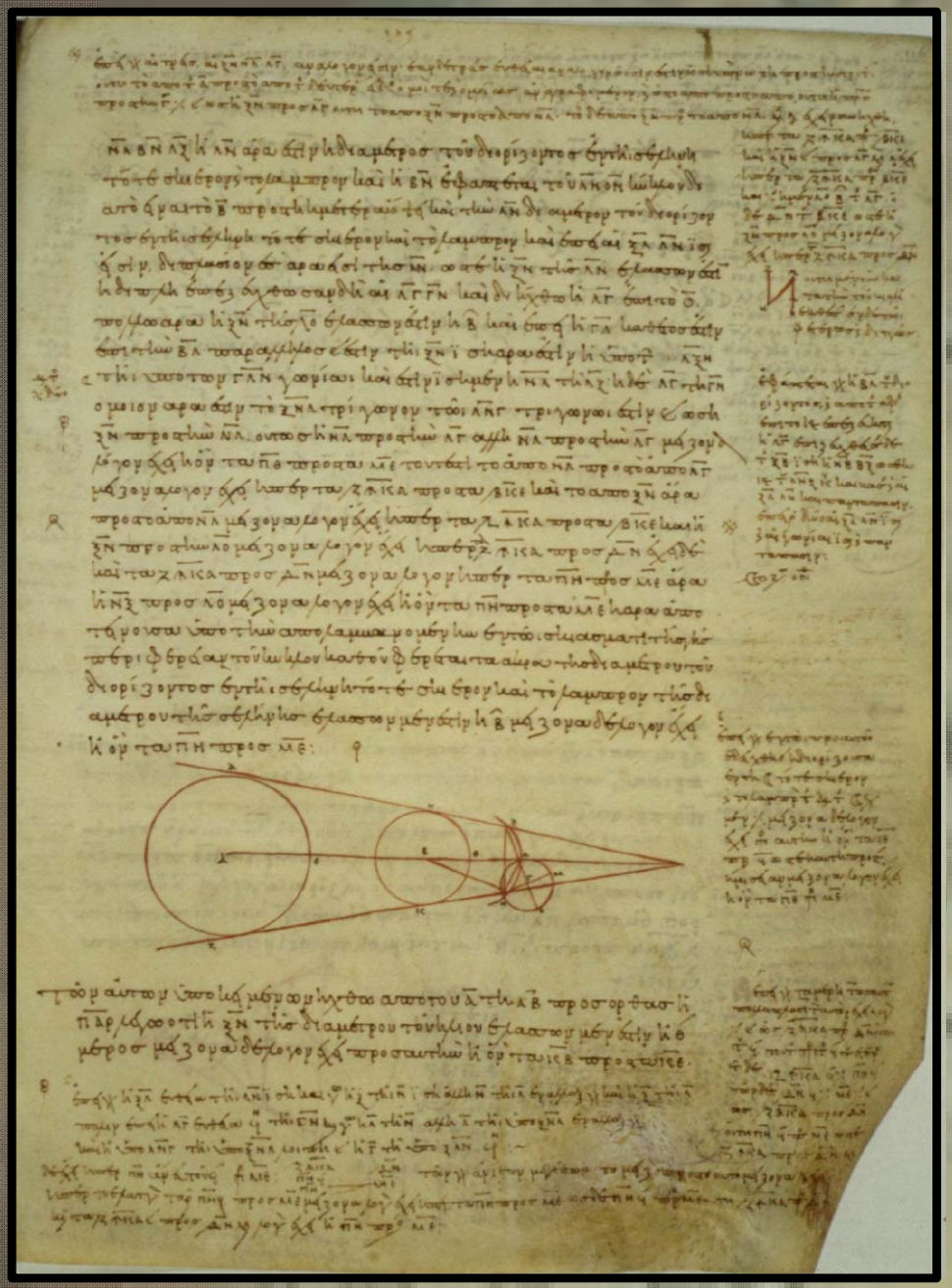
b = 87° real value: b = 89°50

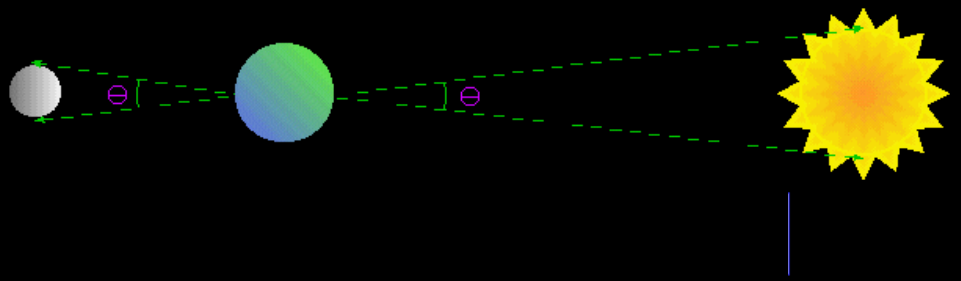
ES = 19 EM real value: ES = 397 EM

Numerically, very unstable procedure, reason for huge error. Nonetheless,

On the Sizes and the Distances
Greek copy 10th century

On the Sizes and Distances





Aristarchus' estimate of size Sun:

angular diameter Sun ~
angular diameter Moon

Dist. Earth-Sun = 19 Dist. Earth-Moon

→ size Sun = 19 x size Moon

→ size Sun > size Earth

On the Sizes and the Distances
Greek copy 10th century

Aristarchus: Heliocentric Universe

Archimedes, "the Sand Reckoner" (~200 BCE):

You King Gelon are aware the 'universe' is the name given by most astronomers to the sphere the center of which is the center of the Earth, while its radius is equal to the straight line between the center of the Sun and the center of the Earth. This is the common account as you have heard from astronomers.

But Aristarchus has brought out a book consisting of certain hypotheses, wherein it appears, as a consequence of the assumptions made, that the universe is many times greater than the 'universe' just mentioned.

His hypotheses are that the fixed stars and the Sun remain unmoved, that

the Earth revolves about the Sun

on the circumference of a circle, the Sun lying in the middle of the orbit, and that the sphere of fixed stars, situated about the same center as the Sun, is so great that the circle in which he supposes the Earth to revolve bears such a proportion to the distance of the fixed stars as the center of the sphere bears to its surface.

Aristarchus: Heliocentric Universe

Aristarchus' idea of Heliocentric Universe encountered sceptical, even hostile, reactions:

- Could not explain the absence of parallax of fixed stars (or they should be very, very far away …)
- Impiety … (even for those "rational" Greeks …)

"Cleanthes thought it was the duty of the Greeks to indict Aristarchus of Samos on the charge of impiety for putting in motion the Hearth of the universe [i.e. the earth], . . . supposing the heaven to remain at rest and the earth to revolve in an oblique circle, while it rotates, at the same time, about its own axis"

Plutarchus, "On the Apparent Face in the Orb of the Moon"

Eratosthenes of Cyrene
Ἐρατοσθένης

276 BC - 194 BC

Eratosthenes

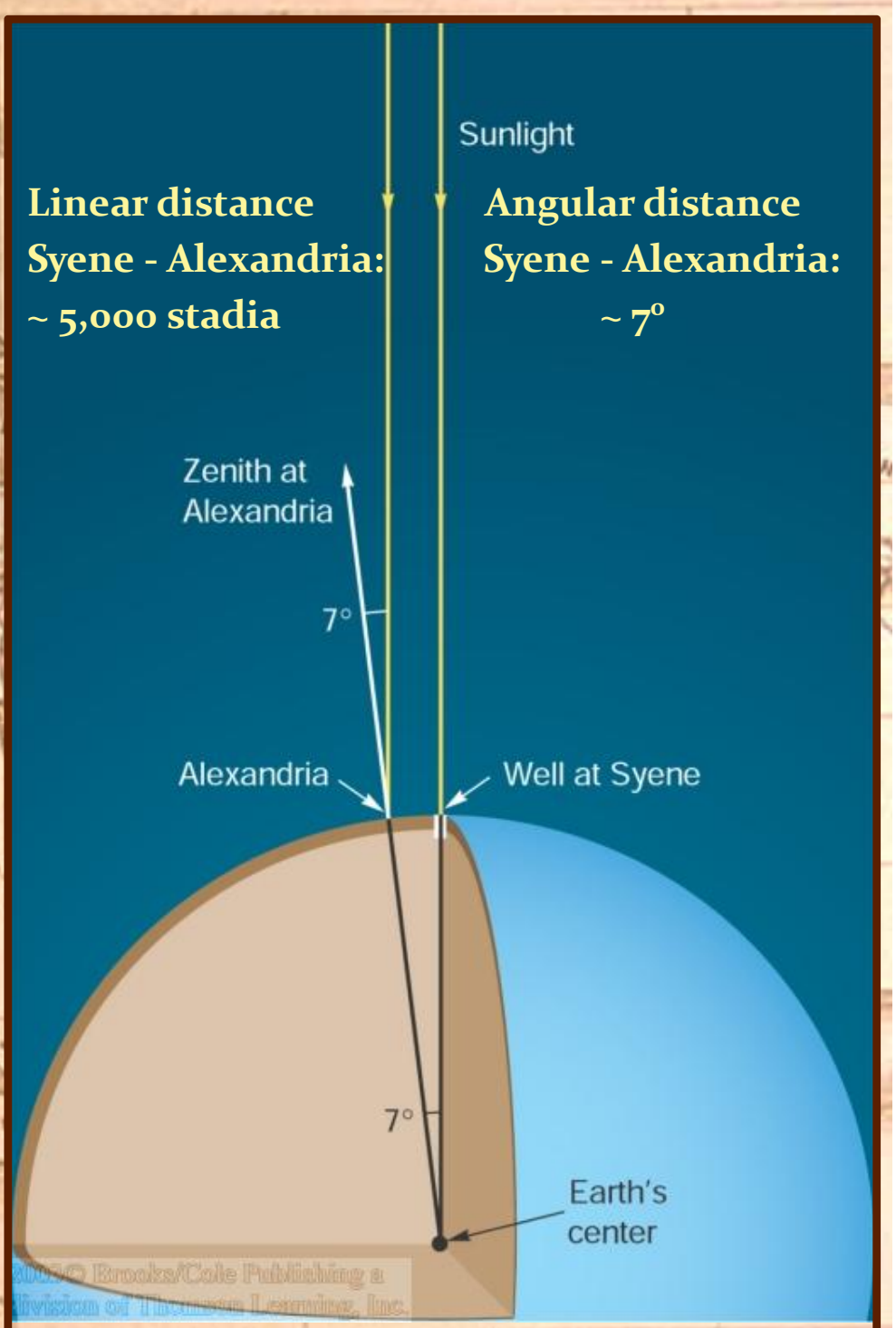
of Cyrene
(276 -194 B.C.E.)

- **Studied in Alexandria & Athens**
  - **Mathematician**
  - **Astronomer**
  - **Geographer**
  - **Poet**
  - **Athlete**
- **2nd Chief librarian Great Library of Alexandria**
- **Friend of Archimedes**
- **Invented armillary sphere (240 BC)**
- **Calculated Earth's Circumference**
- **Became blind in 194 BC, starved himself to death**

Earth Circumference:
Eratosthenes' measurement: 39,690 km - within 1%
(if Egyptian stadia)

Linear distance
Syene - Alexandria:
~ 5,000 stadia

Angular distance
Syene - Alexandria:
~ 7°



Eratosthenes' measurement Earth diameter

Eratosthenes

Earth Circumference Measurement

Archimedes of Syracuse

Αρχιμηδης

c. 287 – 212 BCE

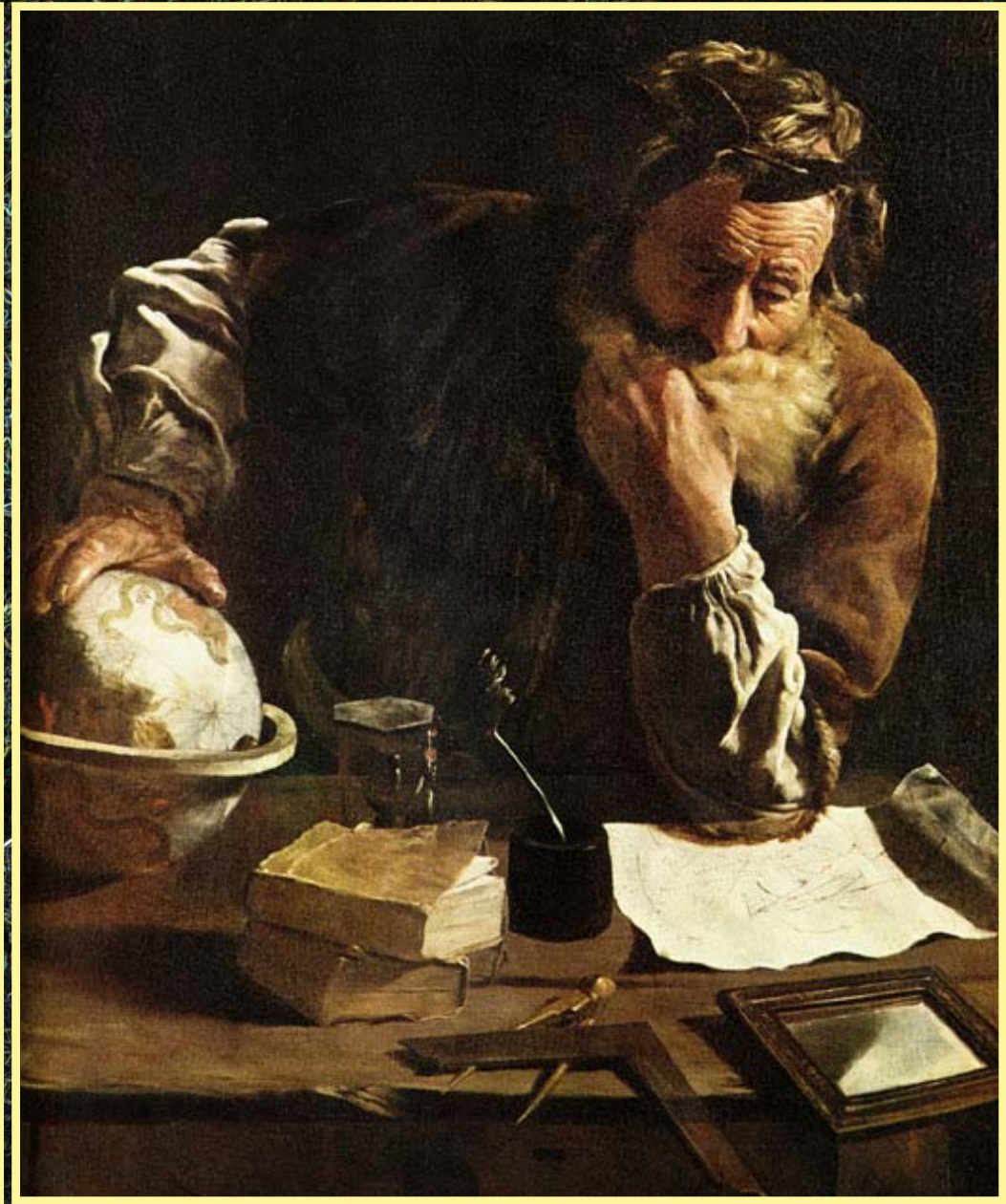
Archimedes

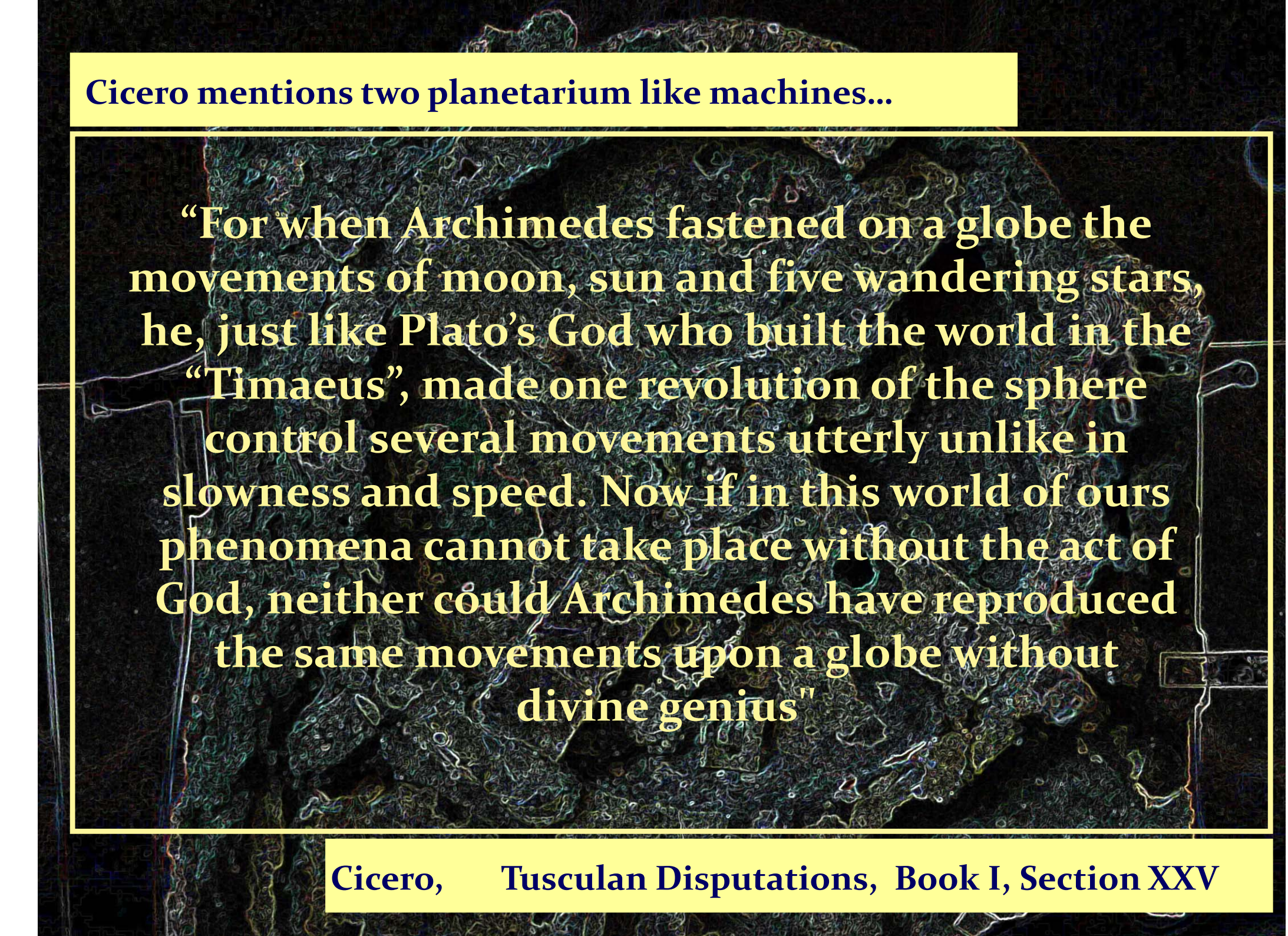
Syracuse, 287-211/212 BC,

Greatest mathematician & scientist of antiquity (all time ?):

- Probably studied in Alexandria, under followers Euclides
- Killed by Roman soldier, upon Roman conquest Syracuse
- Family Hieron II, king Syracuse ?

- Inventions:
  - war machines ...
  - water screw
  - water organ (?)
  - burning mirrors (???)
  - planetarium !!!!!!!





Cicero mentions two planetarium like machines...

"For when Archimedes fastened on a globe the movements of moon, sun and five wandering stars, he, just like Plato's God who built the world in the "Timaeus", made one revolution of the sphere control several movements utterly unlike in slowness and speed. Now if in this world of ours phenomena cannot take place without the act of God, neither could Archimedes have reproduced the same movements upon a globe without divine genius"

Cicero, Tusculan Disputations, Book I, Section XXV

Archimedes

- Pappus of Alexandria:
  Archimedes wrote book
  "On Sphere-Making"

  … is this Antikythera … ?

- Compare with

  Archimedes Palimpsest:
  … "On the Method" …

  Fundamentals Calculus,
  Integral calculus …

Hipparcus
Ιππαρχος

c. 190 – 120 BCE

Hipparchus of Nicaea (190-120 BC)

Antiquities' Greatest Astronomer

Responsible for the true
Revolution in Astronomy

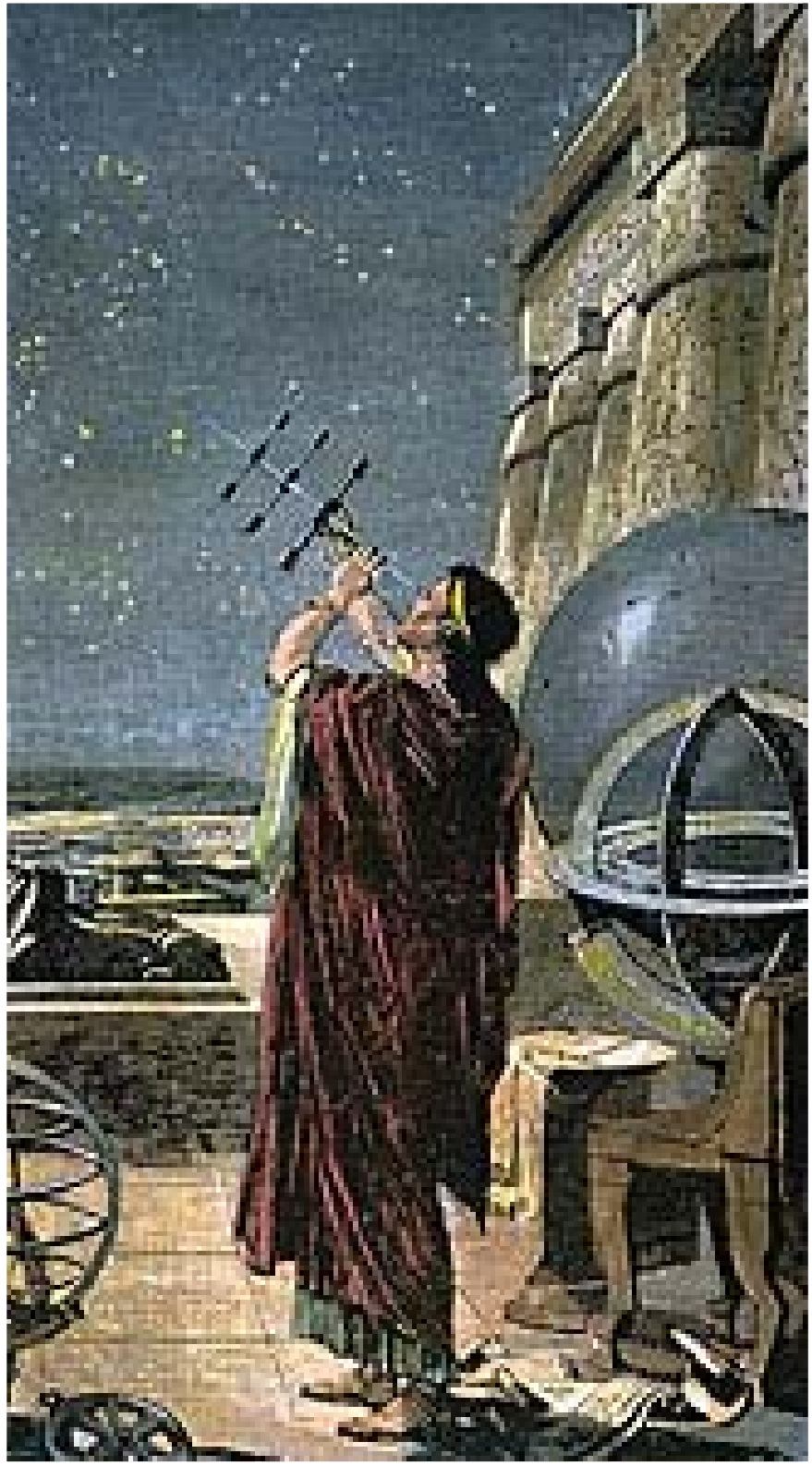
Synthesis of
Babylonian Observational Astronomy
Greek Theoretical/Geometric Models
Astronomy as true Modern Science:
Experiment & Theory

Hipparcus

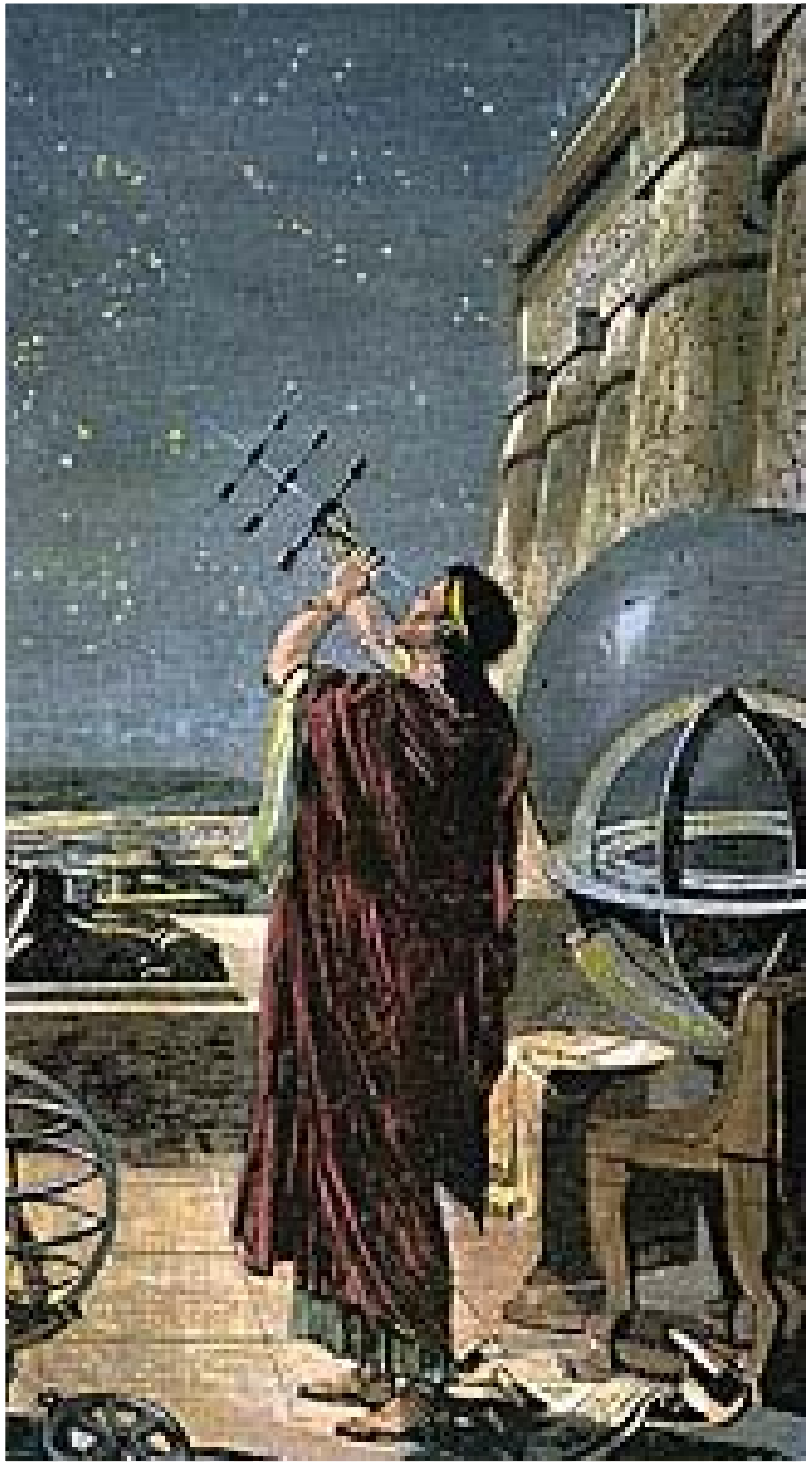
(Nicaea-Rhodos 190-120 BCE)

Greatest astronomer Greek antiquity

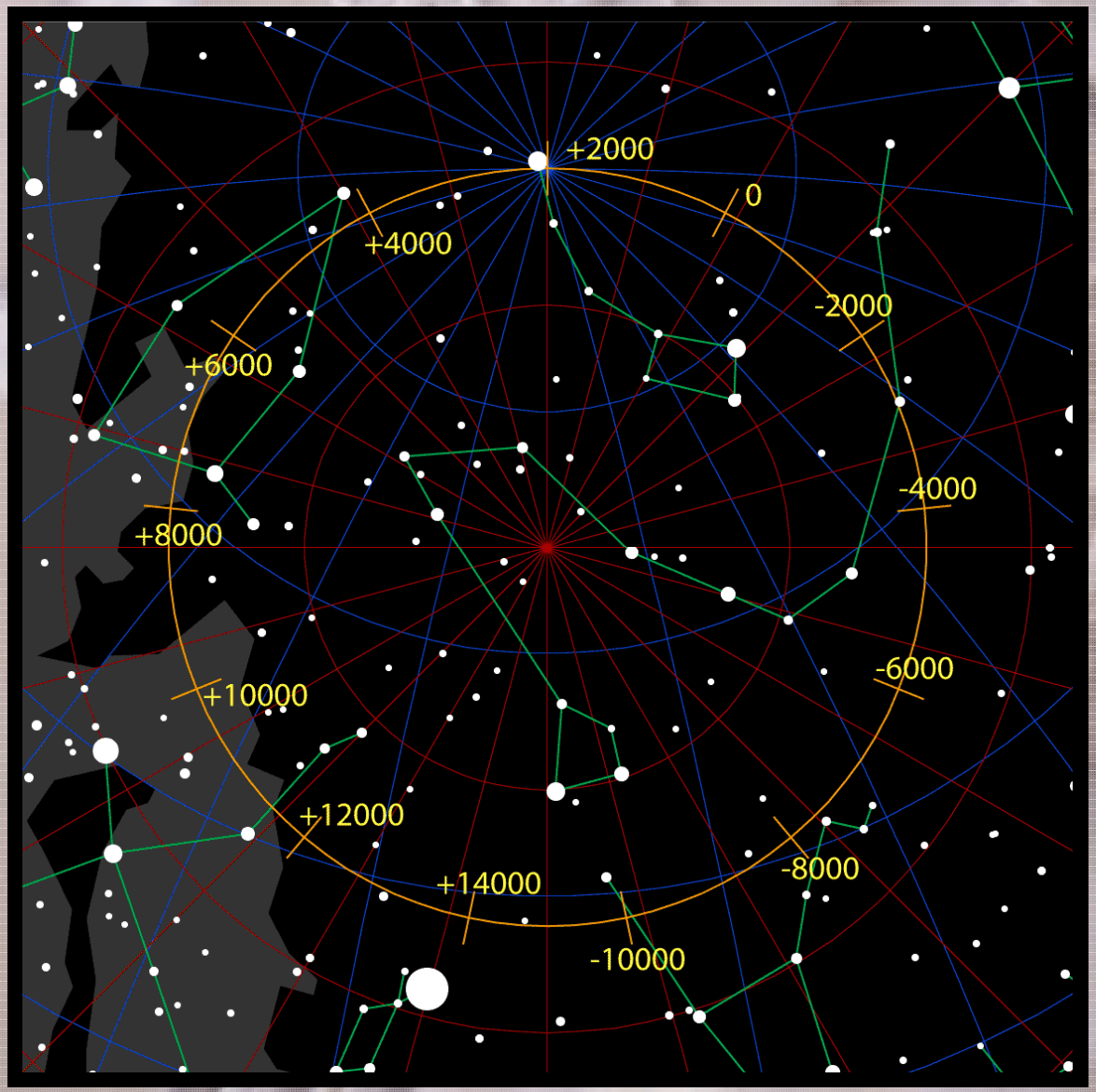
- Trigonometric Tables
- Precession of the Equinoxes
- Motion moon:
  synodic, anomalistic, … month
- Solar & Lunar eclipses
- Orbit of the Moon:
  epicyclic theory
- Distance Moon
- Star catalogue & Celestial Globe
  Lost, yet … Farnese Atlas ?
- Defined Magnitude Scale
- Invented the Astrolabe

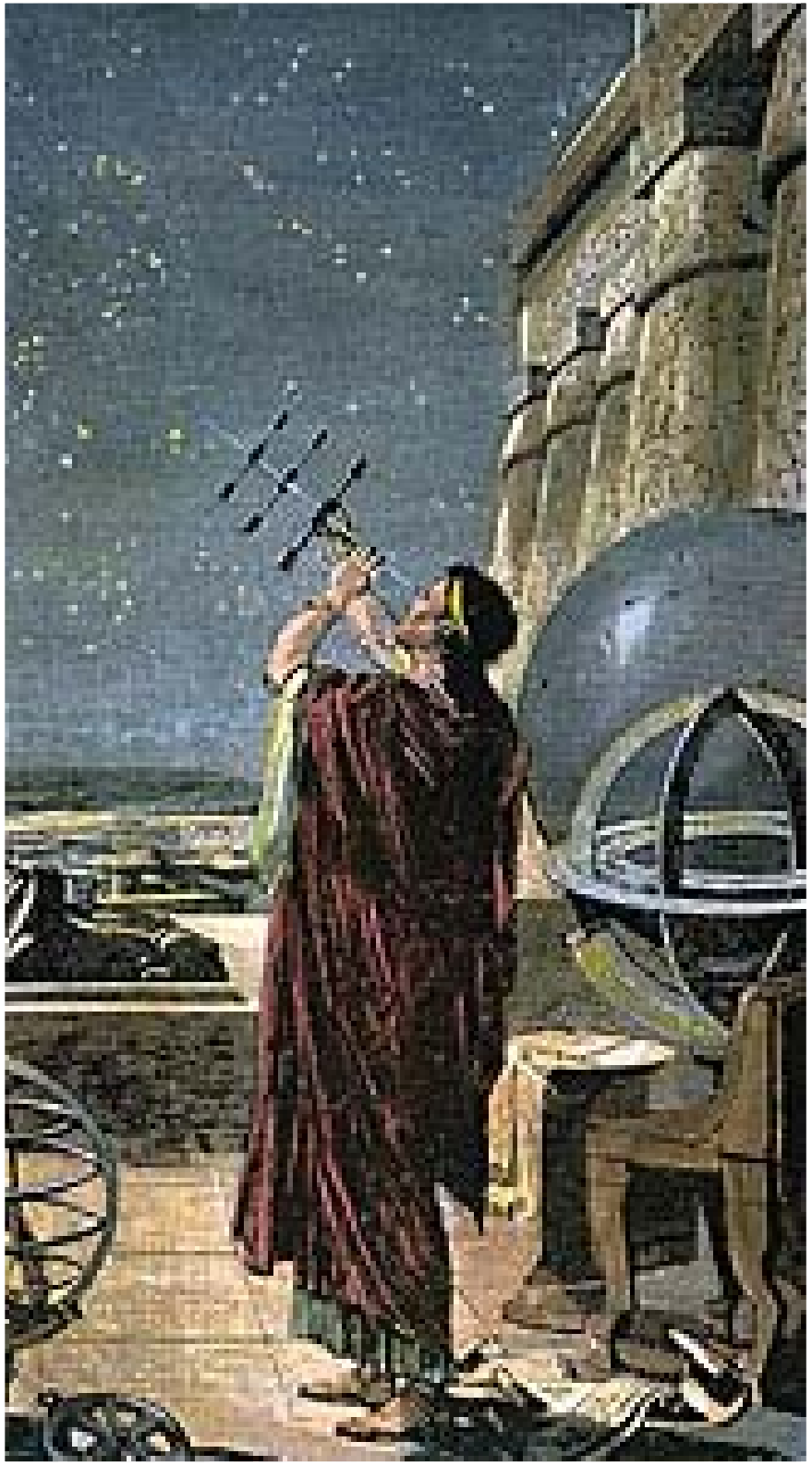


Star Magnitudes

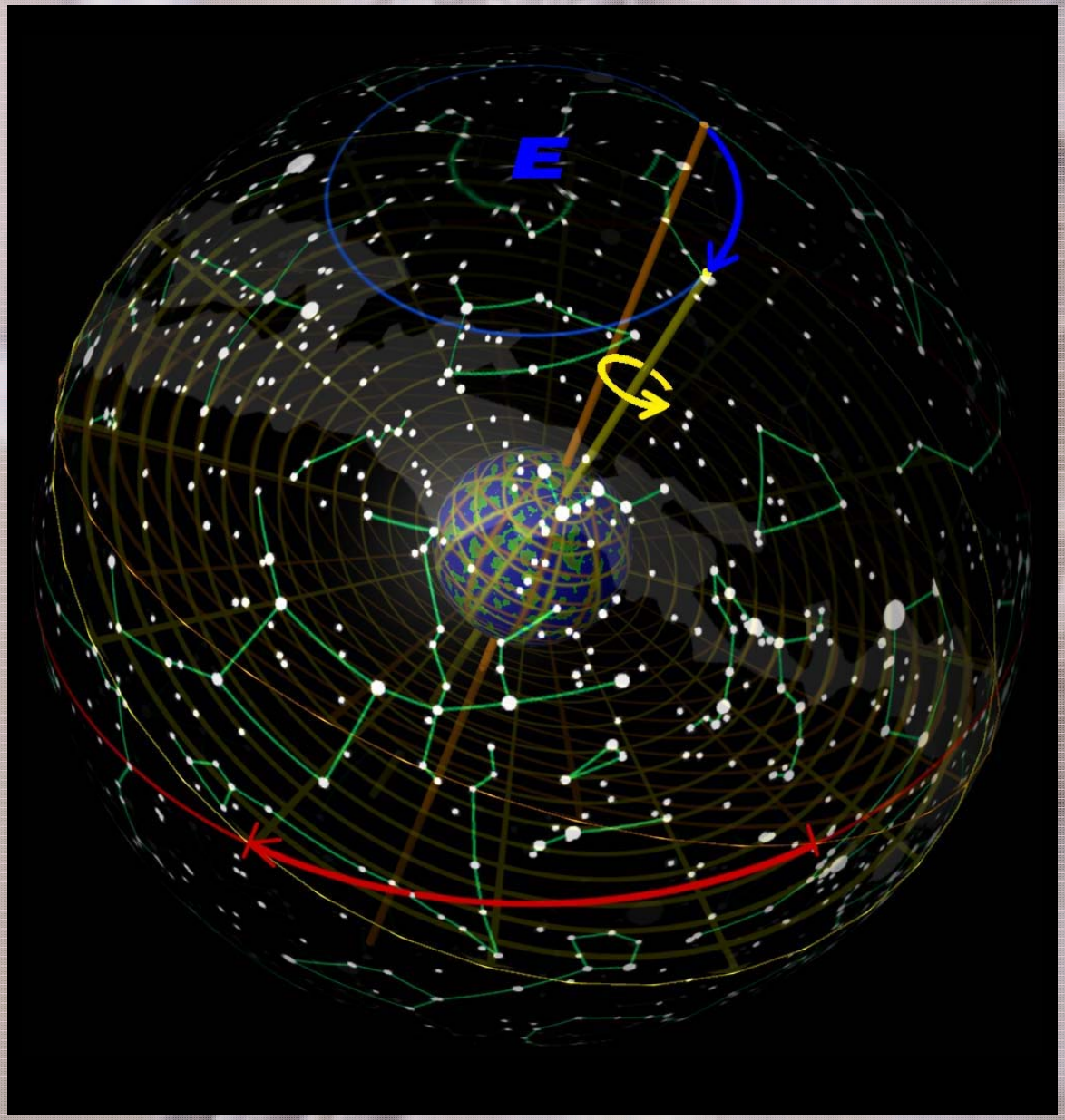


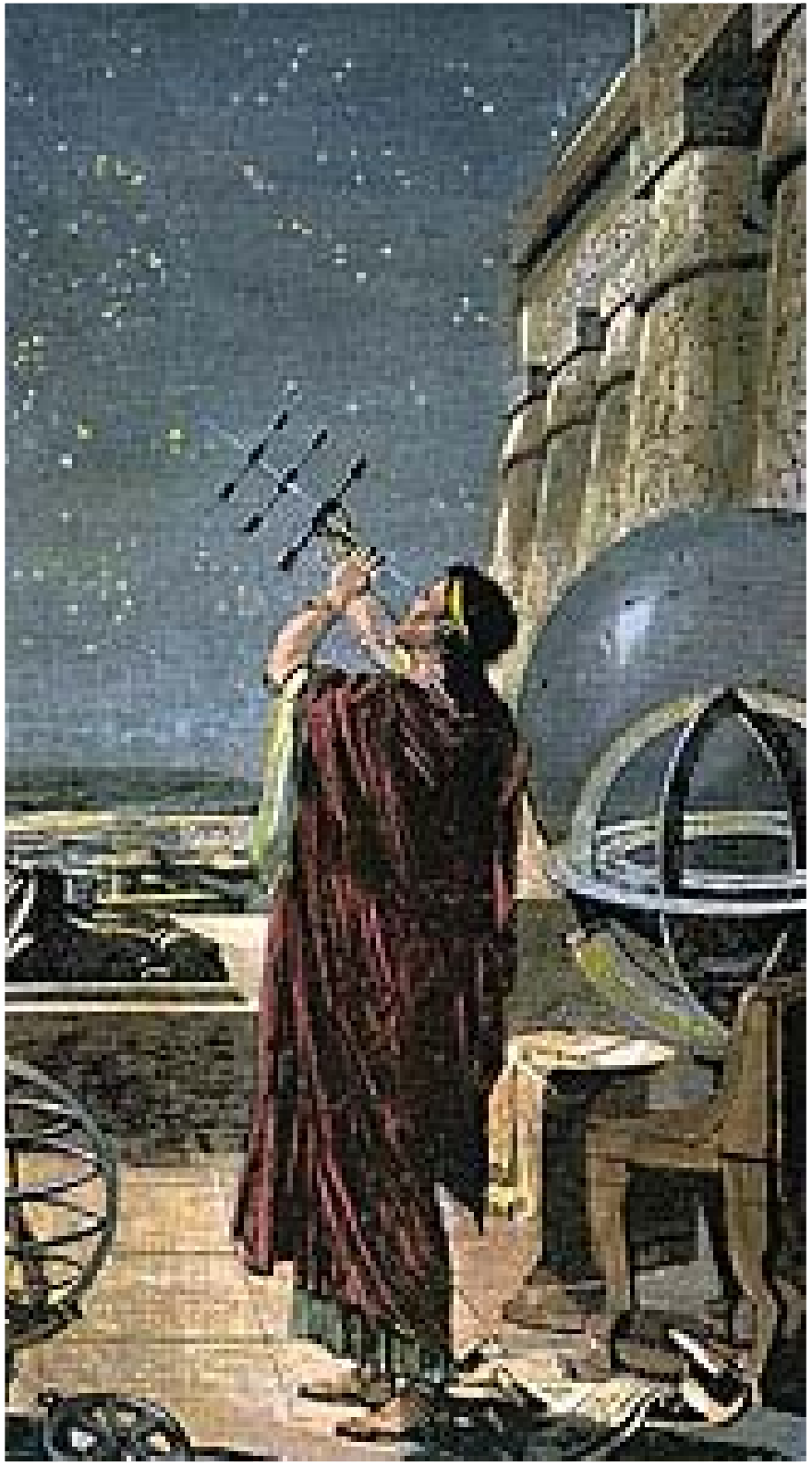
Precession


+2000
0
+4000
-2000
+6000
-4000
+8000
-6000
+10000
+12000
-8000
+14000
-10000

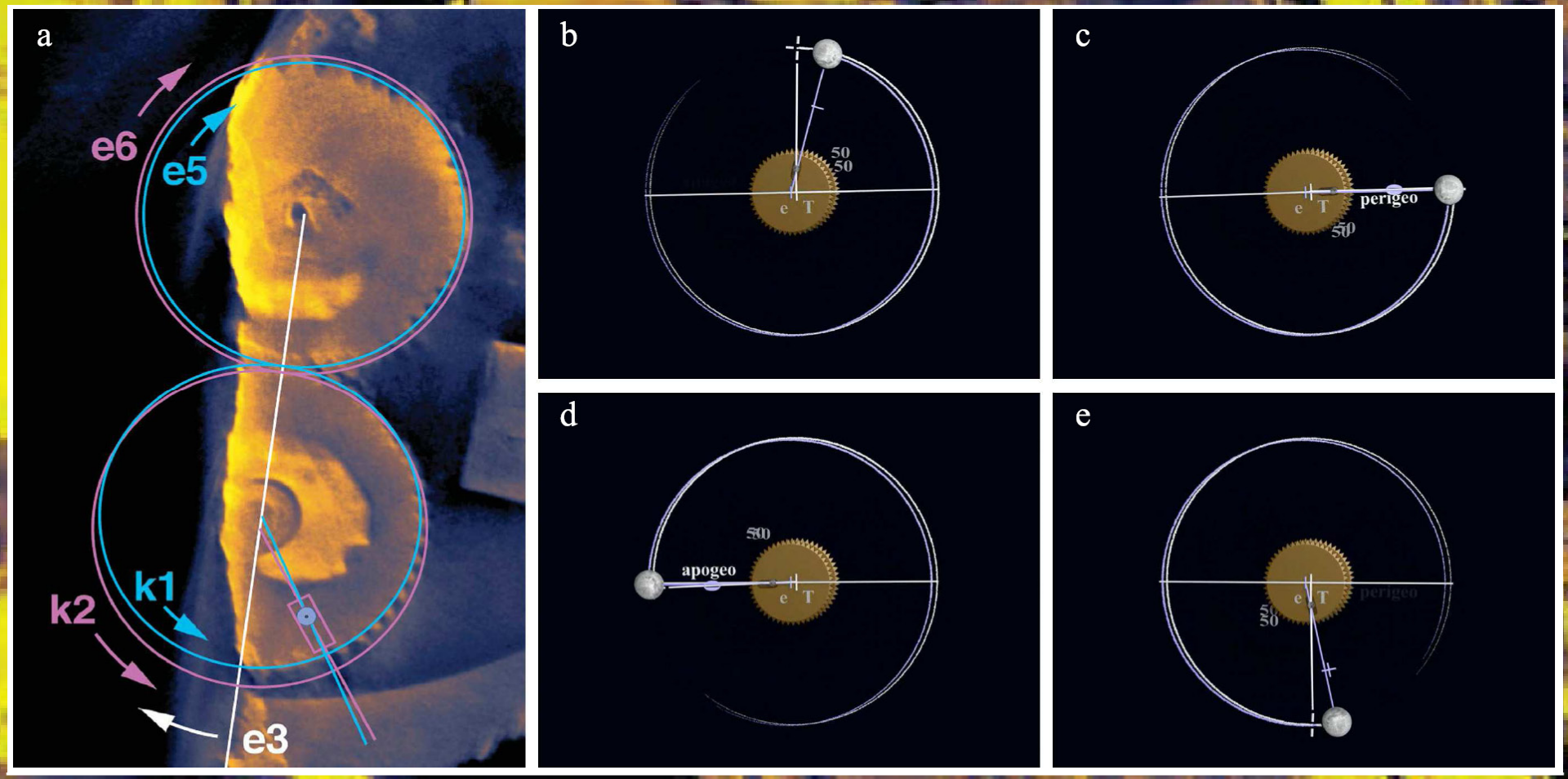


Precession





Greek Miracle ?



Hipparcus' Moon Orbit Computer

Farnese Atlas:

Hipparchus' star catalog ?

Farnese Atlas:

Hipparchus star catalog ?

Farnese Atlas is the oldest surviving pictorial Record of Western constellations

Roman times ~ A.D. 150,
presumed to represent constellations mapped in earlier Greek work

Atlas labors under the weight because he had been sentenced by Zeus to hold up the sky.

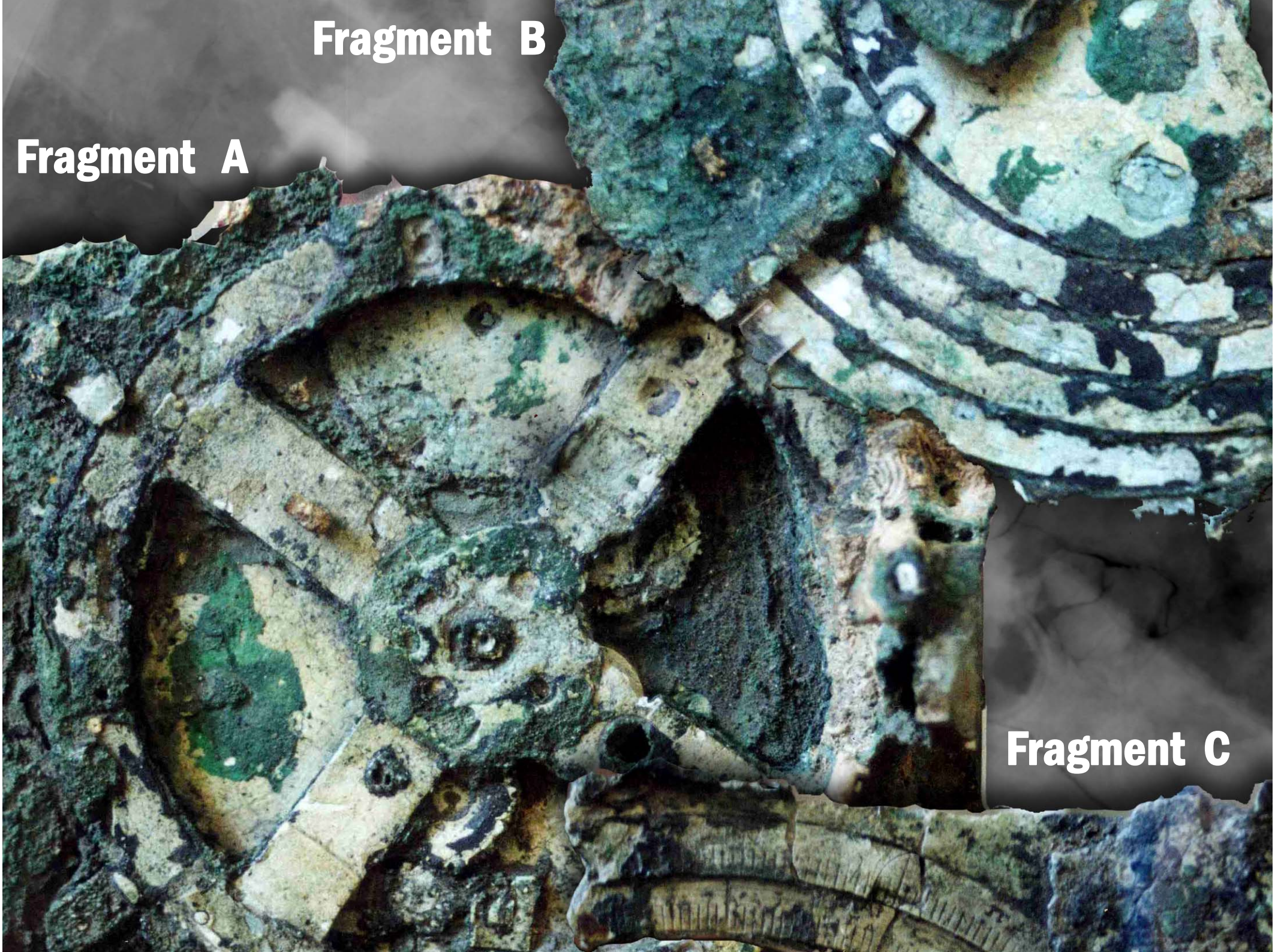
The globe shows:
- a depiction of the night sky as seen from outside the outermost celestial sphere
- low reliefs depicting 41 (42) of the 48 classical Greek constellations including:
    - Aries the ram
    - Cygnus the swan
    - Hercules

Antikythera Mechanism

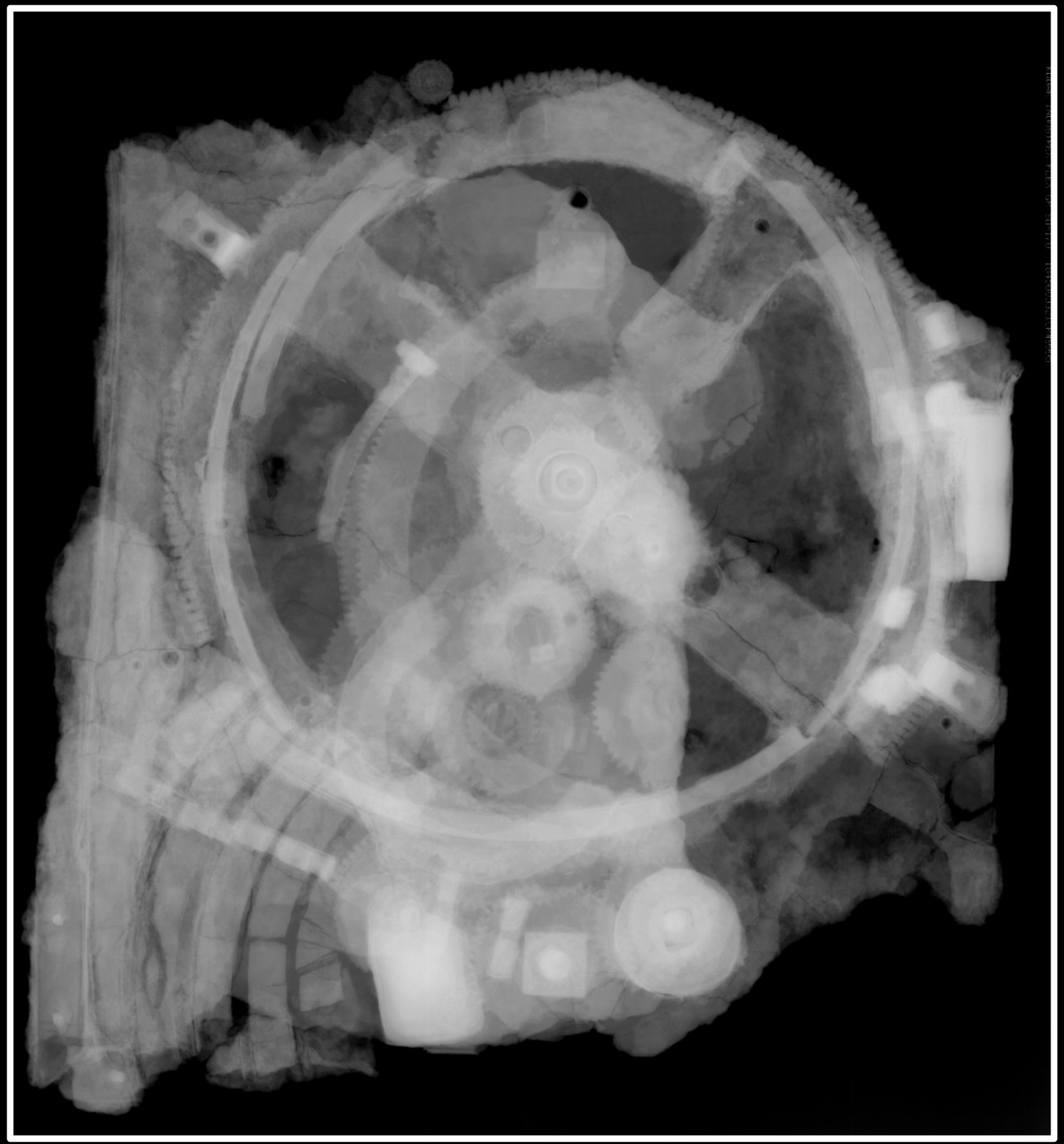
c. 150 BCE

National Archaeological Museum, Athens

Fragment C, Fragment A, Fragment B


Fragment B
Fragment A
Fragment C

Interior



AMRP
X-Tek X-ray
Tomography

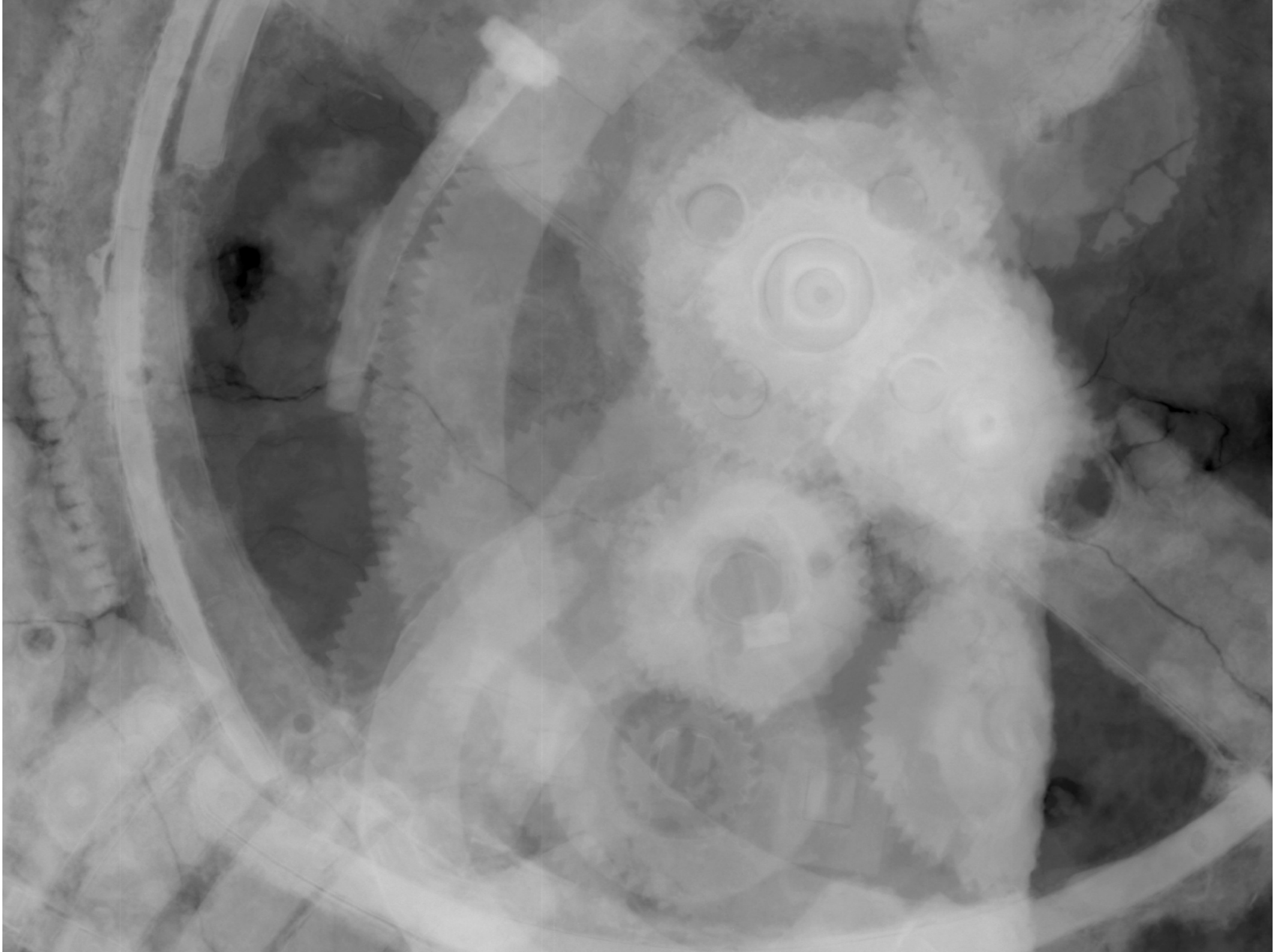
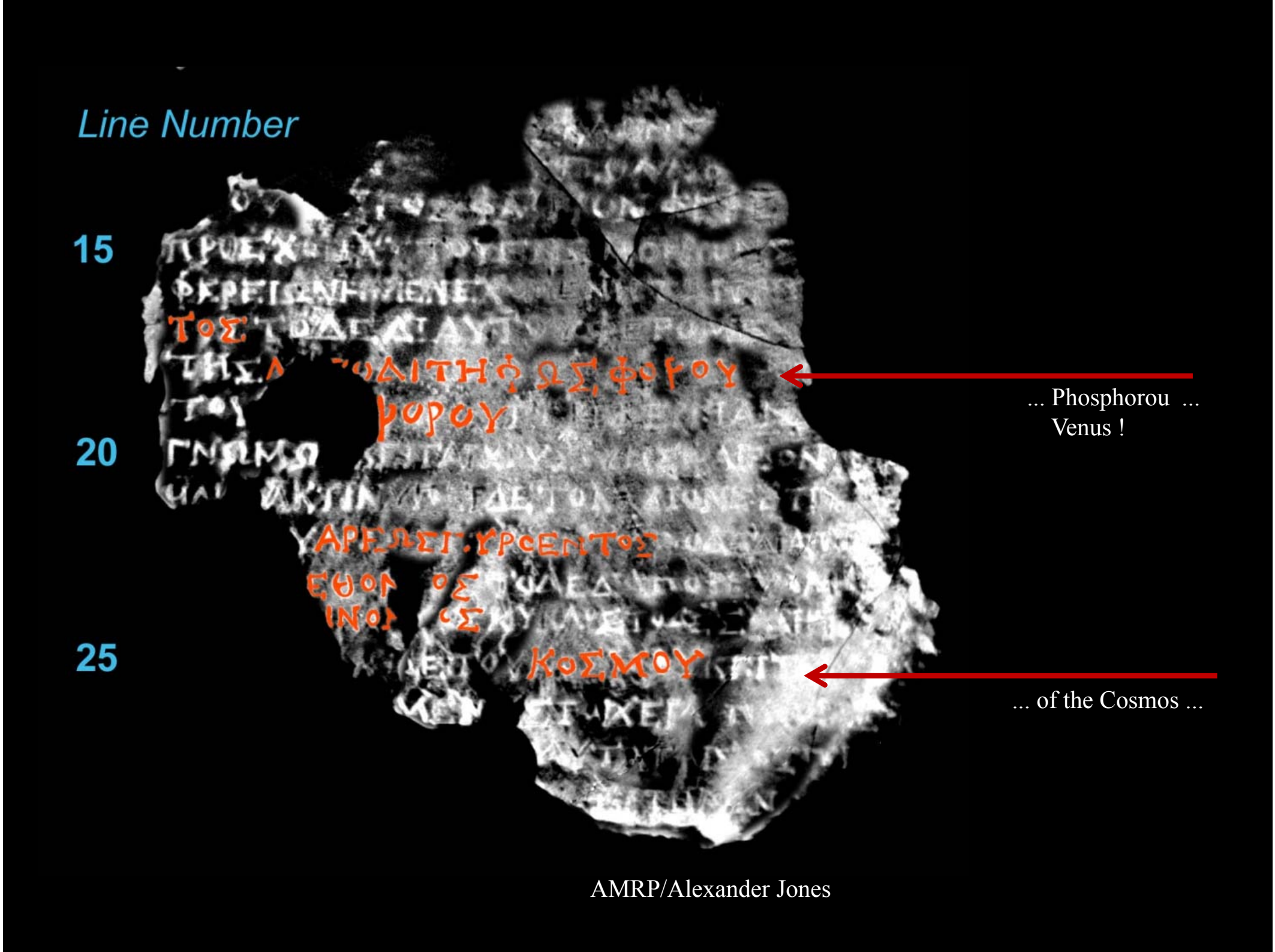


image courtesy: Tony Freeth/Images First Ltd.

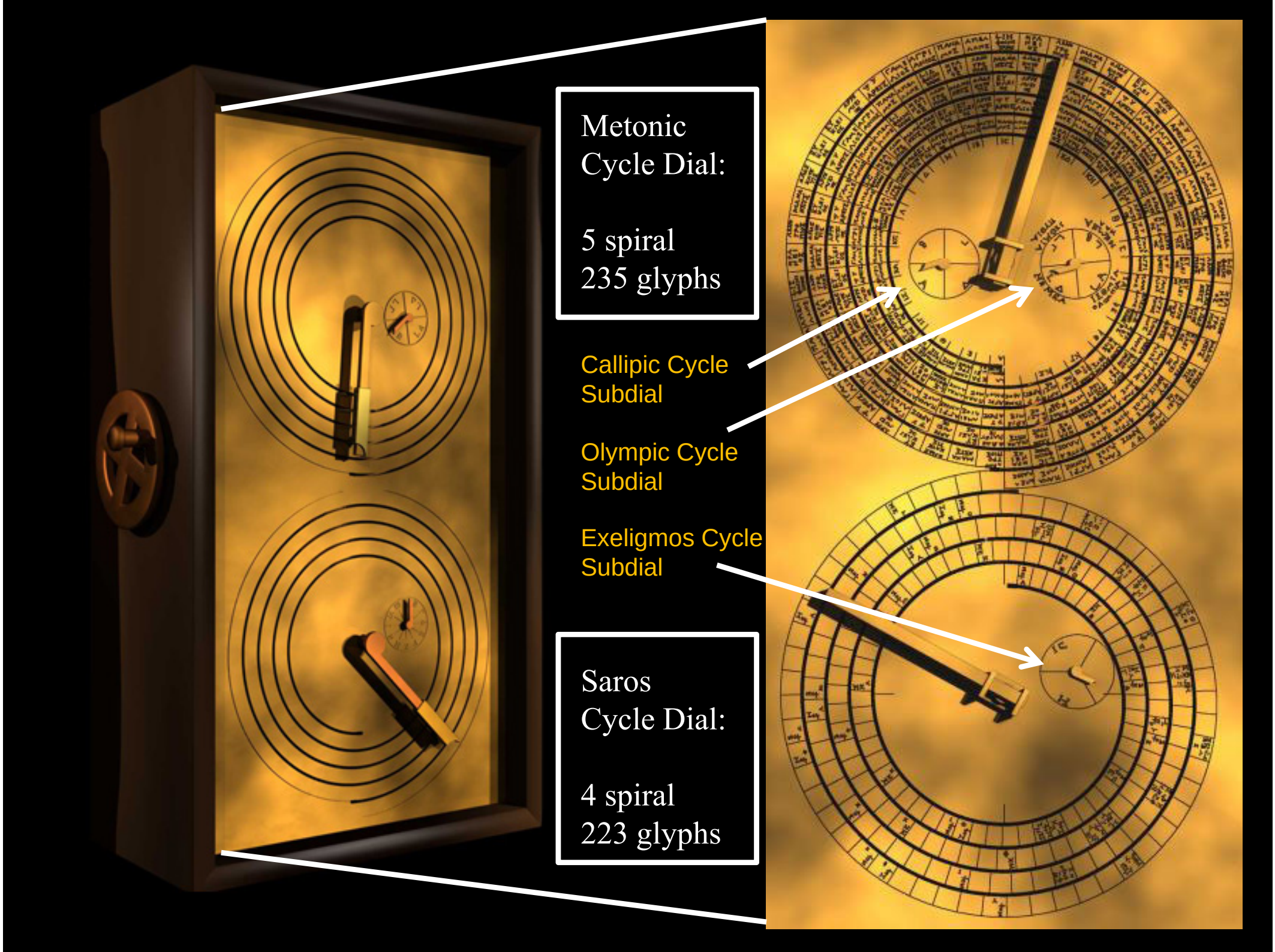

Line Number
15
20
25
... Phosphorou ...
Venus !
... of the Cosmos ...
AMRP/Alexander Jones

Technical Inscriptions:

- “Tap”; “Gnomon”; “Perforations”; “Pointers”; “Gears”;
- “Spiral divided in 235 sections …”
- “small golden ball”
- “small ball”

Astronomical Inscriptions:

- “ΣΤΗΡΙΓΜΟΣ”: stationary point planets’ retrograde motion
- “Venus approaches the Sun”
- “The Hyades set in the evening”
- “Gemini begins to rise”, …
- “ the 76 years, 19 years of the …”


Metonic
Cycle Dial:
5 spiral
235 glyphs
Callipic Cycle
Subdial
Olympic Cycle
Subdial
Exeligmos Cycle
Subdial
Saros
Cycle Dial:
4 spiral
223 glyphs

Astronomical Cycles

- **Metonic Cycle**

  multiple of Tropical Year and Synodic Month

  19 tropical years;
  235 synodic months
  254 siderial months
  6940 days

- Callippic Cycle

  more accurate multiple
  Tropical Year & Synodic Month

  4 Metonic cycles - 1 days;
  76 tropical years;
  940 synodic months

- Saros Cycle

  Eclipse cycle:
  multiple of
  Synodic, Draconic and Anomalistic month

  223 synodic;
  242 draconic;
  239 anomalistic:
  18 yrs, 11 days, 8 hrs (6585 1/3 days)

- Exeligmos Cycle

  3 Saros cycles:
  following Exeligmos cycle, eclipse returns
  at same location Earth

  669 synodic;
  726 draconic;
  717 anomalistic:
  54 yrs, 34 days (19756 days)


Saros Dial

Saros Dial

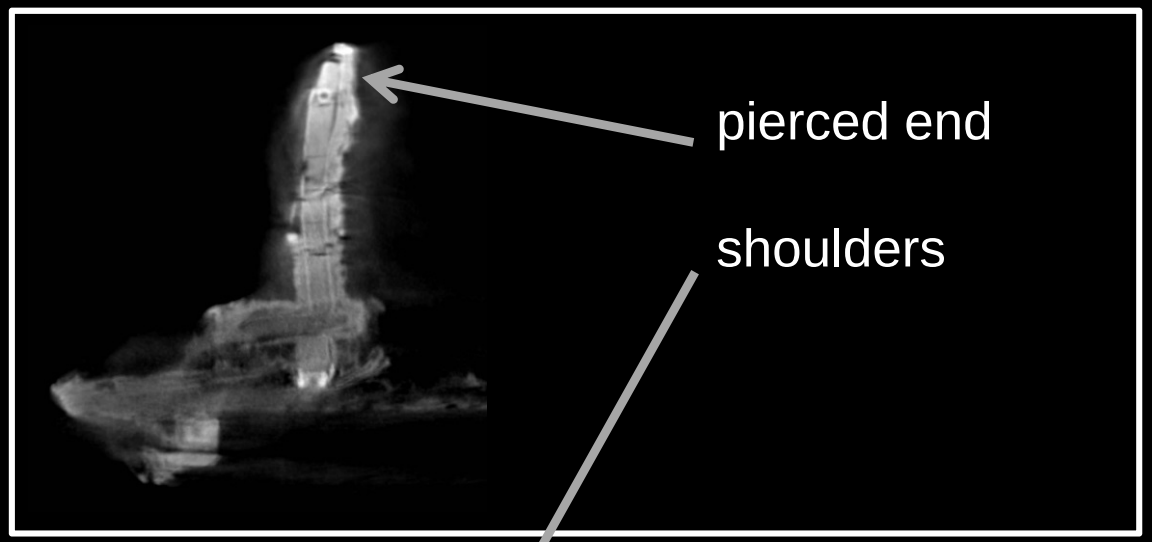
Mechanical Elements

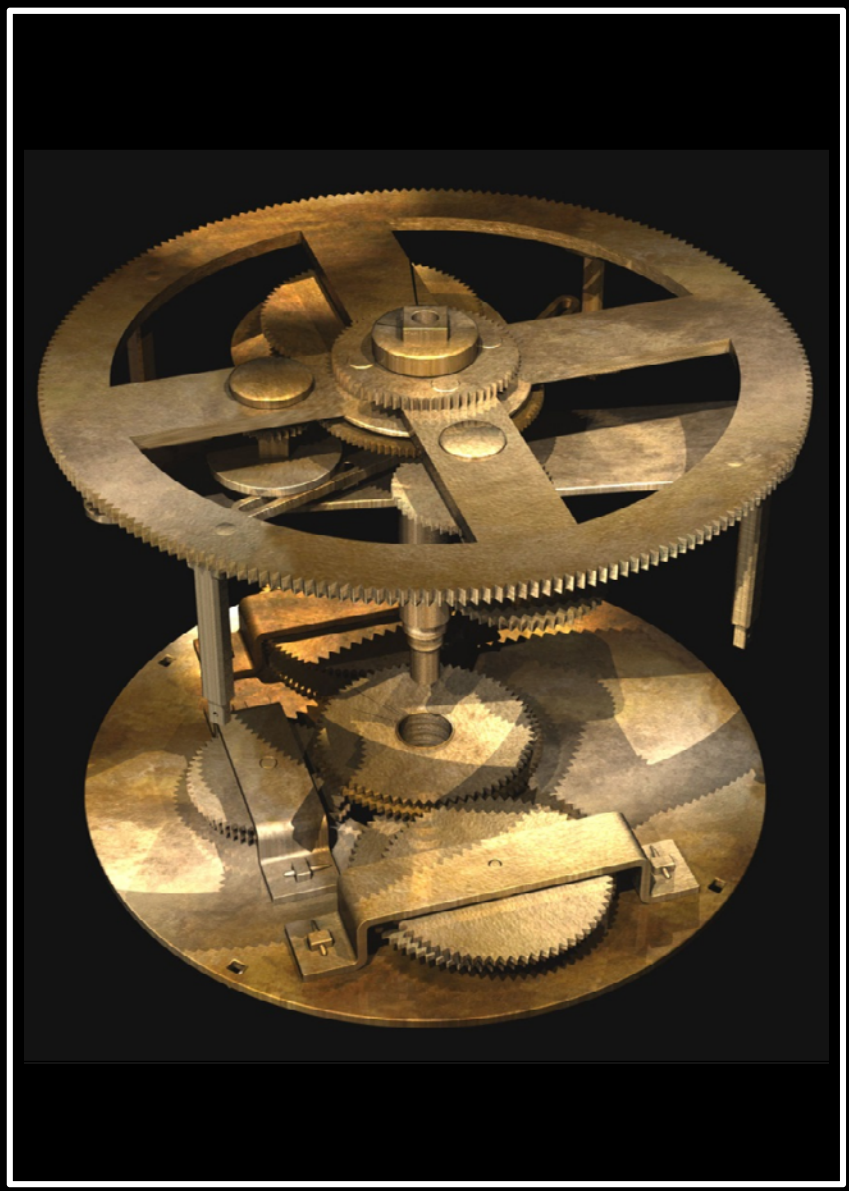
evidence of

pillars, bearing and
other fittings on the

Main Drive Wheel

Mechanical Elements





M. Wright

copper hardware models of

- **Antikythera planetarium**
- **Archimedes Sphera**

Antikythera Mechanism

may be a planetarium
following the
Cosmos of Aristoteles

Moon
Mercury
Venus
Sun
Mars
Jupiter
Saturn

A. Jones found all

5 planet names &
Moon and Sun

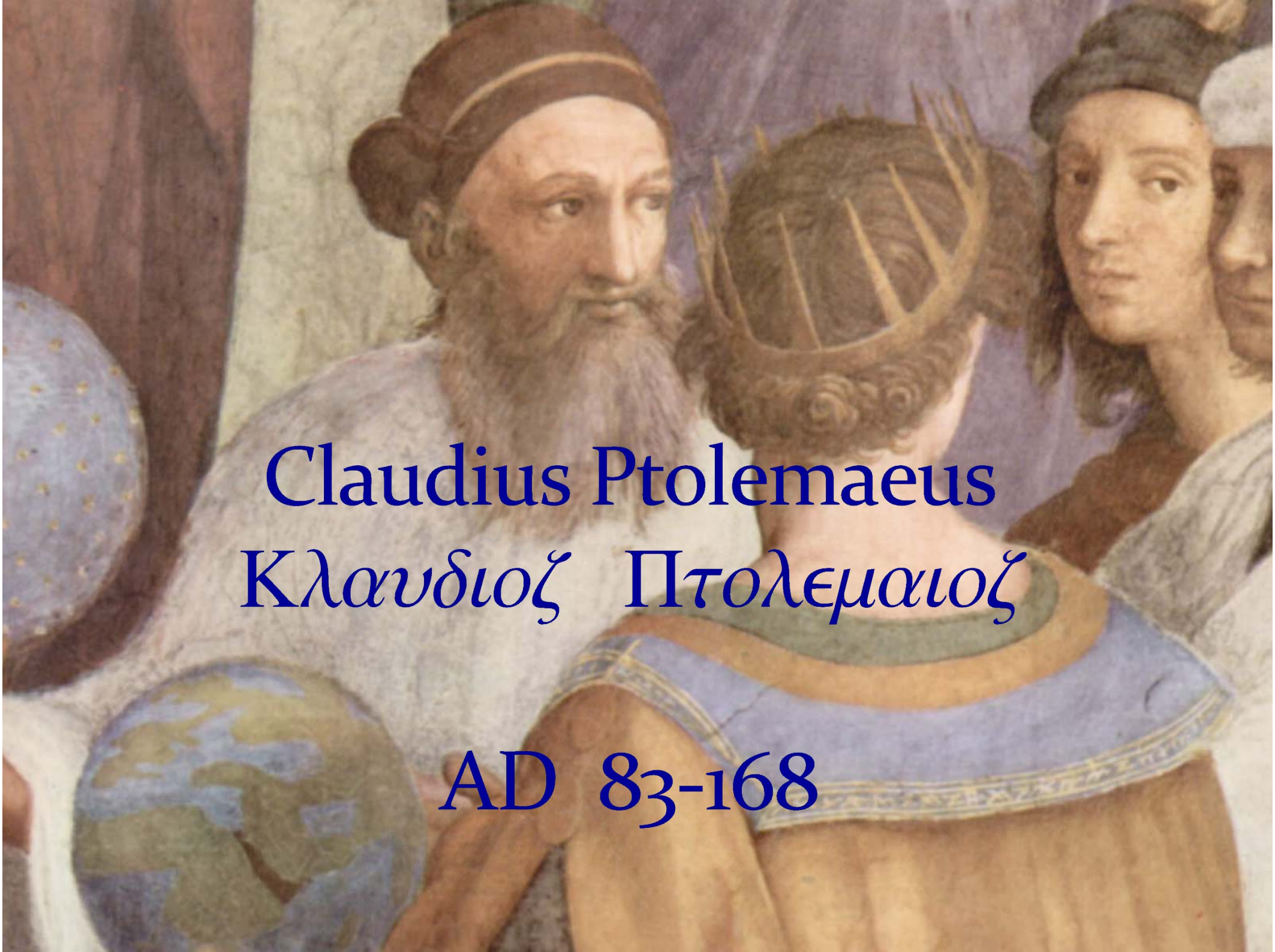
- in inscriptions:
- ordered like Cosmos
- each with descriptive & theophoric name
- e.g. Venus:
  + Phosphoros
  + star of Aphrodite

Freeth & Jones 2012
ISAW publ.

Claudius Ptolemaeus

Κλαυδιος Πτολεμαιος

AD 83-168



Claudius Ptolemaeus

Κλαυδιοζ Πτολεμαιοζ

AD 83-168

Claudius Ptolemaeus

Thebaid/Ptolemais Hermiou-Alexandria 83-168 A.D.

- Mathematician
- Astronomer
- Geographer
- Astrologer

additional interests in

- Optics
- Music
- Philosophy

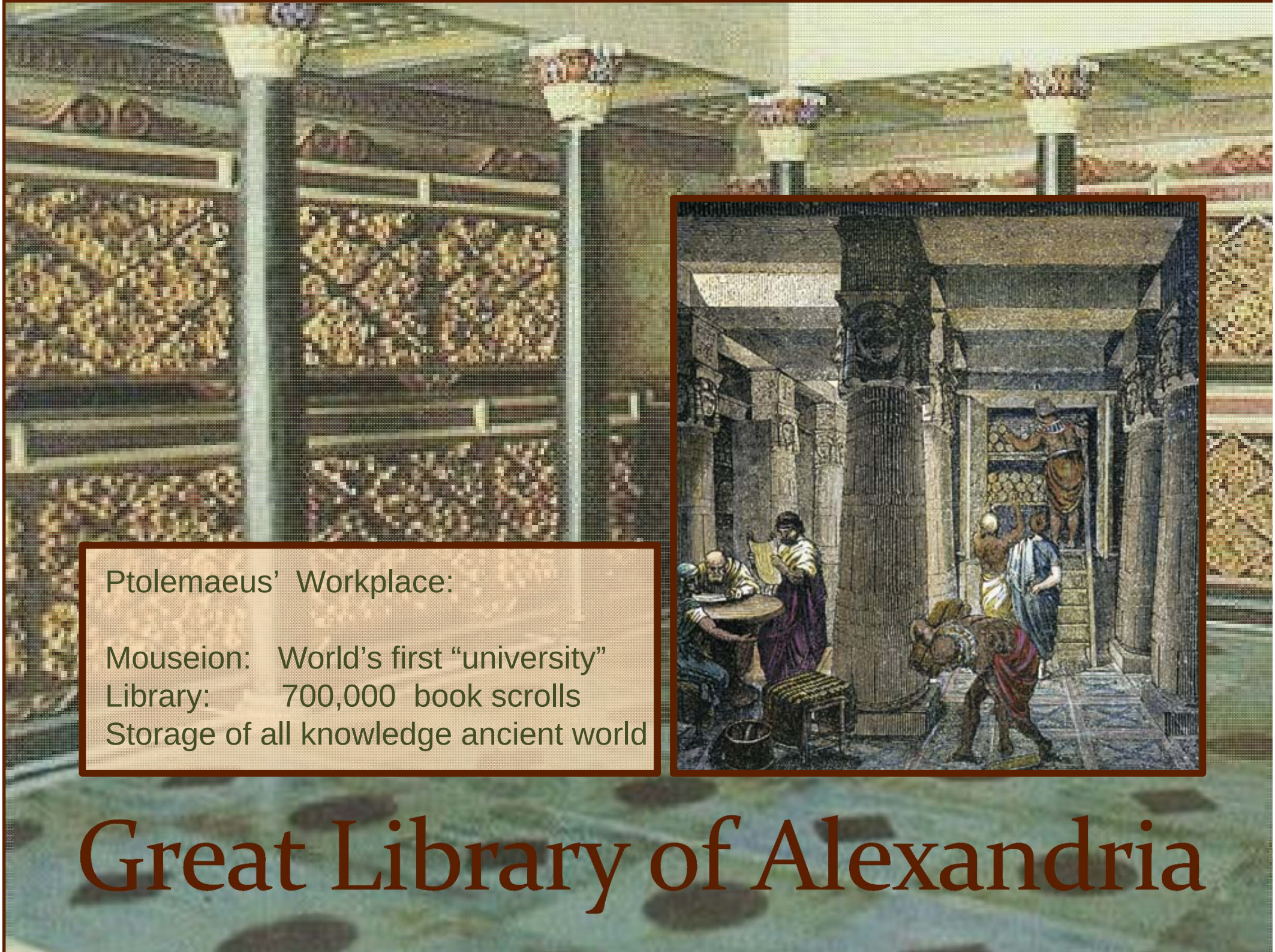
Claudius Ptolemaeus

Culmination & Synthesis
- Hellenistic Astronomy
- Geography in Classical World

Lasting and dominant influence,
- > 1500 yrs,
- European & Islamic science

Mouseion: the Library

Alexandria: Birthplace of the Western Mind



Ptolemaeus' Workplace:

Mouseion: World's first "university"
Library: 700,000 book scrolls
Storage of all knowledge ancient world

Great Library of Alexandria

Ptolemy's Bibliography

Almagest (13 books)	astronomy
Geography (8 books)	geography
Optics (5 books)	physics
Tetrabiblos (4 books)	astrology
Harmonics (3 books)	
Planetary Hypotheses (2 books)	astronomy
Analemma	
Canobic Inscription	
Planispherium	astronomy
Other astronomical works	
Lost works	

Almagest

Geografia

Tetrabiblos

Geografia

Map 147

Geografia

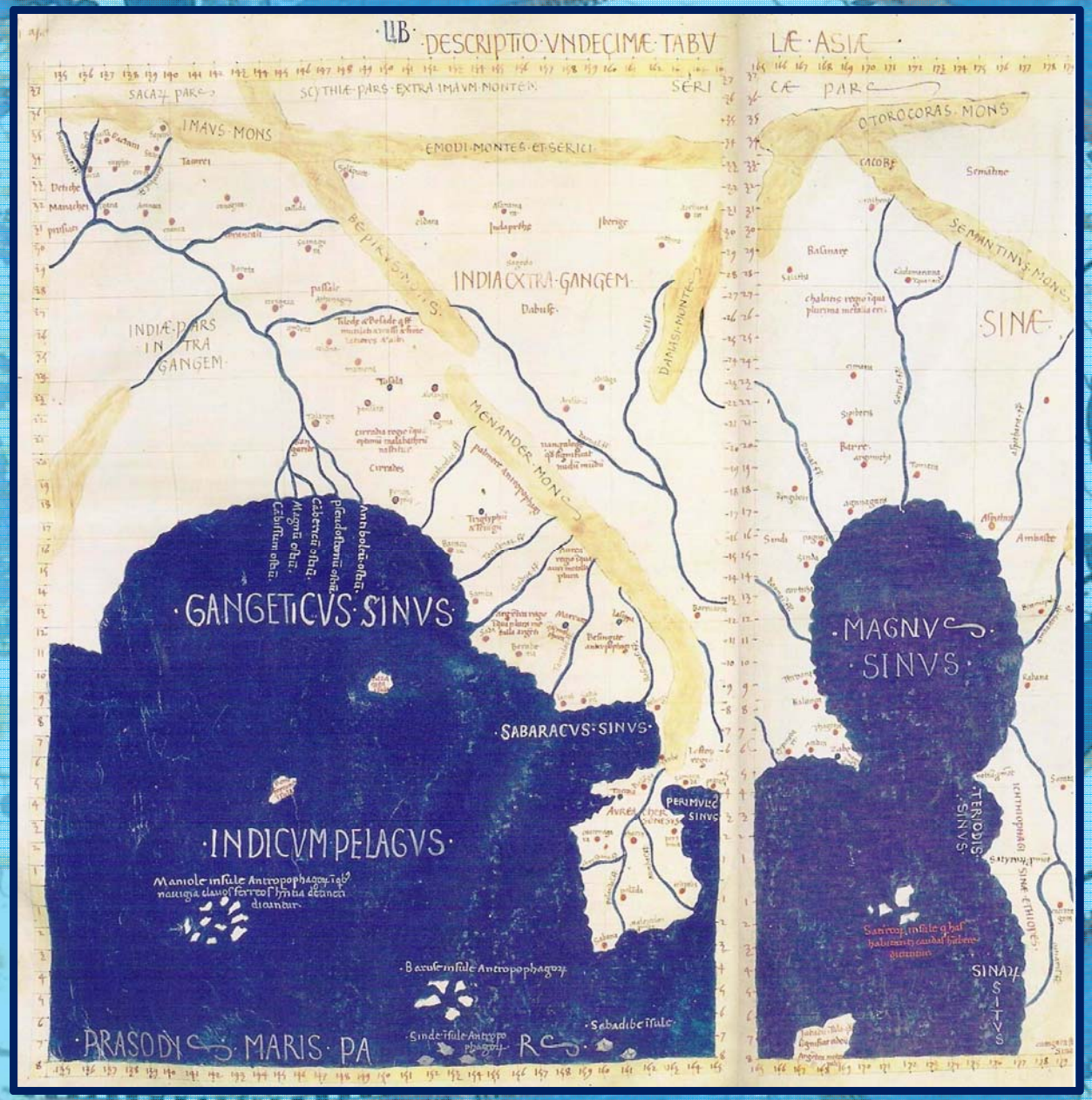
- Standard of geographical theory until the 1500's, until age of exploration
- Only surviving geographical treatise from antiquity
- Represents whole corpus of geographical knowledge acquired in Graeco-Roman antiquity
- Mapping earth with mathematical procedures from astronomy: coordinates, parallels, meridians
- Divided into 8 books:
  - Book 1: Introduction and directions to recreate Ptolemy's Map
  - Books 2-7: Latitudinal and longitudinal data for ~ 8,000 cities
  - Book 8: Description of 28 regional maps

Map 147

Map of Ancient India:

crucial importance for development Roman trade network with India

Geografia

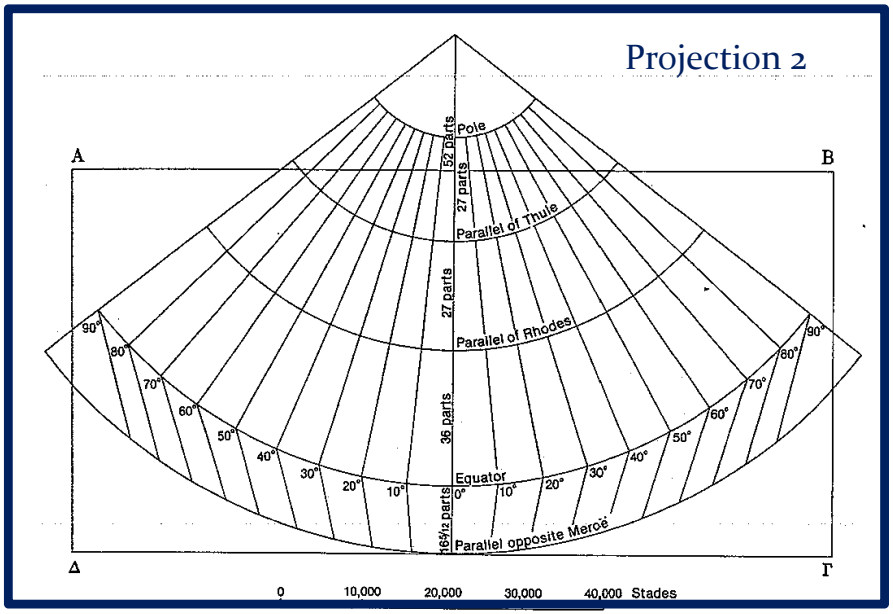


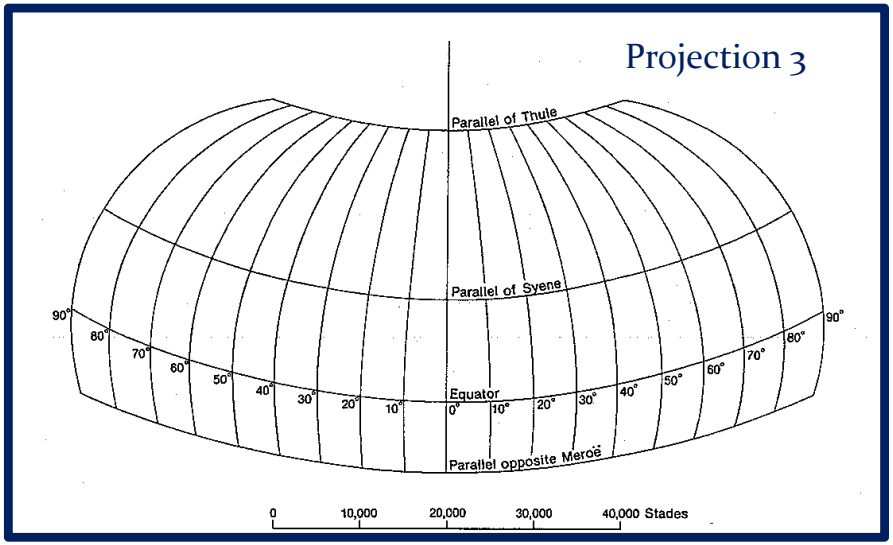
Geografia - Oikoumene/Οικουμενε

- Based on the work of his immediate predecessor,
  Marinus of Tyre (80-130 A.D.)
- Combined data from a variety of sources
- Ptolemy was the first geographer to use longitude and latitude to create coordinates
- Derived 21 latitude lines – fairly accurate
- Described 4 different projections
- Believed the *oikoumene* (inhabited world) to span
  180 degrees (longitude) of the earth's 360
- Limits of the *oikoumene*
  - Northern bound: 63°N (the Thule parallel)
  - Southern bound: 16°25'S
    (the parallel opposite the equator from the one running through Meroë)
  - *Oikoumene* stretches from
    the Canary Islands in the west to China in the east

Geografia: four Map Projections

- Projection 1
  - Straight meridians & Straight parallels
  - Very similar to Marinus' map
- Projection 2
  - Straight meridians & Curved parallels
  - Preferred method of Ptolemy's successors
  - Constant scale in relation to Rhodes parallel
  - 36+1 parallel meridians, each 5 degrees apart
- Projection 3
  - Curved meridians & Straight parallels
  - made extreme parallels more accurate
- Projection 4
  - View of globe from distance
  - External rings represent latitude lines



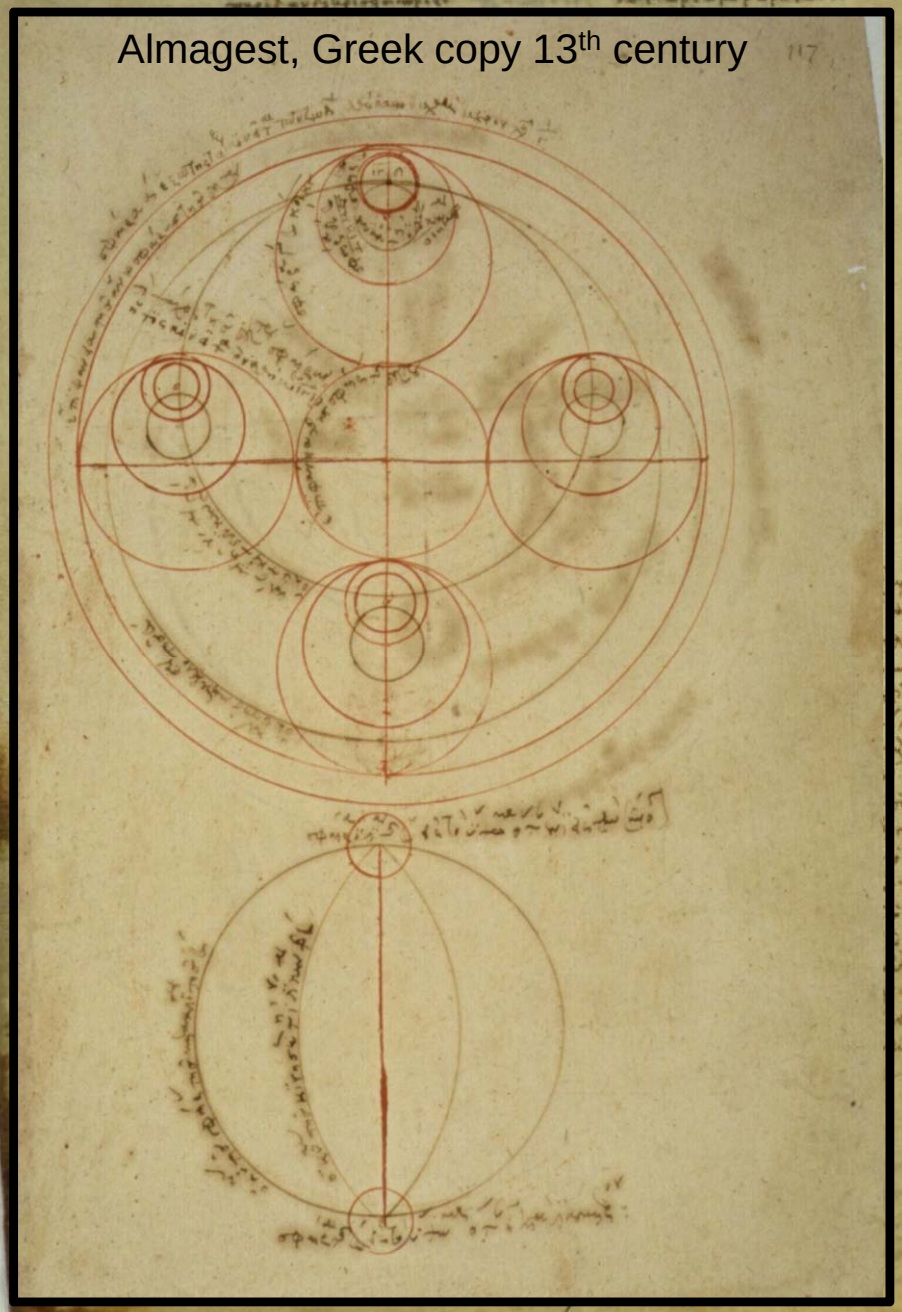


Μαθηματικη Συνταξιζ

Almagest - the Greatest

Almagest, Greek copy 9th century

Μαθηματικη Συνταξις - Almagest



Almagest, Greek copy 13th century

"The Great Book"

Most Important & Influential Astronomical Work of Antiquity

Mathematical and Astronomical treatise proposing the complex motions of stars and planetary paths

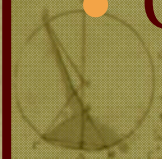
Written in 147 / 148 A.D.:
inscription in Canopus, by Ptolemaeus

Thirteen Books

Original in Greek:
Mathematike Syntaxis - Mathematical Treatise
He Megale Syntaxis - "The Great Treatise"

Best known by its Arab name:
Almagest - "The Great Book"

Almagest the Greatest



- One of the most influential scientific works in history

  (along with Euclid's "Elements", Copernicus' "Revolutionibus",
  Galilei's "Dialogues" Newton's "Principia",
  Darwin's "Origin of Species")

- One of most influential books of all time

  (perhaps only after Bible, Qur'an,
  along with Euclid's "Elements", ...)

Almagest the Greatest

- Masterwork technical exposition
- Brilliant synthesis

Theoretical Astronomy

⟷

Practical Handbook computation Ephemerides

Almagest the Greatest

- Systematic methodology

Observational Data

Numerical parameters planetary models

Construction tables celestial phenomena

(solar, lunar & planetary positions; solar & lunar eclipses, ...)

Almagest the Greatest

- More than any other book, demonstrated

complex phenomena of heavens

⟺

demonstratable & observable regularities

⟺

underlying mathematical description

⟺

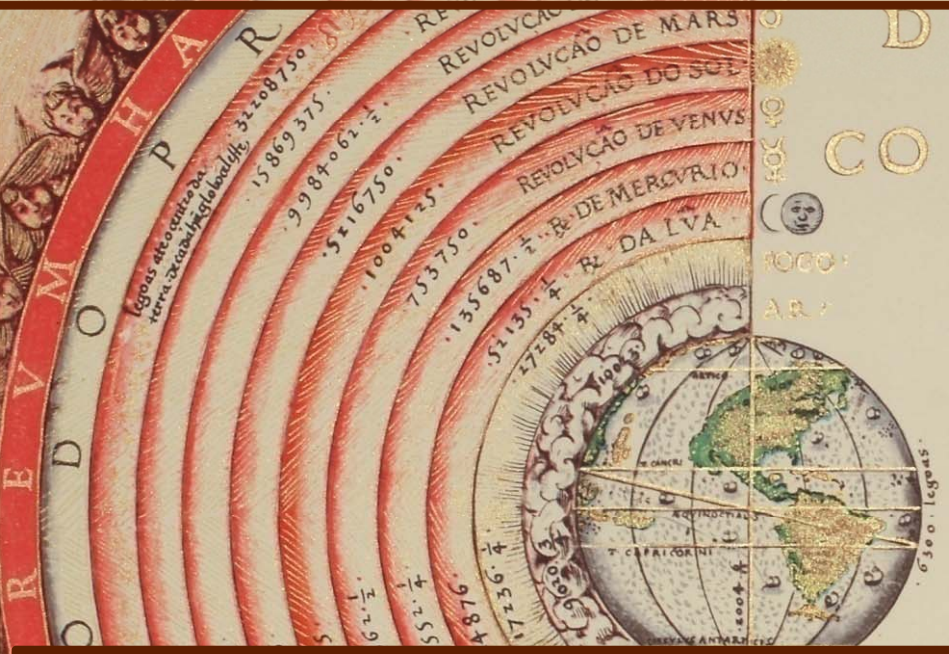
predictions celestial events

Implication:

Secrets other aspects of our world

also understandable via underlying regularities

Geocentric Universe

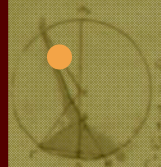


Ptolemaeus' Geocentric Universe is one of the 2 world world systems under discussion in Galileo Galilei's book (1632)

Dialogue Concerning the Two Chief World System

It had to give way to the heliocentric Universe, 1500 yrs after the Almagest

Almagest the Greatest

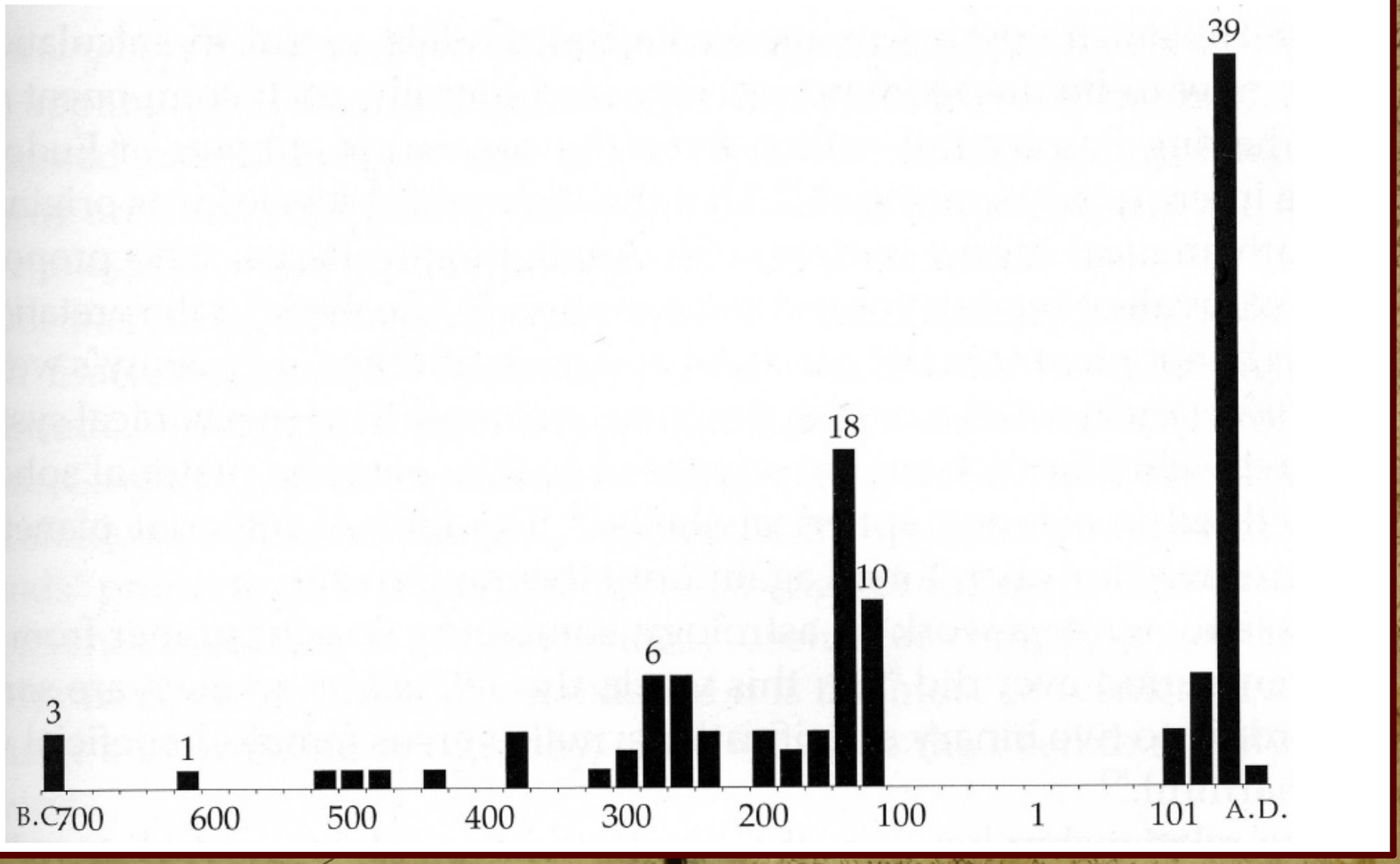


Success Almagest:

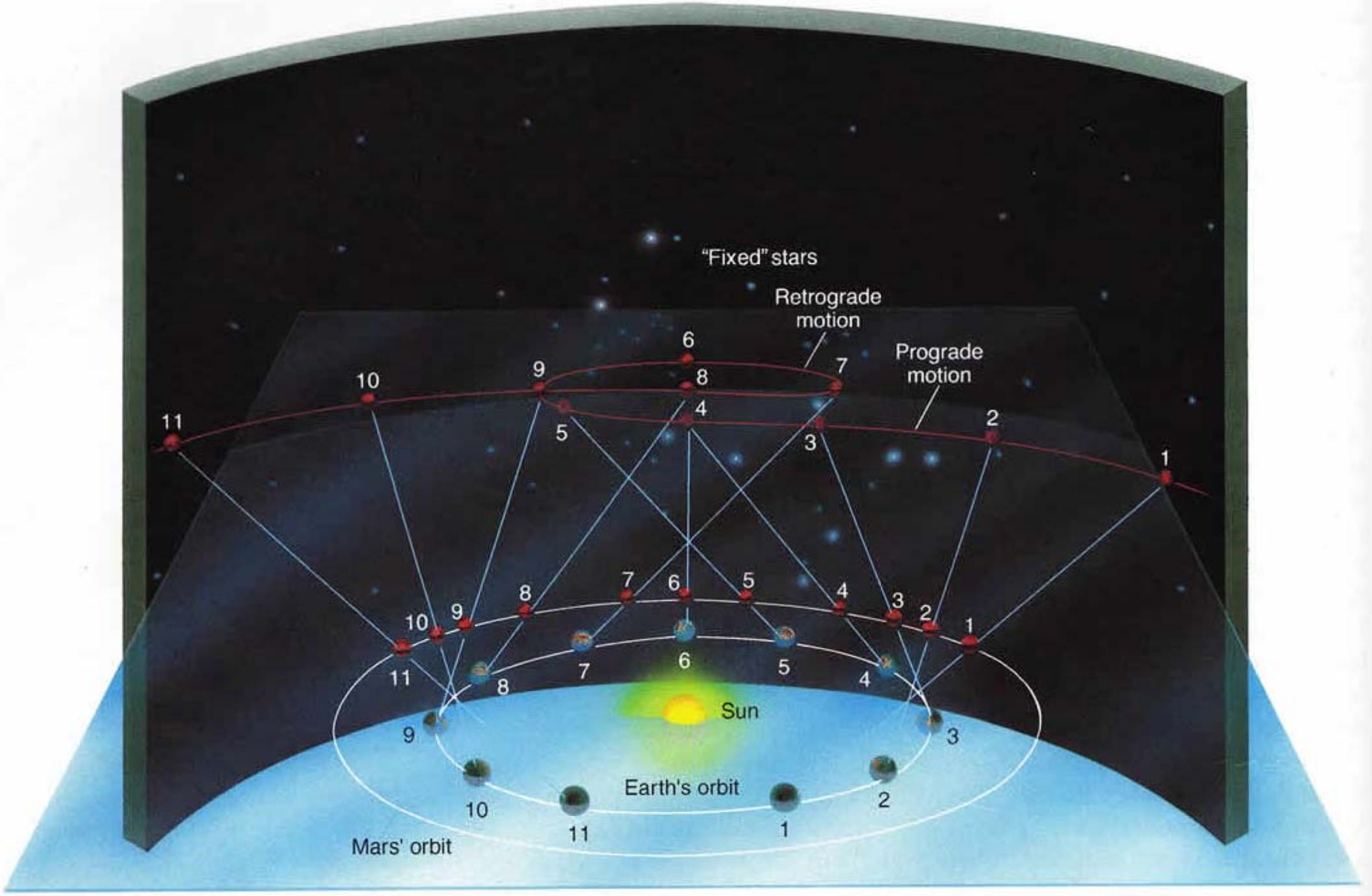
Loss of most of work scientific predecessors:
being obsolete, they ceased to be copied

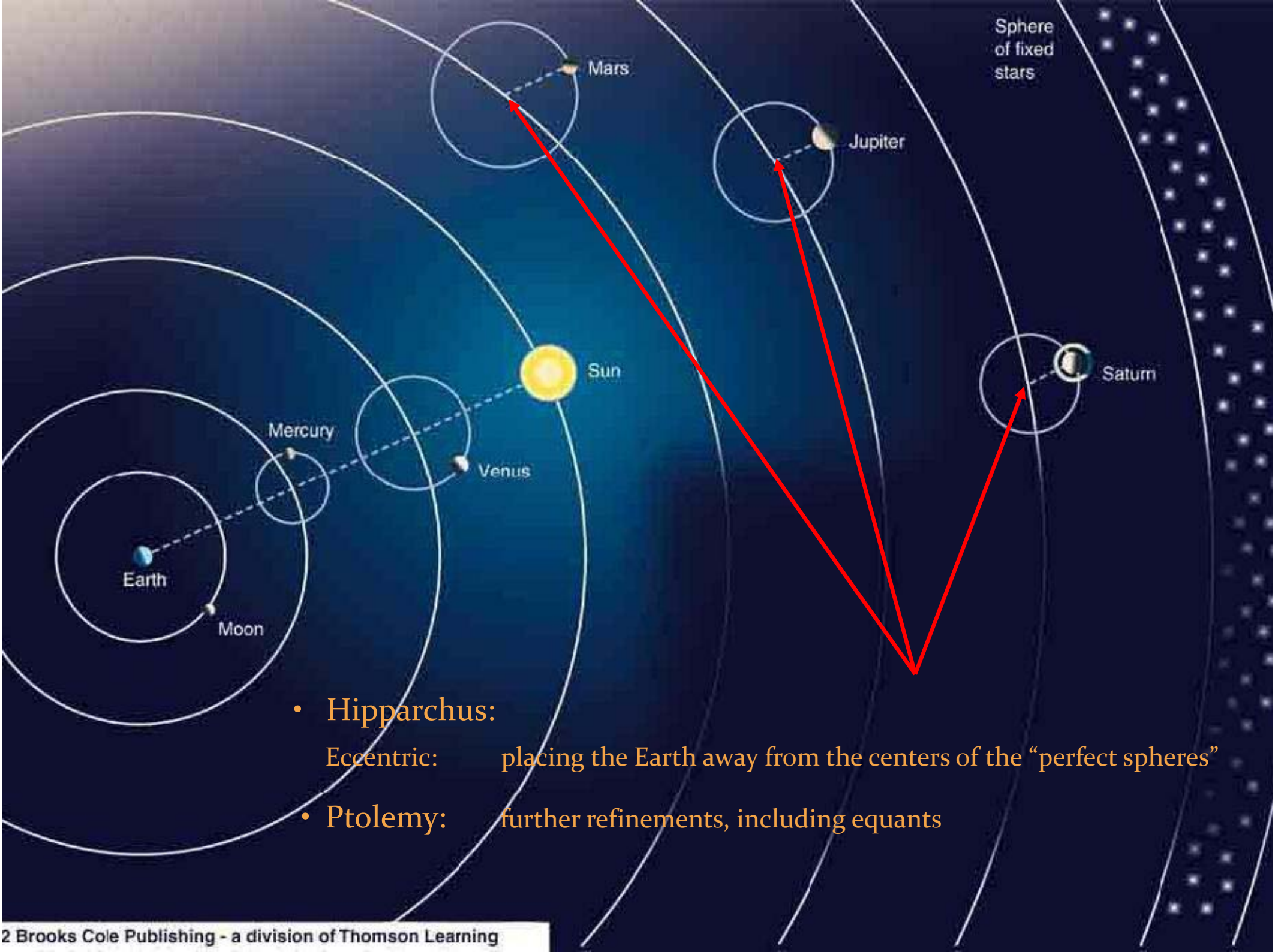
Is this true ?

Almagest the Greatest



Epicyclic Theory


"Fixed" stars
Retrograde motion
Prograde motion
Sun
Earth's orbit
Mars' orbit
1
2
3
4
5
6
7
8
9
10
11

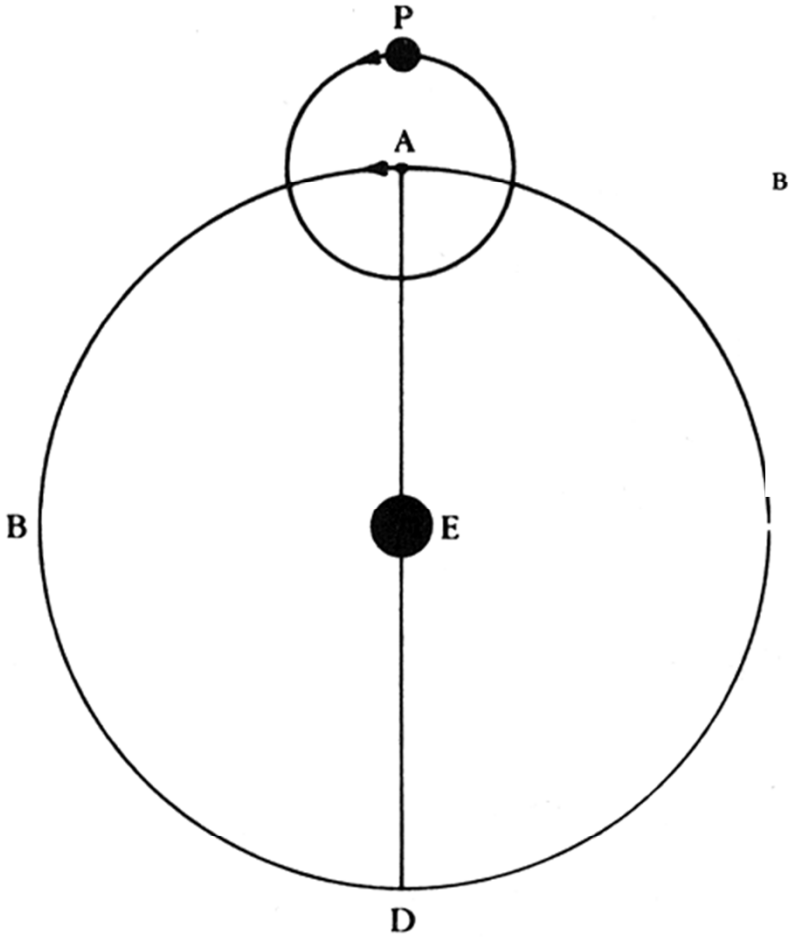


- Hipparchus:

  Eccentric: placing the Earth away from the centers of the "perfect spheres"

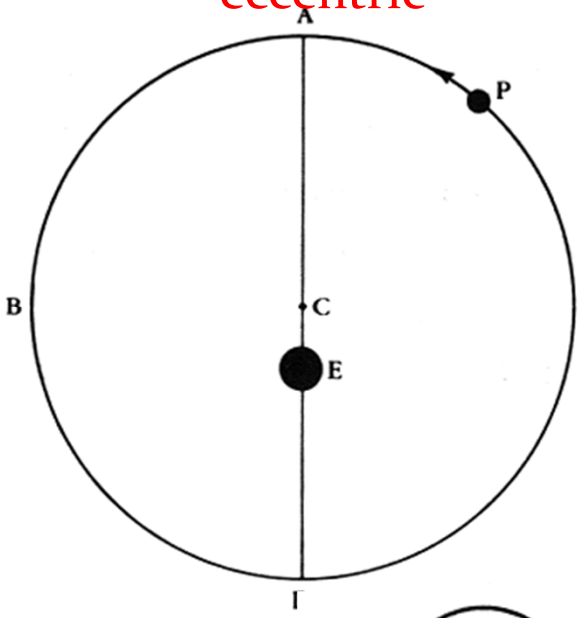
- Ptolemy: further refinements, including equants

Ptolemaeus Epicycle Theory

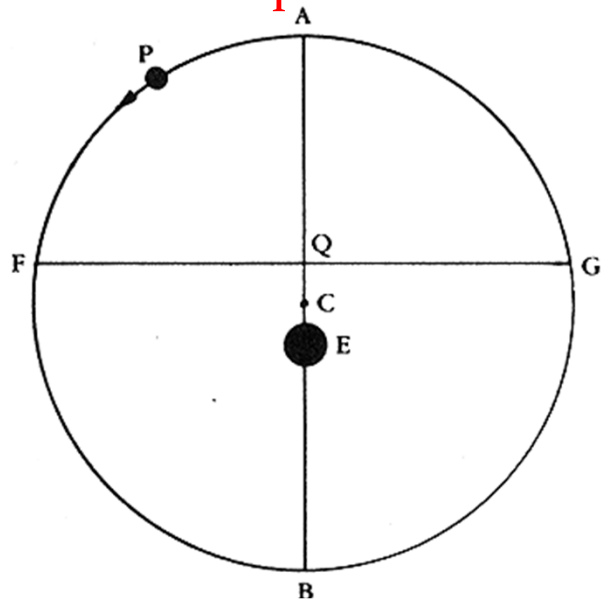


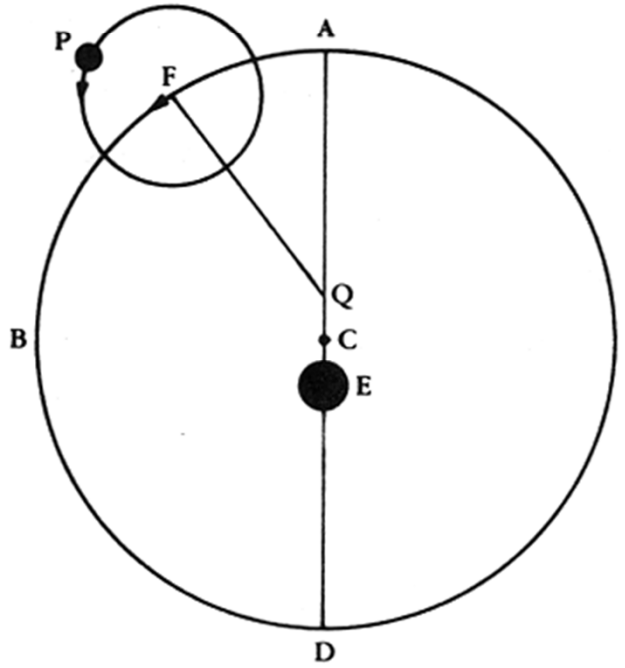
epicycle (basic)

eccentric

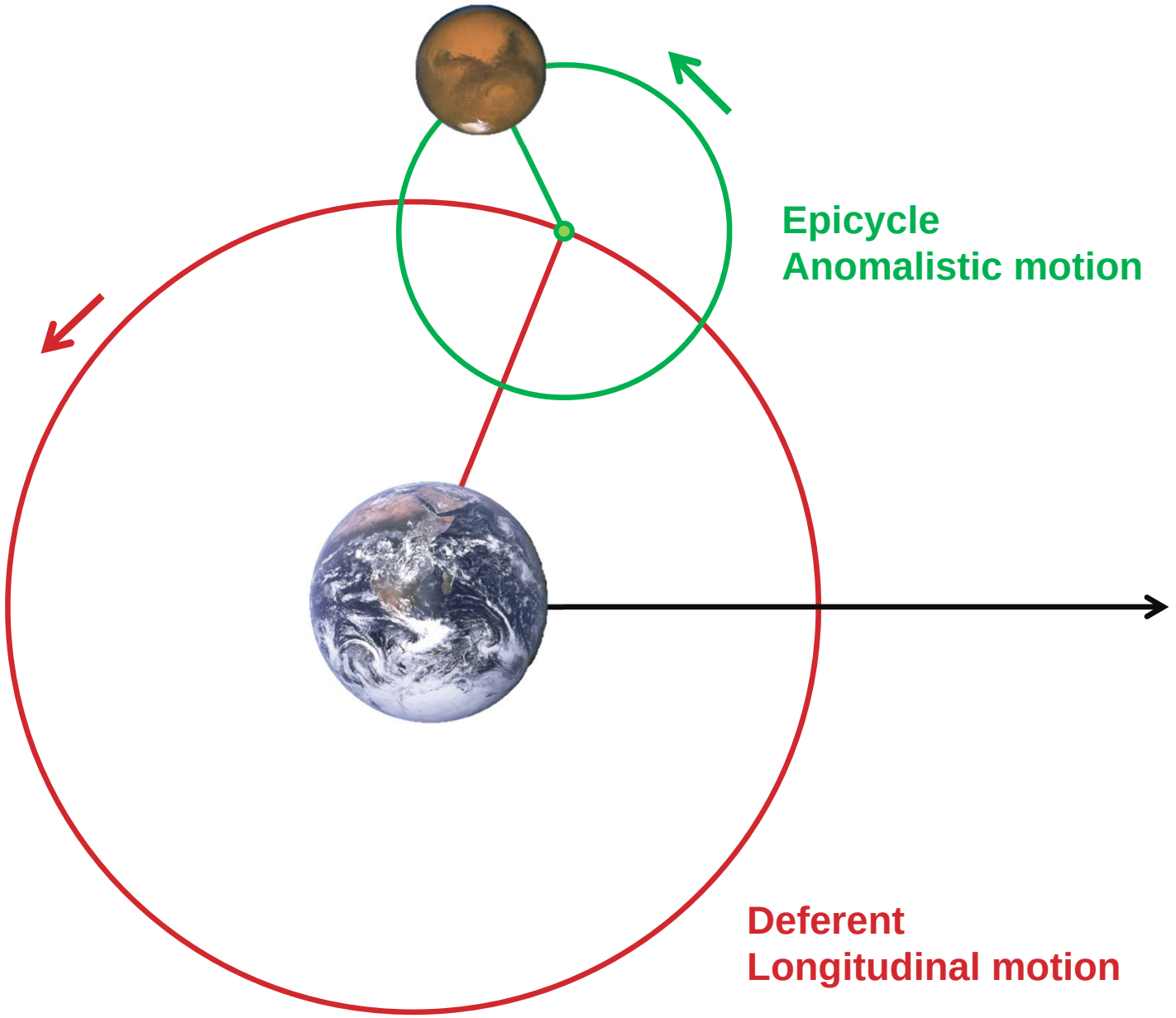


equant

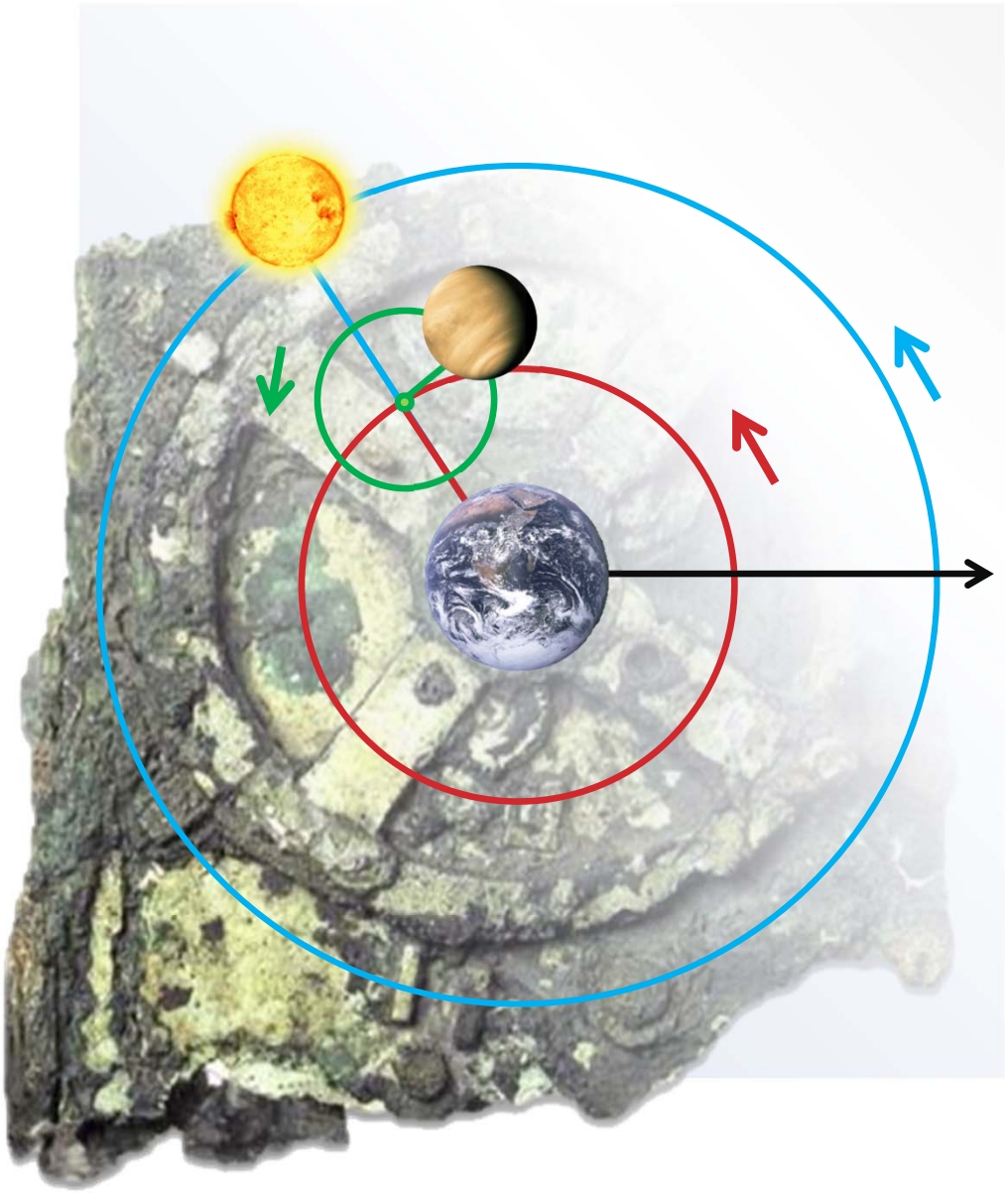


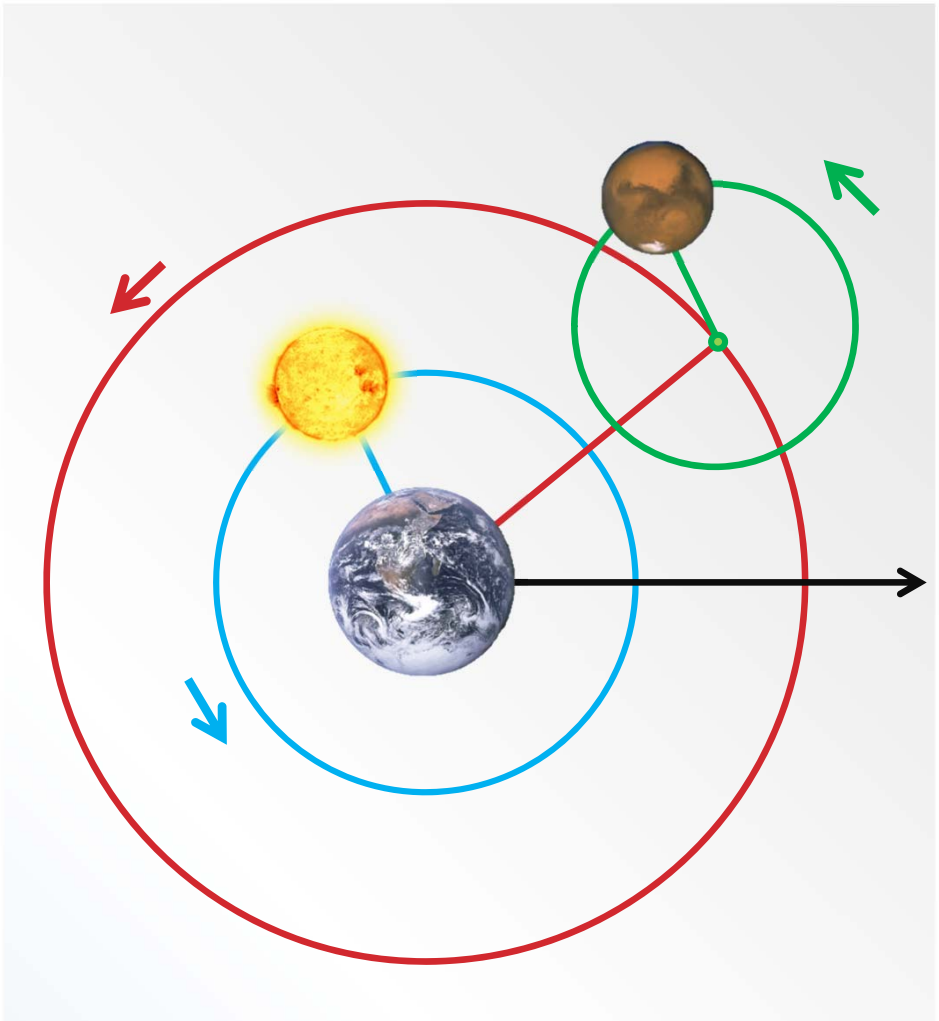


Early geometric planetary models

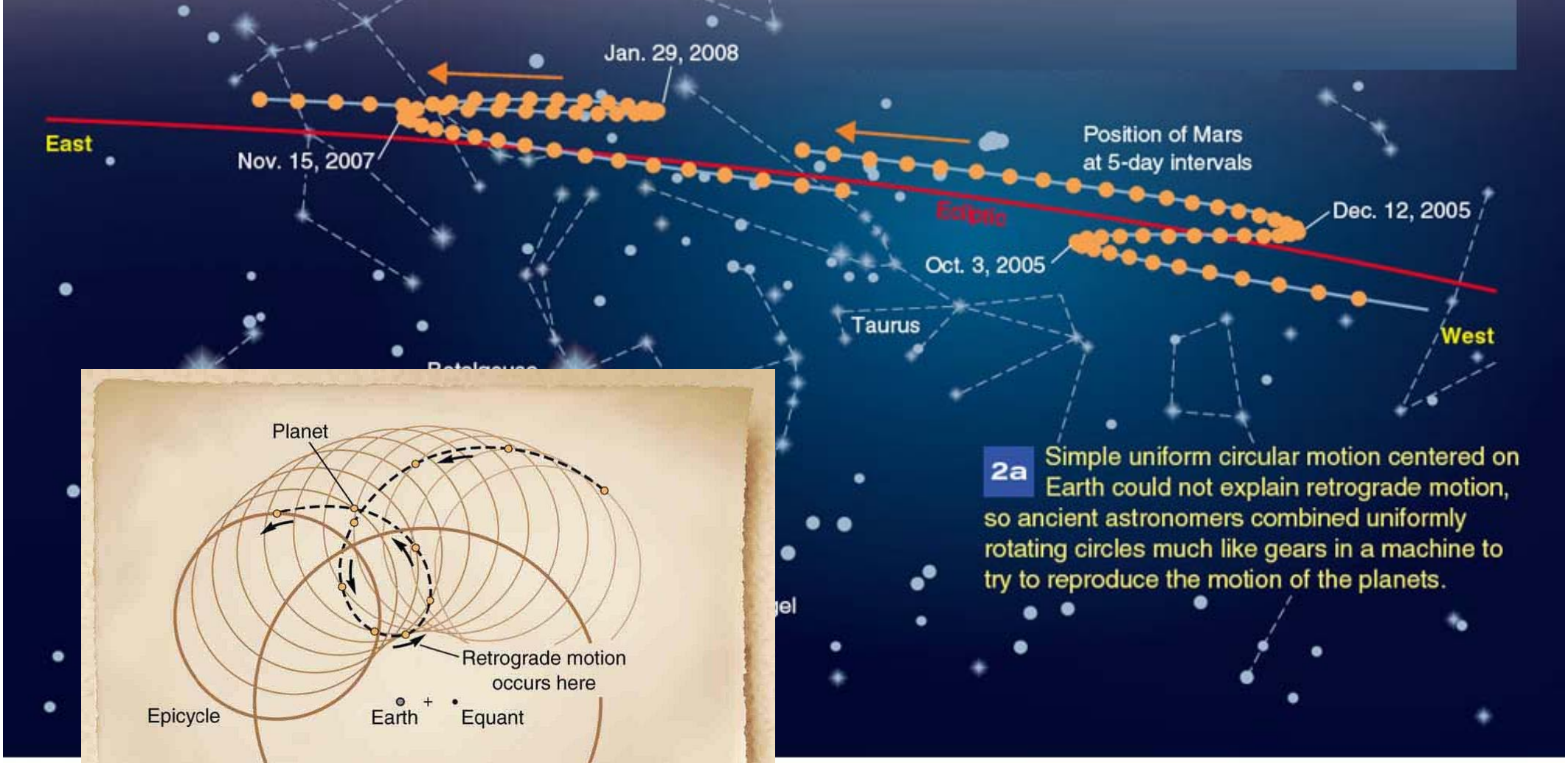


The inferior and superior planets





Period of time = Number of anomalistic periods
+ Number of longitudinal periods



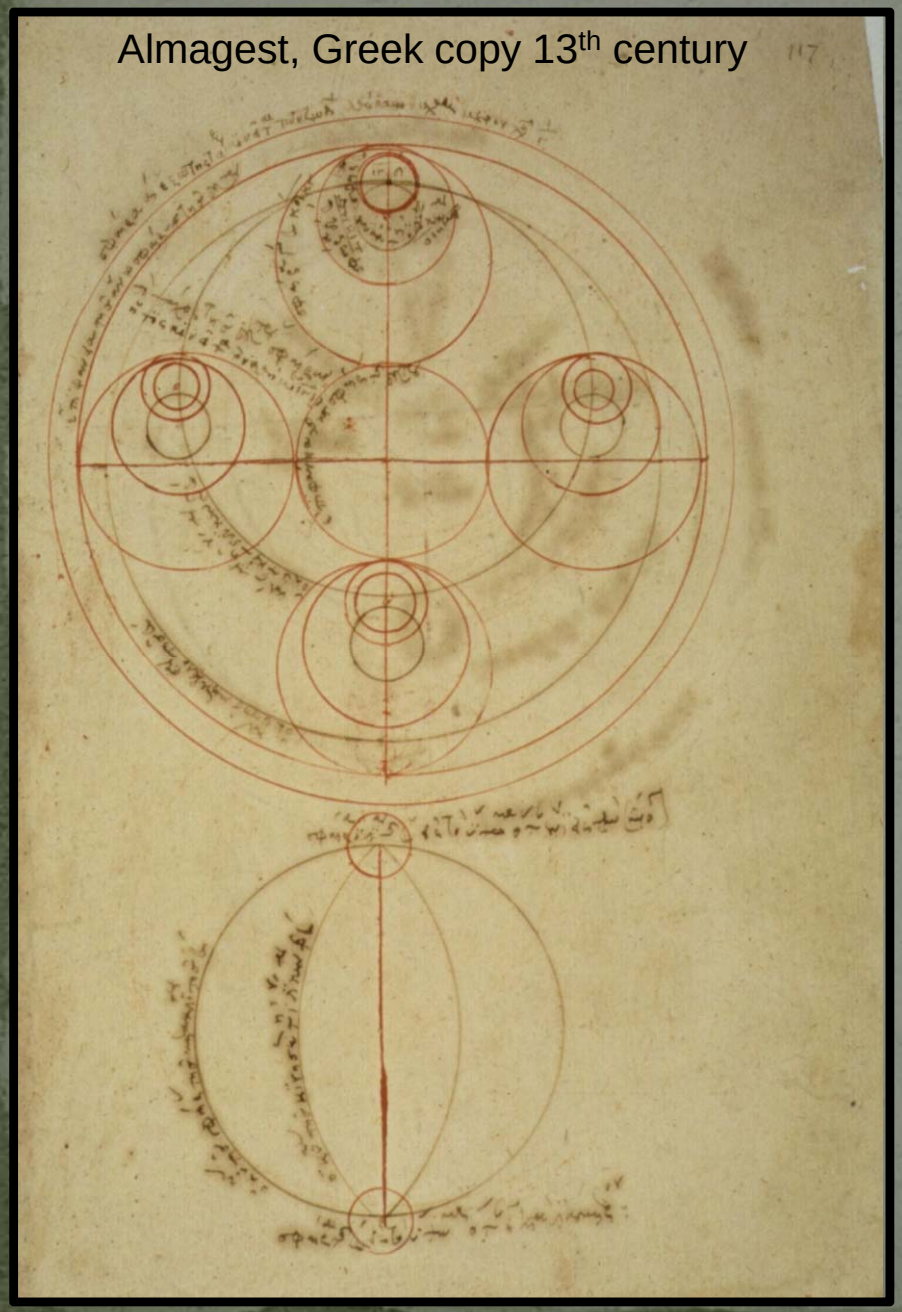
Ptolemaeus Epicycle Theory

Almagest

Η Μεγαλη Συνταξις

Μαθηματικη Συνταξις

Syntaxis - Almagest


Almagest, Greek copy 13th century

"The Great Book"

most Important & Influential Astronomical Work of Antiquity

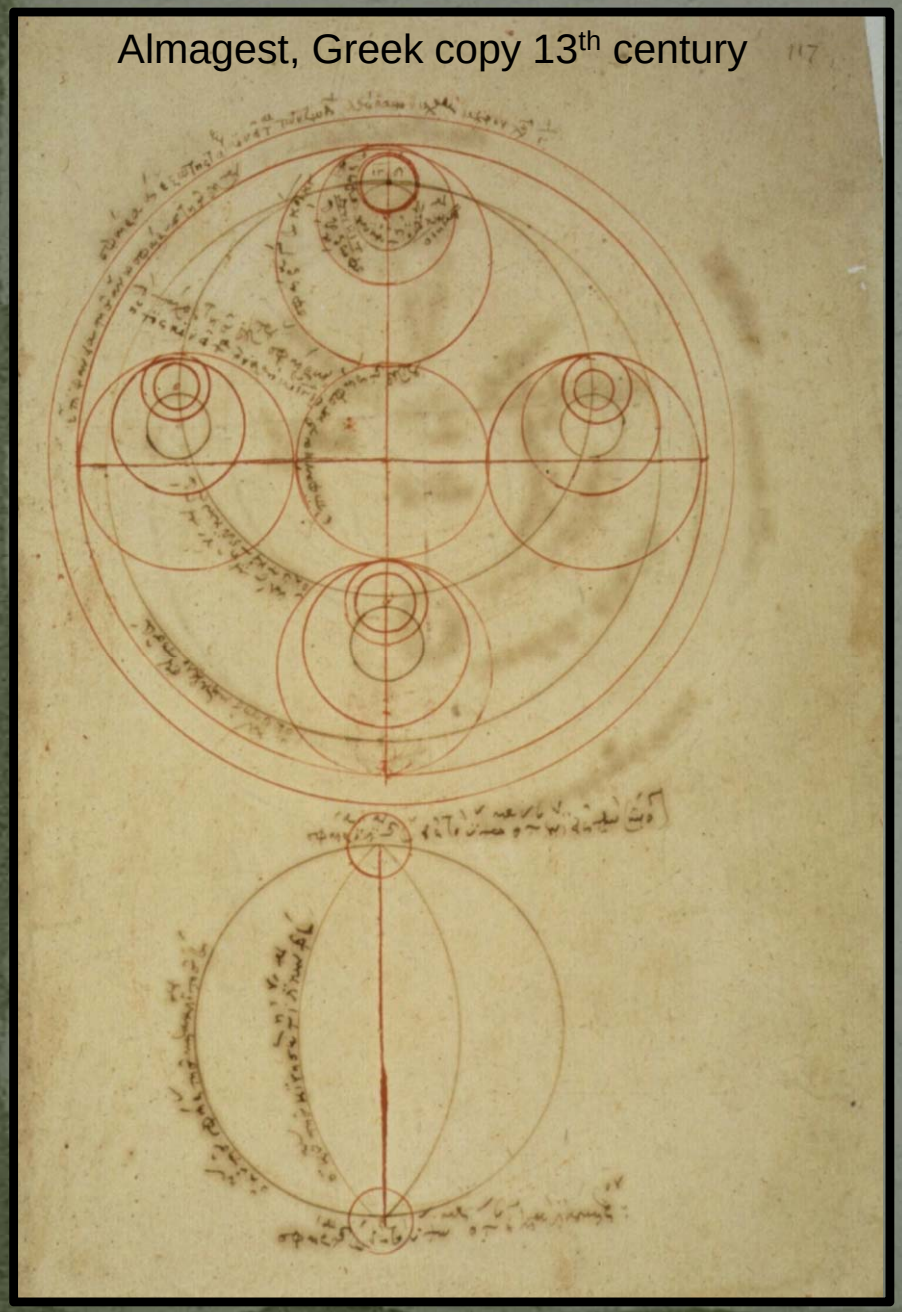
Ptolemy first scientist to spell out inductive method:
- models framed from preliminary facts
- expand models by logical induction
- testing hypothesis against reality

Only surviving comprehensive ancient treatise on astronomy:
- most important source of information on ancient Greek astronomy

Geocentric Model
Epicycle Theory

Dominated astronomy for > 13 centuries
- Roman (Byzantine, Western) world
  Arab world

Syntaxis - Almagest


Almagest, Greek copy 13th century

"The Great Book"

most Important & Influential Astronomical Work of Antiquity

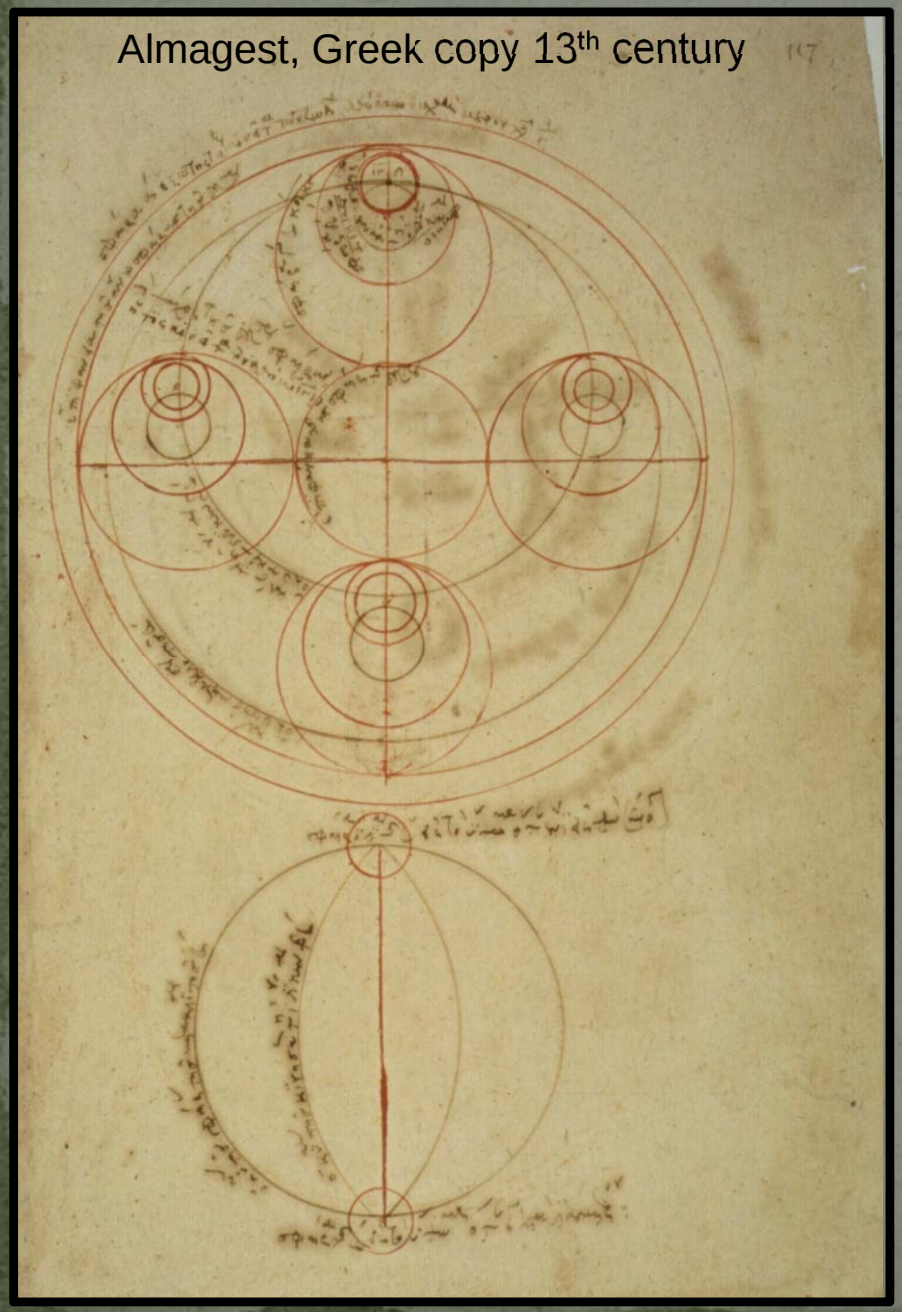
Geometrical models based on 800 yrs observations
(Babylonians, Hipparchus, …)

Models presented in convenient tables

Calculations fairly accurate for prediction
solar and lunar eclipses

Almagest also contains star catalogue
- appropriated version Hipparchus' catalogue
- 48 constellations: modern ones, not full sky

Syntaxis - Almagest

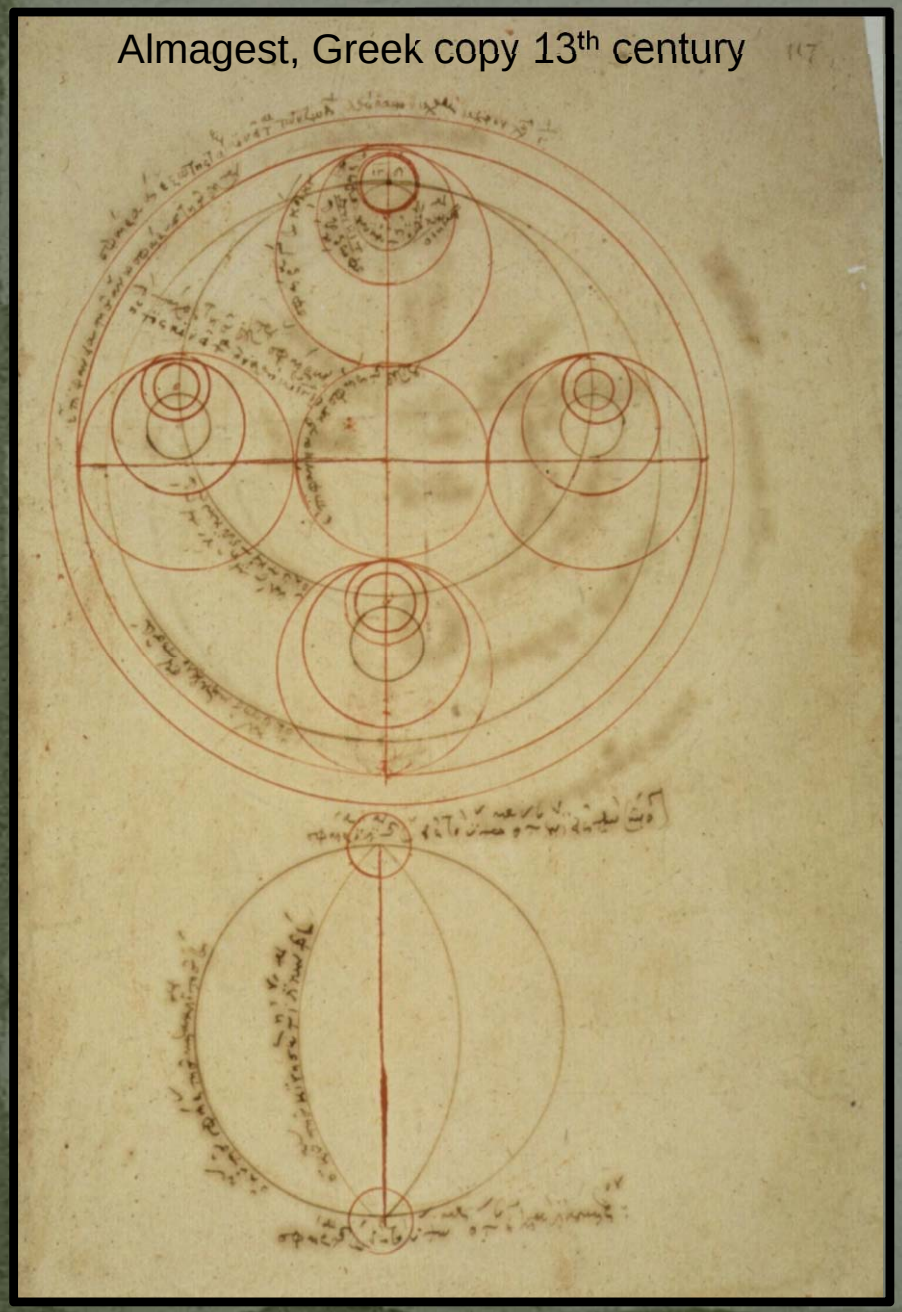

Almagest, Greek copy 13th century

Ptolemaeus' Cosmos

The cosmology of the *Almagest:*
five main points
each subject of a chapter Book I.

- The celestial realm is spherical,
  and moves as a sphere.
- The earth is a sphere.
- The earth is at the center of the cosmos.
- The earth,
  in relation to the distance of the fixed stars,
  has no appreciable size,
  must be treated as a mathematical point
- The earth does not move.

Syntaxis - Almagest



Ptolemaeus' Planetary Models

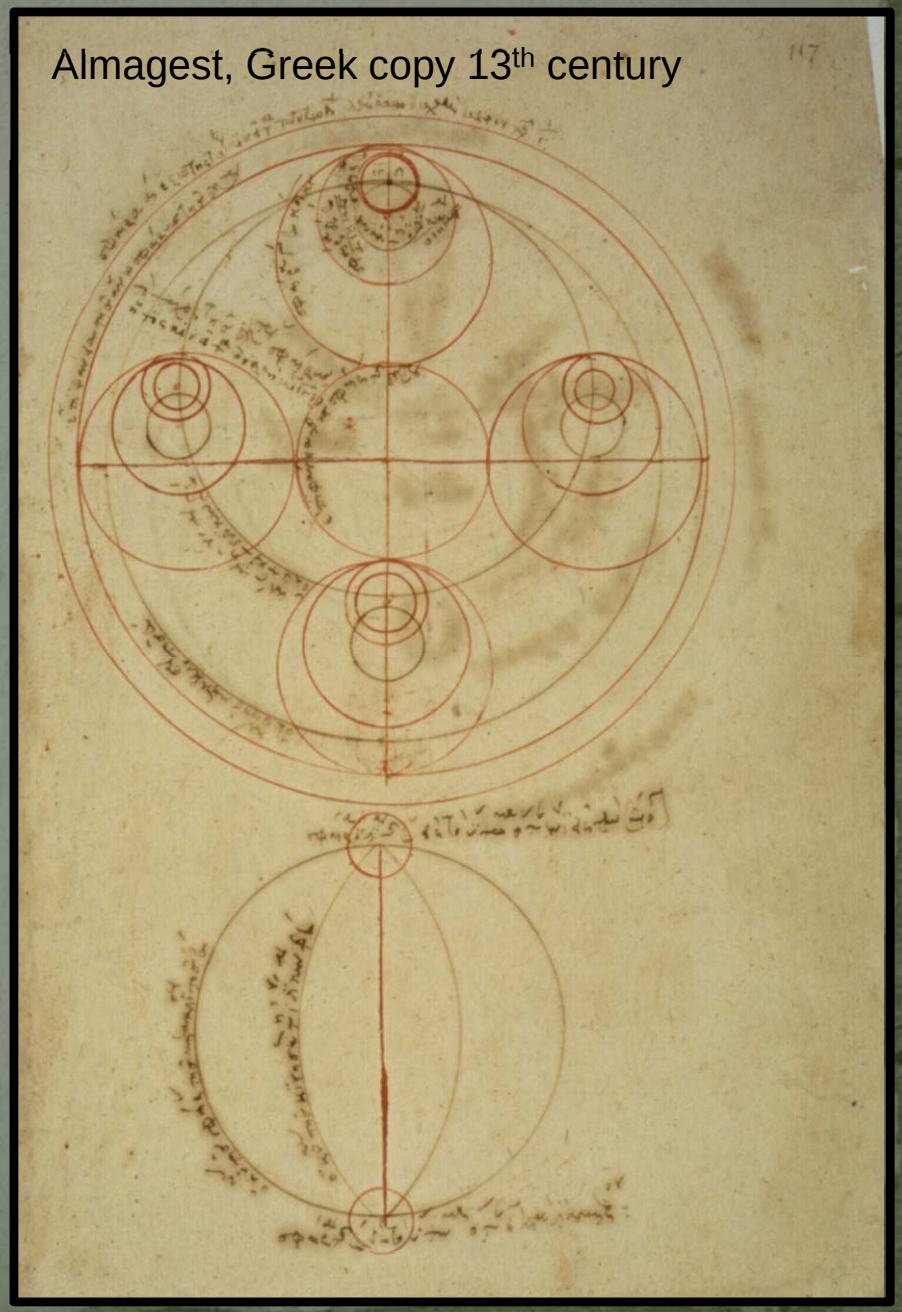
Order of planetary spheres:

- Moon
- Mercury
- Venus
- Sun
- Mars
- Jupiter
- Saturn
- Sphere fixed stars

Syntaxis - Almagest

Almagest: 13 books

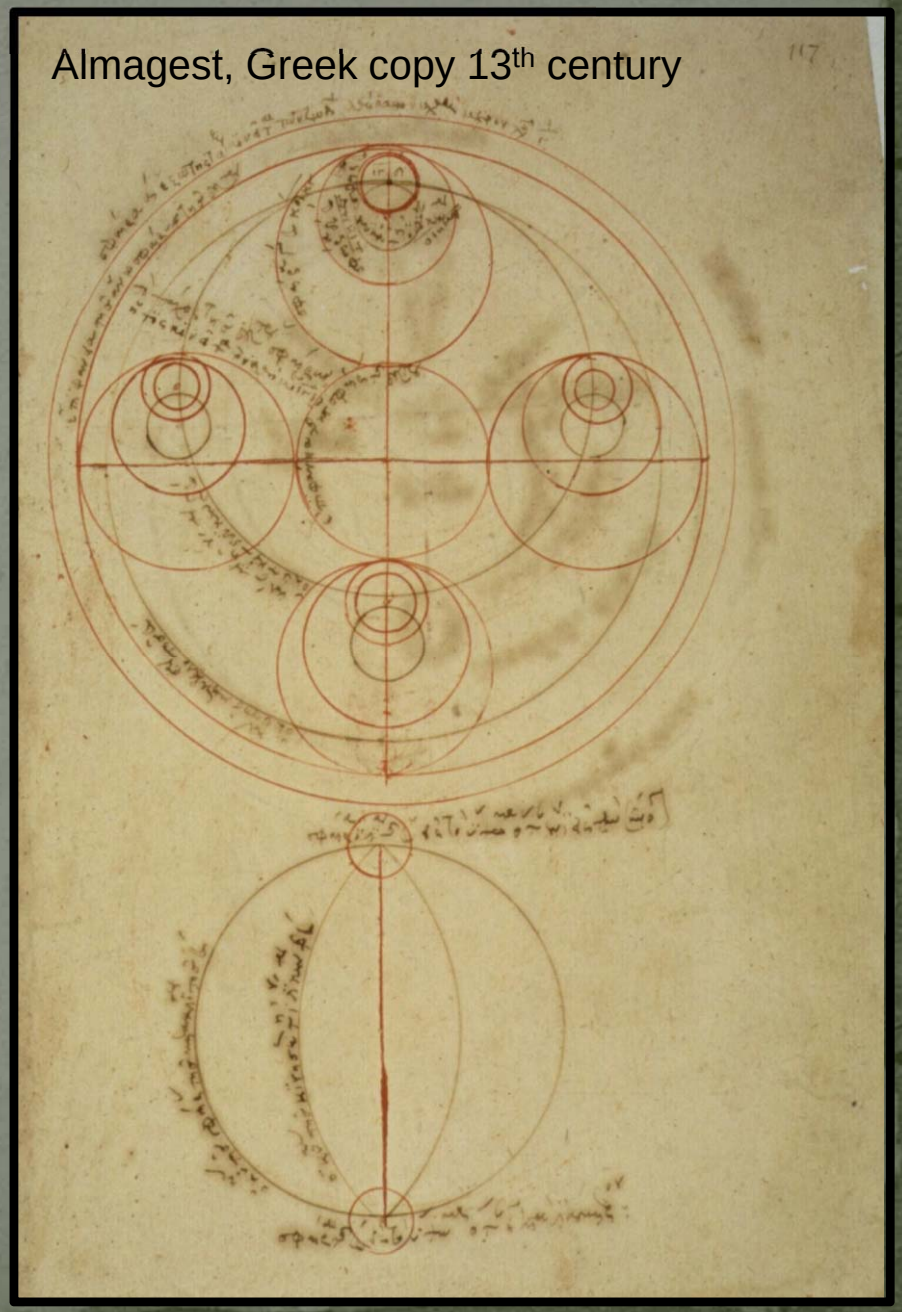
- Book I:
  outline of Aristotelian cosmology:
  - on the spherical form of the heavens,
  - the (spherical) Earth lying motionless at centre
  - the fixed stars and the various planets revolving around the earth
  - followed by explanation of chords with a set of chord tables
  - observations of the obliquity of the ecliptic
  - introduction to spherical trigonometry
- Book II:
  problems associated with the daily motion attributed to the heavens:
  - risings and settings of celestial object
  - length of daylight
  - determination of latitude
  - points at which the Sun is vertical
  - shadows of the gnomon at the equinoxes and solstices
  - other things which change with the spectator's position. There is also
  - a study of the angles made by the ecliptic with vertical, with tables.



Syntaxis - Almagest

Almagest: 13 books

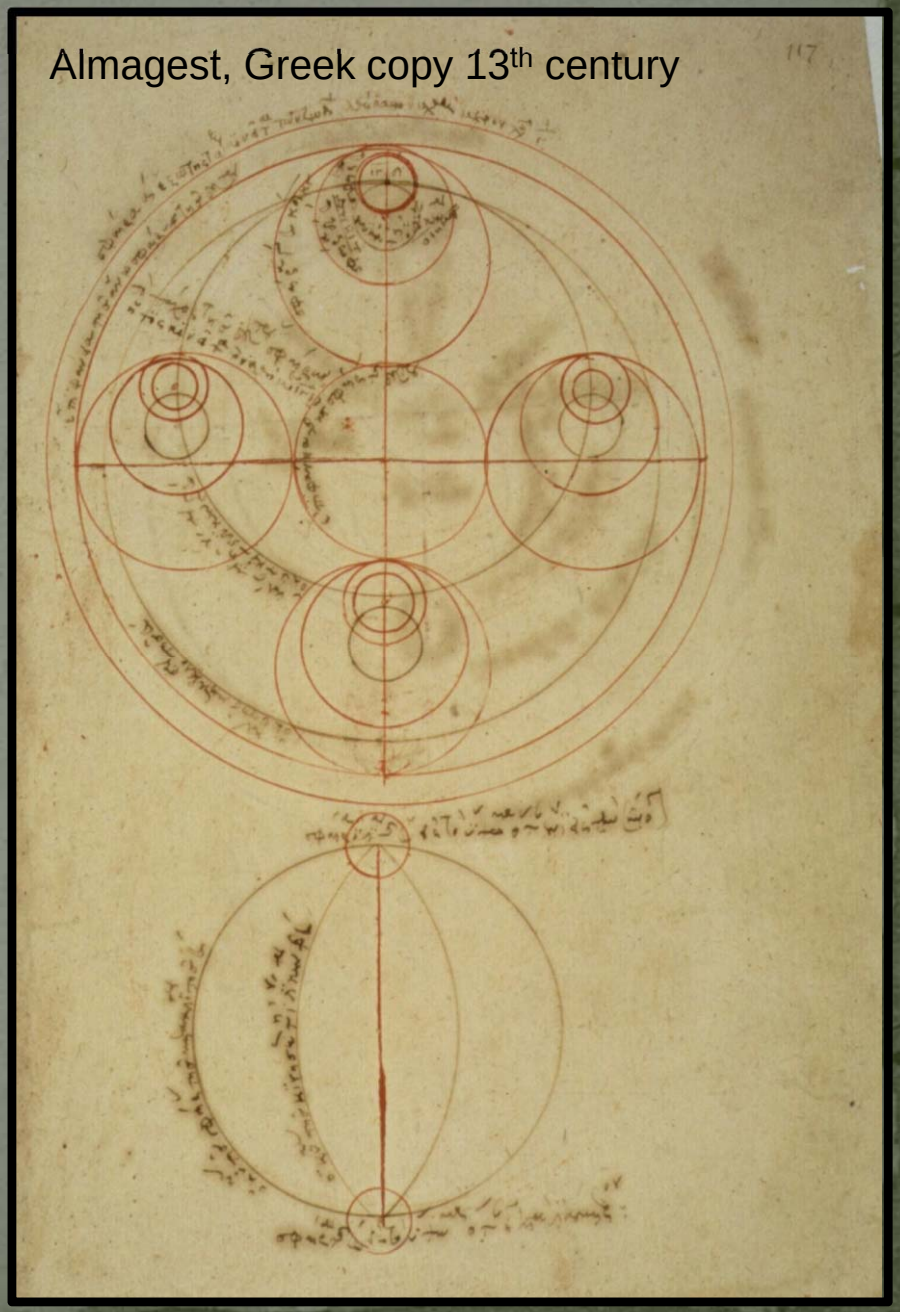
- Book III:
  - length of the year, and the motion of the Sun
  - explains Hipparchus' discovery of the precession of the equinoxes
  - begin explanation epicycles
- Books IV & V:
  the motion of the Moon:
  - lunar parallax
  - motion of the lunar apogee
  - sizes and distances of the Sun and Moon relative to Earth
- Book VI:
  solar and lunar eclipses



Syntaxis - Almagest

Almagest: 13 books

- Books VII & VIII:
- motions of the fixed stars:
  - includes precession of the equinoxes
- star catalogue of 1022 stars:
  - described by positions in the constellations
  - magnitude scale for brightness:
    - + brightness brightest stars marked of the 1st magnitude (m = 1),
    - + faintest 6th magnitude (m = 6), limit human visual perception
    - + each grade of magnitude considered twice the brightness of the following grade (log. scale).
    - + system believed to have originated with Hipparchus
    - + Stellar positions: Hipparchan origin (despite Ptolemy's claim to the contrary)
-



Syntaxis - Almagest

Almagest: 13 books

- Book IX:
  - general issues associated with creating models for the five (naked eye) planets
  - motion of Mercury
- Book X:
  motions of Venus and Mars
- Book XI:
  motions of Jupiter and Saturn
- Book XII:
  stations and retrogradations,
  - occurring when planets appear to pause, then briefly reverse their motion against the background of the zodiac.
  - Ptolemy understood these terms to apply to Mercury and Venus as well as the outer planets
- Book XIII:
  motion in latitude:
  the deviation of planets from the ecliptic