

A detail from Raphael's fresco 'The School of Athens'. It shows two central figures: Plato on the left, an older man with a long white beard wearing a purple robe and a black sash, pointing his right hand towards the sky; and Aristotle on the right, a younger man with a dark beard wearing a blue robe, gesturing with his right hand towards the earth. The background is a light, textured wall.

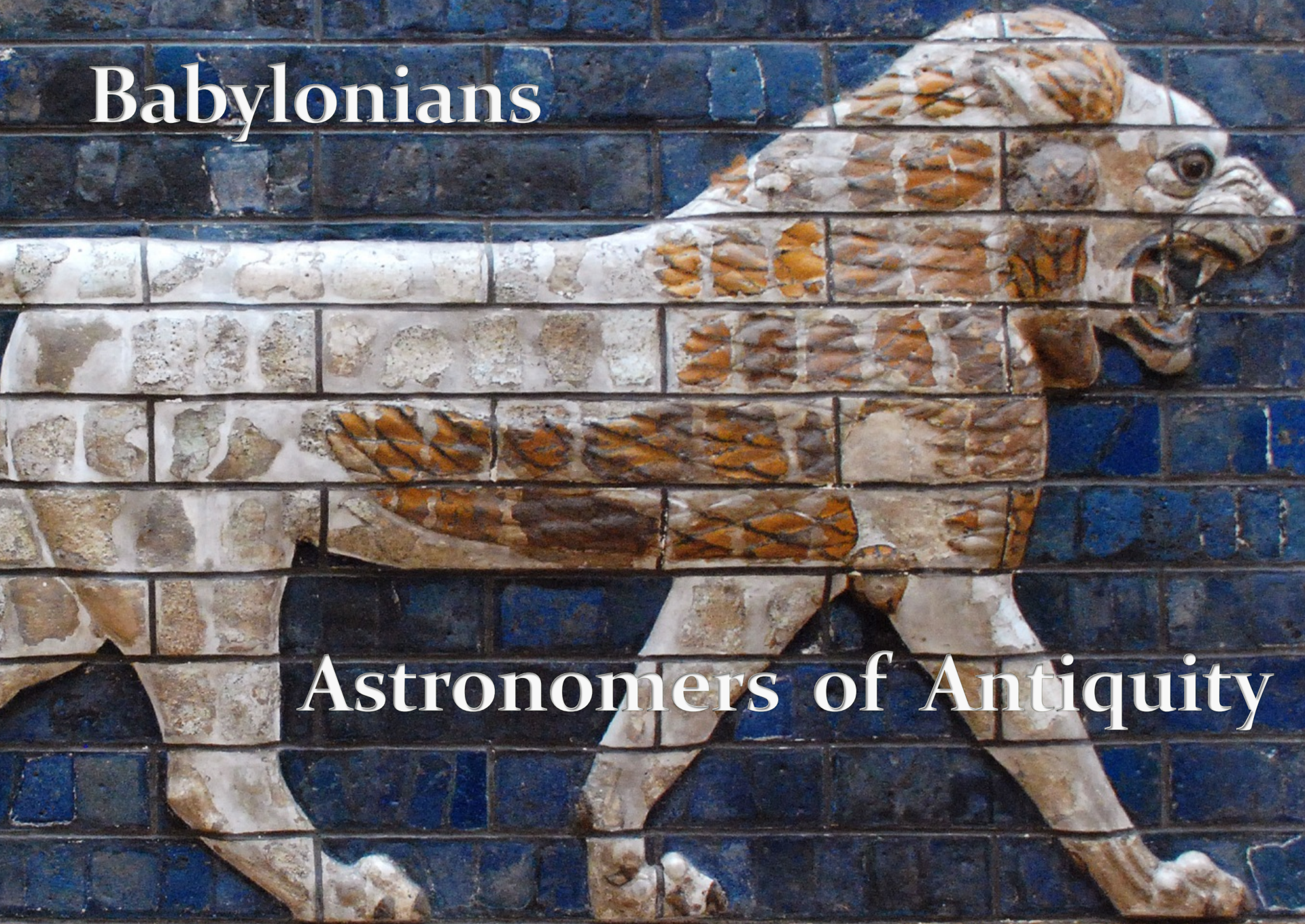
Order in the Cosmos:

how

Babylonians and Greeks

rationalized the heavens

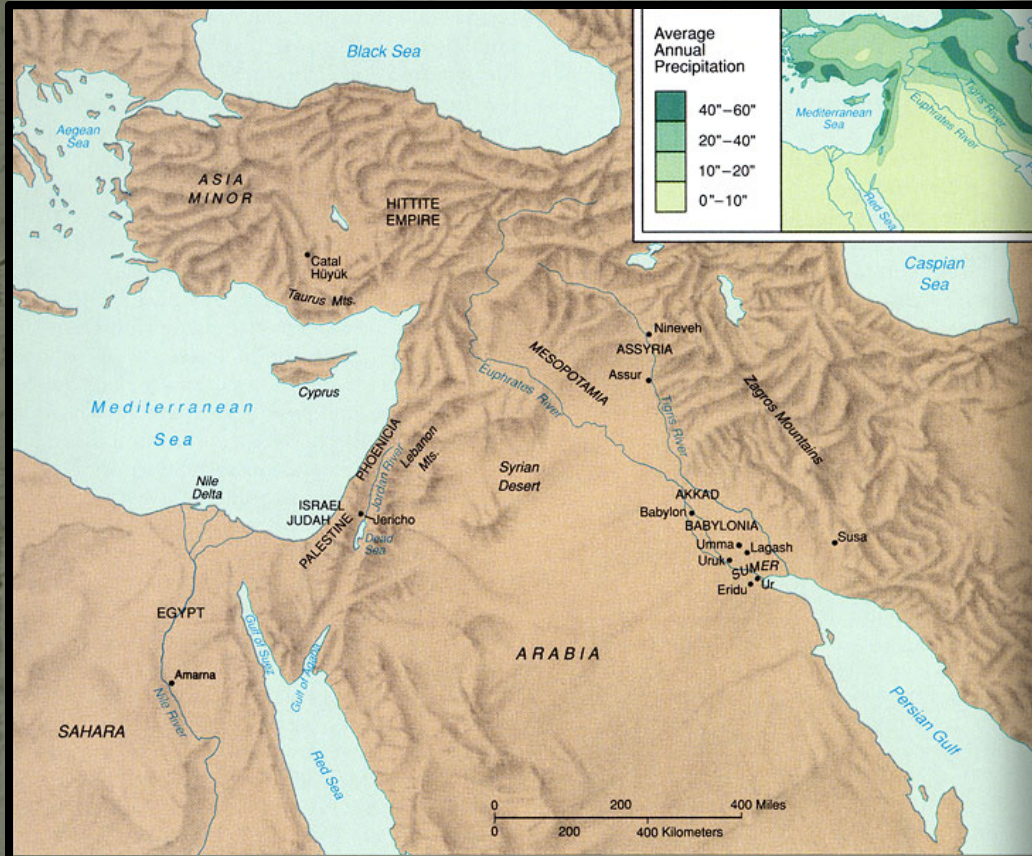
Babylonians



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 1700 BC		Reign of Hammurapi <i>Enuma Elish</i>
1600	Venus observations	
Kassite Dynasty 1500		
1400	<i>Enuma Anu Entil</i>	
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 Chaldaean 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

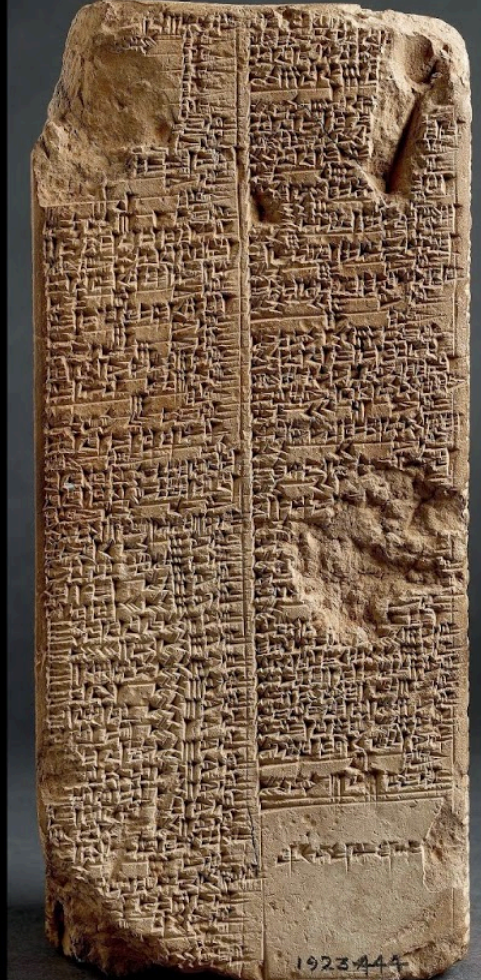
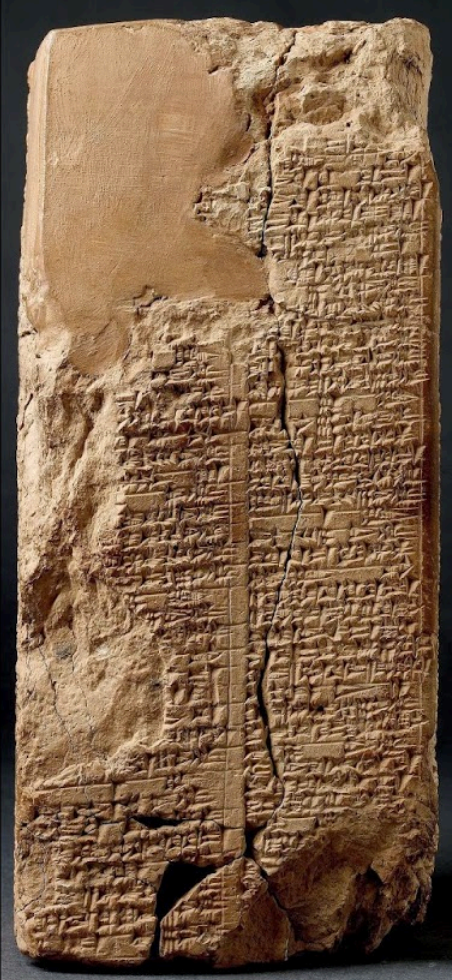
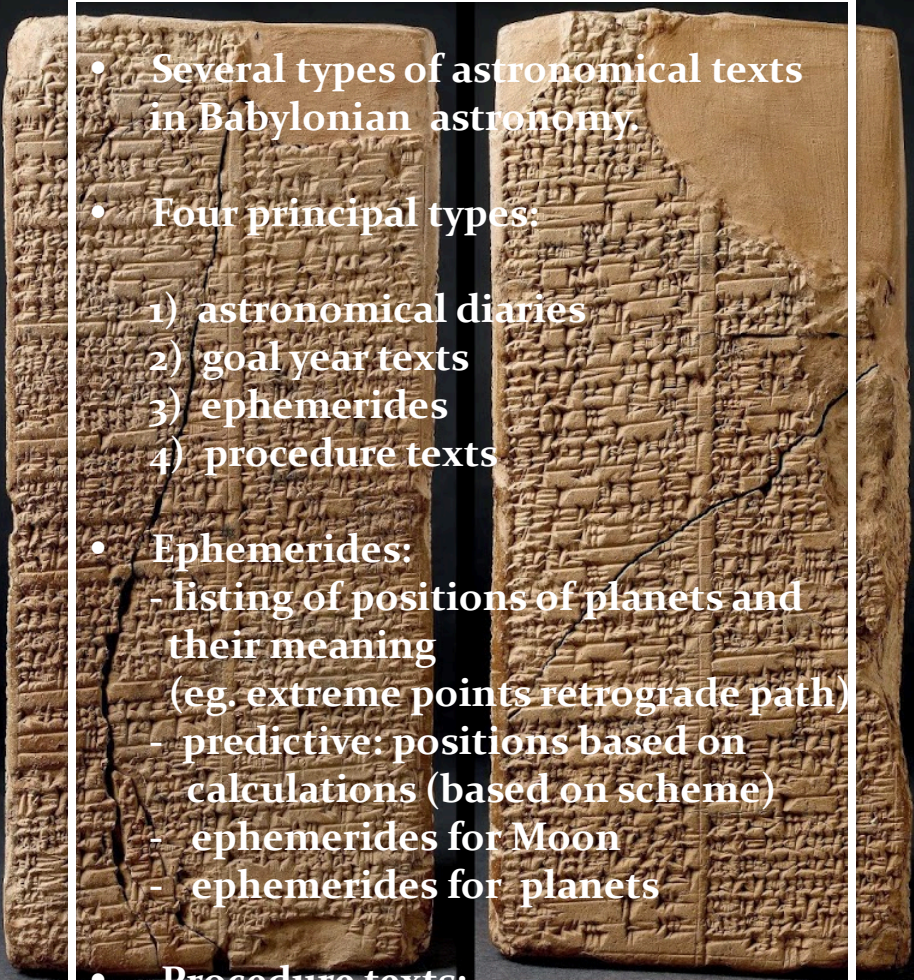
MUL.APIN

68-70 tablets
tablet 63:

Kassite period (1650-1150)
Venus tablet of Ammisaduga
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.

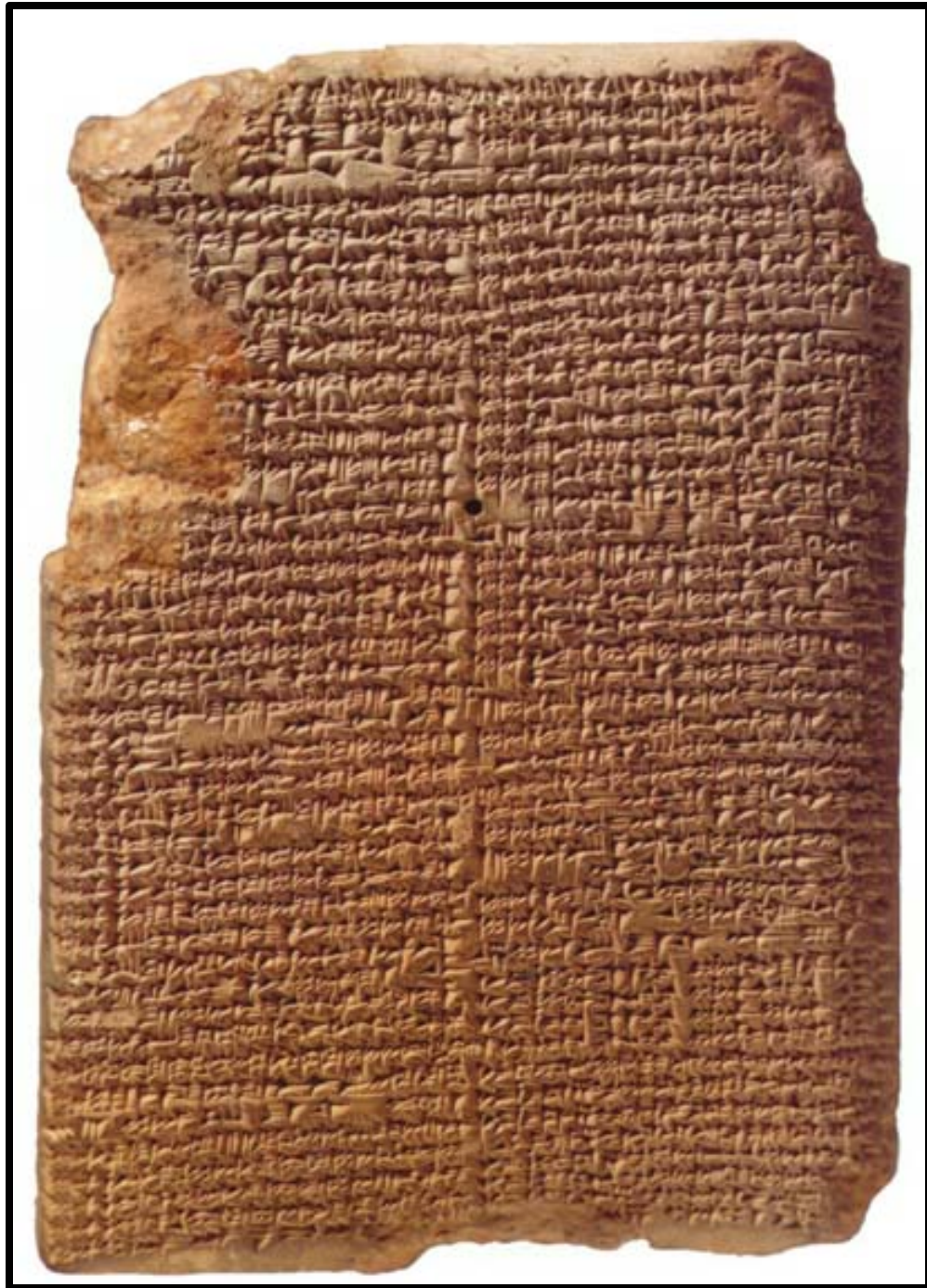


MUL.APIN

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

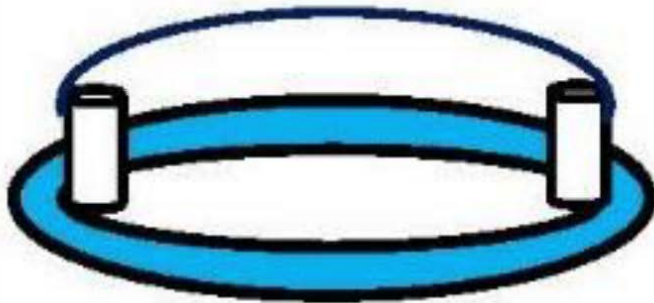
8th Century BCE: mythical cosmology

8^e eeuw v.Chr.

Mythische cosmologie

Homerus & Hesiodus

Wereldbeeld


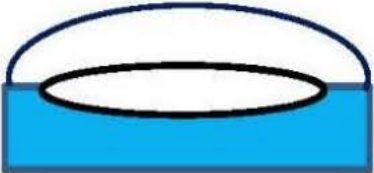

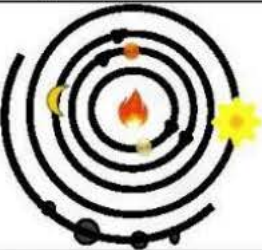


- Aarde platte schijf
- Omringd door rivier
- Hemel op pilaren







Homerus and guide
W-A Bouguereau






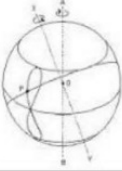


6th Century BCE: Pre-Socratic Ionian Natural Philosophers

8 ^e eeuw v.Chr.	6 ^e eeuw v.Chr. Natuurfilosofen		
Mythische cosmologie			
Homerus & Hesiodus Wereldbeeld	Thales	Anaximander	Pythagoras
			
<ul style="list-style-type: none"> • Aarde platte schijf • Omringd door rivier • Hemel op pilaren 	<ul style="list-style-type: none"> • Aarde platte schijf • Rust volledig op water • Oerelement water 	<ul style="list-style-type: none"> • Aarde platte schijf • Vrijhangend, geometrisch • Lucht, mist, vuur • Oerelement grenzeloos 	<ul style="list-style-type: none"> • Aarde bol • Centraal vuur, aarde, anti-aarde, planeten • Oerelement getallen

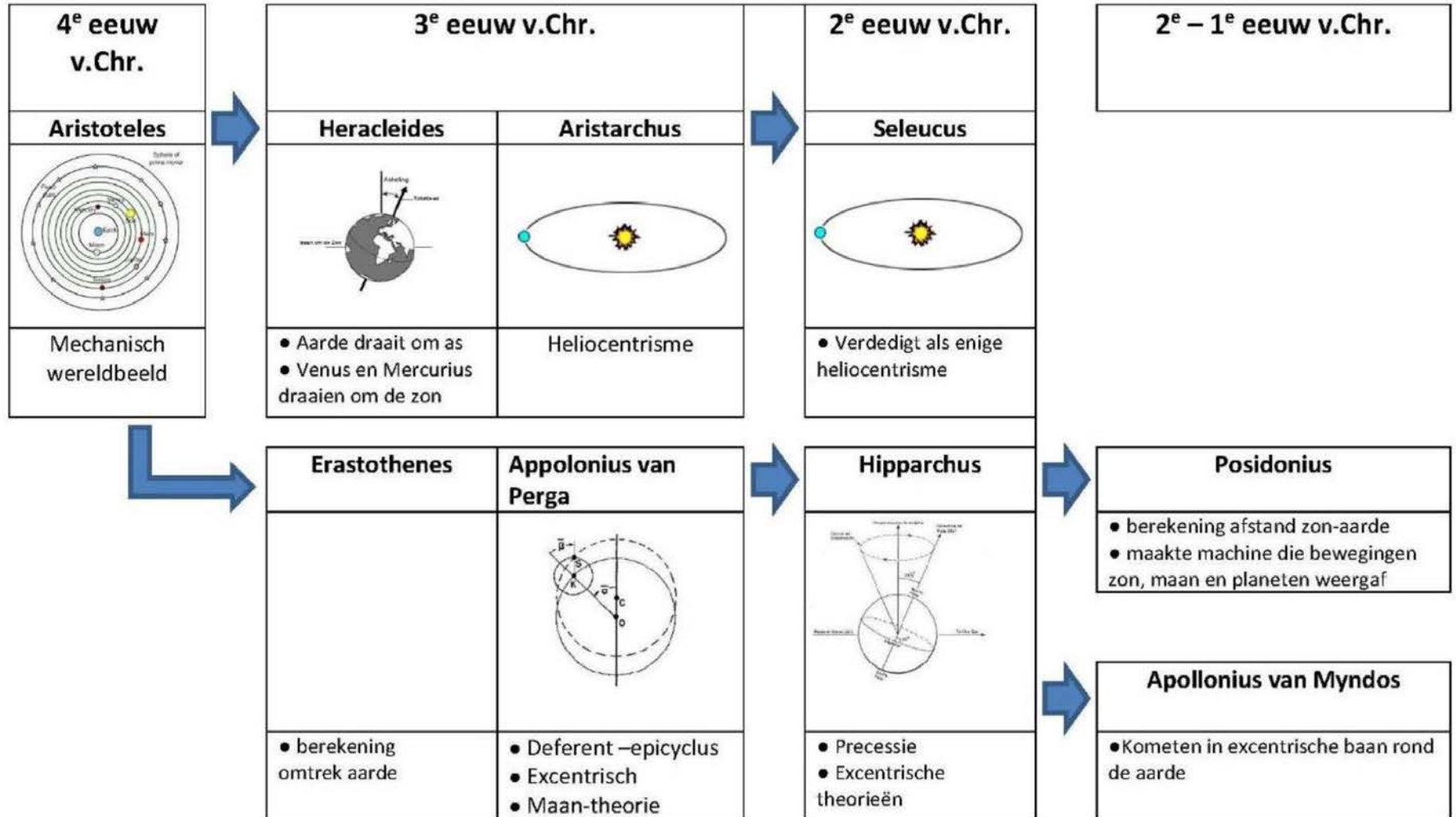
5th Century BCE: Pre-Socratic Natural Philosophers

8 ^e eeuw v.Chr.	6 ^e eeuw v.Chr. Natuurfilosofen			5 ^e eeuw v.Chr.		
Mythische cosmologie						
Homerus & Hesiodus	Thales	Anaximander	Pythagoras	Anaxagoras	Empedokles	Leukippos & Demokritos
Wereldbeeld 				<ul style="list-style-type: none"> • Geen oerelementen • Alles bevat een deel van al het andere • Hemellichamen <u>niet</u> goddelijk 	<ul style="list-style-type: none"> • 4 oerelementen: aarde, lucht, vuur, water • 2 eigenschappen: warm, koud • Alles bestaat uit verhouding van elementen met de 2 eigenschappen (4²= 16 mogelijkheden) 	<ul style="list-style-type: none"> • Alles bestaat uit atomen • Atomen zijn ondeelbaar en onveranderlijk, maar verschillen in vorm en grootte
<ul style="list-style-type: none"> • Aarde platte schijf • Omringd door rivier • Hemel op pilaren 	<ul style="list-style-type: none"> • Aarde platte schijf • Rust volledig op water • Oerelement water 	<ul style="list-style-type: none"> • Aarde platte schijf • Vrijhangend, geometrisch • Lucht, mist, vuur • Oerelement grenzeloos 	<ul style="list-style-type: none"> • Aarde bol • Centraal vuur, aarde, anti-aarde, planeten • Oerelement getallen 			

4th Century BCE: from Plato to Aristoteles

8 ^e eeuw v.Chr.	6 ^e eeuw v.Chr.			4 ^e eeuw v.Chr.			
Mythische cosmologie	Natuurfilosofen			Plato	Eudoxos	Callippus	Aristoteles
Homerus & Hesiodus	Thales	Anaximander	Pythagoras				
Wereldbeeld 							
<ul style="list-style-type: none"> •Aarde platte schijf •Omringd door rivier •Hemel op pilaren 	<ul style="list-style-type: none"> •Aarde platte schijf •Rust volledig op water •Oerelement water 	<ul style="list-style-type: none"> •Aarde platte schijf •Vrijhangend, geometrisch •Lucht, mist, vuur •Oerelement grenzeloos 	<ul style="list-style-type: none"> •Aarde bol •Centraal vuur, aarde, anti-aarde, planeten •Oerelement getallen •geoexcentrisch wereldbeeld 	Geometrisch wereldbeeld			Mechanisch wereldbeeld
				<ul style="list-style-type: none"> •Armilarium •Planeten niet in model opgenomen 	<ul style="list-style-type: none"> •Hippode •Planeten bewegen volgens combinatie van cirkels 	<ul style="list-style-type: none"> •Calliptische cyclus •verbetering model Eudoxos door extra ringen 	<ul style="list-style-type: none"> •4 elementen van Empedokles en voegde 5^e toe: aether
	5 ^e eeuw v.Chr.						
	Anaxagoras	Empedokles	Leukippos & Demokritos				
	<ul style="list-style-type: none"> •Geen oerelementen •Alles bevat een deel van al het andere •Hemellichamen <u>niet</u> goddelijk 	<ul style="list-style-type: none"> •4 oerelementen: aarde, lucht, vuur, water •2 eigenschappen: warm, koud •Alles bestaat uit verhouding van elementen met de 2 eigenschappen 	<ul style="list-style-type: none"> •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



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 ...



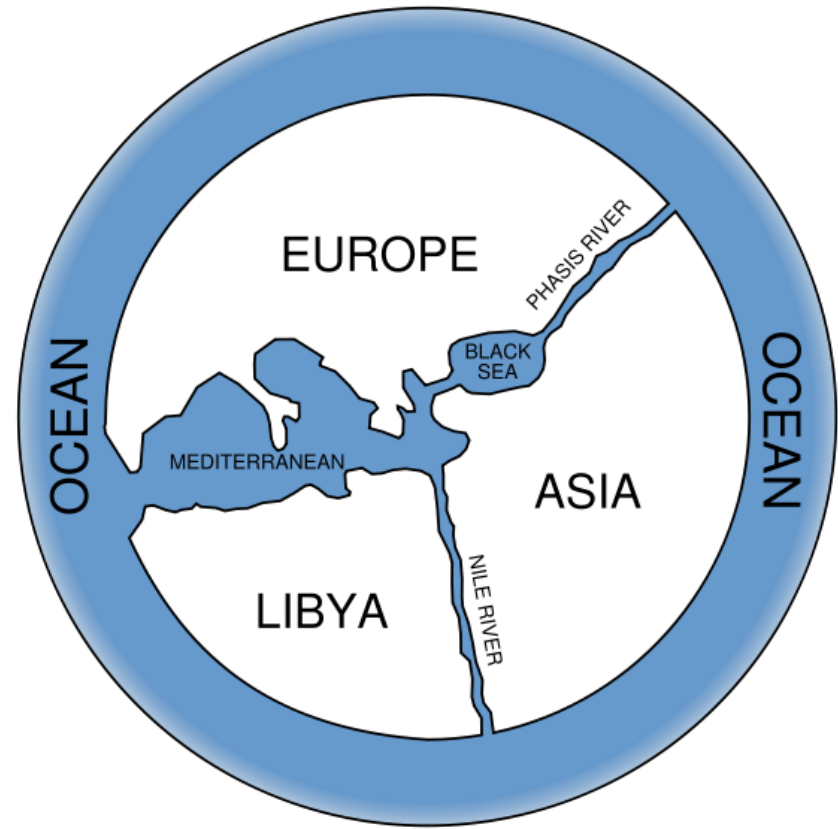
Mathematics as natural language of cosmos
→ Physical cosmos modelled after *ideal form*,
encrypted in concepts of *geometry*

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



Anaximander

the First Cosmologist
(Miletus, 610-546 BCE)

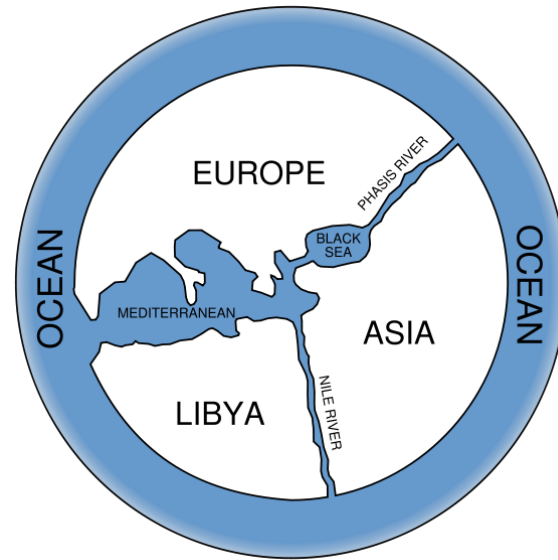


Cartography of Anaximander



Anaximander

the First Cosmologist
(Miletus, 610-546 BCE)



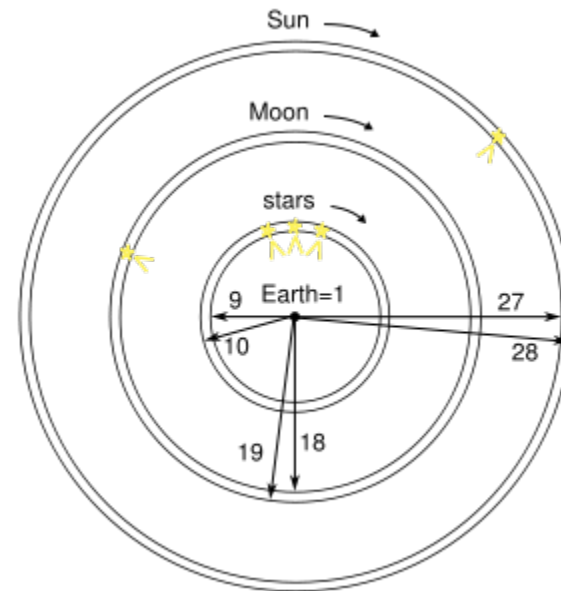
Cosmology of Anaximander:

- 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)



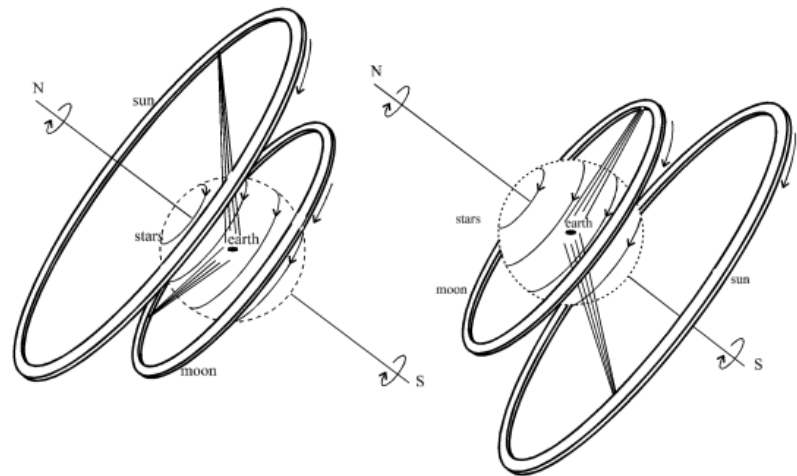
Cosmology Anaximander

- 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

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



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

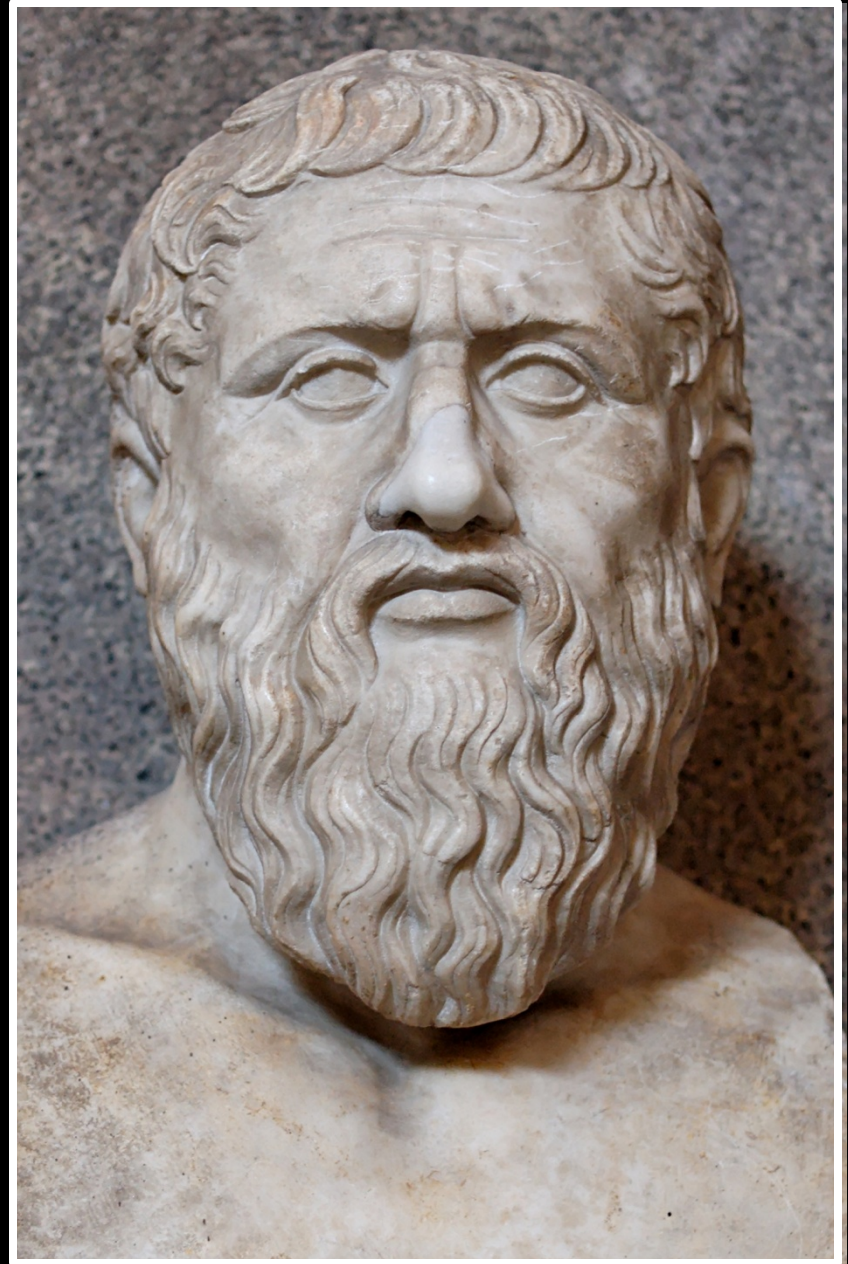
Plato

(Athens,
428-348 BCE)

**Geometry as
organizing principle
of the world**

Founded Academy, Athens

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



Academia Platon

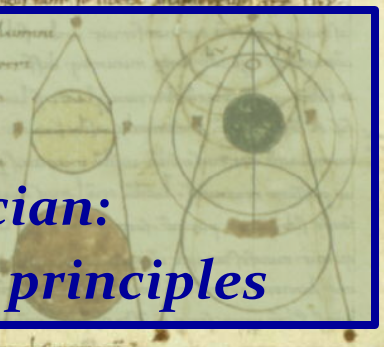
A photograph of the ruins of the Academy in Athens. The scene shows a series of stone steps leading up through a lush, green landscape. A large, prominent tree stands in the center, casting a shadow over the steps. The background is filled with dense foliage and more trees, creating a sense of a secluded, natural setting. The overall atmosphere is peaceful and historical.

**“Let no one unversed
in geometry enter here”**

Timaeus: Plato's Cosmology

Plato's Cosmic Scheme:

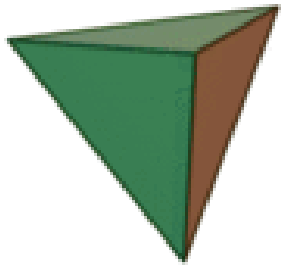
- Demiurge, divine craftsman, is a mathematician:
- Universe constructed according to geometric principles



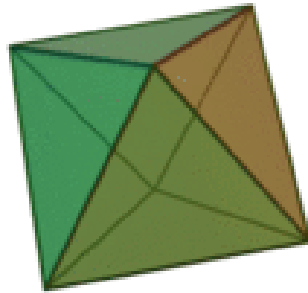
Platonic Solids

the Five Platonic solids

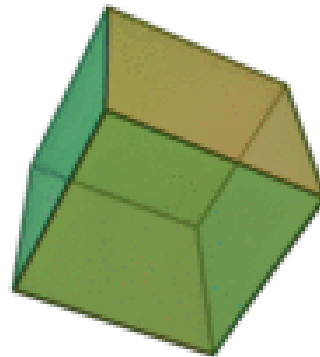
- there are only five convex regular polyhedra !
- Plato identified them with the cosmos and its constituents



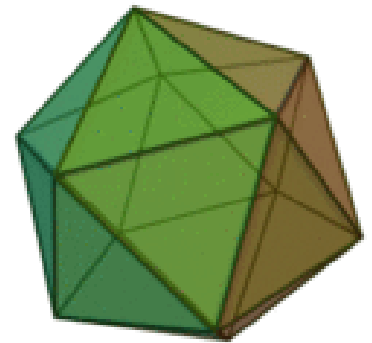
Tetrahedron:
fire



Octahedron:
air



Cube:
earth

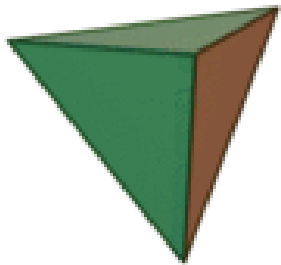


Icosahedron:
water

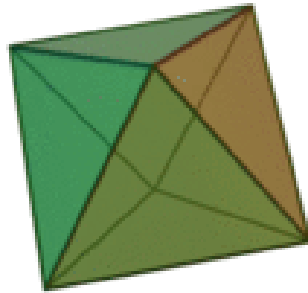
Platonic Solids

Dodecahedron ↔ Quintessence

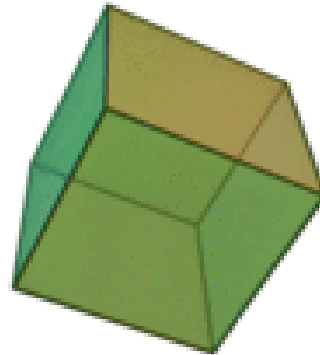
of which the Cosmos itself is made:
“the stuff for embroidering
the constellations on the heavens”



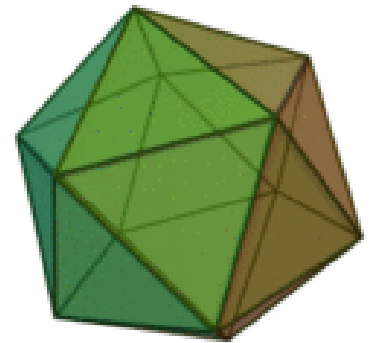
Tetrahedron:
fire



Octahedron:
air



Cube:
earth



Icosahedron:
water

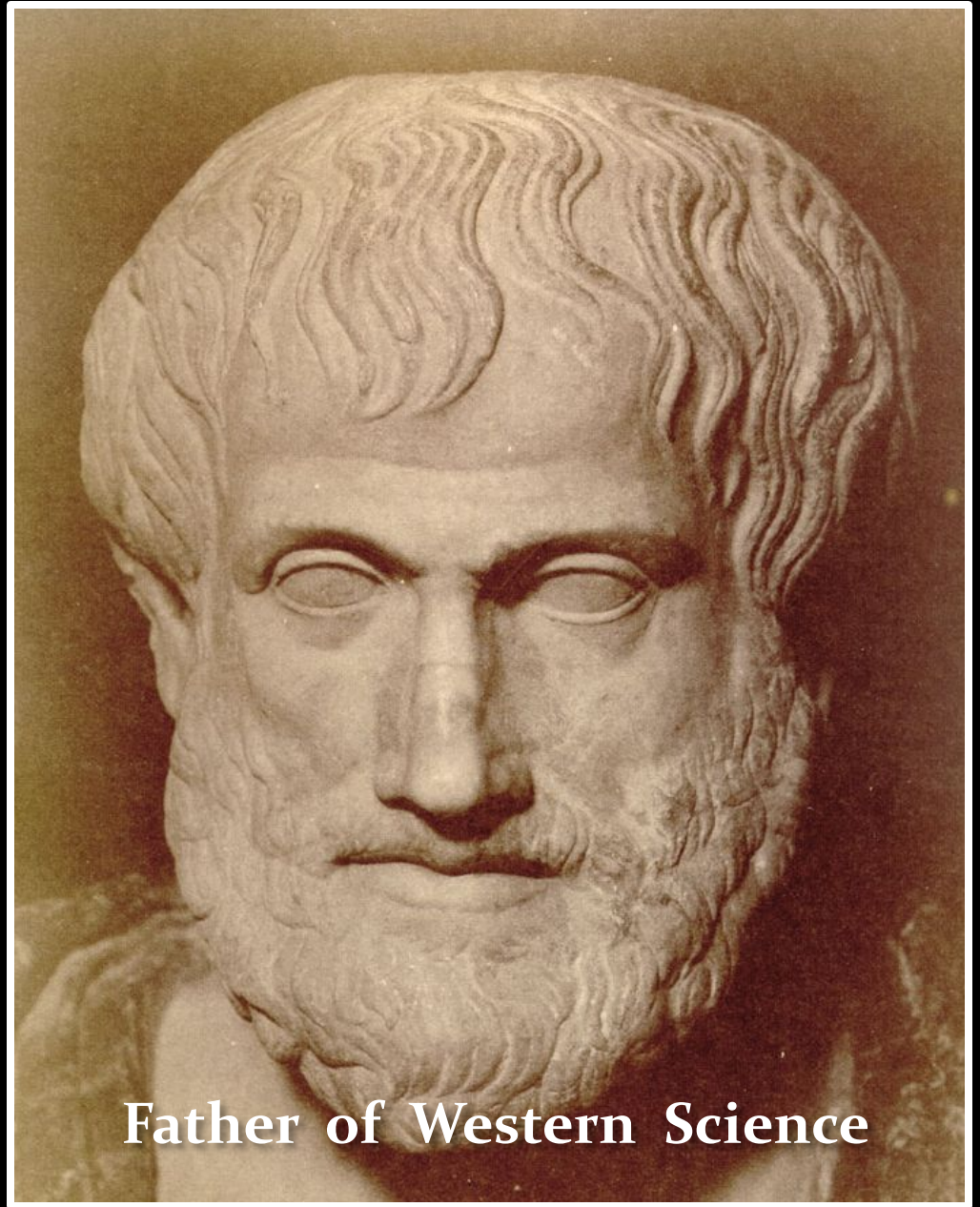
Aristoteles

(Chalcidice-Athens, 384-322 BCE)

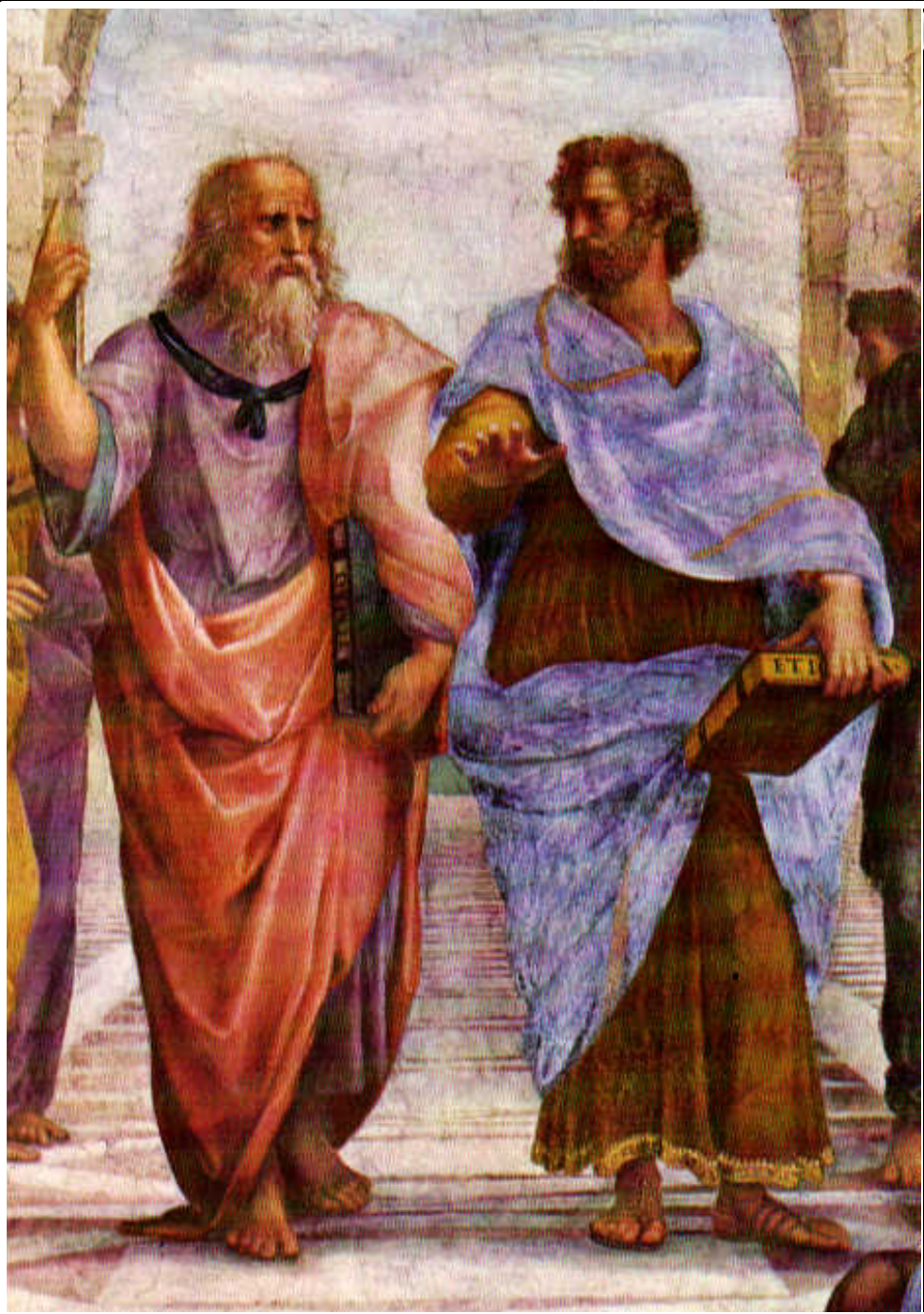
- “Aristotle was the first genuine scientist in history ... every scientist is in his debt”

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



Father of Western Science



*I saw the Master there of those who
know, Amid the philosophic family,
By all admired,
and by all revered;
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 than 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



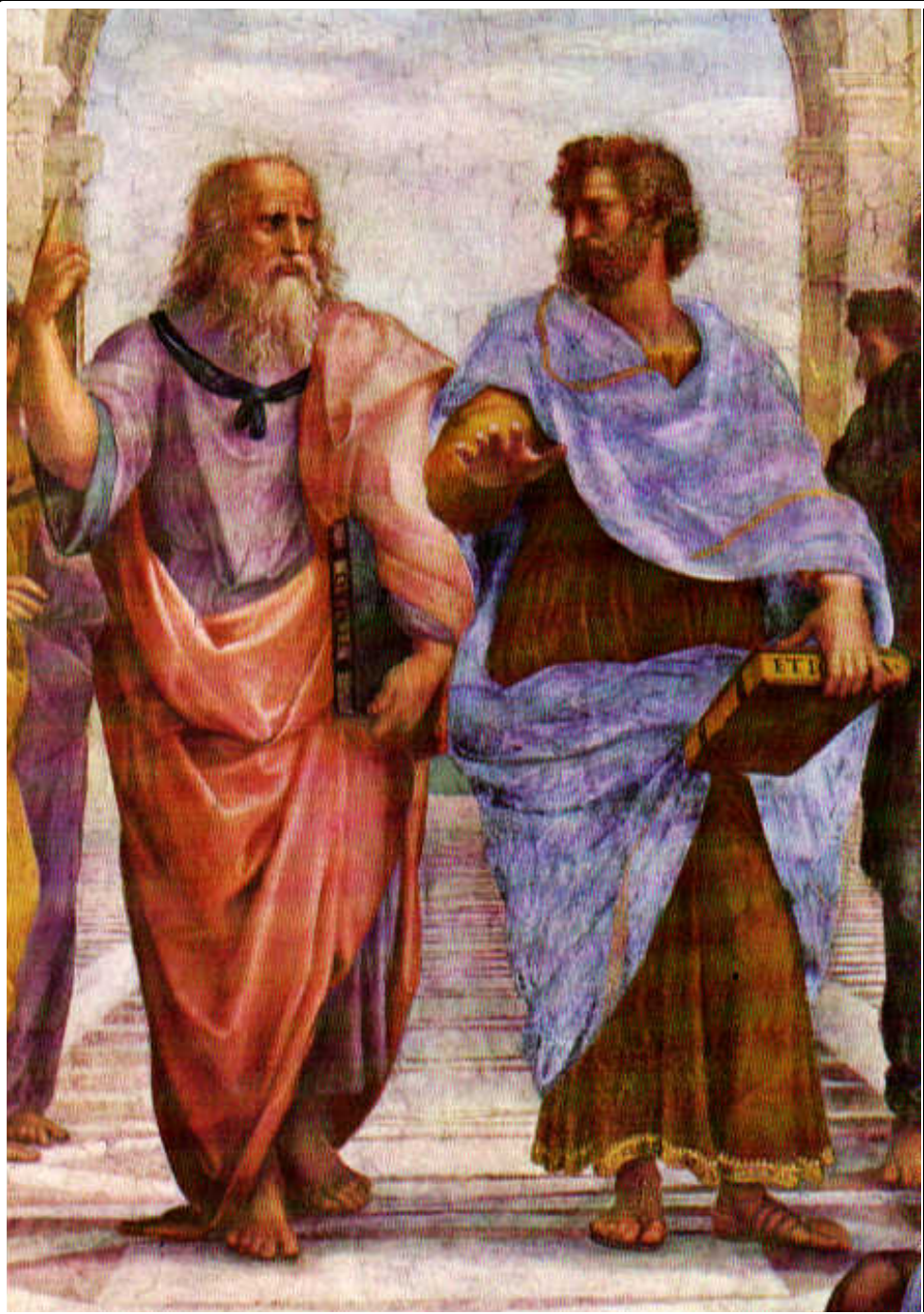
- **Movement of bodies**

- all 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''.

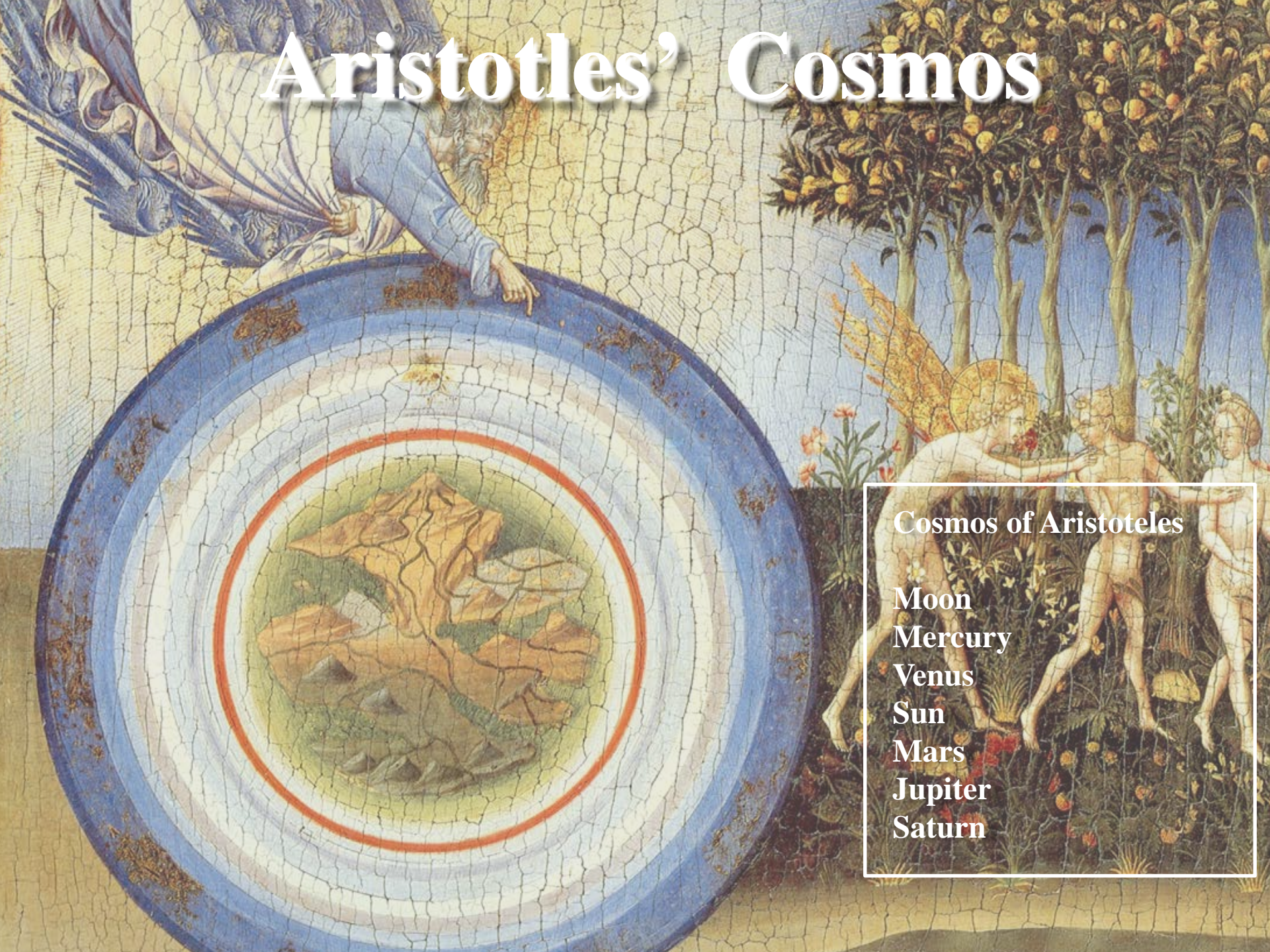
- Note the strange idea that all celestial bodies are perfect, yet they must circle the imperfect Earth.

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

Aristotle's 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