

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 soft, hazy landscape.

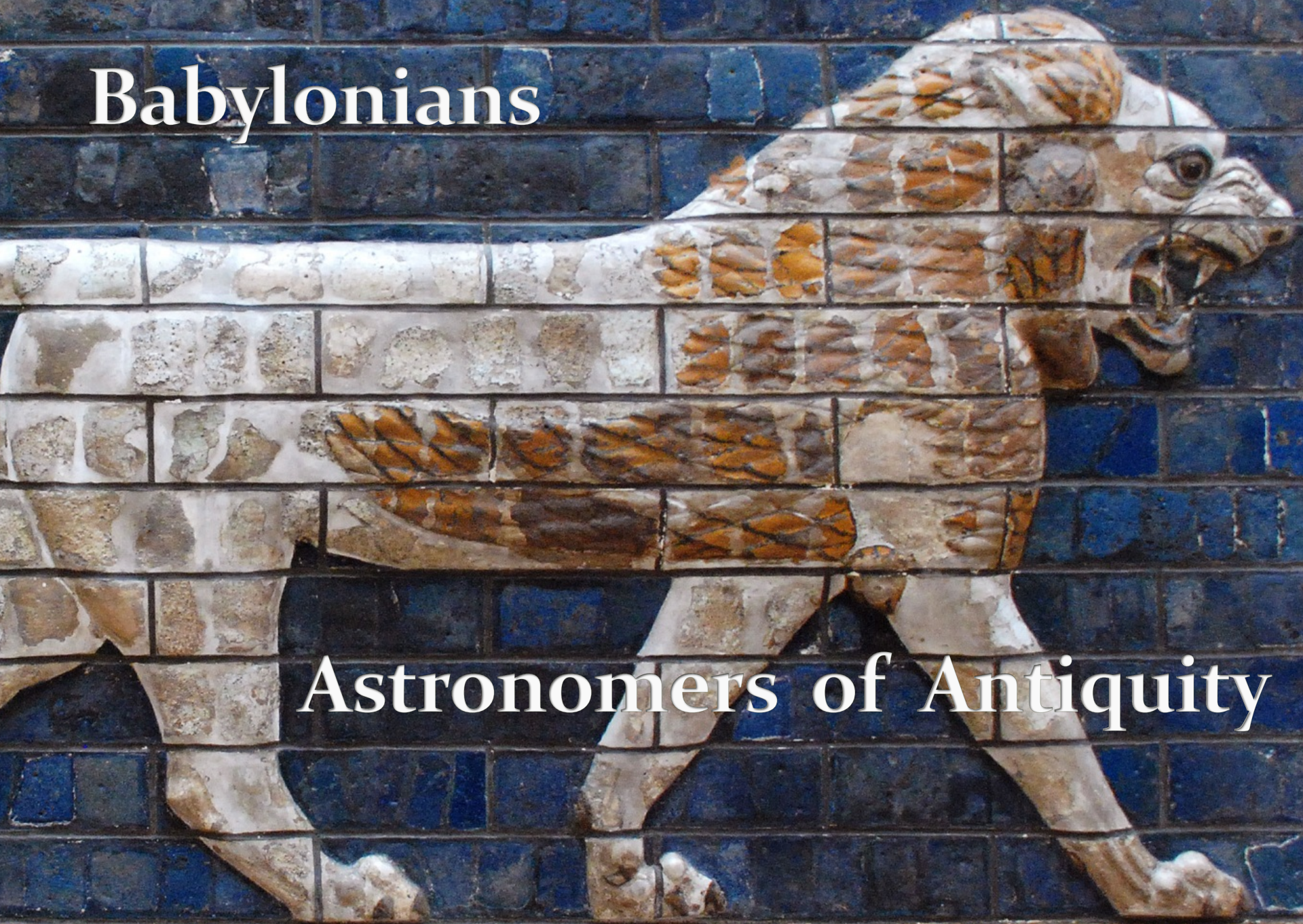
Order in the Cosmos:

how

Babylonians and Greeks

rationalized the heavens

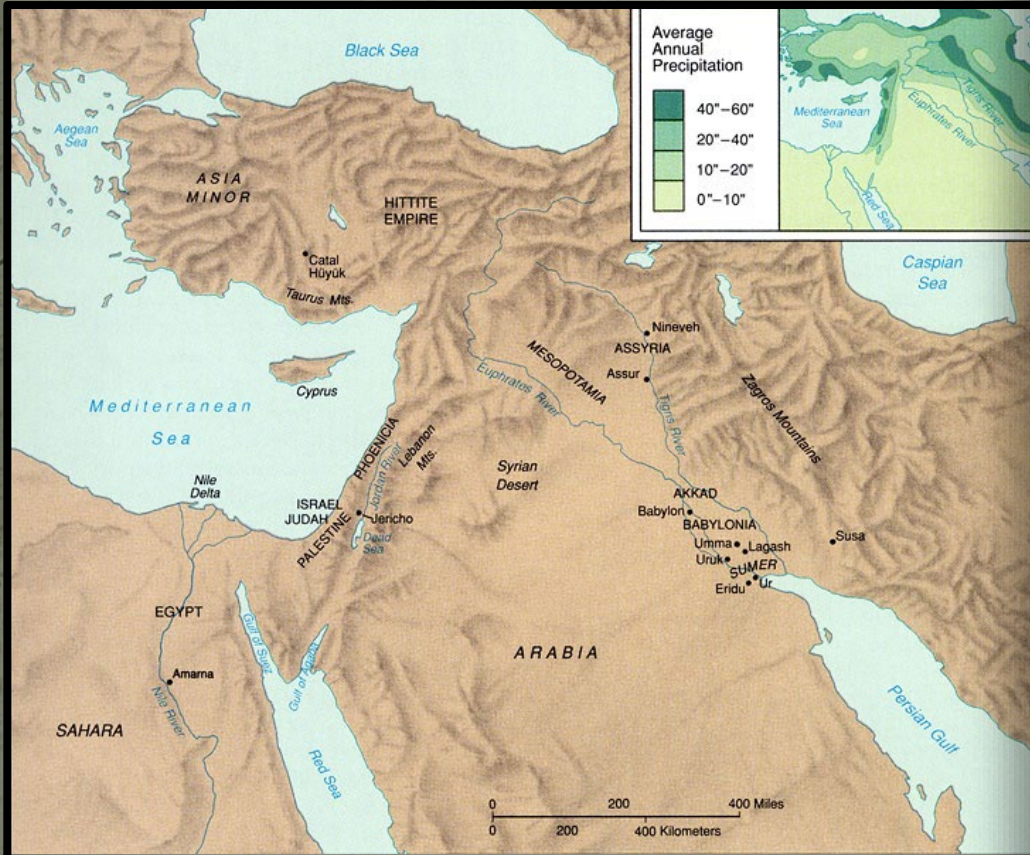
Babylonians



Astronomers of Antiquity



Babylonian Astronomy



Mesopotamia = “land of two rivers”
land between the rivers Euphrates & Tigris

Babylonian Astronomy



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 ...

Babylonian Astronomy

Two distinct periods of flowering:

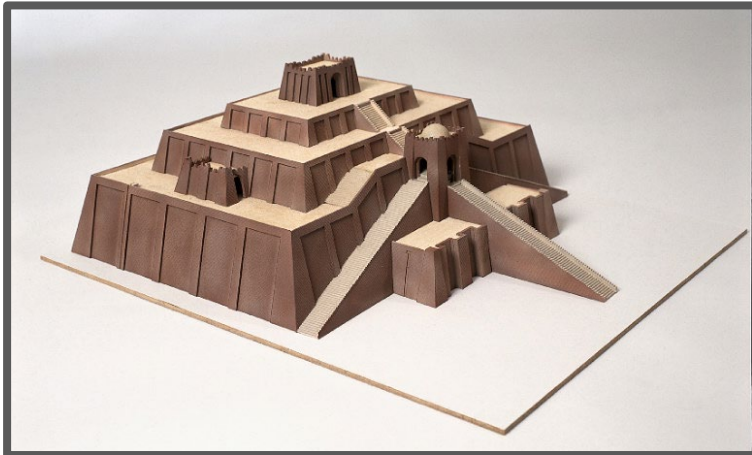
- **Old Babylonian astronomy:**
during and after
First Babylonian dynasty (Hammurabi) 1830-1531 BCE
- **New Babylonian/Chaldean astronomy:**
 - Neo-Babylonian (Nebuchadnezzar) 626-539 BCE
 - Medo-Persian 539-331 BCE
 - Seleucid 335-141 BCE
 - Parthian 129 BCE-224 AD

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

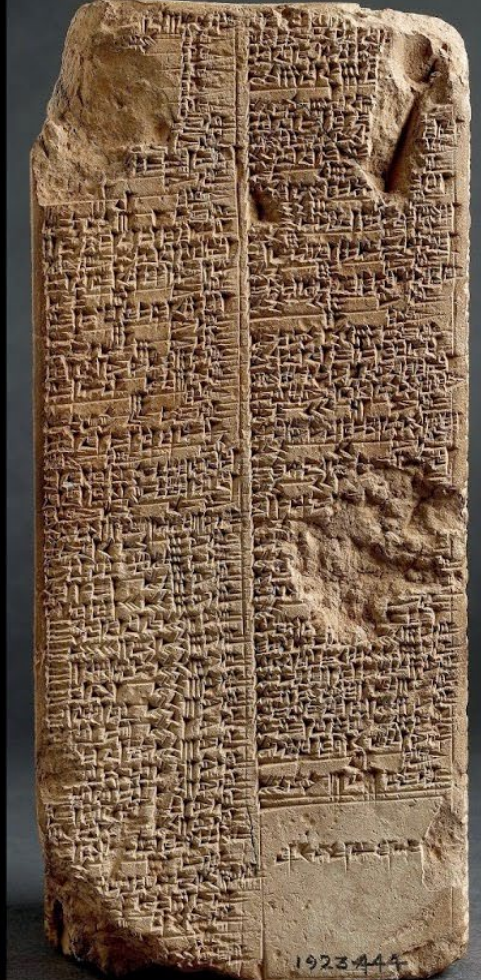
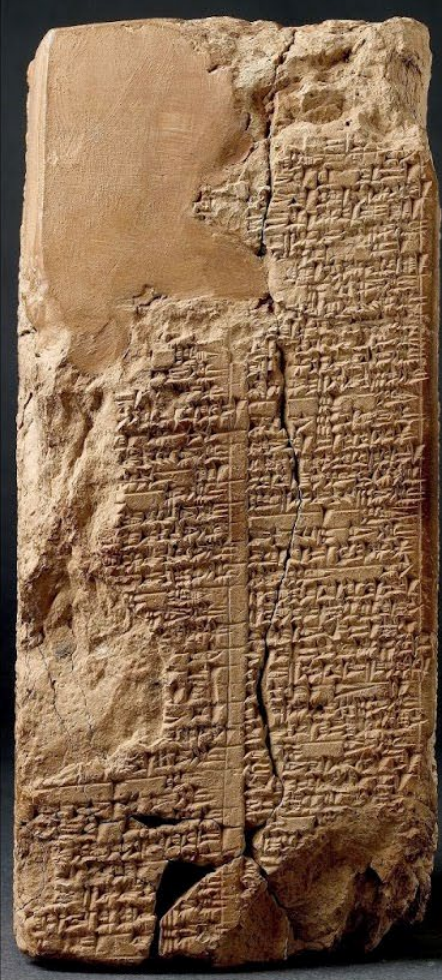
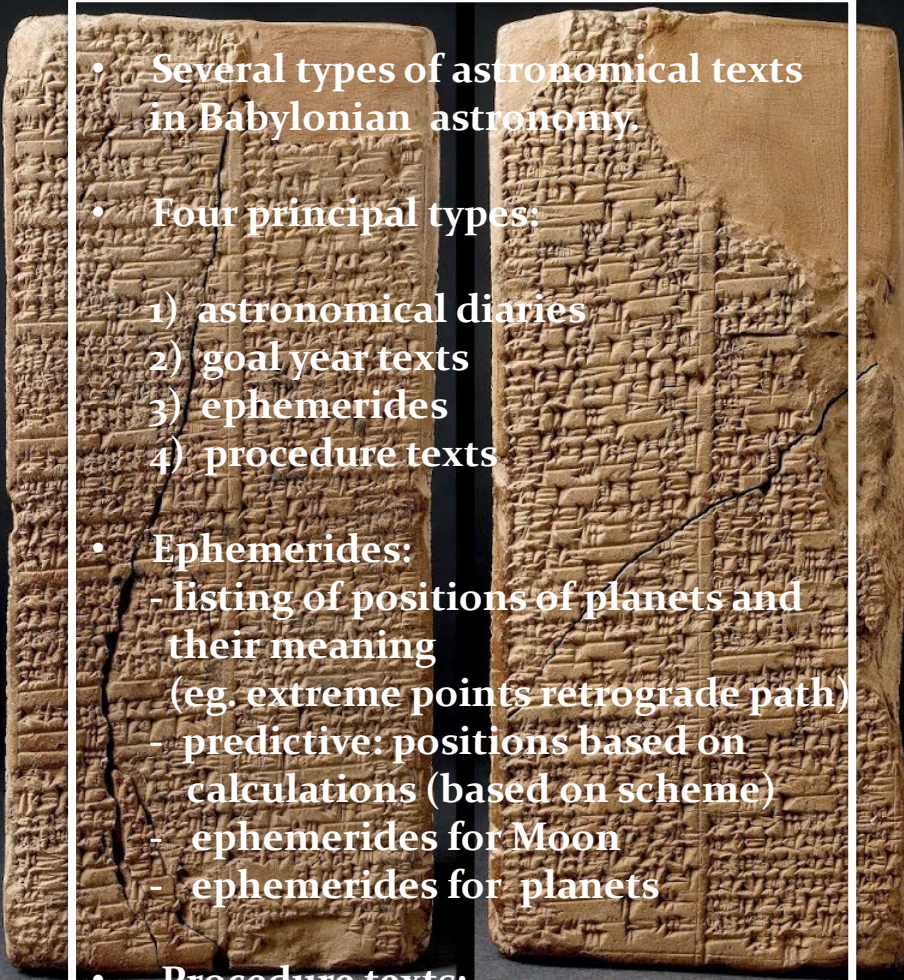
MUL.APIN

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.

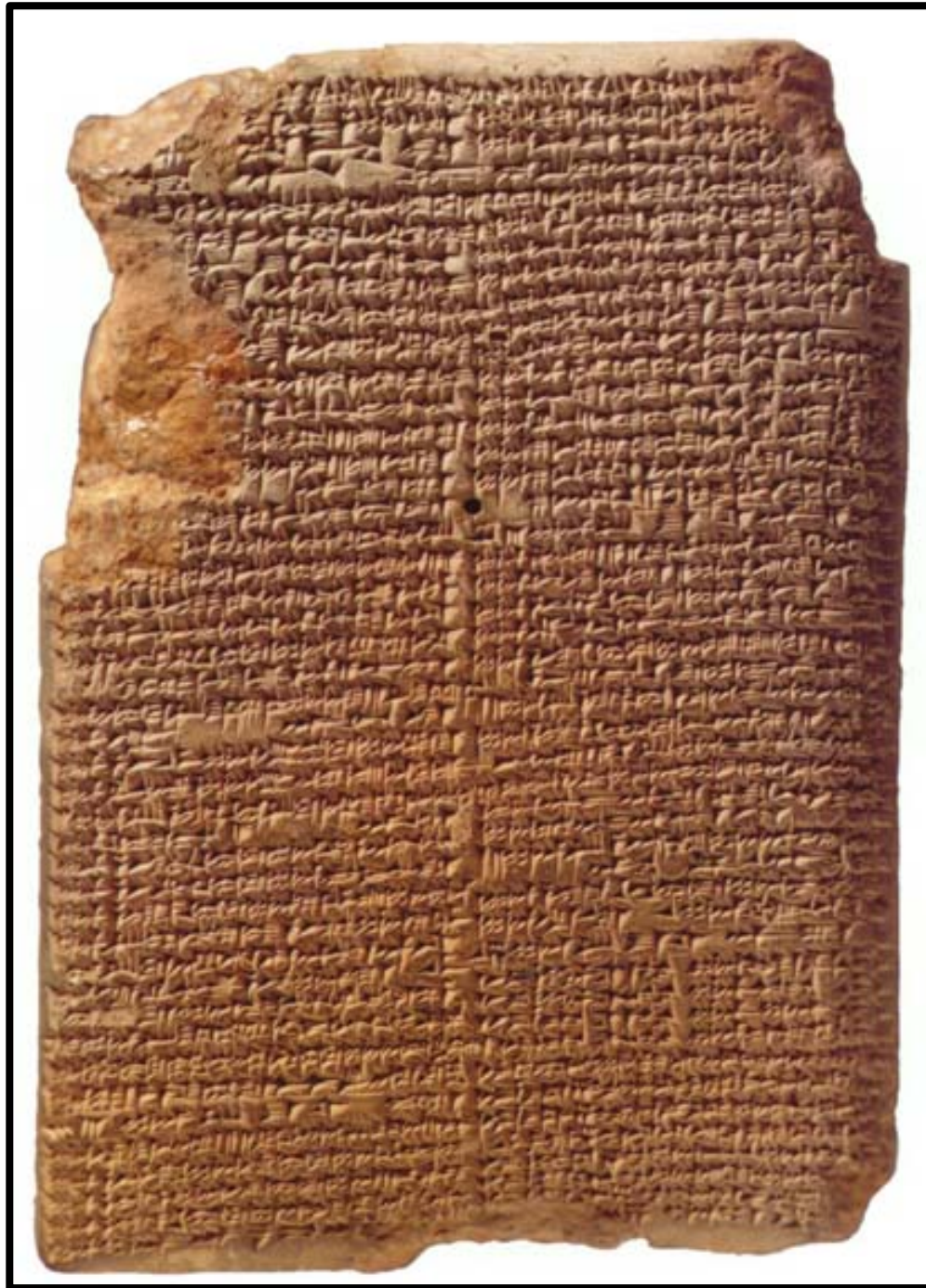


MUL.APIN

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

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

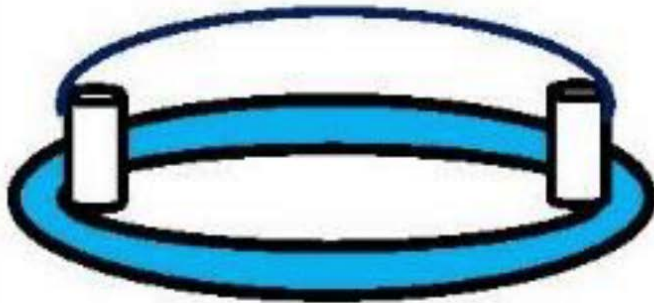
8th Century BCE: mythical cosmology

8th Cent. BCE

Mythical Cosmology

Homerus & Hesiodus

Worldview


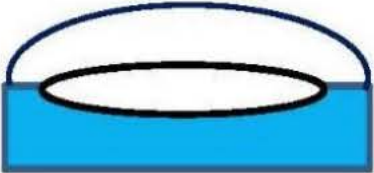

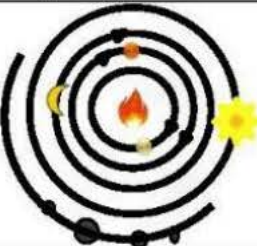


- Earth flat disc
- surrounded by river
- Heavens mounted on pillars







Homerus and guide
W-A Bouguereau

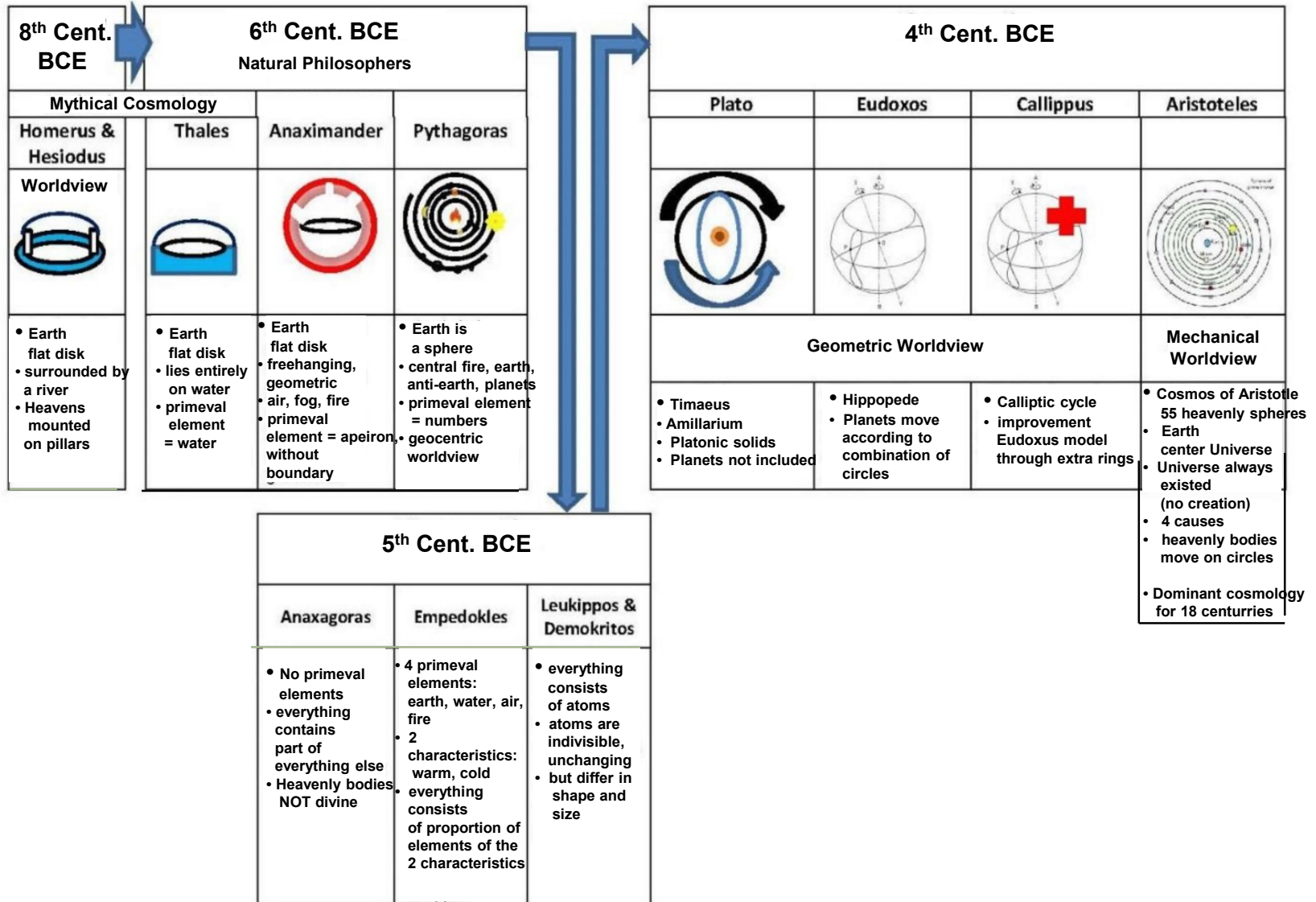
6th Century BCE: Pre-Socratic Ionian Natural Philosophers

| 8 th Cent. BCE | 6 th Cent. BCE Natural Philosophers | | |
|--|---|---|---|
| <p style="text-align: center;">Mythical Cosmology</p> | | | |
| | | | |
| <p style="text-align: center;">Worldview</p>  |  |  |  |
| <ul style="list-style-type: none"> • Earth flat disk • surrounded by a river • Heavens mounted on pillars | <ul style="list-style-type: none"> • Earth flat disk • lies entirely on water • primeval element = water | <ul style="list-style-type: none"> • Earth flat disk • freehanging, geometric • air, fog, fire • primeval element = apeiron, without boundary | <ul style="list-style-type: none"> • Earth is a sphere • central fire, earth, anti-earth, planets • primeval element = numbers • geocentric worldview |

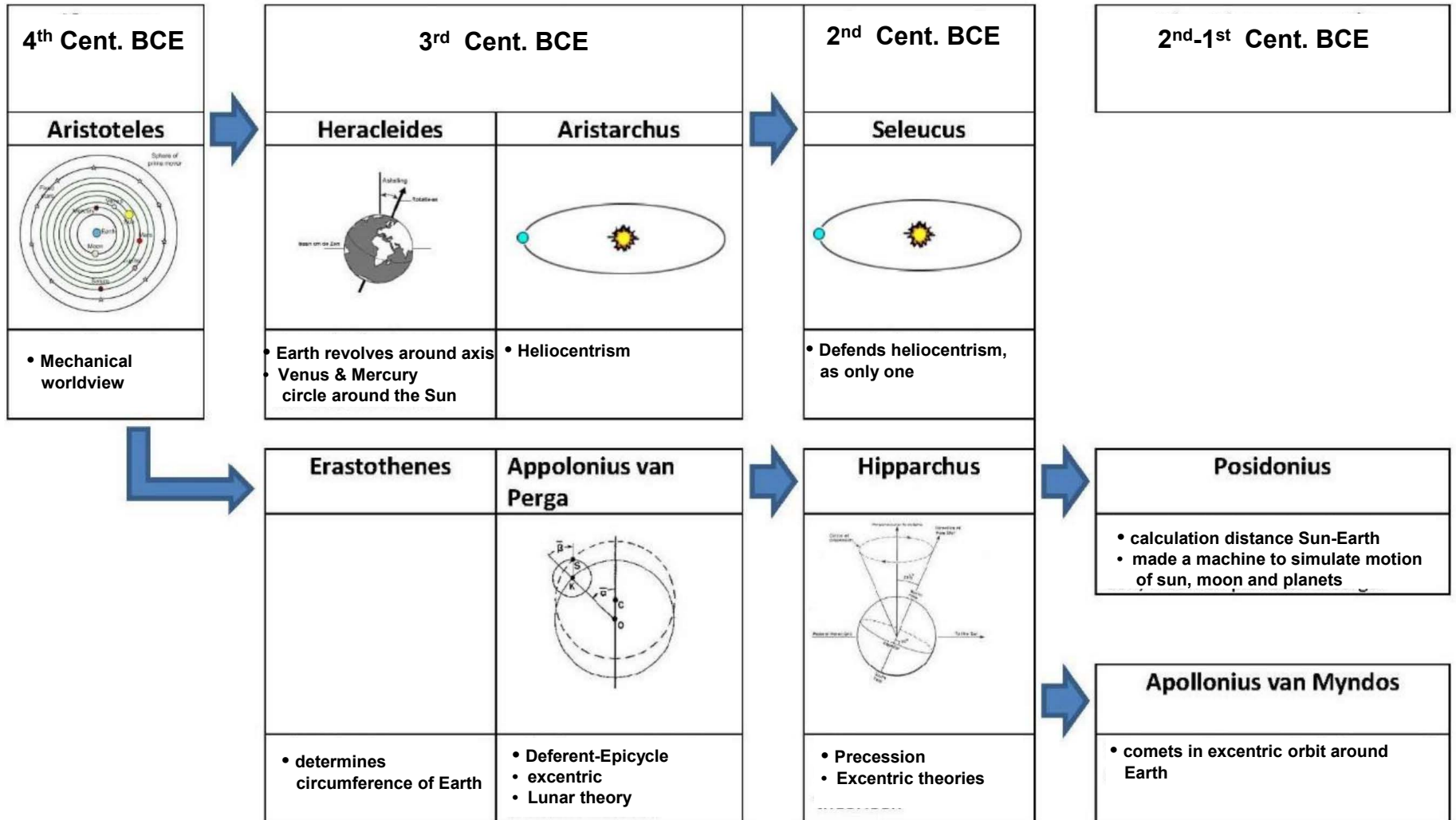
5th Century BCE: Pre-Socratic Natural Philosophers

| 8 th Cent. BCE | 6 th Cent. BCE Natural Philosophers | | | 5 th Cent. BCE | | |
|--|---|---|---|---|---|---|
| Mythical Cosmology | Thales | Anaximander | Pythagoras | Anaxagoras | Empedokles | Leukippos & Demokritos |
| Homerus & Hesiodus | | | | | | |
| Worldview  |  |  |  | | | |
| <ul style="list-style-type: none"> • Earth flat disk • surrounded by a river • Heavens mounted on pillars | <ul style="list-style-type: none"> • Earth flat disk • lies entirely on water • primeval element = water | <ul style="list-style-type: none"> • Earth flat disk • freehanging, geometric • air, fog, fire • primeval element = apeiron, without boundary | <ul style="list-style-type: none"> • Earth is a sphere • central fire, earth, anti-earth, planets • primeval element = numbers • geocentric worldview | <ul style="list-style-type: none"> • No primeval elements • everything contains part of everything else • Heavenly bodies NOT divine | <ul style="list-style-type: none"> • 4 primeval elements: earth, water, air, fire • 2 characteristics: warm, cold • everything consists of proportion of elements of the 2 characteristics | <ul style="list-style-type: none"> • everything consists of atoms • atoms are indivisible, unchanging • but differ in shape and size |

4th Century BCE: from Plato to Aristoteles



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



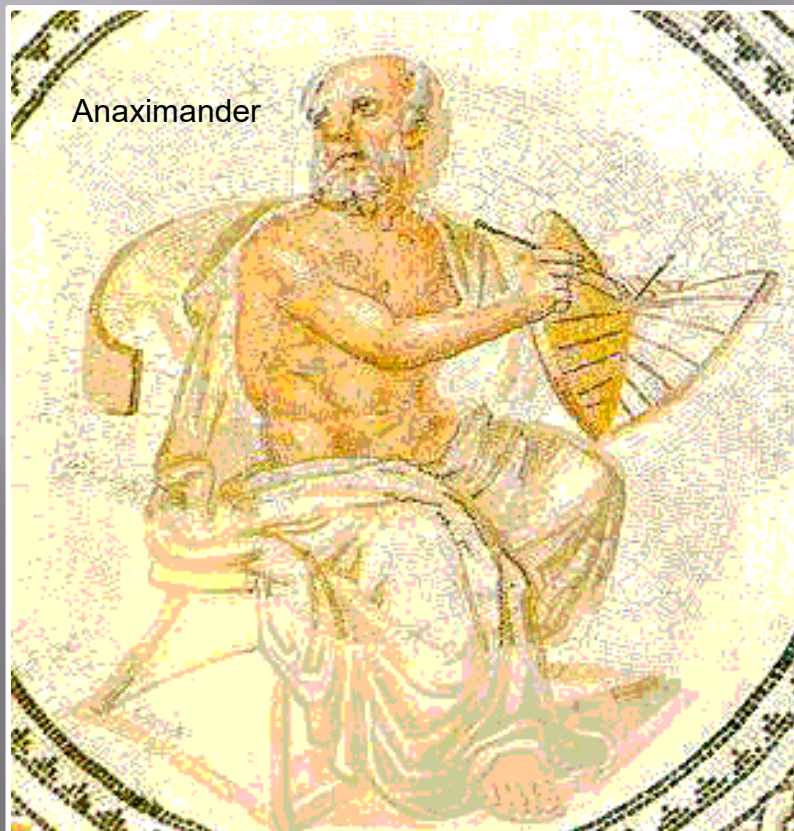
Ionia

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 ...



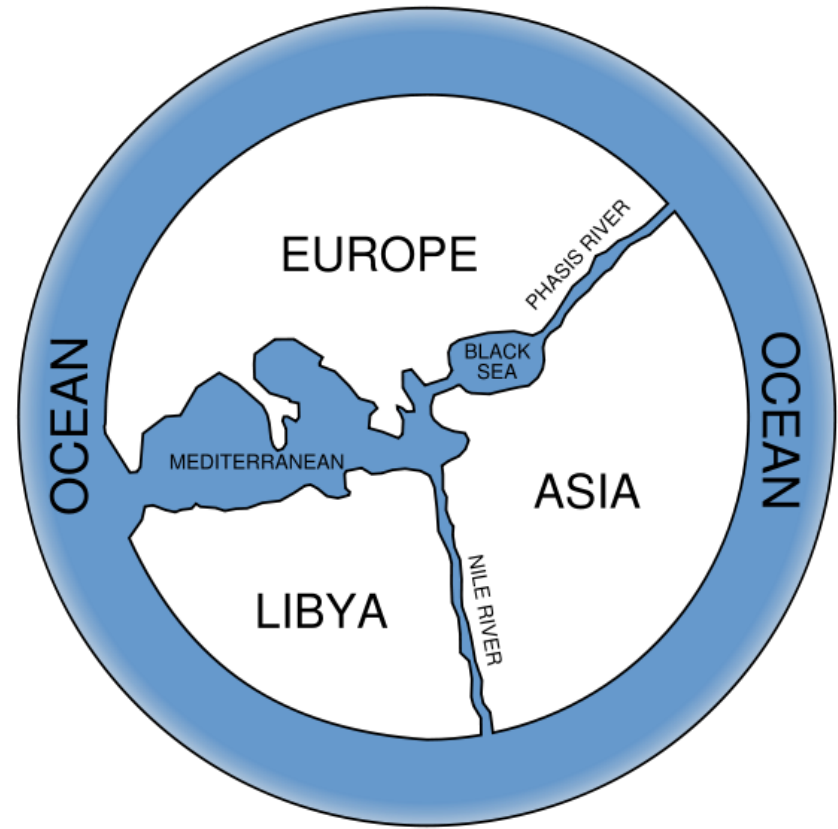
Mathematics as natural language of cosmos
→ Physical cosmos modelled after *ideal form*,
encrypted in concepts of *geometry*

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



Anaximander

the First Cosmologist
(Miletus, 610-546 BCE)

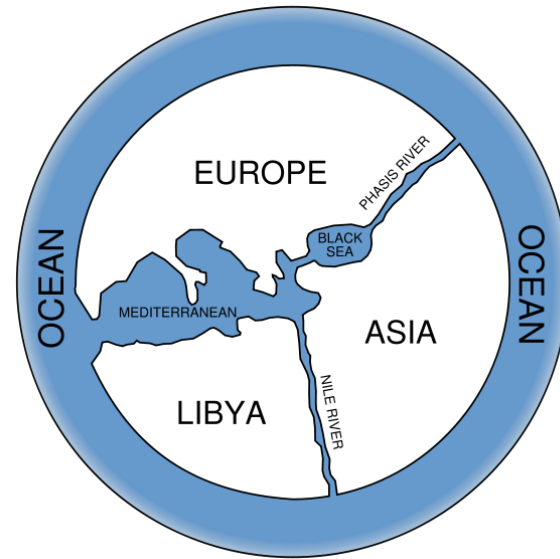


Cartography of Anaximander



Anaximander

the First Cosmologist
(Miletus, 610-546 BCE)



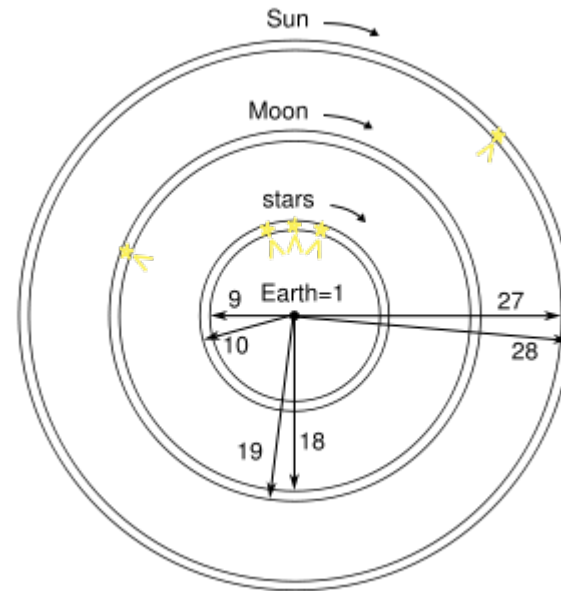
Cosmology of Anaximander:

- 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)



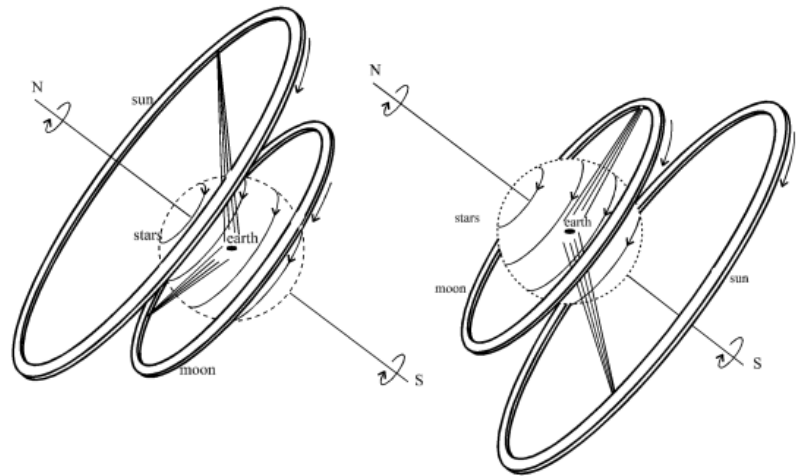
Cosmology Anaximander

- 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



Pythagoras

(Samos, 570-495 BCE)

Pythagoras: Mathematical Cosmology

- replaced Gods, the divine, and myths with principles of higher purity and precision:
- numbers and their relations (rather than anthropomorphic creatures)
- strictly ordered Universe
- on the basis of mathematics
- no room for Gods and their stories



Pythagoras

(Samos, 570-495 BCE)

Pythagoras: Mathematical Cosmology

"The principle of all things is the monad or unit; arising from this monad the undefined dyad or two serves as material substratum to the monad, which is cause; from the monad and the undefined dyad spring numbers; from numbers, points; from points, lines; from lines, plane figures; from plane figures, solid figures; from solid figures, sensible bodies, the elements of which are four, fire, water, earth and air; these elements interchange and turn into one another completely, and combine to produce a universe animate, intelligent, spherical, with the earth at its centre, the earth itself too being spherical and inhabited round about. There are also antipodes, and our 'down' is their 'up'."

Diogenes Laertius



Pythagoras

(Samos, 570-495 BCE)

All is Number

God is Number

Pythagoras & Pythagoreans (his sect/followers)

- practised Numerology – Number worship
- Chaotic world can only be understood in terms of numbers:
 - musical harmony
 - harmony of the spheres



Pythagoras

(Samos, 570-495 BCE)

the Book of Nature

is written in

the Language of Mathematics

- In a sense, the lasting legacy of Pythagoras & the Pythagoreans:
- theme underlying present-day science: nature is written in mathematics



Pythagoras

(Samos, 570-495 BCE)

All is Number

God is Number

Pythagoras & Pythagoreans (his sect/followers)

- practised Numerology – Number worship
- each number its own character & meaning:
 - 1: generator of all numbers
 - 2: opinion
 - 3: harmony
 - 4: justice
 - 5: marriage
 - 6: creation
 - 7: 7 wandering stars (planets)
- odd numbers: female
even numbers: male



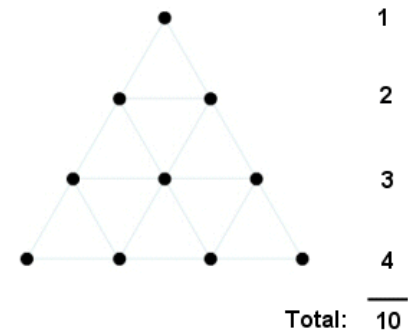
Pythagoras

(Samos, 570-495 BCE)

All is Number

God is Number

The tetractys, an equilateral triangular figure consisting of 10 points arranged in four rows of 1, 2, 3 and 4, was both a mathematical idea and a metaphysical symbol for the Pythagoreans.



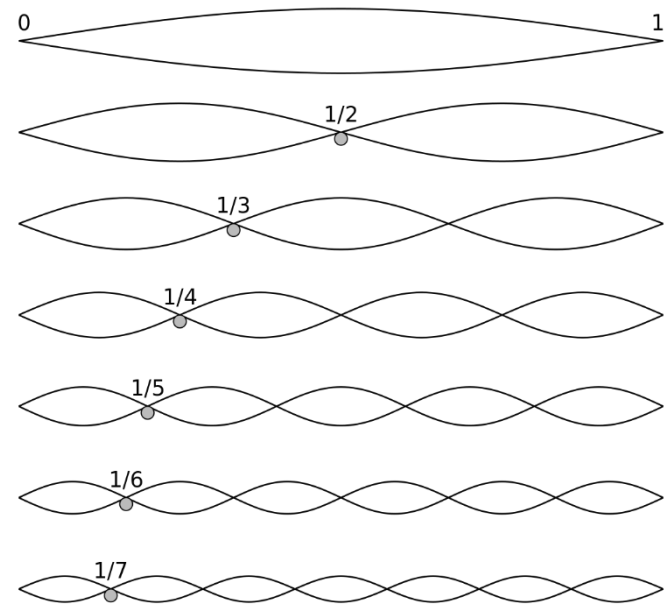
- Holiest number: **Tetractys = 10**
triangular number = $1+2+3+4$



Pythagoras

(Samos, 570-495 BCE)

Musical Harmony - Numbers



Pythagoras is credited with discovery:

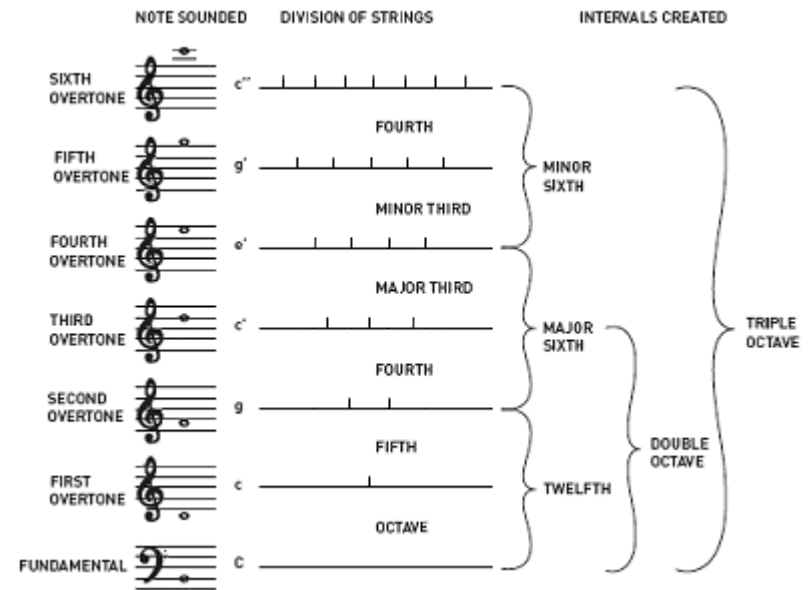
- the pitch of a musical tone
- inversely proportional to the length of the string
- intervals between harmonious sound frequencies define simple numerical ratios



Pythagoras

(Samos, 570-495 BCE)

Musical Harmony - Numbers



Pythagoras is credited with discovery:

- harmonious musical notes – whole number ratios
- described the first 4 overtones
- forming the primary building blocks of musical harmony



Pythagoras

(Samos, 570-495 BCE)

Harmony of the Spheres

Pythagoras:

- The proportion in movements of the celestial bodies – sun, moon, and planets – is such that it resembles musical notes, it is a form of *musica*, and thus produce a symphony:

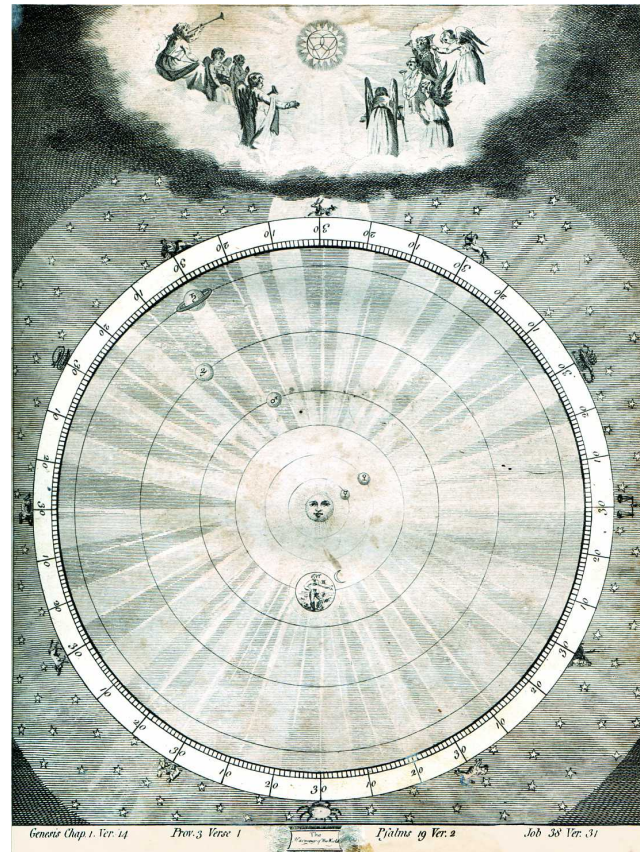
Music of the Spheres

- Pythagoras claimed that the sun, moon and planets emit their own hum, based on orbital revolution (imperceptible to human ear).
- Legend: Pythagoras could hear the 'music of the spheres' enabling him to discover that consonant musical intervals can be expressed in simple ratios of small integers.

Pythagoras

(Samos, 570-495 BCE)

Harmony of the Spheres





Pythagoras

(Samos, 570-495 BCE)

Mystical Sect of Pythagoreans



- Pythagoras established a school/mystical sect
- Croton in southern Italy (530 BCE) nucleus of sect
- Bizarre sect:
 - although largely dominated by mathematics,
 - also profoundly mystical



Pythagoras

(Samos, 570-495 BCE)

Mystical Sect of Pythagoreans

- Pythagoras established a school/mystical sect
- Croton in southern Italy (530 BCE) nucleus of sect
- Bizarre sect:
 - although largely dominated by mathematics,
 - also profoundly mystical,
- Pythagoras imposed
 - quasi-religious philosophies
 - strict vegetarianism
 - communal living
 - secret rites
 - odd rules on all the members of his school
- Two groups of members:
 - **Mathematikoi** - “learners”
extending and developing scientific & mathematical work
 - **Akousmatikoi** - “listeners”
focus on religious & ritualistic aspects of teachings



Pythagoras

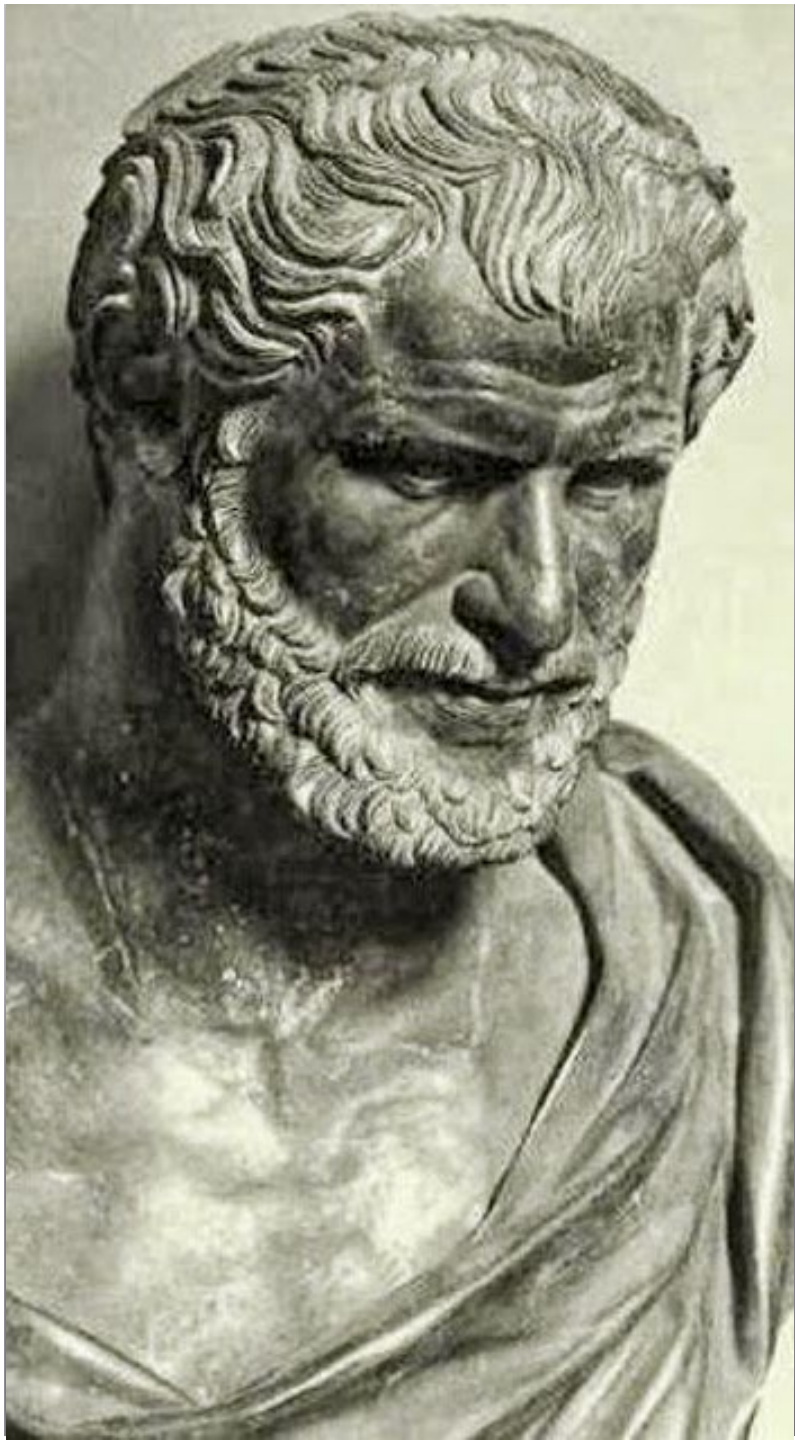
(Samos, 570-495 BCE)

the Book of Nature

is written in

the Language of Mathematics

- No original texts/writings of Pythagoras known, all we know comes via his adherents, Pythagoreans
- Lasting influence:
 - Philosophy Plato heavily dependent on teaching Pythagoreans
 - Nature written in language of mathematics
- Bertrand Russell, *A History of Western Philosophy*:
 - “ ... the influence of Pythagoras on Plato and others was so great that he should be considered the most influential philosopher of all time.”
 - “ I do not know of any other man who has been as influential as he was in the school of thought.”

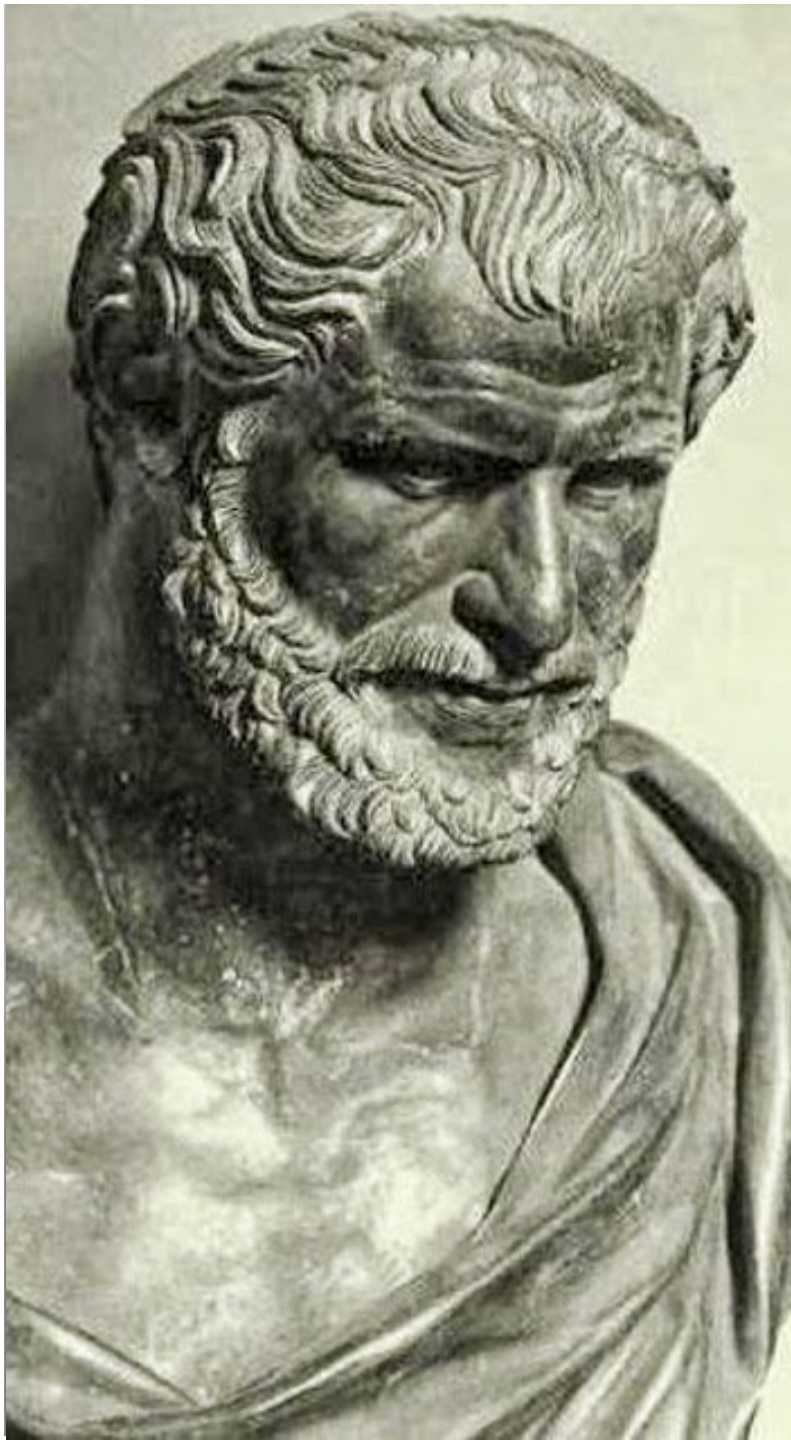


Democritus

(Abdera, 460-370 BCE)

Atomic Theory

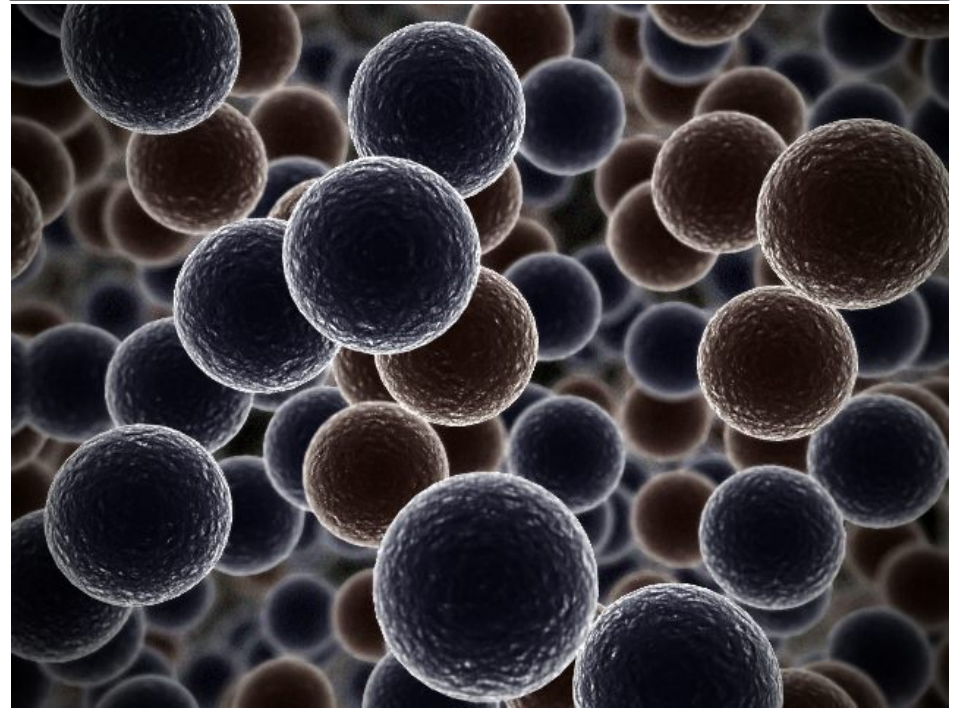
- All matter consists of invisible particles called atoms.
- Atoms are indestructible.
- Atoms are solid but invisible.
- Atoms are homogenous
- Atoms differ in size, shape, mass, position, and arrangement.

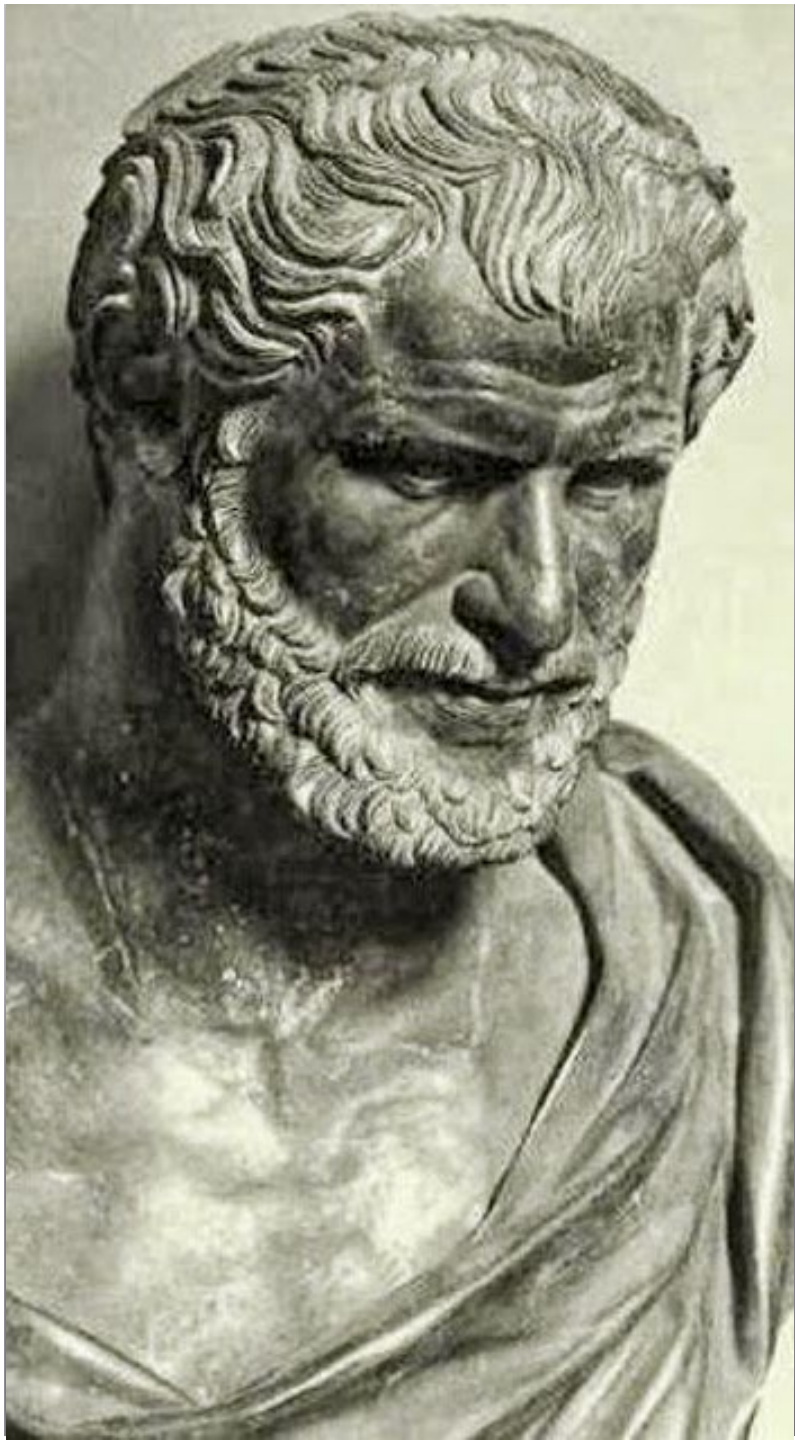


Democritus

(Abdera, 460-370 BCE)

Atomic Theory





Democritus

(Abdera, 460-370 BCE)

Atomic Theory

- All matter consists of invisible particles
- Solids are made of small, pointy atoms.
- Liquids are made of large, round atoms.
- Oils are made of very fine, small atoms that can easily slip past each other.

Classical Greek Cosmology

Plato & Aristoteles

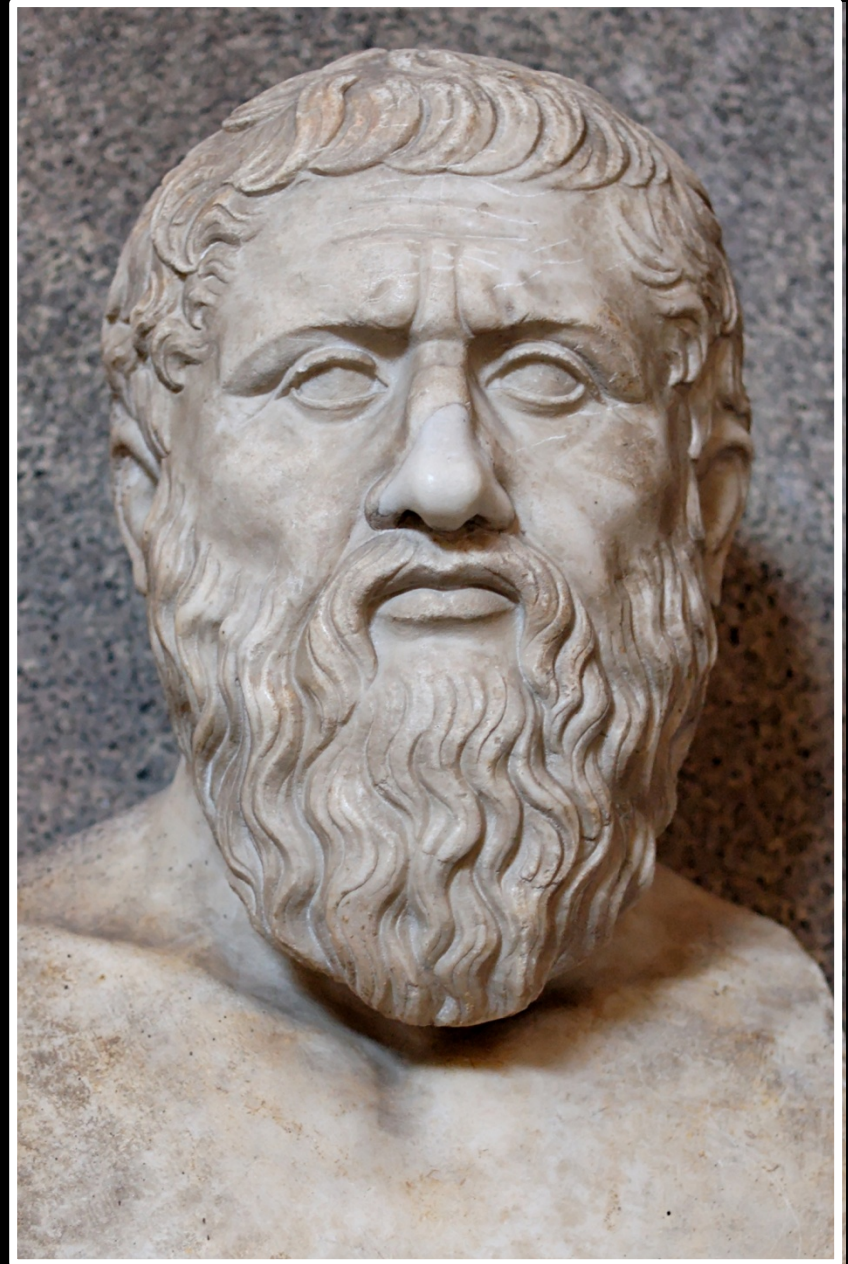
Plato

(Athens,
428-348 BCE)

**Geometry as
organizing principle
of the world**

Founded Academy, Athens

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



Academia Platon

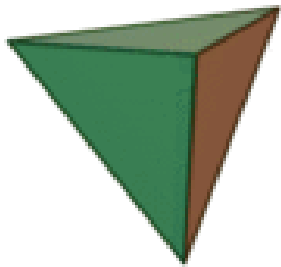
A photograph of the ruins of Plato's Academy in Athens. The scene shows a series of stone steps leading up a grassy slope. In the background, there are several large, mature trees, including a prominent one with a thick trunk and dense foliage. The lighting is bright, suggesting a sunny day, with shadows cast across the ground and the steps.

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

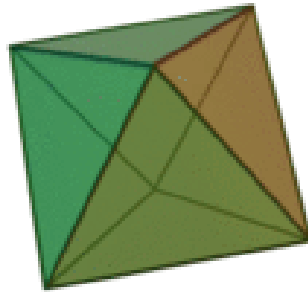
Platonic Solids

the Five Platonic solids

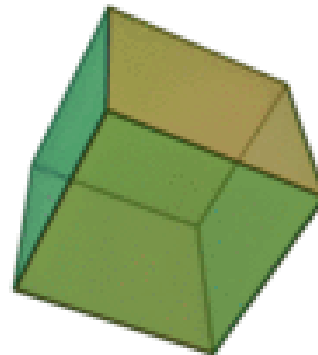
- there are only five convex regular polyhedra !
- Plato identified them with the cosmos and its constituents



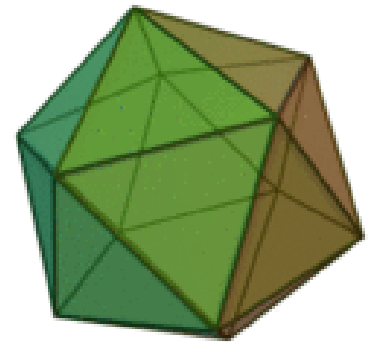
Tetrahedron:
fire



Octahedron:
air



Cube:
earth

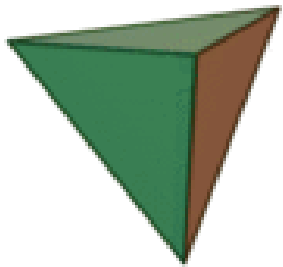


Icosahedron:
water

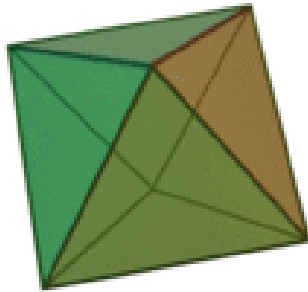
Platonic Solids

Dodecahedron ↔ Quintessence

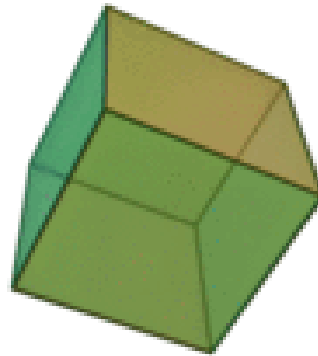
of which the Cosmos itself is made:
“the stuff for embroidering
the constellations on the heavens”



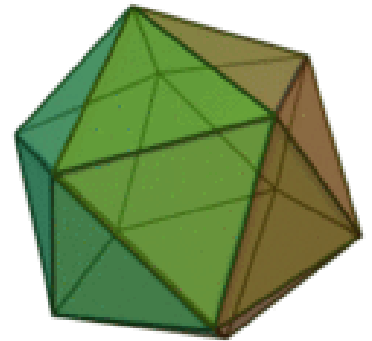
Tetrahedron:
fire



Octahedron:
air



Cube:
earth



Icosahedron:
water

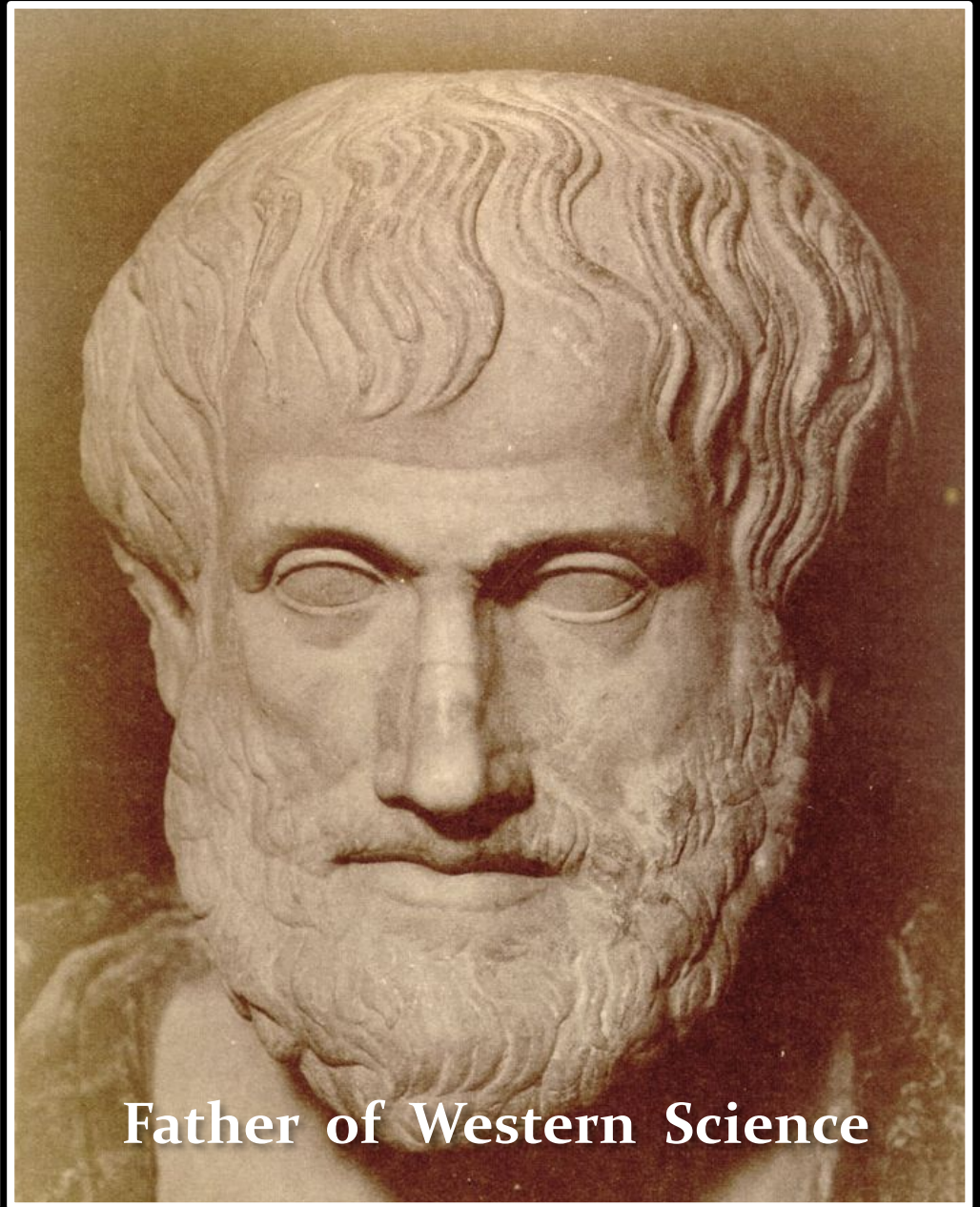
Aristoteles

(Chalcidice-Athens, 384-322 BCE)

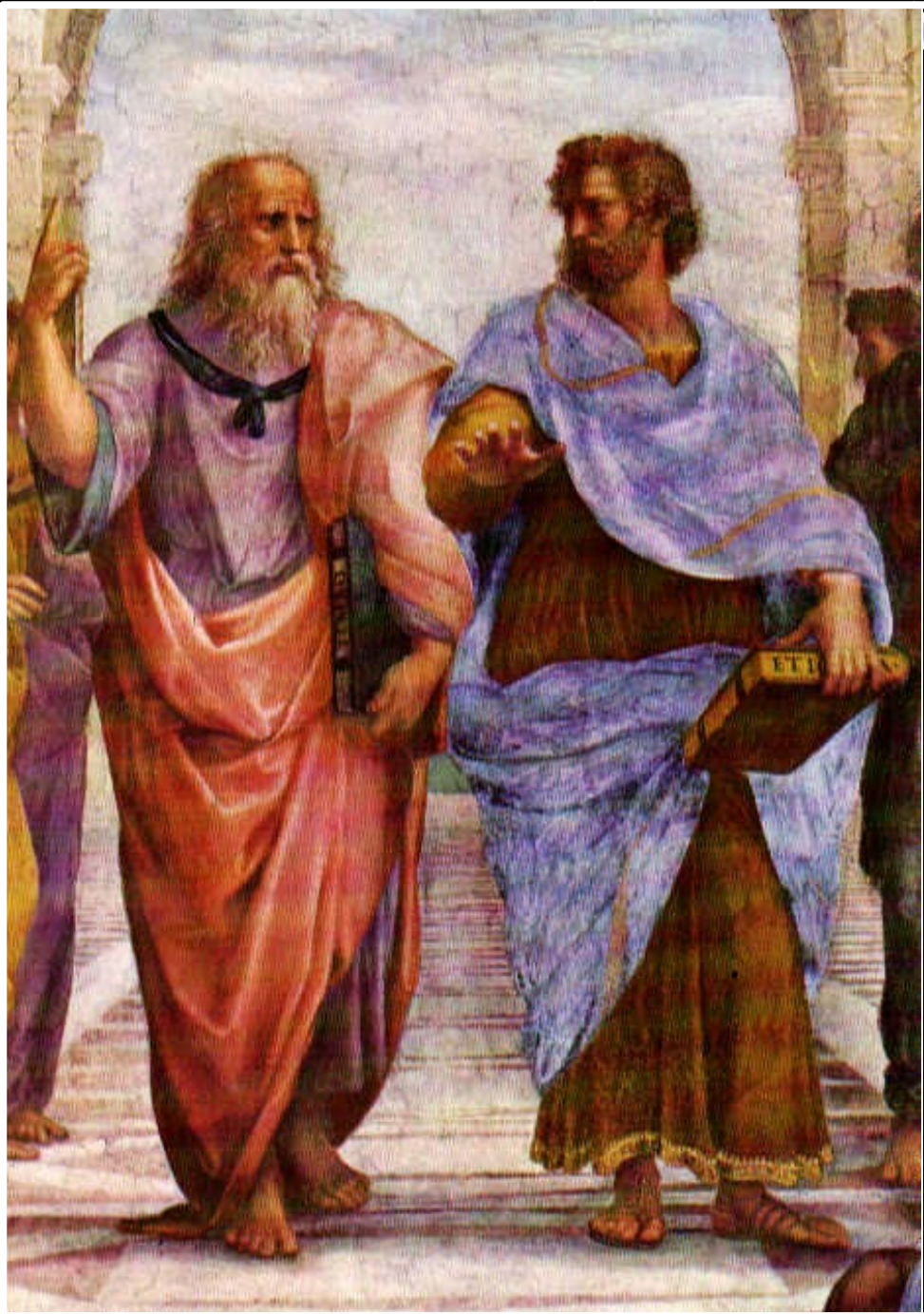
- “Aristotle was the first genuine scientist in history ... every scientist is in his debt”

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



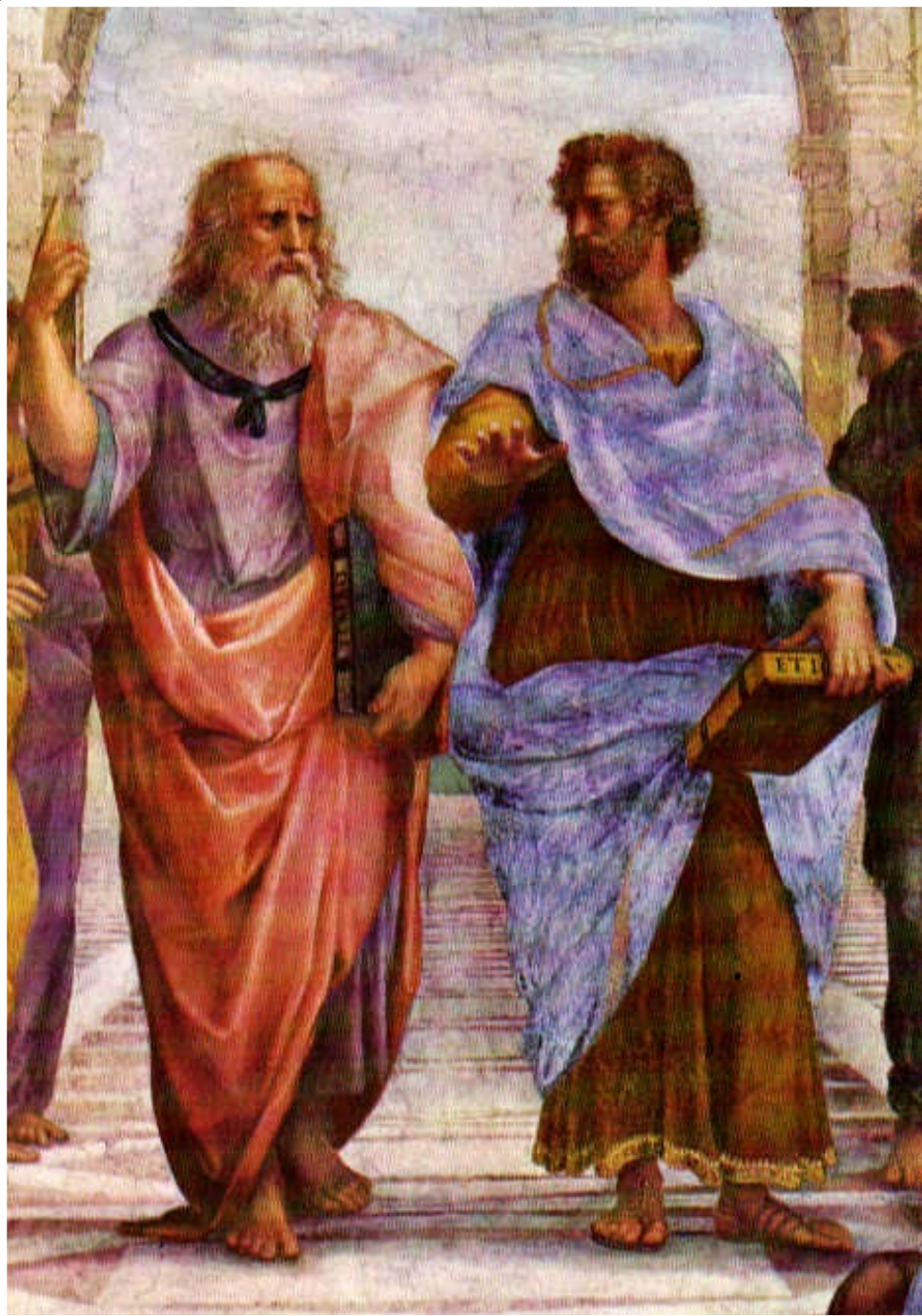
Father of Western Science



*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



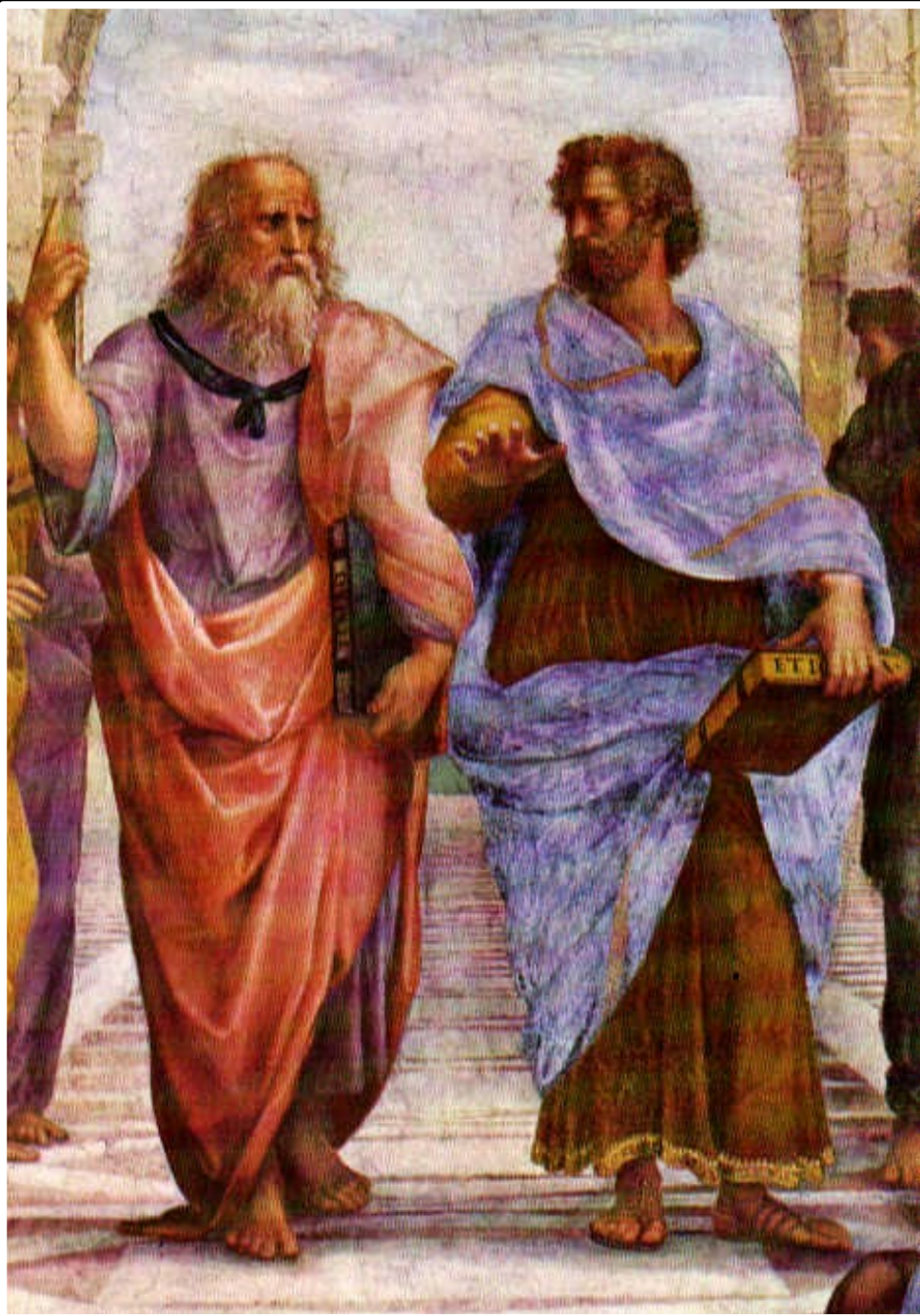
- **Aristotle's cosmological work**
- the most influential treatise of its kind in the history of humanity.

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

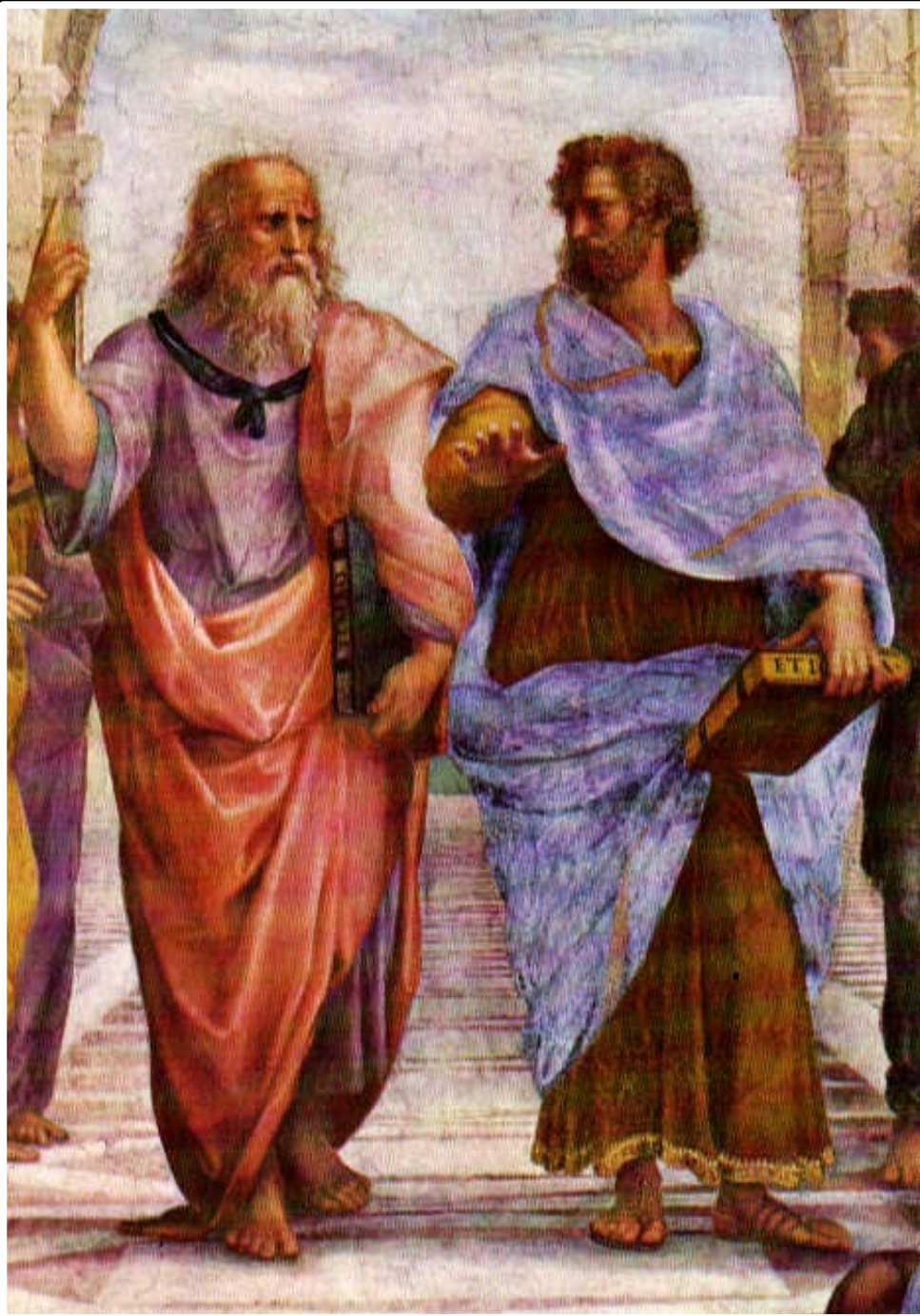


- **Four causes**

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**

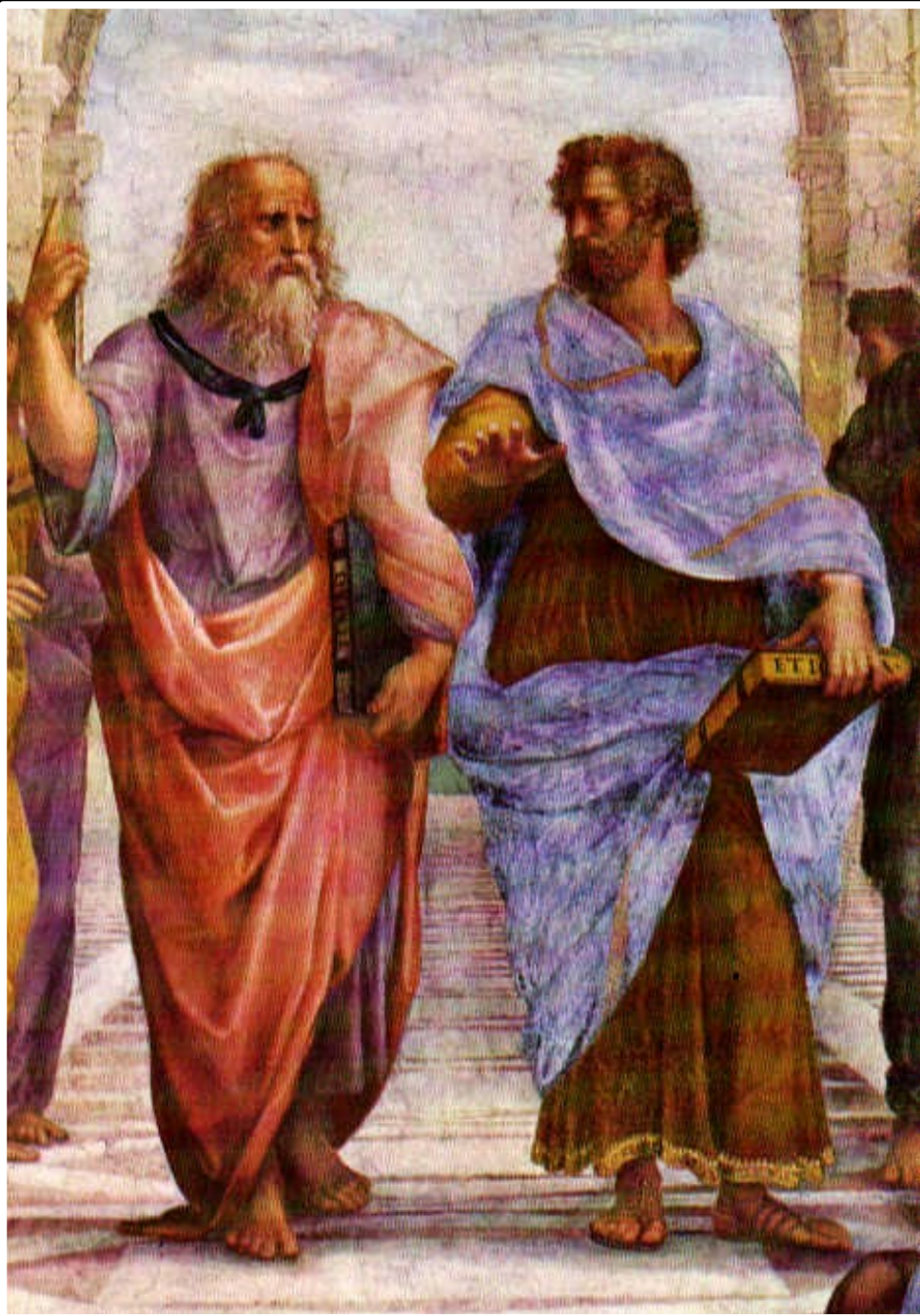
4 elements (Empedokles)

- | | | |
|-----------------|--------------|--------------------------|
| 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



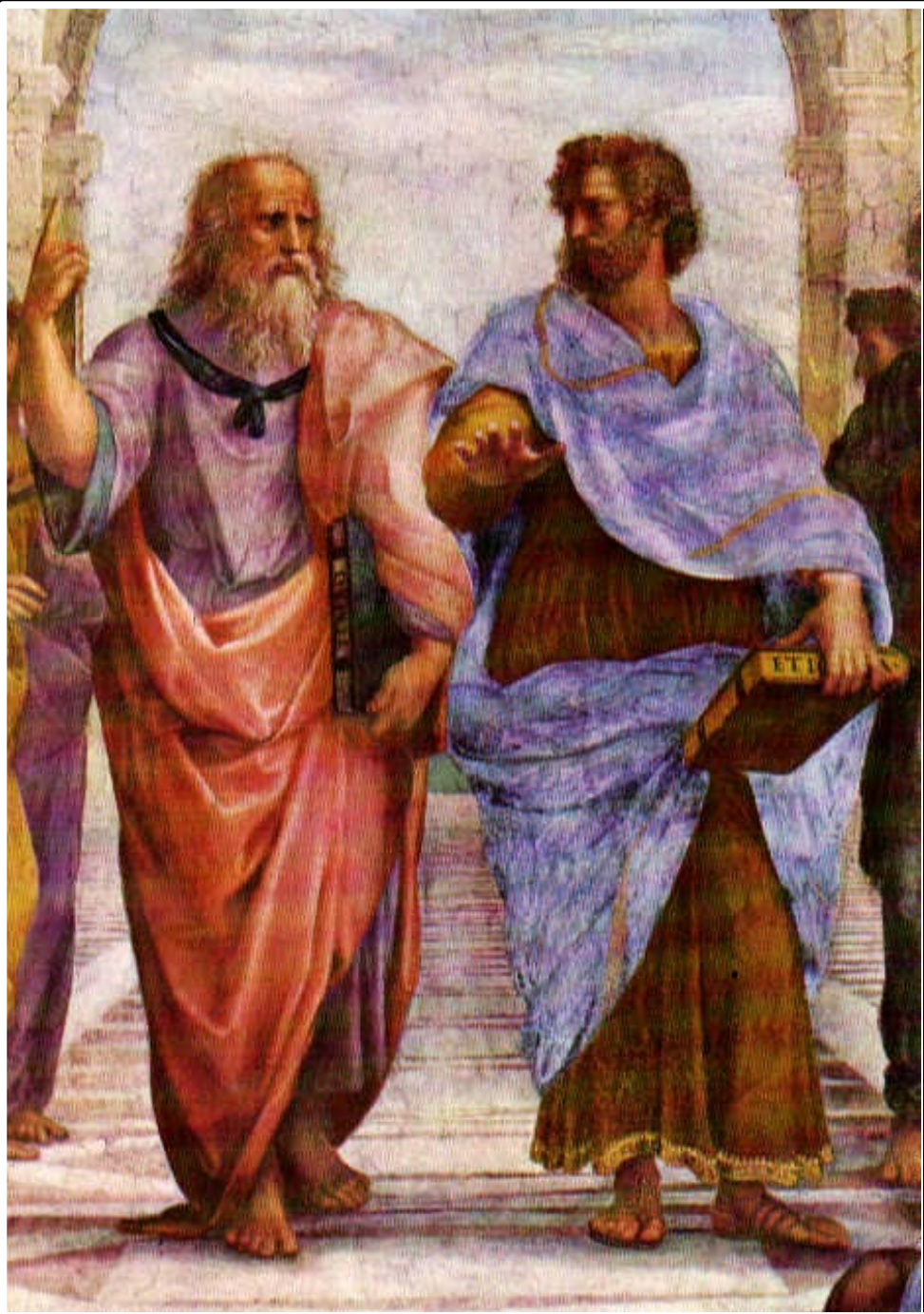
- **Movement of bodies**

- 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''.

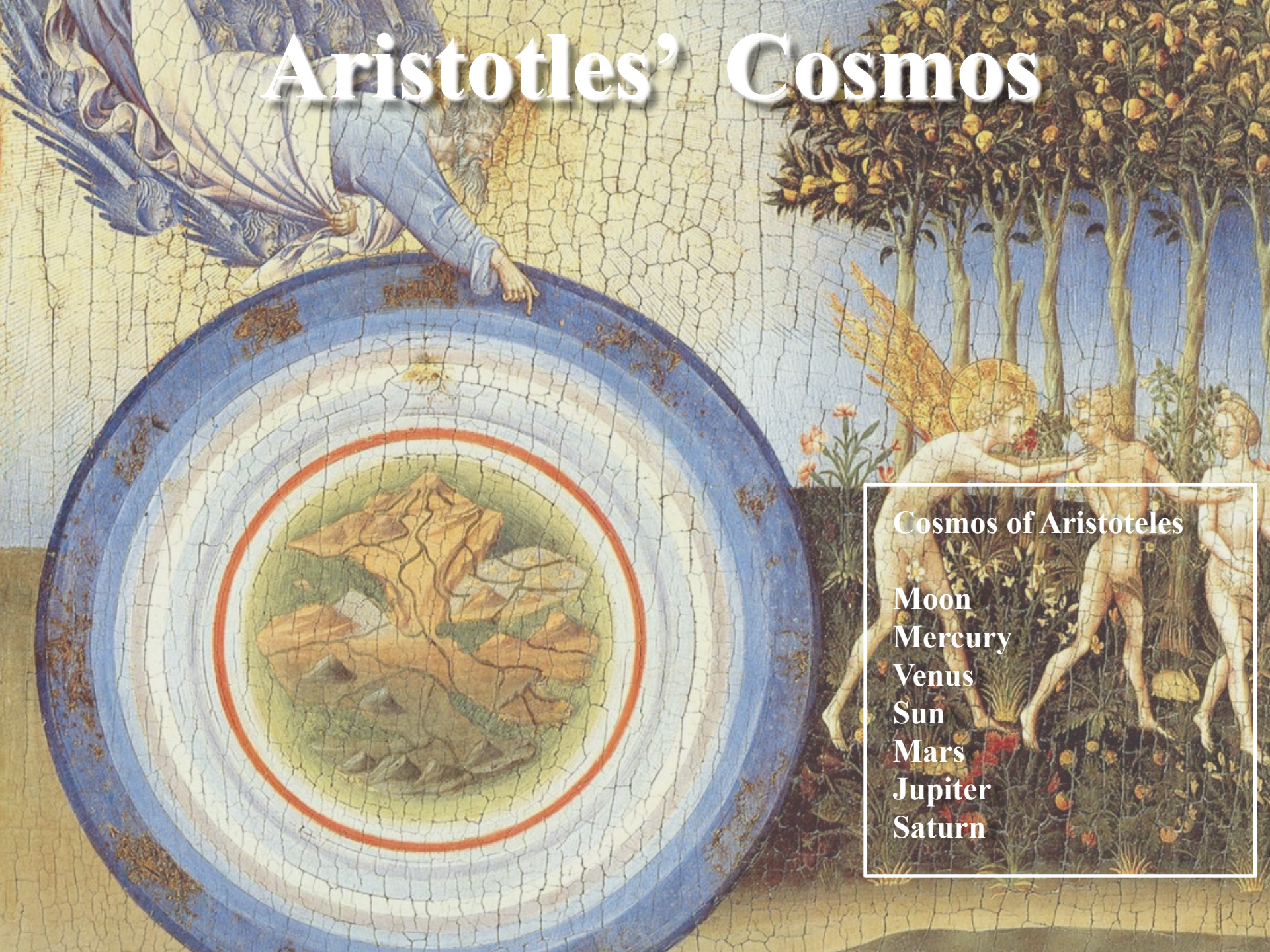
- Note the strange idea that all celestial bodies are perfect, yet they must circle the imperfect Earth.

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