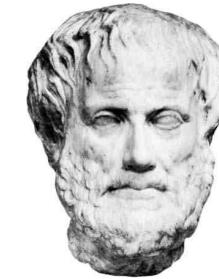


03. Aristotle (384-322 B.C.)

1. Matter and Form

- All being is in the world.
- Forms exist in sensible objects; not in a separate Platonic realm.



1. Matter and Form
2. Change
3. Four Causes
4. Cosmology

Doctrine of Hylomorphism

- A sensible object consists of both *matter* and *form*.
- *Form* determines properties of the object.
 - *Properties cannot exist without a subject in which they adhere.*
- *Matter* provides substratum in which properties adhere.
 - *By itself has no properties (neutral substratum).*
 - *Does not exist without form.*

Aristotle's objection to Plato

There can be no *matter* without *form*, and no *form* without *matter* (with one important exception).

Example

- Gold is yellow, cold, malleable, heavy, smooth, etc; determined by its *form*.
- If all these properties could be stripped away, what would remain would be *matter*.



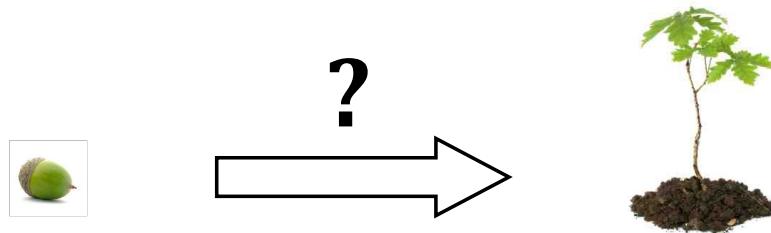
- *Goal of natural inquiry* = To identify the forms of things.
 - *This must start in the sensible world (and not in the realm of reason).*

2. Change

- Problem of change: How can the world exhibit both permanence and change?

Consider the transformation of an acorn into a sapling.

- *How can we identify the sapling with the acorn?*
- *How is this identity transferred during the transformation?*



Aristotle's Account of Change

- Permanence through change is provided by *matter*.
 - *When a sensible object changes, its form changes and its matter remains the same.*
- So: Change is fundamentally real.
 - *Not an illusion; not restricted to a lesser realm.*
- But: What about Parmenides' Objection: Change requires the emergence of something from nothing.

- Aristotle's Response:

- *Change is not a transition from non-being to being, but from potential being (potential form) to actual being (actual form).*

- Example:

- An acorn has both an *actual form* of being an acorn, and a *potential form* of being a sapling and an oak tree.
 - A sapling has both an *actual form* of being a sapling, and a *potential form* of being an oak tree.
 - When an acorn changes into a sapling, its *potential form* transitions into the *actual form* of a sapling.



- Two distinctions underlie Aristotle's concept of change:

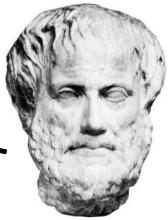
- *matter/form distinction* (static)
 - *potential/actual distinction* (dynamic)

- *Pure potency* = "Prime Matter" (but this doesn't exist: actuality is prior to potency).
 - *Pure actuality* = "Prime Mover" (Aristotle's concept of god).

- This explains *how* change is possible. But it doesn't explain *why* change occurs: What is the *cause* of change?

- Aristotle: Things undergo change due to their *natures*.

"Things are what they do."



- *nature* = an internal goal-directed cause of change; the tendency to actualize a potential.

- The *nature* of an acorn is to become an oak tree.
- The *nature* of a planet is to follow a perfect circular path in the heavens.
- The *nature* of a rock is to fall to the center of the cosmos.
- A rock has the actual form of heaviness and the potential form of being-at-the-center-of-the-cosmos.

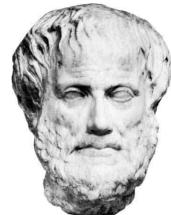


How is this different from contemporary accounts?

- Consider Newton's 1st Law of Motion:
 - *Left unimpeded, a body will continue in a state of rest or in uniform motion along a straight line.*
- *Why* does a body do this?
 - *Inertia* = tendency of a body to obey the 1st Law of Motion.
 - *The more inertia a body has, the greater its tendency to continue at rest or in uniform motion in a straight line.*
- *Why* do bodies have inertia?
 - *No explanation within contemporary physics.*

- Knowledge consists in knowledge of *natures*.
 - *Knowledge consists of* understanding the causes of change.

"If we are ignorant of change,
then we are ignorant of Nature."



Three Points to Remember about Aristotelian natures

1. Not all things follow their natures and achieve their potentials.
 - *Most things are impeded by interactions with other things.*
 - *Left unimpeded, all things would follow their natures.*
2. Only *natural* things have natures, and hence are sources of change.
 - *Artificial things do not have natures.*
3. To determine *natures*, observation is sufficient.
 - *No need for intervention (i.e., controlled experimentation, repeatability, etc.)*

3. The Four Causes

1. Material: What is it made of? (That *in which* change occurs.)
2. Formal: What kind of thing is it? (The form *into which* a thing changes.)
3. Efficient: How was it made? (That *by which* change is brought about.)
4. Final: What is it for? (That *for the sake of which* change occurs.)

- Four ways of explaining what makes a thing what it is.
- Operative in both Art (*techne*) and Nature (*physis*).

marble statue of Zeus

1. marble
2. shape of Zeus
3. chisel and hammer
4. intent of sculptor

acorn

1. material of acorn
2. oak tree
3. rain, sun, soil, nutrients
4. nature of acorn



- Note overlaps: The nature of an acorn is also associated with its form.
 - *In Art, final causes are external/transcendent.*
 - *In Nature, final causes are internal/immanent.*

- Is Aristotle deifying Nature with concept of final cause?
 - No: Nature does not have an overall purpose.
 - Rather: Natural processes are internally goal-directed.

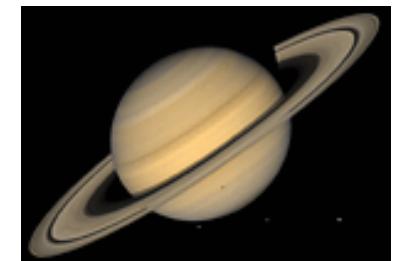
Ex: Functional explanations in contemporary biology.

- Why are grasshoppers green?
- Typical answer: Camouflage is a valuable adaptive trait for grasshoppers.



- But no explanations of this sort in contemporary physics:

- Why does Saturn have rings?
- Typical answer: The rings are the remnant of a moon that broke up in the distant past.



- No appeal to any possible value of having rings for planets.
- Explanations in contemporary physics *tend* to be framed in terms of efficient causes and not final causes.

Why?

But wait!

- *Fermat's Principle of Least Time*: The path taken by a light ray is the quickest possible one.

↗ *geometric optics*



Pierre de Fermat
(1607-1665)

- *Principle of Least Action*: A physical system is described by an action functional $S[q]$, where q represents a possible quantity the system can possess. The *actual* quantity the system possesses is that q_0 that extremizes the action: $\delta S[q_0] = 0$.

↗ *any theory in physics characterized by equations of motion*

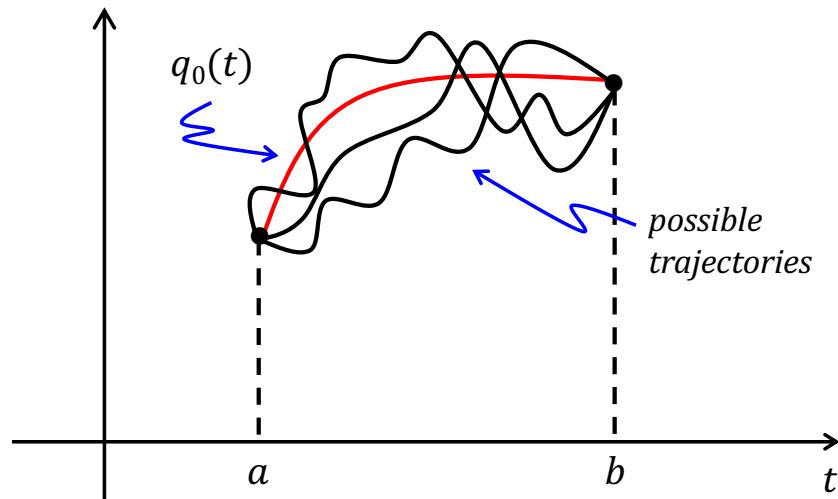


Leonhard Euler
(1707-1783)

Ex 1: Massive Newtonian particle

- Described by the action $S[q(t)] = \int [\frac{1}{2}mq'^2 - V(q)]dt$, where $q(t)$ is a possible trajectory of the particle.
- The actual trajectory $q_0(t)$ is the one for which $\delta S[q_0(t)] = 0$.
- This trajectory satisfies

$$m \frac{d^2 q_0(t)}{dt^2} = - \frac{\partial V}{\partial q}$$



But wait!

- *Fermat's Principle of Least Time*: The path taken by a light ray is the quickest possible one.

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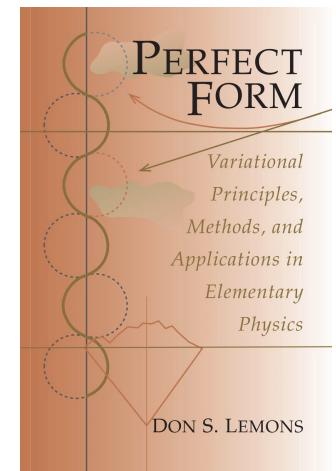


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"...there is absolutely no doubt that every effect in the universe can be explained as satisfactorily from final causes, by the aid of the method of maxima and minima, as it can from the effective causes." (1744).

- *In general*: Any explanation of a phenomenon that appeals to an optimization principle suggests an appeal to a final cause.
 - *Why do engineers/artists seek the least expensive, strongest, most efficient, etc., "optimal" design?*



4. Aristotle's Cosmology

(a) The Four Elements

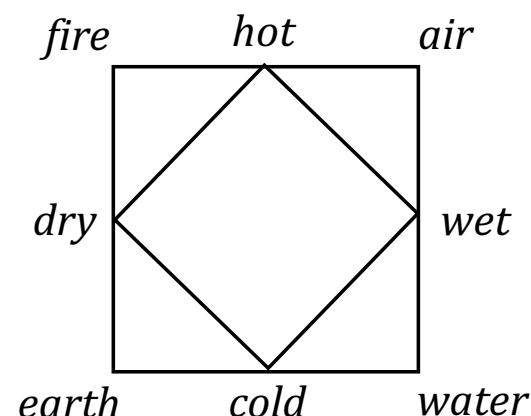
- (a) The Four Elements
- (b) The Cosmos
- (c) Motion
- (d) The Plenum

<u>element</u>	<u>form</u>	
earth	cold/dry	heaviest
water	cold/wet	lighter ₁
air	hot/wet	lighter ₂
fire	hot/dry	lightest

Transformations between elements:

- *Contrary forms* = two forms that cannot both be present in the same thing.
- Forms change *via* transitions between contraries.

<u>cold</u> \Leftrightarrow <u>hot</u>	<u>wet</u> \Leftrightarrow <u>dry</u>
water \Leftrightarrow air	water \Leftrightarrow earth
earth \Leftrightarrow fire	air \Leftrightarrow fire



(b) The Cosmos

A series of concentric spheres divided into two realms:

- **Terrestrial Realm**

*Composed of the elements fire,
air, water, earth.*

- **Celestial Realm**

Composed of the element aether.

- *The spheres of the sun
and planets. In order:*

Moon —————

Sun —————

Venus —————

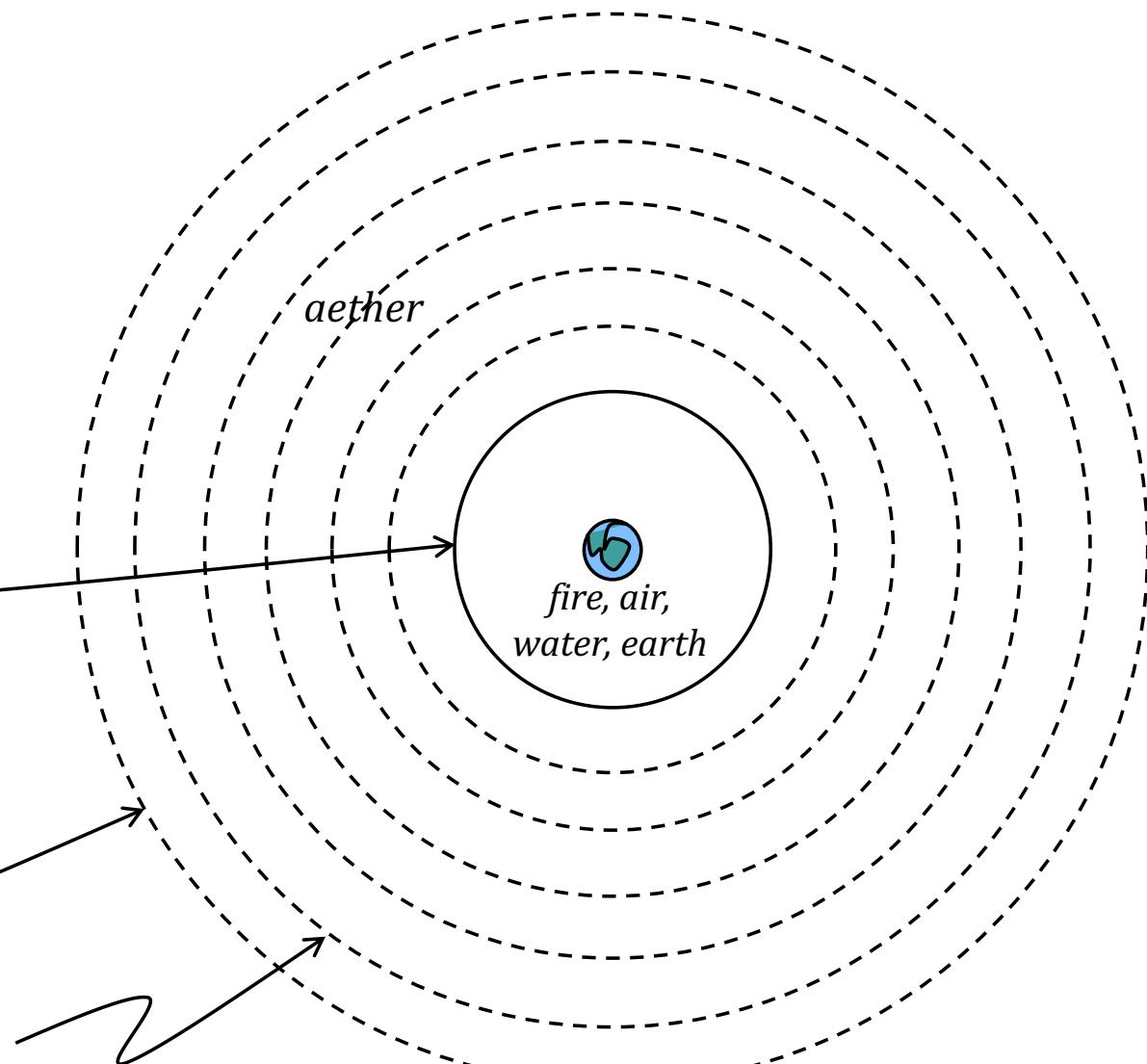
Mercury —————

Mars —————

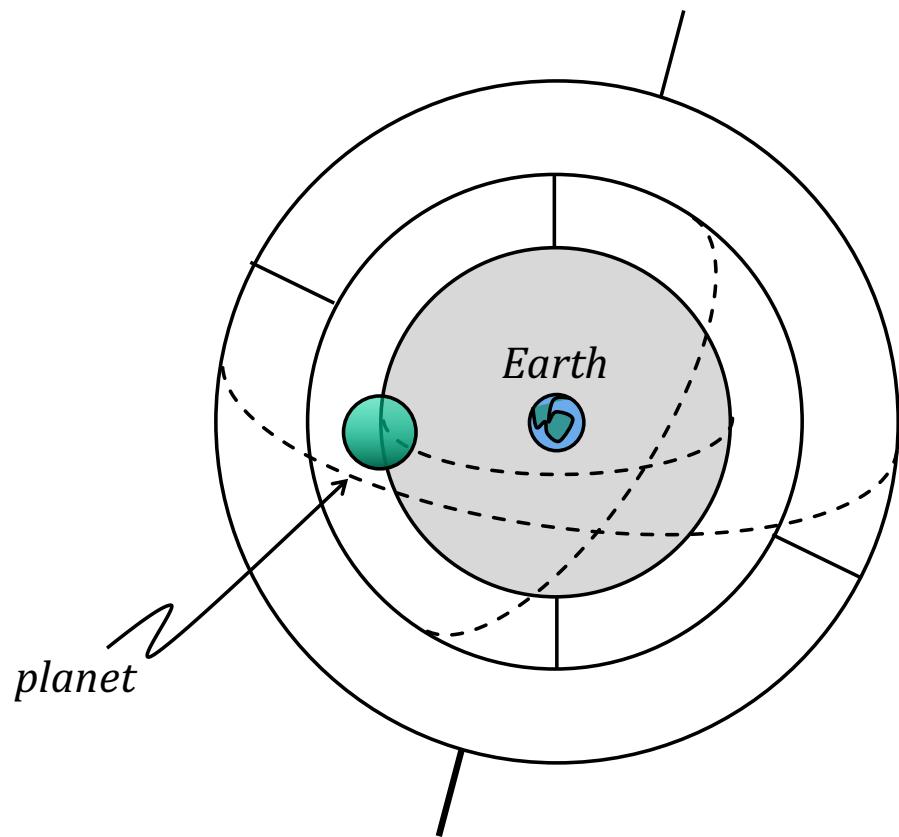
Jupiter —————

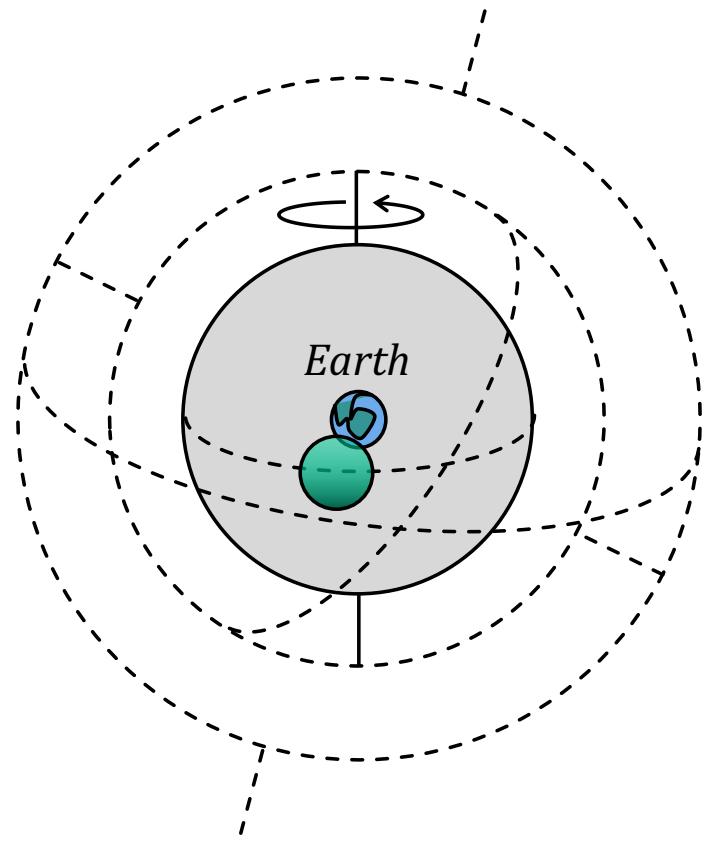
Saturn —————

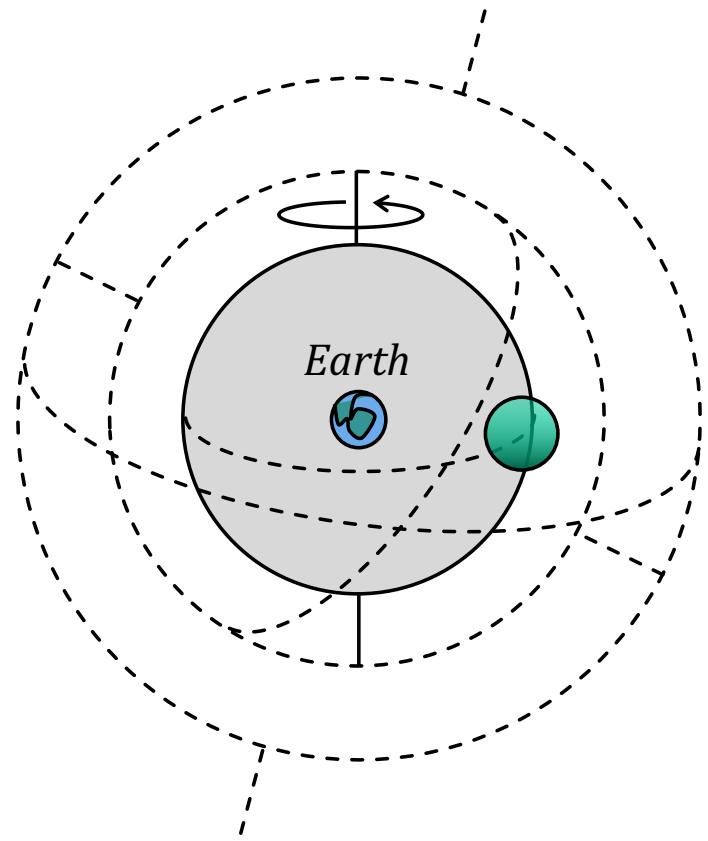
fixed stars —————

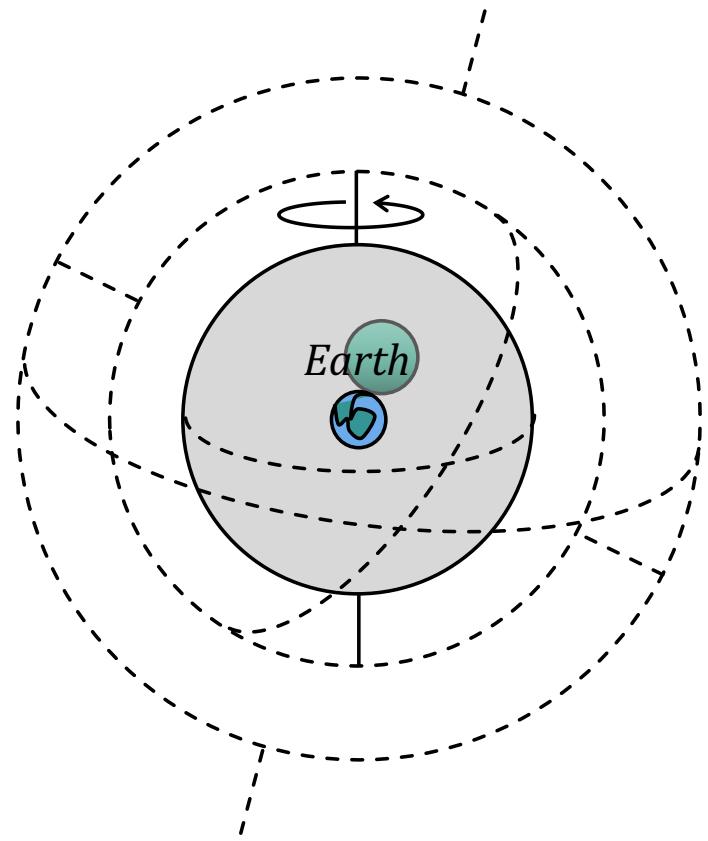


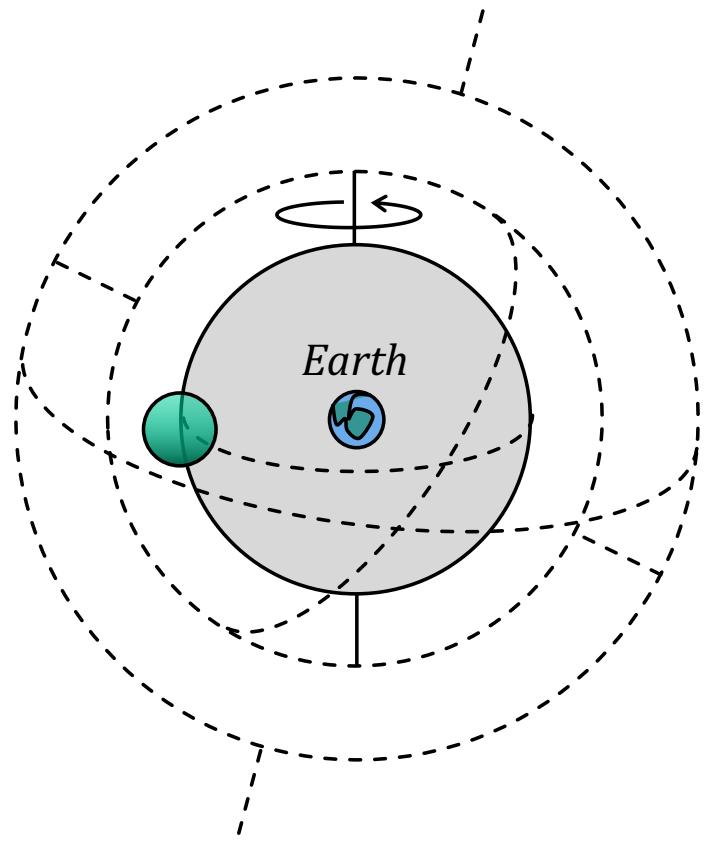
- *Each dotted circle represents a
set of nested spheres...*

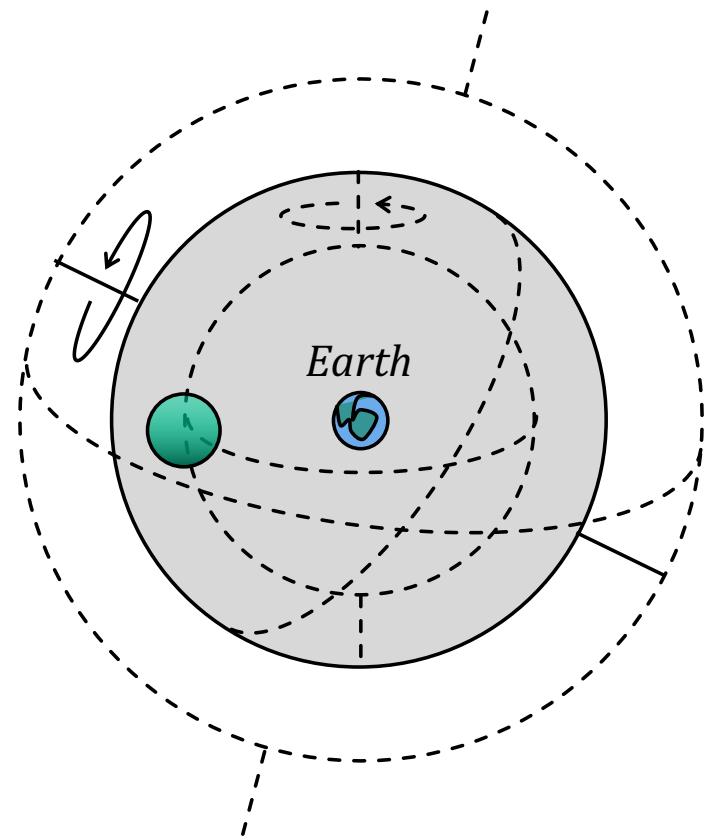


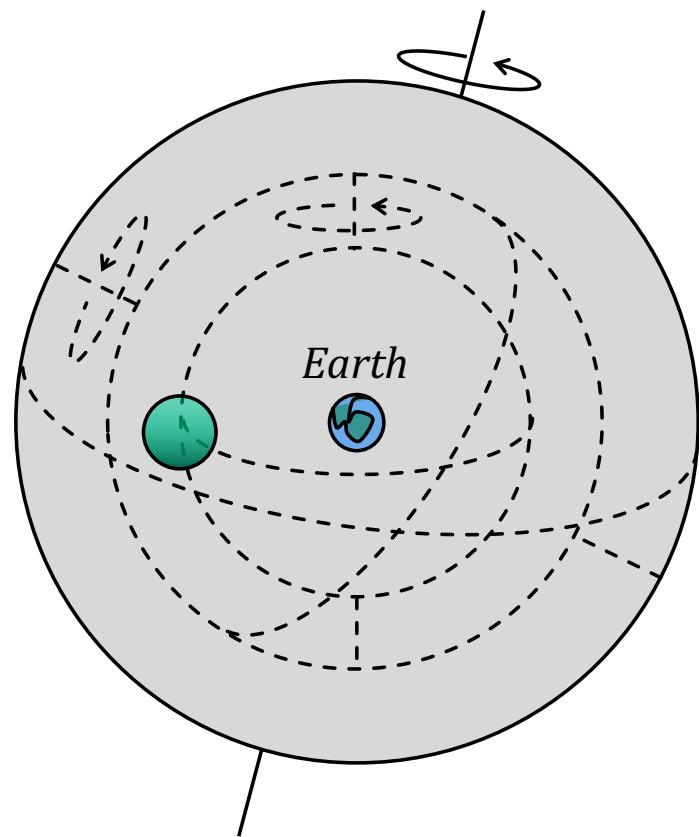


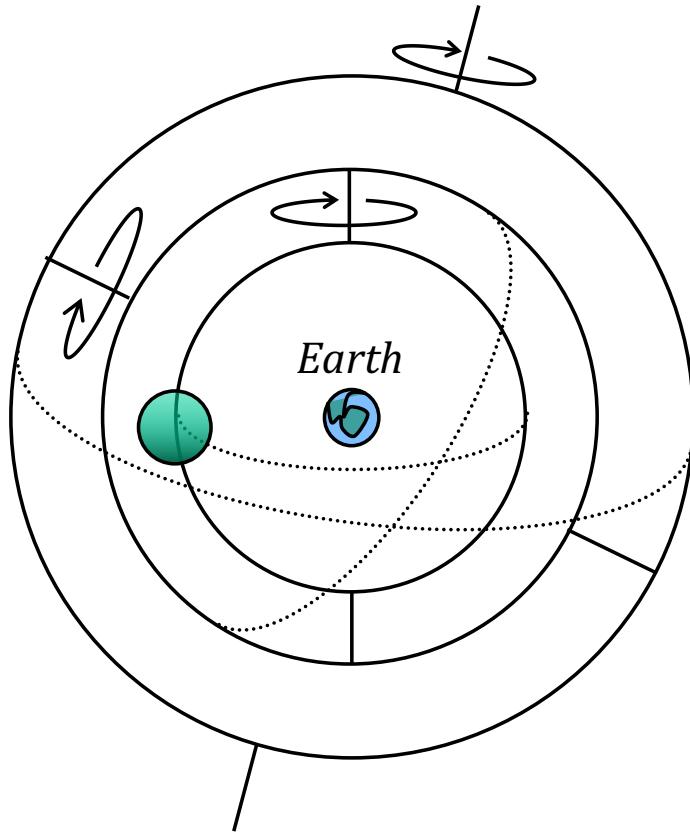












How many spheres?

	<u>Eudoxus</u>	<u>Callippus</u>	<u>Aristotle</u>
Moon	3	5	5
Sun	3	5	$5 + 4$
Venus	4	5	$5 + 4$
Mercury	4	5	$5 + 4$
Mars	4	5	$5 + 4$
Jupiter	4	4	$4 + 3$
Saturn	4	4	$4 + 3$
fixed stars	$\frac{1}{27}$	$\frac{1}{34}$	$\frac{1}{56}$

- Explains retrograde motion.
- Aristotle requires additional spheres to counteract some of the motions of the planetary spheres.
 - *These additional spheres are placed between the outermost sphere of a given planet and the innermost sphere of the next planet and are one less than the number of spheres of the latter.*

(c) Motion

- Two basic principles:

I. *No motion without a mover in contact with moving body.*

II. Distinction between:

(a) *Natural motion:* mover is *internal* to moving body

(b) *Forced motion:* mover is *external* to moving body

3 Types of Natural Motion and Corresponding Elements (Natural Bodies)

- (i) In *straight line* towards center of the cosmos: earth, water
- (ii) In *straight line* away from center of the cosmos: fire, air
- (iii) In *circle* about center of the cosmos: aether ("fifth element")

- Cause of celestial motion = Unmoved Mover ("Prime Mover").
 - *Acts as final cause ("object of desire")*
- Cause of terrestrial motion = celestial realm as final cause.
 - *Cyclic transformation between elements emulates circular motion of heavens.*

(d) The Plenum

- Claim: There is no void (*contra* the atomists).
- Assume:
 - (i) Speed is inversely proportional to resistance ($V \propto 1/R$).
 - (ii) Infinite speed is physically impossible.
- Conclusion: Zero resistance is physically impossible.
- Hence: There can be no body through which motion can occur that has zero resistance (*i.e.*, zero density; *i.e.*, a void).
- But: Could also conclude that Assumption (i) is incorrect.
 - *Zero resistance doesn't necessarily entail infinite speed.*

Aristotle's Physics: A Physicist's Look

ABSTRACT: I show that Aristotelian physics is a correct and nonintuitive approximation of Newtonian physics in the suitable domain (motion in fluids) in the same technical sense in which Newton's theory is an approximation of Einstein's theory. Aristotelian physics lasted long not because it became dogma, but because it is a very good, empirically grounded theory. This observation suggests some general considerations on intertheoretical relationships.

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ARISTOTLE'S PHYSICS 39

The bad reputation of Aristotle's physics is undeserved and leads to widespread ignorance. For instance, think for a moment—do you really believe that bodies of different weight fall at the same speed? Why don't you just try: take a coin and piece of paper and let them fall. Do they fall at the same speed? Aristotle never claimed that bodies fall at different speeds 'if we take away the air'. He was interested in the speed of real bodies falling in our real world, where air or water is present. It is curious to read everywhere: 'Why didn't Aristotle do the actual experiment?' I would retort: 'Those writing this, why don't *they* do the actual experiment?' They would find Aristotle right.

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