Introduction

Christian Wüthrich

http://www.wuthrich.net/

Introduction to Philosophy of Physics

What is philosophy of physics?

philosophy of physics vs. foundations of physics

1. philosophy of physics: turn to physics with originally philosophical questions, hoping to find (partial) answers in physics
   - Example: Is our world deterministic?
   - Example: What are the basic building blocks of the world?
   - Example: Is the causal structure part of the physical world itself?
2. foundations of physics: turn to philosophy with originally physical questions, hoping to find help from philosophical methods
   - Example: What does quantum mechanics tell us about the world?
   - Example: Is the second law of thermodynamics reducible to statistical physics?
   - Example: Is space relational or substantival?

- So what is philosophy of physics? Let's do it, rather than try to offer an abstract definition.
- I will now give an introduction, covering the basics of Newtonian physics as well as notions of laws of nature. This is based fairly closely on the first chapter in Huggett.
- As a foil, we will use the question 'what is change?'—a rather central question in physics.
- To a first approximation, physics can be understood as the science of how bodies move in space over time.

What is change?

Nick Huggett (2010). *Everywhere and Everywhen: Adventures in Physics and Philosophy*. New York: Oxford University Press.

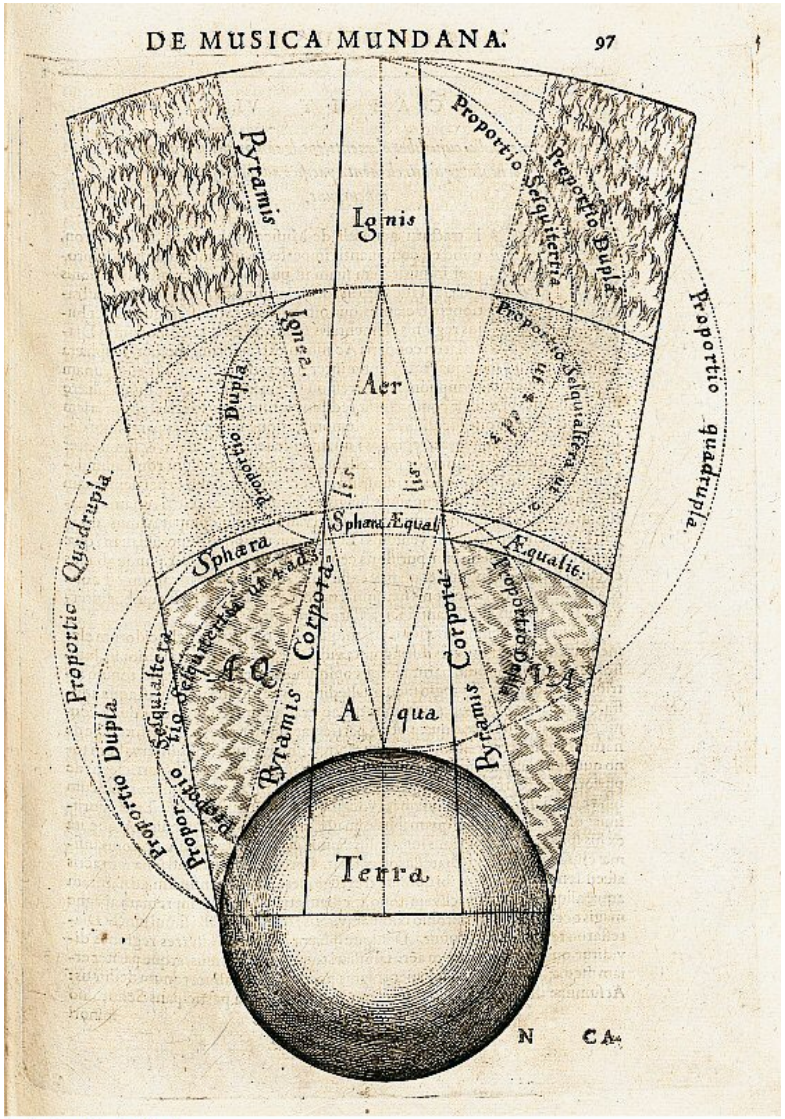
- Challenge: how to understand change—one of the most central concepts of physics.
- The concept of change, and with it what stands in need of explanation by a physical theory, has itself evolved in the course of history, "with dramatic implications for scientific progress." (Huggett, 3)

Aristotle (384-322 BCE)

- teleological physics: physical world strives toward end ('telos')
- motion as the actuality of a potentiality as such
- natural vs. non-natural or forced motion
- natural motion: motion of a body towards its natural place, following natural law

Aristotle's cosmos: sublunar vs. supralunar realm

(1) The sublunar sphere



Quelle: Deutsche Fotothek

- Sublunar sphere: world teeming with life, generation and corruption
- Empedocles's theory of four elements: earth, water, air, fire
- Everything in sublunar realm consists in combinations of those four elements.
- Earth and water are 'heavy' elements tending to centre of world, fire and air are 'light' tending to outer edge of sublunar sphere

$\Rightarrow$ explains 'gravity' e.g. of earth (and 'levity' of fire)

Aristotle's cosmos: sublunar vs. supralunar realm

(2) The supralunar realm

- Supralunar world: 'stationary' state, motions characterized by perfection, repetition, circularity, regularity

$\Rightarrow$ natural motion is circular

$\Rightarrow$ requires different material—but only one since there are no forced motions ('quintessence')

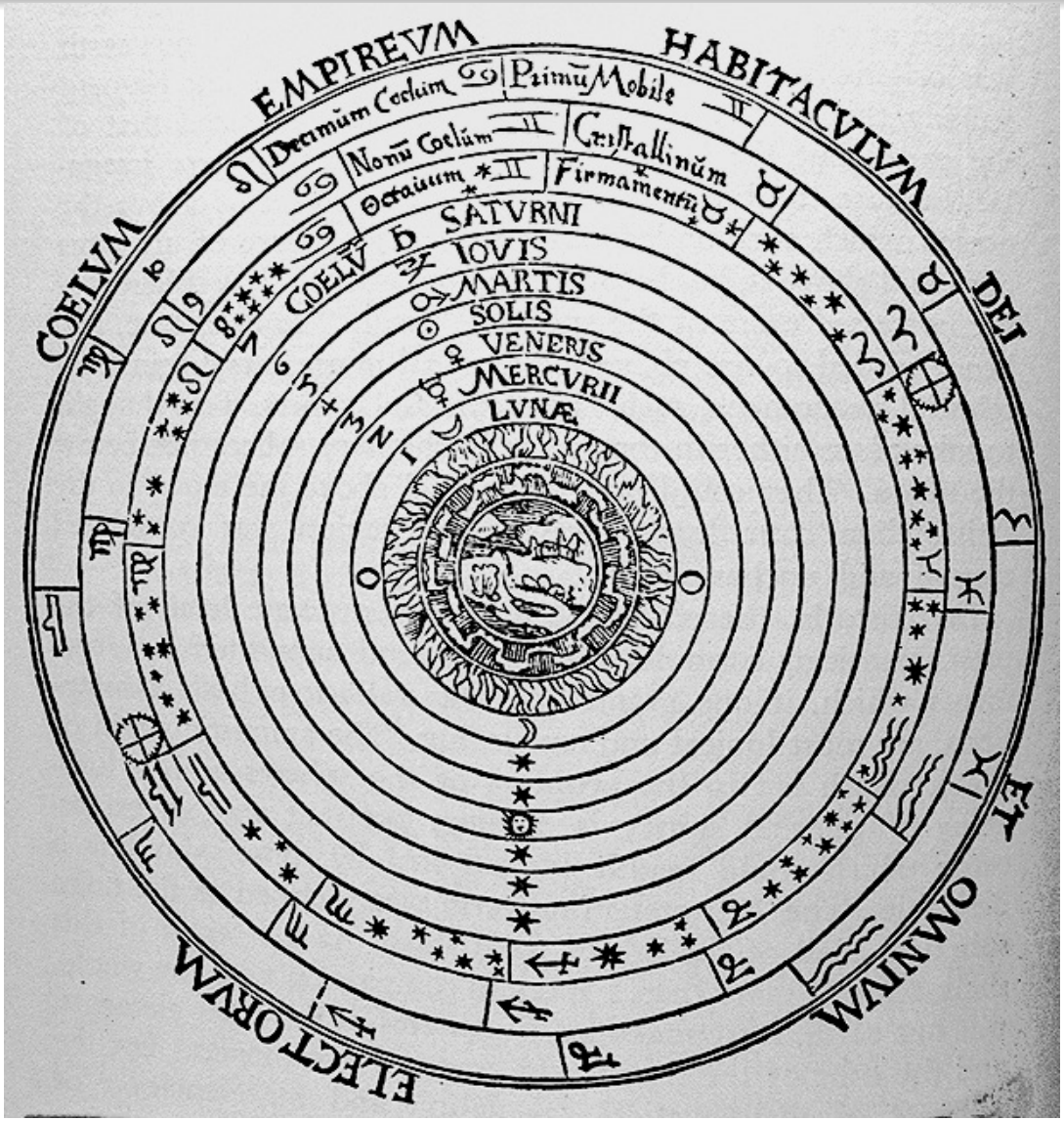
Aristotelian terrestrial physics

Aristotle, *De Caelo*, Bk. 1, Ch. 6 (273b31-274a2, tr. Richard McKeon)

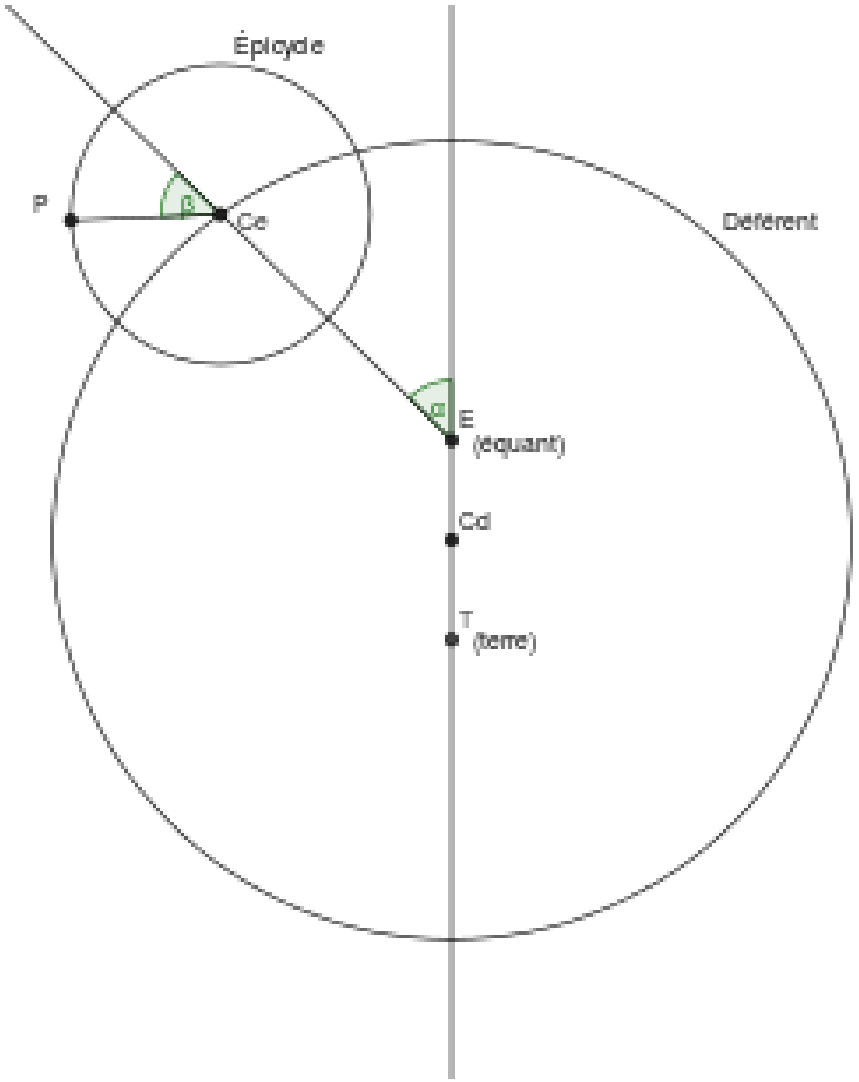
> *A given weight moves a given distance in a given time, a weight which is as great and more moves the same distance in a less time, the times being in inverse proportion to the weights. For instance, if one weight is twice another, it will take half as long over a given movement.*

Ptolemaic astronomy

Claudius Ptolemy (around 150 CE). *Almagest*.



Deferents, eccentrics, epicycles, equants



Problems for Ptolemy

- predictively unreliable
- more and more 'bells and whistles' as model is adjusted to fit new data
- Copernicus: equants are particularly unpleasing
- Ptolemaic astronomy was not replaced for long period despite anomalies because there was no credible competitor.

The scientific revolution, 1543-1687

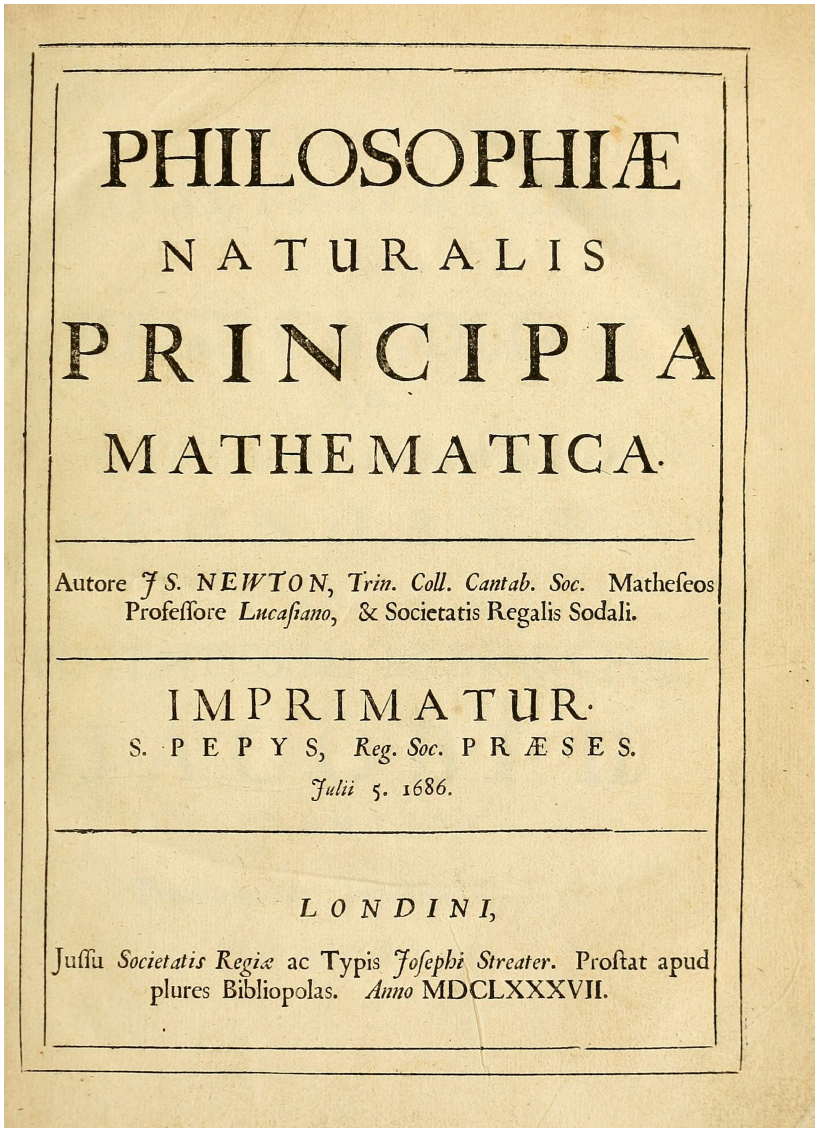
NICOLAI
COPERNICI TO-
RINENSIS DE REVOLVTIONI-
bus orbium cœleſtium,
Libri VI.

IN QVIBVS STELLARVM ET FI-
XARVM ET ERRATICARVM MOTVS, EX VETE-
ribus atq; recentibus obſeruationibus, reſtituti hic autor.
Præterea tabulas expeditas luculentasq; addidit, ex qui-
bus eoſdem motus ad quodlibet tempus Mathe-
matum ſtudioſus facillime calcu-
lare poterit.

ITEM, DE LIBRIS REVOLVTIONVM NICOLAI
Copernici Narratio prima per M. Georgium Ioachi-
mum Rheticum ad D. Ioan. Schoner-
rum ſcripta.

Cum Gratia & Priuilegio Cæſ. Maieſt.

BASILEAE, EX OFFICINA
HENRICPETRINA.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON, Trin. Coll. Cantab. Soc.* Matheſeos
Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

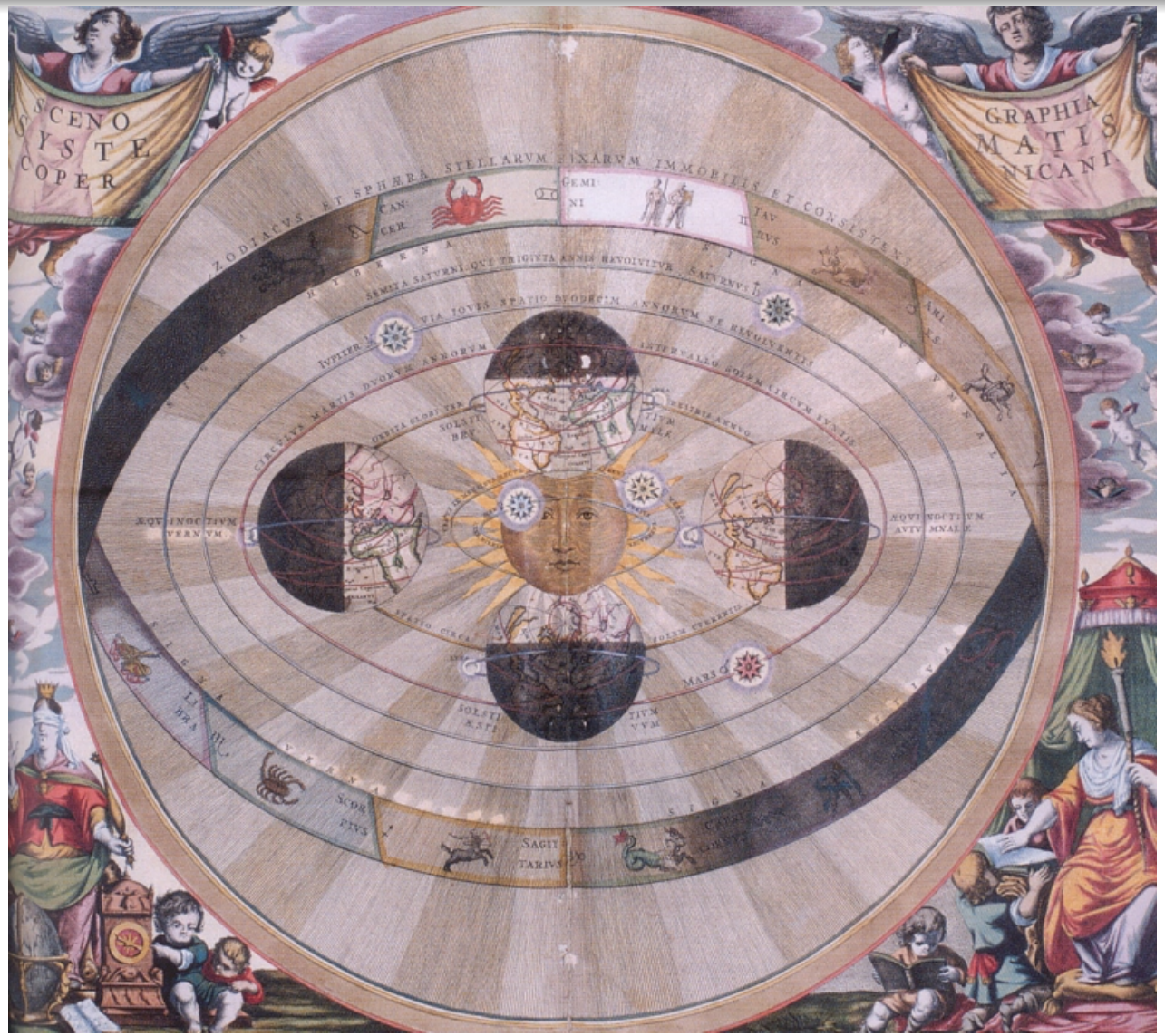
IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud
plures Bibliopolas. *Anno* MDCLXXXVII.

Copernican astronomy

Nicolaus Copernicus (1543). *De revolutionibus orbium coelestium*.



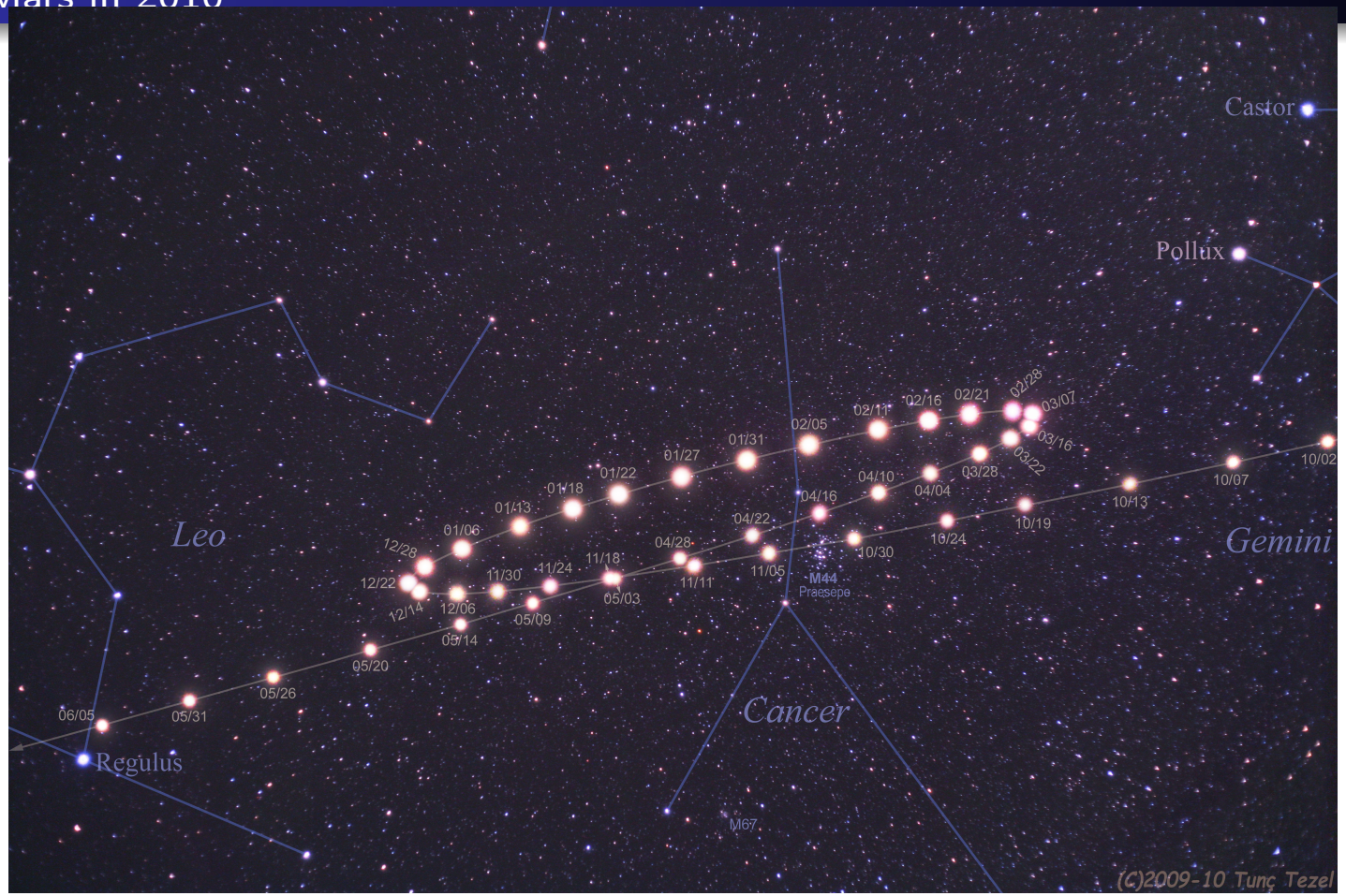
Advantages of the Copernican theory

The advantages of the Copernican theory included:

- Qualitative features of planetary motions can be explained convincingly; for example
  - retrograde motion, and
  - the bounded elongation of inferior planets.
- Variations in brightness of planets can be neatly explained.
- The phases of Venus can also be explained quite naturally.

(a) Retrograde motion: the phenomenon

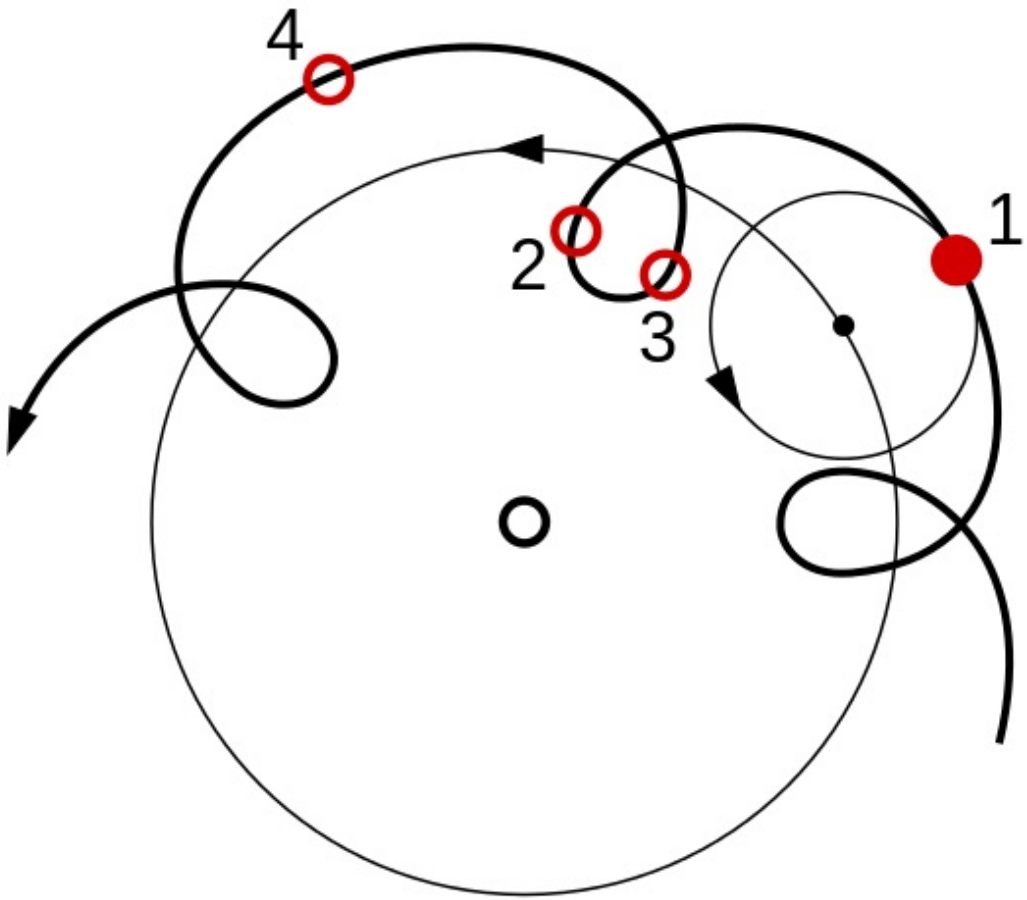
Example: Mars in 2010



Animation:

`https://upload.wikimedia.org/wikipedia/commons/7/70/Apparent_retrograde_motion_of_Mars_in_2003.gif`

(a) Retrograde motion: Ptolemaic explanation



(a) Retrograde motions: Copernican explanation

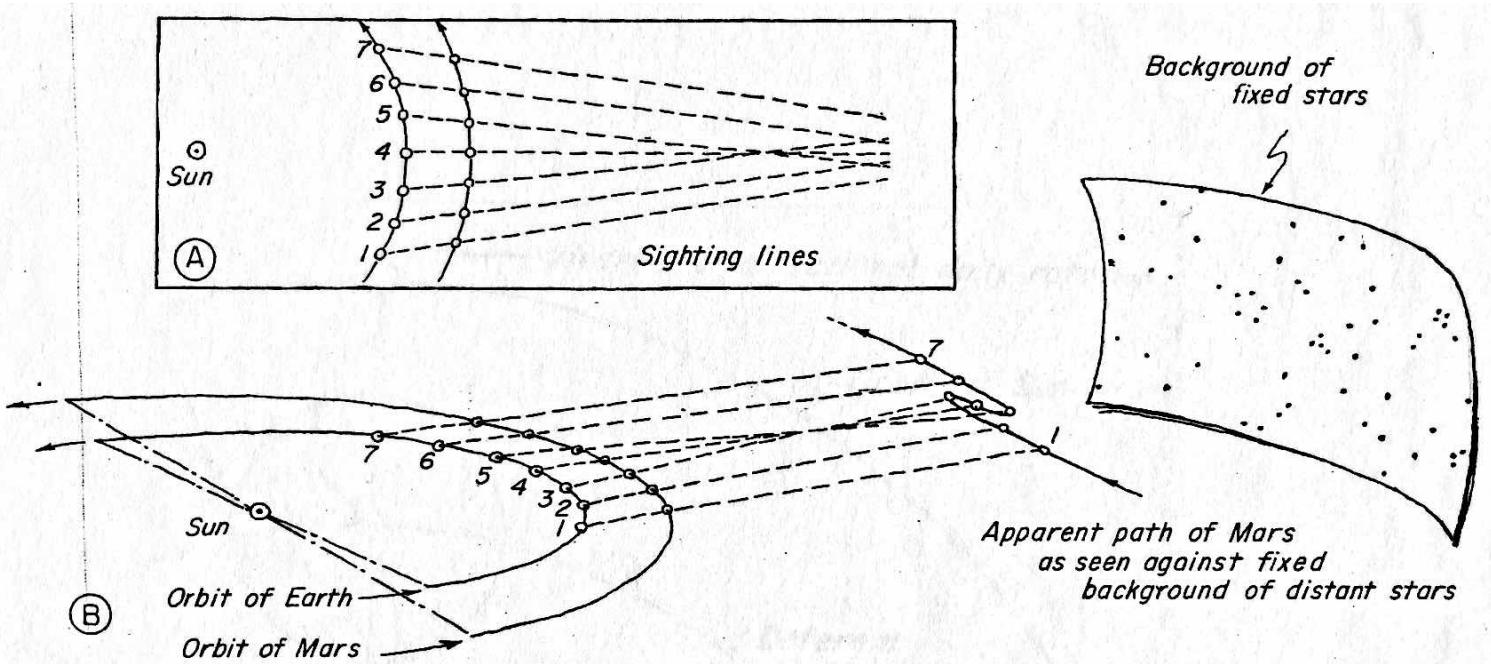
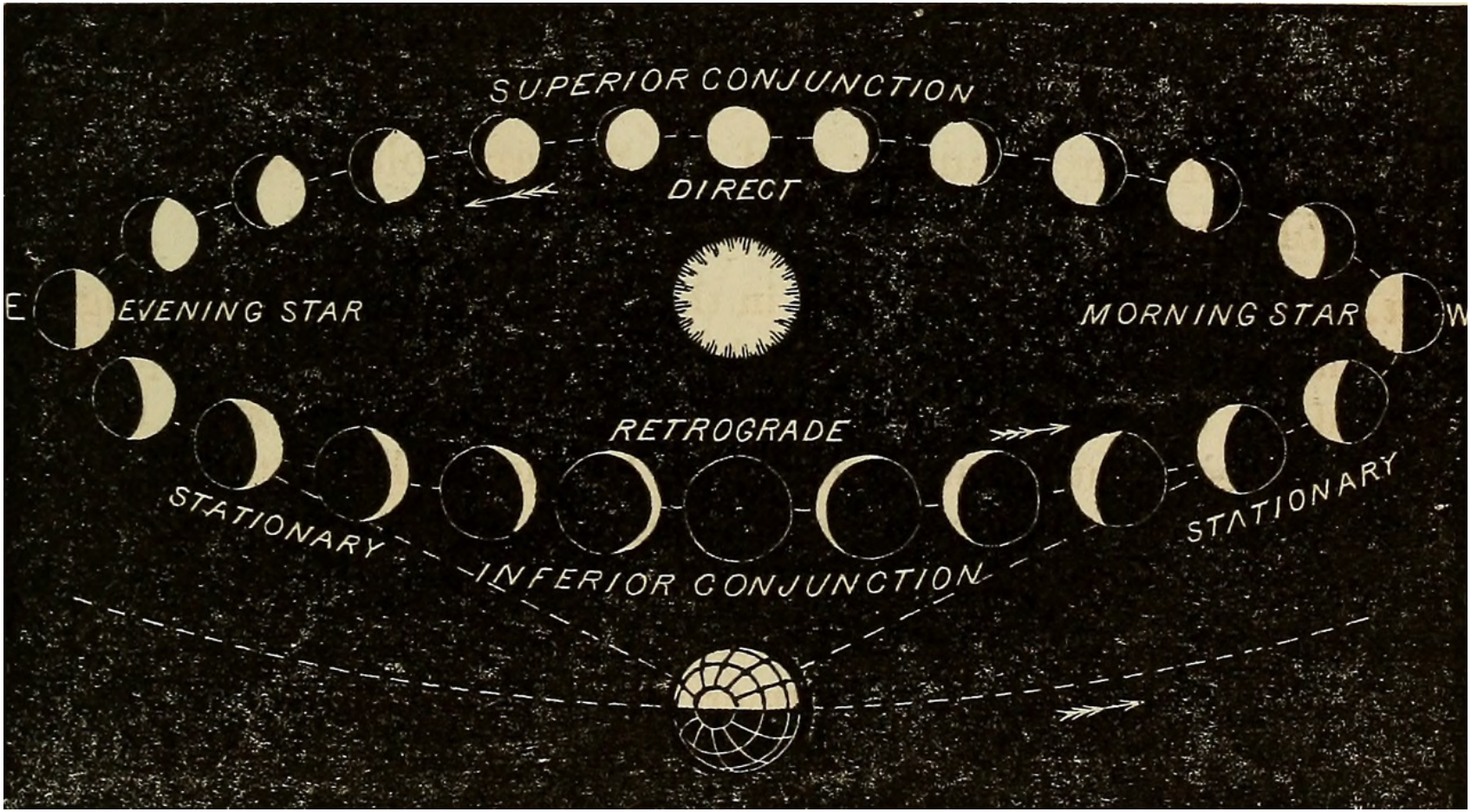


FIG. 9. In the Copernican system the apparent retrograde motion of planets has a simple explanation; it is a matter of relative speeds. Here the sighting lines show why a superior planet, one farther from the sun than the earth is, seems to reverse its direction. It is traveling around the sun more slowly than the earth is.

Animation:

https://astro.unl.edu/classaction/animations/renaissance/retrograde.html

(b) The phases of Venus



Problems for heliocentrism and discussion

- objections against heliocentrism: unobserved stellar parallax, terrestrial physics, theological and psychological arguments
- also had trouble with predictions and accounting for data (Copernicus noted, not without pride, that his theory accounted for the data just as well as did Ptolemy's theory)
- Despite popular belief, Copernican theory was not much simpler than its Ptolemaic opponent—it also needed eccentrics and epicycles.
- It only became much simpler once ellipses were introduced as planetary orbits (by Kepler).

Main problem for heliocentrism

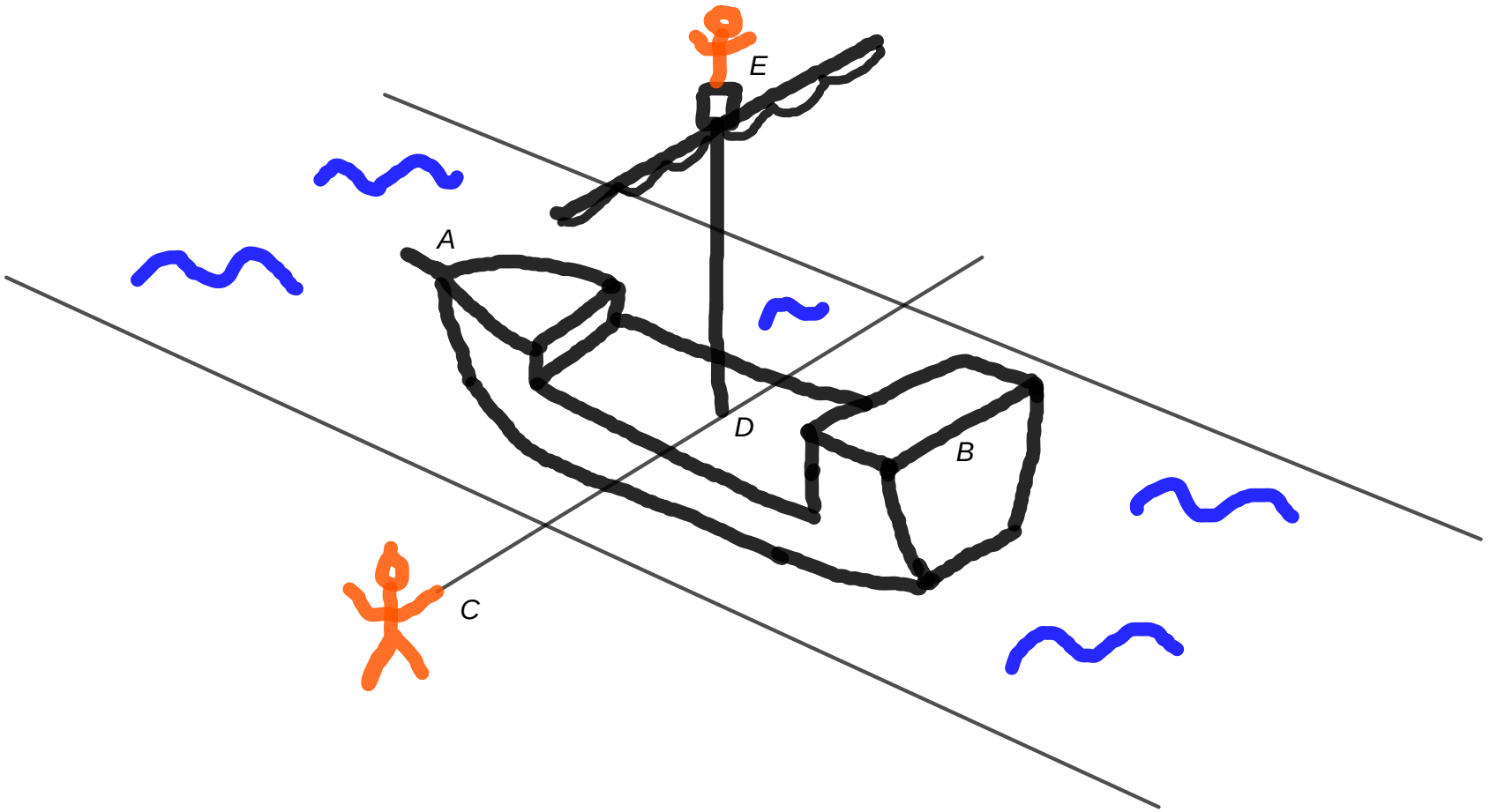
Giordano Bruno (1548-1600)

- Aristotle's view implies that natural motion is toward absolute natural place, and so is not relative to frame of reference
- Although similar, spottier analyses of natural motion challenging Aristotle existed before, we find in Bruno's *La Cena de le Ceneri* (1584) an early version of what we now call 'Galilean relativity':

Bruno, *The Ash Wednesday's Supper*, 3rd dialogue (tr. Stanley L. Jaki, 1975)

> *With the earth move, therefore, all things that are on the earth. If, therefore, from a point outside the earth something were thrown upon the earth, it would lose, because of the latter's motion, its straightness as would be seen [Fig. 6] on the ship AB moving along a river, if someone on point C of the riverbank were to throw a stone along a straight line, [and] would see the stone miss its course [target] by the amount of the velocity of the [ship's] motion. But if someone were placed high on the mast of that ship, move as it may however fast, he would not miss his target at all, so that the stone or some other heavy thing thrown downward would not come along a straight line from the point E which is at the top of the mast, or cage, to the point D which is at the bottom of the mast, or at some point in the bowels and body of the ship. Thus, if from the point D to the point E someone who is inside the ship would throw a stone straight [up], it would return to the bottom along the same line however far the ship moved, provided it was not subject to any pitch and roll.*

Bruno's ship and Galilean relativity



Galileo Galilei (1564-1642)

- developed and defended Bruno's principle of relativity
- systematically challenged Aristotelian physics

Galileo's law of free fall

If the air resistance is negligible, then any two bodies that are dropped together will fall together, regardless of their weights, shapes, and the substances of which they are made.

Galileo, *Dialogues Concerning Two New Sciences*, pp. 66ff (tr. Henry Crew and Alfonso de Salvio, 1914)

> *[It] is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one provided both are of the same material... If we... take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter... But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition. Thus you see how, from your assumption that the heavier body moves more rapidly than the lighter one, I infer that the heavier body moves more slowly... We infer therefore that large and small bodies move with the same speed provided they are of the same specific gravity.*

René Descartes (1596-1650)

- replaced Aristotle's theory of scientific explanation by his mechanical philosophy

$\Rightarrow$ Rather than in terms of the 'natures' of things, Descartes used Archimedean simple machines (lever, wheel/axle, pulley, inclined plane, wedge, screw) as models of explanations.

$\Rightarrow$ All physical change (including living things) is explained in terms of intermeshings, friction, collisions of material parts.

- Change is not a result of forms or natures, but of geometrical changes in the shape or spatial arrangement of things.

$\Rightarrow$ mechanical and atomistic

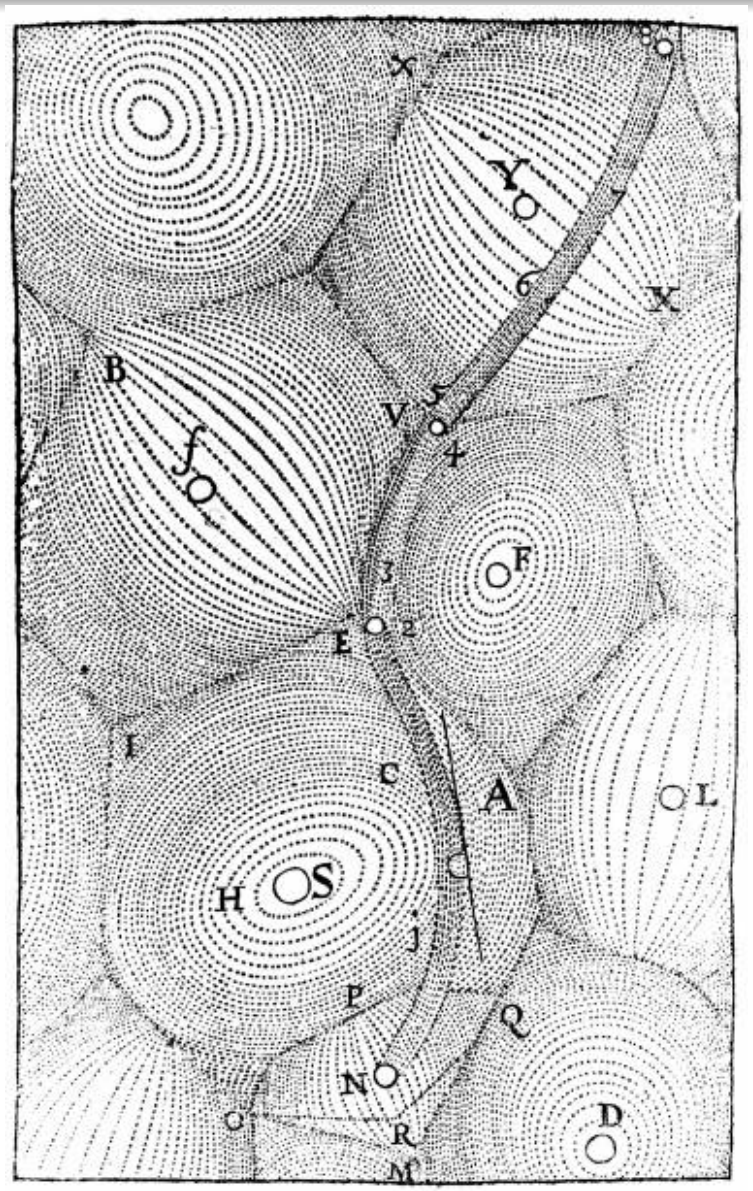
Cartesian physics: basic principles

1. The universe is completely full of matter (plenum universe).
2. All matter is essentially the same.
3. The only fundamental properties of matter are its size, shape, and relative position. All other properties arise solely from the fundamental geometrical properties of bodies

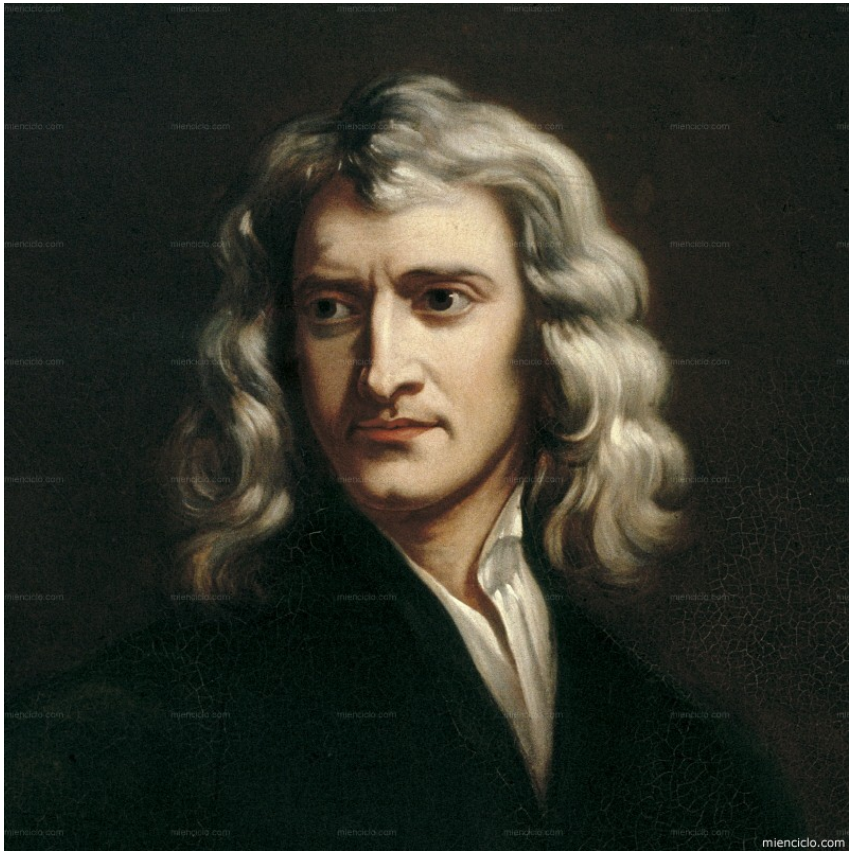
Descartes, *Principles of Philosophy*, part II, sections 23 and 64 (Reidel 1963)

> *Therefore, all the matter in the whole universe is of one and the same kind; since all matter is identified solely by the fact that it is extended. Moreover, all the properties which we clearly perceive in it are reducible to the sole fact that it is divisible and its parts moveable... I know of no kind of material substance other than that which can be divided, shaped and moved in every possible way, and which Geometers call quantity and take as the object of their demonstrations. And that there is absolutely nothing to investigate about this substance except those divisions, shapes and movements.*

Cartesian universe



Isaac Newton (1643-1727)



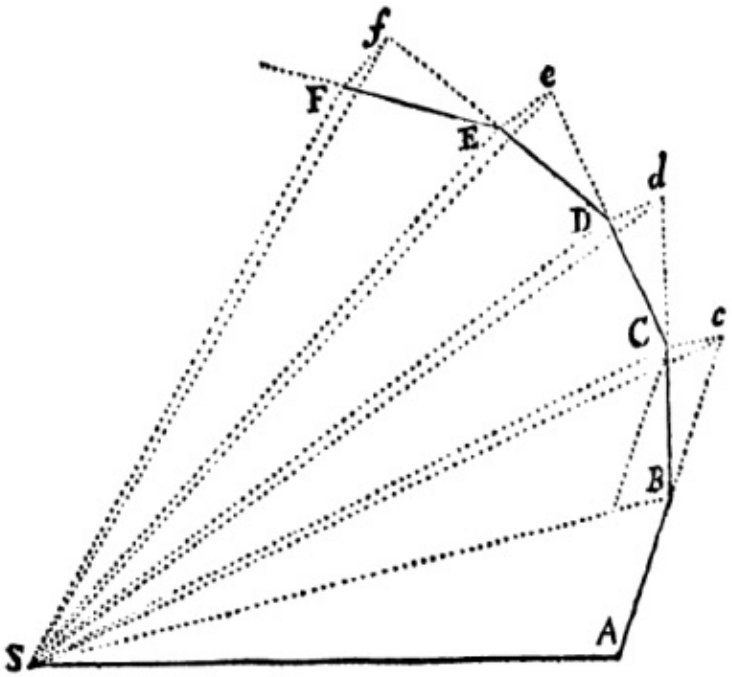
- problem for Descartes: no one ever discovered mechanical account of motion of planets

$\Rightarrow$ Descartes was unable to transform his qualitative account into an empirically successful quantitative theory

- Newton did just that with his law of universal of gravitation

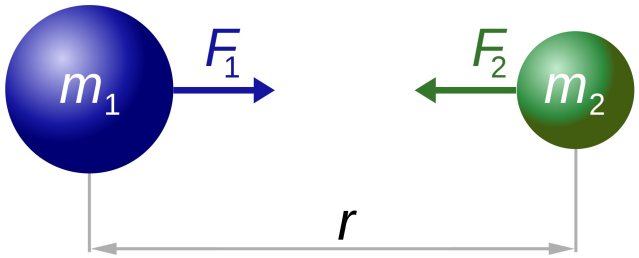
$\Rightarrow$ theory of planetary orbits; Kepler's laws can be recovered to good approximation

Universal gravitation



- natural motion: If no force acts on body, then the body moves at constant velocity in straight line
- gravity acts on planet at points, gives it jerk toward sun; rectilinear inertial motion in between jerks
- motion of planet is "constant falling forward around the sun"
- approximation of ever smaller intervals: motion gets smoothed out to form elliptical orbits

Newton's law of universal gravitation



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

Proposition 75, Theorem 35

If to the several points of a given sphere there tend equal centripetal forces decreasing in a duplicate ratio of the distances from the points; I say, that another similar sphere will be attracted by it with a force reciprocally proportional to the square of the distance of the centres.

Isaac Newton (1687), *Philosophiae Naturalis Principia Mathematica*. Translated by Andrew Motte.

Universal gravitation

- Newton's law of gravity is truly universal: unification of sublunar and supralunar physics (though already in Descartes)
- He is unable to give mechanical explanation of gravity, and so gravity needs to be added to mechanical universe as nongeometric power

Newton, in a letter to Robert Hooke, 1676 (and almost verbatim in *Principia*):

> *I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses; for whatever is not deduced from the phenomena is to be called a hypothesis, and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy.*

Newtonian physics: laws of motion (*Principia*, different translations)

1. Every body persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.
2. A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed.
3. To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

Laws and models: the library simile

Huggett (2010, 11)

So consider the following analogy; imagine a vast heap of books in which each book contains a different consistent story. Now imagine someone giving you a list of things all of which they wish to be true in a story, and [you're] going through the books to pick out just those in which every item on the list is indeed true. Those books form a 'library' of all and only the books that are consistent with the list. The heap of books is in analogy to every logically possible history of the universe (including those with laws of physics quite different from ours); the list corresponds to the laws of physics; and the library you create corresponds to the physically possible histories of the universe (technically called the 'models' of the laws). Just as the list tells us what complete stories are allowed, the laws of physics determine which histories of the universe are possible.

Defining determinism, à la Laplace, Montague, Earman

John Earman (1986). *A Primer on Determinism*. Dordrecht: Reidel.

Let $\mathcal{W}$ denote the set of all physically possible worlds, i.e. those possible worlds which are in accordance with the laws of the actual world. Then:

Definition (Determinism for worlds)

A world $w \in \mathcal{W}$ is deterministic if and only if for any $w' \in \mathcal{W}$, if w and w' agree at any time, then they agree for all times. A world that fails to be deterministic is indeterministic.

Definition (Determinism for theories)

A "theory T is deterministic just in case, given the state description $s(t_1)$ at any time t_1, the state description $s(t_2)$ at any other time t_2 is deducible [in principle] from T." (Earman 1986, 20) A theory that fails to be deterministic is indeterministic.

Physical states

Definition (Physical state)

A physical state is the complete description of the (basic) physical properties of the world at a moment in time.

Example: Newtonian physics

In Newtonian physics, a physical state is given by a description of all the locations, motions, and masses of all the bodies in the world, plus the forces acting on them.

Future- and past-determinism

Definition (Future-determinism)

A theory is future(-history) deterministic if and only if, given the state description $s(t_1)$ at any time t_1, the state description $s(t_2)$ at any later time t_2 ($t_2 > t_1$) is deducible [in principle] from T. A world that fails to be future-deterministic is future-indeterministic.

Definition (Past-determinism)

A theory is past(-history) deterministic if and only if, given the state description $s(t_1)$ at any time t_1, the state description $s(t_2)$ at any earlier time t_2 ($t_2 < t_1$) is deducible [in principle] from T. A world that fails to be past-deterministic is past-indeterministic.

The game of Life

John Conway, 1970s

The basic set-up:

- The world is two-dimensional and infinite, divided into identical squares ('cells').
- Cells may or may not occupied by a single creature; if it is, then the cell is 'alive', otherwise 'dead'.
- The eight cells surrounding any cell are its 'neighbourhood'.
- Time (like space) is discrete (with intervals of, say, a second).
- The physical state of the world is given by a complete description of which cells are alive.

Game of Life: laws

1. If a cell is alive at present and has exactly two or three living neighbours, then it stays alive in the next moment.
2. If a cell is dead at present and has exactly three living neighbours, then it comes alive in the next moment.
3. Otherwise a cell will be dead in the next moment. (Huggett 2010, 13)

Java implementation:

`https://bitstorm.org/gameoflife/`

- Life describes the evolution of things in space over time; more specifically, it describes the properties of places in space over time.

$\Rightarrow$ simple example of a field theory (electrodynamics, general relativity, and the standard model are field theories)

Life is future-deterministic; can you see that it is not past-deterministic? Can you come up with a theory with the reverse properties?