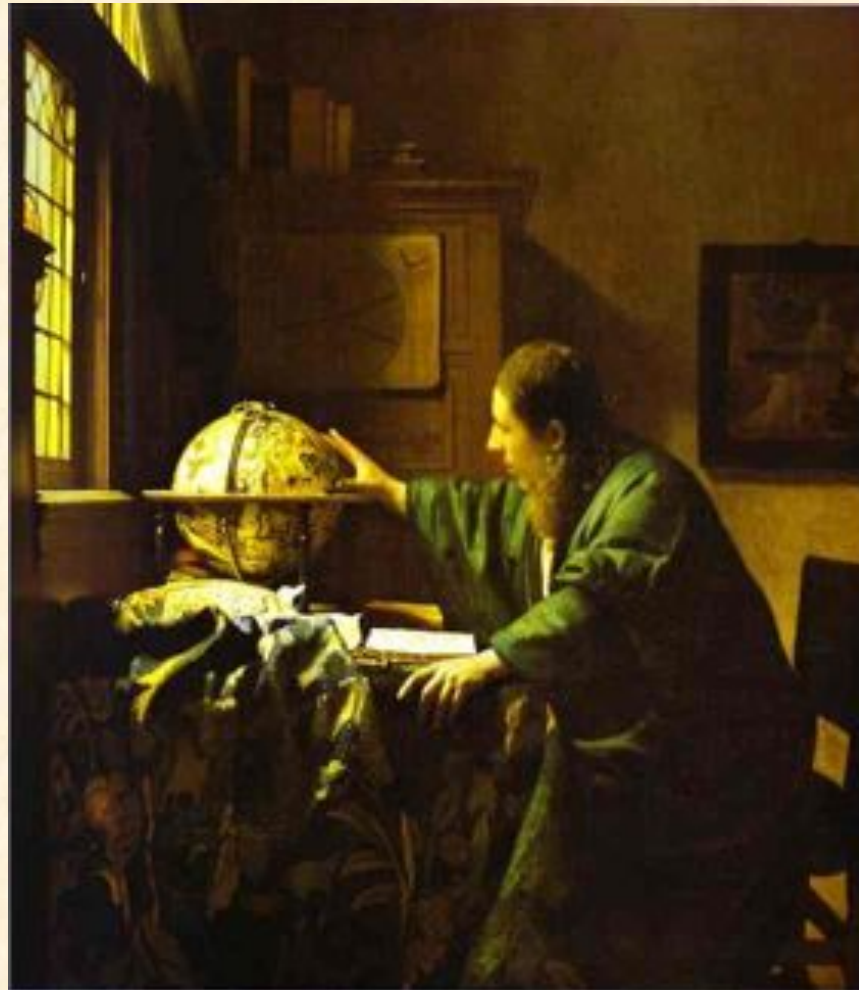


Humanities 3

V. The Scientific Revolution



Lecture 19

Reading the Book of Nature

Outline

- Bacon's Four Idols
- Galileo's Scientific Achievements
- *Dialogue Concerning the Two Chief World Systems*

Friday movie pick: *Galileo's Battle for the Heavens*
(PBS *Nova* program, available in Humanities office)

Bacon: Key Points

- Dissatisfaction with Aristotle's theory of nature and scientific method (I.11-12)
- Plan of the *Great Instauration*: need for a new beginning and why this is now possible
- Religion and the new science
- Method of science is inductive, not deductive. It aims at a "true interpretation" of nature. (26-28)
- Knowledge of causes => power to control nature (3)
- Progress is impeded by *idols* of the mind: false notions that confuse our understanding of nature.

Bacon: The Four Idols

“The idols and **false notions** that have hitherto occupied the human understanding, and lie deep-seated there, have not only so beset men’s minds that their approach to the truth becomes difficult; but even when access to it is given and conceded, they will present themselves and interfere in that very renewal [*instauratio*] of the sciences, unless men are forewarned and protect themselves against them as far as possible.” (I.38)

Idols of the Tribe

- Errors common to human nature: sense perception, biases of judgment (e.g. anthropocentrism and anthropomorphism):
“[T]he human understanding is like an uneven mirror that cannot reflect truly the rays from objects, but distorts and corrupts the nature of things by mingling its own nature with it.” (I.41; 45-52)

Idols of the Cave

- Errors specific to individuals, associated with idiosyncrasies of experience and education:

“either because of his own distinct and individual nature, or because of what he has been taught or gained in conversation with others, or from his reading, and the authority of those whom he respects and admires.... [M]en seek knowledge in lesser worlds, and not in the greater or common world.” (I.42; 53-58)

Idols of the Marketplace

- Errors arising from the commerce among people, related to the misleading character of language:

“speech is the means of association among men; but words are applied according to common understanding. And in consequence, a wrong and inappropriate application of words obstructs the mind to a remarkable extent.” (I.43; 59-60)

Idols of the Theater

- Errors arising from the various dogmas of philosophers and from false “laws of demonstration”:

“all the philosophies that have been received or invented [are like] so many stage plays creating fictitious and imaginary worlds.” (I.44, 61-65)

Three Kinds of “False Philosophy”

- Sophistical: forms theories from common notions on the basis of “too narrow a foundation of experiment” (Aristotle)
- Empirical: builds a complete system of nature from some unusual phenomenon, ignoring contrary evidence (alchemy, magnetism)
- Superstitious: mixes philosophy with theology and “traditions” (natural magic, astrology)

Galileo Galilei (1564-1642)



- 1590-92 Lectures on mathematics in Pisa; publication of *On Motion*
- 1609 Constructs first telescope; observations of moon, sunspots, planets
- 1616 Church condemns Copernicanism
- 1632 Publication of *Two Chief World Systems*
- 1633 Forced to retract his views; confined for life, first in Rome, then outside Florence

Galileo's Physics

- Quantifiable properties (distance, time)
- Functional relationships expressed mathematically (*The Assayer*, 1623: “The book of nature is written in the language of mathematics”)
- Precise measurements
- Ability to confirm or refute hypotheses
- “Galileo ... is the father of modern physics -
- indeed of modern science” — Albert Einstein

Four of Galileo's Achievements

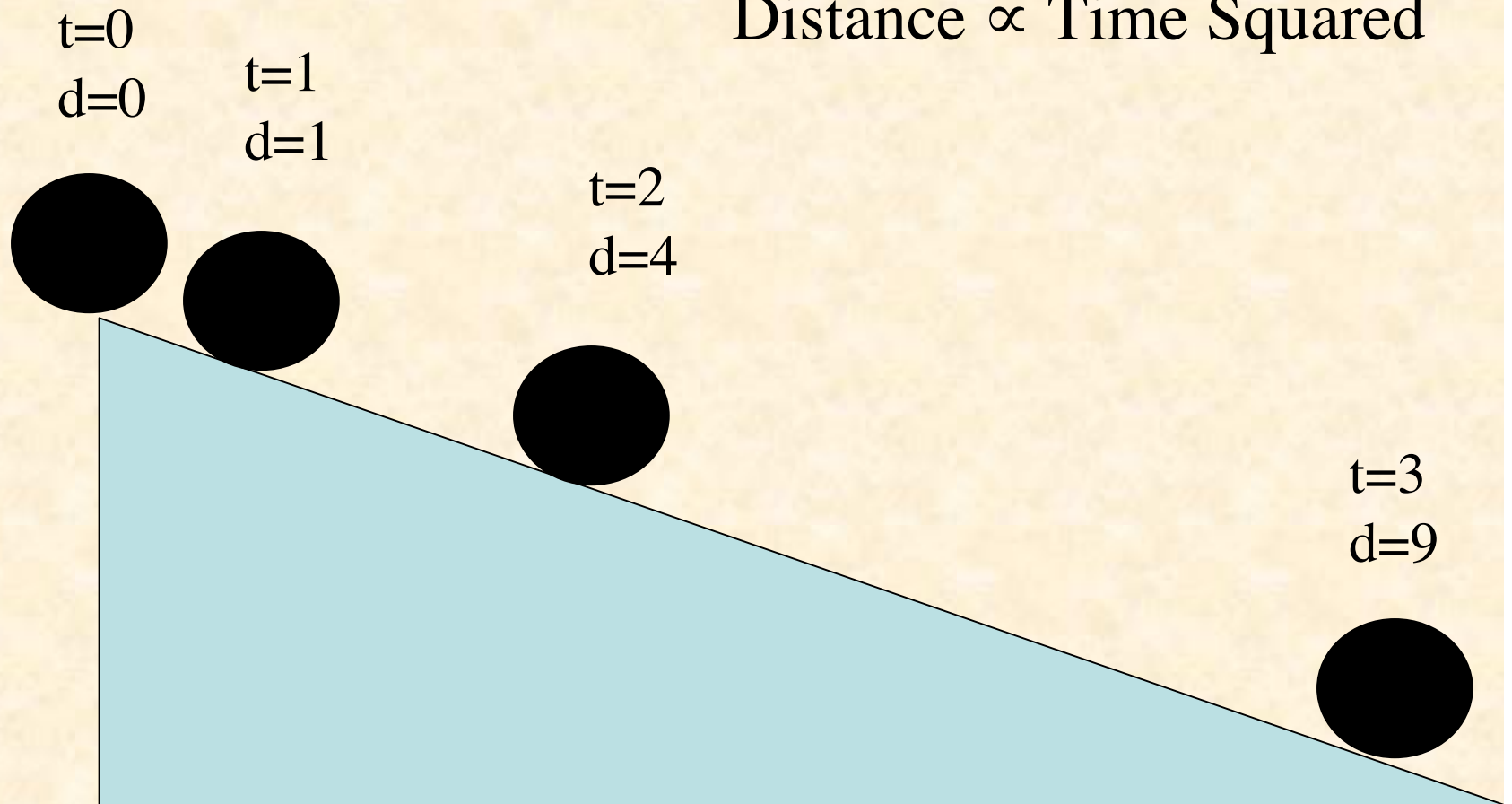
- Analysis of pendulum motion: any pendulum has a constant period, regardless of arc; applied in the measurement of time (in place of water clocks)
- Inclined plane experiments allow an analysis of accelerated motion, showing that $d \propto t^2$
- Telescopic observations of moon, sunspots, moons of Jupiter, and phases of Venus demonstrate falsity of Aristotelian cosmology
- Analysis of terrestrial motion applied in arguments supporting the rotation of the Earth

Analysis of Free Fall

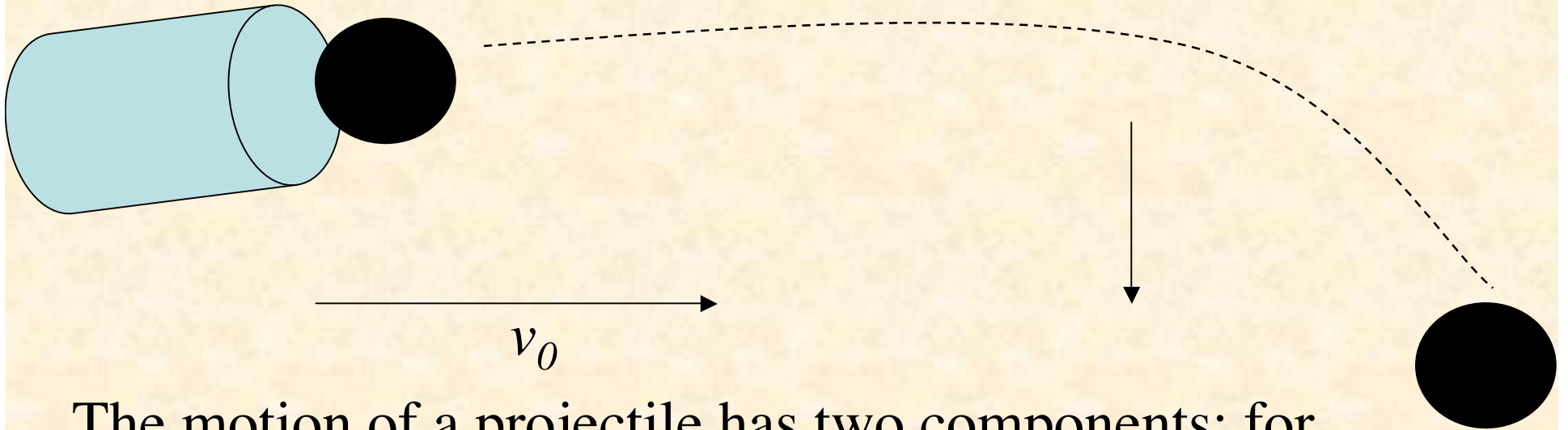
- Aristotle: heavy bodies fall faster than lighter bodies; for any body, distance traveled is proportional to time (no measurable acceleration)
- Galileo: regardless of their weight or density, all bodies fall at the same rate in a vacuum; distance traveled is proportional to square of time (uniform acceleration: equal increments of speed gained in equal times)
- Galileo's analysis of accelerated motion is presented in his final book, *Two New Sciences* (1638)

Galileo's Inclined Plane

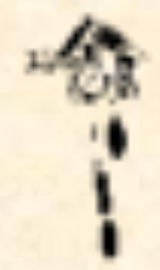
Distance \propto Time Squared



Projectile Motion



The motion of a projectile has two components: for Aristotle, (i) an impressed motion and (ii) a natural motion downward; for Galileo, (i) an inertial motion (v_0) and (ii) a downward accelerated motion



Significance of Telescopic Observations

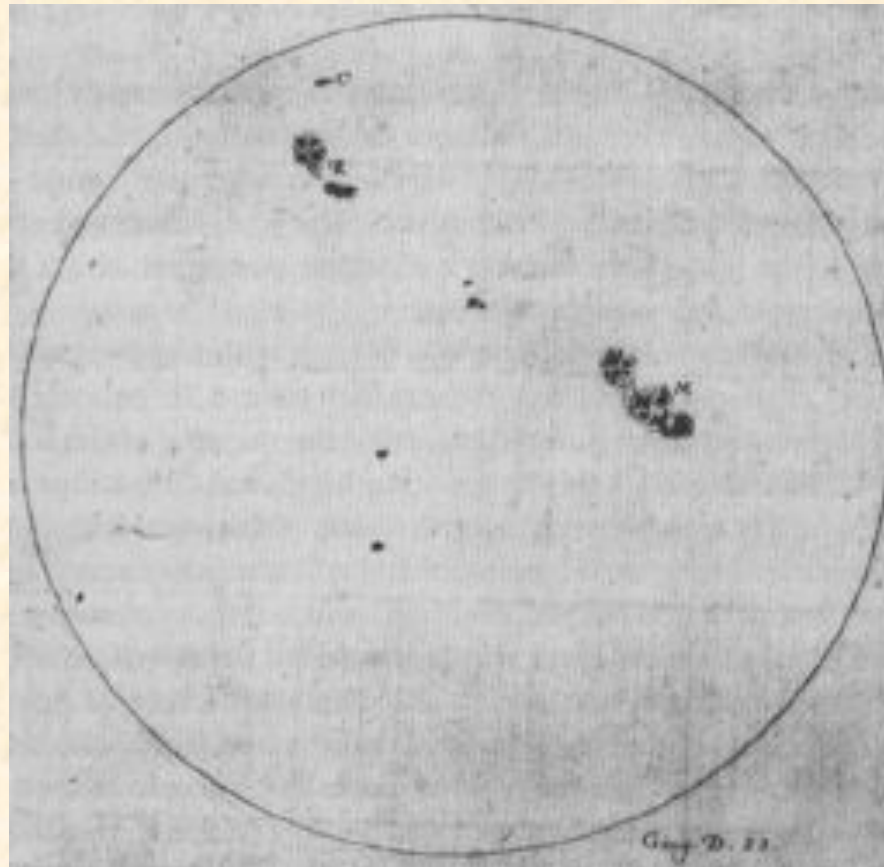
- Face of the Moon: indicated that the Moon was affected by geological variations (mountains, craters) just like the Earth
- Phases of Venus: indicated that Venus must be located between the Sun and the Earth (as the Copernican model predicted)
- Moons of Jupiter: indicated that the Earth was not the only center of motion

Galileo, Moons of Jupiter

1610

7	.	.	○	.	17	.	○	
8	○	.	.	.	18	.	○	
9	.	.	○	19	.	○	.	.
10	.	.	○	20	.	○	.	.
11	.	.	○	21	.	○	.	.
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13	.	.	○	23	.	○	.	.
14	○	.	.	.	24	.	○	.
15	○	.	.	.	25	.	○	.
16	○	.	.	.	26	.	○	.
17	.	○	.	.	27	.	○	.

Galileo, *Letter on Sunspots* (1613)



Do Galileo's Observations Disprove Aristotle's Theory?

- Not necessarily: an opponent could discount the reliability of observations made with the telescope
- To overcome such objections, Galileo had to: (a) show that the telescope offered reliable results up to the limits of the observable (e.g. distant towers); (b) argue that there was no reason to think that the telescope is less reliable in the case of celestial phenomena than in the case of terrestrial phenomena
- Would an Aristotelian be convinced by this?

*Dialogue Concerning the Two
Chief World Systems, Ptolemaic
and Copernican (1632)*

Ptolemaic World System

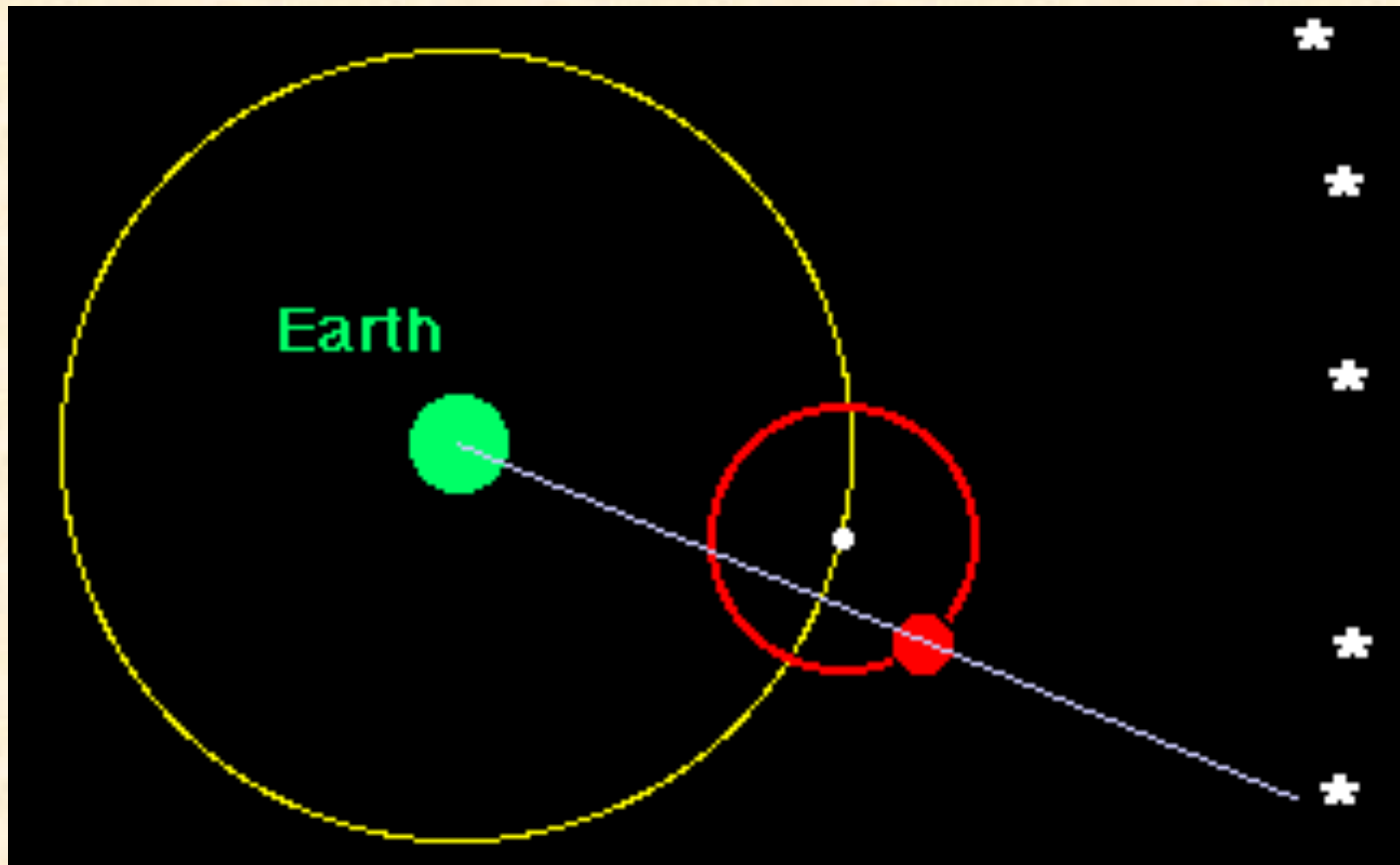
- Based on Aristotle's cosmology (geocentric, Earth immobile)
- Celestial and sublunary bodies have fundamentally different properties (including different principles of motion)
- Aristotle's picture is empirically false: planets are not observed to move with constant circular motions
- In his *Almagest*, the Egyptian geometer Ptolemy (c. 80-c. 170 AD) devised a system of mathematical constructions that "saved the phenomena"

Aristotle's Universe

- 55 concentric spheres
- Earth is at the center and immobile
- outermost sphere is the *primum mobile*, whose motion moves the other spheres
- for Christians, beyond this is heaven where the angels and blessed reside



Ptolemy, Epicycle Model of Retrograde Planetary Motion

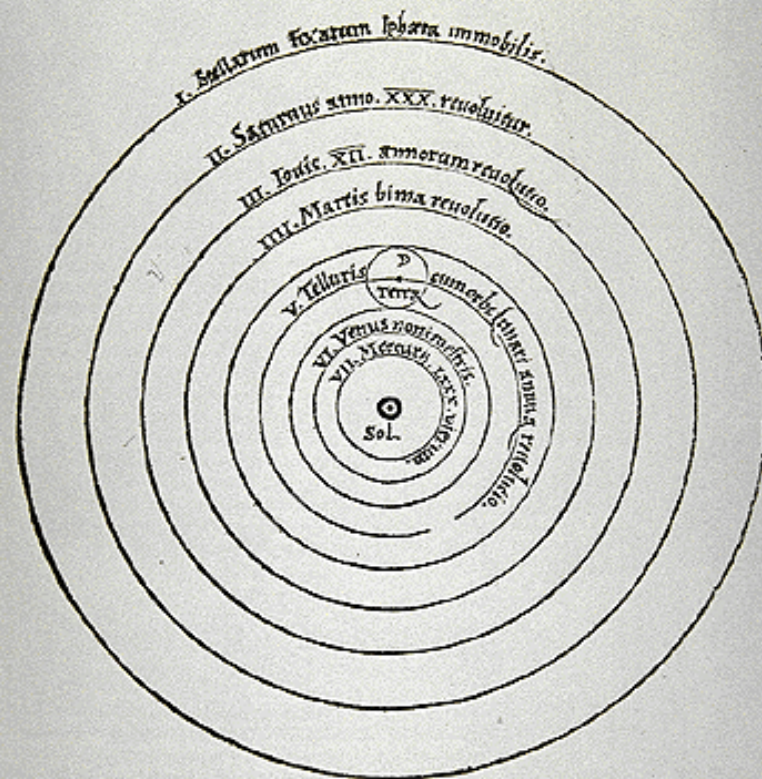


Copernican System

- 1543 Publication of Copernicus' *On the Revolutions of the Celestial Orbs*
- Heliocentric; Earth revolves around the sun and rotates on its axis
- No difference in the physical properties of terrestrial and celestial bodies (same principles of motion)
- Copernicus' picture modified by Johannes Kepler (1571-1630) based on observational data of Tycho Brahe (1546-1601)

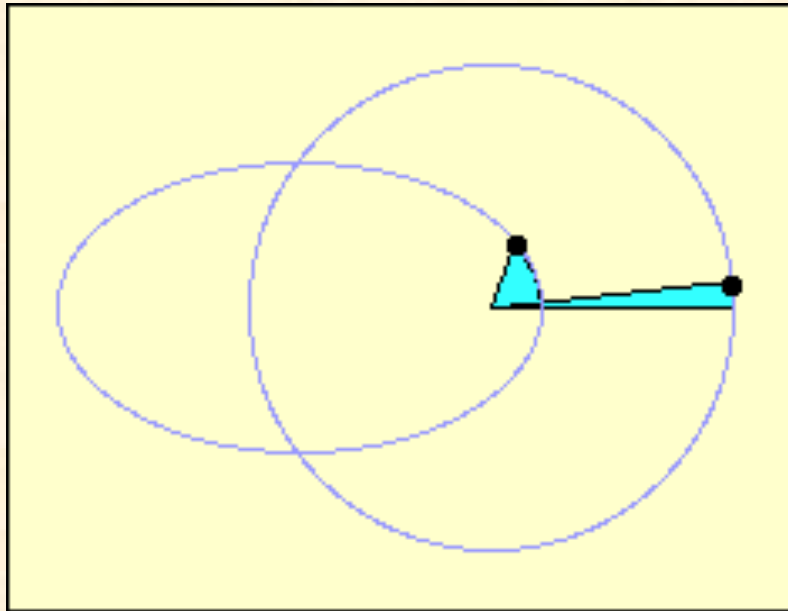
NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur, Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circu currens, In medio uero omnium residet Sol. Quis enim in hoc



pulcherimo templo lampadem hanc in alio uel meliori loco po neret, quam unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uo cant. Trimegistus uisibilem Deum, Sophodis Electra intuentē omnia. Ita profecto tanquam in solio re gali Sol residens circum agentem gubernat Astro rum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximā Luna cū terra cognatio nē habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub
hac

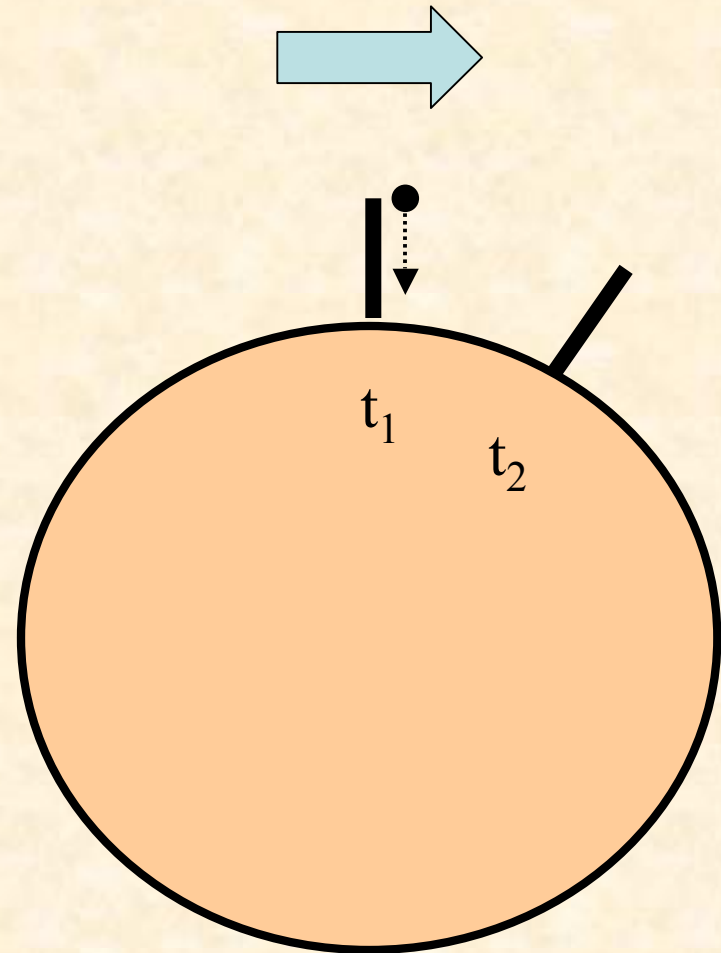
Kepler's Laws



- **First Law (1605):**
Planets move in ellipses with the Sun at one focus
- **Second Law (1602):**
Radius vector describes equal areas in equal times
- **Third Law (1618):** The squares of the periodic times are to each other as the cubes of the mean distances

Tower Objection: Why the Rotation of the Earth is Impossible

Stone released at t_1 . Its natural motion carries it straight down to the base of the tower. Meanwhile the Earth's rotation has carried the tower to a new position at t_2 , so the stone must land behind the tower. Since this isn't observed, the Earth must be stationary.



Galileo's Response: Reconceiving Motion and Mass

Stone released at t_1 . At the moment of its release it is moving in direction a with an *inertial* motion equal to the motion of the tower. It is also subject to a *gravitational* motion in direction b . The sum of these two motions carries the stone to the base of the tower in its new position at t_2 .

