Astronomy 350L

(Fall 2006)

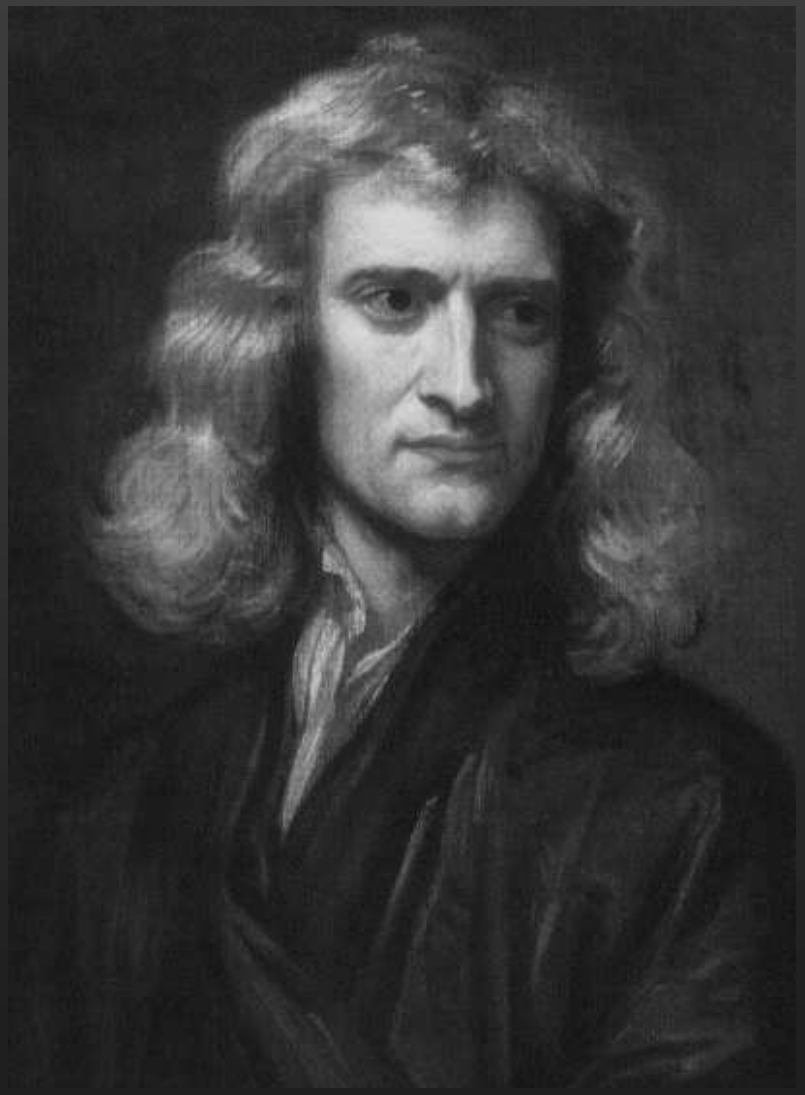
The History and Philosophy of Astronomy

(Lecture 14: Newton)

Instructor: Volker Bromm
TA: Jarrett Johnson

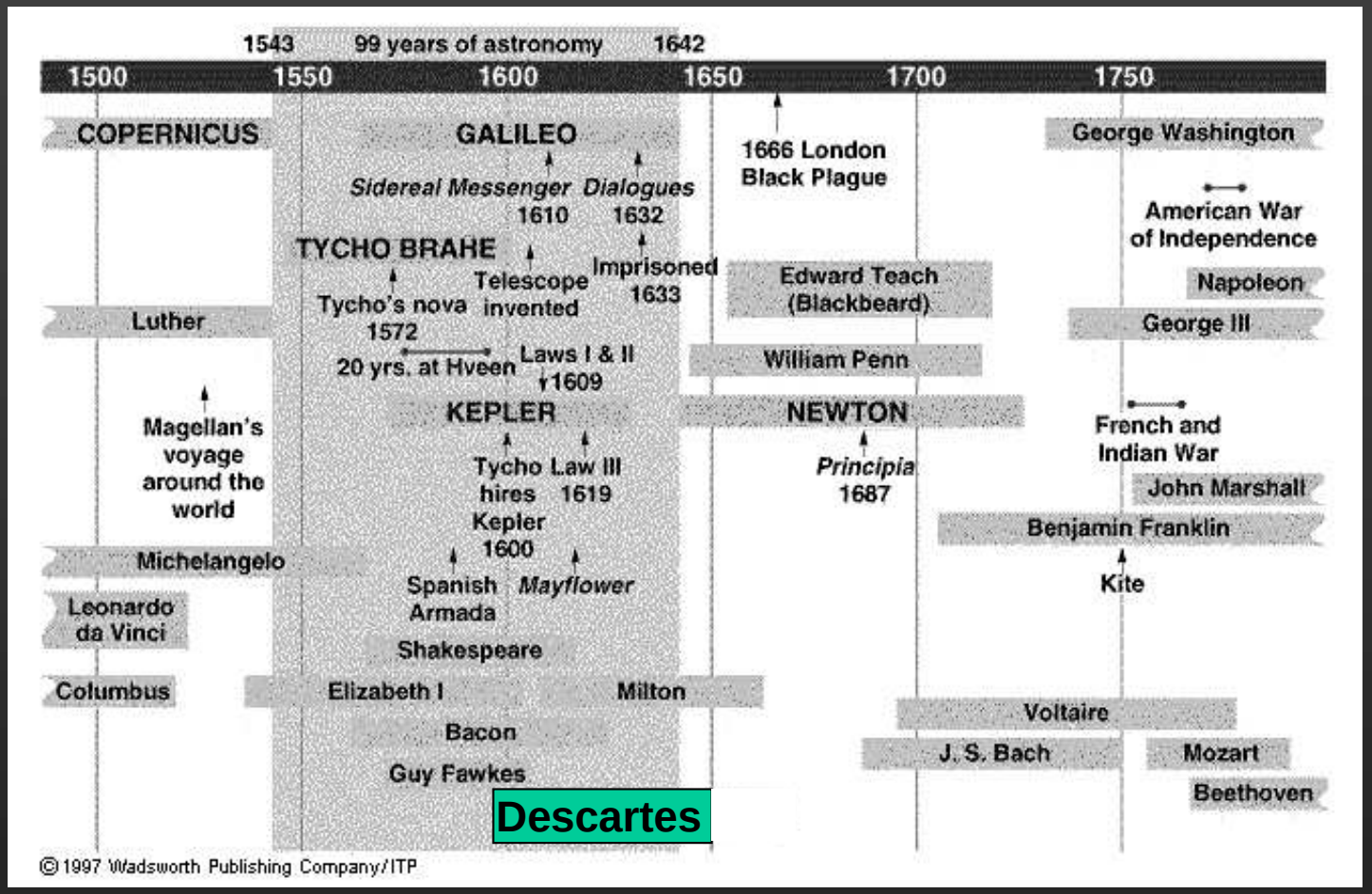
The University of Texas at Austin

Isaac Newton: Founding Father of Physics



- 1642 (Woolsthorpe) – 1727 (London)
- ***Principia*** *Mathematica Philosophiae Naturalis*
  ("Mathematical Principles of Natural Philosophy", 1687)
  - universal gravity (inverse-square law)
  - three laws of motion
- invented calculus (differentiation and integration)

Newton: Timeline and Context



- building upon Galileo, Kepler, and Descartes
- completes Copernican Revolution!

Newton: Geography of his Life

1642: Birth in Woolsthorpe

- born in rural Lincolnshire
- father died *before* his birth (‘posthumous child’)

1642 – 49: The English Civil War

- bitter struggle between King (Charles I Stuart) and Parliament (“Cavaliers” vs “Roundheads”)
- King desires to rule without Parliament

1649: Execution of the King

- King Charles I (Stuart) beheaded

1642 – 49: The English Civil War

- Victory for Parliament
- Republic (“Commonwealth”)
- Oliver Cromwell (1599-1658)
  - Lord Protector
- Anarchy after his death
- Army recalls son of former (executed) king from exile

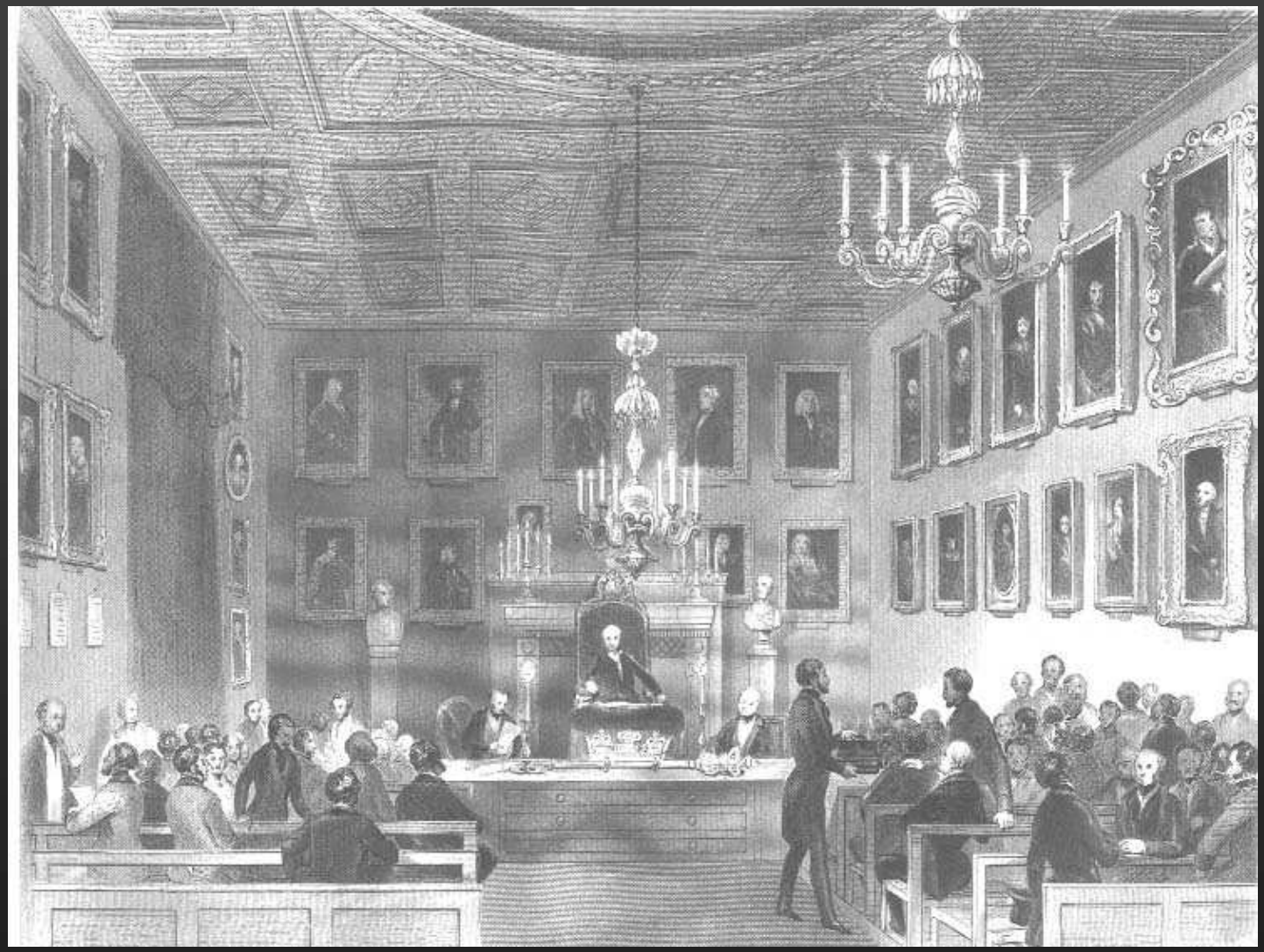
1660: The Restoration

- Return of the Stuarts: Charles II (son of behead king)

London Coffee-House Culture

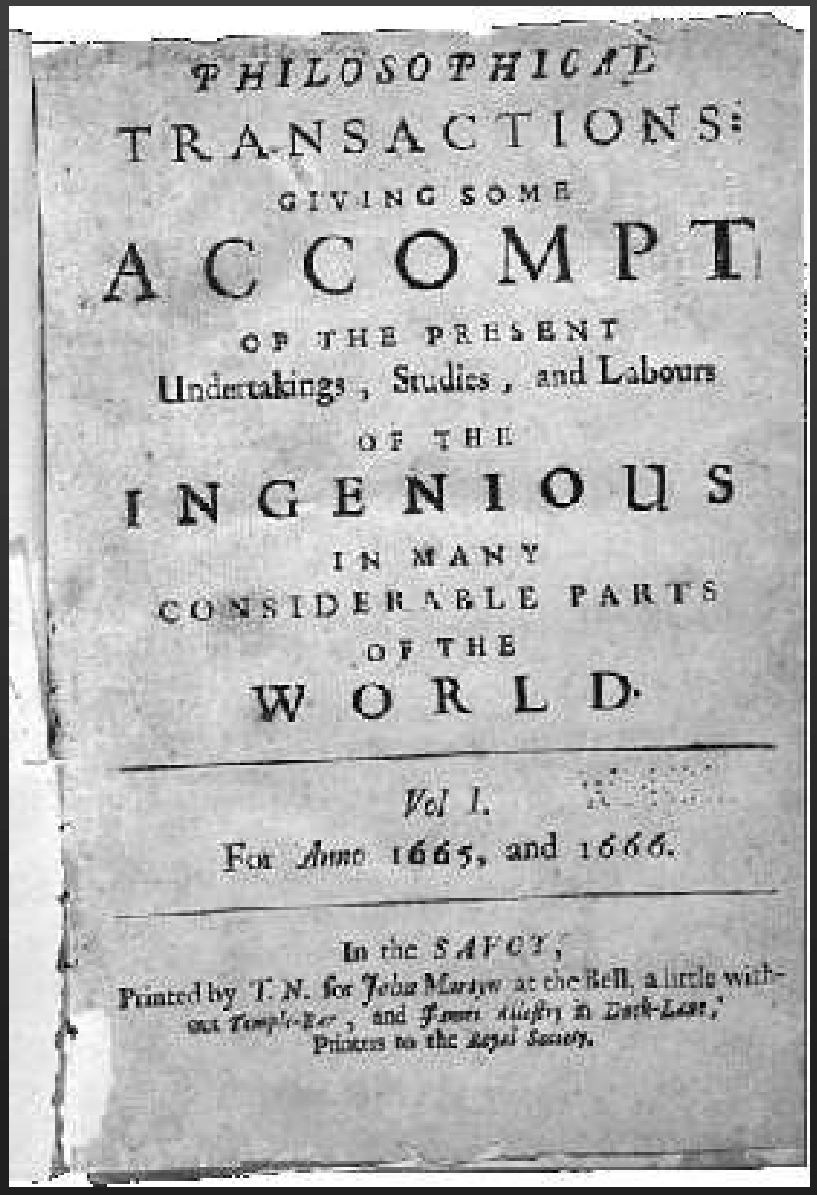
- New venue for meetings of intellectuals

The Royal Society of London



- founded 1660: institution to foster exchange of scientific knowledge

Philosophical Transactions



PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.

Vol I.
For Anno 1665, and 1666.

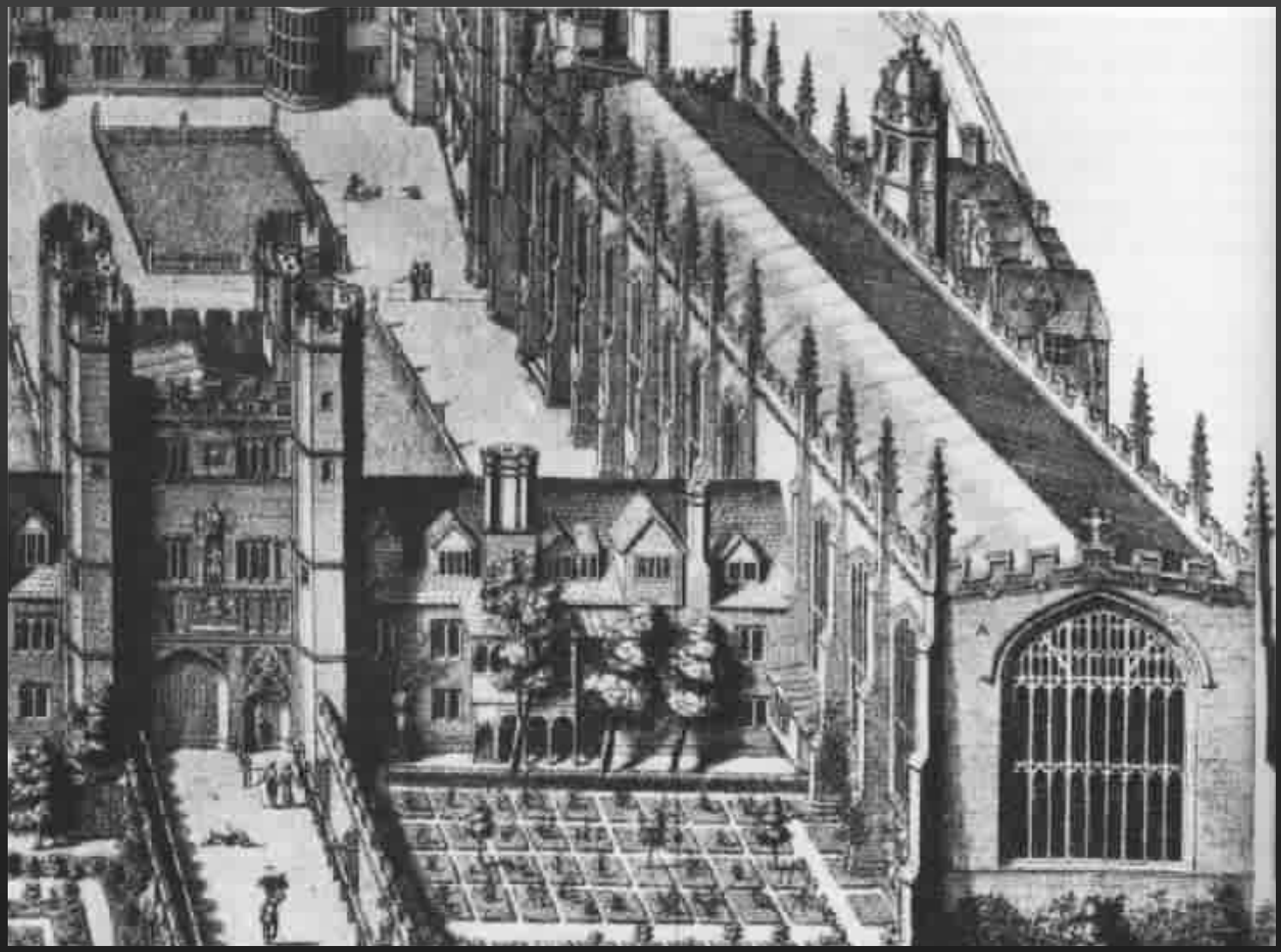
In the SAVOY,
Printed by T. N. for John Martyn at the Bell, a little without Temple-Bar, and James Allestry in Duck-Lane, Printers to the Royal Society.

- published by Royal Society
- first scientific journal
- a public registry of new scientific ideas
- professionalization of science

1661: Newton enters Cambridge University

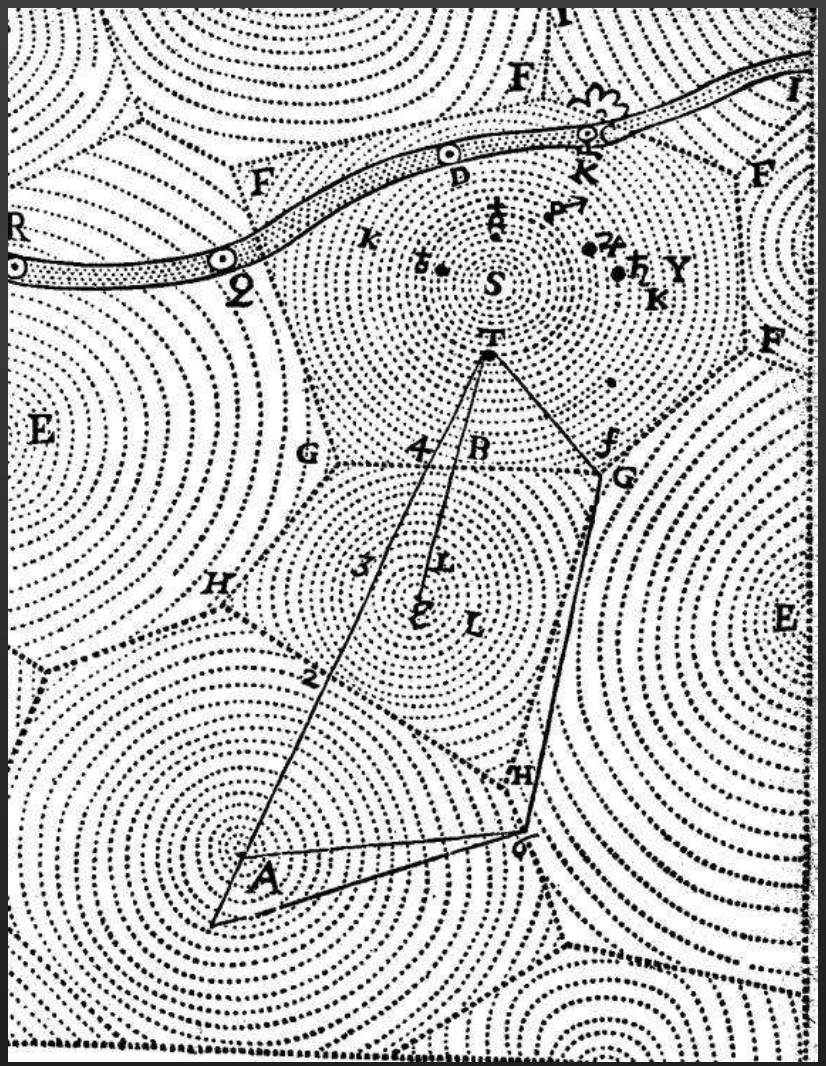
- one of oldest universities in the world

1661: Newton admitted to Trinity College



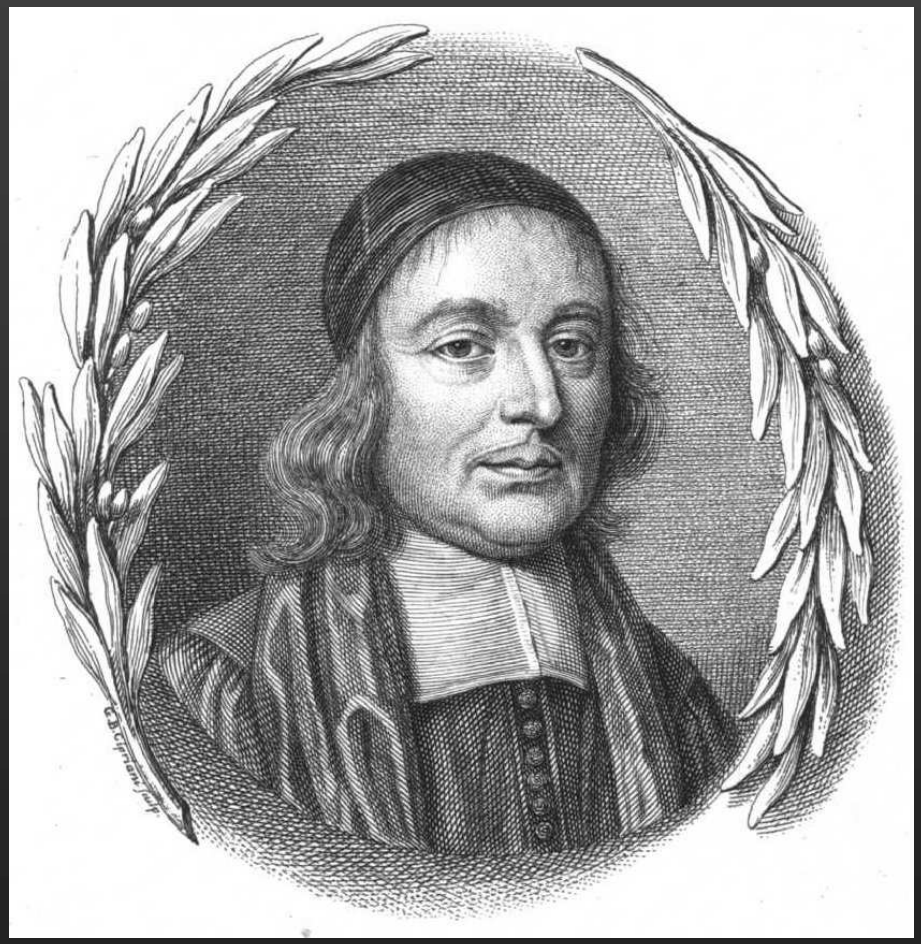
• admitted as “subsizar” (has to perform menial duties for older or richer students)

Student in Cambridge (1661-65)



- Study Descartes' mechanical philosophy!
- *Principia Philosophiae* (1644)
- No vacuum, no atoms!
- Force by direct contact (pressure and tension)

Student in Cambridge (1661-65)

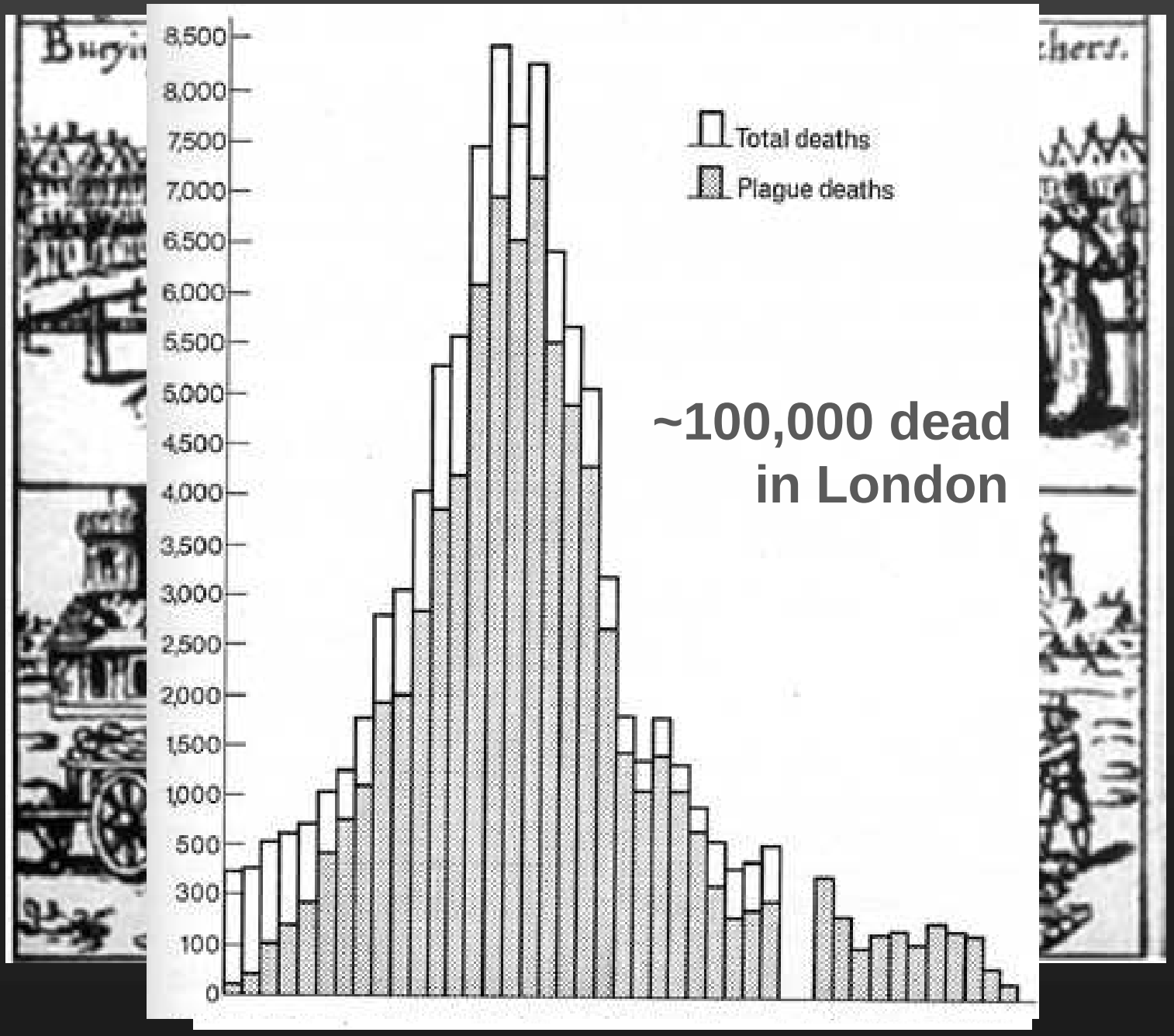


John Wallis, 1616-1703

- Study all the mathematics that there is to know!

- John Wallis *Arithmetica Infinitorum* (1656):
  - predecessor of integral calculus
  - introduces symbol for infinity (∞)

1665: The Great Plague



1666: The Great Fire of London

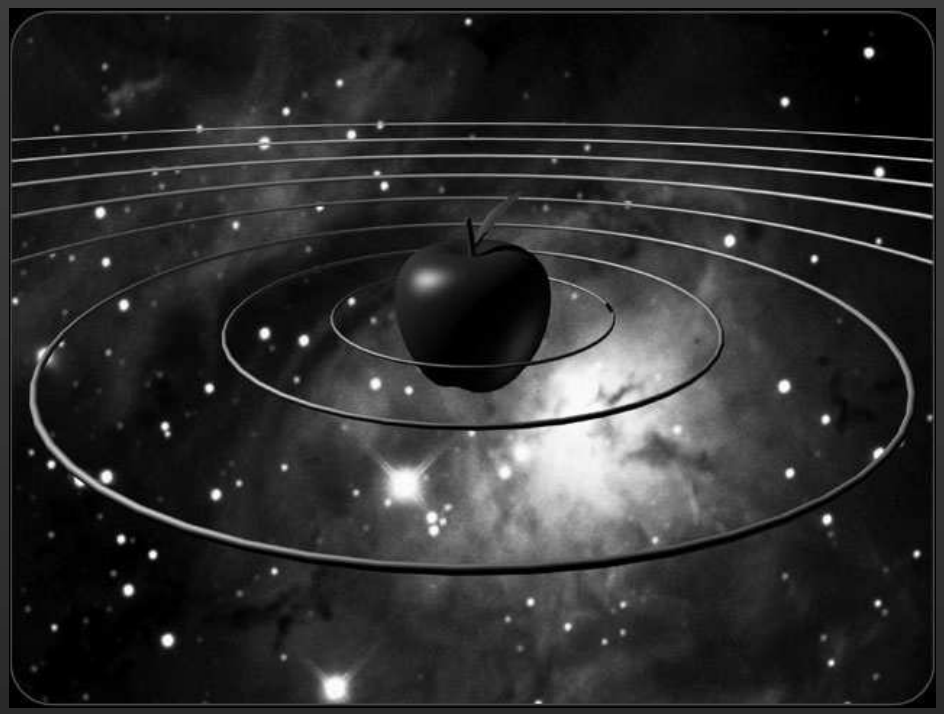
Christopher Wren: England's Greatest Architect

- 1632 – 1723
- Rebuilt London after Great Fire of 1666
- > 50 new churches
- St Paul's Cathedral
- Savilian professor of astronomy at Oxford

Wren: Rebuilding London

- St Paul’s Cathedral

Newton during Plague Year: Annus Mirabilis

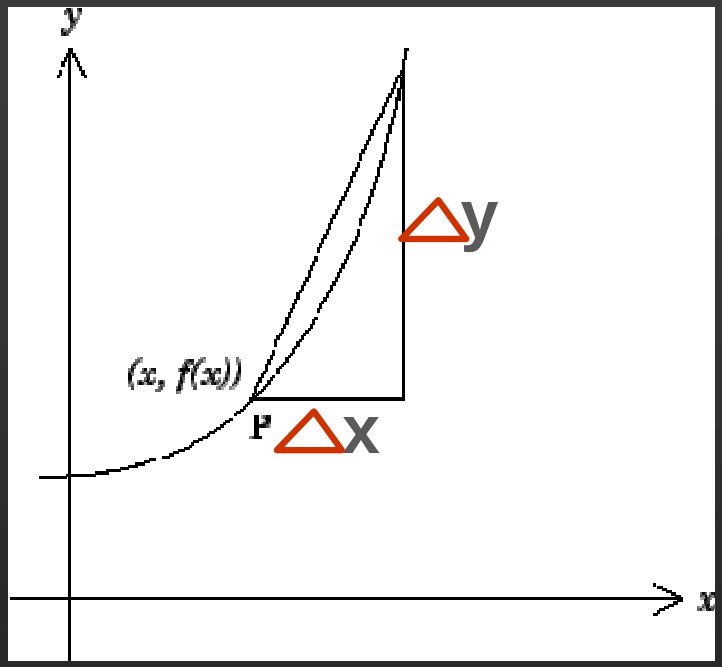


"The Miraculous Year"
(1665-66)

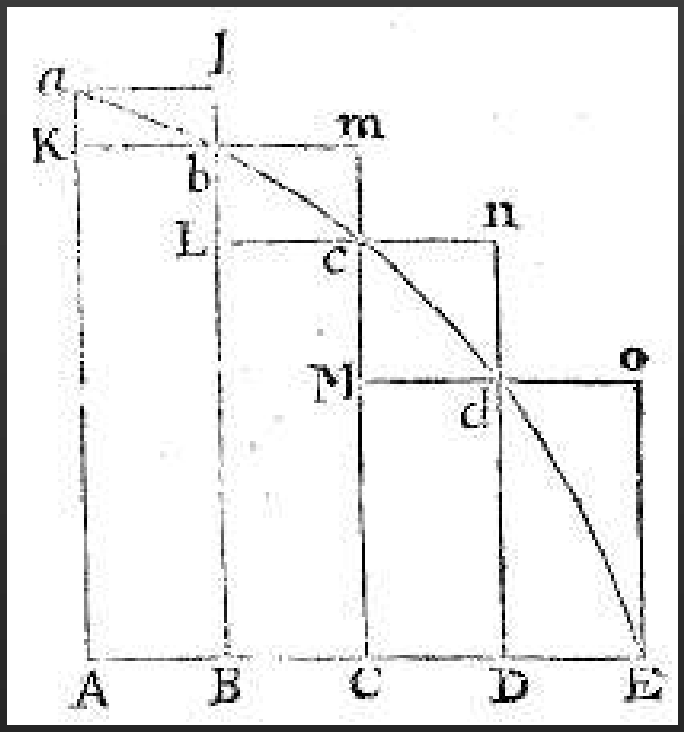
- Return to Woolsthorpe
- 3 Great Discoveries:
  - Calculus
  - Nature of Light
  - Universal Gravity

Annus Mirabilis I: Calculus

Differentiation

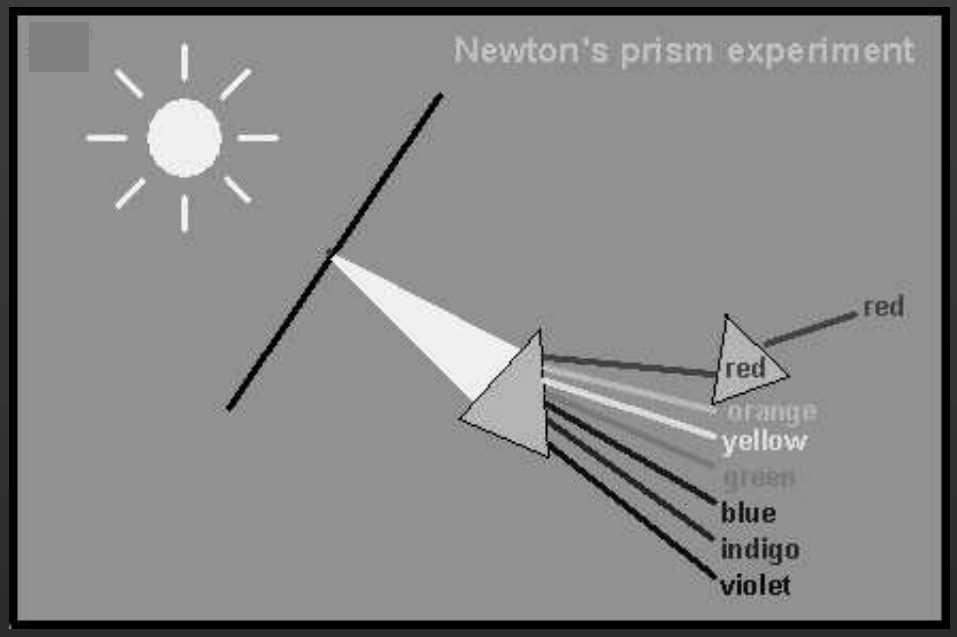


Integration



- independently discovered by Leibniz in Germany (giving rise to ugly priority dispute later on…)

Annus Mirabilis II: Optics



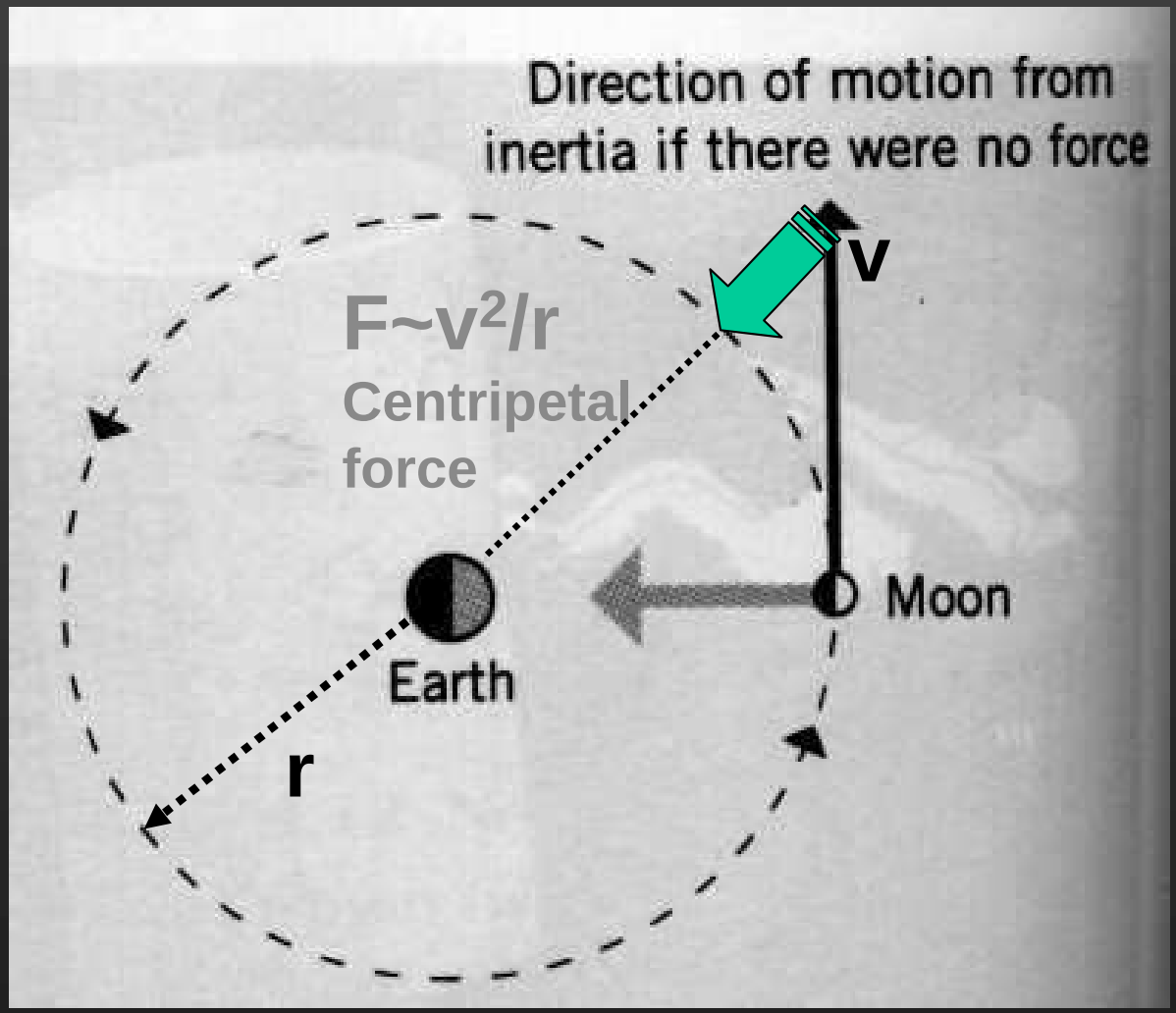
- white light is composed of different colors!

Annus Mirabilis III: Universal Gravity

NEWTON MEDITATING ON THE FALL OF THE APPLE.

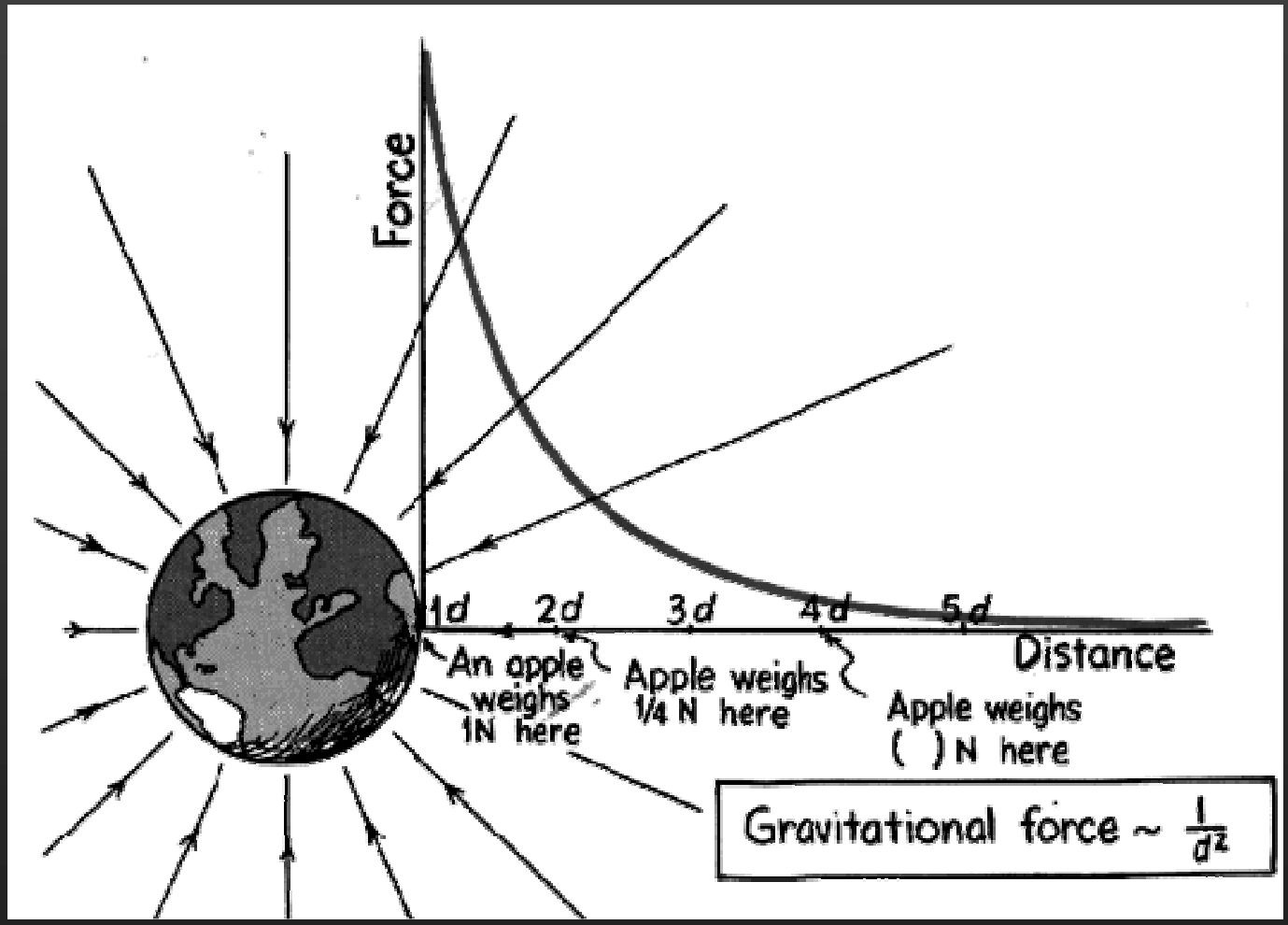
- Newton asks: What if the *same* force (gravity) causes fall of apple and keeps Moon in orbit around Earth???

Annus Mirabilis III: Universal Gravity



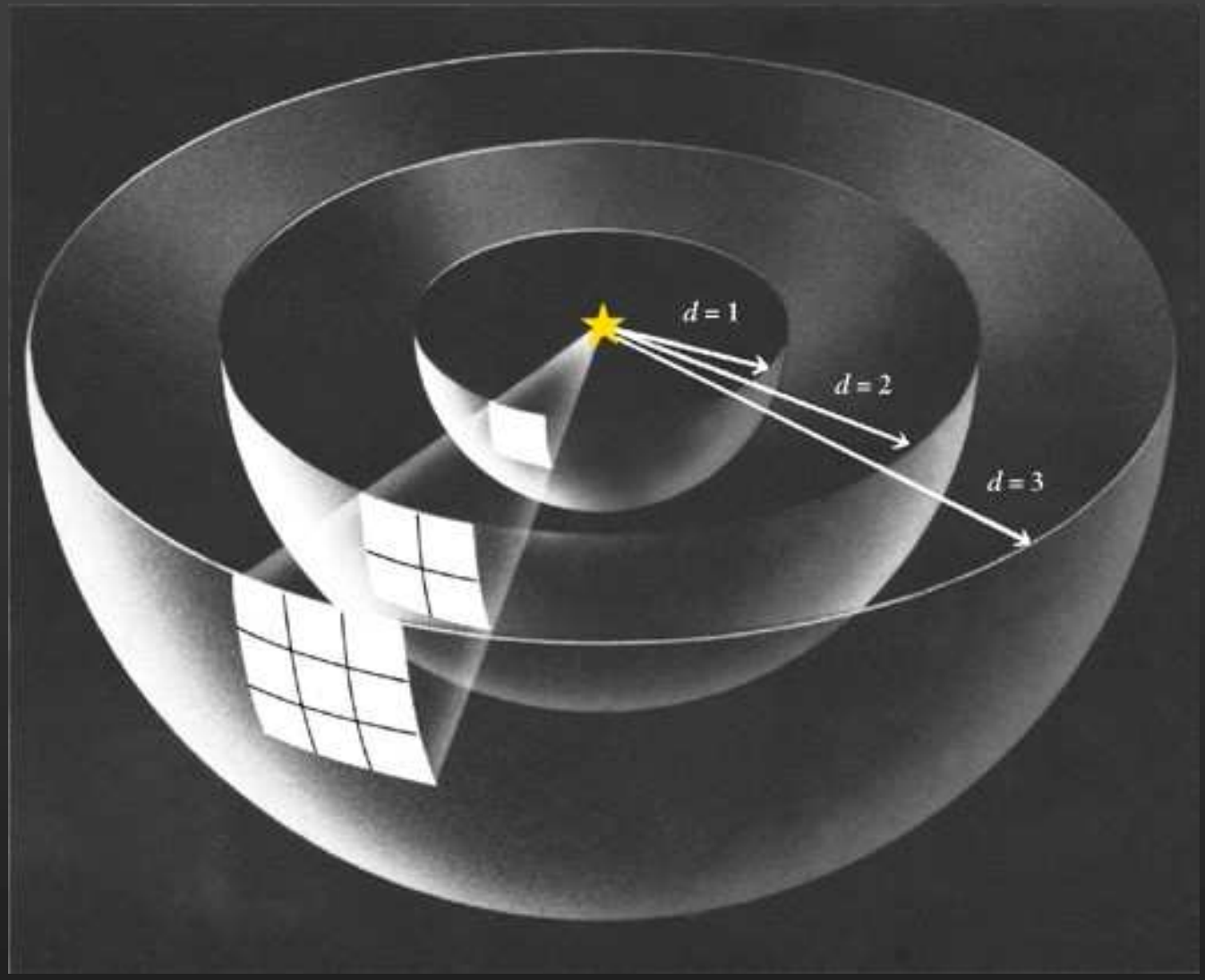
- Moon is constantly falling toward Earth (as is apple)!

Annus Mirabilis III: Universal Gravity



- Earth’s gravitational pull is ~ 1/3600 weaker at location of Moon compared to surface (apple)!

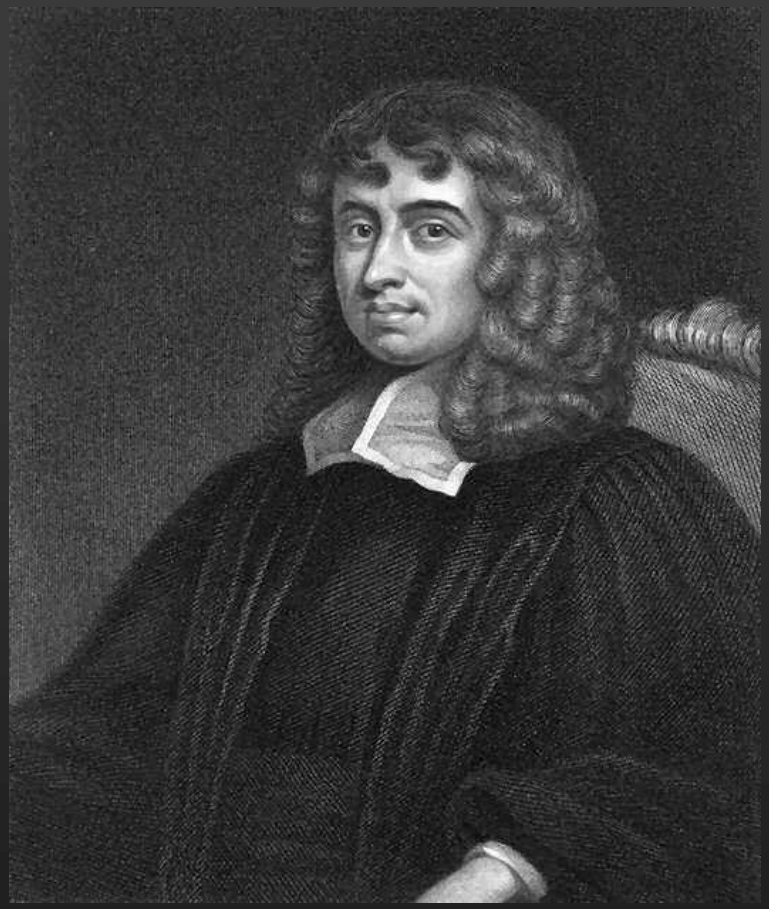
Annus Mirabilis III: Universal Gravity



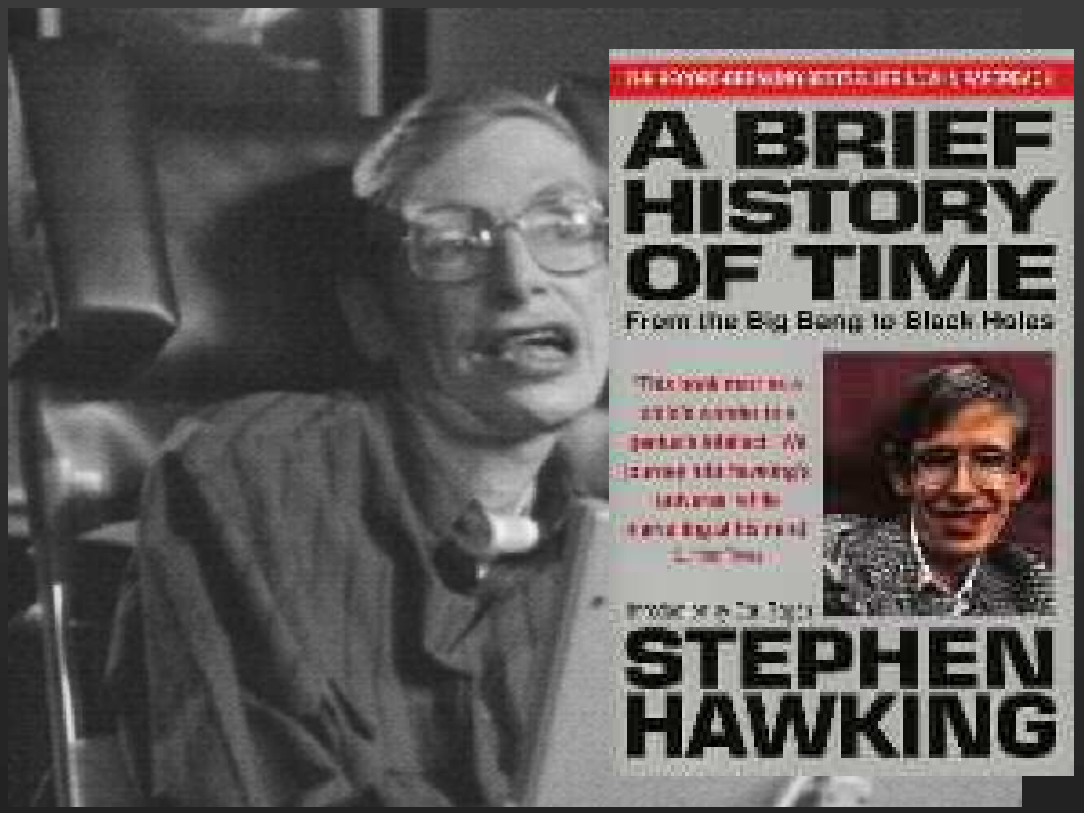
- Intuitive nature of inverse-square law!
  (compare to dilution of light over growing surface)

Newton's Return to Cambridge

- 1669: Lucasian Professor for Mathematics



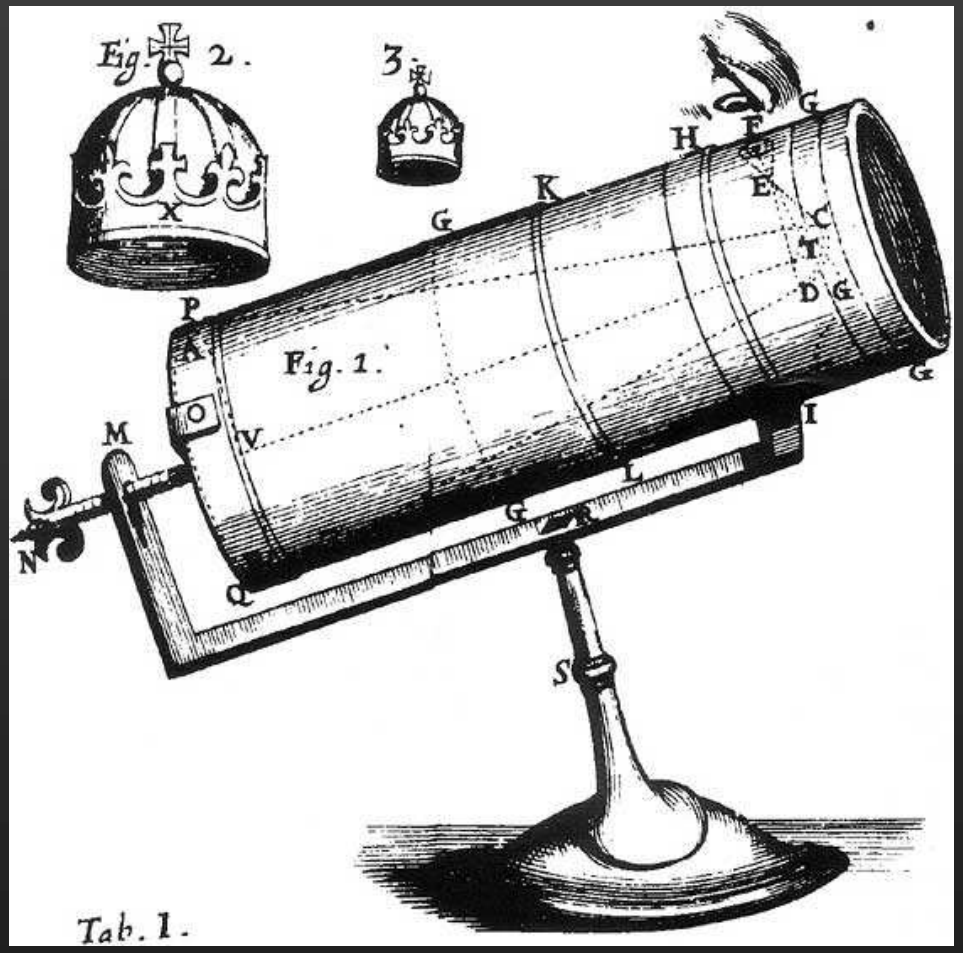
Isaac Barrow:
1st Lucasian Professor



Stephen Hawking:
17th Lucasian Professor

Newton's Return to Cambridge

- 1671: Design for new (reflecting) telescope



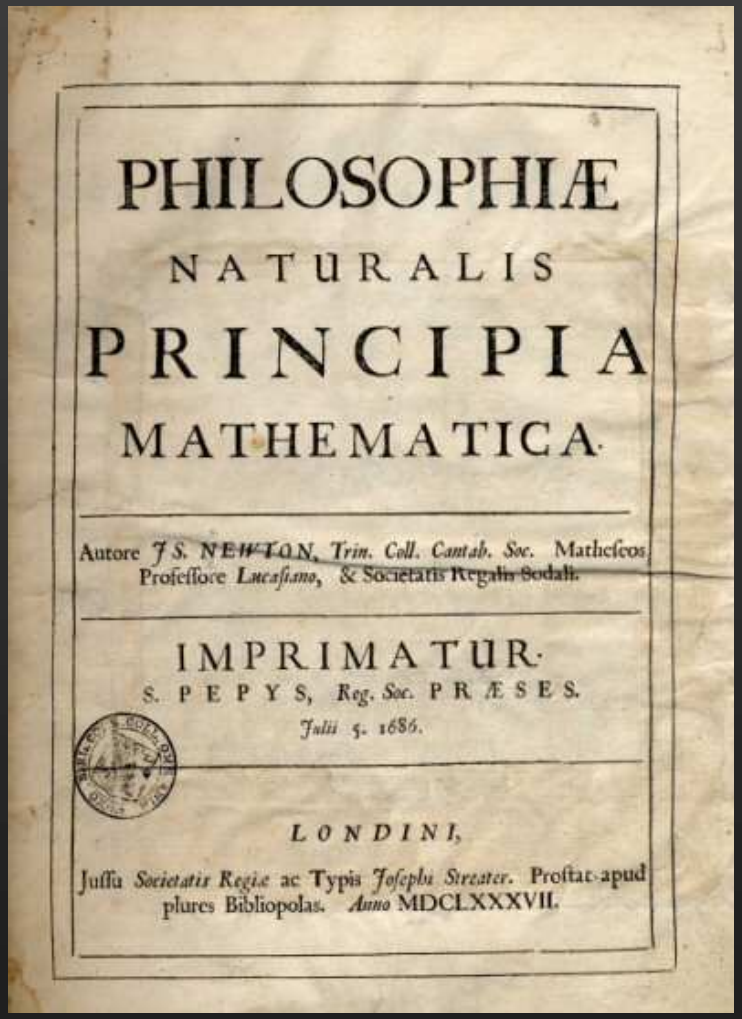
- earns him membership (as fellow) in Royal Society

En Route to the Principia

- Newton was *very* reluctant to publish!

- Edmond Halley (1656-1742)
- member of Royal Society
- Halley's Comet
- first astronomer to observe Southern Sky (from St Helena)
- Convinced Newton to publish *Principia*

Newton's Principia (1687)



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.

- *Philosophiae Naturalis* ***Principia*** *Mathematica* (Mathematical Principles of Natural Philosophy)
- Challenges Descartes' *Principia Philosophiae* (1644)
  - Descartes: qualitative
  - Newton: quantitative, predictive
- *The* foundational text for modern physics and astronomy!

Newton’s Principia: Overall Structure

Book 1: Basic Laws

Book 2: Demolition of Cartesian System

Book 3: *System of the World* (applications)

Principia Book 1: Basic Laws

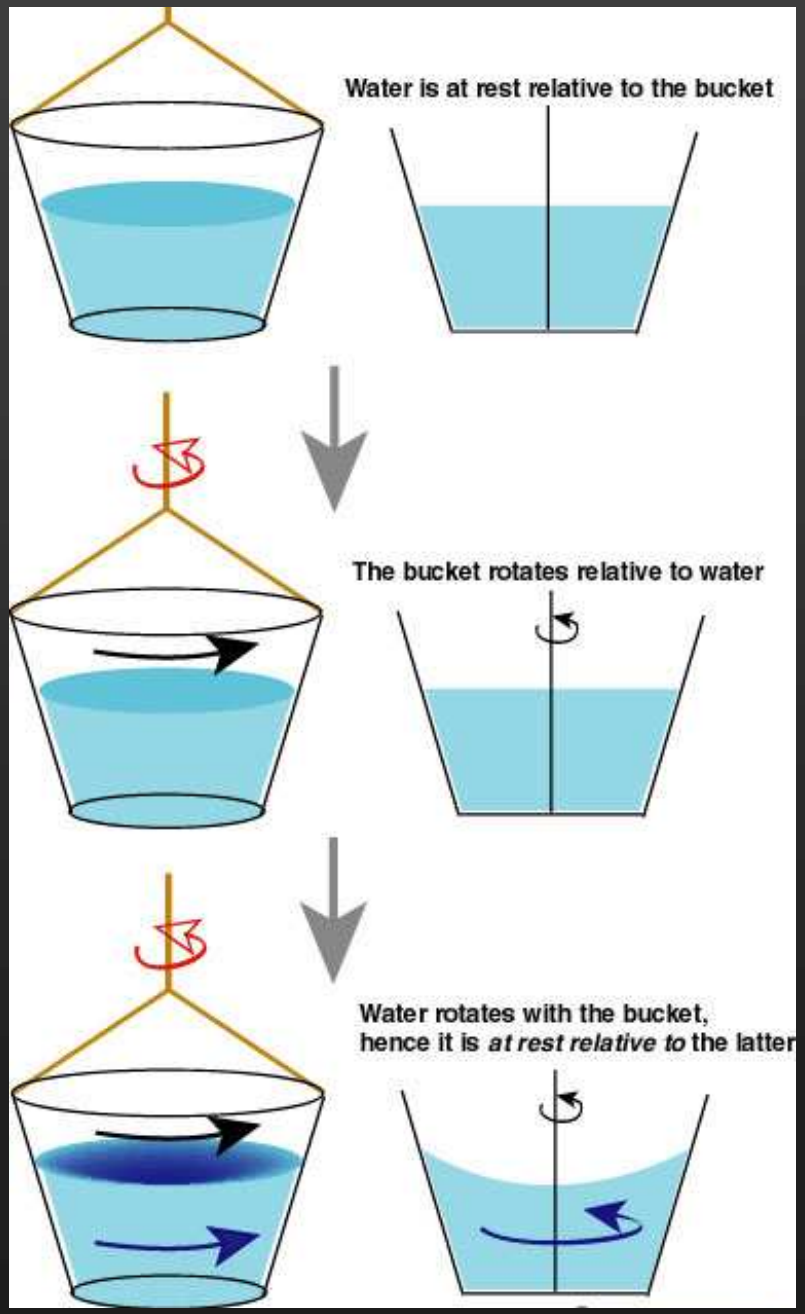
- Scholium: Absolute Space and Time

  “Absolute space…without relation to anything external, remains always similar and immovable”

  “Absolute, true, and mathematical time, of itself,… flows equably without relation to anything external ”

- Passive stage for all motion

Principia Book 1: Basic Laws



- Newton's bucket experiment

Principia Book 1: Basic Laws

- Newton's 1st Law of Motion:

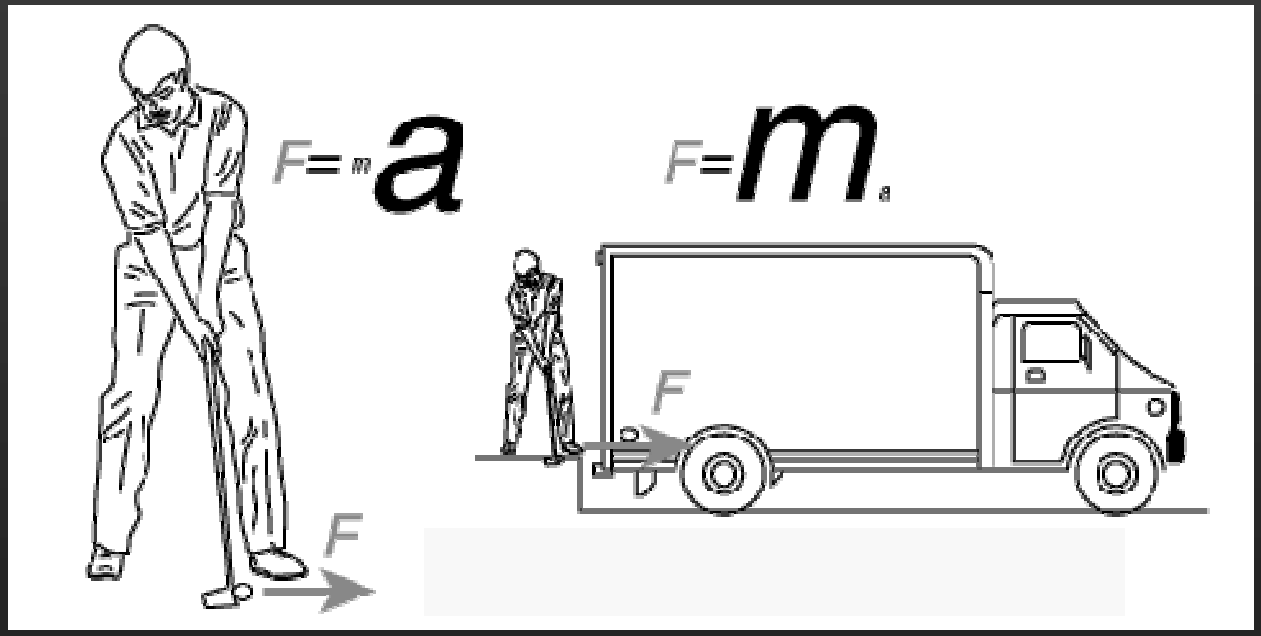
A body stays at rest or moves in uniform straight-line motion unless acted on by a net external force.

- Law of inertia (Galileo, Descartes)
- State of rest and uniform motion are equivalent (relative to observer)

Principia Book 1: Basic Laws

- Newton's 2nd Law of Motion:

Force = mass x acceleration

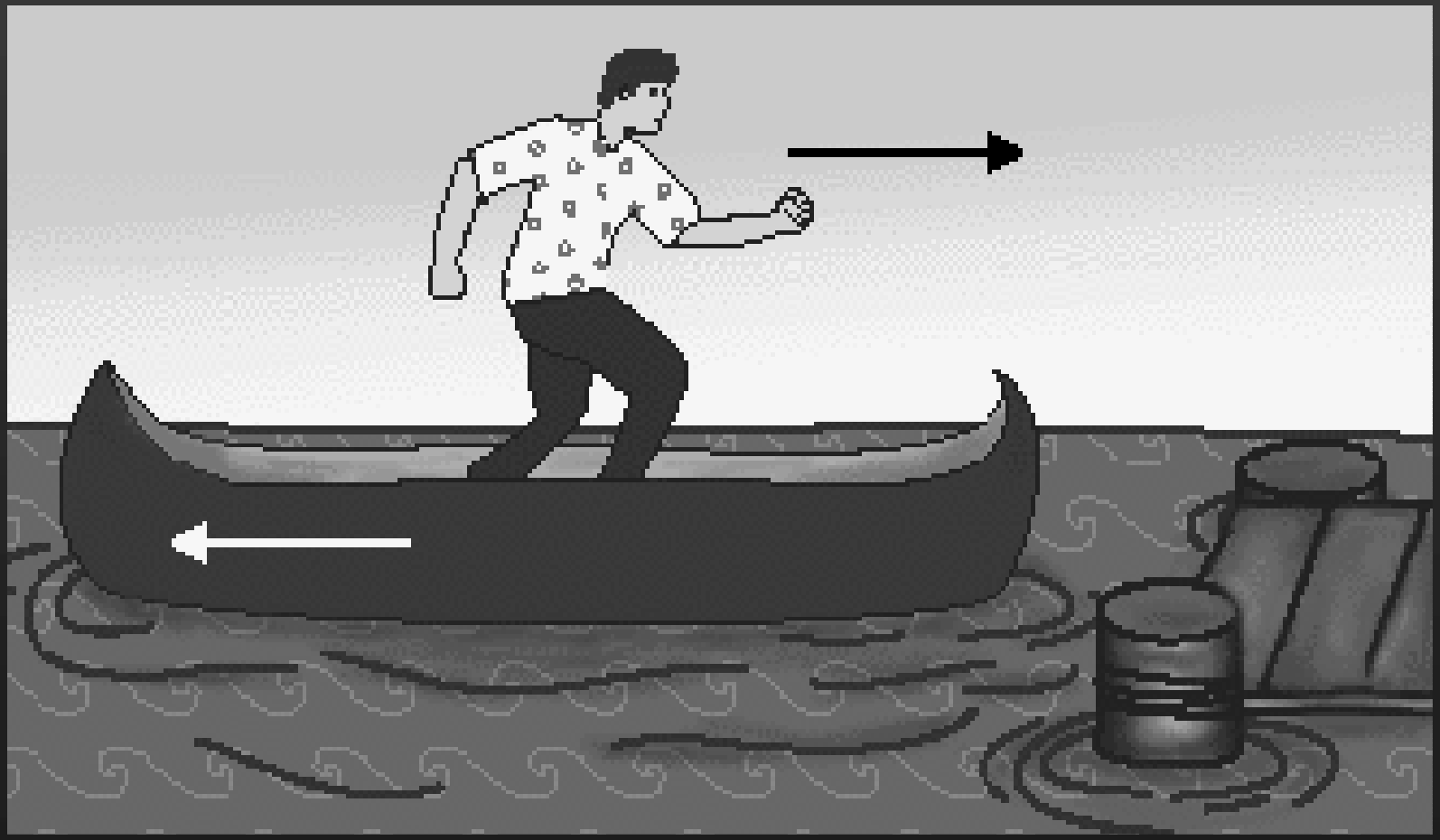


- Same force (F) exerted on a larger mass (m) produces a correspondingly smaller acceleration (a)

Principia Book 1: Basic Laws

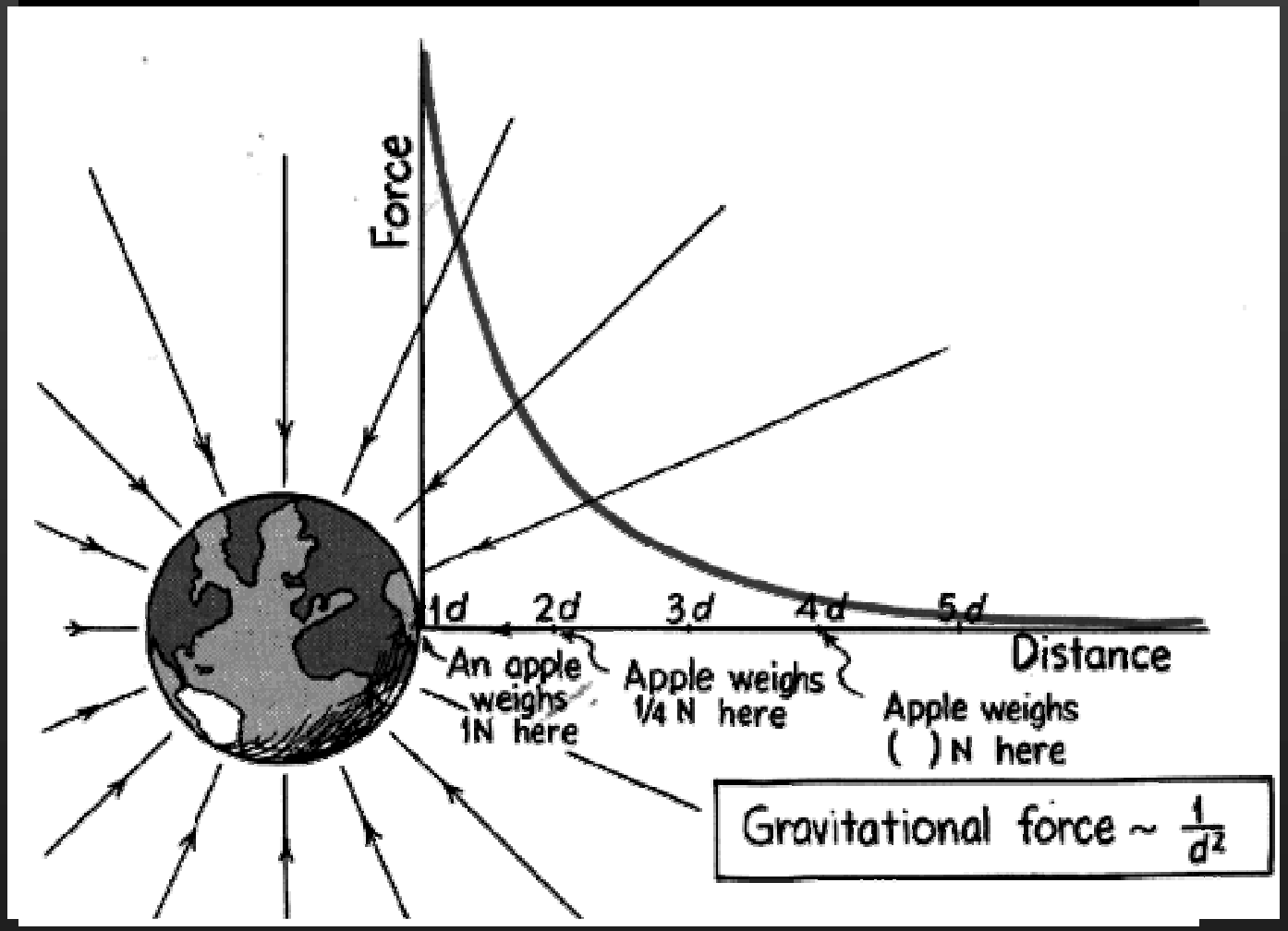
- Newton's 3rd Law of Motion:

Force = Counter-force



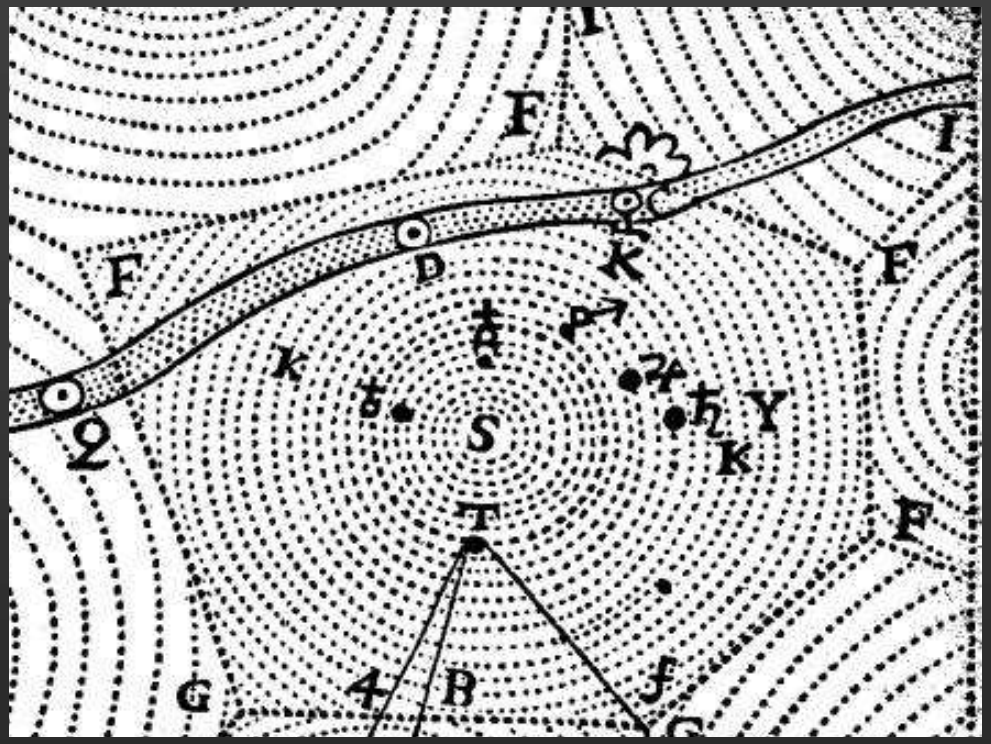
Principia Book 1: Basic Laws

- Newton's Law of Gravity:



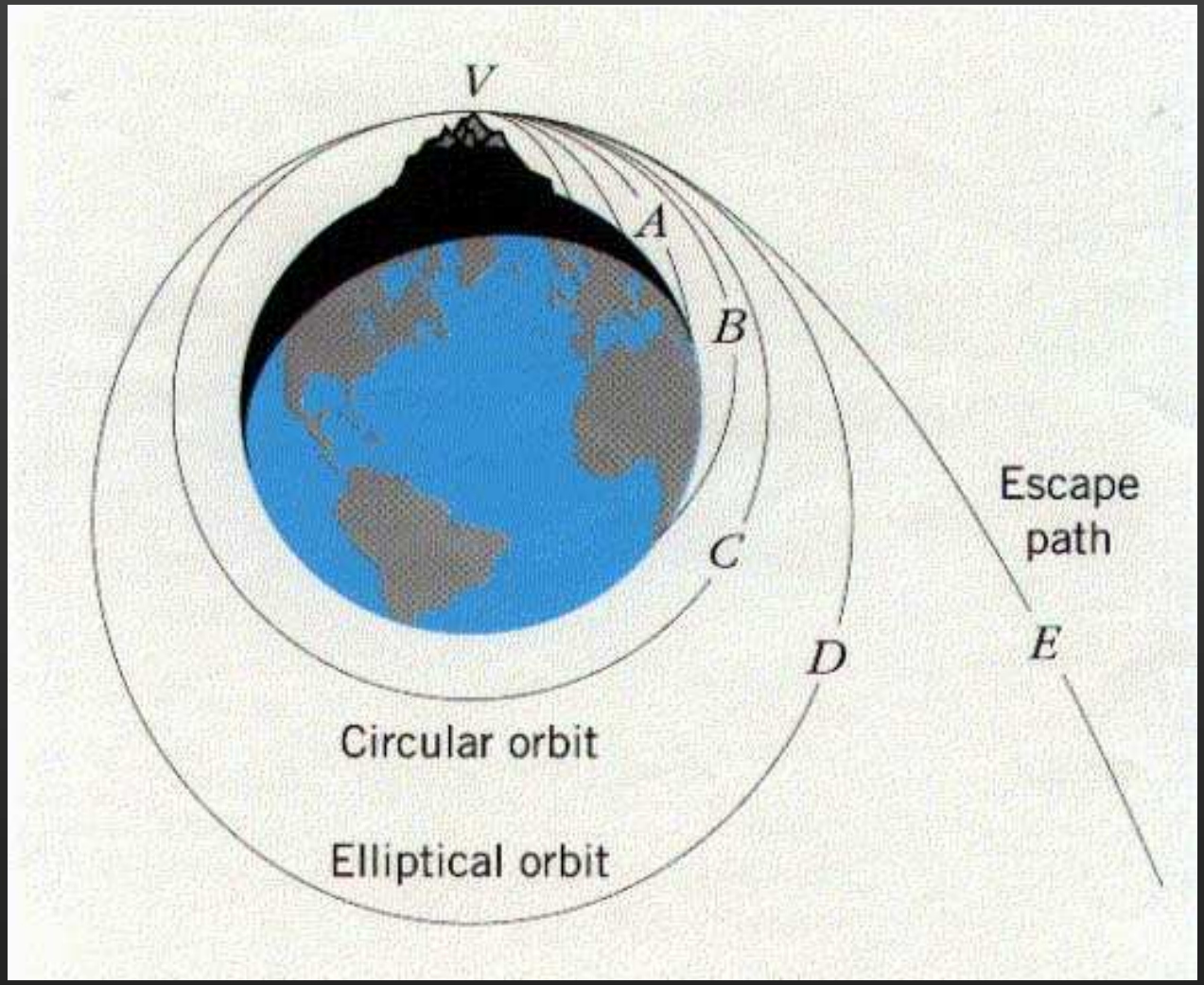
- Gravity is universal and follows inverse-square law!

Principia Book 2: Demolish Descartes



- Newton proves mathematically:
  - Descartes' vortex motion cannot be sustained!
  - it would soon stop because of friction (objects have to move through `plenum')

Principia Book 3: New System of the World

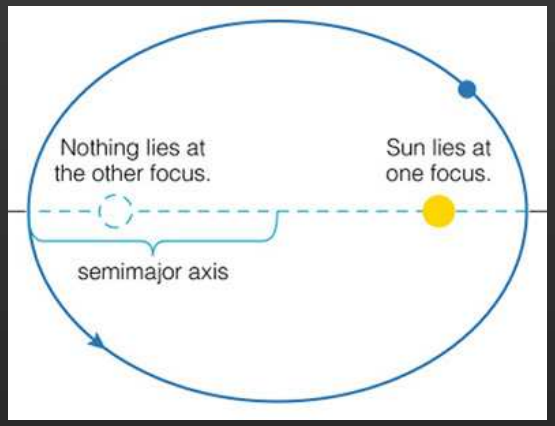


- Newton's laws ➡ celestial motions (ellipse, parabola, hyperbola, circle)

Principia Book 3: New System of the World

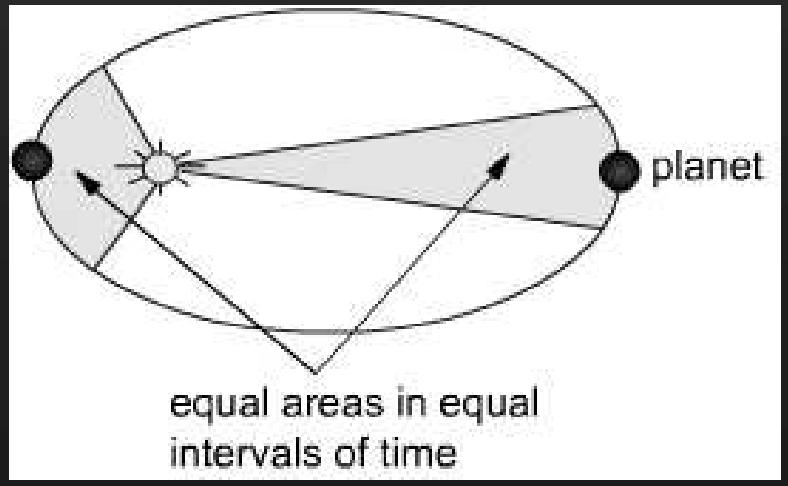
- Newton's laws ⇒ Kepler's Three Laws of Planetary Motion

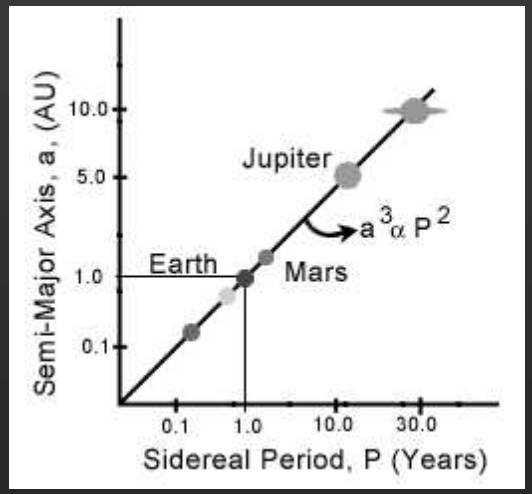
(gravity + laws of motion)



Kepler 1

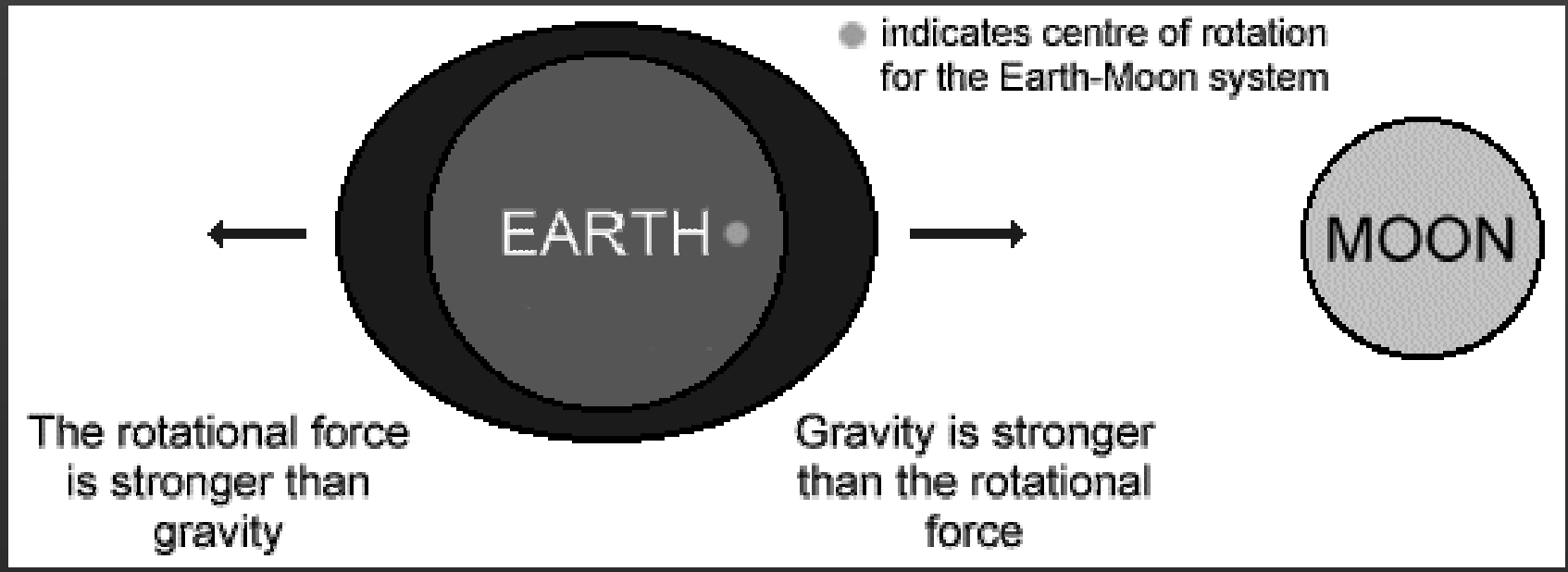
Kepler 2





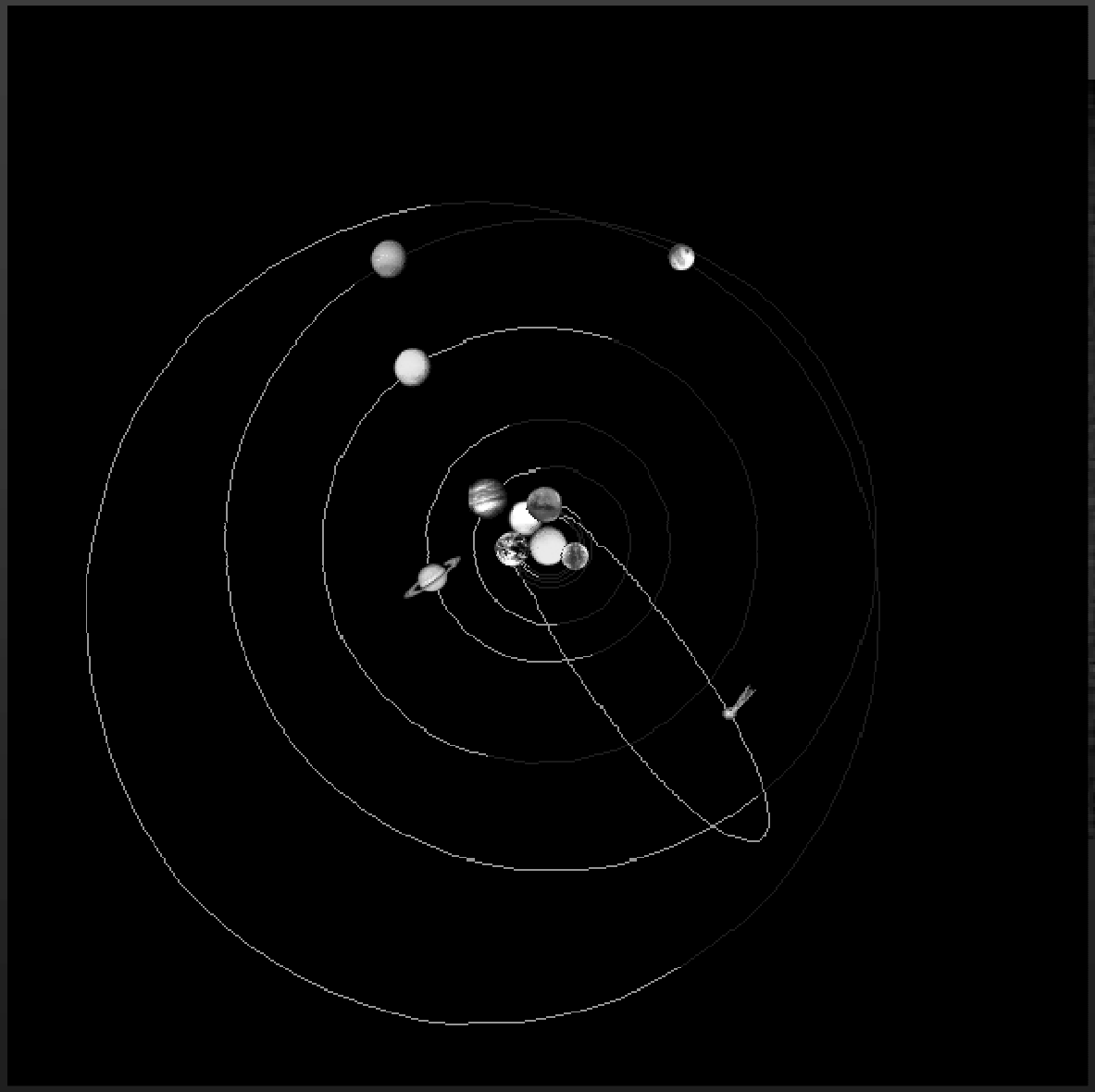
Kepler 3

Principia Book 3: New System of the World



- Newton's laws ➡ ocean tides!

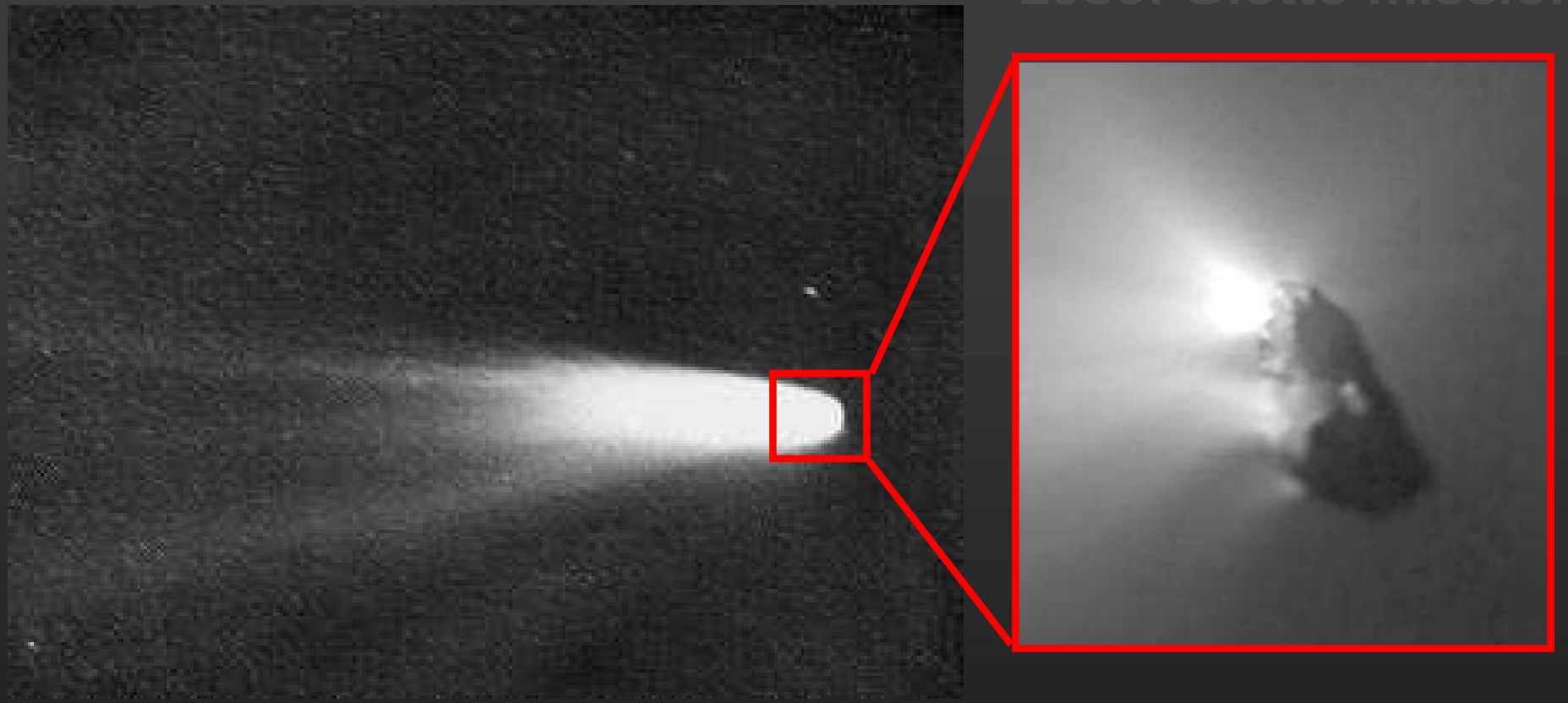
Principia Book 3: New System of the World



- comets move on highly eccentric orbits around Sun!

Halley's Comet

1986: Giotto mission



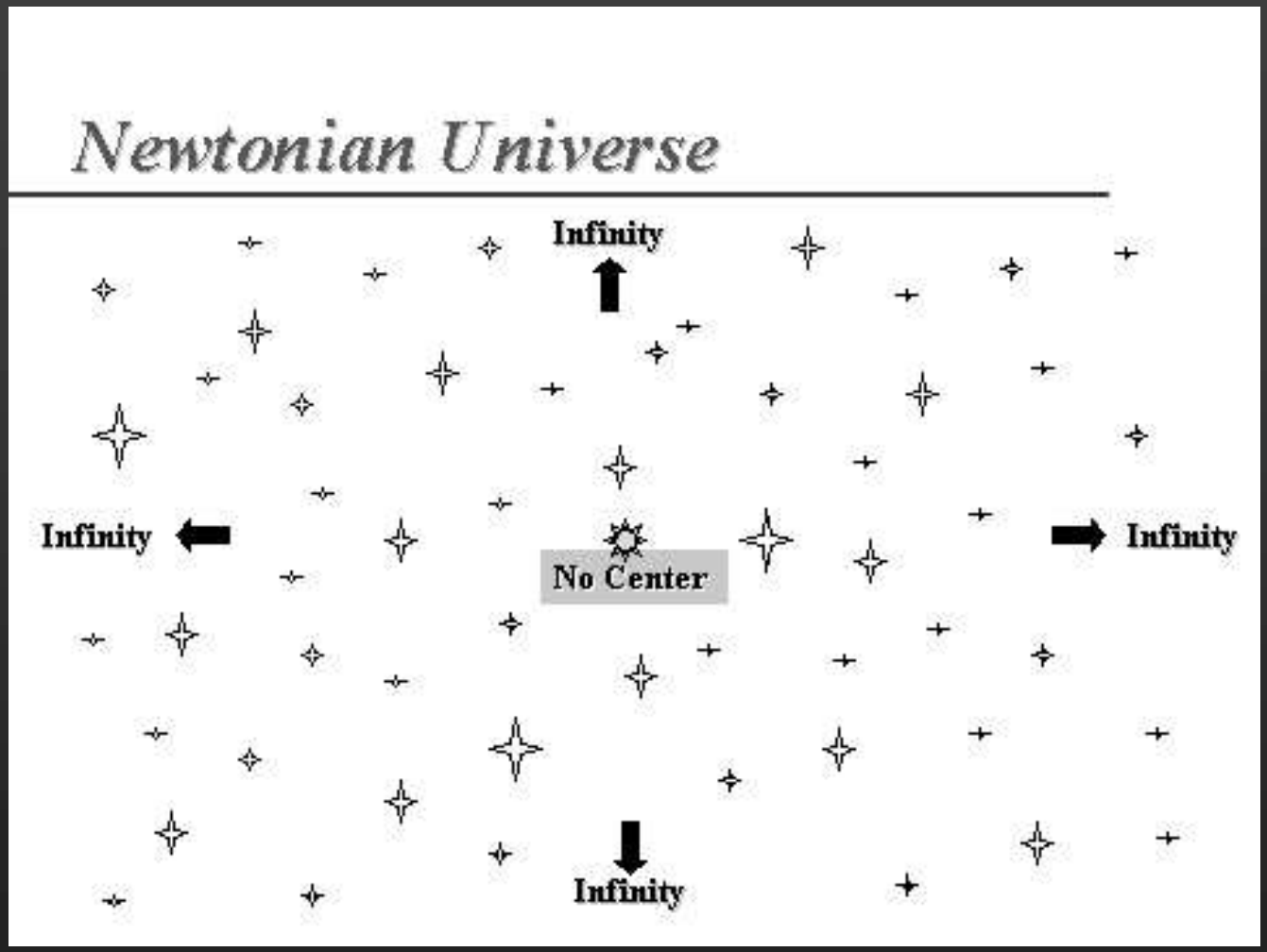
- Next return scheduled for 2061!

Principia Book 3: New System of the World

“void”

- stoic universe (infinite space, finite matter) is unstable!

Principia Book 3: New System of the World

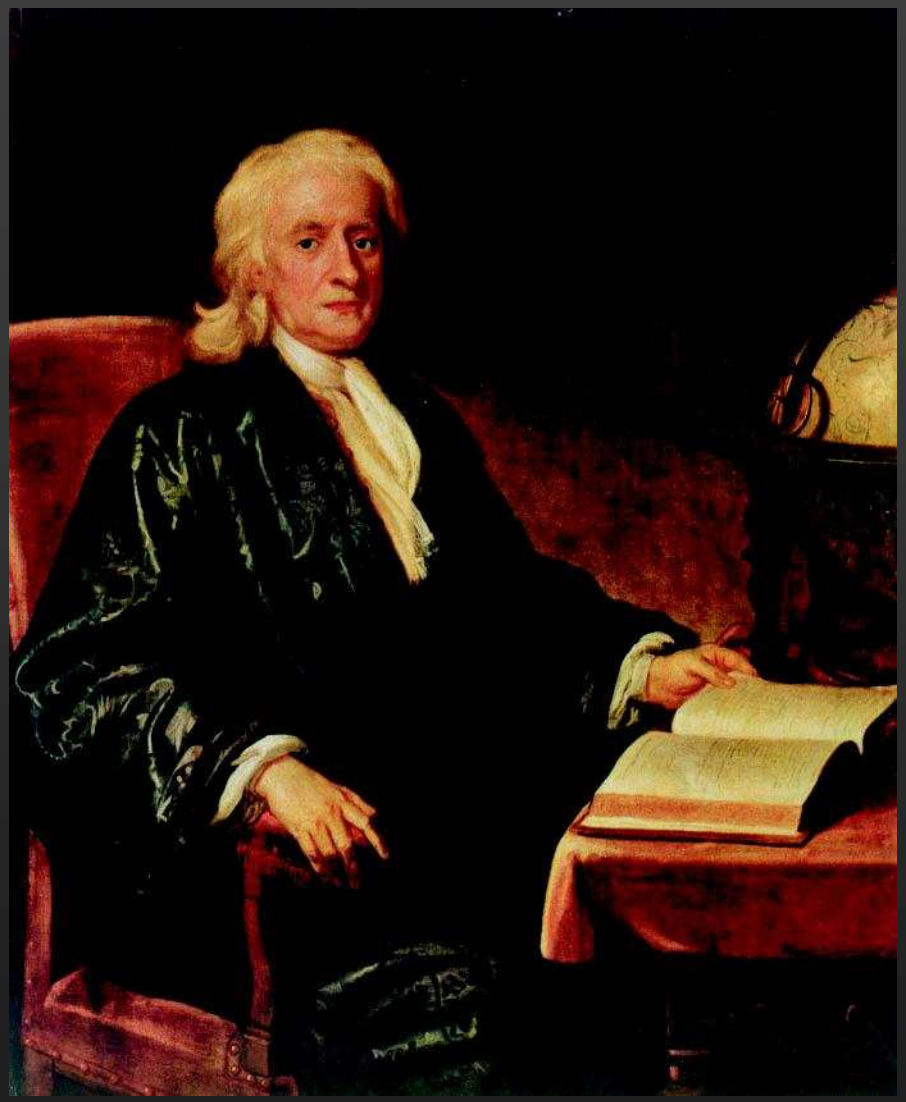


- Need Epicurean universe (infinite space, infinite matter)!

The Infinite Universe: Letters to Bentley (1692-93)

- Richard Bentley (1662-1742)
- erudite theologian
- lectured on how to combat atheism
- basic idea: God’s perfection requires infinite universe
- double-check with Newton on technical details

Newton permanently moves to London



- 1696-1727

- “affairs of state”:
  - member of Parliament
  - master of the Royal Mint (oversees large-scale re-coinage program; becomes very rich)
- President of the Royal Soc.

- stops doing science!

Journey’s End: Death in 1727

- buried in Westminster Abbey

Newton: The Legend

"Nature and Nature's Laws lay hid in night;
God said, *Let Newton be!* And all was *Light*."

(Alexander Pope)

"Newton with his prism and silent face,
The marble index of a mind for ever
Voyaging through strange seas of Thought, alone."

(William Wordsworth)

Newton: The Legend

(William Blake, 1795)

- cold, unfeeling rationalist and law-giver, a demigod

Newton

- Isaac Newton:
  - founder of modern physics and astronomy
  - early life: led reclusive anti-social life in Cambridge
  - later life: tended to affairs-of-state in London (master of the Mint)
- Principia
  - foundational text for modern physics and astronomy
  - laws of motion
  - universal gravity (inverse-square law)
  - demolished Cartesian model
  - explains large number of hitherto unrelated phenomena within one unified theoretical framework
- The Legend:
  - “the marble index of the mind for ever…”