GALILEO GALILEI

1564-1642

Part II: Medieval Science, Kinematics, Astronomy, and That Trial

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February 9, 2024

TAKEOUT FROM OUR

TWO GUYS©

PLATO and ARISTOTLE

PLATO

What can you know?

nothing that's true using your senses

true knowledge:

is only of permanent, static, perfect, unique, things

that exist and accessible only through thought

the Forms

the only true things

the only real things

we perceive imperfect objects —> "participate" in their Forms

Cosmos

circles

ARISTOTLE 1/2

What can you know?

nothing true except through your senses

true knowledge:

is only of individual facts and objects

and the four causes of all change

Substance and Form are coupled together in all objects

all objects made of mixtures of earth, water, air, fire

“change”

all objects possess potential to “become”

change is motion that relieves the tension associated with objects not being fullfilled

ARISTOTLE 2/2

locomotion: inside the orbit of the moon

natural motions: straight paths

mixture of the 4 elements determine natural motions

earthy, watery …toward the center of the universe: heaviness

airy, firey…away from the center of the universe: lightness

unnatural motions: any path

but must have a contact pusher

“speed” is not a thing for Aristotle

locomotion: outside the orbit of the moon:

natural motions: circular paths

single element: “aether” or “quintessence”

his cosmology: stay tuned

LEFT OFF AT ABOUT THE 11TH-12TH CENTURY

when all of Greek philosophy, medicine, and astronomy

were discovered largely in Spain

and translated from Arabic into Latin

LOGIC

Another **FIRST** from Mr. Aristotle

OFFICIALLY

study of propositions

for him, the syllogism form

VALID ARGUMENTS ARE NOT NECESSARILY TRUE ARGUMENTS

- (All apples)(are fruit)
- (All red objects in that tree) (are apples)
- Therefore, (All red objects in that tree) (are fruit)

is a valid syllogism (among 24 of 256 ways to construct an argument):

- (All A)(are B)
- (All C) (are A)
- Therefore, (All C) (are B)

but beware:

- (All elephants)(are English speakers)
- (All squirrels) (are elephants)
- Therefore, (All squirrels) (are English speakers)

is perfectly valid

THIS EVOLVED BY A STUDENT

"propositional logic"

(If those red objects are apples) (then they are fruit.)

(They are apples.)

Therefore, (they are fruit.)

$$A \rightarrow B$$

$$A$$

$$\therefore B$$

a conditional –> truth tables –>
digital logic –> your iphone

ARISTOTLE'S GUARANTEE: LOGIC MEANS NECESSITY

make certain statements and

you can't avoid a conclusion

a tool for knowledge?

the elimination of invalid arguments

with rules

SUPPOSE

you’re a smart, medieval student

used to being in control…after all, you pay only when you like a course or professor

your reaction to authority…student-like

YOU'RE HANDED A TOOL BOX:

that guarantees truth

syllogism and propositional logic is infallible

applied to scripture?

~1120: Peter Abelard (1079-1142), *Sic et Non*

168 logically inconsistent statements in and about the Bible

CHURCH VS ARISTOTLE

faith and abstractions

vs

reason and logic

BY 1200: THE RADICAL ENCLAVES

universities

Bologna, Paris, Oxford, Padua

of Aristotelianism

CHURCH TOOK IT WELL

1210: banned teaching of Aristotle

ignored

sent in the troops to Paris

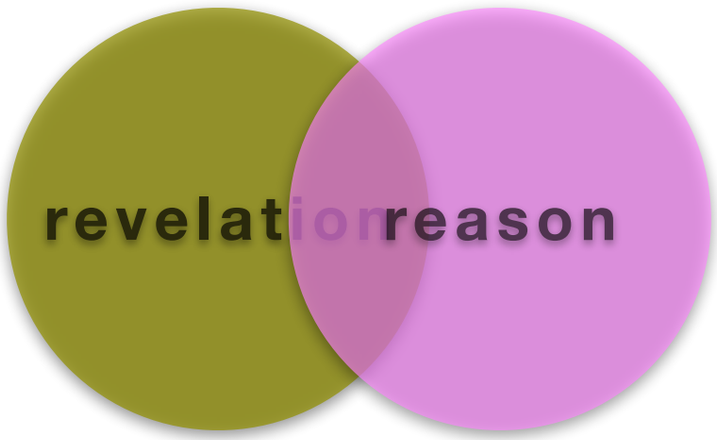
1255: okay. 1277: not okay

Dominicans (1217); Franciscans (1230)

into Paris rode

Thomas Aquinas
1225-1274

Before Thomism



nothing but trouble

1311 “Thomism”

served Catholicism until the Vatican Council II

EVOLVED TO: ARISTOTLE = AUTHORITY

"The Philosopher"

their version of Aristotle

Philosophical Scripture.

legalistic.

authoritarian.

argument ("disputation") was the only acceptable path to knowledge

“SCHOOLMEN”

“Scholasticism” in academia became

s o l i d i f i e d

THE FIRST INTELLECTUAL REACTION

against authoritarianism

humanism…Florence leads

> It is foolhardy...to accept an engagement with these fellows [schoolmen] upon their own terms. It is indeed from the fighting itself that they derive their chief pleasure: their object is not to discover the truth, but to prolong the argument...How do we escape from these maniacs? ...no one could be more utterly different from that great philosopher [Aristotle] than a man who writes nothing, knows little, and constantly indulges in much vain declamation? Who does not laugh at their trivial conclusions...not only are they good for nothing else, but their perverted activity renders them actually harmful. ...if your friend begins to vomit forth syllogisms, I advise you to take flight.
>
> Petrarch, 1350?

MEDIEVAL SCIENTISTS WERE VERY SMART

philosophers and logicians, not “scientists”

Arabs were full-on astronomers and astrophysicists

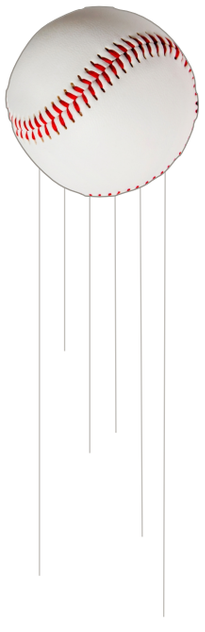
thinking for themselves rather than using Aristotle as Law

PROJECTILES? THROWING STUFF?

everyone knew: goofy

THROW A BALL UP?

unnatural

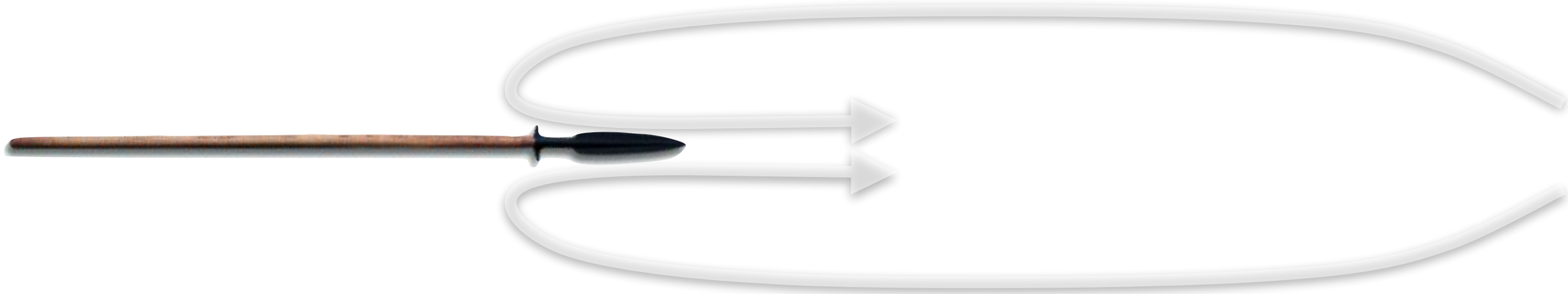


natural

1350

John Buridan, rector U. of P.

collected silly Aristotelian physics examples:



- *sailor at the bow of a ship feels breeze on front, not back*
- *spear pointed at both ends, spear thrown with blunt end first*
- *spinning top*

The unwelcome alternative to Aristotle…"Impetus":

"...some incorporeal motive force is imparted by the projector to the projectile, and ...the air set in motion contributes either nothing at all, or else very little to this motion of the projectile.

John Philoponus, 6th C

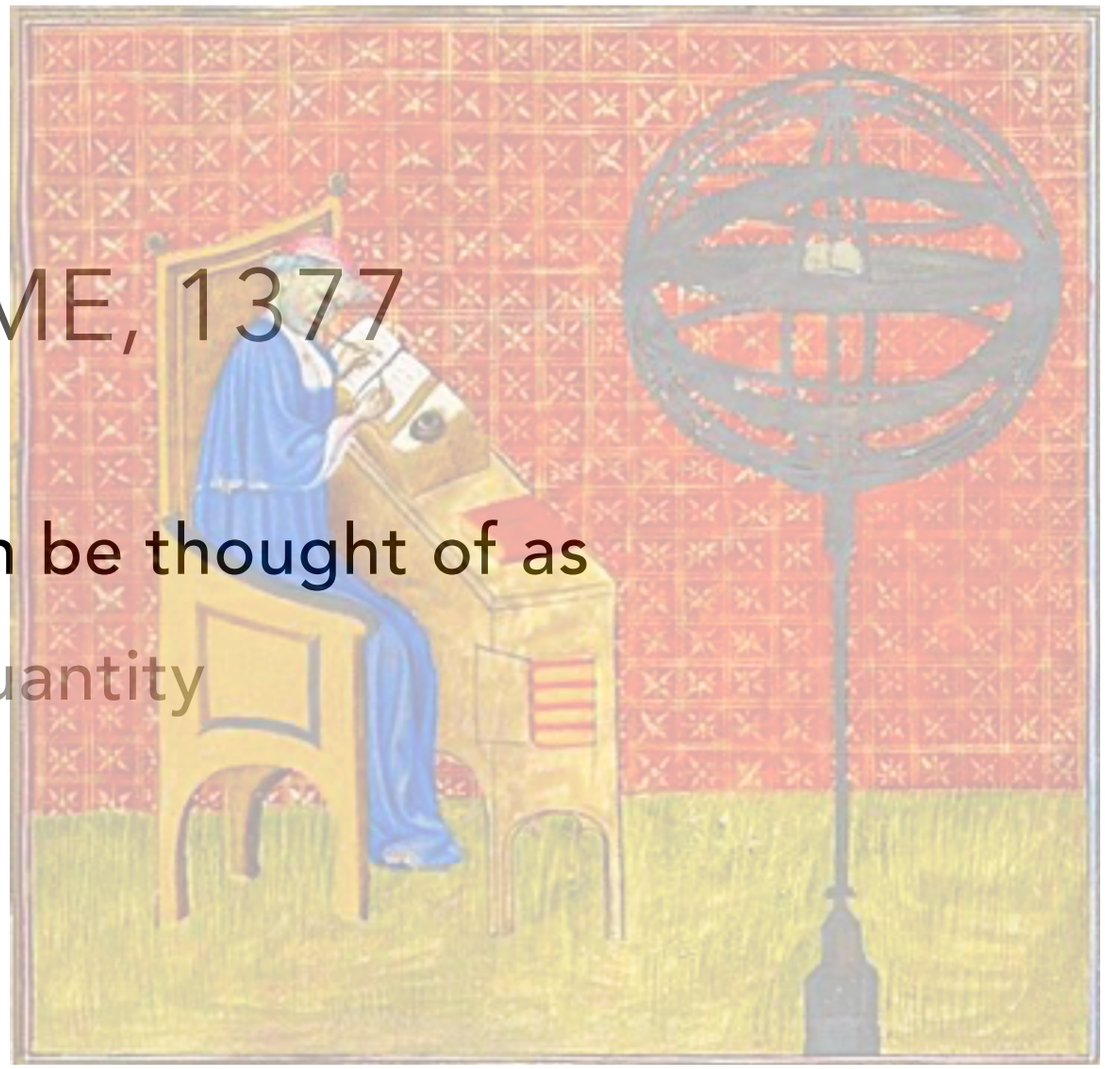
“IMPETUS”

something communicated to a projectile

OXFORD & PARIS

motion

NICOLE ORESME, 1377



every measurable thing can be thought of as

a continuous quantity

“STRENGTH” OF A PROPERTY

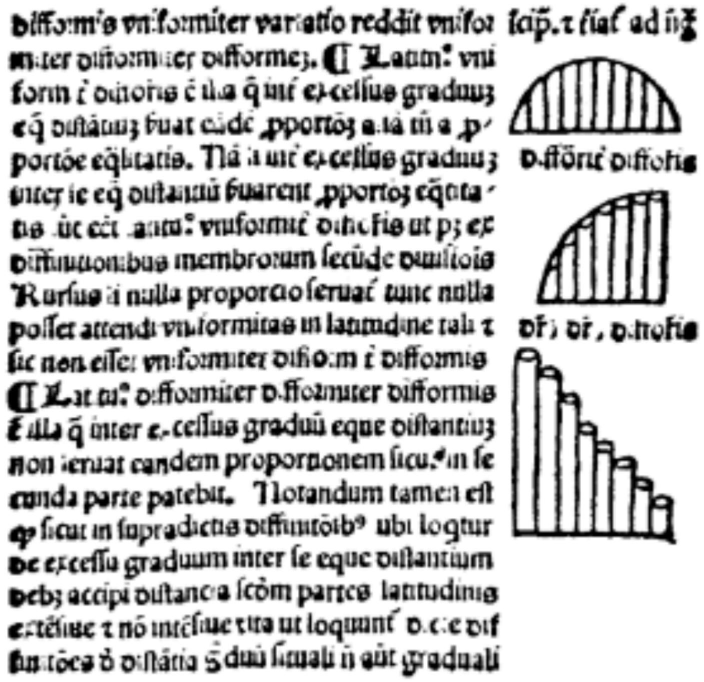
Aristotelian “change” of Aristotelian qualities

represented graphically…*not* Aristotelian

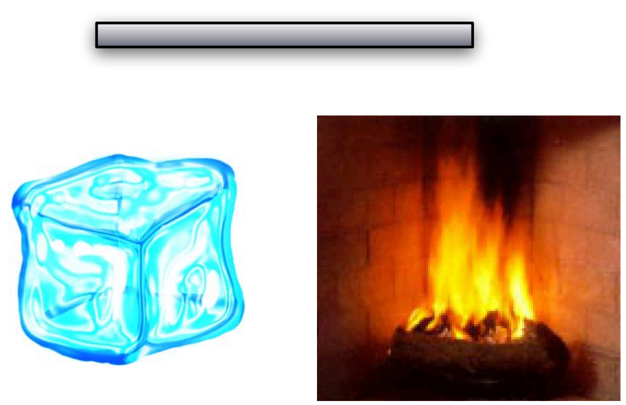
Intensity of Quality

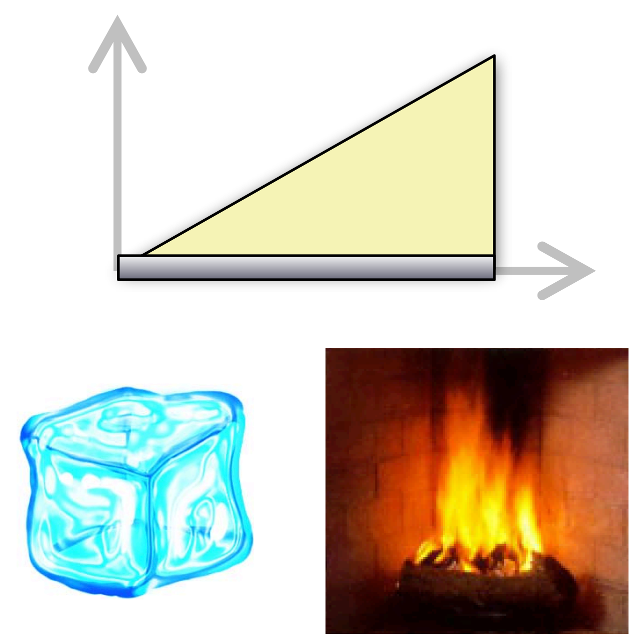
&

Quantity of that Quality


difformis vniformiter variatio reddit vnifor lisp. et fiat ad in
miter difformiter difformem. ¶ Latitudo vni
formiter difformis est illa que inter excessus graduum
eque distantium seruat eandem proportionem a... proportionis equalitatis. Nam si inter excessus graduum
inter se eque distantium seruarent proportionem equalita-
tis ... esset latitudo vniformiter difformis ut patet ex
diffinitionibus membrorum secunde diuisionis
Rursus si nulla proportio seruatur tunc nulla
posset attendi vniformitas in latitudine tali et
sic non esset vniformiter difformis difformis
¶ Latitudo difformiter difformiter difformis
est illa que inter excessus graduum eque distantium
non seruat eandem proportionem sicut in se
cunda parte patebit. Notandum tamen est
quod sicut in supradictis diffinitionibus ubi loquitur
de excessu graduum inter se eque distantium
debet accipi distancia secundum partes latitudinis
extensiue et non intensiue ita ut loquuntur de ... dif
finitionem de distantia secundum duas similes ... gradualis

“EXTENSION” OF THE INTENSITY





a “motion,” remember?

LOCOMOTION

For Aristotle:

distance & time were quantifiable

not speed

LOCOMOTION

for Oresme

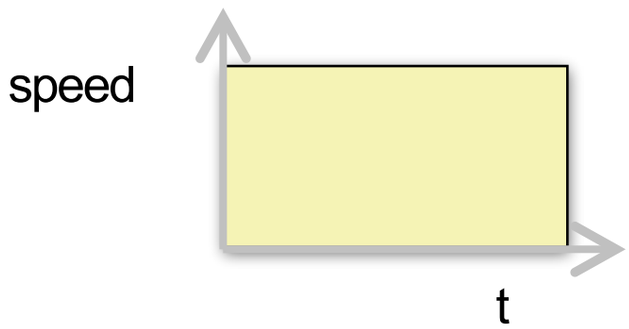
like temperature is Intensity of heating

speed is an Intensity of Locomotion

DISTANCE

"Total Quantity" of Motion…how far

the *area* of the graph

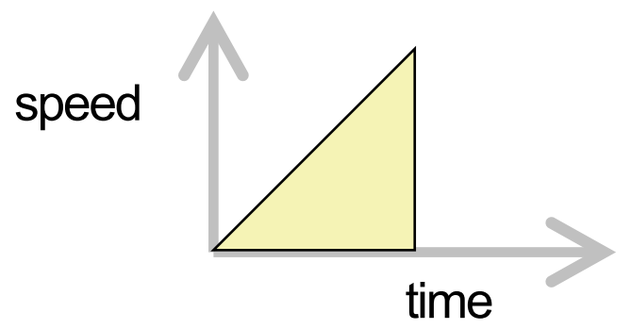


OXFORD'S MERTON SCHOOL

almost...acceleration

“UNIFORMLY DIFFORM” MOTION

uniform *increase* in speed in time



FALLING BODIES:

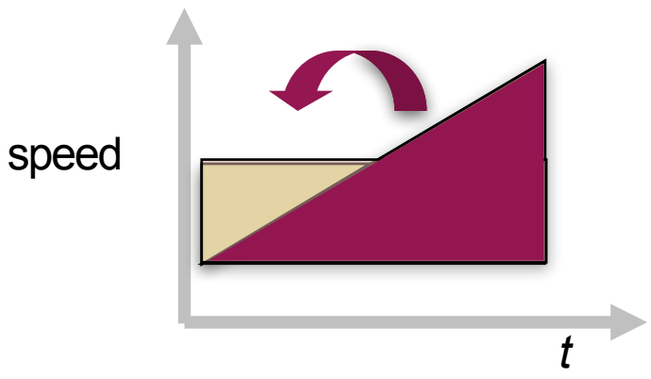
something about the object increased

impetus active in natural motion?

MERTON MEAN SPEED THEOREM

Suppose an object undergoes uniformly difform motion…the Merton mathematicians argued that the distance traveled is the area…

By construction, they found that area by breaking the triangle into a rectangle of height equal to the midpoint…
two graphs, two kinds of motions, one constant, one difform - equal distances



Two motions: uniform and difform...related by the average speed

DESCRIPTION OF MOTION

geometrical

graphical

mathematical in spirit

brand new

BUT: NO MEASUREMENTS

no “why”

BUT WAIT

Oresme was not done

“…if a stone is thrown vertically…it would be rapidly carried to the east “together with the air through which it passes and with all the mass of the lower part of the World”…which participates in the diurnal motion. The stone links its motion with that of the Earth, which gave it impetus to move with it.

Oresme, 1300’s

“If a man were placed in the Heavens, suppose that he were moved with a diurnal [daily] motion...it will seem to him that the Earth is moved diurnally [daily] just as, to us on the Earth, the Heavens seem to move. And similarly, if the earth is moved with a diurnal motion and the Heavens not, it will seem to us that the Earth is still and that the Heavens move.

Oresme

bingo

3 MEDIEVAL CRACKS IN ARISTOTLE'S ARMOR

1. projectiles

2. speed as quantity

3. stationary earth

I lied fourth:

4. incorruptible heavens?

BACK TO OUR GUY

GALILEO'S EDUCATION

irredemably Scholastic

Aristotle all the way down

inseparable from the Church

with a smattering of neo-Platonism

SIGNIFICANT PATRONS

Francesco Maria Bourbon del Monte Santa Maria (1549 – 1627)

Marchese Guidobaldo del Monte (1545 – 1607) Montebaroccio Estate, Urbino

Christopher Clavius, S.J. (1538 – 1612) Jesuit Collegio Romano

BETWEEN 1585 AND 1589

tutored mathematics Florence and Sienna

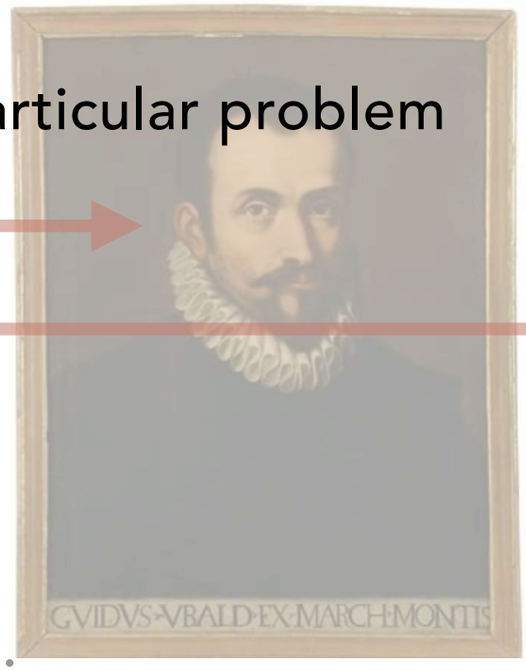
invents hydrostatic balance, "*Little Balance*"

heavily indebted to Archemides and Euclid

1587: centers of gravity – worked on proof of a particular problem

correspondence… Guidobaldo del Monte

visits Rome…meets with Clavius



1588

worked with Dad: tension/pitch for lute strings

applied for multiple academic mathematics positions

invited lectures to Flourentine Academy: shape, size, dimensions of Dante's Hell

1589 Professor of Mathematics at…University of Pisa

the absolute lowest academic position at any medieval/rennaissance university

Philosophy Professor – that's the pinnacle with the $

U OF PISA PROFESSOR

UNIVERSITY OF PISA

Pisa was a backwater and only recently upgraded by Cosimo de' Medici

600 students, 2/3 were reading law

Galileo's mathematics professor incoming salary: 60 florins

Jacopo Mazzoni, philosophy professor incoming salary: 700 florins

battle raged between two philosophers:

Girolamo Borro & Francesco Buonamici: critical of Aristotle's physics

separately critical of Aristotle

de motu

ULTIMATELY, G'S "JUVENALIA"

De motu unpublished

took the title of Borro's massive book, *De motu:*

threw a hunk of wood and lead ball out of his upper house window

Galileo's De motu was a confused mix of Aristotle and new

scathing in his opinions of other faculty:

> “Men are like wine flasks…Go to a tavern. Look at the flasks, before you drink red wine. Some bottles don't have much decoration on them. They're dusty and naked to the bone.... But full of such wine that people rhapsodize upon it, calling it glorious and divine. Then look at the other bottles with the handsome labels. When you taste them, they are full of air or perfume or rouge. These are bottles fit only to pee into!"
>
> Galileo to an assembly of his students

BYE BYE!

after 3 years gone from the University. good riddance.

HELLO!

University of Padua professor
& collector of friends in Venice


Padua
Venice
Pisa
Florence
Rome
~150 miles
North Sea
Baltic Sea
Ligurian Sea
Tyrrhenian Sea
Adriatic Sea
Mediterranean Sea
Glasgow
Edinburgh
Dublin
Manchester
London
IRELAND
UNITED KINGDOM
NETHERLANDS
Hamburg
Bremen
Berlin
DENMARK
Copenhagen
LATVIA
LITHUANIA
Vilnius
POLAND
Dortmund
Köln
Leipzig
BELGIUM
GERMANY
Frankfurt am Main
LUXEMBOURG
CZECHIA
Paris
Stuttgart
Munich
SLOVAKIA
AUSTRIA
LIECHTENSTEIN
FRANCE
SWITZERLAND
HUNGARY
Geneva
SLOVENIA
ROMANIA
CROATIA
Belgrade
Genova
SAN MARINO
MONACO
Marseille
Sarajevo
SERBIA
ITALY
ANDORRA
MONTENEGRO
Sofia
BULGARIA
Rome
NORTH MACEDONIA
SPAIN
Zaragoza
ALBANIA
Madrid
PORTUGAL
GREECE
Lisboa
Athens
Algiers
Tunis
GIBRALTAR
Oran
MALTA
Sanremo
MONACO
Grasse
Antibes
Cannes
Aix-en-Provence
Fréjus
Marseille
Toulon
Bastia
Ajaccio
Piombino
Grosseto
Livorno
Rosignano Marittimo
Siena
Pisa
Camaiore
Lucca
Pistoia
Prato
Empoli
Arezzo
Poggibonsi
Città di Castello
Gubbio
Perugia
Assisi
Val d'Orcia
Viterbo
Terni
Rieti
Spoleto
Ascoli Piceno
Macerata
Fermo
San Benedetto del Tronto
Pescara
L'Aquila
Teramo
Chieti
Lanciano
Vasto
Termoli
Sulmona
Avezzano
National Park of Abruzzo, Lazio and Molise
Guidonia Montecelio
Frosinone
Cisterna di Latina
San Severo
Campobasso
Senigallia
Ancona
Jesi
Osimo
Pesaro
Rimini
Cervia
Ravenna
Lugo
Forlì
Imola
Zadar
Karlovac
Trieste
Treviso
San Donà di Piave
Schio
Valdagno
Vicenza
Brescia
Verona
Lodi
Cremona
Mantova
Rovigo
Porto Viro
Ferrara
Parma
Reggio Emilia
Modena
Sassuolo
Bologna
La Spezia

PADUA IS WHERE HE WORKED

Venice is where he played

GALILEO'S PADUA

PISA WAS THE WARM-UP

all of his scientific work was done at Padua

mechanics

astronomy

UNIVERSITY OF PADUA

18 years

popular professor

all of his mechanics

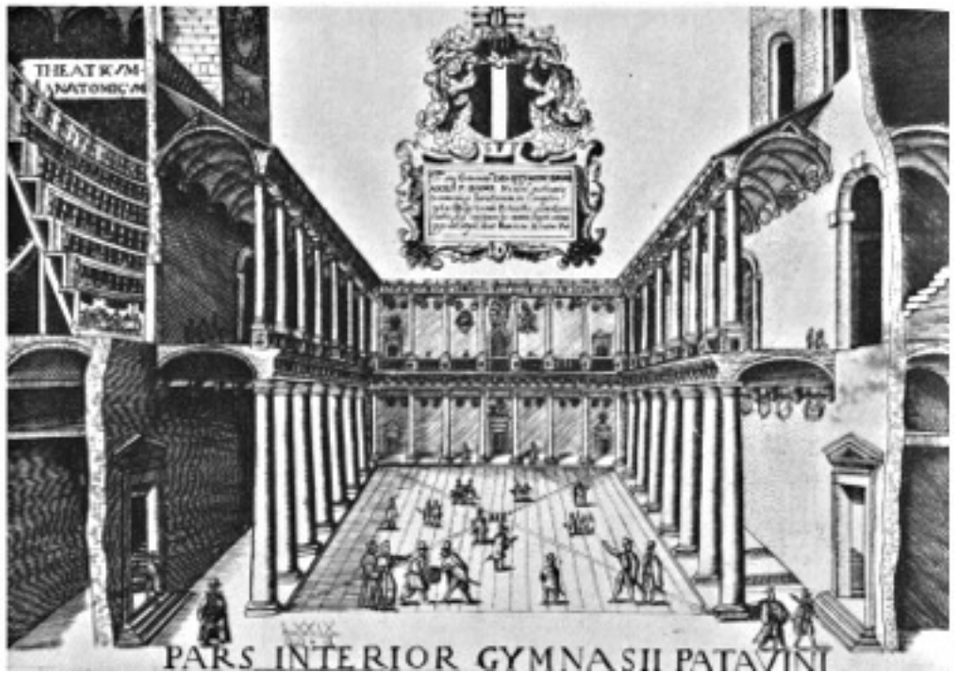
his first telescopes

Family

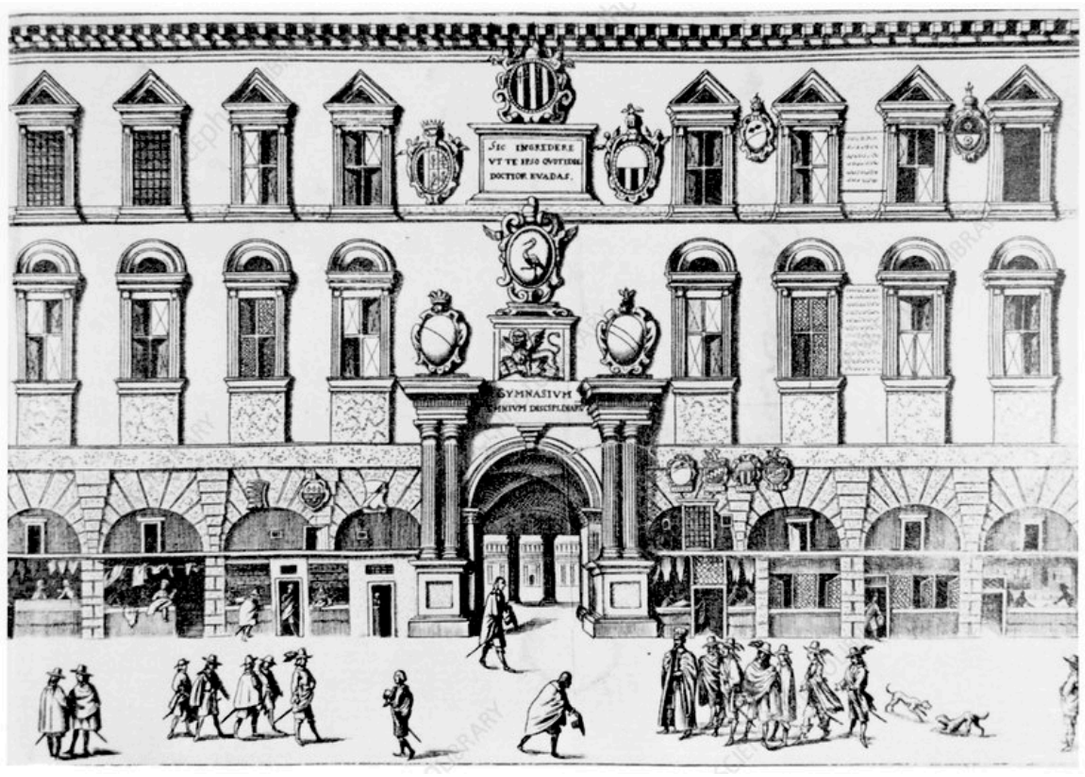
awful financial pressures

1222

“Bo”


PARS INTERIOR GYMNASII PATAVINI


Prospetto dell' Università di Padova
detta Volgarmente il Bò
JO. BAPTISTAE. ZAGERAE. PAULI. F.
Veduta de l' Università de Padova
appellata Communemente lo Bovo
PATAVITII. PATAV. EGREGIO. BONARUM. ARTIUM. CULTORI


SIC INGREDERE
VT TE IPSO MELIOR
DOCTIOR EVADAS

GIANFRANCESCO SAGREDO
(1571–1620)

"I am a Venetian Gentleman. I have never called myself one of the literati, but hold dear the protection of the literati.

My palace in Venice has often been compared to Noah's ark, partly because of its shape, partly because inside I keep all manner of beasts. As a bachelor, I spend my time in conversation."

Galileo had … appetites…and Venice was perfect

1866

“IS YOUR REFRIGERATOR RUNNING?”

Galileo and Sagredo pranked the stuffy

A series of letters to a Venetian Jesuit from a fake noble woman concerned about her religious commitments

A series of letters to one of G’s UPadua mathematician colleagues with a series of fake questions

which the pompous professor answered incorrectly

MARINA GAMBA

Born around 1570 in Venice

Much speculation…possibly a courtesan (200 or so in Venice)

1600: "Virginia, daughter of Marina of Venice, born out of wedlock on August 13th, was baptized by me Giovanni Viola."

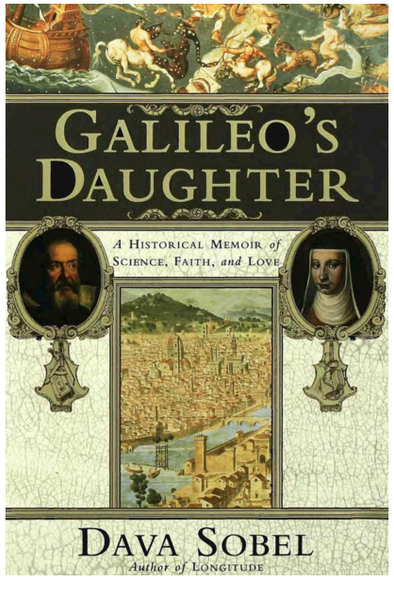
→ Sister Maria Celeste

Convent of San Matteo, Arcetri

1601: "Livia Antonia, daughter of Madonna Marina of Antonio Gamba and of …[sic], was baptized by me Clemente Tisato, rector of San Lorenzo."

→ Sister Arcangela

1606: "Vincenzo Andrea, son of Madonna Marina daughter of Andrea Gamba, father unknown, was baptized by me Father Angelo."



they lived together in Padua

1610 when he moved to Florence: girls came with him, son followed

Marina later married and lived her life…maybe, again, confusion

MONEY ALWAYS AN ISSUE

Still paying for sisters' dowries…a lawsuit from brother in-law

invented a military compass

hired a live-in machinist to make it

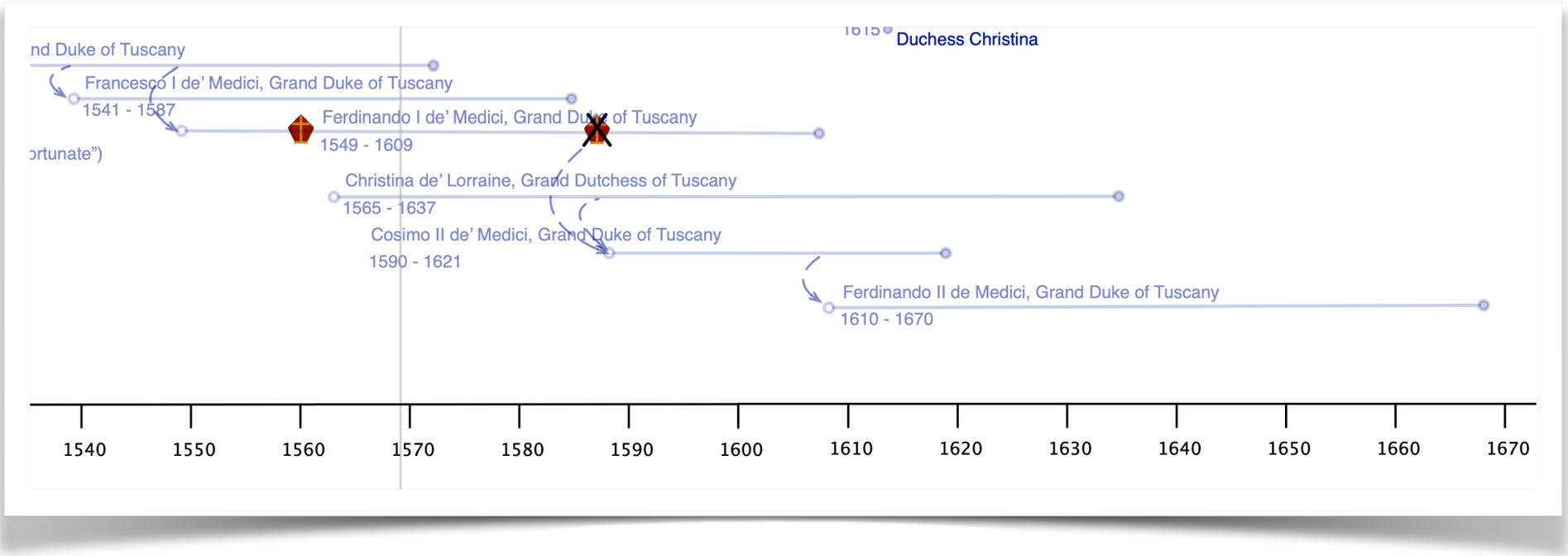
sold a manual, taught young military aristocrats how to use it

took in many student boarders

AND HE CULTIVATED THE DE MEDICI'S

brought back by Christina of Lorraine

to teach Cosimo II every summer



KINEMATICS, ASTRONOMY, AND THAT TRIAL

kinematics

not dynamics – he was uninterested in cause

IMPORTANT PHYSICS CONSIDERATIONS

pendulum

free fall

uniformly accelerated motion

projectiles

materials science

THE CHRONOLOGY IS ARUGED ABOUT TODAY

what did he do at Pisa?

when did he do what he did at Padua?

his “reports” are in his much-later books

Pisa: 1589-1592…maybe: pendulum, falling bodies, inclined plane?

Padua: 1592-1610: certainly: pendulum, falling bodies, inclined plane, projectiles, relativity

Florence, active 1610-1634: Dialogue Concerning the Two Chief World Systems, *1630*

Arcetri, house arrest: Discourse on Two New Sciences, *1638*

GALILEO SCHOLARSHIP

400 years in the making

Vincenzo Viviani (1622–1703)

“last student”

first biography - made up stuff!

preserved papers -> nephew, nephew of nephew…discarded 1737

Giovanni Battista Nelli, in 1750

by accident bought some meat for a picnic:

wrapped in G’s notes!

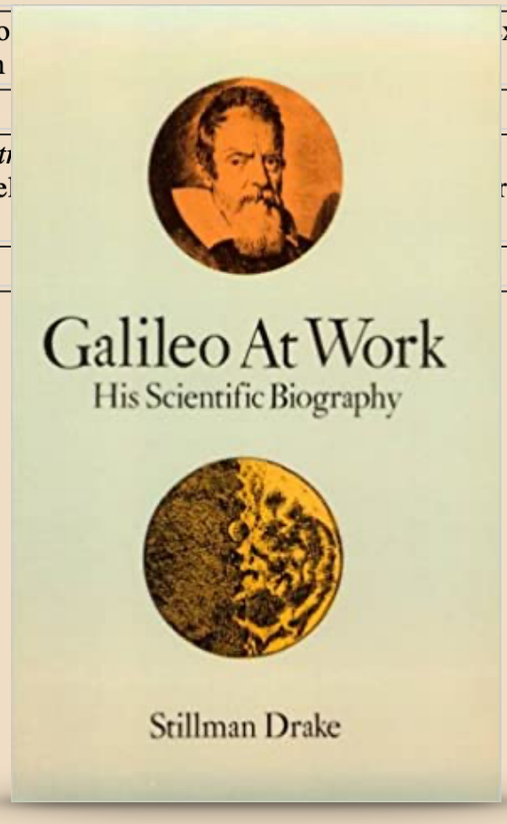
found a bin full of Vivani’s original collection

Antonio Favaro: national edition of Galileo’s works

now: https://www.mpiwg-berlin.mpg.de/Galileo_Prototype/INDEX.HTM

Size	Height 270 mm, width 210 mm.
Watermark	Two watermarks. Unicorn with 4 legs, little circle on top of the forehead. Crown with encircled cross. Drake's identification: Watermark type 3. Drake's description: Mountains below cartwheel 30mm; overall height 53mm.
Comments	Written by Galileo; contains texts, drawing, calculation. Relation to the *Discorsi:* work on 3/07-th-04.
References	Wisan 1974 269; Caverni 1972 534-538; Damerow et al. 1992 213-219, 223, 350-352; Drake 1990 18; Wohlwill 1899 621; Drake 1987 42; Renn 1990 102

Folio 90 r (final text)	
1A	Cadens ex *a* in *c*, conversus, describit parabolam *cd*; si vero momentum velocitatis in *c* duplum foret, describeret parabolam *ce*, cuius *eg* dupla esset ad *gd*: impetus enim duplus in *c* permeat in orizonte duplum spacium tempore eodem. Sed ut acquiratur in *c* momentum duplum, necesse est casum fieri ex [quadru]pla altitudine, nempe ex *cb*. Pariter, ex altitudine [quadru]pla ad *cb* describetur parabola *cf*, cuius amplitudo *gf* [du]pla est ad *ge*.
1B	Verum mobile in *d* videtur supra impetum in *c* addere impetum acquisitum per parabolam *cd*, quod respondet altitudini *cg*. Mobile vero in *e* idem momentum addit supra impetum quem habuit in *c*, qui erat [du]plus ad impetum alterius mobilis; ergo impetus mobilis in *e* videtur esse sexquialterus ad impetum mobilis in *d*. Similiter invenietur impetum in *f* ad impetum in *e* esse ut 5 ad 3.
1C	In elevatione igitur *ea* si proiectum habuerit impetum sexquialterum ad impetum in *d*, proiecti secundum elevationem *da* proiicientur secundum parabolas *ec*, *dc* intra easdem parallelas, sed dixtantia *eg* dupla erit ad *dg*.
2A	Impetus in *c* cadentis ex *a* sit 100 cadentis ex *b* erit 200 impetus in *d* erit 200 impetus in *e* erit 300.
2B	Cadentis in *a* ex *h* impetus in *a* erit 141; conversi vero per parabolam *ae* impetus in *e* erit duplicatus, nempe 282. Constat igitur, maiorem esse impetum venientis per parabolam *ce* in *e*, quam venientis per parabolam *ae*. Et si proiectum ex *e*, secundum elevationem *eh*, habet impetum ut 282, conficiet parabolam *ea*; secundum elevationem vero *ea* conficiet proiectum parabolam *ec*, si habuerit impetum ut 300. Ergo in elevazione [elevatione] semirecti *eh* ab eadem vi longius eiaculatur, quam in elevatione *ea*, quae minor est semirecto.
3	Impetus in *f* est 500, venientis per parabolam *cf*. Venientis vero … x quo patet etiam, longius eiaculari ab eadem vi per elevationem …
4	Impetus in *c* ex *s* erit 50; in *r* erit 150.
5	Impetus vero in *t* ex *c* est fere 70 1/2; conversi per parabolam *t*… r venientis ex *s* per *c* in *r*, qui fuit 150. Unde consta[t], quod in e… fit pr[o]iectio, quam per elevationem *rc*.
C01	sqrt 20000 = 141



I DECLARE BANKRUPTCY

Except for a handful of known events

I'll tell you what he did without trying to unravel the when

and the how

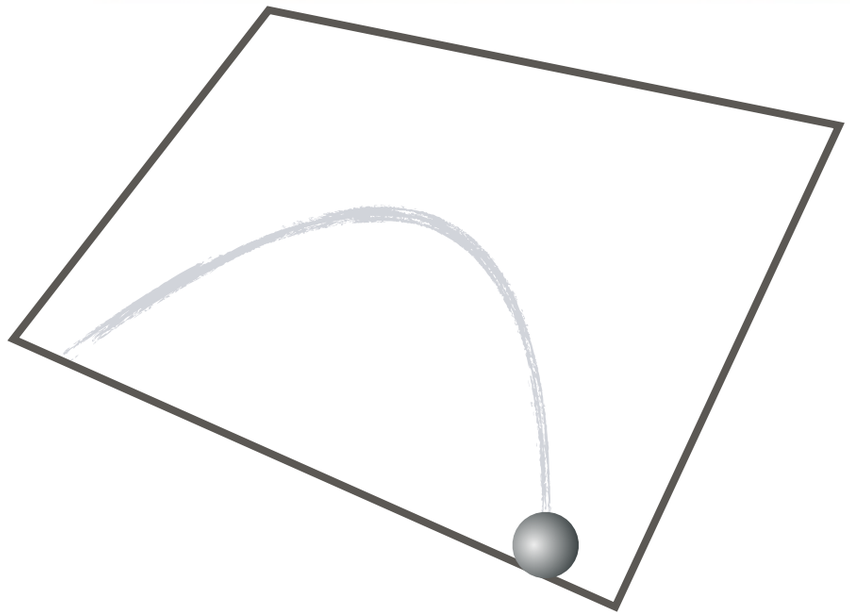
FUN WITH DEL MONTE

1592 guest in Urbino, in transit to Padua

rolled greased ball on incline

parabola

Del Monte? Galileo? Both?



stay tuned

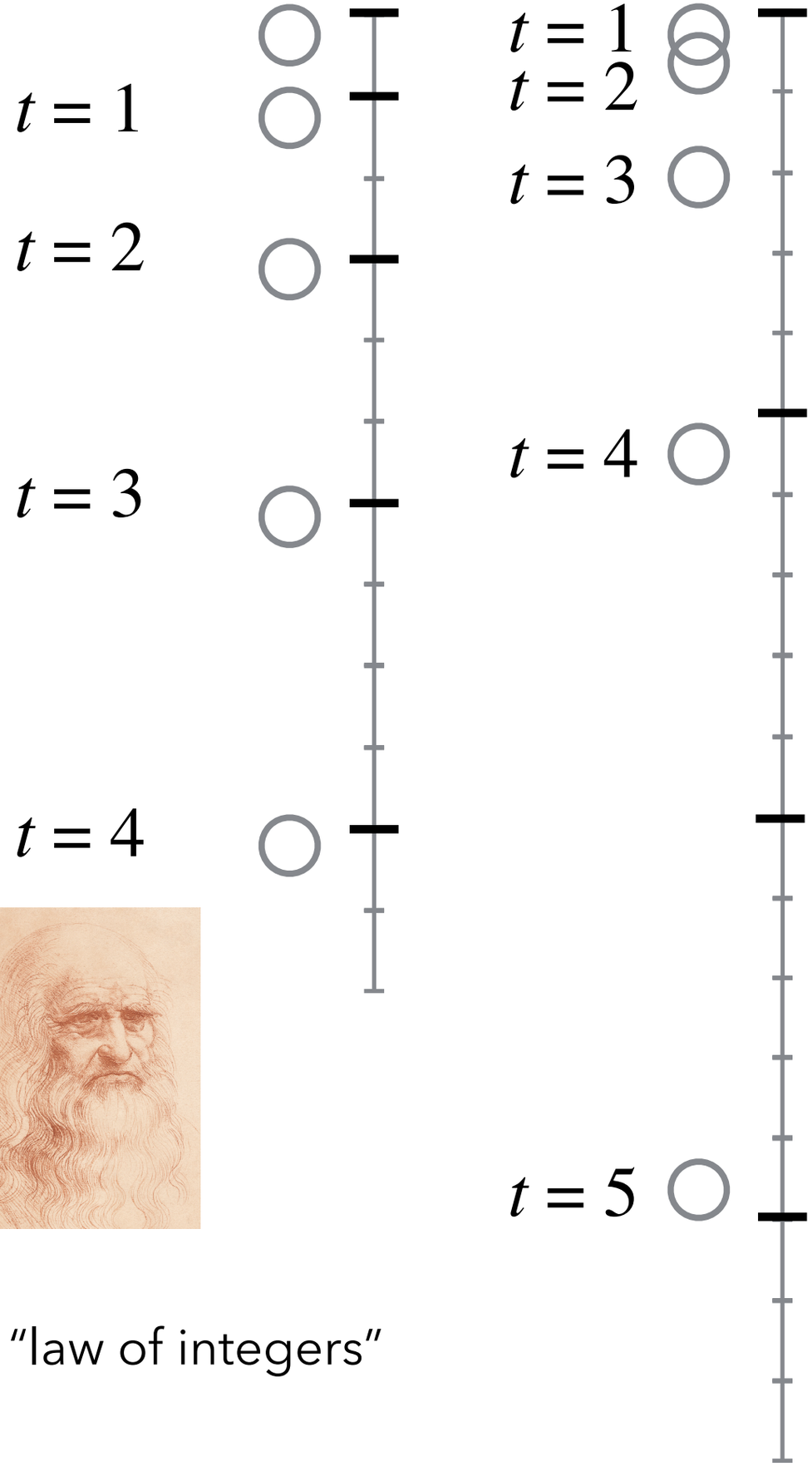
NOTE:

Galileo did amazing things

but

He did not have a system

that comes later



daVinci's "law of integers"

v proportional to distance

CONFUSED FOR A LONG TIME

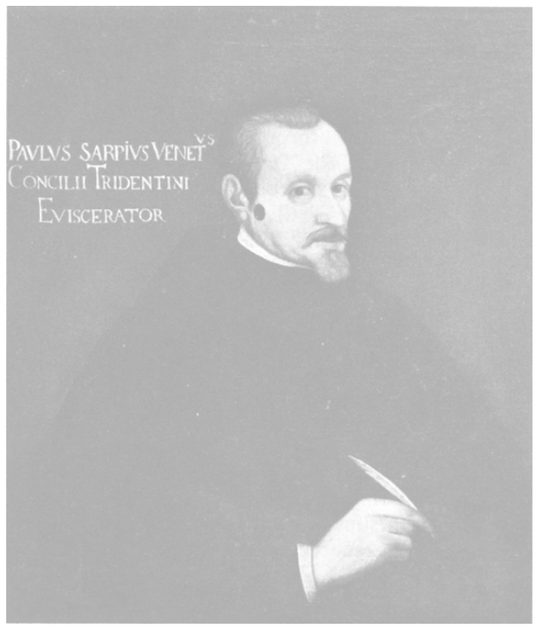
predilection for speed $\propto$ distance

confusing 1604 correspondence with Sarpi:

from $v \propto x$

he claimed that he "demonstrated"* $x \propto t^2$

which is impossible



Paolo Sarpi (1552-1623)

* means geometrically proved…

HOW TO EXPLAIN THIS?

for 3 centuries battle has raged:

did he do the inclined plane experiment before 1604?

discovered the t^2 relation, and

then badly try to prove it?

Stillman Drake: yup. ✓

did he ever do any experiments, ever?

Alexandre Kyore said no in the 1950s

He “couldn’t have” results too good…“thought experiments”

that led to Thomas B. Settle’s repeating of G’s described experiments 1960s-70s

confirmed G’s precision

> And thus, it seems, we shall not be far wrong if we put the increment of speed as proportional to the increment of time; hence the definition of motion which we are about to discuss may be stated as follows: A motion is said to be uniformly accelerated, when starting from rest, it acquires, during equal time-intervals, equal increments of speed.
>
> Third day: *Two New Sciences 1641*

that's new...not any longer equal time -> equal distance

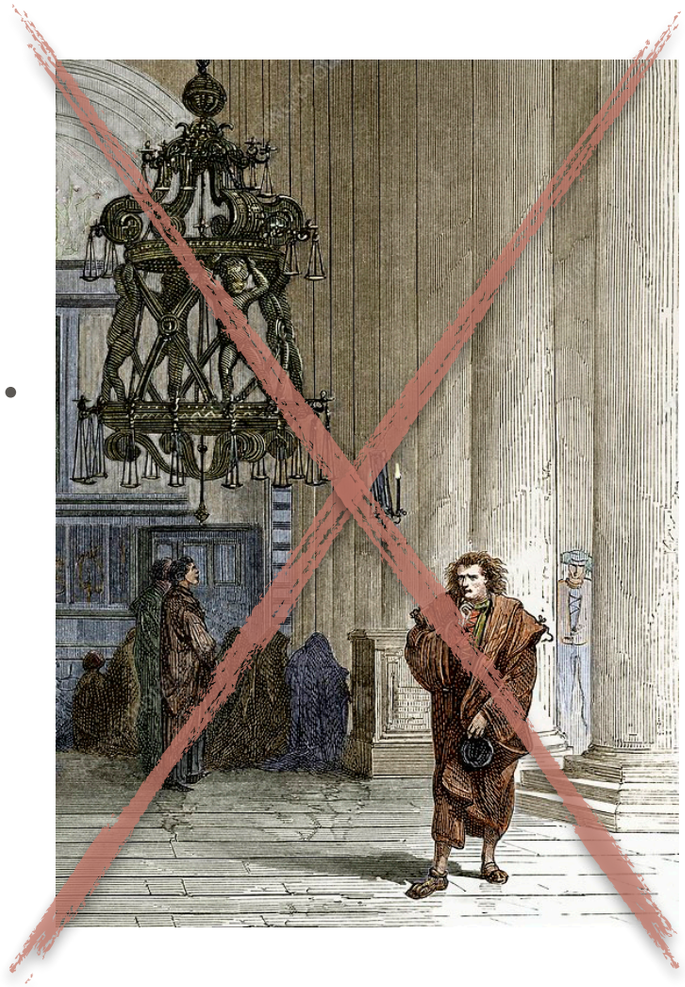
OKAY

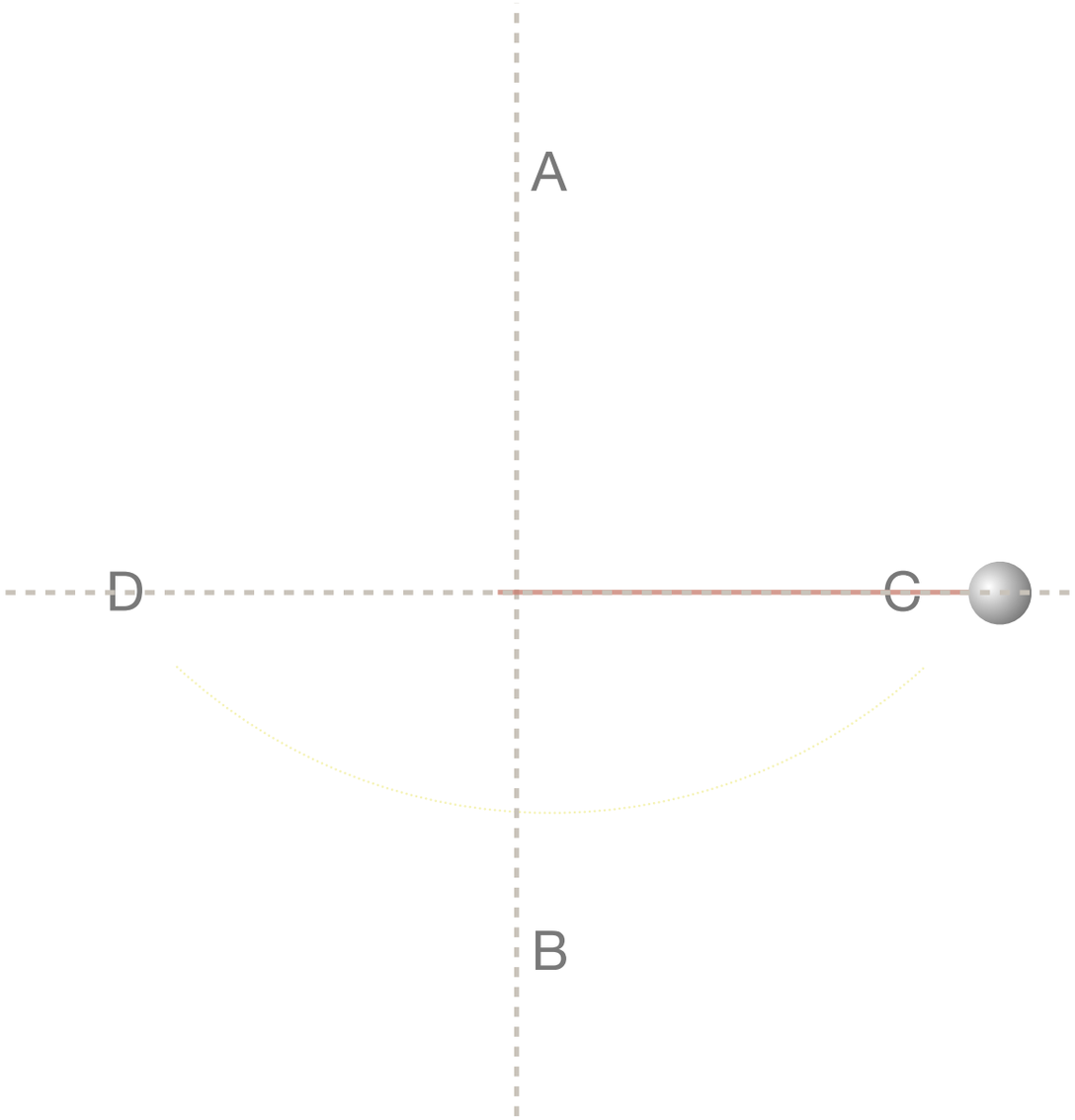
speed increases linearly with time.

So, what about distance and time?

GOES ROUND-ABOUT...

a pendulum





Salviati notes:

"Imagine that this sheet of paper is a vertical wall, that a nail is fixed in it and that a ball of lead weighing an ounce or two is hung from the nail by a thread AB. The thread is to be two or three cubits long, perpendicular to the horizon and at a distance of about two fingers from the wall.

Draw a horizontal CD on the wall to cut the thread AB squarely.

Draw aside the thread AB and the ball into the position AC. Then release the ball.

We will see this descend, describing the arc CB, and pass the extremity B in such a way that it will go up again, along BD, almost to the line CD which has been drawn.

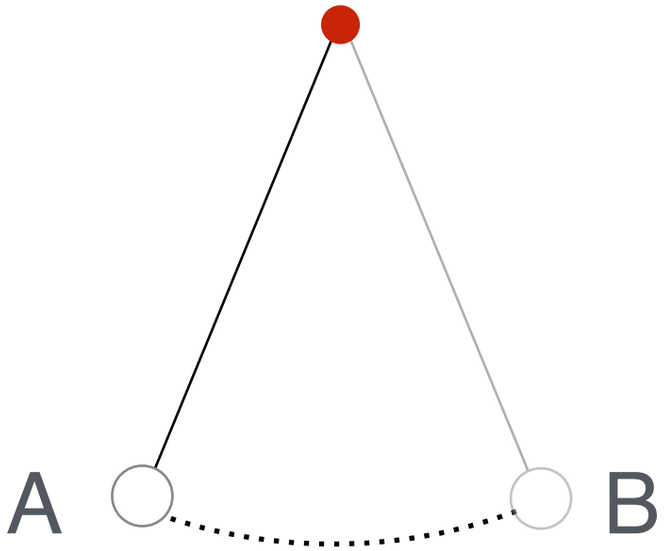
Each time there will be a small deficiency, and this circumstance is precisely due to the resistance of the air and of the thread.

From this we can conclude, in all truth, that the impeto at the point B which is acquired by the ball in its descent of the arc CB is such that it suffices to make it remount the identical arc BD to the same height....

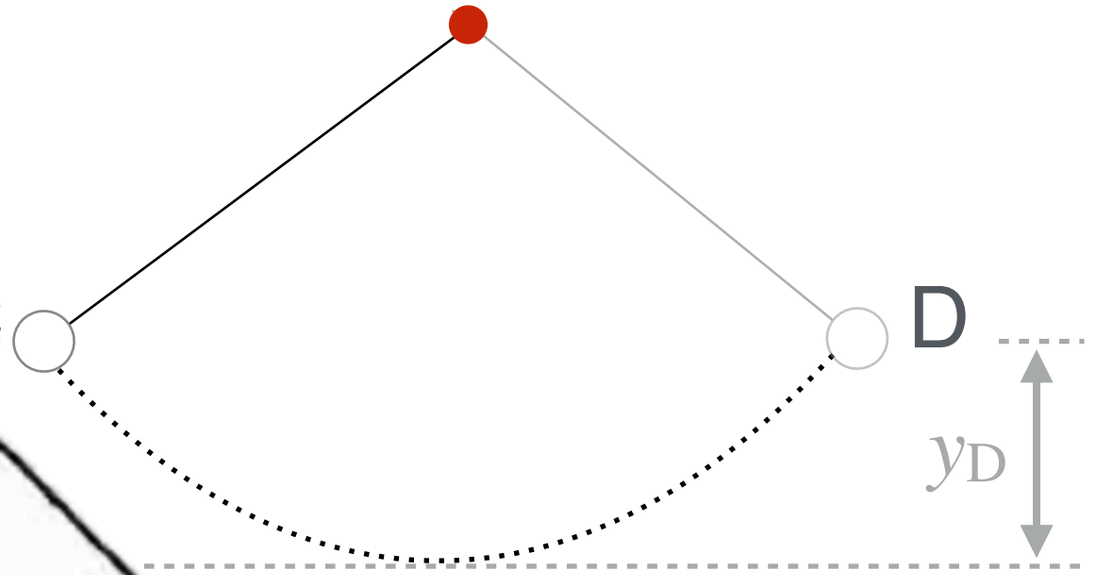
Since the two arcs CB, DB are equal and similarly placed, the momento acquired at B along CB suffices to make the same body rise again along BD."

NOW IT GETS GOOD.

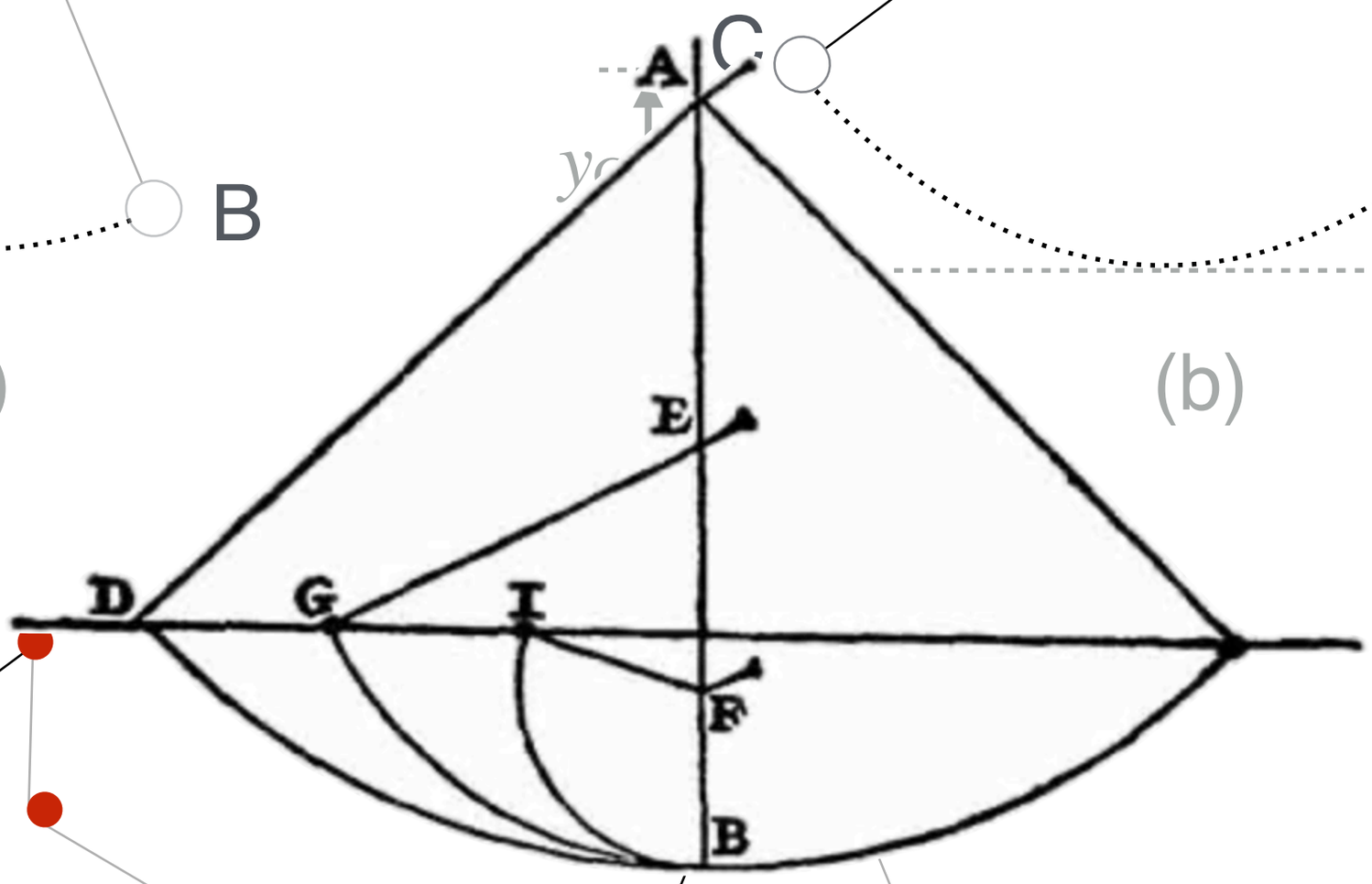
the pendulum is key to a lot

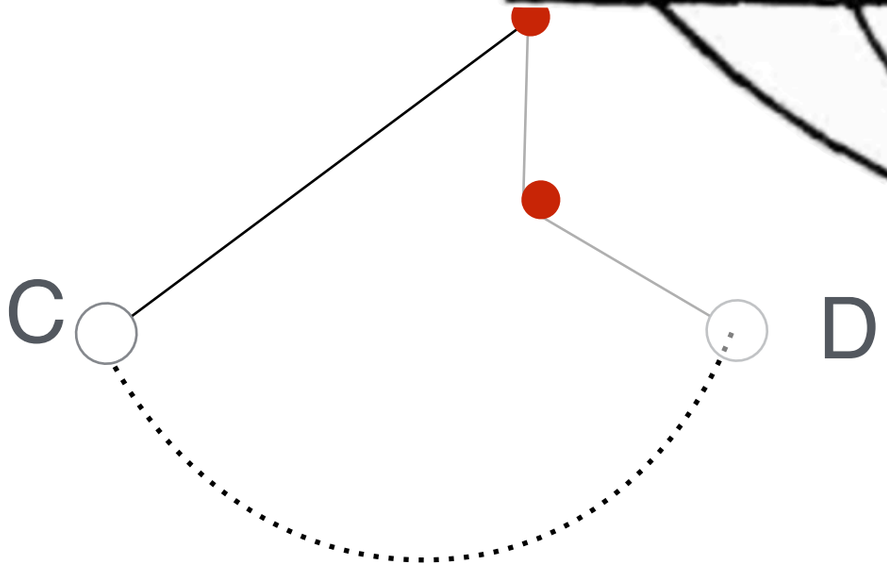


(a)



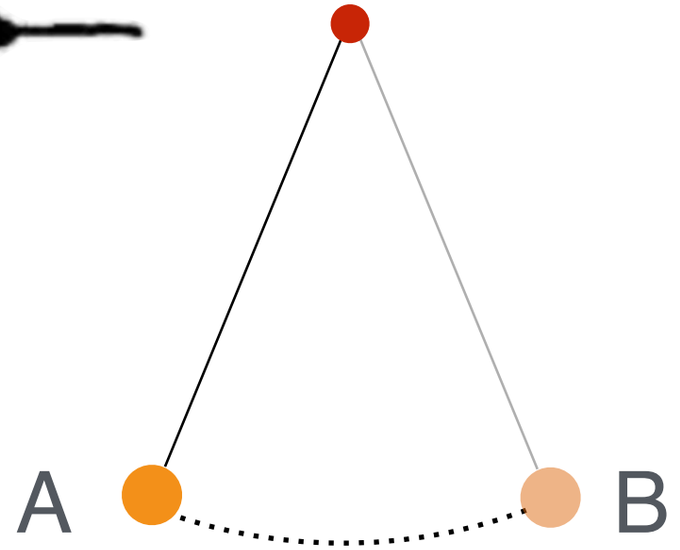
(b)





(c)

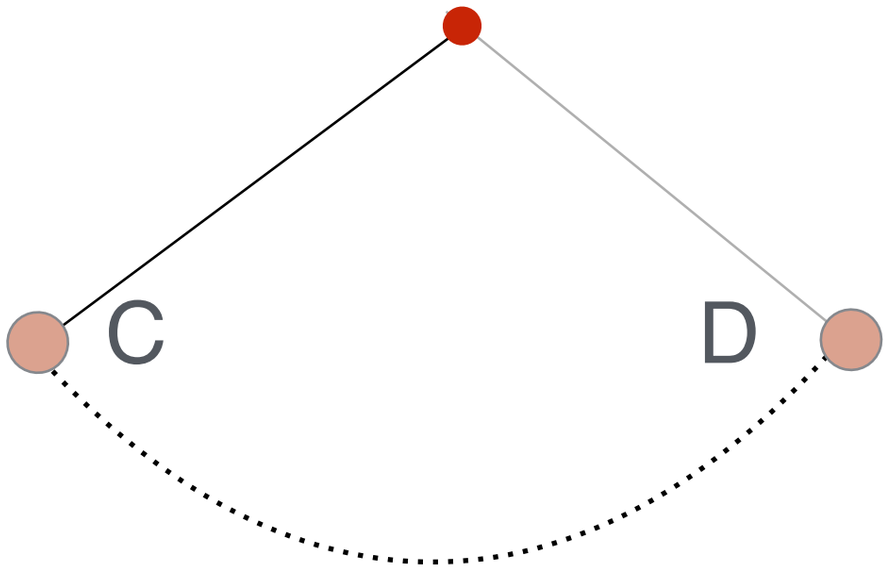
(d)



(e)

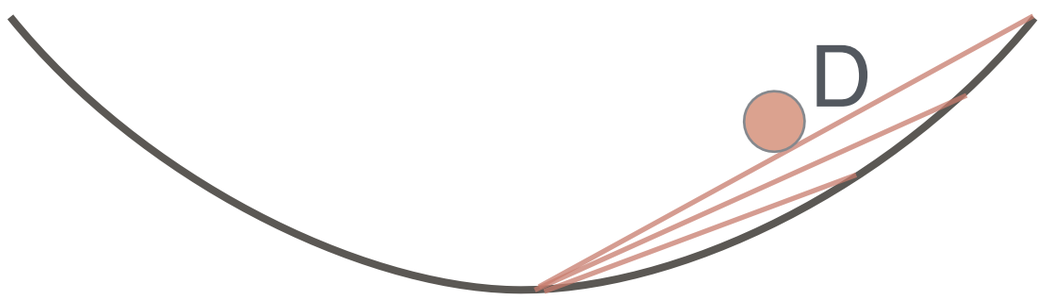
ROLLING INSIDE A BOWL

big argument with del Monte

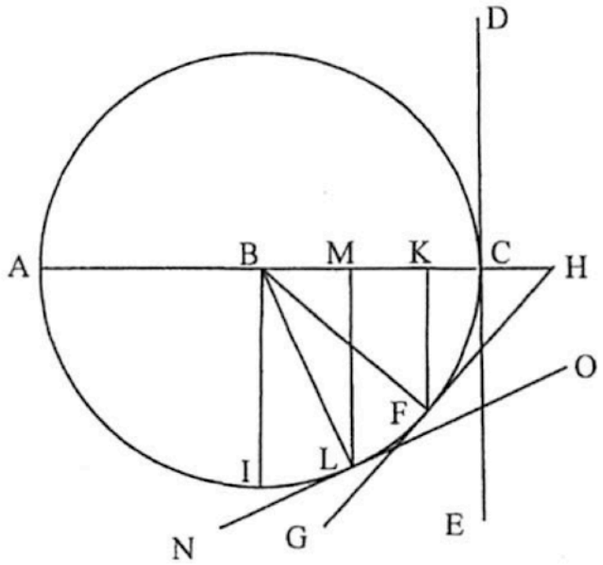


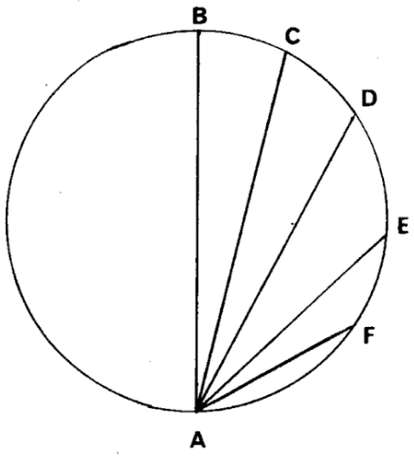
pendulum

rolling inside of a bowl



rolling down chords of a circle





free fall

MEASURING FALLING THINGS IS IMPOSSIBLE

too fast

no clocks

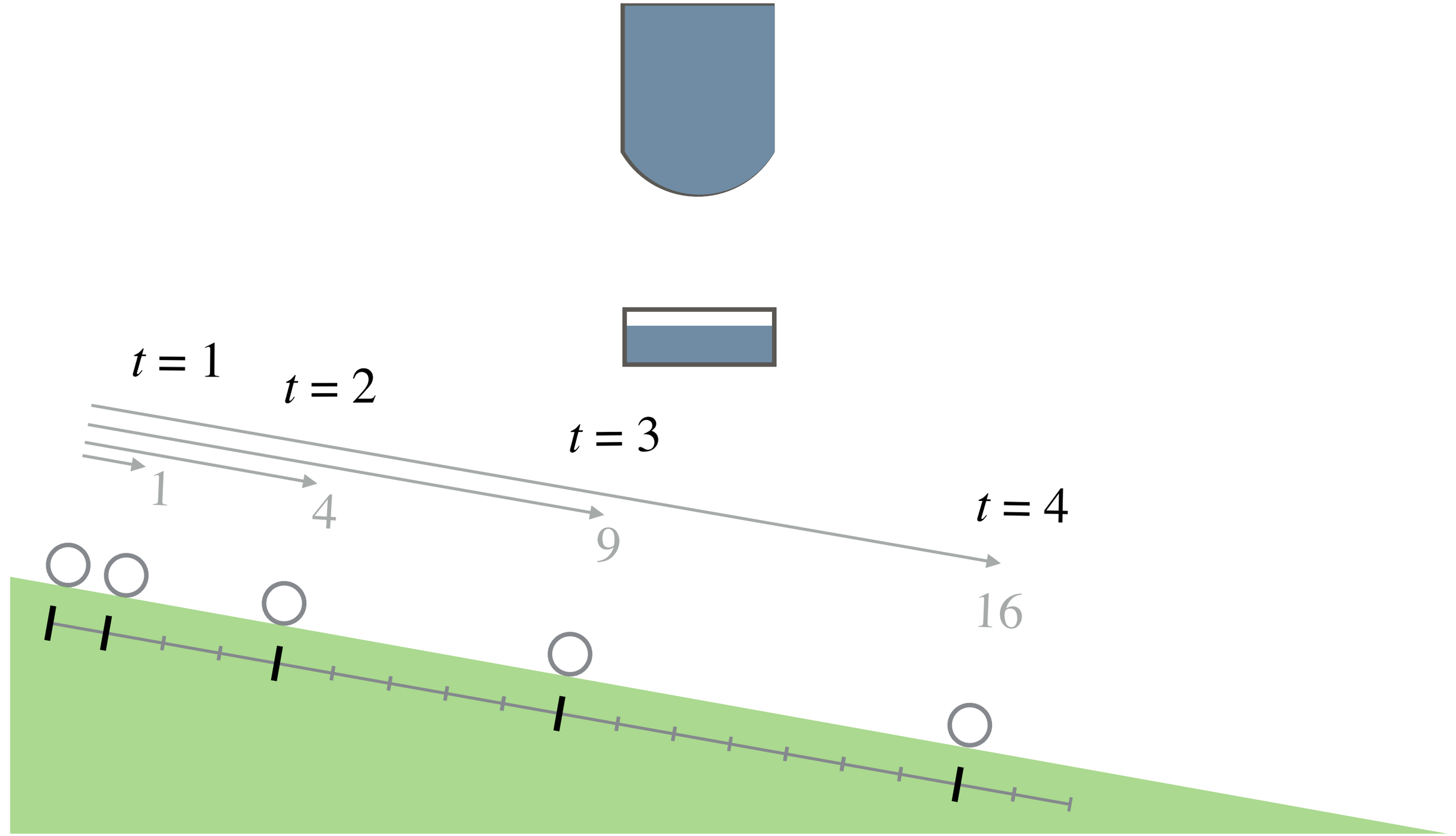
HE DILUTES GRAVITY

an inclined plane

to study vertical, falling motion

no clock

uses: pulse, music, invents a water-drip “clock”



What he called the **odd number rule** and could prove that…:

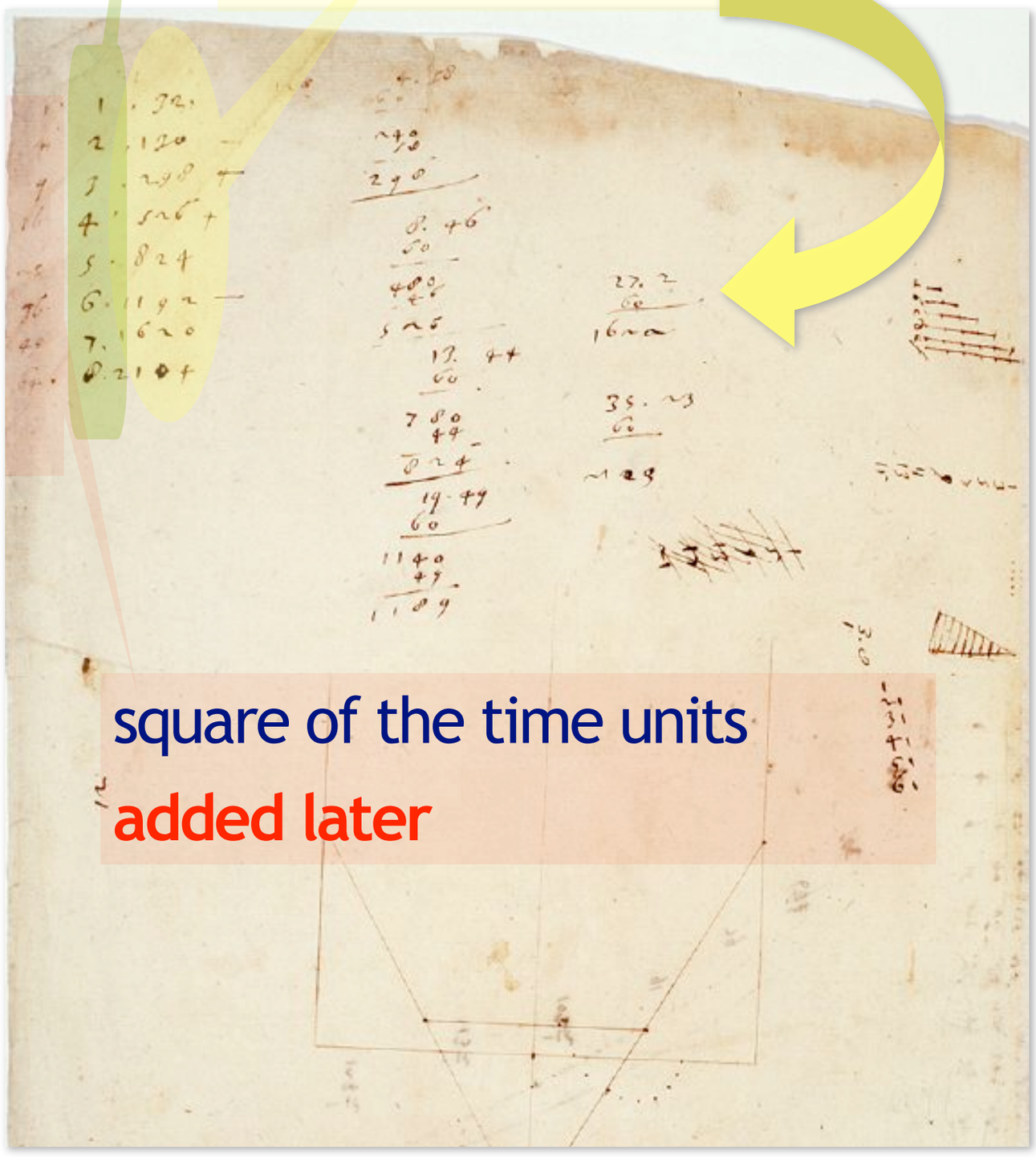
Therefore, he concluded that **freely falling motion is accelerated motion and uniformly accelerated.**

Did he know the Merton rule?

time units

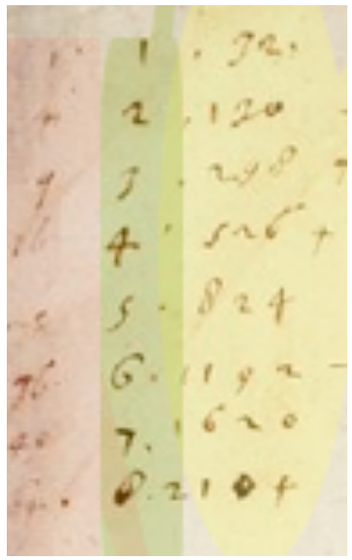
GOOD NOTEKEEPING!

distance data reduced from



square of the time units

added later

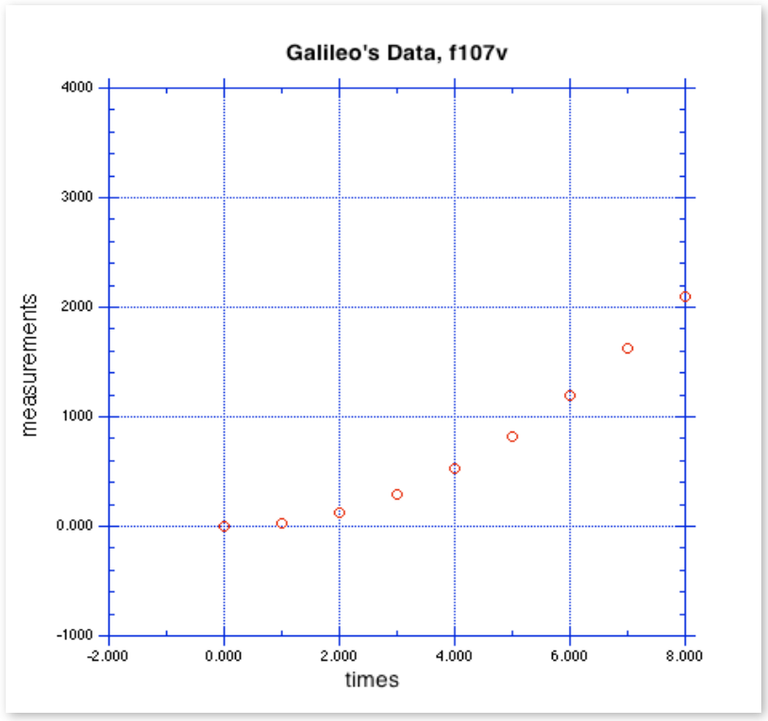


120/32 = 3.75

288/32 = 9

526/32 = 16.4

824/32 = 25.75

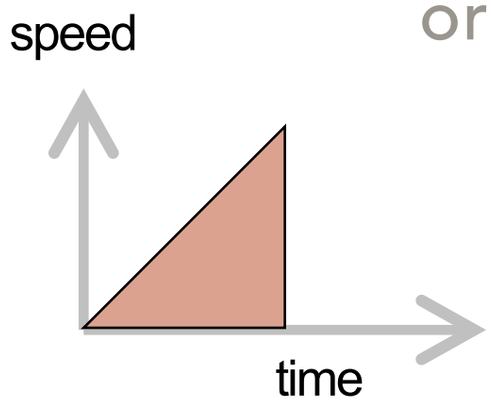


REMEMBER THE SPEED-TIME GRAPH OF THE MERTONS?

his odd number rule either:

rediscovers the Merton idea

or borrows the Merton idea



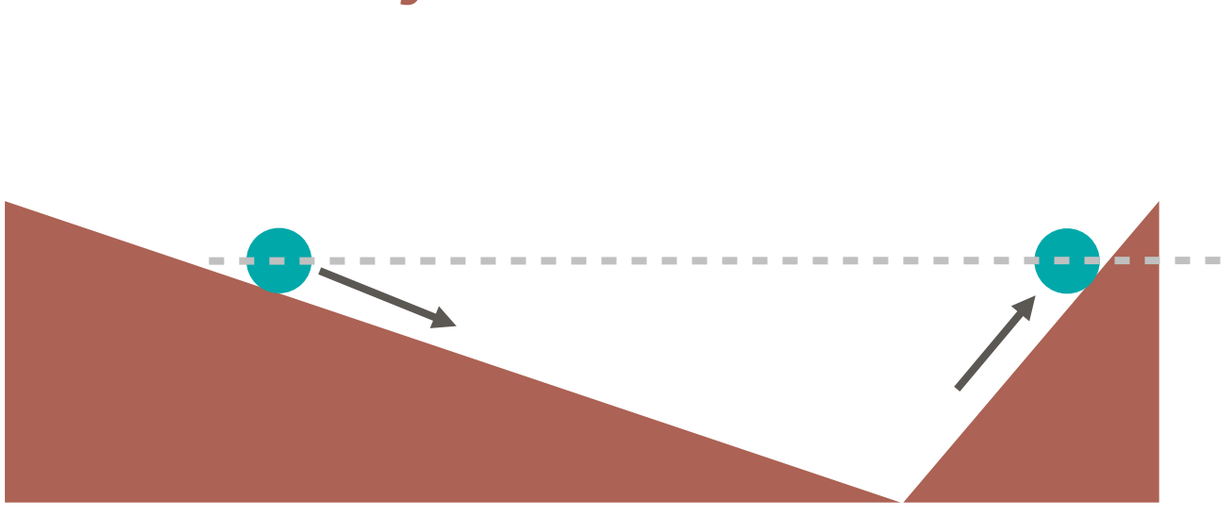
using that distance was the AREA

A WOW1 MOMENT:

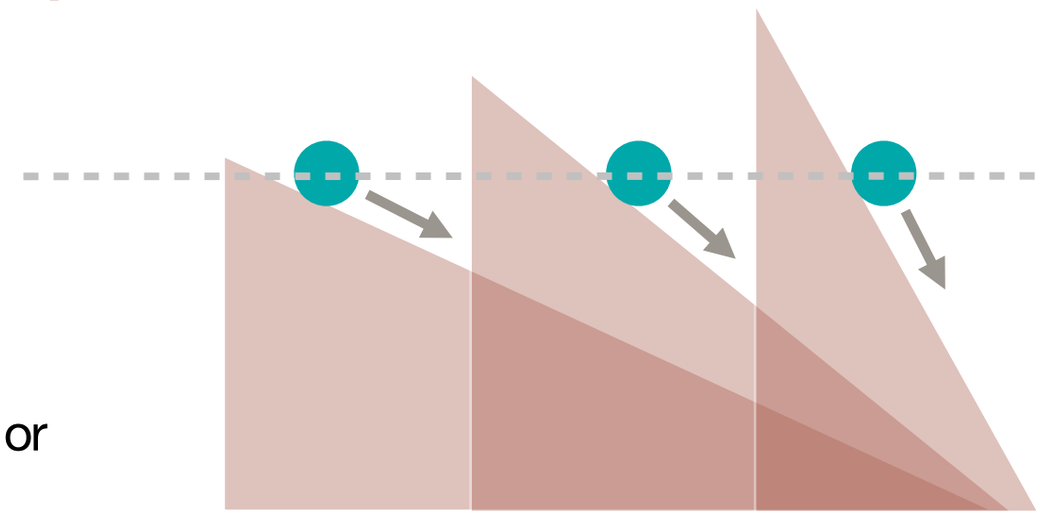
Since pendula go back up...this implies that the speeds at the bottom of the swing are the same, regardless of the length of the arc

as long as the vertical position is the same

Then, why not the same for inclined planes?

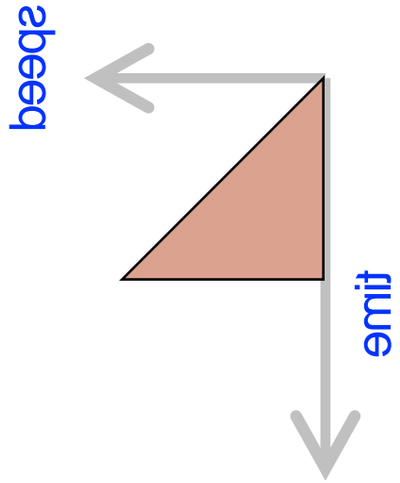


or



A WOW2 MOMENT:

He extrapolates to vertical: free-fall as an extreme inclined plane



counting up the areas:

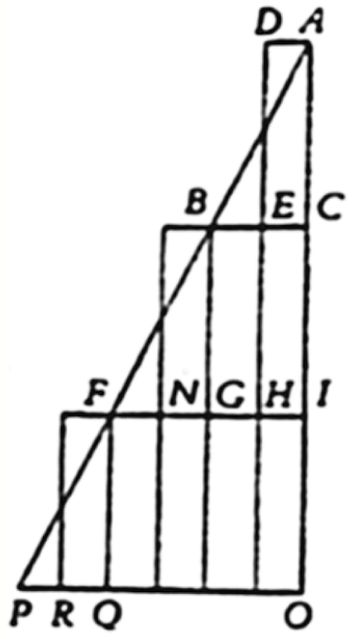
AD, time = 1, distance = 1 triangle's worth

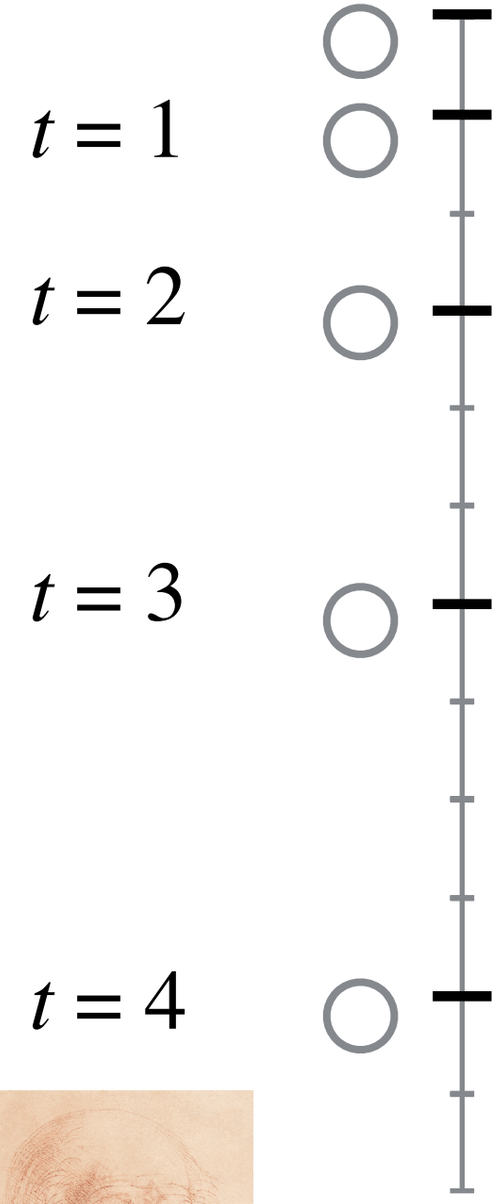
AE, time = 1+ 1 = 2, distance = 1 + 3 = 4

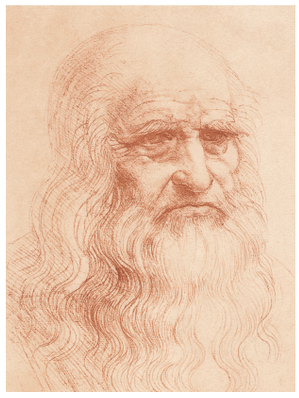
AF, time = 1+1+1= 3, distance = 1+3+5 = 9

AG, time = 1+1+1+ 1 = 4, distance = 1+3+5 + 7 = 16

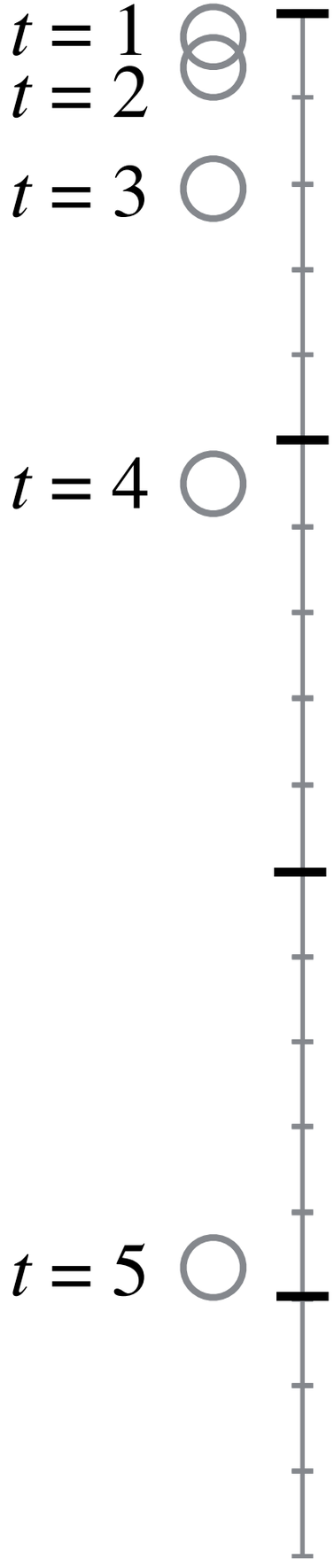
notice...the sums of the odd integers and the square relationship between time and total distance



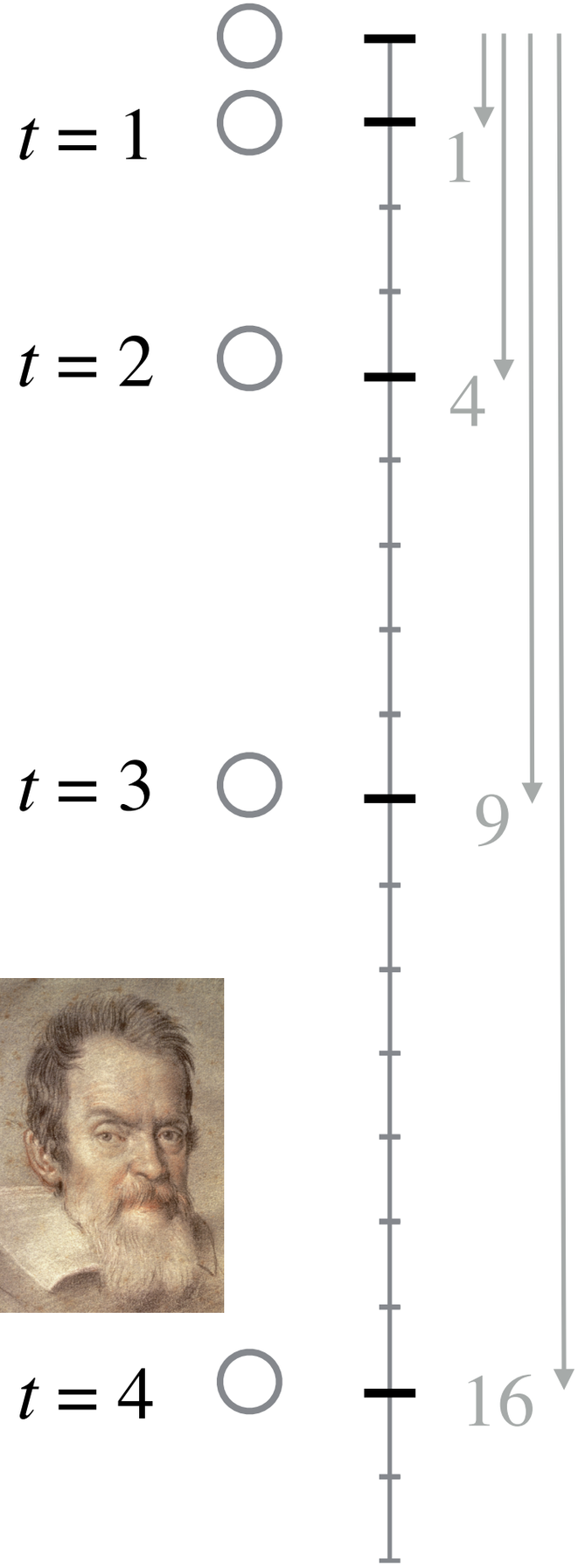




daVinci's "law of integers"



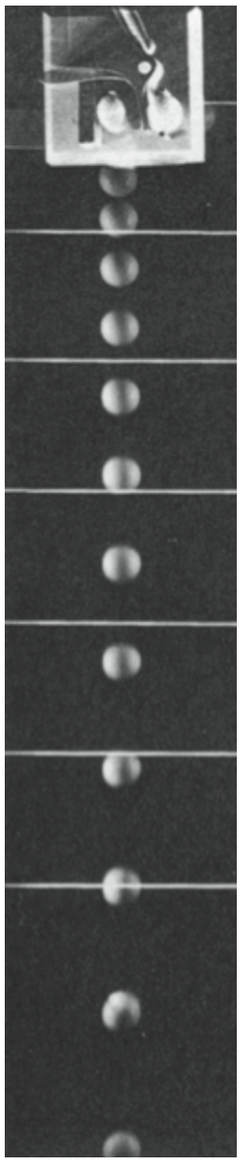
v proportional to distance



v proportional to time

NEAR THE EARTH

extrapolating to vertical fall...



From his ramp, Galileo's finding says, for a constant acceleration, the distance traveled is:

$$x = \frac{1}{2}at^2$$

He extrapolated to vertical drops.

Gravity near the Earth is a special acceleration!

little "*g*" is the symbol now used for the gravitational acceleration near the surface of the Earth.

$$x = \frac{1}{2}gt^2$$

$g = 9.8\ \text{m/s}^2 = 32\ \text{ft/s}^2$

HE DIDN'T "SAY" THAT

Galileo had:

no decimal points

no algebra

no trigonometry

no logarithms

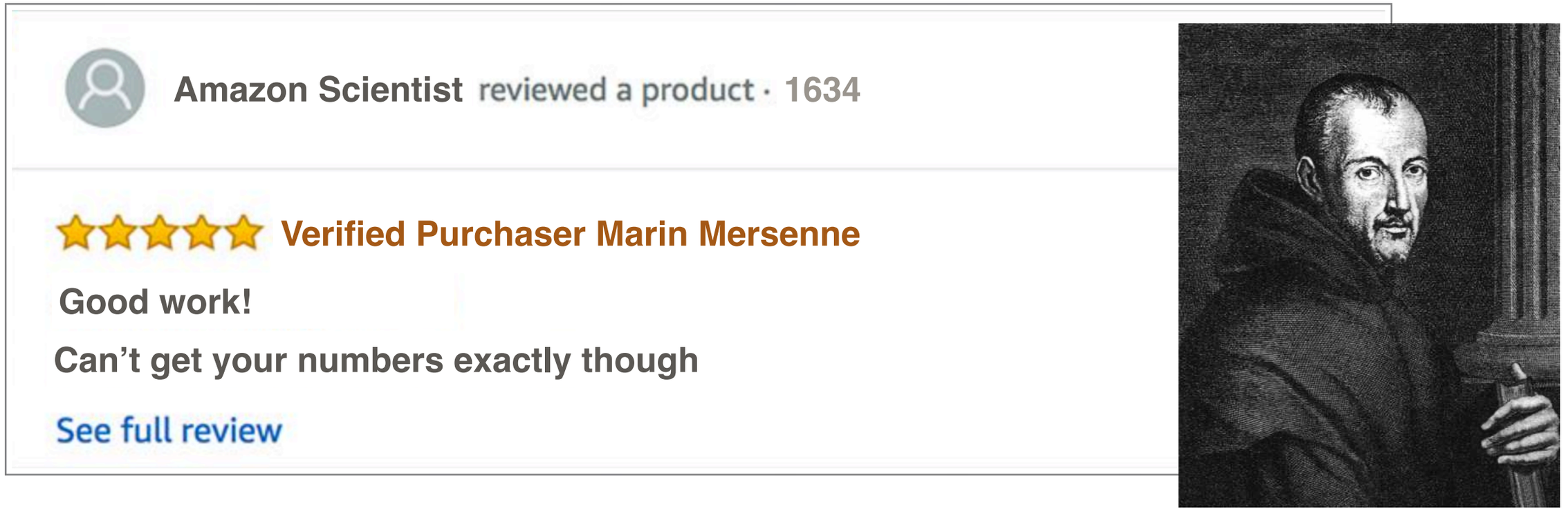
only geometry and ratios

ARISTOTLE HAS LEFT THE BUILDING

Galileo concluded that gravitation is

independent of the material object: pendulum

https://www.youtube.com/watch?v=E43-CfukEgs



Marin Mersenne (1588 – 1648)

GALILEO’S CONCLUSIONS:

free-fall is a constantly accelerated motion

the distance increases as the square of the time in constantly accelerated motion

unless stopped, a moving object will continue forever

BASED ON

reasoning about the pendulum

PENDULUM:
USED:

First, as an object of investigation

HE FOUND THE RULES:

a. the period of a pendulum is independent of:

the mass of the bob

the height of the arc

how does it “know” to adjust its speed at the bottom to cause this?

b. the period of a pendulum *does* depend on:

the length of the cord

PENDULUM:
USED:

Second, as an inspiration for new discoveries

SINCE

it’s governed by the same influence as free fall

the acceleration of a falling object

is independent of its mass

Aristotle is further discredited

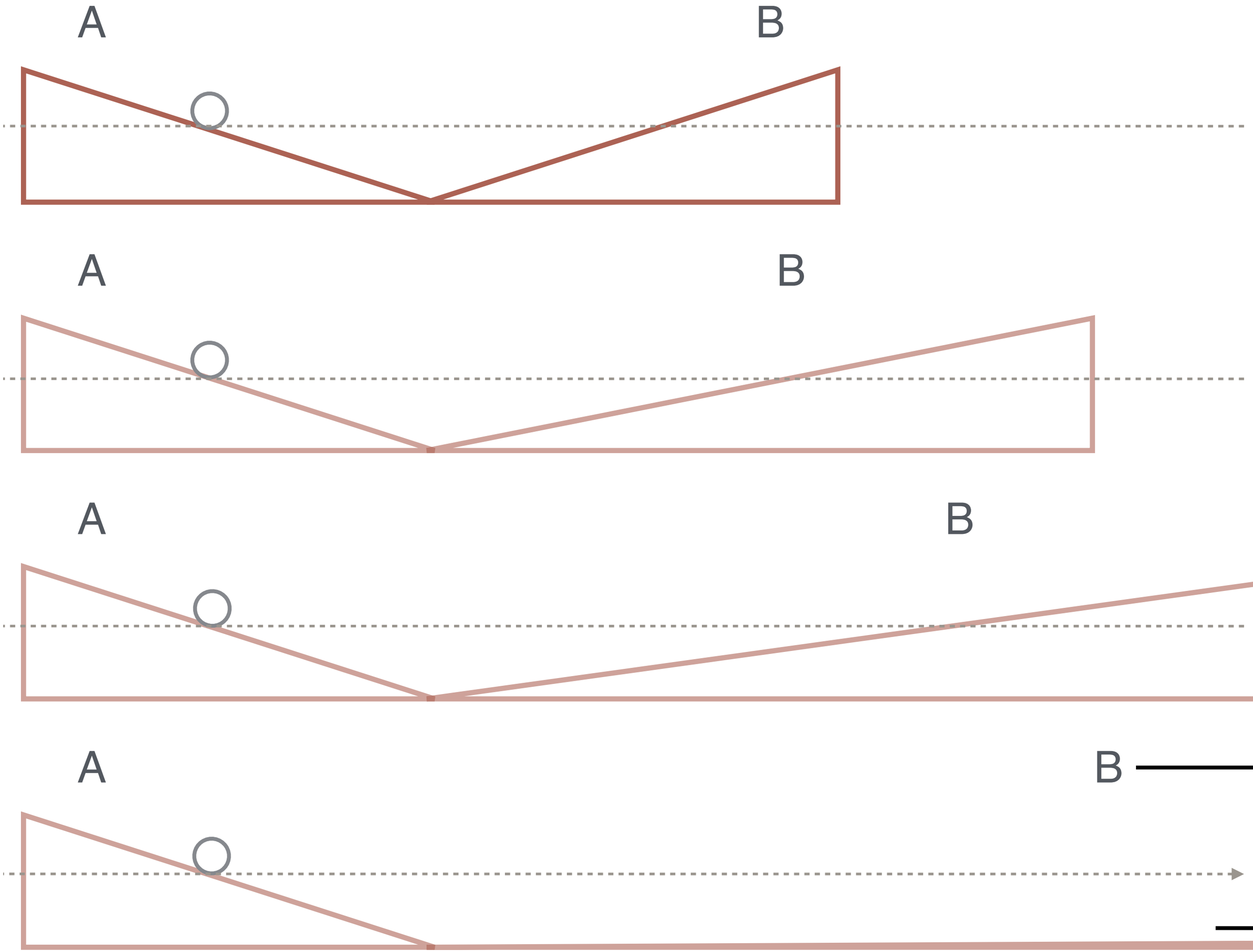
THEN, HE USES THE
INCLINED PLANE

as an inspiration

INSTEAD OF

tilting an inclined plane up

he imagines flattening it out


A
B
A
B
A
B
A
B

NEWTON'S FIRST LAW

not quite, but close

he thought "horizontal"

meant: follow the curvature of the earth

AND

Galileo defined his “momento” as

weight • velocity

which is wrong.

OKAY.
BUT, NEARLY INERTIA & MOMENTUM

he had only a primitive notion

really requires Descartes and Huygens a few years later

and Newton, after that

NOTE 1:

in each use of the inclined plane

he is **taking limits**

conceptually... he's doing calculus

without doing calculus

NOTE 2:

he never saw an object behave like he said it would

not once.

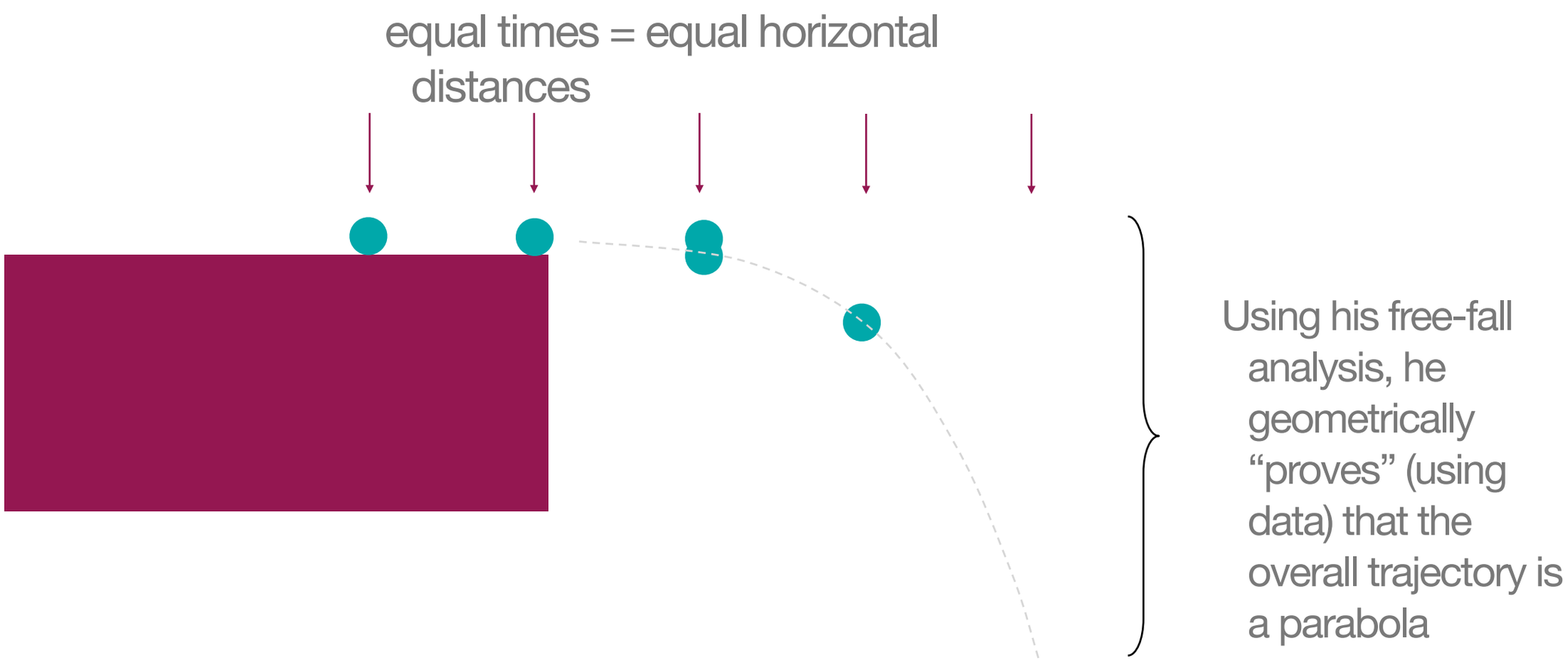
ALWAYS HARD TO FIGURE GALILEO OUT

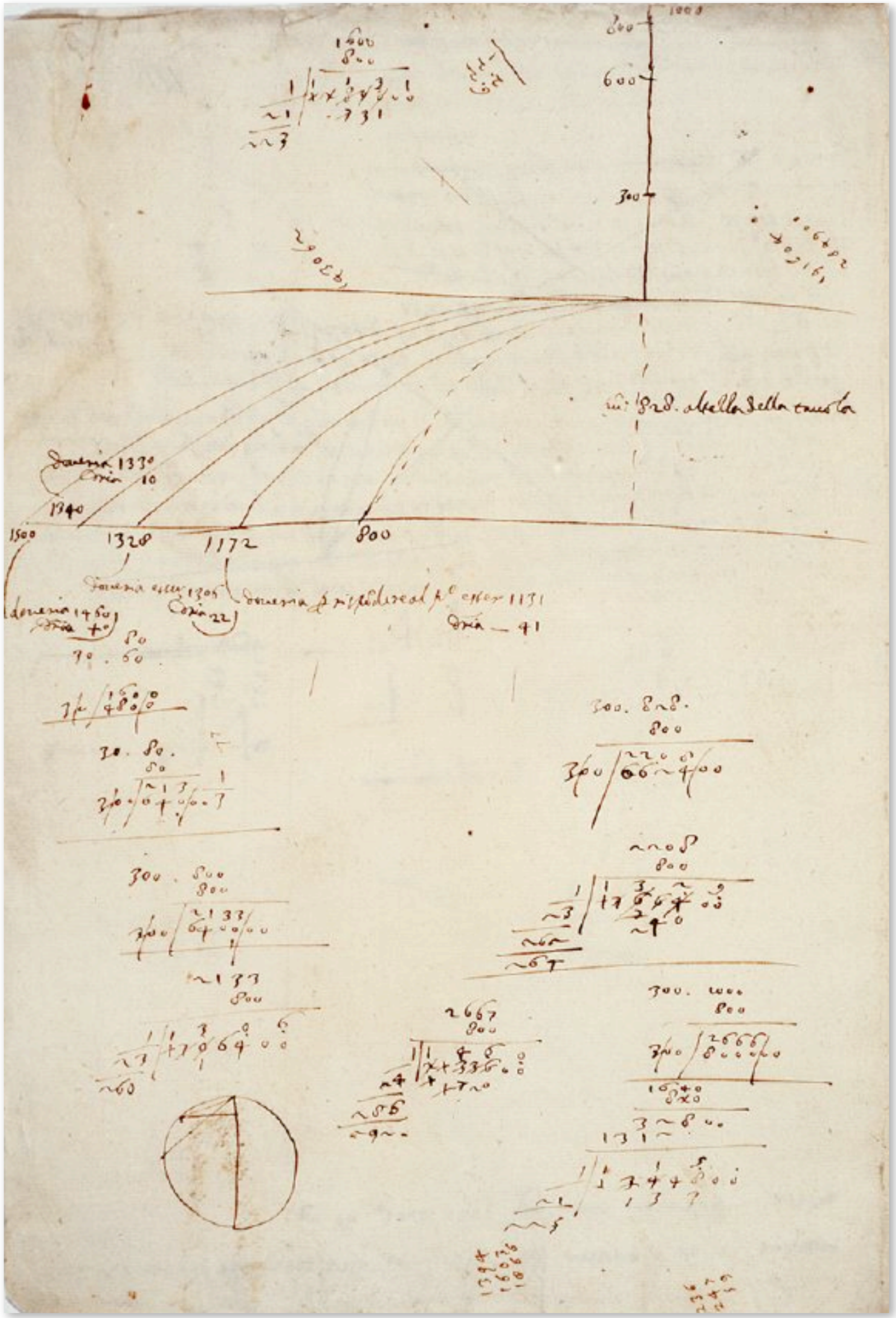
as to when he's describing an experiment he *did*

as compared to one he *imagines*

IT GETS MORE CLEVER:

suppose his ball rolls off a cliff

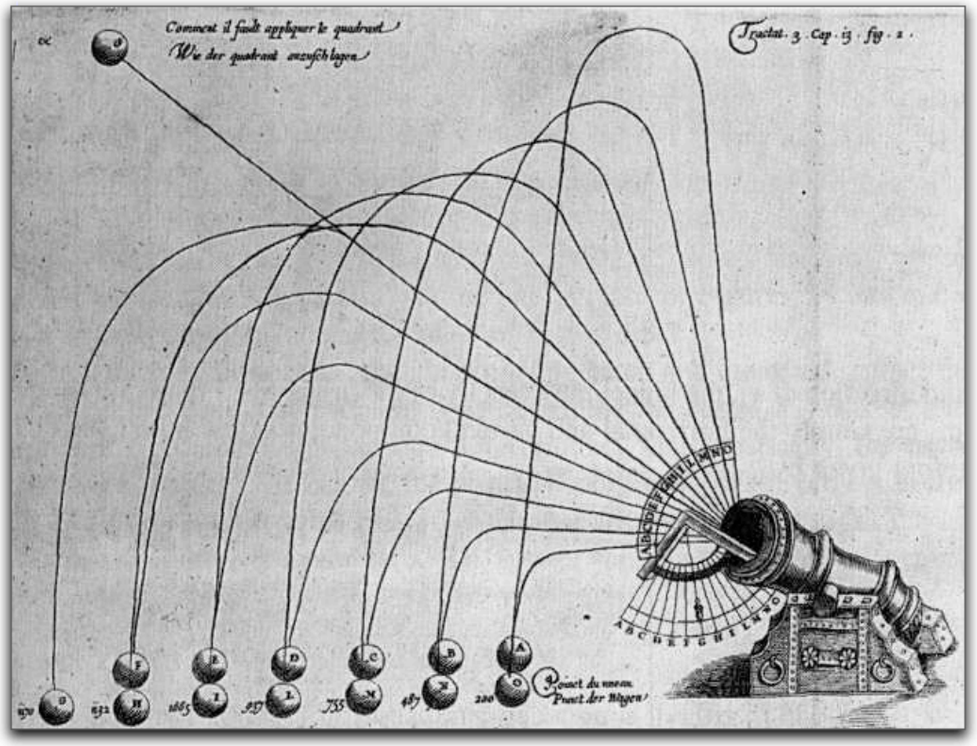




from geometry and his measurements

he could show that

$$y \propto x^2$$



From a 17C book on artillery

REALLY, BRILLIANT.

projectile motion:

the overlap of two separate motions

1) horizontal motion associated with the original horizontal push

2) vertical motion associate with free-fall

TWO SEPARATE MOTIONS

are “attached” to the object

with TIME as the glue...

the parameter holding them in synch

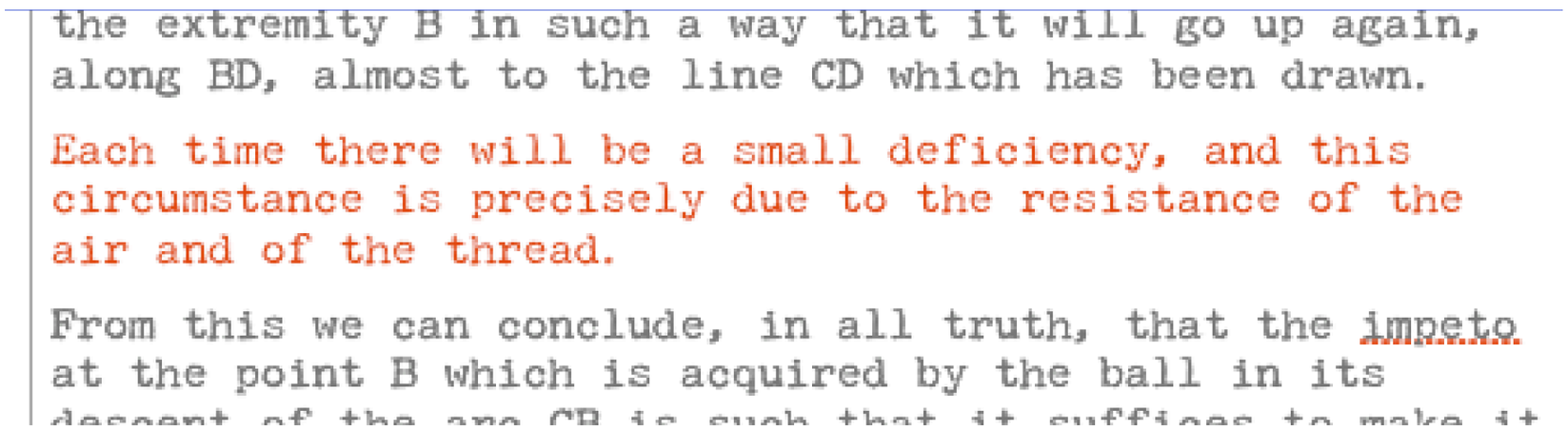
THERE’S A BIG BUT:

HE NEVER MEASURED A PENDULUM BOB

returning to its starting point

not once.

but he said it would...but for air resistance



the extremity B in such a way that it will go up again, along BD, almost to the line CD which has been drawn.

Each time there will be a small deficiency, and this circumstance is precisely due to the resistance of the air and of the thread.

From this we can conclude, in all truth, that the impeto at the point B which is acquired by the ball in its

HE NEVER MEASURED A TRUE QUADRATIC DISTANCE-TIME RELATION

on his inclined plane

not once.

HE NEVER MEASURED A PARABOLA

for a projectile

not once.

THIS IS IMPORTANT:

Galileo’s Representation

involved “seeing” a regularity of Nature

hidden by its particular manifestation

NOT A PARABOLA?

But, you say...

what about baseball?

TOWERING DINGER

The scenario is:

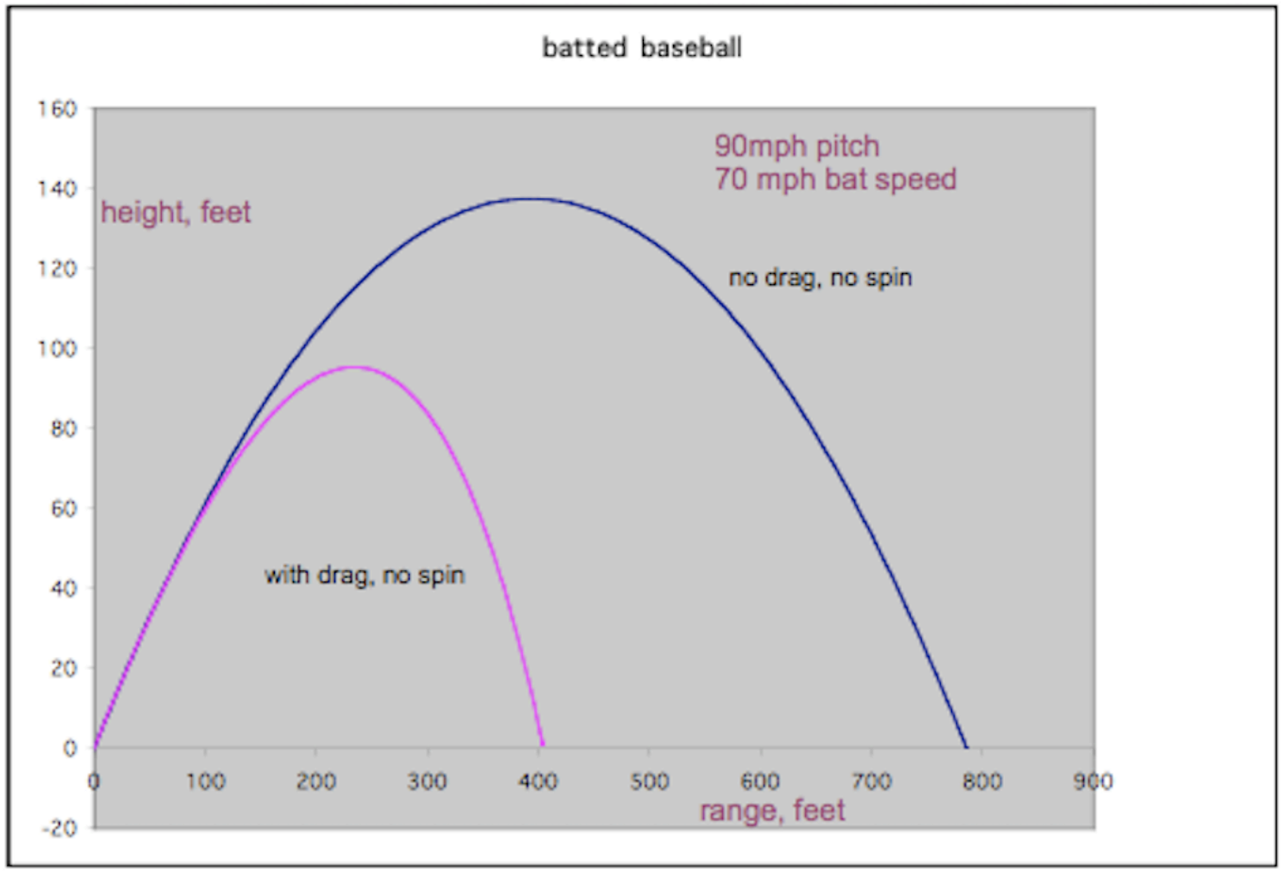
- a 90 mph pitch,
- a 70 mph bat speed (bat speed is much more important than the speed of the pitch)
- 35˚ swing angle (maximum range condition for air resistant motion)

actually, probably a downward trajectory for the pitch and reduced bat angle

- wooden bat recoil
- realistic baseball deformation

not parabolic…

but - remember the brilliance of Galileo's abstraction to what is important?



Mark McGwire had a most pronounced upswing


~35°

THE TOWER

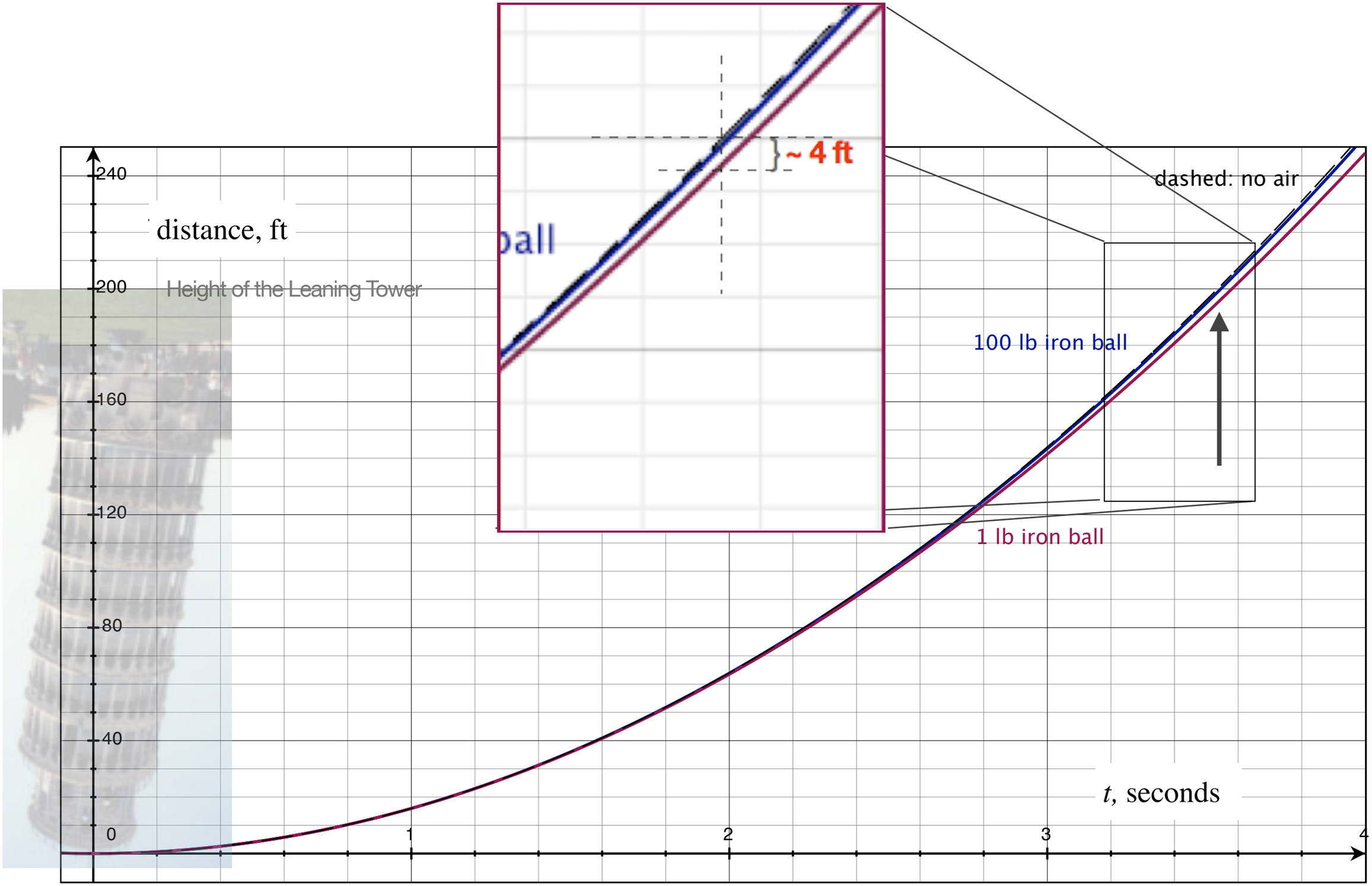
nope.

He never said he did it.

Viviani enthusiastically reported it after his death

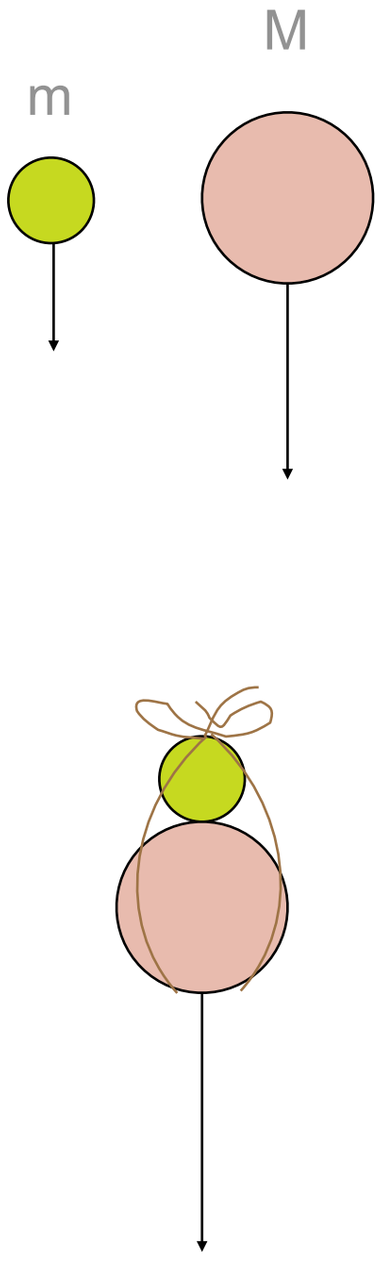
HE CLAIMED

two cannon balls 100lb and 1lb, dropped from the Leaning Tower would land separated by only “two finger-breadths”.


distance, ft
240
200
160
120
80
40
0
Height of the Leaning Tower
~ 4 ft
dashed: no air
100 lb iron ball
1 lb iron ball
t, seconds
1
2
3
4

HIS ORIGINAL ARGUMENT WAS LOGICAL

he out-Aristotled Aristotle



$M > m$

Aristotle said, $v(M) > v(m)$

Now, tie them together, they fall with $v(Mm)$

but, since M+m is bigger than either M or m, then $v(Mm) > v(M)$

um...

But, *m* should retard *mM* and *M* should also retard *mM,* but less?

so, does $v(mM) = v(m)$?

$v(mM) = v(M)$?

$v(M) > v(Mm) > v(m)$...

So, now we've got a paradox using Aristotle's rule

which can only be resolved if $v(M) = v(Mm) = v(m)$...

hence, they all fall at the same rate

HERE'S

SURE.

the ever-present non-uniformity

overlaid on an ever-present permanent-uniformity

NOBODY EVER THOUGHT THAT WAY BEFORE

previously, people tried to account for what they saw

For Aristotle

the rule is: every projectile's motion is different…depending on its composition

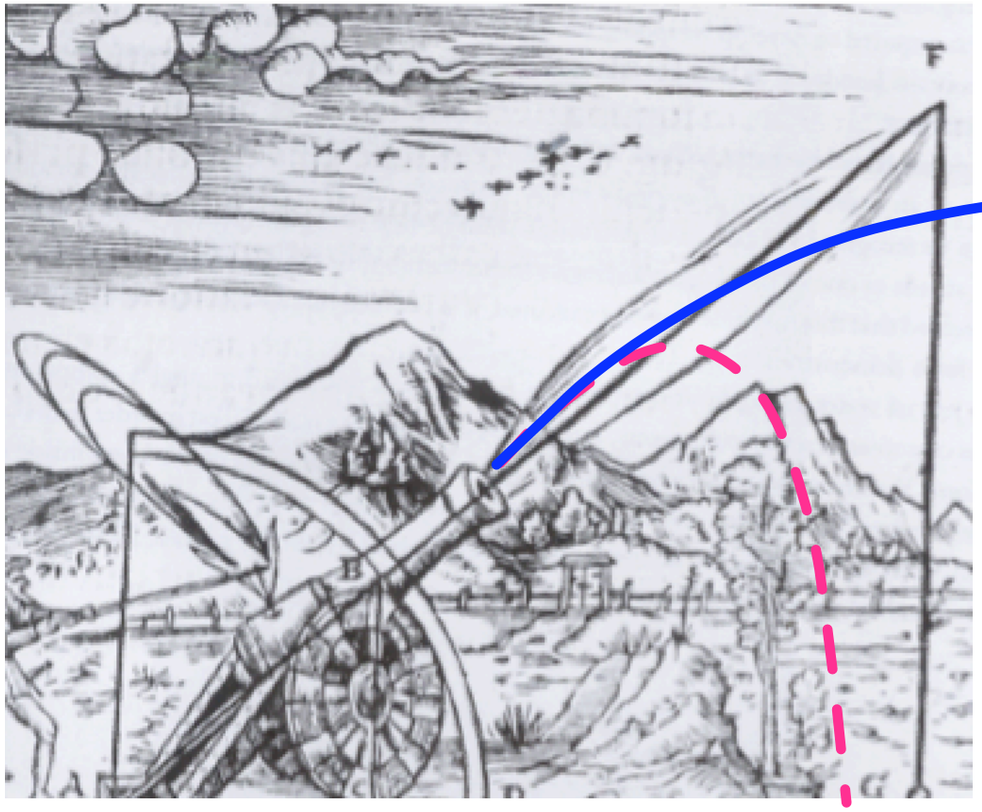
For Galileo

the rule is: every projectile's motion is identical to every other one

GALILEO

learned to observe **more** than...what he saw.

What everyone "saw"



what Galileo "observed"

a Platonic idea

this is what a careful observer

would have perceived…think home run

artistic sensibility

in art:

the fleeting, changing nature of the observed world is

abstracted into something permanent and Representative

in physics:

the fleeting, changing nature of the observed world is

abstracted into something permanent and Representative

GALILEO IS CALLED

the Father of *experimental physics*

for good reason:

he measured things and extrapolated to fundamental, universal rules

MORE.

I THINK HE'S THE FATHER OF ALL OF PHYSICS

because he taught us to abstract

to what's "more real" than raw observation

it's the most fundamental thing that physicists do

DIG OUT WHAT'S BENEATH

actual appearances

WHO IS THIS PEEKING THROUGH?

Plato and the Forms

repackaged

WHAT DO EXPERTS SAY?

artists, critics, philosophers

“The true purpose of painting is to represent objects as they really are, that is to say differently from the way we see them. It tends always to give us their sensible essence, their presence, this is why the image it forms does not resemble their appearance.

Riviere

Art pleases by reminding, not by deceiving.

“...the whole beauty and grandeur of Art...consists in being able to get above all singular forms, local customs, particularities of every kind...[The painter] makes out an abstract idea of their forms more perfect than any one original.

Constable

“[a painting must strive to] obtain knowledge of an object, not as particular thing but as Platonic Ideal, that is to say, the enduring form of this whole species of thing.

Schopenhauer

“In order to paint a beautiful woman, one has to see many beautiful women.

Raphael

TO REPRESENT A VISUAL OR MENTAL EXPERIENCE - **TO MAKE ART**:

Two ingredients:

less

and

more

LESS.

the artistic mission requires some detail

not everything

lines demarcate – but are non-physical

a professional choice to abstract

MORE.

art must include enough

to make contact with **universal** experience

I think that...a definition of the function of art...is very similar to the function of the brain: to represent the constant, lasting, essential and enduring features of objects, surfaces, faces, situations, and so on, and thus allow us to acquire knowledge not only about the particular object, or face, or condition represented on the canvas but to generalise from that to many other objects or faces.

Inner Vision: An Exploration of Art and the Brain,
Semir Zeki, (Neurobiologist)

MY WAY OF LOOKING AT THIS PERIOD:

Galileo caught up with art

GALILEO LEARNED
REPRESENTATION *ALSO* REQUIRES:

less and more.

He saw beneath the appearances…which before him had been the only subject of inquiry

NO OBSERVATION OF CANNON BALLS

would reveal a parabolic trajectory

THIS IS NEW...

2 ingredients define *the* activity of physics:

abstracting

what's useful and necessary from lots of particular, apparent data:

(less = ingredient 1, data-gathering/sifting)

...that which is permanent & universal–meaning: "law-like":

(more = ingredient 2-modeling what's permanent)

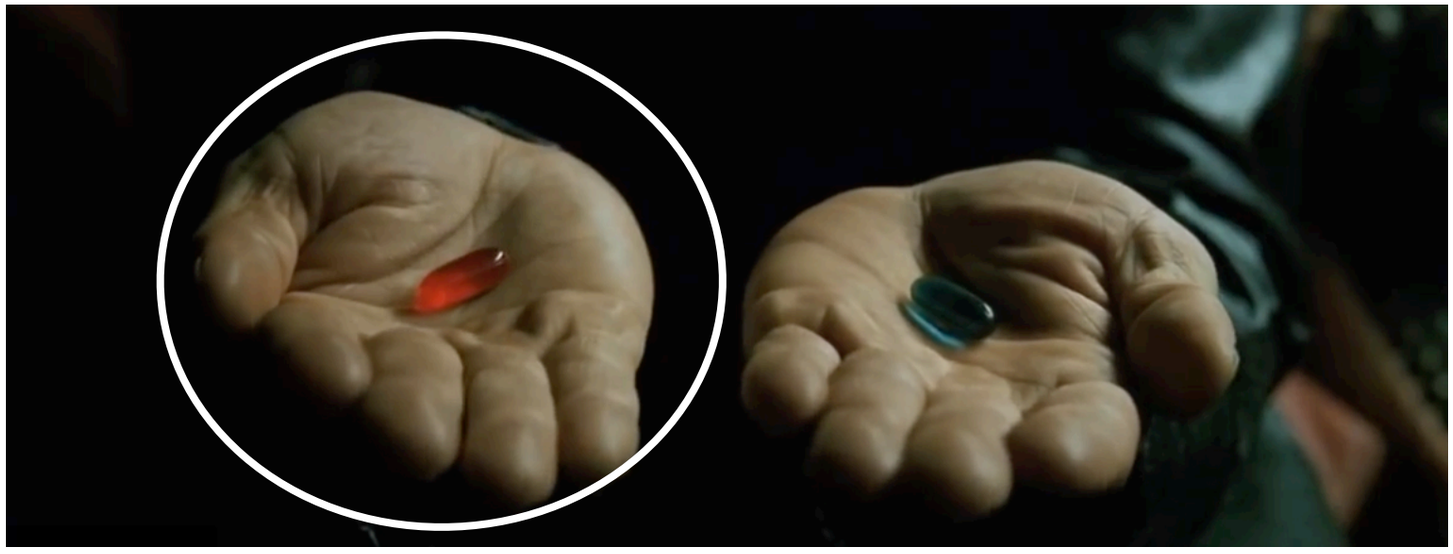
HOW DO YOU LEARN TO DO THAT?

Not by a formula “scientific method”...

but by experience, luck, and unaccountable inspiration

TWO WORLDS

Wachowskis' are Platonists and Galileo was our bridge



ABOUT MOTION, WE LEARNED FROM HIM:

that objects falling in gravity undergo constant accelerated motion (near earth)

that the distance traveled by objects undergoing constant acceleration is proportional to the square of the time elapsed

that violent motions behave the same as natural motions

that projectile violent motions can be analyzed as separate straight-line motions coupled together

that objects at constant speed will stay at constant speed forever

that the Aristotelian pusher is not necessary

that the rules of the pendulum are similarly affected by gravity as free-fall

astronomy

after the Council of Trent…a whole new ballgame

DOES THE EARTH MOVE?

"Thomist" Aristoteleans could countenance a lot

But not a moving Earth

Church especially…

"Then Joshua spoke to the Lord on the day when the Lord delivered the Amorites before the children of Israel; and he said in the sight of Israel: 'Sun, stand still [dom] upon Gibeon; and you, Moon, in the valley of Ayalon.'" (Joshua 10:12)

G: TWO REACTIONS

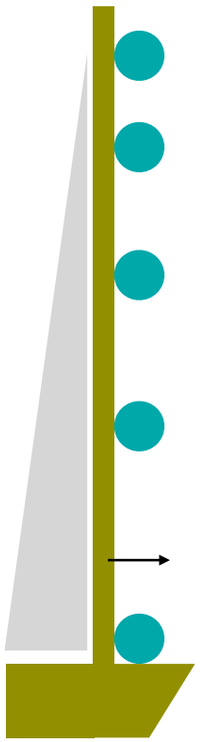
R1: reasoning about relative motion

R2: a proof of the Earth’s motion

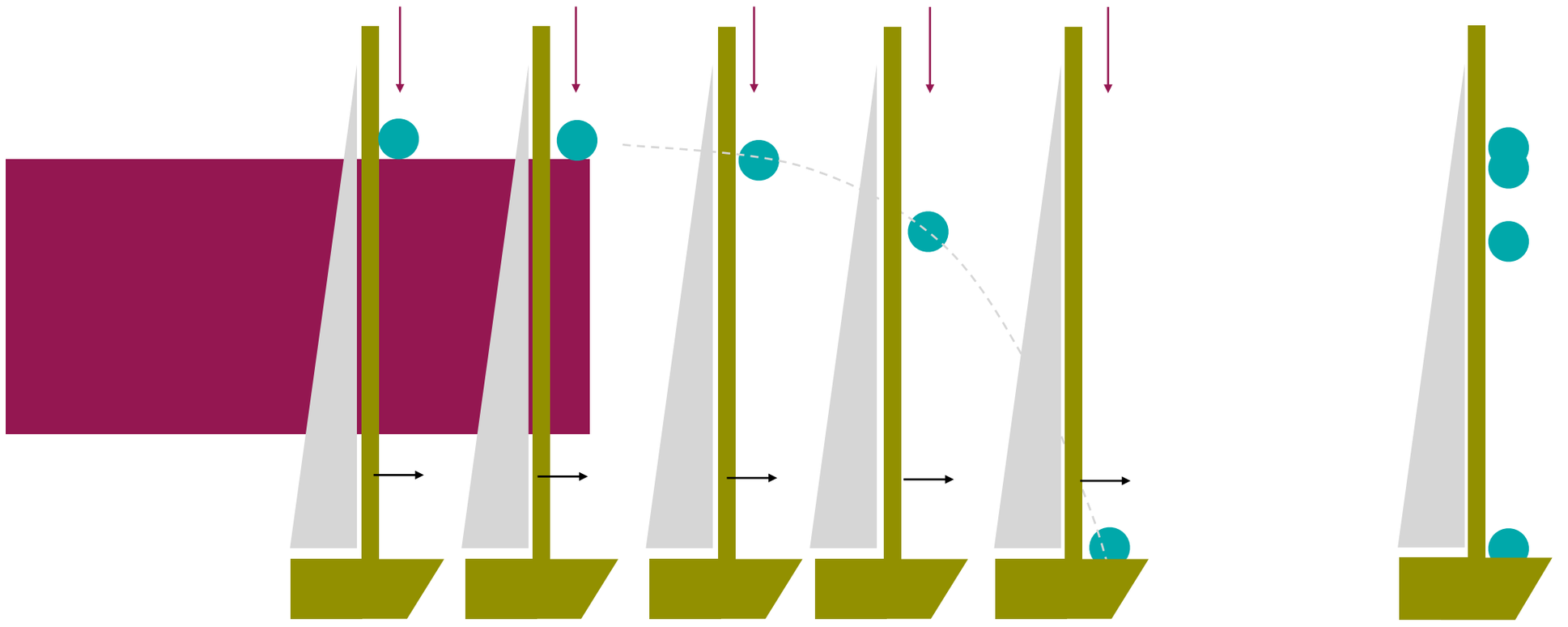
RELATIVITY

remember the ballofthecliff?

ARISTOTLE:



GALILEO:



from land

from boat

THIS WAS HOW HE REASONED

the ball shares

the motion of the ship and the motion of the fall

could not tell the difference from land between that circumstance and the offthecliff circumstance

so must be the same physics...the shared motions

R1: “GALILEAN PRINCIPLE OF RELATIVITY”

if you are in a constant velocity “rest frame”

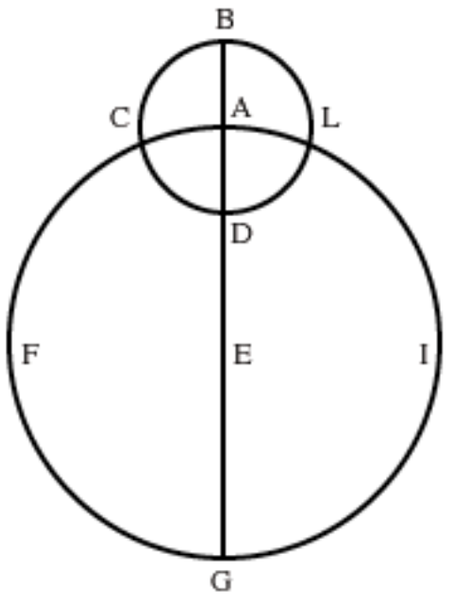
you cannot perform an experiment

that will tell you whether you are at rest or in motion

> Salviati: Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some files, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed...The fish swim indifferently...the drops fall into the vessel beneath; and in throwing something to your friend, you need to throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. [Now] have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating...You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still.

how he said it.

R2: TIDES



his “proof“ that the Earth moves

“dual motions”

earth around the sun

earth around its own axis

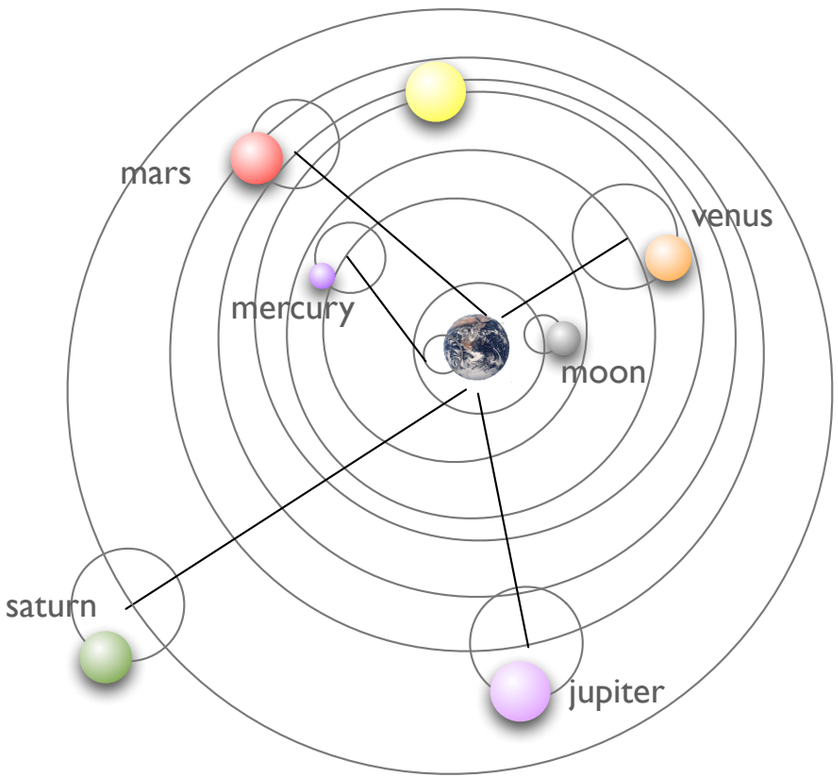
SO:

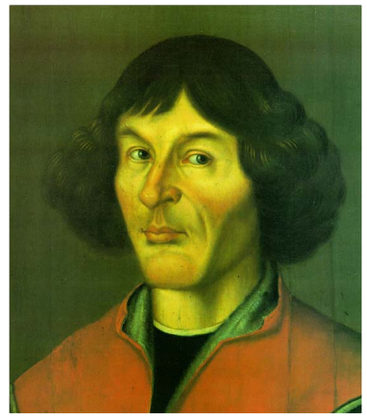
PRE-COSMOLOGY

THE FATHERS

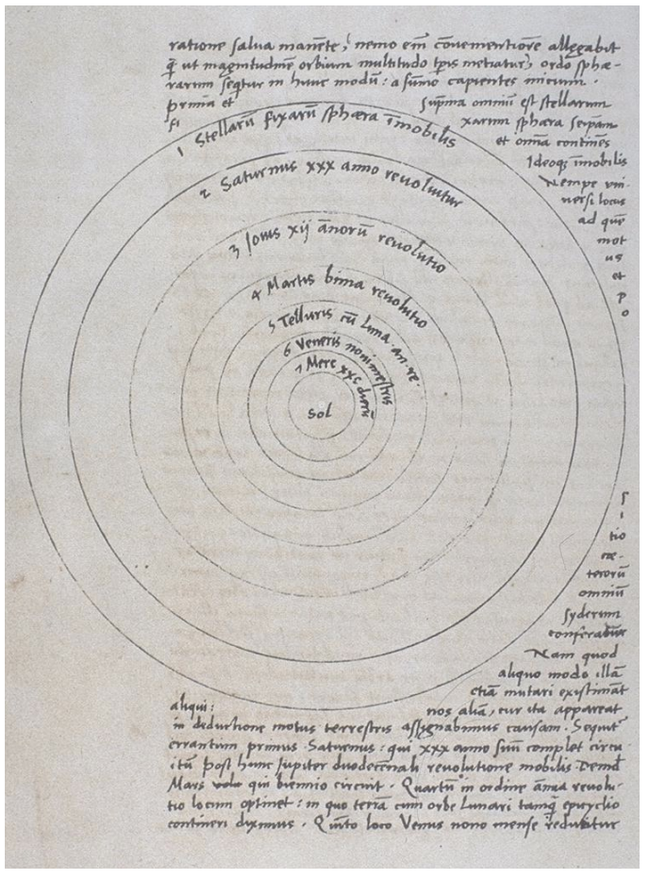
of planetary motion

Claudius Ptolemaeus
c. AD 90 – c. AD 168

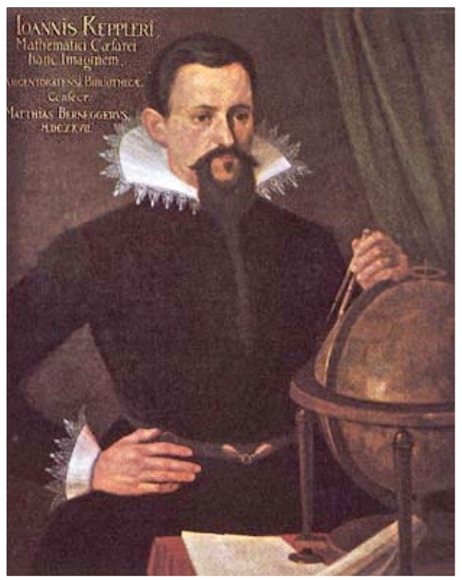




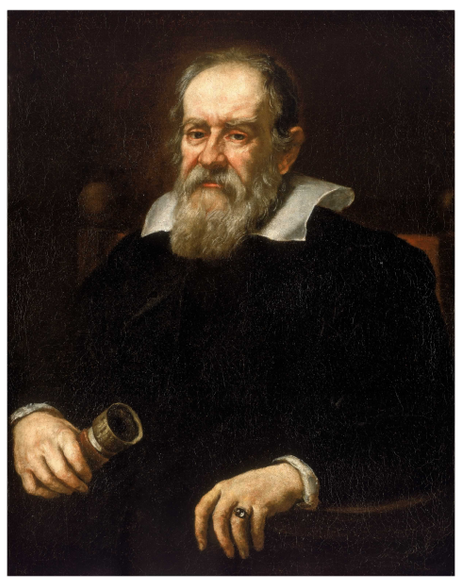
Niclas Koppernigk
1473 – 1543



Tycho Brahe
1546 – 1601



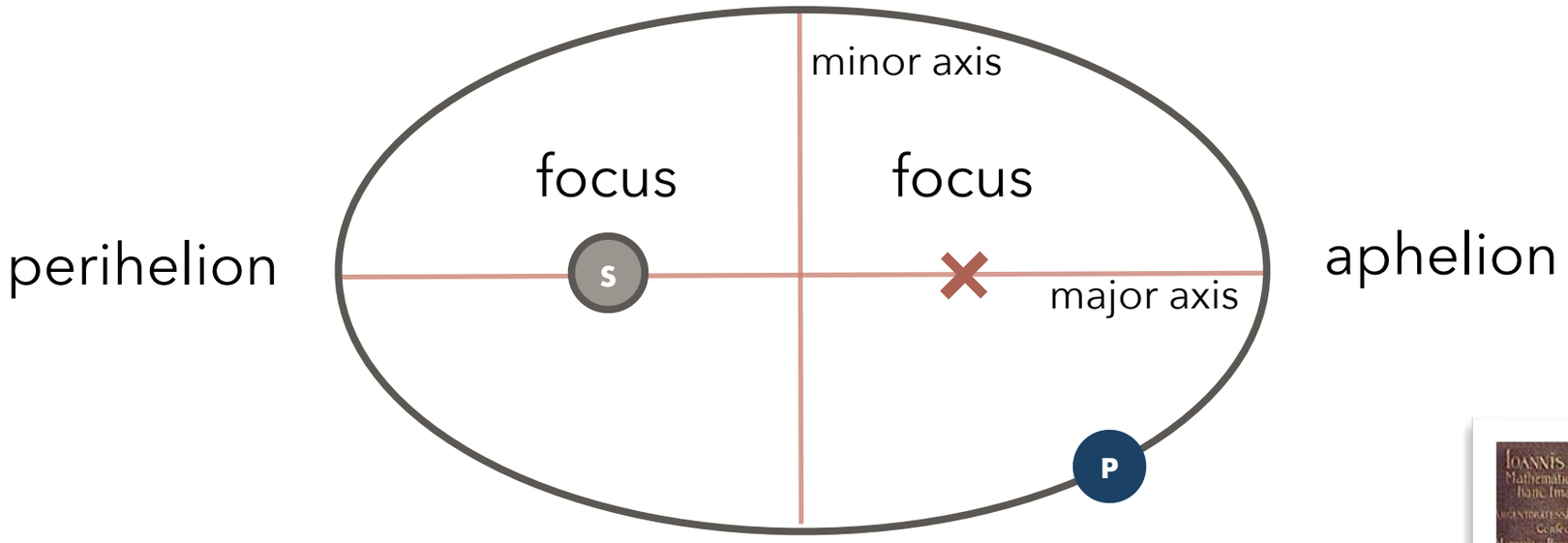
Johannes Kepler
1571 – 1630

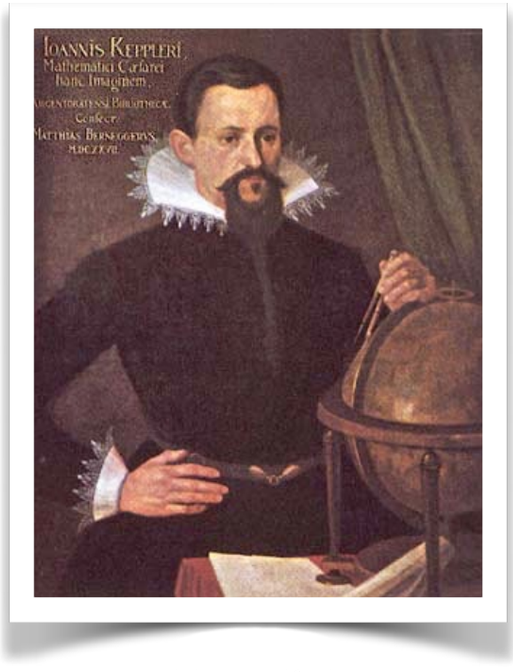


Galileo Galilei
1564 – 1642

YOU KNOW THE ANSWER

the planets circle the Sun following elliptical paths:





Johannes Kepler
1571 – 1630

ARISTOTLE'S COSMOLOGY

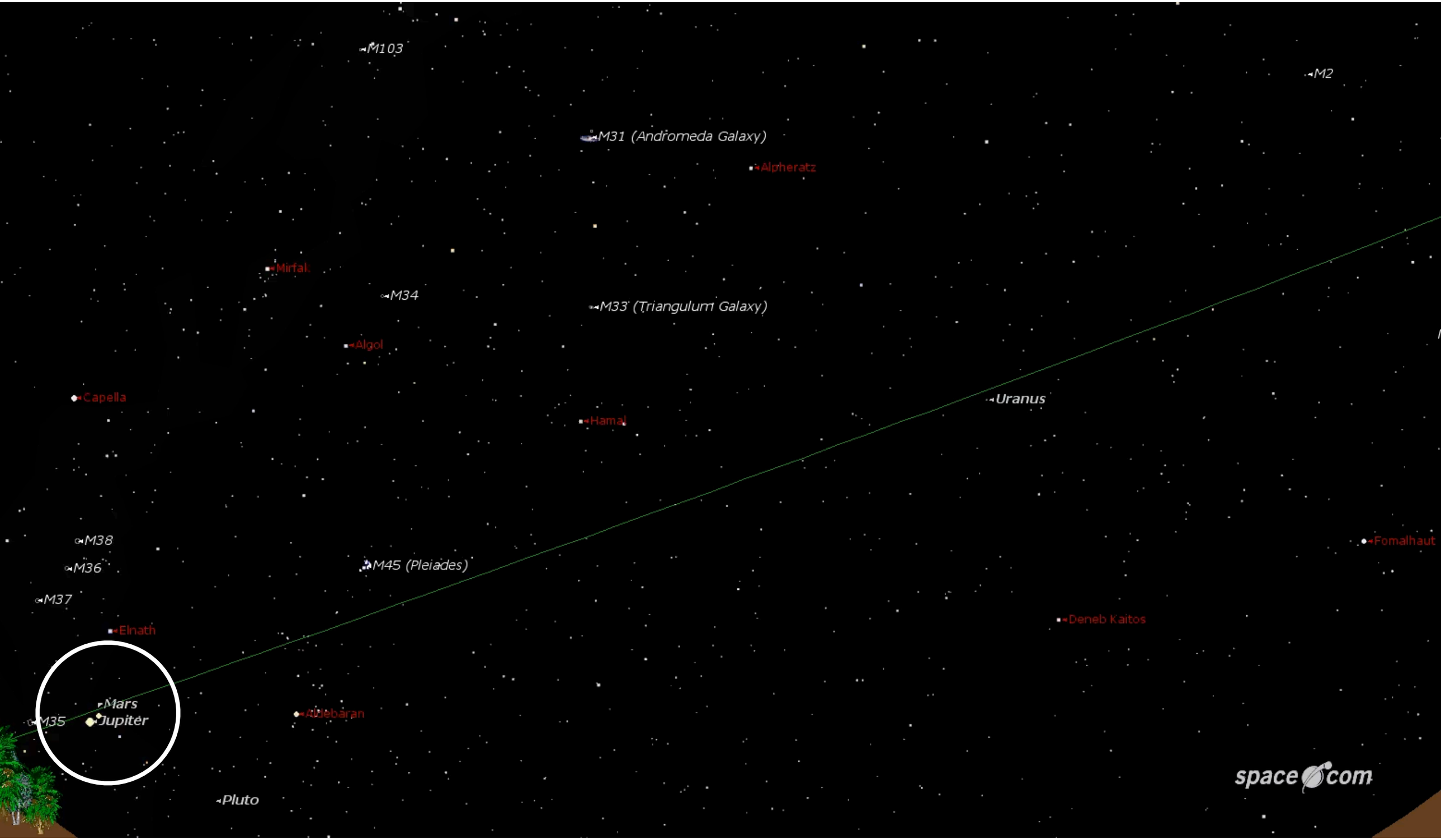
geocentric

an actual, physical model: "crystalline spheres"

to account for planetary motion

retrograde motion, in particular

“retrograde motion,” of Mars: an image every night, same time



HE STOLE EUDOXES' MODEL

but put each Eudoxean independent pieces of circles

into the whole solar system, one on top of the other

then worried about motions of one interfering with the motions of another…

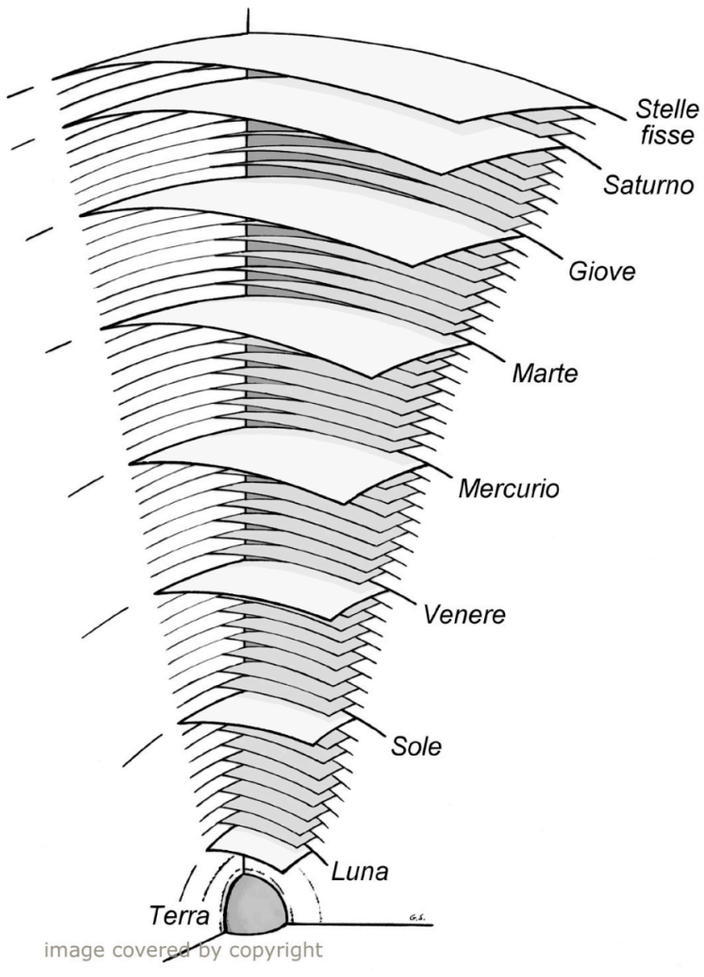
so added new "unwinding spheres" to keep them indendent

Planet	**Eudoxus**	**Callipus**	**Aristotle**	**Unwinding**
Saturn	4	4	4	3
Jupiter	4	4	4	3
Mars	4	5	5	4
Sun	3	5	5	4
Venus	4	5	5	4
Mercury	4	5	5	4
Moon	3	5	5	
Total:	26	33	33	$+22 = 55$

TONS OF SPHERES

that do not solve many problems

byut everyone believed in the spheres



(a)

(b)

PTOLEMY'S COSMOLOGY

geocentric

not an actual model of motions

a calculational tool to predict the sky

MODELS IN PLAY: PTOLEMY'S APPROACH

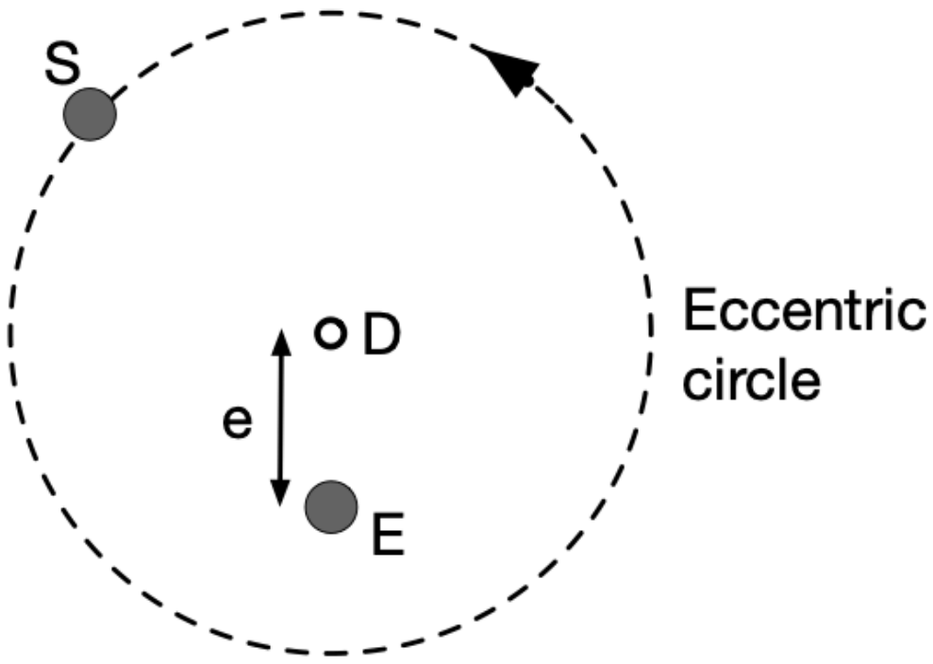
Two anomalies in Hellenistic Astronomy:

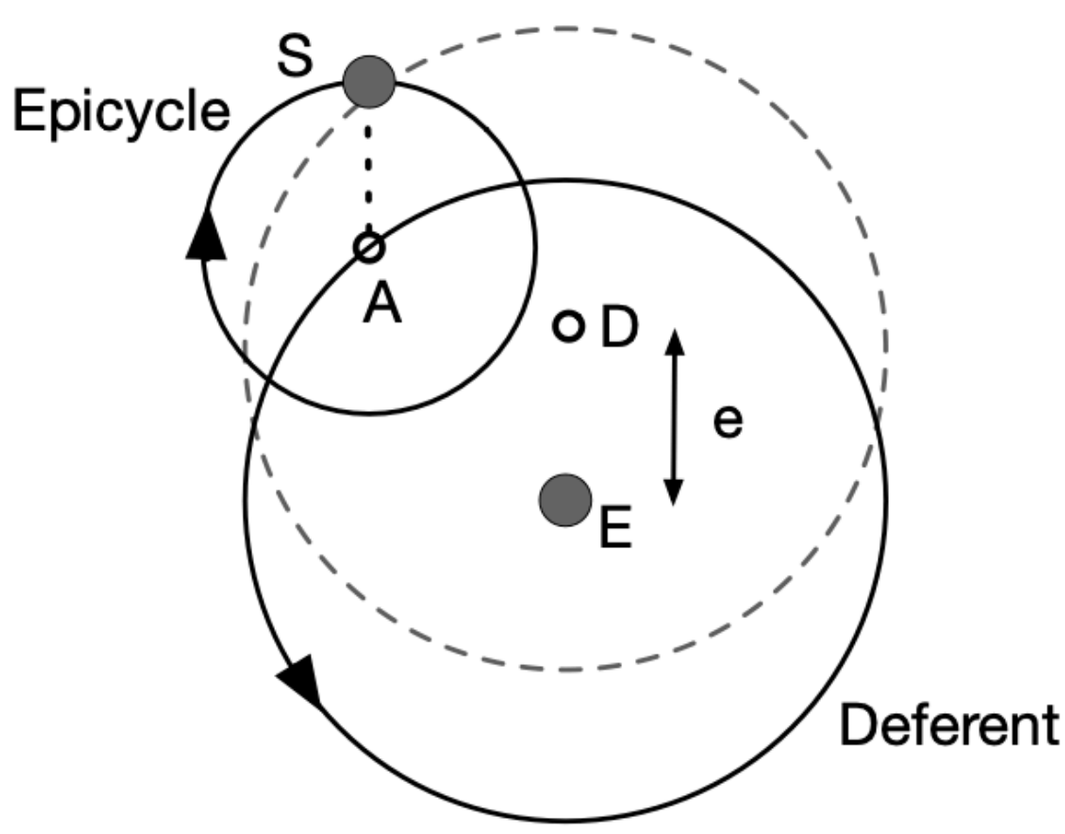
"first": the seasons are different lengths

offset the center of the Sun's orbit from Earth

"second": retrograde motion

epicycles…a calculational tool

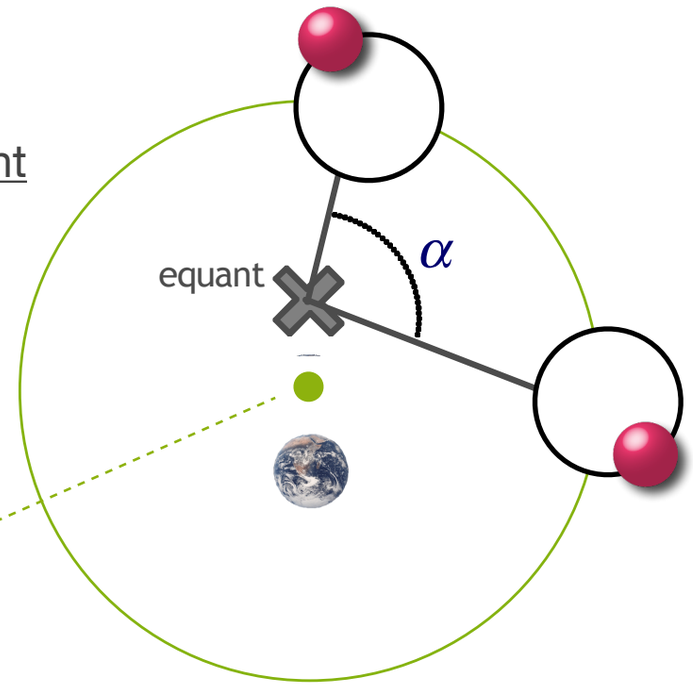




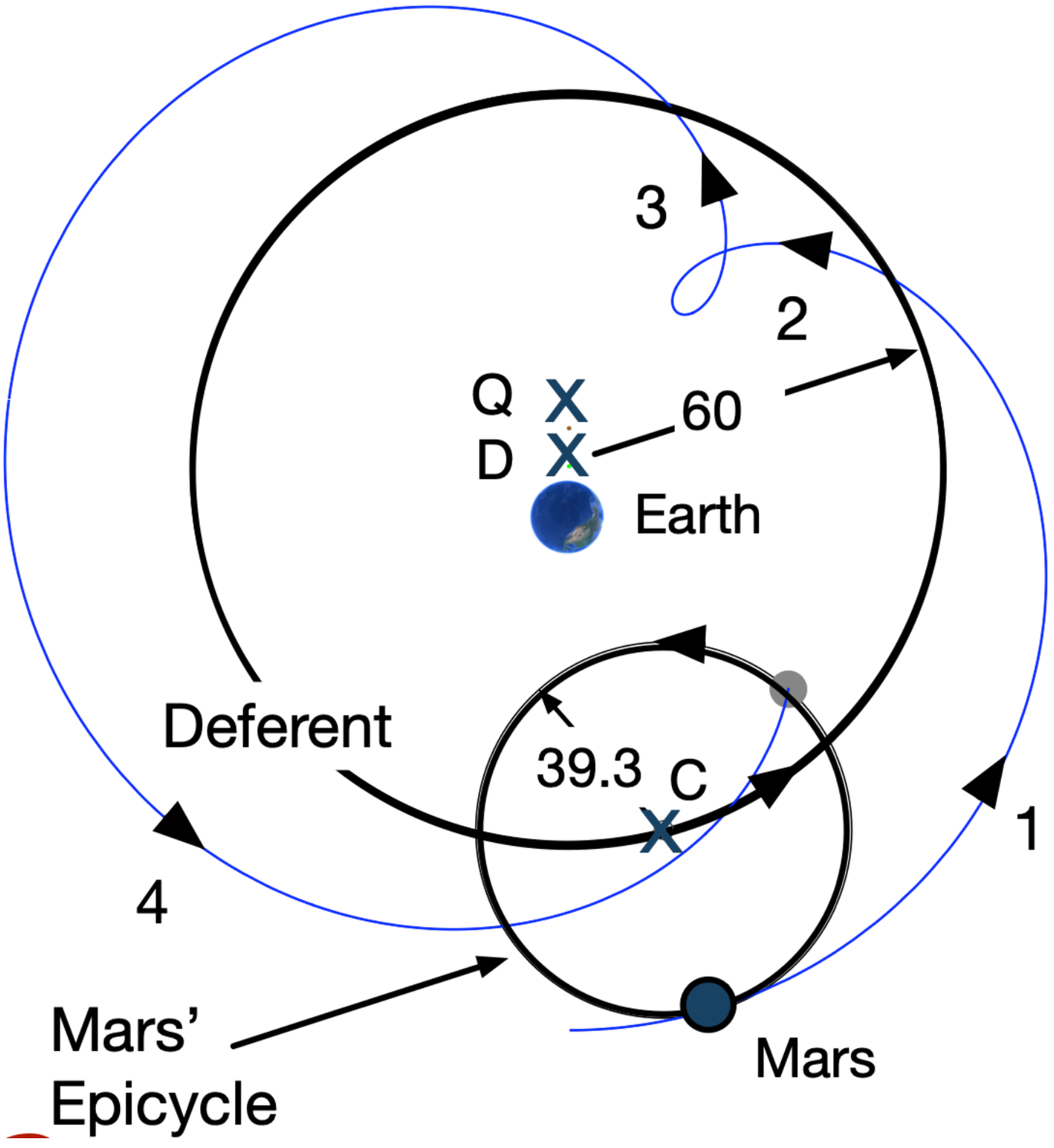
PTOLEMY CHEATED

can you sort of see ellipses in here though?

uniform speed <u>about the equant</u>



center of the deferent circle

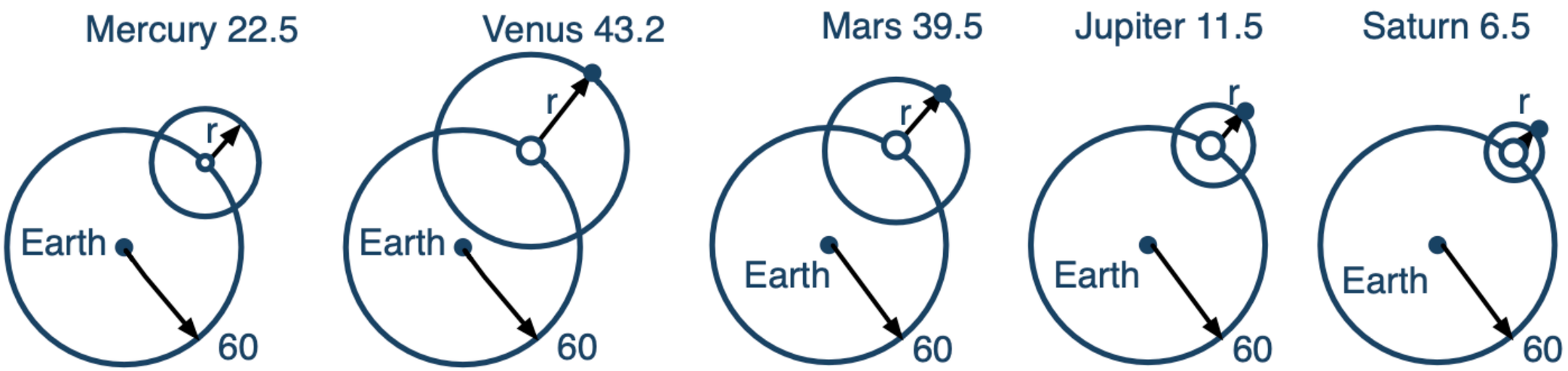

3
2
Q
D
60
Earth
Deferent
39.3
C
1
4
Mars'
Epicycle
Mars

THE DEFERENTS WERE THE SAME RADII

the epicycles ranged in size

These are independent puzzle pieces

for a puzzle not meant to be assembled



IT WORKED TOLERABLY WELL

He produced “Tables”

with one’s latitude and the tables, could produce positions of planets, oppositions, convergences, eclipses

and later when the Muslim astronomers took over

they made it better and produced their own tables

Very few people turned the crank

http://www.copernicuscodemystery.com/index.html

Nicolaus Copernicus 1473-1543

near professional student!

mathematician

canon lawyer

medical doctor

Canon at Frauenburg

diplomat

http://www.panoramio.com/photo/17459090

COPERINICUS' COSMOLOGY

heliocentric

planets and Earth in circular motion around the Sun

retrograde motion, natural

mix

of Platonism, Medievalism, and Aristotelianism

C'S IRRITATION

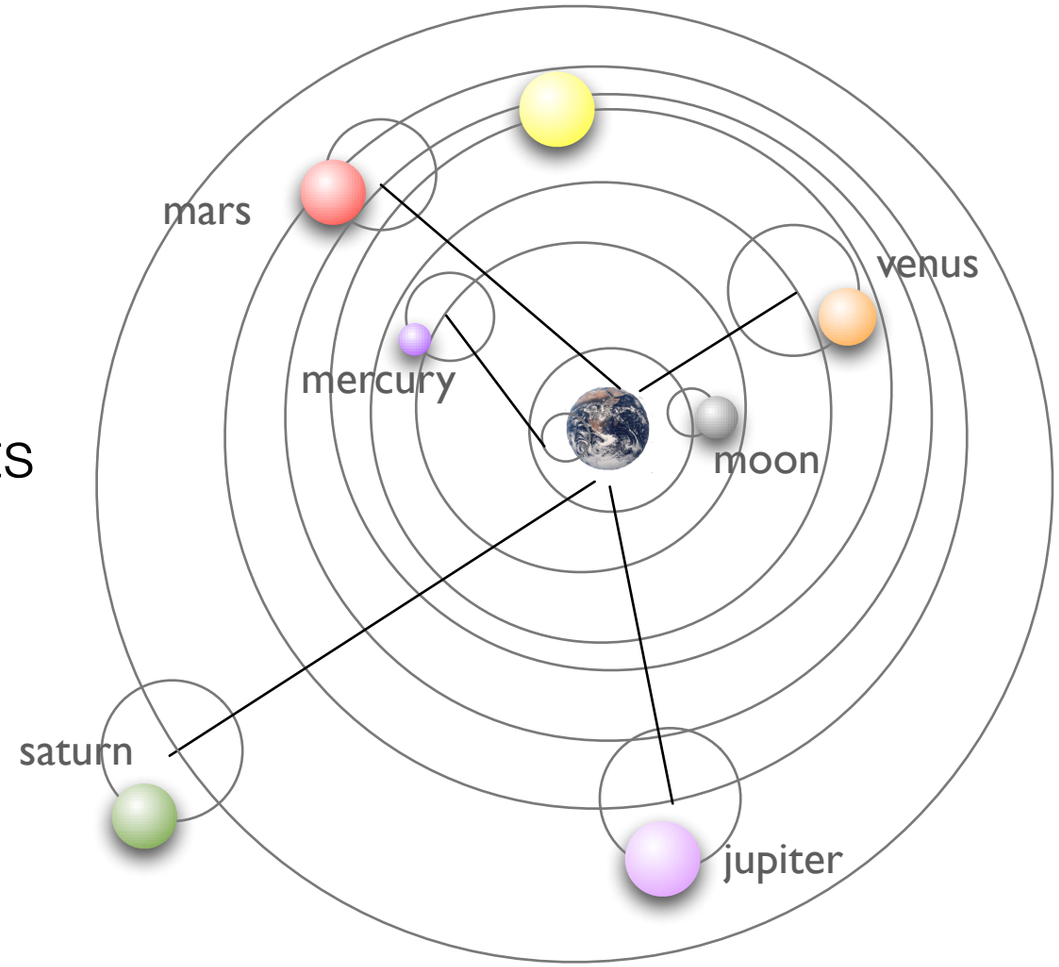
suggests a concern about how the planets really moved

not a calculational engine

A set of criticisms which began with the Arab commentators

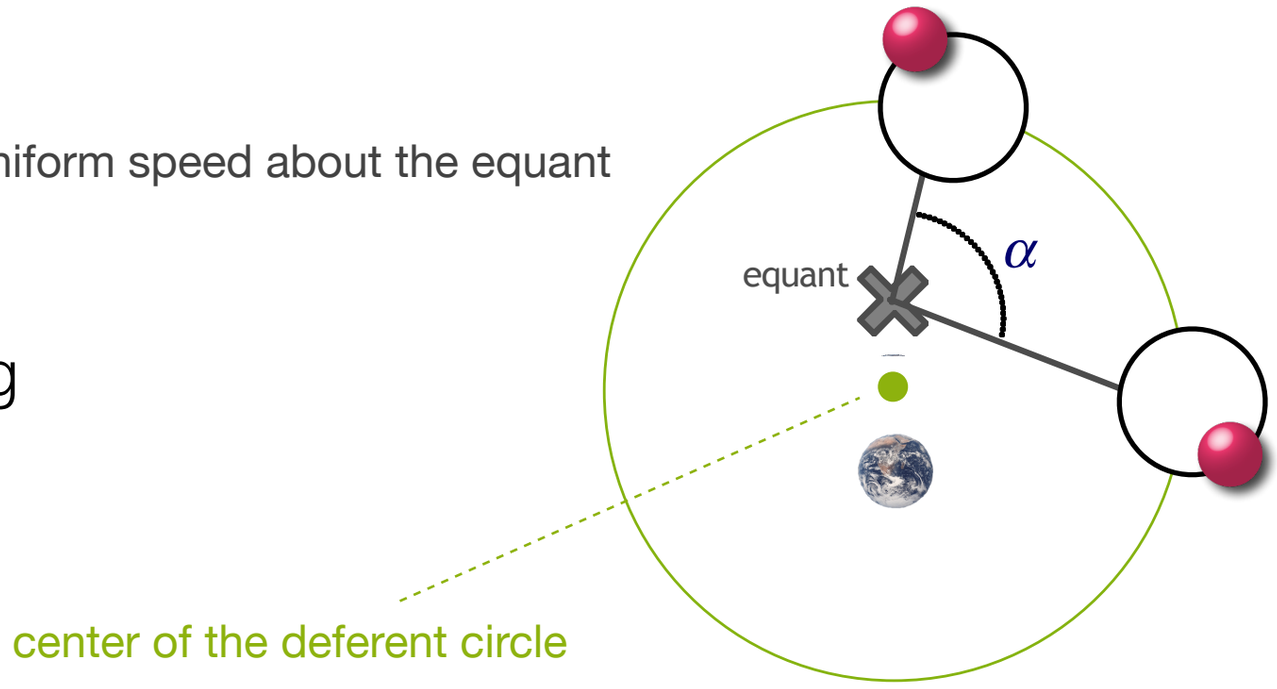
Copernicus was bothered by:

Ptolemy's arbitrary ordering of the planets



and:

Ptolemy's equants were cheating



COPERNICUS WROTE TWO ASTRONOMICAL TEXTS

1514: *Commentariolus "Little Commentary"*

pretty much his whole system

informal

1543: De revolutionibus orbium celestium

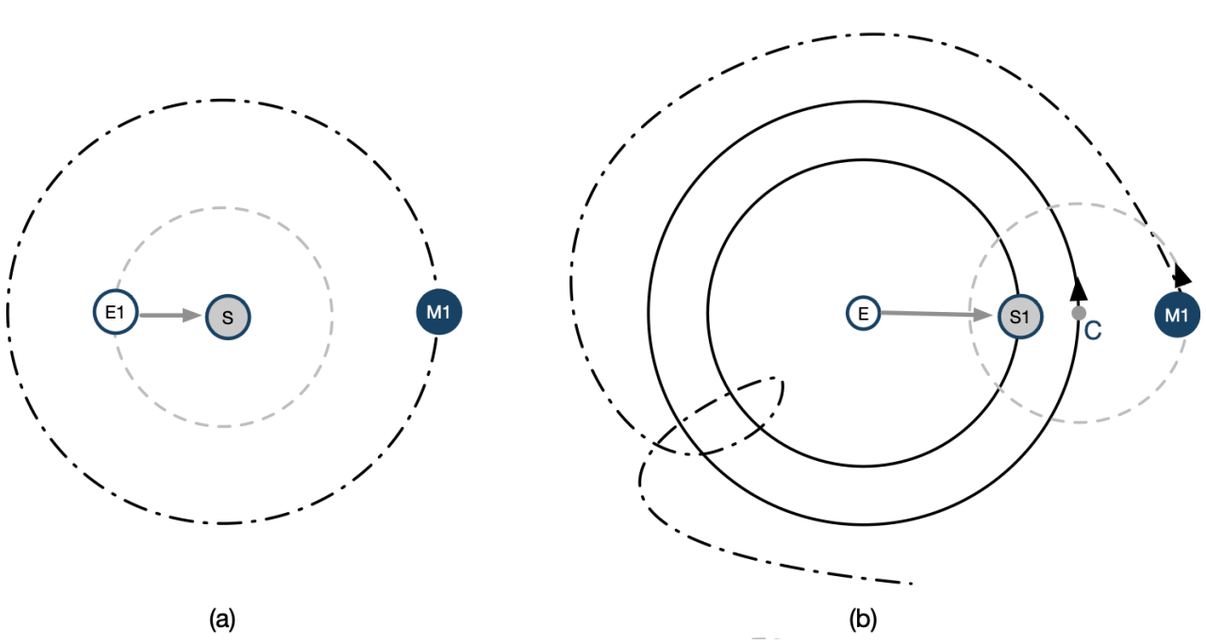
(On the Revolutions of the Celestial Orbs [orbits])

aka "Revolutionibus"

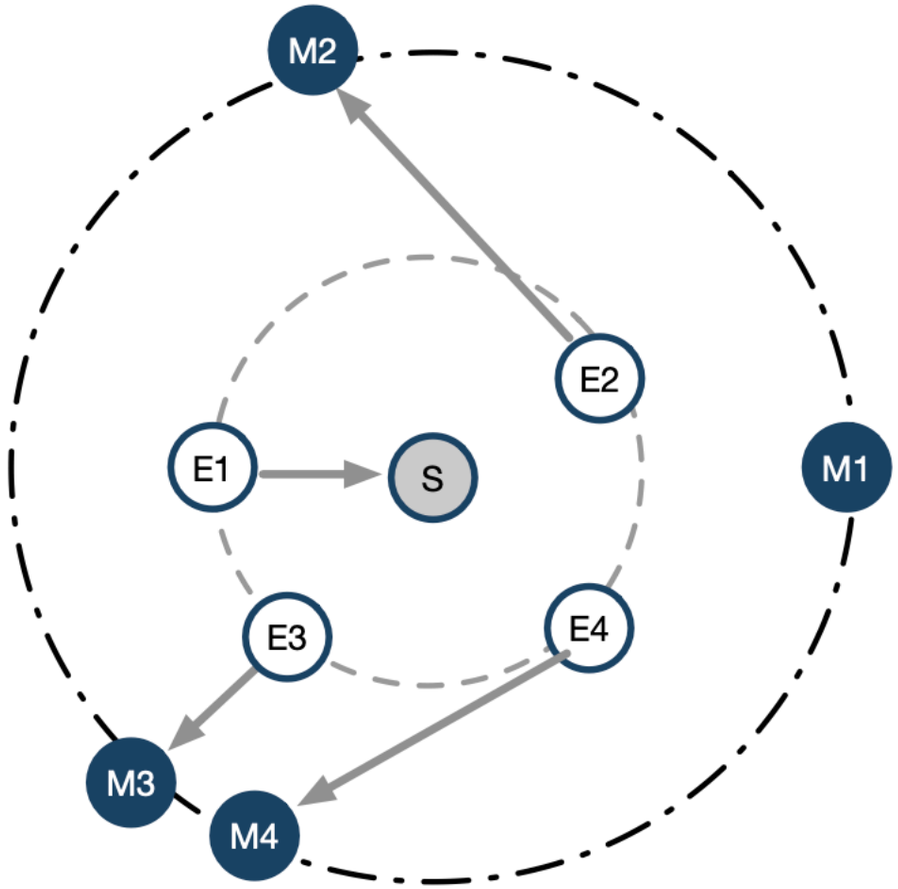
refinements, corrections, upgrades to Commentariolus

EQUIVALENT TO PTOLEMY

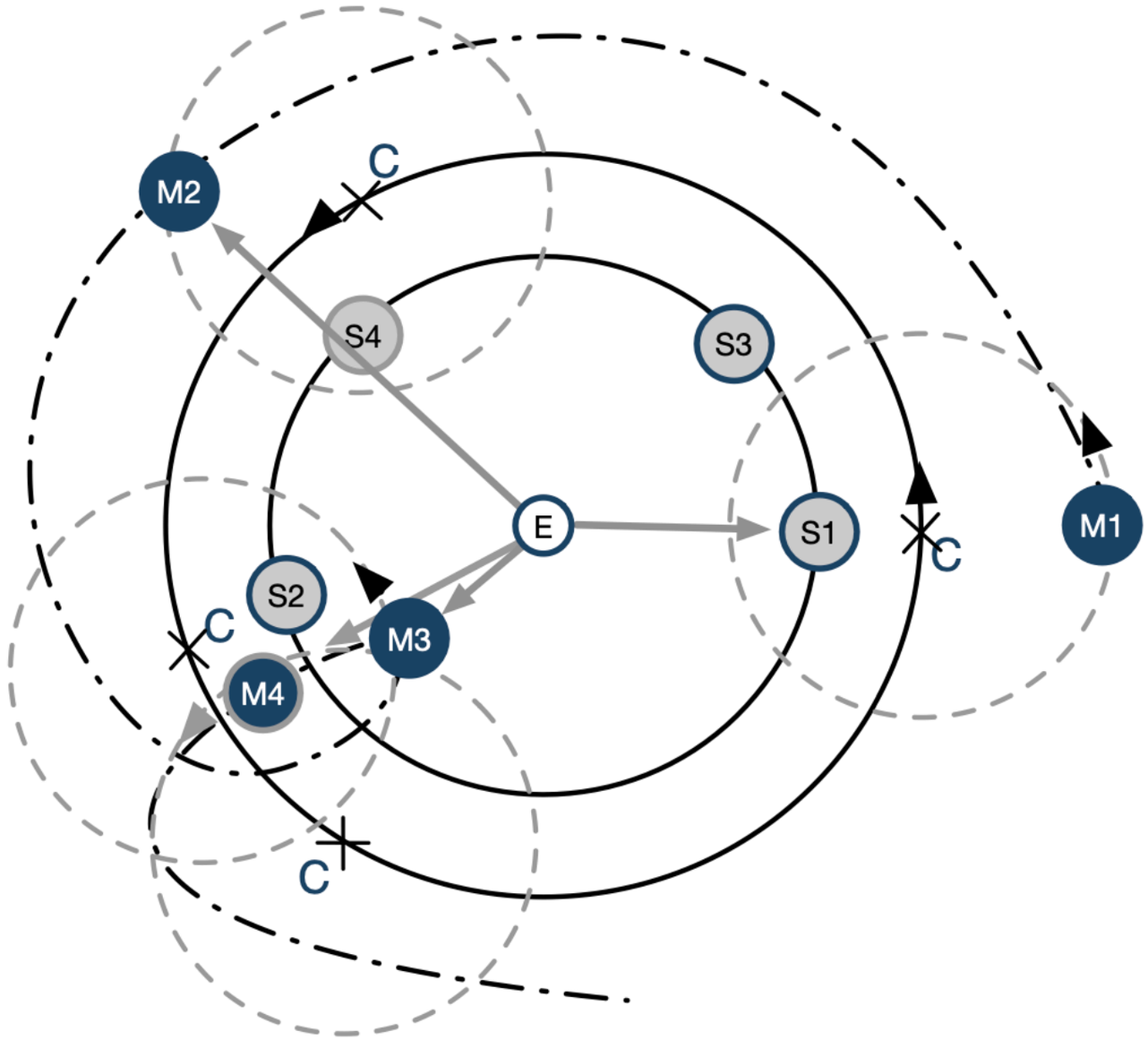
literally a shift of coordinate system…but hard



BOTH ON ONE DIAGRAM



Copernican System



Ptolemaic System

PTOLEMY'S MODEL WORKED WELL!

meaning: it made predictions that matched results

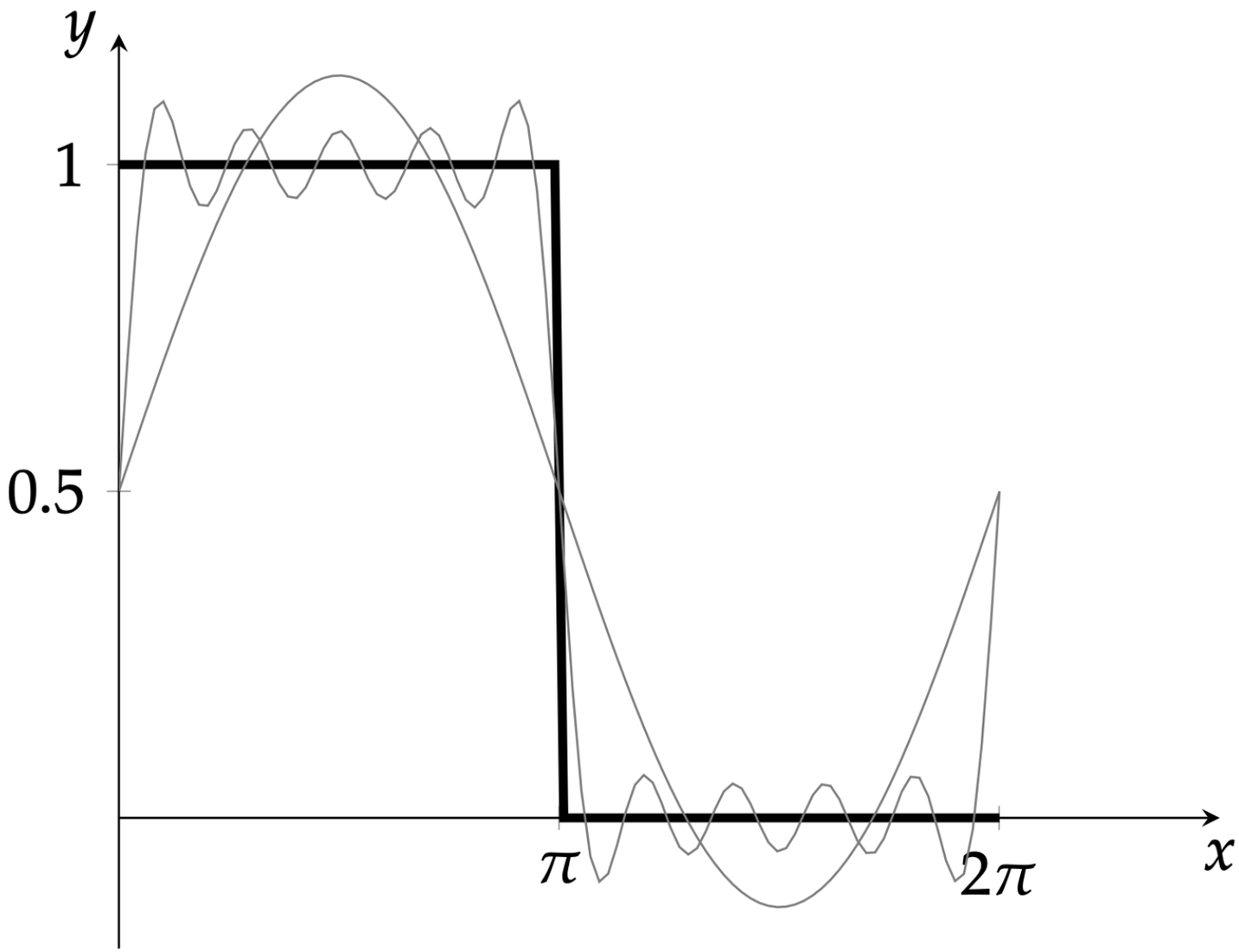
how? When it's so goofy?

Mr Fourier. That's how.

REMEMBER FOURIER SERIES?

can add periodic functions of varying frequencies and amplitudes

and approximate any functional shape



EPICYCLES ARE PERIODIC FUNCTIONS!

you can draw anything with epicycles

50

900

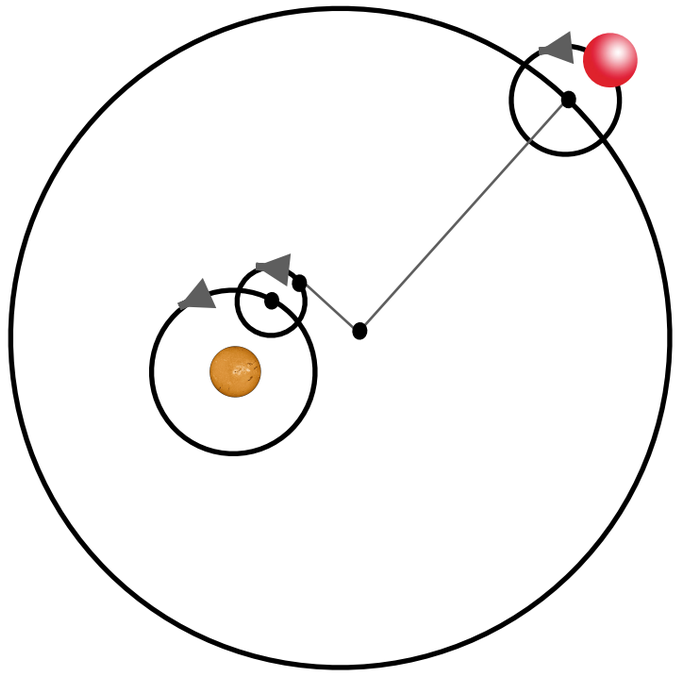
replicating ellipses? A walk in the park

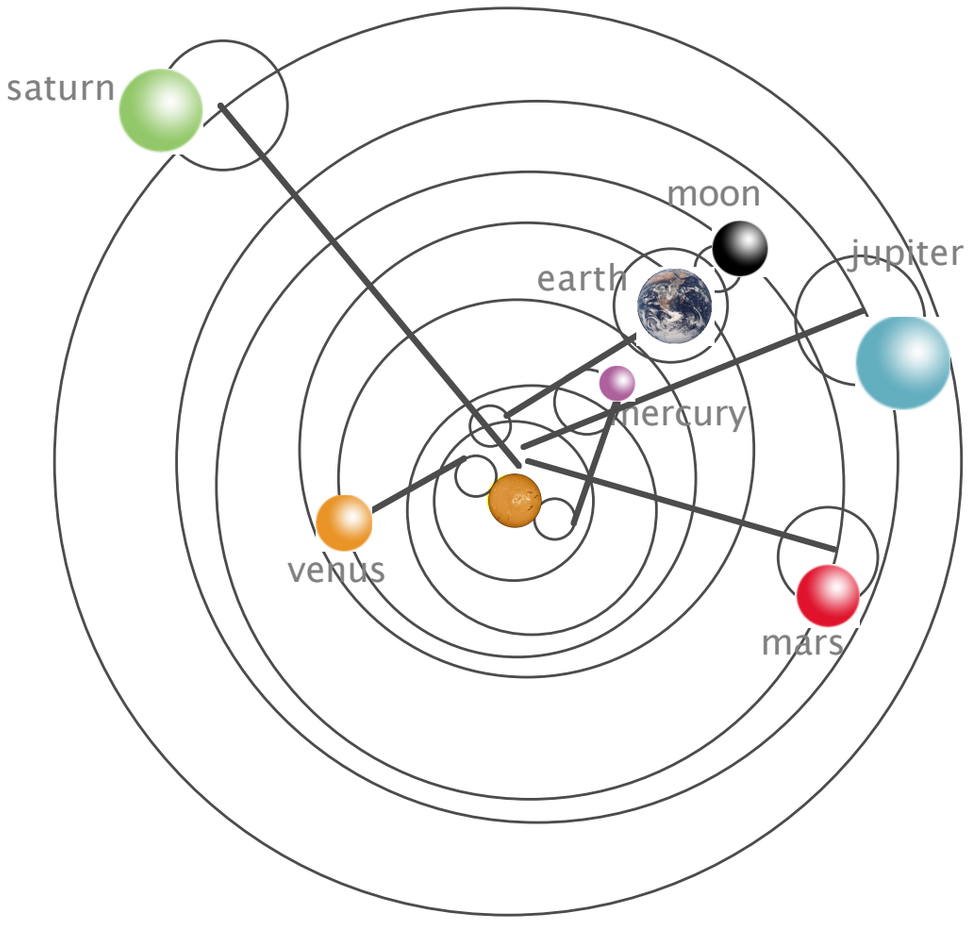
EPICYCLES REQUIRED FOR COPERNICUS

first and second anomalies taken care of in geocentricsm

but circles are note ellipses!

used epicycles





the earth now possessed 9 independent circular motions

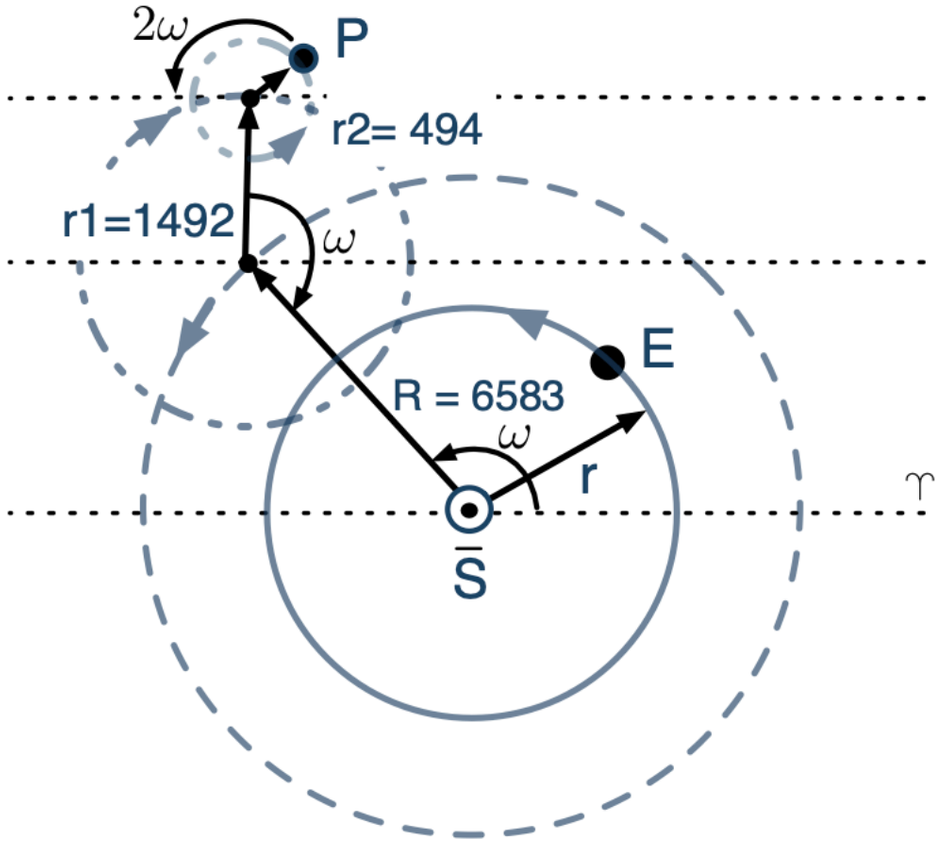
the center of Jupiter's orbit is outside of the orbit of Venus

Mercury's motion was…well, just bizarre - a rolling sphere inside another sphere in order to nearly simulate a (forbidden) straight line motion

ARABS INSTITUTED DOUBLE EPICYCLES

to get rid of the equant

yet achieve the precision of the equant-model



Not Arab's using double epicycle in a geocentric model

this is from *Commentariolus*...

a generic model for the outer planets

Copernicus borrowed a lot from the Arabs

ORDERING OF THE PLANETS

could have been determined by anyone since before Ptolemy!

but it required model-building of heliocentric behavior

I think this is one of two ways

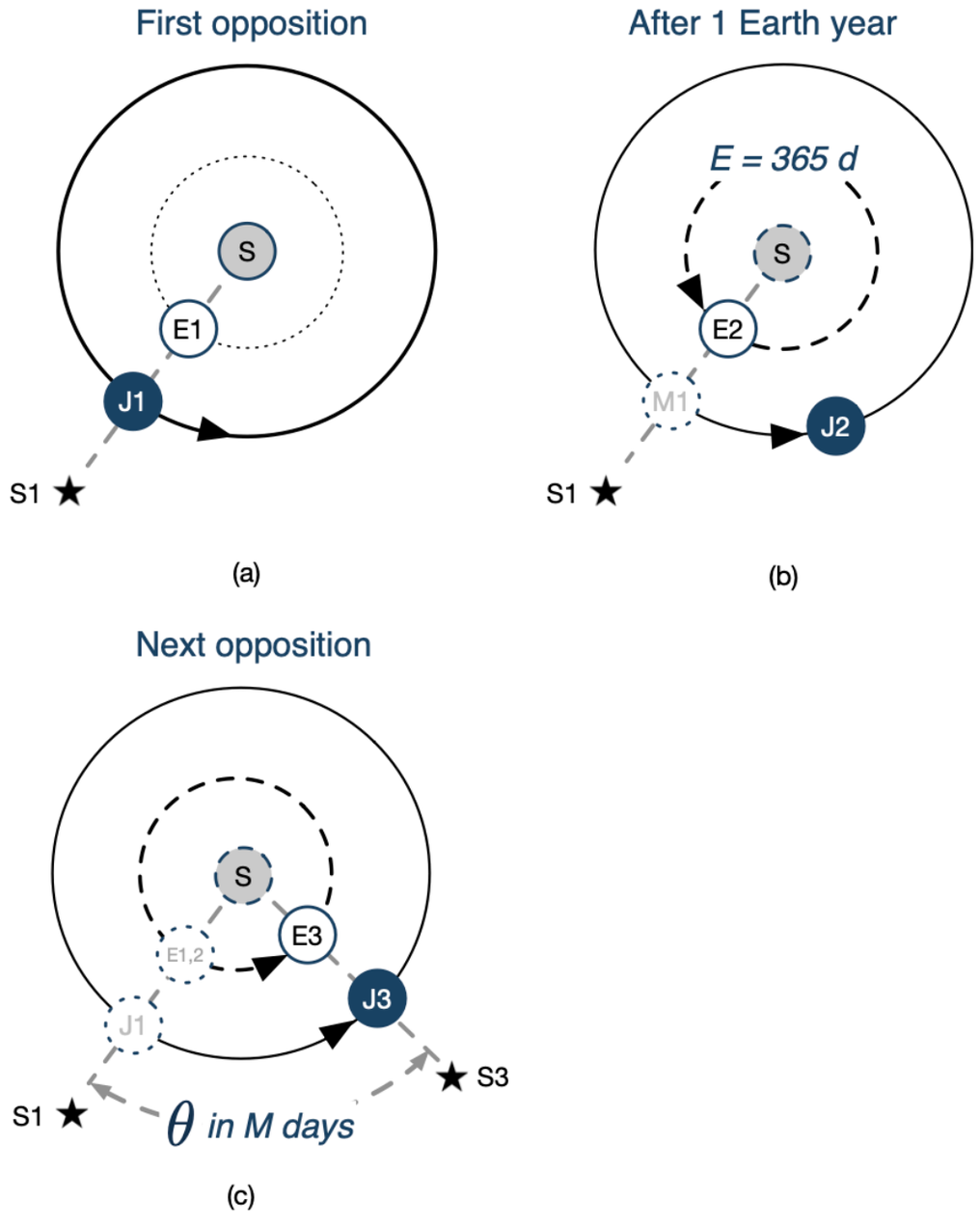
the other also gave distances in AU

He published the results in 1514

30 years before Revolutionibus

as a private letter

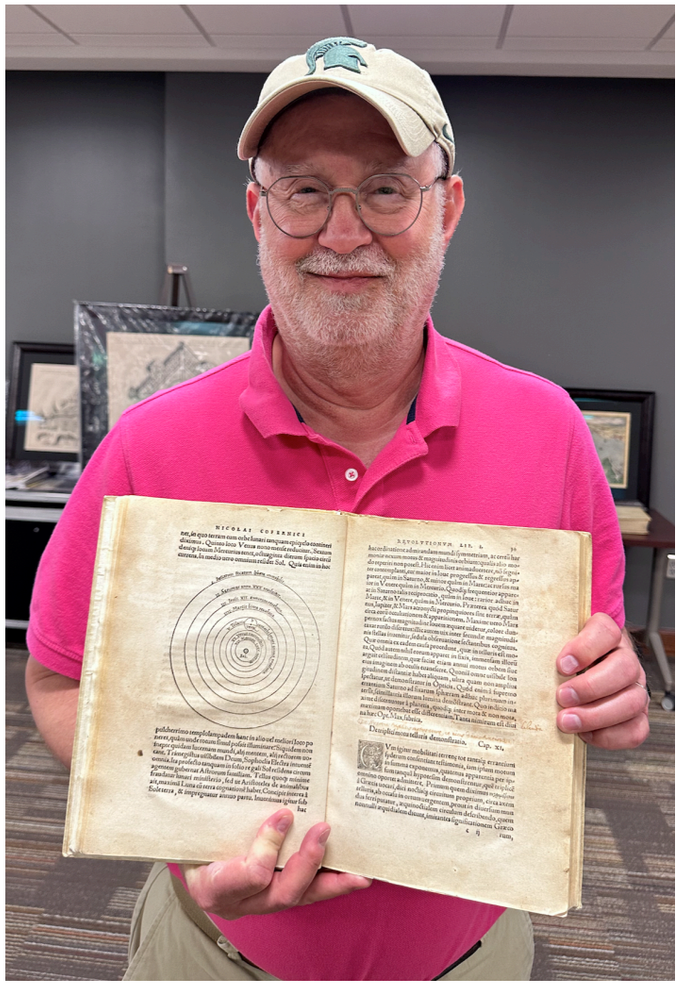
no details:



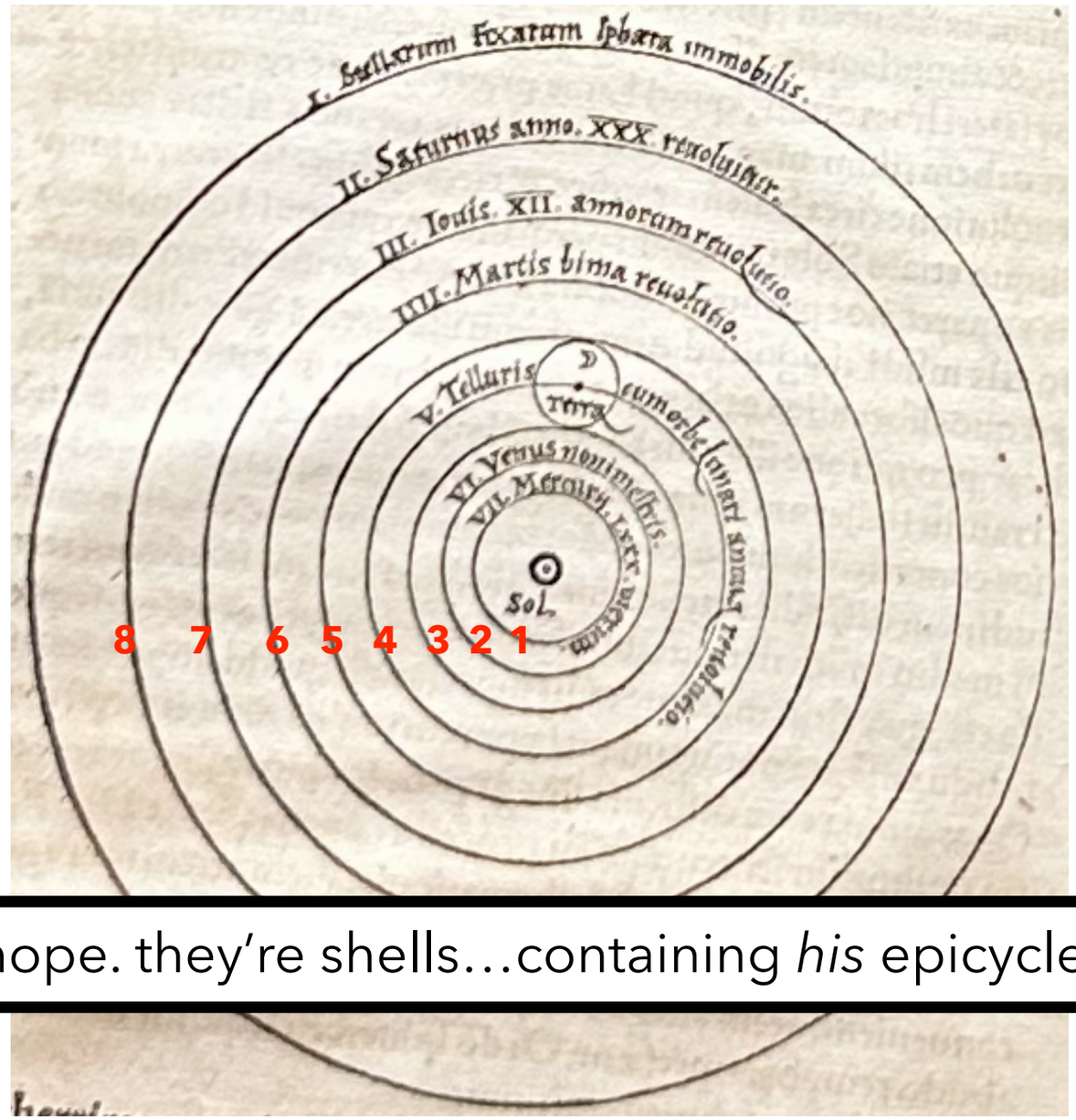
“years” for the planets…C was right

	Ptolemaic		*Comm.*	*Rev.*	Modern	Modern
Planet	**Synodic**	**zodiacal**	**sidereal**	**sidereal**	**synodic**	**sidereal**
Mercury	0.32	1	0.24	0.24	0.32	0.24
Venus	1.60	1	0.75	0.62	1.60	0.62
Earth	0.00	0	1	1.00	1.00	1.00
Mars	2.14	1.88	2.42	1.90	2.14	1.90
Jupiter	1.09	11.86	12	12.00	1.09	11.90
Saturn	1.04	29.46	30	30.00	1.04	29.50
Uranus					1.01	84.00
Neptune					1.01	164.80

MOST FAMOUS PICTURE IN ASTRONOMY?



7 stars
6 saturn
5 jupiter
4 mars
3 earth
2 venus
1 mercury



nope. they're shells…containing *his* epicycles

University of Oklahoma

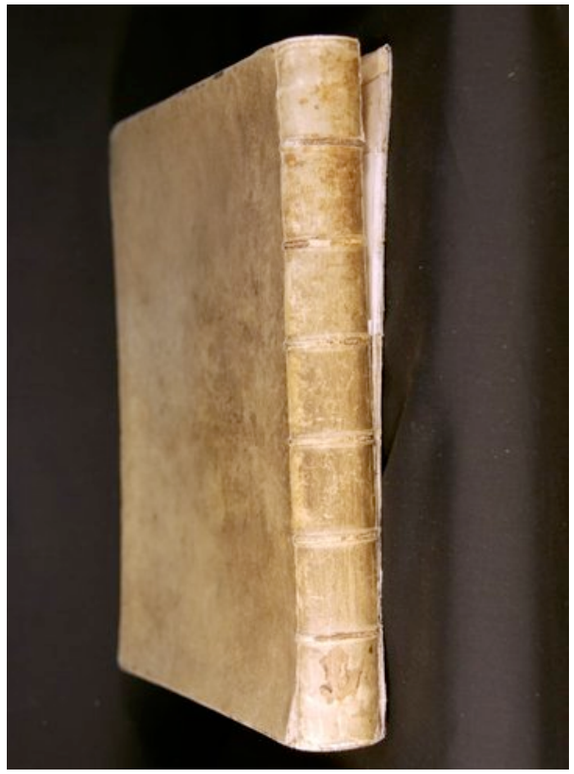
History of Sciences

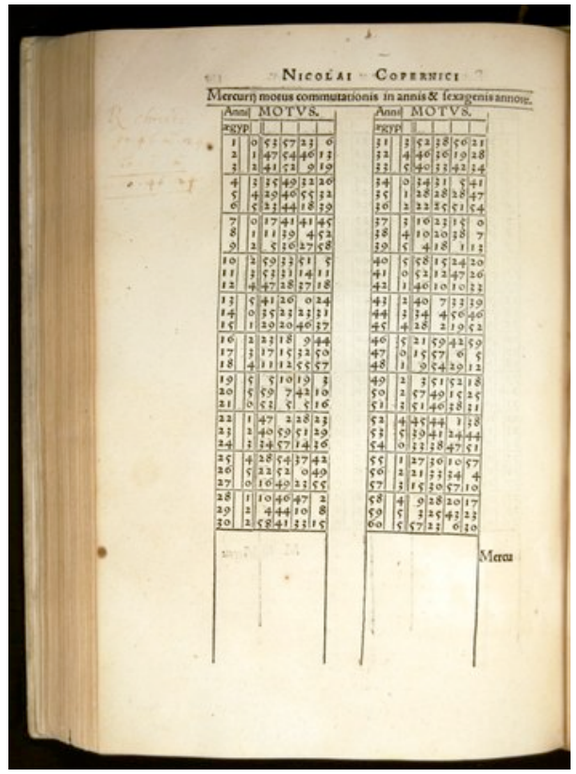
https://repository.ou.edu/uuid/0baac705-7c76-5866-a462-de86130dc733?solr_nav[id]=95eef91b6402247315a2&solr_nav[page]=0&solr_nav[offset]=2#page/18/mode/thumb

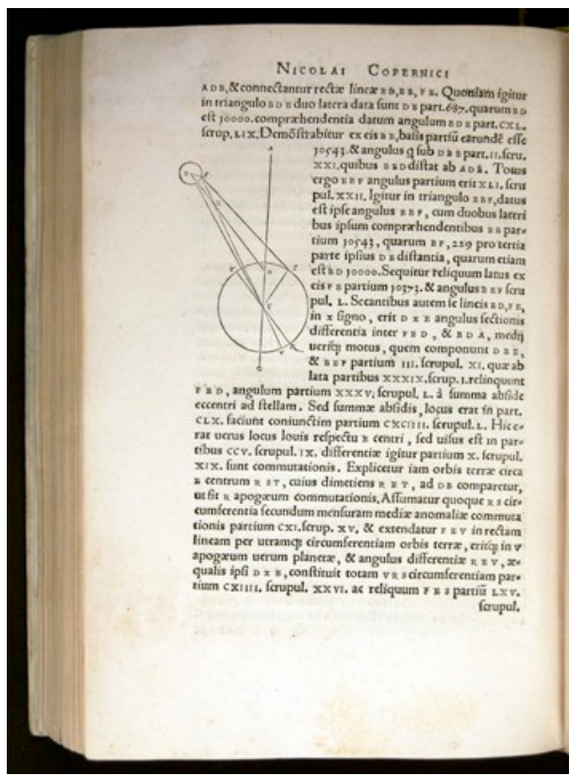
dense

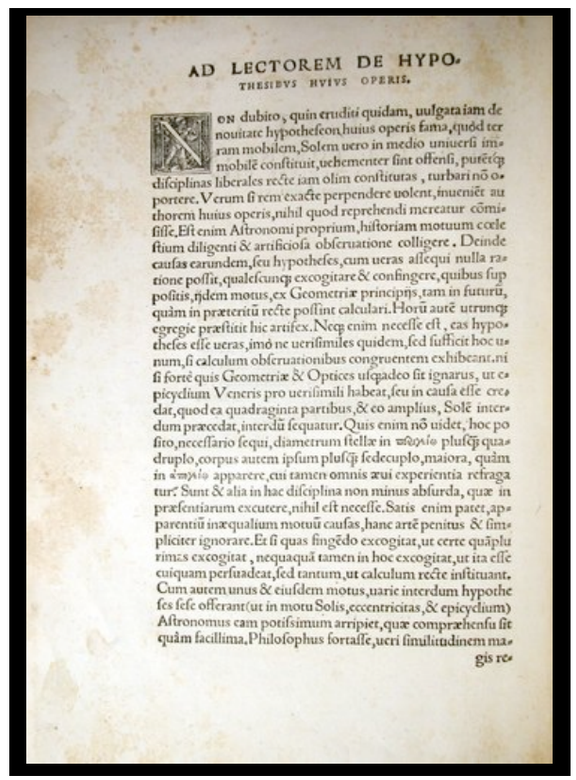
>500 pages of tables, graphs, complicated spherical geometry

and scandal









Since the newness of the hypotheses of this work–which sets the earth in motion and puts an immovable sun at the center of the universe–has already received a great deal of publicity, I have no doubt that certain of the savants have taken grave offense....the author of this work had done nothing which merits blame....this art is absolutely and profoundly ignorant of the causes of the apparent irregular movements...[this author] does not think them up in order to persuade anyone of their truth but only in order that they may provide a correct basis for calculation.

not Copernicus!

preface to *De revolutionibus*

...Your Holiness will perhaps not be greatly surprised that I have dared to publish my studies after devoting so much effort to working them out...you are rather waiting to hear from me ... I was impelled to consider a different system of deducing the motions of the universe's spheres... [previous astronomers'] experience was just like some one taking from various places hands, feet, a head, and other pieces, very well depicted, it may be, but not for the representation of a single person; since these fragments would not belong to one another at all, a monster rather than a man would be put together from them...This would not have happened to them, had they followed sound principles.

Copernicus: Preface to Pope Paul III

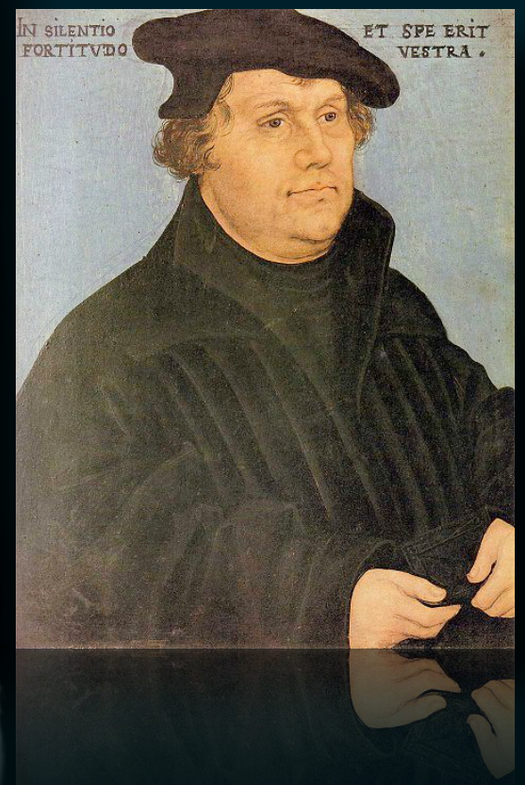
Why therefore should we hesitate any longer to grant to it (earth) the movement which accords naturally with its form, rather than put the whole world in a commotion...? And why not admit that the appearance of daily revolution belongs to the heavens, but the reality belongs to the Earth.

De revolutionibus

There is talk of a new astrologer who wants to prove that the earth moves and goes around instead of the sky... The fool wants to turn the whole art of astronomy upside-down.

However, as Holy Scripture tells us, so did Joshua bid the sun to stand still and not the earth.

Martin Luther



was any Pope concerned?

nope

special lecture for Clement VII

presenter got a book and inscription

Copernicus dedicated Revolutionibus to Paul III

When several years ago I heard your diligence unanimously praised, I began to feel an increasing fondness for you... I have been informed...that you have also created a new theory of the Universe according to which the Earth moves and the Sun occupies the basic and hence central position; ... and also computed the movements of the planets and set them out in tables, to the greatest admiration of all. Therefore, learned man, without wishing to be inopportune, I beg you most emphatically to communicate your discovery to the learned world, and to send me as soon as possible your theories about the Universe, together with the tables and whatever else you have pertaining to the subject... at my expense and send it to me. If you will do me these favors, you will find that you are dealing with a man who has your interests at heart, and wishes to do full justice to your excellence. Farewell.

Nicolaus Schoenberg, Cardinal of Capua

SHUNNED BY THE CHURCH?

He had a stroke.

Rheticus gave Copernicus the printed book on his deathbed

May 24, 1543