The Scientific Methods of Galileo

Arguing for a heliocentric system, and

a new study of motion

Waseda University, SILS,
Introduction to History and Philosophy of Science

Italy in the 16th century

Galileo Galilei (1564–1643)

- Born in Pisa, oldest of six children of a famous musician and composer. Had a monastic education.
- Never married, but had three children with his mistress.
- Worked as a professor of mathematics, University of Padua in Venice, and later mathematician and philosopher of the Medici court, Florence.
- Argued for the *realist* acceptance of the Copernican system.
- Developed a number of new sciences using a combination of *mathematics* and *experimentation*.

Bertini, 1858, Galileo demonstrating his telescope to the Duke of Venice

Galileo's Works

Galileo was a prolific writer, working in both Latin and Italian. He was regarded as having very good prose style.

Works: *The Starry Messenger* (*Sidereus Nuncius*, 1610; Latin), *Letters on Sunspots* (*Istoria e dimostrazioni intorno alle macchie solari e loro accidenti*, 1613, Italian), *Letter to the Grand Duchess Christina* (1615; pub. in 1636, Italian), *Dialogue Concerning the Two Chief World Systems* (*Dialogo sopra i due massimi sistemi del mondo*, 1632; Italian); *Discourses and Mathematical Demonstrations Relating to Two New Sciences* (*Discorsi e dimostrazioni matematiche intorno a due nuove scienze*, 1638; Italian).

The Starry Messenger, 1610

Galileo designed his own telescope and used it to make *new observations* of celestial bodies – in fact, to see things that no one had ever seen before.

- Mountains and valleys on the surface of the moon. (He calculated the hight of the tallest moon mountains.)
- Glow from the earth on the dark side of the moon.
- Many more stars than before. The details of the milky way.
- Satellites (moons) of Jupiter, which he named the Medician Stars.

- Later, he used the telescope to observe the phases of Venus.

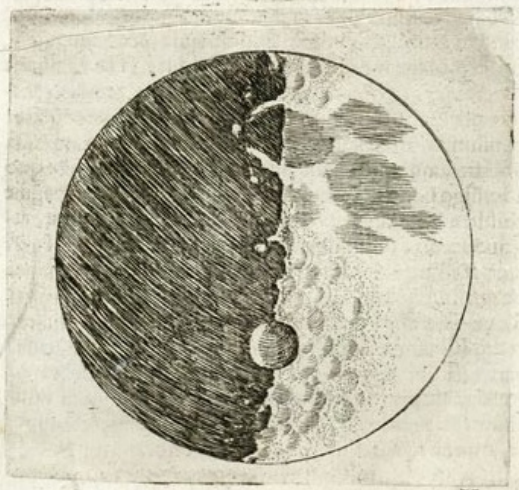
Galileo published the *Starry Messenger* just couple of months after he began his observations.

Galileo's own wash drawings of the lunar surface, found in his notes

Sidereus Nuncius, 1610

OBSERVAT. SIDEREAE

dum daturam. Depreſſiores inſuper in Luna cernuntur magnæ maculæ, quàm clariores plagæ; in illa enim tam creſcente, quam decreſcente ſemper in lucis tenebrarumque confinio, prominente hincindè circa ipſas magnas maculas contermini partis lucidioris; veluti in deſcribendis figuris obſeruauimus; neque depreſſiores tantummodo ſunt dictarum macularum termini, ſed æquabiliores, nec rugis, aut aſperitatibus interrupti. Lucidior verò pars maximè propè maculas eminet; adeò vt, & ante quadraturam primam, & in ipſa fermè ſecunda circa maculam quandam, ſuperiorem, borealem nempè Lunæ plagam occupantem valdè attollantur tam ſupra illam, quàm infra ingentes quædà eminentiæ, veluti appoſitæ præſeferunt delineationes.



Hæc

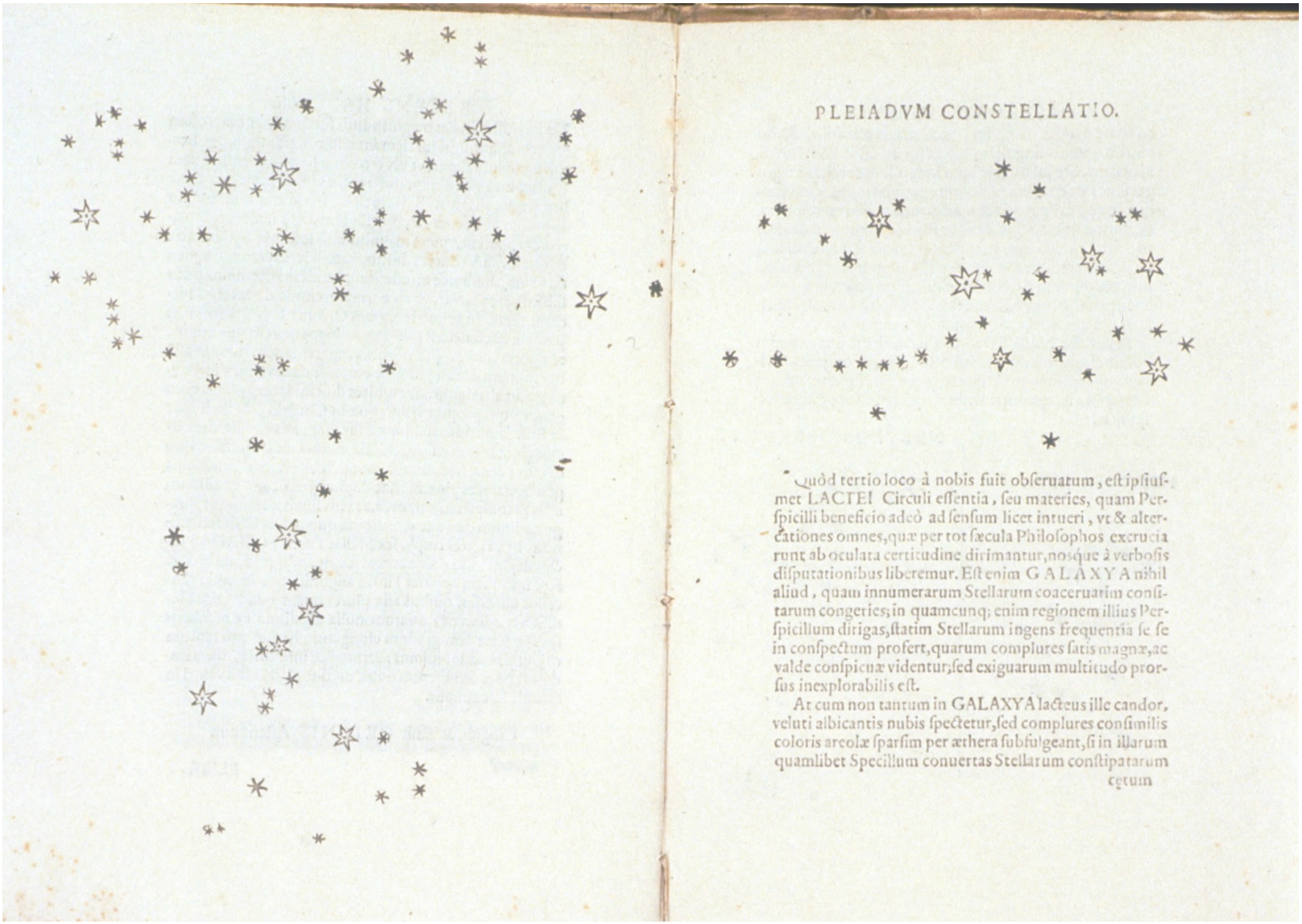
RECENS HABITAE. 10

Hæc eadem mãcula ante ſecundam quadraturam nigrioribus quibuſdam terminis circumuallata conſpicitur; qui tanquam altiſſima montium iuga ex parte Soli auerſa obſcuriores apparent, quà verò Solem reſpiciunt lucidiores extant; cuius oppoſitum in cauitatibus accidit, quarum pars Soli auerſa ſplendens apparet, obſcura verò, ac vmbroſa, quæ ex parte Solis ſita eſt. Imminuta deinde luminoſa ſuperficie, cum primum tota fermè dicta macula tenebris eſt obducta, clariora mõtium dorſa eminenter tenebras ſcandunt. Hanc duplicem apparentiam ſequentes figuræ commoſtrant.

C 2 Vnum

Printed engravings of the surface of the moon in the *Starry Messenger*.

Sidereus Nuncius, 1610

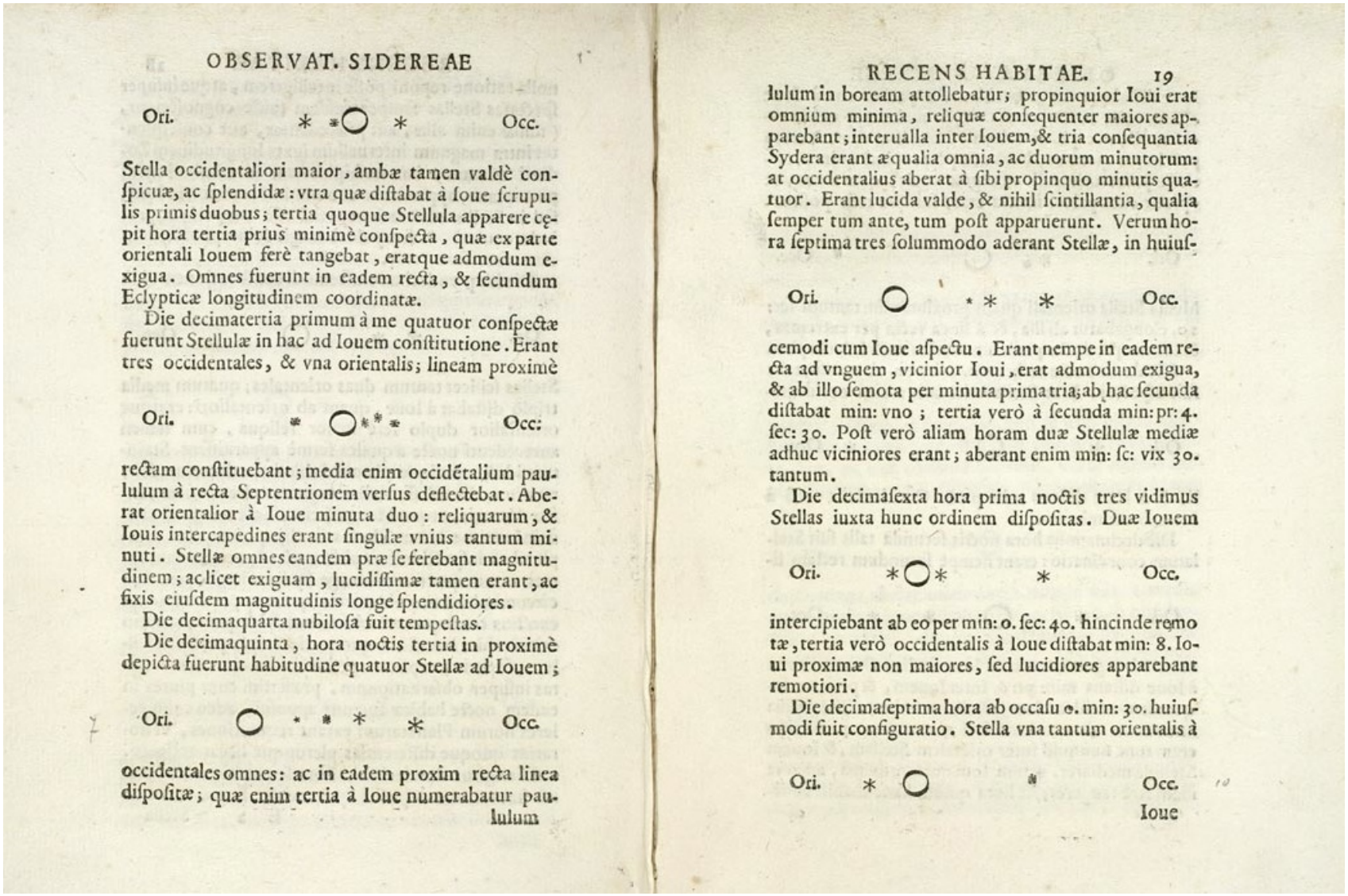


PLEIADVM CONSTELLATIO.

Quòd tertio loco à nobis fuit obſeruatum, eſt ipſiuſmet LACTEI Circuli eſſentia, ſeu materies, quam Perſpicilli beneficio adeò ad ſenſum licet intueri, vt & altercationes omnes, quæ per tot ſæcula Philoſophos excruciarunt ab oculata certitudine dirimantur, nosque à verboſis diſputationibus liberemur. Eſt enim GALAXYA nihil aliud, quam innumerarum Stellarum coaceruatim conſitarum congeries; in quamcunq; enim regionem illius Perſpicillum dirigas, ſtatim Stellarum ingens frequentia ſe ſe in conſpectum profert, quarum complures ſatis magnæ, ac valde conſpicuæ videntur; ſed exiguarum multitudo prorſus inexplorabilis eſt.

At cum non tantum in GALAXYA lacteus ille candor, veluti albicantis nubis ſpectetur, ſed complures conſimilis coloris areolæ ſparſim per æthera ſubfulgeant, ſi in illarum quamlibet Specillum conuertas Stellarum conſtipatarum cętum

The stars in the constellations Orion and the Big Dipper.



OBSERVAT. SIDEREAE

Ori. * *◯ * Occ.

Stella occidentaliori maior, ambæ tamen valdè conſpicuæ, ac ſplendidæ: vtra quæ diſtabat à Ioue ſcrupulis primis duobus; tertia quoque Stellula apparere cępit hora tertia prius minimè conſpecta, quæ ex parte orientali Iouem ferè tangebat, eratque admodum exigua. Omnes fuerunt in eadem recta, & ſecundum Eclypticæ longitudinem coordinatæ.

Die decimatertia primum à me quatuor conſpectæ fuerunt Stellulæ in hac ad Iouem conſtitutione. Erant tres occidentales, & vna orientalis; lineam proximè

Ori. * ◯ * * Occ:

rectam conſtituebant; media enim occidẽtalium paulum à recta Septentrionem verſus deflectebat. Aberat orientalior à Ioue minuta duo: reliquarum, & Iouis intercapedines erant ſingulæ vnius tantum minuti. Stellæ omnes eandem præ ſe ferebant magnitudinem; ac licet exiguam, lucidiſſimæ tamen erant, ac fixis eiuſdem magnitudinis longe ſplendidiores.

Die decimaquarta nubiloſa fuit tempeſtas.

Die decimaquinta, hora noctis tertia in proximè depicta fuerunt habitudine quatuor Stellæ ad Iouem;

Ori. ◯ * * * * Occ.

occidentales omnes: ac in eadem proxim recta linea diſpoſitæ; quæ enim tertia à Ioue numerabatur paulum

RECENS HABITAE. 19

lulum in boream attollebatur; propinquior Ioui erat omnium minima, reliquæ conſequenter maiores apparebant; interualla inter Iouem, & tria conſequantia Sydera erant æqualia omnia, ac duorum minutorum: at occidentalius aberat à ſibi propinquo minutis quatuor. Erant lucida valde, & nihil ſcintillantia, qualia ſemper tum ante, tum poſt apparuerunt. Verum hora ſeptima tres ſolummodo aderant Stellæ, in huiuſ-

Ori. ◯ * * * Occ.

cemodi cum Ioue aſpectu. Erant nempe in eadem recta ad vnguem, vicinior Ioui, erat admodum exigua, & ab illo ſemota per minuta prima tria; ab hac ſecunda diſtabat min: vno; tertia verò à ſecunda min: pr: 4. ſec: 30. Poſt verò aliam horam duæ Stellulæ mediæ adhuc viciniores erant; aberant enim min: ſc: vix 30. tantum.

Die decimaſexta hora prima noctis tres vidimus Stellas iuxta hunc ordinem diſpoſitas. Duæ Iouem

Ori. *◯* * Occ.

intercipiebant ab eo per min: 0. ſec: 40. hincinde remotæ, tertia verò occidentalis à Ioue diſtabat min: 8. Ioui proximæ non maiores, ſed lucidiores apparebant remotiori.

Die decimaſeptima hora ab occaſu 0. min: 30. huiuſmodi fuit configuratio. Stella vna tantum orientalis à

Ori. * ◯ * Occ.

Ioue

Images of the moons of Jupiter. (There are around 40 pages of these.)

The Phases of Venus

Galileo was able to see that Venus has phases, just like the Moon. And, presumably, just like the Earth.

This became yet another argument against the special status of the Earth.

The geometry of phases predicted by the Ptolemaic and the Copernican systems can be compared to the observations.

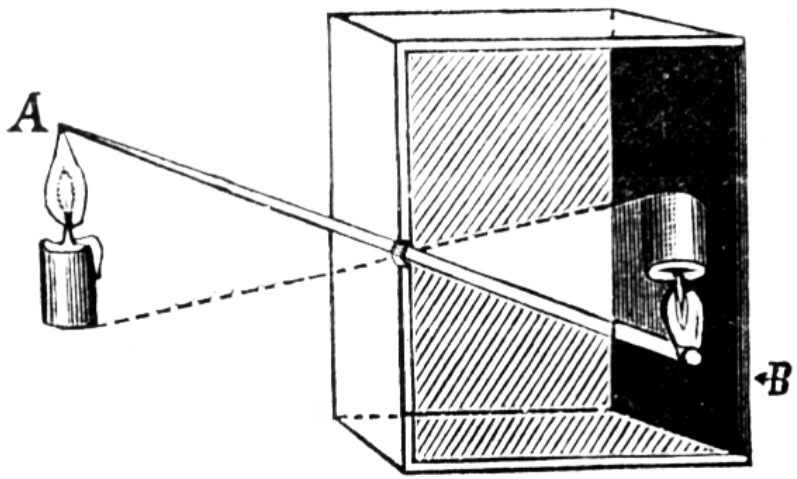
Letters on Sunspots, 1612

Following the publication of a few books on sunspots by German authors (Fabricius, Scheiner, etc.), Galileo published two letters on his own observations and ideas.

They used *camera obscura* techniques to magnify and view the surface of the sun.

Galileo argued that there are actual spots on the surface of the sun.

This was another argument against the special status of the heavenly bodies.

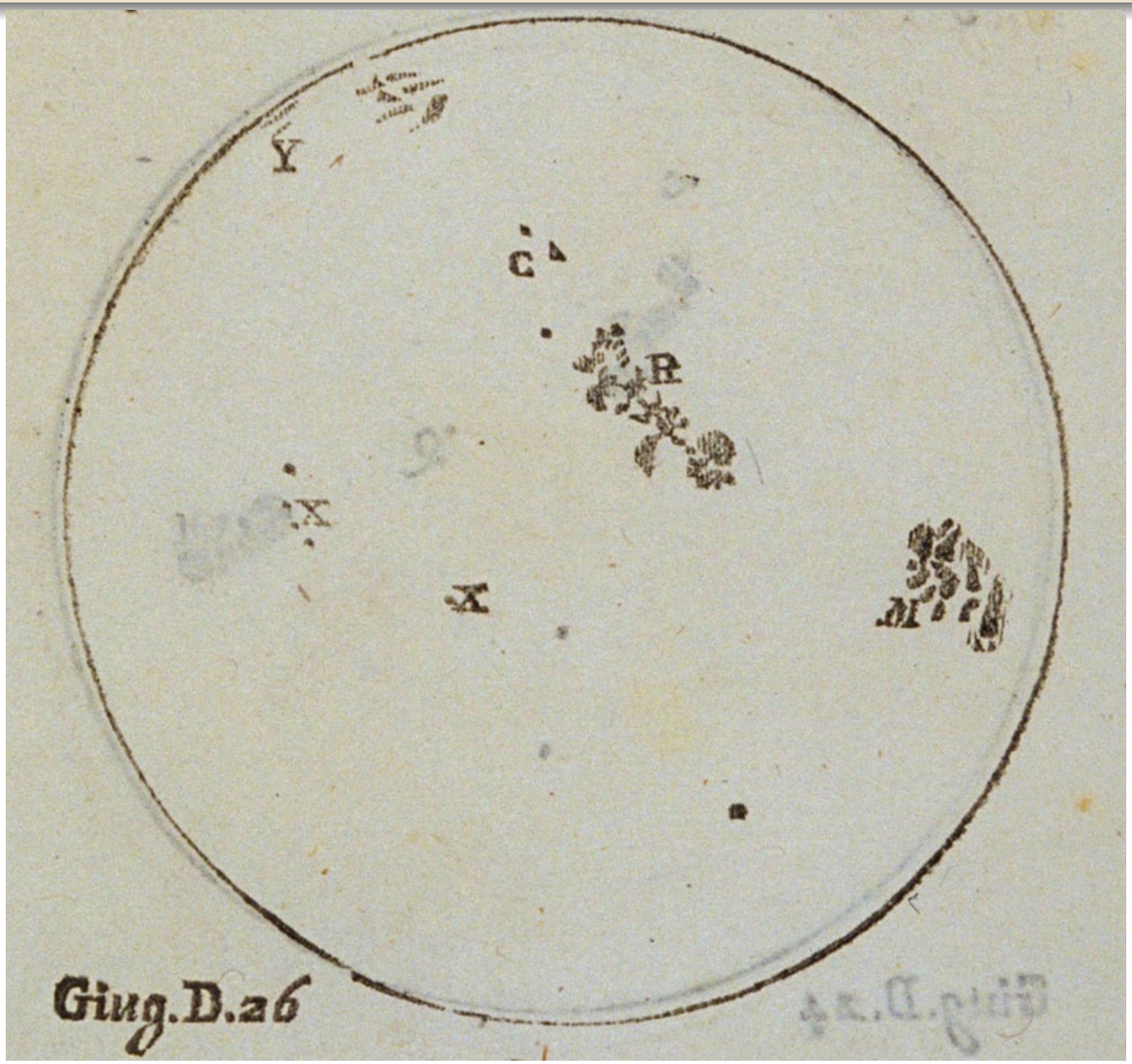


A simple camera obscura

Letters on Sunspots, 1612

Letters on Sunspots, 1612

Letters on Sunspots, 1612



Two Chief Systems of the World, 1632

- A highly literary dialog, in Italian.
- Galileo used three characters to discuss cosmology. *Salviati* argued for the Copernican system, *Simplicio* argued for the Aristotelian/Ptolemaic system, *Sagredo* who starts out neutral, but, of course, becomes convinced of the Copernican system.
- Salviati argues that the new discoveries (surface of the moon, sunspots, moons of Jupiter, phases of Venus, etc.) all contradict various predictions of the old system but can be explained in terms of the new system.
  - The extended argument uses a combination of *disconfirming and confirming reasoning*.
- The publication of this book cost Galileo his freedom.

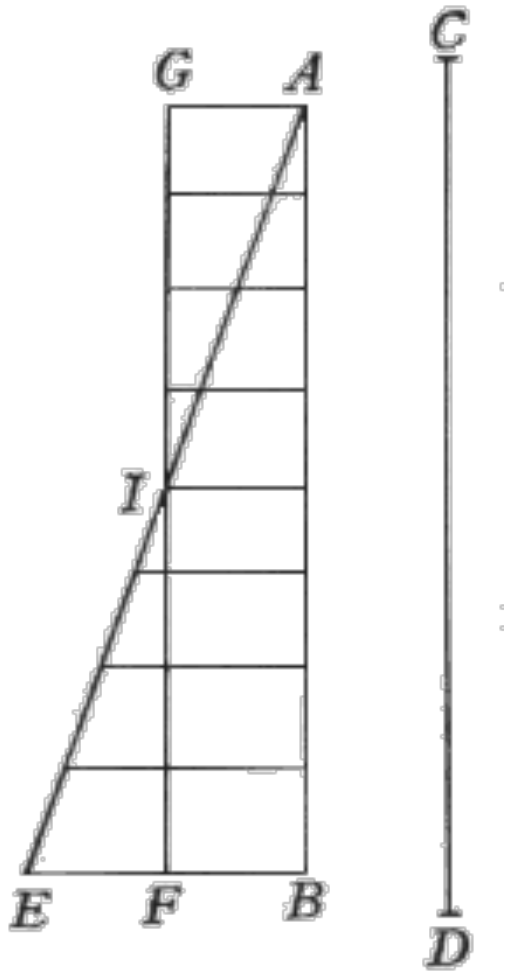
Two New Sciences, 1638

- Published while Galileo was under house arrest.
- Dealt with the topics of *strength of materials*, and *bodies in motion*.
- Book II was a kinematical study of falling bodies and projectiles.
- Most importantly, Galileo developed *mathematical* methods for showing how falling bodies accelerate (mathematically, but not conceptually, equivalent to $d = 1/2gt^2$), and that projectiles move in parabolas.
  - These methods were based on classical Greek *geometry* and *ratio theory*, and were, hence, rather different from modern algebraic and analytical approaches.

Falling Bodies

Galileo used an inclined plane apparatus to deduce a law of falling bodies.

Where line AB represents the time, t, and line EB the final velocity, v_f, then the velocity at any point can be understood as the line parallel to EB, and the triangle ABE can be understood as the distance traversed – that is, $d = \frac{1}{2}vt$.

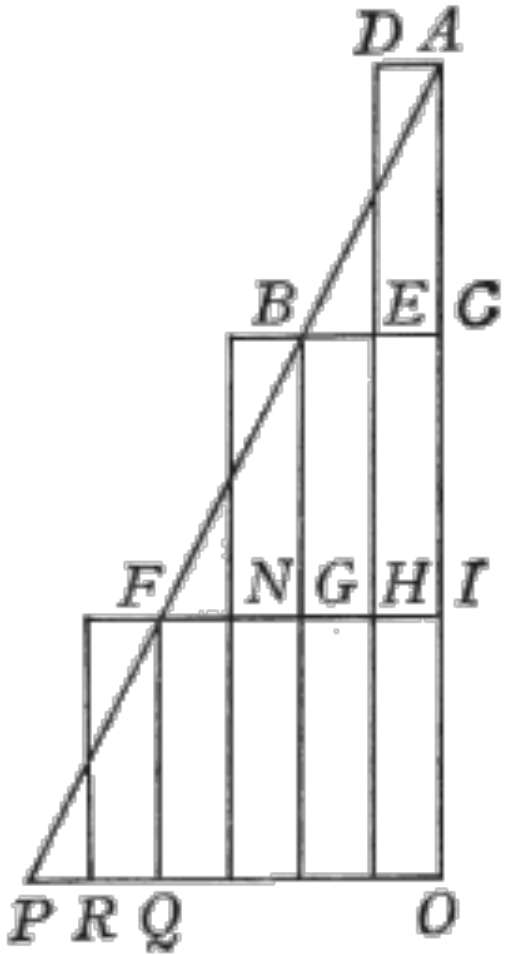


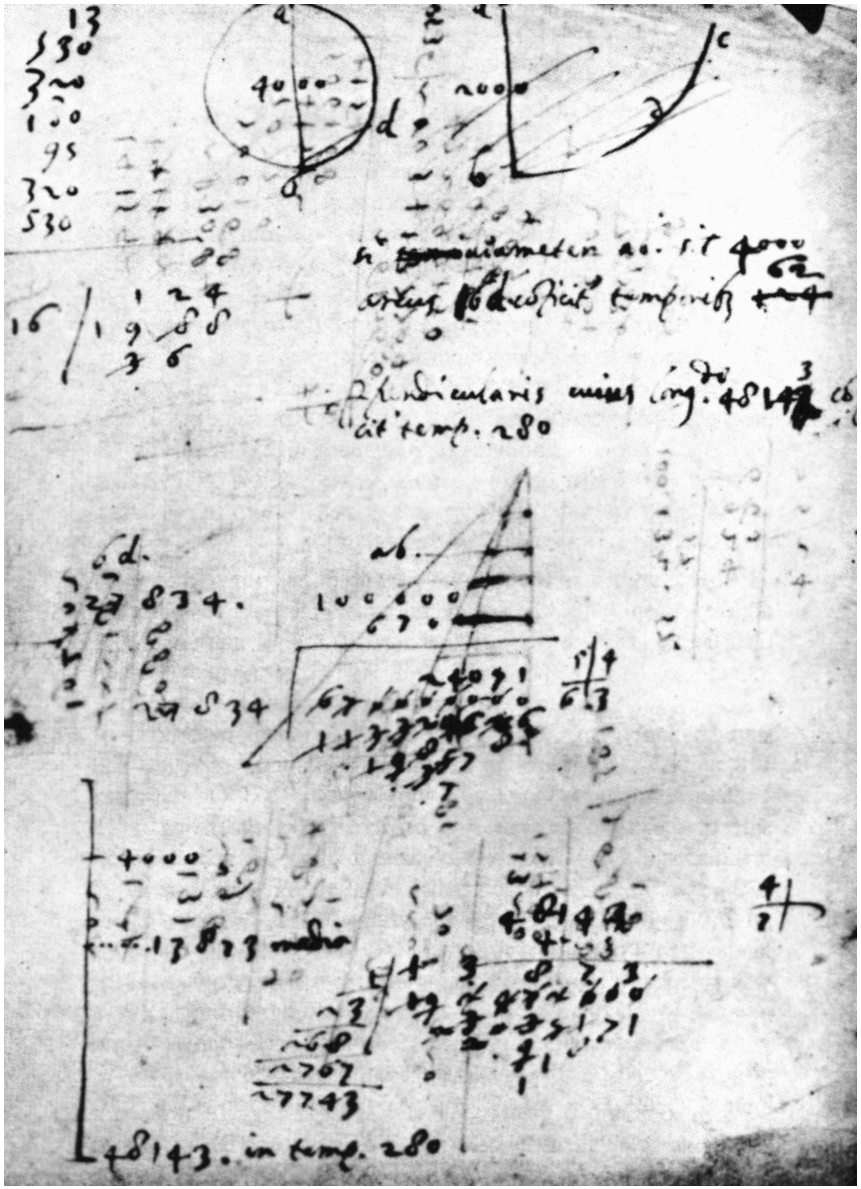
Acceleration of Falling Bodies

Galileo used this model to study how falling bodies accelerate.

He showed that in equal time-intervals the body will traverse distances in the following series 1, 3, 5, 7, 9, …

Note that this is a rather different conception than our modern formulation, $d = 1/2gt^2$, although they are mathematically equivalent.

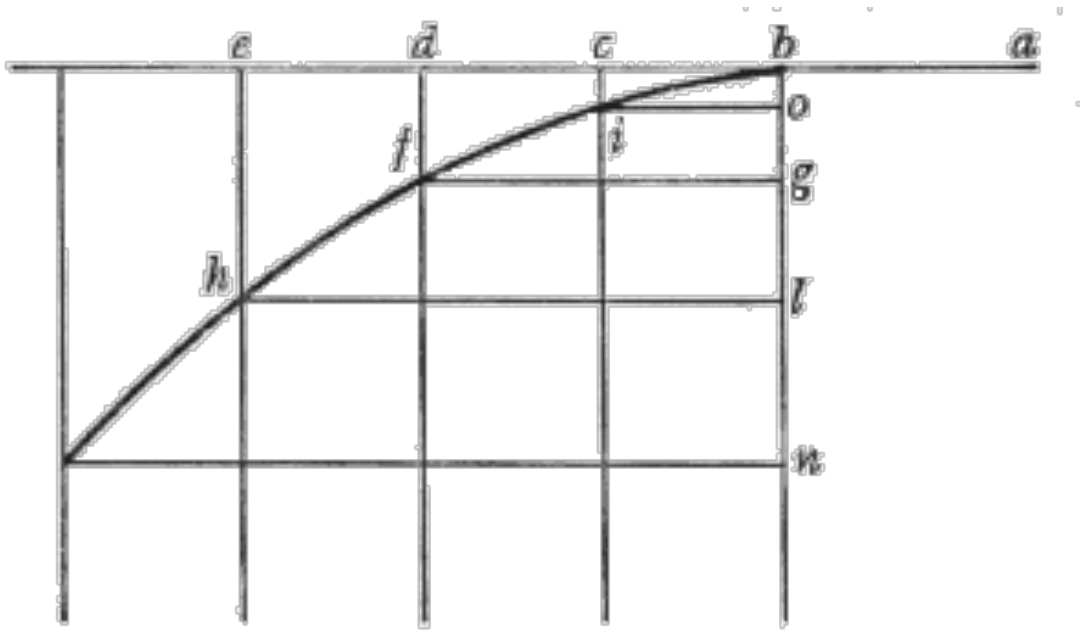


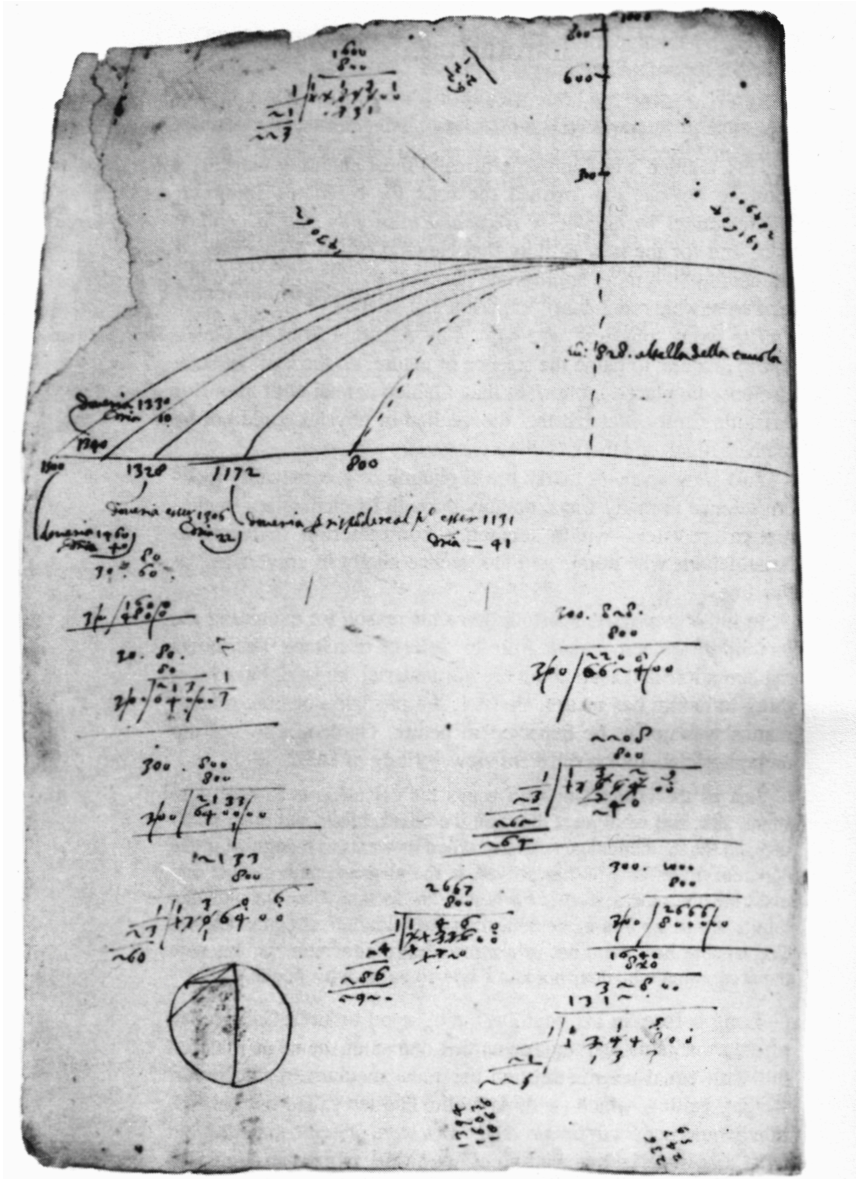


A page from Galileo's notes dealing with the acceleration of falling bodies.

Projectile Motion

Galileo then showed that if a motion is composed of constantly accelerating motion down and constant motion in a straight line, it will produce a parabola.





A page from Galileo's notes treating projectile motion

Overview

Galileo argued for the *reality* of the Copernican system – that his discoveries proved that the Aristotelian cosmos was false.

- The Moon has a surface like the Earth; so, the Earth is *physically* like a heavenly body.
- There are moons around Jupiter; so, the Earth is *physically* like another planet.
- The Sun had spots; so, the heavenly bodies are not perfect.
- Venus receives its light from the sun; the geometry of its phases agree with predictions from the Copernican system.

Galileo established a new *mathematical* science of motion, which would form part of the core of Newton's theory of motion.

- He argued for the existence of inertial systems – such as a moving ship, or galloping horse, in which the parts of the system are stationary relative to one another.
- He argued that bodies in motion could be modeled with well-known geometric curves.