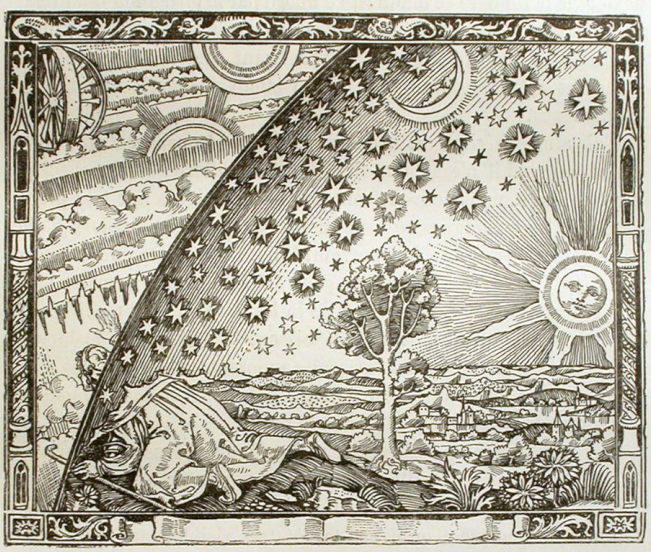
Boldly Explore
Camille Flammarion (1888)

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LA FORME DU CIEL. 163

de l'extrémité rouge du spectre solaire, et réfléchit au contraire les rayons bleus ; mais cette différence n'est sensible que lorsque la lumière traverse de grandes masses d'air. Les montagnes lointaines se nuancent d'une teinte bleuâtre due à cette réflexion des particules de l'air et surtout de la vapeur d'eau qui s'interpose entre ces montagnes et l'observateur. Une expérience de Hassenfratz prouve aussi que le rayon bleu est réfléchi avec plus de force. En effet, plus la couche

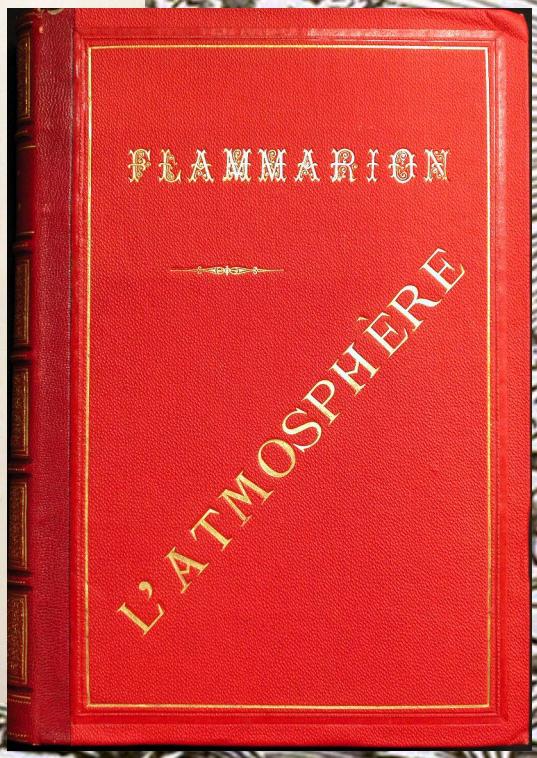


Un missionnaire du moyen âge raconte qu'il avait trouvé le point où le ciel et la Terre se touchent...

atmosphérique qu'un rayon traverse est épaisse, plus les rayons bleus disparaissent pour laisser la place aux rouges ; or, quand le soleil est près de l'horizon, le rayon parcourt une plus grande épaisseur d'air : aussi cet astre nous paraît-il rouge, pourpre ou jaune. Les rayons bleus manquent souvent aussi dans les arcs-en-ciel qui apparaissent peu de temps avant le coucher du Soleil.

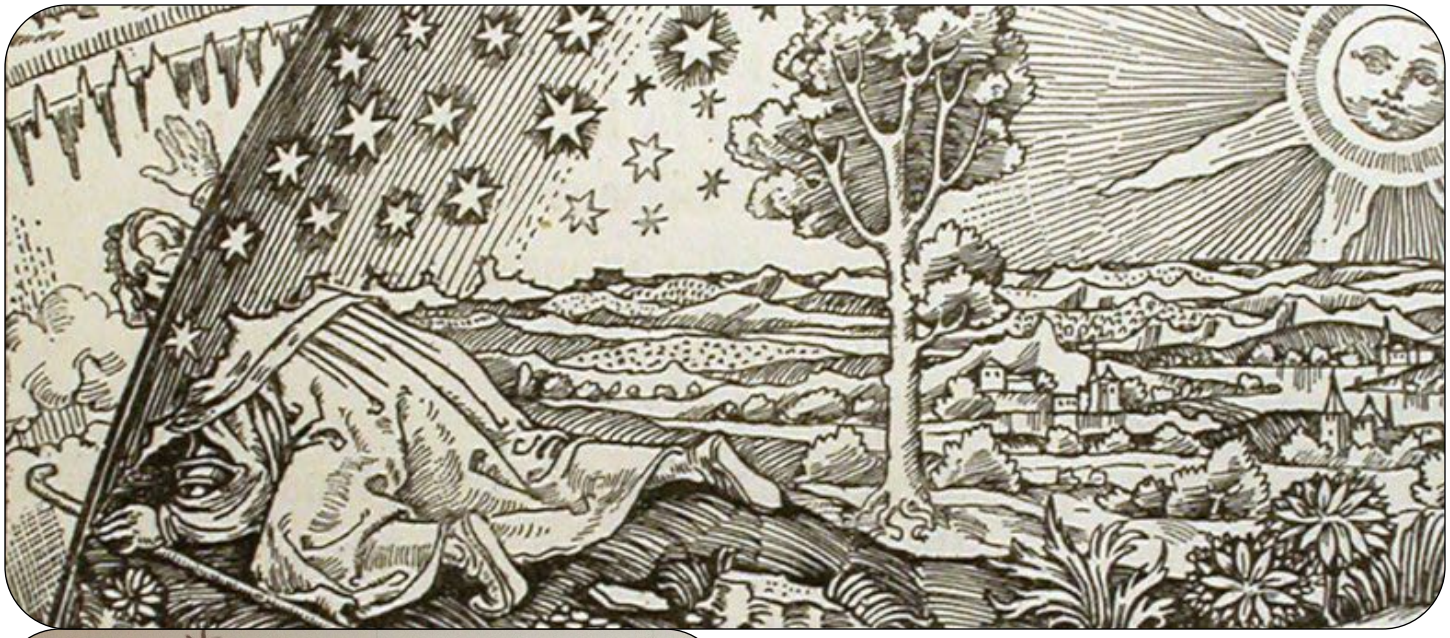
Nous verrons plus loin que c'est la vapeur d'eau répandue dans l'air qui joue le rôle principal dans cette réflexion de la lumière à laquelle est dû l'azur du ciel aussi bien que la clarté diffuse du jour.

Tout récemment, John Tyndall, le savant professeur anglais, vient



Camille Flammarion, *L'Atmosphère* (Paris, 1888)

Where will the quest of discovery lead you?







Boldly Explore: Camille Flammarion (1888)

Science is a quest of discovery, the challenge of boldly exploring where no one has gone before. That is the appeal and rhetorically durable theme which has made this woodcut so appealing.

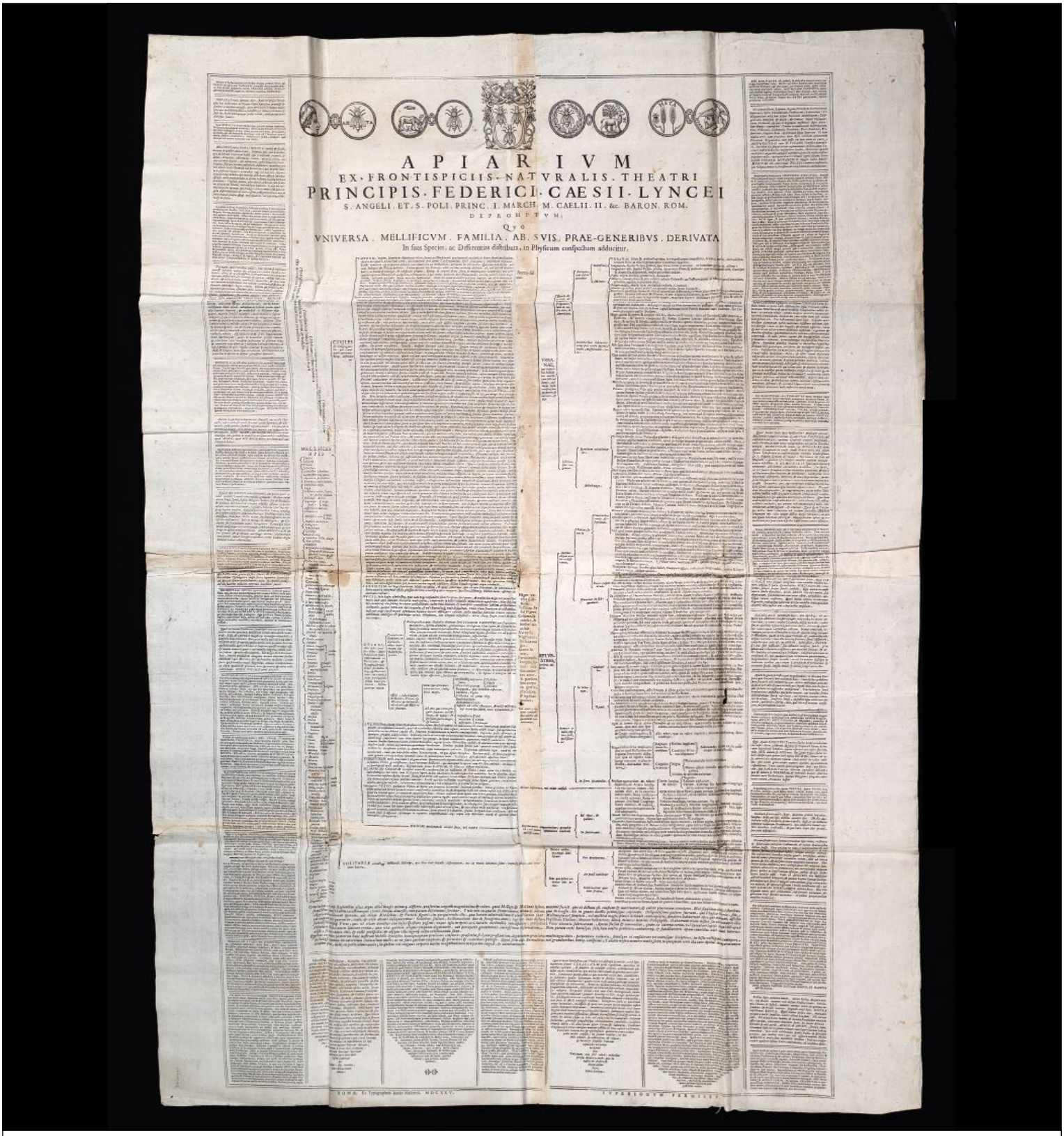
Many have reprinted this illustration through the years, sometimes without knowing its original source. It first appeared in this popular work on meteorology. Flammarion was an astronomer and popular science writer who worked at the Juvissy Observatory in Paris. He was mistaken in his belief that scientists, writers and theologians in the Middle Ages and Renaissance regarded the Earth as flat.

This iconic image bookends *Galileo's World* at the National Weather Center. The exhibit opens with the book and ends with a modern colorized version above cases of current meteorological instruments. Scientists exploring space, Earth and sky today exemplify the same creativity, resourcefulness and determination to explore new worlds of knowledge as the figure in the woodcut. Susanna J. Magruder has provided the colorized version, so create your own wall graphic or put it on a t-shirt or coffee mug!

Kerry Magruder and Susanna J. Magruder

Apiarium (1625)

First published observations
with a microscope



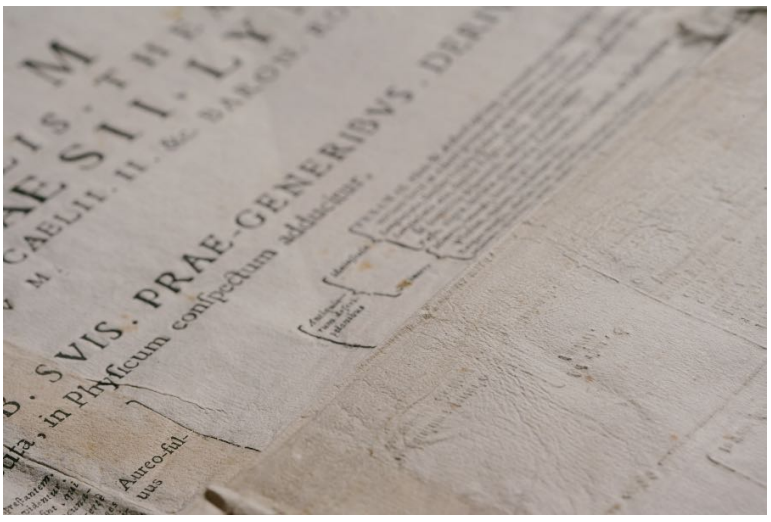
Francesco Stelluti and Federigo Cesi, *Apiarium* (1625), "On Bees."

Classic Source. 17th century. Region: North America, Italy. Biology, Natural History, Medicine.

What is it like to reveal the wonders and marvels of the very small?







"I have contemplated a great many animals with infinite admiration; among them, the flea is most horrible, the mosquito and the moth are beautiful; and with great satisfaction I have seen how flies and other tiny creatures can walk attached to mirrors, and even upside down."

Galileo, letter to Cesi, 1624

Galileo and the Academy of the Lynx were responsible for the first published report of observations made with a microscope (*Apiarium*, 1625), as well as for the telescope (*Sidereus nuncius*, 1610).

At the same time Galileo was making his telescopic discoveries, he was also experimenting with lenses to magnify the small. Another member of the Lynx, Johann Faber, named Galileo's new instrument the "microscope."

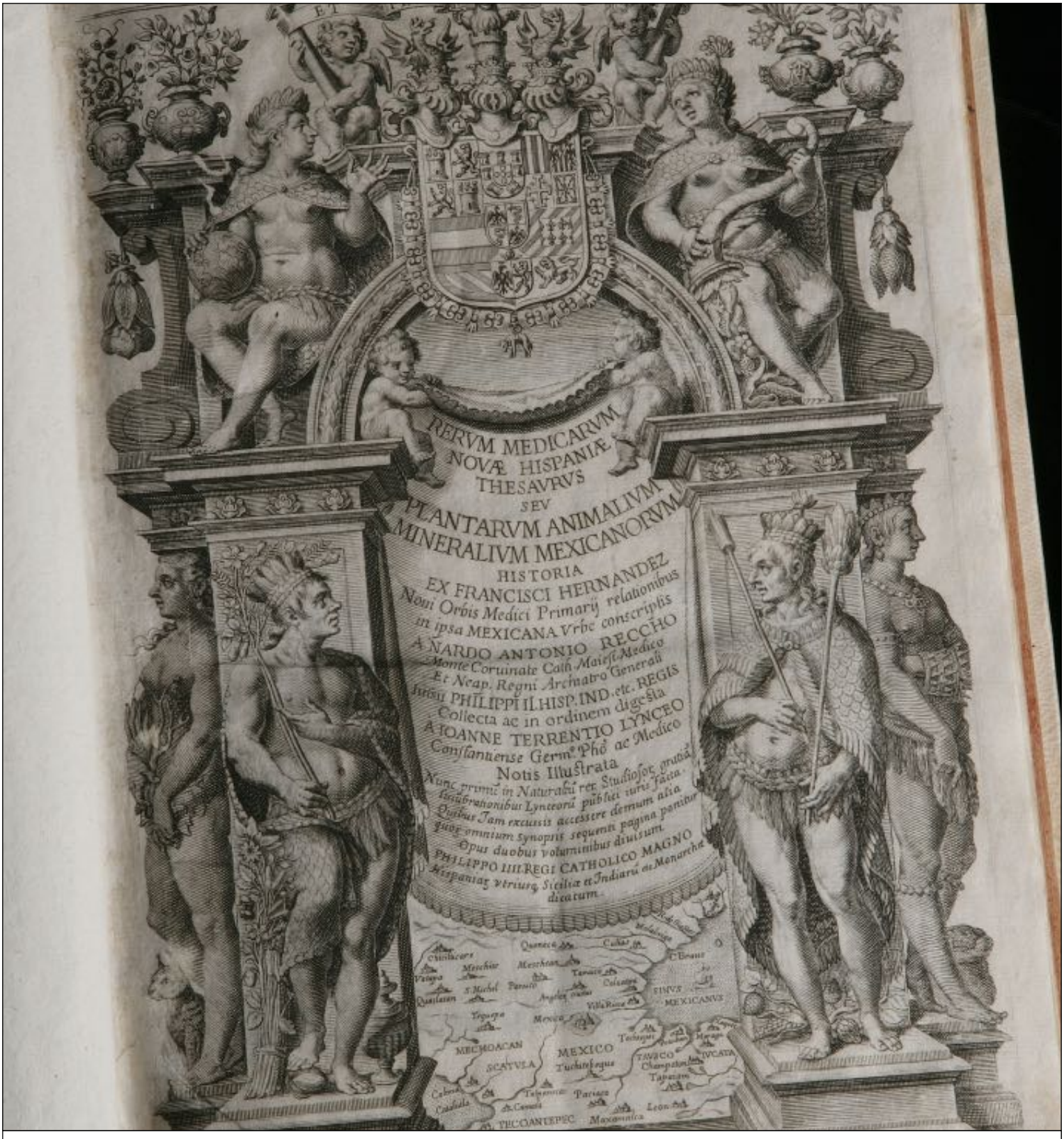
In antiquity, the lynx was renowned for possessing sharp eyesight at night. The founder of the Academy of the Lynx, Federigo Cesi, believed that the eyes of the Lynx would peer more deeply into the secrets of nature than ever before. The keen eyes of the Academy of the Lynx stretched the boundaries of European thought in the life sciences just as with Galileo's discoveries in the physical sciences.

Kerry Magruder

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Hernandez (1651)

"A New Natural History of the Plants,
Animals and Minerals of Mexico"



Francisco Hernandez, *Nova plantarum, animalium et mineralium Mexicanorum historia* (Rome, 1651)

Classic Source. 16th-17th centuries. North America, Italy. Biology, Natural History, Medicine, Colonialism.

How did the natural knowledge of Native Americans shape European science?



> *"In the last few days, when I was in the house of His Excellency the Marquis Cesi, I saw the pictures of 500 Indian plants, and I was expected to affirm either that this or that one was a fiction (denying that such plants were to be found in the world)…, yet neither I nor anyone else present knew their qualities, virtues and effects."*
>
> —Galileo to Piero Dini in Rome, May 21, 1611

The king of Spain commissioned a physician, Francisco Hernandez, to compile Native American plant and animal knowledge. In the 1580's, Hernandez worked closely with Aztec artists and physicians in central Mexico, before sending his manuscript back to Spain. The Hernandez manuscript, long unpublished, became avidly sought after as a rumored guide to "the fountain of youth."

The Academy of the Lynx, founded by Federico Cesi, counted Galileo among its members along with some of the leading naturalists of the day. When Cesi acquired the Hernandez manuscript, they began preparing commentary and approximately 800 woodcut illustrations for the work. They retained the Nahuatl names.

Many believed that cures for every disease lay hidden in the natural resources of the world. It was part of the divine calling of physicians to discover those cures, develop them, and then use them to care for others and remediate the harmful effects of the Fall. This widespread anticipation of the coming restoration of all things underlay the excitement aroused by increasing European awareness of Indigenous botanical and medical knowledge, although exploratory expeditions were grievously tainted by colonial exploitation.

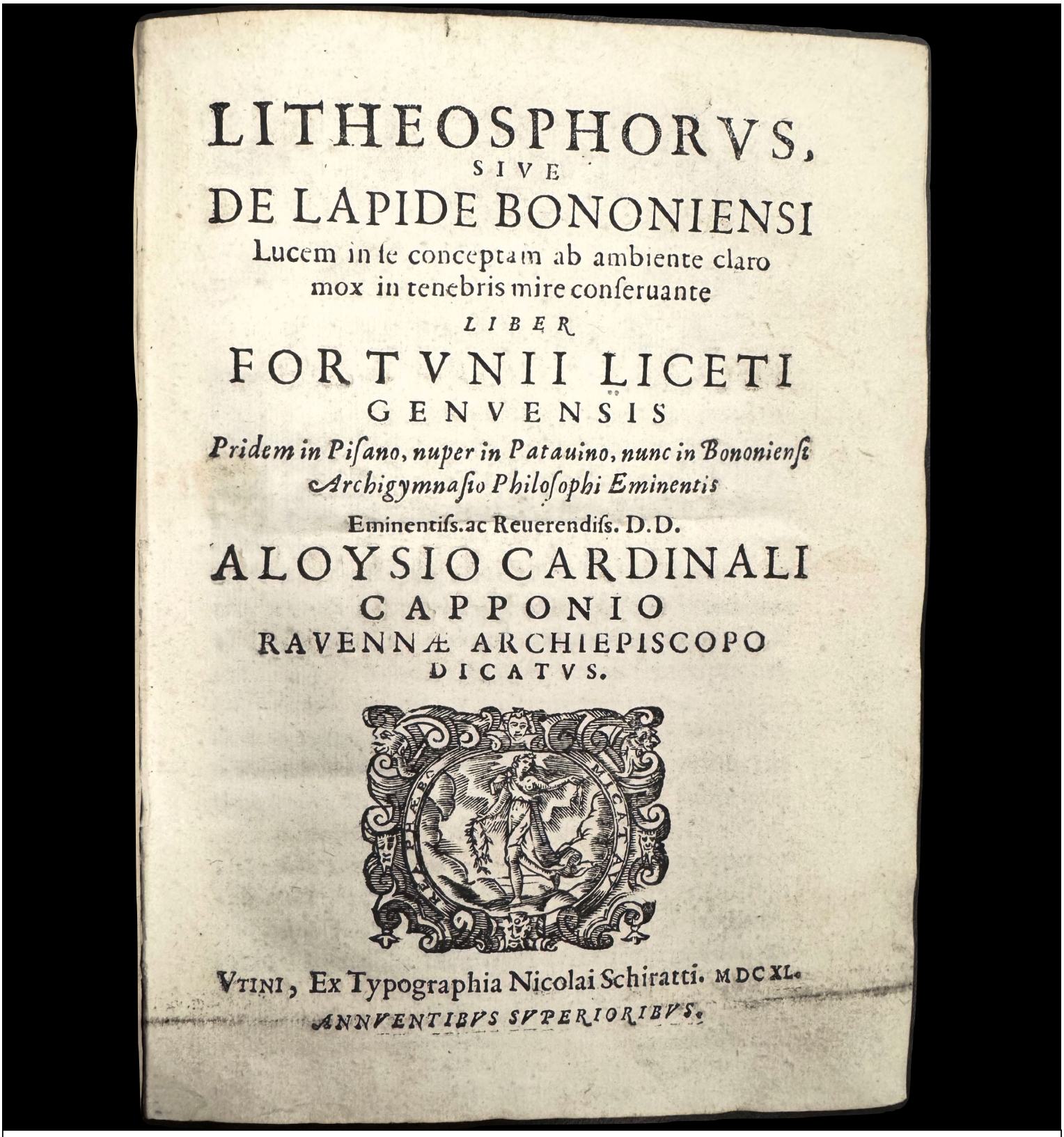
The Indigenous Mexican knowledge reported by Hernandez transformed European natural history in incalculable ways. Subsequent European progress in the life sciences directly depended upon the scientific knowledge of the natives of central Mexico. Erasmus Darwin, for example, grandfather of Charles Darwin, quoted the Lynx edition of Hernandez.

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Galileo and Liceti on Light and Heat

"Phosphorescent Rock, or, On the Light of the Bolognese Stone"



LITHEOSPHORVS,
SIVE
DE LAPIDE BONONIENSI
Lucem in se conceptam ab ambiente claro
mox in tenebris mire conseruante
LIBER
FORTVNII LICETI
GENVENSIS
Pridem in Pisano, nuper in Patauino, nunc in Bononiensi
Archigymnasio Philosophi Eminentis
Eminentiss. ac Reuerendiss. D.D.
ALOYSIO CARDINALI
CAPPONIO
RAVENNÆ ARCHIEPISCOPO
DICATVS.

VTINI, Ex Typographia Nicolai Schiratti. MDCXL.
ANNVENTIBVS SVPERIORIBVS.

Fortunio Liceti, *Litheosphorus, sive, De lapide Bononiensi lucem* (Udine, 1640)

Classic Source. 17th century. Region: Italy. Chemistry, Physics.

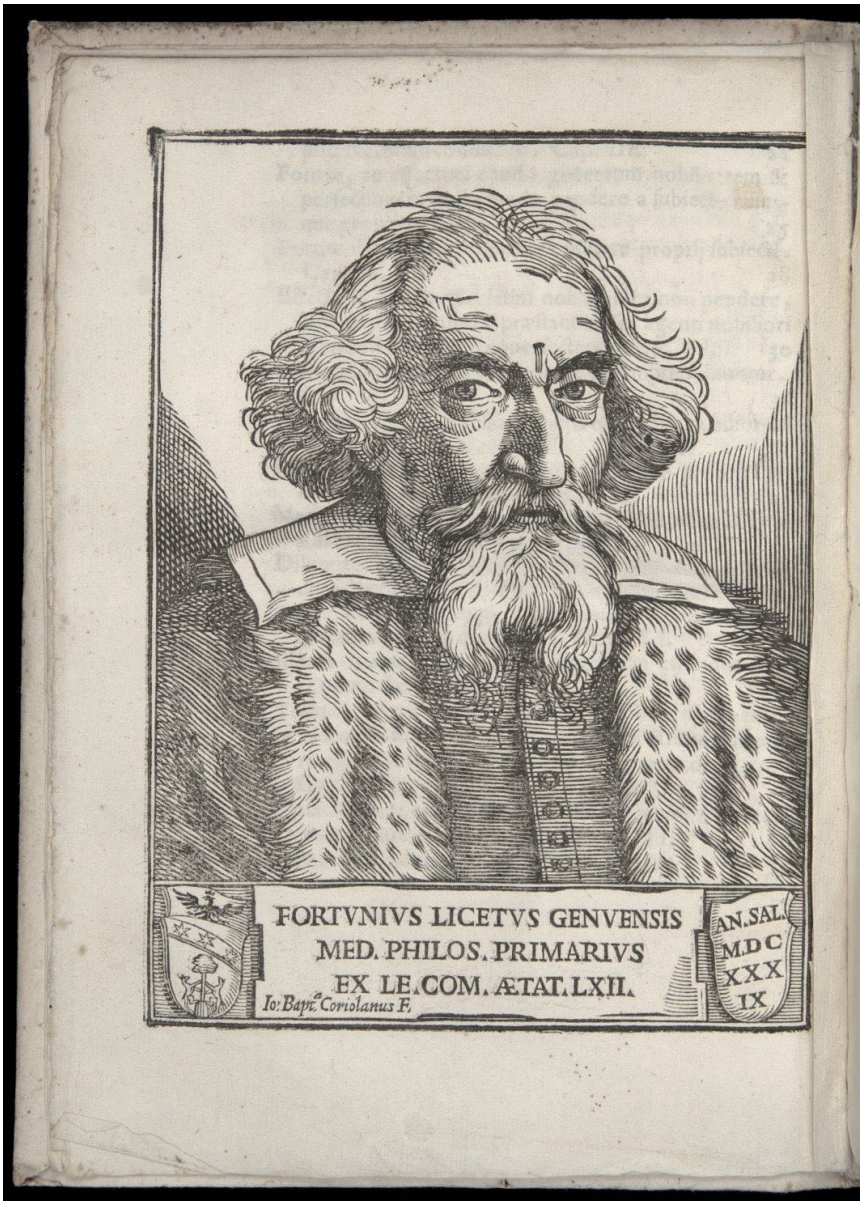
Are light and heat the same?

In the 17th century, most Aristotelians regarded heat and light as the same.

Vincenzo Cascariolo, an alchemist, collected silvery-white stones from a mountain near Bologna. After heating them with charcoal, he found that they glowed in the dark. What a remarkable sight!

According to modern understanding, Bologna stones are made of barite (barium sulfate, $BaSO_4$), along with various impurities. By heating the stones with charcoal (in an oxygen-restricted container), Cascariolo reduced them to barium sulfide (BaS). Afterward, the stones exhibited phosphorescence even at room temperature. This process is not completely understood today. Even if it were completely understood, would it still remain a cause for wonder?

Galileo was one of many who studied these unusual "Stones of Bologna" or "solar sponges," as they were called. Galileo pointed out that their luminescence, even when cool, meant that light is not the same as heat. Light and heat must be distinct.



Fortunio Liceti responded to Galileo. Liceti, a philosopher/physicist at the University of Padua, adapted Aristotelian theory to accommodate many new phenomena, including the Bologna Stone. In extensive correspondence with Galileo during the last years of Galileo's life, Liceti included copies of several of his books. However, neither Galileo nor Liceti persuaded the other to change his views on Aristotelianism.

- If a comprehensive scientific theory is widely accepted, how many observations are needed to refute it?
- What other rocks are made of barite, or $BaSO_4$?
- Are any barite rocks found near you?
- Do you think they might exhibit phosphorescence if heated with charcoal? Why or why not?
- What do you wonder about the Bologna stone?

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“Looking up, I look down.”

Prompt for reflection

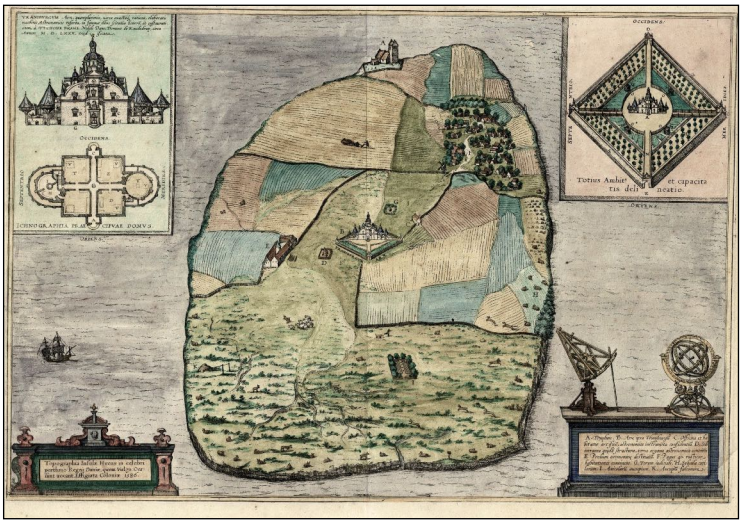


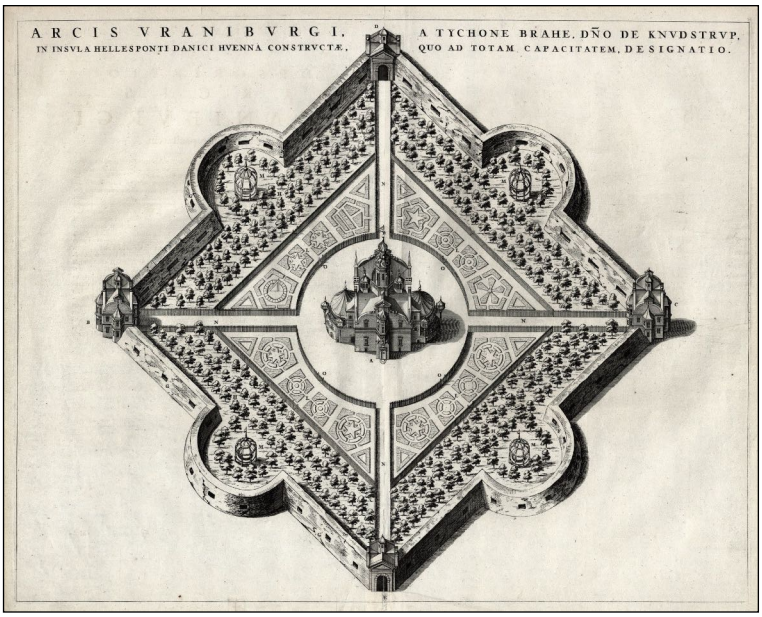
Tycho Brahe and Elias Morsing, *Diarium astrologicum* (Uraniborg, 1586), “Astronomical diary”

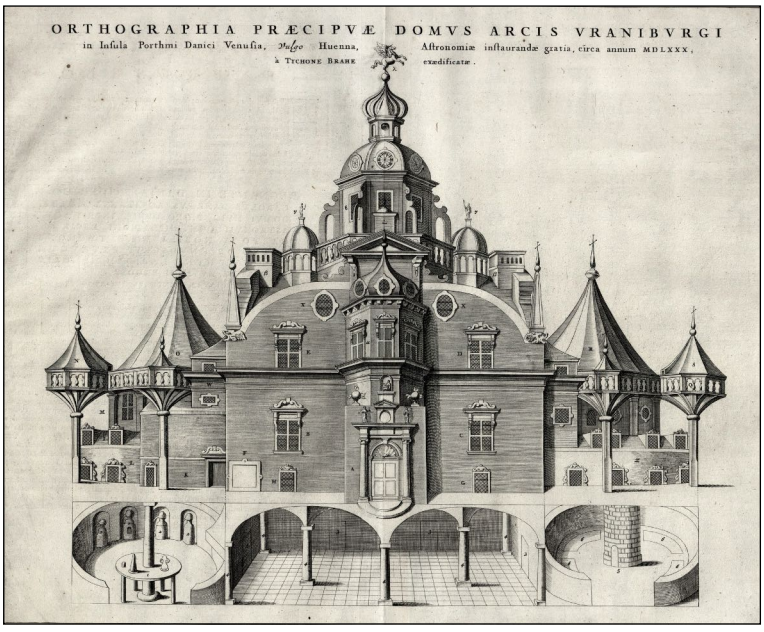
Classic Source. 16th century. Region: Denmark, Sweden. Astronomy, Chemistry, Medicine.

How do we connect or coordinate the inquiries of disciplines today?









On the Island of Hven (top left and right), Tycho Brahe built a collaborative Renaissance research center called Uraniborg, “City of the Stars.”

This first book printed on Tycho’s printing press at Uraniborg displays his motto, “looking up, I look down.” By this phrase, Tycho referred to the interconnectedness of inquiries. Like others such as Robert Fludd, Tycho sought to coordinate the study of astronomy with chemistry and medicine. Astronomy inquired after the cosmos, or macrocosm. Instruments were located on the roof and grounds. Chemistry inquired into the Earth, a microcosm. Furnaces and laboratories were located in the basement. Medicine inquired into the human body, another microcosm. The garden grew all that was necessary for food and for making common remedies.

Tycho’s observations of comets and new stars, proving that changes occur in the heavens beyond the Moon, upended the Aristotelian cosmos, paving the way for Galileo’s fundamental astronomical discoveries and advances in physics.

How might we coordinate the scientific disciplines today?

Is scientific inquiry connected with other subject areas as well, such as art, music, literature, theology, and philosophy?

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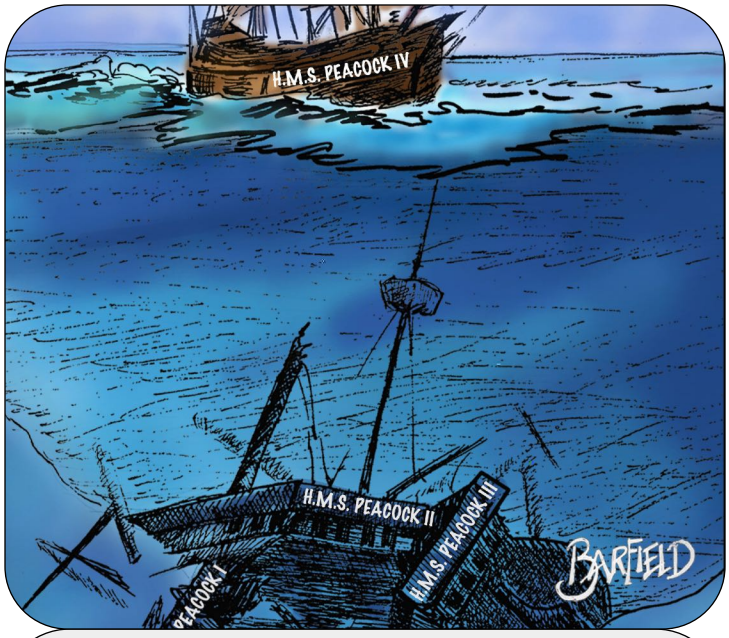
Relativity of Motion

The Moving Ship Thought Experiment: Why were there no eye-witness reports?

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Michael Barfield, "The Answer" (*thepaintedsoul.com*; cc-by-nc-sa)



The Theory of Natural Motion: Aristotle's Version of the Moving Ship Thought Experiment

According to Aristotle, when one drops a ball, the ball falls straight down to the ground, because its "natural motion" seeks the center of the Earth. The ball's natural motion is straight down – not curved, not sideways, not diagonal, but always directly toward the center of the Earth. This natural motion remains the true path of the ball even if the person dropping it is in motion. The person's motion, according to Aristotle, should have no continuing effect upon the ball after they are no longer in contact. Suppose that one is running with the ball at the moment the ball is let go. Once released from the runner's hand, the ball should fall straight down with its own natural motion; whether the runner was in motion or not should make no difference to the ball. This is Aristotle's account of the natural motion of falling bodies.

Now if Aristotle's reasoning were true, one would predict that a cannon ball dropped by a sailor from the crow's mast of a fast-moving ship would splash into the water far behind the ship, for the ship would move out from underneath the ball before enough time elapsed for the ball to fall to the surface of the water. Aristotle carried out experiments, so it only stands to reason (one might argue) that many Aristotelians carried out this experiment. **So why do we have no eye-witness reports refuting this Aristotelian prediction?**

The Relativity of Motion: Galileo's Version of the Moving Ship Thought Experiment

The 2015-2016 year is the centenary of Einstein's General Theory of Relativity. Einstein attributed the formulation of the principle of the relativity of motion to Galileo.

This excerpt from Galileo's *Dialogue on the Two Chief Systems of the World* (1632) illustrates the principle of the relativity of motion:

"Salviati: [You say…] 'Drop a lead ball from the top of the mast of a boat at rest, noting the place where it hits, which is close to the mast; but if the same ball is dropped from the same place when the boat is moving, it will strike at that distance from the foot of the mast which the boat will have run during the time of fall….' [BUT] anyone who… [actually performs that experiment] will find that the experiment shows exactly the opposite of what is written; … the stone always falls in the same place on the ship, whether the ship is standing still or moving."

If sailors actually had performed the experiment, believing with Aristotle that a cannonball dropped from the mast would fall harmlessly into the wake of the ship, why were no reports made to the contrary? This cartoon has the answer.

17th-century investigations of inertia by Galileo, Descartes and Newton represent the culmination of a long line of investigations reaching back from Nicole Oresme and Jean Buridan in the 14th century, through medieval Islamic and European civilizations, to Basil of Caesarea and John Philoponos in late antiquity. Undoubtedly, like Basil, Philoponos, and Oresme, sailors throughout history knew good and well that Aristotle's account of falling bodies was wrong. This explains why the Captain depicted in the first panel of the cartoon has gone mad.

Cartoon Michael Barfield, *thepaintedsoul.com*, cc-by-nc-sa.

Kerry Magruder

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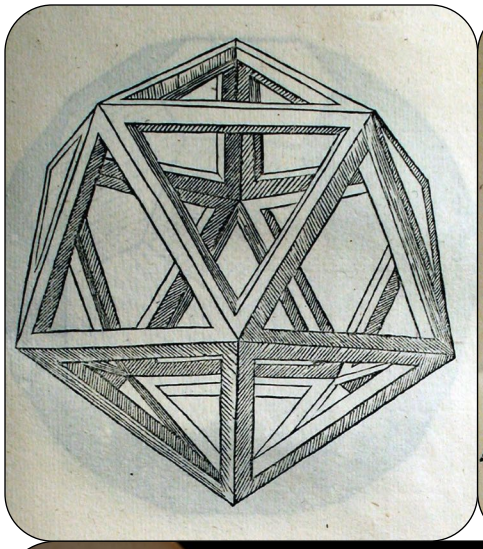
Pythagorean Solids
Five Regular Solids

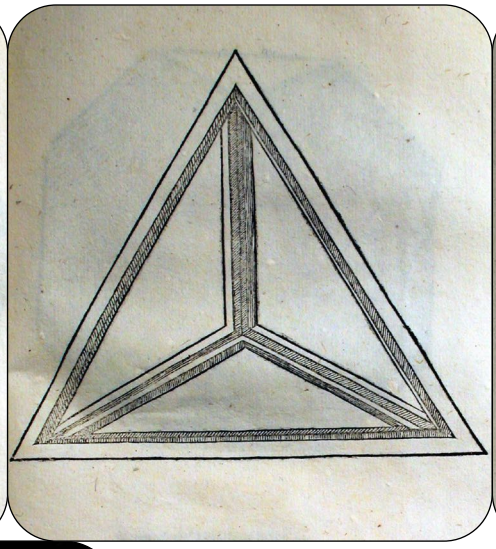
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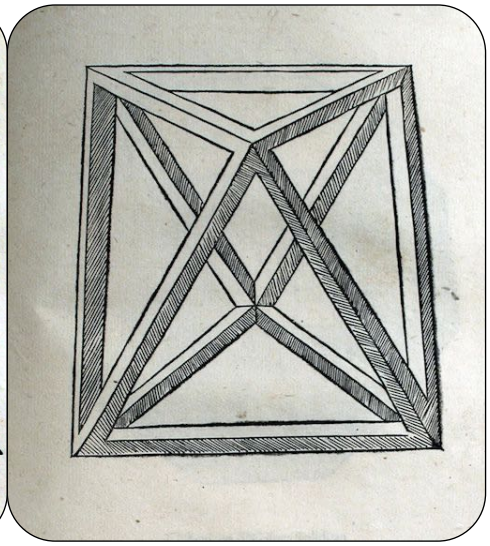


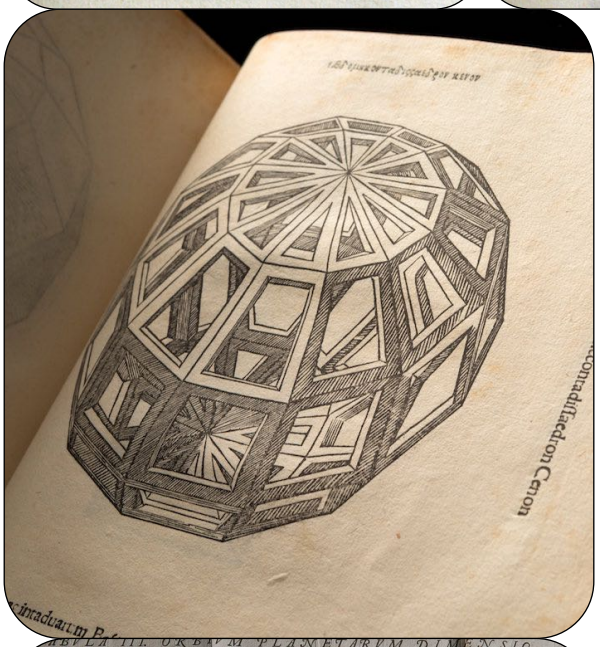
Euclid, *Elements of Geometrie* (London, 1570), trans. Henry Billingsley.

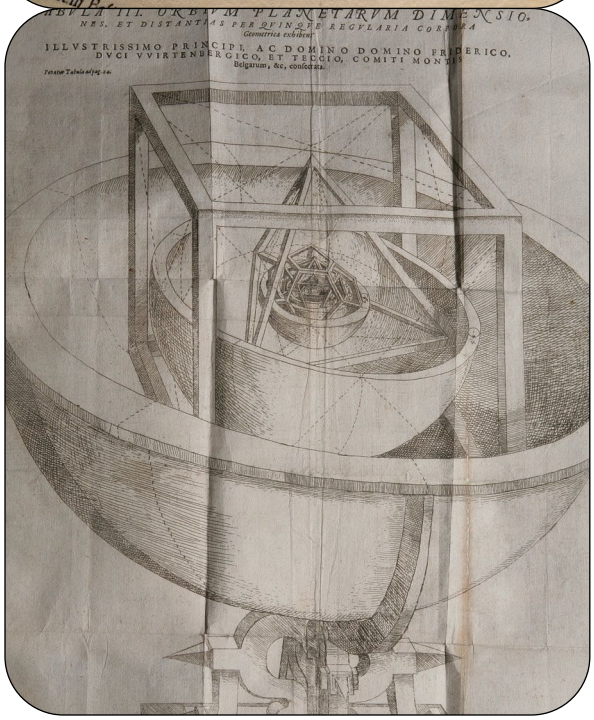
Can you identify the five regular solids?











Pythagorean Solids: 5 Regular Solids

We can define a solid as regular when every face, edge and corner angle is identical, whether a square on every side of a **cube**, or a triangle on every side of a **tetrahedron**. The Pythagoreans proved that there are only five regular solids: The **octahedron**; the **dodecahedron**; and the **icosahedron**. There are no others.

Name	**Face**	**#sides**
Cube	Square	6
Tetrahedron	Equilateral triangle	4
Octahedron	Equilateral triangle	8
Dodecahedron	Pentagon	12
Icosahedron	Equilateral triangle	20

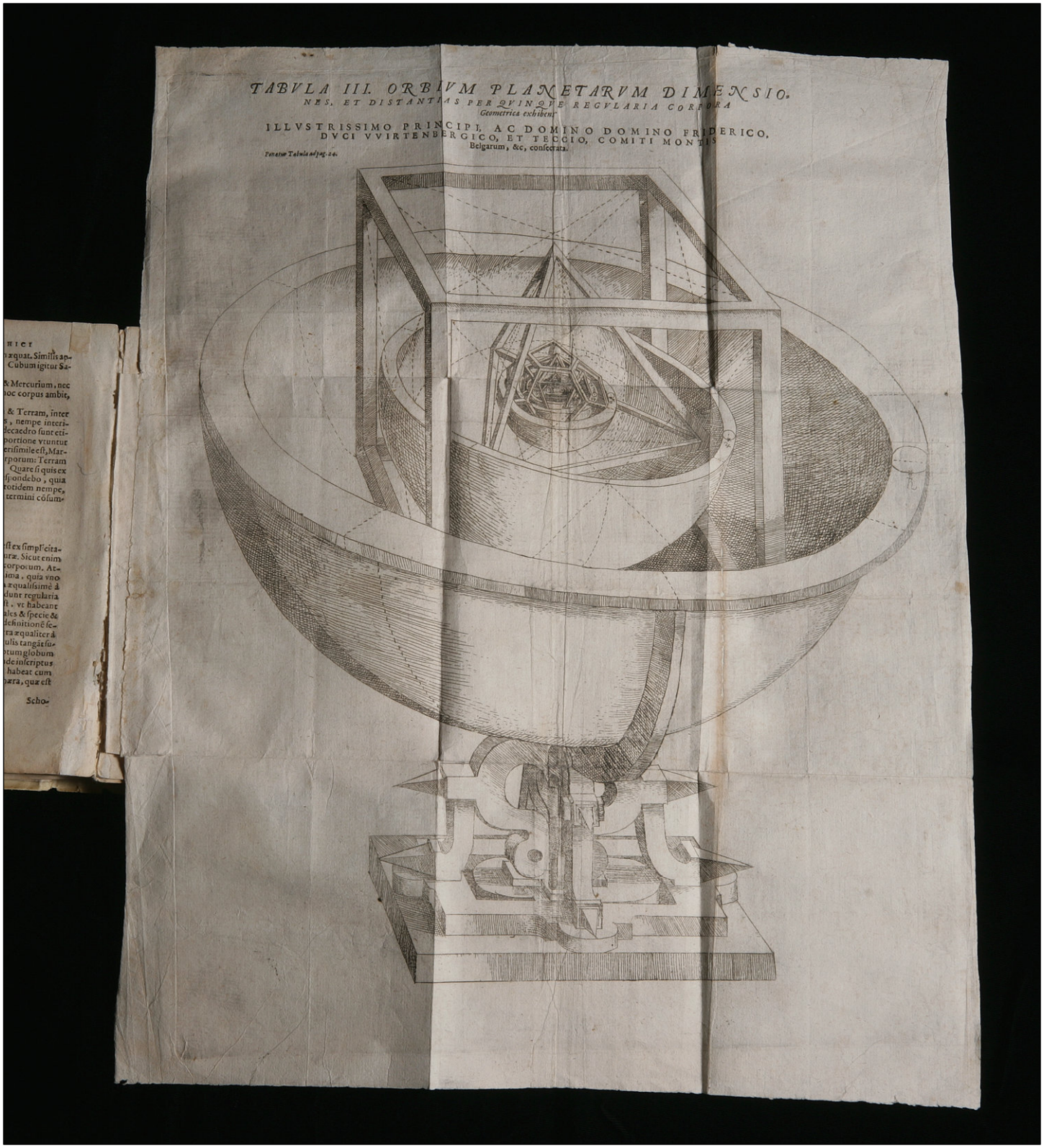
In the images on this page, which is which? And which solid shown is *not* a regular solid?

Because Plato used the 5 regular solids to explain the structure of the Universe in his dialogue, *Timaeus*, they are also called the Platonic Solids. After Plato, astronomers supposed that the geometry of these five solids would hold an essential clue to the true structure of the universe. Euclid analyzed the properties of the regular solids in Book 13 of his *Elements of Geometry*. Kepler used the regular solids to prove Copernicanism. The works of Leonardo da Vinci, Luca Pacioli, Albrecht Dürer, and Lorenzo Sirigatti show that artists, in addition to astronomers, mathematicians and philosophers, were also deeply familiar with the properties of regular solids.

Kerry Magruder

Blueprints of the Universe
Johann Kepler

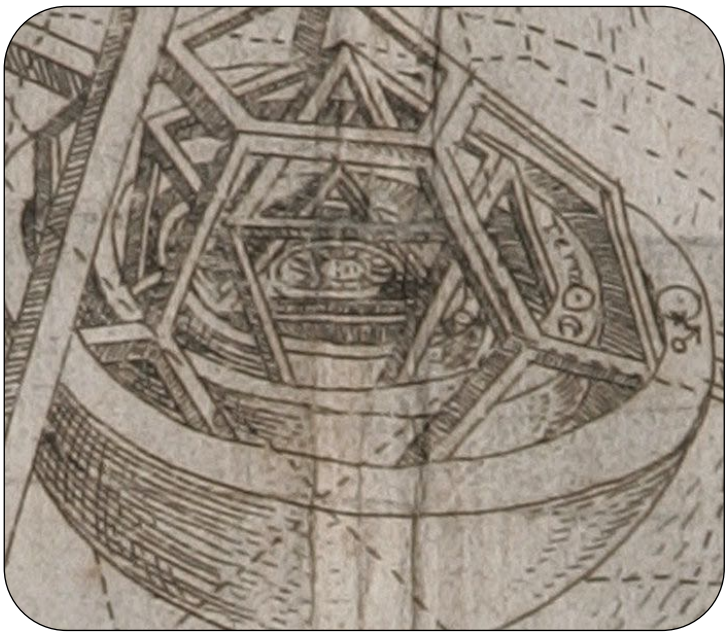
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Johann Kepler, *Mysterium cosmographicum* (Tübingen, 1596), "Mystery of the Cosmos"

Exhibit: Galileo's World | *Gallery:* Music of the Spheres, no. 18
Download learning leaflets at lynx-open-ed.org; read more in the Exhibit Guide (iBook Store).

Is there a mathematical basis of the universe?



Johann Kepler: Blueprints of the Universe

Kepler's blueprint of the universe is rightly considered one of the brilliant illustrations in the history of astronomy. In it, Kepler used the five regular Pythagorean solids to refute the major objections to Copernicanism.

By far the best known 16th-century defender of Copernicus was Johann Kepler. In this work he demonstrated that vast empty regions lying between the planetary spheres, which were required by Copernicus, were not wasted space. Rather, these gaps perfectly matched, within the limits of observational error, the geometry of the 5 regular Pythagorean solids.

In the *Mysterium*, Kepler addressed two major differences between the systems of Ptolemy and Copernicus and turned them both to Copernicus' advantage.

First, the number of the planetary spheres: in the Earth-centered Ptolemaic system there are 7 planets, including the Sun and the Moon, not counting the outermost sphere of fixed stars. In the Copernican system, there are only 6 planets, not counting the outermost sphere of fixed stars: The Sun and the Earth switch places. The number of planets decreases by one, because the Moon is demoted; it becomes a satellite of the Earth, within the Earth's sphere, rather than a planet. So Kepler asked, *why should there be only 6 planets instead of 7*?

Second, and more critically, the distances of the planets: In the Ptolemaic system all the planetary spheres nest together with no intervening spaces. By contrast, in the Copernican system, the spheres of the planets become thin, separated by large distances. Skeptics asked, why would the Divine Architect have wasted so much empty space? Indeed, Kepler calculated that the gaps are quite large, so that most of the universe is empty space.

Kepler's blueprints of the universe used the 5 regular Pythagorean solids to address both the number of the planets and the amazing proportions of the planetary spheres.

For Kepler, the mystery of the universe was now revealed, because the Divine Architect knew Pythagorean geometry and used it to construct a Copernican universe! Instead of nesting one planetary sphere immediately after another, in the ideal blueprints of the cosmos, the Creator alternated planetary spheres with regular solids. The vast empty regions lying between the planetary spheres, as required by Copernicus, were not wasted space. Rather, these gaps perfectly matched the geometry of the solids within the limits of observational error.

Kerry Magruder

> *"And how intense was my pleasure from this discovery can never be expressed in words.... Day and night I was consumed by computing, to see whether this idea would agree with the Copernican orbs, or if my joy would be carried away by the wind. Within a few days everything worked, and I watched as one body [regular solid] after another fit precisely into its place among the planets"* (Kepler, *Mysterium cosmographicum*).

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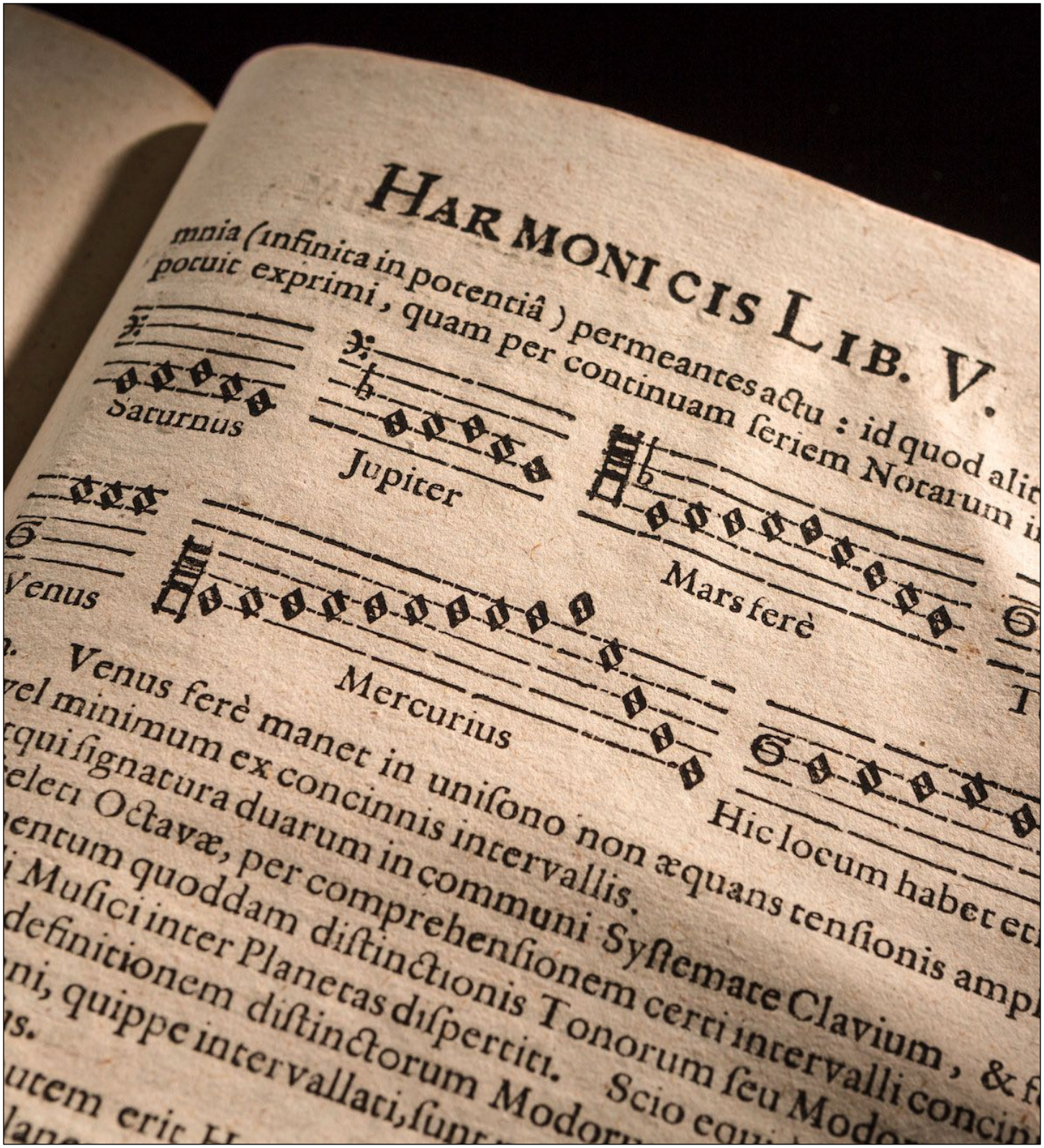
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Johannes Kepler
Harmony of the Universe

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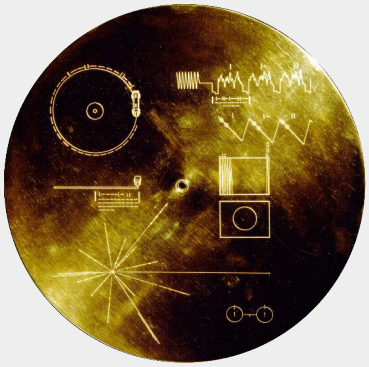


Johann Kepler, *Harmonices Mundi* (1619)

Kepler's Harmony of the Universe: Three Modern Realizations

Carl Sagan, *Cosmos* (New York, 1980).
The Voyager space probes launched in 1977 to explore the outer solar system and travel through interstellar space. Carl Sagan led a NASA committee that prepared two Golden Records to represent humanity and planet Earth to any extraterrestrial intelligence that might someday discover them. Each Golden Record contains hundreds of images and audio recordings, and was inscribed, "*To the makers of music – all worlds, all times*."

The many works of Sagan, professor of astronomy at Cornell, ignited public interest in astronomy for a generation. *Cosmos* became the most widely watched series in the history of American public television, and with it came a deepening appreciation for the history of science.



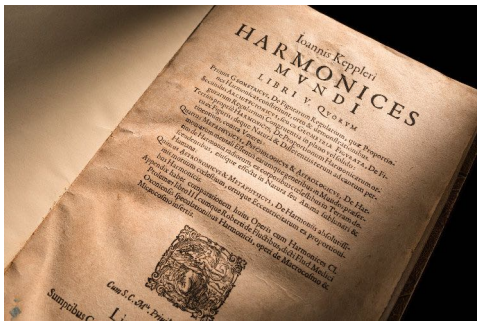
"Kepler's Harmony of the Worlds," in Laurie Spiegel, *The Expanding Universe* Unseen Words, 2012).

On the Golden Records, dozens of musical recordings – from Bach to Chuck Berry to the songs of Humpback Whales – were launched into the ocean of space to represent the music of a small planet. Among the recordings is Laurie Spiegel's interpretation of Kepler's *Harmony of the Universe*.

"Dance Suite," Jonathan A. Annis (OU, 2015).
A different approach to recovering Kepler's music of the spheres is that of OU School of Music graduate student Jonathan Annis. For Galileo's World, Annis composed a suite for harp, flute (doubling alto flute) and oboe (doubling English horn) entirely comprised of musical themes from Kepler's *Harmonices mundi*. Annis arranged the themes, but they derive from Kepler's musical description of the harmonic law.



lynx-open-ed.org/cosmicdance



In this work, Kepler integrated theoretical astronomy and music, showing that the motions of the planets employ the same numerical ratios as the most harmonious scales. Kepler's "harmonic law" still describes how planets and stars and satellites and galaxies revolve around one another in space.

Kepler's integration of theoretical astronomy and music fulfilled an ancient dream. Plato wrote, "As our eyes are framed for astronomy, so our ears are framed for the movements of harmony, and these two sciences are sisters" (*Republic*, VII 530d). From antiquity, music was a sister science to astronomy, with both subordinated to mathematics.

The beauty of music provided the context for what we now call Kepler's "third law." The story of science reveals creative leaps across disciplinary boundaries; in this case, bringing together music and astronomy. Kepler's vision truly was cosmic, of a cosmic hope and consolation amidst earthly sorrow. In the midst of many trials during the writing of this book, Kepler affirmed that:

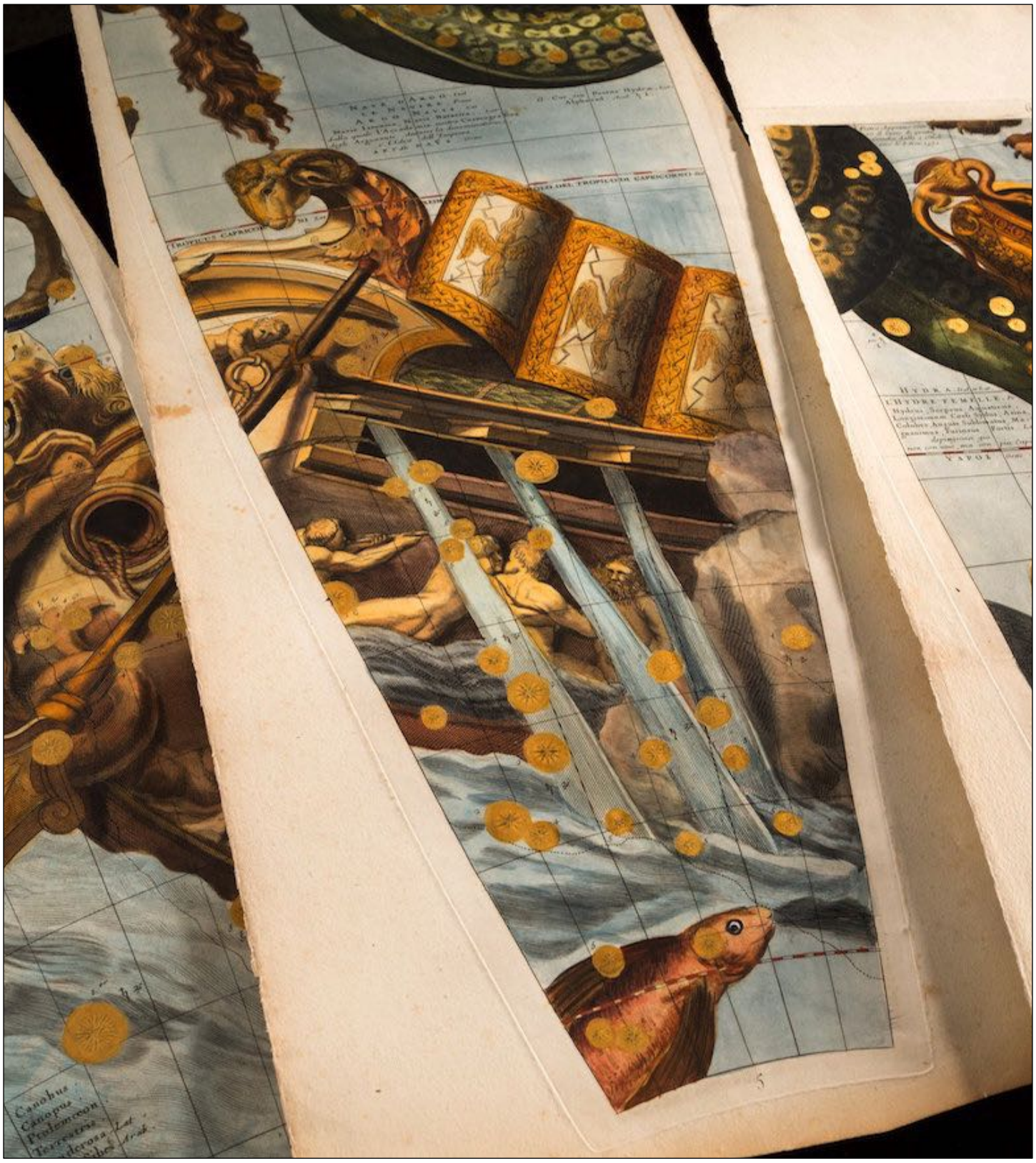
"*The movements of the heavens are nothing except a certain every-lasting polyphony (intelligible, not audible)... Hence it should no longer seem strange that man, the image of his Creator, has finally discovered the art of singing polyphonically, which was unknown to the ancients. With this symphony of voices man can play through, the eternity of time in less than an hour, and can taste in small measure the delight of God the Supreme Artist...*"

Kepler, *Harmonices mundi*, translated in Timothy Ferris, *Coming of Age in the Milky Way*, p. 77.

Kerry Magruder and Brent Purkaple

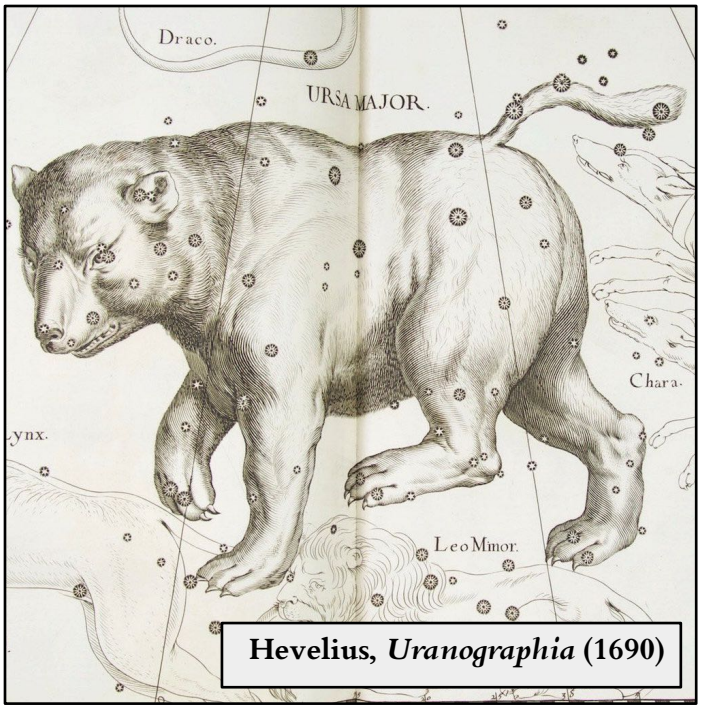
The Celestial Globe
An Introduction

kerrymagruder.com

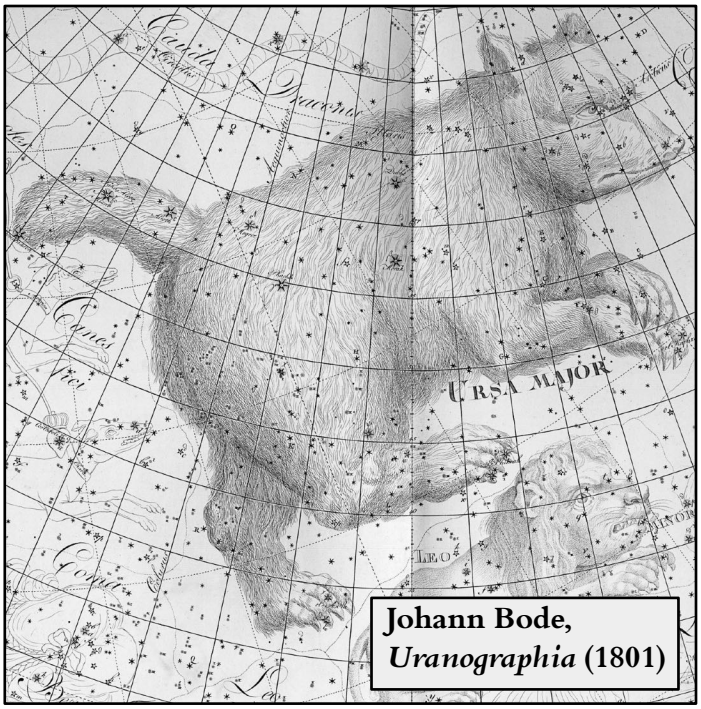


Vincenzo Coronelli, *Celestial Globe Gores* (Paris 1693; reprint ca. 1800).

What's different about these two constellation figures?



Hevelius, *Uranographia* (1690)



Johann Bode, *Uranographia* (1801)

Coronelli, a Franciscan theologian and astronomer, created the **gores** on the front of this sheet. Makers of globes printed sheets of map sections, called gores, which were then hand-colored, cut out and glued onto a wood and paper-maché base.

The gores depicted on the front and below are part of a set of 24 produced to make a 3.5 foot diameter celestial globe. They were designed by Arnold Deuvez and engraved by Jean-Baptiste Nolin in Paris. OU posseses reprints made in 1800 using the original plates created in 1693.





The night sky looks like an **upside-down bowl set on the horizon**, but as it turns around during the night it is easy to think of it as a giant sphere. **Think of the stars as bright points of light lying on the inside surface of a giant celestial sphere. This sphere rotates around us once a day.** A model of the sky as a **celestial globe** explains the appearances of the sky with simplicity and elegance. With good reason this common-sense explanatory scheme was adopted by ancient astronomers, and it remains the most convenient way for pilots, sailors and navigators to learn observational astronomy today.



Observe: Do the constellations on a celestial globe appear reversed, since you're on the "outside looking in"?

Look through and across a celestial globe to inspect constellations as they appear from Earth.

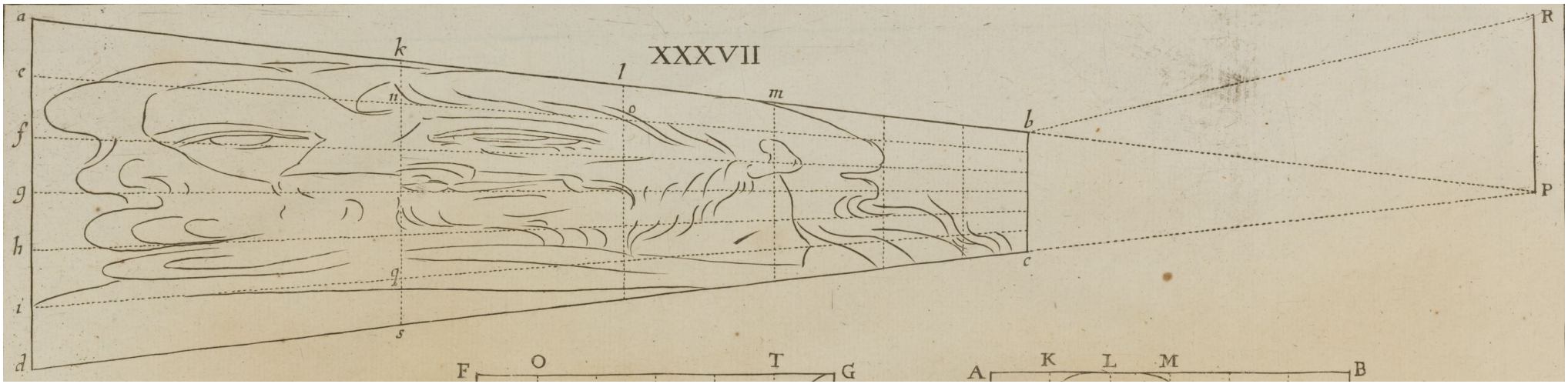
Kerry Magruder and Brent Purkaple

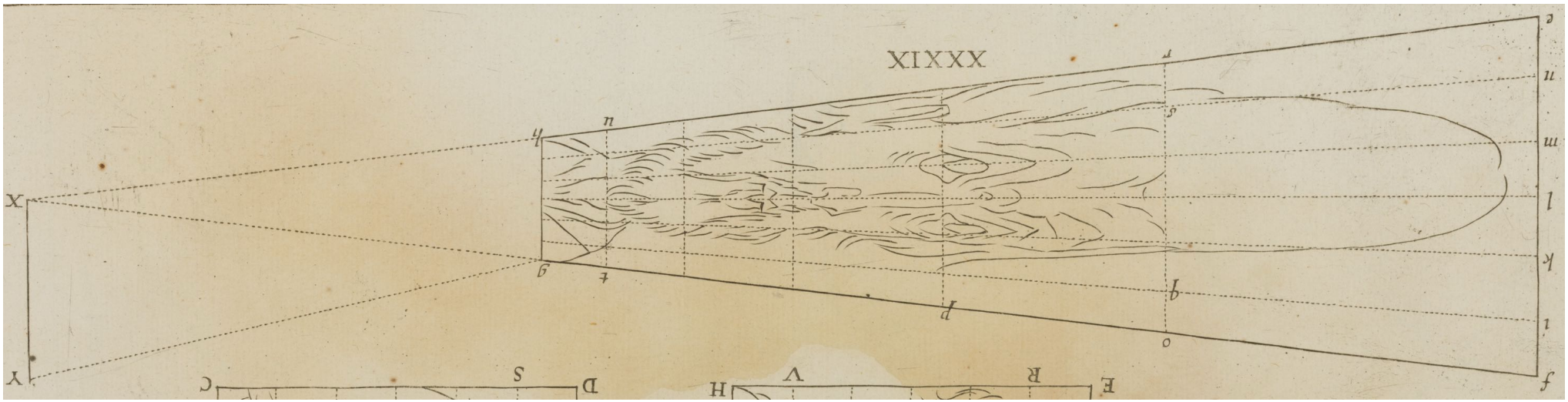
The “Alberti box”

Hold this page sideways up to your eye. Sight along each diagram below. Place the narrow point (“P” or “X”) close to your eye. What pictures do you see?

12. Jean François Nicéron, *La Perspectiva Curieuse* (Paris, 1663), “The Curiosities of Perspective.”

During a visit to Florence, Jean François Nicéron met with Galileo’s artist friend Cigoli. Cigoli showed Nicéron a perspective drawing tool he had invented. Nicéron later published it in this book. In Florence, Nicéron also viewed examples of anamorphic drawing techniques and Alberti’s perspective boxes. This Florentine artistic culture, steeped in the techniques of perspective drawing, was the midwife at the birth of Galileo’s telescopic astronomy.





Peter Apian, *Cosmographia* (1540)



Hoc Schema demonstrat terram esse globosam.



Si terra esset tetragona, vmbra quoq; tetragonæ figuræ in eclipsatione lunari appareret.



Si terra esset trigona, vmbra quoq; triangularem haberet formulam.



Si terra hexagonæ esset figuræ, eius quoq; vmbra in defectu lunari hexagona appareret, quæ tamen rotunda cernitur.



GRAPH. PETRI AP.
DE PARALLELIS CIRCV
LIS. CAP. V.

Paralleli (qui & segmenta dicuntur) s
æqualem distantiam ex omni parte a
habentes, & nunquam, si possent etia
tum protrahi, concurrentes. Quamu
ad libitum possunt describi, tamen (ac
tationem) per certos tam in solida qu
na telluris designatione, latitudinis g
pescimus: quod etiam in figura sequenti arithmeticali s
ri apparet. Hac tamen intercapedine ab inuicem distan
vnius paralleli longissimus, superet paralleli alterius di
xiorem, quarta ferè parte vnius horæ. Eadem habitudi
quorum parallelorum distantia erit imaginanda, tam in p
tentrionali quàm Meridionali.

Ecce Schema diuisionis Parallelorum.



Peter Apian, *Cosmographia* (1540)

Johann Schreck
Galileo's Friend in China

kerrymagruder.com

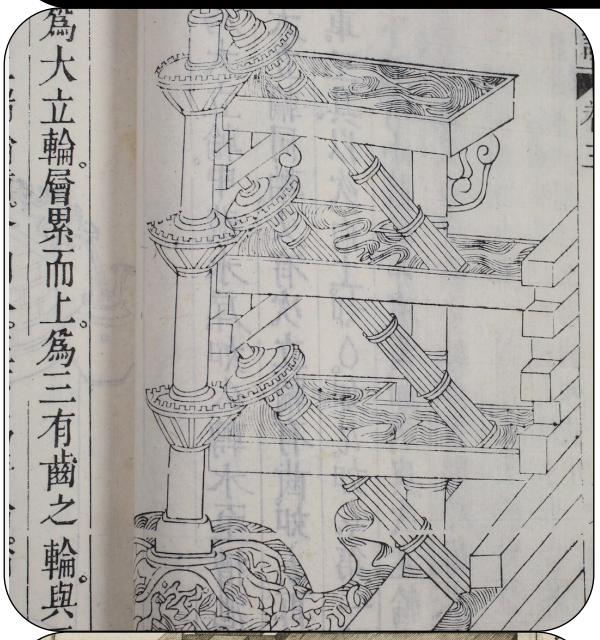


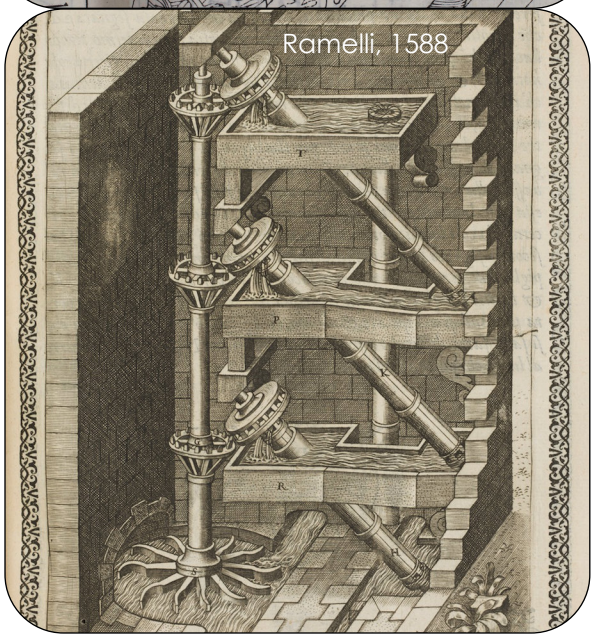
Johann Schreck, *Ensei kiki zusetsu rokusai* (Japan, 1830; "Wonderful Machines of the Far West")

How did knowledge spread in Galileo's world?









Johann Schreck: Galileo's Friend in China

During Galileo's early telescopic observations of sunspots, Johann Schreck assisted him. In 1611, at the villa of Federigo Cesi, Schreck observed the satellites of Jupiter through Galileo's telescope. Galileo was the 6th member invited to join Cesi's Academy of the Lynx; Schreck became the 7th the following week. Shortly thereafter, Schreck traveled with Galileo to Rome to demonstrate the telescope at the Villa Medici.

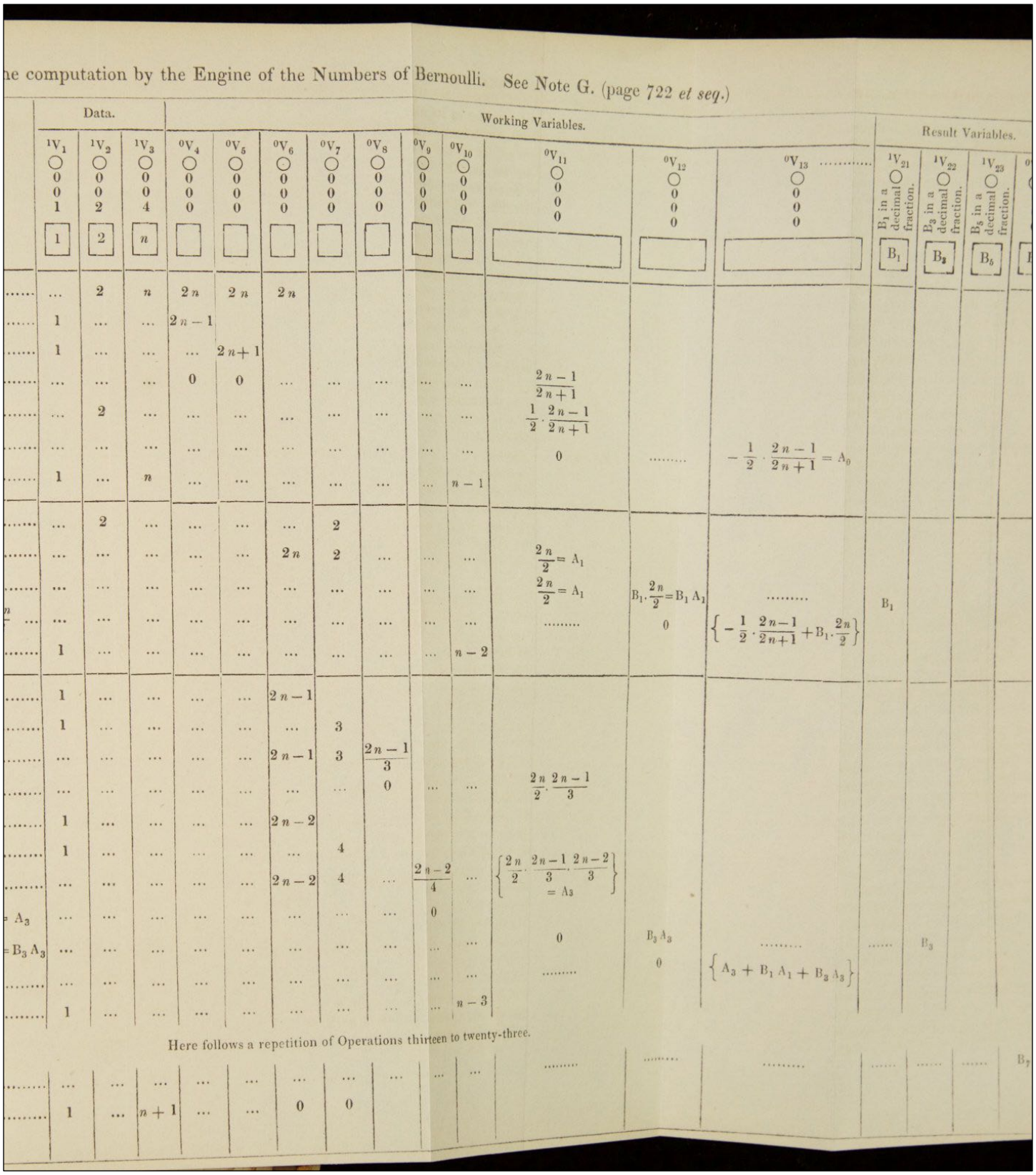
At this time, Nicolaus Trigault was traveling through Europe explaining the China mission of Matteo Ricci and soliciting the help of astronomers. In December of 1611, Schreck became a Jesuit in order to join Ricci and Trigault in China. Schreck prepared for the trip by collecting an extensive scientific library of approximately 7,000 volumes as well as a Galilean telescope. During the four-year journey to China, both on the ship and during a winter layover in India, Schreck tutored his fellow Jesuits in advanced astronomical techniques.

Once he arrived in China, Schreck wrote this engineering work, first printed as *Qi qi tu shuo* in 1627. This is the first edition printed in Japan, with Sino-Japanese notes and Japanese-style illustrations. As is evident from a comparison of the images, one of Schreck's sources for this work was a work by Agostino Ramelli on display in the gallery *Galileo, Engineer*.

Kerry Magruder

Ada Lovelace
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he computation by the Engine of the Numbers of Bernoulli. See Note G. (page 722 *et seq.*)

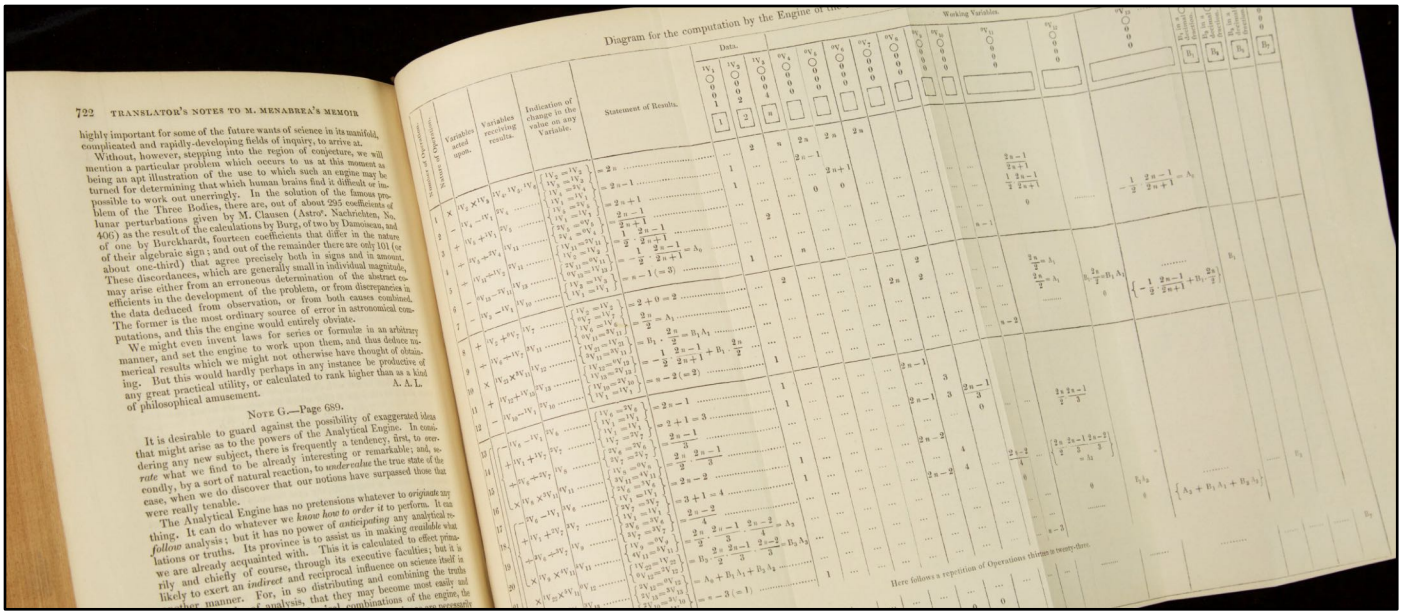
Data.			Working Variables.									Result Variables.			
$^1V_1$ ○ 0 0 1 [1]	$^1V_2$ ○ 0 0 2 [2]	$^1V_3$ ○ 0 0 4 [n]	$^0V_4$ ○ 0 0 0 [ ]	$^0V_5$ ○ 0 0 0 [ ]	$^0V_6$ ○ 0 0 0 [ ]	$^0V_7$ ○ 0 0 0 [ ]	$^0V_8$ ○ 0 0 0 [ ]	$^0V_9$ ○ 0 0 0 [ ]	$^0V_{10}$ ○ 0 0 0 [ ]	$^0V_{11}$ ○ 0 0 0 [ ]	$^0V_{12}$ ○ 0 0 0 [ ]	$^0V_{13}$ ..... ○ 0 0 0 [ ]	$^1V_{21}$ ○ B_1 in a decimal fraction. [B_1]	$^1V_{22}$ ○ B_2 in a decimal fraction. [B_2]	$^1V_{23}$ ○ B_5 in a decimal fraction. [B_5]	
.....	...	2	n	$2n$	$2n$	$2n$										
.....	1	...	...	$2n-1$												
.....	1	...	...	...	$2n+1$											
.....	...	...	...	0	0	...	...	...	...	...	$\frac{2n-1}{2n+1}$					
.....	...	2	...	...	...	...	...	...	...	...	$\frac{1}{2}\cdot\frac{2n-1}{2n+1}$					
.....	...	...	...	...	...	...	...	...	...	...	0	.....	$-\frac{1}{2}\cdot\frac{2n-1}{2n+1}=A_0$			
.....	1	...	n	...	...	...	...	...	$n-1$							
.....	...	2	...	...	...	...	2									
.....	...	...	...	...	...	$2n$	2	...	...	...	$\frac{2n}{2}=A_1$					
.....	...	...	...	...	...	...	...	...	...	...	$\frac{2n}{2}=A_1$	$B_1\cdot\frac{2n}{2}=B_1A_1$	.....			
n ...	...	...	...	...	...	...	...	...	...	...	.....	0	$\left\{-\frac{1}{2}\cdot\frac{2n-1}{2n+1}+B_1\cdot\frac{2n}{2}\right\}$	B_1		
.....	1	...	...	...	...	...	...	...	$n-2$							
.....	1	...	...	...	...	$2n-1$										
.....	1	...	...	...	...	...	3									
.....	...	...	...	...	...	$2n-1$	3	$\frac{2n-1}{3}$								
.....	...	...	...	...	...	...	...	0	...	...	$\frac{2n}{2}\cdot\frac{2n-1}{3}$					
.....	1	...	...	...	...	$2n-2$										
.....	1	...	...	...	...	...	4									
.....	...	...	...	...	...	$2n-2$	4	...	$\frac{2n-2}{4}$	...	$\left\{\frac{2n}{2}\cdot\frac{2n-1}{3}\cdot\frac{2n-2}{3}\right\}=A_3$					
$=A_3$	...	...	...	...	...	...	...	...	0							
$=B_3A_3$	...	...	...	...	...	...	...	...	...	...	0	B_3A_3	.....	.....	B_3	
.....	...	...	...	...	...	...	...	...	...	...	.....	0	$\{A_3+B_1A_1+B_2A_3\}$			
.....	1	...	...	...	...	...	...	...	$n-3$							

Here follows a repetition of Operations thirteen to twenty-three.

.....	...	...	...	...	...	...	...	...	...	...	.....	.....	.....	.....	.....	B_7
.....	1	...	$n+1$	...	...	0	0									

Ada Lovelace, "Notes" to a "Sketch of the Analytical Engine Invented by Charles Babbage, by L.F. Menabrea," in *Scientific Memoirs* (London, 1843), vol. 3.

What is the difference between a calculating machine and a computer?



722 TRANSLATOR'S NOTES TO M. MENABREA'S MEMOIR

highly important for some of the future wants of science in its manifold, complicated and rapidly-developing fields of inquiry, to arrive at.

Without, however, stepping into the region of conjecture, we will mention a particular problem which occurs to us at this moment as being an apt illustration of the use to which such an engine may be turned for determining that which human brains find it difficult or impossible to work out unerringly. In the solution of the famous problem of the Three Bodies, there are, out of about 295 coefficients of lunar perturbations given by M. Clausen (Astro'. Nachrichten, No. 406) as the result of the calculations by Burg, of two by Damoiseau, and of one by Burckhardt, fourteen coefficients that differ in the nature of their algebraic sign; and out of the remainder there are only 101 (or about one-third) that agree precisely both in signs and in amount. These discordances, which are generally small in individual magnitude, may arise either from an erroneous determination of the abstract coefficients in the development of the problem, or from discrepancies in the data deduced from observation, or from both causes combined. The former is the most ordinary source of error in astronomical computations, and this the engine would entirely obviate.

We might even invent laws for series or formulæ in an arbitrary manner, and set the engine to work upon them, and thus deduce numerical results which we might not otherwise have thought of obtaining. But this would hardly perhaps in any instance be productive of any great practical utility, or calculated to rank higher than as a kind of philosophical amusement.

A. A. L.

NOTE G.—Page 689.

It is desirable to guard against the possibility of exaggerated ideas that might arise as to the powers of the Analytical Engine. In considering any new subject, there is frequently a tendency, first, to overrate what we find to be already interesting or remarkable; and, secondly, by a sort of natural reaction, to *undervalue* the true state of the case, when we do discover that our notions have surpassed those that were really tenable.

The Analytical Engine has no pretensions whatever to *originate* anything. It can do whatever we *know how to order* it to perform. It can *follow* analysis; but it has no power of *anticipating* any analytical revelations or truths. Its province is to assist us in making available what we are already acquainted with. This it is calculated to effect primarily and chiefly of course, through its executive faculties; but it is likely to exert an *indirect* and reciprocal influence on science itself in another manner. For, in so distributing and combining the truths and the formulæ of analysis, that they may become most easily and

Diagram for the computation by the Engine of the

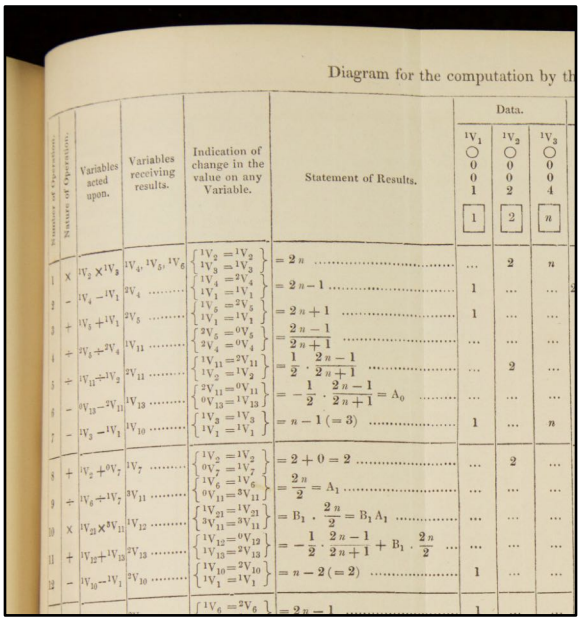
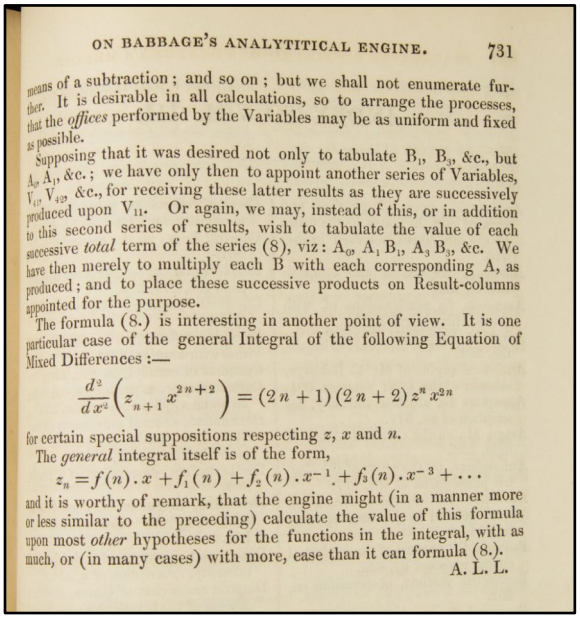


Diagram for the computation by th

Number of Operation.	Nature of Operation.	Variables acted upon.	Variables receiving results.	Indication of change in the value on any Variable.	Statement of Results.	Data. $^1V_1$ 0 0 0 1 [1]	Data. $^1V_2$ 0 0 0 2 [2]	Data. $^1V_3$ 0 0 0 4 [n]
1	×	$^1V_2 \times {}^1V_3$	$^1V_4, {}^1V_5, {}^1V_6$	$\left\{\begin{matrix} {}^1V_2 = {}^1V_2 \\ {}^1V_3 = {}^1V_3 \end{matrix}\right.$	$= 2n$	...	2	n
2	−	$^1V_4 - {}^1V_1$	$^2V_4$	$\left\{\begin{matrix} {}^1V_4 = {}^2V_4 \\ {}^1V_1 = {}^1V_1 \end{matrix}\right.$	$= 2n-1$	1	...	...
3	+	$^1V_5 + {}^1V_1$	$^2V_5$	$\left\{\begin{matrix} {}^1V_5 = {}^2V_5 \\ {}^1V_1 = {}^1V_1 \end{matrix}\right.$	$= 2n+1$	1	...	...
4	÷	$^2V_5 \div {}^2V_4$	$^1V_{11}$	$\left\{\begin{matrix} {}^2V_5 = {}^0V_5 \\ {}^2V_4 = {}^0V_4 \end{matrix}\right.$	$= \frac{2n-1}{2n+1}$	...	...	...
5	÷	$^1V_{11} \div {}^1V_2$	$^2V_{11}$	$\left\{\begin{matrix} {}^1V_{11} = {}^2V_{11} \\ {}^1V_2 = {}^1V_2 \end{matrix}\right.$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	...	2	...
6	−	$^0V_{13} - {}^2V_{11}$	$^1V_{13}$	$\left\{\begin{matrix} {}^2V_{11} = {}^0V_{11} \\ {}^0V_{13} = {}^1V_{13} \end{matrix}\right.$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	...	...	...
7	−	$^1V_3 - {}^1V_1$	$^1V_{10}$	$\left\{\begin{matrix} {}^1V_3 = {}^1V_3 \\ {}^1V_1 = {}^1V_1 \end{matrix}\right.$	$= n-1\ (=3)$	1	...	n
8	+	$^1V_2 + {}^0V_7$	$^1V_7$	$\left\{\begin{matrix} {}^1V_2 = {}^1V_2 \\ {}^0V_7 = {}^1V_7 \end{matrix}\right.$	$= 2+0=2$	...	2	...
9	÷	$^1V_6 \div {}^1V_7$	$^3V_{11}$	$\left\{\begin{matrix} {}^1V_6 = {}^1V_6 \\ {}^0V_{11} = {}^3V_{11} \end{matrix}\right.$	$= \frac{2n}{2} = A_1$	...	...	...
10	×	$^1V_{21} \times {}^3V_{11}$	$^1V_{12}$	$\left\{\begin{matrix} {}^1V_{21} = {}^1V_{21} \\ {}^3V_{11} = {}^3V_{11} \end{matrix}\right.$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	...	...	...
11	+	$^1V_{12} + {}^1V_{13}$	$^2V_{13}$	$\left\{\begin{matrix} {}^1V_{12} = {}^0V_{12} \\ {}^1V_{13} = {}^2V_{13} \end{matrix}\right.$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$	...	...	...
12	−	$^1V_{10} - {}^1V_1$	$^2V_{10}$	$\left\{\begin{matrix} {}^1V_{10} = {}^2V_{10} \\ {}^1V_1 = {}^1V_1 \end{matrix}\right.$	$= n-2\ (=2)$	1	...	...
				$\left\{\begin{matrix} {}^1V_6 = {}^2V_6 \end{matrix}\right.$	$= 2n-1$	1		



ON BABBAGE'S ANALYTTITICAL ENGINE. 731

means of a subtraction; and so on; but we shall not enumerate further. It is desirable in all calculations, so to arrange the processes, that the *offices* performed by the Variables may be as uniform and fixed as possible.

Supposing that it was desired not only to tabulate B_1, B_3, &c., but A_0, A_1, &c.; we have only then to appoint another series of Variables, V_{11}, V_{42}, &c., for receiving these latter results as they are successively produced upon V_{11}. Or again, we may, instead of this, or in addition to this second series of results, wish to tabulate the value of each successive *total* term of the series (8), viz: A_0, $A_1 B_1$, $A_2 B_3$, &c. We have then merely to multiply each B with each corresponding A, as produced; and to place these successive products on Result-columns appointed for the purpose.

The formula (8.) is interesting in another point of view. It is one particular case of the general Integral of the following Equation of Mixed Differences :—

$$\frac{d^3}{dx^3}\left(z_{n+1}\, x^{2n+2}\right) = (2n+1)(2n+2)\, z^n x^{2n}$$

for certain special suppositions respecting z, x and n.

The *general* integral itself is of the form,

$$z_n = f(n).x + f_1(n) + f_2(n).x^{-1} + f_3(n).x^{-3} + \ldots$$

and it is worthy of remark, that the engine might (in a manner more or less similar to the preceding) calculate the value of this formula upon most *other* hypotheses for the functions in the integral, with as much, or (in many cases) with more, ease than it can formula (8.).

A. L. L.

Ada Lovelace: First Computer Programmer

Charles Babbage designed two kinds of mechanical computational machines: a "difference engine," or calculating machine; and an "analytical engine," which was far more. In 1840, Babbage presented his design for the "analytical engine" to a group of mathematical engineers in Turin, Italy. One of them, Luigi Menabrea, who would later become Prime Minister of Italy, published an account of Babbage's design in Geneva. With Babbage's encouragement, the daughter of Lord Byron, Augusta Ada King, Countess of Lovelace, translated Menabrea's article into English and added her own substantive commentary. Lovelace's notes went considerably beyond what Babbage and Menabrea had written. Her lengthy appended notes amount to 40 pages of very dense text compared with only 24 pages, lightly spaced, for Menabrea's article. Lovelace explained how Babbage's "analytical engine," if constructed, would amount to a programmable computer rather than merely a calculator. It would take input from punch cards, and store variables for use in diverse sequential operations. These 19th century mechanical operations are functionally equivalent to the conditional branching, looping, and parallel processing operations of early electronic computers. Although she specified how Babbage's engine could generate a Bernoulli series of numbers, Lovelace argued for the wider potential of the engine to produce analytical results beyond the realm of mathematics.

Kerry Magruder and Brent Purkaple

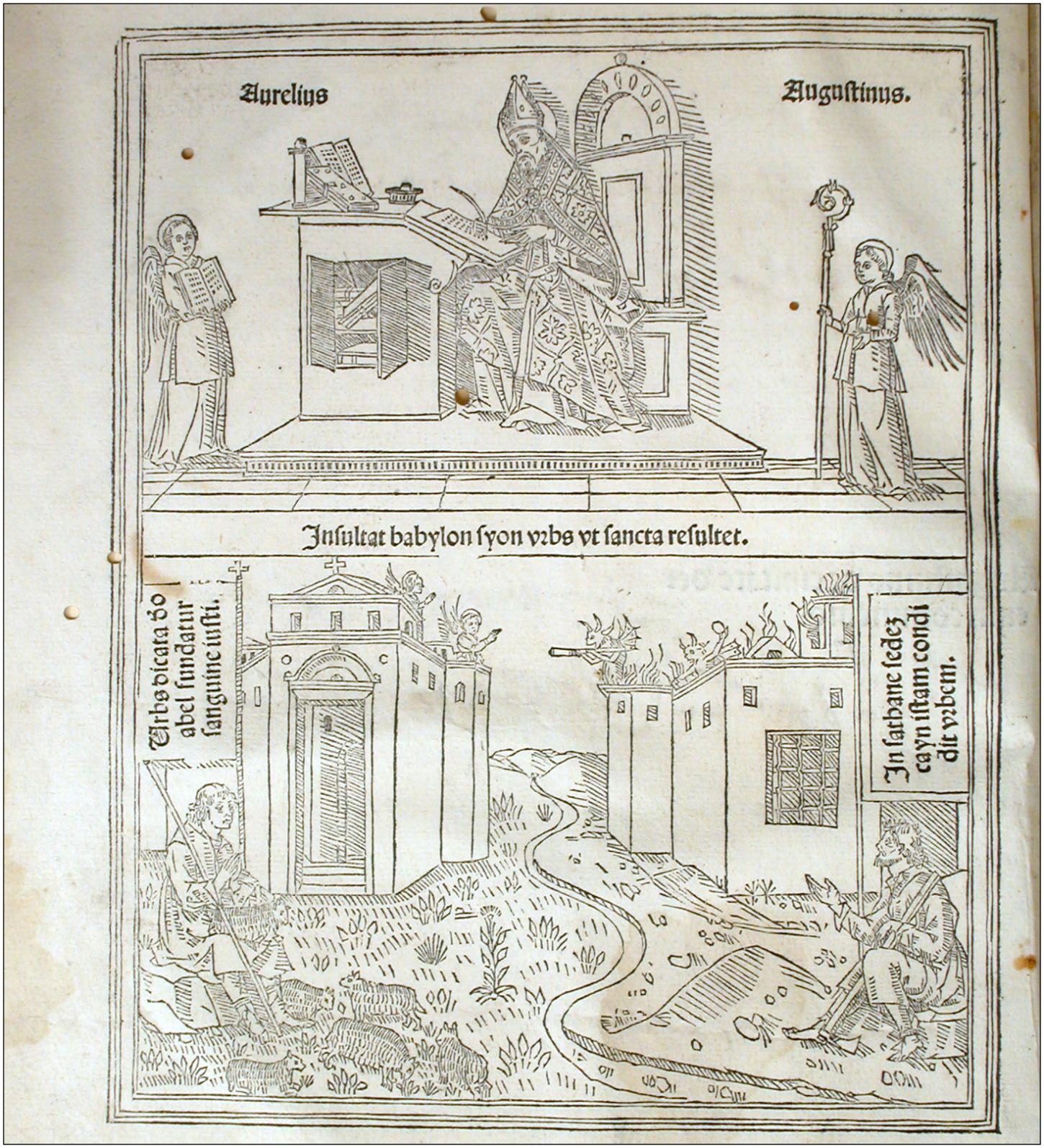
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GALILEO'S WORLD

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Augustine
The Bible and Science

Learning Leaflet: Starting Points
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Augustine, *De civitate Dei* (Venice, 1489))

Augustine of Hippo (Numidia, Algeria), d. 430

Augustine and Western science

Augustine's influence towers over the western theological tradition; just as significant was his influence on science:

• Augustine's Christian Platonism encouraged the study of mathematics;

• Augustine's emphasis on the contingent character of the created order required empirical methods to confirm the conclusions of reason and logic;

• and Augustine's arguments that space and time are fellow creatures, and not eternal, contributed to a sense that even nature has a history and can only be understood in terms of its unfolding over time.

Augustine's *Literal Interpretation of Genesis*

We see Augustine's attitude toward the Bible and science in a commentary on the literal interpretation of Genesis:

"In matters that are obscure and far beyond our vision, even in such as we may find treated in Holy Scripture, different interpretations are sometimes possible without prejudice to the faith we have received. In such a case, we should not rush in headlong and so firmly take our stand on one side that, if further progress in the search of truth justly undermines this position, we too fall with it. That would be to battle not for the teaching of Holy Scripture but for our own, wishing its teaching to conform to ours, whereas we ought to wish ours to conform to that of Sacred Scripture." Augustine, *Literal Meaning of Genesis*, Bk. I, ch. 18; 1:41; cf. Bk. I, ch. 19; 1:41-42.

Augustine articulated several principles to guide the interpretation of the Bible with respect to natural science. They include the principles of:

• **Multiple Interpretations** (that scriptural references to nature are not specific to a single scientific explanation);
• **Unity of truth** (that properly interpreted, science and scripture will not conflict);
• **Accommodation** and
• **Phenomenalism**.

Accommodation & Phenomenalism

Accommodation means that the language of the Bible was written to communicate what is necessary for salvation in a way that could be understood by ordinary people without expert knowledge. There are several ways, for Augustine, that Scriptures are accommodated to common human understanding, including the use of idiom appropriated from the target culture (but stripped of idolatrous connotations), the use of anthropomorphic descriptions of God, and the principle of phenomenalism.

The word phenomena means "appearances," how nature appears to our senses, in contrast to theories, which are explanations involving hidden causes. The principle of "*phenomenalism*" is one form of accommodation. According to the principle of phenomenalism, the original writers of Scripture accommodated their physical statements to the capacities of ordinary people by simply describing sensible phenomena as they would appear to any observer. Therefore physical references in Scripture should be interpreted whenever possible as entailing only those things that are immediately obvious to the senses. The principle of phenomenalism means that the writers adapted Scripture to refer to obvious phenomena in a common-sense manner, and avoided entangling themselves in distracting debates by alluding to hidden causes or bits of secret knowledge that would only confuse the general reader in any culture.

Concerned that some might jeopardize the credibility of Scripture by misconstruing its physical statements, Augustine warned that "in the matter of the shape of heaven the sacred writers knew the truth, but that the Spirit of God, who spoke through them, did not wish to teach men these facts that would be of no avail for their salvation."

Literal Meaning of Genesis, Bk. II, ch. 9; 1:59.

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Why study the past?

Prompt for reflection



God has done all his works to be remembered" (Psalm 111:4)

Why study the past? What episodes would you want to explore?

1. Awaken wonder
2. Focus on deeper perspectives
3. Stories are concrete, memorable, and formative
4. Enter the worlds of the authors we love
5. Make science human and personal
6. Examine the nature of each discipline & subject
7. Reveal the interconnections and relations between disciplines and subject areas
8. The past is a laboratory
9. The past is drama
10. Detect our culture's blind spots
11. Address historical caricatures and myths
12. _____



Most of all, perhaps, we need intimate knowledge of the past. Not that the past has any magic about it, but because we cannot study the future, and yet need something to set against the present, to remind us that the basic assumptions have been quite different in different periods and that much which seems certain to the uneducated is merely temporary fashion. A man who has lived in many places is not likely to be deceived by the local errors of his native village; the scholar has lived in many times and is therefore in some degree immune from the great cataract of nonsense that pours from the press and the microphone of his own age.

old books. It is a good rule, after reading a new book, never to allow yourself another new one till you have read an old one in between. If that is too much for you, you should at least read one old one to every three new ones.

GOD IN THE DOCK

Every age has its own outlook. It is specially good at seeing certain truths and specially liable to make certain mistakes. We all, therefore, need the books that will correct the characteristic mistakes of our own period. And that means the old books. All contemporary writers share to some extent the contemporary outlook — even those, like myself, who seem most opposed to it. Nothing strikes me more when I read the controversies of past ages than the fact that both sides were usually assuming without question a good deal which we should now absolutely deny. They thought that they were as completely opposed as two sides could be, but in fact they were all the time secretly united — united *with* each other and *against* earlier and later ages — by a great mass of common assumptions. We may be sure that the characteristic blindness of the twentieth century — the blindness about which posterity will ask, 'But how *could* they have thought that?' — lies where we have never suspected it, and concerns something about which there is untroubled agreement between Hitler and President Roosevelt[8] or between Mr H. G. Wells and Karl Barth. None of us can fully escape this blindness, but we shall certainly increase it, and weaken our guard against it, if we read only modern books. Where they are true they will give us truths which we half knew already. Where they are false they will aggravate the error with which we are already dangerously ill. The only palliative is to keep the clean sea breeze of the centuries blowing through our minds, and this can be done only by reading old books. Not, of course, that there is any magic about the past. People were no cleverer then than they are now; they made as many mistakes as we. But not the *same* mistakes. They will not flatter us in the errors we are already committing; and their own errors, being now open and palpable, will not endanger us. Two heads are better than one, not because either is infallible, but because they are unlikely to go wrong in the same direction. To be sure, the books of the future would be just as good a corrective as the books of the past, but unfortunately we cannot get at them.

I myself was first led into reading the Christian classics, almost accidentally, as a result of my English studies. Some,

[8] This was written in 1943.

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The importance of this backward or self-critical reference of scientific questioning is very obvious when we study the history of science, which in all its great stages of advance has entailed radical revision of its premisses and methods.[2] Advances can be made only through new ways of looking at things, through asking daring new questions, but new questions require corresponding changes in language and representation; they require changes in the framework of our concepts and in the logical structure of science itself.[3] They may even call for a new meaning of the word 'understanding'.[4] But all that is part of the pain and awe and excitement of radically new knowledge. The refusal to be bound by the rigid framework of our previous attainments, the capacity to wonder and be open for the radically new, the courage to adapt ourselves to the frighteningly novel, are all involved in the forward leap of scientific research, but in the heart of it lies the readiness to revise the canons of our inquiry, to renounce cherished ideas, to change our mind, to be wide open to question, to repent.

Middle left: C.S. Lewis, "Learning in Wartime," in *The Weight of Glory*. Bottom right: C.S. Lewis, "On the Reading of Old Books," in *God in the Dock* (1970), p. 202. Bottom left: Thomas F. Torrance, *Theological Science* (1969), p. 122.

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