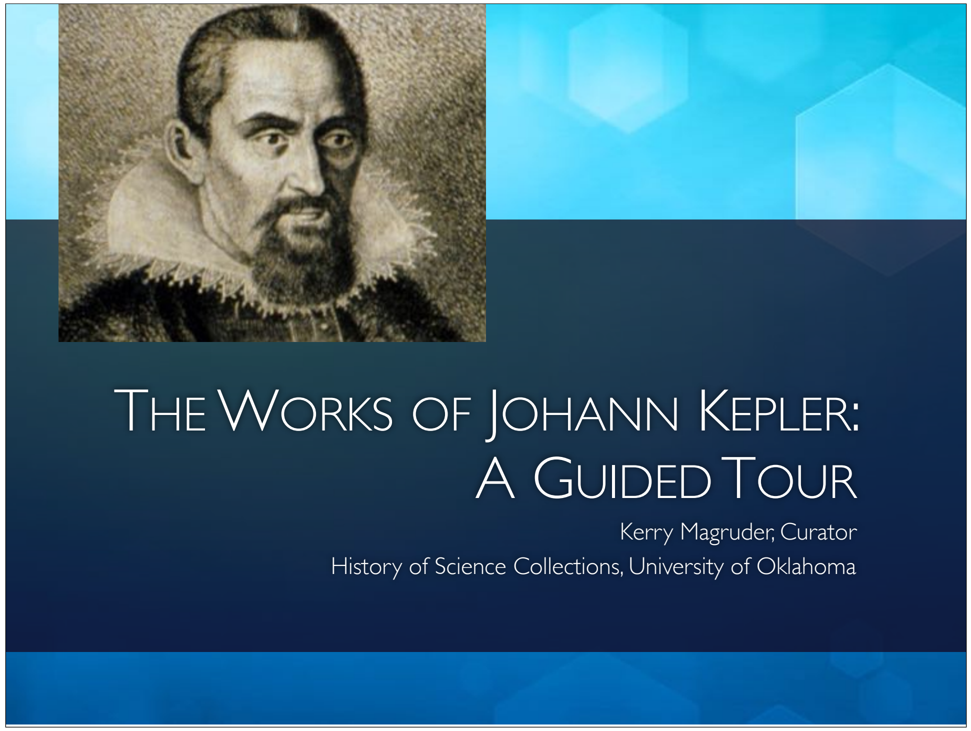
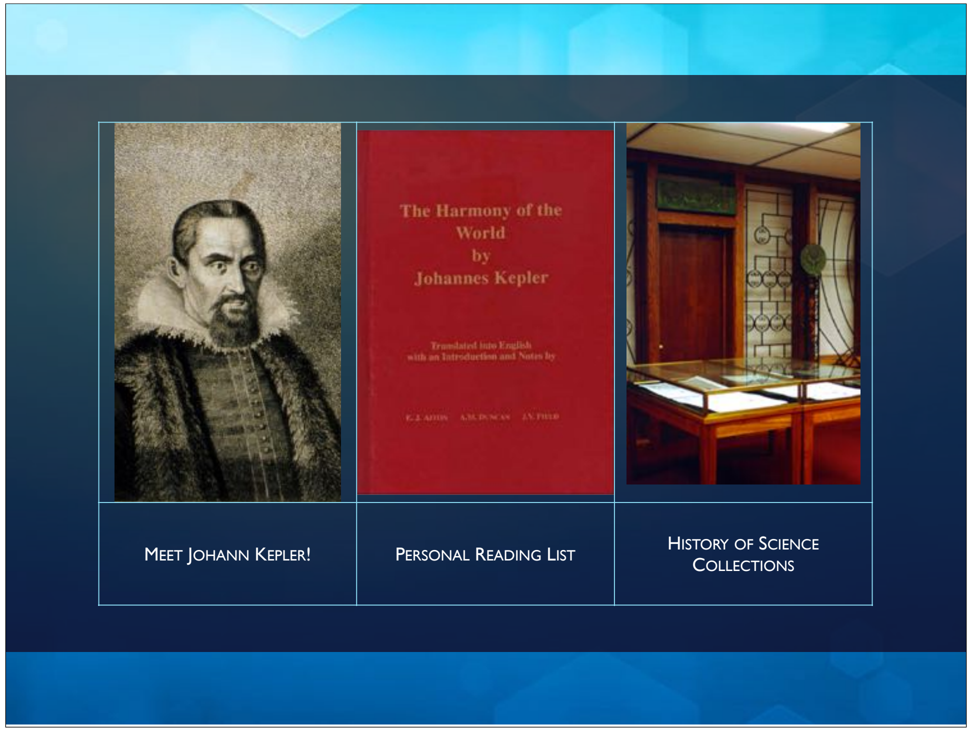


Kerry Magruder, "The Works of Johann Kepler: A Guided Tour." A lecture presented in various places, including the 2013 Okie-Tex star party at Black Mesa, Oklahoma, during the run-up to the Galileo's World exhibit. Revised with minor updates in 2021.

The Kepler space telescope launched in March 2009 to search for terrestrial planets around other suns. One month later, five Jupiter-like planets had been discovered. More than 2,600 planets were confirmed before the Kepler telescope was retired in 2018.

Shown here is an artist's conception of Kepler 20e, one of the smallest exoplanets.

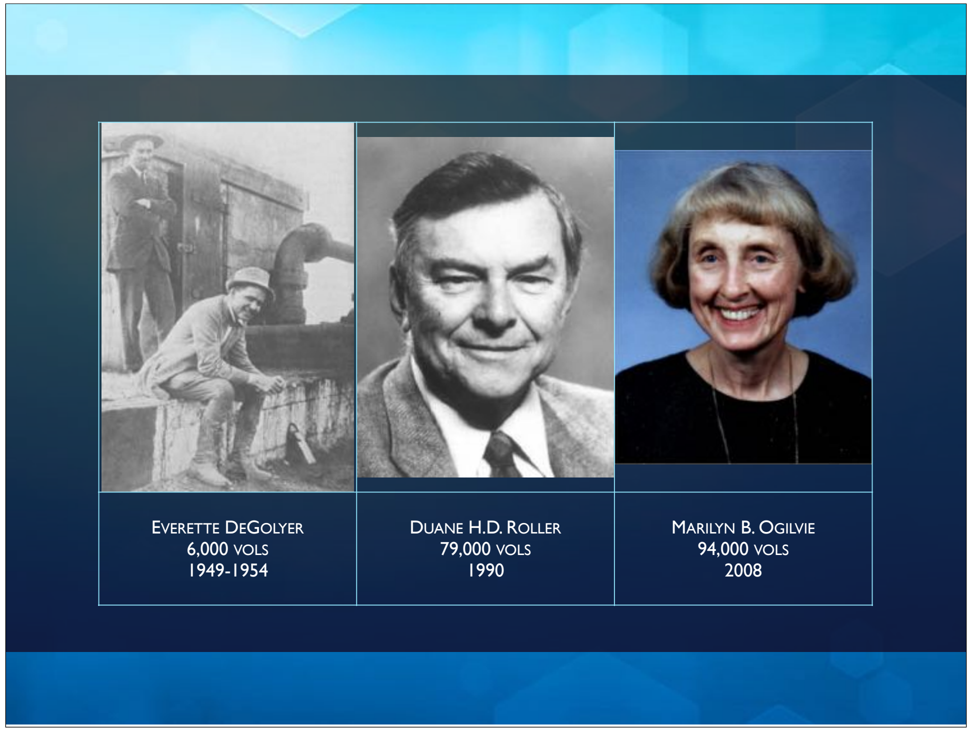
In a science fiction collection entitled “A Kepler’s Dozen,” each short story takes place on one of the specific planets discovered by the Kepler telescope. So, with stories and headlines of exoplanet discoveries, one might wonder who was Kepler, and why is there a telescope named for him?



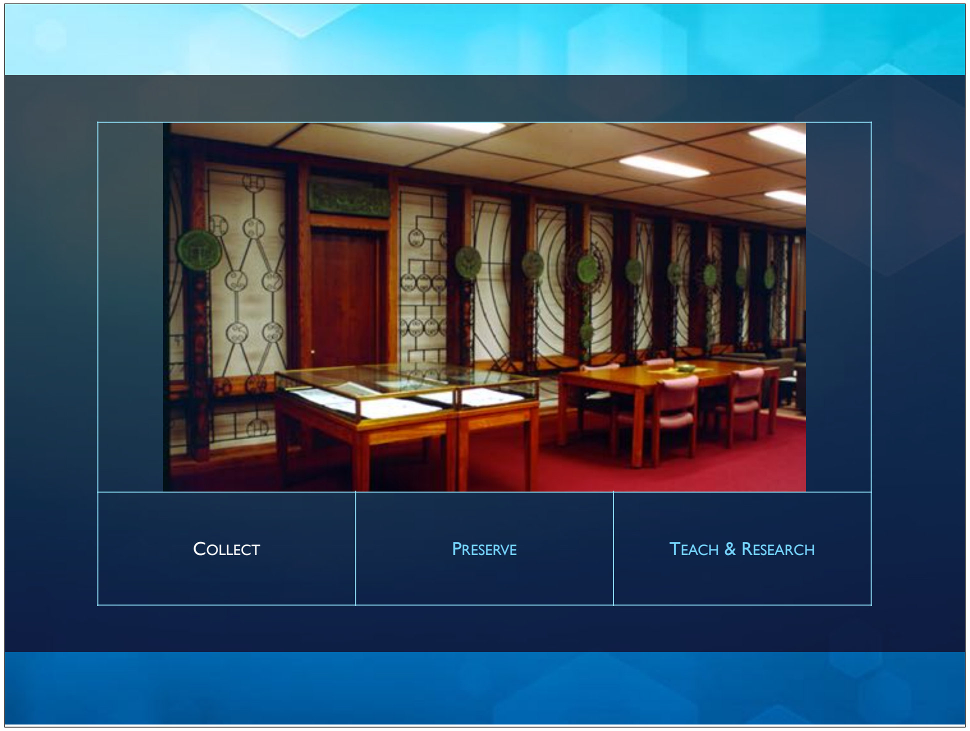
This guided tour of the works of Kepler will interweave three different strands. First, we will see how vast and original Kepler's contributions were, not only to astronomy but also to other fields. The German philosopher Immanual Kant called Kepler "the most acute intellect" who ever lived. Let's explore the whole universe of the mind of Kepler. -- Second, by surveying the works of Kepler you may choose one of them to read. Among the founders of modern science, I find Kepler's works to be most enjoyable and rewarding to read today. His boundless curiosity, enthusiasm, originality, creativity and humble self-discipline shine through his words with utter transparency. In his writings as in his life, he had no guile. -- And third, the presentation will introduce you to the University of Oklahoma History of Science Collections. These are my three goals for us in the next hour.

Research universities are often best known for their athletic programs. But among historians of science,

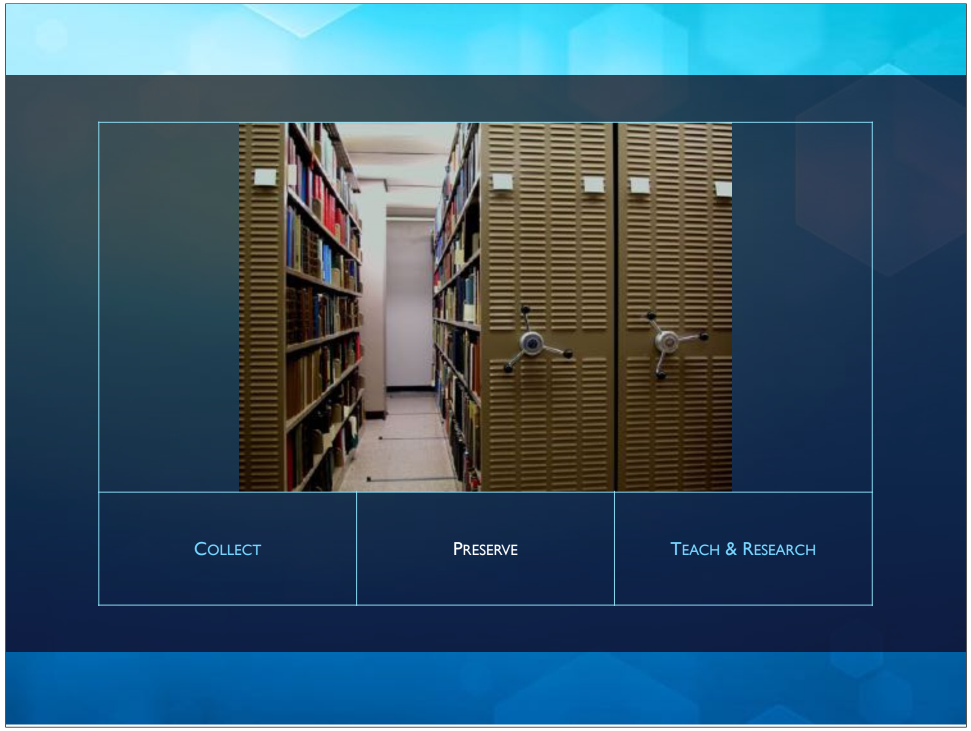
the University of Oklahoma is known for the History of Science Collections.



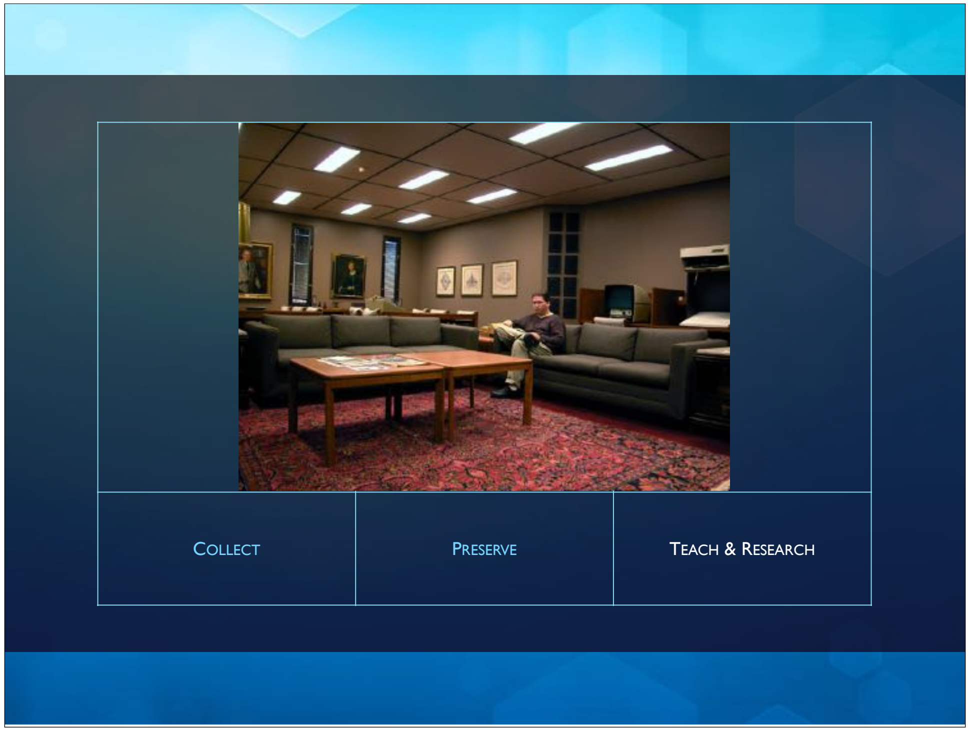
The History of Science Collections began in in 1949 with a gift of 6,000 rare books by Everette Lee DeGolyer, an alumnus of the OU geology school. -- Duane Roller, son of a physicist, became the first curator and professor of the history of science. When he retired in 1990, a separate Department for the History of Science had been created. There are now 11 faculty in the history of science program, and we offer graduate degrees in the history of science. -- Marilyn Ogilvie, a specialist on women in science, became curator in 1991. Under her direction the Collections grew to 94,000 volumes before her retirement in 2008, when I became the third curator.



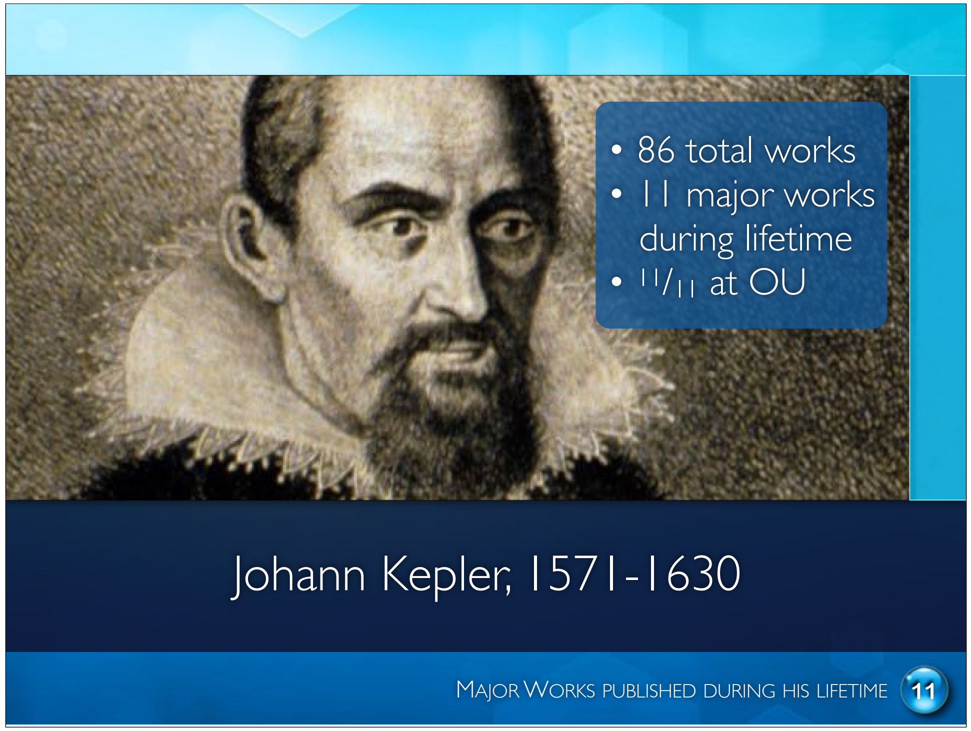
After we collect the books,



we preserve them in climate-controlled vaults.



Then we make them available to students and scholars for teaching and research.

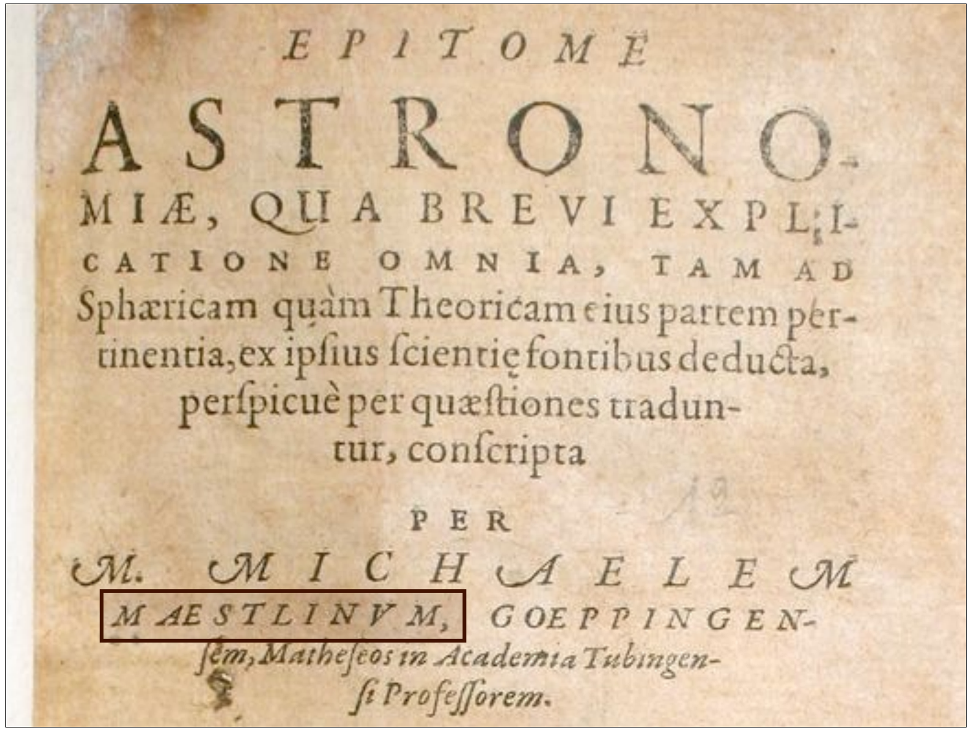


Let's go on a guided tour of the works of Kepler, just as if we were walking through the vaults in Oklahoma. It’s 55 degrees, and the aroma of old books surrounds you. --During his 59 years on this planet, Kepler wrote a total of 86 works, including pamphlets. No library in the world holds them all. We will focus our attention on the 11 most important works he published during his lifetime, mentioning some of his minor works as we go. OU’s Kepler collection is extraordinary, holding all 11 major works published during his lifetime, and a large number of his minor works. All images of rare books in this presentation are from OU’s copies. --So, what are Kepler’s major works? And what stories do they tell?

Kepler was born at this address in Weil der Stadt, a small town near Stuttgart, in 1571. The actual building was destroyed by fire in 1648, but there is reason to believe that it was rebuilt in its earlier form. Then, in the last century, it escaped destruction when a French artillery barrage of Weil der Stadt “was called off in honor of its being Kepler's birthplace.” (W)

At age 13, Kepler entered seminary in this Protestant monastery at Adelberg, to begin study for the clergy.

In September of 1589 Kepler went to Tubingen University to study at the Stift seminary.


EPITOME

ASTRONO-
MIÆ, QUA BREVI EXPLI-
CATIONE OMNIA, TAM AD
Sphæricam quàm Theoricam eius partem per-
tinentia, ex ipſius ſcientię fontibus deducta,
perſpicuè per quæſtiones tradun-
tur, conſcripta

PER

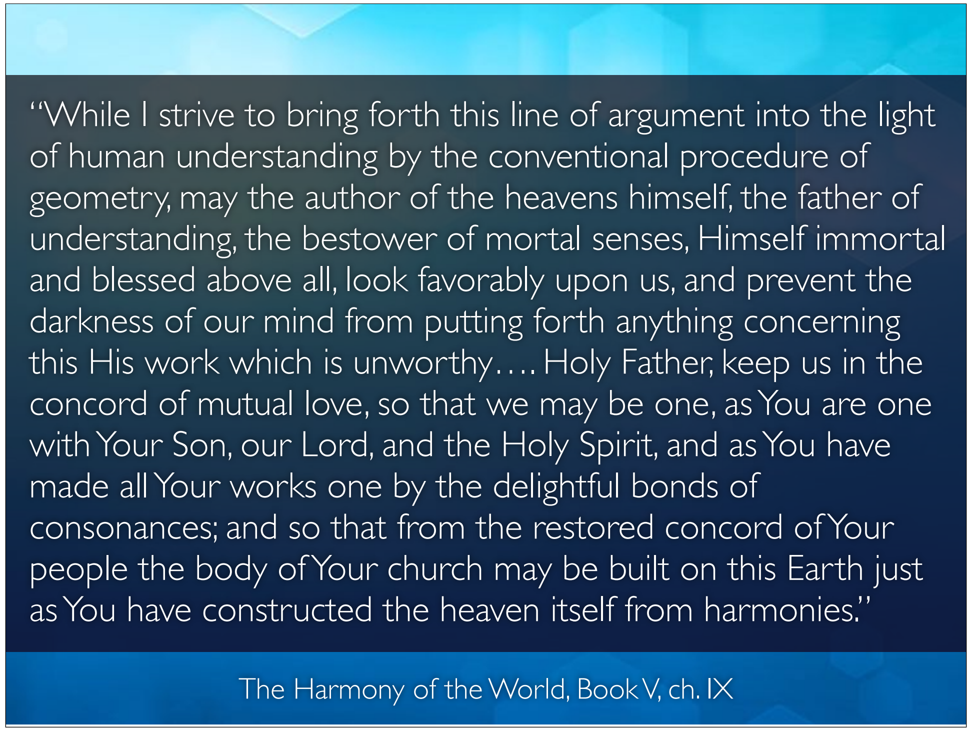
M. MICHAELEM
MAESTLINVM, GOEPPINGEN-
ſem, Matheſeos in Academia Tubingen-
ſi Profeſſorem.

At Tubingen, Michael Mastlin taught Kepler mathematics and astronomy. The articulate Professor Maestlin defended Copernicus and left a lasting impression on Kepler.

Nicolaus Copernicus, *De revolutionibus* (1543)

Although Kepler entered Tubingen university to study theology, to become a Lutheran priest, when he saw this diagram of the Copernican theory, he immediately assented to it “as true in my deepest soul,” writing: “I contemplate its beauty with incredible and ravishing delight...”

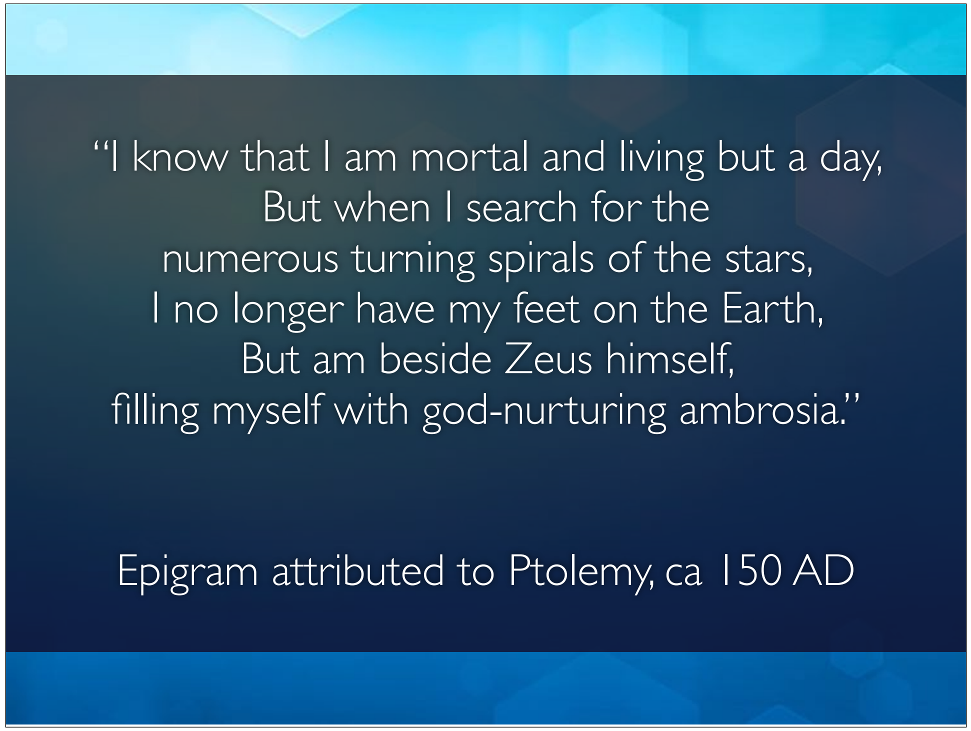
Kepler did not defend the Copernican astronomy because it was proven by observations, for no observational proof was yet at hand. Rather, he pursued it for largely theological reasons: the Creator reveals himself in the Creation, and only such a beautiful theory as the Copernican would be worthy of the Supreme Mathematician. For Kepler, astronomy was a theological calling, no less religious in nature than that of a parish priest. Kepler approached the study of astronomy as one would as a priest of the universe seeking to think God's thoughts after him, and to worship God in the Temple of the universe. Interspersed throughout his writings are prayers like this one:



"While I strive to bring forth this line of argument into the light of human understanding by the conventional procedure of geometry, may the author of the heavens himself, the father of understanding, the bestower of mortal senses, Himself immortal and blessed above all, look favorably upon us, and prevent the darkness of our mind from putting forth anything concerning this His work which is unworthy.... Holy Father, keep us in the concord of mutual love, so that we may be one, as You are one with Your Son, our Lord, and the Holy Spirit, and as You have made all Your works one by the delightful bonds of consonances; and so that from the restored concord of Your people the body of Your church may be built on this Earth just as You have constructed the heaven itself from harmonies."

———

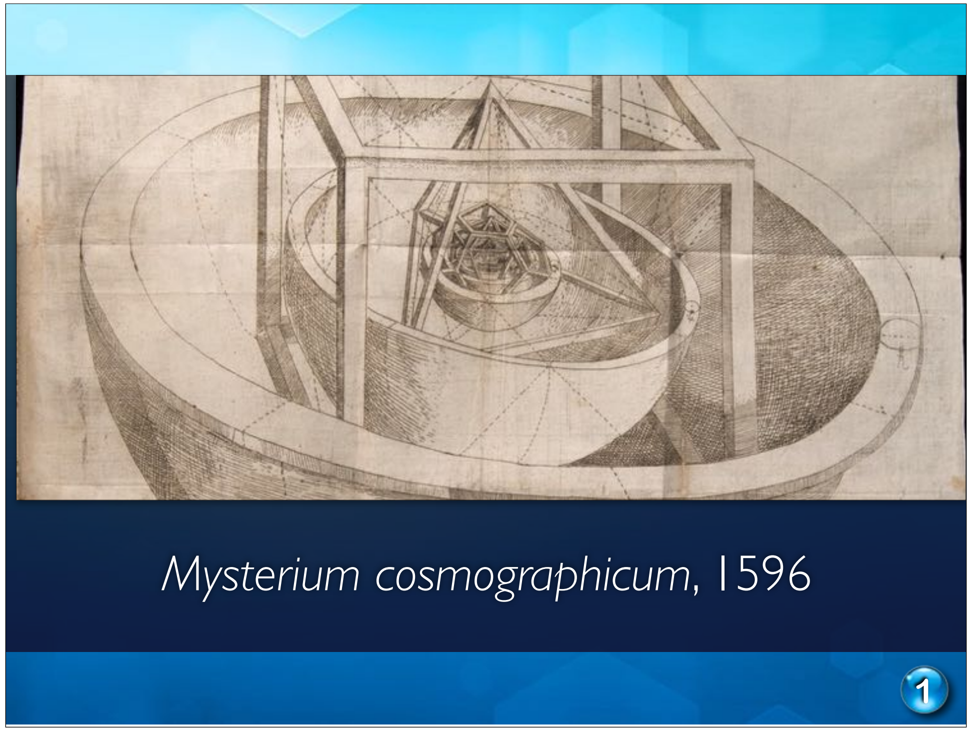
Harmony of the World, pp. 451-452.



It's worth noting that a religious approach to astronomy was far from unusual. Centuries earlier, Ptolemy, a Roman pagan and not a Christian, articulated a theological motive for contemplating astronomy in the opening book of his Almagest. Elsewhere Ptolemy penned an epigram saying: (read). So Kepler's theological approach to astronomy, while extraordinary in itself -- like everything else about Kepler -- nevertheless was not completely without precedent for the discipline of astronomy.

Before Kepler finished his theological studies at Tubingen, he was urged to take a position teaching mathematics at the Protestant seminary in Graz, in modern day Austria.
——————
227.   Graz, showing the Mur River and a hill overlooking the city. Kepler arrived in Graz in April, 1594.
228 Graz, along the Mur River. Explanation: Graz, again looking along the Mur, now closer to the hill. Note the long, two-story, grey building to the left of center. (A small orange building separates it from a large, square, dark-grey building bearing the sign "Kastner-Oehler.") This low grey building was built at the same time as, and next door to, the Protestant Stiftsschule where Kepler taught and which has since been torn down. (See slide 239 for a closer view of this building, taken from the opposite direction.

Kepler lived after his marriage in April, 1597



At Graz in 1596, Kepler published his first book, the Mysterium Cosmographicum....

————

Now for Ptolemy there had been 7 planets that wandered the sky above a motionless Earth: the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn.

On the other hand, Copernicus exchanged the positions of the Earth and Sun, placing the Sun near the center and hurling the Earth into orbit as a planet. This by itself would not change the number of planets. But since the Moon remained as a satellite of the Earth, the number of planets for Copernicus decreased to only 6: the Earth, Mercury, Venus, Mars, Jupiter, Saturn.

Furthermore, contrary to what is often assumed, Copernicus shrank the distances of the planets from the center, so that the sphere of Saturn became nearly half the size as in Ptolemy's model. Yet Copernicus did spread the planets further apart, by thinning the diameter of their individual spheres, so that they were now separated by wide gaps instead of nesting one inside another.

While at Tubingen, Kepler prayed that he might discover why God had created only six planets instead of seven, and why he had set them in the heavens so far apart, at the particular distances which the Copernican theory specified.

In the Mysterium cosmographicum (1596), “Mystery of the Universe” God answered his prayers, or so it seemed. In this book Kepler put forward what would remain his most cherished discovery. However, this discovery is not recognized by modern physicists--and it is not numbered among Kepler’s so called “three laws” in our textbooks.

Five regular solids: left to right, top row first, dodecahedron, icosahedron, octahedron, cube, tetrahedron. Each face and angle are identical, thus these and no others are called regular. Who would have studied these? Pythagoreans.

Kepler, like the Pythagoreans two millenia before him, found in these figures the solution to the mystery of the cosmos. Even Plato had constructed his universe according to the geometry of these solids. Now for Kepler, these solids explained the number of the planets and their distances, as they had guided the Supreme Mathematician’s hand as he had laid out the blueprints of the heavens.

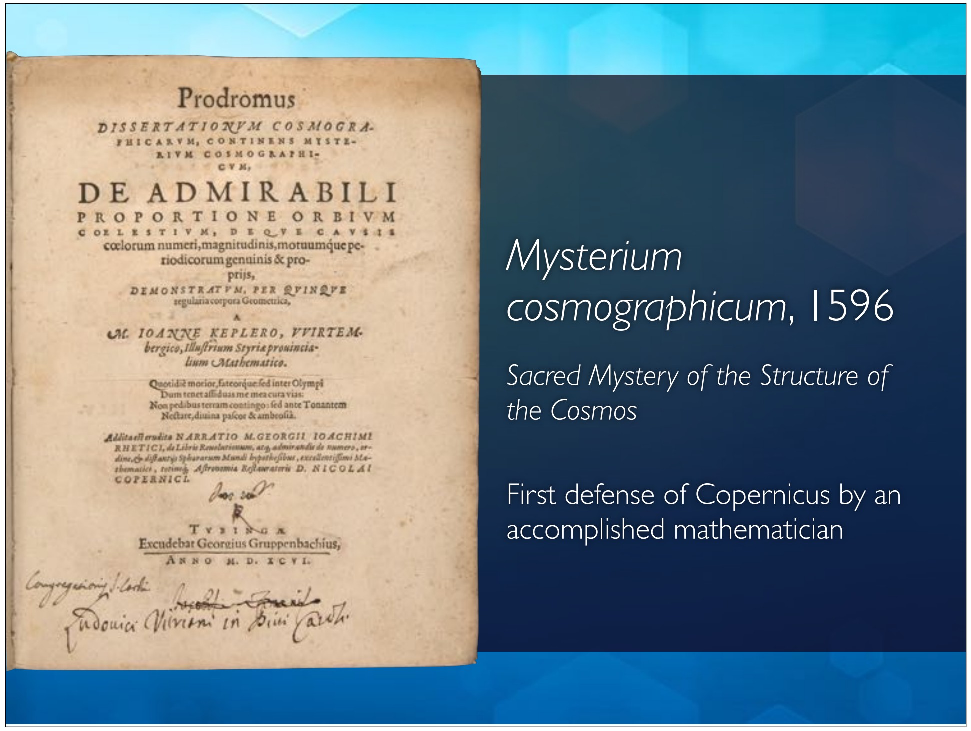
Since there were only five regular solids, Kepler argued that there must be exactly six planets, just as in the Copernican theory. Six planets would have five gaps between them, the thickness of which would be determined by a nesting arrangement of the regular solids.

Kepler did not believe that the solids were physical structures; the mystery of the Copernican distances was explained by their geometry. Indeed Kepler was able to discover an arrangement of regular solid—planetary sphere—regular solid—planetary sphere... and so forth that matched the Copernican values. As he exulted in his discovery:

“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 orbits, 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.”

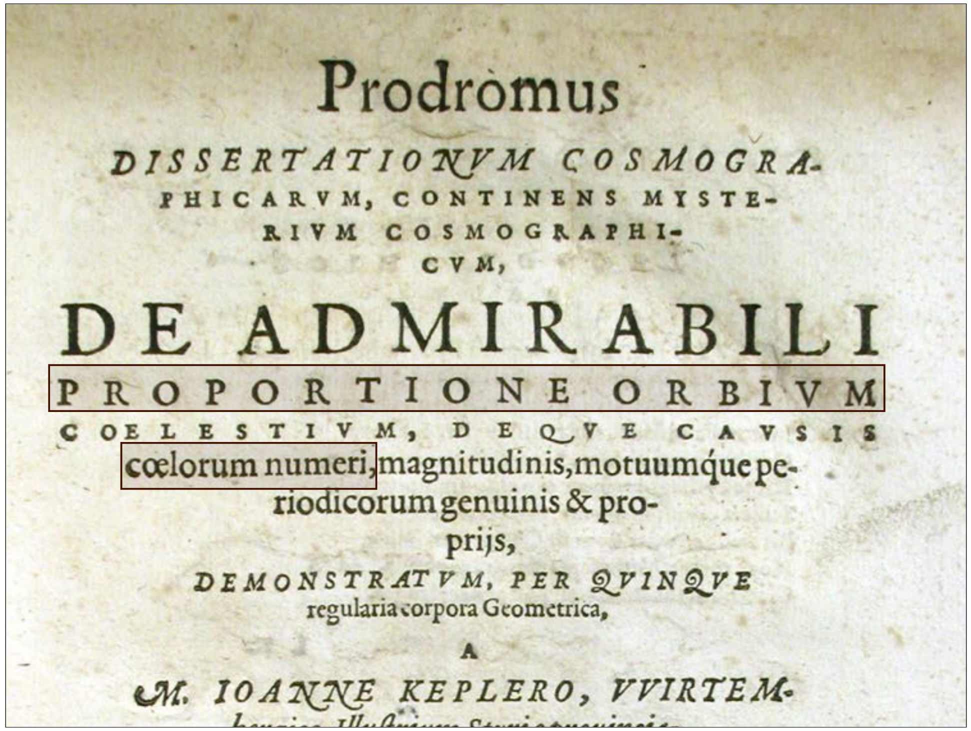
In Kepler’s hands the regular solids furnished proof of the fewer planets and the specific distances required by Copernican theory--closely enough.

What do we have: a theological studies drop-out, sent to the far boondocks, teaching high school mathematics whenever he can take his mind off of his Copernican fantasies--which isn't often (a theory which almost no one else accepts because of its obvious physical difficulties).

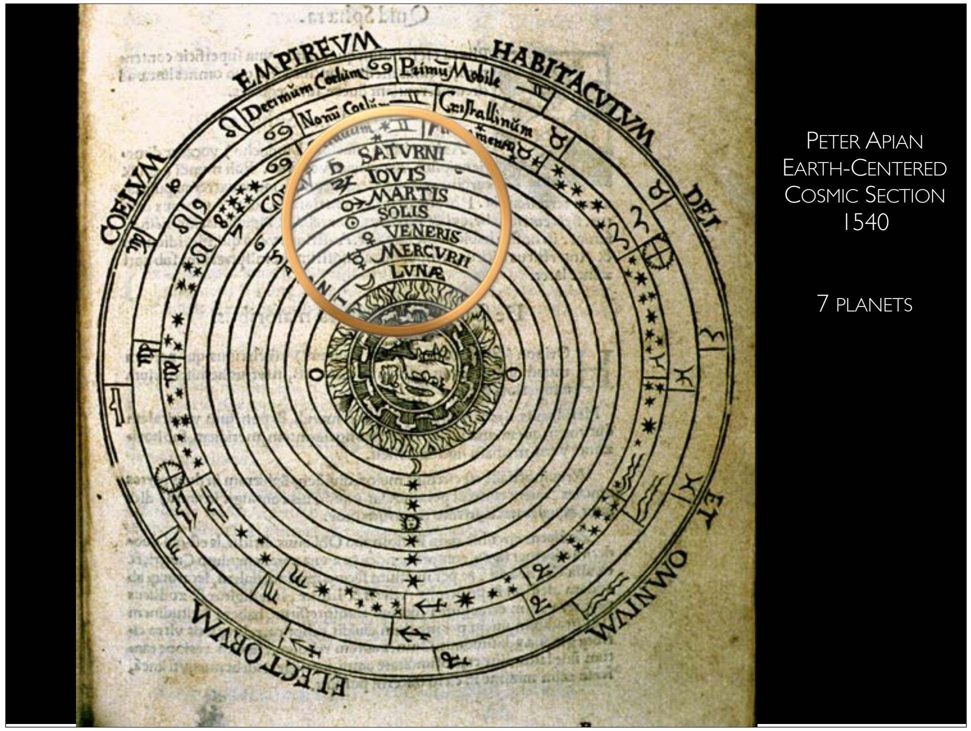


The Sacred Mystery of the Structure of the Cosmos was the first important published defense of the physical truth of the Copernican cosmos by an accomplished mathematician.

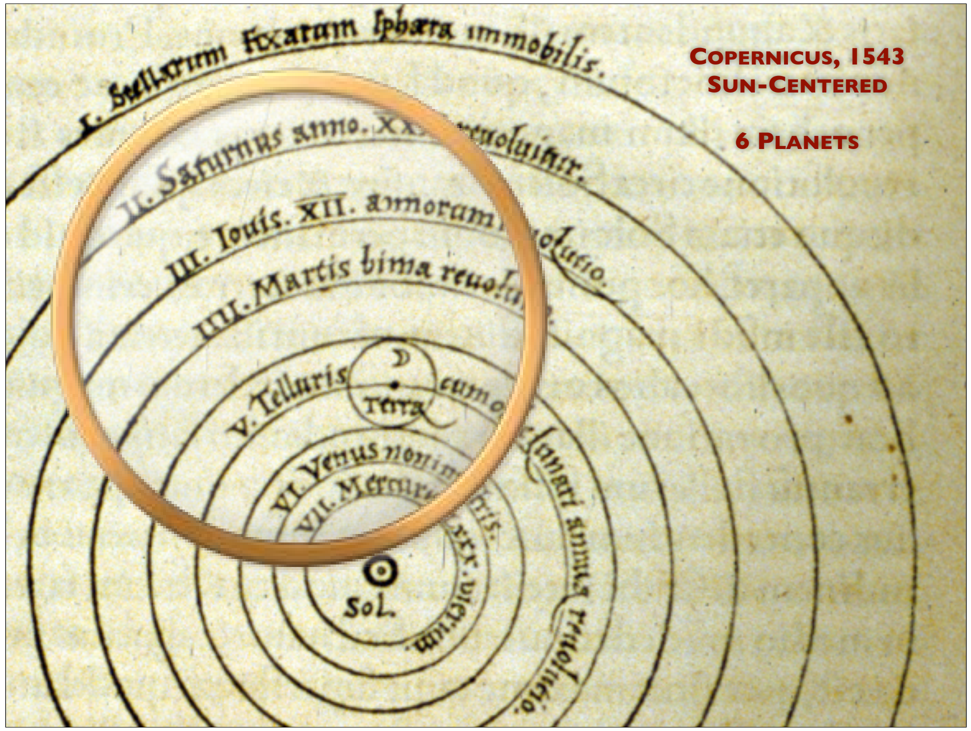
The 16th century was a period of rapid change in astronomy. These are the 3 most significant works published in a 100-year period. At the top, Regiomontanus began the Reformation of astronomy by publishing the first printed edition of Ptolemy's Almagest, greatly updated, in 1496. This Epitome was the point of departure for Copernicus' great work, De revolutionibus, in which Copernicus set the Sun in the center of the universe and hurled the Earth in revolution around it with the other planets. Kepler's first book rightly takes its place among these.


Prodromus
DISSERTATIONVM COSMOGRAPHICARVM, CONTINENS MYSTERIVM COSMOGRAPHICVM,
DE ADMIRABILI PROPORTIONE ORBIVM COELESTIVM, DE QVE CAVSIS cœlorum numeri, magnitudinis, motuumq́ue periodicorum genuinis & proprijs,
DEMONSTRATVM, PER QVINQVE regularia corpora Geometrica,
A
M. IOANNE KEPLERO, VVIRTEM-

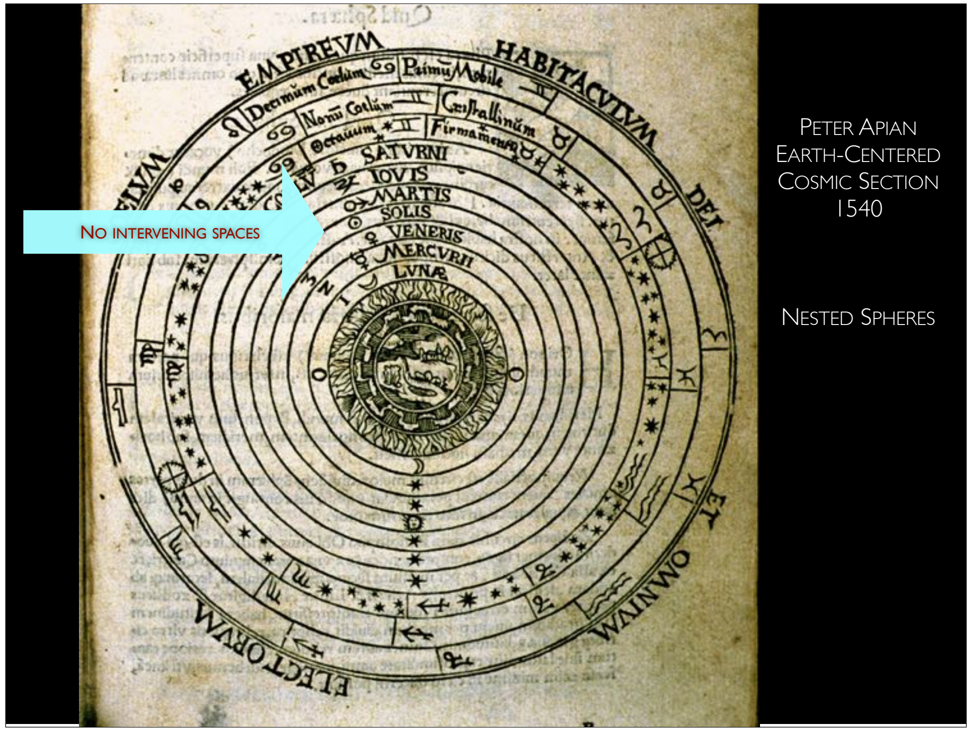
In the Mysterium, Kepler addressed two major objections to Copernicus and turned them both to Copernicus' advantage. These objections concerned the number of the planets
-- and the amazing sizes of the planetary spheres.



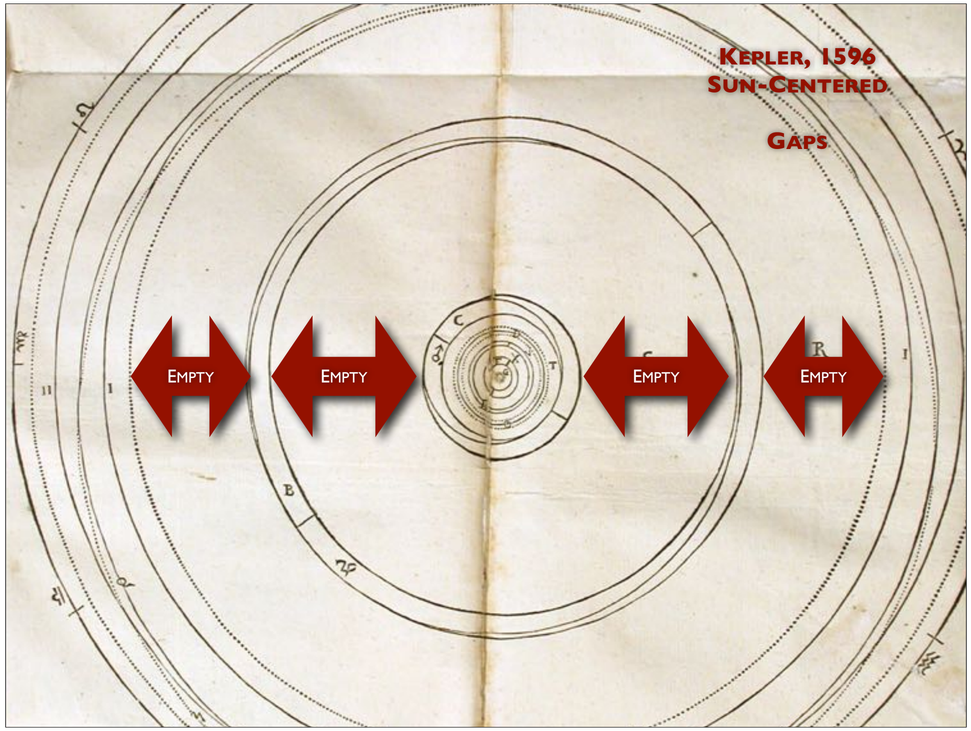
First, the number of the planetary spheres: in the Earth-centered Ptolemaic system there were 7 planets, including the Sun and the Moon, not counting the outermost spheres of fixed stars.



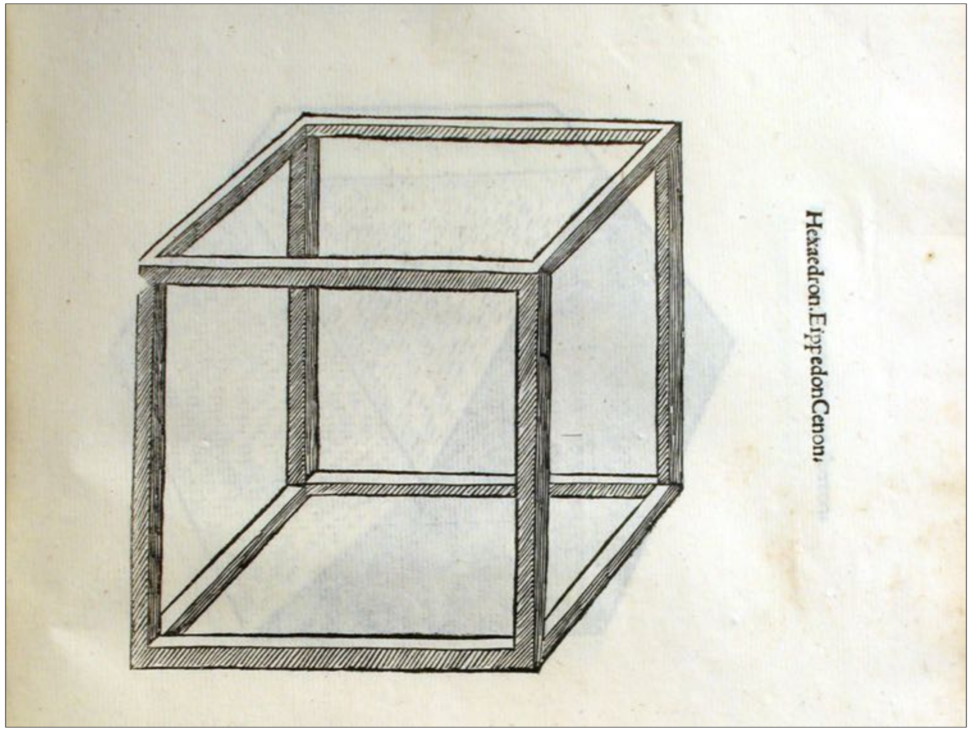
In the Copernican system, there are only six planets, not counting the outermost sphere of fixed stars. The Sun and the Earth switch places. The number of planets decreases by one, because the Moon is demoted; it becomes a satellite of the Earth, within the Earth's sphere, rather than a planet. So Kepler asked, why should there be only six planets instead of seven?



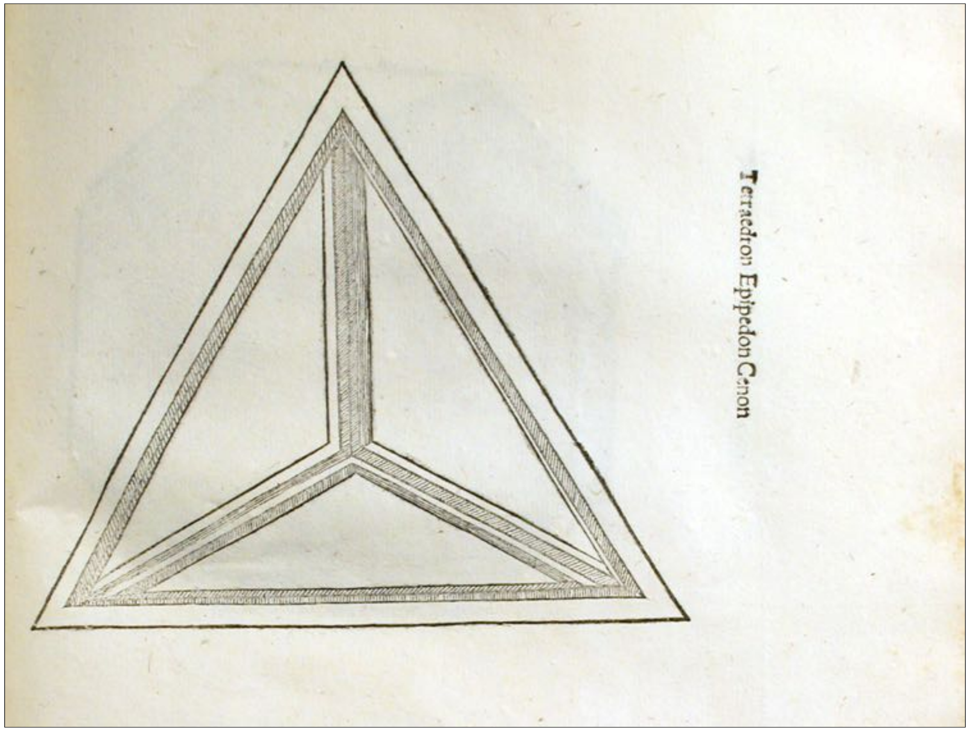
Second, the distances of the planets: In the Ptolemaic system all the planetary spheres nest together with no intervening spaces.



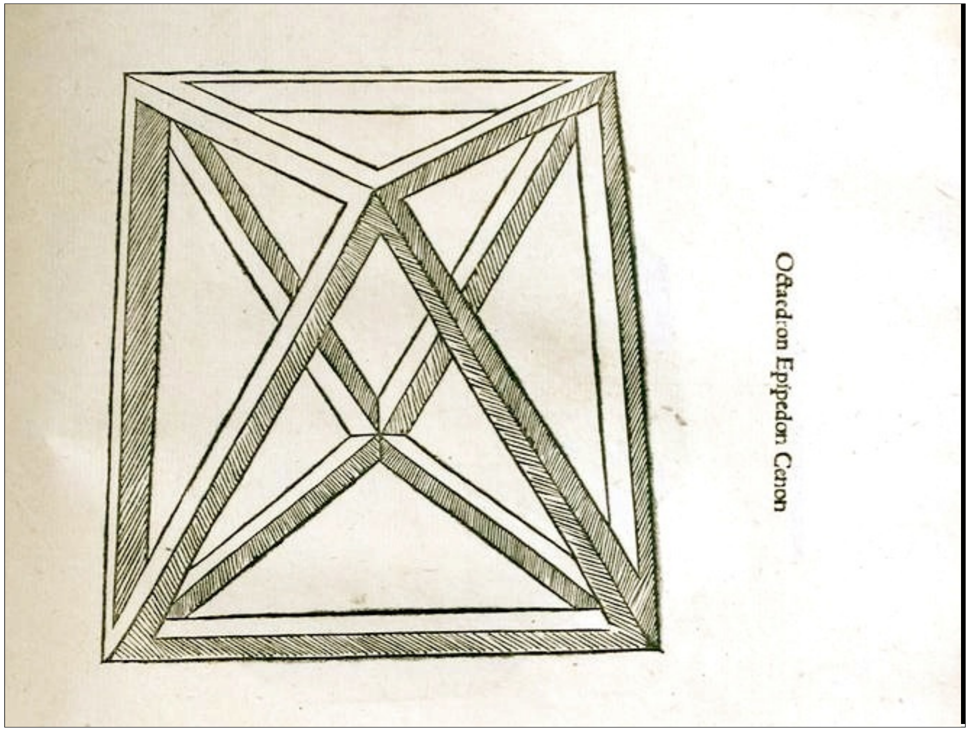
By contrast, in the Copernican system, the spheres of the planets became thin, separated by large distances. Skeptics asked, why would the Divine Architect have wasted so much empty space? Indeed, Kepler calculated that the gaps are quite large, so that most of the universe is empty space!



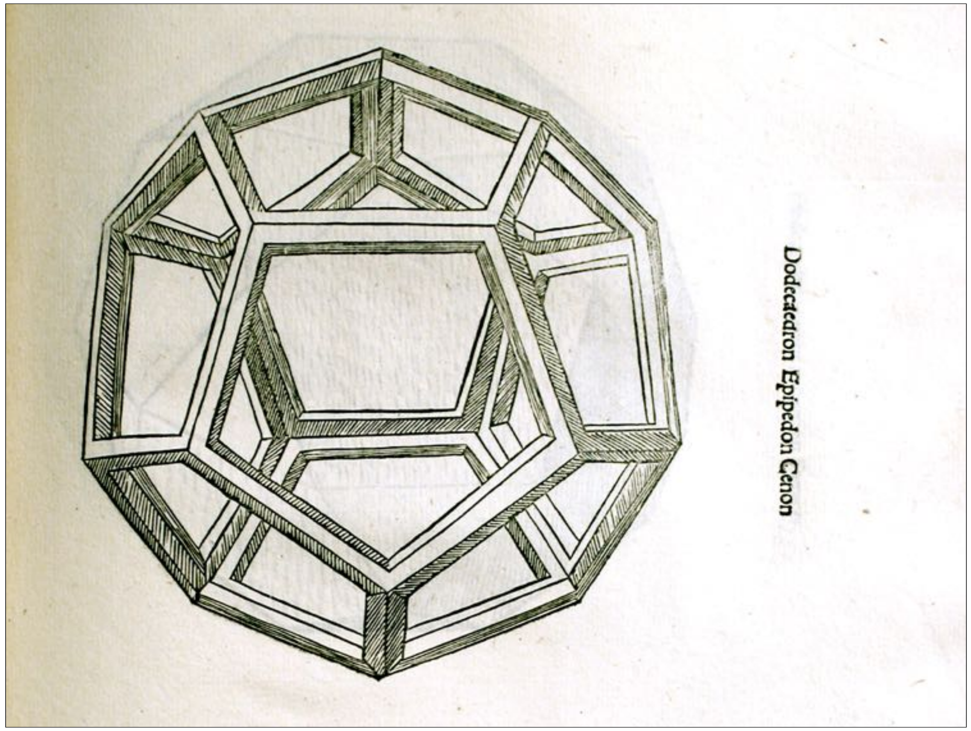
Kepler proved Copernicanism by answering these two questions using the five regular solids of the Pythagoreans. We can define a solid as regular when every face and angle is identical, whether a square on every side of a cube,



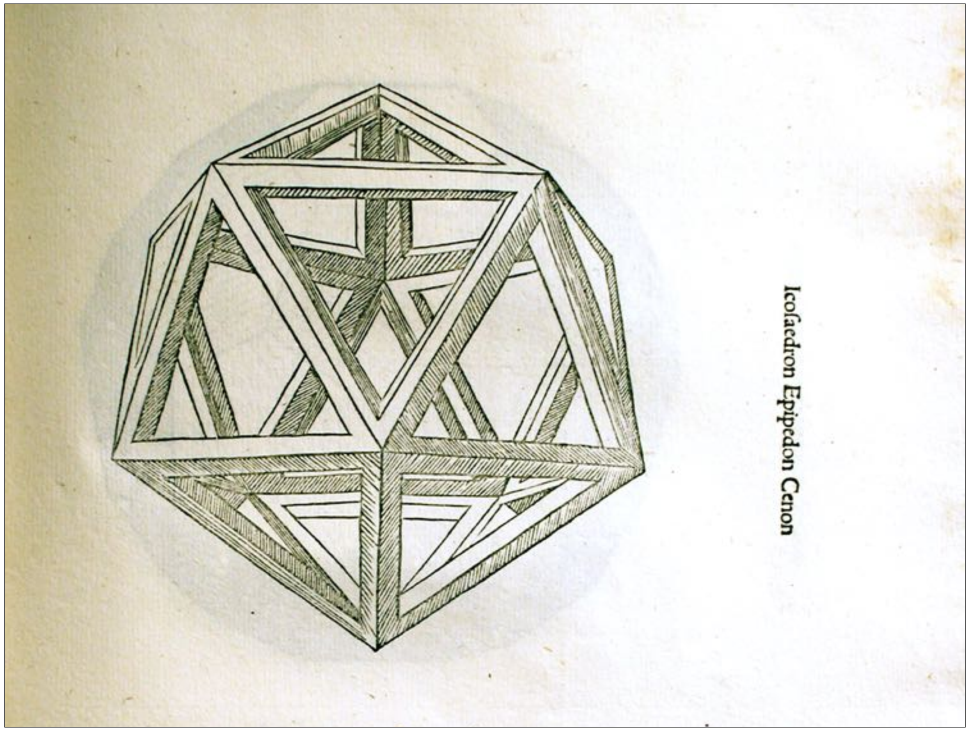
or a triangle on every side of a tetrahedron.



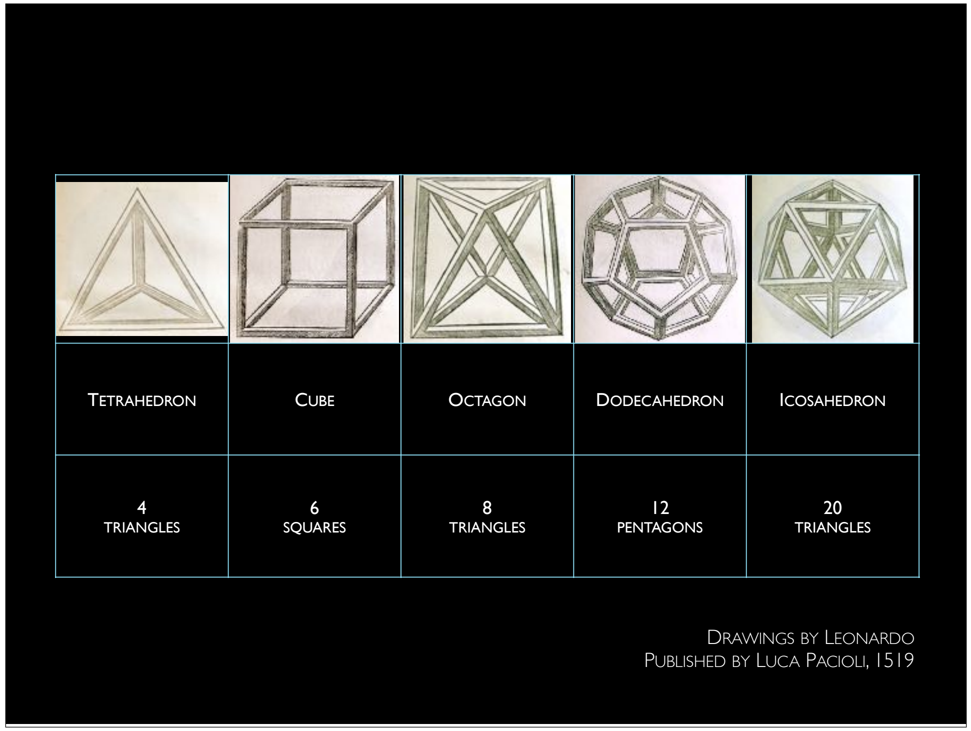
The Pythagoreans proved that there are only five regular solids: The Octahedron has 8 sides;



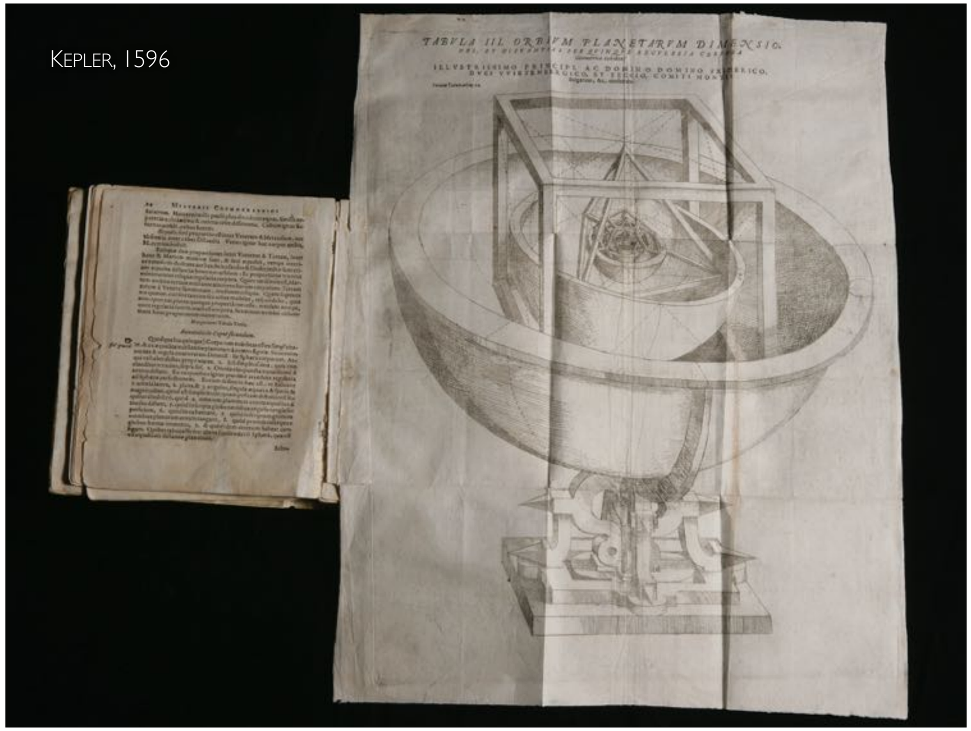
The Dodecahedron has 12 sides;



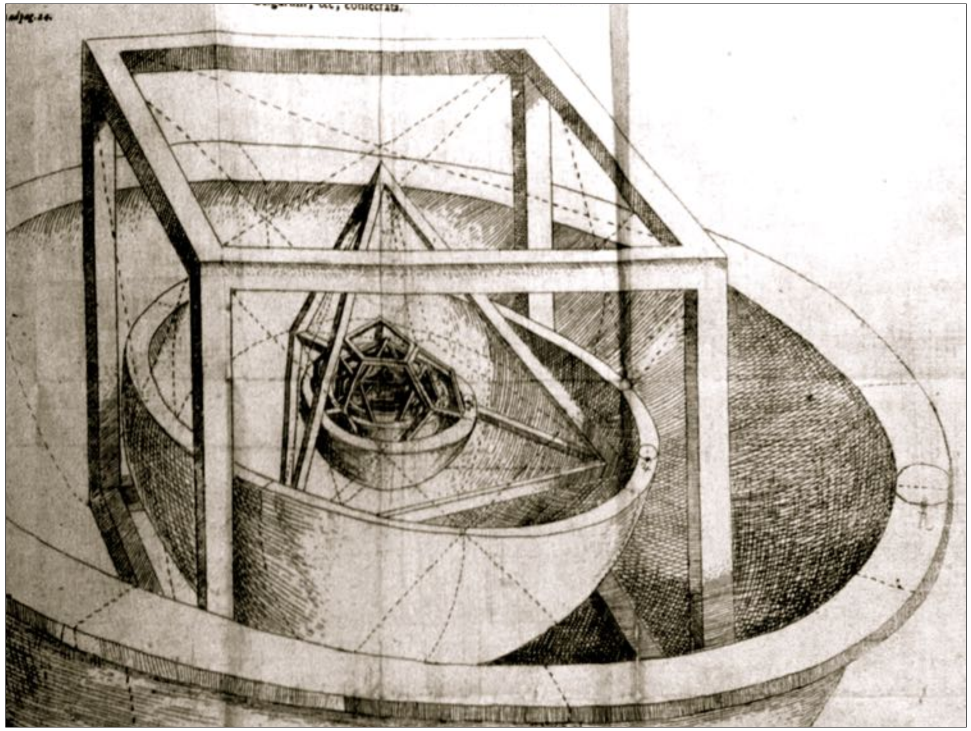
and the Icosahedron has 20 sides. These are Leonardo's drawings of the solids.



There are no others. After Plato, astronomers supposed that the geometry of these five solids would hold an essential clue to the true structure of the universe.



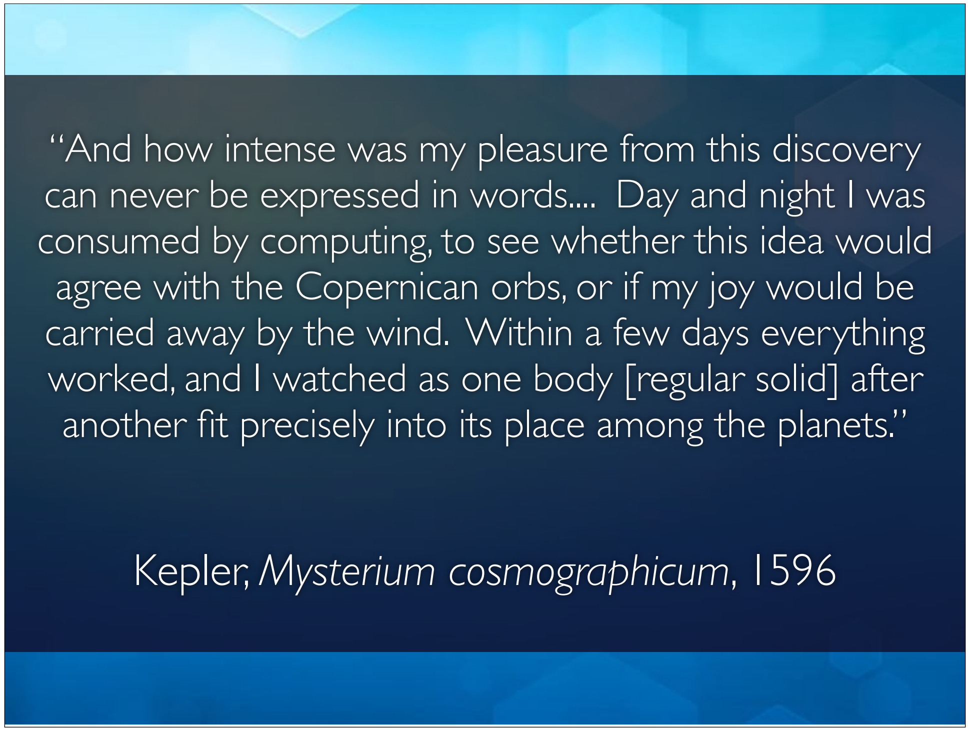
For Kepler, the mystery of the universe was now revealed, because the Divine Architect knew Pythagorean geometry and used it to construct a Copernican universe! Instead of nesting one planetary sphere immediately after another, in the ideal blueprints of the cosmos, the Creator alternated planetary spheres 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!

———————————

Kepler calculated the planetary distances according to Copernicus, and found that the gaps between each planet correspond to the geometry of the solids, using each solid only once. Moreover, the solids explain the number of the planets, for the six planets of Copernicus enclose five gaps. The Ptolemaic system, with 7 planets, would require 6 gaps, but the Pythagoreans demonstrated that there are only 5 solids.



Kepler wrote:

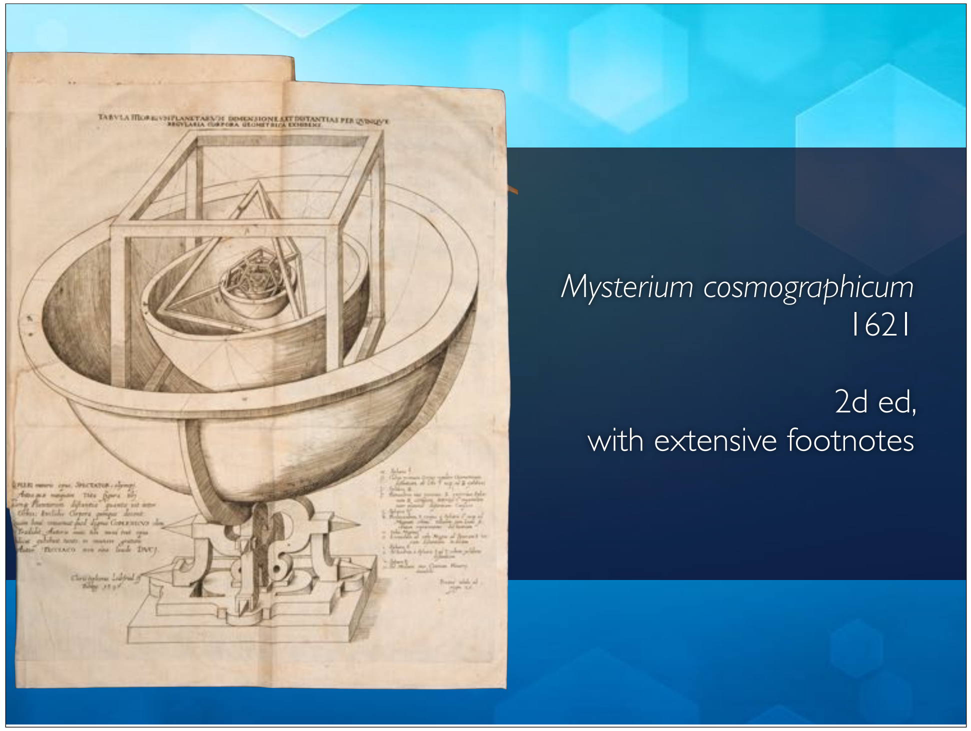
When I was a beginning OU graduate student, Collections curator Duane H.D. Roller wagged his finger at those of us who were enrolled in his class on early modern science, saying, “I’d trade Marjorie for a copy of this book.” Thankfully, it soon became available for a better price.

Kepler mailed copies to various scholars, including Galileo and Tycho Brahe. Galileo was not persuaded by what seemed to him to be the work of a Lutheran mystic. He read no farther than the first few pages, but he wrote back to Kepler that he had already been a Copernican for several years.

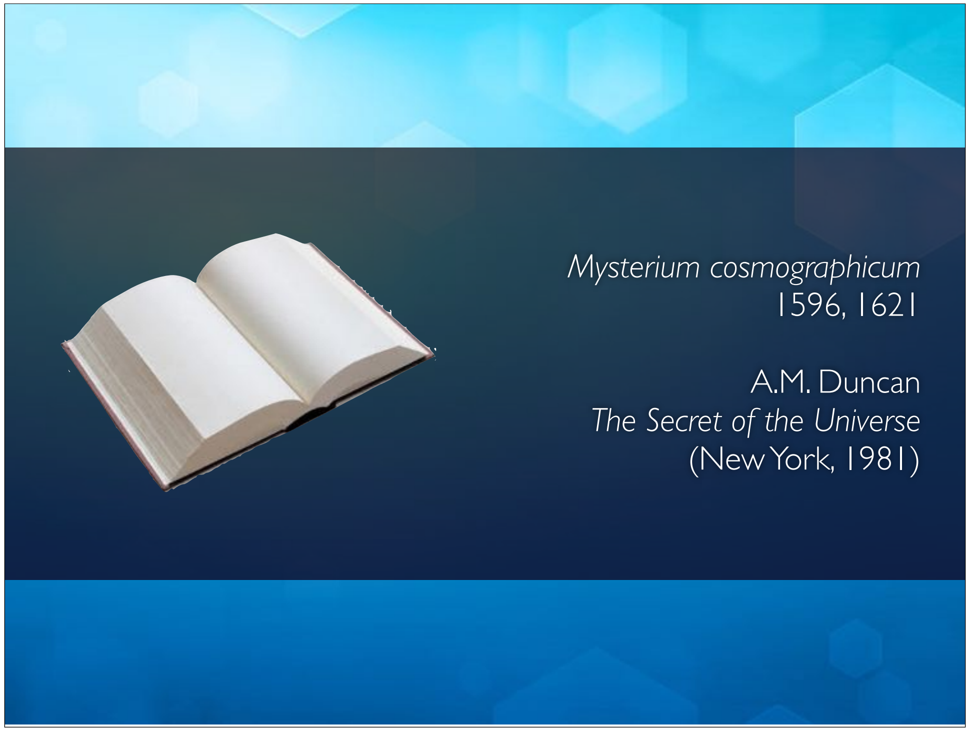
Tycho likewise was not amused at Kepler's flights of fancy, but was impressed by his mathematical ability. So Tycho, who was then the Imperial mathematician and astronomer, offered him a job in Prague as a calculating assistant.

Photo by Duane H. D. Roller

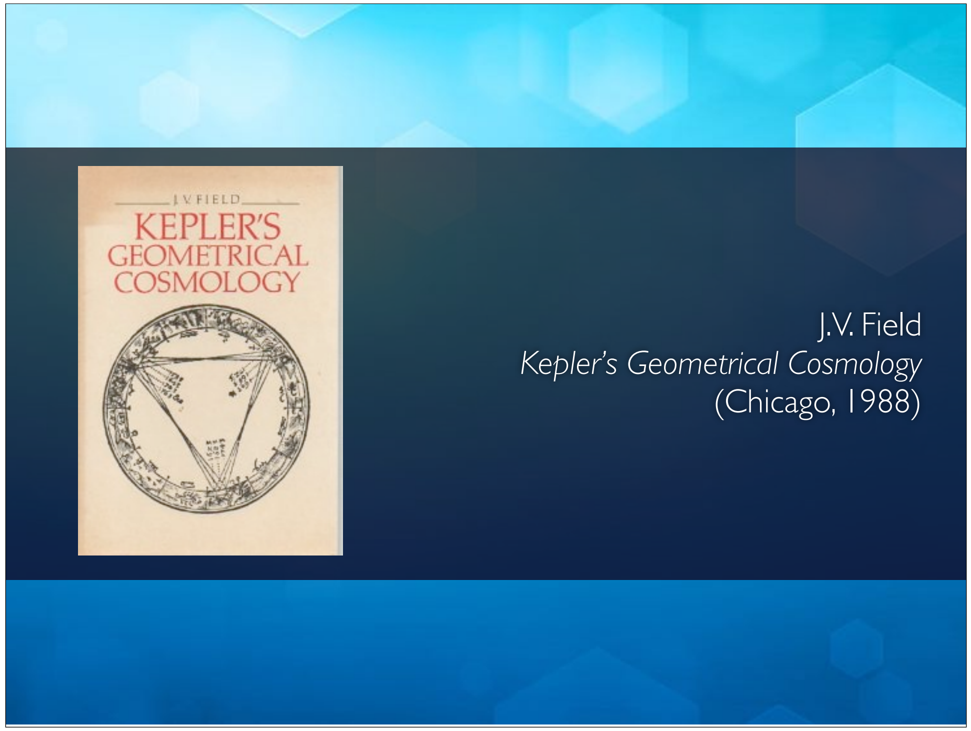
Kepler had to leave Graz when Lutherans were banned from the city because of the Counter-Reformation. In October of 1600, he and his family arrived in Prague. On the skyline is Prague Castle, with St. Vitus' Cathedral inside. Prague Castle was home to Emperor Rudolph II, who did not mind having a Lutheran in his midst. Here Kepler began working for Tycho.



Lest we regard the Mysterium cosmographicum as a piece of juvenilia, and the reasoning from the Pythagorean solids as just a phase he quickly outgrew, Kepler published a second edition in 1621. He chose to retain the original text, and added comments and updates in the footnotes. The solids recur in many other of his later works as well.

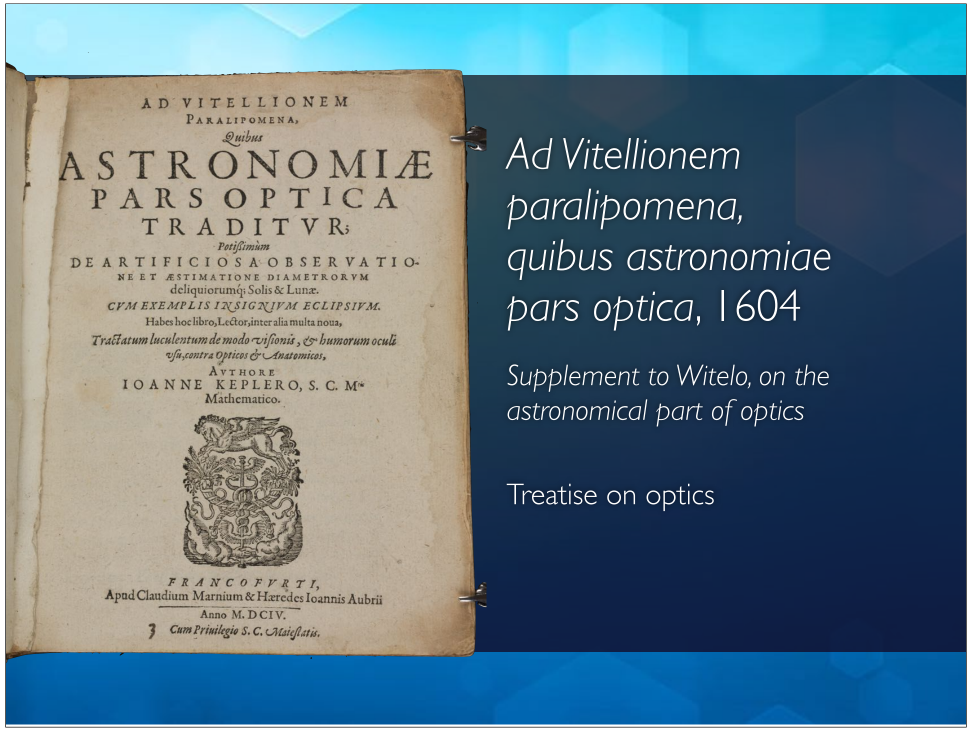


A.M. Duncan translated the Mysterium into English in 1981.

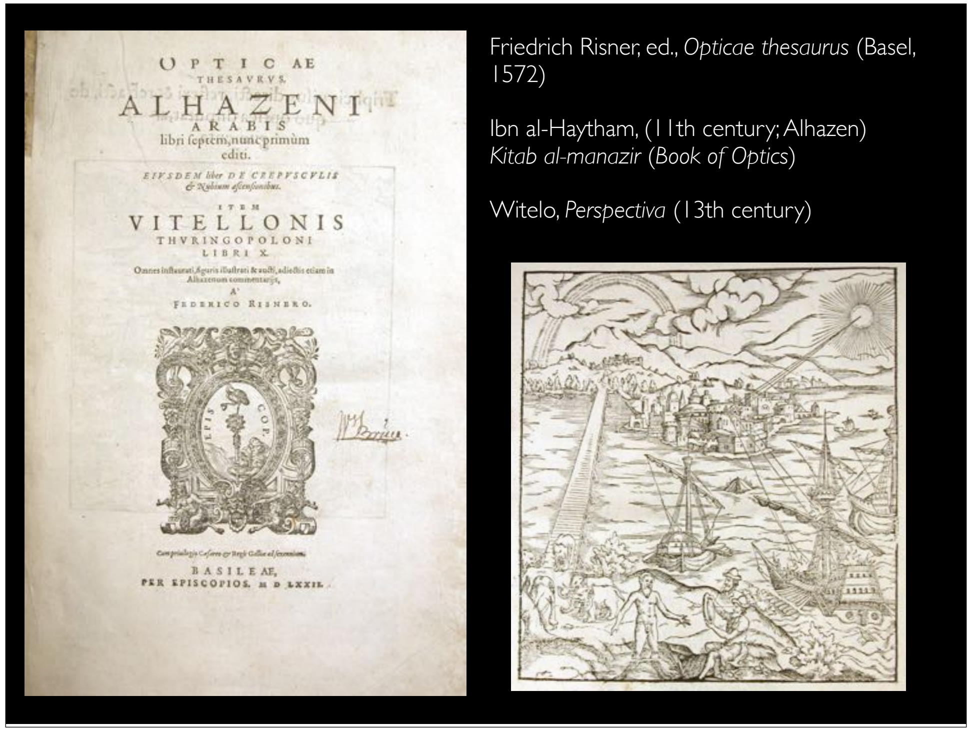


If you want to explore Kepler's use of the regular solids in the Mysterium and throughout his works, a great place to begin is J. V. Field's study, Kepler's Geometrical Cosmology.

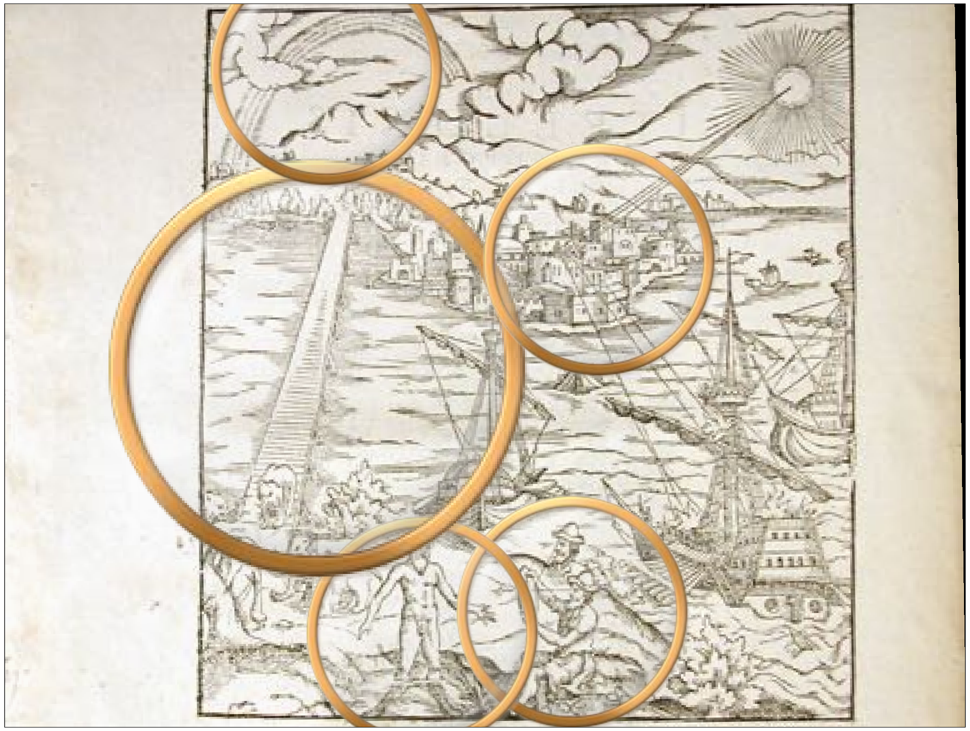
Kepler’s next major work was a rigorous treatise in optics.



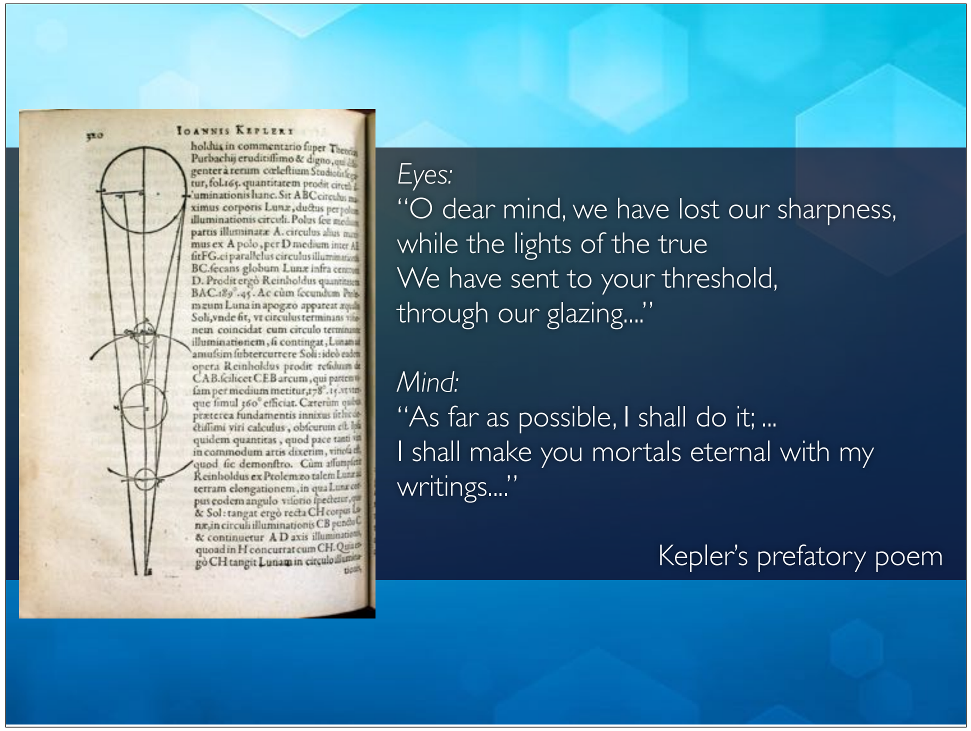
...with an emphasis on the parts of optics relevant to astronomy, as a supplement to the treatise of Witelo. So who was Witelo?



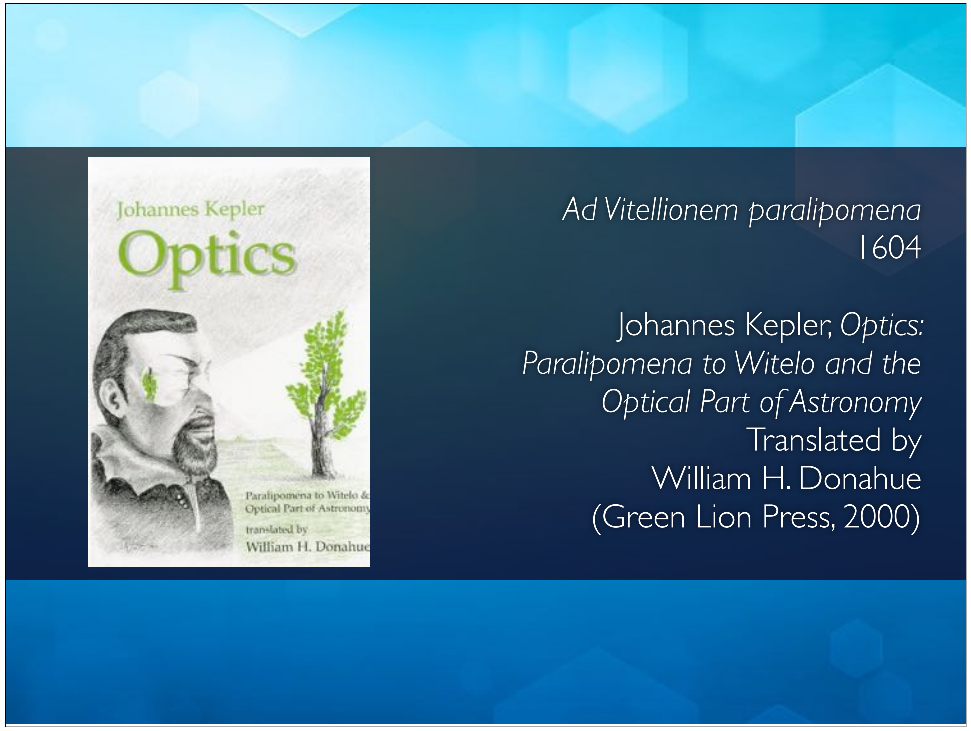
The reference is to this edition by Friedrich Risner containing the optical treatises of both Witelo and Alhazen. Ibn al-Haytham, known in the Latin West as Alhazen, made significant contributions to both astronomy and optics. Alhazen's experimental treatise in optics built upon the foundation laid by Ptolemy and provided a basis for later investigations in optics by Witelo and Kepler, until the invention of the telescope in the early 17th century.



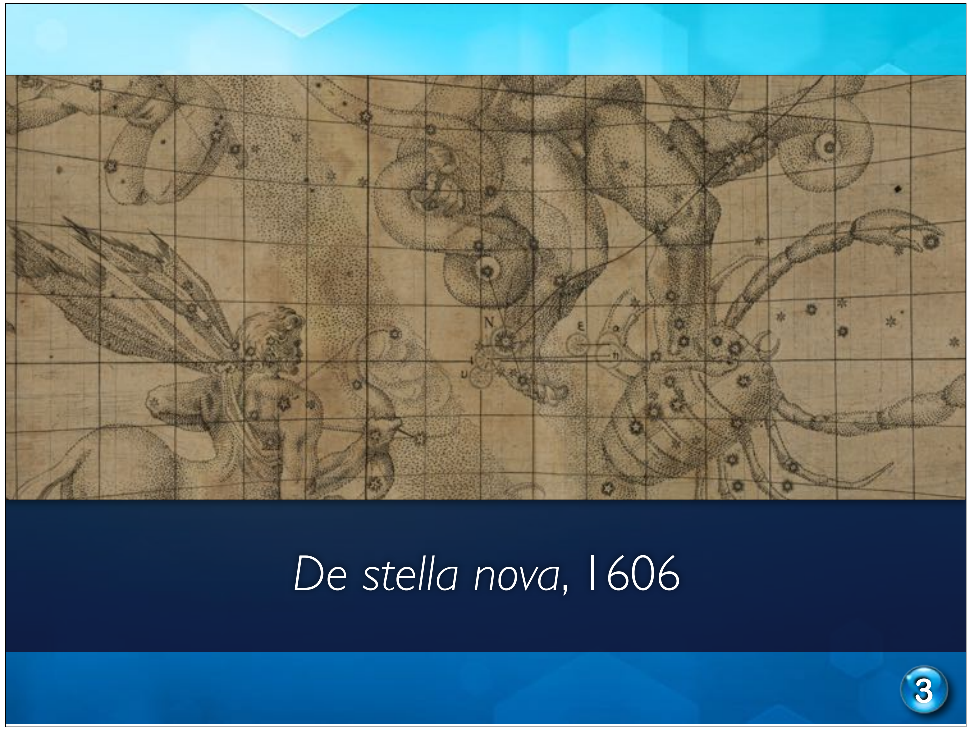
The frontispiece depicts a variety of optical phenomena: Reflection. Refraction. Perspective. Rainbow. Burning mirrors (Archimedes defending the ancient city of Syracuse).



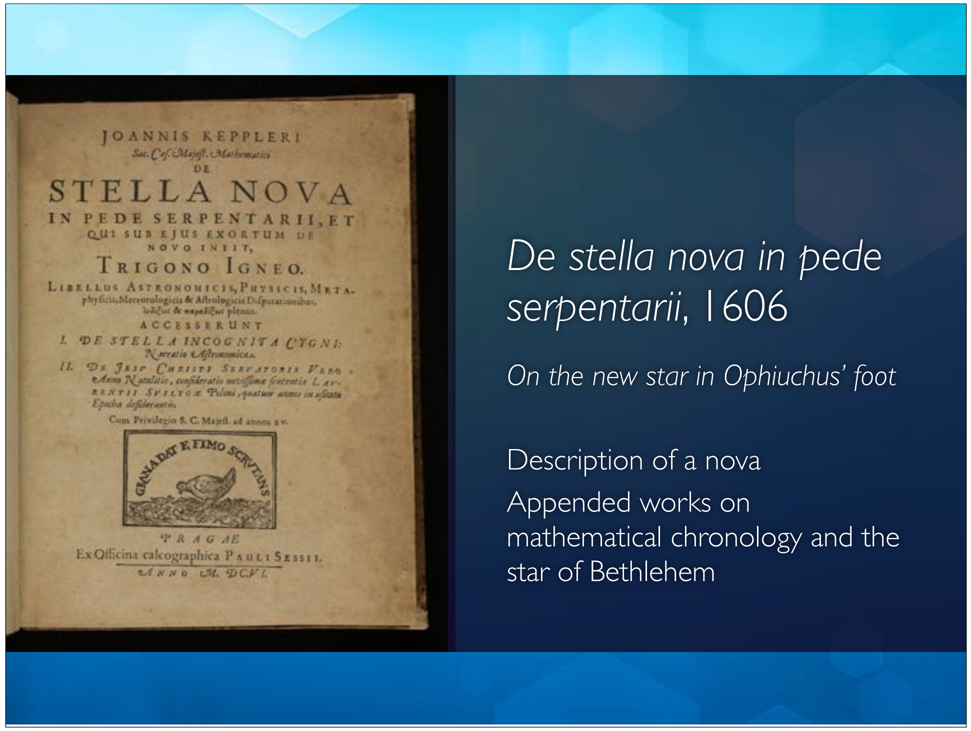
Kepler went beyond both Alhazen and Witelo in optical theory, building upon their foundation. -- He included a poem he wrote as a dialogue between his eyes and his mind. [read] In an ongoing struggle with poor vision, he hoped that his mind would make up for the deficiencies of his eyes.



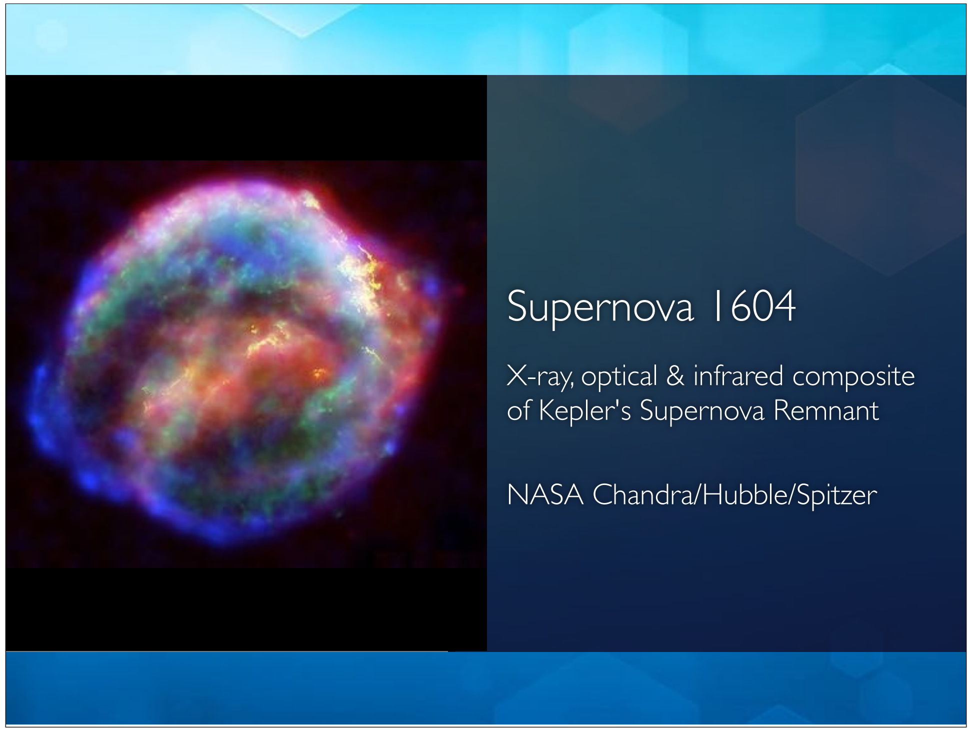
You can read the entire work, including the poem, in this delightful translation. There's no better way to learn mathematical optics than to have Kepler as a tutor.



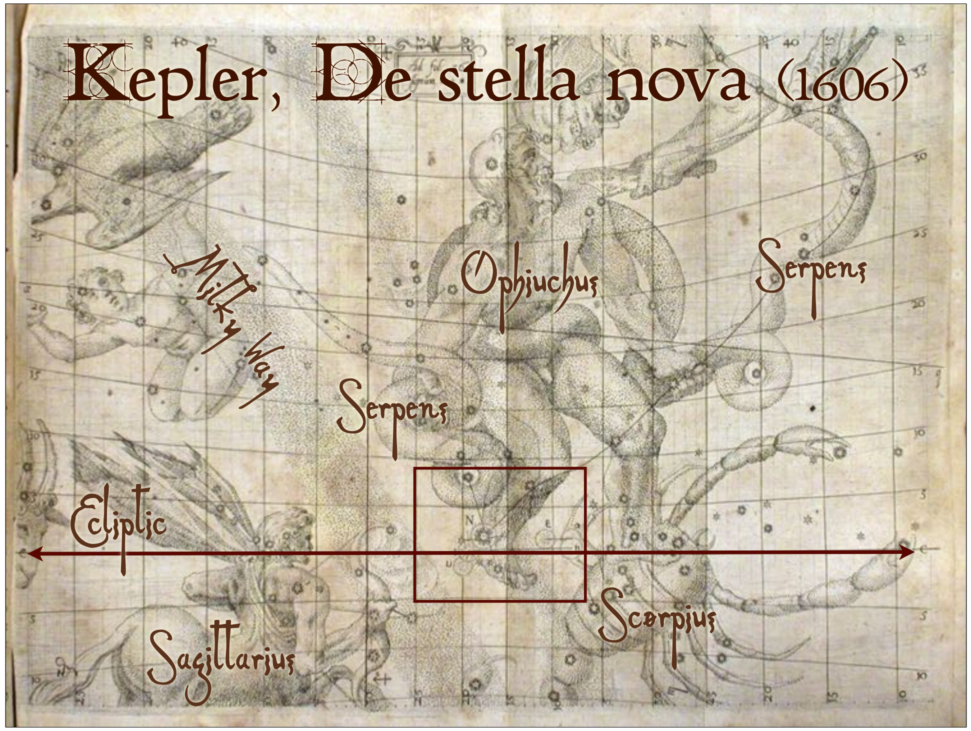
In 1606, Kepler published a little book on a new star.



The star appeared in the foot of Ophiuchus. Kepler's discussion of the new star led him to elaborate upon mathematical chronology, the date of the birth of Christ, and the nature of the star of Bethlehem.



Kepler described what we know as Supernova 1604. It was the second supernova to be observed in a generation, along with the supernova in Cassiopeia in 1572 described by Tycho. No supernova has been observed since within the Milky Way galaxy.



Here's Kepler's star map of the events he observed, published in De stella nova.
It shows the constellations of Ophiuchus, Sagittarius and Scorpius.
Ophiuchus is wrestling Serpens the Snake.
The Milky Way runs diagonally down from the left...
and the Ecliptic runs horizontally through Sagittarius and Scorpius.
Let's look more closely at one smaller area near the foot of Ophiuchus.

E–C = ecliptic

alpha, epsilon = Saturn

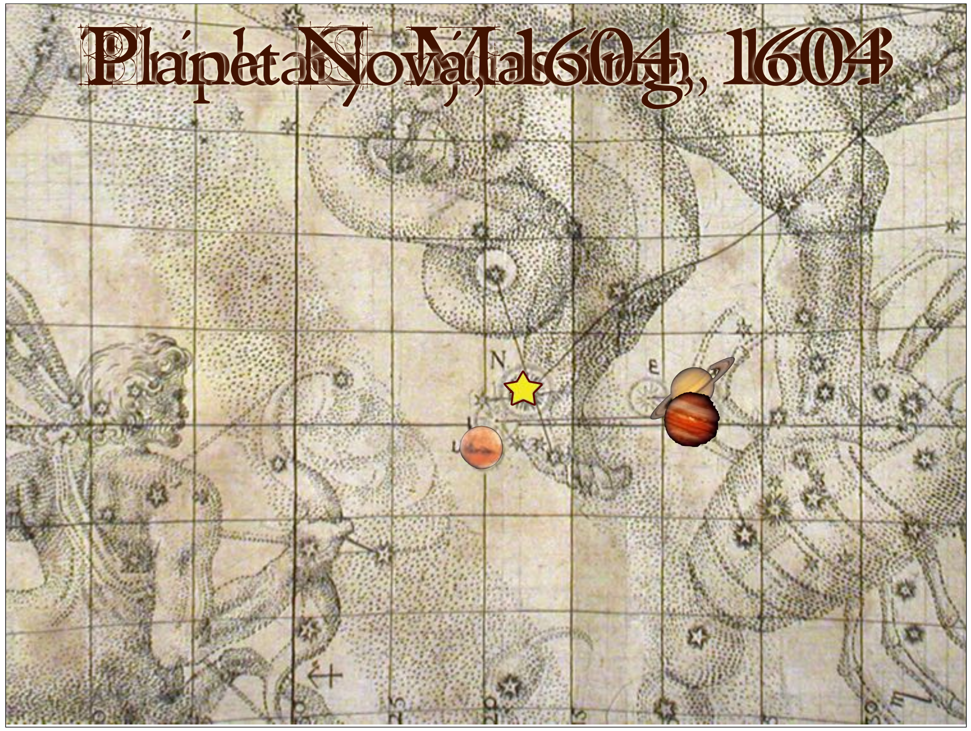
n, i = Jupiter

v = Mars

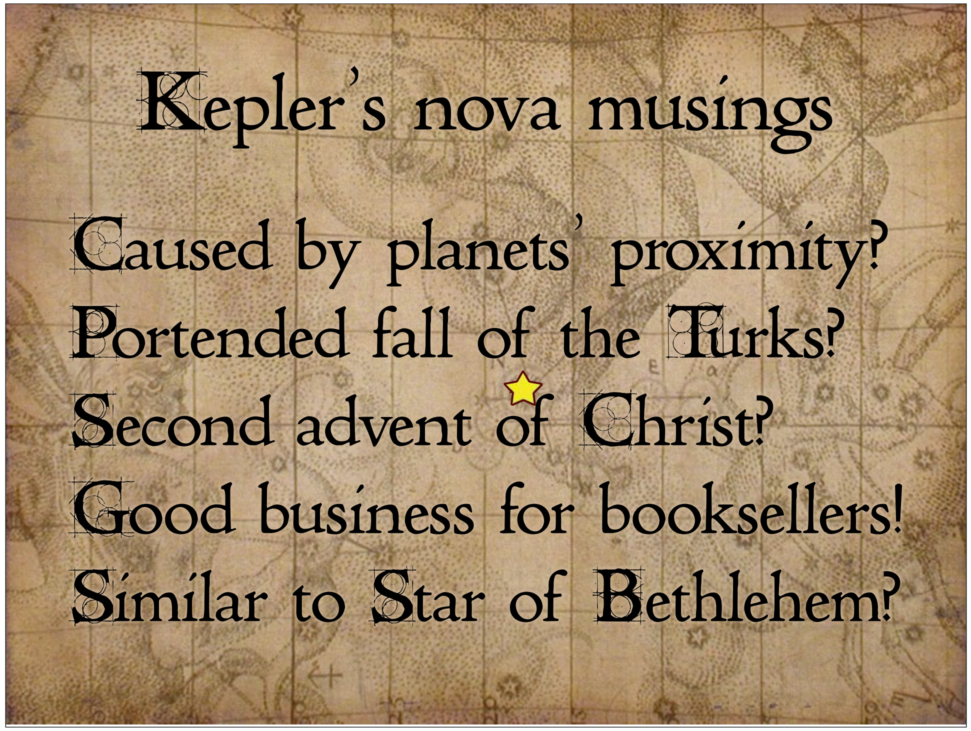
N = nova

alpha, n = conjunction, Dec 1603

epsilon, i, v = massing, Sept-Oct 1604



First, -- a Triple conjunction of Jupiter and Saturn took place in 1603. -- Jupiter -- TC -- It was followed by a planetary massing with Mars in 1604. But after the planetary massing, there suddenly appeared -- a bright star in the ankle of Ophiuchus on October 10, 1604. Aristotle taught that conjunctions and planetary massings produce comets. Here, less ominously, they seemed to have produced a new star. But this was no ordinary star; it was visible in the daytime sky for over a year.

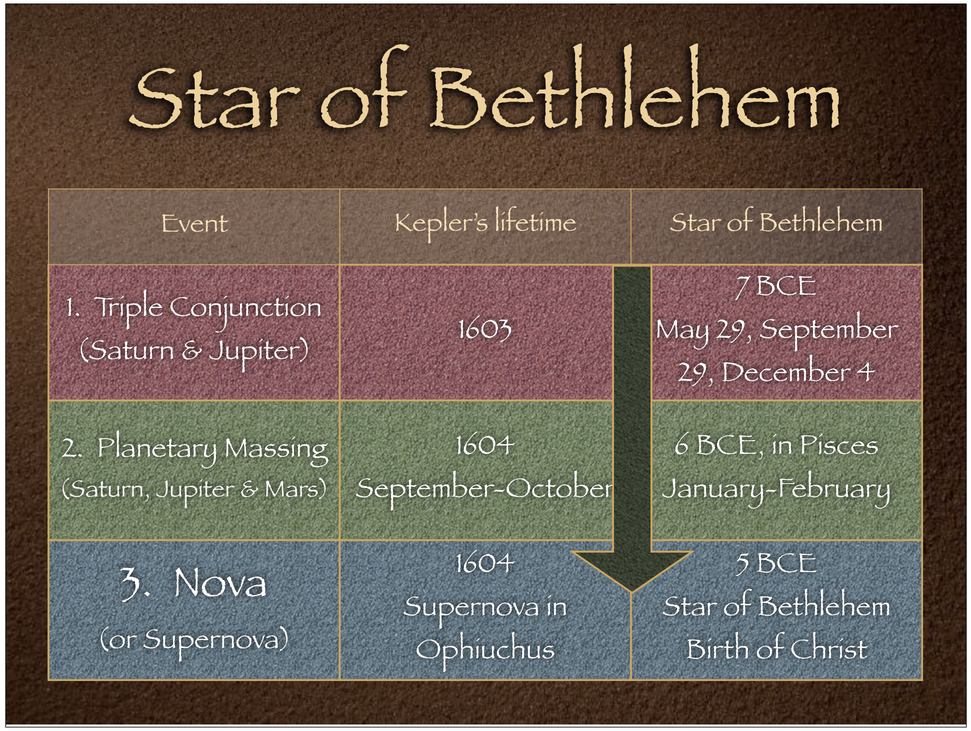


Kepler mused that this new star might have been caused by the planets' proximity, might portend the fall of the Turks, or perhaps the second advent of Christ. Above all, it would definitely result in good business for booksellers, as a rash of hastily produced pamphlets would be rushed into print to explain it! Or maybe, he wondered, something similar might have happened for the Bethlehem Star.

Star of Bethlehem

Event	Kepler's lifetime	Star of Bethlehem
1. Triple Conjunction (Saturn & Jupiter)	1603	7 BCE May 29, September 29, December 4
2. Planetary Massing (Saturn, Jupiter & Mars)	1604 September-October	6 BCE, in Pisces January-February
3. Nova (or Supernova)	1604 Supernova in Ophiuchus	5 BCE Star of Bethlehem Birth of Christ

When Kepler calculated that a similar Triple Conjunction and Planetary Massing occurred in 7 and 6 BCE, before the birth of Christ in 5 BCE, he proposed that this similar sequence might explain the star of Bethlehem.



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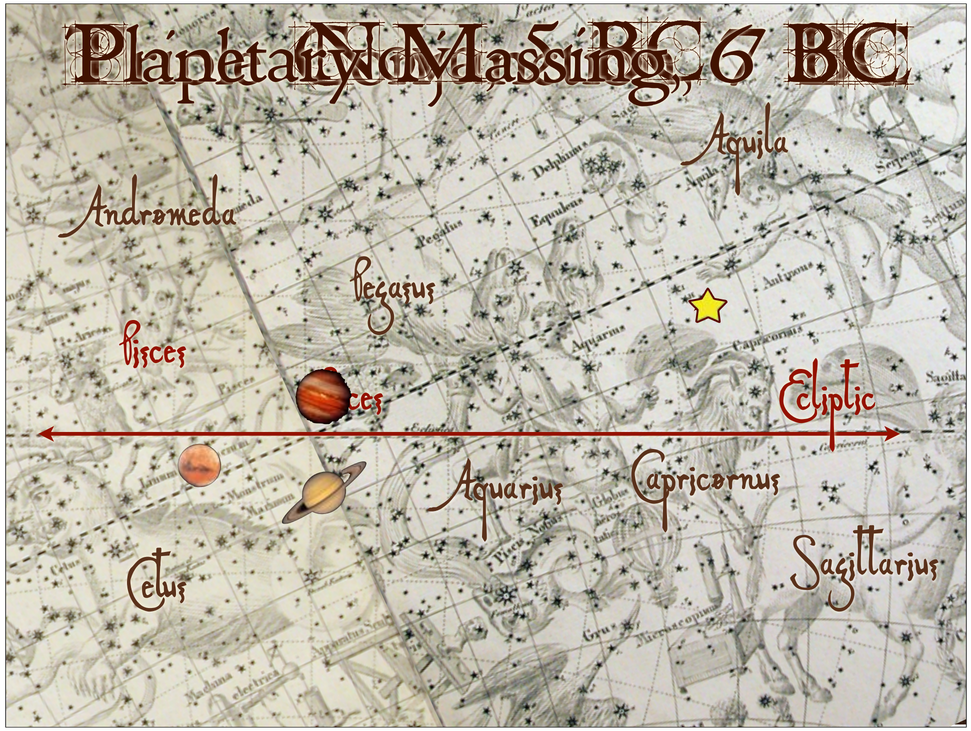
If a triple conjunction and massing in Kepler's own lifetime had produced a nova, then by analogy, the similar triple conjunction and planetary massing which occurred in 7 and 6 BCE should have produced a similar new star, he reasoned. The Babylonian magi, in their ancient tradition of cuneiform astronomy, predicted the triple conjunction of 7 BCE and the planetary massing of 6 BCE, but indeed, any new star in 5 BCE would have been an unexpected surprise.



Here's what took place around the birth of Christ:
Phase I: Triple Conjunction in Pisces
Phase II: Planetary massing with Mars. So much Kepler and the magi could predict.
Phase III: The unknown part, would there have been a new star as in 1604?

Kerry Magruder and Ben Randell, The OBU Planetarium; photo by Bill Pope

Some variation of Kepler's account, either the triple conjunction or all three phases together, are the most common explanations offered in planetarium shows and astronomer talks today.

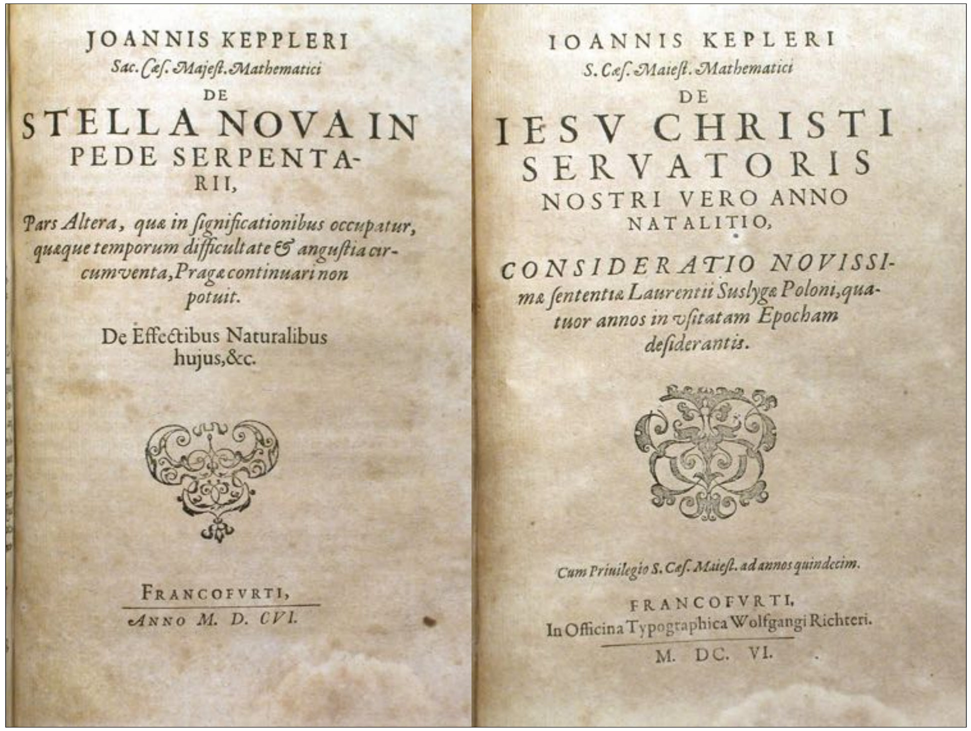

JOANNIS KEPPLERI
Sacræ Cæsar. Majest. Mathematici
DE
STELLA TERTII
HONORIS IN
CYGNO,
QUÆ USQUE AD ANNUM M.DC.
FUIT INCOGNITA, NECDUM
extinguitur,
NARRATIO ASTRONOMICA.
AD
ILLUSTREM ET GENEROSUM DN. DN.
JOANNEM FRIDERICUM HOFF-
MANNUM, L. B. &c. SAC. CÆS. MAJEST.
à Consilijs Aulæ Imperia-
lis, &c.
PRAGAE,
Ex Typographia PAULI SESSII.
ANNO M. DCVI.

168 JOAN. KEPL. DE STEL. CYGNI.

In Hispaniæ parte

FINIS NARRATIONIS D
STELLA CYGNI.

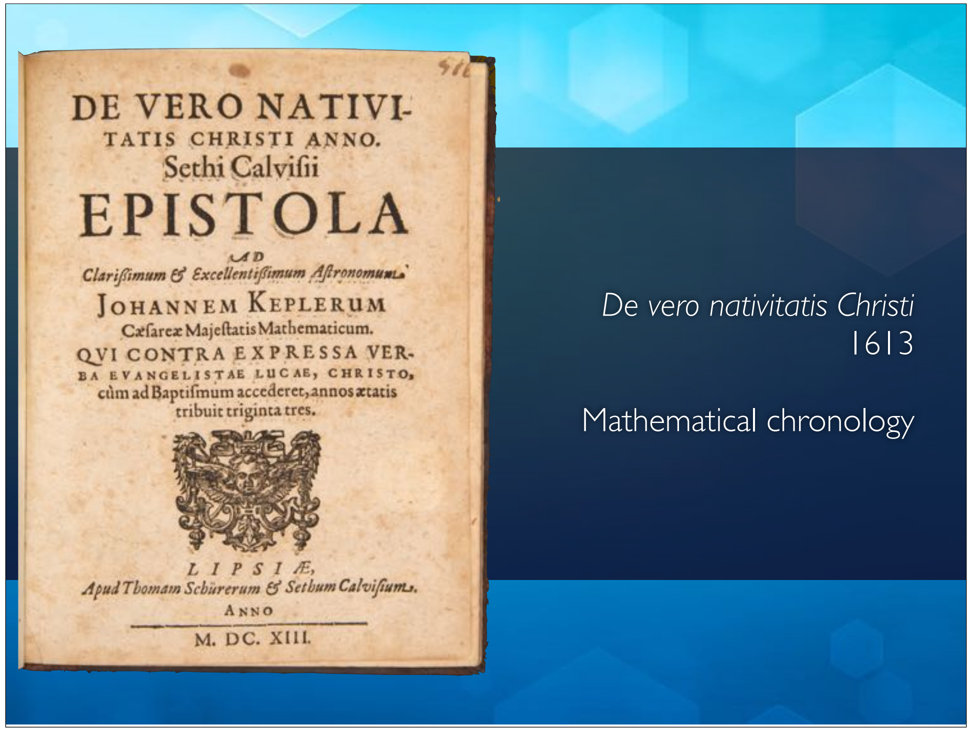
Kepler also included an essay on stars in Cygnus the Swan, and...



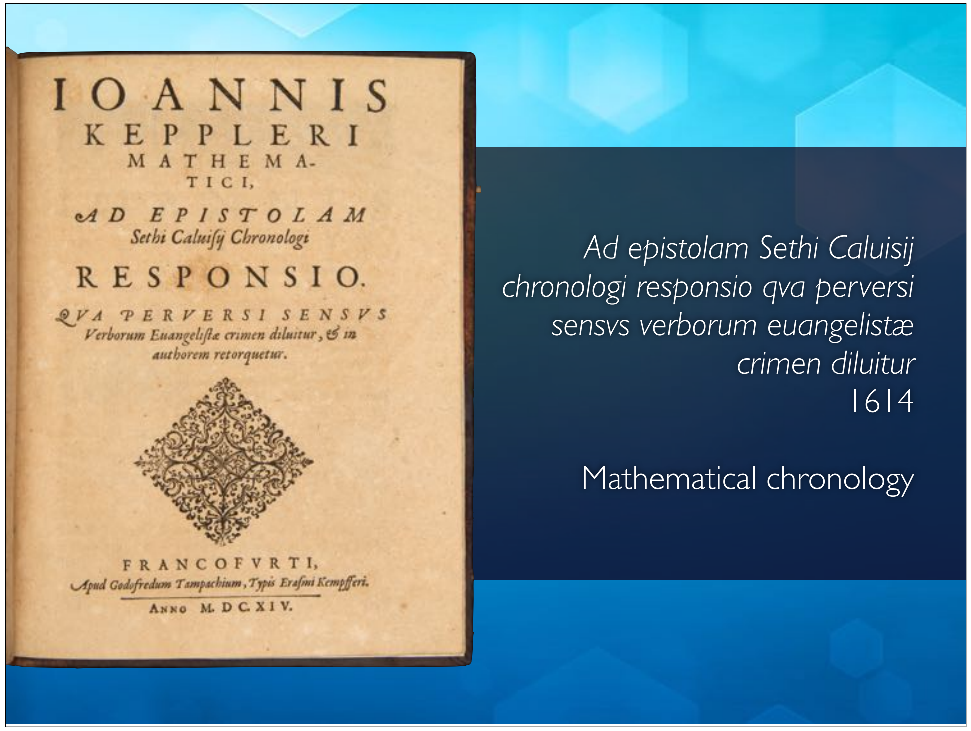
JOANNIS KEPPLERI
Sac. Cæs. Majest. Mathematici
DE
STELLA NOVA IN
PEDE SERPENTA-
RII,
Pars Altera, quæ in significationibus occupatur, quæque temporum difficultate & angustia circumventa, Pragæ continuari non potuit.
De Effectibus Naturalibus
hujus, &c.
FRANCOFVRTI,
ANNO M. D. CVI.

IOANNIS KEPLERI
S. Cæs. Maiest. Mathematici
DE
IESV CHRISTI
SERVATORIS
NOSTRI VERO ANNO
NATALITIO,
CONSIDERATIO NOVISSIMA *sententiæ Laurentii Suslygæ Poloni, quatuor annos in usitatam Epocham desiderantis.*
Cum Priuilegio S. Cæs. Maiest. ad annos quindecim.
FRANCOFVRTI,
In Officina Typographica Wolfgangi Richteri.
M. DC. VI.

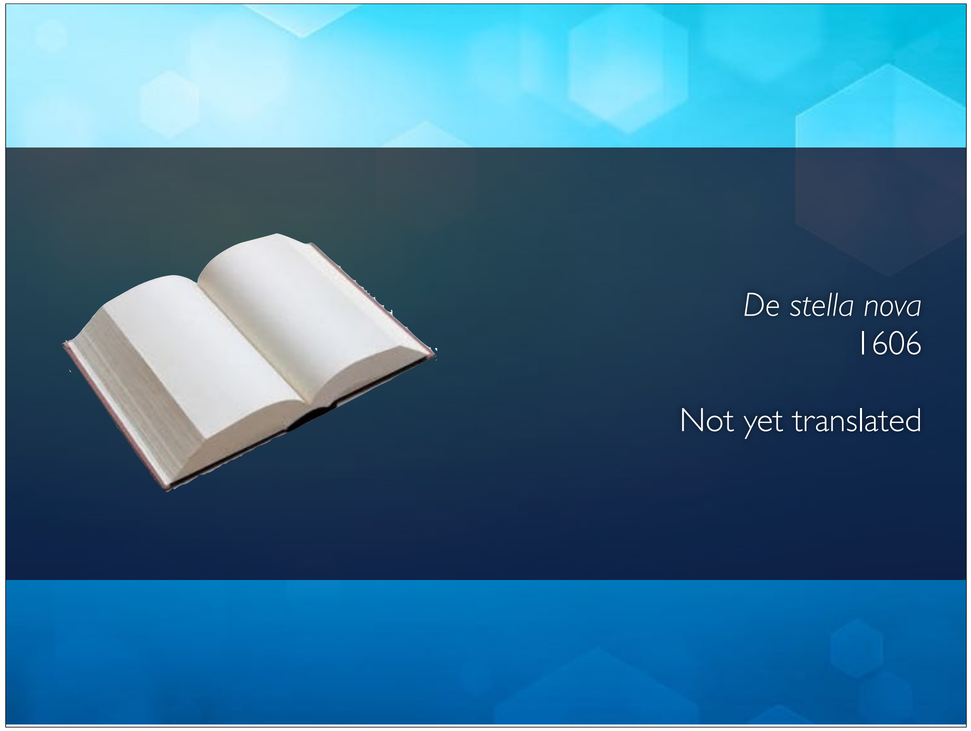
an essay in which he confirmed the conclusions of another chronologist (Laurent Suslyga) that Christ was born several years earlier than 1 CE, a dating that was critical to Kepler’s account of the Star of Bethlehem.



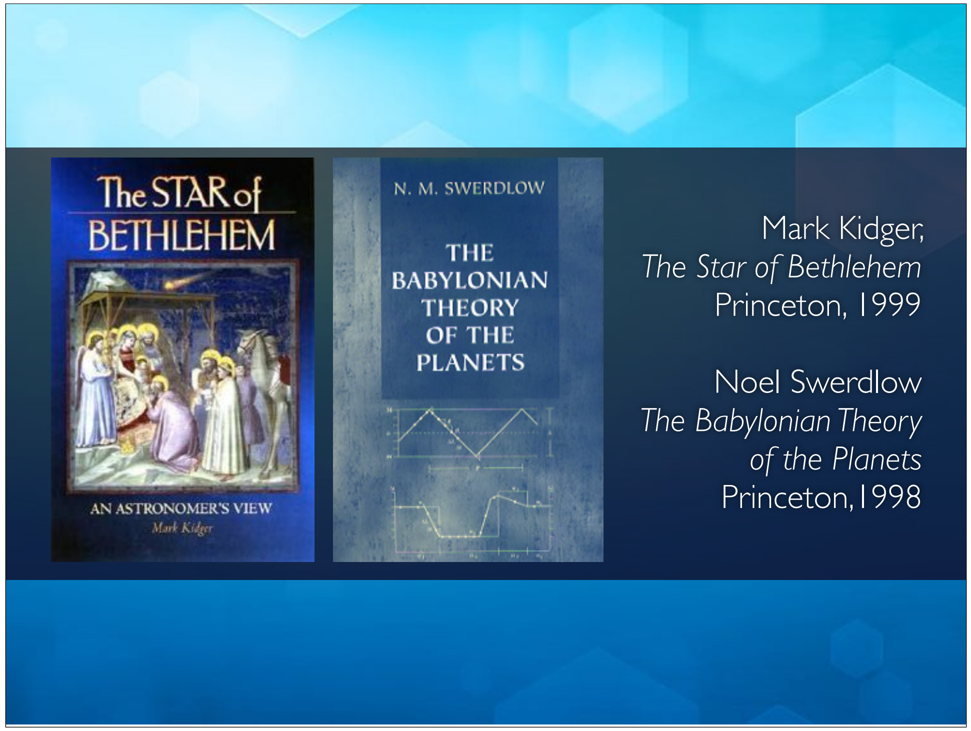
Kepler published a number of additional minor treatises on mathematical chronology, as in this work on the date of Christ's nativity that came out 7 years later.



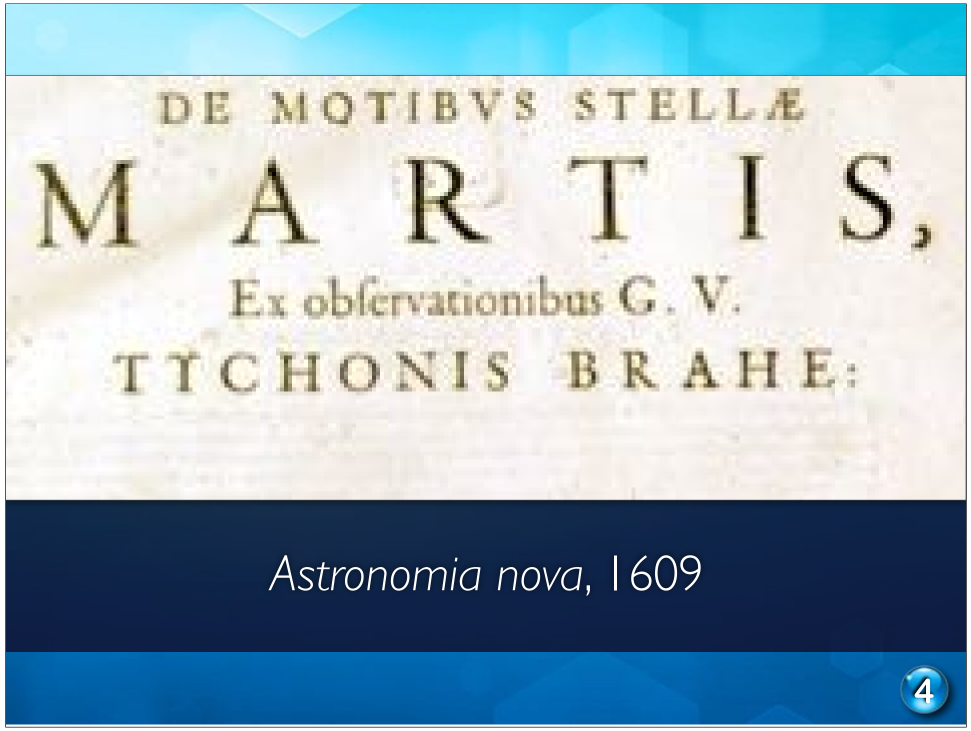
Or this chronological work, published the following year. Annotations in the OU copies of these works have not yet been studied.



Regrettably, De stella nova is not yet translated.

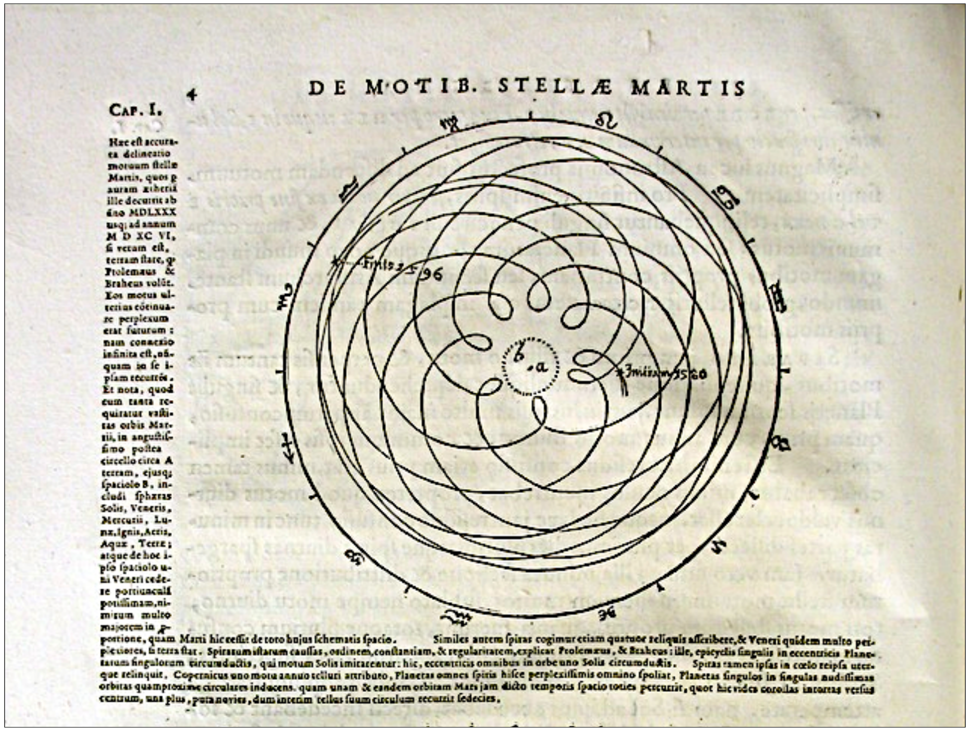


If you're interested in reading more about the Star of Bethlehem, and Kepler's account of it, the literature is as immense as it is unsatisfying. Yet here are two of my favorite sources. Swerdlow does not explicitly discuss the star, but I mention it because of my belief that we will never really have any confidence in theories about the star until we have a better knowledge of Babylonian astronomy.



In 1609, Kepler published his analysis of Tycho's observations of Mars.

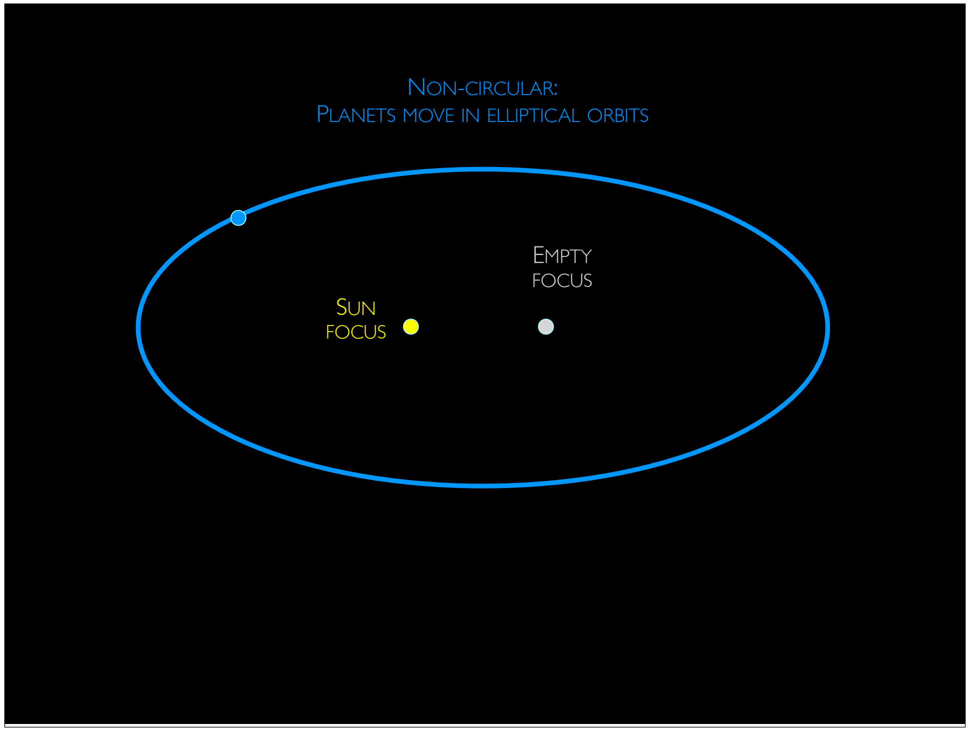
In the aptly named Astronomia nova, or New Astronomy, Kepler put forward what are now regarded as his first two laws. But more fundamentally, he changed the paradigm from focusing on orbs, or solid spheres, to orbits, the actual path a planet takes as it moves through space.



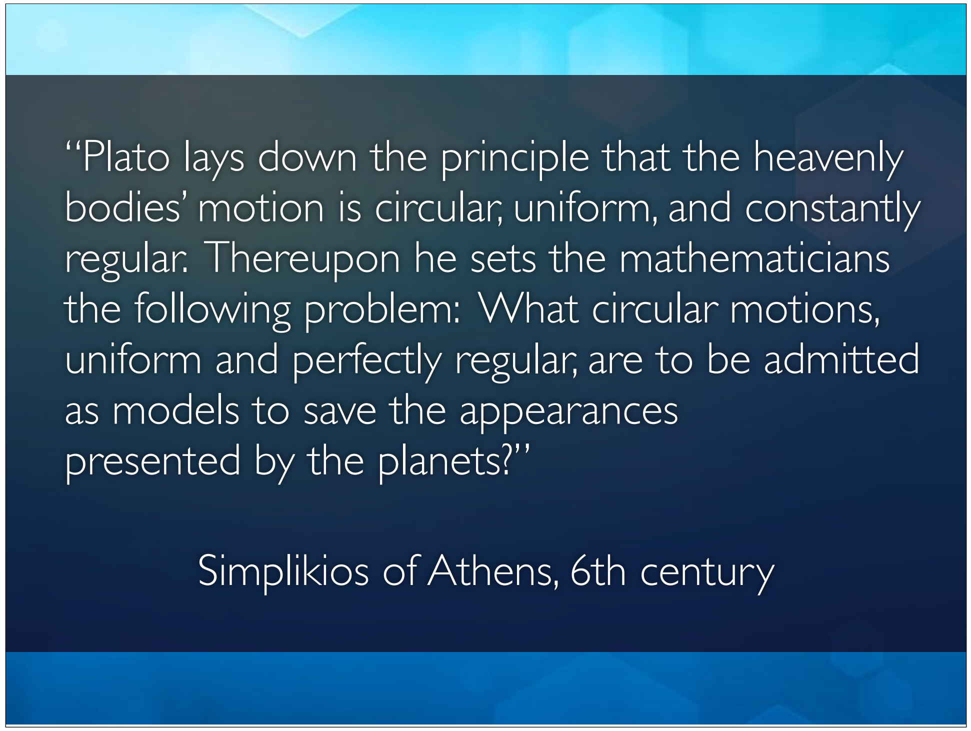
This is Kepler's famous pretzel diagram, where he focused attention on the planet rather than the rotating spheres which carried the planet. In an Earth-centered system, the planet must follow some kind of similar pretzel path as it is carried along within its thick solid sphere. It is difficult for us today to recognize that it was necessary to invent the concept of an orbit, of tracking the actual path of a planet through space.

Sidney Harris has captured something of the novelty of Kepler's paradigm change. [Read] To this point, astronomers thought in terms of orbs or solid spheres, not planetary trajectories.

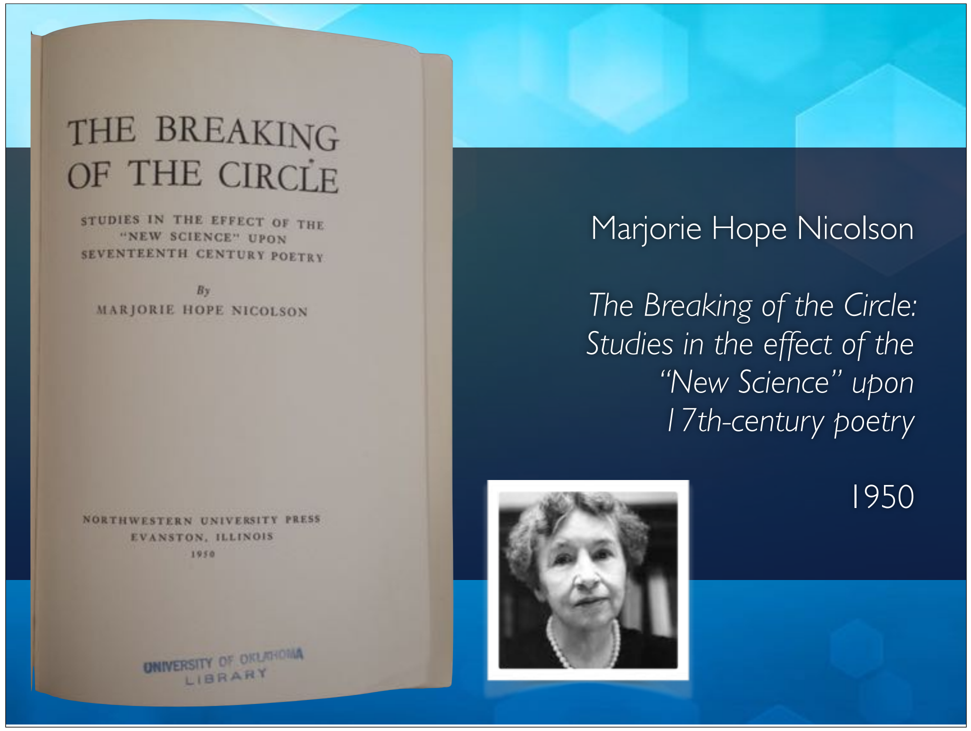
• The fellow on the right must be a physicist, however, for physicists at this time were not trained in mathematics. Astronomers were familiar with the geometry of ellipses from a masterful book on Conic Sections written by an ancient astronomer named Apollonios. Astronomers were held back by lack of Kepler's paradigm shift, not by a lack of mathematics.



So Kepler solved the puzzle of the pretzel diagram by showing that, if the Sun lies at the center, then planets will move in ellipses rather than in circles.



Ancient Greek astronomy was based on the rule of uniform circular motion. For example, Simplikios wrote: (read). Copernicus based his astronomical system on a strict enforcement of the principle of uniform circular motion, rejecting all compromises. For example, Copernicus regarded Ptolemy's astronomy as a corruption because of his use of an equant device.



It is nearly impossible for us today to imagine the hold which the ideal of uniform circular motion exerted upon the European imagination. Nicolson's study of the "breaking of the circle" in 17th-century poetry throws great light on Kepler's bold originality on this point, for he disrupted the entire tradition of Greek astronomy from Plato through Copernicus.
———————
———————

Non-uniform, non-circular planetary motions.
Kepler's "first law": elliptical planetary paths; the "breaking of the circle."

"II: The Broken Circle"

Elementary physics students hear of Kepler today because of his three famous laws, each of which resulted from his quest for a mathematical beauty worthy of the Creator. Indeed they provided crucial raw material for Newton's great synthesis of astronomy and physics: Newton formulated laws of motion which explained Galileo's law for the acceleration of freely falling terrestrial bodies (which actually dates to the 14th century). Then he deduced Kepler's laws of planetary motion, thereby establishing that a Moon falls in its orbit in precisely the same way as an apple falls from a tree (imagine an apple tree as tall as the distance to the Moon!).

Kepler's "first law" (Astronomia nova, 1609) postulated that planets move in elliptical rather than in circular orbits.1 With his first law, then, Kepler repudiated the 2,000 year tradition, established by Plato and upheld by Copernicus, of "saving" or explaining astronomical appearances by combinations of uniform circular motions (see header quote above). This "breaking of the circle," or "shattering of the spheres," represented a major intellectual departure; one which Copernicus himself would have rejected, just as did Kepler's contemporary, Galileo.

For circular motion, from the time of Plato and Aristotle, had reflected the perfection of the concentric celestial spheres (to which the planets were attached). The perfection of the heavenly realms required that these spheres be eternally at rest, without change or corruption. The great spheres which carried the planets were allowed to rotate with uniform speed, however, because while turning they were yet remaining in the same place. From combinations of such uniform circular motion were all celestial motions to be explained.

In departing from this tradition, Kepler diverted attention from the combinations of regular circular motions which might underlay the observed or apparent motions of a planet. Instead he raised the question of what actual physical path would correspond to the apparent motions themselves.

Kepler himself agonized in a labyrinth of calculation before he settled on the form of the ellipse, considering seventy other conceivable shapes for planetary paths, including the pregnant idea of a cosmic eggs. Kepler came upon the ellipse not as a generalization from observational data, but because of its mathematical relation to the circle itself; this made it an appropriate element in the Creator's Divine Plan. For ellipses could be proven to be equivalent to certain combinations of circular motions which were employed by Copernicus. Finally, the ellipse alone correlated as precisely as he desired with the observations of the positions of Mars providentially obtained, he believed, by Tycho Brahe. "His observations convicted the Ptolemaic calculation of an error of 8 minutes of arc," Kepler wrote. "It is only right that we should accept God's gift with a grateful mind. . . . Because these 8 minutes could not be ignored, they have led to a total reformation of astronomy."

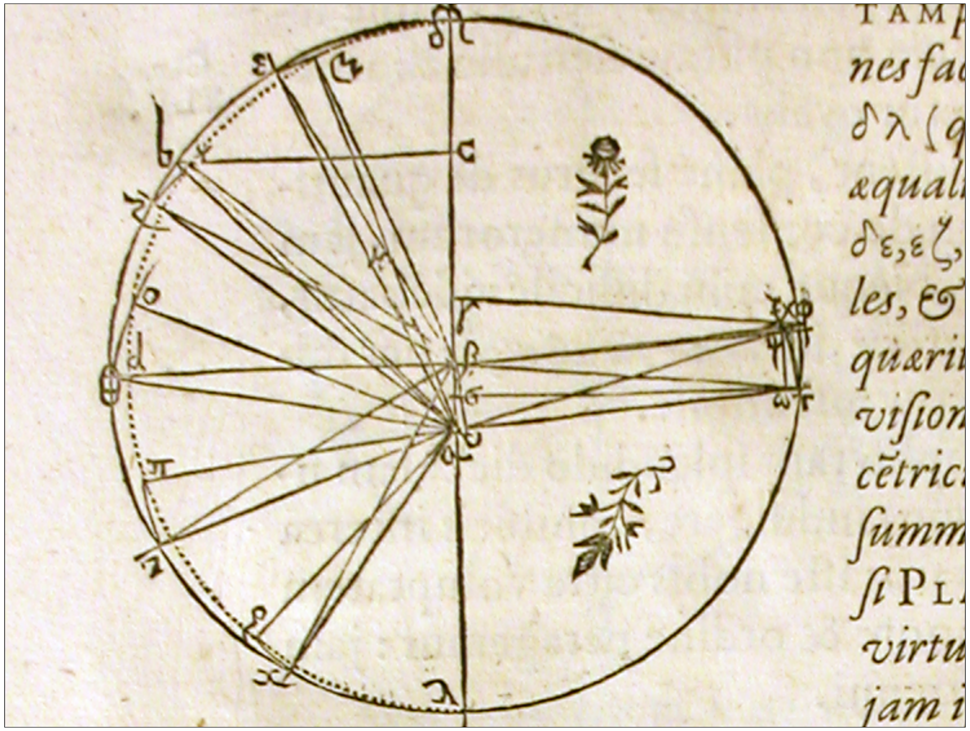
Kepler's "second law" was actually postulated before the "first" (Astronomia nova, 1609). It stated that, although the speed of Mars and its distance to the sun both vary, the line from the sun to Mars sweeps across equal areas of space (not equal angles, as had Copernicus' circles) in equal times. This law he boldly extended to every planet. Kepler did not obtain this law by induction from Brahe's observations any more than the "first," but by an elaborate deduction which involved two erroneous premises! For the first time, a sun-focused astronomy had appeared. Kepler computed planetary positions relative to the location of the sun; Copernicus had based his calculations on the center of the earth's orbit, which was near but not exactly coincident with the position of the sun. (Both Copernicus and Kepler postulated a stationary sun or "heliostatic" system, but neither had a truly sun-centered or "heliocentric" system.)

With Copernicus, the earth was thrown into space and redefined as just another planetary wanderer. This by itself strained and perhaps fractured Aristotle's dichotomy between sublunar earthly corruption, and supralunar celestial permanence and purity. Yet most philosophers, not to mention poets like John Donne, longed for eternity and sought solace in a heavenly perfection:

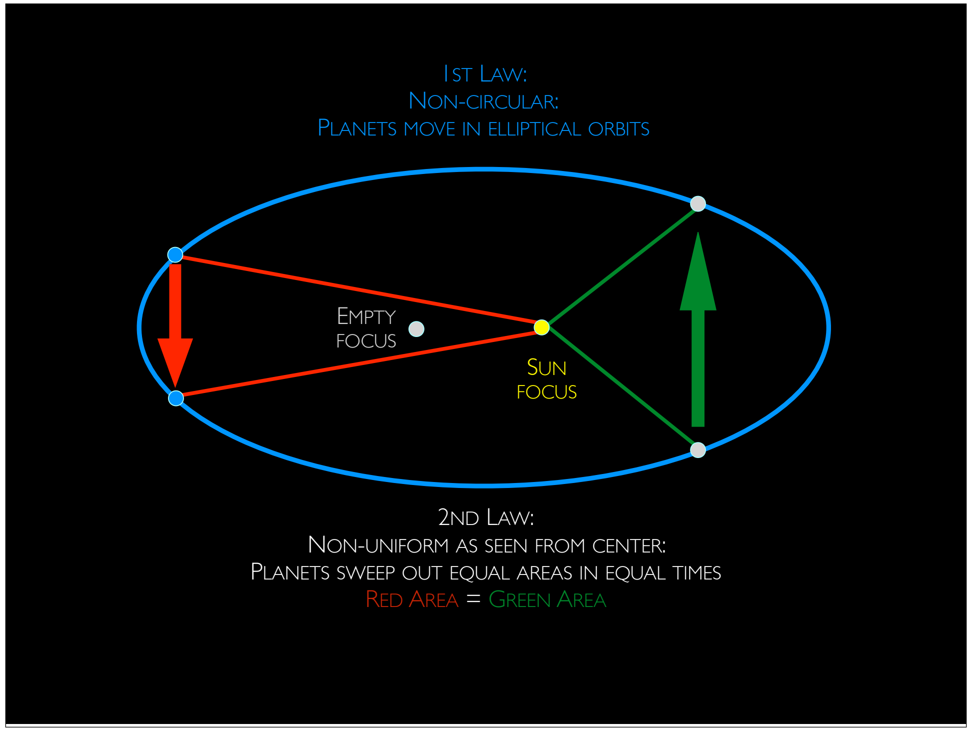
> "[The] new Philosophy calls all in doubt,
> The element of fire is quite put out;
> The sun is lost, and th'earth, and no man's wit
> Can well direct him where to look for it....
> 'Tis all in pieces, all coherence gone;
> All just supply, and all Relation...."
> The Anatomy of the World, 1611

It seemed unlikely that an earth of such obvious corruption could fairly represent a beautiful cosmos, yet if the earth were exalted into planetary status the beautiful cosmos would show itself corruptible after all.

Then Kepler's "breaking of the circle" (first law) and rejection of uniform circular motion (second law) shattered beyond repair what remained of the classical notion of celestial perfection. As any Hebrew prophet of old would have foretold, the entirety of creation proved insufficient to contain the timeless longings of the human soul.

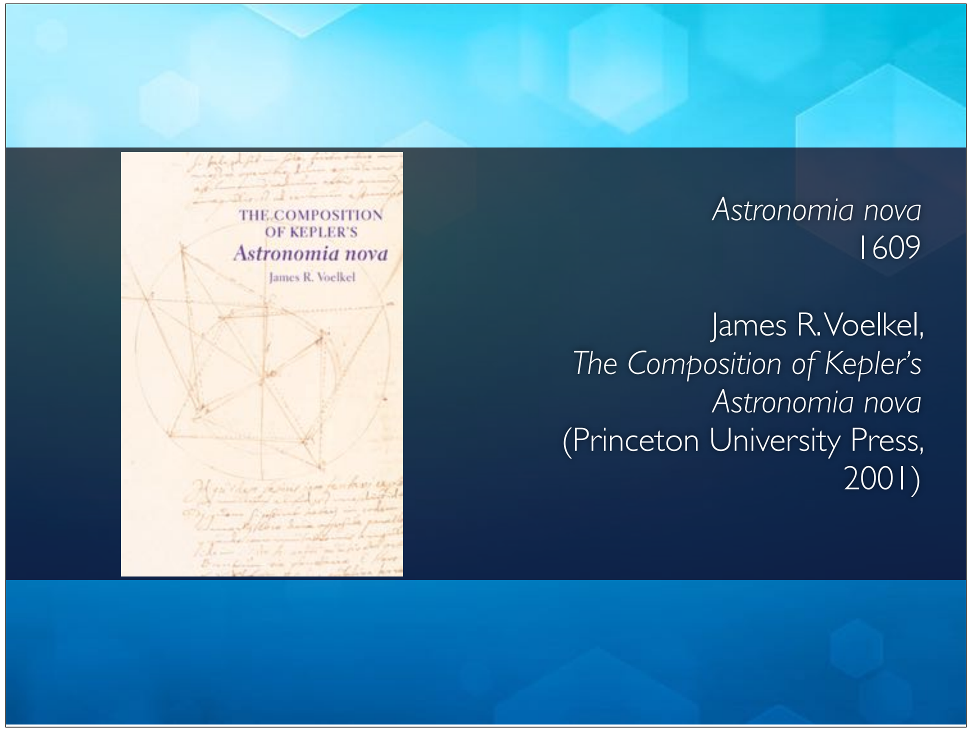


Kepler employed motion that was neither circular nor uniform. For Kepler there are *no* perfect circles in the heavens.



What we call Kepler's first law is that planets move in elliptical orbits rather than being carried on circular spheres. What we call Kepler's second law is that planets move with non-uniform motion as seen from the center. For Kepler, planets sweep out equal areas in equal times as seen from a focus off-center. So Kepler denied that planetary motion was either uniform or circular. That is, Kepler defended Copernicus, ironically, in ways that Copernicus would never have approved. (pause) In effect, with Kepler's first two laws, Kepler re-introduced what Copernicus denied, for Ptolemy's equant point worked very much like the empty focus of Kepler's ellipse.

An excellent translation of Astronomia nova exists, by William Donahue, along with an abridged version.

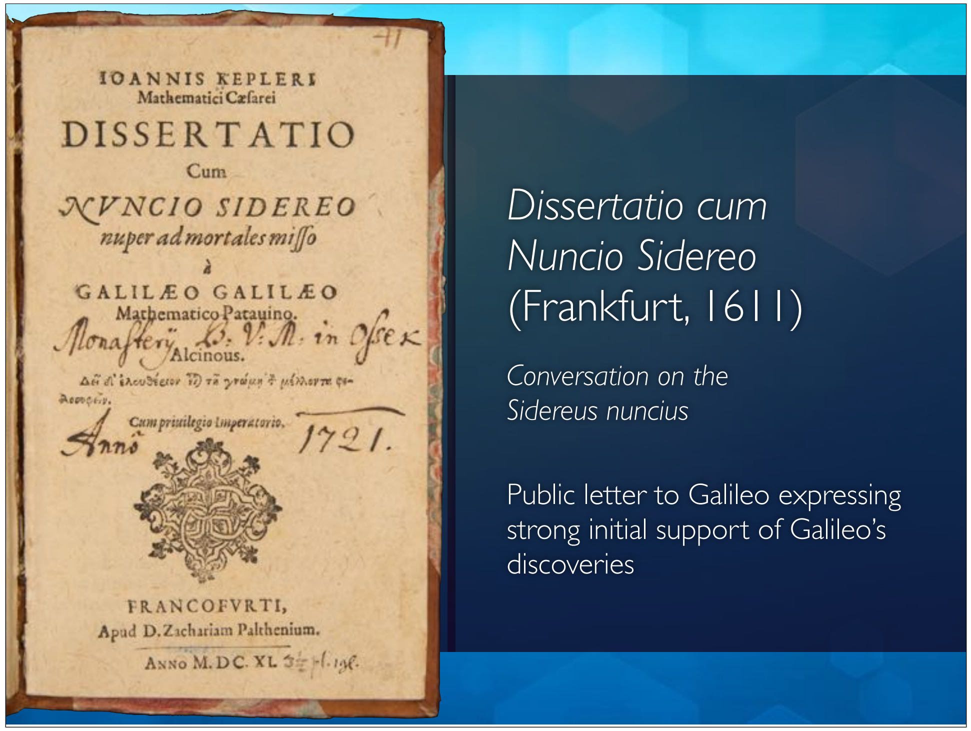


James Voelkel offers an great companion to reading the Astronomia nova.

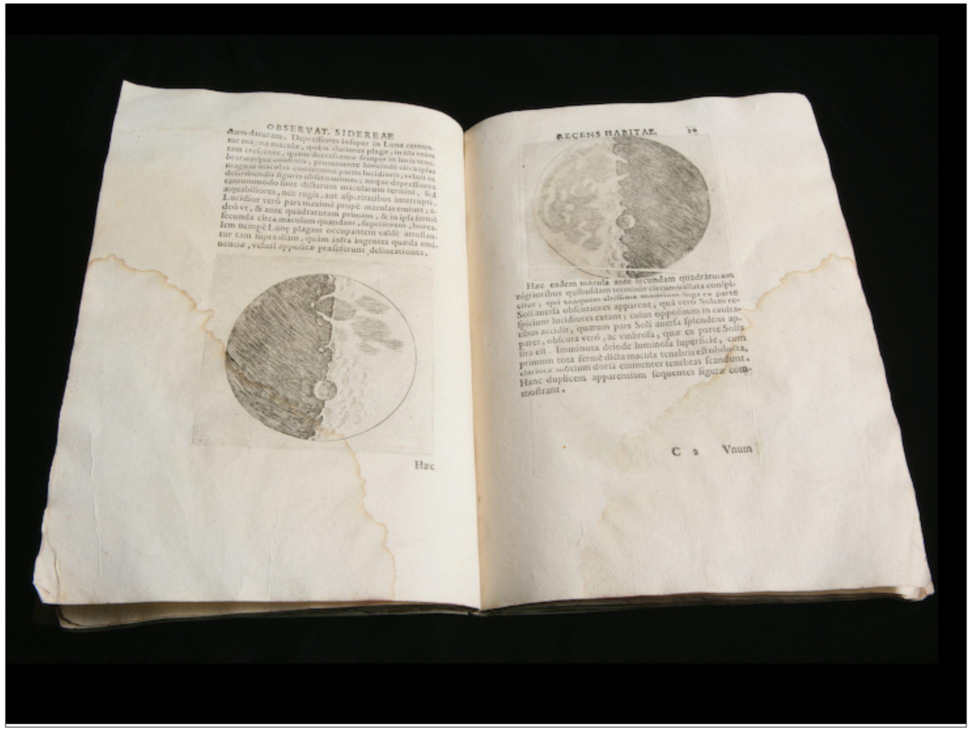
Kepler’s fifth major work played a prominent role in the exciting story of the immediate reception of Galileo’s Sidereus nuncius. It is a relatively recent addition to the OU Kepler collection, acquired in 2013.

———————-

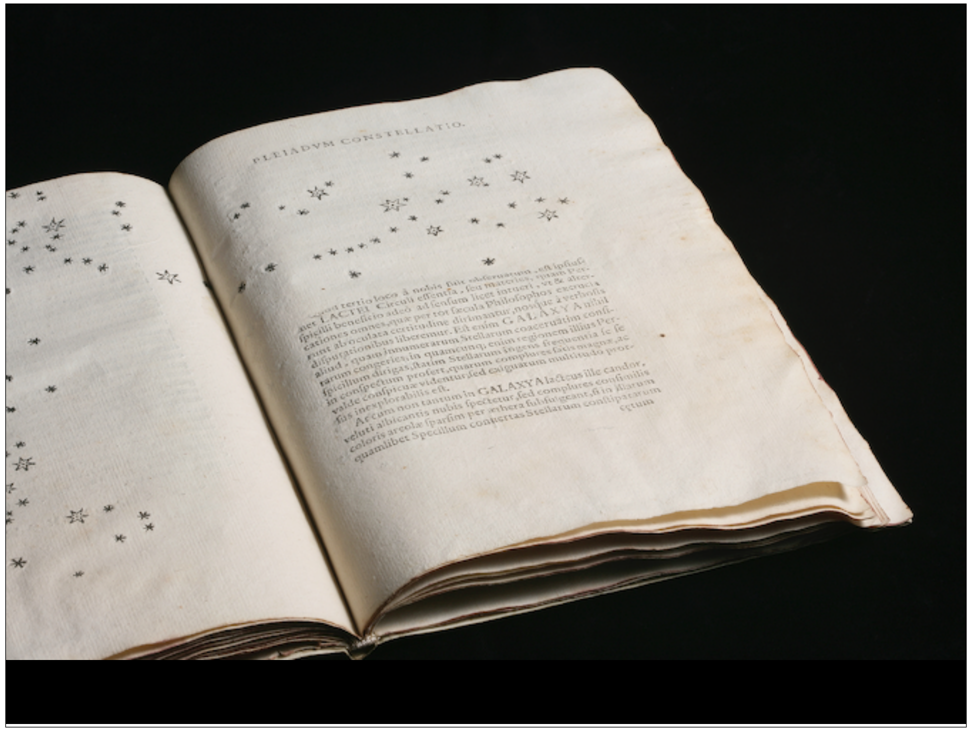
Significance of this ed.:	This is the 3rd ed. of Kepler’s Dissertatio, more rare than the 1st (Prague) and pirated 2nd (Florence) editions, which were both published in 1610. Kepler objected to the pirated Florence ed. in a letter to Galileo written in December, 1610. Kepler may have spearheaded the publication of this Frankfurt edition to retaliate against the Florentine one.



Publication of Galileo's Sidereus nuncius in March of 1610 sparked a fleeting but intense controversy across Europe, and especially in Italy, over the reliability of the telescope and the validity of Galileo's discoveries. A copy of Galileo's Sidereus nuncius reached Kepler on April 8. Only 11 days later he completed the Dissertatio as a first response.

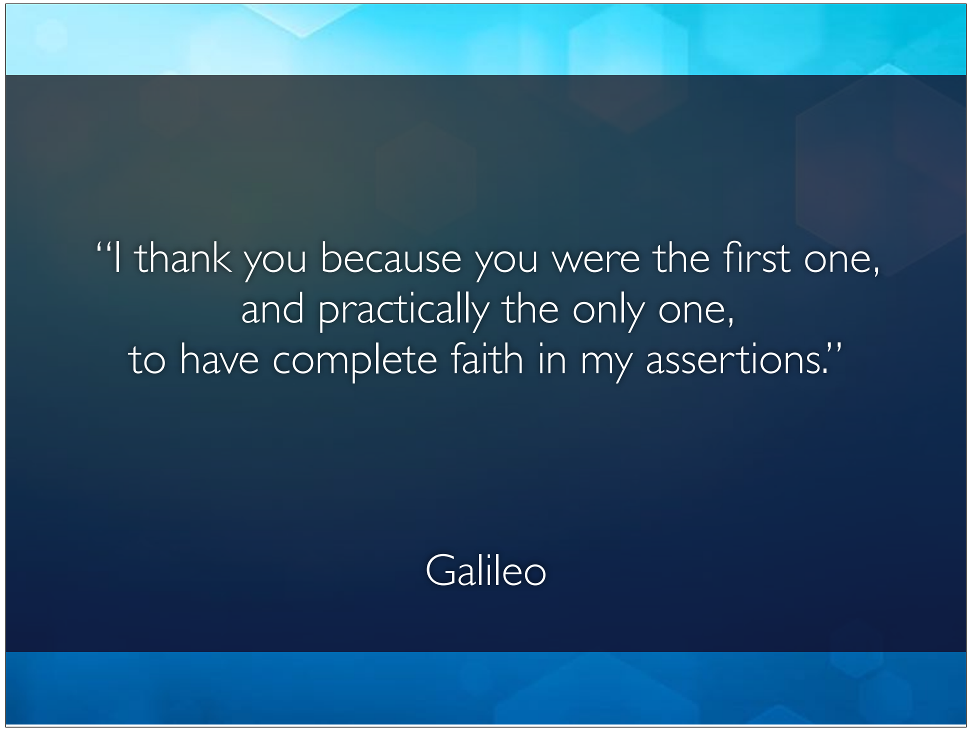


In the Sidereus nuncius, Galileo published the first observations of the heavens made with the telescope. His report caused a sensation, as he claimed to discover four satellites of Jupiter and the existence of mountains on the Moon. The Aristotelians in Italian universities taught that the shading of the Moon was internal, its surface as smooth as a marble. But Galileo's discovery entailed more than just mountains on the Moon: Galileo argued that the Moon and the Earth are similar kinds of bodies. They both have mountains, seas, atmospheres, and both shine by reflected light. All this suggests that the Earth, also, is a wandering planet.

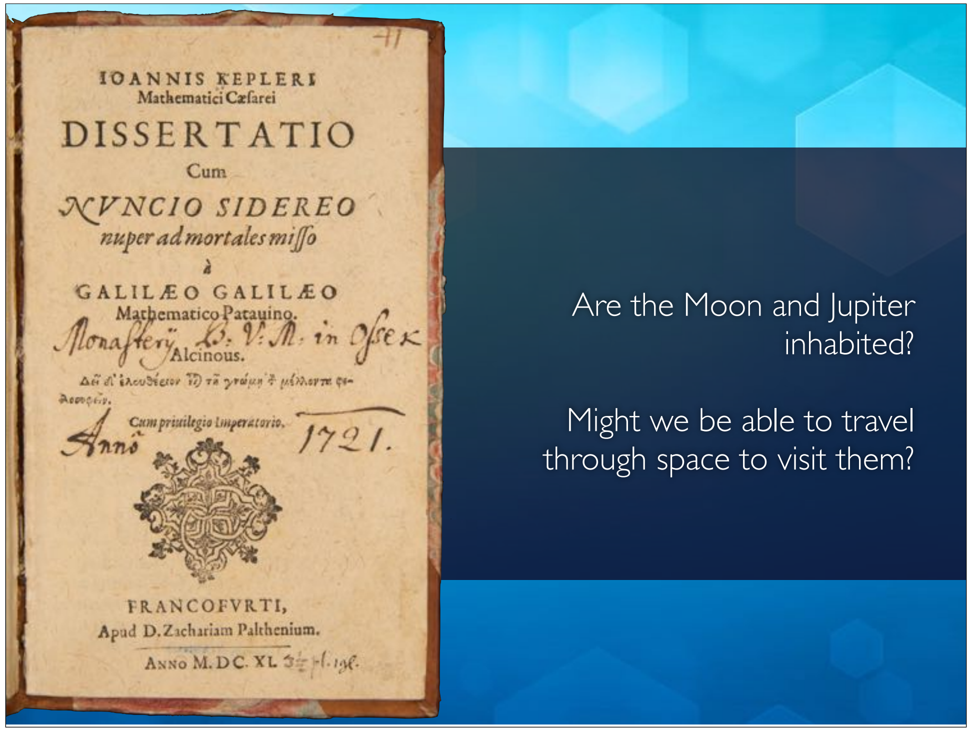


With the telescope Galileo discovered vast numbers of unsuspected stars. On this page he shows 36 new stars around the original six of the Pleiades, and on the left, 80 new stars near the belt and sword of Orion. How could they be embedded within a single celestial sphere? With this indication that the stars may lie much farther away than was thought, the absence of observable stellar parallax was no longer a valid objection to Copernicanism.

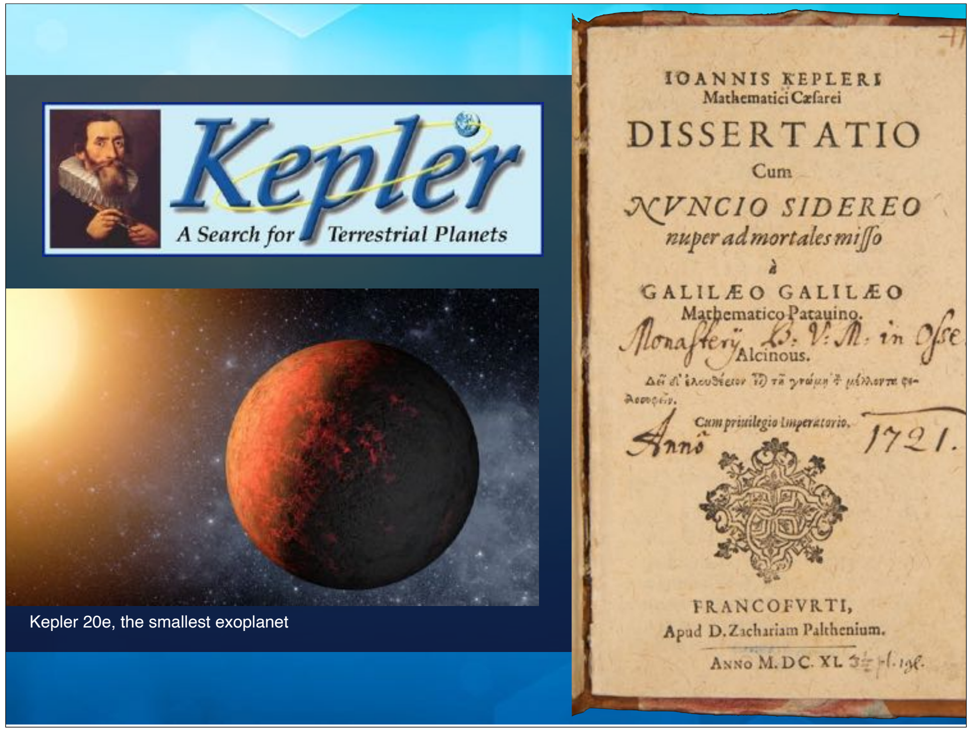
The Oklahoma copy is inscribed by Galileo as a gift to a poet in the Medici court.



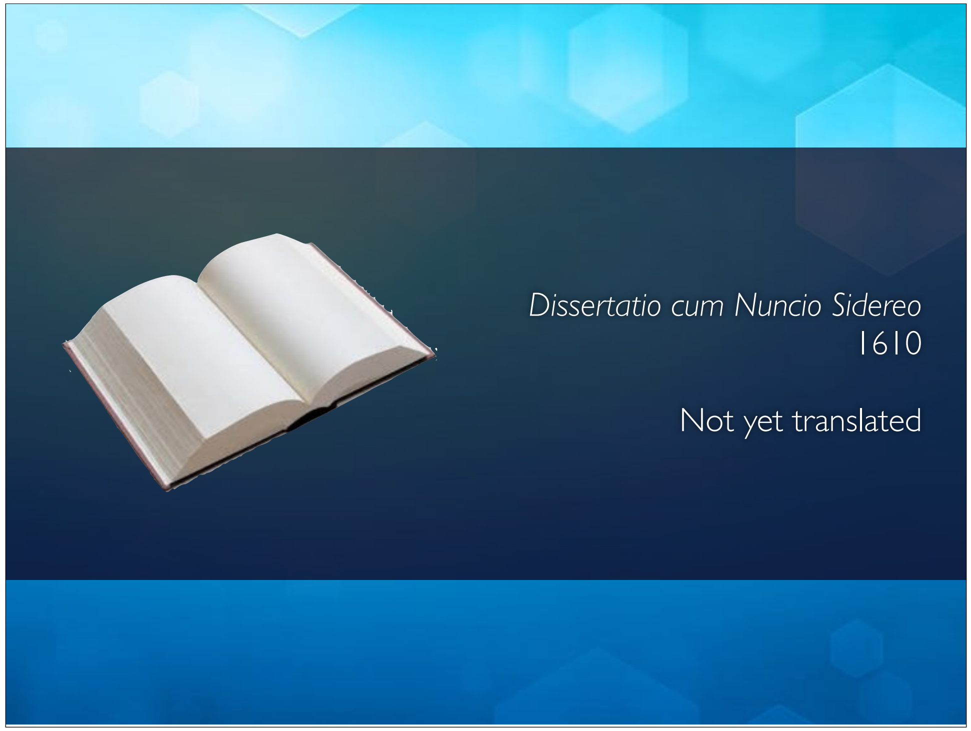
In response to Kepler’s Dissertatio, Galileo wrote to Kepler, “I thank you because you were the first one, and practically the only one, to have complete faith in my assertions.” Even mathematical astronomers who might have been sympathetic to Galileo were not immediately able to replicate Galileo’s observations of the mountains of the Moon and the satellites of Jupiter – for example, Magini could not see them, even using Galileo’s own telescope and with Galileo present to guide him. Opposition from competent mathematicians was very disappointing to Galileo, but Kepler’s Dissertatio was highly regarded and effectively countered their criticisms. Along with the later support of the Jesuits (who affirmed Galileo’s discoveries but reserved judgment on Copernicus), Kepler’s public endorsement of the Sidereus nuncius in this slim Dissertatio helped bring a swift closure to the debate, at least among those who respected mathematical methods and were not swayed by the Aristotelian physicists.



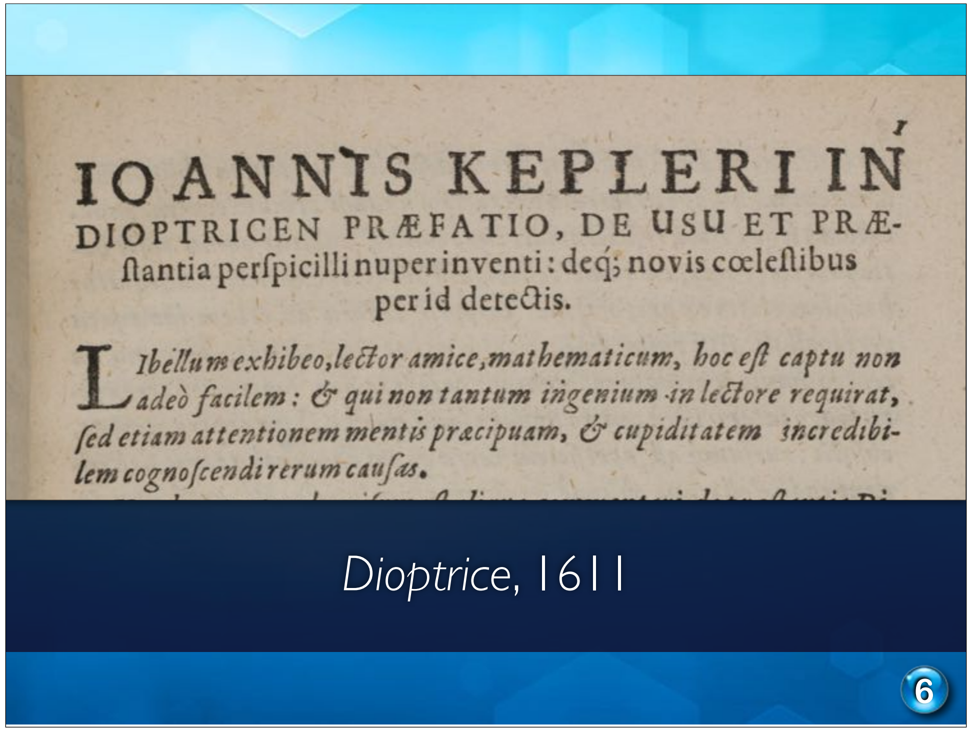
In the Dissertatio, Kepler also considered whether the Moon and Jupiter are inhabited, and he supposed that they are. He speculated that explorers from the Earth might be able to visit them. This is the earliest work by a modern astronomer to entertain the possibility of space travel, predating his own Somnium, which as we shall see was published posthumously more than 20 years later. These questions are conspicuously absent in Galileo’s works.



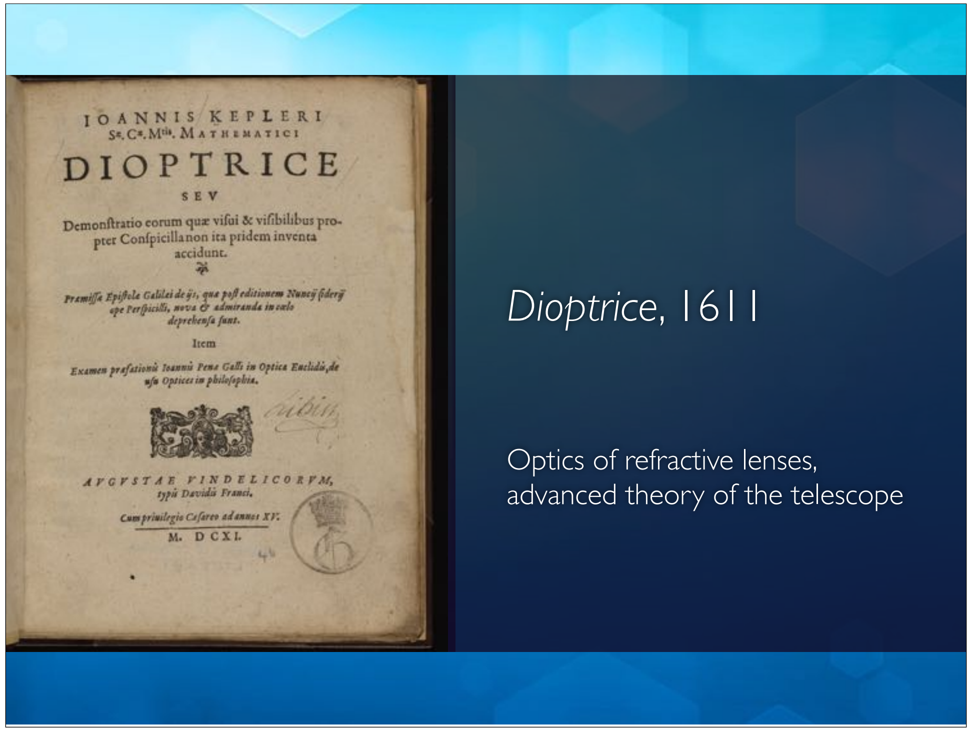
This book therefore explains why the telescope used to search for extra-terrestrial planets is named after Kepler.



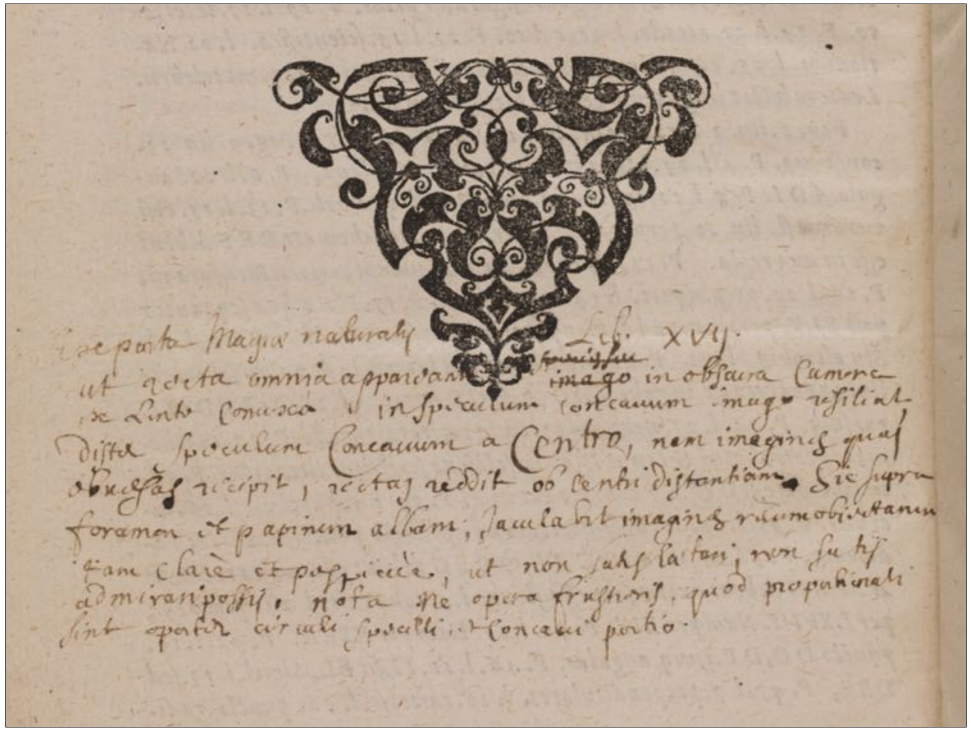
Unfortunately, Kepler’s Dissertatio is not yet translated.



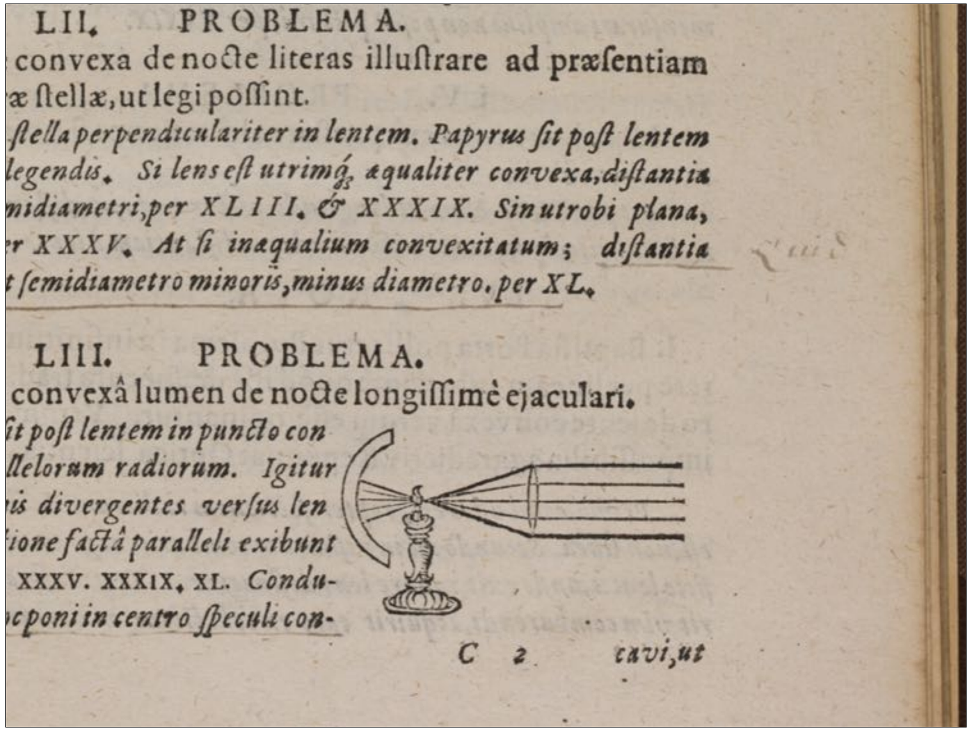
Kepler’s 6th major work was another optical treatise.



In the Dioptrice, he clarified the optics of refractive lenses and greatly advanced understanding of how the telescope actually works.



The OU copy is annotated and unstudied.



LII. PROBLEMA.

convexa de nocte literas illustrare ad præsentiam
æ stellæ, ut legi possint.

stella perpendiculariter in lentem. Papyrus sit post lentem legendis. Si lens est utrimq; æqualiter convexa, distantia nidiametri, per XLIII. & XXXIX. Sin utrobi plana, r XXXV. At si inæqualium convexitatum; distantia t semidiametro minoris, minus diametro. per XL.

LIII. PROBLEMA.

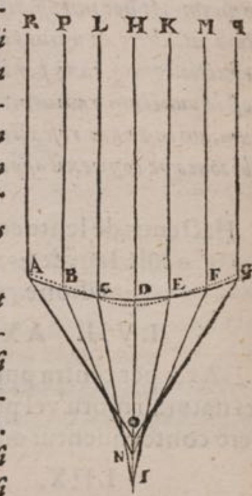
convexâ lumen de nocte longissimè ejaculari.

it post lentem in puncto con llelorum radiorum. Igitur is divergentes versus len ione factâ paralleli exibunt XXXV. XXXIX, XL. *Condu- c poni in centro speculi con-*

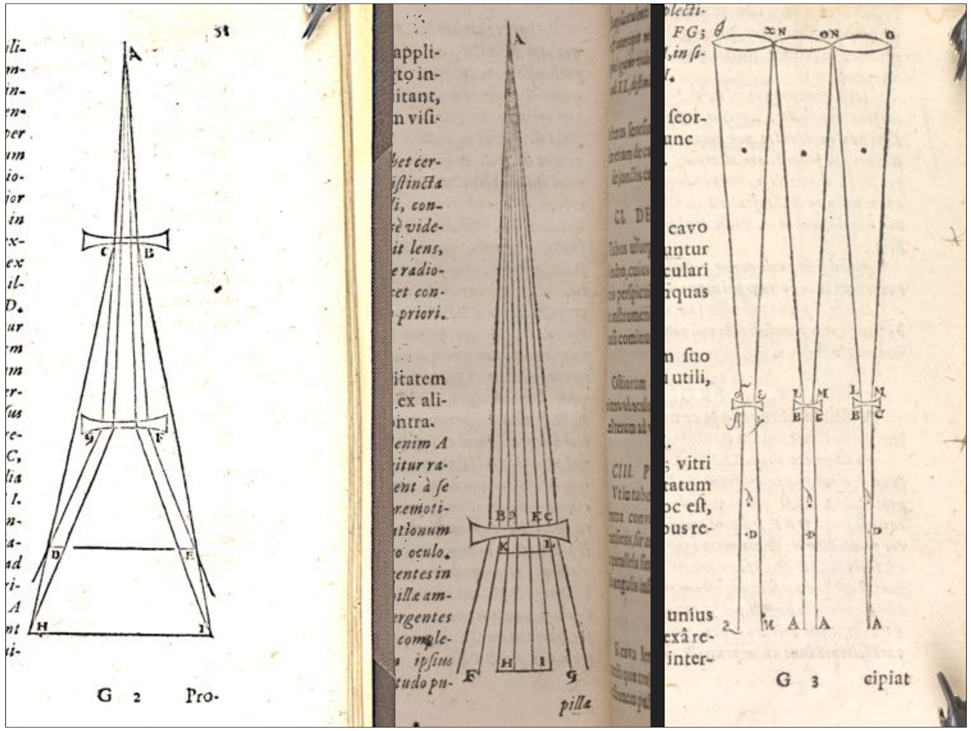
C 2 cavi, ut

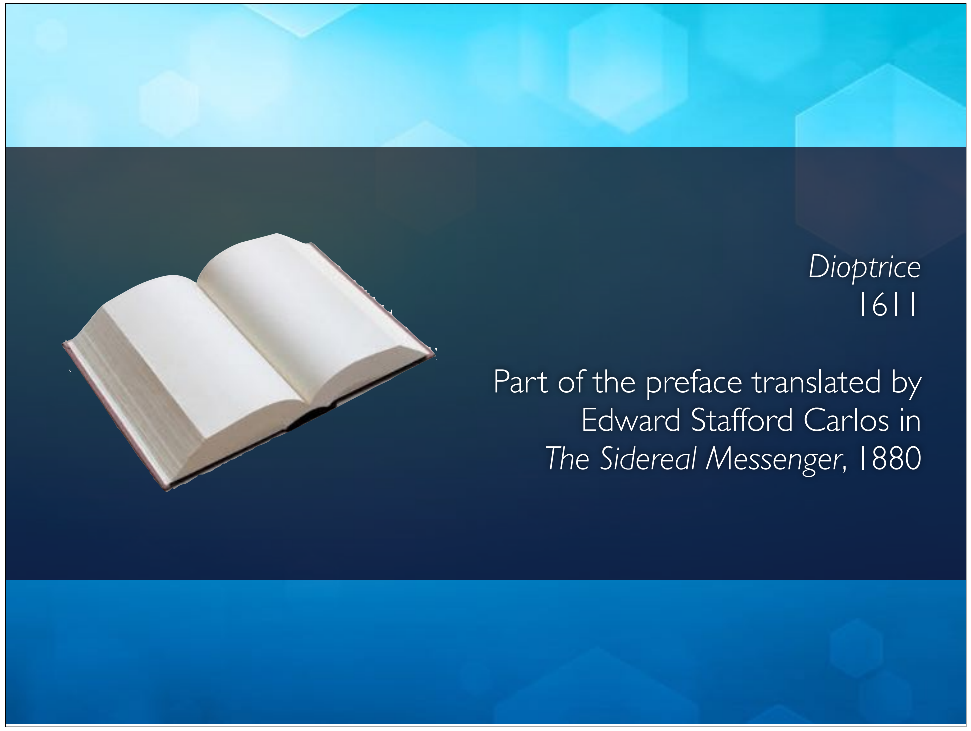
here are a few images

Quod si refractiones omnes essent incidentiæ proportionales, refractione factâ paralleli omnes in idem punctum concurrerent, puta in I, per XXXV. Sed quia non sunt proportionales per XII. Sed augentur supra modulum in magnis inclinationibus, ideoq; L C quidem & K E concurrunt in I, at proximi P B & M F concurrunt altius in N, & ulteriores R A. Q G adhuc altius in O.

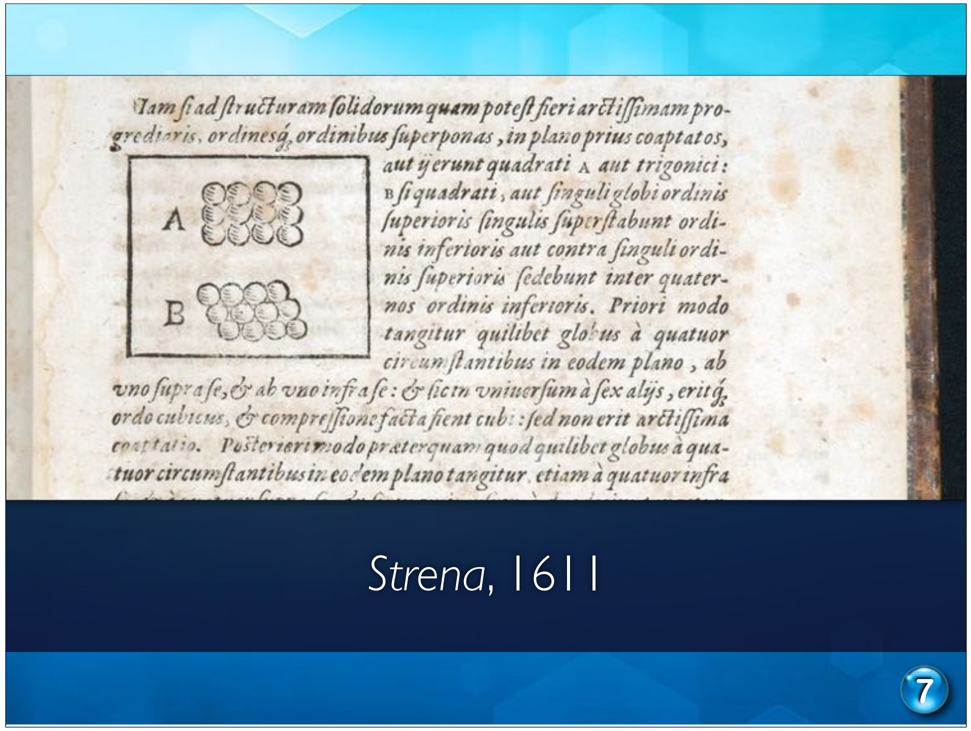


Vt igitur puncta O N I coëant in N oportet in A G fieri minores refractiones, in C E majores. Minor autem erit in A G. refractio, si minor sit illic inclinatio R A, Q G ad superficiē, major in C E, si major inclinatio L C, K E. Minor autem inclinatio fit R A ad A B, si A B termino B ipsi R appropinquet, hoc est, si superficies aliqua sit, quæ circularem superficiem A B C in A secet, altior incedens quàm A B C. Eadem si B C D in E rursum secuerit, major erit ipsius L C super eam inclinatio. Sic & in E, G. Secat igitur nova linea veterem in punctis quatuor. Idem autem facit Hyperbola. Non facit Ellipsis. Nam Ellipsis portionem semicirculo minorem


G 2 Pro-
G 3 cipiat



Again, we have another major work of Kepler's that is not yet translated, although the preface is partly available.

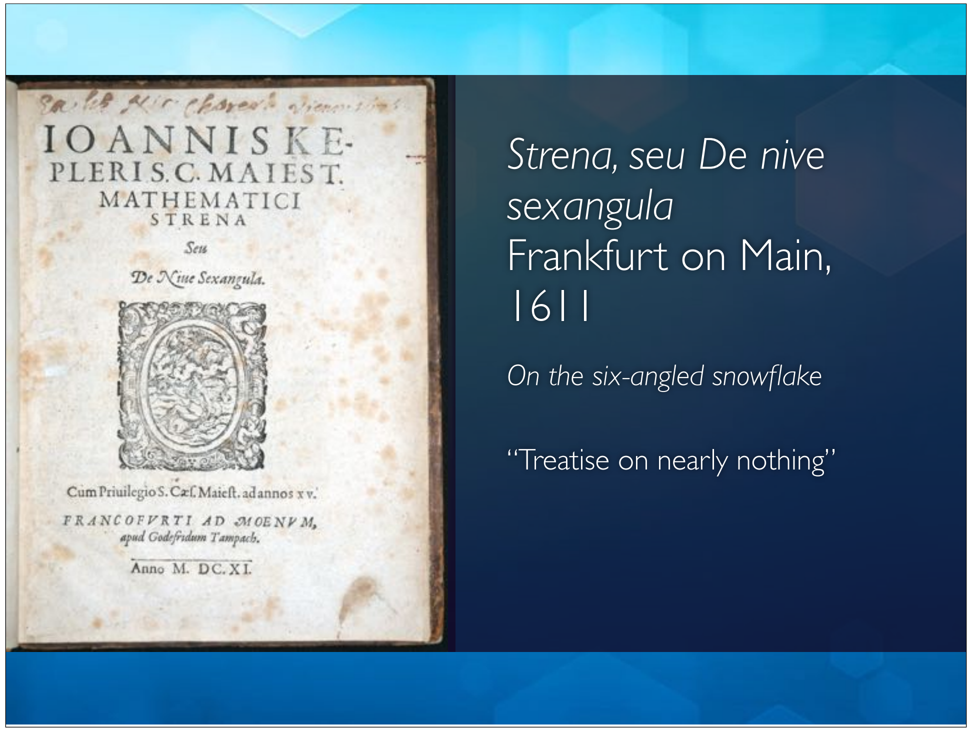


As his 7th major work shows, Kepler's contributions reached beyond the realm of astronomy to meteorology, mathematics, geology, mineralogy and crystallography.

——————–

Wikipedia: The Kepler conjecture, named after the 17th-century German mathematician and astronomer Johannes Kepler, is a mathematical conjecture about sphere packing in three-dimensional Euclidean space. It says that no arrangement of equally sized spheres filling space has a greater average density than that of the cubic close packing (face-centered cubic) and hexagonal close packing arrangements. The density of these arrangements is slightly greater than 74%.

In 1998 Thomas Hales, following an approach suggested by Fejes Tóth (1953), announced that he had a proof of the Kepler conjecture. Hales' proof is a proof by exhaustion involving the checking of many individual cases using complex computer calculations. Referees have said that they are "99% certain" of the correctness of Hales' proof, so the Kepler conjecture is now very close to being accepted as a theorem.



Kepler published this 24-page pamphlet, a study of the snowflake, as a New Year's greeting for a friend.

While crossing the Charles Bridge, Kepler spied a thick snowflake on his shoulder which quickly melted. Regarding the snowflake as a transient archetype of beauty, apparently insignificant, unvalued, and of merely fleeting existence, Kepler composed the Strena as a reflection on that which is “nearly nothing.” It was a whimsical gift for his friend, a patron at court to whom he had previously dedicated “nothing.”

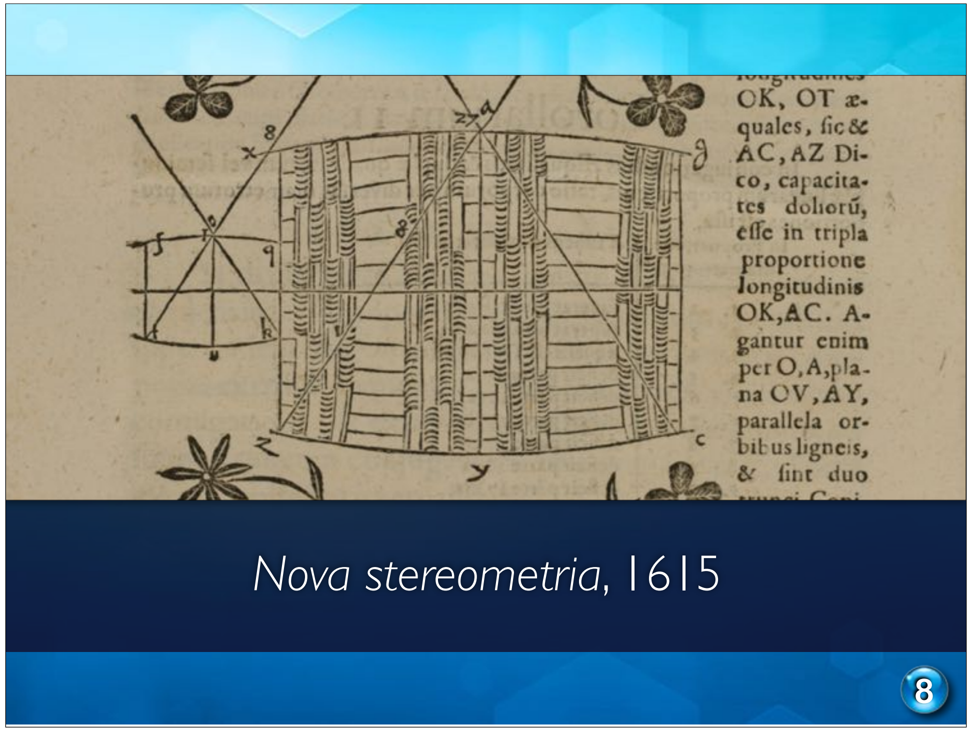
"Here, indeed, was a most desirable New Year's gift for the lover of Nothing, and one worthy as well of a mathematician (who has Nothing, and receives Nothing), since it descends from the sky and bears a likeness to the stars..."

Kepler, *Strena*

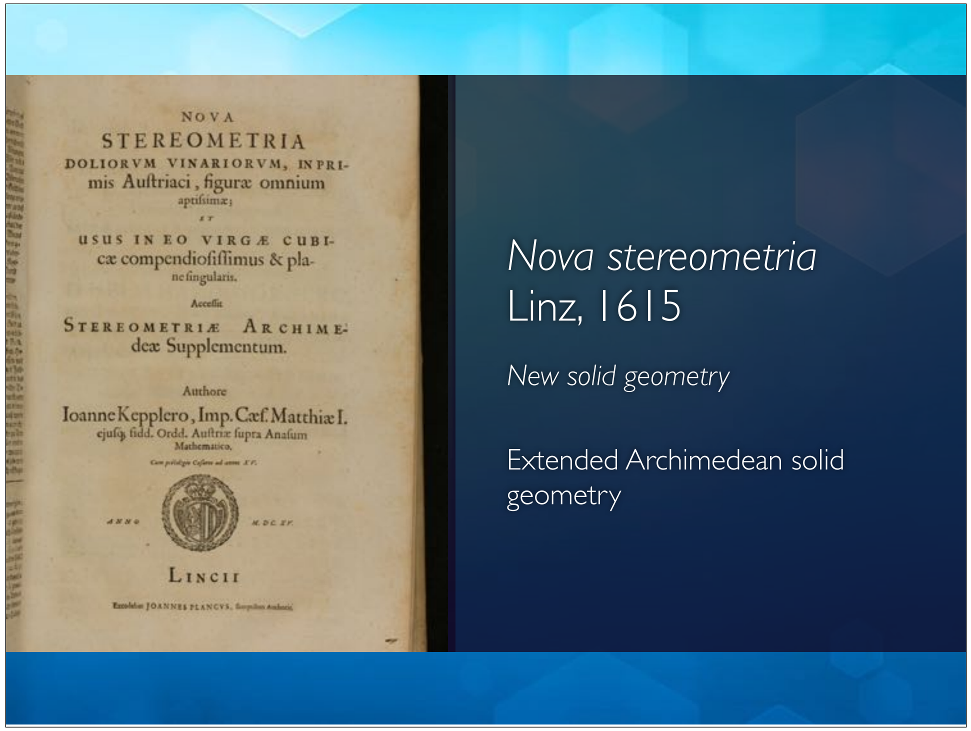
Kepler distinguished the way organisms grow, by differentiation, from the growth of crystals like the snowflake, which is by accretion. The work stimulated inquiry in mineralogy for the next century. -- As recently as 1998, Thomas Hales provided a mathematical proof of what became known as “Kepler’s conjecture” about crystal packing.

Read this delightful treatise for yourself, along with introduction and commentary, thanks to Jacques Bromberg. (It makes for a great Christmas present.)

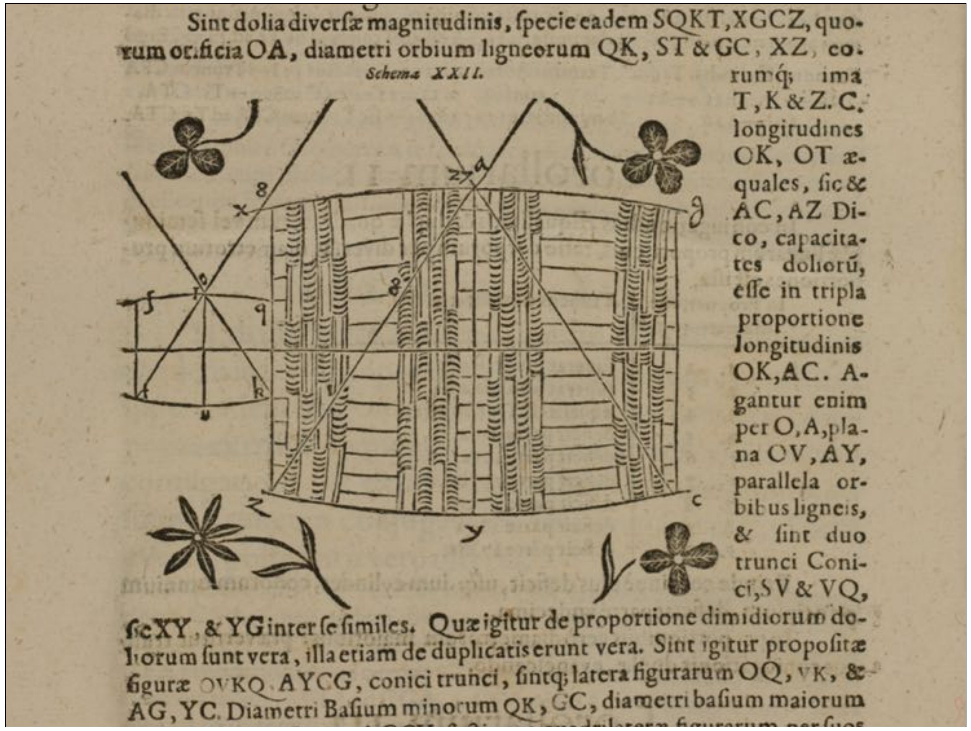
In 1612, Kepler moved to Linz, a city in modern Austria.



Kepler’s 8th major work appeared in 1615, the Nova Stereometria,...



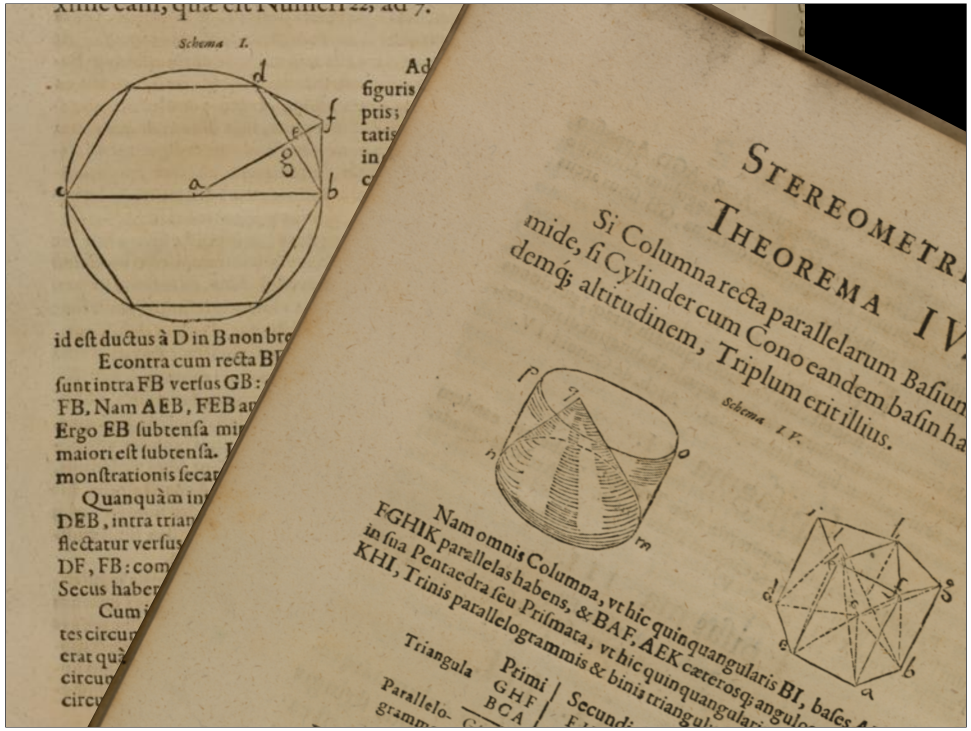
...or, "New Solid Geometry," which extended the methods of Archimedes for analyzing geometrical solids. Kepler printed this work at his own expense. Amazingly, it was the first book printed in Linz.



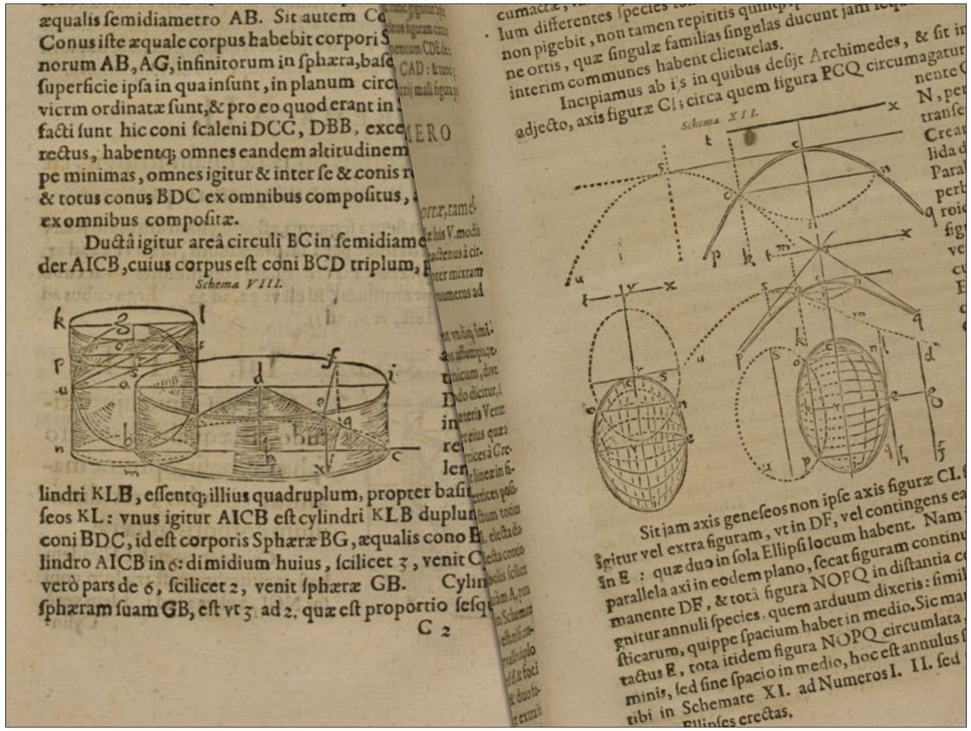
Sint dolia diversæ magnitudinis, specie eadem SQKT, XGCZ, quorum orificia OA, diametri orbium ligneorum QK, ST & GC, XZ, eorumq; ima T, K & Z. C. longitudines OK, OT æquales, sic & AC, AZ Dico, capacitates doliorũ, esse in tripla proportione longitudinis OK, AC. Agantur enim per O, A, plana OV, AY, parallela orbibus ligneis, & sint duo trunci Conici, SV & VQ, sic XY, & YG inter se similes. Quæ igitur de proportione dimidiorum doliorum sunt vera, illa etiam de duplicatis erunt vera. Sint igitur propositæ figuræ OVKQ, AYCG, conici trunci, sintq; latera figurarum OQ, VK, & AG, YC. Diametri Basium minorum QK, GC, diametri basium maiorum

When Kepler built a wine cellar, he noted with amazement that wine merchants estimated the volume of wine in a cask by measuring the depth of the cask, without regard to its shape.

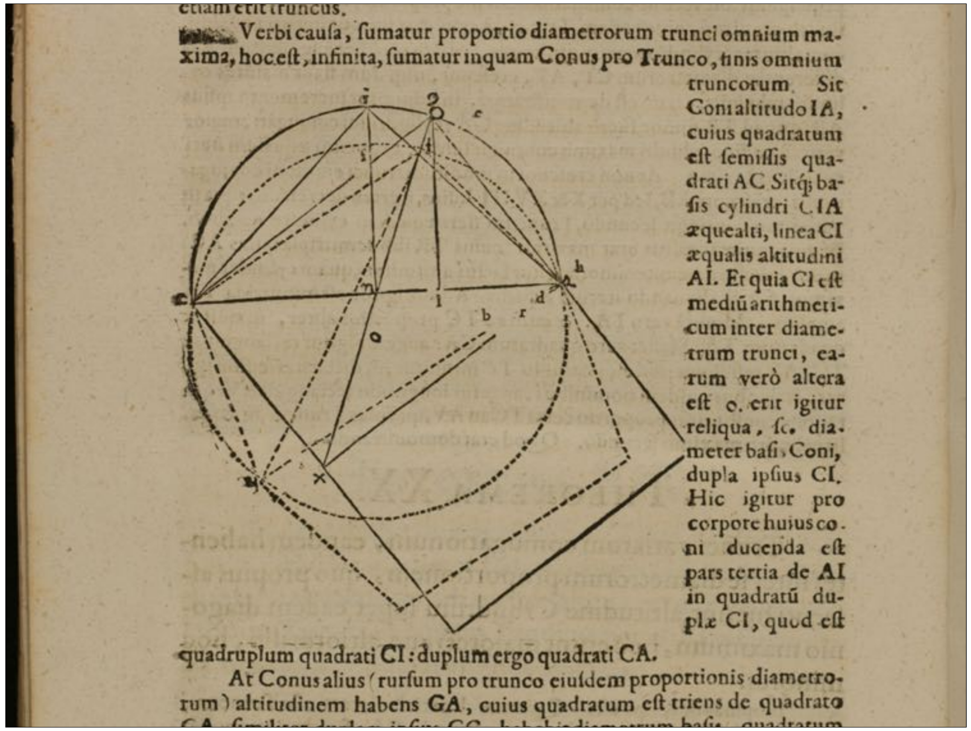
This prompted Kepler to investigate techniques of calculating volumes for 92 different shapes,



incorporating the methods of Archimedes.



In these images you can see evidence of the methods pioneered by Archimedes.

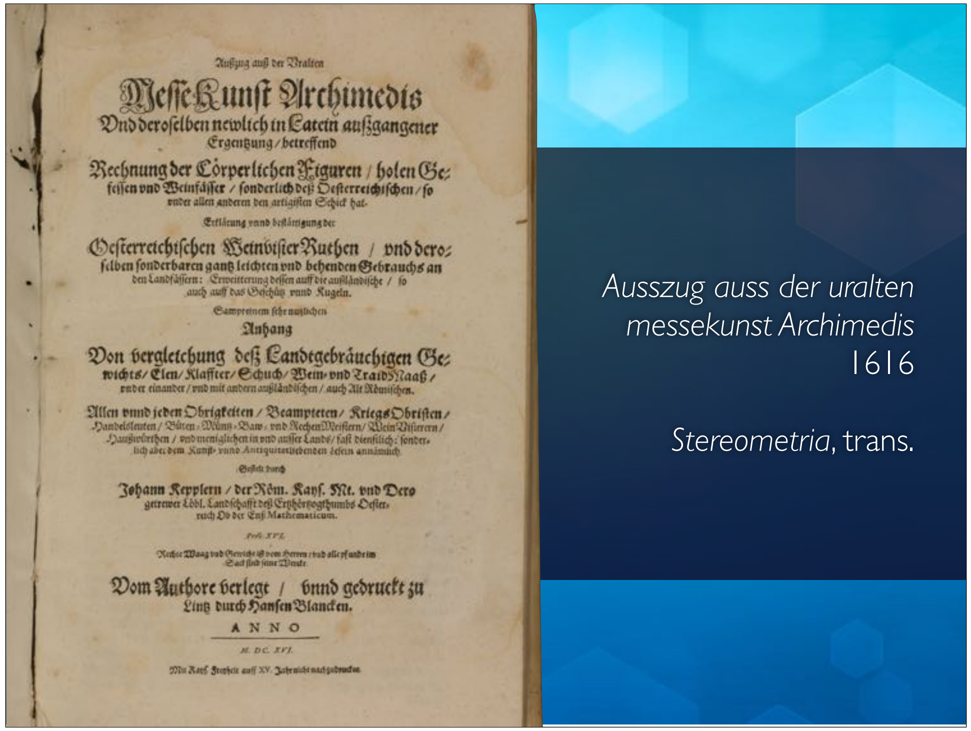


etiam erit truncus.

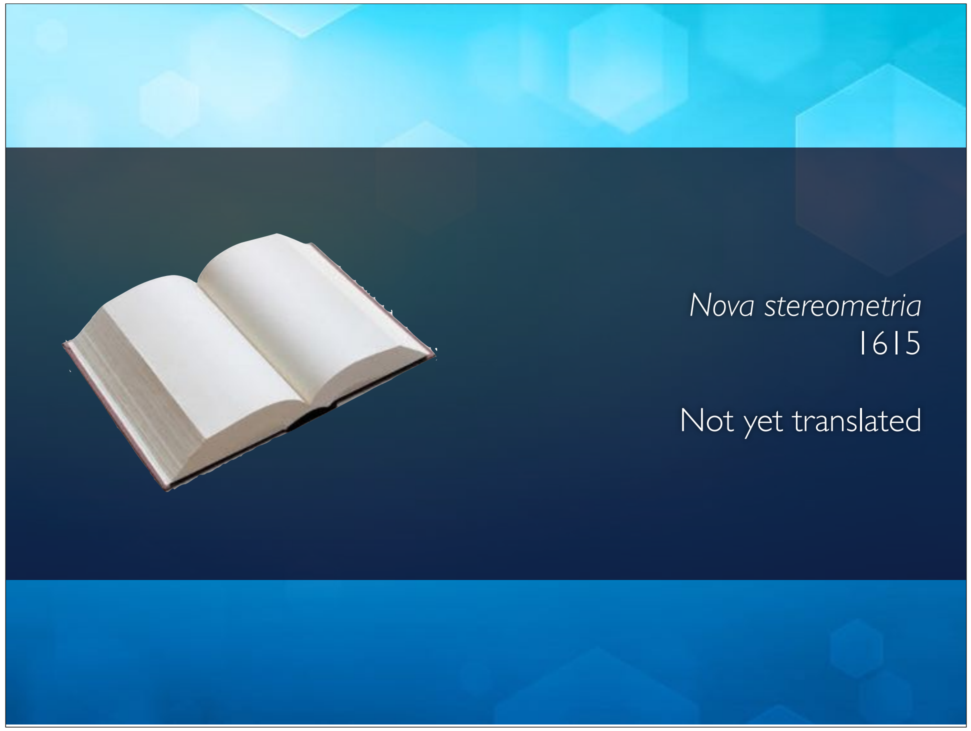
Verbi causa, sumatur proportio diametrorum trunci omnium maxima, hoc est, infinita, sumatur inquam Conus pro Trunco, finis omnium truncorum. Sit Coni altitudo IA, cuius quadratum est semissis quadrati AC Sitq; basis cylindri CIA æquealti, linea CI æqualis altitudini AI. Et quia CI est mediũ arithmeticum inter diametrum trunci, earum verò altera est o. erit igitur reliqua, sc. diameter basis Coni, dupla ipsius CI. Hic igitur pro corpore huius coni ducenda est pars tertia de AI in quadratũ duplæ CI, quod est quadruplum quadrati CI: duplum ergo quadrati CA.

At Conus alius (rursum pro trunco eiusdem proportionis diametrorum) altitudinem habens GA, cuius quadratum est triens de quadrato

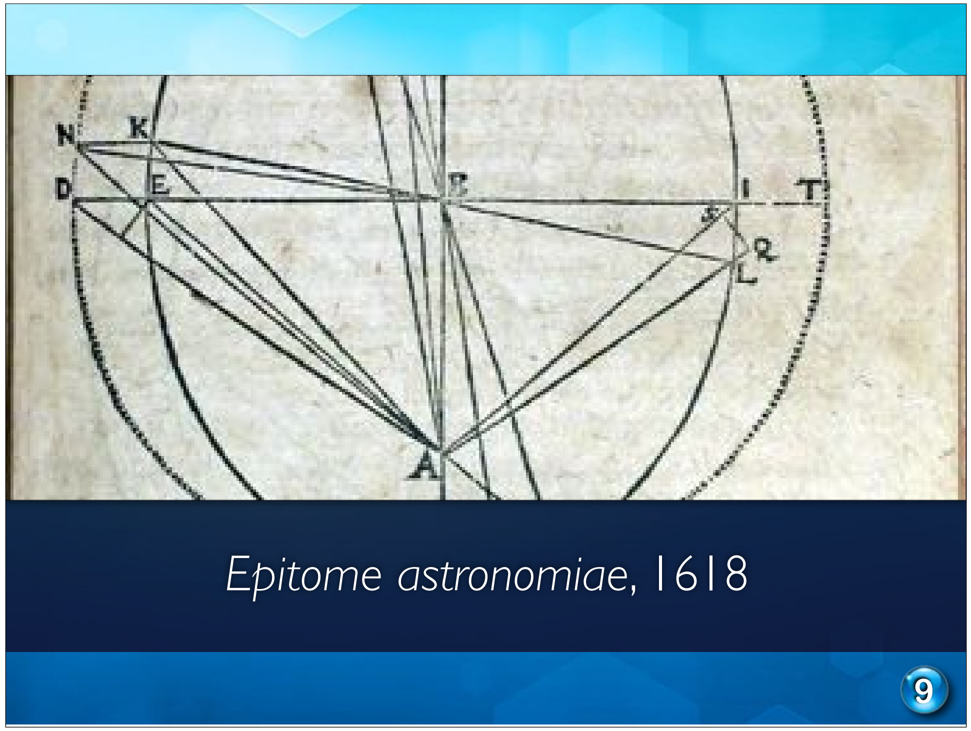
Such as the method of exhaustion.



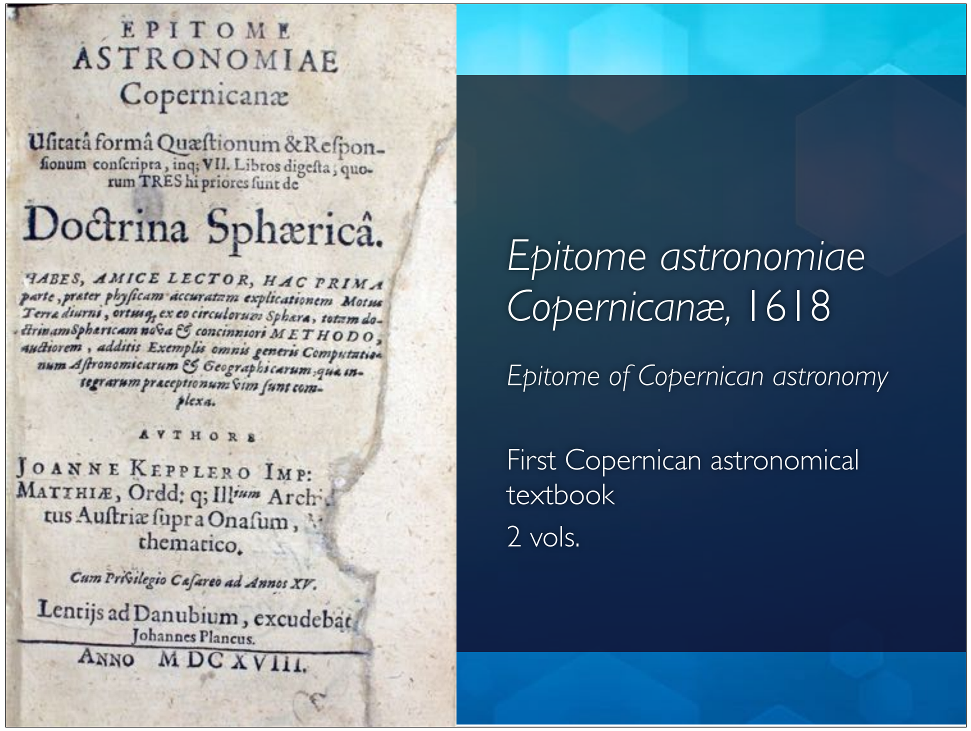
Kepler hoped that this work might interest merchants and wine dealers as well as mathematicians, so the following year he prepared a German translation.



To my knowledge, the Stereometria is not yet translated into English.



Kepler's 9th major work was the Epitome, a textbook in astronomy.



This 2 vol. work assumed the Copernican system throughout, the first astronomical textbook to do so.

vicissim naturalis constantia axis in sua directione, dirigit ipsius etiam volutionis plagam, ut eo inclinato, etiam circulum motûs inclinari necesse sit.

Si axis naturali facultate situm tueretur; nunquam inclinaretur?

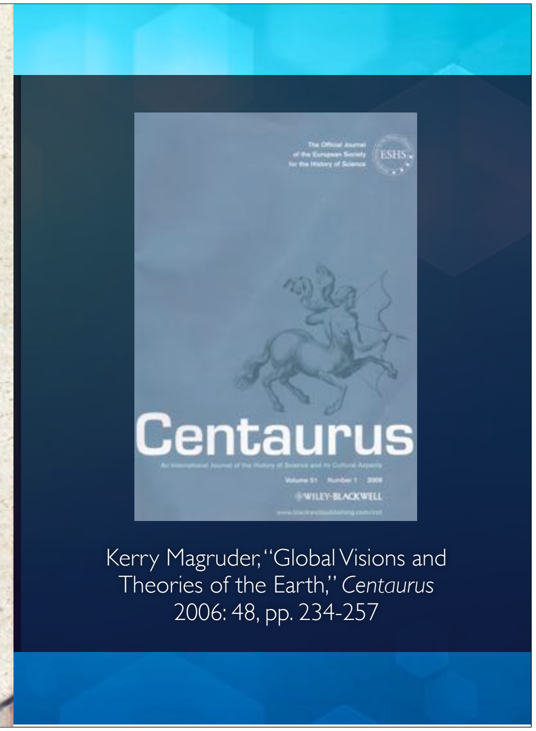
Imò ob id ipsum, quia naturalis est causa directionis, ideò etiam successu sæculorum vinci potest à causa fortiori extranea: de qua plura dicere non est hujus loci, ubi agimus tantum de motu diurno, respectu cujus, axis non inclinatur.

Fortaßis habes hujus facultatis Naturalis documenta etiam alia?

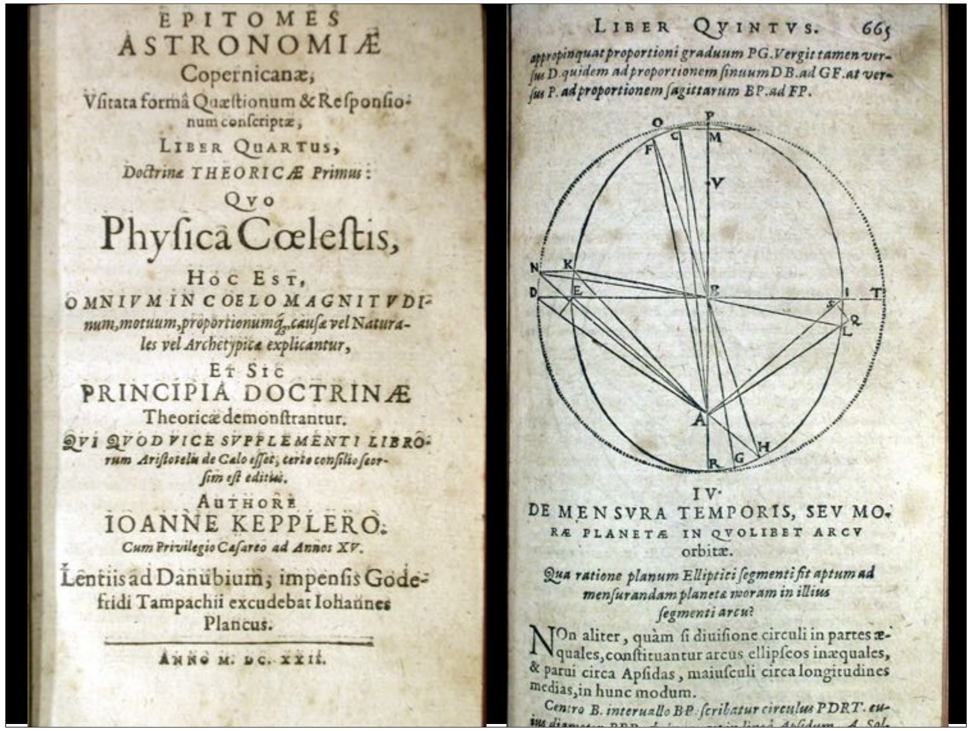
Equidem inest globo Telluris, secundum tractum axis; & fibrarum axi parallelarum, facultas in se dirigendi magnetes & magnetica omnia, magnetibus verò mutua inest facultas, hanc plagâ Telluris quærendi. Cum igitur manifestum sit, Globum telluris informatum esse formâ corporea rectilineâ secundum Tractum axis primi motus, non absurdè eidem formæ tribuitur etiam hæc constantia directionis axis in plagam semper eandem.

Vnum corpus non potest habere duos motus: Terra habet motum rectilineum deorsum; ergo non habet motum circularem?

H 3 r. Terra



If you're curious, I've published a little article which reproduces the illustration shown here, of Kepler's theory of the Earth's magnetism.


EPITOMES
ASTRONOMIÆ
Copernicanæ,
Vsitata formâ Quæstionum & Responsionum conscriptæ,
LIBER QUARTUS,
Doctrinæ THEORICÆ *Primus*:
QVO
Physica Cœlestis,
HOC EST,
OMNIVM IN COELO MAGNITVDInum, motuum, proportionumq́ꝫ, causæ vel Naturales vel Archetypicæ explicantur,
ET SIC
PRINCIPIA DOCTRINÆ
Theoricæ demonstrantur.
QVI QVOD VICE SVPPLEMENTI LIBRORUM Aristotelis de Cælo esset, certo consilio seorsim est editus.
AUTHORE
IOANNE KEPPLERO.
Cum Privilegio Cæsareo ad Annos XV.
Lentiis ad Danubium, impensis Godefridi Tampachii excudebat Iohannes Plancus.
ANNO M. DC. XXII.

LIBER QVINTVS. 665

appropinquat proportioni graduum PG. Vergit tamen versus D. quidem ad proportionem sinuum DB. ad GF. at versus P. ad proportionem sagittarum BP. ad FP.

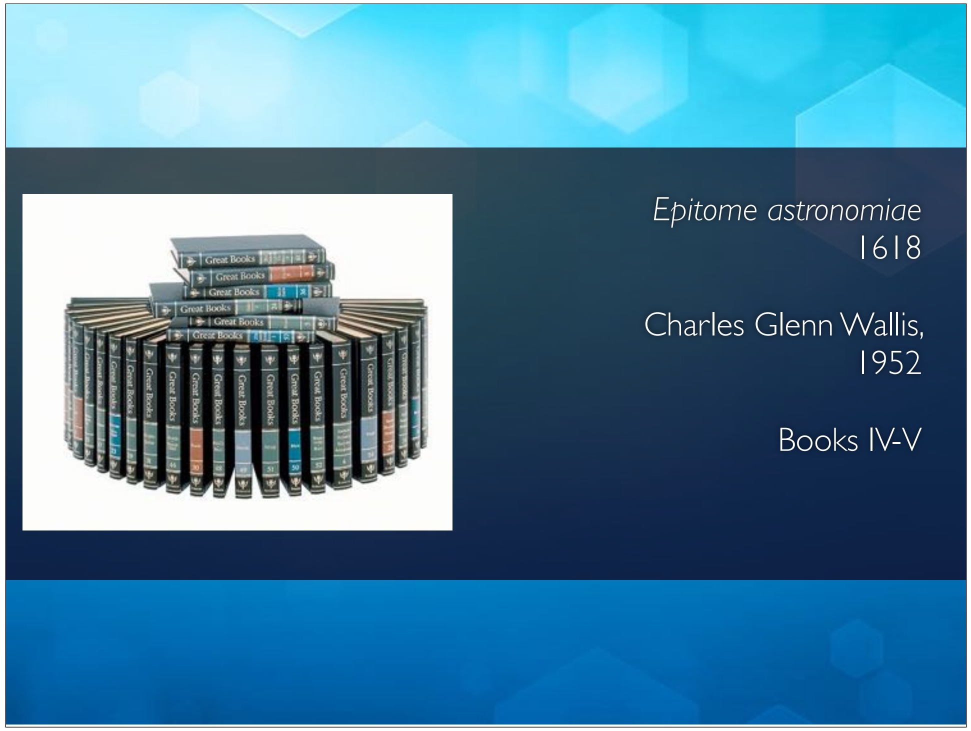
IV.
DE MENSVRA TEMPORIS, SEV MORÆ PLANETÆ IN QVOLIBET ARCV orbitæ.

Qua ratione planum Elliptici segmenti fit aptum ad mensurandam planetæ moram in illius segmenti arcu?

NOn aliter, quàm si diuisione circuli in partes æquales, constituantur arcus ellipseos inæquales, & parui circa Apsidas, maiusculi circa longitudines medias, in hunc modum.

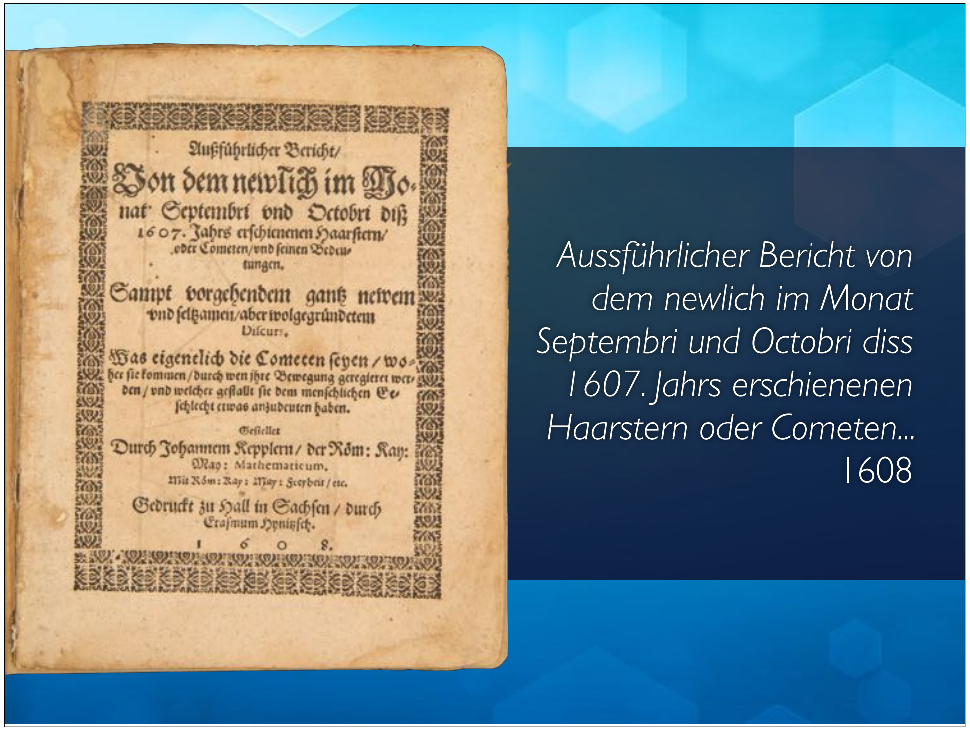
Centro B. interuallo BP. scribatur circulus PDRT. cu-

The second volume of the Epitome appeared four years later, in 1622.



Thankfully, a portion of the Epitome was translated by Charles Wallis as part of the Great Books of the Western World.

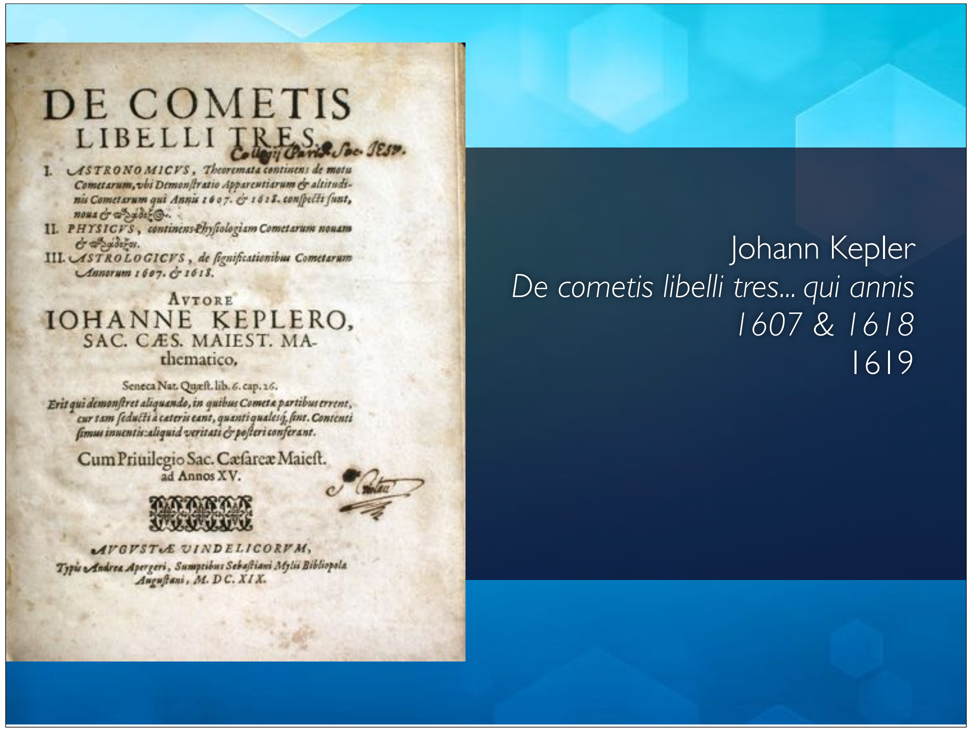
Many of you have witnessed comets in the sky. In 2013, three comets appeared in a single year.



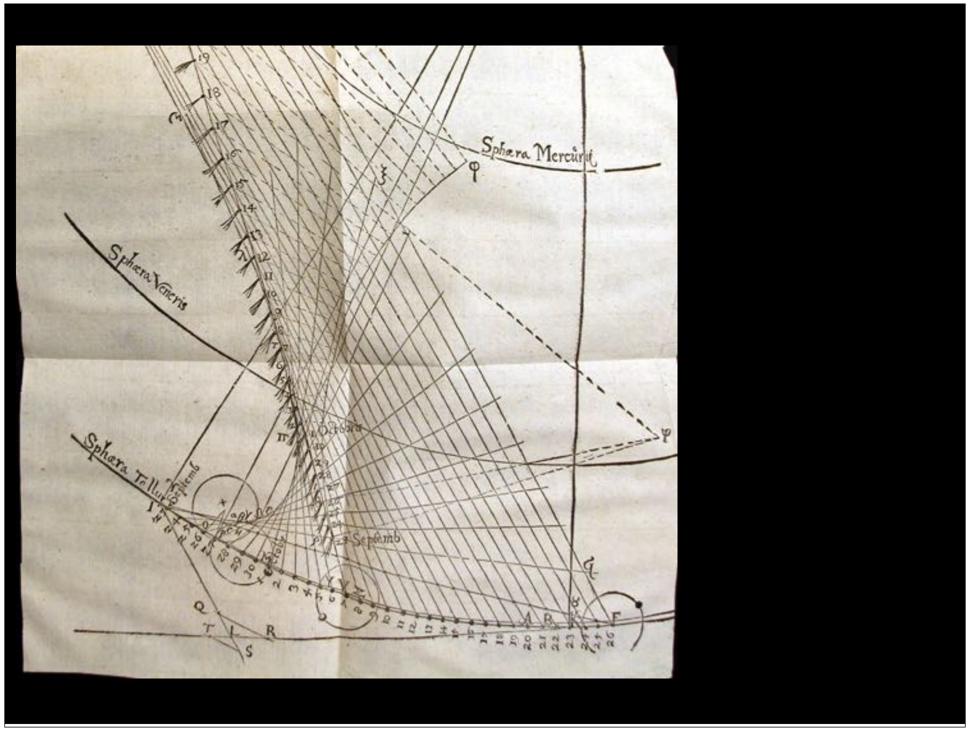
This minor work by Kepler analyzed the trajectory of a comet that appeared in 1607. The OU copy is annotated and not yet studied.

In 1618, three comets appeared visible to the unaided eye in a single year. Oratio Grassi was the leading astronomer in Rome, a professor at the Collegio Romano, and a skillful mathematician.

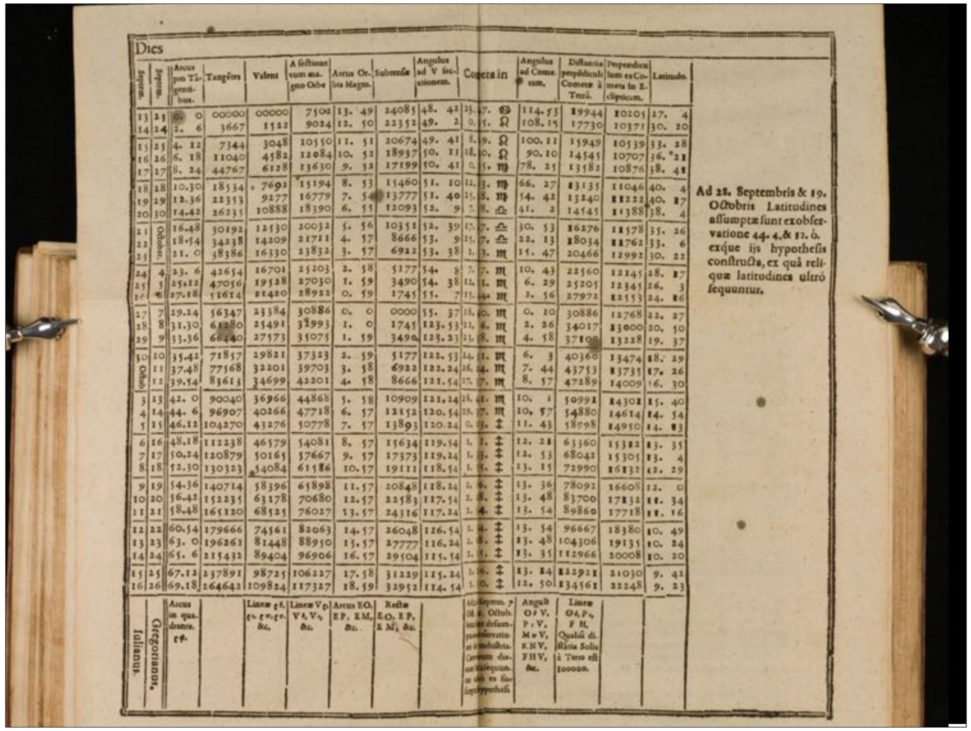
In this book, Grassi accurately described the trajectories of the three comets, demonstrating that they moved beyond the Moon, as consistent with the Tychonic system. As a Jesuit, Grassi was charged with teaching nothing in science contrary to Aristotle, who said that comets were vapors located beneath the Moon. So this book represents an interesting story: the leading Jesuit astronomer in Rome has openly published an account of three well-known comets that was explicitly contrary to Aristotle. One would think that Galileo, whom Grassi admired, would have cheered him on. Yet in making this argument, Grassi unwittingly opened an episode that became known as the “controversy of the comets.” Tellingly, Galileo had been ill during 1618 and was not able to observe the comets himself.



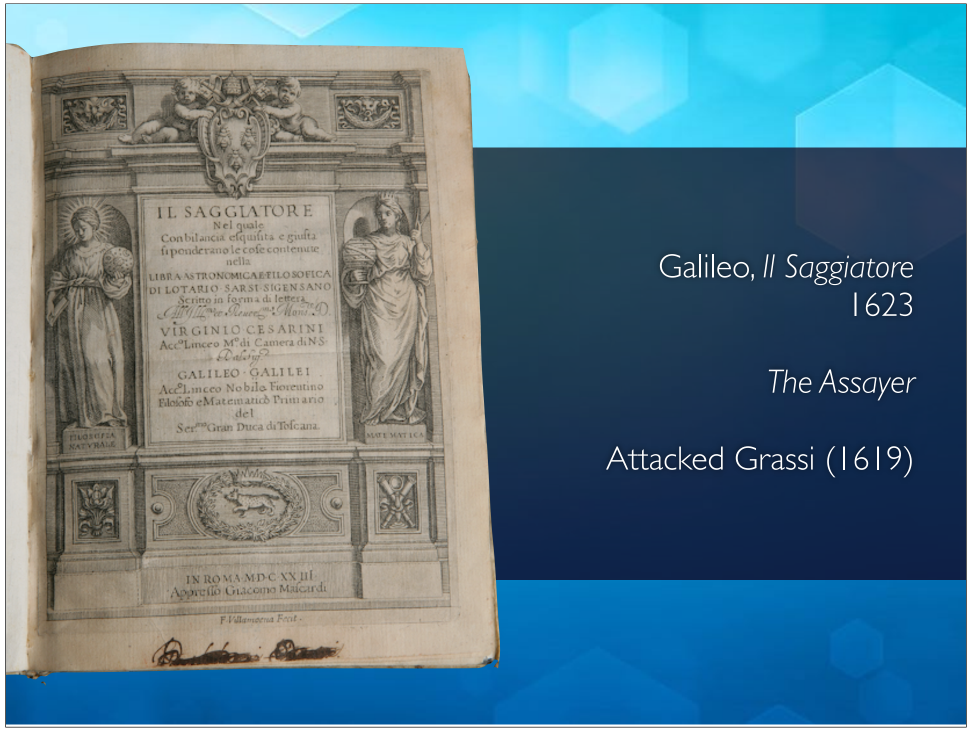
Kepler’s first contribution about the three comets came with this minor work.



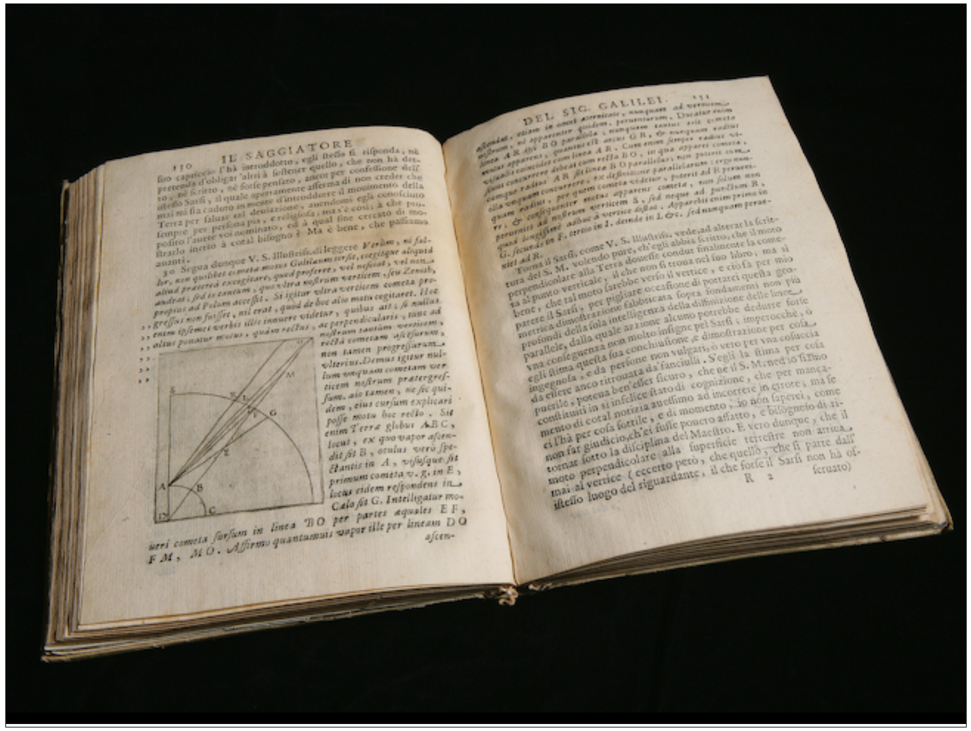
In it, Kepler offered an analysis that agreed with Grassi's.



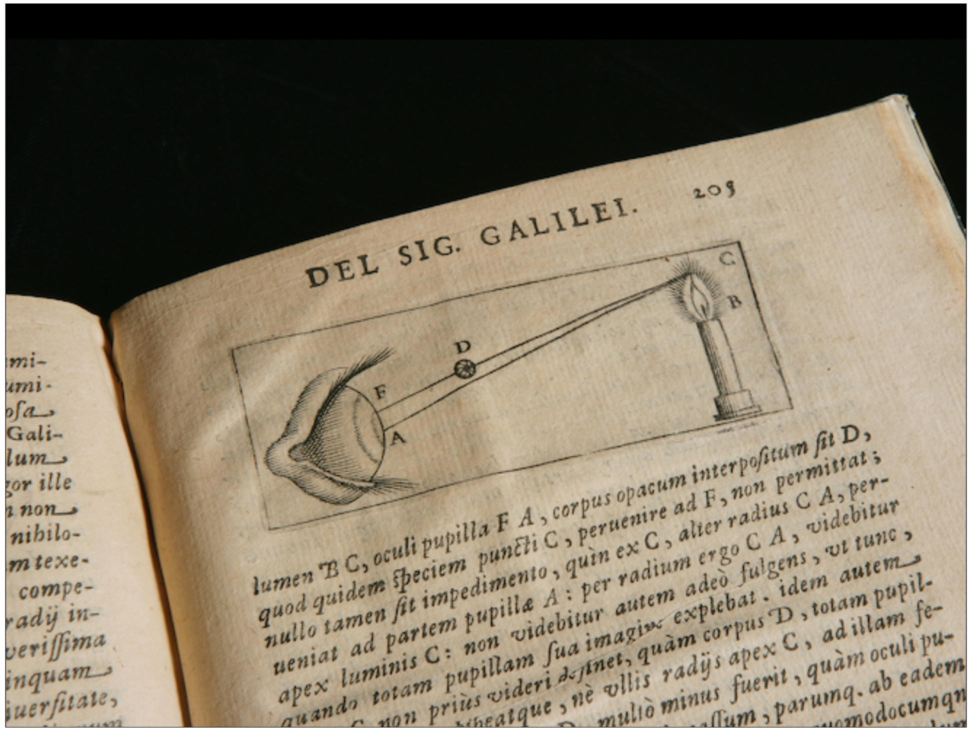
Here's another page.



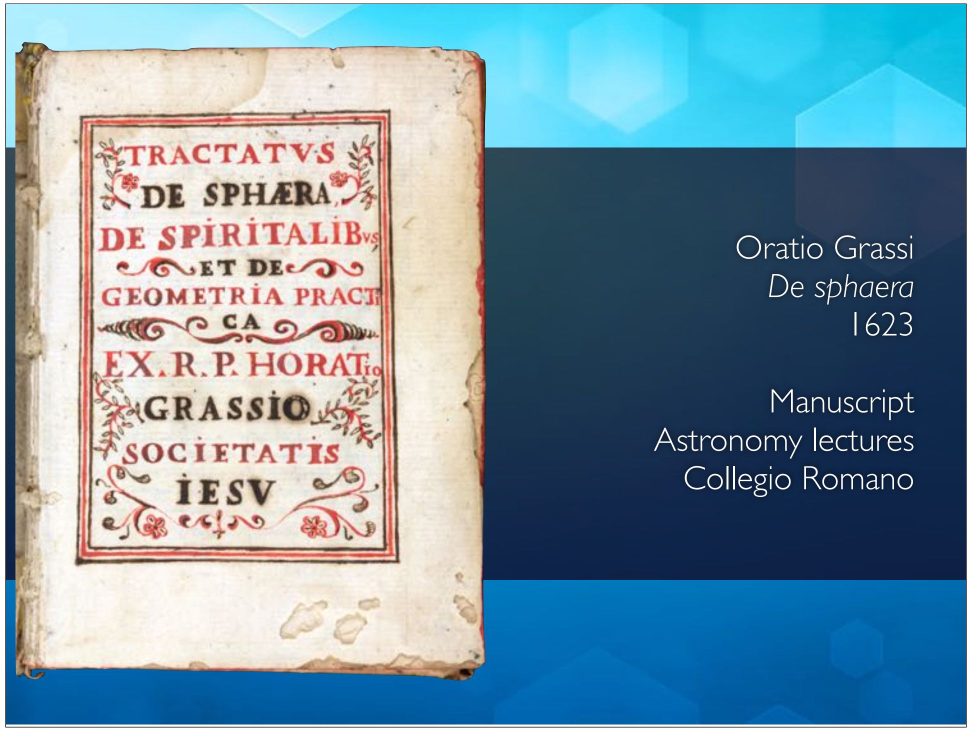
The controversy over the comets began in earnest when Galileo attacked Grassi's account in this work, Il Saggiatore, or The Assayer, published in 1623. (OU holds Galileo's own copy of this book.)



The Assayer contains a magnificent polemic for the new discipline of mathematical physics, and in it Galileo eloquently champions mathematical methods in science. This is one of the reasons mathematicians like Grassi admired him. Ironically, however, its main point was to ridicule a fellow mathematician, none other than Grassi himself. Galileo targeted his wit and sarcasm upon Grassi's argument from parallax that comets move above the Moon.



Galileo mistakenly countered that comets are an optical illusion, so it is a meaningless question to ask where they are located. We have come far from the months after Galileo’s telescopic discoveries when Galileo was celebrated by the Jesuit mathematicians: Galileo's polemical tone against Grassi helped seal significant opposition to him within the Jesuit order. On the other hand, the satirical book was read with delight at the dinner table by the pope, who wrote a poem praising Galileo for the rhetorical performance!

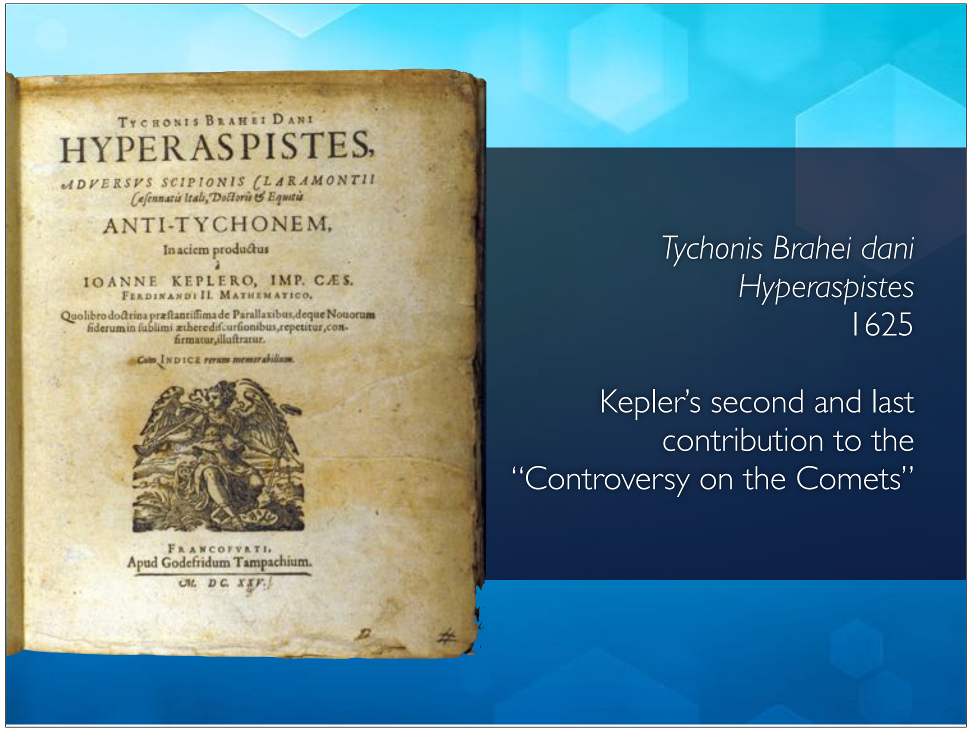


The very same year that Galileo published his satirical Il Saggiatore against Grassi, Grassi himself was delivering these lectures to Jesuit students in the Collegio Romano.

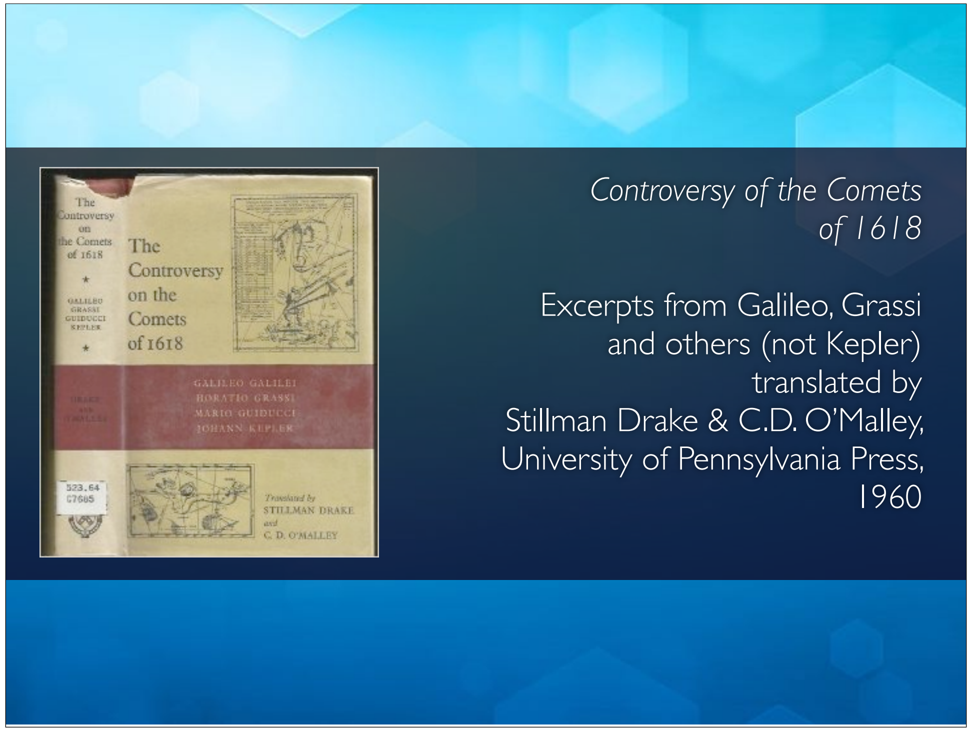
It is beautifully handwritten, a manuscript of Grassi's lectures within the Jesuit university.

This manuscript, never published and new to scholars, was acquired with financial assistance from the OU Athletic Department. Go Sooners!

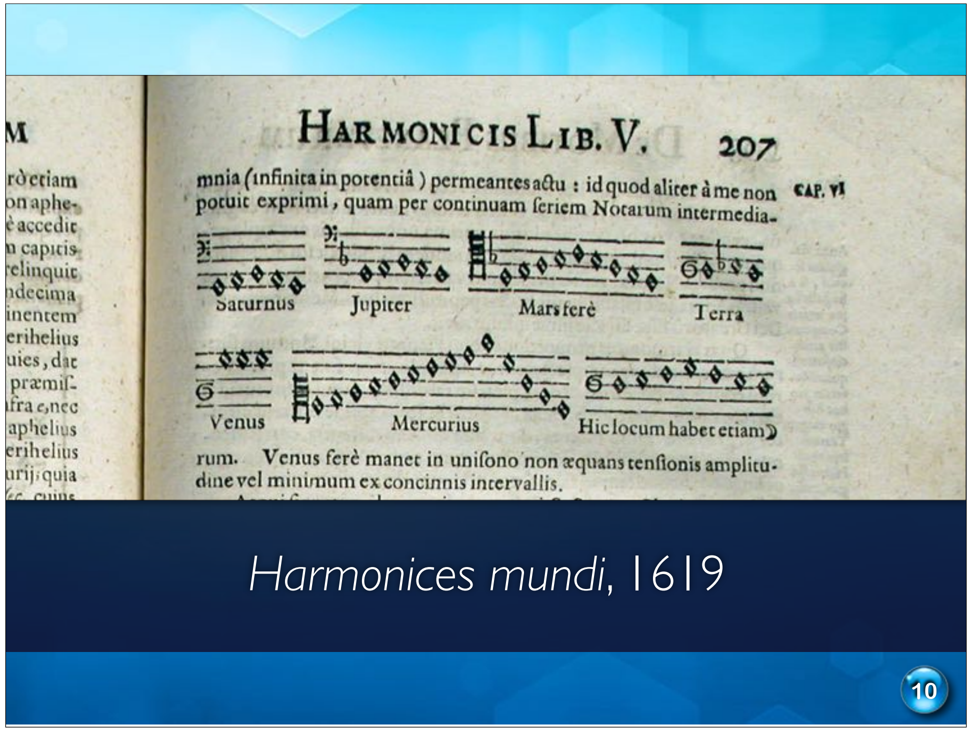
In these lectures Grassi taught his Jesuit students about Galileo’s purported discovery of mountains on the Moon.



Galileo attacked Grassi not only because of his view that comets move beyond the Moon, but even more so because Grassi supported Tycho's cosmology. In a second publication about the comets, Kepler stepped in to mediate. Here Kepler defended Tycho against Galileo's attacks, and thus softened Galileo's attacks against Grassi as well.



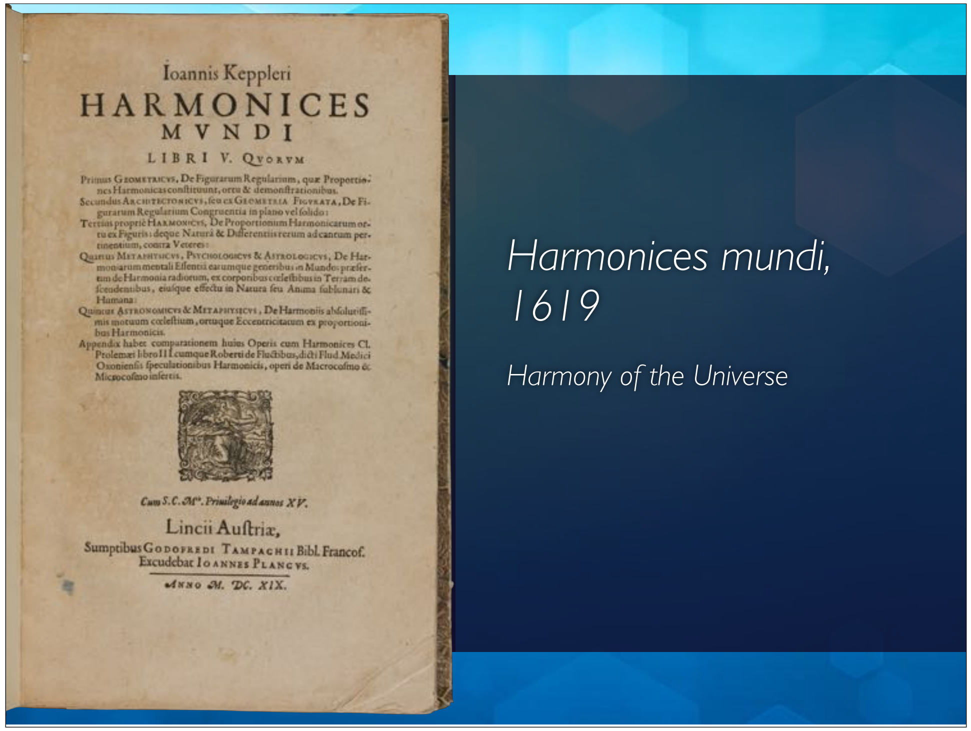
Excerpts from Galileo, Grassi and others involved in the controversy are available in this work by Stillman Drake and C.D. O'Malley. Unfortunately, however, they did not translate Kepler's contributions.



Kepler’s 10th major work appeared in 1619, the Harmony of the Universe.

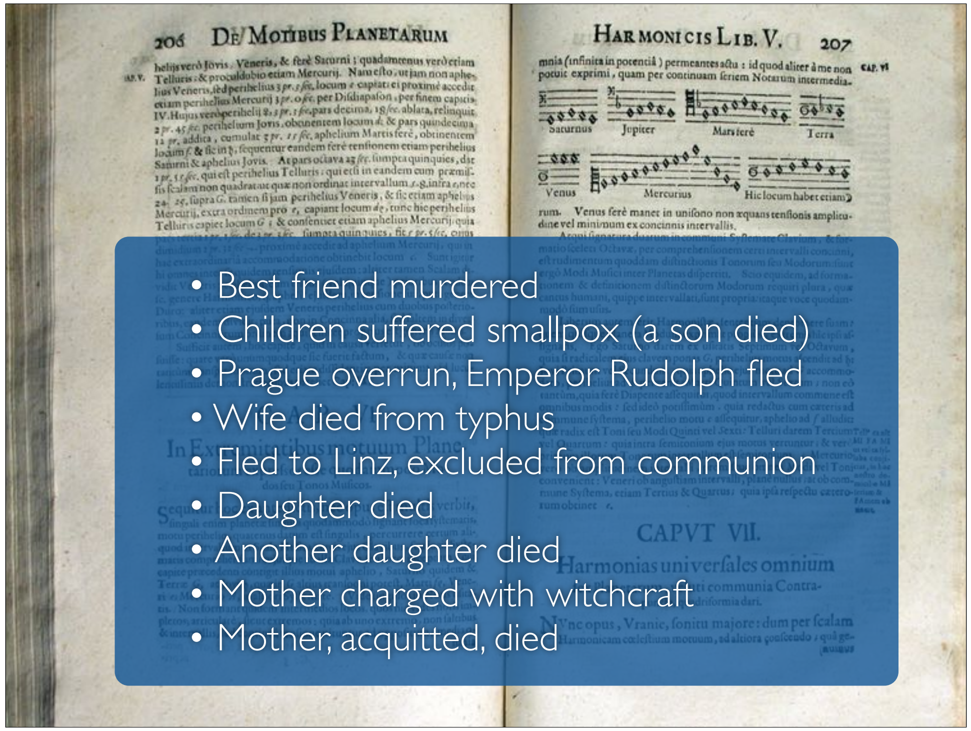
“Holy Father, preserve us in the harmony of mutual love so that we may be one even as you with your Son, our Lord, and the Holy Spirit are one, and as you have through the gentle bonds of harmony made all your works one; and from the renewed concord of your people let the body of your church on earth be built from harmonies as you have constructed the heavens themselves.”

Johannes Kepler, The Harmony of the Universe

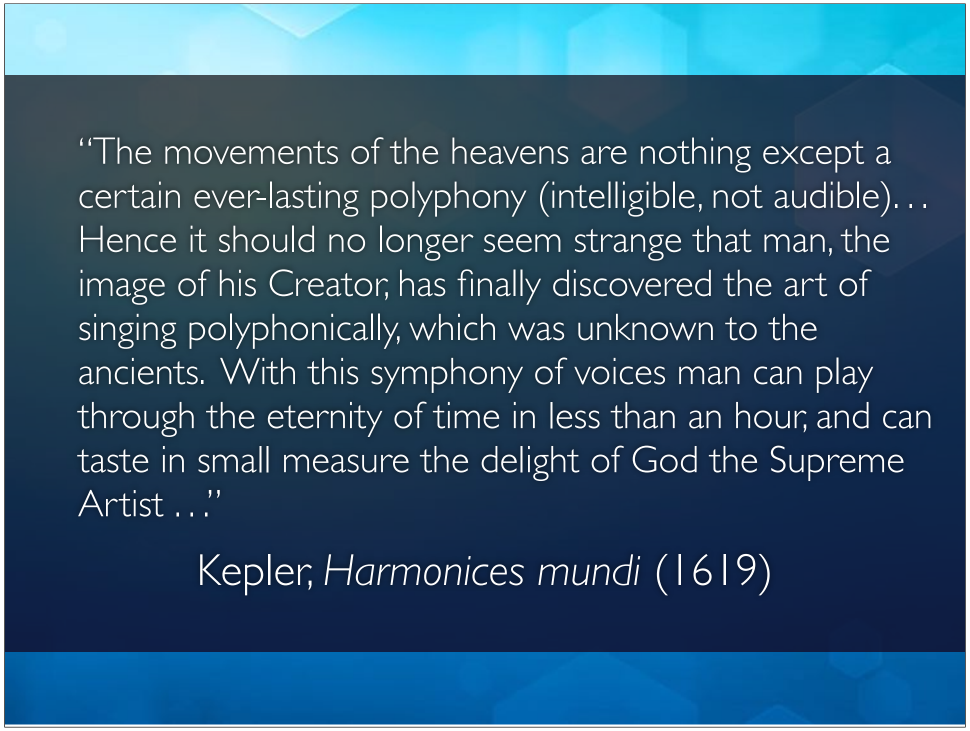


In this work, famous for containing Kepler's "third law", Kepler integrated theoretical astronomy and music. This fulfilled an ancient dream. Plato wrote, "As our eyes are framed for astronomy, so our ears are framed for the movements of harmony, and these two sciences are sisters." [Republic, VII 530d.] From antiquity, music had been considered a sister science to astronomy, with both subordinated to mathematics.

Kepler achieved a synthesis of his new astronomy with recent polyphonic musical theory. Kepler demonstrated that the motions of the planets consisted of precisely the same harmonic ratios as would be fitting for the musical handiwork of the Creator. The beauty of music provided the context for what we call his “third law.”



Kepler's vision truly was cosmic, of a cosmic hope and consolation amidst earthly sorrow. During the writing of this treatise, --his best friend was murdered; --his children contracted smallpox (which killed his son); --Prague was overrun with violence and his employer, emperor Rudolph, forced to abdicate; --and his wife died from typhus (all of these 1611). --In 1612 at Linz, the Lutheran pastor excluded him from communion because of his sympathy for Calvinists, a prohibition which was enforced in spite of Kepler's repeated appeals. --In 1617 and --1618 two daughters died, --Kepler defended his mother against charges of witchcraft and threats of torture (she had enjoyed cooking suspicious mushrooms and spiking friends' drinks with hallucinogens; --though finally acquitted, she died six months later).



In the midst of these trials, Kepler affirmed that: "read"


HARMONICIS LIB. V. 207

mnia (infinita in potentiâ) permeantes actu: id quod aliter à me non potuit exprimi, quam per continuam seriem Notarum intermedia- CAP. VI

rum. Venus ferè manet in unisono non æquans tensionis amplitudine vel minimum ex concinnis intervallis.

Atqui signatura duarum in communi Systemate Clavium, & formatio sceleti Octavæ, per comprehensionem certi intervalli concinni, est rudimentum quoddam distinctionis Tonorum seu Modorum: sunt ergò Modi Musici inter Planetas dispertiti. Scio equidem, ad formationem & definitionem distinctorum Modorum requiri plura, quæ cantus humani, quippe intervallati, sunt propria: itaque voce quodammodò sum usus.

Liberum autem erit Harmonistæ, sententiam depromere suam: quem quisque planeta Modum exprimat propiùs, extremis hic ipsi assignatis. Ego Saturno darem ex usitatis Septimum vel Octavum,

Kepler shows that Copernicanism did not make inevitable the agony of a vast and empty silence, haunted by the meaningless existence of conscious life on only one lonely outpost. As with the Pythagoreans and their music of the spheres, to step outside under the stars at night with Kepler is to enter the presence of the most elegant of symphonies, and even into the majestic presence of a Creator beyond the Cosmos. To Kepler, for the one with ears to hear, the harmonies of the universe unceasingly declare the glory of God.

Laurie Spiegel's tribute to Kepler's Harmonices mundi was chosen by Carl Sagan to travel on the Voyager spacecraft Golden Record. Let's listen to a few seconds excerpt. — PLAY. (no click) One reviewer said of the entire piece: "Spiegel's realization is bracing, menacing, and disorienting, the piercing tones not unlike a choir of air raid sirens. An alien life form encountering it on Voyager's "Golden Record" would conclude that our world was a maddening, maniacal place." Although it's cool to have music honoring Kepler now on board a spacecraft that is leaving the solar system, I don't think that effect is what Kepler had in mind!

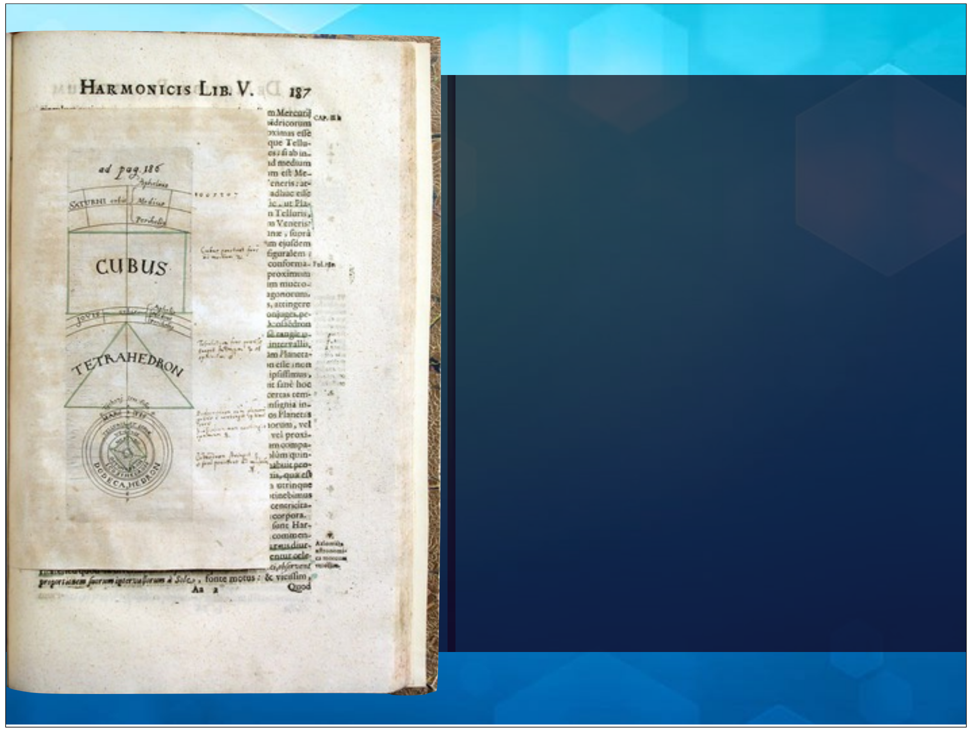
————————————

http://pitchfork.com/reviews/albums/17067-the-expanding-universe/

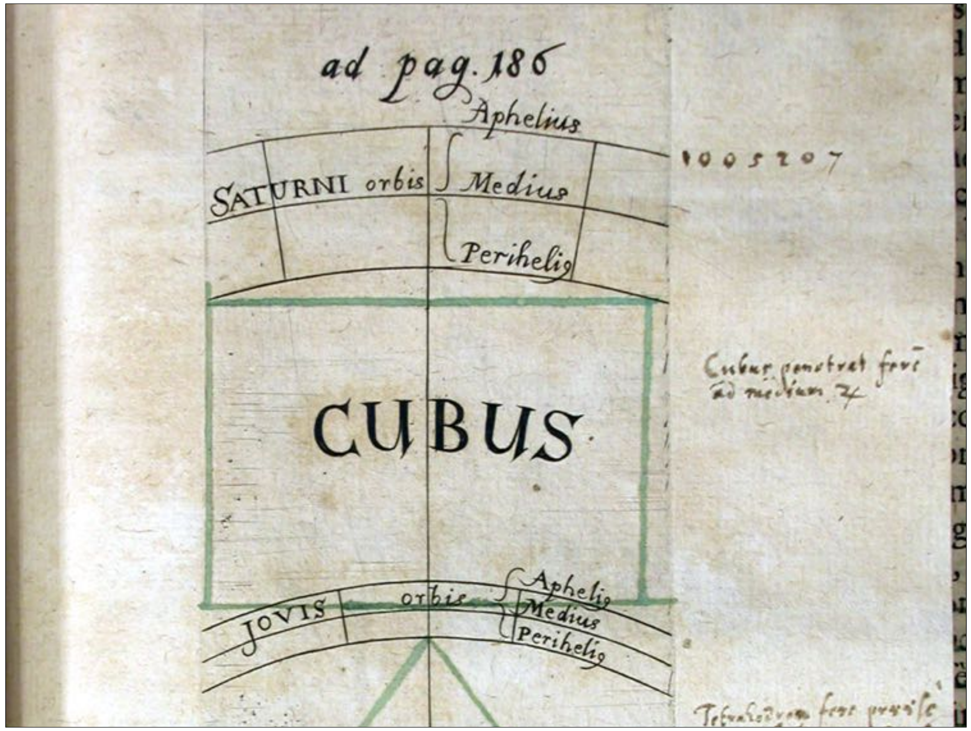
"In 1977, American astronomer Carl Sagan selected the composer Laurie Spiegel's computerized realization of Johannes Kepler's 1619 treatise "Harmony of the Worlds" for inclusion aboard the Voyager 1 and 2 spacecraft's "Golden Record". Kepler's "Harmony of the Worlds" was the lead cut on a collection that held recordings of natural sounds, greetings in 55 languages, selections from Beethoven, Mozart, Blind Willie Johnson, and Chuck Berry, for the sake of demonstrating to other life forms in the galaxy that there is intelligent life on our planet. And now, Laurie Spiegel's music has traveled to the edge of our solar system."

This is Jonathan Annis, an OU graduate student in music composition, who worked on a project replicating Kepler's more pleasing scales of the planets and planetary melodies. Jonathan's suite for harp, flute and oboe is entirely comprised of musical themes from Kepler's Harmonices mundi. Jonathan arranged the themes, but they're all from Kepler's musical description of the universe as a cosmic dance. Let's listen to a 3 minute excerpt. As you do, imagine the planets of the solar system revolving around the Sun; then move on to galaxies revolving around other galaxies in the far reaches of space; all carrying out the steps of an intricately choreographed cosmic dance. This is how Kepler expressed through music what we now call his third law: [listen to a sample, 3:17 mins] Again, every musical motif you heard in this excerpt is taken from Kepler's Harmonices mundi. Kepler's music still describes how the planets revolve around the sun, and how galaxies revolve around other galaxies in deep space. [p. 219]
——————–

Jonathan Annis: "a passacaglia is a dance typically in 3 and built around a memorable theme or ground bass that repeats throughout. The melodic theme that I chose is a fragment of melody found on page 219 of Kepler's Harmony of the World. The melody is six measures long and can be heard woven throughout with no breaks. The only variations I was forced to make from Kepler's were meter, as his was in imperfect tempus (subdivions of 2, or 4/4 meter) and a passacaglia requires a perfect tempos (three subdivions, or 3/4 meter). To facilitate I had to add a quarter note on the third beat of the fifth measure to lead to the final note of the melody. It is orchestrated for harp, flute (doubling alto flute), and oboe (doubling english horn). This movement in particular is scored for oboe, alto flute, and harp. I am so happy that you enjoyed it! If you would like for it to be played at the exhibit opening let me know and I will make it happen."



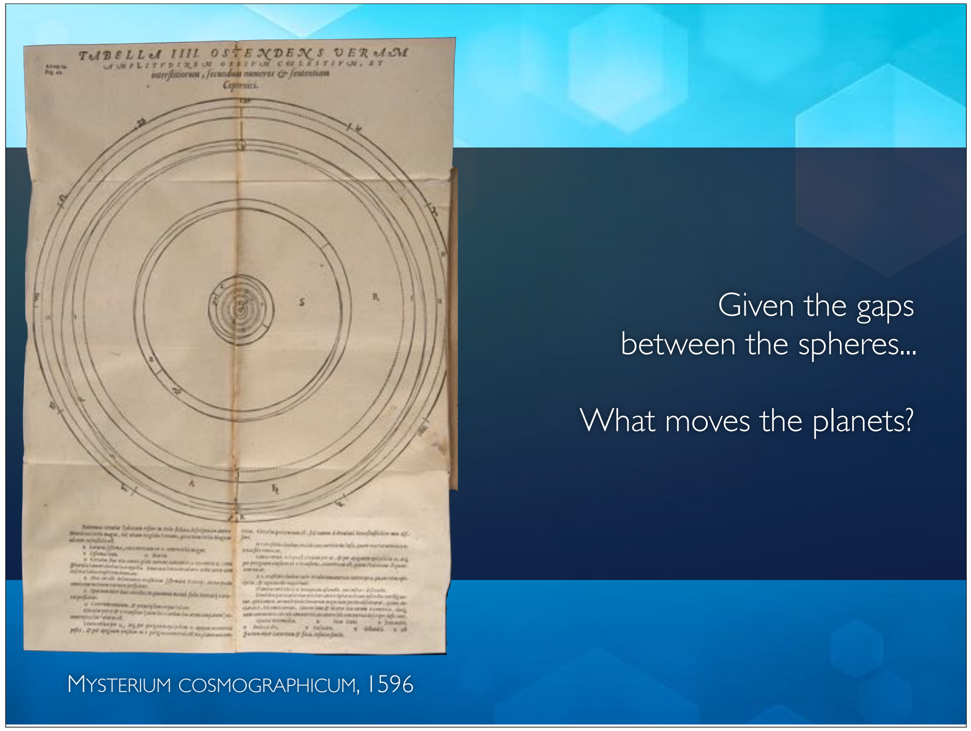
Where there’s music, the Pythagorean solids can’t be far behind.



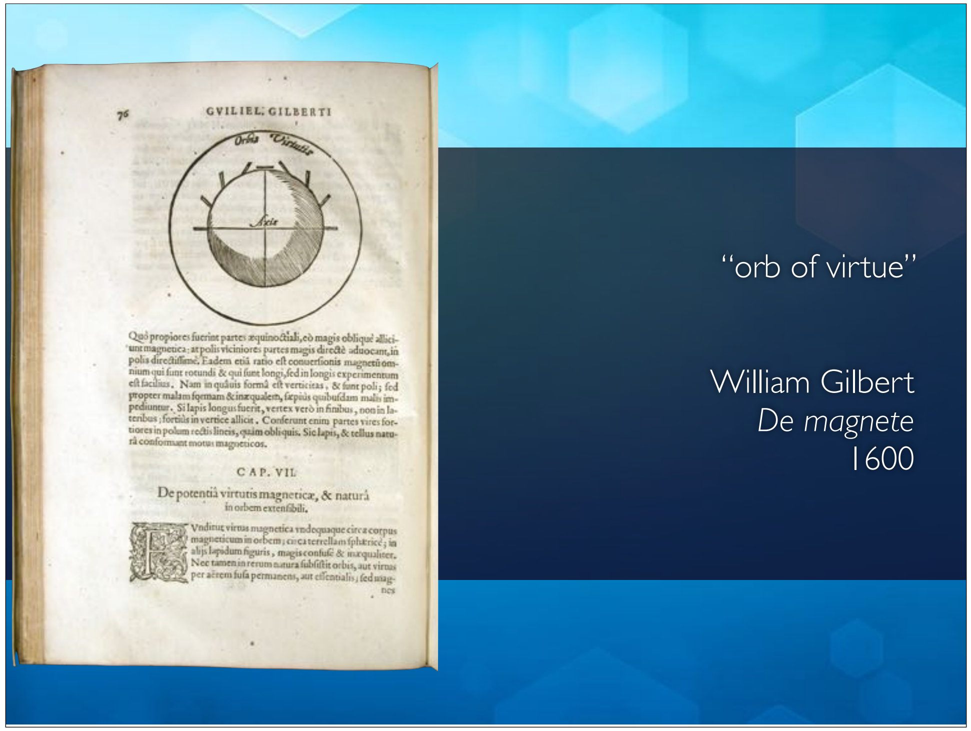
Kepler is still correlating the regular solids with the structure of the cosmos

right in the middle of the Harmony of the Universe

An integration of music, astronomy and the regular solids formed the immediate context of what we now refer to as Kepler's third law.

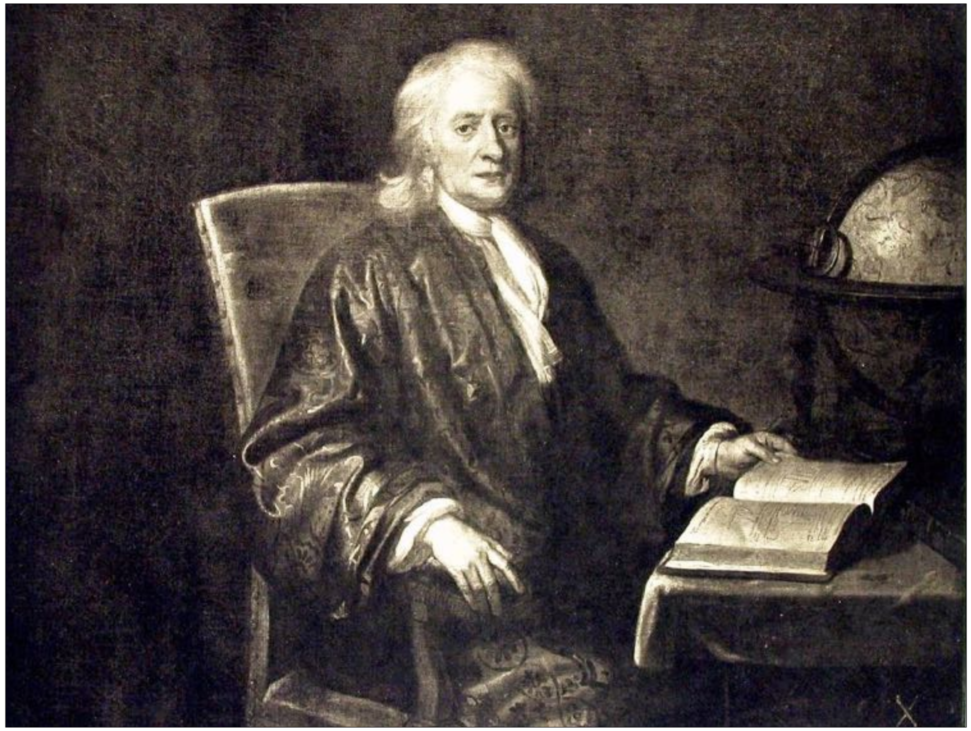


Let's go back to the Mysterium for a moment. If the spheres were not touching each other, and therefore could not pass their motion from one down to the next; or if the spheres had no physical reality at all, as for Kepler; then what moved the planets? In the Harmony of the Universe Kepler came up with an answer for this problem, too.



Kepler drew upon the conclusions of William Gilbert, who was neither an astronomer nor a Copernican. Gilbert was one of Queen Elizabeth's physicians, all of whom she banished from her room as she lay dying, for fear they would speed up the process. For sorrow for the Queen, it has been said, Gilbert followed her in death a few months later. In De magnete, Gilbert argued that the Earth is a magnet, and rotates once a day. The Moon also is a magnet, held near the Earth by the Earth's "sphere of virtue," which carries the Moon around the Earth once a month.

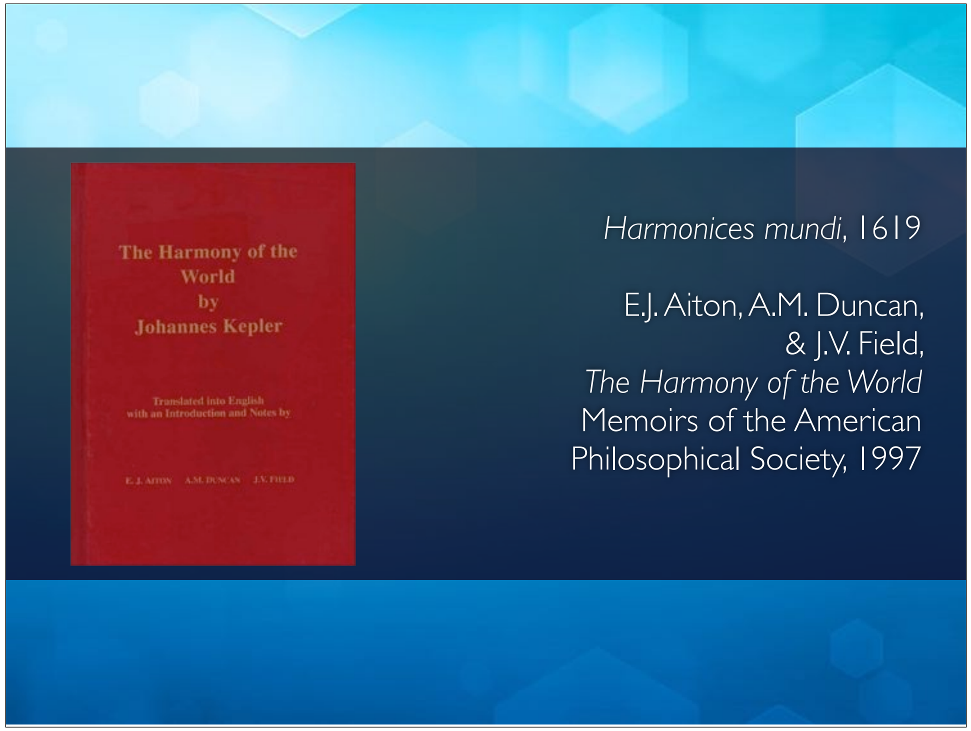
For Kepler, by analogy, the Sun must possess its own kind of magnetic-like virtue which physically propels the planets around in their orbits, their periods varying with their distances. For any system of planets, the square of the time a planet needs to revolve around the Sun, divided by the cube of its distance from the Sun, will be constant for all planets. Thus the times and distances of the planets are related in a geometrical harmony, a harmony of the universe, a cosmic fugue first heard by the mind of Kepler.



In Newton's hands the different magnetic-like "virtues" of the Earth, Sun, and Planets would become merged into a single unified force of universal gravitation. Kepler's integration of the third law with musical theory and the regular solids would be cast aside.

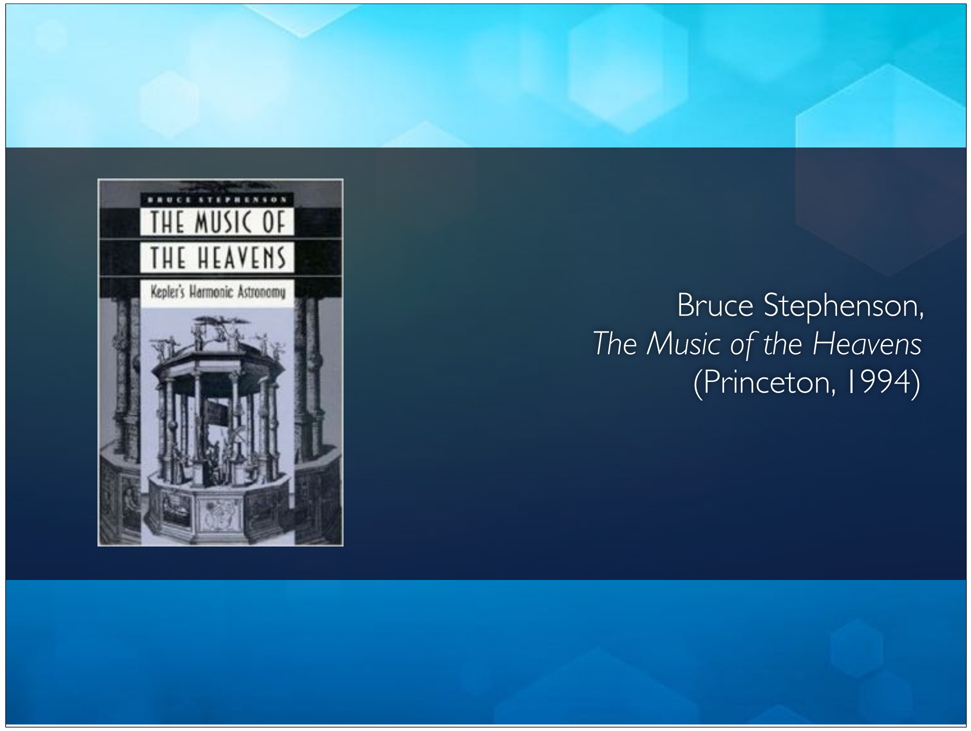
A translation by Wallis of part of the Harmony of the World is available in the Great Books series and online from sacred texts.com.

The Harmonies of the World (Book V)
Also: http://www.sacred-texts.com/astro/how/index.htm



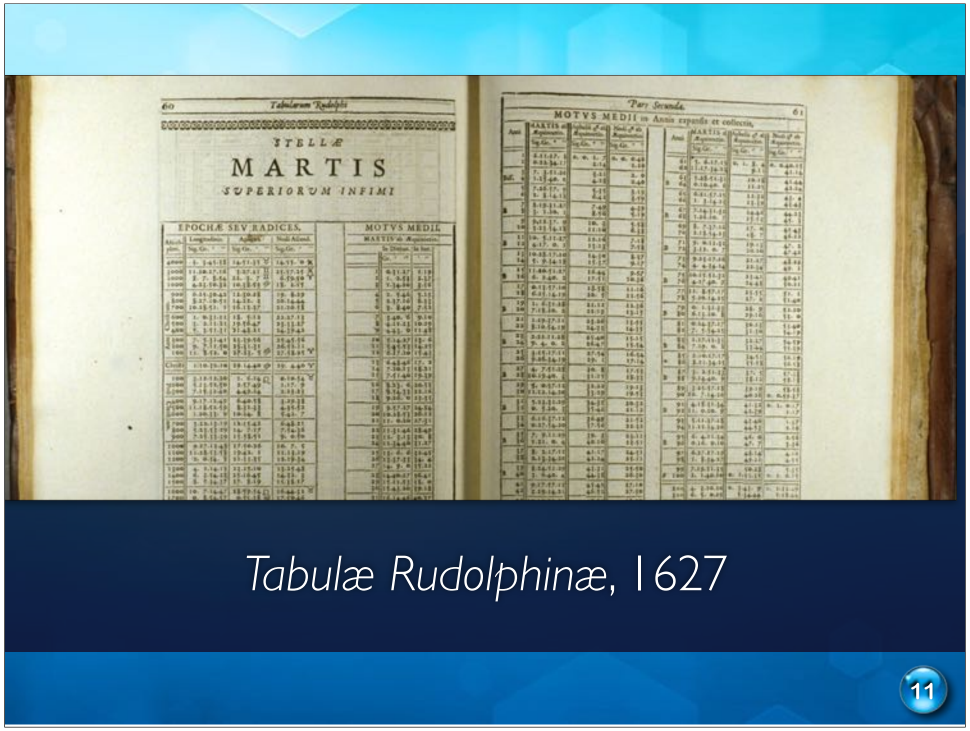
A complete and more accurate translation was published in 1997 by three well-known Kepler scholars. This volume is a great choice to begin reading Kepler for yourself.

The Harmonies of the World (Book V)
Also: http://www.sacred-texts.com/astro/how/index.htm

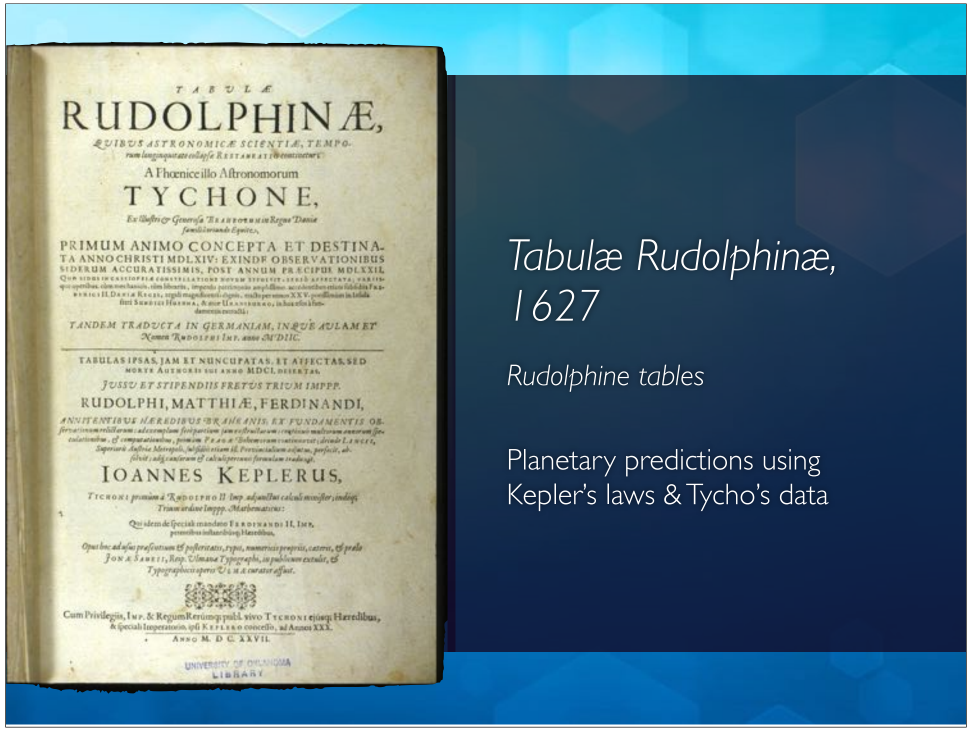


As a guide for exploring Kepler's Harmonices mundi, check out Bruce Stephenson's study, published in 1994.

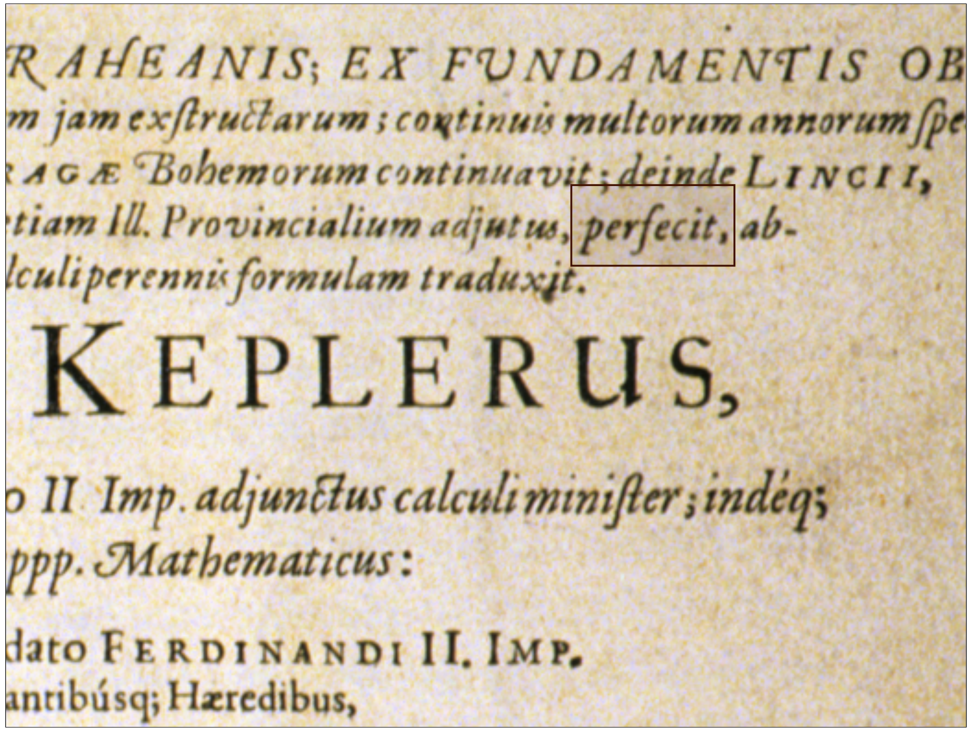
The Harmonies of the World (Book V)
Also: http://www.sacred-texts.com/astro/how/index.htm



Kepler’s 11th major work, the Rudolphine Tables, appeared in 1627.



Kepler used his new astronomy and Tycho's observations to derive predictions of planetary positions.

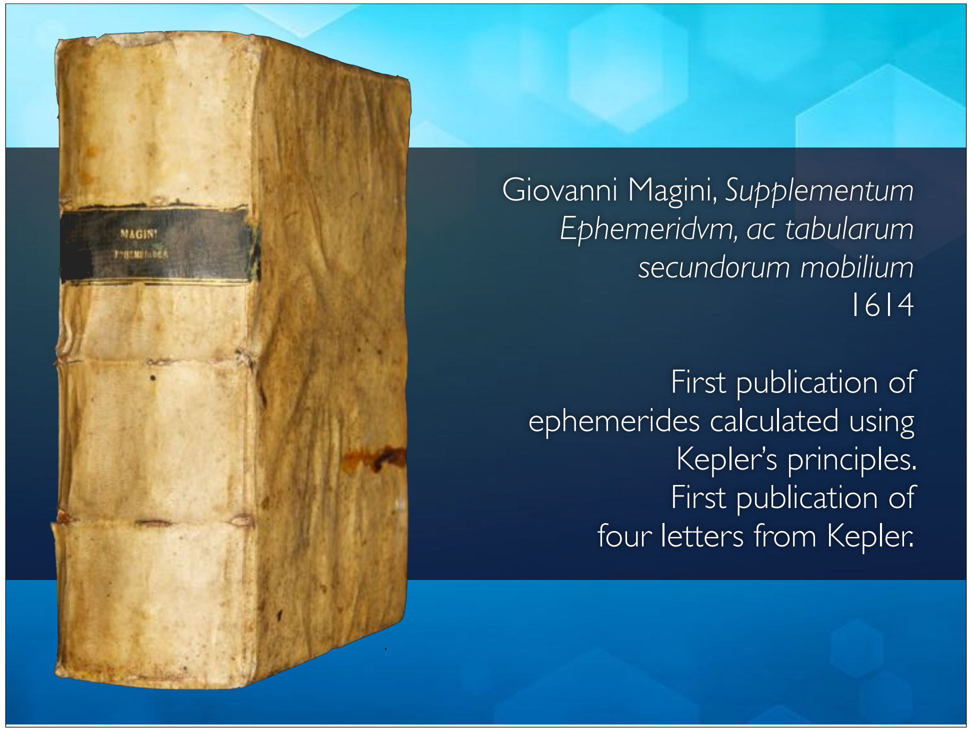

RAHEANIS; EX FUNDAMENTIS OB
m jam exſtructarum; continuis multorum annorum ſpe
RAGÆ Bohemorum continuavit; deinde LINCII,
tiam Ill. Provincialium adjutus, perfecit, ab-
lculi perennis formulam traduxit.

KEPLERUS,

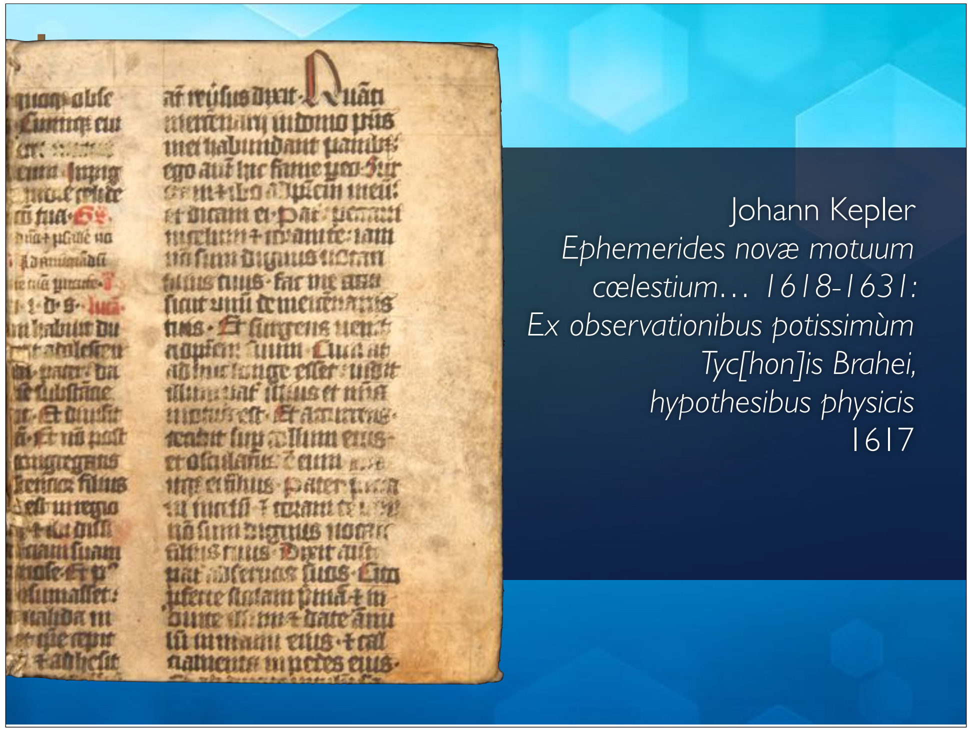
o II Imp. adjunctus calculi miniſter; indéq;
ppp. Mathematicus:

dato FERDINANDI II. IMP.
antibúsq; Hæredibus,

The Oklahoma copy of the Rudolphine tables is an early state of the first issue. The heirs of Tycho did not like Kepler’s statement that he had perfected the observations of Tycho, and asked him to remove it. “Perfecit” is absent from the title pages of later copies of the first edition.



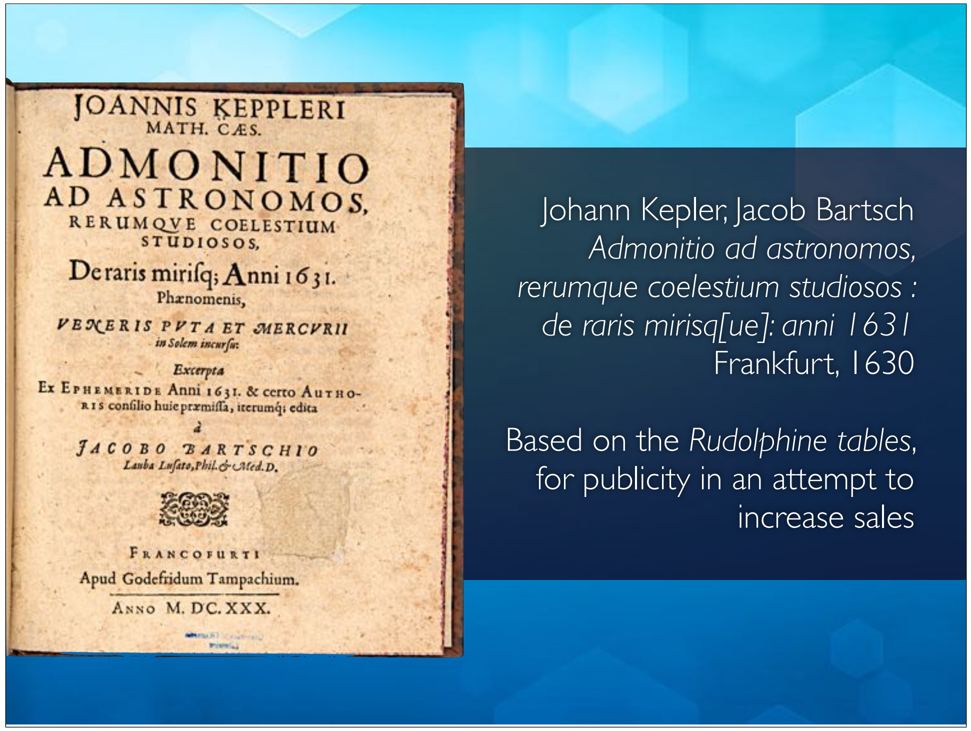
The Rudolphine tables were not the first publication of planetary predictions based upon Kepler's new astronomy. Magini's ephemerides were the first to be calculated according to Keplerian principles, anticipating by more than a dozen years Kepler's own Rudolphine Tables. This volume also includes the first printing of four letters from Kepler to Magini.



In this minor work, published a decade before the Rudolphine Tables, Kepler calculated planetary predictions for the years 1618–1631 based on his new astronomy.

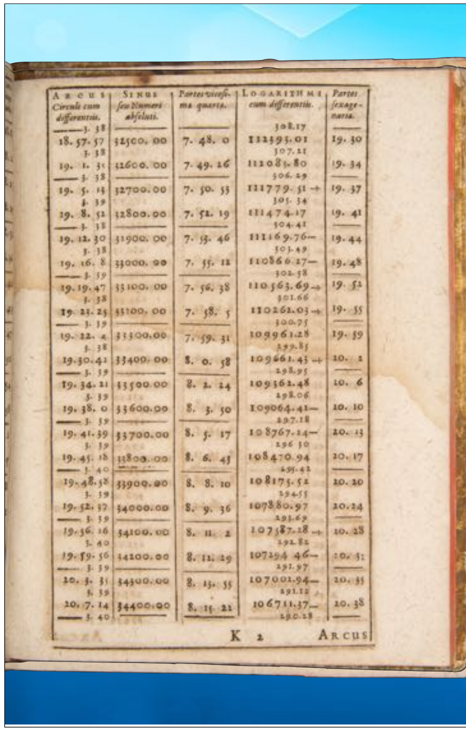
——————

Only vol. 1, parts 1-3 were published, containing the ephemerides for the years 1617-1636. The author's plan to compute the ephemerides for an eighty year period was interrupted by his death. Cf. Caspar, M. Bib. Kepleriana.



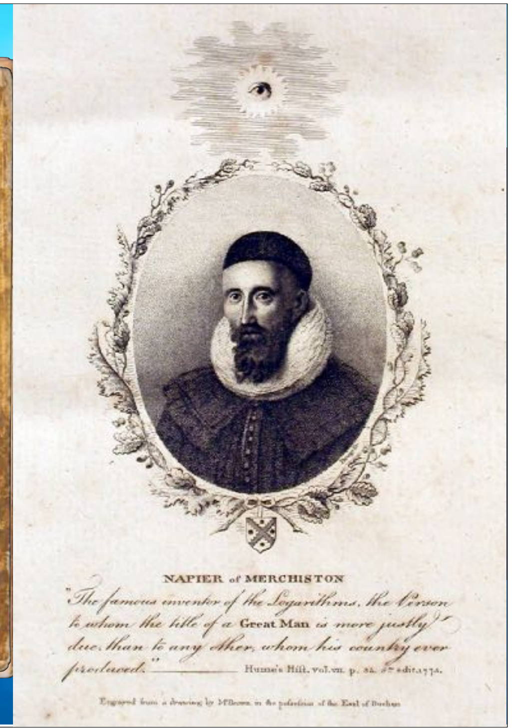
But despite their promise, the Rudolpine Tables were not a best seller. Three years later, in 1630, Kepler and his son-in-law Jacob Bartsch published this little “admonition to astronomers” to stir up interest in the Rudolphine Tables. It contains predictions of the transits of Mercury and Venus across the disk of the Sun in 1631. Owen Gingerich explains, "Although [Kepler] did not live to see his predictions fulfilled, the Mercury transit was observed by Pierre Gassendi in Paris on 7 November, 1631; this observation, the first of its kind in history, was a tour de force for Kepler's astronomy, for his prediction erred by only 10 minutes compared to 5 degrees for tables based on Ptolemy, Copernicus and others."

Owen Gingerich



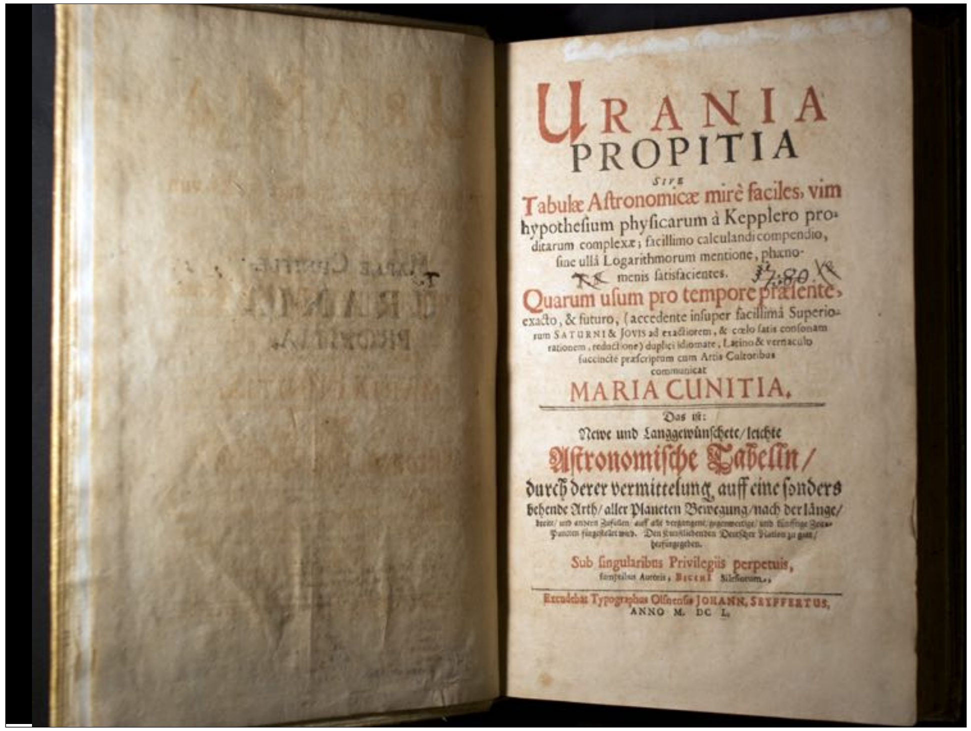
Arcus Circuli cum differentiis.	Sinus seu Numeri absoluti.	Partes vicesima quarta.	Logarithmi cum differentiis.	Partes sexagenaria.
3. 38			308.17	
18. 57. 57	32500. 00	7. 48. 0	111393.01	19. 30
3. 38			307.21	
19. 1. 35	32600. 00	7. 49. 26	111085.80	19. 34
3. 38			306.29	
19. 5. 13	32700.00	7. 50. 53	110779. 51 +	19. 37
3. 39			305. 34	
19. 8. 52	32800.00	7. 52. 19	110474.17	19. 41
3. 38			304.41	
19. 12. 30	32900. 00	7. 53. 46	110169.76 –	19. 44
3. 38			303.49	
19. 16. 8	33000. 00	7. 55. 12	110866.27 –	19. 48
3. 39			302.58	
19. 19. 47	33100. 00	7. 56. 38	110563.69 +	19. 51
3. 38			301.66	
19. 23. 25	33200. 00	7. 58. 5	110262.03 +	19. 55
3. 39			300.75	
19. 27. 4	33300.00	7. 59. 31	109961.28	19. 59
3. 38			299.85	
19. 30. 42	33400. 00	8. 0. 58	109661.43 +	20. 2
3. 39			298.95	
19. 34. 21	33500.00	8. 2. 24	109362.48	20. 6
3. 39			298.06	
19. 38. 0	33600.00	8. 3. 50	109064.41 –	20. 10
3. 39			297.18	
19. 41. 39	33700.00	8. 5. 17	108767.24 –	20. 13
3. 39			296.30	
19. 45. 18	33800.00	8. 6. 43	108470.94	20. 17
3. 40			295.42	
19. 48. 58	33900.00	8. 8. 10	108175.52	20. 20
3. 39			294.55	
19. 52. 37	34000.00	8. 9. 36	107880.97	20. 24
3. 39			293.69	
19. 56. 16	34100.00	8. 11. 2	107587.28 +	20. 28
3. 40			292.82	
19. 59. 56	34200.00	8. 12. 29	107294.46 –	20. 31
3. 39			291.97	
20. 3. 35	34300.00	8. 13. 55	107001.94 –	20. 35
3. 39			291.12	
20. 7. 14	34400.00	8. 15. 21	106711.57 –	20. 38
3. 40			290.28	

K 2 Arcus



Part of the problem was that the Rudolphine tables were cumbersome to use. -- John Napier invented logarithms and explained them in works of 1618 and 1619 (which OU holds). -- Yet Kepler's implementation of logarithms was idiosyncratic. This minor work by Kepler is an example of his experiments with logarithms.

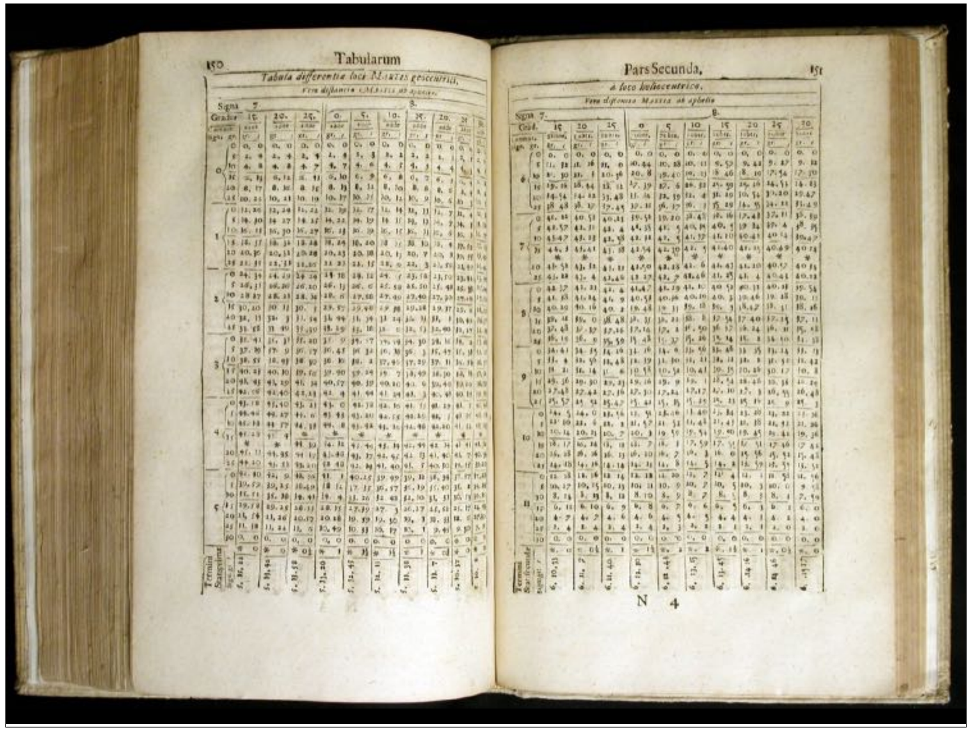
Prior to Newton, fewer than half a dozen astronomers accepted Kepler's three laws. Galileo was typical in ignoring everything Kepler did. Yet this beautiful book is an exception: it clearly demonstrated that Kepler's laws were more accurate than anything that had come before.


URANIA
PROPITIA
SIVE
Tabulæ Astronomicæ mirè faciles, vim
hypothesium physicarum à Kepplero pro-
ditarum complexæ; facillimo calculandi compendio,
sine ullâ Logarithmorum mentione, phæno-
menis satisfacientes.
Quarum usum pro tempore præsente,
exacto, & futuro, (accedente insuper facillimâ Superio-
rum SATURNI & JOVIS ad exactiorem, & cœlo satis consonam
rationem, reductione) duplici idiomate, Latino & vernaculo
succinctè præscriptum cum Artis Cultoribus
communicat
MARIA CUNITIA.
Das ist:
Newe und Langgewünschete/ leichte
Astronomische Tabelln/
durch derer vermittelung, auff eine sonders
behende Arth/ aller Planeten Bewegung/ nach der länge/
Sub singularibus Privilegiis perpetuis,
Excudebat Typographus Olsnensis JOHANN. SEYFFERTUS,
ANNO M. DC L.

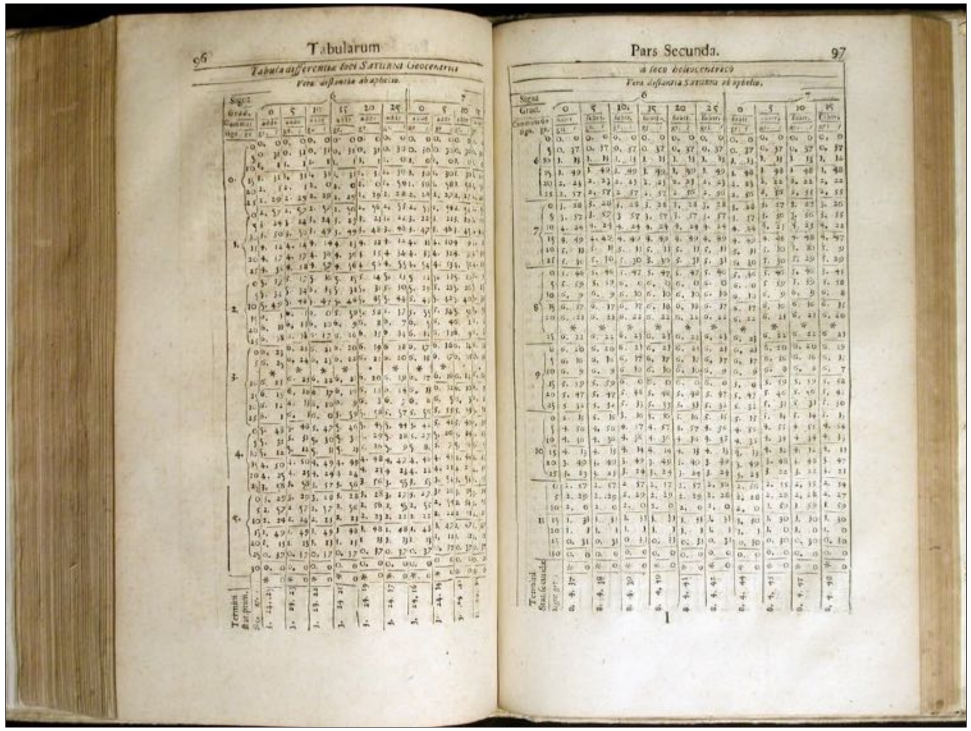
It was written by a self-educated woman, Maria Cunitz, who recast Kepler’s planetary predictions into logarithmic tables.


URANIA
PROPITIA
SIVE
Tabulæ Aſtronomicæ mirè faciles, vim
hypotheſium phyſicarum à Kepplero pro-
ditarum complexæ; facillimo calculandi compendio,
ſine ullâ Logarithmorum mentione, phæno-
menis ſatisfacientes.
Quarum uſum pro tempore præſente,
exacto, & futuro, (accedente inſuper facillimâ Superio-
rum SATURNI & JOVIS ad exactiorem, & cœlo ſatis conſonam
rationem, reductione) duplici idiomate, Latino & vernaculo

Cunitz not only took the physical hypotheses of Kepler seriously, but she recast them using John Napier's recently invented logarithmic notation.

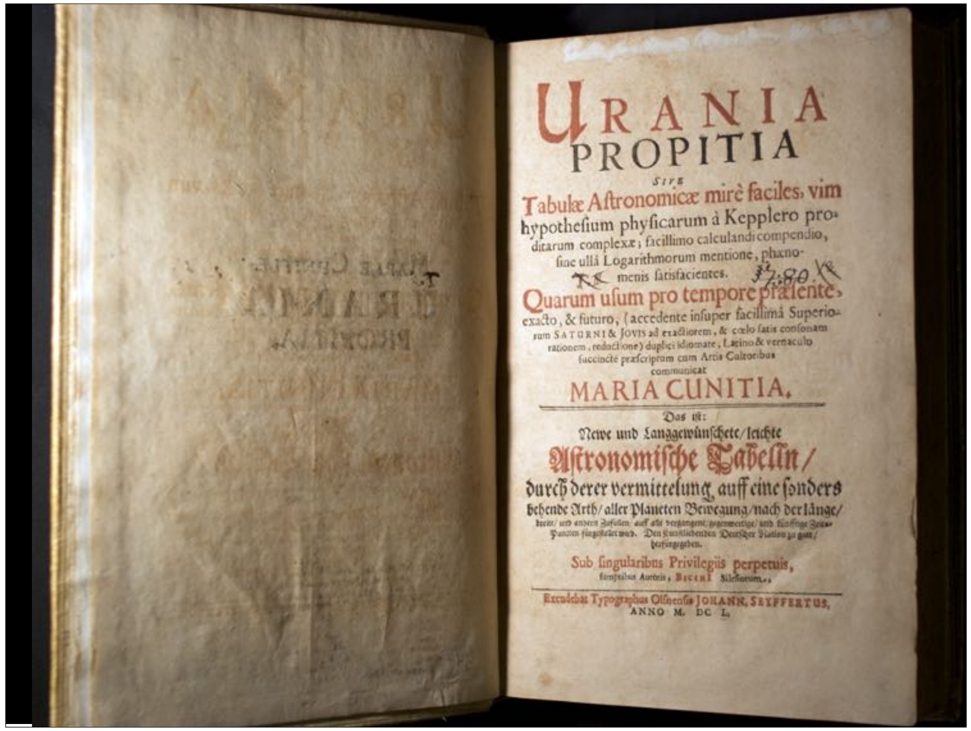


Kepler’s tables may have been cumbersome to use, but these were not. Cunitz made Kepler’s achievement easy to grasp.


96 Tabularum

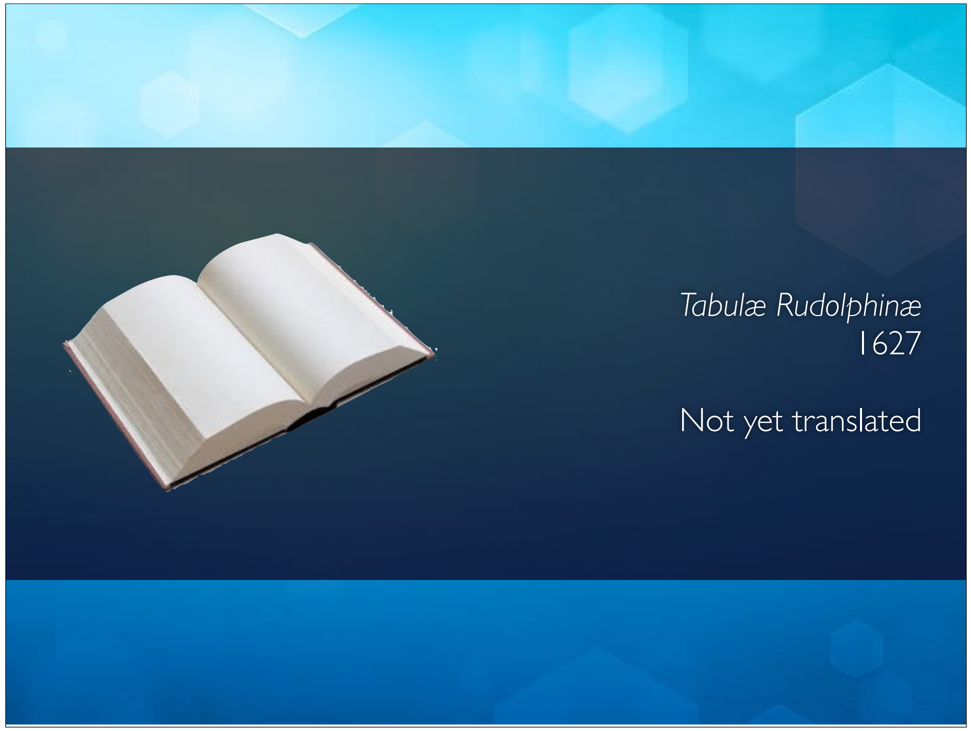
Pars Secunda. 97

These tables would be easy to construct if only one had a computer, but she did not.

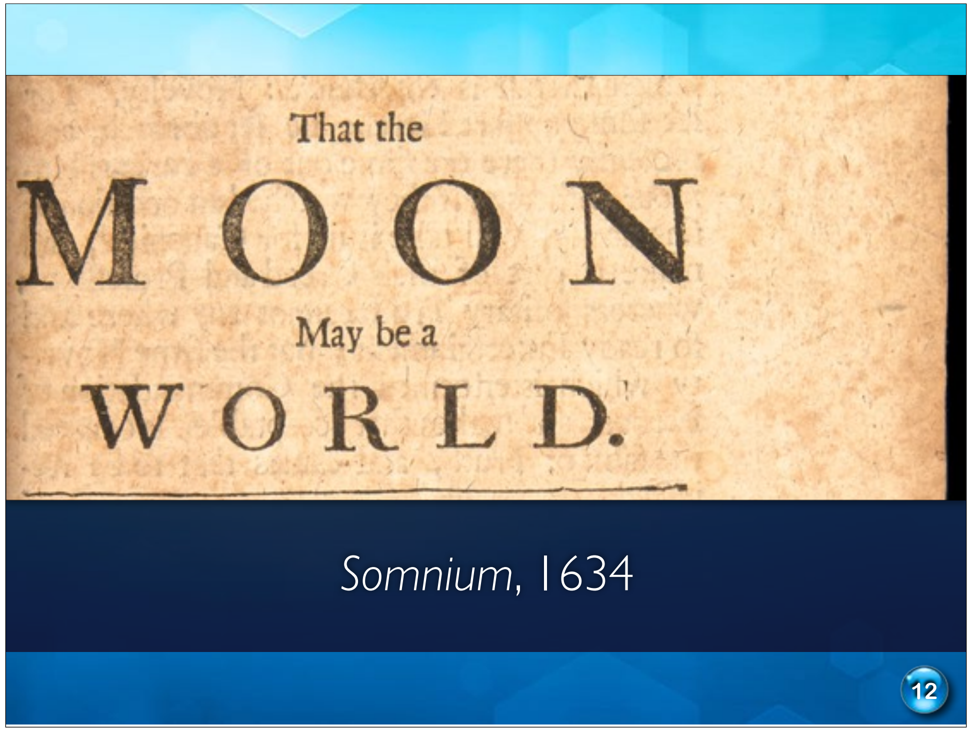


In an age when women were not admitted to European universities, Cunitz was encouraged in her scientific pursuits by her husband. He nicknamed her Urania Propitia, near the heavens. On the title page, Cunitz applied that nickname to Kepler himself. Kepler's laws take us nearer the heavens.

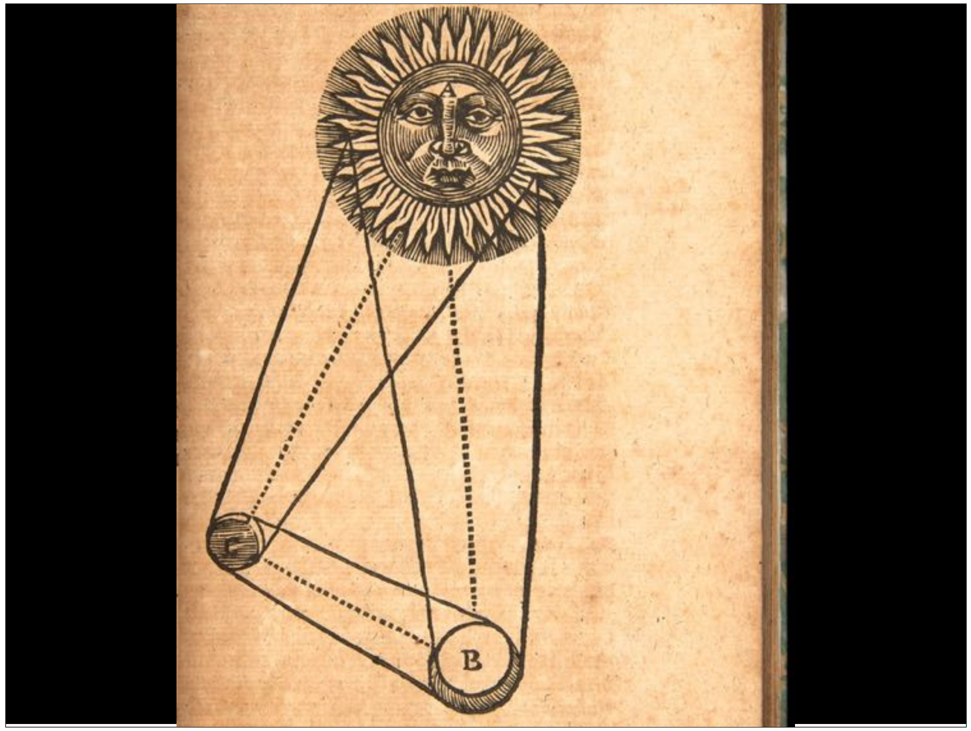
We were able to acquire the Cunitz volume to honor Marilyn Ogilvie upon her retirement as Curator in 2008.



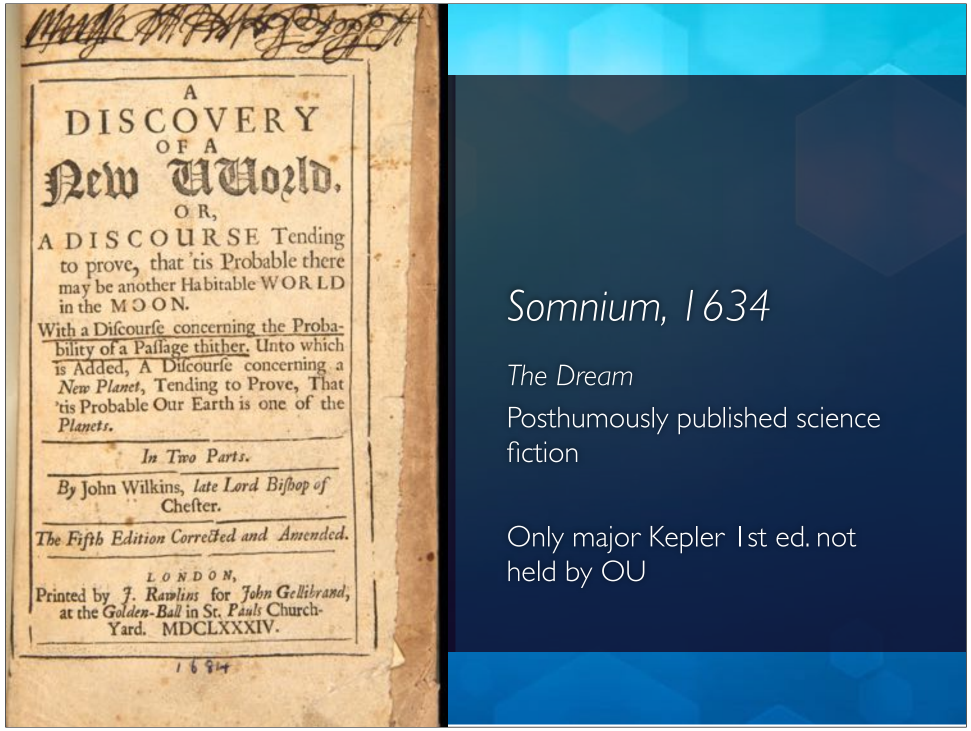
Unfortunately, neither Cunitz nor Kepler’s Rudolphine tables are yet translated, but at least they’re mainly comprised of numbers!



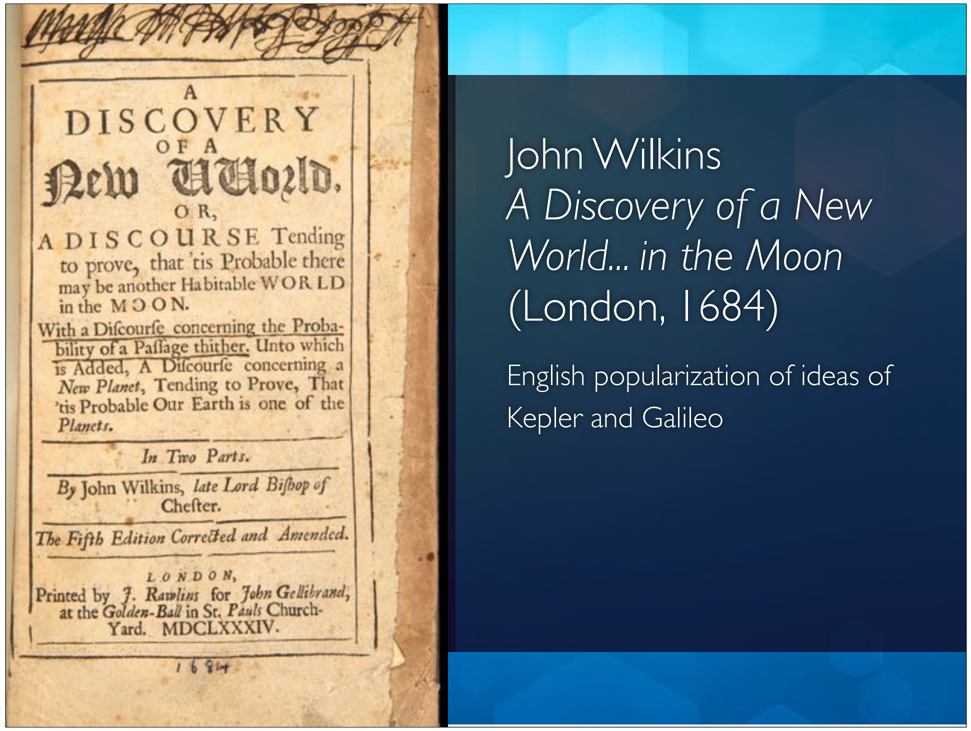
Kepler’s 12th and last major work was the Somnium, or Dream, published posthumously in 1634. In 1593, while a student at Tübingen University, Kepler wrote a dissertation on the following question: what would it be like to stand on the moon and look at the heavens? Kepler argued that it would be much the same as on Earth. Nearly 20 years later, Kepler recast the unpublished narrative by integrating it into a dream framework. After another decade, he drafted a series of explanatory notes. The complete work was finally published after Kepler’s death by his son, Ludwig.



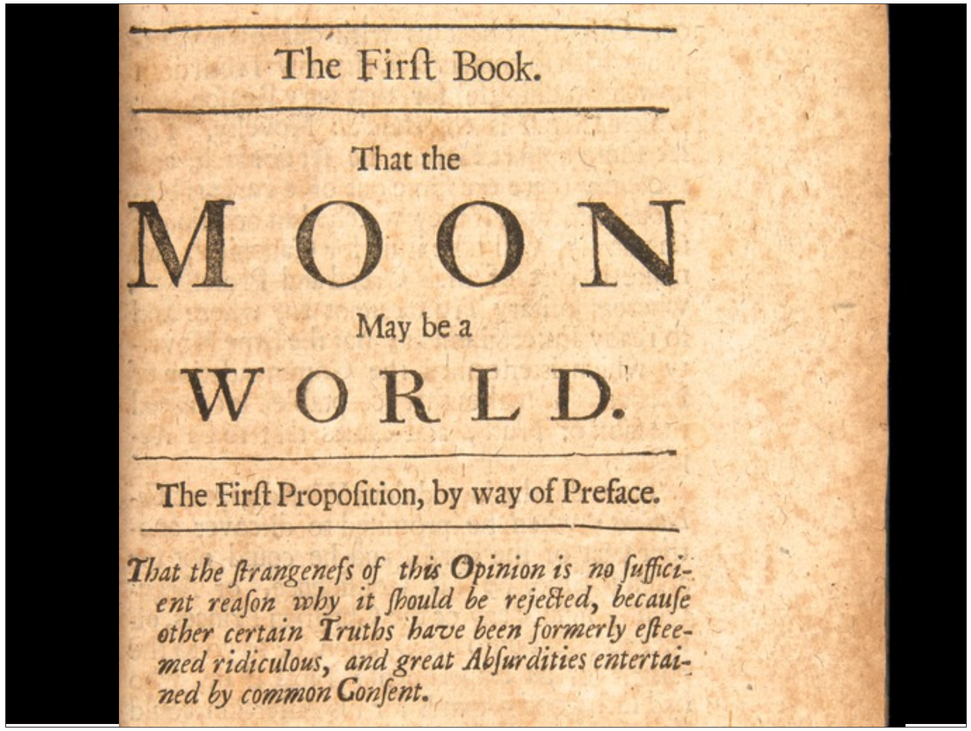
In the Somnium, Kepler reasoned that, seen from the Moon, the Earth would show phases just as does the Moon. The phases shown by the Earth and the Moon would be complementary: if the Moon seen from Earth is a crescent, then the Earth seen from the Moon would appear gibbous.



Kepler's Somnium is the only major work of Kepler's not held by OU. Let me know if you're interested in buying us a copy! The book whose images you're seeing here is by an English author and conveys similar ideas.



In this book, [first published in 1638], the Anglican Bishop John Wilkins defended the idea that the Earth is a planet by enumerating various analogies with the Moon.



The Firſt Book.

That the

MOON

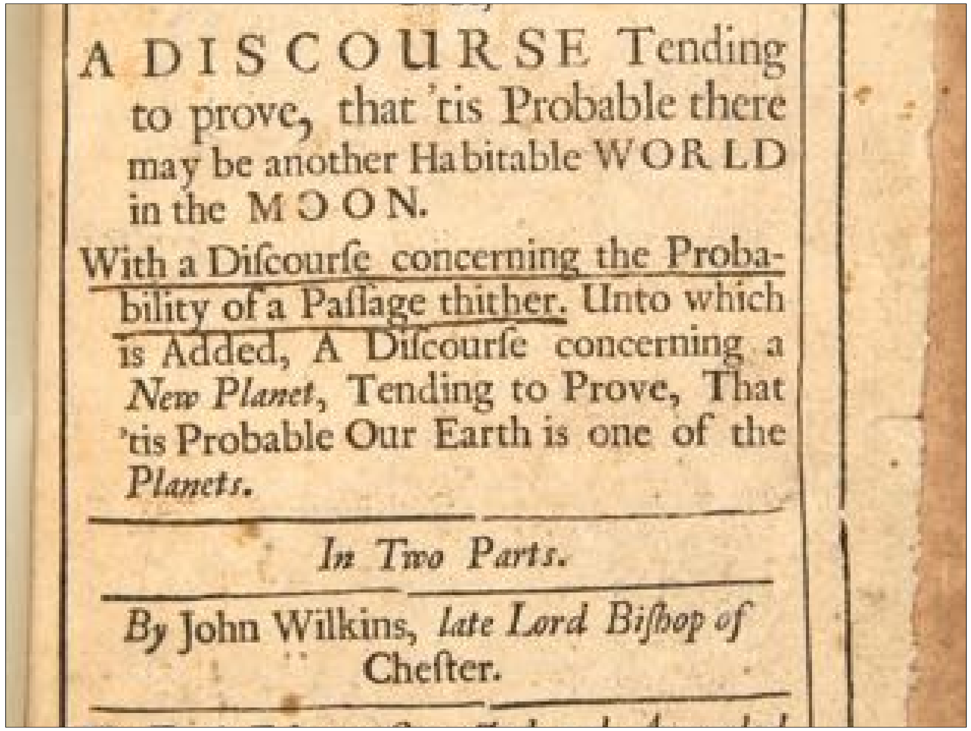
May be a

WORLD.

The Firſt Propoſition, by way of Preface.

That the ſtrangeneſs of this Opinion is no ſufficient reaſon why it ſhould be rejected, becauſe other certain Truths have been formerly eſteemed ridiculous, and great Abſurdities entertained by common Conſent.

Following Galileo and Kepler, Wilkins argued that if the Moon moves through the heavens, and if the Moon and the Earth are similar, each having mountains and oceans and phases, then by analogy the Earth also may be a heavenly body.



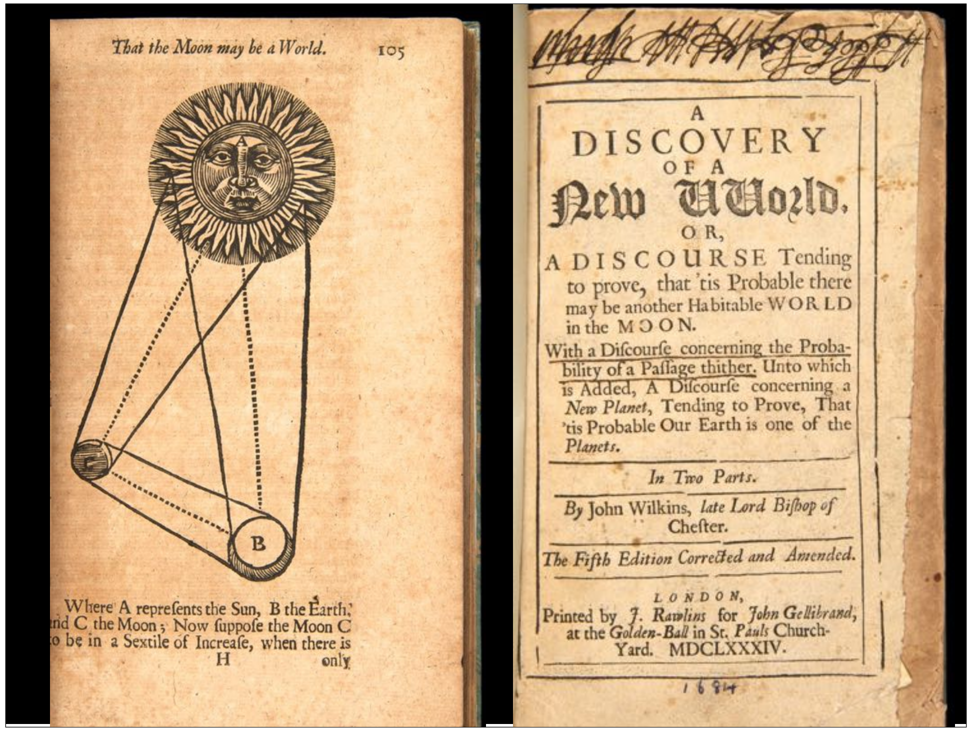
A DISCOURSE Tending to prove, that 'tis Probable there may be another Habitable WORLD in the MOON.

With a Difcourfe concerning the Probability of a Paffage thither. Unto which is Added, A Difcourfe concerning a *New Planet*, Tending to Prove, That 'tis Probable Our Earth is one of the *Planets*.

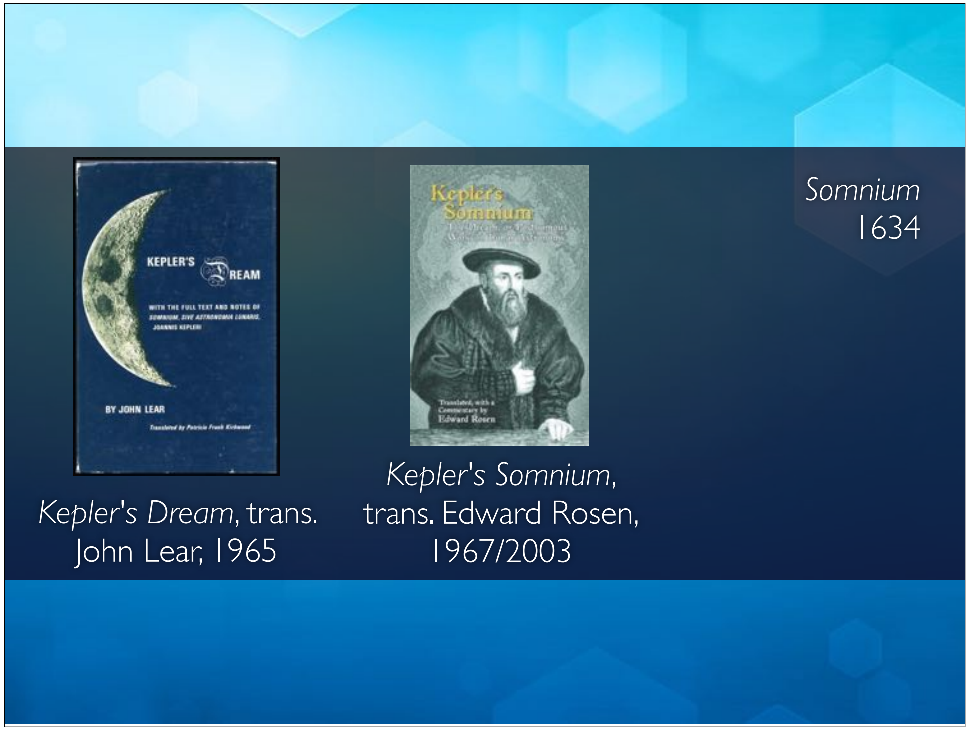
In Two Parts.

By John Wilkins, *late Lord Bifhop of* Chefter.

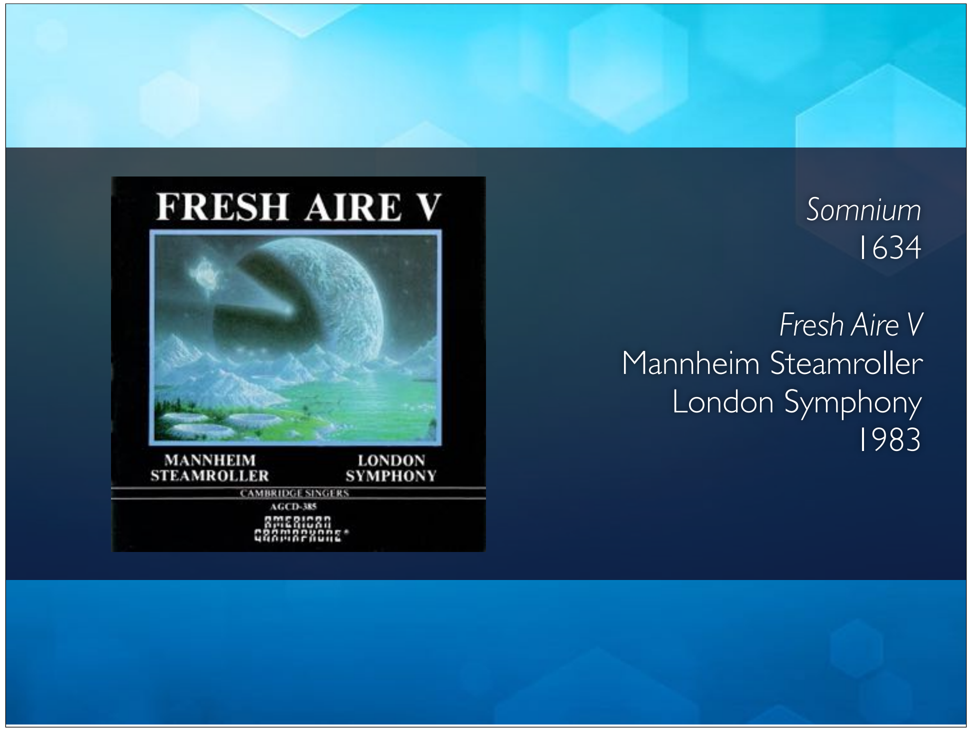
Following Kepler, Wilkins also considered whether the Moon is inhabited and whether it might be possible to reach it by flight. Kepler's influence is palpable here; Galileo did not entertain such questions.



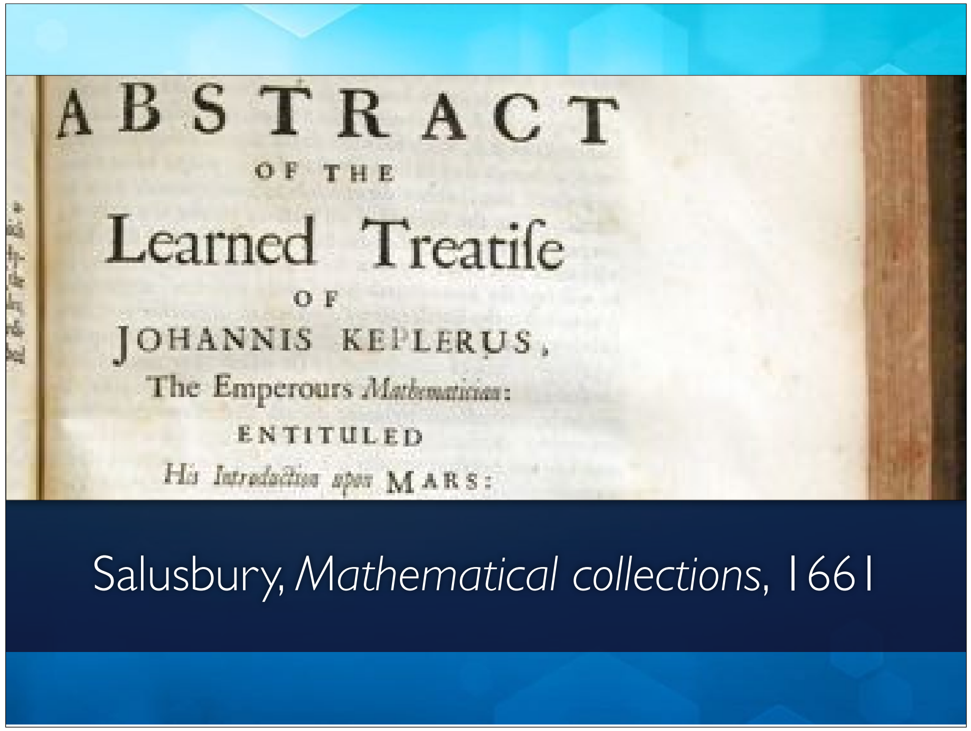
Wilkins, formerly Warden of Wadham College, Oxford, and later Bishop of Chester, was a founding member of the Royal Society of London. He also wrote essays on cryptography, automata, natural theology and the construction of a universal artificial language.



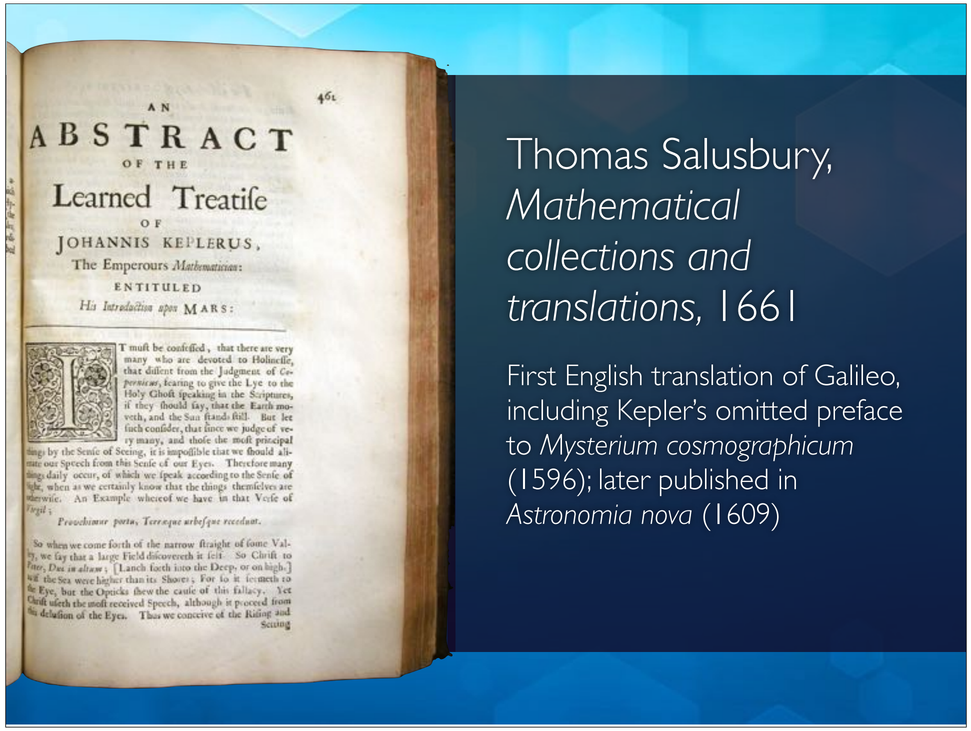
For the Somnium, we have the luxury of two English translations.



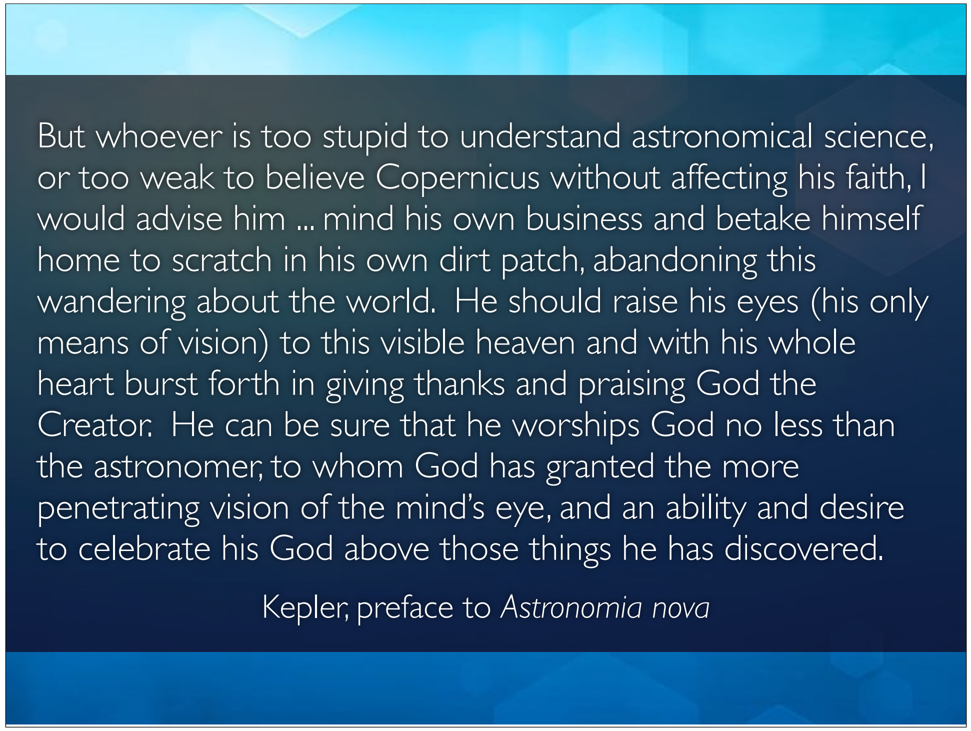
And we may listen to music inspired by the Somnium, such as this 1983 recording by Mannheim Steamroller with the London Symphony.



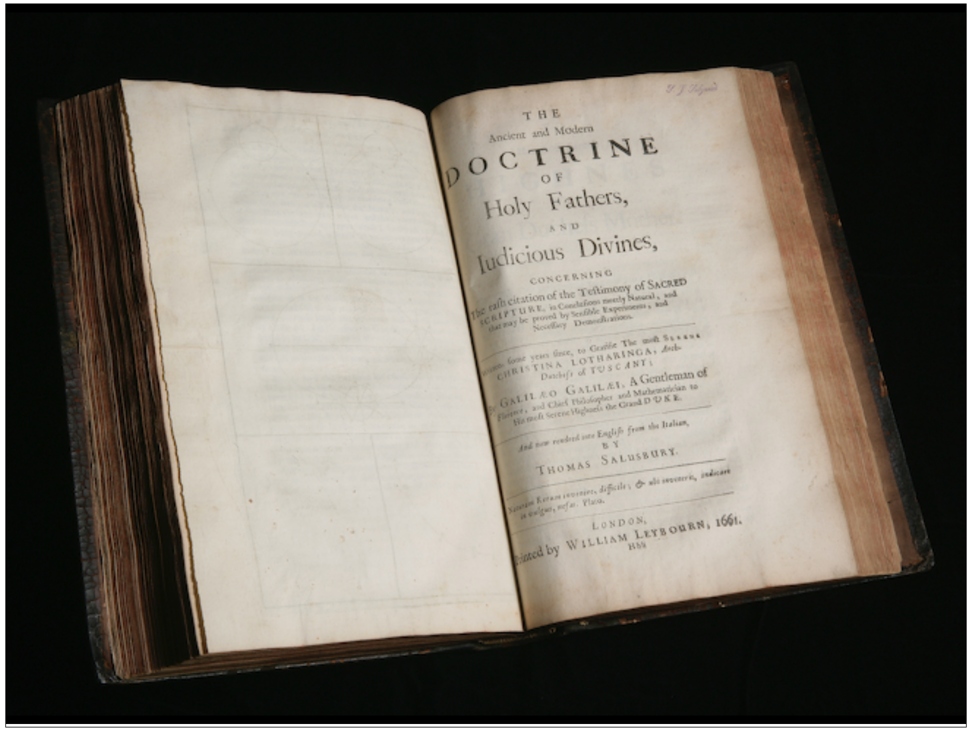
Another posthumously published essay by Kepler appeared in English in 1661. Here a page shows an excerpt from his study of Mars, or Astronomia nova.



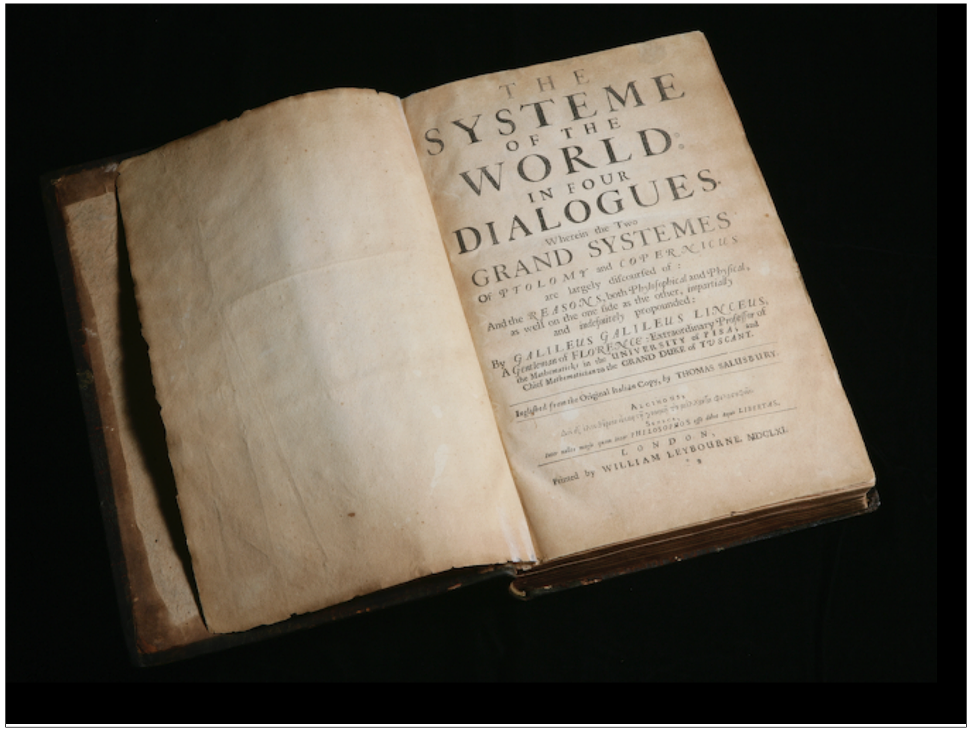
In the Mysterium Cosmographicum, Kepler omitted, at the request of Tubingen theologians, a preface he had written to answer objections to Copernicus based upon passages of scripture. This suppressed preface was later published in the Astronomia nova, and then made available to English readers in this anthology. This extract was the only work of Kepler's translated into English before the end of the 17th century. (pause) In it, after painstakingly proceeding through a host of biblical passages and showing that they had no bearing on Copernicanism, …



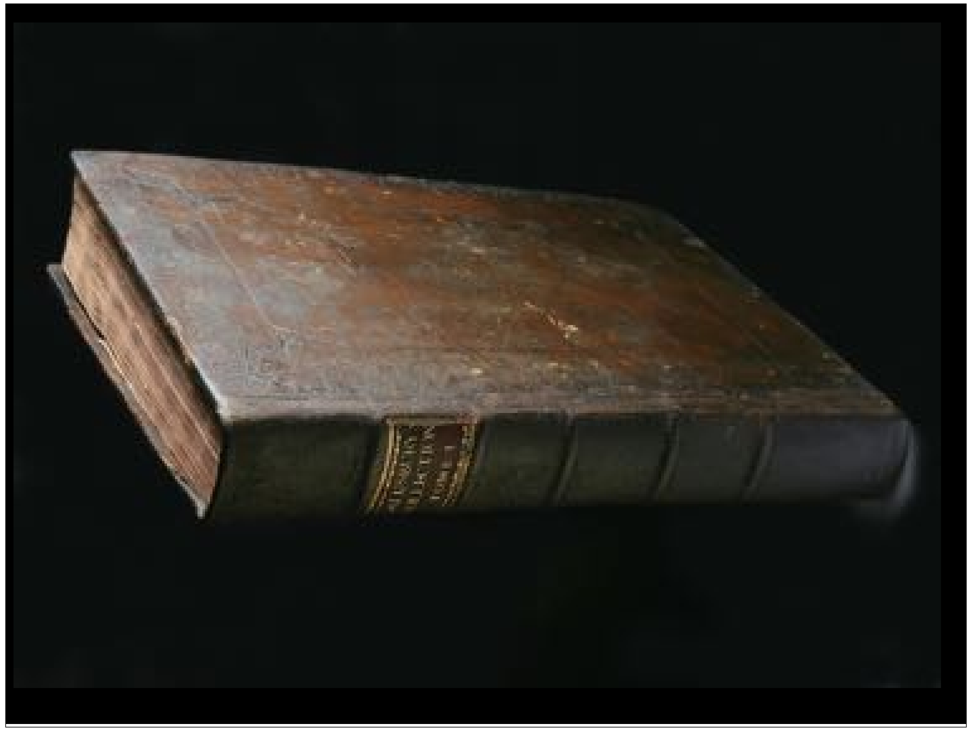
Kepler exclaimed:



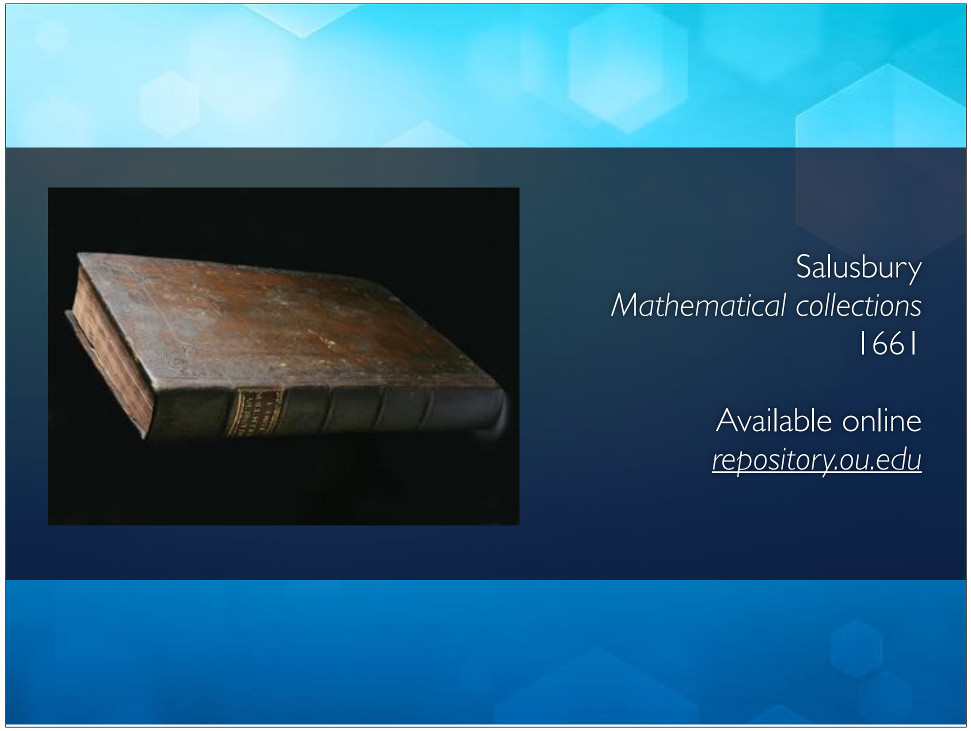
Similar sentiments were penned by Galileo in his Letter to the Grand Duchess Christina, also translated in this volume.



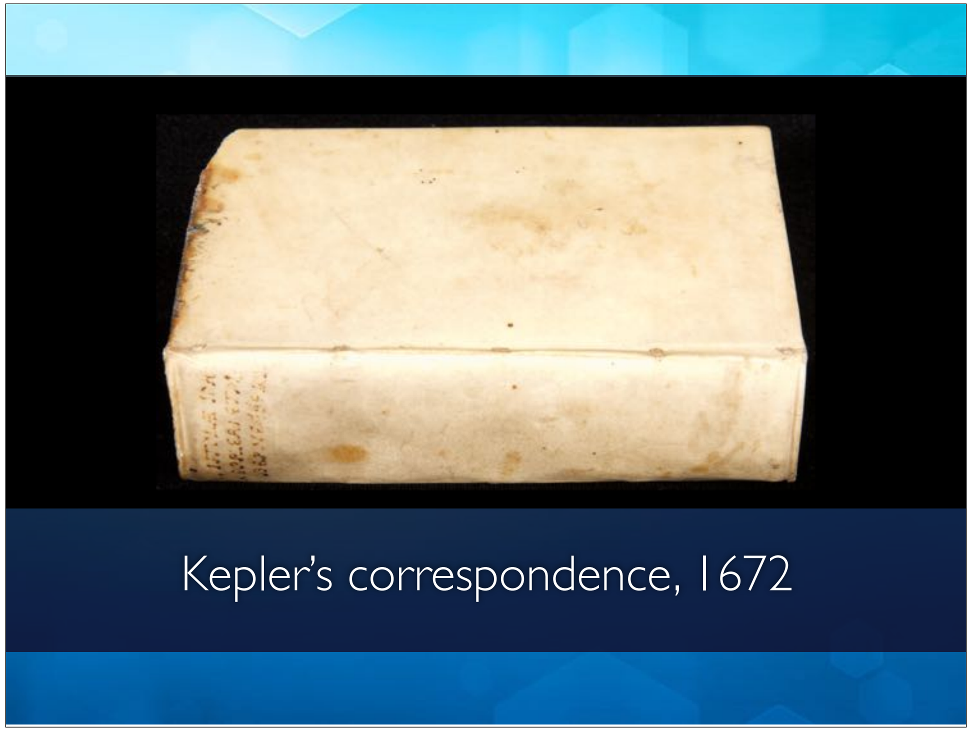
The first work included in the anthology is Galileo’s Dialogue on the Two Chief Systems of the World, the work for which he was put on trial.



The OU copy of this rare work is charred. Most copies perished in the Great Fire of London. This copy has been saved from a fire, probably that fire.



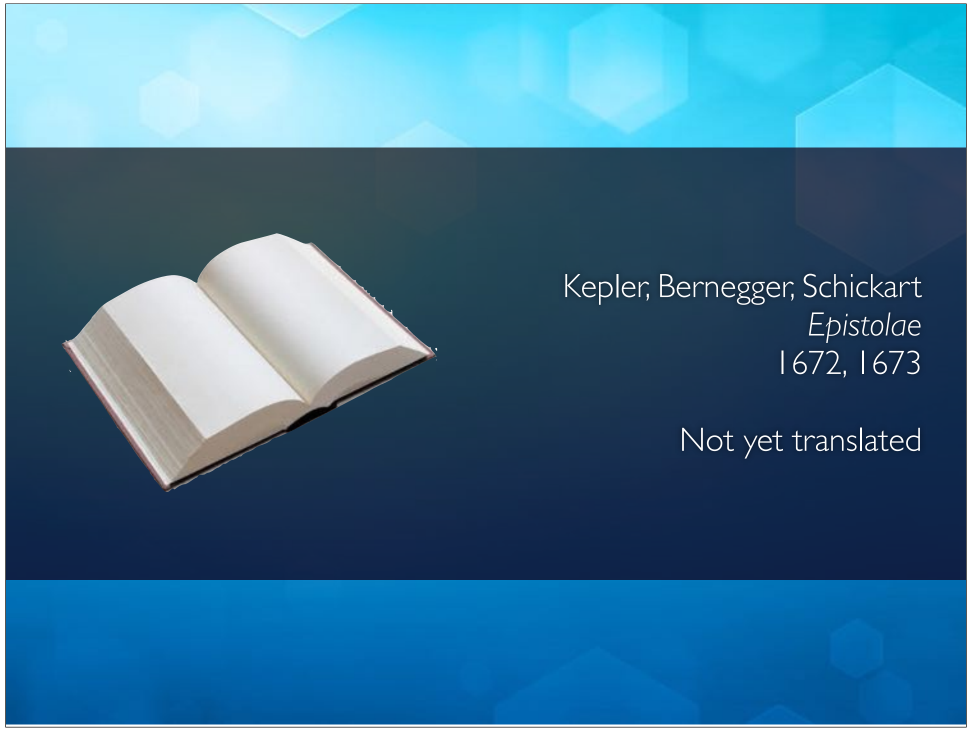
If you want to read more, Salusbury's anthology is available in its entirety on our digital repository, as are nearly all of the other works mentioned today.



The final work we will mention is another recent addition to OU's Kepler collection. It consists of his correspondence, in two rare volumes bound together.

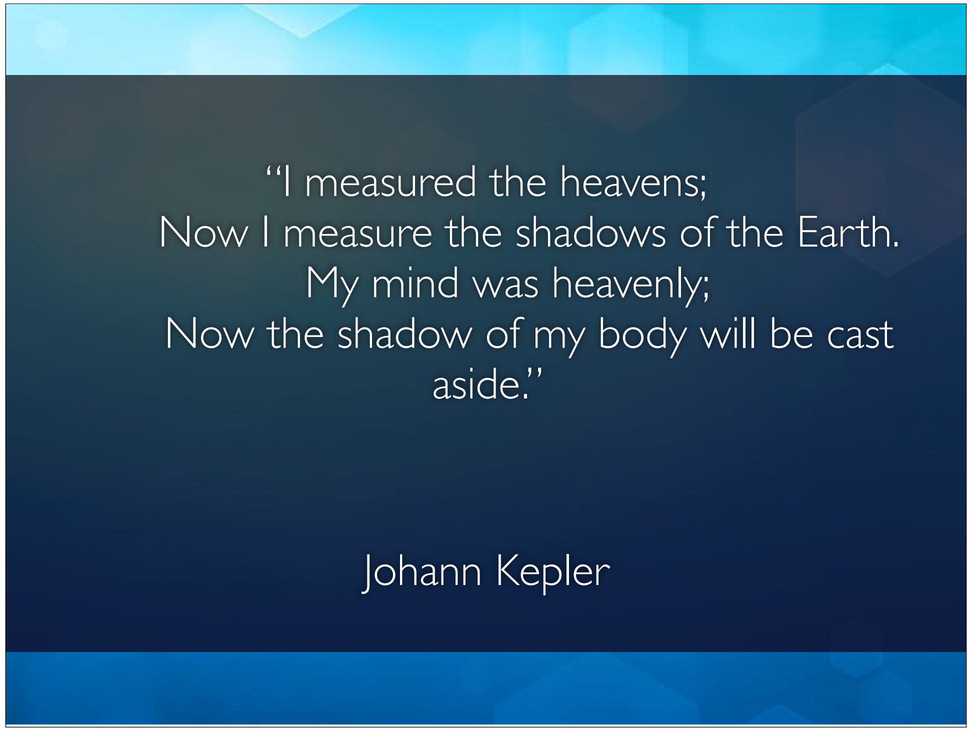
Bernegger, one of Kepler's closest friends, also published Latin translations of Galileo's works [Compasso, Letter to Christina, and Dialogo].
———————
A table, missing in most recorded copies, is an extremely detailed record of the lunar eclipse observed in Linz by Kepler and his assistant Janus Gringalletus in 1619, and the difficulties they experienced while making observations of the nearby stars with the telescope.

Schickard designed the woodcut diagrams and illustrations for Kepler's Harmonices mundi. To calculate Keplerian ephemerides, Shickard built a working model of the first modern mechanical calculator. He also published observations of the three comets of 1618.



Although not yet translated, this is the major source of biographical information about Kepler’s life and works.

In 1630, while traveling to visit the emperor, from whom he hoped to collect an old debt, Kepler stopped in Regensburg [Ratisbon] with a fever. There he died and was buried, in a grave all trace of which soon vanished as one of the casualties of war. His epitaph, composed a few months before, reads as follows:



READ. Kepler knew Ptolemy's epigram, which we quoted earlier and which we may hear echoed in Kepler's words. Perhaps Kepler was also expressing relief at the end of his long struggle with declining eyesight. Even in life, the universe could not contain this theological astronomer whose probing mind searched the universe and measured it throughout.

To begin to explore Kepler and his world, start with these two biographies, both accurate and readable: a brief, readable overview by James Voelkel, and the in-depth, standard biography by Max Caspar. In addition, you may find online my own website for educational outreach that includes information on Kepler, at Lynx Open Ed dot org, and the script for this talk.

Which book of Kepler's will you put on your reading list? The Snowflake?

- Kepler's preface to the Astronomia nova?
- The Harmony of the World?
- The Dream? It doesn't matter which you choose; they're all well worth reading today.
- Thank you very much.