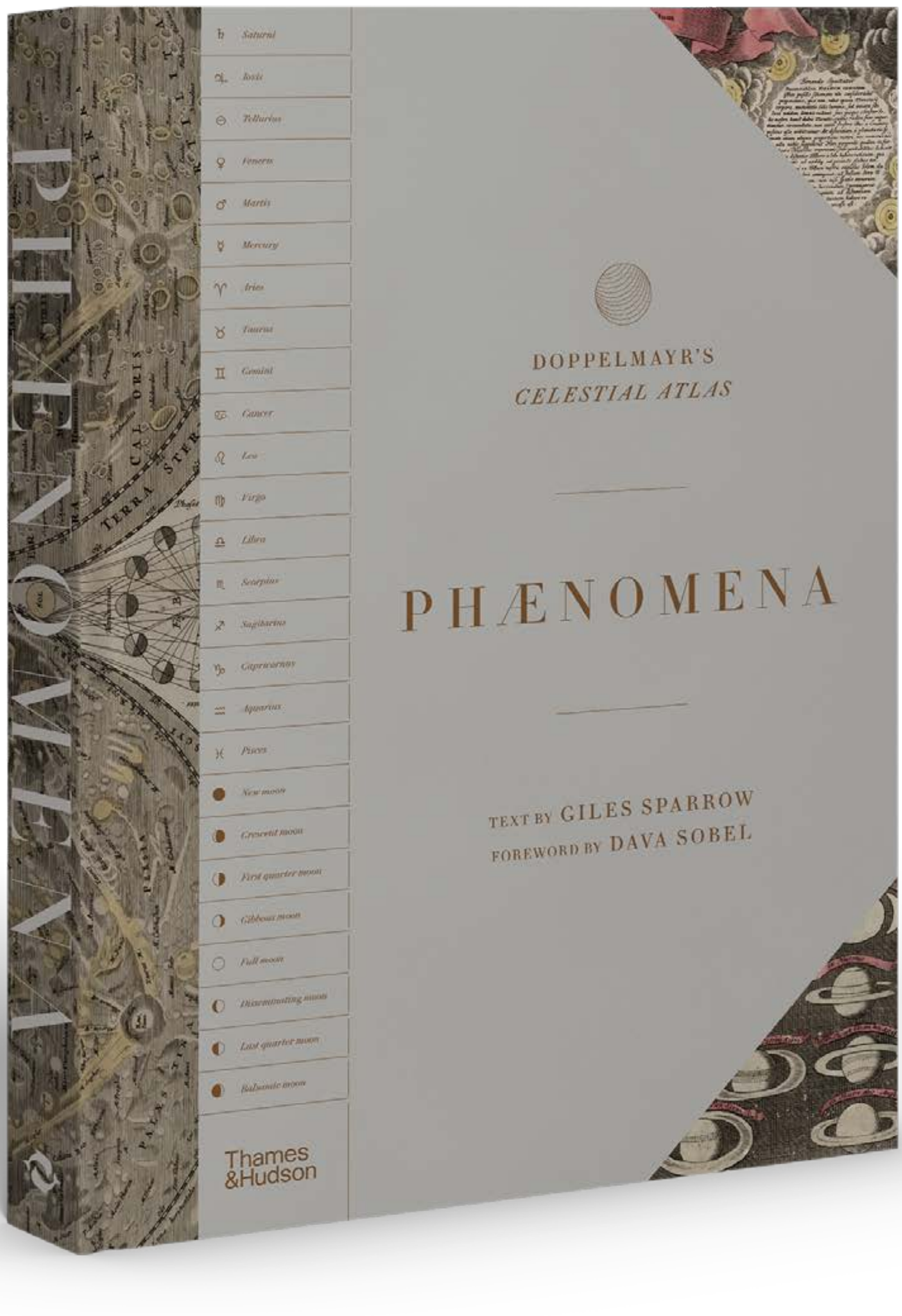
DOPPELMAYR'S
CELESTIAL ATLAS
PHÆNOMENA
TEXT BY GILES SPARROW
FOREWORD BY DAVA SOBEL
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Advance Information

Frankfurt Book Fair 2021

Phaenomena

Doppelmayr's Celestial Atlas

Giles Sparrow

A beautiful showcase of Johann Doppelmayr's magnificent and influential *Atlas Coelestis* (1742) that deconstructs the intricately drawn plates and traces the ideas of the famed astronomers featured.

Giles Sparrow is a writer and editor specializing in astronomy and physics. He studied astronomy at University College London and science communication at Imperial College, and has written for books, magazines and multi-volume encyclopedias on a wide range of topics, from cutting-edge space technology to the history of science, and from distant constellations to ancient archaeology. He is also a partner at Pikaia Imaging, where he combines visual flair with expert knowledge to create intricate star maps and arresting interstellar graphics.

Specification

- 256 pages
- *c.* 600 illustrations
- 36.5 × 26.5 cm (14⅜ × 10½ in.)
- Quarterbound

Autumn 2022

Marketing points

- **Complements the major trend** for interest in astronomy and the zodiac, providing an authoritative and beautiful guide to the heavens for all cosmological enthusiasts.
- **Decodes this influential work** with expert commentary and analysis by Giles Sparrow, relating it to modern understandings of our galaxy and elucidating the work of the influential astronomers featured.
- **Elegantly expands the original manuscript**, adding multiple layers of interest and utilizing stylish design concepts, to create a luxurious presentation in the manner of *STRATA* and *London Poverty Maps*.

Description

First published in 1742, Johann Doppelmayr's *Atlas Coelestis* is an extraordinary exposition of the heavens that charts constellations, planets, comets and moons in captivating detail. A sumptuous introduction to the fundamentals of astronomy, the *Atlas* also illuminates the work of other famed astronomers, including Copernicus, Riccioli, Kepler, Newton and Halley. In *Phaenomena* this magnificent work is both reproduced in its entirety and expertly deconstructed, presenting a celestial treasure trove to delight every seasoned star gazer and amateur astronomer.

Born in Nuremberg in 1677, Johann Doppelmayr was a mathematician, astronomer and cartographer. *Phaenomena* begins by introducing his life and works, placing his extraordinary atlas in the context of the discoveries made during the Renaissance and the Enlightenment, a canon of work that the *Atlas* both draws upon and contributes to. It then presents the thirty beautifully illustrated and richly annotated plates, covering all the fundamentals of astronomy, from the dimensions of the solar system to the phases of the moon, and from the constellations of the Northern and Southern Hemispheres to the courses of comets. Each plate is accompanied by expert analysis from astronomer Giles Sparrow, eloquently explaining Doppelmayr's references, illuminating each exquisite detail and rendering this important cosmological work intelligible for a modern audience. The plates are then carefully deconstructed, isolating key stars, planets, orbits and moons for in-depth explanation. A conclusion reflects upon the *Atlas's* influence on the development of astronomy and traces the course of the science up to the present day. This elegant and comprehensive presentation intelligently expands Doppelmayr's work, creating a spectacular handbook to the cosmos invaluable to any astrological enthusiast.

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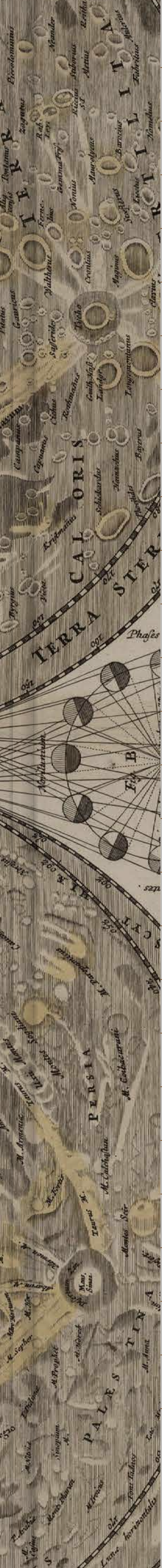

- ♄ *Saturni*
- ♃ *Iovis*
- ⊖ *Tellurius*
- ♀ *Veneris*
- ♂ *Martis*
- ☿ *Mercury*
- ♈ *Aries*
- ♉ *Taurus*
- ♊ *Gemini*
- ♋ *Cancer*
- ♌ *Leo*
- ♍ *Virgo*
- ♎ *Libra*
- ♏ *Scorpius*
- ♐ *Sagitarius*
- ♑ *Capricornus*
- ♒ *Aquarius*
- ♓ *Pisces*
- ● *New moon*
- ◐ *Crescent moon*
- ◑ *First quarter moon*
- ◑ *Gibbous moon*
- ○ *Full moon*
- ◐ *Disseminating moon*
- ◐ *Last quarter moon*
- ◐ *Balsamic moon*

DOPPELMAYR'S
CELESTIAL ATLAS

PHÆNOMENA

TEXT BY GILES SPARROW
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Thames & Hudson

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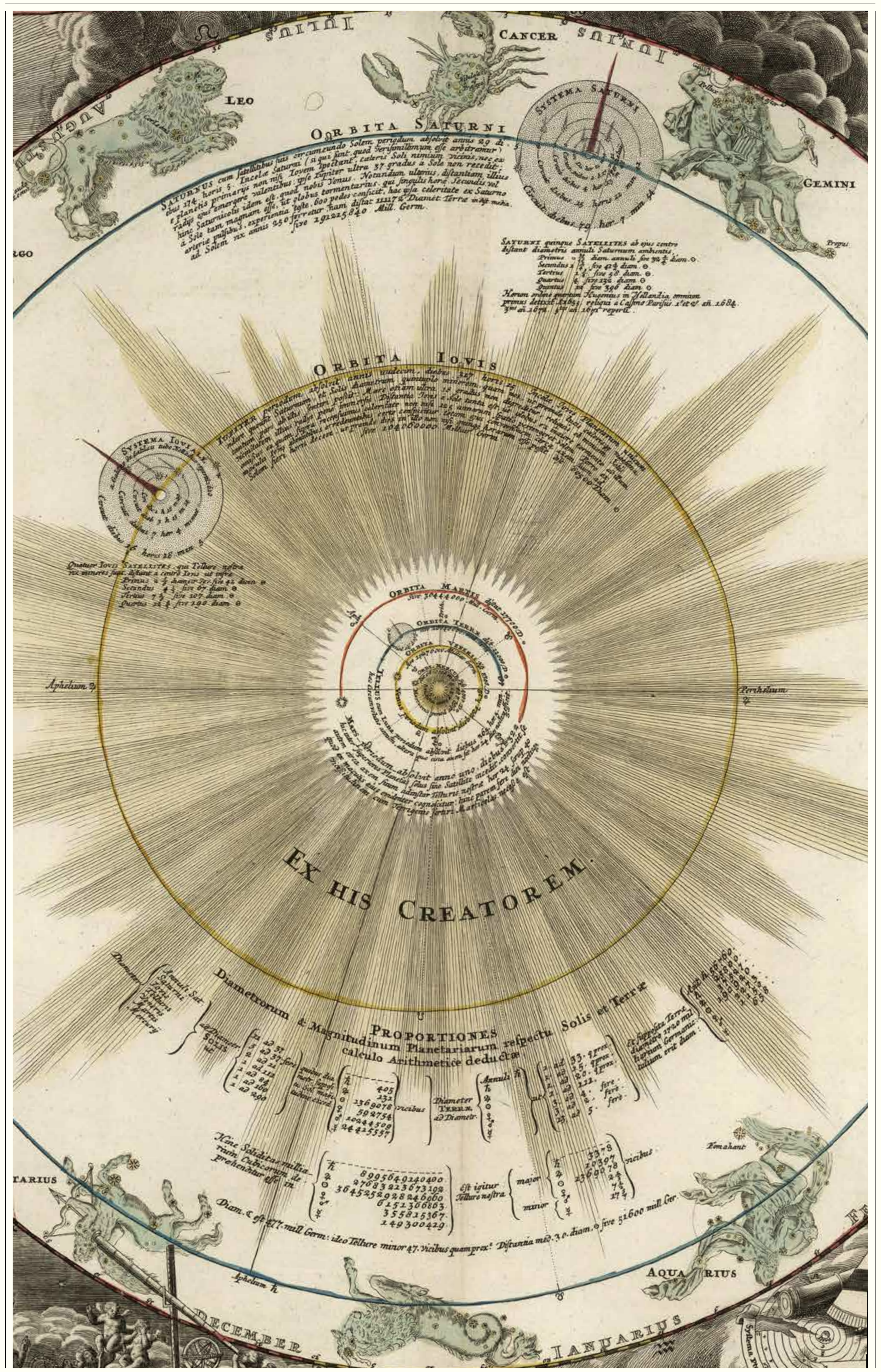

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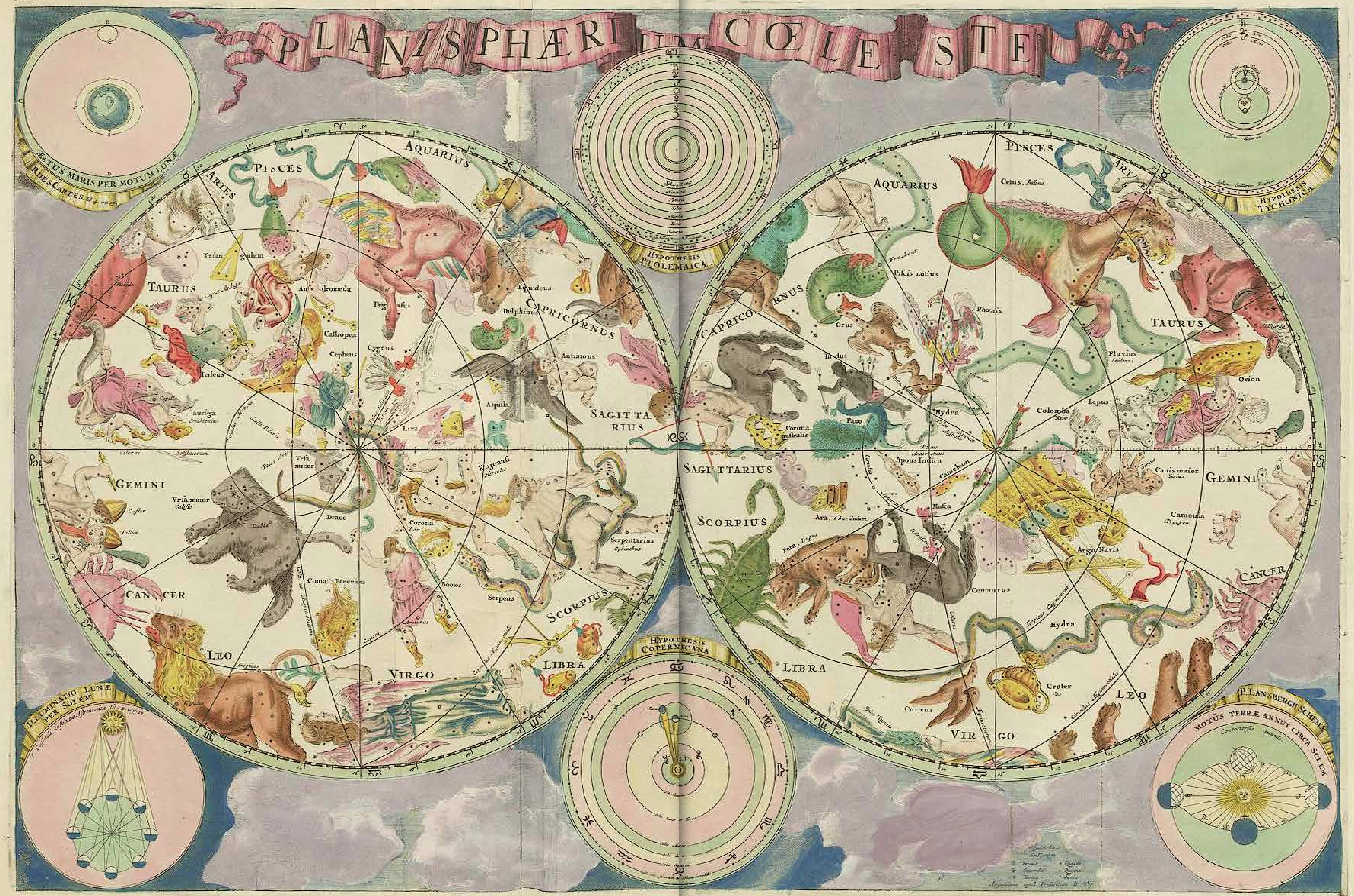
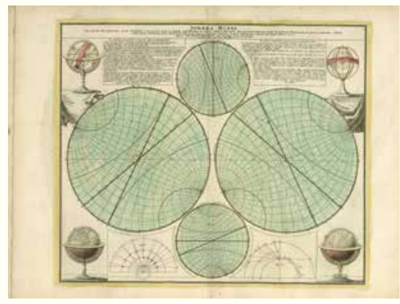
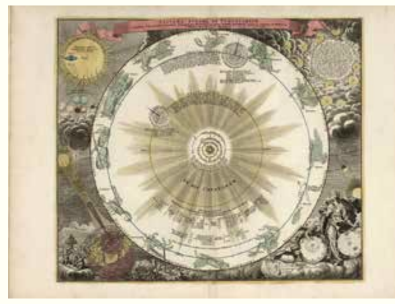

PLANISPHÆRIUM CŒLESTE
ÆSTUS MARIS PER MOTUM LUNÆ
HYPOTHESIS PTOLEMAICA
HYPOTHESIS TYCHONICA
HYPOTHESIS COPERNICANA
ILLUMINATIO LUNÆ PER SOLEM
P. LANSBERGII SCHEMA
MOTUS TERRÆ ANNUI CIRCA SOLEM
PISCES
ARIES
AQUARIUS
TAURUS
Andromeda
Pegasus
Equuleus
Delphinus
CAPRICORNUS
Cassiopea
Cepheus
Cygnus
Antinous
Perseus
Auriga
Aquila
Lira
SAGITTARIUS
GEMINI
Vrsa minor
Vrsa maior
Draco
Engonasi
Serpentarius
Corona
Coma Berenices
Bootes
Serpens
SCORPIUS
CANCER
LEO
VIRGO
LIBRA
Cetus, Balena
Piscis notius
Grus
Phoenix
Indus
Pavo
Hydra
Corona Australis
Fluvius Eridanus
Orion
Lepus
Colomba Noe
Canis maior Sirius
Canicula Procyon
Apous Indica
Cameleon
Musca
Ara, Thuribulum
Fera, Lupus
Centaurus
Argo Navis
Crater
Corvus

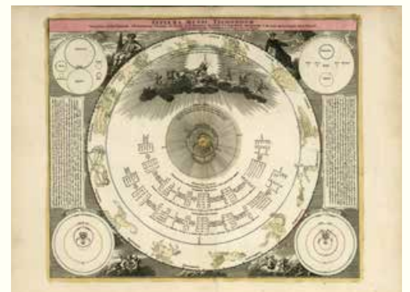
TABLE OF CONTENTS.

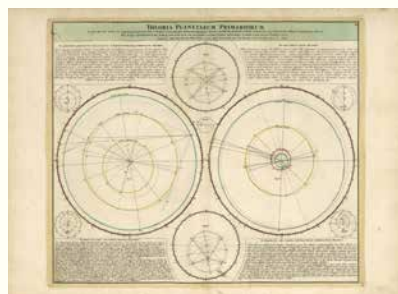
FOREWORD. (10)
INTRODUCTION. (12)
TIMELINE. (16)

THE PLATES.

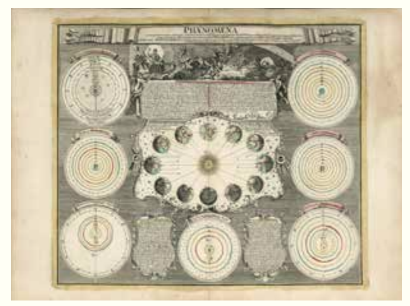

01. SPHAERA MUNDI. (18)

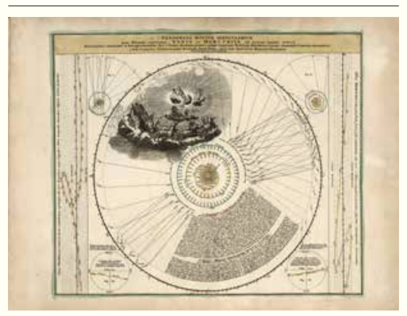

02. SYSTEMA SOLARE ET PLANETARIUM. (24)

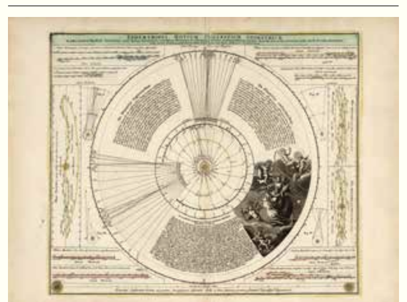

03. SYSTEMA MUNDI TYCHONICUM. (28)

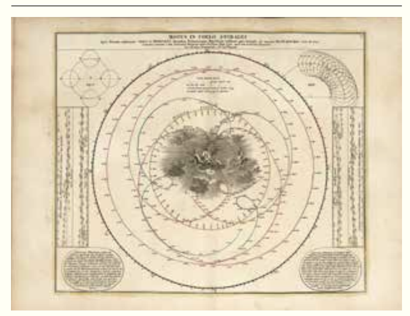

04. THEORIA PLANETARIUM PRIMARIORUM. (34)

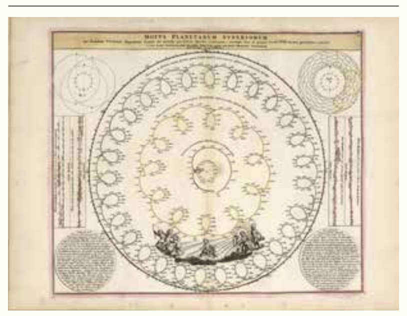

05. PHAENOMENA IN PLANETIS PRIMARIIS. (44)


06. PHAENOMENA. (52)

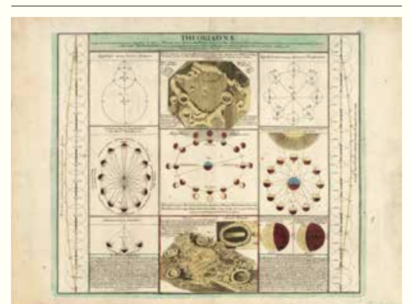

07. PHAENOMENA MOTUUM IRREGULARIUM. (58)

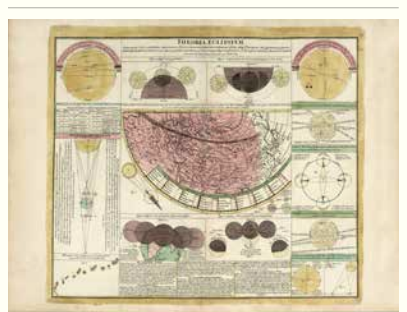

08. MOTUUM COELESTIUM GEOMETRICAE. (66)

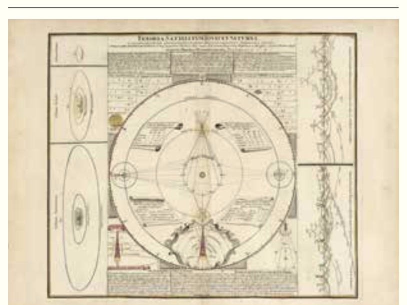

09. MOTUUM COELESTIUM GEOMETRICAE. (72)


10. MOTUS PLANETARUM SUPERIORUM. (76)


11. TABULA SELENOGRAPHICA. (84)


12. THEORIA LUNAE. (92)


13. THEORIA ECLIPSIUM. (98)

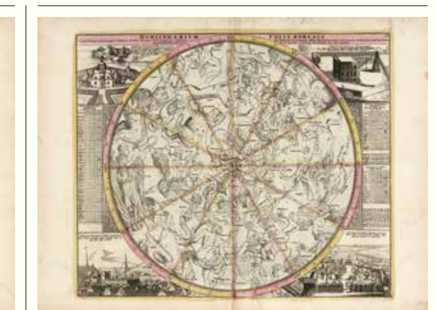

14. THEORIA SATELLITUM IOVIS ET SATURNI. (106)


15. BASIS GEOGRAPHIAE RECENTIORIS ASTRONOMICA. (112)

TABLE OF CONTENTS.


16. HEMISPHAERIUM COELI BOREALE I. (120)


17. HEMISPHAERIUM COELI AUSTRALE I. (132)


18. HEMISPHAERIUM COELI BOREALE II. (140)


19. HEMISPHAERIUM COELI AUSTRALE II. (148)


20. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS I. (156)

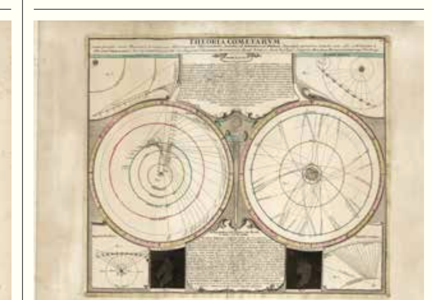

21. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS II. (164)


22. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS III. (172)


23. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS IV. (180)

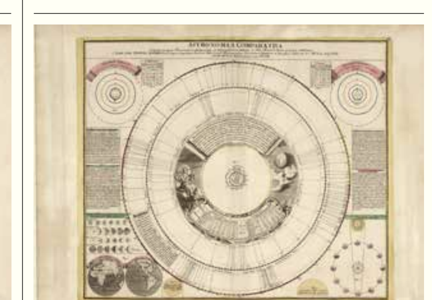

24. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS V. (190)


25. GLOBI COELESTIS IN TABULAS PLANAS REDACTI PARS VI. (196)


26. THEORI COMETARUM. (204)

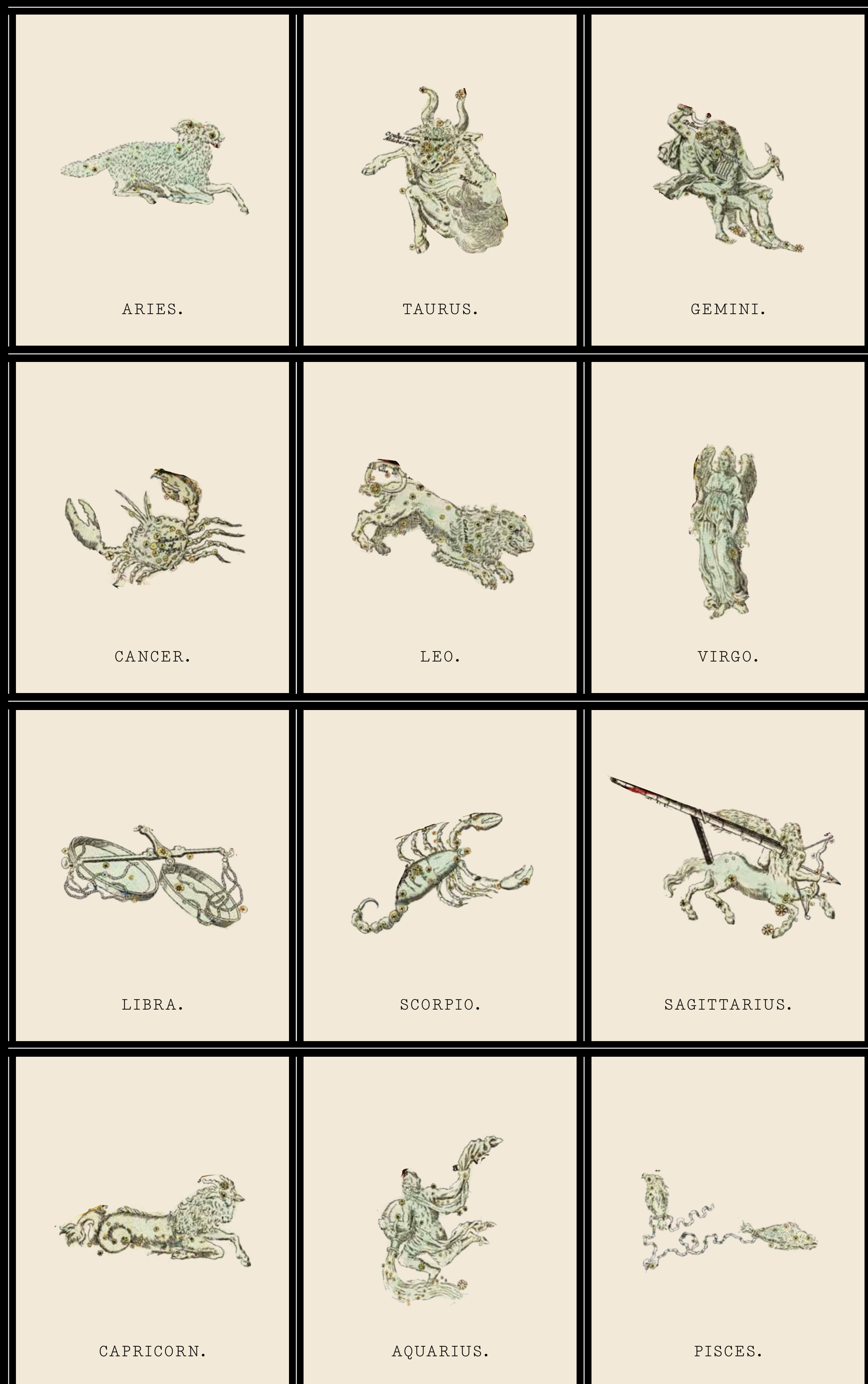

27. MOTUS COMETARUM IN HEMISPHAERIO BOREALI. (210)


28. MOTUS COME TARUM IN HEMISPHAERIO AUSTRALI. (220)


29. ASTRONOMIA COMPARATIVA I. (228)


30. ASTRONOMIA COMPARATIVA II. (234)

LEGACY. (242)
DRAMATIS PERSONAE. (246)
INDEX. (248)
SOURCES. (252)
PICTURE CREDITS. (254)
ACKNOWLEDGMENTS. (256)



INTRODUCTION

The *Atlas Coelestis* by Johann Doppelmayr (1677–1750) is among the most spectacular artistic and scientific feats of astronomy created in the European Enlightenment. Across thirty spectacular plates it gathers together and explains countless aspects of astronomical science as it was known at that time, ranging from the motions of the planets to the timing of eclipses, the passage of comets and the properties of distant stars. Published in 1742 by the great Nuremberg cartographic house founded by Johann Baptist Homann (1664–1724), the 'celestial atlas' collates illustrations created for previous world atlases over the preceding decades with many created especially for the project. Together, they provide an unrivalled insight into the Enlightenment view of the cosmos – a world that had shaken off many of the wrong-headed theories that had persisted since classical times, but for whom many questions remained unanswered.

From a 21st-century perspective, Doppelmayr's time feels comfortably removed from the great revolution that had overturned astronomy in the 16th and 17th centuries. When we consider the Copernican Revolution – which uprooted Earth from its privileged place at the centre of the cosmos and transformed it into one of several planets orbiting the Sun – we may think of it as beginning with Nicolaus Copernicus's (1473–1543) own treatise on the subject, *On the Revolutions of the Heavenly Spheres*, published almost exactly 200 years earlier in 1543. Or perhaps we consider its culmination with the trial of Galileo (1564–1642) before the Inquisition in 1633. History is written by the winners, and it is easy to assume that, despite his condemnation by the Church, Galileo's discoveries and arguments effectively settled the matter in the mind of all rational thinkers.

The truth, of course, is more complex, and Doppelmayr's *Atlas*, with its numerous illustrations of alternative systems of the universe, hints at some of that complexity. Telescopic discoveries, such as the moon-like phases of Venus and the satellites orbiting Jupiter, may have resolved the basic question of whether the Sun or Earth formed the centre of the cosmos, but there were still lingering questions and arguments. What controlled the shape of planets' orbits around the Sun, and the periods in which they orbited? Could the details of orbits be modelled with enough accuracy to predict planetary motions? What was the true scale of the universe, and the true nature of the planets? And above all, if the old order of things – in which materials naturally fell towards the centre of Earth and the universe, and thereby found their orderly place – was swept away, what should replace it?

These days we understand the answer to that last question to be gravity, an attractive force exerted by all heavy objects in proportion to their mass, and it is easy to imagine Isaac Newton's (1643–1727) magisterial *Principia* of 1687 being greeted with relief as the longed-for solution to countless astronomical problems, but Newtonian physics was slow to catch on – particularly in mainland Europe – and these questions remained open for far longer than we might care to imagine. In places, therefore, Doppelmayr's plates offer a glimpse into a cosmos of possibilities in which the universal Newtonian clockwork had not yet quite found its rhythm.

Born on 29 September 1677, Johann Gabriel Doppelmayr was the son of Johann Siegmund and Maria Catharina Doppelmayr. His father, a Nuremberg merchant, made a hobby of experimental physics and, according to Doppelmayr, was the first in the city to build a successful vertical air pump.

After private tuition to the age of twelve, the young Johann Gabriel attended the Aegidianum, or Old Nuremberg Gymnasium, one of Germany's leading Protestant schools. He proved a model pupil and by 16 was attending the public lectures

FIG. 1.

FIG. 1.
The frontispiece of *Harmonia Macrocosmica*, a star atlas produced in 1660 by Dutch-German cartographer Andreas Cellarius, depicts key figures in the debate about the nature of the universe attending on Urania, the Greek muse of astronomy. Those depicted include Tycho Brahe (front left), Nicolaus Copernicus (front right) and Ptolemy of Alexandria (back row, left).

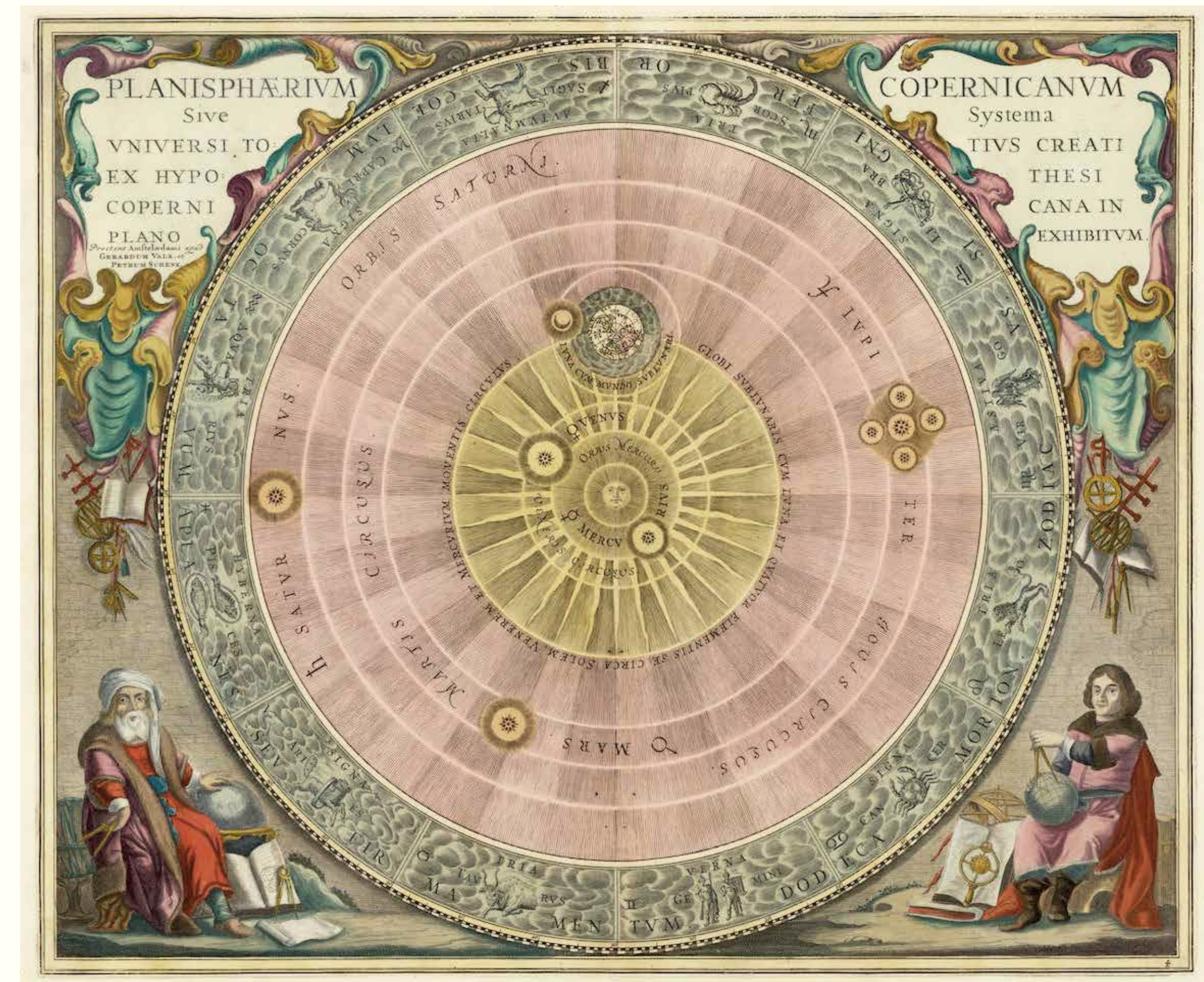


FIG. 2.

FIG. 2.
A plate from Andreas Cellarius' atlas displays the Copernican model of the Universe in plan view, with the Sun at the centre, circled by the planets and ringed by the sphere of the stars (represented by the traditional constellations of the zodiac). Both Earth and Jupiter are depicted with their accompanying satellites.

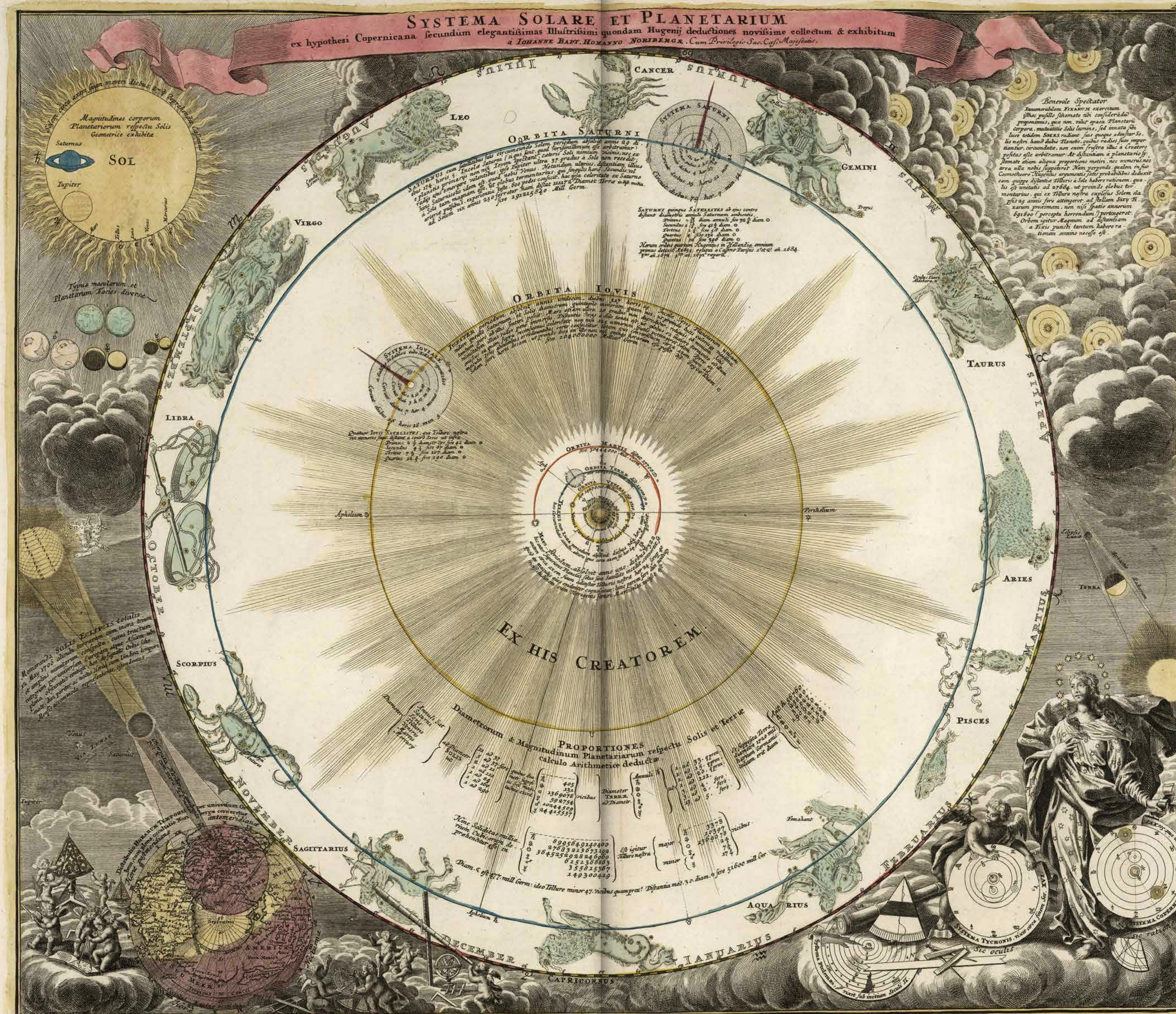
of the gymnasium's most renowned professors. From 1696 he attended university at nearby Altdorf, intending to study for a career in law. It was here that his future took a fateful turn when he joined lectures on mathematics and physics by the influential philosopher Johann Christoph Sturm (1635–1703).

Sturm had gained a reputation as the greatest experimental physicist in Germany He founded the Collegium Curiosum – a private club modelled on scientific academies elsewhere in Europe – and published two volumes describing its experiments and demonstrations. Doppelmayr soon fell under his spell and began to concentrate on the worlds of mathematics and physics, leading to dissertations on the Sun and on vision and the *camera obscura*, a popular optical novelty of the time.

A brief spell at Halle University saw Doppelmayr finally abandon his legal training altogether in favour of physics and mathematics. Making plans to travel to Holland and England to improve his knowledge, he set off on a scientific 'grand tour' in 1700, spending time in Utrecht (where he honed his mathematics and studied other languages) and Leiden (where he learned the secrets of grinding glass to make optical instruments such as telescopes) in Holland before crossing the Channel. Alternating his time in England between London and Oxford, the keen young student Doppelmayr soon made the acquaintance of important scientists of the age, including Astronomer Royal John Flamsteed (1646–1719), Savilian Professor of Astronomy David Gregory (1659–1708) and the venerable scholar John Wallis (1674–1738). Subsequently, he was invited to attend lectures and discourses at the Royal Society, establishing relationships that would last for the rest of his life.

In 1704, Doppelmayr made a triumphant return to the Aegidianum as its newly minted Professor of Mathematics. It was here he would remain for the rest of his life, devoting himself to research, teaching and the popularization of the latest scientific ideas. In 1716, he married Susanna Maria Kellner, the daughter of a prominent local apothecary. They had four children together but only one survived infancy. (This one surviving son, Johann Siegmund, showed his own early aptitude for mathematics, and was taught at first by his father at the gymnasium, but later followed his mother's side of the family to become an apothecary).

Johann Doppelmayr may have no great scientific discovery of his own as a claim to fame, however he


SYSTEMA SOLARE ET PLANETARIUM
ex hypothesi Copernicana secundum elegantissimas Illustrissimi quondam Hugenij deductiones novissime collectum & exhibitum
a IOHANNE BAPT. HOMANNO NORIBERGÆ. Cum Privilegio Sac. Caes. Majestatis.
SOL
ORBITA SATURNI
SYSTEMA SATURNI
ORBITA IOVIS
SYSTEMA IOVIS
EX HIS CREATOREM
PROPORTIONES
Diametrorum & Magnitudinum Planetariarum respectu Solis et Terræ calculo Arithmetico deduct.
CANCER
LEO
VIRGO
LIBRA
SCORPIUS
SAGITTARIUS
CAPRICORNUS
AQUARIUS
PISCES
ARIES
TAURUS
GEMINI
IULIUS
IUNIUS
AUGUSTUS
MAIUS
SEPTEMBER
APRILIS
OCTOBER
MARTIUS
NOVEMBER
FEBRUARIUS
DECEMBER
IANUARIUS
Benevole Spectator
TERRA
SYSTEMA TYCHONIS
SYSTEMA COPERNICI

SYSTEM OF THE SUN AND PLANETS

(SYSTEM SOLARE + PLANETARIUM)

Doppelmayr summarizes the Copernican model of the solar system and demonstrates its usefulness for explaining celestial phenomena.

Plate 2 of the atlas presents a vision of the Enlightenment Universe. Originally compiled for Homann's 1716 *Grand Atlas*, at its heart lies a model of the solar system, centred on the Sun according to the theories of Nicolaus Copernicus (1473–1543), and elaborated with the discoveries made over some 130 years of telescopic observations.

What we now think of as the Copernican Revolution was a long time coming – and followed a prolonged and tortuous path to acceptance. The practice of 'positional astronomy' – the idea that the ancient system of epicycles and equant points could deliver accurate predictions if only it was provided with sufficiently precise initial measurements of planetary positions and movements – reached its peak in medieval Spain during the late 13th century, where Islamic, Jewish and European ideas and scholarship mixed freely. Here, King Alfonso X of Castile (1221–84) sponsored the compilation of astronomical tables that drew on a wide variety of earlier sources and fresh observations to deliver unprecedented accuracy. The resulting 'Alfonsine Tables' were used to create ephemerides – charts of the heavenly bodies that could be used in casting horoscopes.

The only catch was that the same process began to reveal shortcomings in Ptolemy's (*c.* 100–170 CE) complex model of the universe – more accurate measurements made the tables themselves more accurate, but also revealed errors in their predictions that might have been overlooked in previous centuries. Thus Ptolemy's model, like that of Aristotle (384–322 BCE) before him, began to accrue awkward elaborations – epicycles within epicycles just to keep the cosmic clockwork in line with observation.

The first rumblings of a revolution came in 1377, when Nicolas d'Oresme (*c.* 1320–82), philosopher and Bishop of Lisieux in northwestern France, published his *Livre du Ciel et Du Monde* (*Book of the Heavens and the Earth*). In it, he demonstrated that the daily motion of the stars, at least, could be explained as well by a rotating Earth as by a rotating outer celestial sphere. He foreshadowed Galileo's later concept of inertia by arguing that the elements would share Earth's motion and so we should not expect a perpetual wind from the east, and suggested that spinning the relatively small Earth about its axis might prove more economical to the scheme of the universe than causing a vast starry sphere to rotate in a matter of twenty-four hours. And finally, he directly addressed a thorny issue that would come back to haunt Galileo in particular – the fact that several Biblical accounts mention the Sun, and one (in the Book of Joshua) even has it briefly stopped on its path. D'Oresme suggested this was just the Bible speaking to the language and common experience of its characters and audience, and should not be taken as a statement on the true construction of the universe. Nevertheless, he ultimately held back from any statement on the reality of the situation, insisting that he, like all right-thinking people, believed the heavens, rather than the Earth, stood still.

A century and a half later, Nicolaus Copernicus launched his theory in a very different climate. The transformations unleashed by the Renaissance and the Protestant Reformation saw many long-accepted dogmas being openly questioned, while the invention of the printing press allowed new ideas to spread more quickly than ever before. Copernicus was particularly inspired by the *Epitome of the Almagest*, a 1496 book by George von Peuerbach (1423–61) and Regiomontanus (1436–76) that amongst other things drew attention to some of the problems in Ptolemy's theory of lunar motion. After confirming these for himself through observation, he began to read more widely and develop his own ideas. By 1514 he had summarized these in a small book usually referred to as the *Commentariolus* (*Little Commentary*), which he circulated among friends and fellow astronomers in manuscript copies.

Although chiefly famous for placing the Sun, rather than the Earth, at its centre, the Copernican vision of the universe was not as simple or as comprehensive as later depictions (including Doppelmayr's) imply. While the planets were now placed on their familiar paths around the Sun with only the Moon orbiting Earth, Copernicus was forced to retain the smaller epicycles that caused them to wander back and forth even as they generally drifted westwards across the sky. The main reason for this was that he still believed in the necessity of Aristotle's ideal of uniform, circular motion. Changes to the apparent speed and direction of the other planets could not be entirely explained by our shifting point of view on Earth, and so a further mechanism was required.

Even with this unwanted complication, Copernicus's system clearly offered a powerful alternative to Ptolemy's, and word began to spread through academic circles across Europe. Legend has it that the first copies of the finished work, *De Revolutionibus Orbium Coelestium* (*On the Revolutions of the Heavenly Spheres*) were brought to Copernicus as he lay dying from a stroke in May 1543. Whether he knew about printer Andreas Osiander's (1498–1552) addition of a preface, dedicating the work to Pope Paul III (1468–1549) and insisting that the book's hypothesis should merely be treated as a mathematical tool rather than a description of the true nature of the universe, we will therefore never know.

Modern research has challenged the long-standing view that the densely packed, complex *De Revolutionibus* made little impact at the time – in fact a census of all known surviving copies from its early printings suggest that the book was read (and annotated) by many astronomers keen to make use of its mathematical tools. It seems true, however, that many turned a blind eye to its implications for cosmology – though this is perhaps unsurprising given the fervent religious debates of the time and the fact that its ideas were derided by Protestants. Somewhat ironically given their later infamous clash with Galileo, some parts of the Catholic Church offered the theory a warmer welcome, at least while it remained firmly in the realm of mathematical hypothesis. It was only from around 1609 that the invention and development of the telescope revealed new phenomena in the sky for which a Sun-centred, rather than Earth-centred, universe seemed the only plausible explanation.

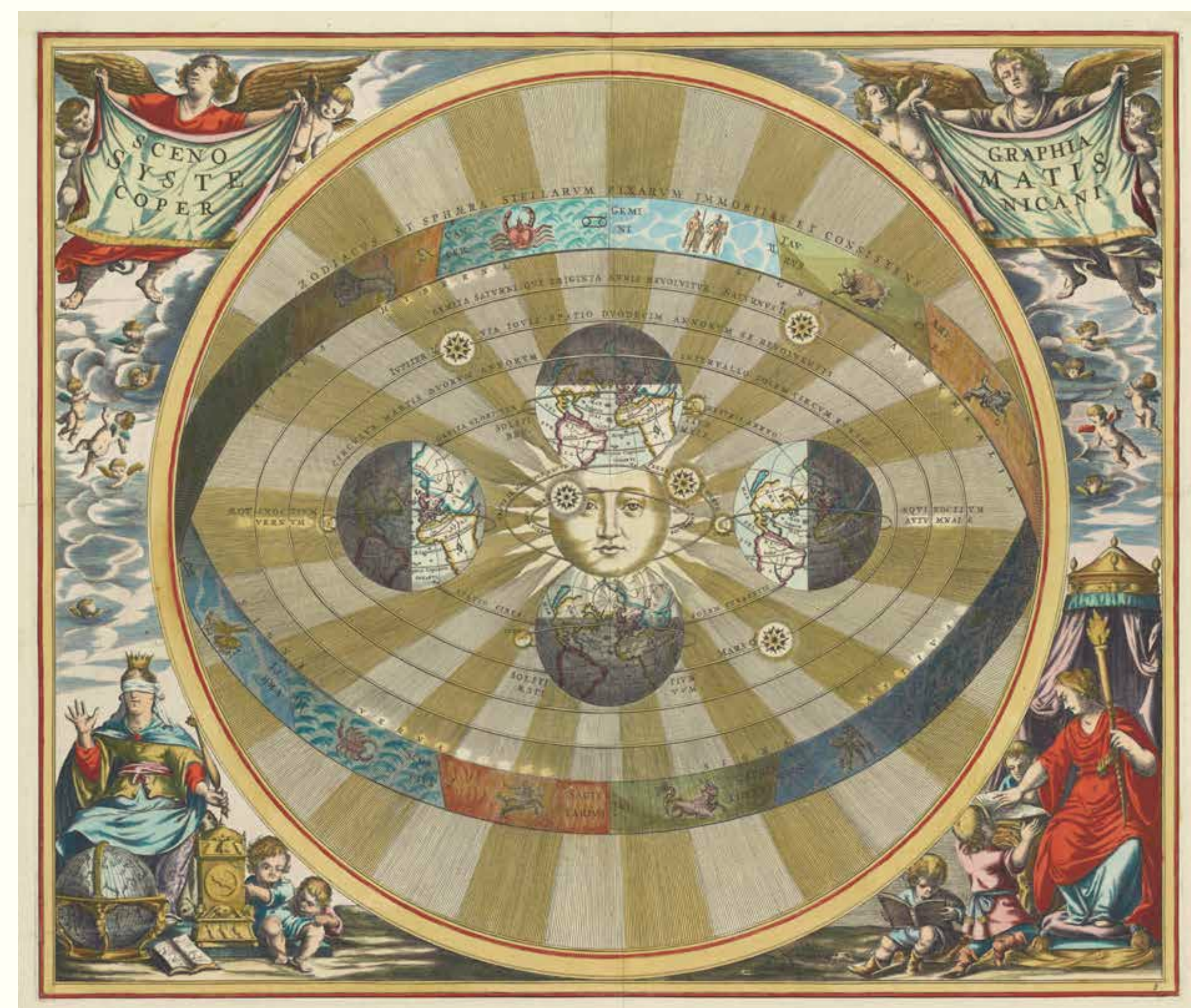


FIG. 1.

FIG. 1. Perhaps the most famous plate from Andreas Cellarius's 1660 *Harmonia Macrocosmica* depicts the Sun at the centre of the solar system, demonstrating how our planet's tilted axis of rotation can tip the northern hemisphere towards and away from the Sun at different times of year, giving rise to the familiar pattern of seasons. Earth is shown at four different points in the year. Anticlockwise from top, these are the winter solstice, vernal or spring equinox, summer solstice and autumnal equinox.

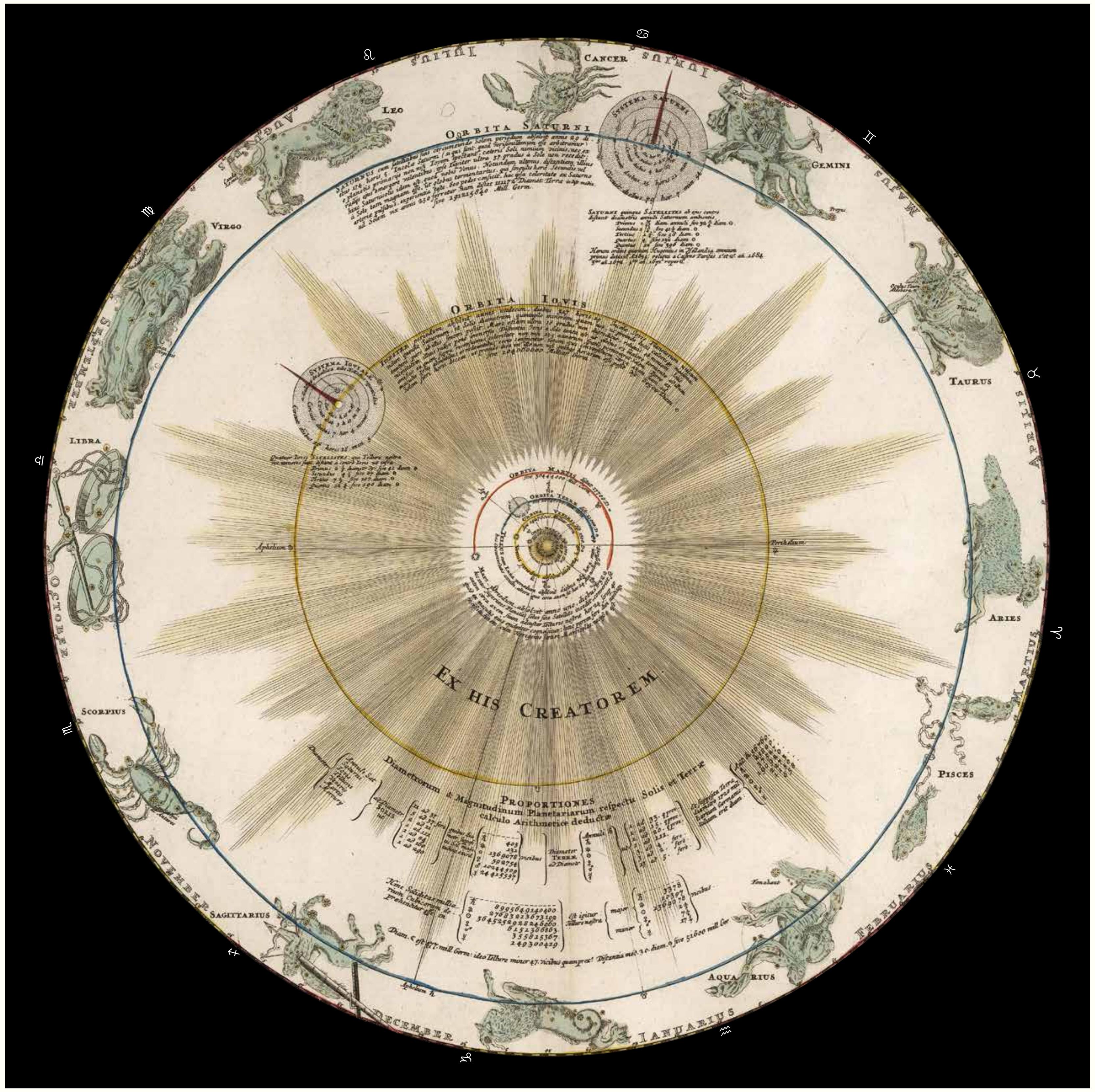


FIG. 1.
THE COPERNICAN SOLAR SYSTEM.

Doppelmayr's atlas makes an unusual (for the time) attempt to depict the relative scales of orbits, showing that the four inner planets cluster relatively close to the Sun, while those of Jupiter and Saturn are much further out. Rays surrounding the Sun also hint at its dwindling influence at greater distances.

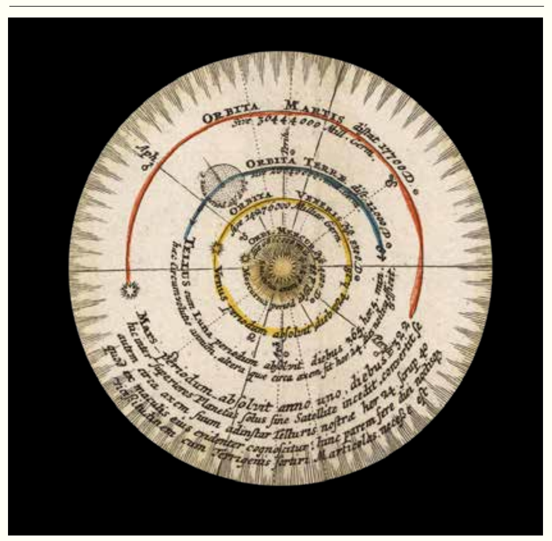


FIG. 2.
THE INNER PLANETS.

Doppelmayr crowds the region around Mercury, Venus, Earth and Mars with information about their orbits. Distance from the Sun is given in Earth diameters, and orbital periods in days and hours. The current directions of perihelion (each orbit's closest point to the Sun) and aphelion (its greatest distance) are shown.

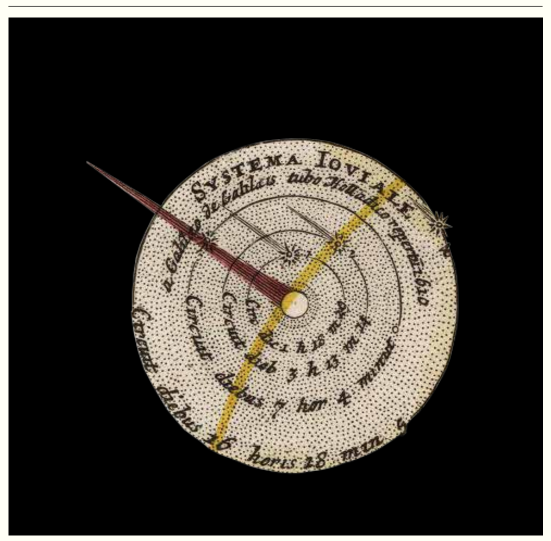


FIG. 3.
THE JOVIAN SYSTEM.

Jupiter is shown with its four major satellites, today known as the Galilean moons. The satellites, numbered 1 through 4 moving outwards, are shown with their orbital periods – the familiar names Io, Europa, Ganymede and Callisto were not widely adopted until the 20th century.

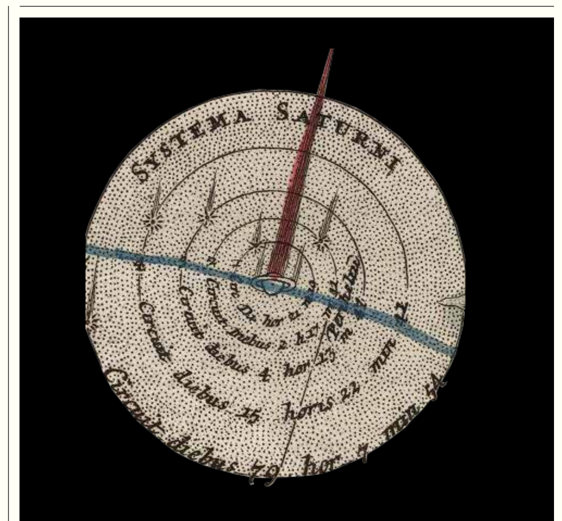


FIG. 4.
THE SATURNIAN SYSTEM.

The outermost planet known in Doppelmayr's time, Saturn is depicted with its surrounding ring system and five known moons: Tethys, Dione, Rhea, Titan and Iapetus (numbered 1 through 5). Titan was discovered by Christiaan Huygens in 1655, and the other four by Giovanni Domenico Cassini between 1671 and 1684.

FIG. 5.
THE SCALE OF THE BODIES OF THE PLANETS WITH RESPECT TO THE SUN.

By combining his knowledge of the distance to the planets with the latest angular measurements of their apparent size in the sky, Doppelmayr was able to estimate the relative sizes of bodies in the solar system. The basis of these calculations are shown in the included table (Fig. 8).

FIG. 8.
PROPORTIONAL DIAMETER AND MAGNITUDE OF THE PLANETS WITH RESPECT TO THE SUN AND EARTH.

Diam.:	*Saturn's rings*	*To the diameter of the Sun:*	*11–37*	*The diameter of the Sun shall exceed:*	------------
	Saturn (♄)		*c. 5–37*		♄ *405*
	Jupiter (♃)		*2–11*		♃ *131*
	Earth (⊖)		*1–111*		⊖ *1369078*
	Venus (♀)		*1–84*		♀ *592754*
	Mars (♂)		*1–160*		♂ *10244509*
	Mercury (☿)		*1–290*		☿ *24415557*

Turns	*Diameter of the Earth.*	*Rings*	*as*	*1–33 approx.*	*Supposing the Earth's diameter to be 1720 German miles, the diameters will be:*	*56760.*
		♄		*1–15 approx.*		♄ *25800.*
		♃		*1–20 approx.*		♃ *37527.*
		⊖		*1–111. approx.*		⊖ *190920.*
		♀		*c. 3–4*		♀ *2273.*
		♂		*c. 3–2*		♂ *1150.*
		☿		*c. 13–5*		☿ *658.*

Hence the volume in cubic miles is:	------------	*It is therefore our earth*		------------	*Turns*
	♄ *8995649140400*		*major*	♄ *3378*	
	♃ *27683213673192*			♃ *10397*	
	⊖ *3645252928246960*			⊖ *1369078*	
	♀ *6151366863*			♀ *2⅓*	
	♂ *355815367*		*minor*	♂ *7½*	
	☿ *149300419*			☿ *17 6/7*	

The diameter of the Moon is 477 Germanic miles: therefore smaller than the Earth nearly 47 times.

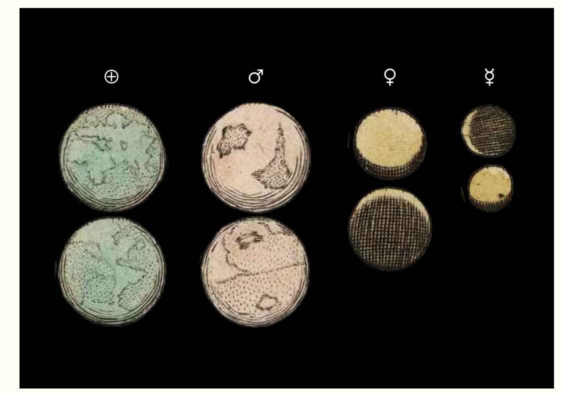


FIG. 6.
MARKINGS AND APPEARANCES OF THE PLANETS.

Here, Doppelmayr shows the typical surface features and appearances of the four inner planets – the seas and continents of Earth, the dark markings on the face of Mars and the changing phases of Venus and Mercury. All are explored in more detail on plate 5.

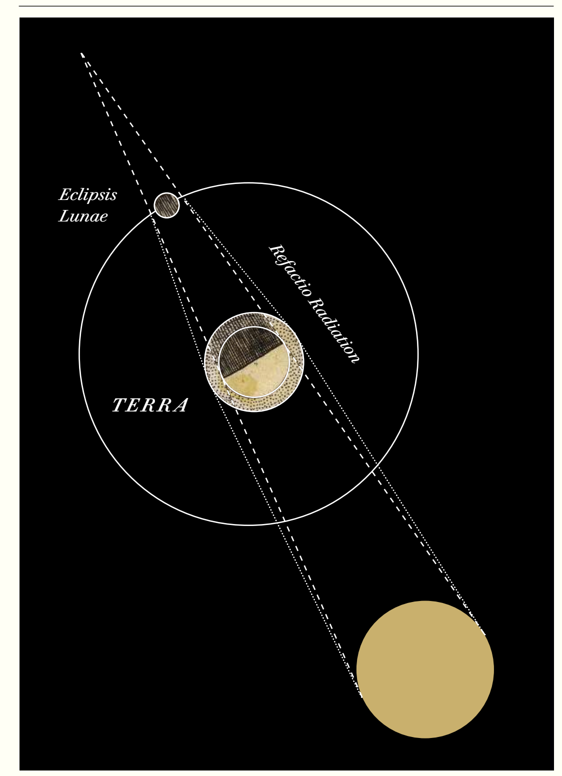


FIG. 7.
THE SOLAR ECLIPSE OF 12 MAY, 1706.

A companion diagram to the solar eclipse depicts the geometry of lunar eclipses, in which the full moon passes through the long cone of shadow cast by Earth. Because Earth is larger than the Moon, the required alignment is far less precise, and lunar eclipses can be seen across Earth's entire night-time hemisphere.

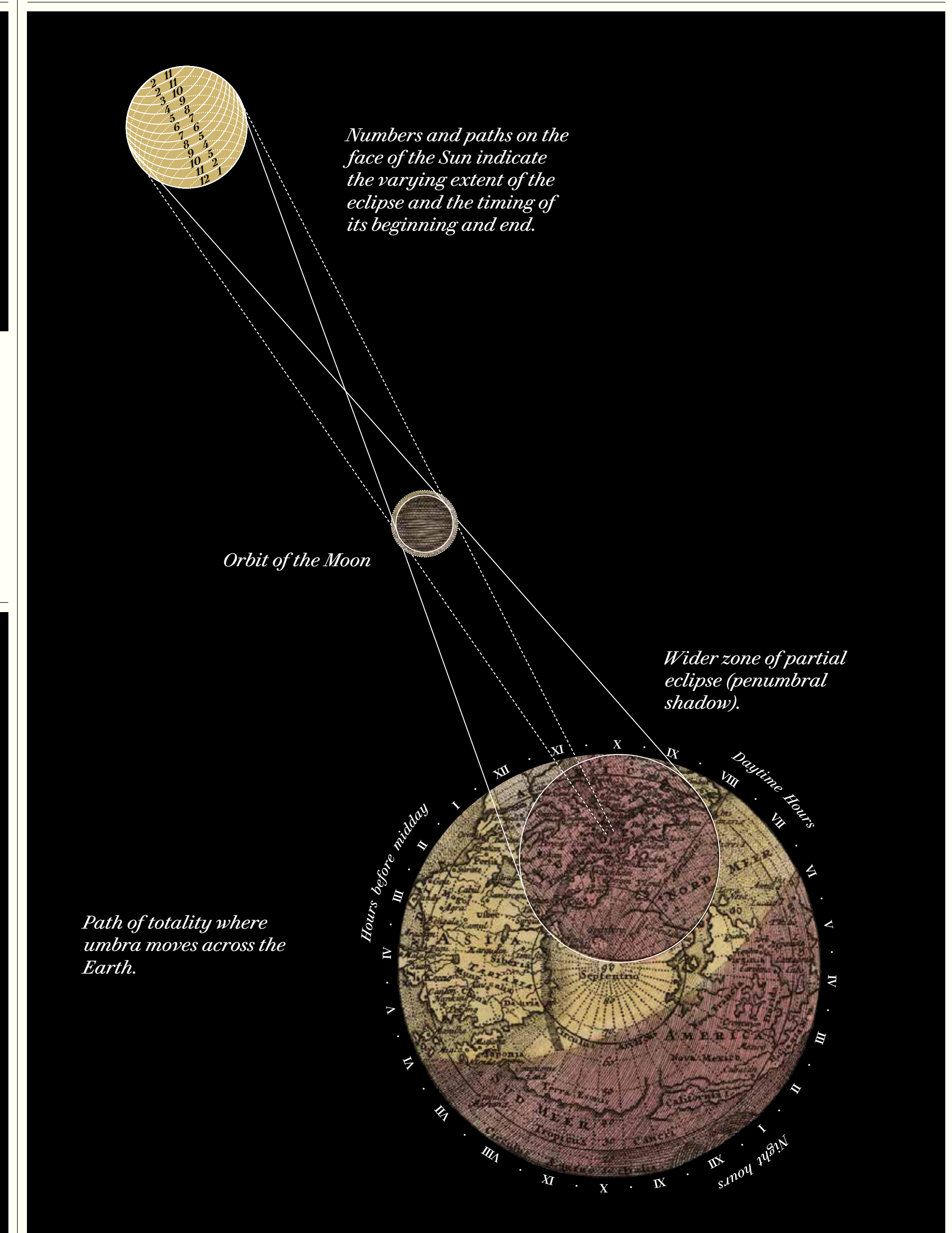
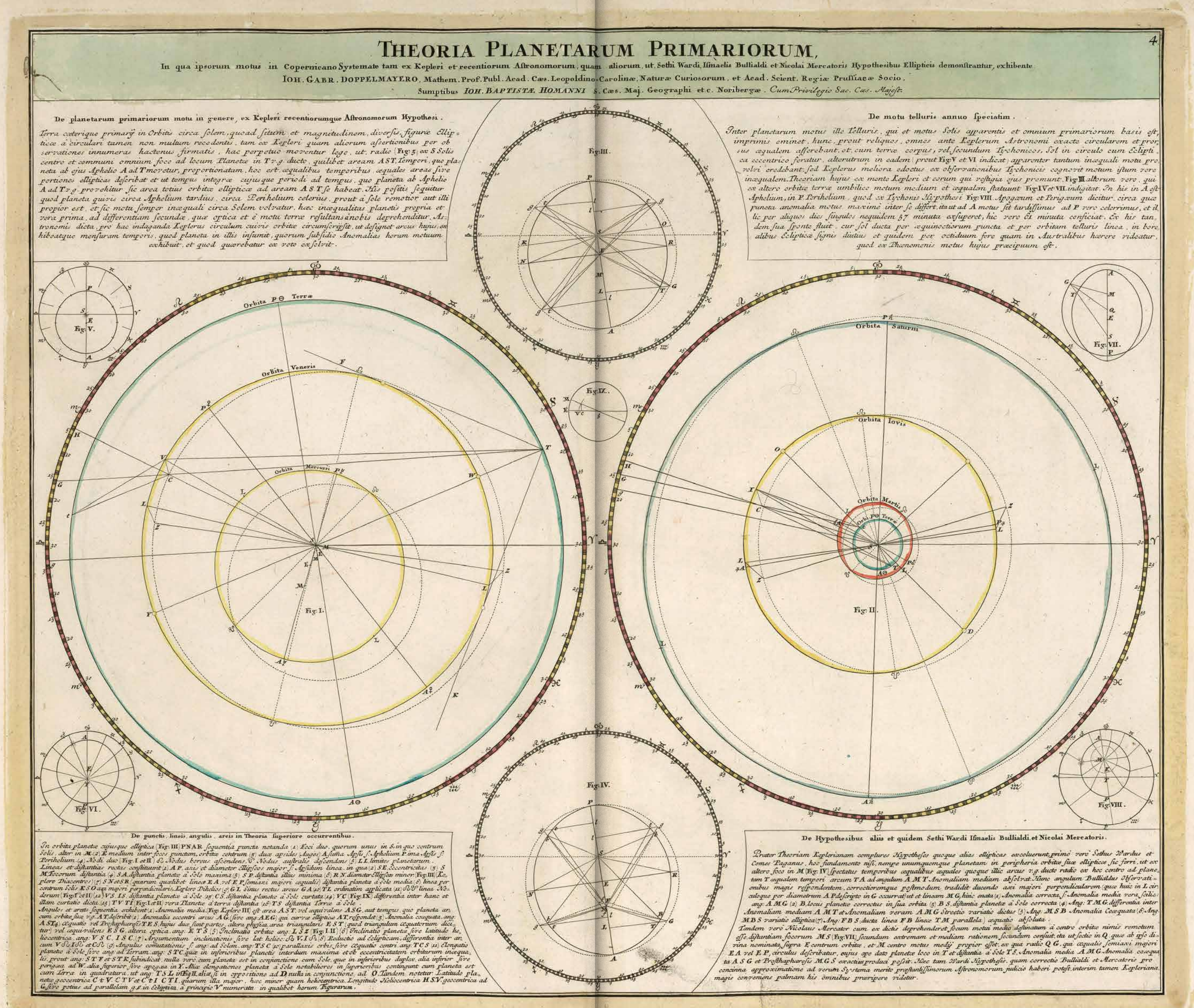


FIG. 9.
THE SOLAR ECLIPSE OF 12 MAY, 1706.

First appearing in Homann's *Neuer Atlas* of 1707, Plate 2 depicts the most recent solar eclipse seen over Europe at the time. The eclipse was the first to have its path across the Earth's surface accurately predicted in advance, along with the extent of the umbral (total) and penumbral (partial) shadows cast by the Moon.


4
THEORIA PLANETARUM PRIMARIORUM,
In qua ipsorum motus in Copernicano Systemate tam ex Kepleri et recentiorum Astronomorum, quam aliorum, ut, Sethi Wardi, Ismaelis Bullialdi et Nicolai Mercatoris Hypothesibus Ellipticis demonstrantur, exhibente
IOH. GABR. DOPPELMAYERO, Mathem. Prof. Publ. Acad. Cæs. Leopoldino-Carolinæ, Naturæ Curiosorum, et Acad. Scient. Regiæ Prussiacæ Socio.
Sumptibus IOH. BAPTISTÆ HOMANNI S. Cæs. Maj. Geographi etc. Norimbergæ. Cum Privilegio Sac. Cæs. Majest.
De planetarum primariorum motu in genere, ex Kepleri recentiorumque Astronomorum Hypothesi.
De motu telluris annuo speciatim.
De punctis, lineis, angulis, areis in Theoria superiore occurrentibus.
De Hypothesibus aliis et quidem Sethi Wardi Ismaelis Bullialdi et Nicolai Mercatoris.
Fig. I.
Fig. II.
Fig. III.
Fig. IV.
Fig. V.
Fig. VI.
Fig. VII.
Fig. VIII.
Fig. IX.
Orbita Terræ
Orbita Veneris
Orbita Mercurii
Orbita Saturni
Orbita Iovis
Orbita Martis

THEORY OF THE PRIMARY PLANETS

(THEORIA PLANETARUM PRIMARIORUM)

Doppelmayr demonstrates how the Copernican system, modified by Kepler's elliptical orbits, accounts for the motions of the planets.

Plate 4 demonstrates how Copernicus's Sun-centred model of the solar system can make intuitive sense of some of the most obvious phenomena in the motions of the planets, before describing the revolutionary ideas of Johannes Kepler (1571–1630), as well as the adornments other astronomers added to Kepler's simplicity in an attempt to explain what drove the planets in their orbits.

Long before the planets were recognized as balls of rock and gas distinct from stars, they had first drawn attention to themselves through their eccentric motions in the sky. While the stars wheeled around the heavens in fixed patterns that never seemed to change, five bright lights wandered among them on varying paths. Two of these lights rarely strayed far from the Sun. One, the brightest of all, traced large loops and often appeared as a brilliant beacon in the dark sky, lingering after sunset or heralding the new day – small wonder that ancient civilizations frequently associated it with their goddess of beauty (the Roman Venus). The other, much fainter, faster-moving and harder to spot, made only brief appearances in the sky at dawn or dusk; the Romans named it Mercury, after the fleet-footed messenger of the gods.

The other three planets moved differently. Largely unshackled from the Sun, they could circle westwards around the entire sky along the band of stars known as the zodiac. Once in each cycle they would approach the Sun's own position and disappear into the sunset sky, before re-emerging weeks or months later to be visible before sunrise. What was more, their general westward track was frequently interrupted by periods of 'retrograde' motion in which they tracked east across the sky for weeks or months before resuming their general westward trend. The least predictable of these three wanderers, which had a baleful red colour and could vary significantly in brightness, became associated with gods of war, such as the Greek Ares and Roman Mars. Steadier in its motion and more predictable in its brilliance was the planet frequently associated with the chief or king of the gods, known since Roman times as Jupiter. Finally, the system was completed by the fainter and more sedate planet associated by both Greeks and Romans with the king's father – Cronus or Saturn.

Tracking the motions of these planets and predicting various events in their passage around the sky became the key concern of ancient astronomy. Such events could include the timing of their conjunctions or comings-together with the Sun, Moon or stars, or simply with each other, the greatest distance or 'elongation' from the Sun achieved by the so-called 'inferior planets' Venus and Mercury and the timing of 'oppositions' when the free-roaming 'superior' planets lay directly opposite the Sun in the sky and were therefore

FIG. 1.

FIG. 1. One of the most common applications of astrology was to medieval medicine. The dominance of certain planets and constellations was seen as influencing the motions of the four classical elements, and (in a model originated by Greek philosopher Empedocles) four humours or fluids within the body. These in turn were linked to bodily organs, physical illnesses and psychological states in a complex model encapsulated by illustrations such as the *Anatomy of Man* from the famous *Très Riches Heures du Duc du Berry* of 1415.

FIG. 2.

FIG. 3.

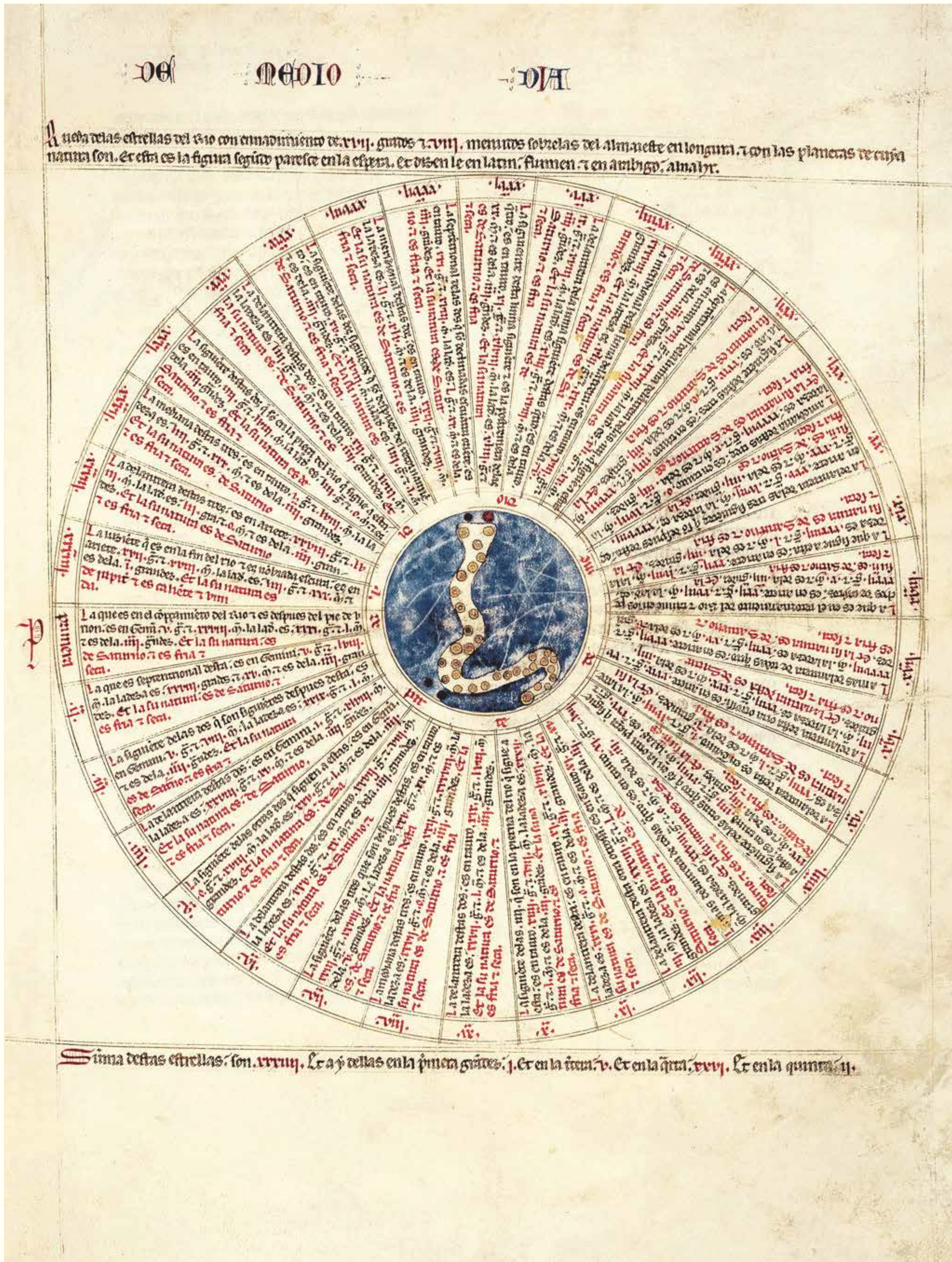
FIGS. 2–3. Two depictions of the Ptolemaic system that dominated medieval astrology, both depicting not only the spheres of the planets and outermost fixed stars, but also the inner sublunary spheres that were considered the rightful positions of the elements fire, air, water and earth. Fig. 2 is Gautier de Metz's *Image du Mond* (1464), and Fig. 3, a late 14th-century edition of the *Breviari d'Amour* by Occitan poet Matfre Ermengau.

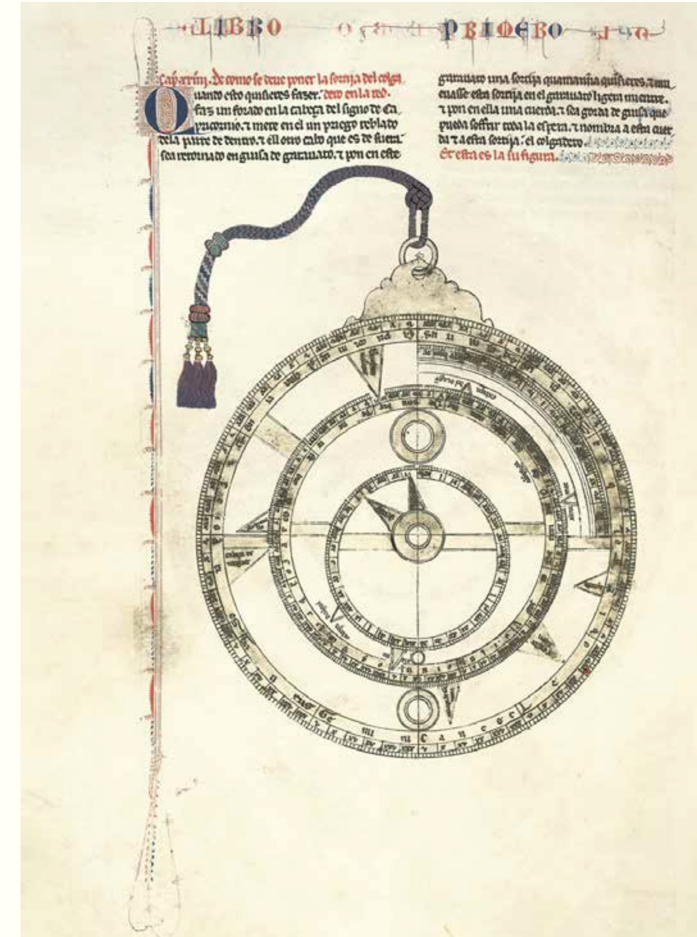
visible throughout the night. Above all, there was the question of how and when the Sun, Moon and planets moved in and out of the various constellations.

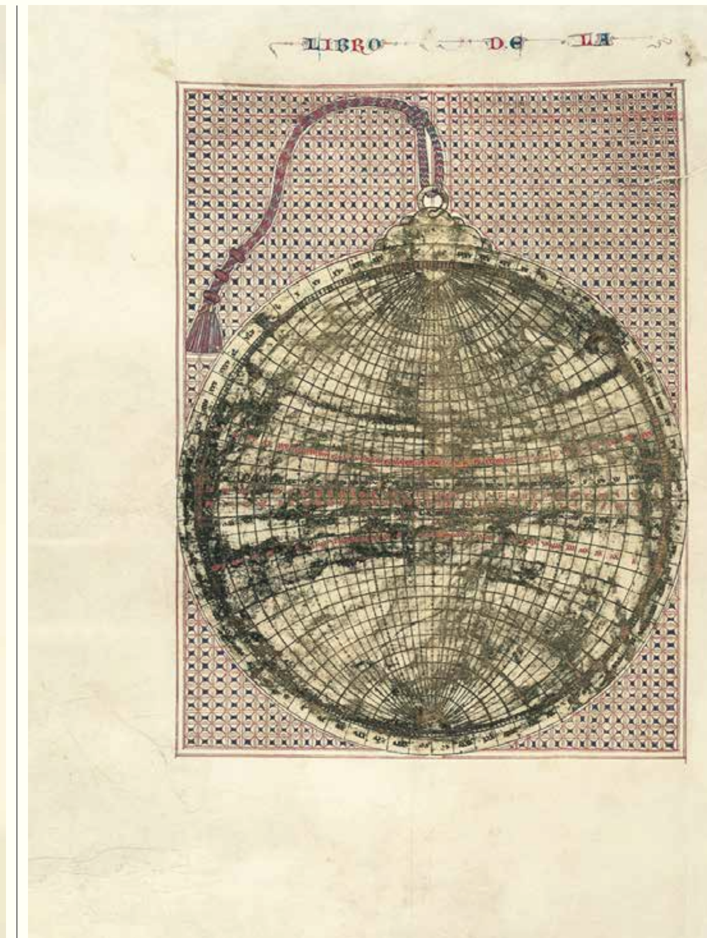
All of these questions had an immense practical importance because, until well into the 17th century, what we think of today as the science of astronomy was inextricably linked to astrology – the forecasting of events on Earth based on those in the heavens. Though modern astrology is widely regarded as a fairly harmless superstition, the classical and medieval form was part of a sophisticated world view that encompassed everything from the organization of states to the treatment of illness. Few scholars believed that the celestial bodies themselves were affecting events and people on Earth, but they did hold to a widespread view that events on Earth and in the heavens both followed pre-ordained cycles; history might not repeat itself, but it certainly rhymed and if, for example, a great king died unexpectedly while hunting during a conjunction of certain planets, then a shrewd ruler might well wish to know when the next such conjunction was due, and modify their plans accordingly. The ability to predict such events, which seem little more than curiosities to modern life, was the driving force of astronomy for two millennia or more.

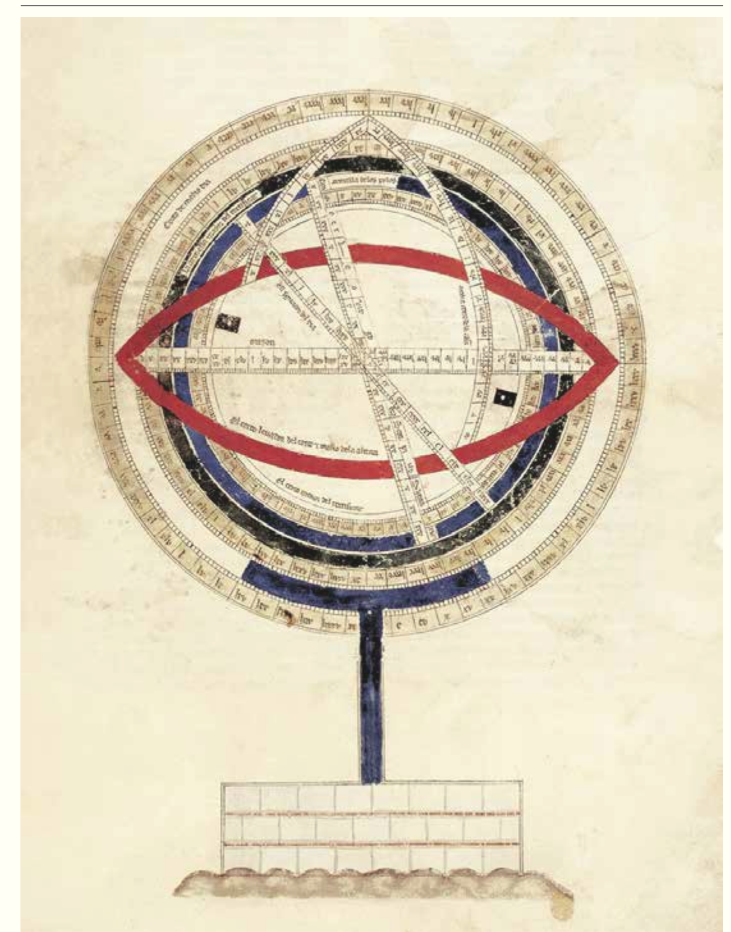
Thus, astronomer/astrologers took a great interest in Copernicus's system long before they properly digested its true implications. While geocentric models of the universe had been forced to employ complex epicycles and other mechanisms to keep the inferior planets anchored to the shifting location of the Sun as the Sun itself circled Earth, the Copernican model had a far simpler explanation: with Earth as third planet, the orbits of each of the two sunward worlds cover only a limited angle in our skies. All planets orbit in the same direction (counter clockwise as seen from above) and circle the Sun at different speeds and in different periods so that the distance and direction from one to another changes. An inferior planet has an orbit smaller than Earth's and reaches its greatest elongation east or west of the Sun as it rounds the outer edge of its orbit seen from our point of view. It comes closest to Earth at a point called 'inferior conjunction' when it lies in exactly the same direction as the Sun (though because the orbits are slightly tilted in respect to each other, it does not usually pass across the face of the Sun itself). At its furthest from Earth, meanwhile, it lies on the opposite side of the Sun at 'superior conjunction'. As it moves between superior and inferior conjunction via its greatest eastern elongation, the planet is visible in the evening sky after sunset (since it lies east of the Sun and sets after it). After inferior conjunction it appears in the morning sky and loops through its western elongation before returning to the next superior conjunction.

In addition, the Sun-centred system offers an easy explanation for the most obvious aspects of motion among the three superior planets.



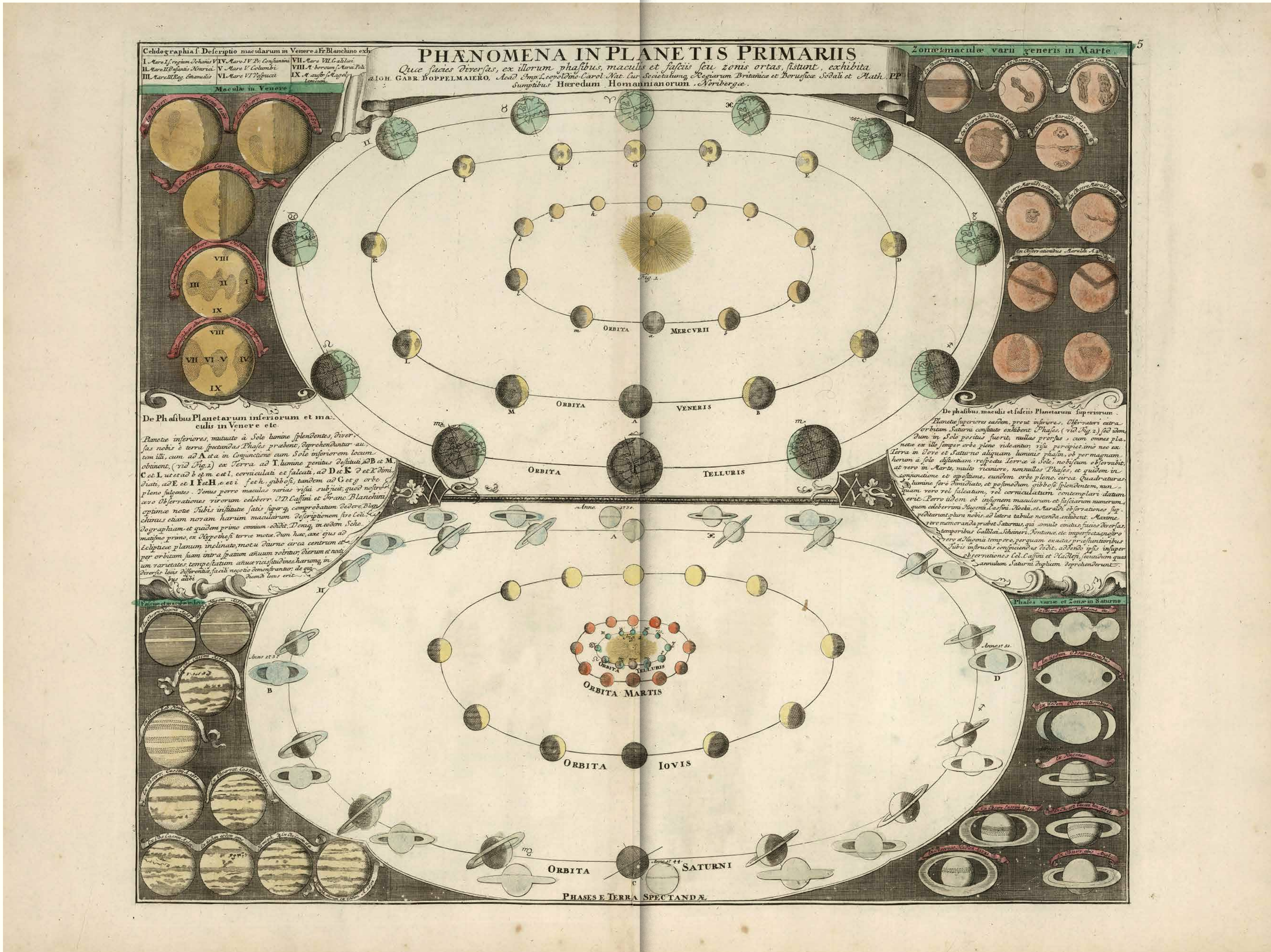






LIBROS DEL SABER DE ASTRONOMIÁ (12th CENTURY).

The *Libros del Saber de Astronomiá* (*Books of the Wisdom of Astronomy*) was an extraordinary astronomical encyclopedia commissioned in the late 12th century under King Alfonso X of Castile. Compiled by Christian, Jewish and Muslim scholars of the Toledo School, it encompasses a vast range of knowledge, including detailed tables for use in astrological prediction. Alfonso also commissioned the Alfonsine Tables – an ephemeris of planetary positions that offered tools for predicting future movements with unprecedented precision – and whose persistent inaccuracies did much to fuel doubts in the geocentric model. Alongside astrological tables, the *Libros del Saber de Astronomiá* includes manuals for the use of instruments such as the astrolabe (top) and armillary sphere (bottom left). As well as offering a tool for measuring inclinations of objects in the sky, disc-shaped astrolabes functioned as elaborate analogue computers, with sliding and rotating pointers to simplify various calculations, and a variety of useful data engraved on either side of the disc. They found uses not only in astronomy, but also as general surveying tools – for instance when calculating the height of distant objects.


5
PHÆNOMENA IN PLANETIS PRIMARIIS
Quæ facies diversas, ex illorum phasibus, maculis et fasciis seu zonis ortas, sistunt, exhibita
à IOH. GABR. DOPPELMAIERO, Acad. Imp. Leopoldino-Carol. Nat. Cur. Societatumq. Regiarum Britanicæ et Borussicæ Sodali et Math. PP.
Sumptibus Hæredum Homannianorum. Noribergæ.
Maculæ in Venere
Zonæ & maculæ varii generis in Marte
ORBITA MERCURII
ORBITA VENERIS
ORBITA TELLURIS
De Phasibus Planetarum inferiorum et maculis in Venere etc.
De phasibus, maculis et fasciis Planetarum superiorum
ORBITA MARTIS
ORBITA IOVIS
ORBITA SATURNI
Phases variæ et Zonæ in Saturno
PHASES E TERRA SPECTANDÆ

PHENOMENA OF THE PRIMARY PLANETS

(PHAENOMENA IN PLANETIS PRIMARIIS)

Doppelmayr shows how the orbits and orientations of the planets in the Copernican system affect their appearance as seen from Earth.

The invention of the telescope is often attributed to a Dutch spectacle maker called Hans Lippershey (*c.* 1570–1619). In the most colourful version of the story, children playing with a pair of ground spectacle lenses found that if they lined up a convex lens behind a concave one, with a significant distance between them, they could create a magnified image. Whether this tale is true or not, Lippershey certainly tried (and failed) to patent the invention in 1608, and as reports of the new device circulated around Europe, many curious people attempted to build their own.

The most famous of these was Galileo Galilei (1564–1642), then Professor of Mathematics at the University of Padua in northern Italy. Galileo was already renowned as a successful inventor and a pioneer of scientific experimentation, and through his methodical approach he was able to rapidly improve the basic telescope design, increasing magnification from around three times in his first attempt of early 1609, to around thirty times in the space of a few months. Late in 1610, this apparently allowed him to be the first person to record the Moon-like phases of Venus though a telescope, opening a new era in which the planets were transformed from mere lights in the sky into worlds with appreciable features of their own.

While Galileo's telescope allowed him to make several other key discoveries within the solar system – including spots on the surface of the Sun, the four major moons circling Jupiter and the fact that there was something odd about the shape of Saturn – the optical arrangement outlined by Lippershey produced a sharp image only for objects in a very narrow 'field of view', and severely limited early telescopic observers. As early as 1611, however, Johannes Kepler (1571–1630) outlined an alternative arrangement in which both the front 'objective' lens and the rear 'eyepiece' were outward-curving, or convex. This produced a wider field of view and theoretically allowed higher magnifications – though at the minor cost of flipping the image itself upside-down.

Perhaps surprisingly, no one seems to have built a 'Keplerian' telescope until Christoph Scheiner (1573–1650) – a Jesuit priest and scientific rival of Galileo – in 1630. Thereafter, however, Scheiner's account of the instrument's advantages led to its rapid adoption.

The underlying principle behind any telescope relies on the fact that rays of light from distant objects are effectively parallel to each other, and so a precisely ground glass lens (or later, a curved mirror) can redirect them into a tightening cone of rays that converge at a single point – the focus. The concave eyepiece of a Galilean telescope intercepts the converging rays before they reach the focus and bends or 'refracts' them back onto diverging paths, so they reach the eye as if they were coming from a closer, or larger, magnified object. The Keplerian design, meanwhile, allows the rays to cross at a focus and then refracts them with a second convex lens to create the diverging light cone viewed by the observer.

The actual magnification achieved by any refracting (lens-based) telescope depends on the shape of the two lenses (the stronger the curved surface, the greater its light-bending effect, and on the distance between them. Unfortunately, simple curved glass lenses come with their own drawbacks – principally the light passing through the lens is bent by different amounts depending on its colour, resulting in a series of colourful 'fringes' known as chromatic aberration. The stronger the lens's curvature, the greater the effect.

While the challenges of chromatic aberration would eventually be overcome in the later 18th century, early telescopic astronomers found an ingenious workaround – minimizing the curvature of the objective lens to create an extremely long cone of light that reached a focus far behind the lens, before being picked up by the eyepiece to create the magnified image. This minimized the problem of coloured fringes and gave rise to higher magnifications.

The final factor that shaped telescopes from the mid-17th century until Doppelmayr's own time is today known as 'light grasp'. Because a telescope's objective lens has a larger light-collecting surface than a human pupil, it effectively delivers more of the light from distant objects into the eye, making faint objects appear brighter. The larger the lens, the more light can be delivered, but the longer the focal length (in fact, all else being equal, doubling the lens's diameter quadruples the focal length). As optical glassmakers improved their techniques for casting and polishing lenses of increasing size, telescopes had to become longer and longer to accommodate them. The result was an era of bizarre-looking instruments – enormous tubes tens of metres long, supported on ingenious scaffolds, and even longer 'aerial telescopes' that abandoned tubes entirely in favour of mounting the objective on a distant mast and linking it to the observer at the eyepiece with strings, controlling wires and other mechanisms.

Precarious though they often seemed, these early devices nevertheless allowed the great astronomers of the 17th and early 18th centuries to begin observing the 'phenomena' of the other planets. Alongside depictions of the markings observed (erroneously) on Venus and more accurately on Mars, Doppelmayr's Plate 5 depicts the phases of Mercury – first observed by Giovanni Battista Zupi (1589–1650) in 1639 – the shifting cloud bands of Jupiter and early observation of Saturn's puzzling shape that was later resolved by Christiaan Huygens (1629–95) in 1655 as the planet's famous ring system.

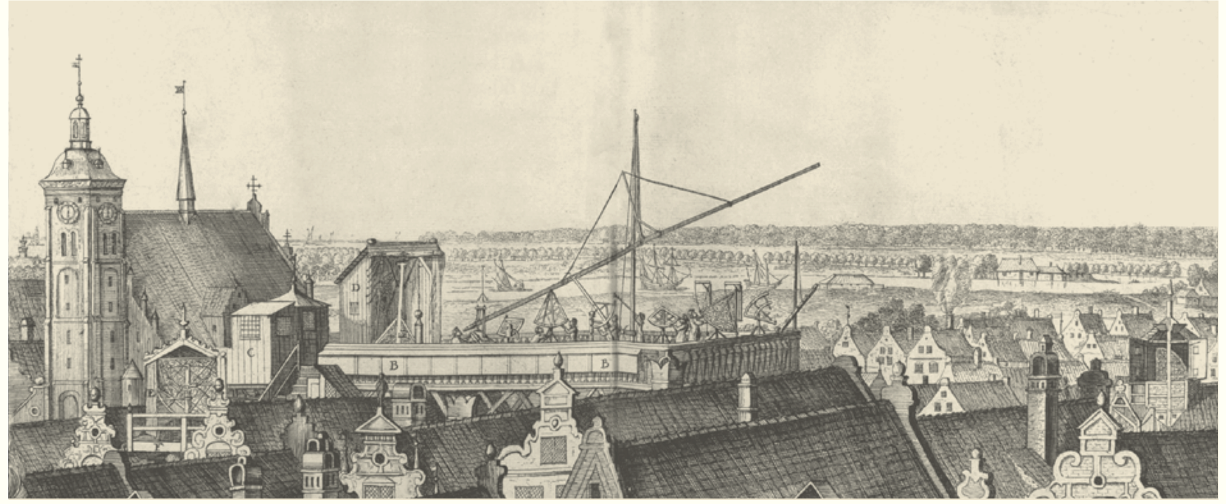


FIG. 1.

FIG. 1. Johannes Hevelius's successful brewing business in Danzig paid for him to construct an ambitious observatory across a platform that straddled the roofs of three houses. This view from his *Machina coelestis* highlights its centrepiece – the enormous 46-metre (151-ft) Keplerian telescope that Hevelius used in mapping the Moon.

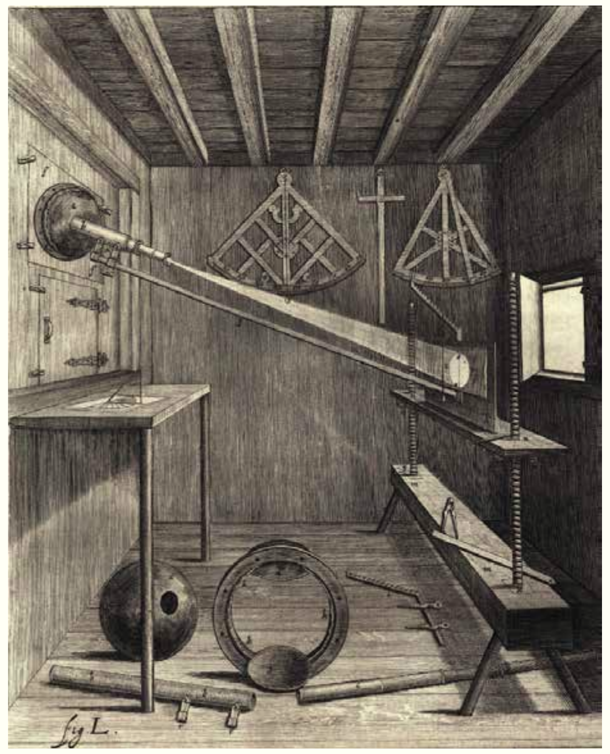


FIG. 2.

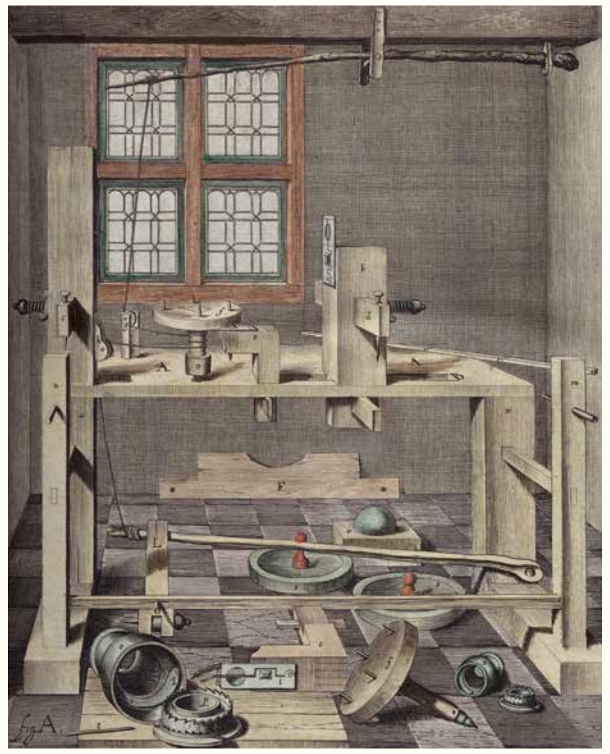
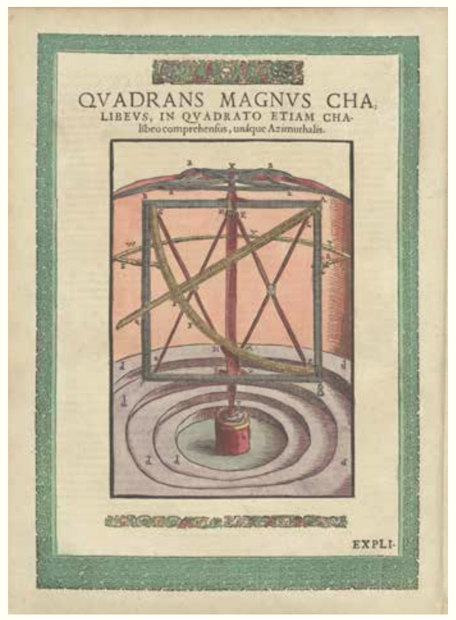
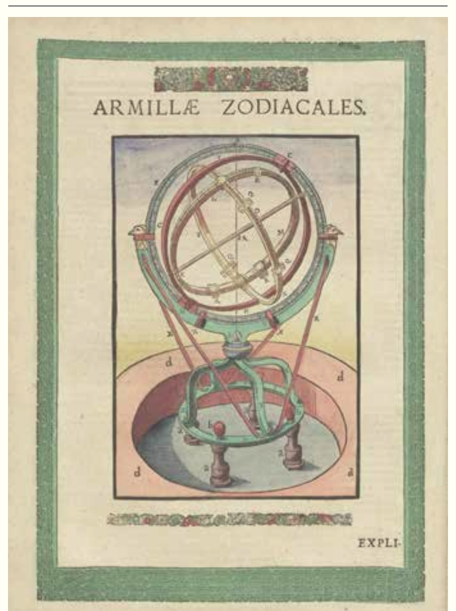
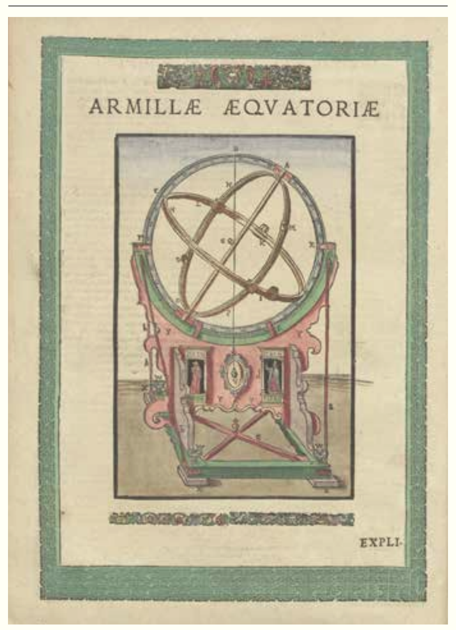


FIG. 3.

FIGS. 2–3. Two more plate from Johannes Hevelius's *Machina coelestis*, in which Hevelius describes the techniques and equipment used at his state-of-the-art observatory. Fig. 2 illustrates an enclosed hut with a hooded aperture for the eyepiece end of a telescope. In daylight, the telescope could be directed towards the Sun, projecting a bright image onto the screen. Fig. 3 shows the various tools that Hevelius used in the painstaking process of grinding, shaping and polishing precision lenses for his optical instruments.

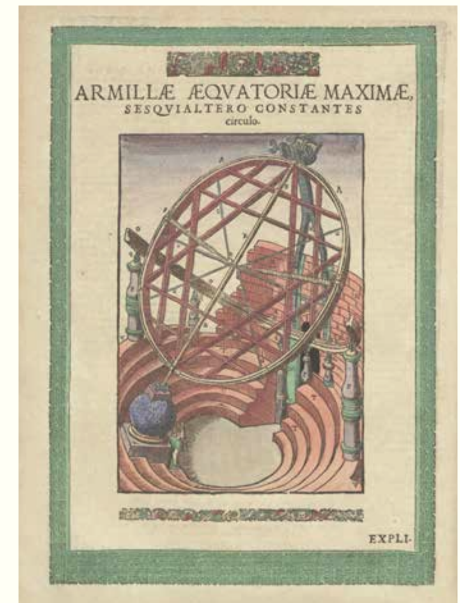


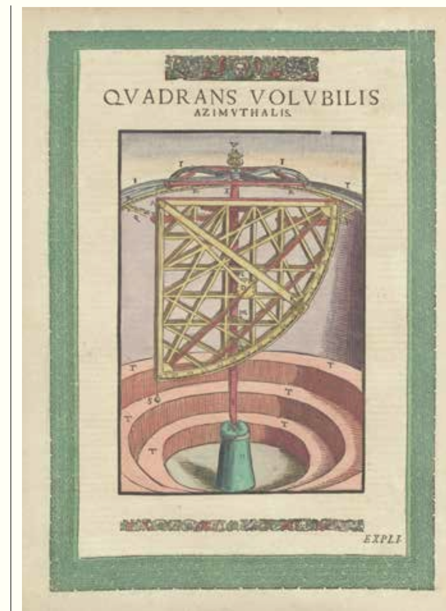


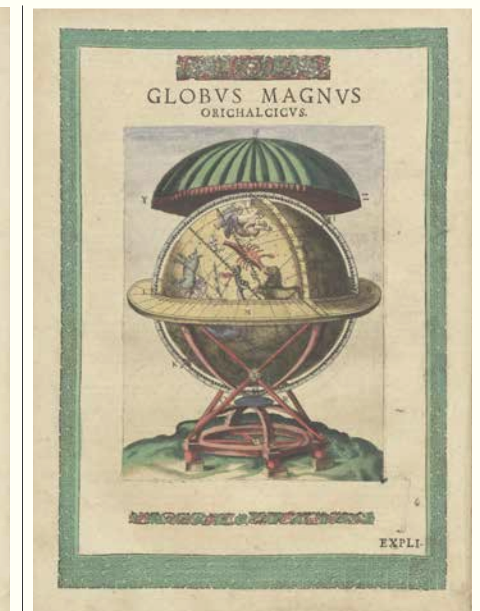


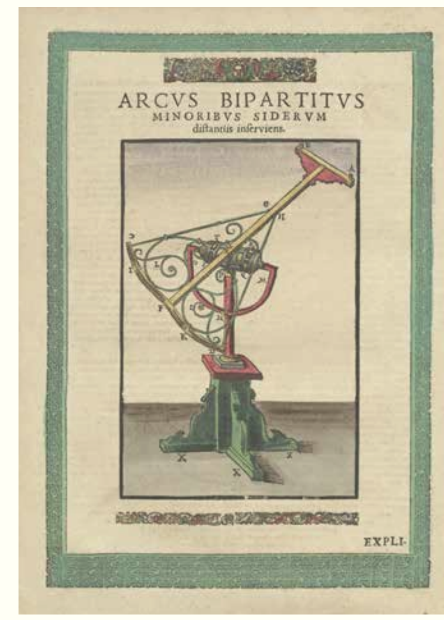
ASTRONOMIAE INSTAURATAE MECHANICA
(INSTRUMENTS FOR RESTORATION OF ASTRONOMY)
(1602).

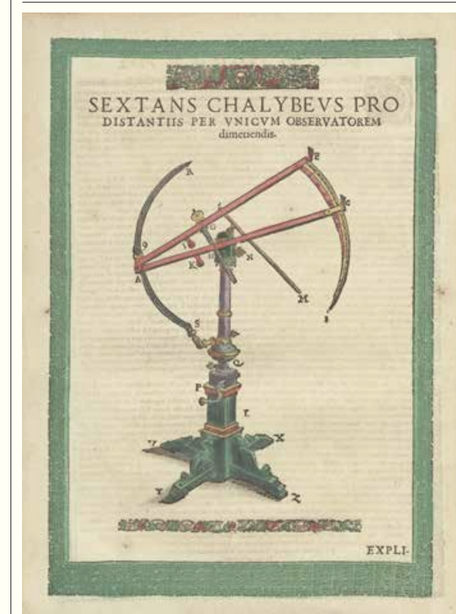
Tyco Brahe's 1602 treatise describes the cutting edge of astronomical technology on the eve of the telescopic revolution. Written in 1598, it describes the instruments used in the great observatory at Uraniborg, with which he recorded the positions of objects in the sky to an unprecedented degree of accuracy. This selection of plates illustrates various quadrants and sextants used for measuring positions and

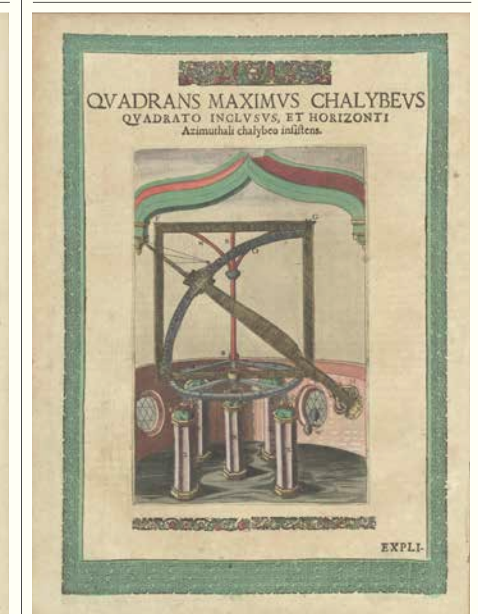


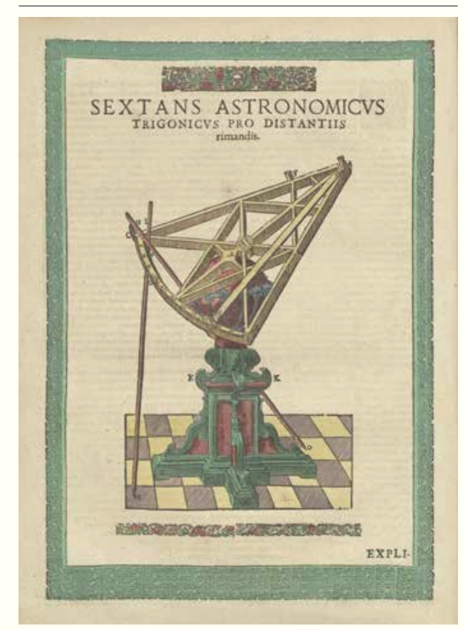


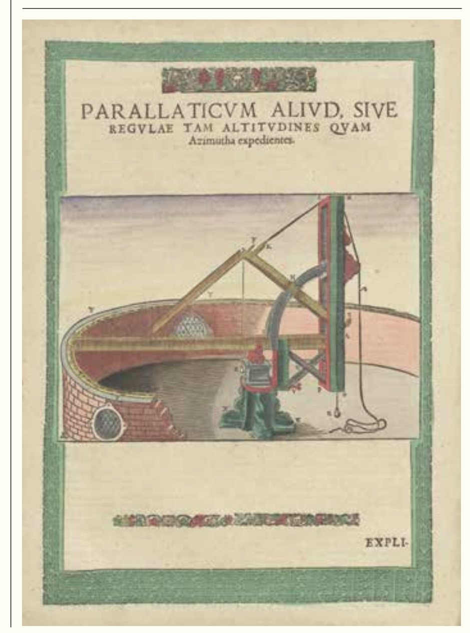


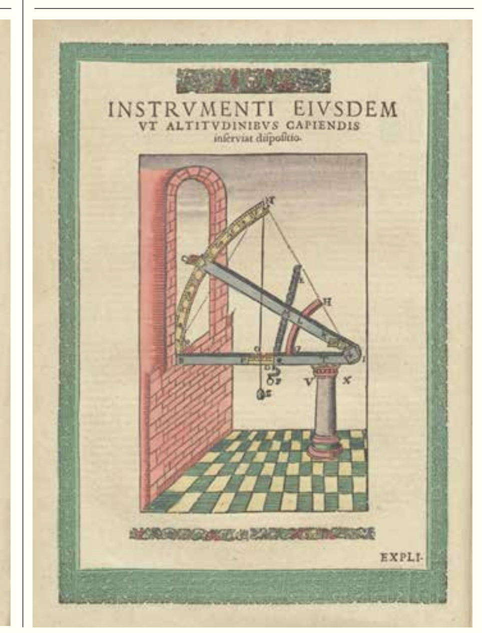












separations, alongside armillary spheres used to model both the zodiacal and equatorial coordinate systems of the heavens. Further plates from Tycho's book include, at top right of this page, the Great Globe – perhaps his greatest achievement. This 1.6-metre (5-ft) hollow wooden sphere took a decade to build to the required accuracy, after which it was covered in brass plates onto which the positions of stars and other objects could be precisely etched. Pivoting 'auxiliary circles' permitted rapid conversion between the unchanging equatorial coordinate system of the sphere, and the localized altitude and azimuth coordinates unique to a particular time and location.

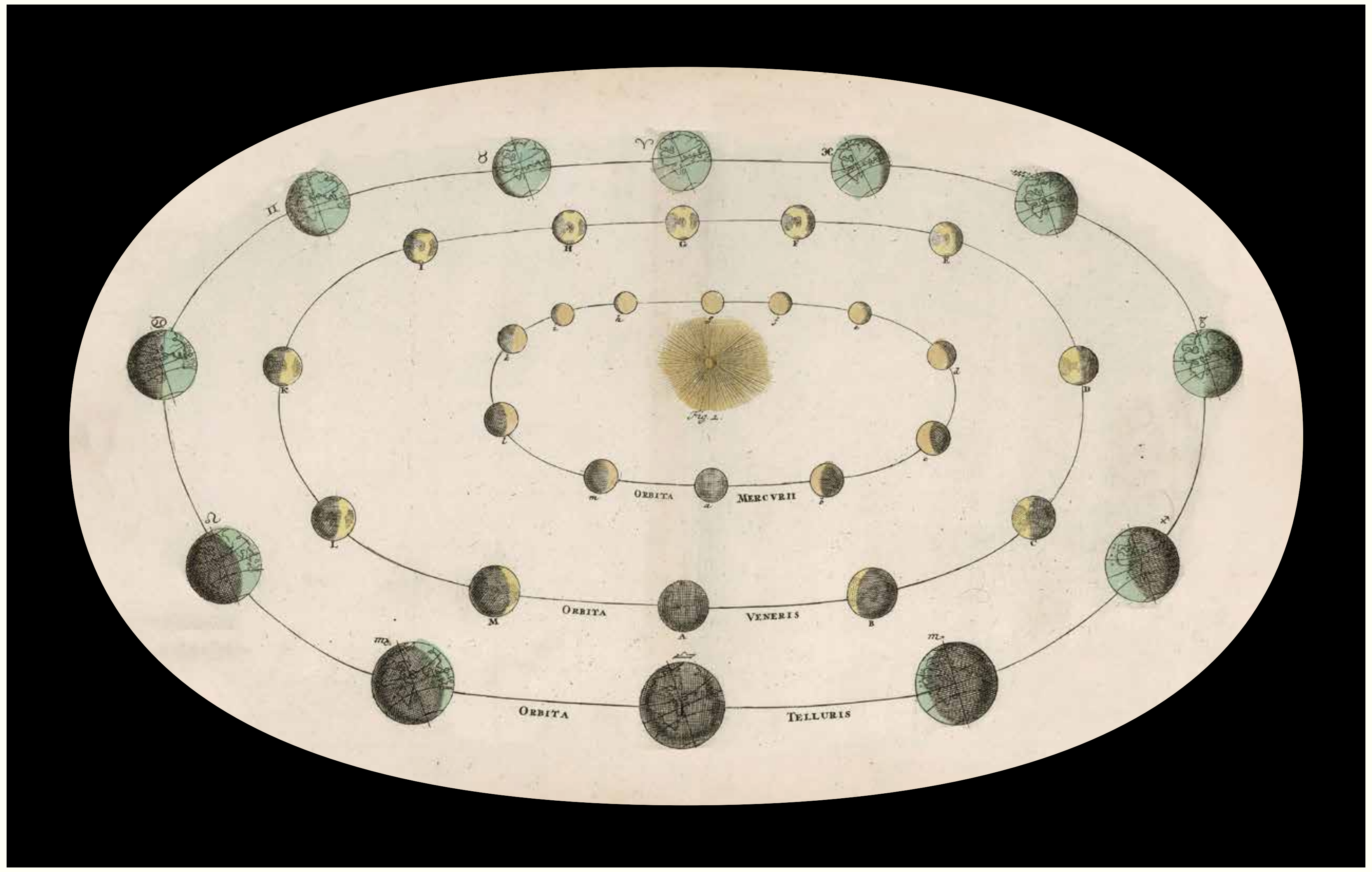


FIG. 1.
PHASES OF THE INFERIOR PLANETS AND MARKINGS OF VENUS.

The upper centre of the plate illustrates the orbits of Mercury, Venus and Earth, explaining why the inferior planets change their appearance as observers on Earth see differing amounts of their sunlit side. The illustration also hints at markings on Venus – a topic that remains controversial today.

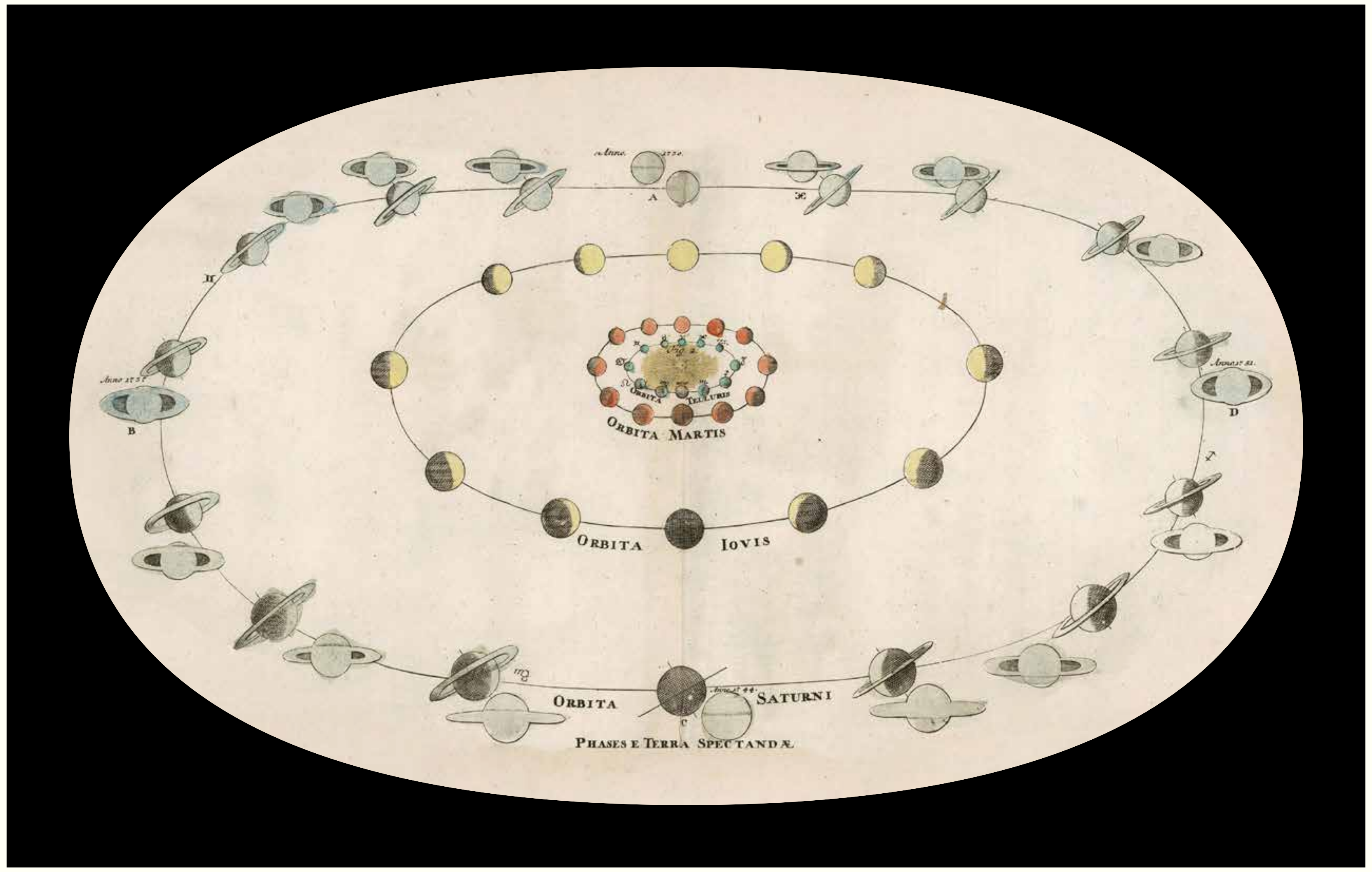


FIG. 2.
PHASES AND APPEARANCE OF THE SUPERIOR PLANETS.

The lower central illustration shows the orbits of Mars, Jupiter and Saturn in relation to the Earth and Sun. These planets are also shown to have a daylight and a dark side, but because we view them from the direction of the Sun, we only see their sunlit hemisphere (with a minor exception for Mars). For Saturn, Doppelmayr shows how its tilted orientation causes our view of the rings to change during the course of each orbit.

FIG. 3.
MARKINGS OF VENUS ACCORDING TO BLANCHINO.

This section shows various dark markings reported on Venus by Francesco Blanchino in his 1728 book on the subject. Beneath each figure he notes the observatory from which the observation was made.

While Venus's brilliant white clouds generally appear uniform for optical observers, dark markings are still occasionally reported – though generally dismissed as illusions or telescopic artefacts.

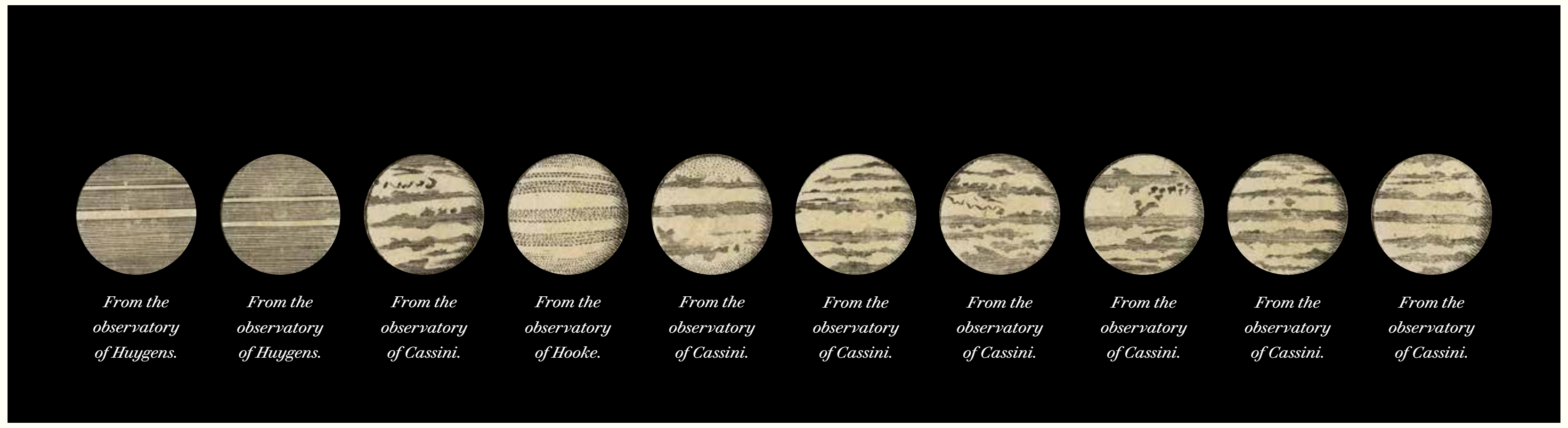


FIG. 4.
MARKINGS OF JUPITER.

Doppelmayr reproduces various sketches of Jupiter by observers, including Christiaan Huygens, Giovanni Domenico Cassini and Robert Hooke. Cassini's sketches in particular show some understanding of the turbulent cloud bands that dominate the planet's appearance.

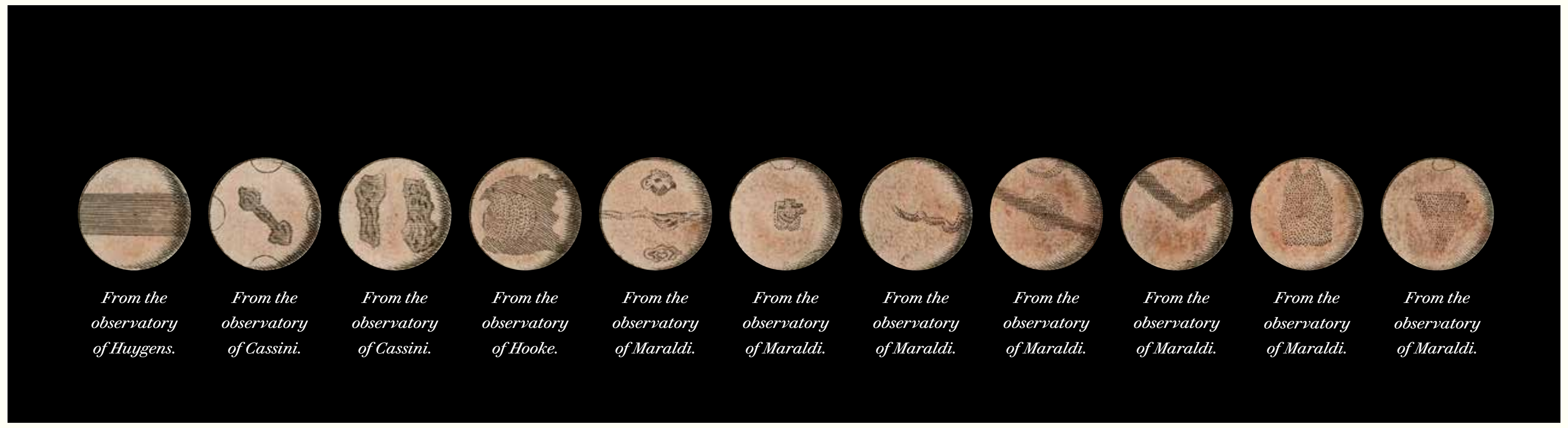


FIG. 5.
MARKINGS AND VARIATIONS OF MARS.

A series of views reproduce observations of Mars by Giovanni Domenico Cassini, Robert Hooke and the Italian Giacomo Maraldi. While early interpretations of the Martian surface varied considerably, the triangle on Maraldi's final drawing seems likely to be a representation of the region now known as Syrtis Major.

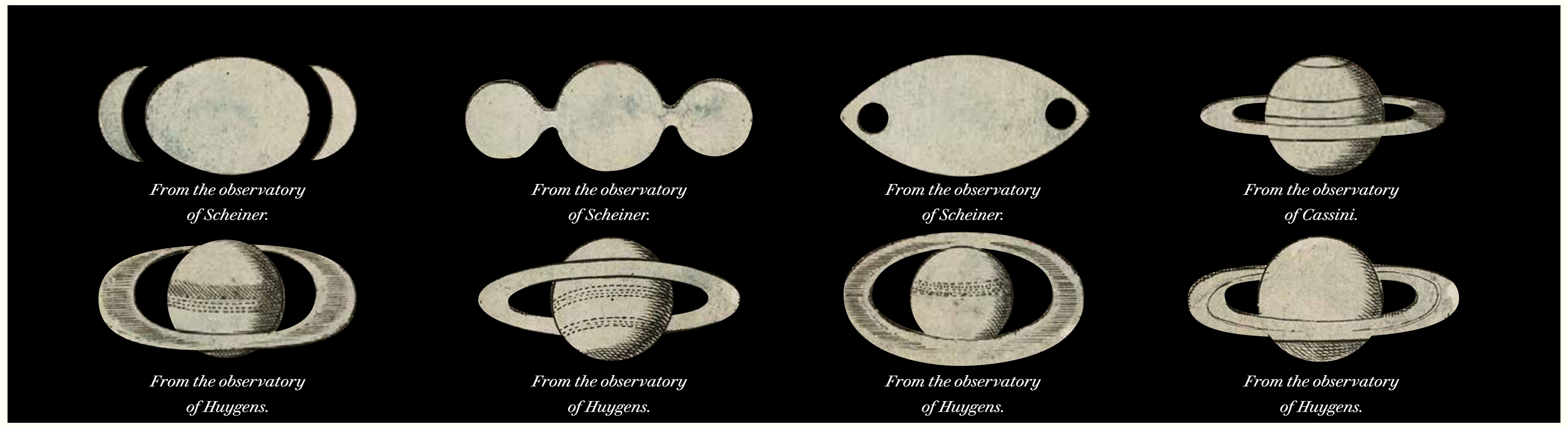


FIG. 6.
CHANGING INTERPRETATIONS AND MARKINGS OF SATURN.

Doppelmayr reproduces a handful of interpretations of Saturn's strange appearance by early telescopic observers, culminating in Christiaan Huygens's recognition of the rings. Four further images show changes in Saturn's appearance, owing to our changing views of the rings and the shadows that they cast upon the planet.

Nullum inter corpora cœleſtia, ex quo tempore Veteres ſacræ Uraniæ addicti omnē moverunt lapidem, ut Siderum naturæ & affectiones quam maxime forent in aprico poſitæ, cunctorum vicit magis admirationem, & multiformi ambage (ſi cum Plinio loqui liceat) torſit contemplantium ingenia, proximum quippe ignorari ſidus indignantiū, quam ipſa Luna, varietate macularum imprimis miranda; ſed nec mirari nos ſubeat, cum medijs tunc deſtituti, quibus nunc Lunam accuratius inſpicere & contemplari nobis hodie datum, oculis ſcilicet armatis; hinc etiam deficiente hoc Tuborum opticorum apparatu diverſas de Lunæ ſubſtantia è maculis nudo oculo viſis fovere opiniones non potuere non Antiqui illi rei ſidereæ Cultores; alij enim cum Clearcho & Argeſinace maculas Lunares noſtri Oceani imaginem in Luna tanquam in ſpeculo conſpicuam eſſe, alii haſce è certis corporibus, quæ Solem inter & Lunam jaceant originem ducere exiſtimarunt; alii Lunam vitream, non quidem exacte pellucidā, ſed ex parte opacam; alii partim igneam, partim opacam putarunt; & quæ ſunt multæ aliæ de corporis Lunaris ſubſtantia ſententiæ.

At multo feliciori ſucceſſu omnium primus celeberrimus ille Florentinorum Mathematicus Galilæus de Galilæis anno ſuperioris ſeculi decimo, quo utiliſſimū Tuborum opticorum inventum luci publicæ traditum, id negotium tentavit, quod dein Scheinerus & alii ſatis ſuperq; dedere probatum, imò plures hodie Tubis prædictis ad majorem perfectionem nunc perductis, rem acu, quod ajunt, multo felicius tangere videntur, ſi pro indubio aſſerunt, quod Luna innumeris ſcateat montibus, qui noſtros altitudine, habito reſpectu globi Lunaris ad noſtrum, ſexagies ferè minoris, ſuperent; porro quod eædem profunditates, quæ prægrandibus ſemper in ambitu ſuo exteriori, plerumque circulari, mœnium inſtar, cinguntur eminentijs, innumeras fere et multō plures, ſed non tantas et tam profundas, quam noſtra exhibeat Terra, ſi huius cavitates ſuis deſtituerentur maribus; denique quod partes multæ in Luna obſcuræ, quæ ſub primo conſpectu non apparent profundæ, ideoq; pro materia liquida, maribus ſcilicet multorum forſan judicio cenſendæ, adhibita accuratiori inſpectione, teſte Viro celeberrimo D.no de la Hire, nihilominus profundæ nec tamen liquidæ deprehendantur; ut hinc haud pauci cum acutiſſimo Galilæo Lunam pro corpore, materiam à Terra diverſam habente exiſtimare poſſent, in qua etiam fortaſſe ſubſtantiæ & res creatæ exiſtant, quæ operationes edant ab imaginatione noſtra ſicut remotas, ita & prorſus alienas; quippe quæ nullam cum noſtris ſimilitudinem habeant, & proin omnino ſint à noſtra cogitatione diſcrepantes.

Quamvis autem Luna profunditatibus et eminentiis quampluri mis ſit referta, ſæpiſſime tamen contingit, ſuperficiem Lunæ in certis à Sole diſtantiis adeo immutatam videri, ut magnus ille montium & profunditatum numerus, qui nuper admodum diſtinctiſſime obſervari poterat, non amplius tunc ſub conſpectum cadat; ratio huius mutationis ex ipſa figura ſuperiori A intermedia facile pateſcit, quod ſcilicet profunditates inter novilunia et quadraturas, Luna creſcente à dextris maxime, decreſcente autem hac à ſiniſtris potiſſimum altiſſimorum circumjacentium montium obtegantur umbris; et quidem quod inſuper tales pro vario Solis ad Lunam poſitu perpetuo immutentur (quæ proinde etiam novæ maculæ denominari ſolent) eminentiæ autem, cum Sol illas à latere illuminat, quam maximè conſpicuæ reddantur; cum è contrario à quadraturis ad oppoſitionem ſuperficies Lunæ, dum Sol hiſce inæqualitatibus magis magisque verticaliter imminere pergit, et omne, quidquid umbroſum ante fuit, pedetentim illuminat, aliam ſemper exhibeat faciem, ut tandem luminoſa et albicans appareat.

Ex hoc fundamento bina noſtra Schemata in delineatione macularum notabilem etiam differentiam involvunt, eò quod primum, HEVELIANUM puta, Lunâ in oppoſitione cum Sole exiſtente, hoc eſt, in plenilunio deſignatum, alterum vero, RICCIOLINUM ſcilicet, è pluribus Lunæ phaſibus in unum corpus fuerit collectum. In denominationibus macularum, utpote ſignis et ſignificationibus arbitrarijs, dictos Auctores inter ſe differre hic in aperto videmus, cum Hevelius nomina marium, regionum, fluminum et montium noſtrorum imitatus, Ricciolus autem illuſtrium & de re ſiderea optimè meritorum Aſtronomorum, complurium præſertim ſuæ Societatis Mathematicorum nomina pro uſu Aſtronomico ſibi elegerit.

Bini circa Lunam limbi ſe invicem ſecantes nihil aliud, quam motus alicuius in Luna libratorii terminos, intra quos perpetua deprehenditur librationis variatio, ſubindicant; qui hodie demum per Tubos è diverſa macularum noñullarum mutatione obſervatus, nec Veteribus olim notus fuit; eandem quippe nobis faciem conſtantiſſime ſemper Lunam obvertere exiſtimantibus: peragit autem hæc motum ſuum libratorium per quatuordecim circiter dies trigeſima ſexta tantum diametri ſuæ parte in plagam ſuperiorem ab Auſtro Corum verſus, dum Luna verſatur in deſcendentibus ſignis, in aſcendentibus autem per idem tempus et ſpatium ſecundum Hevelii et aliorum obſervationes retrorſum iterum, et ſic porro vacillare videtur.

Eodem temporis, menſtruo nempe ſpatio Lunam quoque orbitam ſuam, dum porro et retro librationem abſolvit, peragrare, et pro vario ſitu diverſas phaſes, hoc eſt, luminis figurationes varias, prout figura media inferior B. ſubindicat, ſimul exhibere deprehendimus, cum pars Lunæ illuminata mox creſcere, mox decreſcere pro maiori vel minori Lunæ à Sole diſtantia debeat, quæ ſanè luminis non proprii ſed à Sole mutuati ſigna ſunt indubia; interim non obſtante, quod lumen quoddam debile haud multò ante et poſt novilunia Lunæ quaſi innatum, de quo olim multa inter Aſtronomos movebantur lites, maculas Lunares nonnihil reddat conſpicuas, cum extra omne dubium ſit poſitum, hoc ſuam originem à Terræ noſtræ ſuperficie duodecies, et quod excedit, maiori quam illa Lunæ, radios Solis tunc temporis omnium copioſiſſimos in illam reflectente, habere, eò quod hac reflexione ceſſante, ipſum etiam putativum lumen nonnunquam planè cum ipſa Luna in Eclipſibus diſparuerit.

Ultimo denique loco duplices pro Luna Menſuræ longitudinariæ notandæ quoque veniunt, quarum unam pro diſtantiis et magnitudine macularum ut et diametro Lunari, quæ ſecundum Hevelium 494 menſuratur milliaribus, per Germanica milliaria definiendis, alteram pro quantitate Eclipſium Lunarium tam ſecundum digitos eclipticos quam eorum partes exactè deſcribenda, huic tabulæ appoſuimus.

SELENOGRAPHIC TABLE

(TABULA SELENOGRAPHICA)

Doppelmayr depicts the principle markings on the surface of the Moon, following the naming schemes of his time.

The near side of the Moon is a familiar sight to everyone on Earth, and has been since long before the invention of the telescope. With a diameter of roughly half a degree in the sky, the Moon is large enough to make out both bright and dark markings on its surface. Different cultures have told stories of the patterns they saw there, with the most popular being the 'Man in the Moon' (seen as either a face or a full figure) and the eastern 'Rabbit in the Moon'.

Despite these differences in interpretation, stargazers from classical Greece to India, China and beyond recognized early on that the Moon's changing phases are governed by how much of the visible surface is illuminated by the Sun, but the nature of the surface markings was long disputed. As early as the mid-5th century BCE, Greek philosopher Democritus (*c.* 460–370 BCE) attributed the markings to mountains and valleys on the lunar surface. This early insight was largely forgotten in later centuries, however, as the Aristotelean model of the universe became widespread. While the Moon occupied the innermost of the heavenly spheres and was thus subject to more change than the other celestial bodies, Aristotle (384–22 BCE) nevertheless viewed it as an unchanging and perfect sphere, created by the mixing of fire from the uppermost 'sublunary' sphere and aether from the realm of the heavens.

The changing lunar phases and the relationship between Sun, Earth and Moon provided an ingenious method of estimating their distance and scale: since at its first or last quarter (when exactly half of its disc is illuminated) the Moon must sit at the right-angled corner of a triangle linking it with the Earth and Sun, the observed angle between Sun and Moon will indicate their relative distances and the scale of the entire system. If the Sun was infinitely distant then this angular separation would be precisely 90 degrees, but in the mid-3rd century Greek astronomer Aristarchus of Samos (*c.* 310–230 BCE) estimated it to be just 87 degrees. From this he was able to calculate that the Moon was about twenty Earth radii away, and that the Sun was twenty times further away and twenty times the Moon's size since they appear roughly equivalent in the sky. Since Earth's dimensions were already known, it was simple to prove that the Moon was therefore a substantial body in its own right, while the Sun must be larger than Earth itself.

Aristarchus's geometry was right, but working long before the telescope, his estimates of precisely when the Moon was half-illuminated, and measurements of the angle separating it from the Sun at that moment, were significantly off. Today we know the Moon's distance is closer to sixty Earth radii, and the Sun is about four hundred times further still. Regardless of its precise value, the fact that the Sun was clearly much larger than Earth raised significant questions for classical and medieval thinkers attempting to model an Earth-centred solar system. Indeed, it was enough to convince Aristarchus that the Sun, rather than Earth, must be the centre of everything and led to one of the first attempts at a heliocentric cosmology.

As to the Moon's physical nature, Aristotle's idealized sphere theory benefitted by association from the widespread adoption of his entire paradigm of physics, but it took some time to see off its rivals. As late as the 2nd century CE the Greek philosopher Plutarch (46–119 CE) wrote a remarkable essay in which he argued that the Moon was a world not dissimilar to Earth, with markings created by its landscape features.

With the spread of Christianity, the incorporation of Aristotle's physics and cosmology into the teachings of the Catholic Church ensured that a 'perfect sphere' Moon became the accepted view among European scholars for more than a millennium. It was only at the start of the 16th century that advances in technology provided startling evidence that Aristotle had been wrong.

Beginning in 1609, both Galileo Galilei (1564–1642) and the English observer John Harriot (1745–1817) studied the Moon and made sketches of its appearance through the newly invented telescope. Harriot's drawings went unpublished, while Galileo incorporated them, along with other groundbreaking discoveries, in his *Siderius nuncius* (Starry Messenger) of 1610. Galileo not only recorded details on the surface of the Moon, but showed how their appearance varied with the lunar phases, according to the angle of sunlight striking them and the length of the shadows they cast. Such shadows could only be explained by differences in elevation; the Moon must have hills, valleys and circular pits on its surface. Galileo suggested that the dark and largely smooth areas might be seas, with land forming the brighter areas that separated them. The discovery of Earth-like lunar relief features, coupled with the observation of shifting spots on the Sun (another supposedly unchanging body) helped shake faith in the old Aristotelean ideas almost as much as the theories of Copernicus (1473–1543) and Kepler (1571–1630).

As the century progressed and telescopes improved, stargazers of varying talents attempted to map the lunar surface. The earliest to be published was that of Michael van Langren (1698–1675) in 1645, but Doppelmayr chooses to reproduce two slightly later maps that became standard authorities for more than a century. The first is from Polish astronomer Johannes Hevelius (1611–87) and was published in his 1647 *Selenographia*, the first work dedicated to lunar theory; the second is the work of Jesuit priests Giovannia Battista Riccioli (1598–1671) and Francesco Maria Grimaldi (1618–63), who published it as part of Riccioli's *Almagestum novum* (New Almagest) in 1651. Comparison of the two maps will immediately show two different naming schemes at play, but it is Riccioli's map from which many of our modern names for the lunar markings (in particular those denoting the 'seas' or *maria*) derive.

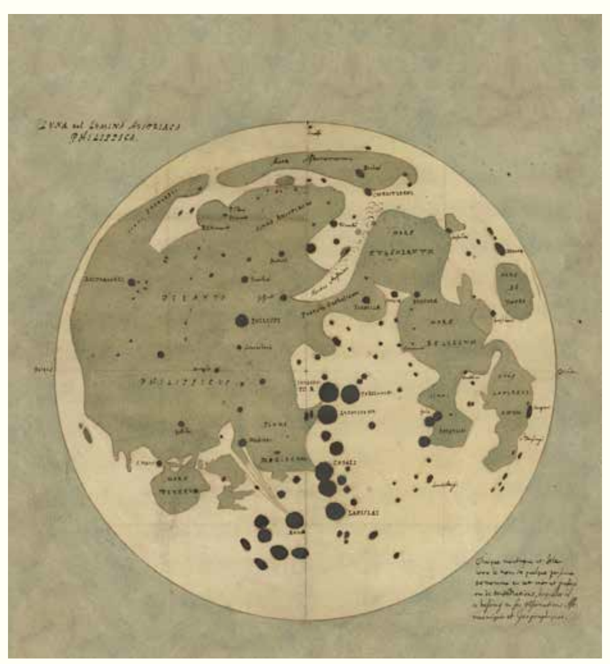


FIG. 1.

FIG. 2.

FIG. 1. The first map of the Moon to include a system of nomenclature, published by Dutch cartographer Michael Florent von Langren in 1645. Few of the roughly 300 names introduced by von Langren have survived and those that persist are now mostly applied to different features.

FIG. 2. Athanasius Kircher's *Typus Corpus Lunaris* of 1669 incorporates Kircher's own observations with those of Christoph Scheiner.

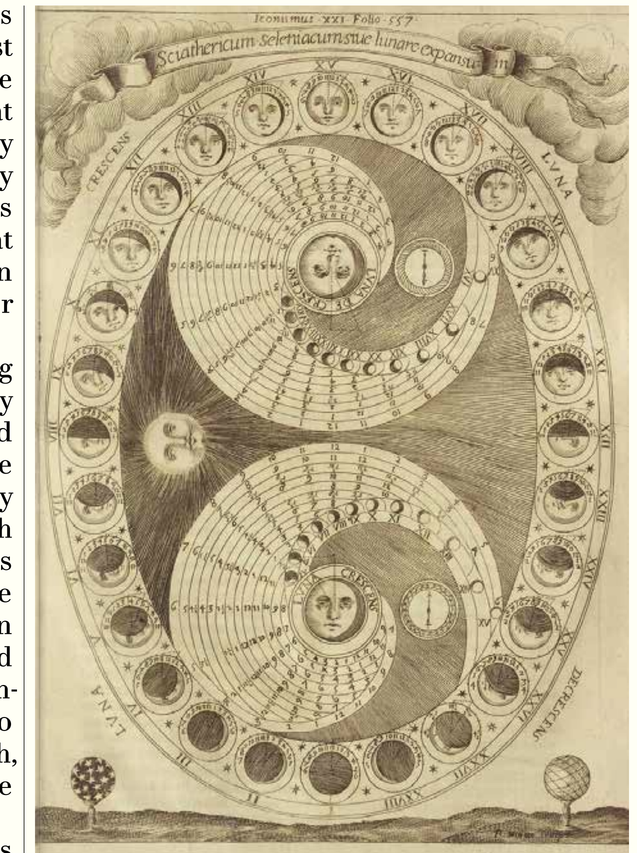


FIG. 3.

FIG. 3. A plate from Kircher's 1646 *Ars Magna Lucis et Umbrae* (*Great Art of Light and Shadow*) depicts the 28 distinct phases that describe the lunar month, from New Moon, through crescent, first quarter and waxing gibbous states to reach Full Moon, and then back through waning gibbous, last quarter and decrescent to the next New Moon.

FIG. 1.
LUNAR MAP AFTER HEVELIUS.

The left-hand side of Plate 11 reproduces one of the three large lunar charts from Johannes Hevelius's *Selenographia* of 1647. The book – the first dedicated entirely to the astronomy of the Moon – introduced a system of nomenclature in which features were named largely after classical features and geographical regions on Earth.

FIG. 2.
LUNAR MAP AFTER RICCIOLI.

The other side of plate 11 is dominated by a map drawn from Giovanni Battista Riccioli's *Almagestum Novum* (*New Almagest*) of 1651. This map was in fact compiled by another Jesuit astronomer, Francisco Maria Grimaldi, and in contrast to Hevelius's first-hand work, draws on several different sources. The resulting map bears a far stronger resemblance to the Moon as most people saw it, and this no doubt encouraged the wide adoption of Riccioli's own naming system in which seas bore the name of abstract concepts, while other features were named after scientists and philosophers both ancient and modern.

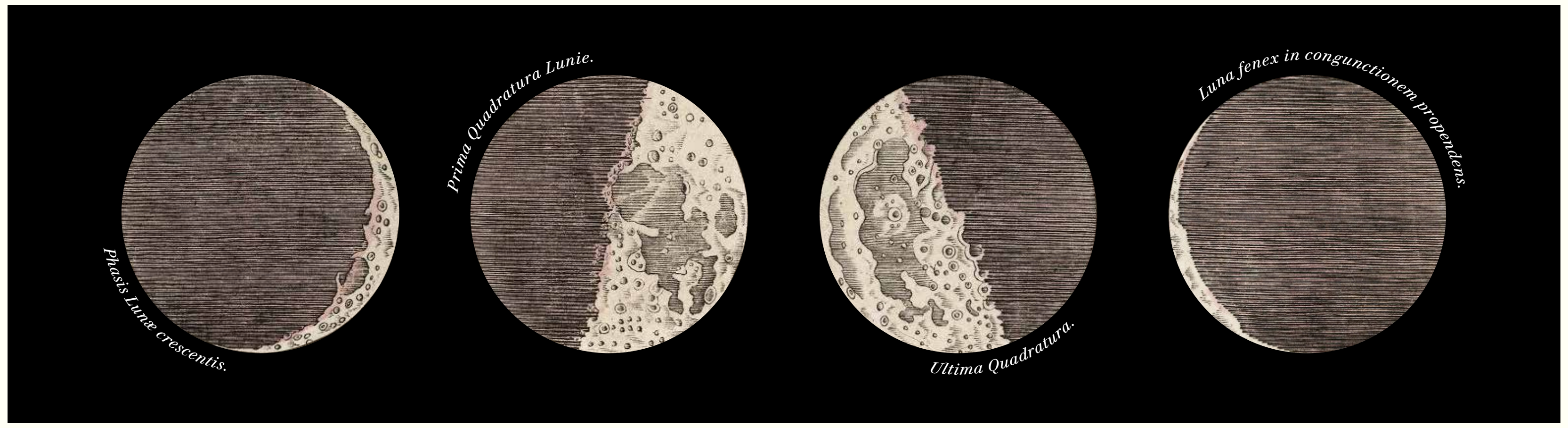


FIG. 3.
PHASES OF THE MOON.

The four corners of Plate 11 are adorned with miniature maps representing the Moon in its crescent (*crescentis*), first quarter (*prima quadratura lunie*), last quarter (*ultima quadratura*) and decrescent (*luna fenex in conguncionem propendens*) phases.

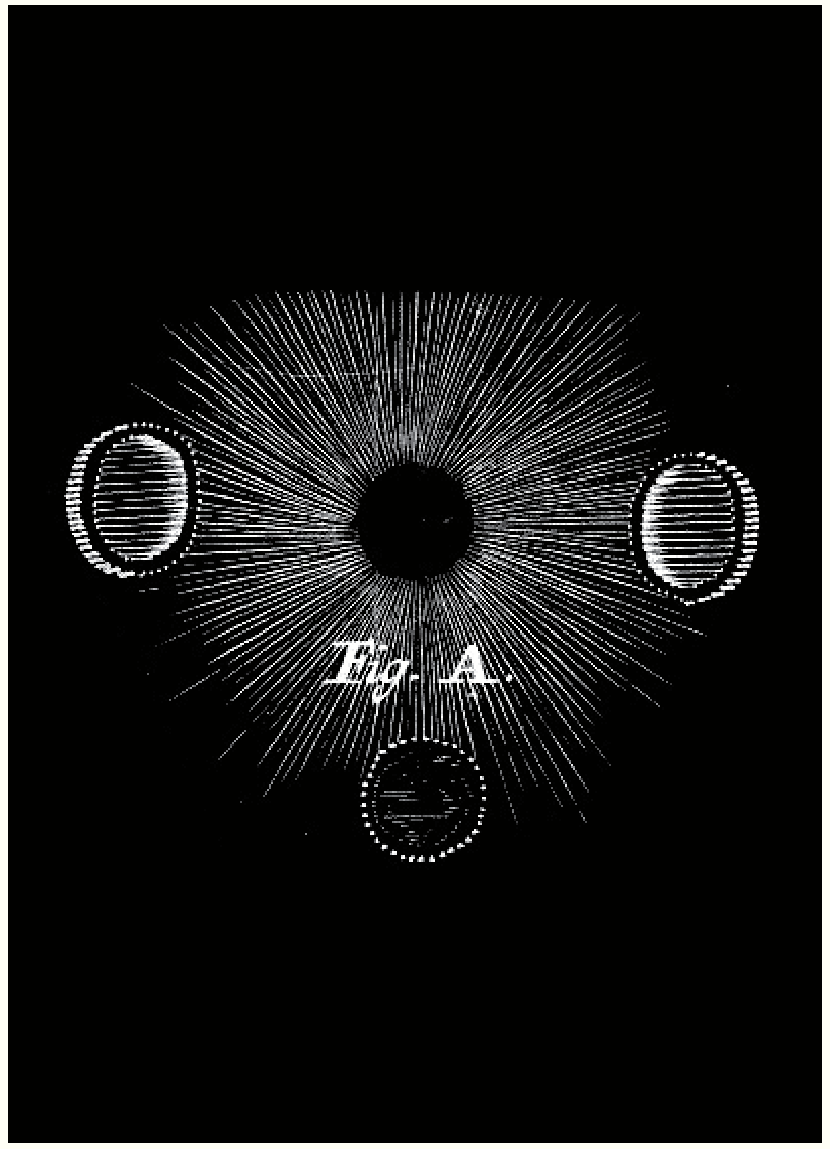


FIG. 4.
SHADOWS ON THE LUNAR SURFACE.

This small diagram illustrates the way in which shadows are cast across craters on the lunar surface in different directions depending on the orientation of the Sun.

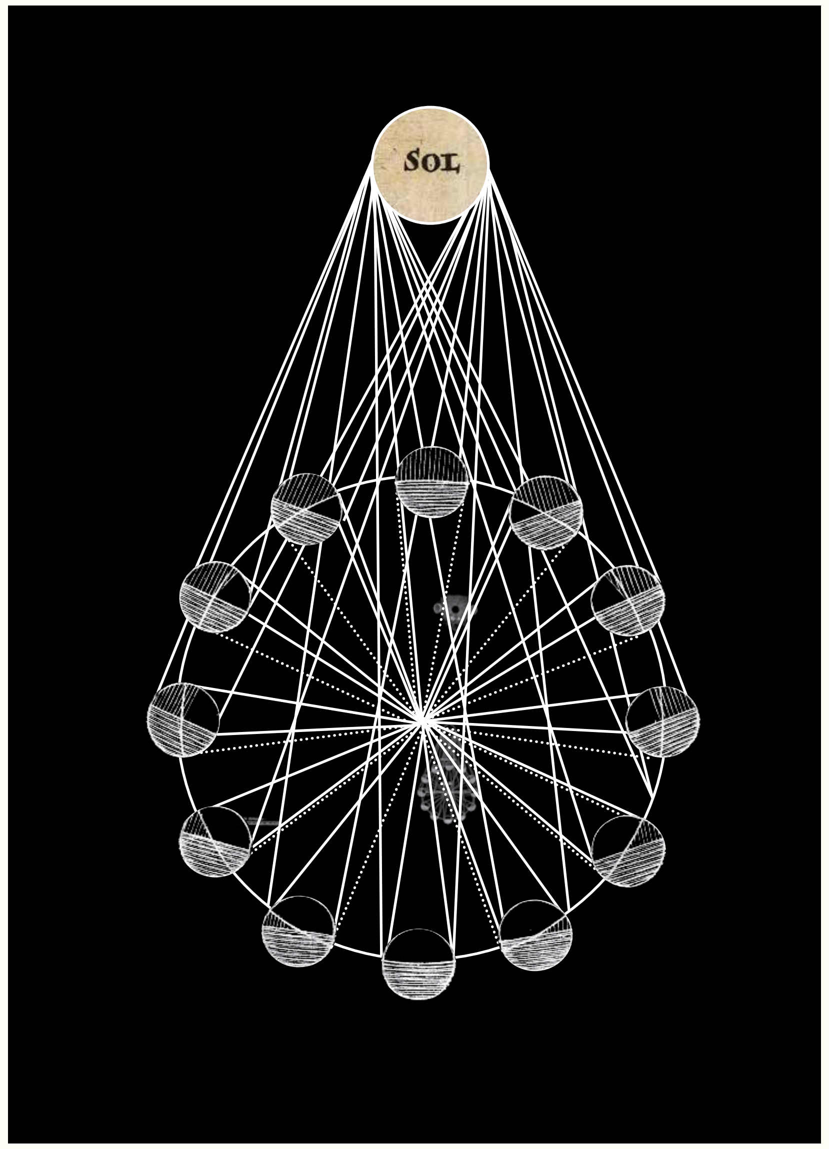


FIG. 5.
LUNAR LIBRATION.

This diagram explains the principle of libration – due to our changing perspective and the Moon's relative proximity to Earth, different regions come into view along the limb of the Moon at different points in its orbit.

FIG. 6.
SCALE, GERMAN MILES.

A map scale shows distances in German *landmeile* (roughly equivalent to 7.5 km or 5 miles).

FIG. 6.
ASTRONOMICAL DIGITS.

A now-obsolete system of measurement dividing the face of the Moon (or Sun) into twelve 'digits', each of which was further divided into 60 minutes.

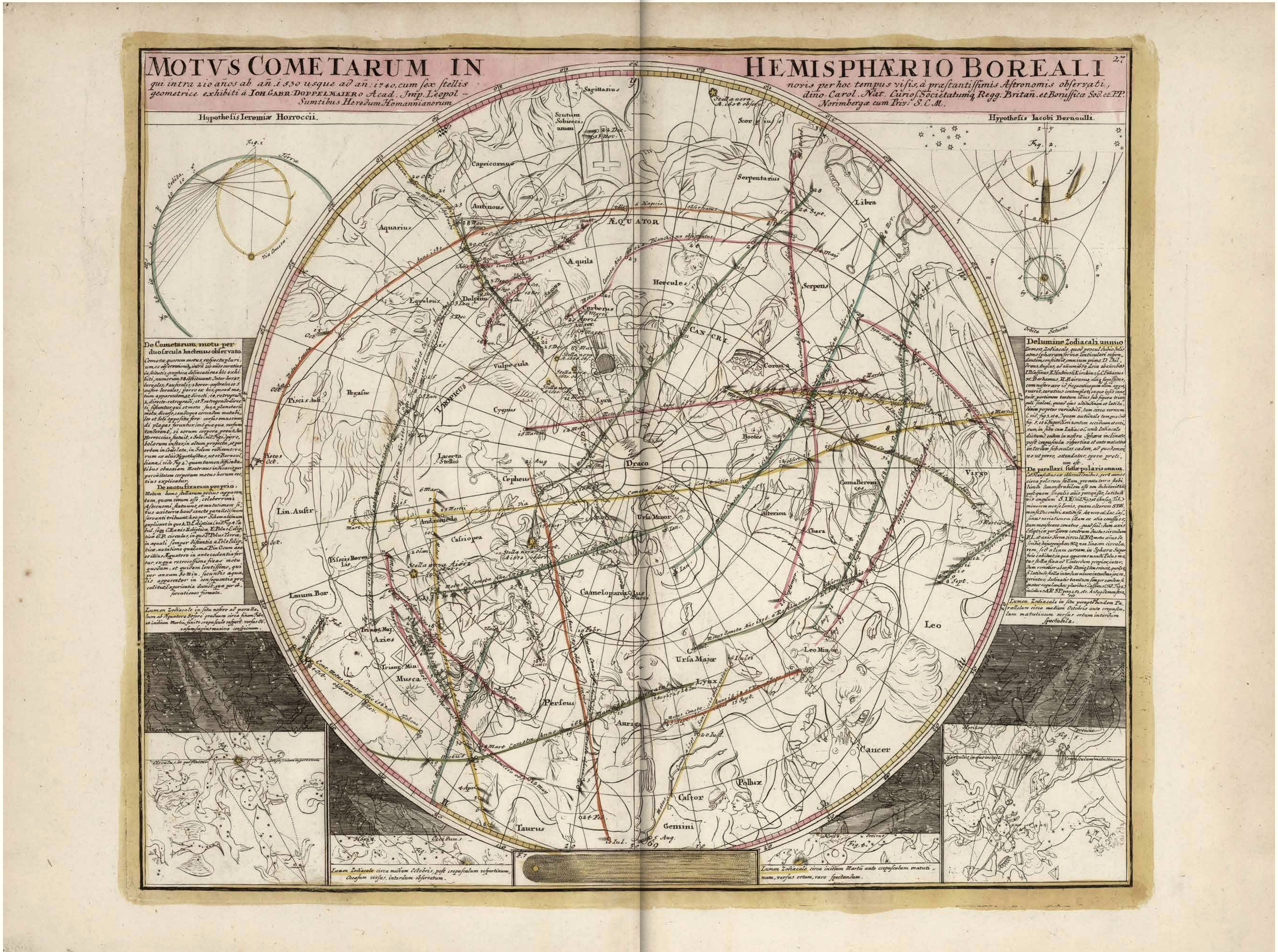

MOTUS COMETARUM IN HEMISPHÆRIO BOREALI
27
qui intra 210 annos ab an. 1530 usque ad an. 1740, cum sex stellis novis per hoc tempus visis, à præstantissimis Astronomis observati,
geometrice exhibiti à IOH. GABR. DOPPELMAIERO Acad. Imp. Leopol-dino-Carol. Nat. Curios. Societatumq Regg. Britan. et Borussica Sod. et P.P.
Sumtibus Heredum Homannianorum
Norimbergæ cum Priv. S.C.M.
Hypothesis Ieremiæ Horroccii.
Hypothesis Iacobi Bernoulli.
De Cometarum motu per duo secula hactenus observato.
De lumine Zodiacali annuo
De parallaxi fixarum annua
De motu fixarum proprio
Æ QUATOR
TROPICUS CANCRI
Draco
Ursa Minor
Ursa Major
Cassiopea
Cepheus
Andromeda
Perseus
Auriga
Camelopardalus
Lynx
Hercules
Aquila
Delphin
Equuleus
Pegasus
Cygnus
Lyra
Vulpecula
Lacerta
Aquarius
Antinous
Capricornus
Sagittarius
Scutum Sobiesci
Serpentarius
Serpens
Libra
Corona
Bootes
Virgo
Coma Beren.
Leo
Leo Min.
Cancer
Gemini
Castor
Pollux
Taurus
Aries
Musca
Pisces
Lin. Austr.
Lin. Bor.
Triang. Maj.
Triang. Min.
Stella nova
Lumen Zodiacale in situ nostro ad parallelum 49 gradus, circa initium Martii, finito crepusculo vespert. versus occasum, saepius conspicuum.
Lumen Zodiacale circa medium Octobris, post crepusculum vespertinum, occasum versus, interdum observatum.
Lumen Zodiacale circa initium Martii ante crepusculum matutinum, versus ortum, raro spectandum.
Lumen Zodiacale in situ perageti fundem parallelum circa medium Octobris ante crepusculum matutinum versus ortum interdum spectabile.

FIG. 1. ARGENTUM.

FIG. 2. AURORN.

FIG. 3. MILES.

FIG. 4. DOMINUS ASCHONE.

KOMETENBUCH (1587).

Created by an anonymous author in Flanders around 1587, the *Kometenbuch* is an extraordinary illuminated manuscript describing the astrological interpretation of comets. Drawing from classical, medieval and Arabic sources, the book's illustrations draw on the sometimes fanciful descriptions of the appearance of historic comets, depicting them as lances, tumbling wheels and even faces. With its roots in a philosophy that saw comets as phenomena of the upper atmosphere appearing in the spheres of air and fire, it is little wonder

FIG. 5. VERU.

FIG. 6. PERTICA.

FIG. 7. ROSA.

FIG. 8. SCUTELLA.

that the book is mostly concerned with the possible consequence of these apparitions for people on Earth. Despite their fantastical elements, the *Kometenbuch* illustrations hint at the wide variety in the appearance of physical comets, created by interactions of their gas and dust tails, central comas, and the way these reflect sunlight. While most comets make only rare returns to the skies of Earth, at least one of those shown here (the comet 'Veru' of 69 CE, at top left of this page) has in modern times been linked to a predictable short-period comet, now known as Swift-Tuttle, that returns once every 133 years.

DRAMATIS PERSONAE

ALFONSO X
OF CASTILE
(1221–84)

NICOLAS
D'ORESME
(*c.* 1320–82)

JOHANNES
REGIOMONTANUS
(1436–1476)

POPE
PAUL III
(1468–1549)

NICOLAUS
COPERNICUS
(1473–1543)

MARTIN
LUTHER
(1483–1546)

PETRUS
APIANUS
(1495–1552)

PHILIP
MELANCHTHON
(1497–1560)

ANDREAS
OSIANDER
(1498–1552)

GEORG JOACHIM
RHETICUS
(1514–74)

TADEÁŠ
HÁJEK
(1525–1600)

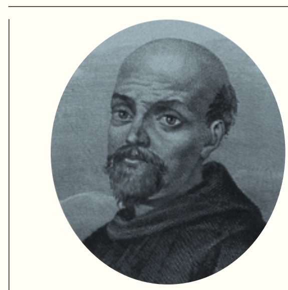
TYCHO
BRAHE
(1546–1601)

RUDOLF II
(1552–1612)

GALILEO
GALILEI
(1564–1642)

HANS
LIPPERSHEY
(c. 1570–1619)

JOHANNES
KEPLER
(1571–1630)



BENEDETTO
CASTELLI
(1578–1643)

GIOVANNIA
BATTISTA RICCIOLI
(1598–1671)

ISMAËL
BULLIALDUS
(1605–94)

JOHANNES
HEVELIUS
(1611–87)

JOHN
WILKINS
(1614–72)

SETH
WARD
(1617–89)

FRANCESCO
MARIA GRIMALDI
(1618–63)

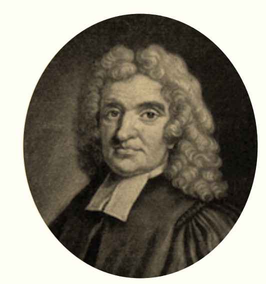
NICOLAUS
MERCATOR
(1620–87)

THOMAS
STREETE
(1621–89)

CHRISTIAAN
HUYGENS
(1629–95)

JOHANN
CHRISTOPH STURM
(1635–1703)

ISAAC
NEWTON
(1643–1727)



JOHN
FLAM2STEED
(1646–1719)

EDMOND
HALLEY
(1656–1742)

DAVID
GREGORY
(1659–1708)

JOHANN BAPTIST
HOMANN
(1664–1724)

JOHN
WALLIS
(1674–1738)

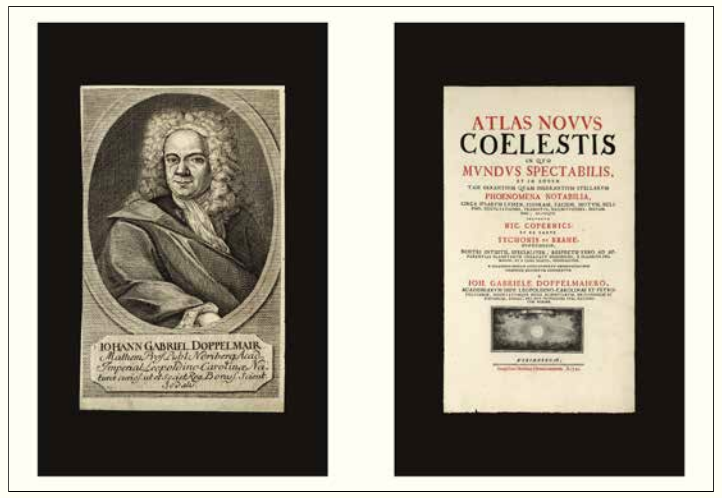
JOHANN
DOPPELMAYR
(1677–1750)

CHARLES
VI
(1685–1740)

JOHN
HARRIOT
(1745–1817)

NICOLAS
BION
(d. 1733)

PHAENOMENA — *Additional Pages*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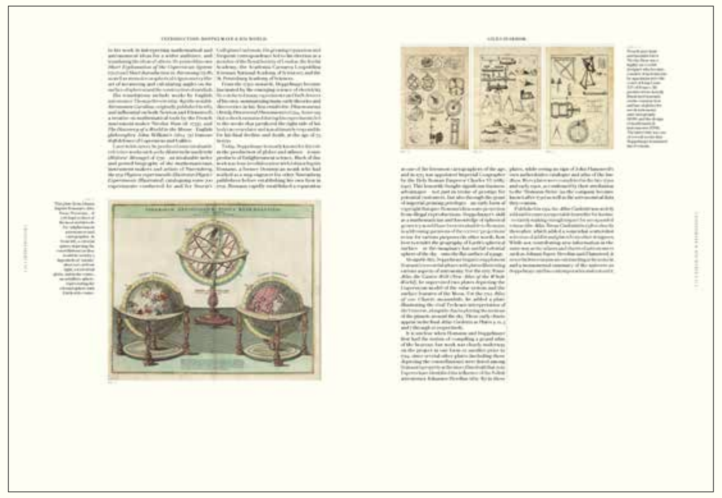
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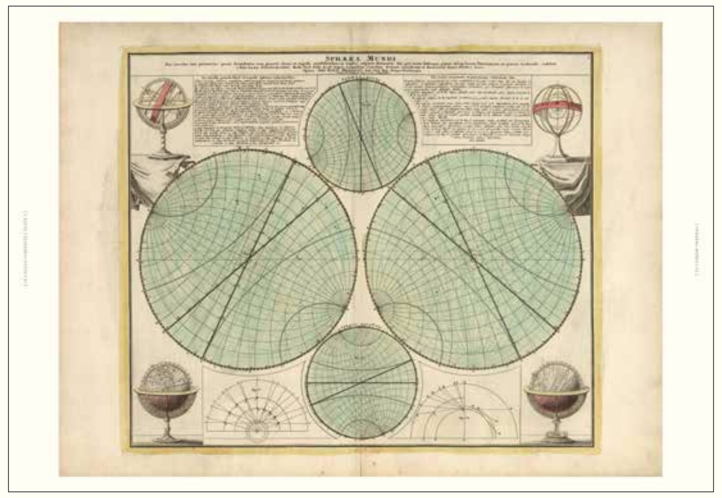
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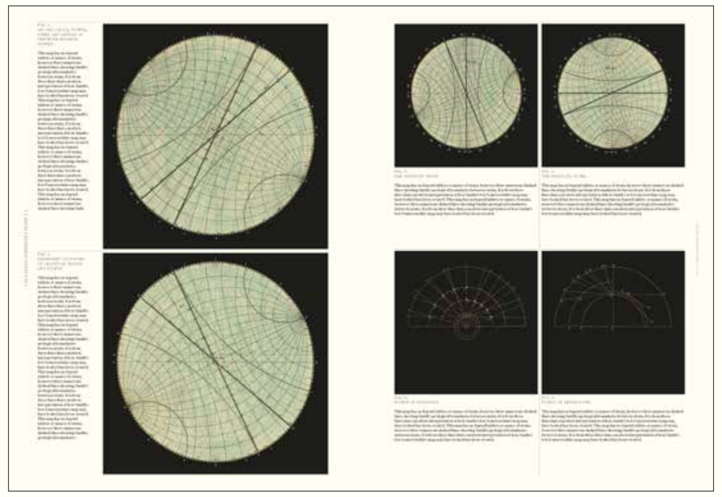
PP. 20–21.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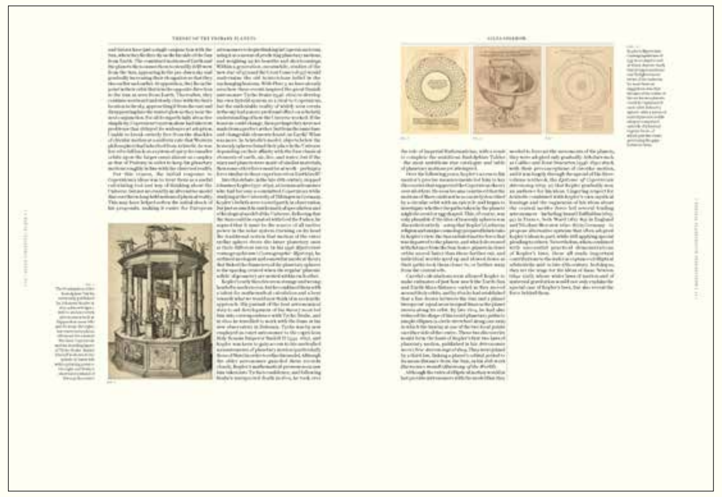
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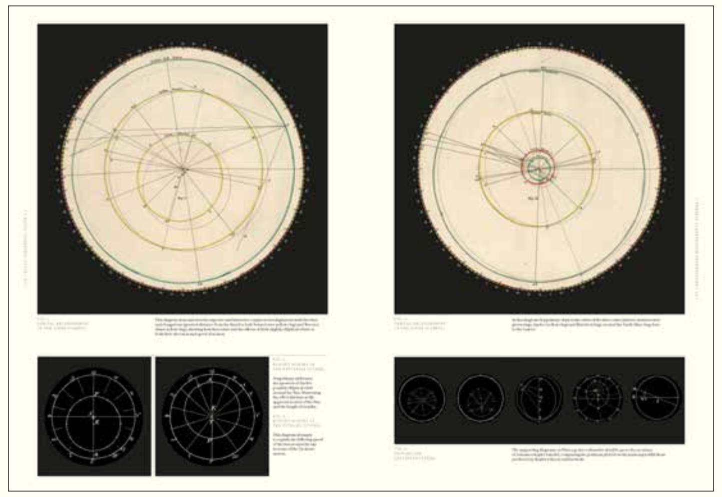
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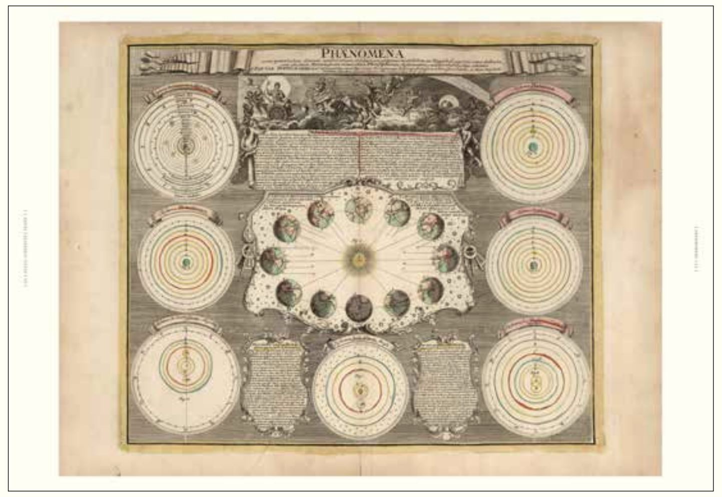
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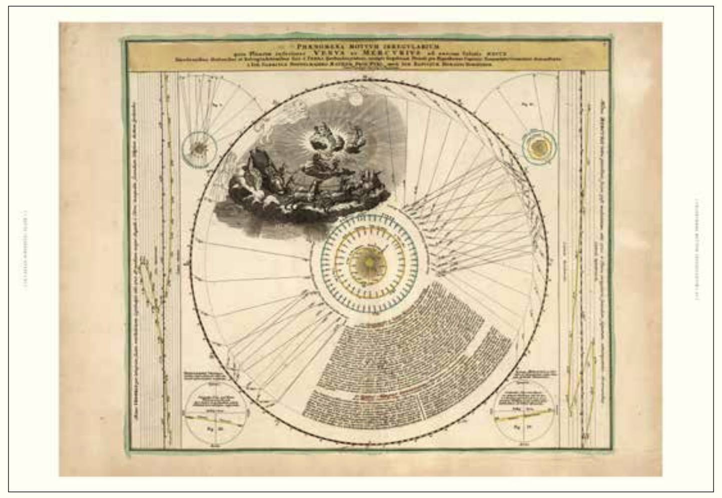
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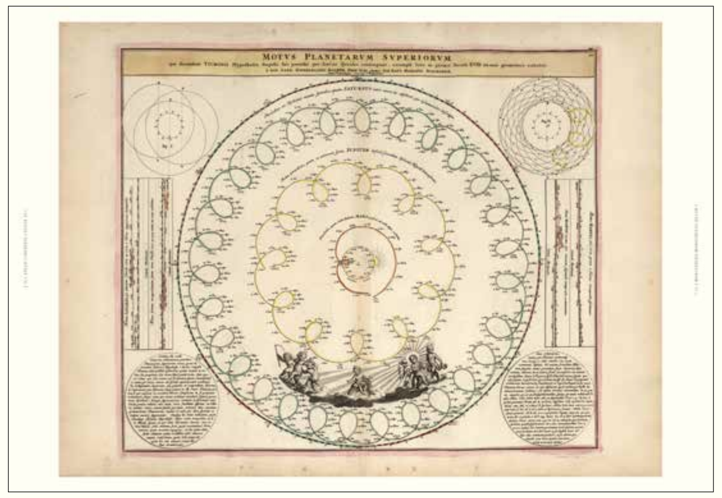
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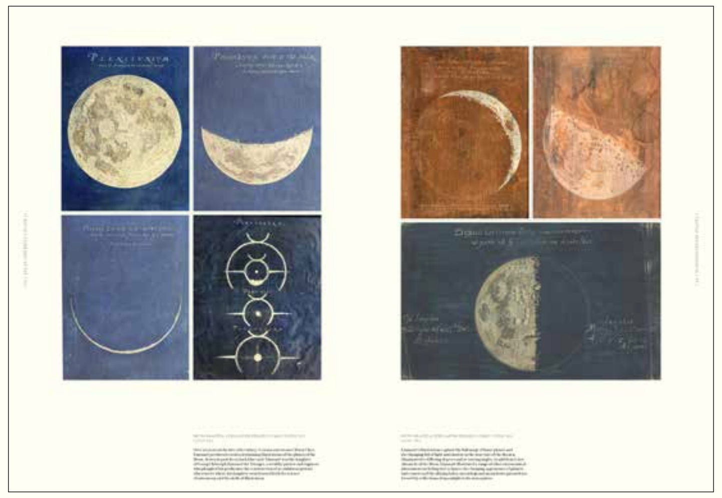
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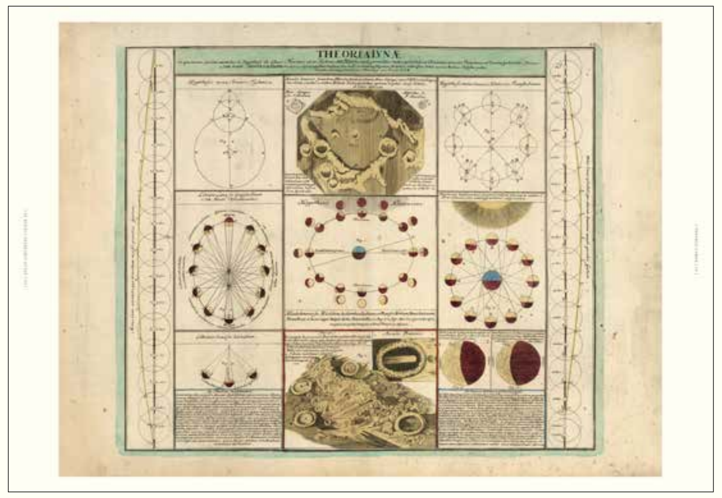
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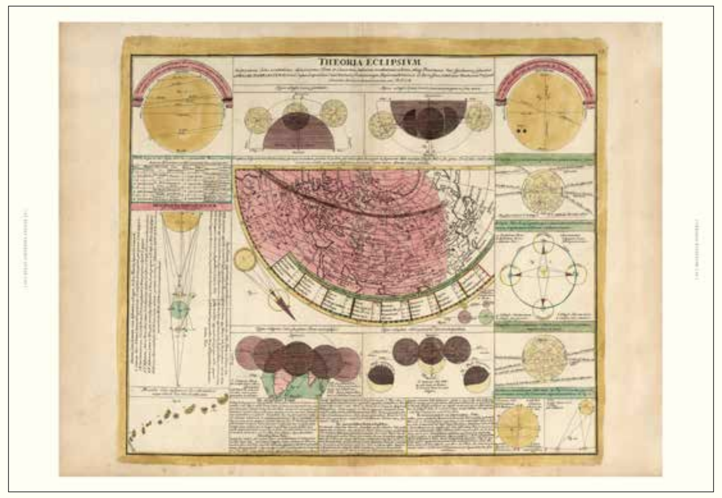
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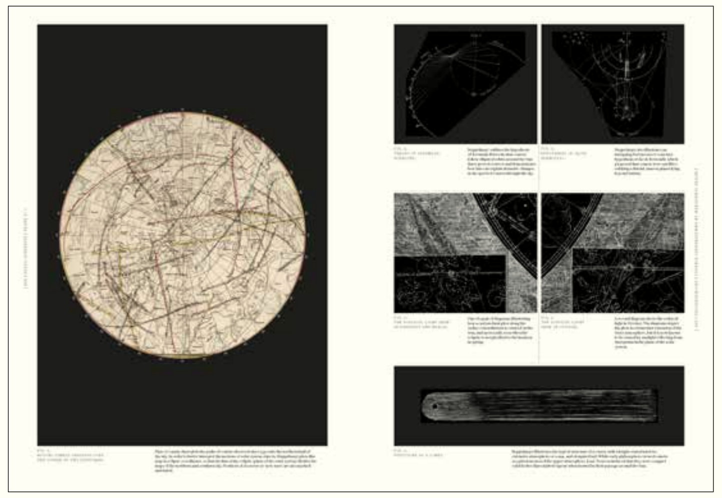
PP. 120–121.


PP. 184–185.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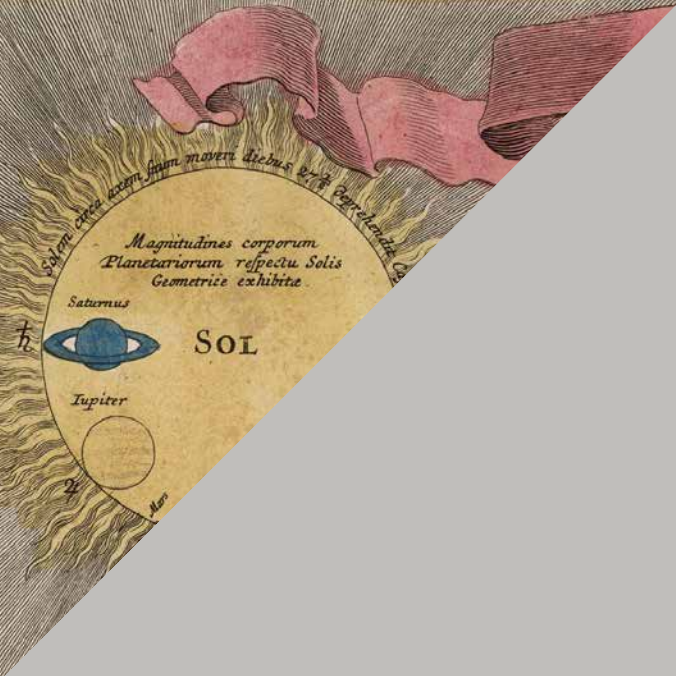

Thames
&Hudson