

LUMEN

The Art and Science of Light
800–1600

Edited by Kristen Collins and Nancy K. Turner


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LUMEN

The Art and Science of Light 800–1600

EDITED BY KRISTEN COLLINS AND NANCY K. TURNER
WITH CONTEMPORARY CONTRIBUTIONS BY GLENN PHILLIPS

With essays by Taha Yasin Arslan, Adam S. Cohen, Seb Falk, Margaret Gaida, Elina Gertsman, Cynthia Hahn, Liz James, Christopher R. Lakey, Bissera V. Pentcheva, G. Gabrielle Starr, and Abbey Stockstill

J. Paul Getty Museum, Los Angeles

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Foreword

Sine luce nihil videtur (Without light, nothing is seen)

—Roger Bacon (ca. 1219/20–ca. 1292)

From antiquity, the understanding and characterization of light has been part of a dynamic scientific discourse on the nature of the cosmos and the mechanics of human perception. While contemporary society separates science and spirituality, in medieval Europe they were comingled: the science of light was harnessed by artists, scholars, and theologians to perceive and understand their world, both the sacred and the secular. *Lumen: The Art and Science of Light, 800–1600*, like the exhibition it accompanies, explores the inextricably entangled domains of science, art, and religious faith during the long Middle Ages in Europe.

Though often interpreted through a theological lens, natural philosophy—the study of the natural world and the cosmos—and its discoveries fed directly into the vast expansion in experimentation and exploration that ultimately led to the European Enlightenment. New investigations in the fields of optics, geometry, and astronomy increased human knowledge and spurred technological innovation not seen since the ancients. This extraordinary period produced the first ground lens, the astrolabe, and myriad developments in timekeeping, navigation, and the study of celestial bodies. Medieval artists, architects, and craftspeople in turn incorporated this new knowledge into their own artistic practices.

Crucially, *Lumen* positions the intersection of art, science, and spirituality in western Europe within the diverse knowledge networks that connected scholars from Samarkand and Cairo to al-Andalus and Oxford. Through this process, the Western tradition originating in the works of Plato, Aristotle, and their followers was absorbed into and enriched by an amalgam of medieval Jewish, Muslim, and Christian scholarship. A common corpus of scientific, mathematical, and philosophical texts was read, translated, and exchanged across religious, political, and geographical boundaries.

Lumen explores the varied ways these revolutionary advances in scientific understanding—especially in optics and light—infused the arts of the period with emotional, metaphorical, and theological meaning. While no exhibition today can convey fully the sense of wonder early astronomers experienced as they charted the stars, or the awe felt by pious worshippers contemplating sunlight passing through stained-glass windows and candlelight reflecting off gold panel paintings, our hope is that visitors to the exhibition and readers of this publication will come away with a richer appreciation of what light, in all its manifestations, could mean to medieval culture in Europe. The curators have invited several contemporary artists to contribute works to the exhibition that employ light or take it as their subject in ways that allow visitors today to imagine something of the experience of their medieval forebears.

This catalogue and exhibition constitute one of the J. Paul Getty Museum's contributions to PST ART: *Art & Science Collide*, a major initiative organized by the Getty Trust that explores the intersections of art and science both past and present. This far-reaching enterprise encompasses more than sixty exhibitions at institutions across Southern California. We wish to thank our corporate partner, Bank of America, Alicia Miñana and Rob Lovelace, and the Getty Patron Program for their support of PST ART. *Lumen* was curated by Kristen Collins, curator in the Department of Manuscripts, and Nancy K. Turner, conservator in the Department of Paper Conservation, Getty Museum; and, for the contemporary works, Glenn Phillips, senior curator, head of exhibitions, and head of modern and contemporary collections at the Getty Research Institute. All deserve our thanks and congratulations. Our greatest debt, however, is to the many lenders who entrusted us with some of the most important works of medieval art from their renowned collections. Among the many other Getty staff who contributed to the success of this exhibition, Carolyn Marsden-Smith, associate director for exhibitions, Richard Rand, associate director of collections, Elizabeth Morrison, senior curator in the Department of Manuscripts, and Amber Keller, principal project specialist for exhibitions, were especially critical to its realization.

Finally, we are profoundly grateful to the members of the scientific advisory board of the *Lumen* exhibition and the distinguished authors who contributed to the catalogue.

Timothy Potts
Maria Hummer-Tuttle and Robert Tuttle Director
J. Paul Getty Museum

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Acknowledgments

This exhibition was sparked nearly twenty years ago when another project afforded us the opportunity to attend Easter services in a sixth-century church. At Saint Catherine's Monastery at Mount Sinai, we observed beams of sunlight made visible on slow-moving clouds of incense and candlelight reflected off golden icons and liturgical vestments. During the dark days of the pandemic, we conceived of this exhibition and publication, planning for a time when people, far from the blue lights of their screens, might gather in rooms filled with glimmering objects that impart the wonder we experienced years before in a Byzantine church. Hoping to convey some of the surprise and awe felt by medieval people observing the cosmos or entering spaces ablaze with candles and lamplight, we have included contemporary works of art in this exhibition. We are grateful to Glenn Phillips for curating the contemporary objects in the show and bringing both rainbows and golden rays with him.

Exhibitions arise from multiple inspirations, experiences, observations, and ideas. *Lumen: The Art and Science of Light* came together felicitously with the Getty Foundation's 2024 Pacific Standard Time initiative, PST ART: *Art & Science Collide*. The initiative challenged us to engage with the history of science, and this exhibition has benefited from the expertise of its scientific committee, several members of which generously contributed essays to this catalogue: Taha Yasin Arslan, Adam S, Cohen, Seb Falk, Helen Evans, Margaret Gaida, Elina Gertsman, Cynthia Hahn, Eva Hoffman, Liz James, Christopher R. Lakey, Richard Leson, Megan McNamee, Bissera V. Pentcheva, G. Gabrielle Starr, and Abbey Stockstill. A fall 2022 session organized by the Getty Foundation with the National Academy of Sciences proved invaluable by facilitating our first conversations with neuroscientists working on intersections of light, the eye, and the brain. We are grateful to Joan Weinstein, Heather MacDonald, Zach Kaplan, and Lu Spriggs for their vision and efforts to connect the many PST partners and constituencies.

We owe sincere thanks to numerous colleagues, who generously offered their time and insights throughout the project. Four former and current members of the Manuscripts Department contributed mightily: Kelin Michael and Sam Truman during the project's early development and Benjamin Allsopp and Abigail Berry during its execution. We are also grateful to the following colleagues for instrumental conversations and good advice along the way: Andrea Achi, Ladan Akbarnia, Isabelle Bardiès-Fronty, Georgios Boudalis, David Brafman, Moya Carey, Michael Chagnon, Jim Ganz, Navina Najat Haidar, Mazie Harris, Virginia Heckert, Jennifer Jahner, Svea Janzen, Arpad Kovacs, Sharon Liberman Mintz, Robert Nelson, Souraya Noujaim, Joshua O'Driscoll, Elena Phipps, Rachel Rivenc, Jiří Vnouček, Juliane von Fircks, and Roger Wieck.

At the Getty Museum, we would like to thank our director, Timothy Potts, for his commitment to the scholarly aims of the exhibition, and Carolyn Marsden-Smith, associate director of exhibitions, for encouraging us to work on such an ambitious scale. Richard Rand, associate director for collections, and Elizabeth Morrison, senior curator of manuscripts, gave crucial support and well-reasoned counsel. We are grateful to John Giurini, assistant director for communications and public affairs, and his team for their enthusiasm and creative outreach and media planning. In the Exhibitions Department, Amber Keller has our everlasting gratitude for her seamless orchestration of the project's many moving parts. We extend our appreciation to Marisa Weintraub for her keen editorial eye and Alex Bispham for her problem-solving capabilities. Davide Gasparotto, Anne Woollett, and Scott Allan in the Department of Paintings supplied generous assistance that went above and beyond the call. Maria Cristina White-da Cruz provided essential help in loan negotiations. In the Manuscripts Department, we extend thanks to Larisa Grollemond, Aleia McDaniel, Orsolya Mednyánszky, Jessica Wheeler, and Stefani Avila for their support and boundless goodwill. In the Department of Paper Conservation, our heartfelt thanks go to Victoria Binder, Christine Cook, Sarah Freeman, Stephen Heer, David McDaniel, Ron Stroud, and Michelle Sullivan for their encouragement and support, without which their colleague could not have co-curated this exhibition.

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In Interpretive Content, we thank Sheila Flaherty-Jones, Tasia Johnson, and Sahar Tchaitchian for honing our exhibition didactics. At the Getty Research Institute, we acknowledge Jay Gam, Ross Garcia, Aimee Lind, and many other staff for their heroic efforts during the pandemic to procure research materials. Daniela Ruano Orantes also provided essential support. This exhibition is indebted to the creative

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vision and technical acumen of our exhibition designers, Alan Konishi and Chaya Arabia, and the sage guidance of Jessica Harden, head of design. We are grateful to Getty Trust architect Naomi Neville as well as to Bob Combs, Raj Kumar, and the entire team in Getty Security for enabling the safe display of multiple installations across the site. The team at Available Light, including Kate Furst, Gabrielle Strong, and Damien Perard, crafted an environment of light and shadow designed to instill a sense of awe.

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KC and NKT

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Introduction

KRISTEN COLLINS AND NANCY K. TURNER

To be human is to crave light. Throughout time, in varying ways and in different cultures, humans have associated light with the divine. Although in contemporary society religion and science are often positioned as distinct enterprises, in antiquity and the Middle Ages the properties of light were part of intersecting theological, artistic, and scientific debates concerning the nature of the cosmos and the mechanics of vision.

The exhibition *Lumen: The Art and Science of Light* and its accompanying volume explore light as it was conceived and represented in the arts and sciences of the Middle Ages and Renaissance. The Latin word *lumen* had multiple meanings: it described a source of light (such as a lamp), a bright color, or the light of the eye. The word *lux* denoted the light of heavenly bodies, of daylight, or of dawn. Throughout the years between 800 and 1600, here referred to as the long Middle Ages, the study of astronomy, geometry, and optics provided a framework that was utilized by theologians and harnessed by artists to better understand and evoke the sacred, as well as to rationalize their world. This story is equal parts science, poetics, and craft: through the manipulation of materials such as gold, crystal, and glass, artists created dazzling light-filled environments, evoking, in the material world, the layered realms of the divine. In the essays in this volume, eleven contributors from the fields of art history, the history of science, and neuroscience examine medieval understandings of light and its deployment in the visual arts.[1]

Scientia is the Latin word for knowledge. The medieval study of light was one of both science (*scientia*) and art (*artes*), as practiced by natural philosophers (i.e., astronomers, theologians, mathematicians, geometers, and physicians) and artists. *Scientia* was derived from a logical demonstration argued from initial premises and definitions so as to arrive at accepted fact, as in the solving of mathematical or geometric proofs. *Artes*, on the other hand, pertained to practical knowledge and technical know-how. As two different forms of knowledge, *scientia* sought out understandings of unchanging principles, such as the nature of light and sight, whereas *artes* attended to things that can change, as when a physician heals an injury with medicine or an artist transforms raw materials into useful and beautiful things.

Using artworks as well as scientific texts and instruments, this exhibition aims to highlight the wide range of intellectual traditions that contributed to medieval scientific thought. One cannot speak of “Islamic science” or

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"Latin science" between 800 and 1600, as the discipline was characterized by active synthesis (and rejection and correction) of multiple strands of the natural, mathematical, and observational sciences across time and geographies. Stories of modern science often begin with the European Enlightenment in the 1600s and 1700s. But throughout the Middle Ages, in Islamic regions and in the Latin West, natural philosophers observed and recorded the movements of the cosmos and improved and refined ancient theories of light and vision.[2] Their knowledge networks stretched across the medieval world, connecting the most sophisticated thinkers of Islamic regions to Christian philosophers and theologians in western Europe. A rich tradition of translation and commentary not only preserved ancient science but also continually developed it. Ancient scientific texts dealing with astronomy, mathematics, and optics were copied, enriched, and transformed by Jewish, Muslim, and Christian scholars, theologians, and artists working in religious institutions, royal courts, schools, and universities. While this exhibition focuses on the arts of western Europe, it engages with a broad network of scholars working to rationalize the science of ancient Greek writers—the philosophers Plato and Aristotle, as well as the mathematician Euclid and the astronomer Ptolemy.

European chronologies of science all too often treat the period of translation of ancient Greek texts into Arabic by Islamic scholars in the eighth and ninth centuries as one of necessary preservation that contributed significantly to the "renaissance of the twelfth century" in Europe as well as the development of Scholasticism in the thirteenth century, when the writings of Aristotle and others were translated by Europeans from Arabic into Latin.[3] But the ancient science that Europe received had been transformed by Arab authors who had also mastered Persian and Indian astronomy and mathematics.[4] Medieval philosophers working in Europe and around the Mediterranean incorporated theories advanced by Aristotle, Euclid, and Ptolemy as they had been refined by the great thinkers of the Abbasid caliphate, centered in Baghdad, by the eighth century; by natural philosophers and peripatetic teachers from the courts of al-Andalus (Muslim-ruled Iberia) in the twelfth century; and by timekeepers at the Ummayad Mosque in Damascus and elsewhere in the fourteenth century.[5] The inheritors of ancient Greek scientific learning harnessed this material for their own specific purposes, but remained united by their foundational texts and the ensuing dialogue that spanned vast regions and centuries.

While medieval science—the purview of mathematicians and natural philosophers—was heavily theoretical and frequently directed toward religious ends, it laid the groundwork for many of the better-known scientific "discoveries" of the Enlightenment. For example, the Mamluk astronomer Ibn al-Shatir (ca. 1305–1375), a timekeeper for the Umayyad Mosque in Damascus, developed a model for the moon that calculated its latitude and distance from earth and corrected problems inherited from the models put forward by Ptolemy. His primary work on planetary theory does not survive, but Copernicus, today celebrated as the father of modern astronomy for his development of a heliocentric model of the universe, came to this same lunar calculation nearly two centuries later, suggesting that aspects of Ibn al-Shatir's work were transmitted beyond Islamic lands.[6] Copernicus did not read Arabic, but scholars in his cohort left behind annotated copies of Arabic astronomical texts, suggesting that his astronomical theory could have been informed by oral transmission in intellectual circles.[7]

During the Middle Ages scientific inquiry increased human knowledge and spurred innovations such as spectacles, or wearable magnifiers.[8] In the melding of science and craft, the medieval era also gave rise to the medium that was to become the defining art form of the Christian West: the stained-glass window (fig. 1).[9] The monk Theophilus (active 12th century) dedicated one chapter of his text *De diversis artibus* (*The Various Arts*) to stained glass—the earliest medieval discussion of the art form.[10] This medium, more than any other, has become synonymous with the topic of light in the medieval era. But by focusing on light's many other manifestations in the premodern visual arts, this volume aims to explore the scientific underpinnings of medieval artisans' understanding and manipulation of light and to demonstrate the ways that such knowledge fed the theological symbolism of both light and vision.

The first section, Astral Light, demonstrates the legacy of ancient science as it was translated into a medieval idiom and utilized for purposes such as timekeeping or the determination of religious feast days. The second section, Light and Vision, examines the mechanics of vision as it was understood and used by medieval

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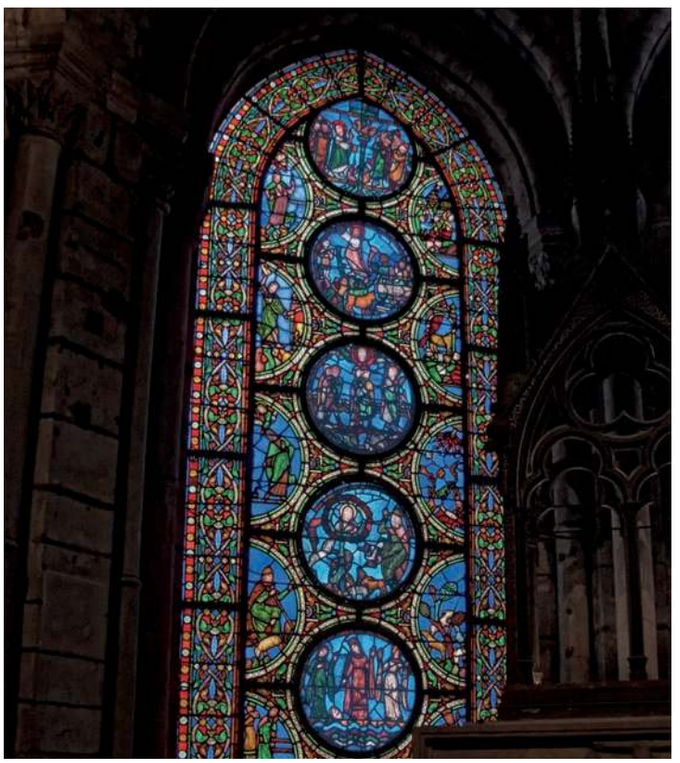


FIGURE 1. Moses Window, ca. 1140–44.
Stained glass. France, Basilica of Saint-Denis

philosophers and artisans. The third and final section, Aura and Performance, explores the deployment of the knowledge of light and its properties in sacred spaces. Throughout the exhibition and this volume, a selection of contemporary artworks is placed in dialogue with medieval and Renaissance works to emphasize the key aspects of movement and active engagement as they relate to light, perception, and the participatory nature of medieval vision. Underlying many of the optical theories of the premodern world was the idea of a dynamic connection between the viewer and the object viewed. Just as the contemporary artworks and installations included here engage moving light to chart the passage of time and to create a sense of wonder and awe, we hope to convey the premodern experiences of light in sacred spaces and appreciate the scientific underpinnings that informed the creation of art during the long Middle Ages.

Notes

1 For an accessible work on the themes of light and vision in the premodern era, see David Park, *The Fire within the Eye: A Historical Essay on the Nature and Meaning of Light* (Princeton, NJ: Princeton University Press, 1997). For foundational work on the topic, see David C. Lindberg, *Theories of Vision from Al-Kindi to Kepler* (Chicago: University of Chicago Press, 1976); David C. Lindberg and Geoffrey Cantor, *The Discourse of Light from the Middle Ages to the Enlightenment: Papers Read at a Clark Library Seminar, 24 April, 1982* (Los Angeles: William Andrews Clark Memorial Library, University of California, Los Angeles, 1985); A. Mark Smith, *From Sight to Light: The Passage from Ancient to Modern Optics* (Chicago: University of Chicago Press, 2014); and A. Mark Smith, "The Roots and Routes of Optical Lore in the Later Middle Ages and Renaissance," in *Perspective as Practice*, ed. Sven Dupré (Turnhout: Brepols, 2019), 241–58.

2 George Saliba, *Islamic Science and the Making of the European Renaissance* (Cambridge, MA: MIT Press, 2007).

3 Michael H. Shank and David C. Lindberg, introduction to *The Cambridge History of Science,* vol. 2, *Medieval Science,* ed. David C. Lindberg and Michael H. Shank (Cambridge: Cambridge University Press, 2013), 25.

4 Margaret Gaida, "Reading between the Lines: Attitudes toward Arabic Astrology in the Latin Marginalia of Alcabitius's *Introductorius ad magisterium iudiciorum astrorum*," in *Knowledge in Translation: Global Patterns of Scientific Exchange, 1000–1800*, ed. Patrick Manning and Abigail Owen (Pittsburgh: University of Pittsburgh Press), 245.

5 Saliba, *Islamic Science,* 73–129.

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8 David C. Lindberg, "Lenses and Eyeglasses," in *Dictionary of the Middle Ages*, ed. Joseph R. Strayer (New York: Scribner, 1989), 7: 538–41; Judith S. Neaman, "The Mystery of the Ghent Bird and the Invention of Spectacles," *Viator* 24 (1993): 189–214; and Vincent Ilardi, "The Invention of Spectacles Revisited," in *Renaissance Vision from Spectacles to Telescopes* (Philadelphia: American Philosophical Society, 2007), 26–28.

9 Medieval stained glass has a vast literature. For a succinct introduction, see Elizabeth Carson Pastan, "Glazing Medieval Buildings," in *A Companion to Medieval Art: Romanesque and Gothic in Northern Europe*, ed. Conrad Rudolph (Malden, MA: Blackwell, 2006), 443–65; and for a new anthology of diverse approaches to the field, see Elizabeth Carson Pastan and Brigitte Kurmann-Schwarz, eds., *Investigations in Medieval Stained Glass: Materials, Methods, and Expressions* (Leiden: Brill, 2019).

10 Theophilus, *The Various Arts / De diversis artibus*, ed. and trans. C. R. Dodwell (Oxford: Clarendon Press, 1986), 37, 47–51.

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Part 1

ASTRAL LIGHT

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Astral Light

KRISTEN COLLINS AND NANCY K. TURNER

This volume's story of light as it intersected with medieval art and science begins with astronomy—an area of study utilized by medieval natural philosophers to understand observed phenomena in the night sky. In an age before mechanical clocks were widely available, people charted the stars to mark the passings of seasons and the hours of the day. The planting of crops and celebration of religious holidays were informed by the movement of the sun, moon, and stars. An image from *The Travels of Sir John Mandeville* (ca. 1400–1425), a fictive travelogue, captures some of the essential aspects of medieval scientific endeavors, which combined observation, computation, and the ability to render the findings visible (opposite and plate 6).[1] The illuminated page shows philosophers on Mount Athos who observe the celestial bodies above with quadrants and astrolabes while recording their findings in the dust.[2] This text and its illuminations also introduce the idea of a medieval world characterized by the travels of individuals, instruments, and texts that were exchanged, copied, and refined across geographies and centuries.[3]

Light was both conceived as divine emanation and understood through mathematical principles; astronomers strove to understand the movements of the planets and stars in geometric terms. By visualizing the universe as a series of spheres and planes, separated by degrees of distance, astral scientists used geometry and mathematical calculations to chart the movements of the cosmos and the passage of time in hours, days, and seasons, as well as to understand their place in the world (fig. 2).

Greek natural philosophers from the sixth and fifth centuries BCE built upon the knowledge of the ancient Babylonians and Egyptians to explain the rotation of the celestial bodies—as they thought, around the earth—and conceived the earth and the rotation of the planets as spherical.[4] In the second century CE in Alexandria, Ptolemy wrote what was to become the most important astronomical text of the Middle Ages, the *Almagest*. This text, known by its Arabic nickname (*al-majisti*, meaning "the greatest"), served as the foundation for mathematical astronomy for nearly fifteen hundred years.[5] It catalogued more than one thousand "fixed" stars (stars in constellations that appeared never to change their positions relative to one another), giving their coordinates in the sky and classifying them into forty-eight constellations; counted seven "wandering stars," or planets (then considered the five visible planets, the sun, and the

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FIGURE 2. *Geometry (One of the Seven Liberal Arts)* in *L'image du monde*, Paris, ca. 1320 (detail). Gossuin de Metz (author) (French, active 13th century), Master of the Roman de Fauvel (artist) (French, active 14th century). Tempera, gold, and ink on parchment, full folio: 38 × 25.5 cm (15 × 10 in.). Paris, Bibliothèque nationale de France, Département des Manuscrits, Ms. Fr. 574, fol. 28v

moon); and used mathematical models to explain the orbits of planets, to measure distances, and to predict the rake of the sun's light at different locations on the earth (plate 17).[6] It also explored the nature of eclipses. In the eighth and ninth centuries the text was first copied from Greek into Syriac and Arabic. The *Almagest* had its greatest impact through its Arabic translations, commissioned by the Abbasid caliph al-Maʾmun (r. 813–33) in Baghdad: the first translation was by al-Hajjaj ibn Yusuf ibn Matar, in about 827–28, and other translations, commentaries, or revisions were made by al-Farghani (d. after 861), Ishaq ibn Hunayn (ca. 830–910), and Thabit ibn Qurra (d. 901).[7] Medieval translation was not an act of preservation so much as a process by which texts were challenged, refined, and tested.[8] Underscoring this spirit of critique, a commentary written in the tenth century by the Arab polymath Ibn al-Haytham (965–ca. 1040) was titled *Doubts about Ptolemy*.[9] In fact, the mathematical inconsistencies in Ptolemy's model of the universe prompted Islamic scholars to question and correct the astronomy of the ancients, creating new models that would ultimately contribute to the rejection of the model of a geocentric universe.[10]

With the rapid spread of Islam in the eighth and ninth centuries, vast administrative territories had shared needs that required tools for the calculation of a lunar calendar and times for prayer.[11] Some of the great observatories of the Islamic world were associated with mosques, where the combined pursuit of science and religion led philosophers and mathematicians to refine the flawed models of the ancients. The practical applications of astronomy became a core area of study at Baghdad's royal library, the House of Wisdom, beginning in the eighth and ninth centuries, and at the great observatories in Damascus, Tabriz, and Samarkand.[12] This scholarship, including major efforts to translate key texts and develop observational tools, was supported by the reigning caliphs for centuries, as political and spiritual power was legitimized through a deep knowledge of the heavens.

The *Almagest* remained little known in the Latin West until the twelfth century. The astronomical interests of Charlemagne, king of the Franks and Holy Roman emperor (r. 768–814), had to be satisfied through other ancient works, such as the *Phaenomena* by the Greek poet Aratos (ca. 315–240/239 BCE) (plates 1, 2). This work, translated into Latin by Germanicus (15 BCE–19 CE), constituted a Roman compendium of classical Greek scientific knowledge about the constellations but was not based on direct observation.[13]

The study of astronomy had immediate practical application in the medieval world, in both Islamic and Christian regions.[14] Charting time by the angle of the sun or by the stars enabled people to know when to attend religious services or how to calculate feast days, and a variety of sophisticated instruments were designed to aid in astronomical calculations.[15]

Astrolabes and quadrants, worked in brass and precious metals, were objects that collapsed the three-dimensional spheres of the universe, representing it in two dimensions on a series of round plates that were engraved with lines to calculate degrees of distance, or the time and length of a given day (plates 7–10, 12–14, 16). And volvelles in Latin manuscripts had moving disks with which readers could determine a variety of astronomical

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phenomena including when the full moon would fall each month—an essential piece of information for the calculation of the date of Easter (plates 22, 23).[16]

Medieval natural philosophers believed that the universe was comprised of seven transparent crystalline planetary spheres (which included the sun and moon) nested inside one another. An eighth sphere contained the so-called fixed stars—constellations whose groupings remained recognizable as they moved through the nighttime sky throughout the year, and a ninth ring contained the primum mobile, or the force that moved the universe, depicted as God in the *Tapestry of the Astrolabes* (plate 11). A diagram with this organization can be seen in a manuscript by the thirteenth-century author Johannes de Sacrobosco (active ca. 1225); this treatise, *De sphera* (The sphere), was to become the most popular astronomical text from the thirteenth until well into the seventeenth century (fig. 3).[17] Sacrobosco was probably English, and he taught at the University of Paris in the early thirteenth century when the works of Aristotle were newly available to Western scholars through the translations (from Arabic into Latin) that were arriving from Iberian centers. The translation of Ptolemy's *Almagest* from Arabic into Latin by Gerard of Cremona (ca. 1114–1187) heralded a later, larger project initiated in Toledo by Alfonso X (r. 1252–84), king of Castile and León.[18] Traveling from his native Italy to Spain—he knew copies of the *Almagest* were available in al-Andalus—Gerard joined many Sephardic Jews whose linguistic skills were essential for the translation of works from Greek into Arabic and from Arabic into Hebrew and Latin.[19]

In both Muslim and Christian European courts, and particularly in Iberia, Jews held important positions as physicians and astrologers. In fact, in the Sephardic community Jewish practitioners of both of these related arts contributed original works on astronomy, astrology, mathematics, philosophy, and medicine, based on Greco-Arabic sciences, in order to understand "the wisdom of the stars" (*hokmat ha-mazzalot*), a term introduced by Abraham ibn Esra (active ca. 11th century).[20] He argued that such knowledge provided a way to understand Hebrew scripture, to establish important dates for religious observance, and to gain greater knowledge of God.[21]

Petrus Alfonsi, working in the twelfth century, was born Moses, a member of the Jewish community in the city of Huesca, at that time in al-Andalus. He may have been working as an astrologer in the court of Alfonso I, king of Aragon and Navarre (r. 1104–34), when he converted to Christianity. Petrus traveled to England between 1110 and 1116, where he produced a Latin translation of and commentary on al-Khwarizmi's astronomical handbook, *Zij al-Sindhind*. In the 1120s he went to France, where he continued to teach and write, leaving a legacy of around 160 manuscript copies of his text. His work is distinguished by his blended interests in mathematical astronomy and theology, a feature not frequently seen

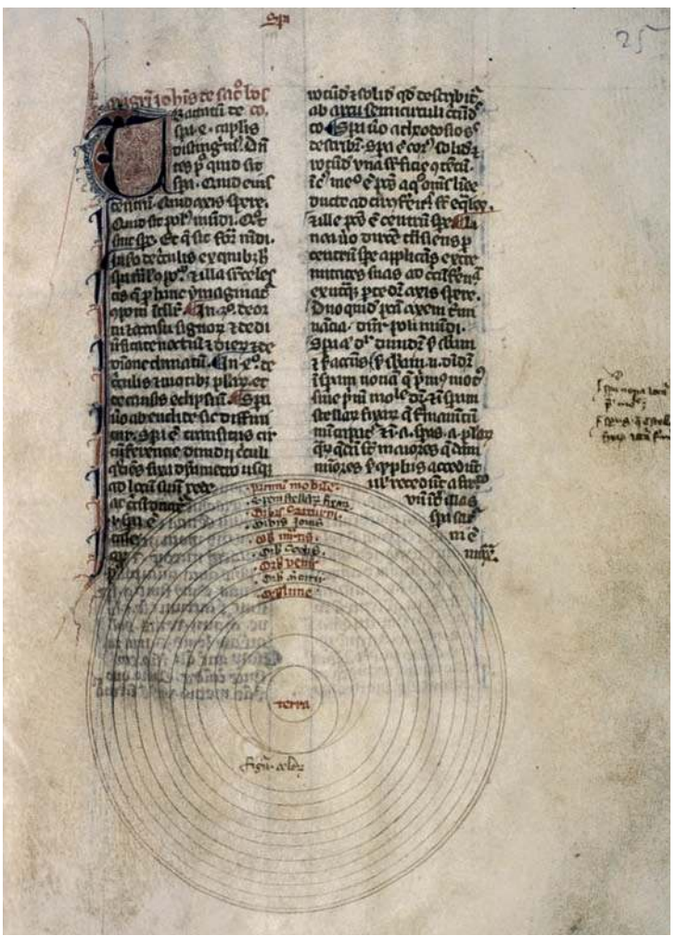


FIGURE 3. *The Nested Spheres of the Universe* in *De sphera*, England, ca. 1321–50. Johannes de Sacrobosco (English[?], active ca. 1225). Ink on parchment, full folio: 25.5 × 18.5 cm (10 1⁄16 × 7 ¼ in.). Oxford, Bodleian Libraries, University of Oxford, MS. Ashmole 1522, fol. 25

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in his counterparts in the Latin West at this moment but one often found in the works of Jewish peripatetic scholars who disseminated scientific learning beyond Iberian borders.[22] Half a century later Moses ben Maimon, known as Maimonides (ca. 1135–1204), fled his native Spain in 1148; he was a student of astronomy and the philosophy of Aristotle, which he aimed to reconcile with the Torah. Maimonides's *Guide for the Perplexed* directed the reader to attempt to know God through the study of astronomy (plate 15).[23]

In addition to the theological and practical aspects (such as timekeeping) of the astral sciences in Hebrew, Muslim, and Christian traditions, astrology constituted an important branch of the astral sciences.[24] Whereas astronomy sought to explain the movements of heavenly bodies and ephemeral phenomena such as comets, astrology was a discipline that engaged with planetary movements as they influenced human activities such as agriculture or medicine—it was a field in which the study of the moon and planets was often used to determine propitious times for medical treatment, such as surgery and bloodletting. The medieval discipline of astrology is often difficult to distinguish from astronomy as the Latin word *astrologia* at times encompassed both branches of study.[25] Similarly, *mathesis*, the Latin word that described the mathematical and astral sciences, could also be used to refer to divination and augury.[26] In the Islamic world from the tenth through the eighteenth century it was a matter of some debate among philosophers whether astrology should be considered a subset of the mathematical or the natural sciences.[27] Although astrology and magic lie, for the most part, outside the scope of this exhibition and this volume, it should be noted that the discipline had a vibrant presence in court culture in both Christian and Islamic regions. Writing in Abbasid Baghdad, Abu Maʿshar (787–886) placed astrology among the highest forms of the Aristotelian sciences.[28] The proliferation of versions of his *Great Introduction to Astrology* at the courts of Latin Europe, including the thirteenth-century court of Frederick II, king of Sicily and Holy Roman emperor, in Palermo and that of Jean de France, duc de Berry, in Bourges around 1400, demonstrates the long-standing and cross-cultural appeal of this branch of the astral sciences.[29] The illumination of Abu Maʿshar holding his book aloft in Frederick II's manuscript elevates him to a philosopher in the Aristotelian mode (fig. 4). While the Latin church tended to treat magic and astrological prognostication with suspicion (for instance, the philosopher Nicole Oresme wrote a treatise against astrology to warn King Charles V of France away from the many astrological texts he was commissioning for his library), the physical evidence shows that astronomy and astrology existed quite literally side by side in medieval books, even in monastic and university contexts.[30]

The study of the planets and fixed stars lent itself to other interpretive endeavors, too. Christian mystics and theologians expressed the idea of humans as microcosms who mirror the movements and behaviors of the larger macrocosm of the cosmos. This concept had been introduced by Plato in the *Timaeus*, where he outlined the principles of the ordered universe that had been organized by a divine Craftsman to produce beneficial effects. The universe was a living creature and humans echoed its forms.[31] Christian medieval writers such as Hildegard of Bingen (1098–1179) extended the correspondences between the human body and the universe. An illumination for one of the visions she recorded in her *Liber divinorum operum* (Book of divine works) reflects a Ptolemaic concept of the nested spheres of the universe, with earth at the center, encircled by the *lux vivens*, or the living light of divinity, in the form of a wheel (plate 27).[32] Her writings repeatedly used cosmological metaphor to reinforce the symmetries between human and world or universe, reflecting the unity of scientific and spiritual knowledge.[33]

Medieval scientific efforts strove to communicate ideas about the universe and gave rise to schematics, models, and diagrams.[34] Graphic representations of the universe often echoed the meanings of the explanatory text that they accompanied and were intended to reduce the complexity of mathematically derived models to a form that was easily understood and remembered.[35] The resulting diagrams, so cryptic for the

FIGURE 4. *Portrait of Abu Maʿshar* in *Liber astrologiae*, southern Italy or Sicily, ca. 1220–40. Georgius Zothorus Zaparus Fendulus (active second half of 12th century). Tempera and gold on parchment, full folio: 19.9 cm × 28.4 cm (7⅞ × 11³⁄₁₆ in.). Paris, Bibliothèque nationale de France, Département des Manuscrits, Latin 7330, fol. 41v

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modern viewer, collapsed the volumetric universe down to a two-dimensional representation of its components, registering movements, densities, and luminosity. But even more than holding mnemonic value, these diagrams enabled a process of visualization whereby the reader might internalize the structure of the universe, entering the information first into the corporeal eye and then into the "mind's eye."[36] This function of the diagram as a tool that enabled cognition is heavily indebted to Aristotelian ideas about the primacy of vision as a means of knowing, a topic to be explored in part 2 of this volume. The study of art has long privileged naturalism, even in the realm of scientific illuminations, but in recent years a growing body of research has come to focus on these often spare and abstracted images, which aimed to show the universe as it *was*, rather than how it looked.[37]

The diagrammatic language of scientific manuscripts took on a sumptuous appearance in illuminated manuscripts made for the courts of the Latin West. An image in Oresme's translation of Aristotle's *De caelo et mundo* (*On the Heavens*), made for Charles V of France (r. 1364–80), depicts the planetary spheres in gold and lapis. Luna, Mercurius, Venus, Sol, Mars, Jupiter, and Saturnus here curve upward around God as the symbolic center of all, rather than around earth as was customary (plate 24). An independent thinker as well as a translator, Oresme challenged Aristotle's notion of a stationary earth, and theorized that the earth, in addition to the stars, could rotate daily—a notion far ahead of his time.[38] Accepted ideas about the form of the cosmos also informed the liturgical arts of the Latin West, in which creation scenes in choir books, frescoes, and altarpieces borrowed from the diagrammatic imagery of science manuals (plates 25, 26).

Philosophers engaging in the astral sciences without the advantage of the observational tools we have today pieced together a theoretical picture of the universe in much the same way that sailors charted unknown seas: by observing and recording movements of the stars and using mathematical calculations to predict distances. These models were all to some degree flawed and subject to scrutiny, debate, and improvement, a dialogic process that defined premodern science. The artworks and instruments in this volume remind us of the intermingled world of science and religion and leave us with luminous echoes of artists' attempts to channel the light of the cosmos through the mechanical arts.

Notes

1 *The Travels of Sir John Mandeville: A Manuscript in the British Library*, ed. Josef Krása, trans. Peter Kussi (New York: G. Braziller, 1983), 20, pl. 19.

2 *The Travels of Sir John Mandeville*, 20, pl. 19.

3 For astrolabes, quadrants, and other astronomical instruments, see the essays by Falk and Arslan, this volume.

4 Vincenz Brinkmann, "Sphaira: The World as Sphere," in *Machine Room of the Gods: How Our Future Was Invented*, ed. Vincenz Brinkmann, exh. cat. (Frankfurt: Deutscher Kunstverlag, 2023), 147–66.

5 Seb Falk, *The Light Ages: The Surprising Story of Medieval Science* (New York: W. W. Norton, 2020), 171.

6 *Ptolemy's "Almagest,"* trans. G. J. Toomer (Princeton, NJ: Princeton University Press, 2020). On the influence of the *Almagest*, see George Saliba, "The Role of the *Almagest* Commentaries in Medieval Arabic Astronomy," in *A History of Arabic Astronomy: Planetary Theories during the Golden Age of Islam* (New York: New York University Press, 1994), 143–62; and David Juste et al., eds., *Ptolemy's Science of the Stars in the Middle Ages* (Turnhout: Brepols, 2020).

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8 David A. King, "Islamic Astronomy," in *Astronomy before the Telescope*, ed. Christopher Walker (London: British Museum Press, 1996), 148.

9 George Saliba, *Islamic Science and the Making of the European Renaissance*, (Cambridge, MA: MIT Press, 2007), 97–108.

10 George Saliba, "Greek Astronomy and the Medieval Arabic Tradition," *American Scientist* 90, no. 4 (July–August 2002): 360–67.

11 For timekeeping in the Islamic world, see the essay by Arslan, this volume.

12 George Saliba, *A History of Arabic Astronomy*, 13.

13 Bruce S. Eastwood, *Ordering the Heavens: Roman Astronomy and Cosmology in the Carolingian Renaissance* (Leiden: Brill, 2007). See also Ranee Katzenstein and Emilie Savage-Smith, *The Leiden "Aratea": Ancient Constellations in a Medieval Manuscript* (Malibu, CA: J. Paul Getty Museum, 1988).

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15 Stephen C. McCluskey, "Gregory of Tours, Monastic Timekeeping, and Early Christian Attitudes to Astronomy," *Isis* 81 (1990): 9–22; and Gerhard Endress, "Mathematics and Philosophy in Medieval Islam," in *The Enterprise of Science in Islam: New Perspectives*, ed. Jan P. Hogendijk and Abdelhamid I. Sabra (Cambridge, MA: MIT Press, 2003), 121–76.

16 For volvelles, see the essay by Falk, this volume.

17 Lynn Thorndike, *The "Sphere" of Sacrobosco and Its Commentators* (Chicago: University of Chicago Press, 1949); Kathleen M. Crowther and Peter Barker, "Training the Intelligent Eye: Understanding Illustrations in Early Modern Astronomy Texts," *Isis* 104 (2013): 429–70; and Falk, *The Light Ages*, 89–96.

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18 Burnett, "Why Study Ptolemy's *Almagest*?," 1.

19 Mariano Gómez Aranda, "The Jew as Scientist and Philosopher in Medieval Iberia," in *The Jew in Medieval Iberia, 1100–1500*, ed. Jonathan Ray (Boston: Academic Studies Press, 2011), 61–63.

20 Gómez Aranda, "The Jew as Scientist and Philosopher," 73; and T. M. Rudavsky, *Jewish Philosophy in the Middle Ages: Science, Rationalism, and Religion* (Oxford: Oxford University Press, 2018), 89.

21 Gómez Aranda, "The Jew as Scientist and Philosopher," 61–62, 72–77.

22 Charles Burnett, "The Works of Petrus Alfonsi: Questions of Authenticity," *Medium aevum* 66, no. 1 (1997): 42–79; David Thomas and Alexander Mallett, "Petrus Alfonsi," in *Christian-Muslim Relations: A Bibliographical History*, vol. 3, *1050–1200*, ed. David Thomas and Alexander Mallett (Leiden: Brill, 2011), 356–57.

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27 Brentjes, "The Astral Sciences," 84.

28 P. Adamson, "Abū Maʿšar, Al-Kindī and the Philosophical Defense of Astrology," *Recherches de théologie et philosophie médiévales* 69, no. 2 (2002): 247; Charles Burnett, "The Certitude of Astrology: The Scientific Methodology of al-Qabīṣī and Abū Maʿshar," in "Certainty, Doubt, Error: Aspects of the Practice of Pre- and Early Modern Science," special issue, *Early Science and Medicine* 7, no. 3 (2002): 198–213; and Charles Burnett, "Abū Maʿshar," in *Encyclopaedia of Islam, THREE,* ed. Kate Fleet et al., first published online 2007, accessed June 19, 2023, http://dx.doi.org/10.1163/1573-3912_ei3_SIM_0032.

29 Five abbreviated versions by Georgius Zothorus Zaparus Fendulus survive. The version once at the court of Frederick II is Paris, Bibliothèque nationale de France, Latin 7330, southern Italy or Sicily, ca. 1220–40 (see fig. 4); the copy presented to the duc de Berry is New York, Morgan Library & Museum, MS M.785, Bruges, Belgium, ca. 1400. For a critical edition of the Arabic text, with facing English translation, see *"The Great Introduction to Astrology" by Abū Maʿshar*, ed. and trans. Keiji Yamamoto and Charles Burnett, 2 vols. (Leiden: Brill, 2019).

30 See, for example, Los Angeles, J. Paul Getty Museum, Ms. Ludwig XII 5 (83.MO.134), a textbook made in England (early 12th century; additions early 13th–16th century), with the *quadrivium* (the four mathematical arts: arithmetic, astronomy, geometry, and music) and added materials including constellations, signs of the zodiac, and instructions for prognostication.

31 *Plato's Cosmology: The "Timaeus" of Plato*, trans. Francis M. Cornford (London: Keegan Paul, 1937).

32 Marsha Newman, "Christian Cosmology in Hildegard of Bingen's Illuminations," *Logos* 5, no. 2 (Winter 2000): 44. For a translation of the complete work, see Hildegard of Bingen, *Liber divinorum operum*, ed. Albert Derolez and Peter Dronke (Turnhout: Brepols, 1996).

33 Newman, "Christian Cosmology," 57.

34 See Jeffrey F. Hamburger, *Diagramming Devotion: Berthold of Nuremberg's Transformation of Hrabanus Maurus's Poems in Praise of the Cross* (Chicago: University of Chicago Press, 2020); and Jeffrey F. Hamburger, David J. Roxburgh, and Linda Safran, eds., *The Diagram as Paradigm: Cross-Cultural Approaches* (Washington, DC: Dumbarton Oaks Research Library and Collection, 2022).

35 Barbara Obrist, "The Idea of a Spherical Universe and Its Visualization in the Earlier Middle Ages (Seventh to Twelfth Century)," in *The Visualization of Knowledge in Medieval and Early Modern Europe*, ed. Marcia Kupfer, Adam S. Cohen, and J. H. Chajes (Turnhout: Brepols, 2020), 230; and Barbara Obrist, "Corporeal and Spiritual Celestial Spheres and Their Visual Figurations: From Adelard of Bath and Honorius to John of Sacrobosco and Michael Scot," in Hamburger, Roxburgh, and Safran, *The Diagram as Paradigm*, 253–84.

36 Crowther and Barker, "Training the Intelligent Eye," 435–36.

37 J. D. North, "Diagram and Thought in Medieval Science," in *Villard's Legacy: Studies in Medieval Technology, Science, and Art in Memory of Jean Gimpel*, ed. Marie-Thérèse Zenner (Burlington, VT: Ashgate, 2004), 265–88; and Hamburger, Roxburgh, and Safran, *The Diagram as Paradigm*. For diagram as gloss, see Megan C. McNamee, "Picturing as Practice: Placing a Square above a Square in the Central Middle Ages," in *Canonical Texts and Scholarly Practices*, ed. Anthony Grafton and Glenn W. Most (Cambridge: Cambridge University Press, 2016), 200–223.

38 Nicole Oresme, *Le livre du ciel et du monde*, ed. Albert D. Menut and Alexander J. Denomy, trans. Albert D. Menut (Madison: University of Wisconsin Press, 1968), 521–25; Marshall Clagett, "Oresme, Nicole," in *Dictionary of Scientific Biography*, vol. 10, ed. Charles C. Gillispie (New York: Charles Scribner, 1980), 225.

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mmanuit pulcitudinem: dixit q' hic p
tholomeus fuit im' in disciplinalē scie
cia ꝑpotens· ꝑminens alijs· in duabz ar
tibz subtil' id est· geometria· z astrolo
gia· & fecit libros multos· de quoz numo
ille est qui megalsti dicit· cuius significa
cō est maior ꝓfectus· quem ad linguam uolentes conuertere arabicam· no
minauerūt almagesti· Hic autem ortus
z educatus fuit in alexandria· cuius si
derū considerauit instrumētis· tempore
regis adriani· z aliox· z sup considerationes abrachis qualiter hodo exꝑtus est·
opus suum edidit· Ptholomeus vo hic
nō fuit unus regum egipti· qui tholomei
uocati sunt· sicut quidam estimauerūt· ꝙz
h fuit eius nomen· ac si alius uocaret
cesarie· aut cesar· Hic autē in statu mo
datus fuit· colore albus· in cesiu largis
subtilis hūs pedes· in maxilla dextra
signū habens subeū· barba eius spissa z mg
dentes anteriores habens dulco optos· z ap
tos· Os cuius priū· loquele bone· in dulcis
fortis ut· tarde sed distincte· multū placebā
tur· z equitabat· raro comedebat· multū
ieiunabat· rectolentem hūs amplectitur·
z mdumīta utitur· Mortuus anno ante
sue· lxx· viij· Hi et fuit de discipulis· z sa
pientibus· ptholomei regis· Comiemēs
ē intelligendus· p deo uerendum· cui ea q
ei fiunt grata cogitat· Intelligens
est q' sp linguam suam refrenat· nisi ad h
ut de deo loquatur· Insipiens ē· qui sin
ꝑpius ignorat q' tractem· Cum aliq's
s' placet· ad hoc deductus est· ut nra di sit
sup ꝓpm· In bono q' ds operatur· q'si
bonitatem largi datoris attendere de
bet· & in malis ad diuisa q'si punitionis
z eius remuneracionis bonitatem·

cordis secretor· sit manifesta· Quam
plurimos non corrigē alios ꝙ ꝓpm non co
rrigent· Quamuis intellectui· animam
renet habenas· Vulgi habenas regere
mali est quia multos ire multos· Fi
ducia est soci consolatus· qua duz non co
gnitus· eam tui amicitia· Securitas
soluit timos dolorem removz· z pauor mi
tigatis consolationem auferet· Inter
dōes alico existit· qui non curret in anus
manus sit mundo· Immodo indeuotus ꝙ
ablacio bonorum altius sit s' bonum· Ho
mines lucrātur census· z census lucrantē
dōes· Quam sciam sua ultra astucias
q'i ipō ē extendit z sic pistor debil' cū mistis
ouibz· Quam i dignitate sua multi ex
tollit· in amissione eius multum deprimit·
Quam male operando multi celari· satis dis
cooptus ē· Quam in mīdicio 2fidit· tem
pestiue deficiet ei· Meditatio· unitatē
existit· diuinis· Intercessor est petentis ul
tia ala· Anima non egredietur a fi
ducia usq; ad mortē· Anima ignorās
suo socio magis communicat· Quidam
rex mirantur ptholomeū ad prandiū· q'
rogās fore se ertisatū· dixit· Regibz cū
git fere qd' 2tum git· 2 sibi dantibz picturas· q'
ei alonge uidentur placent· Propinq
vero non dulcescunt·

Liber hic precepto mamonis regis
arabū qui regnauit in baldach· de
ab alabaz filio ioseph filii ma
tre arismetica· z sergio filio elbex
ano· m anno· xij· c· sette sarracenor
cōstatus est· Quidē liber est mag
nus· dictus almagesti· quem ptholo
meus pheludensis de sacratia stellaz· et
motuū qui sunt mecelo conscripsit·
In hoc autem libro sūt· xiij· dictiones·

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Scientific Instruments of Vision

SEB FALK

The premodern world was a place of intense light and darkness. Artificial light is nothing new—ever since the invention of fire humans have used technologies to illuminate their homes and guide their way—but the flickering of candles, lamps, and torches could never compare to the power and constancy of the sun and stars. So, it is hardly surprising that cultures on all continents have charted the changing seasons, tracking lights and shadows in the sky and on the ground. In this way they achieved practical goals, built an understanding of the world around them, and gave meaning to their existence.

The Middle Ages inherited an understanding of astral light that was sophisticated yet underpinned by simple principles and observations. Every shepherd huddled among his flock in the predawn chill, every sailor getting ready to guide his vessel through sandbanks and out to sea, could see that the sunrise changed its position on the horizon throughout the year. On the equinoxes the sun rises exactly in the east everywhere on earth, but as autumn turns into winter in the Northern Hemisphere, the sun rises farther and farther south. The Stone Age builders of the great passage tomb at Newgrange in Ireland, more than five thousand years ago, knew this: they aligned the tomb's so-called roofbox—an opening above the entrance—precisely so that on the midwinter solstice the sun, rising in the southeast, would penetrate that small opening and flood the chamber within (fig. 5). In fact, this occurred—and still does—for two days each side of the solstice, as the rising sun lingers at that southeastern extreme on the horizon before returning toward the north. (The word *solstice* comes from a Latin word meaning "sun standing still.")

As they watched the sun steadily shift its places of arrival and departure in relation to the familiar landscape of hills and trees, cliffs and rivers, ancient and medieval people saw the days lengthen and shorten and the sun's noonday peak grow higher and lower in the sky. Noting the seasonal changes, they compiled tables so that, month by month and hour by hour, a farmer in the fields could tell the time by the length of his shadow.[1] Cultures across the world also observed changes in the visibility of stars. They recorded the disappearance of certain constellations from the night sky for weeks or months (at these times they were above the horizon only in daytime); their reappearance, when they rose in the twilight just before dawn, was eagerly anticipated.

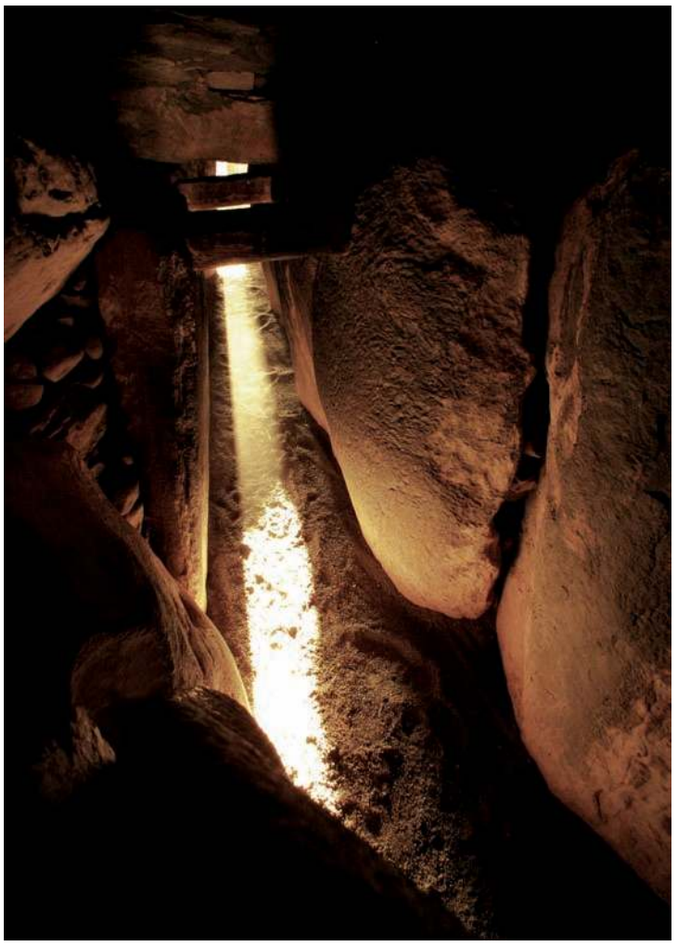


FIGURE 5. Shaft of light entering the passage of the Newgrange tomb, constructed ca. 3200 BCE, County Meath, Ireland

Like members of other cultures, medieval Europeans learned the lore of their ancient ancestors, found new ways to track the stars, and invested the stars' seasonal shifts with new meanings and practical value. They read the agricultural advice of Latin literature, such as the first-century BCE poet Virgil's admonition to "let the Pleiades set in the morning, and the Cretan star of burning Corona depart, before you commit seeds to the furrows."[2] In monasteries junior monks who had the task of waking up their brothers to sing the holy offices would watch carefully as constellations rose over the abbey buildings. A surviving pocketbook from eleventh-century

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France contains a calendar of changing instructions for different feast days, which begins thus: "On Christmas Day, when you see Gemini lying almost over the dormitory, and the sign of Orion above the chapel of All Saints, prepare to stir the signal bell."[3]

Partly as a result of such practical commitment to observing and understanding the universe, monks took a leading role in the intellectual development of western Europe in the period 1000–1500. One task was paramount: calculating the date of Easter. This, the most important date of the Christian year, was set according to the equinox and full moon. Monks therefore had to measure both the solar and the lunar cycle, but because those cycles are incommensurable, models were necessary to map them onto each other. This led monks to draw up astronomical calendars of ever-increasing sophistication.

After 1300 learning largely moved to the newly founded universities—which had educated as many as a million students by the end of the Middle Ages—but monasteries were still venues for the study and practice of astronomy. This activity is exemplified in two monastic manuscripts that feature the use of sighting tubes (fig. 6; plate 18).

A sighting tube (also known as a *dioptra*) was a simple piece of technology that enabled sophisticated understanding of celestial motions. By directing the user's sight toward a particular star, the tubes facilitated closer observation and the exclusion of other, distracting light sources. When fixed on a stand (as in plate 18), a sighting tube would demonstrate the slow motions of the stars, as a star would soon move out of the viewing circle; if two tubes were clamped together, with one aimed at the pole and the other turning around it, the daily rotation of any star around the axis of the heavens could be observed. In the ninth century the churchman Pacificus of Verona described how the positions of certain stars above or below Polaris, seen through a sighting tube, could be used to tell the time at night; plate 18 is a later medieval depiction of this.

Beyond that, a sighting tube could demonstrate the fundamental geometry of the heavens. Euclid, the ancient Greek mathematician who is pictured holding such a tube in his left hand in figure 6, explained that if you point the tube at the horizon to see the constellation of Cancer rising and then move to the other end, you can watch Capricorn setting, thus proving that the two constellations are diametrically opposite each other.[4] Furthermore, astronomers realized that if they could see half the heavens in this way at any time, the earth must be infinitesimally small in size compared with the sphere of stars.[5]

Such fundamental features of the universe were modeled in instruments like the armillary sphere Euclid holds in his right hand (see fig. 6). The bands of brass shaped into this spherical frame represent the key lines of the heavens: the celestial equator, the Tropics of Cancer and Capricorn, the ecliptic (the annual path of the sun through the stars), and so on. Larger, more elaborate versions (such as that shown in plate 32) might have a horizon ring to show the configuration of the sky for the user's specific latitude. More common, though, were the handheld versions found in university lecture halls (plate 21).

In another illustration we see a handheld armillary sphere in use for teaching, as a master expounds on its constituent parts—and the constituent parts of the cosmos—to his clerical students (fig. 7). This image, in a manuscript made around 1300, is framed by the initial letter *T* of *Tractatum*. This, meaning "the treatise," is the first word of the most popular science textbook of the Middle Ages. *De sphera*, by Johannes de Sacrobosco (active ca. 1225), probably an Englishman who taught at the University of Paris, is short—little more than twenty pages in modern printings—but it is a beautifully succinct summary of elementary astronomy, describing how the heavens turn; how the stars rise and set; how observable phenomena vary as you move closer to the equator or the poles; the causes of eclipses; and the basics of planetary motion. This was just a glimpse of what expert astronomers knew, but its simplicity and clarity made it popular. Within a few years of its composition, around 1230, *De sphera* was required reading at the new universities; by the following century eight full days of each student's course in the Faculty of (Liberal) Arts at Oxford University were dedicated to the treatise, as lecturers read from it, explained it, and drew out its implications for fascinated students.[6]

As figure 7 suggests, *De sphera* was an introduction not just to the heavens themselves but also to the burnished brass armillary sphere that modeled the heavens and adorned Oxford's half-timbered classrooms

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FIGURE 6. *Euclid and Hermann the Lame with Astronomical Instruments* in *Divinatory Miscellany*, St. Albans, England, ca. 1250 (detail). Matthew Paris (English, 1200–1259). Ink and colored washes on parchment, full folio: 17.2 × 12.7 cm (6¾ × 5 in.). Oxford, Bodleian Libraries, University of Oxford, MS. Ashmole 304, fol. 2v

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FIGURE 7. *Decorated Initial T: Teacher Holding up an Armillary Sphere* at the start of *De sphera* in *Astronomical Miscellany*, northern France, ca. 1300. Johannes de Sacrobosco (English[?], active ca. 1225). Tempera colors, ink, and gold leaf on parchment, full folio: 25 × 18 cm (9 13/16 × 7 1/16 in.). London, British Library, Harley MS 3647, fol. 22

well beyond the Middle Ages. Students in the Faculty of Arts were expected to learn both astronomy and geometry within the *quadrivium* (the four mathematical arts; the other two were arithmetic and music), and much of the teaching was delivered through hands-on exploration and manipulation of instruments like the sphere.

One particularly important instrument was the quadrant (plate 16). This simplified quarter circle was adapted and developed for a panoply of uses in practical geometry and astronomy. Oxford students studied them through a textbook known as the *Quadrans vetus* (Old quadrant), ascribed to Johannes of Montpellier, who taught at the University of Montpellier in southern France.[7] They learned, for example, how to use the quadrant's protruding sights and hanging plumb bob to measure altitudes, and how, using trigonometry assisted by the engravings on the instrument, those altitudes might be converted to tell the time or reveal the height of a tower. The textbooks often contained attractive illustrations, carefully labeled to make the methods clear. We see a pair of such illustrations in an early fourteenth-century copy of the *Quadrans vetus* (fig. 8). This compilation book, which also contains a painstakingly handwritten copy of Sacrobosco's *De sphera*, among many other standard student texts, was made for the Augustinian Merton Priory, near London. When the priory began sending its monks to Oxford to receive the latest all-around education, the prior gave the volume to one of them to use in his studies.

The diagrams in figure 8 show how the *Quadrans vetus* treatise builds on the basic geometry of right-angle triangles—working out the height of a building using the distance from its base and the altitude angle of its top. Greater complexity is introduced with variables such as the height of the observer's eye and the presence of uneven ground. The diagrams indicate, furthermore, how medieval astronomers thought geometrically about light. The properties of light were much debated at this time—the two Latin words for "light," *lux* and *lumen*, reflect contrasting conceptions of its properties, akin to the wave-particle duality that physicists observe today—but what we see in these diagrams is a clearly geometric conception, with rays of light stretching in straight lines from the observer's eye, through the quadrant's sights, to the faraway object.

The old quadrant was supplemented in the late thirteenth century by the appropriately named "new

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FIGURE 8. *Diagrams of Quadrant in Use for Surveying* in the *Quadrans vetus*, England, early 14th century. Johannes of Montpellier (active 13th century). Tempera colors and colored inks on parchment, full folio: 25.5 × 18.5 cm (10 × 7¼ in.). Oxford, Bodleian Libraries, University of Oxford, MS. Ashmole 1522, fol. 75

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quadrant," designed by Jacob ben Machir ibn Tibbon (also called Profatius), one of many Jewish astronomers working in southern France in this period. With these two treatises, students looked well beyond nearby buildings, using their brass devices to observe movements of the stars. They filled manuscripts with tables of celestial motions and their underlying parameters, allowing them to predict the positions of planets or phenomena such as eclipses—and, on occasion, to note when the phenomena did not match predictions.

The books of medieval astronomers themselves became instruments, as we see in a late fourteenth-century English astronomical and medical miscellany (plate 22). Parchment disks with pointers have been cut out and inserted into the book to create a volvelle—an analog calculator. The instructions for its use are written on the instrument itself. First you turn the disk of the sun to today's date, noting that the calendar ring is paired with an outer ring showing the sun's position on the ecliptic throughout the year. Next you turn the disk of the moon to the number (1 to 29) corresponding to its age—that is, the number of days since the conjunction (new moon). You will immediately find that the lunar pointer indicates the zodiac sign the moon is currently in, as well as the degrees—up to thirty—within that sign. More than that, the outer hole in the assemblage will show you the phase of the moon: crescent, half, gibbous, or—when it is highlighted in a rich red—full.

The instructions for the inner hole reveal that this device, again, has an educational function as well as a practical one. As the Latin written in concentric circles states, "the inner hole shows how the moon will appear in itself, for one half of the moon is always illuminated by the sun." As a result, no matter how you turn the two disks, the inner hole remains a brilliant white circle. The instructions conclude by noting that an eclipse occurs when the earth comes between the sun and moon, "as is clear from the treatise *De sphera*."

In order to use instruments like this one, astronomers often had to refer to tables, so it is not surprising to find two on the page facing this volvelle. In this case the eye-catching table of diagonal words and its sidebar of numbers present some of the same information you can get from the volvelle; they are a little harder to use, but more precise. As the Latin text beneath the volvelle explains, if you know—to the nearest three degrees—where in the zodiac the new moon took place, then reading across from the number of days since that conjunction will tell you the precise location of the moon today. Tables were not as user friendly as instruments, but for those with the expertise to produce and use them, they often permitted positions and times to be calculated with greater precision.

This table and its accompanying instructions—and probably the volvelle, too—were designed by John Somer (active ca. 1380), a Franciscan friar from the southwest of England who spent much of his career working in Oxford. He was commissioned to draw up an astronomical calendar by Joan of Kent, mother of King Richard II (r. 1377–99), in 1380, and his calendar became the most popular of its day, surviving in almost fifty copies. Alongside vital information related to Christian observance, it contained data such as the time of sunrise and the length of each day, the daily noon altitude of the sun, and the date and time (to the minute) of every new moon for the following seventy-six years. It also included tables of eclipses, which predicted their start times to the nearest second and showed how much of the sun would be covered by the moon (or vice versa). Finally, it featured a wealth of information about astrology and its medical applications.[8]

While the practices of astronomy, and the techniques of book production, took enormous strides at the end of the Middle Ages, the drive to draw up precise tables, the appeal of elegant, user-friendly volvelles, and the association between astronomy and power all remained constant. We see this in the aptly named *Astronomicum Caesareum* (Imperial astronomy) (plate 23). Made for Holy Roman Emperor Charles V (r. 1519–56) by his astronomy tutor, Peter Apian (1495–1552), this sumptuous production allied the fast-developing technology of printing with the skills of instrument making honed by astronomers over the previous centuries. In 1540 Apian printed around 150 copies at the press he had set up at the newly founded University of Ingolstadt, on the Danube halfway between Munich and Nuremberg. Each was hand-painted in rich leaf green and burgundy, royal blue, and gold. But underneath that spectacular artistry are more than twenty paper volvelles with up to nine moving parts, each one a carefully calibrated computer for a specific purpose: to find the latitudes and longitudes of planets, to predict eclipses, and to make astrological predictions. In most cases readers could find instructions for

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each instrument on the page facing it, and use the data printed in the tables alongside to set the volvelles' eccentric disks and stretch their delicate threads over the precisely graduated scales.[9]

It is easy to see why the grateful emperor rewarded Apian with three thousand gold coins and later elevated him to the aristocratic status of imperial count palatine. For Apian's imperial pupil—and other members of the court lucky enough to receive a copy—the *Astronomicum Caesareum* made the complexities of astronomical theory more accessible, and more beautiful, than they had ever been. Volvelles were not new, of course. And earlier books had already harnessed the symbolic power of instruments to enliven mathematically mind-bending theories—in an early fourteenth-century copy of Ptolemy's *Almagest*, the culminating masterwork of ancient Greek astronomy, a fox and his friends brandish their brass tools in the margin (plate 17 and p. 14, detail).[10] Yet no previous book had made so many Ptolemaic models into interactive instruments, and certainly none came close to its artistry—or ever would afterward.

This stunning volume also sets astronomy alongside its practical application and cultural offshoot, astrology. Throughout the Middle Ages it was universally believed that the motions of the stars and planets affected the elements down here on earth, shaping the weather, affecting human health, and even influencing behavior. Unsurprisingly, then, the *Astronomicum Caesareum* contains (in addition to tables and circular charts for determining the date of Easter) some of the tools the emperor might need to interpret his horoscope. But the book also draws more deeply on traditional star lore. Its volvelle for the lunar nodes, where the paths of the sun and moon cross, is surmounted by the spread-eagled dragon that, according to ancient legend, swallowed those unfortunate luminaries in the event of eclipses (plate 23). The first full-page woodcut, which is clearly influenced by the celebrated celestial maps of Albrecht Dürer a generation earlier, depicts all the known constellations of classical myth (fig. 9). From Hercules in the north our gaze sweeps past Pegasus, Perseus, and Cassiopeia to the ship Argo, depicted at enormous scale but barely visible in the southern sky.

The images of those constellations— the winged horse Pegasus or the hero Perseus clutching the head of the slain Gorgon Medusa—were as instantly recognizable to medieval viewers as the instruments of astronomy. So, it is not surprising that the two are sometimes found together. In a fifteenth-century tapestry, for example, the familiar images of the constellations are framed by the brass rete—the cutout web of star pointers—of an astrolabe (plate 11; compare plate 12). Most of the figures in the *Astronomicum Caesareum* woodcut are present, located with impressive accuracy on the planispheric grid of the woven astrolabe. It was in the fifteenth century that the astrolabe, the ultimate multifunctional astronomical device, began to peak in popularity and cultural potency.

Such artistry, as the medieval period drew to a close, became a feature of the instruments themselves. As instrument makers competed for clients in an increasingly vibrant artisanal market, the decoration on astrolabes and quadrants became ever more elaborate. While few could match the almost inconceivable symmetry of some Islamic designs,[11] European astrolabe makers from the fourteenth century onward began to adorn their creations with star pointers in attractive animal shapes. While the stars they pointed to were remarkably consistent, sticking closely to standard lists of the brightest stars—these were often known by their Arabic names, as we see in an astronomical miscellany of about 1175 (plate 13)[12]—the pointers could be fashioned into eye-catching forms. On a late fourteenth-century English astrolabe (see plate 12) we find the head of a medieval hound indicating the dog star Sirius, and a diminutive bird for the falling eagle Vega. The meaning of the astrolabe's formidable dragon with outstretched tongue remains elusive, however, and its presence may be more heraldic than astrological.[13] Just as astrolabe makers could choose the saints' days they marked on the instruments' reverse, they could personalize the ornament to suit the tastes of patrons, or simply add embellishments to keep up with decorative fashions. Some historians have linked this particular astrolabe to the great fourteenth-century poet Geoffrey Chaucer, who wrote an accessible English-language guide to the uses of the astrolabe[14]—a link that reminds us that art and science were never far apart in the Middle Ages. Whether practiced by farmers in their fields, monks praising God through the precise timing of their prayers, scholars refining their theories at the new universities, or astronomers working for royal patrons, astronomy was at the heart of medieval European culture.

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FIGURE 9. *Constellation Chart* in *Astronomicum Caesareum*, Ingolstadt, Germany, 1540. Peter Apian (German, 1495–1552). Ink and watercolor on paper, binding: approx. 48 × 32.3 × 3.3 cm (18⅞ × 12¹¹⁄₁₆ × 1⅝ in.). Cambridge, Fitzwilliam Museum, Bequeathed (1904) by Frank McClean, PB 18-2020, B3

Notes

1 Palladius, *The Work of Farming ("Opus agriculturae") and Poem on Grafting*, trans. John G. Fitch (Totnes: Prospect Books, 2013); and *The "Kalendarium" of Nicholas of Lynn*, ed. Sigmund Eisner, trans. Gary Mac Eoin and Sigmund Eisner (Athens: University of Georgia Press, 1980).

2 Virgil, *Georgics* 1.220–21. Translation mine.

3 Oxford, Bodleian Library, MS. Bodl. 38, fol. 19v, translated in Seb Falk, *The Light Ages: The Surprising Story of Medieval Science* (New York: W. W. Norton, 2020), 46.

4 Euclid, *Phaenomena* 1, quoted in J. L. Berggren and R. S. D. Thomas, *Euclid's "Phaenomena": A Translation and Study of a Hellenistic Treatise in Spherical Astronomy* (New York: Garland, 1996), 52–53.

5 Johannes de Sacrobosco, *De sphera*, quoted in Lynn Thorndike, *The "Sphere" of Sacrobosco and Its Commentators* (Chicago: University of Chicago Press, 1949), 84, 122.

6 James A. Weisheipl, "Curriculum of the Faculty of Arts at Oxford in the Early Fourteenth Century," *Mediaeval Studies* 26 (1964): 172.

7 Lynn Thorndike, "Who Wrote *Quadrans Vetus*?," *Isis* 37, nos. 3–4 (July 1947): 150–53; and C. Philipp E. Nothaft, "The *Liber Theoreumacie* (1214) and the Early History of the *Quadrans Vetus*," *Journal for the History of Astronomy* 51, no. 1 (2020): 51–74.

8 *The "Kalendarium" of John Somer*, ed. Linne R. Mooney (Athens: University of Georgia Press, 1998).

9 Owen Gingerich, "Apianus's *Astronomicum Caesareum* and Its Leipzig Facsimile," *Journal for the History of Astronomy* 2 (1971): 168–77; and Margaret Gaida, "Reading *Cosmographia*: Peter Apian's Book-Instrument Hybrid and the Rise of the Mathematical Amateur in the Sixteenth Century," *Early Science and Medicine* 21, no. 4 (2016): 277–302.

10 For the intricate link of Ptolemy's astronomical work with his theory of vision, see the essay by Gaida, this volume.

11 For Islamic astrolabes and quadrants, see the essay by Arslan, this volume.

12 Paul Kunitzsch, *Typen von Sternverzeichnissen in astronomischen Handschriften des zehnten bis vierzehnten Jahrhunderts* (Wiesbaden: Harrassowitz, 1966).

13 John Davis, "*Hic Sunt Dracones*: Are There Dragons on Medieval Astrolabes?," *Bulletin of the Scientific Instrument Society* 143 (2019): 1–12.

14 Chaucer's *Treatise on the Astrolabe* was written around 1390. For another of the so-called Chaucer astrolabes, see Jim Bennett and Giorgio Strano, "The So-Called 'Chaucer Astrolabe' from the Koelliker Collection, Milan: An Account of the Instrument and Its Place in the Tradition of Chaucer-Type Astrolabes," *Nuncius* 29 (2014): 179–229.

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Capturing Light by Hand: Timekeeping in the Islamic World

TAHA YASIN ARSLAN

Time. It is one of the most essential concepts for human beings and drove philosophy and science for thousands of years. Aristotle defined time as a change between before and after, Sir Isaac Newton theorized it as absolute, and Albert Einstein ascertained its relativity. To measure time, one needs to find calculable repetitions in natural phenomena, for which there is no better source than astral light. The sun, the moon, and bright stars like Sirius shine day and night and give us the capacity to periodize our time. While the sun always reaches its highest altitude on a particular line (i.e., the meridian), stars rise from exactly the same point in certain periods. These types of markers were used by ancient civilizations to create concepts of hours, days, and weeks and to make calendars. For instance, Sirius rises from the same point twice in approximately 365.25 days—the length of a year in the Gregorian calendar that remains in use today. Accurate measurement of these cycles was and still is challenging. If one cannot find precise anchor points for time measurements, the accuracy of any type of knowledge that is related to time diminishes. That is why capturing the light of celestial objects with precision is key. This is as true for us as it was for people who wandered the world before us. Astrolabes, such as one made and decorated masterfully by ʿAbd al-Karim al-Misri (active 13th century), are historical examples that demonstrate the combined use of stars and mathematical sciences to measure time (fig. 10). Consequently, there is not much difference between our modern-day principles of time measurement and those of premodern people, particularly the principles used by scholars in the medieval Islamic world.

The Islamic World

In the early 700s the Islamic world was a vast region stretching from the western borders of China and northern India in the east to North Africa and al-Andalus (modern-day Spain and Portugal) in the west, with the Middle East and the Caucasus at its center. These regions were once home to many ancient civilizations such as the Babylonians, Egyptians, Persians, and Greeks. The learned people of the Islamic world therefore inherited from their predecessors an ocean of knowledge, and they wished to absorb it all. The result was an immense effort to acquire ancient books and translate them into Arabic. Translations were undertaken first in Baghdad, the capital of the Abbasid caliphate, and later in other prominent cities like Damascus, Cairo, and Isfahan. For the next two hundred years until the end of the tenth century, any book in Greek, Sanskrit, or Persian that was related to philosophy and science was translated into Arabic.

As early as the first half of the ninth century, during the translation campaign, scholars created a scientific lexicon in Arabic since the language lacked equivalents of many foreign scientific terms. Arabic thus became the lingua franca of the sciences in the Islamic world for a thousand years. This common language allowed a direct connection between generations of scholars, making earlier works accessible to all. Because written Arabic and the various scripts employed for it remained relatively stable for more than a millennium, even in the sixteenth and seventeenth centuries scholars were able to read an eight-hundred-year-old manuscript on astronomy or mathematics without needing a translation or transliteration.

Multiple scientific inheritances, with the help of a brand-new lexicon, proved invaluable in the rapid advancement of scientific knowledge in the ninth and tenth centuries. While some branches of the mathematical sciences had flourished independently in various ancient civilizations, the scholars in the Islamic world combined these detached pieces of knowledge to create new and more advanced scientific traditions. They introduced new formulas and new methodologies of calculations and proofs, and they designed numerous scientific instruments. The newly developed mathematical precision was manifest in action in the conversion of the location-specific astrolabe into a device unbound by geographic restrictions.

FIGURE 10. Astrolabe, Jazira (probably Mayyafarikin), dated 633 AH/1235–36. ʿAbd al-Karim al-Misri (Egyptian, active in Syria, 13th century). Brass, inlaid with silver and copper, H (with throne): 46 cm (18⅛ in.), H (without throne): 40 cm (15¾ in.); Diam: 32.5 cm (12 13/16 in.). London, British Museum, 1855,0709.1

The Emergence of the Knowledge of Timekeeping

From the 800s to the 1800s all branches of the mathematical sciences, whether theoretical or practical, were studied and taught across the Islamic world. Among them, one stands out for its usefulness in the daily lives of

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Muslims: the knowledge of timekeeping. This branch of astronomy harnesses the knowledge of the positions of the sun, the moon, and the stars to calculate time. Its main principles were known long before the emergence of Islam. The Babylonians, Egyptians, and Indians were particularly fond of timekeeping, using it for multiple purposes, from taxation to religious rituals. In fact, we owe the definition of the length of a day as twenty-four hours, of an hour as sixty minutes, and of a minute as sixty seconds to the Babylonians. But none of the ancient civilizations needed timekeeping as much as Muslims did, for a simple reason: Islamic ritual.

Islam actively engages with the lives of its adherents. There are many rules and regulations for Muslims to follow, as well as daily and yearly rituals. Among these, the five daily prayers are the most common. Based on descriptions in the Qurʾan and the teachings of the Prophet, five specific periods throughout the day are designated for each of the five daily prayers. These prayers must be performed while facing in the direction of the House of God—the Kaaba—which is in the city of Mecca. This direction is called the qibla, and when Muslims perform prayers, they are required to find the qibla wherever they are in the world. Another common practice is fasting. Muslims are expected to fast during the entire month of Ramadan, which is the ninth month of the Islamic lunar year, called the Hijri calendar. It is essential to keep track of the beginning and end of Ramadan. Muslims are to abstain from drinking, eating, and sexual relations from the morning twilight until sunset each day. It is a monthlong cleansing and a sort of meditation on many aspects of life. The practice ends with a festival.

Before the introduction of the mathematical sciences in the Islamic world, Muslims regulated the times of many rituals, including prayers and fasting, according to the teachings and practices of the Prophet, experience-based folk astronomy, and approximation via fresh observations.[1] For instance, prayer times were determined by the position of the sun or the length of the shadow of a stationary object. For noon prayer Muslims would have had to observe the sun crossing the meridian, meaning it had to stop ascending and begin descending in the sky. Without astronomical instruments to detect this change easily, Muslims would have exercised caution and waited to be sure that the sun was indeed descending. Similarly, without knowledge of spherical trigonometry or geography, Muslims would have had to use the directions of roads or approximations based on amateur, naked-eye observations of the sun or stars to find the qibla. A sixteenth-century map, with the Kaaba at the center, indicates the approximate qibla for numerous localities (fig. 11).

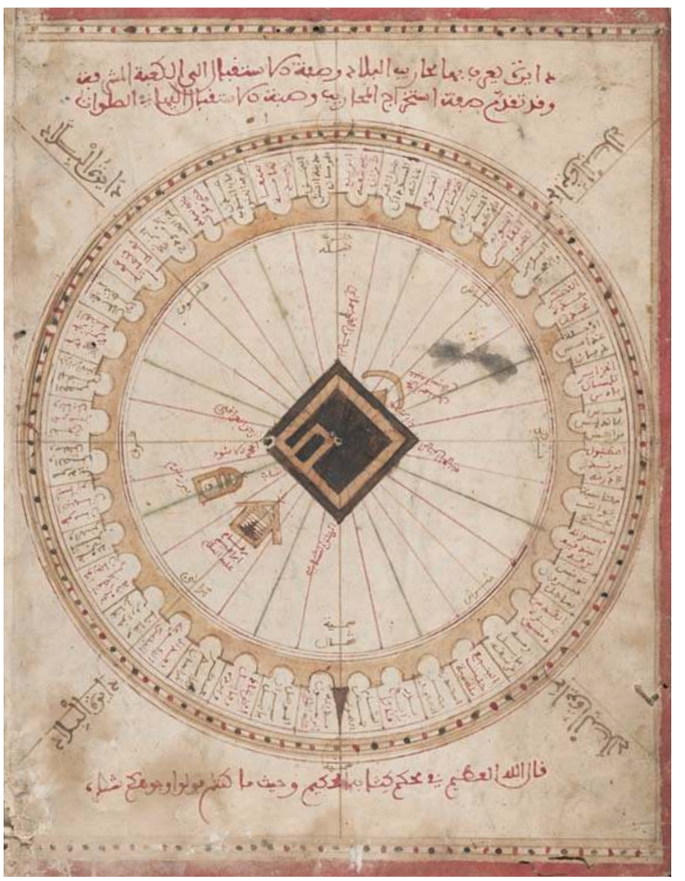


FIGURE 11. *Depiction of the Kaaba and the Qibla of Localities* in *Portolan Atlas* (text in Arabic), place of origin unknown, ca. 1571. ʿAli ibn Ahmad Sharafi al-Sifaqsi (Persian, active 16th century). Brown and colored inks on paper. Oxford, Bodleian Libraries, University of Oxford, MS. Marsh 294, fol. 4b

Predicting the beginning and ending of Ramadan was likewise difficult. Because the length of a lunar month is approximately 29.5 days, the beginning of a lunar month is not fixed like that of a solar month; determining the

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beginning of a lunar month is therefore often challenging, and predicting it requires astronomical calculations. In the early days of Islam the new crescent moon, which signals the beginning of a lunar month, was sought using the naked eye. When the crescent could not be sighted, the fasting would commence as a precaution one day later. Some Muslim countries still use this method.

The prescientific approach to Islamic rituals may have been regarded as adequate for the time being, but Muslims were also encouraged to seek knowledge no matter the difficulty or distance required to claim it. Furthermore, numerous verses in the Qurʾan describe celestial motions using a particular word, "calculation" (*ḥisāb*), which tells us that these phenomena were recognized as calculable as early as the seventh century.[2] Learned Muslims employed the mathematical sciences for religious rituals immediately after they were introduced. There were many factors in the rapid development of the sciences in the Islamic world, but the religious incentive was among the strongest. It certainly created momentum, and consequently the knowledge of timekeeping—which covers all the mathematical and technical aspects of timekeeping measurements, geography, and trigonometry, as well as designing, making, and using instruments of calculation and observation—became arguably the most comprehensive branch of astronomy in the Islamic world around the thirteenth century.[3] Thus, contrary to the popular misconception, Islam was one of the driving forces of scientific endeavors, introducing the concept of "science in the service of religion."[4]



FIGURE 12. *Leo* in *Book of Fixed Stars* (*Kitab Suwar al-Kawakib al-Thabita*) (text in Arabic), place of origin unknown, ca. 1430–40. ʿAbd al-Rahman al-Sufi (Persian, 903–986). Ink on paper, full folio: 24.5 × 18.5 cm (9⅝ × 7¼ in.). Paris, Bibliothèque nationale de France, Département des Manuscrits, Arabe 5036, fol. 136

Tools of Timekeeping

Studies of the history of science often rely on written materials such as treatises, notebooks, travel accounts, and so on as primary sources. Scientific instruments like astrolabes and celestial globes are seldom regarded as such, and yet historical scientific instruments, in particular astronomical ones, provide concrete evidence of scientific endeavors. These instruments survive in two forms: as depicted and described in textual sources and as extant physical instruments in museums, libraries, and private collections. For instance, an illustration from one of the most influential works on fixed stars, *Kitab Suwar al-Kawakib al-Thabita*, by the astronomer ʿAbd al-Rahman al-Sufi (903–986), depicts the constellation Leo (fig. 12) as it is supposed to be shown on a

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FIGURE 13. Celestial Globe, Lahore, Pakistan, ca. 1650. Brass, inlaid with silver, H: 29 cm (11 7⁄16 in.); W: 20.5 cm (8 1⁄16 in.); D: 20.5 cm (8 1⁄16 in.). Chicago, Adler Planetarium, M-14

celestial globe and as it is in fact shown on an unsigned seventeenth-century example from Lahore (fig. 13).

Astronomical instruments offer a wealth of information about mathematical knowledge, artistic styles, religious inclinations, social priorities, and nonscholarly interest in science and in scientific instruments (admired for their beauty or prestige) at the time of their making.[5] One can study an astrolabe or a celestial globe to determine the level of mathematics that was in use, to check the accuracy of the calculations required to draw and engrave astronomically significant curves and lines, or to reveal the artistry and craftsmanship of the instrument's period. Deeper study reveals hints of the transfer of knowledge between regions and periods—between the Islamic world and Europe, for instance—and of the evolution of astronomical instruments in general. Scholarship employing some of the thousands of extant instruments as primary sources allows us to understand the step-by-step development of the knowledge of timekeeping both in accuracy and in practical application. In this regard two types of instruments are highlighted here: astrolabes and quadrants.

ASTROLABES

Of all the scientific instruments in human history, the astrolabe can be construed as the symbol of science in the Islamic world. Knowledge of the astrolabe, which was invented by the ancient Greeks, probably around the second century BCE, reached scholars in the Islamic world in the late eighth century CE via translations of Greek treatises. The astrolabe, an instrument that imitates the motion of the sky, is used for observations, measurements, and calculations for telling time. It has fixed, detachable, and rotating pieces that allow the user to trace the daily path of the sun during the day and of bright stars at night for specific localities. All this is possible because of a mathematical operation called projection—the technique of drawing the three-dimensional sky onto a two-dimensional surface while preserving the relative positions of stars and the sun. The precision of a projection, dependent on the quality of the calculations, is key to accurate timekeeping operations. This is where scholars in the Islamic world come in. Exploiting multiple mathematical traditions, they fused the geometry of the ancient Greeks and the trigonometry of the ancient Indians to improve both the accuracy and the designs of astrolabes as early as the ninth century. Besides inventing various new types of astrolabes, between the late ninth and fourteenth centuries they improved the standard—planispheric—astrolabe by introducing new sets of graphs, curves, and lines related to astronomical and astrological operations, thereby making astrolabes arguably the most sophisticated scientific instruments before the invention of computers.

The thirteenth-century astrolabe by Muhammad b. Abi Bakr encapsulates evidence of mathematical

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advancement, continuity of an instrument-making tradition, and the unique contributions of scholars in the Islamic world (plate 7). It has four plates with projections for different localities, making the astrolabe more efficient than most. The plates are inserted into and fixed at the front of the mater, the main body. On top of them is a rotatable hollowed disk called the rete (or "star net"), which includes an ecliptic ring representing the yearly motion of the sun and thirty-eight star pointers that mark the relative positions of bright stars, all labeled. Plates and rete are standard parts of an astrolabe. What makes this astrolabe unique is hidden inside. The mater contains the earliest working gear mechanism in the world. The purpose of this complex gear train is apparent on the reverse of the astrolabe, where windows indicate the phase of the moon and the day of the lunar month and rings show the motions of the sun and moon against the zodiac and conjunctions of the sun and moon. This type of astrolabe was first introduced by the eleventh-century polymath al-Biruni (973–1048) and improved by Muhammad in this example.

In the Islamic world a standard astrolabe would have had more than a hundred uses. Some of the principal ones were finding the time almost instantaneously by measuring the altitude of the sun during the day or the altitude of a bright star at night; determining the time since or until sunrise, noon, and sunset; identifying the length of days and nights at any date; discerning the height of natural or man-made structures such as mountains or towers; and calculating trigonometric equations without the need for a pen and paper. The chief uses of the astrolabe specifically in Islamic religious observance were finding the beginning of the morning and night prayers by measuring the altitude of the sun below the horizon; finding the beginning of the noon and evening prayers by measuring the altitude of the sun above the horizon; finding the beginning of the afternoon prayers using the length of shadows of objects; and locating the qibla—the direction of Mecca—for prayers.

By the fourteenth century the scientific and technical evolution of astrolabes was complete. Because they were multifunctional, astrolabes dominated astronomy in the Islamic world. More than three hundred extant astrolabes from different regions and centuries can be found in museums and libraries throughout the world, providing ample evidence of the instrument's everlasting popularity. Astrolabes were never the exclusive property of astronomers, however. Rather expensive but extremely elegant works of art, astrolabes were considered status symbols by their owners. Consequently, they were turned into gifts for sultans or rich and powerful families and individuals. Craftsmen continued improving astrolabes' artistic features and designs until perfecting them in the seventeenth to eighteenth century, particularly in Safavid Iran and Mughal India. For instance, the magnificent Persian astrolabe made around 1660 by Muhammad Mahdi al-Yazdi, who was one of history's most prominent astrolabe makers, manifests extremely detailed craftsmanship, with beautiful floral decorations, a combination of engraving and embossing techniques, and silver inlays in the brass. It is undoubtedly a gift worthy of kings (fig. 14).

QUADRANTS

The development of complex multifunctional astrolabes was very helpful to skilled astronomers, but it was not practical and limited the knowledge of timekeeping to experts. A less sophisticated, user-friendly device was required to ensure the conformity of daily religious observances. Providing such an instrument became a focus for astronomers during the Mamluk era.

The Mamluk dynasty, which ruled Egypt, Palestine, and Syria between the thirteenth and fifteenth centuries, wanted to regulate prayer times and consequently established the office of timekeeper.[6] A timekeeper was an astronomer who was employed at a central mosque. The main duty of a timekeeper was to follow the light of the sun during the day and of the shimmering stars at night in order to determine the beginning of prayer times daily. There were more cities and mosques than there were astronomers, however. Prominent Mamluk astronomers such as Ibn al-Shatir (d. ca. 1375), Muhammad ibn Ahmad al-Mizzi (d. 1349), and Sibt al-Mardini (d. ca. 1495) worked to make the knowledge of timekeeping available to educated people who were not astronomers and to enthusiasts with a basic level of astronomical knowledge by compiling easy-to-read treatises and, more important, designing accurate and user-friendly instruments. The result of this endeavor was the development and widespread use of the *rubʿ al-dāʾira*, or quadrant. As the name suggests, the quadrant is in the shape of a quarter circle. It is used for celestial observations and calculations and

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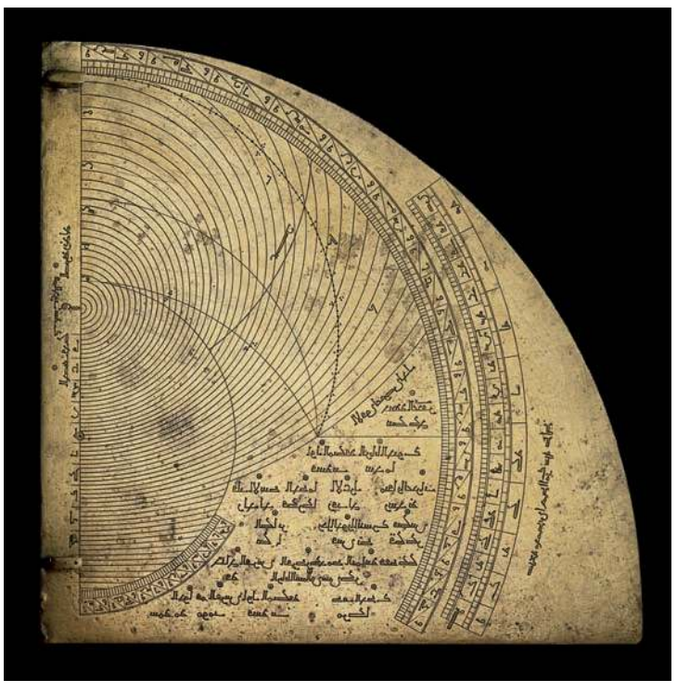
FIGURE 14. Astrolabe, Safavid Persia (Iran), ca. 1660. Muhammad Mahdi al-Yazdi (Persian, active 17th century). Brass, inlaid with silver, Diam: 11.5 cm (4 ½ in.). Oxford, History of Science Museum, University of Oxford, Presented by J. A. Billmeir, inv. 46886

FIGURE 15 (opposite). Astrolabic Quadrant, Damascus, dated 734 AH/1333–34. Muhammad ibn Ahmad al-Mizzi (Syrian, d. 1349). Brass, Diam: 44.7 cm (17 ⅝ in.). London, British Museum, 1888,1201.276

performs almost all the operations of an astrolabe except one: it can be used only at a specific locality (astrolabes can be used in multiple localities and, in some cases, universally). This, however, was not a problem since quadrants were already being made for specific venues (i.e., al-Azhar Mosque in Cairo).

Unlike an astrolabe, a quadrant does not have rotating or detachable pieces, making it much more user friendly for nonexperts. A quadrant has two sides: one side is the astrolabic quadrant, on which are engraved the curves and lines of the projection of the sky, just like on an astrolabe (fig. 15). The other side is called the sine quadrant, which is a trigonometric grid, and it is exactly the same as the sine graph on the back of a standard astrolabe; it is used for trigonometric equations. The astronomers compiled separate user manuals for each side. These

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manuals are among the most copied treatises in the history of astronomy in the Islamic world, and they are almost entirely written in a concise language and with instructions intended for nonexperts. Anyone with a basic knowledge of astronomy can use the quadrant with the help of these manuals. This is arguably one of the earliest examples in history of public engagement with science, of a scientific instrument made accessible to all. The new instrument solved the need for astronomer-timekeepers in places of worship, turning non-astronomer mosque staff into primary timekeepers even in the far corners of the Islamic world.

While astrolabes remained the instrument of choice among highly skilled astronomers and in courtly gift-giving traditions, quadrants took over the timekeeping applications, initially in the Mamluk realm and then, from the sixteenth century, in the Ottoman Empire. Ottoman scholars adopted the Mamluk timekeeping tradition almost completely, including the office of timekeeper and its instrumentation, but they made quadrants their own by using wood as the material instead of the traditional brass.[7] The wooden quadrant could be constructed easily and cheaply by almost anyone; metalworking skills were unnecessary. The Ottomans used quadrants efficiently and continuously until the early twentieth century.

The long tradition of timekeeping in the Islamic world was fruitful for the development of the mathematical sciences and benefited practicing Muslims. From the first astronomers in ninth-century Baghdad to the last Ottoman scholar in Istanbul in the early twentieth century, the knowledge of timekeeping remained a lively topic. The six-hundred-year-long continuous observations of Islamic timekeepers, from the fourteenth to the twentieth century, were and still are, arguably, an unmatched record for astronomical activities. And at the foundation of Islamic traditions of timekeeping was light, which emanates neverendingly from the stars.

Notes

1 David A. King, "Islamic Astronomy," in *Astronomy before the Telescope*, ed. Christopher Walker (London: British Museum Press, 1996), 143–47.

2 Qurʾan 10:5 and 17:12, in *The Clear Qurʾan*, trans. Mustafa Khattab (Bolingbrook, IL: Book of Signs Foundation, 2020).

3 François Charette, *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria: The Illustrated Treatise of Najm al-Dīn al-Mīṣrī* (Leiden: Brill, 2003), 6.

4 David A. King, "Science in the Service of Religion: The Case of Islam," *Impact of Science on Society*, no. 159 (1990): 245–62.

5 Taha Yasin Arslan, "Three-Dimensional Astronomy: Celestial Globes and Armillary Spheres," in *Routledge Handbook on the Sciences in Islamicate Societies: Practices from the 2nd/8th to the 13th/19th Centuries*, ed. Sonja Brentjes (London: Routledge / Taylor & Francis Group, 2022), 474.

6 David A. King, "Mamluk Astronomy and the Institution of the *Muwaqqit*," in *The Mamluks in Egyptian Politics and Society*, ed. Thomas Philipp and Ulrich Haarmann (Cambridge: Cambridge University Press, 1998), 153–62.

7 Taha Yasin Arslan, "Conquering the Time: An Example of a Manual for Making an Astrolabe Quadrant: Muhammad Qunawī's *Hadiyyat al-mulūk*," *Nazariyat Journal for the History of Islamic Philosophy and Sciences* 2, no. 4 (May 2016): 101–2.

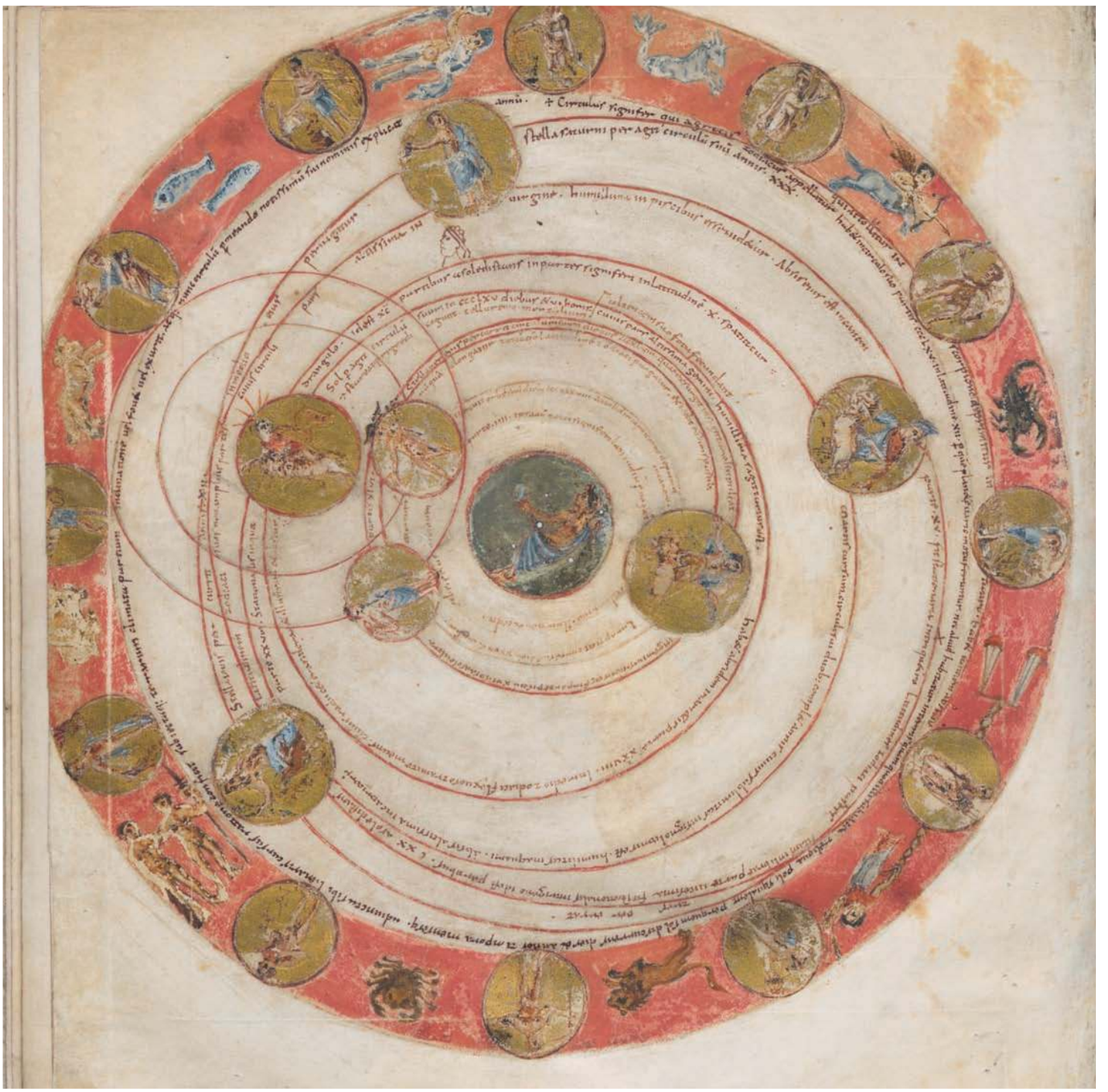
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1

Plate with Aratos and Urania, Byzantine, Syria(?), late 6th–first half of 7th century
Silver, niello, H: 3.4 cm (1⅓ in.); Diam: 23.5 cm (9¼ in.); Wt: 0.938 kg (2.07 lb.)
London, Wyvern Collection, inv. 1885

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2

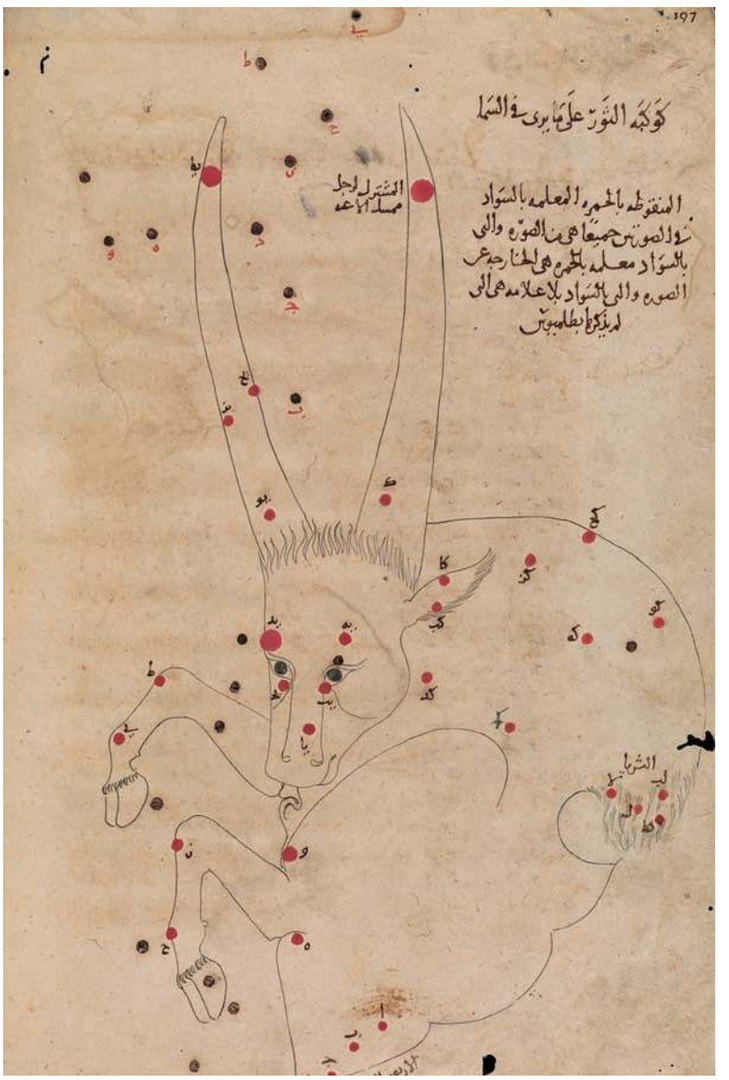
Aratea (in Latin), based on the *Phaenomena* (composed ca. 275 BCE), Carolingian Empire, Aachen, Germany, between 830 and 840
Aratos (author) (Greek, ca. 315–240/239 BCE)
Germanicus (translator) (Roman, 15 BCE–19 CE)
Rufius Festus Avienus (supplemental translator) (Roman, active 4th century)
Tempera, gold, and ink on parchment, full folio: 22.5 × 20 cm (8⅞ × 7⅞ in.)
Leiden, Universiteitsbibliotheek, Ms. Voss. Lat. Q. 79, fol. 93v

PLATES 1, 2

The diagram of the cosmos shows the movements of the planets according to late antique scientific understanding. On the silver plate, the author, the Greek poet Aratos, is shown engaging in conversation with Urania, the muse of astronomy, while he points to a celestial sphere.

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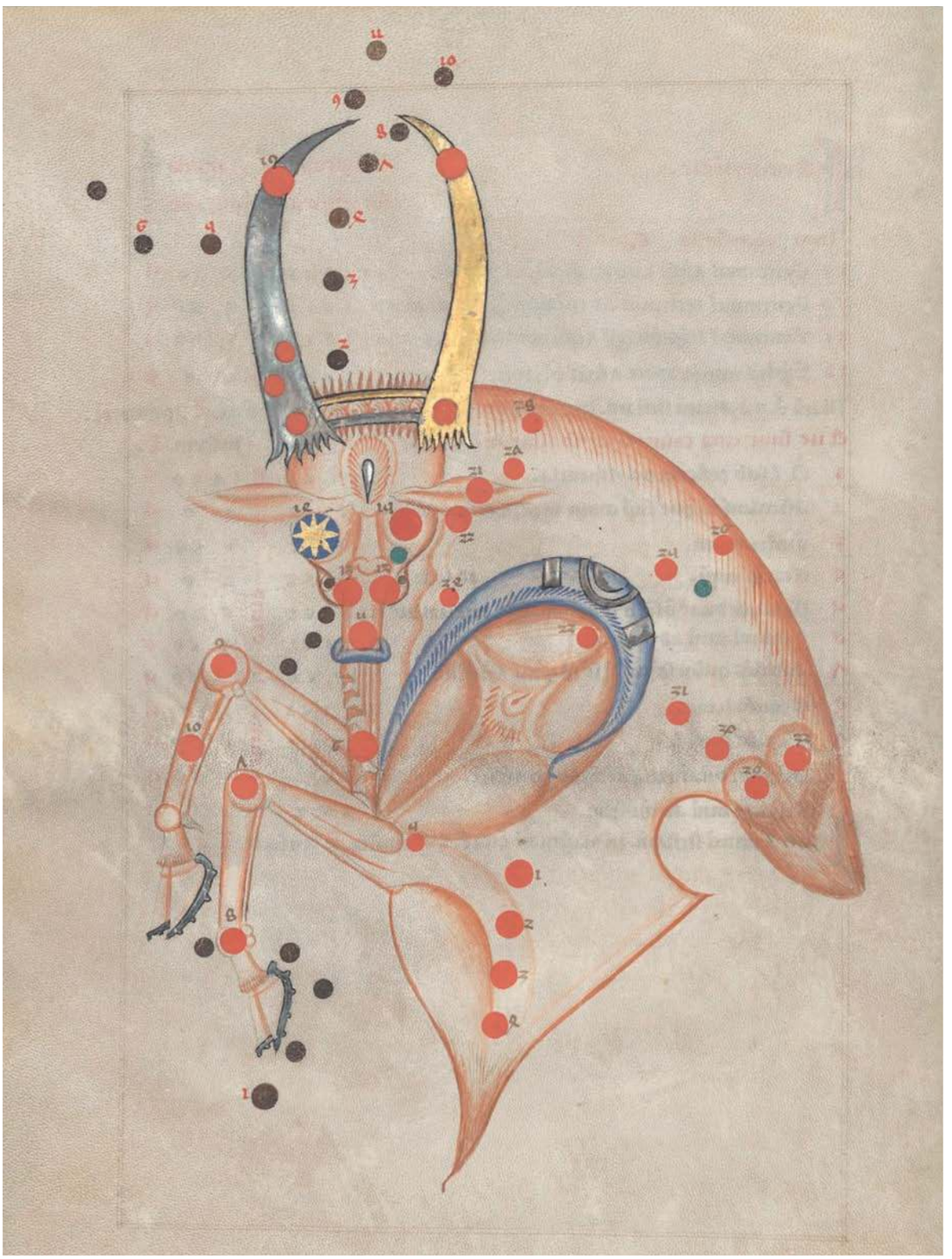
3

Celestial Globe, Persia (Iran), 763–64 AH/1362–63
Jaʿfar ibn ʿUmar ibn Dawlatshah al-Kirmani (Persian, active 14th century)
Brass, inlaid with silver, 19.5 × 21 × 20 cm (7⅔ × 8 ¼ × 7⅞ in.)
Oxford, History of Science Museum, University of Oxford, inv. 44790

4

Taurus (al-Thaur) in *Book of Fixed Stars* (*Kitab Suwar al-Kawakib al-Thabita*) (in Arabic), Buyid Persia (Iran or Iraq), 400 AH/1009–10 or 13th century, with ca. 14th- and 16th-century additions
ʿAbd al-Rahman al-Sufi (Persian, 290–376 AH/ 903–986)
Ink on paper, full folio: approx. 27.3 × 20.3 cm (10¾ × 8 in.)
Oxford, Bodleian Libraries, University of Oxford, MS. Marsh 144, fol. 197

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5

Taurus, the Bull in *Book of Fixed Stars* (in Latin), possibly Bologna, Italy, 1275–1300
ʿAbd al-Rahman al-Sufi (Persian, 290–376 AH/ 903–986)
Tempera, gold, and ink on parchment, full folio: 33.3 × 23.4 cm (13⅛ × 9¼ in.)
Paris, Bibliothèque nationale de France, Bibliothèque de l'Arsenal, Ms-1036, fol. 21v

PLATES 3—5

A celestial sphere from Persia is engraved with constellations and an inscription saying that the instrument is a copy of al-Sufi's *Book of Fixed Stars*. Two copies of this book—one made in Persia, the other possibly in Bologna—attest to the scientific dialogue conducted over time and across distances by natural philosophers who read and improved upon a shared body of scientific knowledge.

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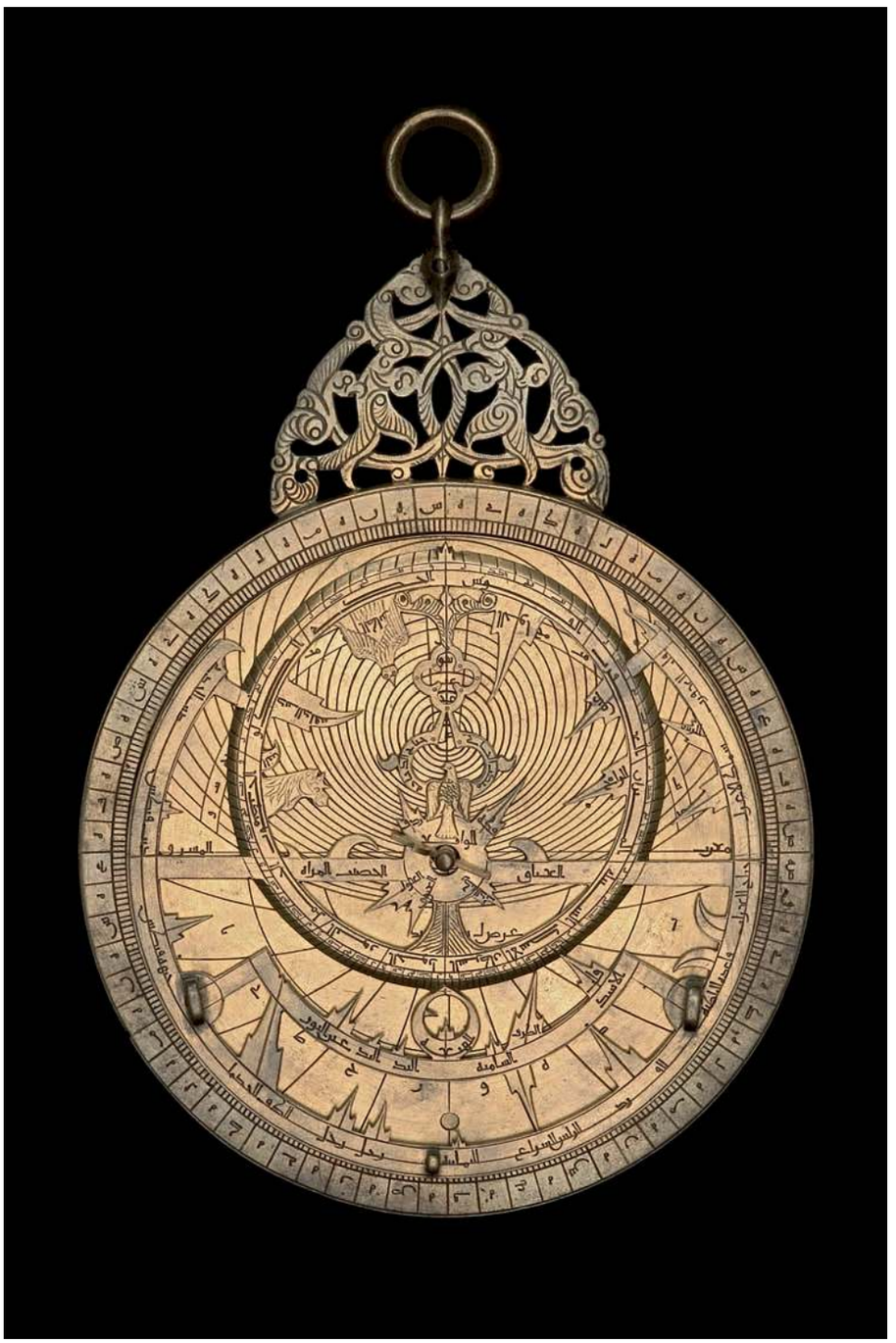


6

Astronomers on Mount Athos
in *The Travels of Sir John Mandeville* (in Czech), Bohemia (Czech Republic), ca. 1400–1425
Sir John Mandeville (author) (active ca. 1357)
Master of the Mandeville Travels (artist) (active 15th century)
Tinted ink drawings on parchment, full folio: 22.5 × 18 cm (8⅞ × 7⅛ in.)
London, British Library, Additional 24189, fol. 15

On Mount Athos, a holy site and home to numerous Eastern Orthodox monasteries, astronomers use instruments of observation to chart the movements of the celestial bodies.

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7 Astrolabe with Geared Calendar, Isfahan, Abbasid Persia (Iran), 618 AH/1221/22
Muhammad b. Abi Bakr (Persian, active 13th century)
Copper alloy, silvered copper alloy, silver, wax, H: 27.5 cm (10 13⁄16 in.); Diam: 18.5 cm (7 1⁄4 in.); D: 5 cm (2 in.)
Oxford, History of Science Museum, University of Oxford, inv. 48213

As the oldest functioning geared mechanism that survives, this Persian astrolabe demonstrates the sophistication of observational science in thirteenth-century Isfahan. Its internal gear train (bottom right) drives the calendar on the object's verso (upper right), where a round window reveals the changing phases of the moon within its cycle and a square window shows the date according to the lunar calendar. The rotating rings at the bottom show the relative positions of the sun and moon, revealing potential eclipses and conjunctions of major stars.

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8

Astrolabe with Lunar Mansions, Ayyubid Syria or Cairo, Egypt(?), 624–25 AH/1227–28
ʿAbd al-Karim al-Misri (Egyptian, active in Syria, 13th century)
Brass with gold and silver damascene work, H: 36 cm (14 3⁄16 in.); Diam: 27.8 cm (10 15⁄16 in.); Wt: 3.8 kg (8.37 lb.)
Oxford, History of Science Museum, University of Oxford, inv. 37148

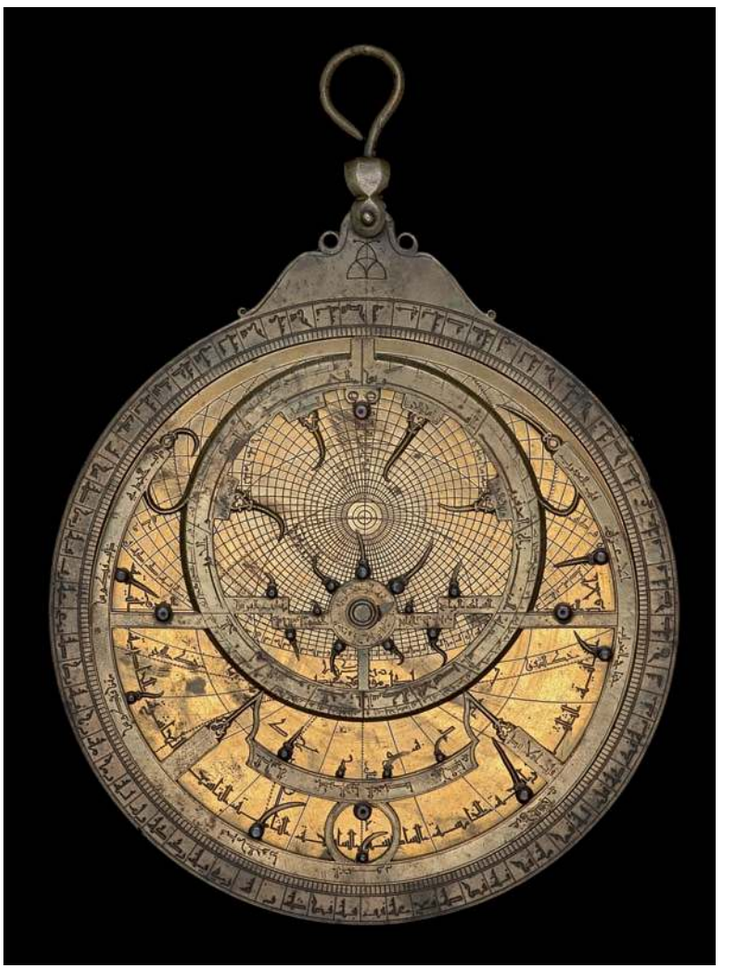
A masterpiece of Ayyubid metalwork, this extraordinary astrolabe was commissioned by the sultan Abu-l-Fatih Musa, whose empire extended into Mesopotamia, Syria, and Armenia. On its back, it includes the lunar cycle with the lunar mansions represented as pictograms. The lunar mansions are the segments of the sun's ecliptic, or circular path, through which the moon passes. The lively pictograms associated with each house are unique in this context and may have talismanic meaning. Talismans often took the form of symbols of the zodiac and other planets and were used to channel the powers of the heavens.

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9

Astrolabe, Taifa Kingdom of Toledo, Toledo, Iberia (Spain), 460 AH/1067–68
Ibrahim ibn Saʿid al-Sahli (active in Valencia and Toledo, ca. 1050–90)
Brass, H: 20.2 cm (7 15⁄16 in.); Diam: 18.5 cm (7 5⁄16 in.); D: 4 cm (1 9⁄16 in.)
Oxford, History of Science Museum, University of Oxford, inv. 55331



10

Astrolabe (with silver star markers), Almohad, Seville, Iberia (Spain), 621 AH/1224–25
Muhammad ibn Fattuh al-Khamairi (active in Seville, Iberia, 13th century)
Brass, H: 25.7 cm (10 1⁄8 in.); Diam: 18.7 cm (7 3⁄8 in.); D: 1.7 cm (11⁄16 in.)
Oxford, History of Science Museum, University of Oxford, inv. 50934

PLATES 9, 10

As two-dimensional models of the universe, astrolabes enabled people to establish times of prayer as well as to make astronomical observations and astrological prognostications. These astrolabes represent the golden age of Andalusian science. Muslim, Jewish, and Christian thinkers, often working together, translated scientific texts and crafted sophisticated—at times bilingual—astronomical instruments.

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11 *Tapestry of the Astrolabes*, probably Tournai, Flanders (Belgium), ca. 1400–1450
Wool, silk, 445 × 800 cm (175 3/16 × 315 in.)
Toledo, Spain, Cabildo Catedral de Toledo, Primada de España, inv. 04/2312

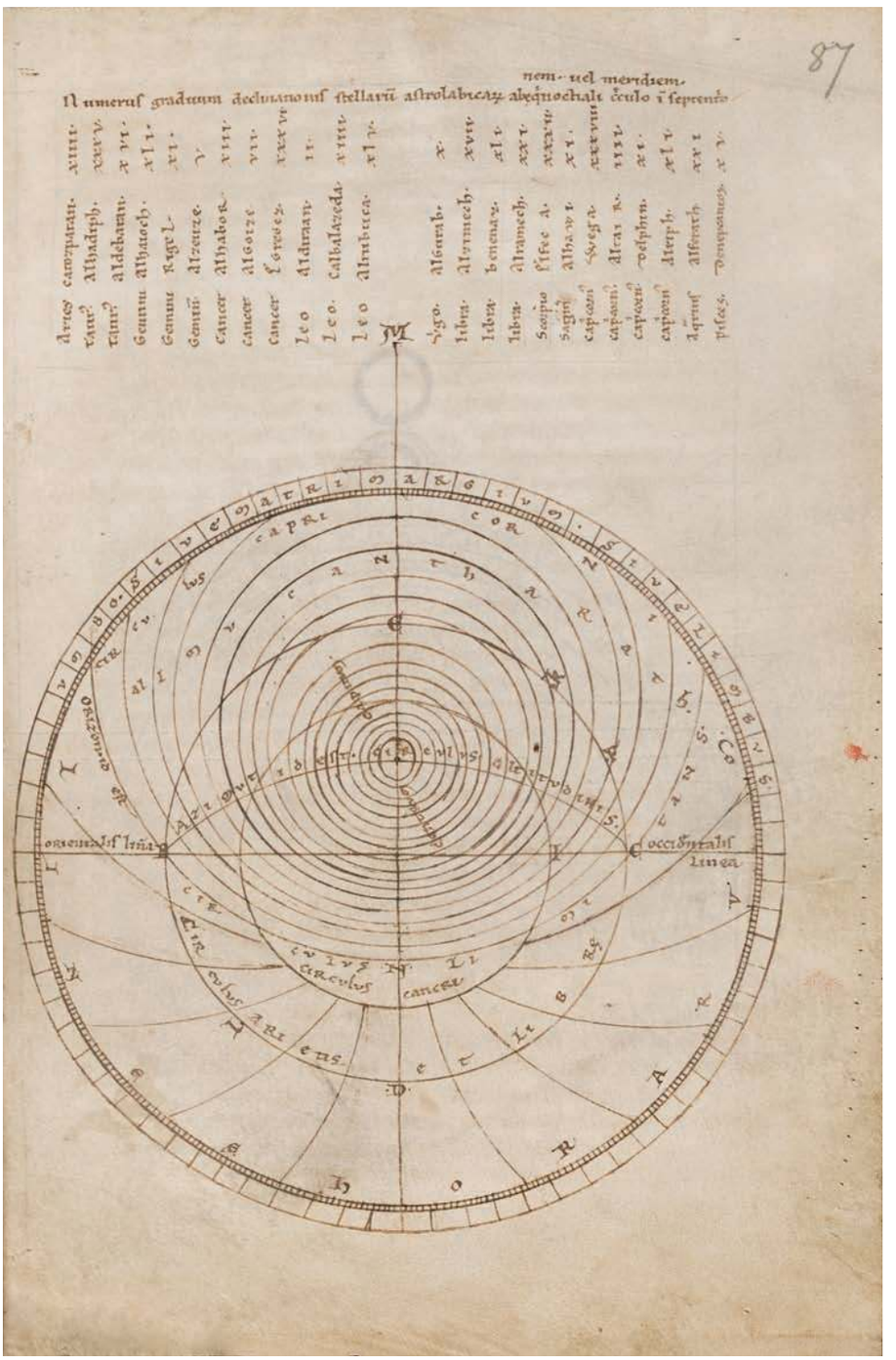
Emanating light, God directs the movement of the cosmos, pictured within the structure of an astrolabe that is set in motion by an angel turning a crank. The personification of Philosophy sits enthroned, surrounded by Geometry, Arithmetic, and Astrology, who points to the stars.

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12

Astrolabe, England(?), ca. 1370
Brass, H: 22 cm (8⅝ in.); Diam: 15.7 cm (6 3/16 in.); D: 1.6 cm (⅝ in.)
Oxford, History of Science Museum, University of Oxford, inv. 49359



13

Diagram of an Astrolabe with Names of Astronomical Signs in Latin and Arabic from the *Liber de astrolobio* in *Astronomical Miscellany*, St. Trond, Flanders (Belgium), ca. 1175
Adelard of Bath (English, 1075–1160)
Ink on parchment, full folio: 23.8 × 15.5 cm (9⅜ × 6 ⅛ in.)
Cambridge, Fitzwilliam Museum, Bequeathed (1904) by Frank McClean, MS McClean 165, fol. 87

PLATES 12, 13

Adelard of Bath was a well-traveled philosopher known for his translations of ancient and recent scientific works from Arabic into Latin. Here, his work on cosmography and the astrolabe is accompanied by a labeled diagram that includes a list of twenty-four stars suitable for inclusion on an astrolabe rete. Their Arabic names are used, and their zodiacal signs (in Latin) and declination are provided.

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14

Astrolabe with Hebrew and Judeo-Arabic Script,
Iberia (Spain) or Italy(?), 14th century
Brass, Diam: 9.2 cm (3⅝ in.)
London, British Museum, 1893,0616.3

15

Moreh Nevukhim (*Guide for the Perplexed*) (in Hebrew), Barcelona, Iberia (Spain), 1347/48
Moses ben Maimon (Maimonides) (author) (Iberian, active in Morocco and Egypt, ca. 1135–1204)
Ferrer Bassa (artist) (Catalonian, 1285–1348)
Levi ben Isaac (scribe) (Iberian, active in Catalonia, mid-14th century)
Tempera, gold, and ink on parchment, binding: 19.4 × 13.3 × 6.5 cm (7⅝ × 5¼ × 2⁹⁄₁₆ in.)
Copenhagen, Royal Danish Library, Cod. Heb. 37, fol. 114a



PLATES 14, 15

Born in Cordoba, the Jewish scholar Moses ben Maimon, known as Maimonides (ca. 1135–1204), studied astronomy and the philosophy of Aristotle, who is pictured here holding an astrolabe. Maimonides brought rabbinic theology into dialogue with ancient philosophy and attempted to reconcile differences between the two.

Incipit Liber Ptholomei de fructu sapientie et de laude philosophie



Qui principem nomine albuquafe. in libro fructus sapientiarum electione. et uiros nominauit pulcritudinem: dixit q' hic ptholomeus fuit unus in discipulis suis. ita potens. prudens alijs. in duabus artibus subtilibus. id est. geometria. et astrologia. et fecit libros multos. de quorum numero iste est qui megaliti dicit. cuius significatio est maior pfectus. quem ad linguam uolentes conuertere arabicam: nominauerit almagesti. Hic autem ortus et educatus fuit in alexandria. cuius studium considerauit instrumentis. tempore regis adriani. et aliorum. et super considerationes abrachis qui in rhodo exercitus est. opus suum edidit. Ptholomeus uero hic non fuit unus regum egipti. qui ptholomei uocati sunt. sicut quidam estimauerunt. licet hoc fuerit nomen. ac si aliquis uocaretur cesare. aut celar. Hic autem in statu modernus fuit. colore albus. in cesitio largus. subtiles habens pedes. in maxilla dextera signum habens subtile. barbam et spissam et mingentes anteriores habens dulce optos. et apertos. Os eius primum. loquele bone in dulcis. sonus nec tacere sed alterum multum praeeligitur. et equaliter. pax comedebat. multum ieiunabat. redolentem habens anhelitum. et in domo nocturna. Mortuus est anno urbis fue. lxx. viij. Hi uero fuerunt de discipulis et sapientibus. ptholomei huius. Quorum est intelligendus per deo uerendum: ei ea que ei sunt grata cogitat. Intelligens est qui linguam suam refrenat: nisi ad hoc ut deo laudetur. Insipiens est. qui sui ipsius ignorat qualitatem. Quem aliquis sapientum placitis: ad hoc deductus est: ut nichil dicat supra ipsum. In bono quod deus operatur: qui bonitatem largi datoris attendere debet. et in malis ad diuisionem qui pugnationis et cetere remuneracionis bonitatem.

Quanto plus finem appropinquas. tanto cum augmento operare. Hominis disciplina sui intellectus socius est. et apud doctos meritos. Non fiunt mortui qui scientiam uiuificauerunt. nec sunt pauperes qui intellectum ditauerunt. Quia inter sapientes humiliores et sapientiores existunt. sicut loca profundiora magis humectat aquas alias laciunt. Non dilectas in animo quod ueritatem concedit. nec respondeas in re quam consilium. et a prudente requiras. Quum consilium in committas. in qui celauerit. Quia in hoc mundo primatum uoluit. cor placens aduersitatibus ipsius. Maxima dominus est dolor minor. Quis gaudeas quod in christi errore. quam quod veneficiendo in carnis. Quum nascens in extremas mamillas ad potandum. et ei mundicie fuerit in dimissio debilitas. parce. Ultime hominis promissiones eam sunt. Iustorum cordia secretorum est monumenta. Quia pro alios non corrigit alius pro ipsum non corrigent. Quia animus intellectui animam regit habenas. Quia uulgi habenas regere meli est quia multos hec multes. Fiducia est socii consolatus. qua luce non consecutus. eam tu angustiasti. Securitas solutum dimittit dolorem remotum. et pauor mentis diuidis consolationem auferet. Inter homines alacer existit: qui non curat in animo animi sui mundi. Immundum deum quod ablacio hominum altius sit supra hominum. Homines lucrantur consilium. et consilium lucrantur homines. Quia in celam sua ultra astucias qui in ipso extendit. et licet pastor debilis ei multis omnibus. Quia in dignitate sua multi ierrollit: in amissione cuius multum deprimit. Quia in male operando multi celant: simul discooperuit se. Quia in medicato sedet. cum pestilentia deficiet ei. Meditatio: animal existit. clausum. Intercessor est pretextus ut alia ala. Anima non egrediatur a fiducia usque ad mortem. Anima ignorat a suo socio magis minuetur. Quidam per minutum ptholomei ad prandium. quod rogas fore se excusatum dixit. Ego uix ego fere quod rem gesserunt uicinitas pictures. quia alia longe uidentur placent. Propinqua uero non dulcescunt.

Liber hic precepto mamomi regis arabum qui regnauit in baldach ab alahal. et filio ioseph filii matre anismetica. et sergio filio elbe. anno. in anno. xij. et. cc. sette sarracenorum translatus est. Quia quidem liber est magnus. dictus almagesti. quem ptholomeus pheludensis de sacuda stellay. et motuum qui sunt in celo conscripsit. In hoc autem libro sunt. xiij. dictiones.

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16

Quadrans vetus Horary Quadrant, France(?), ca. 1300
Brass, 16 × 16 × 1.1 cm (6 5/16 × 6 5/16 × 7/16 in.); Wt: 0.4 kg (0.88 lb.)
Oxford, History of Science Museum, University of Oxford, inv. 52020

Smaller and easier to use than an astrolabe, the horary quadrant enabled laypeople, such as merchants and sailors, to tell time. When one edge was aligned with the sun, a plumb line indicated the time according to the hour lines marked on the instrument's edge.



17 (OPPOSITE)

Almagest (in Latin) in *Scientific Miscellany*, Paris, 1309–16
Claudius Ptolemy (author) (Alexandrian, ca. 100–ca. 170)
Attributed to the Meliacin Master (artist) (French, d. 1312)
Tempera, gold, and ink on parchment, full folio: 40.5 × 29 cm (15 15/16 × 11 7/16 in.)
London, British Library, Ms. Burney 275, fol. 390v

Ptolemy wrote what became the most important astronomical text of the Middle Ages. Known by its Arabic nickname (*al-majisti*, meaning "the greatest"), the *Almagest* provided the foundation for mathematical astronomy for nearly fifteen hundred years.

18

Monk Measuring the Hours of the Night Using Pacificus's Horologium Nocturnum (in Latin) in *Astronomical and Computistical Miscellany*, northern France or England, ca. 1175–1200
Tempera and ink on parchment, full folio: 26 × 19 cm (10 1/4 x 7 1/2 in.)
Venice, Biblioteca Nazionale Marciana, Ms. Lat. VIII 22 (2760), fol. 1

Sighting tubes like the horologium of Pacificus of Verona allowed monks participating in the night offices to determine the time with a device that measured the changing angle of the Pole Star in relation to the bright stars nearby.



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Charles Ross

GLENN PHILLIPS



Imagine a time-lapse video of the night sky: the stars rotate above us in a circular pattern, and at the center of that circle is a star that moves very little at all. This is Polaris, the North Star, the star most directly aligned with the earth's North Pole. The North Star has long been used for navigation, and medieval scholars calculated the time of night, with devices such as the *horologium nocturnum* (plate 18), by noting the location of other stars in relation to Polaris. Yet ancient Greek and Roman astronomers had already begun to hypothesize that our orientation toward Polaris was shifting over time. Medieval scientists knew of these ideas through texts such as Ptolemy's *Almagest*, and Islamic astronomers such as ʿAbd al-Rahman al-Sufi further advanced this work (plates 4, 5, 17). Known as the precession of the equinoxes, the phenomenon is an extremely slow-moving "wobble" in the earth's rotation, much like the wobble one might notice in a spinning top. Precession disrupts the consistent alignment of the earth's rotation (or, as the medieval scientist saw it, the sun's rotation) with the same constellations over time. Today we know that one cycle of this "wobble" takes approximately 25,772 years, or one degree in about 72 years. Over the course of that cycle Polaris will drift farther from the North Pole until we need to designate a new North Star. In one thousand years it will be Errai, followed by a string of others until, in the year 27,800, Polaris becomes the North Star again.

Star Axis is a monumental sculpture and naked-eye observatory in New Mexico that allows us to directly visualize the nearly twenty-six-thousand-year cycle of precession. The work was conceived by Charles Ross in 1971, has been under construction since 1976, and is nearing completion in 2025. At the heart of *Star Axis* is the Star Tunnel, a ten-story structure that is precisely aligned with the earth's axis. A set of stairs beginning at the bottom of the structure leads directly to a circular oculus that, from below, appears quite small. This aperture directly frames the very narrow orbit of Polaris, at its closest to the pole, that we will experience in the year 2100. As one ascends the structure, the oculus grows larger in our field of view, corresponding to the orbits of Polaris in future and past years, which are marked on the handrails above each of the 147 steps. At the top the oculus nearly fills our field of vision and now circumscribes the orbit of Polaris at its farthest extension from the earth's axis, as it was in 11,000 BCE and will be again in 15,000 CE.

Star Axis includes several other elements that help us experience celestial motion. The Shadow Field delineates the shape of shadows cast by the Solar Pyramid over the course of a year. The Hour Chamber, inside the Solar Pyramid, has a tall, triangular opening, framing Polaris at its apex, that precisely frames the relative movement of stars over the course of one hour. The Equatorial Chamber, located perpendicularly to the Star Tunnel, frames the stars that travel directly above the earth's equator. Collectively, the simple and powerful visualizations built into *Star Axis* allow us to grasp phenomena that our predecessors, building on and trusting in one another's work, took more than one thousand years to understand and calculate with precision.

19a (OPPOSITE)

Charles Ross (American, b. 1937)
Star Axis (1971–ongoing)
Granite, sandstone, bronze, stainless steel, earth
View looking up the Star Tunnel

19b (ABOVE)

Charles Ross (American, b. 1937)
Star Axis (1971–ongoing)
Granite, sandstone, bronze, stainless steel, earth
Time-lapse view of the Hour Chamber, with Polaris at top

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353. 7070.

Ci commencent li chapitre du roumanz mestre Gossouin qui est apelez ymage du monde.





Ci[u]mi[n]t li chapitre de cest roumanz q[ue] en a[p]le lymage dou monde. q[ui] est translatez de latin en r[o]manz contient. lv. chapitres. z. cc. vnj.

figures sanz quoi li livres ne porroit estre legierement entendu z. qui est devisez en. iij. parties. dont la premiere partie contient. xxij. chapitres. z. viij. figures sanz le prologue.

Li premiers chapitres

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20 (OPPOSITE)

The Author, Holding an Armillary Sphere, Dictates to a Scribe in *L'image du monde*, Paris, ca. 1320
Gossuin de Metz (French, active 13th century)
Tempera, gold, and ink on parchment, full folio: 38 × 25.5 cm (15 × 10 in.)
Paris, Bibliothèque nationale de France, Département des Manuscrits, Ms. Fr. 574, fol. 1

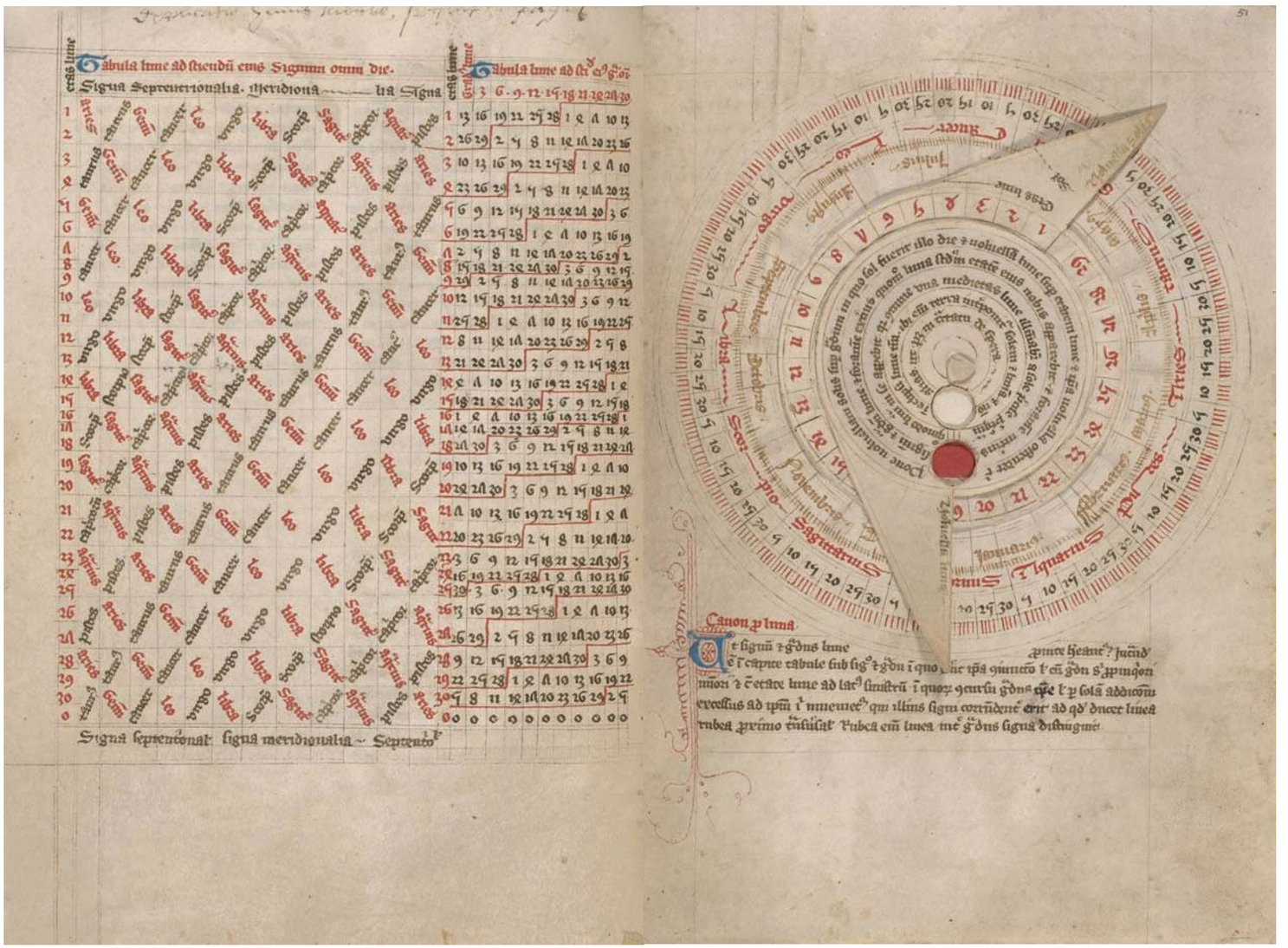
21

Armillary Sphere with Handle, place of origin unknown, ca. 1500
Wood and brass, H: 35 cm (13 13⁄16 in.); Diam: 16 cm (6 5⁄16 in.)
Nuremberg, Germanisches Nationalmuseum, WI23

PLATES 20, 21

Gossuin de Metz, holding a small armillary sphere used for teaching in one hand and gesturing with the other toward an astrolabe and quadrant on the table in front of him, dictates his encyclopedic poem on the nature of God, the seven liberal arts, geography, and cosmography.

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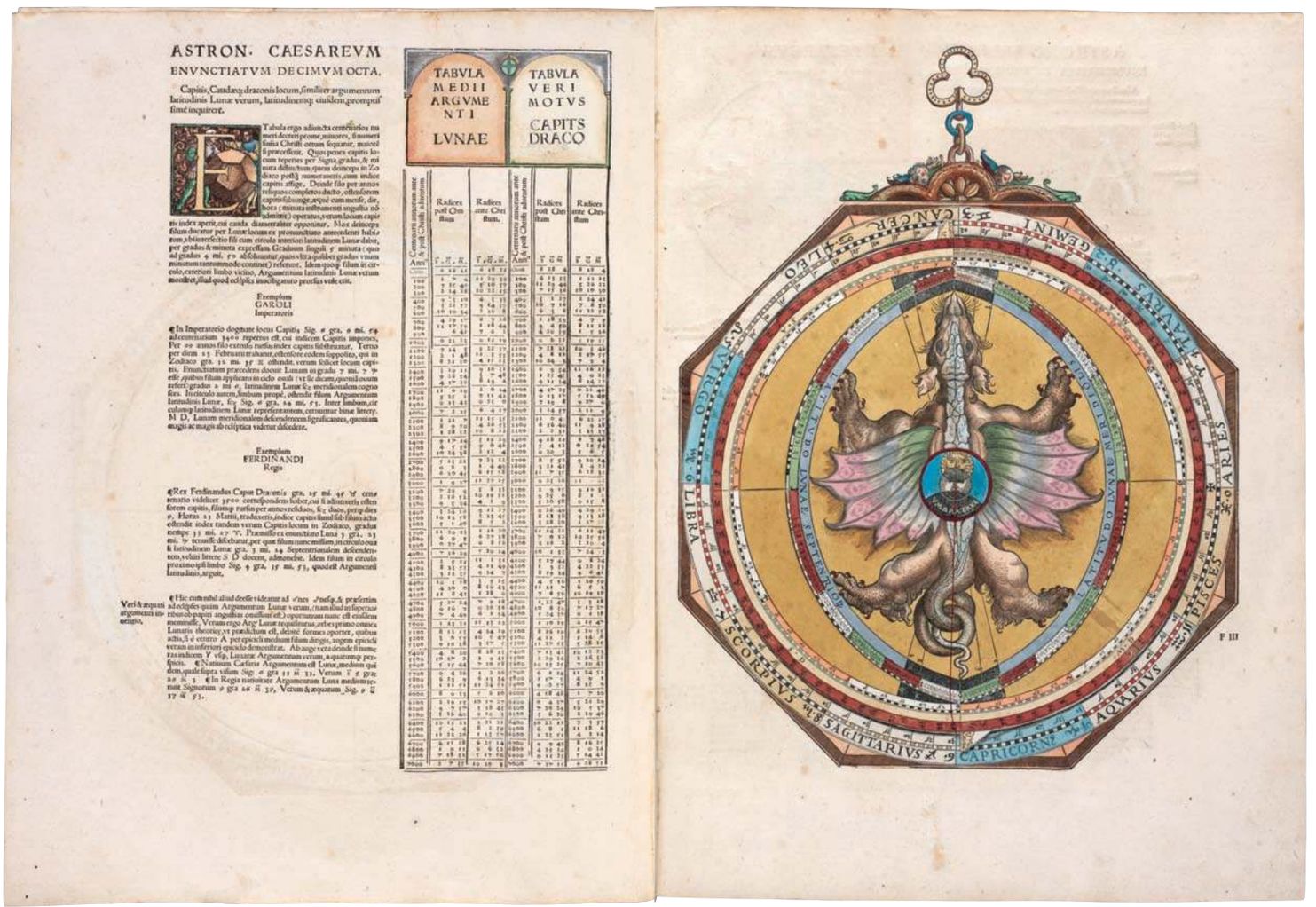


22

Astronomical Table and Astronomical Table with Volvelle (in Latin) in *Astronomical and Medical Miscellany*, Oxford or Worcester(?), England, late 14th century (shortly after 1386)
Pen and ink and tempera on parchment, full folio: 21.3 × 15.2 cm (8⅜ × 6 in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig XII 7 (83.MO.136), fols. 50v–51

Volvelles (from the Latin *volvere*, to turn) mimicked some of the functions of an astrolabe. Rotating parchment disks, when turned, could be used to calculate the phases of the moon.

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23

Lunar Latitude Calculator with Dragon Volvelle in *Astronomicum Caesareum* (in Latin), Ingolstadt, Germany, 1540
Peter Apian (German, 1495–1552)
Ink and watercolor on paper, binding: approx. 48 × 32.3 × 3.3 cm (18 7⁄8 × 12 11⁄16 × 1 5⁄16 in.)
Cambridge, Fitzwilliam Museum, Bequeathed (1904) by Frank McClean, PB 18-2020, fols. 2v–3

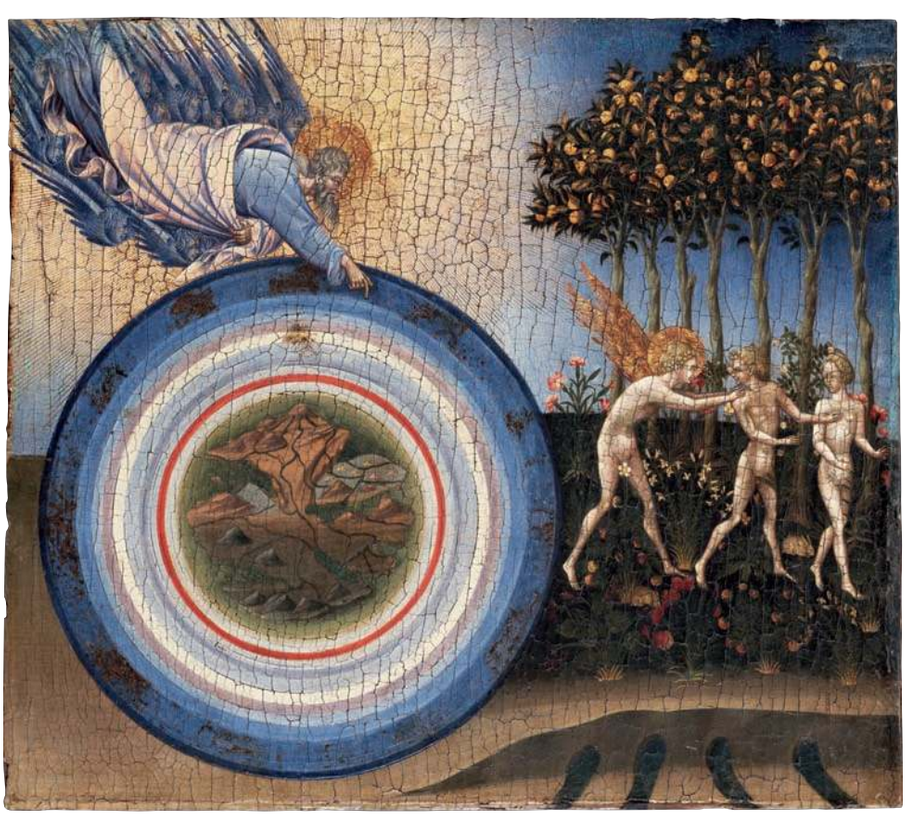
This deluxe volume contained more than twenty volvelles that transformed Ptolemy's mathematical models of the celestial bodies and their movements into devices that could yield information pertaining to astronomy (the movement of the planets) and astrology (the effects of celestial movements on people).

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24

The Nested Spheres of the Cosmos in *De caelo et mundo* (in French), Paris, beginning of 15th century (ca. 1410)
Aristotle (author) (Greek, 384–322 BCE)
Nicole Oresme (translator) (French, ca. 1325–1382 CE)
Tempera, ink, and gold on parchment, full folio: 36 × 25.5 cm (14 3⁄16 × 10 1⁄16 in.)
Paris, Bibliothèque nationale de France, Département des Manuscrits, Ms. Fr. 565, fol. 69
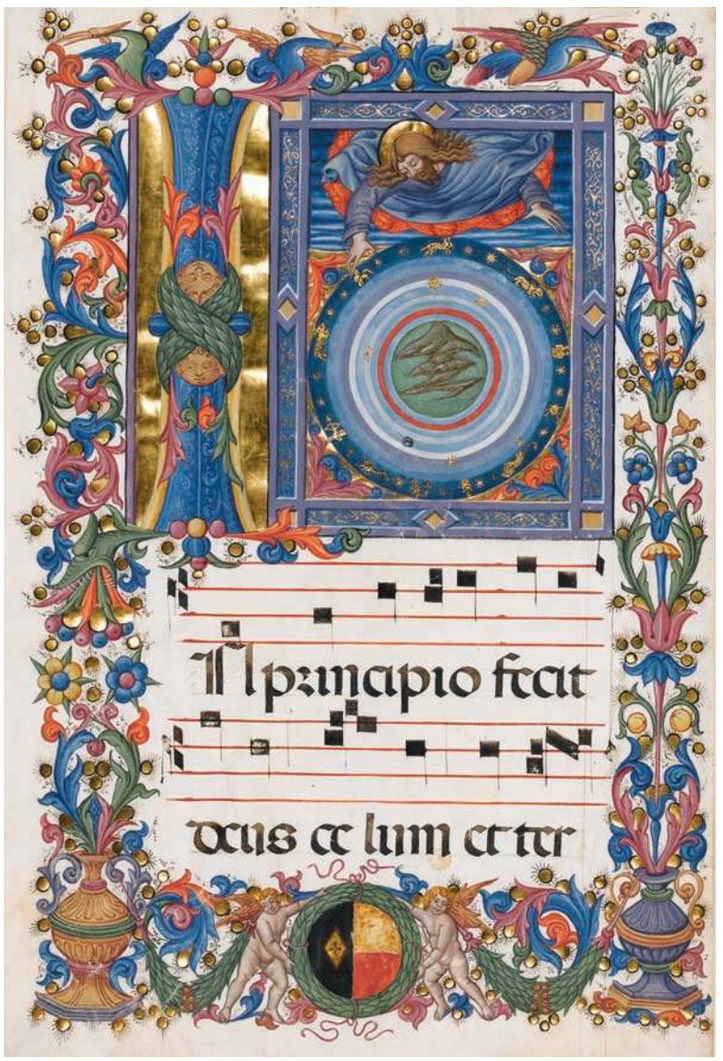


25

The Creation of the World and the Expulsion from Paradise, altar fragment, Siena, Italy, 1445
Giovanni di Paolo (Italian, 1398–1482)
Tempera and gold on wood, 46.4 × 52.1 cm (18 1⁄4 × 20 1⁄2 in.)
New York, Metropolitan Museum of Art, Robert Lehman Collection 1975.1.31

PLATES 24–26

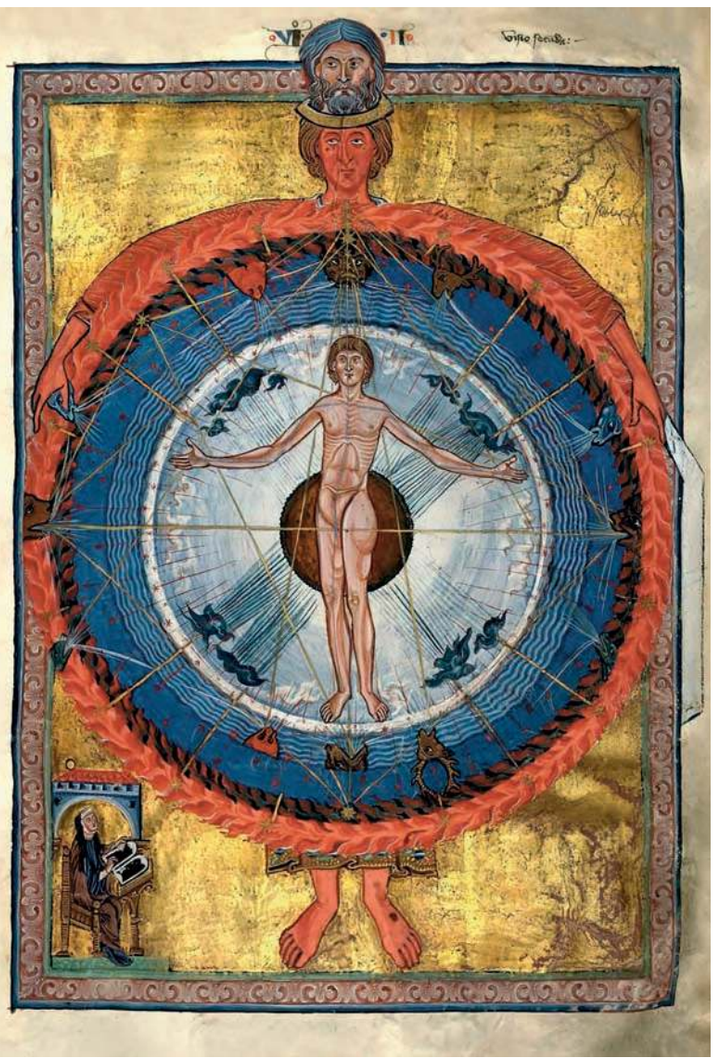
Medieval people believed that the universe consisted of transparent crystalline spheres nested inside one another, with the earth at the center. Imagery of the ordered universe was found not only in scientific manuscripts, like this copy of Aristotle's treatise *De caelo et mundo* (*On the Heavens*), but also in the liturgical arts, where it appears in creation scenes.

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26

The Creation of Heaven and Earth, leaf from a choir book (in Latin), Siena, Italy, ca. 1460–77
Pellegrino di Mariano Rossini (Italian, d. 1492)
Sano di Pietro (Italian, 1406–1481)
Tempera, gold, and ink on parchment, full folio: 57.8 × 40 cm (22¾ × 15¾ in.)
Cambridge, Fitzwilliam Museum, MS 197



27

On the Construction of the World from vision 2 in *Liber divinorum operum* (in Latin), Rupertsberg, Rhineland, Germany, ca. 1210–40
Hildegard of Bingen (German, 1098–1179)
Tempera, gold, and ink on parchment, full folio: 39 × 25.5 cm (15⅜ × 10 1/16 in.)
Lucca, Biblioteca Statale, BS-Lu, ms. 1942, fol. 9

Hildegard of Bingen was known for her deeply religious visionary experiences in which she communed with the fiery, living light (*lux vivens*) of God. Yet her spiritual imagery also reflected the language of science and cosmology; the human at the center of nested spheres echoes Ptolemy's geocentric model of the universe.

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Vija Celmins

GLENN PHILLIPS

How can we fathom the scale of collective effort that led to the emergence of astronomy across most world cultures and perhaps all of human history? Centuries of careful observations of the sun, moon, and stars, sustained and continued across generations, were foundational in establishing timekeeping, calendars, agricultural cycles, geolocation, and navigation. Astronomy prompted advances in mathematics, geometry, and the development of countless instruments of measurement, calculation, and prediction. In the premodern era astronomical knowledge traveled widely between the Islamic and Christian worlds as scholars incorporated advances in scientific knowledge into their understandings of the natural world, the heavens, and the divine.

Astronomical imagery is a recurring subject matter for Vija Celmins. Working across painting, drawing, and printmaking, Celmins has produced startling and wondrous depictions of stars, often from the point of view not of a human observer but of our most advanced scientific machinery. Her source imagery is typically telescopic photography from NASA and scientific publications, including photographs taken by orbiting satellite telescopes detecting stars that will never be visible to the naked eye. Some of these photographs themselves represent impressive accomplishments in astrophotography, compositing multiple exposures that were taken over the course of hours, days, or even years.

Celmins has compared herself to a scribe and explains her process of translating a photograph into other artistic media as "redescribing" a photograph. The process of producing one Night Sky painting can take more than a year of labor, all based on intense, minute, and sustained visual attention. Celmins begins by drawing the pattern of stars on the canvas and then, using a tiny brush, applies layers of liquid cement, building the stars up in thickness. She places multiple layers of black paint across the canvas, modulating her mix of colors until she has achieved her desired density of black. She then pulls away the dots of cement, painting in the cavities left behind with successive layers and tones of lighter paint. Celmins sands the painting to produce an even surface and will often sand and repaint areas multiple times until she is satisfied. The resulting works, somehow both humble and impossibly vast in ambition, often evoke deep emotional responses from viewers. Not only are the stars themselves a source of wonder, but so, too, is the deep and thorough level of touch and attention that Celmins directs toward her art.

28

Vija Celmins (Latvian American, b. 1938)
Night Sky #4, 1992
Oil and canvas mounted on panel
78.11 × 95.89 × 3.81 cm (30¾ × 37¾ × 1½ in.)
Los Angeles, Museum of Contemporary Art, Gift of Lannan Foundation, 97.34

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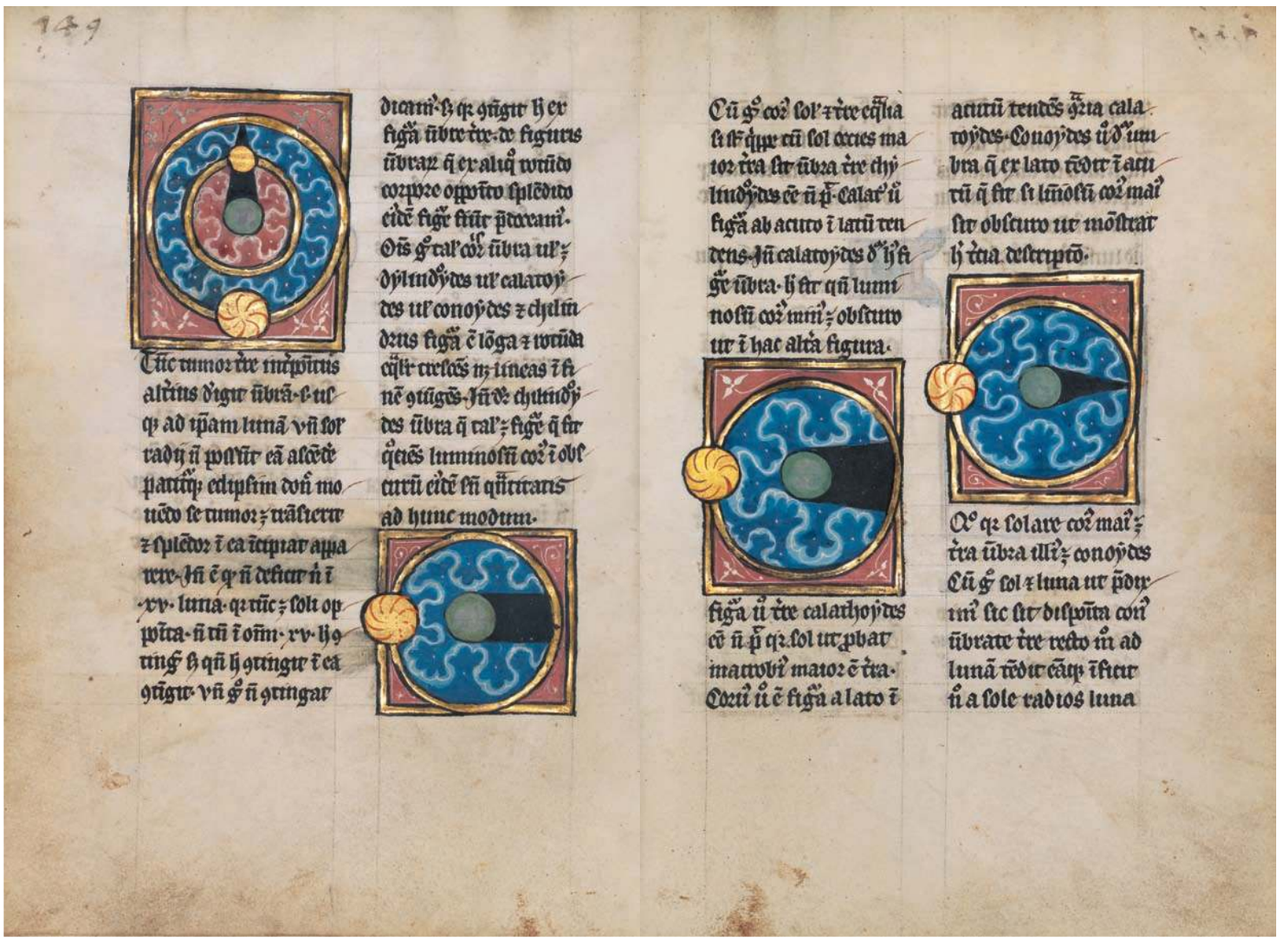


29

God the Geometer in *Bible moralisée* (in Latin), Paris, ca. 1226–75
Tempera, gold, and ink on parchment, full folio: 44.1 × 32 cm (17 × 12½ in.)
Oxford, Bodleian Libraries, University of Oxford, MS. Bodl. 270b, fols. 1v–2

Medieval people believed that the structure of the universe could be explained by using mathematical principles. On the verso, with a compass in one hand and the orb of the world in the other, the figure of God as Geometer represents the divinely created nature of the world. On the facing page, in roundels showing the specific order of creation, light is divided from darkness.

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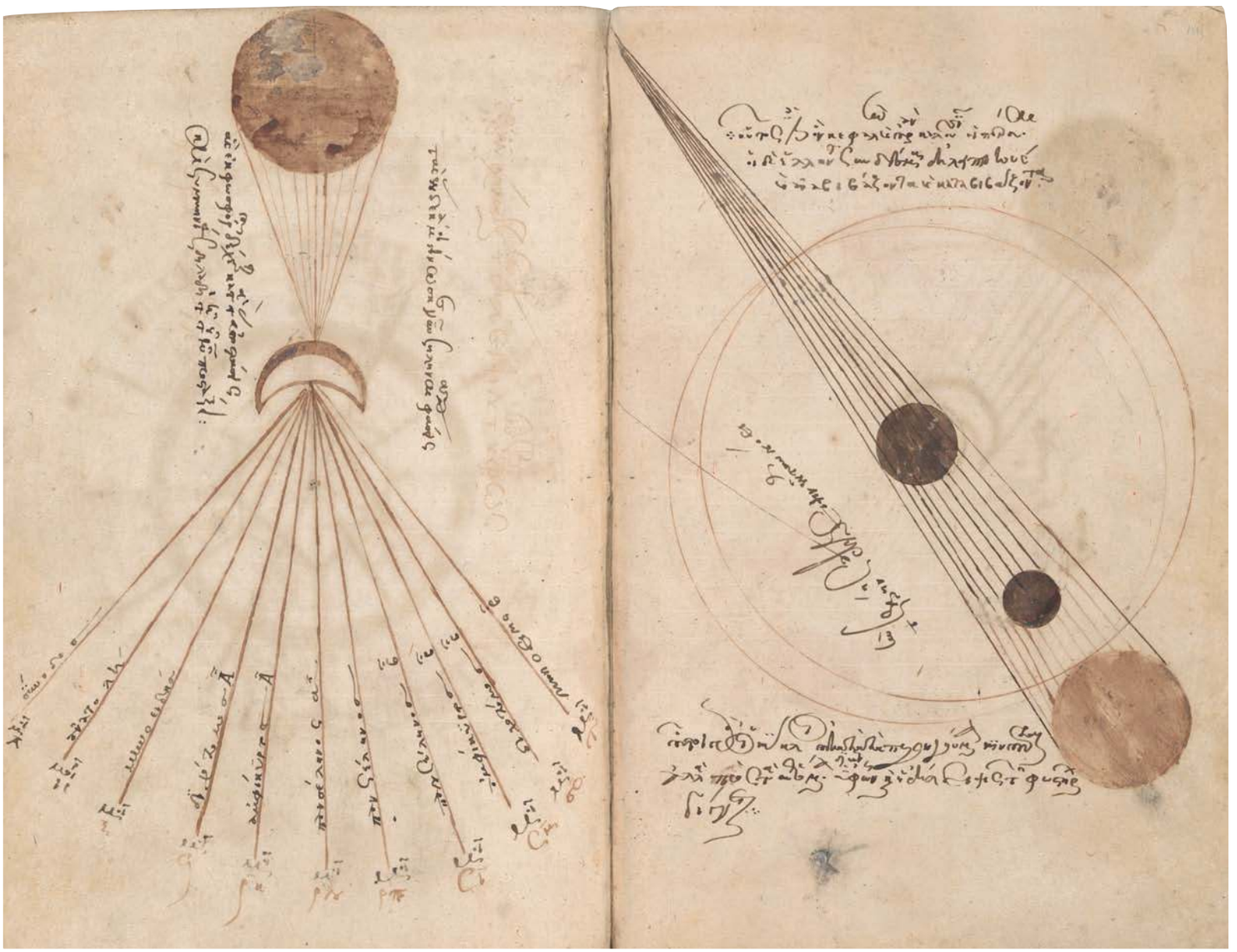


30

Four Diagrams with the Sun and the Moon in the *Philosophia mundi of William of Conches* (in Latin), in a collection of texts on natural philosophy and theology, Thérouanne, France(?), 1277 or after
Tempera colors, gold, and ink on parchment, full folio: 23.3 × 16.4 cm (9 3/16 × 6 1/2 in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig XV 4 (83.MR.174), fols. 149v–150

A treatise on natural philosophy with illuminated diagrams explaining eclipses and other phases of the moon, the *Philosophy of the World* presents an accessible compilation of the science of the world as it was known in twelfth-century Europe.

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31

The Sun Illuminating a Crescent Moon, from Which Emanate Seven Rays and Conditions for a Solar Eclipse in *The Fountain of Knowledge (An Pēgē gnōseōs)* (in Greek), Byzantine, Constantinople (Istanbul, Turkey), 1250–1300
John of Damascus (Arab, ca. 675–749)
Ink on paper, full folio: 25 × 16 cm (9 ⅞ × 6 ⅜ in.)
New York, Columbia University, Rare Book and Manuscript Library, Smith Western Add. MS 10, fols. 113v–114

These striking diagrams of lunar and solar eclipses demonstrate the spread of astronomical knowledge from the Umayyad caliphate of Damascus, where the author was born, to the monastery of Mar Saba, near Jerusalem, where he wrote the text, to Constantinople, where this later copy was made.

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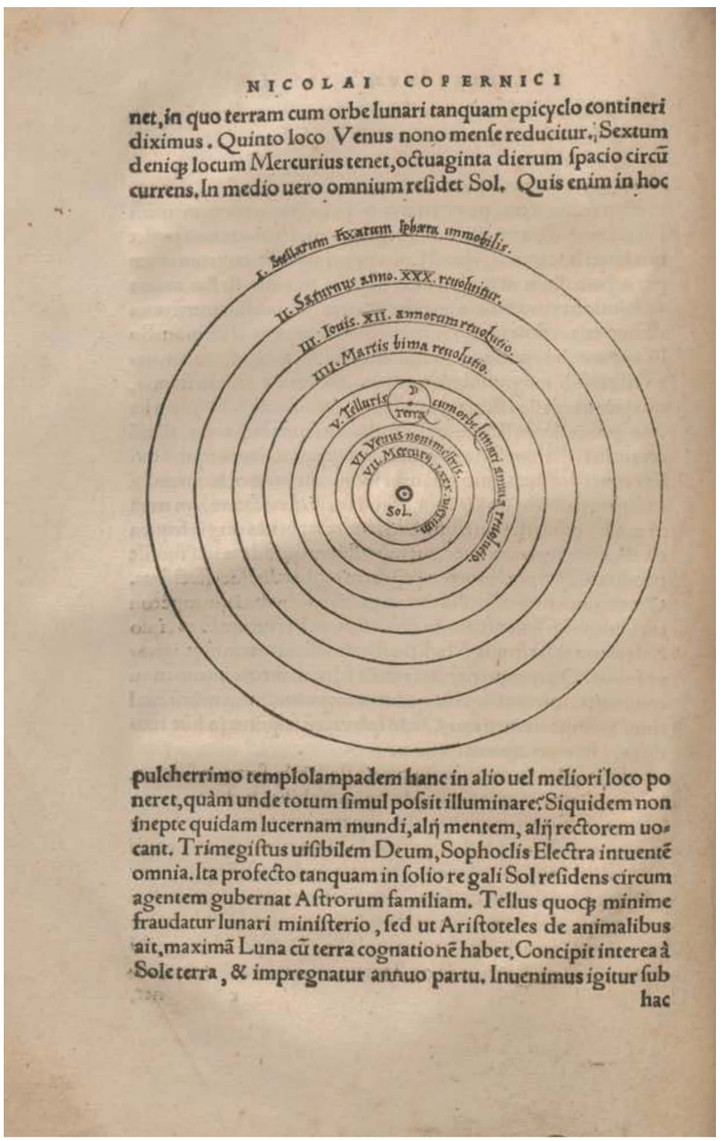
32

Armillary Sphere, Naples, 1601
Cornelius Vinchx (Flemish, active 1599–1623)
Brass, H: 57 cm (22 7/16 in.)
Oxford, History of Science Museum, University of Oxford, inv. 21264

PLATES 32, 33

Since antiquity natural philosophers had visualized the universe through three-dimensional models called armillary spheres. Made more than fifty years after the astronomer Nicolaus Copernicus proposed that the planets orbited the sun, not the earth, this armillary sphere continues to show earth at the center.

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NICOLAI COPERNICI

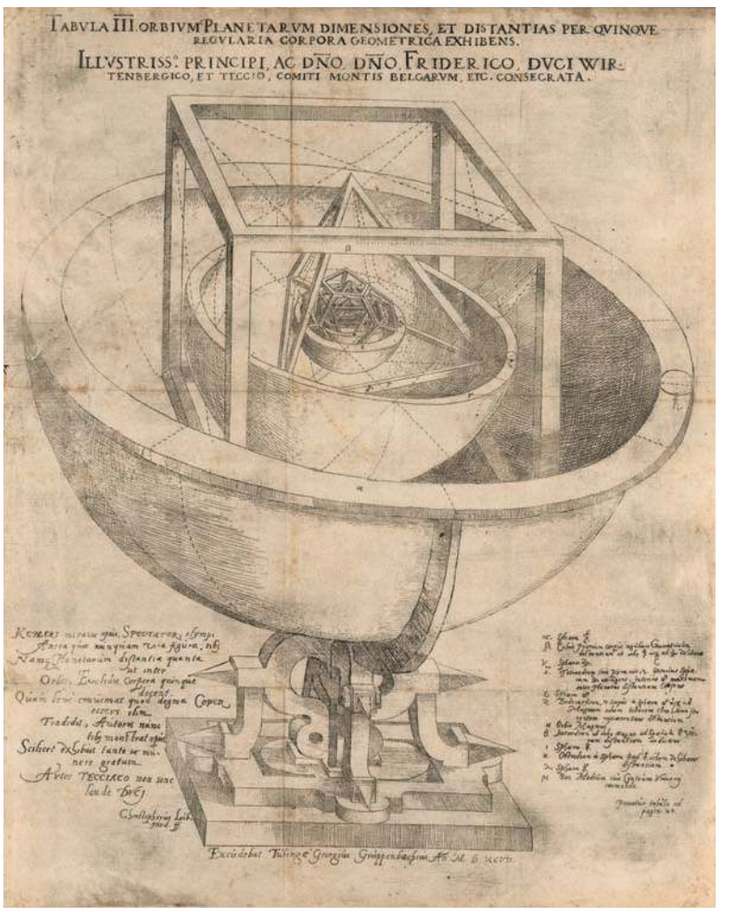
net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

I. Stellarum Fixarum sphæra immobilis.
II. Saturnus anno. XXX. revolvitur.
III. Iouis. XII. annorum revolutio.
IIII. Martis bima revolutio.
V. Tellus cum orbe lunari tanquam epicyclo.
VI. Venus nonimestris.
VII. Mercurius octuagenarius.
Sol.

pulcherrimo templo lampadem hanc in alio uel meliori loco po neret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio re gali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoq; minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

33

The Order of the Celestial Spheres in *De revolutionibus orbium coelestium* (in Latin), Nuremberg, Germany, 1543
Nicolaus Copernicus (Polish, 1473–1543)
Ink on paper, full folio: 27.6 × 27.1 × 5.4 cm (10 ⅘ × 10 ¾ × 2 ⅛ in.)
Los Angeles, Library Special Collections, Charles E. Young Research Library, UCLA, BENJ QB41.C791dr 1543, fols. 9v–10



TABVLA III. ORBIVM PLANETARVM DIMENSIONES, ET DISTANTIAS PER QVINQVE REGVLARIA CORPORA GEOMETRICA EXHIBENS.

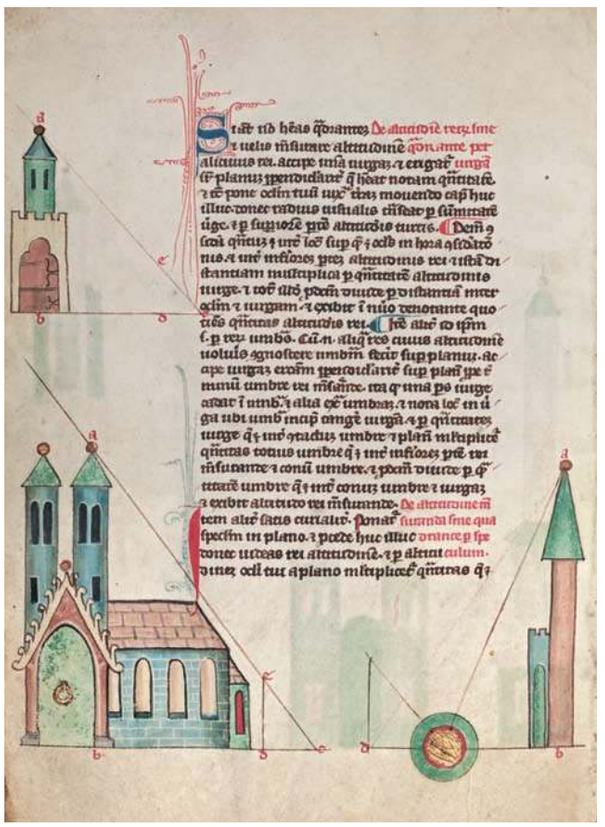
ILLVSTRISS. PRINCIPI, AC DNO. DNO. FRIDERICO. DVCI WIRTENBERGICO, ET TECCIO, COMITI MONTIS BELGARVM, ETC. CONSECRATA.

34

Model of the Universe, with Platonic Solids in *Mysterium cosmographicum*, Tübingen, Germany, 1596
Johannes Kepler (German, 1571–1630)
Ink on paper, foldout plate: 44.1 × 35cm (17 ⅜ × 13 ¾ in.)
Stanford, Department of Special Collections, Stanford Libraries, QB41.K4 1596

Kepler's *Mysterium cosmographicum* offered the first published acceptance of Nicolaus Copernicus's heliocentric model of the universe, which Copernicus had for years refrained from publishing for fear of reprisals. This image offers a geometric rendering of the crystalline spheres of the cosmos, which expressed the mathematical perfection of the universe.

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35

Measurement of a Tower in *Mathematical Miscellany*, France, ca. 1275–1300
Tempera, gold, and ink on parchment, full folio: 22 × 14.7 cm (8 11/16 × 5 13/16 in.)
Copenhagen, Royal Danish Library, MS NKS 275a 4°, fol. 70v

36

Measurement of a Tower by Its Shadow, by Mirror, and by Quadrant, in *Trattato di geometría*, Venice, ca. 1486–1501
Belo Moietta (Italian, active ca. 1490)
Ink and gold on parchment, full folio: 23 × 17.9 cm (9 1/16 × 7 1/16 in.)
Oxford, Bodleian Libraries, University of Oxford, MS. Canon. Ital. 197, fols. 18v–19

PLATES 35, 36

Using rules defined by the ancient geometers Euclid and Pythagoras, texts on practical geometry instruct how one might measure the height of a tower by using its reflection in a mirror, its cast shadow, and stargazing devices such as astrolabes or quadrants.

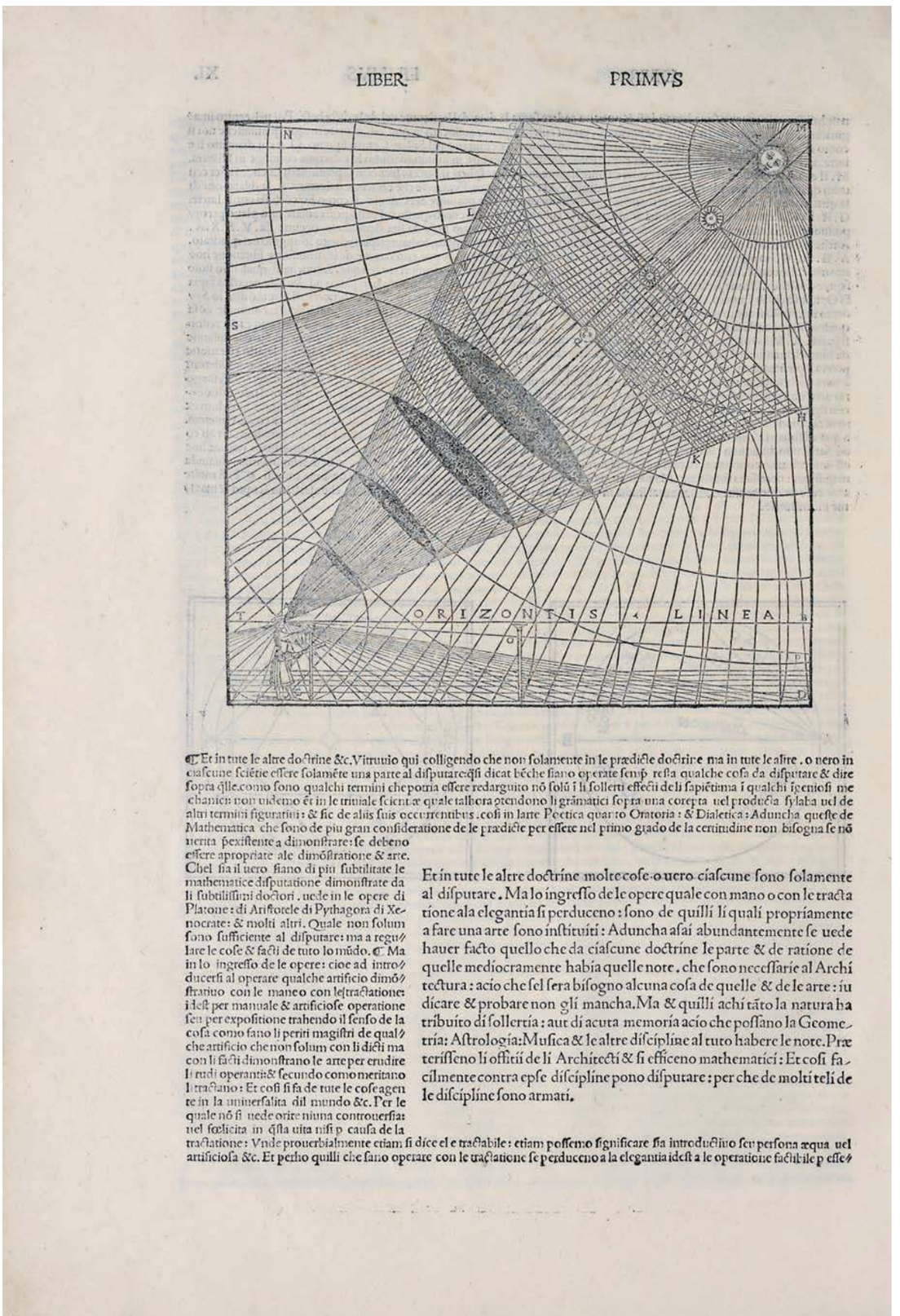


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37

De architectura libri dece,
Citade di Como, 1521
Vitruvius (author) (Roman, d. 15 BCE)
Cesare Cesariano (artist and translator) (Italian, 1475–1543)
Ink on paper, full folio:
42.5 × 31 cm (16¾ × 12¹³⁄₁₆ in.)
Los Angeles, Getty Research Institute, 86-B6552, book 1, XI verso (page Biii)

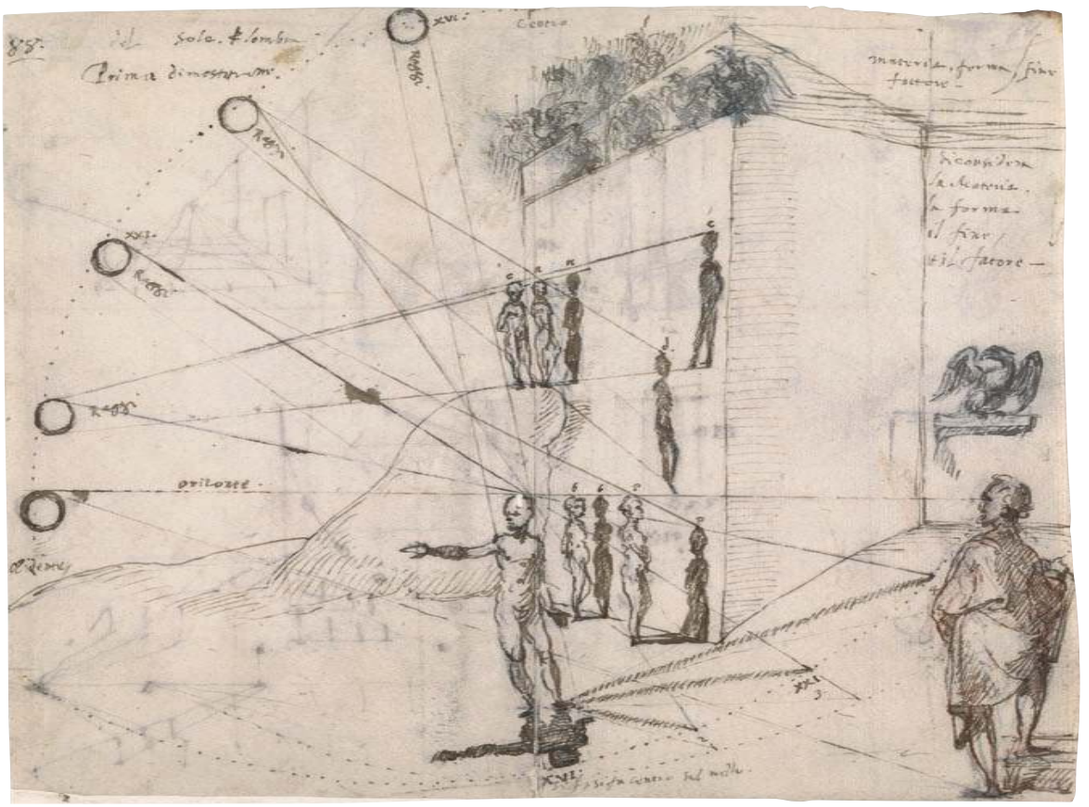
Derived from ancient techniques of land surveying, geometry—or earth (*geo*) measurement (*metria*)—was studied by engineers, architects, and artists. An architect, using a geographer's cross-staff, calculates distances based on the construction of a visual pyramid with rays focused within the architect's eye that extend outward to the horizon and the heavens.



¶ Et in tute le altre doctrine &c. Vitruuio qui colligendo che non solamente in le prædicte doctrine ma in tute le altre . o uero in ciascune scientie essere solamẽte una parte al disputare: ẽsi dicat bẽche siano operate semp̃ resta qualche cosa da disputare & dire sopra ẽlle. como sono qualchi termini che potria essere redarguito nõ solũ i li sollerti effecti de li sapientissima i qualchi ingenioso mechanici non uidemo ẽt in le triuiale scientiæ quale talhora prendono li grãmatici sopra una corepta uel prodicta sylaba uel de altri termini figuratiui: & sic de aliis suis occurrentibus . cosi in larte Poetica quanto Oratoria: & Dialetica: Aduncha queste de Mathematica che sono de piu gran consideratione de le prædicte per essere nel primo grado de la certitudine non bisogna se nõ uerita pexistente a dimonstrare: se debeno essere apropriate ale dimõstratione & arte. Chel sia il uero siano di piu subtilitate le mathematice disputatione dimonstrate da li subtilissimi doctori . uede in le opere di Platone: di Aristotele di Pythagora di Xenocrate: & molti altri. Quale non solum sono sufficiente al disputare: ma a regulare le cose & facti de tuto lo mũdo. ¶ Ma in lo ingresso de le opere: cioe ad introducerfi al operare qualche artificio dimõstrativo con le mane o con le tractatione: i dest per manuale & artificiose operatione seu per expositione trahendo il senso de la cosa como fano li periti magistri de qualche artificio che non solum con li dicti ma con li facti dimonstrano le arte per erudire li studi operanti & secundo como meritano li tractano: Et cosi si fa de tute le cose agente in la uniuersalita dil mundo &c. Per le quale nõ si uede orire niuna controuersia: uel focilita in ẽsta uita nisi p causa de la tractatione: Vnde prouerbialmente etiam si dice el e tractabile: etiam possemo significare sia introductiuo seu persona æqua uel artificiosa &c. Et perho quilli che sano operare con le tractatione se perducono a la elegantia idest a le operatione facilibile p esse

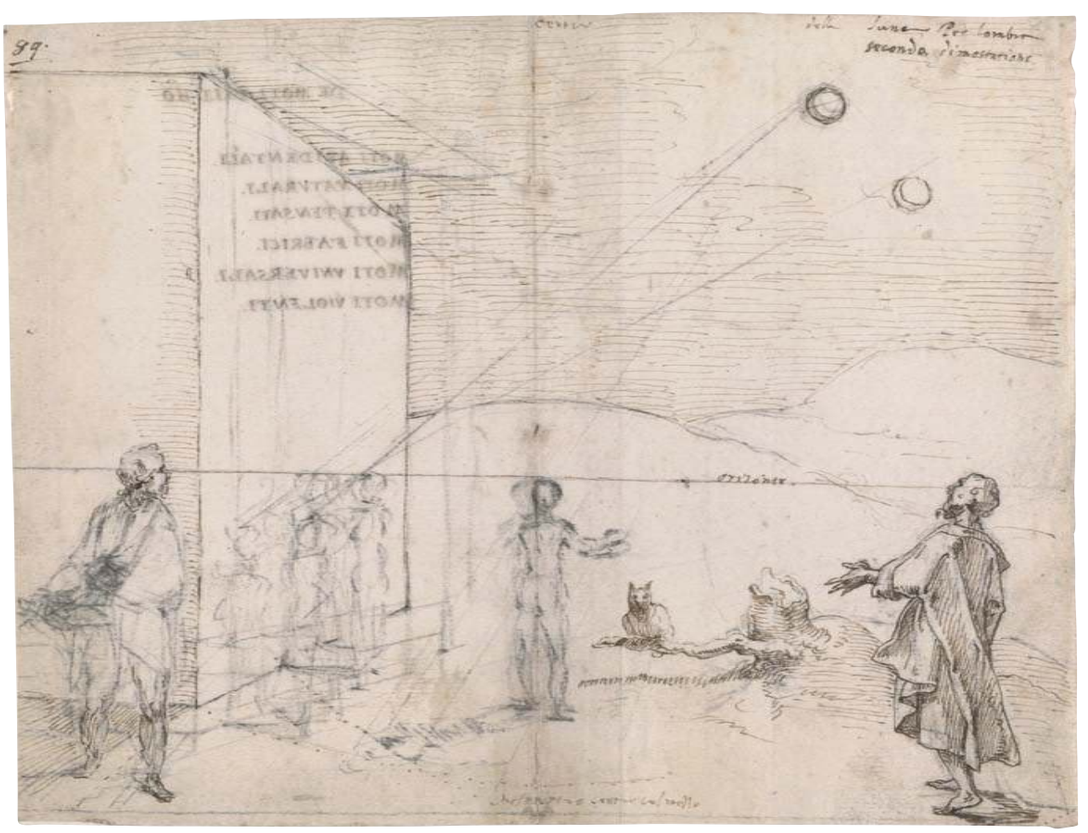
Et in tute le altre doctrine molte cose o uero ciascune sono solamente al disputare. Ma lo ingresso de le opere quale con mano o con le tractatione ala elegantia si perducono: sono de quilli li quali propriamente a fare una arte sono instituiti: Aduncha assai abundantemente se uede hauer facto quello che da ciascune doctrine le parte & de ratione de quelle mediocramente habia quelle note. che sono necessarie al Architectura: acio che sel sera bisogno alcuna cosa de quelle & de le arte: iudicare & probare non gli mancha. Ma & quilli achi tãto la natura ha tributo di sollertia: aut di acuta memoria acio che possano la Geometria: Astrologia: Musica & le altre discipline al tuto habere le note. Prætersseno li offitii de li Architecti & si efficeno mathematici: Et cosi facilmente contra epse discipline pono disputare: per che de molti teli de le discipline sono armati.

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38a

Del sole: Per l'ombra prima dimostratione in *Perspective Treatise (Codex Huygens)*, Milan, ca. 1560–70
Carlo Urbino (Italian, active 16th century)
Pen, brown ink, and black chalk on paper, full folio: 16.7 × 22.4 cm (6 5⁄8 × 8 7⁄8 in.)
New York, Morgan Library & Museum, Purchased in 1938, 2006.14, fol. 88



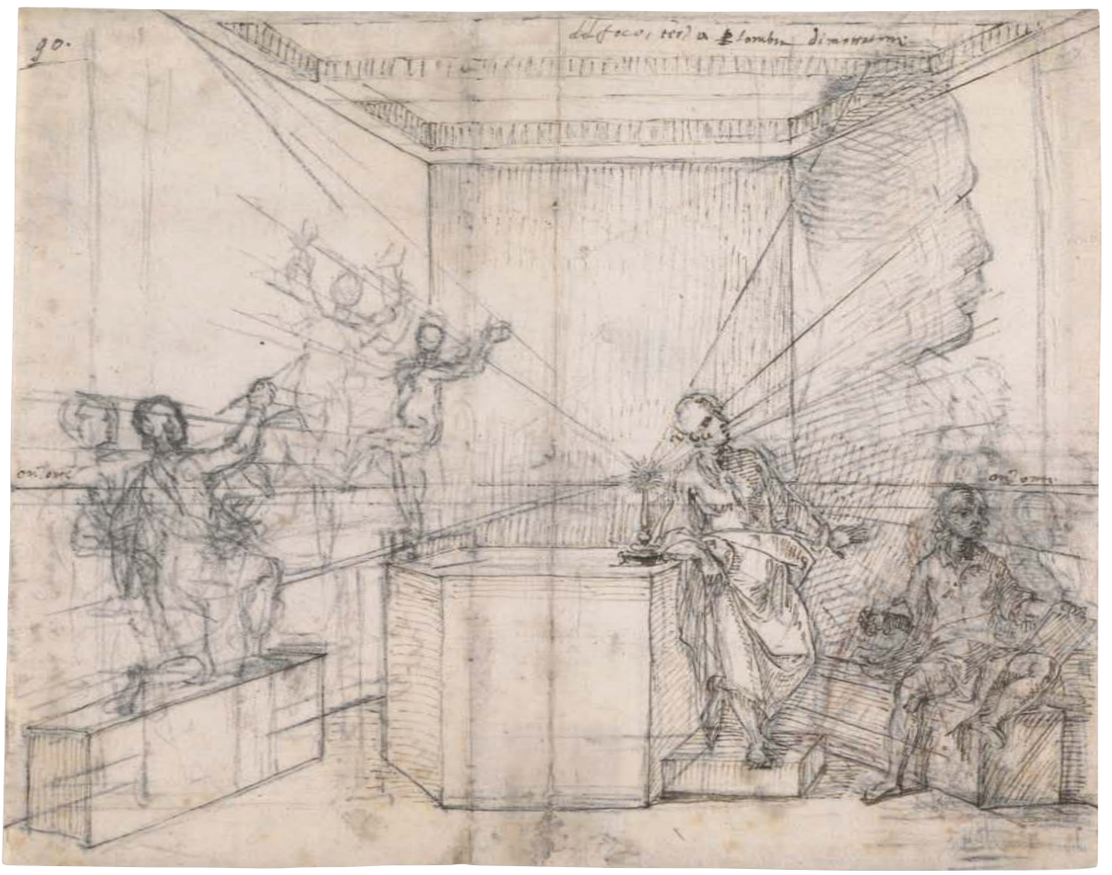
38b

Della luna: Per l'ombra seconda dimostratione in *Perspective Treatise (Codex Huygens)*, Milan, ca. 1560–70
Carlo Urbino (Italian, active 16th century)
Pen, brown ink, and black chalk on paper, full folio: 17 × 22.4 cm (6 3⁄4 × 8 7⁄8 in.)
New York, Morgan Library & Museum, Purchased in 1938, 2006.14, fol. 89

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38c

Del foco: Terza per l'ombra dimostratione in *Perspective Treatise (Codex Huygens)*, Milan, ca. 1560–70
Carlo Urbino (Italian, active 16th century)
Pen, brown ink, and black chalk on paper, full folio: 18.2 × 23 cm (7⅛ × 9¹⁄₁₆ in.)
New York, Morgan Library & Museum, Purchased in 1938, 2006.14, fol. 90



38d

Quinta figura: Cap. V in *Perspective Treatise (Codex Huygens)*, Milan, ca. 1560–70
Carlo Urbino (Italian, active 16th century)
Pen, brown ink, and black chalk on paper, full folio: 18.6 × 13.5 cm (7⁵⁄₁₆ × 5¼ in.)
New York, Morgan Library & Museum, Purchased in 1938, 2006.14, fol. 105



PLATES 38a–d

This group of linear perspective studies, copied after drawings by Leonardo da Vinci, demonstrates the geometric properties of light and shadow. The artist differentiated the rake of shadows cast by the sun, the moon, and candlelight. In one drawing a recumbent figure is aligned with the apex of the cone of vision in the artist's eye.

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Part 2

LIGHT AND VISION

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Light and Vision

KRISTEN COLLINS AND NANCY K. TURNER

Sight can bring about the emotional states of desire and wonder as well as insight. Today it is common to say, "I see," to indicate understanding. Yet, for the medieval viewer, vision was not necessarily immediate; it resulted from prolonged meditation and scrutiny and was physically taxing, as it required, so Saint Paulinus of Nola had said in the early fifth century, "attentive eyes" (*intenti oculi*).[1] By scrutinizing wall paintings, relief sculptures, manuscripts, reliquaries, and other media, for instance, in sacred spaces like churches, one could achieve beyond-normal vision—the second order of sight, or "spiritual vision."

Ancient and medieval optical sciences were first and foremost about sight.[2] Light, because it is essential for vision, is always implicated in the study of optics. How we understand the nature of light and human vision is culturally and historically specific. Isidore of Seville (ca. 560–636), in his discussion of eyes (*oculi*), described how eyes possess a "hidden light" (*occultum lumen*): "The eyes are also called lights (*lumina*) because light (*lumen*) emanates from them, either because they hold a light that has been closed up in them from the beginning, or because they reflect light that has been taken from the outside in order to supply vision."[3] By the thirteenth century in the Latin West, two words were employed to describe and define the various forms of light. *Lux* was the light of a substance or an innate quality of a light, including sunlight or moonlight; it also invoked divine light (*Dominus lucis*, *Lux Mundi*); and it could connote the act of seeing, as well as people who had attained spiritual enlightenment.[4] *Lux* was distinct from *lumen*. *Lumen* conveyed brightness and splendor, as in the "light of glory."[5] *Lumen* could also refer to an artifact that emits light, as in *lumen sanctorum*, a Latin phrase used to refer to a shrine or holy place.[6]

This medieval terminology was developed out of the tangled strands of a long intellectual tradition, from ancient Greek philosophy, Greco-Roman and Arabic medicine, and geometric optics.[7] Medieval scholars and theologians engaged with variants of each of these optical traditions, excerpting and citing whichever sources might have been available to them, depending upon their time and place.

Optical theories of vision and light were central to the intellectual formation of early Christian theologians, particularly Saint Augustine (354–430), whose education was steeped in the classical Greek and late antique Greco-Roman literary traditions.[8] As a convert

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to Christianity, Augustine integrated transcendent Neoplatonist natural philosophy into Christian theology, using the word "emanation" to convey how the Trinity spreads a radiation-like power to believers. For Augustine sunlight's necessity for physical vision is a model for spiritual vision, starting in the eye and illuminating the soul through faith and understanding.[9] Yet Greco-Roman authors presented medieval readers with confusing, often contradictory theories about the mechanics of vision and the properties of light.[10] The so-called long Middle Ages (here defined as lasting from 800 to 1600, based on medieval engagements with ancient Greek and Roman cosmological, mathematical, and optical sciences) was defined by traditions of excerpting and commenting upon ancient authorities.

Two ancient theories of vision dominated medieval optical discourses: extramission, the idea that sight occurred through the emanation of a substance from the eye (called the fire of the eye) that interacted with external objects; and intromission, the concept that the eye received light from the surface of an external "body" or object. A rare Ottonian image depicting the Miracle of Mount Gargano (in southeastern Italy) might serve as an optical metaphor for these theories (plate 48). The legend described a local lord, Garganus, who, upon hearing the cries of a bull separated from its herd and lost in a cavern, aimed and shot an arrow into the mouth of the cave, only to have the arrow returned and enter his own eye. The return of the arrow was credited to a miraculous intervention by Saint Michael the Archangel (not pictured), to whom a sanctuary was later dedicated at the site.[11] By conflating Saint Michael's miracle with Plato's cave (an allegory of knowledge), this image may have served as an allegory of faith, wherein the nonbeliever's arrow is returned directly into his eye through the archangel's intervention, demonstrating that the eyes were the pathway to cognition and belief.[12]

Because injuries to the eye and eye diseases were as prevalent during the premodern era as they are today, physiological models for sight and perception were key to the medieval optical understandings and theories of cognition. Galen (129–ca. 216), a Greek physician working in the Roman Empire, provided a model of the eye, which he described as consisting of nine layers, from the outer conjunctiva to the vitreous humor at center.[13] His model was later adapted and expanded upon, for the first time with anatomical sketches, by Hunain ibn Ishaq (an Iraqi Nestorian Christian, 808–873), al-Razi (considered the father of Persian medicine, 854–935), the Persian polymath Ibn Sina (known in Europe as Avicenna, 980–1037), and the physician Kamal al-Din al-Farisi (ca. 1267–1319). It was al-Farisi who, having dissected a sheep's eye, further codified the eye's structure, which he described as consisting of three humors (crystalline at the eye's center, albuminoid in front, and vitreous behind), surrounded by seven tunics (plate 40).[14] Medieval eye diagrams often resembled images of the nested spheres of the universe, rendering the layers of the eye as concentric circles as seen in a Sephardic miscellany from Provence, an important center of translation during the medieval era (fig. 16, plates 39, 42).

Besides describing the anatomy of the eye, Galen had developed a theory about how light passed through the eye (along with input from the other four sense organs) via successive operations within the mind, a multistep process that accounted for how direct sense experience became abstracted knowledge. A medieval diagram shows the operations that Galen, and later Ibn Sina, believed were requirements for cognition (plate 93). Sensory experience was said to enter the eyes and pass through the optic nerves to the front "ventricle," or chamber, of the brain, called "common sense" (*sensus communis vel sensatio*). Here sensory information was collected, but these impressions were not yet fully retained; next, mental images were formed in the center of the brain, in the second "ventricle" of imagination (*ymaginacio vel formalis*), where judgment (*estimativa*) and cognitive imagination (*cogitativa vel formalis*) occurred.[15] Once mental images were formed and understood, these sensory impressions were accumulated at the back of the brain in the third and "highest" ventricle, the memory (*vis memorativa*), which Ibn Sina called the "storehouse of the intellect" (see plate 93).[16] As Katharine Park has argued, because sense impressions were stored at the back of the brain, the habit of looking upward to recall a memory allowed "the impression-laden spirit" to flow "into the organ of memory in the last ventricle."[17]

Cognition was thus understood according to a dynamic "mobile model" that depended upon vision, which was a "supremely active power," one that could even result in leaving an imprint of one's sight on the thing seen.[18] For example, Saint Francis's visionary

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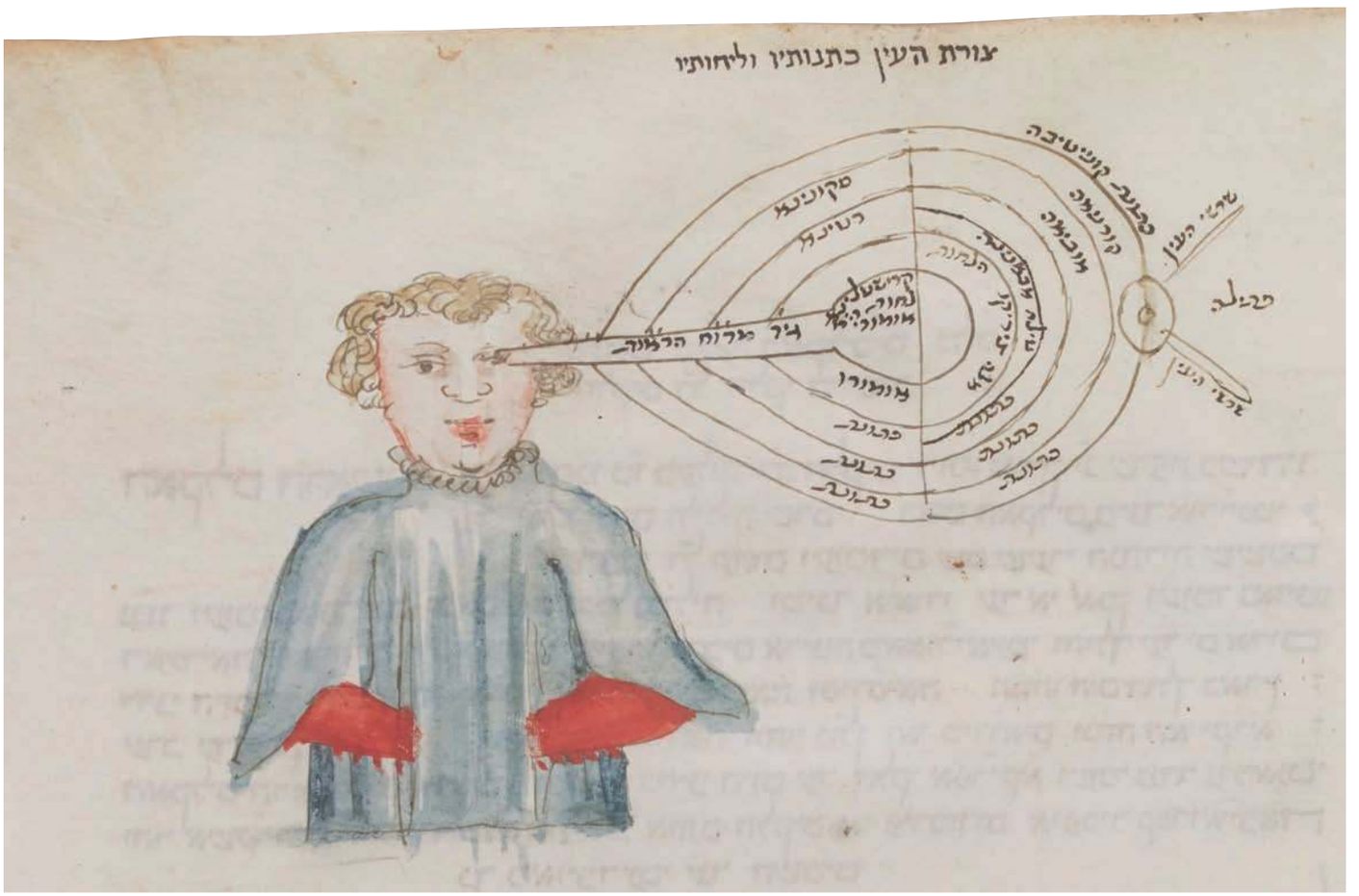


FIGURE 16. *The Structure of the Eye* in a Sephardic miscellany of medical treatises, Provence, late 14th–early 15th century (detail). Tempera colors and ink on parchment, full folio: 35 × 24.5 cm (13¾ × 9⅝ in.). Paris, Bibliothèque nationale de France, Département des Manuscrits, Hébreu 1181, fol. 265

experience of his mystical union with the wounds of Christ utilized the optical understanding of light as composed of linear rays: a single ray of light extended toward Francis from each of Christ's wounds, allowing them to be impressed, like seals into wax, as corresponding marks (stigmata) on Francis's flesh (plate 124).[19] The idea of leaving an imprint, whether signifying a beneficial union with God or malicious intent (i.e., the "evil eye"), reflects the persistence of extramissionist theories of light and vision, which continued to have metaphoric potency well into the fourteenth century.[20]

Similarly, in images of the Annunciation showing the moment when the pure light of God enters the womb of the Virgin Mary to enable the conception of Jesus Christ, rays are often depicted as plentiful as they issue from their source in the Godhead; they become attenuated and more focused as they arrive at the Virgin's eyes and brain (plate 87). In Carlo Crivelli's *Annunciation, with Saint Emidius* (fig. 17) the divine light of God emanates as linear rays from the heavens carrying the dove of the Holy Spirit; the beam is strengthened as it passes through an oculus, or "squint," in the wall and ultimately comes

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into direct contact with a gemstone on the crown of the Virgin's head. Such imagery makes clear the associations between light, divinity, the light-holding properties of gemstones, and the brain as the site of cognition and the soul.

As an aid to achieving spiritual vision, sight was believed to become more focused and intensified when the viewer looked through a "squint" or "hagioscope," an aperture found in churches that allowed certain individuals (royalty, anchorites, women) to see the altar, witness the Mass, and experience "ocular communion," a process in which the viewer received the host in the moment it was held aloft, marking its ritual transformation to the body of Christ. Suzannah Biernoff has argued for a connection between Roger Bacon's optical theories and thirteenth-century devotional practice in which the physicality of vision allowed "a bodily participation in the divine."[21] In a manuscript of the Apocalypse, in images of the visions of John the Evangelist, he looks through squints, depicted as openings in the surrounding frames, that focus his sight on his visions and enable spiritual seeing (plate 49). Even without the aid of squints or apertures through which to witness the holy mysteries, medieval Christian viewers developed their own "hagioscopic gaze," in the words of Hans Henrik Lohfert Jørgensen, that ritually performed the strenuous effort required to see and apprehend the sacred and achieve optical communion with the divine.[22]

By the late twelfth and thirteenth centuries Latin translations of Arabic and Persian commentaries on the optical sciences were being taught at the newly formed European universities. As schools of theology and philosophy, the universities at Oxford and Paris were operated under the jurisdictions of the Franciscans and the Dominicans, two newly reformed Christian orders that emphasized teaching and preaching.[23] Thus the major commentators on optics (*perspectiva* in medieval Latin) were Franciscans and Dominicans; as theoreticians of optics, they were called perspectivists. Light was fully understood as necessary for sight, and the immediate sense of sight depended on color to make objects visible. The ground for perspectivist optics was laid by the Oxford-educated Franciscan Robert Grosseteste (1175–1253), bishop of Lincoln Cathedral, according to whom *lux* denoted "the first corporeal form" (*forma prima corporalis*), a luminosity that transmits the active agent *lumen*, which spreads radially through the transparent medium of air.[24] The perspectivist Roger Bacon (ca. 1219/20–ca. 1292) asserted that the study of astronomy and the study of vision were fundamentally the same since they both involved the study of light; light and vision were understood geometrically, as both followed the logic of straight lines off solid bodies.[25] Based on the geometric understanding of light developed by Euclid, Ptolemy, al-Kindi, Ibn Sina, and Ibn al-Haytham (and later by the Latin perspectivists), light was conceived as linear rays that formed a cone or pyramid of vision, with the beholder's eye at the apex of the cone and the visible surface of the object seen at the cone's widened base.[26] This model enabled the use of proportion to measure accurately the height of a tall object (such as a tower or a cliff) and its distance from the viewer—useful mathematical skills that informed a range of endeavors including land surveying, building, ballistics, and the creation of images.[27] Didactic handbooks on practical geometry conveyed these principles, illustrated with depictions of figures taking measurements with the aid of astrolabes, quadrants, and mirrors (plates 35, 36).[28]

The geometric expression of the cone of vision also helped spatialize the understanding of light and sight as a conical projection, as illustrated in a sixteenth-century copy of Vitruvius (plate 37) and in a group of drawings after Leonardo da Vinci by Carlo Urbino (plates 38a–d).[29] By bisecting the cone of vision perpendicular to the line of sight, artists could depict three-dimensional space with an enhanced degree of veracity (see fig. 17). This technique, indebted to the development of geometric optics and proportion, created the artistic mode of linear/artificial perspective.[30]

Ideas about color promulgated by Ibn al-Haytham (965–ca. 1040) and adapted by Bacon established formal and causal links to light, be it *lux* or *lumen*, depending on color's associations with the object of vision (material color) or with the transparent medium through which color perception was transmitted. From these ideas

FIGURE 17. *The Annunciation, with Saint Emidius*, probably the Marches, dated 1486. Carlo Crivelli (Italian, 1430/1435–1494). Egg and oil on canvas, 207 × 146.7 cm (81½ × 57¾ in.). London, National Gallery, inv. NG 739

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medieval theoreticians improved their explanation of the phenomenon of color and the rainbow.[31] Witelo (ca. 1230–ca. 1278), a Franciscan from Silesia who worked at the papal court of Clement IV in Viterbo, compiled, commented on, and expanded much of what was known about optics from the Greco-Arabic and Persian corpus, creating an encyclopedic work (ca. 1270) that became the most widely read text on optics throughout the late Middle Ages (plate 76); it was read for centuries later, including by luminaries such as Johannes Kepler and René Descartes (plate 34).[32]

Although these thirteenth-century theoreticians discussed magnification through lenses as a function of refraction, where light is deflected as it travels through one medium to another, such theories apparently did not contribute to the invention of spectacles.[33] Shaped rock crystals had long been used on early medieval and high medieval reliquaries to magnify relics mounted beneath them, such as small pieces of the True Cross on the Bernward Cross (plate 66).[34] Magnifying stones (placed directly on a surface) had been used in antiquity, and a group of plano-convex rock crystal reading stones, discovered among eleventh-century Viking burials on the island of Gotland (Sweden), coincide roughly in date with Ibn al-Haytham's work with these devices.[35] But true spectacles—paired lenses mounted inside a frame and worn on the nose—were a medieval invention of the thirteenth century that quickly became ubiquitous, especially for reading (plates 45, 46). Spectacles were a scientific invention that changed the course of human history, enabling reading into old age (fig. 18) and eventually providing the basis for vision into the heavens with the later invention of the telescope.

One of the great, often heralded "discoveries" of the Enlightenment is Sir Isaac Newton's study of the rainbow, but in fact the explanation of the phenomenon of light's division into colored spectra that most closely resembles our modern understanding of the rainbow dates from the thirteenth century. Experimenting with water-filled glass orbs, German Dominican Theodoric of Freiberg (1250–1310) demonstrated how rays from the sun were refracted on entry into raindrops and reflected off the orbs' interior surfaces. The rays of light were then deflected again as they exited the drops and reentered the viewer's eyes, forming the primary rainbow (and any secondary and tertiary bows) (plate 75).[36] The rainbow



FIGURE 18. Detail of apostle reading from *Death of the Virgin*, Austria (possibly Bohemia), ca. 1400. Master of Heiligenkreuz. Tempera and oil with gold on panel. Cleveland Museum of Art, Gift of the Friends of the Cleveland Museum of Art in memory of John Long Severance, 1936.496

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served as a symbol of hope and the promise of God after the biblical flood (Genesis 9:14). In medieval art Christ was often shown seated on a rainbow in images of the Last Judgment, symbolizing the promise of salvation at the end of time (plate 73).[37]

Metaphors of sight and light were thus used to communicate Christian experience of the divine. For example, Thomas Aquinas (1225–1274), a Dominican theologian at the University of Paris, famously engaged with the science of optics to articulate his theology of light (based on Augustine) to convey that what he called the "eye of the soul" required divine illumination, just as the corporeal eye requires the light of the sun.[38] While affirming that human sight occurred through intromissionist rays, Aquinas described the holy scripture as "the ray of divine revelation" that emanates from God, like the sun, as depicted in figure 19.[39]

Optical metaphors pertaining to the eye and the light of God were fundamental to Hebrew, Christian, and Islamic faiths. Light's mystery as a phenomenon—with its properties as a substance that radiates infinitely outward, and with its ability to be channeled, reflected, and refracted in different media—has inspired philosophers, theologians, and artists for centuries. A universal metaphor for the divine, light enabled not only vision of the material world but also "inner sight" (insight), allowing the premodern viewer's inner eye to encounter the divine and, in the words of Nicholas of Cusa, to "see oneself being seen by God."[40]



FIGURE 19. *Saint Thomas Aquinas Shining Light upon the Church*, from Strozzi di Mantova Chapel, Florence, mid-14th century (detail). Andrea di Cione (Italian, d. 1368) and Nardo di Cione (Italian, d. 1366) (designers). Stained glass. Florence, Basilica of Santa Maria Novella

Notes

1 Michael Camille, *Gothic Art: Glorious Visions* (New York: Harry N. Abrams, 1996), 72. Paulinus's phrase "attentive eyes" is quoted and discussed in Christopher R. Lakey, *Sculptural Seeing: Relief, Optics, and the Rise of Perspective in Medieval Italy* (New Haven, CT: Yale University Press, 2018), 20.

2 A. Mark Smith, "Getting the Big Picture in Perspectivist Optics," *Isis* 72 (1981): 568–73.

3 *The "Etymologies" of Isidore of Seville*, trans. Stephen A. Barney et al., with the collaboration of Muriel Hall (Cambridge: Cambridge University Press, 2006), 233.

4 Richard Ashdowne, David Howlett, and Ronald Latham, eds., *Dictionary of Medieval Latin from British Sources* (Oxford: published for the British Academy by Oxford University Press, 2018), s.v. "lux."

5 Leo F. Stelten, *Dictionary of Ecclesiastical Latin* (Peabody, MA: Hendrickson Publishers, 1995), s.v. "lumen."

6 Richard Latham, *Revised Medieval Latin Word-List from British and Irish Sources* (Oxford: Oxford University Press for

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the British Academy, 1980), s.v. "lumen nature"; and Ashdowne, Howlett, and Latham, *Dictionary of Medieval Latin*, s.v. "lumen."

7 For the development of the science of optics, from ancient theoreticians of light and vision to the medieval European "perspectivists," see A. Mark Smith, *From Sight to Light: A Passage from Ancient to Modern Optics* (Chicago: University of Chicago Press, 2014) and the essay by Gaida, this volume.

8 David C. Lindberg, "Science in the Early Church," in *God and Nature: Historical Essays on the Encounter between Christianity and Science*, ed. David C. Lindberg and Ronald L. Numbers (Berkeley: University of California Press, 1986), 23–31.

9 Margaret Miles, "Vision: The Eye of the Body and the Eye of the Mind in Saint Augustine's *De trinitae* and *Confessions*," *Journal of Religion* 63, no. 2 (1983): 130.

10 David C. Lindberg and Katherine H. Tachau, "The Science of Light and Color, Seeing and Knowing," in *The Cambridge History of Science*, vol. 2, *Medieval Science*, ed. David C. Lindberg and Michael H. Shank (Cambridge: Cambridge University Press, 2013), 485–511.

11 John Charles Arnold, "Arcadia Becomes Jerusalem: Angelic Caverns and Shrine Conversion at Monte Gargano," *Speculum* 75, no. 3 (2000): 570–71.

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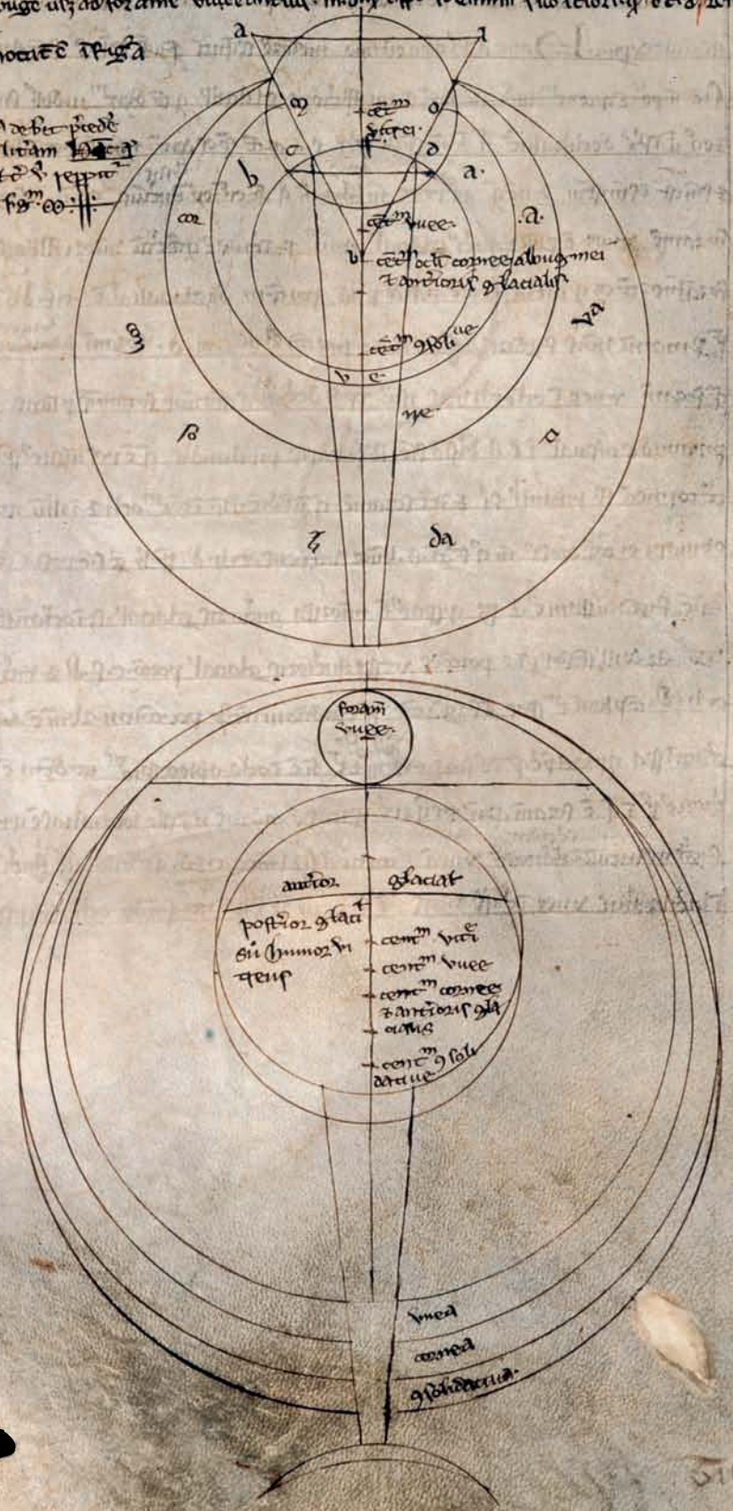
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Optical Theories in Islamic and Christian Contexts

MARGARET GAIDA

Introduction

In the fifteenth century the sculptor and painter Lorenzo Ghiberti heralded the contributions to the science of perspective by the tenth-century Arab polymath Ibn al-Haytham, known in Europe as Alhazen or Alhacen.[1] The introduction of linear perspective to European art during the early fifteenth century has long been associated with Italian Renaissance artists such as Leon Battista Alberti (1404–1472) and Piero della Francesca (ca. 1416/17–1492) and their writings about its methods, particularly with respect to the perspectival images that came to dominate the visual arts (particularly painting). Carlo Crivelli's 1486 painting *The Annunciation, with Saint Emidius* beautifully illustrates how painters crafted illusions of depth among architectural elements and human figures (see fig. 17). But this *apparent* sudden shift in representational mode and the flourishing of perspective during the Renaissance obscure the highly sophisticated and continuous development of the science of optics (called *perspectiva* in medieval Latin) for centuries prior, and across cultures, in the premodern world. Ancient theories of optics and vision were translated from Greek into Arabic during the eighth and ninth centuries in Baghdad. They reached their fullest and most comprehensive formulation by the Islamic mathematician and astronomer Ibn al-Haytham (965–ca. 1040 CE). After its translation from Arabic into Latin in the twelfth century, his monumental synthesis of varying approaches to optics was foundational for many additional centuries of readership and refinement of optical thought. In medieval Europe the early "perspectivists" (that is, theoreticians of optics) Roger Bacon (ca. 1219/20–ca. 1292), John Peckham (1230–1292), and Witelo (ca. 1230–ca. 1278) were instrumental in propagating Ibn al-Haytham's core contribution. And Bacon's theories, in particular, reflected the union of optics and theology in the medieval Latin West.

Ancient Theories of Light and Vision

Across the premodern world, theories about light and vision were intricately tied to broader themes of geometry, astronomy, astral light, and natural philosophy. As we shall see, many scholars who treated the subject of vision were also deeply engaged with understanding larger questions about the structure of the cosmos. As the principal sources of light, the fixed stars and the planets, especially the sun and the moon, formed the luminous framework in which vision occurred.

In ancient Greece the philosopher Plato (ca. 425–ca. 348 BCE) discusses both cosmology and vision in the *Timaeus*, where he describes the process of sight as occurring when a visual fire emanating from the eye encounters objects. Explanations of vision that involved the emanation of a substance from the eye were known as extramissionist. Aristotle (384–322 BCE), conversely, gives an account of sight that is intromissionist, meaning that the eye receives light from an external object. For Aristotle there is not, however, an "influx" of light that is material but, rather, a formal change in the medium that produces vision.[2] Several decades later the mathematician Euclid (325–265 BCE) provided, in his *Optics*, the earliest formulation of a theory of visual rays. Euclid's extramissionist theory linked the geometric properties of light with vision by postulating individual rays emanating outward from a point inside the eye. This point formed the apex of the visual cone, with the base of the cone out in the world at the limit of visibility.[3] What is seen depends on what the rays come into contact with. The link between optics and geometry was developed more thoroughly in the work of Ptolemy (ca. 100–ca. 170 CE), who wrote about optics, astronomy, and astrology in Alexandria in the second century CE. Ptolemy's theory of vision, presented in his *Optics*, is also an extramissionist account that draws on Euclid's visual cone. Ptolemy's visual cone, however, is continuous in all directions; that is, there are no individual rays but, rather, a continuous field of radiation.[4] Ptolemy goes on to explain several different features of light and vision, including reflection, refraction, and visual illusions, using a geometric approach. Ptolemy's *Optics*, much like his astronomical work the *Almagest*, laid out a conceptual and methodological approach to light and vision that framed many subsequent optical treatises.

A few other ancient authors are important to this narrative. They include Galen (129–ca. 216 CE), who wrote an account of anatomical aspects of the eye that influenced later Islamic and Christian authors in the medieval period. The others are known as Neoplatonists, for their reinterpretation of Plato's philosophy. Both Plotinus (ca. 204/5–270 CE) and Porphyry (ca. 234–ca. 301 CE) gave an account of being that incorporates "emanationism," or the creation of the world based on a single, divine oneness emanating outward in all directions (similar to the emanation of light in some of the optical theories),

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and were therefore influential in theological appropriations of these theories by both Muslims and Christians.

While ancient theories were certainly important in the history of optics, this work was eclipsed by that of the most prominent Islamic optical author, Ibn al-Haytham. His comprehensive masterwork on light and vision far surpassed the treatises of his Greek and Roman predecessors and formed the foundation of optical theories in medieval Europe.

Ibn al-Haytham's Foundational *Kitab al-Manazir*

After the rapid expansion of the Islamic world in the late seventh and early eighth centuries, the Abbasid caliph al-Mansur moved the capital to the newly established city of Baghdad in 762 CE. Over the next 150 years, Baghdad quickly became one of the most important centers of knowledge production in the premodern world, far surpassing anywhere in Europe at the time. Hundreds (if not thousands) of Greek, Sanskrit, and Middle Persian scientific and philosophical texts were translated into Arabic, and Islamic scholars began revising, editing, commenting upon, and composing new treatises on mathematics, astronomy, astrology, natural philosophy, medicine, and optics. The ruling elite of Baghdad was keenly interested in astrology and its many applications, including medicine. (The founding date of Baghdad itself had been selected as the most propitious day by three eminent astrologers.) Islamic scholars were therefore eager to analyze and critique the newly translated texts, and quickly found errors in some of Ptolemy's astronomical works. In the ninth century al-Kindi (ca. 800–870 CE) composed a treatise on optical rays, of which a Latin version, *De radiis stellarum*, survives. In this treatise al-Kindi postulates that the propagation of rays occurs when forms of light radiate outward in all directions from every point on visible objects and that this phenomenon can be used as a basis for understanding celestial influence.[5] Whereas the ancient author Ptolemy discussed rays in his astrological work the *Tetrabiblos*, it was al-Kindi who consistently linked astral light, and specifically rays, with vision.

Al-Kindi's thought was influenced by Neoplatonic emanationism and certainly played a pivotal role in the history of optics, but it was not until the tenth century and the work of Ibn al-Haytham that optics found its fullest and most comprehensive theoretical expression. Ibn al-Haytham was a polymath whose interests spanned several different disciplines, including astronomy, optics, mathematics, natural philosophy, and theology. More than ninety different works are attributed to him, and both his astronomical and his optical works were read and studied for centuries after his death across the Islamic world and Europe. Ibn al-Haytham's monumental study of light and vision in seven volumes, the *Kitab al-Manazir* (Book on Optics), was composed in the early eleventh century. The *Kitab al-Manazir* was a novel synthesis of geometric, physical, psychological, and anatomical elements that explained the phenomena of light, vision, and cognition (fig. 20). Most important, it laid the groundwork for all subsequent studies of light and vision in both Europe and the Islamic world.

The focus of Ibn al-Haytham's treatise is on vision, rather than on elaborating a physical theory of the nature of light in the spirit of Aristotle and his commentators.[6] As A. I. Sabra describes the *Kitab al-Manazir*, the work is "an experimental and mathematical investigation of the properties of light and colour in so far as they related to the problems of vision."[7] The first three books include a complete physical understanding of the nature of vision. Book 1 establishes the conditions for vision, the anatomical structure of the eye, and the role of light radiation, and was particularly influential in the Latin tradition of *perspectiva* (fig. 21). Unlike his ancient and Islamic predecessors who debated extramissionist and intromissionist accounts of vision, Ibn al-Haytham makes a clear case for intromission and argues that it is external forms of light, which together compose rays, that enter the eye. He comes to this conclusion based upon his experimental studies of light, often conducted in dark rooms with streams of sunlight entering through small openings. The detailed descriptions of his experimental efforts were also unrivaled for several centuries. In the *Kitab al-Manazir* Ibn al-Haytham describes his experimental setup and apparatus and observations of light on both flat planes and curved surfaces. From these observations he also argues for the rectilinear propagation of light and, lastly, that for vision to occur there must be a transparent medium between the object and the eye.[8]

To understand vision we can imagine a pyramid or cone with its base on the visible object and the apex in the eye. Ibn al-Haytham argues that, in order to avoid total visual confusion, the light can enter the eye only

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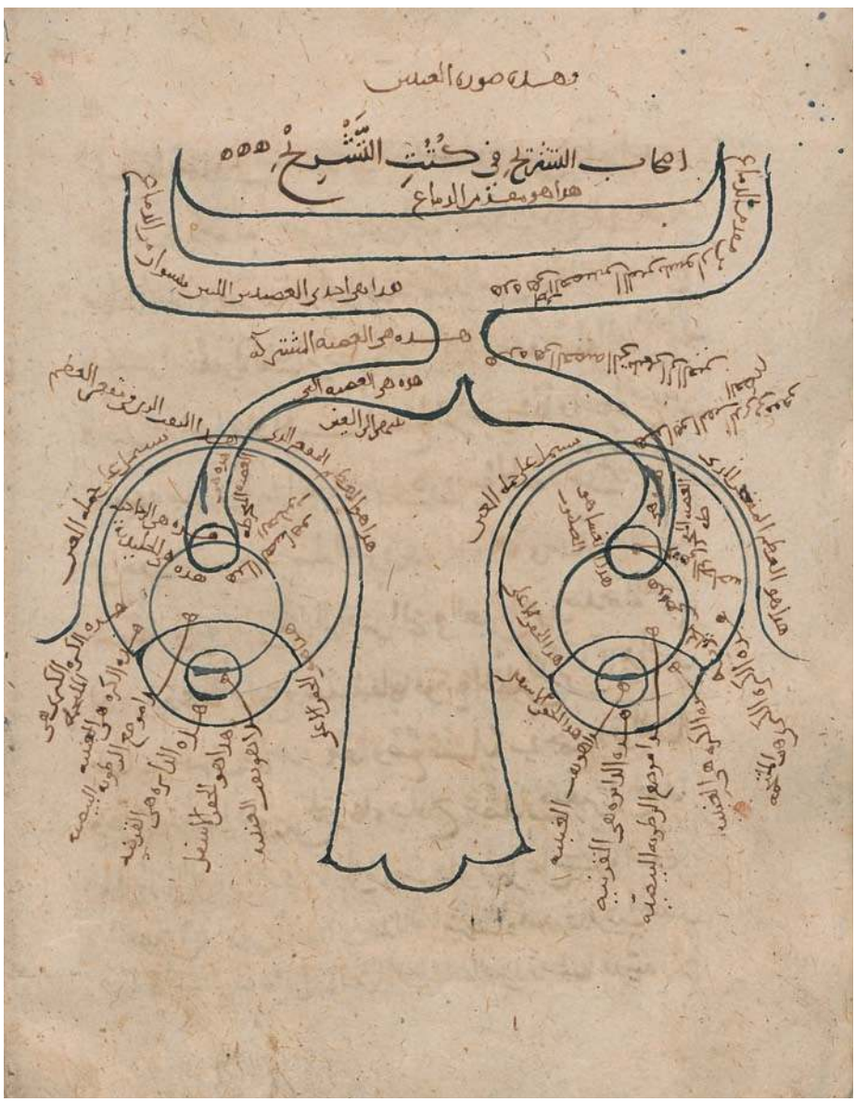


FIGURE 20. *The Structure of the Eye according to Ibn al-Haytham* in the *Kitab al-Manazir*, Basra, 1083. Ibn al-Haytham (Arab, active in Cairo, 965–ca. 1040). Ink on paper. Istanbul, Süleymaniye Library, MS Fatih 3212, vol. 1, fol. 81b (detail)

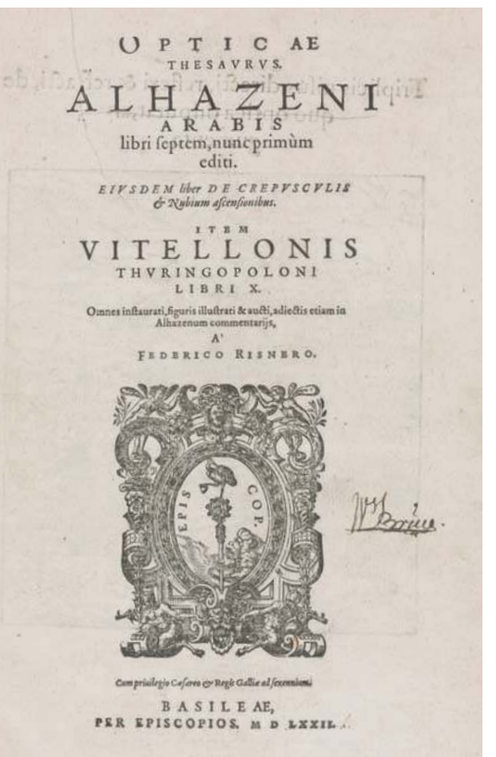

OPTICAE
THESAVRVS.
ALHAZENI
ARABIS
libri septem, nunc primùm editi.
EIVSDEM liber DE CREPVSCVLIS & Nubium ascensionibus.
ITEM
VITELLONIS
THVRINGOPOLONI
LIBRI X.
Omnes instaurati, figuris illustrati & aucti, adiectis etiam in Alhazenum commentarijs,
A'
FEDERICO RISNERO.
Cum priuilegio Cæsareo & Regis Galliæ ad sexennium.
BASILEAE,
PER EPISCOPIOS. M D LXXII.

FIGURE 21. *Opticae thesaurus: Alhazeni Arabis libri septem, nunc primùm editi; Eiusdem liber "De crepusculis" et nubium ascensionibus. Item Vitellonis Thuringopoloni libri X*, Basel, 1572. Ibn al-Haytham (author) (Arab, active in Cairo, 965–ca. 1040); Witelo (author) (Polish, active in Viterbo, ca. 1230–ca. 1278); Friedrich Risner (printer) (German, ca. 1533–ca. 1580). Ink on paper, full folio: H: 32 cm (12 5/16 in.). University of Oklahoma, University Libraries, inv. 2450671-1001

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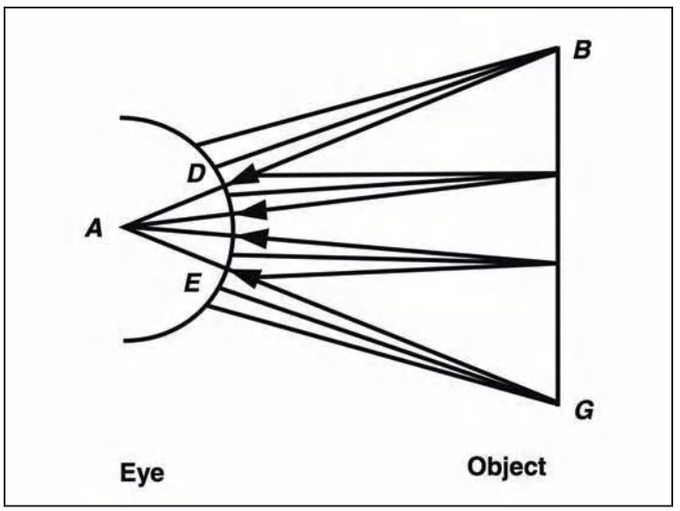


FIGURE 22. Combined extramission–intromission optical model. The incoming rays (intromission) along a set of perpendicular lines (*BDA, GEA*) with one-to-one correspondence with sensitive visual points (*D, E*) are geometrically equivalent to the imaginary visual cone *BAG* formed by rays assumed to issue from the eye (extramission). From Elaheh Kheirandish, "The Mixed Mathematical Sciences: Optics and Mechanics in the Islamic Middle Ages," in *The Cambridge History of Science*, vol. 2, *Medieval Science*, ed. David C. Lindberg and Michael H. Shank (Cambridge: Cambridge University Press, 2013), 100

if its ray lies perpendicular to the surface of the eye. Once inside, the forms of light will then create a one-to-one correspondence with points on the visible object (fig. 22).[9]

The rest of the treatise is an account of the process of transforming light radiation into visible impressions, along with explanations of how errors (misperceptions) occur when the conditions for vision are not met. Ibn al-Haytham also analyzes reflections in mirrors and mirror images and describes the effects of refraction on vision.[10]

Ibn al-Haytham's Legacy and the *Perspectiva* Tradition in Europe

In medieval Europe before the twelfth century, optical knowledge relied primarily on the visual-ray theory in Plato's *Timaeus*, which accounted for vision by visual fires emitted by the eye. For example, the account of light given by Saint Augustine (354–430 CE) was closely correlated with his ideas on divine illumination (fig. 23). His account is extramissionist in that light is diffused from the eyes toward sensible objects. He also writes, "The mind needs to be enlightened by light from outside itself, so that it can participate in truth, because it is not itself the nature of truth. You will light my lamp, Lord."[11] Light was the principle through which Augustine and many Christian scholars influenced by him understood the acquisition of knowledge and truth. The great medieval theologian Saint Thomas Aquinas (1225–1274 CE), too, was influenced by Augustine, though his understanding was very much tempered by the newly translated Aristotelian corpus. Aquinas's theory of perception focused more on the role of light within the medium, arguing that sensible objects as well as divine ideas were necessary for cognition. But divine illumination was a singular instance, not a continuous intervention.[12] The theological dimensions of understanding light and vision among medieval scholars cannot be underestimated, and they informed the study of optics for several centuries.

Robert Grosseteste (1175–1253 CE), bishop of Lincoln Cathedral in England and a prolific thinker whose work greatly influenced the Franciscan order, is known for his Neoplatonic ideas and his focus on mathematics.[13] Grosseteste's "metaphysics of light" distinguished between *lux*, the purest form of light, which is naturally predisposed to emanate outward in all directions from a single point and which gives three-dimensional form to the physical universe, and *lumen*, or the radiating light that returns to its source, in the process creating planetary spheres and the earthly elements.[14] The attention that Grosseteste devoted to the praise of mathematics was foundational for the reception of Greek and Islamic optical theories, particularly in the work of Roger Bacon, one of the most important medieval European natural philosophers.[15]

FIGURE 23. *Saint Augustine in His Study*, Florence, 1480. Sandro Botticelli (Italian, ca. 1445–1510). Fresco, 152 × 112 cm (59 13⁄16 × 44 1⁄16 in.). Florence, church of Ognissanti

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Just as there had been a campaign of translations of ancient works into Arabic in eighth- and ninth-century Baghdad, there was a flurry of translation activities in Europe (and especially Spain and southern Italy) in the twelfth and thirteenth centuries as many important Greek works (such as the Aristotelian corpus) and Islamic scientific and philosophical texts were translated from Arabic into Latin. In the late twelfth or early thirteenth century Ibn al-Haytham's *Kitab al-Manazir* was translated into Latin.[16] The translation circulated as a manuscript under two different titles, *De aspectibus* and *Perspectiva*, and famously became the basis for the development of perspectivist optics, initiated by Roger Bacon in the thirteenth century and continued by John Peckham and Witelo. The transmission of Ibn al-Haytham's work came just after several other ancient optical treatises were translated and began circulating in Europe, including both Euclid's and Ptolemy's optical works, in addition to Aristotle's. In a span of about fifty years, between about 1225 and about 1275, the state of optical knowledge in medieval Europe changed dramatically. The first major effort at synthesis, Bacon's *Perspectiva*, dated circa 1267, must be seen against the larger backdrop of the dynamic encounter between the medieval theological tradition and the Greek and Arabic texts newly translated into Latin (plate 41).

The medieval Latin tradition of *perspectiva* relied heavily on Ibn al-Haytham's optics. There are some important distinctions, however. As a result of the transmission and translation of the text, the first three chapters of book 1 were lost, and *De aspectibus* begins with chapter 4 of book 1. Bacon synthesized the optical ideas in *De aspectibus* with Euclid's and Ptolemy's optical works, al-Kindi's *De radiis stellarum*, Aristotle's *De anima*, and Robert Grosseteste's ideas on light. Also of note are the Neoplatonic sources that were influential for Bacon, which include, besides al-Kindi, the *Fons vitae* of the Jewish Neoplatonist Ibn Gabirol (ca. 1021/22–ca. 1057/58 CE) and the pseudo-Aristotelian *Liber de causis*, dated to the ninth century. Each of these works illustrates the notion of a universal emanation of force that resulted in a hierarchy of being, linked by a causal network.

These various elements led to a substantial reworking of the metaphysical underpinnings of Ibn al-Haytham's theories on optics. Rather than the "forms" of light posited by Ibn al-Haytham, Bacon proposes a "multiplication of species." These "species" are similar to Grosseteste's notion of *lux*, or the metaphysical version of light that is capable of creating space (dimensionality) itself. Bacon's species emanate outward in all directions, like Ibn al-Haytham's forms, but also carry with them certain ontological aspects or properties of the objects from which they emanate. While light is composed of species, the multiplication of species can also be used to explain other phenomena for which a physical or material explanation is not always obvious, such as the Christian theological concept of transubstantiation, when the bread and wine become the body and blood of Christ during Holy Mass, or the power of spoken words in prayer. Still further, the multiplication of species also accounted for the planetary influences of astrology. Planetary species emanated down from the celestial sphere, which could impact individuals, the environment, and the weather.

Conclusion

In considering the development of optics across the premodern world, it is clear that religion and notions of the divine were important in framing how people understood vision. That said, religious ideas were much more prominent in Christian Europe than among the Islamic scholars writing on optics. Among scholars in this field, Grosseteste and Bacon were for many years seen to be pioneers of modern science and experimentalism. Although the two Europeans shared a number of sources with Ibn al-Haytham, including several Neoplatonic texts originally written in Arabic, Ibn al-Haytham devoted his optical project to elucidating the process of vision by analyzing the properties of light based on extensive observation and experiment two centuries earlier than Bacon. Ibn al-Haytham's lengthy treatise is devoid of the hierarchy of being established by emanation from the One, which was popular among his contemporaries, including al-Kindi and Ibn Sina (Avicenna). Theological motivations are not explicitly mentioned in Ibn al-Haytham's text, and it is difficult to identify any implicit theological commitments. Many of Grosseteste's and Bacon's views, by contrast, were very much informed by their understanding of the divine and their Christian metaphysics.

Ibn al-Haytham's approach (which combined mathematics and natural philosophy) also set the stage for centuries of the study of optics in the Islamic world,

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including important treatises on optical phenomena such as the rainbow. One example is the description of the rainbow in a cosmographical work titled *Wonders of Creation*, composed by the thirteenth-century scholar al-Qazwini (1203–1283 CE) (plate 77). In a revision of Ibn al-Haytham's *Kitab al-Manazir* (plate 40), Kamal al-Din al-Farisi (ca. 1267–1319 CE) gave one of the first mathematically correct descriptions of the rainbow. Lastly, it is worth mentioning that the law of refraction, commonly referred to as Snell's law and attributed to the Dutch astronomer Willebrord Snell (1580–1626 CE), appeared in the writings of the tenth-century Persian mathematician Ibn Sahl (active 940–1000 CE), who was a near contemporary of Ibn al-Haytham in Baghdad.

It is a modern preconception that the scientific pursuits of Muslims in the medieval Islamic world were driven primarily by religion. As we have seen from the examples discussed here, it was Christian scholars who were invested in uniting theology and optics. This point reinforces the need for a closer study of how Christian and Muslim scholars interpreted the same scientific sources within their own religious and cultural frameworks. In this case Roger Bacon's theological appropriation of Ibn al-Haytham's *Kitab al-Manazir* and his doctrine of the multiplication of species gave *perspectiva* a subtle Christian hue.

The history of premodern optics in Europe and the Islamic world shows how the study of light informed the understanding of the created world, linking astral light shining down from the heavens to the study of optics for understanding the divine, and to the divine illumination or higher knowledge that carried God's grace for humanity. Light connected the source of all creation to the planets, from which it could be perceived on earth, where the human eye became the vessel for its study.

Notes

1 Ghiberti's comments, in his *Third Commentary*, are based on a fourteenth-century Italian translation of Ibn al-Haytham's book on optics in a manuscript held today at the Vatican Library. See A. Mark Smith, "The Latin Source of the Fourteenth-Century Italian Translation of Alhacen's *De aspectibus* (Vat. Lat. 4595)," *Arabic Sciences and Philosophy* 11 (2001): 27–43.

2 Aristotle, *De anima* 2.7, translated by J. A. Smith, in *The Works of Aristotle*, vol. 3, ed. W. D. Ross (Oxford: Clarendon Press, 1931), 670–74.

3 A. Mark Smith, *From Sight to Light: The Passage from Ancient to Modern Optics* (Chicago: University of Chicago Press, 2015), 47.

4 Smith, *From Sight to Light*, 80–81.

5 For an extensive account of al-Kindi's ideas, see David C. Lindberg, *Theories of Vision from al-Kindī to Kepler* (Chicago: University of Chicago Press, 1976), 18–32.

6 A. I. Sabra, introduction to *The "Optics" of Ibn al-Haytham: Books I–III*, trans. A. I. Sabra (London: Warburg Institute, University of London, 1989), lv.

7 Sabra, introduction to *The "Optics" of Ibn al-Haytham*, lv.

8 Ibn al-Haytham, *Kitāb al-Manāẓir* 1.3, translated by A. I. Sabra, in *The "Optics" of Ibn al-Haytham*, 13–51.

9 Ibn al-Haytham, *Kitāb al-Manāẓir* 2.2, translated by A. I. Sabra, in *The "Optics" of Ibn al-Haytham*, 114–26. For an extensive explanation of these passages, see Lindberg, *Theories of Vision from al-Kindī to Kepler*, 73–75.

10 The burning mirror and the rainbow, topics that are commonly encountered in other optical works, are left out of Ibn al-Haytham's text, most probably because they deal with light and its properties instead of vision. See A. Mark Smith, *Alhacen's Theory of Visual Perception: A Critical Edition, with English Translation and Commentary, of the First Three Books of Alhacen's "De aspectibus," the Medieval Latin Version of Ibn al-Haytham's "Kitāb al-Manāẓir"* (Philadelphia: American Philosophical Society, 2001), xix. For Ibn al-Haytham's account of light and color, see the essay by Stockstill, this volume.

11 Augustine, *Confessions* 4.15.25, trans. Thomas Williams (Cambridge, MA: Hackett, 2019).

12 See Anthony J. Lisska, *Aquinas's Theory of Perception: An Analytic Reconstruction* (Oxford: Oxford University Press, 2016).

13 David C. Lindberg, "The Genesis of Kepler's Theory of Light: Light Metaphysics from Plotinus to Kepler," *Osiris* 2 (1986): 5–42. See also David C. Lindberg, introduction to *Roger Bacon and the Origins of* Perspectiva *in the Middle Ages: A Critical Edition and English Translation of Bacon's "Perspectiva"* (Oxford: Clarendon Press; New York: Oxford University Press, 1996), xxxvii–xl.

14 Smith, *From Sight to Light*, 257.

15 Lindberg, introduction to *Roger Bacon and the Origins of* Perspectiva, xlii–xliii.

16 The translator is unknown, although most modern scholars agree that it was likely Gerard of Cremona (ca. 1114–1187 CE) or a member of his school in Spain. Gerard was a prolific early translator of Arabic texts into Latin. He translated Ptolemy's *Almagest* via the Arabic translation of the Greek work.

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Divine Darkness

ELINA GERTSMAN

In his disquisition on the renovation of the abbey church of Saint-Denis, near Paris, the ambitious head of the abbey and a sometime regent of France, Suger (1081–1151), extolled the extraordinary qualities of "new light" (*lux nova*) that he associated with visual manifestations of the divine. The brilliance of this light preoccupied Suger, as is evident in the inscription in the church's upper choir he helped rebuild: "Bright is that which is brightly coupled with the bright, / And bright is the noble edifice which is pervaded by the new light."[1] This new light—the resplendent light, the light of God, the light that is God—was as physical as it was spiritual, as immediate as it was symbolic. It was the light that pervaded the created world (fig. 24).

In Christian scripture divine light carries no darkness. The First Epistle of John affirms that "this is the declaration which we have heard from him, and declare unto you: That God is light, and in him there is no darkness" (1 John 1:5), and the Epistle of James echoes it in evoking "the Father of lights, with whom there is no change, nor shadow of alteration" (James 1:17).[2] In the theology of the sixth-century Syrian mystic and Neoplatonist Pseudo-Dionysius the Areopagite—who was mistaken by Abbot Suger for the patron saint of his very own abbey—the holy hierarchies of celestial beings arrayed around God's throne are predicated on the proximity to the divine light, starting with the seraphim whose name the mystic glosses as "fire-makers" for their "ability to hold unveiled and undiminished both the light they have and the illumination they give out."[3] The stained glass at Saint-Denis seems, at first blush, to embody the power of divine light to illumine even the darkest spaces, to dispel the shadowy gloom of the building by its radiant bursts of light.

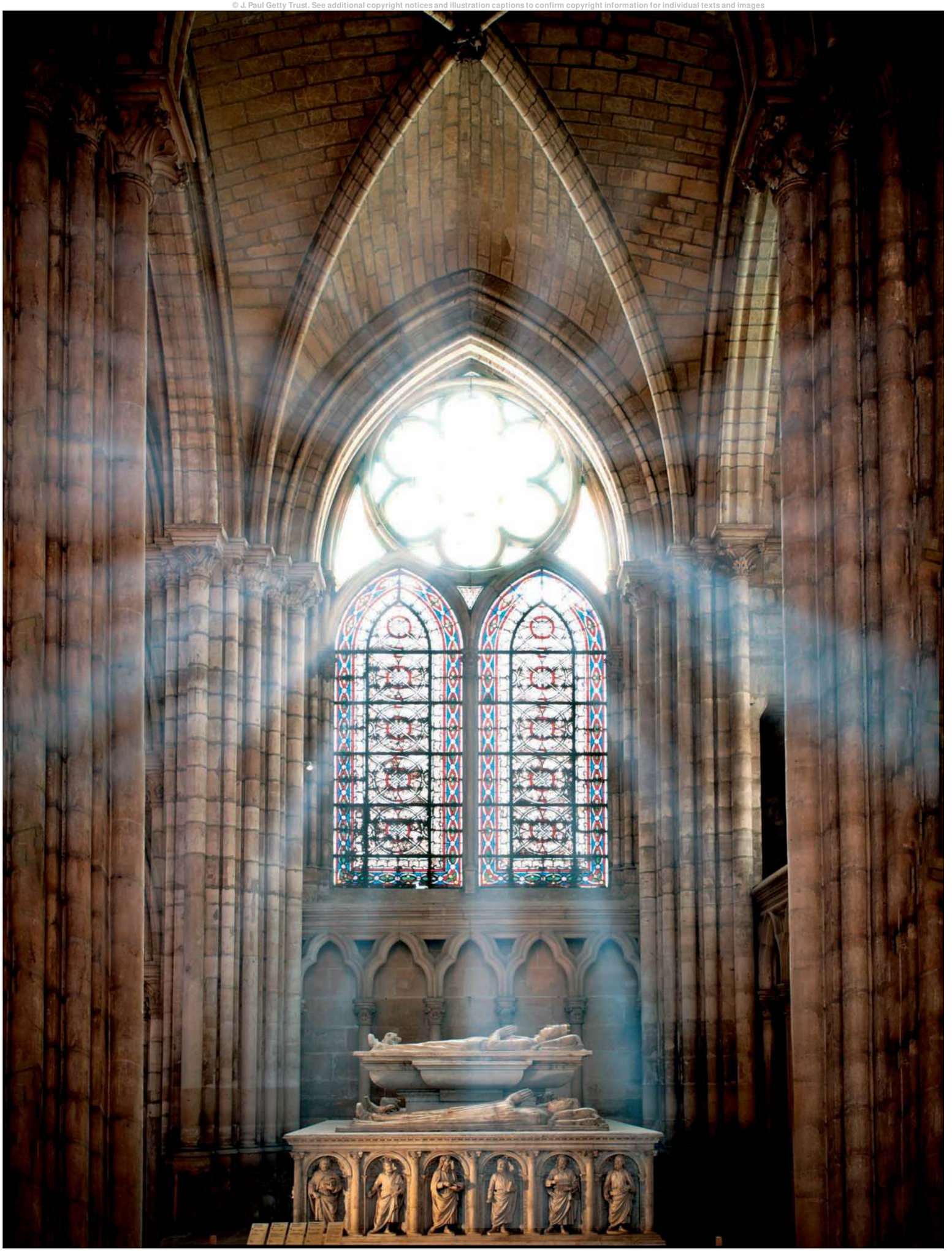
But viewer beware; things are not what they seem. The brilliance of light at Saint-Denis first draws attention to and then eclipses the images in its windows (fig. 25). These images, and the tracery that strains to contain them, dissolve in this light, giving way to the blinding and the incomprehensible, illumination turning into obscuration: a daring feat of reifying the inconceivable workings of the divine. In this way the windows at Saint-Denis lay bare the complexity of medieval conceptions of God as rooted in the twinned notions of light and darkness, built on the predicate of divine unintelligibility and unavailability to the human gaze.

That is because the light of God does not just illumine; it also blinds and veils. This blindness as a function of divine light weaves itself in and out of Christian theology. In the ninth century this idea was taken up by the Irish scholar and intellectual John Scotus Erigena, who evokes, in his *Periphyseon*, the "incomprehensible and inaccessible brilliance of the divine goodness."[4] Mortals are simply unable to see through this brilliance: when, in *The Divine Comedy*, Dante the pilgrim, at long last, arrives to paradise, he can at first withstand the intensity of divine radiance only when it is reflected in the eyes of his beloved, Beatrice.[5] God is secreted in this light-imposed sightlessness, a notion that stems from Isaiah 45:15, "Verily thou art a hidden God, the God of Israel the saviour." Blindness thus becomes a direct corollary of God's unbearable light. The concept of divine obscuration is subsequently found in countless medieval treatises, from the fourth-century writings of Gregory of Nyssa to the anonymous fourteenth-century *Cloud of Unknowing*.

Representing the divine light that conceals through illumination, however, was a tricky business, the kind that demanded an imaginative approach. For instance, in the Rothschild Canticles, an early fourteenth-century compilation of prayers and meditations, this obscuration takes a series of geometric forms across several miniatures, culminating in the miniature on folio 98, where a circular swirl of gold intervenes between the beholder and the image of the Trinity, hiding it behind a burst of stunning light (plate 57).[6] The image evokes the Pseudo-Dionysian concept of apophasis, or negative theology, which underlay a broad swath of Christian writings about God and which held that God could be described only by negation: "[God] is known through knowledge and through unknowing. Of him there is conception, reason, understanding, touch, perception, opinion, imagination, name, and many other things. On the other hand he cannot be understood, words cannot contain him, and no name can lay hold of him. He is not one of the things that are and he cannot be known in any of them. . . . He is known to all from all things and he is known to no one from anything."[7] In the Rothschild Canticles the unknowing, or obscuration of the divine image, is visualized as a gilded

FIGURE 24. Choir of the Basilica of Saint-Denis, France (with sections built and restored)

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diaphragm composed of metallic blades of light whose luminescent vortex, enclosed in a reddish frame, emits a spiky wheel of rays. Its aperture completely closed, this diaphragm of light admits no gaze, forestalling the book's reader-viewer from seeing the divine. It will reopen, but only after death, the experience augured by 1 Corinthians 13:12: "We see now through a glass in a dark manner; but then face to face."

Much less esoteric but equally ingenious is an image that appears in the pages of one thirteenth-century English Psalter (plate 56).[8] The striking image accompanies Psalm 109, placed within the text's opening initial *D*, for *Dominus* (Lord), inscribed inside a thin green frame. At the center the Trinity, figured as the Throne of Mercy, is flanked by angels who carry the sun and the moon in their veiled hands. God the Father holds the cross, rendered as a verdant Tree of Life, with a diminutive crucified Christ upon it. The dove of the Holy Spirit plunges like a missile directly toward Christ's head. Beneath the throne cower three men—one crowned, two wearing pointed hats—the wretched counterpoints to the resplendent Trinity above. These are, surely, the conquered adversaries to which the first verse of the psalm refers: "The Lord said to my Lord: Sit thou at my right hand: Until I make thy enemies thy footstool."[9] Another such enemy, a centaur likewise sporting a pointed hat, is seen in the floral ascender of the initial, aiming an arrow at the top of the letter, which is fashioned into a church and capped with crosses.

Within and around the initial, gold predominates, seemingly a visual comment on verse 3 of the psalm: "With thee is the principality in the day of thy strength: in the brightness of the saints." Two worshippers on either side of the Trinity direct their gazes upon the Godhead, ostensibly modeling the beholder's intended engagement with the miniature. The one on the left looks unswervingly at Christ; the one on the right directs the viewer's gaze to the countenance of God the Father. Neither member of the Trinity engages with the worshippers, however. Christ's head is hung low, his eyes closed; the divine face of the Father is hidden, or obscured, or transposed by a radiant quatrefoil that flowers from his neck. The image is stark, unexpected, shocking. Aside from toying with the notion of perceiving the visually unavailable, hidden God, the image tests the limits of representation of God as light and diagnoses the book's audience, rendered sightless, with spiritual blindness.[10] In other words, this is not only the likeness of a veiled divinity but also a disclosure of the beholder's inability to see.

The image in the Psalter is painstaking in representing the unrepresentability of divine light. The quatrefoil blooming forth from God is rendered in gold of a different quality from the gold that surrounds the rest of the initial. That gold is burnished, reflective, its variance evident in the glow that scatters across the image; it catches visual echoes of the beholder who peers in. Like the moon, it reflects light; it does not emit it. But the quatrefoil's gold is dull, matte, opaque. It does not admit reflection, and it does not admit the viewer. It is the true light that cannot be rendered as light, the inaccessibility of the prototype indexed by the dense surface that reads almost as being concave. This gold points to its own inefficiency at standing in for the true divine *lux*, a visceral reminder about the breach between the image and its prototype, between the image of God and God himself.[11]

Darkness as blindness wrought by light is implied in this illumination; it is directly figured in a fifteenth-century image of the Holy Face interweaved into a twelfth-century *Vita Christi* manuscript (plate 62).[12] That this darkness is the function of blinding radiance rather than a callback to the original darkness of the miraculous imprint that Christ's face left on Veronica's cloth is bluntly brought home both by the text of the prayer, which extols the Holy Face "in qua nitet species divini splendoris" (in which shines the beauty of the divine), and by the flecks of yellow paint applied as if to break through the darkness of God's skin. In other fifteenth-century paintings the twinning of light and darkness to conjure the sacred is visualized even more directly: in Simon Marmion's image of the ascent of Saint Bertin's soul (plate 60b), God's brilliant realm is edged by golden seraphim who dissolve headfirst into the obscurity that surrounds them; in Geertgen tot Sint Jans's *Glorification of the Virgin* (plate 59) the mere presence of Mary and Child disperses the surrounding darkness that, at closer inspection, turns out to be constituted by the angelic host. This is "the darkness of your light" praised by the author of the Rothschild Canticles (fol. 105), the kind that the great fourteenth-century theologian Bonaventure calls "the superluminous

FIGURE 25. Light entering the upper choir of the Basilica of Saint-Denis, France

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darkness of a silence . . . that is resplendent above all splendor, and in which everything shines forth."[13] Bonaventure's evocative poetics inevitably brings to mind the striking miniature of celestial silence from the so-called *Silos Beatus*, which contains Beatus of Liébana's eighth-century commentary on the Book of Revelation, *Tractatus de Apocalypsin*.[14] Copied sometime between 1091 and 1109, the manuscript features an extraordinary image that ostensibly illustrates Revelation 8:1 ("And when he had opened the seventh seal, there was silence in heaven"): a monochromatic yellow rectangle (fig. 26). Outlined with black lines, the luminous form, which appears to emanate from within the page itself, serves as an effective screen that blocks the beholder's gaze; its opaqueness is as deafening as the silence it purports to render, and as obfuscating as the divine light itself.

We find the concept of divine obscuration inherent in light formulated most viscerally, perhaps, in the writings of the fifteenth-century philosopher and theologian Nicholas of Cusa. In his *Apologia doctae ignorantiae* (A defense of "learned ignorance"), invoking Pseudo-Dionysius the Areopagite and embracing the latter's radical conceptualization of the divine as utterly incomprehensible, Nicholas writes: "For God is found when all things are left behind; and this darkness is light in the Lord. . . . Now, Dionysius calls [this] darkness a divine ray." Nicholas hastens, however, to reformulate this darkness as a space expressly made for those who are wedded to "visible things," to "the objects available to the eyes and senses"; God, he writes, "has made [this] darkness His hideaway."[15] Yet, in a different context, he again revises the relational inextricability of divine light from darkness. In his *De coniecturis*, Nicholas offers a diagrammatic continuum between oneness/light and otherness/shadow where "God, who is Oneness, is as the base-of-light but the base-of-darkness is as nothing":

> Hence, the uppermost world abounds with light . . . yet, it is not free of darkness, although because of the upper-world's simplicity the darkness is thought to be absorbed in light. By contrast, in the lowest world darkness reigns, although it is not the case

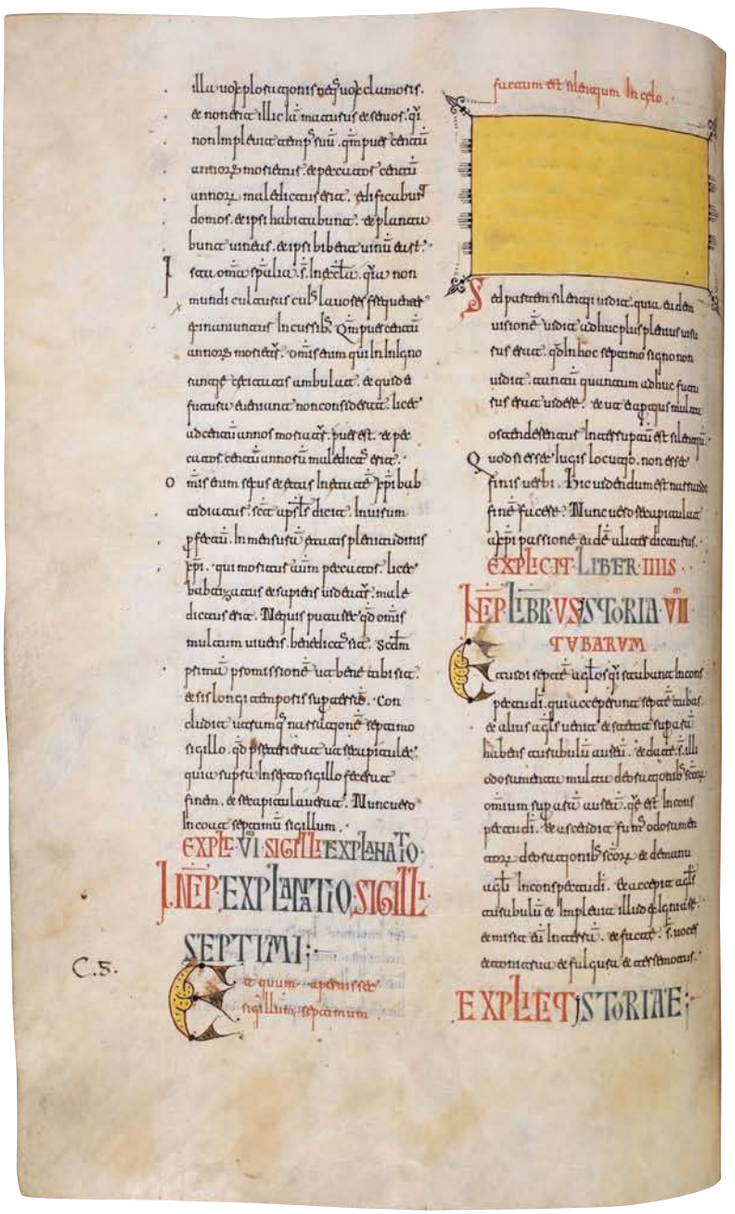


FIGURE 26. Representation of silence as a yellow rectangle, with an inscription: "factum est silentium in celo" (Rev. 8:1), *Silence* in commentary on the Apocalypse (*Silos Beatus*), northern Spain (Santo Domingo de Silos), 1091–1109. Beatus of Liébana (Spanish, ca. 700–800). Parchment, full folio: 38 × 24 cm (14 15⁄16 × 9 7⁄16 in.). London, British Library, Add MS 11695, fol. 125v

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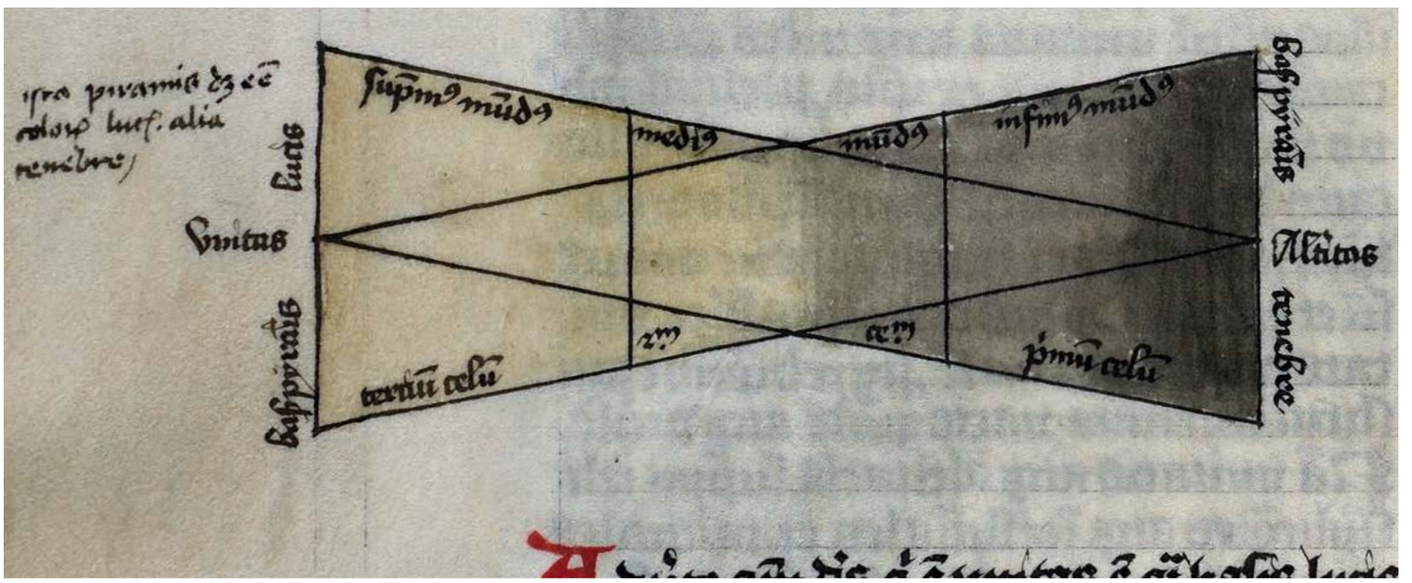


FIGURE 27. *Diagram P* in *De coniecturis*, Rhineland, before 1448. Nicholas of Cusa (German, 1401–1464). Watercolor and black ink, full folio: 34.5 × 26 cm (13 9/16 × 10 ¼ in.). Nuremberg, Stadtbibliothek im Bildungscampus, Cent. II 9, fol. 142v (detail)

> that in that darkness there is no light at all. Yet, the diagram shows that the light is hidden in the darkness rather than shining forth. And . . . light [descends] into darkness . . . In the uppermost heaven whatever things are characterized by otherness return into oneness. For example, [you will see that] divisibility [returns] into indivisibility; darkness [returns] into light . . . and so on.

The dialectic is summed up as an ontological tenet: "If you want to embrace the truth, you must notice that light's descending is nothing other than darkness's ascending. And God's being in the world is nothing other than the world's being in God. . . . And for darkness to elevate itself into light is nothing other than for light to descend into darkness."[16] In Jeffrey F. Hamburger's terms, diagrams in *De coniecturis*, and specifically Nicholas's *figura paradigmatica* (or diagram P), strive to visualize "the linked processes of knowing and unknowing . . . as well as their fundamental incommensurability" (fig. 27).[17]

The inextricability of divine light from darkness and the notion of darkness as God's place of retreat here come to the fore, wrapped in the notion of the divine as the unseeable, the unrepresentable, the conceptually fraught, and the cognitively unapproachable. In images like the Getty's *Vita Christi* miniature, darkness acts as a screen that conceals and obscures representation at the same time that it reveals it. The dark wash over the Holy Face constitutes an evasion of image, the rejection of every possible way in which Christ is rendered in preceding and succeeding miniatures, and a downright denial of the Transfiguration image on folio 55v, where Christ's gilded skin—so unlike the skin of the holy men who surround him but utterly like the rays of light that burst forth and melt into the golden background—is purported to reify his metamorphosis (fig. 28). In comparison to the obscured, disembodied Holy Face, *The Transfiguration* seems impossibly facile. The darkness of the Holy Face is a paradox: a space from which God absents himself and in which he hides his presence, a space that burst through the text of the prayer on the folio, invading it, superseding it. It is the paradox that underlies all images of the divine light that can be seen only peripherally—at some remove, against one's blindness, or else through a glass in a dark manner.

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FIGURE 28. *The Transfiguration* in the *Vita Christi* (with devotional supplements), East Anglia, England, ca. 1480–90. Tempera colors and gold leaf on parchment, full folio: 17 × 11.9 cm (6 11⁄16 × 4 11⁄16 in.). Los Angeles, J. Paul Getty Museum, Ms. 101 (2008.3), fol. 55v

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Notes

1 Suger, *De administratione* 28, in *Gothic Art, 1140–c. 1450: Sources and Documents*, ed. and trans. Teresa G. Frisch (Toronto: University of Toronto Press in association with the Medieval Academy of America, 1987), 8.

2 Quotations here and elsewhere in this essay are from the Douay-Reims translation of the Bible.

3 Pseudo-Dionysius, *The Celestial Hierarchy*, in *The Complete Works*, trans. Colm Luibheid (New York: Paulist Press, 1987), 161–62. The connection between Suger's choir and the metaphysics of light as articulated by Pseudo-Dionysius, first proposed by Erwin Panofsky—in *Abbot Suger on the Abbey Church of St.-Denis and Its Art Treasures*, ed. and trans. Erwin Panofsky, rev. ed. Gerda Panofsky-Soergel (1946; repr., Princeton, NJ: Princeton University Press, 1979)—has been debated, with several recent studies challenging the very notion; for a useful summary of the debate, see Francesca Dell'Acqua, "*L'auctoritas* dello pseudo-Dionigi e Sugerio di Saint-Denis," *Studi medievali*, 3rd ser., 55, no. 1 (2014): 189–213, esp. 191–202.

4 John Scotus Erigena, *Periphyseon (De divisione naturae)* 3.307.680CD, in *Periphyseon*, trans. I. P. Sheldon-Williams (Dublin: Dublin Institute for Advanced Studies, 1981), 167; discussed in Deirdre Carabine, *John Scottus Eriugena* (New York: Oxford University Press, 2000), 46–50. See also Paul Rorem, *Eriugena's Commentary on the Dionysian "Celestial Hierarchy"* (Toronto: Pontifical Institute of Mediaeval Studies, 2005), esp. 108–12; Michael Sells, *Mystical Languages of Unsaying* (Chicago: University of Chicago Press, 1994), 34–62.

5 Dante, *Paradise*, vol. 3 of *The Divine Comedy*, trans. Mark Musa (New York: Penguin, 1986). It is only in canto XXX of *Paradise* that Dante is able to see "both courts of Heaven in their reality" with his own eyes (see esp. lines 95, 97, and 99 for an insistent repetition of "I saw"; *Paradise*, 355). In canto XXXIII he is able to gaze directly into the divine light.

6 See Jeffrey F. Hamburger, *The Rothschild Canticles: Art and Mysticism in Flanders and the Rhineland circa 1300* (New Haven, CT: Yale University Press, 1990), esp. 133–42.

7 Pseudo-Dionysius, *The Divine Names* 7.3, in *The Complete Works*, 108–9.

8 On this psalter, see Yves Christe, *Jugements derniers* (La Pierre-qui-Vire, France: Zodiaque, 1999); *Alfa e omega: Il giudizio universale tra Oriente e Occidente*, ed. Valentino Pace (Castel Bolognese: Itaca, 2006); Herbert L. Kessler, "Turning a Blind Eye: Medieval Art and the Dynamics of Contemplation," in *The Mind's Eye: Art and Theological Argument in the Middle Ages*, ed. Jeffrey F. Hamburger and Anne-Marie Bouché (Princeton, NJ: Princeton University Press, 2006), 413–39; Nigel J. Morgan and Bronwyn Stocks, eds., *The Medieval Imagination: Illuminated Manuscripts from Cambridge, Australia, and New Zealand* (Victoria: Macmillan Art, 2008); and Elina Gertsman, *The Absent Image: Lacunae in Medieval Books* (University Park: Pennsylvania State University Press, 2021), 97.

9 The pointed hat, or *pilleus cornutus*, was often used as a shorthand for representing the Jews in the later Middle Ages.

10 On such blindness as the result of a postlapsarian state of existence, see Robert Javelet, *Image et ressemblance au douzième siècle: De saint Anselme à Alain de Lille*, 2 vols. (Paris: Letouzey & Ané, 1967); and Jean-Claude Schmitt, "*Imago*: De l'image à l'imaginaire," in *L'image: Fonctions et usages des images dans l'Occident médiéval* (Paris: Le Léopard d'Or, 1997), 29–37, esp. 31–33. On the notion of divine hiddenness and unavailability, see, especially, essays in *Histories of the Hidden God: Concealment and Revelation in Western Gnostic, Esoteric, and Mystical Traditions*, ed. April D. DeConick and Grant Adamson (Durham, England: Acumen, 2013).

11 This discussion is developed in Elina Gertsman and Vincent Debiais, *Écarts, excès d'image: Essai sur l'abstraction dans l'art médiéval* (Paris: Cerf, forthcoming).

12 See Herbert L. Kessler, "Configuring the Invisible by Copying the Holy Face," in *The Holy Face and the Paradox of Representation: Papers from a Colloquium Held at the Bibliotheca Hertziana, Rome and the Villa Spelman, Florence, 1998*, ed. Herbert L. Kessler and Gerhard Wolf (Bologna: Nuova Alfa, 1998), 129–51, esp. 136–37.

13 Bonaventure, *Itinerarium* 8.5, trans. in Hamburger, *The Rothschild Canticles*, 135.

14 See, especially, Francisco Prado-Vilar, "*Silentium*: El silentio cósmico como imagen en la Edad Media y la Modernidad," *Revista de poética medieval* 27 (2013): 21–43; Vincent Debiais, *Le silence dans l'art: Liturgie et théologie du silence dans les images médiévales* (Paris: Cerf, 2019); Vincent Debiais, "Color as Subject," in *Abstraction in Medieval Art: Beyond the Ornament*, ed. Elina Gertsman (Amsterdam: Amsterdam University Press, 2021), 33–53, esp. 34–36; and, on the entire manuscript, John Williams, *The Illustrated Beatus: A Corpus of the Illustrations of the "Commentary on the Apocalypse,"* vol. 4, *The Eleventh and Twelfth Centuries* (London: Harvey Miller, 2002), 31–40, no. 16.

15 Nicholas of Cusa, *Apologia doctae ignorantiae*, in *Opera omnia*, ed. Raymond Klibansky (Hamburg: Meiner, 1932), 2: 2–8, quoted from Nicholas of Cusa's *Debate with John Wenck: A Translation and an Appraisal of* De Ignota Litteratura *and* Apologia Doctae Ignorantiae, in *Complete Philosophical and Theological Treatises of Nicholas of Cusa*, ed. and trans. Jasper Hopkins (Minneapolis: A. J. Banning Press, 2001), 1: 473–74. On Nicholas's notion of light, see Jeffrey F. Hamburger, *Color in Cusanus* (Stuttgart: Anton Hiersemann, 2021), esp. chap. 5 on *De coniecturis*.

16 Nicholas of Cusa, *De coniecturis*, par. 41–43, 44–45, in *Opera omnia*, ed. Raymond Klibansky (Hamburg: Meiner, 1932), translated in *Metaphysical Speculations*, in Hopkins, *Complete Philosophical and Theological Treatises of Nicholas of Cusa*, 2: 182–84, 217. On the treatise, see Clyde Lee Miller, *The Art of Conjecture: Nicholas of Cusa on Knowledge* (Washington, DC: Catholic University of America Press, 2021).

17 Hamburger, *Color in Cusanus*, 87. In this sense, he argues, in *De coniecturis* knowledge is construed as "the best way to understand the unity of the absolute even if that knowledge remains inalienably distinct and other from it. In this sense, conjecture represents a path or way of knowing contrary to that of apophasis" (90).

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Crystalline Vision

CYNTHIA HAHN

> Down at the bottom of the spring were two crystals which I gazed at most attentively . . . The crystal is so marvellous and has such power that the whole place [the garden] . . . is revealed there . . . there is nothing so small, so secret, or so hidden that it is not displayed.
>
> —Guillaume de Lorris and Jean de Meun, *Roman de la rose* (ca. 1237–77), lines 1535–1604

Rather than the expression of a modern crystal lover's enthusiasm for the secret powers of a stone, these are the words of a lover in search of his lady at the beginning of a secular French poem of the thirteenth century, the *Roman de la rose*.[1] The text goes on to compare the stone to mirrors as well as to both the beloved's and the lover's eyes, leaving no doubt that crystal is associated not only with *vision and its possibilities* but also with a multivalent and mysterious experience.[2]

What is this wondrous substance that grants an ability to see things entire as well as in detail? So "marvellous" and with "such power" that if one takes the time to gaze into its depths, all will be disclosed, as the text further notes, in "due order"? The remarkable substance is a gem of great prestige in the Middle Ages: clear rock crystal. Pliny the Elder (23–79 CE), the Roman author of the *Natural History* and preeminent lapidary authority throughout the premodern era, attests to its worth—ten times the value of gold—and even says, "Of objects that lie upon the surface of the earth, it is crystals that are most highly esteemed."[3] It was the purest and clearest natural substance known in the Middle Ages.

Although mined from the depths of the earth or found in high mountain streams, rock crystal was also always credited with a celestial nature. It was thought to be a form of hyperfrozen and permanent ice. It caught and reflected light in ways that prompted people to imagine that it glowed with its own interior light, supplying light to the caves of its origins or illuminating the inside of a palace or church (fig. 29).[4] As the poet Dante would have it, describing the Creation in *The Divine Comedy*, "the freezing cold water becomes crystalline stone," and he praises its transmission of light, likening it to the effect of divine light that shines forth "pervading all," like a "triform [Trinitarian] light."[5] In a late medieval French manuscript, divine light "rays" forth from Christ in Majesty, and the artist has included the orb of a crystalline earth beneath the figure's feet, illuminated by the rays (plate 53).[6]



FIGURE 29. Rock crystal, from Tibet

Dismissed today as almost valueless—as common, clear quartz—rock crystal in the Middle Ages was no less ubiquitous but demonstrably not at all "common." The finest-quality stone was precious and often imported via far-flung networks of African trade.[7]

The ineffable and contradictory qualities of the stone—its status as always two things at once—are a key aspect of the medieval value of rock crystal. It is bright and present but also transparent and ready to disappear. It is considered both water and stone, both of earth and of heaven, and, as we will see, it is both the means and the end of vision. Finally, and most important, it is both material and spiritual, even proximate to the divine.

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Given such high status, it is striking that a fourteenth-century poem from Ireland satirizes lazy and gluttonous monks and takes crystal somewhat for granted:

> When the monks go in to Mass,
> All the windows made of glass
> Are turned into a crystal bright
> To give the monks some extra light.[8]

Nonetheless, despite the monks' inattention, in this bit of singsong rhyme, crystal's efficacious qualities come into play: its transmission of light allows texts to be read, and the sacrament and prayer to be performed with divine grace. Throughout the Middle Ages the light, the beauty, and even the timelessness of crystal linked it to an aesthetics of a natural revelation of the divine.

Although today replaced with clear glass, manufactured in quantity after the fifteenth century and dubbed *cristallo*, the use of rock crystal persisted for centuries. One might, in a practical sense, ask why. The reasons for the stone's continuing popularity are complex.

Rock crystal can occur naturally in prism-like formations; however, in the Middle Ages stones were typically tumbled and polished, then sliced in half, producing a domed cabochon shape. The faceting of diamonds and other gems was not common until after the fourteenth century, but some imperfect crystals have natural facets and interior planar imperfections (see fig. 29). In one thirteenth-century reliquary now in Copenhagen, an image of Christ in Majesty painted on parchment is embedded into a rock crystal (plate 65). The gem is not perfect and occludes rather than permits perfect vision. Although some of them may be the result of later damage, the imperfections catch and amplify light, creating a "heavenly" atmosphere.

In a dark environment the irregularities of crystal catch, reflect, and even seem to amplify light, making the gem a popular material for lamps, especially in the Islamic and Byzantine worlds.[9] Crystal was often confused with the carbuncle, the legendary gem said to glow in the dark.[10] Some vessels, especially from the Islamicate world, were cut to amplify this effect, with many added facets (plate 70).

Although the cabochon shape is less reflective than a faceted shape, it had its virtues. As early as the eleventh century, artisans found a way to shape domed crystals into surprisingly effective lenses. Examples discovered in Viking graves on Gotland, an island off the coast of Sweden, and now in museums in Visby (on Gotland) and Stockholm, have confounded modern researchers. Despite being made before the development of advanced optical theory, these function as lenses with minimal distortion.[11] Although the lenses were once thought to be Byzantine in origin, a site discovered at Fröjel on Gotland in 1999 indicates local manufacture of rock crystal objects and suggests that the making of such lenses was local, too.

Centuries before the "invention" of lenses and spectacles (possibly by an Italian artisan in the late thirteenth century), there is textual evidence in Islamic circles that rock crystal was used for "reading stones."[12] In his book on minerals the Central Asian polymath al-Biruni (973–1048) describes a unique gem that requires explanation through the "discipline of optics." As a "hemisphere" with a flat side, it could be placed on a book so that "small writings can be read . . . because the writing becomes larger for the sight."[13] Another source, a poem by the Arabic poet Ibn Hamdis (1055–1133), presents a riddle describing a powerful but mysterious object:

> 1 This is a frozen brook held with the hand
> In which the glance dives in search of the pearls of the mind
> 2 It drapes the lines in lights when they are in their obscurity
> As if a fountain of light would be gushing from it
> 3 It reveals to the eye the writing of the book
> As clearly as the air, but its body is of stone[14]

The riddle's subject is, of course, again a rock crystal lens, but Ibn Hamdis also references many other powers associated with the stone: that it is frozen water, that it can help one read even obscure lines of writing, that it emits a "fountain of light," and that "the glance" can enter the stone "in search of pearls of the mind." Once again rock crystal is granted a mystical ability to reveal knowledge to the questing intellect via sight. A twelfth-century Islamic gemologist even suggests that "gazing at a piece of rock crystal . . . brings comfort to the soul, joy to the heart, and relieves toothache," a diverse set of powers indeed, all contingent on sight.[15]

Also found among the Visby crystals were spherical pendants. Similar objects survive from Merovingian

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cemeteries, preserved as elite grave goods (5th–7th centuries), and the crystal orb was already an important form in antiquity—Pliny recommends doctors close a wound through burning "by means of a crystal ball so placed as to intercept the sun's rays."[16] But the spherical form seems to have bequeathed power as well; a shape that could sustain and reward the gaze, it served as the terminus on a scepter and became the far-seeing crystal ball of fortune-tellers. The crystal sphere even came to be the preferred representation of the earth in the Salvator Mundi image type, giving Christ an all-powerful overview of the world he saves (plate 72). In sum, the most valued qualities of rock crystal are persistently centered on its effect on vision. The crystal enhances sight, brings light to dark environments, and supplies the ability to see all—to examine both the whole and the tiniest detail.

Christian religious sources consistently associate crystal with light, as well as marking it as native both to the surfaces and waters of the earth and to the skies. The material is ubiquitous in the Old Testament and its qualities are even lent to other things: it is strongly associated with gold and appears on the bejeweled breastplate of the high priest.[17] The gates of heaven are made of crystal (or carbuncle), among other precious stones, and the heavens are called crystalline.[18] In the New Testament crystal serves as a portal or aperture and as a glorification of the Heavenly Jerusalem. While recalling the beasts in the vision of Ezekiel, the book of Revelation describes a "sea of glass like unto crystal" (Rev. 4:6) and calls jasper "clear as crystal" (Rev. 21:11). Three materials are elided in a description of the Heavenly Jerusalem—"the wall of it was of jasper: and the city was pure gold, like unto clear glass"—and once again the surface of the earth is likened to crystal: "the street of the city was pure gold, as it were transparent glass" (Rev. 21:18–21). The river of life is described as "bright as crystal" (Rev. 22:1).[19] Most important, the book of Revelation references the *crystalli horribilis* (terrible crystal) that appears above the heads of the beasts in the vision of Ezekiel. Medieval interpreters drew the conclusion that the heavens were crystalline in nature (which was certainly in consonance with the ancient astronomical description by Ptolemy of the "crystalline spheres" of the heavens).

In an extended passage in one of his homilies on the book of Ezekiel, Pope Gregory the Great (r. 590–604) gives two important, variant interpretations. He refers to crystal as a figure of Christ—that is, the gem's nature, as water that has frozen, parallels the incorruptible glory of Christ's resurrection. But Gregory also focuses on the enduring hardness of crystal and compares this quality of crystal to the "angelic power" that allows the residents of heaven to remain with their gazes fixed upon God, despite his fearful and terrible aspect.[20] As privileged viewers, angels are granted a specifically *crystalline vision* that allows them to see the divine. The Frankish archbishop Hrabanus Maurus (ca. 780–856) goes one step further and designates the angels themselves as crystalline.[21]

It is this heavenly nature that allows crystal to be understood as the material that allows not only angelic but also human perception of the divine. One sees crystal and it is heavenly, one tastes the divine and it is associated with the angelic feeding of the faithful with the "crystalline beauty" of the celestial bread, according to the theologican Richard of Saint-Victor (d. 1173).[22] On a late medieval pax, an object meant to be presented to the devotee for a reverential kiss, the technique of reverse glass painting is used with rock crystal to depict a heavenly apparition (fig. 30). The angels, seen through the crystal, are depicted as one with the heavens, and the minute image allows the individual devotee a privileged celestial view of Mary and Christ. As used here, rock crystal facilitates sight—sharpening it, amplifying it, perhaps lighting and focusing it—but also ultimately *effectively conveys* visions of the divine.

Such associations with light and purity are reason enough for rock crystal's continued use, as well as preferential use to ornament reliquaries, containers of the most precious of earthly materials, the remains of saints (plate 69). It is often claimed, however, that reliquaries use rock crystals primarily to allow clear sight of relics (in contrast to early reliquary forms that hid relics securely inside). When Eastern reliquaries flooded into the West after the sack of Constantinople in 1204, devotees perhaps became accustomed to a more open display of relics—there may have been an increased *desire to see* on the part of the Western faithful.[23] Additionally, lens-shaped, even imperfect cabochons magnify small things, and the resulting image seems to hover behind the stone in what could be understood as a mystical space (fig. 31).[24] A Carolingian crystal depicting the Crucifixion demonstrates how an image floats in an indeterminate

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FIGURE 30. *Madonna and Child*, Netherlandish, early 16th century. Gilded brass and reverse-painted rock crystal, with gems. Staatliche Museen zu Berlin—Preussischer Kulturbesitz, Kunstgewerbemuseum, K 4123

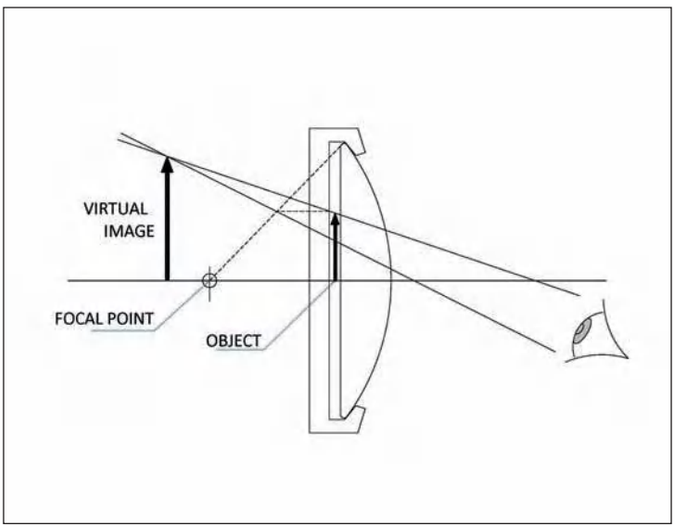


FIGURE 31. Diagram of perceived image through a plano-convex lens. When the object is located between the eye and the focal point, the image will always be located on the same side of the lens as the object and at some distance from the lens.

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space behind the surface (plate 64). On the cross from Hildesheim, five very fine rock crystals amplify the vision of the relics, including those of the True Cross at the center (plate 66).

Nonetheless, in many reliquaries there is a decided lack of transparency. The visibility of relics is frustrated because many crystals on reliquaries and other sacred objects are not lens quality. Some, such as those creating a radiating star of reflection on the Hildesheim liturgical fan (plate 121), have a "hogback" central ridge, or they have other imperfections.[25]

Some crystals, as is the case with the Copenhagen reliquary described above and with the Hildesheim reliquary cross, even obscure vision (plates 65, 66). The crystal in a reliquary monstrance is *spolia*, that is, a reused perfume bottle with the Islamicate carving that amplifies light reflections (see plate 69). In its present state, rather than allow unimpeded vision, it aggressively captures light and creates a radiance of dispersed light. The devotee may wish to see, but vision is not enabled. Instead, perhaps the eyes are best described as "dazzled."

Additionally, rock crystals often neither display a relic nor create a focus but are scattered over the surface of the reliquaries. On a thirteenth-century altar frontal, a series of crystals once outlined the *Majestas Domini*, signifying the "rays" of light of Christ's majesty as well as marking out the structure; the whole altar is presented as a kind of divine vision (plate 119). Most of the crystals are currently missing, but the settings survive. Relics may have been visible sequestered inside a tube-shaped reliquary elevated on lion's feet, but only if they were not wrapped in cloth (plate 65). Nevertheless, the extra rock crystal elements along the top edge serve to catch light and, with their beauty, honor the relics contained within.

Ultimately, rock crystal can never be said to serve the role of a passive and transparent "window." Vision might be equally dependent on the capabilities of the viewer. Gregory of Tours (538–594) wrote of a jewel on a cross, "Whenever the gem is adored, it appears clear if the man is free from sin; but if as usually happens, a man has brought some guilt . . . to him the gem appears as totally opaque."[26] One might even argue that clear vision was not desirable or possible in dark and crowded sacred spaces filled with moving people and objects.

If devotees did have the opportunity to meditate at length upon a relic, crystals proved ideal for such contemplation—but not for the reasons usually given. Cabochons were often backed with gold or silver foil or even red pigment or textile (fig. 32). Gold and silver could produce a brilliant and mirror-like effect, and red colors might simulate a carbuncle, the mythical red gem that emitted light. Texts throughout the Middle Ages implied that gems and especially crystals themselves glowed, or interacted with light in very special ways that implicated the divine. A crystal's rounded shape is the equivalent of an oculus of sorts, or of an actual eye, opening up celestial vision and amplifying and fortifying the viewer's gaze.

Furthermore, although, as noted above, angels had perfect and "crystalline vision," at times they modeled less perfect (i.e., human) sight by using mechanical technology such as mirrors or darkened glass to contemplate God (plate 55).[27] According to the Islamic scholar of optics Ibn al-Haytham (965–ca. 1040), known in Europe as Alhacen or Alhazen, the mirror produces a virtual image, an *ymago*, a construct allied to the faculty of *imagi-nation*.[28] Mirrors were often made from cabochon crystals backed with silver, and Alhazen notes that, as the convex shape of the mirror enlarges and distorts the virtual image, it produces a very distinctive vision in which the large and far away is captured on the tiny surface. This is sight very like a spiritual vision (or like the lover's vision with which we began). In his *Anti-Claudianus* (ca. 1182) the Christian theologian and poet Alan of Lille writes, "The Mirror of Faith allows us to see . . . God indirectly and *live*," that is, "through a glass, darkly" (1 Cor. 13:12).

Finally, when we think of how such understandings of vision intersect with the use of crystals on sacred objects and in vision "technologies," we must remember that, rather than serving as transparent windows, crystals allow access to a particular mode of sight. They allow entry into a celestial environment. They re-create an aesthetic of divinely created beauty while serving as precious ornament.[29] Crystals, in their beauty and through their powers, invite the eye to see with a "crystalline vision." Nevertheless, at the same time they remind viewers that theirs is an imperfect and mundane vision, not the heavenly vision they so ardently desire (plate 50). In the end, despite the promise and expectation of vision, few of the divine rays of light actually descend to our world. Perhaps we can only hope that by gazing into a crystal we can find the solace we seek.

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FIGURE 32. Phylactery, Limoges(?), France, 13th century. Gilded copper, rock crystal, 19 × 19 × 4.1 cm (7½ × 7½ × 1⅝ in.). Baltimore, Walters Art Museum, Museum purchase, 1949, 53.139

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Notes

1 The epigraph is taken from Guillaume de Lorris and Jean de Meun, *The Romance of the Rose*, trans. Frances Horgan (Oxford: Oxford University Press, 1994), 24–25.

2 Marisa Galvez, "Dark Transparencies: Crystal Poetics in Medieval Texts and Beyond," *Philological Quarterly* 93, no. 1 (2014): 25. See also Marisa Galvez, "Shards in Hand: Crystal Dwelling as Ecology," *Postmedieval* 13, no. 1 (2022): 179–95, especially for connections between medieval and modern.

3 Pliny, *Natural History,* trans. D. E. Eicholz (Cambridge, MA: Harvard University Press, 1962), 10: 37.77. All quotations in this essay are from Eicholz's translation.

4 Marisa Galvez, "Crystal Desire in Medieval Texts and Beyond," in *Seeking Transparency: Rock Crystals across the Medieval Mediterranean*, ed. Cynthia Hahn and Avinoam Shalem (Berlin: Gebr. Mann, 2020), 84–85 passim.

5 Dante, *Paradiso*, canto XXIX: 22–36, discussed in Richard Kay, "Dante's Empyrean and the Eye of God," *Speculum* 78 (2003): 45.

6 *Dialogues* 4.7, in *Saint Gregory the Great: Dialogues*, trans. Odo John Zimmerman (New York: Fathers of the Church, 1959), 201.

7 Stéphane Pradines, "Madagascar, the Source of the Abbasid and Fatimid Rock Crystals: New Evidence from Archaeological Investigations in East Africa," in Hahn and Shalem, *Seeking Transparency*, 35ff.

8 "The Land of Cockaygne," lines 113–20, in *The Kildare Lyrics*, London, British Library, MS Harley 913, fols. 3–6v, translated in Galvez, "Crystal Desire," 79.

9 Avinoam Shalem, "Fountains of Light: The Meaning of Medieval Islamic Rock Crystal Lamps," *Muqarnas* 11 (1994): 1–11.

10 On the confusion, see Pliny, *Natural History* 37.25.11. For glowing carbuncles, see Paul Frankl, *The Gothic: Literary Sources and Interpretations through Eight Centuries* (Princeton, NJ: Princeton University Press, 1960), 168–69, 181.

11 However, some, set in and backed with silver, may function as mirrors or amulets, and others as firestarters. See Bernd Lingelbach and Olaf Schmidt, "Der Zeit voraus: Asphärische Linsen aus dem 11. Jahrhundert," 6, https://web.archive.org/web/20120205212621/http://www.leinroden.de/22visby.pdf; and Olaf Schmidt, Karl-Heinz Wilms, and Bernd Lingelbach, "The Visby Lenses," *Optometry & Vision Science* 76, no. 9 (September 1999): 624–30.

12 Farid Benfeghoul, "Through the Lens of Islam: A Note on Arabic Sources on the Use of Rock Crystals and Other Gems as Vision Aids," in Hahn and Shalem, *Seeking Transparency*, 13.

13 *Kitab al-Jamahir fi Maʿrifat al-Jawahir*, translated in Benfeghoul, "Through the Lens of Islam," 245–46.

14 *Kitab al-Jamahir fi Maʿrifat al-Jawahir*, 245.

15 Benfeghoul, "Through the Lens of Islam," 243n53.

16 Pliny, *Natural History* 37.10.

17 Job 28:17. The breastplate has a clear, hard stone called *adamas*, which could be crystal, but it also has a carbuncle, which, as noted above, was confused with crystal.

18 In Isaiah 54:12 and in Ezekiel 1:2.

19 In this essay I quote from the King James version of the Bible.

20 Gregory the Great, *Homiliarum in Ezechielem prophetam libri duo*, Patrologia Latina 76, cols. 849–50, discussed in Genevra Kornbluth, *Engraved Gems of the Carolingian Empire* (University Park: Pennsylvania State University Press, 1995), 18; and Herbert L. Kessler, "Speculum," *Speculum* 86 (2011): 11.

21 Carlo Berardi, "Flawless Transparency: On Rock Crystal and Its Fortune in the Middle Ages," in *The Nature of Art: Pliny the Elder on Materials*, ed. Anna Anguissola and Andreas Grüner (Turnhout: Brepols, 2020), 319–29.

22 Richardus S. Victoris, *Mysticae adnotationes in Psalmos*, Patrologia Latina 196, col. 328C. He was commenting on Psalm 81:10.

23 Gia Toussaint, "The Sacred Made Visible: The Use of Rock Crystals in Medieval Church Treasuries," in Hahn and Shalem, *Seeking Transparency*, 225–36.

24 Kornbluth, *Engraved Gems*, 20; and Genevra Kornbluth, "Active Optics: Carolingian Rock Crystal on Medieval Reliquaries," *Different Visions* 4 (2013), https://differentvisions.org/issue-four/2019/07/active-optics-carolingian-rock-crystal-on-medieval-reliquaries/.

25 Pliny (*Natural History* 37.10) already notes that crystal "is subject to defects" and "clouded by spots."

26 Gregory of Tours, *De gloria martyrum*, 12, quoted from *Glory of the Martyrs*, trans. Raymond Van Dam (Liverpool: Liverpool University Press, 1988), 34. On crystal, clear and without the stain of sin, see Christel Meier, *Gemma Spiritalis: Methode und Gebrauch der Edelsteinallegorese vom frühen Christentum bis ins 18. Jahrhundert* (Munich: Fink, 1977), 237.

27 Kessler, "Speculum," 21–26.

28 A. Mark Smith, "What Is the History of Medieval Optics Really About?," *Proceedings of the American Philosophical Society* 148 (2004): 191. For Ibn al-Haytham, see the essays by Gaida and Stockstill, this volume.

29 Cynthia Hahn, "Reliquaries and the Boundaries of Vision: Relics, Crystals, Mirrors, and the 'Vision Effect,'" in *Medieval Art at the Intersection of Visuality and Material Culture*, ed. Raphaèle Preisinger (Turnhout: Brepols, 2021), 181–210. See also Stefania Gerevini, "Rock Crystal in the Medieval West: An Essay on Techniques and Workshops," in Hahn and Shalem, *Seeking Transparency*, 89–100; and Bissera V. Pentcheva, "The 'Crystalline Effect': Optical and Sonic Aura and the Poetics of the Resurrected Body," in Hahn and Shalem, *Seeking Transparency*, 211–24.

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Optics, Light, and Color in Byzantine Art

LIZ JAMES

As inheritors of the ancient Greek scientific tradition, medieval Byzantine scholars and theologians actively refined, debated, and expanded Classical theories of vision and ideas about the ways in which sight worked. One set of opinions was derived from Plato. This, sometimes known as extramission, suggested that optical rays emerged from the eye to touch the object of vision and then returned to the eye bearing the essence of the thing seen, which was passed on to the mind and memory.[1] Another theory followed Aristotle and his views. Aristotle had suggested that between sight and the thing seen lay a medium, which he labeled "the transparent." This was moved and arranged and rearranged by the things seen; the transparent transmitted the form of these things to the pupil of the eye (which was also believed to be transparent). In this model, sight was not the result of the eye sending out emissions. Rather, sight was caused by the transparent medium between that which sees and that which is seen being moved by the things seen. Significantly, it was color that caused the transparent to ripple and pass on sensations of sight to the eye. The nature of vision was an ongoing debate among Byzantine intellectuals. The eleventh-century polymath Michael Psellos discussed both Plato and Aristotle on vision, coming down on the side of Aristotle. In the twelfth century the writer Nikolaos Mesarites described how students at the school of higher learning associated with the church of the Holy Apostles in Constantinople constructed arguments for and against "whether our power of sight directs itself outward or whether images are received by us."[2]

Whatever their understanding of how sight functioned, the Byzantines placed great significance on this sense and on the role that color and colors played within vision. Vision in Byzantium was active, even forceful; optics, light, and color were all entwined. Light was needed for vision; colors gave what was perceived form and meaning; light and color united to picture the divine. Theologians from the fourth century onward consistently emphasized that sight was the first sense, the most necessary of the senses. John of Damascus in the eighth century added that "sight is primarily the perception of color; with color it discriminates the body that has color."[3] Byzantine art is an art in full color: there are almost no monochromatic images, and Byzantine theology argued strongly for the need for color. The church father John Chrysostom, writing in the fourth century, had asserted in his *Homily on Paul's Letter to the Hebrews*, "As long as someone traces the outline as in a drawing, there remains a sort of shadow; but when they paint over it brilliant tints and lay on colors, then an image appears."[4] Through sight and color truth could be apprehended. In contrast, an uncolored image was incomplete. During and after the period of Iconoclasm in eighth- and ninth-century Byzantium, when the place of religious images in belief was hotly contested, those who supported religious images accused their opponents of whitewashing pictures, of literally decoloring them and so making them invisible.[5] Unsurprisingly, therefore, light and color were intrinsic to Byzantine art, an art designed to be brought to life by light.

"Color," however, is not a straightforward term. Studies of color perception characterize color as having three key components: hue, saturation, and brightness. When we are asked "What color is it?," our reaction is to refer to the hue, with words like "green" or "red" or "blue." The Byzantines thought about color differently than we do. They were more interested in the two other qualities of a color: its brightness, or relative lightness and darkness, and its saturation, or how deep or pastel the shade. They also understood colors as positioned on a scale that went from light to dark. This scale contained perhaps ten separate colors: white, yellow, gray, pale, red, blue, purple, bright, dark, and black.[6] These words cover both the qualities of hue ("white" and "red") and those of brightness ("pale" and "bright"). When the Byzantines described colors, they often spoke—where we would use a hue word—of the brilliant, glittering effect of colors and of the dynamism of colors, colors that flowed and changed. We read in many Byzantine texts of "bright marble," of churches "spangled" with mosaic "like stars," or "glittering," and of the wonders of varied colors; only occasionally are specific colors (in our sense) mentioned. Polychromacity was a virtue.[7] The words used for various colors in medieval Greek convey this difference. The Greek word *leukos* is often translated as "white," but is perhaps better rendered as "bright" or "radiant." When the authors of the Gospels wrote of Christ's white robes at the Transfiguration, the Greek word they used was *leukos*, and it was coupled with "dazzling" and "glistening" and compared to light ("white as light").[8] In images of the Transfiguration, Christ is clad in white robes, but, for his

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FIGURE 33. *The Transfiguration*, 6th century. Mosaic. Sinai, Egypt, Holy Monastery of Saint Catherine

Byzantine audience, these would also have been bright robes, robes woven from light, just as the Evangelists described them (fig. 33).

Rainbows offer an intriguing angle on the ways in which the medieval world saw and described colors. "Everyone knows" what a rainbow looks like; today we understand how white light breaks down into seven colors of the rainbow: red, orange, yellow, green, blue, indigo, and violet. (This is because Sir Isaac Newton had a weakness for indigo and wanted the color scale to match the seven harmonies of the musical scale.) Medieval images of rainbows, however, tend to picture only three or four colors, because medieval perceptions were derived from Aristotle. He had observed how the rainbow was formed through reflection of the sun's rays and identified that reflection as having three colors: red, green, and purple, or, put another way, bright, less bright, and dark.[9] Later writers added in yellow, which Aristotle had seen as a color secondary to his three primaries. Rainbows were frequently used in Christian art in images of Christ in Majesty, perhaps at the Second Coming, the Day of Judgment (plate 73). As evocations of light and glory, the light-bearing aspects of the colors underline the blinding splendor of divinity.

Interactions between light and colors are central to how Byzantine art was created. Artists seem to have been alert to the ways in which light changes the appearance and feel of an image—not just the lines in a picture but also the relative tonal values. They knew that blues lighten in dim light and that in bright light reds come forward while darker colors retreat. The balance of reds and blues across an image often speaks to this. In the

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image of the Transfiguration in a thirteenth-century Gospel book, blues and reds are balanced (plate 115). Christ wears a red undertunic and a blue (bright) overtunic; next to him the colors of Moses's garments are reversed. In the lower register Saint John, below Christ, wears blue and red, and Saint James, at the right, red and blue, balancing and creating color diagonals with Christ and Moses. On the left of the image, Elijah's brownish hues above are picked up in Saint Peter's below, again balancing the two registers of the image. But there is another basic optical phenomenon at play in images of the Transfiguration. Many of the depictions of the glory (also called a mandorla) surrounding Christ have a dark blue center. That dark center had a symbolic significance: it was a visualization of what medieval theologians called the "divine darkness" of God.[10] But it also had a practical function: light colors work well on a dark background, and Christ appears even more luminous, even more clothed in brightness, because he is placed on a dark background. This is one of the ways in which the mosaic of the Transfigured Christ at Saint Catherine's Monastery on Mount Sinai gains its effect (see fig. 33). It is a significant aspect of color for icons since most icons would have been seen in low lighting, illuminated by glimmering candles, making the placing of light and dark colors even more important.

As the dark center of *The Transfiguration* suggests, in Byzantine art the use of color was both practical and symbolic, making an image visible and adding to its potential meanings. In this context perhaps the most important color of all was gold. It was regarded with some ambivalence: too much gold was a bad thing, for the rich would not enter the kingdom of heaven, but gold was also the purest and highest of all metals and, as a color, brings brightness and luster to a work of art. Gold always glitters, if it is lit properly, and the use of gold was another way to bring images to life through the interplay with flickering, unsteady lights. We are used to seeing works of art lit steadily (sometimes with a reduced light, but still steadily). But in the medieval world lighting came from fires, candles, and oil lamps. It was always unstable and quite often low. The image of Saint John in a fourteenth-century Greek Gospel book (plate 80) and the Christ in Glory and the gold words on a purple background in a tenth-century Gospels (plate 79) would be brought to life in different ways by candlelight, whereas on the flat page, lit by electricity, the gold waits to be awakened. The image of the Transfiguration in the thirteenth-century Byzantine Gospel book discussed above also has a gold background, but here the gold halos of the apostles at the bottom of the scene will also come to life in low lighting (plate 115). The metallic threads of a fourteenth-century *sakkos* (plate 116) will, in the right light, create gleam, luster, shine, movement—all those qualities of color valued above and beyond hue. Gold in a mosaic, an enamel, a manuscript is meant to interact with light and is meant to move and be reflective.

Byzantine glass mosaics in architectural, specifically church, spaces are one of the best materials for playing with light. Each glass piece (called a tessera), each cube of glass, is a little mirror, set to reflect light.[11] Each tessera is set by hand, and the more uneven the surface of a mosaic, the better the play of light. Lit in such a way as to allow the gold to be reflective, the mosaic changes in appearance and becomes more vibrant, as different aspects are thrown into view. The mosaic of the Mother of God and her child in the apse of Hagia Sophia in Constantinople (modern Istanbul) can change in appearance as the light, both natural and artificial, illuminating it alters. Sometimes the figures loom, the faces bright against the background, the cross in Christ's halo and the cloth in Mary's hand the most visible details, the gold muted and almost invisible.[12] In other lights, the Child's gold and silver robes throw him into prominence, his mother a dark foil between him and the gold background (fig. 34). The gold background has become a glowing field, a shimmer that can dazzle and change the perception of an image, a world in which certain details emerge from the gloom in a way that they do not when the lights are fully turned on. Often, when reproduced in a book, the gold background of a mosaic or an icon can look yellow and a bit brassy and even static. This is because gold, as a metal, has a much higher degree of reflectivity than paint, so it reflects much more light back than paint does.[13]

Different devices can be used to reflect light in different ways. With an icon the curvature of the panel makes a difference in how light plays across its surface. With a mosaic the surface is broken up by the different ways in which the tesserae are set. With the apse mosaic in Hagia Sophia the gold glass tesserae of the background are set in (more or less) horizontal lines across the apse.

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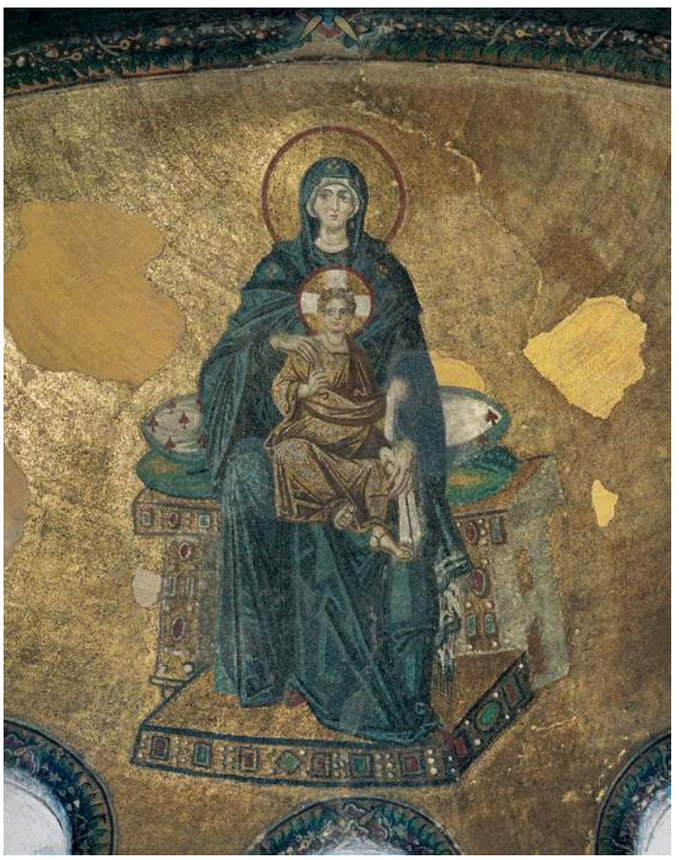


FIGURE 34. *The Mother of God and Child*, 9th century. Mosaic. Istanbul, Hagia Sophia



Detail, fig. 34

Around Mary's body there are two lines of gold tesserae that follow the shape of her body, outlining it. But around and inside her halo the internal gold tesserae and the dark boundary lines and the first few rows of the background gold tesserae are laid running as incomplete circles around her head. This makes the halo stand out from the gold background. Something similar is done with the Christ child's halo, where the gold is also set in a circular pattern, with the cross inside having its arms set in straight lines. The tesserae of the cross arms are also a matte white marble in contrast to the glass of the gold and this, too, helps make the cross stand out.[14] Silver tesserae are used almost as flashings in his tunic and in his hair, making both glimmer and glint against the dark contrast of Mary's blue robe (see fig. 34, detail).

Byzantine glass enamels operate similarly in varying lighting conditions. This is apparent in the rare and beautifully preserved book covers—of gold, enamel, pearls, and precious stones—made for liturgical manuscripts used in San Marco in Venice (plate 81). Here the contrasting surfaces—shiny gold; more matte surfaces with the beading creating shadows; the opaque glass as blocks of solid color—all make a difference in the ways in which light might be reflected back to the viewer, the person holding the cover. Covers such as these formed part of a dazzling assemblage of objects placed on and around

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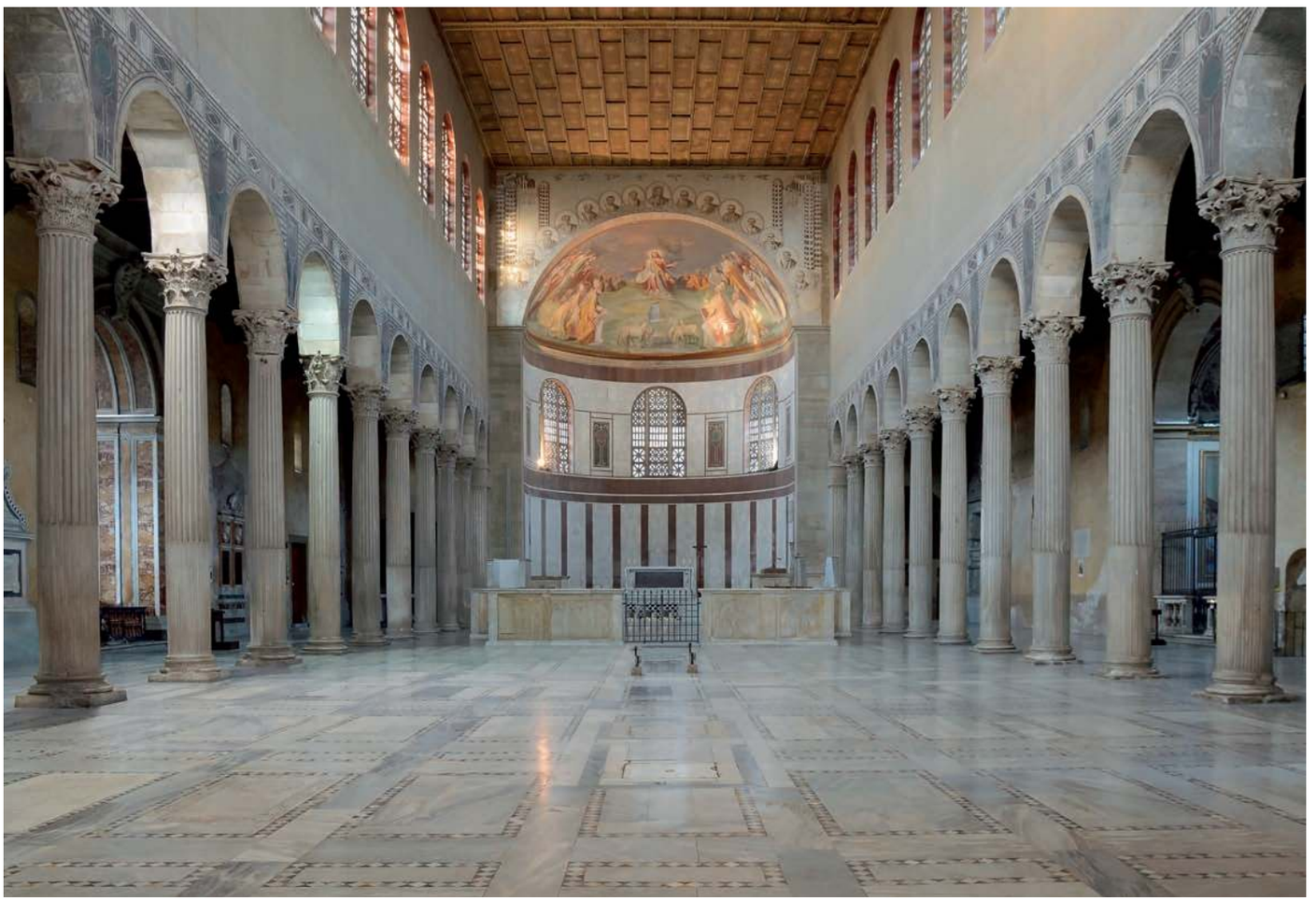


FIGURE 35. Interior view of the church of Santa Sabina, Rome, constructed in the 5th century

the altar: chalices, patens, candlesticks, even altarpieces, and the priests themselves, gorgeously vested in bright, moving embroidered garments.

Whereas Renaissance paintings, for example, need high levels of light to be fully appreciated in all their lifelike detail, fading into darkness when the lights are dimmed, images with expanses of gold as intrinsic parts come to life in low light; the power of gold as a reflectant surface animates them and changes them into paintings with light. It is a matter less of the amount of light than of the sort of light and where it is directed. The emphasis on the play of light and color is very apparent in the spaces in which Byzantine religious art operated—churches. It is clear that church spaces were designed with optical shifts of natural and artificial light in mind. Churches in the fourth and fifth centuries tended to be long, rectangular buildings, or basilicas, into which light flooded in from windows high up on the walls (fig. 35). By perhaps the ninth century, smaller, centrally planned churches with a dome were more popular, reducing light significantly and changing the experience of being in the building.[15] The central space is lit by windows in the drum of the dome and surrounded by several more separate and enclosed areas (fig. 36). In these buildings light needed more careful manipulation through windows but especially through lights and lamps. Where these were

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FIGURE 36. Interior view of the Katholikon of the monastery of Hosios Loukas, Phokis, Greece, constructed in the 11th century

positioned made a difference, and monastic foundation documents (*typika*) often make special provision for the location and tending of lamps and candles in the church. The *typikon* of the twelfth-century Byzantine monastery of the Mother of God Kosmosoteira in Bera (modern Pherrai in Thrace, northern Greece) was very clear:

> There should be four lamps lit in the very middle of the church, and two candelabra with eight candleholders should stand by the two icons set out for veneration . . . so that the images appear alive to the beholder, and as though letting out a beautiful sound from their mouths toward him.[16]

The whole experience—the feel—of worship, of participation in the liturgy, and indeed of simply being inside the church could be conditioned by the lighting. Light guided the worshipper through the church, picking out the shimmering mosaics, the colored wall paintings, the icons; it demarcated boundaries; it revealed the holy.

Color was what made the world visible, giving it form and being. But color and light formed a bridge between the material and the spiritual; through color and light, art and theology were inextricably linked. The fourth-century Byzantine theologian Gregory of Nyssa created an image of God the creator as a master painter dealing in color: "as painters transfer the human form to their pictures by means of certain colours . . . thus God also paints the image [humanity] with various colours according to his own beauty."[17] As another Byzantine author, the sixth-century historian and poet Agathias, said, "Art can convey by colors the prayers of the soul."[18] Light mattered; color was the true matter of divinity.

Notes

1 On extramission and tactility in Byzantine theories of vision, see Robert Nelson, "To Say and to See: Ekphrasis and Vision in Byzantium," in *Visuality before and beyond the Renaissance: Seeing as Others Saw*, ed. Robert Nelson (Cambridge: Cambridge University Press, 2000), 143–68.

2 "Nikolaos Mesarites: Description of the Church of the Holy Apostles in Constantinople," trans. Glanville Downey, *Transactions of the American Philosophical Society*, n.s., 47, no. 6 (1957): 895. For Aristotle, Psellos, and the transparent medium, see Roland Betancourt, *Sight, Touch, and Imagination in Byzantium* (Cambridge: Cambridge University Press, 2018).

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3 John of Damascus, *On the Orthodox Faith* 2.18, in *St. John of Damascus: Writings*, trans. Frederic H. Chase Jr. (Washington, DC: Catholic University of America Press, 1958), 242.

4 John Chrysostom, *Epistola ad Hebraeos*, homily 17.2.

5 An image in the Khludov Psalter (Constantinople, 9th century; Moscow, State Historical Museum, MS. D.129, fol. 67r) accompanying Psalm 68 shows the Iconoclast patriarch, John the Grammarian, whitewashing an image of Christ, while above him, in an image of the Crucifixion, a soldier holds a sponge to Christ's face using the same gesture. For an illustration of the image, see "Chludov Psalter," Wikipedia, https://en.wikipedia.org/wiki/Chludov_Psalter.

6 On Byzantine color words and the emphasis on light and dark, see Liz James, *Light and Colour in Byzantine Art* (Oxford: Clarendon Press, 1996).

7 "Bright marble" was used by the ninth-century patriarch Photios in homily 10.4, in *The Homilies of Photios, Patriarch of Constantinople*, trans. Cyril Mango (Cambridge, MA: Harvard University Press, 1958), 185. "Spangled like stars" is used in the inauguration anthem of Hagia Sophia in Edessa; see Andrew Palmer and Lyn Rodley, "The Inauguration Anthem of Hagia Sophia in Edessa: A New Edition and Translation with Historical and Architectural Notes and a Comparison with a Contemporary Constantinopolitan Kontakion," *Byzantine and Modern Greek Studies* 12 (1988): 131. "Glittering" is very common. See, for example, Paul the Silentiary's account of Hagia Sophia in Constantinople in which he says that the roof of the church is made from "gilded tesserae from which a glittering stream of golden rain pours abundantly"; Paul the Silentiary, *Description of Hagia Sophia*, translated in Cyril Mango, *The Art of the Byzantine Empire 312–1453: Sources and Documents* (Toronto: University of Toronto Press, 1986), 86; see *Johannes von Gaza und Paulus Silentarius*, ed. Paul Friedländer (Leipzig: Teubner, 1912), lines 668–70, for the original Greek.

8 "Dazzling" is from Luke 9:29, "glistening" from Mark 9:3, and "white as light" from Matthew 17:2. I quote the Revised Standard Version of the Bible.

9 For Aristotle these were the three colors that could not be created by mixing color. For Aristotle on the rainbow, see his *Meteorologica*, trans. H. D. P. Lee (Cambridge, MA: Harvard University Press, 2014), book 3, chap. 2, line 372ff. For more material about Byzantine rainbows, see Liz James, "Colour and the Byzantine Rainbow," *Byzantine and Modern Greek Studies* 15 (1991): 66–95.

10 For a discussion of divine darkness, see the essay by Gertsman, this volume.

11 On the reflective qualities of mosaic, see Liz James, *Mosaics in the Medieval World* (Cambridge: Cambridge University Press, 2017), 46–95.

12 Different varieties of light were offered as an explanation for a discrepancy in color perception that spread virally on the internet in 2015: the colors of a dress were perceived by some viewers as white and gold, and by others as blue and black. See Wikipedia, s.v. "The Dress," https://en.wikipedia.org/wiki/The_dress.

13 On gold in Byzantine art, see Rico Franses, "When All That Glitters Is Not Gold: On the Strange History of Viewing Byzantine Art," in *Icon and Word*, ed. Antony Eastmond and Liz James (Farnham, England: Variorum, 2003), 13–24. Photographs of images with a lot of metallic gold can have "hot spots"—places where light is concentrated—and this, it is believed, makes a bad image.

14 Cyril Mango and Ernest J. W. Hawkins, "The Apse Mosaics of St. Sophia at Istanbul: Report on the Work Carried out in 1964," *Dumbarton Oaks Papers* 19 (1965): 115–51, gives details of the mosaic; plates 4 and 8 therein show Mary's and Christ's halos, albeit in black and white.

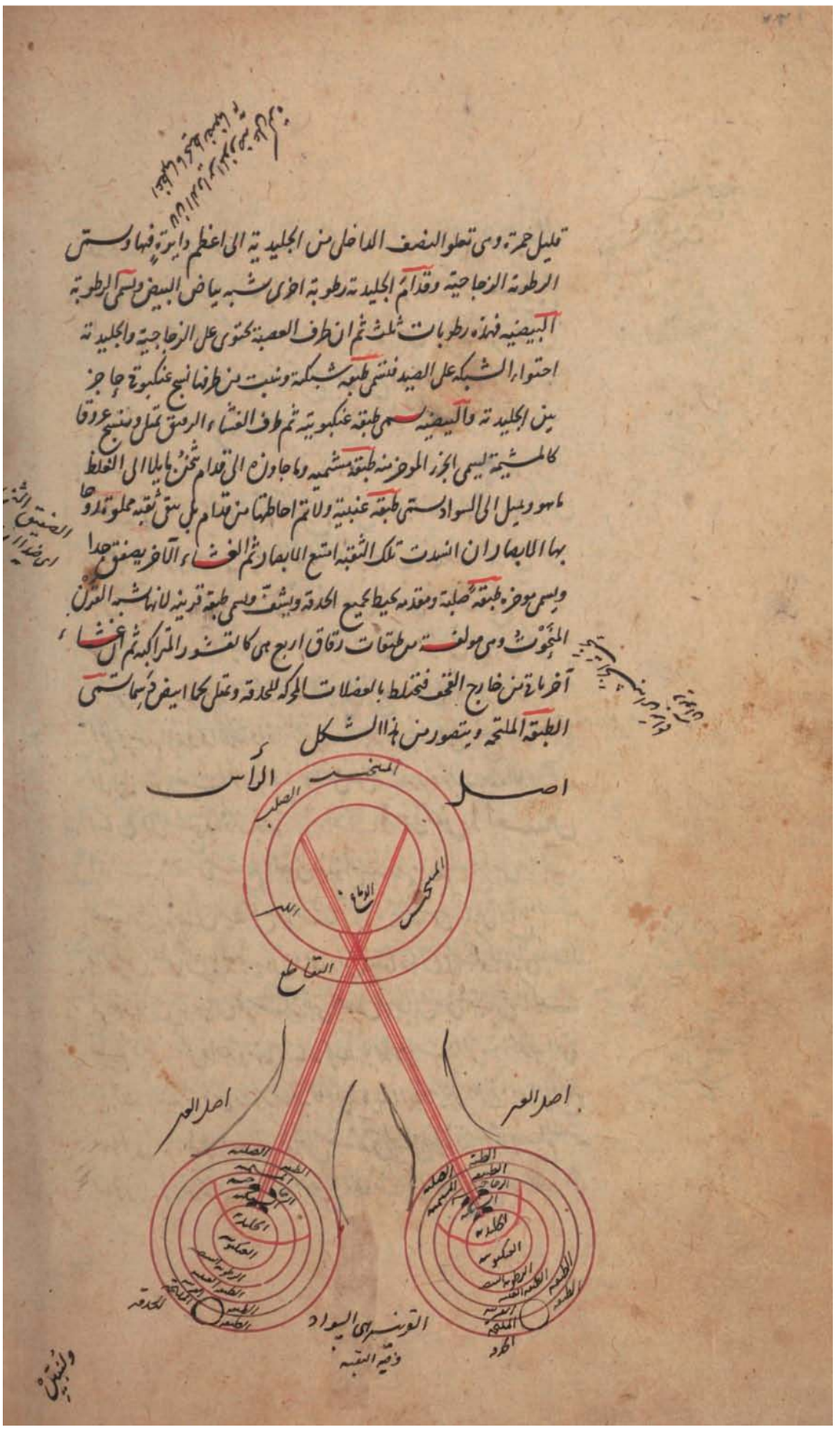
15 Claire Nesbitt, "Shaping the Sacred: Light and the Experience of Worship in Middle Byzantine Churches," *Byzantine and Modern Greek Studies* 36, no. 2 (2012): 139–60.

16 "*Kosmosoteira: Typikon* of the *Sebastokrator* Isaac Komnenos for the Monastery of the Mother of God *Kosmosoteira* near Bera," trans. Nancy Patterson Ševčenko, in *Byzantine Monastic Foundation Documents*, ed. John Thomas and Angela Constantinides Hero (Washington, DC: Dumbarton Oaks Research Library and Collection, 2000), 2: 802.

17 Gregory of Nyssa, *De hominis opificio (On the Making of Man)*, 5.1, https://www.documentacatholicaomnia.eu/03d/0330-0395,_Gregorius_Nyssenus,_De_opificio_hominis_[Schaff],_EN.pdf.

18 This comes from an epigram on an image of the archangel Michael by Agathias (*Greek Anthology* 1.34), in *The Greek Anthology: Books 1–5*, trans. W. R. Paton, rev. M. A. Tueller (Cambridge, MA: Harvard University Press, 2014), 20–23.

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39

Schematic Diagram of the Eye and Visual System in *The Key to the Mujiz (Hall al-Mujiz)* (in Arabic), place of origin unknown, 810 AH/1407

Jamal al-Din Muhammad ibn Muhammad al-Aqsara'i (author) (Persian, active in Aqsara, Turkey, d. 1379)

'Ali ibn Mu'in ibn Ahmad (copyist) (active 15th century)

Ink on paper, full folio: 21.6 × 12.5 cm (8½ × 4 15⁄16 in.)

Bethesda, Maryland, National Library of Medicine, National Institutes of Health, MS A 67, fol. 167v

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40

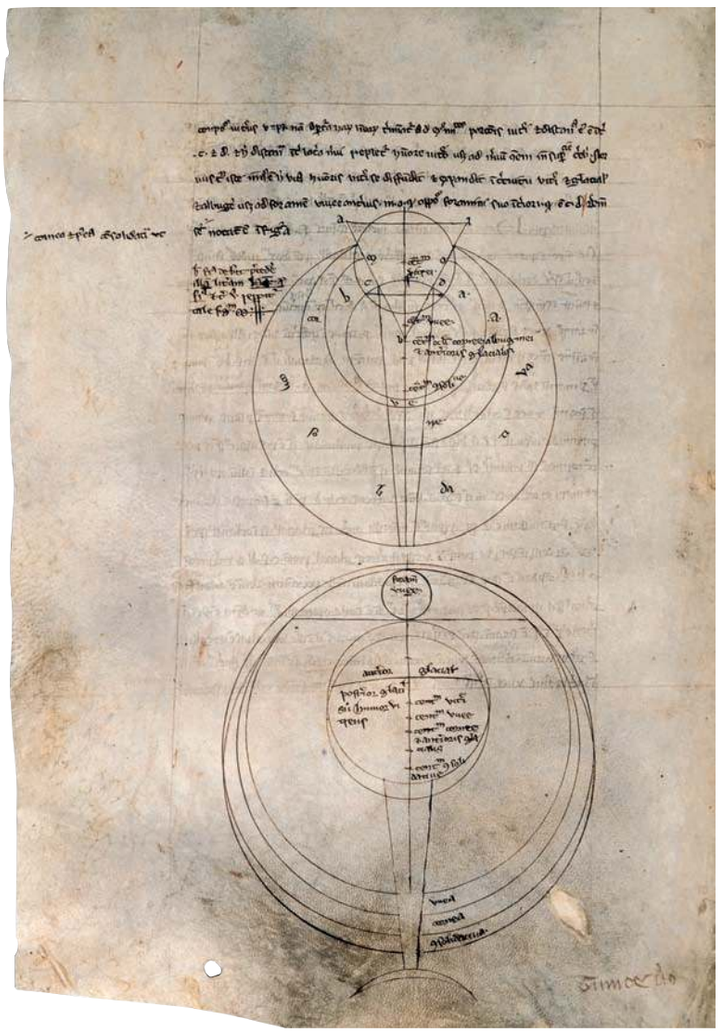
Diagram of the Eye in *Revision of "The Book of Optics for Those Possessing Sight and Insight" by Ibn al-Haytham* (in Arabic), Edirne Ili, Ottoman Turkey, 917 AH/1511
Kamal al-Din al-Farisi (author) (Persian, ca. 1267–1319)
Ibn al-Haytham (original author) (Arab, active in Cairo, 965–ca. 1040)
Ink on paper, full folio: 25.8 × 16.5 cm (10 3/16 × 6 1/2 in.)
Jerusalem, National Library of Israel, Project "Warraq," Ms. Yah. Ar. 384, fol. 37

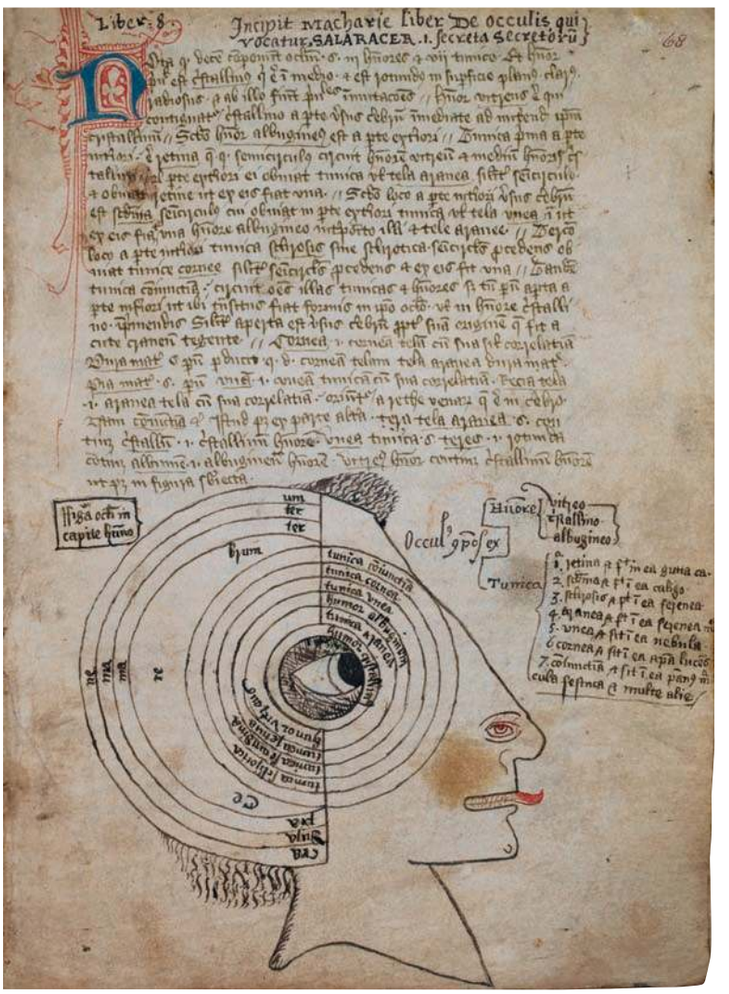


PLATES 39, 40

Written in the eleventh century, Ibn al-Haytham's seminal work on optics continued to be copied and revised throughout the medieval period, including by Kamal al-Din al-Farisi, who provided the text with illustrations of the eye. Some diagrams also described the connection between the eyes, the optic nerves, and the chambers of the brain.

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41 (ABOVE)

Geometrical Diagrams of Rays Entering the Eye and Striking the Crystalline Humor in *De multiplicatione specierum* (in Latin), probably Oxford, England, 1275–1300
Roger Bacon (English, ca. 1219/20–ca. 1292)
Ink on parchment, full folio: 34 × 27 cm (13 3⁄8 × 10 5⁄8 in.)
London, British Library, Royal Ms. 7 F VIII, fol. 54v

The Franciscan friar and English philosopher Roger Bacon's works synthesized Arabic and Western scientific treatises on optics. Demonstrating the theory of intromission, whereby light enters the eye and is refracted within the crystalline humor, where images are received, the diagram provides the earliest illustration of Ibn al-Haytham's seminal text on optics.

42 (ABOVE, RIGHT)

Diagram of the Seven Tunics and Three Humors of the Eye and the Skull in *Medical Miscellany*, including the *Book of Macharias on the Eye Called Salaracer, or the Secret of Secrets* (in Latin), England, 1375–1425
Ink on parchment, full folio: 23 × 17 cm (9 1⁄16 × 17 11⁄16 in.)
London, British Library, MS Sloane 981, fol. 68

43 (OPPOSITE)

Eye Model, France, before 1700
Silver, glass, H: 10 cm (3 15⁄16 in.); Diam: 4 cm (1 5⁄16 in.)
Jena, Stiftung Deutsches Optisches Museum (D.O.M.), inv. 873610_0002621

PLATES 42, 43

Sometimes re-created in three-dimensional models, the physiological structure of the human eye was understood in terms of "tunics" that surrounded successive layers, such as the retina, albuminoid, and crystalline lens. Such images and objects helped medical practitioners and teachers better understand the organ of sight.

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Fred Eversley

GLENN PHILLIPS



Fred Eversley in 2017 with *Untitled (Parabolic Lens)*, 1971

Since the late 1960s Fred Eversley has been creating highly polished, spin-cast polyester resin sculptures, most commonly taking the form of plano-concave parabolic lenses. These sculptures, which can range from transparent to reflective depending on the opacity of the dyed resin, act as both Minimalist sculptures and fully functional optical devices. Like his medieval predecessors whose fine work with rock crystal embodied an achievement in artistic, technical, and scientific understanding for their time, Eversley presents in his artworks a confluence of artistic and scientific ideas that were prevalent in Southern California in the 1960s and 1970s.

Eversley began his career as an aerospace engineer, settling in Venice, California, in 1963. There he met artists such as Charles Mattox, John McCracken, and Robert Irwin, whose works were exploring human perception and the potential for new materials, such as plastics, in art making. Eversley began his own experiments with polyester resin in 1967, soon developing a method to spin-cast three-color, three-layer cylinders that could be sliced into sections in various shapes and then polished. The resulting transparent paraboloid sculptures offered fascinating optical effects, condensing and elongating the reflections of their surroundings within their vaulted arching forms. By 1969 Eversley had begun experimenting with the production of parabolic lenses by spinning liquid resin around a vertical axis in a circular mold set atop a motorized turntable, letting the gravitational force create a perfect parabolic top surface. Precise adjustments in speed and timing, and alterations in the layering and density of dyes, have allowed for a startling amount of variation within this seemingly simple form.

Across his work Eversley's sculptures activate a range of sensory phenomena. As lenses, mirrors, or combinations of both, the sculptures reflect, refract, and focus not only light but also sound, motion, and other forms of energy. When looking through one of Eversley's lenses, viewers might see far more of what lies in front of them than the human field of vision allows, while also seeing themselves and the environment behind them reflected on the surface of the lens itself. These multiple layers of reflection tend to evoke an immediate spirit of investigation, setting viewers in motion: they move closer, back, and around the lens, all the while noting the constant changes in what they see. In fact, this is what the artist intended. While the works are today most commonly encountered in museums, Eversley prefers that they be used as interactive objects of discovery. He has said, "My pieces require to be lived with for a long time to realize their full potential, and hopefully played with, i.e., picked up, moved around, combined with other objects, viewed under all types of light and viewed from every perspective angle."

44

Fred Eversley (American, b. 1941)
Untitled (Parabolic Lens), 1971
Three-color, three-layer cast polyester, Diam: 92.7 cm (36½ in.), D: 25.1 cm (9⅞ in.)
New York, Museum of Modern Art, Acquired through the generosity of Michael S. Ovitz and Gary and Karen Winnick, and Committee on Painting and Sculpture Funds, 2017, 782.2017

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45

Slit Bridge Spectacles, possibly from Germany, ca. 1600
Horn and glass, H: 5.2 cm (2 1/16 in.) x D: 0.3 cm (1/8 in.) x W: 8.4 cm (3 5/16 in.)
Jena, Stiftung Deutsches Optisches Museum (D.O.M.), inv. 8736100026774

46

Carved Recess for Spectacles in Cistercian Breviary (in Latin), Hauterive, Switzerland(?), beginning of 15th century
Ink on parchment (folio); wood, leather (binding), full folio: 13 × 9.5 cm (5 1/8 × 3 3/4 in.)
Fribourg, Bibliothèque cantonale et universitaire, MS L.64



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47

Pentecost in Benedictional (in Latin), Regensburg, Ottonian Germany, ca. 1030–40
Tempera colors, gold, and ink on parchment, full folio: 23.2 × 16 cm (9⅛ × 6⅝ in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig VII 1 (83. MI.90), fol. 47v

Linear rays of light emanate from the concentric spheres of the heavens, bringing divine knowledge to the apostles below.



PLATES 45, 46

Spectacles, one of the most important inventions of the thirteenth century, became widespread and changed the course of human history, as they were indispensable as magnifiers and especially useful for reading finely written texts.

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48

The Miracle of Mount Gargano in the *Irmengard Codex*, Evangeliary (in Latin), Reichenau, Ottonian Germany, shortly after 1053
Tempera colors, gold, and ink on parchment, full folio: 22.2 × 18.7 cm (8¾ × 7⅜ in.)
Los Angeles, J. Paul Getty Museum, Ms. 125 (2023.6), fol. 210

A rare image of the Miracle of Mount Gargano might serve simultaneously as an allegory of faith and as an optical metaphor: the arrow of truth enters the eye (the window to the soul), enabling spiritual vision.

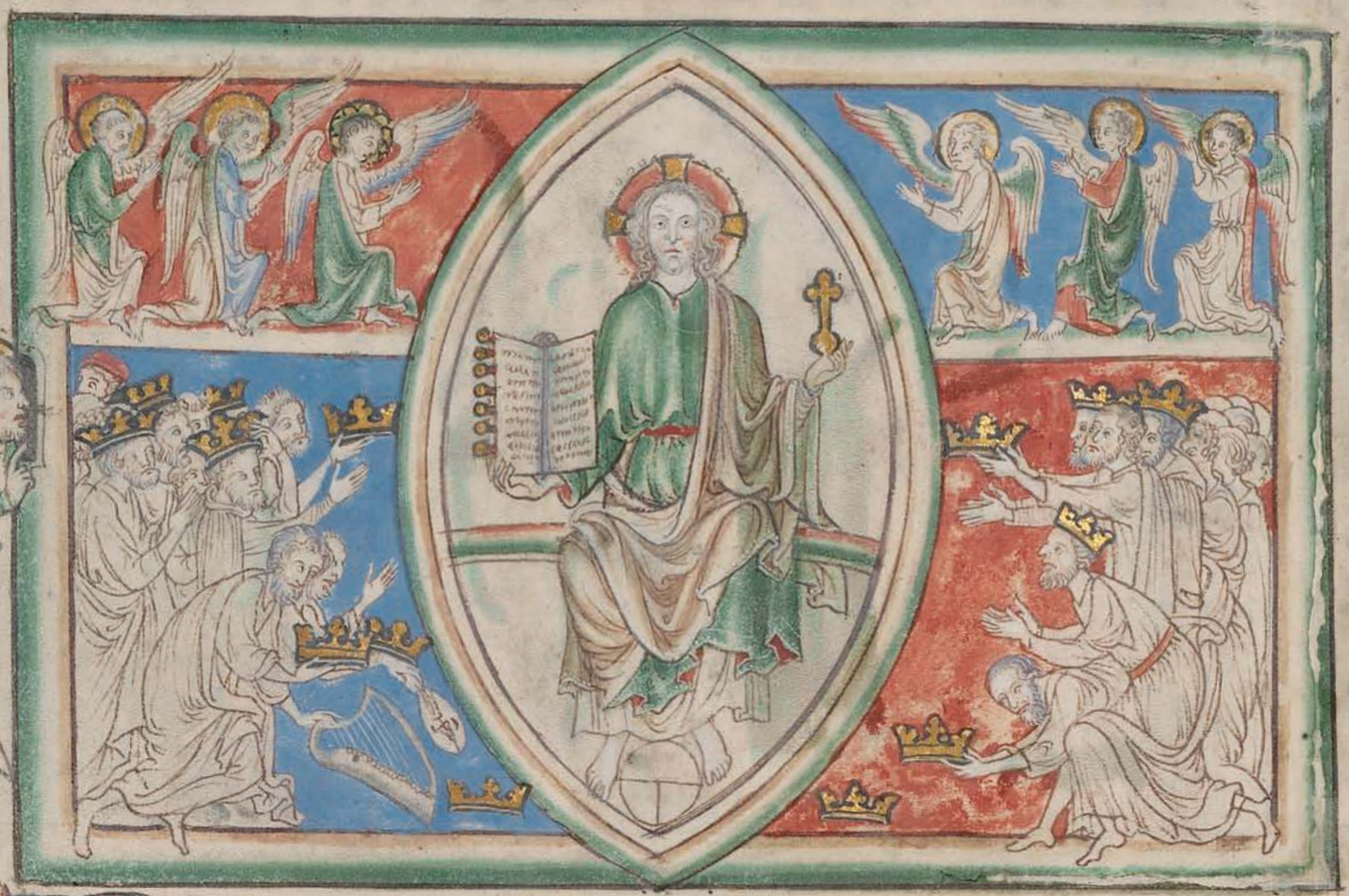
49 (OPPOSITE)

The Twenty-Four Elders Pay Homage to the Throne of God in *Getty Apocalypse* (in Latin), London(?), ca. 1255–60
Tempera colors, gold leaf, colored washes, and pen and ink on parchment, full folio: 31.9 × 22.5 cm (12⁹⁄₁₆ × 8⅞ in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig III 1 (83.MC.72), fol. 4v

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John the Evangelist peers through an opening in the image's frame to behold his apocalyptic visions. Vision was believed to intensify as it was focused through a small opening or window, called a “squint” or “hagioscope.”

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Post hec vidi viginti quatuor
seniores ante sedentē i throno.
adorantes uiuentem i secula
seculoꝝ. & mittebant coronas
suas ante thronum dicentes.
Dignus es dñe deus nr accipe glorā
& honorem & uirtutem qua tu creasti om
nia. & ꝓp uoluntatem tuam creata sunt.

Et uidi in dextera sedentis ꝑ
thronū librum scriptum intꝰ
& foris signatum septē sigillis.

coronas: opa bona diuina. ꝑ
ꝯ. coronas suas ante thronum. mittunt dñi
quicquid boni agunt deo tribuunt & sibi.

secundū apli preceptum. Qui gloriatur in
dño glorietur. Vnde & dñs dicit audiam.
Dignus es dñe & nr accipe gloriam & hono
rem & uirtutē. Scripsit enim sūe animalia
gloriam & honorē & benedictionē deo dicisse.
hec xxiiii. seniores dicunt gliam & hono
rē & uirtutem deo accepisse. uirtutem & benedic
tione omittentes. Dant tm̄ ei gloriam &
qui quid boni faciunt eo studio faciūt ut
glorificetur ds & ipsos. sic ipe dicit i evāl. Vi
deant opa ura & glorificent ptem uram qui i
celis. Dant honorē qui eccl̄ie. que agunt.
honorem dei no suum querūt. Sup̄ hec
omnia tm̄ hec ponūt hi ut uirtus. Ol. a te
omnia magna facimur & ideo tibi ab ipo alba
quenit uirtus ut benedicāmꝰ. & Quia tu
creasti omnia &c. Si creatur quicq̄ creatū fūe
hac ea fecisti intelligendū est quo? illud fecit
que fuerat ut dicit g̃ creamur creati i ꝓtesta
te & uoluntate dei ad̄ creaturam creati. Creatu
ra ē ex qua aliquo dicitur ds. sp̄s g̃ qui dicta
creatur ex nichilo i nob cor mundū crea. ol. u

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50

The Beatific Vision, Vision of Benedict and Paul, and the Vision of the Layman and Woman in *Omne bonum (Absolucio–Circumcisio)* (in Latin), London, ca. 1360–75
James le Palmer (English, ca. 1327–1375)
Tempera, gold, and ink on parchment, full folio: 45.5 × 31 cm (17 15⁄16 × 12 1⁄5 in.)
London, British Library, Royal Ms. 6 E VI/1, fol. 16

Light rays shining from the beatific vision of the Godhead reach the clergy (in the middle zone) first and then extend with less intensity to those inhabiting the earthly sphere below.

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51

The Elevation of the Host in Missal (in Latin), Bologna, between ca. 1389 and 1400
Master of the Brussels Initials (Italian, active ca. 1389–1410)
Tempera, gold, and ink on parchment, full folio: 24 × 33 cm (9 7⁄16 × 13 in.)
Los Angeles, J. Paul Getty Museum, Gift of the Emerson Family in honor of John S. Bonnell, Ms. 34 (88.MG.71), fol. 130 (detail)



52 (RIGHT)

Solar Monstrance, France, late 15th–early 16th century
Gilded copper, enamel on silver, precious stones, glass,
H: approx. 61 cm (24 in.)
Paris, Musée de Cluny, Cl.992



53 (FAR RIGHT)

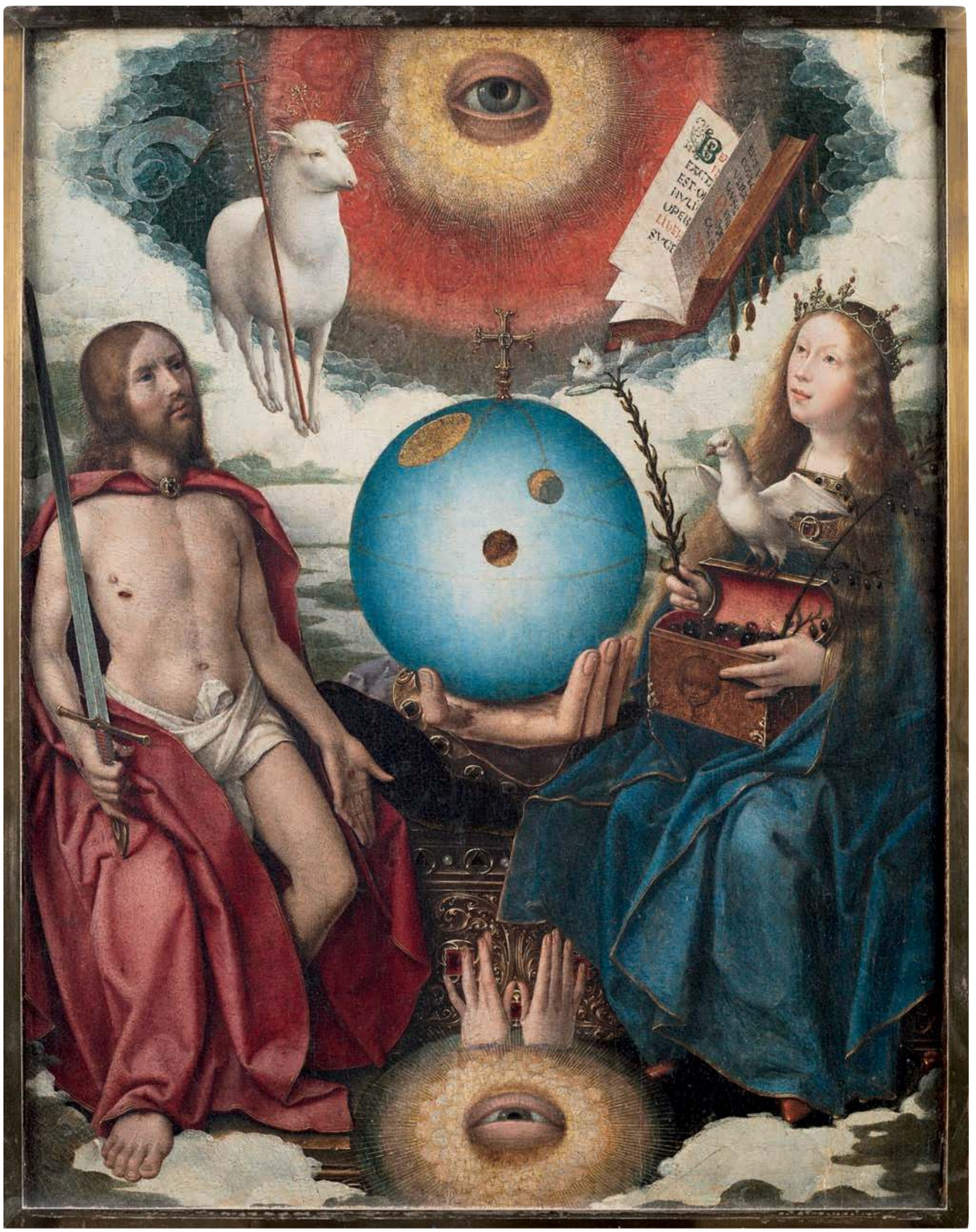
Christ in Majesty, Leaf from a Missal (in Latin), Toulouse, France, ca. 1460
Antoine de Lonhy (French, active ca. 1460–90)
Tempera colors, gold leaf, and gold paint on parchment, full folio: 34.5 × 25 cm (13 9⁄16 × 9 13⁄16 in.)
Los Angeles, J. Paul Getty Museum, Ms. 69 (2001.84), recto



PLATES 51–53

Ocular communion occurred during the moment of the elevation of the Host during the Mass. Monstrances, reliquaries, and images of the Host demonstrate the medieval emphasis on access to the Host through vision.

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54 *The Cosmos under the Eye of God, in the Presence of Christ the Judge and the Church*, Bruges or Antwerp, Flanders (Belgium), ca. 1510–15
Jan Provost (Flemish, ca. 1465–1529)
Oil on oak, framed: 61 × 50 cm (24 × 19 11⁄16 in.); unframed: 50.5 × 40 cm (19 7⁄8 × 15 3⁄4 in.)
Paris, Musée du Louvre, Department of Paintings, RF 1973 44

In Christianity the eye was a metaphor for the divine. These rare images of two disembodied eyes (signifying that which sees and that which is seen by God) visualize the complex theological idea of "reflexive seeing," which drew on optics and theories of vision.

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55 *God the Father with Angels*, pinnacle to the Baroncelli Altarpiece, Florence, ca. 1328–35
Giotto (Italian, ca. 1267–1337)
Tempera and gold on panel, 71.4 × 75.2 cm (28⅛ × 29⅝ in.)
San Diego Museum of Art, Gift of Anne R. and Amy Putnam, inv. 1945.26

Giving form to a biblical verse "For now we see through a glass, darkly; but then face to face" (1 Cor. 13:12; King James), angels gaze through darkened glass at the light emanating from God, signifying the inability of humans to perceive him.

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56

The Unseen Godhead in Psalter (in Latin), London, ca. 1250–70(?)
Tempera, gold, and ink on parchment, full folio: 29.5 × 21.5 cm (11⅝ × 8⅜ in.)
Cambridge, Masters and Fellows of Trinity College, Ms. B.11.4, fol. 119 (detail)



57

The Trinity in the Rothschild Canticles, Anthology of Meditations and Prayers (in Latin), Flanders or the Rhineland, turn of the 14th century
Tempera, gold, and ink on parchment, full folio: 11.8 × 8.4 cm (4 11⁄16 × 3 5⁄16 in.)
New Haven, Connecticut, General Collection, Beinecke Rare Book and Manuscript Library, Yale University, Beinecke MS. 404, fol. 98

PLATES 56, 57

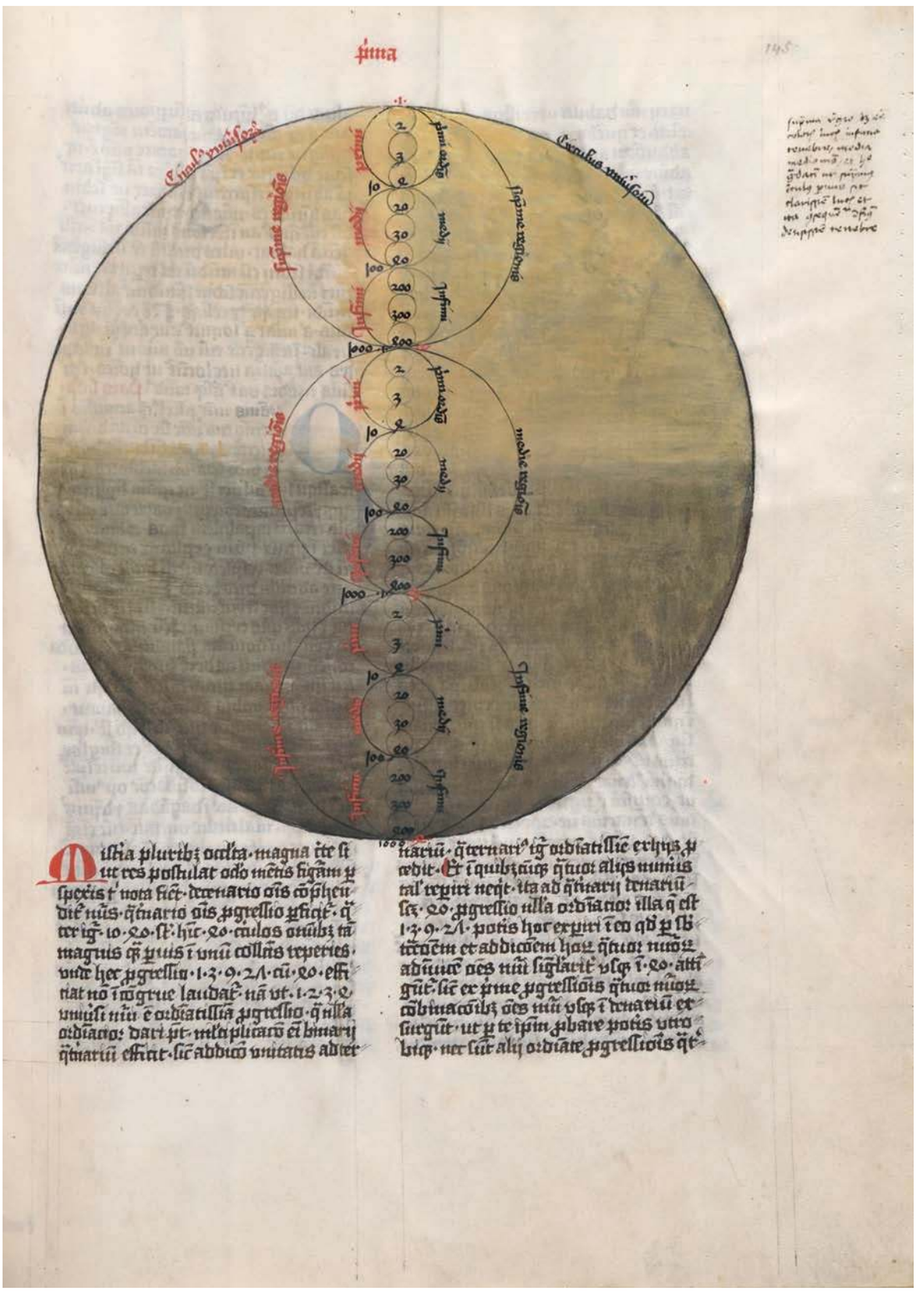
Unusual depictions of God and the Trinity, with faces obscured by light-filled, gilded, and swirling forms, demonstrate how visual artists represented the limits of knowledge and perception.

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58

Diagram U in *De coniecturis* (in Latin), Nuremberg, Germany, before 1448
Nicholas of Cusa (German, 1401–1464)
Ink and opaque paint on parchment, full folio: 34.5 × 26 cm (13 9/16 × 10 1/4 in.)
Nuremberg Stadtsbibliothek im Bildungscampus, Ms. Cent. II 9, fol. 145

Medieval artists and theologians used both darkness and light as metaphors for the unknowable. Appealing to the mind and the eye, the illustrator of Nicholas of Cusa's diagram of the universe as a graded succession of several worlds gives form to the contrast between the most brilliant and inaccessible "absolute light" of God and the densest, most absorbing darkness of unknowing.



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59

The Glorification of the Virgin, Haarlem, northern Netherlands, ca. 1490–95
Attributed to Geertgen tot Sint Jans (Netherlandish, ca. 1455–1495)
Oil on panel, 24.5 × 20.5 cm (9⅝ × 8 1⁄16 in.)
Rotterdam, Museum Boijmans Van Beuningen, 2450 (OK)

The glorified Virgin and child are surrounded by a luminous host of angels who are themselves enveloped in darkness that conveys the ineffable space in which God dwells.

60a (OPPOSITE, LEFT)

A Choir of Angels, from left-hand shutter of an altarpiece, Valenciennes, France(?), ca. 1459
Simon Marmion (Flemish, active 1449–89)
Oil on oak, 57.6 × 20.9 cm (22¾ × 8¼ in.)
London, National Gallery, NG1303

60b (OPPOSITE, RIGHT)

The Soul of Saint Bertin Carried Up to God, from right-hand shutter of an altarpiece, Valenciennes, France(?), ca. 1459
Simon Marmion (Flemish, active 1449–89)
Oil on oak, 57.7 × 20.5 cm (22¾ × 8 1⁄16 in.)
London, National Gallery, NG1302

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PLATES 60a, 60b

Having once framed an elaborate and brilliantly gilded and jewel-encrusted altarpiece, these two painted panels convey the limits of human perception through the darkness that envelops God and his host of angel musicians.

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Anish Kapoor

GLENN PHILLIPS

Many of the developments in medieval and Renaissance painting in western Europe can be charted by artists' increasingly sophisticated understanding of how light behaves when it hits a variety of different surfaces. Understanding the behavior of light led artists to create more realistic depictions of shadow—in the folds of a cloth, in the corners of a room—allowing for ever more convincing depictions of three-dimensional space across a flat pictorial surface.

Anish Kapoor has spent much of his career working contrary to these developments, producing works that upend perception and at times even challenge our ability to perceive. With surfaces and materials that range from impossibly saturated to impeccably reflective, Kapoor's sculptures and installations can physically embody ideas that more often belong to the world of philosophy, metaphysics, or psychoanalysis: the void, the formless, the unknowable. These states have been with us across time, and in Western medieval thought might be where one would locate the divine: in a place beyond knowing, beyond vision, and beyond dimension.

Vantablack, a coating that absorbs 99.965 percent of visible light, is considered one of the darkest pigments ever created. Objects coated in Vantablack reflect so little light back to a viewer that they inhibit our ability to perceive depth and texture. Kapoor's Non-Object Black works are a series of abstract sculptures coated in Vantablack that, when approached head-on by a viewer, appear to be perfectly flat geometric shapes such as diamonds, squares, and circles. It is only by moving around the objects and viewing them from different angles and profiles that one can begin to approximate their true form and the extent of their three-dimensionality. Hovering, as they do, between geometric simplicity and complexity, the works hark back to religious icons and other artworks that prompt us to consider what lies beyond our apprehension.

61

Anish Kapoor (Indian-British, b. 1954)
Non-Object Black, 2018
H: 55 cm (21⅝ in.); W: 18 cm (7 1/16 in.); D: 12 cm (4¾ in.)
Courtesy the artist and Regen Projects, Los Angeles

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62

The Holy Face in the *Vita Christi* (in Latin; with devotional supplements), East Anglia, England, ca. 1190–1200 and 1480–90
Tempera colors and gold leaf on parchment, full folio: 17 × 11.9 cm (6 11⁄16 × 4 11⁄16 in.)
Los Angeles, J. Paul Getty Museum, Ms. 101 (2008.3), fol. 77

A pilgrim's token of the Holy Face has been pasted onto the page and is surrounded by a prayer that describes darkness as "the stamp of light."



63

Reliquary Diptych with the Holy Face, France, 14th century, with later modification
Silver (repoussé and gilded), velvet, silk and metal embroidery, varieties of wood, painting, rock crystal, glass, verre églomisé, decorative stones, H: 36.3 cm (14 5⁄16 in.); W: 48.8 cm (19 3⁄16 in.); D: 4.2 cm (1 5⁄9 in.)
Cologne, on permanent loan to the Museum Schnütgen from the Ernst von Siemens Kunststiftung, G 693

The shadowy visage of Christ, mounted in shining gold and crystal, seemingly defies viewers' attempts to see the Holy Face.

64 (OPPOSITE)

Saint-Denis Crystal, Carolingian, Paris, ca. 846–69
Rock crystal, metal, 15.5 × 11 × 4.5 cm (6 1⁄8 × 4 5⁄16 × 1 3⁄4 in.)
London, British Museum, 1855,0305.1

The domed cabochon of the Saint-Denis crystal both magnifies the scene of the Crucifixion and conceals details that can be perceived only as one moves around the object: light shifts the relationship between figure and ground in the scene according to the viewer's line of sight.

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65 Reliquary with Paintings on Parchment, Cologne, Rhine-Meuse region, Germany(?), early 13th century
Rock crystal, painted parchment, wood, fabric-wrapped relics, 17 × 17.4 × 6.9 cm (6 11/16 × 6 7/8 × 2 ¾ in.)
Copenhagen, National Museum of Denmark, inv. 9082

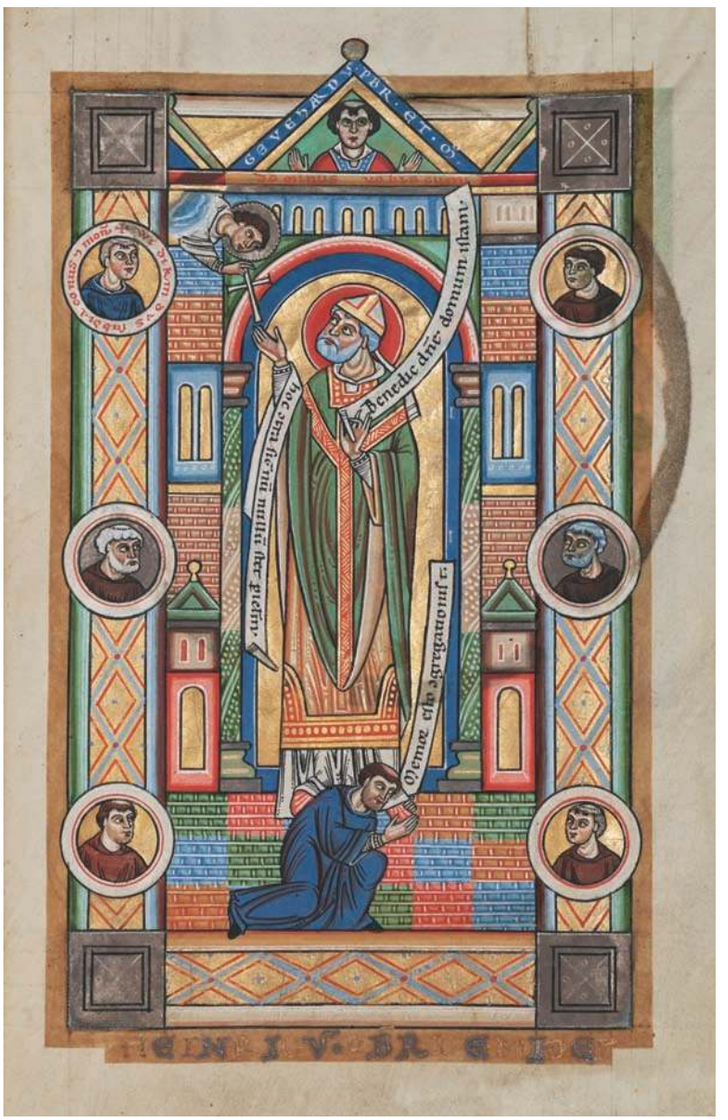
The imperfect rock crystal of this reliquary—clear and yet in places cracked and cloudy—simultaneously invites and rebuffs the viewer's vision of the painted parchment within, offering a visual metaphor for the human inability to perceive the divine.

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66

Large Cross of Bishop Bernward, Hildesheim, Germany, ca. 1150
Oak wood, gold, gilt silver, filigree, precious stones, 48 × 37 cm (18⅞ × 14⁹⁄₁₆ in.)
Dommuseum Hildesheim, DS L109



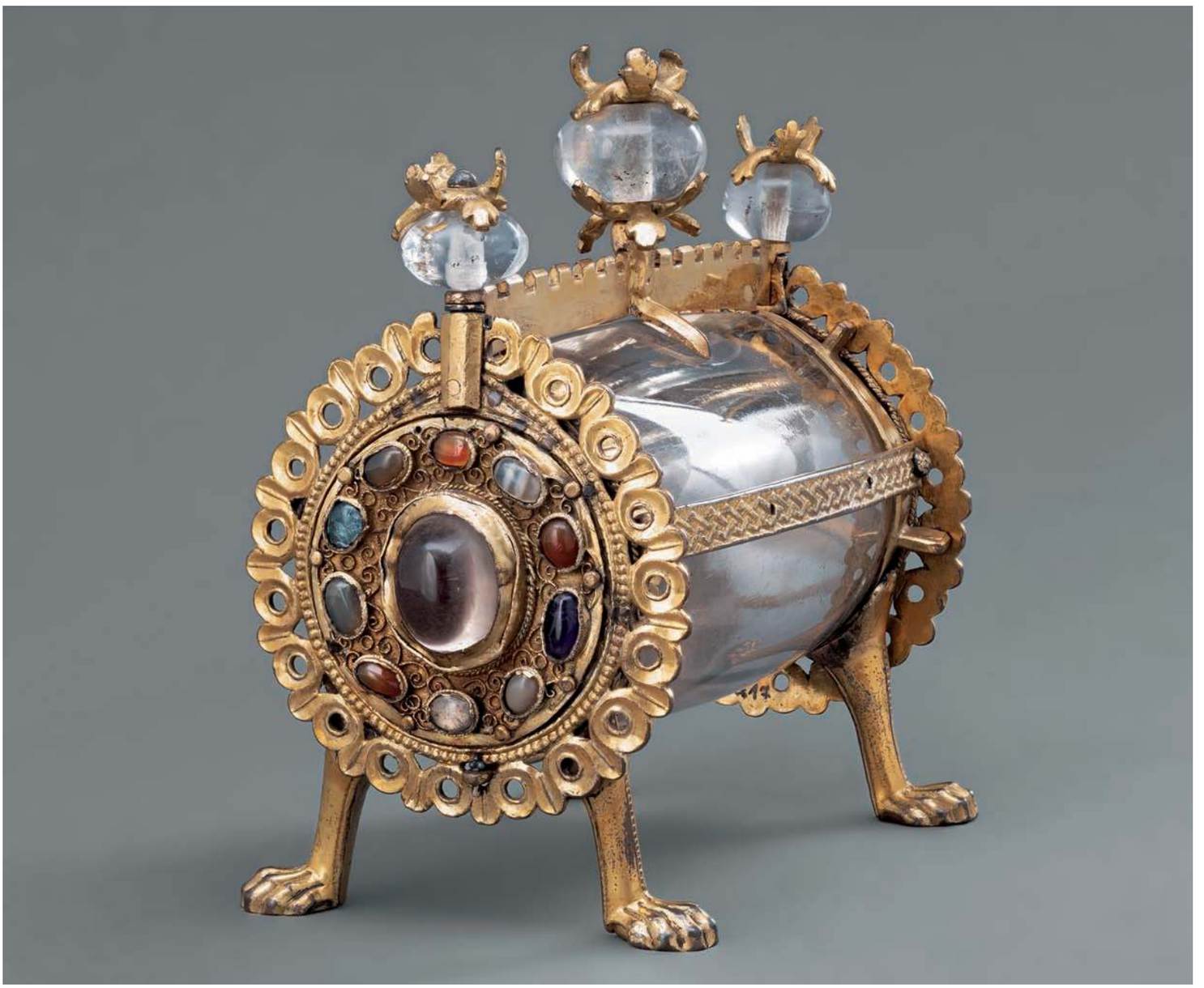
67

Saint Bernward Receiving the Relic of the True Cross in the *Stammheim Missal* (in Latin), Hildesheim, Germany, 1170s(?)
Tempera colors, gold leaf, silver leaf, and ink on parchment, full folio: 28.2 × 18.9 cm (11⅛ × 7⁷⁄₁₆ in.)
Los Angeles, J. Paul Getty Museum, Ms. 64 (97.MG.21), fol. 156

PLATES 66, 67

A relic of the True Cross was given to Bernward, bishop of Hildesheim, an event celebrated in a manuscript made for his church. Acting as a lens, the rock crystal at the center enhanced the relic's visibility, bringing the viewer closer to the divine.

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68

Rock Crystal Reliquary on Lion's Feet, Cologne, Germany, ca. 1200
Rock crystal, gilt copper, gold filigree, precious stones, glass stones, 16.3 × 17.5 × 10.3 cm (6 7/16 × 6 7/8 × 4 1/8 in.)
Cologne, Museum Schnütgen, inv. G 17

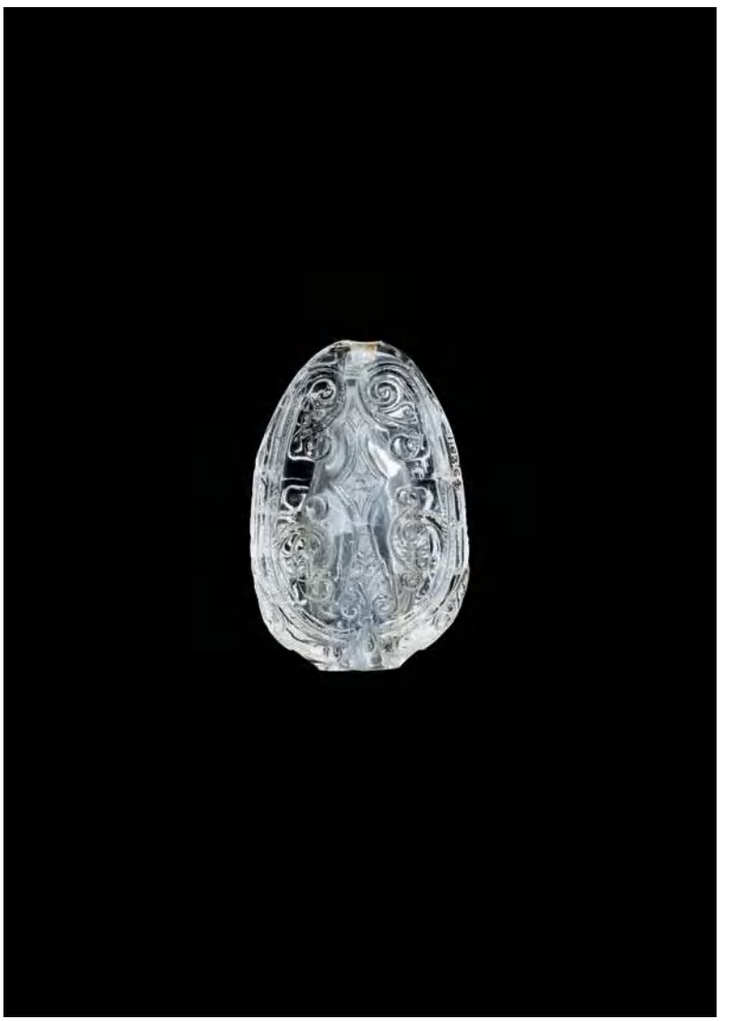
Around the turn of the thirteenth century, an emphasis on vision in Christian theology resulted in the increased visibility of relics. This reliquary's curved crystal chamber would have magnified the objects within.

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69

Reliquary Monstrance with a Tooth of Saint John the Baptist, Germany, 1433; rock crystal container, Fatimid, 900–1200
Weddeghe Velstede (German, active 1432–73)
Silver gilt, rock crystal, 45.1 × 14.6 cm (17¾ × 5 ¾ in.)
Art Institute of Chicago, Gift of Mrs. Chauncey McCormick, 1962.91



70

Flask, Cairo, Fatimid Egypt(?), 975–1050
Rock crystal, 11 × 8.5 cm (4⅓ × 3⅓ in.); Wt: 0.28 kg (0.62 lb.)
London, Victoria and Albert Museum, 1163–1864

PLATES 69, 70

According to Ibn al-Haytham, rock crystal (often thought to have magical properties) was one of the most transparent substances, following only the celestial body, air, and water. Medieval rock crystal carving reached its zenith during the Fatimid caliphate, and Islamic luxury objects were repurposed for Christian reliquaries throughout the Middle Ages.

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71

Saint Christopher Carrying the Christ Child in Book of Hours (in Latin), Catalonia, Spain, ca. 1400
Tempera, gold, and ink on parchment, full folio: 11.5 × 8.8 cm (4½ × 3½ in.)
Stockholm, Nationalmuseum, NMB 1792, fol. 19 (detail)

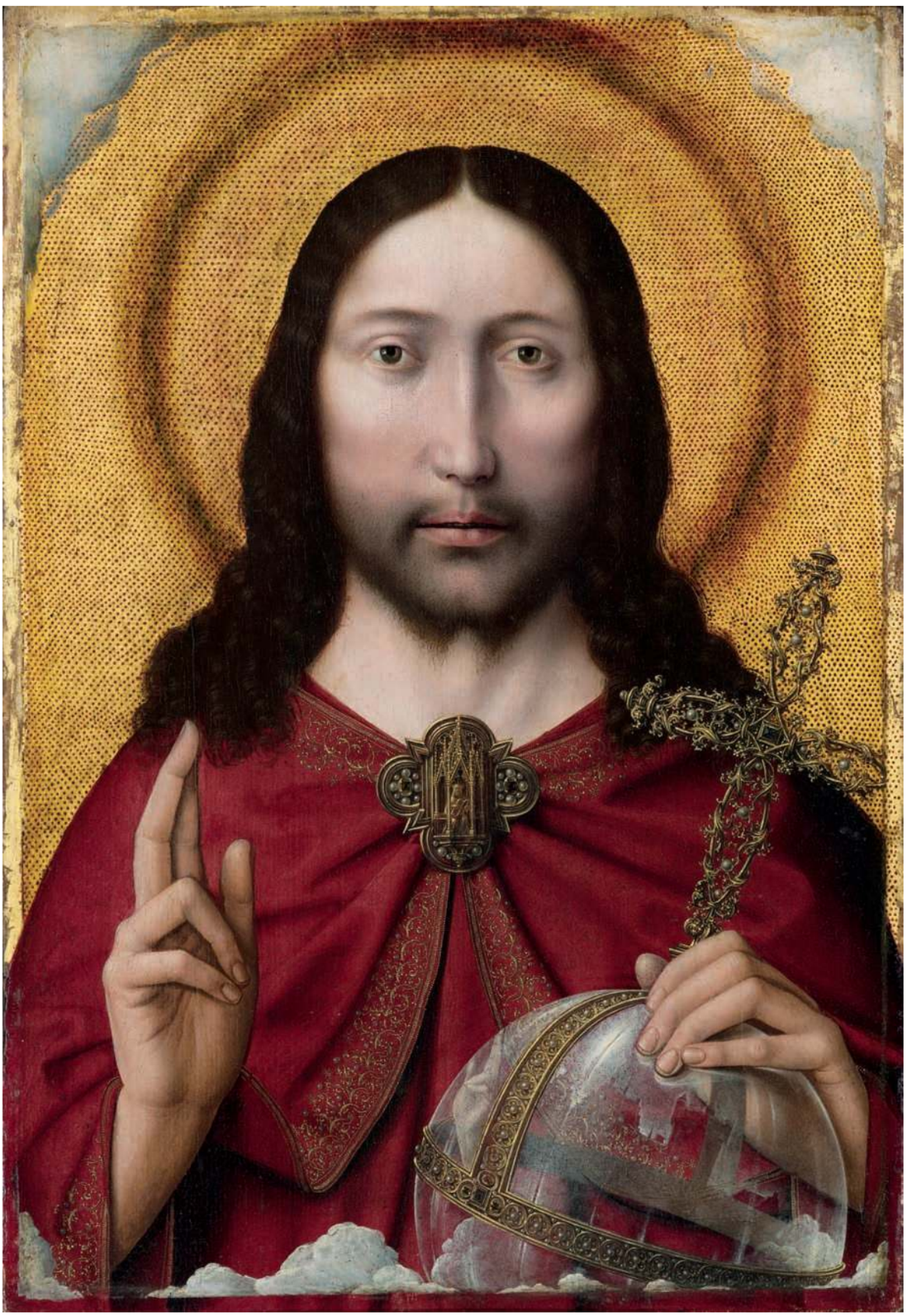
The medieval artisan painted both the reflection of Saint Christopher in the water and the refraction of the walking stick, which appears bent where it is partially submerged. The optical effects emphasize a mistrust of vision appropriate to the subject matter, as according to the story, Christopher did not recognize the child he carried as Christ.

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72

Salvator Mundi, Antwerp, Flanders (Belgium), ca. 1500–1510
Quentin Massys and Studio (Flemish, 1466–1530)
Oil on panel, framed: 71.4 × 54.3 cm (28⅛ × 21⅜ in.); unframed: 53.3 × 36.8 cm (21 × 14½ in.)
Raleigh, North Carolina Museum of Art, Gift of the Samuel H. Kress Foundation, GL.60.17.62

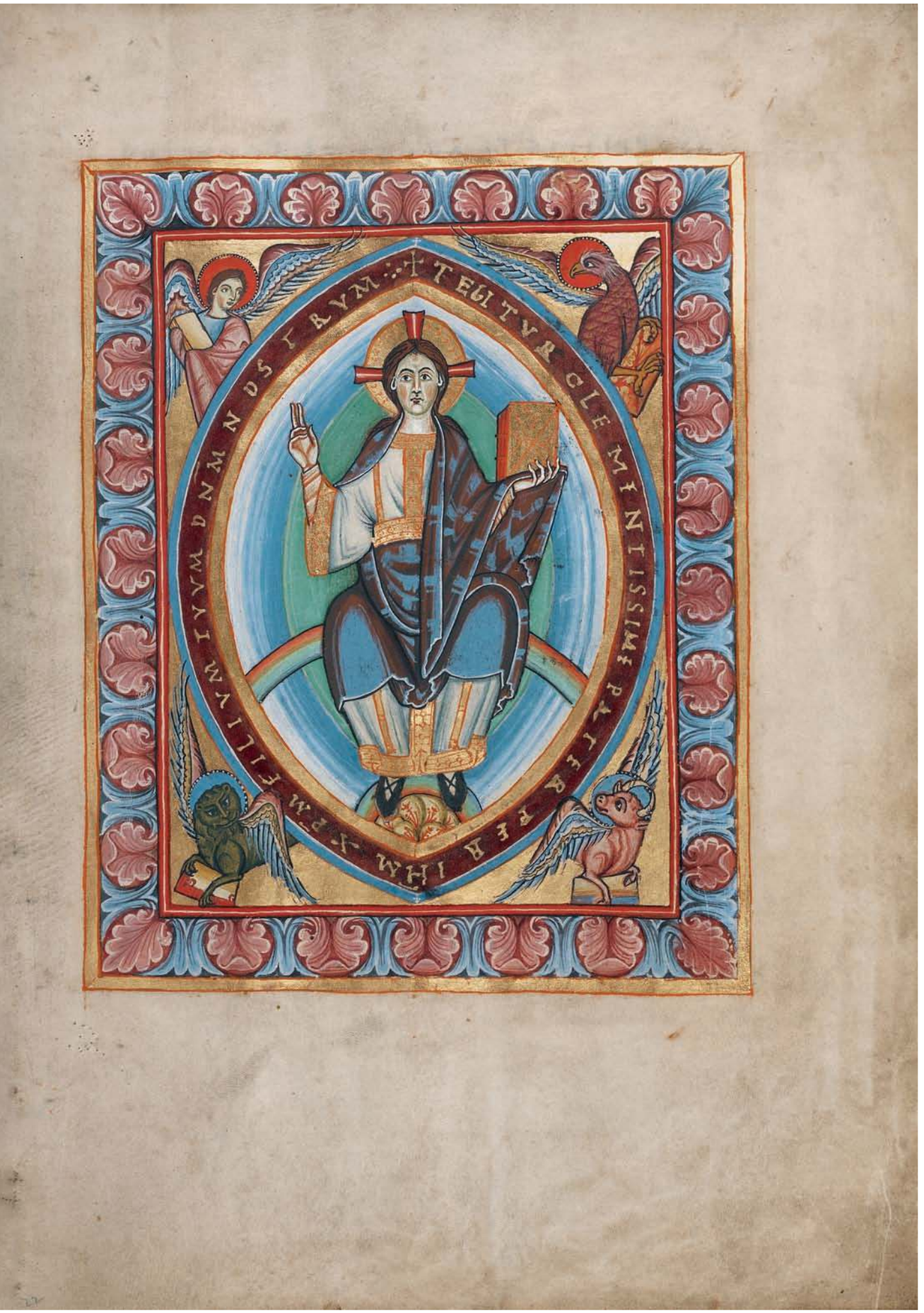
Optical knowledge and keen observations of the interaction of light with transparent media are evident in images such as the Salvator Mundi, where reflections of Christ's hands and of a distant cityscape are reflected on the surface of the crystalline globe.



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73

"Vere Dignum" Monogram and *Christ in Majesty* in Sacramentary (in Latin), Mainz and Fulda, Ottonian Germany, ca. 1025–50
Tempera colors, gold, and ink on parchment, full folio: 26.7 × 18.9 cm (10½ × 7 7/16 in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig V 2 (83. MF.77), fols. 21v–22

In the book of Genesis, God said to Noah, "I have set my rainbow in the clouds, and it will be a sign of the covenant between me and the earth" (Gen. 9:13; New International). Beginning in the early medieval era, Christ was shown seated on a rainbow in scenes of the Last Judgment as a symbol of both his mercy and his judgment.

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Charles Ross

GLENN PHILLIPS



We all know that days grow shorter in the winter and longer in the summer, but today we rarely consider that this is the result of the sun following a different arc through the sky every day. This arc varies not only by day of the year but also by location on the planet. Premodern scholars were highly attuned to these celestial variations, which they derived from mathematical calculations and the use of devices such as astrolabes, calibrated to individual locations.

Charles Ross's Solar Spectrum installations, which include *Conversations with the Sun* and *Dwan Light Sanctuary*, are a series of site-specific works that are also attuned to their planetary locations. The works consist of a mounted array of large acrylic prisms that cast continually changing patterns of spectral light across the spaces in which they are located. Each prism is precisely positioned and angled to capture sunlight at a particular time of day or time of year. To calculate these positions, Ross works with an architectural scale model of the space, positioned on a "sun angle machine" that he invented and that he later discovered was akin to a machine used by Renaissance architects to study the movement of shadows across facades. Ross's sun angle machine is calibrated to the building's location and orientation. Using a fixed point of light, he can swivel the model to chart precisely the daily path that the sun will follow over the course of a year. This allows him to find optimal locations for each of the prisms, which are then fabricated and mounted into the finished installation.

Over the course of each day the spectral bands will move throughout the space in relation to the sun, taking a slightly different path on each successive day. As seasons change, some prisms in the array will fall outside the sun's path, and new ones will begin to take center stage. Over time one can begin to grasp the full scale of the earth's rotational cycle around the sun, and perhaps even feel connected to the premodern experience of astronomical observation and calculation necessary to mark times of day or times of year. Yet, even brief encounters with the Solar Spectrum installations can help one visualize this cycle. Bands of dispersed spectral light move across surfaces at a rate faster than that of a sunbeam, allowing careful observers more readily to perceive the movement of the sun, caused by the rotation of the earth.

As part of the exhibition *Lumen: The Art and Science of Light,* the J. Paul Getty Museum commissioned a new Solar Spectrum installation, *Spectrum 14*, for its rotunda.

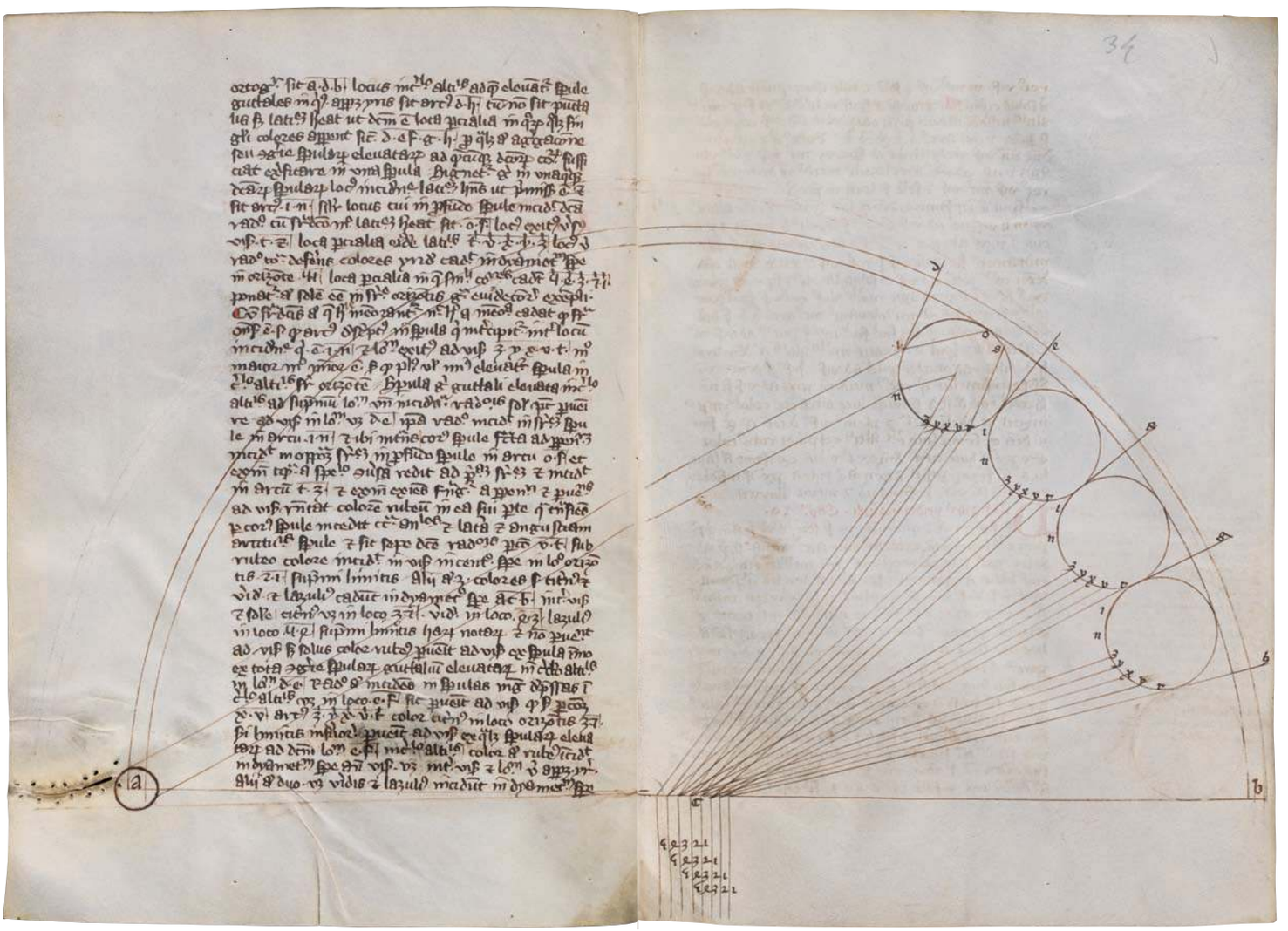
74a (OPPOSITE)

Charles Ross (American, b. 1937)
Conversations with the Sun, 2004
Nine acrylic prisms tuned to the sun, suspended in skylights
Tokyo, Meiji University

74b (ABOVE)

Charles Ross (American, b. 1937)
Dwan Light Sanctuary, 1996
Twenty-four acrylic prisms tuned to the sun, suspended in skylights and apses
Montezuma, New Mexico, United World College

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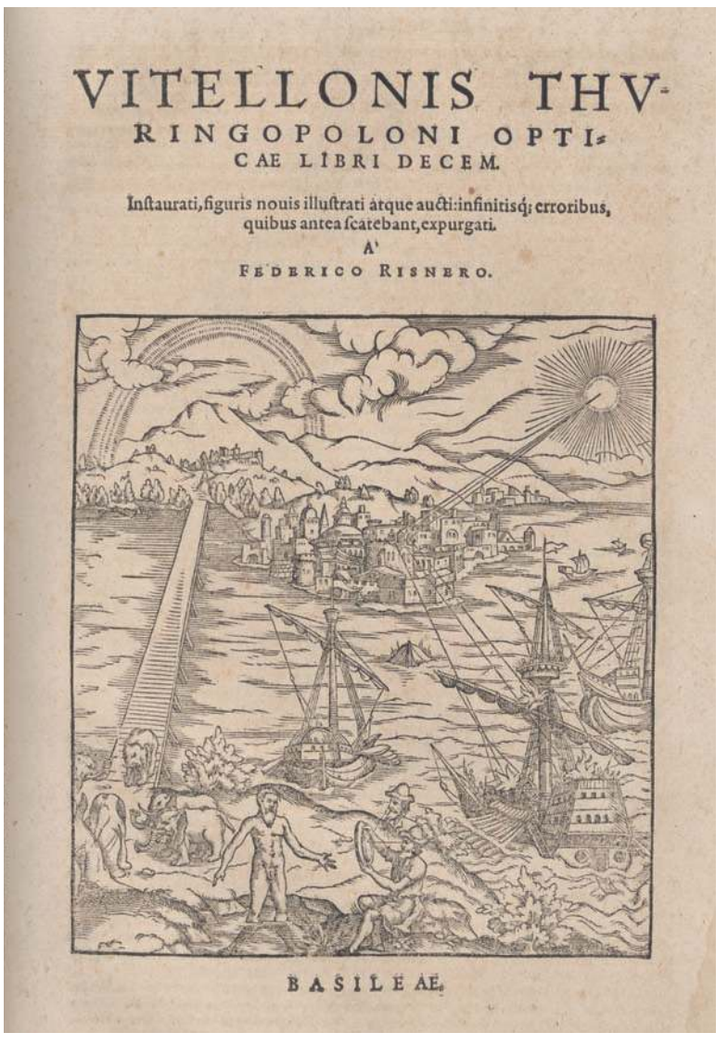


75

The Formation of the Main Rainbow in *De iride et radialibus impressionibus* (in Latin), III, 2, 5, Germany(?), 14th century
Theodoric of Freiberg (German, 1250–1310)
Ink on parchment, full folio: 20–21.5 × 14.5–15 cm (7 ⅞–8 ⅜ × 5 ¹¹⁄₁₆–5 ⅞)
Basel, Universitätsbibliothek, F.IV.30, fols. 33v–34

Three hundred years before Isaac Newton, the Dominican theologian Theodoric of Freiberg understood the rainbow as a phenomenon that resulted when linear rays of light reflected and deflected off water droplets, diagrammed with one color corresponding to each droplet.

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76

Title Page Frontispiece in *Opticae thesaurus* (in Latin), Basel, Switzerland, 1572
Ibn al-Haytham (author) (Arab, active in Cairo, 965–ca. 1040)
Witelo (author) (Polish, active in Viterbo, ca. 1230–ca. 1278)
Ink on paper, 35.9 × 22.9 cm (14 × 9 in.)
Stanford Medical History Center, B353H.A39, vol. 2, fol. *1 recto

This sixteenth-century printed compendium of optical studies shows the active chain of scientific ideas stretching back through the centuries. It includes the thirteenth-century friar Witelo's commentary on Ibn al-Haytham's treatise on optics, composed in the early eleventh century.



77

The Rainbow from *Wonders of Creation (Aja'ib al-Makhluqat)* (in Persian), Safavid Persia (Iran), beginning of 17th century
al-Qazwini (Persian or Arab, 1203–1283)
Opaque watercolor and ink on paper, full folio: 37.5 × 24 cm (14¾ × 9½ in.)
Paris, Bibliothèque nationale de France, Département des Manuscrits, MS Smith-Lesouëf 221, fol. 58v

Al-Qazwini's encyclopedic *Wonders of Creation*, a text not known in the Latin West, was based on earlier investigations into the rainbow by scientists such as Ibn Sina and demonstrates independent developments of optical knowledge in the eastern Islamic sphere.

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78

Folio in the Blue Qurʾan (in Arabic), Kairouan,
Aghlabid Tunisia(?), Umayyad Córdoba, Spain(?), or
Abbasid Baghdad, Iraq(?), ca. 900
Gold pigment and silver on parchment, binding:
28.6 × 37.6 × 1.5 cm (11¼ × 14 13⁄16 × ⅝ in.)
Dublin, Chester Beatty, Is 1405A

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79

Two Folios in *The Golden Gospels of Henry VIII* (in Latin), Ottonian Trier, Germany, between 977 and 993
Purple parchment surface-dyed with orchil, granular gold ink, full folio: 36.5 × 27 cm (14⅜ × 10 ⅝ in.)
New York, Morgan Library & Museum, Purchased by J. Pierpont Morgan (1837–1913) in 1900, MS M.23, fols. 72v–73

PLATES 78, 79

Colors were understood as material attributes of light, appreciated for their luminosity and relative brightness (value), not necessarily for their hue. Sacred texts written in gold on luminous purple and blue pages materialized divine light.

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80

Saint John in New Testament (in Greek), Malesina, Byzantium (Greece), mid-14th century
Tempera, gold, and ink on paper, full folio: 28 × 20 cm (11 × 7⅞ in.)
Athens, National Library of Greece, cod. 150, fol. 165v

Receiving divine inspiration from God, Saint John is surrounded by gradients of blue light bridging the heavenly and earthly realms. Blue was understood in the Byzantine sphere as conveying the brightness of light.

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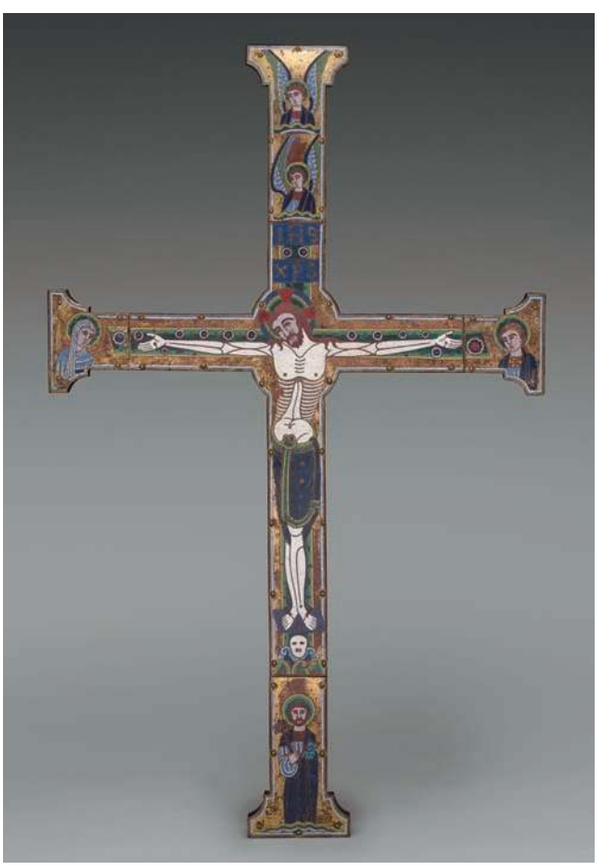


81 (ABOVE)

Book Covers, Constantinople, Byzantium, late 10th–early 11th century
Gilded silver on wood with gold cloisonné enamels, pearls, precious stones, 29 × 21 cm (11 7⁄16 × 8 1⁄4 in.)
Venice, Biblioteca Nazionale Marciana, MS Lat. CL.1.100

82 (RIGHT)

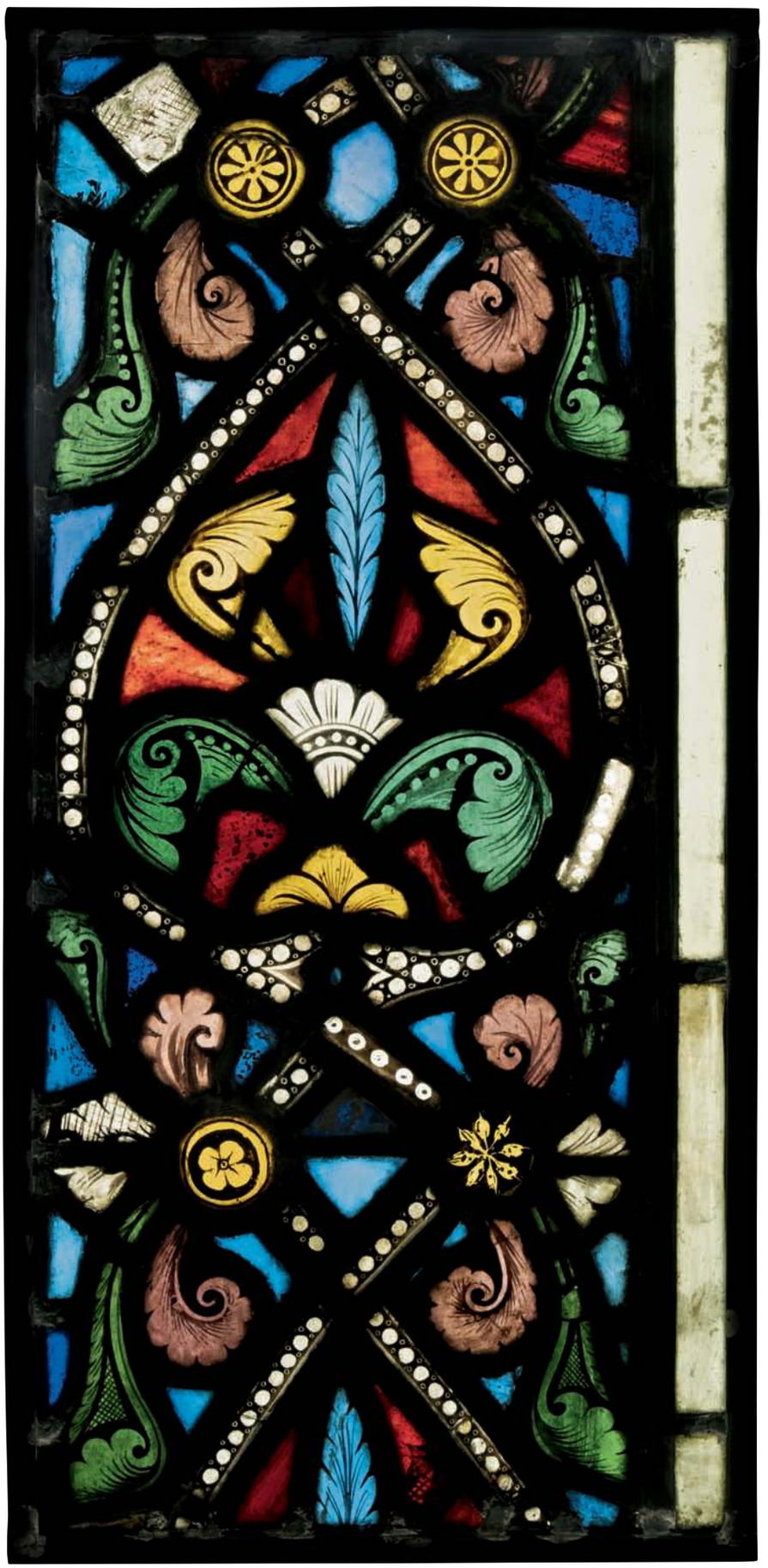
The Spitzer Cross, Limoges, France, ca. 1190
Master of the Royal Plantagenet (French, active 12th century)
Champlevé enamel, gilded, engraved, and stippled copper, 67.4 × 41.9 × 0.2 cm (26 9⁄16 × 16 1⁄2 × 1⁄16 in.)
Cleveland Museum of Art, Gift of J. H. Wade, 1923.1051



PLATES 81, 82

The luminous medium of enamel was used by medieval artists on objects for liturgical use to channel light and to depict color, which was understood as the material form of light.

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83

Border Section from Moses Window, Abbey Church of Saint-Denis, France, ca. 1140–44
Stained glass, 49 × 23.2 cm (19¼ × 9⅛ in.)
Bryn Athyn, Pennsylvania, Glencairn Museum, 03.SG.182

Abbot Suger's reconstruction of the abbey church of Saint-Denis, outside Paris, ushered in the Gothic era, known for its light-filled architectural spaces and luminous stained glass.

84 (OPPOSITE, LEFT)

Lancet Redemption Window, Montreuil-sur-le-Loir, France, ca. 1220, framing and yellow border glass added later
Pot-metal glass, framed: 275.2 × 44.5 cm (108⅜ × 17½ in.); original state: 255.7 × 29.1 cm (100 11/16 × 11 7/16 in.)
Saint Louis Art Museum, Musuem Purchase, 3:1935

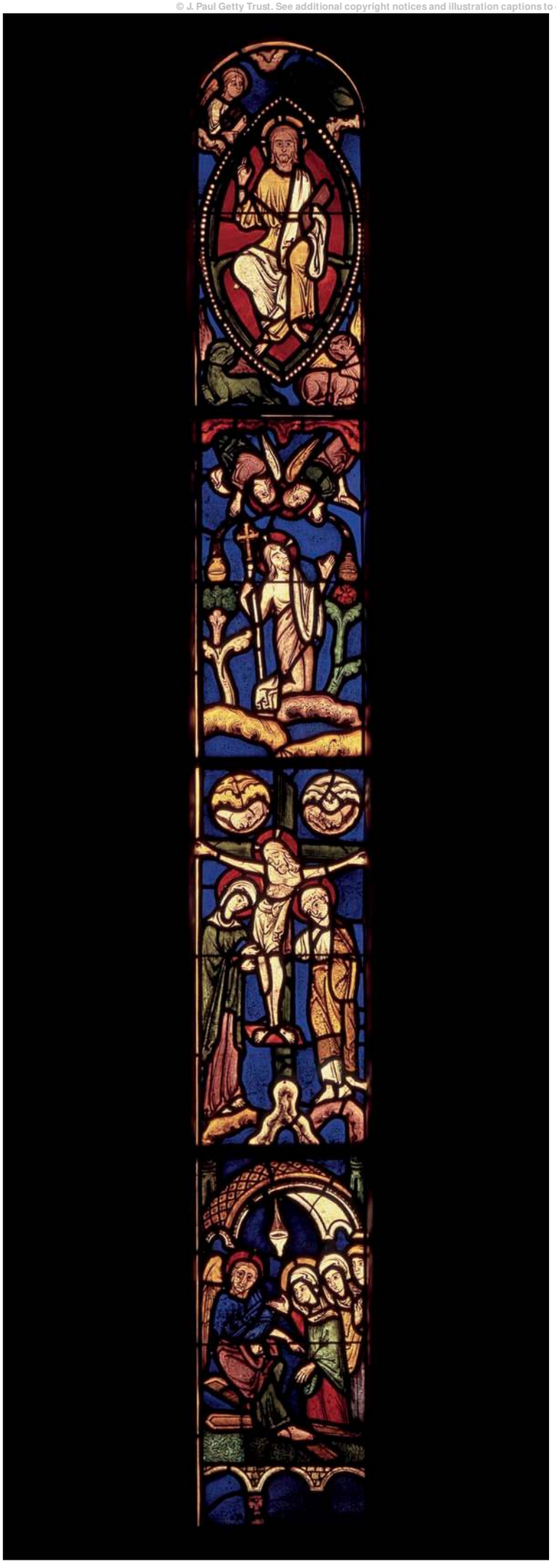
85 (OPPOSITE, RIGHT)

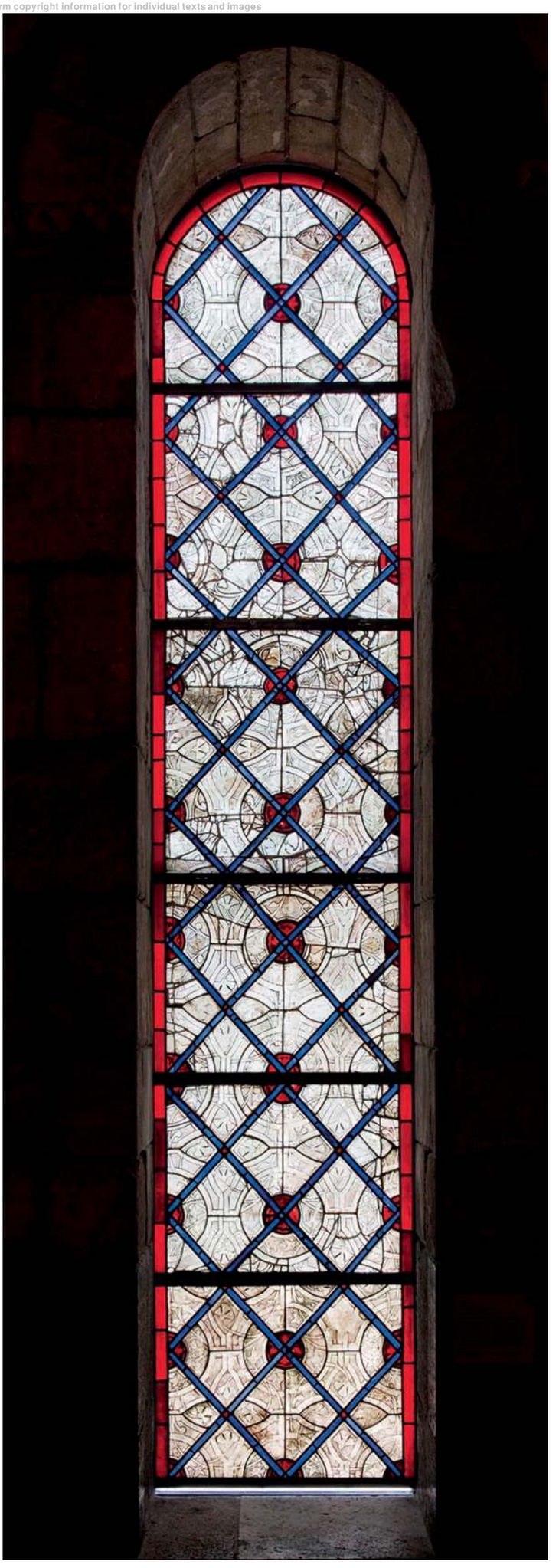
Grisaille Panels, Normandy, France(?), 1270–80, red border glass added later
Pot-metal and colorless glass with vitreous paint, overall (all four panels): 238.8 × 60.2 cm (94 × 23 11/16 in.);
New York, Metropolitan Museum of Art, The Cloisters Collection, 2010, 2010.253.1–12

PLATES 84, 85

Passages of grisaille glass would have flooded the church with light, seemingly dissolving sections of architecture into light. By contrast, the deeply colored stained glass not only depicted biblical scenes but also created intensely colored zones tuned to specifically chosen sections of the church.

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86

Lamp, Mamluk Egypt or Syria, mid-14th century
Glass, free-blown and tooled, enameled and gilded, 34.5 × 28.58 cm (13 9/16 × 11 1/4 in.); Diam: 29.2 cm (11 1/2 in.)
Los Angeles County Museum of Art, William Randolph Hearst Collection, 50.28.4

Spaces of the mosque would have been punctuated by pools of light and shadow created by gilded and enameled glass lamps hanging from chains. Ambient patterns and shadows were cast by the flickering lamplight as it shone through calligraphic inscriptions or Qurʾanic verses.

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87

The Annunciation, Spain, late 15th century
Master of the Retable of the Reyes Católicos (Spanish, active ca. 1485–1500)
Oil on panel, 153.4 × 94 cm (60⅜ × 37 in.)
Fine Arts Museums of San Francisco, Gift of the Samuel H. Kress Foundation, 61.44.21

The Annunciation was frequently depicted by linear golden rays of light that extend from the heavens to the top of the Virgin's head (the seat of the soul). The dove of the Holy Spirit and the infant Christ travel along these rays, bringing cognition and belief.



88

Saint Bridget of Sweden's Eucharistic Vision in *Devotional Miscellany* (in Latin), Naples, last quarter of 14th century
Tempera, gold, and ink on parchment, full folio: 26.8 × 19.2 cm (10 9⁄16 × 7 9⁄16 in.)
New York, Purchase by J. Pierpont Morgan (1837–1913) in 1912, Morgan Library & Museum, MS M.498, fol. 4v

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The image of Saint Bridget receiving a mystical vision conveys the medieval visual understanding of light as a carrier of knowledge. Linear, white rays of light flow from Christ's hands into Bridget's eyes and mind to give spiritual seeing.

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E. V. Day

GLENN PHILLIPS



In Christianity the Annunciation is the biblical story in which the angel Gabriel appeared to the Virgin Mary and announced that she would bear the son of God through the Holy Spirit. It is one of the most commonly depicted scenes in Western Christian art. Medieval and early Renaissance artists developed a number of visual approaches to representing this encounter, among them the use of golden rays of light directed at Mary to signify the immaterial presence of the Holy Spirit and the moment of conception of Jesus Christ (plate 87). So common, in fact, is the use of golden rays in art that it hardly seems strange to see that a painting that otherwise employs the most advanced techniques of realism might also have as one of its central motifs a geometric line illustration that would be more at home in a treatise on geometry, astronomy, or linear perspective (plates 31, 35–38a–d). Yet these are also the moments that demonstrate the degree to which medieval and Renaissance artists might be well versed in scientific ideas, as it would be impossible to participate in the development and mastery of perspective without studying mathematics, light, and vision.

E. V. Day's *Golden Rays / In Vitro* uses gilded aircraft cable, precisely stretched and anchored, to dramatically transfer the golden rays of Christian art history back to the three-dimensional world. Day playfully notes a degree of continuity between the religious visual motif of the golden rays and atomic-era sci-fi imagery of superpowered laser beams, ray guns, and X-ray vision. Likewise, the notion of the golden rays as a representation of divine communication from the heavens feels resonant with our current world of satellite communication, fiber optics, and invisible electromagnetic signals all around us. Was the Annunciation the original high-speed wireless download?

Golden Rays / In Vitro was first presented at the American Academy in Rome, where Day was an artist in residence from 2017 to 2018. For that presentation the rays originated at the skylight of Day's studio and appeared to pass through a large glass window before terminating in the ground outside the building. Day was responding to a common motif in Annunciation paintings, in which the rays pass through a perfectly placed window, as if the building in which Mary is situated had been designed with this divine encounter in mind. The glass window led to an additional association for Day: in vitro fertilization. Perhaps our closest equivalent to immaculate conception, this process allows for fertilization to take place outside the human body, in a glass petri dish.

89

E. V. Day (American, b. 1967)
Golden Rays/In Vitro, 2018
Aircraft cable, gold leaf, monofilament, hardware
Installation view at the American Academy in Rome

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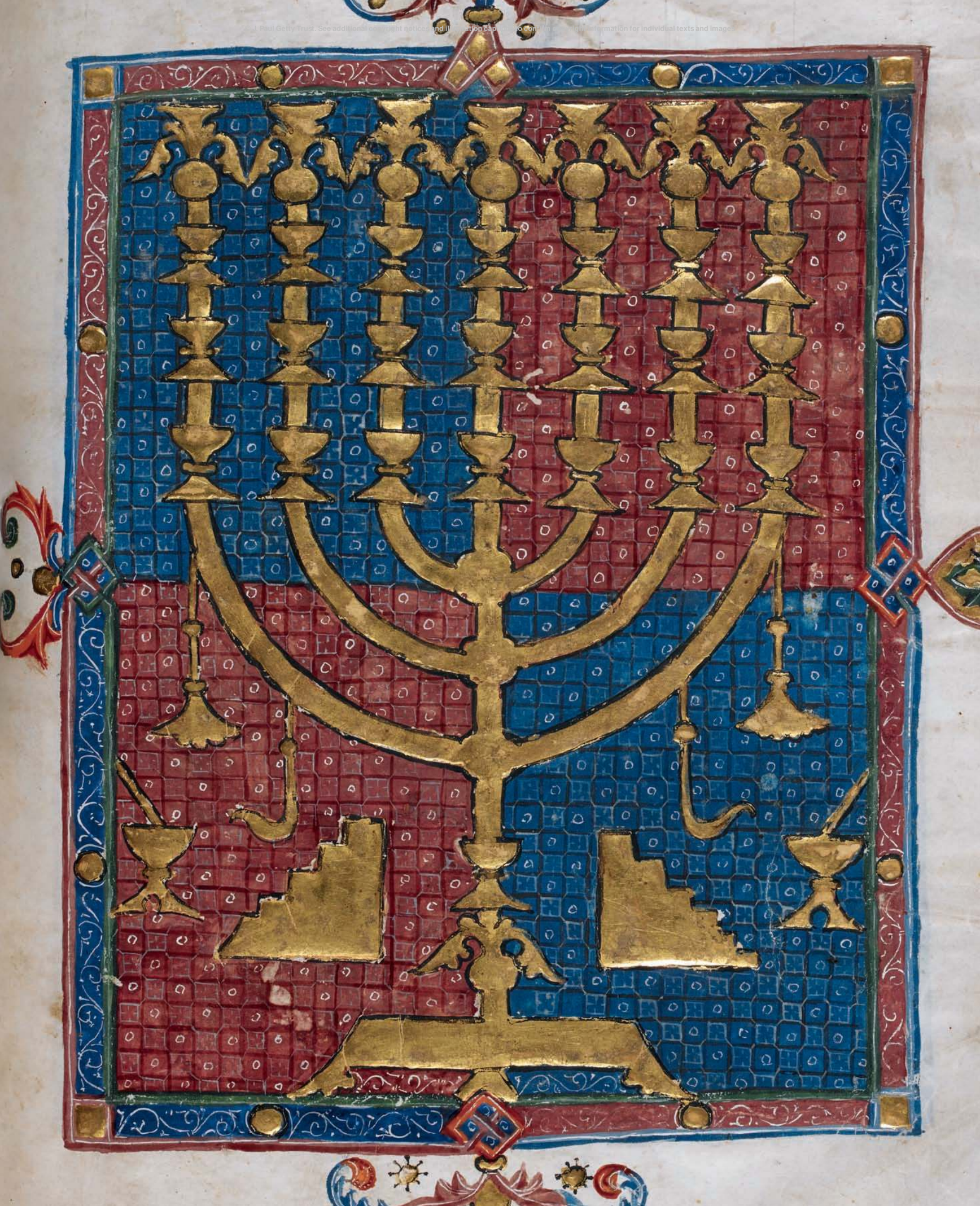
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Part 3

AURA AND PERFORMANCE

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Aura and Performance

KRISTEN COLLINS AND NANCY K. TURNER

Informed by tacit understanding of scientific knowledge, medieval artists materialized and manipulated light in religious spaces and in individual objects to evoke divinity, to focus attention, and to create transformative experiences for the viewer. Medieval sacred spaces were rich sensoria, spatial experiences of light and visual phenomena, choreographed movements, and ritual performances, layered with sonic, olfactory, and tactile encounters. In churches, in mosques, or in private devotion the experience of the sacred became sensible (*sensibilis*): it was perceived, and believed, on the evidence of the senses. In sacred spaces activated by ceremony the play of moving light on gold, crystal, gems, figured marble, shining colored mosaics, rich textiles, and colored and gilded paintings would have been combined with the sounds of voices raised in song or chant and the smell of perfumed incense. Through a layering of sensory information the experiences became embodied in the viewers, allowing them access to divinity through perceptible experience.[1] Often oriented toward an altar, prayer niche, or other focal point, such experiences included objects whose participation contributed to the enactment of religious performance (fig. 37).[2] Through this medieval sensorium one's learned expectations were conditioned and fulfilled through repeated observed practices (orthopraxy), along with periodic elements of surprise.[3]

Any discussion of sight and light engages with medieval hierarchies of the senses. According to Plato and Aristotle and their later interpreters, vision was the primary sense that informed knowledge and belief. Light, being necessary for vision, was fundamental to the activation and animation of sacred spaces. Whether filtering through Gothic glass in a Latin church (plate 84) or cascading off the surfaces of glazed muqarnas in a shrine in fourteenth-century Iran (plate 112), light in medieval spaces was always in motion. Moving light, whether from the slow passage of the sun or moon or from the flickering of candles and lamps, reflected off golden objects, polished marble and tilework, and hung in visible projections on slow-moving clouds of incense.

Religious experience relied on light and sight; light catalyzed a viewer's vision to shift from the physical and material to the immaterial and ineffable.[4] Saint Augustine's hierarchy of three types of vision—natural (optical, physical) vision; spiritual (imaginative) vision; and intellectual vision (vision of divine truth and sight of incorporeal beings)—suggests a cognitive process that

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enables the viewer to transition from one kind of vision to another.[5]

Medieval diagrams demonstrate the prevailing theories about how sense perception carried images to the brain, which served as the basis of the intellect, reasoning, and memory (plates 91–93). The medieval theory of cognition was twofold: universal knowledge consisted of general ideas, such as mathematical truths (including numerical operations), and abstract propositions, such as the nature of God; by contrast, particular knowledge was grounded in sense perception.[6] Specific sensory and cognitive mechanisms were first located within the brain by the Greek physician Posidonius of Byzantium (active 4th century), who observed that injuries to the back of the skull resulted in memory loss; wounds to the front affected sensory recognition; and damage to the brain's midsection affected reasoning ability.[7] For the Persian polymath Ibn Sina, known in the West as Avicenna (980–1037), input from the five senses was received in and passed successively through five ventricles, or chambers, of the brain, each containing a different cognitive faculty. (The physical arrangement of the ventricles had been described centuries earlier by Galen.)[8] Among competing ideas, Ibn Sina's theory of ventricles is said to have had the most influence in Christian Europe, including the works of Thomas Aquinas (1225–1274) and Roger Bacon (ca. 1219/20–ca. 1292).[9] In the Latin West the connections between the senses and cognition were further developed by clerics and physicians alike, among them Adelard of Bath (1075–1160), William of Conches (ca. 1080–before 1154), and members of the medical university at Salerno in southern Italy.[10]

Religious rites and rituals—whether in spaces built for historical Jewish, Christian, or Islamic practice—were designed to engage all the senses. Called "embodied cognition" by neuroscientists and neuroanthropologists today, religious experiences are created by complex social institutions and cannot be reduced to various brain mechanisms, not least because there appears to be no difference between normal brain activity and religious thought.[11] Construed from personal perceptions of shared phenomena, religious experiences were (and are), first and foremost, culturally and historically situated.[12] The exhibition and this accompanying volume have organized objects into groupings designed to give a broad overview of light in Jewish, Christian, and Islamic practice while acknowledging the differences in belief and religious ritual that occurred over time and across cultures. What can be said from the perspective of shared experience is that, for most people, knowledge is gained through vision (for the sighted), learned experience, memory, and "predictive processing."[13]

Light was fundamental to Jewish life and religious observance, whether in the synagogue or at home. Jewish devotional practices were structured around daily morning prayers, weekly Sabbath prayers (as sunset fell), and festival prayers on holy days (determined by the Jewish lunisolar calendar)—all based on the light of the heavens.[14] Writers of the Hebrew Bible frequently correlated light with the eye, as in Proverbs 15:30: "What brightens the eye gladdens the heart"; the verse expresses an extramissionist view of light as the fire that emanated from the eye.[15] Later, kabbalism (Jewish mysticism) emphasized the idea of "emanations," including the fire of the divine eye, regarded as the first emanation that, as given in the *Zohar*, "hastened to gaze to create the world."[16] The desire to reach God and the Eternal Jerusalem, conceived as the gateway to the heavens, was expressed both verbally and visually in Hebrew Bibles, in illuminations that depicted glittering gilded implements from the Tabernacle and the Temple and Zechariah's prophetic menorah of the restored Temple in Jerusalem (Zech. 4:1–14) (plate 98). Proverbs 6:23 reads, "the commandment is a lamp, the teaching [Torah] is a light"; in other words, the Bible—the book central to Jewish devotion—was itself light.[17]

It is in the Byzantine cultural sphere, where ekphrases of the sensory experiences of religious ritual achieved a kind of literary status, that we gain an immediate idea of the sensory impact of light, art, and ritual from verbal description.[18] Among the best known is the ninth-century patriarch Photios's ekphrasis of the Church of the Virgin of the Pharos, in Constantinople (modern Istanbul), about which he exults:

> It seems that everything is in ecstatic motion, and the church itself is circling round. For the spectator, through

FIGURE 37. Light falling on liturgical objects on the altar during Easter liturgy, Saint Catherine's Monastery, Mount Sinai, Egypt

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> his whirling about in all directions and being constantly astir, which he is forced to experience by the variegated spectacle on all sides, imagines that his personal condition is transferred to the object.[19]

Research into Byzantine church spaces has identified how the use of sunlight entering through windows at the base of the dome, for instance at Hagia Sophia in Constantinople (see figs. 53, 54), helped to create directional beams and enhance the ambient lighting within.[20] Specific materials—such as colored figured marble polished to a high gloss and gilded and colored-glass mosaics—further reflected and refracted light within the church space.[21] And as the officiants of the Mass passed around the altar with censers, incense was deployed as a medium onto which light was cast, and by which it was held, to mark divine presence within church space.[22]

Expressing awe and wonder, Photios described the dazzling and dizzying energy of sensory experience and the "saturated phenomenon," which Nicoletta Isar defines as "vision in excess" created by the "choral light" and animated materials found within Byzantine church spaces.[23] This animation would have been intensified by the movement of the officiants of the liturgy, their gold-embroidered vestments glittering, and the imagery on the vestments becoming animated, as they moved through the space (plate 116). "Chorography," or "choral vision," refers to the whirling of the mind (read: soul), based on the Platonic and Neoplatonic notion of *chorós* as found in the writings of Pseudo-Dionysius, Plotinus, and others. As in Photios's ekphrasis of the Church of the Virgin of the Pharos, light becomes an energetic force that moves the viewers to a spiritual vision as they move through the circular Byzantine church space and witness, most spectacularly, the lowering, raising, and spinning of a large *choros* (chandelier) in the center of the church apse (fig. 38; plate 114).Through "choral vision" the soul achieves an elevated state of harmony and gnosis, to contemplate the divine through a "dance of light."[24]

The Neoplatonic theology of Pseudo-Dionysius the Areopagite had in the sixth century harmonized the philosophy of pagan writers of the third century with Christian meaning; in it he emphasized visible light as a material manifestation of the divine.[25] In the eighth and ninth centuries the rites of Byzantine churches came to be performed largely behind an iconostasis or screen



FIGURE 38. *Choros* in motion, Vatopedi Monastery, Mount Athos, Greece

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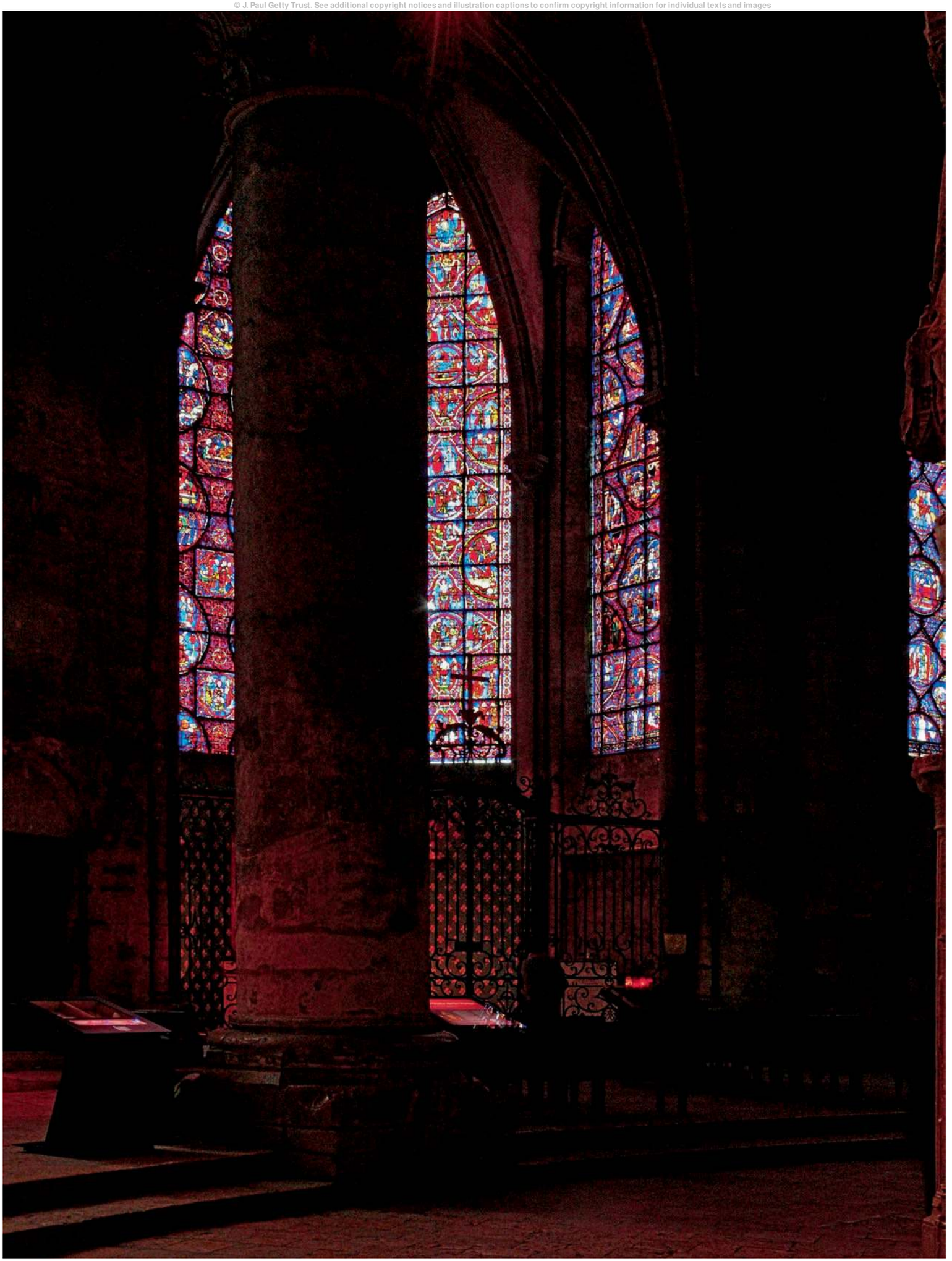
dividing the light-filled spaces of the altar from the darkness in which congregants gathered. The entrances by the clergy outside the iconostasis at high points in the liturgy brought to life, with light, movement, and visibility, the theology that was being circulated through scholarly translation practice.[26] New scholarship on late antique and Byzantine churches has shown that the strategic placements of apertures, windows, and lighting devices were fundamental to the phenomenological staging of the liturgies.[27] Solar alignments were used to highlight wall paintings, mosaics, or altars at high points of the liturgical year.[28]

Although Latin writers in the Christian West did not practice the poetics of Byzantine ekphrasis, stained glass stands as a visual testament to their shared love of light in places of worship. The windows allowed medieval Christians to channel divinity through the creation of ambient luminosity and directed the viewer's gaze to the Latin church's often complex theological imagery.[29] The simple window glazing employed in antiquity had around the eighth century developed into an art form in which the brightly colored geometric patterns of the opus sectile hardstone floors of late antique monuments were now found in jewel-toned panels of window glass. The early geometric patterns came to be mixed with figurative scenes; the earliest such glass still in situ (dating from ca. 1100) is found in Augsburg, Germany, where stately figures of the prophets once faced now-lost images of the apostles. During the Gothic period the lengthening of windows and thinning of the tracery surrounding them enabled architecture's seeming dissolution into light and created privileged zones of light within the church (plates 84, 85).[30]

No cleric is more linked with the topic of light in the Middle Ages than Abbot Suger of Saint-Denis (1081–1151). His renovation of the Carolingian royal abbey of Saint-Denis, near Paris, with the addition of a chevet that allowed light into the former gloom of the choir, is generally celebrated as the earliest occurrence of Gothic architecture. Light imagery abounds in his descriptions of the church, said by him to be "blooming with incomparable luster," so that it "might shine with inestimable splendor."[31] He described the choir as being suffused "with the most wonderful and uninterrupted light of the most sacred windows, pervading the interior beauty."[32] Suger has long been noted for his invocation of a Pseudo-Dionysian metaphysics of light, a theological tradition that celebrated the use of material light to manifest divine light.[33] In his description of the church he writes, "We had . . . painted, by the very expert hand of many masters from different nations, a splendid variety of new windows . . . urging us onward from material things to those that are immaterial."[34] Pseudo-Dionysius was a sixth-century Syrian mystic whose texts had been translated into Latin by the ninth-century scholar John Scotus Erigena (810–ca. 877), who was working in the court of the Carolingian king Charles the Bald (r. 840–77). But scholars over the past several decades have come to challenge the idea that Suger's project consciously channeled Neoplatonic theology, arguing that his imagery of light was instead drawn chiefly from the liturgy and the scriptures.[35] Others have suggested that because Suger's expansion of Saint-Denis coincided with Bernard of Clairvaux's famous attack on the excesses of monastic arts, Suger, like any good statesman, packaged his commission in a mystical theology of light to fend off criticism.[36] Still others have ascribed to the abbot a more pragmatic association with light, suggesting that the admission of sunlight through the enlarged windows could have presented a reminder of the passage of time and the liturgical hours that guided the prayers of clerics and laypeople alike.[37] Suger's so-called Moses window, still in situ at Saint-Denis, utilizes traditional strategies of typological analogy, linking Old Testament and New (see fig. 1). The abbot composed verses describing the subject matter of the window as a symbol of Christ's dual nature: Christ, who is full of the divine fire, is compared to the bush that burned without being consumed (Exod. 3:2–4). Yet, in his description of the precious sapphire glass that colored his windows, Suger displays sensory appreciation for the saturated colors of his commission and perhaps also a material pleasure in the costly glass (plate 83).[38]

William Durand (ca. 1230–96), bishop of Mende, France, likened stained-glass windows to the five senses, "which must be well structured on the outside, lest they allow in the vanities of the world; and they are open within to acquire more freely the spiritual gifts."[39] The senses were deliberately activated through light and color. For example, the deep red used in the Chapel of the Martyrs at the Cathedral de Nôtre-Dame de Chartres, when illuminated by morning light, created an immersive environment in which the theme of sacrifice was

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amplified by light and color (fig. 39).[40] In a broader sense glass and its interaction with light set the church in motion. Late medieval glass with narrative scenes often contained scrolls with excerpts from liturgical texts. Madeline Caviness has described such glass, which frequently had limited legibility, as functioning like a "solar prayer-wheel, proclaiming its message even when it was out of sight as long as daylight activated it."[41] While Gothic windows presented complex theological narratives and relationships, they also created sensorial experiences as people moved through church spaces under varied lighting conditions provided by alternating walls of deep color and passages of grisaille glass (plates 84, 85).[42] The stained glass that graced Gothic churches, like the sculpture and other artworks within, should be considered in terms of the progress of the viewer through different ambient zones and changing patterns of sunlight that activated the imagery in the glass.[43]

Besides glass, a panoply of dazzling materials—rock crystal, precious stones, gems, embroidered textiles, and gilded surfaces—contributed to the sensorium of the Latin church. Altars were the locus of visual attention during liturgical celebration. Gilded relief altar frontals of the twelfth and thirteenth centuries synopsized Christian salvation history and provided the embodied presence of holy figures. For example, the Ølst golden altar frontal features Christ in Majesty, seated on a rainbow, at center; the Christological narrative unfolds in sections around him (plate 119). The frames around Christ and each of the scenes were originally studded with rock crystal cabochons (only one is extant), a material ensemble that would have dazzled the eye, calling to mind the bejeweled gates of the Heavenly Jerusalem. An inscription on a similar altar frontal from Stadil Church in western Jutland, Denmark, directly addresses the viewer:

> You see this panel shining with golden splendor, but even more it shines through the knowledge it spread of the sacred history. For it reveals to those pure in heart the mysteries of Christ, whose own luster outshines gold. Thus, you who read by means of that [panel], purify your mind by faith if you want to behold the joys of the divine light.[44]

FIGURE 39. Chapel of the Martyrs (13th century), Cathedral de Nôtre-Dame de Chartres, France

The animating force of light has given the altar a voice. And speaking through the metaphor of light, the altar promises sacred knowledge (*cognitione sacre*), conveyed through the splendor of the altar's materials and the way its textured surface interacted with light.

Whereas an altar frontal was activated by the perceptual shifts that occur as it receives and reflects moving sunlight, candlelight, or lamplight, many other objects were intended to be seen in motion. Movable icons and paintings might be processed through the church or outdoors, in the daylight or the moonlight, during Christian ritual (plates 123, 124).[45] As the object moved, the visual conditions changed for each viewer, making the experience variable and unrepeatable. The moving object thus introduced an element of surprise as the sensorium extended to the environment outside the church.

Mosque spaces were activated by multiple sensory experiences, but the primary sensory experience was the light of God. As the Sura al-Nur, the so-called light verse in the Qurʾan (24:35), states without equivocation:

> His light is like a niche in which there is a lamp
> —the lamp is in a glass, and the glass like a brilliant star
> —lit from a blessed tree, an olive tree
> Neither from the east nor from the west,
> Whose oil almost glows,
> —Light upon light.
> God guides to His light to those whom He wishes;
> And God coins parallels for the people.
> And God is aware of everything.[46]

The Sufi theologian al-Ghazali (d. 1111) interpreted the light verse symbolically, according to the stages of cognition, or the five hierarchical levels of the brain called human spirits and lights through which knowledge is acquired: the niche represents the first chamber that receives sensory input; the glass, imagination, where images are stored in memory; the lamp, intellection, the means of abstract thought and conceptualization of the divine; the tree, deductive propositions of logical reasoning; and the oil, the highest form of spiritual

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FIGURE 40. Tile Panel with a Mihrab Niche, Syria, probably Damascus, ca. 1575. Fritware, underglaze-painted, 123 × 62 cm (48⅜ × 24⅜ in.). Toronto, Aga Khan Museum, AKM 585

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knowledge as achieved by mystics and saints.[47] Sections of the "light verse" and other Qurʾanic verses that reference the assimilation of God, light, and the heavens often appeared on lamps used in mosques and in shrines (plates 86, 99, 100). In ceramic and stonework, lamps are often depicted hanging in the mihrab, a niche in the qibla wall indicating the direction of Mecca, the focal point of prayer in the mosque (fig. 40).[48] Understood cosmologically, materially, and allegorically, light—particularly artificial lamp light—was what Julie Bonnéric has called a "sacralizing tool" in mosques; it indicated the presence of God.[49]

Through the use of light and of light-reflective and light-refractive materials, religious spaces—temples, churches, cathedrals, and mosques—became saturated sensoria that appealed to the eye and inspired the mind's eye to rise, to be drawn closer to spiritual contemplation of the beauty and oneness of God. "Science" is not the first word that comes to our minds when we, as modern viewers, enter these spaces of wonder. Yet it was indeed an accumulation of knowledge of light, optics, and the brain during the long Middle Ages that made such dazzling spectacles of luminosity and wonder possible.

Notes

1 Hans Henrik Lohfert Jørgensen, "Sensorium: A Model for Medieval Perception," in *The Saturated Sensorium: Principles of Perception and Mediation in the Middle Ages*, ed. Hans Henrik Lohfert Jørgensen, Henning Laugerud, and Laura Katrine Skinnebach (Aarhus: Aarhus University Press, 2015), 25. For an overview of ritual, sacred space, and the materials within, see Jaś Elsner, "Material Culture and Ritual: State of the Question," in *Architecture of the Sacred: Space, Ritual, and Experience from Classical Greece to Byzantium*, ed. Bonna D. Wescoat and Robert G. Ousterhout (Cambridge: Cambridge University Press, 2012), 1–26.

2 Kristin Bliksrud Aavitsland, "Incarnation: Paradoxes of Perception and Mediation in Medieval Liturgical Art," in Jørgensen, Laugerud, and Skinnebach, *The Saturated Sensorium*, 79; and Elsner, "Material Culture and Ritual," 1–2.

3 Mary Carruthers, *The Craft of Thought: Meditation, Rhetoric, and the Making of Images, 400–1200* (Cambridge: Cambridge University Press, 2000), 1–3. Carruthers discusses orthopraxy as the repetitive experiences that do not align with texts but nevertheless form a lived orthodoxy.

4 Educated medieval viewers understood that contemplation of things construed as beyond one's perceptions (what might today be called "extrasensory") led to a detachment of the soul from the body, which was a state of learning and philosophical understanding. See Megan C. McNamee, "Early Romanesque Abstraction and the 'Unconditionally Two-Dimensional Surface,'" in *Abstraction in Medieval Art: Beyond the Ornament*, ed. Elina Gertsman (Amsterdam: Amsterdam University Press, 2020), 279n9.

5 Henning Laugerud, "Memory: The Sensory Materiality of Belief and Understanding in Late Medieval Europe," in Jørgensen, Laugerud, and Skinnebach, *The Saturated Sensorium*, 259.

6 Simon Kemp and Garth J. O. Fletcher, "The Medieval Theory of the Inner Senses," *American Journal of Psychology* 106, no. 4 (Winter 1993): 559.

7 Ynez Violé O'Neill, "Diagrams of the Medieval Brain: A Study in Cerebral Localization," in *Iconography at the Crossroads: Papers from the Colloquium Sponsored by the Index of Christian Art, Princeton University, 23–24 March 1990*, ed. Brendan Cassidy (Princeton, NJ: Princeton University Press, 1993), 94.

8 Kemp and Fletcher, "The Medieval Theory of the Inner Senses," 562.

9 Kemp and Fletcher, "The Medieval Theory of the Inner Senses," 562–63.

10 O'Neill, "Diagrams of the Medieval Brain," 94–95.

11 For an overview, see Michael Bull and Jon P. Mitchell, *Ritual, Performance and the Senses* (London: Bloomsbury, 2015), especially Greg Downey, "The Importance of Repetition: Ritual as a Support to Mind," 47–49.

12 Constance Classen, "Foundations for an Anthropology of the Senses," *International Social Science Journal* 49, no. 153 (1997): 401–12.

13 For the predictive processes of the brain—how the brain anticipates what it will perceive—see the essay by Starr, this volume.

14 For the ways in which medieval Jews incorporated light into their lives—in daily life, science, philosophy, and mysticism—see the essay by Cohen, this volume.

15 J. H. Chajes, "Re-Envisioning the Evil Eye: Magic, Optical Theory, and Modern Supernaturalism in Jewish Thought," *European Journal of Jewish Studies* 15, no. 1 (December 2020): 33n9.

16 Quotation given from the *Zohar* in Chajes, "Re-Envisioning the Evil Eye," 39.

17 Abbey Kornfeld, "Seeking the Eternal Jerusalem," in *Jerusalem, 1000–1400: Every People under Heaven*, ed. Barbara Drake Boehm and Melanie Holcomb, exh. cat. (New York: Metropolitan Museum of Art, 2016), 271; and Elizabeth Eisenberg, entries on cats. 21 and 137b, in Boehm and Holcomb, *Jerusalem, 1000–1400*, 51–52, 279. Quotations from the Hebrew Bible in this paragraph are from the 1917 Jewish Publication Society translation, https://www.sefaria.org/Genesis.1?ven=The_Holy_Scriptures:_A_New_Translation_(JPS_1917)&lang=en&with=Translations&lang2=en.

18 Ruth Webb, "The Aesthetics of Sacred Space: Narrative, Metaphor, and Motion in *Ekphraseis* of Church Buildings," *Dumbarton Oaks Papers* 53 (1999): 64; and Robert S. Nelson, "To Say and to See: Ekphrasis and Vision in Byzantium," *Visuality before and beyond the Renaissance: Seeing as Others Saw*, ed. Robert S. Nelson (Cambridge: Cambridge University Press, 2002), 143–68.

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19 Quoted in John Gage, *Colour and Culture: Practice and Meaning from Antiquity to Abstraction* (London: Thames and Hudson, 1993), 276n115, quoting Cyril Mango*, The Art of the Byzantine Empire, 312–1453: Sources and Documents* (Englewood Cliffs, NJ: Prentice Hall, 1972), 185.

20 Nadine Schibille, "Light as an Aesthetic Constituent in the Architecture of Hagia Sophia in Constantinople," in *Manipolare la luce in epoca premoderna*, ed. Daniela Mondini and Vladimir Ivanovici (Mendrisio: Mendrisio Academy Press and Silvana Editoriale, 2014), 31–43; and Iuliana Gavril, "Building with Light: Spatial Qualities of the Interior of Hagia Sophia in Constantinople," in Mondini and Ivanovici, *Manipolare la luce in epoca premoderna*, 45–59. These features are also seen in Byzantine mosaics on the Italian Peninsula; see Eve Borsook, "Rhetoric or Reality: Mosaics as Expressions of a Metaphysical Idea," *Mitteilungen des Kunsthistorischen Institutes in Florenz* 44, no. 1 (2000): 5.

21 For the transformation of the interior of Hagia Sophia by its reflective surfaces of marble and gold, see the essay by Pentcheva, this volume.

22 Tera Lee Hedrick and Nina Ergin, "A Shared Culture of Heavenly Fragrance: A Comparison of Late Byzantine and Ottoman Incense Burners and Censing Practices in Religious Contexts," *Dumbarton Oaks Papers* 69 (2015): 348; and Liz James, "Senses and Sensibility in Byzantium," *Art History* 27, no. 4 (September 2004): 522–37.

23 Nicoletta Isar, "Dazzling Radiance: A Paradigm and a Quiz in Byzantine Chorography and Hierotopy," in *Icons of Space: Advances in Hierotopy*, ed. Jelena Bogdanović (London: Routledge, 2021), 50–52, 61.

24 Isar, "Dazzling Radiance," 52–56.

25 For Pseudo-Dionysius, see Paul Rorem, *Pseudo-Dionysius: A Commentary on the Texts and an Introduction to Their Influence* (New York: Oxford University Press, 1993); and Francesca Dell'Acqua and Ernesto Sergio Mainoldi, eds., *Pseudo-Dionysius and Christian Visual Culture, c. 500–900* (Cham, Switzerland: Palgrave Macmillan, 2020).

26 Jelena Bogdanović, "Rethinking the Dionysian Legacy in Medieval Architecture: East and West," in *Dionysius the Areopagite between Heresy and Orthodoxy*, ed. Filip Ivanović (Newcastle Upon Tyne: Cambridge Scholars Publishing, 2011), 129.

27 See Mondini and Ivanovici, *Manipolare la luce in epoca premoderna*; essays in this volume provide a range of compelling examples, based on recent research into positional light in church spaces.

28 See Gabriel-Dinu Herera, *The Symbolic Presence of the Sun at Pătrăuţi*, by Gabriel-Dinu Herea, trans. Alice Isabella Sullivan (Timisoara: Editura Universitatii de Vest, 2020); *Natural Light in Medieval Churches*, ed. Vladimir Ivanovici and Alice Isabella Sullivan (Leiden: Brill, 2023); Vladimir Ivanovici, *Manipulating Theophany: Light and Ritual in North Adriatic Architecture (ca. 400–ca. 800)* (Berlin: De Gruyter, 2016); and Daniela Mondini, "Da Ravenna a Vals: Luce e oscurità in architettura dal medioevo al presente," in *L'architetto generalista*, ed. Christoph Frank and Bruno Pedretti (Mendrisio: Università della Svizzera Italiana, 2013), 269–75.

29 The scholarship on medieval stained glass is vast; for bibliography, see the publications of the Corpus Vitrearum Medii Aevi, https://corpusvitrearum.org/.

30 Madeline Caviness, "Performative Interaction of Liturgy and Light: Investigations," in *Investigations in Medieval Stained Glass: Materials, Methods, and Expressions*, ed. Elizabeth Carson Pastan and Brigitte Kurmann-Schwarz (Leiden: Brill, 2019), 178.

31 *De cons.*, 2.8, trans. in *Abbot Suger on the Abbey Church of St.-Denis and Its Art Treasures*, ed. and trans. Erwin Panofsky, rev. ed. Gerda Panofsky-Soergel (1946; repr., Princeton, NJ: Princeton University Press, 1979), 87.

32 Panofsky and Panofsky-Soergel, *Abbot Suger*, 101.

33 Panofsky and Panofsky-Soergel, *Abbot Suger*. Panofsky's work has continued to inform this topic despite a growing body of important literature that has countered this view (see note 36 below).

34 Panofsky and Panofsky-Soergel, *Abbot Suger*, 75–77.

35 Andreas Speer, "Is There a Theology of the Gothic Cathedral? A Re-Reading of Abbot Suger's Writings on the Abbey Church of St.-Denis," in *The Mind's Eye: Art and Theological Argument in the Middle Ages*, ed. Jeffrey F. Hamburger and Anne-Marie Bouché (Princeton, NJ: Princeton University Press, 2006), 65–83; Bogdanović, "Rethinking the Dionysian Legacy in Medieval Architecture," 109–34; Conrad Rudolph, "Inventing the Exegetical Stained Glass Window: Suger, Hugh, and a New Elite Art," *Art Bulletin* 93, no. 4 (December 2011): 399–422; Francesca Dell'Acqua, "*L'auctoritas* dello pseudo-Dionigi e Sugerio di Saint-Denis," *Studi medievali*, 3rd ser., 55, no. 1 (2014): 189–213; and Felipe de Azevedo Ramos, "The Metaphysics of Light in the Aesthetics of Suger of Saint-Denis," *Dionysius* 32 (December 2014): 116–39.

36 Rudolph, "Inventing the Exegetical Stained Glass Window," 399.

37 Andreas Speer, "Art as Liturgy: Abbot Suger of Saint-Denis and the Question of Medieval Aesthetics," in *Roma, magistra mundi: Itineraria culturae medievalis; Mélanges offerts au Père L. E. Boyle à l'occasion de son 75e anniversaire*, ed. J. Hamesse (Louvain-la-Neuve: Fédération des Instituts d'Etudes Médiévales, 1998), 872; Speer, "Is There a Theology of the Gothic Cathedral?," 75.

38 For Suger and the dual effect of the Saint-Denis windows, both to illumine and to obscure (as the images in the glass dissolve in blinding light), see the essay by Gertsman, this volume.

39 William Durand, *Rationale divinorum officiorum*, 1.2.24, ed. A. Davril, OSB, and T. M. Thibodeau (Turnhout: Brepols, 1995), 18–20; and Herbert L. Kessler "'Consider the Glass, It Can Teach You': The Medium's Lesson," in Pastan and Kurmann-Schwarz, *Investigations in Medieval Stained Glass*, 143.

40 Claudine Lautier, "La polychromie de la cathédrale de Chartres et le vitrail," in *Licht(t)räume: Festschrift für Brigitte Kurmann-Schwarz zum 65. Geburtstag*, ed. Katharina Georgi, Barbara von Orelli-Messerli, Eva Scheiwiller-Lorber, and Angela

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Schiffhauer (Petersberg, Hesse: Imhof Verlag: 2016), 124–33, 128; and Kessler, "'Consider the Glass,'" 126.

41 Madeline Caviness, "Performative Interaction of Liturgy and Light," in Pastan and Kurmann-Schwarz, *Investigations in Medieval Stained Glass*, 184.

42 Herbert L. Kessler ("'Consider the Glass,'" 126) suggests that the field of Gothic glass should embrace the methodologies more frequently employed in Byzantine art history, which considers the effects of moving light and perception.

43 Jacqueline E. Jung, "The Kinetics of Gothic Sculpture: Movement and Apprehension in the South Transept of Strasbourg Cathedral and the Chartreuse de Champmol in Dijon," in *Mobile Eyes: Peripatetisches Sehen in den Bildkulturen der Vormoderne*, ed. David Ganz and Stefan Neuner (Leiden: Brill, 2013), 134–73.

44 Quoted in Aavitsland, "Incarnation," 85.

45 For double-sided paintings mounted on poles in order to be processed outdoors on special feast days, see the essay by Lakey, this volume.

46 *The Qur'ān*, trans. Alan Jones (Edinburgh: Edinburgh University Press, 2007), 325. See also Arzina R. Lalani, "Concept of Light in Ismaili Philosophy," *Ishraq: Islamic Philosophy Yearbook* 5 (2014): 406; For light in Islamic art, see Ladan Akbarnia, "Light in Sufism," in *The Light of the Sufis: The Mystical Arts of Islam*, ed. Ladan Akbarnia with Francesca Leoni (New Haven: Yale University Press, 2010), 10–21; and Sabiha Al Khemir, *Nur: Light in Art and Science from the Islamic World* (Seville: Focus-Abengoa Foundation, 2014).

47 Avinoam Shalem, "Amazement: The Suspended Moment of the Gaze," *Muqarnas* 32 (2015): 4–5; Ladan Akbarnia, "Light in Sufism," 11.

48 Nuha N. N. Khoury, "The Mihrab Image: Commemorative Themes in Medieval Islamic Architecture," *Muqarnas* 9 (1992): 16.

49 Julie Bonnéric, "The Symbol of Light in Classical Mosques," in *Ancient Lighting Devices: Acts of the 4th and 5th Congresses of the International Lychnological Association (Ptuj, May 2012; Sibiu, September 2015)*, ed. L. Chrzanovski, V. Vidrih Perko, and A. Nestorovic (Drémil Lafage: Éditions Mergoil, 2019), 42.

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Ohr Hashem: The Light of God in Medieval Jewish Art

ADAM S. COHEN

> In the beginning God created the heaven and the earth. Now the earth was unformed and void, and darkness was upon the face of the deep; and the spirit of God hovered over the face of the waters. And God said: "Let there be light." And there was light. And God saw the light, that it was good; and God divided the light from the darkness. And God called the light Day, and the darkness He called Night. And there was evening and there was morning, one day.
>
> —Genesis 1:1–4

The Hebrew Bible (Torah) begins, literally, at the beginning: the creation of the entire cosmos, which is initiated by the creation of light, called forth by God's very first utterance.[1] Light was distinguished from darkness, and it was called "good." For Jews in medieval Europe, the fact that the sacred biblical text began with this account of light's creation had a profound impact on everything from the performance of daily ritual practices to theological, philosophical, and scientific discourses. Objects in this exhibition, considered alongside complementary works, demonstrate the multiple practical and intellectual ways that medieval Jews incorporated light into their lives and thought about its effects and meanings.

Every day of the year the core of the morning prayer service opened with this invocation:

> Blessed are You, Lord our God, King of the Universe, Who formed light, created darkness, made peace, and created all things. He illuminates the earth for those who dwell on it, with compassion, and in His goodness renews every day, continually, the work of creation.[2]

A few paragraphs later this theme is expanded:

> He renews in His goodness, each day, continuously, the works of creation, as it is said [Ps. 136:7]: "[Give thanks to Him] Who makes the luminaries [the heavenly bodies] for His kindness is everlasting." Shine a new light upon Zion, and may we be privileged soon to enjoy its brightness. Blessed are You, Lord, Who forms the luminaries.

The daily prayer counterbalances a universalizing statement about God as the creator of all things—above all, light—with a desire that God shine the light particularly on Zion, a symbol specific to the Jewish people.[3]

Every week of the year, as sunset fell on Friday, medieval Jewish households kindled lights to inaugurate the holy Sabbath (they did the same for each festival). The Mishnah, the compilation of the Oral Law, provided numerous legal instructions about this practice; the late antique Talmudic commentaries on the Mishnah offered key symbolic interpretations, and homiletic texts (*midrashim*) from throughout the Middle Ages expanded on these.[4] The lights were understood symbolically to be the essence of joy (*oneg*) that was central to the Sabbath experience; they were equated with peace, harmony, and domestic tranquility. A poor Jew was legally required to prioritize buying oil for the Sabbath lamp even over buying food or wine for the sacred day. At the other end of the socioeconomic spectrum some wealthy medieval Jews acquired substantial brass or bronze lamps, such as a technologically impressive twelfth-century example in Erfurt, Germany; it boasts twelve nozzles for wicks and four zones of figural decoration that show Hebrew prophets and scenes from the lives of David and Samson (fig. 41).[5] Although very few of these medieval lamps survive, their importance is attested by the many times they are depicted in household scenes in the Haggadah, the book containing the prayers and texts for the Passover (*Pesach*) seder (fig. 42).[6]

Every year on Passover Jews celebrated the Exodus from Egypt, highlighted by the evening seder (literally, "order"), a ritual conducted at home that featured telling the story of God's redemption of the children of Israel, singing songs of praise, and eating various ritual foods. These included four cups of wine, a bitter herb (*maror*), and matzo, the unleavened bread. In preparation,

FIGURE 41. Sabbath Lamp, probably Erfurt, Germany, ca. 1160–80. Bronze, shaft: H: 41 cm (16 1/16 in.); max. Diam: 8.6 cm (3 3/8 in.); oil bowl: Diam: 35 cm (13 3/4 in.); total H: 76 cm (29 15/16 in.). Erfurt, St. Marien Cathedral

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FIGURE 42. Seder Scene in the Erna Michael Haggadah, southern Germany or Bohemia(?), 1400–1420. Handwritten on parchment; dark brown and red ink, tempera, gold and silver leaf; square and semicursive Ashkenazic script, full folio: 35 × 25.5 cm (13¾ × 10 1/16 in.). Jerusalem, Israel Museum, Gift of Jakob Michael, New York, in memory of his wife, Erna Sondheimer Michael, B66.03.0549, fol. 40

however, Jews had to search their homes to make sure there was no leaven anywhere, a ritual depicted in many medieval Haggadahs (fig. 43). In the lower right corner of this page, the head of the household is diligently investigating a small alcove, and he holds a large candle to make sure he can see into every nook and cranny. Light was here a practical instrument for ritual performance.

The four illustrations on this page mark the transition from the ancient Exodus narrative to the contemporary lives of the book's owners. The book, probably made in Catalonia in the 1320s, is commonly called the Golden Haggadah because of the lavish use of gold throughout. It creates a shimmering, ever-changing play of light on the surface of each page, which not only captures the viewer's attention but also speaks to the high status of a patron who could afford such a richly decorated book.

In medieval Germany (Ashkenaz) Jews supplemented festival prayers with complex liturgical poems (*piyyutim*; sing. *piyyut*).[7] One recited on Passover was "The Light of Salvation," whose text was based on the Song of Songs.[8] This biblical love song was understood by Jews as a mystical description of the relationship between God and the children of Israel, and it was given special attention on the holiday of redemption. In decorating the text of this *piyyut*, the artist of one mahzor (the community's special festival prayer book) made the unusual choice to emphasize a cosmic dimension (fig. 44).[9] The opening word—*Ohr*, "Light"—has been enlarged (as was typical)

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FIGURE 43. Passover Scenes in the Golden Haggadah, Catalonia, Spain, ca. 1320–30. Vellum and paper codex, full folio: 24.5 × 19–20 cm (9⅝ × 7½–7⅞ in.). London, British Library, Add MS 27210, fol. 15 (detail)

and rendered in glittering gold. At the top of the page are medallions with the sun and the moon, also in gold to demonstrate the radiance of these luminaries. Although artistically modest, the conception of the page reminds the Jew praying on Passover that the historical Exodus was set in motion when God called forth light at the very beginning of time.

Light's role in creation was in many ways central to medieval philosophy, and it is in philosophical texts that we find the most explicit expressions of what (some) medieval Jews thought about light. Perhaps the greatest of these thinkers was Rabbi Moses ben Maimon, known as Maimonides (ca. 1135–1204).[10] His monumental *Guide for the Perplexed* set out a rationalist theological approach to the Bible and the world. What distinguished the *Guide* was Maimonides's willingness to grapple with key perspectives in non-Jewish philosophy, which meant acknowledging that such figures as Aristotle had expressed truth. Maimonides's goal was to demonstrate how that truth was consistent with, and indeed embedded within, the Hebrew Bible.

A luxurious manuscript of the *Guide for the Perplexed,* completed in Barcelona in 1347/48 for Menachem Betsalel, physician to King Peter IV of Aragon, captures the spirit of Maimonides's treatise (plate 15).[11] In book 2 of the *Guide*, Maimonides affirms twenty-five Aristotelian propositions about the nature of the universe, such as "Motion is only possible in time, and the idea of time

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FIGURE 44. Decorated page with Passover prayer (*piyyut*), Festival Prayer Book (mahzor), Franconia, late thirteenth century. Parchment, leaf: 50 × 36–36.7 cm (19 11/16 × 14 3/16–14 7/16 in.). Arras, Bibliothèque municipale, MS 560, fol. 72

cannot be conceived except in connection to motion; things that do not move have no relation to time."[12] In the illustration that introduces book 2, several philosophers gesticulate in the act of discourse, but most prominent is the seated figure, presumably Aristotle, who holds a book and an astrolabe. The astrolabe was a complex device widely employed in the medieval Islamic world for astronomical calculations based on the observable movements of the heavenly bodies, and several extant examples have Hebrew characters (plate 14).[13] Jews played an important role in medieval science, especially astronomy. Some were actively involved in transcultural activities, such as Isaac ben Sid and Judah ben Moses ha-Cohen, who in the mid-thirteenth century wrote the Castilian version of the Alfonsine Tables at the court of Alfonso X (the Wise), king of Castile and León.[14] Others brought scientific inquiry to their own community by writing in Hebrew: in the fourteenth century, for example, Samuel ben Judah of Marseille (b. 1294) began a commentary on Ptolemy's *Almagest* (the most fundamental work for medieval astronomy, which Samuel knew in an Arabic translation), while Levi ben Gerson (Gersonides) contended with Aristotle and Ibn Rushd (Averroës) in wrestling with such problems as the precise relation between the sun's light and heat.[15] In Menachem Betsalel's illustrated *Guide*, the astrolabe represents the rational science of Aristotle (and others), and the latter's gaze directs the viewer to the top of the square composition, which shows the sun, moon, and stars—the luminaries whose motions the astrolabe charts and, by extension, the entire cosmological system that the philosopher-scientist seeks to understand.

In the second part of book 2, Maimonides pivots to the question of prophecy, which to him was another means by which the intellect can know God. He characterizes prophecy as comparable to lightning flashes that illuminate a person's understanding of the divine. Most people, of course, toil endlessly in the dark, but some are occasionally granted such flashes. The greatest prophet was the biblical Moses, whose lightning flashes were as frequent as if he were perpetually in daylight, that is, in possession of a completely rational understanding of God. Other medieval Jewish philosophers disagreed with Maimonides, including Hasdai Crescas (1340–ca. 1410), whose philosophical response to Maimonides was titled *Ohr Hashem* (*Light of the Lord*).[16] It opens with a series of verses from the book of Psalms that emphasize light—for example, "Shine Your face upon Your servant; save me with Your loving kindness" (Ps. 31:17). Like Maimonides, Crescas focused on the nature of Moses's prophecy, but for him the beams of light that shone from Moses's face (Exod. 34:29–35) were a demonstration not of the prophet's own intellect but of God's miraculous gift. Just as this was bestowed upon Moses as a sign of the Lord's love and spiritual presence, so could it be granted to any Jew.[17]

Medieval kabbalistic (mystical) thinkers sought to connect spiritually with God, and because the first and

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primary creation was light—and thus the thing most immediately attached to God—it was the subject of intense inquiry. Two of the most important medieval treatises (both anonymous works written in Spain) signaled the centrality of light in their titles: the *Zohar* (the word means "radiance") and the *Sefer HaBahir* (*The Book of Illumination*).[18] A third, by Rabbi Joseph Gikatilla (1248–1305), was titled *Sha'arei Ohrah* (*Gates of Light*). In a fifteenth-century manuscript the scribe introduced the work with images that crystallize several important kabbalistic ideas (fig. 45).[19] The page is dominated by a large golden menorah (candelabrum) flanked by two sefirotic tree diagrams; the sefirot were the ten divine emanations or attributes whose nature and relationships kabbalists sought to comprehend. The diagram on the left is inscribed with ten names of God, and balancing it on the right is the same diagrammatic structure with ten kinds of light. One, for example, is *ohr m'bahir* (light from illumination), which standard kabbalistic texts define as *zohar m'ziv* (radiance from splendor). Even without getting into the deep and sometimes unfathomable details of kabbalah, the paired diagrams demonstrate the intrinsic divinity of light.

The manuscript's opening page also makes clear that the menorah served as a central vehicle for kabbalistic thought. For Gikatilla and others, the menorah that God instructed Moses to craft for the desert Tabernacle (Exod. 25:31–40) and that was later in the permanent Temple in Jerusalem (1 Kings 7:49; 2 Chron. 4:7) was a microcosm of the universe: "The menorah is made completely of pure gold, and the lamps are aligned so as to shed light, just as the seven planets are positioned so as to shed light; and these seven lamps correspond to the seven planets."[20]

Other kabbalists linked the details of the menorah to the sefirotic emanations, emphasizing that just as the menorah was cast in a single piece but had different branches emitting light, so were the emanations multiple facets of a single divine unity.

The menorah was one of the most common motifs in medieval Hebrew manuscript illumination, appearing in dozens of Bibles and telescoping a range of overlapping meanings. It was often juxtaposed to an array of other golden implements from the Tabernacle and Temple (Exod. 25ff.); collectively, they visually communicated that the Bible was a "miniature sanctuary" (*mikhdashyah*) that in some measure replaced the lost Temple in Jerusalem.[21]

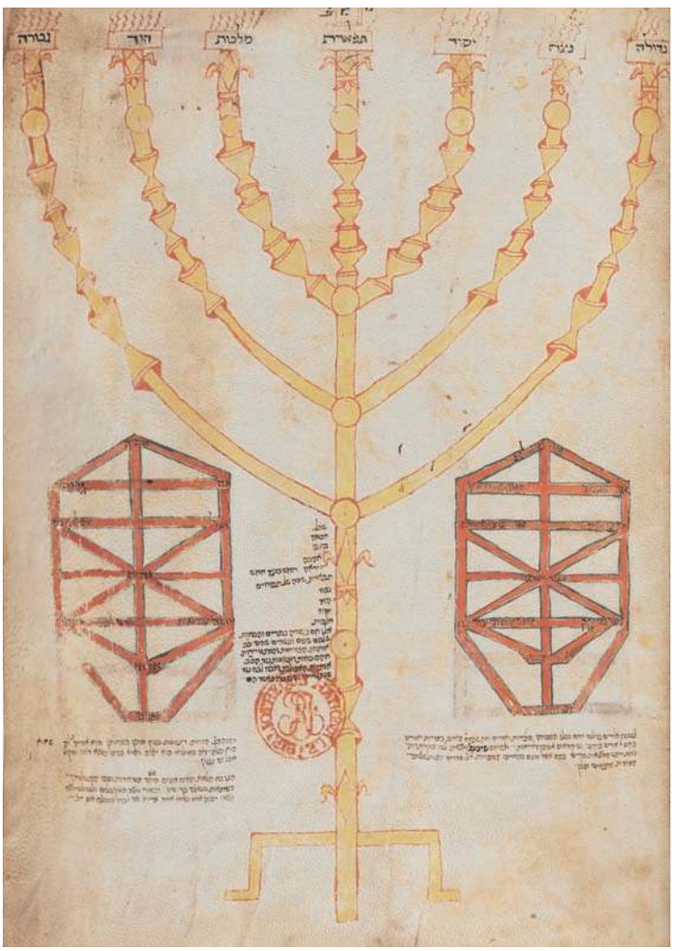


FIGURE 45. Menorah and Sefirotic Tree Diagrams in *Sha'arei Ohrah* (The Gates of Light), Toledo, 15th century. Joseph Gikatilla (Spanish, 1248–1305). Tempera colors and ink on parchment, full folio: 27 × 19.8 cm (10⅝ × 7 15/16 in.). Paris, Bibliothèque nationale de France, Hébreu 819, opening page

One additional detail, in the fourteenth-century Duke of Sussex's Catalan Bible, in the lower left corner of folio 4r, is a small green tree that evokes Jerusalem's Mount of Olives, the site where, according to the prophet Zechariah, God will restore Israel's sovereignty (Zech. 14) (plate 97).[22] In a related vision Zechariah sees a golden menorah whose lamps would be fed by the oil from two olive trees (Zech. 4:1–3). It was specifically Zechariah's future, messianic menorah that one artist chose as the

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FIGURE 46. *Menorah of Zechariah* in the Cervera Bible, Cervera, Catalonia, Iberia (Spain), 1299–1300. Joseph ha-Tzarfati (French[?], active ca. 1300). Tempera, gold, and ink on parchment, full folio: 28.2 × 22 cm (11⅛ × 8⅔ in.). Lisbon, Biblioteca Nacional de Portugal, IL.72, fol. 316v

sole full-page illumination in a deluxe Bible completed in Cervera (Catalonia) in 1300 (fig. 46).[23] Even though it lacks the framing verses that in other Bibles make the point explicit, a golden menorah like the one depicted in the late thirteenth-century Rothschild Pentateuch encapsulates a cluster of metaphors that equate its light with the light of God, the divine wisdom of the Torah, and the illumination gained by the individual studying it (plate 98).[24] Not every medieval Jew was an enlightened philosopher in the Maimonidean sense, but anyone looking at the brilliant golden candelabra in these Bibles would have been reminded of the lost Temple of the past, of aspirations for a restored Temple in the future, and of the many ways that God and his light illuminated Jewish practice and belief in the medieval present.

Notes

I thank Kristen Collins, Nancy K. Turner, Yossi J. H. Chajes, and Linda Safran for their most helpful assistance.

1 In this essay I quote from the 1917 Jewish Publication Society translation of the Torah, available online at https://www.sefaria.org/Genesis.1?ven=The_Holy_Scriptures:_A_New_Translation_(JPS_1917)&lang=en&with=Translations&lang2=en. All translations from the Hebrew are taken from sefaria.org.

2 The translations of this and the following prayer book excerpts are based on *The Metsudah Siddur: A New Linear Siddur with English Translation and Anthology of Classic Commentaries = Sidur Metsudat Avraham*, by Avrohom Davis (New York: Metsudah Publications, 1981), https://www.sefaria.org/Siddur_Ashkenaz%2C_Weekday%2C_Shacharit%2C_Blessings_of_the_Shema%2C_First_Blessing_before_Shema.1?ven=Ha-Siddur_Ha-Shalem_(1949)&vhe=Daat_Siddur_Ashkenaz&lang=bi.

3 These prayers are still part of the Jewish liturgy and can be found in any edition of the prayer book. For a modern commentary, see Elie Munk, *The World of Prayer*, 2 vols. (Jerusalem: Feldheim, 1961–63), 1: 10–13, 90–97, 106. In traditional Hebrew sources "Zion" could refer to a mountain in Jerusalem, all of Jerusalem, the entire land of Israel, or the Jewish people as a whole. The tension between the universal and the particular recurs in the philosophical texts discussed below.

4 There is extensive literature on the practical and symbolic aspects of the Sabbath lights. Particularly clear is Ismar Schorsch, "The Meaning of the Shabbat Candles," JTS Torah Online, accessed April 30, 2023, https://www.jtsa.edu/torah/the-meaning-of-the-shabbat-candles/.

5 Hans Gerhard Meyer, *Eine Sabbatampel im Erfurter Dom* (Hildesheim: Olms, 1982); and Hiltrud Westermann-Angerhausen, "Die Bronzeampel im Erfurter Dom: Technische Aspekte und kunsthistorischer Kontext eines Bronzegusses aus dem 12. Jahrhundert,"

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in *Zu Bild und Text im jüdisch-christlichen Kontext im Mittelalter* (Jena: Bussert & Stadeler, 2014), 166–81.

6 For a brief consideration of seder depictions, see Vivian Mann, "'New' Examples of Jewish Ceremonial Art from Ashkenaz," *Artibus et Historiae* 9 (1988): 13–24, esp. n. 55. For an introduction to the Haggadah, see Adam S. Cohen, *Signs and Wonders: 100 Haggada Masterpieces* (New Milford, CT: Toby Press, 2018), esp. 35, 39, and 73 for images of medieval lamps.

7 Laura Lieber, "Piyyut," in *Oxford Bibliographies Online*, doi: 10.1093/OBO/9780199840731-0059. Sefaradi (or Sephardic) Jews in Iberia followed local rabbinic opinions that rejected these as obscure barriers to prayer rather than enhancements.

8 The composition is attributed to Rabbi Solomon the Babylonian, a tenth-century liturgist from Italy (despite his nickname). For a brief consideration, see Leon Weinberger, *Jewish Hymnography: A Literary History* (Liverpool: Littman Library of Jewish Civilization, 1998), 144, 154.

9 On this manuscript, see Gabrielle Sed-Rajna, *Les manuscrits hébreux enluminés des bibliothèques de France* (Leuven: Peeters, 1994), 201–5. The mahzor was one of the most richly decorated Hebrew manuscripts in medieval central Europe; for an overview, see Gabrielle Sed-Rajna, *Le mahzor enluminé* (Leiden: Brill, 1983).

10 Maimonides, who was born in Córdoba, fled Spain after the Almohad conquest in 1148; in Fustat, Egypt, he was head of the Jewish community and served as physician to Sultan Salah al-Din Yusuf ibn Ayyub (Saladin). Key scholarly works from the vast literature on Maimonides include Kenneth Seeskin, ed., *The Cambridge Companion to Maimonides* (Cambridge: Cambridge University Press, 2005), and Moshe Halbertal, *Maimonides: Life and Thought* (Princeton, NJ: Princeton University Press, 2013).

11 The manuscript was written in Hebrew by a scribe named Levi ben Isaac and illuminated by the workshop of Ferrer Bassa, a Christian painter who produced illuminated manuscripts for King Peter. Both Menachem Betsalel and Bassa died in 1348, presumably victims of the bubonic plague that swept through Europe.

12 *The Guide for the Perplexed by Moses Maimonides*, trans. Michael Friedländer, 4th rev. ed. (New York: E. P. Dutton, 1904), 146, sefaria.org https://www.sefaria.org/Guide_for_the_Perplexed%2C_Part_2_Introduction.21?lang=en.

13 For astrolabes in the medieval Islamic world, see the essay by Arslan, this volume; for astrolabes in medieval Europe, see the essay by Falk, this volume. See, in general, Josefina Rodríguez-Arribas et al., eds., *Astrolabes in Medieval Cultures* (Leiden: Brill, 2019), which emerged from a Warburg Institute project, Astrolabes in Jewish Culture.

14 See the essays in Gad Freudenthal, ed., *Science in Medieval Jewish Cultures* (New York: Cambridge University Press, 2011), esp. Bernard R. Goldstein, "Astronomy among Jews in the Middle Ages," 136–46.

15 In addition to Goldstein, "Astronomy," see the essays collected in Y. Tzvi Langermann, *The Jews and the Sciences in the Middle Ages* (Aldershot, England: Variorum, 1999), esp. "Gersonides on the Magnet and the Heat of the Sun," 267–84.

16 Hasdai Crescas, *Light of the Lord (Ohr Hashem)*, trans. Roslyn Weiss (Oxford: Oxford University Press, 2018). Despite being highly regarded by the kings of Aragón, Crescas was briefly imprisoned in 1378 on a charge of desecration of the Host; his son was among those murdered in the Barcelona pogrom of 1391.

17 James A. Diamond, "The Inexhaustible Metaphor of Light: Illuminating the Fault Lines between Crescas and Maimonides," *Journal of Textual Reasoning* 13, no. 1 (2022), https://scholarworks.wm.edu/jtr/vol13/iss1/.

18 Still fundamental is Gershom Scholem's 1962 work, originally published in German but now available as *Origins of the Kabbalah*, ed. R. J. Zwi Werblowsky, trans. Allan Arkush (Philadelphia: Jewish Publication Society; Princeton, NJ: Princeton University Press, 1987). See also Elliot Wolfson, "Hermeneutics of Light in Medieval Kabbalah," in *The Presence of Light: Divine Radiance and Religious Experience*, ed. Matthew Kapstein (Chicago: University of Chicago Press, 2004), 105–18.

19 See, in general, Elka Morlok, *Rabbi Joseph Gikatilla's Hermeneutics* (Tübingen: Mohr Siebeck, 2011); and J. H. Chajes, *The Kabbalistic Tree* (University Park: Pennsylvania State University Press, 2022). On the manuscript, see Sed-Rajna, *Les manuscrits hébreux enluminés*, 108–9.

20 Cited in Moshe Idel's illuminating essay "*Binah*, the Eighth *Sefirah*: The Menorah in Kabbala," in *In the Light of the Menorah: Story of a Symbol*, ed. Yael Israeli (Jerusalem: Israel Museum; Philadelphia: Jewish Publication Society, 1999), 143–46.

21 Bezalel Narkiss, "The Menorah in Illuminated Hebrew Manuscripts of the Middle Ages," in Israeli, *In the Light of the Menorah*, 81–86; and Katrin Kogman-Appel, "Sephardic Ideas in Ashkenaz: Visualizing the Temple in Medieval Regensburg," *Simon Dubnow Institute Yearbook* 8 (2009): 245–77.

22 On the theme in general, see Eva Frojmovic, "Messianic Politics in Re-Christianized Spain: Images of the Sanctuary in Hebrew Bible Manuscripts," in *Imagining the Self, Imagining the Other*, ed. Eva Frojmovic (Leiden: Brill, 2002), 91–128.

23 Thérèse Metzger, "L'illustration biblique dans la bible hébraïque Ms. Iluminado 72 de la Bibliothèque nationale de Lisbonne," *Revista da Biblioteca Nacional* 5, no. 2 (1990): 61–108. The Bible contains a second, smaller menorah between Exodus and Leviticus (fol. 60), which is where many Bibles have pictures of the Temple implements. In a decorative colophon on folio 449, the artist identifies himself as Joseph the Frenchman, but nothing further is known about him.

24 Frojmovic, "Messianic Politics."

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Capturing the Gaze

ABBEY STOCKSTILL

Writing at the beginning of the eleventh century, the medieval mathematician and physicist Ibn al-Haytham (965–ca. 1040) described a key principle of aesthetics in the Islamic world: "Bright and pure colors and designs are more beautiful when regularly and uniformly ordered than when they have no order."[1] Colors, as manifestations of light, were best observed when clearly distinguished from one another. For him, colors were beautiful not in isolation but in their combination. Contrast, conjunction, proportion, and harmony among colors elicited an innate sense of aesthetic pleasure regardless of one's sociocultural background. This was more than his individual artistic opinion, however; in the time of Ibn al-Haytham the aesthetics of beauty had enormous philosophical and metaphysical import.

Ibn al-Haytham is perhaps most famous for his treatise on optics, known as the *Kitab al-Manazir*, in which he understood vision to be a compilation of properties perceived by the eye, through rays that emanated from the object itself (a theory known as intromission). This was a revolutionary understanding of vision at the time, breaking with the Euclidean theory that proposed vision to be a geometric process in which the eye emitted a series of rays that fell upon objects and refracted light back to the eye at different angles (often referred to as the extramission theory).[2] This theory, which had been translated from Greek into Arabic early in the ninth century, held great sway in both intellectual and medical circles. It had been translated and critiqued by the Abbasid-era scholar al-Kindi (ca. 800–870), who offered mathematical proofs for the seven key components of Euclid's argument, and the physician al-Razi (854–935) relied on this understanding of the eye in his early medical writings on neurology.[3] Ibn al-Haytham, by comparison, favored an understanding rooted in the physical sciences, or "natural philosophy," in which vision was not an automated process performed by the eye, but rather a psychological relationship between the mind and the world around it, as channeled through the eye itself (plate 40).

Instrumental to this process of perception were the key qualities of light and color, two sides of the same optical property. The eye received the rays of light and color emitted by any visible object which the mind then combined into a coherent image, taking into account twenty-two properties to discern the object before it. Of these, only light and color were considered inherent attributes—that is, absolutes that were perceived automatically by pure sensation (*bi mujarrad al-ḥiss*). To be fully appreciated, the others demanded faculties of judgment (*al-tamyīz*), comparison (*al-qiyās*), and inference (*al-istidlāl*) that required training and skill. Color, understood as a quality of light, was subjective only in its discernment. Ibn al-Haytham gives the example of distinguishing between different shades of green, a process that he describes as actually falling under another property of perception: similarity (*naẓīr*).[4] Depending on the disparity between the "strengths" of the two colors, discernment of them will be more or less effective. But Ibn al-Haytham was adamant that this is a process that occurred within the eye, rather than within the object. Any difficulty one had in distinguishing colors from one another lay within the individual capacity for discernment, not within what he terms the sensation of the color itself.

Essentially, Ibn al-Haytham was making a medieval distinction between what are today termed *saturation* and *value*. Saturation, the intensity or strength of a given color, and value, the amount of lightness or darkness in a color, were interpreted properties and therefore subject to intellectual fallibility. This phenomenon was explored by his contemporary Ibn Sina (known as Avicenna in European sources; 980–1037), who theorized that the visible color spectrum was a manifestation of three paths from white to black featuring different saturations and values of pale, red, and indigo.[5] Nearly two centuries later Nasir al-Din al-Tusi (1201–1274) expanded on Ibn Sina's color theory, stating that there were no fewer than five paths between whiteness and blackness, adding yellow and green to Ibn Sina's collection.[6] But this debate was precisely what Ibn al-Haytham cautioned against, as the fluidity of saturation and value muddied the full expression of the color spectrum. The key guiding principle was light's, and therefore color's, essential nature as a sensation, a quality meant to be not intellectually experienced but profoundly comprehended as a universal truth. At its most immediate level, light made the physical world tangible to visual perception through color, while remaining an invisible quality in and of itself. But on a more philosophical level, light could refer allusively to the eye, which was conceived as the instrument of intellect.

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FIGURE 47. Two Pages of a Qurʾan, showing the first five verses of the Sura al-Nur (in Arabic), Seljuq Iran, 582 AH/ca. 1186. Black ink and gold on paper, full folio: 43 × 31.5 cm (16 15⁄16 × 12 3⁄8 in.). Dublin, Chester Beatty, CBL Is 1438, fols. 124b–125

The connection between knowledge and light was another Classical inheritance, one that was expanded upon in the intellectual milieu of Abbasid Baghdad and as part of the so-called Sunni revival of the eleventh and twelfth centuries. This period saw a rise in institutionalized Islamic mysticism, Sufism, as a way to reconcile the necessity of describing the divine attributes with the ultimate knowledge that the full aspect of God would remain perennially unknowable.[7] In the Qurʾan God is repeatedly described using metaphors of light as a symbol of knowledge, as opposed to the darkness of ignorance. Sura al-Nur, the famous "light verse" of the Qurʾan (24:35), describes God as the light of the heavens and the earth (fig. 47):

> His light is like a niche in which there is a lamp
> —the lamp is in a glass, and the glass like a brilliant star
> —lit from a blessed tree, an olive tree
> Neither from the east nor from the west,
> Whose oil almost glows,
> —Light upon light.

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God guides to His light to those whom He wishes;
And God coins parallels for the people.
And God is aware of everything.[8]

Here we see a connection between the experience of knowledge and the act of looking, framed as God's guidance along a path of righteousness. Prevailing Sufi thought considered light something immaterial, the means of perception rather than perception itself.[9] The metaphoric nature of such descriptions connected spiritual and intellectual enlightenment to the physiological experience, linking the physical and the metaphysical.

Philosophers of the period thus understood the act of looking, of utilizing the divine light of illumination, as the intuitive perception of the reflected beauty of God within the created universe. Recognizing beauty in both its naturally occurring and its man-made forms was an act of devotion and contemplation of the divine. Ibn al-Haytham's *Kitab al-Manazir* was part of a much larger intellectual debate on the question of beauty, on whether an objective conception of beauty existed, and, if so, how it was to be defined. Treatises such as the tenth-century *Rasaʾil al-Ikhwan al-Sifaʾ* (The letters of the Brethren of Purity) popularized this debate by discussing aesthetics through a cosmological framework, in which beauty held the power to purify the soul. A form of aesthetic perception known as *dhawq* was understood as the psychological effect of "moving the soul." Although the experience was subjective, the standards that elicited it were not, and thus a formal codification of aesthetic principles was necessary.[10]

This was no abstract concept but a concrete one based on the understanding of architecture and the decorative arts as expressions of applied mathematics. The field of mathematics was considered the highest of the sciences and the root from which all other sciences derived, which is why scholars like al-Kindi and Ibn al-Haytham tended to express their scientific models through mathematical formulations. And if mathematics was the abstract method through which metaphysical enlightenment could be reached, then geometry was its physical manifestation.[11] Proportional ratios linked fields as seemingly disparate as poetry, music, painting, calligraphy, and architectural craft, each of which was intended to delight the soul with its harmonies. Each of these disciplinary proportions was understood to echo the divine within the soul, paralleling the harmonies of divine creation as illustrated in the astronomical cosmos and natural world. For example, this period saw an increasingly formalized proportion in the Arabic script based on the length of the first letter in the Arabic alphabet, the *alif*, from which the rest of the script—whether encoded on the page, in cloth, or out of stone—was derived.[12] Likewise, the practice of creating complex geometric patterns that were logical yet dizzyingly complex took on connotations of aesthetic purity and emotional immediacy. Within this model beauty is conceived as a harmonious parallel in which, Gülru Necipoğlu has written, the "creative imagination of the artist or artisan, nurtured by the inner (spiritual) senses, [is] complemented by the outer (corporeal) senses."[13] The duality established here connected the human world with the divine, the mortal with the eternal, and the point at which the two touched was the expression of harmonious proportion, whether natural or man-made.

For Ibn al-Haytham stronger colors were inherently more beautiful than softer ones, for they indicated a greater presence of light (*nūr*), which he considered the ultimate source of visual beauty. But these bright colors could be enhanced or accentuated through their proportional variation, since the kinetic nature of distinct contrasts engaged the gaze in a prolonged act of looking. Geometric strapwork, calligraphy, and vegetal scrolls were all artistic methods intended to force the viewer's gaze to pause, to become caught in the process of looking. The interplay between light and color within a textured surface challenged the sense of perception, eliciting a meditative attitude while simultaneously blurring the boundaries between the other optical properties.

This preference for abstraction and complex geometric forms has been called the "*girih* mode" by scholars (*girih* is a modern Persian artisanal term meaning "knot"), in reference to interlocking geometric strapwork often based on star-and-polygon patterns (fig. 48; plate 106).[14] The intricacy of these patterns meant that they could be applied in an infinite variety of combinations, filling both two- and three-dimensional spaces. Flat surfaces became fields for articulating complex geometries through pattern, texture, and color, and ornament became the chief medium of artistic expression. Muqarnas, the three-dimensional puzzle-like form of architectural vaulting that is one

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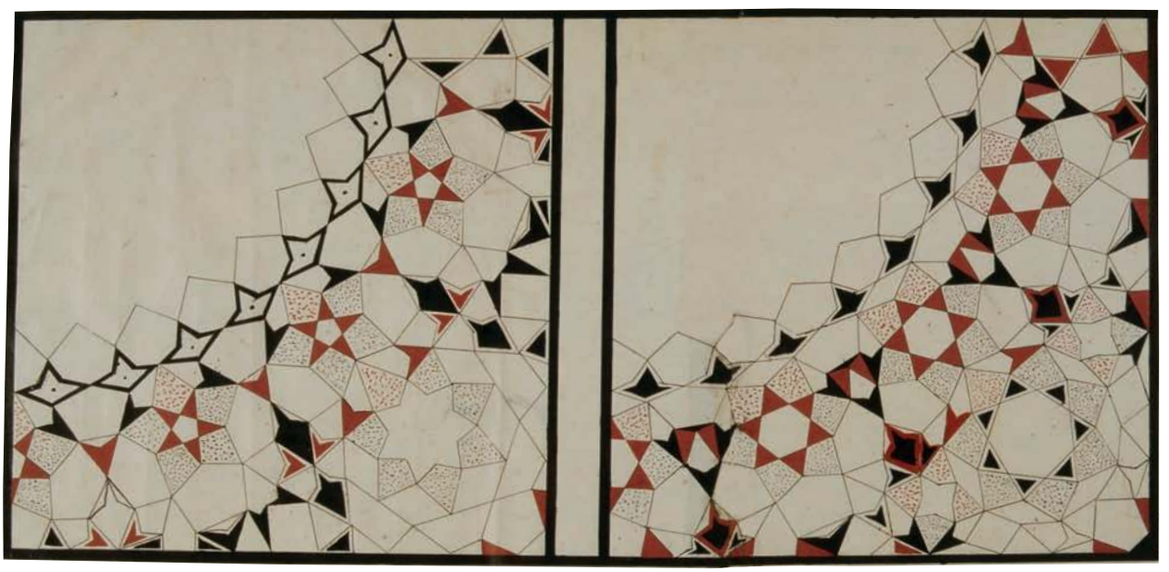


FIGURE 48. Geometric Patterns from the Topkapı Scroll, Timurid Iran, late 9th or early 10th century AH/late 15th or early 16th century. Ink and colors on paper, 29 m × 34 cm (1141¾ × 13 3⁄16 in.). Istanbul, Topkapı Palace Museum, MS H. 1956

of the most recognizable innovations of Islamic architecture, emerged from this practice (figs. 49, 50).[15] Often articulated through brightly colored tile, brick, or painted stucco, muqarnas blurred the boundaries of a given space, creating undulating movement across a static surface.

Most scholars have tended to focus on individual ornamental elements in isolation, seeking mimetic meaning in the abstract or else tracing the development of a motif across time and space.[16] Ornament, as a tactile and kinetic surface treatment, held moralistic or qualitative value for many of the twentieth-century scholars who discussed its application across the Islamic world.[17] But as the medieval sources hint, ornament in the Islamic tradition was concerned more with the phenomenological potential of its interaction with the viewer. This was not the product of the individual object or material; it was, rather, the experiential effect of the object, the environment, and the viewer coming together in a particular moment. What is more, ornament became a mediator for the spiritual experience of art, what Oleg Grabar termed a relationship of love in the Neoplatonic tradition in which the work of art, its creators, and its viewers were drawn together toward the divine.[18] The visual arts were active participants in the communication between the divine and natural realms, and the aesthetic principles undergirding art in the Islamic world were created with the purpose of eliciting specific and targeted psychological responses in the eyes and minds of the faithful.

Although no texts exist from the artist's perspective to explicitly detail how the conjunction of these elements worked, many objects and spaces in the Islamic world exhibited self-referential inscriptions or motifs that encouraged the viewer to meditate and reflect. In the Alhambra, the famous fourteenth-century network of palaces built by the last Nasrid kings of Granada, the Sala de Barca features poetic inscriptions that make reference to its own architectural spaces, inviting the viewer to stop and reflect—not only to read the inscriptions but also to meditate on the experience of being in the royal presence.[19] Although they did not claim the title of caliph (which encompassed both spiritual and political

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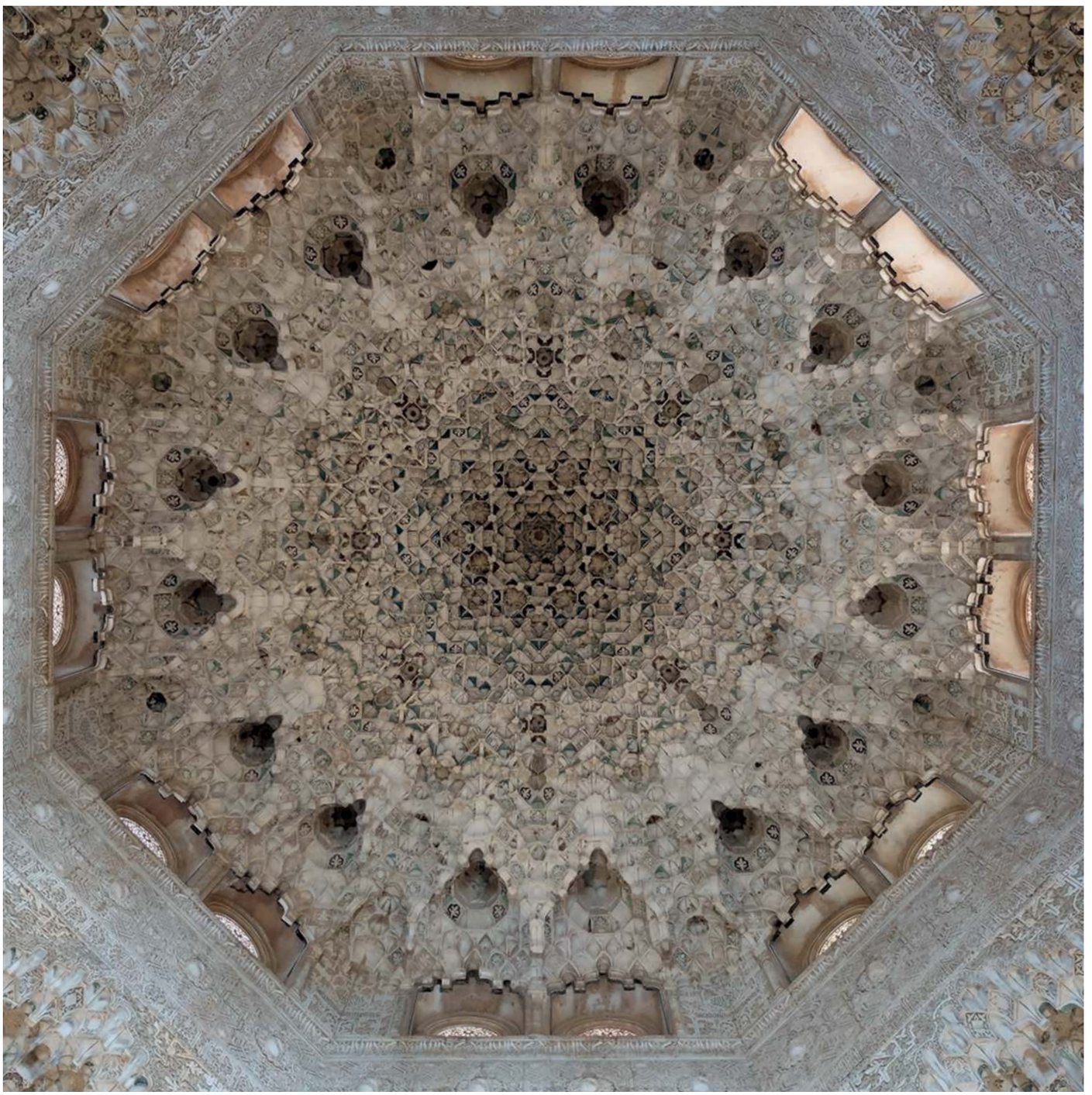


FIGURE 49. Muqarnas Dome, Sala de Dos Hermanas, ca. 1354–58. Granada, Alhambra

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FIGURE 50. Muqarnas Element, Spain, late 15th or 16th century. Carved wood, 86 × 73.5 cm (33⅞ × 28 15⁄16 in.). Toronto, Aga Khan Museum, AKM 892

leadership), the Nasrids nevertheless participated in a long lineage in the Islamic West of divinely sanctioned rulers, and these inscriptions facilitated that indirect connection through references to the perfection of God's creation. Poems such as that inscribed at the base of the muqarnas dome in the Sala de Dos Hermanas made allusions to celestial bodies that rotated around the figure of the Nasrid king, an effect heightened by the shifting light patterns along the ceiling (see fig. 49).[20]

A tile panel from Natanz, Iran, features the curved outline of a mihrab niche and a hanging lamp among inscriptions of Qurʾanic verses, hinting at the illuminationist metaphors espoused by medieval Sufi doctrine (fig. 51). The arch itself is formed through a manipulation of the calligraphic script, turning a portion of the sura—"he will suffice for you against them"—into the architectural voussoirs framing the lamp of illumination. The panel likely adorned a shrine, and its mediation between the act of prayer and the visitation of a tomb perpetuates a cycle of contemplation of the divine. A similar panel, a carved marble relief identified as a mihrab plaque commemorating its donor, Fatima bint Zahir al-Din, features assorted verses from multiple suras making reference to the utility of prayer, good deeds, and the contemplation of God (plate 101). The text fills the available negative space, and because the Qurʾanic quotations are fragments rather than complete verses, there is no clear beginning or ending to the act of reading.

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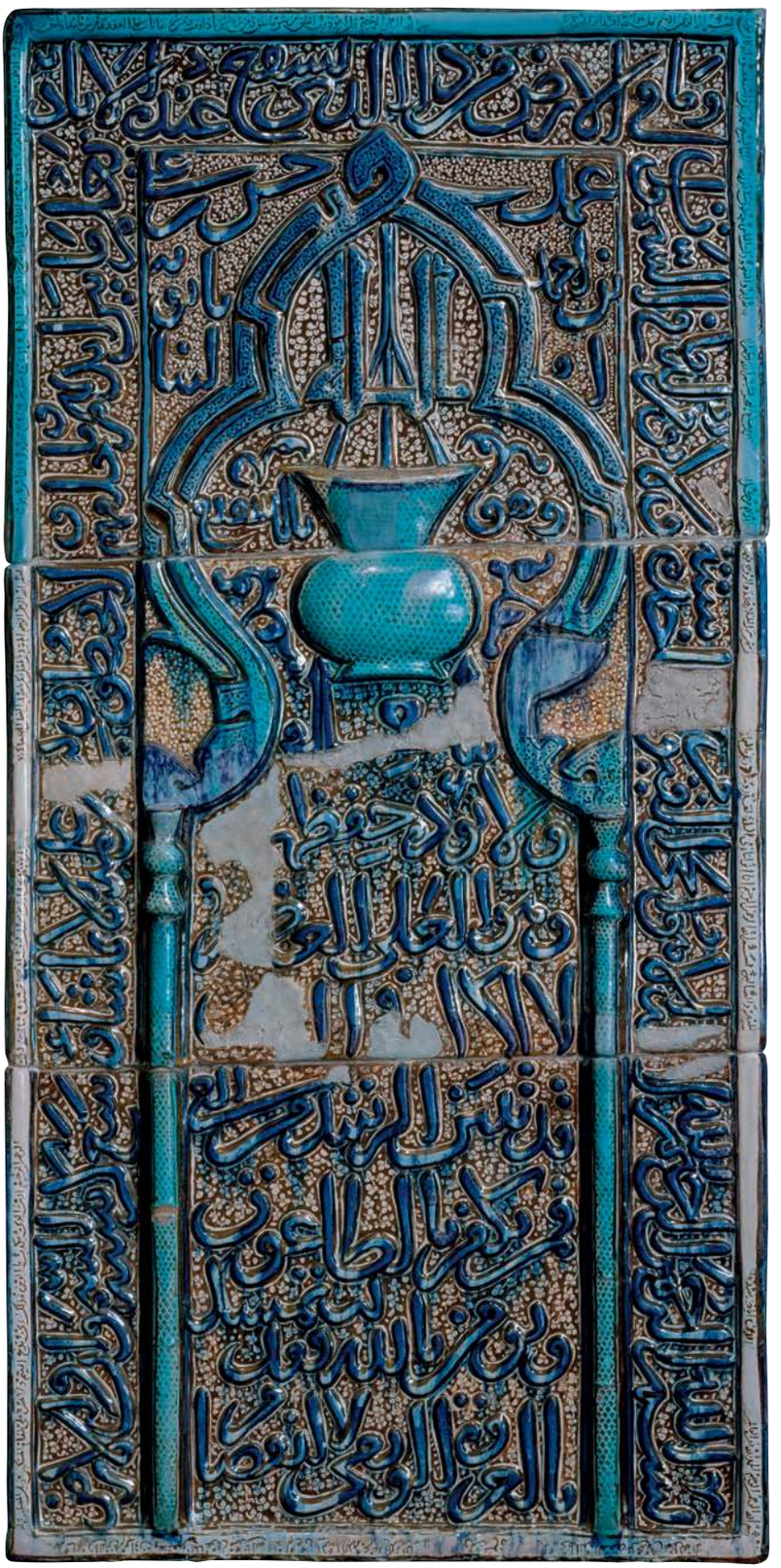


FIGURE 51. Tile Panel in the Form of an Architectural Niche, Natanz, Iran, first half of 14th century. Hasan ibn ʿAli ibn Ahmad Babavaih (active 14th century). Stonepaste; inglaze painted in blue, luster-painted on opaque white glaze, modeled, 123.2 × 59.7 cm (48½ × 23½ in.). New York, Metropolitan Museum of Art, Rogers Fund, 1909, 09.78

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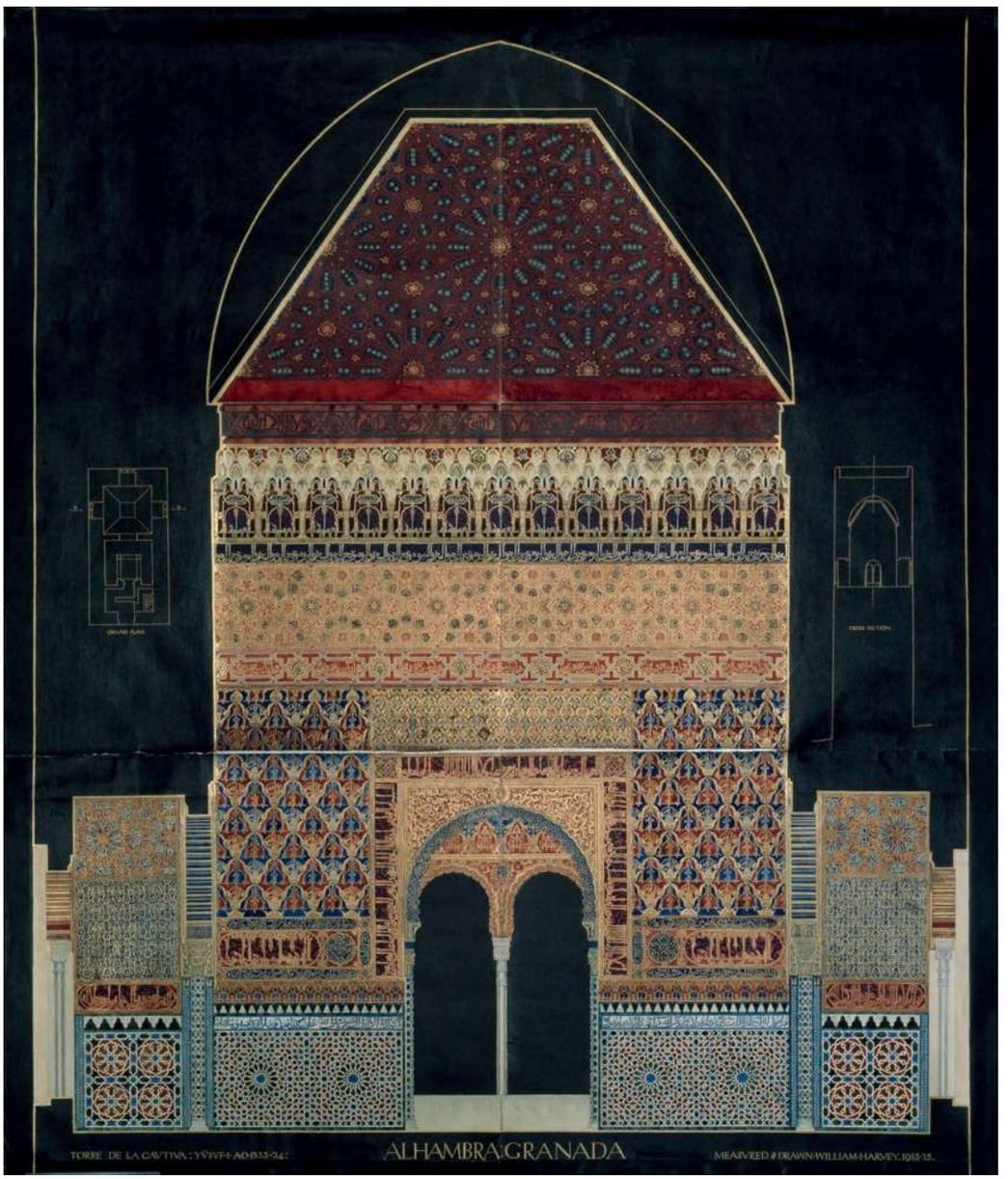


FIGURE 52. Drawing of a Section of the Tower of the Captive in the Alhambra, Granada, Spain, ca. 1913–15. William Harvey. Pen and ink, India ink, watercolor, and pencil on paper mounted on canvas, 119.1 × 95.6 cm (46 ⅞ × 37 ⅝ in.). London, Victoria and Albert Museum, E.1274-1963

The viewer must continually move between the ornamental and the epigraphic, engaging in a potentially perpetual act of looking and contemplation.[21]

But beyond the individual objects and media themselves, the act of looking elicited by ornamental programs was intended to move between the disparate elements, particularly within architectural spaces (fig. 52). Dynamic aesthetics, prompted by highly varied colors, materials, and textures, captured the gaze so that the mind entered a meditative state. The intricate geometric patterns, when paired with symmetry-based color schemes akin to those discussed by Ibn Sina and al-Tusi, drew upon what is now termed dichroism, that is, the property of a surface to reflect the light of one color and transmit the light of other colors.[22] Polychrome decoration laid over geometric pattern, of the kind seen across the Islamic world from Spain to Iran, created an aesthetic effect of undulation. One could not stare at a given element

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without a sensation of movement and liveliness emanating from the architecture itself. This sensation would only have been heightened by lighting conditions. Most architectural spaces took advantage of the natural lighting around them, with attention paid to the angle of the sun and moon at certain times of year. But other spaces were exclusively lit by lamplight, in which the flickering flame only added to the kinetic effects of the ornamental schema (plates 99, 100).[23]

This perceptive capacity was exploited and engaged across the Islamic world, prompted by works like Ibn al-Haytham's *Kitab al-Manazir* and the *Rasa'il* of the Brethren of Purity, as well as by the philosophers and intellectuals they inspired. The famed al-Ghazali (1058–1111), a Sufi theologian and mystic at the Seljuq court, understood the highest function of this gaze as the intuitive perception of divine beauty within the reflected divinity of the created universe. In al-Ghazali's words: "The reaction of every healthy constitution . . . proves that the contemplation of flowers and birds of a beautiful colour, graceful design and form gives pleasure. On seeing them even worry and grief leave the human mind, though there is no benefit to be derived beyond the mere looking. These objects give pleasure and everything pleasurable is loved."[24] Al-Ghazali embraced the paradoxical dualism of the gaze: the appreciation of beauty, the finding of aesthetic pleasure, could exist alongside (and even lead to) mystical enlightenment or rapture. Visual perception was the most immediate of the senses; its physiological effects intertwined with spiritual experience. By stimulating and perpetuating the act of looking, the complex interplay of light and color in the geometric and arabesque designs of the Islamic world moved the soul to divine inspiration.

Notes

1 *The "Optics" of Ibn al-Haytham: Books I–III*, trans. A. I. Sabra (London: Warburg Institute, University of London, 1989), 203.

2 David C. Lindberg, *Theories of Vision from al-Kindi to Kepler* (Chicago: University of Chicago Press, 1996), 12.

3 Lindberg, *Theories of Vision from al-Kindi to Kepler*, 20.

4 *The "Optics" of Ibn al-Haytham*, 127.

5 *Psychologie d'Ibn Sina (Avicenne) d'après son œuvre "aš-Šifā',"* ed. and trans. Ján Bakoš (Prague: Éditions de l'Académie Tchécoslovaque des Sciences, 1956), 2: 75–81.

6 Al-Tusi's color theory, which was part of a lapidary titled *Tansukhname-yi Ilkhany*, was frequently copied in conjunction with Ibn al-Haytham's *Kitab al-Manazir* as part of Kamal al-Din al-Farisi's commentary on the latter. See Eric Kirchner, "Color Theory and Color Order in Medieval Islam: A Review," *Color Research and Application* 40, no. 1 (February 2015): 5–16, https://doi.org/10.1002/col.21861.

7 Yasser Tabbaa, *The Transformation of Islamic Art during the Sunni Revival* (Seattle: University of Washington Press, 2001), 14–15.

8 *The Qur'ān*, trans. Alan Jones (Edinburgh: Edinburgh University Press, 2007), 325.

9 Franz Rosenthal, *Knowledge Triumphant: The Concept of Knowledge in Medieval Islam* (Leiden: Brill, 2007), 159–60.

10 Gülru Necipoğlu, *The Topkapı Scroll: Geometry and Ornament in Islamic Architecture* (Santa Monica, CA: Getty Center for the History of Art and the Humanities, 1995), 185.

11 Necipoğlu, *The Topkapı Scroll*, 186.

12 Alain George, *The Rise of Islamic Calligraphy* (London: Saqi Books, 2010), 95–102.

13 Gülru Necipoğlu, "The Scrutinizing Gaze in the Aesthetics of Islamic Visual Cultures: Sight, Insight, and Desire," *Muqarnas* 32 (2015): 30.

14 Tabbaa, *The Transformation of Islamic Art*, 76; and Necipoğlu, *The Topkapı Scroll*, 100–101.

15 Yasser Tabbaa, "The Muqarnas Dome: Its Origin and Meaning," *Muqarnas* 3 (1985): 69–71.

16 See, for example, Tabbaa, "The Muqarnas Dome," or Ernst Kühnel's classic work *The Arabesque: Meaning and Transformation of an Ornament*, trans. Richard Ettinghausen (Graz: Verlag für Sammler, 1977).

17 Gülru Necipoğlu and Alina Payne, introduction to *Histories of Ornament: From Global to Local*, ed. Gülru Necipoğlu and Alina Payne (Princeton, NJ: Princeton University Press, 2016), 1.

18 Oleg Grabar, *The Mediation of Ornament* (Princeton, NJ: Princeton University Press, 1992), 45.

19 Olga Bush, *Reframing the Alhambra: Architecture, Poetry, Textiles and Court Ceremonial* (Edinburgh: Edinburgh University Press, 2018), 86–87.

20 Oleg Grabar, "From Dome of Heaven to Pleasure Dome," *Journal of the Society of Architectural Historians* 49, no. 1 (1990): 16.

21 Margaret Graves, "Say Something Nice: Supplications on Medieval Objects and Why They Matter," in *Studying the Near and Middle East at the Institute for Advanced Study, Princeton, 1935–2018*, ed. Sabine Schmidtke (Piscataway, NJ: Gorgias Press, 2018), 327.

22 Bush, *Reframing the Alhambra*, 40; and E. Makovicky and P. Fenoll Hach-Ali, "Coloured Symmetry in the Mosaics of Alhambra, Granada, Spain," *Boletín de la Sociedad Española de Mineralogía* 22 (1999): 143–83.

23 See Joseph T. Kider et al., "Recreating Early Islamic Glass Lamp Lighting," *International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)*, 2009, doi: 10.2312/VAST.

24 Quoted in Richard Ettinghausen, "Al-Ghazzālī on Beauty," *Art and Thought: Issued in Honour of Dr. Ananda K. Coomaraswamy*, ed. K. Bharatha Iyer (London: Luzac, 1947), 162.

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Radiant Light and Sound in the Medieval Church

BISSERA V. PENTCHEVA

Sound and sight in the medieval church work together to precipitate a profound spiritual transformation that can lead to transcendence. In his ekphrasis of the sixth-century church of Hagia Sophia in Constantinople (modern Istanbul), the courtier and contemporary Paul the Silentiary (ca. 520–580) perceives the light reflecting in this marble- and mosaic-clad interior as the animating force transforming both the building and its inhabitants into a vibrant matter: "The ceiling encompasses gold-inlaid tesserae, whose pouring down in glittering gold-streaming ray irresistibly bounces off the faces of the faithful."[1] In Paul's words Hagia Sophia is a system in which, once the energy of light is introduced, it bounces off, reflects, and quickens all matter, giving animacy to the inanimate. Marble acquires the appearance of shimmering pools of living waters, and the human faces become lit and in-spirited. Similarly, Paul likens the reverberant acoustics of Hagia Sophia to a thundering voice. This essay explores the interaction of light and sound in two limited case studies: Hagia Sophia in the Byzantine East (fig. 53) and the golden retable of the Pentecost at the Benedictine monastery of Stavelot, in the Latin West (plate 90).

Light in Motion: Hagia Sophia

The play of light in Hagia Sophia mesmerizes viewers. Thomas Whittemore (1871–1950), the American archaeologist in charge of the restoration of the Byzantine mosaics (1932–50), remarked on this, writing, "Direct light rushes in in shining streams, dazzles, keeps constantly moving, and revolving,"[2] and "Hagia Sophia is a liturgical instrument tuned by light."[3] Hagia Sophia was designed to stage the rise and orbiting movement of the sun. The orientation of the eastern apse coincides with the winter solstice, which makes for a spectacular sunrise in December, enhancing the visual splendor during the Christmas season that celebrates both the inauguration of Hagia Sophia on December 23, 537, and the birth of Christ.[4] The main axis of the building is positioned approximately thirty-two degrees south of east, and it aligns with the azimuth of the sun for Christmas, December 25. On this day, as the sun rises, the first rays pass through the center of the main east–west axis. Similarly, half a year later, at the summer solstice, the last rays of the setting sun align with this east-west axis, bathing the apse in a golden glow.

Hagia Sophia's large interior volume and the reflective surfaces of marble and gold mosaics result in audiovisual aesthetics evoking the sea, as the Bosphorus lies just outside the church. Light touching the marble floors and walls produces a liquescent effect, whereby the solidity of stone perceptually transmutes into the quivering of water (fig. 54). Gold enhances this aesthetic of liquidity as light transforms metal and glass tesserae and polished Proconnesian marble into the incandescence of molten metal or the opalescence of mother of pearl. The image of water is linguistically invested in the Greek words for "marble" (*marmaron*) and "coruscation" (*marmarygma*). These words derive from the Sanskrit root *marmar-*, for "rustling" and "murmuring." In turn the onomatopoeic character of *marmar-* elicits the image of lapping waves in the Greek *marmaron* and *marmarygma*.[5]

The vision of the sea created in the interior of Hagia Sophia has its acoustic corollary in the resonant sound. The reverberation in the register of the human voice is more than ten seconds.[6] Such resonant acoustics are frequently referred to, in audio-engineering, as "wet." Subconsciously, the term links the visual aesthetics of the sea prevalent in Hagia Sophia with the sea's wet audio manifestation. The reverberant acoustics affect both speech and chant, transforming the human voice into an emanation, obfuscating the semantics of what is pronounced and enhancing instead the taste of sound. Wet acoustics appear to liquify the perceptual experience of sound. The Byzantine liturgical music composed for Hagia Sophia amplified these aural effects of smearing and occlusion of meaning with its prominent use of melismas (the singing of many notes to a syllable) and intercalations of nonsemantic vocables (vowels and consonants interspersed between the syllables of a word; for example, the word *kyrie*, meaning "Lord," can be transformed by the inclusion of many nonsemantic vocables into *ky-ou-y-hy-hy-ri-e*). Both devices—melismas and nonsemantic vocables—stretch the semantic chains, making meaning dissolve into a taste of sound.[7]

The melodic ornament (melismas and intercalations) can push the chant beyond the register of the human language. The same devices combined to decorate the apex of the melodic compositions can in turn trigger the phenomenon of "golden" aural "waterfall," causing it to rain from the dome.[8] These aural effects have begun to be explored in the music composed specifically for Hagia

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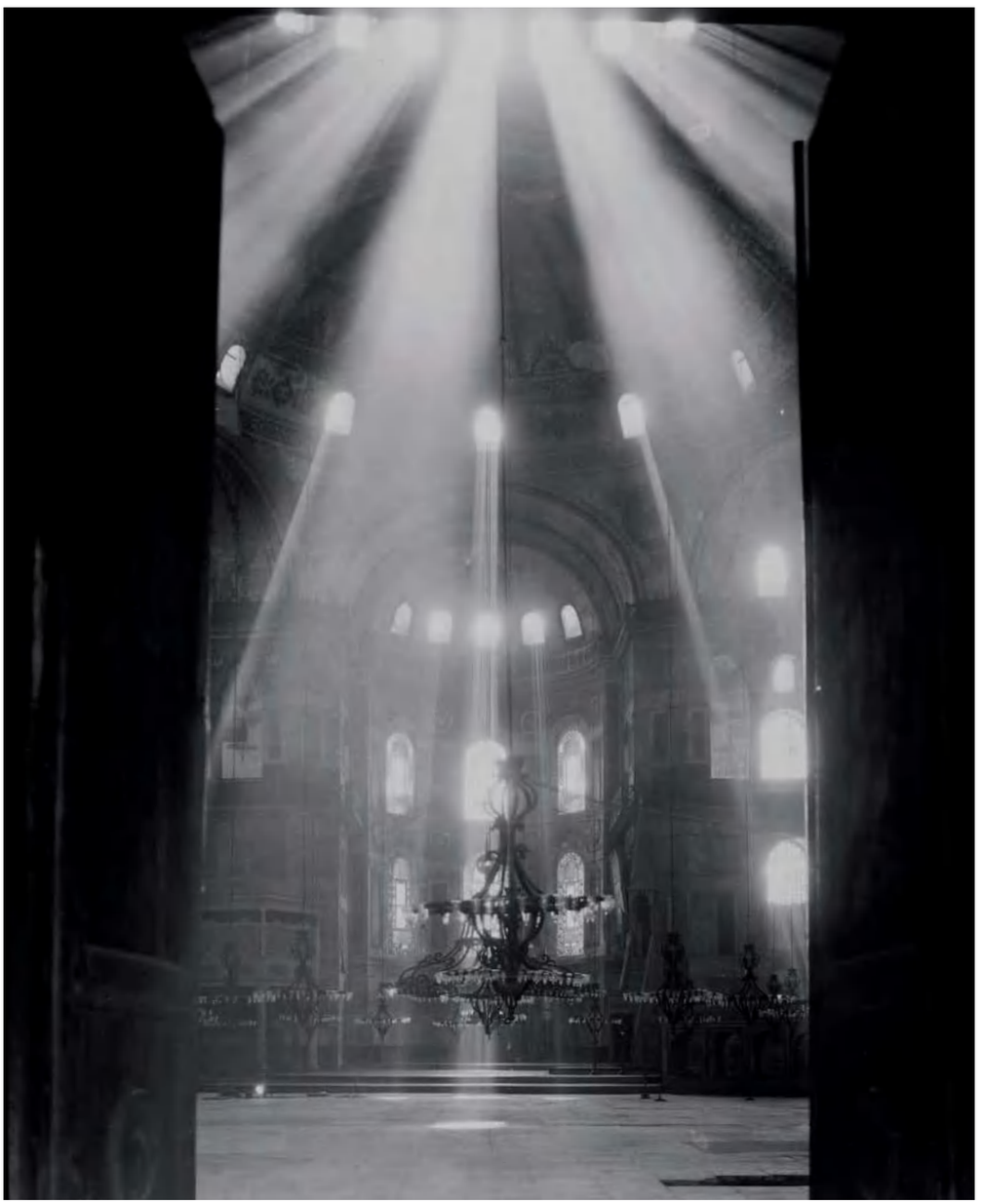


FIGURE 53. *Hagia Sophia, Study of Light, Istanbul, Turkey* (apse), possibly Pierre Iskender (1909–2003), 1948. Photograph, 25.4 × 20.3 cm (10 × 8 in.). Washington, DC, Dumbarton Oaks Research Library and Collection, The Byzantine Institute and Dumbarton Oaks Fieldwork Records and Papers, ca. late 1920s–2000s

Sophia for the Feast of the Exaltation of the True Cross, when this feast was adopted by the emperor Herakleios in Constantinople in 628.[9] In these songs particular words through which the divine is elicited, when sung in the reverberant interior of Hagia Sophia, make God's invisible presence sonically manifest in the acoustic energy gathering in and reflected from the dome. This aural golden rain finds an optical corollary in the rays of the sun descending from the gold-clad drum of the dome (see fig. 53). The divine emerges in Hagia Sophia in the phenomenon of the pouring down of physical light and sound.[10] Byzantine miniature painters recognize this audiovisual rain: the light in their depictions of the Annunciation of Mary resembles streams of water descending from a golden dome (fig. 55).

At night the church interior recedes into darkness and becomes illuminated by metal chandeliers organized in circles.[11] Paul the Silentiary likens the nocturnal

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FIGURE 54. *Hagia Sophia, Study of Light, Istanbul, Turkey* (light from northwest exedra, gallery level, view toward east end), possibly Pierre Iskender (1909–2003), 1936. Photograph, 25.4 × 20.3 cm (10 × 8 in.). Washington, DC, Dumbarton Oaks Research Library and Collection, The Byzantine Institute and Dumbarton Oaks Fieldwork Records and Papers, ca. late 1920s–2000s

appearance of Hagia Sophia to the nighttime sea in which silver ships carrying cargoes of light choreograph luminous constellations.[12] The Middle Byzantine chandelier in this exhibition offers a compelling example of the earlier oil lamps; because the chandeliers' overall shape is a circle, they are known as *choroi* (from *choros*, "circle") (plate 114).[13] The outer rim forms a gigantic crown, studded with candleholders. Numerous smaller metal disks with cruciform arrays of glass vials for the oil lamps bring this radiance closer to the visitor. If modern lights privilege the pouring of illumination to the floor, the medieval hanging lights (when suspended from the apex of mosaic-clad arches and likely the rim of the dome) target the illumination of the ceiling or are designed to appear like globes of light resembling stars that miraculously hover in the air. The Byzantine *polykandela* chandeliers mobilize a series of smaller units that range in size but repeat the same form. This fractal system then

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FIGURE 55. *The Annunciation*, accompanying Psalm 71 (72):1, "O God, give thy judgment to the king, and thy righteousness to the king's son," in Psalter (in Greek), Byzantium, 9th century. Tempera on parchment. Mount Athos, Greece, Pantokratoros Monastery, MS gr. 61, fol. 93v

visualizes cosmic light as it multiplies, creating its replicas that intensify, through reflections, the overall luminous spectacle of circles, *choroi*, and spheres of light.

Light as Re-Formation: Retables at Stavelot

Medieval writers were disposed to read the light imprinted on the face of the faithful symbolically, as an act of re-formation reattuning humanity with the divine. Similarly, they viewed the process of softening metal and wax through contact with fire as a model of redemption through re-formation.[14] Charismatic leaders in the eleventh and twelfth centuries advocated for a monastic reform in the Latin West; they offered different models.[15] Re-formation was understood as a return to the perfect form: the image of God. A human being is born in this divine model (Gen. 1:27).[16] Yet, like a shape impressed in soft wax, this form could deform through sin, slipping away from the divine example. The question is how to correct this deformity and return to the original, and thus be re-formed, returning to a con*form*ity with the divine. This is where the staging of light in the ecclesiastical interior plays a determining role. My focus is a special panel, known as a retable, decorated with images in precious metal; it was set on top of the main altar table at the monastic church of Stavelot (see plate 90). Retables function as a visual stage set (mise-en-scène) for the Eucharist. At this ritual, meaning, image, gesture, and sung word all coincided to give vividness to the sensory encounter with the divine.[17]

Benedictine abbots frequently regarded sight as the stimulus for re-formation. Among them, Wibald (1130–1158), abbot of Stavelot, Malmedy, and Corvey, saw the power of using the splendor of images shaped in gold and enamel to lead the monastic community in a return to the divine. The monumental enamel and repousée retables commissioned and collected at Stavelot mold the human figures with exquisite skill and have the capacity to tell the *miracula* in eloquent narrative series.[18]

An imposing object, about 215 centimeters (84 ⅝ in.) in length and 85 centimeters (33 ½ in.) in height, the Stavelot retable likely stood on the main altar. The priest faced it as he officiated the liturgy. The object channeled light optically and symbolically and became the visual focus of attention during the rite. It is made of copper, gilded and chased with repoussé figures. The surface is accented with filigree and enamels. Inscriptions in vernis brun set in the cornice and apse of the architectural frame record the words of the elaborate chant: the responsory "Factus est repente" sung at Pentecost.[19] The retable shows Christ at the center as the source of divine light guiding re-formation. Many of the faces of the apostles resemble his face (figs. 56–58). This cloning, while the result of the stereotypical treatment of the figures, still impresses the viewer enough to consider the power of Christo-mimesis. Light enables this imitation and transformation. The French theologian Peter Lombard (ca. 1100–1160) singles out light as the energy guiding this process: "The light of your face, Christ, is understood as the light of your grace. Thanks to it, your

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FIGURE 56. Face of Christ, Stavelot Retable (detail, plate 90)



FIGURE 57. Face of an Apostle, Stavelot Retable (detail, plate 90)



FIGURE 58. Two Apostles, Stavelot Retable (detail, plate 90)

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image is re-fashioned [*reformatur*] in us, so that we become similar to you and your form is sealed upon us, like the imprint of a mold on wax."[20] Recuperating in one's being the image of God is seen as the process of softening matter to receive the divine mold.[21] The prototype itself is created by light striking the soul. Furthermore, the German theologian Gerhoch of Reichensberg (1092/93–1169) likens the Christo-mimesis by imprint to the process of making a metal statue from a mold: "God, you are like a golden substance, and your Son, the splendor of your glory and the figure of your substance, [He] shows himself like a royal and priestly image in purest gold, impressing himself as an incorruptible seal of each of his servants who conforms himself to Him [Christ]. You, Father, perfect this work of sealing through Him and with Him and in Him, by configuring your servants to your Son."[22] Gerhoch insists on conceptualizing faith as the softening of gold to receive the imprint of the divine mold and become Christo-mimetic. His repetition, in Latin, of the words for "gold," "splendor," and "seal" shows how imprinting of the divine prototype on gold reforms humanity, restoring its likeness to Christ.

Divine light becomes bounded light in the bodies of the apostles depicted on the retable. They inhabit an interior: an aisled basilica with an apse. Body and architecture are equated, and both reveal the order and harmony engendered by the Holy Spirit. The golden panel thus gives visibility to the architectural metaphor of the radiant church in its nascent state at Pentecost. Defined by seven columns, the Stavelot fictional space can be read as receding in depth. This understanding of the pictorial space envisions an apse. The central image shows Christ in the arc of heaven from which his vivifying energy emanates as rays of light. This radiance spreads across the miniature church interior, drawing in the apostles. The retable functions as a miniature rendition of the material sanctuary.

The optical splendor of this panel contains traces of the sonic energy that would have been activated in the sanctuary. Verses from Acts run along the cornices and apse of the fictional architecture of the retable, reading: "A sound suddenly came from heaven and like the blowing of a violent wind, it filled the whole house, where they [the apostles] were sitting and all of them were filled with the Holy Spirit" (Acts 2:2, 4) (see plate 90). These lines form the responsory (here missing its final, fifth line) for the celebration of Pentecost.[23] This standard chant is found in the sacramentary of Wibald of Stavelot.[24] The melody is composed in mode 7 authentic (centered around the pitch *G*).[25] It starts with a leap of a fifth (*G*-*d*) that communicates this sudden manifestation of the divine. The apex (*f*) is reached at the word *sonus* (sound). The next time the melody climbs up is at "repleti sunt" and "Spiritui Sancto" ([the apostles] were infused with the Holy Spirit). The bodies of the apostles, filled with divine radiance, attune to the divine image and thus become re-formed. The aural radiance stirs the imagination to interpret the reflective and incandescent gold as the stimulus for recuperating the image of God in oneself.

Sound and light in the Byzantine East and the Latin West orchestrated a profound spiritual experience, enveloping the faithful in radiance and "wet" acoustics. We have only begun the exploration of this audiovisual phenomenon. Art historical scholarship has mainly studied the images and the spaces, isolated from the acoustics and the liturgical music. Yet medieval art is like film; the visual and the sonic are overlaid.[26] As a result the divine can appear as a phenomenon freed of anthropomorphic shape. In Hagia Sophia, the Lord is manifested non-figurally in the opalescent marble, shimmering gold mosaics, and acoustics rain, all produced by the reflection of light and sound from polished surfaces. By contrast, the rich figural program at Stavelot taught, through its Christo-mimetic images seen in the flickering light of candles, that the divine form can be recuperated. The faithful willing to soften through repentance their petrified deformed forms could recuperate the image of God. Like molten metal made incandescent by fire, they could become radiant mirrors infused by the energy of the Spirit.

Notes

1 Paul the Silentiary, *Descriptio Sanctae Sophiae*, vv. 668–70.

2 Thomas Whittemore, "Study of Light," 1944, Washington, DC, Dumbarton Oaks, The Byzantine Institute and Dumbarton Oaks Fieldwork Records and Papers, MS.BZ.004, 3.

3 Thomas Whittemore, "Studies of Light," 1945, Washington, DC, Dumbarton Oaks, The Byzantine Institute and Dumbarton Oaks Fieldwork Records and Papers, MS.BZ.004, box 32.

4 Whittemore, "Study of Light," 1945; Iakovos Potamianos and Wassim Jabi, "Geometry, Light, and Cosmology in the Church of Hagia Sophia," *International Journal of Architectural Computing* 5, no. 2 (2007): 305–19; Nadine Schibille, "Astronomical and Optical

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Principles in the Architecture of Hagia Sophia in Constantinople," *Science in Context* 22 (2009): 27–46; and Melike Inanici, "Lighting Analysis of Hagia Sophia," *Ayasofya Müzesi Yıllığı* 14 (2014): 166–202.

5 Fabio Barry, "Walking on Water: Cosmic Floors in Antiquity and the Middle Ages," *Art Bulletin* 89, no. 4 (2007): 627–56; Bissera V. Pentcheva, "Hagia Sophia and Multisensory Aesthetics," *Gesta* 50, no. 2 (2011): 93–111; and Bissera V. Pentcheva, *Hagia Sophia: Sound, Space, and Spirit in Byzantium* (University Park: Pennsylvania State University Press, 2017), 121–49.

6 Reverberation measures how long it takes for a sound that has been fired in a space to decay below thirty decibels, the threshold of human hearing. On the acoustics of Hagia Sophia, see Pentcheva, "Hagia Sophia and Multisensory Aesthetics," 101–16; and Pentcheva, *Hagia Sophia*, 99–120.

7 Pentcheva, *Hagia Sophia*, 99–149.

8 Bissera V. Pentcheva, "The Glittering Sound of Hagia Sophia and the Feast of the Exaltation of the Cross in Constantinople," in *Icons of Sound: Voice, Architecture, and Imagination in Medieval Art*, ed. Bissera V. Pentcheva (New York: Routledge, 2020), 52–100, esp. 60–70. On the Byzantine cathedral chant, see Alexander Lingas, "From Earth to Heaven: The Changing Musical Soundscape of Byzantine Liturgy," in *Experiencing Byzantium*, ed. Claire Nesbitt and Mark Jackson (Farnham, England: Ashgate, 2013), 311–58.

9 Little Byzantine cathedral chant has been transcribed and recorded. I rely on the repertoire of Cappella Romana, especially the CD *The Lost Voices of Hagia Sophia: Medieval Byzantine Chant* (2019), produced in collaboration with the Icons of Sound project that I codirect at Stanford and auralized in the acoustic signature of Hagia Sophia; see "Auralization," Icons of Sound, Center for Computer Research in Music and Acoustics, Department of Music, Stanford University, accessed April 16, 2022, https://ccrma.stanford.edu/groups/iconsofsound/auralizations/.

10 Pentcheva, "The Glittering Sound," 52–100.

11 Nicoletta Isar, "*Chorós* of Light: Vision of the Sacred in Paulus the Silentiary's Poem *Descriptio S. Sophiae*," *Byzantinische Forschungen* 28 (2004): 215–42. Note that the original *choroi* have not survived, and what one sees today are nineteenth-century replacements.

12 Paul the Silentiary, *Descriptio Sanctae Sophiae*, vv. 851–54.

13 *Byzantium: Faith and Power*, ed. Helen C. Evans, exh. cat. (New York: Metropolitan Museum of Art, 2004), cat. no. 60; and Laskarina Boura, *Lighting in Early Byzantium* (Washington, DC: Dumbarton Oaks Research Library and Collection, 2008).

14 N. M. Häring, "Character, Signum und Simulacrum: Der Weg von Petrus Damiani bis zur eigentlichen Aufnahme in der Sakramentenlehre im 12. Jahrhundert," *Scholastik* 31 (1956): 41–69; Robert Javelet, *Image et ressemblance au douzième siècle: De saint Anselme à Alain de Lille*, 2 vols. (Paris: Letouzey & Ané, 1967); Brigitte Bedos-Rezak, "Medieval Identity: A Sign and a Concept," *American Historical Review* 105, no. 5 (2000): 1489–1533; Thomas Dale, "The Individual, the Resurrected Body, and Romanesque Portraiture: The Tomb of Rudolf von Schwaben in Merseburg," *Speculum* 77, no. 3 (2002): 707–43; Brigitte Bedos-Rezak, "Replica: Images of Identity and the Identity of Images in Prescholastic France," in *The Mind's Eye: Art and Theological Argument in the Iconoclast Era*, ed. Jeffrey F. Hamburger and Anne-Marie Bouché (Princeton, NJ: Princeton University Press, 2006), 46–64; Thomas Dale, "Romanesque Sculpted Portraits: Convention, Vision, and Real Presence," *Gesta* 46, no. 2 (2007): 101–19; Cynthia Hahn, "The Spectacle of the Charismatic Body: Patrons, Artists, and Body-Part Reliquaries," in *Treasures of Heaven: Saints, Relics, and Devotion in Medieval Europe*, ed. Martina Bagnoli et al., exh. cat. (Cleveland: Cleveland Museum of Art; Baltimore: Walters Art Museum; London: British Museum, 2010), 163–72; and Aden Kumler, "The Multiplication of the Species: Eucharistic Morphology in the Middle Ages," *Res* 59–60 (2011): 179–91.

15 Giles Constable, "Renewal and Reform of Religious Life," in *Monks, Hermits and Crusaders in Medieval Europe*, by Giles Constable (London: Variorum Reprints, 1988), 37–67.

16 Here and elsewhere I quote the *Biblia sacra vulgata* (Stuttgart: Deutsche Bibelgesellschaft, 1994).

17 Bissera V. Pentcheva, "Optical and Acoustic Aura in the Medieval Image: The Golden Retable of the Pentecost at Stavelot," *Material Religion* 16, no. 1 (2019): 9–40.

18 Susanne Wittekind, *Altar–Reliquiar–Retabel* (Cologne: Böhlau, 2004), 302–52; and Cynthia Hahn, *Strange Beauty: Issues in the Making and Meaning of Reliquaries, 400–circa 1204* (University Park: Pennsylvania State University Press, 2012), 209–21.

19 Chant no. 006717, Cantus Index, accessed October 13, 2023, https://cantusindex.org/id/006717; and Pentcheva, "Optical and Acoustic Aura in the Medieval Image," 9–40.

20 Peter Lombard, *Commentarium in Psalmos Davidicos*, ps. 4, v. 7 (Patrologia Latina 191, col. 88).

21 C. Stephen Jaeger, *The Envy of Angels: Cathedral Schools and Social Ideals in Medieval Europe, 950–1200* (Philadelphia: University of Pennsylvania Press, 1994), 258–77; Rachel Fulton, *From Judgment to Passion: Devotion to Christ and the Virgin Mary, 800–1200* (New York: Columbia University Press, 2002), 254–65; Bedos-Rezak, "Replica," 39–64; Hahn, *Strange Beauty*, 130–32; and Thomas Dale, *Pygmalion's Power: Romanesque Sculpture, the Senses, and Religious Experience* (University Park: Pennsylvania State University Press, 2019), 95–102.

22 Gerhoch of Reichensberg, *Commentarius aureus in Psalmos et cantica ferialia*, pt. 2, ps. 30 (Patrologia Latina 193, cols. 1306–7), quoted in Fulton, *From Judgment to Passion*, 257.

23 Chant no. g01446, Cantus Index, https://cantusindex.org/id/g01446.

24 Brussels, Royal Library of Belgium, MS. Lat. 2034–2035, fol. 4v.

25 Chant no. 006717, Cantus Index, accessed October 13, 2023, https://cantusindex.org/id/006717.

26 Bissera V. Pentcheva, *AudioVision in the Middle Ages: Sainte-Foy at Conques*, exh. cat. (Santa Cruz, CA: Community Printers, 2023).

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Dazzling Splendor in a Processional Standard by Gentile da Fabriano

CHRISTOPHER R. LAKEY

Around 1420 Gentile da Fabriano (ca. 1370–1427) produced a double-sided standard depicting *The Stigmatization of Saint Francis* (plate 124) on one side and *The Coronation of the Virgin* (plate 123) on the other for the church of San Francesco in his home town of Fabriano.[1] Processional standards (*standardi* or *gonfaloni*) were a special type of liturgical object, usually double-sided paintings that were mounted onto a pole in order to be held and processed outside on special feast days associated with Christ, the Virgin, and a church's titular saint, as can be seen in Cola di Pietro's *Processione dei Bianchi* (1401) at the church of San Francesco (now Santa Maria Assunta) in Vallo di Nera, Umbria (fig. 59).[2] Although it is difficult to ascertain how or how often Gentile's paintings were deployed when not in procession (though they were likely placed on altars), one of their liturgical functions was to be processed out of doors, and Gentile's use of gold leaf—its refinement and tooling on both sides of the banner—is of particular interest in relationship to the science and theory of light in the Middle Ages.

Often, as is the case with Gentile's standard, artistic practice was deployed in the service of optical theory in order to bring together theological accounts of the divine, which medieval people understood to be represented on earth in the form of light. Gold was an important artistic medium that could achieve this goal. Indoors or out, gold was a metallic, spectral material that reflected and refracted rays of natural light, and artists understood how to manipulate gold leaf in certain ways in order to make figures or objects more or less visible according to the play of light and shadow.[3] In both panels of the standard Gentile brilliantly displays his knowledge of medieval optics through his manipulation of the panels' gilded surfaces in order to enhance the paintings' Franciscan theology. For instance, in *The Stigmatization* Gentile followed traditional techniques of paintings on gold ground yet enhanced gold's optical effects by adding a layer of red glaze over the seraph and then scratching or scraping away the paint in the wings to reveal the gold underneath, resulting in a dazzling display of divine light both literally and iconographically (see detail at left and fig. 63). This light would have been scattered due to the fact that the rays of light were scraped out of the ground, producing a rough surface. This kind of technique was described in the early fifteenth-century *Il libro dell'arte* (Book of art) by Cennino Cennini (ca. 1370–ca. 1440), in which he explains the steps involved in applying gold leaf to a wood support or panel.[4] First, the



FIGURE 59. *La processione dei Bianchi*, Italy, 1401 (detail). Cola di Pietro (Italian, active 1383–1401). Fresco. Umbria, Italy, Vallo di Nera, church of Santa Maria Assunta

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artist would scratch the outlines of figures and objects that were not to be gilded with a special needle (in *The Coronation of the Virgin* the dove, Christ, and the Virgin's head and hands, among other areas); second, a red (or green) clay, called bole, would be mixed with egg white to form a type of adhesive to apply, a number of times, over a wet surface; third, the gold leaf would be cut into specific dimensions and laid over the areas to be gilded. Often the gold leaf would then be burnished or, in *The Coronation*, glazed to produce a shimmering effect.[5] Even a quick glance at *The Coronation* reveals how Gentile applied gold leaf throughout the panel to symbolize the heavenly sphere in which the coronation took place and to heighten the regality of both Christ and the Virgin through their sumptuous garb, which was glazed and painted with brilliant pigments of red, blue, and green on top of the gilding.

Furthermore, Gentile used a variety of techniques to produce a somewhat textured surface including *pastiglia*, tooling, and incision. Gentile employed a special tool to press or scrape (*radere*) into the gilding, and red bole in order to visibly enhance both the rays of light that emanate in all directions from the Holy Spirit, which hovers above the holy figures in the form of a dove, and also the rays of light that spring from the seraph's wings in *The Stigmatization*. Although it is a later addition, the crown that Christ places on Mary's head, which rises from the surface like a type of relief sculpture, was produced using a medieval technique called *pastiglia*.[6] It was first molded in gesso (a type of gypsum), then gilded, and then affixed to the panel. The gilded surfaces of Christ's and the Virgin's halos and brocades are broken up by different tooling techniques, which Cennini refers to as granulation, whereby Gentile used pointed tools to punch and scrape the perimeter edges and interiors of the halos not only to break up the surface to account for the play of natural light and shadow but also to make the surface "in relief so that, with a sensitive imagination and a light touch, on a gold ground you can make foliate decorations . . . which show up [*traspaiano*] in the gold."[7] The concept of transparency that Cennini alludes to was important not only to artistic practices such as granulation but also to optical theory, according to which it was believed that the more transparent (or bright, or illuminated) an object was, the more visible it would be to a beholder.[8] Gentile plays up both accounts of transparency as the halos are not simply differentiated from the gold background by their punched borders; their interiors also contain geometric designs and inscriptions in granulation, to be more visible or to shine through (*traspaiano*) against the ground. Christ's halo is inscribed with the words "YHS / XPS / FIL[IUS]" (Jesus Christ Son of God), while Mary's hem is inscribed "Ave Maria g[ratia] plen[a] dominus tecum be[nedicta]" (Hail Mary, full of grace, the Lord is with you).

Although the Coronation of the Virgin had a long history of artistic expression in the Middle Ages that was not associated with any one religious order, the texts painted on the angels' scrolls at bottom left and right connect this work directly to the Franciscans and *The Stigmatization*. The angel on Mary's right holds a scroll that reads, "Timete dominum et date illi hono[rem]" (Fear the Lord and give him honor), and the angel's scroll on Christ's left declares, "Dignus est agnus qui o[ccisus est]" (Worthy is the Lamb, who was slain). Both texts come from the book of Revelation (14:7 and 5:12, respectively), but they can also be found in a prayer written by Saint Francis himself known as "An Exhortation to Praise God," which contains a compilation of biblical passages that attested to the readiness of all creation to receive God.[9] This readiness to receive God is depicted quite literally in the canonical scene of *The Stigmatization of Saint Francis* in which the saint is depicted receiving the five wounds, or stigmata, of Christ as rays of light that shoot forth from a homunculus crucified Christ carried by a seraph (the highest-ranked being in the angelic order). This scene is regarded as a key miracle in the life of Saint Francis, linking him physically to Christ, which during the later Middle Ages gave rise to the popular, yet polemical to some, notion that he was an *alter Christus* (another Christ).[10] According to his hagiographers, the miraculous event took place in September 1224 at the Franciscan hermitage on Mount La Verna in the Tuscan Apennines. It was here, according to Saint Bonaventure, the theologian who was one of his earliest hagiographers, that Francis had a vision of the crucified Christ and "was to be totally transformed into the likeness of Christ crucified, not by the martyrdom of his flesh but by the enkindling of his soul. As the vision was disappearing, it left in his heart a marvelous fire and imprinted in his flesh a likeness of signs no less marvelous [i.e., the stigmata]."[11]

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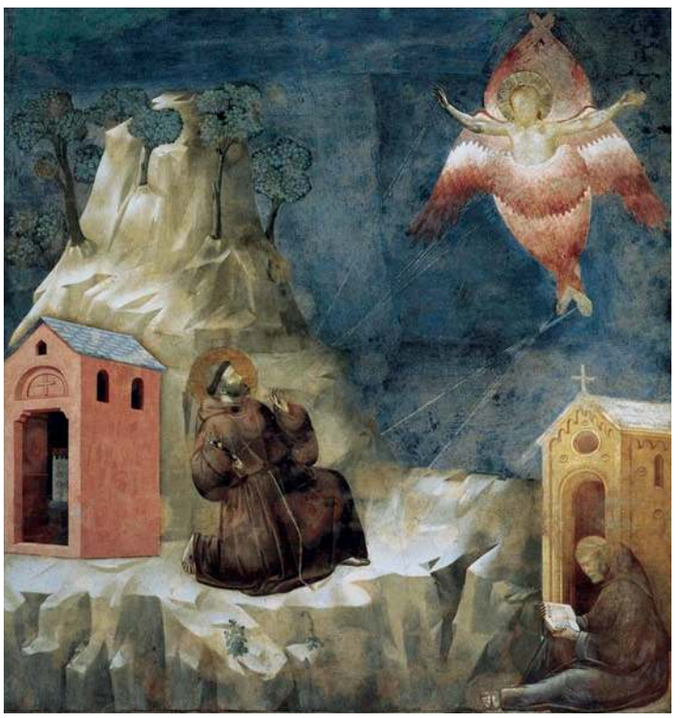


FIGURE 60. *The Stigmatization of Saint Francis*, Italy, ca. 1290–96. Giotto (Italian, ca. 1267–1337). Fresco, 270 × 230 cm (106 5/16 × 90 9/16 in.). Assisi, Upper Church of the Basilica of San Francesco

However iconic this scene is for the life of Francis, after his death, in 1226, it took some convincing by leading Franciscans and their supporters for the miracle's veracity to be upheld. For instance, Pope Gregory IX issued several papal bulls in its defense in 1237, and Fra Bonizo, the Franciscans' cardinal protector, publicly stated in 1251 that he had seen Francis's wounds.[12] Yet, by the time Gentile painted his version, around 1420, its authenticity was well established, as was its iconography, after Giotto painted the scene for the Upper Church of the Basilica of San Francesco in Assisi (the mother church of the Franciscan order and the place of Francis's burial) between 1290 and 1296 (fig. 60).[13] On the left Giotto painted Francis in a naturalistic setting, meant to invoke the terrain of Mount La Verna, kneeling in front of a small chapel, looking obliquely up to the hovering Christ-seraph who directs rays of light from the five wounds he suffered during the Crucifixion (on his hands, feet, and side) back to Francis. On the right Brother Leo, a companion of Francis's and a witness to his stigmatization, sits in quiet contemplation adjacent to a small church, reading a book. The rays of light were originally gilded and would have radiated brightly against the brilliant blue background.

Light was always an important theme in depictions and descriptions of the stigmatization well before Giotto's stabilization of its iconography. Some of the earliest examples of this scene demonstrate this point, as light, pictured as gold, plays an important role in visualizing Francis's miracle and his communication with the seraph.[14] For instance, in the Pescia Dossal from 1235 (a vita icon, or an icon of a saint surrounded by narrative panels of his or her life), Bonaventura Berlinghieri depicts Francis's acknowledgment of the seraph and his stigmatization with a band of gold that cuts through the mountain and touches Francis's halo (fig. 61; see top image in detail). In the Bardi Dossal, another vita icon of Saint Francis, painted by Coppo di Marcovaldo in the mid-thirteenth century for the Bardi family chapel in Santa Croce, Florence, the Stigmatization is located just underneath the left foot of Saint Francis, which prominently displays its stigma and directs viewers to the scene by its downward, pointing gesture (fig. 62, and detail). In this image Francis kneels, looks up at the seraph, and receives the stigmata as indicated by three bands of gold that connect his halo to the angelic creature, the gold being differentiated against the brown mountain backdrop in order to enhance its visibility and to make certain viewers understood that divine illumination was involved in the miracle.

This divine illumination was also a theme in written descriptions of the miracle, Franciscan theories of optics, and theology. A text that postdates the earliest pictures of the Stigmatization, but not Gentile's, perfectly sums up the role light played on Mount La Verna. According to the author of the *Fioretti* (*Little Flowers of Saint Francis*), a collection of stories about the life of Francis written in the later fourteenth century, after Francis received the stigmata "the whole mount of La Verna seemed to flame forth with dazzling splendour, that shone and illuminated [*inluminava*] all the mountains and the valleys round about, as were the sun shining on earth."[15] The entire text is shot through with metaphors of divine illumination,

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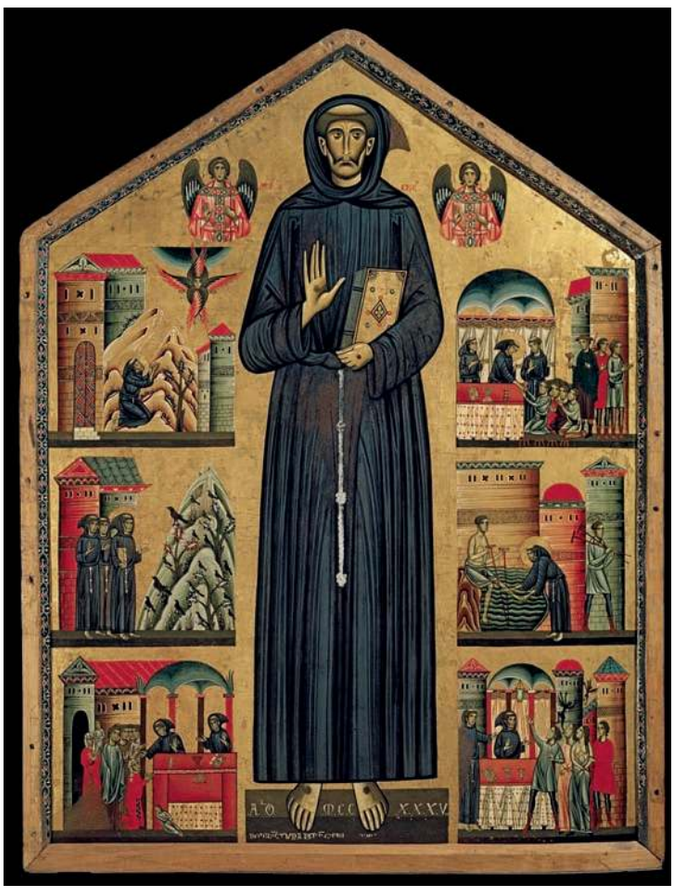
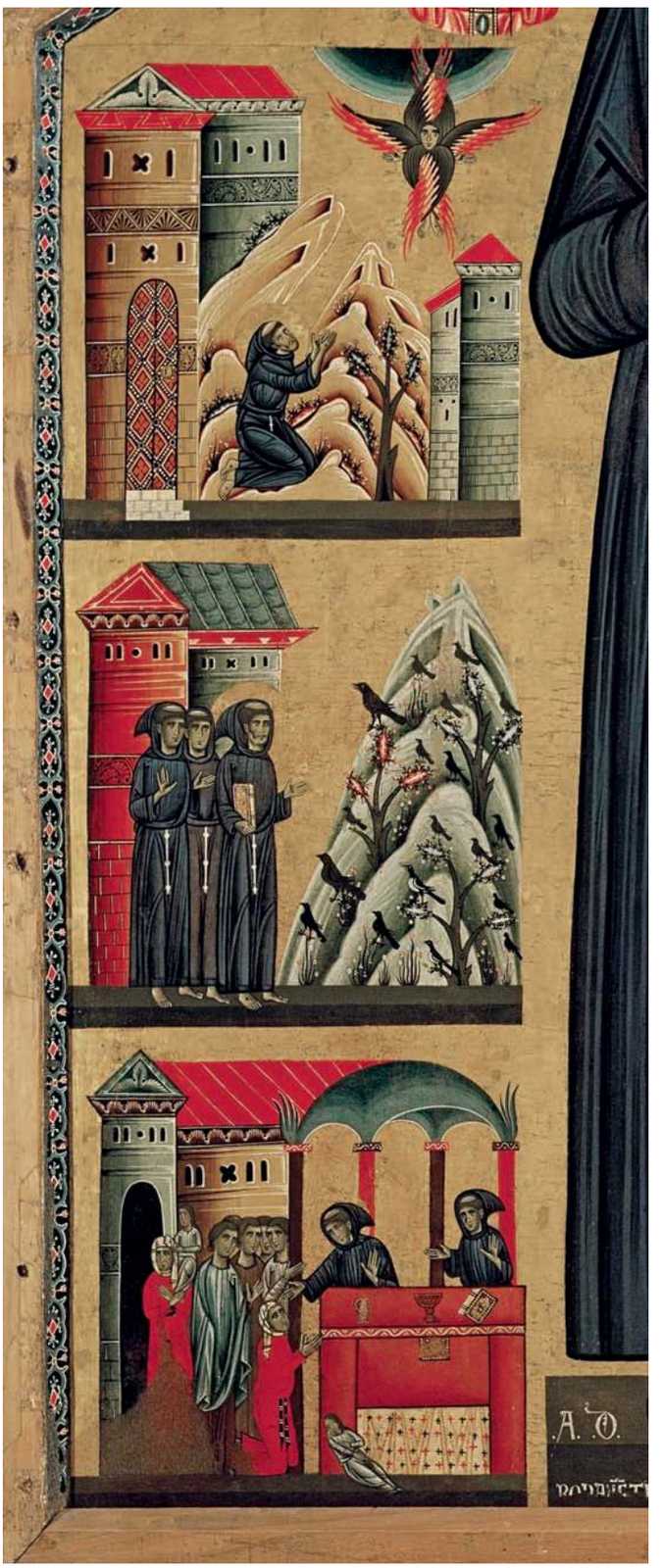


FIGURE 61. *Saint Francis Altarpiece* (Pescia Dossal), Italy, 1235. Bonaventura Berlinghieri (Italian, 1210–1287). Tempera on panel, H: 152.4 cm (60 in.). Pescia, Italy, church of San Francesco

Detail, fig. 61 (right)



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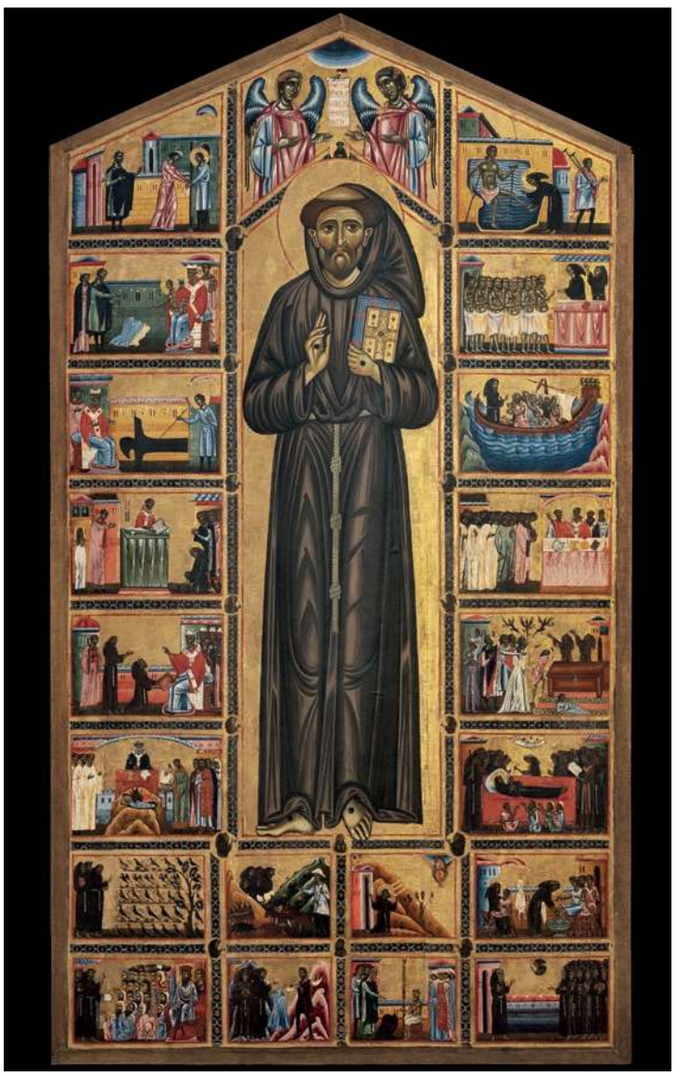




FIGURE 62. *Saint Francis and Twenty Stories from His Life* (Bardi Dossal), Italy, ca. 1245–50. Attributed to Coppo di Marcovaldo (Italian, ca. 1225–1276). Tempera and gold on panel, 230 × 123 cm (90 9⁄16 × 48 7⁄16 in.). Florence, Basilica of Santa Croce, Bardi Chapel

Detail, fig. 62 (above)

and its language derives from medieval optical theory, which the Franciscans wildly supported and contributed to in the middle of the thirteenth century. According to medieval optics, light consisted of three main categories. *Lux* was its formal cause; it is the source of natural light, its pure form, which humans could not see. *Lumen* is the replication of *lux* in all directions; it is the physical actualization of *lux*, or its "species." Roger Bacon (ca. 1219/20–ca. 1292), a Franciscan friar and philosopher, made this clear in his *De multiplicatione specierum* (On the multiplication of species, ca. 1260), stating, "And to explain the meaning of 'species' with an example, we say that the *lumen* of the sun in the air is the species of the solar *lux* in the body of the sun; and *lumen* falling perchance through a window or an aperture is sufficiently visible to us, and it is the species of the *lux* of a star."[16] *Lumen* then radiates through a transparent medium such as air and illuminates an opaque body. Illumination is the third category of light, sometimes referred to as splendor.

Theologians often describe the process outlined above in terms of how one could see the divine. According to Saint Bonaventure, for example, the ability to understand how God participates in the material world requires divine illumination. He explores this powerful

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metaphor in his sermon *De altitudine perfectionis christianae* (On the height of Christian perfection) in which he explains the three principal operations of corporeal light (*lux visibilis*): to exorcise darkness, to make forms manifest, and to delight in the power of sight. Spiritual light (*lux spiritualis*) has three parallel operations: to purge, to illuminate, and to perfect.[17] This concept spread throughout high scholastic circles. For instance, around 1280 Bartholomew of Bologna (d. 1294), one of Bonaventure's followers, wrote the treatise *De luce* (On light), which Francesca Galli describes as a "compendium for students and preachers which draws a tight web of parallels between certain properties of natural luminous phenomena in the sensible world and corresponding qualities in spiritual light."[18] In this text Bartholomew explains the concept of exemplarism by way of the notion that God impressed human souls with divine illumination.[19] This divine illumination could be revealed in the world only if one concerned oneself with acts of faith and prayer, a key notion in Franciscan theology.[20] One example he uses to describe how the process of light affects the sensible world that is pertinent to the relationship between art and light is a gilded panel, about which he writes, "when rays emanating from a luminous body reach another body that is smooth, polished, or shining, such as a sword or gilded panel [*tabulam deauratam*], and rebound back this is called *splendour*."[21]

In many ways Gentile's *Stigmatization of Saint Francis* expertly ties together Franciscan theology and its relationship to optical theory, as well as keeping to tradition by following Giotto's lead in the figural arrangement and naturalistic setting. For his version of the Stigmatization, Gentile was heralded for his high degree of naturalism, especially in the depiction of the landscape and the cast shadows that appear throughout.[22] Yet, what might be his crowning achievement in this work is the relationship between the golden rays and the translucent, flaming red seraph. The light that appears from them produced a double effect of light: the pictorial light that illuminates the hills and Francis and casts shadows and the refraction of natural light from parts of the seraph's glow due to Gentile's use of the glaze over the gold (fig. 63). As one side of a processional standard, the painting would have been processed around the town (and perhaps elsewhere). We can even imagine that Gentile, as one of the most innovative artists of his time, would have understood how beholders might temporarily have been blinded if sunlight hit at the right angle, reproducing the blinding effects of the divine light from which Brother Leo shields his eyes iconographically but also in mimicry of the beholders' actions in the real world. When *The Stigmatization* was seen together with *The Coronation of the Virgin*, viewers would have understood how Gentile's expert knowledge and execution of artistic techniques related to light (glazing, gilding, tooling) worked together with the paintings' iconography and liturgical function to produce a dazzling example of how art and science worked hand in hand in the long Middle Ages.



FIGURE 63. Seraph from *The Stigmatization of Saint Francis*, half of a processional standard for the church of San Francesco, Fabriano, Italy, ca. 1420 (detail, plate 124). Gentile da Fabriano (Italian, ca. 1370–1427)

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Notes

1 Keith Christiansen, *Gentile da Fabriano* (London: Chatto & Windus, 1982), 93–96; and Emanuela Daffa, "Gentile da Fabriano, *Stigmatization of St. Francis*," in *Gentile da Fabriano and the Other Renaissance*, ed. Laura Laureati and Lorenza Mochi Onori, exh. cat. (Milan: Electa, 2006), 182–84.

2 On their general use and type, see Victor M. Schmidt, *Stendardi e gonfaloni processionali dalle Marche: Tardo Medioevo e Rinascimento* (Fermignano: Edizioni Centro Studi "G. Mazzini," 2020). On Cola di Pietro's frescoes, see Katherine Ludwig Jansen, *Peace and Penance in Late Medieval Italy* (Princeton, NJ: Princeton University Press, 2018), 51–54; and Schmidt, *Stendardi e gonfaloni processionali*, 9–11.

3 On the different ways artists manipulated gold leaf, see, among others, Mojmír S. Frinta, "Raised Gilded Adornment of the Cypriotic Icons, and the Occurrence of the Technique in the West," *Gesta* 20, no. 8 (1981): 333–47; Norman Muller, "In a New Light: The Origins of Reflective Halo Tooling in Siena," *Zeitschrift für Kunstgeschichte* 75, no. 2 (2012): 153–78; Christopher R. Lakey, "The Materiality of Light," *English Language Notes* 53, no. 2 (2015): 119–36; and Saskia C. Quené, "Figures, Grounds, and Gold: Relocating the Madonna of Humility," *Different Visions: New Perspectives on Medieval Art* 9 (2023): 1–29.

4 Quotations in this essay are from *Cennino Cennini's "Il libro dell'arte,"* trans. Lara Broecke (London: Archetype Publications, 2018).

5 Cennini goes into great detail concerning these practices in chapters 123–39 of his book; see *Cennino Cennini's "Il libro dell'arte,"* 159–70. For the precise measurements of the gold leaf applied to *The Coronation of the Virgin*, see Douglas MacLennan et al., "Visualizing and Measuring Gold Leaf in Fourteenth- and Fifteenth-Century Italian Gold Ground Paintings Using Scanning Macro X-ray Fluorescence Spectroscopy: A New Tool for Advancing Art Historical Research," *Heritage Science* 7, no. 25 (2019), https://doi.org/10.1186/s40494-019-0271-0.

6 On this point, see Keith Christiansen, "*The Coronation of the Virgin* by Gentile da Fabriano," *J. Paul Getty Museum Journal* 6–7 (1978–79): 1–12.

7 *Cennino Cennini's "Il libro dell'arte,"* chap. 140, 174–76. Gentile was well known during his lifetime for his elaborate use of different techniques to enhance the visual effects of gold in his painting. On this, see, most recently, David Young Kim, *Groundwork: A History of the Renaissance Picture* (Princeton, NJ: Princeton University Press, 2022), 67–74.

8 On the relationship between transparency, optical theory, and artistic practice, see especially Paul Hills, *The Light of Early Italian Painting* (New Haven, CT: Yale University Press, 1987), 64–71.

9 I quote from the Douay-Rheims version of the Bible. For the prayer in Latin, see Kajetan Esser, ed., *Die Opuscula des hl. Franziskus von Assisi* (Grottaferrata: Editiones Collegii S. Bonavaneturae ad Claras Aquas, 1976); English translation by Pierbattista Pizzaballa, "The Writings of St. Francis of Assisi," part 1, no. 10, The Liturgy Archive, http://www.liturgies.net/saints/francis/writings.htm#Exhortatio.

10 On the history of this concept in the visual arts, see E. James Mundy, "Franciscus Alter Christus: The Intercessory Function of a Late Quattrocento Panel," *Record of the Art Museum, Princeton University* 36, no. 2 (1977): 4–15; and Donal Cooper and Janet Robson, *The Making of Assisi: The Pope, the Franciscans, and the Painting of the Basilica* (New Haven, CT: Yale University Press, 2013), 127–38.

11 Quoted in Cooper and Robson, *The Making of Assisi*, 127. For the Latin, see Saint Bonaventure, *Legenda maior Sancti Francisci*, vol. 2 of *Fontes franciscani*, ed. Enrico Menestò et al. (Assisi: Edizioni Porziuncola, 1995), 631–32.

12 See Julian Gardner, *Giotto and His Publics: Three Paradigms of Patronage* (Cambridge, MA: Harvard University Press, 2011), 38; and Cooper and Robson, *The Making of Assisi*, 127.

13 On the iconography of the stigmatization, see Chiara Frugoni's detailed history of the years both before and after Giotto painted his fresco in Assisi, *Francesco e l'invenzione delle stimmate: Una storia per parole e immagini fino a Bonaventura* (Turin: G. Einaudi, 1993); and Cooper and Robson, *The Making of Assisi*, 127–29.

14 For this theme in general, see *Franziskus: Licht aus Assisi; Katalog zur Ausstellung im Erzbischöflichen Diözesanmuseum und im Franziskanerkloster Paderborn*, ed. Christoph Stiegemann, Bernd Schmies, and Heinz-Dieter Heimann, exh. cat. (Munich: Hirmer Verlag, 2011).

15 Quoted in Christiansen, *Gentile da Fabriano*, 21; see also Hills, *The Light of Early Italian Painting*, 115. For the Italian, see *I "Fioretti" di Sancto Franciescho*, ed. Luigi Manzoni (Rome: E. Loescher, 1902), 194.

16 David C. Lindberg, *Roger Bacon's Philosophy of Nature* (Oxford: Clarendon Press, 1983), 2–5. For Bacon, see the essay by Gaida, this volume. See also Hills, *The Light of Early Italian Painting*, 11–12; and Lakey, "The Materiality of Light," 121–27.

17 Saint Bonaventure, *De altitudine perfectionis christianae*, in *Opera theologica selecta*, 5 vols. (Quaracchi: Collegium S. Bonaventura, 1941–49), 5: 393.

18 Francesca Galli, "The *Perspectiva ad usum praedicatorum* in Late 13th-Century Florence," *Micrologus* 29 (2021): 189.

19 For a discussion of the view that divine light is the vehicle by which God's form is sealed upon the faithful, see the essay by Pentcheva, this volume.

20 On this text, see Francesca Galli, *Il "De luce" di Bartolomeo da Bologna: Studio e edizione* (Florence: SISMEL–Edizioni del Galluzzo, 2021).

21 Quoted in Hills, *The Light of Early Italian Painting*, 11.

22 Keith Christiansen, "The Art of Gentile da Fabriano," in Laureati and Mochi Onori, *Gentile da Fabriano and the Other Renaissance*, 30–31.

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90 Stavelot Retable, Mosan region, ca. 1160–70
Embossed and engraved gilded copper, champlevé enamel, vernis brun, red jasper, rock crystal and glass replacements, wood core, 85 × 215 × 11 cm (33½ × 84⅝ × 4⅓ in.)
Paris, Musée de Cluny, Cl. 13247

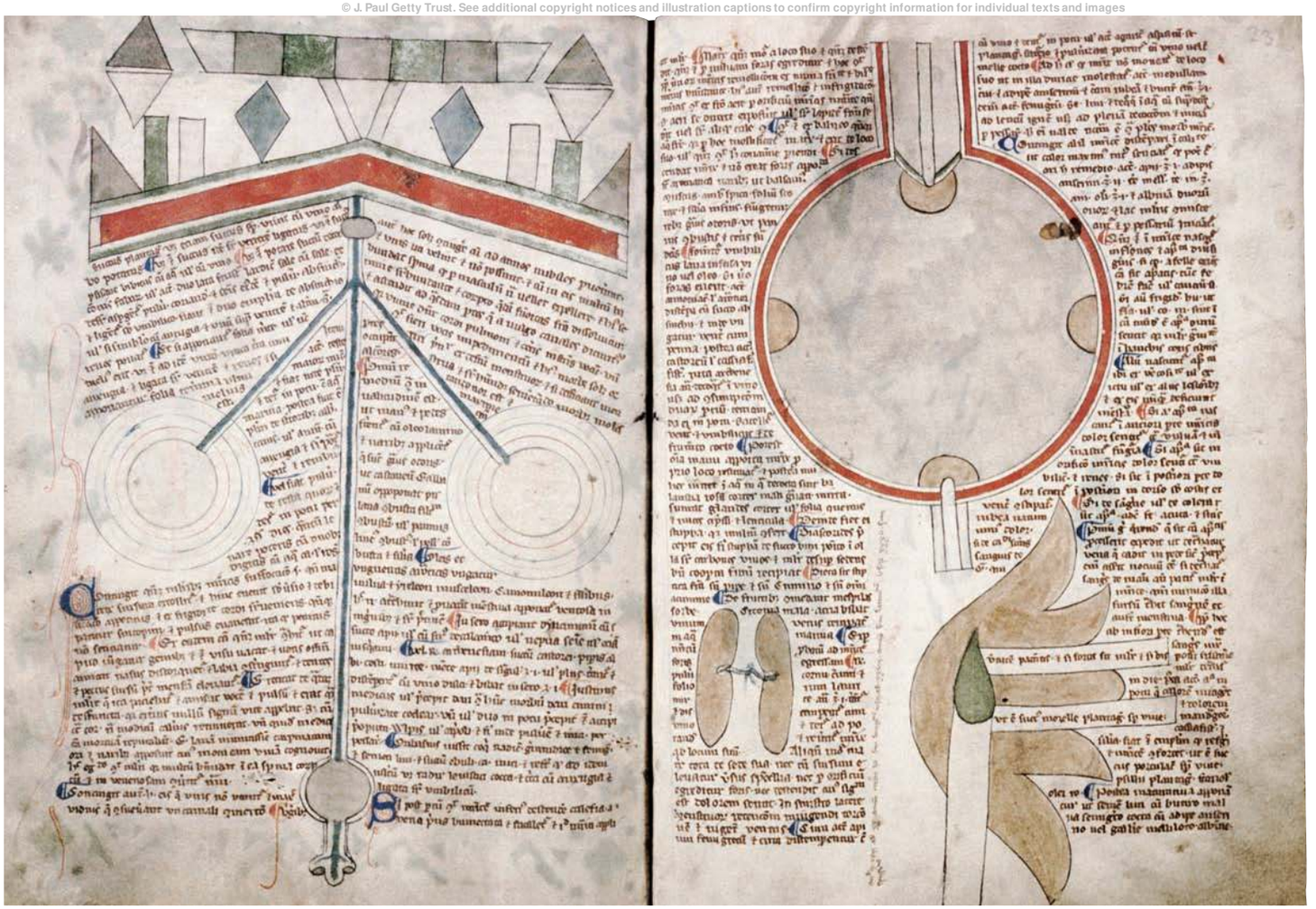
In medieval spaces of worship, artisans harnessed the effects of sunlight and dancing flame on gold to create environments of wonder. This golden retable once sat on top of the main altar at the monastery of St. Remaclus at Stavelot (Belgium), where it provided a luminous backdrop for the performance of the liturgy.

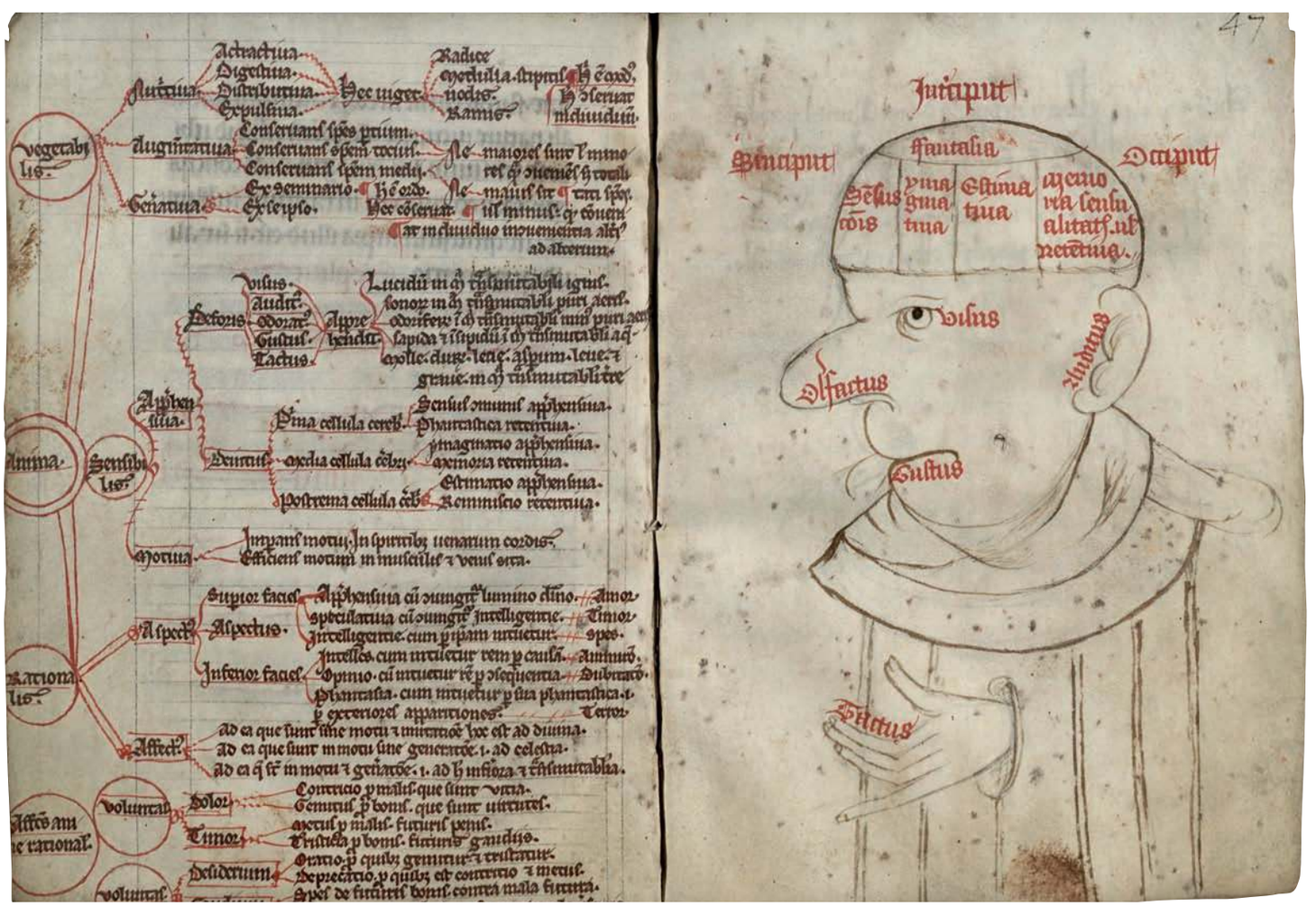
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Plates 90–125



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91 (OPPOSITE, TOP)

Diagram of the Eye and Brain and Diagram of the Digestive System in *A Major Miscellany of Medical Texts* (in Latin), England, end of 13th century–beginning of 14th century
Color washes and ink on parchment, full folio (each): 27 × 19.5 cm (10⅝ × 7⅔ in.)
Oxford, Bodleian Libraries, University of Oxford, MS. Ashmole 399, fols. 22v–23

92 (OPPOSITE, BOTTOM)

The Five Senses and Diagram of the Human Brain in *De spiritu et anima* (in Latin), France(?), 13th century
Pseudo-Augustine
Ink on parchment, full folio (each): 16 × 11.5 cm (6 5/16 × 4½ in.)
Cambridge, Masters and Fellows of Trinity College, MS O.7.16, fols. 46v–47

93 (RIGHT)

Diagram of the Human Brain with Five Cells, or Ventriculi, Representing the Five "Powers" of Thought in *Trilingual Compendium of Texts* (in Latin), England, first half of 14th century (after 1307)
Tempera and ink on parchment, full folio: 21.5 × 14.8 cm (8½ × 5 13/16 in.)
Syndics of Cambridge University Library, Ms. Gg. 1.1, fol. 490v (detail)



PLATES 91–93

Knowledge and cognition were understood as resulting from the flow of information perceived through the eyes and other sense organs. This input traveled first through sensory nerves, then through *vermes* (worm-like structures in the brain) to the "chambers" of fantasy, imagination, cogitation, and estimation, and, finally, to the "storehouse" of memory.

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94 (OPPOSITE)

Ramsey Abbey Censer, East Anglia, England, ca. 1325
Silver, silver gilt, H (not including chain): 27.6 cm (10 13⁄16 in.); Diam: 13.6 cm (5 5⁄16 in.); Wt: 1.48 kg (3.26 lb.)
London, Victoria and Albert Museum, acquired with the aid of a generous donation from Mr. C. W. Dyson Perrins FSA, M.269-1923

95

Incense Burner, Mamluk Damascus, 9th century AH/15th century
Brass, silver, Diam: 13.4 cm (5 ¼ in.)
London, British Museum, donated by Sir Augustus Wollaston Franks, 1882,0321.19

PLATES 94, 95

In Christian church ceremony, rays of light became visible as projections seen on slow-moving clouds of incense. In Muslim practice incense demarcated mosque space as a heavenly paradise by introducing floral scents. The Mamluk incense burner would have been suspended from a ceiling, or possibly rolled on the floor.

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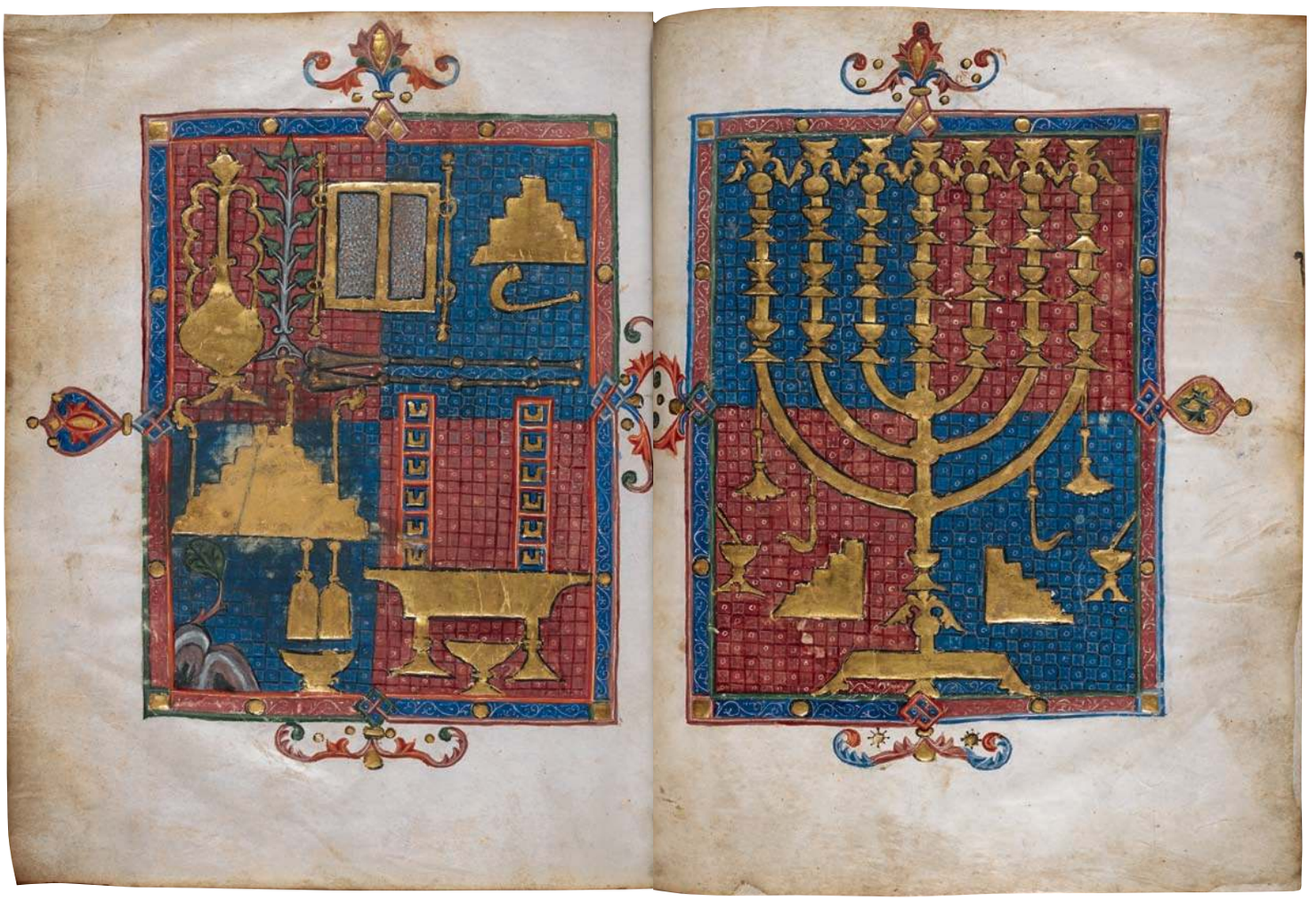


96

Kennicott Bible (Bible with David Kimhi's "Sefer Mikhlol"; in Hebrew), La Coruña, Galicia, Iberia (Spain), 1476
Tempera, gold, and ink on parchment, full folio (each): 32 × 26.2 cm (12⅜ × 10⅜₁₆ in.)
Oxford, Bodleian Libraries, University of Oxford, MS. Kennicott 1, fols. 122v–123

Gold and jewel-colored geometric interlace patterns provided transitions between textual divisions in Sephardic Bibles. As abstract forms, they have been likened to textile veils or doors that help signal and open a new space or section of the text.

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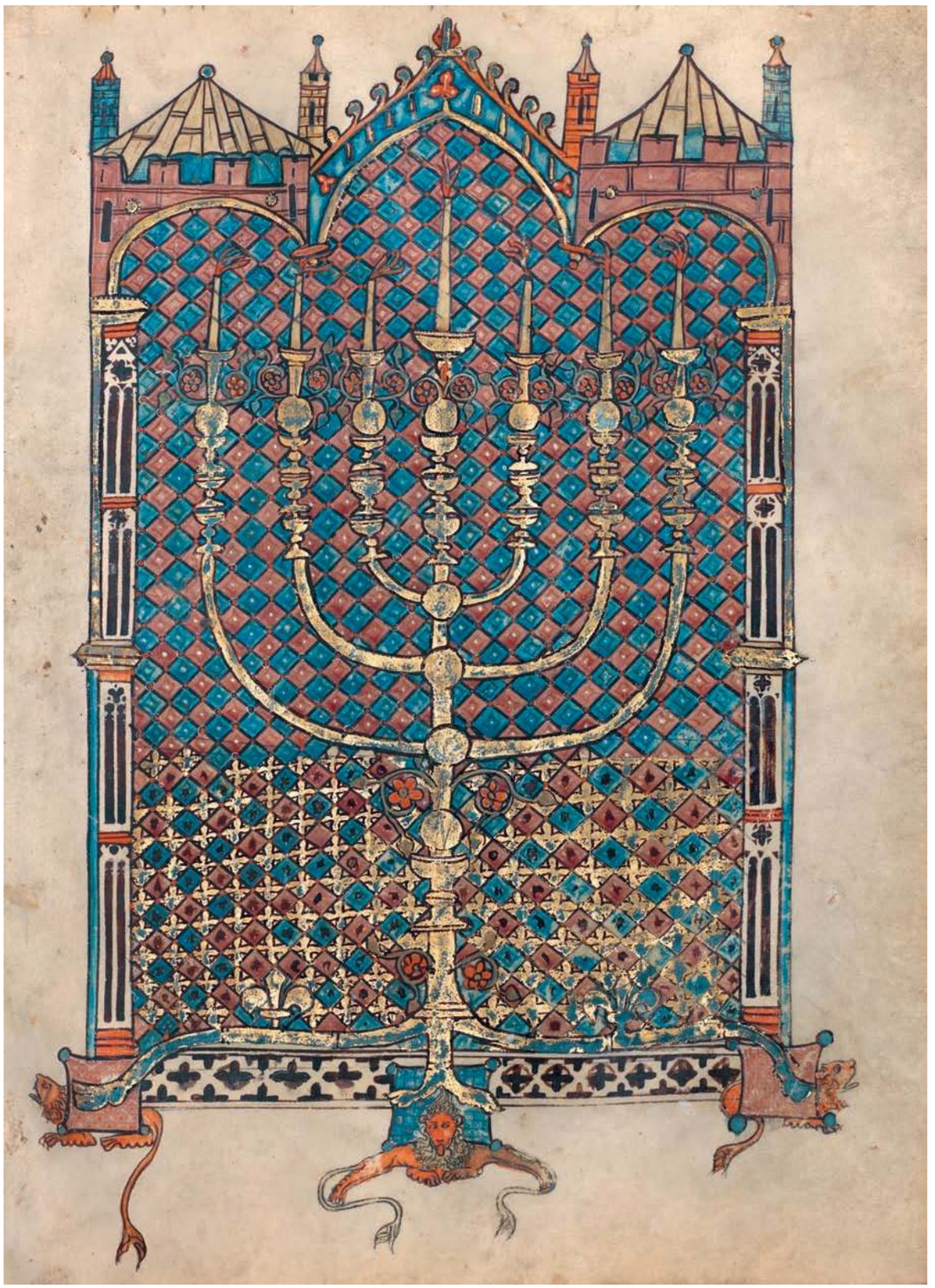


97

Messianic Vision in Duke of Sussex's Catalan Bible (in Sephardic Hebrew), Catalonia, Iberia (Spain), mid-14th century
Tempera, gold, and ink on parchment, full folio: 23.5 × 19 cm (9¼ × 7½ in.)
London, British Library, Add MS 15250, fols. 3v–4

As a physical substitute for the lost Temple of Jerusalem, this Bible would have been of singular importance in the devotions of Sephardic Jews, who emphasized the restoration of the Temple in their religious observance.

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98

Menorah in Rothschild Pentateuch (in Hebrew and Aramaic), Germany or France, 1296
Elijah ben Meshallum (artist) (active 13th century)
Elijah ben Jehiel (artist) (active 13th century)
Rashi (commentator) (French, 1040–1105)
Tempera colors, gold, and ink on parchment, full folio: 27.5 × 21 cm (10 13⁄16 × 8 1⁄4 in.)
Los Angeles, J. Paul Getty Museum, Acquired with the generous support of Jo Carole and Ronald S. Lauder, Ms. 116 (2018.43), fol. 226v

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The desire to reach God and the Eternal Jerusalem was expressed both verbally and visually in Hebrew Bibles in illuminations that depicted glittering gilded implements from the Tabernacle and the Temple and Zechariah's prophetic menorah of the restored Temple in Jerusalem (Zech. 4:1–14).

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99

Mosque Lamp, Mamluk Egypt, Cairo, ca. 730 AH/ca. 1330
Glass, free-blown and tooled, enameled and gilded, H: 35.9 cm (14 in.); Diam (top): 26.4 cm (10 in.)
London, British Museum, bequeathed by Miss Edith Godman, G.497



100

Mosque Lamp of Amir Qawsun, Egypt, ca. 729–35 AH/ca. 1329–35
ʿAli ibn Muhammad al-Barmaki (Egyptian[?])
Blown glass, colorless with brown tinge, blown applied foot, enameled and gilded, H: 35.9 cm (14⅛ in.); max. Diam: 25.6 cm (10 1/16 in.)
New York, Metropolitan Museum of Art, Gift of J. Pierpont Morgan, 1917, 17.190.991

PLATES 99, 100

Mosque lamps often included calligraphic dedicatory inscriptions or lines of the so-called light verse from the Qurʾan (24:35): “[God’s] light is like a niche in which there is a lamp / —the lamp is in a glass, and the glass like a brilliant star.”

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101

Panel of al-Khatun (the lady) Fatima bint Zahir al-Din, Abbasid caliphate, Iran(?), 5th–6th century AH/ 11th–12th century
Marble, carved in relief, 65.4 × 43.2 cm (25¾ × 17 in.); Wt: 37.6 kg (83 lb.)
New York, Metropolitan Museum of Art, Purchase, V. Everit Macy Gift, 31.50.1

A mihrab is a prayer niche in a mosque's qibla wall, which faces Mecca, the focal point of prayer. It is often decorated with a hanging lamp or a depiction of one—a metaphor for the light of God.

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102

Candlestick, Abbasid/Ilkhanid(?)
Iran, 7th century AH/
13th century
Brass, engraved and inlaid with silver, H: 16.3 cm (6⅖ in.); Diam (of base): 17.8 cm (7 in.)
Los Angeles County Museum of Art, The Nasli M. Heeramaneck Collection, Gift of Joan Palevsky, M.73.5.123

Brass objects inlaid with precious metals were utilized in courtly as well as religious settings in medieval Iran. This one was designed to hold a large candle. Its inlaid-silver and golden metallic surfaces would have reflected the warm, scintillating light of the flickering candle.



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103

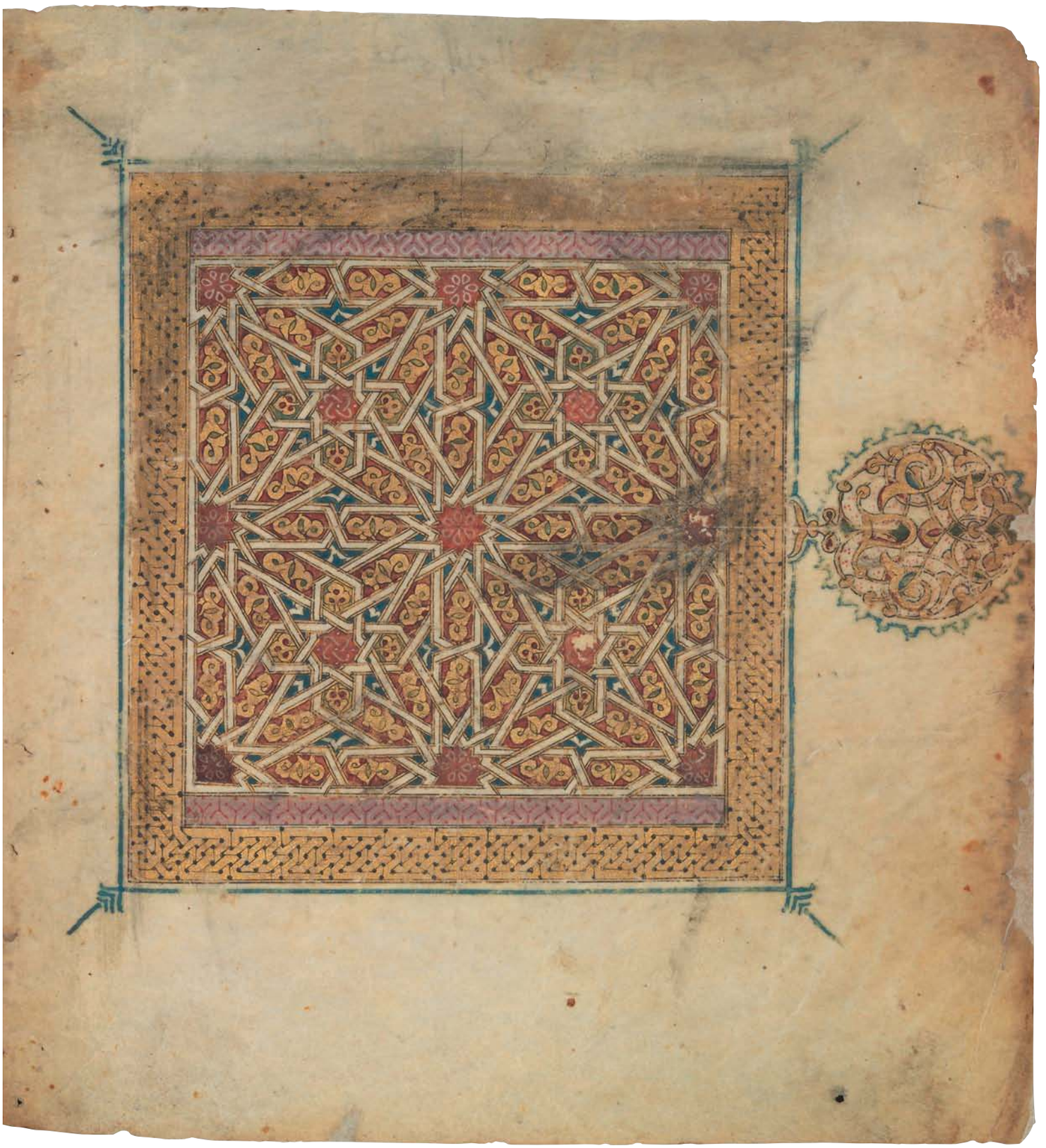
Two Decorated Text Pages (Sura al-Anʿam 6:119–21) in Qurʾan (in Arabic), Aghlabid Tunisia(?), 2nd–3rd century AH/9th century
Pen and ink, gold leaf, and tempera on parchment, full folio: 14.4 × 20.8 cm (5 11/16 × 8 3/16 in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig X 1 (83.MM.118), fols. 8v–9

Here written entirely in letters of gold, the divinely inspired words of the Holy Qurʾan channeled the light of God.

104 (OPPOSITE)

Section from a Qurʾan Manuscript (in Arabic), attributed to Morocco (Marinid sultanate) or southern Iberia (Nasrid kingdom), ca. 700 AH/ ca. 1300
Ink, gold, and opaque watercolor on parchment, full folio: 20.2 × 19.2 cm (7 15/16 × 7 9/16 in.)
New York, Metropolitan Museum of Art, Purchase, Lila Acheson Wallace Gift, 2004, 2004.90, folio 1v

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105

Two Pages from volume 7 of seven-volume Qurʾan (in Arabic) commissioned by Rukn al-Din Baybars, later Sultan Baybars II, Cairo, Mamluk Egypt, 703 AH/1304
Abu Bakr Sandal (illuminator) (Egyptian, active early 14th century)
Tempera, gold, and ink on paper, full folio (each): 47.5 × 32 cm (18 11⁄16 × 12 5⁄8 in.)
London, British Library, Add MS 22412, fols. 1v–2

The sophisticated geometric constructions on the page reflect the order and unity of the universe and encourage deep contemplation of the words of the Qurʾan.

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106

Door Leaves with Star Polygon Motif
Cairo, Egypt, 683-714 AH/1285-1315
Wood (rosewood, ebony), ivory
(Each) 164.5 × 37.2 × 3.2 cm (64 ¾ × 14 ⅝ × 1 ¼ in.)
Paris, Musée du Louvre, Department of Islamic Art, OA 7462 a-b

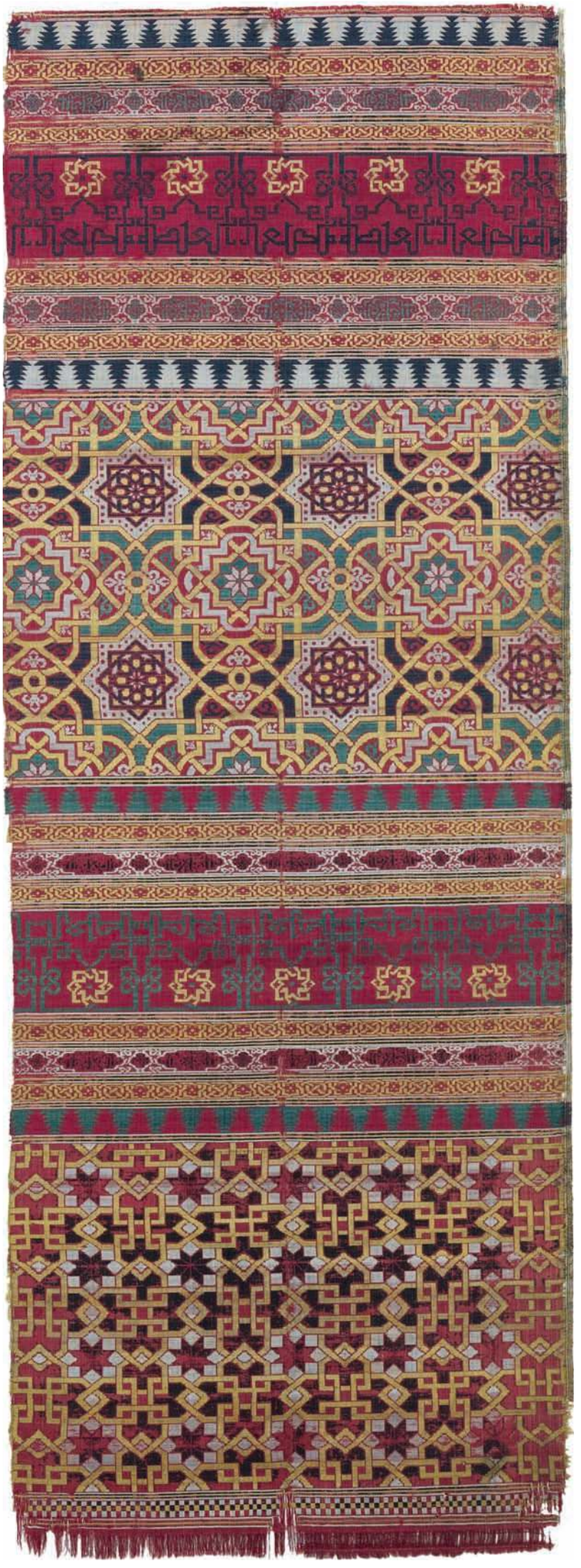
107 (OPPOSITE)

Textile Fragment, Iberia (Spain)(?),
8th century AH/14th century
Silk, lampas, textile: 102 × 36.3 cm (40 3/16 × 14 5/16 in.); mount: 114.9 × 50.2 × 2.5 cm (45 ¼ × 19 ¾ × 1 in.)
New York, Metropolitan Museum of Art, Fletcher Fund, 1929, 29.22

PLATES 106, 107

The study of mathematics underlying medieval people's exploration of the heavens led to art forms, in textiles as well as in architecture, that expressed the perfection of God's creation. Complex geometric designs could signify the boundlessness of the divine and invite the viewer to enter a state of contemplation and prayer.

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108

Keystone with Muqarnas, Toledo, Mudéjar Spain, 9th century AH/15th century
Gilded pine, 25 × 24 cm (9 ⅞ × 9 7/16 in.); Diam: 59 cm (23 ¼ in.)
Madrid, Museo Arqueológico Nacional, inv. 50484



109

Muqarnas, Bursa, Ottoman Turkey, early 9th century AH/early 15th century
Earthenware, cuerda seca technique, 34 × 11.4 cm (13 ¾ × 4 ½ in.)
The Edwin Binney, 3rd, Collection of Turkish Art at the Los Angeles County Museum of Art, M.85.237.79



110

Muqarnas Panel, Granada, Nasrid Iberia, 730–92 AH/ca. 1330–90
Molded plaster, 16 × 36 × 7 cm (6 5/16 × 14 3/16 × 2 ¾ in.)
London, Victoria and Albert Museum, Given by Dr. W. L. Hildburgh, A.171-1919

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111

Muqarnas, Samarkand, Timurid Uzbekistan, 750–800 AH/1350–1400
Glazed ceramic, 30 × 18.2 × 14 cm (11 13⁄16 × 7 3⁄16 × 5 ½ in.)
Paris, Musée du Louvre, Department of Islamic Art, Donated by Emanuele Pantanella and Letizia Signorini, MAO 2223



112

Muqarnas Tile, Iran, 7th or 8th century AH/13th or 14th century
Glazed ceramic, 25.5 × 23. 6 × 6.5 cm (10 1⁄16 × 9 1⁄16 × 2 9⁄16 in.)
Paris, Musée du Louvre, Department of Islamic Art, Donated by Emanuele Pantanella and Letizia Signorini, MAO 2145

PLATES 108–12

Used in both palaces and mosques, muqarnas (or, in Iberia, *mocárabes*) formed complex surfaces designed to reflect and refract light. Made of gilded wood, glazed ceramic, or painted plaster, these tiered, honeycomb-like structures would have formed lofty vaulted spaces recalling the dome of the heavens.

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Monir Shahroudy Farmanfarmaian

GLENN PHILLIPS



View of Shah Cheragh shrine in Shiraz, Iran

When we encounter major sites of sacred architecture through photographs, we may gain a sense of the masterful ways these spaces employ light, but we do not experience the degree to which that light is in motion. Whether through the flickering of candles, changes in sunlight, or motion captured by reflective surfaces, these environments are continually articulating themselves through the combination of light and movement. Monir Shahroudy Farmanfarmaian experienced a particularly powerful instance of the kineticism of sacred architecture while visiting the Shah Cheragh shrine in Shiraz, Iran. The vaulted domes and walls of this site are covered in dazzling and intricate mirror mosaics that fracture and dematerialize space while reflecting and amplifying the movement and activity in the shrine below. Monir began exploring these mosaic techniques in her artwork in the 1970s, eventually working with master craftspersons to produce sculptural and wall-mounted works that incorporated mirror mosaic and reverse-glass painting.

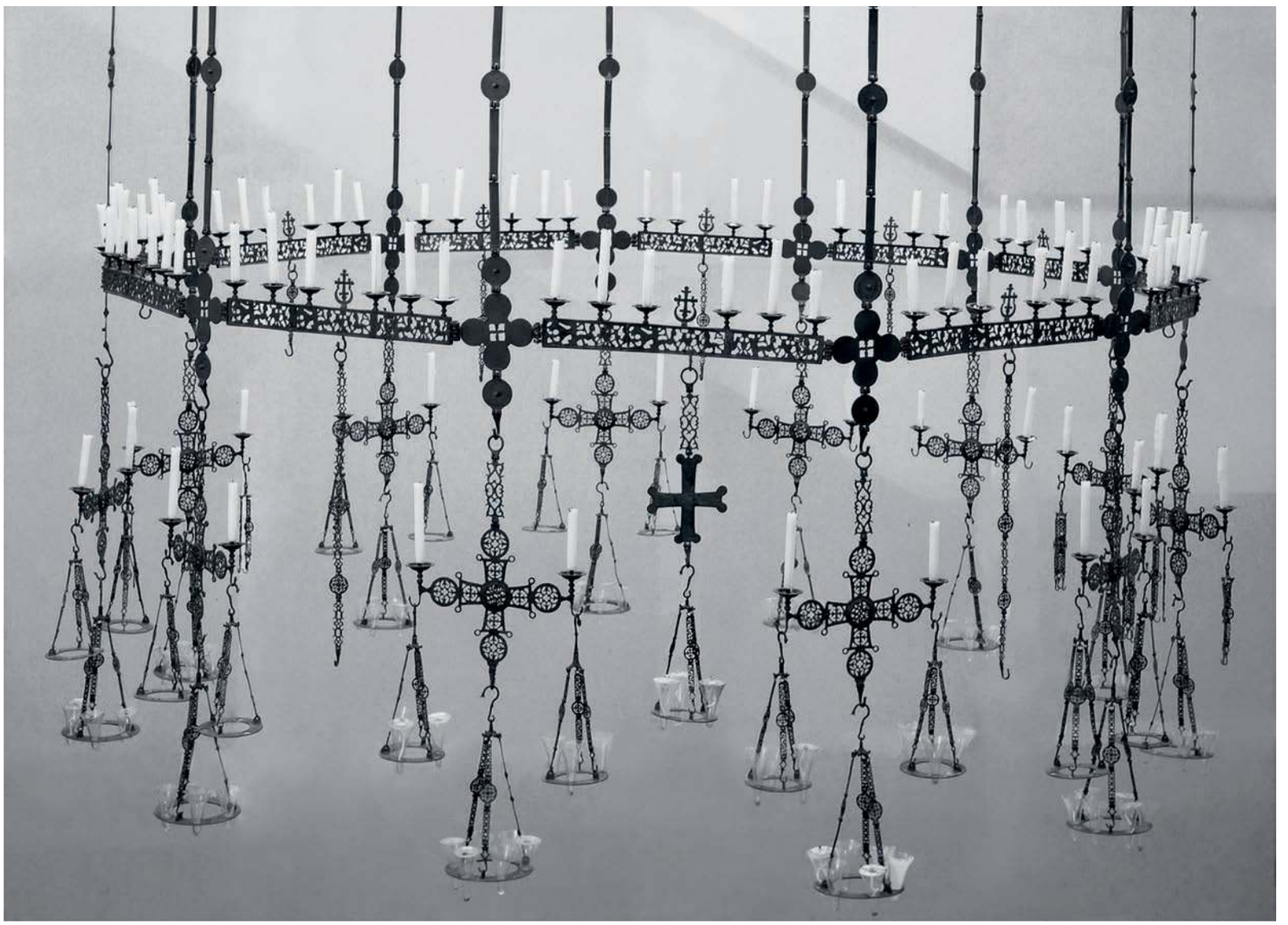
Monir's life and career were split between her home country of Iran and the home she made in New York City. Her studies brought her to New York at a young age, and she experienced the culture and world of modern abstract art in both the United States and Europe. Once back in Iran, with a young family, she developed a deep appreciation of traditional craft and immersed herself in the history of Islamic geometry, Sufi cosmology, and the rich visual traditions of Iran. The Iranian Revolution of 1979 forced her back to New York, into exile. It would be another twenty-six years before she would be able to return to her homeland and continue producing the mirror mosaics she had been forced to leave behind.

Untitled (Muqarnas), produced when the artist was ninety years old, adopts the sacred and decorative forms common in vaulted domes and archways in Islamic architecture, which are themselves expressions of the perfection of creation in Islamic art. Commonly made from painted plaster, carved wood, or ceramic tiles, the geometrically complex muqarnas forms enact a wondrous play between the light and the shadow that dance across their surfaces (see plates 108–12). In architectural settings the muqarnas are commonly located high overhead, but Monir's *Untitled (Muqarnas)* brings the form closer to eye level. Upon approaching the work, one is surrounded by the many points of light that glance off its surface and into the surrounding space. As one looks closer, one participates in a continuously evolving experience of light and motion. The mirrored mosaic, amplified by the honeycomb forms of the muqarnas, produces an infinite play between the complex geometries of the work and the changing environments and activities that are reflected in its surface.

113

Monir Shahroudy Farmanfarmaian (Iranian, 1922–2019)
Untitled (Muqarnas), 2012
Mirrors, reverse-glass painting, and plaster on wood, each section: 149.8 × 155 × 30.5 cm (59 × 61 × 12 in.)
Atlanta, High Museum of Art, Purchase with funds from the Farideh & Al Azadi Foundation, 2019.174

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114

Munich Choros, Byzantium (Anatolia/Turkey), 13th–14th century
Cast copper alloy, H: 57.6 m (2267¾ in.), Diam: 34 m (1338⁹⁄₁₆ in.); total display H: 107.6 m (4236¼ in.); Wt: 193.6 kg (426.81 lb.)
Munich, Archäologische Staatssammlung, Inv.–No. 2003_8660

The church offered one of the few places where a medieval viewer might experience an environment ablaze with light. This enormous circular chandelier (*choros*) hung high from the apex of a central dome. Holding a profusion of pendant lamps and candleholders, it would have created a spectacular visual array designed to inspire awe.

115 (OPPOSITE)

The Transfiguration in Gospel Book (in Greek), Nicaea or Nicomedia, Byzantium (Anatolia/Turkey), late 13th century
Tempera colors and gold leaf on parchment, full folio: 20.6 × 14.9 cm (8⅛ × 5⅞ in.)
Los Angeles, J. Paul Getty Museum, Ms. Ludwig II 5 (83.MB.69), fol. 45v

The Gospel of Mark (9:2–13) describes Christ's metamorphosis on Mount Tabor, in the presence of three of his disciples and of Moses and Elijah. Before a voice from out of a cloud announced Christ's divinity, his garments shone with blinding light.

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FRONT



116 Vatican *Sakkos*, Constantinople, Byzantium (Istanbul, Turkey) or Thessaloniki, Greece, 14th century
Blue silk with silver, silver gilt, and colored silk threads, 162 × 144 cm (63¾ × 56¾ in.)
Vatican, Fabbrica di San Pietro, CSPV inv. 0107

The images on the garment show, on the front, Christ seated on a rainbow and, on the back, the transfigured Christ, shining with blinding light on Mount Tabor. The garment's reflective silks and gold and silver threads would have sparkled with the movement of the wearer. A *sakkos* such as this one was worn on feast days by Byzantine patriarchs, and later by high-ranking archbishops.

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BACK



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117

Mosaic Icon with the Virgin Episkepsis, Constantinople, Byzantium (Istanbul, Turkey), late 13th century
Glass paste, gold and silver tesserae on wax gum, 107 × 73.5 cm (42⅛ × 28 15⁄16 in.)
Athens, Byzantine and Christian Museum, inv. BXM 990



118

Enthroned Madonna and Child, possibly from Constantinople, Byzantium (Istanbul, Turkey), 1250–75
Tempera on poplar panel, 130.5 × 77 × 6 cm (51⅜ × 30 5⁄16 × 2⅜ in.)
Washington, DC, National Gallery of Art, Gift of Mrs. Otto H. Kahn, 1949.7.1

PLATES 117, 118

Unlike Gothic churches in northern Europe, in which light was filtered through glazed windows, Byzantine churches made use of large quantities of natural light that interacted with golden icons and faceted mosaics whose tesserae were positioned at varying angles to maximize their reflective power.

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119

Ølst Golden Altar, Ølst, Denmark, 1200–1225
Fire-gilt copper sheet over oak, 106 × 183 cm (41¾ × 72 1/16 in.)
Copenhagen, National Museum of Denmark, inv. D.5144

Once studded with large rock crystals, this gleaming golden altar frontal presents, at center, an image of the Last Judgment, with Christ seated on a rainbow. This imagery, along with its gleaming surfaces, would have called to mind the bejeweled gates of the Heavenly Jerusalem.

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120

Gloucester Candlestick, Gloucester, England, 1107–13
Cast and gilded copper alloy, niello, glass, 58 × 20 × 20 cm (22 13⁄16 × 7 7⁄8 × 7 7⁄8 in.); Wt: 5.76 kg (12.7 lb.)
London, Victoria and Albert Museum, 7649-1861

Romanesque metalcraft created undulating surfaces across which light and shadow moved in the dynamic lighting environment of the church. The inscription circling the grease pan of this candlestick reads, “Shining doctrine proclaims [that] the substance of light [is] a work of virtue so that man not be thrown into darkness by vice.”

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121

Liturgical Fan, Hildesheim, Germany, ca. 1130–50
Gilded copper alloy, rock crystal, semiprecious stones, ancient intaglios, H: 52.5 cm (20 11/16 in.); Diam: 41 cm (16 1/8 in.)
Dommuseum Hildesheim, DS 27a

Used in early Christian times to wave flies away from the altar, the liturgical fan was by the eleventh century ceremonially extended over the gifts during the Canon of the Mass. The movement of the golden, crystal-encrusted object would have created light-filled moments during the Christian rite.



122

Treasure Binding of Gospel Book, Canterbury(?), Anglo-Saxon England, ca. 1065
Belgian gold repoussé attached to wooden board, gold filigree and gem mounts, modern tin rim, 29.3 × 19.1 cm (11 9/16 × 7 1/2 in.)
New York, Morgan Library & Museum, MS M.709, front cover

Jeweled covers enshrined precious Gospel books that were displayed on the altar during the Mass. Colored gemstones were valued by medieval viewers especially for their light-holding properties—an appreciation carried over from antiquity, when gems were thought to physically (not merely symbolically) contain light.

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123

The Coronation of the Virgin, half of a processional standard for the church of San Francesco, Fabriano, Italy, ca. 1420
Gentile da Fabriano (Italian, ca. 1370–1427)
Tempera and gold leaf on panel, 93 × 64.1 cm (36⅝ × 25¼ in.)
Los Angeles, J. Paul Getty Museum, 77.PB.92



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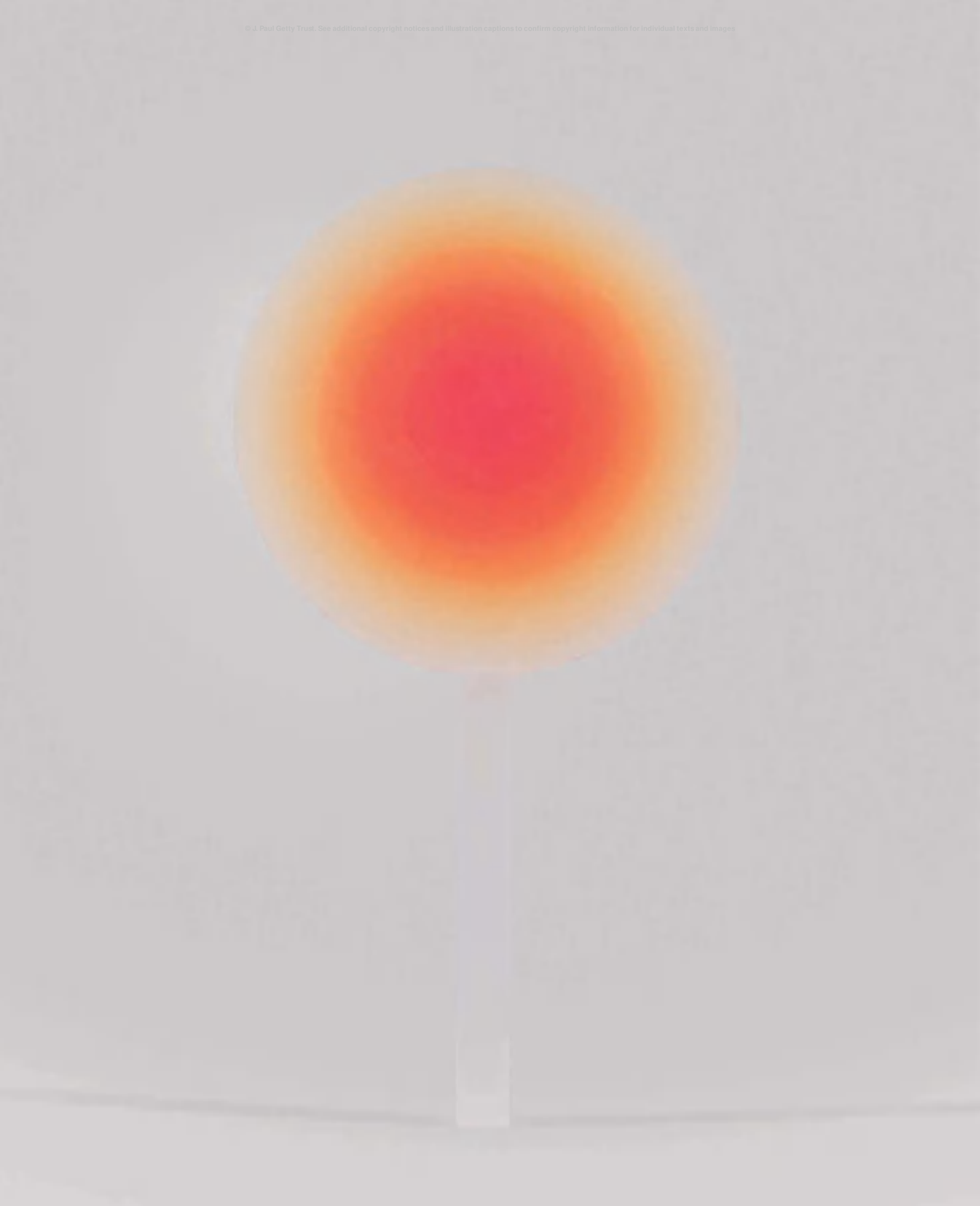
124

The Stigmatization of Saint Francis, half of a processional standard for the church of San Francesco, Fabriano, Italy, ca. 1420
Gentile da Fabriano (Italian, ca. 1370–1427)
Tempera and gold leaf on panel, 89 × 65 cm (35 × 25 9/16 in.)
Parma, Fondazione Magnani-Rocca, Mamiano di Traversetolo, 583 A.F. n.6

PLATES 123, 124

Once part of a two-sided processional standard, these two paintings had varied surface treatments designed to flash in strong sunlight when paraded outdoors or to catch moving lamplight on an altar or elsewhere in the church when the standard was at rest.

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Helen Pashgian

GLENN PHILLIPS

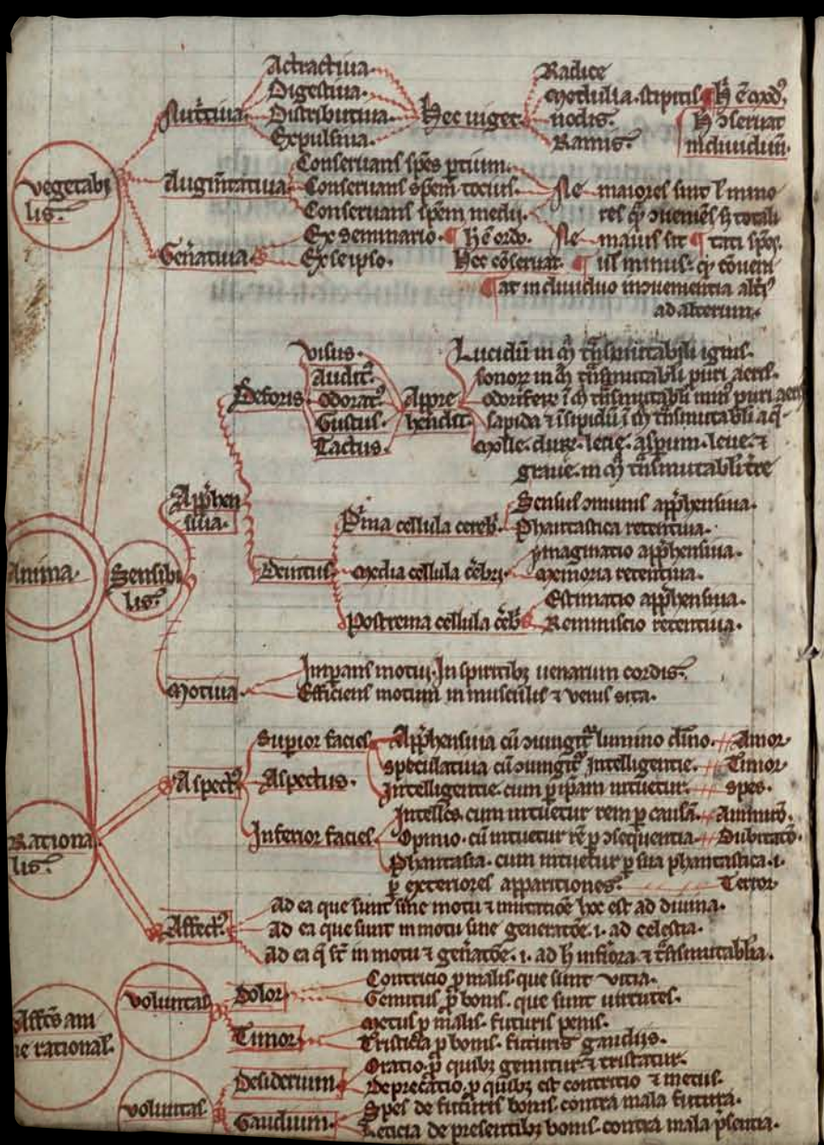
The experience of viewing Helen Pashgian's *Untitled (Lens)* can begin as one of confusion. Here is a luminous orange disk, vibrant at its center and gradually fading to yellow at the edge. The edge itself, however, seems more difficult to discern than it should be: Where does Pashgian's artwork end and the surrounding room begin? Careful concentration should provide an answer but instead yields a new phenomenon: the eyes begin to form afterimages (in this case a foggy aqua) that create a halo around the work—an auratic presence not coming from the object but evoked by the human retina. It feels wrong to look away and barely right to blink: that afterimage belongs on top of the disk just so, yet it still feels as if there might be movement happening around the piece. As the lights in the room slowly dim and grow (they are on a programmed cycle), the effects only intensify. After extended concentration by the viewer, the lens's thin acrylic pedestal, and indeed everything else in the room, may even seem to fall away completely, leaving only the experience of a hovering, halo-encircled light. If ancient and medieval scientists were not yet sure whether vision occurred via the eye's receiving or transmitting information, it may be perceptual effects akin to these that left room for debate. The experience of Pashgian's work involves a communion between the artist's precisely tuned objects and the viewer's physiological response to those objects, with each producing only one portion of the overall physical experience.

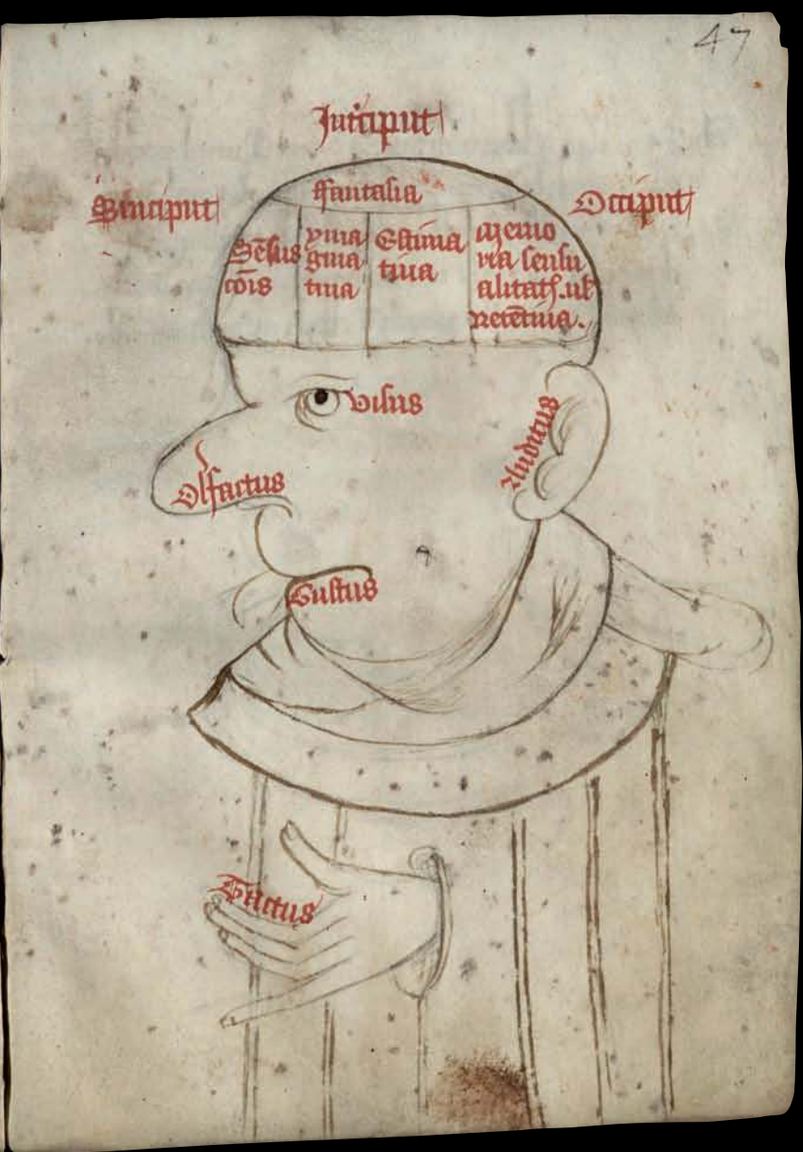
Pashgian, together with Robert Irwin and James Turrell, among others, was part of a group of Southern California artists whose work in the 1960s and 1970s came to be known as the Light and Space movement. These artists used high-tech materials and a sophisticated understanding of human perception to create objects and environments that were often so spare in their presentation as to push vision to the edge of malfunction. By challenging depth and edge perception and using new materials to capture rarely depicted effects of light, these artists created works that could evoke an awe and wonder in their audiences that may be our closest equivalent today to the perceptual effects of sacred spaces on a medieval viewer. While it may seem counterintuitive to compare these radically minimal artworks to magnificently ornate medieval spaces, they are united in the degree of effort and control that their creators have expended to produce environments that are utterly beyond the outside world, energized and transformed by light, and worthy of pilgrimage. It is spaces like these that invite us to slow down, to focus attention, and to contemplate vision, the self, and perhaps the beyond.

125

Helen Pashgian (American, b. 1934)
Untitled (Lens), 2023
Cast urethane
Diam: 127 cm (50 in.)
Courtesy the artist

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Epilogue: Light and the Neuroscience of Awe and Wonder

G. GABRIELLE STARR

Light is among the richest sources of information available to the senses. However, its metaphoric value—its long and deep connection to the very idea of knowledge—tends to obscure how much vision is *not* a faithful rendering of the world.[1] This seeming paradox is central to understanding how people find beauty in what we see. Indeed, one of the more interesting puzzles in aesthetics is how sensations evolve into complex aesthetic experiences, whether they involve beauty and awe, solemn contemplation, or even fear and trembling. For visual aesthetics, answers begin with understanding how light becomes available to human beings as knowledge. Increasingly, neuroscientists are using two important frameworks, one centered around action and the other around probability, to help model these processes. As I will sketch below, it is because of the ways humans acquire knowledge—including how we learn through vision and the sensory perception of light—that aesthetic pleasures and experiences emerge.

Light and Vision

To get a "glimpse" of how much the senses, as interfaces between body, mind, and world, shape the fabric of human existence, consider that humans might have been designed like bats, relying on sound for navigation. Or, like whales, we could have evolved to live underwater, where sound travels faster and farther than through air, and light fades more quickly. Even imagining life in such bodies would require radical change in the metaphors used to describe how humans "see" and know.[2] But humans evolved aboveground and are far more active in daylight than at night.

Privileging sunlight was a solid evolutionary bet. Visible light provides detailed, actionable information from an abundant, predictable, and exogenous (both external and independent) source. This last feature is particularly important: because sunlight is produced at such a distance and with such power, it offers (absent technological innovation) clear rules of engagement and apparent neutrality. The sun does not care whom it shines on, sinner or saint, and at noon we all cast the same shadow. By contrast, sound requires a proximal agent—the wind through the trees, a door creaking, or an animal growling. This makes it inherently more subject than sunlight to intentional interference or distortion: the same living agents that make noise can manipulate it by moving stealthily, say, or by mimicking some other cause or sound. Sunlight, however, emanating from far above, appears to the naked eye as a neutral messenger, revealing the world as it really is.

Sighted individuals are generally accustomed to taking light as a simple representation of truth; they thus tend to ascribe to light characteristics that properly belong to sight. Color, for example, names a particular aspect of visual experience, not something with independent, physical existence.[3] As we understand it today, visible light is a form of electromagnetic radiation distinguishable by intensity, wavelength (the distance between the peak and trough of its waveform), frequency (the number of peaks or troughs per second passing an observer), and polarization (the geometric relationship between a wave's direction of motion and that of its peak and trough). Color experience involves a combination of hue (general wavelength range, e.g., blue), saturation (perceived purity of hue), and brightness. Modern neuroscience has demonstrated that human color perception is based on which wavelengths reach the retina at the back of the eye; this in turn depends on the wavelengths emitted, atmospheric conditions (the earth's atmosphere scatters some wavelengths more than others), and the particular wavelengths an object absorbs or reflects. But color, like all aspects of vision, is a perception assembled in the brain from information received from the retina.

Because the processes by which the brain assembles perception are not available to one's own awareness, it is easy to misattribute components of perceptual processes to their objects. This kind of misattribution may be harder to escape for sight than for touch or smell; the ineluctable connection of sight and light renders them subjectively interchangeable. Hence, the common description of moonlight as pale, and the idea that colors fade to black with sunset. It was only in the thirteenth century that scholars began to separate light from color perception: Kamal al-Din al-Farisi (ca. 1267–1319) noted, in his groundbreaking commentary on optics, *Tanqih al-Manazir*, that objects seemed to take on a different hue in different light, making him one of the first scholars recorded to have approached color as an effect, not a thing in itself (plate 40).[4] The different effect of different kinds of light might, even to modern readers, seem strange: moonlight, after all, is reflected sunlight, and while moonlight is shifted slightly toward

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the blue end of the spectrum, it contains the same range of wavelengths as sunlight.[5] Al-Farisi's core observation, however, has less to do with where light comes from than with how humans perceive it. The relative paucity of color humans perceive in moonlight (or any dim light) comes because humans evolved to have one system for seeing in low-light conditions, and another for brightly lit environments.[6]

The Eye and Brain Bases of Vision

Since antiquity the gross anatomy of the eye was generally understood (although imperfectly; the lens was thought to be in the center of the eye), and Islamic scholars such as Ibn al-Haytham (965–ca. 1040) held the most accurate knowledge.[7] It was Ibn al-Haytham who, as far as is documented, first understood that refraction—the bending of light when it passes through a transparent substance like glass, water, the cornea, or the aqueous and vitreous fluids inside the eye—was the key to focusing light and creating an image (see plate 40). The principle that light is bent in passing through transparent media enabled the production of crystalline lenses used for reading as well as creating visual effects.[8] Microscopy is necessary, however, to build a detailed understanding of vision.[9] Rods, specialized cells in the retina, have the ability to detect single photons. They are most active in low light but are not sensitive to wavelength. Cones can also detect single photons but are most active during bright conditions and are specialized for low, medium, or high wavelengths (and hence can discriminate colors across a wide range of the color spectrum). So, the reason one perceives less color as the sun goes down *is not* because moonlight is "pale"; it is because of the switch from cones to rods, a physiological change focused on detecting motion rather than color contrast.

Remarkably, retinal cells function as dark detectors. Rods and cones transmit signals when they are *unable to absorb light.* This makes sense metabolically: the default circumstance for a retinal cell is daylight, so a continuous signal that the sun is still shining is both wasteful and not particularly useful.[10] Dark detection also makes evolutionary sense: what animals care most about tend to be changes in prevailing conditions. Detecting movement is essential for animals, and the eye thus evolved to detect interruptions in light, interruptions necessarily produced because something comes between the sun and the perceiver. Again, the key is that sunlight is far harder to manipulate than other sources of information available to the senses, and thus is a reliable bet for high-stakes signals. Detecting color adds nuance (allowing us to determine how ripe an apple is) but is not necessary in the same way as perceiving motion is. So, as night falls the eye maximizes its ability to detect changes in light, sacrificing color for movement detection.

Signals from the retina travel down the optic nerve to the brain, entering via a structure called the lateral geniculate nucleus. From there, posterior brain regions denoted as V1 (i.e., visual area 1) through V8 extract

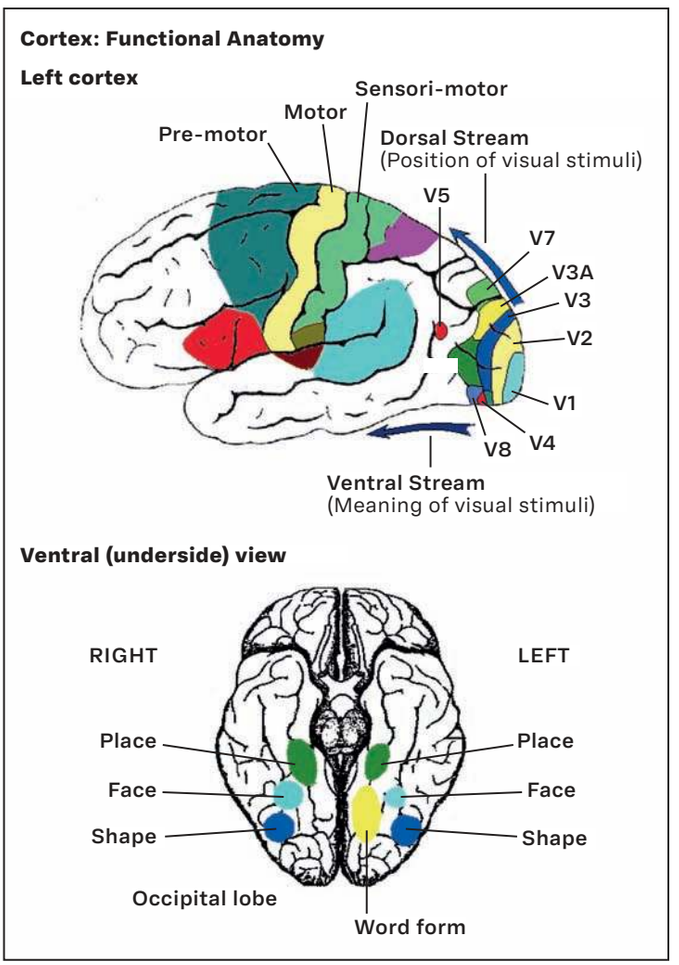


Figure 64. Functional and anatomical segmentation of the human brain. (Occipital lobe zones after Nikos K. Logothetis, "Vision: A Window on Consciousness," *Scientific American*, November 1999.)

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specific information. V5, for example, provides data about direction of motion, while areas in V4 both indicate direction of motion and assist in shape and color detection. In V1, the primary visual cortex, information from both retinas is spatially mapped, separating input from the left and right eyes. Visual information, along with input from other senses, memory, and elsewhere, is then integrated (in complex and still poorly understood processes) (fig. 64).

The brain also contains regions dedicated to important classes of perceptions, including a structure in the inferior temporal lobe (the fusiform face area, located below and behind the ear) specialized for face detection. From the visual cortex, information can travel toward the ventral/bottom surface of the brain, enabling objects to be labeled with semantic information (the "what" pathway), and toward the dorsal/top surface, enabling motor analysis and action (the "where" pathway). This bifurcation is significant, indicating that two of the most important classifications of visual data are what it is and what one can do with it. These classifications offer clues to understanding aesthetic pleasures.

Sensation, Perception, and Prediction

The senses exist primarily to help human beings act in the world around us, *not* to portray it accurately.[11] In fact, much of what seems objective reportage is not. Color is an entirely subjective phenomenon, and the information sent from the retina generally involves detecting the absence of light or variations in it, rather than recording light received from the world. But there are viscerally resonant examples, too. Most people routinely experience phantom tastes. You may have experienced one as an unpleasant surprise: Busily daydreaming, or intent on a conversation, you reach for a glass. Able to firmly grasp even what you do not clearly see, you swallow something . . . horrible. You think you are drinking water, but it turns out to be iced tea; instead of tasting what is in your mouth, you find that the taste seems off, as if the tea is mixed with water, or bad, and unlike what it truly is. If the senses were intended to deliver accurate information about the world, you should have tasted what was in your mouth. Indeed, if that were their purpose, the senses would have failed; but this is not what the senses are for.

Because action is the goal of perception, we care not only about *what* an object is but also about how we might use, react to, or feel about it. Perceptions thus reveal the routes—often called affordances—through which we can manipulate, interact with, and even change the objects we perceive and the environment in which we live.[12] But in order to represent the world fast enough for reaction, *the brain anticipates what it will perceive*, much in the same way that word-processing software anticipates what you are about to type.[13] This is why the phantom taste "mistake" is not a malfunction: the brain creates expectations about what comes next.

The phantom taste phenomenon points toward a fundamental principle: human experience sits on the knife's edge of past and future. It is quite intuitive that humans depend on understanding the past to help predict the future; that is one way of thinking about learning, and it is easy to see this is necessary for survival. But what is a little harder to see is that we use the past to predict *the present*. Indeed, the predictive processes of the brain are fundamental to navigating an uncertain world.[14]

All organisms need information to live, but even essential information can be hard to verify and interpret; analysis of past experiences provides a framework for assessing current circumstances. This provides a foundational cognitive principle, so that even the conviction that one thing is cause and another its effect is a mental construct based on probabilistic analysis, not a physical observation, a construct so powerful that it influences the perception of time. Indeed, the perceived time connecting a cause with its effect is shorter than the actual time separating the two, because neural processes anticipate sensation to shape perception.[15]

Prediction shapes the knowledge humans build from sensations and the pleasures we feel in response to what we sense, think, and know. Recent work by researchers who focus on visual perception has argued that there is a kind of gloss, clarity, and substantiality to what we think of as "real": once the brain has resolved perceptual data into the configuration that is most likely correct, that is what we "see," and this is the basis of the kind of confusion one might experience with an optical illusion of, say, a duck that sometimes looks like a rabbit, or a "face" that suddenly, indelibly emerges in the bark of an old oak tree (fig. 65).[16]

The gloss of clarity accompanying perception is a signal that a prediction about what one is supposed to

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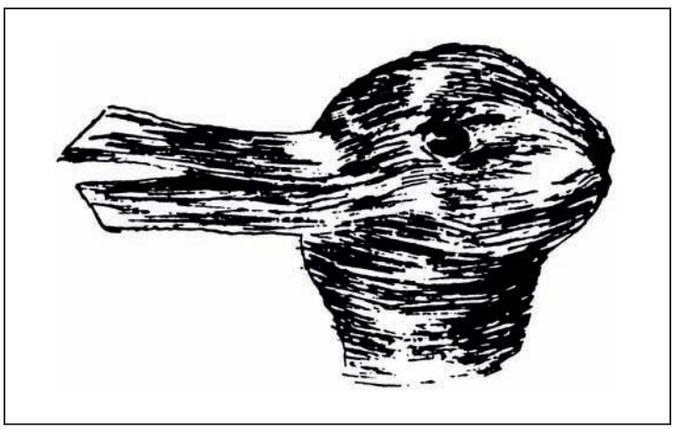


FIGURE 65. An optical illusion. Whether one sees a rabbit or a duck is determined by a governing interpretation that drives the perceptual process.

perceive is correct. This offers one way of understanding why we "believe" some perceptions and not others.[17]

Predictive Processing and Aesthetic Pleasures

The world becomes intelligible when it conforms to predictions, beginning with neural calculations about the identity and use of the objects of perception. Confirmed predictions are rewarding, and while they do not always generate conscious pleasure, this mechanism is the foundation on which many pleasures rely.[18] At a macro level imagine an archer aiming at a bull's-eye. The calculations needed to predict the mechanics of an arrow's flight yield to pleasure when she hits her target. At a neural level these predictions involve reward signals that enable humans and other animals to fine-tune behavior to obtain what they desire. This has far-reaching implications for understanding aesthetic pleasures.

The pleasures that emerge because a percept appears vivid, especially when the world around it is obscured, can be significant. Take the stained-glass windows in houses of worship, which transform light into a devotional medium by screening out the objects beyond the sanctuary and coloring the world within it. Aesthetically, however, by contrast with the darkness created by thick walls and narrow apertures, these windows, in their brightness and luminosity, generate a hyperreality that can itself be pleasing. Their compelling vivacity allows these artworks to borrow the gloss of "belief" that accompanies everyday vivid perception.

The connection between pleasure and prediction applies not just to facets of perception that are unconscious but also to conscious judgments across different contexts and artistic genres, where the expectations of participants, audiences, viewers, or readers shape both satisfactions and frustrations. This can be readily understood with music, literature, or dramatic arts, where expectations about sequences of notes or events make a framework for evaluating the suitability of what comes next. But it also matters in an art like architecture, where expectations about the use of spaces shape the pleasures one may take in them.[19] In this way familiarity with, say, a particular tradition of worship can shape expectations about how one enters a sanctuary, its proportions, and even the origin of light within it.

Surprise, Curiosity, and Wonder

The picture I am sketching of aesthetic experience emphasizes the relationship between aesthetics and knowledge; this means that aesthetic experiences contain both universal elements (e.g., the mechanisms of pleasure) and highly individual ones, because each person has a unique path through life, assembling a unique history that shapes one's perceptions.[20] Foundational ideas and beliefs may influence more than expectations; by shaping experience they may predispose individuals to particular kinds of experiences.[21] Thus Anjan Chatterjee and colleagues suggest religious experience may "prime" individuals to experience wonder in relation to both the natural world and objects of human culture.[22]

Learning about the world requires developing and testing expectations. As I have argued, because pleasure can be a consequence of gaining actionable knowledge, aesthetic pleasures can emerge as humans learn about the environment and the objects or people in it.[23] Aesthetic pleasures, however, do not always involve confirmation of expectations; indeed, some of the most intense experiences come when one can gain new knowledge in the context of uncertainty—for example, when in a new or confusing artwork what had seemed chaotic resolves into sudden comprehension.[24] In effect aesthetic pleasures can serve to orient individuals toward opportunities for the highest *gain* in understanding.[25] Such

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FIGURE 66. *The Coronation of the Virgin*, Florence, Italy, ca. 1434–35. Fra Angelico (Italian, 1395–1455). Tempera on panel, 112 × 114 cm (44 × 45 in.). Florence, Gallerie degli Uffizi, inv. 1890 n. 1612

experiences take time, and complex artworks may be designed to reward audiences by setting the stage for epiphanies and revelations—indeed, such moments are central to many of the artworks in this exhibition, enabling aesthetic facets of learning to represent and perhaps fuel the acquisition of spiritual knowledge (fig. 66).

To create their effects, objects from the distant past depended on knowledge and experiential frameworks different from those of today; indeed, what counts as wondrous to one generation or epoch is mundane to another. However, while modern audiences may need additional context to orient themselves toward the world that gave birth to an object, focusing on the sensory landscape an artifact creates and the contexts in which it is displayed or encountered can still generate pleasures in line with its aesthetic design.

For the works in the exhibition, although these experiences may begin with light, they are not exclusively visual. The experience of being within a temple includes acoustic elements, whether the echoes of feet or voices, or the muffling of sound from the outside world.[26] Equally, the awe or wonder engendered by a procession through a cathedral may rely on the ways vision is obscured: a flash of gilded thread appears as embroidered fabric moves with its wearer; smoke wafting from incense veils not just the gilded censer but also the face of the celebrant. The dynamic interplay of the senses

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can thus set the stage for revelatory surprise: the words of a liturgy or prayer clarify the darkness of the world, or shared notes raised in song produce a sense of community that solidifies the bonds within a congregation.

All this points toward important epistemic functions for art and toward some of the more virtuoso effects of powerful artworks; such effects emerge as viewers reorient themselves and, in the words of Pietro Sarasso and colleagues, "stop for knowledge."[27] Neurologically, perceiving beauty, Sarasso and his coauthors have noted, can lead to the inhibition of neural motor processing and, as my colleagues and I discovered, to the activation of a brain system (the default mode network) generally reserved for introspection, daydreaming, memory, and imagining the self and others.[28] These high-level global brain networks may enable rapid access to a wide range of cognitive processes, accommodating synthesis of information about emotion, self-awareness, and even social interaction.[29] Aesthetic experience, then, can fundamentally involve not just knowledge but also curiosity and even creativity.[30] Ultimately, aesthetic experiences are an outgrowth of the search for knowledge, and thus they and the arts that can engender them are foundational, perhaps even essential, to human experience. If the senses enable humans to move through the world as agents—exploring, engaging, and interacting—aesthetic pleasures matter in part because they are motivational, leading us on by their very pleasure and inviting us to pause while we explore. It is thus that humans thrive on beauty and, as it enables us to make meaning out of the world around us, the power of art strikes so close to mind and heart.

Notes

1 For a wonderful account of the cultural history of blindness and sight, including the ways in which vision is mapped onto knowledge while blindness is figured as a special kind of insight, see M. Leona Godin, *There Plant Eyes: A Personal and Cultural History of Blindness* (New York: Vintage, 2021).

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4 Eric Kirchner, "Color Theory and Color Order in Medieval Islam: A Review," *Color Research & Application* 40, no. 1 (2015): 5–16. Al-Farisi observed that firelight seems to cast differently colored shadows, too.

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13 Karl Friston, "The Free-Energy Principle: A Unified Brain Theory?," *Nature Reviews Neuroscience* 11, no. 2 (2010): 127–38.

14 Andy Clark, *Surfing Uncertainty: Prediction, Action, and the Embodied Mind* (Oxford: Oxford University Press, 2015).

15 Patrick Haggard, Sam Clark, and Jeri Kalogeras, "Voluntary Action and Conscious Awareness," *Nature Neuroscience* 5, no. 4 (2002): 382–85.

16 Faces emerge everywhere we look because the fusiform face area (see fig. 65) preferentially identifies ambiguous face-like objects as faces; see Nouchine Hadjikhani et al., "Early (N170) Activation of Face-Specific Cortex by Face-Like Objects," *Neuroreport* 20, no. 4 (2009): 403. On the gloss of reality, see Whitman Richards, Allan Jepson, and Jacob Feldman, "Priors, Preferences and Categorical Percepts," in *Perception as Bayesian Inference*, ed. David C. Knill and Whitman Richards (Cambridge: Cambridge University Press, 1996), 93–122.

17 David Hume pointed out that humans differentiate imagined circumstances, whether dreams or figments, from reality because one is more vivid than the other. See David Hume, *A Treatise of Human Nature*, ed. Ernest Mossner (New York: Penguin, 1985), part 3, section 7.

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Through the manipulation of materials such as gold, crystal, and glass, medieval artists created dazzling light-filled environments, evoking in the earthly world the layered realms of the divine. *Lumen: The Art and Science of Light, 800–1600*, explores how light was studied by Christian, Jewish, and Muslim philosophers, theologians, and artists during the long Middle Ages, when science and religion were firmly intertwined.

Telling a story that is equal parts science, poetics, and craft, this sumptuously illustrated volume includes essays from contributors in the fields of art history, the history of science, and neuroscience to consider how investigations in the fields of optics, geometry, and astronomy informed the artistry of the Middle Ages and Renaissance. The book also features several contemporary artworks, placed in dialogue with historic objects, to convey the timeless sense of wonder conjured by starry skies or light moving over precious materials.