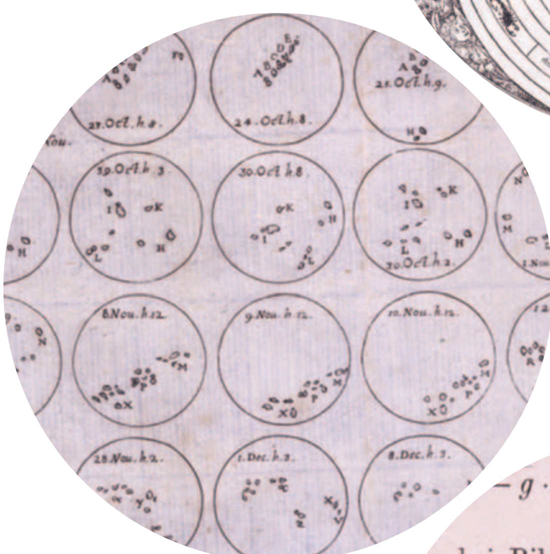
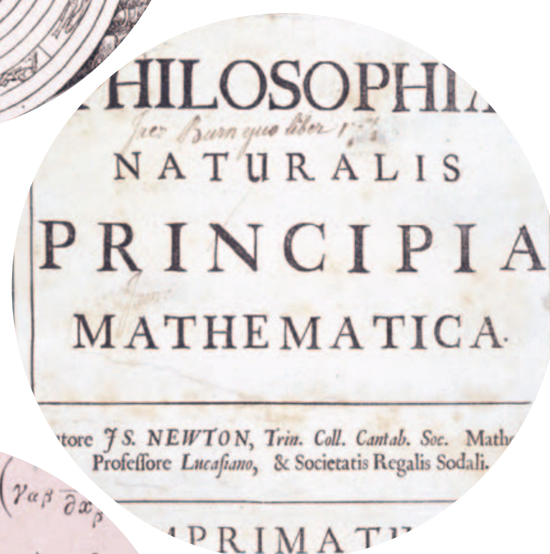
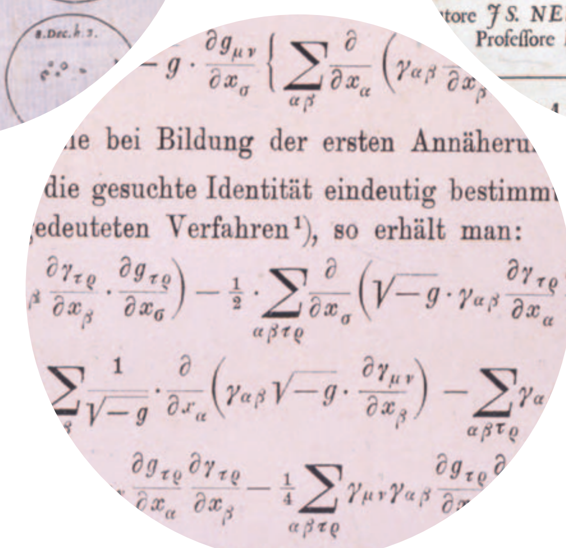
Celestial Harmony:
Four Visions of the Universe







An exhibition at the Milton S. Eisenhower Library

April 26 – May 30, 2004

Celestial Harmony

Four Visions of the Universe

An exhibition at the Milton S. Eisenhower Library

The Classical and Geocentric Universe of Plato, Aristotle, and Ptolemy: 350 B.C. to 1543 A.D.

The Revolutionary and Heliocentric Universe of Copernicus, Kepler, and Galileo: 1543 to 1638

The Clockwork Universe of Newton and Laplace: 1687 to 1900

The Expanding and Relativistic Universe of Einstein and Hubble: 1900 to Present

This exhibition of rare books in astronomy and physics, from the collection of Elliott Hinkes (Hopkins A&S '64, SOM '67), tells a story about our views of the universe from the 15th to the 20th centuries. Only a few works and a cursory overview can be offered. Nonetheless, the selection represents the most prominent works that have shaped the four great views of the universe.

It is easy to appreciate the physical beauty of these books, the bindings, typography, and illustrations that represent a time when great pains were taken in their production. But the essential element of this collection, and of this exhibit, is in the scientific discovery that runs through these works, a coherent sequence of progressively more informed and detailed knowledge about our universe, invariably, if sometimes haphazardly, built on earlier discoveries. The night skies appear more or less the same today as they did a millennium ago. Our understanding of what we see is more enlightened now and more complete because of this long chain of scientific discovery. It is true that mankind has progressively been pushed off center stage from the middle of Ptolemy's universe to just one satellite of an ordinary star among billions of stars, in one ordinary galaxy from among billions of galaxies. But the view from this remote vantage point is infinitely more grand, and more awe inspiring than anything Ptolemy or Copernicus could have imagined. We conclude this exhibition with a view of the universe from the perspective of the Hubble telescope and the research currently taking place.

—*Contributed by Elliott Hinkes*

The Classical and Geocentric Universe of Plato, Aristotle, and Ptolemy: 350 B.C.–1543 A.D.

Euclid (ca. 330–260 B.C.).
Elementa Geometriae.

Venice: Ratdolt, May 25, 1482. 1st edition. Lewis Carroll's copy.

Euclid's *Elementa*, a compilation of early Greek mathematics and geometry, is the oldest scientific text still in use. Transmitted to the West through Arabic sources, this 12th-century translation by Adelard of Bath was edited by Companus of Navarra in the 13th century. The *Elementa* remained unchallenged for 2,000 years. In the early 19th century, Lobachevski (on exhibit) and a few others challenged the parallel axiom and its attendant "flat space" imperative, to posit successfully the modern theories of curved space. This shift helped open the way for Einstein's cosmological structure and predictions concerning space-time and the expanding universe.

Hartmann Schedel (1440–1514).
Liber Chronicarum.

Nuremberg: Koberger, July 12, 1493. 1st edition. Illustrated and engraved by Michael Wohlgemuth, Wilhelm Pleydenwurff, and Albrecht Dürer. *(shown below)*

Considered the greatest illustrated book of the 15th century, the *Nuremberg Chronicle* depicts the history of the world from creation to the time of its publication. This first edition was compiled by the physcian and humanist Hartmann Schedel, and printed in the German industrial city of Nuremberg by Koberger.

Johannes Müller (a.k.a. Regiomontanus) (1436–1476) and Georg Peurbach (1423–1461).
Epytoma in Almagestum Ptolemaei.

Venice: August 31, 1496. 1st edition.

Ptolemy's *Almagest* was begun by Peurbach but completed by his student Regiomontanus. This abbreviated Latin version is taken from a surviving medieval Arabic manuscript. Claudius Ptolemy (100-178 A.D.) most likely borrowed extensively from Hipparchos (190–120 B.C.) and based his theories on the works of both Plato (427–367 B.C.) and Aristotle (384–322 B.C.).

Ptolemy accepted the Platonic view of the cosmos: eternal, infinite, uniformly spherical, unchanging, perfect, and set in motion by divine action. He united these long-held beliefs with Hipparchos' astronomical and mathematical data to create a model of the universe which relatively accurately accounted for a wide range of astronomical observations; periods of planetary orbits, planetary orbital retrogression, future planetary positions, lunar phases, and eclipses.

Claudius Ptolemaeus (100–178).
Almagestum.

Venice: 1528. 1st Latin edition.

The first Latin translation from the original Greek rather than from an intermediate Arabic source, the *Almagest* was published in a series of "first editions." The first printed edition of any kind is the Regiomontanus 1496 *Epitome* (on exhibit). The first complete edition was published in 1515, and the first Greek text was published in 1538.

Alessandro Piccolomini (1508–1578).
De la sfera del mondo...

Venice: 1540. 1st edition.

Alessandro Piccolomini was a noted scholar, cosmographer, and ecclesiastic. *On the Globe of the World* first appeared in 1540. The book begins by discussing the known cosmographies of the time and their associated methodologies. Piccolomini's work includes diagrams relating to the Earth's great circles, the relationships between the moon, sun, and Earth, and other planetary observations.

Aristarchus of Samos (310–230 B.C.)
De magnitudinibus et ditantiis solis et lunae...

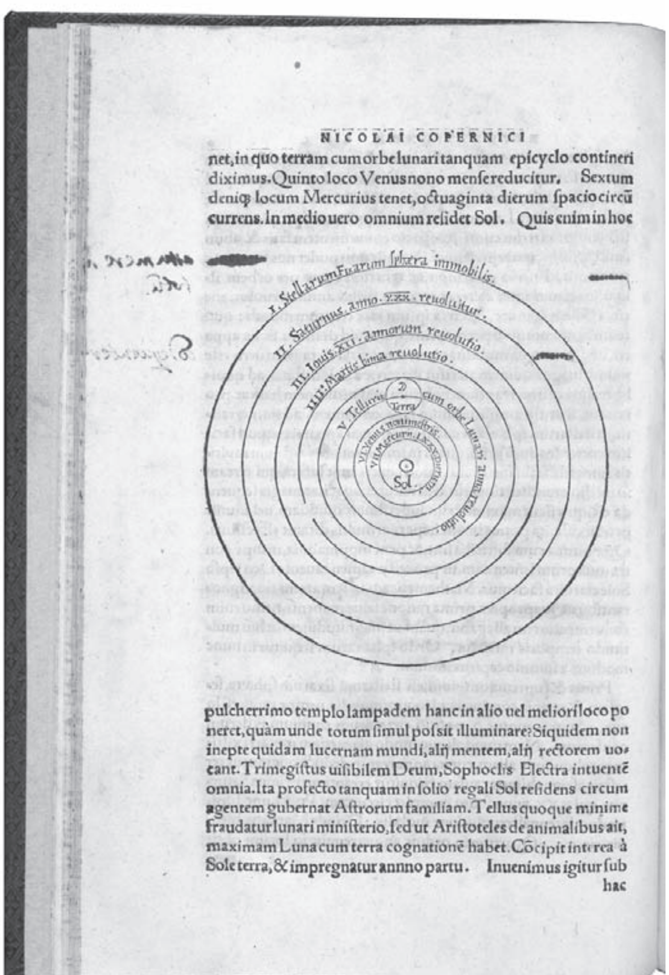
Pesaro: 1572. 1st edition. Edited by Commandino.

Aristarchus of Samos was a remarkable figure in Greek astronomy. Anticipating Copernicus by some 1,800 years, he proposed that the sun was fixed at the center of the universe and that the Earth, rotating on its own axis, revolved around the sun. These early proclamations do not survive, unfortunately, but they are discussed by Archimedes (287–212 B.C.) in *The Sand-reckoner.*

The Revolutionary and Heliocentric Universe of Copernicus, Kepler, and Galileo: 1543–1638

Nicolaus Copernicus (1474–1543).
De revolutionibus orbium coelestium.
Basel: 1566. 2nd edition. *(shown below)*

De revolutionibus represents Copernicus' lifelong belief that the universe was sun centered, not earth centered. Making very few astronomical observations himself, Copernicus relied almost exclusively on Aristotelian theory, logic, and observational data. The theory of a heliocentric universe was not original to Copernicus. He most certainly knew of Aristarchus' theories. But Copernicus formally documented the heliocentric universe, correctly positing the rotation of the Earth on its axis, placing the planets in their correct order around the sun and the moon around the Earth, explaining the apparent motion of the sun through the ecliptic, and the apparent retrograde motion of the planets, relative to the Earth's orbit. Despite its tepid reception, the book is generally recognized as one of the three most influential works in the history of science, the others being Newton's *Principia* and Darwin's *On the Origin of Species*.


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

pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, 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 regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximam Luna cum terra cognationẽ habet. Cõcipit interea à Sole terra, & impregnatur annno partu. Inuenimus igitur sub hac

Tycho Brahe (1546–1601).
Astronomiae instauratae progymnasmata...et nova stella anno1572.
Frankfurt: 1610. 1st edition.

Tycho Brahe published his *Astronomiae instauratae progymnasmata ...et nova stella anno1572,* after years of extensive astronomical observations following the 1572 appearance of the "new star" or supernova in the constellation of Cassiopeia. The supernova was widely observed throughout Europe and led Brahe to reconsider Plato's view of the perfect, unchanging universe and to spend decades re-charting the heavens. Brahe's star catalogs, the first since antiquity, were said to be 60 times more accurate than previous star catalogs. Upon his death, his meticulous observational data were given to his assistant Kepler. This work, together with Kepler's subsequent interpretations, formed the foundation of modern scientific astronomy.

Johannes Kepler (1571–1630).
Harmonices mundi libri V.
Linz: 1619. Folio. 1st edition.

A culmination of 20 years of work, Kepler's *Harmonices mundi libri* is a book of five chapters dealing with geometry, musical theory, astrology, and astronomy. Most of the book is based on Kepler's theories of Platonic solids and musical harmony, and his prior two laws of planetary motion. After considerable discourse on philosophy, theology, music, and mysticism, he eventually declares what would become known as Kepler's Third Law: the squares of the orbital periods of the planets are equal to the cubes of their orbital radii (P squared=R cubed). Thus, a planet three times as far from the sun as the Earth will have a period or planetary year of about 5.2 years to circle the sun. In an entry for May 15, 1618, Kepler notes that he derived this monumental discovery of planetary motion only 12 days before the final chapter was submitted for publication. Kepler's Third Law would enable Newton to derive a general law of gravitation and to determine the mass of bodies from observing the distance between the orbiting objects and their periods.

Johannes Kepler (1571–1630).
Prodromus dissertationem...Mysterium Cosmographicum...
Frankfurt: 1621. Folio. 2nd edition.

Kepler intended this work to reinforce Copernican theory and to explain "the number, size, and motions of the orbs [of the planets]." This edition of Kepler's first book, *Prodromus dissertationem...Mysterium Cosmographicum...*, serves as the watershed between medieval astronomy and empirical astronomy. An exact reprint of the first edition, this second edition includes Kepler's marginal notes and commentary. As such, it provides a rare opportunity to read a mature Kepler commenting on his younger self. Kepler's notes are often highly critical: "O what a mistake!" as he incorporates 25 years of new learning since the first edition. In the introduction of the second edition, Kepler could say that "[everything] I have written since [the first edition] would be referred to some particular chapter of this little book."

Galileo Galilei (1564–1642).

Istoria e dimostrazioni intorno alle macchie solari...

Rome: 1613. 1st edition. *(shown below)*

Called the "father of modern science," Galileo defined the modern method of scientific experimentation. A professor of mathematics, he is credited with being the first to unite mathematics and physics, and to have reformed the Aristotelian doctrine of motion by replacing it with a verifiable science of motion. In astronomy, he was the first to turn the telescope to the heavens.

In 1613, Galileo published *Istoria e dimostrazioni…* In this work, he dismantled the received wisdom about these perfect heavenly bodies by demonstrating that sunspots generated and dissolved on the surface of solar bodies. He also announced his support of the Copernican system and offered early theories of solar revolution and conservation of angular momentum and inertia. Taken together, Galileo's publications represent much more than accurate astronomical observations; they helped to convince the scientific community that Copernicus' and Kepler's harmony of the cosmos was close to the truth.

Galileo Galilei (1564–1642).

Dialogo...sistemi del mondo Tolemaico e Copernicano.

Florence: 1632. 1st edition.

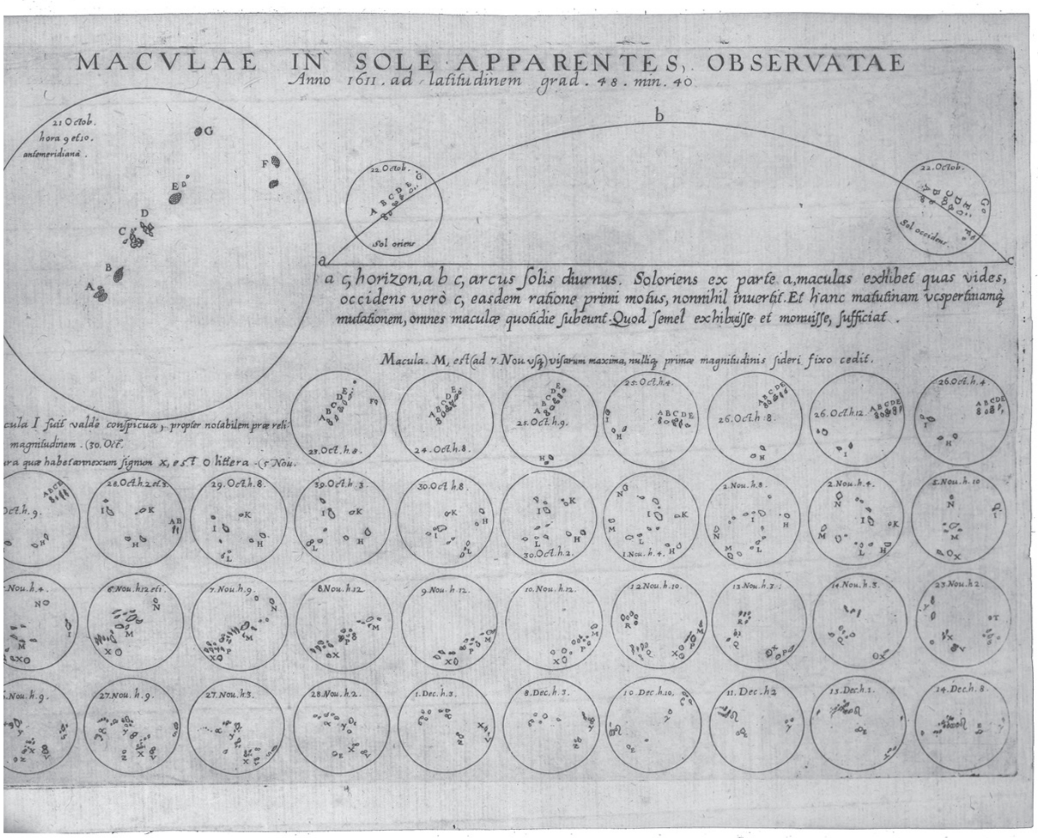
In classic Socratic method, Galileo presents a dialog between advocates for the Copernican and the Aristotelian views of the cosmos. Designed as an appeal to the public for scientific inquiry, the three protagonists—new radical, old conservative, and agnostic—engage in rigorous debate. The deck is stacked, however, as Galileo ridicules the opposing views, and even goes so far as to name the Aristotelian model "Simplicio." During the four days of discussion, Galileo provides us with his beliefs; that heavenly bodies are subject to the same laws of physics as earthly bodies; that the Earth rotates on its axis and orbits the sun; and that the tides reflect the Earth's motion.

Christiaan Huygens (1629–1695).

Systema Saturnium...

Hague: 1659 [bound with *De circuli...* Leiden: 1654]. 1st edition.

In *Saturnium*, Huygens elaborates upon his earlier observation that the arms of Saturn, first noted by Galileo, actually represent "a thin flat ring nowhere touching [the planet] and inclined to the ecliptic." This conclusion was based not only on astronomical observation but also on mechanical considerations. Huygens would also include a number of other detailed astronomical observations such as his comments on the nebula Orion. Quick to apply the science of mechanics to astronomy, Huygens in some measure anticipates Newton's *Principia*.

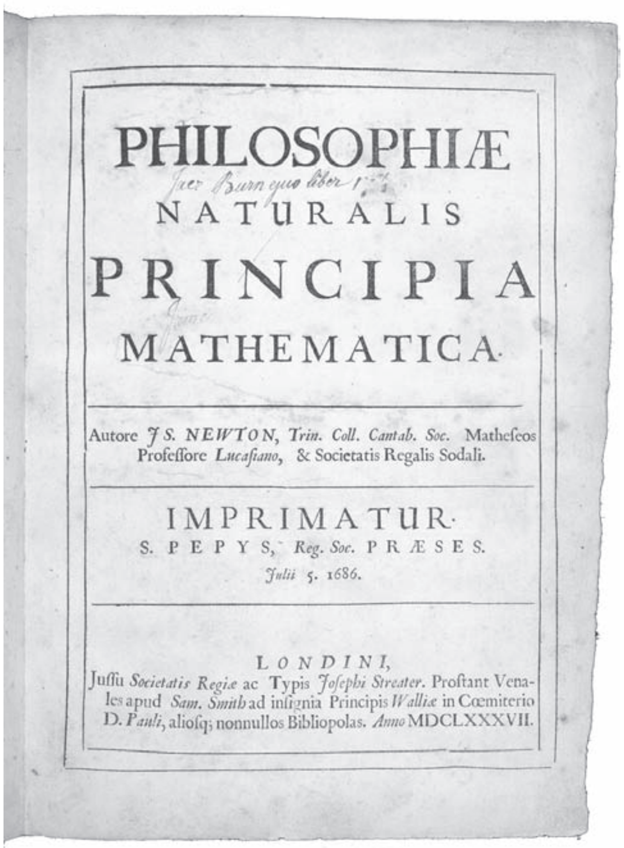


The Clockwork Universe of Newton and Laplace: 1687 to 1900

Sir Isaac Newton (1643–1727).
Philosophiae naturalis principia mathematica...
London: 1687. 1st edition. *(shown below)*

A conscientious but unexceptional student, Isaac Newton attended Cambridge until the plague closed the university from 1665 to 1667. During this period, Newton returned to his mother's farm where he embarked on what is considered his most productive period. He invented the calculus, developed a theory of optics, and formulated the laws of motion and universal gravitation. Upon returning to Cambridge, Newton was heralded a genius and at age 26 was appointed Lucasian Professor of Mathematics. He promptly became a recluse and devoted his efforts for the next 18 years to writing and reformulating his ideas.

Newton's great synthesis was uniting the terrestrial laws of Galileo with the celestial laws of Kepler to form a single law of universal gravitation. Newton provided this synthesis first by stating his famous three laws of motion; then, rediscovering Huygens' centripetal acceleration law, he was able to define gravitational mass as equal to inertial mass, concluding that a force (gravity) must pull planets out of their natural tendency to continue on a straight line.



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

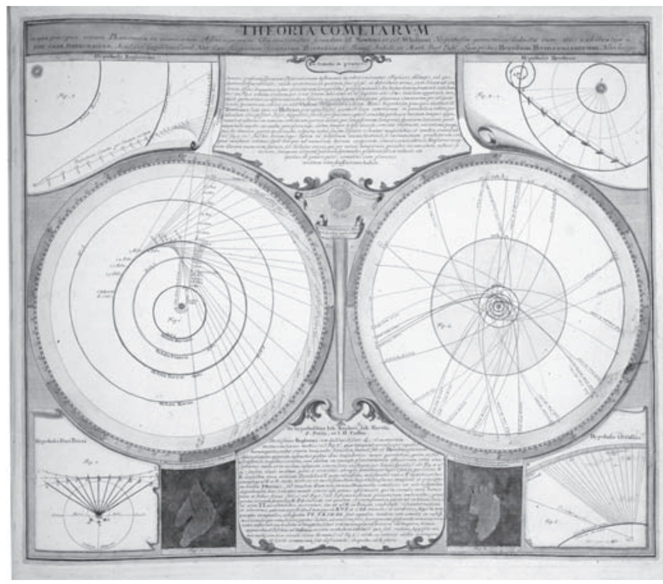
Autore *JS. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostant Venales apud *Sam. Smith* ad insignia Principis *Walliæ* in Cœmiterio *D. Pauli*, aliosq; nonnullos Bibliopolas. *Anno* MDCLXXXVII.

Johann Doppelmayr (1677–1750).
Atlas coelestis...
Nuremberg: 1642. Folio. 1st edition. *(shown below)*

Doppelmayr was a professor of mathematics in Nuremberg, an experimental physicist, and an astronomer. Considered his major work, *Atlas coelestis* is one of the most educational celestial atlases ever produced. Doppelmayr collaborated with the famous cartographer Johann Baptista Homann (1664–1724), a former Dominican monk, who in 1688 settled in Nuremberg and started an influential cartographic publishing firm. Doppelmayr had prepared many of the astronomical and cosmographical plates used by Homann and would in turn use many of these plates in his own atlas.



Sir William Herschel (1738–1822).
"Account of a comet". In *Philosophical Transactions... for 1781,* vol. 71, pp. 492–501. London: 1782. 1st edition.

On March 13, 1781, Sir William Herschel identified a new "comet" that was later to become the planet Uranus. The first addition to the solar system in over 4,000 years, this discovery secured Herschel's fame. With more money and progressively larger telescopes, which Herschel built himself, he discovered the moons of Uranus and Saturn, identified and cataloged 2,500 nebulae, confirmed the disklike structure of the Milky Way, and concluded that binary stars were held in orbit around one another by the force of gravity. In 1800, he was the first to identify invisible infrared light, thus anticipating later investigations of light beyond the visible spectrum.

Joseph Fraunhofer (1787–1826).
Bestimmung des Brechungs- und Farbenzerstreungs...
Munich: 1817. Offprint from Denk. Konig. Acad. Wiss. Mun V, 1817. 1st edition.

In his famous 1672 prism experiment, Newton succeeded in showing that sunlight (white light) could be split into the multiple colors of the rainbow. Fraunhofer, a practicing optician, carefully examined the spectral light with a telescope and found hundreds of dark lines crossing the rainbow spectrum. He labeled the lines with letters and noted that the lines from the sun and planets showed the same pattern, while the light from other stars differed. The solar spectrum came to be known as the Fraunhofer spectrum. Later works by Robert Bunsen (1811–1899) and Gustav Kirchhoff (1824–1887) clarified the meaning of these lines. The explanation would only be completed with the Doppler effect, wherein it was discovered that a shift in the dark lines caused by the motion of a body toward or away from the spectroscope could be used to measure radial velocity of a star or galaxy. This finding eventually proved the idea of an expanding universe.

Gustav Kirchhoff (1824–1887).

Untersuchungen uber das Sonnenspectrum...

Berlin: 1862. 1st edition.

Kirchhoff and Robert Bunsen (1811–1899) had already identified the spectral bright line patterns of gaseous elements on Earth. They knew that a heated solid body emitted a continuous spectrum but discovered that when light from such a body passed through a gas vapor and was analyzed in the spectroscope, a pattern of dark "absorption" lines appeared, specific to each gas element. When Kirchhoff looked at the solar spectrum through various vapors, he found that certain dark lines in the solar spectrum became even darker, implying absorption in the sun's atmosphere at the same wavelengths as the specific vapor used. His final evidence came as the separate analysis of individual gas bright line patterns from earthly elements corresponded to the dark line patterns seen in the solar spectrum, proving that these earthly elements must therefore exist in the sun's atmosphere, absorbing light from the sun at specific wavelengths. Quantification of these elements in the sun and other stars would await Cecilia Payne's Ph.D. in 1925 (on exhibit).

Pierre Laplace (1749–1827).

Traite de mecanique celeste.

Paris: 1798–1827. 1st edition with all supplements.

Published over 27 years, Laplace attempted to reduce astronomy to a series of problems in mechanics and to relate all observed data to the effects of gravity. Applying the mathematical formulae of dynamics and mechanics and Newtonian gravitational theory, Laplace explained planetary and lunar motion, the motion of comets, of tides, and the masses of the planets and moon. Laplace presented this ultimate "Clockwork Universe" to Napoleon in 1799, whereupon Napoleon is alleged to have said he would read it as soon as he had six months' time. When Napoleon asked Laplace why he never mentioned the Creator in his work, Laplace is alleged to have answered, "I have no need of such a hypothesis."

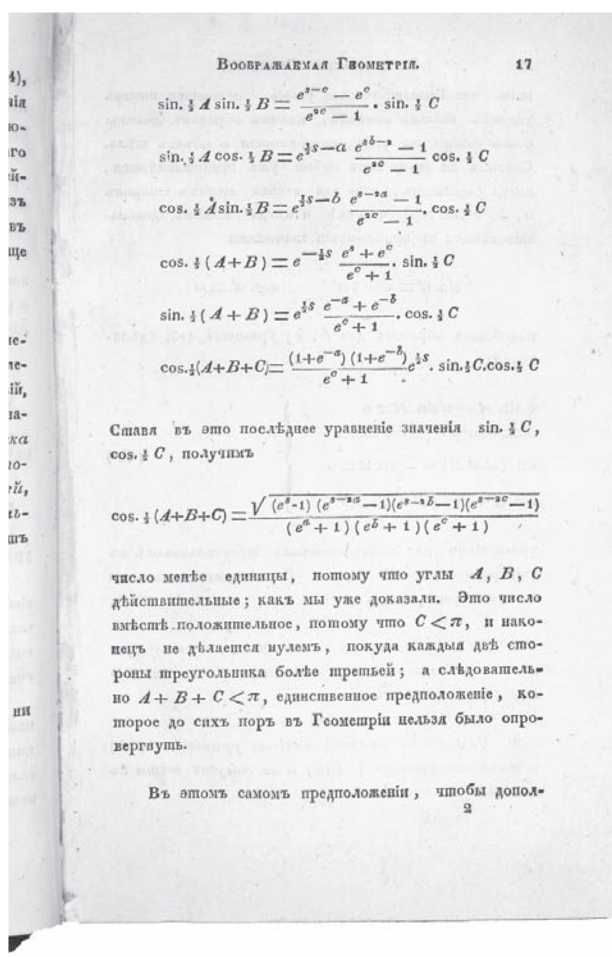
The Expanding Universe of Einstein and Hubble: 1900 to Present

Nikolai Lobachevski (1792–1856).

Voobrazhaemaya geometriya

Kazan: 1835. 1st separate printing of Lobachevski's second article.
(shown below)

While Lobachevski was recognized throughout Russia, world fame would come posthumously after Einstein incorporated Lobachevski's ideas to formulate his curved space-time. Lobachevski and Janos Bolyai (1802–1860) had both independently concluded that Euclid's fifth basic assumption (parallel postulate) could not be proved. "Given any straight line and a point not on it, there exists one and only one straight line which passes through that point and never intersects the first line, no matter how far they are extended." Thus a non-Euclidian geometry was born, which Lobachevski named imaginary geometry. Curved space allowed Einstein to postulate that if gravity was not a force but a curved space-time, and if light takes the shortest path along this space, then light itself will curve along this shape, just as a plane flies in a curve along the Earth's shape. Mass bends space-time which in turn bends light.



Воображаемая Геометрія. 17

$$\sin.\tfrac{1}{2}A\sin.\tfrac{1}{2}B = \frac{e^{s-c}-e^{c}}{e^{2c}-1}.\sin.\tfrac{1}{2}C$$

$$\sin.\tfrac{1}{2}A\cos.\tfrac{1}{2}B = e^{\frac{1}{2}s-a}\,\frac{e^{s-2b}-1}{e^{2c}-1}\cos.\tfrac{1}{2}C$$

$$\cos.\tfrac{1}{2}A\sin.\tfrac{1}{2}B = e^{\frac{1}{2}s-b}\,\frac{e^{s-2a}-1}{e^{2c}-1}.\cos.\tfrac{1}{2}C$$

$$\cos.\tfrac{1}{2}(A+B) = e^{-\frac{1}{2}s}\,\frac{e^{s}+e^{c}}{e^{c}+1}.\sin.\tfrac{1}{2}C$$

$$\sin.\tfrac{1}{2}(A+B) = e^{\frac{1}{2}s}\,\frac{e^{-a}+e^{-b}}{e^{c}+1}.\cos.\tfrac{1}{2}C$$

$$\cos.\tfrac{1}{2}(A+B+C) = \frac{(1+e^{-a})(1+e^{-b})}{e^{c}+1}e^{\frac{1}{2}s}.\sin.\tfrac{1}{2}C.\cos.\tfrac{1}{2}C$$

Ставя въ это послѣднее уравненіе значенія $\sin.\frac{1}{2}C$, $\cos.\frac{1}{2}C$, получимъ

$$\cos.\tfrac{1}{2}(A+B+C) = \frac{\sqrt{(e^{s}-1)(e^{s-2a}-1)(e^{s-2b}-1)(e^{s-2c}-1)}}{(e^{a}+1)(e^{b}+1)(e^{c}+1)}$$

число менѣе единицы, потому что углы A, B, C дѣйствительные; какъ мы уже доказали. Это число вмѣстѣ положительное, потому что $C < \pi$, и наконецъ не дѣлается нулемъ, покуда каждыя двѣ стороны треугольника болѣе третьей; а слѣдовательно $A+B+C < \pi$, единственное предположеніе, которое до сихъ поръ въ Геометріи нельзя было опровергнуть.

Въ этомъ самомъ предположеніи, чтобы допол-
2

Christian Doppler (1803–1853).
"Bemerkungen zu meiner Theorie des farbigen Lichtes..."

In *Annalen der Physik un Chemie,* band 68, no. 5, pp. 1–35. Leipzig: 1846. 1st edition.

In 1842, Christian Doppler proposed that the frequency of sound would be heard differently if either the sound or the observer were moving toward or away from each other. Doppler also proposed that the speed of the approach or recession of the source or the observer could be calculated by the change in frequency of the sound. A colorful experiment was conducted in 1845 by a musician and friend C. H. D. Buijs-Ballot (1817–1890). Buijs-Ballot had musicians play a given note on a moving train while stationary trackside observers recorded the approaching and receding note. The experiment confirmed the "acoustical" Doppler effect. The Doppler effect is known to apply to all forms of wave phenomena, including all parts of the electromagnetic spectrum: optical, radar, radio, and x-rays. From these observations came the concepts of redshift (light moving away from us) and blueshift (light moving toward us), which could be detected by measuring the shift in spectral absorption lines.

Albert Einstein (1879–1955) and Arthur Eddington (1882–1944).
"Revolution in science. New theory of the universe..."

In *The London Times*: November 7, 1919.

The bending (deflection) of light by gravity was not a new idea. Newtonian mechanics allowed calculations of deflection based on the speed of light and the gravitational strength of the sun. In 1911, based on special relativity, Einstein predicted an essentially identical deflection and urged solar eclipse observations. Bad weather and World War I intervened. During the interim, Einstein formulated the general theory of relativity. The warping of space-time had the effect of approximately doubling his calculated deflection to 1.75 arcseconds.

In 1919, Arthur Eddington's expedition to Brazil to observe the solar eclipse allowed him to confirm that the actual deflection was very close to Einstein's 1.75 arcseconds. Had WWI not intervened, Einstein's 1911 prediction would have been proved incorrect, and subsequent corrections to the general theory of relativity would have looked like number juggling. Einstein became an international celebrity and was accorded the highest scientific respect. While awarded a Nobel Prize for his photoelectric theory, Einstein never received the Nobel Prize for either his special theory or general theory of relativity, a slight of incomprehensible magnitude.

Arthur Eddington (1882–1944).
"The Internal Constitution of the Stars."

Presidential address to the mathematical and physical science section. Offprint from Observatory. Vol. 43, 1920.

Eddington outlined the likely source of stellar energy to be nuclear "subatomic" energy. Based on emerging atomic theory of the time and the fact that traditional thermal or gravitational energy sources could not possibly power stellar energy for the billions of years, Eddington postulated the "transmutation" of mass into energy, as originally theorized by Einstein (on exhibit). Specifically, Eddington noted that the mass of the helium atom was slightly less than the mass of the four hydrogen atoms presumably fusing to form it. He concluded that the missing mass "can only represent the mass of electrical energy set free in the transmutation." A series of investigations by a number of physicists proved Eddington right.

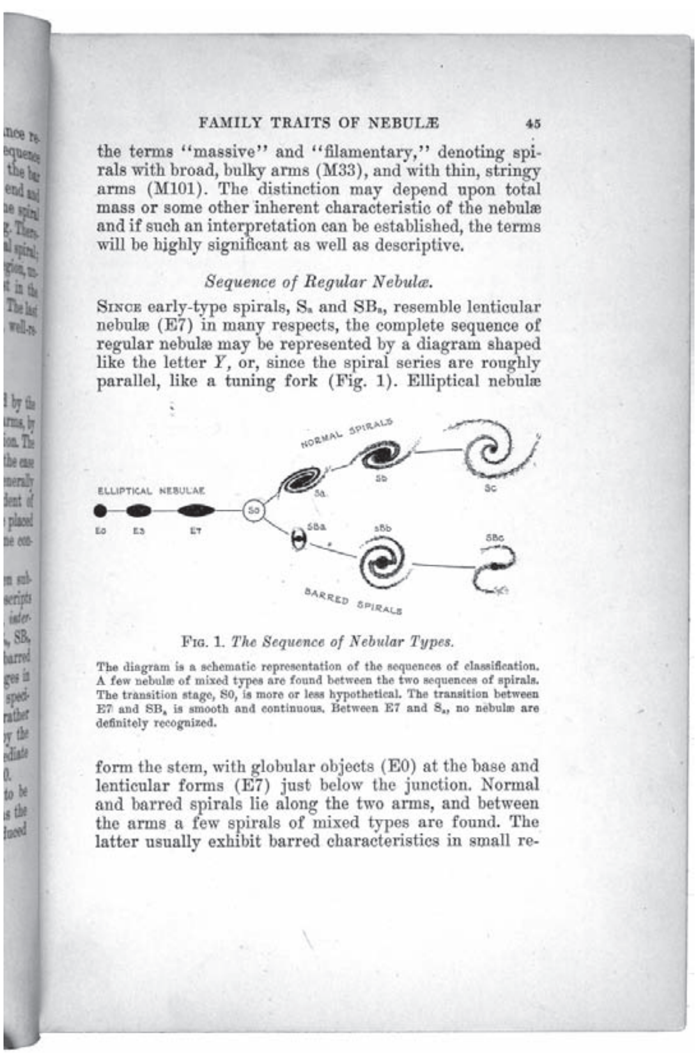
Cecilia Payne (1900–1979).
Stellar Atmospheres.

Harvard Observatory Monographs, no. 1. Cambridge: 1925. 1st edition.

In *Stellar Atmospheres*, Cecilia Payne calculated the physical composition of stars based on spectral absorption line data, estimated stellar temperatures, and the Saha equations. Payne was able to show that while solar hydrogen spectral absorption lines were fairly faint (suggesting little hydrogen) when compared to calcium absorption lines, hydrogen was many times more abundant than calcium in the sun. The faintness of the hydrogen lines was attributed to temperature-dependent gas ionization tendencies, making less hydrogen available to form absorption lines, while relatively small amounts of stellar calcium at the temperature of the sun could be shown to absorb proportionately many more photons and therefore produce dark absorption lines. Her conclusions about the abundance of stellar hydrogen and helium were not well received. Her analysis however, would shortly be proved correct.

EDWIN HUBBLE (1889–1953).
"Cepheids in spiral nebula."
In *Publications of the American Astronomical Society,*
33rd meeting, Dec. 30, 1924 – Jan. 1, 1925. Vol. 5, 1927,
pp. 261–4. 1st edition. *(shown below)*

Hubble's paper settled a 300-year debate regarding the distance to and significance of the spiral nebulae. Cepheid variable stars brightened and dimmed in a cyclic fashion, and the length of the cycle related to a star's intrinsic luminosity. By measuring a star's apparent luminosity on photographic plates, and its intrinsic brightness from Cepheid length-of-cycle data, and using the inverse square law for decreasing brightness with distance, the distance to a given star could be calculated. Using the largest telescope in the world, Hubble was able to find Cepheid variables in the Andromeda nebula and another spiral nebula, and calculate the distance to these nebulae. He estimated the distance to be 285,000 parsecs (930,000 light-years), much farther than previously thought and, clearly, beyond the Milky Way. The scale of the universe had just been significantly increased.



FAMILY TRAITS OF NEBULÆ 45

the terms "massive" and "filamentary," denoting spirals with broad, bulky arms (M33), and with thin, stringy arms (M101). The distinction may depend upon total mass or some other inherent characteristic of the nebulæ and if such an interpretation can be established, the terms will be highly significant as well as descriptive.

Sequence of Regular Nebulæ.

SINCE early-type spirals, S_a and SB_a, resemble lenticular nebulæ (E7) in many respects, the complete sequence of regular nebulæ may be represented by a diagram shaped like the letter *Y*, or, since the spiral series are roughly parallel, like a tuning fork (Fig. 1). Elliptical nebulæ

FIG. 1. *The Sequence of Nebular Types.*

The diagram is a schematic representation of the sequences of classification. A few nebulæ of mixed types are found between the two sequences of spirals. The transition stage, S0, is more or less hypothetical. The transition between E7 and SB_a is smooth and continuous. Between E7 and S_a, no nebulæ are definitely recognized.

form the stem, with globular objects (E0) at the base and lenticular forms (E7) just below the junction. Normal and barred spirals lie along the two arms, and between the arms a few spirals of mixed types are found. The latter usually exhibit barred characteristics in small re-

ABBÉ GEORGES LEMAÎTRE (1894–1966).
"Un univers homogène de masse constante..."
in *Annales de la Société Scientifique de Bruxelles,* vol. XLVII.
Louvain: 1927. Presentation inscription from Lemaître.

Based on fragmentary evidence from the early 1920s suggesting that galaxies were receding from the Earth and on the general theory of relativity, Lemaître constructed a mathematical model for an expanding universe, contrary to the static universe favored by Einstein. His work was published in a relatively obscure journal and, like Alexander Friedmann's work on the same subject in 1922, was forgotten. Hubble's 1929 paper documenting astronomical observations of an expanding universe would later confirm Lemaître's theories, and Lemaître's work would be rediscovered. Lemaître would also propose that the universe could be traced back to a dense "primeval super-atom." This concept would become the standard model of the Big Bang theory.

EDWIN HUBBLE (1889–1953).
The Realm of the Nebulae.
New Haven: 1936. 1st edition.

Hubble was the towering figure of 20th-century astronomy. In the years between 1920 and 1930, Hubble solved four of the central problems in cosmology; provided a classification system for nebulae; proved that galaxies were distant island universes similar to our Milky Way Galaxy, rather than part of it; proved that galaxies were distributed homogeneously in space, suggesting that space was itself homogeneous, without center or edge; and proved that remote galaxies were receding from each other at a velocity proportional to their distance from the Earth. The last discovery became known as Hubble's law, and provided the evidence to support the theory of an expanding universe, as foretold by Alexander Friedmann, and accepted readily by Eddington and Lemaître but only reluctantly by Einstein.

Expanding Our Current Understanding

Remarkable progress in the study of the universe has been made in recent years. Many of the most dramatic developments are extensions of the works exhibited here. The bending of light by gravitational fields, first confirmed by Arthur Eddington, has become the most direct method for measuring the mass contained in galaxy clusters. A recent image from the Hubble Space Telescope taken with the Advanced Camera System developed here at Johns Hopkins University shows the galaxy cluster Abell 1685 (on exhibit). The bright yellow galaxies are members of the cluster. The elongated blue and red images are galaxies at greater distances. They looked stretched and sometimes multiplied because of the gravity of the intervening clusters. Measurements of this effect have led astronomers to conclude that approximately 30 percent of the energy in the universe is associated with visible galaxies.

Whereas Hubble's law was derived from observing a handful of galaxies, large-scale surveys of the universe provide data on more than a million galaxies. The most extensive survey to date is the Sloan Digital Sky Survey (SDSS), a collaboration of many institutions, including Johns Hopkins. The results of the SDSS can be found at their Web site, http://cas.sdss.org/dr2/en . Extension of Hubble's law has been performed by two competing groups of researchers using supernovae light that is distinguishable across billions of light-years. Both teams have concluded that the expanding universe is accelerating due to "dark energy," a poorly understood component of the universe first suggested by Einstein as the "cosmological constant."

Our current model of the universe belongs to a family of models first explored by Georges Lemaître, which mix matter and dark energy to produce a universe whose expansion decelerates in its early years and accelerates as it ages. And yet, in its wonder, complexity, and enormity, the universe is but an extension of our neighborhood.

Contributed by Professor Ethan T. Vishniac
Department of Physics and Astronomy

Acknowledgments

We wish to thank Dr. Elliott Hinkes for his generosity in exhibiting these works from his personal collection.

This exhibit would not have been possible without the support of the Friends of the Libraries and the assistance of the following individuals:

Professor Ethan T. Vishniac
Department of Physics and Astronomy

Sophia K. Jordan
Director of Preservation and
Chair, Exhibits Committee

Linda Claremon
Associate Director for
Library Development

Martha Edgerton
Conservator

Pamela Higgins
Director of External Relations

Susan M. Vazakas
Science Reference Coordinator

Jay VanRensselaer
Homewood Photographic Services

Lena Warren
Conservator

Exhibition brochure designed
and produced by Johns Hopkins
University Office of Design and Publications

Suggestions for Further Reading

Michael Crowe. *Modern Theories of the Universe: From Herschel to Hubble.* New York, NY: Dover Publications, 1994.

Owen Gingerich. *The Eye of Heaven: Ptolemy, Copernicus, Kepler.* New York, NY: American Institute of Physics, 1993.

Marc Lachize-Rey and Jean-Pierre Luminet. *Celestial Treasury: From the Music of the Spheres to the Conquest of Space.* Cambridge: Cambridge University Press, 2001.

Percy Muir and John Carter. *Printing and the Mind of Man.* 2nd ed., rev. and enl. Munich: K. Pressler, 1983.

Web Sites:

The most extensive survey of the galaxies to date is the Sloan Digital Sky Survey: http://cas.sdss.org/dr2/en

The extension of Hubble's law by two competing groups of researchers using supernovae: http://cfa-www.harvard.edu/cfa/oir/Research/supernova/HighZ.html and http://panisse.lbl.gov

Regarding the acceleration of the expanding universe: http://cfa-www.harvard.edu/cfa/oir/Research/supernova/HighZ.html and http://panisse.lbl.gov

Tutorial on modern cosmology with references to the latest discoveries: http://www.astro.uclas.edu/~wright/cosmolog.htm

The Sheridan Libraries encompass the Milton S. Eisenhower Library and its collections at the Albert D. Hutzler Reading Room in Gilman Hall, the John Work Garrett Library at Evergreen House, and the George Peabody Library at Mount Vernon Place. Together these collections provide the major research library resources for the university, serving Hopkins academic programs worldwide.

Upcoming Exhibitions:

A Cathedral of Books: Rediscovering George Peabody's Gift to Baltimore

George Peabody Library
May 11–August 8, 2004

This exhibition celebrates the grand reopening of the George Peabody Library following renovations made possible by the Save America's Treasures program, administered by the U.S. Department of the Interior. The exhibit showcases over 100 works from an exceptional collection that has contributed to Baltimore's vibrant literary and artistic culture for more than 125 years.

The Photography of Harry B. Leopold

Milton S. Eisenhower Library
June 28–September 30, 2004

Harry Leopold (1891–1977) began his career as a staff photographer for the *Baltimore Sun* in 1918. The exhibition features images from the private collection of his granddaughter, Kristin Leopold, as well as from the Ferdinand Hamburger Archives of The Johns Hopkins University.

THE SHERIDAN LIBRARIES
JHU LIBRARIES