COPERNICUS AND HIS *Revolutions*

Produced for the

Cosmology and Cultures Project

of the

OBU Planetarium

by

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Credits

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2. Introduction

A. Summary

Length	Variable (typically 40-50 mins): see "Instructor Notes"
Presentation mode	May be presented in either of two ways: 1. Self-contained DVD presented on a TV or data projector, or 2. Planetarium show using star projector and video projector, with optional whole-dome effects
Audience	General undergraduate
Classes	History of Science; Astronomy
Periods	15th Century, 16th Century
Observational emphases	Diurnal motion Annual (direct) motion of Sun Direct motion of Sun, Moon, planets Lunar occultation Retrograde motion Stellar parallax
Constellations	Taurus Orion
Astronomical Terms	Ecliptic Zodiac Geocentric Heliocentric
Other Topics	Historiography Printing Revolution Renaissance Reformation
Dome special effects	None required. Optional SFX projectors include: 1. Taurus, Orion constellation figures 2. Celestial equator and ecliptic projector
Reviewers and Content advisors	Peter Barker Bernard Goldstein Katherine Tredwell Dennis Danielson Mike Keas JoAnn Palmeri (Special thanks to these historians of science; all mistakes that remain are the sole responsibility of Kerry Magruder.)

B. Synopsis

1. Introduction

2. The Renaissance Cosmos
   A. Italian Renaissance and Greek emigration
   B. The Geocentric Universe
   C. University Reforms
   D. Mathematical devices used in Ancient Geocentric systems: Ptolemaic astronomy
   E. Geocentric Astronomical Innovations: Maragha School, Peurbach, Regiomontanus

3. Copernicus: Early Life and Training
   A. Childhood in Torun
   B. University of Cracow
   C. University of Bologna, astronomy and law
   D. University of Padua, medicine
   E. University of Ferrarra
   F. Return to Poland

4. Publishing the Revolutions
   A. Catholic background: Cardinal Schönberg
   B. Lutheran role: Nuremberg circle; Rheticus, Osiander, Petraeus
   C. Polish circumstances: Bishop Dantiscus, Bishop Giese, Duke Albrecht

5. *De Revolutionibus*
   A. The Triple Motion of the Earth
   B. Dedication to the Pope
   C. The role of Humanism and ancient texts
   D. The role of Observations
   E. The Problem of the Equant
   F. The Universe as a Coherent and Integrated System: harmonies between the planetary motions, their order and distances
   G. Aesthetic considerations: planetary distances, the dignity of the center, a moving Earth amidst the heavens

6. Problems for Heliocentrism
   A. Optical Illusions: "common sense" and the relativity of motion, diurnal and retrograde phenomena
   B. Aristotelian Physics
   C. Astronomy: The absence of stellar parallax and the problem of planetary satellites
   D. Aesthetics: Definitions of simplicity and elegance; hierarchy; size of the universe

7. Reception of the *De Revolutionibus*
   A. Osiander's Preface
   B. The Wittenberg Interpretation: Erasmus Reinhold
   C. Tycho Brahe
   D. Johann Kepler
   E. Early Catholic Reception: Offusius and the Paris circle
   F. Post-Trent Catholic Reception: Galileo

8. What was the "Copernican Revolution"?
   A. Revolution in Physics: Newton, Scientific Revolution
   B. Observational proof
   C. Reformation of Astronomy
   D. Post-Copernican Revolution in Astronomy: non-circular planetary orbits, fluid heavens, non-hierarchical cosmos of Descartes, telescope of Galileo, etc.

9. Epilogue: The Legacy of Copernicus
   A. The "Copernican Principle" of modern cosmology
   B. The Cosmos is made for science

C. Instructor Notes

About the Show

After watching this show, students will be better prepared to discuss the following question: *Given the evidence as one would have perceived it around 1615, which astronomical model or system would you have accepted?* Obviously, this is an open-ended question for which there is no right or wrong answer.[1]

This course is intended for undergraduates who are engaged in serious study of astronomy or the history of science; it is not designed as a first exposure to these topics on a high school level.

For introductory astronomy courses, this show provides an overview of the life and work of Nicolaus Copernicus, with an explanation of the advantages and disadvantages of his heliocentric model as they were perceived at the time.

For history of science courses, this show places Copernicus and the "Copernican revolution" in historical context by providing a sense of the state of mathematical astronomy when Copernicus was educated as a young man, and also briefly surveying the reception of Copernican ideas up to about 1620.

Because of the relativity of motion, early arguments about the systems of Copernicus, Ptolemy, Tycho Brahe and others did not turn on the kind of phenomena that can be replicated in the planetarium. Therefore, rather than relying upon the star projector to play the central role, this show is an image-driven biographical story, narrated in documentary style, containing a large number of images from original works in the remarkable Copernicus collection of the History of Science Collections of the University of Oklahoma Libraries.

Modules

The show consists of modules that may be watched separately or in any combination, depending on the nature of the class and the aims of the instructor.

Unless undergraduate students have significant prior exposure to the history of astronomy and to the *De Revolutionibus*, it is not advisable to present the entire 79-minute show in one sitting (although that might be appropriate for advanced students).

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1. For a readable survey of early mathematical astronomy organized around this question see Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution* Dover Publications, 2001).

To view the entire show, *three sittings* are recommended (see table below, far-right column).

To present the show to an astronomy class in one sitting, one might omit modules #2, 4, and 7. To present the show to a history of science class in one sitting, one might add module #4.

Module	Astronomy	History of Science		
		1 Lesson	2 Lessons	3 Lessons
1. Introduction	X	X	1	2
2. The Renaissance Cosmos			1	1
3. Copernicus: Early Life and Training	X	X	1	2
4. Publishing the *Revolutions*		X	2	2
5. *De Revolutionibus*	X	X	2	2
6. Problems: Optical Illusions, Physics, Astronomy, Aesthetics	X	X	2	2
7. Reception of the *De Revolutionibus*			2	3
8. What was the "Copernican Revolution"?	X	X	2	3
9. Epilogue: The Legacy of Copernicus	X	X	2	3
Length: 79 minutes (total)	39 min	46 min	28 min 51 min	19 min 37 min 24 min

If a history of science course includes a more detailed presentation of Islamic, medieval and Renaissance astronomy, omit module #2; or, if more extensive coverage of Tycho, Kepler and Galileo is provided by other means, omit module #7. In other words, to show "Copernicus and his *Revolutions*" within the limits of a class period, simply omit either of two modules: Renaissance background, or Reception (or both). Either way, one can keep the introduction and epilogue and have a coherent account of Copernicus, and perhaps schedule the omitted chapters for different class periods.

The two sections that rely most upon the star projector are #3, "Early Life" (lunar occultation of Aldebaran), and #6, "Problems" (stellar parallax). Therefore, it is best to view these modules in the planetarium theater, rather than in a classroom (although the DVD does include sequences of images that will substitute for star projector effects, if necessary).

3. Before the Show

A. Vocabulary and Definitions

These are some of the terms and definitions used to describe basic celestial phenomena explained in "Copernicus and his *Revolutions*."

1. Ecliptic: the annual path of the Sun as it moves around the sky.
2. Zodiac constellation: a constellation that contains the ecliptic (see list).
3. Direct motion: The ordinary eastward motion of the Sun, Moon and planets along the ecliptic.
    - For example, the Sun moves about 1 degree a day roughly eastward along the ecliptic.
    - The Moon moves an average of about 10 degrees a day roughly eastward along the ecliptic.
    - The motion of any planet in a roughly eastward direction along the ecliptic is called its direct motion.
4. Retrograde motion: Literally, retrograde means to reverse direction. For a planet, retrograde motion occurs in a roughly westward direction, reversing the usual direct motion.
5. Occultation: When a star or body is hidden by a nearer planet (or Moon). The show describes an occultation of Aldebaran by the Moon.

B. Pre-Test

You may or may not know the answers to many of these questions before viewing "Copernicus and his *Revolutions*." It does not matter if you do not know very many answers now. Read over them and take your best guess, so that you will be better able to remember the answers as they are explained in the show.

1. T or F? Astronomers from antiquity to the Renaissance believed the planets are carried on large, transparent, celestial spheres, which rotate around the Earth.
2. T or F? Copernicus argued that the Earth is a planet that moves around the Sun each year.
3. T or F? Until Copernicus set the Earth in motion, there was no way to explain the apparent "retrograde" motion of the planets.
4. T or F? Renaissance astronomers made accurate predictions using Earth-centered models.
5. T or F? A lunar occultation is the same as a lunar eclipse.
6. T or F? The Catholic Church warned Copernicus not to publish his astronomical models.
7. T or F? Copernicus was a Polish Roman Catholic, but the *De revolutionibus* of Copernicus was edited and printed by German Lutherans.
8. T or F? Copernicus dedicated the *De revolutionibus* to the Pope.
9. T or F? Copernicus rejected geocentric, Ptolemaic models of astronomy because they were contradicted by his observations.
10. T or F? Copernicus rejected geocentric, Ptolemaic models of astronomy because they were overly complex, containing far too many circles.
11. T or F? Copernicus sought to reform astronomy according to the principle of uniform circular motion.
12. T or F? Ptolemaic models for the various planets were integrated together, sharing the same center (namely, the Earth).
13. T or F? The most important advantage offered by Copernicus was a vision of the universe as a coherent and integrated system, where planets move together in elegant harmony.
14. T or F? The Ptolemaic system determined specific values for the distances of the planets, and also specified their order or sequence.
15. T or F? The Copernican system determined specific values for the distances of the planets, and also specified their order or sequence.
16. T or F? Because of the relativity of motion, the models of Ptolemy and Copernicus produce equivalent observations.
17. T or F? From antiquity, stellar parallax was not observed, and most astronomers took this observation as a decisive refutation of Sun-centered theories.
18. T or F? Copernican models used a total number of circles about the same as for Ptolemy.
19. T or F? Copernicus rejected the ancient idea of solid celestial spheres.
20. T or F? Copernicus rejected the ancient idea of a hierarchical cosmos, arguing instead that the Earth's vantage point is unremarkable (not special).
21. T or F? Copernicus rejected the ancient ideal of uniform circular motion.
22. T or F? Copernicus rejected Earth-centered models because of telescopic observations.

4. Production Script

A. Production Notes

1. The DVD is designed for dual use, either in a planetarium or on a TV in the classroom. Therefore many of the images projected by a planetarium's video projector may be too bright unless the video projector's intensity is reduced. Experiment by trial and error to find the level of video intensity that works best in your theater or classroom.

2. The presentation of this show in a planetarium theater requires a video projector. If you wish to supplement the video projection with slides, images listed (without bullets) in the Audio-Visuals column of the script may be found on an accompanying CD.
   - i These images all appear in the video, but for your own theater choreography one may wish, in some cases, to dim the video projector and display them in different fields of view using slide projectors. If so, the Audio-Visuals column serves as an image list, making it easy to identify the images you want and convert them to slides. (Alternatively, an economical way to convert them to film is to pause the DVD at the desired point and, using an extremely long shutter speed, photograph the image displayed on a high resolution monitor.)
   - ii You may also use these images for publicity and for your own educational purposes (see the "Distribution" section at the end of this packet).

3. Star projector functions and whole-dome planetarium effects are indicated with bullets (•) in the Audio-Visuals column. These whole-dome effects are optional, so different installations may integrate them with the show in varying degrees. For example, some bulleted instructions call for the video projector to be faded off and on again relatively quickly; depending on the projector and the automation system, this may not be feasible in some theaters. As noted above, all non-bulleted items describe images or other visuals appearing in the video; ignore these when programming theater automation.

4. Footnotes in the script are of three types:
   - i Numbered citations or pedagogical notes for the Narration column,[2]
   - ii Alphabetical notes with production tips for the Audio-Visuals column,[a] and
   - iii Image credit information for images in the Audio-Visuals column,[*] as needed. However, all images from books are provided by the History of Science Collections, University of Oklahoma Libraries; and all photographs of places related to Copernicus' life are courtesy the Duane H.D. Roller slide archive of the OU History of Science Collections. These sources are not noted in the script.

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2. This is an example of a narration note.

(a) This is an example of a production note.

*- This is an example of an image attribution credit.

5. As explained above, to view the entire show, *three sittings* are recommended, but it is also possible to combine modules in different ways to create a single sitting show for astronomy or history of science students. Therefore, to make best use of the show, seven automation files should be programmed: one for each column or sitting as indicated in the first table above (see "Instructor Notes"). Of course, it is always possible to manually pick and choose the modules to show using the DVD menu. For automated presentations, however, one will program automation files for several varieties of presentations. According to the Table of Modules in "Instructor Notes," above, there are seven likely variations of the shows:
   - i "Ast" = Astronomy class, 1 sitting
   - ii "HOS 1" = History of science class, 1 sitting
   - iii "HOS 2-1" = History of science class, 2 sittings, show 1 of 2
   - iv "HOS 2-2" = History of science class, 2 sittings, show 2 of 2
   - v "HOS 3-1" = History of science class, 3 sittings, show 1 of 3[b]
   - vi "HOS 3-2" = History of science class, 3 sittings, show 2 of 3
   - vii "HOS 3-3" = History of science class, 3 sittings, show 3 of 3[b]

   To facilitate programming, create separate automation files for the different modules. Then create seven show files that reference the modules included in each variation. The table below provides the start times for each module, and also indicates which modules are included in each variation.

Module	Start	Length	Ast	HOS 1	HOS 2-1	HOS 2-2	HOS 3-1	HOS 3-2	HOS 3-3
1. Introduction	0:0	2:34	x	x	x			x	
2. The Renaissance Cosmos	2:34	18:48			x		x		
3. Copernicus: Early Life and Training	21:22	6:00	x	x	x			x	
4. Publishing the *Revolutions*	27:22	6:49		x		x		x	
5. *De Revolutionibus*	34:11	12:44	x	x		x		x	
6. Problems: Optical Illusions, Physics, Astronomy, Aesthetics	46:55	8:32	x	x		x		x	
7. Reception of the *De Revolutionibus*	55:27	14:28				x			x
8. What was the "Copernican Revolution"?	1:09:55	3:34	x	x		x			x
9. Epilogue: The Legacy of Copernicus	1:13:29	5:21	x	x		x			x
Length: 78:50 (total)	1:18:50	78: 50	38: 45	45: 34	27: 22	51: 28	18: 48	36: 49	23: 23

(b) Remember that the two sections that rely most upon the star projector are #3 and #6. Therefore, shows (v) and (vii) would be the best choices to present in the classroom, if not all may be presented in the planetarium.

B. Theater Preparation

1. Prepare constellation figures for Orion and Taurus (and pointers to Orion's belt and Aldebaran, if automated).[c]
2. Set planets to display annual (direct) and then retrograde motions.
3. Be prepared, after display of annual (direct) and retrograde motions, to bring the Moon west of Aldebaran in order to demonstrate a lunar occultation of Aldebaran.
4. Start the show with the star projector off, and theater lights dimmed.

C. Script

Min	Sec	Audio-Visuals	Narration
0	0	•Star projector off introCredits/cc introCredits/acls	The Cosmology and Cultures Project of the OBU Planetarium, with a grant from the American Council of Learned Societies, presents
0	28	introCredits/title Sounds of battle	Copernicus and his Revolutions
0	32	1. Introduction: Revolutions	
0	58	ou-roller/CopernicusPortrait	Copernicus voice: "We are not sufficiently safeguarded to repel an attack and we fear lest the enemy, who is already so near, should beseige us also. Therefore, we humbly appeal to your Holy Majesty to come to our aid as quickly as possible and to support us. For we are completely devoted to Your Majesty, even if we were to perish."[3]
1	23	show/AllensteinMap	In 1520, Nicolaus Copernicus appealed to the King of Poland for aid in defending the Castle of Allenstein. The Teutonic Knights, a German order of militant monks, were invading Warmia, a Catholic territory in which Copernicus served as a vassal to the Bishop. The Teutonic Knights inhabited lands to the east of Warmia, and were loyal to the Holy Roman Emperor rather than the King of Poland.
		ou-roller/ CopernicusPainting	The Knights intercepted Copernicus' letter, and no aid came from the King of Poland. Yet the castle did not fall. Copernicus thwarted this early modern political revolution. However, his actions in defense of Allenstein pale in significance to the intellectual revolution attributed to his book,

3. Jan Adamczewski, *Nicolaus Copernicus and His Epoch* (Washington, D.C.: Copernicus Society of America, 1973), 133.

(c) Optional: The script often calls upon the star projector to project a starfield (this occurs roughly wherever the image "Taurus starfield" is used on the DVD). In these cases, for an added touch of realism, prepare the star projector to move to appropriate latitudes as needed. Warsaw: 52° N. Cracow: 50° N. North Italy: 45° N.

2	07	ou-hsci/Copernicus-1543-tp	De revolutionibus, or, On the Revolutions of the Celestial Orbs.
2	17	ou-hsci/Copernicus-1543-section	In 1543, Copernicus argued that the Sun rather than the Earth lies in the center of the universe. The Earth moves around the Sun as a planet.
2	25		Why did he do this? Why did he believe it? How revolutionary was De revolutionibus?
2	34	**2. Background: The Renaissance Cosmos** show/title-RenCosmos	
2	43	ou-roller/FlorenceSkyline	Let's begin the story in the Quattrocento, the century of the Italian Renaissance, one hundred years before the publication of Copernicus' great work...
2	54	Map: Animated track of journey from Constantinople to Ferrara: show/FromCtoF1 show/fromCtoF2	Fearing the advance of the Turks, the Byzantine emperor in Constantinople, John Palaeologos, appealed to Pope Eugenius IV in Rome to form a council to discuss church unity and military aid. Thus in 1438 the Byzantine emperor, accompanied by 700 Greek scholars and officials, journeyed to the Council of Ferrara.[4]
3	25	ou-roller/Ferrara	These Greek scholars, and the Greek texts they brought with them, invigorated the University of Ferrara for the remainder of the century. To the great humanist scholar Rudolf Agricola, Ferrara seemed "the very home of the Muses."[5] Nor was Ferrara only a center for the humanities: many of the Greek visitors, including Joannes Bessarion, Archbishop of Nicaea,[6] were Neoplatonists highly interested in mathematical astronomy.

4. These scholars included Georgios Gemisthos (or Plethon; ca. 1360-1452), from Mistra in the Peloponnessos; and the future Roman cardinal Joannes Bessarion (1402-1472). Guarino de Verona (1374-1460), a friend of Vittorino da Feltre (ca. 1378-1446), resided in Constantinople for nearly five years. While there he lived in the house of the scholar who earlier had taught Greek to the Florentines, Manuel Chrysoloras (ca. 1335-1415). After 1429, Gaurino taught Greek and Rhetoric at the University of Ferrara. Italian scholars with an interest in Greek after Chrysoloras, such as Guarino de Verona and Giovanni Aurispa (also at Ferrara), collected Greek manuscripts. Aurispa alone brought 232 manuscripts back from Byzantium, including a collection of Plato a copy of which was acquired by Vittorino. Interestingly, Pawel Czartoryski, "The Library of Copernicus," *Studia Copernicana*, 16 (1978): 355-396, has described books which were known to be annotated by Copernicus, some of which might have been acquired in Ferrara, e.g. Bessarion's *In Calumniatorem Platonis*; a Greek-Latin dictionary by Johannes Crastonis published in Modena (near Ferrara) in 1499-1500; and two works by the Ferraran lecturer in medicine, Joannes Michael Savonarola.

5. Werner L. Gundersheimer, *Ferrara: The Style of a Renaissance Despotism* (Princeton: Princeton University Press, 1973), 212.

6. Bessarion studied Neoplatonism and Pythagorean philosophy with Gemisthos at Mistra, and became the Archbishop of Nicaea before the Council of Ferrara/Florence. After returning to Byzantium, Bessarion was named a Roman Cardinal (1439). Appreciating both the Turkish threat and the Latin invitation, he returned to Italy in 1440 and engaged himself in reforming monasteries. After the fall of Constantinople in 1453, Bessarion was in a position to assist his refugee countrymen, and to collect Greek manuscripts obtained from Byzantium.

3	54	ou-hsci/Sacrobosco-1519-03v	These Renaissance scholars, theologians, and astronomers shared a common geocentric, or Earth-centered, view of the universe.
4	03	ou-hsci/Sacrobosco-Sphaera-1490-fp	In university study, the most common introduction to the geocentric cosmos was De Sphaera, On the Spheres, a medieval work by Sacrobosco, first printed in Ferrara in 1472.
4	17	Musical Transition (beginning): Geocentric overview[7]	
4	25	ou-hsci/Apian-1540-cosmicSection	Four elements comprise all that exists below the Moon: earth, water, air and fire.
		Earth show/gravityLines	Just as a rock falls to the ground, so earthy material strives naturally to move toward the center of the universe. Therefore by gravity, earth congregates in a spherical body at the center of the universe.
		Water ou-hsci/Apian-1540-cosmicSection	Water mixes with earth to form the seas upon a habitable globe;
		Air ou-hsci/Apian-1540-cosmicSection	Clouds churn in the region of air;
		Fire ou-hsci/Apian-1540-cosmicSection	and just as fire strives naturally to move upward, so exhalations from volcanos and earthquakes rise to the region of fire, just below the Moon, causing fiery phenomena such as meteors and comets.
		ou-hsci/Fludd-1617-t1-41-elements	The four elements of these sublunar regions constantly mix together in unceasing processes of generation and corruption.
		Face of Moon ou-hsci/Riccioli-1651-Moon	As the Moon revolves around the Earth, we see only one familiar side.
			This could be explained if the Moon were embedded within a giant solid transparent sphere that carries it around us once a month.
		ou-hsci/Apian-1540-cosmicSection	On the boundary between heaven and Earth, the Moon patrols the great frontier between the regions of corruption below and the pure celestial spheres above.
		ou-hsci/Apian-1540-cosmicSection	High overhead the stars appear fixed in the patterns of the constellations, as if they were bright points of light embedded within their own transparent celestial sphere.

7. This section is particularly indebted to a most insightful account of the sensibility associated with the medieval and Renaissance cosmos: C.S. Lewis, *The Discarded Image* (see also the work by Grant listed in “Further Reading”).

		Stellar sphere ou-hsci/Apian-1540-cosmicSection	In its daily or diurnal motion, the sphere of fixed stars turns once around the Earth every day.
			Each star traces one full circle every 24 hours.
6	19	Orb of Sun ou-hsci/Apian-1540-cosmicSection	The Sun also has its own sphere. With an annual motion, the sphere of the Sun carries it around the Earth once each year.[8]
6	27	Rotating cosmic section: ou-hsci/Apian-1540-cosmicSection •Star projector fade on •Diurnal motion on slowly •Video projector fade off Taurus starfield	Celestial spheres, made of a fifth element called ether or the quintessence, explain the obvious motions of the Sun, Moon and stars. They also can account for the planets. Exalted far above the Earth and the sublunar elemental regions, the solid spheres, incorruptible, effortlessly turn in place, creating a harmony of motions known as the music of the spheres. Aristotle taught that the spheres turn by eternal desire. Dante wrote of "the love that moves the Sun and other stars."
7	14	Outer orbs •Star Projector fade off •Diurnal motion off •Video Projector fade on	Three superior planets turn in spheres above the Sun:
			Saturn, the father of time,
			Jupiter, the king of planets.
			Mars, the red planet of war,
		Inner orbs ou-hsci/Apian-1540-cosmicSection	Two inferior planets move back and forth beneath the Sun: Venus, goddess of love; Mercury, swift messenger of the gods.
		Sun in middle... Above... Below...	In this geocentric cosmos, the Sun occupies a privileged place in the middle of the heavens, from which it illumines the entire universe, pervading the spheres above and below with light,
		Shadow of Earth in space: ou-hsci/Barozzi-1585-V7r	except where that light is obscured by the small conical shadow of our darkened Earth.
8	07	Taurus starfield •Star projector fade on •Diurnal motion on slowly •Video projector fade off	Across our nighttime sky, within that silent shadow of mortality, we gaze upon distant spheres brightly illumined, filled with joy and life.[9]

8. If the Sun rises with a star today, it will rise again with that same star one year from now.
9. Ideas about the spheres and the heavenly beings varied: some thought the spheres themselves were sentient, semi-divine or rational beings; others populated them with various orders of angels, of glorified saints (Dante), or even of extra-terrestrial inhabited worlds. But regardless of the specific character of the heavenly beings, the universe was a party to which mortal humans were not invited. See Lewis, *Discarded Image*.

8	15	Cosmic section •Star projector fade off •Diurnal motion off •Video projector fade on	The vigor, power and dignity of the spheres diminish as one descends from the breathtaking daily pace of the outer sphere of fixed stars.
8	28	Dissolve meteorological regions to Fludd again ou-hsci/Fludd-1617-t1-41-elements	To lie at the center was not a place of privilege, but a cosmic reminder of human insignificance. The greatest king on Earth rules only the gutter of the universe, the theater of corruption and decay, in contrast to the glories of the unspoiled heavens. In this sense, the cosmos was geocentric, but not anthropocentric.[10]
8	53	Musical Transition (closing)	
8	57	cosmic section again ou-hsci/Apian-1540-cosmicSection	From Dante to Chaucer to Shakespeare, this was the common conception of the cosmos. Yet common conceptions are not mathematical predictions.
		ou-roller/Ferrara ou-hsci/Sacrobosco-1519-03v	When the Greek scholars arrived at the Council of Ferrara, they sparked a renewed effort to understand the complex mathematical models necessary to create accurate predictions using these geocentric conceptions.
		ou-hsci/Sacrobosco-1519-32r	The Byzantine Archbishop Joannes Bessarion, who came to the Council of Ferrara, typifies this Greek impetus to the study of mathematical astronomy.[11] Bessarion influenced not only the University of Ferrara, but also the Universities of Bologna and Vienna.
		Maps: show/Const-Bologna show/Bologna	Constantinople fell to the Turks in 1453. Bologna, once a leading university, was closed. Pope Pius II sent Bessarion to restore the university.
		Paccioli images ou-hsci/Paccioli-1509...	Cardinal Bessarion, like other Neoplatonists, emphasized the study of mathematics. In Florence, a center of Neoplatonism, a friend of Leonardo da Vinci's named Luca Paccioli taught young Dominico di Novara.
		Back to Bologna show/Bologna	Bessarion's reforms perhaps account for the later presence of Dominico di Novara at Bologna, where di Novara taught astronomy to Copernicus.
		show/Bologna-Vienna	The pope then sent Bessarion to reform the University of Vienna, on the beautiful blue Danube. In Vienna, a foundation was laid for a rebirth of mathematical astronomy.
10	34	Musical Transition (beginning): geometrical devices	

10. Aristotle: "That which contains or limits is more precious than that which is limited." The motif of cosmic insignificance was a commonplace from Cicero to Thomas Aquinas and thereafter.
11. Bessarion brought to Ferrara "a number of books on mathematics and geometry," Joseph Gill, *The Council of Florence* (Cambridge: Cambridge University Press, 1959), 164.

10	44	Eccentric ou-hsci/Peurbach-1543-060 show/deferent	Ever since Plato, astronomers assumed that planets move with combinations of uniform circular motions. For example, one model might show the Sun moving at a constant speed around a large circle, called the deferent.
		Days of seasons show/eccentric show/seasons1 show/seasons2	If the Earth is placed just off-center or eccentric to the deferent, then this kind of eccentric model can account for the unequal lengths of the seasons. The Sun moves on the deferent with constant speed around the center, but as seen from the eccentric Earth, its motion does not appear uniform.
11	22	Direct motion ou-hsci/Sacrobosco-1534-E7r show/Tau1-direct show/Tau2-direct	Outer planets such as Mars pose another kind of problem, because at times they appear to move in loops. From night to night, an outer planet usually moves roughly eastward against the background of fixed stars.
		First station show/Tau3-1stPt	Sometimes it stops, rising several nights in a row near the same star.
		Retrograde show/Tau4-retro	Then it moves backwards, reversing its path in the sky. Mysteriously, the planet appears much brighter during this backward or retrograde motion.
		Second station show/Tau5-2dPt Direct show/Tau6-direct	Eventually, the planet comes to another halt, after which it resumes its ordinary eastward motion. Eccentric models alone do not explain these retrograde loops of the planets, nor do they explain why planets are brightest when they are retrograding.
		Epicycle ou-hsci/Sacrobosco-1534-E7r ou-hsci/Ziegler-Jacob-1531-29	To explain retrograde motion, astronomers since Hipparchos of Nicaea in the second century BC developed planetary theories using epicycle models. In an epicycle model, the planet does not ride directly on the large deferent circle. Rather, it moves with constant speed on a second circle, or epicycle.
		show/epicycle1	At the same time the planet moves with constant speed on the epicycle, the center of the epicycle moves with constant speed on the large deferent circle.
		“Deferent + Epicycle” show/epicycle-direct	When the planet is on the outermost point of the epicycle it moves roughly eastward with a speed equal to the motion of the deferent circle plus the motion of the epicycle.
		“Deferent – Epicycle” show/epicycle-retrograde	When the planet lies within the deferent circle, the planet retrogrades with the speed of the deferent minus the epicycle. All that is necessary to have the planet move backwards is to set the speed of the epicycle greater than the speed of the deferent.

		show/epicycle-retrograde	Epicycle models easily account for the changing brightness of a planet, because the planet moves closer as it becomes brighter during retrograde motion.
13	28	show/factors	These models are quite versatile: In order to make planetary models more accurately conform to observations, the astronomer may adjust the radius and speed of the epicycle, the radius and speed of the deferent, and even the degree of tilt of the epicycle to the plane of the deferent.
		Equant ou-hsci/Ptolemy-1496-fp ou-hsci/Ptolemy-1496-tp	In the 2nd century AD, Claudius Ptolemy composed a thorough and systematic account of geocentric astronomy. Later Islamic astronomers called Ptolemy's book Almagest, or "The Greatest." In the Almagest, Ptolemy added a third geometrical device, the equant, in order to predict the positions of the planets even more accurately.
		show/equant show/equant-noEpi show/equant-nonuniform	In Ptolemy's models the Earth is eccentric to the deferent, as before. However, for Ptolemy the deferent circle turns uniformly not around its center but around another point, the equant, located off-center an equal distance opposite the Earth. In an equant model, a point on the circumference of the deferent circle appears to speed up and slow down even as seen from the center, rather than moving with uniform motion.
14	39	Taurus starfield •Star projector fade on •Video projector fade off	Musical Transition (closing)
14	49	•Star projector fade off •Video projector fade on ou-hsci/Sacrobosco-1478-Gerard-tp	Ptolemy's Almagest came to western Europe through Gerard of Cremona's 1175 Latin translation. Cremona's Latin translation provided the basis for European developments in astronomy to the fifteenth century. Gerard of Cremona's Theorica planetarum, or Theory of the Planets, offered a simple introduction to Ptolemaic planetary calculations, often studied as a sequel to Sacrobosco's Sphaera.
		Theoricae novae planetarum ou-hsci/Peurbach-1534-tp	When he came to the University of Vienna, Cardinal Bessarion met Georg Peurbach, a professor of astronomy who was trying to improve the planetary models outlined in the medieval Theoricas. Peurbach's Theoricae novae planetarum—the New Theory of the Planets—launched the reform of mathematical planetary astronomy that culminates with Copernicus.

		show/Islamic Map with locations: Haytham (Cairo); al-Tusi and ash-Shirazi (Maragha); ash-Shatir (Damascus).	Peurbach's reforms were rooted in a tradition founded by Ibn al Haytham in the early 11th century. In the 13th century at the Observatory of Maragha in northwest Iran, Nasir al-Din al-Tusi (1201-1274) and Qutb ad-Din ash-Shirazi (1236-1311) developed similar models, as did Ibn ash-Shatir (1305-1375) the following century in Damascus. These astronomers criticized Ptolemy for geometrical devices like the equant that could not be represented by physical models.
		show/equantSphere Circle diagram with axis coming up from the center; add equant point off center with equal angles indicated	In a rotating sphere, the axis of rotation runs through the center of the sphere. Yet Ptolemy's equant requires a sphere to rotate uniformly around a point not on its axis, which is mechanically impossible for a rigid sphere.[12]
		Homocentric orbs show/homocentric ou-hsci/Peurbach-1534-tp	These Arabic astronomers often incorporated eccentrics within larger homocentric spheres, and they insisted that the equant point must be avoided at all costs. Peurbach's three-dimensional diagrams reflect this Arabic critique. The solid celestial spheres are homocentric, that is, they are nested together, sharing a common center.
		Eccentric deferents ou-hsci/Peurbach-1543-004	To incorporate eccentric models, Peurbach's homocentric spheres contain off-center channels in which planets move. These eccentric channels within the spheres correspond to the deferents, or carrying circles.
		Epicycles ou-hsci/Ziegler-Jacob-1531-29	The epicycles are smaller, secondary globes that contain the planets within these channels. The result is a model of the cosmos as orderly as moving clockwork; both physically plausible and, it was hoped, susceptible of mathematical rigor.

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12. We can't take a styrofoam ball and model its rotation around an equant. A sphere is defined by a point and a given radius that sweeps out a circumference in 3 dimensions. A rotating sphere has an additional entity, an axis, that passes through the center. If one changes any of those three entities (center, radius, axis of uniform rotation) one no longer has the same sphere. Yet the equant model does precisely this: it calls for a sphere to rotate uniformly around a point not on its axis (the equant). One might as well try to shift the center to the equant, shorten or lengthen the radius on the fly, and smoosh the circumference as the sphere continues to rotate. The only way to do it is to make the sphere elastic or fluid, like a nerf ball; otherwise it's mechanically impossible for a rigid physical sphere to move this way. And if it does move this way, by definition it's not really a sphere anymore, because the center, radius, and axis are not constant. See Noel Swerdlow and Otto Neugebauer, *Mathematical Astronomy in Copernicus's De Revolutionibus* (Springer-Verlag, 2 vols). Swerdlow and Neugebauer explain this in a summary point about Ptolemy's astronomy (p. 41): Ptolemy's "*Planetary Hypotheses* contain physical representations of the models that are supposed to exist in the heavens and produce the apparent motions of the planets, but these lead to difficulties, the most notable being the violation of uniform circular motion by spheres that are required to rotate uniformly with respect to points not located on their axes, and thus rotate nonuniformly about their axes." Further on (pp. 43-44), they summarize the Arabic critique of the equant: "...when Ptolemy's planetary model is physically represented as complete spheres, a problem arises in that the sphere carrying the epicycle must rotate uniformly around a point, the equant point, not on its axis, so that the motion of the sphere with respect to its axis is nonuniform. The serious physical, or mechanical, problem is that there is no way of compelling a sphere, a 'simple body' in the Aristotelian sense, to do this all by itself."

		ou-hsci/Peurbach-1542-pl-I ou-hsci/Peurbach-1534-tp	In the fifteenth century, Georg Peurbach's Theoricae novae planetarum replaced Gerard of Cremona's Theorica planetarum as the standard introduction to Ptolemaic planetary astronomy.[13]
17	46	Taurus starfield •Star projector fade on •Video projector fade off	Musical transition
17	54	•Star projector fade off •Video projector fade on ou-hsci/Sacrobosco-1478-Gerard-tp	Peurbach undertook preparation of an edition of Ptolemy's Almagest using Gerard of Cremona's Latin translation. Bessarion scorned Cremona's text as a worthless version, obtained through Syriac, Persian, Arabic, and then either Hebrew or Castilian intermediates.
		Map: Vienna to Rome show/ViennaRome	He urged Peurbach to go with him back to Rome, learn Greek, and read the manuscript Bessarion had brought from Byzantium—a Greek text that, in Bessarion's eyes, was "worth more than a province." When Peurbach died, his student Regiomontanus[14] accepted the offer. In Italy, Regiomontanus learned Greek, studied Bessarion's Greek manuscript of the Almagest, and became the first Latin-speaking European to fully master ancient and Islamic mathematical astronomy.
		show/Nuremberg Petreius' hammer/anvil printer's device: ou-hsci/Copernicus-1566-pd	Regiomontanus completed his Latin epitome of Bessarion's Greek Almagest just seven years after Gutenberg printed the Bible in Germany with movable type.[15] Regiomontanus returned to Nuremberg, and set up his own printing press to further the project of reforming astronomy. The same hammer that lit the fires of the Protestant Reformation would spread the word of the coming restoration of astronomy.
		Delirium, in Peurbach, ou-hsci/Peurbach-1542-153	Regiomontanus demonstrated the superiority of Peurbach to the Latin tradition of Cremona in a "Dialogue on the Delirium of Gerard of Cremona's Theorica."
		ou-hsci/Regiomontanus-1533-0tp	Regiomontanus dedicated an advanced treatise on spherical trigonometry to his friend and patron Cardinal Bessarion.
		ou-hsci/Regiomontanus-1476-No	The Kalendarium of Regiomontanus, published in 1476, predicted the positions of the Sun and Moon for 40 years.
		ou-hsci/Regiomontanus-1476-tp	Columbus took a later German edition on his 4th voyage...

13. Peurbach's student Regiomontanus published the first edition of Peurbach's *Theorica novae planetarum* in 1472. At least 56 editions of Peurbach appeared before 1653.
14. Johannes Müller adopted the name Regiomontanus as an adaptation of his birthplace, Königsberg, King's Mountain, or Regiomontanus (or Monterey).
15. Begun in 1460 by Peurbach, at Bessarion's request, the Epitome was completed by Regiomontanus not long after Peurbach's death in 1461. Gutenberg printed the Bible with movable type in 1454-55.

		Kalendarium eclipse 1504 ou-hsci/Regiomontanus-1476-Ecl-1497	and used its prediction of the 1504 lunar eclipse to frighten his Jamaican hosts. These were successful predictions, based in part upon Peurbach and the Greek Almagest as well as Cremona.
		Epitome ou-hsci/Ptolemy-1496-tp	Regiomontanus hoped to publish the Epitome of Ptolemy's Almagest with his own press in Nuremberg, but his premature death delayed its appearance for twenty years. Finally published in 1496, it was the first printed edition in any form of Ptolemy's Almagest, and its only printing in the fifteenth century.
		ou-hsci/Ptolemy-1496-C4v-C5r	Far from merely abridging the Almagest, or introducing it like a Theorica, the Epitome was a major contribution to Renaissance astronomy, containing new techniques, methods, observations and critical reflections.
		Epitome Bk V, Section 22 ou-hsci/Ptolemy-1496-mirum	"Sed mirum est...." What a marvel! At the end of Book V, Section 22, Regiomontanus called attention to the astonishing fact that Ptolemy's lunar theory required the Moon occasionally to appear four times its usual size. This impossible wonder arrested the attention of Copernicus.
		ou-hsci/Ptolemy-1496-fp	A magnificent full-page woodcut depicts Ptolemy and Regiomontanus seated beneath an armillary sphere. Together they epitomize the tradition of mathematical Earth-centered astronomy, from its ancient culmination in Ptolemy to its rebirth in Regiomontanus.
21	22	3. Copernicus: Early life and training[16]	
21	32	show/Torun	The village of Torun lies on the banks of the Vistula river, which drains into the Baltic.
		Birthplace home ou-roller/Torun	Copernicus, born in this house, though the son of a merchant, was the nephew of an Archbishop, Lucas Waczenrode. Uncle Lucas took Copernicus under his wing and set him on the path of financial security, funding his education for the church hierarchy through study of law and medicine.
		1491-1494. University of Cracow. show/TorunCracow	When he was 18, Copernicus went to Cracow, the capital of Poland, to the university where Uncle Lucas likewise had studied.[17] In Cracow Copernicus studied the liberal arts, which included mathematics and astronomy.

16. This section owes much to Duane H.D. Roller, who took all of the photographs of historical places. For an authoritative biography, see Swerdlow (Further Reading).

17. The Cracow cathedral was built by two brothers. According to a local story, they competed fiercely to see which could build the larger tower. The one who murdered the other did it. This is the oldest standing university building in Europe. It was built around a courtyard - in which an old slide shows many historians of science — taken by OU History of Science Collections curator Duane Roller.

		ou-roller/Cracow	At this time Copernicus mastered the geometry of Euclid, the basics of astrology, the introductory planetary theory of Peurbach's Theoricae novae, and the use of astronomical tables.[18]
		Bologna map show/BolognaCracowTorun	In 1496, at the age of 22, Copernicus traveled to study canon law at the University of Bologna, again at his uncle's instigation. Bologna, the most famous school of law in the world, had reopened after the reforms of Cardinal Bessarion.
		University of Bologna ou-roller/Bologna	At Bologna Copernicus assisted the Platonist astronomer Dominico Maria di Novara, with whom he observed a lunar occultation of Aldebaran.
22	55	•Star projector fade on •Position Taurus front center (diurnal motion) •Video projector fade off	Musical transition (opening): Lunar occultation
23	02	•Constellation figure: Taurus. •Point out Aldebaran •Constellation figure off (keep pointer on Aldebaran)	High overhead in the winter sky, the bright star Aldebaran forms the red eye of the constellation of Taurus the Bull.
23	10	•Turn on ecliptic.	Aldebaran lies close to the ecliptic, the path followed by the Sun in its annual motion around the sky.
23	15	•Turn on constellation figures of zodiac (Taurus + any others) •Turn on Moon (positioned just above western horizon)	Zodiac constellations are those which, like Taurus, include the ecliptic. They also contain the paths of the other planets and the Moon.
23	26	•Move Moon in direct (annual) motion toward Aldebaran •Turn off constellation figures	As the Moon revolves around the Earth once a month, it moves roughly eastward each night, against the backdrop of fixed stars, about the width of one's fist held at arm's length.[19]

18. In Cracow Copernicus acquired his own copies of the medieval Alphonsine Tables, and an updated version of astronomical tables published by Regiomontanus. 1492 *Alphonsine Tables* (Venice); 1490 *Tabulae directionum* (Regiomontanus, Augsbg).

19. One's fist held at arm's length is a common approximation of 10° angular distance. The average distance moved by the Moon from night to night is easy to calculate, because the Moon completes one complete 360° circuit of the sky roughly every month (27.3 days to return to the same place among the stars; 29.5 days to return to the same phase alignment with the Sun). 360° ÷ 27.3 days = 13.2° per day. However, the Moon does not move with uniform speed, so this average distance is merely a rough approximation.

23	39	•Moon moves in direct (annual) motion very close to Aldebaran •When the Moon occults Aldebaran, pause it.	As the Moon moves in front of a star like Aldebaran, it suddenly hides, or occults, the star. To observe the precise instant of a lunar occultation provides an ideal test of mathematical models of the motion of the Moon.
23	55	•Turn off pointer •Turn off ecliptic	Copernicus later used the occultation of Aldebaran, observed in Bologna with di Novara in 1497, to disprove Ptolemy's model of lunar distance.
24	06	•Fade off Moon slowly Taurus starfield	Musical transition
24	15	•Star projector fade off •Video projector fade on show/PaduaTorun (map)	After his study of law at Bologna, Copernicus turned to medicine at the University of Padua in 1501.
		Padua medical school ou-hsci/Vesalius-1543-	In medicine, the University of Padua was pre-eminent—the school attended by founders of modern medicine like Andreas Vesalius... and William Harvey.
		Zodiac man, slow pan. ou-hsci/Reisch-1599-417 ou-hsci/Barozzi-1585-F2r	It was not at all unusual for those with knowledge of astronomy to study medicine. Educated people believed that a planetary influence, or influenza, might affect the course of a disease. University-educated physicians depended upon their ability to prognosticate planetary positions. They used mathematical astronomy to prescribe the appropriate times for administering medicines and other therapeutic measures.
		Cop portrait with lily. ou-hsci/Copernicus-SPC-1541	In this portrait of Copernicus, the lily signifies a practitioner of the medical profession.[20] By this time, with the support of Uncle Lucas, Copernicus had been appointed as Canon of the Cathedral of Frauenburg, in Poland. Upon his return, Copernicus would serve as the physician of Archbishops and Dukes.
		show/PaduaTorun show/equantSphere2	In addition to its fame as a medical school, the University of Padua was a hotbed of Aristotelianism, where physicists insisted upon the physical reality of the celestial spheres. These Aristotelians scorned astrologers who made predictions on the basis of geometrical models that were physically impossible. In order to defend astrology as a mathematical science, it would be necessary to reform astronomy by using only those models that were consistent with the physical reality of the spheres.

20. Marian Biskup and Jerzy Dobrzycki, *Copernicus: Scholar and Citizen* (Warsaw: Interpress Publishers, 1972), 48.

		show/Ferrara-Torun ou-roller/Ferrara	Copernicus did not graduate from Padua, but transfered to the University of Ferrara. Here Copernicus received his Doctorate of Canon Law in 1503. Foreigners were known to favor the University of Ferrara,[21] particularly if they wished to study Greek.
		Calcagnini book, ou-hsci/Calcagnini-1544-000tp	Copernicus' interests in law and astronomy were shared in Ferrara by his friend Celio Calcagnini, who became a jurist and a professor of astronomy at Ferrara. As an astronomer, Calcagnini's renown extended to England and the court of young Henry VIII.[22]
		Heading of Earth moves: ou-hsci/Calcagnini-1544-388	Like Copernicus, Calcagnini asserted that the Earth moves, and the sphere of fixed stars stands still.[23]
		show/Frauenberg-Torun1	By early 1506, Copernicus returned to his homeland. In later years, Calcagnini traveled across the Alps to Poland in order to visit his long-time friend.
		show/Frauenberg-Torun2	At first Copernicus worked at Heilsberg Castle as an administrator and as personal physician to his Uncle Lucas, the Archbishop.
		show/Frauenberg-Torun3	When his uncle died in 1512, Copernicus took up his position as canon at the cathedral in Frauenburg, in the territory of Warmia.[24]
		show/Wittenberg-Torun	Five years later word arrived that Martin Luther posted 95 theses upon the door of the Wittenberg Cathedral, the symbolic end of the Renaissance and beginning of the Reformation.[25]
27	22	4. Publishing the Revolutions	

21. William Harrison Woodward, *Studies in Education during the Age of the Renaissance, 1400-1600* (1906; rpt. New York: Teachers College Press, Columbia University, 1967), 168.
22. Von Chledowski, 146. This fact is perhaps less surprising given the longstanding relations between England and the University of Ferrara. For example, Reginald Chichele, the Rector of the University of Ferrara in 1446, was the nephew of the Archbishop of Canterbury (Powicke and Emden, 2: 55). Calcagnini is hardly ever cited in the literature on Copernicus, but Chledowski compared the fame of Calcagnini with that of the contemporary Ferraran poet Ludovico Ariosto, claiming that he was known throughout Europe as a jurist and astronomer; Casimir von Chledowski, *Der Hof von Ferrara* (München: Georg Müller, 1921), 145-146: "Calcagnini gehört zu den Universalgenies der Renaissance, als Jurist und Astronom war er in ganz Europa berühmt." Note the congruence of these two areas of interest with those of Copernicus (who took his degree from Ferrara in law).
23. Celio Calcagnini (1479-1541), "Quod caelvm stet, terra moveatvr, vel de perenni motv ter," in Caelii Calcagnini, ferrariensis, protonotarii apostolici, opera aliqvot: ad illustrissimum & excellentiss principem D. Hercvlem secundum,... (Basileae, 1544).
24. Now Frombork, Poland.
25. Whether Luther actually posted his theses on the doors of Wittenberg Cathedral is now uncertain, but the claim is left (indirectly qualified) in the script because of its emblematic character as the starting date for the Reformation.

		Map: Pan to Rome ou-Roller/Vatican	Word of Copernicus began to spread, largely due to the Commentariolus, a manuscript Copernicus circulated privately among a few friends. In Rome, the secretary of Pope Clement VII presented a lecture on Copernicus' new astronomical ideas, and the Pope himself invited Copernicus to join the Church's effort to reform the calendar.
		Schönberg letter ou-hsci/Copernicus-1543-000-2r	In 1536, Cardinal Schönberg invited Copernicus to publish his views at the Cardinal's expense:
		Schönberg quote ou-hsci/Copernicus-1543-000-2r	Schönberg voice: "Some years ago... I began to have a very high regard for you. For I learned that you had not merely mastered the discoveries of the ancient astronomers uncommonly well but had also formulated a new cosmology. In it you maintain that the Earth moves; that the Sun occupies the lowest, and thus the central, place in the universe; that the eighth [starry] heaven remains perpetually motionless and fixed; and that, together with the [four] elements included in its sphere, the Moon... revolves around the Sun in the period of a year. I have also learned that you have written an exposition of this whole system of astronomy, and have computed the planetary motions and set them down in tables, to the greatest admiration of all. Therefore with the utmost earnestness I entreat you, most learned sir, unless I inconvenience you, to communicate this discovery of yours to scholars.... Moreover, I have [given instructions] to have everything copied in your quarters at my expense...."
		ou-hsci/Copernicus-1543-000-2r	Copernicus was not yet ready to publish. Seven years later Cardinal Schönberg's letter would be placed near the beginning of De revolutionibus.
29	11	Musical transtion: Lutheran role[26] •Star projector on during transition (with video projector)	
29	17	show/Nuremberg-Rome-Frauenberg •Star projector off	As in Rome so in Nuremberg; the Lutherans also became interested in Copernicus' astronomical reforms.[27]
		show/Wittenberg-Nuremberg	Charged with reforming the University of Wittenberg, Luther's designated assistant, Philip Melanchthon, appointed
		ou-hsci/Reinhold-1585-000Illust	the well-known astronomer Erasmus Reinhold as professor of astronomy.

26. Throughout this entire section, I have depended entirely upon the pathbreaking study of Peter Barker and Bernard Goldstein (see Further Reading).

27. Luther was perceived as a revolutionary despite regarding himself as a conservative attempting only to reform the Church. Similarly, Copernicus sought to cleanse astronomy of corruptions such as the equant, in order to restore fundamental principles such as uniform circular motion. It is no coincidence that in the 16th century, Lutherans proved most receptive to Copernicus' new astronomy.

		ou-hsci/Rheticus-1566-C1566-f197r	Melanchthon then hired the 22-year old Georg Joachim Rheticus as professor of mathematics.
		show/Wittenberg-Nuremberg show/N-circle-0R	It was not long before Rheticus traveled to Nuremberg, where a circle of remarkable Lutherans were committed to advancing the legacy of Regiomontanus:
		show/N-circle-2W	Bernhard Walther, an associate of Regiomontanus, carried out systematic observations for 30 years.[28]
		show/N-circle-3S	Johann Schöner, a student of Walther, edited Regiomontanus' manuscripts for printing.
		show/N-circle-4O	Andreas Osiander, a leading Lutheran theologian, secured the favor and patronage of Albrecht, Duke of Prussia.
		show/N-circle-5P	Petreius, an influential printer, actively searched for worthy titles in astronomy, ancient or modern, to publish with his press.
		show/N-circle-6G	Even the papal astronomer Luca Guarico, in Rome, was known to visit Nuremberg, and Petreius published some of his books. In a tumultuous century, astronomy remained one endeavor in which Catholics and Protestants might still collaborate.
		show/Nuremberg-Rome-Frauenberg ou-hsci/Apian-1534-000tp	In the spring of 1539 the young Rheticus left Nuremberg to visit Copernicus in Frauenburg. His mission on behalf of the Nuremberg circle was to report on the progress of Copernicus' work. Rheticus brought Copernicus a gift of several books, including an edition of the complete Greek text of Ptolemy's Almagest. Impressive editions like this, printed by Petreius, showed that the Nuremberg circle stood ready to publish Copernicus' own work as soon as it might be ready.[29]
		show/Nuremberg-Rome-Frauenberg show/F-Dantiscus show/F-Giese	Seeking the great astronomer in Frauenburg, Rheticus instead found a churchman in trouble. Because of his long-term mistress, Copernicus fell out of favor with his new Bishop, Dantiscus. Yet Copernicus enjoyed an ally and friend in Tiedeman Giese, Bishop of a nearby city. Giese and Rheticus conceived a plan to outmaneuver Dantiscus.
		Narratio prima ou-hsci/Rheticus-1566-C1566-f197r show/F-Albrecht ou-hsci/Rheticus-1566-C1566-f197r	To attract attention to Copernicus' ideas, Rheticus composed a short treatise outlining Copernicus' new astronomy, published in Poland in 1540. Rheticus dedicated the Narratio prima, or First Account, to Albrecht, Duke of Prussia. Duke Albrecht ruled Lutheran lands adjacent to Frauenburg. The Narratio prima was a resounding success, and heightened anticipation among both Catholics and Lutherans for the promised work by Copernicus himself.

28. According to Swerdlow, Copernicus used three of Walther's observations of Mercury in *De revolutionibus* (p. 53).
29. Several but not all of these books books given to Copernicus from the Nuremberg circle were printed by Petreius.

		show/F-Albrecht De Lateribus ou-hsci/Copernicus-1542-00-tp-v ou-hsci/Copernicus-1542-00-tp	Because the Narratio prima aroused such keen interest, Duke Albrecht arranged for Copernicus to serve as his personal physician until the issue with Dantiscus cooled off. Faced with the Duke's support for Copernicus, Dantiscus made a complete about face, writing a poem in praise of Copernicus which he hoped Copernicus would publish. Thus in the middle of the Reformation a traveling young Lutheran professor and a Lutheran Duke intervened to ensure the security of a minor Catholic churchman in a neighboring territory, with the result that Copernicus was thereafter free to publish his great work.
		show/Leipzig ou-hsci/Copernicus-1543-tp ou-hsci/Copernicus-1543-000-2r	During his stay in Frauenburg, Rheticus edited Copernicus' manuscript of De revolutionibus. When it was nearly complete in the autumn of 1542, Rheticus left to take up his responsibilities as professor of astronomy at Leipzig. On the way to Leipzig, Rheticus took the manuscript to Nuremberg for final editing by Osiander, after which it was printed by Petreius. In summary, Rheticus encouraged Copernicus to complete the great work, and he edited the manuscript. With the Narratio prima, Rheticus awakened widespread interest in its imminent publication. However, despite the crucial roles Rheticus played in bringing the project to completion, the first edition of Copernicus' book nowhere mentions Rheticus by name. Perhaps to avoid offending superiors in the Church, the front matter only mentions Catholic supporters such as Cardinal Schönberg.
		ou-hsci/Copernicus-1543-section	In 1543 Copernicus died. It is said that on his deathbed he awakened from a coma long enough to recognize proof pages for the work, now in press after so many long years of preparation.
34	11	5. The De Revolutionibus	
34	23	Book I, headings ou-hsci/Copernicus-1543-001r	In Book I Copernicus laid out his basic assumptions, including that the universe is spherical and that the Earth is spherical. Ptolemy began the Almagest in the same way.
		ou-hsci/Copernicus-1543-section	Copernicus departed from Ptolemy in Chapter 10 by switching the positions of the Sun and the Earth.
		Triple motion heading: ou-hsci/Copernicus-28 Three motions depicted: ou-hsci/Copernicus-1543-section	In the following chapter, Copernicus described the triple motion of the Earth. First, the Earth rotates around its axis once each day. Second, it revolves in orbit around the Sun once each year. Third, because Copernicus accepted the reality of the solid spheres, he had to postulate another motion of the Earth's axis (which we don't need today), to keep from tilting the north pole toward the Sun throughout the year.

		ou-hsci/Copernicus-1543-dedication	Copernicus dedicated the De revolutionibus to none other than the pope. Pope Paul III was known for his humanist interests, as Copernicus explained:[30]
		ou-roller/CopernicusPortrait	"I have preferred dedicating these late-night studies to you, Your Holiness, rather than to anyone else. For even in this very remote corner of the Earth where I live you are considered the highest authority by virtue of your exalted office and your love for all literature, even astronomy."[31]
		ou-hsci/Copernicus-1543-dedication	Copernicus noted that while some theologians might mistakenly regard his system as contrary to the Bible, his arguments rested on mathematics, and those with no expertise in mathematics should not rush to judge:
		ou-roller/CopernicusPortrait	"Perhaps there will be babblers who claim to be judges of astronomy although completely ignorant of the subject and, badly distorting some passage of Scripture to their purpose, will dare to criticize and censure my teaching. I shall not waste time on them; I have only contempt for their unfounded criticism.... Astronomy is written for astronomers."[32]
36	24	•Video projector off •Star projector on	Musical transition
36	35	•Video projector on •Star projector off ou-roller/Vatican	Revolutionaries in every age cite ancient precedents for their own novel claims. This tactic appealed to the heart and soul of Renaissance humanism. With regard to scholarship, humanism stood for the principle of "ad fontes," to the sources, a return to ancient texts. In his preface to Pope Paul III, Copernicus justified his novel claims by citing ancient advocates of the motion of the Earth including Philolaus the Pythagorean, Herakleides of Pontos, and Aristarchos of Samos.
		ou-roller/CopernicusPortrait	"Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the Earth."
		ou-hsci/Copernicus-1543-section	The ancient texts may have provided an opportunity to consider a heliocentric system, but what compelled Copernicus actually to adopt this almost universally rejected theory?
37	32	Taurus starfield •Video projector fade off •Star projector fade on	The answer is not observations. Ptolemaic astronomy was neither overly complex nor inaccurate. Copernicus used about the same total number of circles as Ptolemy. And in theory, a geocentric system may be updated to yield accurate predictions for any epoch.

30. Some of the works of Paul's astronomer, Luca Guarico, were published by Petreius.
31. Copernicus, Preface. Danielson, 107.
32. Copernicus, Preface. Danielson, 107.

37	50	OBU Planetarium star projector[†] •Turn on star projector spotlights •Star projector fade off	This fact bears significant interest for the philosophy of science, and just this kind of updating is actually performed by the engineers of planetarium equipment today. A mechanical-optical star projector accurately projects the positions of the planets using an observer-centered system.
38	12	•Turn off star projector spotlights •Video projector fade on ou-hsci/Copernicus-1543-section	Simplicity and accuracy do not explain why Copernicus rejected an Earth-centered system. When he conceived the heliocentric cosmos, Copernicus' aim was not to account for new observations, but merely to equal Ptolemy in mathematical power. Kepler dryly noted that Copernicus "represented Ptolemy rather than Nature." Observations did not compel Copernicus to hurl the Earth into the heavens or switch the Sun into the center.
		show/starfield	Yet observations were important to Copernicus for another purpose: to justify his theory. To make his case as compelling as possible, Copernicus devoted most of his adult life to a thorough re-determination of the numerical parameters used in the models. If he could pull it off, this ambitious feat would make his system the basis for future work in mathematical astronomy. He would become nothing less than the Ptolemy of his time.
			Why, then, did he do it?
		show/equantNonuniform show/equantSphere2	First, Copernicus wanted to eliminate the equant. In the Commentariolus manuscript, Copernicus scorned Ptolemy's use of the equant, calling it "not sufficiently pleasing to the mind." Ptolemy believed the equant was necessary to achieve agreement with observations, but for Copernicus, accurate predictions were not the only aim of theory. In addition, for Copernicus as for the Arabic astronomers, one must in principle be able to construct physical models of the revolutions of the spheres.
		Crank diagram ou-hsci/Copernicus-1543-067v	The lunar theory of Copernicus provides another interesting example of this Islamic legacy. Ptolemy's models predicted a fourfold change in the apparent size of the Moon. To correct for this inaccuracy, Copernicus used a crank mechanism identical to that which ash-Shatir developed in the 14th century.
		show/Islamic4 show/fromCtoF2	The aims and methods of the Maragha School, including the lunar crank mechanism, reached Byzantium by the 15th century. No one knows precisely how they were brought to northern Italy where Copernicus likely learned of them, whether by the Greek visitors to the Council of Ferrara or by some other route.

†- Photograph by Bill Pope.

		show/equantSphere2 show/deferent	Thus, by ridding astronomy of the corruptions introduced by Ptolemy's equant, Copernicus sought to recover a pure astronomy consistent with the classical ideal of uniform circular motion. This quest might appeal to the ideals of Renaissance humanism, but why would any reader believe Copernicus had achieved the truth?
40	52	•Star projector on (with video projector)	Musical transition
41	00	ou-hsci/Copernicus-1543-section •Star projector off	The most important advantage offered by Copernicus was a vision of the universe as a coherent and integrated system, where all the planets move together in elegant harmony.
		Separate models show/Ptolemy-separate	In contrast, Ptolemy considered each planet in isolation. In the geocentric cosmos, each planet was explained separately by its own individual model.
		Separate models stacked, not same center: show/Ptolemy-diffCenters	Ptolemaic models for the various planets did not even share the same center. So not only did Ptolemaic models fail to be precisely centered on the Earth, but they each fell off-center by slightly different amounts. Copernicus compared this fragmented portrait of the cosmos with a sculpture assembled piece-meal, more like a monster than the balanced form of a man:
		ou-roller/CopernicusPortrait (optional: Mr. Potatohead parts superimposed upon a cosmic section?)	[Astronomers have not] "deduced... the main point, that is, the structure of the universe and the true symmetry of its parts. On the contrary, they have been like someone attempting a portrait by assembling hands, feet, a head and other parts from different sources. These several bits may be well depicted, but they do not fit together to make up a single body. Bearing no genuine relationship to each other, these fragments, joined together, produce a monster rather than a man."[33]
		Earth-Sun line show/Earth-Sun-Outer	In Ptolemaic planetary models, the line from the Earth to the Sun was inexplicably linked to the motions of the planets. First, for the outer planets, radius lines in each large epicycle always remain parallel to the line from the Earth to the Sun.
		show/Earth-Sun	Second, for the inner planets, the centers of the epicycles at all times remain on the line from the Earth to the Sun.
			In the Ptolemaic system there was no reason why the Earth-Sun line should be linked to the motions of the planets in these ways. It was merely an odd coincidence. On the other hand, Copernicus explained, if one accepts the motion of the Earth, then all of the planets are necessarily linked in an intricately choreographed cosmic dance.

33. Copernicus, Preface. Danielson, 106.

		show/Ptolemy-Order-Distances	In the Ptolemaic system, one could not determine the order or sequence of the planets. For example, Mercury might lie closer to the Sun than Venus, or the other way around. The same uncertainty held for the order of the outer planets.[34] Nor could one determine the distances to the planets. Because it was impossible to measure the relative sizes of planetary deferent circles, the distances to the planets could not be calculated directly, apart from the assumption of nesting solid spheres.
		Triangulation diagram: show/Cop-VenusMercury show/Cop-VenusMercury2 show/Cop-VenusMercury3	On the other hand, the Copernican system fixes the order of all of the planets, specifying that Mercury must be closer to the Sun than Venus. And the Copernican system also specifies the distances of the planets, calculating the sizes of the planetary deferents by means of triangulation measurements.
		ou-roller/CopernicusPortrait	"if the motion of the other planets is viewed in relation to the circular motion of the Earth... then... the order and sizes of all the orbs and spheres and heaven itself are so interconnected that in no portion of it can anything be shifted without disrupting the remaining parts and the entire universe."[35]
		show/Cop-VenusMercury3 show/Cop-periods[36]	In addition to explaining the harmonies between the planetary motions, their order and distances, the Copernican system presents several aesthetic advantages. In contrast to the Ptolemaic system, where there was no relationship between the planetary periods and their distances, the Copernican order of the planets corresponds with the length of their periods. The closer the planet to the Sun, the faster it moves. This trend continues without interruption from Mercury's period of 80 days to Saturn's period of 30 years. The infinite period of the now immovable fixed stars completes a perfectly consistent sequence.
		ou-roller/CopernicusPortrait	"No one can propose a more fitting first principle than that the magnitude of a planet's sphere is proportionate to its period of revolution."[37] "Thus we discover in this orderly arrangement the marvelous symmetry of the universe and a firm harmonious connection between the motion and the size of the spheres...."[38]

34. Copernicus, *De revolutionibus*, 1.10 (f. 8v).
35. Copernicus, Preface. Danielson, 107.
36. Table of Copernican planetary periods: Mercury: 80 days; Venus: 9 months; Earth: 1 year; Mars: 2 years; Jupiter: 12 years; Saturn: 30 years; Fixed stars: immobile. Copernicus used two different sets of planetary distances. This table is taken from his famous diagram. He used a different set of values in the technical part of the book. I thank Katherine Tredwell for calling this and many other details to my attention.
37. Copernicus, Book I, Chapter 10. Danielson, 116.
38. Copernicus, Book I, Chapter 10. Danielson, 117.

		ou-hsci/Copernicus-1543-dedication	In the Preface, Copernicus infused the center of the cosmos with new dignity, describing it as the center of a Temple, fit only for a lamp as noble as the Sun:
		ou-roller/CopernicusPortrait	"Behold, in the middle of the universe resides the Sun. For who, in this most beautiful Temple, would set this lamp in another or a better place, whence to illumine all things at once? For aptly indeed do some call him the lantern—and others the visible god, and Sophocles' Electra, the Watcher of all things. Truly indeed does the Sun, as if seated upon a royal throne, govern his family of planets as they circle about him."[39]
		ou-hsci/Copernicus-1543-section	At the same time, Copernicus elevated the Earth's status by transforming it into a planet that moves in the heavens. In the geocentric cosmos, both the center and the Earth were unworthy. In contrast, for Copernicans such as Galileo, the Earth "is not the sump where the universe's filth and ephemera collect," but rather participates in the dance of the stars.
46	55	6. Problems: Optical Illusions, Physics, Astronomy, Aesthetics	
47	07	show/title	In 1543 little proof was available that the Earth moves; there were many reasons not to accept it.
47	15	Problem: Optical illusions show/title	Of course, the motion of the Earth cannot be directly observed. The evidence of our senses often deceives us, yet we naturally give weight to common sense and ordinary observation.
		ou-roller/CopernicusPortrait	"This whole matter is difficult, almost paradoxical, and certainly contrary to many people's way of thinking.... God helping me, I shall make these things clearer than sunlight, at least to those not ignorant of the art of astronomy."[40]
		ou-hsci/AlHazen-1572-fp	According to optics, to overcome the prejudices of common sense, one begins by considering the perspective of the observer:
		ou-roller/CopernicusPortrait	"We must examine carefully the relationship of the earth to the heavens. Otherwise, in our desire to investigate things of the highest order we may remain ignorant of what is nearest to us, mistakenly attributing things that are earthly to things that are heavenly."[41]

39. Copernicus, Book I, Chapter 10. Danielson, 117.
40. Copernicus, Book I, Chapter 10. Danielson, 116.
41. Copernicus, Book I, Chapter 4. Danielson, 111.

		Problem: Optical Illusions of Relative Motion ou-hsci/AlHazen-1572-fp	Because of relative motion, what we observe as the apparent motion of the planets is largely due to the motion of the Earth. We ride a boat sailing through space, and what we observe is not a true movement of the planets but a combination of their movement and our own.
		ou-roller/CopernicusPortrait	"It is like the case spoken of by Virgil's Aeneas: 'We sail forth from the harbor, and lands and cities draw backwards.' For when a ship glides along smoothly, its passengers see its motion reflected by everything outside of the ship and, by contrast, suppose themselves and everything else on board to be motionless. No wonder, then, that the movement of the Earth makes us think the whole universe is turning round."[42]
		Diurnal ou-hsci/Ptolemy-1541-circumpolar	Relative motion explains why the stars appear to rotate around the Earth once each day. The same diurnal motion of the stars results whether the heavens spin around the Earth, or whether the Earth spins in the opposite direction.
		Retrograde ou-hsci/Retrograde-Ptolemy ou-hsci/Retrograde-Cop	Relative motion also explains why the planets appear to reverse direction and trace retrograde loops in the sky. The large epicycle that accounts for the retrograde motion of the outer planets in the geocentric system is no longer needed when the center is shifted to the Sun, for in the Copernican model these epicycles are replaced by the circle of the annual motion of the Earth.
		ou-roller/CopernicusPortrait	"If the Earth moves [instead of the Sun]... then the risings and settings of the constellations and fixed stars... will appear just as they do. Furthermore, the stations and retrograde motions of the planets will be seen not as their own motions but as earthly motion transmuted into apparent planetary motions."[43]
		ou-hsci/Retrograde-Cop	Because of the relativity of motion, the models of Ptolemy and Copernicus produce equivalent observations.
50	14	•Star projector on (with video projector)	Musical transtion
50	24	Problems: Physics •Star projector off show/gravityLines	The Copernican cosmos flatly contradicted Aristotelian physics. According to Aristotle, every element seeks its natural place; an earthy body falls toward the center of the universe. If earth falls from all sides, then the Earth must be a sphere at rest in the center of the universe.

42. Copernicus, Book I, Chapter 8. Danielson, 115.
43. Copernicus, Book I, Chapter 9. Danielson, 115.

		Clouds, Wind ou-hsci/Apian-1540-cosmicSection	Moreover, if the Earth is moving, why doesn't it leave its atmosphere behind? Copernicus suggested that the Earth and its circumjacent elements move together. If it is natural for the Earth to move, then it will also be natural for the water and air to move with it.
		ou-hsci/DiggesSection	This was a huge if, amounting to a thorough redefinition of natural place. Many medieval physicists, including Jean Buridan, Nicole Oresme, and William Ockham, were willing to take this step. However, to those who did not share this belief that earth could have a natural motion other than toward the center of the universe, Copernicus seemed to beg the question.
51	24	Problems: Astronomy •Star projector on •Diurnal motion to place Orion front center •Video Projector fade off	Musical transition
51	37	•Orion constellation figure •Point out Betelgeuse •Point out Rigel •Point out belt, sword •Fade out figure •Point out middle star of belt (Alnilam) •Keep pointer on middle star	If the Earth moves, one should observe stellar parallax. Consider the constellation of Orion the Hunter. The reddish star Betelgeuse marks his right shoulder. Bright Rigel represents his left foot. In between are the three stars of his belt, from which hangs a sword. Focus on the middle star of Orion's belt. Close your right eye, and hold up your thumb so that it aligns with this star. Without moving your thumb, close your left eye and open your right. When you switch back and forth between eyes, does the position of your thumb appear to shift along the belt of Orion? This is stellar parallax, and something like it should be observed if the Earth shifts its position in space every six months as it moves in orbit around the Sun.
52	24	Stellar parallax Diagram: show/stellarparallax •Pointer off •Star projector fade off •Video projector fade on	From antiquity, stellar parallax was not observed, and this failure disproved the heliocentric model. Most people took this observation as a decisive refutation of the theory. Persuaded on other grounds, however, Copernicus insisted upon the deficiency of human observation. Setting aside the evidence of the senses, Copernicus argued that the fixed stars must lie at such immense distances that the parallax caused by the Earth's motion is too small to be observed.[44]
52	55	•Moon around Earth SFX (or ou-hsci/Copernicus-1543-section)	Others were troubled by the idea of planetary satellites. As the Moon revolves around the Earth, how could the Moon keep up if at the same time the Earth is moving around the Sun?

44. Copernicus, Book I, Chapter 10.

53	07	Problems: Aesthetic •Star projector on (with video projector)	Musical transition
53	17	Circle count •Star projector fade off	Simplicity is pre-eminent among aesthetic criteria, but how is simplicity defined? If it consists simply of counting circles, then Copernicus did not represent a significant improvement. Copernicus still used many epicycles, with a total number of circles about the same as for Ptolemy.
		Copernicus' cosmic section, point to Sun then Moon ou-hsci/Copernicus-1543-section	Copernicus showed how the motions of the planets are linked in many elegant ways. Yet critics did not admire the needless proliferation of centers of revolution. In the Ptolemaic system all planets revolved around a single body, the Earth. In the Copernican system not every body revolves around the center, because the Moon, no longer a planet, revolves around the Earth instead of the Sun. Why should there be multiple centers of revolution in a single universe?
		ou-hsci/Copernicus-1543-section	Did the Copernican system threaten the aesthetic sensibility embodied in the hierarchical Renaissance cosmos? Although Copernicus insisted upon the solid spheres of the planets, he inserted a vast distance between the planetary spheres and the fixed stars, a giant gap conspicuous by its absence in the famous Copernican section. One might wonder if the universe were actually infinite in size...
		ou-roller/CopernicusPortrait	"So vast, without any doubt, is the handiwork of the Almighty Creator."[45]
		ou-hsci/DiggesSection	Copernicus echoed medieval speculations that the universe might continue outward to an indefinite extent, with a hollow sphere as its center for the planets.[46] The English Copernican Thomas Digges portrayed the Copernican system this way in 1576.
		Descartes cosmic section: ou-hsci/Descartes-1644-vortices92	On the other hand, Copernicus and Digges portrayed solid planetary spheres in a determinate, hierarchical order. Theirs was not the randomly structured cosmos of the ancient atomists nor the dynamic, ever transforming universe of the Stoics. The latter found expression in the endless impermanent vortices of Descartes, where worlds upon worlds continually form and dissolve in the flux of time.
55	27	7. Reception of the De Revolutionibus	

45. Copernicus, Book I, Chapter 10. Danielson, 117.
46. Copernicus, Book I, Chapter 8. Danielson, 114. For medieval debates on the infinity of the universe and the possibility of extracosmic void space see Grant (Further Reading).

55	38	Osiander preface ou-hsci/Copernicus-1543-preface	No more than a dozen mathematicians accepted the physical truth of Copernicus in the first half-century. Far more shared the view of Andreas Osiander who, as the final editor of De revolutionibus, contributed an unauthorized foreword. In this anonymous letter "to the reader, on the hypotheses of this work," Osiander noted that mathematical works were often regarded as hypothetical, because one could save the phenomena with various mathematical devices, even with false ones. Perhaps to ward off controversy, Osiander praised Copernicus not for discovering true causes but merely for providing calculations that more accurately save the phenomena:
		Osiander quote	Osiander voice: "Since [the astronomer] cannot in any way attain true causes, he will adopt whatever suppositions enable the motions to be calculated.... For hypotheses need not be true nor even probable. On the contrary, if they provide calculations consistent with the observations, that alone is enough.... Different hypotheses are sometimes offered for one and the same motion (for example, either an eccentric or an epicycle model will explain the Sun's motion). The astronomer will adopt whichever hypothesis is easier to grasp.... So as far as hypotheses are concerned, let no one expect anything certain from astronomy... lest he accept as truth ideas conceived for another purpose, and depart from this study a greater fool than when he entered it."
		Osiander preface ou-hsci/Copernicus-1543-preface	Osiander's foreword is typical of the immediate Lutheran reception of Copernicus. No sense of crisis compelled them to undergo a revolutionary paradigm shift. They adopted Copernicus' work selectively, accepting his mathematical system while rejecting its physical implications.
		show/Wittenberg-Nuremberg	At the University of Wittenberg, Erasmus Reinhold adopted Copernican ideas in this piecemeal fashion. Reinhold admired the mathematical elegance of Copernican models, and used them as the basis for his Prutenic tables.
		Reinhold, Prutenic tables (1551). ou-hsci/Reinhold-1585-000tp	Reinhold published these astronomical tables in 1551 to replace the outdated Alphonsine Tables. Subsequent astronomers including Caspar Peucer used Reinhold's Prutenic tables and similarly admired Copernican models, while rejecting the motion of the Earth.
58	08	ou-hsci/Reinhold-1585-133v	According to the Wittenberg interpretation, accurate astronomical predictions calculated on the basis of tables derived from the Copernican system did not necessarily imply that the Copernican models were physically true.[47]
58	22	Tycho Brahe	Musical transition

47. The classic scholarship on the Wittenberg Interpretation is by Robert Westman.

58	33	ou-hsci/Brahe-portrait show/Denmark ou-hsci/Brahe-Hveen-print-clr2	The island of Hven lies off the coast of Denmark. With his income as feudal lord of Hven, Tycho Brahe built a castle of the stars, Uraniborg, in the center of the island. Here Tycho welcomed scholars from across Europe to collaborate in the advancement of astronomy, alchemy and medicine.
		Closeup of gardens ou-hsci/Brahe-1596-260	Medical research depended upon the tending of orchards and herb gardens.
		Castle cross-section, pan to basement ou-hsci/Brahe-Uraniborg-view-print	Alchemical work required furnaces, which at Uraniborg were tended night and day in round subterranean laboratories.
		ou-hsci/Brahe-Uraniborg-view-print ou-hsci/Brahe-1602-opB1	Astronomy required instruments, housed in the roof beneath removable panels, and on the nearby grounds. Tycho's large-scale instruments, together with sophisticated new error correction techniques, increased observational precision by a factor of twenty.
		Tychonic system: pan slow from Earth to Sun ou-hsci/Brahe-1648-97	Tycho did not test the Copernican system by observation so much as co-opt it to create his own. To create the Tychonic system, Tycho transformed the Copernican models back into an Earth-centered system.[48] In the Tychonic system the Earth is not a planet, and lies at the center of the cosmos. All of the planets revolve around the Sun, while at the same time the Sun revolves around the Earth.
		Tychonic system: zoom intersecting orbs ou-hsci/Brahe-1648-97	In the Tychonic system, the sphere of Mars intersects the sphere of the Sun. For this reason, the Tychonic system was not an option for Copernicus or anyone who believed in solid celestial spheres.
			Tycho, Kepler, and others of their generation determined that comets move above the Moon and pass through multiple spheres.
		Beati: fluid heavens section ou-hsci/Beati-1662-104pl	For this and other reasons, the ancient solid spheres melted. No longer were planets carried by giant transparent spheres. Rather, planets would swim through fluid heavens as fish swim through the sea.
		ou-hsci/Brahe-1648-97 Fade into Riccioli fp ou-hsci/Riccioli-1651-0fp	So long as one no longer insisted upon solid spheres, the Tychonic system provided all of the mathematical elegance of the Copernican system, with none of its physical inconveniences. For us today, with 20/20 hindsight, the Tychonic system may seem like an unstable compromise between Ptolemy and Copernicus. At the time it was the golden mean which avoided speculative extremes, and it became the most widely adopted system at the turn of the 17th century.

48. In this Tycho was greatly assisted (perhaps unwillingly) by Paul Wittich, a traveling astronomer who visited Hven.

01:01	01	Johann Kepler	Musical transition
01:01	10	Maestlin. show/Tuebingen ou-hsci/Maestlin-1610-000tp	At the University of Tübingen, one Lutheran endorsed the Copernican system as physically true. The articulate Professor of Astronomy, Michael Maestlin, defended Copernicus with thoroughness, insight and understanding that left a lasting impression on students like Johann Kepler.
		Kepler portrait: ou-hsci/Kepler-furrobe ou-hsci/Kepler-1596-0tp	In 1596, exactly 100 years after Regiomontanus' Epitome of Ptolemy's Almagest, Kepler published his first book, the Mysterium Cosmographicum, or Sacred Mystery of the Structure of the Cosmos. The Mysterium Cosmographicum was the most important published defense of the physical truth of the Copernican cosmos by an accomplished mathematician in the 16th century.
		Title page phrases ou-hsci/Kepler-1596-0tp	Kepler addressed two major objections to Copernicus and turned them both to Copernicus' advantage. These objections concerned the number of the planets and the sizes of the planetary spheres.
		Cosmic section closeup on Moon ou-hsci/Copernicus-1543-section	First, the number: in the Ptolemaic system there were 7 planets, including the Sun and the Moon. In the Copernican system, there are only six planets. The Sun and the Earth switch places. The number of planets decreases by one, because the Moon is demoted; it becomes a satellite of the Earth rather than a planet. So Kepler asked, why should there be only six planets instead of seven?
		Kepler distance diagram ou-hsci/Kepler-1596-48-pl4	Second, the distances of the planets: In the Ptolemaic system all the planetary spheres nest together with no intervening spaces. In the Copernican system, the spheres of the planets became thin, separated by large distances. So Kepler was asked, why would the Creator have wasted so much empty space?
		Solids montage ou-hsci/Kepler-1596-24	Kepler answered these two questions and proved Copernicanism using the five regular solids of the Pythagoreans. In a regular solid, every face is identical, whether a square on every side of a cube, or a triangle on every side of a tetrahedron.
		Individual solids ou-hsci/ Paccioli-1509-tetra-II Paccioli-1509-cube-VIII Paccioli-1509-oct-XVI Paccioli-1509-dodec-XXVIII Paccioli-1509-icos-XXII	The Pythagoreans proved that there are only five regular solids: The tetrahedron, with 4 sides; Cube, with 6 sides; Octahedron, 8 sides; Dodecahedron, 12 sides; and Icosahedron, 20 sides.
		Solids montage ou-hsci/Kepler-1596-24	There are no others. After Plato, astronomers supposed that the geometry of these five solids would hold an essential clue to the true structure of the universe.

		Kepler blueprints ou-hsci/Kepler-1596-24	For Kepler, the mystery of the universe was now revealed, because the Divine Architect knew Pythagorean geometry and used it to construct a Copernican universe! Instead of nesting one planetary sphere immediately after another, in the ideal blueprints of the cosmos, the Creator alternated planetary spheres with regular solids. Kepler calculated the planetary distances according to Copernicus, and found that the gaps between each planet correspond to the geometry of the solids, using each solid only once. Moreover, the solids explain the number of the planets, for the six planets of Copernicus enclose five gaps. The Ptolemaic system, with 7 planets, would require 6 gaps, but the Pythagoreans demonstrated that there are only 5 solids!
		ou-hsci/Kepler-furrobe	Kepler mailed copies to various scholars, including Galileo. Galileo was not persuaded by what seemed to him to be the work of a Lutheran mystic, but he wrote back to Kepler that he had already been a Copernican for several years.
		Astronomia nova tp: ou-hsci/Kepler-1609-tp Kepler ellipses: show/Kepler1 Kepler equal areas: show/Kepler2	Ironically, Kepler defended Copernicus in ways that Copernicus would never have approved. Copernicus based his system on a strict enforcement of the principle of uniform circular motion, but Kepler employed motion that was neither circular nor uniform. In the aptly named Astronomia nova, or New Astronomy, Kepler put forward what are now regarded as his first two laws: planets move in ellipses rather than in circles, and instead of moving in uniform motion as seen from the center, they sweep out equal areas in equal times. In effect, Kepler re-introduced what Copernicus denied, for Ptolemy's equant point worked very much like the empty focus of Kepler's ellipse.[49]
		Kepler tables: ou-hsci/Kepler-1627-tp	In the Rudolphine Tables, published in 1627, Kepler used his new laws and Tycho's observations to derive planetary positions. Just as the Prutenic Tables furthered the Wittenberg reception of Copernicus, so Kepler advanced his new astronomy with the Rudolphine tables.
1:05	56	Catholic reception	Musical transition
1:06	08	Gingerich map of readers misc/Gingerich-2004-147	In a magisterial survey of the readers of Copernicus, Harvard astronomer and historian Owen Gingerich shows that Lutherans were not the only sixteenth century astronomers sympathetic to Copernicus.[50]

49. Swerdlow and Neugebauer (p. 38): "The point E, called in the middle ages the 'equant point,' corresponds to the empty focus of the ellipse in Kepler's model for planetary motion.... Ptolemy's model, in both direction and distance, was the best earlier approximation to Kepler's first two laws of planetary motion."

50. See Gingerich, *Census*. A very interesting account of the writing of the *Census* is *The Book Nobody Read* (see Further Reading). The following account of Offusius relies entirely upon Gingerich's analysis; see Gingerich, *Book Nobody Read*, ch. 11.

		Oklahoma annotations. various pages ou-hsci/Copernicus-1543-046v; 097v; 127r; 127v; 179r, etc.	For example, within only a decade of its publication, Jofrancus Offusius annotated his copy of the De revolutionibus. Offusius taught a circle of astronomers in Paris who disseminated his comments in the margins of eight surviving copies. This is the copy of De revolutionibus that enabled Professor Gingerich to identify the teacher as Johannes Franciscus Offusius Vesalius. Vesalius refers to his hometown of Wesel, a village on the Rhine river near the Dutch-German border.
			Thus the De revolutionibus was far from a book that nobody read. Even in Catholic territories, astronomers subjected it to serious technical study. Offusius and his students admired the accomplishments of Copernicus in much the same way as their Lutheran counterparts in Wittenberg. That is, Offusius praised the elegance of Copernican models, but was not fully persuaded that they were physically true.
		ou-roller/CopernicusPortrait	When the Counter-Reformation began in earnest after the Council of Trent, the Catholic reception of Copernicus became immensely complicated by the desire to avoid unsanctioned novelties. A Catholic astronomer once hailed by cardinals and popes now became suspect, associated with northern heretics.
		Galilleo portrait: ou-hsci/Galileo-portrait-Ballaguy ou-hsci/Galileo-1610-001r Orion page: ou-hsci/Galileo-1610-pleiades	Galileo bided his time, waiting for the right opportunity to defend Copernicus publicly. That moment came in 1610 with the announcement of his sensational telescopic discoveries, published in the Sidereus nuncius, or Starry Messenger. With the telescope Galileo discovered vast numbers of unsuspected stars. On this page he shows the familiar 9 stars in the belt and sword of Orion surrounded by 80 new stars.[51] Most significantly, even the familiar bright stars appear as small points of light, not as enlarged globes like the planets. Therefore all stars may be much farther away than was previously believed. With this confirmation that the stars are indeed farther away than was thought, Galileo refuted the absence of observable stellar parallax as a valid objection to Copernicanism.

51. Swerdlow, Galileo, p. 251.

		Jupiter pages ou-hsci/Galileo-1610-022v ou-hsci/Galileo-1610-024v	Galileo also discovered four satellites revolving around Jupiter, printing more than 60 observations of their positions from night to night. These satellites removed an anomaly in the Copernican system, for why should the Earth have its own Moon unlike any of the other planets? The satellites of Jupiter proved that multiple centers of revolution exist in the solar system. The satellites also proved, contrary to the argument of Aristotelian physicists, that a moving planet would not leave its Moon behind. Jupiter was a miniature Copernican system set in the sky to persuade Catholics not to abandon their own astronomer.
		Cop corrections: ou-hsci/Copernicus-28	Nevertheless, in 1616 Galileo was instructed to hold to Copernicanism only hypothetically, and the De revolutionibus of Copernicus was put on the Index of Prohibited Books until it could be corrected. Four years later, a total of ten corrections were issued, which Catholic readers at the time wrote into their copies of the book. In this example, where Copernicus presented a "Demonstration of the triple motion of the Earth," the censors corrected it to "Demonstration of the hypothesis of the triple motion of the Earth."
1:09	55	8. What was the Copernican Revolution?	
01:10	05	ou-hsci/Galileo-portrait-Ballaguy Galileo Discorsi: ou-hsci/Galileo-1638-0tp	The Copernican idea that the Earth moves as a planet sparked a revolution in physics. Widespread adoption of the Copernican system required a thorough revision of physics, which Galileo completed in his Discorsi, published 80 years after Copernicus' De revolutionibus.
		Newton portrait: ou-hsci/Newton-LPC-Vanderbank ou-hsci/Newton-1687-12	Once Newton unified the terrestrial physics of Galileo with the celestial mechanics of Kepler's laws, Copernicus became a symbol of a Scientific Revolution, a complete overthrow of Aristotelian physics and cosmology.
		Aberration, Bradley: ou-hsci/PhilTrans-1729-n406-637	Still, direct observational proof of the motion of the Earth was hard to find. The first direct evidence of the annual revolution of the Earth came in 1725, when James Bradley detected stellar aberration, a shifting of light from distant stars.
		Parallax, Bessel: show/stellarparallax ou-hsci/Bessel-1875-000fp	Stellar parallax was not confirmed until 1827, when Wilhelm Bessel found a shift in the position of double star 61 Cygni.
		Foucault article: ou-hsci/ComptesRendus-1851-135	The Foucault pendulum swings in a constant direction, and thus reveals the rotation of the Earth turning underneath. Yet the Foucault pendulum was not conceived until 1851, three centuries after Copernicus.

		Ramelli waterwheel ou-hsci/Ramelli-1588-166-fig107	Revolutionaries do not always intend their own revolutions. Even the word "revolution" contains ambiguities: a revolution may refer to one complete turn of a wheel, a significant repetition, as Copernicus described the "revolutions" of the celestial spheres. In this sense, Copernicus' contemporaries regarded him as one who restored a tradition rather than defying or overthrowing it. In contrast to his physics, in many ways the astronomy of Copernicus was not revolutionary.
		Copernicus cosmic section vs. Beati fluid heavens	Copernicus defended the ancient notion of solid spheres, in contrast to the fluid heavens of later astronomers. Tycho and Kepler, not Copernicus, melted the cosmic spheres.
		Copernicus cosmic section vs. Descartes vortices	Copernicus envisioned a hierarchical cosmos, unlike the endless vortices of Descartes.
		Copernicus cosmic section vs. Kepler's ellipses	The geometric devices of Copernicus remained the circles, deferents, epicycles, and eccentrics of the ancient astronomers. Kepler with his ellipses, not Copernicus, broke away from the hold of the fundamental axiom of ancient astronomy, that the heavens move only with combinations of circular motions.
		Copernicus cosmic section vs. Kepler's equal areas	While Copernicus rejected Ptolemy's equant because it compromised the ancient ideal of uniform circular motion, Kepler reintroduced non-uniform motion with his equal-areas law.
		Tycho quadrant ou-hsci/Brahe-1602-opB1	Copernicus achieved renown as a mathematician rather than an observer, in contrast to contemporary Wittenberg astronomers. Tycho Brahe, the greatest observer of the century, rejected the Copernican cosmos.
		Galileo's image of Orion ou-hsci/Galileo-1610-pleiades	And Copernicus died nearly sixty years before Galileo trained the telescope on the circling moons of Jupiter and the distant stars of Orion.
		Fade to stars	In many ways these post-Copernican achievements were more revolutionary than the De Revolutionibus.
01:13	29	**9. Epilogue: The Legacy of Copernicus**	
01:13	40	Portraits: ou-hsci/... Copernicus-SPC-1541 Darwin-Berlin-LPC Freud-1922-ft	It is often said that three revolutions created the modern world: first, Copernicus removed humanity from the center of the universe. Second, Darwin removed humans from their special dignity above the animals. Finally, Freud removed Reason from its throne as governor of the human psyche.
01:14	02	•Star projector fade on •Video projector fade off Taurus starfield	Yet it was not Copernicus who created the modern cosmos. C.S. Lewis contrasted earlier and modern conceptions of the universe:

01:14	13	•Diurnal motion on slowly Lewis voice Semi-transparent rose window superimposed upon stars	"Pascal's terror at [the eternal silence of infinite space] never entered [the mind of Dante. Dante was] like a man being conducted through an immense cathedral, not like one lost in a shoreless sea."
01:14	25		"To look out on the night sky with modern eyes is like looking out over a sea that fades away into mist...
01:14	32	•Video projector fade on •Diurnal motion off (keep stars on through credits) Semi-transparent rose window superimposed upon stars, Gregorian tones	To look up at the towering medieval universe is much more like looking at a great building. The 'space' of modern astronomy may arouse terror, or bewilderment or vague reverie; the spheres of the old present us with an object in which the mind can rest, overwhelming in its greatness but satisfying in its harmony."[52]
01:14	51	•Video projector fade off Taurus starfield	Looking up toward the stars from the cathedral at Frauenburg, contemplating the harmony of the revolutions of the solid celestial spheres, Copernicus may have been closer to Dante than to Pascal.
01:15	03		Yet great turning points are sometimes recognized only with hindsight.
01:15	10	•Video projector fade on Copernican Principle: "Nothing is special."	Many astronomers believe the ultimate significance of Copernicus lay in showing that nothing is special about our view of the universe; they regard our location in the cosmos as unremarkable, a random point in space and time, and attribute this idea to Copernicus.
01:15	27	•Video projector off Taurus starfield	But this Copernican Principle was not proposed by Copernicus or early Copernicans.
01:15	34	•Video projector on Triangulation, moving platform: show/Cop-VenusMercury2 show/Cop-VenusMercury3	Rather, they claimed that riding on a moving platform enables us to see farther and more clearly. The wonderful symmetry of the universe, the order and distances of the planets, the harmony of planetary motions, all would remain unmeasured and forever unknown were we never to escape the center. The moving Earth therefore occupies a privileged position, as Kepler explained:

52. C. S. Lewis, *The Discarded Image: An Introduction to Medieval and Renaissance Literature* (Cambridge: Cambridge University Press, 1994), p. 99-100.

01:16	02	Kepler portrait	“In the interest of that contemplation for which man was created, and adorned and equipped with eyes, he could not remain at rest in the center. On the contrary, he must make an annual journey on this boat, which is our Earth, to perform his observations.... We humans who inhabit the Earth can with good reason, in my view, feel proud of the pre-eminent lodging place of our bodies, and we should be thankful to God the Creator... ”
		Back to triangulation: show/Cop-VenusMercury3	For Copernicus as for Kepler, it was only because the Earth had escaped from the center, that those planetary measurements necessary for the perfection of astronomy might be attained. The Earth’s motion made it possible to solve the riddle of the planetary motions.
		Authentic Copernican Principle: “The cosmos is made for scence.”	Perhaps it is ironic that Copernicus would scarcely recognize the principle that now bears his name. For Copernicus, the cosmos is made for science. We are not the center of the universe, but we are special because we move.
01:17	01	NASA/earth	We sail through the heavens on a ship whose course is set for discovery. That journey of discovery still lies before us. Heirs of the revolutions of Copernicus, we remain voyagers in the starry night.
01:17	27	Credits: Speakers credits/written •Star projector: slowly fade off credits/voices	Written & Produced by Kerry Magruder Narrator: Candace Magruder Copernicus: Kerry Magruder Cardinal Schönberg: Phil Kemp Andreas Osiander: J Harvey C. S. Lewis: Phil Kemp Johann Kepler: J Harvey
01:17		credits/ou-hsci credits/ou-roller credits/photography credits/thanks credits/thanks2 credits/cc credits/acls Creative Commons license: credits/distribution •Room lights: slowly fade on	Book Images courtesy History of Science Collections, University of Oklahoma Libraries Photographs and travel slides courtesy Duane H.D. Roller Archive, History of Science Collections, University of Oklahoma Libraries Digital photography by Hannah Magruder Soundtrack by Eric Barfield Special thanks to... Peter Barker, Bernie Goldstein, Katherine Tredwell, Dennis Danielson, Mike Keas JoAnn Palmeri, Hannah Magruder, Rachel Magruder, Susanna Magruder, Candace Magruder. The Cosmology and Cultures Project of the OBU Planetarium
01:1	20	End	

5. After the Show

A. Theater Activities

1. Stellar parallax activity (coming soon)
2. Compare Orion and Pleiades unaided eye with Galileo's telescopic depictions (coming soon)

B. Lab or classroom activities

1. Copernican vs. Ptolemaic explanation of retrograde motion
2. Kepler's diagrams of Copernican planetary distances
3. Observe Jupiter's satellites through a telescope. Compare with Galilean positions.
4. Compare Orion and Pleiades in star atlases with Galileo's telescopic depictions.
5. Foucault pendulum activity.
6. The Paper Plate Astronomy website by Chuck Bueter, sponsored by the Great Lakes Planetarium Association, includes several relevant activities: *http://analyzer.depaul.edu/paperplate/activities.htm*.
    - "Geocentric vs. Heliocentric": Make a moveable model that compares features of two systems. *http://analyzer.depaul.edu/paperplate/Geocentric%20vs%20Heliocentric.htm*
    - "Retrograde Motion": Show how planets appear to loop westward against background stars. *http://analyzer.depaul.edu/paperplate/Retrograde%20Motion.htm*
    - "Ptolemaic Polemic": Make Ptolemaic models with equants, epicycles, and deferents to explain retrograde motion. *http://analyzer.depaul.edu/paperplate/Ptolemaic%20Polemic.htm*

C. Discussion Questions

1. How did the story of Regiomontanus (and to some extent, Copernicus) exemplify characteristic themes of the Renaissance (humanism, hermeticism, printing, etc.)?

2. What was the importance of the Printing Revolution for the *De Revolutionibus*?

3. How did the Reformation affect Copernicus and his work?

4. How did the Counter-Reformation affect the reception of Copernicus?

5. Evaluate the following explanations for the superiority of Copernicanism:
    - The Ptolemaic system was unable accurately to predict the positions of the planets.
    - The Ptolemaic system had no explanation of retrograde motion.
    - Copernicanism was simpler; the Ptolemaic system was monstrously complex.

6. It is often said that Copernicus only proposed his system as a *hypothesis* to "save the phenomena," and did not believe it was physically real. Discuss the historical evidence pertinent to this claim.

7. It is often said that by removing the Earth from the center of the universe, Copernicanism rejected the anthropocentric orientation of the medieval cosmos. Discuss the historical evidence pertinent to this claim.

8. It is often said that Copernicus refrained from publishing his views until his death because of fear of suppression by the Roman Catholic Church. Discuss the historical evidence pertinent to this claim.

9. Thomas Kuhn, in *The Structure of Scientific Revolutions*, described a revolution as taking place when a sufficient number of unsolved puzzles or "anomalies" accumulate into "crisis" proportions, prompting a "paradigm shift" in which investigators adopt a different and "incommensurable" point of view that resolves the crisis. How suitable is this description for the 16th century development and reception of Copernicus' *De Revolutionibus*?

10. The “Copernican Principle” is described in the script as holding that “The position of the Earth is unremarkable, a random point in space and time.” Sometimes this principle is also called the “Principle of Mediocrity.” Explain the historical origin of this idea. A more historically authentic re-definition of an alternative “Copernican Principle” is proposed in the script as “The cosmos is made for science.” Why is this alternative principle more appropriately attributed to Copernicus than the usual definition?

11. *Given the evidence in 1615, which system of the world had at that time the strongest claim for acceptance?* Discuss. Michael J. Crowe comments that “it is an irony of current educational practice that whereas everyone believes the earth orbits the sun, few persons can cite the evidences that led to this conviction.”[53] Put yourself into a time machine and travel back to the year 1615, before Apollo missions to the moon or Space Shuttle astronauts in orbit became part of our cultural consciousness. This date even falls before Galileo's first encounter with the Inquisition. Appeals to events or discoveries occurring after 1615 would seem rather arbitrary and out of place. Obviously there is no “correct” answer to this sort of question.

53. Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution*, p. iv.

6. Further Reading

A. Background: The Renaissance Cosmos

This section of the show is indebted to a classic interpretation of medieval and Renaissance sensibilities about the cosmos, C. S. Lewis, *The Discarded Image: An Introduction to Medieval and Renaissance Literature* (Cambridge: Cambridge University Press, 1994). Many primary sources, accompanied by brief, judicious comments, may be found in Dennis R. Danielson, *The Book of the Cosmos* (Perseus Books Group, 2002). An introductory survey of mathematical astronomy from antiquity to Copernicus is Michael J. Crowe, *Theories of the World from Antiquity to the Copernican Revolution* (Dover Publications, 2001), which includes excerpts from Book I of Ptolemy's *Almagest*. A more advanced survey text is James Evans, *The History & Practice of Ancient Astronomy* (Oxford University Press, 1998), and the standard study is Otto Neugebauer, *History of Ancient Mathematical Astronomy* (Springer Verlag, 1975). The standard study of Renaissance scholastic cosmology is Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200-1687* (Cambridge: Cambridge University Press, 1996). A representative figure of the Islamic tradition that influenced Copernicus is introduced in Nasir Al-Din Muhammad Ibn Muhammad Tusi, and F. Jamil Ragep, *Nasir Al-Din Al-Tusi's Memoir on Astronomy* (Springer, 1993).

B. The De Revolutionibus

Owen Gingerich's personal account of his endeavor to examine every surviving copy of *De Revolutionibus* provides a very readable and delightful introduction to Copernicus and his era: Owen Gingerich, *The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus* (Walker & Company, 2004). The scholarly account is Owen Gingerich, *An Annotated Census of Copernicus' De Revolutionibus* (Brill Academic Publishers, 2002). For the text of Copernicus' *De Revolutionibus*, excerpts are available in the two works mentioned above by Crowe and Danielson. There is no widely acclaimed English translation of the complete work, but perhaps the best of those available is Nicholas Copernicus, *On the Revolutions* (Baltimore and London: The Johns Hopkins University Press, 1992). The standard study of Copernicus' mathematical astronomy is Noel M. Swerdlow, and Otto Neugebauer, *Mathematical Astronomy in Copernicus's De Revolutionibus* (Springer, 1984). The first part of this work is the best available biographical account of Copernicus.

C. Publishing the Revolutions

This section of the show is based on the recent scholarship of Peter Barker and Bernard Goldstein, particularly Peter Barker, and Bernard R. Goldstein, "Patronage and the Production of *De Revolutionibus,*" *Journal for the History of Astronomy,* 34 (2003): 345.. See also Dennis Danielson, "Achilles Gasser and the origins of Copernicanism," *Journal for the History of Astronomy*.

D. Reception of Copernicus

The 16th- and 17th-century reception of Copernicus is far too broad a topic to cover here, but one accessible starting point, with far more detail about Copernicanism in the Galileo affair, is Magruder, Kerry V., "The Works of Galileo: A Guided Tour." *http://hsci.cas.ou.edu/exhibits/exhibit.php?exbgrp=1*. See also Katherine Tredwell, “Early Copernicans,” *Journal for the History of Astronomy*.

7. Images

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