# THE SHAPE OF THE EARTH

Produced for the

Cosmology and Cultures Project

of the

OBU Planetarium

by

Kerry Magruder

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# Credits

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# 1. Contents

# 2. Introduction

## A. Summary

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| Length | 47 minutes |
| Presentation mode | May be presented in either of two ways:<br>1. Self-contained DVD presented on a TV or data projector, or<br>2. Planetarium show using star projector and video projector, with optional whole-dome effects |
| Audience | General undergraduate |
| Classes | History of Science; Astronomy |
| Periods | Ancient, Medieval, Early Modern |
| Observational emphases | How to find the Big Dipper and Polaris<br>How the stars move each day (diurnal motion)<br>How circumpolar stars change when traveling north or south<br>How to use the Big Dipper as a star clock<br>How the shadow of the Earth on the Moon appears during a lunar eclipse<br>What causes the seasons?<br>Why do we need time zones? |
| Constellations | Ursa Minor, Polaris<br>Ursa Major, Big Dipper |
| Astronomical Terms | Diurnal motion<br>Circumpolar stars<br>Ecliptic, Celestial equator<br>International Date Line<br>Circumference of the Earth |
| Other Topics | Historiography |
| Dome special effects | None required. Optional SFX projectors include:<br>1. Fog<br>2. Ursa Major constellation figure<br>3. Big Dipper outline<br>4. Celestial equator<br>5. Meridian or altitude grid<br>6. North pole arrow |
| Reviewers | Jeffrey Burton Russell<br>Mike Keas<br>JoAnn Palmeri<br>Katherine Tredwell<br>(Special thanks to these historians who reviewed the content of the show; all mistakes that remain are the sole responsibility of Kerry Magruder.) |

## B. Synopsis

1. Introduction
   Students in an astronomy class meet Nicole Oresme, a medieval physicist, and begin a journey through time.

2. Shape of the Earth in Greek Antiquity
   Presentation of the chief arguments for the sphericity of the Earth from the Pythagoreans, Plato, Aristotle, and later Greek astronomers.

3. Ancient Rome

4. Middle Ages
   Emphasis upon Oresme's paradoxes about the shape of the Earth.

5. Columbus and the Myth of the Flat Earth

6. Epilogue

## C. Instructor Notes

For introductory observational astronomy courses, this show provides an overview of some very basic sky phenomena (see "observational emphases" and "astronomical terms," previous page).

For history of science courses, this show can be used at the beginning of the semester to encourage students to critically evaluate their own preconceptions and biases about premodern history. It is also appropriate for a medieval science unit.

The narrative strategy of the show features a fictional dialogue with the historical figure Nicole Oresme, by all accounts one of the greatest scientists of the 14th century. Oresme is most often cited for his development of a graphical representation of the Mean Speed Theorem, an antecedent of Galileo's law of free fall, but he contributed to many other areas of inquiry as well. Oresme probably obtained his bachelor of liberal arts at the University of Paris in the 1340's under the equally-renowned Jean Buridan. By 1348 Oresme was studying theology at the University of Paris in the College of Navarre, where he received a masters in theology in 1355. In 1356 he became master of the College. In 1377, King Charles V of France made him Bishop of Lisieux. Oresme died in 1382. Based largely on a vernacular work Oresme composed for Charles V, the show tries to capture something of the whimsical love of paradoxes that is characteristic of Oresme and many other 14th-century scientists.

"The Shape of the Earth" presents many kinds of evidence for the sphericity of the globe. The show is organized chronologically, so it may help to have a more systematic outline of these various kinds of evidence, as follows (all of which were known to Aristotle):

A. *Aesthetical evidence*: the sphere is the most beautiful shape.

B. *Astronomical evidence*:

1. If Flat: stars would rise and set simultaneously for all longitudes.
2. If Concave: rising stars would be seen first at western latitudes.
3. East-West convexity: the same lunar eclipse observed in different locations, but not at same local times.
4. North-South convexity: circumpolar stars not the same for all; new stars appear if travel north or south.
5. 3D sphere: Earth's shadow always curved during lunar eclipse.
6. Macrocosm-microcosm analogy: Circumpolar stars (and rising and settings of other stars) suggest that the universe is spherical.

C. *Terrestrial evidence*: Ships "hull down." Terrestrial landmarks seen first from the mast.

D. *Theoretical evidence*: According to gravity, earthy objects tend on all sides toward the center.

# 3. Before the Show

## A. Video: A Private Universe

The show mentions two phenomena whose causes are often misunderstood: lunar phases and the seasons. Lunar phases are not caused by the Earth's shadow upon the Moon (that's a lunar eclipse) but by how much of the Moon's illuminated side is turned toward the Earth. And the seasons are not caused by how close the Earth is to the Sun, but by the tilt between the celestial equator (determined by the apparent daily rotation of the stars) and the ecliptic (the apparent annual path of the Sun).

Because these phenomena and their causes are pointed out, but not carefully explained in the show, an ideal pre-show lesson plan would ensure that students thoroughly understand these concepts before they view the show. Although medieval students understood these causes, in contrast, some years ago a justly-acclaimed documentary film, "A Private Universe," demonstrated that most seniors standing in a commencement line at Harvard could not explain them correctly. Watching this highly-recommended film is a superb way to heighten undergraduate student attentiveness to in-class modeling of the lunar phases and the seasons.

For lesson plans elucidating these concepts see the website, "Teachers' Lab: A Private Universe Project," *http://www.learner.org/teacherslab/pup/*. Order the 20-minute "Private Universe" video at *http://www.learner.org/catalog/series28.html*.

For a lunar phase modeling exercise targeted at the undergraduate level, see the "Lunar Cycle Lab" at *http://homepage.mac.com/kvmagruder/bcp/zodiacal/moon/lab.htm* (answer key at *http://homepage.mac.com/kvmagruder/bcp/zodiacal/moon/labkey.htm*), and the Lunar Cycle home page at *http://homepage.mac.com/kvmagruder/bcp/zodiacal/moon/index.htm*.

Engaging, easy-to-do activities for learning about lunar eclipses and the seasons are included in the Paper Plate Astronomy website of Chuck Bueter, sponsored by the Great Lakes Planetarium Association: *http://analyzer.depaul.edu/paperplate/activities.htm*. See:

1. Lunar eclipse simulator, showing the curved shadow of a 3D globe upon the Moon: *http://analyzer.depaul.edu/paperplate/Lunar%20Eclipse.htm*
2. The Seasons: *http://analyzer.depaul.edu/paperplate/Seasons.htm*

## B. Pre-Test

For each question, circle "T" or "F" to complete this true-false quiz prior to viewing the show. After the show, you will grade your own quiz to provide a springboard for discussion.

1. T or F? Ancient Greeks from Plato to Aristotle to Ptolemy thought the Earth is flat.
2. T or F? The Pythagoreans argued that the Earth is a sphere because the sphere is the most beautiful shape.
3. T or F? The Pythagoreans argued that the Earth is a sphere because of an analogy between the macrocosm (universe) and microcosm (Earth).
4. T or F? Aristotle's theory of gravity required the Earth to be flat.
5. T or F? Lunar eclipses prove that the Earth is a sphere.
6. T or F? Roman writers such as Cicero and Pliny believed the Earth is flat.
7. T or F? Catholic theologians such as Augustine and Aquinas believed the Earth is flat.
8. T or F? Belief in a spherical Earth was considered heresy by popes in the middle ages.
9. T or F? Medieval natural philosophers such as William of Ockham and Nicole Oresme believed the Earth is flat.
10. T or F? Columbus argued that he could sail around the world against Spanish Inquisitors who thought the Earth was flat.
11. T or F? Circumpolar stars may dip below the horizon as they make their daily circle around the north star.
12. T or F? The ancient Librarian of Alexandria, Eratosthenes, accurately determined the circumference of the Earth.
13. T or F? The necessity for the International Date Line was not recognized until the journeys of Columbus and later voyagers.
14. T or F? Stars appear to rise in the east, turn overhead, and set in the west just as if they were fixed to the inside of a giant celestial sphere.
15. T or F? Fixed stars appear to move in circles around the Earth at a constant distance from the north pole or from the celestial equator.
16. T or F? Belief in a spherical Earth was suppressed by kings in the middle ages.
17. T or F? The existence of time zones confirms that the surface of the Earth is curved from east to west.
18. T or F? The change of visible circumpolar stars confirms that the surface of the Earth is curved from north to south.
19. T or F? Medieval writers of literature such as Dante and Chaucer believed the Earth is flat.

# 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.
    - 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.)
    - 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 non-bulleted items when programming theater automation.

4. Footnotes in the script are of three types:
    - numbered citations or pedagogical notes for the Narration column,[1]
    - alphabetical notes with production tips for the Audio-Visuals column,[a] and
    - image credit information for images in the Audio-Visuals column,[*] as needed.

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1. 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.

## B. Theater Preparation

1. Prepare constellation figures for Ursa Major and the Big Dipper.
2. During several transitions between different eras, as the students are traveling through time, the script calls for a Fog SFX projector. If you do not have a fog SFX, use any whole-dome effect that creates an atmospheric mood (e.g., clouds, warp effect, meteors).
3. Prepare the star projector to move to latitudes as needed. Athens: 38° N. Paris: 49° N.
4. Start the show with the star projector off, and theater lights dimmed.

## C. Script

| Min | Sec | Audio-Visuals | Narration |
|---|---|---|---|
| 0 | 0 | intro/cc<br>•Star projector off<br>intro/acls | The Cosmology and Cultures Project of the OBU Planetarium, with a grant from the American Council of Learned Societies, presents |
| | | intro/title | The Shape of the Earth |
| Introduction | | | |
| 0 | 58 | Classroom scene: Flat-earth woodcut on overhead<br>show/classroom<br>ou-hsci/Flammarion | Professor (idiot voice):<br>In today's lecture, we will learn about the Dark Ages, when people thought the Earth was flat. Here we have a medieval woodcut showing a bishop trying to reach the stars by traveling across a flat Earth.... |
| 1 | 14 | •Swirling fog on | |
| | | Library scene, with desk<br>show/CosmicZone | Student: Where are we? |
| | | | Student Dimbulb: This looks like a haunted house! |
| 1 | 30 | •Swirling fog off | Student : No, it's a Library... look at all the old books! |
| | | | Student: How did we get here? |
| | | | Oresme: Bonjour! I'm the one who brought you here. And yes, you're in the Otherworldly Library of the History of Science. The books and scientists in this place live in a special time dimension, called the Cosmic History Zone. |
| | | | Students: Who are you? |
| | | Book closeup<br>show/book-on-desk | Oresme: Who am I? Don't you know me? I'm the famous author of the book you can see right there on the desk! |
| | | | Student: What? Le livre du Ciel et du monde? |
| | | | Oresme: Hey, you can read medieval French! Great! For the rest of you, it means The Book of the Heavens and the Earth. It was a best-seller in its time. |

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| | | | Student Dimbulb: How come I've never heard of it? |
| | | Printing press<br>show/CosmicZone<br><br><br><br>Portrait of Galileo<br>ou-hsci/Galileo-portrait | Oresme: You haven't heard of it? Ach! Maybe that's because I wrote before Gutenberg invented the printing press in 1454. But even before printing, lots of people copied my manuscript. It circulated widely, and made me famous. It's not a technical work like the disputations I wrote as a professor. This book was for Charles V, King of France. He and all the nobles in his court found it greatly entertaining. Even after Gutenberg, people like Copernicus and Galileo still read it. I bet you've heard of them! |
| | | | Student: When did you live? |
| | | show/razor<br>razor with Ockham label | Oresme: I lived in the 1300's, the 14th century. You may have heard of some of my friends. Do you know about Ockham's Razor? |
| | | | Student Dimbulb: A razor? When were they invented? I thought you old guys always wore beards. |
| | | | Other students (unison): Doh! |
| | | | Oresme: You're right about one thing: in my day at the University of Paris, we had a rule: No beardless masters teaching on the bridge! We didn't want some young know-it-all like your flat-earth professor lording it over our students. |
| | | | Student: Isn't Ockham's Razor the idea of William Ockham, that we should reject unnecessary hypotheses? |
| | | | Oresme: Right! "It is vain to do with more what can be accomplished with less." Ockham also wrote about life on other worlds, impetus, and gravity. |
| | | | Student: Really? That doesn't sound like the Dark Ages. |
| | | Cathedral interior<br><br>Illuminated mss<br>ou-hsci/Crescenzi-1471-01 | Oresme: Of course not! Ours was an age when cathedrals transformed stone into light, we held public disputations to determine the truth, and we wrote beautiful handwritten manuscripts. I call our time the Age of Illumination!<br>How about my friend Jean Buridan? Have you heard of Buridan's Ass? |
| | | MariaEvans/† | Students (unison): Buridan's WHAT? |

†- Images of Mel the mule are provided by Maria Evans.

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| | | MariaEvans/ | Oresme: Jean Buridan, a great logician, had a donkey. Because that donkey was taught by such a master, it became really smart. One day Buridan grew careless, and left the donkey exactly half-way between two identical stacks of hay. Naturally, the very logical donkey starved to death, because there was no sufficient reason to choose one haystack over the other... |
| | | | Student Dimbulb: Is that for real? |
| | | show/CosmicZone<br>book on table again<br><br>show/Oresme | Students: Ugh!<br>You're weird!<br>So what is your name?<br>There it is, on the book: Nicole Ore-eez-may. |
| | | text: Oresme and Orême<br>show/Oreme | Oresme: No, you're saying it wrong; the "s" is silent. In your modern French they add a circumflex accent over the "e" to show that an "s" has been dropped, like this: Nicole Oreme. |
| | | show/CosmicZone | Students: Nicole Oreme. [unison]<br>Student: Alright, now we know who you are, but why did you bring us here? |
| | | | Oresme: Are you complaining that I saved you from that dry and boring lecture? Besides, your professor didn't know what he was talking about, so you should thank me for setting you straight. |
| | | | Student: What do you mean? |
| | | Flat earth woodcut again<br>ou-hsci/Flammarion | Oresme: Remember, he was starting to tell you that people in the Middle Ages thought the Earth was flat. |
| | | | Student: What's wrong with that? |
| | | show/CosmicZone | Oresme: AHH! What do they teach in schools nowadays? Hmm, this is going to be harder than I thought. I think I need to take you on a little journey... a trip of time travel... |
| 5 | 25 | •Swirling fog on | |
| Shape of the Earth in Greek Antiquity | | | |
| 5 | 28 | ou-roller/parthenon | |
| | | | Student: Hey, where are we now? |
| 5 | 38 | •Swirling fog off | Student Dimbulb: Seems vaguely familiar; I think I've been here before. |
| | | | Student (sarcastic): No you haven't! This is the Parthenon, in Athens. We're in Greece! |
| | | | Student: Cool! |

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| | | ou-hsci/Cudworth-1678-0fp‡ | Oresme: Yes, ancient Greece is the first stop on our flat Earth tour! So far as we know, the Pythagoreans were the first to argue that the Earth is a sphere. |
| | | | Student: Why did they think that? |
| | | show/aesthetic | Oresme: They don't say. They're a secretive bunch, even up here in the Cosmic History Zone. But in part I think it was an aesthetic decision, because the sphere is the most beautiful shape. |
| | | show/ascetic<br>show/aesthetic | Students: What's an ascetic argument?<br>Not ascetic, it's aesthetic! Aesthetics is the study of beauty.<br>Like me. |
| | | ou-roller/parthenon | Oresme: And what is most beautiful must be true. |
| | | | Student Dimbulb: Wow... |
| | | ou-hsci/Sacrobosco-1534-B6r | Oresme: Then there's an argument from analogy: if the Earth is a miniature cosmos, or microcosm, then why shouldn't the Earth have the same shape as the cosmos? The Pythagoreans liked to draw correspondences between the macrocosm and the microcosm. |
| | | | Students: Hey, wait a minute!<br>Why did they think the cosmos was a sphere, anyway? |
| | | Big Dipper rotating<br>ou-hsci/Ptolemy-BearCircum | Oresme: Why, it's obvious, of course![2] The Big Dipper turns around the north pole once a day. Actually, all the stars trace circles around the sky, and come back to the same place every 24 hours. They look just like they're bright points of light embedded in a giant transparent sphere that rotates around us once a day. The sphere of fixed stars has a north pole, an axis, and an equator. Think of the Big Dipper as stuck on the inside of this giant turning sphere, and it's easy to tell time by the Big Dipper when you're outside at night. |
| 7 | 21 | •Star Projector: fade stars on<br>•Video projector fade out[b] | Students: I guess we spend our evenings indoors watching TV.<br>To tell time, I just look at my wristwatch.<br>I'd love to learn how to tell time by the Big Dipper! |

2. Oresme frequently has difficulty recasting his knowledge into modern terms. In places like this he often assumes a geocentric cosmos, because that is how the motions of the stars and planets actually appear.

(b) The script suggests one way to choreograph star projector effects for the following three minutes of the show. In many planetarium theaters some of the phenomena described, such as the rising and setting of a star in 12 hours, or its passing the meridian in 6 hours, would be dizzying to demonstrate with the star projector in rapid succession, so the video may be sufficient without starfield effects. However, in theaters that can easily switch between the video and the starfield, it's highly desirable to identify the Big Dipper and the north star on the

‡- On the frontispiece by Ralph Cudworth, Pythagoras is the middle figure on the left side.

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| 7 | 30 | | Student Dimbulb: What's the Big Dipper? |
| 7 | 39 | •Point out stars of bowl, then handle | Oresme: I can show you how to find the Big Dipper, and how to tell time by it. To find the Big Dipper, face north. Four stars make a bowl, and three stars make its handle. |
| 7 | 50 | •Ursa Major constellation figure | Oresme: The Big Dipper is part of the constellation Ursa Major or Big Bear, and the handle is the Bear's tail. |
| | | | Students: I didn't know bears had long tails!<br>He looks more like a squirrel than a bear. |
| 8 | 03 | •Ursa Major figure off<br>•Point out Dipper pointers and trace line to north star<br>•North pole arrow on | Oresme: These two stars on the pouring side of the bowl point to Polaris, the north star. All the stars in the sky appear to turn in circles around the north pole, just as if the stars were fixed to a giant transparent sphere. |
| | | | Student: So how can we tell time with the Big Dipper? |
| 8 | 20 | •Diurnal motion slow<br>•Turn on Celestial equator | Oresme: Every night stars rise in the east, move overhead, then set in the west. Every 24 hours, each star traces a circle at a constant distance from the the north pole. Stars on the celestial equator turn in a giant circle exactly between the north and south poles. |
| 8 | 41 | •Video projector fade on<br>•Turn off celestial equator<br>•Turn off North Pole arrow<br>show/diurnalDipper | Oresme: A star now rising on the equator will return to this same point in 24 hours.<br>In 12 hours, it will travel to the opposite side; instead of rising on this horizon it will be setting in the west.<br>In 6 hours, the star will go halfway to the other horizon, and be crossing a midline overhead. |
| 9 | 01 | ou-hsci/Ptolemy-BearCircum<br>show/diurnalDipper | Oresme: In the same way, a line from the pointer stars of the Big Dipper moves like the hand of a clock, turning counterclockwise around the north star. In 24 hours, the pointers will return to the orientation they have now.<br>In 12 hours, they will line up on the opposite side of the north star.<br>In 6 hours the pointer stars will make one quarter turn. |
| 9 | 26 | show/diurnalDipper | Oresme: Remember that any star goes all the way around the sky every 24 hours, then you can think it through. It just takes practice. |
| 9 | 35 | •Video projector fade off | Students: So that's how cowboys could tell when to change night watches out on the range.<br>Cool! |

planetarium dome, to project an Ursa Major constellation figure, and to demonstrate slow diurnal motion.

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| 9 | 40 | | Oresme: Later we can practice telling time by the stars some more, but now I want to show you evidence the ancient Greeks knew from astronomy that the Earth is a sphere. |
| 9 | 51 | | Students: OK.<br>Sounds fun! |
| | | | Student Dimbulb: This shouldn't take long. |
| 9 | 54 | •Video projector fade on<br>•Fade out stars<br>•Stop diurnal motion<br>ou-hsci/Apian-1540-sphericalEarth | Oresme: Here's an argument from Aristotle, one of his favorites.<br>In a lunar eclipse, the Sun, Earth and Moon are aligned. The Sun casts the Earth's shadow on the Moon. By the 4th century BC, lunar eclipse observations from Babylon went back several centuries. In every lunar eclipse, to observers located anywhere north or south, or in different locations east and west, the Earth's shadow on the Moon always appears curved.<br>If the Earth were flat or any shape other than a globe, at least some of those eclipse shadows would be straight or angular. The edge of the Earth is curved, no matter how the Earth's shadow is cast onto the Moon, from any angle as seen from north/south/east or west. Therefore the Earth must be a three-dimensional sphere.<br>We see its silhouette on the face of the Moon.[3] |
| | | | Students: That makes sense!<br>Aristotle was one smart dude!<br>Anyone can understand this. |
| | | | Student Dimbulb: Why didn't I think of that? |
| | | ou-hsci/Sacrobosco-ship-scene | Oresme: People didn't need to sail around the world to discover that the Earth is round. And even sailing across the Mediterranean Sea confirms the Earth is curved. |
| | | | Student: How's that? |
| | | ou-hsci/Sacrobosco-1550-B3r | Oresme: As a ship draws near to a harbor, the lookout at the top of the mast is the first to call out land-ho. At that time the hull of the ship is too far down in the water to see the shore. |
| | | | Student: I get it; because the Earth is round, the water rises up between the boat and the shore. |

3. Aristotle, *On the Heavens*, II.14.

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| | | ou-hsci/Ptolemy-1496-fp | Oresme: Let's fast forward to 150 AD, when Ptolemy wrote the greatest book of ancient astronomy, usually known from its Arabic title, Almagest, which means "The Greatest." In it Ptolemy listed some of the arguments for the sphericity of the Earth that persuaded earlier Greeks from Plato to Aristotle.[4] |
| | | | Student: Wait a minute. Ptolemy's Almagest—wasn't that the standard book on astronomy through the Middle Ages? |
| | | ou-hsci/Ptolemy-1549-Lt-50 | Student: Right! So, if Ptolemy shows without a doubt that the Earth is a sphere, then no one should say that in the Middle Ages they thought the Earth was flat! |
| | | | Student: Nobody afterward could ignore Ptolemy's arguments, if he really could prove the Earth is a sphere. |
| | | ou-hsci/Barozzi-1585-B3v (top left)<br><br>ou-hsci/Barozzi-1585-B3r | Oresme: Very good. I'm glad you recognize how important Ptolemy was. So let's list his arguments and see whether Ptolemy proved the shape of the Earth.<br>First, if the Earth were flat, stars would rise and set at the same moment regardless of where you are on the Earth.[5]<br>But in reality, if we see a star rising on our horizon, our friend who has traveled far west of here will not see that star rise until later. This means that the surface of the Earth between us is curved.<br>The same delay occurs for the Sun. By the time our friend to the west sees the sunrise, it may be mid-morning or later here. |
| | | | Students: I get it! If places on the Earth to which we can easily travel have different time zones, then the surface of the Earth is curved!<br>Say, wouldn't the reality of different time zones also apply to observations made at the same instant? So, if we watch a lunar eclipse at midnight tonight, and our friend sees the very same eclipse at the same moment, then our friend will say the eclipse happened at a different hour, perhaps at 10 o'clock his time. Right?[6] |

4. Ptolemy, *Almagest* Bk I, ch. 4.
5. Or if the surface of the Earth were concave, the western observer would see a star rise before the eastern observer.
6. Ptolemy cited the lunar eclipse of September 30, 331 B.C., which occurred 11 days before the battle of Arbela where Alexander the Great defeated the Persian king Darius III. Greek historians noted that the lunar eclipse occurred at the fifth hour in Arbela, but the same eclipse was observed three hours earlier (at the second hour, local time) in Carthage, farther west in northern Africa. The three-hour time difference reported by the Greek historians was erroneously inflated, but this lunar eclipse provided a famous example of the simultaneous observation of an event by in two different local time zones. See James Evans, *The History & Practice of Ancient*

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| | | | Oresme: Precisely. Simultaneous events occur at different hours, local time, in different places upon the Earth. This proves the Earth must be curved from east to west. |
| 13 | 30 | •Set star projector latitude to Athens, 38°N.<br>•Stars fade on | Student: OK, so the Earth isn't flat. But why couldn't it be a cylinder, curved only in one dimension, east to west. What proves that the Earth is curved from north to south? |
| 13 | 36 | •Video projector fade off<br>•Turn on altitude projector<br>•Turn on North pole arrow[c]<br>•Point out bowl of Big Dipper<br>•Move diurnal motion to show Big Dipper handle dipping below horizon.<br>show/dipperAthens | Oresme: Great question! The Big Dipper can help us find an answer. The four stars in the bowl of the Big Dipper are circumpolar; they circle around the pole without ever dipping below the horizon. Here in Athens we can see the four stars of the bowl travel their entire circle around the sky, although the tip of the handle dips below the horizon. |
| 13 | 54 | •Slowly move star projector latitude to Paris, 49°N.[7] Keep altitude projector, pole arrow, and stars on.<br>show/dipperParis | Oresme: But if we travel north to Paris, the pole rises higher in our sky and new circumpolar stars appear. From Paris, even the handle is circumpolar! If you think about it, the change in which stars are circumpolar proves that the Earth must be curved from north to south.[8] |
| 14 | 17 | •VIdeo projector fade on<br>•Fade off star projector<br>•Turn off altitude projector, pole arrow.<br>ou-hsci/Barozzi-1585-B4v | Students: And if the Earth is curved both north to south and east to west, then it must be a sphere!<br>Well, it must be curved on top, but I'm not sure that this proves it must be a sphere.<br>Why couldn't it be like a turtle, curved on top but flat on the bottom? |

*Astronomy* (Oxford University Press, 1998), p. 51.

7. Declinations: Tip of Big Dipper handle (Alkaid): 49° N. Lowest star of bowl: 54° N. A star will be circumpolar if the co-latitude plus the co-declination does not exceed 90. (90 - Latitude) + (90- Declination) < 90. Athens/Bowl: 52+36=88 (circumpolar). Athens/Alkaid: 52+41=93 (not circumpolar). Paris/Bowl: 41+36=77 (circumpolar). Paris/Alkaid: 41+41=82 (circumpolar).

8. The standard ancient example was Canopus, alpha-Carina, the second-brightest star in the sky, sometimes known as the "bright star of the Egyptians." Because of its location far south of the celestial equator, Canopus was visible in Egypt but not in Greece. See James Evans, *The History & Practice of Ancient Astronomy* (Oxford University Press, 1998), p. 48. The Big Dipper is used in the script because of its greater familiarity for northern inhabitants today.

(c) Project both the north pole arrow and the altitude grid to suggest the concept that the altitude of the north star is always equivalent to one's latitude on Earth. The north pole arrow will point to the current latitude on the altitude grid.

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| | | show/turtle<br><br>Lunar eclipse shadow<br>ou-hsci/Apian-1540-sphericalEarth<br><br>Converging lines toward center with spherical Earth<br>show/gravityLines | Oresme: The old turtle theory, eh? But don't forget Aristotle's argument from the Earth's shadow on the Moon. Lunar eclipses prove the far side of the Earth is curved.<br>But there's another argument Aristotle took not from astronomy, but from his physics. For Aristotle, all things strive toward their natural place. The natural place of earth is the center of the universe; earthy things are always striving to reach the center. This is Aristotle's explanation of gravity. Therefore, earth falls toward the center from all sides. Aristotle's physics of natural motion proves that the Earth must be spherical. |
| | | | Student: But our professor said that Aristotle didn't have Newton's theory of gravity, and that's why the ancients thought the Earth was flat. |
| 15 | 37 | | Oresme: Who does your professor think he is, anyway? Some kind of rocket scientist? Anyway, it's ridiculous to think that Aristotle's theory of gravity and a flat Earth could go together: Aristotle's theory of gravity by itself is enough to prove that the Earth is round! |
| 15<br><br><br><br>16 | 45<br><br><br><br>09 | Text on overhead<br>show/Gamow<br>ou-hsci/Flammarion<br><br><br><br>•Swirling fog on | Professor (idiot voice): "In the days when civilized men believed that the world was flat they had no reason to think about gravity. There was 'up' and 'down.' All material things tended naturally to move downward, or to fall, and no one thought to ask why. The notion of absolute up and down directions persisted into the Middle Ages, when it was still invoked to prove that the Earth could not be round."[9]<br>[Students snicker, cat-call, snore] |
| Ancient Rome | | | |
| 16 | 21 | LauraGibbs/Pantheon§ | |
| | | | Student: Whee, time traveling is fun! |
| | | | Student: Hey, where are we now? |
| | | | Student Dimbulb: Seems vaguely familiar; I think I've been here before. |
| 16 | 35 | •Swirling fog off | Student (sarcastic): No you haven't! This is the Pantheon, in Rome. |
| | | | Student: Cool! |

9. Astrophysicist George Gamow, "Gravity," *Scientific American*, March, 1961.

§- The photograph of the Pantheon is provided courtesy of Laura Gibbs.

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| | | LauraGibbs/Pantheon | Oresme: Once Plato and Aristotle argued that the Earth is a sphere, few Western Europeans found reason to disagree. In Latin literature, writers like my friend Cicero described the spherical Earth. |
| | | show/Cicero | Cicero: "Men were created with the understanding that they were to look after that sphere called Earth, which you see in the middle of the Temple [of the universe]."[10] |
| | | LauraGibbs/Pantheon | Oresme: A few Latin writers made a point of disputing the shape of the Earth, but they did so because they were skeptics and they wanted to make a philosophical point. If something as widely accepted as the sphericity of the Earth might turn out to be uncertain, then all knowledge about anything would be suspect. |
| | | | Student: Who were these writers? |
| | | show/Lactantius | Oresme: Some of these skeptics were Epicureans, a few were atomists, one was the theologian Lactantius, who just on principle rejected everything Greek. Lactantius was not influential in the early Church, and was even declared a heretic. Later on, in the Renaissance, he became more widely known when his style was admired by humanist scholars. But no one ever took him seriously on the shape of the Earth. |
| | | LauraGibbs/Pantheon | Students: But what about the Church?<br>Early Christian theologians were ignorant of the Greek arguments for the shape of the Earth, right?<br>Yes; didn't early theologians like Augustine teach the flat Earth? |
| | | ou-hsci/1489-Augustine-fp | Oresme: No, and No. The Church Fathers knew the Earth was round and did not teach otherwise. Augustine makes a good example, because in his commentary on the Literal Meaning of Genesis he made clear that the Earth is a globe.[11] |
| | | | Student: But Augustine denied the existence of the Antipodes. Didn't that mean he thought people on the other side of the Earth would fall off? |

10. Cicero, *Dream of Scipio*, in Macrobius, 142.
11. Augustine, *Literal Meaning of Genesis*, 30, 33: "At the time when it is night with us, the Sun is illuminating with its presence [other parts of the world....] For the whole 24 hours of the Sun's circuit there is always day in one place and night in another." "Although water still covered all the Earth, there was nothing to prevent the massive watery sphere from day on one side by the presence of light, and on the other side, night by the absence of light."

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| | | | Oresme: No. You're the victim of a bad English translation; if you learn Latin for yourself you won't fall for such tricks. Augustine, like many ancient geographers, believed that the equatorial zones were too hot to travel across. Therefore, if people do live in the antipodes, or southern hemisphere, then they're not part of the history recorded in the Bible. And in his book The City of God, that history and the unity of the human race were what mattered to him. Augustine didn't say that the Antipodes don't exist; rather, there's no way to get there from here.[12] |
| | | List of names<br>show/RomanWriters | Oresme: As with Cicero and Augustine, so it was with other well-known Latin writers from Pliny in the first century B.C., to Bede and Martianus Capella, to Macrobius around 400 A.D. These are not obscure authors like Lactantius. Don't you find it odd, then, that medievals are now said to have believed in a flat Earth? |
| 19 | 21 | LauraGibbs/Pantheon<br>•Swirling fog on | Students: All this contradicts what I learned in school.<br>I guess people in the past were smarter than we tend to think.<br>Yeah... |
| Middle Ages | | | |
| 19 | 31 | Notre Dame Cathedral backdrop | |
| | | ou-roller/notreDame | Students: The Cathedral of Notre Dame!<br>We know this one! |
| | | | Student Dimbulb: Where's the hunchback? |
| 19 | 44 | •Swirling fog off | Student: I really have been here before! This is one of my favorite places! |
| | | | Oresme: Mine, too. This is where I worked, as a professor at the University of Paris in the 1300s. |
| | | | Student: They had universities in the Dark Ages? |
| | | KerryMagruder/<br>DadCommencement | Oresme: The Middle Ages invented universities. That's why you'll wear a medieval cap and gown if you graduate. |
| | | | Student (sarcastic): That's a big if, Dimbulb! |

12. Augustine, *City of God*, Book 16, Chapter 9.

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| | | ou-hsci/Apian-1540-sphericalEarth<br>ou-hsci/Riccioli-1651-204c-phases | Oresme: All of our graduates back then knew how to prove that the Earth is round. And all of our students could explain what causes the phases of the Moon and the seasons.[13] |
| | | | Student Dimbulb: The phases are just the Earth's shadow on the Moon, right? |
| | | ou-hsci/Apian-1540-sphericalEarth<br>ou-hsci/Flammarion-1881-131-phases | Oresme: No, when the Earth casts its shadow upon the Moon, that's a lunar eclipse.<br>Lunar phases depend on how much of the near side of the Moon is illumined by the Sun.<br>Score one for medieval universities. |
| | | show/seasons1 | Student Dimbulb: OK, but the seasons are caused by the Earth moving closer to the Sun in summer, and farther away in winter, right? |
| 20<br><br><br><br><br>20 | 47<br><br><br><br><br>58 | show/seasons2<br>show/sphere2-ecliptic<br>•Turn on Ecliptic/Equator; turn off video projector; point to intersection between ecliptic and equator[d]<br><br>•Turn off Ecliptic/Equator | Oresme: No; seasons result not how far away we are, but from the tilt between the equator and the ecliptic, which is the path the Sun follows around the sky.[14]<br>Score two for medieval universities.<br>Everyone studied basic astronomy back then; astronomy was one of the seven liberal arts. The average student in medieval universities understood more about astronomy than university students do today.[15] |
| | | | Students: Now wait a minute!<br>We all know far more today than you guys did! |
| | | ou-hsci/Apian-1540-cosmicSection | Student Dimbulb: You thought the Earth was in the middle of the universe! How ridiculous! |
| 21 | 22 | •Full dome images fade on[e]<br>Orion nebula<br>Eagle nebula<br>Sombrero galaxy<br>(or other NASA images) | Oresme: You're right that we didn't know as much as you can learn today. You can follow probes into other worlds, gaze upon massive explosions of giant stars, discern the colorful clouds of deep space, and view distant galaxies filled with myriads of stars. I envy you greatly! But I didn't say that we knew more facts. I said that we understood more. |

13. These are the two questions which a group of Harvard seniors failed miserably, as documented in *A Private Universe* (1987), created and produced by Matthew H. Schneps and Philip M. Sadler, Harvard Smithsonian Center for Astrophysics. This film is highly recommended as a pre-visit activity for this show; see *http://www.learner.org/teacherslab/pup/*.

14. From a Sun-centered perspective, seasons are explained as resulting from the tilt of the Earth with respect to the plane of the Earth's orbit around the Sun. But the appearances are exactly the same as for the geocentric cosmos.

15. This claim is made by the historian of medieval cosmology Edward Grant; see ...

(d) If pointing out the intersection between the ecliptic and celestial equator grids is too cumbersome to do at this precise moment, there is a graphic in the video that will suffice.

(e) The video projects a succession of three NASA images, but this reference to modern discoveries is a great opportunity to use all-sky projectors or whole-dome video, if your theater has this capability, to project your

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| 21 | 49 | •Full dome images off<br>•Various constellation figures on; fade them off when photo of Earth from space appears)<br><br>NASA/earth | Oresme: You have far greater opportunities than ever before, yet few of you even know the names of the constellations. But in the Middle Ages, universities required every student to study astronomy. Every medieval student understood what causes the Moon's phases, what causes the seasons, and that the Earth is round. They knew how to prove it, too. You believe the Earth is round, but if you didn't have photographs from outer space, could you prove it? |
| | | •Video projector fade on<br>ou-hsci/Apian-1540-sphericalEarth | Students: I can now, thanks to the arguments you've explained so far.<br>Yeah, thanks!<br>And I'd love to learn more about the constellations. |
| 22 | 27 | •Star projector fade off<br>ou-roller/NotreDame | Oresme: Please forgive me! I apologize for my arrogance. My friend Bernard of Chartres reminded us that we medieval scholars owe all we understand to those who came before, for we are just "Puny dwarfs perched on the shoulders of giants." And if I am a dwarf, I am at least wise enough to choose giants' shoulders to stand on. |
| | | | Students: I don't think you're a dwarf!<br>Me either.<br>I'd put you among the giants, definitely.<br>Tell us about some other giants of the Middle Ages who said the Earth is round. We stand on their shoulders, too. |
| | | ou-hsci/1496-Aquinas-ST-sp<br>ou-hsci/1496-Aquinas-ST-tp | Oresme: Merci, you are too kind. But giants did walk the Earth in those days. Thomas Aquinas, Dante, Chaucer, and many others all knew the shape of the Earth. For instance, when Aquinas wrote his Summa, the greatest theological work of the Middle Ages, at the very beginning he took for granted that readers knew the Earth is round. That's the example he used when he wanted to show that fields of science are distinguished by their methods rather than their subject matter: |
| | | show/Aquinas | Aquinas: "Sciences are distinguished by the different methods they use. For the astronomer and the physicist both may prove the same conclusion—that the earth, for instance, is round: the astronomer proves it by means of mathematics, but the physicist proves it by the nature of matter."[16] |

16. Aquinas, ST 1,1,1.
favorite examples of spectacular deep space scenery. Or make a collage of nebulae and galaxies using whatever auxiliary slide or SFX projectors you have.

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| | | | Oresme: Aquinas meant that astronomy can prove the Earth is round from astronomical evidence like lunar eclipses or changing circumpolar stars. On the other hand, physics can prove the Earth is round from its own kind of evidence, the principle of gravity. |
| | | Dante portrait by Luca Signorelli, in the Dome of Orvieto**<br>misc/DanteSignorelli<br><br>show/Dante-center | Students: Speaking of gravity, I remember reading Dante in literature class. When Dante describes his travels down through the Earth and out the other side, he assumes the Earth is round.<br>Right—and when he's crawling down through the very center of the Earth, he passes the center of gravity and begins climbing upward to reach the other side.<br>That's Satan's belly-button! Dante made the Earth's center of gravity the devil's navel.[17]<br>Oooh.<br>Gross! |
| | | ou-hsci/Dante-1897-00tp<br><br>ou-roller/NotreDame | Oresme: Scholars know that Dante even wrote a formal disputation in Latin about the shape of the Earth, in which he defended his idea of Mount Purgatory. But the Inferno was a work of literature, written in Italian. That shows that even non-university people who read Dante knew the Earth is a globe. Knowledge of the sphericity of the Earth in the Middle Ages reached beyond the educated elite to the emerging mercantile class, and it permeated aspects of popular culture such as almanacs, feudal ceremonies, sermon illustrations, and cathedral iconography. |
| | | KerryMagruder/StVitusEntrance | Student: I love the symbolism of cathedral sculpture! Gothic art was a form of teaching, read by peasants who didn't know how to read. |
| | | | Student Dimbulb: How can someone read a sculpture? |
| | | | Student: It's easy! If a man has bare feet, he's an apostle. If he holds some keys, he must be St. Peter. If he's bald with a sword he's St. Paul. |
| | | show/sceptor | Oresme: And he's Atlas if he holds a celestial globe on his shoulders.<br>Have you seen this symbol before? A globe with a cross on top? |
| | | | Students: Yes, that's really familiar!<br>But I don't know what it means, exactly. |

17. Dante was proficient in astronomy; Chaucer even more so. Chaucer wrote an important manual for using the astrolabe; for Chaucer, see John D. North, *Chaucer's Universe* (Oxford: Clarendon Press, 1988).

**- Dante's portrait is taken from *http://cirt.isrds.rm.cnr.it/operaArte/*.

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| | | show/sceptor | Student: Isn't that a feudal symbol, always held by a ruler or king? |
| | | KerryMagruder/PragueCastle | Oresme: Yes. It symbolized the divine right of kings to rule Christendom. The cross stands for the authority of the king and the globe stands for the realms given kings to rule. |
| | | KerryMagruder/ItalianCourt-KutnaHora | Students: A spherical Earth!<br>That symbol is everywhere! |
| | | show/sceptor | Oresme: Now you see that knowledge of the shape of the Earth was widespread. People took it for granted, but I delighted in proposing paradoxes that would test whether they had really thought through the consequences of a spherical Earth.[18] |
| | | | Students: I love paradoxes!<br>Tell us some! |
| | | show/horizonFlat2 | Oresme: Now really, isn't belief in a round Earth a little surprising? After all, the circle of the horizon looks flat to the eye, so it's rather amazing that people take for granted that the Earth is really too large to see its curvature directly. But here are my paradoxes; I bet you haven't thought of them before: |
| | | show/tower | Oresme: If you build a tall tower so that each side goes straight up, do you want it wider at the top or at the base? |
| | | | Student: I want it wide at the base, of course, to make it stable. |
| | | show/tower2 | Oresme: Wrong! If each side goes straight up, then the top has to be wider than the base! Each side makes a line that, if extended, would run through the center of the Earth. Therefore the lines must diverge as they go away from the center. |
| | | | Students (not impressed): Yeah right...<br>Awww! |
| | | show/table | Oresme: Do you know why water spilled on a table doesn't run off the side? |
| | | | Students: Sure, it has surface tension.<br>Hydrogen bonds!<br>We've studied chemistry! |

18. Oresme, Bk. II, ch. 31, pp. 573–581.

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| | | show/table | Oresme: What? Oh yes, I guess you're right. But when I wrote my book, I thought it was because the Earth is round. The legs of the table are like the sides of the tower; they must diverge as they rise higher above the Earth. Therefore the table top is wider than the base, and the middle of the table is closer than the edges to the center of the Earth. The water won't spread out to the edges, because to do so it would have to flow uphill. That's why a drop of water seems to pool in the middle. |
| | | | Students: That's wrong, but actually it's kind of clever...<br>Tell us another paradox. |
| | | show/tunnel | Oresme: OK, what's the best way to go from Rome to Paris? |
| | | | Students: Through Spain.<br>Through Switzerland.<br>Over the Alps. |
| | | | Oresme: Wrong! If the Earth is a sphere, then the shortest line between two points on its surface is a tunnel. |
| | | | Students: [Laughter] |
| | | show/Dante-center<br><br><br><br>show/Dante-center (upside down) | Oresme: Remember how Dante placed Satan at the center of the Earth?[19] Was he standing right side up or upside down?<br>In my own book, I wrote that "Assuming that the Earth were perforated or pierced... and that a man were at the center standing straight with his head in one direction from the center and his feet in the other, I say that such a man would have his head and also his feet on top or upwards, and he would be no more in a lying than in a standing position, nor facing downward more than upward." |
| | | | Students: In other words, he's weightless.<br>Zero-gravity. |

19. Dante, *Inferno*, canto 34.

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| | | ou-Roller/NotreDame | Oresme: Right. OK, here's my favorite. This paradox is such a marvel that I cast it into Latin verses arranged in four stanzas of six lines each. I like to show this poem to those of noble ingenuity, such as yourselves, who wish to test their understanding. You know that Easter Sunday is the most important date in the church year, and Catholic churches should celebrate Easter mass according to the same rule. Wouldn't it be awful if priests in two different cities celebrated Easter on different days? |
| | | | Student (not impressed): Horrors. |
| | | show/8-9-10-days | Oresme: Well, imagine three priests in the same city several days before Easter. One remains in the city; two depart on separate journeys. These two travel at the same speed on a road that encircles the Earth; one goes west and the other goes east, and at the end of their journeys all three are reunited on the same day. The priest who travels west returns in 8 days and 8 nights. At the same rate of speed and in the same amount of time the priest who travels east returns, but he counts 10 days and 10 nights. And the priest who stayed home counts 9 days and 9 nights. Therefore, 8, 9 and 10 days are exactly identical! |
| | | | Students (unison): What? |
| | | show/8-9-10-days | Oresme: There's more: The priest who traveled east celebrated Easter during the first part of his journey, but then the following day he arrived where people were still fasting in Lent, though they calculate the day of Easter in the same way. Therefore Easter and the day before Easter are the same day! "Hallelujah! I tell you, this story contains nothing that is not pure and simple truth."[20] |
| | | | Students:<br>I think you invented the International date line.<br>I think he understands it better than I do.<br>And he lived in the Middle Ages.<br>This is unbelievable.<br>My brain feels like a pretzel. |
| 31 | 10 | Book<br>•Swirling fog on<br>show/LeLivre | Oresme: "Thus by the grace of God, I finished my book. Glory to God and the King, for never in this world was there a book on natural philosophy more beautiful or more powerful."[21] |

20. The paradoxes recounted above are taken from Oresme, 573-581. The quote is from p. 581.
21. Oresme, 731.

| Columbus and the Myth of the Flat Earth[22] | | | |
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| 31 | 22 | Ocean scene. Wave sounds. ou-hsci/Sacrobosco-ship-scene | |
| 31 | 47 | •Swirling fog off | Students: Where are we now?<br>Hand me that bucket; I'm feeling seasick. Oogh. |
| | | | Oresme: We're on the Santa Maria, heading west across the Atlantic. It's 1492. |
| | | | Students (unison):<br>When Columbus sailed the ocean blue! |
| | | | Students: I've been wondering about Columbus.<br>Me too!<br>Didn't Columbus set out to prove the Earth is round?<br>Didn't the churchmen in Spain argue that his ships would sail off the edge of the Earth? |
| | | ou-hsci/Sacrobosco-1537-fp | Oresme: Haven't you been listening? Why would Columbus have to argue that the Earth is round at a time when people believed the physics of Aristotle and the astronomy of Ptolemy? When the works of theologians like Augustine and Aquinas, and of writers like Cicero and Dante, all assumed that the Earth is round? Have you learned nothing? |
| | | | Students:<br>Yes, but we've been told about Columbus so often.<br>And if everyone really knew the Earth is round, then why did Columbus have such a hard time getting support for his voyage?<br>That doesn't make sense. |
| | | show/hemisphere | Oresme: Oh, Columbus had new ideas, all right. And he deserves a lot of credit for thinking he could sail around the world. Back then, you see, we thought that the far side of the Earth, where the Americas are now, was just a watery hemisphere without any dry land. The reasons are complicated, but if there were just one wide ocean then it would be too far and too dangerous to cross. The sailors would starve and the ships would fall apart for lack of repairs. |
| | | | Student: If everyone thought it was so risky, then why did Columbus dare to try it? |

22. For insightful discussion of this section see Jeffrey Burton Russell, *Inventing the Flat Earth: Columbus and Modern Historians* (Praeger Paperback, 1997); and Stephen Jay Gould, *Rocks of Ages: Science and Religion in the Fullness of Life* (Ballantine Books, 2002).

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| | | ou-hsci/Sacrobosco-1537-fp | Oresme: Columbus believed the Earth is much, much smaller than it actually is. If the Earth were as small as he thought, then China would lie about where he found the New World. |
| | | | Students:<br>That's why Columbus thought he had landed in China!<br>And why the New World is named after Amerigo Vespucci, a geographer who recognized that the New World is not China. |
| | | | Student Dimbulb: I like the sound of North Columbia better. |
| 33 | 52 | •Swirling fog on | Oresme: Columbus was lucky to find land in the western hemisphere right when he needed it. We were wrong about that. But we were right about the size of the Earth; it's not nearly as small as Columbus thought it was. |
| 34 | 08 | Library backdrop<br>show/CosmicZone<br>•Swirling fog off | Students:<br>So in the Middle Ages, you knew not only that the Earth is round, but also how big it is? That's amazing.<br>How did you know the size of the Earth? |
| | | Eratosthenes movie:<br>Alexandria<br>Syene<br>Well<br>Sunlight at Syene | Oresme: A Librarian in ancient Alexandria figured it out before 200 B.C. He wasn't the first or the last, but his estimate was the best, and was never forgotten. From Alexandria at the mouth of the Nile, Eratosthenes heard that farther south on the Nile, there was a town called Syene where one day each year the Sun would shine onto the bottom of a well. |
| | | | Student: Syene—that's called Aswan today. |
| | | Stick shadow at Alexandria | Oresme: Right. So in Syene at noon on the day of summer solstice, when the Sun reached its highest point in the sky, it reflected on the bottom of the well. So at that moment in Syene the Sun was directly overhead. But at the same moment, farther north in Alexandria, the Sun cast a small shadow. Eratosthenes figured that by measuring the shadow in Alexandria, he could figure out how much of the curve of the Earth separated Alexandria from Syene. |
| | | | Student: How did he figure that? |
| | | Stick angle, center angle | Oresme: By simple geometry, you can prove that the angle of the shadow from the top of a stick to the ground, like this, is the same as the angle from the center of the Earth between Alexandria and Syene. |

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| | | Paralllel rays<br><br>Syene line<br><br>Alexandria line<br><br><br><br>center glass<br>stick glass | Students: Alternate interior angles are equivalent!<br>I see! The rays of light from the Sun are parallel, because the Sun is so far away.<br>The line from the center of the Earth to Syene goes straight out to the Sun along one of the rays.<br>But the line from the Earth's center to Alexandria intersects the sunlight at Alexandria. There, the sunlight casts the shadow of the stick.<br>And the stick is on the line from Alexandria to the Earth's center.<br>So the angle from Syene to the Earth's center to Alexandria is an alternate interior angle to the angle of the stick's shadow.<br>And alternate interior angles are the same. |
| | | | Oresme: Very good! You know your Euclid, and so did Eratosthenes. He measured the angle of the stick's shadow to be about one 50th of a circle. Therefore the distance from Alexandria to Syene must be about one 50th of the distance around the Earth.<br>Soldiers paced off that distance at 250,000 stades, or stadium lengths. Multiply 250,000 stadium lengths by 50 and you have the circumference of the Earth. Eratosthenes' figure turns out to be almost exactly right. |
| | | | Students: Neat!<br>I bet Columbus didn't like Eratosthenes. |
| | | | Oresme: And notice, this measurement of the size of the Earth doesn't prove the Earth is round. From the start, it assumes the sphericity of the Earth. This wasn't controversial. |
| | | | Student (angry): Tell me one thing: Why do so many people today think Columbus had to prove the Earth is round? Humpf! |
| | | show/CosmicZone | Oresme: Yes, that is an interesting question, indeed. Up here in the Cosmic History Zone, we call it the "Flat Earth Myth." The Flat Earth Myth does not refer to medieval belief in a flat Earth, but to the modern belief that medieval people thought the Earth is flat, when it's so easy to show that they knew the Earth is round. |
| | | | Students: I never thought about it that way.<br>Who started the Flat Earth myth? |
| | | KerryMagruder/Irving-nd6-000fp | Oresme: Well, I hate to name names, but Washington Irving fooled a lot of readers when he dramatized the myth. |

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| | | | Students: Legend of Sleepy Hollow!<br>Rip Van Winkle! |
| | | KerryMagruder/Irving-nd6-000tp | Oresme: We all enjoy Irving's far-fetched tales, but his Life of Christopher Columbus presented itself as biography, not fiction. Unfortunately, it was about as factual as the headless horsemen. Irving fabricated a tale of Columbus pleading his case before a council of Inquisitors at a convent in Salamanca, who assailed him with citations from the Bible and the teachings of the Church. Irving's account is nothing but misleading and mischievous nonsense. It should have been read only as a pleasant romance.[23] |
| | | | Students: Irving was great at fiction.[24]<br>But were there others who spread the Flat Earth Myth? |
| | | ou-hsci/White-1897-00tp | Oresme: Oh yes. One writer can't concoct a myth all by himself, even one as skillful as Irving.[25] Other French and American writers endorsed the myth, and by the end of the 19th century it was being taught in universities. Andrew Dickson White, President of Cornell University, echoed Irving in his book, The History of the Warfare of Science with Theology in Christendom... |
| | | White quote | White (same voice as Professor Idiot): "The warfare of Columbus the world knows well: how the Bishop of Ceua worsted him in Portugal; how sundry wise men of Spain confronted him with the usual quotations from the Psalms, from St. Paul, and from St. Augustine; how, even after he was triumphant, and after his voyage had greatly strengthened the theory of the earth's sphericity...the Church by its highest authority solemnly stumbled and persisted in going astray.... In 1519 science gains a crushing victory. Magellan makes his famous voyage.... Yet even this does not end the war. Many conscientious men oppose the doctrine for two hundred years longer."[26] |
| | | show/CosmicZone | Students: Oh, give me a break.<br>Where does he get off?<br>Get out of here! |

23. Russell, ch. 4.
24. Russell, p. 57.
25. Oresme's judgment uncharacteristically lapses here; he's forgetting about J.R.R. Tolkien. But an author that can single-handedly construct a myth only comes once every few centuries (Dante, also, perhaps?).
26. Andrew Dickson White (1832–1918), *History of the Warfare of Science with Theology in Christendom*, 2 vols. Vol. 1, pp. 108–109.

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| | | show/Cosmas | Oresme: But wait! He had a shred of "proof"! To support the Flat Earth Myth, White and others dug up a real honest to goodness flat Earther, Cosmas Indicopleustes, a Greek writer from the 6th century. Cosmas thought the universe was a huge, rectangular vault above a flat Earth lying on its floor. |
| | | show/CosmicZone | Student Dimbulb: See, I knew in the Dark Ages they believed in a flat Earth. |
| | | | Oresme: But Cosmas was neither typical nor influential. He was refuted by contemporaries such as John Philoponos. His work survives in only 3 manuscripts, and his book wasn't even translated into Latin until the 18th century. He had zero influence on the Latin West. Yet White and others take him as typical of the Middle Ages! |
| | | | Student Dimbulb: So Cosmas wasn't even known in the Dark Ages? |
| | | | Oresme: Right. At most there were a dozen Flat Earth writers before modern times, and none of them had any influence nor were any accepted as authorities. The Catholic church, for instance, has always taught the sphericity of the Earth. |
| | | | Student: I guess White went looking for something, then found only what he wanted to find. |
| | | | Student Dimbulb: Everyone is biased; there's nothing you can do about that. |
| | | | Students: But don't you see? White did exactly what he accused the medievals of doing, believing in whatever he wanted, without regard for the weight of the evidence.[27]<br>He repeated others' errors for his own purposes without checking the sources for himself. |
| | | | Oresme: That's a lesson for all of us, in any age, that goes far beyond the Flat Earth myth. |

27. Russell, p. 44: "The curious result is that White and his colleagues ended by doing what they accused the fathers of, namely, creating a body of false knowledge by consulting one another instead of the evidence."

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| | | show/CosmicZone | Students (pensive): Maybe we don't know as much about the past as we think.<br>I wonder what else I believe about the past that's wrong.<br>Maybe history isn't a simple story of inevitable progress.<br>Maybe people in the past were smarter and more resourceful than we think.<br>Maybe in the Dark Ages people were more like us than we realize. |
| | | ou-Roller/NotreDame | Oresme: It's true that we undervalue the past, in order to convince ourselves of the superiority of the present. Back in your Middle Ages, we called ourselves the Via moderna, the Modern Way, in contrast to those who came before. You do the same thing when you call our Via moderna the 'Dark Ages.'[28]<br>But myths have a life of their own. Once the Flat Earth Myth made it into your textbooks, it became impervious to evidence or correction.[29] So pardon my asking, but who lives in a Dark Age now? |
| | | show/CosmicZone | Students: I know one thing; I'm never going to use the phrase "Dark Ages" again!<br>You know, I think history would be very dull if people in the past were not as smart and creative as we are.<br>What might we gain from studying history if they really were just as bright and inventive as we are? |
| | | | Oresme: Those are great ideas to think about! That's why I brought you into the Cosmic History Zone in the first place. And now I have only more thing left to show you... an old woodcut. |
| 42 | 26 | ou-hsci/Flammarion | Students: We've seen that before...<br>The professor's flat Earth picture! |
| Epilogue | | | |
| 42 | 32 | Dreamlike transition, ripple dissolve, classroom backdrop | |

28. Russell, p. 76: "The assumption of the superiority of our views to that of older cultures is the most stubborn remaining variety of ethnocentrism."
29. Russell, p. 29: "The schoolbooks of the nineteenth century are inconsistent, but show an increasing tendency over the century to the Flat Error, a tendency that becomes especially pronounced from the 1870s onward …. Earlier in the century the dominant force behind the Error was middle-class Enlightenment anti-clericalism in Europe and 'Know-Nothing' anticatholicism in these United States. The origin of the Error resides in these milieus."

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| 42 | 40 | Closeup on Bernal caption<br>misc/bernal | Idiot Professor voice: "In medieval times there was a return to the concept of a flat Earth and a dogmatism about the crystalline celestial spheres, here epitomized in a woodcut showing the machinery responsible for their motion discovered by an inquirer who has broken through the outer sphere of fixed stars."[30] |
| 42 | 56 | Dreamlike transition, ripple dissolve, library backdrop | |
| 43 | 02 | show/CosmicZone | Student Dimbulb: Finally, this is evidence no one can deny. Dr. Ore-ez-may, doesn't this medieval woodcut prove they thought the Earth is flat? I can see it with my own eyes. |
| | | | Oresme: Who said it's a medieval woodcut? Look what NASA, your modern space agency, said about it: |
| | | nasa/exobiology<br>nasa/nasa | Voice: "A famous early 20th century engraving (1911) erroneously thought to be a 17th century woodcut of a Medieval astronomer passing through the sphere of the stars to see the mechanisms of the Ptolemaic universe beyond."[31] |
| | | show/CosmicZone | Student Dimbulb: So this woodcut isn't original at all, and was only used to spread the Flat Earth Myth? |
| | | ou-hsci/Flammarion-1888-000cover<br><br>ou-hsci/Flammarion-1888-163 | Oresme: Right. Actually, NASA got the date wrong; but it's not medieval in origin. The woodcut first appeared in the 19th century, in a book by Camille Flammarion, published in France in 1888.[32] Flammarion was an astronomer and a very popular science writer. Although he used the woodcut to propagandize the flat Earth myth, I very much like it nevertheless. Don't you think this image can carry a different message than the Flat Earth Myth? In our common quest to understand the mysteries of the cosmos, we are boldly going where no one has gone before. |
| | | | Student Dimbulb: I think I've heard that somewhere before.... |
| | | ou-hsci/Flammarion | Students: I love this woodcut, too.<br>It shows us on a cosmic quest, searching for truth.<br>That figure is curious, determined to discover something new.<br>I want to be like that.<br>He looks a lot like you, Nicole Oresme. |

30. J.D. Bernal, *Science in History*, vol. 1 of *The Emergence of Science* (4 vols).
31. NASA, *Exobiology in Earth Orbit* (NASA SP-28, 1989).
32. Camille Flammarion, *L'Atmosphere: Météorologie Populaire* (Paris, 1888), p. 163.

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| 44 | 35 | Woodcut fades slowly | Voice: "The search for truth is long and laborious and easily set aside. And since the present is transformed day by day, minute by minute, second by second, into the past, while the future is unknown and unknowable, we are left on the dark sea without stars, without compass or astrolabe, more unsure of our position and our goal than any of Columbus's sailors. The terror of meaninglessness, of falling off the edge of knowledge, is greater than the imagined fear of falling off the edge of the earth. And so we prefer to believe a familiar error than to search, unceasingly, the darkness."[33] |
| 45 | 00 | •Star projector fade on<br>•Video projector fade out | |
| 45 | 18 | •Star projector: very slow diurnal motion<br>•Stars off after credits begin[f] | |
| 45 | 28 | Credits:<br>show/credits/ | Written & Produced by Kerry Magruder<br>Nicole Oresme: Kerry Magruder<br>Students: Rachel Magruder, Hannah Magruder, Kevin Kemp, Chris Kemp, Kara Kemp<br>Idiot Professor: Phil Kemp<br>Andrew Dickson White: Phil Kemp<br>Cicero, Aquinas: J Harvey<br>NASA writer: Sylvia Patterson<br>Jeffrey Burton Russell: Candace Magruder |
| | | show/credits/ | Images courtesy History of Science Collections, University of Oklahoma Libraries<br>Digital photography and processing by Hannah Magruder<br>Soundtrack by Eric Barfield<br>Special thanks to... Jeffrey Burton Russell, Mike Keas JoAnn Palmeri, Hannah Magruder, Rachel Magruder, Susanna Magruder, Candace Magruder. |

33. Jeffrey Burton Russell, *Inventing the Flat Earth: Columbus and Modern Historians* (Praeger Paperback, 1997).

(f) Alternatively, to close on a reflective mood, make the theater completely dark by fading stars off by the time "darkness" is spoken by the narrator. Briefly lower the intensity of the video projector, if necessary.

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# 5. After the Show

## A. Theater Activities

1. Assemble a star clock and tell time by the Big Dipper: Kerry Magruder and Ben Randell, Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/instruments/starclock/clock.htm*.
2. How to use a planisphere as a star chart for different times of night: *http://homepage.mac.com/kvmagruder/bcp/instruments/planisphere/planisphere.htm*.
   Does the star chart depend on your east-west location?
   Does the star chart depend on your north-south location?

## B. Discussion Questions

1. How do aesthetic principles support the sphericity of the Earth?
2. What evidence from astronomy proves the sphericity of the Earth?
3. What evidence from physics proves the sphericity of the Earth?
4. Debate Oresme's contention that students in medieval universities understood more about observational astronomy than university students do today.
5. Critique the quotation from George Gamow: "In the days when civilized men believed that the world was flat they had no reason to think about gravity. There was 'up' and 'down.' All material things tended naturally to move downward, or to fall, and no one thought to ask why. The notion of absolute up and down directions persisted into the Middle Ages, when it was still invoked to prove that the Earth could not be round." George Gamow, "Gravity," *Scientific American*, March, 1961.
6. What is the Flat Earth Myth?
7. How did the Flat Earth Myth arise?
8. Why is the Flat Earth Myth so durable?
9. What does the Flat Earth Myth suggest about our understanding of history?
10. Discuss the meaning of the concluding quotation from Jeffrey Burton Russell, *Inventing the Flat Earth*: "The search for truth is long and laborious and easily set aside. And since the present is transformed day by day, minute by minute, second by second, into the past, while the future is unknown and unknowable, we are left on the dark sea without stars, without compass or astrolabe, more unsure of our position and our goal than any of Columbus's sailors. The terror of meaninglessness, of falling off the edge of knowledge, is greater than the imagined fear of falling off the edge of the earth. And so we prefer to believe a familiar error than to search, unceasingly, the darkness."

## C. Lab or Classroom Activities

1. Ask students to read the text of Oresme excerpted from *Le Livre du Ciel et du Monde*, and then discuss Oresme's paradoxes, particularly the poem about the International dateline.
    - Identify the International dateline on a globe.
    - Has anyone in the class traveled across the dateline? Which way, and what happened?
    - Discuss works of literature or movies in which the plot involves the dateline (e.g., Jules Verne, *Around the World in 80 Days*; Umberto Eco, *The Island of the Day Before*; etc.).
    - Does the Moon have a dateline? If we settled other planets, would they also have International datelines?

2. How did Eratosthenes determine the circumference of the Earth?
   Does his method *prove* that the Earth is spherical, or merely *assume* that it is so?

   Exploring Eratosthenes' accomplishment in more detail makes an ideal follow-up activity for the show. Descriptions of Eratosthenes' calculation are readily available; one excellent popular presentation is found in the book (and in one episode of the companion six-part PBS video series) by noted physicist Philip Morrison, *The Ring of Truth* (Random House, 1987).

3. Measure your terrestrial latitude using a paper plate or a protractor (overnight assignment).

   Because the altitude of the north star equals one's latitude on Earth,[34] surveyors and navigators have always relied upon measurements of the former. Here are two ways students may easily measure the north star's altitude:

    - Protractor method, available on the Basic Celestial Phenomena website of Kerry Magruder:
      *http://homepage.mac.com/kvmagruder/bcp/instruments/quadrant/index.htm*
    - Paper plate method by Chuck Bueter, sponsored by the Great Lakes Planetarium Association: *http://analyzer.depaul.edu/paperplate/Latitude%20by%20Polaris.htm* (see also the altitude activity at *http://analyzer.depaul.edu/paperplate/Altitude%20Measurer.htm*). Other paper plate activities by Bueter may also be of interest: *http://analyzer.depaul.edu/paperplate/activities.htm*.

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34. For a brief explanation of why this is so, see Kerry Magruder, Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/sphere/lataltpolaris.htm*.

## D. Group Activity: The Shape of the Earth

You are members of a Star Trek Federation surveying party sent to map the surface of a newly-discovered, Class-M planet orbiting a small yellow star in the Virgo cluster. While orbiting the planet, you experience navigation trouble and crash-land on the planet's surface. Natives (living in stone age conditions) rescue you from the debris and take you under their care. Since you have all been professionally trained in philology, within only a few weeks you have learned their language and begin conversing comfortably with them about how they live, what they believe, who you are, and where you have come from. In conversation with one of the leaders of the natives, you carelessly mention that their planet is as round as a ball. Until now, the natives were listening to you with a large measure of curiosity and respect, but now they are either amused at your attempt to trick them or angry at your apparent deceitfulness. Sensing your mistake, you protest that they have misunderstood your intent, and that you are telling them the truth. Being reasonable life-forms, the natives ask you to show them proof that their planet is spherical. (Helpless and unable even to support yourselves in their world, clearly your credibility is not yet sufficient to support an argument based only on mere authority.) You happen to have a photograph in your pocket, taken while your survey craft was in orbit around the planet, that clearly shows the spherical planet against the dark background of space. As you show it to them, they begin to lose their patience with your protracted magic and tomfoolery. To persuade them now that you really are telling the truth, you will have to start with evidence that is accessible to them, and arguments based on experiences or observations which are within their reach. Since before joining the Starfleet Academy you took an astronomy or history of science course, you are prepared to argue on this basis. How do you begin? What evidence can you present to persuade them that their planet is spherical?

### Instructions

Divide into small groups. Half of your group will play the part of Trekkers; the others are natives of this planet, which happens to be just like Earth, and happens to be in a solar system just like our own.

*Natives:*

- Are undecided or agnostic about the shape of the Earth.
- Are skeptical of unsupported assertions of the spherical Earth.
- Emphasize intelligent common-sense and ordinary observation. Natives are intelligent and curious; critical but not obstinate; open but not credulous.

*Trekkers:*

- Defend spherical Earth view
- Use evidence accessible to Natives

Discuss! Natives and Trekkers within each group switch roles after about 10 minutes.

# 6. Further Reading

Nicole Oresme, *Le Livre du Ciel et du Monde* (Madison: University of Wisconsin Press, 1968).

This vernacular work by Oresme contains the paradoxes explained in the show as part of a comprehensive overview of physics and cosmology written for Charles V, King of France, in the 14th century. This edition displays in facing pages the text in medieval French and the modern English translation by Menut.

Jeffrey Burton Russell, *Inventing the Flat Earth: Columbus and Modern Historians* (Praeger Paperback, 1997).

Russell's accessible essay is a superb overview of the Flat Earth Myth.

Stephen Jay Gould, *Rocks of Ages: Science and Religion in the Fullness of Life* (Ballantine Books, 2002).

Relying upon Russell, Gould places the flat-Earth myth in the context of the historiography of science and religion.

David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450* (University Of Chicago Press, 1992).

Standard introductory survey of ancient and medieval European science.

Felipe Fernandez-Armesto, *Columbus* (Oxford University Press, 1991).

A readable biography of Columbus by a noted Columbus scholar.

Kerry V. Magruder, "This is not a Medieval Woodcut." *http://homepage.mac.com/kvmagruder/flatEarth/*.

This website explores the Flammarion woodcut as an example of visual rhetoric.

Forthcoming: The German historian Reinhard Krüger is producing a 4-volume scholarly history of ideas of the shape of the earth before the 16th century. Once it appears, it likely will become the standard scholarly source on the topic.

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