Exploring the Copernican Revolution through computer simulations

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ABSTRACT: The author and a colleague have developed a course for liberal arts students that focuses on the development of astronomical theories from the Ancient Greeks to Isaac Newton. In the first part of the course students use planetarium software (Starry Night) to observe a wide variety of celestial motions. The remainder of the course is devoted to studying the various theories that have been presented to explain and predict these motions. Students work with open-source computer simulations developed by the author to visualize the predictions of astronomical models and compare these predictions to their earlier "observations". This approach helps students to see the great power and sophistication of Ancient Greek astronomical theories, as well as the aesthetic features of the Copernican theory that paved the way to its ultimate acceptance. The simulations developed by the author (and worksheets to guide their use) are available for free at http://facultyweb.berry.edu/ttimberlake/copernican/.

Overview of the Course

Content

- Development of astronomy: observations, Ancient Greek astronomy, Copernicus, Tycho, Kepler, Galileo, Newton.
- Focus is on how scientific theories are evaluated and how theories change over time.

Why teach a course on the Copernican Revolution to non-science majors?

- Students already know the facts (Earth orbits the sun), but they don't know the reasons for believing this.
- These students don't need to know cutting-edge astronomy – they need to understand how science works.
- Students find the historical content (as well as the scientific content) interesting.
- For a full description see post on AST 120 at berryactivelearning.blogspot.com.

Teaching methods

- Active learning: students spend their class time working in groups of 3-4 completing activities (75 minutes) or labs (120 minutes). 24 students per section. Class meets in a lab room with 7 computers.
- Activities and labs consists of worksheets with a sequence of questions the students must answer.
- Answering the questions frequently requires working with a computer simulation (as well as calculating, drawing diagrams, using logical reasoning, etc.).
- I have developed over 50 computer simulations for these activities and labs.

Why use computer simulations?

- Many students need a visual image in order to understand a concept.
- Astronomical theories are abstract. The simulations let students see how the theories connect to observations.
- Theories can be simulated in a virtual world even if they don't work in the real world. For example, students can see what the motion of a planet would look like if the planetary theory of Eudoxus were true.
- Simulations are practical when real observations would be impractical. (Saturn's zodiacal period is 30 years...)
- Students are comfortable with simulations and generally enjoy them.

Observing the Skies with Starry Night

Starry Night is commercial software ($80-250 per license).

- Simulates the night sky in the past, present, and future.
- Observations can be made from anywhere on Earth (and elsewhere).
- Many (but unfortunately not all) of the features of this software are available in free programs like Celestia and Stellarium.

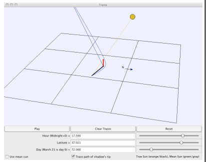
Open-Source Computer Simulations

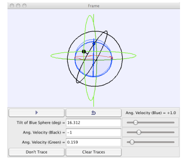
My simulations are…

- Java programs (so they can run on any computer).
- created using the Easy Java Simulations package by Francisco Esquembre, which is part of the Open Source Physics project headed by Wolfgang Christian.
- open-source and available for free.

Sample Simulations

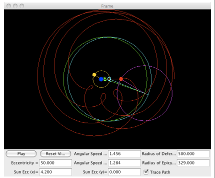
Gnomon: simulates the shadow cast by an upright stick (or gnomon) at any time on any day of the year at any location on Earth. Can be used to illustrate various aspects of the apparent motion of the sun. Best if combined with some observations using a real gnomon.

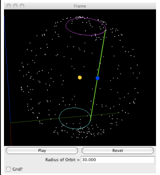




Eudoxus: simulates the planetary theory of Eudoxus in which the planet resides on an Earth-centered sphere which is linked to several other spheres. Each sphere rotates about a different axis. This model is capable of reproducing retrograde motion, but not variations in brightness.

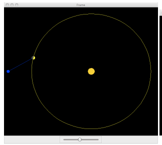
SuperiorPtolemaic: simulates Ptolemy's theory for a superior planet in which the planet moves along a small circle called an *epicycle* which in turn moves along a larger circle called a *deferent*. To ensure that retrograde motion occurs only when the superior planet is in opposition to the sun (i.e. on the opposite side of Earth from the sun) the motion of the planet on its epicycle must be synchronized with the motion of the sun.

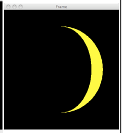


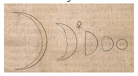


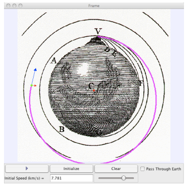
EarthParallax: this simulation shows how Copernicus' theory of Earth's motions predicts that the north and south celestial poles will trace out circles on the celestial sphere over the course of a year. No such motion of the poles is observed, so Copernicus was forced to propose that the orbit of Earth was MUCH smaller than the celestial sphere.

VenusPhases and VenusPhasesPt: shows the predicted phases of Venus for the Copernican and Ptolemaic systems. These can be compared to Galileo's drawings of Venus to effectively refute the Ptolemaic theory.



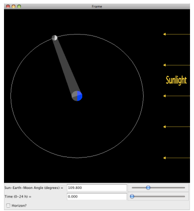


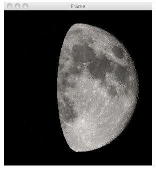




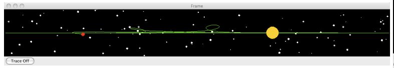
NewtonsMountain: illustrates Newton's idea that a projectile fired horizontally from a TALL mountain would orbit the Earth (just like the Moon) if given sufficient speed.

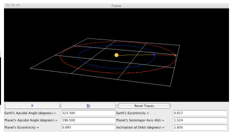
MoonPhases: illustrates how the observed phase of the moon depends on the relative positions of the moon, sun, and Earth.



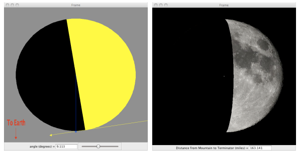


KeplerSystem: simulates the motion of Earth and one other planet according to Kepler's three laws of planetary motion.

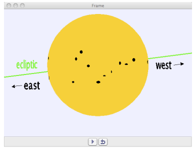




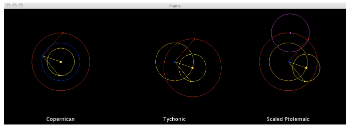
MoonMountain: illustrates Galileo's method for measuring the height of a mountain on the Moon.



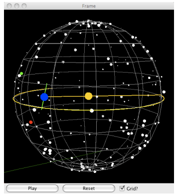
Sunspots: simulates Galileo's observations of the motion and changing appearance of sunspots.



All3Systems: shows the underlying geometric equivalence of the (simplified) Copernican, Tychonic, and Ptolemaic systems.



EarthOrbit: illustrates Copernicus' theory of the annual motion of Earth about the sun.



Student Projects

- **Project 1:** construct Ptolemaic and Copernican orbits for imaginary inferior and superior planets (and home star / home planet) given observational data. Tests understanding of the main features of the two systems and understanding of how theories are connected to observation.
- **Project 2:** write a defense of the Copernican system against an Aristotelian attack. Tests understanding of Galilean/Newtonian physics and how it fits with the idea of a moving Earth.

Resources

- All simulations, activity handouts, and lab handouts are available from: http://facultyweb.berry.edu/ttimberlake/copernican/
- Paul Wallace and Todd Timberlake have written a textbook for this course. A pre-publication version can be obtained by sending an email request to: ttimberlake@berry.edu.

Future Plans

- Continue to improve the simulations and the textbook. Hopefully we will submit the book for publication in a few years.
- Find a way to incorporate more primary source material into the course.
- Develop a new course on the history of galactic astronomy from Galileo to Hubble. I will be writing my own textbook and I expect to create many new simulations for that course.