THE COPERNICAN REVOLUTION

- In 1514, the pope asked the mathematician and astronomer Nicolaus (or Nic(h)olas) Copernicus (Polish: Mikolaj Kopernik) to reform the calendar
  - In 1543, Copernicus published *On the Revolution of the Celestial Spheres*, which overturned Ptolemaic cosmology, but he was very shrewd: he waited until his deathbed

- Earth just another planet, orbiting the Sun at the center of the solar system (which you must understand was the *entire Universe* back then). Moving, rotating
  - Humankind lost its place at the center of everything, and the imperfect and perfect mixed

- He was not the first to put forth a heliocentric instead of geocentric cosmos, but this concept finally caught on after him (eventually…)
  - Greek Philolaus posited the existence of a “central fire” (not the same as the Sun)
  - Aristarchus of Samos proposed the Sun is larger than the Earth and the Earth must thus orbit it and not the other way around (text lost)
A PARADIGM SHIFT

Pieter Schenk, 1708

Artist unknown, 1580
HELIOCENTRISM

- Copernican system still not quite there yet, requiring some “epicycle” fudge factors
  - Didn’t fit observations better, but far fewer epicycles than Ptolemy’s (think Occam)
  - Finally fixed with Kepler, first to break away from the constraint of circular orbits (Kepler’s laws of planetary motion; including, planets move around in ellipses)
  - But the sphere of “fixed” stars remained, at the edge of the Universe

- No direct proof until Galileo, whom we discussed in the context of the telescope
  - Heliocentrism survived unpersecuted for a while as just a “mathematical model”
  - Ptolemy’s grossly inaccurate maps of the Earth helped cast doubt on his astronomy

- Tycho Brahe offered a compromise that saved theological face, keeping us special: the planets orbit the Sun, but the Sun orbits the Earth. Observations couldn’t distinguish
  - Today we know that this is an untenable solution: gravitationally unstable, parallax, etc.
ACTIVITY

- Prove that the Earth revolves around the Sun (any technique)
- Retrograde motion of certain planets like Mars: stops, curly-cues
- The “fudge factors” (Ptolemaic epicycles) a thing of the past
- The shapes of the phases of the planet Venus
- Stellar aberration: apparent motion of stars due to Earth’s velocity
- Stellar parallax (better than ever with Hubble Space Telescope)
- Radar ranging: see the cosmic distance ladder lecture
- No exoplanets have ever been discovered with stars orbiting them
- Gravity: Sun not just bigger, but more massive than Earth
- Doppler shift: redshifted (local) objects blueshifted half the year
(This animated gif was converted from a QuickTime movie that I obtained from Dr. Ted Snow's web site at The University of Colorado, Boulder.)
GALILEO: NEWTON’S PRECURSOR

- Rolled balls of same size and shape, but different masses, down inclined planes
  - Only to discover that heavier objects did not roll faster, as Aristotle claimed
- Watching a cathedral lamp, puzzled out rules of pendulum (periodic) motion
- Abstract thought not enough for Galileo, a scientist: facing reality best
- Turning his telescope upward, applied physics to astronomy (astrophysics!)
  - Figured same rules, same laws of physics/motion apply on earth and “in heaven”
- Together with astronomers Brahe and Kepler laid foundations for Newton
- Published (controversial) work on the heliocentric worldview he supported
THE NEWTONIAN UNIVERSE

- Synthesized the data of Galileo (motion on Earth, orbits of Jupiter’s moons) and Kepler’s theory (orbits of planets) into three laws of motion, and his law of gravity
  - Law of inertia: objects at rest stay at rest; in motion, stay in motion
  - F = ma: A force applied to a mass yields an acceleration, a change in velocity (NOT in a constant velocity as Aristotle had believed)
  - For every action there is an equal and opposite reaction (on different masses)
  - Found mathematical formula explaining gravity as force: more when closer or more mass
  - Planetary motions could now be predicted millennia in advance *from 1st principles*
  - Newtonian gravity good enough to get us to the Moon! (No Einstein)
  - Halley’s comet, binary star systems, new planets like Neptune. Newton, Newton, Newton!

- Published the *Principia Mathematica*. One of greatest minds science has ever seen.
  Influenced surely by Descartes, who saw Universe as giant mechanized clock with laws
AN INFINITE UNIVERSE

- Problem: gravity + infinitely large Universe = a disaster of cosmic proportions
  - The math says gravity has infinite reach, and all things with mass attract each other. No such thing as negative mass, so no repulsion to counterbalance attraction
  - Universe should eventually collapse into a gigantic, spherical fireball centrally located

- OK, but…let’s assume stars are spaced out equally throughout all space (Newton)
  - Unstable solution: slightest disturbance sends entire system out of equilibrium
  - Patch up the solution: God fixes it, intervening constantly to halt de-stabilization

- Fatal flaw is assumption of a static (eternally unchanging) universe, inherited from Aristotle. Newton did not think it through quantitatively, and assumed no such thing as a center of motion (believed nonsensical for an infinite volume). So, cosmos static
OLBERS’ PARADOX

- The sky is dark at night, but a uniform distribution of an infinite number of stars would leave no gaps
  - Every line of sight should end on the surface of a star, so why aren’t we fried by a hot glowing sky?

- Finite speed of light doesn’t save us, because if the Universe is infinitely old, then ALL of the light should have reached the Earth “by now” (stars always “on”)
  - Kepler suggested the Universe is finite (doesn’t work perfectly since light from many, many stars hurts)
  - Olbers suggested interstellar dust clouds. Wrong again! Clouds would heat (infinite amount of time)

- So, Universe must have an origin! (Edgar Allan Poe)
HOMEWORK

- Read Chapter 4 of *Hyperspace* (stop on p. 94) and Chapter 11 of *Physics of the Impossible*, by Michio Kaku (linked from course site: see entry for today in table).

“…what hinders the fix’d Stars from falling upon one another?”
- Isaac Newton, Opticks (1704)
THE ASYMPTOTE TO TRUTH

- In math, an asymptote is a line which something gets closer and closer to but never quite touches.
- I like to think of science (note: this is just my personal opinion – not going to be tested on!) as always asymptoting towards “The Absolute Truth”.
- There is still an infinite amount of knowledge to be gained, but gets harder to learn more over time.
  - Also harder to be wrong: for example, the ancient Greeks didn’t possess our telescopes, microscopes, atom smashers, and rockets!