

ASTRONOMY 9: HISTORY OF COSMOLOGY
Handout #17

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Cosmology and Astronomy after Newton

- Newtonian mechanics and law of gravitation show great success!
- Physical laws are the *same* on earth and in heavens

I. The universe is made of galaxies!

A) Thomas Wright (1750, England)

- Idea of the “galaxy” or “island universe”, a great system of stars
- Believes our galaxy is spherical, with stars distributed in a shell on the surface

B) Immanuel Kant (1724–1804, Germany)

- Important philosopher, wrote *Critique of Pure Reason*
- Also cosmological speculation, *Universal Theory...*
- Remarkably “modern” idea of **galaxies**
- Reads misleading review of Wright’s book which suggests a disk-shaped galaxy
- Stars circle in great disks, much like a big solar system
- Looking through the plane of the disk \Rightarrow Milky Way
- Postulates “nebulae” (fuzzy patches) are distant galaxies
- Even argues galaxies are themselves hierarchically clustered into ever-larger structures, approaching the perfection of God
- Argument is largely philosophical; no conclusive *scientific evidence* regarding nature of the nebulae for another 150 years!

C) Lord Rosse (1845)

- Builds 72-inch telescope in Ireland
- Discovers some nebulae are distinctly spiral

II. Cosmology and Determinism

A) Pierre Simon Laplace (1749–1827, France)

- Used Newton’s calculus to explain almost all “anomalies” in planetary motion
- Mercury still shows a mysterious shift of 43 arc-seconds per century in the location of its perihelion (point closest to Sun)
- Shows that solar system is (almost) stable \Rightarrow no need for divine intervention; **determinism**
- 1796: Nebular hypothesis: solar system formed from spinning disk-shaped nebula of gas and dust
- To Napoleon, on God: “I have no need for that hypothesis.”

III. New Views of the Sky

A) Christiaan Huygens (1629–1695, Holland)

- Discovers that Saturn’s rings are rings
- Argues that light is made of *waves*
- Fights with Newton (says light is made of particles)
- Evidence for *both*; not resolved until 20th-century quantum physics!
- Also argues Newton’s law of gravity is unsatisfactory because there is no physical mechanism

B) Charles Messier (1730–1817, France)

- 1760s: Catalogs 101 fuzzy objects which were not comets (so comet-hunters wouldn’t be confused!)
- Example: M31 is known today as the Andromeda galaxy

C) William Herschel (1738–1822, Germany and England)

- Self-taught expert in telescope design

- Sister Caroline discovers several comets
- William finds a “comet” in 1781, turns out to be a new planet; named after George III, later changed to Uranus
- Builds 49-inch diameter reflecting telescope in Slough, England
- Catalogs 848 new binary stars (in orbit around each other)
- Catalogs 2500 “nebulae”, some resolve into stars!
- 1780s: finds whole solar system is moving relative to other stars, towards Hercules!
- Halley had also found some indication of this in 1718, based on Tycho’s earlier positions
- No more “fixed stars”!
- New limits on parallax \Rightarrow stars even farther away than previously thought

IV. Final Proof of Earth’s Motion

A) James Bradley (1693–1792, England)

- First direct evidence of Earth’s orbital motion around Sun!
- Looking for parallax, but failed to measure it
- Instead, discovered “aberration of starlight”: small yearly shift in positions of all stars
- Imagine Earth is moving through a “rain” of starlight
- When moving through the rain, it appears to fall from a direction different from vertical
- The faster you move, the more horizontal it is
- Allows Bradley to measure the speed of light: 295,000 km/s (=183,000 mi/s); note modern value is 299,792.458 km/s!

B) Fredrich Wilhelm Bessel (1784–1846, Germany)

- Predicts existence of Neptune based on anomalies in orbit of Uranus
- 1838: First detection of annual stellar **parallax**, more proof the Earth moves!
- General formula for parallax:

$$\tan \alpha = \frac{1 \text{ AU}}{d}$$

α is half the angular shift during six months

- For distance d big compared to 1 AU, $\tan \alpha \approx \alpha$ is a *very* good approximation, where α is in radians ($360^\circ = 2\pi$ rad)
- New unit of distance: the **parsec** (distance a star must have so that its parallax is 1 arc-second = 1/3600th degree):

$$\frac{d}{1 \text{ parsec}} \approx \frac{1 \text{ arcsec}}{\alpha}$$

Note 1 parsec \approx 206,265 AU \approx 3.26 light-years.

- For 61 Cygni, measured $\alpha = 0.3$ arcsec $\Rightarrow d = 3.3$ parsecs

C) Jean-Bernard-Leon Foucault (1819–1868)

- Foucault pendulum: first laboratory proof of Earth’s rotation!
- Heavy iron ball swinging from 220-foot wire
- Pendulum wants to swing in the same plane (inertial frame)
- Earth is rotating, so this plane rotates relative to observer on Earth!
- Example: at north or south pole, rotates 360° in 1 day

V. Why is the sky dark at night?!

- Called “Olbers’ paradox” after Heinrich Olbers (1826)
- But idea had been around since Kepler (1610)!
- Also discussed by Edmund Halley (1720) and Jean-Phillipe de Cheseaux (1744)
- Basic idea: in an infinite, homogeneous, Newtonian universe where stars have been around forever, all lines of sight should intersect the surface of a star
- So the sky should be as bright as the surface of the sun!
- More to say about this later ...