A brief history of cosmology

- Basic concepts
  - spatial extent
    - finite (with edges)
    - finite (unbounded)
    - infinite
  - our location
    - Earth at centre
    - Sun at centre
    - solar system near centre
    - solar system far from centre
    - no centre
  - past and future
    - both finite
      - creation, future destruction
    - both infinite
      - no beginning, no end
    - finite past, infinite future
  - dynamics
    - static
    - expanding
    - cyclic

Early ideas: astronomy

- Clearly understood concepts in Greek and Hellenistic astronomy
  - shape and size of the Earth (Eratosthenes, BC 276-197)
  - size and distance of the Moon (Aristarchos, BC 310-230)
  - Sun is much larger than Earth (Aristarchos)
    - exact value was wrong by a large factor: method sound in principle, impossible in practice!

- Ideas raised but not generally accepted
  - Earth rotates on its axis (Heraclides, BC 387-312)
  - Sun-centred solar system (Aristarchos)
**Early ideas: cosmology**

- Aristotle/Ptolemy
  - Earth-centred, finite, eternal, static
- Aristarchos/Copernicus
  - Sun-centred, finite, eternal, static

*At this time, little observational evidence for Sun-centred system!

**Renaissance**

- Birth of modern science
  - scientific method
    - Galileo
  - better observations
    - Tycho, Galileo
  - development of mathematical analysis
    - Kepler, Galileo, Newton

*Newtonian cosmology*
Newtonian Cosmology

• Newton’s *Philosophiae Naturalis Principia Mathematica*, 1687
  ▶ Newtonian gravity, \( F = \frac{GMm}{r^2} \), and second law, \( F = ma \)
  ▶ Approximate size of solar system (Cassini, 1672)
    ▶ from parallax of Mars
  ▶ Finite speed of light (Ole Rømer, 1676)
    ▶ from timing of Jupiter’s moons
  ▶ No distances to stars
  ▶ No galaxies

Newtonian Cosmology

• Newton assumed a static universe
  ▶ Problem: unstable unless completely homogeneous
    ▶ Consider mass \( m \) on edge of sphere of mass \( M \) and radius \( r \)
    ▶ mass outside sphere does not contribute (if spherically symmetric)
    ▶ mass inside behaves like central point mass
  ▶ if there exists an overdense region, everything will fall into it
Olbers’ Paradox

- Named for Wilhelm Olbers, but known to Kepler and Halley
  - Consider spherical shell of radius $r$ and thickness $dr$
  - Number of stars in this shell is $4\pi r^2 n \, dr$, where $n$ is number density of stars
  - Light from each star is $L/4\pi r^2$, therefore light from shell is $nL \, dr$, independent of $r$
  - therefore, in infinite universe, night sky should be infinitely bright (or at least as bright as typical stellar surface – stars themselves block light from behind them)
- Why is the sky dark at night?

Resolution(s)

- Light is absorbed by intervening dust
  - suggested by Olbers
    - doesn’t work: dust will heat up over time until it reaches the same temperature as the stars that illuminate it
    - (I’m not sure 17th century astronomers would have realised this)
- Universe has finite size
  - suggested by Kepler
    - this works (integral is truncated at finite $r$)
    - but now Newtonian universe will definitely collapse
- Universe has finite age
  - equivalent to finite size if speed of light finite
    - light from stars more than $ct$ distant has not had time to reach us
    - (currently accepted explanation)
- Universe is expanding
  - effective temperature of distant starlight is redshifted down
    - this effect not known until 19th century
    - (does work, but does not dominate (for stars) in current models)

*Olbers + Newton could have led to prediction of expanding/contracting universe*
Further developments

- James Bradley, 1728: aberration
  - proves that the Earth orbits the Sun
  - also allowed Bradley to calculate the speed of light to an accuracy of better than 1%
- Friedrich Bessel, 1838: parallax
  - distances of nearby stars
    - a discovery whose time had come: 3 good measurements in the same year by 3 independent people, after 2000 years of searching!
- Michelson and Morley, 1887: no aether drift
  - the speed of light does not depend on the Earth’s motion

State of Play ~1900

- We know
  - speed of light
  - distance to nearby stars
  - the Earth is at least several million years old
- Our toolkit includes
  - Newtonian mechanics
  - Newtonian gravity
  - Maxwell’s electromagnetism
- We don’t know
  - galaxies exist
  - the universe is expanding
  - the Earth is several billion years old
- We are worried about
  - conflict between geology and physics regarding age of Earth
  - about to be resolved
  - lack of aether drift