Chapter 34: Cosmology

According to the current models of the stellar life cycle, our sun will eventually become a

- a) Cloud of hydrogen gas
- b) Protostar
- c) Neutron star
- d) Black hole
- e) White dwarf

Cosmology: How the Universe Works

- Cosmology is the study of the structure and dynamics of the universe. To understand the universe we need to be able to tell
  1. Where things are
  2. How things are moving

The Astronomical Distance Ladder

- Methods for measuring distance
  - Radar ranging: works in the solar system
  - Triangulation: can be used up to 3,000 light years (nearest 120,000 stars)
  - Brightness-distance: works for any object where we can measure the brightness of the light arriving at earth and also have some way of knowing how bright the object "really" is (i.e. its brightness at a standard distance).

The Basic Idea Behind Finding Distances to Stars:

- "Real" brightness at a standard distance
- Farther away
- Farther away still

- We measure the brightness we see.
- We infer the real brightness.
- We calculate the distance from the difference between the apparent and absolute brightness.

Color-Brightness Relation

- The next rung on the distance ladder is from the relation between brightness and color.
- Star colors and brightnesses are determined by their masses.
Variable Stars as Distance Indicators
- A class of very bright stars called Cepheids, have a tight relation between their real brightness and their pulsation periods.
- Pulsation period → real brightness
- Compare measured brightness to real brightness → distance
- The primary mission of the Hubble Space Telescope was to find distances to nearby galaxies using Cepheid variable stars.

Type 1a Supernovae
- Certain types of supernovae have a predictable (very high) brightness. When we observe them we can tell how far their galaxy is from our own, even at very great distances.

A Vast Universe of Galaxies
- Anciently mankind thought that the universe was the solar system inside a sphere of stars.
- By the 1900s we knew the sun was just one of billions of stars within the Milky Way galaxy.
  - At this time the Milky Way was thought to be the entire universe.

William Parsons studied external Galaxies, but thought they were solar systems forming in the Milky Way
- The "Leviathan of Parsonstown" Parsons' 72-inch telescope
- William Parsons, 3rd Earl of Rosse

External Galaxies
- It wasn't until 1923 that we fully realized the universe consisted of more than the Milky Way.
- In 1923 Edwin Hubble determined that Cepheid variable stars in the Andromeda galaxy are 2.5 million light-years away.
- Since the Milky Way is only 100,000 light-years across, it became apparent that Andromeda was a separate system of stars.

We are not alone in the universe
- Soon it was realized that the spiral-shaped "nebula" were galaxies of stars similar to the Milky Way.
  - On average over 100 billion stars per galaxy!
  - Huge! The universe itself is only 10^2 time larger than a typical galaxy.
  - At least 50 billion of them.
The Hubble Deep Field

Elliptical Galaxies (20%)

Spiral Galaxies (75%)

Barred Spirals
Irregular/Peculiar (5%)  

Galaxy Clusters  
- Galaxies are held together in small to large groups by gravity.

Harlow Shapley was able to point out that we are not at the center of the galaxy  
- He found the position by measuring distances to the globular star clusters that orbited about the center of the Milky Way.

Position of the Sun in the Milky Way  
- The sun is 2/3 the way from the galaxy center to the edge.  
- Its position was found by measuring distances to the globular star clusters that orbited about the center of the Milky Way.  
- Variable stars were used to find the distances.

Cosmological Redshift and The Doppler Effect  
- A profound discovery of the early 1900s was that all distant galaxies have their absorption and emission spectral lines shifted to the red.  
- The amount of the shift is related to the speed of the galaxy.  
- Shift can be found because spectral emission lines have a characteristic pattern.

Hubble Law  
- The speed a galaxy moves away from us is proportional to its distance: The farther away the galaxy is, the faster it recedes.  
- The Hubble Law is used to find distances to the farthest galaxies.
Because all distant galaxies are moving away from us (and hence are red-shifted) we know that the universe is expanding.

- If the universe is expanding, the farther away two galaxies are, the faster they move apart.
- Also, all galaxies would appear to be moving away from all other galaxies so our view is not unique.

Types of Cosmologies

- Early ideas of the universe held that it was:
  - Infinitely old
  - Infinitely large
  - Unchanging in time
- But this cannot be true because
  - The universe is seen to be expanding and thus it is changing with time.
  - An infinitely large and old universe would never know darkness. This is Olber's paradox.

Olbers' Paradox

- All lines of sight end on a star! The sky should be ablaze with starlight!
- The solution is that the universe has a time of creation
  - Light has not had time to reach us from the greatest distances
  - Glowing stars and galaxies have not always existed.

The observed expansion of the universe has led to the only currently viable cosmological theory: The Big Bang

- The universe was created about 13.7 billion years ago, and began as a great infusion of pure energy
- Space expanded from that point in time. The energy cooled into matter.

Fred Hoyle

- Fred Hoyle gave the Big Bang theory its name in a mocking manner, but it stuck
- Worked to disprove it, because it required an act of creation.
- To date, it is the best theory we have to describe the creation and development of the universe.

Experimental Evidence

- Cosmological red shift
  - Everything is moving away from us
- Helium/hydrogen ratio (25%/75%)
  - Fusion early after the big bang would produce that ratio of H to He
Evidence Supporting the Big Bang

- We see a faint glow left from the original high temperatures
  - Called the Cosmic Microwave Background or 3° K Background Radiation.

Looking back in time

- A quasar is a supermassive black hole radiating through its accretion disk.
- They are formed by the collapse of supermassive stars that burned very quickly.
- Because they are so bright, they can be seen at extraordinarily large distances, and allow us to calibrate the age of the universe (about 13.7 billion years).

Big-Bang Theory

- The universe began with an incredibly dense concentration of mass energy.
- In the process of rapid expansion and cooling matter was formed:
  - Point-like particles (electrons, quarks, photons, etc.)
  - Nucleons (protons and neutrons)
  - Simple nuclei (hydrogen and helium)
  - More complex nuclei, atoms, and molecules

As the universe expanded, it would have cooled down

The Ultimate Fate of the Universe

- Gravity always pulls, never pushes, so the expansion must slow down unless there is another force pushing out.
- Not enough mass: open universe
- Just right: flat universe
- Too much mass: closed universe (big crunch)
- Another Force:
  - Dynamomy universe
  - This is what we think is happening as best we can observe.