The Fate of the Universe
Learning Objectives

- How are the shape and the fate of the Universe related? How does this relate to the total amount of gravity and so the total amount of stuff (i.e. mass) in the Universe?
- What *shape* are open, closed and flat Universes? Which contains the most mass? What is the critical density?
- What are the ultimate fates of open, closed and flat Universes? What are the Big Chill and the Big Crunch?
- How does the CMB demonstrate that the Universe is flat?
- How do type Ia supernovas demonstrate the Universe is becoming more *open*? How does this suggest that our Universe has started to accelerate? What is Dark Energy?
- What is the fate of a Dark-Energy-dominated Universe?
The Shape of Fate

- The Universe’s fate is governed by its *shape*
- Think about it like this….part one:
  - Shape:
    - If there is *lots* of gravity then all space pulls on all other space and space is curved in on itself
  - Fate:
    - If there is *lots* of gravity then gravity beats the expansion of the Universe and the Universe eventually collapses again
The Shape of Fate

- The Universe’s fate is governed by its *shape*
- Think about it like this….part two:
  - **Shape:**
    - If there is *little* gravity then space doesn’t pull much on other space and space curves away from itself
  - **Fate:**
    - If there is *little* gravity then the expansion of the Universe beats gravity and the Universe expands *forever*
The Shape of Fate

- The Universe’s fate is governed by its *shape*
- Think about it like this….part three:
  - **Shape:**
    - If there is *just enough* gravity then space pulls on itself in a perfectly balanced way and doesn’t curve towards or away from itself
  - **Fate:**
    - If there is *just enough* gravity then the Universe’s expansion balances gravity and the Universe stops expanding at some point
The Shape of Fate

- The Universe’s fate is governed by its *shape*

- Three possibilities:
  - **Flat** - gravity and the expansion are balanced, the expansion will stop in the *very* distant future
    - Just enough stuff for gravity to perfectly balance the expansion is called the *critical density*
  - **Closed** - gravity of matter is strong enough that space recollapses
  - **Open** - the expansion will continue forever
Types of Universes

Distance to some particular galaxy

- open
- flat
- closed

The Big Chill
The Big Crunch

start now time future
An open or flat Universe will end in a **Big Chill**:
- Galaxies eventually exhaust their gas supply
- No more new stars
- Old stars eventually die, leaving only dust and stellar corpses

A closed Universe will end in a **Big Crunch**:
- Expansion will stop, gravity will win, and the Universe will collapse back in on itself
- Ends as it began, incredibly hot and dense
  - And round and round we go?
Negatively Curved Space
(How an open Universe looks)
Remember - Tiny Temperature Variations in the CMB

- Cosmological variations are less than 1 part in 100,000 around the 2.73 K background temperature of the Universe.
The CMB and the Shape of the Universe

- **a** If universe is closed, hot spots appear larger than actual size
- **b** If universe is flat, hot spots appear actual size
- **c** If universe is open, hot spots appear smaller than actual size
A Census of Matter

% of critical density

~25% Count up all the Dark matter
   Needed to explain:
   galaxy rotation curves
   clusters of galaxies

~5% Count up all the Ordinary matter
   Made of protons, neutrons, electrons...
   like you and me

~30% Total Not enough to make the Universe flat?!?!?!?!?
There is something weird going on with the expansion.

The first evidence for this was that distant type Ia supernovas appear dimmer (i.e. farther away) than their redshift suggests they should be, unless the expansion of the Universe is speeding up.
The Universe is measurably, geometrically flat
But the amount of matter in the Universe isn’t enough to generate sufficient gravity to make the Universe flat
So, a new type of stuff which physicists have decided to call dark energy seems to exist
   It’s not obviously related to dark matter
   It acts like a repulsive form of gravity
Dark energy is actually accelerating the Universe (its also called cosmic acceleration)
Confirmed by supernova measurements
If the expansion of the Universe accelerated at some point then these distances are larger than advertised in earlier lectures (but the principle of an horizon etc. is the same, it’s just that the math is a bit trickier)
The Distant Future

- Dark Energy makes us blissfully ignorant
- At the time of the CMB the Universe is flat
- But the expansion is accelerating – so the Universe is becoming more open
- So open, that eventually even the Andromeda galaxy could be pushed to a distance that is farther away than the time needed for its light to reach us
- The fate of our Universe depends on the true nature of Dark Energy
Types of Universes

Distance to some particular galaxy

The Big Chill

The Big Crunch

start now time future

open

acceleration

flat

closed
Next Time

Extrasolar Planets