A Journey Back in Time to the Big Bang

- Pulling back from the WMAP spacecraft, we see that we are a tiny speck in our Milky Way Galaxy.
- As the journey continues, we see that the Milky Way is but a tiny speck in the Universe as we pass quasars that were some of the early brightest structures that we can detect with conventional instruments.
- Finally we arrive at the beginning of time as we understand it. The super heated, roiling ionized hydrogen gas of a universe newly made glows throughout the universe. The energy from sonically condensed and rarified ripples in this gas, released as it cooled to 3000°K, is the basis for the data collected by WMAP.
- Credit: NASA / WMAP Science Team, http://map.gsfc.nasa.gov/media/030657/index.html

Current Assignments ...

For today
- Read Sections 11.2 - 11.7

Office hours: 3-4 Tuesdays & Thursdays

For Lecture 19
- Read Chapter 12

Homework #3
- Late deadline 11:00 AM, Friday, March 15

Homework #4
- Posted March 7. Due 11:00 AM, Friday, March 22

Writing Assignment #2
- Posted Feb. 28. Due 11:00 AM, Thursday, April 4

Suggested Conceptual Exercises
- Ch. 11: 1,3,5,7,9,11,13,15,17,19,21,23,25,27,29,31,33,35,37,39,41,43,45

Tutorial #8

Review of Lecture 17

Textbook, Sections 11.1 - 11.2
- General relativity
- The big bang

"Matter tells spacetime how to curve, and curved spacetime tells matter how to move".

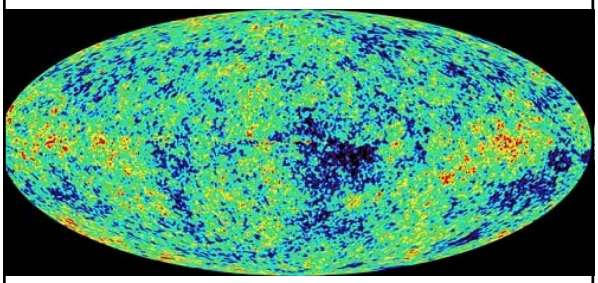
Plan for Lecture 18

Textbook, Sections 11.2 - 11.7
- The big bang
- The shape of the universe
- Dark matter and dark energy
- Cosmic inflation

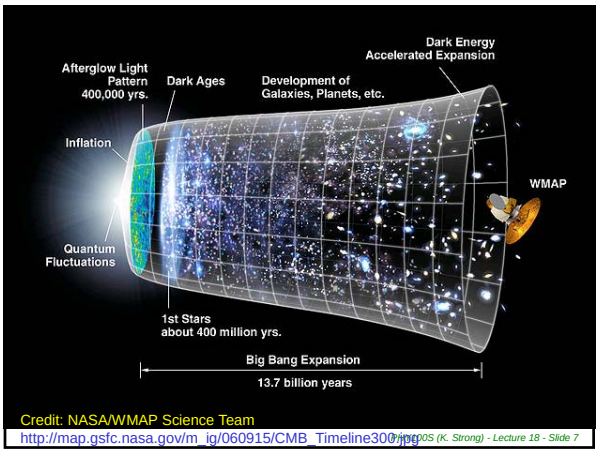
From L17: Evidence for the Big Bang

1. In 1929 it was discovered that the universe was expanding; extrapolating backwards led to the big bang.
2. The cosmic microwave background (CMB), left over from the big bang, has been observed and agrees with theoretical predictions.
3. The CMB has been mapped in great detail; its small variations are just as they should be to create galaxies as we see them today.
4. Theory predicts just which elements, and in what ratios, should be produced in the big bang; these agree well with observations.

The Oldest Light in the Universe



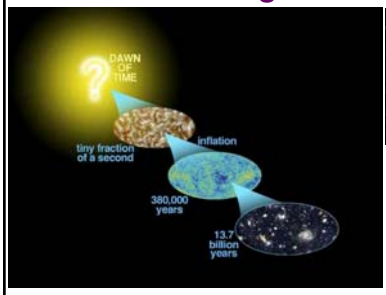
NASA's Wilkinson Microwave Anisotropy Probe (WMAP)
http://science.nasa.gov/headlines/y2003/11feb_map.htm
Credit: NASA/WMAP Science Team

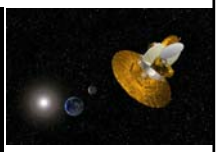


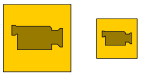
Credit: NASA/WMAP Science Team

http://map.gsfc.nasa.gov/m_ig/060915/CMB_Timeline300.jpg

The Oldest Light in the Universe







http://map.gsfc.nasa.gov/media/030651/index.html

NASA's Wilkinson Microwave Anisotropy Probe (WMAP)

http://science.nasa.gov/headlines/y2003/11feb_map.htm

Credit: NASA/WMAP Science Team

The Expanding Universe

- The big bang was not really an explosion.
- It created space and time.
- The expanding universe continues to create spacetime.
- It is not expanding into anything.

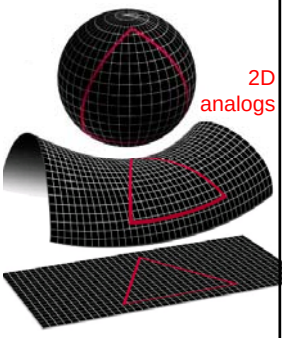
Textbook Figure 11.14

The expanding surface of a balloon is a 2D analog of 3D space.

The Shape of the Universe

Three possibilities:

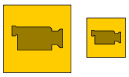
- Closed - like the surface of a sphere. Parallel lines eventually meet.
- Open - like a saddle, infinite in extent. Parallel lines diverge.
- Flat - no curvature, extends infinitely far in all directions. Parallel lines remain parallel.



2D analogs

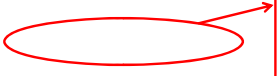
http://map.gsfc.nasa.gov/universe/bb_concepts.html

Which Shape Is the Universe?



http://map.gsfc.nasa.gov/media/030639/index.html

Textbook Figure 11.16



The measured angle is close to 1° → consistent with a flat universe.

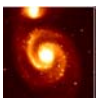
What is the Universe Made Of?

Many forms of matter:

http://astro.berkeley.edu/~mwhite/darkmatter/dm.html

- protons, neutrons, electrons (form atoms)
- neutrinos
- black holes
  - → regions of spacetime from which nothing can escape, even light
- dark matter
  - → does not interact with EM radiation
  - → can be detected due to its gravitational effects
  - → comprises most of the mass of the universe

Not dark matter



Dark matter

What Is Dark Matter?

We don't know! Some possibilities:

- MACHOs (MAssive Compact Halo Objects), including brown dwarfs
  - → Dim objects, intermediate between stars and planets, that are not luminous enough to be directly detectable by telescopes.
- Supermassive black holes
- WIMPs - Weakly Interacting Massive Particles
  - → New forms of matter, maybe particles produced shortly after the big bang.

Detection of Dark Matter - 1

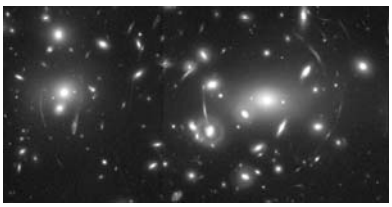
- By measuring the motions of stars and gas, astronomers can "weigh" galaxies.
- The mass of the galaxies, including the Milky Way, is ~10 times larger than the mass that can be associated with stars, gas and dust.

Textbook Figure 11.20

→ **Dark matter provides this mass.**

Detection of Dark Matter - 2

- Galaxies can also be "weighed" by measuring how they distort light coming from other galaxies (gravitational lensing)
  - → Again, there is missing mass - dark matter.



NASA Hubble Space Telescope image of the rich galaxy cluster, Abell 2218.
The arc-like pattern spread across the picture like a spider web is an illusion caused by the gravitational field of the cluster.

Credits: W.Couch (University of New South Wales), R. Ellis (Cambridge University), and NASA
http://hubblesite.org/newscenter/archive/releases/1995/14/image/a/

The Accelerating Universe

- Because of the gravitational attraction between all the matter in the universe, we might expect its expansion to be slowing.
- 1998 - Observations of exploding supernovas gave information about distances, speeds, and accelerations across the universe.
  - →The most distant galaxies were too far away to be explained without acceleration.
- The result: The expansion of the universe is apparently accelerating!

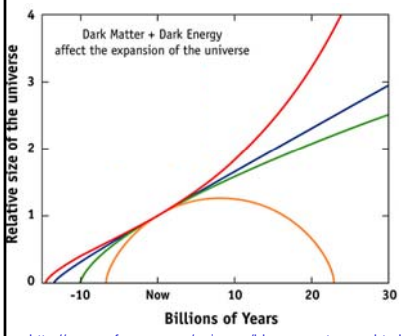
Dark Energy

- This acceleration cannot be driven by any matter or field that we know of
  - → It must be driven by something new.
- This energy that is slowly pushing the universe apart is called dark energy.
- When the mass of the dark energy and dark matter is added to the luminous and non-luminous matter, the result is just enough for the universe to be flat.

What is the Universe Made Of?

Textbook Figure 11.21

The Fate of the Universe: endless expansion or big crunch?

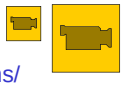


- Orange = closed, high density universe which expands for several billion years, then ultimately turns around and collapses under its own weight.
- Green = flat, critical density universe in which the expansion rate continually slows down (the curves becomes ever more horizontal).
- Blue = open, low density universe whose expansion is also slowing down, but not as much as the previous two because the pull of gravity is not as strong.
- Red = universe in which a large fraction of the matter is in a form dubbed "dark energy" which is causing the expansion of the universe to speed up (accelerate).
- There is growing evidence that our universe is following the red curve.

http://map.gsfc.nasa.gov/universe/bb_concepts_exp.html
http://map.gsfc.nasa.gov/universe/uni_fate.html

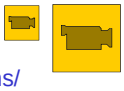
The Fate of the Universe

Universe 1 - accelerated expansion with dark energy



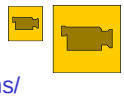
- http://snap.lbl.gov/multimedia/animations/accel_full.avi

Universe 2 - the universal expansion, stopping and reversing



- http://snap.lbl.gov/multimedia/animations/Expand&contract_full.avi

Universe 3 - constant expansion with no dark energy



- http://snap.lbl.gov/multimedia/animations/Expanding_full.avi