How Did the Universe Begin?

- As we will discuss in this lecture, it looks like the Universe started about 14 billion years ago and has been expanding (space stretching) ever since.

- The model of what happened is called the Big Bang. We will discuss in this lecture why most people accept the Big Bang model.

- There is a lot we don’t understand. What came before? What caused the big bang? Why is there more matter than anti-matter in the Universe?
The Pace of Science (1)

- Astronomers have studied the sky for thousands of years, but 90% of all astronomical information has been obtained since 1900. For example, in 1900 scientists believed that the universe:
  - Was infinitely old
  - Was infinitely large
  - Contained only one galaxy (the Milky Way)
  - Did not change with time
  - Was uniform throughout (problem with Olber’s paradox)
- All of these are false!
What do We Know About the Universe?

(Left) A picture of distant galaxies taken by the Hubble Space Telescope.

There are approximately 200 billion galaxies, each composed of billions of stars.

Looking at distant galaxies is like looking back in time.
Sloan Digital Sky Survey of Galaxies
Edwin Hubble

- In 1922 Edwin Hubble measured the brightness of variable stars in the Andromeda galaxy.
- He discovered that the Andromeda galaxy was about 3 million light years away.
- He was the first person to demonstrate the size of the Universe and that the Milky Way is not the only galaxy.
Hubble Expansion

- Because he was able to measure distance, Hubble observed that on average all galaxies seem to be moving away from us.

- The speed is related to distance. Galaxies farther away are moving faster.

- We can tell how fast something is moving away by the Doppler effect.

No matter where you are, everything is moving away!
Hubble’s Law

- The further away an object is, the faster it is receding.
- The Hubble Constant: $H_0 = 77$ km/s/Mpc
- Age of the Universe $\approx 1/H_0$

Some data for Type I supernovae.
The Pace of Science (2)

- “The universe is 10-15 billion years old.” – Mrs. McClanahan, Dr. Folden’s eighth grade science teacher (1991).

- “The universe is 13.7 ± 0.2 billion years old.” – WMAP survey team (2003).

- This is a tremendous increase in precision in only 12 years!

Lecture 19 ISP209 Spring 2007
Microwave Map of the Sky

Earth with the same projection

WMAP Observatory

WMAP Data

Earth with the same projection

2007
What We Have Learned from WMAP

- The Universe is 13.7 billion years old
- The Universe is flat and will continue to expand forever: the mass of the universe is at the “critical mass”.
- The Universe is made of mostly an unknown form of matter and an unknown form of energy (dark).
Why does time always move in one direction?

- Inflation during the Big Bang resulted in a universe that had a very low entropy, much too low for its size. It was like the Universe started with all heads.
- Hence, everything in the universe moves toward reaching the correct amount of entropy.
- Time has a direction because going back in time would imply the entropy could be decreased. That is very improbable.
- The universe tends toward increasing entropy.
- What is time?
The existence of an unknown scalar field caused the rapid inflation of the Universe. Space stretched by $10^{50}$ times!
The History of the Universe

What we see as we look away from the Earth

We are effectively looking back in time.
Evidence for the Big Bang

- The expansion of the universe: All galaxies appear to be moving away from us.

- The abundances of the lightest elements produced in the Big Bang: the universe is mostly hydrogen and helium.

- The cosmic microwave background radiation: It looks like we are in the middle of a big oven with a temperature of ~3 Kelvin.
### History of the Universe in One Year

- **Recorded History:** Last 15 seconds!
- **Human Lifetime:** ~0.18 seconds (on this scale)

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<thead>
<tr>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
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<td><img src="image9" alt="Galaxy" /></td>
<td><img src="image10" alt="Brain" /></td>
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<tr>
<td>New Year's Day: The Big Bang</td>
<td>Milky Way forms</td>
<td>Sun and planets form</td>
<td>Oldest known life (single celled)</td>
<td>First multi-cellular organisms</td>
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<td>15</td>
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<td>20</td>
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<td>22</td>
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<td>First dinosaurs appear</td>
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<th>31</th>
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<tbody>
<tr>
<td>10:15am</td>
<td>Apes appear</td>
<td>First human ancestors to walk upright</td>
</tr>
<tr>
<td>9:24pm</td>
<td>Homo erectus appears</td>
<td>Anatomically modern humans appear</td>
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<tr>
<td>10:48pm</td>
<td>Invention of writing</td>
<td>Pyramids built in Egypt</td>
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<tr>
<td>11:59:45pm</td>
<td>1 second before midnight: Voyage of Christopher Columbus</td>
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What is the Fate of the Universe?

- The current age of the Universe is 13.7 billion years (or about $10^{10}$ years).
- $10^{100}$ years: All stars will have used up their nuclear fuel.
- $10^{100}$ to $10^{150}$ years: The “Dark Ages”
- $10^{150}$ years: All black holes will have evaporated.
- $10^{1000}$ years: The Universe will reach its lowest energy state.