Wednesday April 13

Syllabus and class notes are at: www.as.utexas.edu

Reading for this week: Chapter 15

If you want help on anything covered in the course, come to discussion session Thursday at 6:00 in RLM 15.216B or to our office hours.

Come up to the front and pick up your test.
The University of Texas at Austin
The Donald D. Harrington Fellows Program presents
A Symposium on
Abrupt Climate Change

Program:
Afternoon: 1:30 - 4:45
A.C.E.S. Building, Ávaya Auditorium Rm. 2.302

Richard Alley (Penn State)
Thomas Stocker (Bern, Switzerland)
Philip Marcus (UC Berkeley)

Reception: 5:00 - 6:30 A.C.E.S. Atrium
Evening: 7:00 - 8:00
Lonnie Thompson (Ohio State)

Environmental Science Institute’s ESI
Hot Science - Cool Talks Outreach Lecture Series
Welch Hall Rm. 2.224

Friday, April 15, 2005
UT-Austin Campus
1:30 - 8:00 pm
Open to the public

www.esi.utexas.edu/spotlights/harrington.html

More information at:
www.esi.utexas.edu

Images by Michael Van Weer, NASA, NSF, DAP, and ResourceFusion
Topics for this week

How does the big bang theory explain Hubble’s law?
How does the big bang theory explain the microwave background radiation?
Describe some of the events that occurred in the first few minutes after the big bang.
Describe how supernovae are used to measure the rate of expansion of the Universe in the past.
Describe how matter and energy cause the expansion of the Universe to accelerate or decelerate.
Do we think the Universe is finite or infinite?
Do we think the Universe will eventually collapse or expand forever?
Hubble’s Law and the Big Bang Theory

Distant galaxies are moving away from us with speeds proportional to their distances from us. Our favored interpretation is that the Universe is expanding, so the space between the galaxies is expanding. But other ideas have been suggested.

Do we have other evidence that the Universe actually began with an explosion? Our best evidence involves microwave radiation discovered 40 years ago.
Radiation from the Early Universe

In ~1950 George Gamow predicted that there should be radiation left over from the early Universe.

About 400,000 years after the big bang, the Universe was filled with ionized gas at a temperature of 3000 K, and was 1000 times smaller than it now is.

The ionized gas emitted black body radiation like a glowing solid at 3000 K, or a red giant star.

As the Universe cooled below 3000 K, protons and electrons combined to make hydrogen atoms.

The Universe then became transparent, and the photons emitted by the ionized gas could fly across space, and should still be around.

Why don’t we see a 3000 K glow in all directions?
The Background Radiation

The light that is reaching us now has had its wavelengths Doppler shifted by the expansion of the Universe. For this purpose it is easiest to look at the Doppler shift as being a stretching of wavelengths of light by the same factor as distances in the Universe have been stretched.

For 3000 K, $\lambda_{\text{max}} = 1 \mu \text{m}$. Stretched by a factor of 1000, this light appears now with $\lambda_{\text{max}} = 1 \text{ mm}$. What temperature black body has $\lambda_{\text{max}} = 1 \text{ mm}$?
The present universe as it appears from our galaxy
The Microwave Background

The radiation predicted by Gamow should now look like black body radiation from an object at a temperature of 3K.

In 1964, Penzias and Wilson observed microwave radiation with a brightness corresponding to a 3K black body. This radiation is the redshifted radiation emitted by the hot gas that filled the Universe 400,000 years after the big bang.
$T = 2.735 \pm 0.06 \text{ K}$
Thinking farther back

If the Universe has been cooling as it expanded, and it was at a temperature of 3000K 400,000 yr after the big bang, it should have been even hotter earlier.

We can ask what the temperature was at different times and what should have been happening then.
Cooling in the big-bang universe

Formation of elements

Formation of galaxies

Recombination

Radiation dominates

Matter dominates

Time

1 s 1 min 1 h 1 day 1 y 10^2 y 10^4 y 10^6 y 10^8 y 10^10 y

Temperature (K)

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Before 400,000 ABB

\[ t = 10^{-6} \text{ sec} \quad T \sim 10^{13} \text{ K} \quad \gamma + \gamma \leftrightarrow p^+ + p^- \]

\[ t = 1 \text{ sec} \quad T \sim 10^{10} \text{ K} \quad \gamma + \gamma \leftrightarrow e^- + e^+ \]
\[ \quad p^+ + e^- \leftrightarrow n + \nu \]

\[ t = 2 \text{ min} \quad T \sim 10^9 \text{ K} \quad p^+ + n \leftrightarrow d^+ \]
\[ \quad d^+ + d^+ \leftrightarrow \text{He}^{++} \]
\[ \quad n \rightarrow p^+ + e^- + \nu \]

Heavier elements weren’t formed because \(^{8}\text{Be} \rightarrow 2 \quad ^{4}\text{He}\)

Where did the elements other than hydrogen in your body come from?
Even Earlier

The uniformity of the microwave background radiation is something of a puzzle.

The gas that emitted the radiation we see from one direction could not have communicated with the gas we see in the opposite direction (and won’t for another 13 billion years).

Why were these two regions of the Universe at the same temperature?

Our favored explanation is that they were once close enough together to communicate by light, but between $10^{-35}$ sec and $10^{-32}$ sec ABB the Universe grew in size by a factor of $10^{50}$.

This expansion is called inflation.