# Wednesday, Nov. 12

Syllabus, class notes, and homeworks are at:
www.as.utexas.edu → courses → AST 301, Lacy

Reading for this week: chapter 13.1, 13.2, 15

The help session this week (only) is in WEL 3.260 at 6:00 on Wednesday. (Note the unusual place and time.)

Homework question #1 is confusing. I tried to simplify it some on a revised version. (It is still not easy.) You can do either version.

# 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?

# The age of the Universe

We can calculate when the big bang occurred by asking how long it would have taken distant galaxies to get to where they are.

If different galaxies started out moving away from us faster than others did, and they all started at the same time, the ones moving away faster would have gotten farther by now.

If the galaxies' speeds have not changed we can calculate how long ago they started moving.

The time to travel a distance d at speed v is given by

time = distance / speed

If we use Hubble's law that speed = H x distance, we get

time = distance / (H x distance) = 1 / H

Using our best number for H, we get the time since the big bang = 13 billion years.

# Turning Hubble's law around

Once we know that more distant galaxies have greater redshifts, we can use a galaxy's redshift to estimate its distance.

speed = Hubble's constant x distance, so

distance = speed / Hubble's constant

From their redshifts, we know that most of the galaxies in the Hubble (Space Telescope) "Deep Field" picture are very distant.

Since light took a long time to get to us, we are seeing them as they were long ago.

# Expanding space

Even if Hubble's law would look the same from all places, is there actually some galaxy that we're all moving away from?

Does the Universe have a center or edges?

What is the Universe expanding into?

This isn't a problem if the Universe is infinite.

It would have no edges then.

But the Universe might be finite. We don't know.

Even then it would not have a center or edges.

Like the surface of a sphere has no center or edges.

The best way to look at the expansion of the Universe is to say that space is expanding.

# Stretching photons

Saying that space is expanding does not mean that galaxies are expanding or the solar system is expanding.

Gravity keeps the stars orbiting in a galaxy and the planets orbiting in the solar system. The sizes of their orbits don't change.

But the expansion of space does affect photons as they travel to us across space from distant galaxies.

As they travel through expanding space, the wavelength of the light in a photon is stretched.

If space stretches by a factor of 2 while a photon is traveling, the wavelength of the light also stretches by a factor of 2.

This is another way of looking at the redshifts of distant galaxies.

# 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, $\lambda_{max}$ = 1 $\mu$m.

Stretched by a factor of 1000, this light appears now with $\lambda_{max}$ = 1 mm.

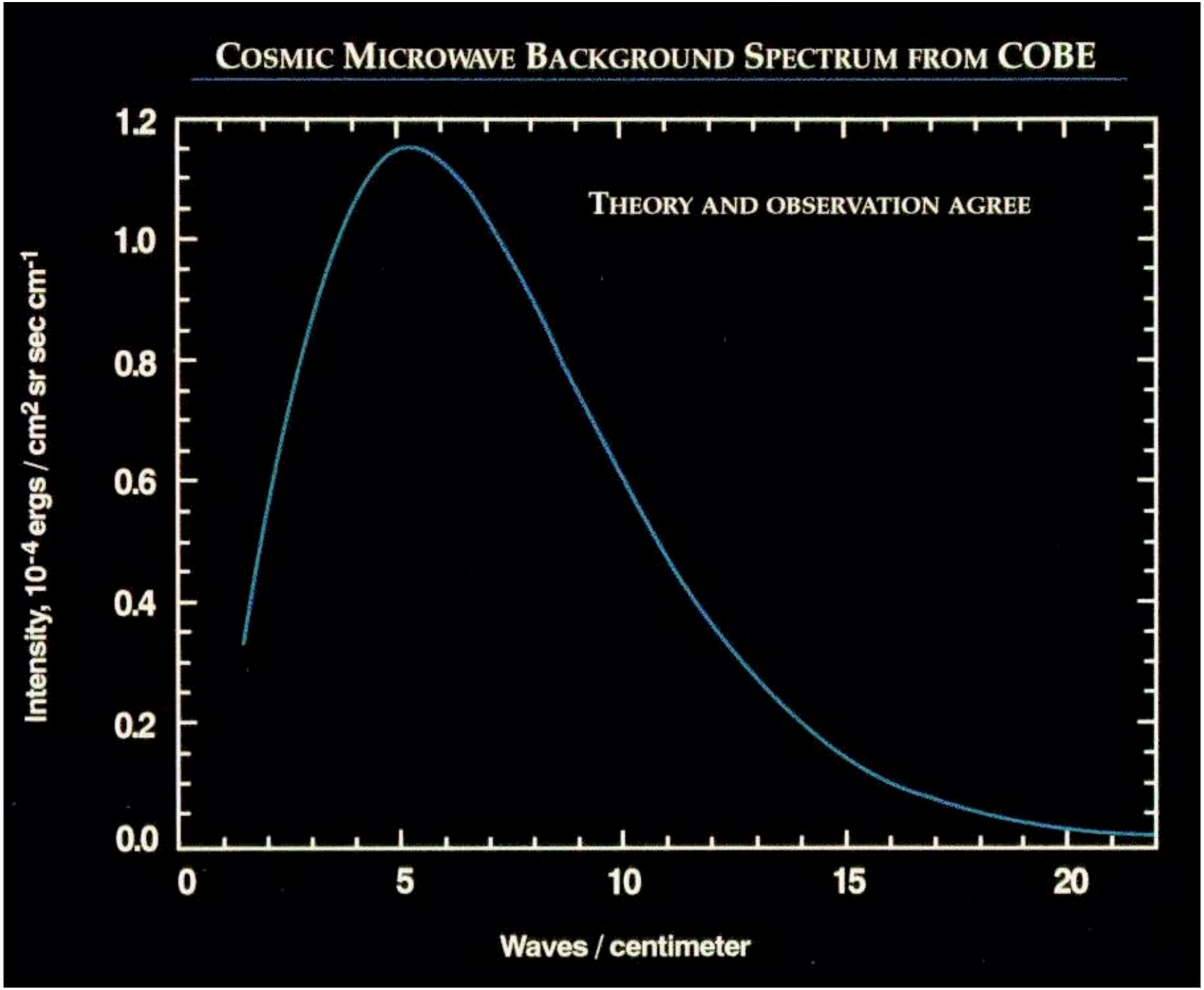
What temperature black body has $\lambda_{max}$ = 1 mm?

# 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.


COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10-4 ergs / cm2 sr sec cm-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter

# 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.

# Before 400,000ABB

| | | |
|---|---|---|
| $t = 10^{-6}$ sec | $T \sim 10^{13}$ K | $\gamma + \gamma \leftrightarrow p^+ + p^-$ |
| t = 1 sec | $T \sim 10^{10}$ K | $\gamma + \gamma \leftrightarrow e^- + e^+$ |
| | | $p^+ + e^- \leftrightarrow n + \nu$ |
| t = 2 min | $T \sim 10^9$ K | $p^+ + n \leftrightarrow d^+$ |
| | | $d^+ + d^+ \leftrightarrow He^{++}$ |
| | | $n \rightarrow p^+ + e^- + \nu$ |

Heavier elements weren't formed because $^8Be \rightarrow 2\ ^4He$

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