This evening

Course evaluation questionnaire, 15 minutes at beginning of class, conducted by Mr. Huang

There may be time for review at the end of this class. Please have those questions ready!

Blank copies of all the quizzes are available.
The April Brooks Observatory sessions

The one remaining special session for ASTR 1010 is tomorrow, Thursday, April 24, beginning at 8:45 PM.

You may also attend regular Friday public observing at Brooks, weather permitting, this Friday, April 25 or Friday, May 2. Bring a blue ticket.

Your report will be due at the final exam, Wednesday, April 30, or by email no later than 12 noon, Wednesday, May 7. Not required if you have already been to Brooks this semester & written a report.

Elevator to 5th floor of this building, walk up to 6th floor. Bring a blue ticket with your name and my name (Nancy Morrison) written on it. Extra blue tickets are available.
The last available planetarium shows are:

- Fridays, April 25, 7:30 PM, and **May 2, 8:30 PM**
- Saturdays, April 26 and May 2, 1:00 PM. Report due as noted above.

**Office hours next week**

- **Monday** 5–7 PM
- **Tuesday** 4–7 PM
- **Wednesday** 4–7 PM
About the final exam

Wednesday, 30 April 2008, 7:30–9:30 PM, MH 1005

Comprehensive

Between 75 and 100 multiple-choice questions similar to tests. Treatment of any questions beyond 75 is TBD.

Counts 37.5% of grade (75 points out of 200)

Study suggestions

• Old tests: make sure you understand missed questions
• Homework, especially frequently missed questions
• Look for connections across segments of course
Properties of the universe: recap

1. Space expands: all clusters of galaxies move apart at a rate proportional to distance
2. Large-scale filamentary structure
3. As we look farther away, we also look back in time.
4. Age of the universe - 2 estimates, which agree
5. Average density: equals the critical density
6. Accelerating expansion and dark energy
7. Cosmic microwave background with temperature $3^\circ$ K
8. Space is flat (not curved like the surface of a sphere)
The cosmic horizon

Since the expansion of the universe began, light has had time to travel across 14 billion light years of space. This distance represents a boundary to the universe, the cosmic horizon.

As time passes, the horizon expands (so the universe expands), and in the past it was much smaller.

When the light of the cosmic microwave background was emitted, the horizon was smaller than the background we see today.

So the different parts of the universe didn’t communicate with each other, and it’s impossible to explain why the microwave background is nearly uniform.
The solution of this “horizon problem” is the hypothesis of inflation, a brief period of very rapid expansion early in the history of the universe.

The uniformity of the primordial fireball was established before inflation, when the universe was smaller than its cosmic horizon.

Inflation also explains why the universe is flat (the “flatness problem”). It may have been curved before inflation, but if it was, inflation made it so large that it appears flat, just as the Earth appears flat to us who live on it.
The Big Bang

Run the clock backward to times when clusters of galaxies closer together, temperature and average density higher

Reach a time when the radius of the entire universe was zero.

When time and the cosmic expansion began: the Big Bang

The Big Bang may have resulted from quantum fluctuations in the energy of empty space, which is zero on average but with uncertainty.
Early history of the universe

- A split second after the Big Bang, time existed and physical laws applied.

- During the first second, the universe was extremely hot, dense and filled with high-energy radiation, mostly gamma rays.

- Matter consisted of protons and electrons. Atomic nuclei, if any existed, could not have stayed bound together; the gamma rays would have split them apart.

- Because of the expansion of the universe, the gamma rays were “stretched” and lost energy.
• After about 3 minutes, nuclear fusion could occur. Protons fused to make helium in a process similar to the proton-proton chain.

• But the universe continued to expand and cool, allowing time enough for about 23% of the mass in the universe to be converted from hydrogen to helium. No time for any heavier elements to form.
  This means that 10% of the atoms today are helium atoms.

• After about 400,000 years of expansion, the universe was cool enough to allow hydrogen atoms to form by combination of protons and electrons: about 3,000 K.
• Once the hydrogen recombined, it could no longer absorb the prevailing thermal radiation, so space became *transparent*, and photons could travel freely over great distances.

• Before this time, the universe was opaque, and photons were constantly being absorbed and re-emitted, also known as *scattered*.

• Now, we are seeing them as of the last time they interacted with matter, as if they were being radiated from a *surface of last scattering*. This is the cosmic background radiation, now redshifted so that its temperature is $3^\circ$ K.
• Also at the time of recombination, the formation of galaxies and stars became possible.

Time line of the universe

[On linked page, scroll down to see image shown.]
Origin of the elements

• Hydrogen: primordial. Protons came into being a split second after the universe itself did.

• Helium: built up by nuclear fusion about 3 minutes after the Big Bang (as did traces of lithium, beryllium, boron).

• All other elements: built up by nuclear fusion in and by stars.
  – Thermonuclear fusion in the core
  – Various other processes occurring in supernova explosions, etc.
– Some of the heavy elements made in a massive star’s core are thrown out into space during the supernova explosion.

– There, it forms part of the interstellar material.

– Eventually, it is incorporated into a later-generation star or planet.
More insights into origins

- Galaxies
- Stars
- The solar system and other planetary systems
- The Earth
- Life on Earth, or at least carbon-bearing compounds, its raw materials
Universe before inflation

Universe after inflation

Horizon

Horizons not to scale