- Honor credit– need to have those papers this week!
- THE FINAL IS DECEMBER 15th: 7-10pm!
- Today is last lecture with material. Friday will be a review session only.
- I will have office hours Thursday and Friday from 10:30 to 11:30, and Monday 11:45 to 12:45, or by appointment.

Final Exam

- **Date:** Monday, Dec 15th
- **Place and Time**: In the Greg 100 classroom 7pm until 10pm. The test is designed for 2 hours.
- **Format**: 80 multiple choice problems and 4 bonus questions (extra credit).
- **Bring:**
  - Yourself, well-rested and well-studied.
  - A student ID
  - A #2 pencil
  - On the test you will be given numbers or equations (if any) that you will need. You may **not** use your book or your class notes. However, you **may** bring ***1 piece of regular, 8.5"×11" paper*** with notes written on it. You may write whatever notes you like on (both sides of) the paper. It is a very good idea to write your own sheet, as the exercise of deciding what is important, organizing it, and writing it down, is a good way to study.

Final Exam

- **Topics included**: There will be 20 question on the material from Exam #1, 20 questions on the material from Exam #2, and 40 questions on the new material– Extraterrestrial life to the early Universe. Lecture and reading material are both included. My goal is to test for understanding of the concepts we have discussed, and how they fit together.
- **Study tips.** We have covered a lot of material in a short time, so here are some tips on how to approach your studies for the exam.
  - Topics covered in lectures should be stressed.
  - Homework questions have good examples of questions that may show up on the exam. An excellent way to begin studying is to review the homework problems, particularly those you missed (or got right but were not so sure about). Be sure you understand what the right answer is, and more importantly, **why** it is right.
  - You will need to understand and be able to use any equations that have been introduced in class. Calculations using these equations will be kept simple--it is possible to do the exam without a calculator, but you can bring one if you wish.

Outline

- How Illinois is probing the early Universe.
- The probably origin of Dark Matter.
- The Big Bang explains the Early Universe.
  - The Planck Era
  - The GUT epoch
  - The inflationary period…
- The Big Bang Nucleosynthesis– making hydrogen, deuterium, helium, and lithium.
- What is the fate of the Universe?
- Matter and antimatter.

THE VERY EARLY UNIVERSE

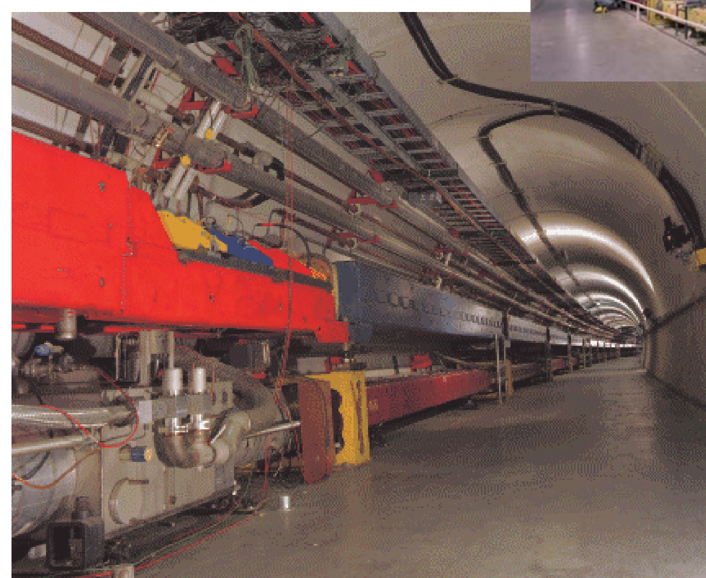
Since Big Bang works well so far, we have confidence to think about times earlier still:

t << 1 sec !

- Temperature and energies are ***ultrahigh***

Q: How to probe such high energies?
Hint: it's in the Great State of Illinois

Fermilab



INNER SPACE / OUTER SPACE

Fermilab is a telescope!

Probes conditions in Universe at 10^{-12} s

…but also…

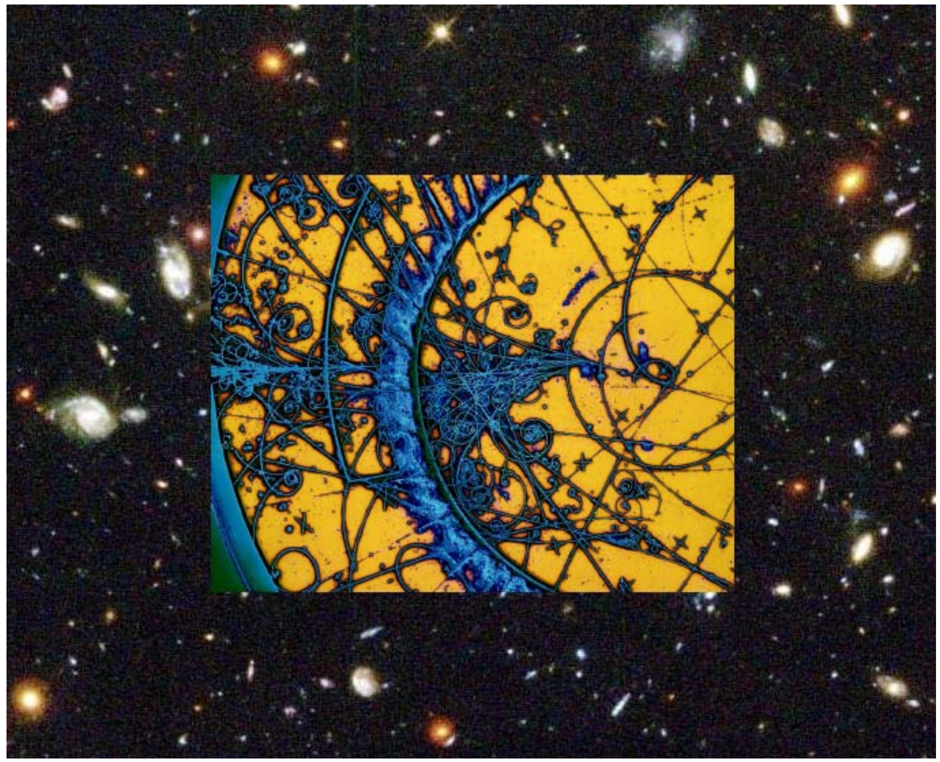
"The Universe is the poor man's accelerator"

Probes conditions inaccessible at laboratories

The Early Universe:
ORIGIN OF DARK MATTER?

Exotic particles are created in high-energy collisions

- Perhaps these are dark matter?
- Leftover “fossils" of the very early universe!



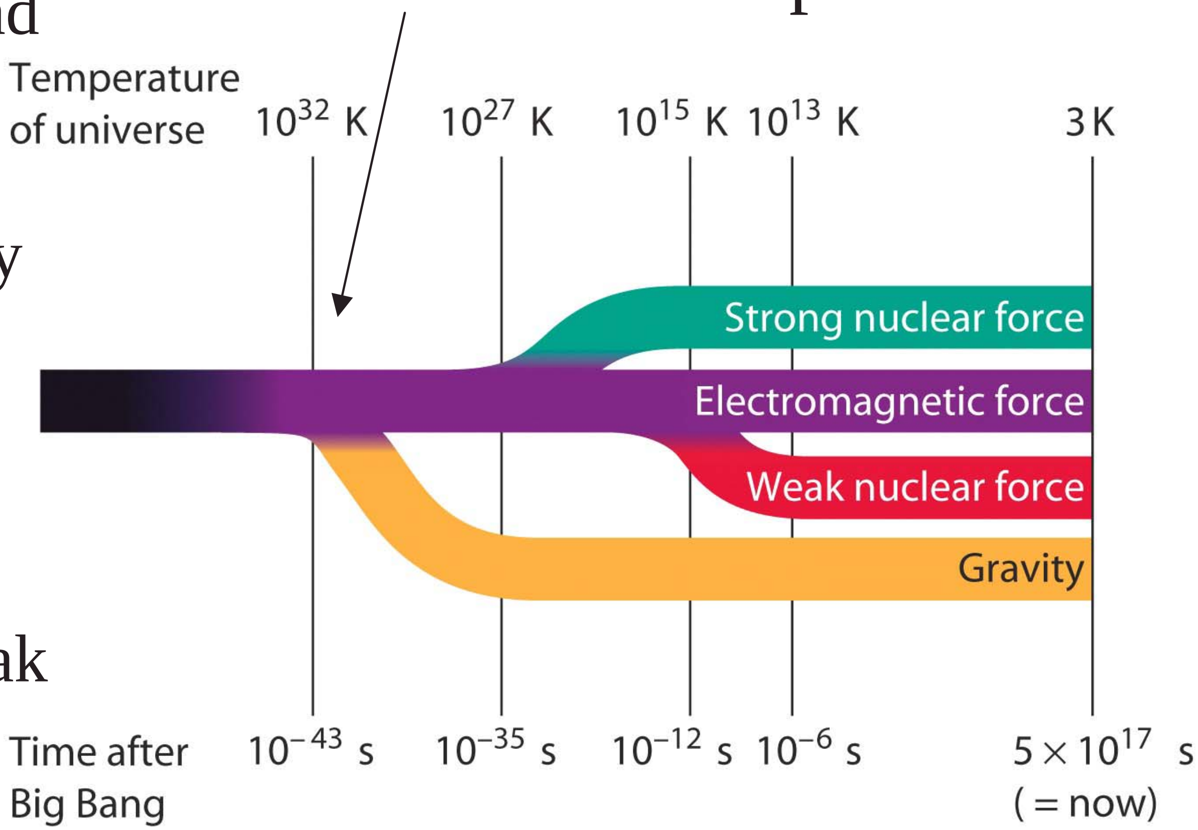
Deep connections between

- The very small and
- The very large

How do we understand the early Universe?

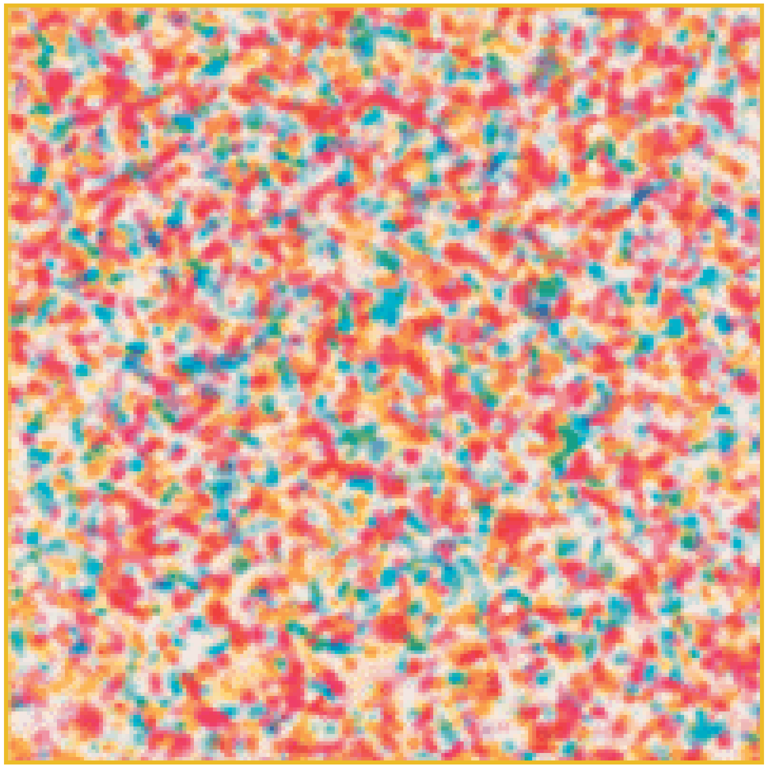
The first time after the Big Bang that we can understand is about 10^{-43} seconds and after. For anything before that we would need a theory of everything. At that time all the 4 forces are equivalent– Gravity, Electromagnetic, Strong Nuclear Force, and the Weak Nuclear Force.

The Planck Epoch



The GUT Era

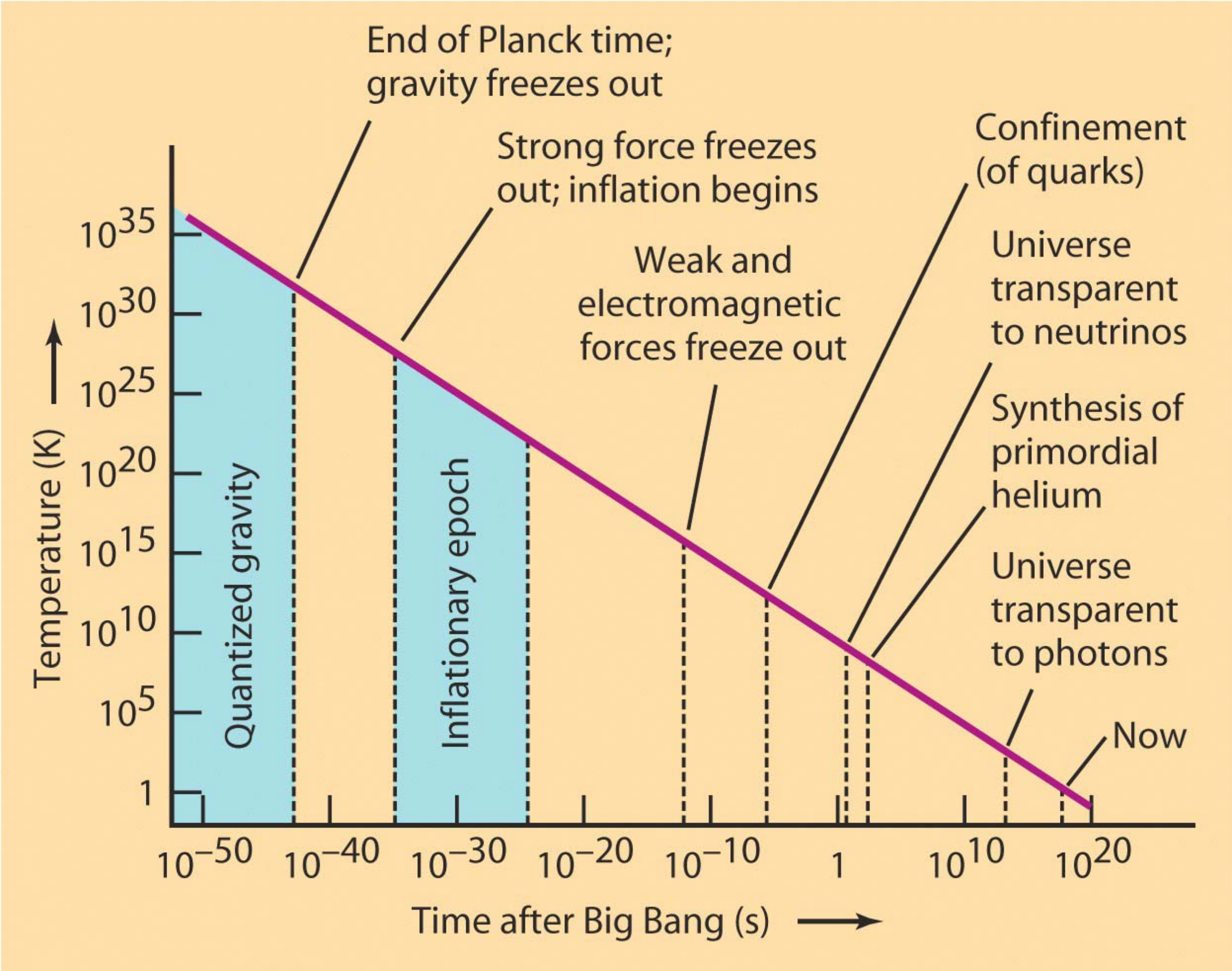
- From the Planck era to about 10^{-35} seconds is the Grand Unification Theory era.
- Forces: gravity + (strong/weak/electromagnetic)
- Matter forms– A sea of free quarks, photons, and some other particles.
- These fluctuations are small, but as the Universe expands, they get large enough to be the seeds of galaxies.



http://www.powersof10.com/powers/power/-16.html

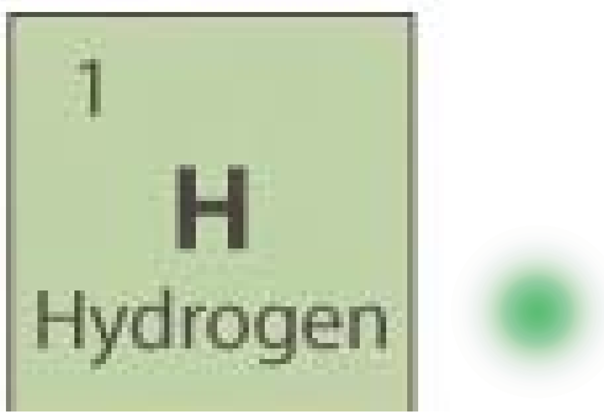
Inflationary Period and On

- Universe went through period of extremely rapid expansion early in its history (before 10^{-32} sec)
- Expansion by more than factor of 10^{50}
- **10^{-12} second:** electromagnetic and weak forces separate
- **10^{-6} second:** free quarks condense into protons and neutrons
- **1 second:** Universe becomes transparent to neutrinos

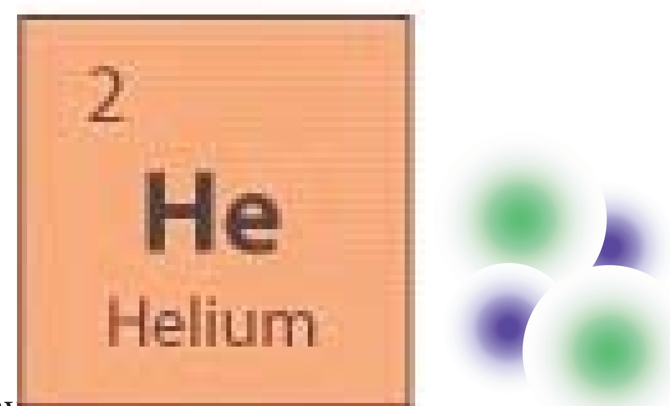


Big Bang Nucleosynthesis

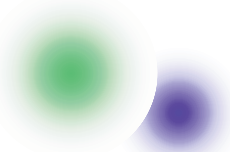
After about 3 seconds, the temperature falls to 10^9 K and protons and neutrons can "shack-up" to form the first light elements. The Universe is a supercollider.



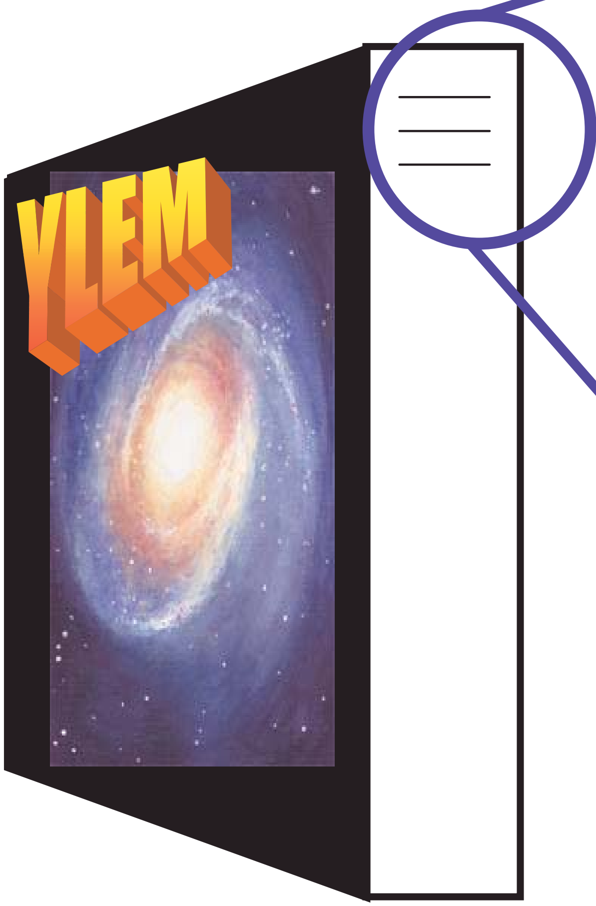
(a proton)



Also: Deuterium



End Result:
Big Bang Correctly Predicts Abundances



Nutrition Facts

Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

Hydrogen .... 0.75 g
Helium .... 0.25 g
Deuterium .... 10^{-4} g
Lithium, etc. .... 10^{-10} g

What is the Universe's Fate?

Today: Universe is expanding. What next?
Competition: gravity vs inertia

or

Compare: pop fly!

- Quantitative question:
- Launch speed vs speed to escape Earth

For Universe:

- Gravity: galaxy mass density ρ (Greek rho)
- Inertia: expansion

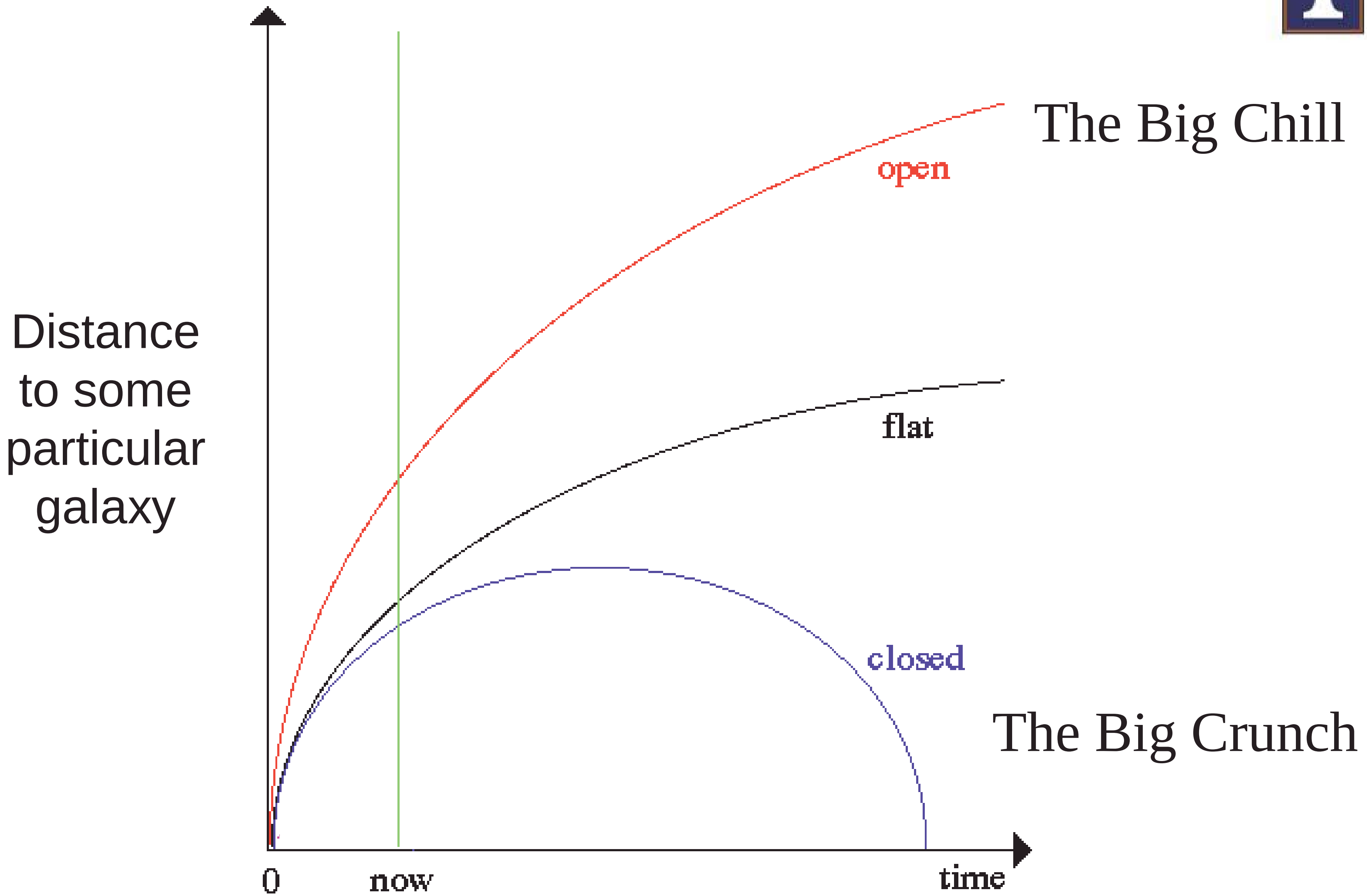
$\rightarrow \rho_{critical}$

Both are observable!

Fate $\longrightarrow$ **quantitative** question :

- if $\rho < \rho_{critical}$ expand forever
- if $\rho > \rho_{critical}$ expansion halts, collapse

What kind of Universe do we live in?



A Census of Matter

% of critical
density

22%   Dark matter

Needed to explain:
- galaxy rotation curves
- clusters of galaxies

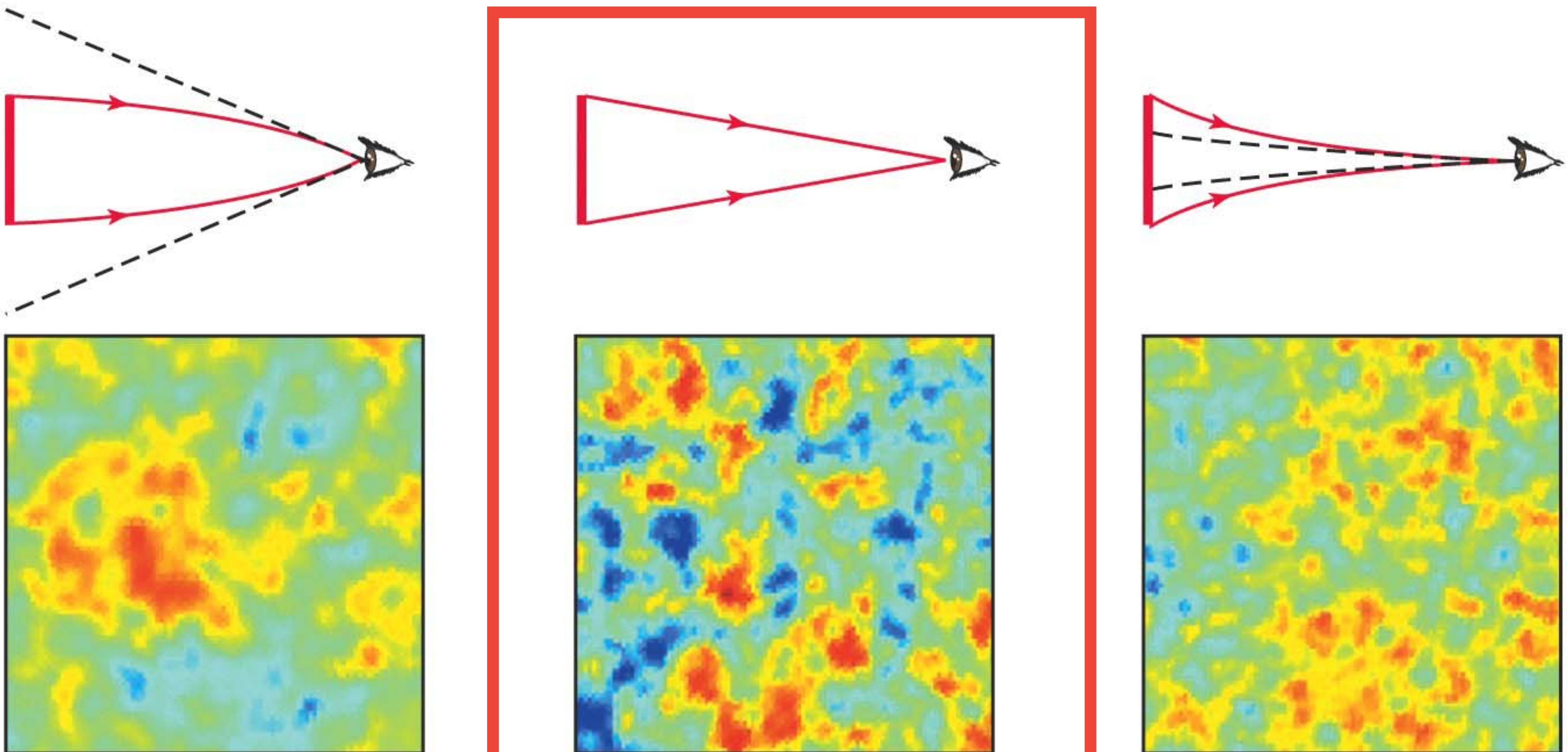
4.5%   Ordinary matter

Made of protons, neutrons, and electrons

<1.5%   Neutrinos

28%   Total   Not enough to close the Universe

CMB Measurements: Universe is Flat



a If universe is closed, hot spots appear larger than actual size

b If universe is flat, hot spots appear actual size

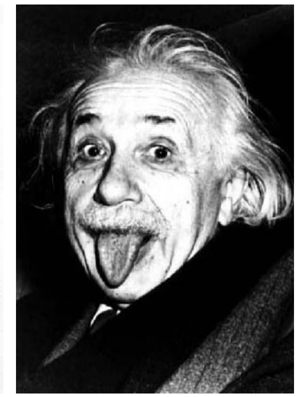
c If universe is open, hot spots appear smaller than actual size

The Big Chill

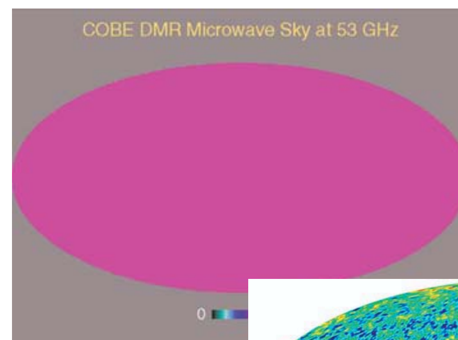
- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, then there is something else afoot.
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe.
- So, a new type of energy called Dark Energy (repulsive gravity and not related to Dark Matter) exists. The dark energy is dominating the fate of the Universe.
- 70% of the Universe is this dark energy.
- Einstein's biggest blunder might have been correct after all.

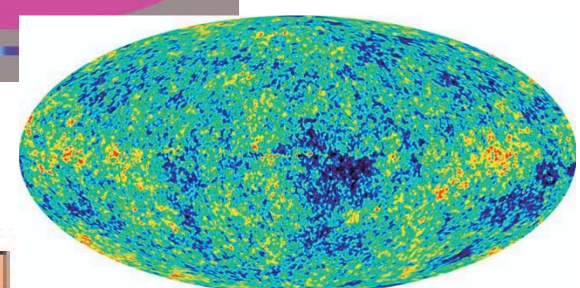
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

3. Hubble: v=HR
   + Einstein General Relativity
   = Big Bang and expanding Universe
   with age t = 13.7 billion yrs

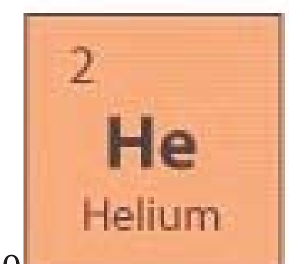



2. Cosmic microwave background
   Primordial fireball– Big Bang working at
   t = 400,000 yrs
   - Nearly uniform temperature in all directions early Universe was very homogeneous
   - Tiny temperature fluctuations: “seeds" of galaxies





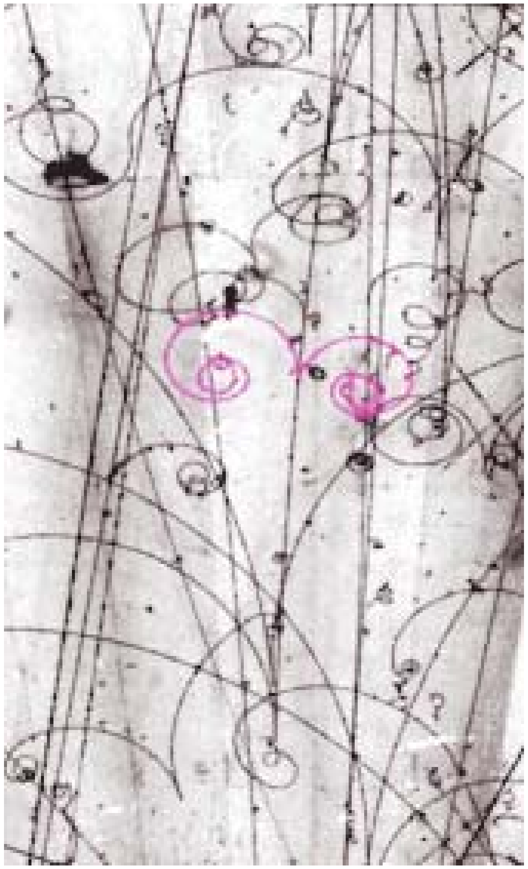
1. Big Bang Nucleosynthesis
   H and (almost all) He come from Big Bang
   Big Bang model working at t = 1 s



Matter versus Antimatter in the Universe

Antimatter Review

- Antimatter exists!
- Partner for each type of matter particle: anti e^-=e^+ positron, antiprotons, antineutrons
- Antimatter stable by itself
  - could have anti-atoms, anti-rocks, anti-people, anti-galaxies
- but when matter + antimatter partners combine
  - Energy: annihilation
  - all $E = mc^2$ ⇒ high energy photons=gamma-rays



example: paperclip + anti-paperclip annihilation

- Energy release same as small nuclear bomb

The Universe is Made of Matter

You, and I, and the whole Earth are all made of matter not antimatter. *Why?*

Can keep going.

The Moon is made of matter, not antimatter. Why? You tell me.

Mars is made of matter, so is the whole solar system: solar wind, meteorites, etc.

Local "neighborhood" in Milkyway is matter, gas between the stars, but no sign of explosions and gamma rays.

The Universe is made of matter.

How did this come to be?

The Early Universe and Antimatter

Strong evidence says:

The early universe had both matter and antimatter, but

- For every 1,000,000,000 antimatter particles,
- There were 1,000,000,001 matter particles

Then annihilation happened, only the matter excess remained.

How did the matter excess get there?

Most likely guess:

- The Universe began with equal amounts of matter & antimatter.
- But very high energy reactions slightly favored matter.
- Fermilab experiments: such reactions are possible!
- Stay tuned!

Example of inner space--outer space, particle--cosmology connection.

Putting it in Perspective

The Meaning of Life
Monty Python (1983)
"The Galaxy Song"

Remaining Questions

- What is fate of Universe?
- What is the dark matter?
- How did galaxies form?
- What happened at $t = 0$?


Thank You & Good Luck!
Dec 10, 2003
Astronomy 100 Fall 2003