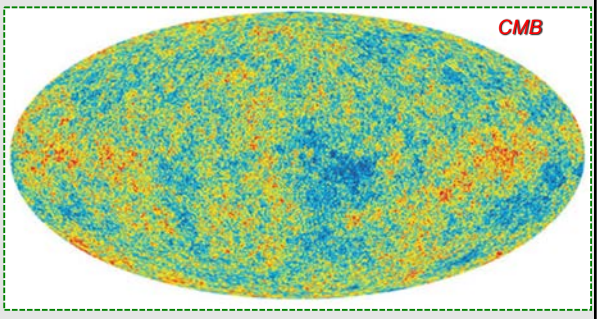
ASTR 1040: Stars & Galaxies



Prof. Juri Toomre TAs: Daniel Sega, Max Weiner
Lecture 29 Tues 28 Apr 20
zeus.colorado.edu/astr1040-toomre

Our Schedule

- *Final Exam on Wed May 6,* 4:30pm-7:00pm, comprehensive, on Canvas/Quizzes, closed book, 2 crib sheets allowed (4 sides)
- *Review #4* next Mon May 4, 4:30pm-6:30pm by Max Weiner, on zoom
- *Review Set #4* posted on Modules
- All *observatory night reports*, extra-credit, due by Thur (Apr 30) latest
- *Overall course grade estimate to date posted*
- Finish reading *23.4 Dark Energy and Fate of Universe*
- Today: *First few minutes of our Universe*

THIRD MID-TERM EXAM

- *Grade boundaries, based on 120 points (graded on a "curve"):*

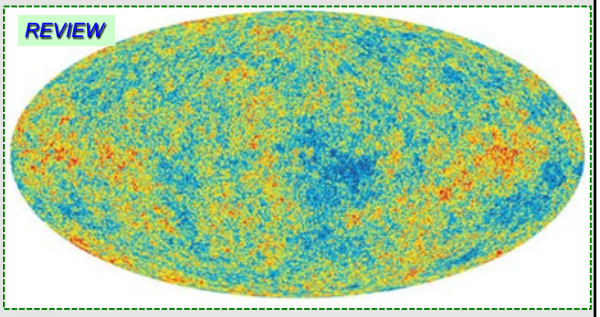
- *If 108/120 (90%) or over, A's [41%]*
- *96/120 (80%) or over, B's [40%]*
- *84/120 (70%) or over, C's [19%]*

Also +, plain, and – within these ranges

Go through answers – and talk to us if do not understand our choices.

CMB: Light from beginning of time

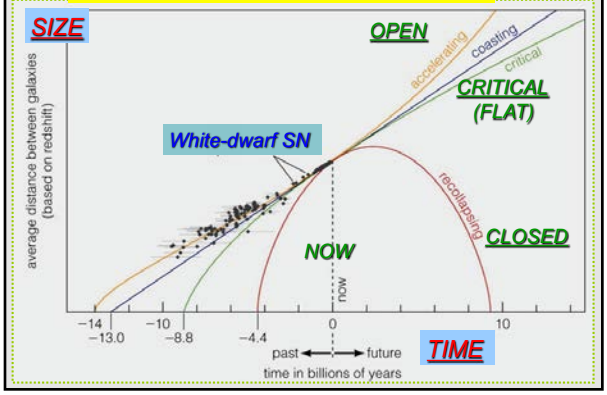
REVIEW



- *This faint light looks like a solid glowing wall*
- *Thermal spectrum at 3000 K (visible), if redshifted by factor Z~1000 → 3 K ! (microwaves)*

Models of universe – and its fates

REMINDER

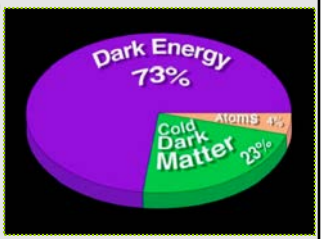


White-dwarf SN → accelerating universe

Conjecture: An unknown force at large scales begins to counteract pull of gravity

"Dark energy" – outweighs every other form of mass/energy

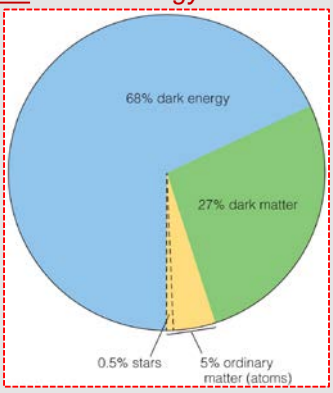
~73% (maybe 68%)



Baryons: 4.4% (5%) Dark Matter: ~23% (27%) with a FLAT universe and early inflation

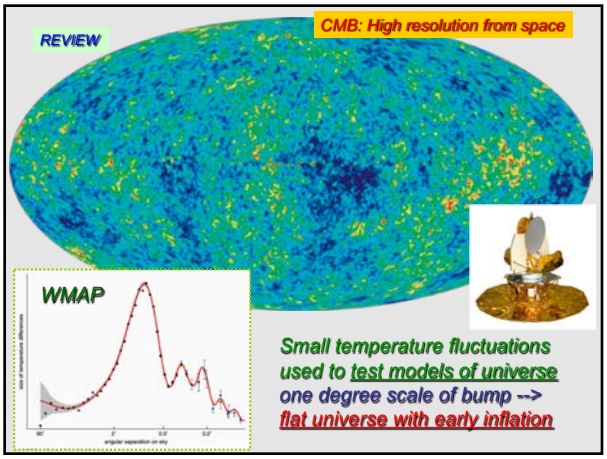
Accelerating Universe: Mass-Energy Pie Chart

- *Dark energy* —more prevalent than every other form of mass/energy!
- A repulsive force that counteracts gravity?



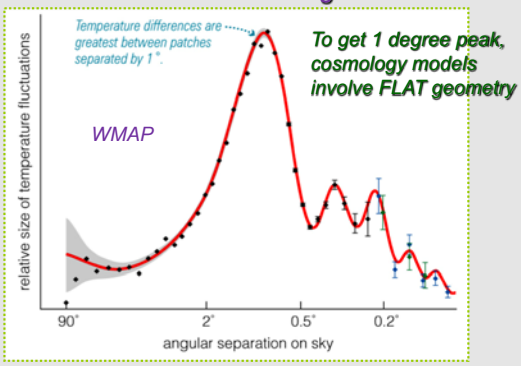
REVIEW

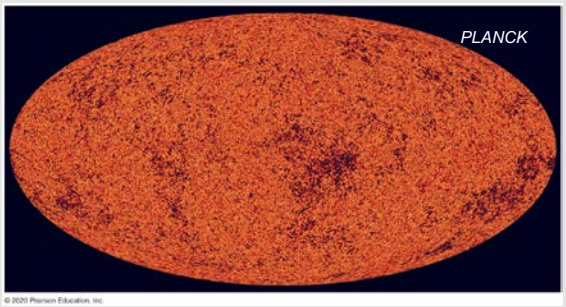
CMB: High resolution from space

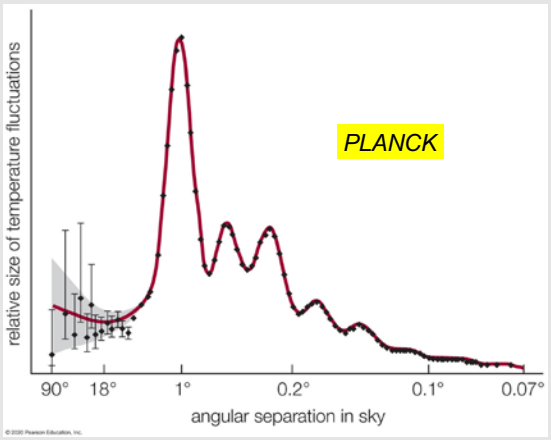


Small temperature fluctuations used to test models of universe one degree scale of bump --> flat universe with early inflation

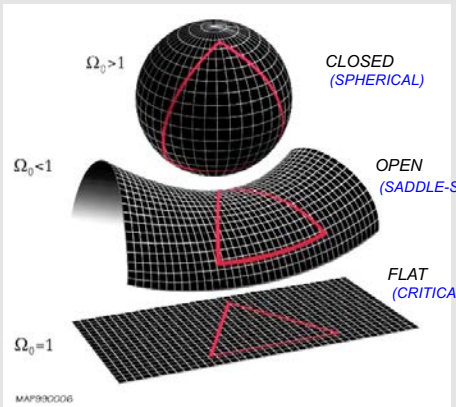
Variations in CMB on small scales: "sound waves bouncing around"







"Overall Geometry" of Universe

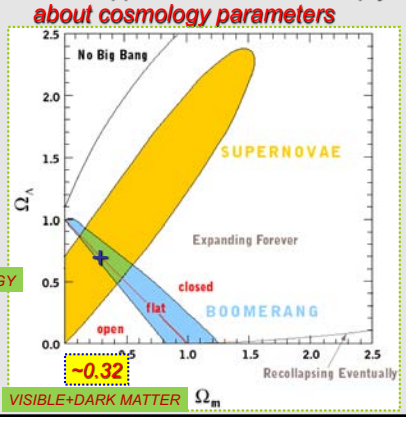


What CMB ripples and distant SN imply about cosmology parameters

current favorite values:

~0.68

DARK ENERGY

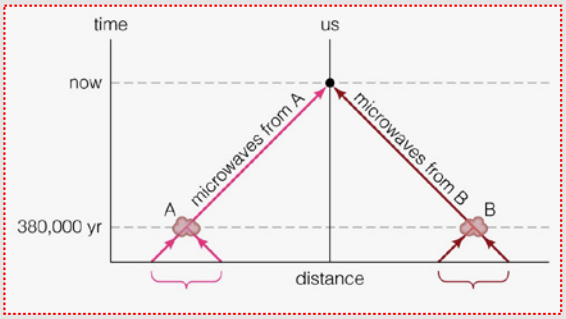


~0.32

VISIBLE+DARK MATTER

Questions or Comments

Major puzzle: Why is CMB so uniform?

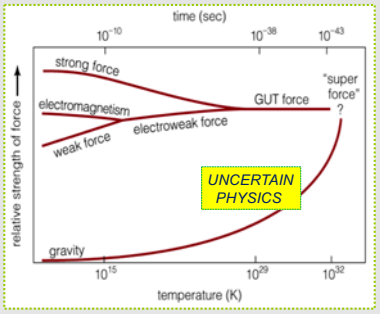


Major proposition: INFLATION

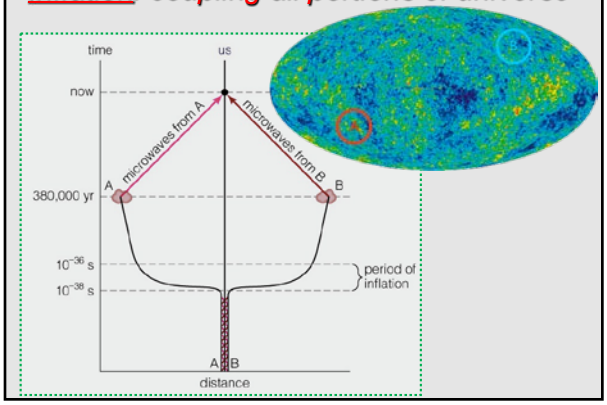
VERY EARLY:
strong force becomes distinct from **electroweak**, huge amount of energy released

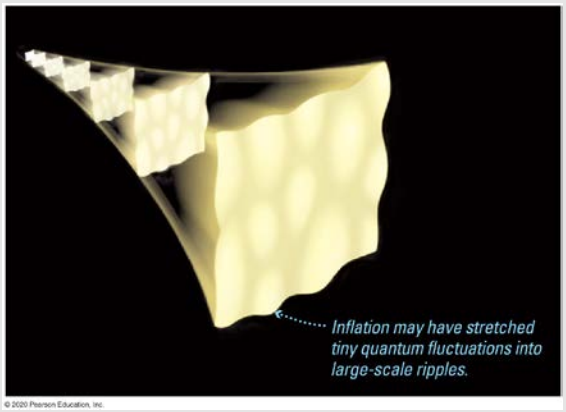
Universe INFLATES: atomic nucleus size to solar system size in 10^{-36} sec

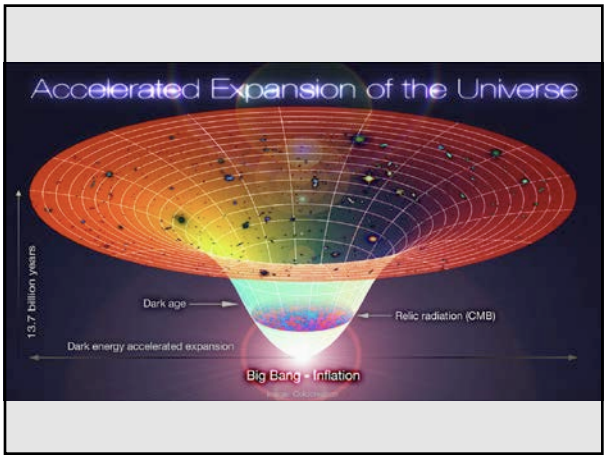
DOES NOT COOL



Inflation: coupling all portions of universe



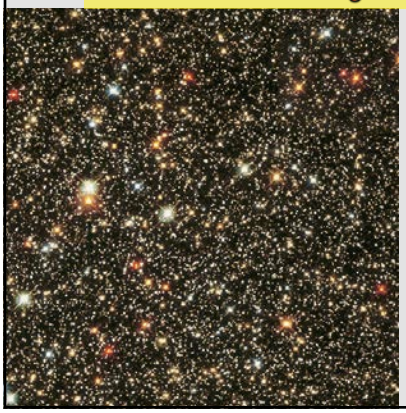




Poll 1: What is Olber's paradox?

A. If the universe was infinite, any direction you looked you would eventually see a star
B. If the universe was infinitely old, the starlight would have time to get here
C. The sky should look bright at night– because all directions would have starlight
D. All of the above

Darkness of the night sky



Olbers' Paradox

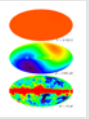
If universe were
1) infinite
2) unchanging
3) everywhere the same
Then stars would cover the night sky

SO WHY NOT?

Questions or Comments

22

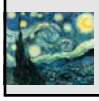
"Observational Pillars" of Big Bang Theory



1. The universe is aglow with thermal radiation, the Cosmic Microwave Background (CMB)

2. The observed abundances of light elements agree with Big Bang predictions

3. The universe is expanding



4. The night sky is dark

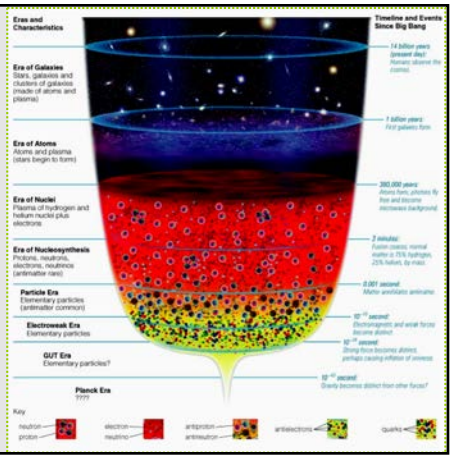
1 billion years

380,000 years

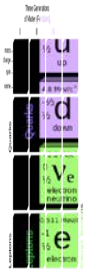
3 minutes

0.001 sec

Evolution of Universe

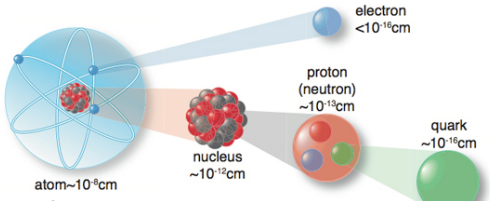


Briefly recall physics in our realm now: "Standard Model"



particle	properties	habits
up quark down quark	+ or - charge large mass	always in groups of 3, form nucleons: proton = u+u+d neutron = u+d+d
neutrino	no charge tiny mass	barely interacts
electron	- charge small mass	orbits nucleus

Quarks and gluons: building blocks



Ancient Greeks hypothesize "atmos" or indivisible particles

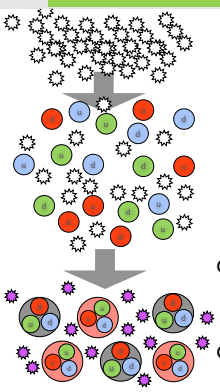
1700s-1800s many different kinds of atoms discovered (elements)

early 1900s - atoms composed of nucleus and electrons

nucleus composed of protons, neutrons

1960s - protons and neutrons composed of quarks

In the earliest stages after inflation



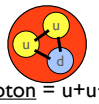
High-energy photons create quarks, anti-quarks

Quark-gluon plasma - at very high temperatures ($T>10^{12}$ K), strong force not strong enough to hold quarks together.

Once photon energy drops below 10^{12} K, strong force overcomes kinetic energy.

Quarks are immediately confined → protons, neutrons

From quarks to atoms



proton = u+u+d

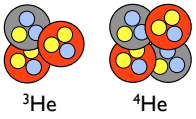
everything held together by Strong force

neutron = u+d+d

hydrogen = proton

deuteron = p + n
(isotope of hydrogen)

tritium = p + 2n
(isotope of hydrogen)



helium isotopes
2 protons
+ 1,2 neutrons

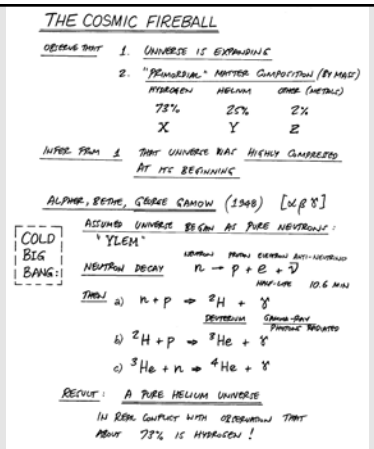
Questions or Comments

First Big Bang Idea

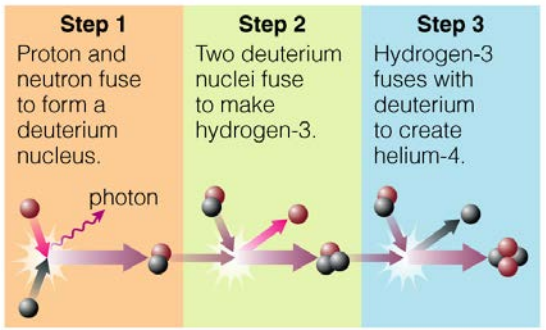
"COSMIC FIREBALL"

George GAMOW (1948)

Oops ! Pure HELIUM



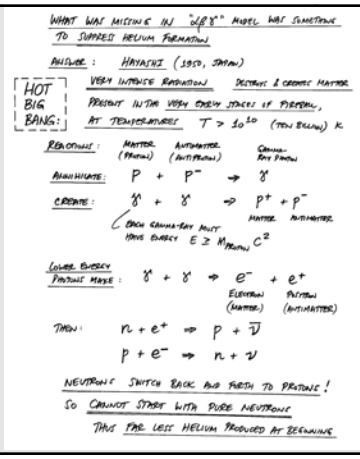
Making helium in first 3 minutes



JUST DO NOT MAKE EVERYTHING INTO HELIUM !

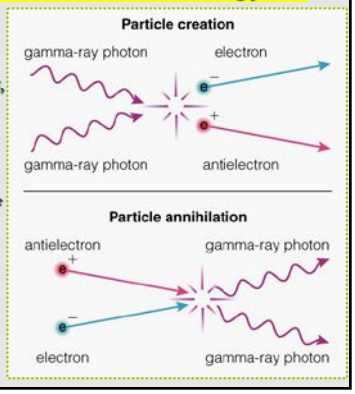
HOT Big Bang (1950)

did the trick!

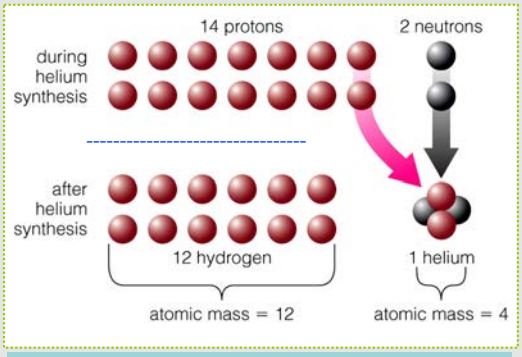


Matter, Anti-matter and Energy

- At high temperatures, photons convert into particle+antiparticle pairs, and vice-versa
- Matter & energy are the same: $E = mc^2$
- Early universe was full of particles and radiation
- Universe ratio today:
  - 1 billion photons (light)
  - 1 leftover proton (matter)



H and He ratio after ~3 minutes

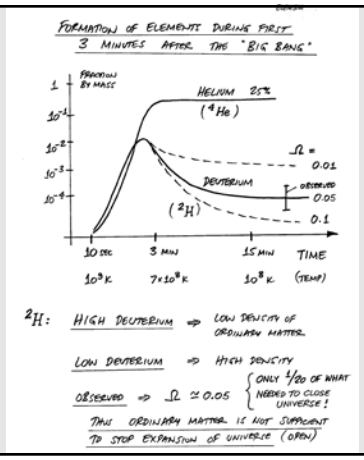


75% hydrogen, 25% helium, trace of deuterium

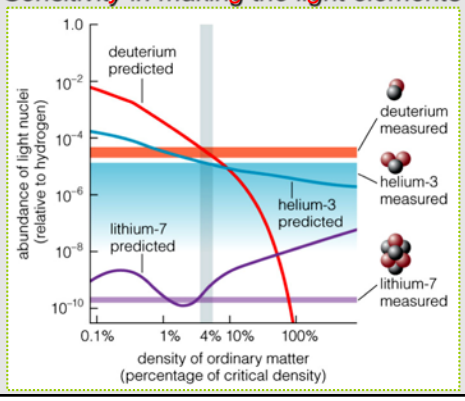
During first 3 minutes

Making the elements

How much DEUTERIUM made depends on density of ordinary matter (baryons)



Sensitivity in making the light elements



After first 3 minutes

RADIATION ERA

--> 380,000 yr

MATTER ERA

AFTER THE FIRST 3 MINUTES :

RADIATION ERA : 1 sec → 1 million yr
10^{10} K → 3000 K

- INCLUDES EPOCH OF ELEMENT FORMATION
- MOST ENERGY IN UNIVERSE IN FORM OF RADIATION
- RADIATION PRESSURE PREVENTS STRUCTURE FROM FORMING

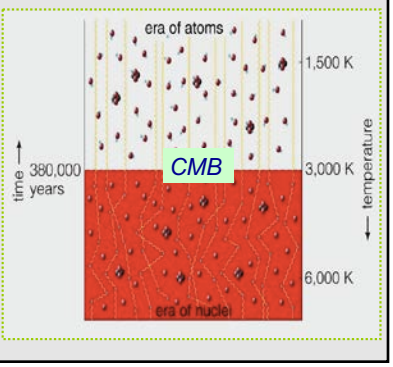
ENDS WITH RECOMBINATION — H and He become NEUTRAL, RADIATION UNCOUPLES FROM MATTER

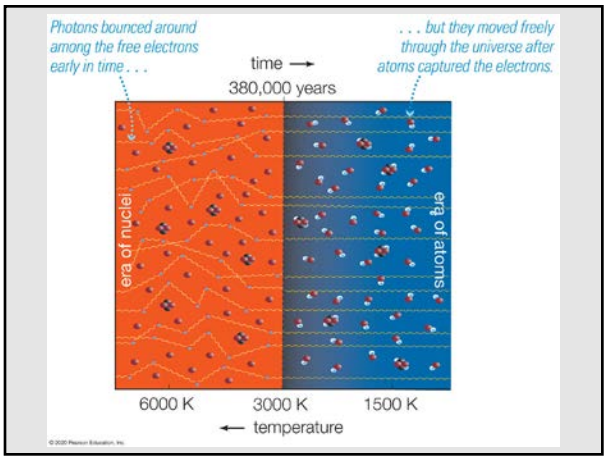
MATTER ERA : 1 million yr → NOW (15 Billion yr)
3000 K → 2.7 K

- CLUMPING OF MATTER (MATTER NOW NOT AFFECTED BY RADIATION PRESSURE)
- QUASARS FORM, THEN GALAXIES AND CLUSTERING OF GALAXIES

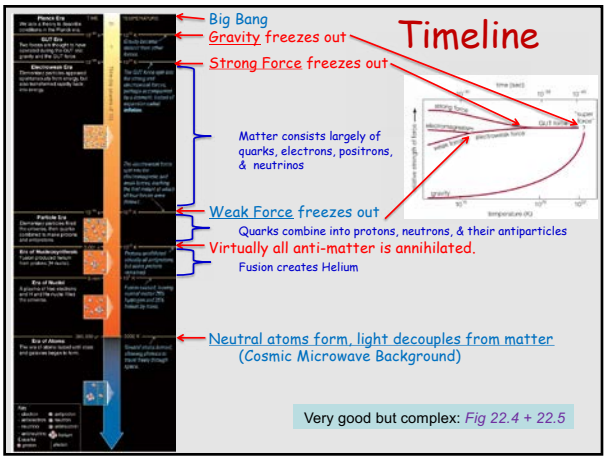
After "recombination": Era of Atoms

- Finally cool enough for electrons to combine with nuclei to form atoms (380,000 yrs)
- Photons now "decoupled" = free to become CMB of future
- Universe becomes transparent to light





Timeline



Very good but complex: *Fig 22.4 + 22.5*