Expanding Universe

- As Universe expands it cools
- Physical processes at any time depend on:
  - Temperature
  - Nature of forces and particles
- Current Temperature is 3 degrees K
Confinement of quarks means protons and neutrons are created
early Universe hot enough to make particle-antiparticle pairs out of very high energy photons.

**Examples**

\[
\text{photon} \rightarrow electron + positron
\]

\[
\text{photon} \rightarrow quark + antiquark
\]

\[
\text{photon} \rightarrow proton + antiproton
\]

Protons and neutrons are made from quarks.  
\(p=uud\) and \(n=u dd\) where \(u=\text{up quark}\) and \(d=\text{down quark}\).  
(There are 6 types of quarks. DH helped discover the top quark in 1995 and a poster on the first top quark ever observed is outside my office. Or look at http://nicadd.niu.edu/~hedin/top.html)
Antimatter

Most particles also have an antiparticle. They have been created at accelerators since the 1930s and are also produced in radioactive decays and in cosmic ray interactions in the upper atmosphere.

**Examples**

- \( \text{electron} \rightarrow \text{positron} \)
- \( \text{proton} \rightarrow \text{antiproton} \)
- \( \text{neutron} \rightarrow \text{antineutron} \)

For 25 years, Fermilab operated a proton-antiproton collider, and so first had to “make” the antiprotons, store them, and then use them in the accelerator. Positrons are commonly used in medical physics such as the PET (positron emission tomography) scanning technique.
after 0.000001 seconds, too cool to make protons and antiprotons, neutrons and antineutrons. The qqq is a p or n
Matter – Antimatter Asymmetry

- early universe: very hot, makes matter-antimatter
- For some reason matter becomes more abundant in the early stages of Universe
- Antimatter completely annihilated
- Hence we're left only with matter today: 
  \(0.25\) protons, \(~10^9\) photons, 
  \(~10^8\) neutrinos+antineutrinos)/m\(^3\)
- Fossil evidence from before 1 second
Matter – Antimatter Asymmetry

- early universe: very hot, makes matter-antimatter
- But somehow it makes 1,000,000,001 protons (matter) for every 1,000,000,000 antiprotons (antimatter)
- All the antiprotons annihilate with protons leaving just 1 proton
- Those remaining protons (and neutrons and electrons) make up all the matter in the Universe: stars, planets, us
Ancient scientists (e.g. Archimedes): Universe is made from perfectly symmetric objects like circles and spheres → wrong models of the orbits of the planets

Now know: “perfect” symmetry gives a lifeless Universe → it is the asymmetries that give it complexity
- Differences in DNA (you vs me, humans vs clams)
- Difference in particle properties: neutron mass is larger then proton mass → n decays while p is stable → we exist
- matter is slightly different than antimatter → we exist
Observations 50 Years ago

1 Universe is mostly matter, need matter-antimatter differences in very early Universe. Andrei Sakharov
2 matter-antimatter differences observed in strange quarks Jim Cronin and Val Fitch
3 matter-antimatter differences observed in electron and muon charge asymmetries in strange quark decays. Mel Schwartz

Sakharov, 1975 Nobel Peace Prize (for resisting the Soviet government) Cronin and Fitch, 1980 Nobel Prize for Physics for this observation Schwartz, 1988 Nobel Prize for Physics (for discovering the muon type neutrino)
Matter-antimatter difference experiment at Fermilab Proposed in 1979. (Note DH was working with Cronin and Schwartz)

A Study of Direct CP Violation in the Decay of the Neutral Kaon via a Precision Measurement of $|n_{00}/n_{+-}|$

R. Bernstein, J.W. Cronin, and B. Weinstein
University of Chicago, Enrico Fermi Institute, Chicago, Illinois

B. Cousins, J. Greenhalgh, and M. Schwartz
Stanford University, Department of Physics, Stanford, California

D. Hedin and G. Thomson
University of Wisconsin, Department of Physics, Madison, Wisconsin

CP violation in strange quark decay
Fermilab proposal 617 January 1979

wrong. very small effect. new physics must come from somewhere else

ABSTRACT

In this proposal, we describe an experiment to measure the ratio $R$ of the CP violating amplitudes $|n_{00}|$ and $|n_{+-}|$ to a precision of better than 1% thereby improving the present results by about one order of magnitude. If the CP violation is confined to the mass matrix, $R = 1.0$ exactly. Recent theoretical considerations which unify the CP violating interaction with the CP conserving weak and electromagnetic interactions among six quarks predict $R$ differing from 1.0 by sizable amounts.
All observations of matter-antimatter differences BEFORE 2018 are much, much lower than the amount needed in the first instance of creation to explain the amount of matter in the Universe

→ Need something new. High priority for past 40 years. Still no definitive answer. One of primary reason for future muon (heavy electron, common in cosmic rays) and neutrino programs at Fermilab.
Creation of Light Nuclei

- During first few minutes have about the same number of protons and neutrons and can have the following reactions:
  
  \[ p + n \rightarrow pn \text{ (deuterium)} + \gamma \]
  
  \[ pn + n \rightarrow pnn \text{ (tritium)} + \gamma \]
  
  \[ pn + p \rightarrow ppn \text{ (Helium-3)} + \gamma \]
  
  \[ pn + pn \rightarrow \text{Helium-4} + \gamma \]
  
  \[ pnn + pn \rightarrow \text{He-4} + n \]

Best reaction for fusion reactor or hydrogen bomb
Creation of Light Nuclei

Protons and neutrons combine to make Helium: **first 10 minutes**

Relative number of protons and neutrons depends on:
- neutron being a little heavier than the proton
- neutron decays with 15 minute lifetime
- how quickly Helium is made which depends on the temperature and density

- We end up with $\#n/#p = 14\%$ or 2 neutrons for every 14 protons
- Almost all the neutrons are in He giving about 75% H and 25% He by mass after first 3 minutes (and still mostly today)
- fraction of H, He, H2(pn), He3(ppn), Li in old stars are “fossil” record from this time. **Gives temperature of Universe at t=1 minute**
Neutron Lifetime

- neutron decays with 15 minute lifetime

- What if lifetime was 15 hours?

  → About same number of protons and neutrons and all go into making Helium

  → Universe is mostly composed of He and Hydrogen is then relatively rare

  → Stars are very different

  → Life as we know it does not exist
Evidence for Big Bang

- galaxies all moving away from us (Hubble Law). Well measured with some understanding of how the Hubble constant changes with time

- cosmic microwave background at 3 degrees K. Well measured and small fluctuations point to mass-energy fluctuations from earlier times.

- relative amount of Hydrogen to Helium (plus other light elements) seen throughout the Universe. Well measured and gives the temperature of the Universe at about 1 minute after the Big Bang

→ moment of Creation about 13-14 billion years ago
Acceptance of Big Bang

In the last 100 years science has shown that our Universe began about 13-14 billion years ago.

But somehow 40% of Americans don’t “believe” in this as it is “against” their religious views. This seems to deny the wonder of the Universe that was created (!!), which can be credited to the Creator.

I have to admit I don’t get it. Science and religion should not have to be “opposed” on this, and for many religions they are not.

(see next slide for Einstein’s take)(see course web page for an interview with Brian Cox)
Big Bang, God, and Einstein

• Though the Hubble Law was predicated by Einstein’s general theory of relativity, Einstein never really accepted that the Universe had a beginning. He died in 1955 when many other scientists thought the Universe existed for an infinite amount of time (they had wrong ideas to explain away Olber’s paradox).

• Einstein did say “I cannot prove to you that there is no personal God, but if I were to speak of him, I would be a liar. I do not believe in the God of theology who rewards and punishes evil. My God created laws that take care of that. His universe is not ruled by wishful thinking, but by immutable laws.”

• Einstein never said “What I believe is that the universe is so extraordinary only God could have created it. Our job is to understand it.” That was said by the actor Geoffrey Rush in the TV show Genius.
Exploring Very Early Times

• “Fossil” evidence available to astronomy are remnants from the first few minutes and later after the Big Bang

• For earlier times → use physics

• Particle accelerators can briefly reproduce the Temperature of early times. The highest energy machine is equivalent to about 1 picosecond (0.000000000001) after the universe began

• Understood earlier by extrapolation. Going back to the moment of Creation needs a complete knowledge of gravity and a more complete understanding of time itself
Unsolved Mysteries: Include

- Dark Matter earlier lecture
- Dark Energy earlier lecture
- Domination of Matter this lecture
- Why the strength of the forces and the masses of particles seem to be “just right” → multiple universes - Multiverse??
- Weakness of Gravity → Extra Dimensions??
- Look at Multiverse and Extra Dimensions in last lecture though won’t be on exams and is very speculative
Test 3 Overview

• Will be all multiple choice and administered through Blackboard

• Formation of planets. temperature of solar nebula, and how it varies with distance \( \rightarrow \) type of planet formed. Heavy elements freeze out first. Extrasolar planets detected in a number of ways (motion of stars, planet eclipsing star, directly). Planetary atmospheres: high temp and/or low surface gravity prevent the planet from holding on to light gases like hydrogen.

• Life in the Universe. Need star to be long-lived and not in binary system. Need planet to be the right distance from its star. Communicate with ET by radio with Drake equation giving estimate of number of possible civilizations in Milky Way.
Galaxies. Ellipticals: little rotation, little gas/dust or active star formation. Spiral: rotation/gas/dust and active star formation, and irregulars active star formation but indistinct shape. Galaxies are moving away from us with $v = Hv$, where $v$ = velocity, $d$ = distance, and $H$ = Hubble constant. Milky Way has inner nucleus, spiral arms (active star formation, halo of old stars (early shape))

Cosmology. Hubble law $\Rightarrow$ Universe is expanding, gives universe’s age, depends on Hubble “constant” changes with time. Closed universe has gravity slowing the expansion so it starts to contract. Open universe expands forever. Early universe was very hot and when matter was created. First electrons, protons and neutrons, then protons and neutrons give hydrogen and helium nuclei minutes after the Big Bang. 400,000 years later atoms form, Universe became transparent, and light appeared, seen as the cosmic microwave blackbody radiation temperature of 3 degrees K.
Type Ia supernovas are best for distant objects as always about the same absolute luminosity. Note once Hubble Law $v=Hd$ is determined, can then use this to measure distance to any galaxy by measuring $v$ through the Doppler shift