Stars, Galaxies & the Universe
Announcements

- **Reading Quiz #13**– in class Wednesday (bonus points today)
- **HW #11 due on Friday (12-3) by 5 pm!**
- **Final Exam will be cumulative; Thursday 16 Dec @7:30 am in VAN LR 1; 150 points – 50 questions @3 pts each! We will have a review session sometime during Finals Week.**

- Tuesday (12-14) evening @ 7 pm?

Stars, Galaxies & the Universe
Lecture Outline

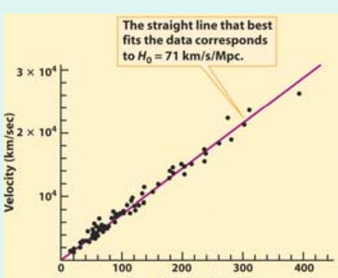
Cosmology (Ch. 26)

(1) What is cosmology?
(2) Age of the Universe & Fate(s) of the Unvierse
(3) The Early Universe ("Big Bang")

(4) The Fate of the Universe: (WEDNESDAY)
- Dark Matter, Dark Energy

Hubble expansion $v = H_0 d$

For how long has the universe been expanding?



Time = distance/velocity

$= d/H_0 d$

$= 1/H_0$

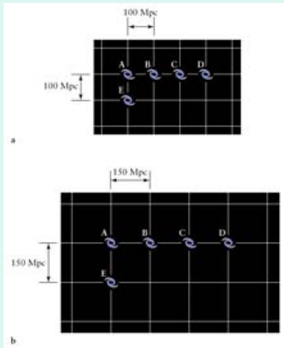
= 1/(71 km/s/Mpc)

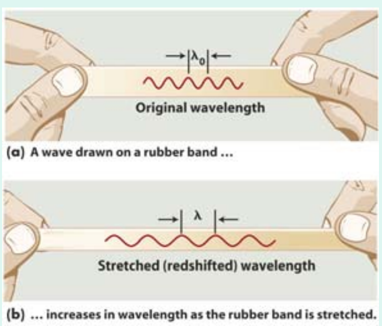
= 13.8 Gyr

For Ho = 58 km/s/Mpc, Universe age > 13.8 Gyr

For Ho = 74 km/s/Mpc Universe age < 13.8 Gyr

- **Overall, Hubble's Law tells you that the further away the galaxy, the faster the galaxy is receeding – universe is expanding!**
- **Although universe is expanding, it looks the same from ANY galaxy – we are not at the center!**
- **The galaxies themselves are not getting bigger, expanding, but the SPACE between them is expanding**





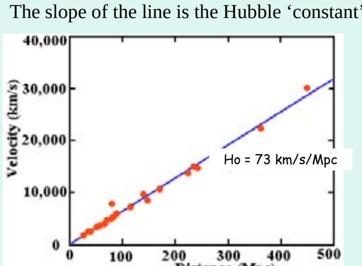
→ photons get *redshifted* as they travel toward us from distant parts of the universe

→ this is because the SPACE has actually expanded: *photons stretched!*

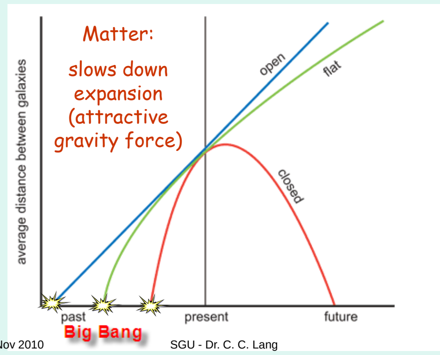
Hubble diagram, version I: velocity vs. distance

At fairly nearby distances, the velocity-redshift plot for galaxies is linear.

The slope of the line is the Hubble 'constant'



Cosmic Scale Factor vs. time

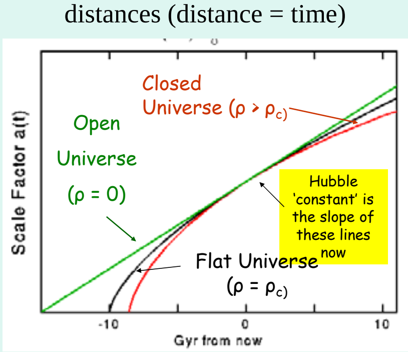


Omega is a measure of the density of the universe compared to the "critical density" (flat universe)

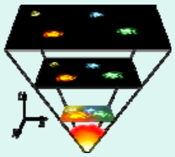
$$\Omega = \rho/\rho_{crit}$$

1. $\Omega > 1$ – more density than critical - CLOSED
2. $\Omega = 1$ – equal density to critical - FLAT
3. $\Omega < 1$ – less density than critical - OPEN

Hubble Diagram version II: over larger distances (distance = time)



Big Bang **Principles:**



1. The universe was once in a hot, dense state from which it began to expand (Hubble's law/redshifts for distant objects indicate the universe is expanding).

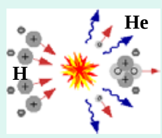
2. The Big Bang occurred **everywhere**, not in any one place or in any one direction.

3. Two things to keep in mind:

• *under extreme density, temperature, interactions between light, matter, particles happen QUICKLY!*

• *after ~1 second, the universe changed very slowly; we can not understand the physics during the first 10^{-43} second (Planck time)*

Another mystery of the early universe:



The universe is full of helium and other 'heavy metals'

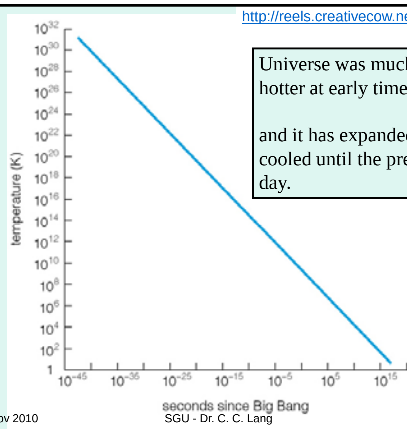
→ Sun is made of 74% H, 25% He, 1% 'metals'

→ 25% He can not come from Sun's fusion alone!

→ There must be another source of nuclear fusion

The Early Universe must have been hot enough and dense enough for nuclear fusion to take place – Big Bang!

http://reels.creativecow.net/film/big-bang

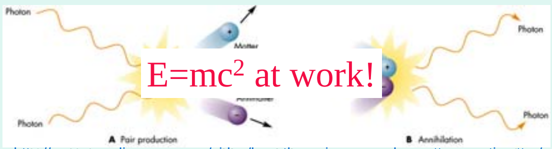


Universe was much hotter at early times

and it has expanded and cooled until the present day.

The first microsecond (10^{-6} sec):

- $T \sim 10^{13}$ K – a million times hotter than the Sun's core
- radiation associated with this extreme T were very high energy GAMMA RAYS
- so hot and dense, neutrinos interacted with matter
- particles and anti-particles produced, then destroyed



E=mc^2 at work!

http://www.yourdiscovery.com/video/how-the-universe-works-matter-v-antimatter/

After the first second:

- the resulting photons could no longer make particles
- neutrinos stopped interacting with matter – the universe became much l e s s d e n s e as it expanded .

For the next 300 seconds:

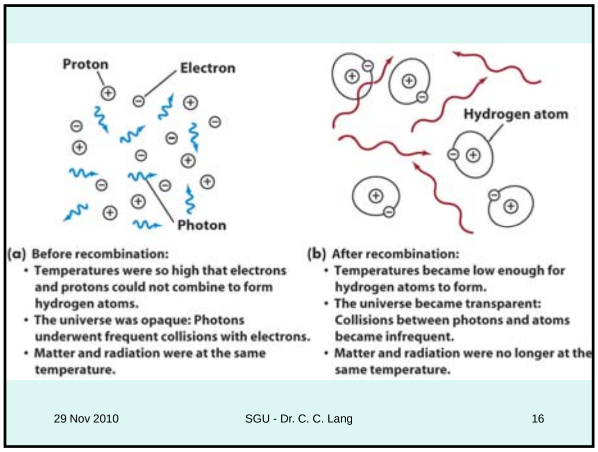
- Temperatures were right for nuclear reactions to take place
- much of the Hydrogen (25%) formed into Helium
  – "primordial" Helium abundance

For the next 380,000 years:

- still too hot for atoms to remain stable
- the universe kept expanding and cooling down

- finally, after 380,000 years, ions and electrons combined to form ATOMS! "reionization"

- the TEMPERATURE **dropped** to T ~3,000 K!
- the CMB radiation was emitted (now we see it at T~3 K!)
- the universe was finally transparent


Proton
Electron
Photon
Hydrogen atom
(a) Before recombination:
• Temperatures were so high that electrons and protons could not combine to form hydrogen atoms.
• The universe was opaque: Photons underwent frequent collisions with electrons.
• Matter and radiation were at the same temperature.
(b) After recombination:
• Temperatures became low enough for hydrogen atoms to form.
• The universe became transparent: Collisions between photons and atoms became infrequent.
• Matter and radiation were no longer at the same temperature.
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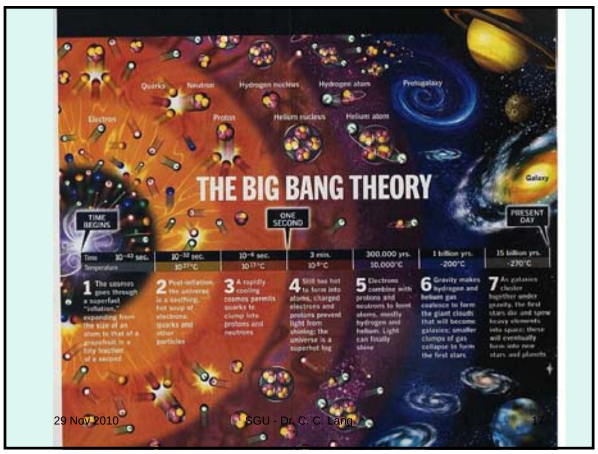
THE BIG BANG THEORY
TIME BEGINS
ONE SECOND
PRESENT DAY
Quarks
Neutron
Hydrogen nucleus
Hydrogen atom
Protogalaxy
Electron
Proton
Helium nucleus
Helium atom
Galaxy
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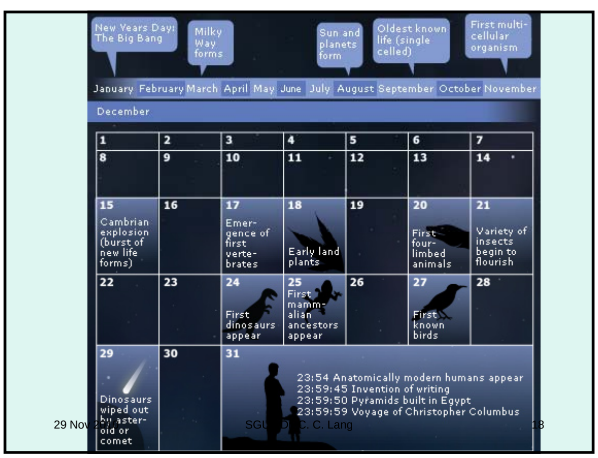
New Years Day: The Big Bang
Milky Way forms
Sun and planets form
Oldest known life (single celled)
First multi-cellular organism
January February March April May June July August September October November
December
15 Cambrian explosion (burst of new life forms)
17 Emergence of first vertebrates
18 Early land plants
20 First four-limbed animals
21 Variety of insects begin to flourish
24 First dinosaurs appear
25 First mammalian ancestors appear
27 First known birds
29 Dinosaurs wiped out by asteroid or comet
31
23:54 Anatomically modern humans appear
23:59:45 Invention of writing
23:59:50 Pyramids built in Egypt
23:59:59 Voyage of Christopher Columbus
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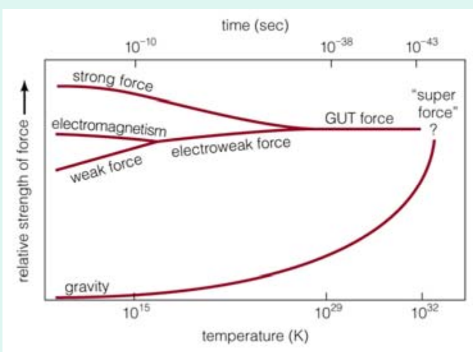
Shortcomings of the Big Bang Model

- So far, we have considered the evidence which supports the Big Bang theory.
- Prior to 1980, cosmologists had identified three major questions which the theory was unable to answer:
  1. **Where does structure come from?**
  2. **Why is the large-scale Universe so smooth (horizon problem)?**
  3. **Why is the density of matter almost critical ?**
- In 1981, physicist Alan Guth realized that the Grand Unified Theories could hold the answers to these questions.
- When the strong force froze out of the GUT force…
  - it should have released enough energy to expand the Universe 10^{30} times in less than 10^{-36} sec
  - we call this dramatic expansion **inflation**



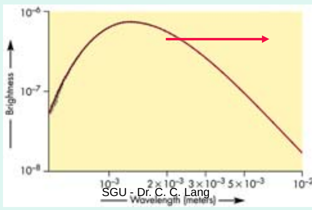
Planck Time:
http://www.yourdiscovery.com/video/how-the-universe-works-planck-time/

Is there *any* evidence that the Big Bang happened?

What would the gamma rays emitted during the Big Bang epoch look like now??

→ Theory (from 1940s) says that the T~3,000 K (Temperature of universe after ~380,000 years when atoms could emit light) should be DETECTABLE!

→ This radiation will have been redshifted by the expansion of the universe; cooled from T=3000 K to T=3 K
→ detectable in the microwave part of spectrum!



→Two scientists working at Bell Labs in New Jersey (Arno Penzias & Robert Wilson) were using a modest radio telescope to carry out experiments related to earth-satellite communications (telephone relay calls)
→ They were puzzled when they saw a signal at T~3 K coming from the entire sky!

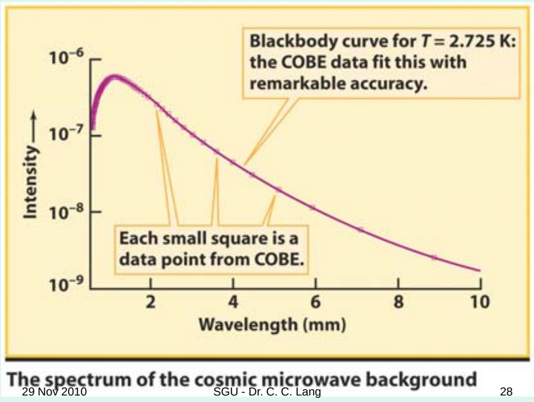
Discovered a background signal around T~ 3 K from
ALL PARTS OF THE SKY
→at first they thought it was pigeon droppings on the dish!

In 1978,
Arlo Penzias and
Robert Wilson won
the Nobel Prize for
their "accidental"
discovery of the T=3 K
background radiation

also known as "CMB"
Cosmic Microwave Background

1% of the TV "static" you see is from CMB radiation!

isotropic



The spectrum of the cosmic microwave background

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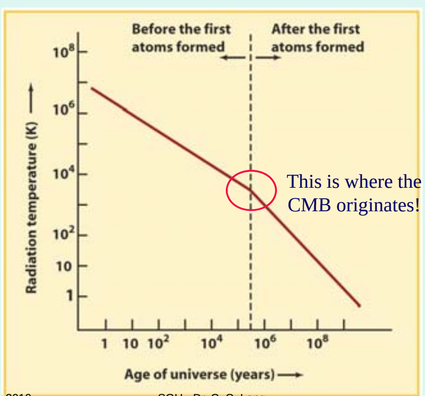

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