1. Reminders and readings

Reminders and readings

- Exam Thursday, Mar.2 --- in class
- Homework 3 solutions posted
- Discussion session today 4:30
- Work on practice exam - answers posted

Read:

- Hoffmann, Chapters 2 to 8, 11, 13, 14 to p.186. This is to be read over the *two weeks following exam*.
  It covers the historical development of quantum physics.
  You may choose to read all the chapters - they're interesting.
- Feynman, Chapter 6.

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 1

2. Cosmology

Cosmology

- What is the structure of Universe? Physical basis for structure? How did it evolve?
- Einstein (1916) General Relativity & Field Equations
  - 1 sol'n: Static universe & cosmological principle ⇒ gravity (~ -1/r) & Cosmological Constant (~+r) delicately keep from collapsing
- Hubble expansion (1929) from galactic red shifts:
  $v = H r$ $H = (23\ Km/sec)/(10^6\ c \cdot yr)$
  $1/H = 1.3 \times 10^{10} yr$ Hubble time (constant?)
  - Cf. Expanding balloon (2 d surface in 3 d space)
  - Other sol'ns: Uniform density expanding universe (Friedmann)
    open flat closed (see graph)

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 2

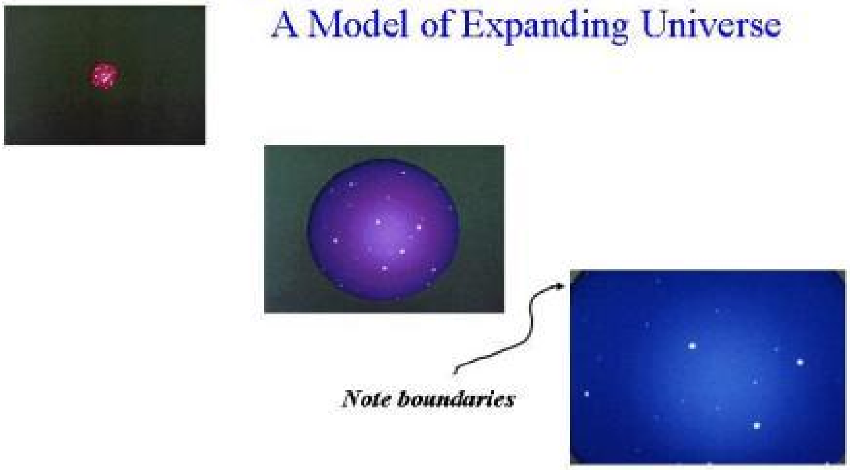
3. Lecture 11: Cosmology and Quantum Introduction: Slide 3

3 stages in expansion of 2 dimensional surface

Consider spacing of points on surface

Scale increases in time

A Model of Expanding Universe



5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 3

4. Effects of Dark energy

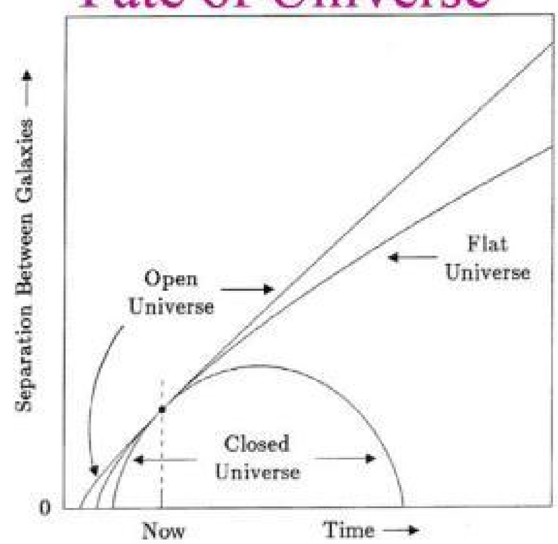
Effects of Dark energy

- Three possible outcomes
  - Big rip
  - Einstein
  - Big crunch

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 4

5. Fate of Universe

Fate of Universe



5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 5

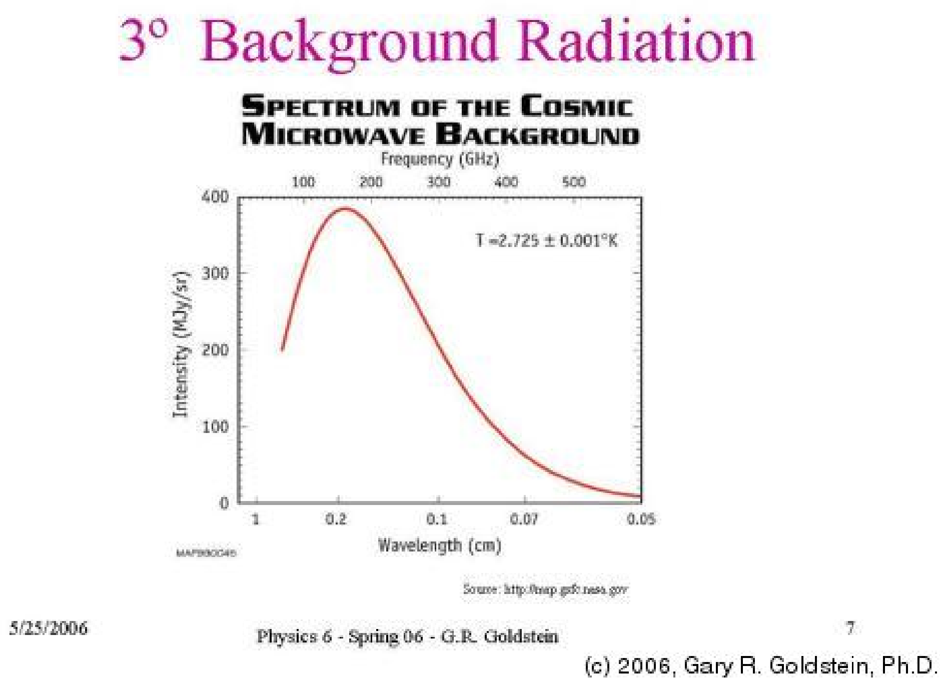
6. Big Bang

Big Bang

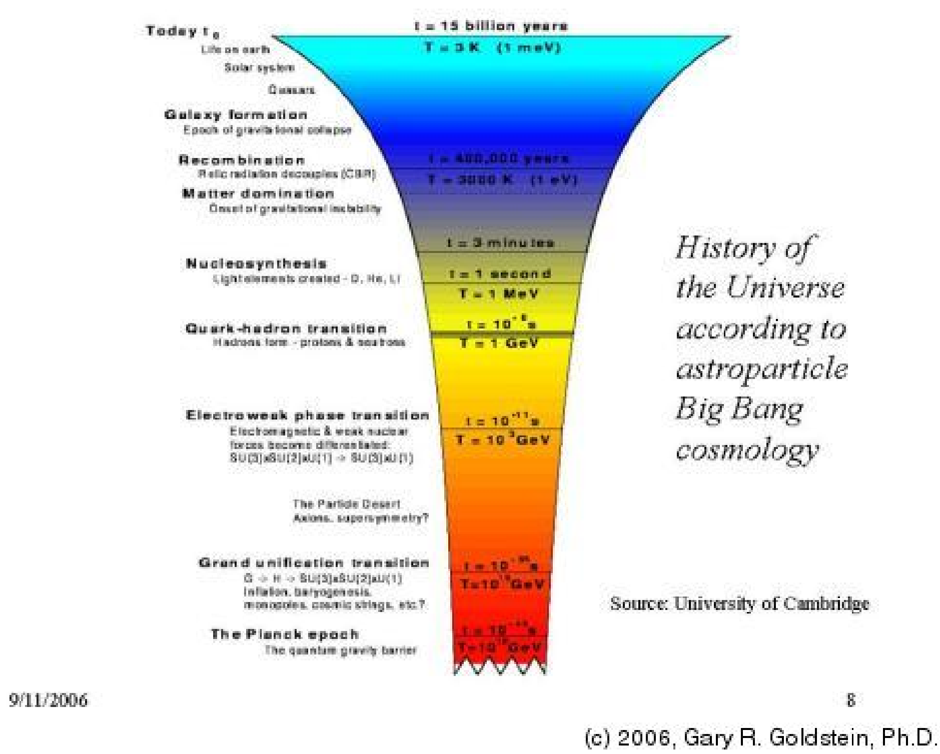
- Why big bang?
  - Expansion had a beginning - time scale of $1/H \sim 10^{10}$yr
  - Farthest galaxies appear earliest in evolution
  - Extrapolate back in time
- Primordial super-hot, super-dense, radiation (photons, gluons, gravitons,…) with all E of universe
  - Super-super particle accelerator! All matter-energy
- E distributed as T : matter&radiation equilibrium until expansion; ave $E\gamma \sim 1$eV (atoms form) - decoupling → blackbody radiation spectrum at t~10^5yr
- λ_{max} grows with R(t), $\lambda_{max}T$= const, so T_{rad} falls as 1/R(t) to current value of 2.7K.

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 6

7. 3º Background Radiation



8. Lecture 11: Cosmology and Quantum Introduction: Slide 8



9. Quantum Physics - beginning history

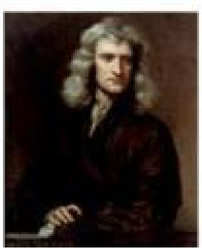
Quantum Physics - beginning history

- End of 19th Century - puzzles (anomalies)
  - Atomic spectra - discrete with regularities
  - X-ray discovery
  - Blackbody radiation
  - Photoelectric effect   All about nature of light
- Early 20th Century discoveries - Atoms, nuclei, molecules, states of matter
  - Radioactivity and nuclear transmutation
  - electron and atoms

5/10/2006   Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein   9

10. Light and waves

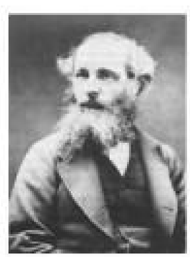
Light and waves



Newton (1642-1727) thought light consisted of corpuscles = particles

T. Young (1773-1829) showed light behaves like a wave - interference

Maxwell (1831-1879) showed that light was an Electromagnetic wave
Part of a vast spectrum



5/10/2006   Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein   10

11. Electromagnetic waves

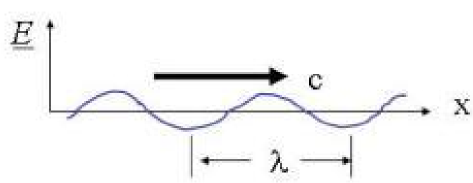
Electromagnetic waves

- Maxwell (~1860) theorized that light is an EM wave - disturbance or changing of E&M force fields
- Propagates at $c=3.0\times10^8$ m/sec
- What are other wave properties of EM waves?

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 11

12. Properties of EM waves

Properties of EM waves

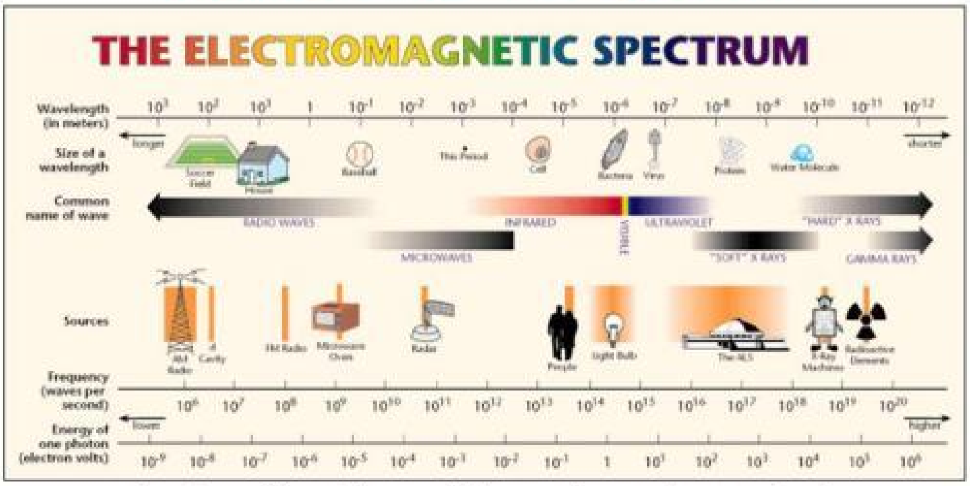


- λ is wavelength
- f is frequency or rate at which cycles pass a fixed point
- $c = \lambda f$ for any wave (travelling plane wave)
- Enormous spectrum of possibilities -> radio, radar, X-rays, …

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 12

13. Maxwell EM wave spectrum

Maxwell EM wave spectrum



http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 13

14. Blackbody radiation

Blackbody radiation

- Heated objects radiate EM (and absorb)
  - Sun &stars (earth absorbs, reflects & re-radiates)
  - Each square centimeter of the solar surface emits as much light as a 6000 Watt lamp. The temperature of the photosphere is about 5800 K.
  - Solar energy is created deep within the core of the Sun. The core temperature is 15,000,000° C and pressure is 340 billion times Earth's air pressure at sea level, both so intense that nuclear fusion takes place.
- EM spectrum depends on Temperature(K)
- Ideal radiator = Blackbody (also ideal absorber)
- Intensity ~ R(λ,T) (Universal function)
  - I(Intensity) is power per unit area (W/m^2)
- Total (all λ) $I \sim T^4$ Stefan's Law (big effect!)
- Peak I at $\lambda \sim 1/T$ Wien's Law

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 14

15. Blackbody spectrum

Blackbody spectrum

Image not available due to copyright restrictions.

6/6/2006 Physics 6 - Spring 06 - G.R. Goldstein 15

16. Quantum physics’ first problem

Quantum physics' first problem

- Blackbody radiation - intensity vs. frequency
- Problems in interpretation - UV Catastrophe
- Planck: oscillating molecules in walls emit & absorb EM radiation in discrete amounts only
- **E=hf** with $h=6.6\times10^{-34}$ Joule sec (not the Classical $E\sim(f\times$**Electric force**$)^2$) h is very small!
- What is EM radiation? Waves or Particles?
  - Interference or collisions?

5/10/2006 Physics 6 - G.R. Goldstein - Spr.03Physics 6 - Spring 06 - G.R. Goldstein 16