Expanding Universe

November 20, 2002

1) Hubble's Law
2) Expanding Universe
3) Fate of the Universe

Final Exam will be held in Ruby Diamond Auditorium

NOTE THIS!!!

not UPL

Dec. 11, 2002 10am-noon

Review of Particles and Telescopes

- Dark Matter
- Particle physics
  - atoms
  - quarks
  - table of particles
  - WIMPs
- Telescopes
  - refracting, reflecting
  - usable wavelengths
  - satellites and other methods

Measuring Distances

- Stereoscopic viewing
  - only "small" distances
- Standard candles
  - objects which have known luminosities
  - Cepheid variables
    - variation tells luminosity – good to 65 million LY
  - Type Ia supernova
    - all have same luminosity
    - good to 8 billion LY
- Comparison to nearby galaxies

Galactic Redshifts

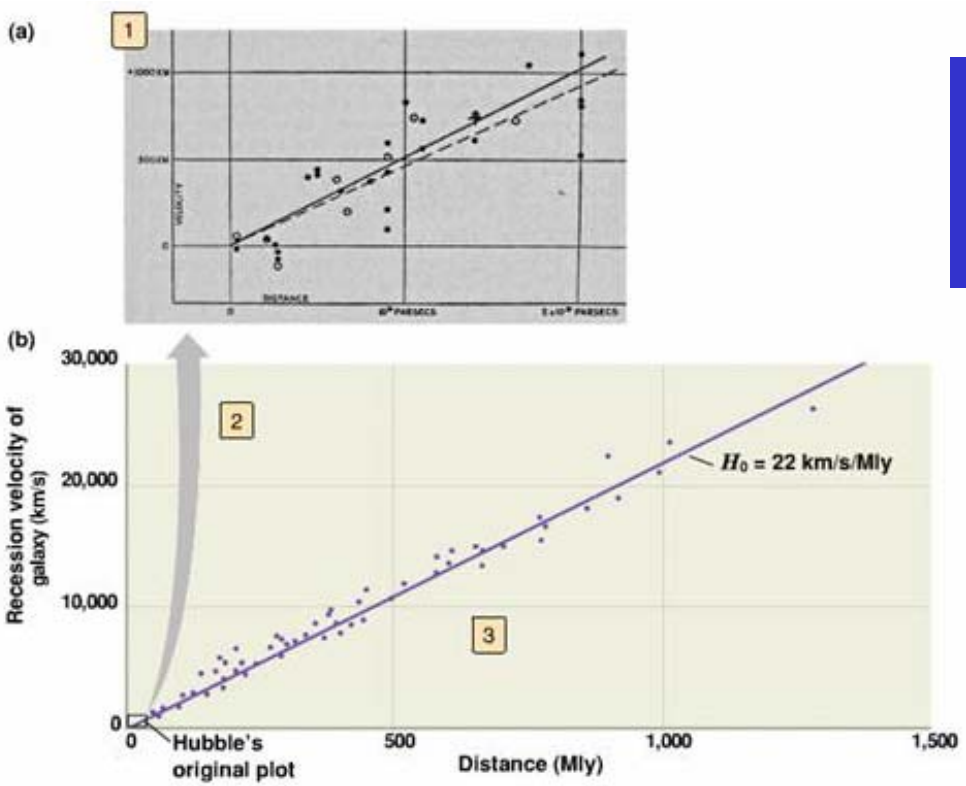
- Edwin Hubble (1889-1953) and colleagues
  - measured the spectra (light) of many galaxies
  - found nearly all galaxies are red-shifted
- Redshift

$$Z = \frac{\lambda_{\text{observed}} - \lambda_{rest}}{\lambda_{rest}}$$

- From Ch. 4, z = v/c

Hubble's Law

- Hubble found the amount of redshift depended upon the distance
  - the farther away, the greater the redshift



$$v = H_0 \times d$$

What is H_0?

Hubble's Law

- Holds for all galaxies with measured redshift and distance
- THEREFORE, measuring the redshift tells us the distance
  - redshifts up to 90% of the speed of light have been measured
    - ultraviolet wavelengths can be shifted into the visible
- H_0 is Hubble's constant = 22 km/(s MLY)
  - MLY = megalightyear

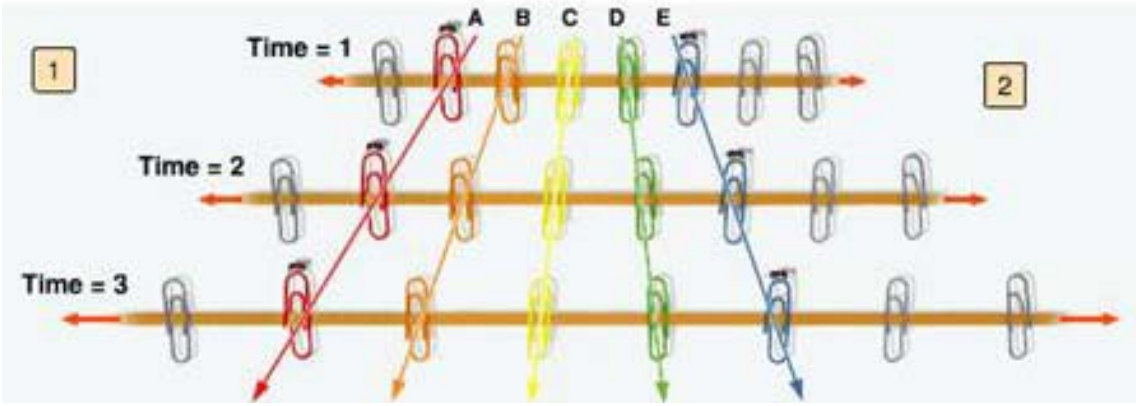
Consequences

- If everything is moving away from us and things farther are moving faster
- Then the Universe is expanding!

This doesn't mean what you are probably thinking

Expanding Universe

- Space is expanding not matter flying apart
- Examples:
  - dots
  - rubber band
  - raisin bread
  - ants on a balloon



- It does <u>not</u> mean we are at the center of the Universe
  - every part of the Universe sees everything moving away from it

Cosmological Redshift

- We now know 3 kinds of redshift
- Doppler shift
  - due to motion
- Gravitational shift
  - due to distortion of space-time by mass
- Cosmological shift
  - due to stretching of space
    - not due to relative motion
  - as space stretches, the wavelength stretches and becomes longer

Looking Back in Time

- Remember it takes time for light to reach us
  - travels at 300,000 km/s
  - So we see things as they were some time ago
- The farther away, the further back in time we are looking
  - 1 billion LY means looking 1 billion years back in time
- So the greater the redshift, the further back in time
  - redshift of 0.1 is 1.4 billion lightyears which means we are looking 1.4 billion years into the past

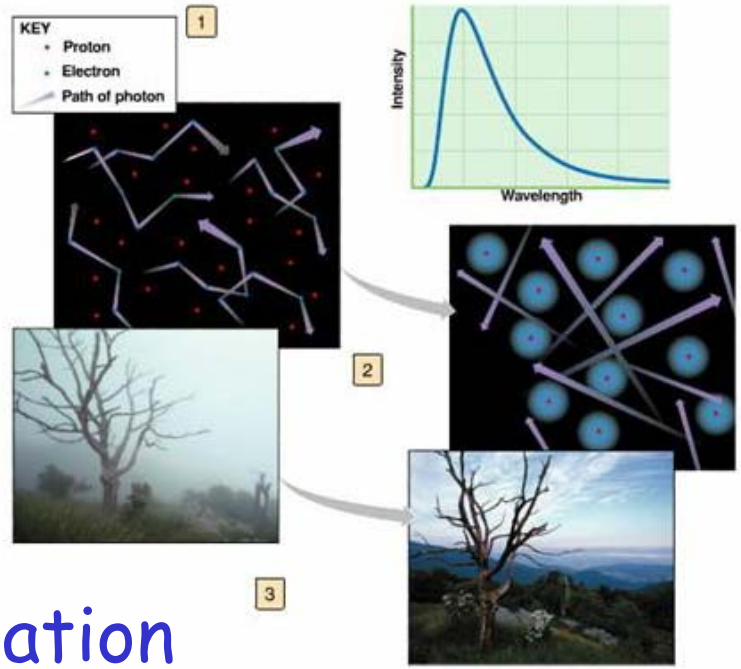
Thinking Back in Time

- If all galaxies are moving away from each, then in the past all galaxies were closer to each other
- Going all the way back, it would mean that everything started out at the same point
  - then began expanding
- This starting point is called the Big Bang
- We can calculate the age of the Universe using Hubble's Law

Big Bang

- At the beginning of our Universe, all matter was together in a very compact form
  - matter was nothing like it is now
  - very "hot"
- Then space started expanding
  - things "cooled"
  - eventually normal matter formed
- Big Bang model makes a number of testable predictions

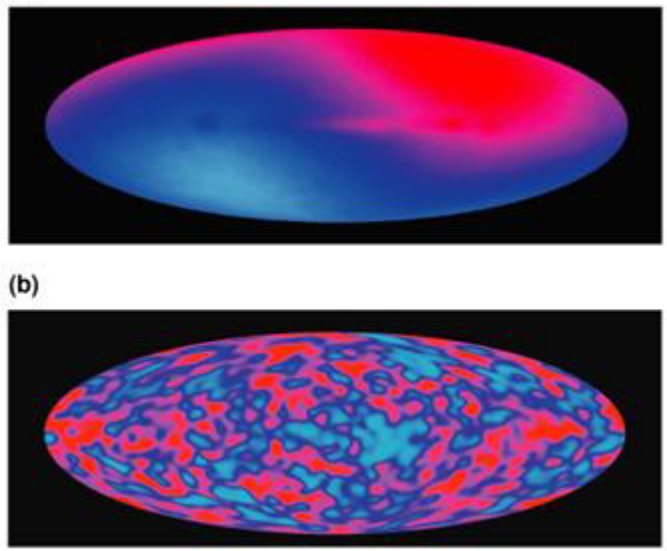
Glow of the Universe

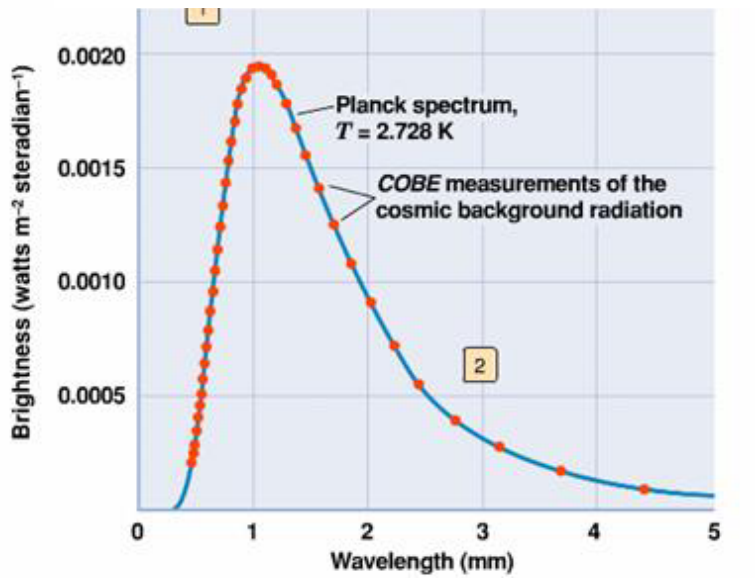


- The early Universe was hot and dense
  - glowed with blackbody radiation
  - but so dense the light kept getting absorbed
- Eventually the Universe cooled enough to form hydrogen atoms
  - blackbody radiation could now travel freely
  - called "recombination of the Universe"
- Light from this time should be all around us

Cosmic Microwave Background (CMB)

- This light should be cosmologically redshifted
  - into microwave region
- CMB was first seen in 1960s
  - twenty years after prediction
- COBE mapped the CMB
  - measured the spectrum
  - wonderful match between theory and data
  - we will come back to this



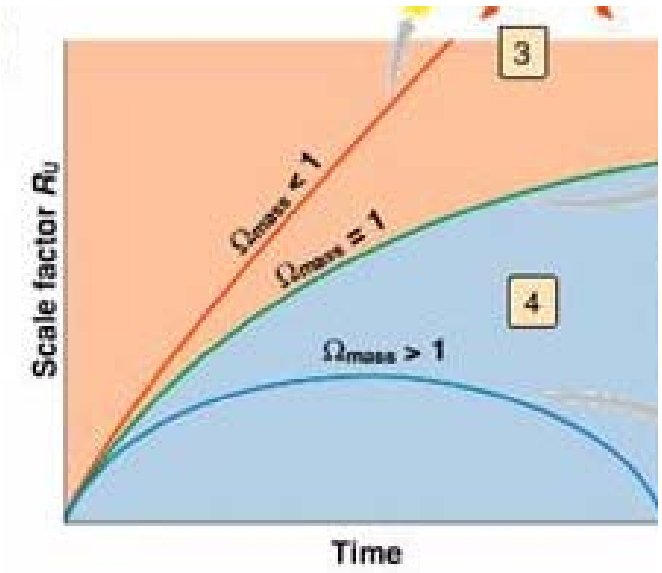


Composition of Light Elements

- Big Bang model predicts the percentage of light elements
  - hydrogen, deuterium (heavy hydrogen), helium, lithium, beryllium, boron
  - elements formed before recombination
  - percentages depend upon density and temperature of early Universe
- Observed percentages agree with Big Bang model predictions

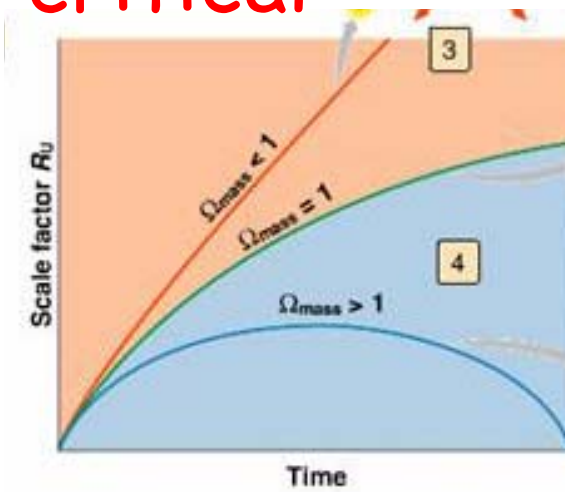
Fate of the Universe

- The Universe is expanding
- But gravity should be pulling it back in
- So what should the Universe's fate be:
  - Continue expanding forever
  - Have expansion keep getting slower forever
  - Expansion stops and eventually Universe collapses upon itself
- These possibilities are called
  - open universe
  - flat universe
  - closed universe

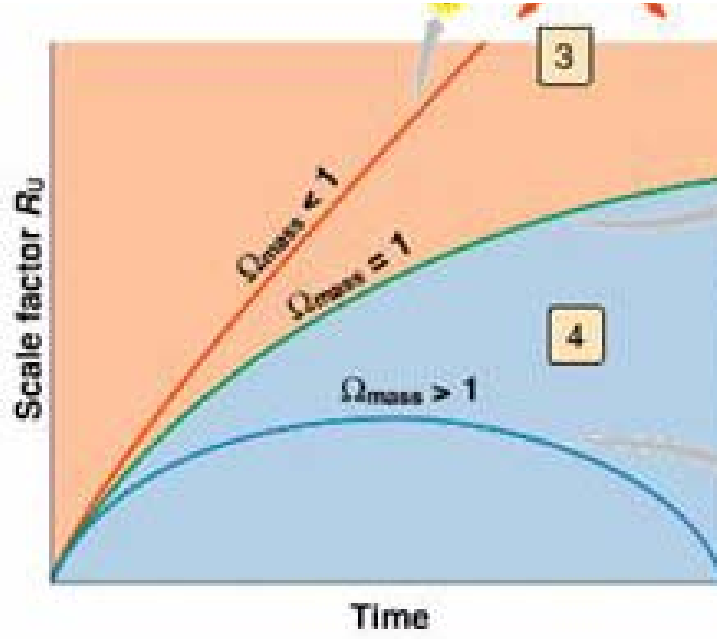


Enough Matter?

- The amount of matter in the Universe helps determine its fate
  - if there is enough mass, gravity wins
  - given H_0 = 22 km/(s MLY), critical mass density is 8×10^{-27} kg/m^3
- define Ω_{MASS} as the actual density of mass in the Universe divided by the critical density
  - $\Omega_{MASS} < 1$ is an open universe
  - $\Omega_{MASS} = 1$ is a flat universe
  - $\Omega_{MASS} > 1$ is a closed universe



Enough Matter?



- Visible matter
  - only 2% of critical density
  - $\Omega_{MASS} = 0.02$
- Dark matter in galaxies
  - about 10 times as much
  - $\Omega_{MASS} = 0.2$
- Dark matter between galaxies
  - raises total to 30% of critical density
  - $\Omega_{MASS} = 0.3$
- We do not observe enough matter to cause the Universe to be closed
- But it's not the end of the story

Is the Expansion Slowing Down?

- Use Type 1a supernovae
  - a standard candle
  - use brightness to determine distance
  - use redshift to determine distance
  - compare distances
  - data lies below prediction
- Answer: The rate of expansion is speeding up!