The Big Bang

- Review of Hubble expansion
- Assumptions in cosmology
- The Big Bang
- Cosmic microwave background
Hubble expansion $v = H_0 d$

The straight line that best fits the data corresponds to $H_0 = 71 \text{ km/s/Mpc}$. 

![Graph showing the relationship between velocity and distance with a best-fit line indicating $H_0 = 71 \text{ km/s/Mpc}$]
What would be the recession speed of a galaxy at a distance of 7 Mpc?

A) 0.1 km/s
B) 10 km/s
C) 250 km/s
D) 500 km/s
E) 1000 km/s

\[ \text{Speed} = H_0 \times \text{distance} \quad H_0 = 71 \text{ km/s/Mpc} \]
When was this galaxy in the same place as the Milky Way? 

time = distance / velocity 

= 7 Mpc/(0.5 Mpc/Gyr) = 14 Gyr ago
If the Hubble constant were doubled, what would be the recession speed of a galaxy at a distance of 7 Mpc?

A) 0.1 km/s  
B) 10 km/s  
C) 250 km/s  
D) 500 km/s  
E) 1000 km/s  

\[ \text{Speed} = H_0 \times \text{distance} \quad H_0 = 2 \times 71 \text{ km/s/Mpc} \]
When was this galaxy in the same place as the Milky Way?

\[
time = \frac{\text{distance}}{\text{velocity}}
\]

\[
= \frac{7 \text{ Mpc}}{1.0 \text{ Mpc/Gyr}} = 7 \text{ Gyr ago}
\]
If Hubble's constant were twice as large as we now think it is, our estimate of the age of the universe would

A) be unchanged
B) increase by a factor of 2
C) increase by a factor of 4
D) decrease by a factor of 2
E) decrease by a factor of 4
Quasars are receding from us at high velocities because

A) matter in black hole jets moves at close to the speed of light
B) matter moves rapidly when close to a black hole
C) quasars are at large distances
D) we smell bad
The variety of different active galaxies can be explained as due to

A) different orientations of the accretion disk
B) different forms of matter being accreted
C) different shapes of black holes
D) different velocities of black holes
Assumptions in Cosmology

Copernican principle:
- We do not occupy a special place.
- There are no special places.
- The universe is homogeneous if viewed at sufficiently large scales.
- The laws of physics are the same everywhere.
How can we test the Copernican principle?

• Does the Universe look the same in all directions? (Isotropy)
• Are the spectral lines from atoms the same in distant galaxies?
• Do the same laws of gravity apply in other galaxies?
Implications of the Copernican Principle

• The average density of matter and energy is the same throughout the Universe.
• The same Hubble expansion law is seen for all observers anywhere in the Universe.
• The curvature of the Universe is the same everywhere.
Big Bang

• Our conclusion that the Universe actually began at some point in time is based on extrapolating back the observed Hubble expansion of galaxies

• Is there any other evidence?
Temperature

- Temperature is a measure of how fast the atoms in a gas move.

  - Hotter
    - atoms move faster
    - higher energy density

  - Cooler
    - atoms move slower
    - lower energy density

Anything will melt if the temperature is high enough.
Big Bang

If the Universe was smaller in the past, but had roughly the same amount of matter and energy, then the density of matter and energy must have been higher in the past.
History of the Universe

Big Bang

Radiation-dominated era

Lepton epoch

Quark epoch

Electroweak epoch

Grand unification epoch

Quantum gravity epoch

The universe becomes transparent

Decoupling of matter-radiation

Formation of atoms

Nucleosynthesis of helium

Disappearance of positrons

Confinement of quarks

Formation of protons, neutrons

Disappearance of antiprotons

Asymmetry of quarks

Magnetic monopoles?

Cosmic inflation?

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Present

10 billion years

1 billion years

4 billion years

2 billion years

1 billion years

100 years

10^(-3) sec.

10^(-6) sec.

10^(-13) sec.

10^(-26) sec.

Big Bang

The Desert

Helium nucleus

Hydrogen atom

Heavy atom

Protoplanet

Heavy star

Protoplanet

Helium atom

Hydrogen atom

Radiant galaxy

We are here

History of the Universe

Big Bang
Big Bang

Disappearance of Antiquarks
10^{-10} sec.

ELECTROWEAK EPOCH

Asymmetry Q - \bar{Q}, L - \bar{L}
Magnetic Monopoles?
10^{-34} sec.

Cosmic Inflation?

GRAND UNIFICATION EPOCH

10^{-43} sec.

QUANTUM GRAVITY EPOCH
First protons and neutrons at about 1 second. Helium nuclei formed at about 100 seconds. Observed ratio of Helium/Hydrogen matches Big Bang prediction. Universe is opaque.
At one million years, electrons combine with nuclei and atoms form. Universe becomes transparent.
A Before recombination: The universe was opaque

B After recombination: The universe was transparent
Cosmic Microwave Background

The Universe glows at 2.7 K in every direction.
Discovered by Arno Penzias and Robert Wilson in 1960-65 while employed by AT&T’s Bell Labs and attempting to find the source of noise in an antenna used to bounce telephone signals bounced off metallic balloons high in the atmosphere.

They won the Nobel prize in 1978.
Radiation is a blackbody spectrum originally emitted at 3000 K but red shifted by a factor of 1000.
Three pieces of evidence for the Big Bang model

• Hubble expansion: galaxies are moving away from us with speed proportional to distance.
• The ratio of Helium to Hydrogen in gas clouds unaffected by stars matches with that predicted.
• The cosmic microwave background: a 2.7 K glow seen in all directions.