The Big Bang and Cosmology

Hubble discovered in the 1920’s that the universe is expanding. This suggests that the universe began with a Big Bang. The main evidence today is:

1. Redshifts \( z = \frac{v}{c} \) of galaxies increase with their distance (Hubble’s Law):

\[
v \approx HD
\]

Hubble’s constant is \( H \approx 50 \text{ km/sec/Mpc} \).

\[
D = vt
\]
gives the age of the universe as

\[
t = \frac{D}{v} \approx \frac{1}{H} \approx 20 \text{ Billion yrs.}
\]

2. Microwave background radiation with a uniform temperature \( T = 2.7 \text{ K} \).

This originated at the decoupling era when the universe was 300,000 yrs old and hot \( (T \approx 3000 \text{ K}) \).

3. Cosmic nucleosynthesis of light elements \( (\text{He, Li, Be, B}) \) when the universe was seconds old and hotter \( (T \approx 10^9 \text{ K}) \).
The Future of the Universe
Depends upon density $d$:

$$\Omega = d/d_c$$

$$d_c = 3H^2/8\pi G \approx 3 \text{ H atoms/m}^3 \text{ (critical density)}$$

- $\Omega > 1 \ (d > d_c)$: closed universe which will eventually recontract.
- $\Omega < 1 \ (d < d_c)$: open universe which will expand forever.
- $\Omega = 1 \ (d = d_c)$: critical case, leads to stalled expansion, but not recontraction. This case is mathematically elegant, and solves the so-called flatness problem. If $\Omega$ is not exactly 1, then $\Omega$ should either be much much much less than 1 or much much much greater than 1 at present.

Observed abundances of light nuclei ($_1H^1$, $_2\text{He}^4$, $_2\text{He}^3$, $_1\text{H}^2$, $_4\text{Li}^7$) agree with theory if the density of ordinary baryonic matter (neutrons, protons and nuclei) is about 4% of the critical density ($\Omega_{baryon} \approx 0.04$).
But measurements of our Galaxy’s mass and motions of galaxies in clusters imply a large amount of “missing mass” or “dark matter” ($\Omega_{\text{dark matter}} \approx 0.26$) that is not in the form of baryons and is not yet directly observable. Perhaps it consists of neutrinos, black holes, or as-yet unknown particles.
Moreover, observations of
- fluctuations in cosmic background radiation
- extremely distant supernovae
show that
- the universe’s expansion is now accelerating, not decelerating as gravity alone would cause
- the total $\Omega$ is 1.

This implies the existence of yet another form of mass-energy, the so-called “dark energy”, with $\Omega_{\text{dark energy}} \approx 0.7$. Therefore $\Omega_{\text{dark energy}} + \Omega_{\text{dark matter}} + \Omega_{\text{baryon}} = 1$. Dark energy is not matter and no one knows what it could be; one suggestion is that it is the exotic matter that was proposed for faster-than-light travel.