1. Observational Basis of the Big Bang Cosmological Model

The Standard Big Bang Model: Key Observations

1. The night sky is dark.
2. General relativity accurately describes gravity on solar system scales.
3. The universe is expanding: $\mathbf{v} = H_0\mathbf{r}$ (Hubble's law). (NB: Isn't perfect – peculiar velocities. Breaks down when $v \sim c$.)
4. The observed universe is isotropic on very large scales.
5. The inferred ages of globular clusters are $\sim 1/H_0$, to within a factor of two.
6. We observe a nearly isotropic background of microwave radiation with a *blackbody* spectrum, $T \sim$ 2.7K.
7. The helium abundance in the lowest metallicity stars is $\approx 25\%$ (by mass).
8. Abundances of other light elements are $\sim 10^{-5}$ (D, ^{3}He), $\sim 5 \times 10^{-10}$ (^{7}Li), to within a factor of 20.

Implications and connections

(1) rules out a static, infinite universe.

Combination of (4) with the "Copernican Principle" (nothing special about us) implies the "Cosmological Principle": the universe is homogeneous and isotropic. First introduced by Einstein as an unsupported assumption. Now good evidence that it is true on large scales.

Combination of the cosmological principle, the validity of GR, and some plausible assumptions about the material content of the universe (non-exotic equation of state) implies that the universe has expanded from a very dense, very hot state. According to classical GR, this initial state was a singularity.

Note: the "plausible assumption" of a non-exotic equation of state does not appear to hold true today.

Definition of the Big Bang Theory: The universe has expanded from a very dense, very hot state that existed at some finite time in the past.

In more detail, the BBT assumes that the universe on large scales is homogeneous and isotropic, that it is accurately described by GR, and that matter and radiation obeyed the same physical laws in the past that they do today.

The BBT predicts (3), which is the only expansion law consistent with the cosmological principle. $\mathbf{v}_1 = H\mathbf{r}_1$, $\mathbf{v}_2 = H\mathbf{r}_2 \Longrightarrow \mathbf{v}_2 - \mathbf{v}_1 = H(\mathbf{r}_2 - \mathbf{r}_1)$.

The BBT also predicts (5), since the expansion age of the universe is $\sim 1/H_0$ (precise value depends on matter and energy content of the universe).

The BBT also predicts (6), though it does not predict the value of the temperature itself.

Given $T = 2.7$K and a mean baryon density consistent with observations, the BBT predicts (7) and (8).

We now have a more detailed "standard model" of cosmology that specifies the forms of matter and energy present in the universe and describes the origin and evolution of inhomogeneities.

Usually referred to as "ΛCDM", where CDM stands for cold dark matter and Λ refers to a "cosmological constant," a form of energy that pervades empty space and whose energy density is constant in space and time.

The ΛCDM model also incorporates primordial inhomogeneities arising from quantum fluctuations during inflation, a rapidly accelerated expansion phase of the very early universe.

We will discuss the key observations underlying ΛCDM mid-way through the course.