Cosmology

Cosmology: study of the origin, structure and evolution of the Universe

What would we like a theory of cosmology to explain?

- `**Origin**' of the Universe (what was the Universe like at much earlier epochs?)
- **Fate** of the Universe
- How did the **structure** seen in today's Universe form?
- How did the **elements** form?
- + …

We will discuss the **hot big bang** model for understanding some of these problems.

Elements of the hot big bang model

Model rests on a number of fundamental assumptions and observations:

1. Universe is homogenous and isotropic

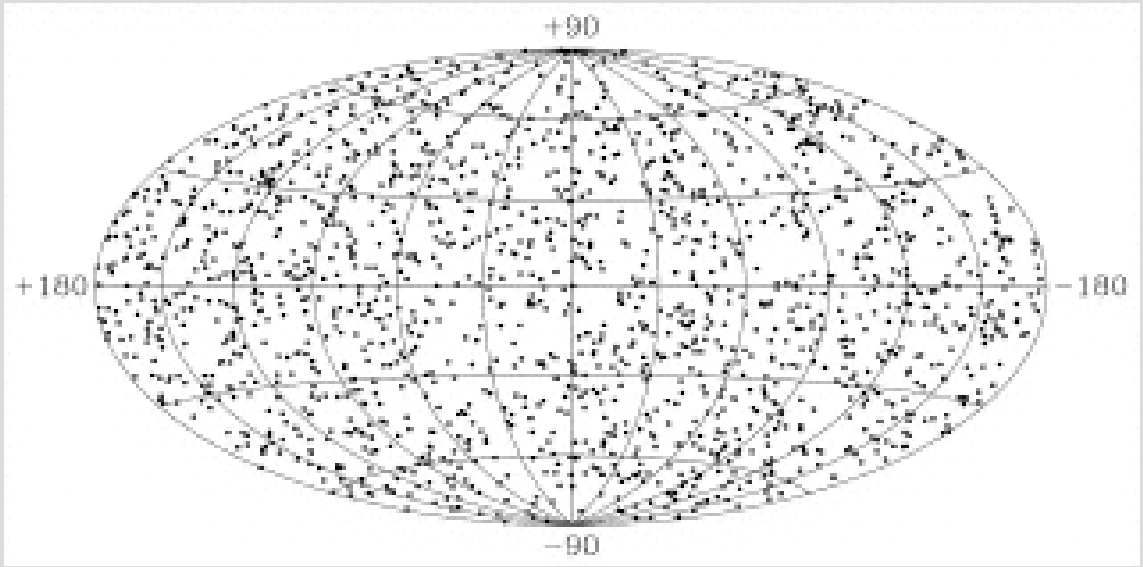
When averaged over sufficiently large volumes, the Universe is **isotropic** (same in all directions) and **homogenous** (other observers at different locations see the same general picture of the Universe at the same time).

Described as the **cosmological principle** - evidently makes the mathematical description much easier as there are no special places or directions.

`Nearby' galaxies are strongly *clustered*. Angular distribution of the most distant sources is much closer to isotropic:

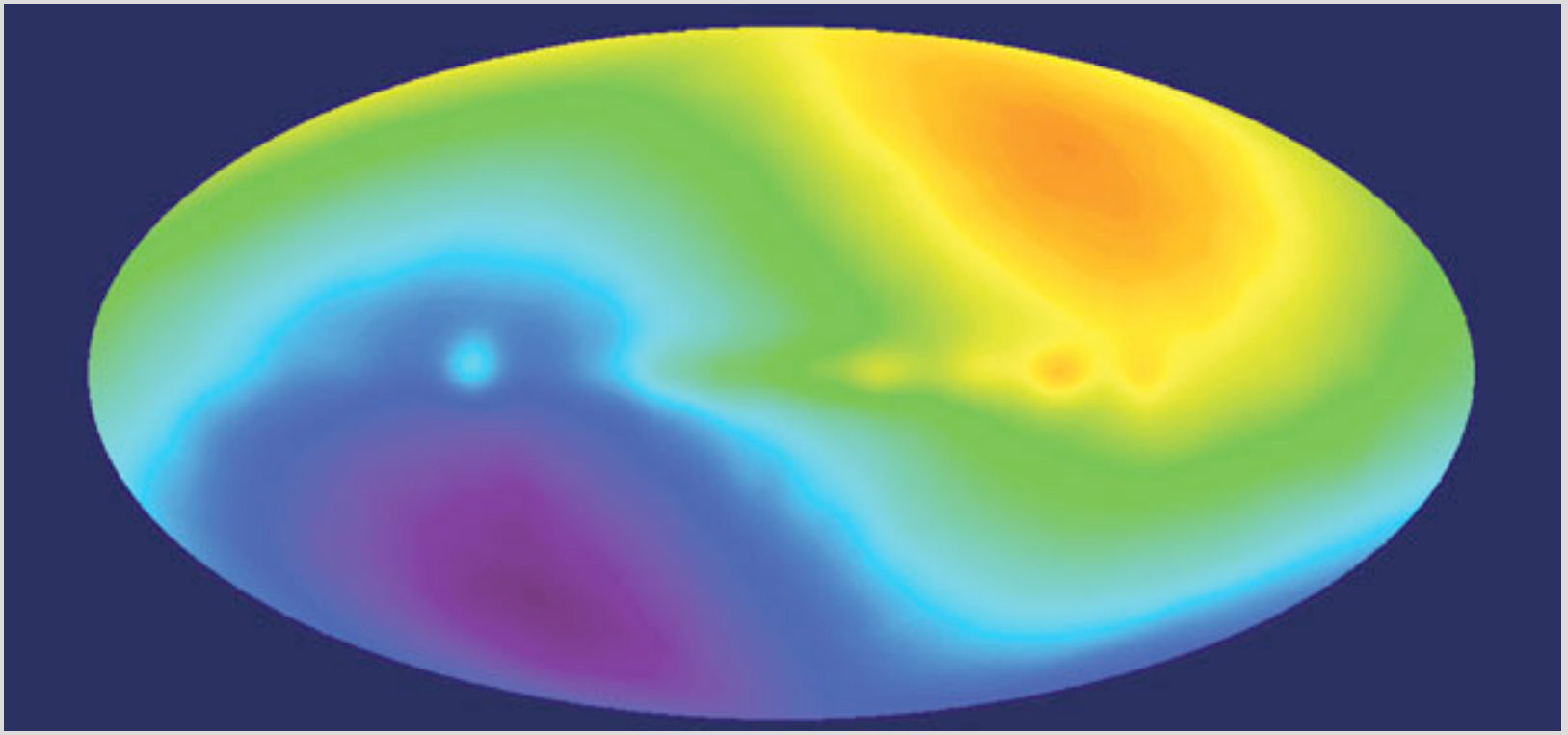
Radio sources
Texas survey at
365 MHz

~ 65,000 sources



Gamma ray bursts
BATSE catalog of
first ~ 1000 bursts

X-ray background and (especially) the cosmic microwave background are very close to isotropic once the dipole has been subtracted:



CMB: isotropic at 10^{-5} level once the dipole and Galactic emission have been accounted for.

2. Universe is expanding

The mean distance l between conserved particles is increasing with time at the rate:

$$\frac{dl}{dt} = H_0 l$$

Constant of proportionality is time-dependent, the present value is **Hubble's constant** H_0. Best observational estimates of H_0 are:

$$H_0 = 71 \pm 4 \ \mathrm{kms}^{-1} \ \mathrm{Mpc}^{-1}$$

(this is value quoted by the WMAP team from observations of the microwave background - HST Key Project result from measurements of Cepheids in external galaxies is identical within the errors).

Can define a Hubble length:

$$c / H_0 \sim 4000 \text{ Mpc}$$

at which this expression for the recession velocity extrapolates to the speed of light - more detailed relativistic treatment is needed for distances of this order.

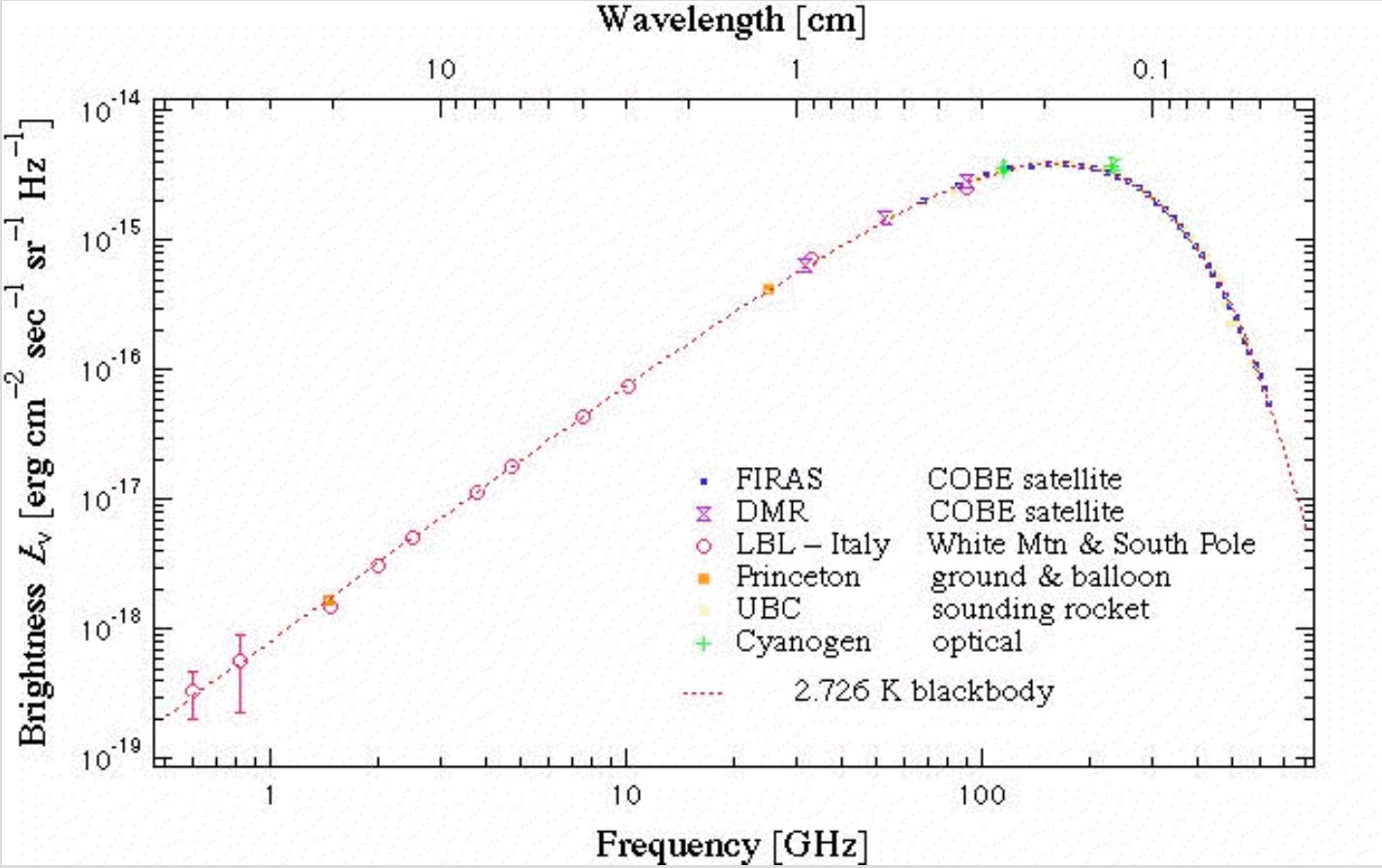
Can also define a Hubble time:

$$1 / H_0 \sim 10^{10} \text{ years}$$

…this is to order of magnitude the age of the Universe.

3. Universe expanded from a hot dense state

Implied by a naïve extrapolation of the expansion back to much earlier times. Direct evidence from the existence and spectrum of the microwave background, which is very well fit by a blackbody spectrum:



4. Dynamics of the Universe are described by Einstein's theory of General Relativity

Need a theory of gravity in order to make quantitative predictions - e.g. for how the expansion will evolve with time. Newtonian gravity is not (quite) sufficient - mathematical description relies instead on General Relativity.

Conservative view: validity of General Relativity on scales of the Universe not proven from cosmological measurements (though certainly *consistent* with available observations).

Belief in validity of relativistic description rests on other measurements / experiments which are fully consistent with predictions of General Relativity.