Lecture I

Natural system of units we work with:

$$\hbar = c = k_B = 1$$

Table 1.1 Conversion of natural units into CGS units.

Energy	$1\,\mathrm{GeV} = 1.6 \cdot 10^{-3}\,\mathrm{erg}$
Mass	$1\,\mathrm{GeV} = 1.8 \cdot 10^{-24}\,\mathrm{g}$
Temperature	$1\,\mathrm{GeV} = 1.2 \cdot 10^{13}\,\mathrm{K}$
Length	$1\,\mathrm{GeV}^{-1} = 2.0 \cdot 10^{-14}\,\mathrm{cm}$
Time	$1\,\mathrm{GeV}^{-1} = 6.6 \cdot 10^{-25}\,\mathrm{s}$
Particle number density	$1\,\mathrm{GeV}^3 = 1.3 \cdot 10^{41}\,\mathrm{cm}^{-3}$
Energy density	$1\,\mathrm{GeV}^4 = 2.1 \cdot 10^{38}\,\mathrm{erg} \cdot \mathrm{cm}^{-3}$
Mass density	$1\,\mathrm{GeV}^4 = 2.3 \cdot 10^{17}\,\mathrm{g} \cdot \mathrm{cm}^{-3}$

Table 1.2 Conversion of CGS units into natural units.

Energy	$1\,\mathrm{erg} = 6.2 \cdot 10^{2}\,\mathrm{GeV}$
Mass	$1\,\mathrm{g} = 5.6 \cdot 10^{23}\,\mathrm{GeV}$
Temperature	$1\,\mathrm{K} = 8.6 \cdot 10^{-14}\,\mathrm{GeV}$
Length	$1\,\mathrm{cm} = 5.1 \cdot 10^{13}\,\mathrm{GeV}^{-1}$
Time	$1\,\mathrm{s} = 1.5 \cdot 10^{24}\,\mathrm{GeV}^{-1}$
Particle number density	$1\,\mathrm{cm}^{-3} = 7.7 \cdot 10^{-42}\,\mathrm{GeV}^3$
Energy density	$1\,\mathrm{erg} \cdot \mathrm{cm}^{-3} = 4.8 \cdot 10^{-39}\,\mathrm{GeV}^4$
Mass density	$1\,\mathrm{g} \cdot \mathrm{cm}^{-3} = 4.3 \cdot 10^{-18}\,\mathrm{GeV}^4$

Weak gravitational interactions → huge Planck scale

$$G = M_{Pl}^{-2}$$

$$M_{Pl} = 1.2 \cdot 10^{19}\,\mathrm{GeV}$$

$$l_{Pl} = \frac{1}{M_{Pl}} = 1.6 \cdot 10^{-33}\,\mathrm{cm},$$

$$t_{Pl} = \frac{1}{M_{Pl}} = 5.4 \cdot 10^{-44}\,\mathrm{s},$$

$$M_{Pl} = 2.2 \cdot 10^{-5}\,\mathrm{g}.$$

Typical time/length scales in astrophysics/Cosmology

*** astronomical unit (a.u.), which is the average distance from the Earth to the Sun,

$$1\,\text{a.u.} = 1.5 \cdot 10^{13}\,\text{cm}$$

*** light year, the distance that a photon travels in one year,

$$1\,\text{year} = 3.16 \cdot 10^{7}\,\text{s}, \quad 1\,\text{light year} = 3 \cdot 10^{10}\,\frac{\text{cm}}{\text{s}} \cdot 3.16 \cdot 10^{7}\,\text{s} = 0.95 \cdot 10^{18}\,\text{cm}$$

*** parsec (pc) — distance from which an object of size 1 a.u. is seen at angle 1 arc second,

$$1\,\text{pc} = 2.1 \cdot 10^{5}\,\text{a.u.} = 3.3\,\text{light year} = 3.1 \cdot 10^{18}\,\text{cm}$$

*** The traditional unit of length in cosmology is Megaparsec,

$$1\,\text{Mpc} = 3.1 \cdot 10^{24}\,\text{cm}$$

Hierarchy of length scales in astrophysics/Cosmology

- Scale of the Solar system: ~100 a.u.
- Nearest stars (Proxima and Alpha Centauri): ~1.3 pc from the Sun
- The Center of our Galaxy: ~8 kpc
- Diameter of the Milky Way's disk: ~30 kpc
- Distance to largest satellites of our Galaxy (Magellanic Clouds): ~50 kpc away
- The nearest galaxy M31: ~800 kpc
- Typical size of clusters of galaxies: ~1-3 Mpc
- The distance to the center of the nearest cluster: ~15 Mpc
- Typical size of superclusters of galaxies – the largest gravitationally bound objects: ~100 Mpc

Determination of the Hubble parameter

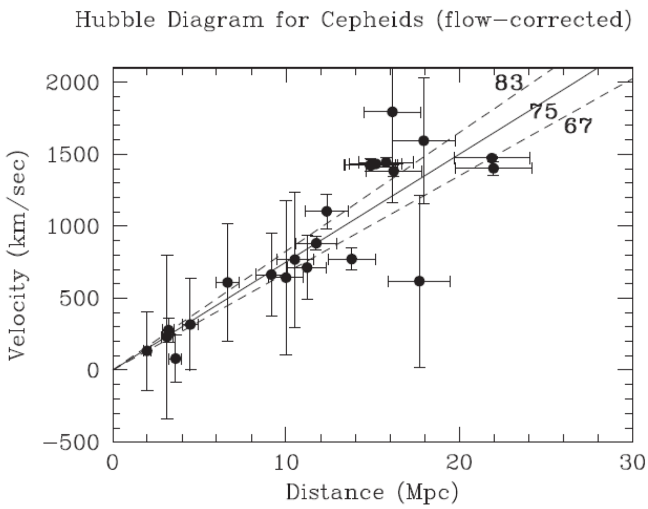


Fig. 1.2 Hubble diagram for Cepheids [10]. Solid line shows the Hubble law with the Hubble constant $H_0 = 75\,\text{km}/(\text{s} \cdot \text{Mpc})$, as determined from these observations. The dashed lines show the uncertainty in the determination of the Hubble parameter.

The Cosmic Microwave Background spectrum

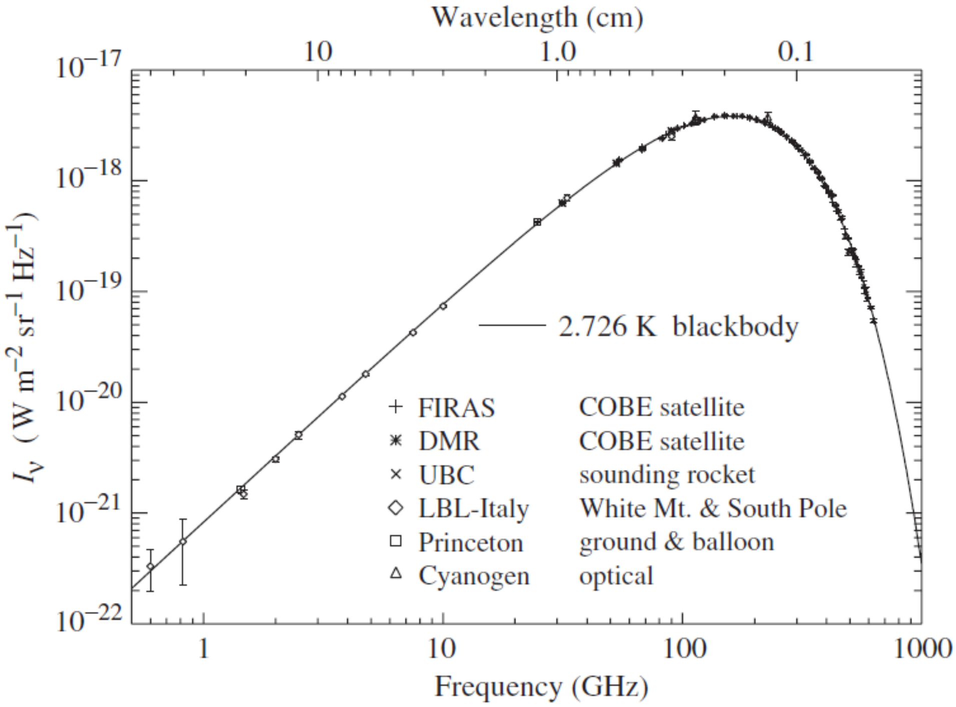
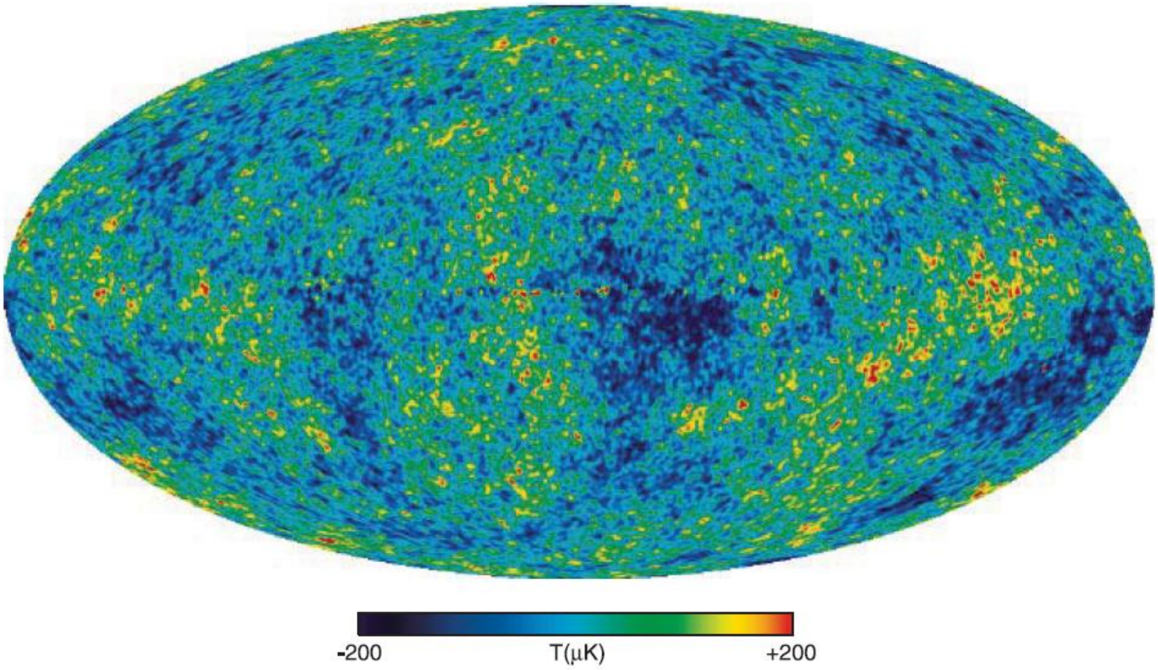
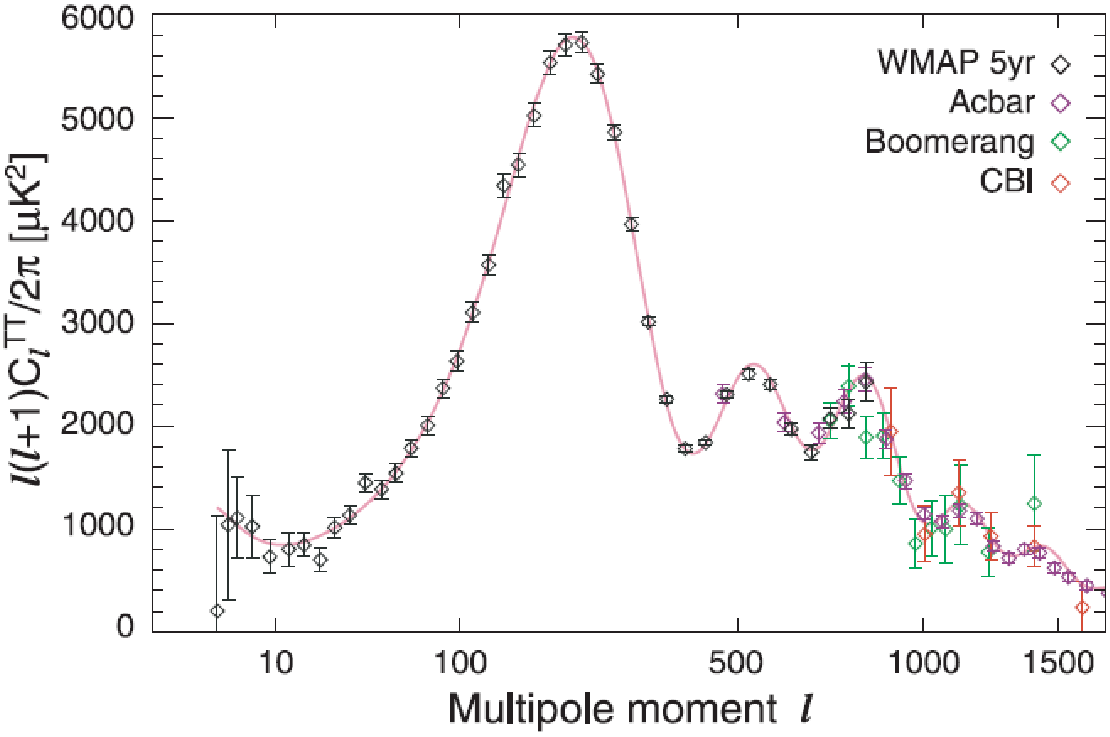


Fig. 1.3 The measured CMB spectrum [16]. Dashed line shows the black-body, Planckian spectrum.

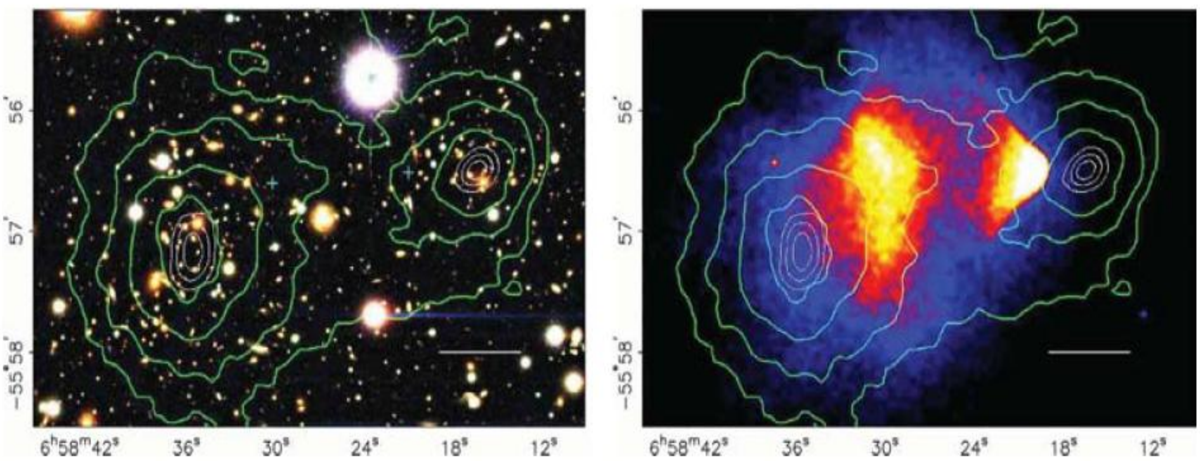
WMAP sky



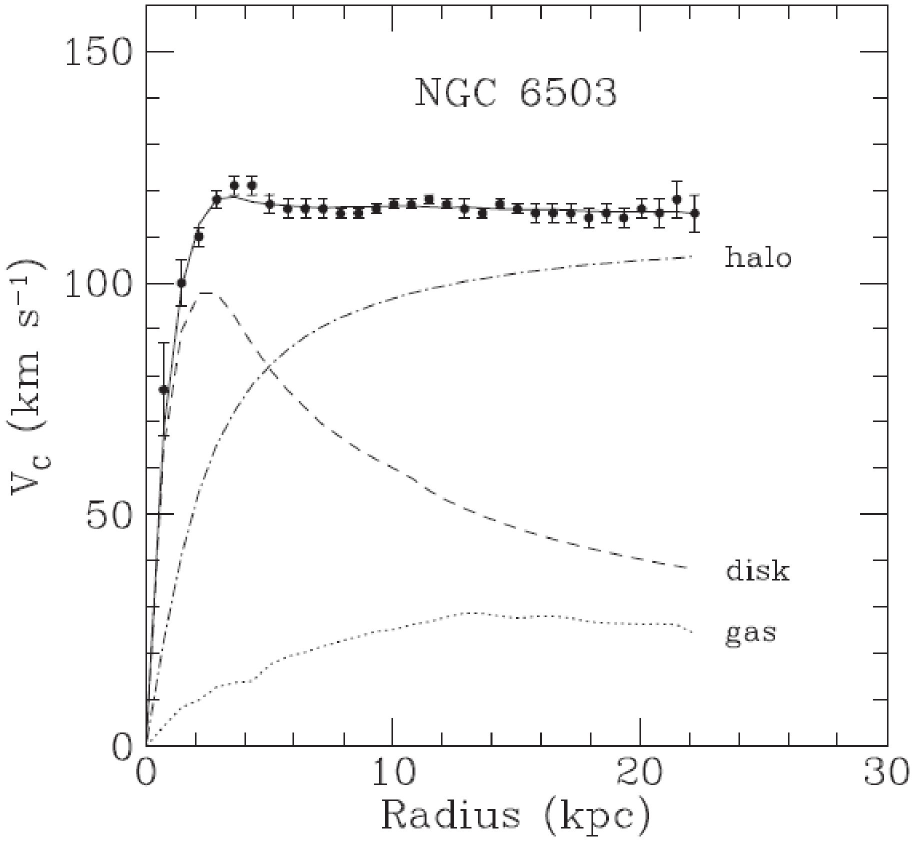
The CMB temperature anisotropy



The "Bullet Cluster"



Typical galactic rotation curve



Stages of the Universe evolution we are going to discuss over in our course