Lecture 2. Cosmography of the Universe

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2.1. Length scales in the Universe

At the current epoch the Universe exhibits many scales of structure and we will start off by specifying the typical length scales associated with these structures. The typical separation between stars in the disk of the Milky Way (our own galaxy) is around a parsec

$$1 \text{ pc} = 3 \times 10^{16} \text{ m} \tag{1}$$

and this is a convenient unit to use. For comparison, the distance from the Earth to the Sun, which defines the Astronomical Unit, is

$$1 \text{ AU} = 1.5 \times 10^{11} \text{ m} = 0.000005 \text{ pc}. \tag{2}$$

Most of the stars in our Galaxy - including the Sun - are contained in a disc with a radius of about

$$10 \text{ kpc} = 10^4 \text{ pc} \tag{3}$$

and thickness of 300 pc; these are the so-called "Population I" stars. There is also a nuclear bulge and a spheroidal distribution of "Population II" stars; many of the latter are contained in Globular Clusters, each of which has a radius of about 10 pc and contains around 10^6 stars (see Fig. 2.1. These features are common to all spiral galaxies.
The typical separation between large galaxies like our own is around

$$1 \text{ Mpc} = 10^6 \, pc, \tag{4}$$

but many galaxies are assembled into groups or clusters where the separation may be much smaller. For example, the Milky Way is part of a Local Group and this also comprises the Large Magellanic Cloud (LMC) at a distance of 55 kpc, the Small Magellanic Cloud (SMC) at 67 kpc, M31 (Andromeda) at 710 kpc, M33 at 850 kpc, and several dozen dwarf galaxies. Other nearby groups are M81 at a distance of 2.9 Mpc and M101 at 6.8 Mpc. The structure of Milky way is shown in Fig. 2.2 , see also Fig. 2.3.

About 1% of galaxies are contained in much larger groups - containing hundreds or even thousands of members - and such "clusters" have scales of order a Mpc. For example, the Virgo cluster at a distance of about 20 Mpc contains hundreds of galaxies, while the Coma cluster at a distance of 100 Mpc contains thousands. It is now known that clusters themselves may clump into "superclusters" with scales of order 10 Mpc. In particular, our own Local Group is part of the Virgo Supercluster. (See Fig. 2.4 and Fig. 2.5.

The recent redshift surveys, which give 3-dimensional information about the Universe, indicate that there is structure on even larger scales than this . Most galaxies seem to lie on giant sheets or filaments with scales of up to 100 Mpc. (There are hints of this even from the projected distribution of galaxies in the sky but one needs distance information - which can only come from measuring redshifts - to confirm the reality of this structure.) Superclusters correspond where the sheets intersect and, in between the sheets, are giant voids. Some people claim that the voids are distributed like bubbles, with an average bubble radius of about 20 Mpc. Only on scales larger than about 100 Mpc is it safe to assume that the Universe is smooth and unstructured. (SeeFig. 2.6 and Fig. 2.7. For comparison, the radius of the observable Universe (i.e. the distance light could have travelled since the Big Bang) will be shown to lie between 6000 and 10^4 Mpc. The Universe itself may be much larger than this and possibly infinite in extent.

2.2. Mass scales of the Large Scale Structure

Let us now specify the mass scales associated with these scales of structure. The mass of the Sun

$$1\ M_{\odot} = 2 \times 10^{30}\ \mathrm{kg} \tag{5}$$

is a convenient unit to use for this purpose. Recall that all stars have a mass in the range $0.1\ M_{\odot}$ to $100\ M_{\odot}$, smaller objects being too small to ignite their nuclear fuel and larger ones being unstable to pulsations. Globular Clusters have a mass of around $10^6\ M_{\odot}$, while spiral galaxies like our own all have a mass of order $10^{11}\ M_{\odot}$. There are other sorts of galaxies and these span a much larger mass range - from $10^8\ M_{\odot}$ to $10^{12}\ M_{\odot}$, but spirals are most numerous. Clusters have a mass of around $10^{13}\ M_{\odot}$, superclusters around $10^{15}\ M_{\odot}$, and filaments around $10^{17}\ M_{\odot}$. The visible Universe itself has a total mass of around $10^{22}\ M_{\odot}$, so the number of galaxies in the Universe is comparable to the number of stars in the Galaxy. The mass and length-scales associated with the various scales of structure described above are indicated in the Table below. Of course, it should be stressed that the numbers here are merely indicators of the order of magnitude. There is a quite wide dispersion in the values observed for particular systems and the horizon size depends on Hubble parameter.

2.3. The table of length and mass scales of objects in the Universe

Object	Mass (in $M_\odot$)	Radius (in pc)
Globular clusters	10^6	10
Spiral galaxies	10^{11}	10^4
Clusters	10^{13}	10^6
Superclusters	10^{15}	10^7
Filaments and voids	10^{17}	10^8
Horizon	10^{22}	10^{10}