33 Astro notes 2018/11/14 - Wed - Distance, Large-scale Structure

33.1 Extragalactic Distance Scale

Discussing modern ladder as constructed in Riess et al. (2016, http://adsabs.harvard.edu/abs/2016ApJ...82
A summary of the ladder indicating which measurements overlap is shown in figure 10.

Continuing from last time...

Cepheids - slowly pulsating giant stars. Bright - show period-luminosity relation from Figure 6. Each galaxy has multiple cepheids of various periods. Ones towards the end are those with other measurements of their distance. (Cepheids for the MW, eclipsing binaries for LMC and M31, and the maser)

Note distant objects have mostly long-period Cepheids, though we mostly have parallax distances for short-period Cepheids.

Hooking the ladder together - Figure 10 and other figures. Determines the match-up between distance scales.

Piecing together a distance scale like this makes systematic errors very important. Everything depends on how things were put together. (show figure 1)

Figure 13 shows current tension between measurement of H_0 from local distances and from CMB.

CMB method measures the size of structures in the early universe, but requires various other parameters about the cosmological expansion to get H_0.

33.2 Large-scale structure

On the largest scales, the universe is thought to be homogeneous and isotropic. As far as we know this is true. But obviously on smaller scales this is not true. Here we discuss structure on scales above galaxy cluster scales but below the scale at which the universe is homogeneous and isotropic. These are the scales of filaments, voids and superclusters.

Movie showing the 3D filamentary structure of the universe out to tens of Mpc. Note that these simulations are *dark matter only* which is most of the matter anyway:

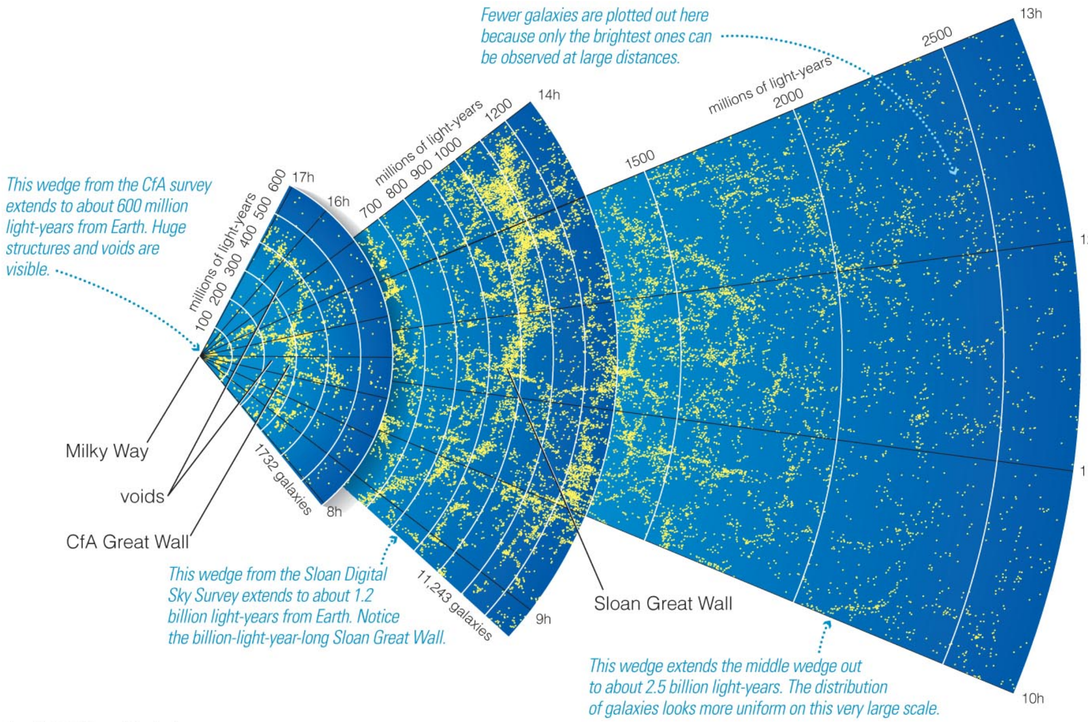
http://astronomy.ua.edu/townsley/ay101/lectures/vid/cr.avi

Clusters grow by forming galaxies and having them group together. Creates voids and filaments. The following is a simulation of structure formation in the universe on very large scales. We will discuss the initial conditions later when we discuss the cosmic microwave background (CMB) and again when we discuss inflation. The CMB is the earliest emitted light that we can see from the first time that the universe became transparent to photons, and so contains information about the early structure of matter in the universe. These simulations begin after the formation/emission of the CMB. So we know what the initial conditions are.

http://astronomy.ua.edu/townsley/ay101/lectures/vid/lcdm_color1_highres_divx.avi

33.3 Large-scale structure

How is large-scale structure measured? Large-scale galaxy surveys show exactly the structure seen in these simulations. Galaxy positions from the CfA survey and the Sloan Digital Sky Survey (SDSS): (figure from Bennett et al. The Essential Cosmic Perspective)



The connection between the cosmic microwave background and this later epoch means that we understand the matter dynamics during the history of the universe very well. This constrains how much dark matter there is.

(there are several similar figures from various surveys including CfA redshift survey and the 2DF survey in Carroll & Ostlie)

From these we can constrain the distribution of galaxies. The pattern seen above means galaxy positions are correlated in a specific way. This can be measured with the 2-point correlation function. In a uniform distribution, the probability of finding a galaxy in some volume dV would be

$$dP = ndV$$

where n is just the uniform number density. In a correlated structure this becomes

$$dP = n[1 + \xi(r)]dV$$

where $\xi(r)$ is the two point correlation function, and r is the distance from any given galaxy. if $\xi > 0$ it means that galaxies are more likely than average to be found at that separation, and if $\xi < 0$ they are less likely than average to be found at that separation. Once galaxy positions are known, this is fairly straightforward to calculate by averaging over the sample in radial bins. We find that

$$\xi(r) = \left(\frac{r}{r_0}\right)^{-\gamma}$$

where $r_0 \approx 6h^{-1}$ Mpc and $\gamma = 1.8$. This is the structure of the universe on large scales, and the power 1.8 is characteristic of the filament and void structure. Note that generally galaxies are correlated (i.e. small r is favored).

It is also found that when averaged over larger and larger regions r_0 does not change. This means that there is a characteristic scale for structure in the universe, but despite being correlated, the universe is still isotropic on large scales $dP \to ndV$ for averaging over $r \gg r_0$. (note this means the universe is not fractal)

From Carroll & Ostlie:

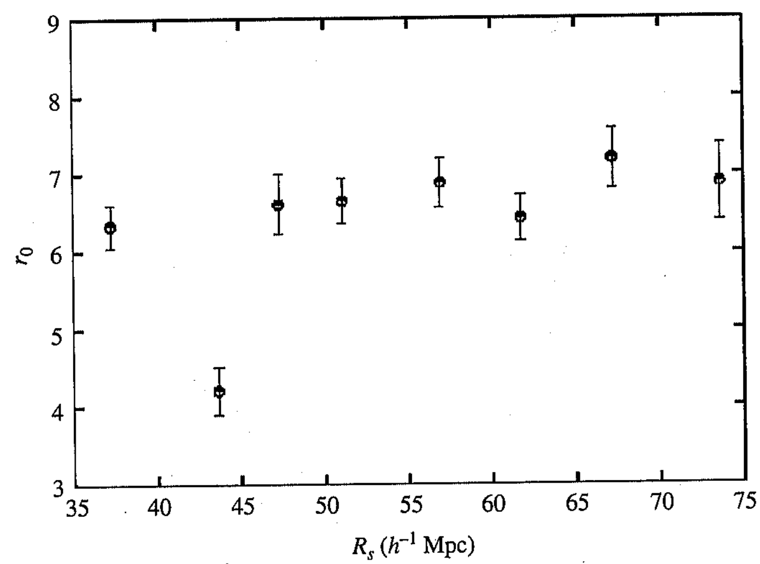


FIGURE 27.29 The correlation length r_0 as a function of the sample depth R_s for the CfA-II catalog (a galactic redshift catalog compiled by the Harvard Center for Astrophysics). The flat plateau on the right indicates a transition to homogeneity for this study at about $R_s \approx 60$–$70h^{-1}$ Mpc. (Figure adapted from Martinez et al., *Ap. J.*, 554, L5, 2001.)