Introduction to Cosmology and SZ clusters

11/1/20

Goals for this project

Concepts I want you to take away:

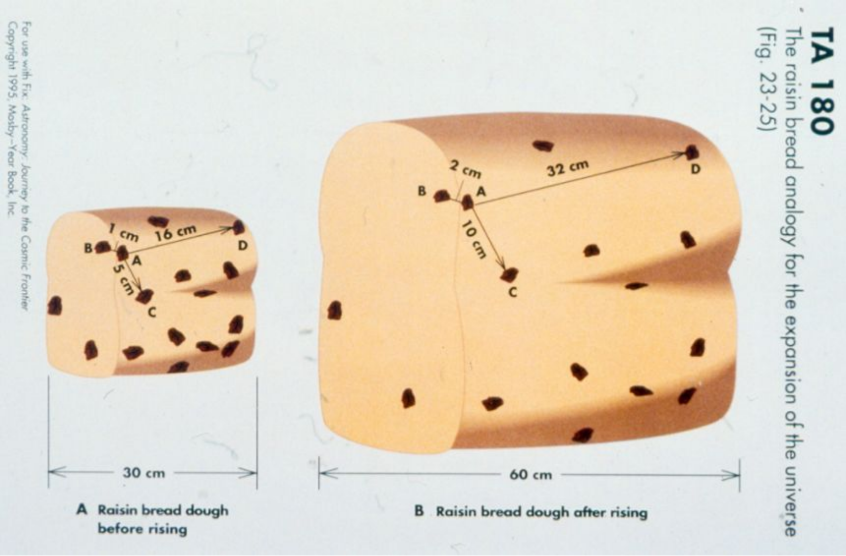
- How distances work at cosmological scales
- What is the Cosmic Microwave Background?
- How do massive galaxy clusters distort the CMB?

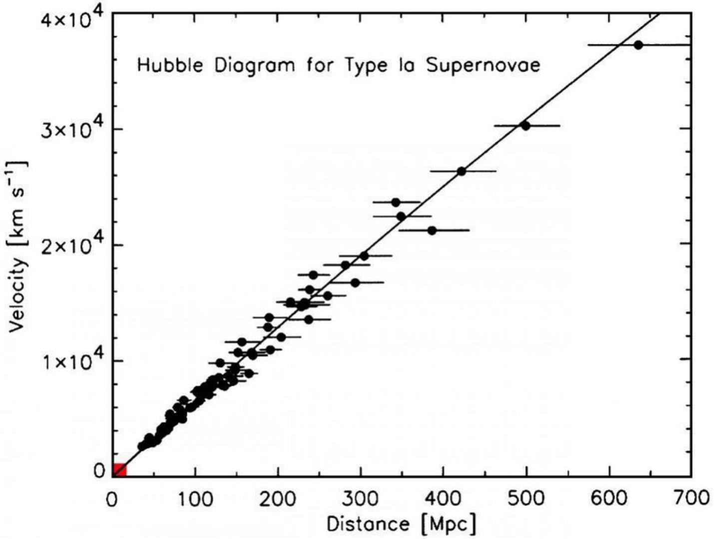
Practical Goals:

- How to read in a .fits file to python and understand what a fits file is
- How to plot distributions of galaxies in “common” units
- Make a histogram of galaxy redshift and plot the masses versus redshift
- Bin clusters by redshift and then plot number density by mass per volume, and then fit a power law to that
- Investigate correlation between other cluster properties and mass

Distances

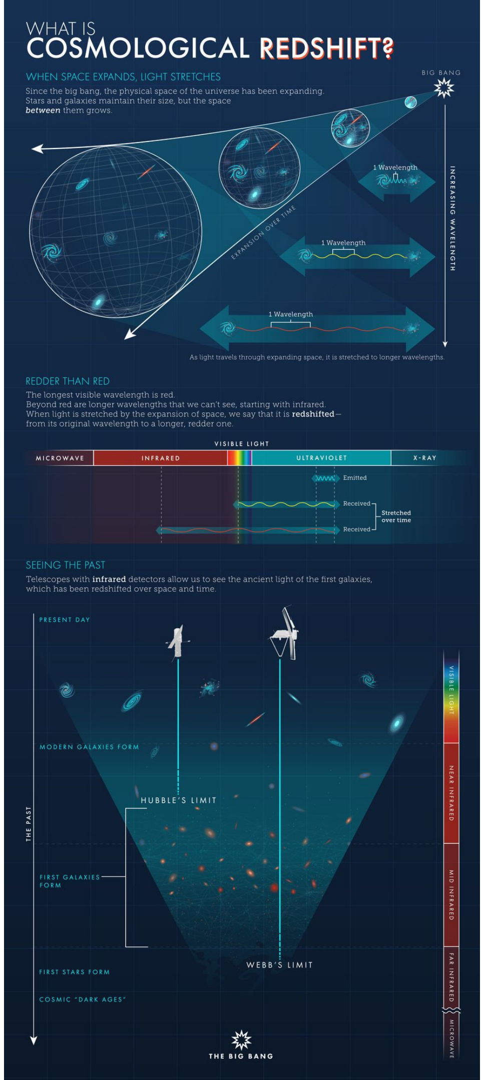
- First of all let me start with a fact that is going to blow your minds (in you don't already know it), the universe is expanding. That expansion is actually accelerating, but that's not important for the discussion here.
- This concept is weird because it's the expansion of spacetime itself not any physical object
- This expansion means that things that are a distance away from us have a velocity equal to the distance times a constant (called the Hubble Parameter)





Distances

- Since objects appear to be receding away from us due to the expansion, the light emitted from them is shifted by the doppler effect, thus one measure of distance to an object is characterized by how much commonly known emission lines are redshifted
- This is only a good distance measure if the object is far enough away that its apparent motion to us is due to the expansion of the universe ("in the Hubble Flow")
- You may recall from previous physics courses that the redshift of an object must be less than 1 (otherwise the math works out that the object is moving faster than the speed of light), but in cosmology we'll be seeing redshifts greater than 1 (and that doesn't violate the theory of relativity)



Distances

- Besides redshift, there are other distance measures in cosmology but to understand them completely (like derive from scratch) you need to understand General Relativity
- I'll give the result for the co-moving distance. This distance is commonly referred to as the distance to an object if "we removed the expansion of the universe"
- Most other useful distances are actually defined in terms of this one
- In the E(z) equation the Omegas are the fraction of the total energy density by matter, radiation, and Dark Energy

$$D_C = D_H \int_0^z \frac{dz'}{E(z')}$$

$$E(z) \equiv \sqrt{\Omega_M\,(1+z)^3 + \Omega_R\,(1+z)^2 + \Omega_\Lambda}$$

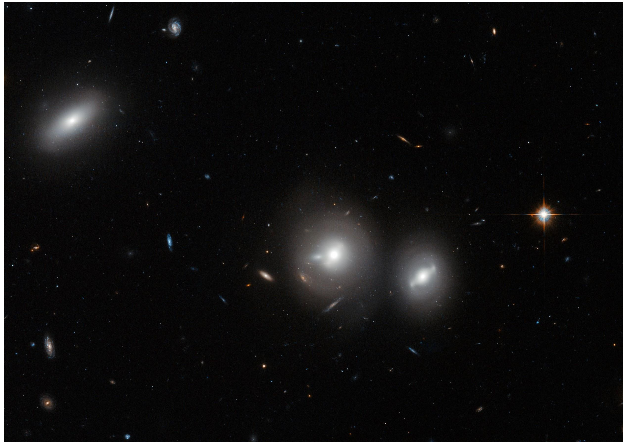
$$D_H \equiv \frac{c}{H_0} = 3000\,h^{-1}\ \mathrm{Mpc} = 9.26 \times 10^{25}\,h^{-1}\ \mathrm{m}$$

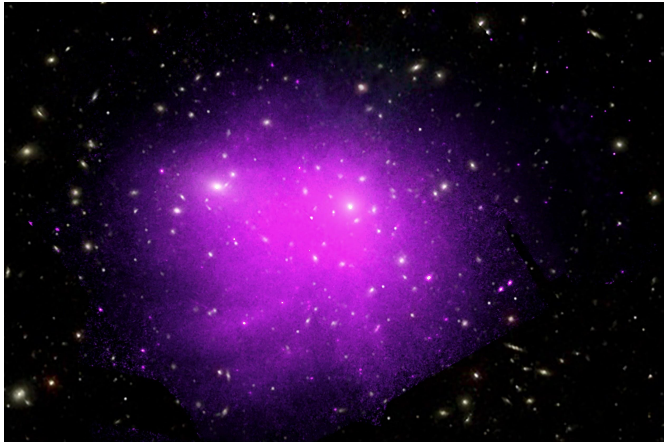
Exercise: Plot the comoving distance up to a redshift of 4 for two different cosmologies

- One where Omega_M = 1 and the rest are 0
- One where Omega_M = 0.25 and Omega_L = 0.75

Galaxy Clusters

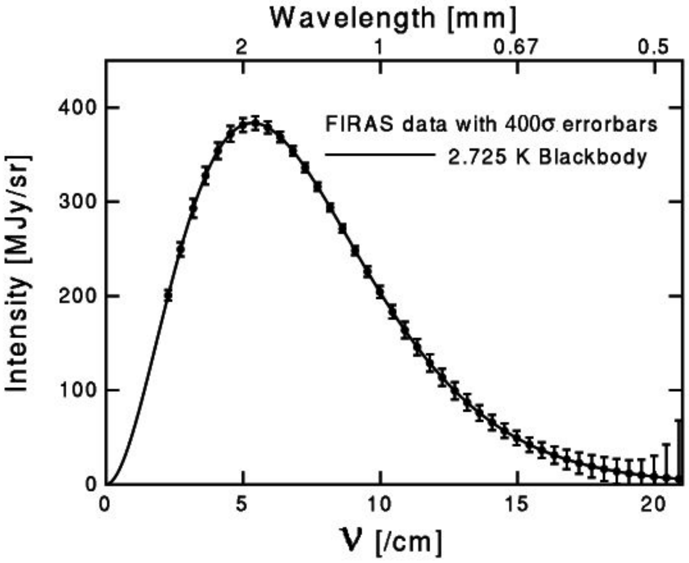
- Galaxy clusters are gravitationally bound groups of galaxies
- They are the largest gravitationally bound object in the universe (masses on order of 10^13-10^15 solar masses)
- (We believe) They formed relatively recently in the history of the universe (and oddly enough Dark Matter may prevent any more from forming)
- Below to the left is an HST image of the (famous) Coma Cluster in the optical, to the left is an image of it in the X-ray from the Chandra telescope
- What the X-ray image shows is that there is an abundance of hot ionic gas in the cluster invisible to the naked eye

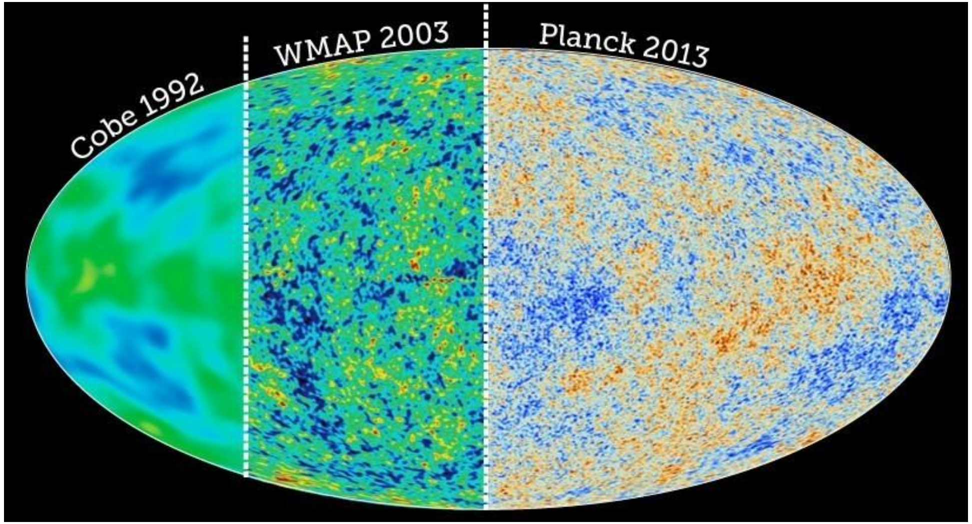




The Cosmic Microwave Background

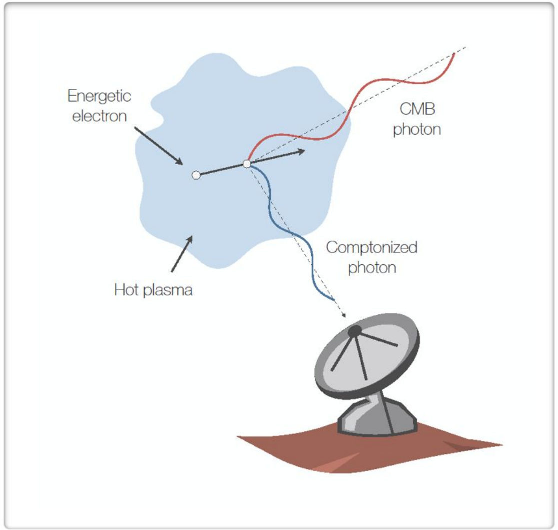
- This is left over light from the Big Bang emitted at a redshift of z~1100 or when the universe was just 300,000 years old (for ref it's over 13 Billion years old today)
- It is a nearly uniform across the sky and has an intensity related to frequency like a black body
- Current experiments have measured the differences in temperature of the CMB to micro-Kelvin precision

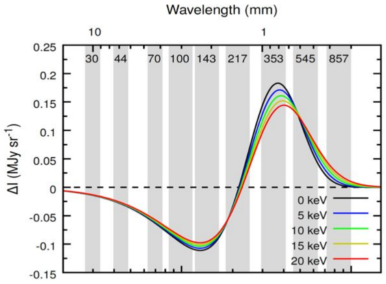


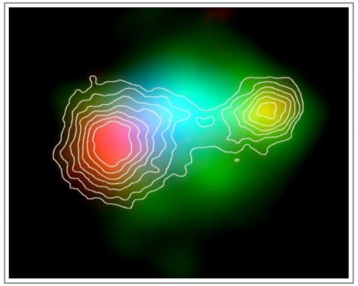


The Sunyaev-Zel'dovich (SZ) Effect

- The neat thing about the CMB is that since it was emitted at a z~1100 it interacts with all the matter between it and us
- In particular, a CMB photon can interact with an electron from the hot gas in galaxy clusters. This effect boosts the energy of the photon and shifts the CMB blackbody spectrum
- This is known as the SZ effect

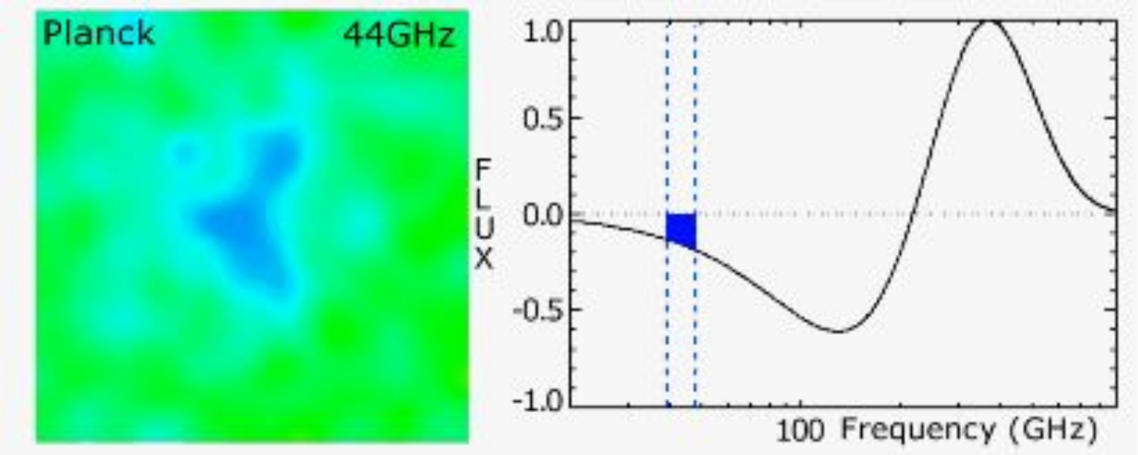






The SZ Effect

- CMB experiments make maps of the sky at different frequencies and run algorithms to find (and remove) the SZ clusters
- In general, removed SZ clusters are then cataloged and their positions referenced to known optically confirmed galaxy clusters.
- Some SZ catalogs are the SPT-SZ and the ACT DR5 catalog



The ACT DR 5 SZ catalog

- Consists of over 4000 optically confirmed galaxy clusters
- The data product (ie the catalog) can be downloaded from here. You want to download the .fits file
- Like most good things in science, there’s a paper that accompanies the catalog. It describes a lot of the columns in the fits file.
- A lot of the plots you’ll be making for this project should match plots made in the paper, so it’s a nice double check

To do this week

- Download the ACT DR5 SZ catalog from the previous slide
- Read it into python using astropy. Here's a link to the astropy documentation about reading in fits files. The way I like to do this is to just save the file as a variable and then treat it like a list.
- Play around with the data set. Make plots or histograms or whatever…
- Recreate the left plot in figure 16. You'll need to convert from redshift to comoving distance and convert the Right Ascension (RA) into angles that python likes. No need to include the dotted circles
- Recreate figure 18. You only have the ACT data set so you'll only be able to reproduce the blue markers