**Lecture 7: nebulae & galaxies**

* 1. Nebulae
     1. There are three primary types of "nebulae" within our galaxy
     2. Here are pictures: **identify them!**
     3. Gas lit up by massive young stars (HII regions)
     4. Gas lit up by dying evolved low mass star (Planetary Nebulae)
     5. Galaxies are a third type. You might think that is obvious.
     6. But you have to remember that astronomers didn't always have data this good
     7. Recall seeing M31 through the telescope?
     8. To the first astronomers these often didn't look much better
     9. E.g. here are some examples from William Herschel in the early 1800s
     10. Some I am pretty sure are galaxies ... others I'm not so sure!
  2. Milky Way
     1. One thing astronomers were pretty sure about was the Milky Way
     2. Recall what the Milky Way looks like on the sky
     3. When Galileo first looked at this through a telescope in early 1600s ...
     4. became clear it was just made up of individual stars
     5. and that we were somewhere inside of a disk of such stars
     6. But what wasn’t clear for another 300 years was whether there was anything outside
     7. or even whether we were in the center of it or not
     8. This was the situation in about 1920
  3. Great Debate
     1. Occasioned a “Great Debate” in 1920 between Harlow Shapley and Heber Curtis
     2. Many issues at stake, but two of the most important were:
     3. **are we near the center of the MW?**
     4. **is the MW 10 kpc or 100 kpc in size?**
     5. **are the spiral nebulae within the MW or not?**
     6. Evidence included the following
     7. Shapley showed distances of the GC: these were (a) wrong and (b) don't reflect the size of the disk of stars making up the MW
     8. however they do show that we are not near the center
     9. Curtis pointed out in the debate that the distant stars in MW would have to be VERY luminous to extend this far out or further; pretty much was right
     10. Shapley pointed out that the ROTATION of distant spiral nebulae had been observed. If they were as bright as the galaxy they had to be millions of lightyears away. These motions would need to be faster than the speed of light! So they can't be far away.
     11. **What was wrong with this argument?**
     12. Another important item that was known was that the nebulae were fast moving away from us. The meaning of this was somewhat unclear and would be for a few years yet!
     13. Most convincing evidence came later from Hubble, who used Cepheid variables in Andromeda to show it was far away; the Cepheids in M31 are MUCH further away!
     14. Even naked eye galaxies turn out to be far away: Andromeda is 2 Mlyrs, SMC and LMC are each about 150,000 lyrs
  4. Expansion
     1. That leaves one puzzle. Why are the nebulae moving away?
     2. Edwin Hubble solved this problem by using a different standard candle
     3. Cepheids aren't bright enough (!) or common enough to use for very distant galaxies
     4. Hubble used a more approximate distance indicator: what is the brightest star in the galaxy?
     5. Look at the galaxies he was trying to do this with! Not so easy.
     6. But he inferred distances, and plotted against velocity
     7. Found that they were correlated.
     8. Whoa! This is what we mean when we say the universe is expanding
     9. A result of the confluence of several simultaneous ideas coming together over a period of about 20 years
     10. The modern Hubble diagram uses Cepheids for many nearby galaxies, and then other techniques further away.
     11. First question: **does this mean we are at the center of the Universe?**
     12. No! All other galaxies see the same effect!
     13. **How can I calculate the AGE of the Universe from this effect? When all the galaxies were in one place?**
     14. **WHAT are we expanding into?** We don't know, we are expanding out as far as we can see.
  5. SDSS
     1. The largest scale survey of the universe have USED the Hubble Law to make 3D maps
     2. Idea is that you measure the velocity and infer the distance from that. Much easier than measuring the distance directly!
     3. Biggest is SDSS at APO
     4. Spent 11 years making images of the night sky, locating the galaxies
     5. See a great variety of galaxies when you do so!
     6. At the same time followed up with spectra ~ 1 million. Use Doppler shifts to get the velocities
     7. How so many? Using spectroscopic plates with hundreds of objects per plate
     8. Drill holes in plate at locations of galaxies at high accuracy.
     9. Ship to APO
     10. Every day plug plates to observe the next night. Lots of plugging!!
     11. Each plate observed about 90 minutes, go to next.
     12. In the end, makes a map of distances to all the galaxies
     13. Scale on this map at start is already 300 million pc, or about 1 billion light years
     14. We can look at this on the scale of as far back as we could possibly see (the CMB). A pretty big map.