Summary of Lecture 23

Key points include:

1. Galaxies are collections of millions to (in the most extreme cases) trillions of stars. We live in the Milky Way galaxy, so we'll start there with our overall study of galaxies.
2. For our Milky Way, most ($\sim 80\%$) of the visible mass is in stars, and most of that ($\sim 80\%$) is spread out in a *disk* (looking like a frisbee), which extends tens of thousands of light years from the Galactic center. We can tell that most of the stars are in a disk, and that we are in the disk, because we see far more stars along the band of the Milky Way than in other directions; that is, it looks like an edge-on disk.
3. Most of the rest of the stars are in the *bulge*, which is closer to spherical and is concentrated within a few thousand light years from the Galactic center. A small fraction of stars in the Milky Way ($< 1\%$) is in the *halo*, which extends hundreds of thousands of light years from the Galactic center.
4. The stars in the disk move in nearly (but not perfectly) circular orbits, in roughly the same plane. In contrast, the bulge and halo stars have orbits that can be (but need not be) very elliptical, and their orbits are oriented randomly.
5. Between the stars we have the *interstellar medium*. This contains gas and dust. Most of the non-stellar mass is in gas, which is mainly hydrogen. Some of the gas is cool enough that it has mainly molecular hydrogen; some is hotter and has atomic hydrogen; some is even hotter and has fully ionized hydrogen. There is also a small amount of dust in our galaxy.
6. We can measure the mass of our galaxy using the speeds of stars, their distance from the center of the Milky Way, and Newton's laws. We could also measure the mass by looking at the stars and gas and estimating those masses. Interestingly (foreshadowing!) the mass measured the first way exceeds the mass measured the second way, particularly farther away from the center. Dark matter!
7. Gas is recycled in the Milky Way. Stars form in molecular clouds, then they live their lives and give gas back to the interstellar medium via winds, planetary nebulae, and supernova explosions. This gas then cools and can form stars later.
8. Dust dims light and reddens it, like the extra-red sunsets you get when there are lots of particles in the air.
9. We can see various *nebulae* throughout our galaxy. *Ionization nebulae* show lots of emission lines and are around short-lived, high-mass stars, which means that stars are

actively forming. *Reflection nebulae* scatter the light from nearby stars; in the same way that our sky is blue because blue light scatters more easily than red light, reflection nebulae appear blue.

10. Our galaxy, and galaxies like ours, have spiral arms. You might think that these would wind up with time, but they aren't persistent. Instead, they indicate a wave of star formation, and since the most massive stars live a few million years (compared with the roughly 200 million year orbital time around the Milky Way), they don't have enough time to wind up. Spiral arms are bright because, since they are sites of active star formation, the most massive and therefore brightest stars tend to be in spiral arms.

11. There are two populations of stars in our Milky Way. *Population I* stars are in the disk, orbiting basically in circles, with a range of ages, and have substantial amounts of elements heavier than helium (called "metals" in astronomy even if they are thinks like neon that aren't considered metals in chemistry). *Population II* stars are in elliptical orbits of all orientations, are old, and have few metals.

12. Some galaxies have *active galactic nuclei*, or AGN, which means that they have extremely bright centers. These are powered by supermassive black holes at their centers, which shine because there is a lot of gas spiraling into the black holes and the gas heats itself up by friction. The black holes themselves do *not* shine.