ASTR 592
M/W/F 3:00 - 3:50 PM
Due April 29

Problem Set #6

1. The Intergalactic Medium

(a) If the gas in galaxy clusters was either ejected from the galaxies or fell into the cluster along with galaxies as the cluster was forming, then the kinetic energy **per unit mass** of the gas can be assumed to be the same as for a galaxy, with both moving at an average random speed v_{RMS}. Assume a mass m of gas has $KE = \frac{3}{2}mv_{RMS}^2$. At a temperature T, the average energy of a gas particle is $\frac{3}{2}k_BT$ where k_B is Boltzmann's constant. If the gas is mainly ionized hydrogen, these particles are protons and electrons. Show that if energy is shared equally between them, then:

$$T \approx \frac{(m_p/2)v_{RMS}^2}{k_B} \approx 6 \times 10^6 \left(\frac{v_{RMS}}{300\,\mathrm{km\,s^{-1}}}\right)^2 \mathrm{K}$$

(b) The compact group Hickson 51 consists of 7 nearby galaxies. The hot gas surrounding these galaxies extends to 370 kpc from the group center. In Hickson 51, the X-ray spectrum of the gas corresponds to typical photon energies of k_BT=1.15 keV. What gas temperature is indicated by the X-ray measurements?

(c) Assume that the gas is made up of ionized hydrogen. What is the typical kinetic energy of a gas particle at this temperature?

(d) If the gas and galaxies in this group are virialized, what is the velocity dispersion of galaxies in the group?

(e) Assume that the cluster is a uniform-density sphere with a radius of 370 kpc. What mass must this galaxy group have for the hot gas to be in virial equilibrium?

(f) Hickson 51 has a luminosity of 2×10^{11} $\mathrm{L}_\odot$. Assuming the galaxies in this cluster have $M/L \sim 20$, and that the X-ray emitting gas has a mass of 1.6×10^{12} $\mathrm{M}_\odot$, how much dark matter is in this cluster?

2. Galaxy Masses, Mass-to-light Ratios, and Dark Matter

(a) For this problem, select 3 Milky Way satellite galaxies from Table 4.1 (Page 152) in Sparke & Gallagher. For simplicity, assume that the listed distance d, the distance from the sun, is actually r, the distance to the Galactic center. Plot these galaxies on a rotation curve of the Milky Way below:

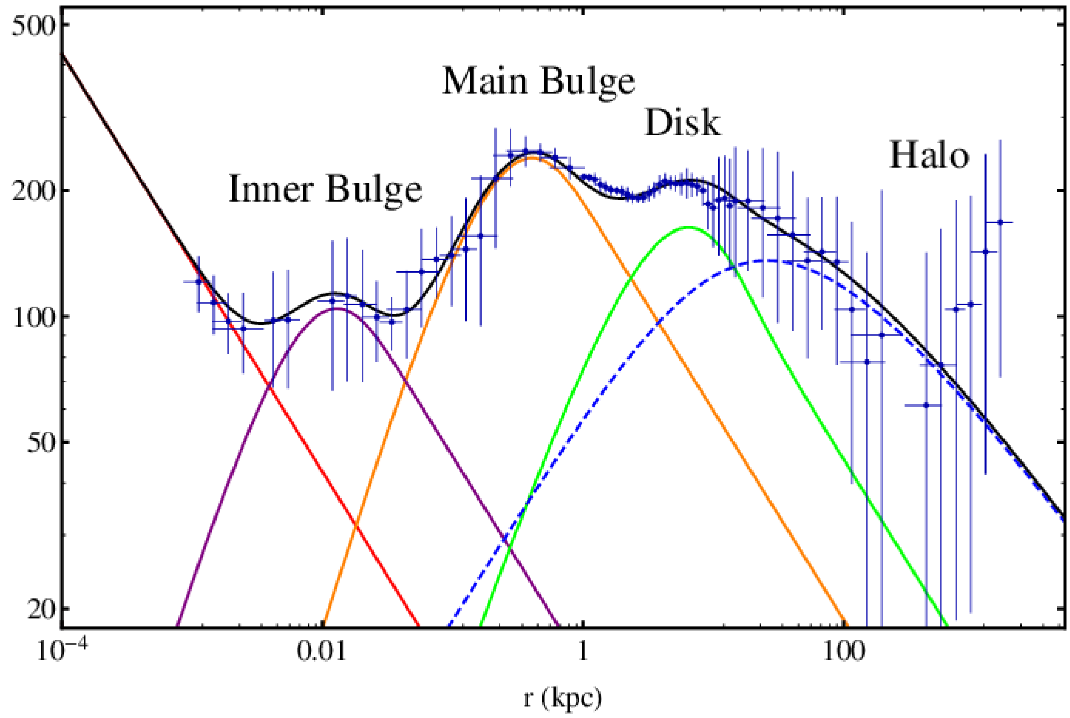

Figure 1: The rotation curve of the Milky Way using data from Sofue 2013. The X-axis is rotational velocity, in units of km s^{-1}

(b) Treat the Milky Way as a point mass and assume that the force of other dwarf galaxies upon each other (the 'internal' force of the cloud of satellite galaxies) is negligible, so that the only force they experience is an external force from the Milky Way. For the most distant dwarf galaxy you plotted, assume that its radial velocity is characteristic of its full 3D velocity, and use this to estimate the mass of the Milky Way. How does this compare to its actual mass?

(c) What is M/L for the Milky Way? How does this compare to values of:

- 2.5 in the immediate neighborhood of the Sun
- 5 for a typical "old" stellar population
- The value you derived in class for the galaxy Willman 1