Problem Set #4
Due March 5, 2009

8. **M/L of the Milky Way**: In the previous homework set, you calculated the rotation curve of the Milky Way. Assume that the rotation curve you determined remains flat to maximum radius of the luminous disk matter ~20 kpc. Show that the M/L_V ratio of the Milky Way within this radius is $M/L_V \sim 15$ (Hint: see Sparke & Gallagher Eq 3.20 and Table 4.1). Compare this to the stellar M/L_V ratio of the disk using the conversions given in Bell et al. (2003, ApJS 149, 289, Figure 6) and assuming an average color for the disk of (g-r) ~ 0.2. Is dark matter required? What is the M/L_V if the rotation curves is flat to 50 kpc? Explain your answers.

To transform V-band to g-band from Blanton & Roweis (2007):

$$V = g - 0.3516 - 0.7585*[(g-r) - 0.6102]$$

9. **Measuring the Milky Way's central Black Hole:** This problem is based on Ghez et al. (1998, referred to here as G98) and Ghez et al. (2008). You will use the proper motion data in Table 1 of G98 (available on class website or ADS) to reproduce their primary result: $M_{MW\ BH} = 3 \times 10^6\ M_{sun}$ within 0.015pc, providing the best evidence for a black hole at the center of a galaxy.

a) Reproduce Figure 4 of G98, changing the axes to units of pc. Calculate the signal-to-noise for the proper motion by combining the proper motions and errors in both Ra/Dec. Note, I needed to use a threshold S/N > 3 to reproduce Fig 4.

b) Use the equation for M_{min} given in Section 4 of G98 to derive an expression for the combined measurement error on mass, given the uncertainties on velocity (ra, dec) and radius (ra,dec). Assume errors in these quantities are uncorrelated

c) Reproduce Figure 6, including error bars. Instead of plotting M_{lum}, include the most recent constraints (based only on S0-2) from Ghez et al. (2008). Explain why each data point represents a lower limit on the central mass.

d) Given these data what is the strongest observational constraint you can place on the mass at the center of the Galaxy? How does your minimum radius compare the Schwarzschild radius for this estimate (show your calculation for r_S)? What mass density does this imply for the Milky Way's center (M_{sun} per pc^{-3}). Given the size/densities of white dwarfs or neutron stars, does your mass density absolutely imply a black hole?