ASTR 422
Problem Set 5
Due Friday, November 16, 2007

1. One of the difficulties in nailing down the relation between black holes and their host bulges is that the black hole controls a fairly small volume that cannot be easily resolved.

(a) Suppose the radius of influence $r_{\rm infl} = GM/\sigma^2$ must subtend at least one arcsecond for motions to be resolved. Use the $M - \sigma$ relation to derive the minimum black hole mass whose radius of influence can be resolved, as a function of the distance from us.

(b) Do Web research to determine the angular size of the radius of influence of the black holes in the Milky Way, Andromeda, and M87. Please give the answers in arcseconds and indicate the URL you used.

2. This problem will give you practice in manipulating somewhat complicated equations.

Suppose that the universe were as people in the 1950s would have thought, in which $\Omega_{\rm baryon} = 1$ and there is no dark matter or dark energy. Calculate the redshift of decoupling to three significant figures, assuming equilibrium ionization at all times. Please indicate to me how you solved the problem, rather than simply quoting the answer. Also, explain qualitatively why the answer is or is not significantly different from what we computed with $\Omega_{\rm baryon} = 0.04$.

3. Secondary anisotropies. For this problem, the relevant cross section is for Thomson scattering, $\sigma = 6.65 \times 10^{-29}$ m^2.

Consider large scale structure, at size scales of 100 Mpc and typical distances of 4 Gpc. What are the typical fraction of photons scattered within such structure (assuming it is basically spherical and has roughly the average baryon density that gives $\Omega_{\rm baryon} = 0.044$, all of it ionized)? That is, if we take the current number density of electrons (not bothering with increased density at higher redshift), what fraction of photons will scatter after having traveled 100 Mpc? Will this interfere significantly with the observed CMB spectrum, assuming that photons scattered by the structure increase their temperature by a fractional amount $\sim 10^{-3}$?

4. Dr. Sane has a new theory of particle physics in which there is a new particle that he calls a "saneon". Saneons have rest mass-energies $E = 1$ MeV (slightly more than electrons), and no antiparticles, meaning that they do not annihilate. Dr. Sane believes that saneons had a number density comparable to that of electrons, positrons, and photons when the universe was one second old. Drew Baden, chair of UMd physics, is considering

hiring Dr. Sane onto the faculty, and has asked for your analysis of the good Doctor's idea. Do a quantitative analysis to determine if this idea is reasonable.