ASTR498E High Energy Astrophysics (Spring 2006)

Homework 2

Due date; 2nd March 2006

1. **Bondi accretion in the cores of elliptical galaxies :** One of the few astrophysical settings in which spherical Bondi accretion may be relevant is in the center of "quiet" giant elliptical galaxies. Such galaxies possess central supermassive black holes surrounded by an extended atmosphere of hot (X-ray emitting) interstellar medium (ISM).

   (a) In the galaxy M87, X-ray observations suggest that the central regions of the ISM have a density of 1 proton/cm^3 and a temperature of $T \approx 5 \times 10^6\,\mathrm{K}$ (and therefore is fully ionized). Furthermore, studies of cooler gas orbiting the central object indicate a $3 \times 10^9\,\mathrm{M}_\odot$ black hole at the center of this galaxy. Use these numbers to estimate the accretion rate of the ICM onto this black hole. List any additional assumptions that you may have to make. [You will need to know that the sound speed of a gas with temperature T is given by $c_s^2 = \gamma k_B T/\mu m_p$, where k_B is Boltzmann's constant and μ is the mean atomic weight of the gas (i.e., the number of proton masses per particle).]

   (b) It is commonly assumed that black hole accretion disks are very efficient at extracting and radiating the gravitational potential energy of the accreting gas, achieving efficiencies of 10% or more (i.e., 10% of the rest-mass energy of the accreted material is extracted and radiated). If you make this assumption, what would you expect for the radiative luminosity of the accretion flow onto the M87 black hole.

   (c) Observations indicate that the actual radiative luminosity eminating from the core of M87 is rather small, $L < 10^{41}\,\mathrm{erg\,s^{-1}}$. Discuss possible resolutions for the discrepancy between your calculated luminosity and the observed luminosity. [Hint — as part of your answer, examine the photograph of M87 from the notes for class-1 (page 8) and note any unusual features].

2. **The temperature of an accretion disk :** Consider an accretion disk that carries a mass flux $\dot{M}$ towards a central object of mass M. Suppose that the accretion disk is geometrically-thin (i.e., pancake like). Assuming that each radius of the the disk locally radiates the energy released as matter gradually spirals through the disk, and that the energy is radiated as a perfect black body, show that the temperature of the accretion disk surface as a function of radius must be

$$T = \left(\frac{GM\dot{M}}{8\pi r^3 \sigma_{\mathrm{SB}}}\right)^{1/4} \qquad (1)$$

   [Hint - you will have to use the viral theorem (or some equivalent line of reasoning) to work out the change in total energy when as fluid element flows through the disk. Also remember that the disk has two sides.]

3. **The growth of supermassive black holes :** This question addresses one issue associated with the formation of supermassive black holes.

   (a) Suppose we start with a stellar mass black hole with a mass $M = 50\,\mathrm{M}_\odot$. How long does this black hole have to accrete matter at the Eddington limit in order to reach a luminosity of $L = 10^{47}\,\mathrm{erg\,s^{-1}}$? You may assume that the radiative efficiency of the accretion disk, η (defined by $L = \eta \dot{M} c^2$), is a constant throughout the evolution; your final answer should contain η as a free parameter.

   (b) Some cosmologists believe that the first generation of stars (Pop III) went supernova at a redshift of about $z = 15$, thereby producing the first generation of stellar-mass black holes with masses of about $50\,\mathrm{M}_\odot$. By a redshift of $z \approx 5$, we observe powerful quasars with a luminosity of $10^{47}\,\mathrm{erg\,s^{-1}}$. Is it plausible that the supermassive black holes powering these quasars have grown from the $z = 15$ stellar mass black holes? If you think it is plausible, discuss the requirements needed to make such a scenario work. [Hint — you will have to figure out how much time has passed from redshift $z = 15$ to redshift $z = 5$. You can do this using "Ned Wright's Cosmology Calculator (`http://www.astro.ucla.edu/ wright/CosmoCalc.html`). You must reference this website if you end up using it.]