High-Energy Astrophysics

Problem Set 2

Due: 4/13/18

1. The *Chandra X-ray Observatory* detected about 220 X-ray photons from Sgr A* during a 4.0×10^4 s observation. The effective area of *Chandra* is 600 cm^2.

   (a) If each photon has an typical energy of 1 keV, calculate the observed flux of Sgr A* (in erg cm^{-2} s^{-1}).

   (b) The Galactic Center is 8 kpc away. Assuming there is little absorption along the line-of-sight (not true!), estimate the X-ray luminosity of Sgr A*. Do you have to make any other assumptions?

   (c) Observations indicate that Sgr A* is inside a hot ($kT \approx 1.3$ keV) nebula with density $n \approx 26$ cm^{-3}. The estimated black hole mass is 4×10^6 M$_\odot$. Assuming $\gamma = 5/3$, what is the expected Bondi accretion rate onto the black hole?

   (d) With this accretion rate and observed luminosity, estimate the radiative efficiency of Sgr A*.

   (e) What is the Eddington luminosity of Sgr A*, and the observed Eddington ratio?

   (f) Discuss the uncertainties that have gone into your estimates of the radiative efficiency and Eddington ratio. Which is less certain?

2. Derive the seven equations describing the α disk in the gas-pressure dominated regime with electron scattering opacity. That is, find the equations for Σ, H, ρ, T_c, τ, ν and v_R in terms of α, η (the radiative efficiency), $M/M_\odot$, $\dot{M}/\dot{M}_{\rm Edd}$, $R/R_{\rm Sch}$ and f, where $R_{\rm Sch}$ is the Schwarzschild radius, $\dot{M}_{\rm Edd}$ is the Eddington mass accretion rate and $f^4 = (1-(R_*/R)^{1/2})$. Verify that the disk is thin in this regime. Use $\kappa_{\rm es} = 0.4$ cm^2 g^{-1}.

3. As above, except for the radiation pressure dominated regime with electron scattering opacity. Show that

$$\Sigma = (0.43)\alpha^{-1}\left(\frac{\eta}{0.1}\right)\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right)^{-1}\left(\frac{R}{R_{\rm Sch}}\right)^{3/2} f^{-4}$$

$$H = (2.2 \times 10^6)\left(\frac{\eta}{0.1}\right)^{-1}\left(\frac{M}{M_\odot}\right)\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right) f^4$$

$$\rho = (1.9 \times 10^{-7})\alpha^{-1}\left(\frac{M}{M_\odot}\right)^{-1}\left(\frac{\eta}{0.1}\right)^2\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right)^{-2}\left(\frac{R}{R_{\rm Sch}}\right)^{3/2} f^{-8}$$

$$T_c = (3.7 \times 10^7)\alpha^{-1/4}\left(\frac{M}{M_\odot}\right)^{-1/4}\left(\frac{R}{R_{\rm Sch}}\right)^{-3/8}$$

$$
\begin{aligned}
\tau &= (0.17)\alpha^{-1}\left(\frac{\eta}{0.1}\right)\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right)^{-1}\left(\frac{R}{R_{\rm Sch}}\right)^{3/2} f^{-4} \\
\nu &= (3.6\times 10^{17})\alpha\left(\frac{M}{M_\odot}\right)\left(\frac{\eta}{0.1}\right)^{-2}\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right)^{2}\left(\frac{R}{R_{\rm Sch}}\right)^{-3/2} f^{8} \\
v_r &= (1.8\times 10^{12})\alpha\left(\frac{\eta}{0.1}\right)^{-2}\left(\frac{\dot{M}}{\dot{M}_{\rm Edd}}\right)^{2}\left(\frac{R}{R_{\rm Sch}}\right)^{-5/2} f^{4}
\end{aligned}
$$

From these, derive an expression for the dividing line in radius between the gas-pressure and radiation pressure dominated regions.