

High-Energy Astrophysics (Ay125), Spring 2009

Problem Set 6

Due: In class, 14 May 2009

1. Problem 5.6 in Frank, King, and Raine.
2. (ST 13.3): A bump is observed in the spectrum of Her X-1 at ~ 58 keV with width ~ 12 keV. This has been interpreted as the photon emitted when an electron makes a transition from the first to the lowest Landau level. Determine the magnetic field implied by the frequency and the temperature implied by the width.
3. (ST 13.10) Consider a binary-star system in which one member undergoes a supernova explosion and ejects a considerable fraction of its mass. Assume that the mass is lost in a time much shorter than the orbital period. Calculate the condition on the fraction of mass lost necessary for the preservation of this binary system, assuming a circular orbit. How is the result changed if the orbit is elliptical?
4. (ST 14.14) **Accretion from stellar wind in Cyg X-1:**
 - (a) Estimate the rate of gas accretion onto the compact secondary M_x (the black hole) in Cyg X-1. Assume that accretion is from the stellar wind of the primary with the wind velocity constant and comparable to the escape velocity from the primary surface,

$$V_w = \eta \left(\frac{2GM_*}{R_*} \right)^{1/2} \quad \eta = \frac{V_w}{V_{\text{esc}}}. \quad (1)$$

Here $M_* \gg M_x$ and R_* are the mass and radius of the primary. Show that the accretion rate is given by

$$\begin{aligned} \dot{M} &\simeq \frac{1}{4} \left(\frac{r_a}{a} \right)^2 \frac{V_{\text{rel}}}{V_w} \dot{M}_w \\ &\simeq (7 \times 10^{-9} M_\odot \text{ yr}^{-1}) \xi^2 \eta^{-4} \left(\frac{M_x}{10 M_\odot} \right)^2 \left(\frac{M_*}{30 M_\odot} \right)^{-8/3} \\ &\quad \times \left(\frac{R_*}{20 R_\odot} \right)^2 \left(\frac{P}{5.6 \text{ day}} \right)^{-4/3} \left(\frac{\dot{M}_w}{10^{-6} M_\odot \text{ yr}^{-1}} \right), \end{aligned} \quad (2)$$

where \dot{M}_w is the steady-state spherical wind ejection rate ($\dot{M}_w = 4\pi\rho r^2 V_w = \text{constant}$), a is the separation between the primary and

the secondary, and P is the period of the orbit, assumed circular. (**Hint:** $V_{\text{rel}}^2 \simeq V_x^2 + V_w^2$, where V_x is the velocity of the secondary relative to the primary. Note that the normalization of the factors here has been chosen to fit the observations of the Cyg X-1 binary system.)

- (b) Show that the normalization of parameters here is consistent with the observed x-ray luminosity of $\sim 5 \times 10^{37} \text{ erg s}^{-1}$, assuming around 10% efficiency of conversion of rest mass to radiation.
 - (c) Calculate the fraction \dot{M}/\dot{M}_w of emitted gas that actually accretes onto the compact secondary.
5. (ST 14.22) **More on accretion from a wind:** Consider the same system as in the previous problem.

- (a) Show that the net angular momentum per unit mass carried by the accreted gas is

$$l = \frac{1}{2} V_x a \left(\frac{r_a}{a} \right)^2. \quad (3)$$

- (b) Estimate the ratio of l from spherical-wind accretion to l from Roche lobe overflow.
 - (c) Assume that the outer edge of the disk forms at the radius r_D at which Eq. (3) equals the angular momentum per unit mass of a gas element in circular orbit about the hole: $l = (GM r_D)^{1/2}$. Calculate r_D/r_I (where r_I is the radius of the innermost stable circular orbit) for the parameters appropriate to the Cyg X-1 binary system.
6. (ST 15.1) Consider a neutral beam of cold plasma, initially moving with velocity v in a field-free region, incident normally to a plane surface, beyond which there is a uniform B field parallel to the plane. Neglect the effect of collisions between particles.

- (a) Describe the motion of the electrons and ions as they penetrate the plane surface. In particular, argue that a current will be established parallel to the surface, and estimate the penetration depth of the ions.
- (b) Estimate the ion and electron contributions to the surface density \mathcal{J} and the corresponding jump in the magnetic field that the current generates.
- (c) Argue from part (b) and the expression,

$$\frac{B^2}{8\pi} = \frac{1}{2} \rho(r_A) v^2(r_A), \quad (4)$$

for the Alfvén radius r_A , that these screening currents induced at the Alfvén surface will cancel the stellar field outside r_A .