Fall 2005 ASTR 1120-001 General Astronomy: Stars & Galaxies.
Problem Set 4. Due T 1 Nov

Your name:

Your ID:

Except for the tutorial, for which you should submit answers on line, please *show your working* on this sheet, and write your answers on this sheet. Attach extra sheets if you need them. If you mess up, you can get another copy of the problem set at `http://casa.colorado.edu/~ajsh/astr1120_05/prob.html`.

1. Tutorial on Doppler Effect

Go to `http://www.astronomyplace.com`, press on the Cosmic Perspective 3rd Edition icon, log in. Join our class 'cm651430', so that you can record your work and submit it for grade on line. Click on Tutorials, and do the tutorial on the Doppler Effect. You can redo the tutorial as often as you like, to improve your grade.

Your score should be recorded automatically, but as a double check against your score disappearing into a black hole:

My score was ______________________________.

If you like, you can comment here on the tutorial:

2. Quasar

(a) Schwarzschild radius

The black holes which power quasars have masses typically about $10^8\,\mathrm{M}_\odot$. The Schwarzschild radius R of a black hole is proportional to its mass M, with the Schwarzschild radius of a $1\,\mathrm{M}_\odot$ object being 3 km. What is the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole? Express your answer in km, and then in Astronomical Units ($1\,\mathrm{AU} = 1.5 \times 10^8\,\mathrm{km}$).

The Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole is __________ km = __________ AU.

(b) How long to fall in?

If you fell (woops) through the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole, how many minutes would it take you to fall to the central singularity? [Hint: From your own point of view, you would fall at the speed of light, $c = 3 \times 10^8\,\mathrm{m/s}$.]

I would hit the singularity in ____________________________________ minutes.

(c) Tidal force

The tidal force between your head and your toes at the Schwarzschild radius of a $1\,\mathrm{M}_\odot$ black hole is about $10^9 g$ (a giga-gee). What is the tidal force at the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole? Would you get ripped apart while entering the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole? Would you get ripped apart somewhere inside the black hole (explain)? [Hint: The tidal force at distance R from the center of an object of mass M is proportional to M/R^3. Remember that the Schwarzschild radius R is proportional to M.]

The tidal force between head and toes at the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ is _______ g.

I would/would not be ripped apart at the Schwarzschild radius of a $10^8\,\mathrm{M}_\odot$ black hole.

I would/would not be ripped apart somewhere inside the black hole because

3. The Black Hole at the center of our Galaxy

The animation of infrared observations by Eckart, Genzel et al. (2002) at http://www.mpe.mpg.de/www_ir/GC/ (see Figure 1) shows stars buzzing like bees around the position of SgrA*, the unresolved point radio source thought to mark the black hole at the center of our Galaxy.

In a gravitating system like this, the orbital motions of the stars at distance r from SgrA* yield a measure of the enclosed mass $M(r)$ interior to r, including both black hole and stars. Astronomers deduce the distances r of stars from SgrA* from their angular separation on the sky multiplied by the known distance 8,000 pc, eight thousand parsecs, to the Galactic center.

Figure 2 shows measurements of the enclosed mass M plotted versus the radial distance r in parsecs from the Galactic center. [Enclosed mass means the mass contained inside a sphere of radius r.] What aspect of the curve of enclosed mass M versus radius r suggests that there is a large mass of small radius – a black hole – at the Galactic center? What is the mass $M_\bullet$ of Sagittario, in $M_\odot$ (solar masses), according to the curve?

The mass $M_\bullet$ of Sagittario is ______________________ $M_\odot$.

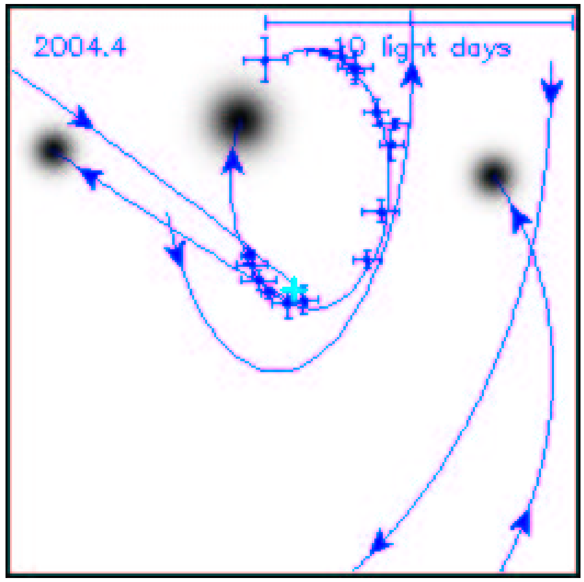

Figure 1: Observed motions of stars near SgrA* (marked with a cross), from `http://www.mpe.mpg.de/www_ir/GC/`.

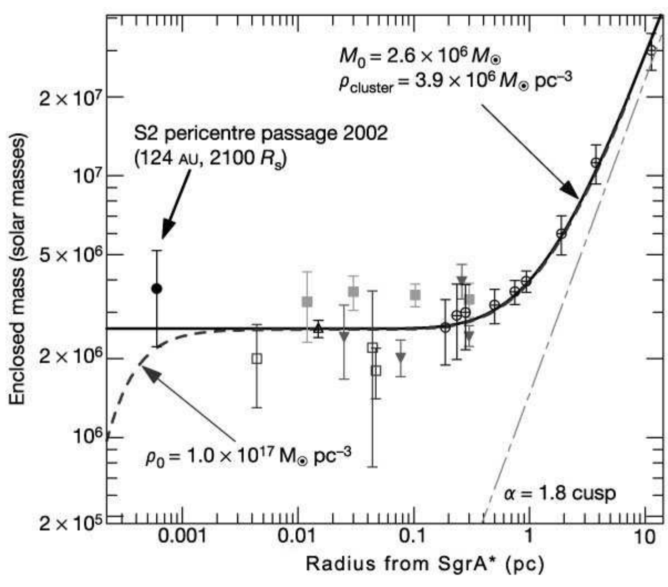

Figure 2: Enclosed mass $M(r)$ as a function of distance r from SgrA*, from Schödel et al. 2002, Nature 419, 694.