AY C10/L&S C70U **Name:** ____________________
Fall 2018
Worksheet 8
10/22/2018

This worksheet focuses on white dwarfs, neutron stars, black holes, and galaxies. There are 3 pages (including this cover page) and 3 questions. Accuracy is definitely desired, but effort and clear physical reasoning are far more important than the final answer.

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1. Professor Filippenko mentioned in lecture that degeneracy pressure is ultimately caused by quantum uncertainty: when particles are confined in space, the spread in their velocities grows.

   (a) Suppose that you tried to squeeze a lump of degenerate matter. **What would happen** to the velocities of particles within the lump and **how does this give rise** to "degeneracy pressure"?

   (b) Both neutron stars and white dwarfs cool very rapidly after they form, but do not shrink as they cool as a normal star would. **Explain why** in two or three sentences.

   (c) **What happens** to electron degeneracy pressure at the Chandrasekhar limit? Explain in a sentence or two.

2. José uses the general-relativistic magnetohydrodynamic (GRMHD) Einstein Toolkit in order to simulate binary systems of neutron stars and black holes. Such numerical (computational) codes are often needed in astrophysics, because analytical (pen-and-paper math) methods are increasingly incapable of solving problems in black hole dynamics. In the questions below, we will investigate some aspects of a simulation he recently ran.

(a) Black holes can have a mass, charge, and angular momentum, but black holes in nature typically do not have one of these characteristics. **Which of the listed characterstics** is this? **Explain** in a sentence or two.

(b) In the simulation in question, the black hole has a mass of 5 $M_\odot$ and the neutron star has a mass of $2M_\odot$. **Compute the Schwarzschild radius** of each body, given that $R_S = GM/c^2$.

(c) The two bodies begin the simulation with a semimajor axis of 1 AU. **What will happen** to this semimajor axis and why?

(d) In the simulation, the neutron star rotates extremely rapidly and emits a stream of radiation from two points opposite to one another. This is known as a *pulsar*.

  i. Pulsars rotate more rapidly than their parent stars, often completing tens of rotations a second. **What is the cause** of this rapid rotation?

  ii. Pulsars emit a jet of radiation in two directions. **What gives rise** to this radiation, and **is it aligned** with the star's rotation axis?

3. *Upcoming Lecture Material* Astronomers use *rotation curves* to plot the rotational velocity of a system as a function of the radius r away from its center. These curves depend on the mass enclosed M_{enc} as a function of r. Rotation curves are ultimately based on the formula for Keplerian orbital velocity, $v_{\text{orb}} = (GM_{\text{enc}}/r)^{1/2}$. ***We will not cover this material in section, but it will be useful practice for your exam.***

   (a) **Invert the formula given** and isolate M_{enc} on one side. This will give you the formula from your course reader.

   (b) Suppose that all the mass in a system is concentrated in the center of the system, i. e. the mass enclosed by a sphere of any radius is a constant $M_{\text{enc}}(r) = M_0$. **Obtain** $v_{\text{orb}}(r)$ and **sketch** the rotation curve.

   (c) Now, imagine that the mass is more widely distributed—instead of being concentrated at the center, the mass is distributed more broadly such that $M_{\text{enc}}(r) = M_0(r/r_0)$. As before, **obtain** $v_{\text{orb}}(r)$ and **sketch** the rotation curve.

   (d) Astronomers X and Y are vigorously debating the identity of a recently discovered, rotating gaseous object. X strongly believes that the object is a spiral galaxy, while Y holds that it must be a protoplanetary disk. The object is too far away for its distance to be measured via parallax, but Doppler-shift measurements indicate a rotation curve of $v_{\text{orb}} \propto r^{-0.1}$. **Who is more likely** to be correct, and why?