Physics 306, Honors Astronomy, Exam 3

NAME____

You are graded on your work, with partial credit where it is deserved.

1. (4) A very tough friend of yours (who can withstand the tidal forces) sits in his spaceship just outside the event horizon of a black hole and talks to you via radio transmissions. What do you notice about the speed and pitch of his speech?

2. (a) List the 3 principal inner regions of the Sun (inside its surface), and give one nontrivial fact about each region.

(i) (2)

(ii) (2)

(iii) (2)

(b) List the 3 principal outer regions of the Sun (at and outside its surface), and give one nontrivial fact about each region.

(i) (2)

(ii) (2)

(iii) (2)

3. (14) Below draw a **large rough sketch of the Herzsprung-Russell diagram**, and roughly show the following features on this diagram, **with a clear labeling of each feature**:

(1) the main sequence
(2) approximate positions of supergiants, giants, and white dwarfs
(3) tick marks for temperatures T corresponding to 3000 K (cool star), 6000 K (our Sun), and 30,000 K (hot star).
(4) tick marks for luminosities L corresponding to 1000 $L_\odot$ (bright star), $L_\odot$ (our Sun), and 0.01 $L_\odot$ (dim star).
(5) Cepheid instability strip
(6) position of a blue giant star on the main sequence
(7) position of a red dwarf on the main sequence

Again, these are only supposed to be **only roughly correct**, but they should be **clearly readable** in your large sketch.

4. (a) (4) Why is energy gained when light nuclei undergo fusion or heavy nuclei undergo fission? You may want to use a crude qualitative sketch, of energy per particle as a function of the number of particles.

(b) (4) Why are higher temperatures required for the fusion of more highly charged nuclei (e.g., He versus H or C versus He)?

(c) (4) Why is the corona of the Sun best viewed with X-ray telescopes?

5. (a) (4) What supports a white dwarf against the inward pull of gravity? Briefly explain the origin of this effect.

(b) (4) A star starts with about the same average mass density and size as our Sun, and collapses to a white dwarf at the end of its life as a normal star. Using what you know about the size and average mass density of the Sun, and what you know about the size of a white dwarf, make a crude estimate of the mass density of a white dwarf.

(c) (4) What is the Chandrasekar limit? (I.e., explain the concept and also give the approximate value in solar masses.) What is the reason for this limit?

(d) (4) What supports a neutron star against the inward pull of gravity?

(e) (4) Using what you know about the size of a neutron star, use the same approach as in part (b) to make a crude estimate of the mass density of a neutron star.

(f) (4) What is the approximate upper limit on the mass of a neutron star?

(g) (4) Why do we see many neutron stars as pulsars? I.e., what is the reason that they appear to pulsate as seen from Earth?

(h) (4) Very crudely, what is a typical rotational speed of a pulsar (for example, the Crab pulsar)? Give the answer in revolutions per some unit of time.

6. (a) (5) Recall that a mass m, moving with velocity v, must be subjected to a centripetal force

$$F = m\frac{v^2}{r}$$

if it is to be kept in a circular orbit of radius r. If this force is due to the gravitational attraction of a much larger mass M, then we also have

$$F = G\frac{mM}{r^2} \ .$$

Combine these equations to find the expression for M in terms of m, v, and r.

(b) (5) What is the Tully-Fisher relation and how is it used? (As always, be as specific as possible.)

7. (a) (4) The energy of motion (or kinetic energy) for a mass m moving with velocity v is

$$E_{motion} = \frac{1}{2}mv^2 .$$

The gravitational potential energy of a mass m at a distance R from the center of a larger mass M is

$$E_{gravitational} = -G\frac{mM}{R} .$$

Now suppose that a mass m is launched with a velocity v which is equal to the escape velocity v_{escape} – i.e., the minimum velocity such that m can completely escape from the gravitational pull of M .

Combine the above equations to find an expression for v_{escape} in terms of M , R, and G.

(b) (4) For a black hole, the Schwarzschild radius R_S is the distance from the center to the event horizon. Using the above equations for a photon with mass m, find the expression for R_S in terms of M , G, and the speed of light c.

(c) (4) Explain why each of the two equations given in part (a) is actually not quantitatively valid (even though the final answer is correct because of a cancellation of errors).

$E_{motion} = \frac{1}{2}mv^2$ is not really valid at or near the speed of light, because:

It is not really valid to use $E_{gravitational} = -G\frac{mM}{R}$ in a strong gravitational field, because:

(d) (4) Given $G = 6.67 \times 10^{-11}\,\mathrm{m}^3/\mathrm{kg\,s}^2$, calculate the Schwarzschild radius R_S for a supermassive black hole with $M = 3.0 \times 10^9\ M_\odot$ where $M_\odot = 2.0 \times 10^{30}$ kg. Express your answer in AU, with 1 AU $= 1.5 \times 10^8$ km.

As always, credit will be given for **specific** ideas that are **clearly** stated.

8. (10 points maximum possible extra credit) Discuss some of the main ideas that you learned while attending talks at our conference, by the four astronomers on Saturday (October 20), or alternatively by the early morning speakers on Friday (October 19) or Saturday (October 20). Please be as specific as possible, and also briefly say which talks you attended.

9. 8. (5 points maximum possible extra credit) Discuss some important ideas that you learned about the Sun, and the history of solar astronomy, from the movie "Solar Max".

Enjoy the weekend!