Physics 108 – Introduction to Cosmology

Spring 2012 Myers

Homework 9

Please write all your work and answers on separate paper. (You can turn in this page with the questions or not, as you wish). Show all your work on calculations and explain your reasoning whenever you can.

1. **Galactic Black Hole:** There is strong evidence that suggests that there is a huge black hole in the center of the Milky Way galaxy. The mass contained within the black hole is estimated to be $4\times10^6\ M_\odot$ (4 million times the mass of the Sun).
    a. What would be the radius of the event horizon (the "Schwarzschild radius") of such a large black hole, measured in meters?
    b. What would be the radius of the event horizon, measured in Astronomical Units (AU)?

2. **L-H See-ya!** When the Large Hadron Collider (LHC) began operation in Geneva, Switzerland, in September of 2008, there was public concern that it might create microscopic black holes. We can assess the threat by estimating the size of any black holes the LHC might create:
    a. The LHC collides protons which have energies up to 3.5 TeV each, (where 1 TeV $= 1\times10^{12}$ eV) resulting in an overall available energy of 7.0 TeV. Given that 1 eV $= 1.6\times10^{-19}$ Joules of energy, what is the maximum energy of each collision, in Joules?
    b. Einstein's famous equation $E = mc^2$ says that energy has mass, and mass has energy. Here $c = 2.9979\times10^8$ m/s is the speed of light in vacuum. Using the energy of the collision from part a) above, how much mass does that energy have? (For E in Joules, m will be in kilograms.)
    c. The size of a black hole is measured by the radius of the event horizon, which is known as the "Schwarzschild radius." What is the Schwarzschild radius for a black hole with the mass computed in part b) above (in meters)?
    d. When the principles of quantum physics are brought into General Relativity there seems to be a smallest distance scale, called the Planck length. The value of the Planck length is $L_P = 1.6\times10^{-35}$ meters. It is not clear that the size of the event horizon makes any sense if it is smaller than the Planck length. So is the size of the black hole computed in part c) above larger or smaller than the Planck length?
    e. Should anyone have been concerned about the LHC creating a black hole?
    f. The LHC will eventually produce collisions with energies up to 14 TeV. Should we worry then?

3. **Kepler and Drake:** The Kepler Mission (`http://kepler.nasa.gov`) will help refine estimates for some of the factors in the Drake equation. Although results right now can only be considered to be preliminary, it is tempting to see what we might find using the data collected so far.

    a. Estimate f_p, the fraction of stars that have planets, by dividing the number of stars Kepler has found to have planets by the total number of stars Kepler is observing.

    b. Estimate n_e, the number of planets per star which could support life, by dividing the number of planets found by Kepler in a habitable zone, divided by the total number of stars found to have planets.

    c. Use Drake's original assumptions for the other factors to compute a revised value for N, the number of "communicating" civilizations possible.