Problem Set #8

Astro 2: Spring 2012

Due: June 5, 2012 (in class)

Problem 1 *The Milky Way before Our Time*

The oldest star clusters in the Milky Way Galaxy (MWG) are about 12 billion years old, based on the turnoff points of the main sequences on their HR diagrams. Furthermore, the oldest white dwarfs in the Milky Way are also about 12 billion years old, based on the temperatures of the coolest ones. For these reasons, and other ones, we think the galaxy is around 12 billion years old.

About 1% of the baryonic mass (ordinary matter) of the MWG is in the form of heavy elements and about 3% is in the form of helium produced inside of stars. The mass per nucleon of helium and the heavy elements is about 0.7% less than that of hydrogen. The total MWG baryonic mass is presently about $10^{11} M_{sun}$, and the present luminosity of the MWG is about $10^{10} \mathcal{L}_{sun}$. From the provided information, prove that the MWG was much more luminous in the past than it is today.

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Problem 2 *On the Eating Habits of SMBHs*

On Thursday, a Ph.D. student named Eli Quetin told you about the tidal disruptions of stars that pass too close to the quiescient supermassive black holes (SMBHs) in normal galactic nuclei.

When a 1 M_{sun} star is disrupted by a SMBH with $10^7 M_{sun}$, about half of the mass of the star is expected to be accreted and half ejected. Assume tha the accreted mass gives off 0.05 $M_{sun}c^2$ of energy in the form of light. Assume that the luminosity is the Eddington value. That is, the accretion process has a 10% efficiency as far as producing light goes.

(a) What is the Eddington luminosity for this SMBH? (Answer: $3 \times 10^{11} \mathcal{L}_{sun}$)

(b) What is the rate of mass accretion needed to produce that luminosity? (Answer: $6.6 \times 10^{-9} M_{sun}/\text{sec}$)

(c) How long will it take for the black hole to swallow up the accreted 0.5 M_{sun}? (Answer: 2.4 years)

(d) It is impossible for a SMBH with $M > 10^8 M_{sun}$ to disrupt a star tidally. However, the SMBH can still swallow the star whole. Explain why this is.

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Problem 3 The Cryogenic Dark Matter Search

As you know, the idea that MACHOs form the bulk of the dark matter halo of the Milky Way Galaxy has been ruled out by microlensing observations. The current best thought is that the dark matter is comprised of weakly interacting massive particles (WIMPs). Although physicists have yet to detect these WIMPs, theoretically they could have been produced in the first instants following the Big Bang.

Dr. Harry Nelson of our very own physics department is part of a collaboration trying to detect WIMPs as they fly though specially built laboratories on Earth. Their experiment is called the Cryogenic Dark Matter Search (CDMS). Check out the Wikipedia page on the experiment:

`http://en.wikipedia.org/wiki/Cryogenic_Dark_Matter_Search`

and also look at this poster found on the CDMS webpage:

`http://cdms.berkeley.edu/edu-poster.jpg`

Naturally, there is a good discussion in your textbook as well.

(a) Why are the CDMS and similar experiments conducted deep underground?

(b) What is a phonon?

(c) If phonons are detected, a test must be made to be sure that the WIMP interaction is not really caused by an ordinary charged particle. Explain.

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Problem 4 Dark Matter Density

The best estimate of the dark matter mass density near the solar system is equivalent to the mass of one proton per 3 cubic centimeters. It is hard to find useful comparisons for this number in daily experience. Try this comparison: suppose all the mass in the planets out to (and including) Neptune, as well as the mass of the Sun, were spread out uniformly within a sphere of radius equal to the typical radius of Neptune's orbit. About how many protons per cubic centimeters would there be? (Answer: $\approx 3 \times 10^{12}$ protons/cm^3)

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