AY C10/L&S C70U **Name:** ____________________
Fall 2018
Worksheet 9
10/30/2018

This worksheet focuses on cosmology and the expanding Universe, while reviewing earlier concepts. There are 2 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. In this question, we investigate some aspects of Olbers' paradox. Suppose that the Universe is infinitely large, infinitely old, static, and consists entirely of Sun-like stars.
   (a) Suppose that in such a universe, you looked up at the night sky. **What would you expect** to see, along every line of sight, and why?

   (b) Suppose that the Universe is actually finite in age, and is expanding at some rate. **List two ways** in which this would change the apparent brightness of the sky, and the direction in which they would change it.

2. Suppose that we are looking at some spherical region of the Universe, centered on Earth, with radius $a = 500$ Mpc. The total mass of "normal" baryonic matter is M_{baryon} and that of dark matter is M_{dark}. The Universe is expanding with a Hubble parameter of $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.
   (a) **Find the recessional velocities** of galaxies located at positions $0.1a$, $0.5a$, and a. **How might we measure** these recessional velocities, and **how could this method** have been used to determine Hubble's law?

   (b) Arguing from Einstein's principle of general relativity and Newtonian gravity, **describe two independent ways** in which we can infer the existence of dark matter.

(c) The Andromeda galaxy is located approximately 2 million light years away, and Hubble's law predicts that it should be receding at approximately $40\,\mathrm{km\,s^{-1}}$. In actuality, though, Andromeda is actually on a collision course with the Milky Way! **Does this observation discredit** Hubble's law, and why or why not?

3. In this question, we will investigate various methods and implications of measuring cosmic distances.

   (a) Suppose that we observe a Type 1a supernova in a distant galaxy of brightness b_{1a}, whose luminosity is an already-known $L_{1a} = 10^{11} L_\odot$. **Devise a method** to compute the distance to this galaxy, and carry through the calculation.

   (b) The galaxy hosts a quasar in its center, which is observed with a brightness $b_{\rm quasar} = 10^5 b_{1a}$. **Compute the luminosity** of this quasar. Using the scaling relations $L \propto M^4$ and $\tau_* \propto M^{-3}$, **what would be the lifetime** if this were a star?

   (c) Quasars are in fact powered by accretion disks around supermassive black holes. Accretion processes tend to be strong emitters of the $H\alpha$ (Balmer-α) line in hydrogen, $\lambda_{H_\alpha} = 656.3$ nm. If we measure this line with a wavelength of 3281.5 nm, **compute z for this quasar**.

   (d) The highest-resolution telescopes in the world have resolutions of order 10^{-2} arcsec. Assuming that galaxies typically range in distance from $10^6 - 10^{10}$ parsecs, **would their parallax shifts** be measurable?