ASTRONOMY 294Z
The History of the Universe
Professor Barbara Ryden

Problem Set # 3
Due Tuesday, January 29
at class time

NAME (please print clearly): _____

SCORE (instructor use only): _____

1) [20 points] You are given a ticket for running a red traffic light. For an observer halted at the red light, the light emits a wavelength $\lambda_0 = 700\,\text{nm}$. You tell the traffic cop that because you were approaching the light, the Doppler shift made it appear green ($\lambda = 500\,\text{nm}$). How fast would you have been going if this were true? If the speed limit is 35 miles per hour, and the speeding fine is \$1 for every mile per hour over the limit, how large a fine would you have to pay? [Hint: 1 kilometer = 0.621 miles, 1 hour = 3600 seconds.]

2) [20 points] Assume that a typical galaxy contains 100 billion stars, and that there is one galaxy per cubic megaparsec, on average. How many galaxies are within a Hubble distance, $c/H_0 = 4300$ megaparsecs, of us? How many *stars* are within a Hubble distance of us?

3) [20 points] The Sahara has an area of $A = 9{,}000{,}000$ square kilometers. The average depth of sand in the Sahara is $d = 10$ meters. What is the total volume of sand in the Sahara, expressed in cubic meters? If an average grain of sand has a volume of 1 cubic millimeter, how many grains of sand are in the Sahara? [Assume the grains are tightly packed together, with no air spaces between them.] Is the number of grains of sand in the Sahara greater than or less than the number of stars within a Hubble distance of us (as computed in the previous problem)?

4) [20 points] The mass of the Sun is $M_{\rm sun} = 2 \times 10^{33}$ grams. The mass of a hydrogen atom is $M_{\rm H} = 1.7 \times 10^{-24}$ grams. If the Sun consisted entirely of hydrogen atoms, how many atoms would it contain? Dividing this number of atoms by the volume of the Sun, show how many hydrogen atoms there would be, on average, *per cubic meter* of the Sun. [Hint: you may assume the Sun is a sphere of radius $R_{\rm sun} = 700{,}000$ kilometers.]

5) [20 points] If every star within a Hubble distance of us were as massive as the Sun and were made entirely of hydrogen, how many hydrogen atoms would be within a Hubble distance of us? [Hint: use your answers to problems 2 and 4.] Dividing this number of atoms by the volume of space within a Hubble distance of us, show how many hydrogen atoms there would be, on average, *per cubic meter* of the visible universe. [Hint: since most of the universe consists of nearly empty space, this number will be very very very much smaller than the number of atoms per cubic meter within a dense star like the Sun.]