ASTRONOMY 102

Problem Set #1 **Due: Wednesday 23rd January 2008, by 5 p.m., Hennings 312 slot**

Instructor: Douglas Scott **(Must be handed in on time, otherwise marks will be deducted)**

Answer all three questions, although only one question will be chosen at random for grading

Note: please indicate your answers clearly, e.g. by highlighting or drawing a box around each one, and also staple your sheets together – this will please the person marking and assigning grades!

1. A very big number!

(a) Let's assume (for simplicity) that the observable Universe can be approximated as a sphere around us with radius equal to the light travel time in the age of the Universe (say 13.5×10^9 years). And let's assume a rounded value of 10^{-15}m for the size of an atomic nucleus. What is the ratio of the volume of the observable Universe to the volume of a nucleus?

(b) Let us now (again for simplicity) assume that the size of a nucleus is the smallest scale that is ever important to consider. One can imagine describing the current state of the Universe by giving a number '0' or '1' (called a 'bit' of information, here describing whether that tiny volume contains a particle or not) to every one of the cells of nuclear volume in the observable Universe. How many bits do I need to describe the current state of the observable Universe?

(c) Now let's think about the time dimension. To describe the whole history of the observable part of the Universe we need to consider how many time intervals there have been through cosmic history. Let's approximate the smallest time interval as the time it takes light to cross a nucleus. How many time intervals does that correspond to for the age of the Universe?

(d) Hence, if we want to describe the history of 'everything' by saying whether each 4-dimensional micro-volume has a particle in it or not, how many bits of information do we need?

2. The Big Light Bulb!

(a) Imagine that you are given 1 kg of hydrogen in a box. How many atoms of hydrogen do you have? How many protons? How many neutrons? How many electrons?

(b) In a fusion reaction it is possible to convert 4 hydrogen atoms into 1 helium (^{4}He) atom, which weighs about 0.71% less than 4 hydrogens. If you managed to do this to your 1 kg of hydrogen, how many protons, neutrons and electrons would you end up with?

(c) How much energy would you produce? (in Joules)

(d) How long would you be able to light a 100 Watt light bulb with this energy?

(e) Given the luminosity of the Sun, how many kilogrammes of hydrogen are being used up every second?

(f) What fraction of the Sun's mass has been used up this way in its 4.6 billion year history?

3. Red light, green light

(a) Someone gives you a red lightbulb, and you look at its spectrum, finding out that the light is dominated by a single spectral line at 700 nm. If this bulb was part of a traffic light, then how fast would you need to be travelling in order to be able to claim that the light looked green (500 nm) to you? Do you need to be travelling towards or away from the light?

(b) What is the frequency (in Hertz) of these 700 nm photons?

(c) What is the energy of each photon?

(d) If this is a bright 1 kW light bulb (and all the energy goes into 700 nm photons), how many photons is it producing each second?

(e) Now imagine putting the light bulb at the distance of the Sun (1 AU) and consider a human being (like yourself) observing it. For simplicity assume that your pupil is a circle of diameter 1 cm, and that the bulb gives off photons equally in all direction. By considering the fraction of the total surface area at 1 AU which is covered by your pupil, how many photons enter your eye per second?