Problem Set 5

1) [20 points] Since E = Mc2 , one kilogram of matter is equivalent to an energy E = (1 kg) × (3 × 108 m/sec)2 = 9 × 1016 kg m2/sec2 . An energy of 1 kg m2/sec2 is known as 1 joule, for short. (The joule is not a unit of energy that is used much in everyday life. To give you a sense of its size, burning one tablespoon of gasoline releases half a million joules of energy, as does metabolizing one ounce of dark chocolate.)

The total annual energy consumption in the U.S.A. is 1020 joules. If you were capable of converting mass to energy with 100% efficiency, how much mass M would you need to produce an energy E = 1020 joules? An adult male African elephant has a mass M = 5000 kilograms; if the elephant’s mass were converted to energy with 100% efficiency, would that be enough to supply the U.S.A.’s energy consumption for one year?

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2) [20 points] The Sun actually does convert mass into energy; it does this by nuclear fusion. During one second, the Sun produces an energy $E = 3.9 \times 1026$ joules, which then is carried away by photons. How much mass M must the Sun convert into energy E each second?

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3) [20 points] In the previous problem, you computed the mass M that the Sun converts into energy each second. The energy is then carried away by photons into the darkness of interstellar space. Thus, every second, the mass of the Sun is becoming smaller by an amount M. The current mass of the Sun is Msun = 2.0 × 1030 kilograms. Using the value of M (the mass lost in one second) computed in problem #2, calculate how many seconds it will be before the Sun’s mass drops to zero. Is this length of time greater than or less than the Hubble time?

Problem Set 5

4) [40 points] In the middle of the 20th century, a popular alternative to the Big Bang model was the Steady-State model. In the Steady-State model, matter is continuously created as the universe expands, so that the density of matter in the universe remains constant with time. The average temperature of this matter remains constant, as well. Explain why the discovery of the Cosmic Microwave Background in the 1960s was a fatal blow to the SteadyState model.