UCSD Physics 162 *Cosmology* Assignment 3

Prof. B. Keating Assigned: April 21, 2009 Due: April 28 In Class

1 Radiation Domination

(a) Derive the fluid equation when, instead of assuming the universe is "matter dominated" as we did in class, that it is radiation dominated. That is, assume the energy density, is provided by radiation, not matter $\epsilon = \epsilon_{rad}$.

(b) Make a sketch of the behavior of the behavior of $\epsilon_{rad}(t)$ and $\epsilon_{matter}(t)$ vs. the scale factor $a(t)$.

(c) Assume that $\epsilon_{rad} = \epsilon_{matter}$ at some early time such that $0 < a(t) < 1$. What conclusions can you infer for the time preceding this time about matter vs. radiation domination? What about after this time, and in the future?

2 Sound Speed of Light?

What does the "speed of sound" in radiation mean? Where does the factor of $\sqrt{3}$ come from in its definition? Hint: consider the definition of pressure (using momentum transfer) in a **3**-dimensional "gas" of photons.

3 Curvature Domination

Assume the universe reduces it matter density (it slims down) as it ages. Write down the Friedman equation, including k and matter. How ϵ_{matter} behave as a function of cosmic scale factor $a(t)$? Assume $k < 0$, what happens as $a(t)$ grows towards infinity? Write down the Friedman equation in this limit. How does $a(t)$ behave as a function of time? What about the Hubble parameter $H(t)$ in this curvature dominated universe: how does it behave vs. time compared to a matter dominated universe?

4 Ryden HW Problem 4.1

5 Ryden HW Problem 4.2

6 Ryden HW Problem 4.3