Astro 7B – Cosmology Week 2

1. **Coming to a consensus (model)** Plot the following quantities for OUR universe. Qualitative sketches, simple scaling relations, and asymptotic values suffice.
   (a) $a(t)$. It will probably be easiest to plot log-log.
   (b) $\ddot{a}(t)$. It will probably be easiest to plot log-log.
   (c) Ω, Ω_m, Ω_r, Ω_λ, all as a function of scale-factor a.
   (d) u_Λ, u_m and u_r, all as a function of scale-factor a.
   (e) $T_{\rm CMB}$ vs. scale-factor a and redshift z.
   (f) Label (i.e., provide a number) on your first plot the scale factor at the time of radiation-matter equality. What was the temperature of the CMB at this time? Did radiation-matter equality happen BEFORE or AFTER recombination? (use $\Omega_{\rm r,0} \sim 10^{-4}$)
   (g) Same, but for matter-Λ equality.

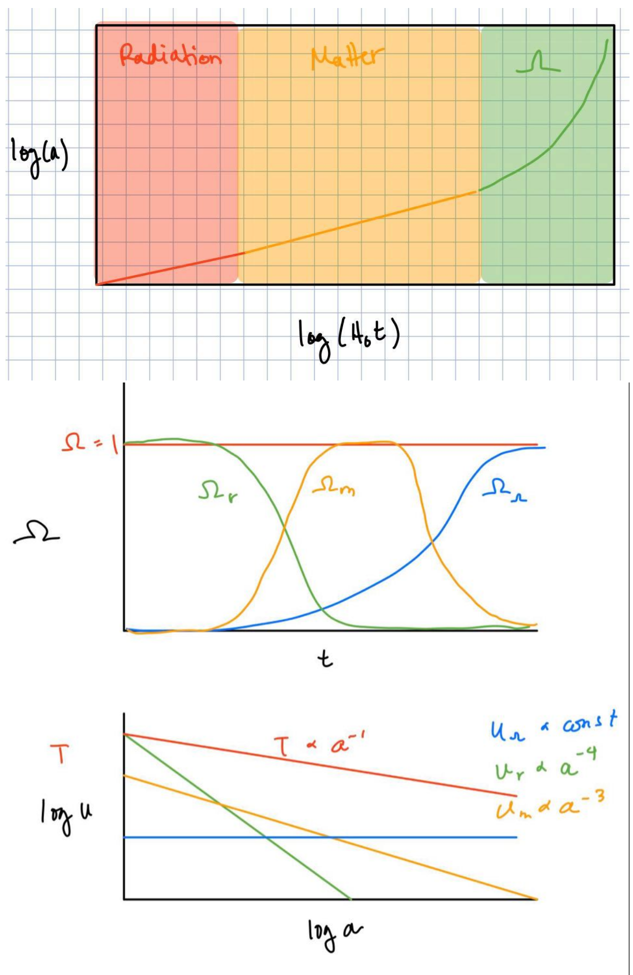

Figure 1: Caption

2. **(Just for kicks) The most embarassing problem in all of physics** Many physicists expect(ed), given that dark energy is the "vacuum energy" of free space, that we should be able to get an (order of magnitude) estimate of the dark energy density using a dimensionally correct combination of the

fundamental constants we already know (e.g., $\hbar, c, G$). This is a measure of how close our compatible our current theories of physics are .

(a) Construct the "Planck mass" $m_{\rm planck}$, which is just the combination of $\hbar, c$, and G that gives units of mass. Evaluate numerically (in grams).

(b) Construct the "Planck length"$l_{\rm planck}$, which is just the combination of $\hbar, c$, and G that gives units of length. Evaluate numerically (in cm).

(c) From $m_{\rm planck}$ and $l_{\rm planck}$, construct an ENERGY DENSITY (you will need a factor of c^2 too). This is basically what modern fundamental physics predicts for the dark energy density. Compare to OBSERVED dark energy density today, $u_\Lambda \sim u_{c,0} \sim 10^{-8}$ erg/cm^3. This impressive discrepancy is often referred to as "the most embarassing problem in all of physics". The fact that our current slate of fundamental constants can't get us even close to the right answer suggests that we need some new fundamental theory, with its own fundamental constant(s) to go along with it.