# Problem set 8

## Problem 1

Considering the scale factor $a(t)$ for the expansion of the Universe, and assuming a flat Universe:

(a) Determine the time dependence for $a(t)$, assumed to be proportional to a power $\alpha$ of time, $a(t) \propto t^\alpha$, in the case of a Universe containing only radiation. Consider the radiation density to vary as a function of $a$ as $\rho_R \propto a^{-4}$.

(b) Determine the expression of $a(t)$ for a matter-dominated Universe (baryonic and dark matter), knowing that the density of matter varies as $\rho_M \propto a^{-3}$.

(c) Determine $a(t)$ for the dark energy $\Lambda$, for which the density is constant ($\rho_\Lambda = \mathrm{cst}$).

(d) Use the above results to explain the evolution of the composition of the Universe (see Fig. 1)?
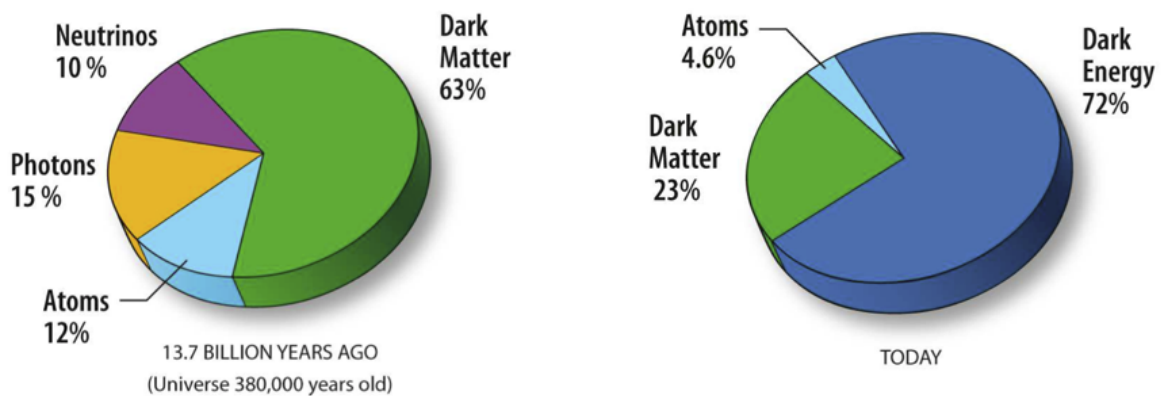


Figure 1: *Composition of the Universe* 13.7 *billion years ago and today.*