

# Astroparticle Physics (Physics 711)

## Exercise 3

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### Problem 1: Dark Energy (5P)

What is the minimum value of  $\Omega_\Lambda$  that will result in an accelerated expansion today in case of a flat Universe? What is the value of  $\Omega_\Lambda$  needed to achieve acceleration at a redshift of  $z = 0.5$ ? Neglect the contribution to the energy density from radiation.

### Problem 2: CMB (5P)

- a) Calculate the fraction of the total energy density of the Universe  $\Omega_{\text{phot}}$  which is in the form of relic photons from the Big Bang, starting from the thermal 2.725 K black body spectrum photon density  $dn(\omega, T)/d\omega$ . Calculate  $\Omega_{\text{phot}}$  for today and for the time of decoupling.
- b) Show that the black body spectrum of the cosmic microwave background after decoupling continues to be a black body spectrum during the expansion of the Universe.