CosmoVerse Corfu: From ΛCDM to EDE

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1 Pen&paper Warm-up: The composition of the Universe

In this exercise we want to understand how the composition of the universe evolves with time. We will later verify your analytic results using the `CLASS` Boltzmann solver. Assume $\Omega_k = 0$ throughout.

a) Start from the continuity equation and derive the density ρ as a function of the scale factor a for matter, radiation and a cosmological constant. Assume a linear equation of state: $p = w \cdot \rho$.

b) In cosmology, it is common to express the timeline of the universe in terms of redshift since it is observable as changes of wavelength in galaxies. Express ρ_m, ρ_r and ρ_Λ as a function of redshift $1 + z = \frac{a_0}{a}$.

c) Rewrite $\rho(z)$ in terms of fractional densities $\Omega_i = \frac{\rho_i}{\rho_{\text{crit}}}$, where $\rho_{\text{crit}} = \frac{3H_0^2}{8\pi G}$.

We now want to compute the redshift z_{eq} at which $\rho_r(z) = \rho_m(z)$, which is called the matter-radiation equality. For that we assume the following fractional densities: $\Omega_{m,0} = 0.3144$, $\Omega_{r,0} = 9.229 \cdot 10^{-5}$, $\Omega_\Lambda = 0.6855$.

d) First, make a qualitative sketch of the situation by drawing $\Omega(z)$ as a function of z for each energy density (this doesn't have to be to scale!). Mark z_{eq} on the plot.

e) Now compute z_{eq}! Is it before or after the redshift of recombination $z_{\text{rec}} = 1100$ (when the CMB was emitted)?

2 Numerical exercise

Open now the Jupyter notebook on the Google Colab! We will use the Boltzmann solver `CLASS` to verify our results!