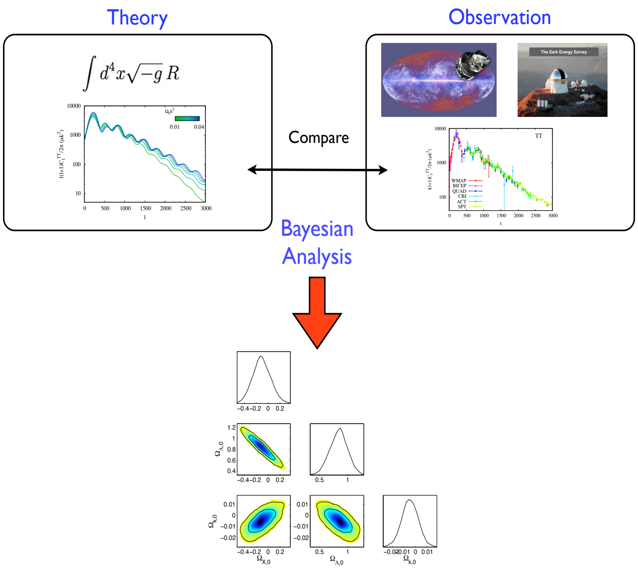
# Updated Cosmology

## with Python




**José-Alberto Vázquez**

ICF-UNAM / Kavli-Cambridge

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# Homework 8

Consider the Universe from the previous exercise.

The *comoving distance* $d_c$ is defined as

$$\chi_e = c\int_t^{t_0} \frac{dt}{R(t)} = \frac{c}{R_0}\int_0^z \frac{dz}{H(z)}. \tag{99}$$

The *luminosity distance* $d_L$ is given by

$$d_L \equiv (1+z)R_0 S_k(\chi). \tag{100}$$

The angular distance is given by

$$d_A \equiv \frac{R_0 S_k(\chi)}{(1+z)}. \tag{101}$$

where

$$R_0 = h_0^{-1}\sqrt{-k/\Omega_{k,0}} = \frac{H_0^{-1}}{\sqrt{|\Omega_{k,0}|}}. \tag{102}$$

a) By using the initial conditions from the previous homework (but $k$=0), plot the Comoving distance $d_c$, luminosity distance $d_L$, and angular distance $d_A$ for the $\Lambda$CDM model (see figure below).

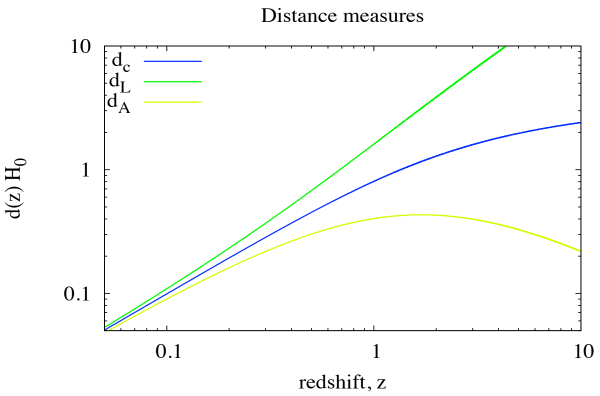


**Figure 12:** Comoving distance $d_c$, luminosity distance $d_L$, and angular distance $d_A$ for a universe filled with the same constituents.

b) Now using the CPL parameterisation, plot these three distances for $[w_0 = 0.9, w_a = 0.5]$ and $[w_0 = -1.1, w_a = -0.5]$.

c) Repeat the same process in b), but now use the equation of state $w(z) = w_0 + w_a ln(1 + z)$ (with same combinations of $w_0$ and $w_a$).

2) As part of some models that allow deviations from ΛCDM we also use the polynomial-CDM model, that can be thought as a parameterisation of the Hubble function. This model has the following Friedmann equation:

$$\frac{H(z)^2}{H_0^2} = \Omega_{m,0}(1+z)^3 + (\Omega_{1,0} + \Omega_{k,0})(1+z)^2 + \Omega_{2,0}(1+z)^1 + (1 - \Omega_{m,0} - \Omega_{1,0} - \Omega_{2,0} - \Omega_{k,0}),$$

where $\Omega_{1,0}$ and $\Omega_{2,0}$ are two additional parameters, which within the ΛCDM both of them remain absent ($\Omega_{1,0} = 0$ and $\Omega_{2,0} = 0$). Nevertheless, $\Omega_{2,0}$ could be interpreted as a 'missing matter' component introduced to allow a symmetry that relates the big bang to the future conformal singularity [see JCAP09(2012)020].

By using the initial conditions from the previous homework (but $k$=0), plot the Comoving distance $d_c$, luminosity distance $d_L$, and angular distance $d_A$ for $[\Omega_{1,0} = 0.2, \Omega_{2,0} = -0.2]$ and $[\Omega_{1,0} = -0.2, \Omega_{2,0} = 0.2]$.