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Make a suitable title: my paper on the cosmic microwave background and formation of structures in our Universe

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ABSTRACT

An abstract for the paper. Describe the paper. What is the paper about, what are the main results, etc.

Key words. cosmic microwave background – large-scale structure of Universe

1. Introduction

Write an introduction here. Give context to the paper. Citations to relevant papers. You only need to do this in the end for the last milestone.

2. Milestone I

In this section we want to study the evolution of the uniform background in the Universe. Our main goal of this section will be to implement methods that computes the Hubble parameter, as well as related time- and distance measures Rewrite. To do this, we will solve simple ordinary differential equations (ODEs) numerically. For the fiducial cosmology we will use results from Planck Collaboration et al. (2020). We will then test our implementation with known theoretical solutions, to assess the validity of our methods.

The main goal of this section is mainly concerned with using known parameter values to predict/solve the background cosmology. Another interesting aspect is to use data to constrain such cosmological parameters. To do this, we will use data from supernova observations Betoule et al. (2014), containing luminosity distance associated with different values of redshift. Implementing our solver, we will implement a simple Markov chain Monte Carlo (MCMC) algorithm, in order to estimate the best fits of h, Ω_m and Ω_Λ, which are the Hubble parameter, and the density parameter of matter and dark energy, respectively.

2.1. Theory

The theory behind this milestone. Defnie ALL parameters

When we don't assume $k = 0$ and omit neutrino contribution, i.e. setting $\Omega_{\nu 0} = 0$, the Friedmann equation can be written as

$$H = H_0\sqrt{(\Omega_{b0} + \Omega_{\mathrm{CDM}0})a^{-3} + \Omega_{\gamma 0}a^{-4} + \Omega_{k0}a^{-2} + \Omega_{\Lambda 0}}, \quad (1)$$

where $H \equiv \dot{a}/a$ is the Hubble parameter. Dot denotes a derivative with respect to cosmic time, t. We also introduce the scaled Hubble factor, $\mathcal{H} \equiv aH$. Rather than working with the scale factor, $a(t)$, we will be working with the logarithm of the scale factor

$$x \equiv \ln a, \quad {}' \equiv \frac{\mathrm{d}}{\mathrm{d}x}. \quad (2)$$

The resulting expression for $\mathcal{H}(x)$ is thus

$$\mathcal{H}(x) = H_0\sqrt{(\Omega_{b0} + \Omega_{\mathrm{CDM}0})e^{-x} + \Omega_{\gamma 0}e^{-2x} + \Omega_{k0} + \Omega_{\Lambda 0}e^{2x}}. \quad (3)$$

We will need the first and second derivative of $\mathcal{H}(x)$. To simplify the resulting expressions, we define a function, $g(x)$, to be the derivative of the term inside the square root in Eq. (3).

$$g(x) \equiv -(\Omega_{b0} + \Omega_{\mathrm{CDM}0})e^{-x} - 2\Omega_{\gamma 0}e^{-2x} + 2\Omega_{\Lambda 0}e^{2x}, \quad (4)$$

$$\frac{\mathrm{d}\mathcal{H}(x)}{\mathrm{d}x} = \frac{H_0^2}{2\mathcal{H}(x)}g(x), \quad (5)$$

$$\frac{\mathrm{d}^2\mathcal{H}(x)}{\mathrm{d}x^2} = \frac{H_0^2}{2\mathcal{H}(x)}\left[g'(x) - \frac{1}{2}\left(\frac{H_0 g(x)}{\mathcal{H}(x)}\right)^2\right]. \quad (6)$$

$$\Omega_k(x) = \frac{\Omega_{k0}}{\mathcal{H}(x)^2/H_0^2}, \quad (7)$$

$$\Omega_{\mathrm{CDM}}(x) = \frac{\Omega_{\mathrm{CDM}0}}{e^x\mathcal{H}(x)^2/H_0^2}, \quad (8)$$

$$\Omega_b(x) = \frac{\Omega_{b0}}{e^x\mathcal{H}(x)^2/H_0^2}, \quad (9)$$

$$\Omega_\gamma(x) = \frac{\Omega_{\gamma 0}}{e^{2x}\mathcal{H}(x)^2/H_0^2}, \quad (10)$$

$$\Omega_\Lambda(x) = \frac{\Omega_{\Lambda 0}}{e^{-2x}\mathcal{H}(x)^2/H_0^2}, \quad (11)$$

$$(12)$$

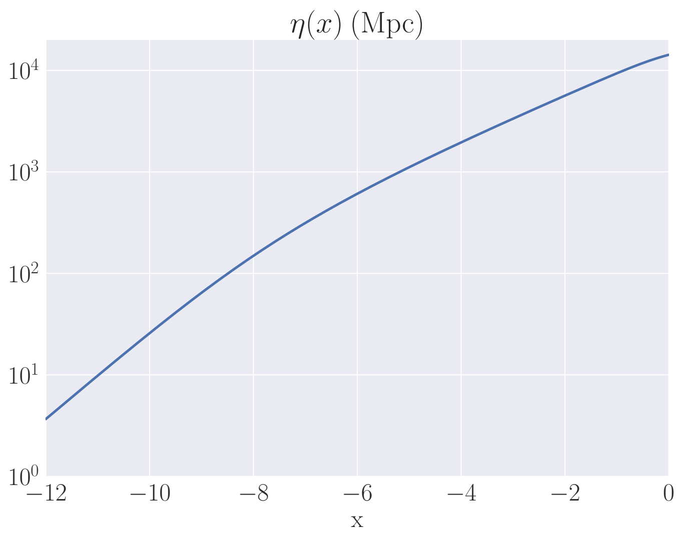
The density parameter of the photons today, $\Omega_{\gamma 0}$, is given by

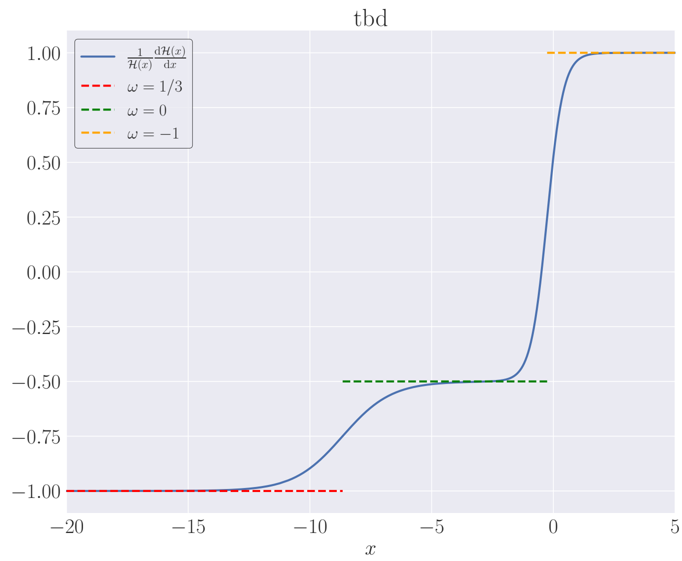
$$\Omega_{\gamma 0} = 2\cdot\frac{\pi^2}{30}\frac{(k_b T_{\mathrm{CMB}0})^4}{\hbar^3 c^5}\cdot\frac{8\pi G}{3H_0^2}, \quad (13)$$

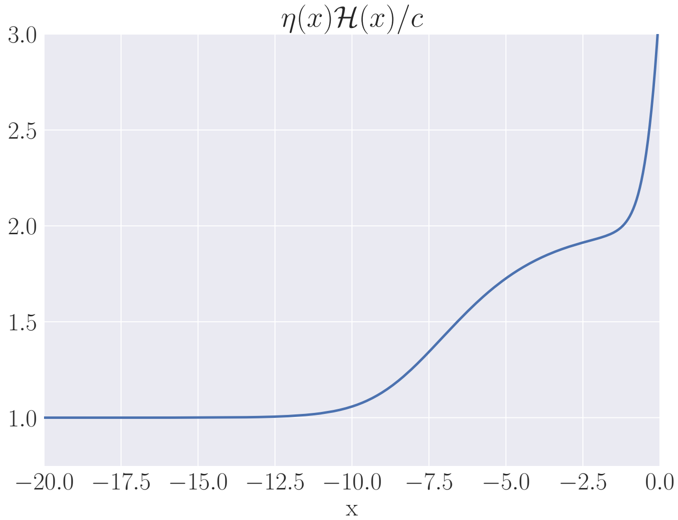
where $T_{\mathrm{CMB}0}$ denotes the temperature of the CMB today.

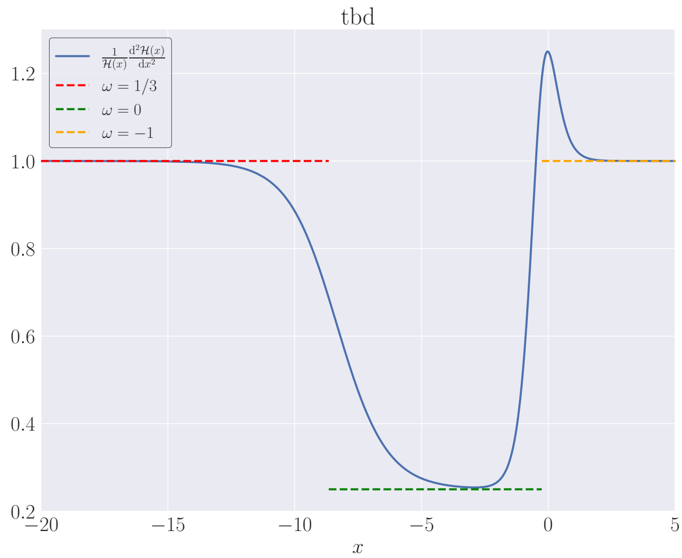
2.2. Implementation details

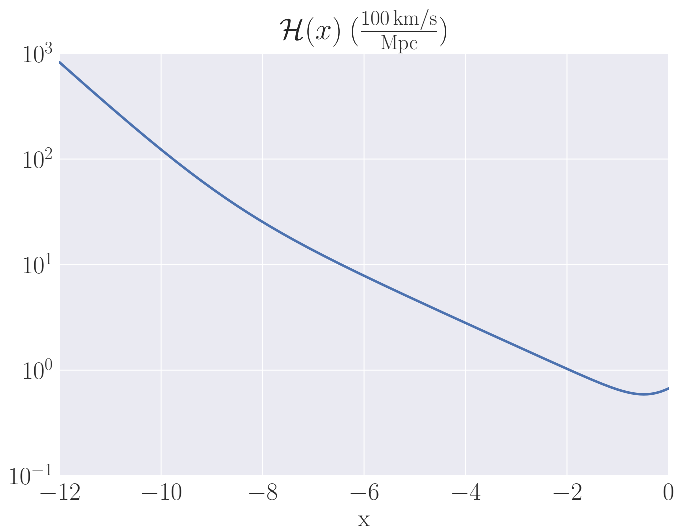
Something about the numerical work.

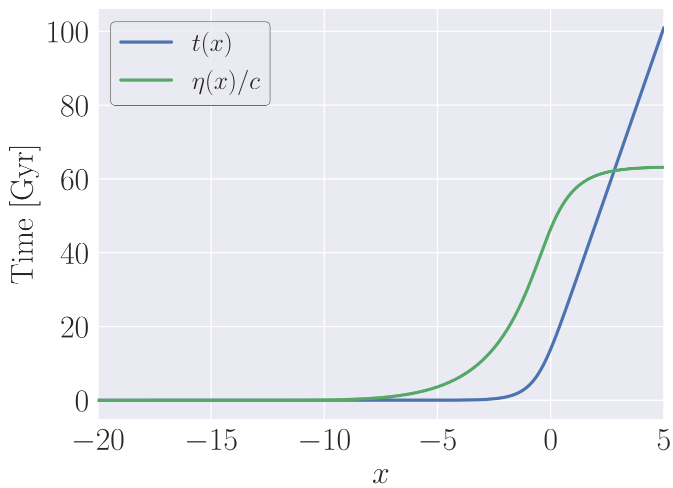












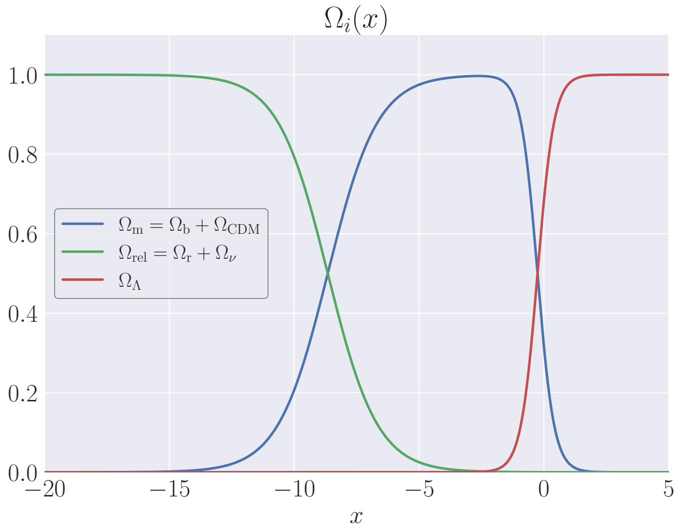
2.3. Results

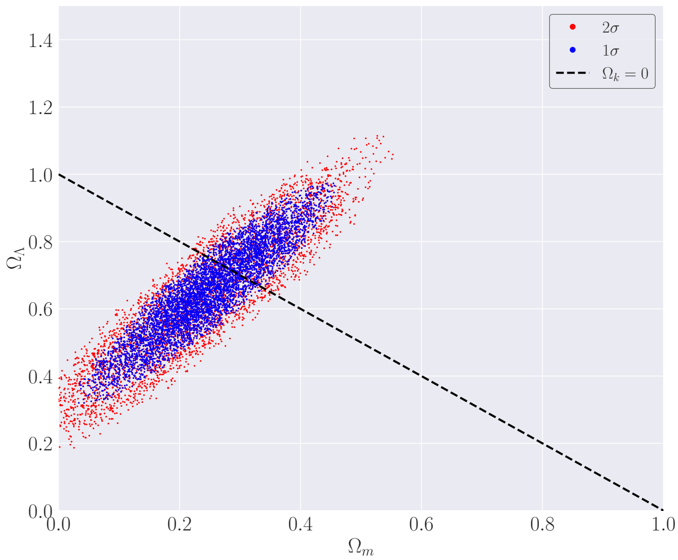
2.3.1. Sanity checks

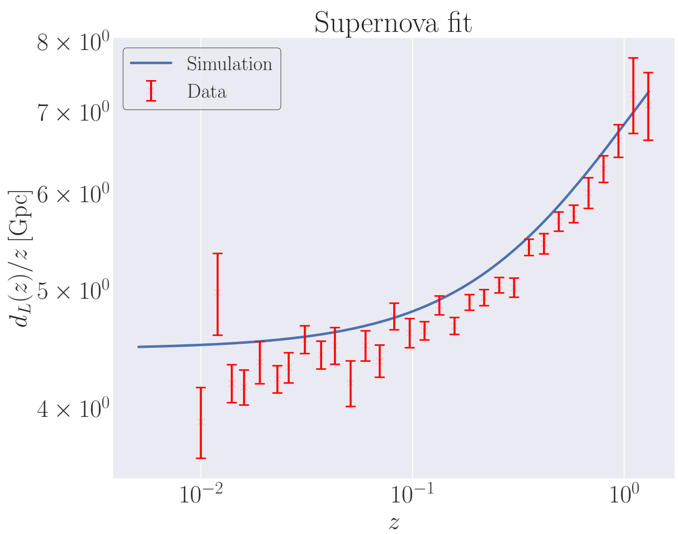
Show and discuss the results.

3. Milestone II

Some introduction about what it is all about. And more so that







3.1. Theory

The theory behind this milestone.

3.2. Implementation details

Something about the numerical work.

3.3. Results

Show and discuss the results.

4. Milestone III

Some introduction about what it is all about.

4.1. Theory

The theory behind this milestone.

4.2. Implementation details

Something about the numerical work.

4.3. Results

Show and discuss the results.

5. Milestone IV

Some introduction about what it is all about.

5.1. Theory

The theory behind this milestone.

5.2. Implementation details

Something about the numerical work.

5.3. Results

Show and discuss the results.

6. Conclusions

Write a short summary and conclusion in the end.

Acknowledgements. I thank my mom for financial support!

References

Betoule, M., Kessler, R., Guy, J., et al. 2014, A&A, 568, A22
Planck Collaboration, Aghanim, N., Akrami, Y., et al. 2020, A&A, 641, A6