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Temporary title: CMB power spectrum...

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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 milestone we will look at the expansion history of a homogeneous and isotropic universe governed by the well known Friedmann equation 2. The universe we consider consists of baryonic matter (Ω_b), dark matter (Ω_{CDM}), radiation (Ω_γ), neutrinos (Ω_ν) and dark energy (Ω_Λ), where Ω is the mass/energy density divided by the critical density (ρ_c). Since our goal in the end is to study the cosmic microwave background (CMB), the homogeneous solution of the universe is of great interest. This is because the CMB is close to being homogeneous with perturbations of order 10^{-5}.

2.1. Theory

The parameters we use for our universe are given below.

$$\boxed{\begin{aligned} h &= 0.67,\\ T_{\mathrm{CMB0}} &= 2.7255\,K,\\ N_{\mathrm{eff}} &= 3.046,\\ \Omega_{\mathrm{b0}} &= 0.05,\\ \Omega_{\mathrm{CDM0}} &= 0.267,\\ \Omega_{k0} &= 0,\\ \Omega_{\nu 0} &= N_{\mathrm{eff}}\cdot\frac{7}{8}\left(\frac{4}{11}\right)^{4/3}\Omega_{\gamma 0},\\ \Omega_{\gamma 0} &= 2\cdot\frac{\pi^2}{30}\frac{(k_b T_{\mathrm{CMB0}})^4}{\hbar^3 c^5}\cdot\frac{8\pi G}{3H_0^2},\\ \Omega_{\Lambda 0} &= 1-(\Omega_{k0}+\Omega_{b0}+\Omega_{\mathrm{CDM0}}+\Omega_{\gamma 0}+\Omega_{\nu 0}),\end{aligned}} \tag{1}$$

where the subscript 0 denotes today's value. h is the dimensionless Hubble constant. More details can be found at Winther (2023).

The Friedmann equation is given by

$$H = H_0\sqrt{(\Omega_{b0}+\Omega_{\mathrm{CDM0}})a^{-3}+(\Omega_{\gamma 0}+\Omega_{\nu 0})a^{-4}+\Omega_{k0}a^{-2}+\Omega_{\Lambda 0}}, \tag{2}$$

where a is the scale factor and $H = \frac{\dot a}{a}$. We will not use cosmic time (t) as our time variable. Instead, we use $x = \ln a$ as our dimensionless time variable. This implies that $a = e^x$ for conversion. Since $a(t = 0) = 0$ and $a(t = t_0) = 1$ we get $t = 0 \iff x = -\infty$ and $t = t_0 \iff x = 0$. The cosmic time as a function of x be found from the differential equation

$$\frac{dt}{dx} = \frac{1}{H}, \tag{3}$$

which can be solved numerically.

We also use a scaled Hubble parameter defined by $\mathcal{H} \equiv aH$ The evolution of the Ωs can be expressed as a function of a as showed below.

$$\begin{aligned} \Omega_k(a) &= \frac{\Omega_{k0}}{a^2H(a)^2/H_0^2}\\ \Omega_{\mathrm{CDM}}(a) &= \frac{\Omega_{\mathrm{CDM0}}}{a^3H(a)^2/H_0^2}\\ \Omega_b(a) &= \frac{\Omega_{b0}}{a^3H(a)^2/H_0^2}\\ \Omega_\gamma(a) &= \frac{\Omega_{\gamma 0}}{a^4H(a)^2/H_0^2}\\ \Omega_\nu(a) &= \frac{\Omega_{\nu 0}}{a^4H(a)^2/H_0^2}\\ \Omega_\Lambda(a) &= \frac{\Omega_{\Lambda 0}}{H(a)^2/H_0^2}.\end{aligned} \tag{4}$$

2.2. Implementation details

Something about the numerical work.

2.3. Results

Show and discuss the results.

3. Milestone II

Some introduction about what it is all about.

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

Winther, H. A. 2023, Numerical Project Milestone 1