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Calculate the CMB power spectrum: Cosmology II

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February 20, 2023 GitHub repo link: https://github.com/Johanmkr/AST5220/tree/main/project

ABSTRACT

SOME ABSTRACT

Contents

Nomenclature

Constants of nature

G - Gravitational constant.
$G = 6.6743{\times}10^{-11}$ m^3 kg^{-1} s^{-2}.
k_B - Boltzmann constant.
$k_B = 1.3806 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}.
$\hbar$ - Reduced Planck constant.
$\hbar = 1.0546 \times 10^{-34}$ J s^{-1}.
c - Speed of light in vacuum.
$c = 2.9979 \times 10^8$ m s^{-1}.

Cosmological parameters

H - Hubble parameter.
H_0 - Hubble constant fill in stuff.
$e^x\mathcal{H}$ - Scaled Hubble parameter.
$T_{\rm CMB0}$ - Temperature of CMB today.
$T_{\rm CMB0} = 2.7255$ K.
η - Conformal time.
χ - Co-moving distance.

Density parameters

Density parameter $\Omega_X = \rho_X/\rho_c$ where ρ_X is the density and $\rho_c = 8\pi G/3H^2$ the critical density. X can take the following values:

b - Baryons.
CDM - Cold dark matter.
γ - Electromagnetic radiation.
ν - Neutrinos.
k - Spatial curvature.
Λ - Cosmological constant.

A 0 in the subscript indicates the present day value.

1. Introduction

Some citation: Pedregosa et al. (2011) and another citation Goodfellow et al. (2016). Figure 1 makes sure that you do all the work.

2. Milestone I - Background Cosmology

Some introduction to milestone 1

2.1. Theory

The main time variable will be $x = \ln a$.

The Hubble equation, where we allow for curvature is citation?:

$$H(x) = H_0\sqrt{\Omega_{\rm M0}e^{-3x} + \Omega_{\rm R0}e^{-4x} + \Omega_{k0}e^{-2x} + \Omega_{\Lambda 0}}, \quad (1)$$

where $\Omega_{\rm M0} = \Omega_{b0} + \Omega_{\rm CDM0}$ and $\Omega_{\rm R0} = \Omega_{\gamma 0} + \Omega_{\nu 0}$ are the present day values of the total matter and radiation densities.

Fig. 1. Penguin making sure that you do all the work necessary!

Something aboutu the curvature, and the evolution of density parameters here.

derive?

$$\frac{\mathrm{d}\eta}{\mathrm{d}x} = \frac{c}{\mathcal{H}(x)}. \tag{2}$$

$$\frac{\mathrm{d}t}{\mathrm{d}x} = \frac{1}{H(x)}. \tag{3}$$

$$\chi(x) = \eta_0 - \eta(x). \tag{4}$$

$$r(\chi) = \begin{cases} \chi \cdot \frac{\sin\left(\sqrt{|\Omega_{k0}|}H_0\chi/c\right)}{\sqrt{|\Omega_{k0}|}H_0\chi/c} & \Omega_{k0} < 0 \\ \chi & \Omega_{k0} = 0 \\ \chi \cdot \frac{\sinh\left(\sqrt{|\Omega_{k0}|}H_0\chi/c\right)}{\sqrt{|\Omega_{k0}|}H_0\chi/c} & \Omega_{k0} > 0 \end{cases} \tag{5}$$

$$d_A(x) = e^{x} r(\chi(x)). \tag{6}$$

$$d_L = e^{-x} r(\chi(x)). \tag{7}$$

$$\chi^2(h, \Omega_{m0}, \Omega_{k0}) = \sum_{i=1}^{N} \frac{(d_L(z, \Omega_{m0}, \Omega_{k0}) - d_L^{\mathrm{obs}}(z_i))^2}{\sigma_i^2} \tag{8}$$

2.2. Methods

2.2.1. Initial equation

$$\begin{aligned} \Omega_k(a) &= \Omega_{k0} e^{-2x} \left(\frac{H_0^2}{H(x)^2}\right) \\ \Omega_{\mathrm{CDM}}(a) &= \Omega_{\mathrm{CDM}0} e^{-3x} \left(\frac{H_0^2}{H(x)^2}\right) \\ \Omega_{b0}(a) &= \Omega_{b0} e^{-3x} \left(\frac{H_0^2}{H(a)^2}\right) \\ \Omega_{\gamma 0}(a) &= \Omega_{\gamma 0} e^{-4x} \left(\frac{H_0^2}{H(x)^2}\right) \\ \Omega_{\nu 0}(a) &= \Omega_{\nu 0} e^{-4x} \left(\frac{H_0^2}{H(x)^2}\right) \\ \Omega_{\Lambda 0} &= \Omega_{\Lambda 0} \left(\frac{H_0^2}{H(x)^2}\right) \end{aligned} \tag{9}$$

$$\begin{aligned} \Omega_{\gamma 0} &= \frac{16\pi^3 G}{90} \cdot \frac{(k_b T_{\mathrm{CMB}0})^4}{\hbar^3 c^5 H_0^2} \\ \Omega_{\nu 0} &= N_{\mathrm{eff}} \cdot \frac{7}{8} \cdot \left(\frac{4}{3}\right)^{4/3} \cdot \Omega_{\gamma 0} \end{aligned} \tag{10}$$

2.2.2. ODEs

We solve the differential equation for $\eta(x)$, eq. 2 using an ordinary differential equation solver, with Runge-Kutta 4 RK4?as the advancement method. The initial condition is given by $\eta(x_{\mathrm{start}}) = c/\mathcal{H}(x_{\mathrm{start}})$

2.3. Results

3. Milestone II

Some introduction to milestone 2

3.1. Theory

Some theory

3.2. Methods

some methods

3.3. Results

4. Milestone III

Some introduction to milestone 3

4.1. Theory

Some theory

4.2. Methods

some methods

4.3. Results

5. Milestone IV

Some introduction to milestone 4

5.1. Theory

Some theory

5.2. Methods

some methods

5.3. Results

6. Conclusion

Some overall conclusion

References

Goodfellow, I., Bengio, Y., & Courville, A. 2016, Deep Learning (MIT Press), accessed Nov. 5 2022 at http://www.deeplearningbook.org

Pedregosa, F., Varoquaux, G., Gramfort, A., et al. 2011, Journal of Machine Learning Research, 12, 2825

Appendix A: Some appendix

Appendix B: Some appendix