Understanding the CMB TT Spectrum

Cristhian A. Calderon Cordova[1], Celia Escamilla-Rivera[2]

[1] *Universidad Nacional de Ingenieria, Peru*

[2] *Instituto de Ciencias Nucleares, Mexico*

calderonc@uni.pe [1], *celia.escamilla@nucleares.unam.mx* [2]

Abstract

The Cosmic Microwave Background (CMB) is an open window to the early Universe. To compute the CMB Spectrum we need to perturb the FLRW metric that describes a homogeneous and isotropic universe at large scales. Furthermore, at early times photons have interacted with electrons by Compton scattering, before traveling through the space-time toward us. This interaction produces a perturbation in the temperature of the photons and this can be described by the Boltzmann equa- tion. Solving these equations we can find the CMB Temperature Power Spectrum, in which their peaks are related to the shape and matter components of our universe. In this work, we will show how we can compute the quantities that describe the current percent of matter density, energy density, and shape of the current universe.

Introduction

Background Universe: Our universe is homogeneus and isotropic on large scales and it can be studied with the FLRW metric that satisfy the cosmological principle.

$$ds^2 = -dt^2 + a^2(t)\left(\frac{dr^2}{1-kr^2} + r^2 d\theta^2 + r^2 sen^2\theta d\varphi^2\right) ,$$

This metric has to satisfy Einstein Field Equations.

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu} \, . \qquad (1)$$

Then, we get the Friedmann equations.

$$H^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2}, \qquad (2)$$

$$\frac{\ddot{a}}{a} = \frac{-4\pi G}{3}(\rho + 3P). \qquad (3)$$

Friedmann equations can be written,

$$\Omega_M + \Omega_K = 1 \, , \qquad (4)$$

where

$$\Omega_M = \frac{8\pi G\rho}{3H^2}, \qquad \Omega_k = -\frac{k}{(aH)^2} \qquad (5)$$

Perturbed Universe: Our universe is far from be homogeneus and isotropic.

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + \delta g_{\mu\nu} \, . \qquad (6)$$

Fixing the Newtonian Gauge we can state the perturbed metric.

$$g_{\mu\nu} = a(\eta)^2 \begin{pmatrix} -(1-2\Phi) & 0 \\ 0 & (1+2\Phi)\delta_{ij} \end{pmatrix},$$

Inserting the metric in the Einstein Field equations we got the equation of evolution of the perturbation Φ.

$$\ddot{\Phi}_k + 3\mathcal{H}(1+w)\dot{\Phi}_k + wk^2\Phi_k = 0 \, . \qquad (7)$$

Computing the CMB Spectrum

The interaction between photons and electrons induced a perturbation in the photons temperature $\Theta = \frac{\delta T}{T}$. This interaction can be described by Boltzmann equations $df/dt = C[f]$. Then, we get

$$\dot{\Theta} + ik\mu\Theta + \dot{\Phi} - ik\mu\Phi = -\dot{\tau}[\Theta_0 - \Theta + \mu v_b] \, . \qquad (8)$$

To fit the data we set the cosmological parameters:

$$\Omega_k \leq 0.01, \; \Omega_b = 0.0492, \; \Omega_{cdm} = 0.264, \; \Omega_r = 8.051 \cdot 10^{-5}, \; \Omega_\Lambda = 0.689 \, .$$

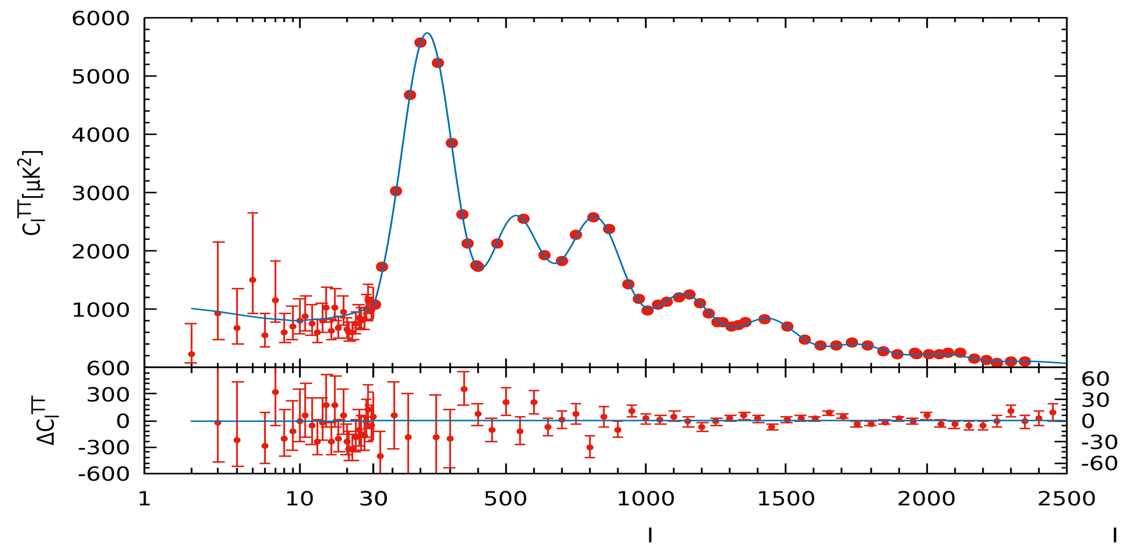

Figure 1: CMB Temperature Spectrum with data from Planck Collaboration 2018.

Understanding the CMB Spectrum

Dark Matter Neccesity:

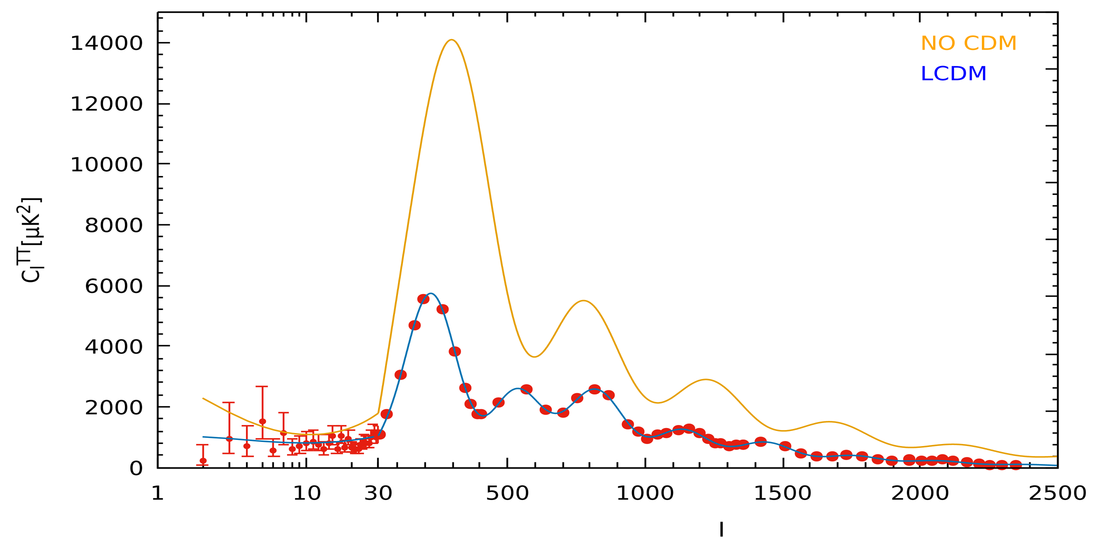

Figure 2: Comparison between ΛCDM model and a universe with no dark matter.

Shape of the universe:

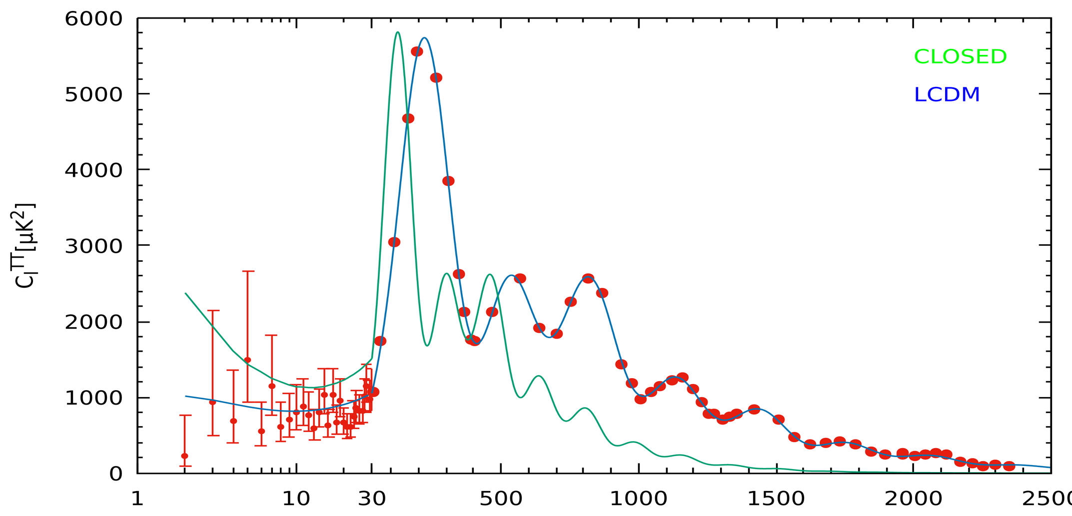

Figure 3: Closed Universe.

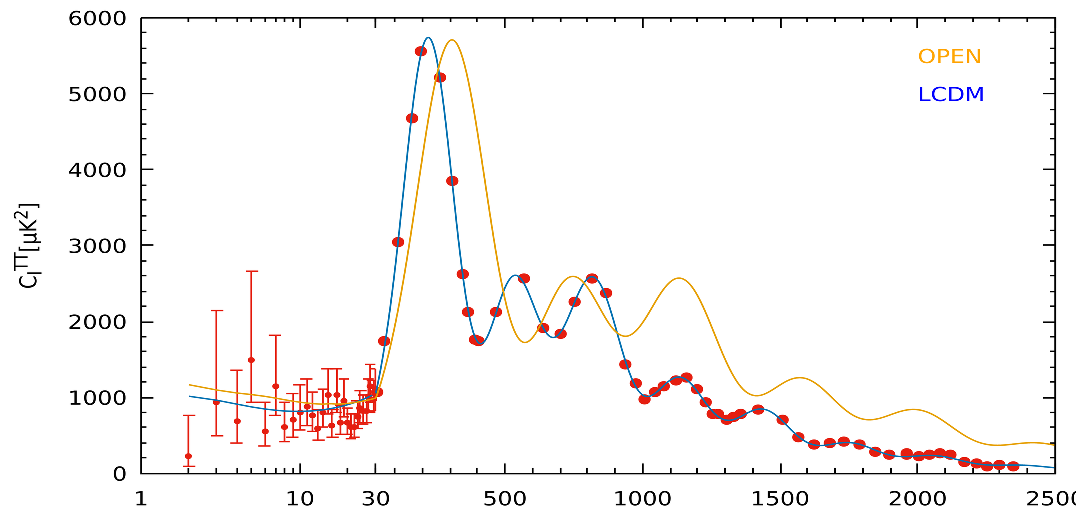

Figure 4: Open Universe.

Conclusion

Observations from the Cosmic Microwave Background set and constrain cosmological parameters.

References

Planck 2018 results. VI. Cosmological parameters. `https://arxiv.org/pdf/1807.06209`