Understanding the CMB Temperature Spectrum

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Background Universe

FLRW Metric

Our universe is homogeneus and isotropic on large scales

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

Fridman equations

This metric has to satisfy the Einstein equations, so we get

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

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

Background Universe

Fridman equations

They can be written in function of density parameter

$$\Omega_M + \Omega_K = 1\,, \tag{4}$$

where

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

Cosmological Parameters

For matter,

$$\Omega_b, \quad \Omega_{cdm}, \quad \Omega_r\,. \tag{6}$$

For curvature,

$$\Omega_k \tag{7}$$

Boltzmann equation for photons

The interaction between photons and electrons induced a perturbation in the photons temperature Θ.

$$\Theta = \frac{\delta T}{T} \,. \tag{8}$$

. This interaction can be described by Boltzmann equations,

$$\frac{df}{dt} = C[f] \,. \tag{9}$$

so we get the Boltzmann equations for photons.

$$\dot{\Theta}_k + ik\mu\Theta_k + \dot{\Phi}_k - ik\mu\Phi_k = -\dot{\tau}[\Theta_{k0} - \Theta_k + \mu v_b] \,. \tag{10}$$

Cosmological Parameters

$$\Omega_k = -0.044^{+0.018}_{0.015}, \quad \Omega_b = 0.0492 \pm 0.0003, \quad \Omega_r \propto 10^{-5}$$
$$\Omega_{cdm} = 0.264 \pm 0.002, \qquad \Omega_\Lambda = 0.689 \pm 0.006\,.$$

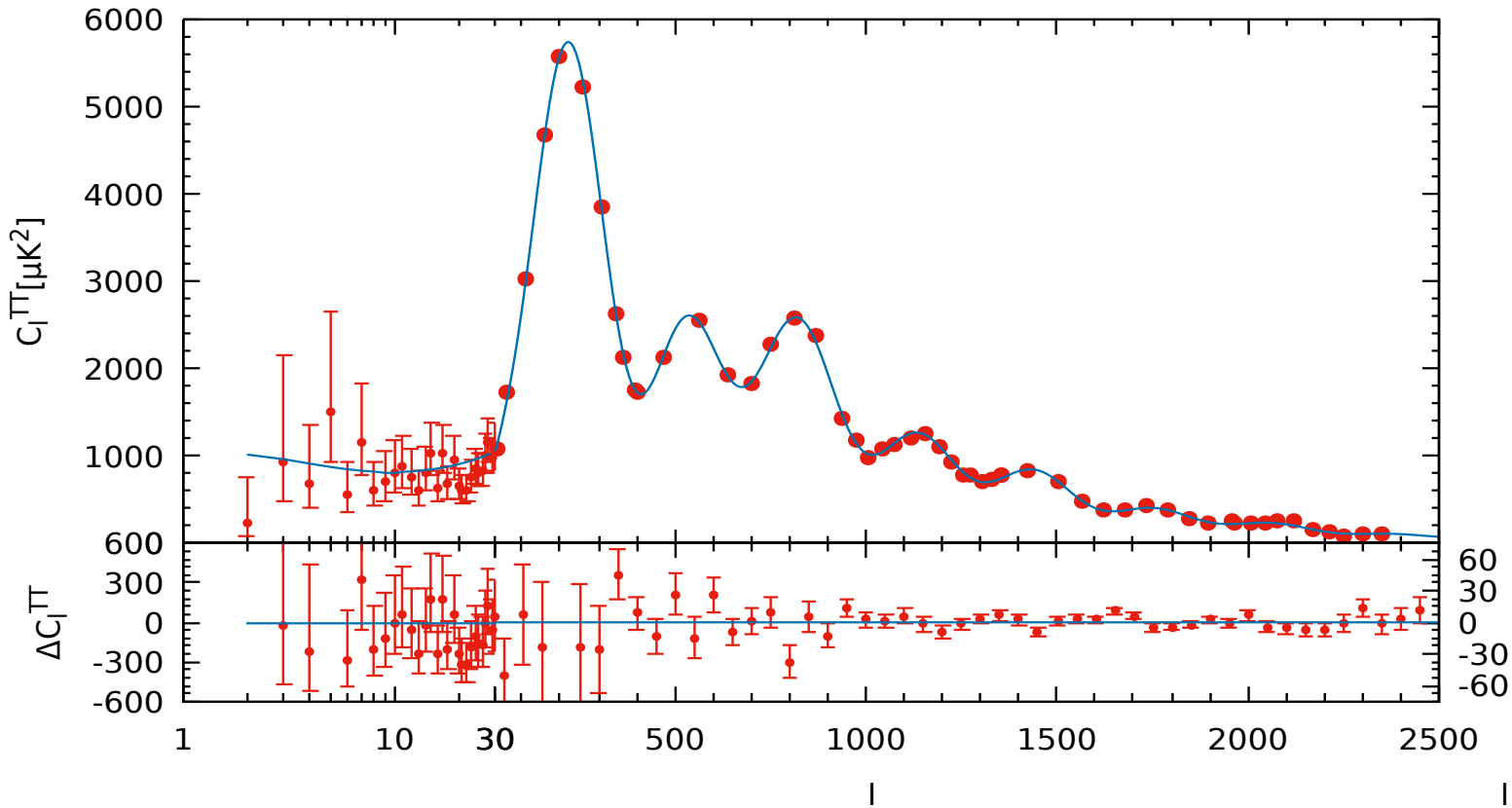

Figure 1: CMB Temperature Spectrum.

Dark Matter Neccesity

Why do we need dark matter in cosmology?
Let's look for a universe without Dark Matter.

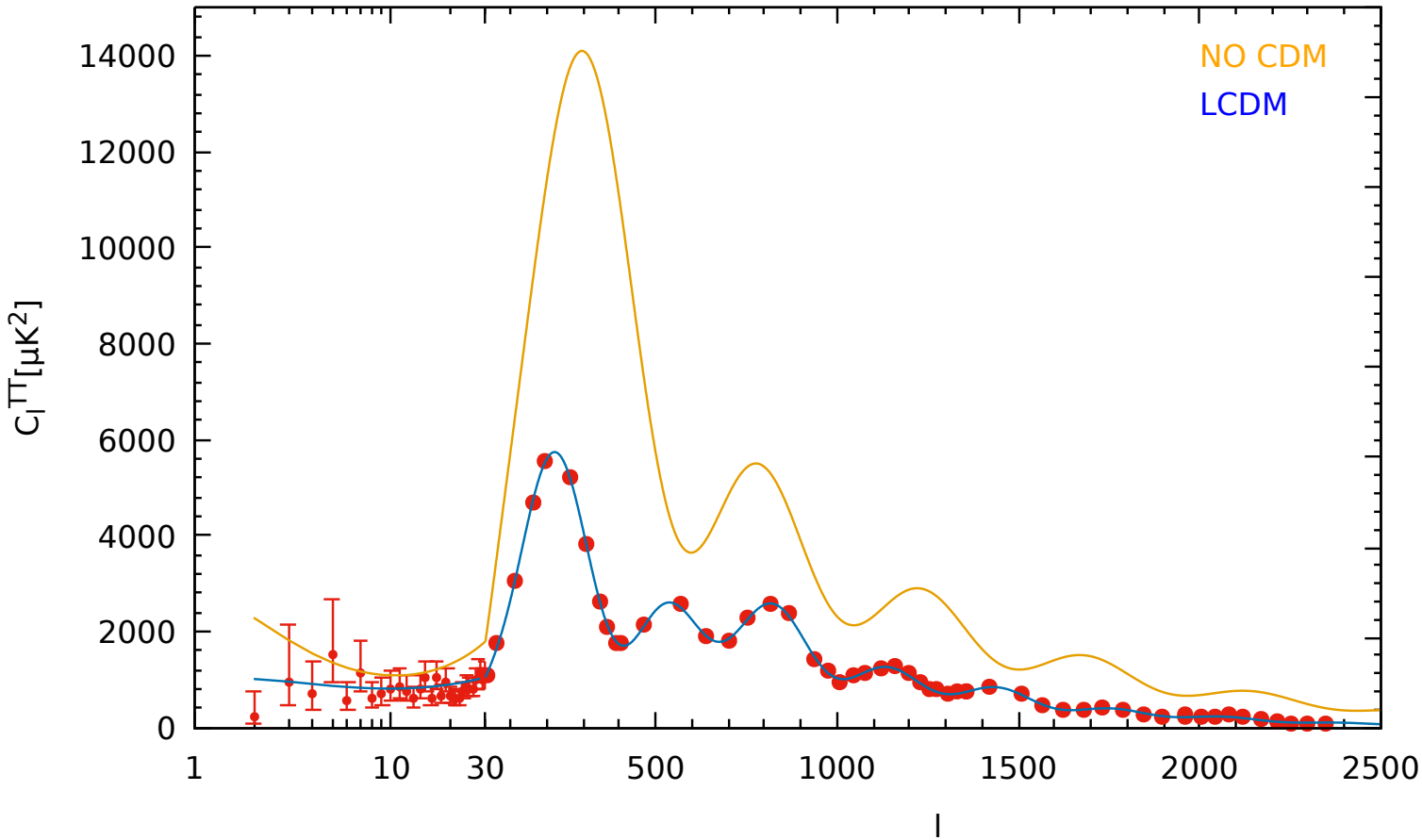

Figure 2: A universe with no Dark Matter.

Closed and open universe.

$\Omega_k = -0.3$.

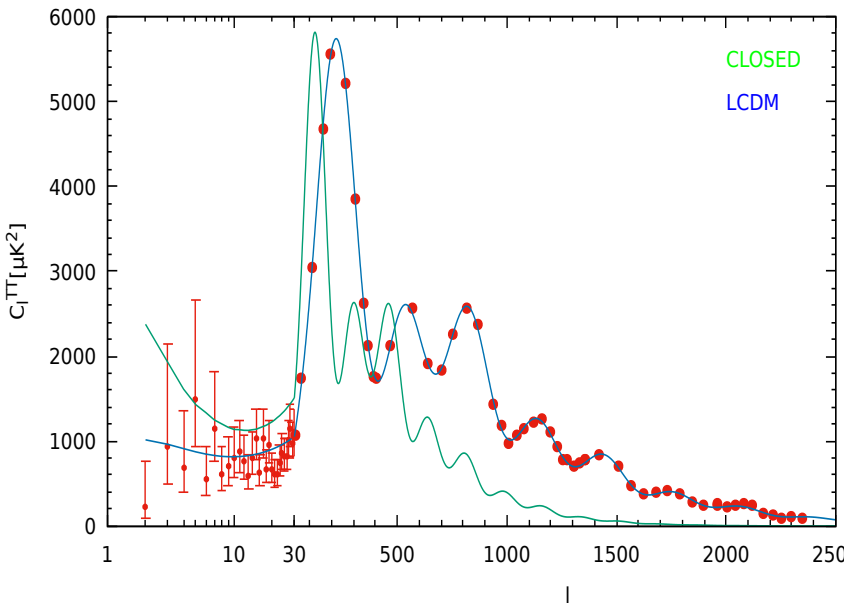

Figure 3: Closed Universe.

$\Omega_k = 0.3$.

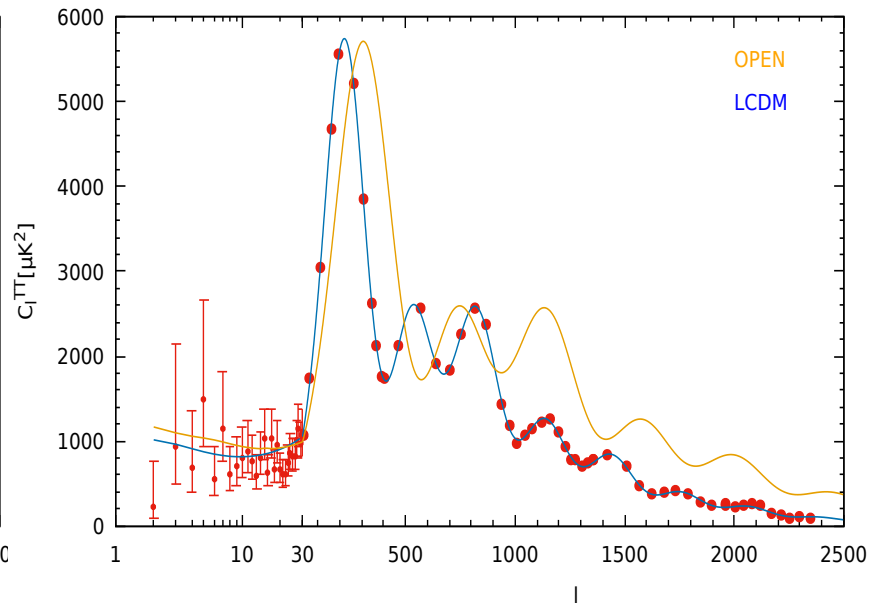

Figure 4: Open Universe.

Conclusions

1. Observations from CMB set and constrains cosmological parameters.
2. We need dark matter and dark energy.
3. Universe is flattened.