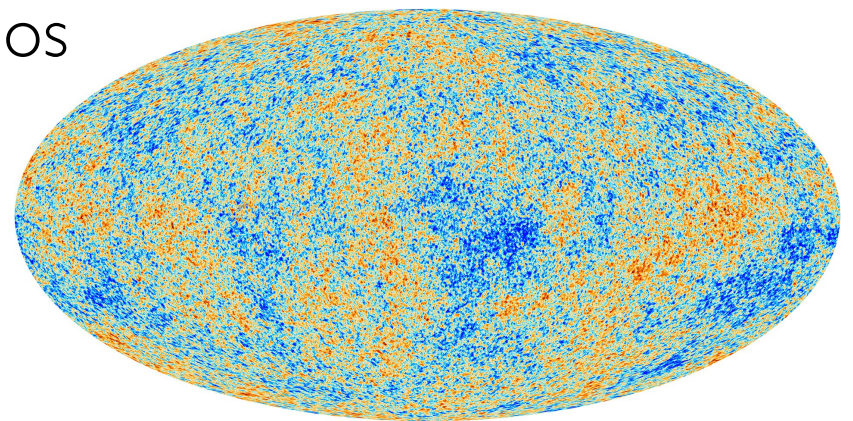
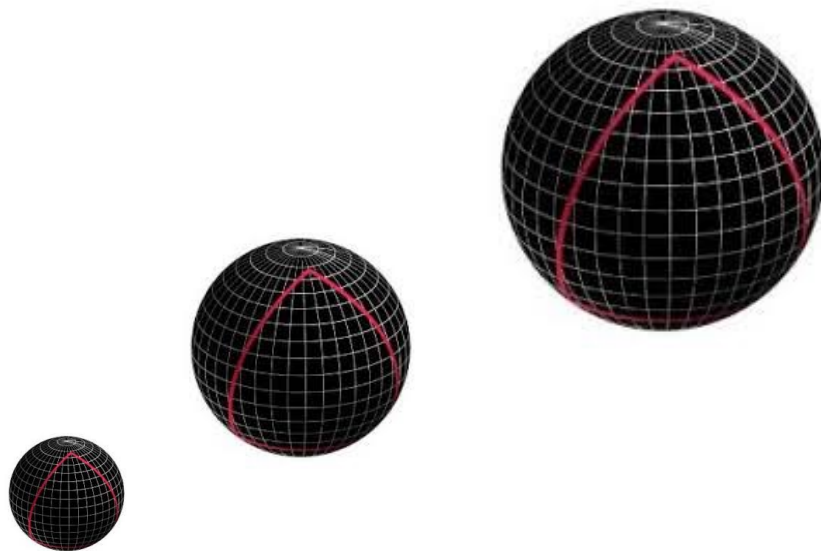

Inflation in closed FLRW model and the CMB

Brajesh Gupta

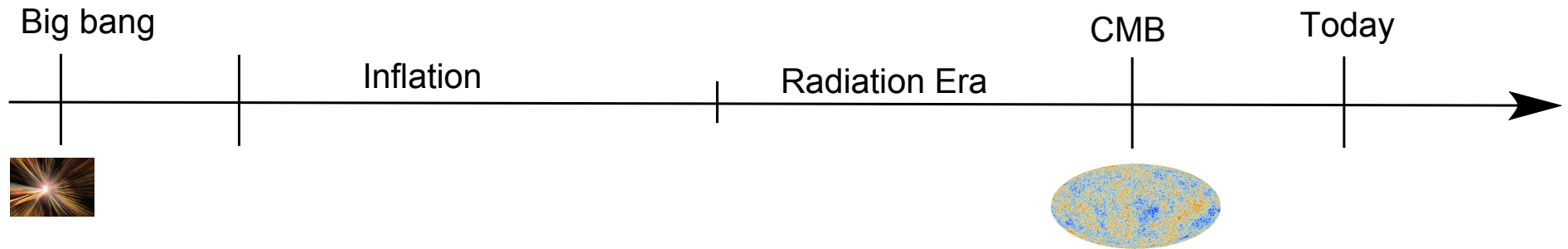
Institute for Gravitation and the Cosmos
Penn State



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GR-21, NY

based on [arXiv:1605.07556](https://arxiv.org/abs/1605.07556) with **Beatrice Bonga** and **Nelson Yokomizo**

Λ CDM + Inflation



$$H^2 = \frac{8\pi G}{3} \rho_\phi + \frac{\Omega_k}{a^2}$$

$$H^2 = H_0^2 (\Omega_m a^{-3} + \Omega_r a^{-4} + \Omega_\Lambda + \Omega_k a^{-2})$$

$$\left. \frac{\rho_k}{\rho_\phi} \right|_{\text{end inf}} \approx \left. \frac{\rho_k}{\rho_r} \right|_{\text{beg rad}},$$

$$\left. \frac{\rho_k}{\rho_r} \right|_{\text{beg rad}} \approx 10^{-57}$$

ρ_ϕ is almost constant

- ❖ Curvature affects inflation and limits the number of folds

QI: Can we find initial conditions giving enough e-folds?

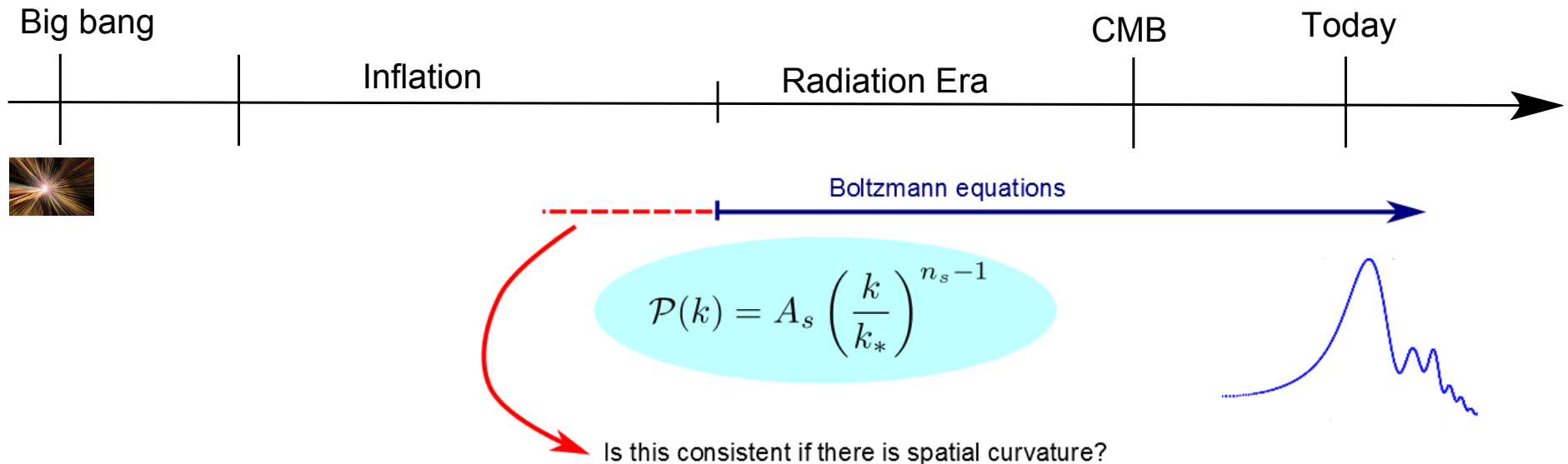
Λ CDM + Inflation: *determining parameters*

Planck

$$\Omega_K = -0.052^{+0.049}_{-0.055}$$

Planck + BAO

$$\Omega_K = 0.000^{+0.005}_{-0.005}$$



Q2: Modifications in the spectrum of primordial perturbations?

Q3: Implications for CMB? Robustness of bound on Ω_k ?

Background dynamics

Model: single scalar field with quadratic potential

Equations of motion:

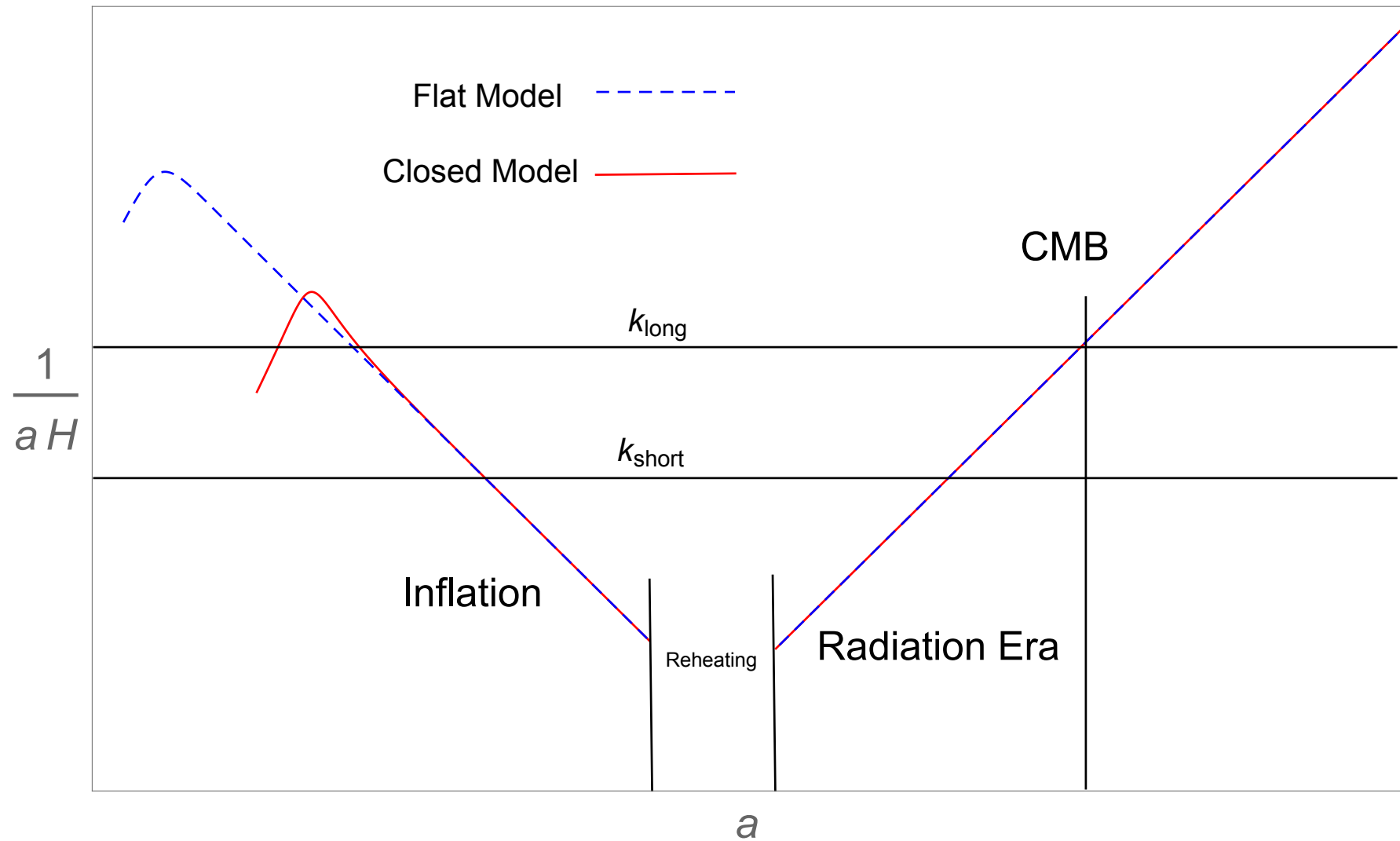
$$H^2 = \frac{8\pi G}{3} \left(\frac{\dot{\phi}^2}{2} + \frac{m^2 \phi^2}{2} \right) - \frac{1}{a^2}$$

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$

Initial conditions: Number of e-folds large enough so that all observable modes are within the horizon at the onset of inflation.

A family of solutions compatible with observations was determined.

Background dynamics



Perturbations: EOM and initial conditions

Gauge invariant variables:

$$q = \frac{\dot{\phi}}{H} \zeta = \frac{v}{a}$$

[mode expansion in hyperspherical harmonics]

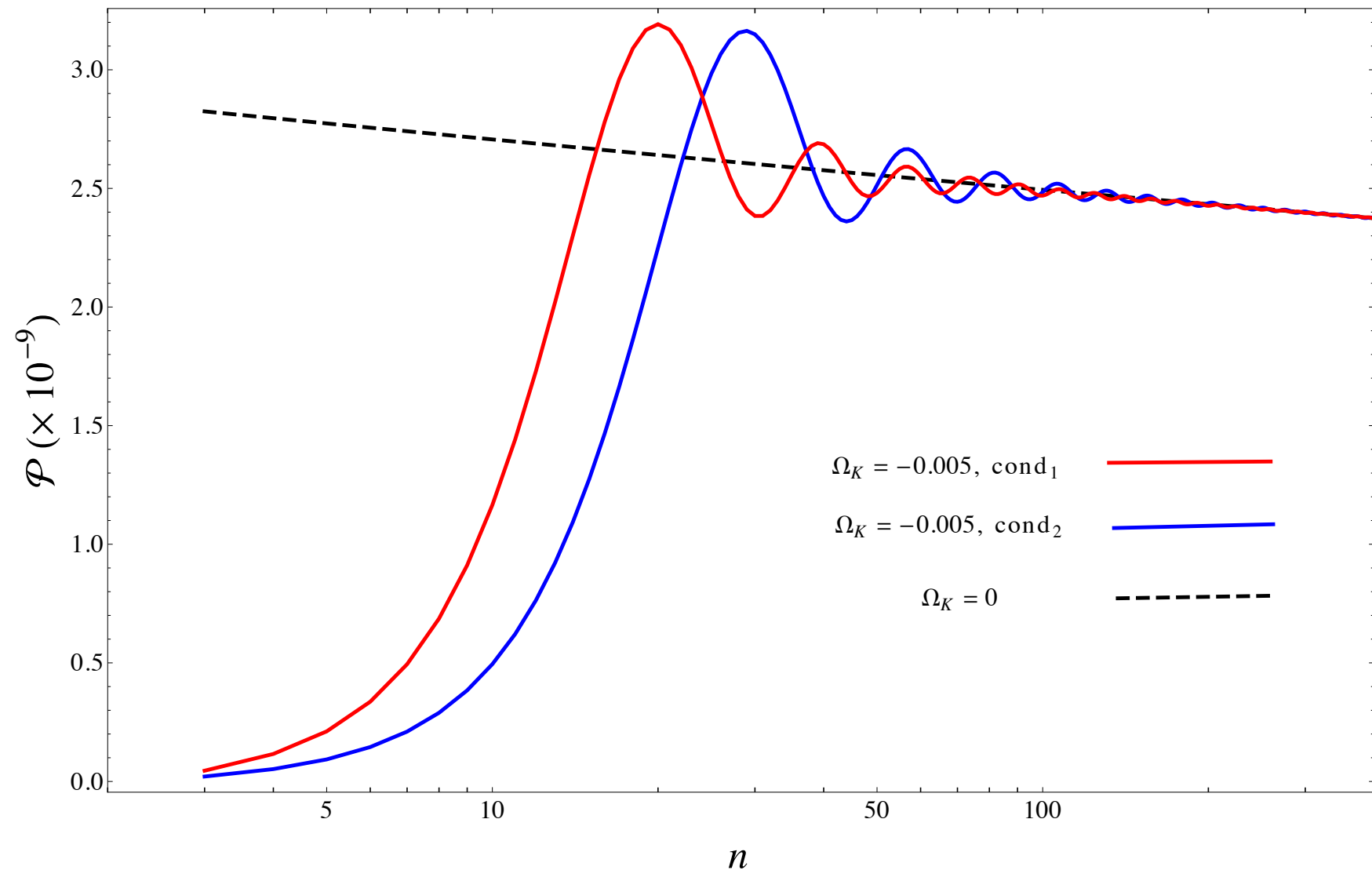
$$= \sum q_{nlm}(t) Q_{nlm}(\bar{x})$$

Equations of motion:

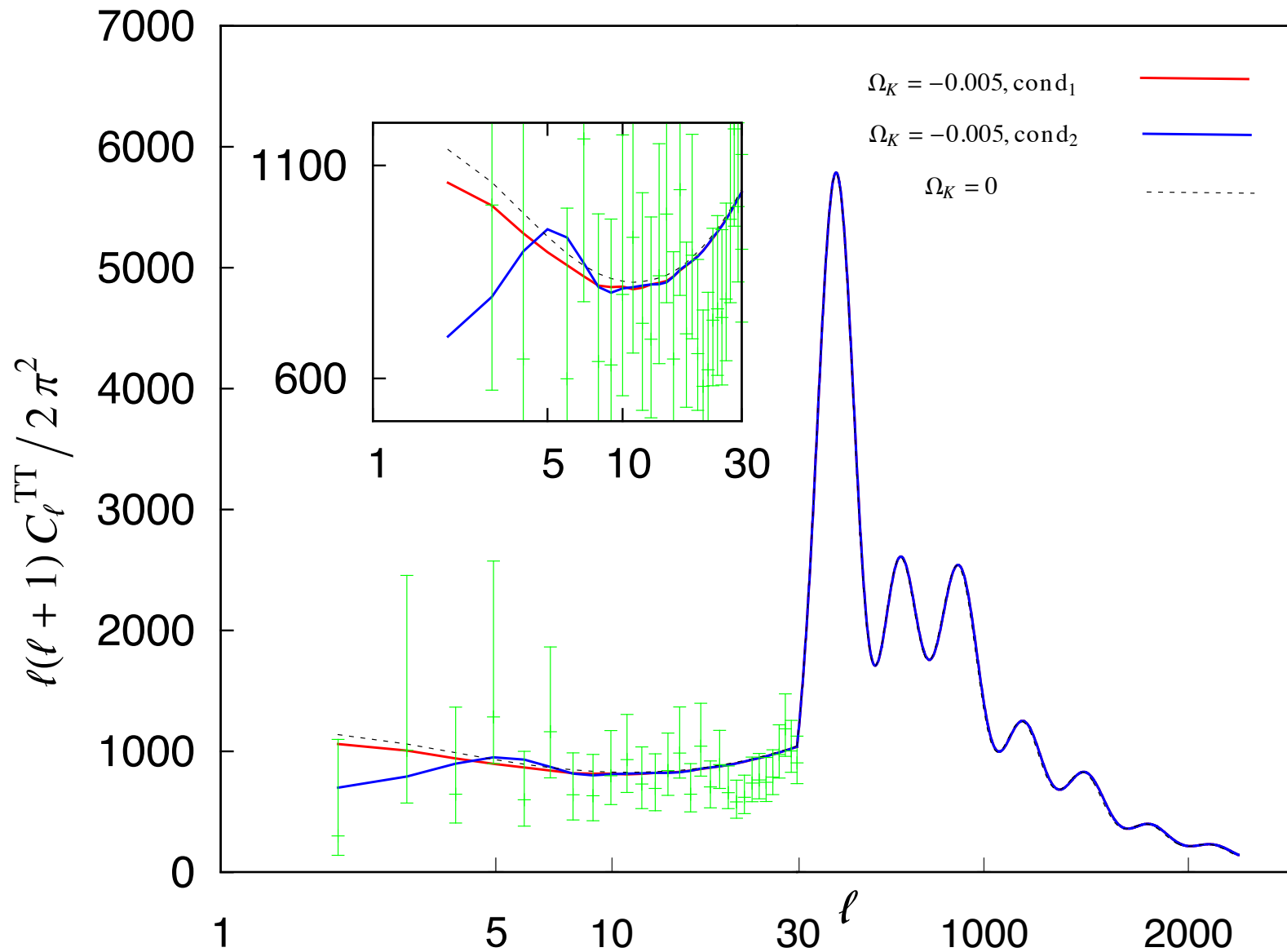
$$\ddot{q}_{nlm} + b(t, n)\dot{q}_{nlm} + c(t, n)q_{nlm} = 0$$

- ❖ Initial conditions for the perturbations set at the **onset of inflation**. **Instantaneous vacuum** is chosen (ground state at t_0).

Primordial power spectrum and CMB spectrum



CMB Spectrum



Summary

- ❖ Spectrum of primordial perturbations is modified at scale set by curvature. New features include power suppression and oscillations.
- ❖ Temperature anisotropies in the CMB suppressed at large angular scales, $\ell \lesssim 10$. For lowest ℓ 's, suppression up to $\sim 30\%$ wrt spectrum of flat model.
- ❖ Bound on Ω_K unchanged, since new features are restricted to a small region of the spectrum.

Perturbations

ADM action

$$\gamma_{ij} = \dot{\gamma}_{ij} + \delta\gamma_{ij}$$

Linear order constraints (Phase space : $\Gamma_o \times \Gamma_1$)

Canonical transformation

Gauge invariant variables (Reduced phase space : $\Gamma_o \times \tilde{\Gamma}_1$)

Quadratic action in GI variables

EOM of motion of GI variables