Cosmic Microwave Background from Late-Decaying Scalar Condensations

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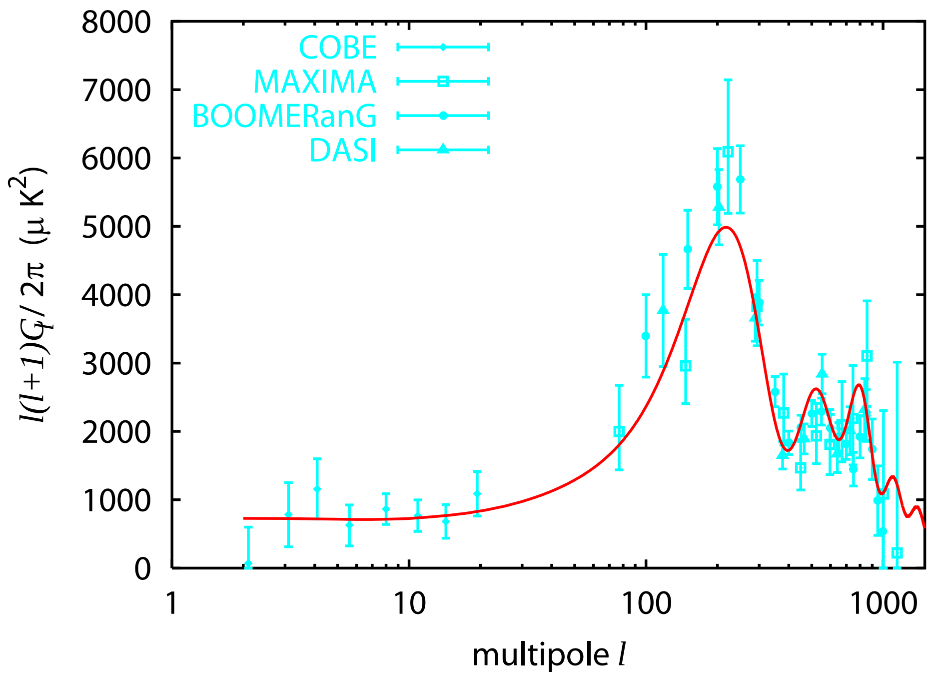
Refs.: Moroi & Takahashi, PL B522 ('01) 215 [hep-ph/0110096]
Moroi & Takahashi, hep-ph/0206026

Measurements of the anisotropy of the cosmic microwave background (CMB) is getting better and better

- Observable: CMB angular power spectrum

$$\langle \Delta T(\vec{x}, \vec{\gamma}) \Delta T(\vec{x}, \vec{\gamma}') \rangle_{\vec{x}} = \frac{1}{4\pi} \sum_l (2l+1) C_l P_l(\vec{\gamma} \cdot \vec{\gamma}')$$



C_l parameterizes fluctuation for $\theta \sim \pi/l$

Observed C_l is well explained by the scale-invariant adiabatic primordial fluctuation

$\Rightarrow$ Evidence of inflation?

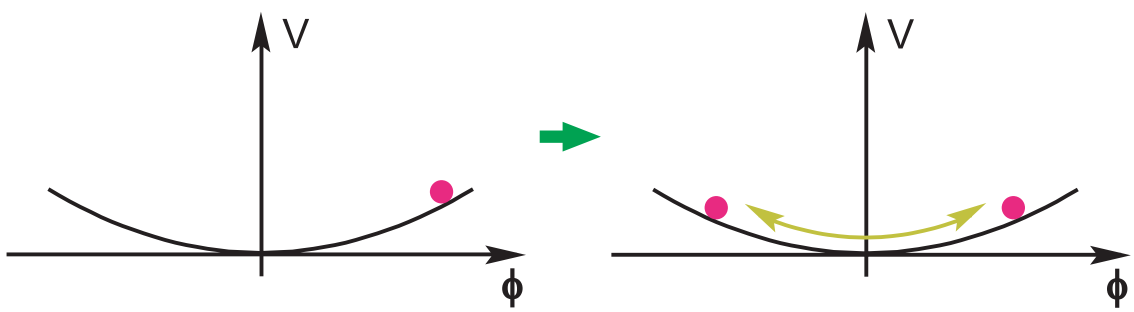
With an exotic scalar field ϕ, simple inflationary scenario may be changed

- Fluctuation of the scalar field may significantly affect the CMB anisotropy

In cosmology based on SUSY, there exist scalar fields which may once dominate the universe

- Affleck-Dine field for baryogenesis / leptogenesis
  [Affleck & Dine]
- Cosmological moduli fields
  [Coughlan et al.; TM, Yamaguchi & Yanagida]
- Right-handed sneutrino (for leptogenesis)
  [Murayama & Yanagida; Hamaguchi, Murayama & Yanagida]

Cosmological scenario with ϕ:



1. In the early universe, $\phi \neq 0$

   $\Rightarrow$ When $H \gtrsim m_\phi$, $\phi \sim \phi_{\rm init}$

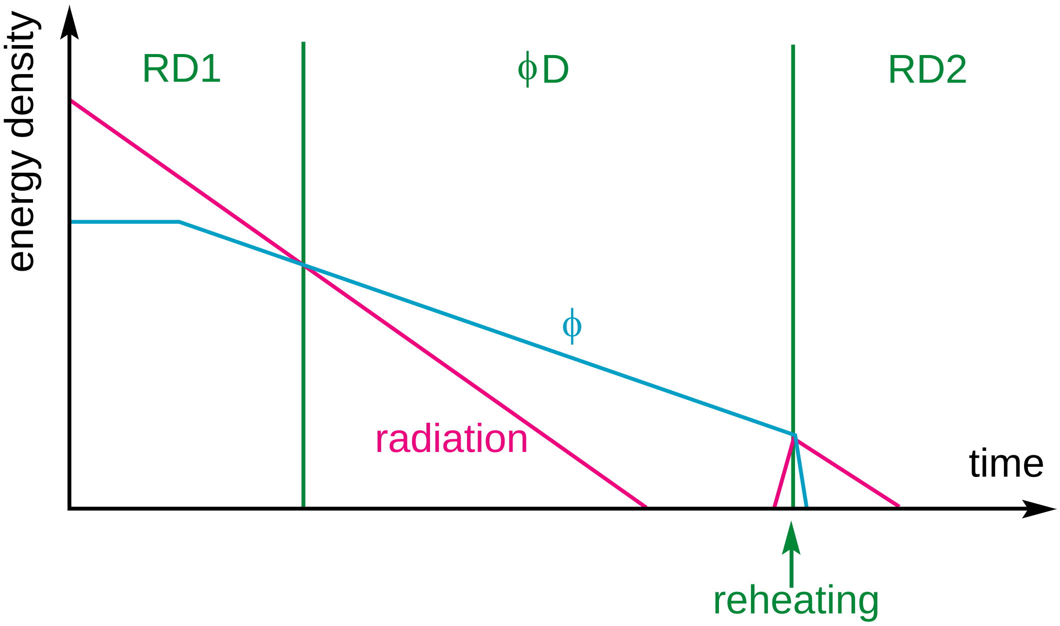
2. When $H \sim m_\phi$, ϕ starts to oscillate

   $\Rightarrow$ ρ_ϕ takes over ρ_r at some point

3. When $H \sim \Gamma_\phi$, ϕ decays and reheats the universe

Scalar field ϕ behaves as:

- Vacuum energy, if $H \gtrsim m_\phi$
- Non-relativistic matter, if $H \lesssim m_\phi$



- CMB we observe today originates to ϕ
- CMB anisotropy is affected if ϕ has a fluctuation

Origin of the primordial fluctuation of ϕ: Inflation

During inflation, (light) scalar field is fluctuated

$$\delta\phi_{\text{init}} \simeq \frac{H_{\text{inf}}}{2\pi} \quad \Rightarrow \quad S_\phi \equiv \left[\frac{\delta\rho_\phi}{\rho_\phi}\right]_{\text{init}} = \frac{2\delta\phi_{\text{init}}}{\phi_{\text{init}}}$$

$\delta\phi_{\text{init}}$: New source of cosmic density perturbations

$\Rightarrow$ Density perturbation in ϕ is converted to that of radiation when ϕ decays

$$\left[\frac{\delta\rho_\gamma}{\rho_\gamma}\right]_{\text{RD2}} = \frac{4}{9} S_\phi, \quad \cdots$$

Density perturbation from $\delta\phi_{\mathrm{init}}$ is characterized by the "entropy"

1. If baryon is also from ϕ, the baryon-to-photon ratio does not fluctuate

$$\Rightarrow \quad \frac{\delta(n_b/n_\gamma)}{(n_b/n_\gamma)} = 0$$

2. If baryon is from somewhere else, the baryon-to-photon ratio has fluctuation

$$\Rightarrow \quad \frac{\delta(n_b/n_\gamma)}{(n_b/n_\gamma)} = -\frac{9}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$\Rightarrow$ Adiabatic and isocurvature perturbations are generated with cross-correlation

In both cases, there are two <u>uncorrelated</u> sources of fluctuations

- Ψ_{inf}: From fluctuation of the inflaton field χ
- S_ϕ: From fluctuation of ϕ

Total angular power spectrum: $C_l = C_l^{(\mathrm{inf})} + C_l^{(\delta\phi)}$

- $C_l^{(\mathrm{inf})} \sim O(\Psi_{\mathrm{inf}}^2)$
- $C_l^{(\delta\phi)} \sim O(S_\phi^2)$
- Notice: $\langle \Psi_{\mathrm{inf}} S_\phi \rangle \propto \langle \delta\chi_{\mathrm{init}} \delta\phi_{\mathrm{init}} \rangle = 0$

Case 1: Purely adiabatic case

[Enqvist & Sloth; Lyth & Wands; TM & Takahashi]

Baryon and CDM are somehow produced from the decay products of ϕ

In this case, $C_l^{(\mathrm{inf})}$ and $C_l^{(\delta\phi)}$ are both from "adiabatic" fluctuations

$$\Psi_{\mathrm{inf}}(k) = \left[\frac{H_{\mathrm{inf}} \delta\chi_{\mathrm{init}}}{\dot{\chi}} \right]_{k=aH} \simeq \left[\frac{H_{\mathrm{inf}}}{2\pi} \frac{3H_{\mathrm{inf}}^2}{V'_{\mathrm{inf}}} \right]_{k=aH}$$

$$S_\phi(k) = \frac{2\delta\phi_{\mathrm{init}}(k)}{\phi_{\mathrm{init}}} \quad \text{with} \quad \delta\phi_{\mathrm{init}}(k) \simeq \left[\frac{H_{\mathrm{inf}}}{2\pi} \right]_{k=aH}$$

⇒ $C_l^{(\mathrm{inf})}$ and $C_l^{(\delta\phi)}$ have the same shape, if Ψ_{inf} and S_ϕ have the same scale-dependence

⇒ CMB anisotropy may be dominantly from $\delta\phi_{\mathrm{init}}$, if ϕ_{init} is small

Importantly, scale dependences of Ψ_{inf} and S_ϕ are in general different

In many models, $\delta\phi_{\mathrm{init}}$ has milder scale dependence than Ψ_{inf}

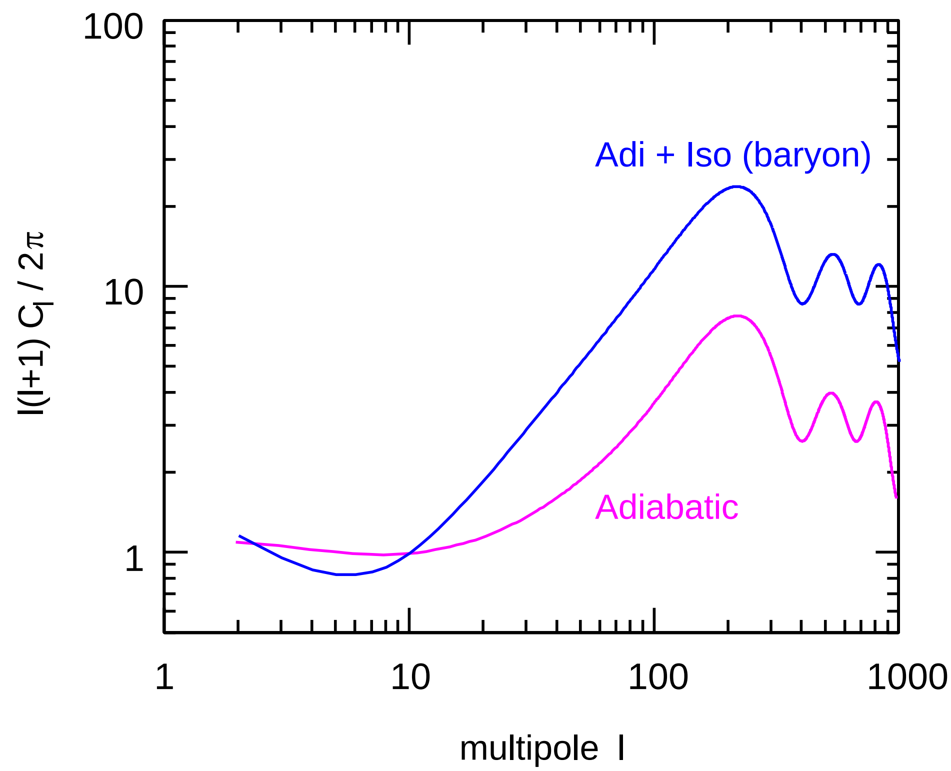
⇒ Constraints on inflaton potential can be relaxed if ϕ_{init} is small

Case 2: With extra perturbations in baryon

[TM & Takahashi]

Baryon has some different sources

CMB angular power spectrum with correlated mixture of adiabatic and isocurvature fluctuations



Total CMB angular power spectrum

$$C_l = C_l^{(\mathrm{inf})} + C_l^{(\delta\phi)}$$

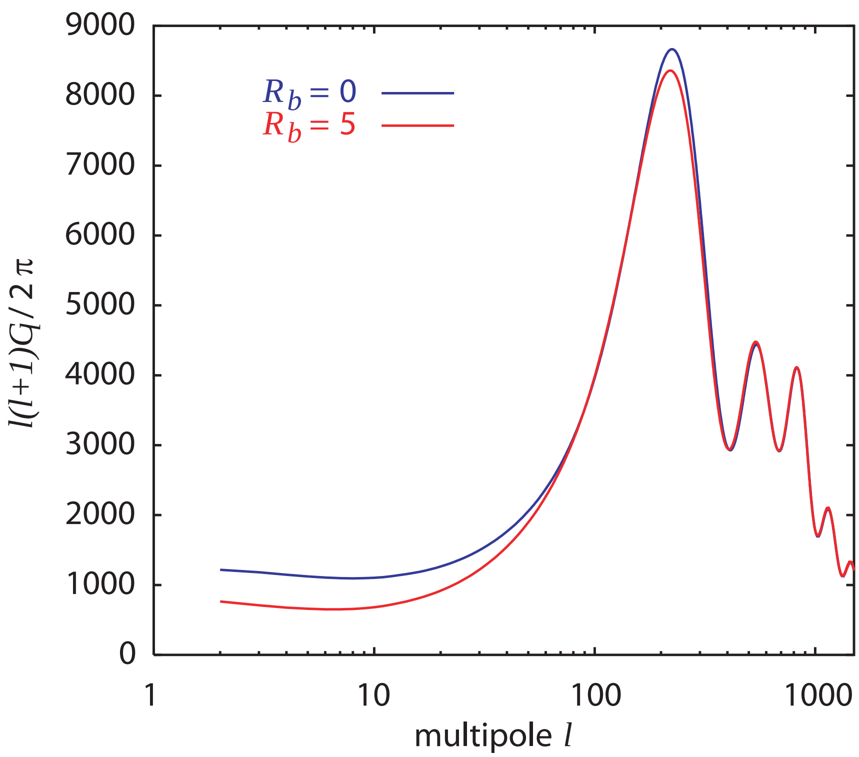
- $C_l^{(\mathrm{inf})}$: Adiabatic
- $C_l^{(\delta\phi)}$: Adiabatic + Isocurvature (with correlation)

With correlated entropy in baryonic sector

To parameterize the relative size of $\Psi_{\rm inf}$ and S_ϕ:

$$R_b \equiv \left[\frac{S_\phi}{\Psi_{\rm inf}}\right]_{\rm RD2}$$

$R_b \neq 0$: The acoustic peaks are enhanced relative to C_{10}



- MAP experiment may observe the distortion
- Too large R_b is already excluded by the present data

  χ^2 analysis with the current data $\Rightarrow R_b \lesssim 5$

Summary

Today, I discussed effects of late-time entropy production on the cosmic density perturbations

- The CMB we observe today originates to a scalar field
- The scalar field may acquire sizable amplitude fluctuation during inflation

Motivations

- Affleck-Dine baryogenesis
- Cosmological moduli fields
- Right-handed sneutrino for leptogenesis
- $\cdots$

Then, we saw

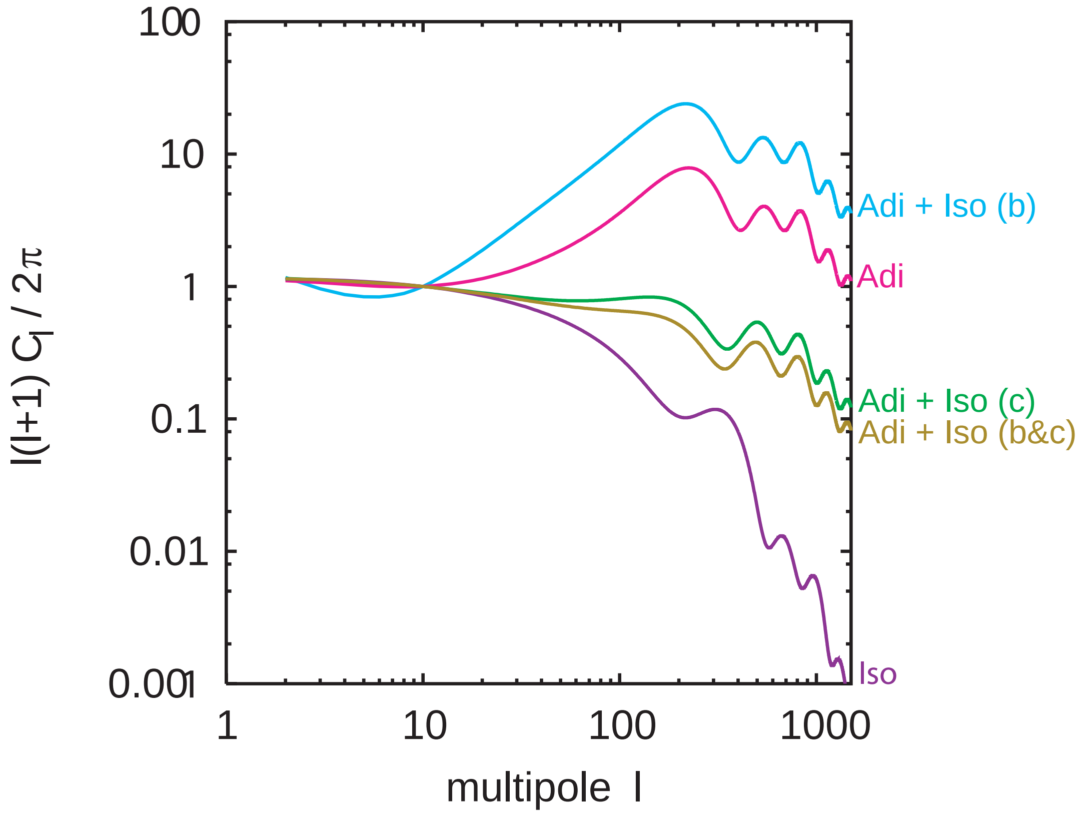
- Constraints on inflation models may change

  $\Rightarrow$ It is easier to have a scale-invariant spectrum

- There can exist correlated mixture of adiabatic and isocurvature fluctuations

  $\Rightarrow$ MAP experiment may observe a distortion of the spectrum from the adiabatic one

Shape of the angular power spectrum depends on which component has the correlated entropy



Total angular power spectrum:

$$C_l = C_l^{(\mathrm{inf})} + C_l^{(\delta\phi)}$$

Case with correlated entropy in the baryonic sector

⇒ Acoustic peaks are <u>enhanced</u> relative to the SW tail

Case with correlated entropy in the CDM sector

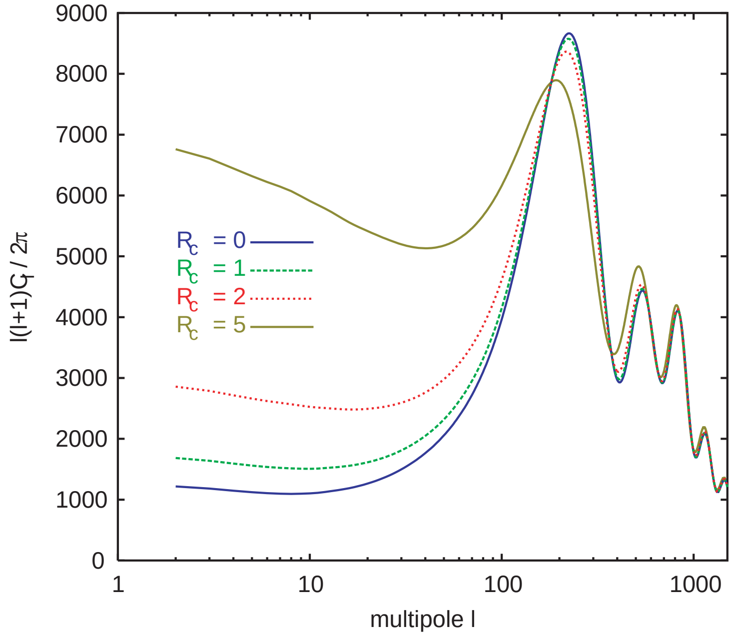
⇒ Acoustic peaks are <u>suppressed</u> relative to the SW tail

Case with the correlated entropy in the CDM sector

$$\frac{\delta(n_{\mathrm{CDM}}/n_\gamma)}{(n_{\mathrm{CDM}}/n_\gamma)} = -\frac{9}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

To parameterize the relative size of Ψ_{inf} and S_ϕ:

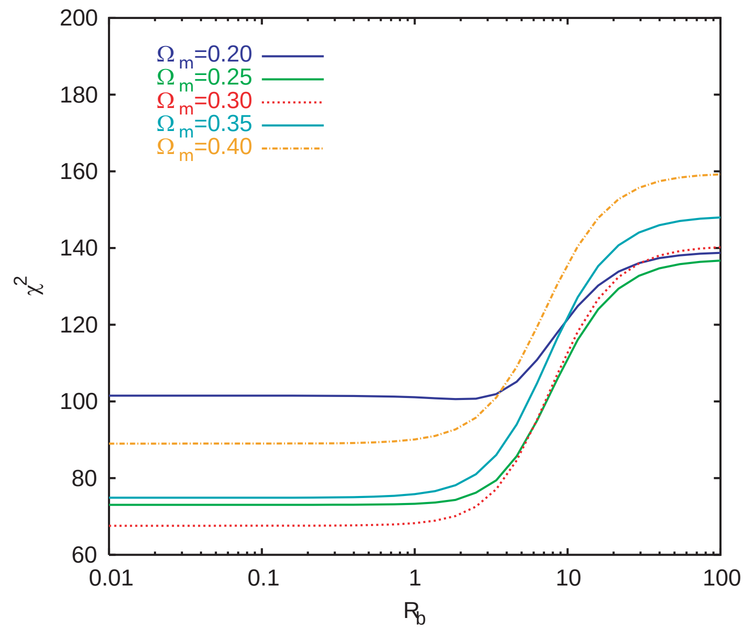
$$R_c \equiv \left[\frac{S_\phi}{\Psi_{\mathrm{inf}}}\right]_{\mathrm{RD2}}$$



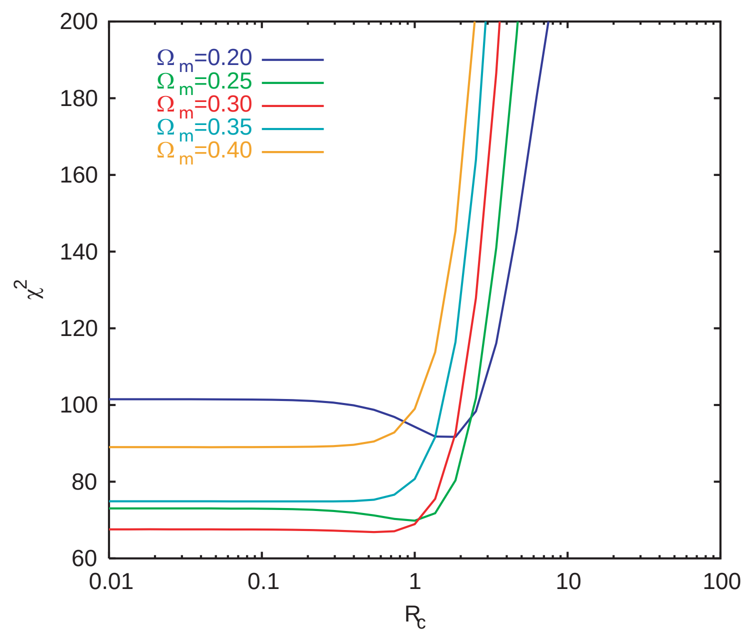
Constraint on the R_c-parameter

- $R_c \gtrsim 2$ is excluded

χ^2 as a function of R_b



χ^2 as a function of R_c



64 d.o.f. $\Rightarrow$ $\chi^2 < 84$ for 95 % C.L.

With uncorrelated and uncorrelated isocurvature modes

$$C_l = C_l^{(\mathrm{adi})} + C_l^{(\delta\phi)} + C_l^{(\mathrm{iso})}$$

- Correlated baryonic isocurvature fluctuation pushes up the acoustic peaks
- Uncorrelated isocurvature mode suppresses heights of the acoustic peaks

⇒ C_l may be consistent with the present observations without $C_l^{(\mathrm{adi})}$

Define

$$R_b \equiv \left[S_{b\gamma}^{(\delta\phi)} / \Psi^{(\mathrm{inf})} \right]_{\mathrm{RD2}}, \qquad \alpha_b = \left[S_{b\gamma}^{(\mathrm{uncorr})} / \Psi^{(\mathrm{inf})} \right]_{\mathrm{RD2}}$$

Then, we obtain constraint on the R_b vs. α_b plane