Alleviation of anomalies from the non-oscillatory vacuum in Loop Quantum Cosmology

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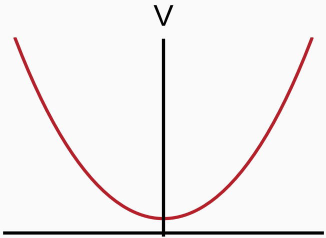
SFRH/BD/143525/2019

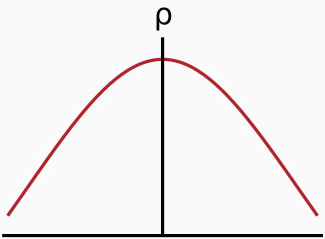
Cosmological perturbations in Loop Quantum Cosmology

Loop Quantum Cosmology

- Based on Loop Quantum Gravity,
- Big-bang singularity $\longrightarrow$ quantum bounce,



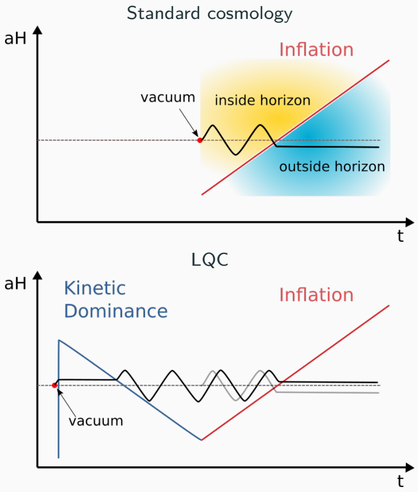
Volume has positive minimum.



Energy density has finite maximum.

Well defined pre-inflationary dynamics $\longrightarrow$ excite perturbations

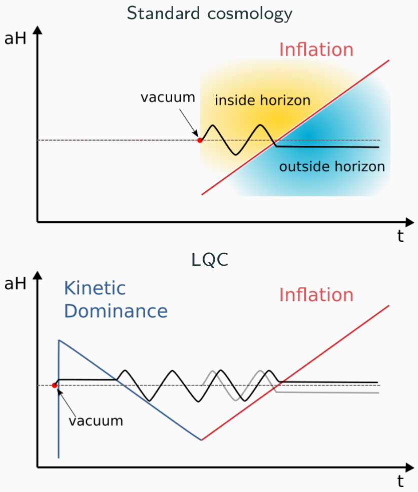
Cosmological perturbations



Loop Quantum Cosmology:

- Different background affects dynamics of perturbations,

Cosmological perturbations

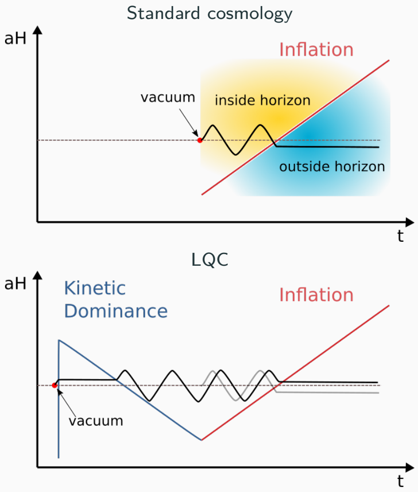


Loop Quantum Cosmology:

- Different background affects dynamics of perturbations,
- $+$ corrections to equations of motion,

$$u_k'' + \omega_k^2(t) u_k = 0.$$

Cosmological perturbations



Loop Quantum Cosmology:

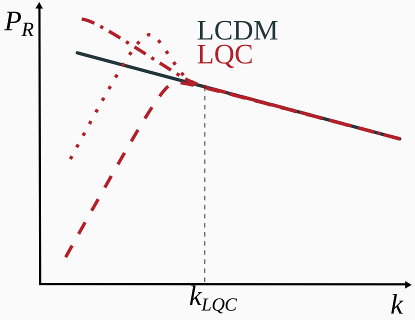
- Different background affects dynamics of perturbations,
- $+$ corrections to equations of motion,

$$u_k'' + \omega_k^2(t) u_k = 0.$$

- Affects primordial power spectrum.

Primordial power spectrum of LQC

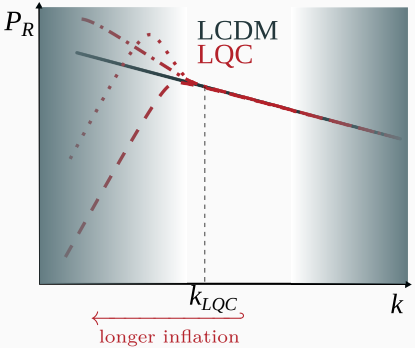
- Shape depends on **vacuum**
- Departs from near-scale invariance for $k \leq k_{LQC}$
- LQC affects *infrared* spectrum



Primordial power spectrum of LQC

- Shape depends on **vacuum**
- Departs from near-scale invariance for $k \leq k_{LQC}$
- LQC affects *infrared* spectrum
- Effects in *observable window*?

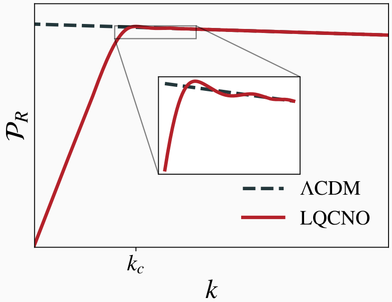
  More inflation $\longrightarrow$ lower k_{LQC}



Too much inflation $\Rightarrow$ no visible effects

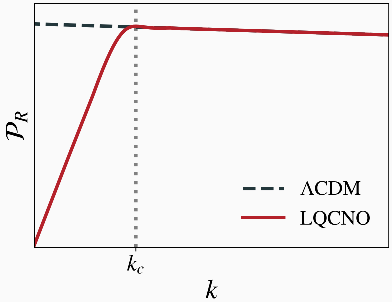
Vacuum choice

Non-Oscillatory (NO) vacuum



- Minimize oscillations *in time*,
- Motivation: oscillations spoil effects of the bounce,
- Most PPS from LQC have power suppression in IR.

Non-Oscillatory (NO) vacuum



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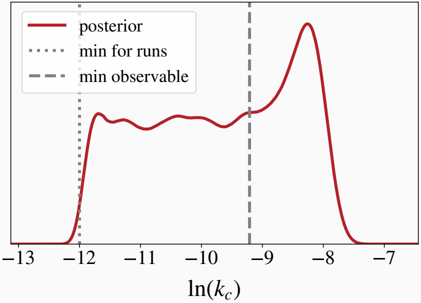
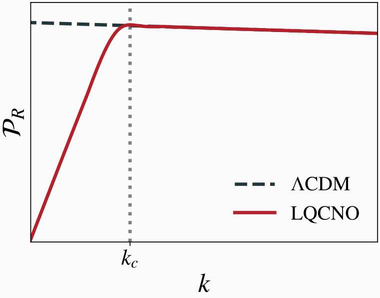
Parametrize:

- Fixed slope of suppression and amplitude of oscillations.
- $k_c \longleftrightarrow$ e-folds

Bayesian Analysis

Posterior of $\ln(k_c)$





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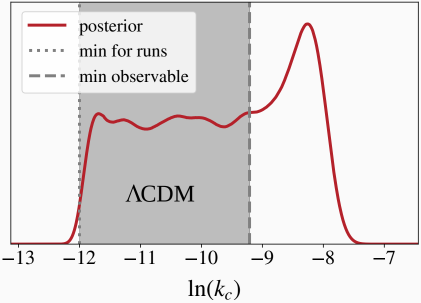

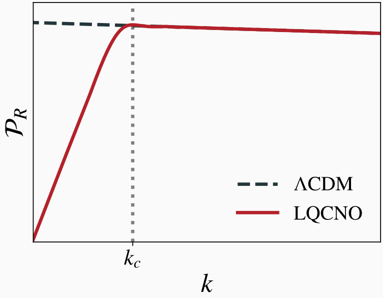

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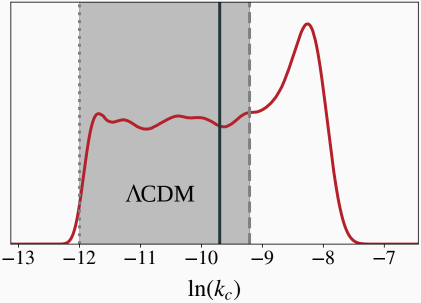

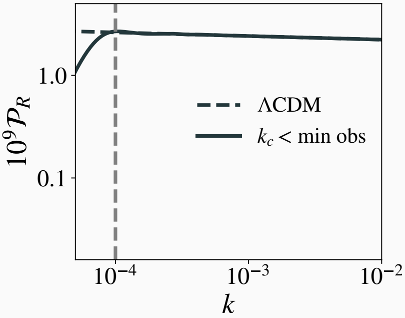

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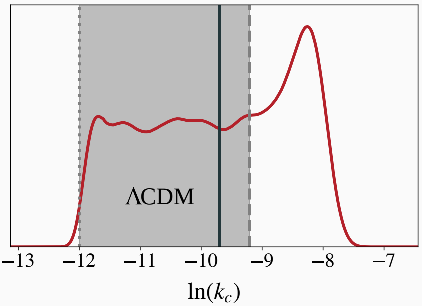

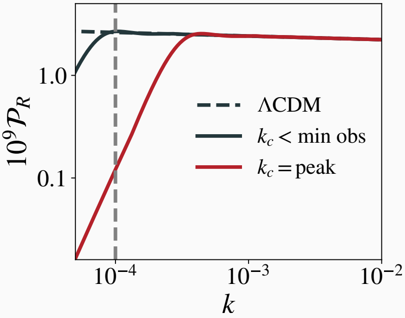

Data prefers some observable effects.

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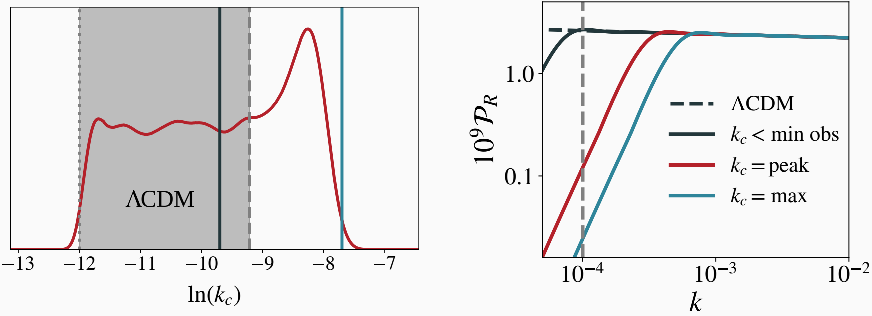

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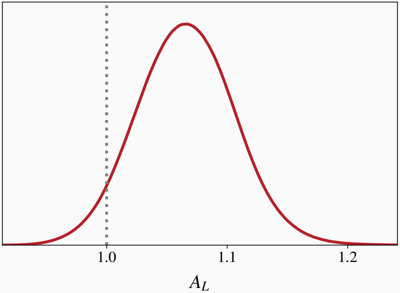
Alleviation of Anomalies

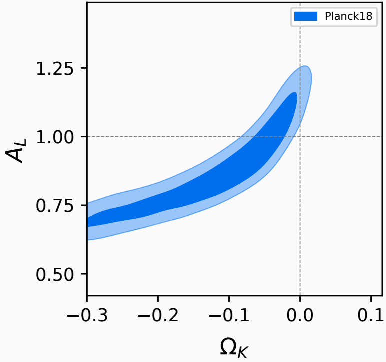
Lensing anomaly

ΛCDM



- Phenomenological parameter A_L: CMB is more/less lensed.
- Consistency check: ΛCDM+A_L
- $A_L > 1$ at $\sim 2\sigma$,

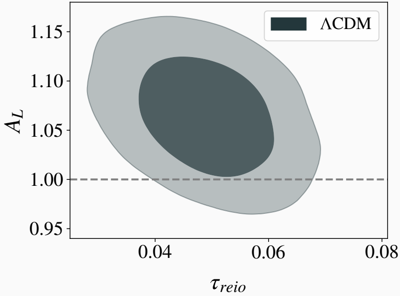
ΛCDM



- Phenomenological parameter A_L: CMB is more/less lensed.
- Consistency check: ΛCDM+A_L
- $A_L > 1$ at $\sim 2\sigma$,
- A_L consistent with 1 if $\Omega_k < 0$
  $\longrightarrow$ inconsistencies with BAO,
  $\longrightarrow$ crisis in cosmology?

[Di Valentino et al. *Nat Astron* **4**, 196–203 (2020)]

Lensing anomaly



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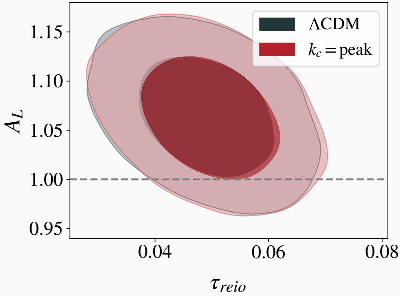
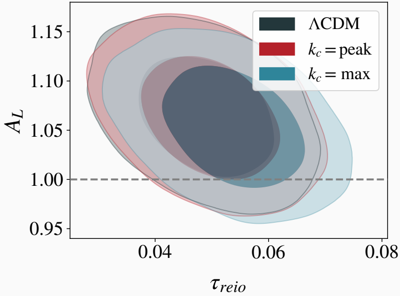


- Some alleviation is possible,
- Better for higher k_c,

Lensing anomaly



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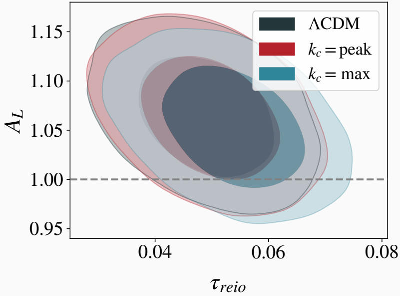
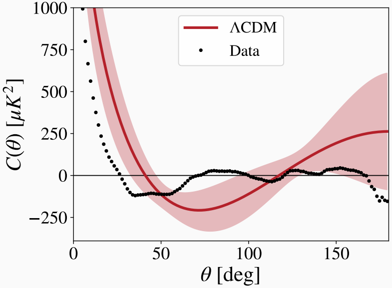


- Some alleviation is possible,
- Better for higher k_c,
- Constraints on τ_{reio} will constrain LQC.

Power suppression anomaly

$C(\theta)$ is remarkably consistent with 0 for large angles.

$$S_{1/2} = \int_{-1/2}^{1} C^2(\theta) d(\cos\theta)$$



ΛCDM: $S_{1/2} \sim 35000$

Data: $S_{1/2} \sim 1200$

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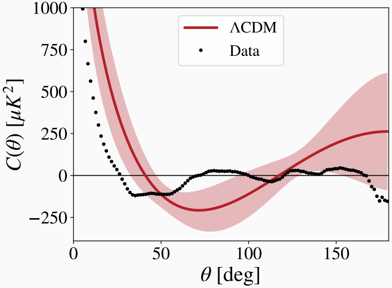

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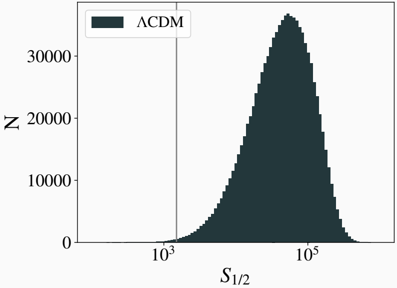
$\hookrightarrow$ Unlikely realizations of ΛCDM Universe.

How unlikely?

Power suppression anomaly

Consider $S_{1/2}$ distribution due to cosmic variance.

p-value = fraction of realizations with $S_{1/2} \leq$ observed.



	p-value
ΛCDM	$\sim 0.1\%$

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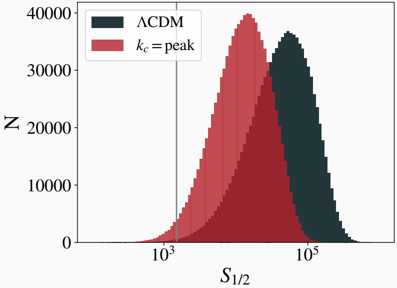

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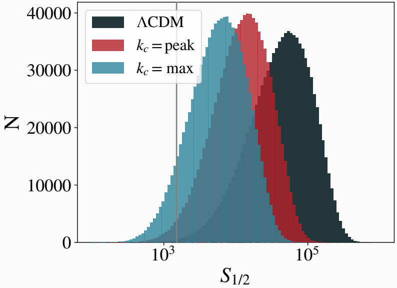
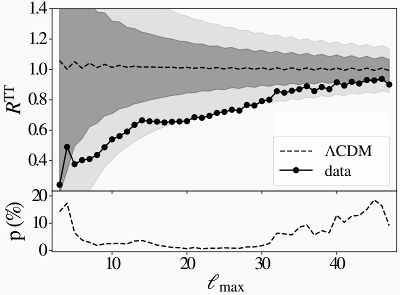


	p-value
ΛCDM	$\sim 0.1\%$
$k_c =$ peak	$\sim 2\%$
$k_c =$ max	$\sim 5\%$

Parity asymmetry anomaly

$R^{TT} < 1$: more power in odd ℓ up to ℓ_{max}



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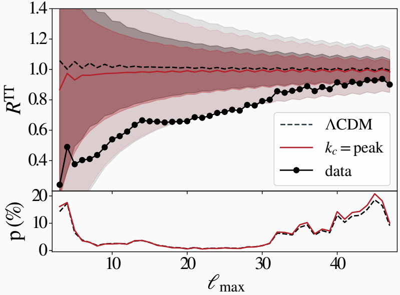

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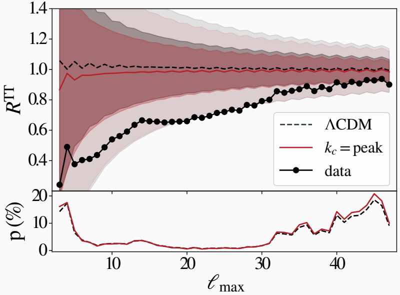

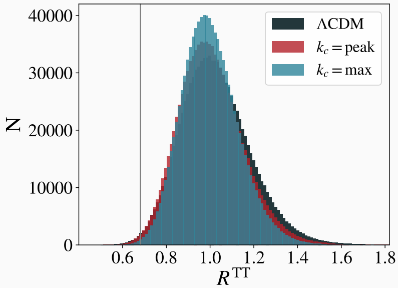

Conclusions

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Thank you for your attention