

# STATES OF LOW ENERGY AND ALLEVIATION OF ANOMALIES IN LOOP QUANTUM COSMOLOGY

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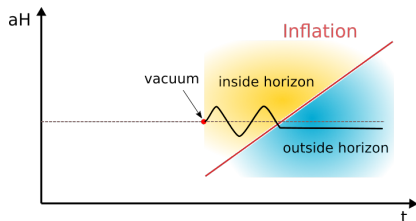
LOOPS22, Lyon, July 19th 2022



# COSMOLOGICAL PERTURBATIONS

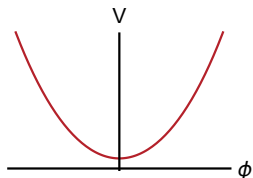
Standard cosmology:

- Theory  $\longleftrightarrow$  observations (CMB),
  - During inflation modes freeze once they cross out of the horizon
  - Cross back in after inflation ends
- $\Rightarrow$  What we see in the CMB is generated in the very early universe

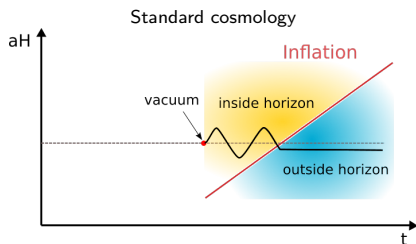


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Loop Quantum Cosmology:

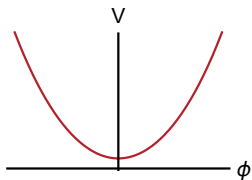


- Bounce kinetically dominated
- Inflation potentially dominated

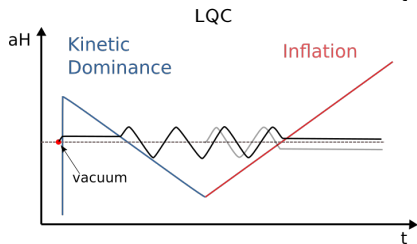
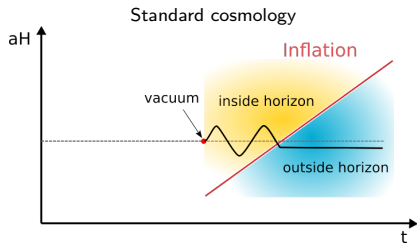


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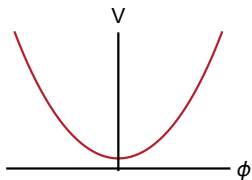


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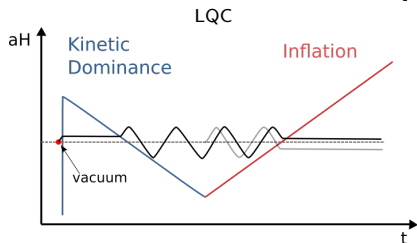
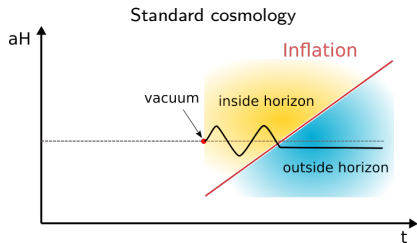
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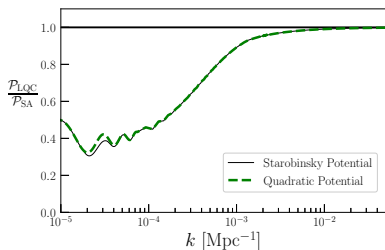
→ **Vacuum?**



# ALLEVIATION OF ANOMALIES

[ASHTEKAR ET AL., FRONT.ASTRON.SPACE SCI. **8** (2021) 76]

- Primordial Power Spectrum (PPS) is affected by quantization  
Ashtekar et al.:



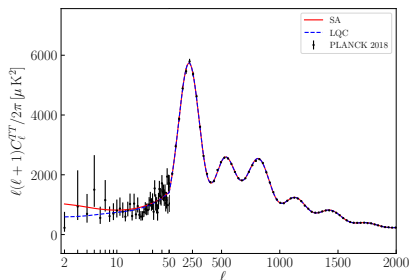
- $k \lesssim k_0$ : feel differences in curvature close to bounce
- $k \gg k_0$ : wavelength is much smaller than curvature radius close to bounce, not affected

Plots: SA corresponds to  $\Lambda$ CDM

# ALLEVIATION OF ANOMALIES

[ASHTEKAR ET AL., FRONT.ASTRON.SPACE SCI. **8** (2021) 76]

- Power suppression anomaly



- For  $\ell \lesssim 30$  observed power is lower than  $\Lambda$ CDM prediction
- LQC suppresses  $\ell \lesssim 30$  **only**
- In terms of quantity  $S_{1/2}$ :

$$S_{1/2}^{\Lambda\text{CDM}} \sim 35 \times \text{observed}$$

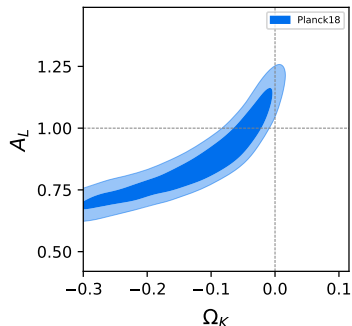
$$S_{1/2}^{\text{LQC}} \sim 12 \times \text{observed}$$

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# ALLEVIATION OF ANOMALIES

[ASHTEKAR ET AL., FRONT.ASTRON.SPACE SCI. **8** (2021) 76]

- Lensing amplitude ( $A_L$ ) anomaly [Di Valentino, et al., Nature Astron. **4** (2019) 2]



- CMB is lensed due to inhomogeneities
- Consistency check: introduce new parameter  $A_L$  ( $= 1$  in  $\Lambda$ CDM)
- $\Lambda$ CDM:
  - $A_L > 1$  at  $1.9\sigma$  level
  - Need  $\Omega_k < 0$  to maintain  $A_L = 1 \rightarrow$  inconsistencies with BAO  $\rightarrow$  crisis in cosmology?

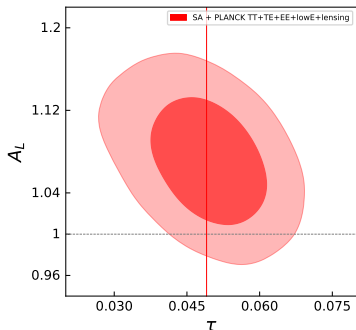
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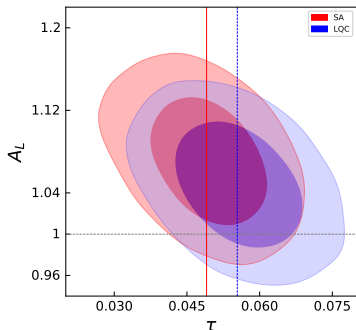


Plots: SA =  $\Lambda$ CDM

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- LQC:

- $A_L = 1$  within  $1\sigma$  region
- $\tau$  best fit affected by  $\sim 10\%$   
(in  $\Lambda$ CDM relative error  $\sim 13\%$ )

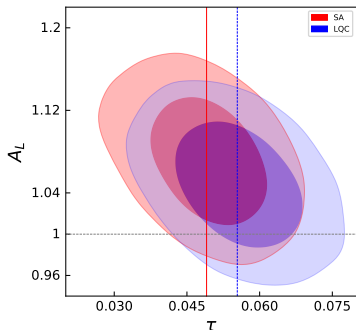
Note: Significance of each is low,  
together imply the observed universe  
emerges once in  $\sim 10^6$  realizations

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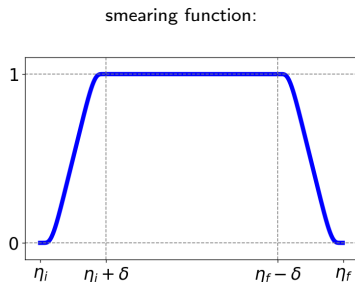
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→ **Prevalent in LQC?**

Plots: SA =  $\Lambda$ CDM

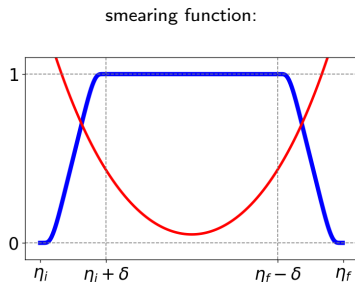
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- States of Low Energy (SLEs)
  - Minimize smeared energy density
  - Hadamard
  - Allow to disentangle effects from KD and from bounce



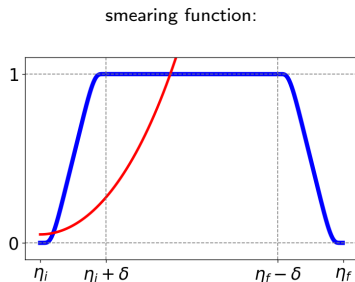
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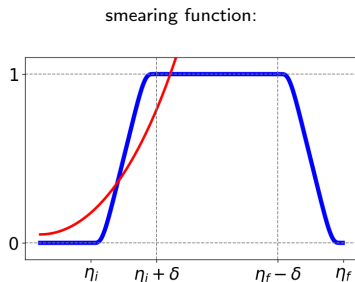
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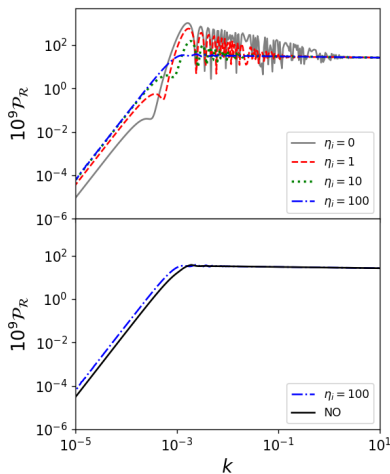
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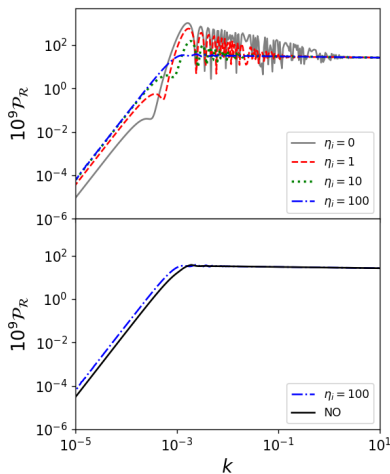
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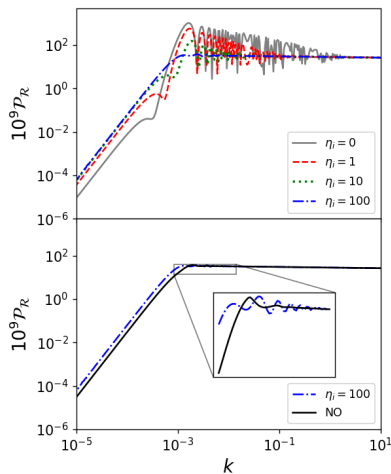
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  - Allow to disentangle effects from KD and from bounce
  - Reproduce NO for particular smearing function
- Non-Oscillatory (NO)
  - Minimize oscillations of perturbations **in time** from bounce to onset of inflation



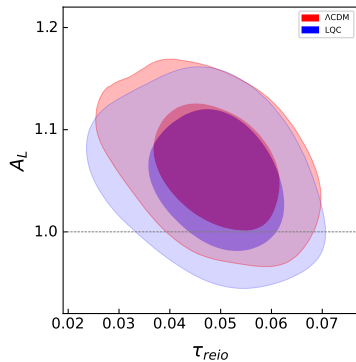
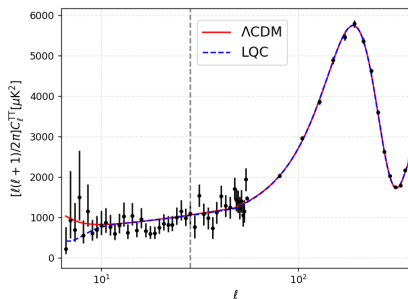
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# SLEs: ALLEVIATION OF ANOMALIES

- NO-like [PRELIMINARY]



# SUMMARY AND OUTLOOK

- Effects of LQC may help alleviate anomalies
  - Power suppression
  - Lensing amplitude
- Prevalent result of LQC?
  - PPS with suppression ( $\checkmark?$ )
  - PPS with enhancement/ oscillations?
- Future work:
  - perform MCMC analysis for different vacuum choices
  - leave parameters of quantization free
  - compare quantization prescriptions

Thank you for your attention