LQC and CMB Anomalies: A controversy with Scientific American

Ivan Agullo

Louisiana State University

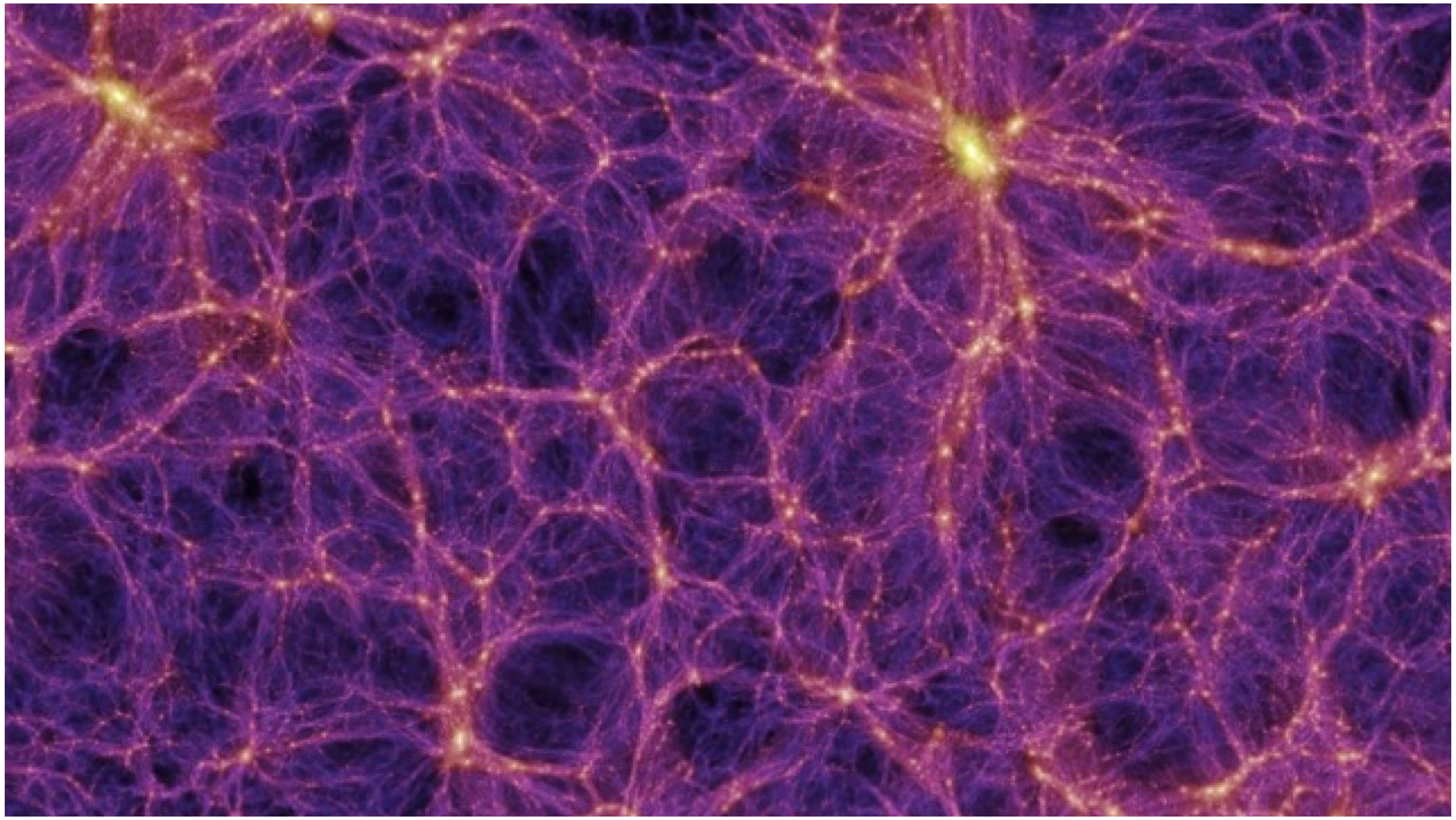
ILQGS, Oct 3rd 2023

Some of my pre-LQC work on Primordial Cosmology

Mirror mirror on the wall, which is the prettiest scientific idea of them all?

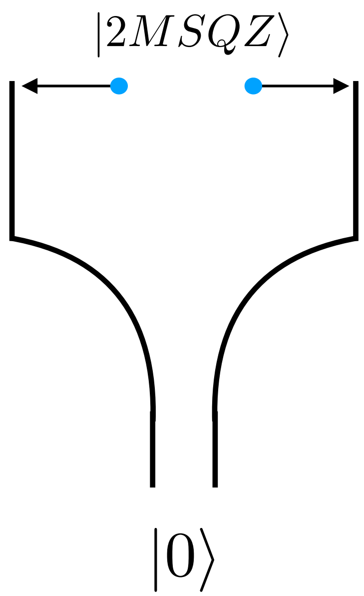
Certainly, one of the prettiest is:

The large-scale structure of the universe could have been originated from vacuum fluctuations



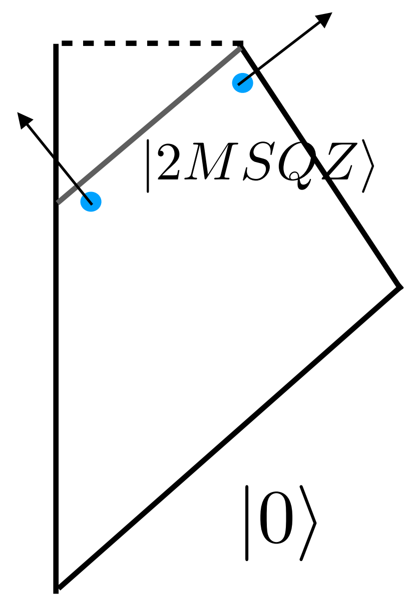
Vacuum fluctuations versus The Cosmic Expansion

(Two mode squeezed vacuum)



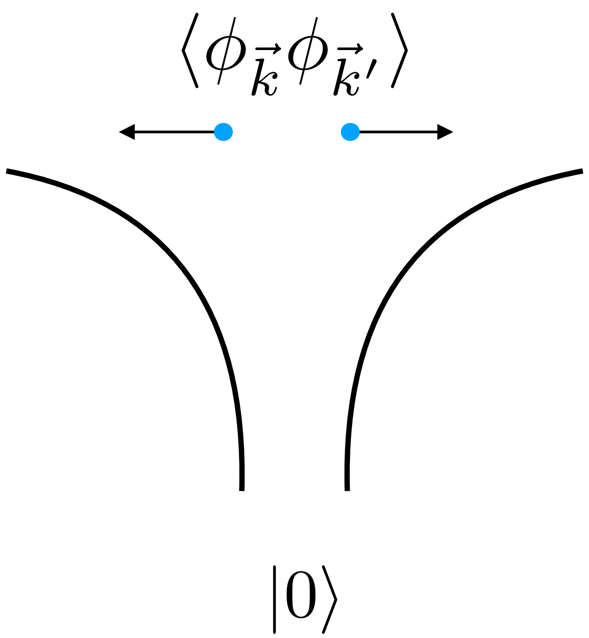
Expanding Universe

Parker '66
(See also Schrodinger '39)



Black hole

Hawking' 74

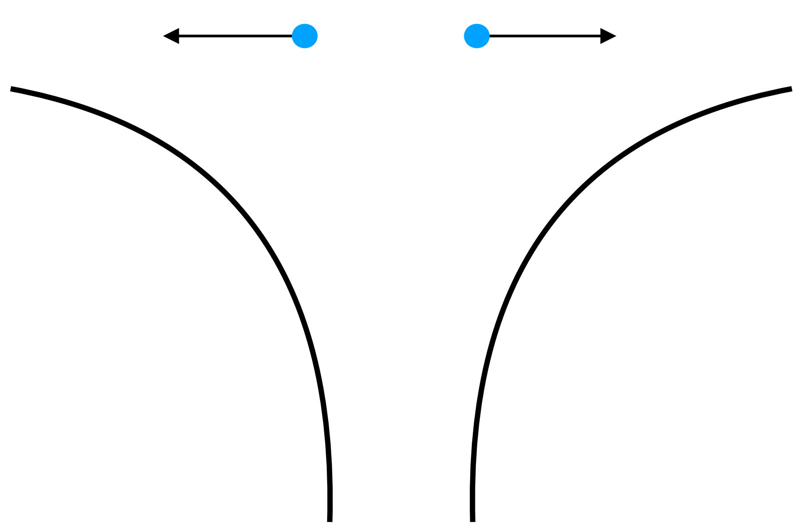


Inflation

Mukhanov&Chibisov'81
Hawking '81
Guth& Pi '82
Starobinsky'82
Bardeen&Steinhard&Turner'83

Common view point: Inflation serves as a complete memory-loss mechanism for the universe

The exponential expansion erases the details of what the universe was like before inflation. Hence, it suffices to consider vacuum fluctuations at the onset of inflation. Anything else is washed away by the exponential expansion

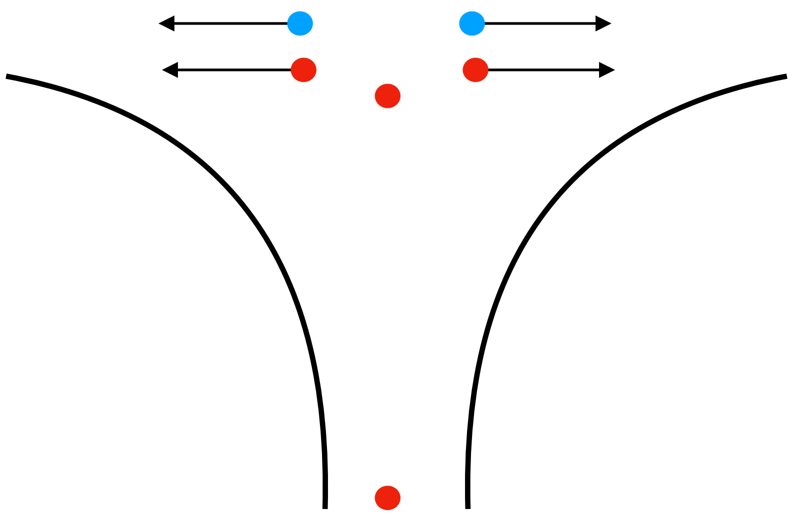


$|0\rangle$

If true, this would dissipate hopes of observing remnants of the Planck era

Agullo-Parker'10:
Non-Gausianity and the stimulated creation of quanta in the inflationary universe

- True classically
- Also true for quantum fermionic fields
- But for bosonic quantum fields: stimulated particle creation occurs, preventing dilution



Messages:

There is red-shift, but not dilution

Correlation functions of bosonic quantum fields keep memory of the initial state

Non-Gaussianity are very sensitivity to the presence of quanta

Window to the pre-inflationary universe

LQC and Observations

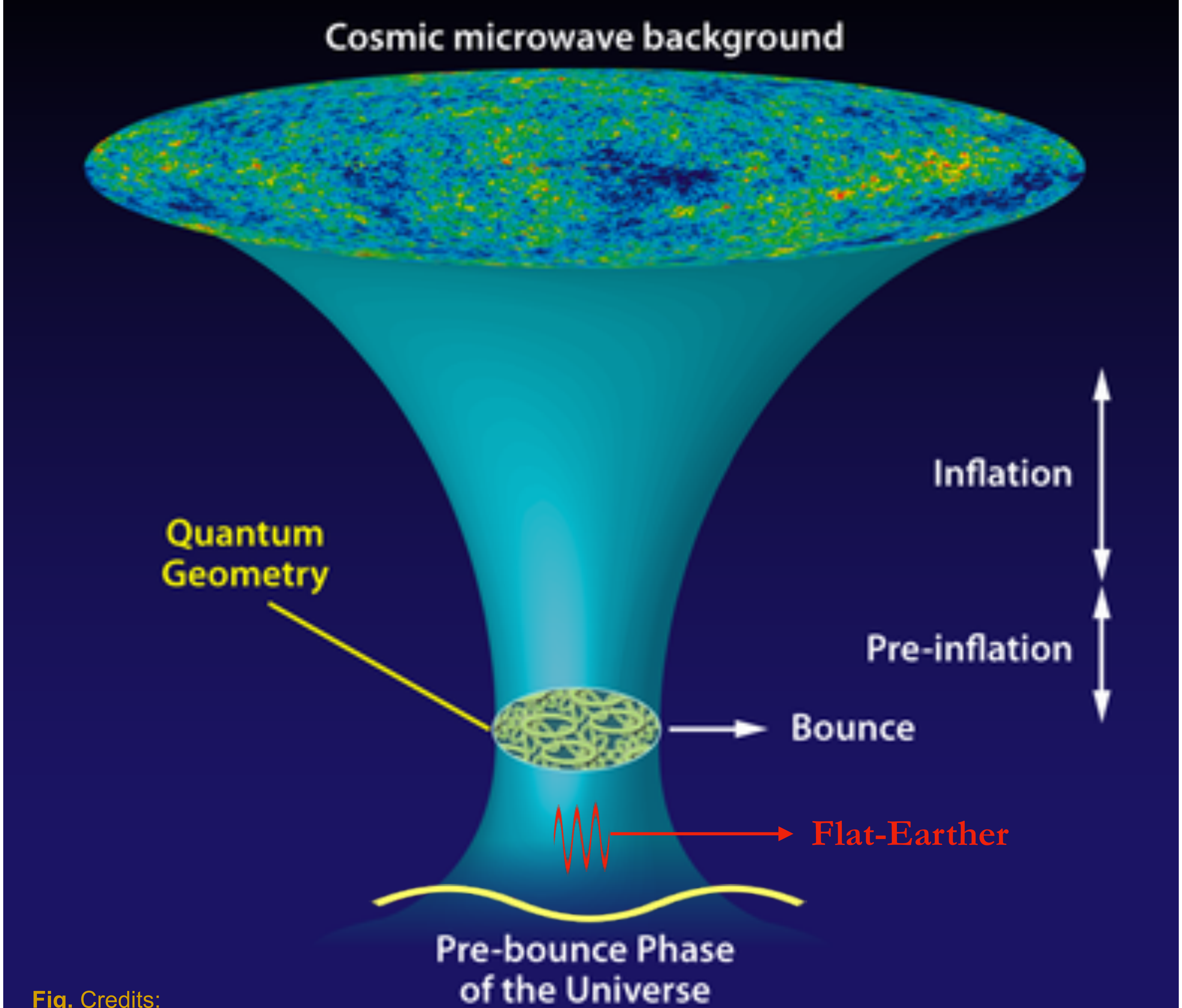
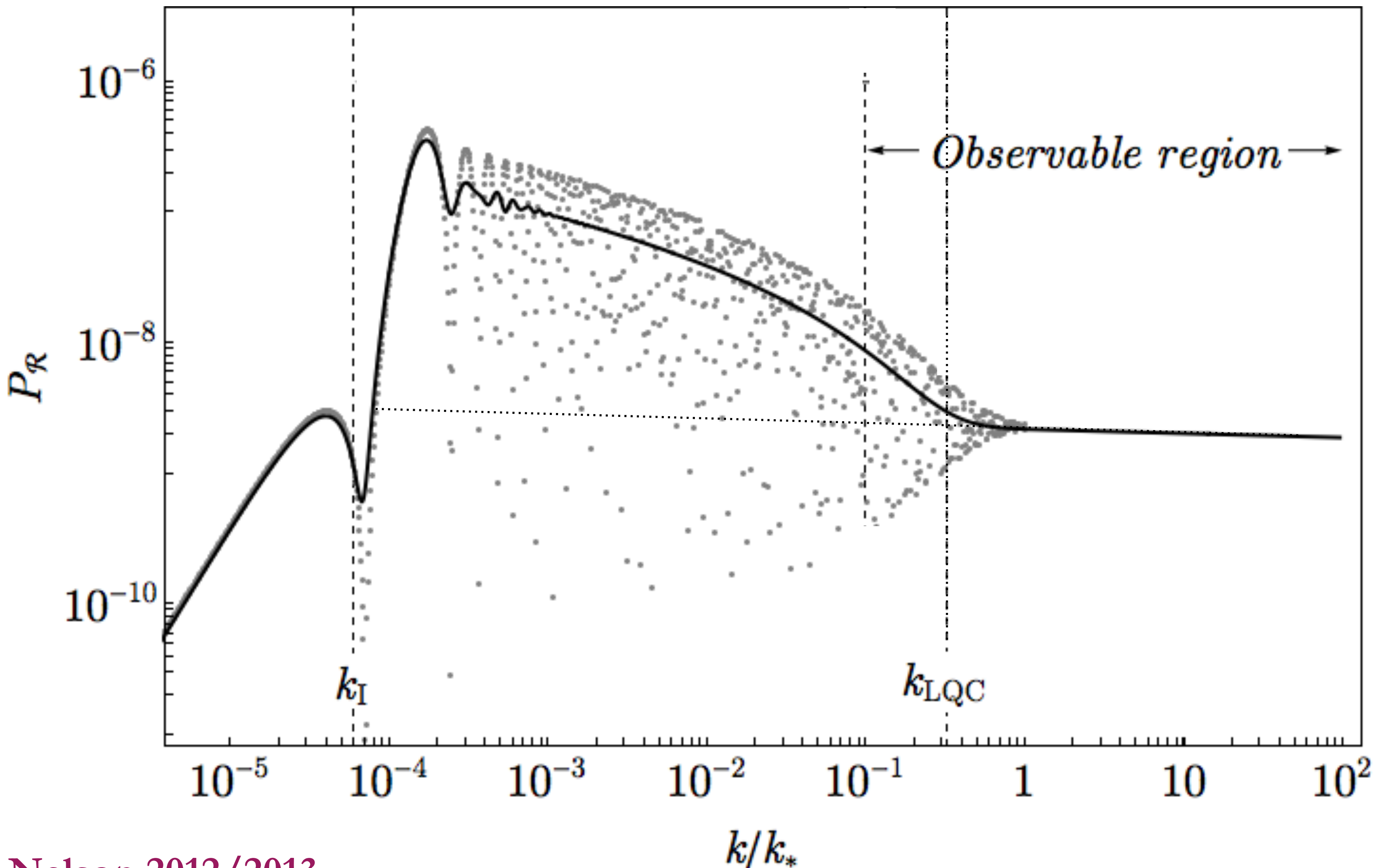


Fig. Credits:
P. Singh, Physics 5, 142 (2012)

Scalar Power Spectrum



Agullo-Ashtekar-Nelson 2012/2013

$$\langle \mathcal{R}_{\vec{k}} \mathcal{R}_{\vec{k}'} \rangle = \delta\underbrace{(\vec{k} + \vec{k}')}_{\text{Homogeneity}} P_{\mathcal{R}}(k)$$

Comoving curvature perturb.

Non-Gaussianity

They quantify non-Gaussian aspects of the quantum state of cosmological perturbations

Some degree of Non-Gaussinity is unavoidable due the non-linear nature of gravity

In standard inflation with vacuum initial conditions: $\mathcal{O}(\epsilon) \lesssim 10^{-2}$

One aspect of non-Gaussities is the three-point correlation function of scalar perturbations:

$$\langle \mathcal{R}_{\vec{k}_1}\mathcal{R}_{\vec{k}_2}\mathcal{R}_{\vec{k}_3}\rangle = \overbrace{\delta(\vec{k}_1+\vec{k}_2+\vec{k}_3)}^{\textbf{Homogeneity}}\,\overbrace{B_{\mathcal{R}}(k_1,k_2,k_3)}^{\textbf{Bispectrum}}$$

$$B_{\mathcal{R}}(k_1,k_2,k_3) = f_{NL}(k_1,k_2,k_3)\left(\Delta_{\mathcal{R}}(k_1)\Delta_{\mathcal{R}}(k_2)+\Delta_{\mathcal{R}}(k_1)\Delta_{\mathcal{R}}(k_3)+\Delta_{\mathcal{R}}(k_2)\Delta_{\mathcal{R}}(k_3)\right)$$

Quantifies non-Gaussianity

where $\Delta_{\mathcal{R}}(k) \equiv \frac{2\pi^2}{k^3}P_{\mathcal{R}}(k)$

$f_{NL}(k_1,k_2,k_3)$ **is identically zero if the quantum state is Gaussian**

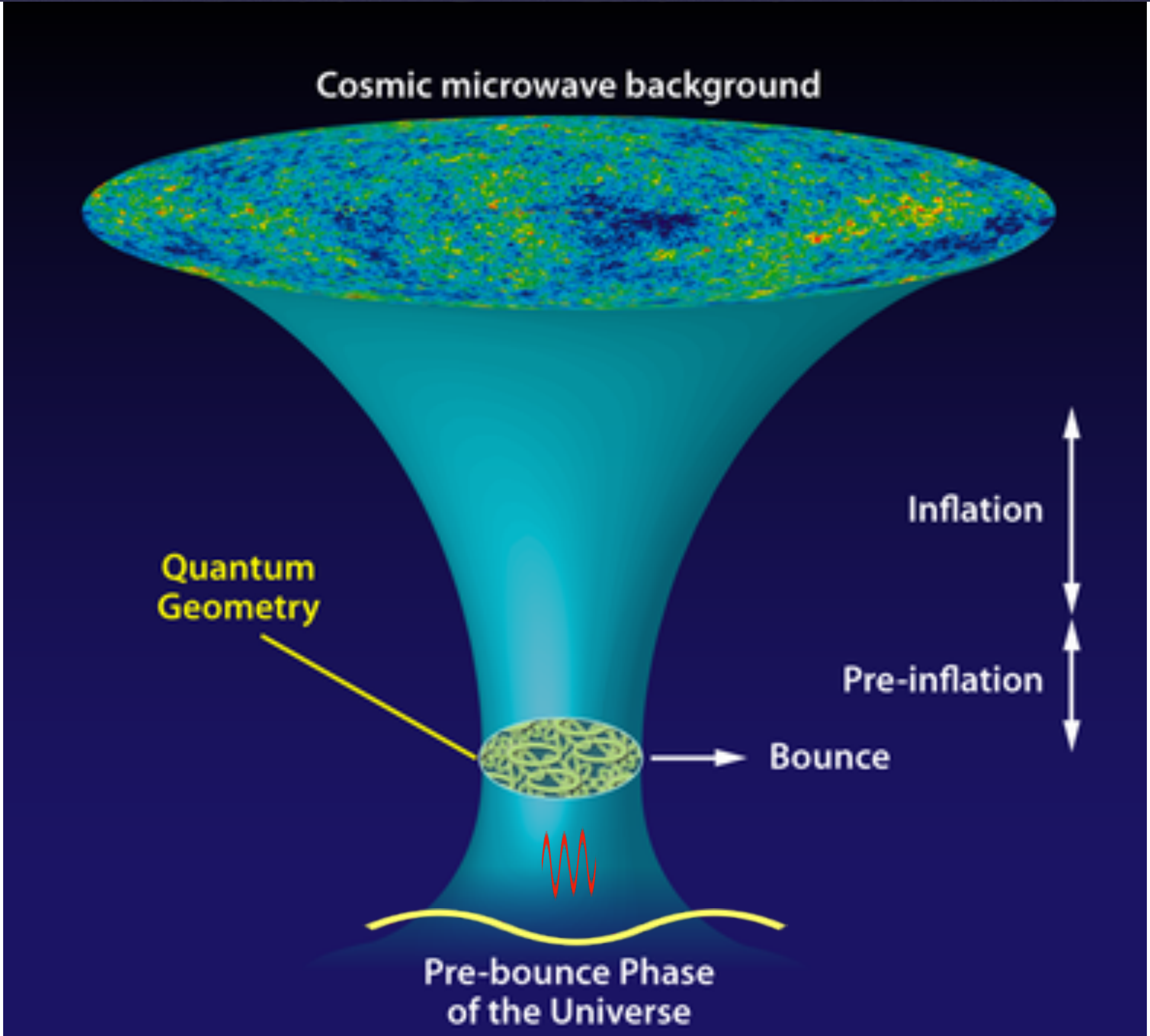
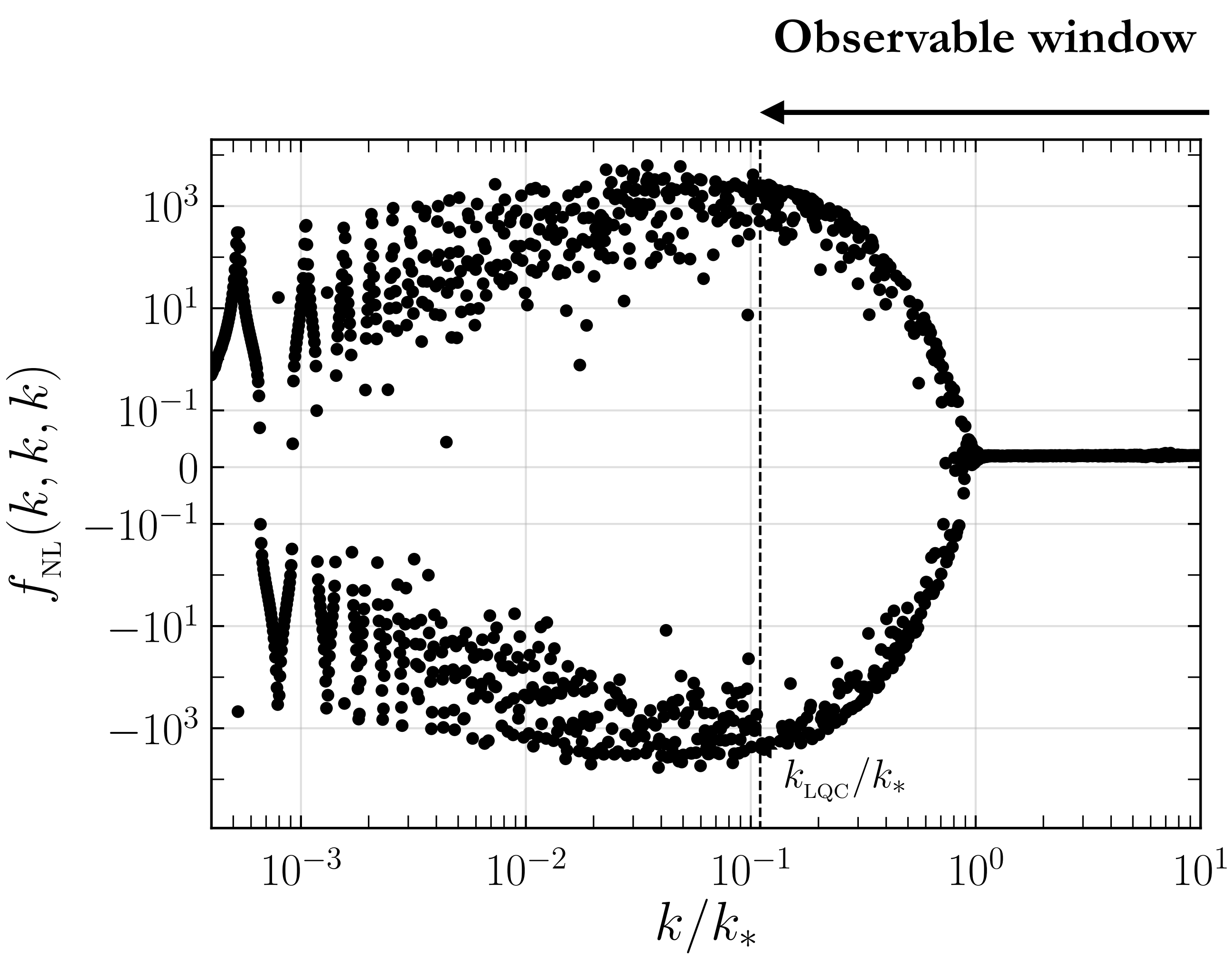


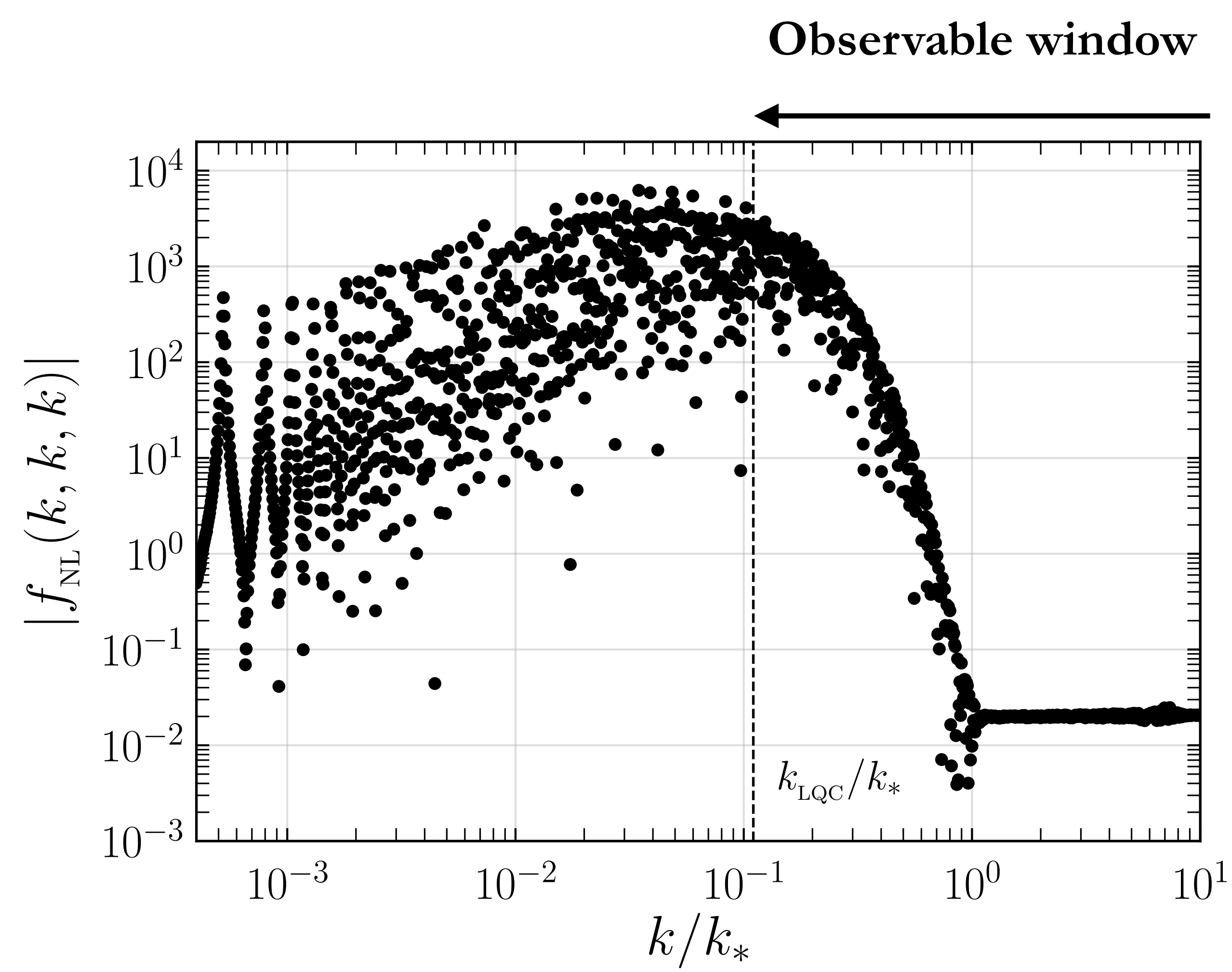
Fig. Credits:
P. Singh, Physics 5, 142 (2012)

Results:

Agullo-Bolliet-Sreenath 2018

Equilateral configurations, k1 = k2 = k3 (Qualitatively similar results for other configurations)





$$\boxed{|f_{NL}|_{\max} \sim 10^3}$$

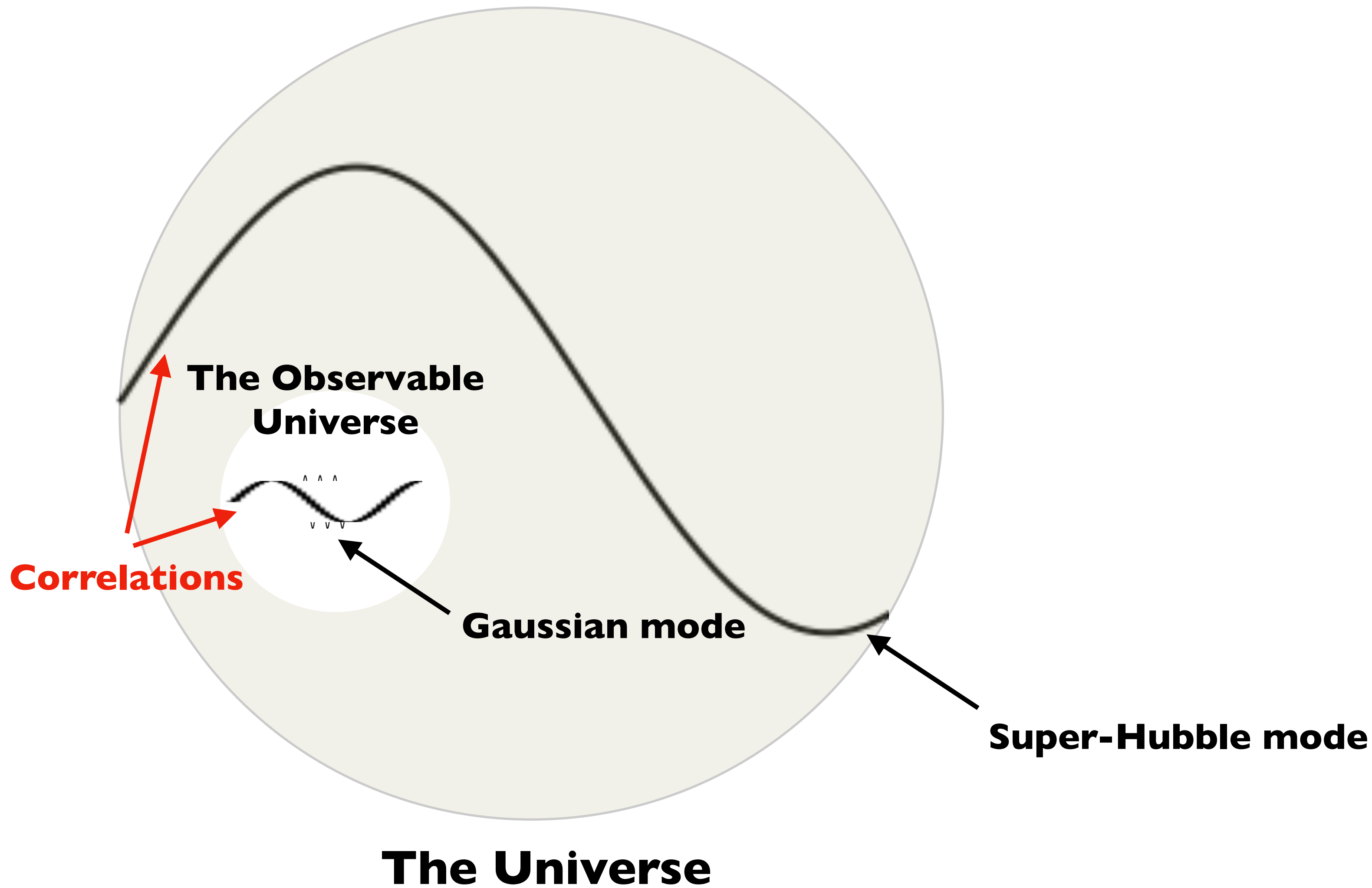
We will see this is compatible with CMB constraints

Messages:

The bounce generates strong non-Gaussian correlations

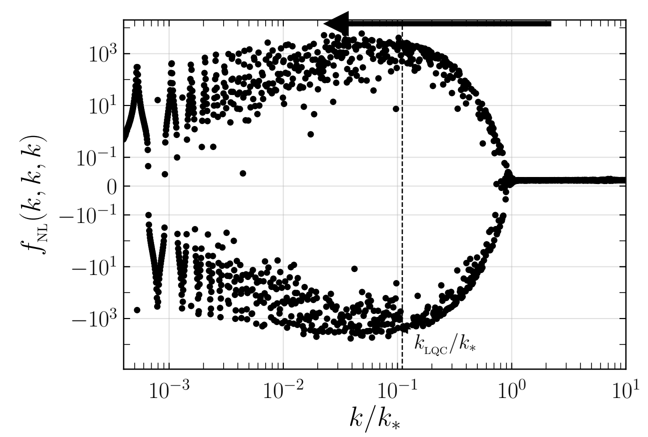
But only among the most infra-red modes we can observe and/or super-Hubble modes

The bispectrum is highly oscillatory. It oscillates around a small value $\bar{f}_{NL} \sim 10^{-2}$


The Observable Universe
Correlations
Gaussian mode
Super-Hubble mode
The Universe

But LQC bispectrum is complicated (because the oscillations) :

Observable window

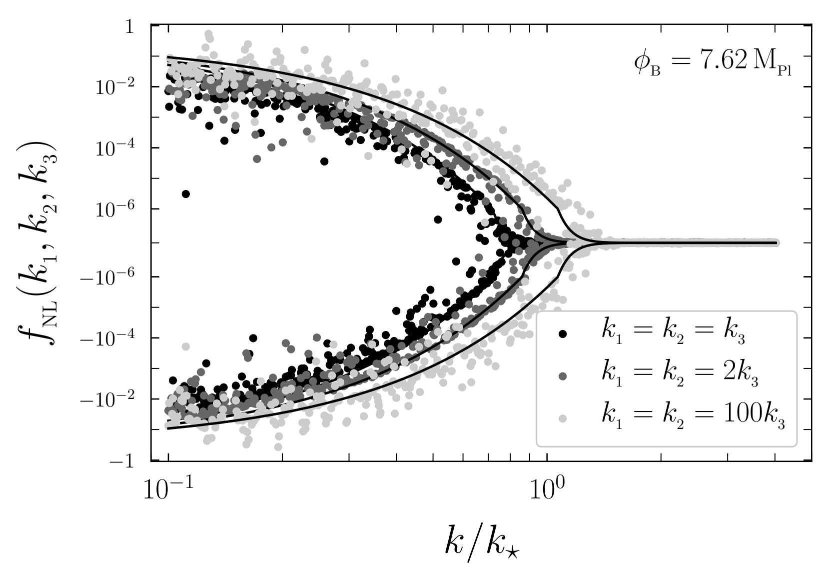


Analytical approximation for the amplitude $|f_{NL}(k_1,k_2,k_3)|$ **Agullo-Bolliet-Sreenath 2018**

$$\boxed{|f_{NL}(k_1,k_2,k_3)| \approx N\, e^{-\alpha\,(k_1+k_2+k_3)/k_{\rm LQC}}}$$ **where** $$\alpha = \frac{\pi}{12}\frac{\Gamma[5/6]}{\Gamma[4/3]}$$

(Approximation based on Cauchy's integral theorem and the poles of the scale factor, extending time to take values in the complex plane)

Great approximation for the amplitude of f_{NL} **(although it does not capture the oscillations):**



Can we observe the Bispectrum directly in the CMB?

Probably not:

In the CMB we have access to the projection of the bispectrum on a sphere

$$B_{\mathcal{R}}(k_1, k_2, k_3) \longrightarrow b_{\mathcal{R}}(\ell_1, \ell_2, \ell_3) \quad \text{angular bispectrum}$$

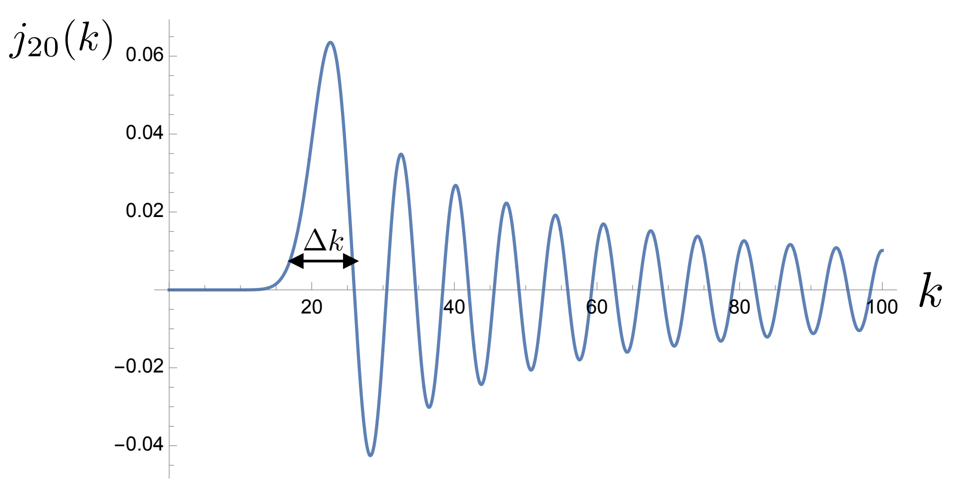
The change $k \longrightarrow \ell$ involves integrating $B_{\mathcal{R}}(k_1, k_2, k_3)\, d^3k_1 d^3k_2 d^3k_3$ against spherical Bessel functions $j_\ell(k)$

$\longrightarrow$ Introduces an effective average in k_i, on a window $\sim \Delta k$

$\longrightarrow$ The average of $B_{\mathcal{R}}(k_1, k_2, k_3)$ to the resulting $b_{\mathcal{R}}(\ell_1, \ell_2, \ell_3)$ is very small

$\longrightarrow$ Unobservable

Example:

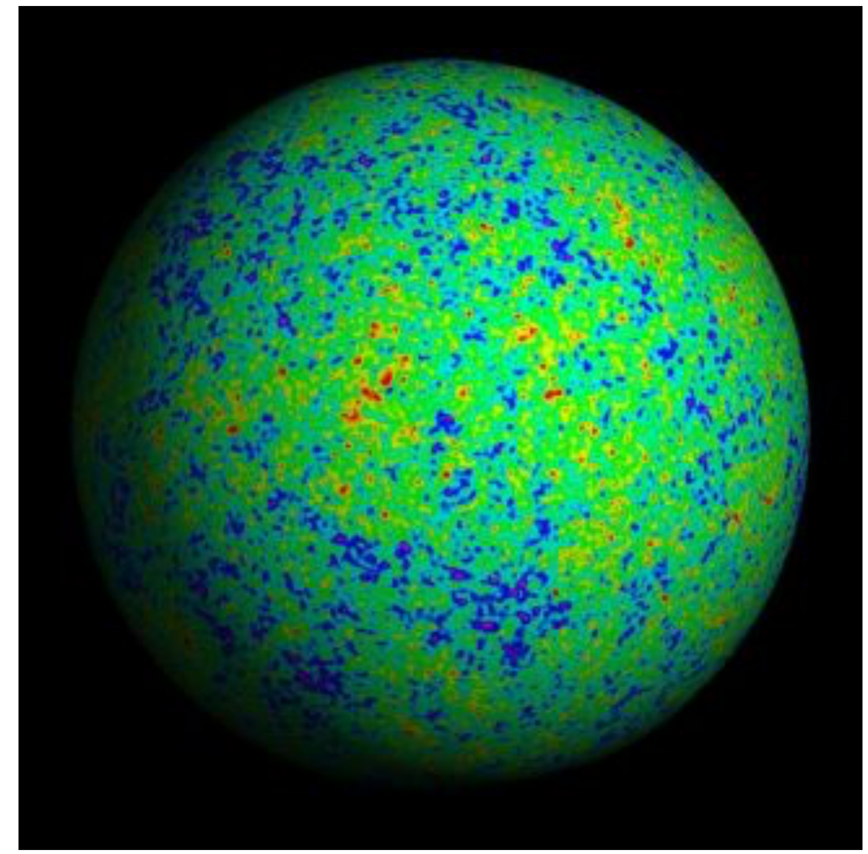


The projection onto the CMB sphere averages the bispectrum put to a very small value

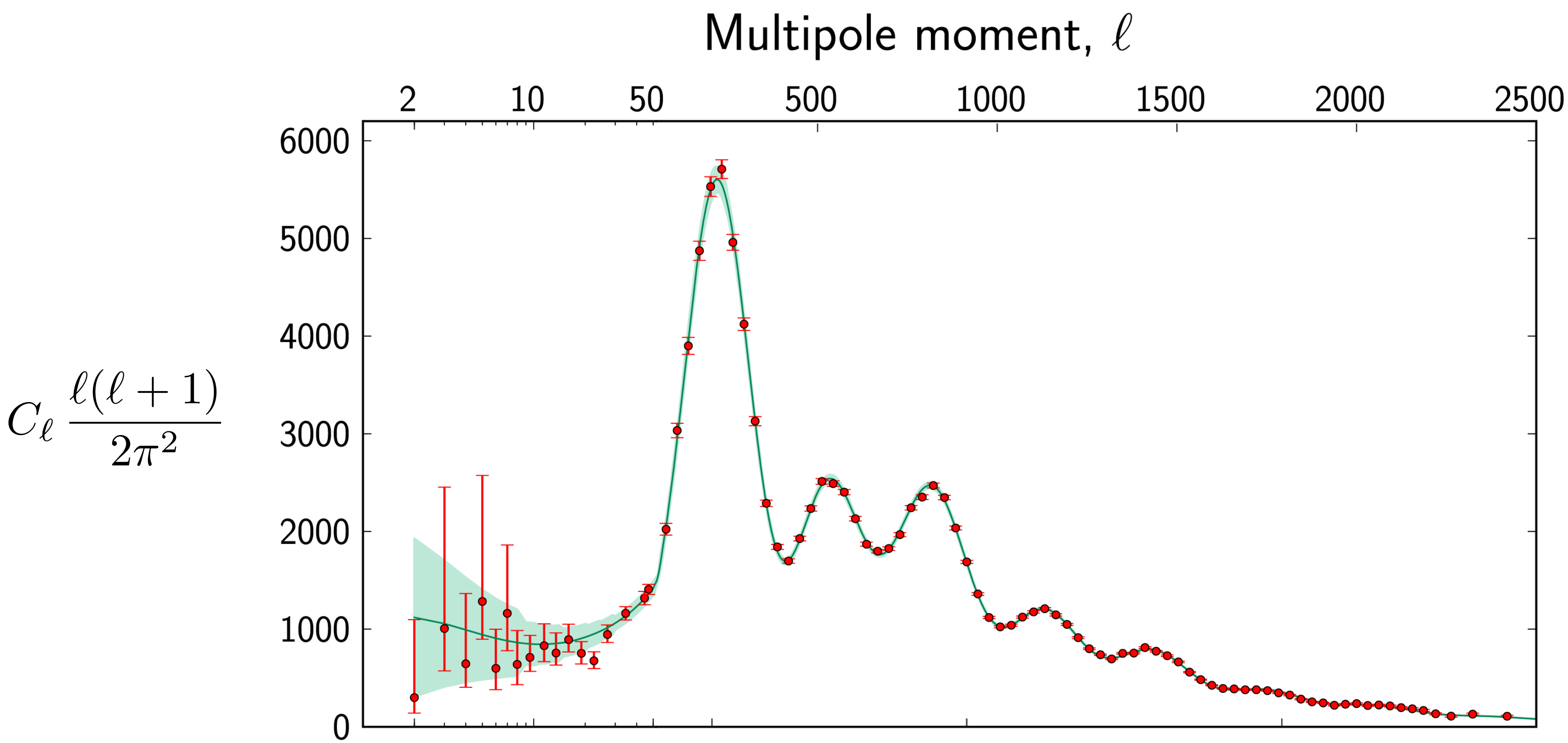
Roshna and Sreenath JCAP 2023

Fossils in the sky?

Footprints of Planckian Dinosaurs?



Scalar power spectrum



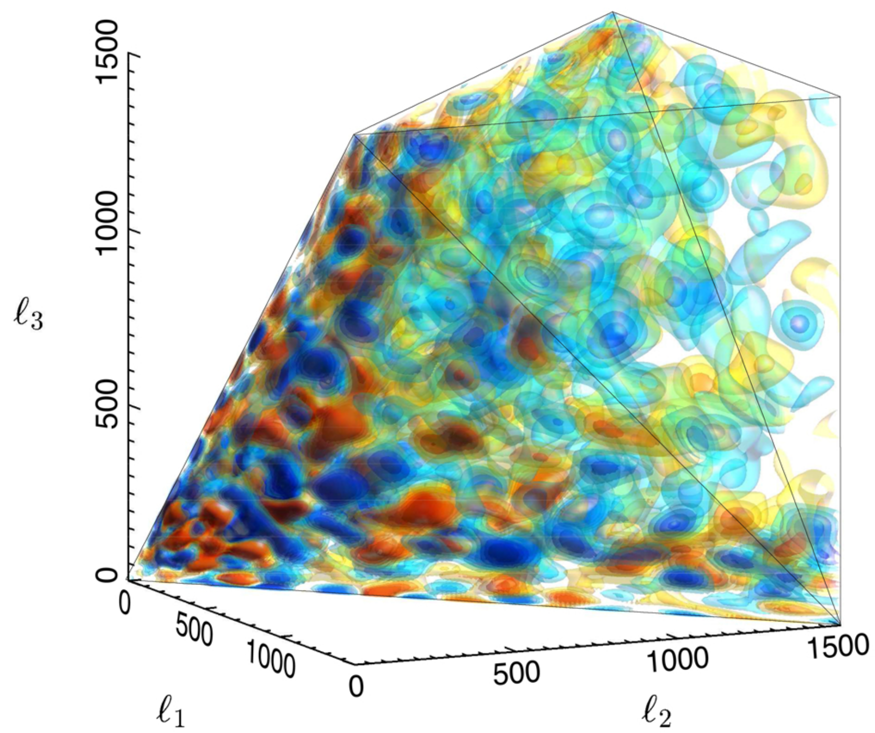
Excellent agreement with standard inflation for $\ell \gtrsim 30$

For $\ell \lesssim 30$ **cosmic variance is large**

Non-Gaussianity

P. A. R. Ade *et al.* (Planck), "Planck 2015 results. XVII. Constraints on primordial non-Gaussianity," Astron. Astrophys. **594**, A17 (2016), arXiv:1502.01592 [astro-ph.CO].

(See also Planck 2018; similar results, but also data on E-polarization)

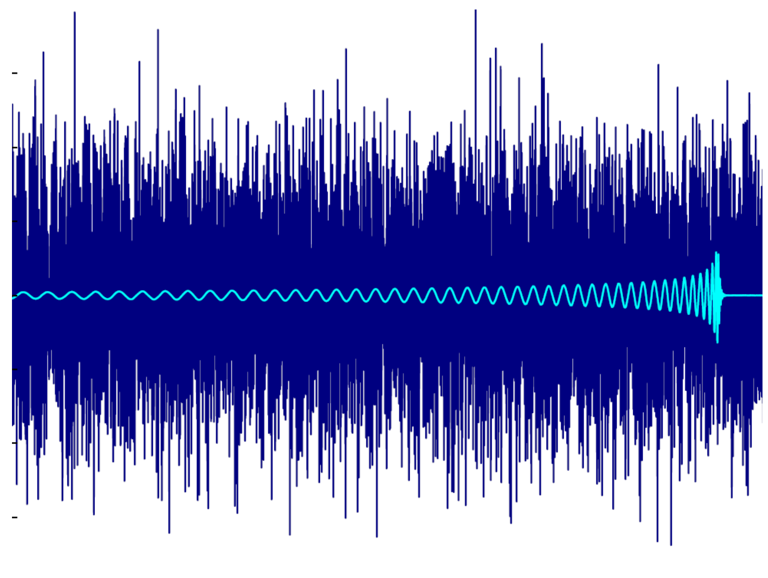


Planck sensitivity is good at large multiples:

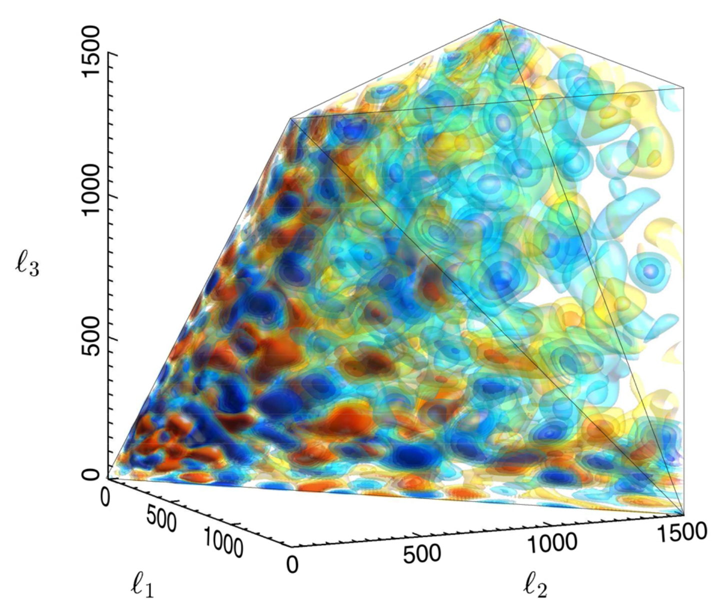
$$|\Delta f_{NL}| \sim 10 \text{ for } \ell \gtrsim 1000$$

Errors bar grow for low multipoles, approx. as $1/\sqrt{\ell}$

Planck's strategy is similar to GW observations: Use templates

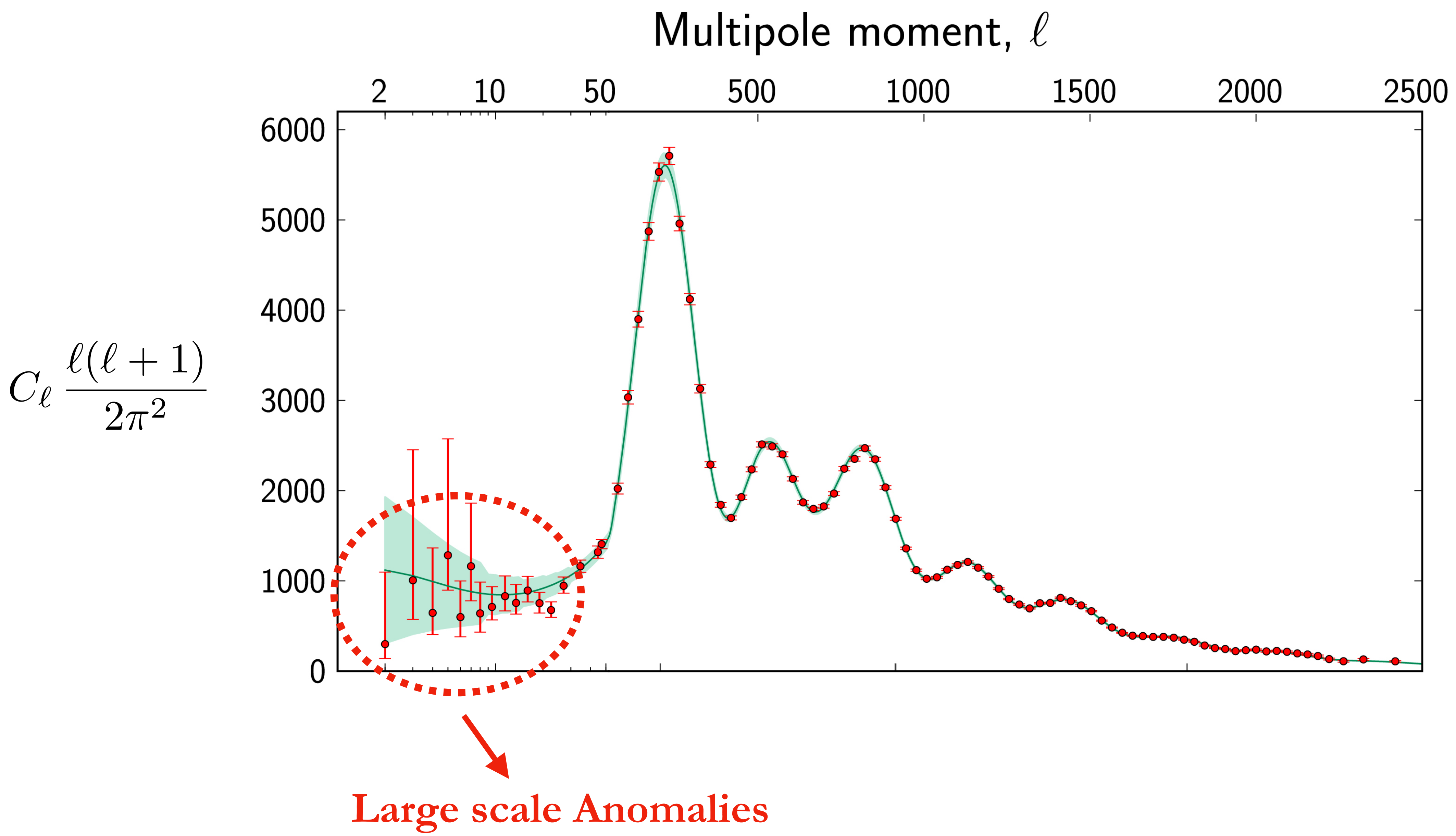


Example: signal and noise in LIGO



Planck has not confirmed any existing model

But there is something "funny" in Planck data for the Power Spectrum


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
6000
5000
4000
3000
2000
1000
0
$C_\ell \, \frac{\ell(\ell+1)}{2\pi^2}$
Large scale Anomalies

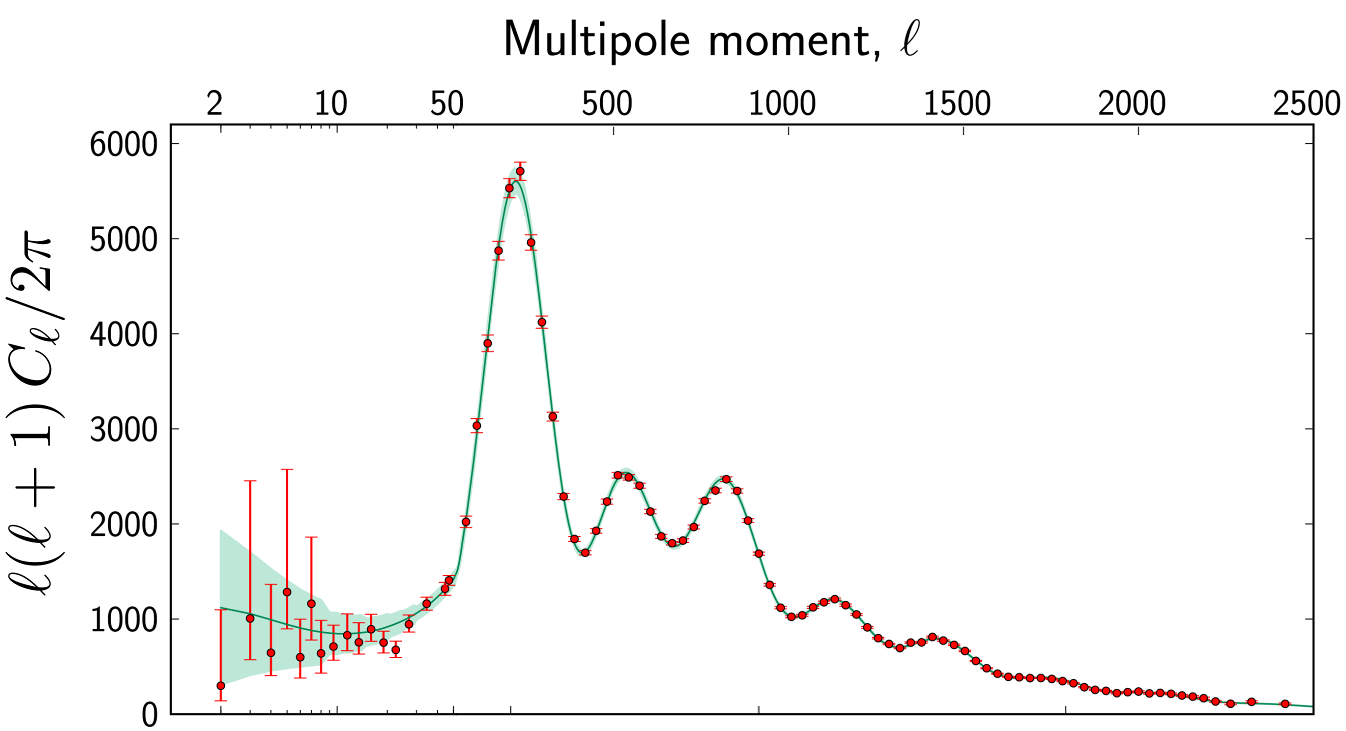
1. Lack of correlations (Power suppression)

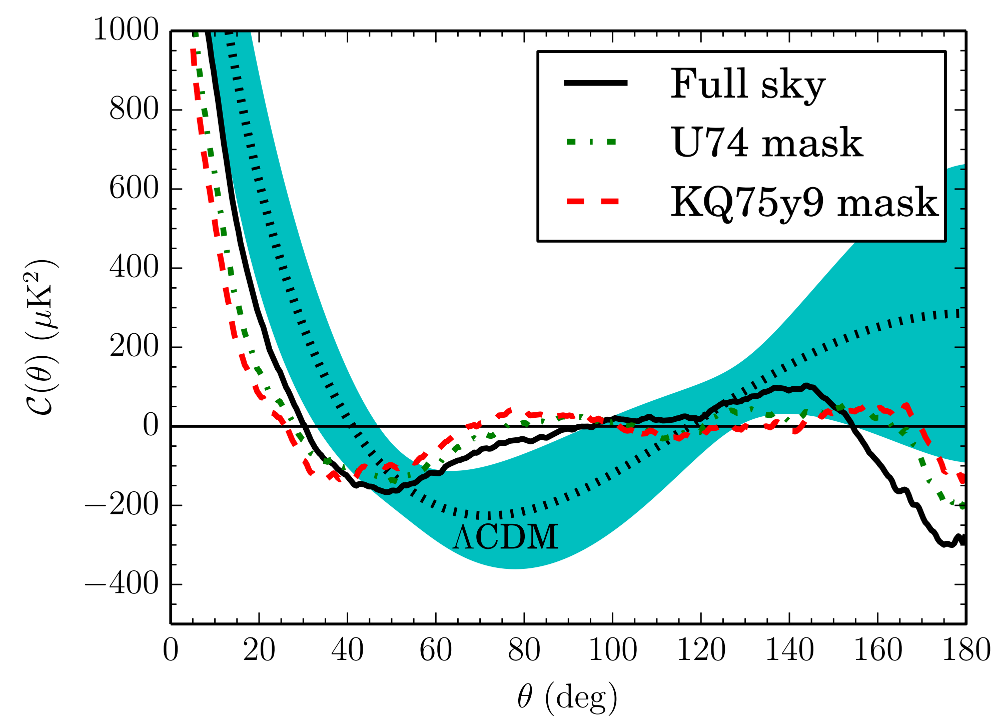
2. Dipolar or hemispherical asymmetry

3. Odd parity preference

4. Moderate tension with the lensing parameter A_L

1. Lack of correlations (Power suppression)

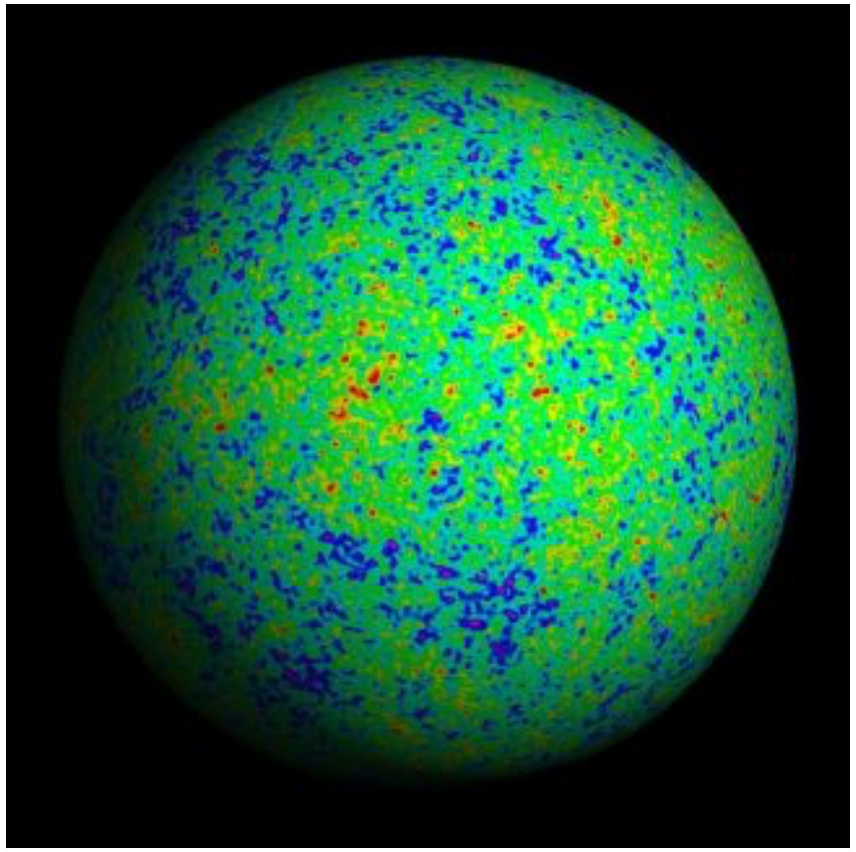




Surprising lack of correlations for >60 degrees

Copi, Hunterer, Schwarz and Starkman 2015

2. Dipolar or hemispherical asymmetry



One hemisphere of the CMB contains significantly more two-point correlations than the other (for an concrete choice of "equatorial plane")

COBE, WMAP, Planck

3. Odd parity preference

Statistically unexpected asymmetry in the magnitude of the angular Power spectrum when considering odd and even multipoles separately

4. Moderate tension with the lensing parameter A_L

They are called "anomalies" because they are not incompatible with the LambdaCDM model

They are "unexpected" statistically speaking

Planck 2018 results. I.
Overview, and the cosmological legacy of _Planck_

It would nevertheless be premature to completely dismiss all the CMB anomalies as simple fluctuations of a pure ΛCDM cosmology, since if any of the anomalies have a primordial origin, then their large-scale nature would suggest an explanation rooted in fundamental physics. Thus it is worth exploring any models that might explain an anomaly (or even better, multiple anomalies) naturally, or with very few free parameters.

LQC Origin of CMB Anomalies?

LQC corrections appear at the same scales as the anomalies

Natural to see if LQC can account for them in a natural manner

Agullo 2015, Martin de Blas-Olmedo 2016, Ashtekar-Gupt 2017, Xhu-Wang-Kristen-Cleaver-Sheng 2018, Ashtekar-Gupt-Jeong-Sreenath 2020, Agullo-Kranas-Sreenath 2020, Elizaga-Navascués-Mena-Marugan 2021, Elizaga-Navascués-Mena-Marugan-Yebana-Carrilero 2023, Martin-Benito&Neves&Olmedo 2023

Two main strategies within LQC:

1. Change the initial state of cosmological perturbations in the Planck era

   Martin de Blas-Olmedo 2016, Ashtekar-Gupt 2017, Ashtekar-Gupt-Jeong-Sreenath 2020, Elizaga-Navascués-Mena-Marugan 2021, Martin-Benito&Neves&Olmedo 2023

2. Use non-Gaussianity

   Agullo 2015, Agullo-Kranas-Sreenath 2020

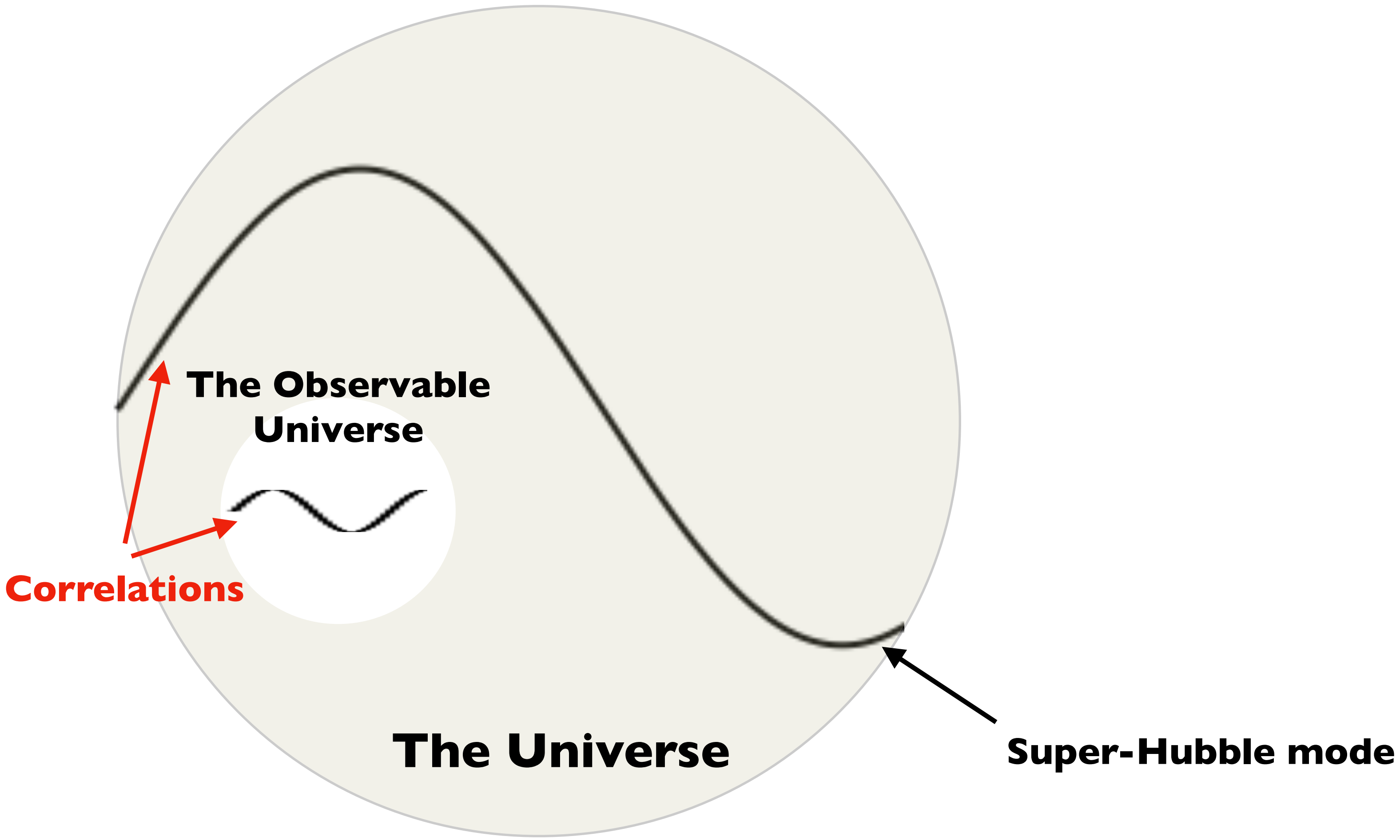
Let's focus on the second strategy

Agullo 2015, Agullo-Kranas-Sreenath 2020

Non-Gaussian modulation of the power spectrum

(Lewis, Jeong&Kamiokowski, Schmitd&Hui)

Correlations between CMB modes and super-Hubble modes can modify the statistical properties of the CMB



Non-Gaussian modification of the two-point function

Agullo-Kranas-Sreenath Class. Quant. Grav. 28 065010 (2021), Gen. Rel. Grav. 53 2 17 (2021)

Goal: Evaluate how likely the observed anomalies are in a universe ruled by LQC

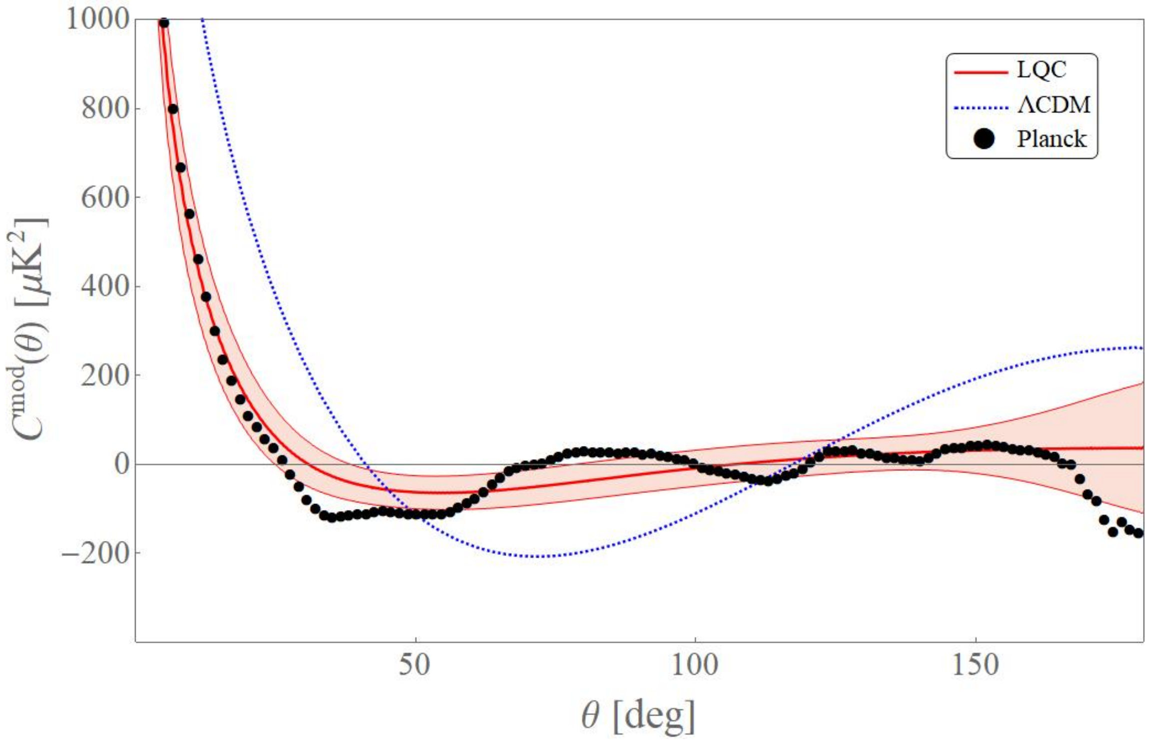
But we were unable to include the oscillatory character of $f_{NL}(k_1, k_2, k_3)$

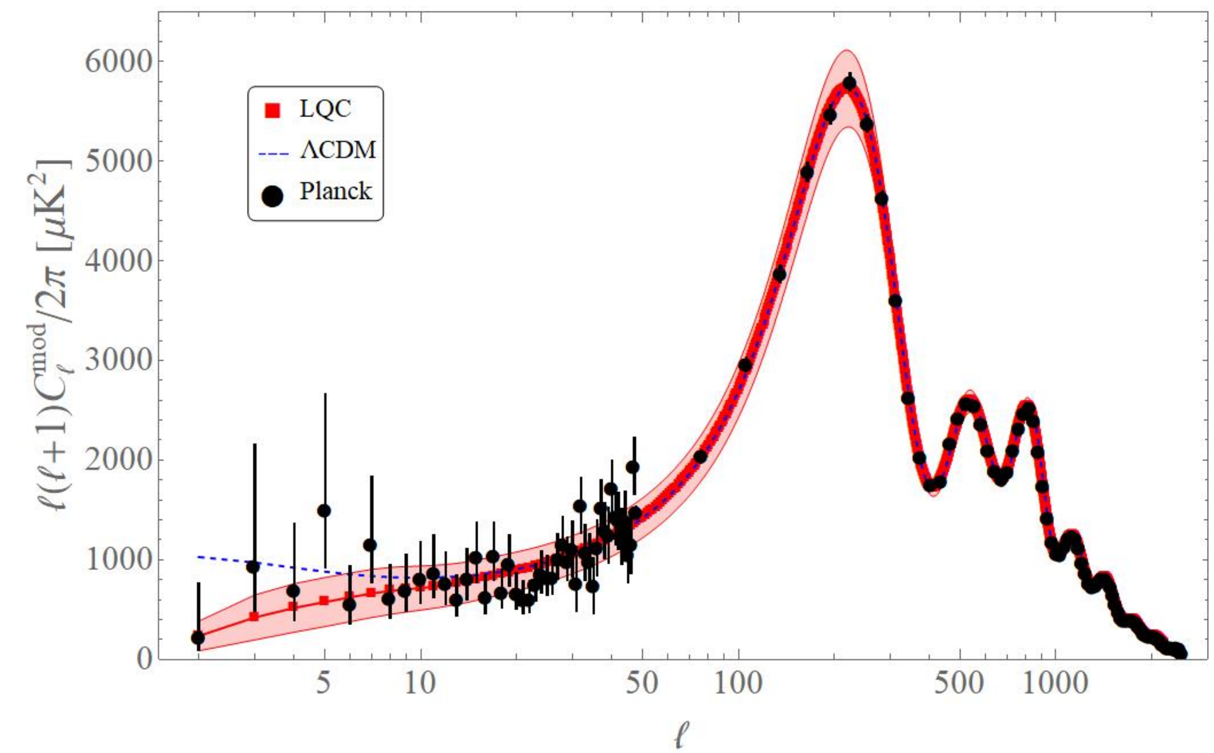
Our strategy: forget about the oscillation and pretend $f_{NL}(k_1, k_2, k_3) = |f_{NL}(k_1, k_2, k_3)|$

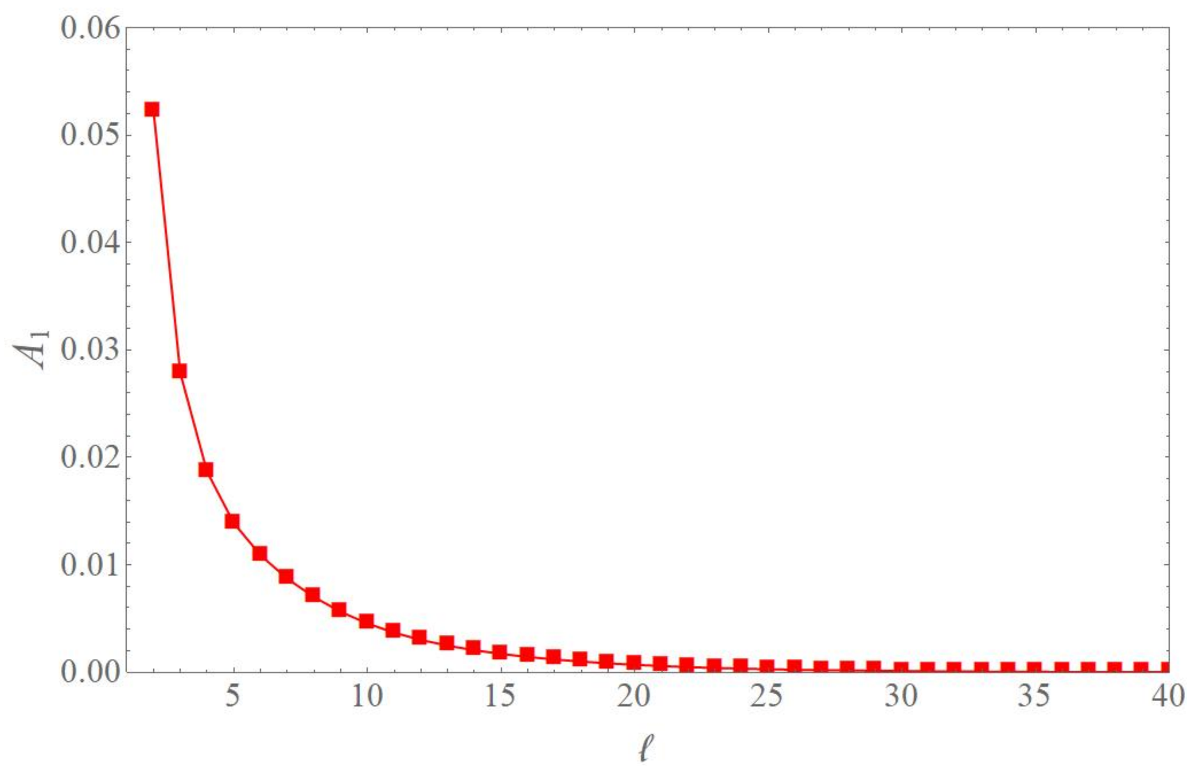
Because we use the magnitude of $f_{NL}(k_1, k_2, k_3)$ and disregard the potential effect of oscillation, the analysis only provides an upper bound for the probability of the observed anomalies

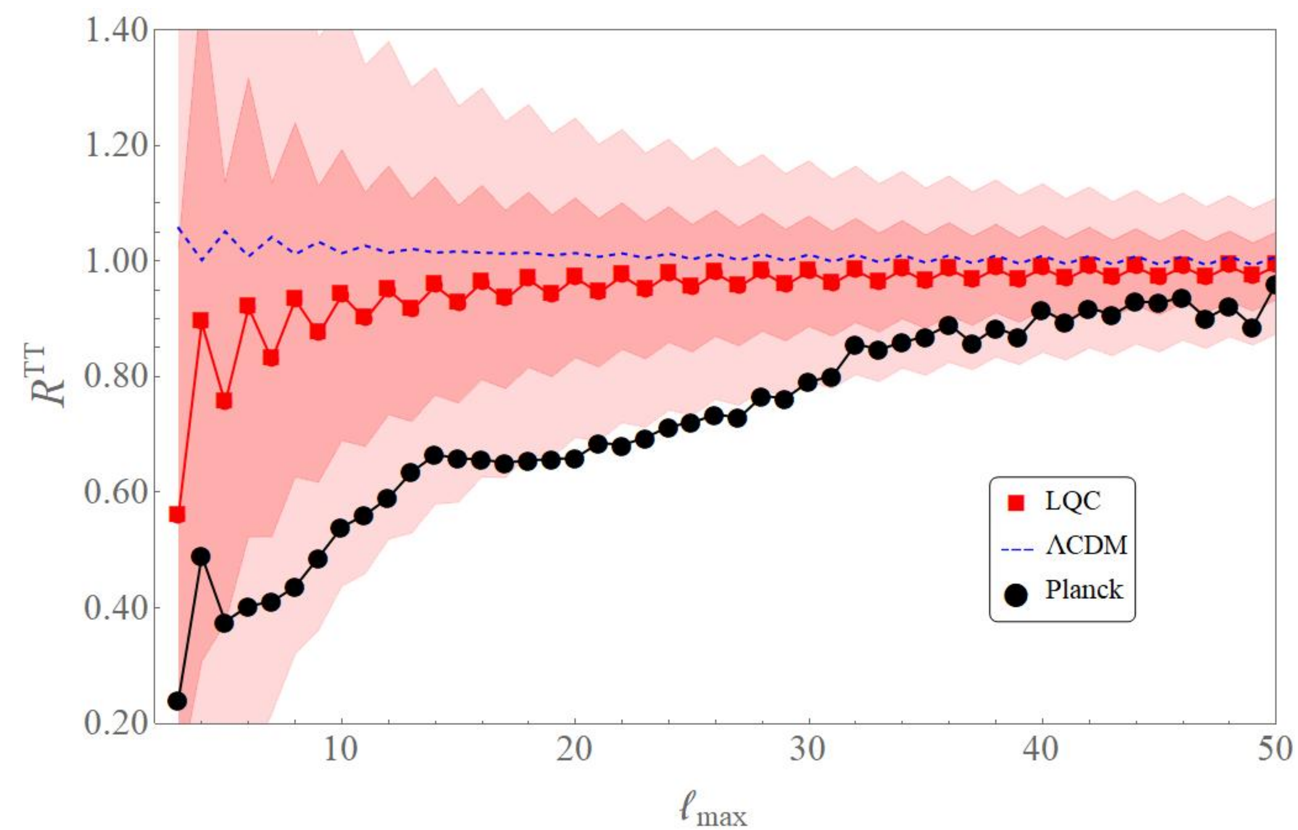
We found power-suppression + dipolar modulation + parity violation compatible with observation have a maximum probability close to 20%

How much oscillations in $f_{NL}(k_1, k_2, k_3)$ modify these probabilities? I am not sure









Agullo, Kranas, Sreenath, 2020

To summarize

Agullo 2015, Agullo-Kranas-Sreenath 2021

Agullo 2015, Agullo-Kranas-Sreenath 2021

Little hope of observing the predictions for LQC in the CMB Bispectrum, because:

Its amplitude is below Planck's sensitivity

Oscillations are likely to average out the projection of the Bispectrum onto the CMB sphere to a very small value

But it is possible that non-Gaussianity are behind the anomalies we see in the power spectrum

Delgado & Durrer et al.:

Comparison with CMB Data

Their goal: look for the LQC-Bispectrum in CMB data

Two papers:

The CMB bispectrum from bouncing cosmologies

Paola C. M. Delgado[1], **Ruth Durrer**[2] **and Nelson Pinto-Neto**[3]

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Krakow, Poland

[2]Université de Genève, Département de Physique Théorique and CAP, 24 quai Ernest-Ansermet, CH-1211 Genève 4, Switzerland

[3]Department of Cosmology, Astrophysics and Fundamental Interacions-COSMO, Centro Brasileiro de Pesquisas Físicas-CBPF, rua Dr. Xavier Sigaud 150, 22290-180, Rio de Janeiro, Brazil

E-mail: paola.moreira.delgado@doctoral.uj.edu.pl, ruth.durrer@unige.ch, nelsonpn@cbpf.br

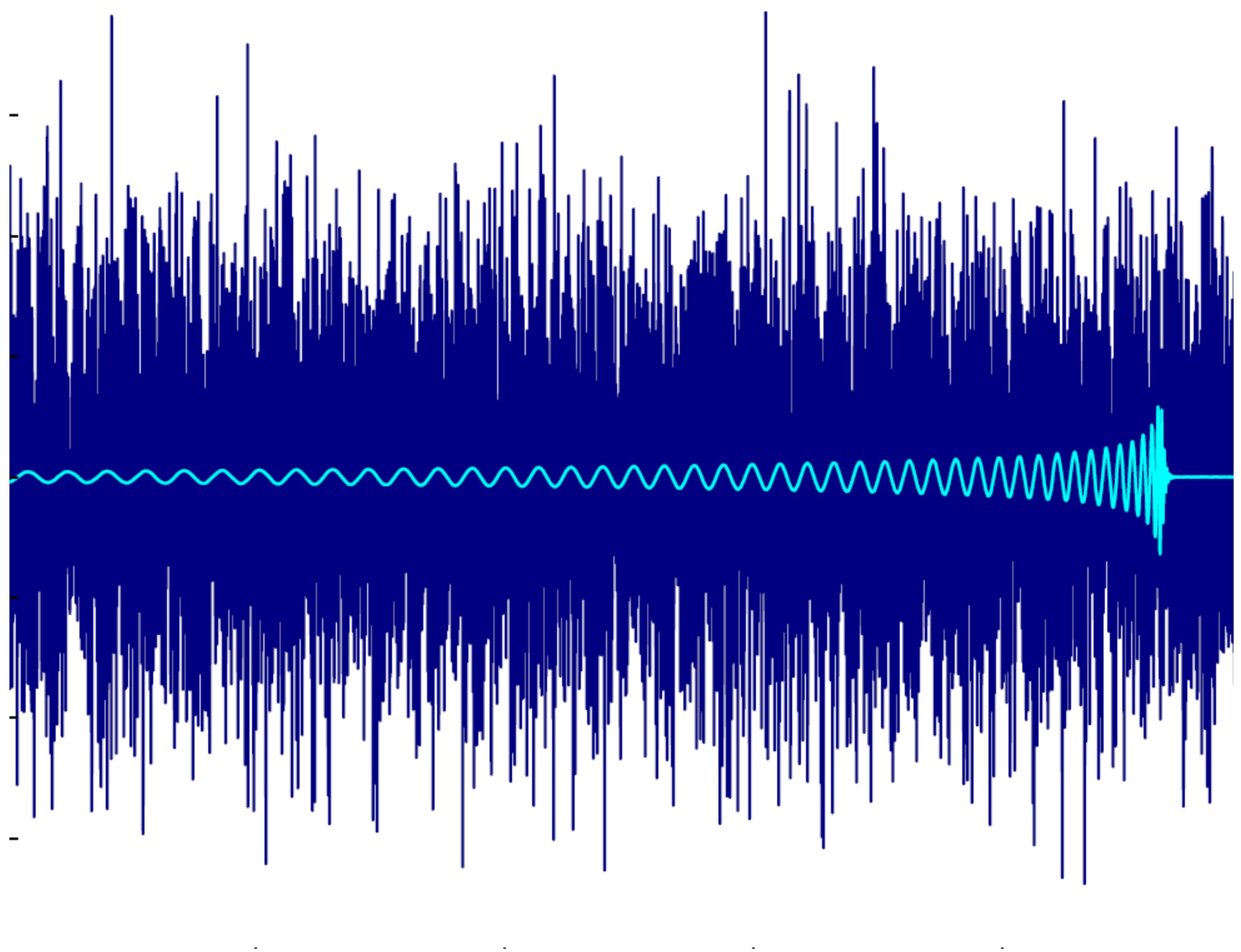
Abstract. In this paper we compute the CMB bispectrum for bouncing models motivated by Loop Quantum Cosmology. Despite the fact that the primordial bispectrum of these models is decaying exponentially above a large pivot scale, we find that the cumulative signal-to-noise ratio of the bispectrum induced in the CMB from scales $\ell < 30$ is larger than 10 in all cases of interest and therefore can, in principle, be detected in the Planck data.

Journal of Cosmology and Astroparticle Physics, Volume 2021, November 2021

They consider $f_{NL}(k_1, k_2, k_3) = N\, e^{-\alpha\,(k_1+k_2+k_3)/k_{\rm bounce}}$ **(No oscillations)**

with $N \sim 10^3$

Analogy: signal and noise in LIGO



The signal is always buried under noise. Nevertheless, cumulative signal-to-noise ration is large enough

Interesting!

May 2023

Constraining the bispectrum from bouncing cosmologies with Planck

Bartjan van Tent,[1] Paola C. M. Delgado,[2] and Ruth Durrer[3]
[1] *Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France.*
[2] *Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-348 Krakow, Poland.*
[3] *Department of Theoretical Physics, Université de Genève, Quai E. Ansermet 24, Genève, 1211, Switzerland.*

Bouncing models of cosmology, as they arise e.g. in loop quantum cosmology, can be followed by an inflationary phase and generate close-to-scale-invariant fluctuation spectra as observed in the Cosmic Microwave Background (CMB). However, they are typically not Gaussian and also generate a bispectrum. These models can help to mitigate the large-scale anomalies of the CMB by considering substantial non-Gaussianities on very large scales, which decay exponentially on sub-horizon scales. It was therefore thought that this non-Gaussianity would not be visible in observations, which can only probe sub-horizon scales. In this letter we show that bouncing models with parameters such that they can significantly mitigate the large-scale anomalies of the CMB are excluded by the Planck data with high significance of, depending on the specific model, 5.4, 6.4 or 14 standard deviations.

Summary:

If: $f_{NL}(k_1, k_2, k_3) = N\, e^{-\alpha\,(k_1+k_2+k_3)/k_{\rm bounce}}$ **(No oscillations!)**

Then: $N \sim 10^3$ **is rule out by Planck data for the angular bispectrum**

Messages I extract from this paper:

1. It is a nice analysis, applicable to models with $f_{NL}(k_1, k_2, k_3) = N\, e^{-\alpha\, (k_1+k_2+k_3)/k_{\rm bounce}}$

2. It does not apply to LQC, because in LQC $f_{NL}(k_1, k_2, k_3)$ is highly oscillatory

3. It also does not restrict LQC's capacity to explain the anomalies

Particularly, because there are other means of accounting for the anomalies in LQC which do not rely on non-Gaussuanity

Martin de Blas-Olmedo 2016, Ashtekar-Gupt 2017, Ashtekar-Gupt-Jeong-Sreenath 2020, Elizaga-Navascués-Mena-Marugan 2021, Martin-Benito&Neves&Olmedo 2023

Scientific American and The Controversy

On April 9th 2023 I received an email from James Riordon, a journalist from Scientific American (Sciam), asking my opinion about van Ten-Delgado-Durrer paper.

Because I though it was an interesting piece of work, I wrote a detailed response:

My letter (I highlight in yellow the mots important info):

Did the universe have a beginning? If it did, how was it (physically speaking)? These are open questions in contemporary physics. A primary goal of my work in the last years has been to envisage ways of answering these and similar questions using data. Is there any sort of signal in the universe that can help us to understand its potential origin (or lack of)?
In collaboration with my students and postdocs, I proposed that non-Gaussianity in the cosmic microwave background is a promising avenue to gain information about the cosmic origins. By non-Gaussianity, I refer to deviations from a simple Gaussian-like profile in the distribution of temperature anisotropies in the cosmic microwave background (CMB). The statement is that, although small, deviations from a perfect Gaussian shape can teach us valuable lessons about the early phases of the universe.

Mathematically, non-Gaussianity is quantified by a function called the bi-spectrum, which measures the statistical correlations in the density of the universe among three different locations. These correlations can be originated from quantum fluctuations, which were amplified by the expansion of the universe. Different expansion histories produce different amplifications. In this way, the form of the bispectrum can teach us about the history of the cosmos.

With my research group, I computed the form of the bispectrum that a cosmic bounce followed by a phase of inflation would generate. We found that such a cosmological scenario produces a bispectrum with a very specific form, which, if observed, would serve as a smoking gun for the existence of a bounce (instead of a "bang").

However, our calculations were limited. They provided the form of the bispectrum at the end of the inflationary phase. But what we observe is the CMB, which was created almost 400K years later.

In this article, van Tent and collaborators have been able to evolve the bispectrum we computed across the "late" history of the cosmos, have computed the impact it leaves in the CMB, and most importantly, have contrasted the results with data from the Planck satellite. This is a beautiful analysis that fills the gap between our calculations of the primordial bispectrum in the very early universe and what is actually observed. I was delighted when I saw this paper. It blows my mind to think that we can learn about the way the universe began by looking at the sky.

The "sad" part of this story is that van Tent and collaborators do not find in data from the Planck satellite the signals that are expected from a cosmic bounce.

Does this mean that the universe did not begin with a bounce? No. The bispectrum used in this article actually is an *upper bound* to the true bispectrum produced by a cosmic bounce. In particular, as described in my previous papers, most bouncing scenarios produce a bispectrum containing strong oscillations superposed to the functional shape used by van Tent et al. This happens, for instance, for the bounce predicted by loop quantum cosmology. These oscillations, not included in van Tent et al.'s analysis, average out to a very small value of the bispectrum. Importantly, what we observed in the CMB is a coarse-grained version of the bispectrum, since the finite resolution of our detectors effectively averages out any oscillation in the data. This implies that the absence of a positive signal in the data that van Tent et al have analyzed cannot rule out the existence of a bounce—instead, the absence of the signal can be attributed to the presence of oscillations (this has been, in fact, proven quantitatively in the recent analysis in arXiv:2301.05406)

I did not hear back from the journalist.

Until a friend of mine sent me the link of this article in Sciam:

QUANTUM PHYSICS

The Universe Began with a Bang, Not a Bounce, New Studies Find

New research pokes holes in the idea that the cosmos expanded and then contracted before beginning again

By James Riordon on May 24, 2023

I was shocked by this title. (It is difficult to understand from many viewpoints; e.g., Van Tent et al analysis does not provide any support to the Big Bang model. There are many other alternatives for the early universe…)

However, I still hold out hope to read a quote from me stating that the analysis by van Tent-Delgado-Durrer does not apply to LQC because they do not account for oscillations.

To my great surprise, that portion of my letter was ignored. Even worse, I was quoted in a manner that reasonable readers might interpret as if I concur with the title of this Scientific American article.

I contacted the Editors of Scientific American, expressing my concern that my words had been misrepresented and quoted in a manner that did not align with my actual opinion.

Initially, they ignored my request. I submitted a "Letter to the Editor" with the intention of having it published alongside the article, but they declined to publish it.

Finally, I had the opportunity to discuss with the Editor-in-Chief, who agreed to revise the article. However, the modifications made were purely cosmetic and did not address the core issue.

I explained to the Editor-in-Chief that the revisions were inadequate and requested that any reference to me be removed from the article since it did not accurately reflect my true opinion. Unfortunately, my request was denied.

The article is open access. Please, check it yourself.
https://web.archive.org/web/20230524192405/https://www.scientificamerican.com/article/the-universe-began-with-a-bang-not-a-bounce-new-studies-find/

I paste here a portion of it where my opinion is supposedly "quoted"

"If observed," Agullo says, the bispectrum "would serve as a smoking gun for the existence of a bounce instead of a bang." Agullo's group previously calculated the bispectrum as it would have appeared shortly after a cosmic bounce. Durrer and her colleagues took the calculation further, but when they compared it with the present-day Planck CMB data, there was no significant sign of a bispectrum imprint.

Although lots of other bouncing cosmos models may still be viable, the failure to find a significant bispectrum means that models that rely on LQC to deal with the anomalies in the CMB can be ruled out. It's a sad result for Agullo, who had high hopes of finding concrete evidence of a bouncing universe. He still considers many bouncing universe models viable, however. And Paola Delgado, a cosmology Ph.D. candidate at Jagiellonian University in Poland, who worked on the new analysis that was co-authored by Durrer, says there's one potential upside. "I heard for a long time that [attempts to merge quantum physics and cosmology] cannot be tested," Delgado says. "I think it was really nice to see that for some classes of models, you still have some contact with observations."

I'm in sharp disagreement with the text highlighted

This is the revised version. I highlight the new sentences introduced during the revision process.

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Obviously, the new sentences do not fix (at all) the main problem.

My actual opinion is, instead, that the analysis of van Tent et al. does not apply to the LQC bounce.

Conclusion

- It is fascinating that Planck scale physics can be tested using data

- LQC has made significant progress in this regard

- Watch out for journalists: remain open, but they may be inclined towards sensationalist head lines not always aligned withy scientific rigor

- Demand to read the text before publication before contributing