Hearing the spacetime curvature in quantum noise

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M. Saravani, S. Aslanbeigi, A. Kempf, Phys. Rev. D **93**, 045026 (2016)

Background

- Why is quantum gravity hard?

  GR is structurally very different from quantum theories

- Any bridge between GR and QT desirable.
- Here: build one of those bridges.

Idea

- Quantum fields fluctuate, have quantum noise

- Spacetime curvature affects that quantum noise

Key question:

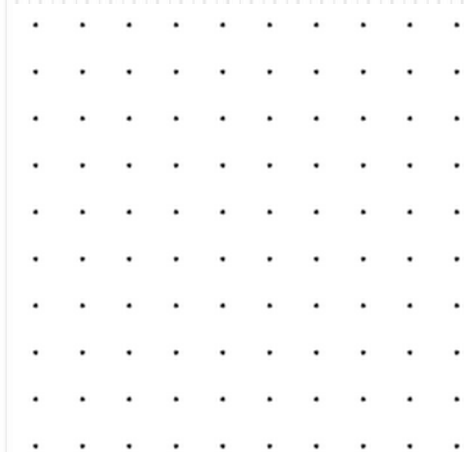
- Can we get the curvature back from the quantum noise?

- Is the metric expressible in terms of quantum noise?

How could this work?

- First in flat spacetime:

$$\nabla^2\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = \frac{m^2c^2}{\hbar^2}\psi$$

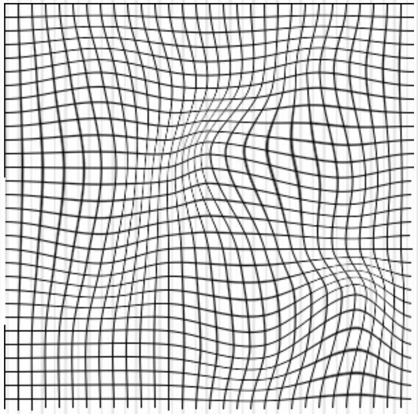


- Coupled harmonic oscillators
- Their quantum fluctuations are correlated
- Quantified by: 2-point functions such as the propagator

In curved spacetime

- Klein Gordon equation now:

$$\left(\frac{1}{\sqrt{g}}\partial_\mu \sqrt{g} g^{\mu\nu}\partial_\nu + \frac{m^2c^2}{\hbar^2}\right)\psi = 0$$



- Curvature affects the coupling of the oscillators

➔Curvature affects the correlations of quantum noise

➔Curvature affects the propagator

Does the propagator know all about the curvature?

Result

- For dimensions D>2, the metric can be expressed in terms of the Feynman propagator:

$$g_{ij}(y) = -\frac{1}{2}\left[\frac{\Gamma(D/2-1)}{4\pi^{D/2}}\right]^{\frac{2}{D-2}} \lim_{x\to y} \frac{\partial}{\partial x^i}\frac{\partial}{\partial y^j}\left(G(x,y)^{\frac{2}{2-D}}\right)$$

- Proof: covariance, geodesic coordinates, asymptotic behavior
- Also in paper: worked-out examples

➔ In principle: Can replace the metric with the propagator!

Intuitively, why does this work?

- Recall that in 3+1 dimensions:

$$\textit{curvature} \;=\; \textit{causal structure} + \textit{scalar function}$$

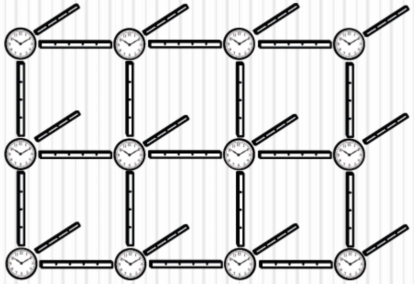
- Propagator knows the causal structure

- But: propagator also indicates effective spacetime distances!

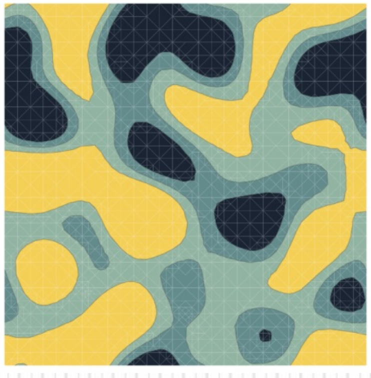
  And knowing infinitesimal distances is to know the metric.

Interpretation

- Einstein built general relativity on rods and clocks



- But no rods and clocks at sub-atomic scales!
- Instead: as distance proxy, use strength of noise correlators:



Accelerators measure curvature

- Accelerators test Feynman rules, including the propagators
- Measuring the propagator locally is to measure the metric

With a mobile accelerator one could measure the metric anywhere

What can we use this tool for ?

- We have a bridge between GR and QFT:
  From the propagator we can calculate the metric.

Assume some arbitrary model for the Planck scale.

How does bridge hold up ***when approaching*** *the Planck scale ?*

- We can calculate the corresponding impact on the metric!

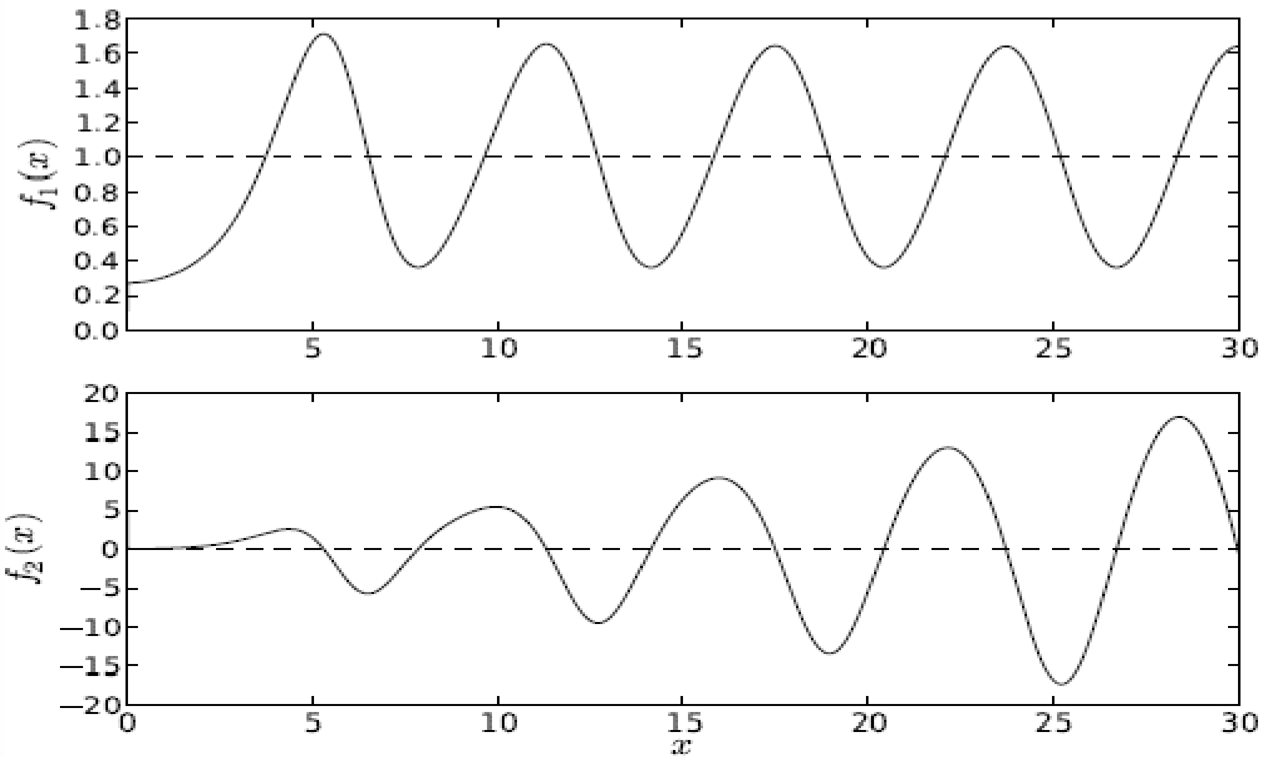
Example: sharp natural UV cutoff

$$g_{ij}^{\Lambda}(y) \equiv -\frac{1}{2}\left[\frac{\Gamma(D/2-1)}{4\pi^{D/2}}\right]^{\frac{2}{D-2}} \lim_{x\to y} \frac{\partial}{\partial x^i}\frac{\partial}{\partial y^j} G_\Lambda(x,y)^{\frac{2}{2-D}}$$

- Notice: the UV limits x $\longrightarrow$ y and Λ $\longrightarrow \infty$ compete !
- Do they commute?
- It's more subtle: only "on average" they do

Example D=3 flat space:

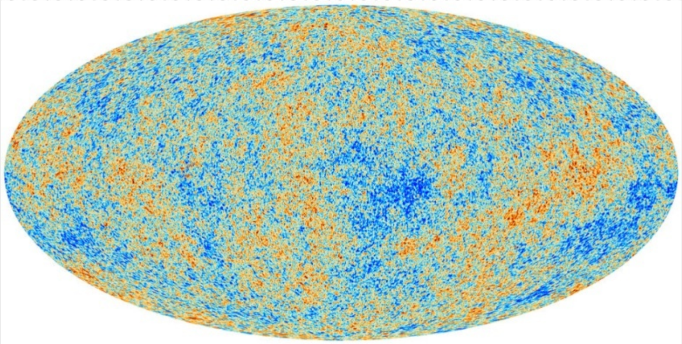
$$g_{\alpha\beta}(x,y) = \delta_{\alpha\beta} f_1(\Lambda r_{xy}) + \frac{(x_\alpha - y_\alpha)(x_\beta - y_\beta)}{r_{xy}^2} f_2(\Lambda r_{xy})$$



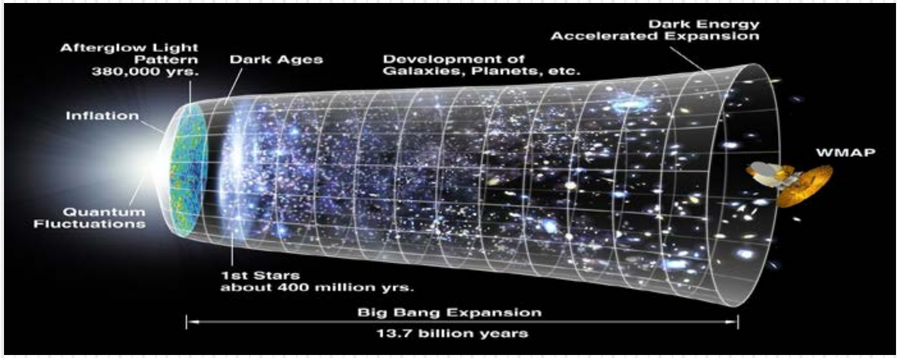
- **Oscillations. We recover usual metric "on average"**

Oscillations visible in the CMB ?

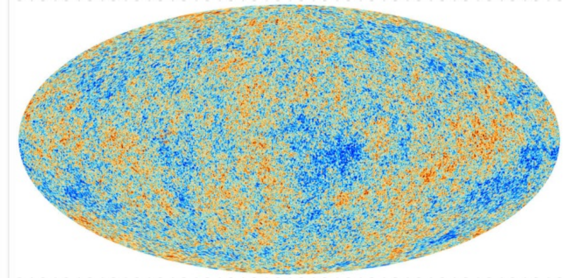
CMB's structure originated close to Planck scale



Hubble scale in inflation only about 5 orders from Planck scale.



Natural UV cutoffs in inflation



Multiple groups have non-covariant predictions for CMB.

- Effect could be first or second order in (Planck length/Hubble length) i.e. could be say O(10^-5) or O(10^-10)

Big challenge was:

Predictions with local Lorentz covariant bandlimit cutoff!

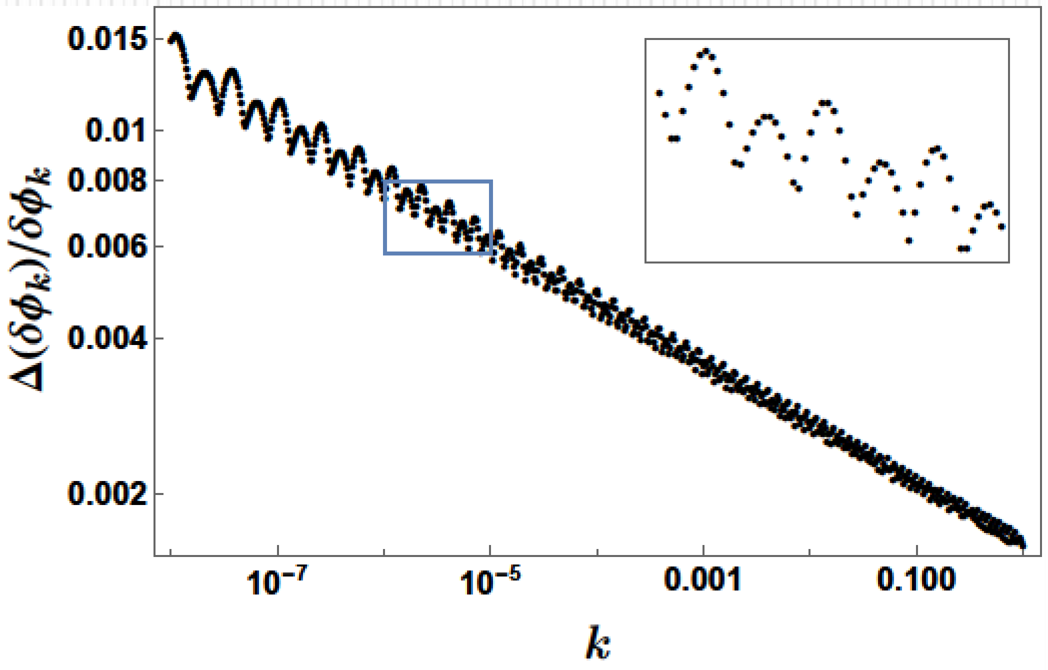
Recent paper with former students:

Aidan Chatwin-Davies, (CalTech) and Robert Martin (U. Cape Town)

- ACD,RTM, AK, Phys. Rev. Lett. **119**, 031301 (2017)

Results for sharp covariant cutoff

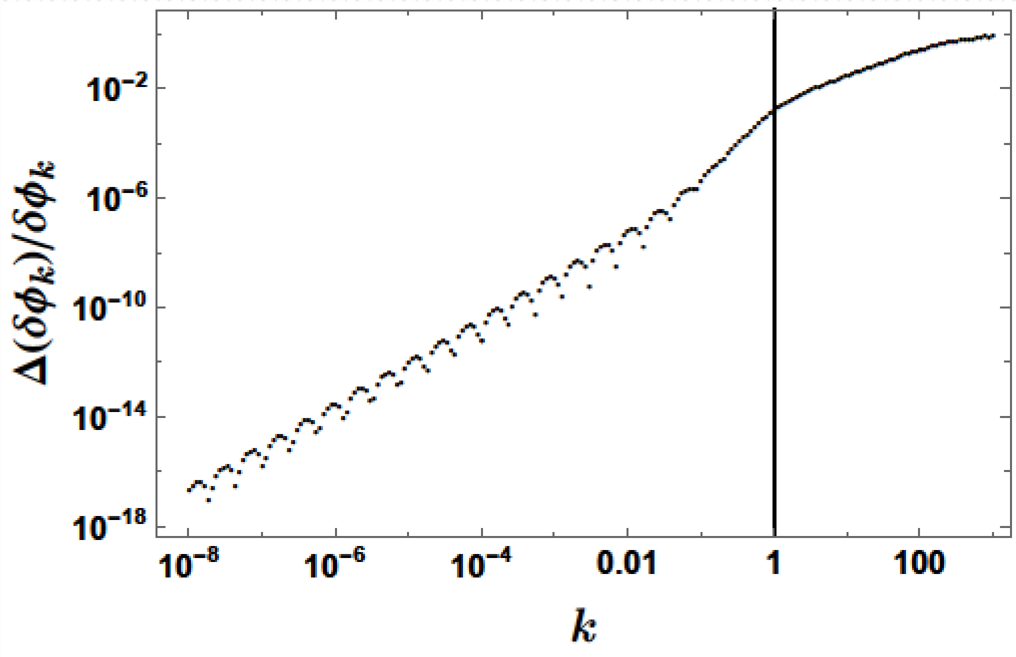
- Power law inflation: relative change in (tensor) spectrum



- Effect is linear in (Planck length/Hubble length)
- Plus characteristic oscillations.

Results for sharp covariant cutoff

- However, this was assuming decoherence at horizon crossing!



- If decoherence at re-heating, then spectrum is very robust.

Summary

- Quantum noise knows all about curvature
- Metric expressible through Feynman propagator
- Covariant natural UV cutoff ➔

  Oscillations in inflationary predictions for CMB