Trans-Planckian Physics in Quantum Cosmology

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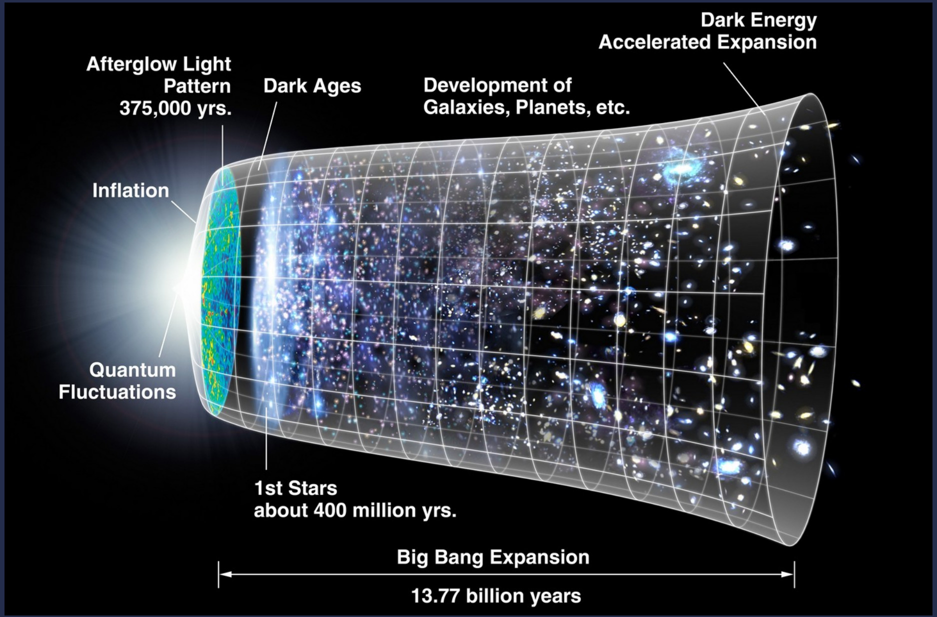
IPARCOS

⟨G|ℏ⟩ Quantum Fields & Gravity Group

01

The Trans-Planckian problem in Cosmology

The Universe is expanding!



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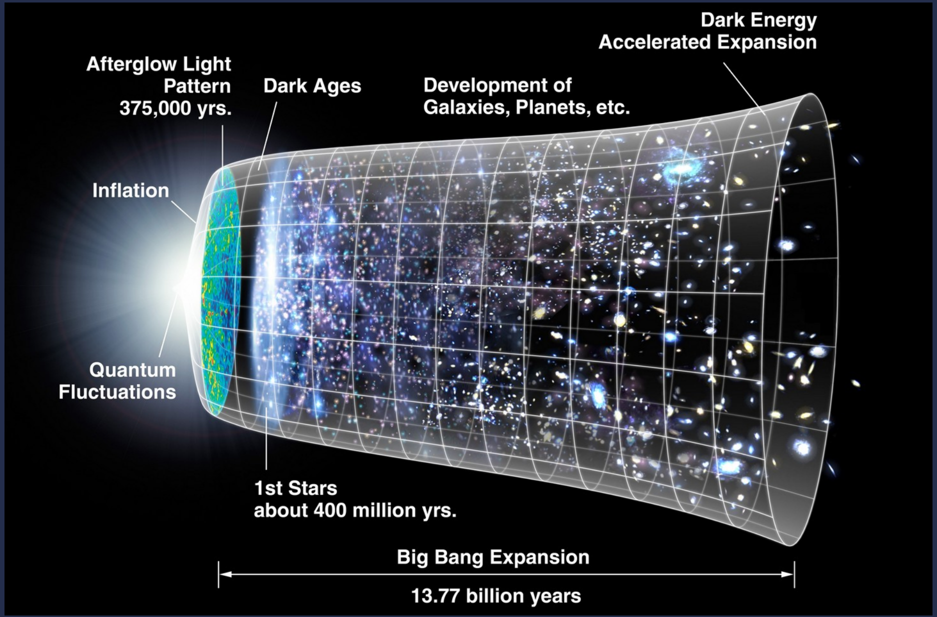

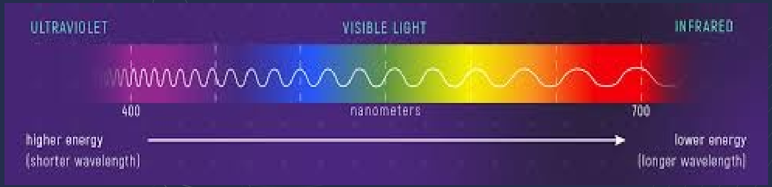

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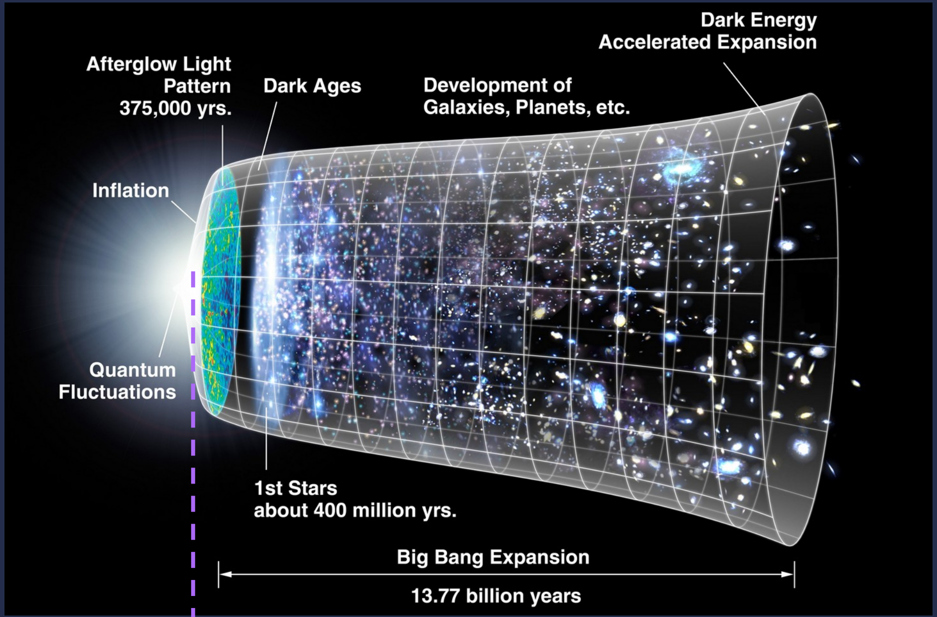
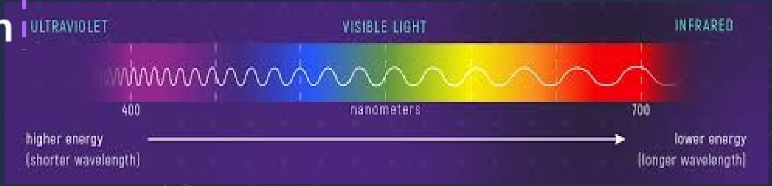


Planck's length
L_P



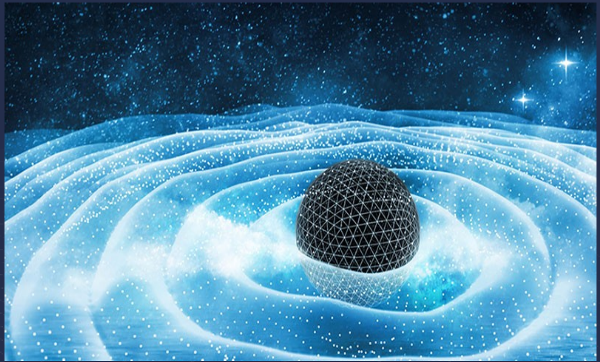
At Planck's length we are entering in the framework of Quantum Gravity. Then... what about cosmological predictions?

02
Semiclassical Gravity

Quantum fields in curved spacetimes

Semiclassical Einstein's equations

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G\left(T_{\mu\nu}^{cla} + \langle T_{\mu\nu} \rangle\right)$$



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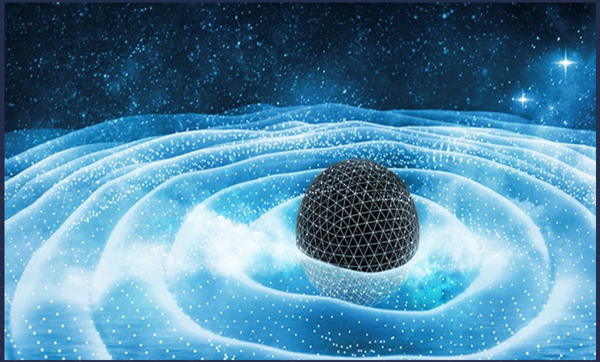

Einstein's tensor. Responsible for the curvature of the spacetime. Purely classical.

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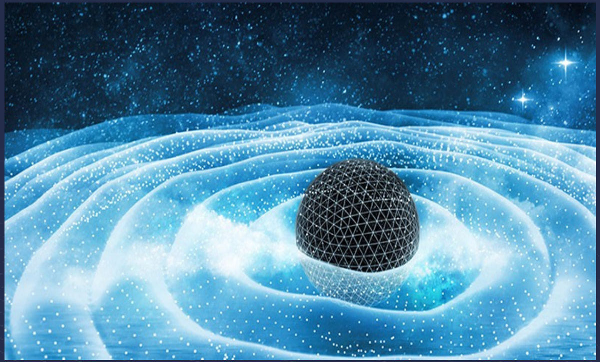

Vacuum expectation value of the stress-energy tensor. It contains information about the QFT. Purely quantum.

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Semiclassical Einstein's equations

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G\left(T_{\mu\nu}^{cla} + \langle T_{\mu\nu}\rangle\right)$$

1. Energy of the particles $E \ll \frac{1}{L_P}$ (**no quantum gravity**)
2. Negligible *backreactions* $|\langle T_{\mu\nu}\rangle| \ll \frac{1}{L_P^2}$ (**no changes in the geometry** from QF)
3. Low curvature $R \ll \frac{1}{L_P^2}$ (the background $g_{\mu\nu}$ is fixed, i.e., **no quantum fluctuations**)

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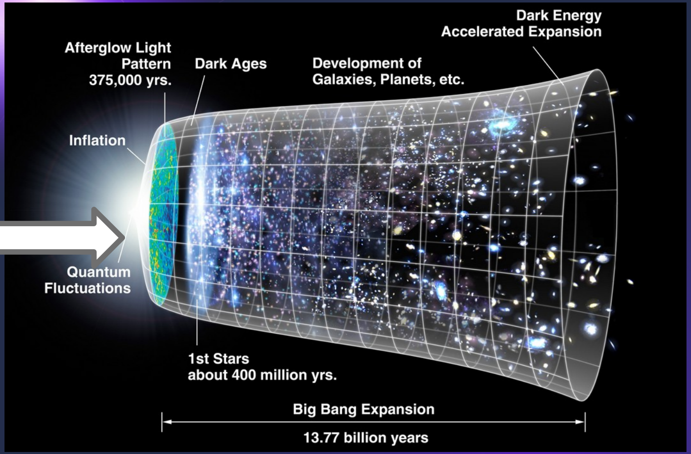
It breaks down here



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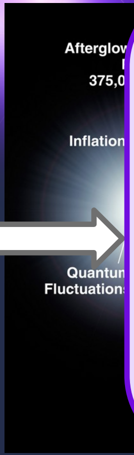
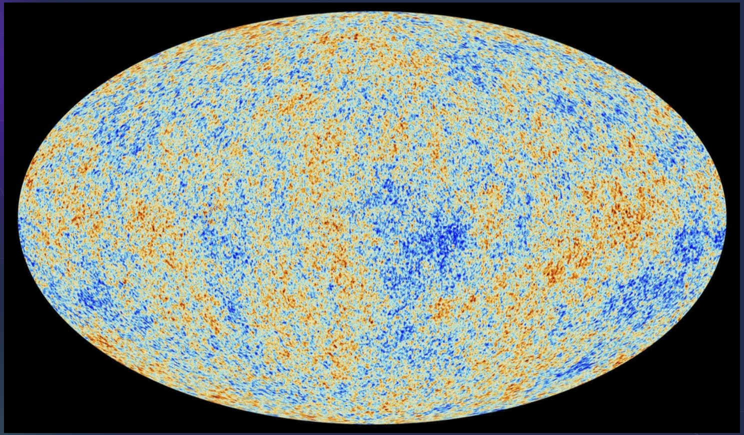


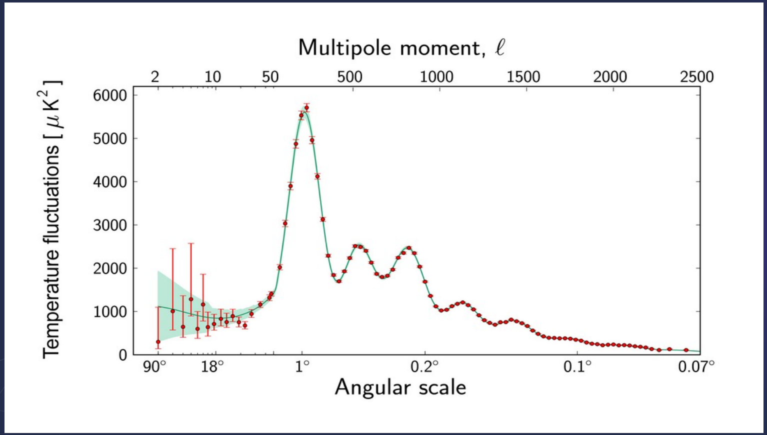
TRANS-PLANCKIAN PROBLEM IN COSMOLOGY

03
Cosmology

A quick overview of the problem

The standard study of the Cosmos using QFTCS give rise to one of the most impressive predictions in Cosmology, the Cosmological Microwave Background (CMB) and its power spectrum





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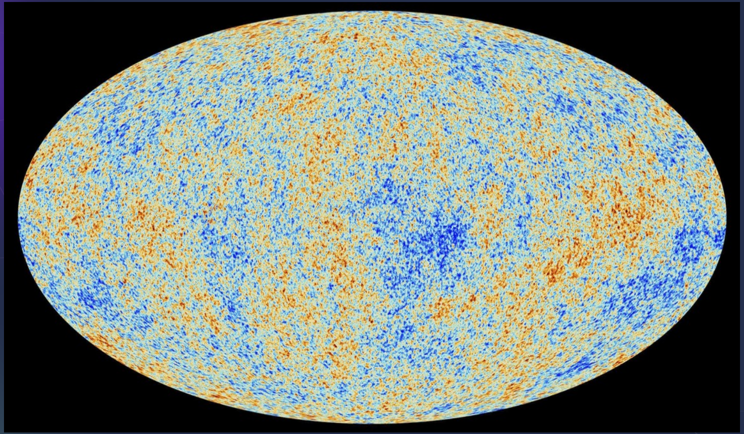
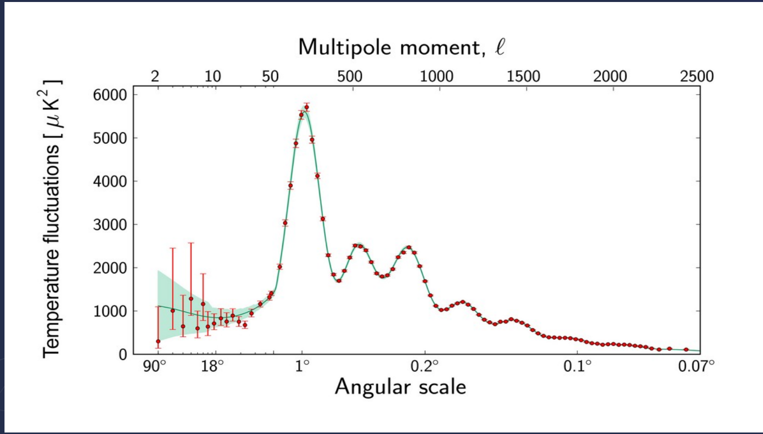




And what about the trans-Planckian problem?

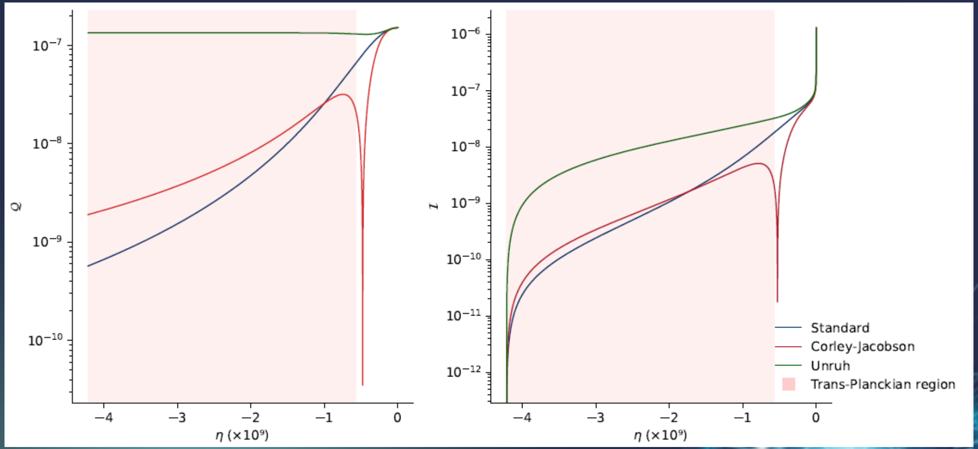
04
In this thesis

1. Energy of the particles $E \ll \frac{1}{L_P}$ (no quantum gravity)

i) Near L_P quantum gravity effects are expected

ii) The expression for “the energy of the particles”, what is called standard *dispersion relation* should be changed. In the literature this is done by introducing *ad hoc* the so called *modified dispersion relations (MDRs).*

iii) Is the CMB compatible with this change?



2. Negligible *backreactions* $|\langle T_{\mu\nu}\rangle| \ll \frac{1}{L_P^2}$ (no changes in the geometry from QF)

i) Under what circunstances the backreactions are negligible?

ii) Physical quantities (like $\langle T_{\mu\nu}\rangle$ and $\langle\phi^2\rangle$) are divergent, therefore, must be regularized and renormalized. We have developed a new regularization method and we are collaborating with other members of IPARCOS

iii) Semiclassical gravity is not a perturbatively renormalizable theory with the standard disperssion relation. What happens in the presence of MDRs?

3. Low curvature $R \ll \frac{1}{L_P^2}$ (the background $g_{\mu\nu}$ is fixed, i.e., no quantum fluctuations)

Since quantum gravity effects are expected to appear at scales near L_P, our porpouse for future work is to include them. How? We plan to develop a MDR coming from a quantum theory approach, namely, from *Loop Quantum Gravity.*

In this approach, spacetime itself becomes quantum and, therefore, we expect that a natural dispersion relation arises from the theory. In this scenario, we could test the robustness of the Power Spectrum and the renormalizability of the resulting semiclassical limit

Conclusions

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As future work, we want to derive a MDR based on LQG

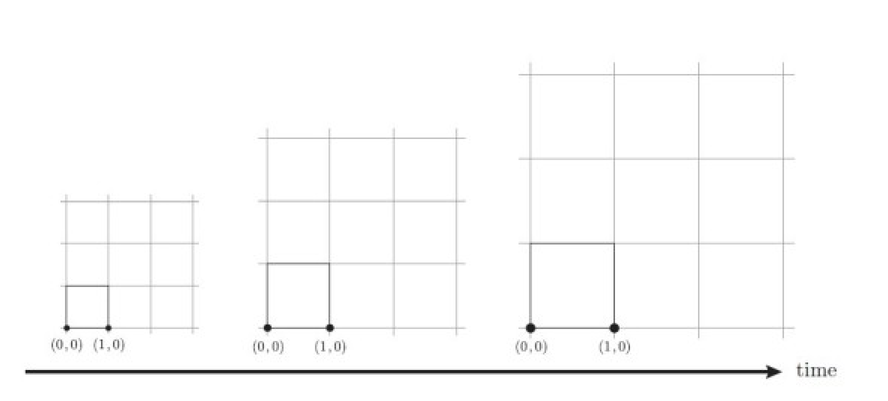

"That's all Folks!"

Back up slides

Cosmological spacetime FLRW

$$ds^2 = -dt^2 + a^2(t)d\vec{\mathrm{x}}^2$$

Cosmological redshift



$$L_{\mathrm{fis}}(t) = a(t)L_{\mathrm{com}}$$

$$\mathrm{k}_{\mathrm{fis}}(t) = \frac{\mathrm{k}_{\mathrm{com}}}{a(t)}$$

Canonical quantization: Real scalar field

$$(\Box - m^2)\phi = 0$$

After the expanssion in modes, the temporal satisfies

$$\ddot{F}_k + \omega_k^2 F_k = 0$$

with

$$\omega_k^2 \equiv \left(\frac{k}{a}\right)^2 + m^2 + \sigma, \qquad \sigma \equiv -\frac{3}{2}\frac{\ddot{a}}{a} - \frac{3}{4}\frac{\dot{a}^2}{a^2}$$

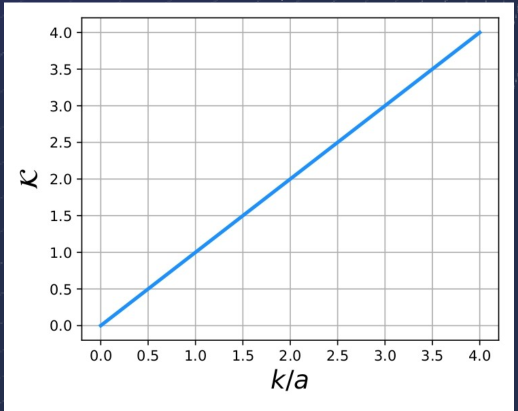
Back up slides

MDRs:

$$\omega_k^2 = \mathcal{K}^2 + m^2 + \sigma\,, \quad \mathcal{K} \xrightarrow[k\to 0]{} k/a$$

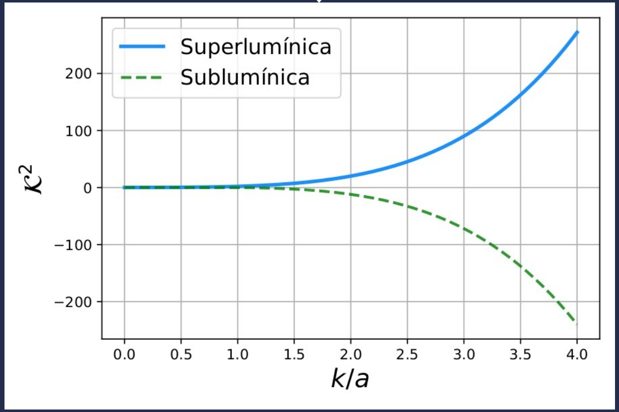
Standard

$$\mathcal{K} = k/a$$



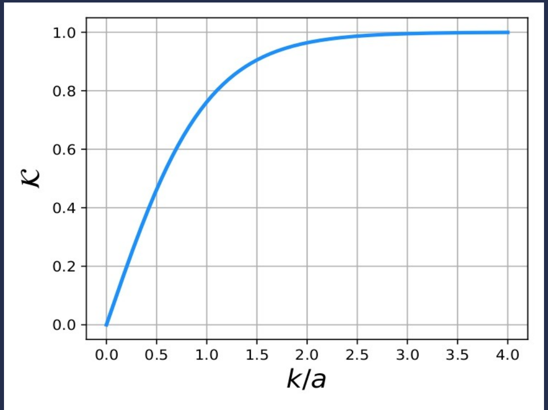
Corley-Jacobson

$$\mathcal{K}^2 = \frac{k^2}{a^2}\left(1 \pm \frac{k^2}{a^2\kappa_c^2}\right)$$



Unruh

$$\mathcal{K} = \kappa_c \tanh\left(\frac{k}{a\kappa_c}\right)$$



Back up slides

Density of states

$$\rho_k \equiv \left|\frac{dk}{d\omega_k}\right|$$

Standard

$\rho_k \sim const.$

Superluminal

$$\rho_k \sim \frac{a\kappa_c}{k}$$

Unruh

$$\rho_k \sim \cosh^2 \frac{k}{a\kappa_c}$$