Title: Tempus Discretum: On the nature of cosmic time

Speakers: Niayesh Afshordi

Collection/Series: Lee's Fest: Quantum Gravity and the Nature of Time

Date: June 04, 2025 - 9:45 AM

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Abstract:

What if the cosmic clock actually ticks? In this talk, I will explore growing evidence—from the structure of the cosmos to the frontiers of quantum gravity—that time may not be continuous, but fundamentally discrete. By rethinking the flow of time as a sequence of quantized events, we uncover surprising connections that challenge our classical intuitions and open new paths in fundamental physics.

Tempus Discretum

On the nature of cosmic time

Niayesh Afshordi

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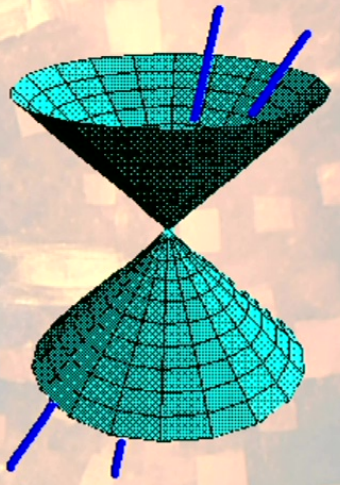
PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

The problem with Relativistic Causality, Locality



- ***Big Bang:***
  - Cosmological horizon problem
  - Superhorizon scale-invariant correlations
- ***Black Holes:*** Information (aka Firewall) paradox
- ***Vacuum:*** Cosmological constant problems
- ***Quantum Mechanics:*** Bell's inequalities and non-local realism (Antony's talk, yesterday)
- ***Non-Renomalizability of Quantum Gravity***

arXiv > astro-ph > arXiv:0807.2639

Astrophysics

[Submitted on 16 Jul 2008]

Gravitational Aether and the thermodynamic solution to the cosmological constant problem

Niayesh Afshordi (Perimeter Institute)

arXiv > hep-th > arXiv:0904.4841

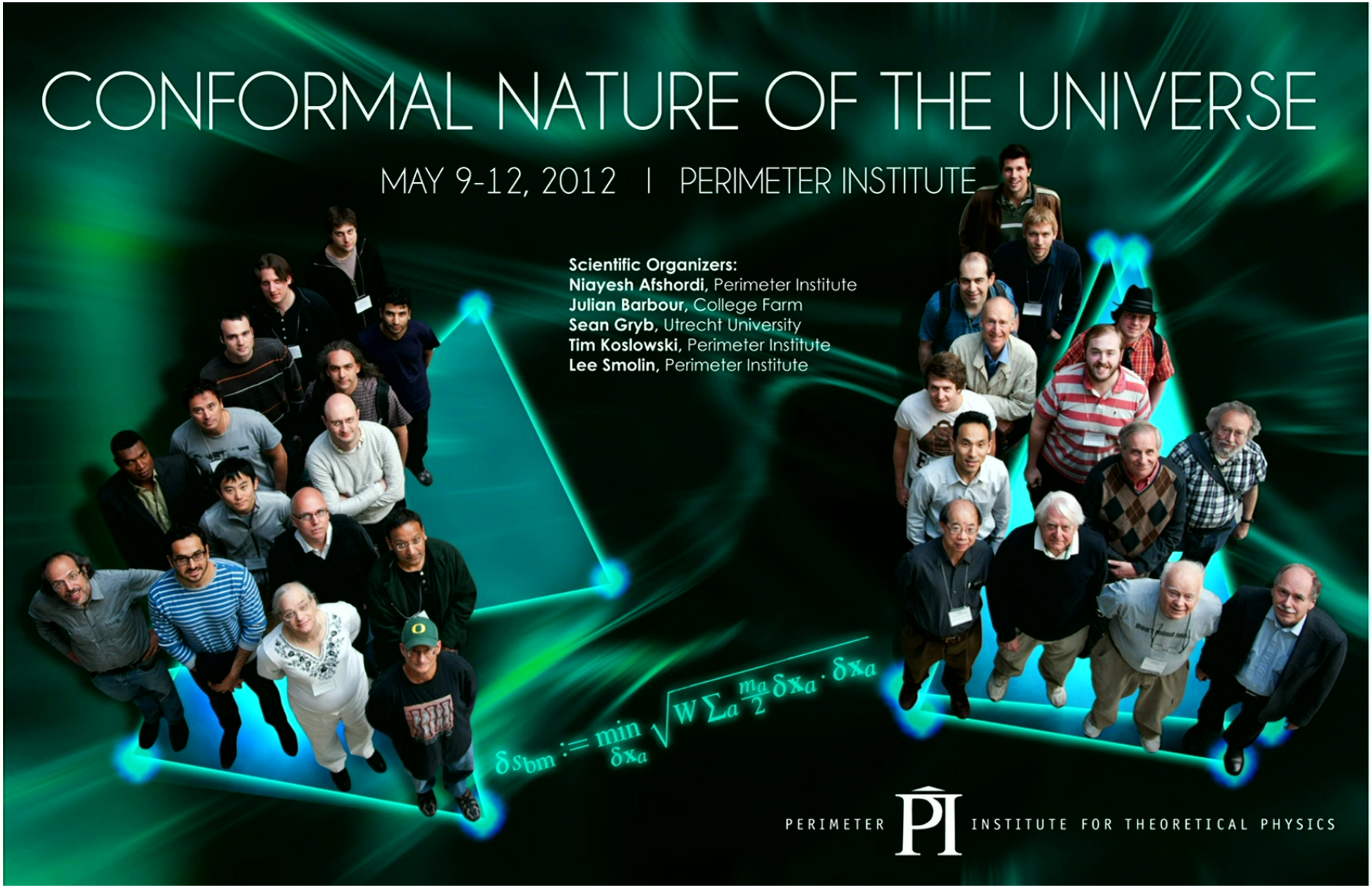
High Energy Physics - Theory

[Submitted on 30 Apr 2009]

The quantization of unimodular gravity and the cosmological constant problem

Lee Smolin

- It has been said that there is a strong case for multiverse cosmologies and the anthropic principle, because they provide the only known solution to the cosmological constant problem. To the extent that proposals such as Afshordi's[1] and the present solve one and perhaps all of the cosmological constant problems, this argument cannot be made.


CONFORMAL NATURE OF THE UNIVERSE
MAY 9-12, 2012 | PERIMETER INSTITUTE
Scientific Organizers:
Niayesh Afshordi, Perimeter Institute
Julian Barbour, College Farm
Sean Gryb, Utrecht University
Tim Koslowski, Perimeter Institute
Lee Smolin, Perimeter Institute
$\delta s_{bm} := \min_{\delta x_a} \sqrt{W \sum_a \frac{m_a}{2} \delta x_a \cdot \delta x_a}$
PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS

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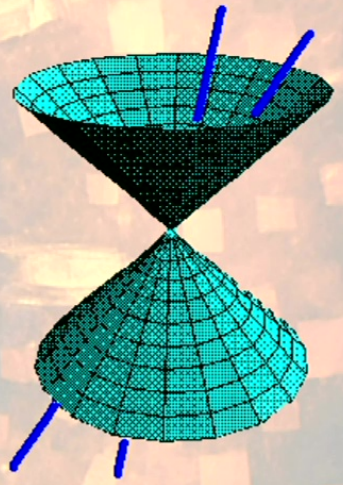

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What if the cosmic clock actually ticks?

(Effective) Cuscuton Theory; *aka spacetime soap bubbles*

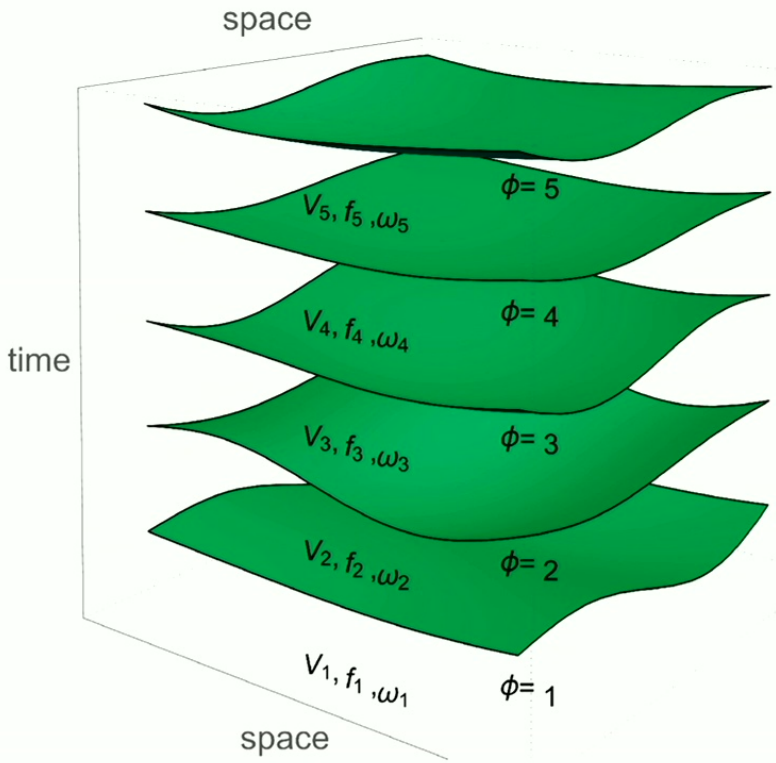
NA, Chung & Geshnizjani 2006; NA & Mylova 2024

- Covariant action for "discrete time" interfaces

$$
\begin{aligned}
S_\varphi &= \int d^4x\sqrt{-g}[\mu^2\sqrt{|g^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi|} - V(\varphi)] \\
&= \int d^4x\sqrt{-g}[\mu^2\frac{|g^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi|}{\sqrt{|g^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi|}} - V(\varphi)] \\
&= \int d^4x\sqrt{-g}[\mu^2|u^\mu\partial_\mu\varphi| - V(\varphi)] \\
&= \mu^2\int_\varphi d\varphi\ \Sigma(\varphi) - \int d^4x\sqrt{-g}V(\varphi)
\end{aligned}
$$

Surface Tension — Pressure difference

Surface term — Volume term



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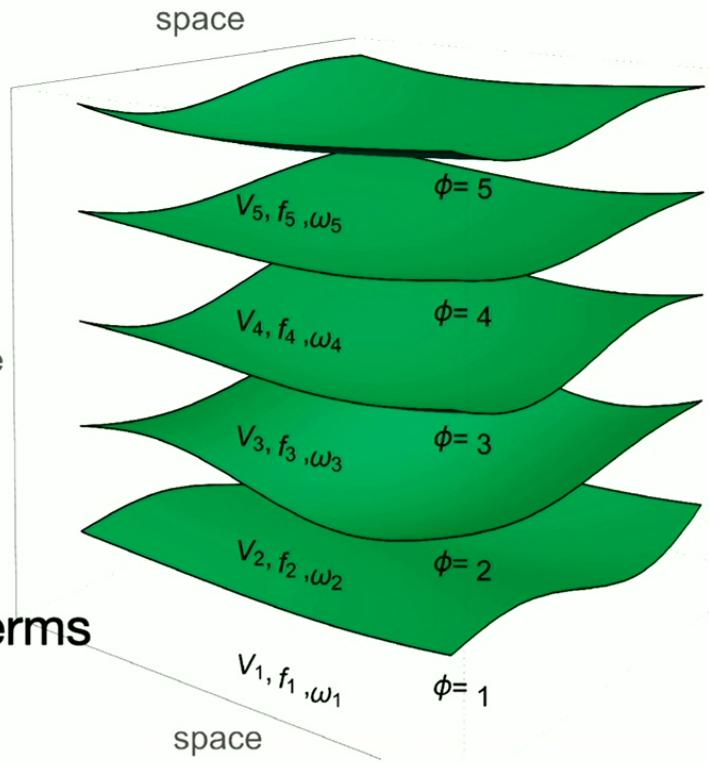
\end{aligned}
$$

Surface Tension — Surface term

Pressure difference — Volume term

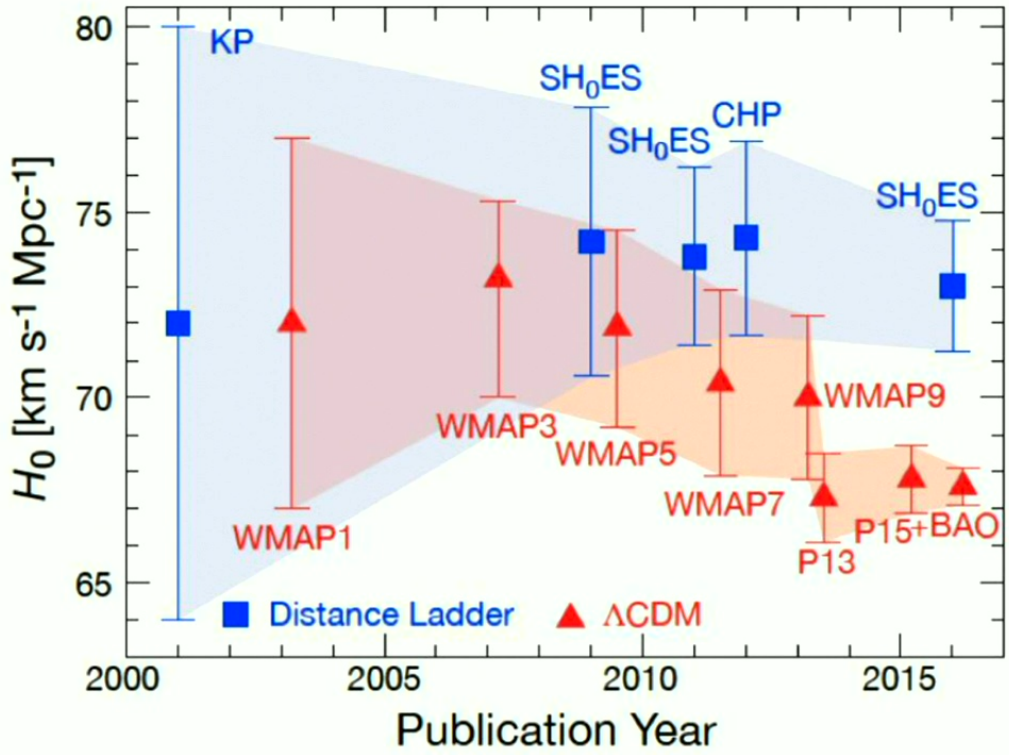


Does the cosmic clock violate Lorentz symmetry?

- $E \propto p^3$ @high energies → Renormalizability (Horava 2009)
- Unique single-parameter extension of GR in IR (NA 2009; Loll & Pires 2014), if
  - *No new degree of freedom*
  - *No new scale*
  - Only distinguishable from GR on cosmic scales: $G_{\text{Newton}} = G_{\text{Friedmann}}\left[1 + \frac{3}{2}(\lambda - 1)\right]$
  - Horava → quadratic cuscuton: $S_{\text{GR}} + \frac{\lambda - 1}{8\pi G_{\text{Newton}}} \int d^4x \sqrt{-g} \left(\sqrt{\partial^\mu \varphi \partial_\mu \varphi} + \frac{\varphi^2}{2} \right)$
  - Non-dynamical, sound speed →∞

Lee: Niayesh thinks everything is cuscuton!

Hubble Tension in Standard Cosmology

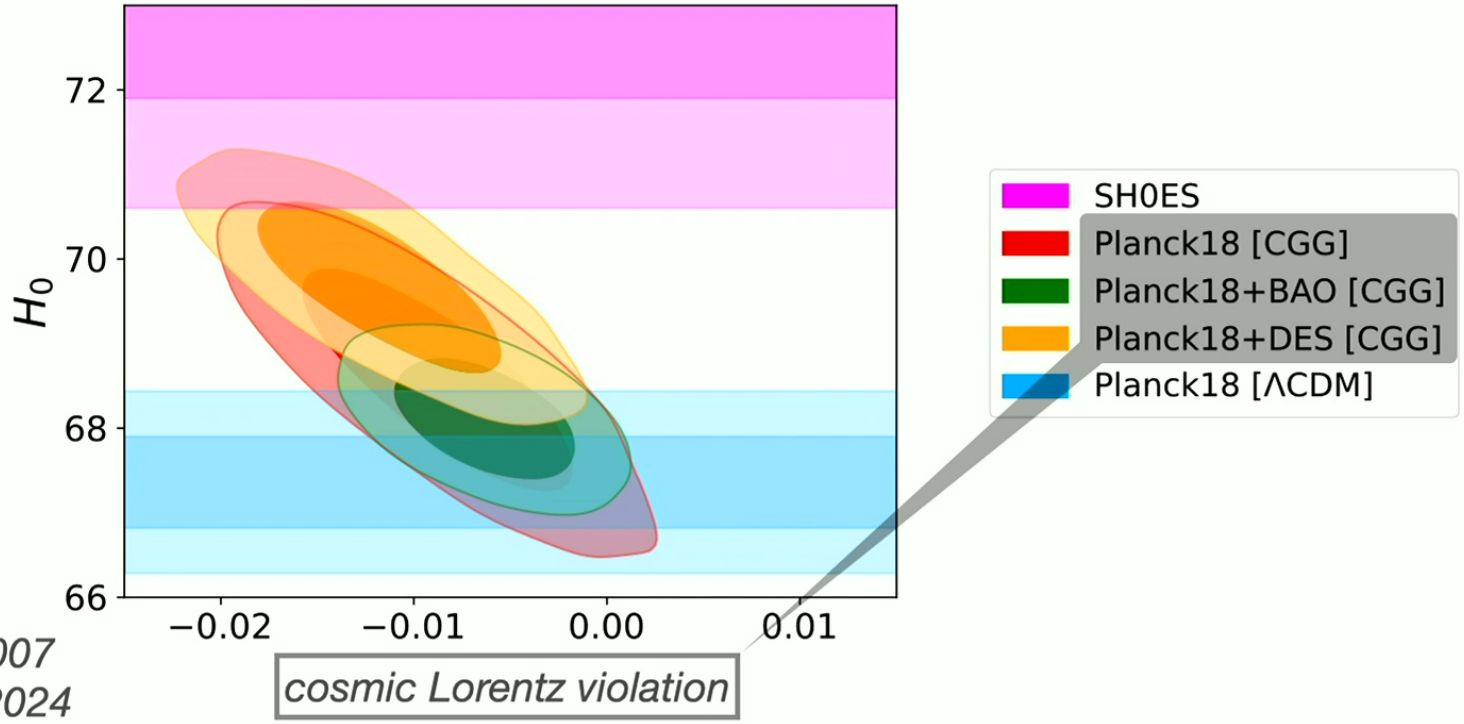


Freedman 17

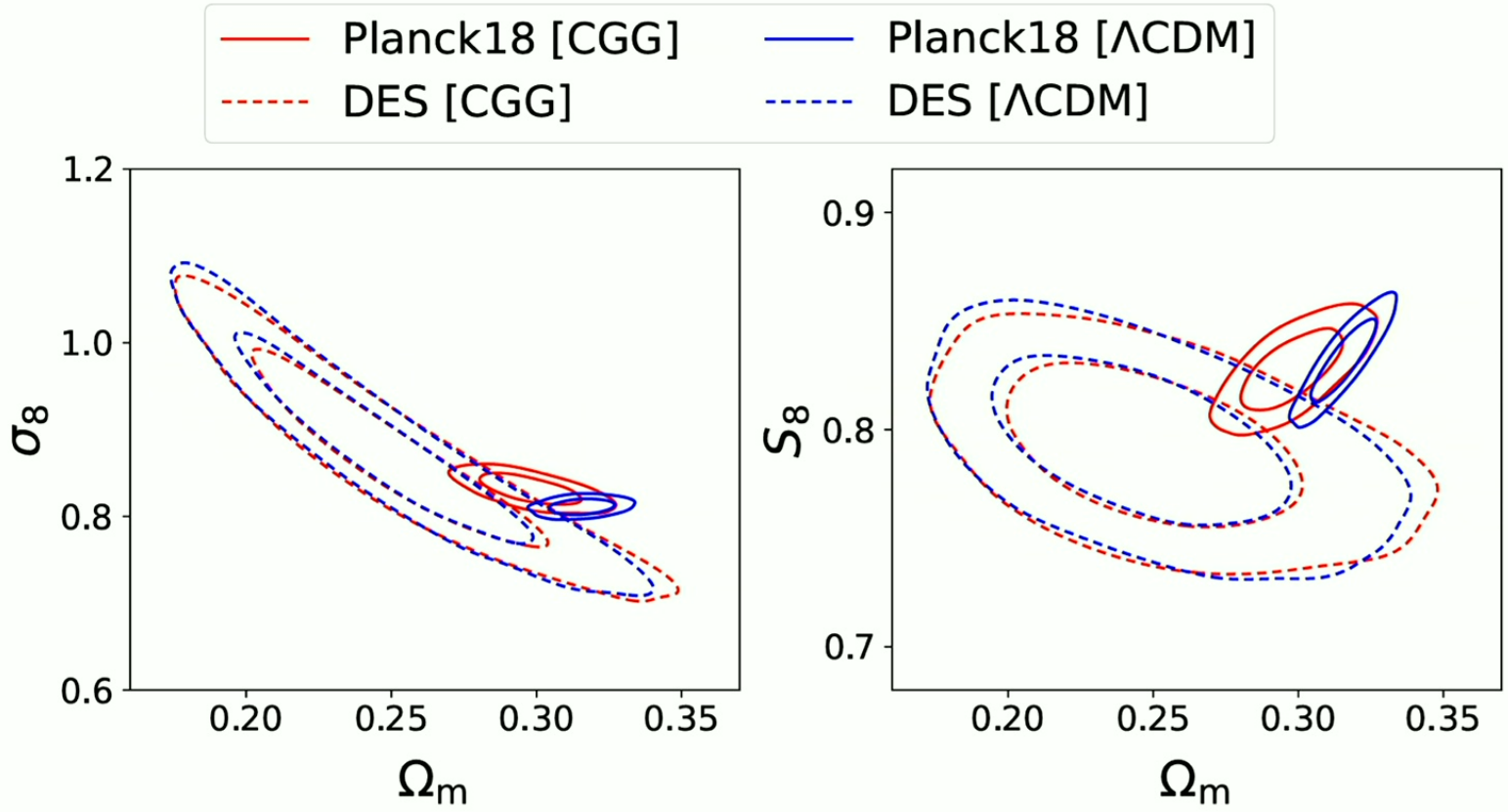
Quantum Gravity and Hubble Tension:
A Cosmic Glitch in Gravity

- Can Hubble tension be a signature of Lorentz violation in the theory of gravity?

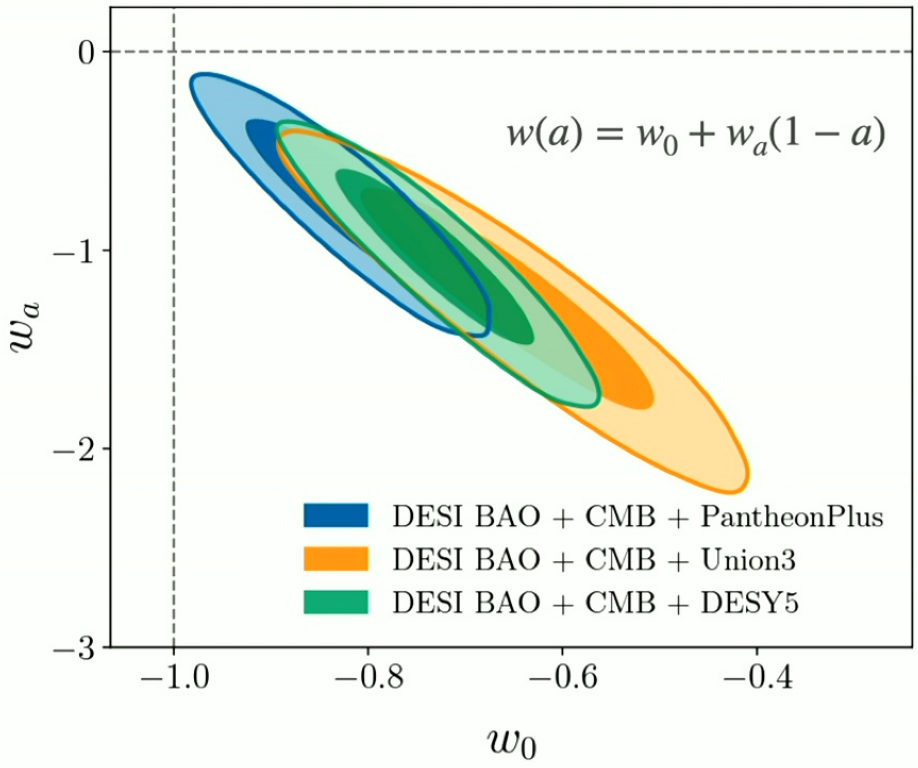
Robbers, NA & Doran, 2007
Wen, Hergt, NA & Scott, 2024



S_8 tension

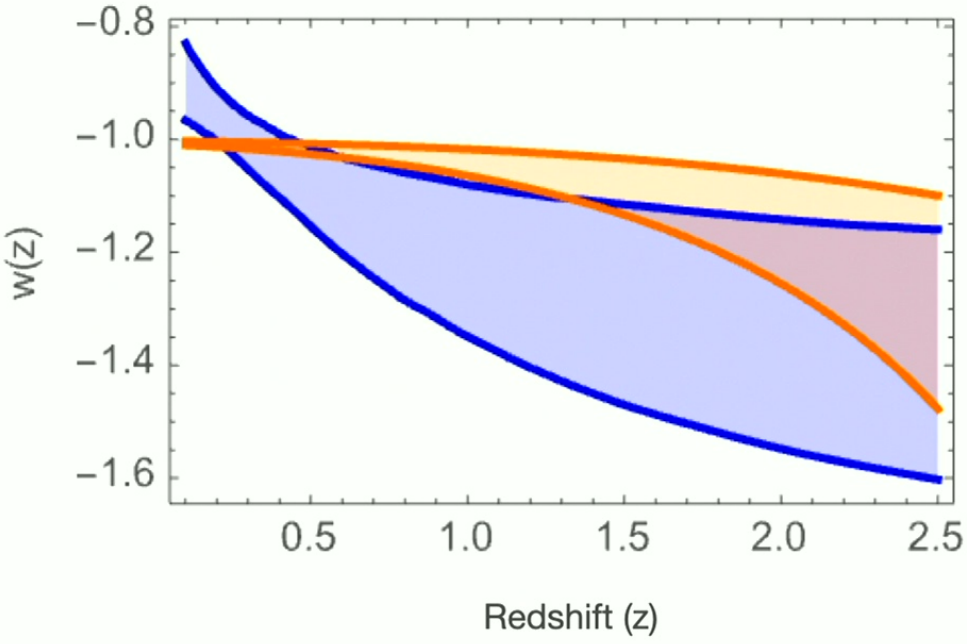

Planck18 [CGG]
DES [CGG]
Planck18 [ΛCDM]
DES [ΛCDM]
1.2
1.0
0.8
0.6
σ_8
0.20
0.25
0.30
0.35
Ω_m
0.9
0.8
0.7
S_8
0.20
0.25
0.30
0.35
Ω_m

DESI tension?



DESI collaboration 2024
DESI collaboration 2025

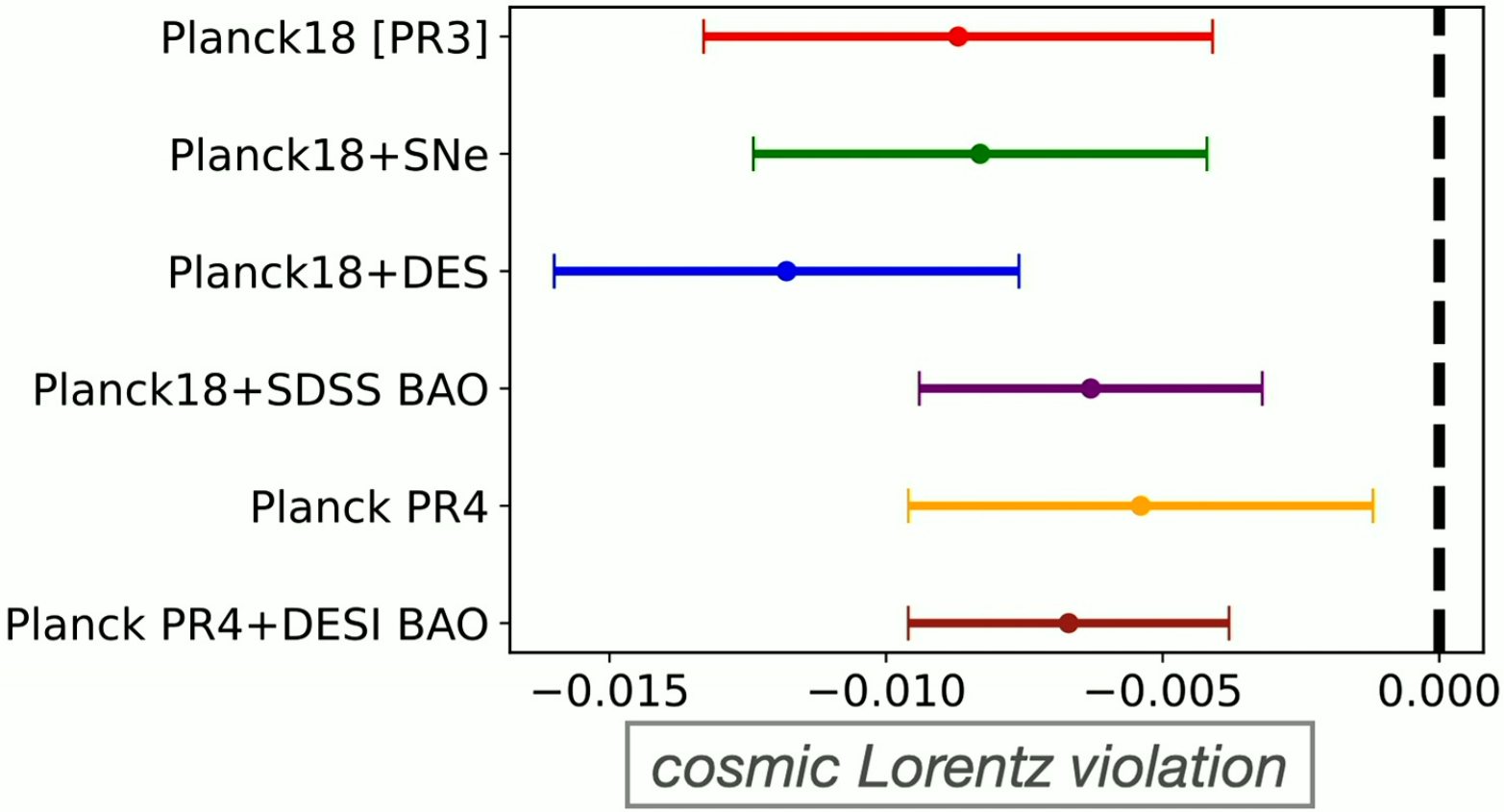
:



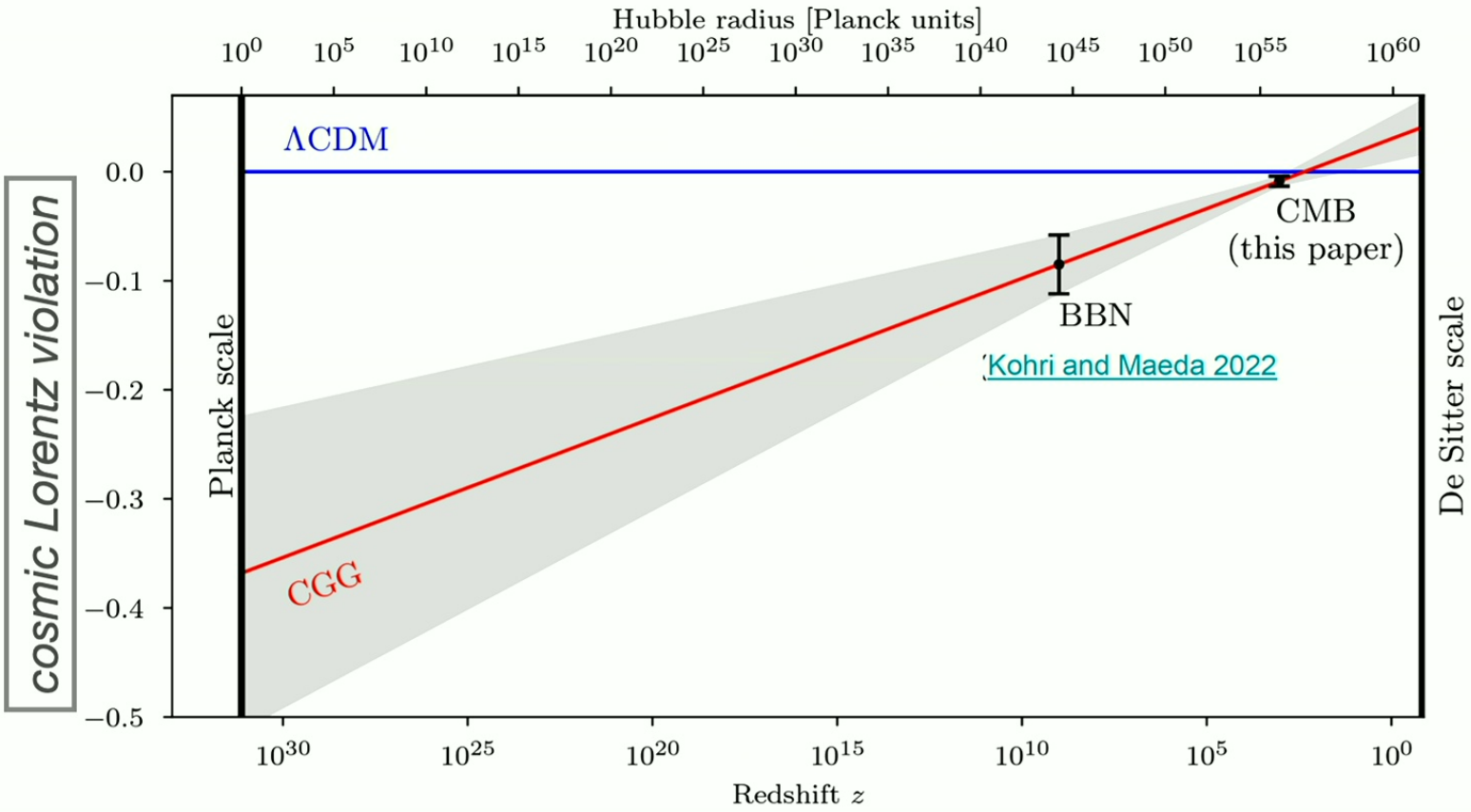
DESI+CMB+Panthoen (w0−wa)
DES+CMB (CGG)
(90% confidence intervals)

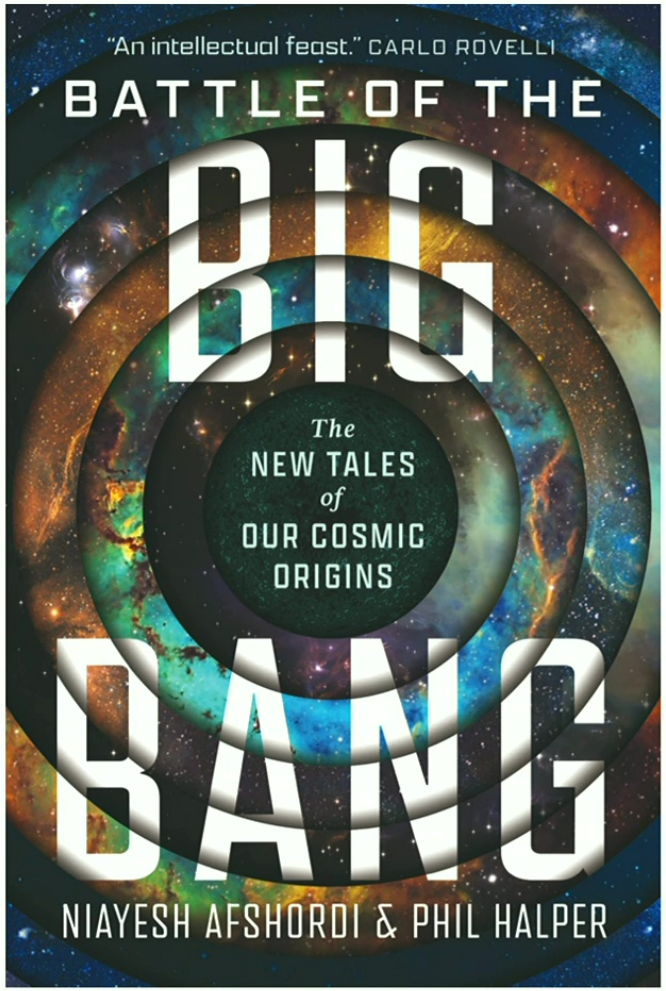
Is gravity weaker on superhorizon scales?

(Horava's little λ-1)



Running of Lorentz violation w/ scale?





- Published last week!
- See public talk tonight

Tempus Discretum: An aether revival

- **Horava-Lifshitz gravity:** $\text{Energy} \propto \text{momentum}^3$ makes quantum gravity renormalizable (but *violates Lorentz symmetry*)
- **Dark Matter** (e.g. Magueijo, Mukohyama, …)
- **Dark Energy** (ease/resolve Hubble, S_8, DESI tensions, *solar system?*)
- **Big Bang Reference Frame** (resolve horizon/structure problems, *3pt function?*)
- **Bell's inequality:** realist quantum mechanics

Happy Birthday Lee!