

Dynamical Dark Energy from Causal Set Theory

Thomas Brosnan

5th December 2025

Outline

- ① Dark Energy
- ② Causal Set Theory
- ③ Everpresent Lambda

Dark Energy

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- This works well as in a FLRW universe, it gives rise to a constant energy density (no matter the size of the universe) and hence the scale factor grows as $a(t) \sim e^{Ht}$.

Problems with the Cosmological Constant

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$$\langle \rho \rangle \simeq 2 \times 10^{71} \text{ GeV}^4 \implies \Lambda_{\langle \rho \rangle} = 8\pi G \langle \rho \rangle \simeq 4 \times 10^{34} \text{ GeV}^2$$

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- Sometimes this is classed as the worst prediction in physics ever.

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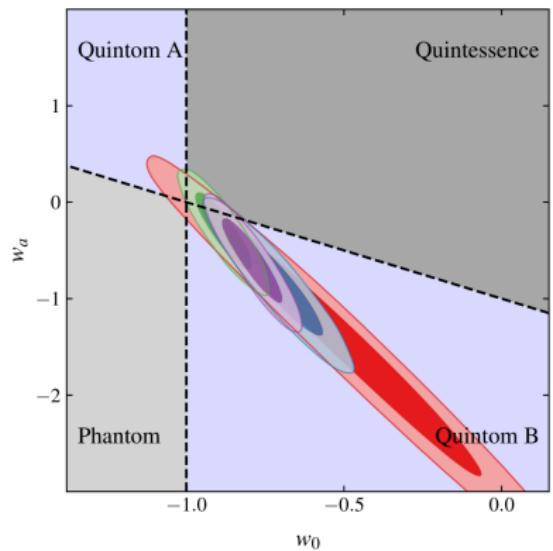
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■ DR2 ■ DR2 + PantheonPlus
■ DR2 + Union3 ■ DR2 + DESY5



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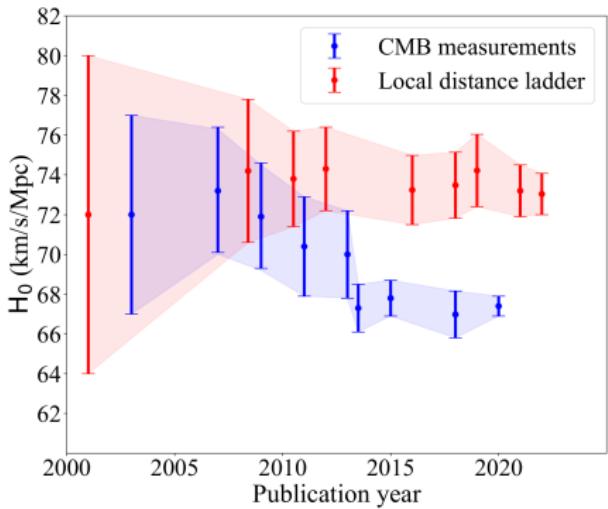
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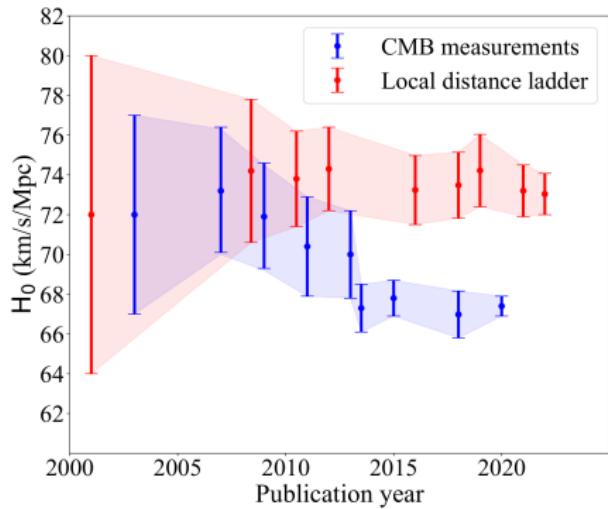
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- Even more problems: Cosmic Co-Incidence problem, why is the energy density of matter $\rho_m \simeq \rho_\Lambda$?

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- Causal Set Theory: see rest of presentation!
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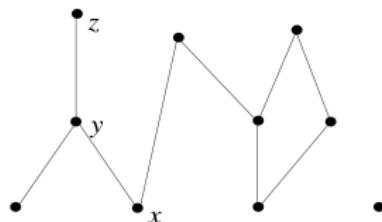
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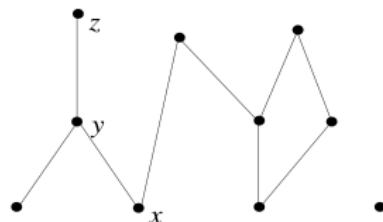
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- Two key take aways: Causal Sets are discrete and preserve causality.



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- Causal Sets can alleviate these problems while still treating spacetime in a proper manner.

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Order + number = geometry

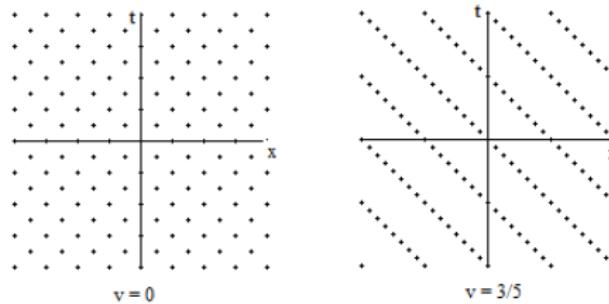
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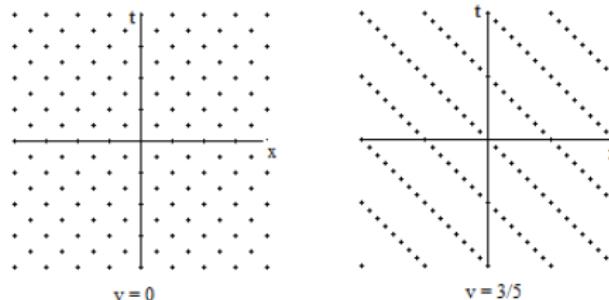
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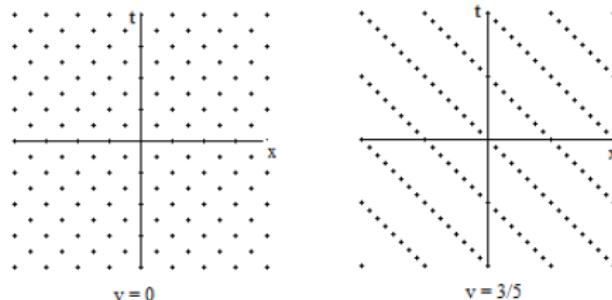
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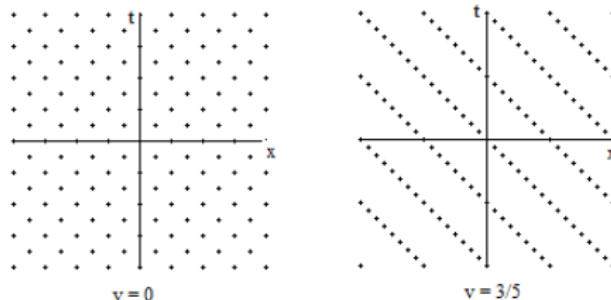


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- This is further supported by a Theorem by D.Meyer and R.Sorkin that says a causal set sprinkled into (M, g) approaches (M, g) in the infinite density limit.

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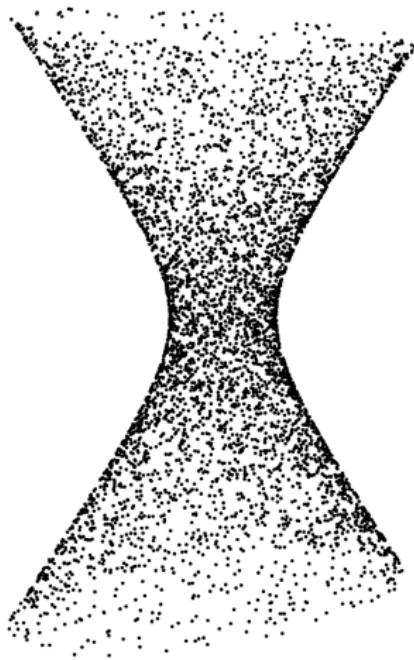
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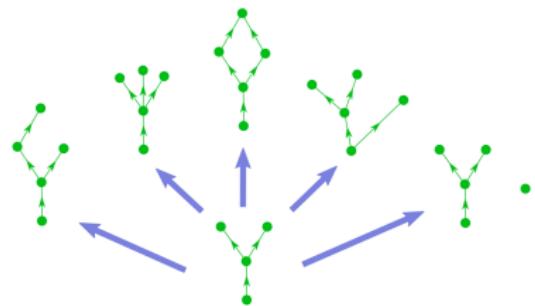
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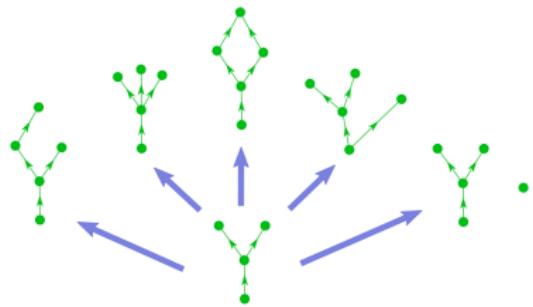
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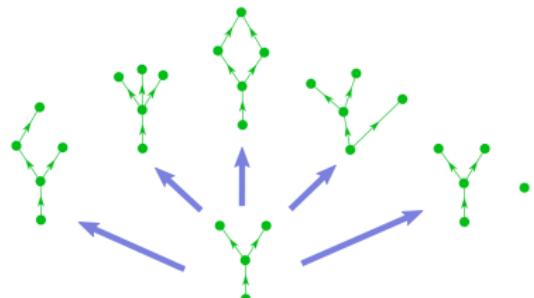
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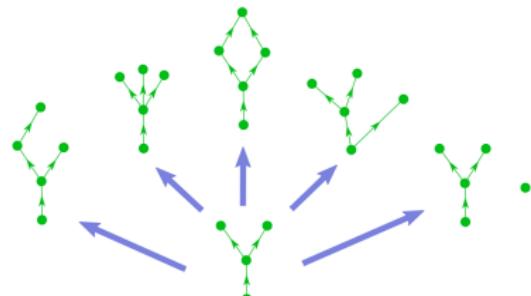
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- Following the CSG models, N and hence the volume V is kept constant. This means N (or V) plays the role of time.

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- This is analogous to the relation between $\Delta E\Delta t \sim \frac{1}{2}$ from non-relativistic QM.

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- These two together mean that a causal set with a fixed number of elements N , there are an ensemble of continuum spacetimes that it can resemble, with mean $V = \rho N$ and standard deviation $\Delta V = \sqrt{V}$.

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$$\Lambda_{CS} \simeq 1 \times 10^{-85} \text{ GeV}^2$$

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- So this was a prediction of the Cosmological Constant! Not a retrodiction. At the time Λ was believed to be 0.

Everpresent Lambda Cosmologies

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- “Everpresent Lambda” models: Λ fluctuates dynamically.

Everpresent Lambda Cosmologies

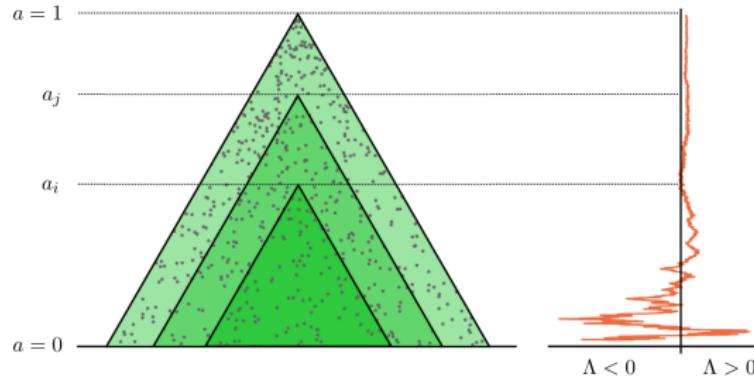
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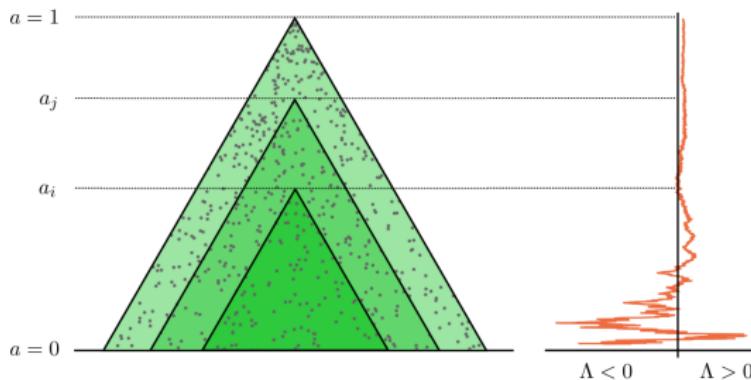
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- In these models Λ can theoretically become negative, so evidence of this would be compelling evidence for Everpresent Lambda.

Thanks for Listening!