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UNIVERSITÄT
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SEIT 1386

Cobordism and Cosmology

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Based on work in progress with Arthur Hebecker, Alexander Westphal and Sebastian Zell

Stringpheno Padova, June 25, 2024

Predictions in cosmology

Assumption: String theory describes the real world

- String theory has a multitude of solutions
- Presumably, many of them are of 'our kind'

Question: In which vacuum do we live?

Fundamental issue: 'Everything that can happen, will happen, infinitely many times'

The Measure Problem [Linde and Mezhlumian, 1993, Freivogel, 2011]

The Local Wheeler-DeWitt Measure [Friedrich et al., 2022] c.f. [Nomura, 2011, Nomura, 2012]

Idea: Use quantum mechanics to define a probability measure

Local Wheeler-DeWitt Measure:

- State of the universe: $\Psi \in \mathcal{H} = \bigoplus_{i \in \text{vacua}} \mathcal{H}_i$
- Local: Only region within the horizon is relevant
- *Cosmological central dogma*: $\mathbf{dim}(\mathcal{H}_{\text{dS}}) = \mathbf{exp}(\boldsymbol{S_{dS}})$

  [Banks, 2001, Susskind, 2021]
- WDW equation: $H\Psi = \chi$

Making Predictions:

$$\frac{\langle \Psi | \, P_\alpha \, | \Psi \rangle}{\langle \Psi | \, P_\beta \, | \Psi \rangle} \, .$$

Probability for 'finite-dimensional vacua':

$$J_i = \sum_{j \, \in \, dS} \left(p_i \Gamma_{i \to j} - p_j \Gamma_{j \to i} \right) + \; p_i \sum_{y \, \in \, \textit{Terminals}} \Gamma_{i \to y}$$

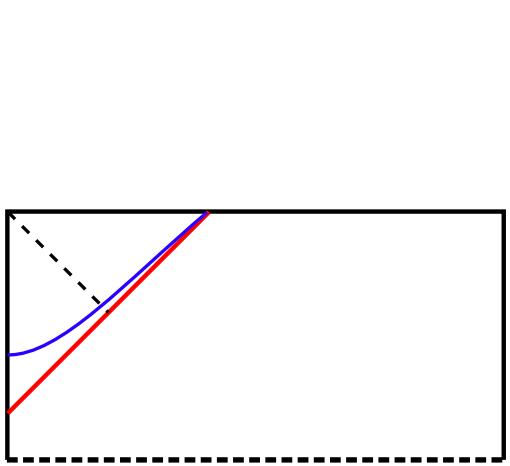
Projecting on observers

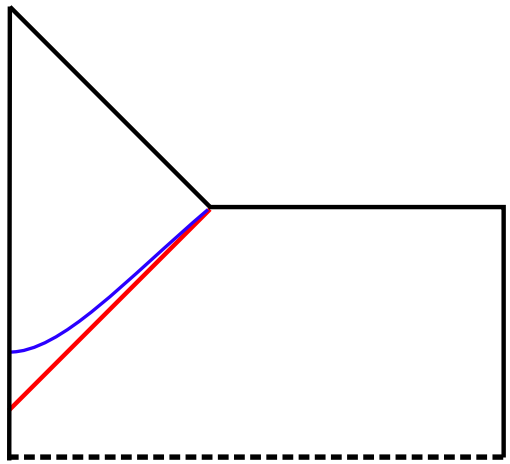
Problem: Ψ is not normalizable

Potential solution: After projection on observers, $P_{\rm obs}\Psi$ is normalizable

Criterion: $|P_{\rm obs}\Psi|^2 < \infty$ if Ψ only describes finitely many observers

Observers from inflation



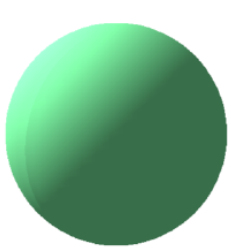
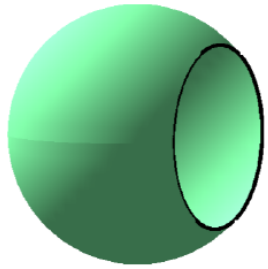
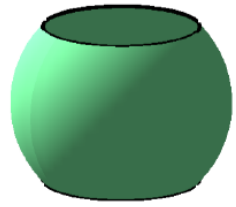
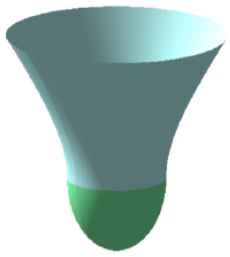
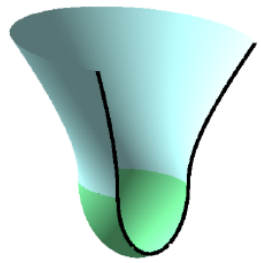
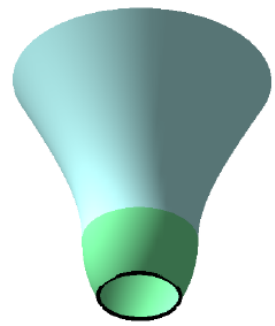


relevant size: $\dfrac{1}{H_{reh}^3}$, $\quad p(\text{obs(i)}) \propto p(\text{inf(i)}) = J_i + \sum_{o \neq i} J_o \dfrac{\Gamma_{o\to i}}{\Gamma_o} + \ldots$

Vacuum creation rates [Hartle and Hawking, 1983, Linde, 1984, Vilenkin, 1983, Vilenkin, 1984]

[Hawking and Turok, 1998, Blanco-Pillado et al., 2012, Friedrich et al., 2023, Friedrich and Hebecker, 2024]

Cobordism conjecture: ETW branes generally exist [McNamara and Vafa, 2019]

	No-Boundary (nb)	Bubble of Something (bos)	Boundary (b)
			
			
$\mathcal{S} =$	$-8\pi^2 M_P^2 \ell_{dS}^2$	$-4\pi^2 M_P^2 \ell_{dS}^2 \left(1 - \frac{T\ell_{dS}}{\sqrt{T^2\ell_{dS}^2+4M_P^4}}\right)$	$-8\pi^2 M_P^2 \ell_{dS}^2 \sqrt{\frac{T^2\ell_{dS}^2}{T^2\ell_{dS}^2+4M_P^4}}$

Predictions in cosmology: The scale of inflation

$\Gamma \propto \exp(-\mathcal{S})$ [Hartle and Hawking, 1983]

- Direct creation from nothing is most likely
- Scale of inflation is predicted to be as low as possible
- Ruled out by observation [Maldacena, 2024]

$\Gamma \propto \exp(+\mathcal{S})$ [Linde, 1984, Vilenkin, 1983, Vilenkin, 1984]

- $T\ell_{dS} \gg M_P^2$: Bubble of something
- $0 < -T\ell_{dS} \ll M_P^2$: Boundary creation
- Most likely scale of inflation is determined by tensions of ETW branes

Conclusions

- The measure problem is a fundamental challenge in theories allowing for multiple vacua
- Local approach: Initial conditions for the universe are important
- Vacuum creation rates depend on tensions of ETW branes
- Observational predictions depend on the availability of ETW branes and fundamental properties of the path integral
- 'Hartle-Hawking' choice of sign: Ruled out by observation

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Thank you!