Title: A toy model of quantum gravity in cosmological spacetimes

Date: Jun 24, 2011 09:00 AM

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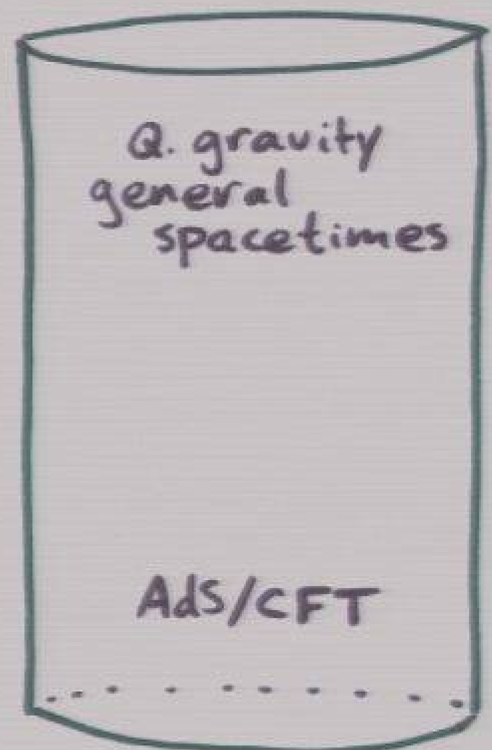
Abstract: In this talk, I attempt to gain insight into the description of quantum gravity on cosmological spacetimes by considering the physics of families of accelerating observers in spacetimes which admit non-perturbative descriptions vis AdS/CFT.

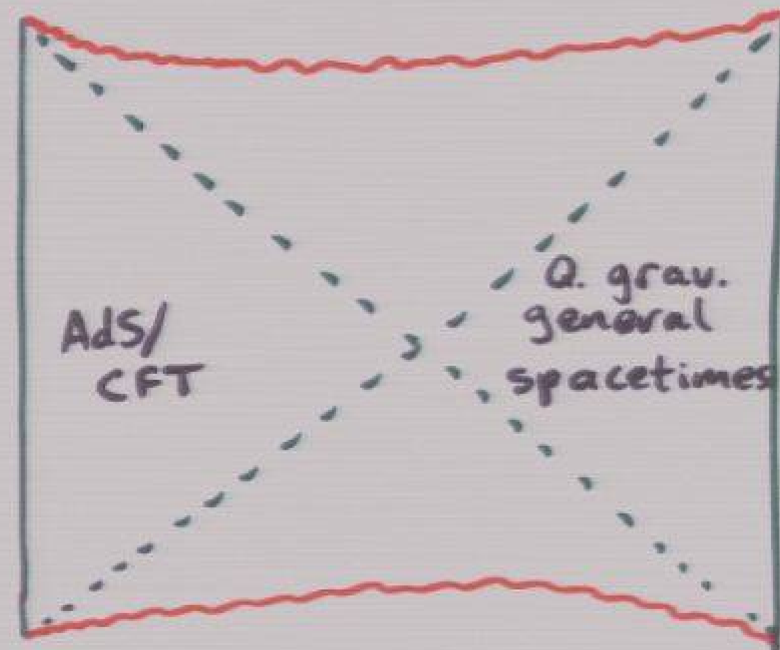
BIG QUESTION: What does a nonperturbative description of quantum gravity for general spacetimes look like?

WE KNOW: Nonperturbative description of quantum gravity for asyptotically AdS, etc...

Does this help?

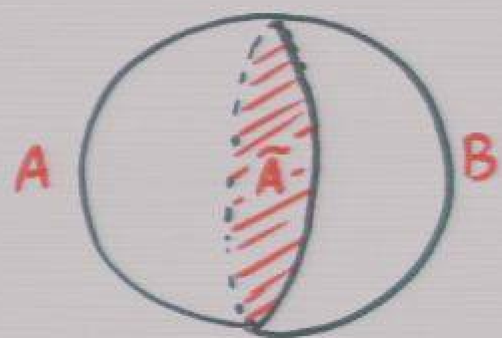
2 possibilities:



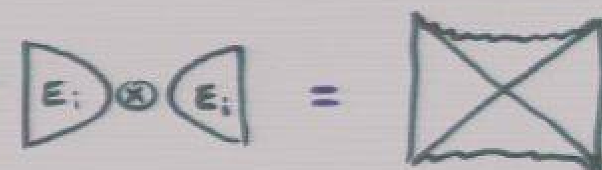


(conjectural) Lessons from AdS/CFT

I) Spacetime emerges from entangling degrees of freedom in the nonperturbative description



$\sum e^{-\beta E_i}$



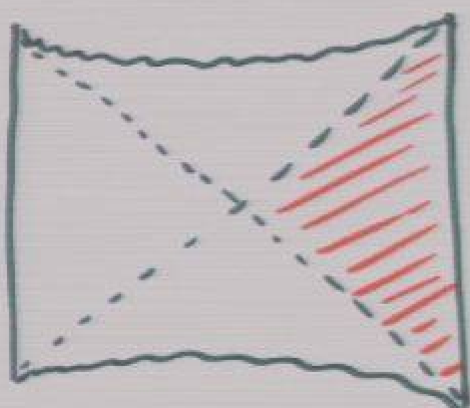
$$\frac{\text{area}(\tilde{A})}{4G_N} = \text{entanglement entropy}$$

Ryu, Takayanagi

Measures of entanglement give direct information about geometry

II) certain density matrices describe (causal) patches of spacetime

see 0907.2939

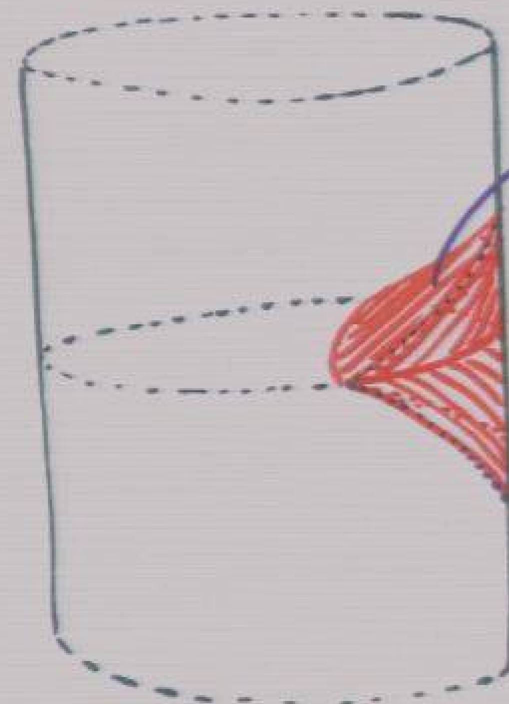


full spacetime:

$$\sum e^{-\frac{\beta E_i}{2}} |E_i\rangle \otimes |E_i\rangle \equiv |\psi\rangle$$

one side:

$$\mathrm{tr}_B |\psi\rangle\langle\psi| = \rho^A_{Th}$$

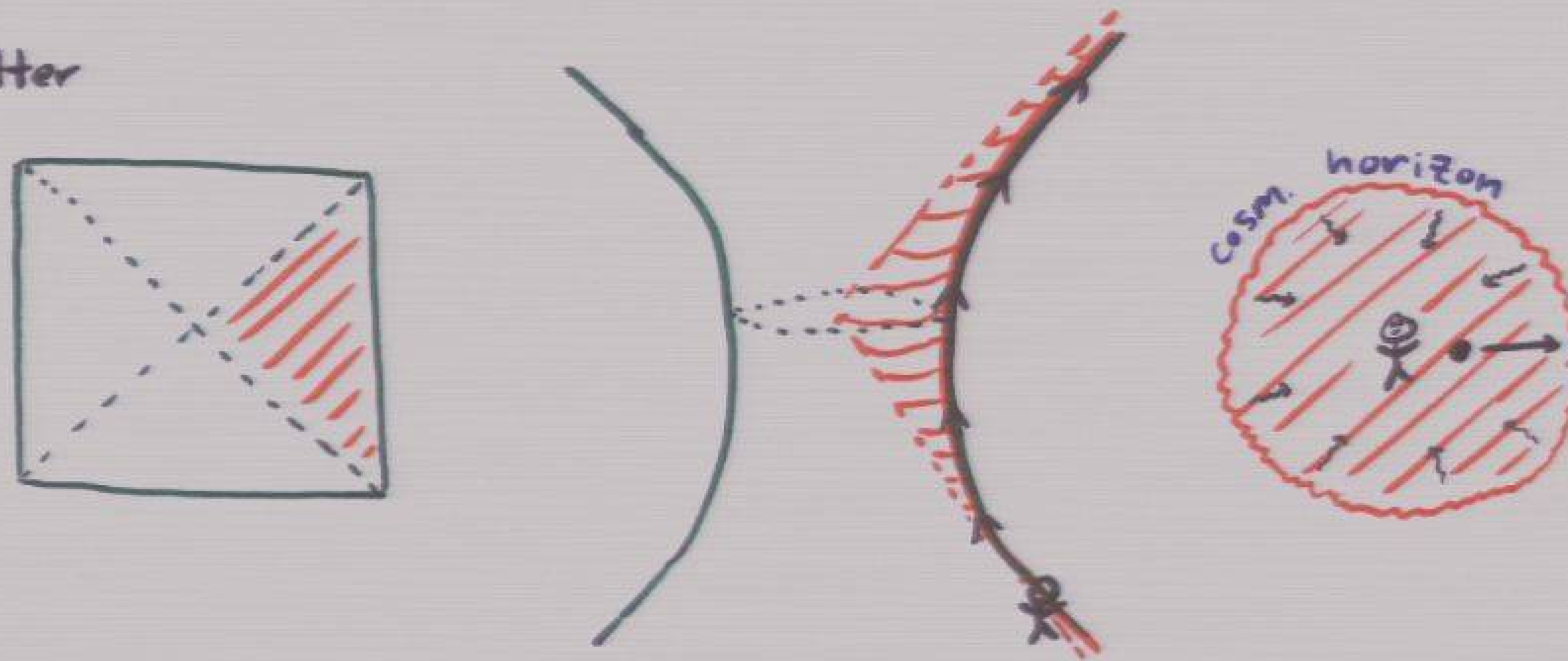


von Neumann entropy of ρ:
area of a horizon or
minimal surface

Cosmological Spacetimes

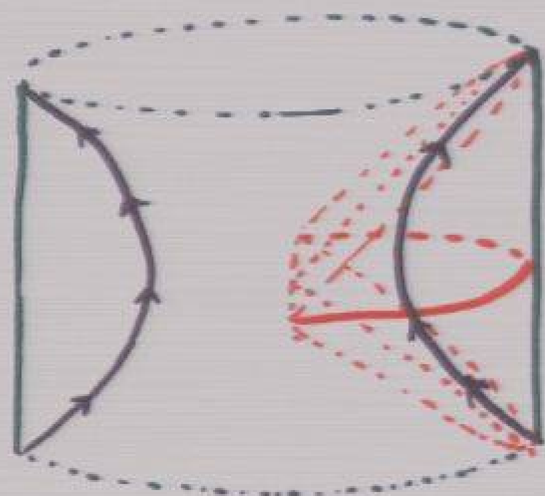
- No causal patch has complete information about spacetime

e.g. de Sitter



Plausible that data accessible to single observer encoded in density matrix for some system

AN AdS ANALOGY

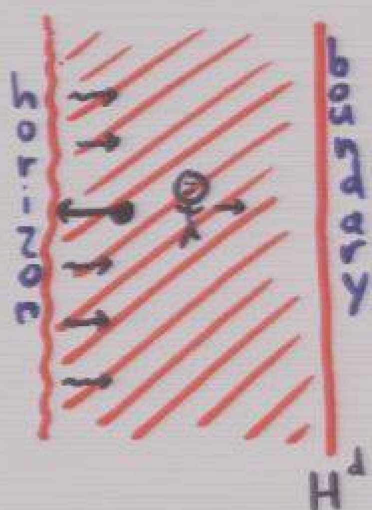


- consider family of accelerating observers in AdS
- Each one : causal patch – "hyperbolic black hole"

dual to ↓

thermal state of CFT on $H^d \times$ time

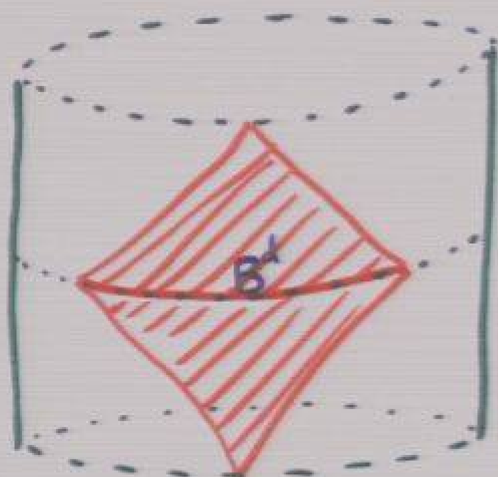
e.g. Myers, Sinha



each patch described by density matrix ρ_{Th} for CFT on H^d

$S(\rho) \sim$ horizon area

More general: arbitrary state for global spacetime



$S^d \times$ time

- still have description via family of patches
- "causal development" of B^d conformal to $H^d \times$ time

e.g. Casini, Huerta, Myers

$\exists$ map

$$|\psi\rangle_{S^d} \xrightarrow[\text{trace over } B^d]{} \rho_{B^d} \xrightarrow[\text{unitary}]{} \rho_{H^d}$$

Patchwise description of spacetime via family of density matrices w. constraints

$$\underset{\text{entanglement entropy}}{S(\rho_{B^d})} = \underset{\text{thermal entropy}}{S(\rho_{H^d})}$$

Density matrices & entanglement in QFT

Recent work: focused on density matrix for spatial region

Locality $\Rightarrow \mathcal{H} = \mathcal{H}_A \otimes \mathcal{H}_{\bar{A}}$

define ρ_A

calculate $S(\rho_A)$ (divergent)

$$I(A,B) = S(A) + S(B) - S(A,B) \quad \text{finite}$$

MUTUAL INFORMATION

Connection to Wilsonian Picture

Usually: description of low-energy physics via Wilsonian effective action $S_W(\phi_{|\vec{p}|<\mu})$

$|\vec{p}|<\mu$ d.o.f. in mixed state

$$\langle \hat{\phi} | \rho_{|\vec{p}|<\mu} | \tilde{\phi} \rangle = \frac{1}{Z} \int_{\phi(\tau\to-\infty)=\hat{\phi}}^{\phi(\tau\to\infty)=\tilde{\phi}} [d\phi_{|\vec{p}|<\mu}]\, e^{-S_W^\mu}$$

$$\int [d\phi]\, \mathcal{O}_\phi\, e^{-S_W} = \mathrm{Tr}(\rho^\mu \mathcal{O}_\phi)$$

NEW OBSERVABLES IN QFT

Given density matrix for subset of momenta, can define observables based on spec.(ρ)

examples: $S(|\vec{p}|<\mu)$

$I(\vec{p},\vec{q})$

spectrum$(\rho(\vec{p}))$

Try to calculate these in perturbation theory for weakly coupled field theories

QUESTION: Given a QFT, is there a precise notion of a density matrix describing the IR physics?

work with V. Balasubramanian, M. McDermott

WARNING: the rest of the talk has nothing to do with cosmology or AdS/CFT.

NEW OBSERVABLES IN QFT

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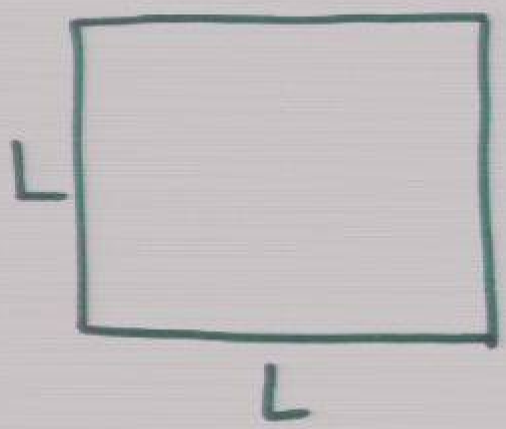
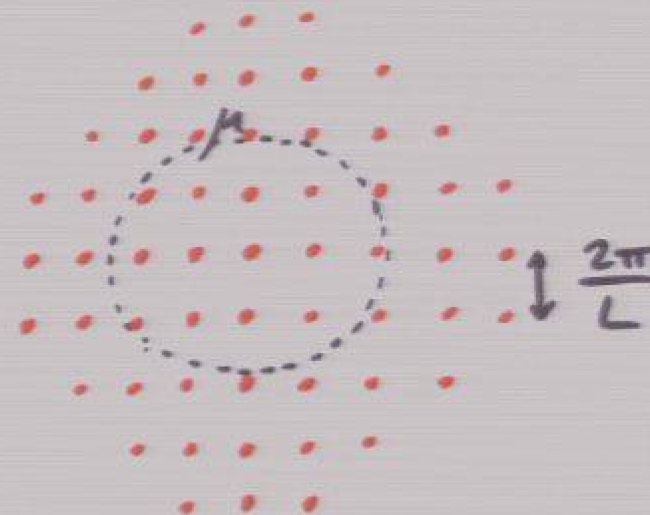
Start with finite volume:





$\mathcal{H} = \bigotimes_{p_i} \mathcal{H}_{p_i}$ Basis $|\{n_i\}\rangle = (a^\dagger_{p_i})^{n_i}|0\rangle$

$\lambda = 0$: vacuum $\bigotimes_{p_i} |0\rangle$ No entanglement

λ small: $\mathcal{H}_{QFT} = \mathcal{H}_{|p|<\mu} \otimes \mathcal{H}_{|p|>\mu}$

$$H = H_{|p|<\mu} + H_{|p|>\mu} + \lambda H_{int}$$

$$|\Omega\rangle = |0\rangle \otimes |0\rangle + \lambda |n_i\rangle \otimes |N_i\rangle C_{nN} + \ldots$$

Compute $|\Omega\rangle$, $\rho_{|\vec{p}|<\mu}$, $S(\mu)$

in PERTURBATION THEORY

Leading order:

$$S = \sum_{\substack{n\neq 0 \\ N\neq 0}} \frac{|\langle n_i, N_i | H_{int} | 0,0\rangle|^2}{E^2_{n,N}} \{-\lambda^2 \log \lambda^2\}$$

$$+ \mathcal{O}(\lambda^2)$$

states with at least one particle $|p|<\mu$ + at least one w. $|\vec{p}|>\mu$

Infinite volume:

Projects to states with

$$S = -V\lambda^2 \log\lambda^2 \int_0^\infty d\tau\, \tau \int d^dx \left\langle \mathcal{H}_I(-i\tau, x)\, P(\mu)\, \mathcal{H}_I(0,0) \right\rangle$$

$$+ \mathcal{O}(\lambda^2)$$

Example: ϕ^3 theory in d+1 dimensions

large μ: determined by increase in d.o.f. with μ
+ μ dependence of dimensionless
coupling.