Think Globally - observe locally

Steven B. Giddings -- UCSB/CERN

more discussion:

arXiv:0705.1178, and in progress, w/ Marolf

and hep-th/0512200 w/ Marolf and Hartle

hep-th/0612191 w/ M. Gary

4th International Sakharov Conference

Tuesday talk:

http://www.physics.ucsb.edu/~giddings/moscow.pdf

Motivation:

- In cosmology, observe locally. Yet, no local observables in quantum gravity!!
- Even more acute issue: landscape, measures
- de Sitter is a simple toy cosmology; approximately relevant to our early and late universe; yet various puzzling features
- Likely connection to other issues: high-energy scattering, black hole info; nonperturbative structure of gravity

Goals:

- Explain an approach to local observation in quantum gravity
- Outline some inherent limitations that appear to emerge
- Illuminate some puzzles of de Sitter space

Some puzzling statements made about dS:

Can only make sense of "causal patch" of one observer?

Recurrences? (Goheer, Kleban, Susskind)

Always metastable?

Approach perturbatively: LEFT of gravity

$$S[g,\phi] = S_{EH}[g] + S_m[g,\phi]$$

$$g_{\mu\nu} = \bar{g}_{\mu\nu} + \frac{h_{\mu\nu}}{M_P}$$

(small parameter: $p_i \cdot p_j / M_P^2$)

Bear in mind/investigate: when does it break down?

Even in this framework, appear to learn interesting things

How to describe states of theory?

First issue: "linearization stability" (Moncreif, ...)

1) For given vector ξ , states should satisfy constraints:

$$H[\xi]|\Psi\rangle = 0$$

2) For perturbations about dS, non-trivial consequence:

Let ξ be a Killing vector...

$$H[\xi] = \int d^3x \sqrt{{}^3g} \left[M_p \xi^\mu (Lh)_\mu + \xi^\mu (T^\phi_{\mu\perp} + T^h_{\mu\perp}) \right]$$

(for simplicity: work in 4d, though generalizes)

Perturbative EM tens.

$$H[\xi] = \int d^3x \sqrt{{}^3g}\left[M_p \xi^\mu \cancel{(Lh)_\mu} + \xi^\mu_{\mathrm{KV}} (T^\phi_{\mu\perp} + T^h_{\mu\perp})\right]$$

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0: KV

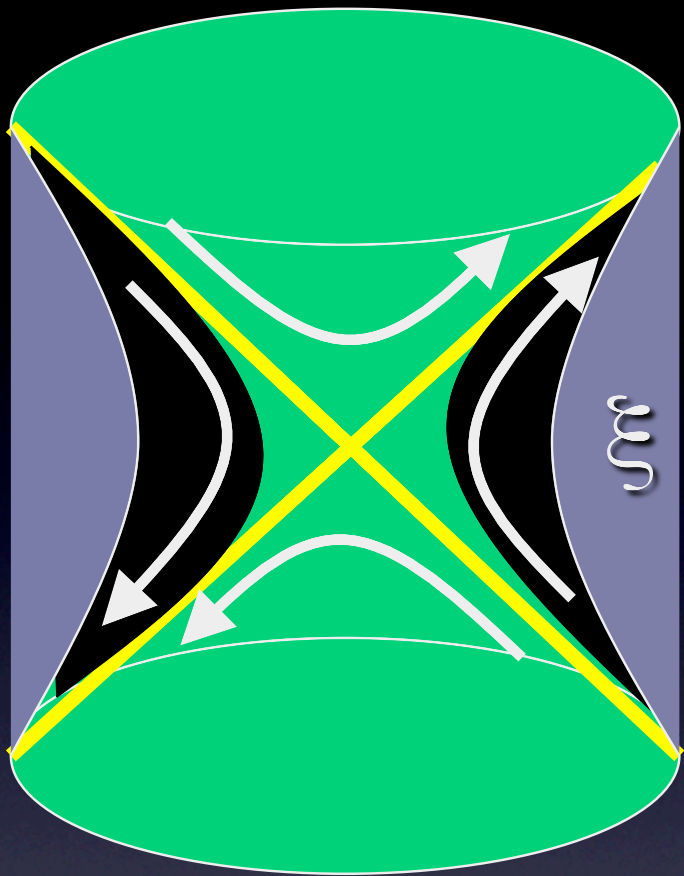
Perturbative EM tens.

This is the statement: total energy (momentum) = 0, which should be true on closed space

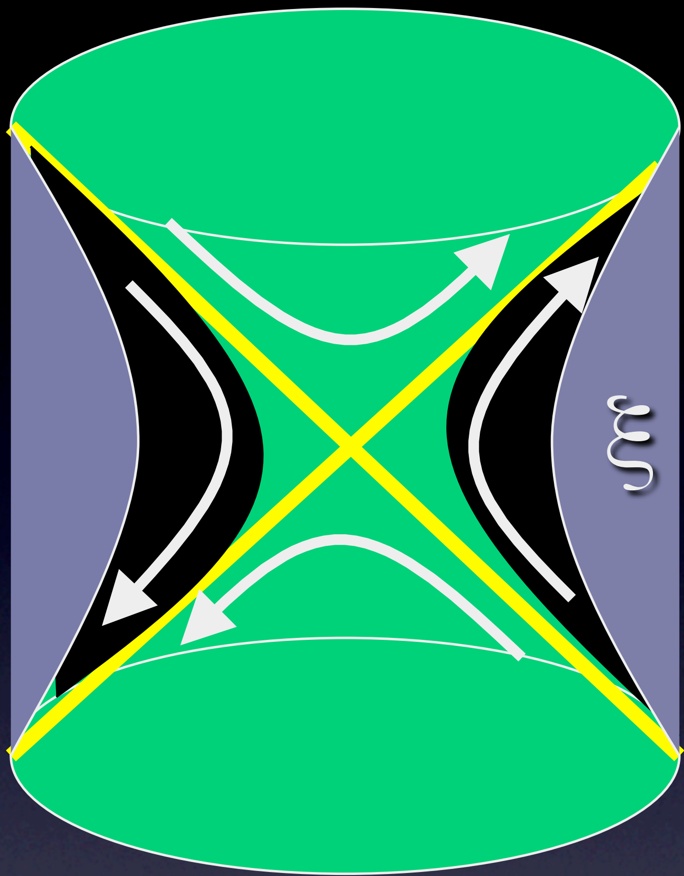
- Gauss' law constraint

(e.g. SdS -- two black holes)

That is, states should be dS invariant



~Time translation, in one patch



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In addition to $H[\xi]|\Psi\rangle = 0$, observables should satisfy

$$[H[\xi], \mathcal{O}] = 0$$

So, questions:

1) how to find such states? (Only perturbative dS invariant state is $|0\rangle$!)

2) how do they "evolve"

3) what are (~) local observables?

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State in original (aux.) Hilbert space

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Norm? $= \infty$?

$$\langle\Psi_1|\Psi_2\rangle = \int dg \langle\Psi_1\|U(g)\|\Psi_2\rangle$$

(Appropriate properties: Higuchi; Marolf/Morrison; etc.)

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In fact, apparently can be derived from functional integral over metrics

3) local quantities -- observables?

$$[H[\xi], \mathcal{O}] = 0$$

but, for local observable,

$$[H[\xi], O(x)] \sim \xi^\mu \partial_\mu O(x)$$

Proposed resolution: via a relational approach

Einstein (1916)

DeWitt (1962, 1967)

Page and Wooters (1983)

Banks (1985)

Hartle (1986)

Rovelli (1990, 1991, 2002)

Tsamis and Woodard (1992)

Smolin (1993)

Ashtekar, Tate, Uggla (1993)

Marolf (1994)

Gambini, Porto, Pullin (2003-2006)

Dittrich (2004-2006)

Thiemann (2004-2006)

Pons and Salisbury (2005)

...

In particular, in hep-th/0512200 w/ Marolf and Hartle , explored implementation of these ideas

1) in a quantum framework;

2) with proposals about how to recover local operators of QFT (approximately)

"proto-local observables"

An example illustrating some of the general ideas (more examples exist):

Example: "Z-model" (sketch -- ideas)

Begin w/ a field theory w/ local operator $\mathcal{O}(x)$

Introduce four fields Z^i, and a state $|\Psi\rangle$ such that

$$\langle\Psi|Z^i|\Psi\rangle = \lambda\delta^i_\mu x^\mu$$

Define operators

$$\mathcal{O}_{\xi^i} = \text{“}\int d^4x\sqrt{-g}\,\delta(Z^i(x)-\xi^i)\,\mathcal{O}(x)\text{”}$$

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Then:

$$\langle\Psi|\mathcal{O}_{\xi_1}\cdots\mathcal{O}_{\xi_N}|\Psi\rangle \approx \mathcal{O}(x^\mu_1)\cdots\mathcal{O}(x^\mu_N)$$

where $\quad x^\mu_A = \frac{1}{\lambda}\delta^\mu_i\xi^i_A$

Precise, explicit illustration in 2d gravity ...

2d Liouville gravity:

$X^0, \cdots, X^i$ c massless scalar fields

$$\mathcal{Z} = \int \mathcal{D}g\mathcal{D}X e^{iS[X,g]}$$

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$$= \int \mathcal{D}\phi\mathcal{D}X e^{i(S_L[\phi,\hat{g}]+S[X,\hat{g}])}$$

w/

$$S_L = \frac{c-25}{48\pi}\int d^2x\sqrt{\hat{g}}\left(\frac{1}{2}\hat{g}^{ab}\partial_a\phi\partial_b\phi + \hat{R}\phi\right)$$

Simplest case -- c=25: $\phi \leftrightarrow X^{25}$

Analogue to Z-model (and fully diff invt):

$$Z^i \leftrightarrow X^0, X^1$$

$$\mathcal{O} \leftrightarrow \mathcal{O}[X^2, \cdots, X^{24}]$$

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$|\Psi\rangle$; $\mathcal{O}_\xi$:

1) can be constructed via "textbook" string worldsheet techniques

2) can be shown to approximately localize

more detail: hep-th/0612191 w/ M. Gary

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This indicates how to proceed with second question: time evolution. This should be relational as well, relative to features of state.

Work in progress w/ Marolf:

- Other detailed examples
- Question of measurement
- Further examination of states/observables in dS

Even more interesting set of questions: what are limitations of this approach?

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Suggestion: if there are such limitations to local constructs, and if there are no alternative local constructs, these could correspond to fundamental limitations to locality and particularly local QFT.

One such proposed limitation:

localization fails w/strong backreaction

e.g. "locality bound" (w/ Lippert)

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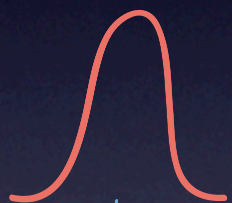

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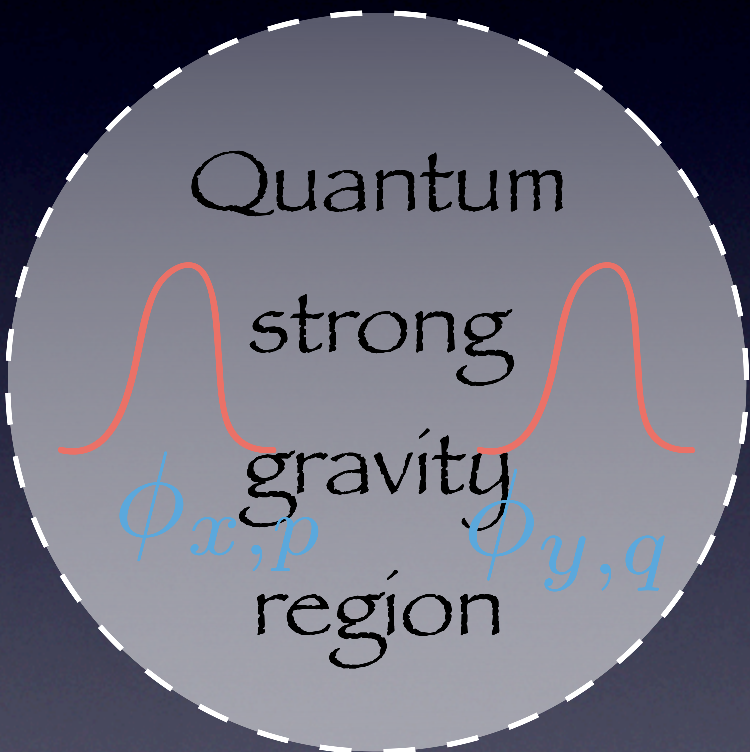

$$|x-y|^{D-3} \lesssim |p+q| \quad :$$

Localization apparently fails (limit of QFT)

An apparently related issue:

let $\mathcal{O}_1$, $\mathcal{O}_2$ be such relational observables; work in dS

$$\langle\Psi_1|\mathcal{O}_1\mathcal{O}_2|\Psi_2\rangle$$ has IR divergences!

Two ways to understand:

1) $$\int dx_1 dx_2 \langle\Psi_1\|O(x_1)O(x_2)\|\Psi_2\rangle$$

$$\sim \int dx dy \langle 0\|O(x-y)O(x+y)\|0\rangle$$

$\times$ integral diverges ...

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2) $$\int dx_1 dx_2 \langle \Psi_1 | O(x_1) O(x_2) | \Psi_2 \rangle$$

$$\sum_\alpha | \Psi_\alpha \rangle \langle \Psi_\alpha | : \quad \infty \quad \text{states}$$

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2) $$\int dx_1 dx_2 \langle \Psi_1 \| O(x_1) O(x_2) \| \Psi_2 \rangle$$

$$\sum_\alpha \|\Psi_\alpha\rangle\langle\Psi_\alpha\| : \quad \infty \text{ states}$$

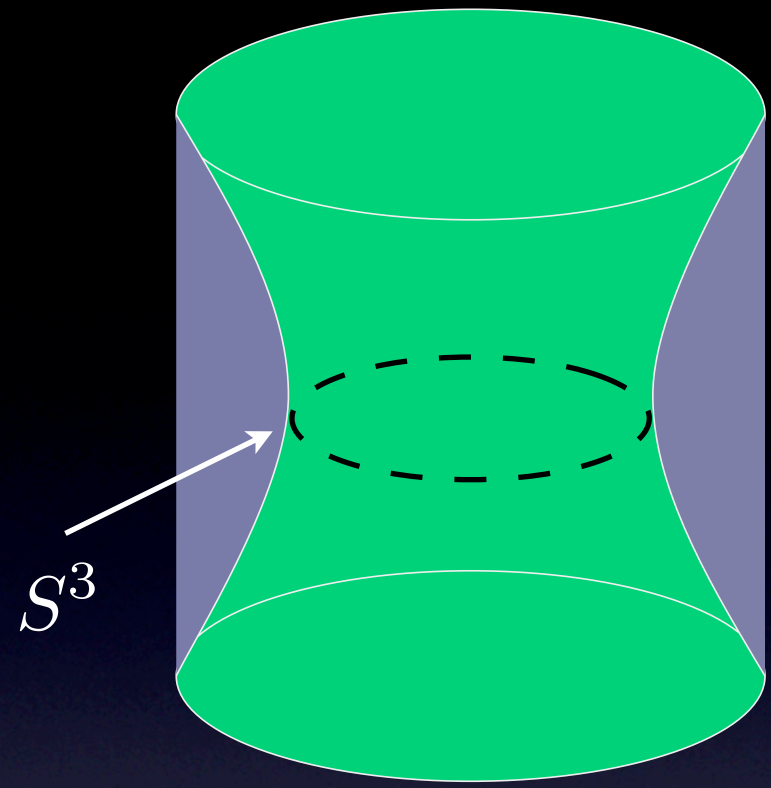
But expect dS has finitely many states $\sim \exp(S_{dS})$

- which could then regulate the divergence...

One proposed implementation:

(related to observations by Banks, Fischler, ...)

Let $$F = \int_{S^3} \sqrt{{}^3 g}\, T_{ab} n^a n^b$$



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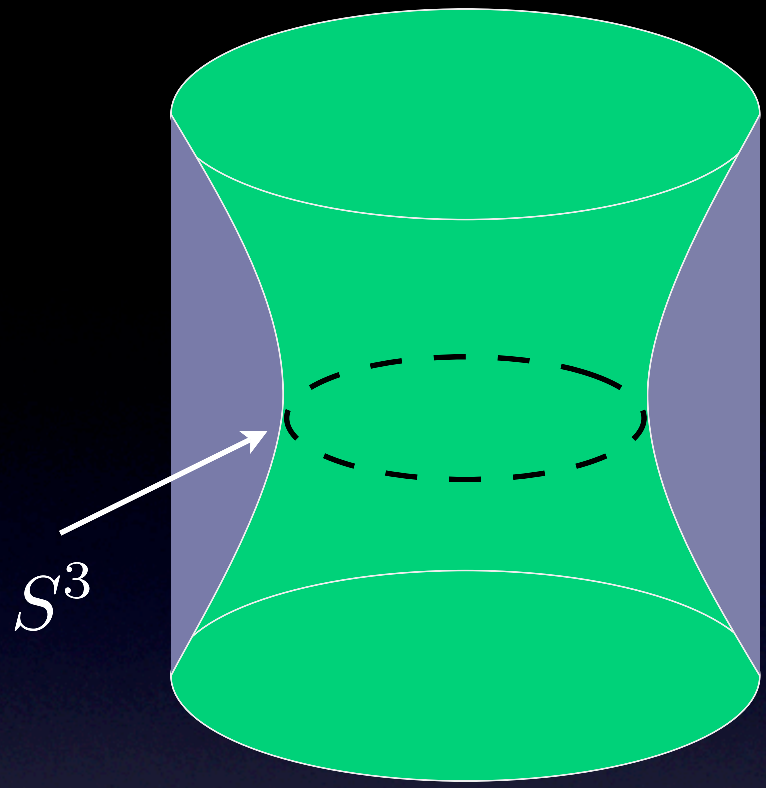

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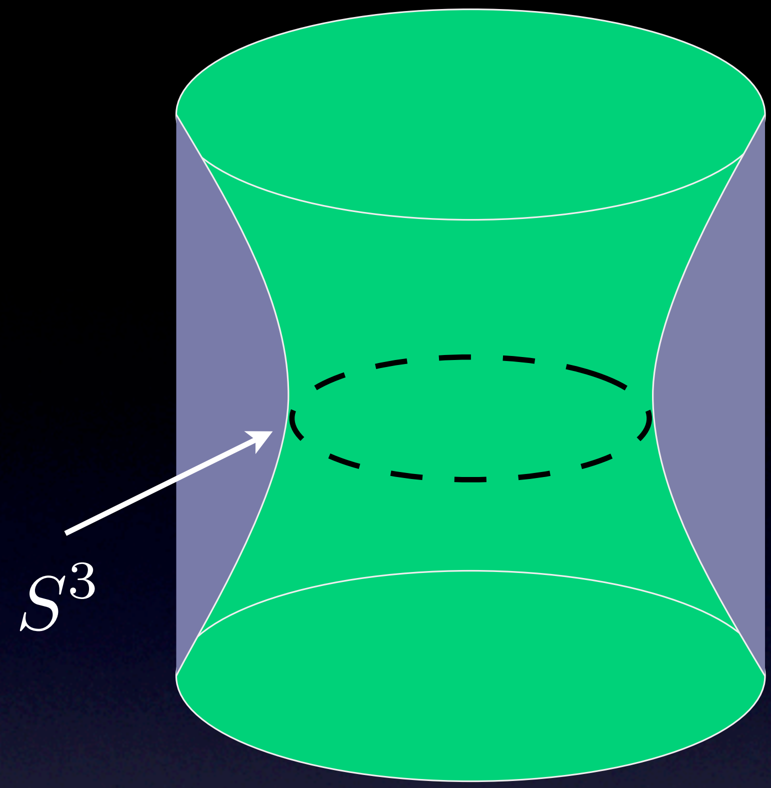

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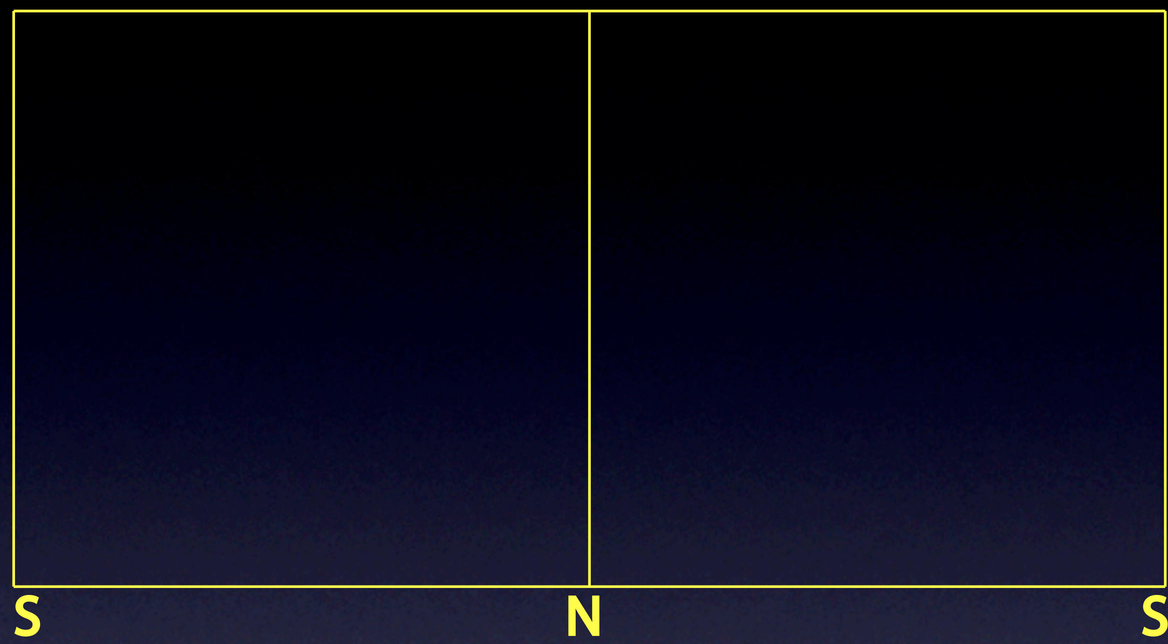
Indeed, multiple considerations suggest that one only can give a complete local QFT description over a region of volume ~ $R_{dS}^4 e^{S_{dS}}$

One is:

The Boltzmann brain population explosion:



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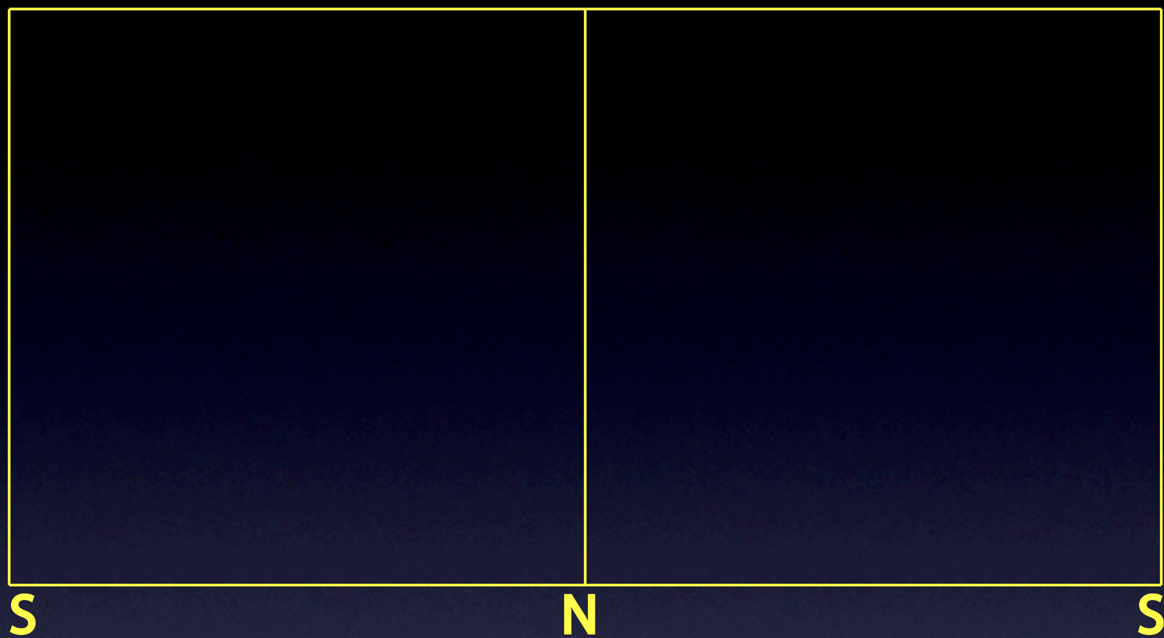

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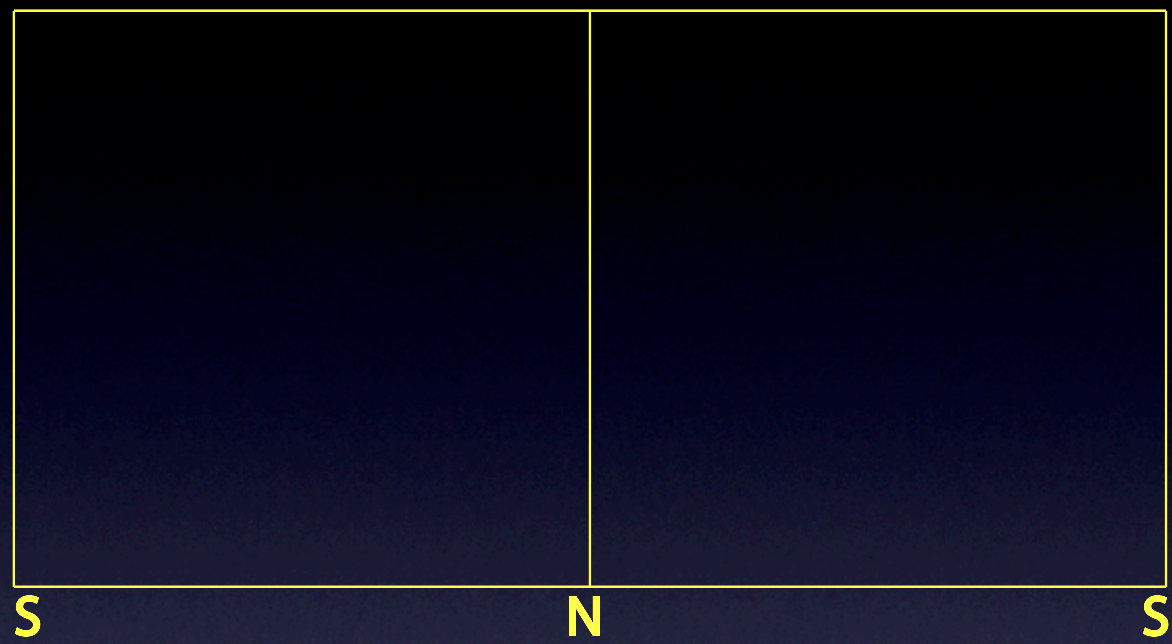

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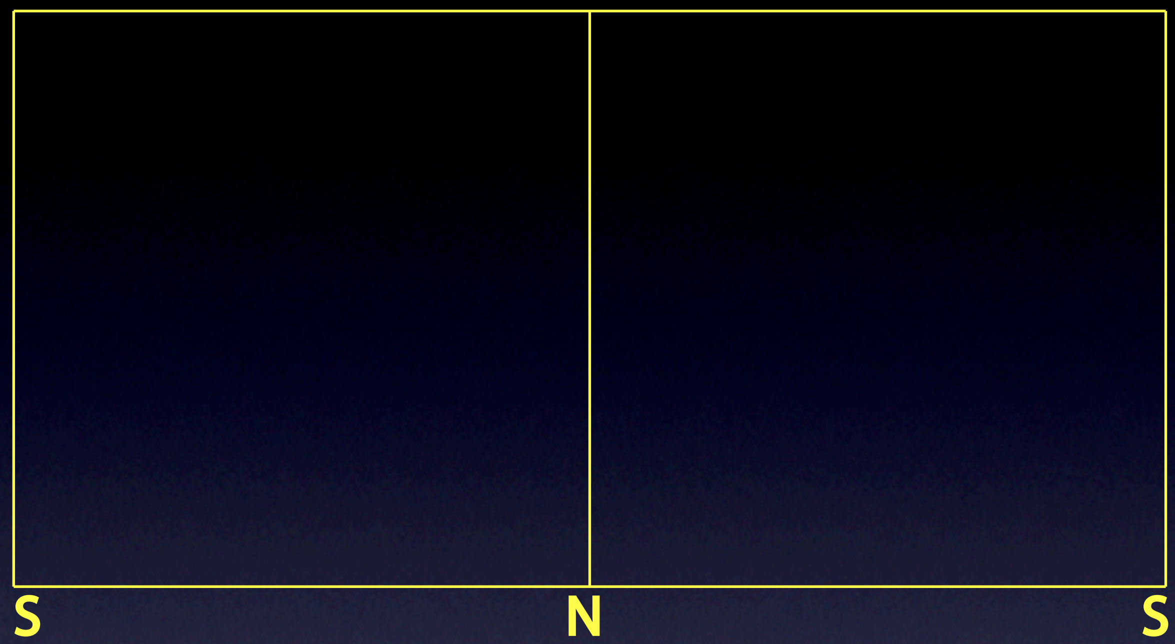

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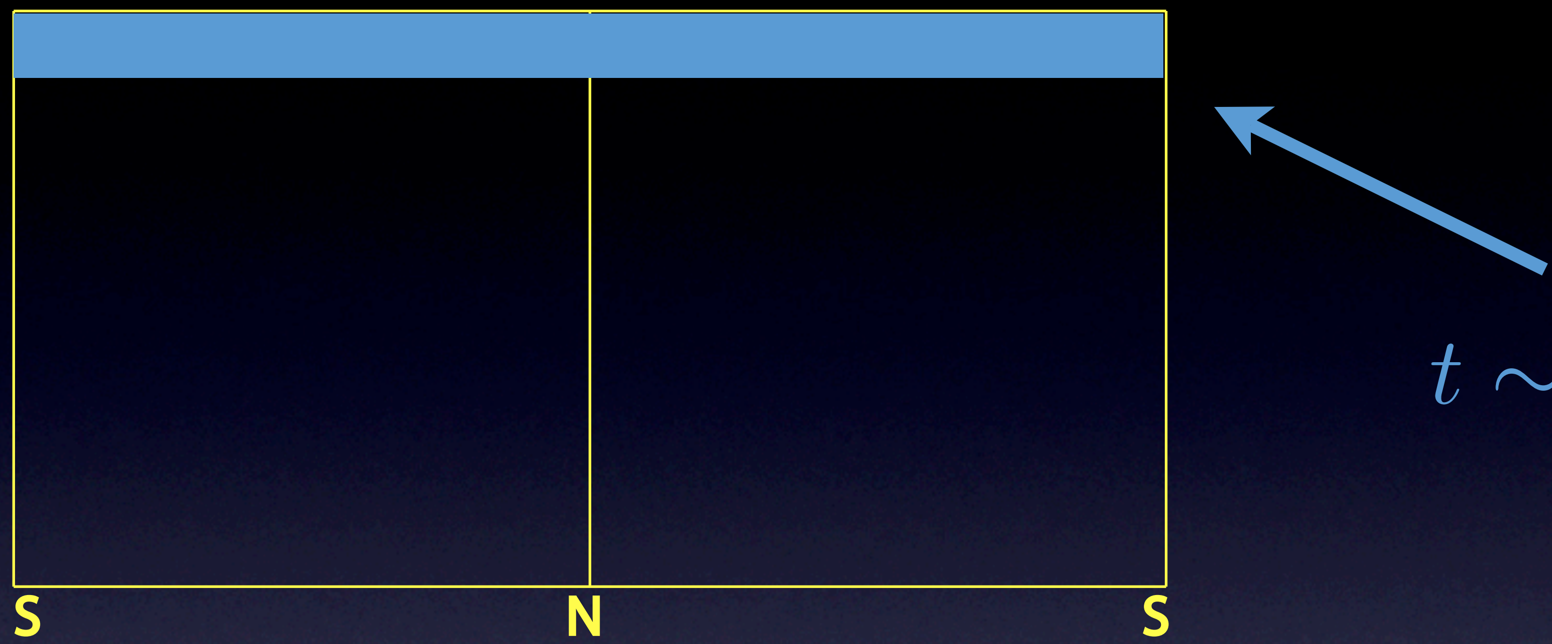

$t \sim R_{dS} S_{dS}$

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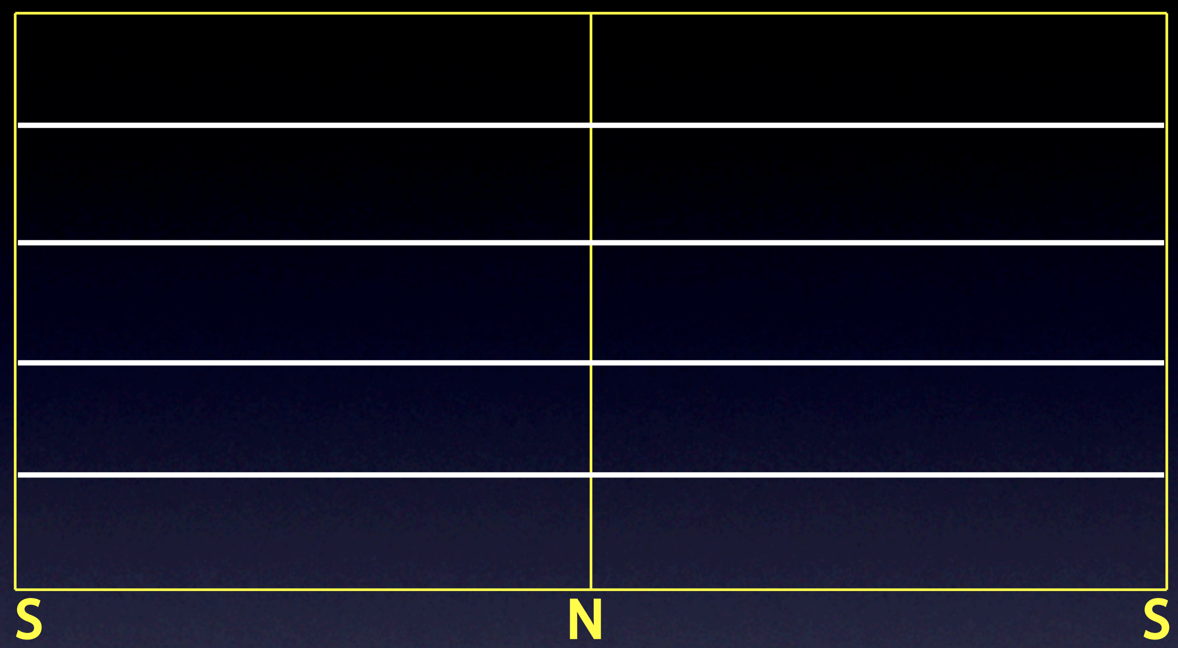

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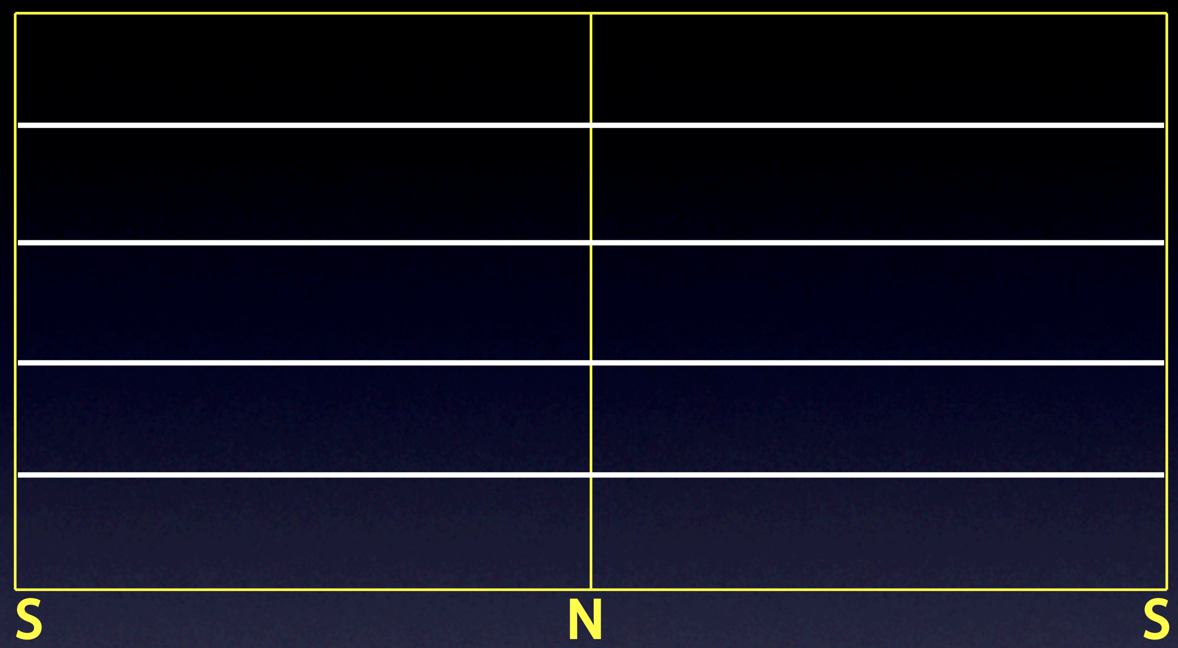

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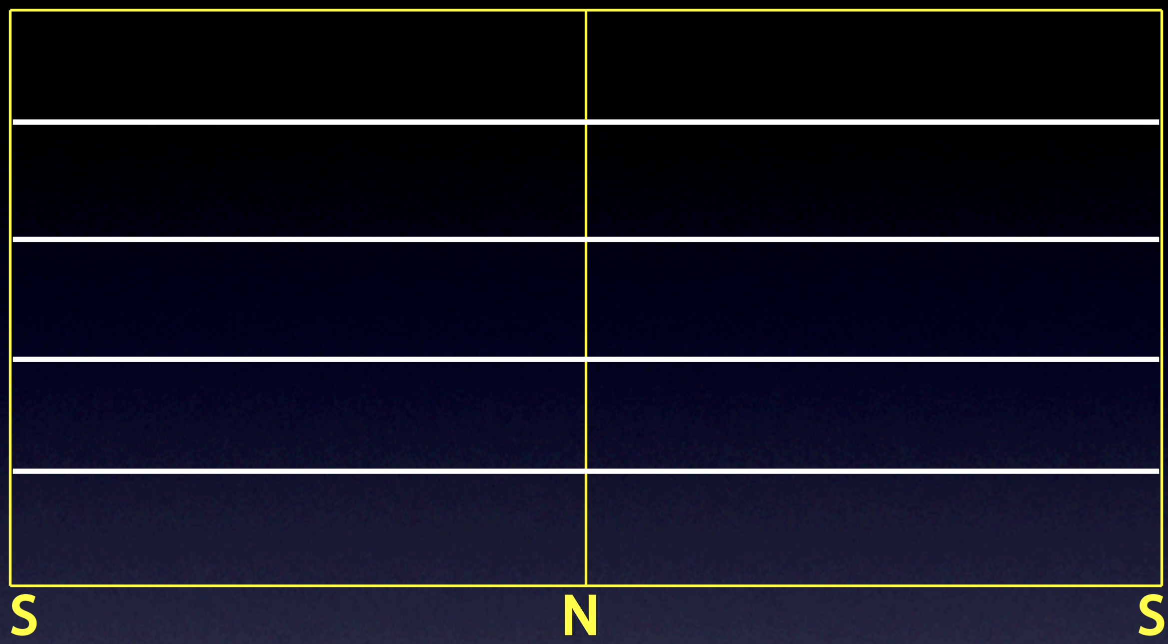

When do fluctuations make important corrections to nice slice state?

One argument (with parallels in BH case): hep-th/0703116

fluctuations/backreaction: $t \sim R_{dS} S_{dS}$

A plausibly related story:

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slow roll inflation goes eternal at $t \sim R_{dS}^3$.

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Other indicators?

Woodard;
Ford & collaborators
Mottola

$\Bigg\}$ arguments for important role of large fluctuations.

$t \sim R_{dS} S_{dS}$?

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Though, no role for recurrences in the story?

Can be finite states; but $H[\xi]|\Psi\rangle = 0$

Important to more fully explore such limitations, and implications for constraints on the underlying theory

To conclude:

1) Have presented some elements of pert. description of part of global dS, respecting symmetries of QG (low-E)

2) Have argued that observables must be relational, and at best are approximately local (not for "stringy" reasons!)

3) Have outlined some proposed and possibly important limitations to complete local, QFT descriptions

4) Of course, lack a full nonperturbative treatment (but such limitations may be a guide to its nature)

5) Seems inevitable that such considerations extend to landscape -- if they permit its existence