

Title: Constructing Quantum Space Time

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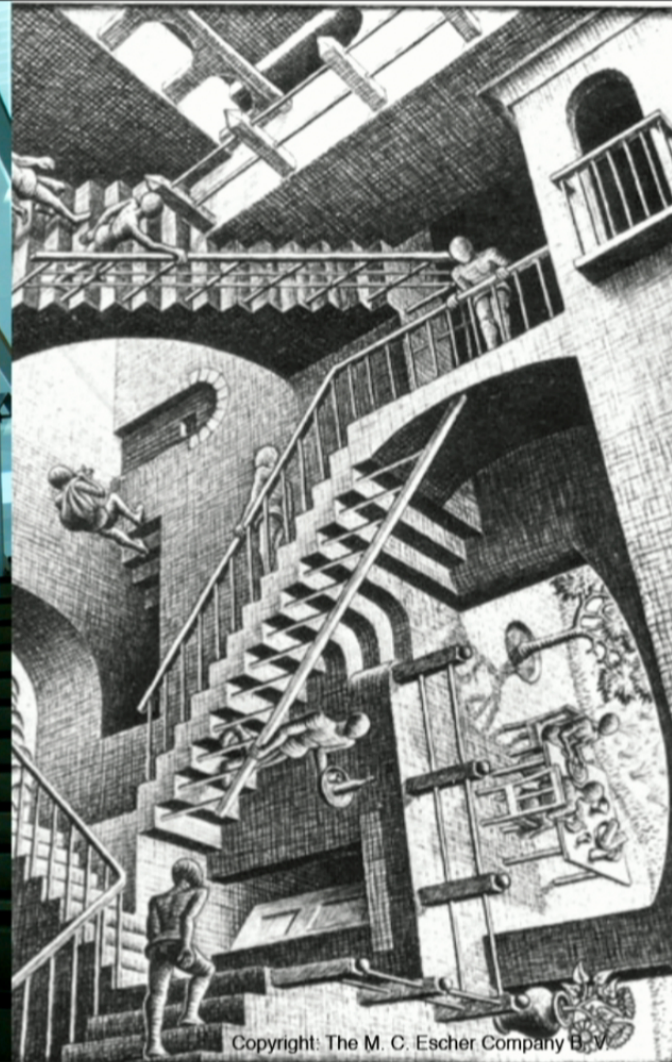
Abstract:

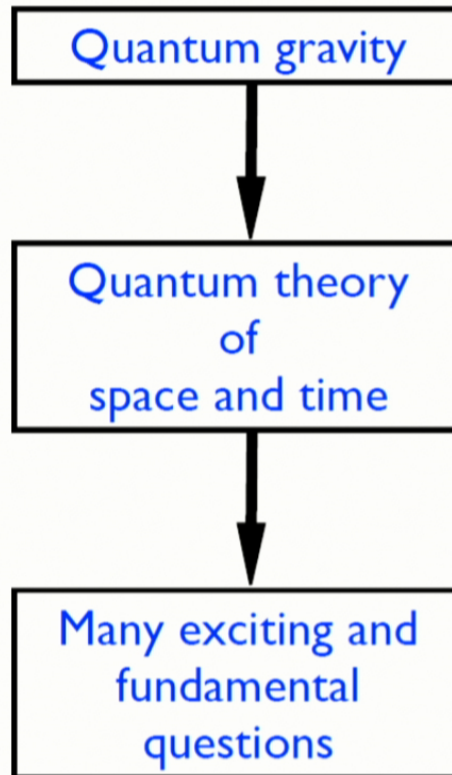
# Constructing quantum space time

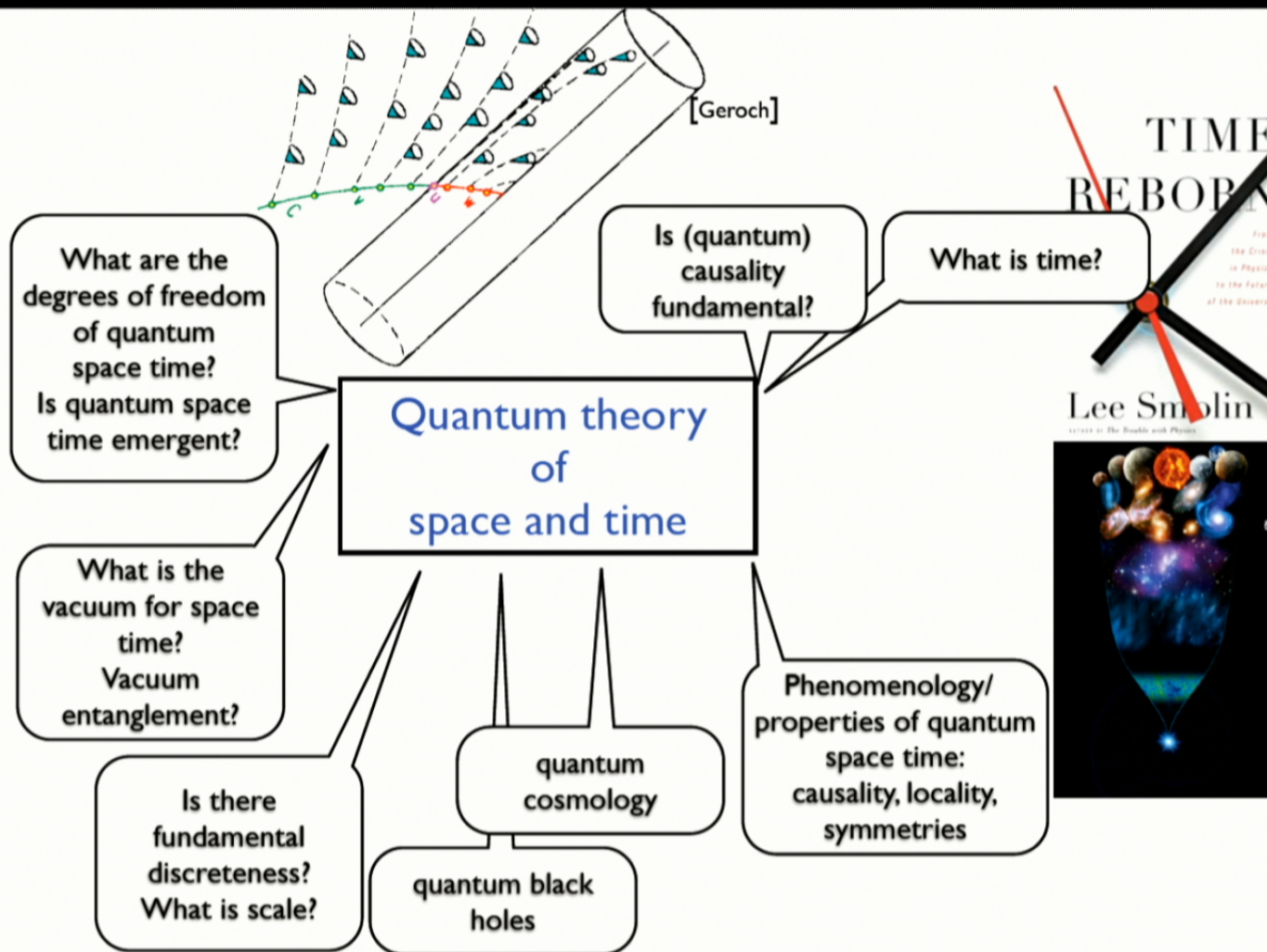
Bianca Dittrich

*PI - day, Jan 2014*

Raussendorf



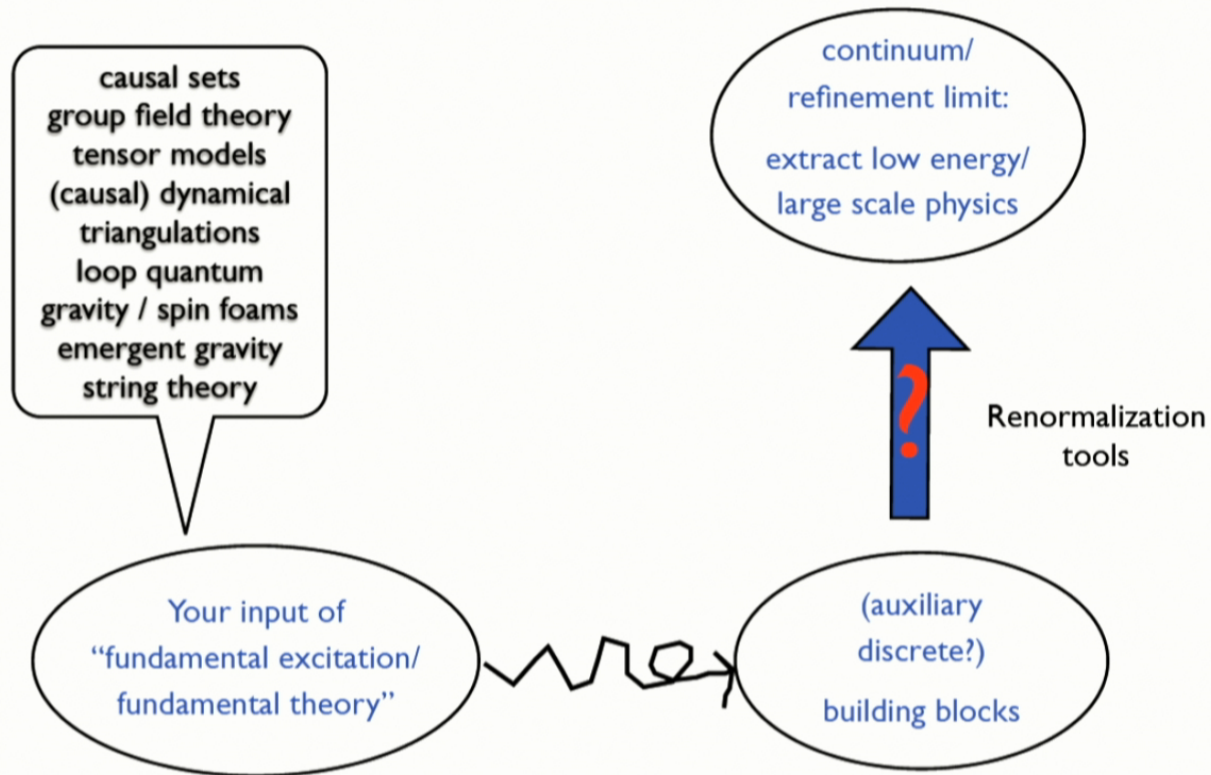






# Reconstructing (quantum) space time

## Bottom-up design



# Top-down approach

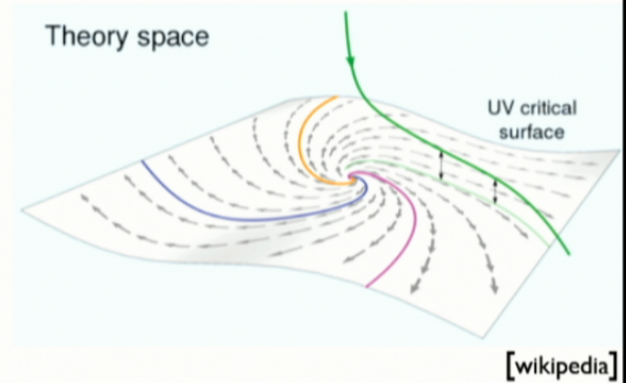
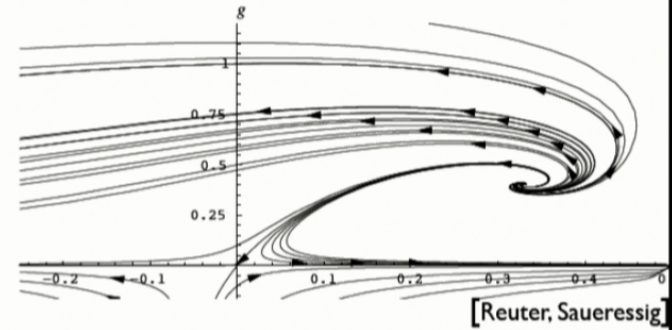
Einstein gravity, metric  
degrees of freedom  
(+matter)



Functional  
Renormalization  
Group Flow

(asymptotically safe)  
uv (non-Gaussian) fixed  
point

consistency conditions leading  
to predictions for matter sector  
[Eichhorn et al]



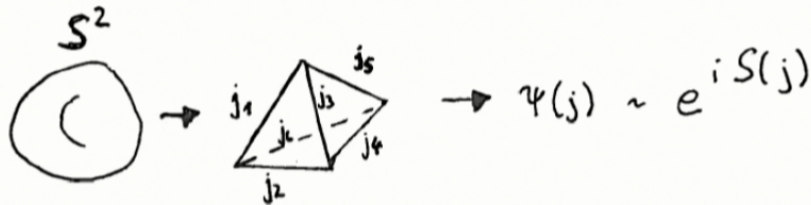
Thinking about Nothing ...

... and Refining



# What is vacuum?

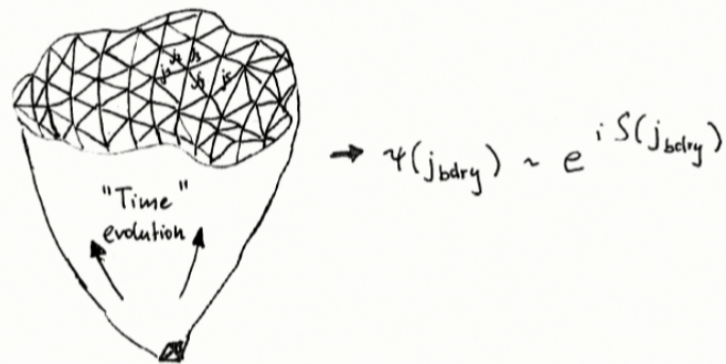
coarse representation of vacuum



(Hartle-Hawking) wave function associated to closed boundary of space time, given by amplitude for basic space time building block

[Oeckl: generalized boundary proposal]  
[Hoehn: discrete generalized boundary proposal]

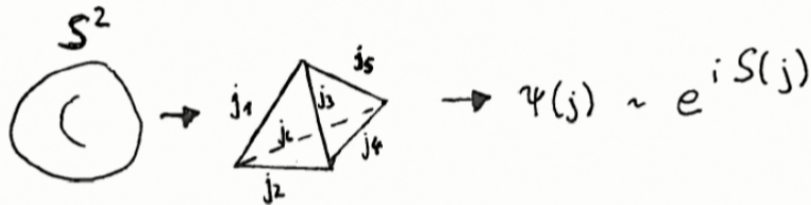
finer representation of vacuum



refined vacuum wave function

# What is vacuum?

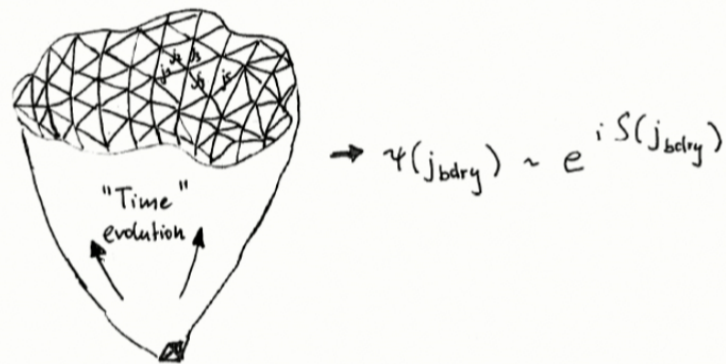
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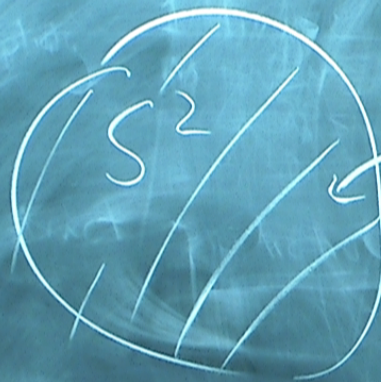
[Oeckl: generalized boundary proposal]  
[Hoehn: discrete generalized boundary proposal]

finer representation of vacuum



refined vacuum wave function





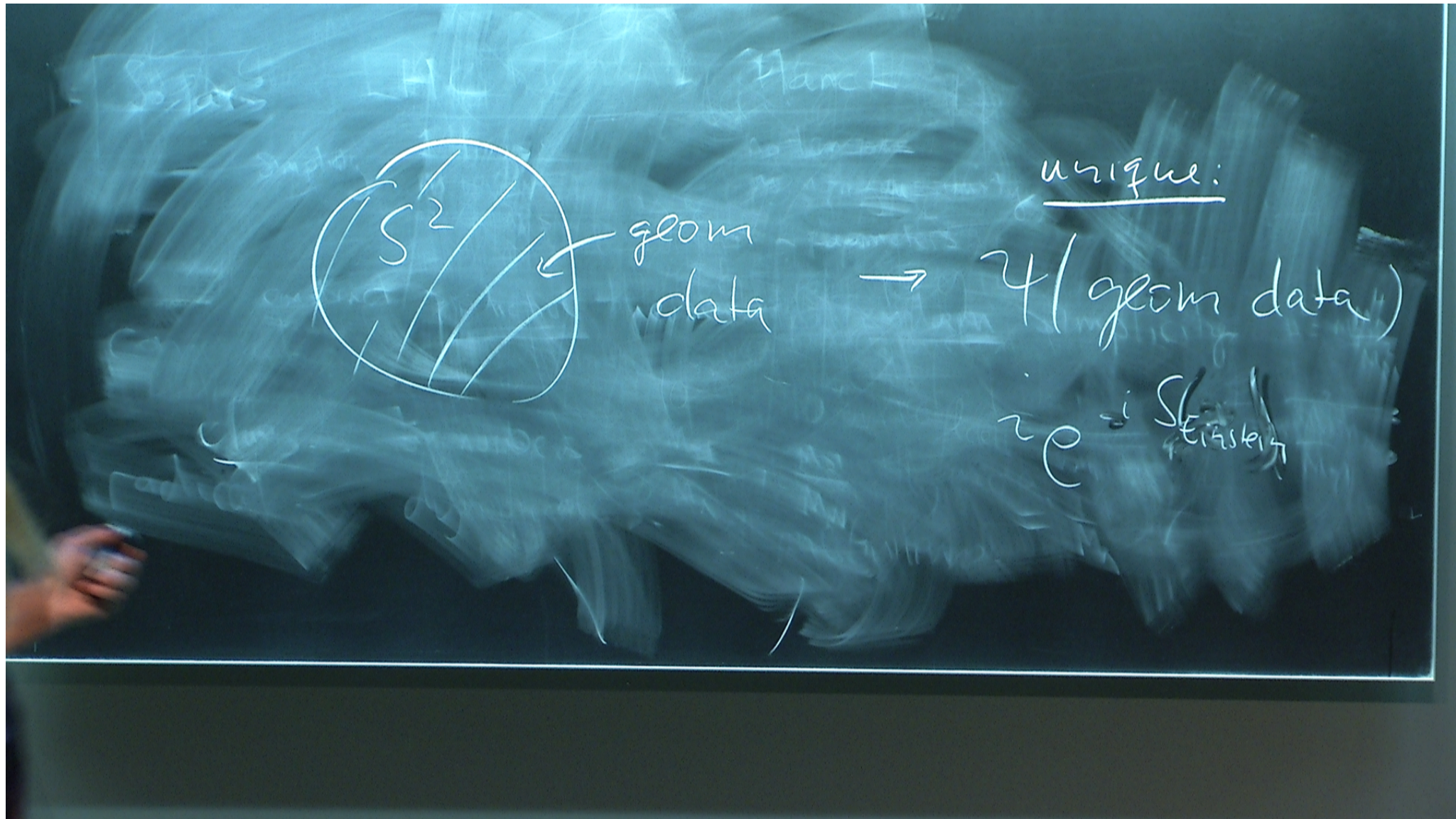
geom  
data



4/(geom data)

unique:

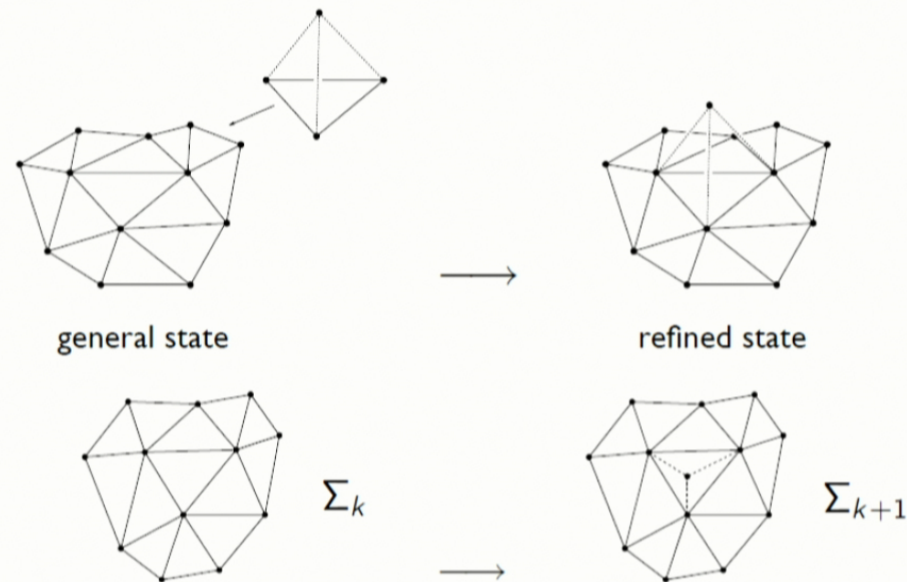






# Refining states by time evolution: adding degrees of freedom in vacuum state

Same refining can be applied to a general state:



[BD, Hoehn, Steinhaus]

fits nicely (motivated by)  
the heuristics  
of tensor network  
renormalization

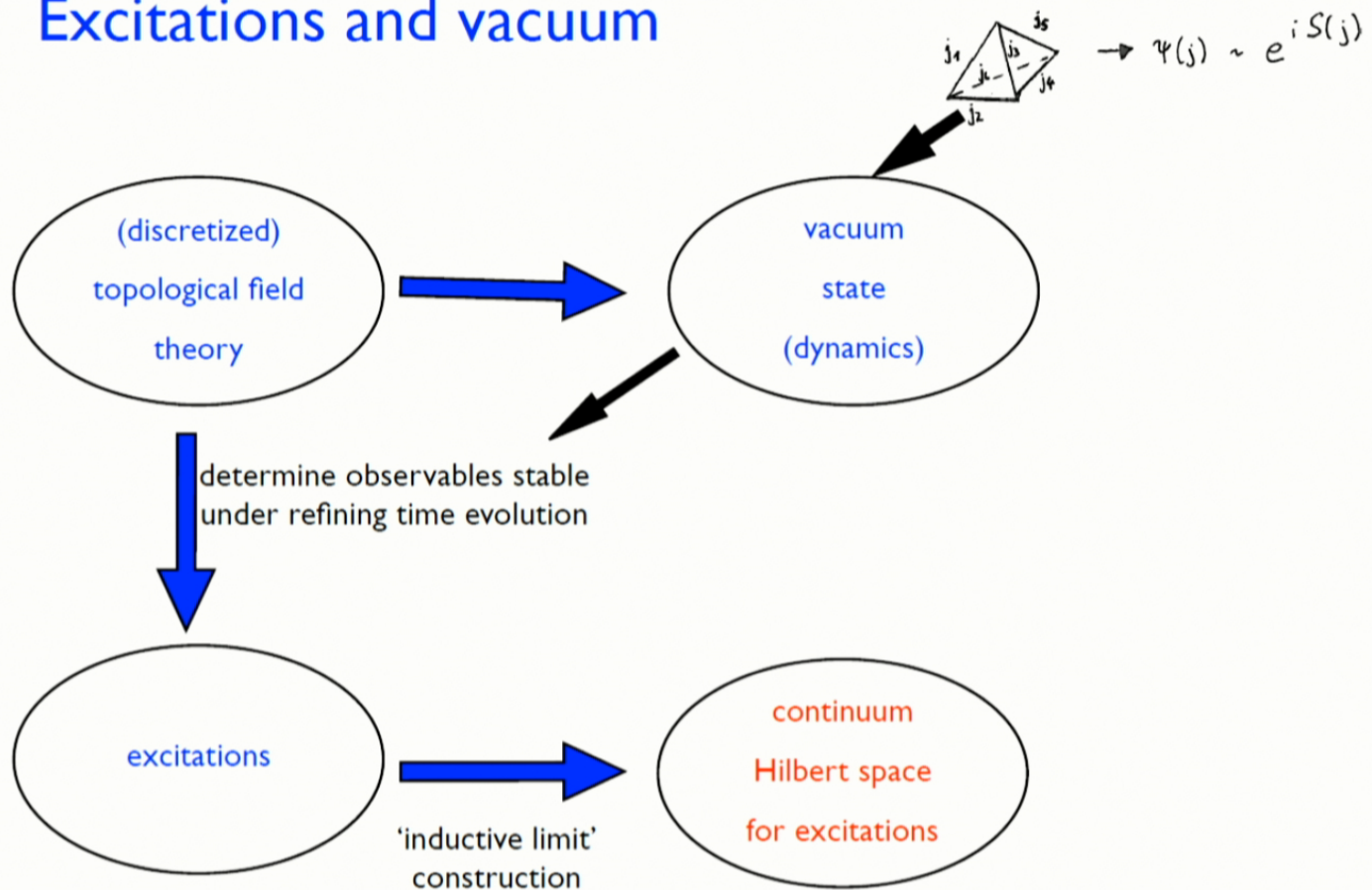
[... Gu, Vidal, Wen]

This notion of refinement can be used to define the refinement/continuum limit formulation of a theory.

[BD, Steinhaus 13]

For topological (discretization independent) theories:  
allows the construction of the continuum via projective/ inductive limit techniques,  
used in Loop Quantum Gravity

## Excitations and vacuum



# Loop quantum gravity vacua

geometric variables:  $\{A, E\} = \delta$

connection

flux: spatial geometry

[Bianchi 09: defect lines]  
[Freidel, Geiller, Ziprick 11: classical]

[BD, Geiller 14: Hilbert space]

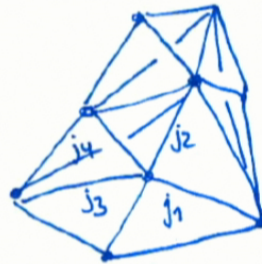
Ashtekar - Lewandowski vacuum (90's)

$$\psi_{vac}(A) \equiv 1, \quad E \equiv 0$$

peaked on degenerate (spatial) geometry  
maximal uncertainty in connection

excitations:

spin network states supported on graphs



(representation)  
labels for edges

[Koslowski: vacuum with shifted E]

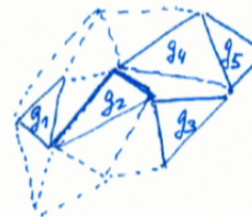
BF (topological) theory vacuum

$$\psi_{vac}(E_{Gauss}) \equiv 1, \quad F(A) \equiv 0$$

peaked on flat connections  
maximal uncertainty in spatial geometry

excitations:

flux states supported on (d-1)D-surfaces



(group) labels  
for faces

shift connection to homogeneous curvature?



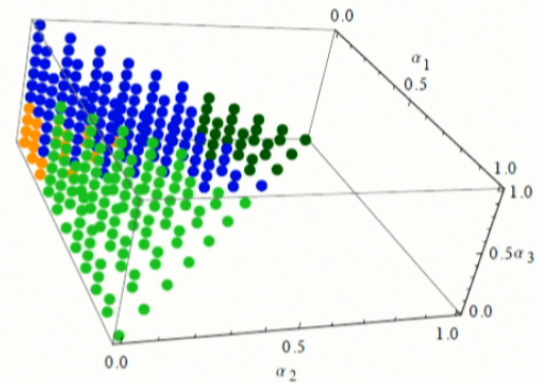
# Refinement/continuum limit of spin foams

... non-topological theories

using tensor network renormalization techniques:

[BD, Kaminski, Martin-Benito, Steinhaus, ...]

[phase diagram for quantum group spin nets]



using coherent spin networks [Bonzom, Livine, Freidel, Hnybida]  
[Banburski, Chen, Hnybida, ]

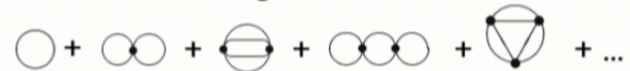
# Continuum limit via summing over geometries

matrix models 2D  
tensor models 3+ D  
group field theories  
(causal) dynamical triangulations

Generate discrete structures via Feynman expansion

$$\int_{-\infty}^{\infty} \frac{d\varphi}{\sqrt{2\pi}} e^{-\varphi^2/2 + \lambda\varphi^4/4!}$$

expansion in lambda:  
sum over amplitudes associated to Feynman  
diagrams



(with combinatorial factors)

# Matrix models

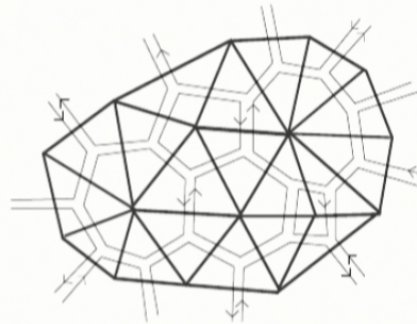
$$\int dM e^{-\frac{1}{2} \text{tr} M^2 + \frac{g}{\sqrt{N}} \text{tr} M^3}$$

integral over  $N \times N$  hermitian matrix

large  $N$  expansion: spherical  
triangulations dominate

continuum limit: tune  $g$  to critical  
value so that surfaces with many  
triangles dominate

expansion in  $g$ :  
sum over amplitudes associated to 2D  
triangulations

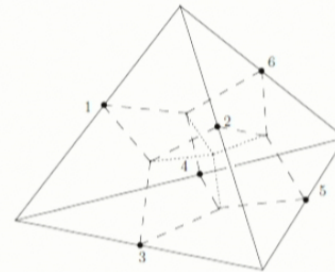
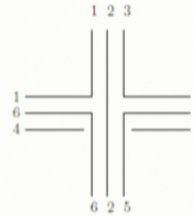


# Tensor models / group field theories

$$\int dT e^{-S(T)}$$

integral over  $N \times N \times N$  tensors

expansion in  $g$ :  
sum over amplitudes associated to 3D  
triangulations



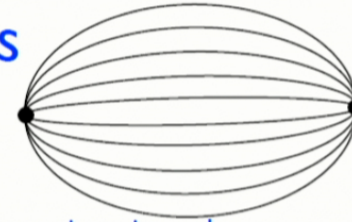
Tensor models / group field theories

combinatorical amplitude

spin foam amplitude



# Tensor models / group field theories



I/N expansion (in topologies)? Need colored tensor models. Expansions in melons.  
[Gurau]

Can we control topologies / type of triangulation appearing in the sum?

Construction of continuum limits.

Renormalization properties of group field theories.

[Bonzom, Ben-Geloun, Freidel, Gurau, Oriti, Ousmane Samary, Rivasseau, ...]

# Non-perturbative study of tensor/matrix models?



## Functional Renormalization Group Flow

Flow in what?

[Brezin, Zinn-Justin 92]

Matrix/tensor size  $N$

[Sfrondrini, Koslowski 10]

[Eichhorn, Koslowski 13]:

\*study of functional renormalization  
flow equation for matrix models

\*recipe for tensor models

\*interacting fixed point?

Gives a (puzzling) answer to:

What is (renormalization) scale?

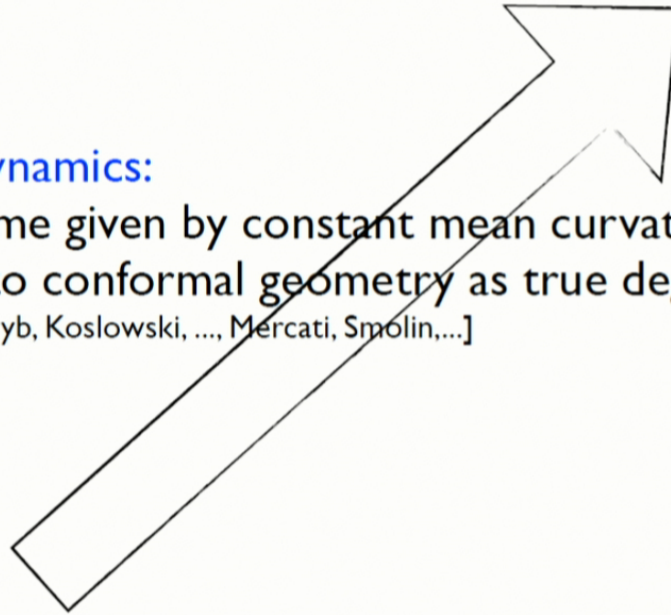
# Gravitational arrow of time

[Barbour, Koslowski, Mercati 13]

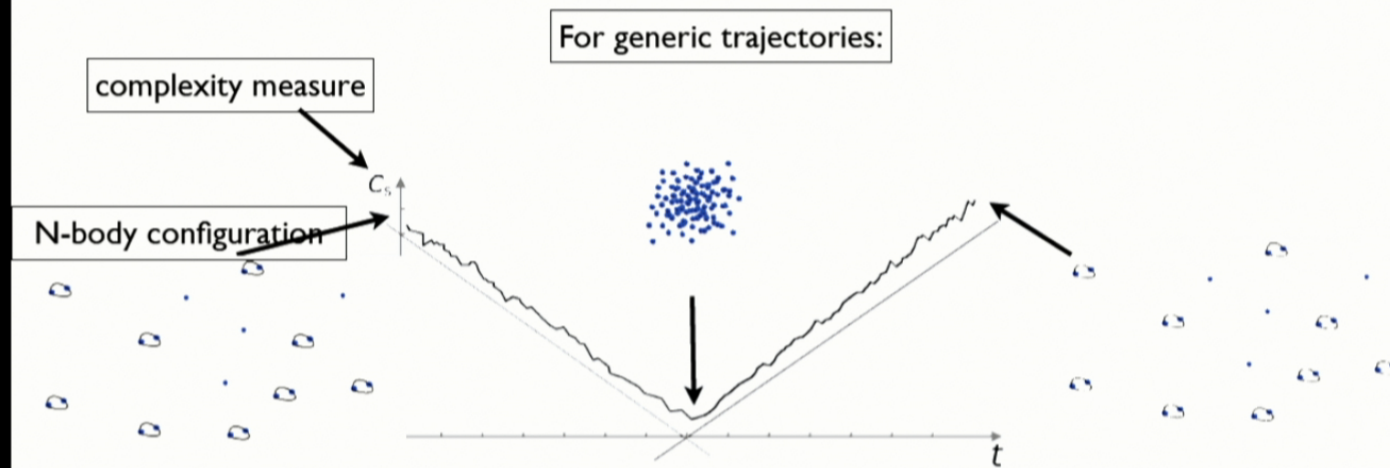
shape dynamics:

global time given by constant mean curvature gauge,  
leading to conformal geometry as true degree of freedom

[Gomes, Gryb, Koslowski, ..., Mercati, Smolin,...]



Analogue shape dynamics system:  
consider Newtonian N-body problem in 'shape space'



Two futures, one past!

Explains irreversible behaviour with time symmetric laws.

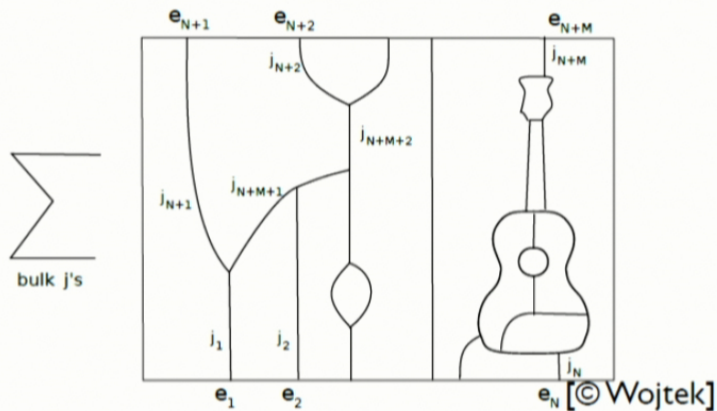


Many things to happen in the near future!

Pirsa talks:  
Loops 13, July 2013

Workshop:  
Renormalization approaches in QG, April 2014

The music of quantum gravity:



[TorQ: A shift in time at PI]