

Title: Reconstructing the Quantum Gravity Effective Action

Date: Nov 22, 2018 02:30 PM

URL: <http://pirsa.org/18110075>

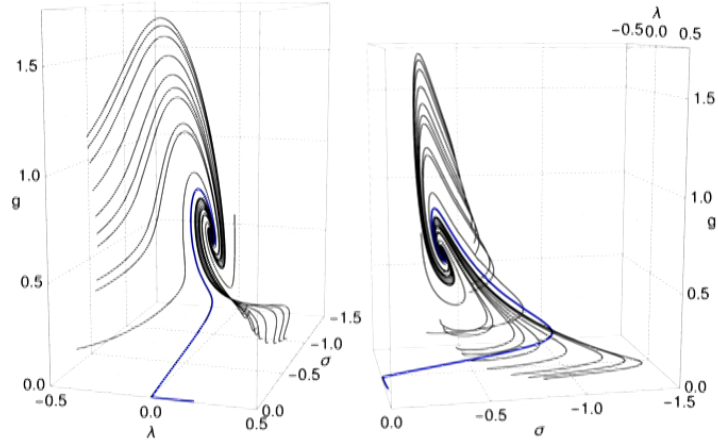
Abstract: <p>I will present a new method to constrain the quantum effective action of gravity, inspired by recent results from causal dynamical triangulations (CDT). After a short introduction to CDT, I will start from a parameterisation of the effective action to calculate correlation functions for observable quantities. Matching these correlators to CDT data allows to reverse-engineer the couplings which describe the effective dynamics. As a concrete example, the autocorrelation of spatial volume fluctuations is considered. The comparison to CDT data suggests the existence of non-local interaction terms, which might have interesting phenomenological consequences for the interpretation of dark energy.</p>

Reconstructing the Quantum Gravity Effective Action

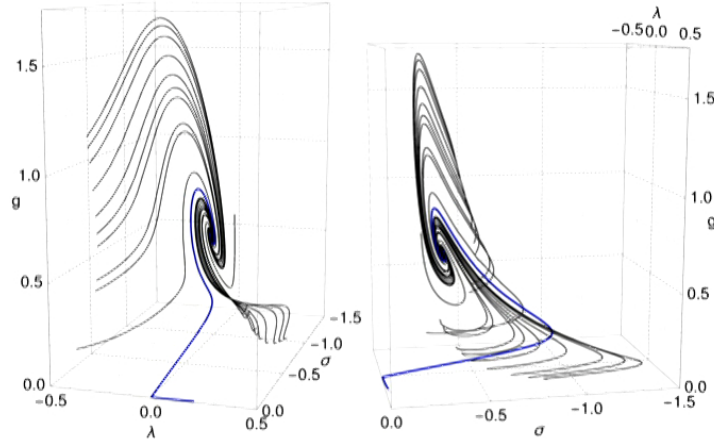
Benjamin Knorr and Frank Saueressig
PRL 121 (2018) 16, 161304

Radboud University





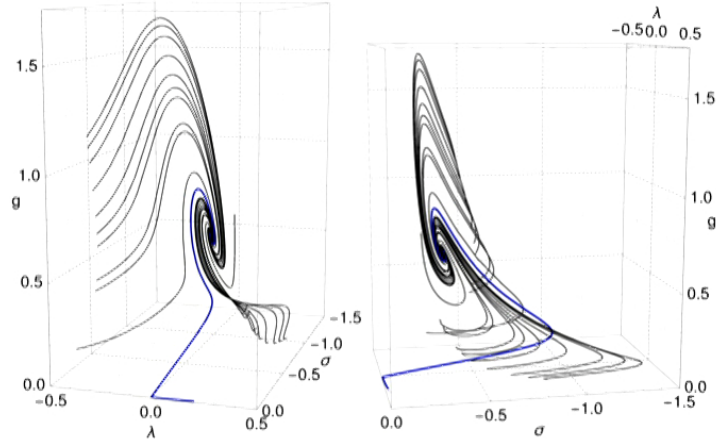
Two-loop counterterm is asymptotically safe
 Gies, BK, Lippoldt, Saueressig



Two-loop counterterm is asymptotically safe
Gies, BK, Lippoldt, Saueressig

$$g_{\mu\nu} = \sigma_{\mu\nu} + n_{\mu}n_{\nu}$$

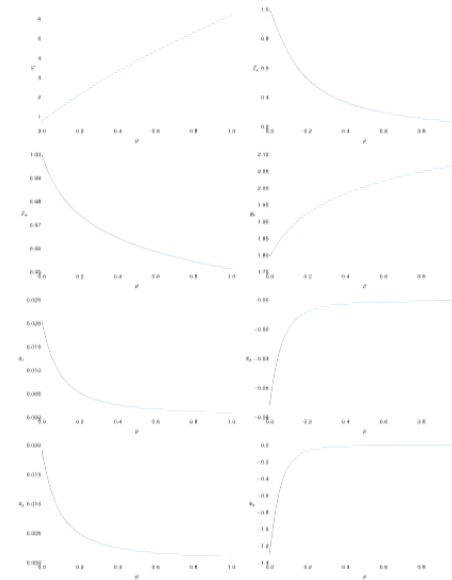
Lorentz symmetry is relevant
BK



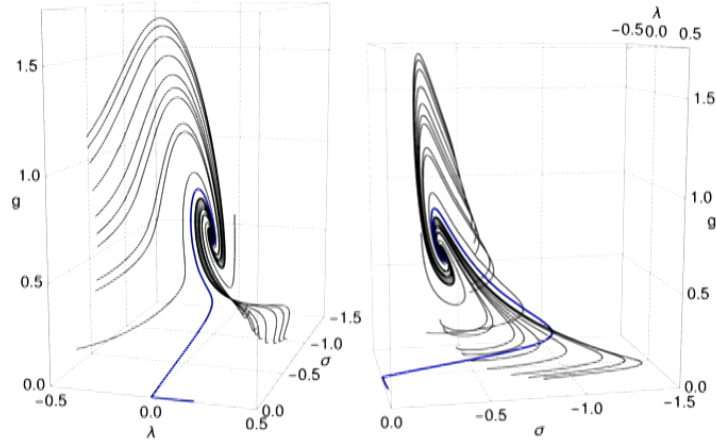
Two-loop counterterm is asymptotically safe
Gies, BK, Lippoldt, Saueressig

$$g_{\mu\nu} = \sigma_{\mu\nu} + n_{\mu}n_{\nu}$$

Lorentz symmetry is relevant
BK



Ising and Gross-Neveu model in next-to-leading order
BK

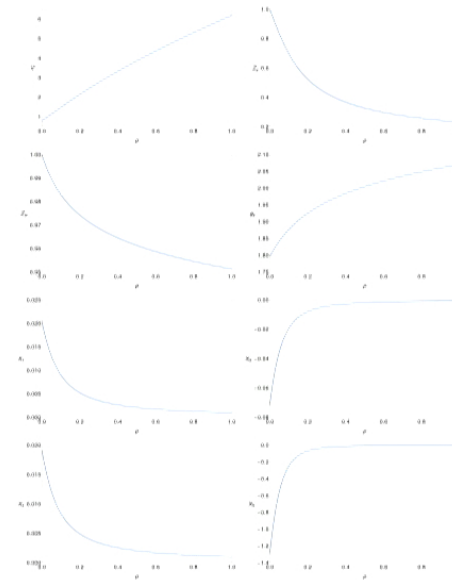


Two-loop counterterm is asymptotically safe
Gies, BK, Lippoldt, Saueressig

today:
EFT for gravity

$$g_{\mu\nu} = \sigma_{\mu\nu} + n_{\mu}n_{\nu}$$

Lorentz symmetry is relevant
BK



Ising and Gross-Neveu model in next-to-leading order
BK

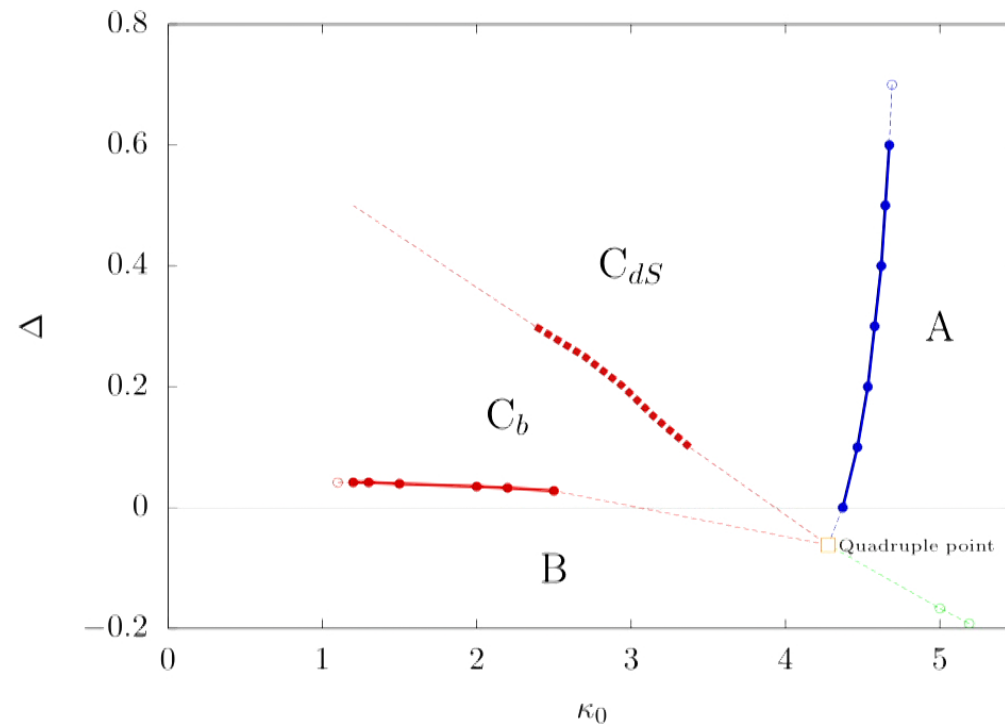
Outline

- CDT 101
- a matching template: reconstructing the effective action
- results and comparison to CDT data
- outlook

CDT 101 - some basics

- central idea in Causal Dynamical Triangulations: build spacetime out of fundamental building blocks (simplices)
- implement causal structure by foliation - Wick rotation well-defined
- calculate partition function as usual by Monte Carlo methods
- note: in general, spacelike and timelike links have different lengths

CDT 101 - phase diagram



1610.05245

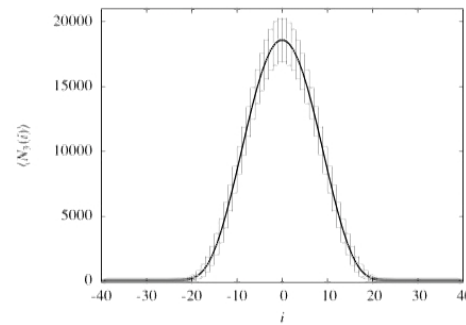
Ambjorn, Gizbert-Studnicki, Jurkiewicz, Klitgaard, Loll

CDT 101 - some results

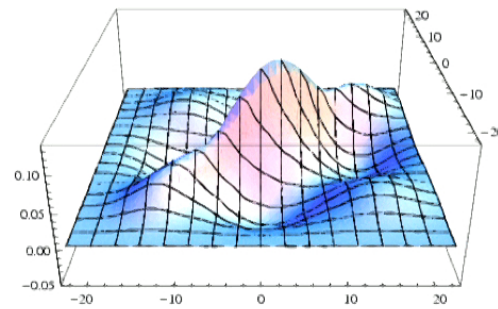
- in recent years, many results accumulated:
 - phase diagram with 4 different phases
 - study of spectral dimensions
 - autocorrelator of 3-volume fluctuations
 - effect of spatial topology (sphere vs. torus)

CDT 101 - 3-volume and fluctuations

$$\langle V_3(t) \rangle$$

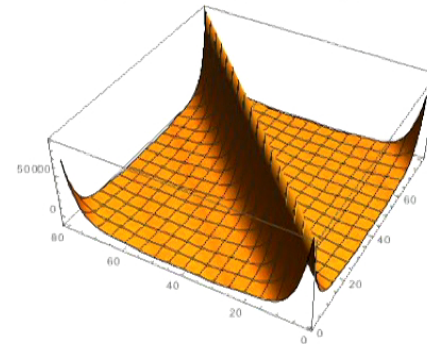
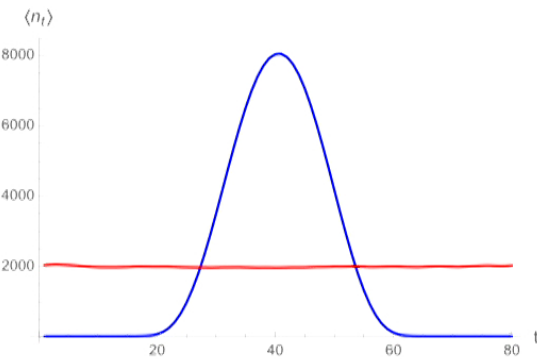


$$\langle \delta V_3(t) \delta V_3(t') \rangle$$



S¹xS³ 0807.4481

Ambjorn, Goerlich, Jurkiewicz, Loll



S¹xT³ 1604.08786

Ambjorn, Drogosz, Gizbert-Studnicki, Goerlich, Jurkiewicz, Nemeth



Can we extract information on the effective action
of gravity from these correlators?

Effective action - a matching template

- idea:
 - start with ansatz for effective action
 - calculate correlators measured in CDT
 - fit to data, extract parameters
 - if fit unsatisfactory: extend ansatz for effective action
- advantages:
 - EFT spirit, independent of UV completion
 - access to IR of quantum gravity

IR effects of quantum gravity

- graviton is supposedly massless
- massless particles are expected to give rise to non-local terms in the effective action

- 2d QG:

$$\Gamma \propto \int d^2x \sqrt{-g} R \frac{1}{\square} R$$

- QCD: non-local interactions correctly describe non-perturbative gluon propagator in IR

$$\Gamma_{\text{nl}} \propto \text{Tr} \int d^4x F_{\mu\nu} \frac{1}{\square} F^{\mu\nu}$$

- 4d: dynamical explanation for dark energy? (Maggiore-Mancarella model)

IR effects of quantum gravity - Maggiore-Mancarella model

- phenomenological ansatz for effective action of quantum gravity:

$$\Gamma_{MM} = \frac{1}{16\pi G_N} \int d^4x \sqrt{-g} \left[-R - \frac{b^2}{6} R \frac{1}{\square^2} R \right]$$

- phenomenological status:

- FRW background evolution
- stable cosmological perturbations
- fits CMB, BAO, SNe, structure formation data and local H_0 measurements
- predicts finite sum of neutrino masses (in contrast to Λ CDM)
- gravitational waves propagate with speed of light

review: [1712.07066](#)
Belgacem, Dirian, Foffa, Maggiore



IR effects of quantum gravity - Maggiore-Mancarella model

- phenomenological ansatz for effective action of quantum gravity:

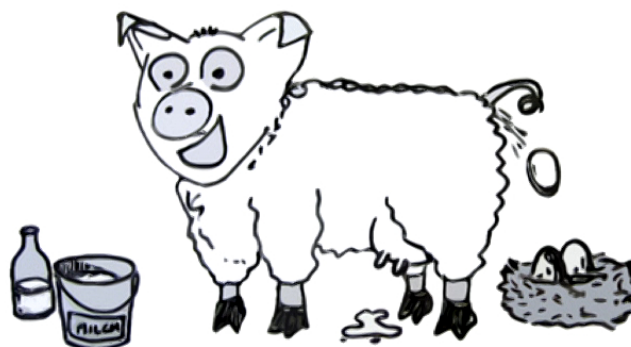
$$\Gamma_{MM} = \frac{1}{16\pi G_N} \int d^4x \sqrt{-g} \left[-R - \frac{b^2}{6} R \frac{1}{\square^2} R \right]$$

- phenomenological status:

- FRW background evolution
- stable cosmological perturbations
- fits CMB, BAO, SNe, structure formation d
- predicts finite sum of neutrino masses (in c
- gravitational waves propagate with speed c

review: [1712.07066](#)
Belgacem, Dirian, Foffa, Maggiore

Wikipedia
by Pixelrausch
CC BY-SA 2.0



Reconstructing the effective action of QG

- inspired by phenomenology, we make the ansatz

$$\Gamma_{QG} \approx \frac{1}{16\pi G_N} \int d^4x \sqrt{-g} \left[-R + 2\Lambda - \frac{b^2}{6} R \frac{1}{\square^2} R \right]$$

- at present: only data for one correlator available, cannot fix other non-local terms yet
- effect of this term: gauge-invariant mass term for two-point function
- in general: inverse operator might contain endomorphism



Calculating the correlator I

- CDT data: expectation value of geometry is sphere/torus - use fixed on-shell metric

$$\bar{g}_{\mu\nu} = \text{diag}(1, a(t)^2 \bar{\sigma}_{ij}(x))$$

- use definition of 3-volume:

$$\delta V_3(t) = \frac{1}{2} \int d^3x \sqrt{\bar{\sigma}} a(t)^3 \bar{\sigma}^{ij} \delta \sigma_{ij}$$

- insert into correlator:

$$\langle \delta V_3(t) \delta V_3(t') \rangle = \frac{1}{4} \int_x \int_{x'} \langle \hat{\sigma}(x, t) \hat{\sigma}(x', t') \rangle$$

$$\hat{\sigma} = a(t)^3 \bar{\sigma}^{ij} \delta \sigma_{ij}$$

Calculating the correlator II

$$\langle \delta V_3(t) \delta V_3(t') \rangle = \frac{1}{4} \int_x \int_{x'} \langle \hat{\sigma}(x, t) \hat{\sigma}(x', t') \rangle$$

- key ideas:
 - propagator admits expansion into product eigenfunctions:

$$\langle \hat{\sigma}(x, t) \hat{\sigma}(x', t') \rangle = \sum_{n,m} \frac{1}{\lambda_n^x + \lambda_m^t} \Phi_n^*(x) \Phi_n(x') \Psi_m^*(t) \Psi_m(t')$$

- use orthogonality of spatial eigenfunctions - only need to know temporal spectrum and eigenfunctions
- use ansatz for effective action to calculate spectrum and eigenfunctions
- calculate (temporal) propagator



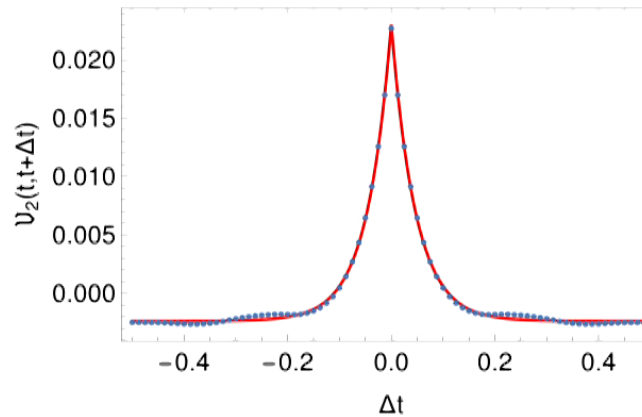
Calculating the correlator III

- real world check:
 - torus: can do calculation analytically to the end
 - sphere: analytical solution unknown
- general properties:
 - (potentially singular) Sturm-Liouville problem, depending on boundary conditions
 - general expectation: eigenvalues grow quadratically asymptotically, slow convergence of propagator



Comparison to CDT - torus

- due to symmetry, correlator only depends on time difference
- fitting the data:

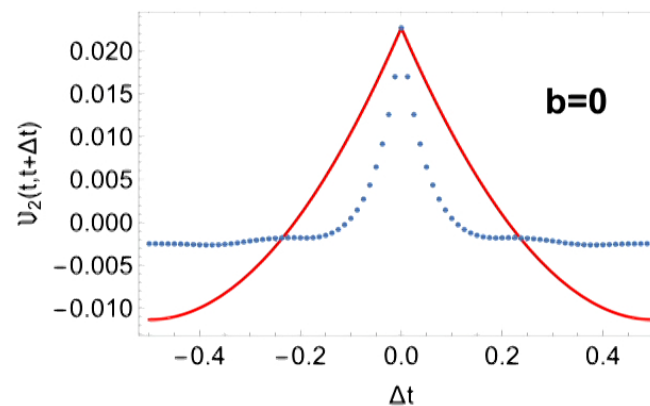
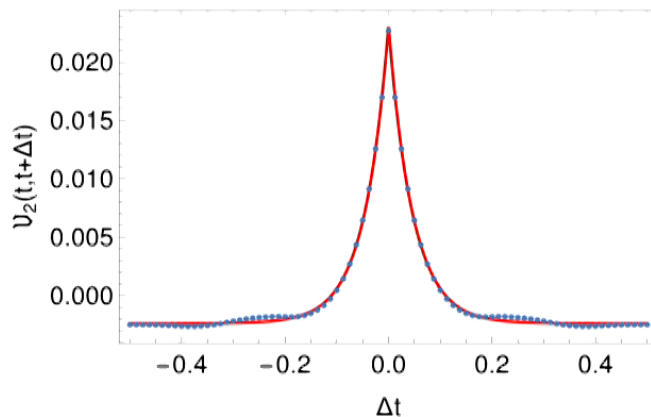


$$G_N = 0.14a_{CDT}^2$$
$$b = 6.93/a_{CDT}$$

- fitting lowest eigenvalues gives lattice spacing:

$$r = 3.09a_{CDT}$$

Comparison to CDT - torus - remarks



- non-zero value of b - evidence for non-local interactions from first principle CDT simulations!
- fit with $b=0$ disagrees *qualitatively*
- checked higher order curvature terms - completely subdominant (ca. 3 orders of magnitude smaller)

Comparison to CDT - sphere

- similar analysis already done in 0807.4481
- eigenproblem agrees (with $b=0$), thus compatible with data
- can extract Newton's constant by matching lowest eigenvalue:

$$G_N = 0.23a_{CDT}^2$$

- relation between lattice spacing and physical radius agrees with relation on torus at same bare parameters

Ambjorn, Goerlich, Jurkiewicz, Loll



Quo vadis, background independence?

- different values for coupling constants on different geometries - no background independence?
- three remarks:
 - on sphere, higher order operators contribute to what we called Newton's constant due to non-vanishing curvature
 - endomorphism necessary for well-defined non-local operator, at present not enough information to clearly resolve b on sphere
 - background independence in principle only necessary in continuum limit



Outlook: more correlators to investigate

- the more correlators we have, the better we can constrain the effective action
- two immediate candidates to extend the present analysis:
 - higher order three-volume autocorrelations:

$$\langle \delta V_3(t_1) \dots \delta V_3(t_n) \rangle$$

- three-curvature correlations:

$$\langle \delta^{(3)} \mathcal{R}(t) \delta^{(3)} \mathcal{R}(t') \rangle$$

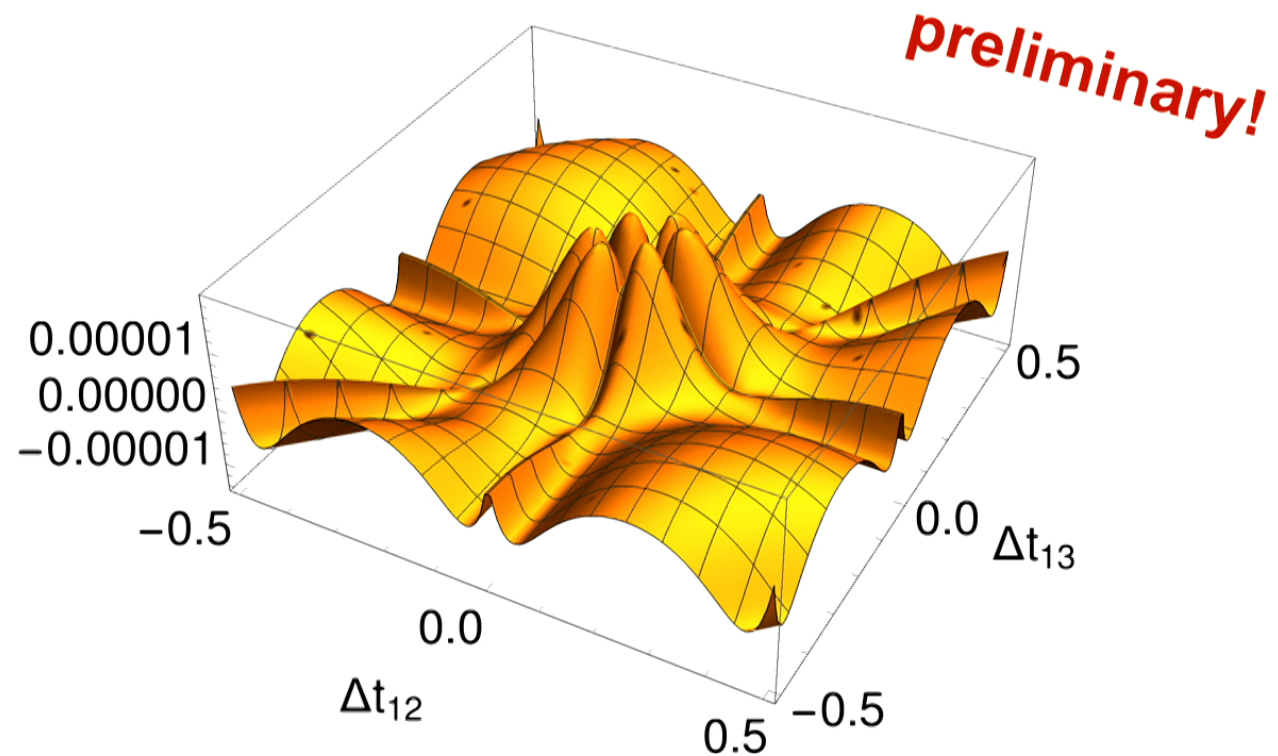
Three-point correlator on the torus I

- taking derivative of two-point correlator w.r.t. appropriate source gives

$$\langle \delta V_3(t_1) \delta V_3(t_2) \delta V_3(t_3) \rangle = -\frac{1}{8} \int_{\substack{\underline{x}_1, \underline{x}_2, \underline{x}_3 \\ x, y, z}} \Gamma^{(3)}(x, y, z) G(x, x_1) G(y, x_2) G(z, x_3)$$

- symmetry again restricts dependence of correlator
- assume that higher order terms are negligible, we can *predict* this correlator

Three-point correlator on the torus II



Summary

- central idea: constrain effective action by correlators that can be calculated in different approaches
- CDT: evidence for non-local interactions which could explain dark energy dynamically
- future work:
 - constrain form/get control over non-local terms
 - finish analysis of other correlators
 - apply to other approaches: causal sets, LQG, direct RG calculation ...



$$T_k \equiv \int d^d x \sqrt{g} \left(R - \frac{1}{2} (\Delta \phi)^2 + C_{\text{Fierz}} \frac{g(\Delta) C_{\text{Fierz}}}{f} \right)$$

