Title: Panel Discussion - QFT vs beyond-QFT approaches (Buoninfante, Rejzner, Smolin, Vieira)

Speakers: Luca Buoninfante, Benjamin Knorr, Katarzyna Rejzner, Lee Smolin, Pedro Vieira

Collection: Puzzles in the Quantum Gravity Landscape: viewpoints from different approaches

Date: October 24, 2023 - 3:45 PM

URL: https://pirsa.org/23100008

Panel Discussion
“QFT vs beyond-QFT approaches”

Key Question:

Do we need to abandon (standard) QFT framework for Quantum Gravity?

Questions that were asked to address:

1. Why QFT approaches are the most promising approaches to QG?

2. What challenges you see for beyond-QFT approaches?

Einstein's General Relativity: $S_{EH} = \frac{M_p^2}{2} \int d^4x \sqrt{-g}(R - 2\Lambda)$

Issues:

1. Theoretical: perturbatively non-renormalizable

2. Observational: cannot explain CMB anisotropies (early times physics)

Simplest model to explain 2. :

$$S = S_{EH} + S_\phi + \cdots, \qquad S_\phi \equiv \text{inflaton action}$$

How to select "fundamental" Lagrangians in perturbative QFT?

- Guidance from Nature: experiments!
- Guiding principles: in particular, renormalizability criterion!

'Unique' (strictly) renormalizable QFT of gravity in $D = 4$:

[Stelle, PRD (1977)]

$$S = \frac{1}{2}\int d^4x\,\sqrt{-g}\left(M_p^2(R - 2\Lambda) + \frac{\alpha}{6}R^2 - \frac{\beta}{2}C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma}\right)$$

Massive spin-0 dof: $m_0^2 = \frac{M_p^2}{\alpha}$,

$\alpha \sim 10^{10}$: natural explanation for inflation!!!

[Starobinsky, 1980+]

Some comments

$$S = \frac{1}{2}\int d^4x\,\sqrt{-g}\left(M_p^2(R-2\Lambda)+\frac{\alpha}{6}R^2-\frac{\beta}{2}C_{\mu\nu\rho\sigma}C^{\mu\nu\rho\sigma}\right)$$

- Quadratic Gravity *vs* EFT of GR at $E \gtrsim m_0 \sim 10^{13}$GeV ($\ll M_p$)

- Quadratic Gravity *vs* String theory/Swampland

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Does any beyond-QFT approach do better than perturbative QFT?

(uniqueness, predictivity, simplicity, new observed physics beyond Einstein's GR, NO conjectures, no problem with matter couplings, good methods to perform ''quantitative'' computations,...)

QG as a QFT or not?

Benjamin Knorr

NORDITA
The Nordic Institute for Theoretical Physics

QG is a QFT

- QFT is a **predictive** and **quantitative** framework:
  - SM has some of the most precise predictions in all of physics
  - universality (independence of microscopic details) via second order phase transitions
  - EFT works extremely well if we do not know the fundamental theory

Benjamin Knorr - Nordita

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- QFT is a **predictive** and **quantitative** framework
- QG must be consistent with a lot of constraints - easiest in a QFT setup
- we accept non-perturbativity in QCD - why do we not accept it in gravity?

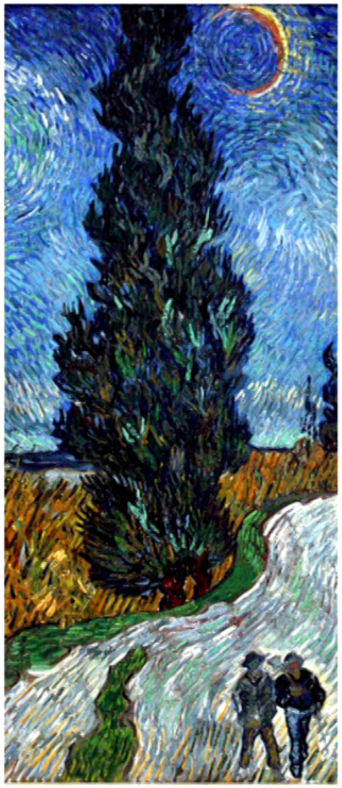
Benjamin Knorr - Nordita

Why not successful yet?

- non-QFT approaches (string theory) vastly outnumber QFT approaches in people power
- many modern tools/new ideas/enough computational power only available since recently:
  - Functional Renormalisation Group (mid to late 90s)
  - large scale computer simulations (EDT/CDT)
  - non-local QG

QFT approaches to QG

- Take a background metric g and perturb with a symmetric 2-form h. What can go wrong?!
- The theory is power-counting non-renormalisable, so either we treat it as an effective theory, or we look for a non-Gaussian fixed point (assymptotic safety)
- But what if spacetime is actually discrete? Can we do QFT on it? Yes! (e.g. QFT on causal sets).
- Some things to consider: Lorentzian signature, background independence, gauge invariant observables, locality vs non-locality.
- My own work: algebraic QFT methods in effective QG, asymptotic safety and QFT on causal sets.



What can we learn from QFT approaches?

- Connecting to QFT on curved spacetimes, GR, QFT on Minkowski spacetime. How do these emerge from QG? What effects can we reasonably expect to measure when testing QG?
- Fundamental discreteness can work as a UV cutoff and help address the issue of divergences in QFT (e.g. QFT on causal sets can be viewed this way).
- Promising intersections between asymptotic safety, QFT on causal sets and the algebraic approach to QFT/QG.

By QFT versus beyond QFT we mean the difference between background independent and background dependent. As we argued years ago the way we go Beyond QFT is by identifying and destroying background structures.

To build an QFT pick certain fixed non-dynamical structures, geometries, gaugecture: a finite dimensional manifold, $\mathscr{M}$, on which has be Roughly speaking, a structure is part of the definition of a QFT if it can be completely constructed before we “run the model’. Time is absent because it can be replaced by a timeless computation..

Beyond QFT models must be run to understand them. Time then becomes dynamical hence real.

This means that in a background independent theory (quantum gravity for short)

- **There is nothing outside the universe. No boundaries. No asymptotic boundaries. No nonvanishing global conservation laws, whether from global or asymptotic conservation laws.**
- **The universe might at one time have been different, but it happened just once**, and as it evolves its own dynamical laws, it leaves behind no asymptotic structures.

Dynamics beyond QFT: Either Dirac is right, and time is gauged; the Inner or time is real and laws of nature evolve.

There are just a few attempts so far to build a proper quantum theory of gravity.
1) covariant path integral models
2) Dirac Hamiltonian models.
3) built by discrete rules.

The first leads to spin foam models.
The second leads to LQG models.
The third lead to causal sets and their generalizations.

People use various techniques to constructor them, such as triangulations of various sorts, discrete,cut-offs, regulators, etc; but these are all just details.

The best studied quantum theories of gravity are LQG.

Our understanding his incomplete, but much is known.

Basic strategy:

- Take classical GR. In chiral form, Ashtekar, Plebanski...
- Coordinatize phase space in holonomy- areas variables: complete
- Quantize algebra of kinemmatical then spatial diffeo variables,
  either continuum or discret —> get spatially diffeo and spin foam spatially diffeo