Title: Spacetime structure from interactions between quantum fluctuations

Speakers: Anna Karlsson

Series: Quantum Gravity

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Abstract: I will discuss an attempt at approaching quantum features of spacetime from a microscopic point of view. In combination with quantum gravity, one can consider a scenario in which spacetime has structure at the level of quantum interactions, and classical spacetime emerges at larger scales. This type of scenario would require entangling interactions, and a reliance on information exchange would have effects on the classical field theory.

Spacetime structure from interactions between quantum fluctuations

Anna Karlsson
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Based on: 1806.05710, 1903.02104

Institute for Advances Study,
and Chalmers

Motivation

What assumptions do we make about quantum structure of spacetime, and how does that impact the validity regime of the classical theory?

Quantum gravity with or without quantum spacetime? ← And quantized in what sense?

Gravity: classical field theory (curvature) vs Microscopic theory?

String theory,
AdS/CFT
and subsequent building blocks

e.g.

Discreteness through spin foam
Tensor networks
etc.

Motivation

Typically, curvature alone is considered to carry the important physics → Inert spacetime: background or discrete patches, e.g. is a part of extending Einstein's field equations past black hole horizons

Since curvature is intimately coupled to spacetime, the question of emergent gravity is natural to extend to a question of emergent spacetime (i.e. the concept itself)

At the classical level, flat space properties can be decoupled from the curvature field theory, but that's not obviously true at the quantum level

To cover all possible scenarios, questions to be adressed is if the quantum structure is

spacetime or gravity only & discretized or emergent ?

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To cover all possible scenarios, questions to be adressed is if the quantum structure is

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…and if that can be found valid or ruled out

Emergent spacetime?

The question of how much of the classical structure we see is an effective theory, with a different origin

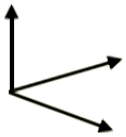
Combined with the consideration that quantum physics is not just *quanta*, but interactions (in the sense of what is observable trough measurements)

Consider: Can there be spacetime structure at the quantum level, based on interactions between particles?

Choices:
← what and
← how

E.g. space requires notions of
- length
- scalar product ⟶

$$\sum_{i=1}^{d} |\hat{e}_i\rangle\langle\hat{e}_i| \longleftrightarrow \frac{1}{N}\sum_{n=1}^{N} f(a_n, b_n) \xrightarrow{N\to\infty} a \cdot b$$

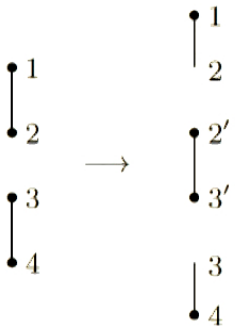


Interestingly, these are close at hand through entanglement: $x_i, p_i \quad \{S_i\}$

A heuristic picture

An interaction origin would build on information exchange between particles and the emergence would be a statistical effect

Would require an equilibrating, entangling process



In recasting spacetime as emergent from interactions (connectivity between particles) distance would be substituted with average frequency of interaction between pairs of particles and local time would be set to the (relative) frequency with which a particle interacts, in total

$$dl \sim c/f, \quad dt \sim 1/f_t$$

E.g. with a Gaussian profile for the quantum interactions, the norm and the variance would be the independent parameters

$$ds^2 \sim \langle -c^2 f_t^2(\mathbf{x}) dt^2 + \sum_i \sigma_i^{-2}(\mathbf{x}) dx_i^2 \rangle$$

Not without consequences

An interaction origin would build on information exchange between particles and the emergence would be a statistical effect

In playing with this *hypothetical* origin, there are two immediate effects:

New physics at a black hole horizon (not due to the gravity theory, but the spacetime origin)

Additional structure in classical, flat spacetime

Pure speculation, but makes it a bit interesting

Scale unclear, but conceptual overlap with particle diffraction

We should make sure of what (type of) quantum structure to expect: gravity only, or spacetime also

Summary

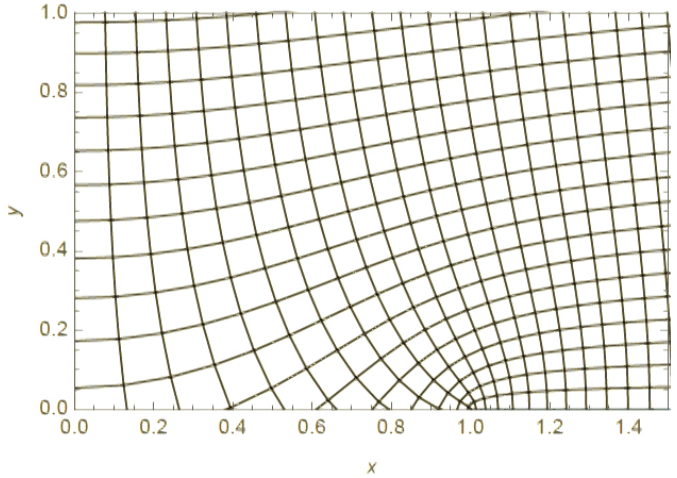
Relevant to look at the assumptions we make about gravity and spacetime and ask if those assumptions necessarily are correct in a quantum picture

One such instance is what spacetime is at the quantum level, with implications for quantum gravity

So far, an interaction origin of spacetime is pure speculation and should be treated as such. However, it should be possible to verify/rule out, and the conceptual discussion is interesting

Connects to expectations from classical theory and how that influences how we model quantum phenomena.
Not always giving an accurate picture, hence important to analyse

Possible additional flat structure?



Slit at $|x| < 1\,,\ y = 0$

$$ds^2 = -dt^2 + dz^2 + L^2\frac{e^{2a}}{4}(da^2 + d\phi^2)$$

Elliptic coordinates: $x = L\cosh a \sin\phi\,,\quad y = L\sinh a\cos\phi$

Flat in: $\xi = e^a \sin\phi \times L/2\,,\quad \eta = e^a\cos\phi \times L/2$