QUANTUM EMERGENCE OF EXPANDING SPACETIMES

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Motivation: Emergence of spacetime

In analogy to the theory of fluids:

MACROSCOPIC WORLD
FLUID SPACETIME
(Navier-Stokes eqs.) (Gravity eqs.)

MICROSCOPIC WORLD
MOLECULES ??

Observer in our expanding universe

Challenge: Emergence of our universe

- Our universe is currently in an era of accelerated expansion.
- All distant objects are expanding away from us.
- Because of this expansion, there are regions causally inaccessible to an observer, generating a cosmological event horizon!

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MOLECULES ??

There is no distant boundary and observers do not fall towards the horizon. We need a different framework.

Question: WHAT ARE THE “MOLECULES” OF OUR UNIVERSE?

A novel proposal

Embed a patch of expanding universe into a contracting spacetime.

Gravitational action:

\[ S_{\text{grav}} = \frac{1}{16\pi G_N} \int d^2 x \sqrt{g} \left( \frac{1}{2} \nabla^2 \phi - \frac{1}{2} \phi \nabla^2 \phi + \frac{1}{2} R + V(\phi) \right) \]

Key properties:
- External distant boundary.
- Yet, expanding in interior.
- Precise quantitative measurements.

Applications

a) Shockwaves

In contrast to black holes, shockwaves connect otherwise disconnected observers.

b) Hydrodynamic modes

near the spacetime boundary can be fully characterised.

\[ S_{\text{pert}} = \int_0^{2\pi} du \left( \gamma \delta \tau'(u)^2 + \delta \tau''(u)^2 \right), \quad \delta \tau(u) : \text{hydrodynamic boundary mode}, \quad \gamma = \begin{cases} -1 : \text{black hole horizon} \\ \pm 1,1 : \text{cosmological horizon} \end{cases} \]

Main results

1. We provided a modern framework to treat the cosmological horizon.
2. Cosmological horizons are strikingly different to black hole horizons.
3. Quantitative evidence both at a static and at a dynamical level.

Future directions

- This work opens an innovative direction to study the emergence of our universe.
- Search for microscopic quantum models compatible with macroscopic observations.
- More generally, what are the fundamental features of a quantum spacetime?