De Sitter Space as Coherent State of Gravitons

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with

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Cosmology and Particle Physics:

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Ana Fernandes Alexandre (Cosmology, GUTs)

Giordano Cintia (Superfluid DM, Quantum Breaking)

Lukas Eisemann (Quantum Breaking, Black Holes, Enhanced Memory Cap.)

Manuel Ettengruber (Joint Supervision by Caldwell & Dvali, IR Neutrino Ph.)

Anna Jankowsky (SUSY GUTs)

Oleg Kaikov (Quantum Breaking, Black Holes, Enhanced Memory Capacity)

Emmanouil Koutsangelas (Dark Matter as Many Copies of SM, Axions)

Andrei Kovtun (Quantum Breaking)

Otari Sakhelashvili (Non-perturbative QFT, Entropy Bound and Unitarity)

Anja Stuhlfauth (GUTs, Light Color-Triplet Ph.)

Juan Sebastian Valbuena Bermudez (Int. of Top. Defects, Black Holes)

Michael Zantedeschi (Quantum Breaking, PBHs)

Marco Michel (Quantum Breaking, Black Holes, Enhanced Memory)

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De Sitter Space

It is a special background of cosmological significance, as it is sourced by the fundamentally classical source.

Understanding fundamental properties of de Sitter is of utmost importance; e.g. for dark energy, cosmological constant problem.

Standard treatment: QFT in fixed de Sitter background geometry.

Misconception: treating dS on equal footing as Minkowski space, which qualifies as a legitimate vacuum.

De Sitter Space as Coherent State of Gravitons

Coherent state description of de Sitter space: Dvali, Gomez '13, Dvali, Gomez, Zell '17

Q: What are the properties of constituent quanta? Vacuum?

A: Need for off-shell longitudinal gravitons, over the Minkowski spacetime.

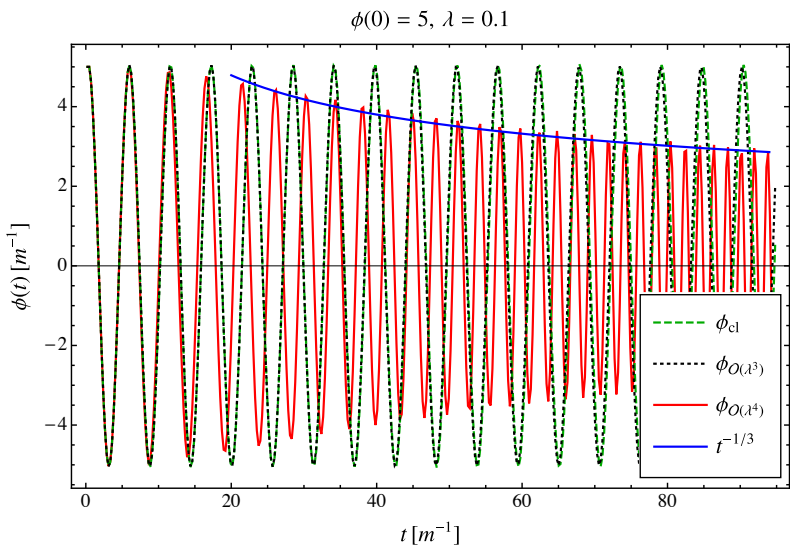
Coherent States in Interacting QFT

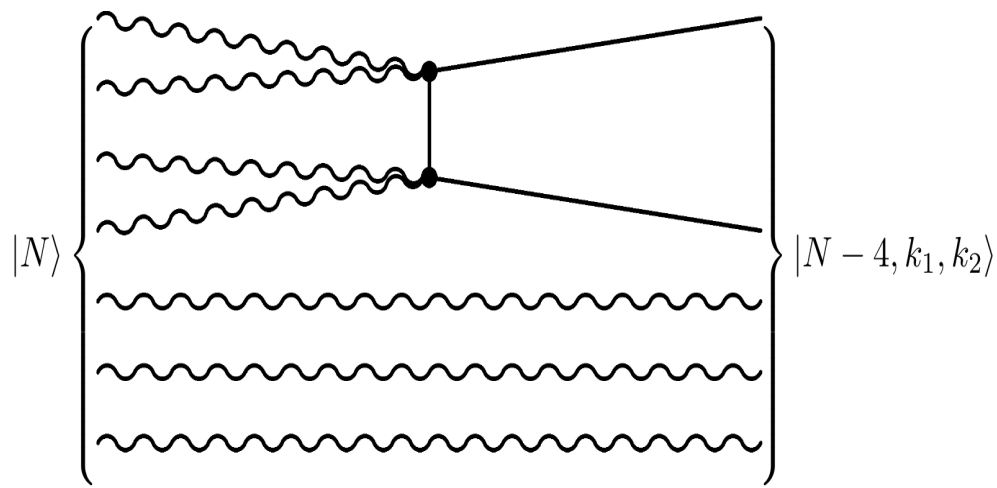
LB, M. Zantedeschi, Phys. Rev. D **104**, no.8, 085007 (2021)

LB, G. Cintia, M. Zantedeschi, [arXiv:2108.13235].

$$|C\rangle = e^{-i\int d^3x\left(\phi_{cl}(x)\hat{\pi}(x)-\pi_{cl}(x)\hat{\phi}(x)\right)}|\Omega\rangle.$$

$$\langle C|\hat{\phi}|C\rangle(t=0) = \phi_{cl}(x)\,,$$
$$\langle C|\hat{\pi}|C\rangle(t=0) = \pi_{cl}(x)\,.$$





de Sitter in Linearized Gravity

The same fundamental questions, regarding the consistency of the coherent state description, as in Einstein's theory arise:

- Vacuum?
- Longitudinal polarizations?

Consistency of Coherent States in Linearized Gravity

LB, G. Dvali, O. Sakhelashvili, "De Sitter space as BRST invariant coherent state of gravitons," [arXiv:2111.12022].

States must satisfy physicality conditions.

In BRST quantization

$$\hat{Q}|phys\rangle = 0.$$

In the absence of cosmological constant, constructing the graviton coherent state as

$$|h\rangle = e^{-i\int d^3x\left(h^c_{ij}\hat{\pi}_{ij} - \pi^c_{ij}\hat{h}_{ij} + \dots\right)}|\Omega\rangle\,,$$

BRST requirement was shown to hold if

$$\left(\nabla^2\delta_{ij} - \partial_i\partial_j\right)h^c_{ij} = 0\,, \quad \text{and} \quad \partial_i\pi^c_{ij} = 0$$

de Sitter in Linearized Gravity

Cosmological Constant:

$$\Delta\mathcal{L} = -\lambda\hat{h}\,.$$

Classically:

$$h_{ij} = -\frac{\lambda}{6}\left(t^2\delta_{ij} + x_i x_j\right)\,, \quad h_{00} = h_{0j} = 0\,.$$

Corresponding to de Sitter background in the limit

$$M_{\rm pl} \to \infty\,, \qquad \lambda = \textit{fixed}\,, \qquad H^2 \simeq \frac{\lambda}{M_{\rm pl}} \to 0\,.$$

In this limit

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{h_{\mu\nu}}{M_{\rm pl}} \qquad \to \qquad \eta_{\mu\nu}$$

de Sitter in Linearized Gravity

LB, G. Dvali, O. Sakhelashvili, "De Sitter space as BRST invariant coherent state of gravitons," [arXiv:2111.12022].

A coherent state over Minkowski, even in the presence of CC?

$$|dS\rangle = e^{-i\int d^3x\,\left(h^c_{ij}\hat{\pi}_{ij}+\dots\right)}|\Omega\rangle$$

The theory at hand is described by $\hat{H} = \hat{H}_0 + \int \lambda\hat{h}$.

Minkowski state $|\Omega\rangle$ is defined as the vacuum of $\hat{H}_0$.

Hence, it's no longer physical: $\hat{Q}|\Omega\rangle \neq 0\,,\quad$ since $\quad\hat{Q} = \hat{Q}_0 + \Delta\hat{Q}$.

Nevertheless:

$$\hat{Q}|dS\rangle = 0\,,\qquad \text{as long as}\qquad \left(\nabla^2\delta_{ij} - \partial_i\partial_j\right)h^c_{ij} - \lambda = 0\,.$$

de Sitter in Linearized Gravity

LB, G. Dvali, O. Sakhelashvili, "De Sitter space as BRST invariant coherent state of gravitons," [arXiv:2111.12022].

Despite the limitations of the construction, the state is shown to exhibit some of the properties of de Sitter upon reintroducing interactions with spectator fields softly.

If our construction can be extended to Einstein's gravity without obstruction, our analysis seems to indicate that $|dS\rangle$ should proceed to lose the coherence gradually.

The possibility of quantum breaking is also substantiated by the analogous setup in QED.

Black-Hole-like systems:

G. Dvali, "Bounds on Quantum Information Storage and Retrieval,"[arXiv:2107.10616].

G. Dvali and R. Venugopalan, "Classicalization and unitarization of wee partons in QCD and Gravity: The CGC-Black Hole correspondence," [arXiv:2106.11989].

G. Dvali and O. Sakhelashvili, "Black-Hole-Like Saturons in Gross-Neveu," [arXiv:2111.03620].

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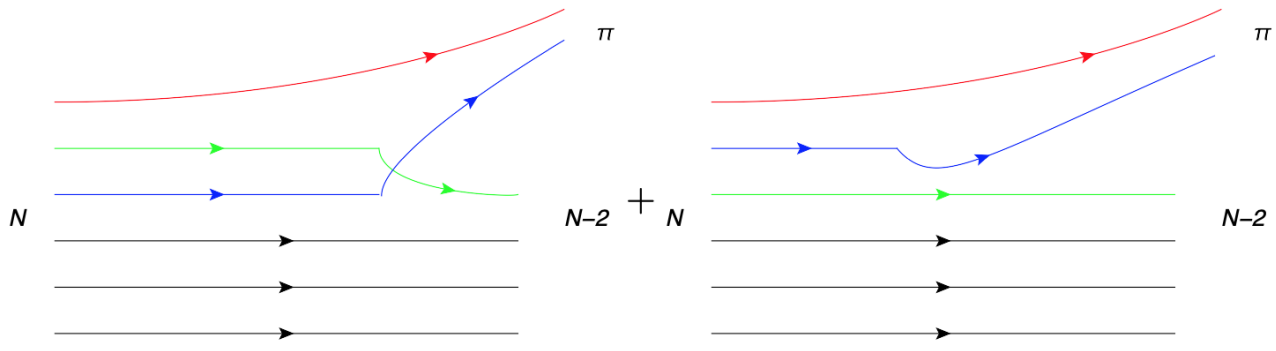
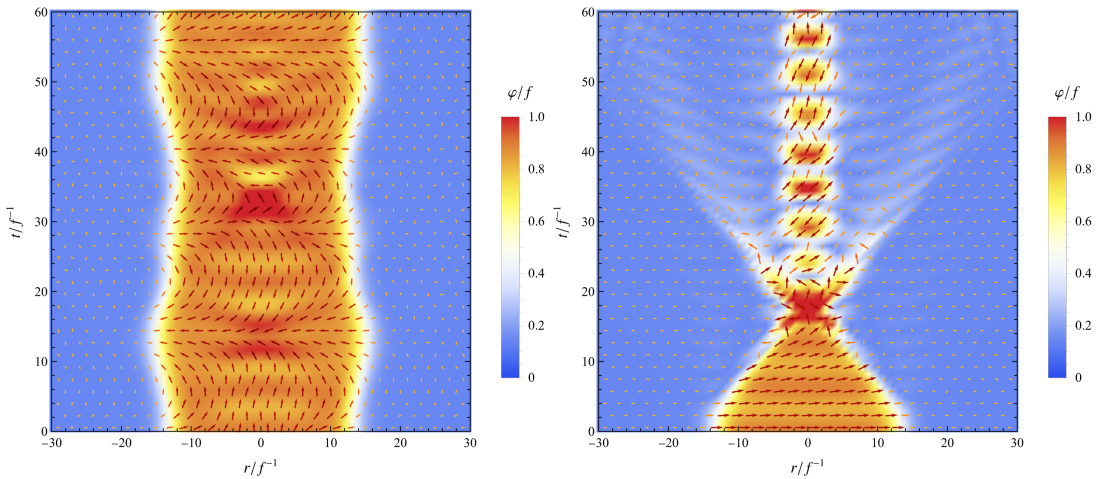
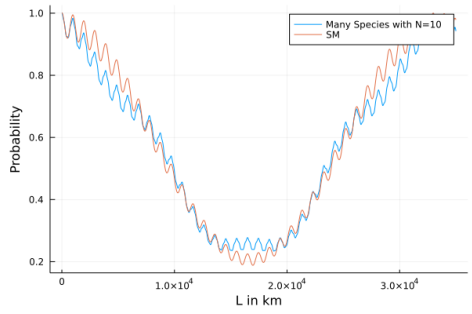
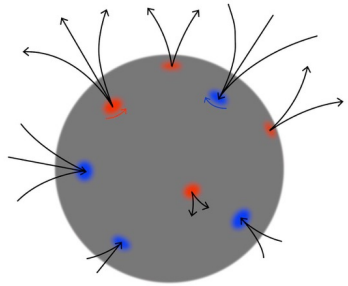
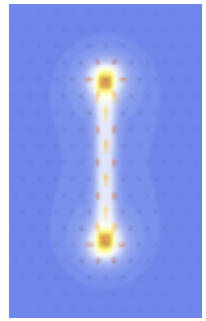




In preparation







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Anca Preda, Goran Senjanovic, Michael Zantedeschi,"Minimal SO(10) Theory: a Case for Hadron Colliders"

LB, Mark Trodden, "Corpuscular Approach to Beginning of Inflation"

Thank you!