



Quantum Discord and Decoherence of inflationary perturbations

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arXiv:2112.05037 AM, Jérôme Martin², Vincent Vennin^{2,3}

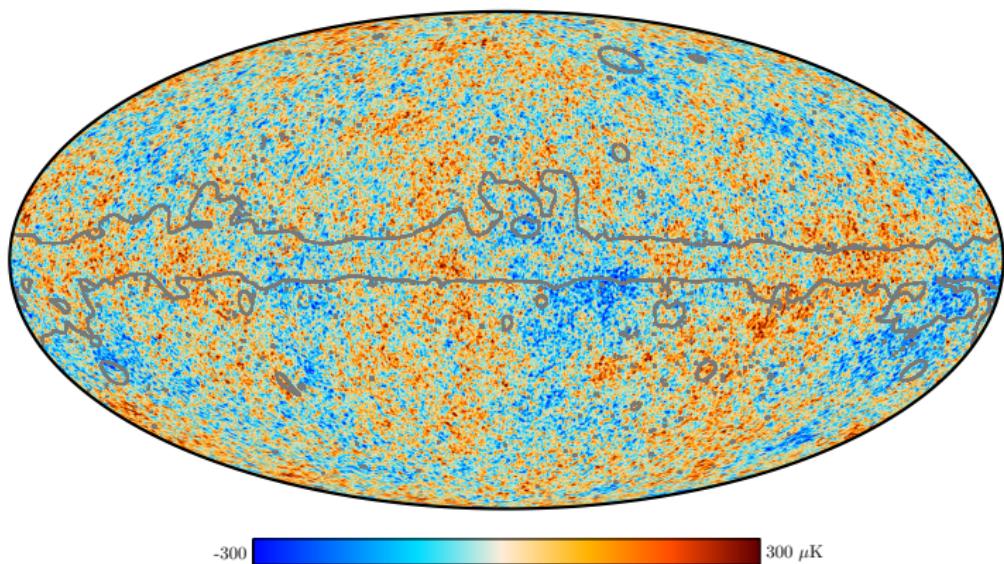
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INTRODUCTION : QUANTUM FEATURES IN THE EARLY UNIVERSE ?

CONTEXT I, INHOMOGENEITIES IN THE EARLY UNIVERSE

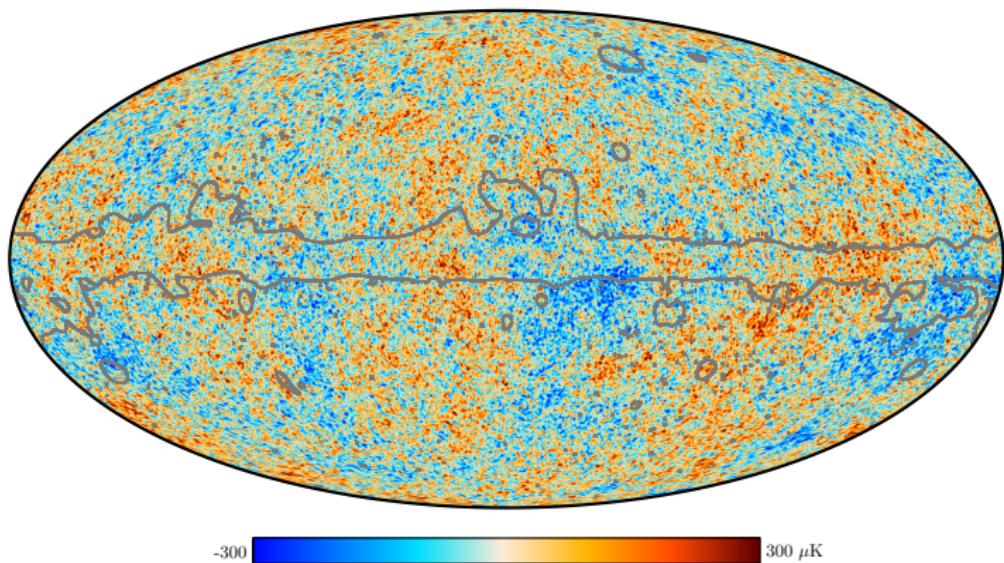
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1. [Planck-Collaboration et al., 2020b]

CONTEXT I, INHOMOGENEITIES IN THE EARLY UNIVERSE

- Early Universe is homogeneous within a very good approximation¹ $\Delta T/T \sim 10^{-4}$ **Origin of inhomogeneities ?**



1. [Planck-Collaboration et al., 2020b]

CONTEXT II, INHOMOGENEITIES IN THE EARLY UNIVERSE

- Proposition $\sim 80s^2$: Inhomogeneities come from minimal (vacuum) quantum fluctuations at the beginning of inflation stretched to cosmological scales by expansion!

2. [Mukhanov and Chibisov, 1981]

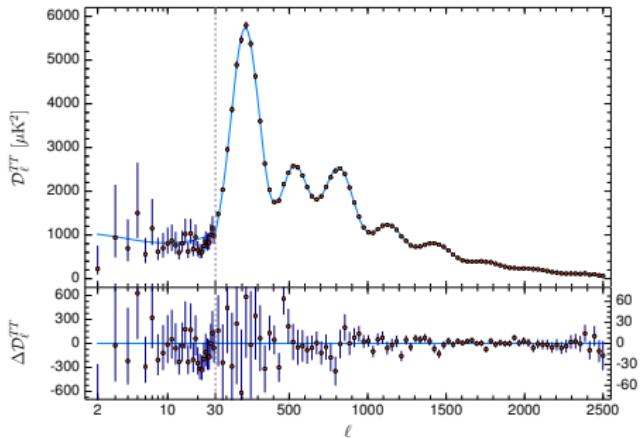
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- Indirect proof : very good agreement with observational data.²



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- Interactions with extra d.o.f lead to **decoherence** of quantum systems : **ingredient of quantum-to-classical transition.**

CHARACTERIZING QUANTUMNESS OF INFLATIONNARY PERTURBATIONS

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$$\mathcal{D}(\mathcal{S}_1, \mathcal{S}_2) \equiv \mathcal{I}(\mathcal{S}_1, \mathcal{S}_2) - \max_{\{\hat{\Pi}_j^{\mathcal{S}_2}\}} \mathcal{J} \left(\mathcal{S}_1, \mathcal{S}_2, \{\hat{\Pi}_j^{\mathcal{S}_2}\} \right)$$

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with \mathcal{I} and \mathcal{J} two measures of mutual information between \mathcal{S}_1 and \mathcal{S}_2 .

If \mathcal{S}_i described by classical probabilities $\mathcal{D}(\mathcal{S}_1, \mathcal{S}_2) = 0$.
Quantum description $\mathcal{D}(\mathcal{S}_1, \mathcal{S}_2) \geq 0$.

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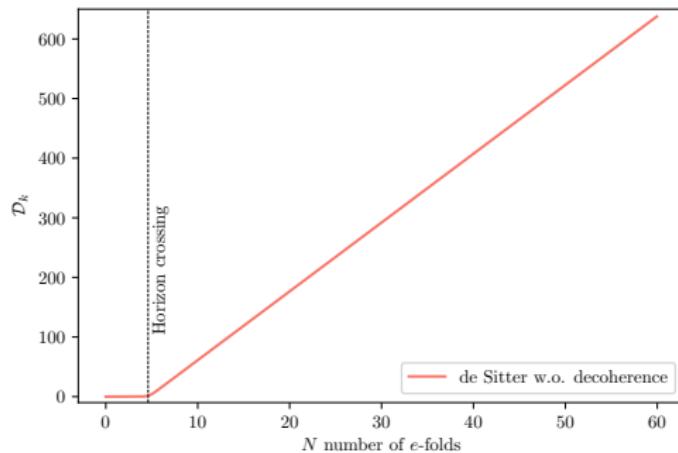
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Take-home message 1

Without decoherence Quantum Discord is strongly amplified by inflation and final state is very quantum in this sense.²

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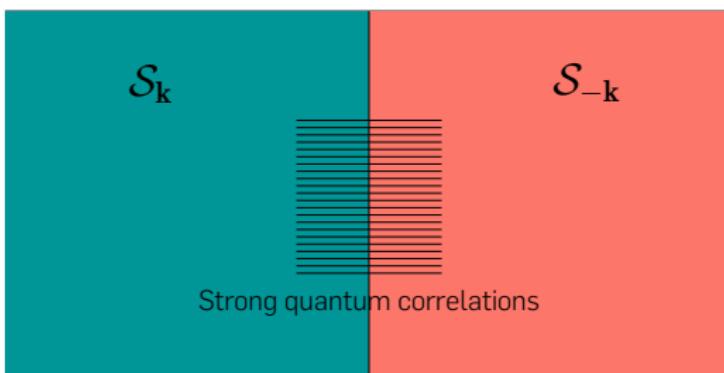
Can this result be due to oversimplified models ?

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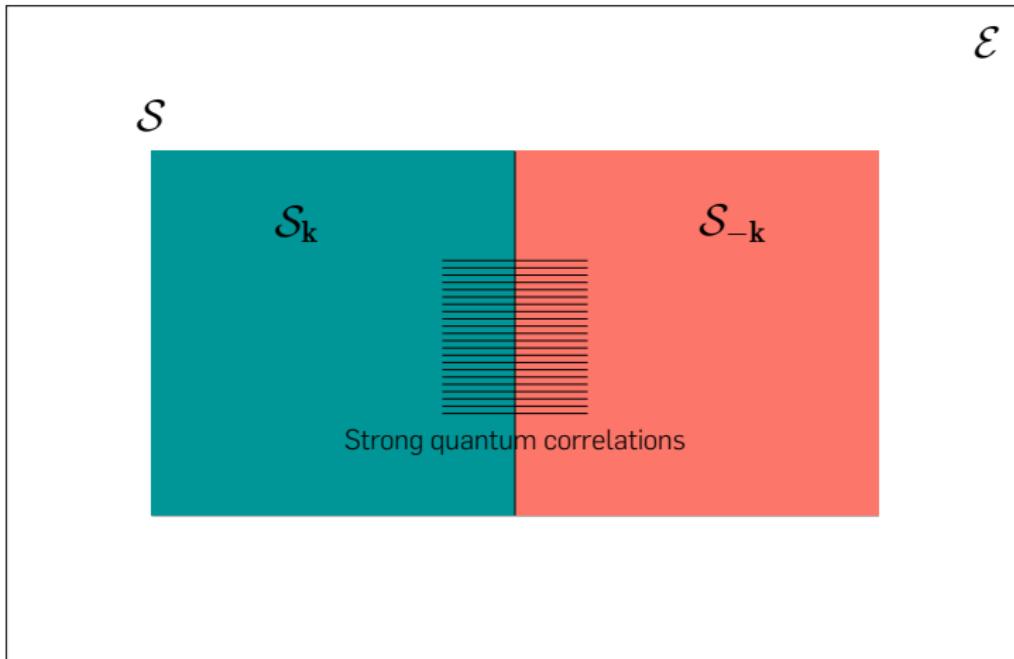
DECOHERENCE AND LOSS OF QUANTUMNESS

NON-LINEARITIES, INTERACTIONS : DECOHERENCE

\mathcal{S}

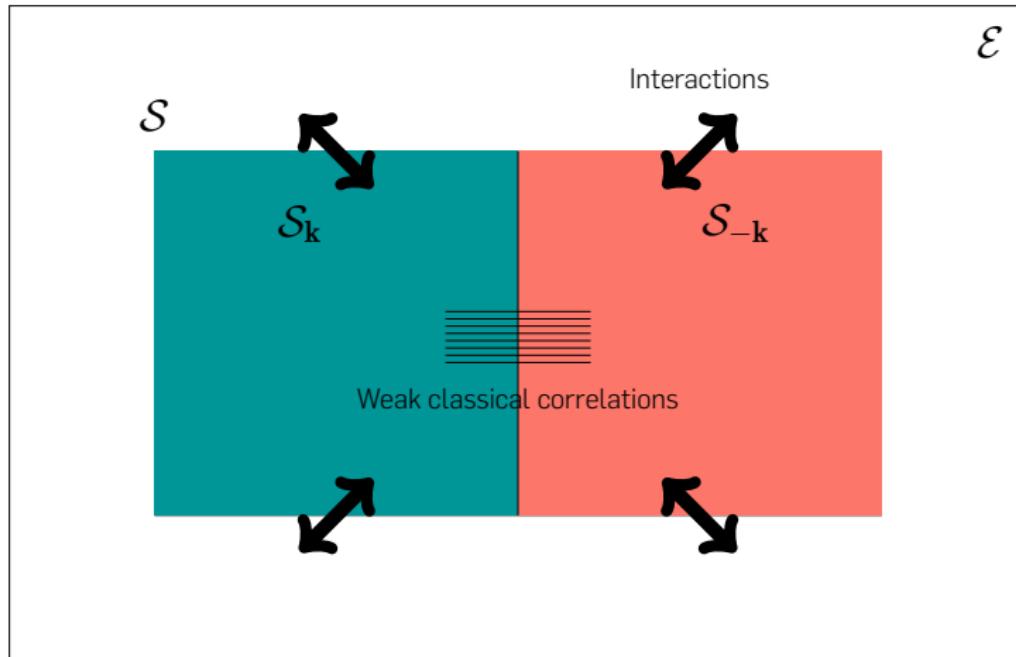


NON-LINEARITIES, INTERACTIONS : DECOHERENCE



In fact \mathcal{S} has an environment \mathcal{E} (e.g. $\mathcal{S}_{\pm k'}$ with $k' \neq k$) or other fields.

NON-LINEARITIES, INTERACTIONS : DECOHERENCE



Interactions S / \mathcal{E} destroy correlations $\mathcal{S}_k / \mathcal{S}_{-k}$: decoherence.

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$$\frac{d\hat{\rho}_{\mathcal{S}}}{d\eta} = -g^2 \eta_C \int d^3x d^3y C_{\mathcal{E}}(x, y) \left[\hat{O}_{\mathcal{S}}(x), \left[\hat{O}_{\mathcal{S}}(y), \hat{\rho}_{\mathcal{S}} \right] \right] .$$

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Assumptions:

- Perturbation $g \ll 1$.
- \mathcal{E} stationnary and not perturbed by \mathcal{S} .
- Consider evolution of \mathcal{S} for $\eta \gg \eta_C$ auto-correlation time of \mathcal{E} .

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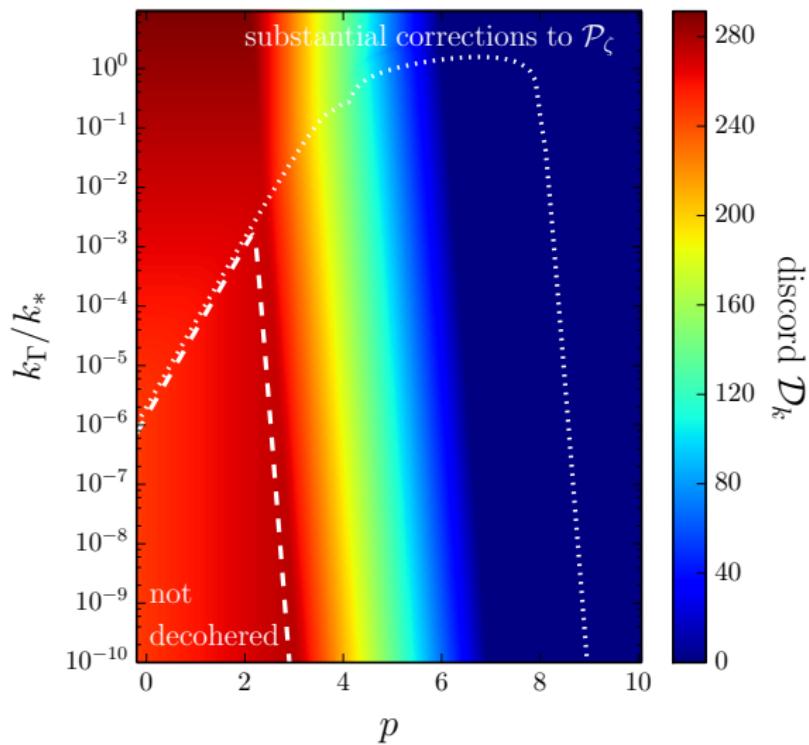
- Free-parameters : k_{Γ} and p .

3. [Martin and Vennin, 2016]

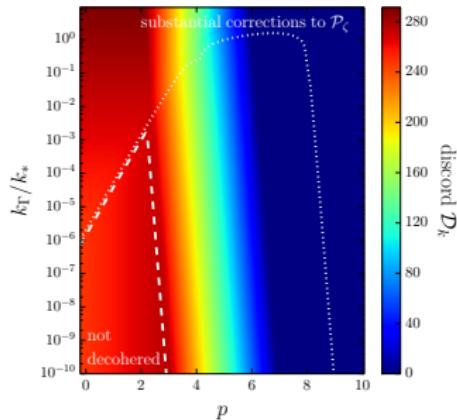
COMPETITION OF ENTANGLEMENT AND DECOHERENCE

Is Quantum Discord spoiled by decoherence ?

COMPETITION OF ENTANGLEMENT AND DECOHERENCE



COMPETITION OF ENTANGLEMENT AND DECOHERENCE



Take-home message 2⁴

Fate of Quantum Discord is the result of a competition between generation of entanglement by inflation and decoherence due to interactions.

4. [arXiv:2112.05037 Martin et al., 2021]

FUTURE DIRECTIONS

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- Compare the effect of decoherence on different criteria (Bell Inequalities, non-separability etc.).

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- Use a more realistic interaction for decoherence, for instance non-linearities of pure gravity and see if we recover similar results.

Thank you for your attention !

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