A novel approach to particle production via communication between quantum particle detectors

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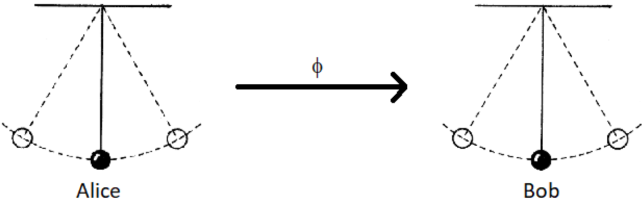
Outline

- **Starting point:** the results in the paper in the QR code;
- **Ending point:** an idea that *could* be interesting (not yet tested)
- **Core of the talk:** your feedback during coffee breaks

recap of the paper $\longrightarrow$ possible developments $\rightarrow$ your valuable feedback



$$\lambda_A(t) = \delta(t - t_I^A)\,; \quad \lambda_B(t) = \delta(t - t_I^B)\,.$$

- The input is considered to be a Gaussian state.
- The resulting quantum channel is a *one-mode Gaussian channel*.
- Its capabilities to transmit classical information is quantified by its *classical capacity*, reading

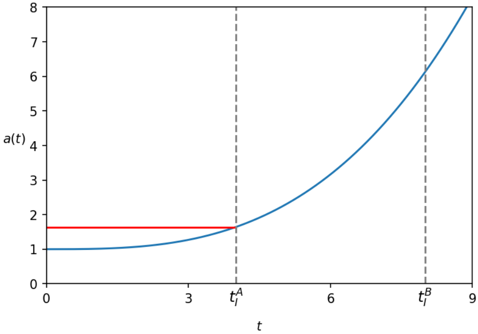
$$C = \Omega \frac{\langle \left[\hat{\Phi}_{f_A}(t_I^A), \hat{\Phi}_{f_B}(t_I^B) \right] \rangle}{\langle \hat{\Phi}^2_{f_A}(t_I^A) \rangle \langle \hat{\Phi}^2_{f_B}(t_I^B) \rangle}\,,$$

where Ω encloses the energetic parameters of the detector.

- A cosmological expanding background was considered

$$ds^2 = -dt^2 + a^2(t)(d\mathbf{x} \cdot d\mathbf{x}) = a^2(\eta)(-d\eta^2 + d\mathbf{x} \cdot d\mathbf{x}) \,.$$

- We choose expansions so that $\dot{a}(t_I^A) \sim 0$, i.e. we approximate the effects of an expansion prior to t_I^A to be negligible and the modes at $t \sim t_I^A$ to be Minkowskian.



Self-consistent only if the universe is accelerating.

Classical capacity in a C.E. universe

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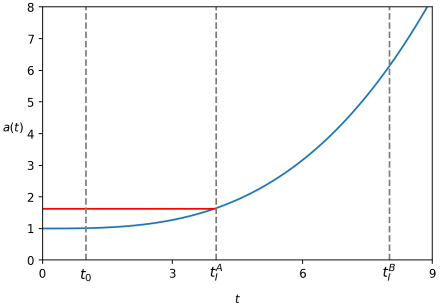
$$C = \Omega \frac{\langle \left[\hat{\Phi}_{f_A}(t_I^A), \hat{\Phi}_{f_B}(t_I^B) \right] \rangle}{\langle \hat{\Phi}^2_{f_A}(t_I^A) \rangle \langle \hat{\Phi}^2_{f_B}(t_I^B) \rangle} = \text{const} \times \frac{\epsilon^2}{d^2} (1 + (1 - 6\xi) F) \, ;$$

$$F = \int_{\eta_I^A}^{\eta_I^B} d\eta a'^2(\eta) \left(\frac{\pi \epsilon}{2} - \frac{4\epsilon^2 (\eta_I^B - \eta)}{(\eta_I^B - \eta)^2 + \epsilon^2} \right) \, .$$

- F is usually positive, except for peculiar situations where the expansion suddenly grows at $\eta \lesssim \eta_I^B$.
- w.r.t. the Minkowski spacetime, where $C = \text{const} \times \frac{\epsilon^2}{d^2}$, the classical capacity **increases** if $\xi < 1/6$, decreases if $\xi > 1/6$ and remains the same if $\xi = 1/6$.
- This is due to the **effective mass** the field assumes when coupled with the scalar curvature $R(\eta)$, i.e.

$$M_{\text{eff}} = a(\eta) \sqrt{\xi - \frac{1}{6}} \sqrt{R(\eta)} \, .$$

Next step: expansion prior to the protocol



The mode are considered to be the Minkowski ones at $t = t_0$. In that case, the factor F becomes

$$F \to F - 4\epsilon^2 \int_{\eta_0}^{\eta_I^A} d\eta a'^2(\eta) \left(\frac{\eta_I^B - \eta}{(\eta_I^B - \eta)^2 + \epsilon^2} + \frac{\eta_I^A - \eta}{(\eta_I^A - \eta)^2 + \epsilon^2} \right) .$$

$\Rightarrow$ The factor F **always decreases**, eventually becoming negative. Therefore, a universe expansion prior to the protocol **increases** its classical capacity if $\xi > 1/6$, an **decreases** it if $\xi < 1/6$.

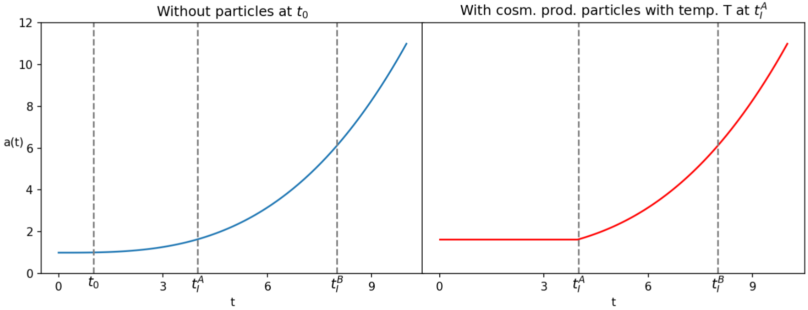
Another step: presence of particles

- In general, a cosmological expansion always creates a bath of particles. Each particle is perfectly entangled with the same one with opposite momentum. *L H Ford 2021 Rep. Prog. Phys. 84 116901*
- For high enough energies, the bath is always thermal, with a temperature T. *Phys. Rev. D 56, 4905 – Published 15 October 1997*
- What happens to the protocol when those particles are present when the protocol starts (i.e. at t_I^A)?

$$C = \Omega \frac{\langle \left[\hat{\Phi}_{f_A}(t_I^A), \hat{\Phi}_{f_B}(t_I^B) \right] \rangle}{\langle \hat{\Phi}^2_{f_A}(t_I^A) \rangle \langle \hat{\Phi}^2_{f_B}(t_I^B) \rangle} \,; \quad \langle a^\dagger_{\mathbf{k}} a_{\mathbf{k}'} \rangle = \frac{\delta^3(\mathbf{k}-\mathbf{k}')}{e^{|\mathbf{k}|/T}-1} \,; \quad \langle a_{\mathbf{k}} a_{\mathbf{k}'} \rangle = \frac{e^{\frac{|\mathbf{k}|}{2T}} e^{i\varphi}}{e^{|\mathbf{k}|/T}-1} \delta^3(\mathbf{k}+\mathbf{k}') \,.$$

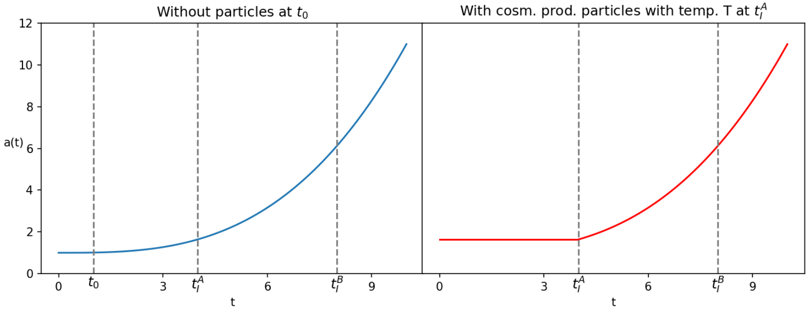
$$\langle \hat{\Phi}^2 \rangle \sim \langle 0 | \, \hat{\Phi}^2 \, | 0 \rangle + \frac{T^2}{12} + \frac{T^2}{2} \cos(\varphi) \sim \langle 0 | \, \hat{\Phi}^2 \, | 0 \rangle + \frac{T^2}{12} \,.$$

$\Rightarrow$ If, at the start of the protocol, particles created by a cosmological expansion are present, then its classical capacity **always decreases**.



- **Fact:** Both those effects modify the classical capacity of the capacity.
- **Proposal:** What if the modification given by a prior expansion is due to the presence of particles created by the prior expansion?
- In this way, by studying the modification of the capacity, one can infer an effective particle production from t_0 to t_I^A.

How to do it?

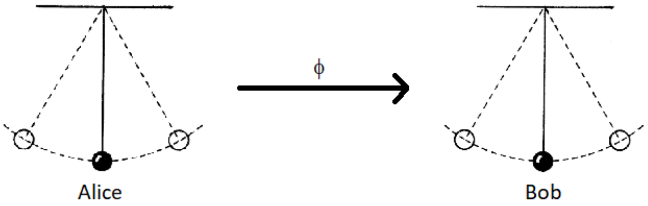


- Presence of particles $\Rightarrow$ noise $\sim T^2/6$;
- A prior expansion creates noise only if $\xi < 1/6$.

By equating the two noisy contributes one finds a particle production with an effective thermal spectrum

$$T^2 = 24(1-6\xi)\epsilon^2 \int_{\eta_0}^{\eta_I^A} d\eta a'^2(\eta) \left(\frac{\eta_I^B - \eta}{(\eta_I^B - \eta)^2 + \epsilon^2} + \frac{\eta_I^A - \eta}{(\eta_I^A - \eta)^2 + \epsilon^2} \right) .$$

In conclusion...



- The communication protocol in the figure is sensible to prior expansions. This could be used in practice to test the value of ξ and to know more about the history of our Universe.
- If $\xi < 1/6$, an expansion prior to the communication protocol creates a noise on wi-fi communication, which can be associated to a noise created by cosmological particle production.
- Therefore, thanks to this protocol, we can infer the temperature of the cosmological particle production *even* when the expansion is still ongoing (not possible with the Bogoliubov coefficients approach).

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Thank you for your attention