Decoherence due to accelerated time-delay/evolution

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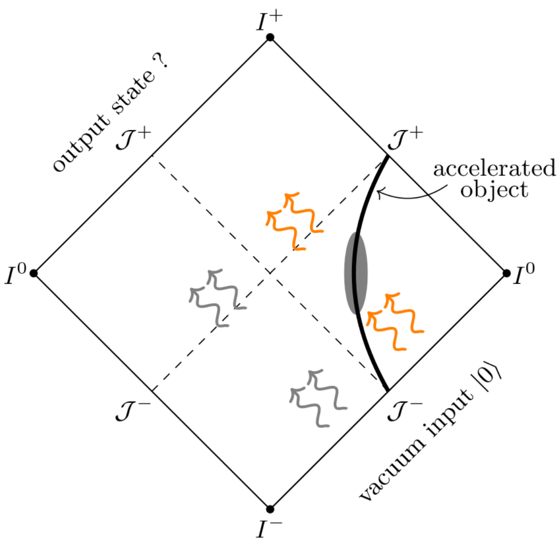
What is decoherence?

- When a quantum pure states evolve into a classical mixed state
- Quantum mechanics assumes unitary evolution
- Generally linked with tracing out of information
- Can decoherence occur when the full system is considered?

Recent findings of Decoherence

- Considers an accelerated observer sending a signal, which is analysed via self-homodyne detection
- An accelerated observer sends a squeezed state
- The variance is measured to be **mixed** by a observer that is stationary, observing particles from the whole space-time



$$\hat{S}_1(r) = \exp\left\{\frac{r}{2}\left(\hat{b}_g^{R\dagger}\right)^2 - \frac{r}{2}\left(\hat{b}_g^{R}\right)^2\right\}$$

Daiqin, T. Ralph: arXiv:1705.07432

Apparent **Decoherence** from accelerated sources

- Accelerated Unitary Time-Delay/Evolution

- Gain understanding of decoherence
- Gain understanding of vacuum correlations
- Gain understanding of vacuum squeezing
- Equivalence principle: Helps explain black hole information paradox

Overview of Talk

- Introduce the Unitary Time-Evolution
  - Analysis via Schrodinger Picture
  - Analysis via Heisenberg Picture
- Possible Implications for Black Hole Information Paradox
- Analogous Experiments

Background Theory

- Single Frequency Minkowski Modes

$$\hat{e}_k = \int d\omega \ A_{k\omega}\hat{c}_\omega + B_{k\omega}\hat{d}_\omega$$

$$A_{k\omega} = \frac{i\sqrt{2\sinh[\pi\omega/a]}}{2\pi\sqrt{\omega k}}\Gamma[1-i\omega/a](\frac{k}{a})^{i\omega/a} = B^*_{k\omega}$$

- Single Frequency Unruh Modes

$$\hat{c}_\omega = \cosh(r_\omega)\hat{a}_\omega - \sinh(r_\omega)\hat{b}^\dagger_\omega$$

$$\hat{d}_\omega = \cosh(r_\omega)\hat{b}_\omega - \sinh(r_\omega)\hat{a}^\dagger_\omega$$

- Single Frequency Rindler Modes

$$\hat{a}_\omega = \cosh(r_\omega)\hat{c}_\omega + \sinh(r_\omega)\hat{d}^\dagger_\omega$$

$$\hat{b}_\omega = \cosh(r_\omega)\hat{d}_\omega + \sinh(r_\omega)\hat{c}^\dagger_\omega$$

Accelerated Unitary Time-Evolution

$$\hat{U} = e^{-i\hat{H}_R\Delta}$$

- Rindler Frame:

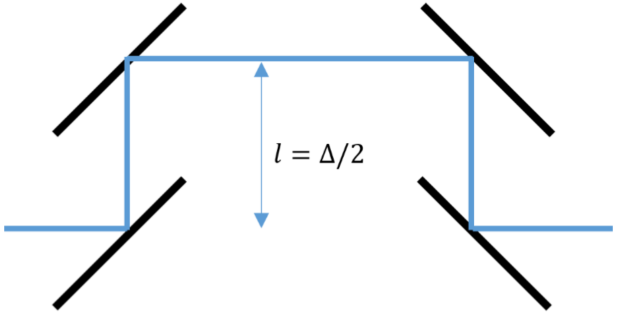
$$\hat{U}\left|0_M\right\rangle = \hat{U}\prod_\omega \sqrt{1-\exp[-2\pi\omega/a]}\sum_{n_\omega=0}^{\infty}\frac{\exp[-n_\omega\pi\omega/a]}{n_\omega!}(\hat{a}_\omega^\dagger \hat{b}_\omega^\dagger)^{n_\omega}\left|0_R\right\rangle$$
$$= \prod_\omega \sqrt{1-\exp[-2\pi\omega/a]}\sum_{n_\omega=0}^{\infty}\frac{\exp[-n_\omega\pi\omega/a]}{n_\omega!}(\hat{a}_\omega^\dagger e^{-i\Delta\omega}\hat{b}_\omega^\dagger)^{n_\omega}\left|0_R\right\rangle$$

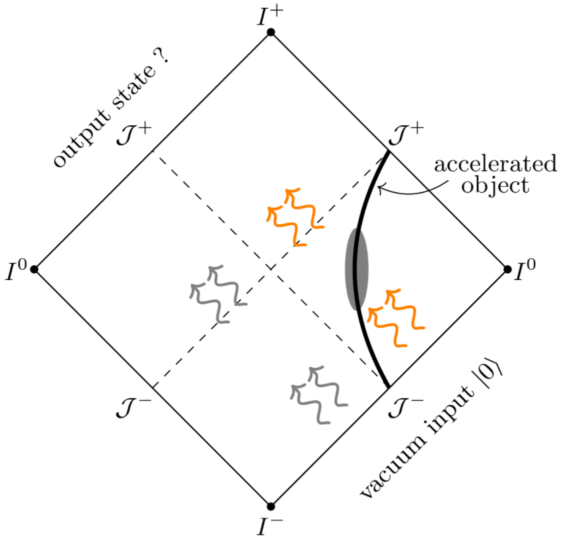
- Minkowski Frame:

$$\hat{U}\left|0_M\right\rangle = \hat{S}(r_\omega,0)^\dagger e^{-i\Delta\omega\hat{c}_\omega^\dagger\hat{c}_\omega}\hat{S}(r_\omega,0)\left|0_M\right\rangle$$
$$= \hat{S}(r_\omega,0)^\dagger\hat{S}(r_\omega,\omega\Delta)\left|0_M\right\rangle$$
$$\hat{S}(r_\omega,\theta) \equiv \exp\left[\int \mathrm{d}\omega\, r_\omega(e^{i\theta}\hat{c}_\omega\hat{d}_\omega - e^{-i\theta}\hat{d}_\omega^\dagger\hat{c}_\omega^\dagger)\right]$$

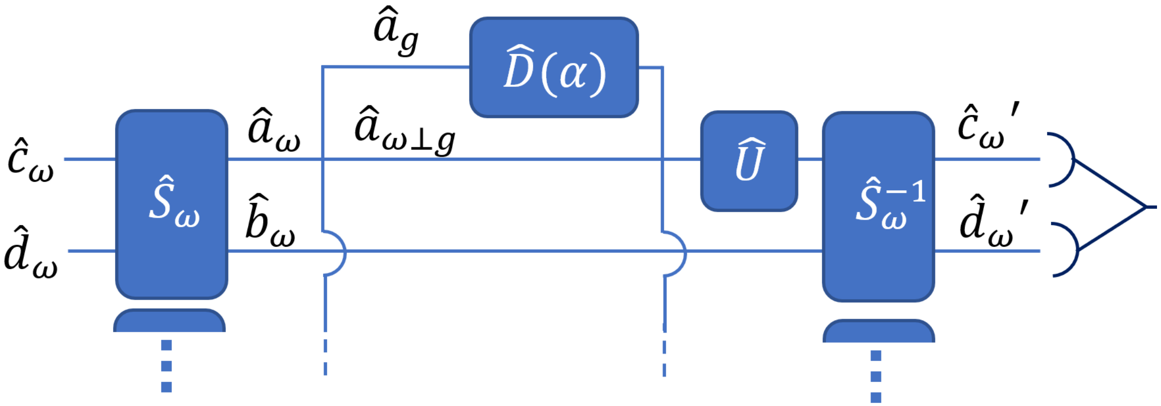
Experimental Setup

Time Delay Source





Circuit Model Analysis

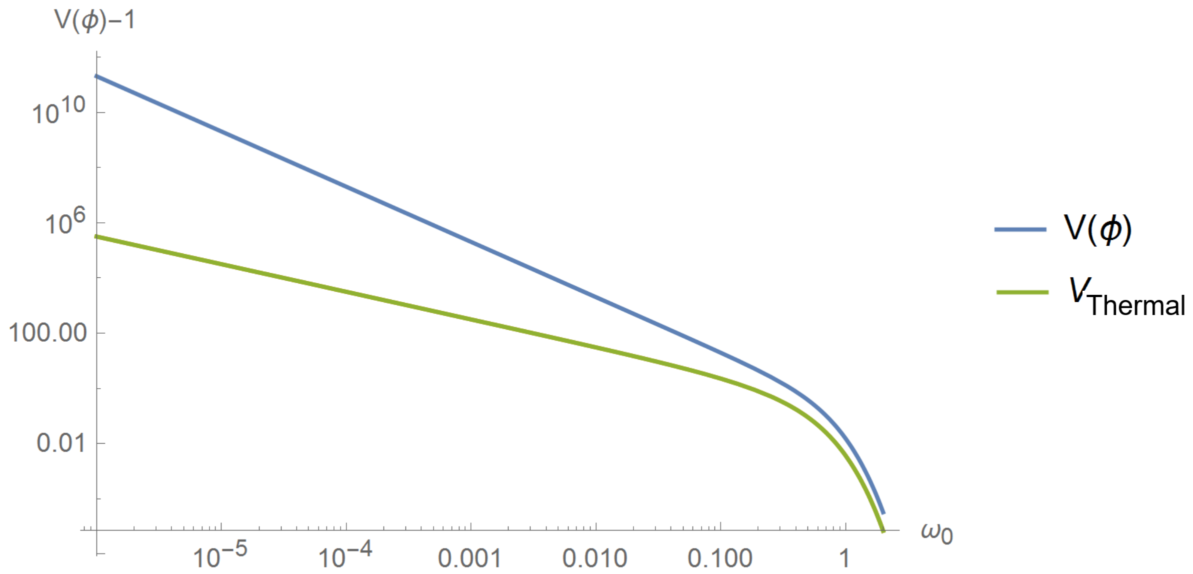


$$V(\phi) \equiv \frac{\langle \hat{N}^2 \rangle - \langle \hat{N} \rangle^2}{\langle \hat{N} \rangle}$$

$$\hat{c}'_\omega = \hat{c}_\omega \left(\cosh(r_\omega)^2 e^{-i\omega\Delta} - \sinh(r_\omega)^2\right) + \hat{d}^\dagger_\omega \cosh(r_\omega)\sinh(r_\omega)(e^{-i\omega\Delta} - 1) + \cosh(r_\omega) g(\omega)^* e^{-i\omega\Delta}\alpha$$

$$\hat{d}'_\omega = \hat{d}_\omega(\cosh(r_\omega)^2 - \sinh(r_\omega)^2 e^{i\omega\Delta}) + \hat{c}^\dagger_\omega \cosh(r_\omega)\sinh(r_\omega)(1 - e^{i\omega\Delta}) - \sinh(r_\omega) g(\omega) e^{i\omega\Delta}\alpha^*$$

Results



$$V\,(\phi) = 1 + 2\,\mathrm{csch}(\pi\omega/a)^2$$

$$V_{\text{Thermal}}\,(\phi) = 1 + 2\sinh(r_\omega)^2$$

Interpretation of Results

- The quantum process involved are completely unitary
- The decoherence arises due to the vacuum correlation that pre-exists before the unitary time-evolution
- The interaction distorts the vacuum correlation, and this correlation must be extracted for purity

Black Hole Information **Paradox**

- Initial pure state of a black hole
- Hawking radiation (Thermal)
- Final mixed state of thermal bath

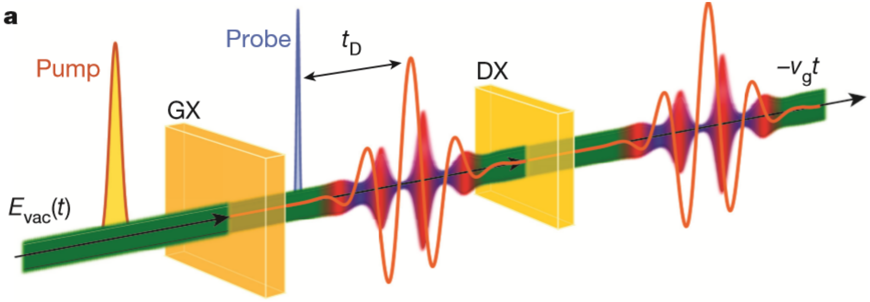
- Correlations between early time radiation and late time radiation?
- Correlations between the thermal bath and curved space time?
- Correlations exists between the distorted **vacuum fluctuations**?

Black Hole Information Paradox?

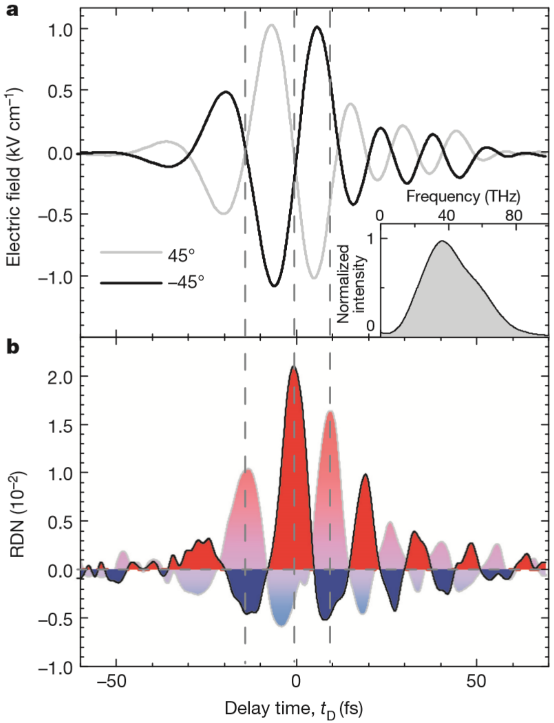
- The quantum process involved are completely unitary
- The decoherence arises due to the vacuum correlation that pre-exists before the evaporation of black hole
- The black hole distorts the vacuum correlation, and this correlation must be extracted for purity

Subcyle Quantum Electrodynamics

DOI: 10.1038/nature21024

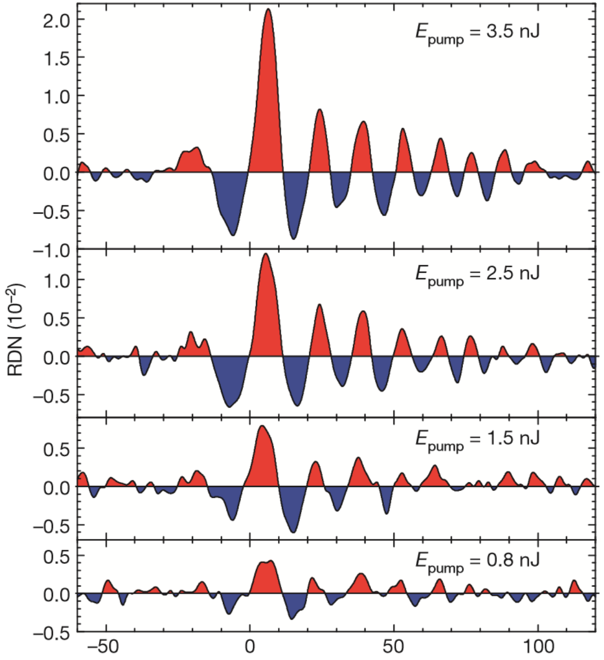


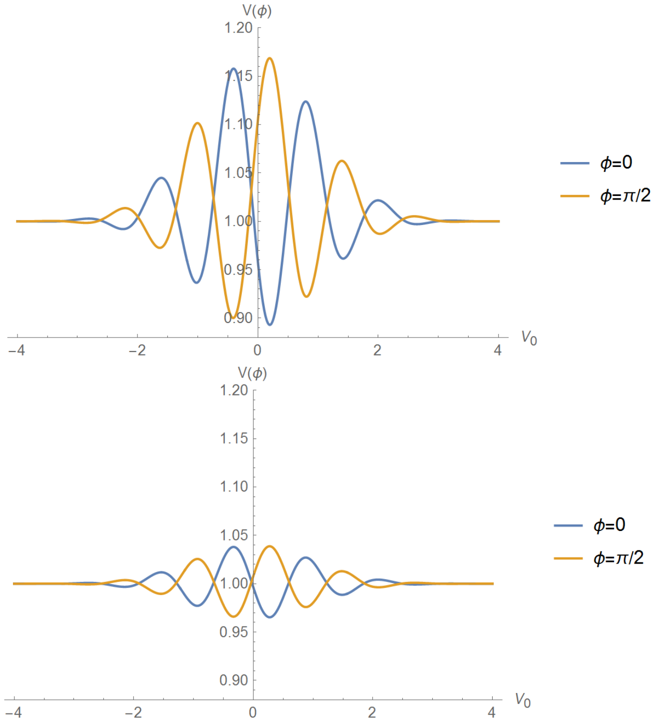
$$\mathrm{RDN}(t_D) = \frac{\sqrt{\Delta E_{SN}^2 + \Delta E_{rms}^2(t_D)} - \sqrt{\Delta E_{SN}^2 + \Delta E_{vac}^2}}{\sqrt{\Delta E_{SN}^2 + \Delta E_{vac}^2}}$$



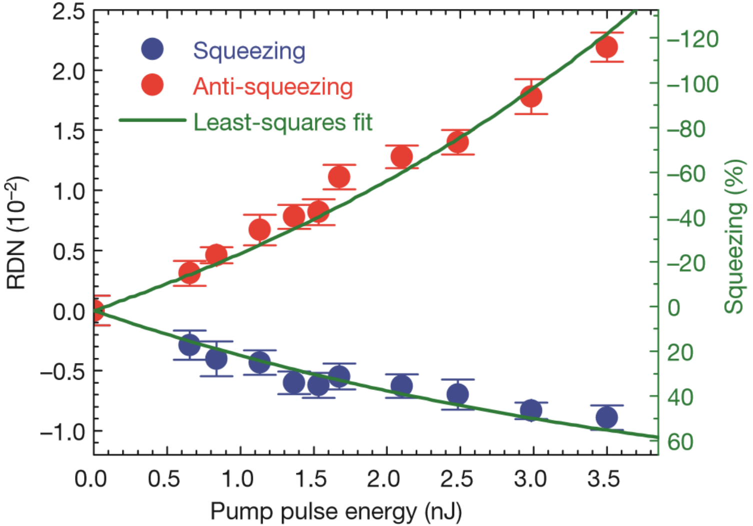
E. Yablonvitch, 1989 DOI: 10.1103/physrevlett.62.1742

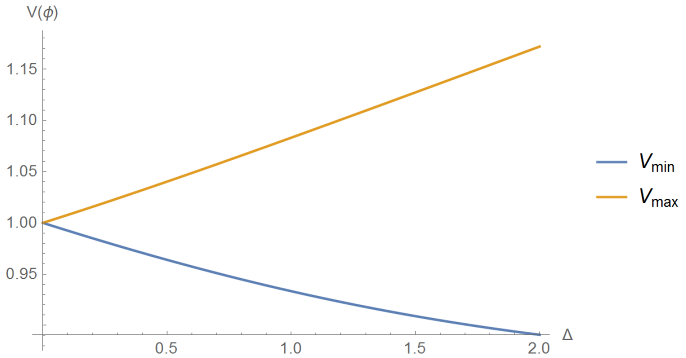
Comparing Results

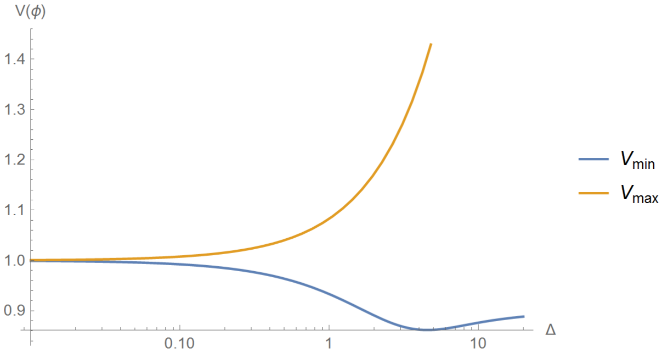




Maximum and Minimum Variances







Conclusion and Future Work

- The experiment observed virtual photons (decoherence) due to short intense non-linear extraction of information
- Squeezing was observed due to tracing out parts of the signal

- A more comprehensive analysis of the experiment
- Improvement of the model to observe a thermal statistic

Thanks!

Any questions?