Universidade de Coimbra
Departamento de Física

Single-particle interference as a witnesses of Unruh effect

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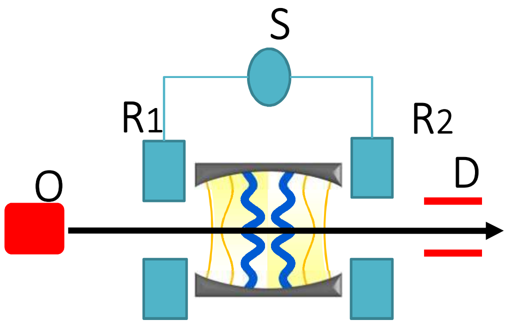
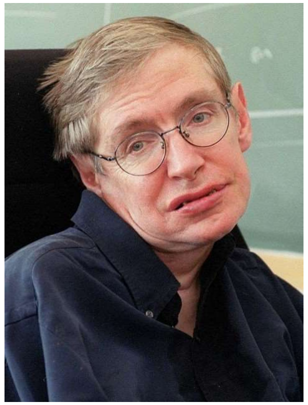


Event horizons

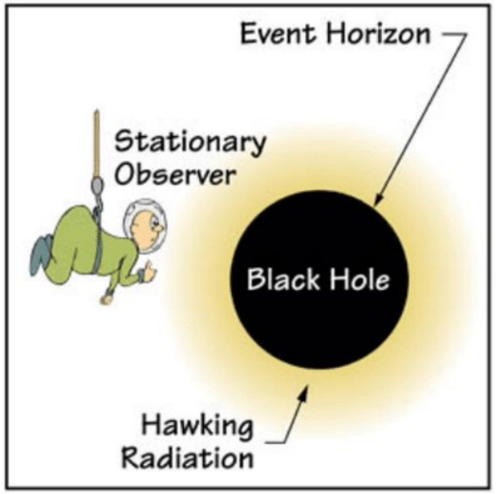


THE HAWKING EFFECT (1974) Black holes emit a black body radiation at a temperature inversely proportional to its mass.

$$T = \frac{\hbar c^3}{8\pi G M k_B}$$

For a one solar mass black hole, the peak Hawking radiation temperature is:

$$T_H = \frac{\hbar c^3}{8\pi G M_\odot k_B} = 6.170 \times 10^{-8}\ K\,.$$



S. Hawking, *Nature,* **248**, 30 (1974).

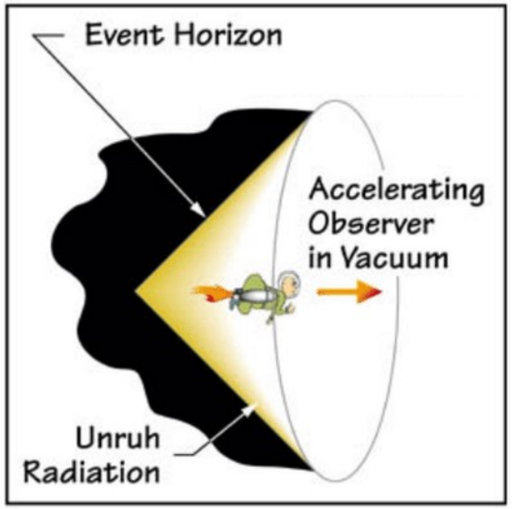
Accelerating observers

THE UNRUH EFFECT (1976) observers uniformly accelerated through Minkowski spacetime registers a thermal radiation at a temperature proportional to its accelaration:

$$T = \frac{\hbar a}{2\pi c k_B}$$

Vacuum ⟷ **thermal state**

for inertial observer — for accelerating observer



W.G. Unruh, PRD 14, 870 (1976).

Unruh Effect

- Observer accelerating at the Earth's gravitational acceleration of $g = 9.81\ \mathrm{m \cdot s^{-2}}$

  The temperature of the vacuum is only $\approx 10^{-20}$ **K**.

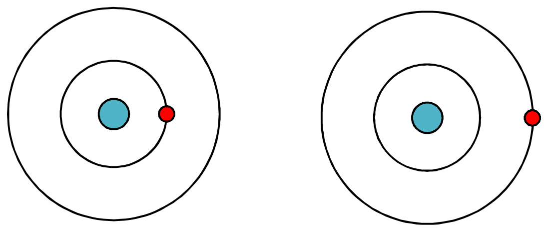
- For an experimental test of the Unruh effect it is planned to use accelerations:

$$\approx 10^{20}\ \mathrm{m \cdot s^{-2}} \longrightarrow \approx 1\ \mathrm{K}$$

Detector model

- **Detector Unruh-Wald**

Two-level system

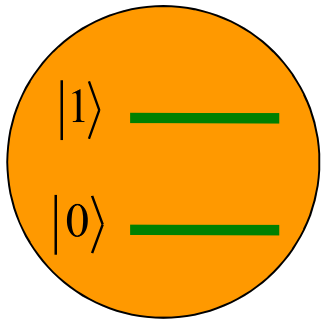


$|0\rangle$ $|1\rangle$

Environment

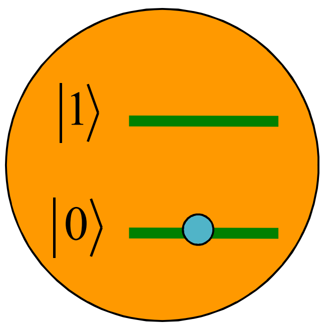
Scalar field ϕ

Detector



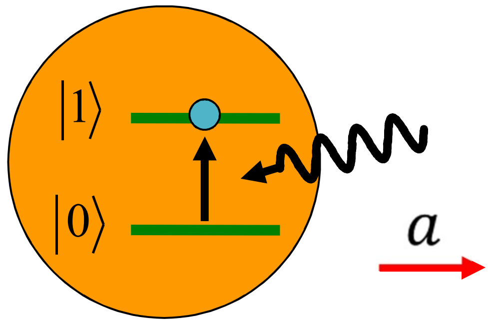
Inertial

$a = 0$



Non-inertial

$a \neq 0$



Using Berry's Phase to Detect the Unruh Effect at Lower Accelerations

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We show that a detector acquires a Berry phase due to its motion in spacetime. The phase is different in the inertial and accelerated case as a direct consequence of the Unruh effect. We exploit this fact to design a novel method to measure the Unruh effect. Surprisingly, the effect is detectable for accelerations 10^9 times smaller than previous proposals sustained only for times of nanoseconds.

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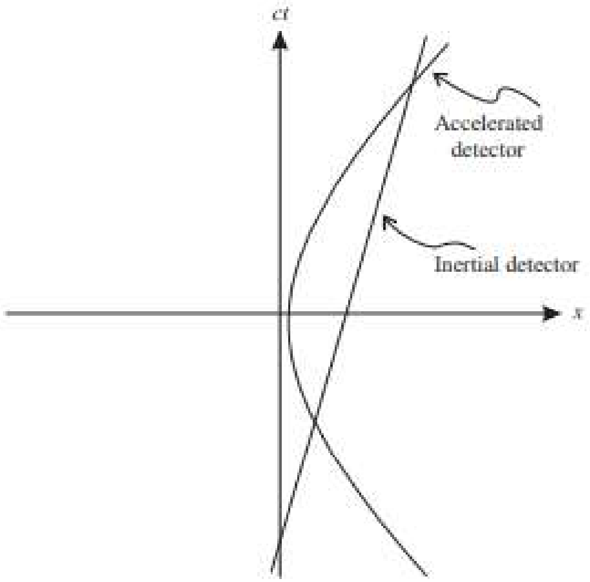


$$\delta = \gamma_I - \gamma_a$$

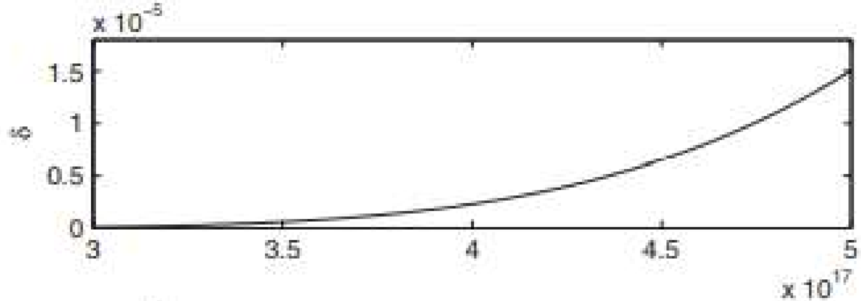
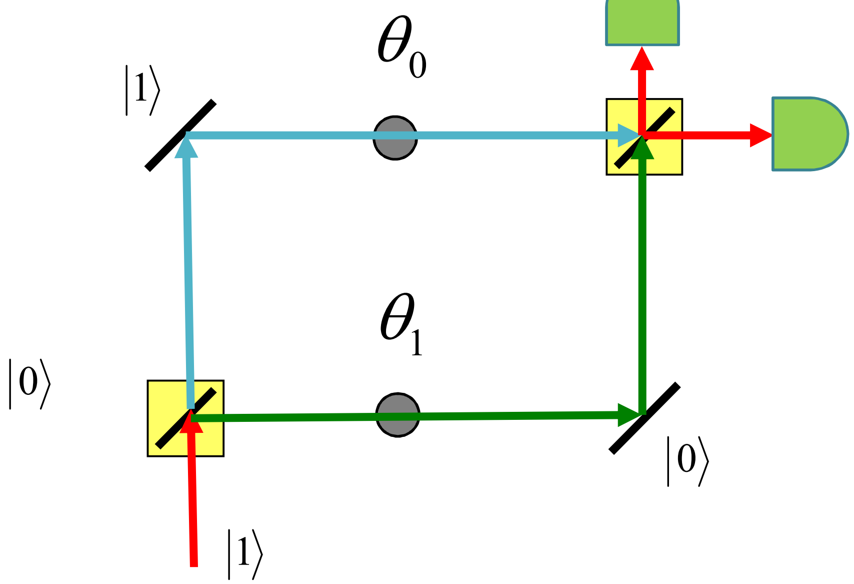


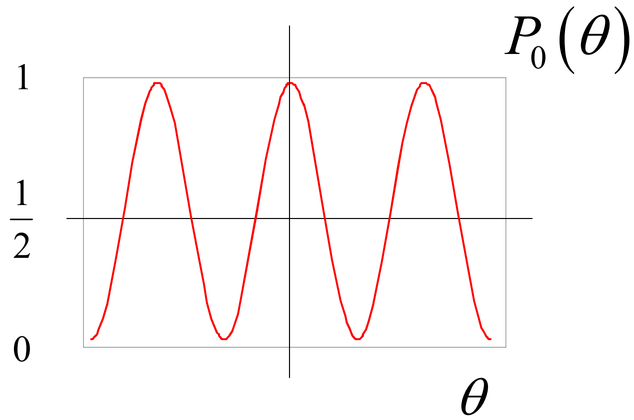
FIG. 1. Trajectories for an inertial and accelerated detector.

Quantum interferometry

$$P_0 = \cos^2\left(\frac{\theta_1 - \theta_0}{2}\right)$$



$$P_1 = \sin^2\left(\frac{\theta_1 - \theta_0}{2}\right)$$



Quantum interferometry

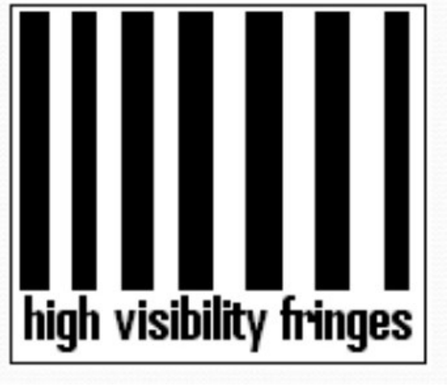
Visibility of interference fringes

- It is defined as:

$$V = \frac{p^{max} - p^{min}}{p^{max} + p^{min}} \qquad 0 \leq V \leq 1$$

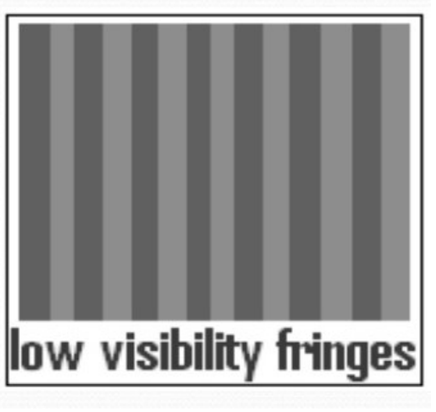
- High visibility:

$p^{min} = 0$,
V = 1.

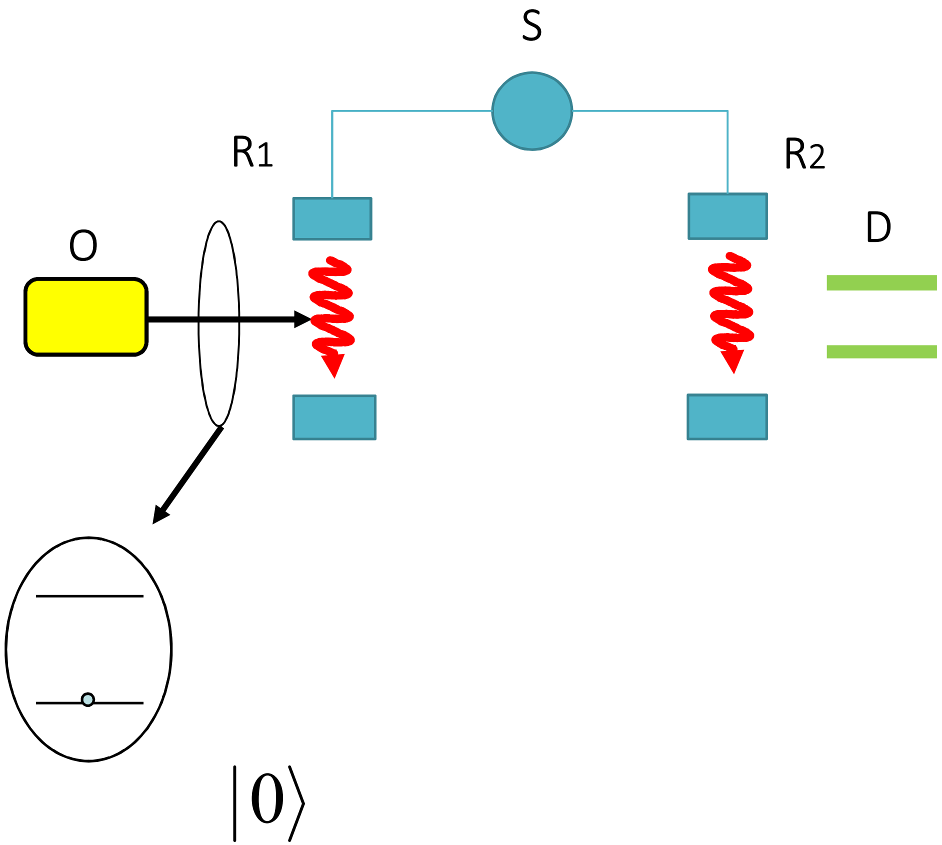


- Low visibility:

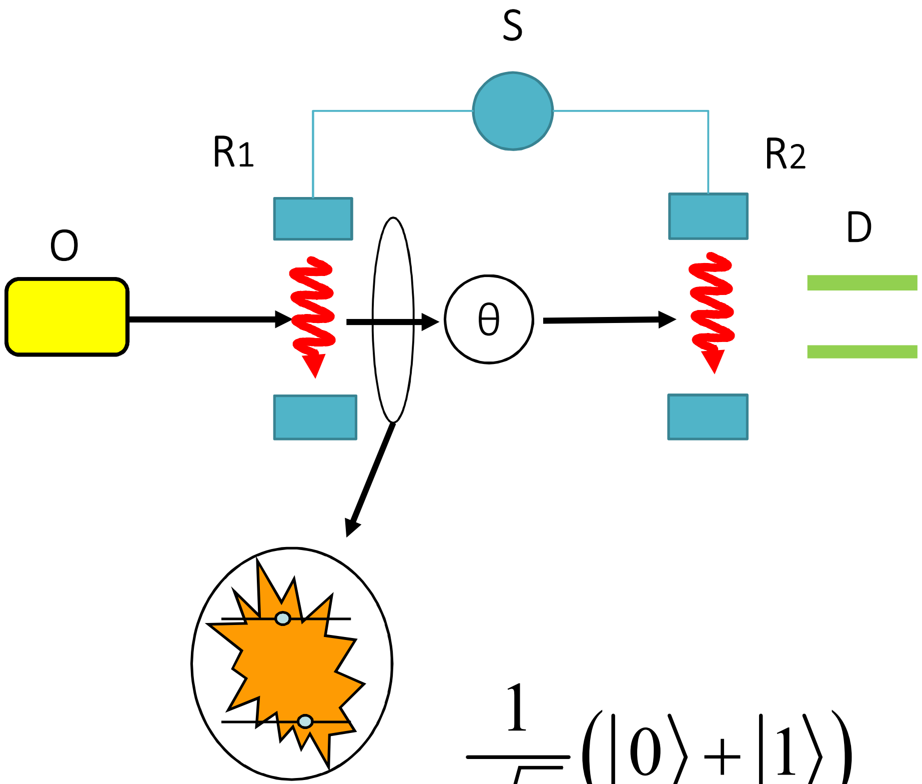
$p^{min} = p^{max}$,
V = 0.



Quantum interferometry

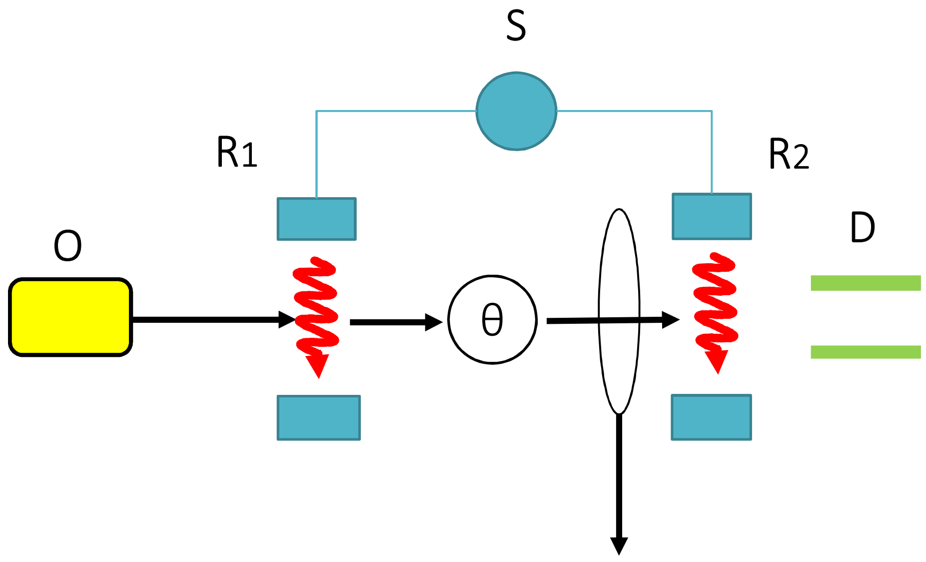


Quantum interferometry



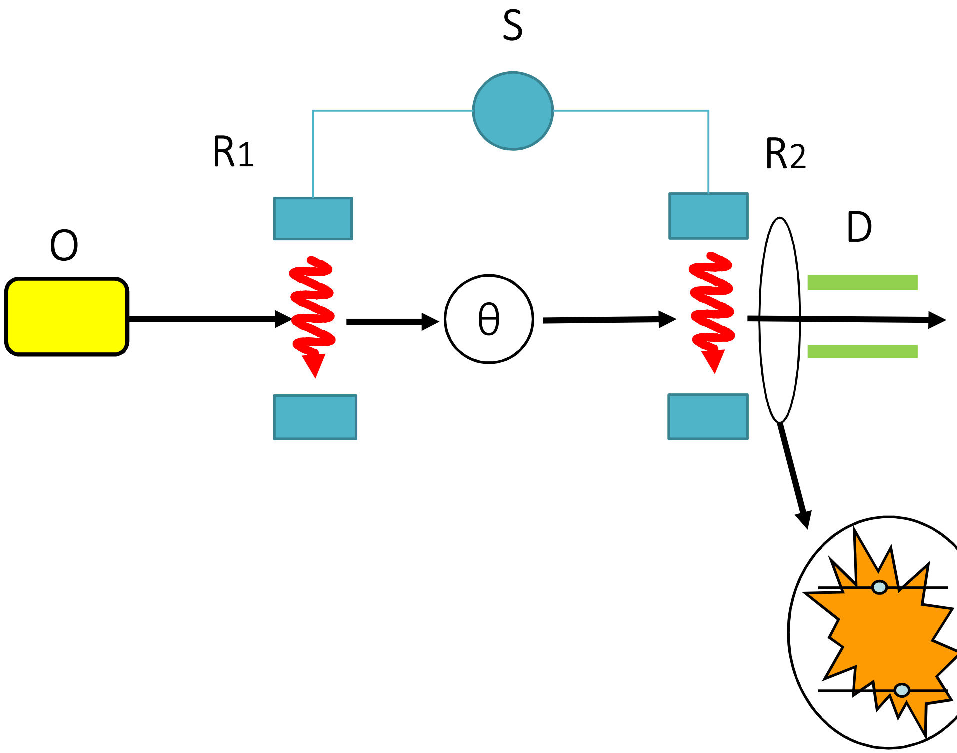
$$\frac{1}{\sqrt{2}}\left(|0\rangle + |1\rangle\right)$$

Quantum interferometry



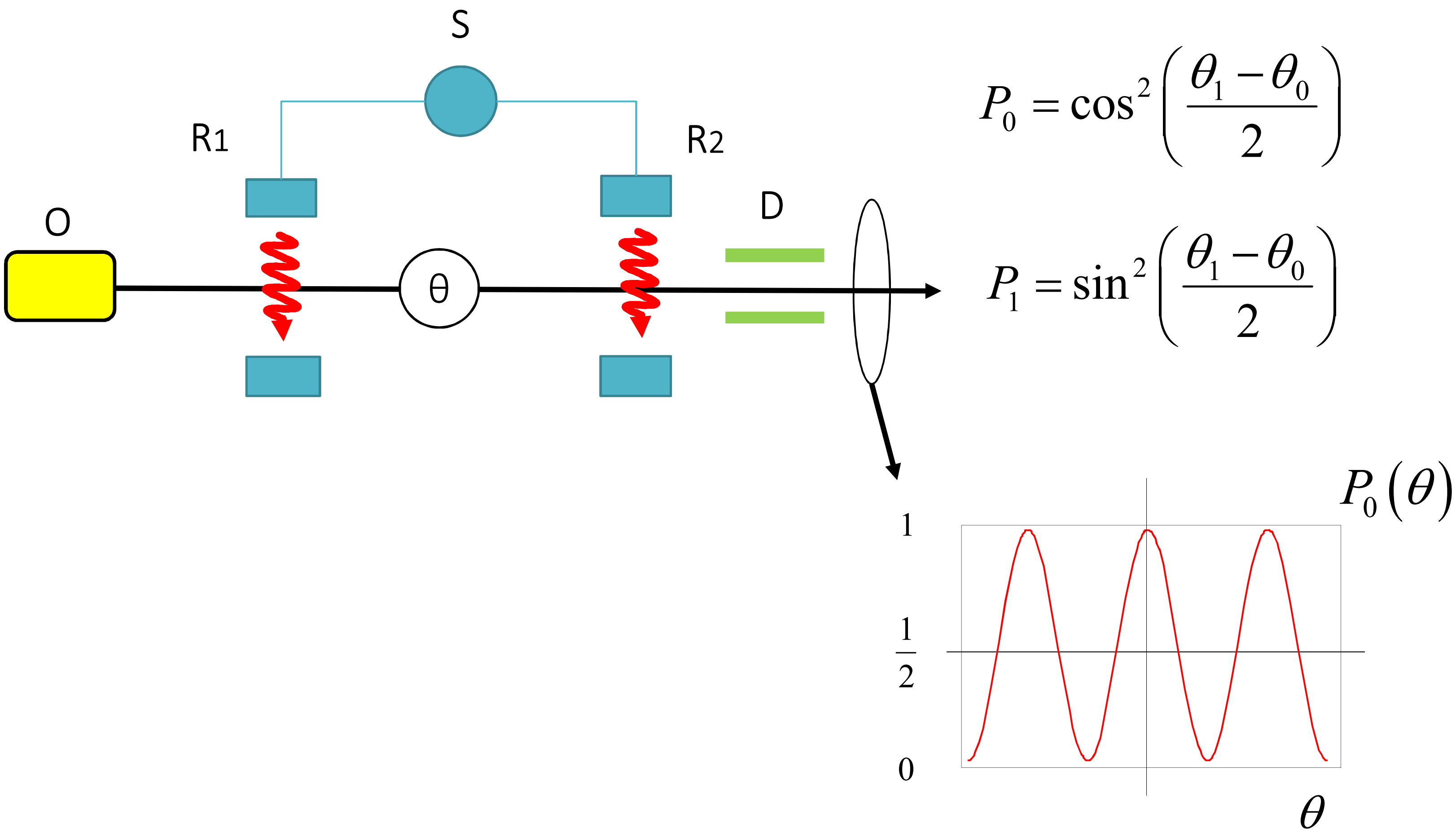
$$\frac{1}{\sqrt{2}}\left(|0\rangle + e^{i\theta}|1\rangle\right)$$

Quantum interferometry



$$\cos\left(\frac{\theta}{2}\right)|0\rangle - i\sin\left(\frac{\theta}{2}\right)|1\rangle$$

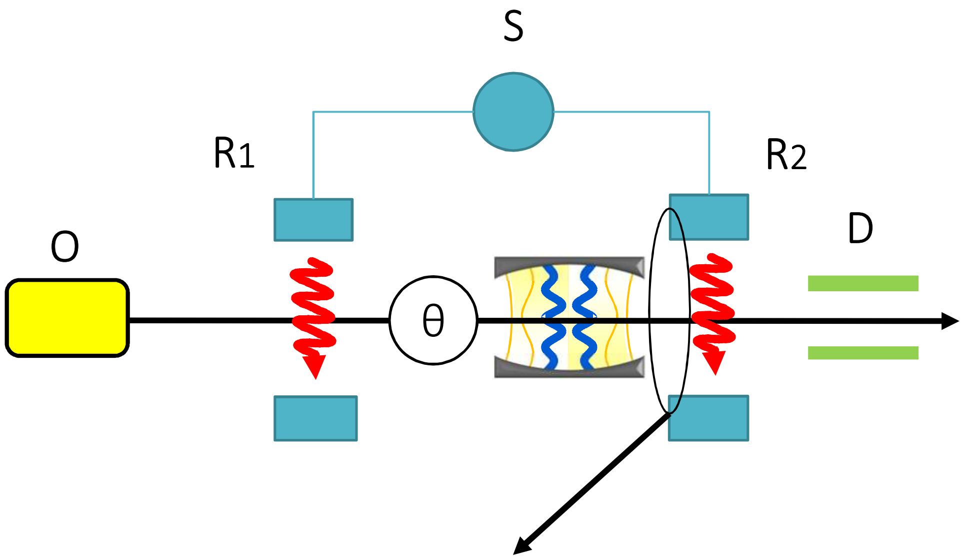
Quantum interferometry



$$P_0 = \cos^2\left(\frac{\theta_1 - \theta_0}{2}\right)$$

$$P_1 = \sin^2\left(\frac{\theta_1 - \theta_0}{2}\right)$$

Quantum interferometry + Environment



$$|0\rangle|e\rangle \rightarrow \frac{1}{\sqrt{2}}\left(|0\rangle|e_0\rangle + e^{i\theta}|1\rangle|e_1\rangle\right)$$

Entanglement between the atom and the environment (field)

Inertial $(a = 0)$

$$P_0 = \frac{1}{2}\left[\cos^2\left(\frac{\theta}{2}\right) + |\mu|^2\right]$$

$$V = \frac{1}{1 + 2|\mu|^2} \approx 0.98 \; for \; \mu = 0.1$$

Non-inertial $(a \neq 0)$

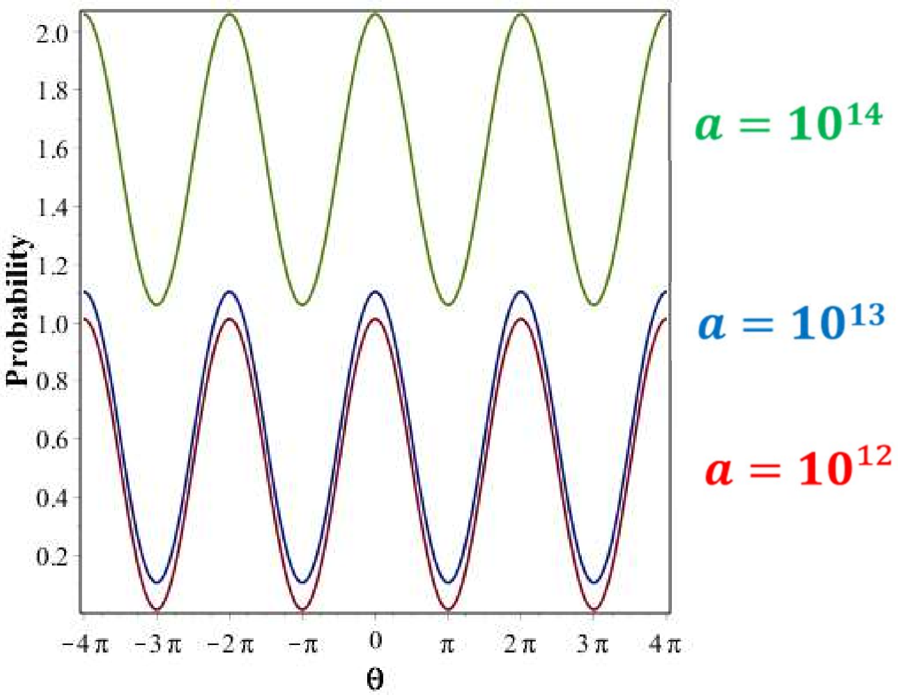
$$P_0 = \frac{1}{2}\left[\cos^2\left(\frac{\theta}{2}\right) + |\mu|^2 coth\left(\frac{\pi\omega c}{a}\right)\right]$$

$$V = \frac{1}{1 + 2|\mu|^2 coth\left(\frac{\pi\omega c}{a}\right)}$$

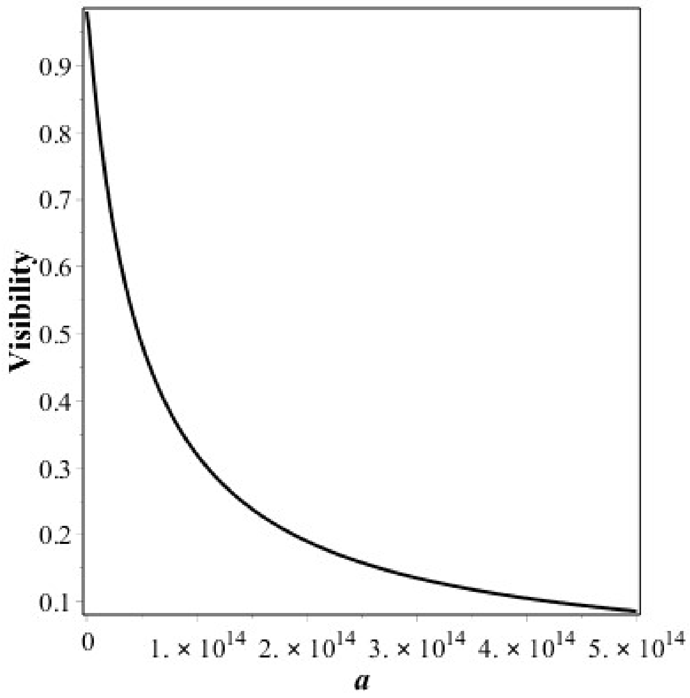
Results

Non-inertial Case ($a \neq 0$)

Probability (P_0)



Visibility (V)



Summary

- The environment (scalar field) has an effect on the visibility of the interference fringes
- The visibility of the interference fringes are different for the inertial and accelerated case due to the Unruh effect
- This setup may provide a feasible way for the detection of the Unruh effect

Obrigado!