Quantum Correlations : Dynamical Realization of Unruh effect for inertial observers

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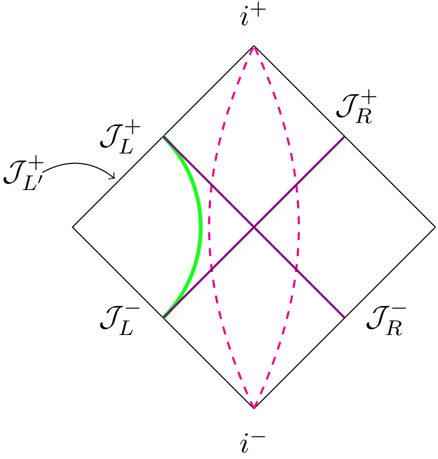
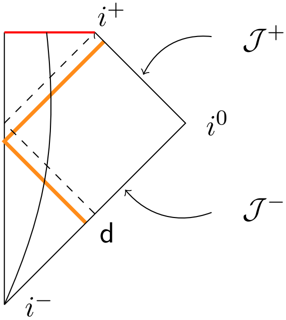
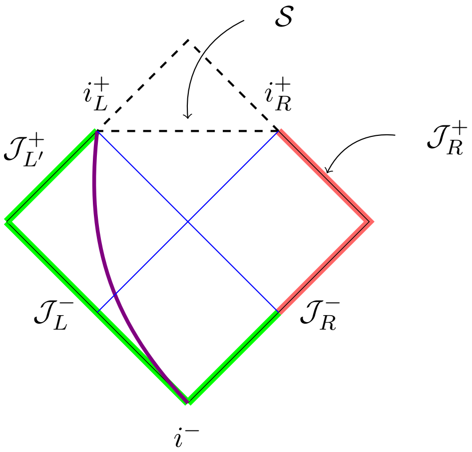
The Unruh effect



Black holes

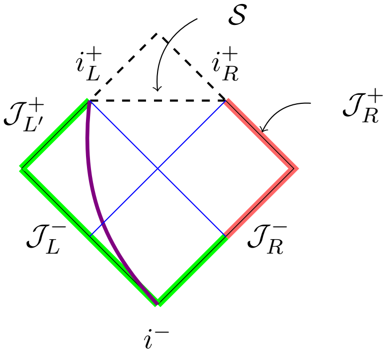


Truncated (Hypothetical) spacetime



- A portion of spacetime is denied.
- The timelike observers end on $i^{\pm}$.

Truncated (Hypothetical) spacetime



- Timelike observers have limited access to a past Cauchy surface.
- Reduced density matrix (for a vacuum state) will be thermal.
- Bogoliubov coefficients are obtained by overlapping past and future suited mode functions.

2-dimensional dilaton (CGHS) Black Hole

$$\mathcal{A} = \frac{1}{2\pi}\int d^2x\sqrt{-g}\left[e^{-2\phi}\left(R + 4(\nabla\phi)^2 + 4\lambda^2\right) - \frac{1}{2}\sum_{i=1}^{N}(\nabla f_i)^2\right].$$

- Metric, Dilaton field, Matter field, Cosmological constant.
- Two dimensional metric is conformally flat.

$$ds^2 = -e^{2\rho}dx^+dx^-.$$

- Classical solutions : Black Hole of mass M

$$ds^2 = -\frac{dx^+dx^-}{\frac{M}{\lambda} - \lambda^2 x^+ x^-},$$

Linear Dilaton Vacuum

$$ds^2 = -\frac{dx^+dx^-}{-\lambda^2 x^+ x^-}.$$

2-dimensional dilaton (CGHS) Black Hole

- Equations of motion

$$-\partial_+\partial_- e^{-2\phi} - \lambda^2 e^{2\rho-2\phi} = 0,$$
$$2e^{-2\phi}\partial_+\partial_-(\rho-\phi) + \partial_+\partial_- e^{-2\phi} + \lambda^2 e^{2\rho-2\phi} = 0,$$

$$\partial_+^2 e^{-2\phi} + 4\partial_+\phi\partial_+\left(\rho-\phi\right)e^{-2\phi} + T_{++} = 0,$$
$$\partial_-^2 e^{-2\phi} + 4\partial_-\phi\partial_-\left(\rho-\phi\right)e^{-2\phi} + T_{--} = 0.$$

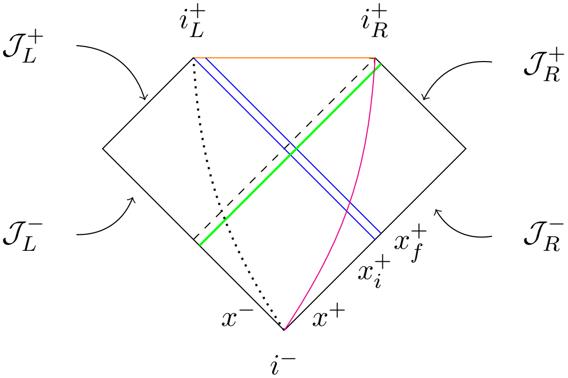
- Matter field $f_i = f_{i+}(x^+) + f_{i-}(x^-)$.

$$\partial_\pm^2 e^{-2\phi} = -T_{\pm\pm}$$

Results in a black hole geometry

$$ds^2 = -\frac{dx^+dx^-}{\frac{M(x^+)}{\lambda} - \lambda^2 x^+x^- - P^+(x^+)x^+},$$

2-dimensional dilaton (CGHS) Black Hole



- Let a matter shell collapse.
- Observers before the arrival of shell always find themselves in flat spacetime.
- Post shell, geometry is black hole region.

2 dimensional dilaton black hole

- The geometry can be completely quantified in terms of the matter field parameters.
- The vacuum state on $\mathcal{J}_L^-$ results in late-time thermal radiation at $\mathcal{J}_R^+$
- A portion of $\mathcal{J}_L^-$ is causally insulated from $\mathcal{J}_R^+$.

On $\mathcal{J}_L^-$:

$$\pm\lambda x^{\pm} = e^{\pm\lambda z^{\pm}} \Rightarrow ds^2 = -dz^+dz^-$$
$$u_\omega = \frac{1}{\sqrt{2\omega}}e^{-i\omega z^-}.$$

On $\mathcal{J}_R^+$:

$$z^+ = \sigma^+_{\text{out}}; \qquad z^- = -\frac{1}{\lambda}\ln\left[e^{-\lambda\sigma^-_{\text{out}}} + \frac{P^+}{\lambda}\right].$$
$$v_\omega = \frac{1}{\sqrt{2\omega}}e^{-i\omega\sigma^-_{\text{out}}}\Theta(z_i^- - z^-).$$

Courtesy: Conformal flatness

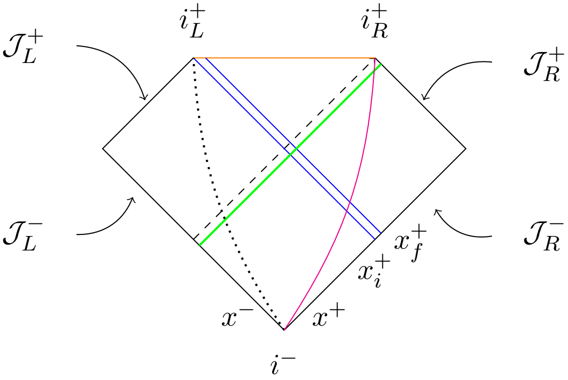
2 dimensional dilaton black hole

$$\alpha_{\Omega\omega} = \frac{1}{2\pi\lambda}\sqrt{\frac{\omega}{\Omega}}\left(\frac{P^{+}}{\lambda}\right)^{i(\Omega-\omega)/\lambda} B\left(-\frac{i\Omega}{\lambda}-\frac{i\omega}{\lambda}, 1+\frac{i\Omega}{\lambda}\right),$$

$$\beta_{\Omega\omega} = \frac{1}{2\pi\lambda}\sqrt{\frac{\omega}{\Omega}}\left(\frac{P^{+}}{\lambda}\right)^{i(\Omega+\omega)/\lambda} B\left(-\frac{i\Omega}{\lambda}+\frac{i\omega}{\lambda}, 1+\frac{i\Omega}{\lambda}\right),$$

- The emission profile is non-thermal in general.
- Late time observers Bogoliubov coefficients are again Rindler like.
- Thermal radiation at a temperature λ.
- Associated thermal flux of Hawking radiation.

2-dimensional dilaton (CGHS) Black Hole

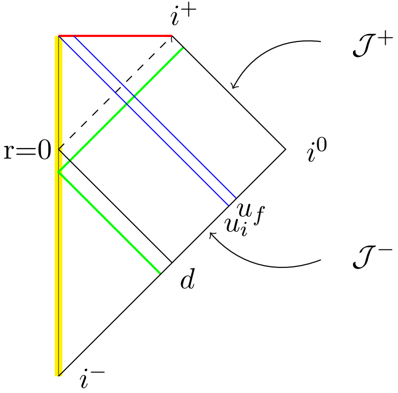


- The Philosophy of semi-classical analysis is similar to right moving observers, with $P^+/\lambda^2 \leftrightarrow x_i^+$.
- Tracing over of a portion of $\mathcal{J}_R^+$ is equally mandated !
- Conformal flatness guarantees exactly similar Bogoliubov coefficients.

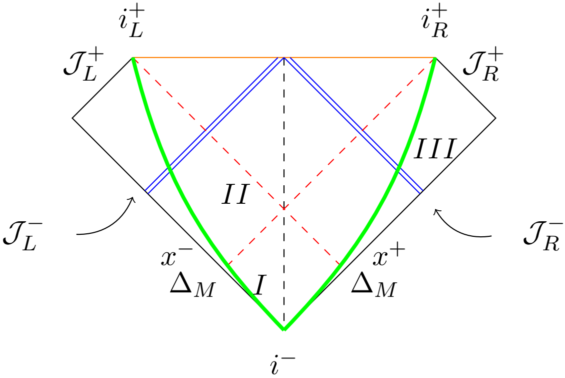
2-dimensional dilaton (CGHS) Black Hole

- **Inertially (left-moving) observers see a thermal radiation at the same temperature, but no flux (Unruh radiation)**.
- They can not see any black hole, no curvature (no usage of equivalence principle), no moving mirror ... $\Rightarrow$ No classical source. These observers view the correlations, in the limited acess region as induced by some excited state.
- Quantum correlations$\Rightarrow$ "Thermal Field".
- Right Moving Observers : Quantum correlations$\Rightarrow$ Vacuum Polarization : Flux Creation.

Black hole : Bogoliubov Coefficients



Black hole : Bogoliubov Coefficients



- $r = 0$ observer is in similar setting.

Conclusions

- Any Tracing over leads to ("thermal") radiation for observers who trace over.
- The past casual support of any future achronal surface decides the amount of tracing over to be done.
- The experience of a time like observer will be similar to a Rindler observer **locally**.
- The Bogoliubov coefficients will be different once we move away from the specified future surface $\Rightarrow$ non thermality.

Thank you for the attention!