Black Mirrors: CPT-Symmetric Alternatives to Black Holes

arxiv:2412.09558 [hep-th]

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SCHWARZSCHILD: Über das Gravitationsfeld eines Massenpunktes 189

Sitzber. Deut. Akad. Wiss. (1916)

Über das Gravitationsfeld eines Massenpunktes nach der EINSTEINschen Theorie.

Von K. SCHWARZSCHILD.

(Vorgelegt am 13. Januar 1916 [s. oben S. 42].)

Figure 1: Karl Schwarzschild (9 Oct. 1873 - 11 May 1916)

$$ds^2 = -\left(1 - 2m/r\right) dt^2 + \frac{dr^2}{1 - 2m/r} + r^2(d\theta^2 + \sin^2\theta d\phi^2).$$

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On Continued Gravitational Contraction

J. R. Oppenheimer and H. Snyder
University of California, Berkeley, California

(Received July 10, 1939)

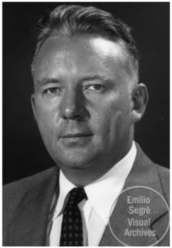
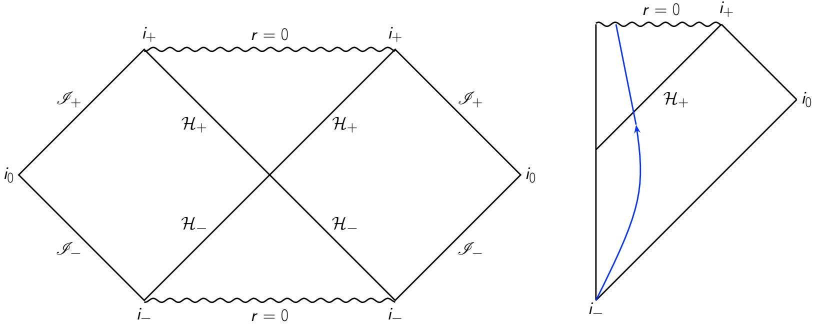


Figure 2: Julius Robert Oppenheimer (1904-1967) and Hartland Snyder (1913-1962)

Conventional black holes



(a) (b)

Figure 3: (a) The Penrose diagram representing the Kruskal extension of the Schwarzschild solution (Kruskal (b) The Penrose diagram of the more realistic model of Oppenheimer-Snyder describing spherical collapse.

Problems with black holes: Cauchy horizons

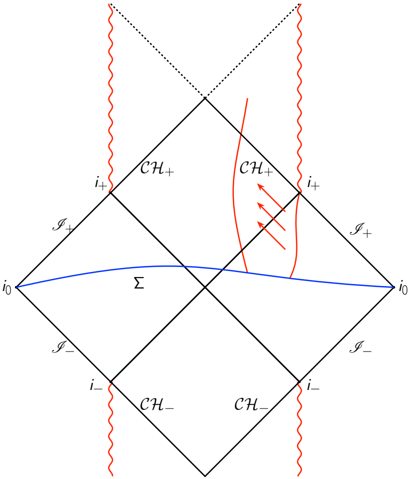


Figure 4: Cauchy horizons in a Kerr black hole: Initial data in Σ cannot be evolved past $\mathcal{CH}_+$. These are stable under non-linear perturbations (Dafermos, Rodniaski, Luk).

Problems with black holes: The information paradox

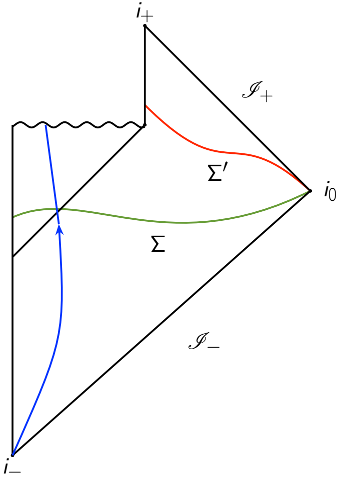


Figure 5: Evaporating black holes breaks unitarity in the semiclassical approximation, as Σ' cannot be evolved backwards to Σ.

The Black Mirror

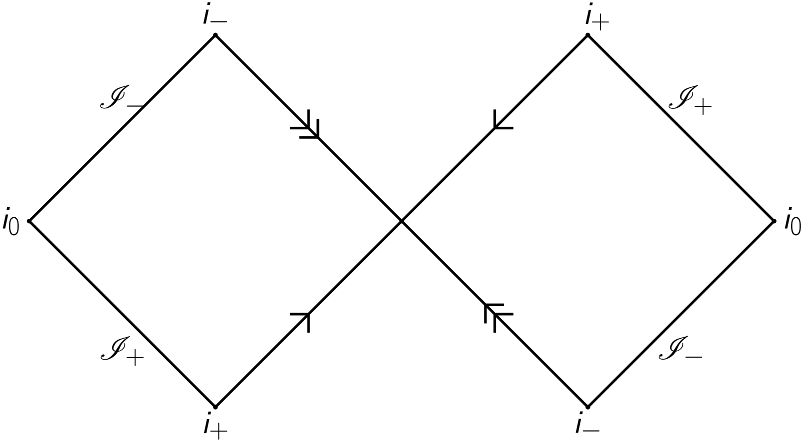


Figure 6: The Black Mirror as a quotient of an asymptotically flat and spherically symmetric black hole. The temporal and spatial orientation of the two regions are opposite to each other.

Motivation: Gravity obeys CPT

The CPT symmetric universe[1]

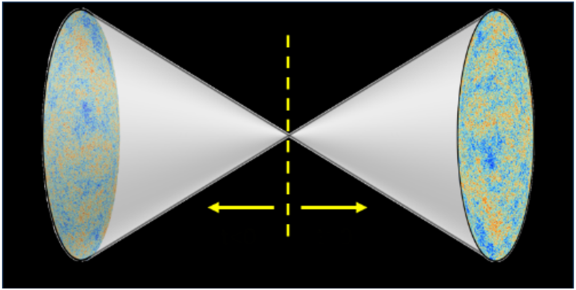


Figure 7: The CPT symmetric universe consists of two mirror images joined at the initial singularity.

[1] L. Boyle, K. Finn, N. Turok, CPT-symmetric universe, *Phys. Rev. Let.* **121**, 251301.

PT transformations

Definition. A PT transformation is a reflection of the space-time that reverses temporal and spatial orientations.

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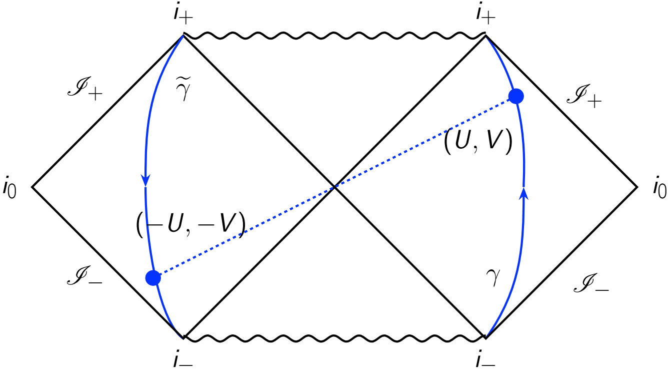

Figure 8: The map $(U, V) \to (-U, -V)$ is a PT transformation; it reverses the orientation of Cauchy surfaces $t = \mathrm{const.}$ and reverses the time orientation.

C tranformations

- Conserved charges:

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- For Kerr black holes, this is achieved by the inversion of the 2-sphere:

$$(\theta, \phi) \to (\pi - \theta, \pi + \phi).$$

Conserved charges of Black Holes

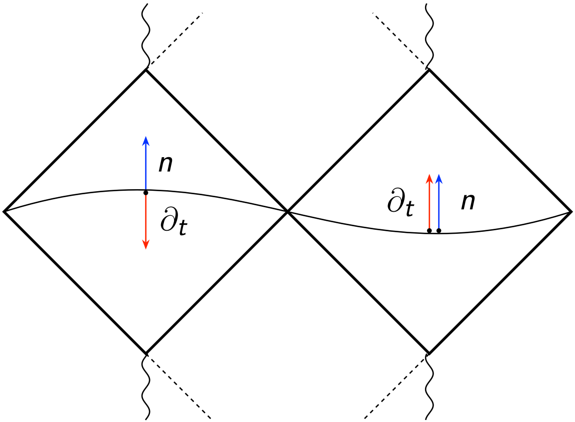

Figure 9: The conserved charges of an asymptotically flat Black Hole are zero. For black mirrors, the conserved (net) charges calculated by the 2-integrals are non-zero!

The Black Mirror as a saddle point of the action

Start with the general spherically symmetric metric:

$$ds^2 = -a(t,x)^2 dt^2 + 2S(t,x)dtdx + L(t,x)^2 dx^2 + r(x)^2 d\Omega^2$$

Vary the total gravitational action (EH + boundary terms):

$$\mathcal{S} = \frac{1}{2}\int dtdx \left(aL + \frac{r'(ar' + 2ra')}{L} + 2S\frac{rr'\dot{L}}{aL^2} \right),$$

with the additional boundary condition that $x \to -x$ is an isometry.

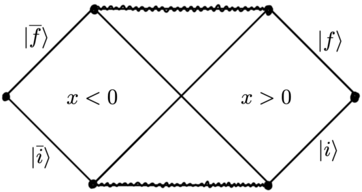

Figure 10: CPT symmetric boundary conditions at infinity

The saddle-point of this action for $L = 1$ and $S = 0$ that respects CPT symmetry ($x \to -x$) is

$$r = 2m\cosh^2\chi, \quad a = \tanh\chi$$

where

$$x = m\,(2\chi + \sinh(2\chi))\,.$$

This is equivalent to the Einstein-Rosen parametrization

$$r(\sigma) = 2m\left[1 + \left(\frac{\sigma}{4m}\right)^2\right].$$

The entropy of black mirrors

If we repeat this procedure in Euclidean time and integrate over

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- the positively oriented region, then we get the Gibbons-Hawking entropy.

Summary

The Black Mirror is a saddle-point of the gravitational action that

- is comprised of two black hole exteriors glued at their horizons via antipodal identification.
- The two exteriors are CPT images of each other represents a pure state of the gravitational field.

Future directions

- Construct quantum fields in a Black Mirror background and study the Hawking radiation. Is it unitary?
- Extend this to dynamical space-times and make contact with observation. (See Pau-Amaro Seoane *arXiv:2508.13272 [gr-qc].)*
- Understand this orientation flip at the horizon using the Hironaka singularity blowup techniques.

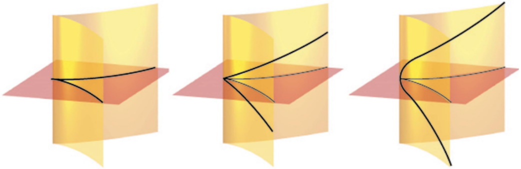


Figure 11: The cusp of $y^2 = x^3$ can be resolved via vertical dragging (taken from Hauser (2003))

Matter fields in the CPT symmetric universe collapsing to Black Mirrors

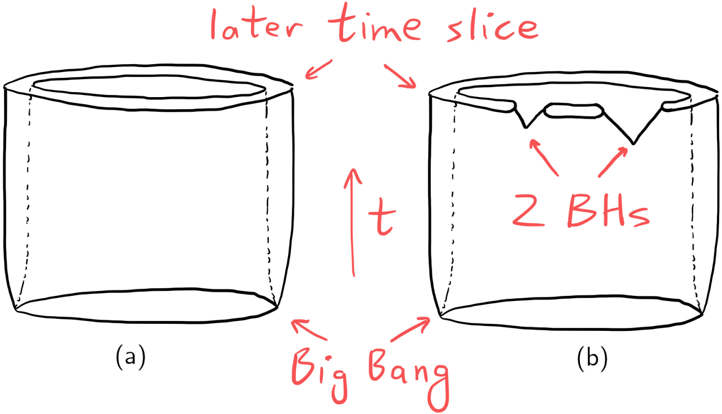
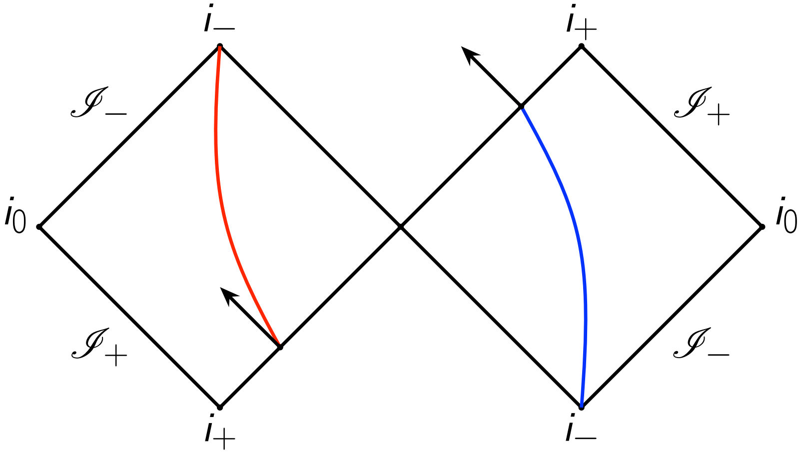
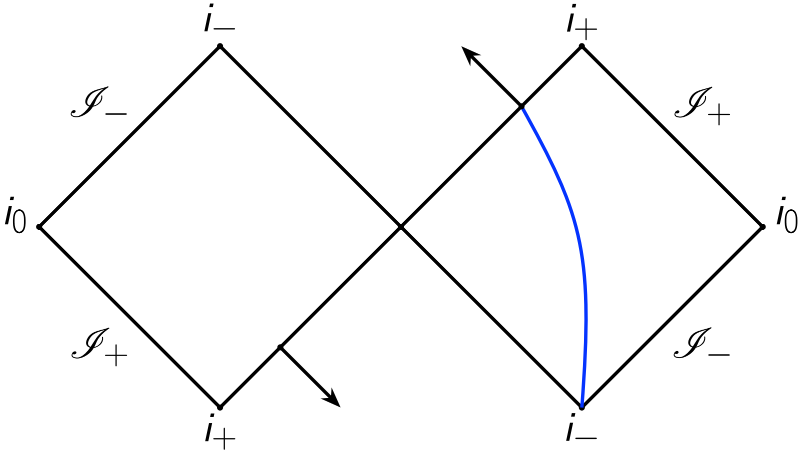


Figure 12: In the CPT symmetric universe, one can construct an initial value problem with initial conditions on the singularity $t = 0$ and evolve them such that the reflection $t \to -t$ is an isometry.

Case 1: CPT acts on points



Case 2: CPT acts on the tangent bundle



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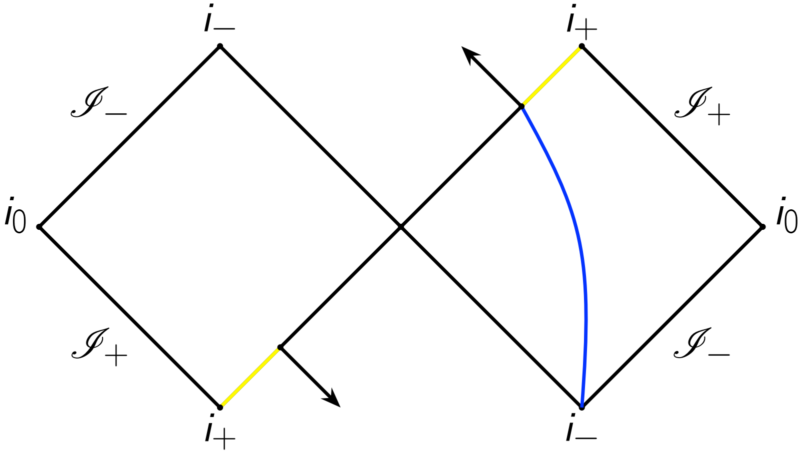

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