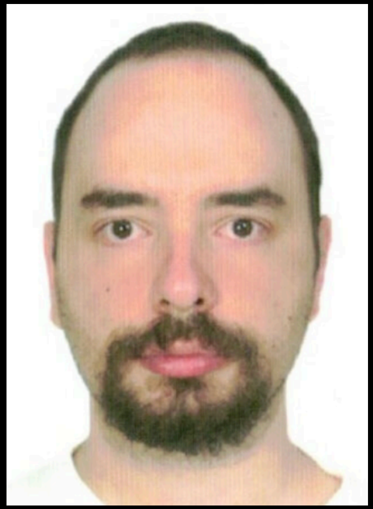
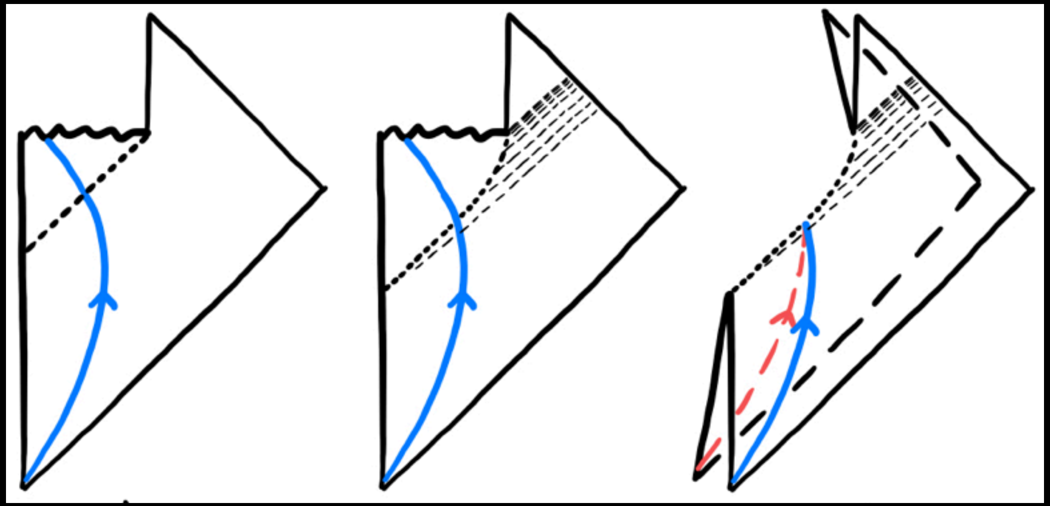
Black Mirrors: CPT-Symmetric Alternatives to Black Holes





Latham Boyle
Higgs Centre for Theoretical Physics
University of Edinburgh

(based on arXiv:2412.09558, with Kostas Tsanavaris & Neil Turok)

(also see arXiv:1212.4176 by Afshordi&Saravani)

Schwarzschild Metric (1916)

SCHWARZSCHILD: Über das Gravitationsfeld eines Massenpunktes 189

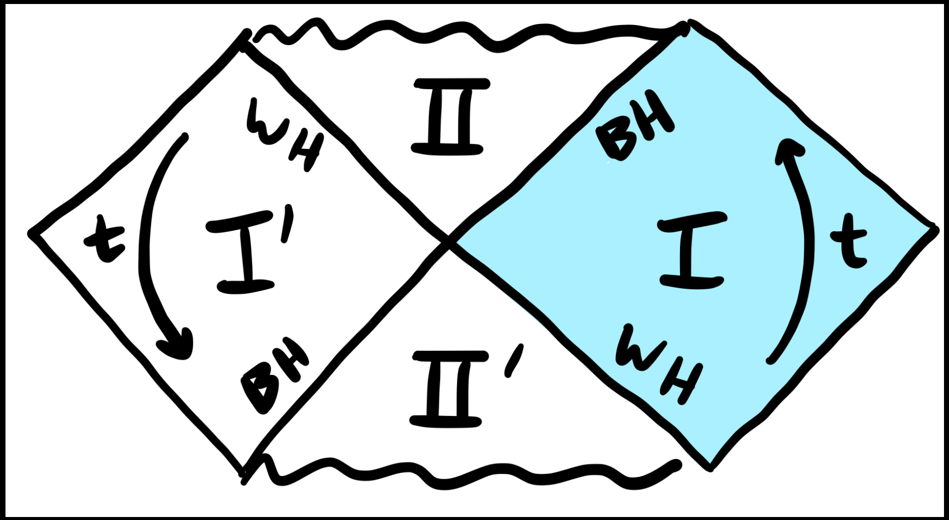
Über das Gravitationsfeld eines Massenpunktes nach der EINSTEINschen Theorie.

Von K. SCHWARZSCHILD.

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

$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

$$f(r) \equiv 1 - \frac{2m}{r} \quad \text{and} \quad d\Omega^2 \equiv d\theta^2 + \sin^2\theta\, d\varphi^2.$$



Einstein-Rosen Bridge/Wormhole (1935)

JULY 1, 1935 PHYSICAL REVIEW VOLUME 48

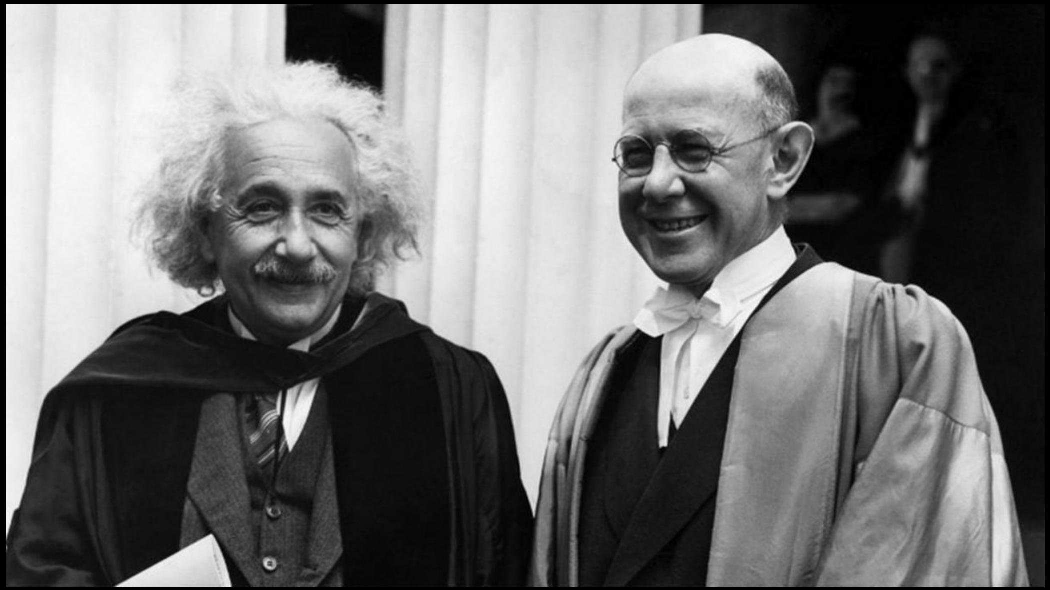
The Particle Problem in the General Theory of Relativity

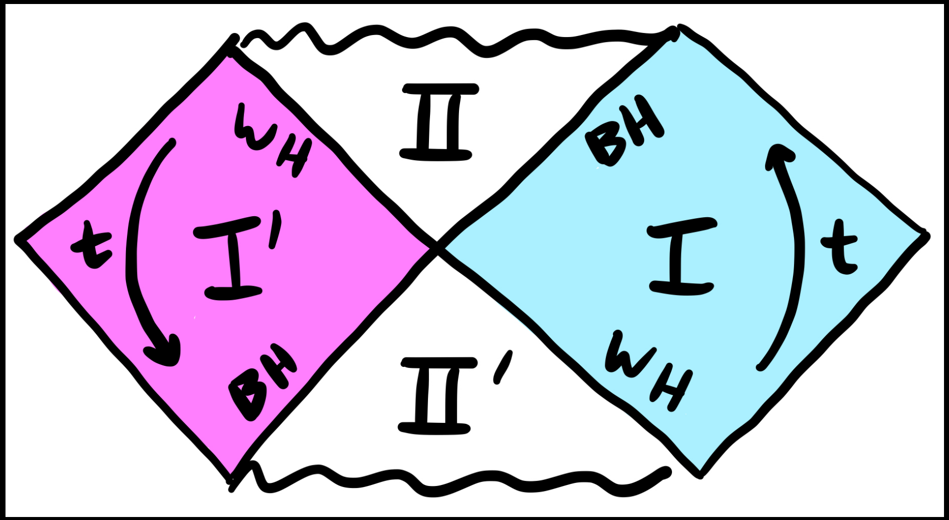
A. EINSTEIN AND N. ROSEN, *Institute for Advanced Study, Princeton*

(Received May 8, 1935)

$$ds^2 = -\frac{2m}{r(\sigma)}\left(\frac{\sigma}{4m}\right)^2 dt^2 + \frac{r(\sigma)}{2m}d\sigma^2 + r(\sigma)^2 d\Omega^2$$

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





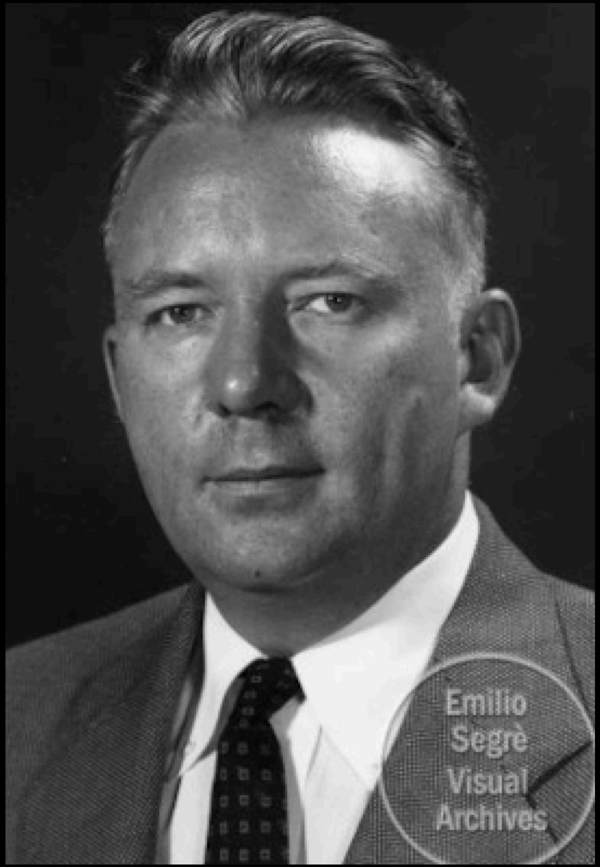
Oppenheimer-Snyder (1939)

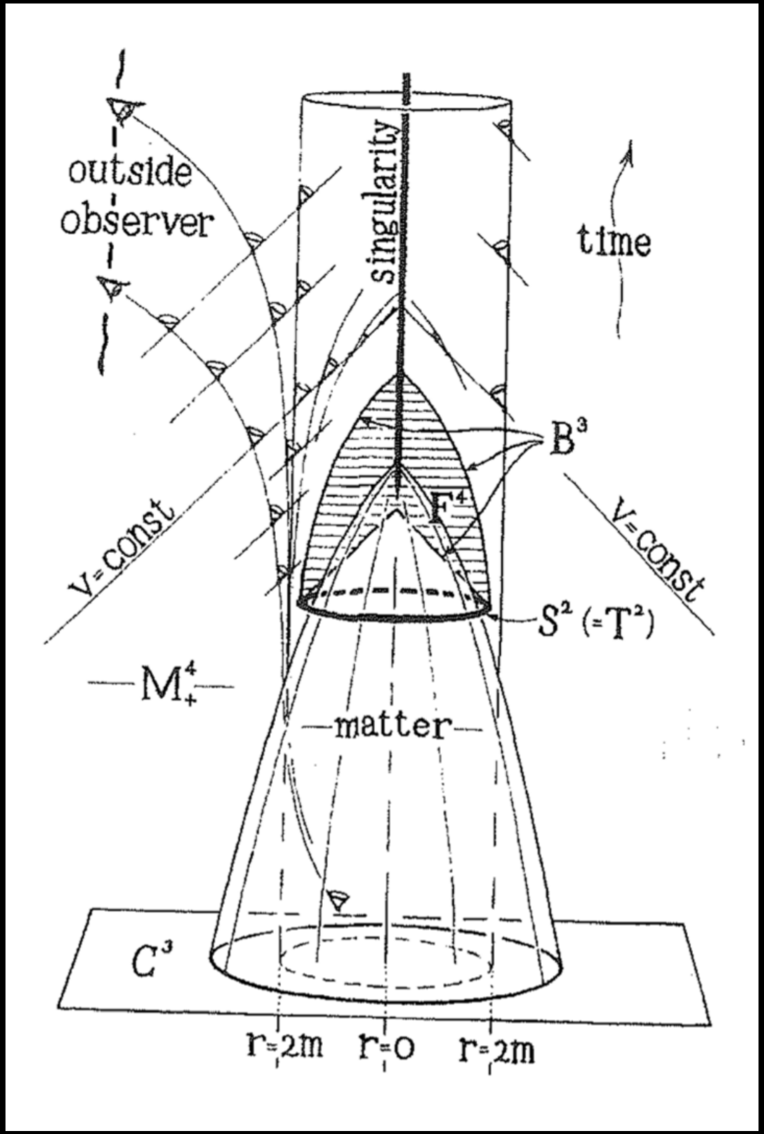
SEPTEMBER 1, 1939 PHYSICAL REVIEW VOLUME 56

On Continued Gravitational Contraction

J. R. OPPENHEIMER AND H. SNYDER
University of California, Berkeley, California

(Received July 10, 1939)

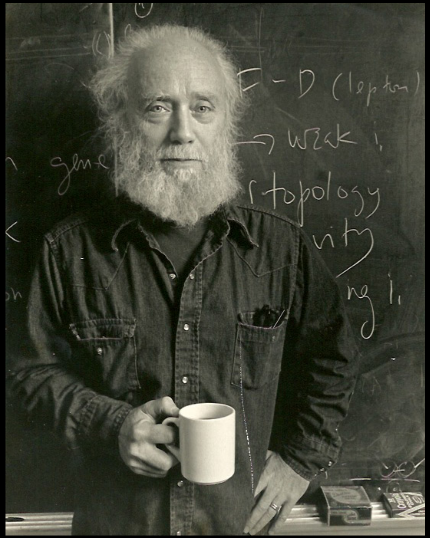




Eddington-Finkelstein (Penrose?) Coordinates

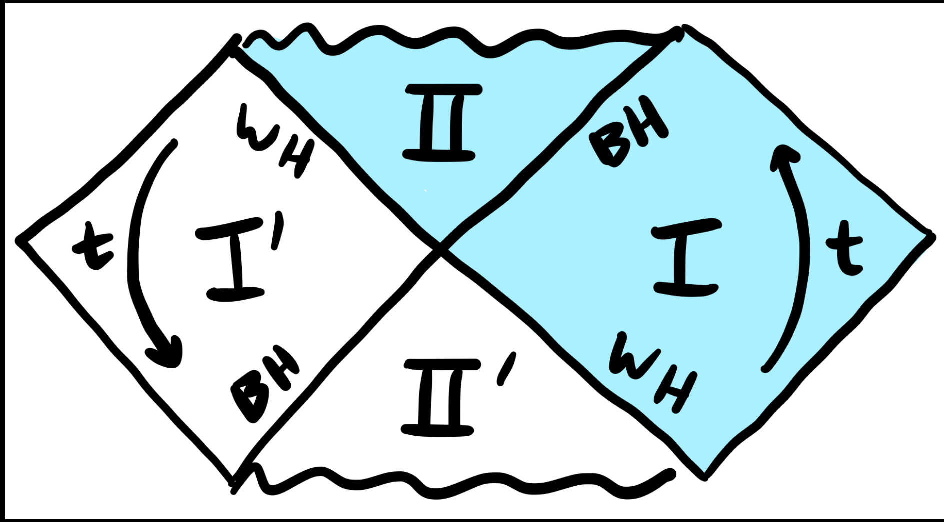
GRAVITATIONAL COLLAPSE AND SPACE-TIME SINGULARITIES

Roger Penrose
Department of Mathematics, Birkbeck College, London, England
(Received 18 December 1964)



$$ds^2 = -f(r)dv_{\pm}^2 \pm 2\, dv_{\pm}\, dr + r^2 d\Omega^2$$

$$dv_{\pm} = dt \pm \frac{dr}{f(r)}$$



Reasons to be suspicious of the interior:

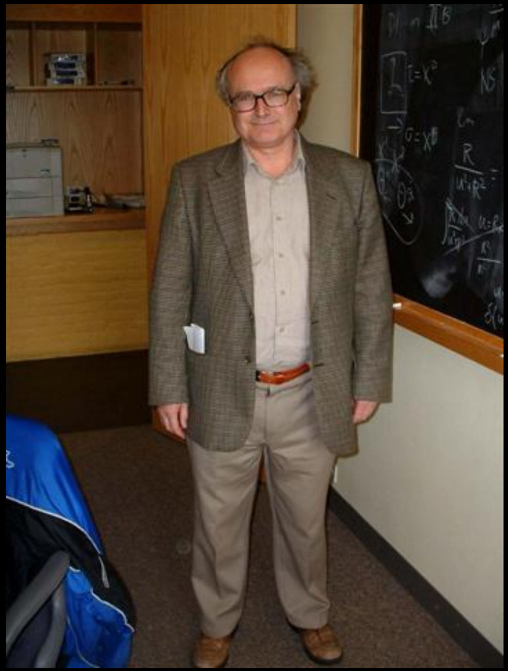
1) Hidden from observation?
2) Curvature singularities
3) Cauchy horizons (breakdown of causality)
4) Information paradox (violation of unitarity?)
5) Does hole evaporate before inflating matter gets in?

Euclidean Schwarzschild Metric (Gibbons-Hawking, 1977)

PHYSICAL REVIEW D VOLUME 15, NUMBER 10 15 MAY 1977

Action integrals and partition functions in quantum gravity

G. W. Gibbons* and S. W. Hawking
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, England
(Received 4 October 1976)



$$ds^2 \approx \frac{\sigma^2}{(4m)^2} d\tau^2 + d\sigma^2 + (2m)^2 d\Omega^2$$

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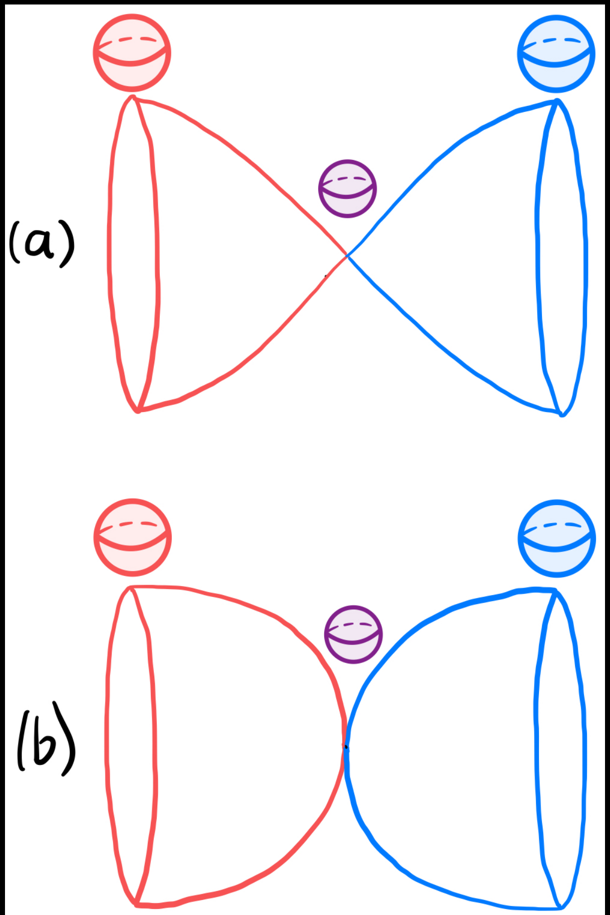
$$\tau \sim \tau + 8\pi m$$



The Black Mirror Solution

$$ds^2 = -\frac{2m}{r(\sigma)}\left(\frac{\sigma}{4m}\right)^2 dt^2 + \frac{r(\sigma)}{2m}d\sigma^2 + r(\sigma)^2 d\Omega^2$$

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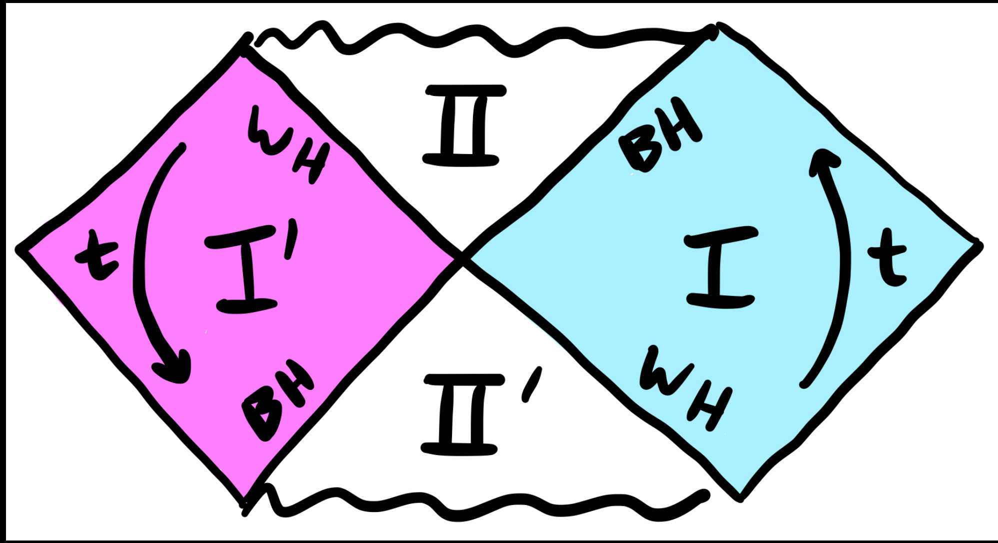

$$ds^2 = -\frac{2m}{r(\sigma)}\left(\frac{\sigma}{4m}\right)^2 dv_\pm^2 \pm \frac{\sigma}{2m}d\sigma\, dv_\pm + r(\sigma)^2 d\Omega^2$$

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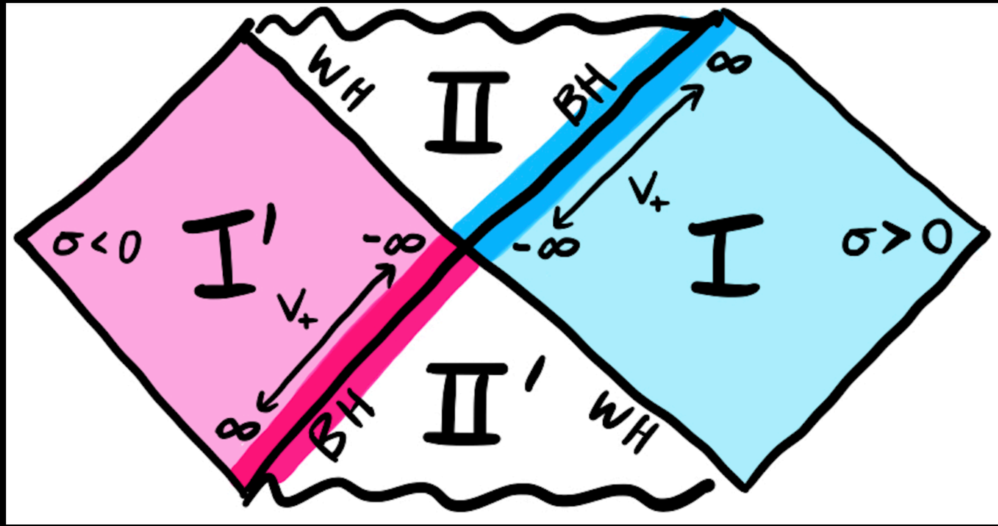

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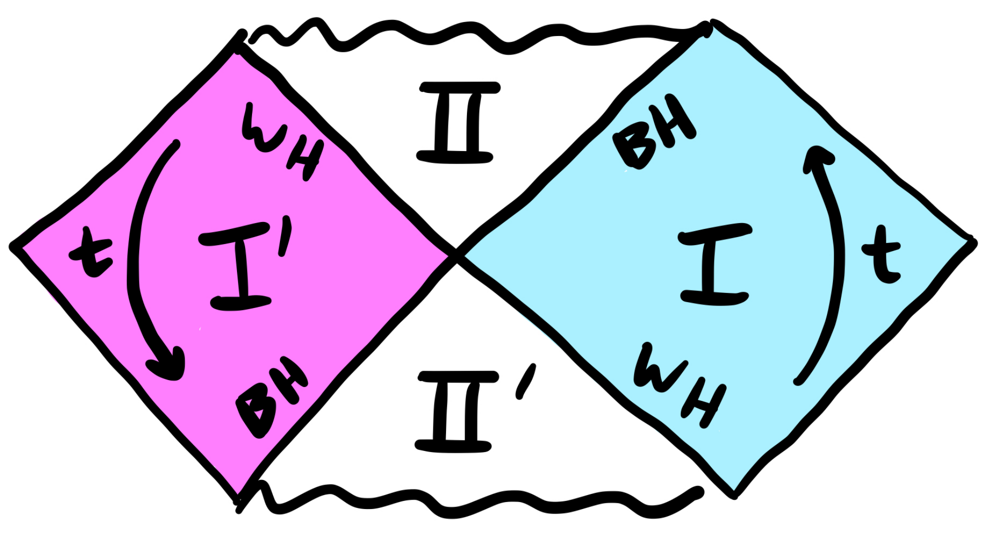

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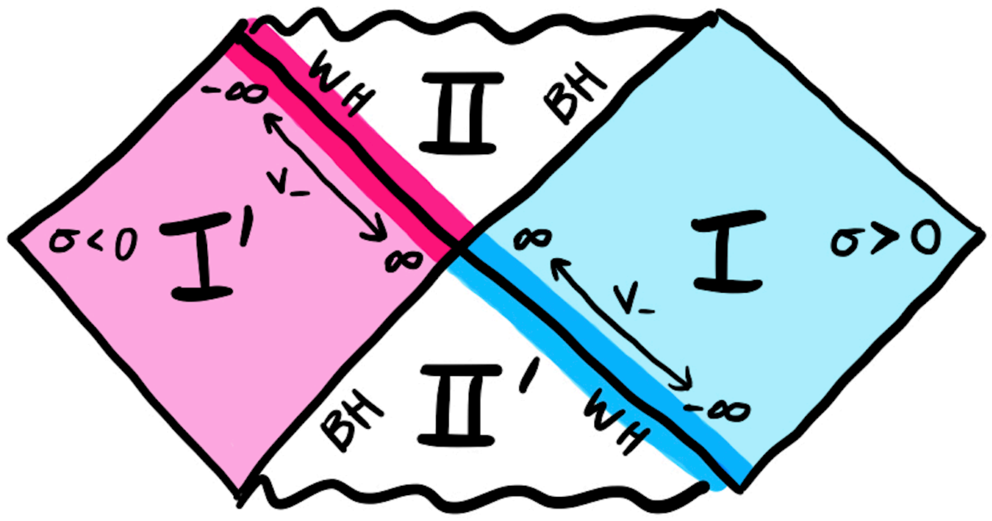

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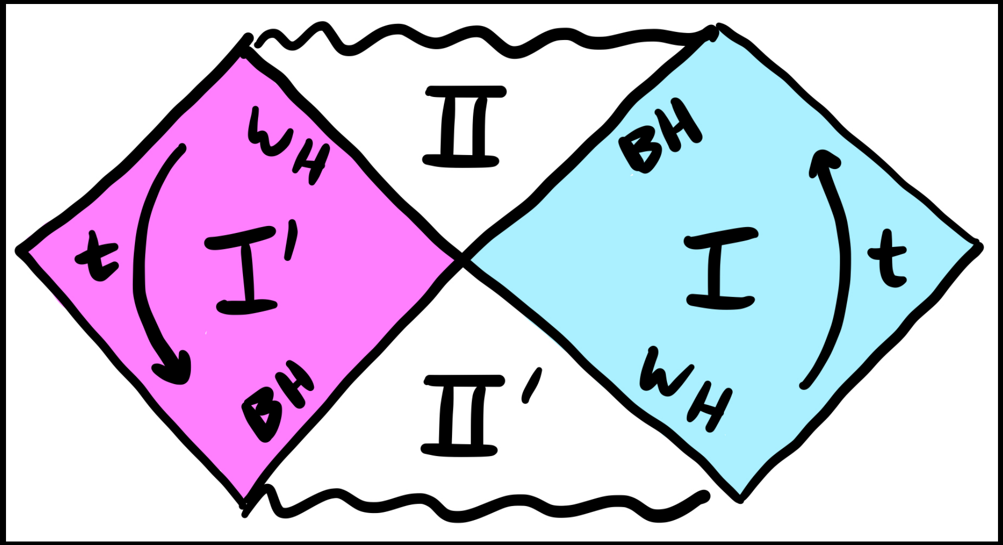

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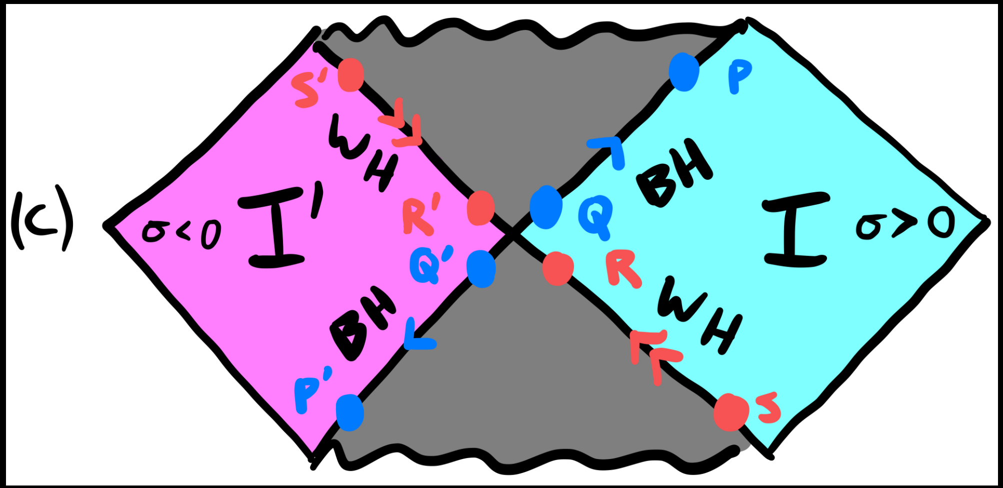

$$g_{\alpha\beta}, \quad R^{\alpha}{}_{\beta\gamma\delta}, \quad \text{all curvature invariants } R^{\alpha\beta\gamma\delta}R_{\alpha\beta\gamma\delta}$$

are smooth, analytic, and finite

$$R_{\mu\nu} = 0 \ \text{ everywhere (vacuum solution)}$$

But no free lunch!

$g_{\mu\nu}$ eigenvalues: holomorphic, two simple zeros

$g^{\mu\nu}$ eigenvalues: meromorphic, two simple poles

Matching surface (horizon) is a *Carrollian* geometry

The Charged, Rotating Black Mirror Solution

$$ds^2 = \tilde{\eta}_{ab}\tilde{e}^a\tilde{e}^b, \quad \tilde{\eta}_{ab} = \begin{pmatrix} -\frac{\Delta_r}{\rho^2} & \pm 1 & 0 & 0 \\ \pm 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\begin{aligned} \tilde{e}^0 &= dv - \frac{a\sin^2\theta}{\Xi}d\hat{\phi} \\ \tilde{e}^1 &= dr \\ \tilde{e}^2 &= \frac{\rho}{\Delta_\theta^{1/2}}d\theta \\ \tilde{e}^3 &= \frac{\Delta_\theta^{1/2}\sin\theta}{\rho}\left(a\,dv - \frac{r^2+a^2}{\Xi}d\hat{\phi}\right) \end{aligned}$$

$$\begin{aligned} F = &-\frac{1}{\rho^4}\left[q_e(r^2 - a^2\cos^2\theta) + 2q_m r\,a\cos\theta\right]\tilde{e}^0\wedge\tilde{e}^1 \\ &+\frac{1}{\rho^4}\left[q_m(r^2 - a^2\cos^2\theta) - 2\,q_e r\,a\cos\theta\right]\tilde{e}^2\wedge\tilde{e}^3 \end{aligned}$$

$$\Delta_\theta \equiv 1 - \frac{a^2}{\ell^2}\cos^2\theta, \quad \Delta_r \equiv (r^2+a^2)\left(1+\frac{r^2}{\ell^2}\right) - 2mr + q^2$$

$$\rho^2 \equiv r^2 + a^2\cos^2\theta, \quad \Xi \equiv 1 - \frac{a^2}{\ell^2}$$

$$r(\sigma) = r_+ + \sigma^2$$

Vanishing entropy on full space —> pure state
Non-vanishing entropy on half-space —> entanglement entropy

PHYSICAL REVIEW D VOLUME 15, NUMBER 10 15 MAY 1977

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G. W. Gibbons* and S. W. Hawking

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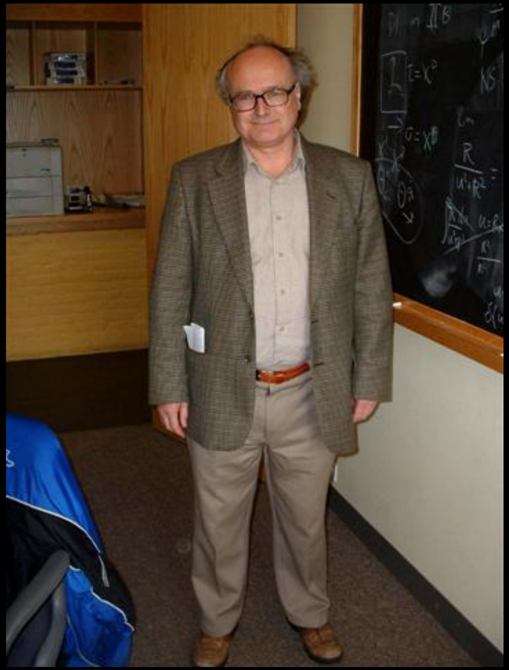

$$t(\tau) = -i\tau$$

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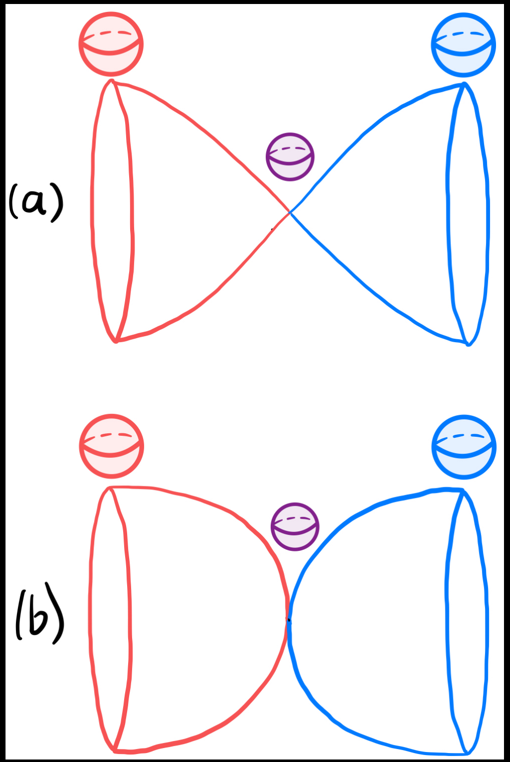
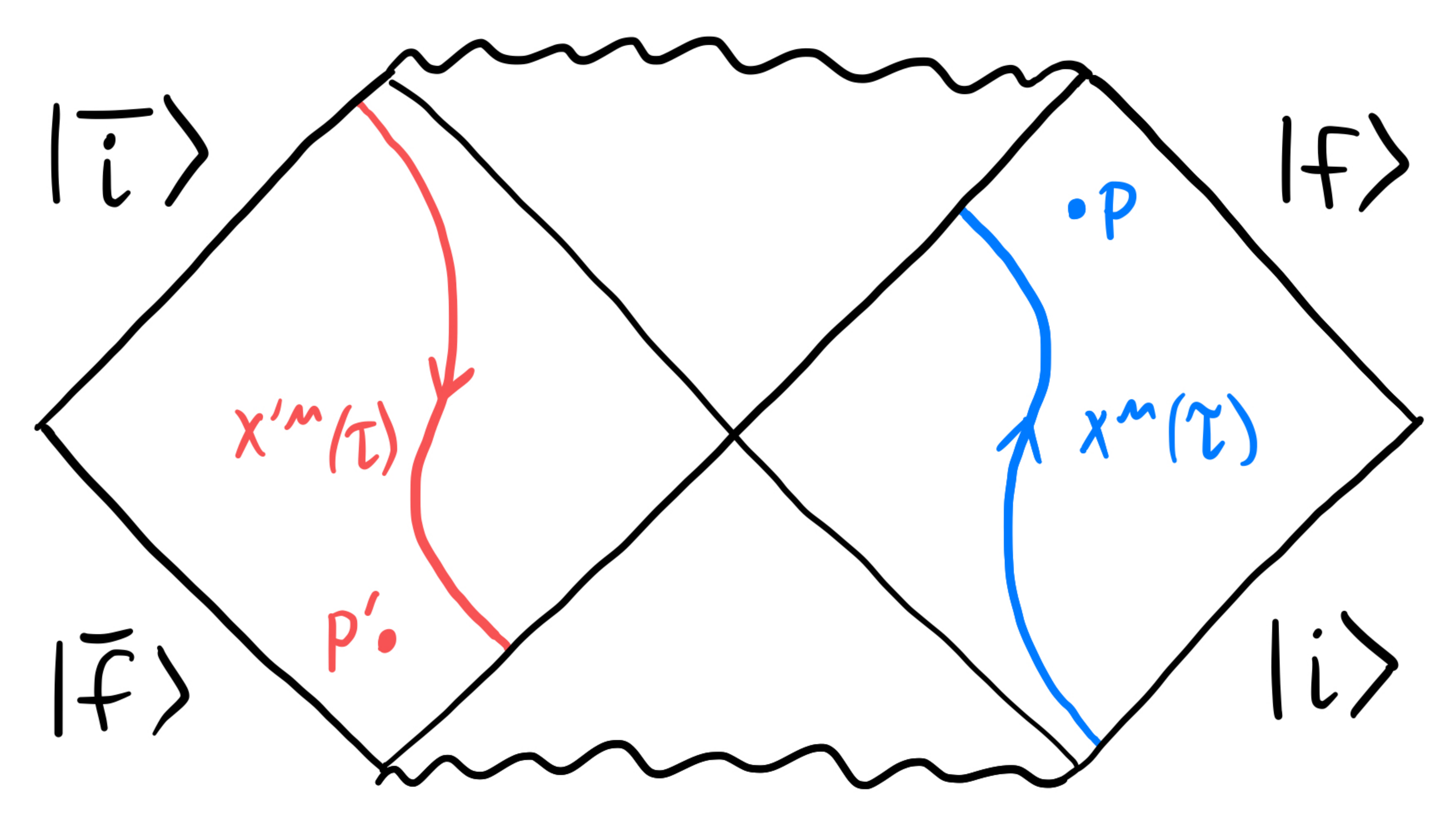
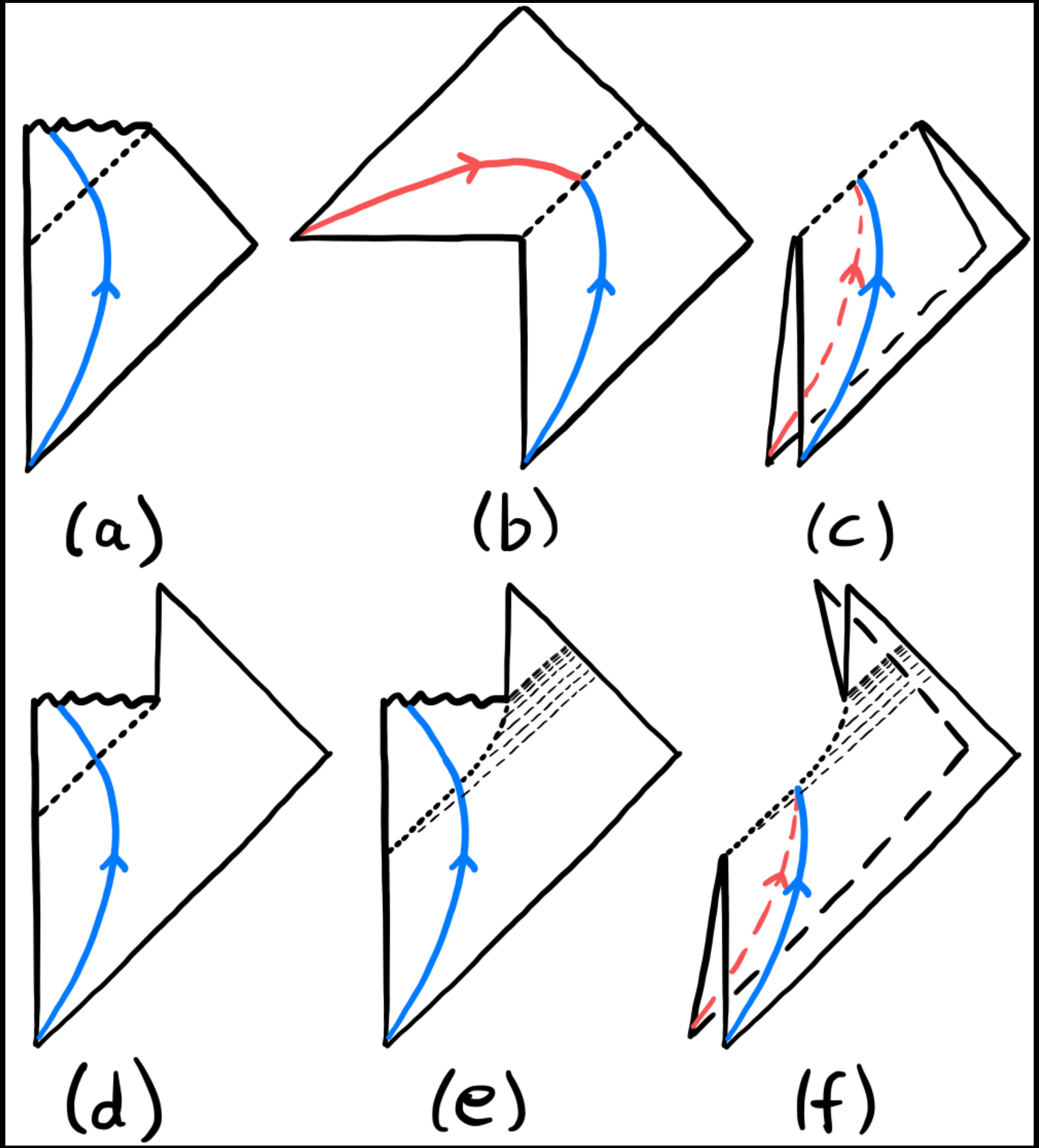


The Black Mirror Solution From CPT-symmetric b.c.'s



The Black Mirror Solution



dynamical collapse

and evaporation

A $U/\bar{U}$ pair?

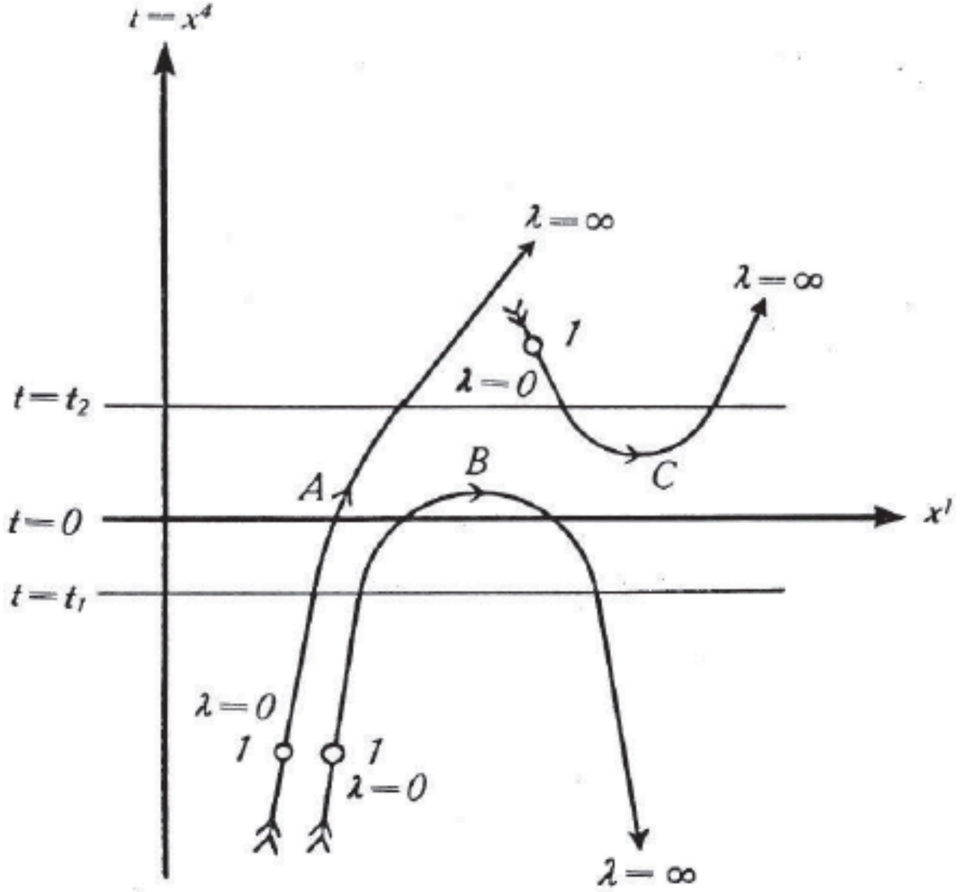
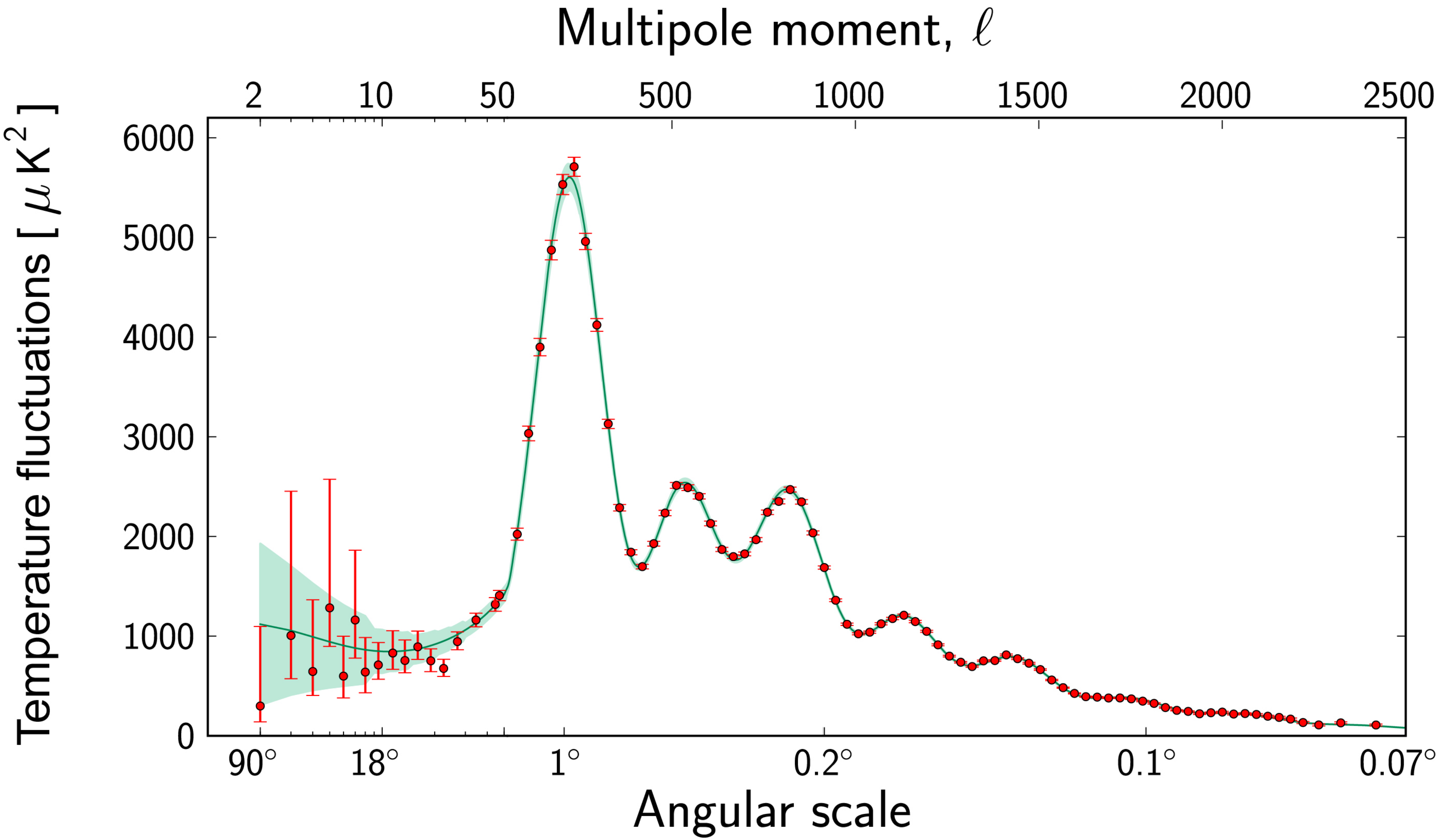
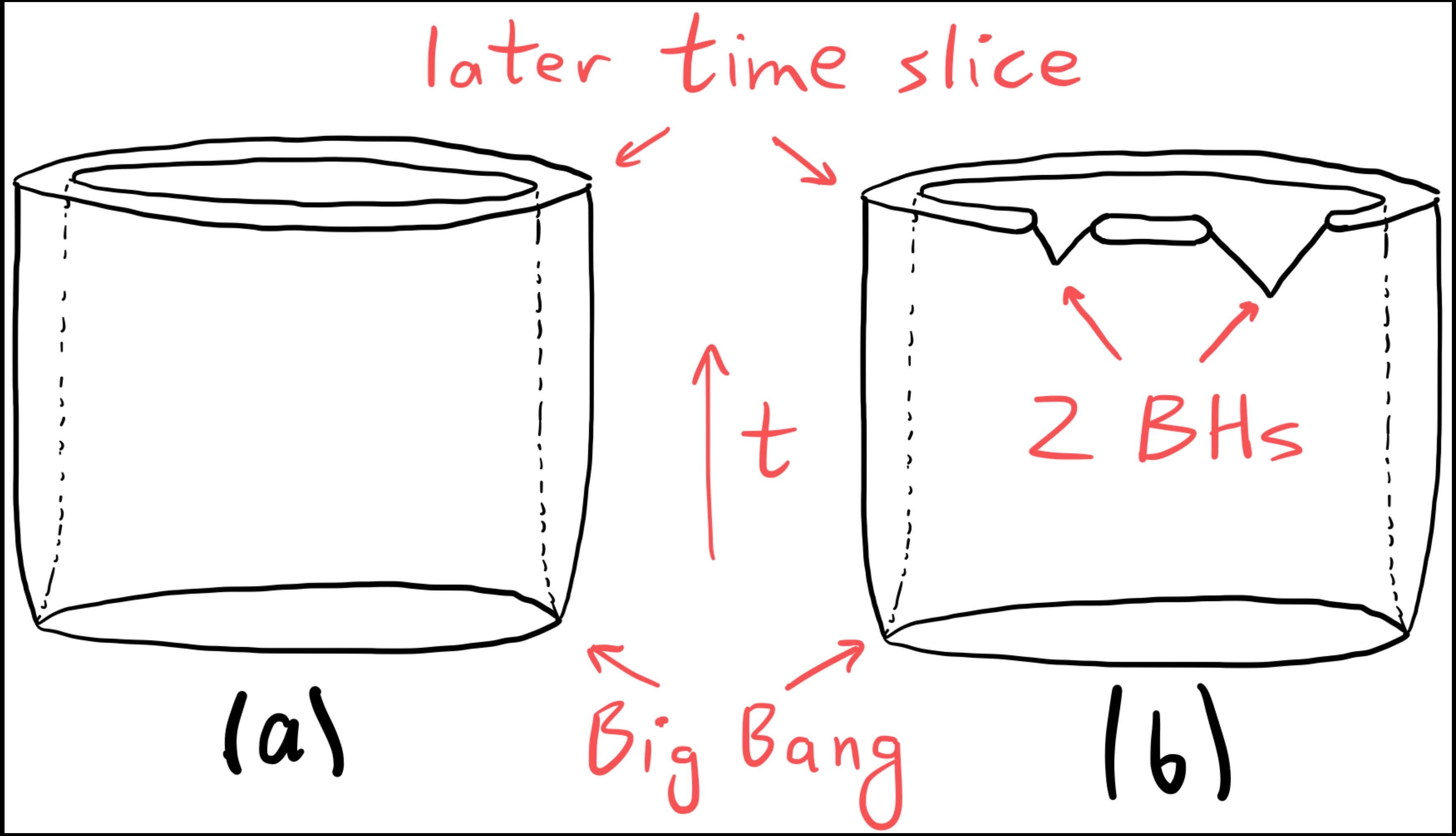


Fig. 1.

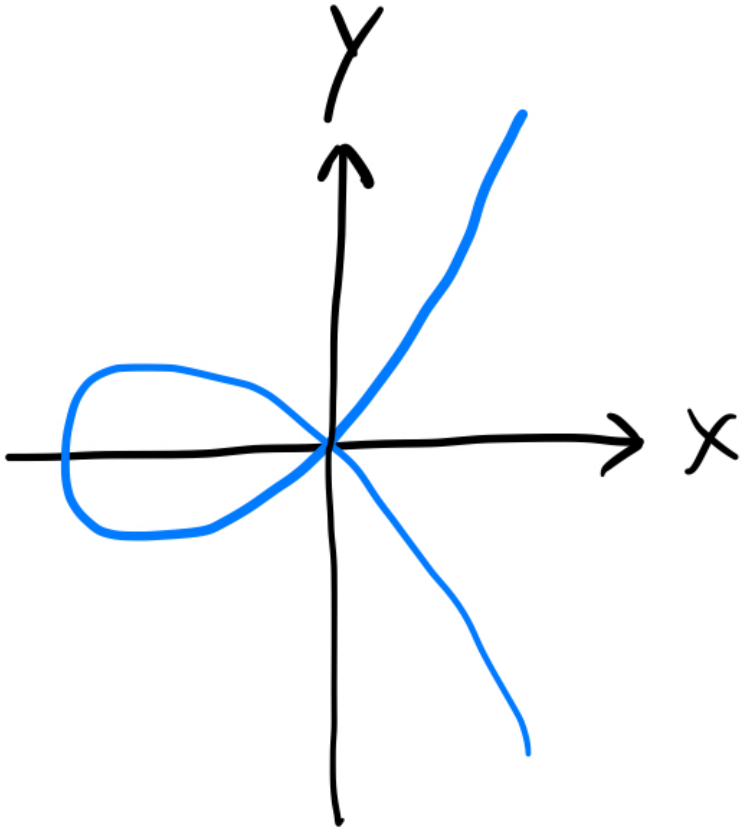
(Stueckelberg, 1941)


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale

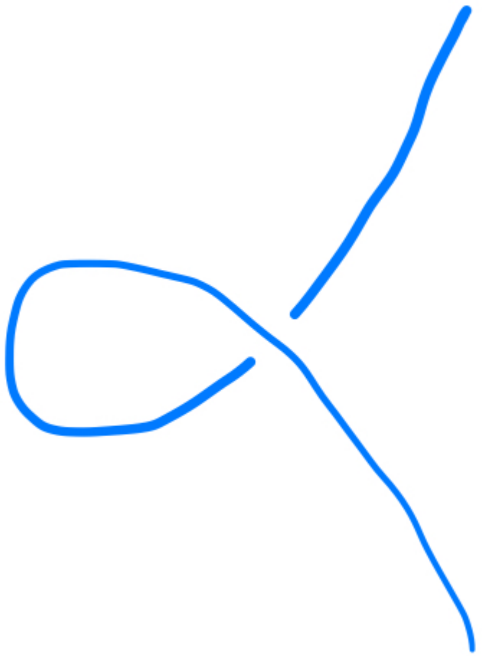
The Black Mirror Solution From Cosmology



Algebraic variety → Blow-up (Hironaka)



$$y^2 = x^2 + x^3$$



Reasons to be suspicious of the interior (revisited):

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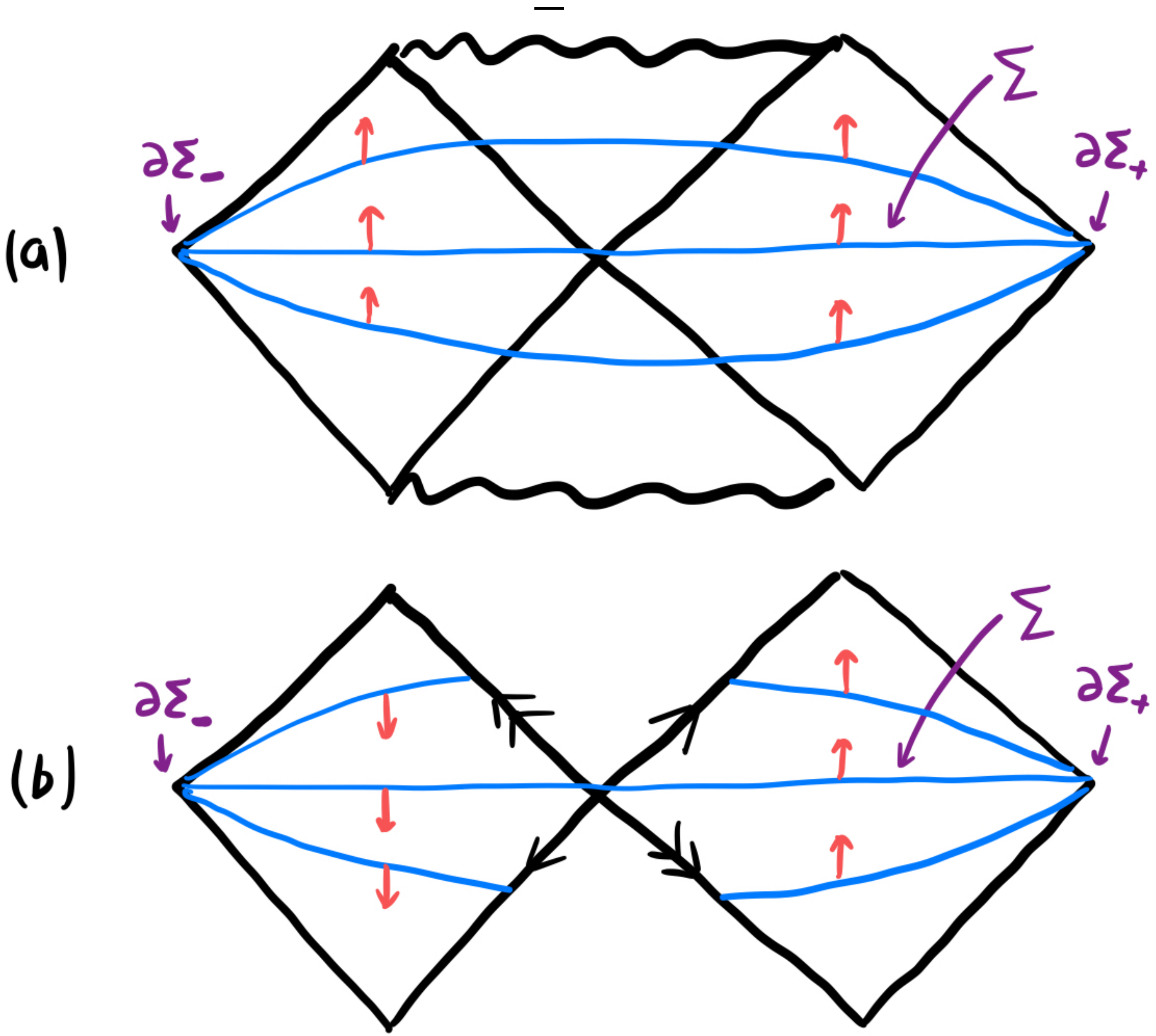
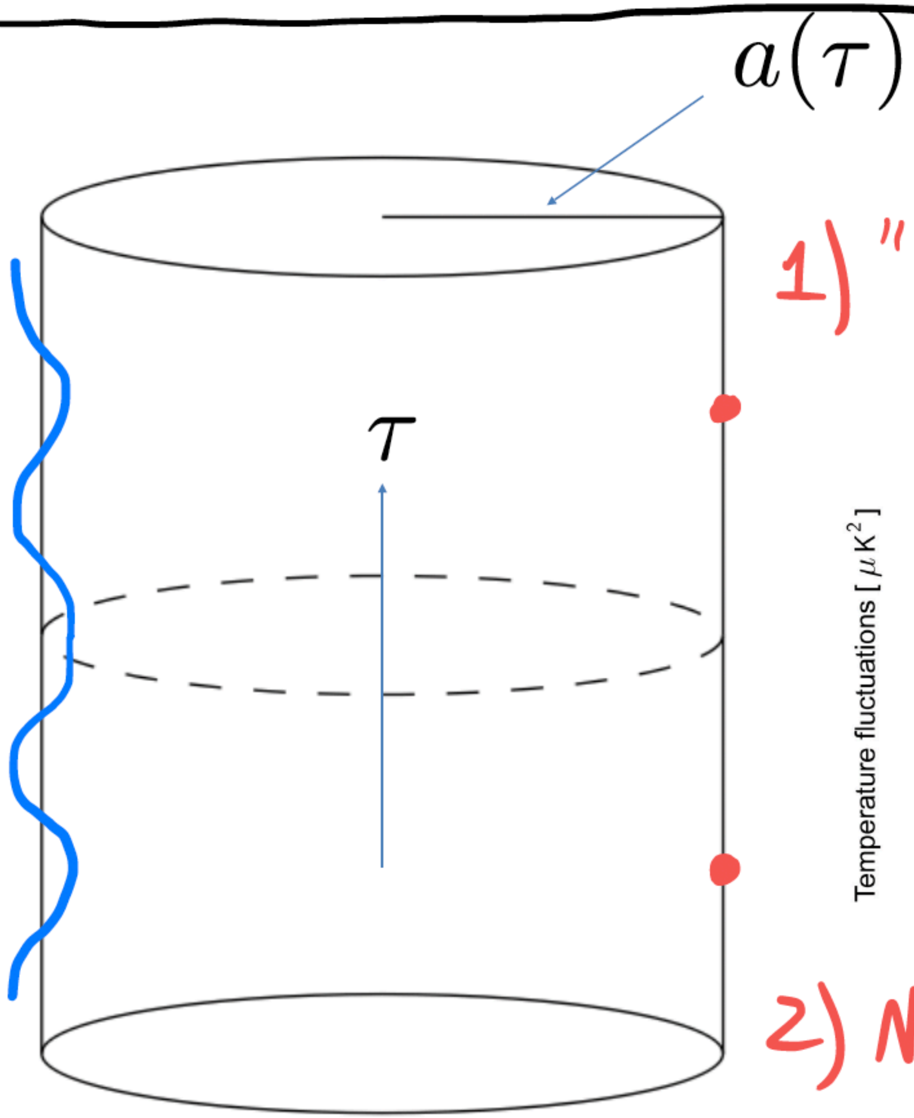
Thank you for listening!


(a)
∂Σ₋
Σ
∂Σ₊
(b)
∂Σ₋
Σ
∂Σ₊

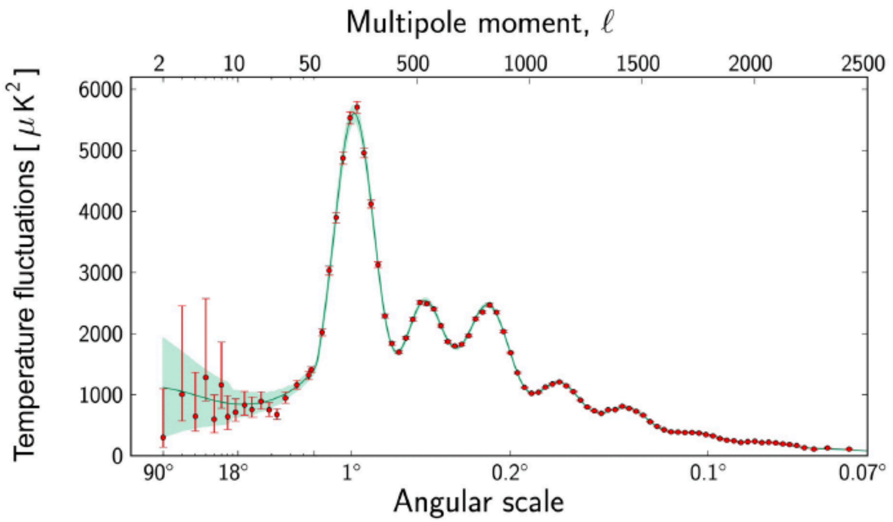
Primordial Perturbations



The Big Bang is a Mirror!

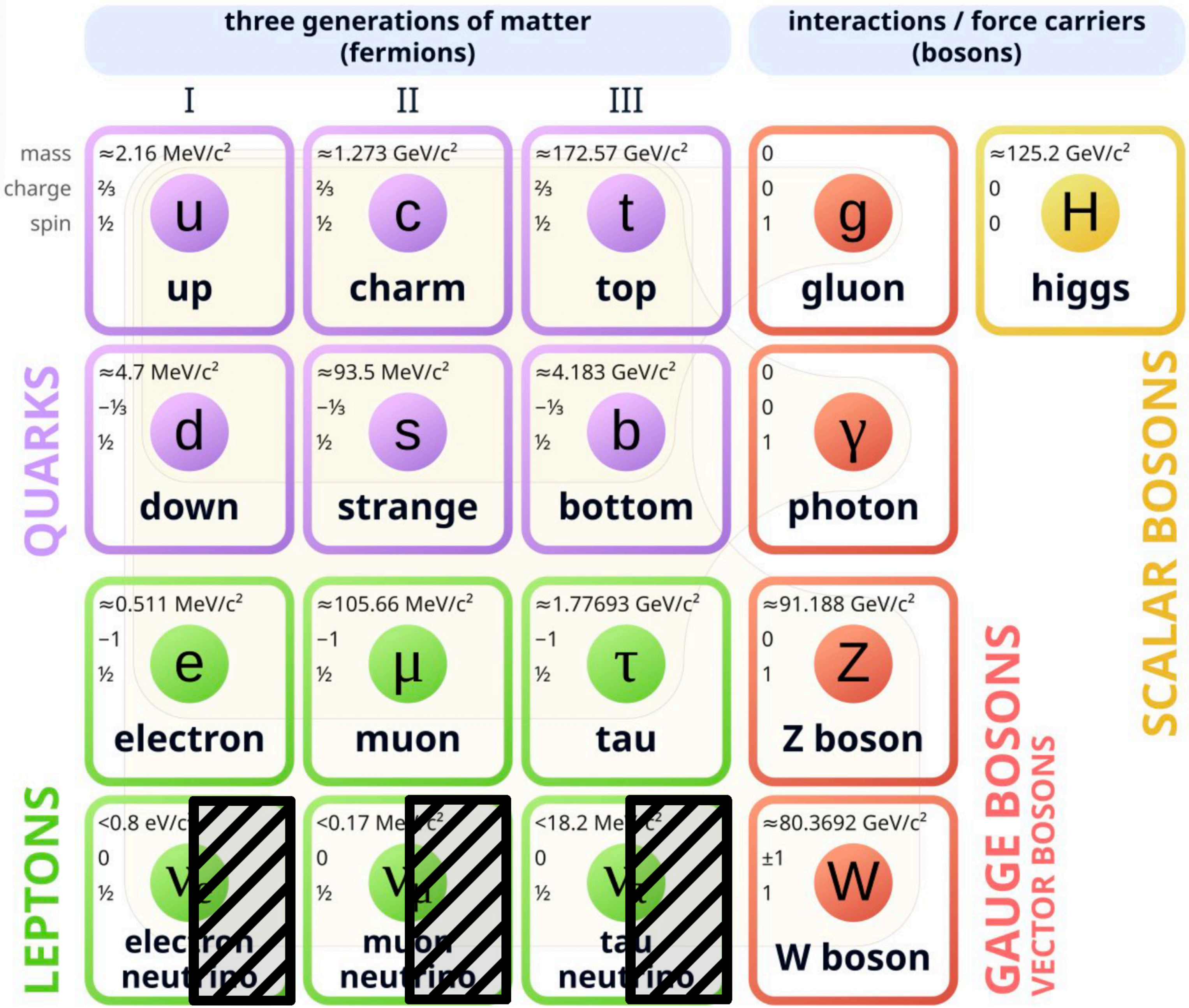
Explains:

1) "Ringing" CMB spectrum:

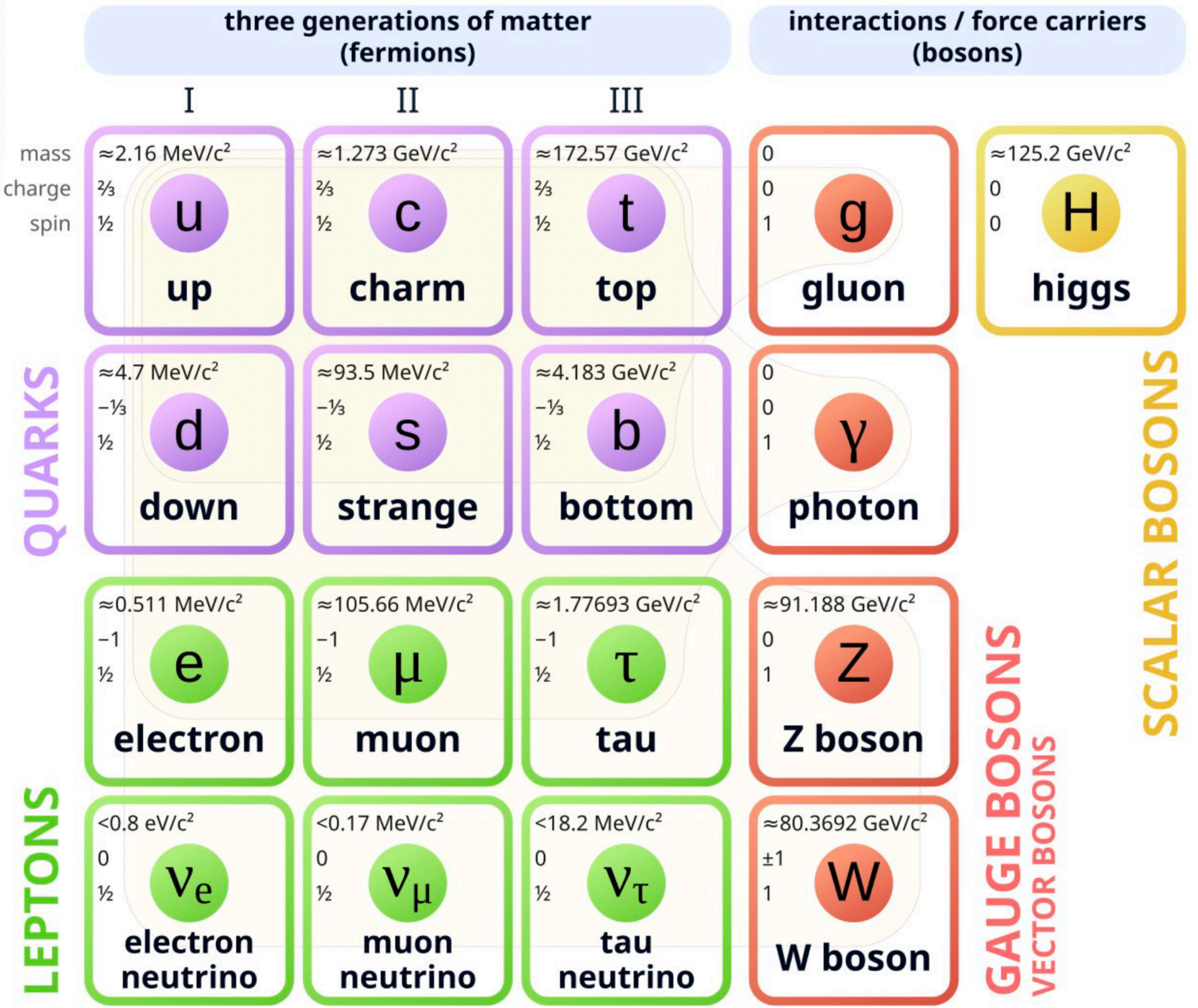


2) No primordial vorticity
3) No singular perturbations

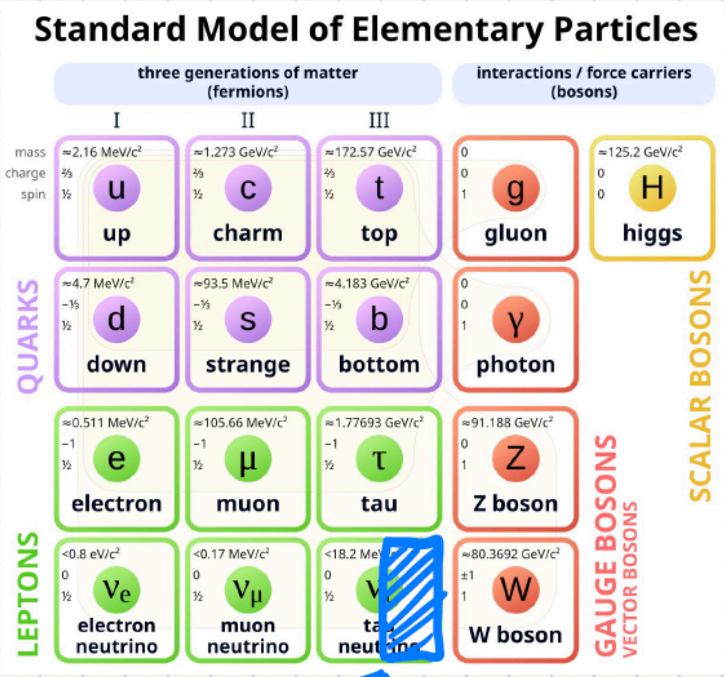
Standard Model of Elementary Particles



Standard Model of Elementary Particles



Dark Matter



- Dark matter radiated from Big Bang
- Just like Hawking radiation from Black Hole

Predictions:

1) $m_{DM} = 4.8 \times 10^8$ GeV $\simeq 5 \times 10^8\, m_{proton}$
2) Dark matter is <u>cold</u>
3) lightest neutrino is <u>massless</u>

★ <u>just confirmed by DESI!</u> ★

4) neutrinoless double beta decay rate (still a decade or two away)
5) no primordial gravitational waves (in contrast to inflation, tested by CMB polarization expts.)

The gravitational entropy of the universe

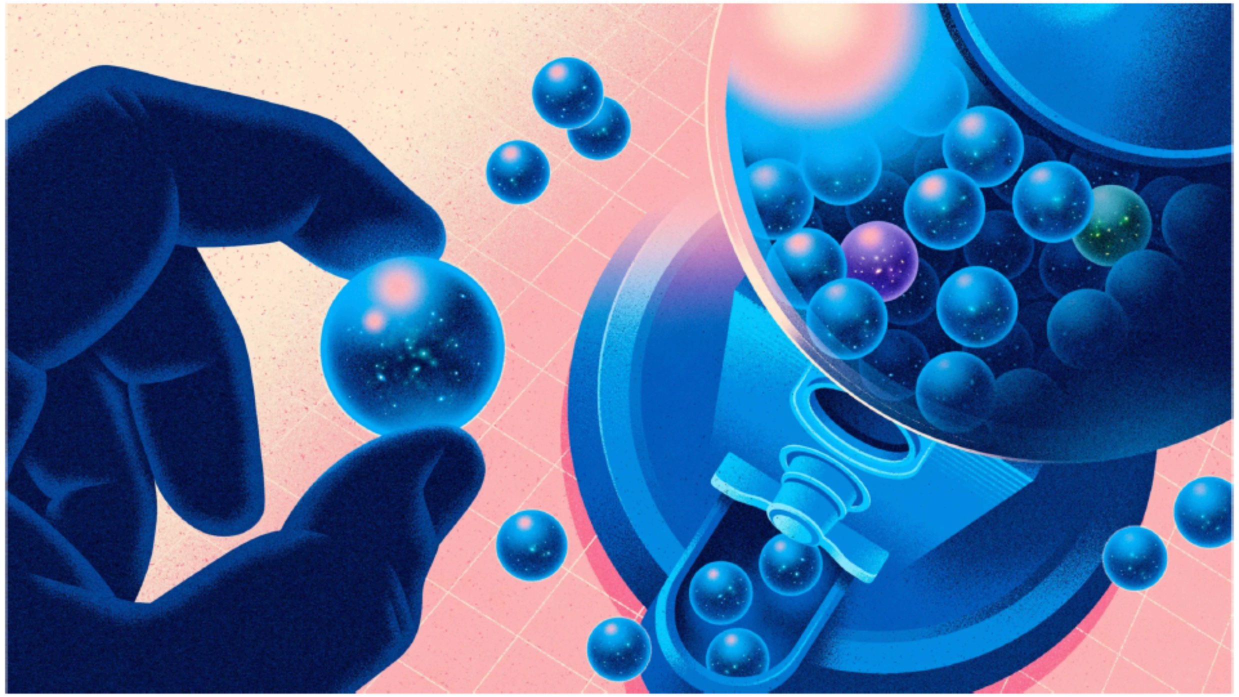
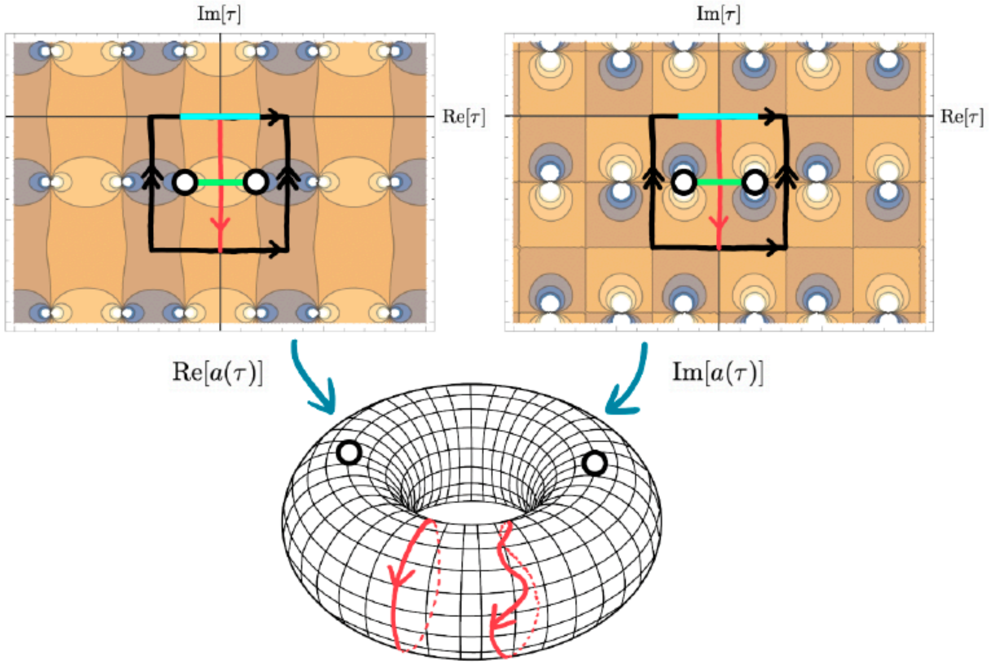


Image Credit: Quanta Magazine

Explains: cosmic flatness, homogeneity, isotropy, and tiny positive cosmological constant

Step 1. Obtain general solution for the cosmic scale factor:

$$H^2 = \frac{8\pi G}{3}\left(\frac{r}{a^4} + \frac{\mu}{a^3} + \lambda\right) - \frac{\kappa}{a^2}$$



Step 2. Obtain general formula for the *gravitational* entropy of an FRW universe:

Flat universes and tiny positive Lambda are favoured!

Step 3. Add cosmological perturbations (small inhomogeneities and isotropies):

If the Big Bang is a mirror, these *cost* entropy!

Grav. entropy is largest for universes like ours:
homogeneous, isotropic and flat
(with tiny positive Lambda)!

A measure on the
space of universes.

Arrow of Time