Title: Gravity: A different Perspective

Date: Jun 02, 2010 04:00 PM

URL: http://pirsa.org/10060000

Abstract: Combining the principles of general relativity and quantum theory still remains as elusive as ever. Recent work, that concentrated on one of the points of contact (and conflict) between quantum theory and general relativity, suggests a new perspective on gravity. It appears that the gravitational dynamics in a wide class of theories - including, but not limited to, standard Einstein's theory - can be given a purely thermodynamic interpretation. In this approach gravity appears as an emergent phenomenon, like e.g., gas or fluid dynamics. I will describe the necessary background, key results and their implications as suggested by my recent work in this area.

GRAVITY: A DIFFERENT PERSPECTIVE

T. Padmanabhan

(IUCAA, Pune)

Perimeter Institute, Canada

2 June 2010

THE ATTRACTION OF QUANTUM GRAVITY

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Hathaway's Einstein theories

NO fashion magazines for Hollywood actress Anne Hathaway, she spends her free time studying books on physics to enhance her knowledge on the universe.

The Devil Wears Prada star admits she shuns fashion magazines and instead stocks up on books by scientist Albert Einstein and physics textbooks in a bid to better understand the universe, reported a website. "I'm interested in elementary particles. What I like thinking about is how time and space exist in the universe and how we understand it. Any spare time I have, I bury my head in a physics textbook. I'm reading a lot about Einstein. I like theories and I want to understand string theory," she said.

— IANS

GRAVITY AND QUANTUM THEORY

Points of Contact and Conflict ?

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Points of Contact and Conflict ?

- POSSIBLE ROLE OF GRAVITY AS UV REGULATOR
- SINGULARITY IN COSMOLOGY AND BLACK HOLE COLLAPSE
- THE VALUE OF COSMOLOGICAL CONSTANT
- THERMODYNAMICS OF HORIZONS

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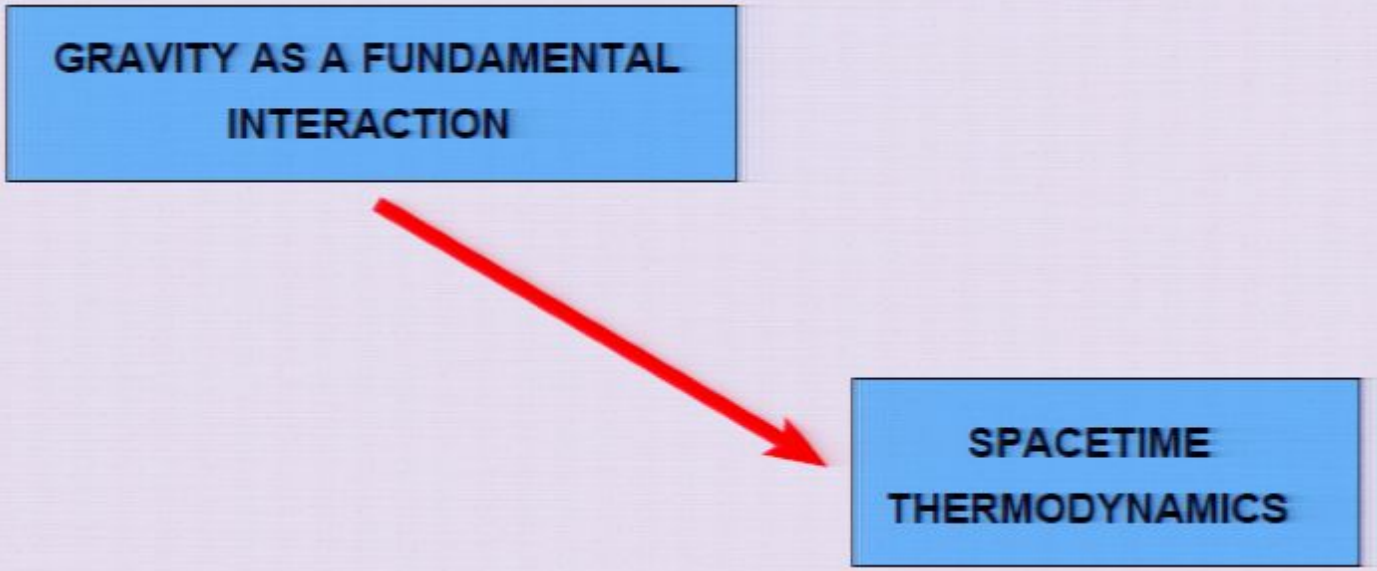
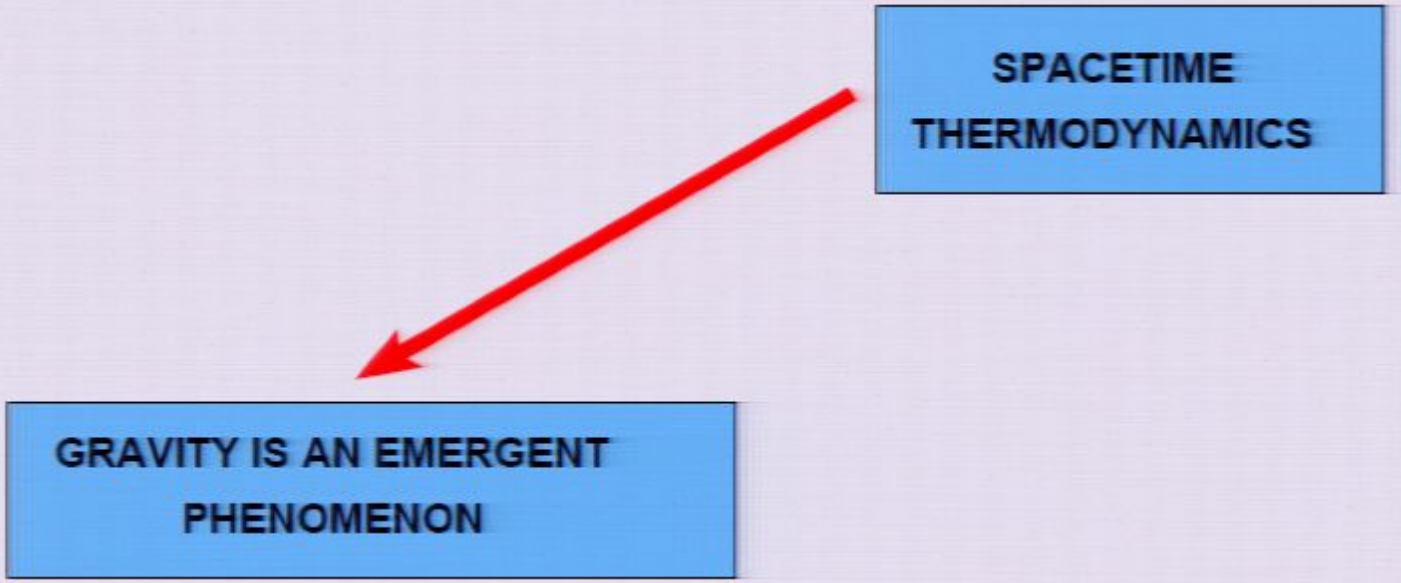
CONVENTIONAL VIEW

GRAVITY AS A FUNDAMENTAL INTERACTION

CONVENTIONAL VIEW



NEW PERSPECTIVE



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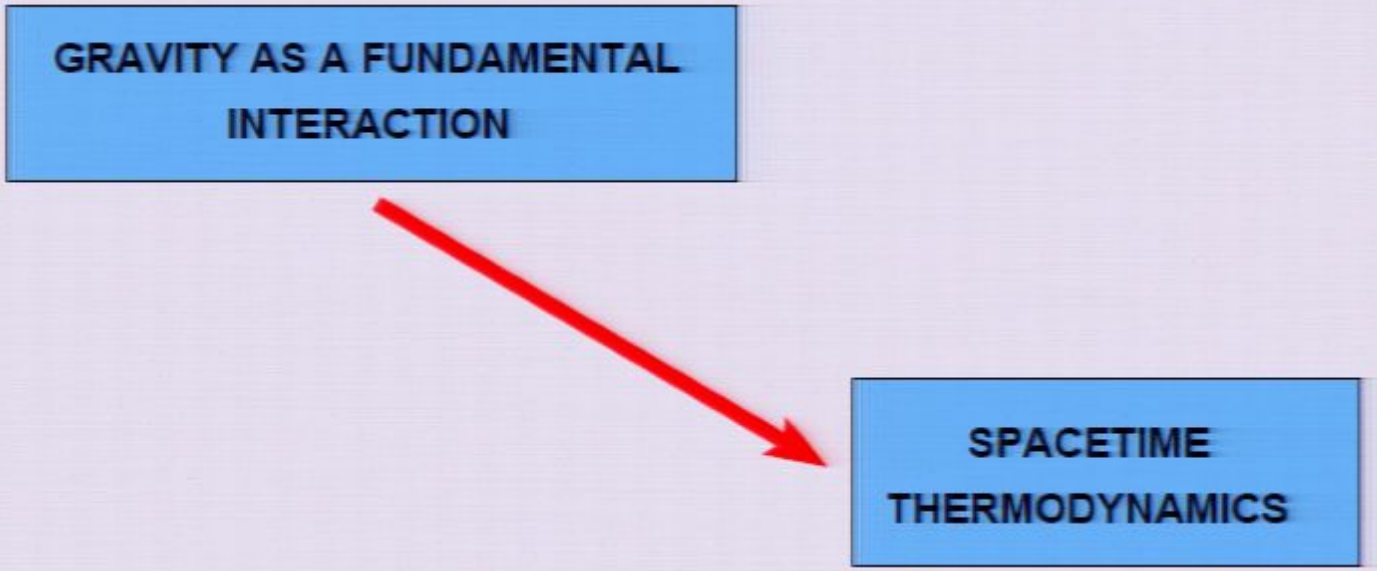

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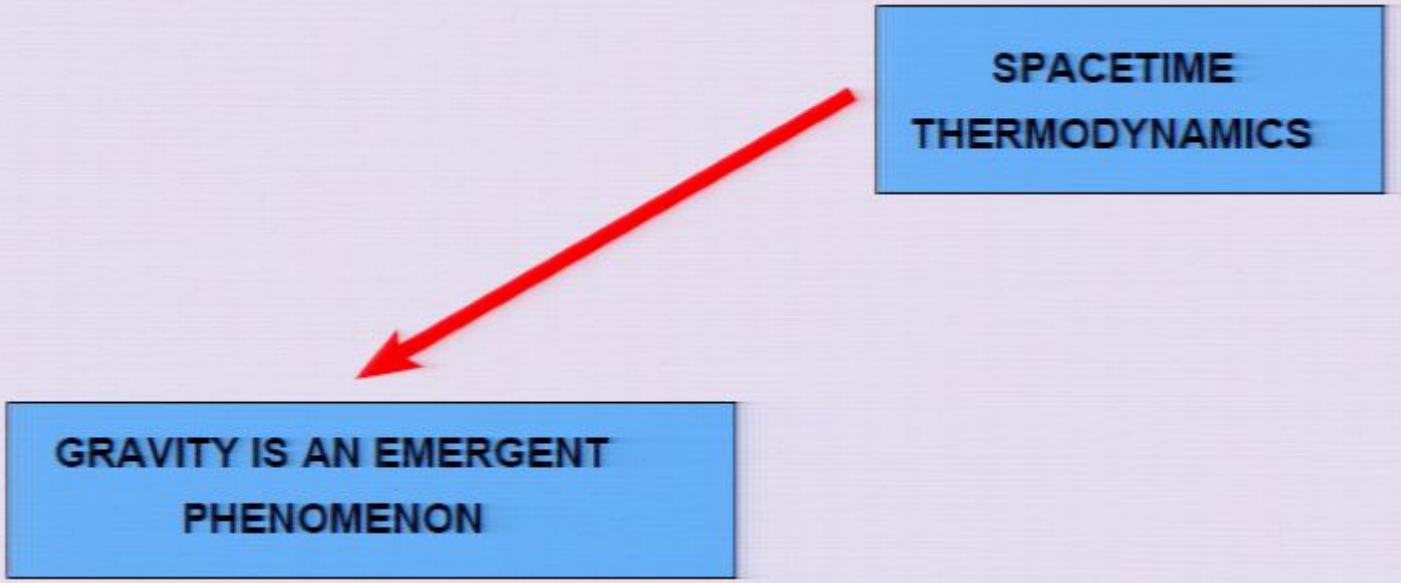

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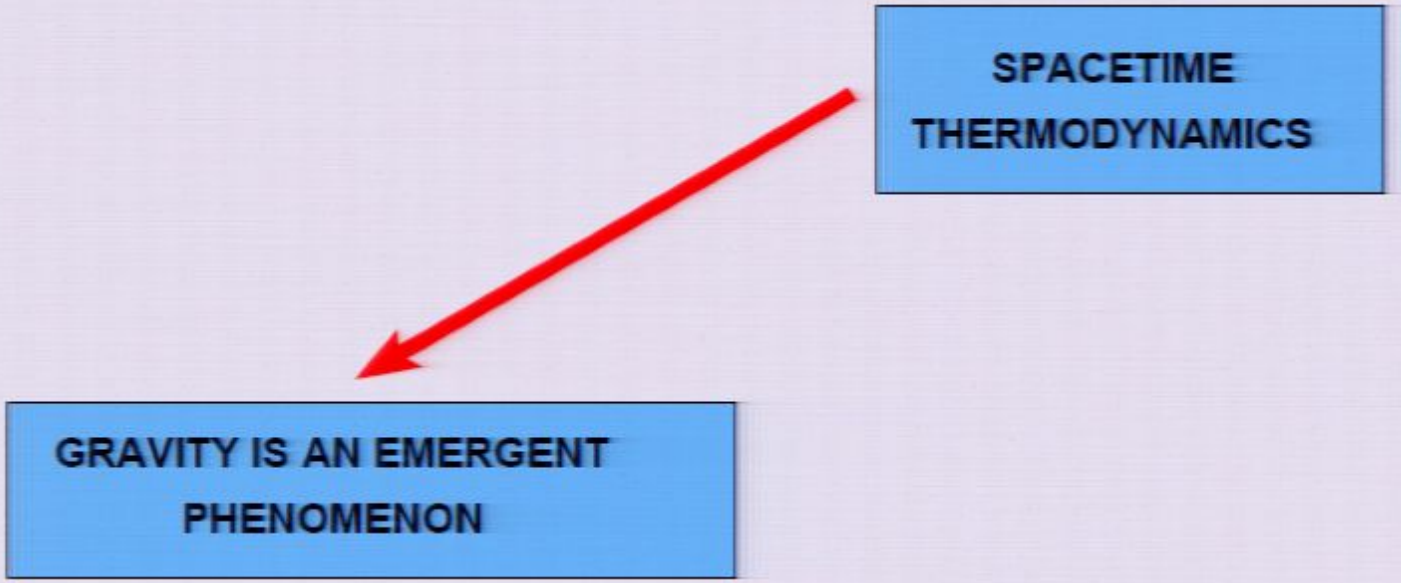

GRAVITY IS THE THERMODYNAMIC LIMIT OF THE STATISTICAL MECHANICS OF 'ATOMS OF SPACETIME'

PLAN

- THE CONVENTIONAL APPROACH TO GRAVITY AND HORIZON THERMODYNAMICS
- 'INTERNAL EVIDENCE' FOR AN ALTERNATIVE PERSPECTIVE
- THE CONCEPT OF EMERGENT PHENOMENON
- DYNAMICS FROM ENTROPY DENSITY OF SPACETIME
- CONCLUSIONS, OPEN QUESTIONS ....

T.P, *A Dialogue on the Nature of Gravity*, [arXiv:0910.0839]

T.P, *Thermodynamical Aspects of gravity: New Insights*, [arXiv:0911.5004], Rep.Prog.Physics, **73**, 046901 (2010),

T.P, *Surface Density of Spacetime Degrees of Freedom from Equipartition Law in theories of Gravity*, [arXiv:1003.5665].

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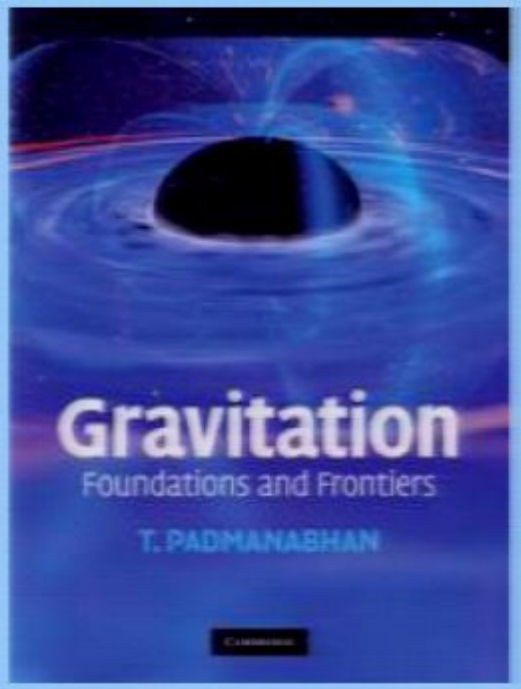

TEXT BOOK DESCRIPTION OF GRAVITY

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- General Covariance
- Action functional (?)

$$A = \int d^D x \sqrt{-g} \left[L(R^{ab}_{cd}, g^{ab}) + L_{matt}(g^{ab}, q_A) \right]$$

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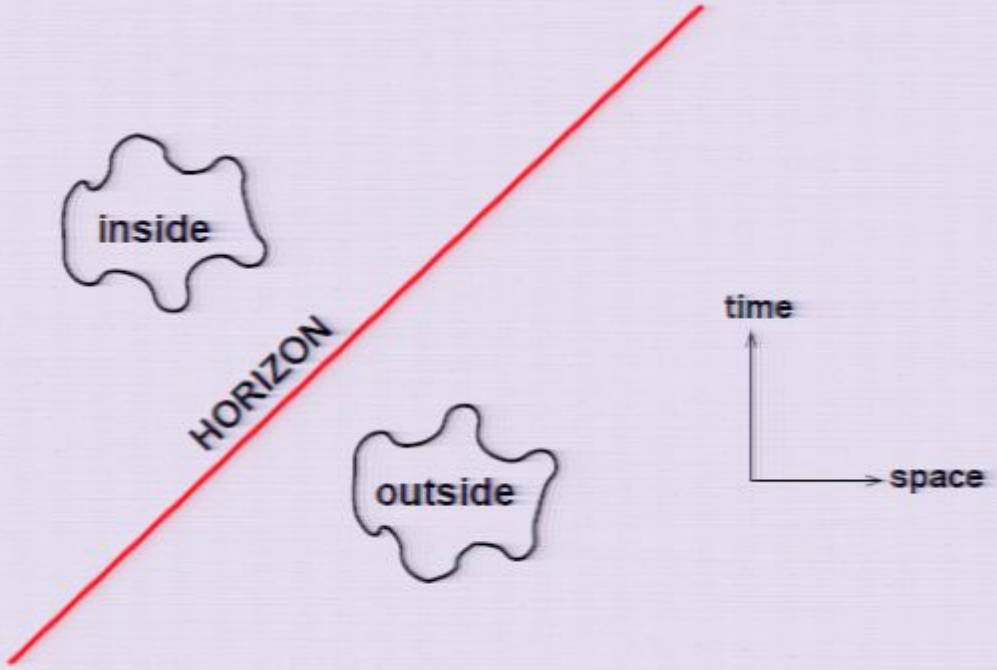
- Horizons arise inevitably in the solutions to these field equations.

ENTROPY OF HORIZONS



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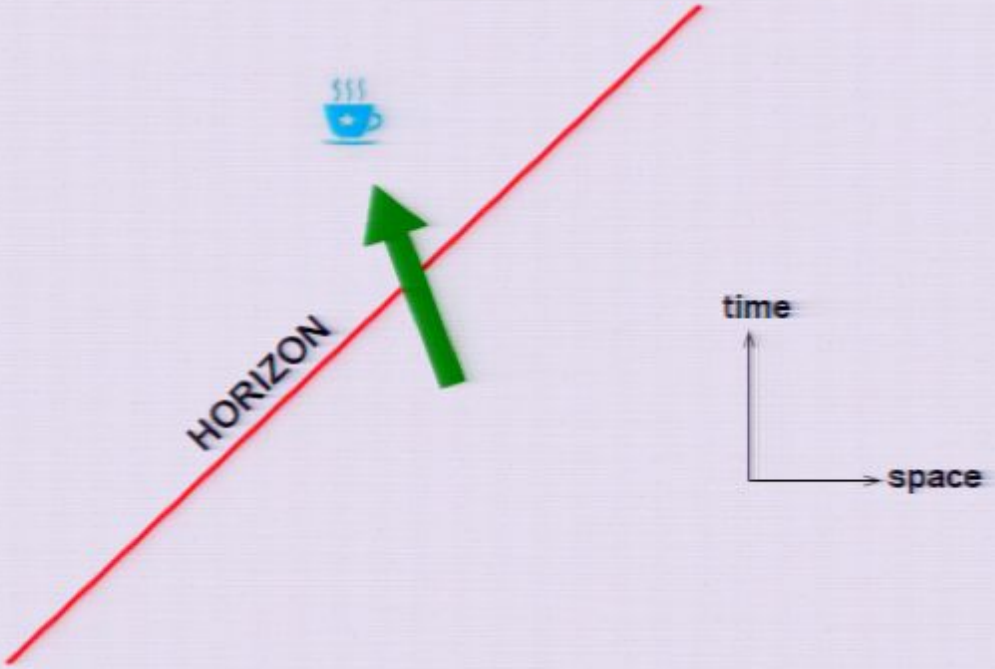

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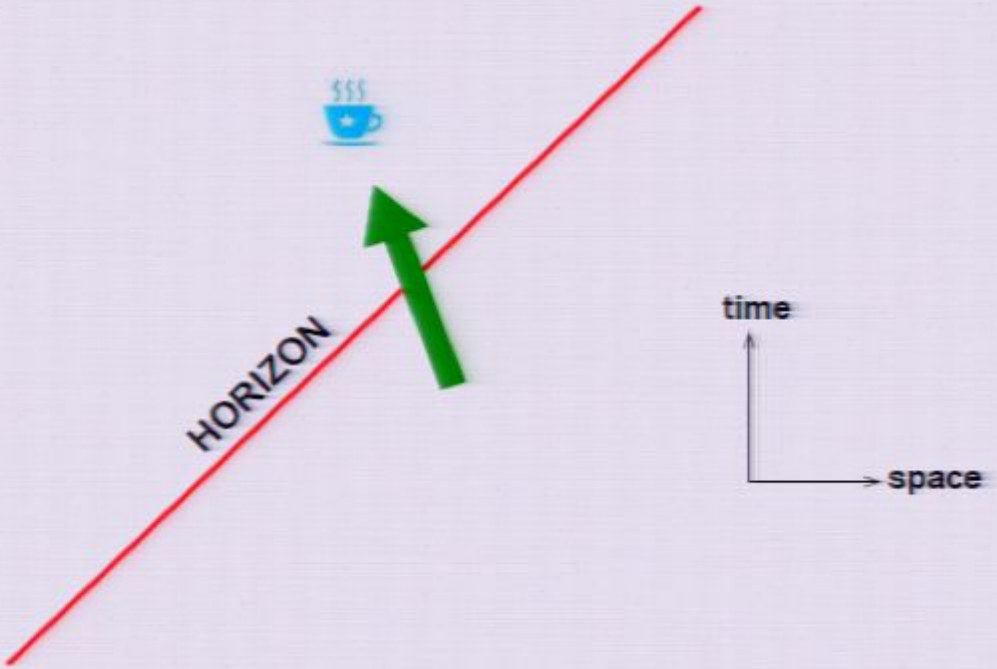

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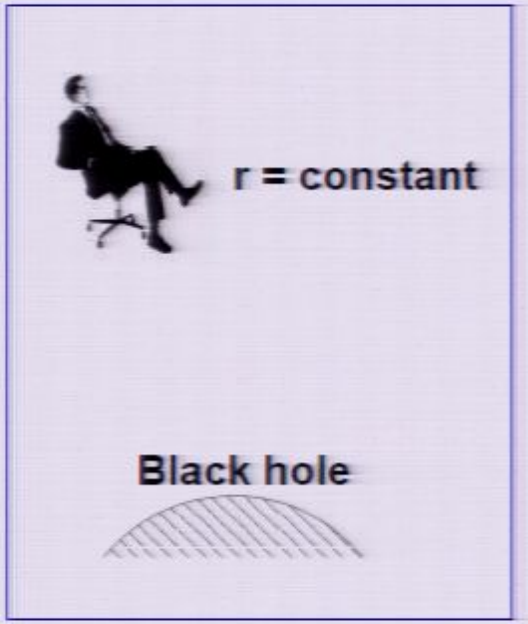

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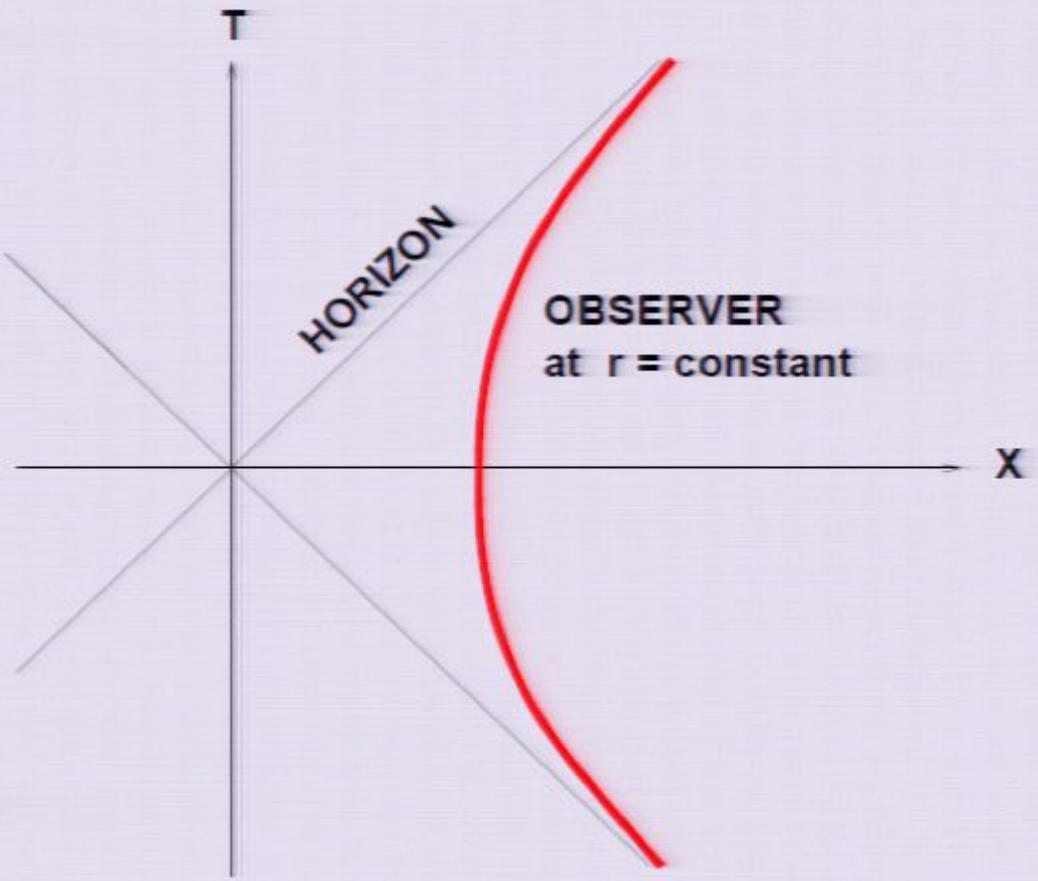

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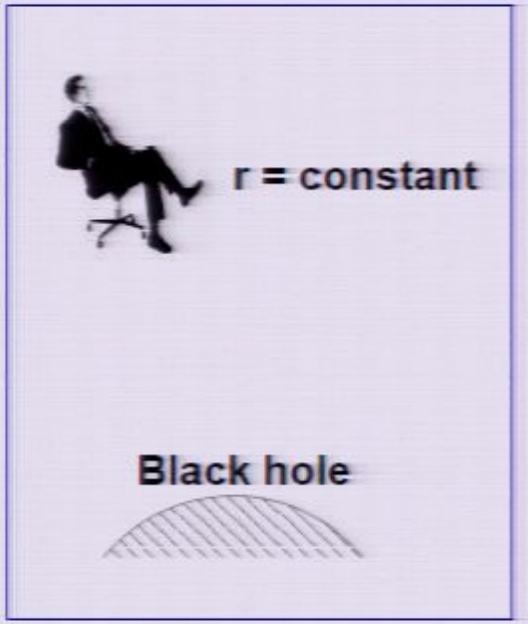

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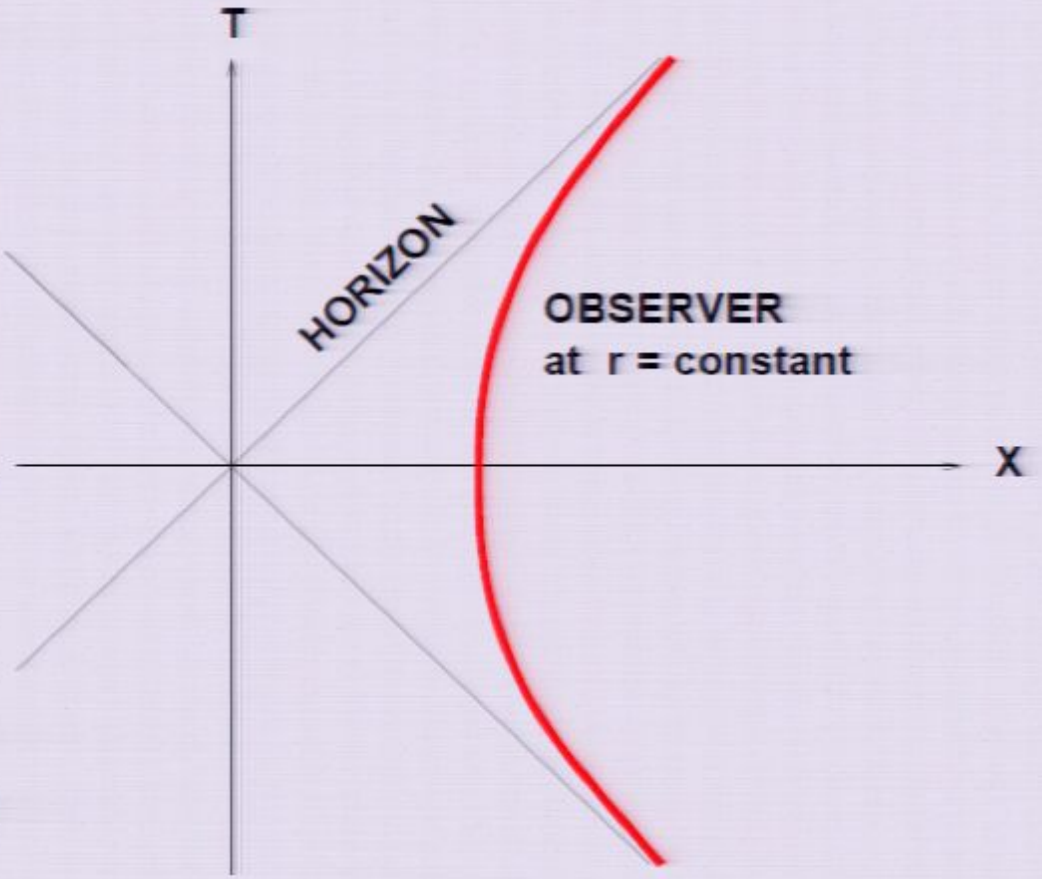

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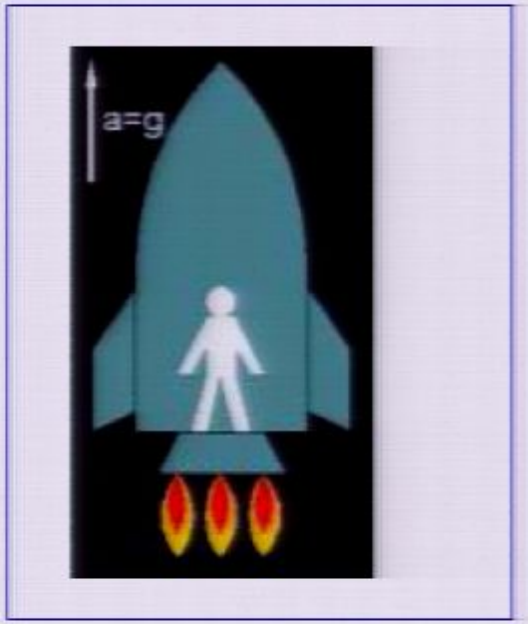

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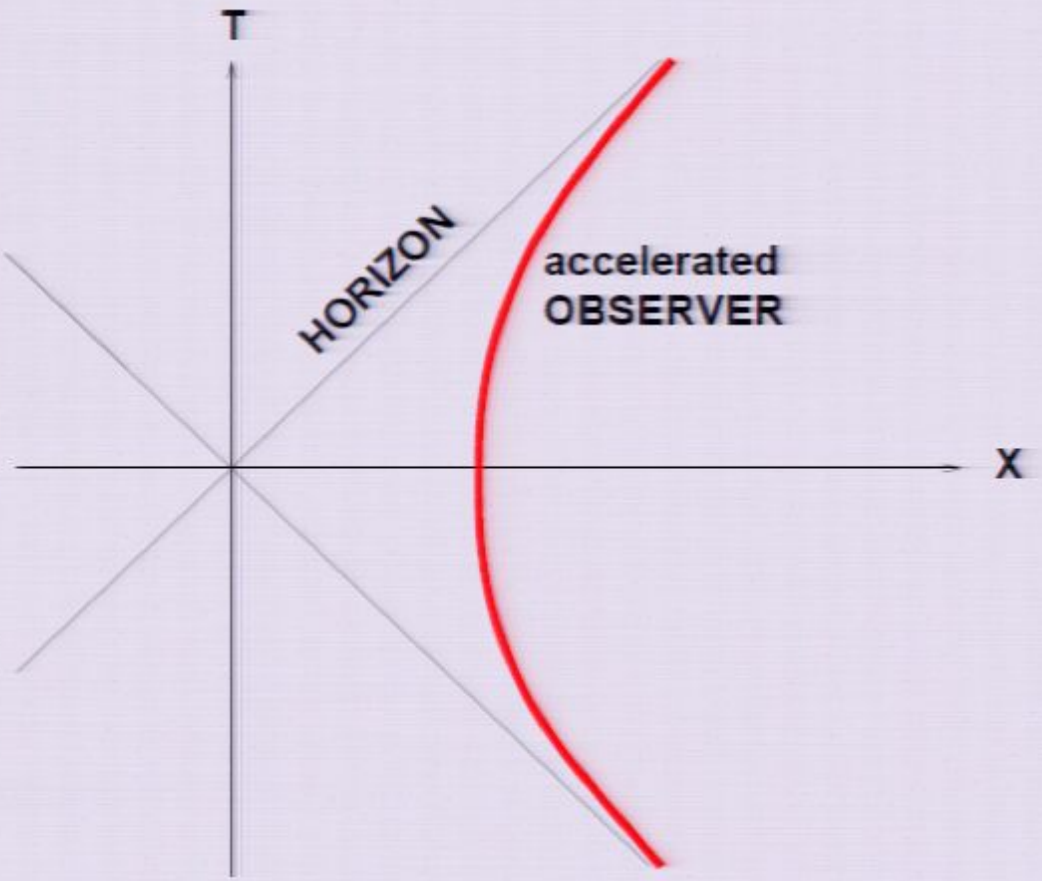

Temperature
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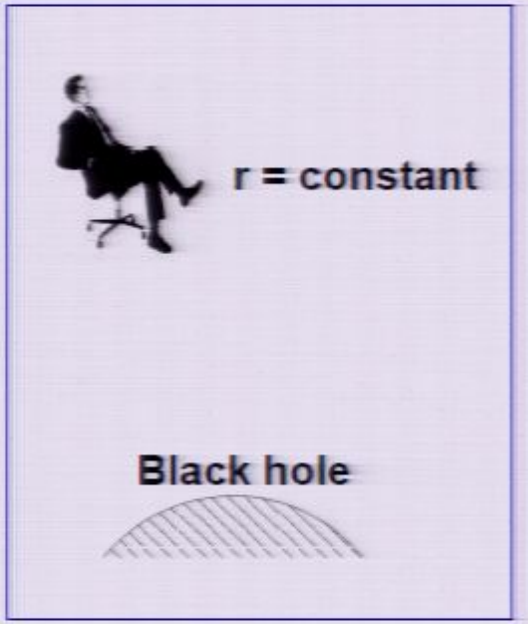

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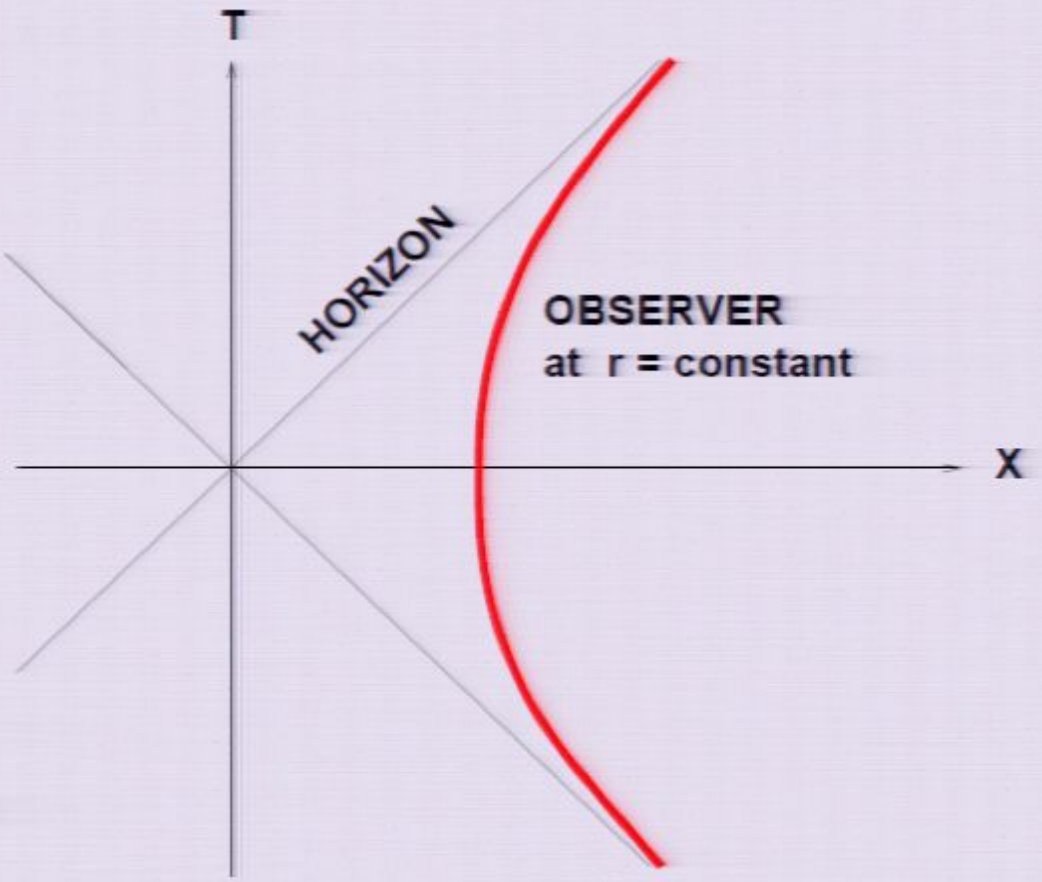

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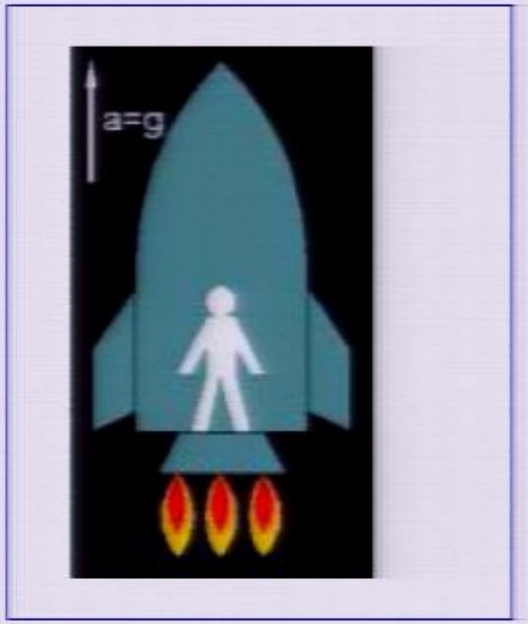

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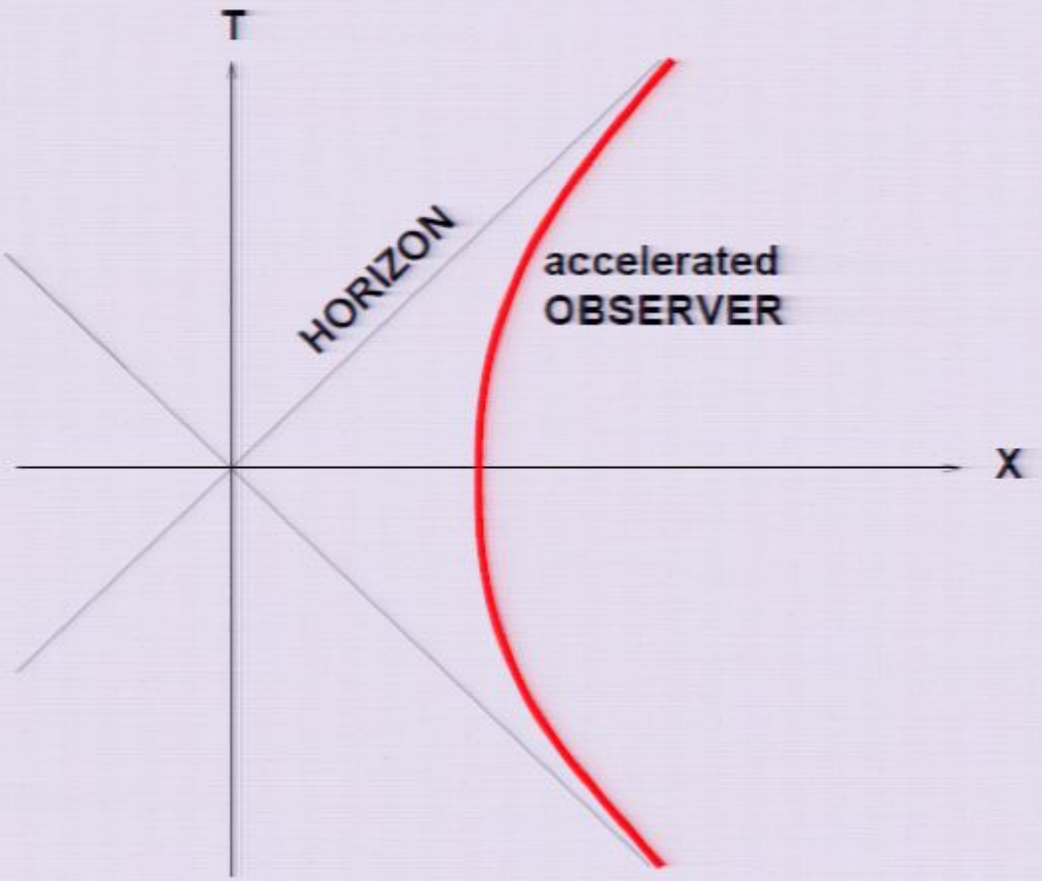

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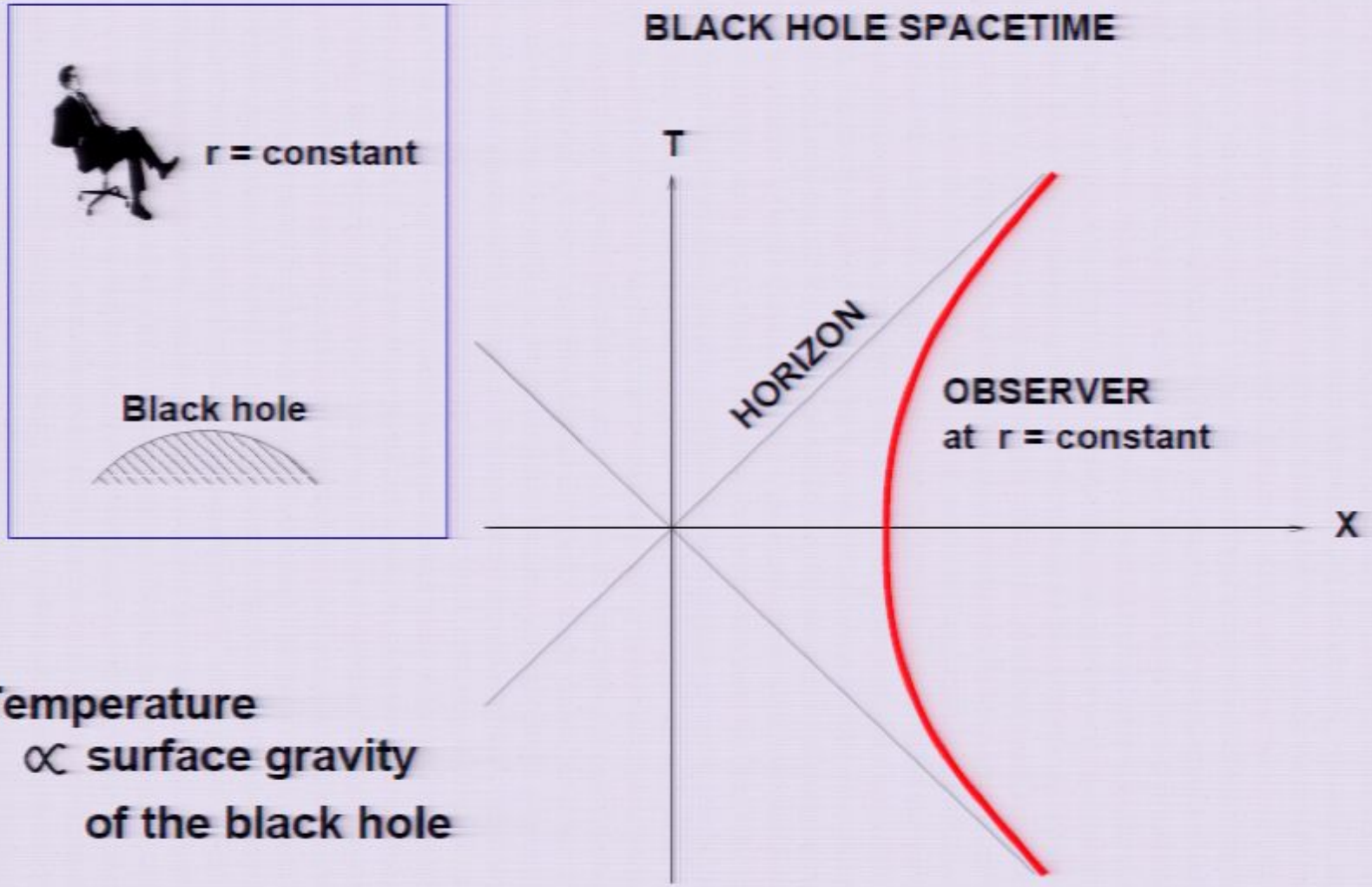

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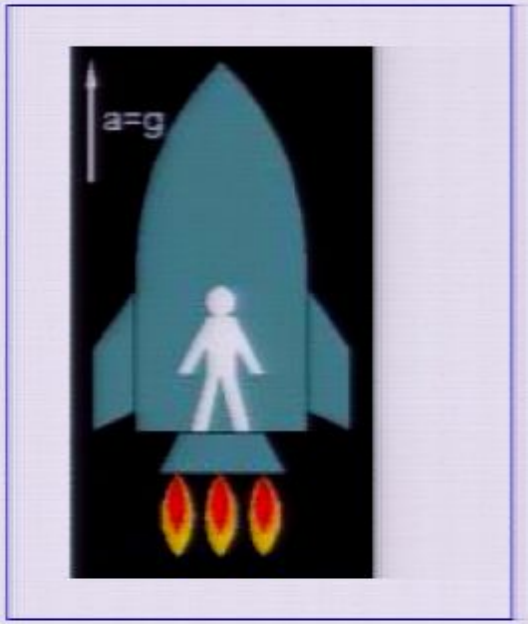

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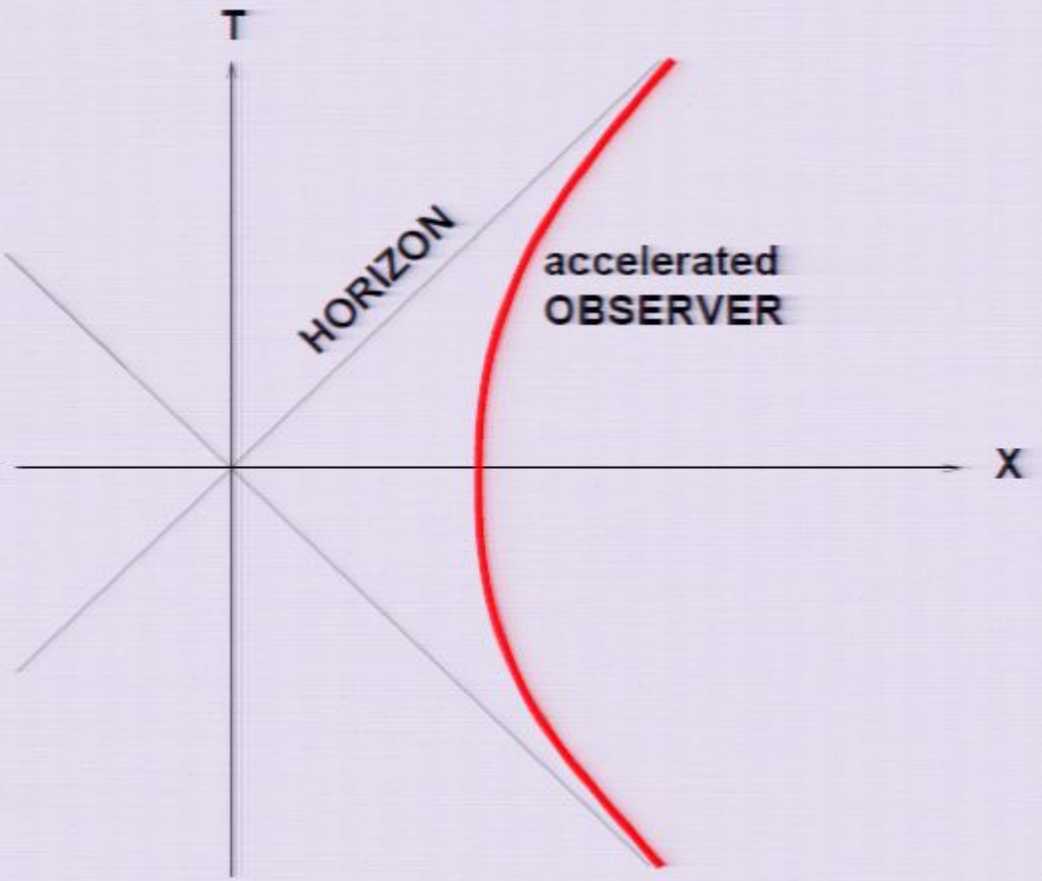

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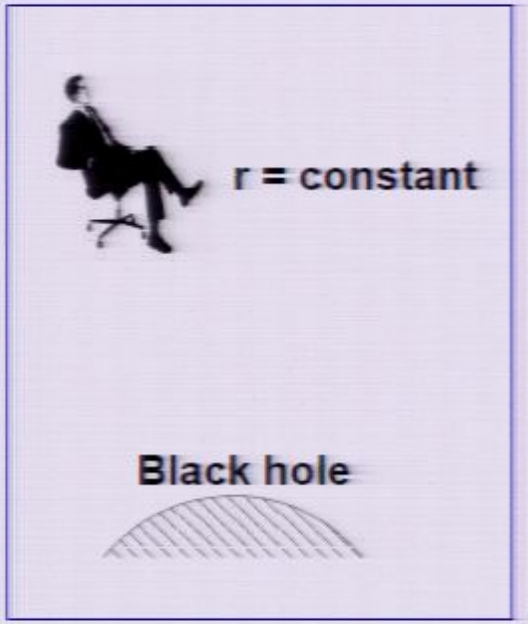

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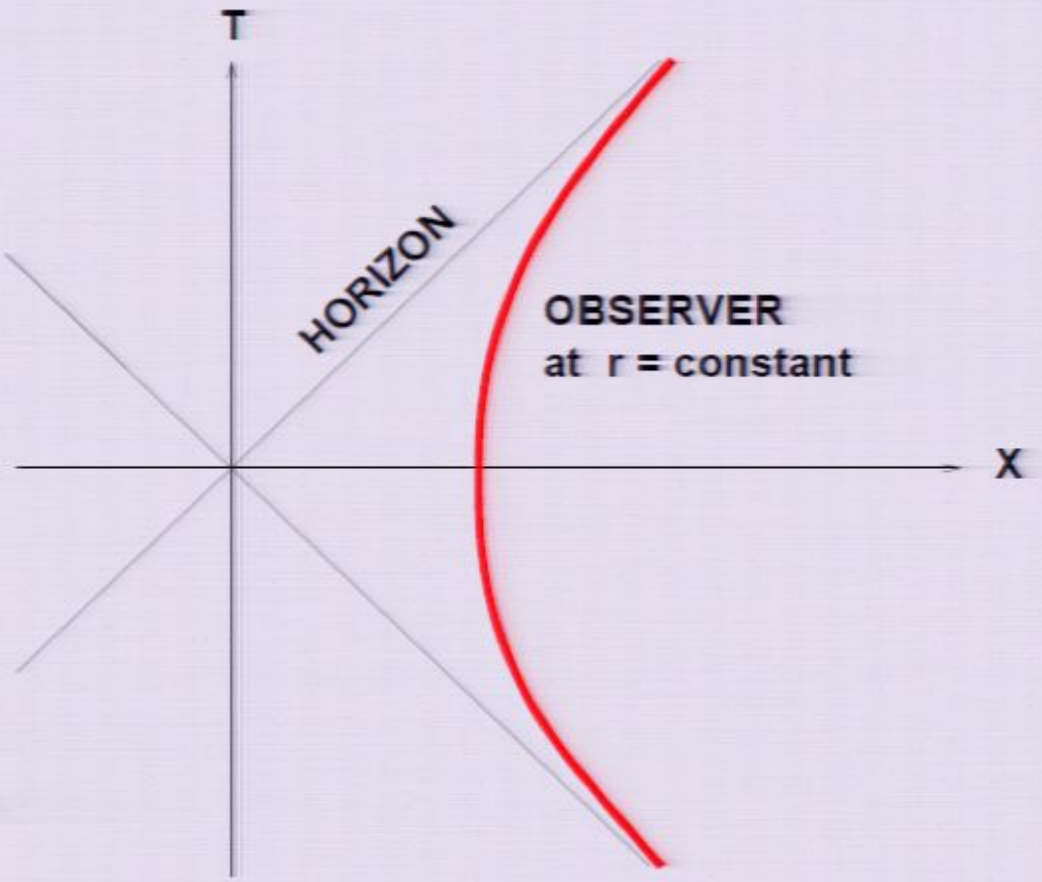

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- *The connection between horizons and temperature is quite generic.*

OBSERVERS WHO PERCEIVE A HORIZON ATTRIBUTE TO IT A TEMPERATURE

$$k_B T = \frac{\hbar}{c}\left(\frac{g}{2\pi}\right)$$

WHY ARE HORIZONS HOT ?

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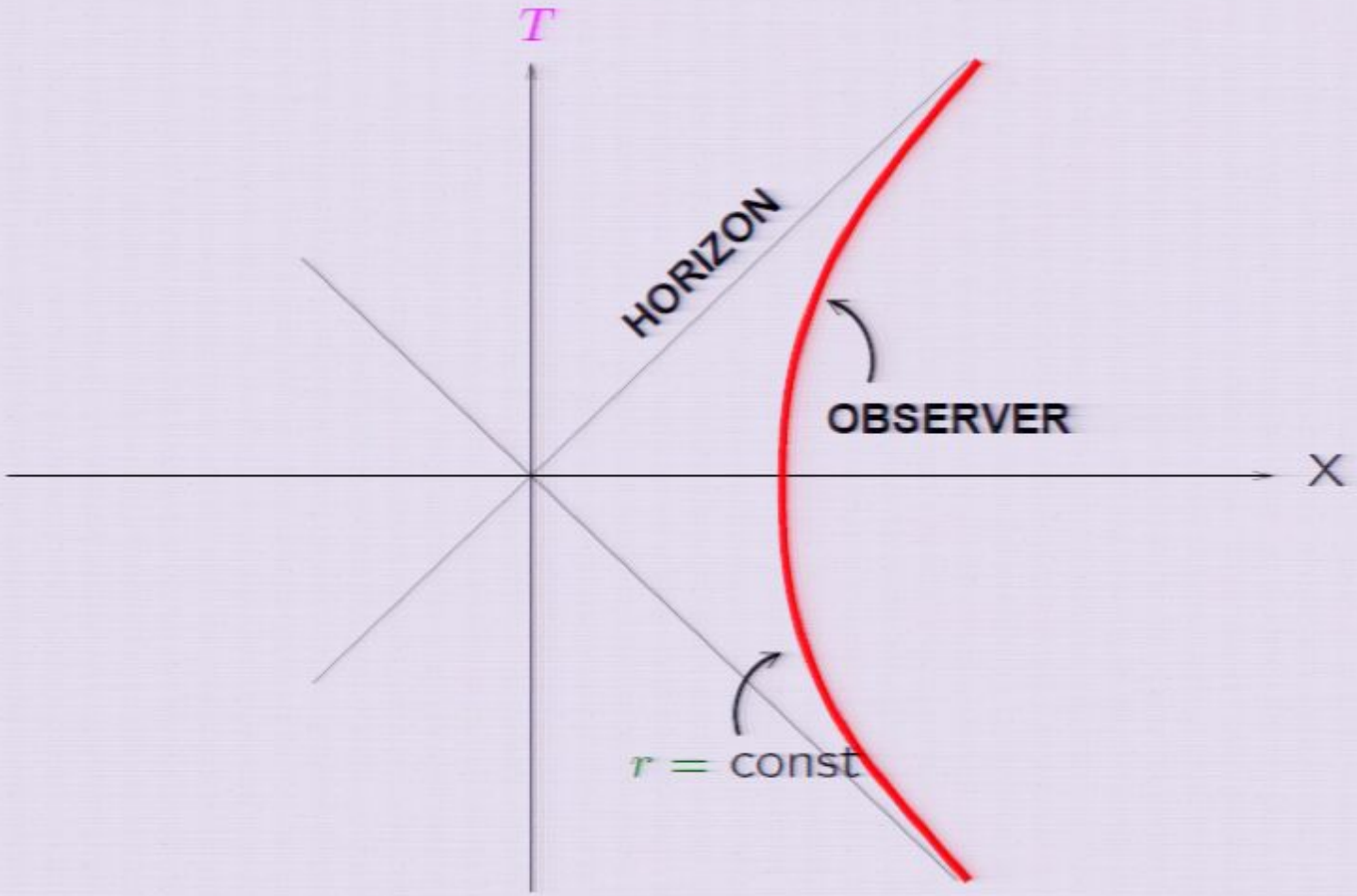
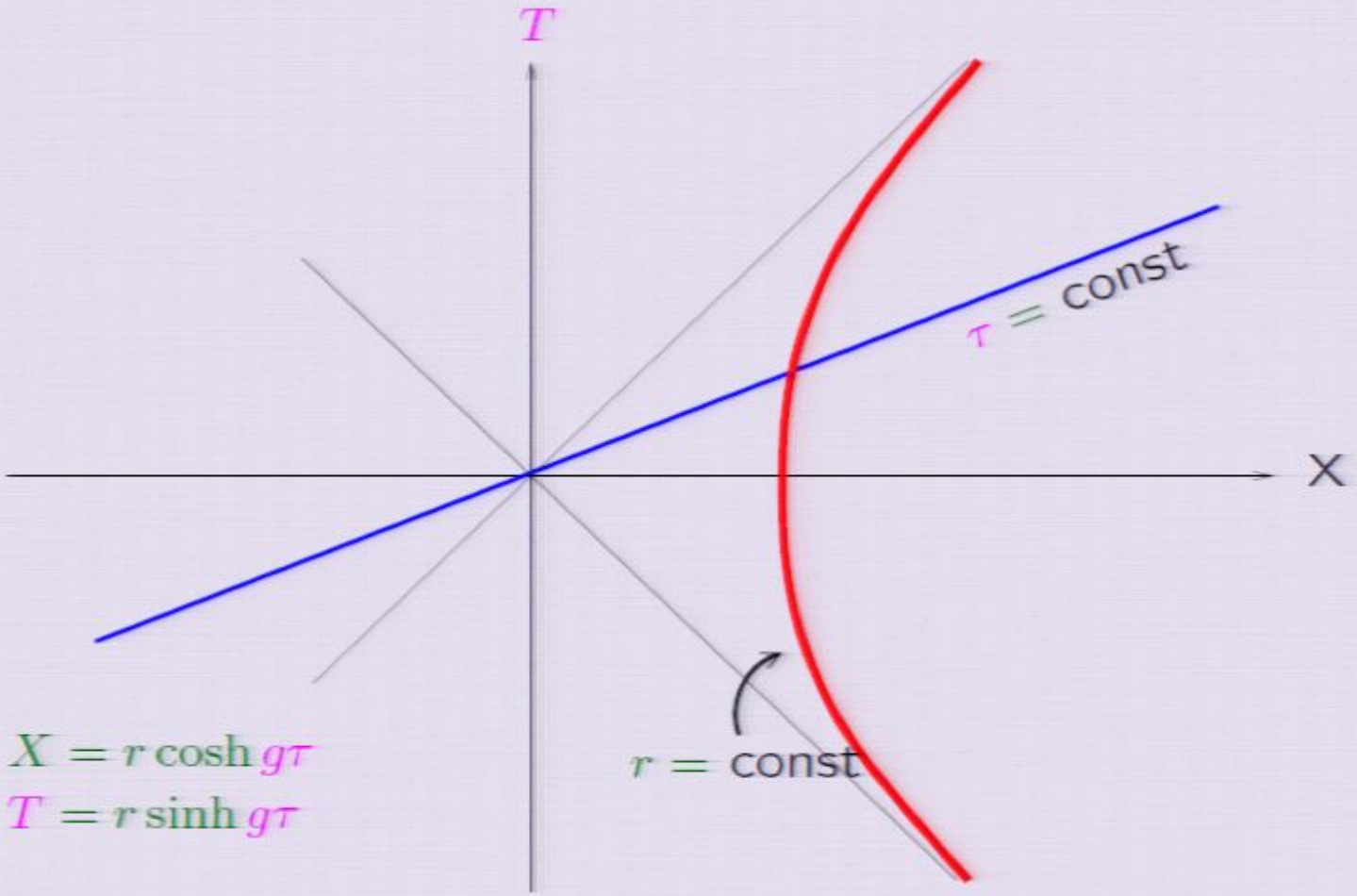
SPACETIMES WITH HORIZONS EXHIBIT PERIODICITY IN IMAGINARY TIME $\Longrightarrow$ TEMPERATURE


T
HORIZON
OBSERVER
X
r = const

$$ds^2 = -dT^2 + dX^2 = -g^2 r^2 d\tau^2 + dr^2$$



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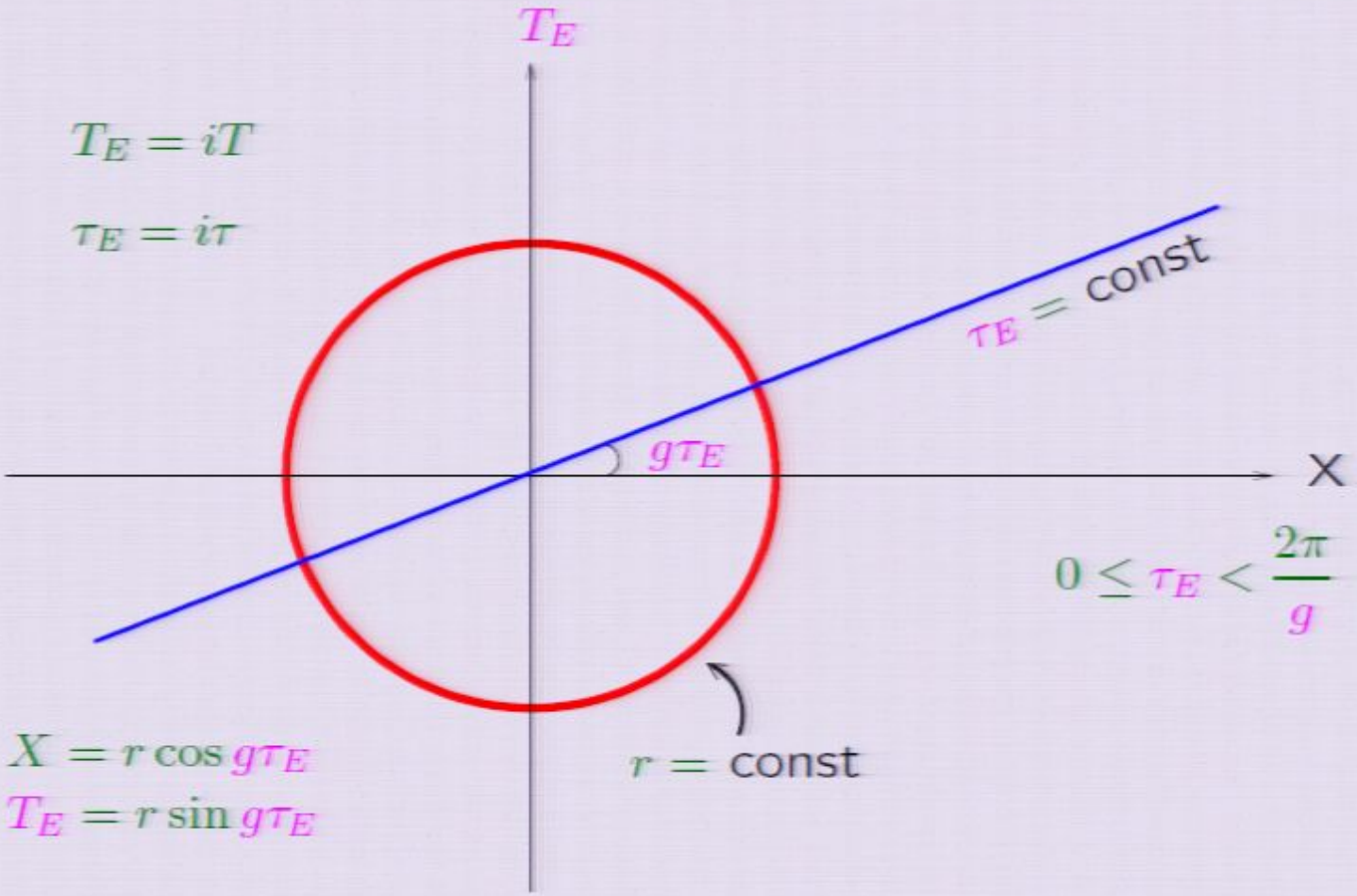

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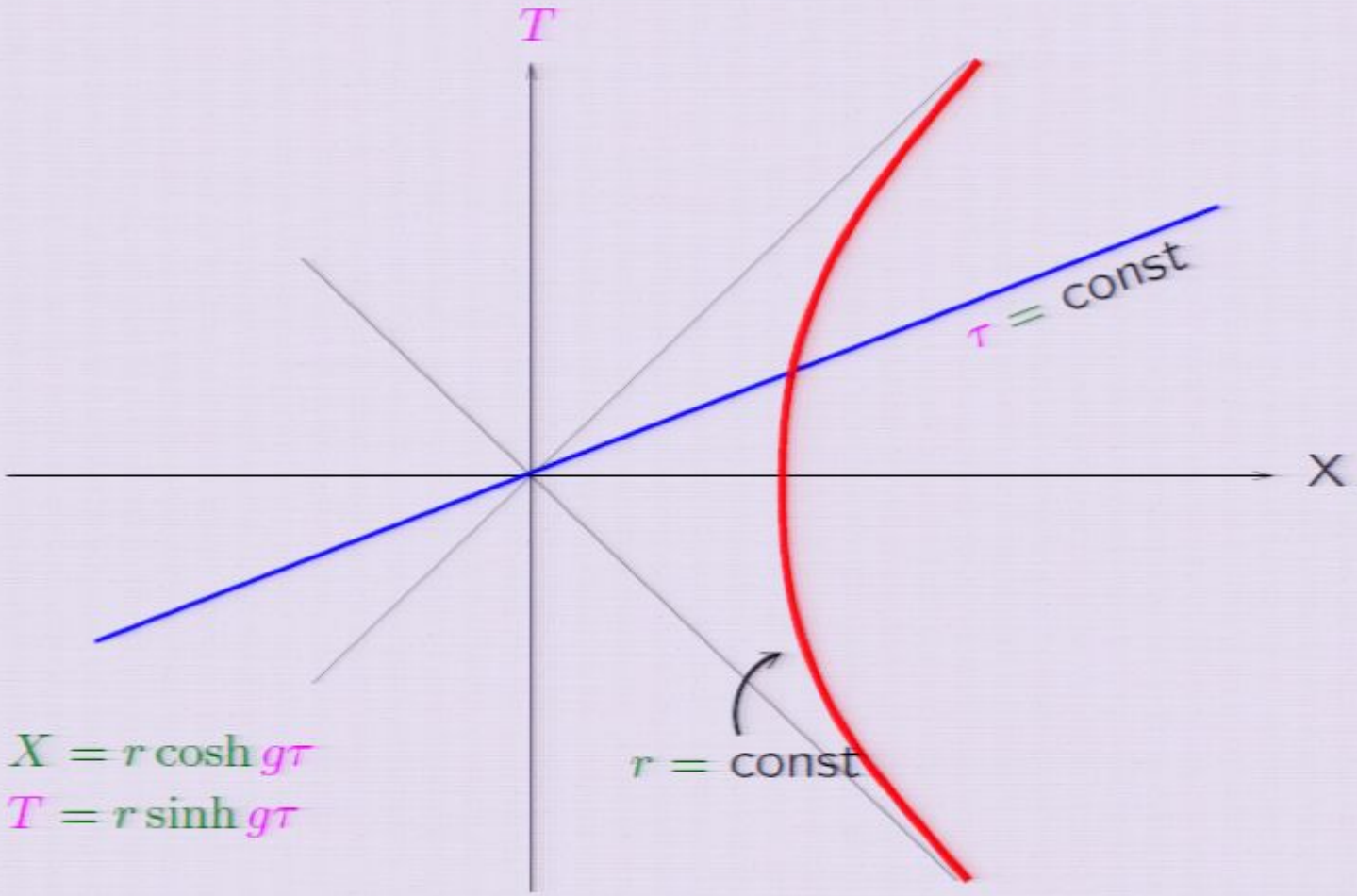

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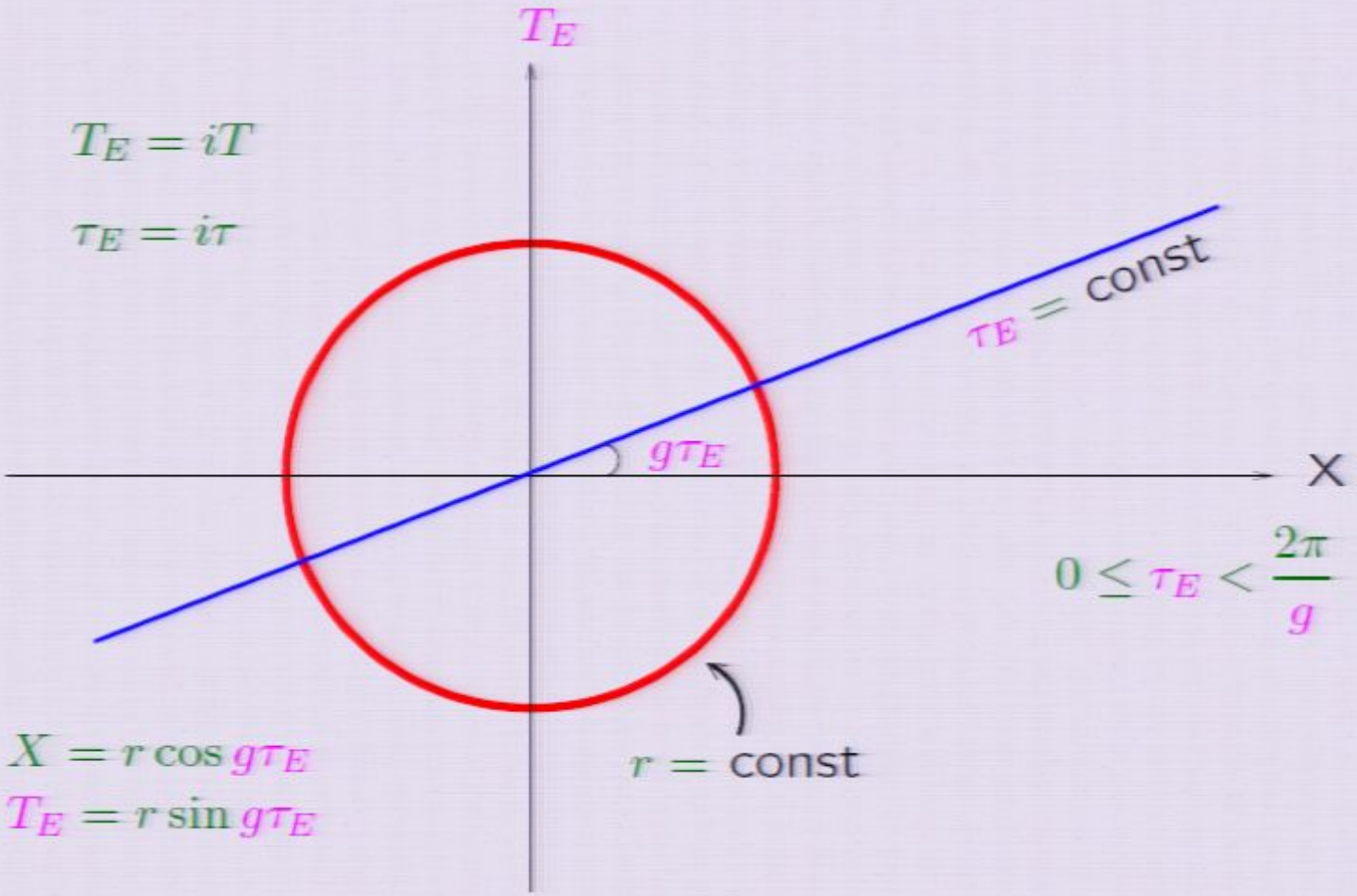

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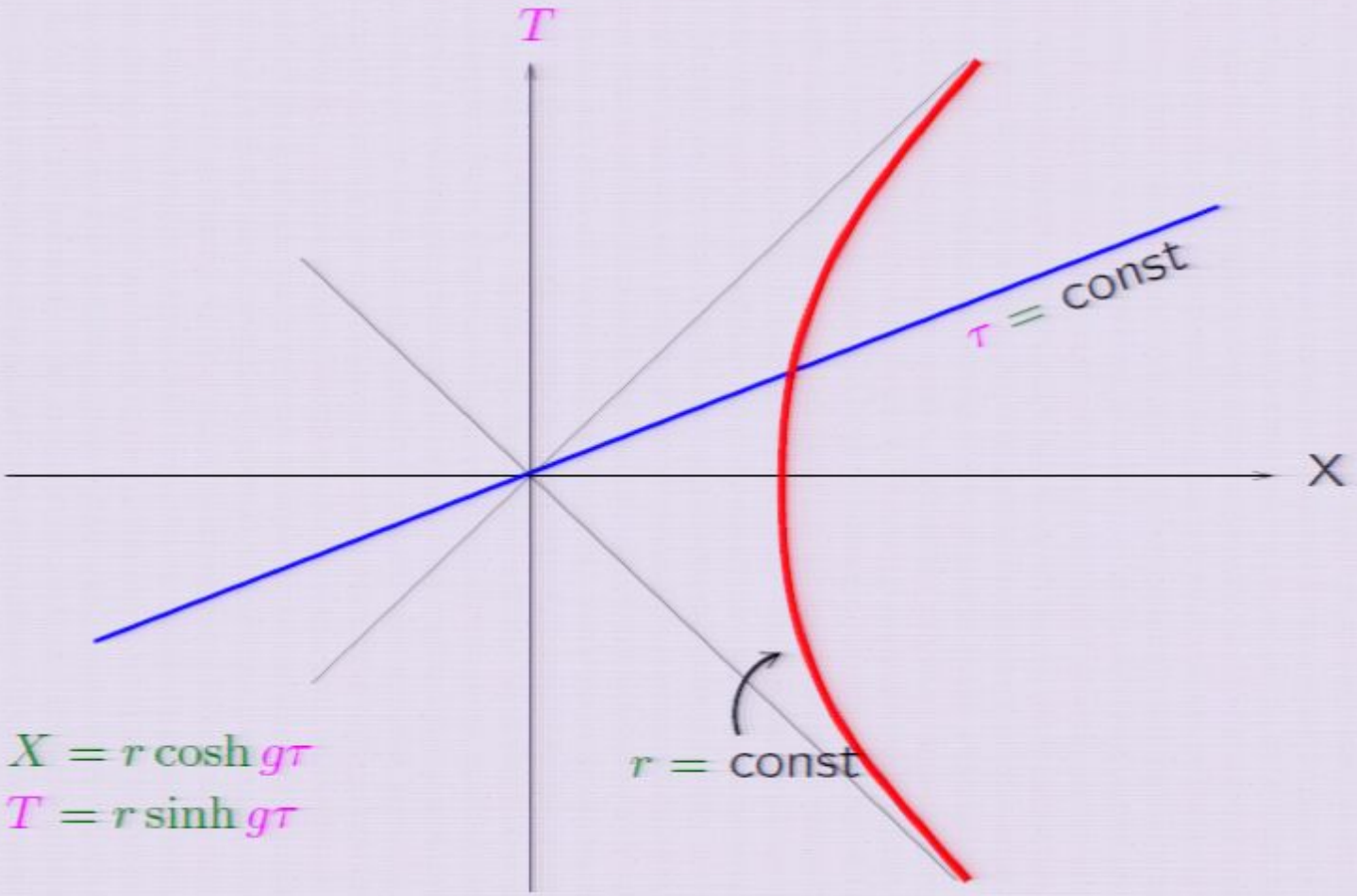

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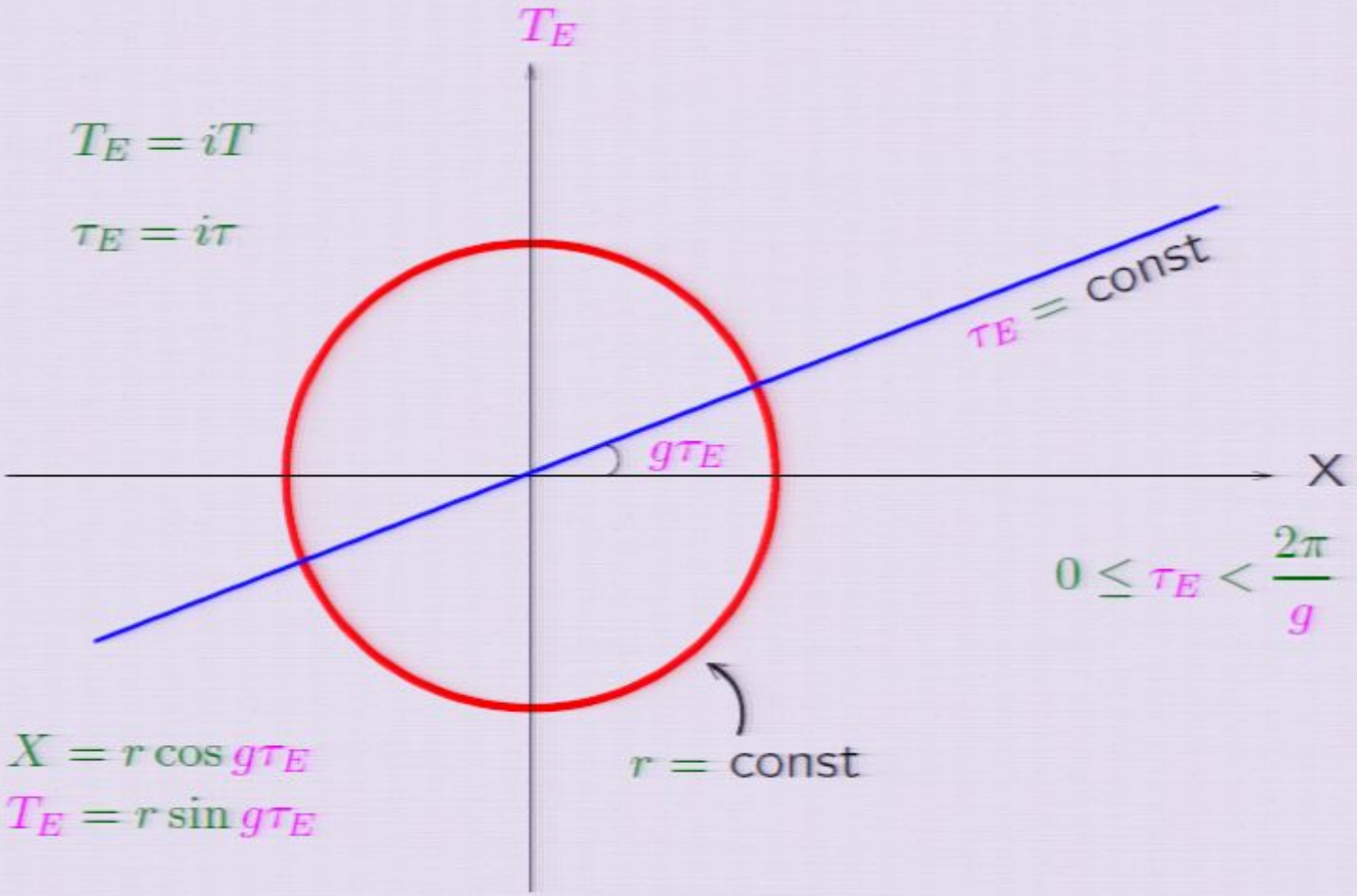

MOTIVATING THE ALTERNATIVE PERSPECTIVE

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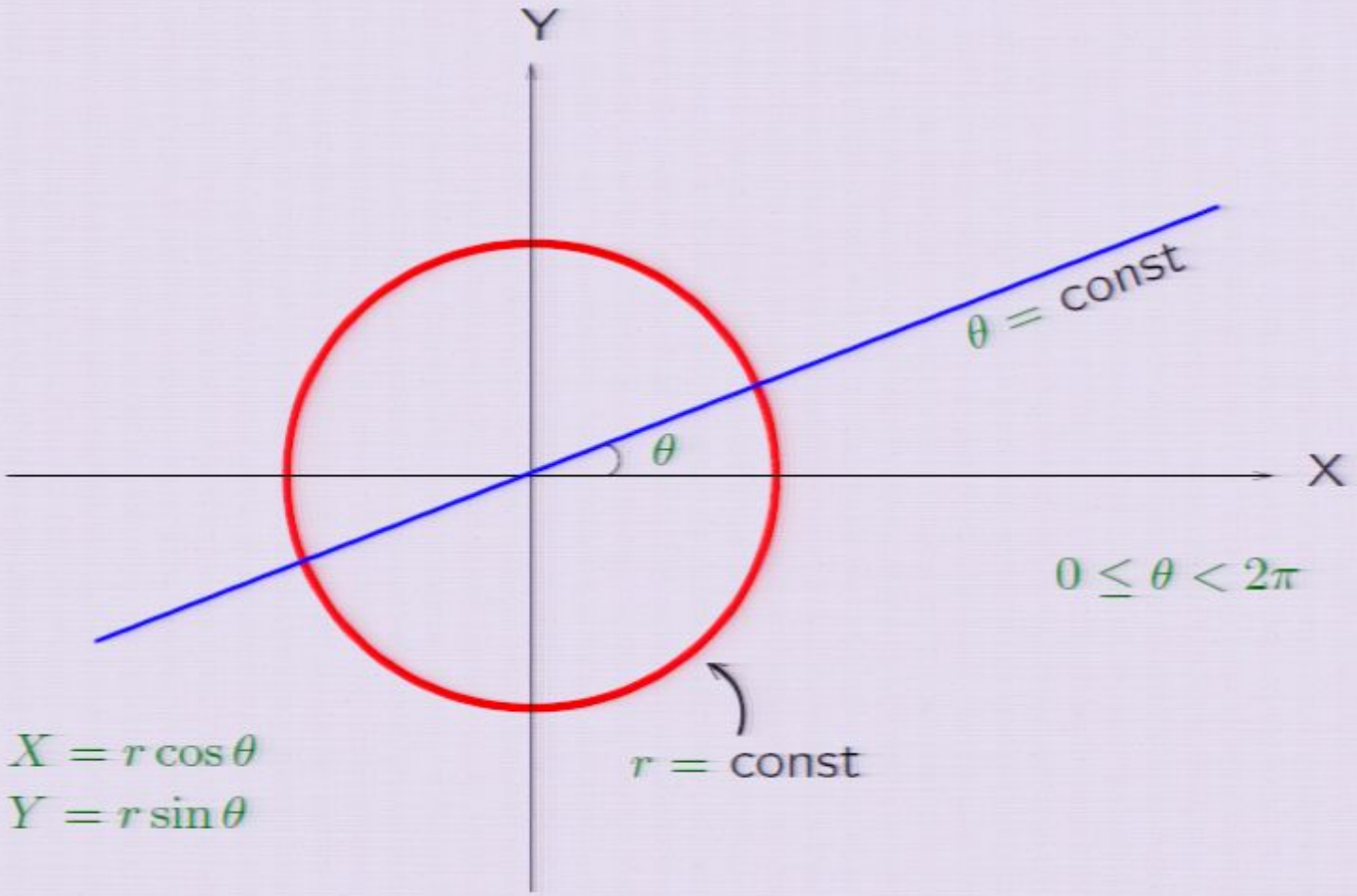

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Example: $m_{inertial} = m_{grav}$ is 'internal evidence' for geometrical nature of gravity.

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$$\frac{\hbar}{c}\left(\frac{g}{2\pi}\right)\ \frac{c^3}{G\hbar}d\left(\frac{1}{4}4\pi a^2\right) - \frac{1}{2}\frac{c^4 da}{G} = \underbrace{P d\left(\frac{4\pi}{3}a^3\right)}_{P\,dV}$$

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$$\underbrace{\frac{\hbar}{c}\left(\frac{g}{2\pi}\right)}_{k_B T}\ \underbrace{\frac{c^3}{G\hbar}d\left(\frac{1}{4}4\pi a^2\right)}_{k_B^{-1}dS}\ \underbrace{-\frac{1}{2}\frac{c^4 da}{G}}_{-dE} = \underbrace{P d\left(\frac{4\pi}{3}a^3\right)}_{P\,dV}$$

- Read off (with $L_P^2 \equiv G\hbar/c^3$): [TP, 2002]

$$S = \frac{1}{4L_P^2}(4\pi a^2) = \frac{1}{4}\frac{A_H}{L_P^2}; \quad E = \frac{c^4}{2G}a = \frac{c^4}{G}\left(\frac{A_H}{16\pi}\right)^{1/2}$$

HOLDS TRUE FOR A LARGE CLASS OF MODELS!

- Stationary axisymmetric horizons and evolving spherically symmetric horizons in Einstein gravity, [gr-qc/0701002]
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IN ALL THESE CASES FIELD EQUATIONS REDUCE TO $TdS = dE + PdV$ *ON THE HORIZON!*

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T.P, 2004; A. Mukhopadhyay, T.P, 2006

S.Kolekar, T.P, *Holography in Action*, [arXiv:1005.0619]

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- Action for gravity has exactly this structure! [TP, 02, 05]

$$A_{grav} = \int d^4x\ \sqrt{-g}\, R = \int d^4x\ \sqrt{-g}\ [L_{\rm bulk} + L_{\rm sur}]$$

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- You find that the part you threw away, the $A_{\rm sur}$, evaluated on any horizon gives its entropy !

- In a Riemann normal coordinates around any event $\mathcal{P}$, the action reduces to a pure surface term! One can get the field equations from $A_{total} = A_{sur} + A_{matter}$ using the horizon displacements. [TP, 2005]

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- Field equations can be interpreted as: [TP, 08,09]

$$\left\{ \begin{array}{c} \text{Loss of matter entropy} \\ \text{due to flow of energy} \\ \text{across the hot horizon} \end{array} \right\} = \left\{ \begin{array}{c} \text{Gain of gravitational entropy} \\ \text{for infinitesimal virtual} \\ \text{displacements of the horizon} \end{array} \right\}$$

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- So after you have "solved" the cosmological constant problem, if someone introduces $L_{matter} \to L_{matter} - \rho$, you are in trouble again!
- The only way out is to have a formalism for gravity which is invariant under $T_{ab} \to T_{ab} + \rho g_{ab}$.

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GRAVITY AS AN EMERGENT PHENOMENON

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SOLIDS	SPACETIME
Mechanics; Elasticity ($\rho, \mathbf{v}$ ...)	Einstein's Theory (g_{ab} ...)
Statistical Mechanics	Statistical mechanics
of atoms/molecules	of "atoms of spacetime"

EQUIPARTITION OF MICROSCOPIC DEGREES OF FREEDOM

TP (2004), *Class.Quan.Grav.*, **21**, 4485. [gr-qc/0308070]; T.P. arXiv: 0912.3165

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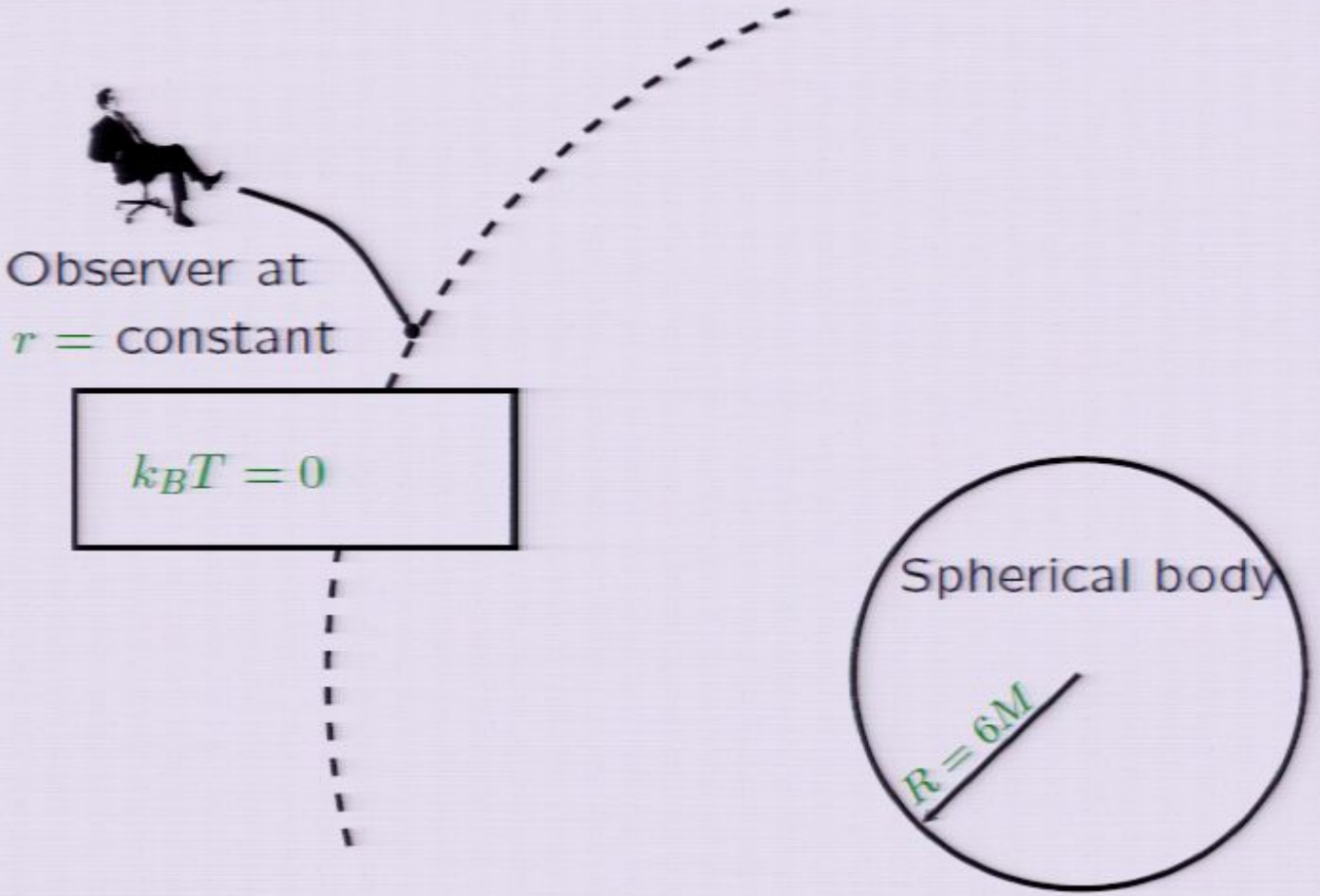

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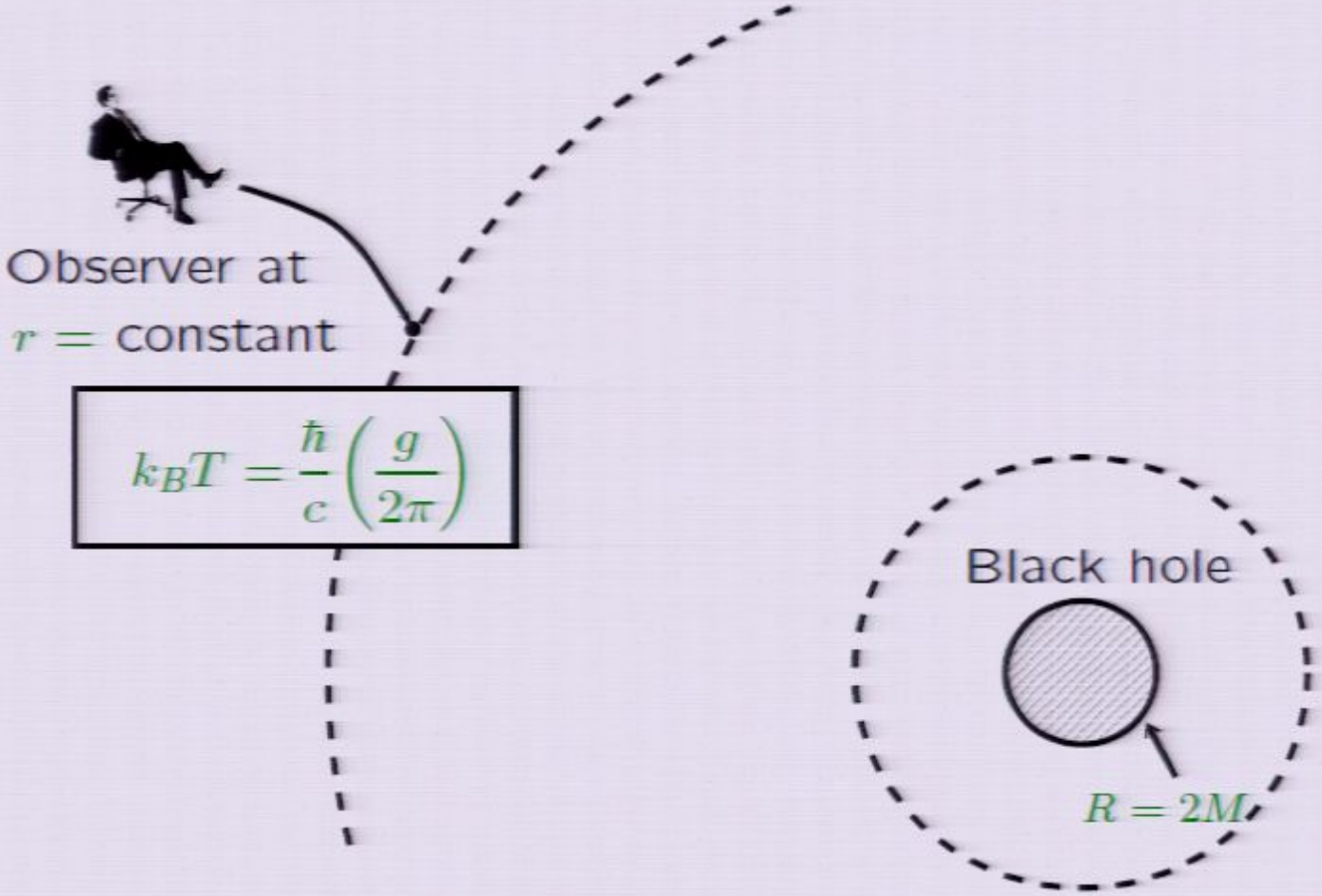
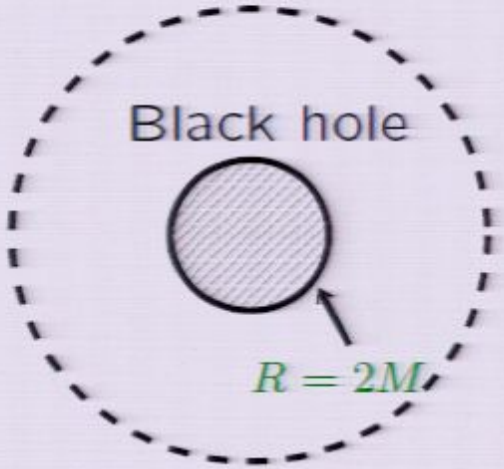


HEATING UP A SPACETIME

Observer at
$r =$ constant

$$k_B T = \frac{\hbar}{c}\left(\frac{g}{2\pi}\right)$$

The whole spacetime is hot;
not just the horizon



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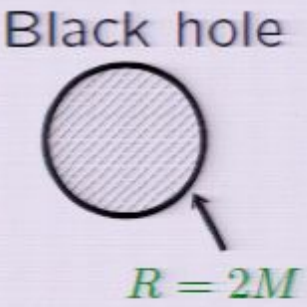

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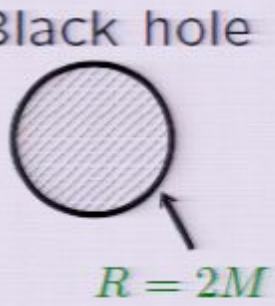

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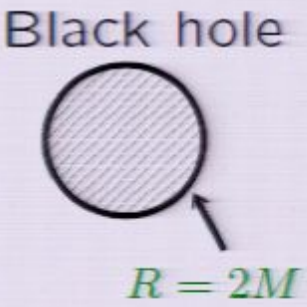

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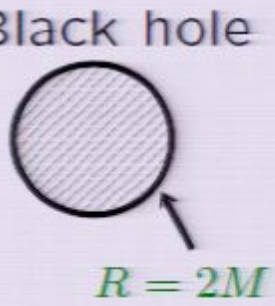

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Boltzmann Postulate: If you can heat it, it has substructure!

EQUIPARTITION OF "AREA BITS": $S = (1/2)\beta E$

TP (2004), *Class.Quan.Grav.*, **21**, 4485. [gr-qc/0308070]

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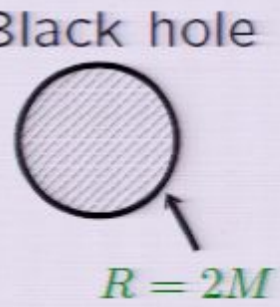

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- NEW FEATURE: Thermal behaviour of spacetime is strongly observer dependent.
- The nature of independent variables q_A and the form of entropy $S[q_A]$ depend on the class of observers and the model for gravity.
- We need a (phenomenological) entropy function for spacetime maximizing which for all class of observers should give the field equations.

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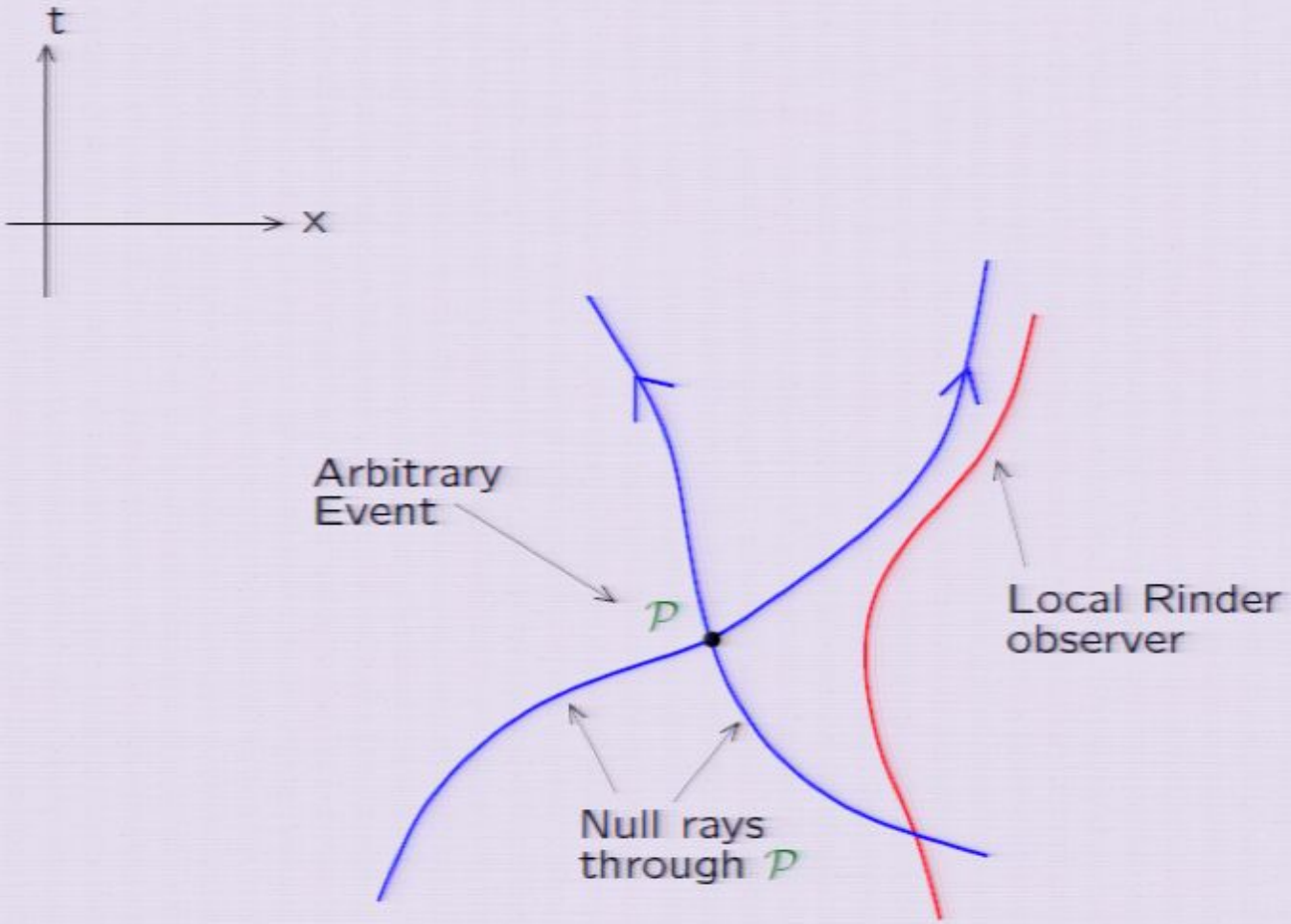
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x
Arbitrary
Event
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Local Rinder
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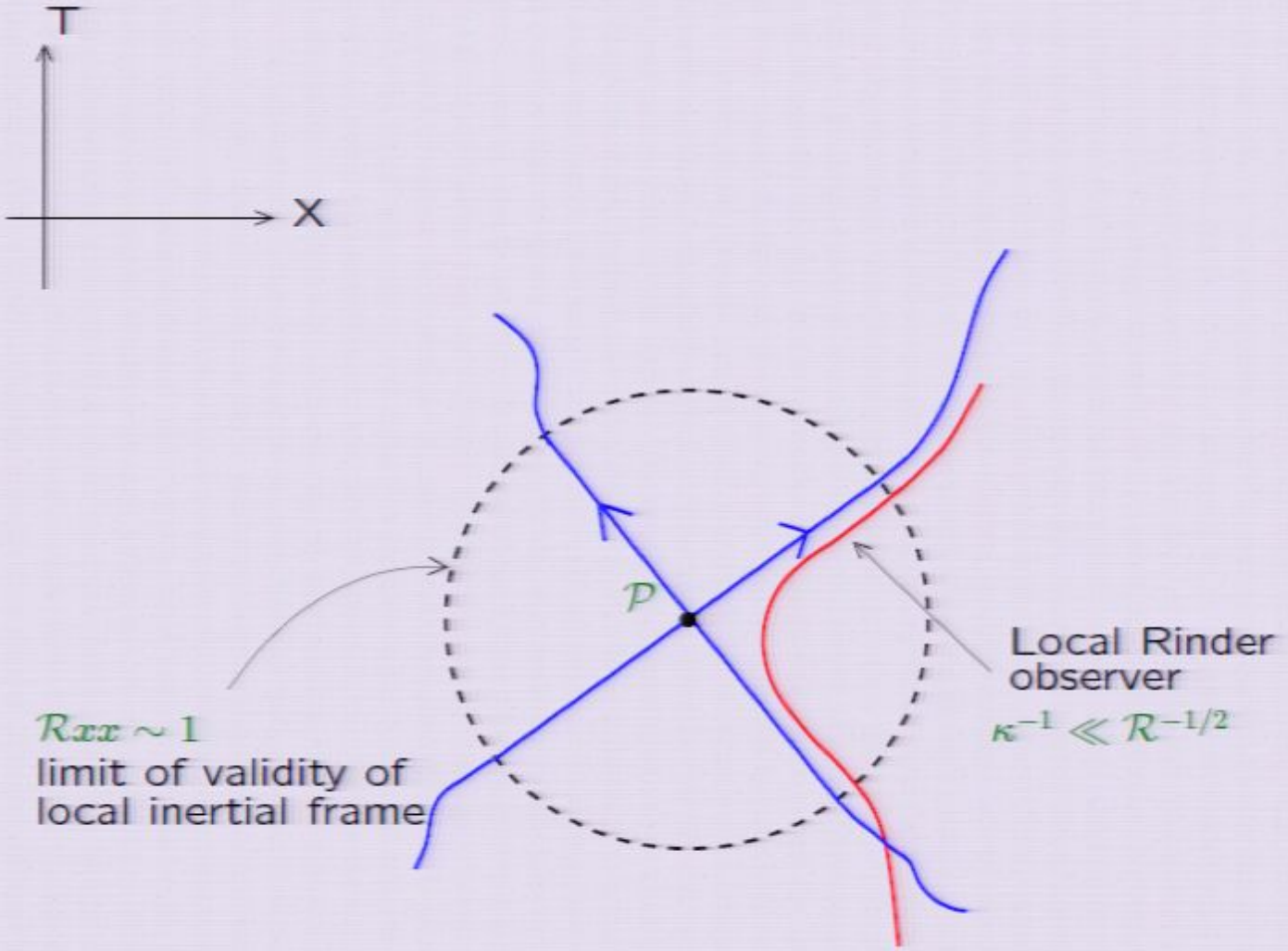
Null rays
through $\mathcal{P}$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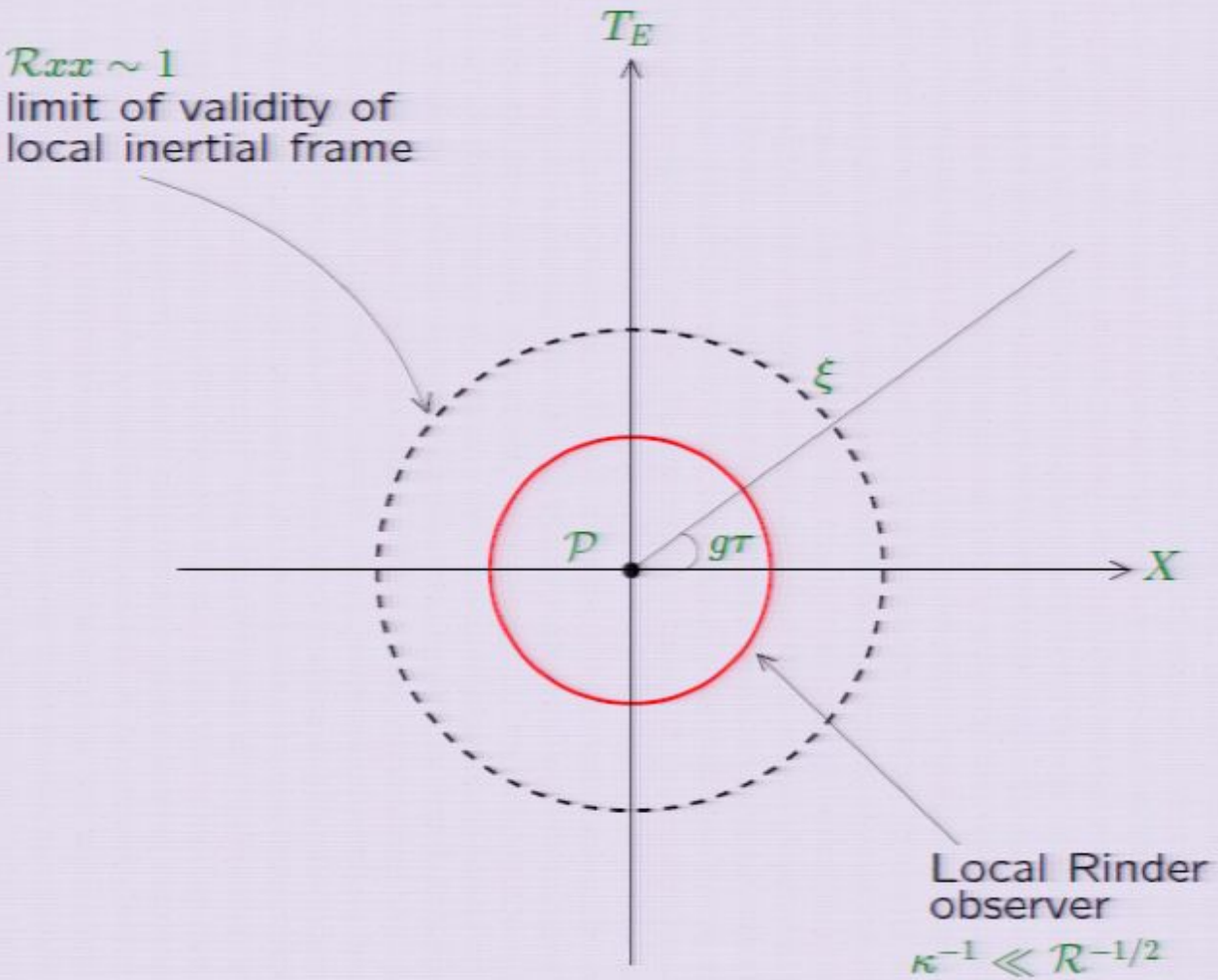
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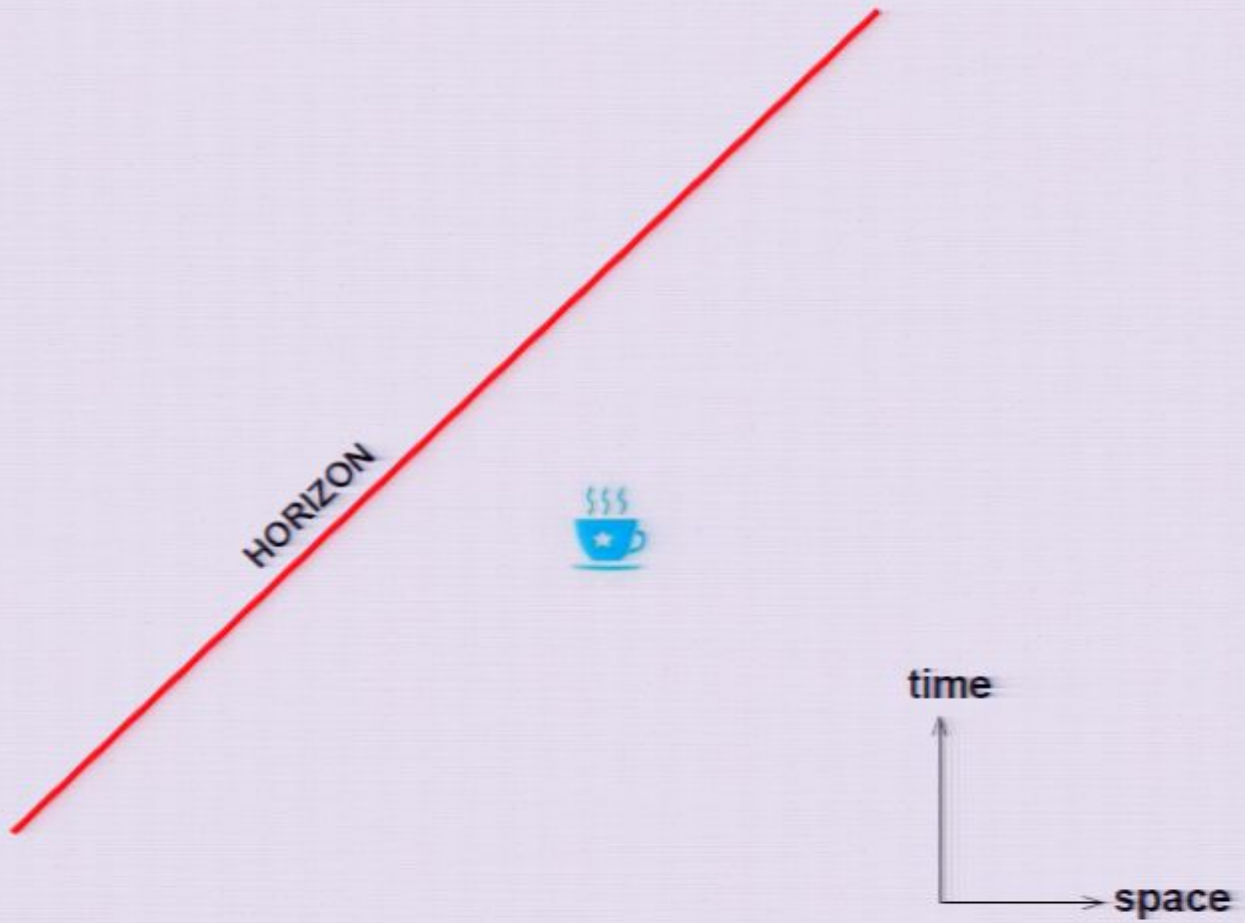
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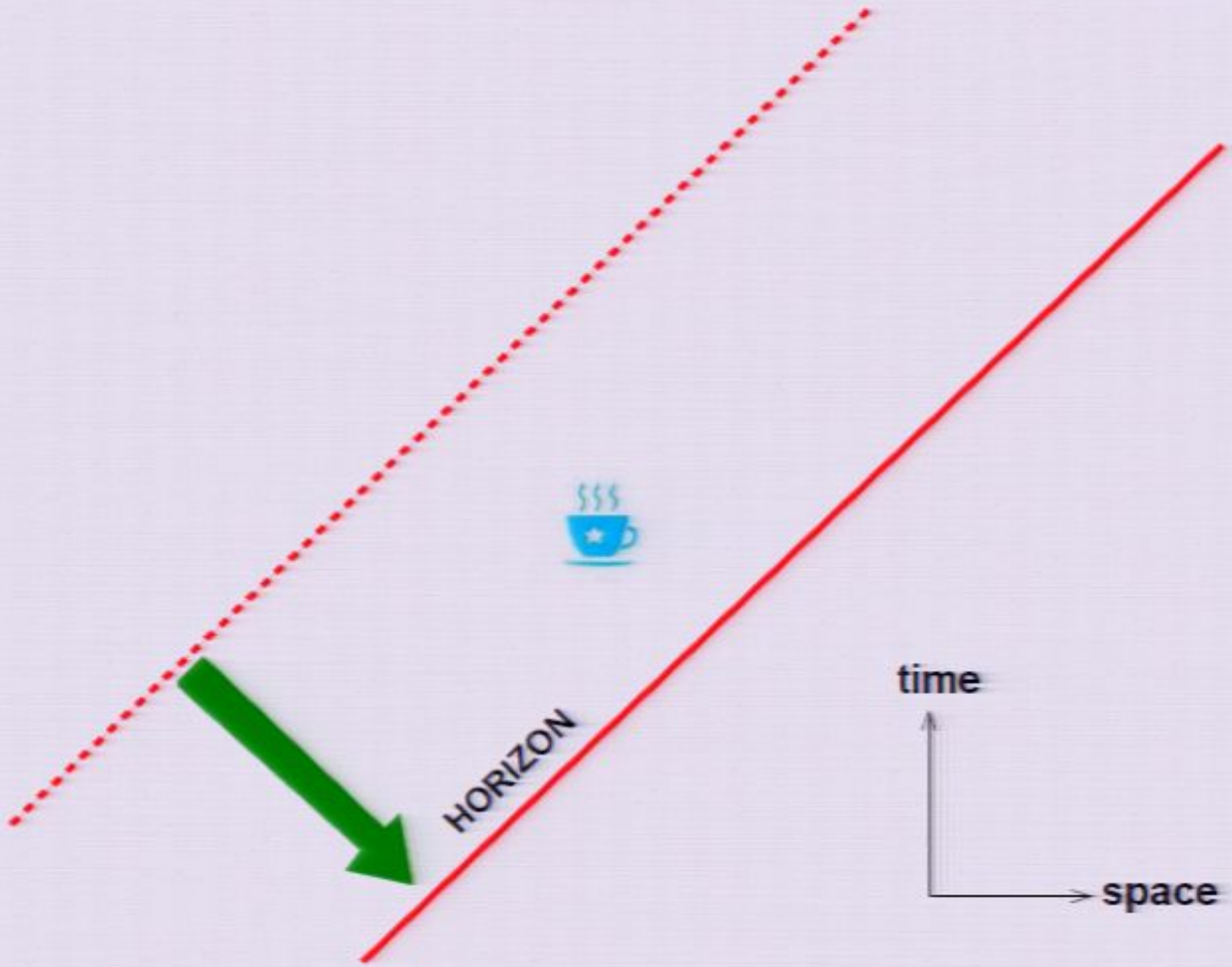
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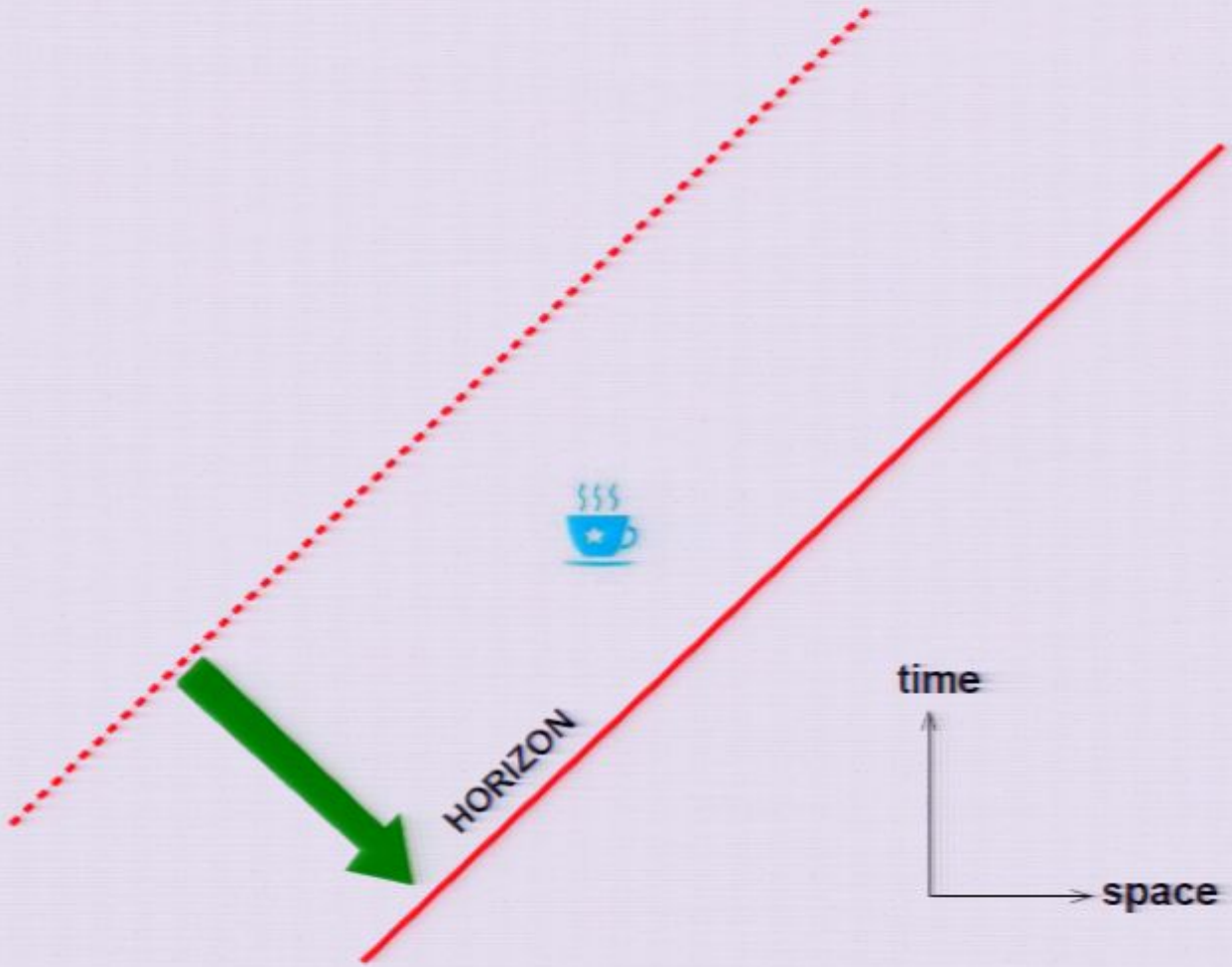
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- The field equations now have a new symmetry. The action and field equations are invariant under $T_{ab} \to T_{ab} + \rho_0 g_{ab}$. Gravity does *not* couple to bulk vacuum energy (cosmological constant).

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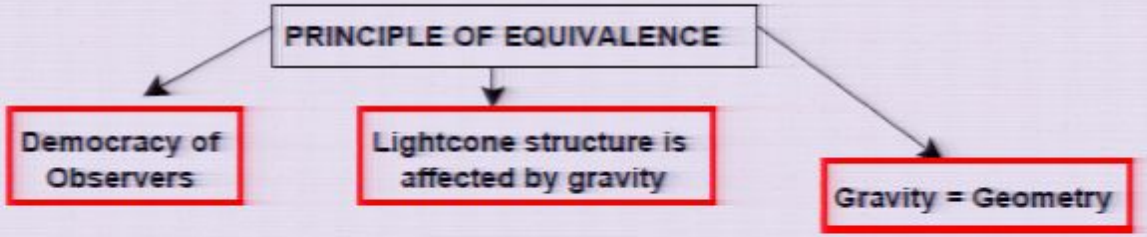
- Connects with the equipartition idea.

PRINCIPLE OF EQUIVALENCE


PRINCIPLE OF EQUIVALENCE
Democracy of Observers
Lightcone structure is affected by gravity
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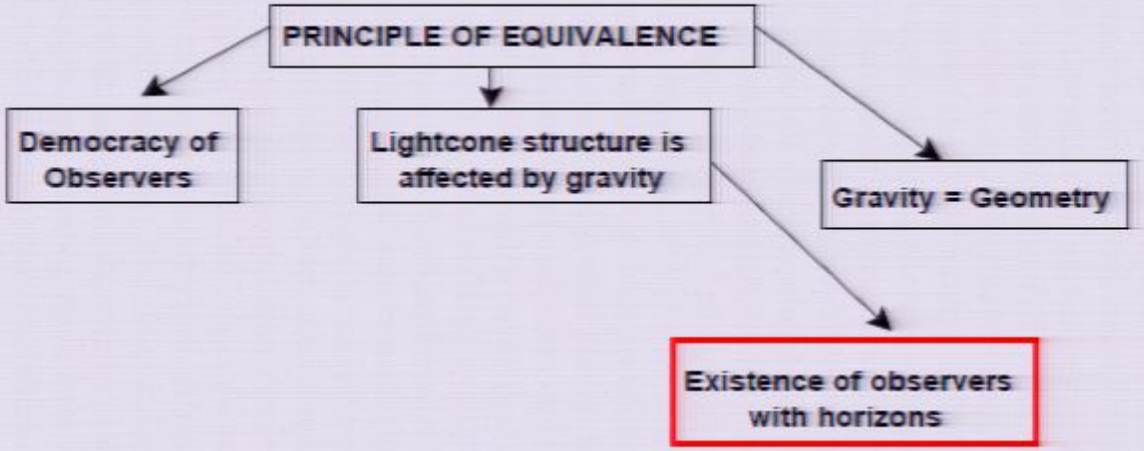
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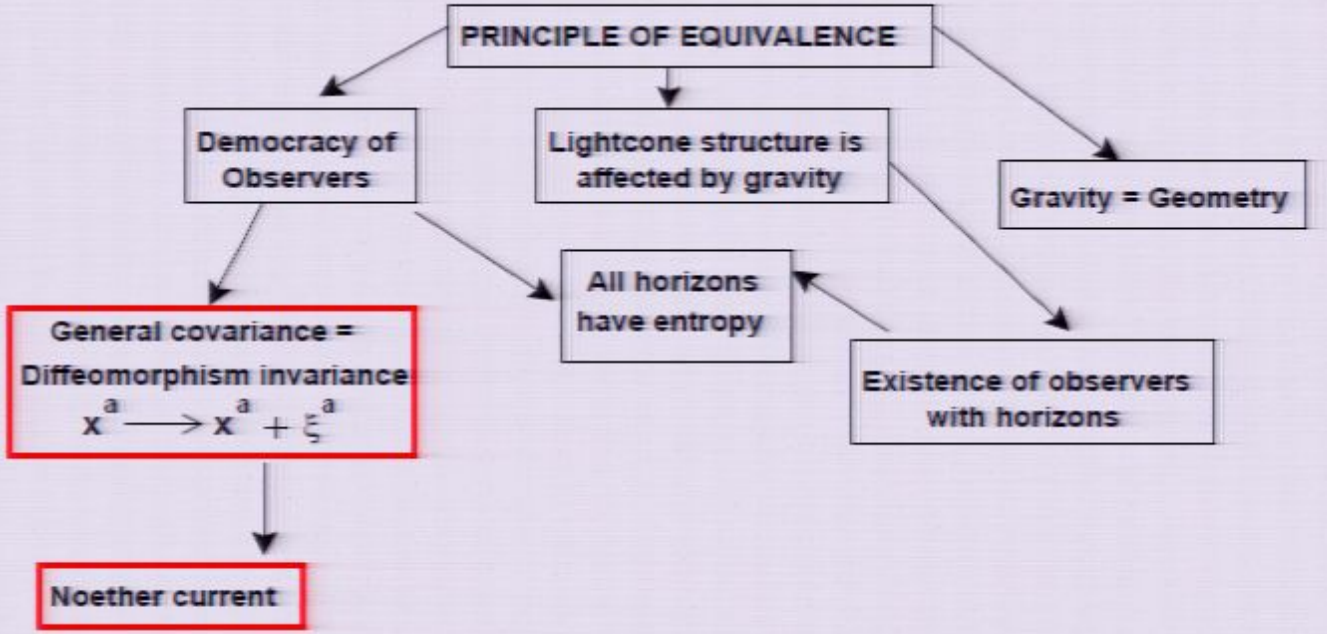
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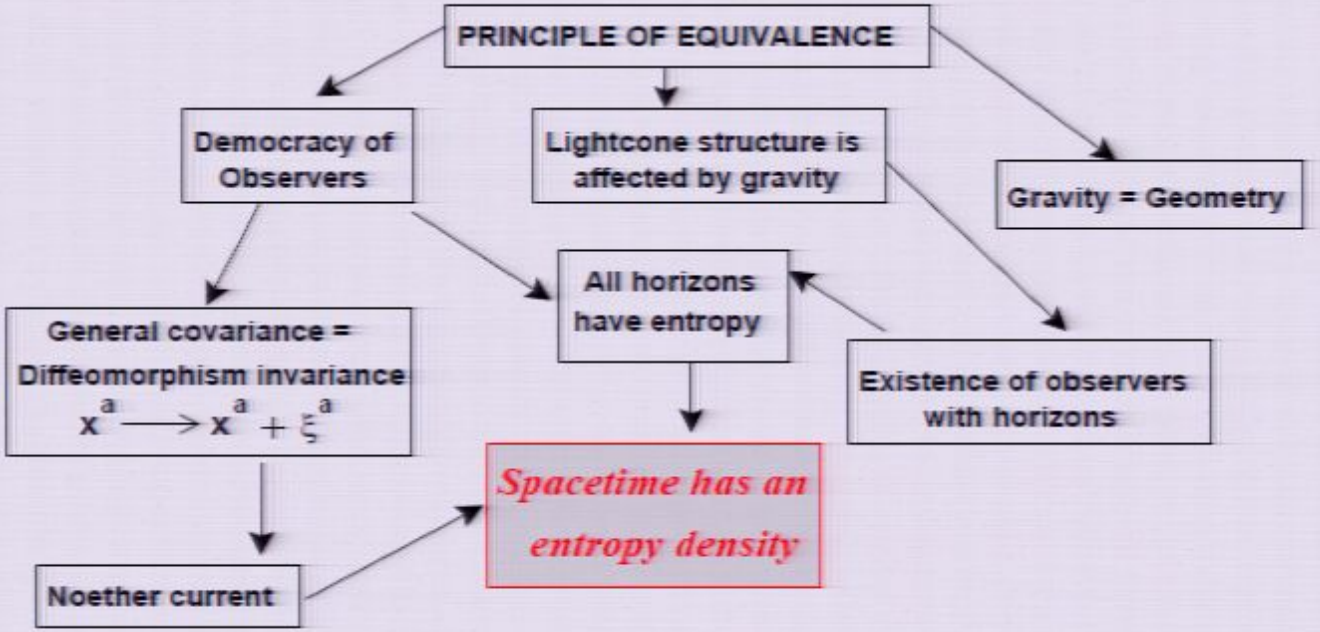
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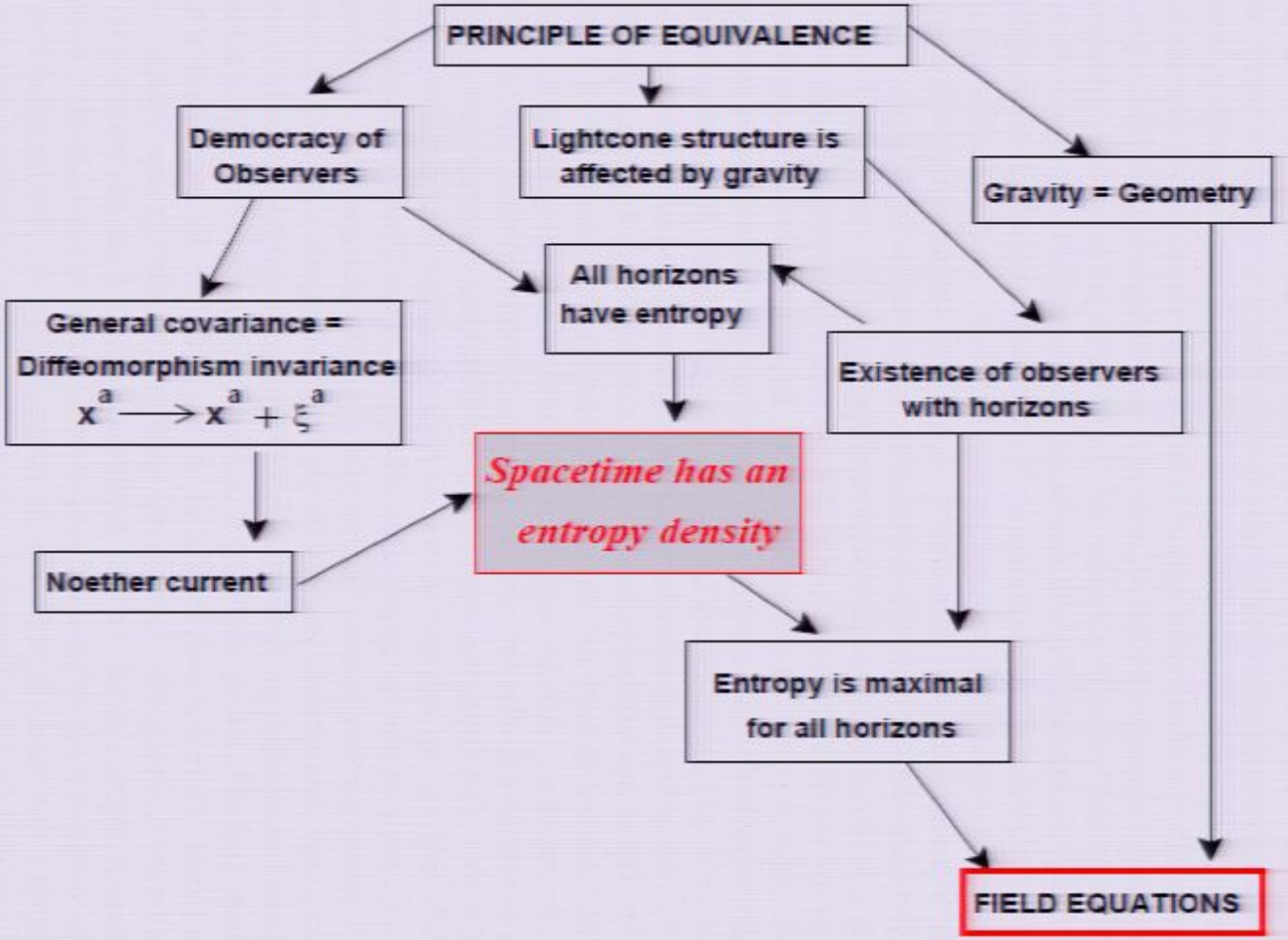
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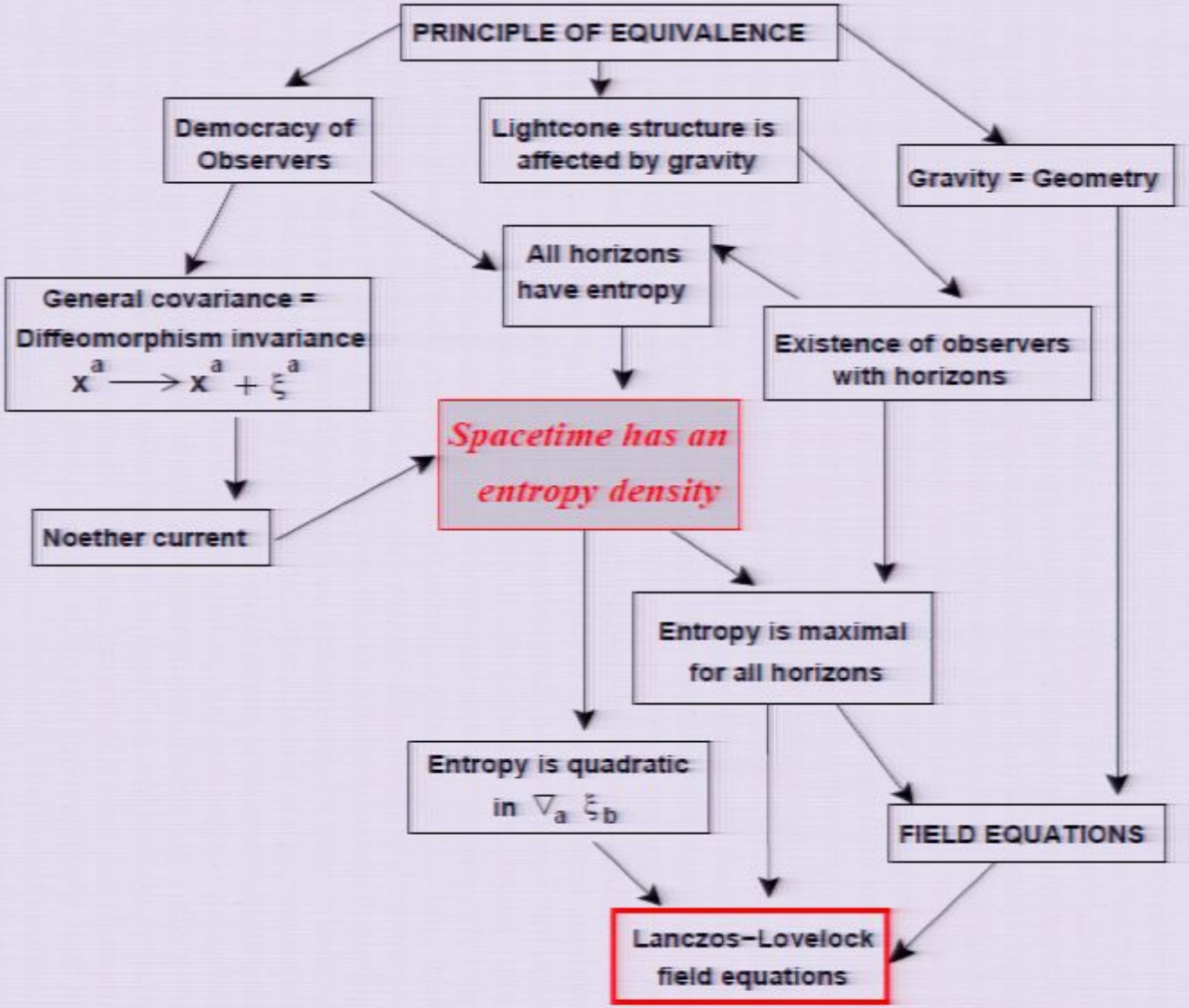
FIELD EQUATIONS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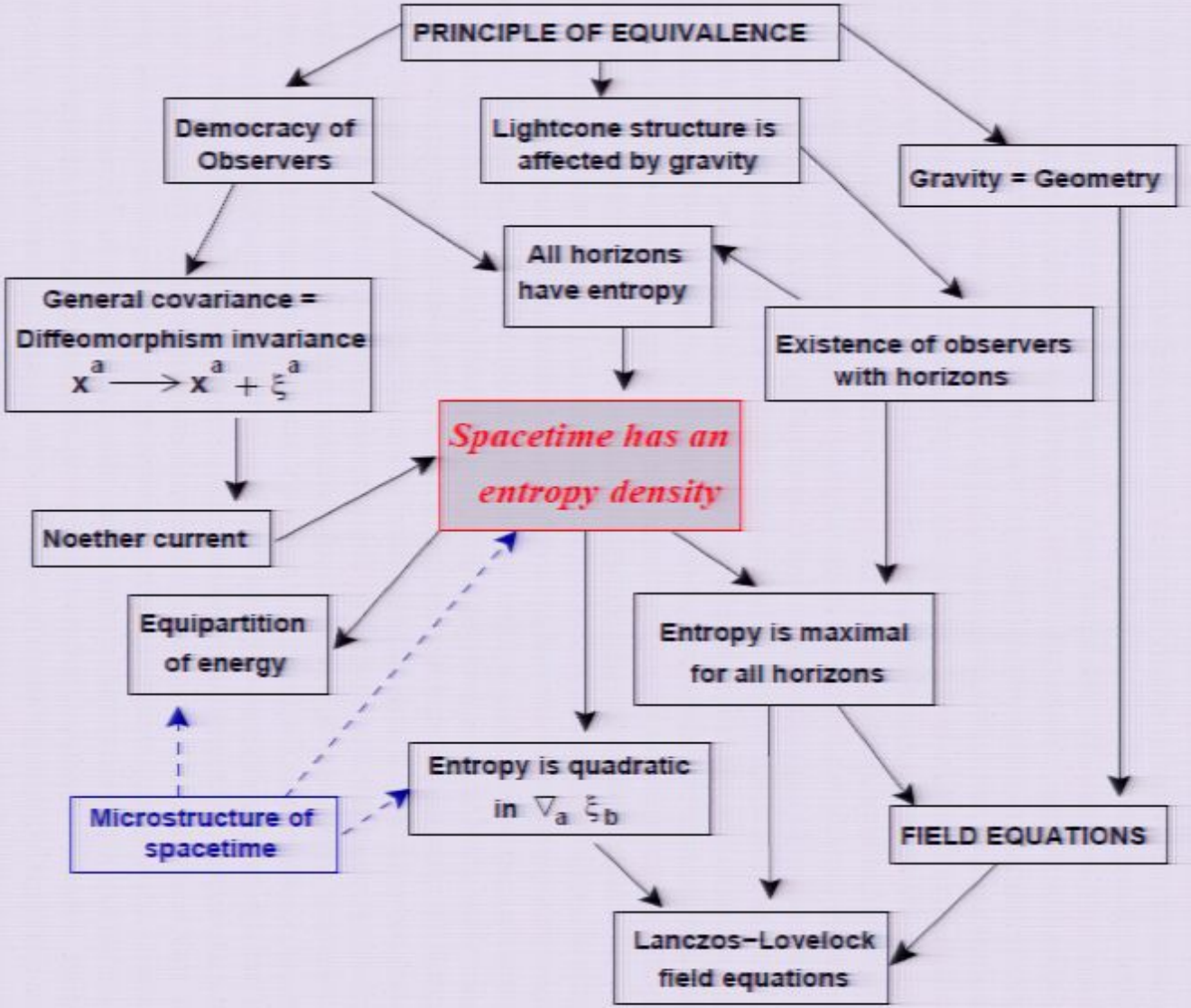
FIELD EQUATIONS
Lanczos–Lovelock field equations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- Can one do better than a host of other 'QG candidate models' ? e.g., cosmological constant problem, singularity problem ...

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