Emergent Gravity - Thermodynamic perspective

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  Emergence $\rightarrow$ Change of dynamical variables in the description
- One can obtain wide class of gravitational theories from thermodynamic extremum principle.
  Horizon Thermodynamics $\longleftrightarrow$ Gravity

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- Temperature of matter told you that it has atomic structure

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- Equipartition Law:

$$\boxed{E = \frac{1}{2}nk_B T \rightarrow \int dV \frac{dn}{dV}\frac{1}{2}k_B T = \frac{1}{2}k_B \int dn T}$$

demands granularity with *finite* n; degrees of freedom scales as volume.

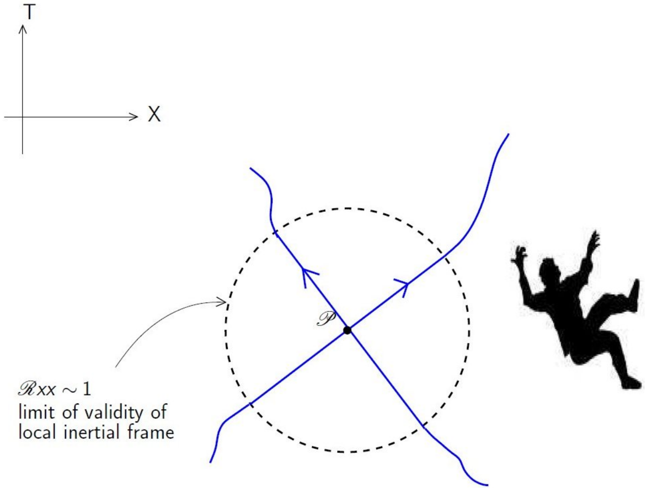
Spacetimes can be hot!!

Observers who perceive a null surface
as horizon attribute a temperature to it

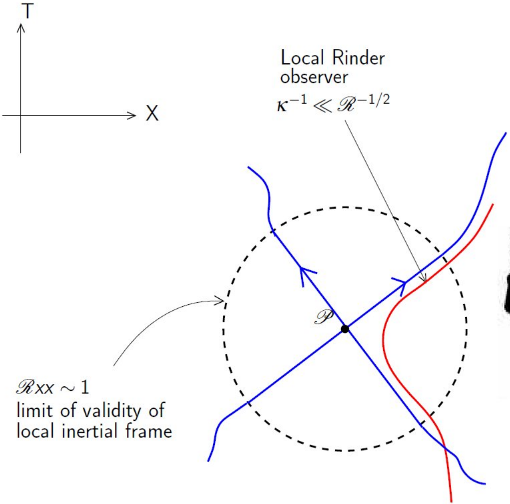
$$\boxed{k_B T = \frac{\hbar}{c}\left(\frac{g}{2\pi}\right)}$$

[Davis-Unruh temperature]

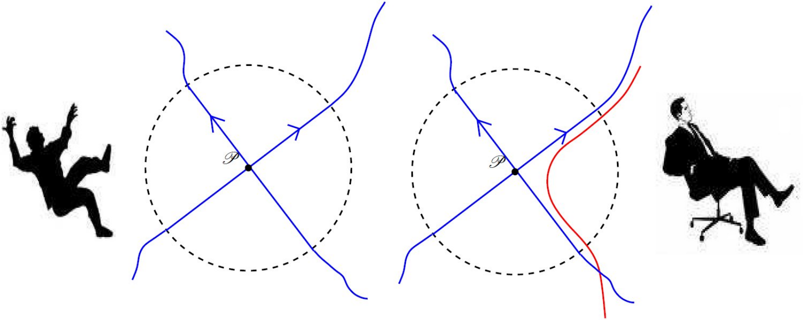
Free-fall observer



Local Rindler observer



Equivalence Principle



Vacuum fluctuations $\Longleftrightarrow$ Thermal fluctuations

A VERY NON-TRIVIAL EQUIVALENCE!

Gravitational field equations as thermodynamic identity

Static, spherically symmetric spacetime with horizon

$$\boxed{ds^2 = -f(r)c^2dt^2 + f^{-1}(r)dr^2 + r^2 d\Omega_2^2}$$

Location of horizon is at $r = a$, $f(a) = 0$

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Temperature of horizon: $\boxed{k_B T = \dfrac{\hbar c f'(a)}{4\pi}}$

Gravitational field equations as thermodynamic identity

Einstein equation evaluated at horizon $r = a$:

$$\boxed{\frac{c^4}{G}\left[\frac{1}{2}f'(a)a - \frac{1}{2}\right] = 4\pi P a^2}$$

Gravitational field equations as thermodynamic identity

Horizons at a and $a + da$:

$$\underbrace{\frac{\hbar c f'(a)}{4\pi}}_{k_B T} \underbrace{\frac{c^3}{G\hbar} d\left(\frac{1}{4} 4\pi a^2\right)}_{dS} - \underbrace{\frac{1}{2}\frac{c^4 da}{G}}_{dE} = \underbrace{P d\left(\frac{4\pi}{3} a^3\right)}_{PdV}$$

$$\boxed{S = \frac{1}{4L_P^2}(4\pi a^2) = \frac{1}{4}\frac{A_H}{L_P^2}} \quad \boxed{E = \frac{c^4}{G}\left(\frac{A_H}{16\pi}\right)^{\frac{1}{2}}} \quad L_P^2 = \frac{G\hbar}{c^3}$$

Field equations become of the form $\boxed{TdS = dE + PdV}$

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- To explain essential role of quantum mechanics in explaining gravity.
- If we fail:
  - (a) The world is fundamentally quantum mechanical even on macroscopic scales.
  - (b) Quantum mechanics is also emergent from some deeper structure, representation of a stochastic process or as a form of organizational rule as statistical mechanics.

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- Matter sector is put in by hand. If spacetime is emergent then matter d.o.f. must also be emergent. Do this properly!
- Falsifiable predictions to rule out the paradigm?
- A new level of observer dependence in thermodynamic variables, vacuum fluctuations vs. thermal fluctuations. Broader implications?

Thank you!

Literature

- T. Padmanabhan, 'Thermodynamical Aspects of Gravity : New insights', [arXiv:gr-qc 0911.5004]
- T. Padmanabhan, 'Gravitation - Foundation and Frontiers', Cambridge University Press, 2010
- T. Padmanabhan, 'Gravity as an emergent phenomenon: A conceptual description' [arXiv:gr-qc 0706.1654]