Something special at the event horizon

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- This talk is based on works collaborated with M. Eune, Y. Gim, exciting discussions with S.-H. Yi
- Recent development in theoretical physics in KIAS, Seoul
- June 11th (Wed), 2014-June 13th (Fri), 2014

Contents

[1]History

- Hawking, Commun. Math. Phys. 43, 199 (1975)

Outstanding calculation of Hawking radiation has invoked some issues in quantum theory of gravity.

- For static black holes, Hawking radiation: Hawking temperature(thermal equilibrium), Israel-Hartle-Hawking state,

- Thermodynamic phase transition: Gross-Perry-Yaffe, Phys. Rev. D25 (1982) 330; Hawking-Page, Commun. Math. Phys. 87 (1983) 577.

- Recent issues are related to thermal effects of geometry such as AdS/CFT, AdS/CMT, etc. Maldacena, Int. J. Theor. Phys. 38, 1113 (1999); Hartnoll, Class. Quant. Grav. 26, 224002 (2009)]; Son, Phys. Rev. D 78, 046003 008).

- For evaporating black hole: Hawking radiation, quasi-Hawking temperature(quasi-thermal), Unruh state.
- Information loss problem: not yet solved, remnant or not
- Black hole complementarity: Susskind, Thorlacius and Uglum [Phys. Rev. D 48, 3743 (1993)]; Stephens, `t Hooft and Whiting [Class. Quant. Grav. 11, 621 (1994)].
- BHC: Two disconnected patches, Two independent observers, Information cloning problem
- Firewalls: Almheiri, Marolf, Polchinski and Sully [JHEP 1302, 062 (2013)].

[2]Motivation and purposes

- What actually happens in freely falling frames?
- How to get firewalls based on the semi-classical quantum field theory?
- Otherwise, is there any firewall-like object near the horizon?

[3]Freely falling frames

- Two-dimensional Schwarzschild metric: (not s-wave reduction of 4D)

$$ds^2 = -f(r)dt^2 + \frac{1}{f(r)}dr^2$$

$$f(r) = 1 - 2M/r$$

- Two velocity

$$u^\mu = \left(\frac{dt}{d\tau}, \frac{dr}{d\tau}\right) = \left(\frac{\sqrt{f(r_s)}}{f(r)}, -\sqrt{f(r_s) - f(r)}\right).$$

- (In-ward) radial velocity

$$v = -f(r)\sqrt{f(r_s) - f(r)}/\sqrt{f(r_s)}$$

It vanishes at any starting position and has a maximum at a finite distance. Note that it also vanishes at the horizon!

- Proper time

$$\tau = 2M\frac{\sqrt{f(r_s)(1-f(r_s))}+\sin^{-1}\sqrt{f(r_s)}}{(1-f(r_s))^{3/2}}$$

At infinity, it is infinite while it is zero at the horizon. It will take finite proper time to reach the horizon when the free fall begins at finite distance.

- Freely falling frame

Birrell and Davis, Quantum field theory in curved space (1982)

- Black hole complementarity

Susskind, Thorlacius, Uglum, PRD 48, 3743 (1993); Stephens, t` Hooft, Whiting, CQG 11, 621 (1994).

- Information cloning problem

Susskind, Thorlacius, PRD 49, 966 (1994), Hayden, Preskill, 0708.4025

Appendix: Quick review of black hole complementarity and information cloning problem

- distant observer, freely falling observer-> two descriptions
  (i) distant observer: black hole! (horizon, Hawking radiation, temperature, ….)
  (ii) freely falling observer: no black hole! (nothing except at the origin)

- Information cloning problem
  (i) scrambling time (thermalized and emitted) in Schwartzschild time
  (ii) $E \sim M$

[4]Energy densities

- Velocity in light cone coordinates

$$u^+ = \frac{1}{\sqrt{f(r_s)} + \sqrt{f(r_s) - f(r)}},$$
$$u^- = \frac{\sqrt{f(r_s)} + \sqrt{f(r_s) - f(r)}}{f(r)},$$

$$\sigma^\pm = t \pm r^*$$

$$r^* = r + 2M \ln(r/M - 2)$$

- Energy momentum tensor (Christensen and Fulling, PRD15, 2088 (1997)

$$\langle T_{\pm\pm} \rangle = -\frac{N}{48\pi}\left(\frac{2Mf(r)}{r^3} + \frac{M^2}{r^4}\right) + \frac{N}{48}t_\pm,$$
$$\langle T_{+-} \rangle = -\frac{N}{48\pi}\frac{2M}{r^3}f(r),$$

(NB) (i)conformal anomaly(one), covariant conservation law(two) with two unknowns

(ii) conformal versus gravitational anomaly

- Energy density

$$\epsilon(r|r_s) = -\frac{N}{48\pi r^4 f(r)}\left[8Mrf(r_s) + 4M^2\left(\frac{f(r_s)}{f(r)} - \frac{1}{2}\right) - \pi r^4\left(\sqrt{\frac{f(r_s)}{f(r)}} - \sqrt{\frac{f(r_s)}{f(r)} - 1}\right)^2 t_+ \right.$$

$$\left. - \pi r^4\left(\sqrt{\frac{f(r_s)}{f(r)}} + \sqrt{\frac{f(r_s)}{f(r)} - 1}\right)^2 t_-\right]$$

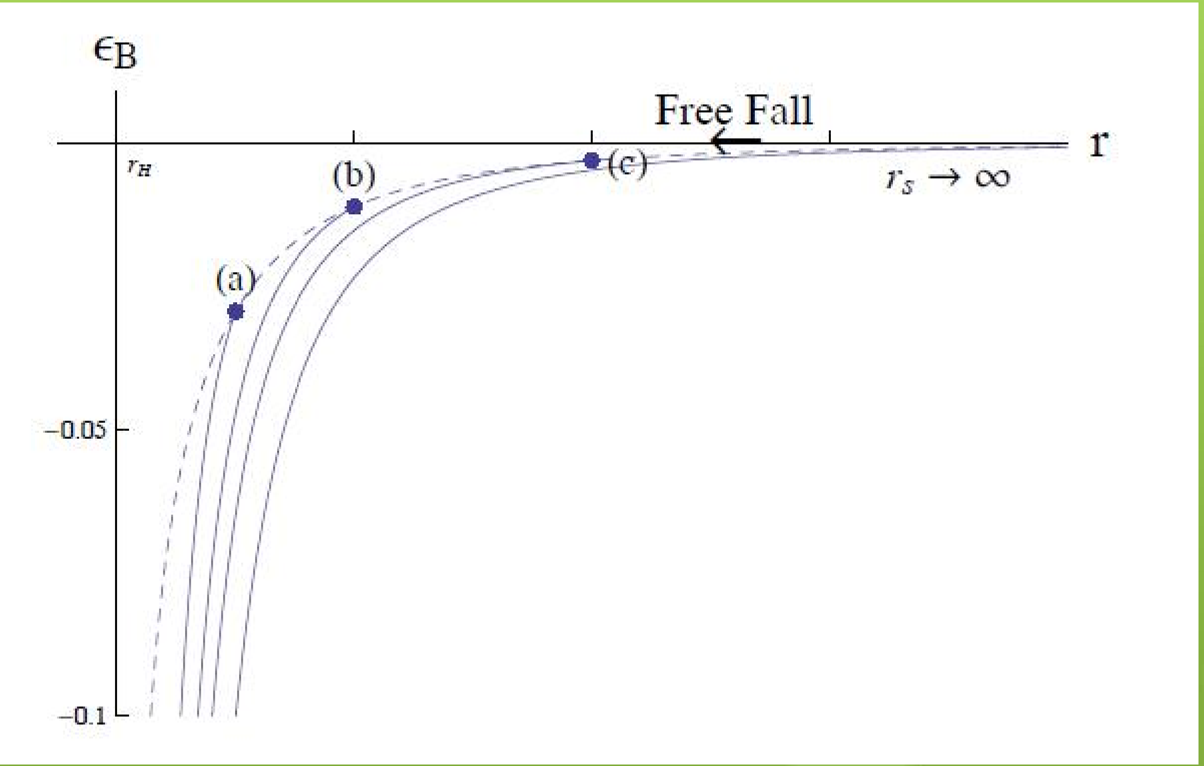
- Black hole states:
  Boulware state, Unruh state, and Israel-Hartle-Hawking state

- Boulware state

$$\epsilon_B(r|r_s) = -\frac{NM^2}{12\pi r^4 f(r)}\left[\frac{2rf(r_s)}{M} + \frac{f(r_s)}{f(r)} - \frac{1}{2}\right]$$

$$\epsilon_B(r_s|r_s) = -N[4Mr_s f(r_s) + M^2]/[24\pi r_s^4 f(r_s)]$$

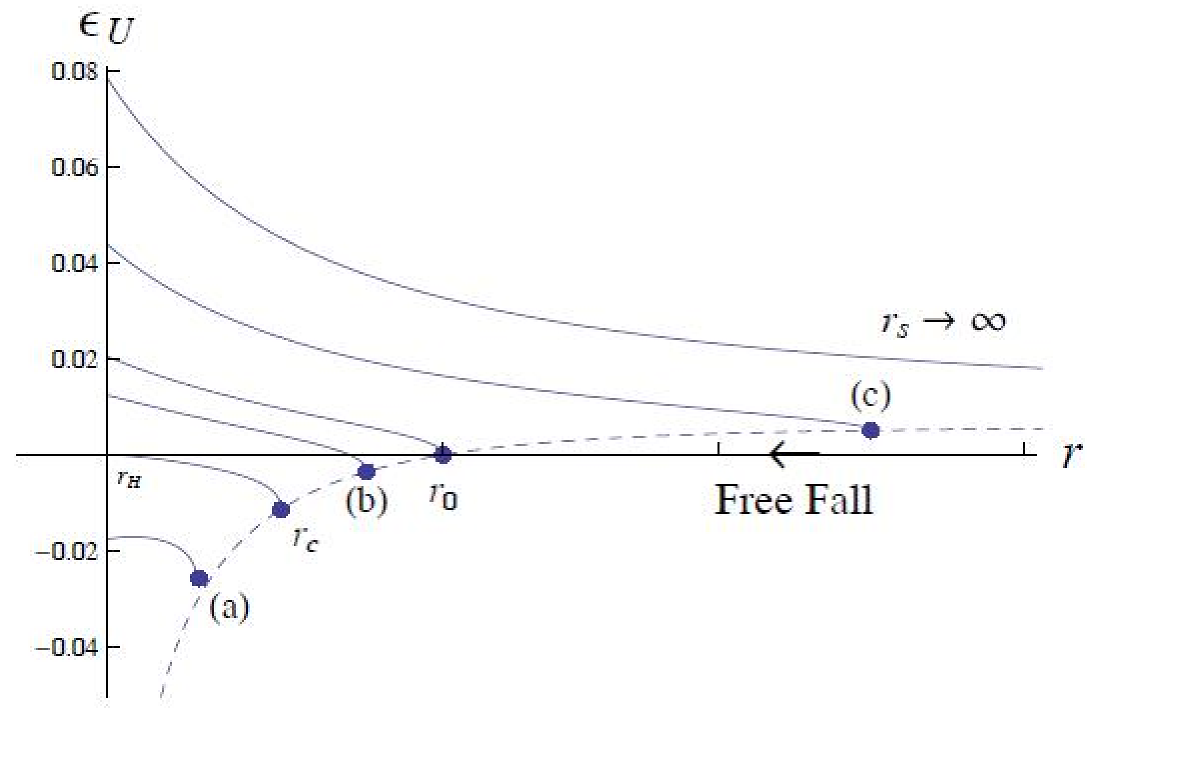
where it is always negative.



- Unruh state

$$\epsilon_U(r|r_s) = -\frac{NM^2}{12\pi r^4 f(r)}\left[\frac{2rf(r_s)}{M} + \frac{f(r_s)}{f(r)} - \frac{1}{2} - \frac{r^4}{64M^4}\left(\sqrt{\frac{f(r_s)}{f(r)}} + \sqrt{\frac{f(r_s)}{f(r)} - 1}\right)^2\right]$$

$$\epsilon_U(r_s|r_s) = -NM^2[4r_s f(r_s)/M + 1 - r_s^4/(32M^4)]/[24\pi r_s^4 f(r_s)]$$

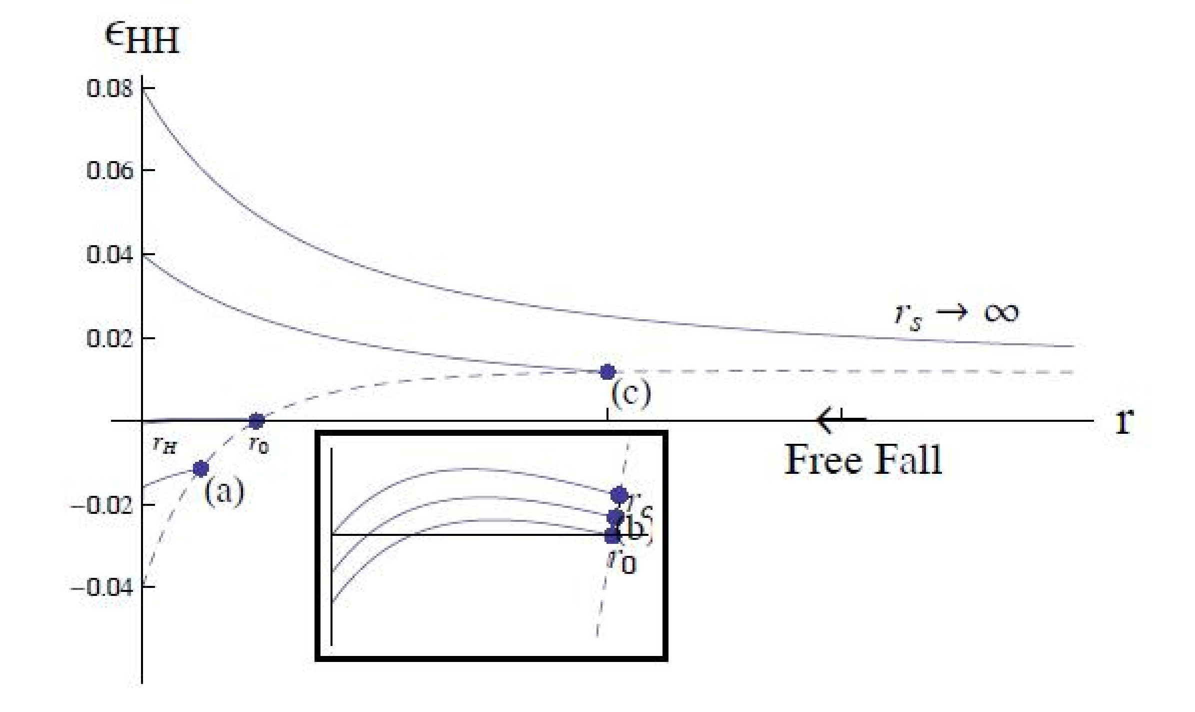


$r_0 \approx 4.2M$ $r_c \approx 3.1M$

- Israel-Hartle-Hawking state

$$\epsilon_{HH}(r|r_s) = -\frac{NM^2}{12\pi r^4 f(r)}\left[\frac{2rf(r_s)}{M} - \left(\frac{r^4}{16M^4} - 1\right)\left(\frac{f(r_s)}{f(r)} - \frac{1}{2}\right)\right]$$

$$\epsilon_{HH}(r_s|r_s) = -N[8Mr_s f(r_s) + 2M^2 - r_s^4/(8M^2)]/[48\pi r_s^4 f(r_s)],$$



$r_0 \approx 2.98M$ $r_c = 3M$

$$\epsilon_U(2M|2M) = -\infty$$

$$\epsilon_U(\infty|\infty) \to \pi(N/12)T_{\mathrm{H}}^2$$

$$\epsilon_{HH}(2M|2M) \to -N/(96\pi M^2)$$

$$\epsilon_{HH}(\infty|\infty) \to \pi N T_{\mathrm{H}}^2/6,$$

$$\epsilon_{HH}(\infty|\infty) = 2\epsilon_U(\infty|\infty).$$

[5]Conclusion and discussions

- The present work seems to be complementary.
  (everything in a text book vs. completely wrong results)

- Energy densities depend on both free-fall position and black hole state.

  Boulware: negative
  Unruh : negative for r< 3.1 M while positive for r > 3.1 M.
  Israel-Hartle-Hawking: negative for r <3M while positive for r> 3M.

B. Freivogel, arXiv:1401.1492[hep-th]
S. Singh, S. Chakraborty, arXiv:1404.0684[gr-qc]

- Firewall or firewell?

- Well-established Unruh effect

- BHC based on this work

- Evaporation of black hole