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Devoted to memory of Alexei Alexandrovich Starobinsky

Schwinger vs Unruh

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It is shown that the temperatures which characterise the Unruh effect, the Gibbons–Hawking radiation from the de Sitter cosmological horizon and the Hawking radiation from the black hole horizon acquire the extra factor 2 compared with their traditional values. The reason for that is the coherence of different processes. The combination of the coherent processes also allows us to make the connection between the Schwinger pair production and the Unruh effect.

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There were many discussions concerning the problem with a factor 2 in the temperature of Hawking radiation, see, e.g., [1, 2]. The doubling of the Gibbons–Hawking temperature was also discussed for the de Sitter expansion [3]. Since the Schwinger pair creation bears some features of the thermal radiation, one may also expect the factor 2 problem.

The Schwinger pair creation [4, 5] of particles with mass M and charges $\pm q$ in electric field $\mathcal{E}$ per unit volume per unit time is given by:

$$\Gamma^{\rm Schw}(M)=\frac{dW^{\rm Schw}}{dt}=\frac{q^2\mathcal{E}^2}{(2\pi)^3}\exp\left(-\frac{\pi M^2}{q\mathcal{E}}\right). \quad (1)$$

Since $a=q\mathcal{E}/M$ corresponds to the acceleration of a charged particle, there were attempts to connect the Schwinger mechanism with the Unruh effect [6], see [7–10] and references therein.

If one tries to make the direct analogy between these processes, this is already problematic. The original state is the vacuum in the constant electric field. Being the vacuum it does not provide any physical acceleration. Acceleration in electric field appears only in the presence of a charged particle. That is why one can try to find the situation, when the two effects are physically connected. The connection may arise if we split the pair creation in several steps. In the first step the pair of particles with masses M are created by Schwinger mechanism. Then the created particles with positive and negative charges are accelerated by electric fields and they play the role of two Unruh–deWitt detectors. If due to the acceleration the mass of each detector is increased by m, the total process is equivalent to the pure Schwinger effect of creation of particles with masses $M+m$:

$$\Gamma^{\rm Schw}(M+m)=\Gamma^{\rm Schw}(M)\,\Gamma_+^{\rm Unruh}(m)\Gamma_-^{\rm Unruh}(m). \quad (2)$$

Each of the two Unruh processes is governed by the temperature $\tilde T_{\rm U}$, which is twice the Unruh temperature:

$$\Gamma_\pm^{\rm Unruh}(m)=\exp\left(-\frac{m}{\tilde T_{\rm U}}\right)\,,\ \tilde T_{\rm U}=\frac{a}{\pi}=2T_{\rm U}. \quad (3)$$

The coherence of processes (or co-tunneling) plays an important role in temperature doubling. A similar temperature doubling occurs in the de Sitter Universe. According to [3] the comoving observer perceives the de Sitter environment as the thermal bath with temperature $T=H/\pi$. It is twice larger than the Gibbons–Hawking temperature [11] of the cosmological horizon, $T_{\rm GH}=H/2\pi$. The temperature $T=H/\pi$ determines in particular the process of ionization of an atom in the de Sitter environment. Here the atom plays the role of the local Unruh–deWitt detector, which is excited in the de Sitter environment. The temperature $T=H/\pi$ determines the thermodynamics of the de Sitter state [3] and the local entropy density of this state $s_{\rm dS}=(3\pi/4G)T$. The entropy density is linear in temperature, which demonstrates that de Sitter thermal state experiences the analog of the Sommerfeld law in Fermi liquids.

The difference between the local T and $T_{\rm GH}=H/2\pi$ of Gibbons–Hawking process also comes from the analog of co-tunneling. In the Gibbons–Hawking process, two particles are coherently created: one particle is created inside the horizon, while its partner is simultaneously

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created outside the horizon. Since de Sitter Universe behaves as the thermal bath with temperature $T = H/\pi$, then the rate of the coherent creation of two particles, each with energy E, is $w \propto \exp(-\frac{2E}{T})$. However, the observer who uses the Unruh–DeWitt detector can detect only the particle created inside the horizon. For this observer the creation rate $w \propto \exp(-\frac{2E}{T})$ is perceived as $\exp(-\frac{E}{T/2}) = \exp(-\frac{E}{T_{\rm GH}})$, and thus the Hawking radiation looks as the thermal process with the Gibbons–Hawking temperature, while the real temperature of the de Sitter environment is twice larger.

The doubling of the Unruh and de Sitter temperatures may also have connection with the 't Hooft proposal of the doubling of the temperature of the Hawking radiation from the black hole [12, 13]. In this scenario the coherence is supported by the partner (the clone) of the black hole – the mirror image of the black hole space-time. Instead of the clone, the coherence can be provided by the simultaneous creation of two particles in the tunneling process [14, 15]: the particle outside the black hole horizon and its partner – the hole created inside the horizon. Due to coherence of these two processes the physical temperature is twice the Hawking temperature. However, the external observer has no information about the physics inside the horizon and perceives the radiation as thermal with the Hawking temperature.

The double Hawking temperature may arise also from the Brown–York approach [16]. According to [17] the only way to reconcile the Brown–York black hole energy $E = 2M$ with the relation $dE = TdS$ is by introducing the Brown–York temperature $T_{\rm BY} = 2T_{\rm H}$.

In conclusion, due to coherence of different processes, all three effects (Unruh effect, Gibbons–Hawking radiation from the cosmological horizon and Hawking radiation from the black hole horizon) acquire the extra factor 2 compared with their traditional values.

In the case of de Sitter, the double Gibbons–Hawking temperature $T = 2T_{\rm GH} = H/\pi$ coincides with the thermodynamic temperature of the de Sitter state, which in particular responsible for the ionization rate of an atom in the de Sitter environment. This temperature also determines the local entropy $s_{\rm dS}$ of the de Sitter, which being integrated over the Hubble volume $V_{\rm H}$ reproduces the entropy of the cosmological horizon, $s_{\rm dS} V_{\rm H} = A/4G$, where A is the horizon area.

In the case of the Unruh effect, the double Unruh temperature is supported by the analog of the Unruh effect in the accelerated superfluid liquid such as ^{3}He-B. In the Unruh process, two Bogoliubov fermions (quasiparticle and quasihole, each with energy E), are created simultaneously. Since the two fermions are created in unison, such coherent process looks as thermal but with the factor 2 in the exponent, $e^{-2E/T}$. This is the reason why the temperature T corresponding to this coherent process is twice the Unruh temperature, $T = 2T_{\rm U}$, where $T_{\rm U} = \hbar a/2\pi$ and a is the acceleration of the liquid.

In case of the black hole Hawking radiation, the double Hawking temperature emerges also due to the combination of the coherent processes. Such coherence is similar to that in the scenario suggested by 't Hooft, where the black hole interior is considered as a quantum clone of the exterior region, which leads to the doubling of the Hawking temperature.

The coherence of the processes is also used for the consideration of the back reaction of the black hole to the Hawking radiation and the detector recoil to the Unruh effect [7, 8, 15, 18, 19].

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