Virtual event horizons: is the threshold curvature that corresponds to the onset of the uselessness of mass-energy for work a variable measure?

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Abstract

The duality between entropy and curvature is discussed. The possibility of a gravity-mediated local UV cutoff is discussed.

1 Real and virtual event horizons

According to the laws of black hole thermodynamics and the holographic principle [1, 2], the activity of the quantum fields at the event horizon radius

$$R_{\text{bh}} = 2M \tag{1}$$

of a large Schwarzschild black hole corresponds to a Bekenstein-Hawking entropy of

$$S_{\text{bh}} = \frac{A_{\text{bh}}}{4}, \tag{2}$$

where

$$A_{\text{bh}} = 4\pi R_{\text{bh}}^2. \tag{3}$$

In terms of information theory, it takes S_{bh} natural units of information to encode the number of distinct quantum microstates $e^{S_{\text{bh}}}$ that are formed by the activity of the quantum fields at R_{bh}. The black hole entropy S_{bh} is the maximum entropy that this given amount of mass-energy M can possess, and if M were to be in the form of every day material instead (ie. a car), then the entropy S of M would surely be less than the maximum S_{bh}. The black hole entropy S_{bh} also corresponds to a threshold where this given amount of mass-energy M becomes unusable for work.

Dividing the black hole entropy by the black hole event horizon area provides a measure of curvature

$$\kappa_{\text{bh}} = \frac{S_{\text{bh}}}{A_{\text{bh}}} = \frac{1}{4} \tag{4}$$

that is common to all Schwarzschild black holes. It is important to stress that *this measure of curvature corresponds to the threshold where mass-energy is hidden behind a black hole event horizon*, and to stress that *this curvature threshold is dual to the aforementioned entropy threshold where mass-energy becomes unusable for work*. From this we may conclude that being behind an event horizon and being unusable for work are analogous circumstances.

The quantum fields outside of the event horizon are also active to a lesser extent, and some of this activity eventually leads to and corresponds to photons that escape the black hole's gravitation, ultimately causing the black hole to radiate away both energy and entropy.

At some distant time later, the quantum field activity of these photons at some distant shell of radius

$$R_{\text{shell}} \gg R_{\text{bh}}, \tag{5}$$

$$A_{\text{shell}} = 4\pi R_{\text{shell}}^2 \gg A_{\text{bh}} \tag{6}$$

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will correspond to a Planck black body spectrum of temperature

$$T_{\text{shell}} = \frac{1}{8\pi M}, \tag{7}$$

which, via M, corresponds back to the black hole entropy

$$S_{\text{shell}} = S_{\text{bh}}. \tag{8}$$

Since $R_{\text{shell}} > R_{\text{bh}}$ by definition, the shell's measure of curvature will be less than the maximum

$$\kappa_{\text{shell}} = \frac{S_{\text{shell}}}{A_{\text{shell}}} < \frac{1}{4}. \tag{9}$$

The shell's measure of curvature corresponds to a length scale

$$\ell_{\text{shell}} = \sqrt{\frac{1}{4\kappa_{\text{shell}}}} > 1 \tag{10}$$

and an energy scale

$$E_{\text{shell}} = \frac{1}{\ell_{\text{shell}}} < 1. \tag{11}$$

Here we have defined a global frame of reference F at the centre of the curved spacetime formed by a radiating Schwarzschild black hole of mass-energy M, where the background curvature $\kappa_{\text{bh}} = 1/4$ marks the black hole event horizon. We have also defined a local frame of reference F_{shell} that is centred at some point along R_{shell}, where the background curvature $\kappa_{\text{shell}} < 1/4$ is inherited from F.

May we conclude, similar to the global entropy-curvature threshold duality at the black hole event horizon R_{bh} in frame F, that this (non-maximum) background curvature κ_{shell} in frame F_{shell} defines a local (non-maximum) threshold at R_{shell} where a test mass-energy $M_{\text{test}} \ll M$ of sufficient curvature

$$\kappa_{\text{test}} = \frac{S_{\text{test}}}{16\pi M_{\text{test}}^2} \geq \kappa_{\text{shell}} \tag{12}$$

would become unusable for work because M_{test} would become hidden behind a virtual event horizon? In other words, may we conclude that κ_{shell} is a gravity-mediated local UV cutoff that marks the boundary between real and virtual mass-energy?

From this perspective, it seems that a test mass-energy of curvature $\kappa_{\text{test}} \geq \kappa_{\text{shell}}$ (ie. $\ell_{\text{test}} \leq \ell_{\text{shell}}$) would become small details lost amongst the generally larger details of the spacetime background. It also seems that neither electromagnetism nor real mass-energy would exist in a totally flat spacetime, where $\kappa_{\text{shell}} = 0$.

2 Further questions

Could such a gravity-mediated local UV cutoff possibly be the *raison d'être* for the dark matter particles that are commonly thought to produce the non-Newtonian nature of the galactic rotation curves? Likewise, could such a gravity-mediated local UV cutoff possibly explain the non-observation of cosmic rays with ultra high energies above the GZK cutoff? In other words, is it possible that individual dark matter particles and individual above-GZK cosmic rays each possess too much entropy to be usable for work (as defined locally by κ_{shell}), even though none of these individual particles are black holes in the traditional sense? It may be important to note that the energy scale of the gravitational field at the surface of an idealized spherical Earth is on the order of the GZK cutoff energy scale (ie. 10^{19} eV). Confidence in the matter of whether the GZK cutoff energy scale is variable/local or constant/global can be gained through future ultra high energy cosmic ray detection attempts at locations other than on the surface of the Earth, such as in microgravity and on the surfaces of the Moon and Mars.

Is it possible that virtual mass-energy is often temporarily allowed into the realm of real mass-energy because the virtual mass-energy's entropy is often temporarily reduced to the point where it corresponds to a curvature that is less than the background curvature? If so, is the inevitable return of the virtual mass-energy back to the virtual realm due to an inevitable increase in the virtual mass-energy's entropy?

References

[1] ’t Hooft G. The holographic principle. (2000) arXiv:hep-th/0003004v2

[2] Susskind L, Bigatti T. TASI lectures on the holographic principle. (2000) arXiv:hep-th/0002044v1