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Black Hole Hawking radiation

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Abstract: Hawking radiation is black-body radiation that is predicted to be released by black holes − which make a black hole to glow like a piece of hot metal, due to quantum effects near the event horizon. It is named after the English theoretical cosmologist Stephen Hawking, who provided a theoretical argument for its existence in 1974. Hawking radiation − which is widely regarded as one of the first real steps toward a quantum theory of gravity and allows physicists to define the entropy of a black hole − reduces the mass and energy of black holes and is therefore also known as black hole evaporation. Because of this, black holes are not quite black! Instead, they glow slightly with photons, neutrinos, and other massive particles. They shrink and ultimately vanish. Micro black holes are predicted to be larger emitters of radiation than larger black holes and should shrink and dissipate faster.

Keywords: Black hole; Hawking Radiation; Event Horizon; Quantum effects; Schwarzschild radius; black hole evaporation.

"The area formula for the entropy — or number of internal states — of a black hole suggests that information about what falls into a black hole may be stored like that on a record, and played back as the black hole evaporates."

"There is no escape from a black hole in classical theory, but quantum theory enables energy and information to escape."

— Stephen Hawking

Stars of radius smaller than its **Schwarzschild radius**

$$r_S = \frac{2GM}{c^2}$$

$$Mc^2 = \frac{\text{Planck Force}}{2} \times r_S$$

further collapse to produce dark or frozen stars (i.e., the mass of a star is concentrated in a small enough spherical region, so that its mass divided by its radius exceeds a particular critical value, the resulting space-time warp is so radical that anything, including light, that gets too close to the star will be unable to escape its **gravitational grip**). And these dark stars are sufficiently massive and compact and possess a strong gravitational field that prevent even light from escaping out its influence: any light emitted from the surface of the star will be dragged back by the star's gravitational attraction before it could get very far. Such stars become black voids in space and were coined in 1969 by the American scientist **John Wheeler** "the black holes" (i.e., black because they cannot emit light and holes because anything getting too close falls into them, never to return).

Classically, the gravitational field of the black holes (which seem to be among the most ordered and organized objects in the whole universe) is so strong that they would prevent any information including light from escaping out of their influence i.e., any information is sent down the throat of a black hole or swallowed by a black hole is forever hidden from the outside universe (this goes by the statement that "**black holes have no hair**"— that is, they have lost all information, all hair, except for these three parameters: its mass, spin and charge), and all one could say of the gravitational monster what the **poet Dante** said of the entrance to Hell: "**All hope abandon, ye who enter here.**" Anything or anyone who falls through the black hole will soon reach the region of infinite density and the end of time. However, only the laws of classical general relativity does not allow anything (not even light) to escape the gravitational grip of the black hole but the inclusion of **quantum mechanics** modifies this conclusion − quantum fields would scatter off a black hole.

Because energy can be created out of nothing, the pair of short lived virtual particles (one with positive energy and the other with **negative energy**) appears close to the event horizon of a black hole. The gravitational might of the black hole inject energy into a pair of virtual particles ... that tears them just far enough apart so that one with negative energy gets sucked into the hole even before it can annihilate its partner ... its forsaken partner with positive energy... gets an energy boost from the gravitational force of the black hole ... escape outward to infinity (an abstract mathematical concept that was precisely formulated in the work of mathematician **Georg Cantor** in the late nineteenth century)... where it appear as a real particle (and to an observer at a distance, it will appear to have been emitted from the black hole). Because **E= mc squared** (i.e., energy is equivalent to mass), a fall of negative energy particle into the black hole therefore reduces its mass with its horizon shrinking in size. As the black hole loses mass, the temperature of the black hole (which depends only on its mass) rises and its rate of emission of particle increases, so it loses mass more and more quickly. We don't know does the emission process continue until the black hole dissipates completely away or does it stop after a finite amount of time leaving black hole remnants.

The attempt to understand the **Hawking radiation** has a profound impact upon the understanding of the black hole thermodynamics, leading to the description of what the black hole entropic energy is.

- **Black hole energy = 2 × Black hole temperature × Black hole entropy**

$$\frac{Mc^2}{2} = T_{BH} \times S_{BH}$$

$$\frac{Mc^2}{2} = \textbf{Black hole entropic energy}$$

This means that the entropic energy makes up half of the mass energy of the black hole. For a black hole of one solar mass ($M = 2 \times 10^{30}$ kg), we get an entropic energy of 9×10^{46} joules – much higher than the thermal entropic energy of the **sun**.

Given that power emitted in Hawking radiation is the rate of energy loss of the black hole:

$$P = -c^2 \frac{dM}{dt} = 2 \times \frac{-dE_S}{dt}$$

The more power a black hole radiates per second, the more entropic energy being lost in Hawking radiation. However, the entropic energy of the black hole of one solar mass is about 9×10^{46} joules of which only 4.502×10^{-29} joules per second is lost in Hawking radiation.

As photons approach the event horizon of a black hole (**light's point of no return**), the light particles with sufficient energy avoid being pulled into the black hole by traveling in a nearly tangential direction known as an **exit cone**. A photon on the boundary of this cone doesn't have enough energy to escape the gravity might of the black hole, and instead they are forced to travel in a circular orbit. These circular orbits of radius

$$r = \frac{3GM}{c^2} = \frac{3r_S}{2}$$

$$Mc^2 = \frac{\text{Planck Force}}{3} \times r$$

are unstable, meaning that after bending through a finite angle around the black hole, the photon will either fall in or bend back out.

The energy of a photon moving in a circular orbit is given by:

$$E = \hbar\omega = \frac{\hbar c}{r}$$

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$$E = \frac{\hbar c^3}{3GM}$$

$$E = \frac{8\pi}{3} k_B T_{BH}$$

where: k_B = Boltzmann constant = $1.38064852 \times 10^{-23} \frac{J}{K}$.

$$\boxed{E = 8.3775\, k_B T_{BH}}$$

The peak wavelength of this radiation is given by:

$$\lambda_{max} = \frac{hc}{4.9651 k_B T_{BH}}$$

$$E_{max} = 4.9651 k_B T_{BH}$$

$$\frac{E}{E_{max}} = \mathbf{1.687}$$

$$\boxed{E = \mathbf{1.687}\, E_{max}}$$

$$E = \frac{\hbar c^3}{3GM} = mc^2$$

$$3mM = (\text{Planck mass})^2$$

Because of this condition the photons orbiting the small black hole carry more mass than those orbiting the big black hole.

Conclusion:

Though the emission of particles from the primordial black holes is currently the most commonly accepted theory within scientific community, there is some disputation associated with it. There are some issues incompatible with **quantum mechanics** that it finally results in information being lost, which makes physicists discomfort and this raises a serious problem that strikes at the heart of our understanding of science. However, most physicists admit that black holes must radiate like hot bodies if our ideas about **general relativity** and **quantum mechanics** are correct. Thus even though they have not yet managed to find a primordial black hole emitting particles after over two decades of searching. Despite its strong theoretical foundation, the existence of this phenomenon is still in question.

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