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There is not a Case for 'Black Hole' Evaporation and Explosion, but Perhaps for Hawking Radiation

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ABSTRACT

In 1974 Hawking hypothesised that the event horizon of a black hole would emit blackbody radiation due to quantum effects. However, following many years of international observations including 11 years of a dedicated mission from the Fermi space telescope, Hawking radiation and its subsequent black hole evaporation have not been observed or verified experimentally.

Hawking black hole evaporation and explosion are contradicted by:
1. A lack of empirical support.
2. Contradictions with established science including general relativity, celestial mechanics and quantum theory.
3. Speculations regarding quantum gravity and generalised entropy, theories as yet unproven.

Analysis of the gravitational interactions of particle and anti-particle pairs has indicated that the mass-energy of a black hole will not decrease over time as predicted by Hawking. As black hole evaporation cannot occur, the subsequent black hole explosion will not occur either. The mass-energy of a black hole may actually increase due to quantum effects. However, Hawking radiation in the form of low energy anti-matter emission from a black hole is theoretically possible.

KEYWORDS: *Hawking radiation, black hole evaporation, primordial black hole, quantum tunnelling, virtual particles*

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1. INTRODUCTION

Hawking radiation is blackbody radiation that is hypothesised to be released from a black hole event horizon, due to quantum effects, including quantum tunnelling and virtual particle pairs and entropy considerations. Stephen Hawking provided the principal theoretical argument for its existence in 1974 [1][2]. According to theory, any black hole will create and emit particles such as neutrinos or photons at the rate that of a body with a temperature. Also termed „black hole evaporation", Hawking radiation would tend to reduce the mass of black holes. Without substantial accretion of new matter, black holes would be expected to shrink and ultimately vanish, with micro-black holes predicted to be larger emitters of radiation than supermassive black holes.

Hawking and Bekenstein noted that the loss of information, or reduction in entropy, as particles fall into a black hole event horizon would result in a violation of the second law of thermodynamics. Entropy would reside in the surface area of the event horizon and be relatively large. Hawking and Bekenstein calculated that entropy, S, of a black hole is:

$$S = kA / 4L_p^2 \qquad (1)$$

where A is the area of the event horizon of the black hole, k is Boltzmann"s constant, c speed of light and the Planck length is $L_p = \sqrt{G\hbar/c^3}$.

If black holes have entropy given in (1) then they must have a temperature and having a temperature must radiate. Hawking showed that black holes emit black body radiation inversely proportional to the mass. Hence, Hawking radiation should occur from black holes according to blackbody spectrum with a temperature, T, given by energy, E:

$$E = kT = \hbar c^3/8\pi GM \qquad (2)$$

Where G is gravitation constant, $\hbar = h/2\pi$ and M is the mass of the black hole.

It can be seen in formula (2) that black holes will emit Hawking radiation at a rate inversely proportional to their mass and small black holes will radiate more strongly than super massive black holes.

Primordial black holes are a hypothetical type of black hole formed in the early Universe. Initially proposed by Zel"dovich and Novikov in 1966, they were also studied by Hawking in 1971 [3] [4]. As primordial black holes did not form from stellar gravitational collapse, their mass could be well below one stellar mass. Hawking radiation would detect primordial black holes, and Hawking theorized that large numbers of small primordial black holes might exist in the Milky Way galaxy. Since this emission further decreases their mass, black holes with relatively small mass would experience runaway evaporation, creating a burst of radiation in the final phase, termed „burn phase", and this would readily be detected if it exists [5][6].

According to Fabbri, however, observation of Hawking radiation from ordinary black holes is hopeless [7]:

„The bad news is that, unfortunately, in ordinary situations where the black holes are created from gravitational collapse of massive stars the Hawking flux at $T_H \sim 10^{-7}K$, $M_{Sun}/M \leq 10^{-7}$ K gets completely overwhelmed by the cosmic microwave background radiation at $T_{CMB} \sim 3$ K."

Given current technology, the view is that Hawking radiation from black holes cannot be measured. Super massive black holes emit such low energy Hawking radiation that the cosmic microwave background radiation would overcome it's effects.

2. Physical Arguments concerning Hawking Radiation

2.1. Introduction

Based upon quantum effects and the uncertainty principle, Hawking has claimed that virtual electron and positron pairs will be created on the event horizon of a black hole. Positrons with negative mass-energy will be attracted to the black hole gravitationally thus decreasing black hole mass-energy [1][2]. The electron will be radiated away to the Universe resulting in Hawking radiation. The negative mass energy of the positron will decrease the mass of the black hole over a long period of time resulting in black hole evaporation and finally explosion.

From experiment tests, it is presently unknown whether anti-matter is attracted to matter gravitationally or not. The two cases of gravitational matter and anti-matter attraction will be considered in regard to Hawking radiation.

2.1.1. Matter and Anti-matter Gravitational Repulsion

If anti-matter has negative mass-energy then according Newton's Law of Gravitation the attraction between a matter mass M_1 and an anti-matter mass M_2 will be reversed into repulsion by the reversal of the sign:

$$Fg = - G.M_1.-M_2 / R^2 = + G.M_1.M_2 / R^2$$

This would require that positrons be repelled in an anti-gravitational manner away from the „black hole". There would a high probability that emitted positrons would be annihilated on contact with any incoming matter and so this radiation would likely not be verified experimentally. The electron, as positive mass-energy, would be attracted into the „black hole", thus increasing the mass-energy of the black hole, contrary to Hawking's hypothesis!

As the black hole mass cannot decrease, black hole evaporation will not occur over a long period of time.
Furthermore, no black hole explosion would subsequently be possible.

2.1.2. Matter and Anti-Matter Gravitational Attraction

If both matter and anti-matter are attracted into the powerful gravitational well of the „black hole", then there will be no emission of radiation as there will be no net addition to the mass-energy of the black hole. The mass-energy of the electron and positron will simply cancel one another out. A subsequent black hole explosion by black hole evaporation would not be possible in this case either.

2.1.3. Summary regarding Black Hole Evaporation and Explosion

The conclusion is that if the creation of particle-anti particle pairs occurs at the event horizon of a black hole, then black hole evaporation and subsequent explosion will not occur, independent of whether matter and anti-matter are gravitationally attracted, or not.

A surprising theoretical result is that Hawking radiation in the form of anti-matter emission is possible from the black hole event horizon. This form of Hawking radiation may be too low in energy to observe experimentally and simply be swamped by the cosmic microwave background radiation. Furthermore, low energy positron anti-matter emission from the event horizon will probably be annihilated by impact with matter in the surrounding space of the black hole thus nullifying experimental observation. Hence, Hawking positron emission may be possible but will be experimentally undetectable and negligible.

3. Is there Empirical Support for Hawking Radiation?

3.1. The Fermi Space Telescope

In June 2008, the Fermi space telescope was launched to perform observations from low Earth orbit. As the most sensitive gamma-ray telescope in space, designed to perform an all-sky survey studying astrophysical and cosmological phenomena such as active galactic nuclei, pulsars, dark matter and other high-energy sources [8]. One of the five key objectives of the Fermi space telescope mission has been to identify evaporating primordial micro-black holes in the Milky Way galaxy from gamma burst signatures, that is, the Hawking radiation component. Theory suggests that small primordial black holes would be bright sources of gamma rays.

According to Hawking, the average density of primordial black holes could be less than 200 per cubic light year and measurements indicate that the average density of primordial black holes must be less than one million per cubic light year [5]. Although, large numbers of smaller primordial black holes might be clustered in the Milky Way galaxy's halo region, if hawking radiation does not exist, primordial black holes would be difficult to detect due to their small size and gravitational influence.

To date, there has been no evidence of primordial black holes [9]. In addition, there has been no observation of Hawking radiation in the final burn phase that would accompany black hole evaporation [10][11]. Furthermore, CERN has found no evidence that primordial black holes exist [12]. After 11 years and 4 months of dedicated research neither Hawking radiation, nor primordial black holes nor black hole evaporation have been observed. According to Johnson who created the algorithm that searches for gamma rays from primordial black holes in Fermi's Large Area Telescope data [11]:

"*Even though we didn't detect any [primordial black holes], the non-detection sets a limit on the rate of explosions and gives us better constraints than previous research.*"

It could be argued that the phenomenon of gravity waves predicted by Einstein's general relativity in 1916 was not confirmed by observation until 2016, following 100 years of observations [13]. However, gravity waves were calculated to be miniscule in magnitude and only made possible in recent years by extremely sensitive equipment, employing laser interferometer gravitational wave astronomy (LIGO). On 11 February 2016, the LIGO and Virgo Scientific

Collaboration announced they had made the first direct observation of gravitational waves from a binary black hole merger with an energy of 5.3 x 10^{54} ergs [14].

If in the vicinity of the Milky Way galaxy, Hawking radiation in the burn phase of black hole evaporation emits gamma rays that are relatively large in magnitude. According to Hawking, a primordial black hole of mass one billion tons would have a temperature of 120 billion degrees Kelvin, corresponding to an energy of 10 million electron volts and release energy at the rate of 6000 Megawatts [5]. In addition, a black hole explosion or evaporation would produce a massive amount of high energy gamma rays estimated by Hawking to be „*10 million one megaton hydrogen bombs*" or 10^{30} ergs in 0.1 seconds [1][5]. Hawking radiation could have, but has not, been observed from a primordial or micro black holes or black hole evaporation from the Fermi space telescope.

Accordingly, the lack of evidence of Hawking radiation could be viewed as a true negative result. The 'specificity', that is, the ability of a test to correctly not detect the hypothesis, would be 100% [15]. Moreover, in March 2018 it was reported that Hawking would not be awarded a Nobel prize, as his hypotheses regarding Hawking radiation, black hole evaporation and primordial black holes lacked evidence and have not been experimentally verified [16].

3.2. The Search for Primordial Black Holes in Dark Matter and Simulated Hawking Radiation

Searches for primordial black holes from 2001 to 2011 via gravitational effects ruled out the existence of large numbers of primordial black holes with masses ranging from 10^{10} down to 10^{-8} solar masses [17, 18]. Furthermore, the recent work of Zumalacárregui and Seljak shows that black holes with masses greater than 0.01 solar masses occur in insufficient numbers to account for all the dark matter [19]. Their search for lensing of supernovae by black holes comes up empty, leading researchers to conclude that primordial black holes cannot account for all dark matter. The result, taken together with those from other experiments rules out the idea that dark matter could be entirely accounted for with primordial black holes [20].

In 2016, Steinhauer observed spontaneous radiation from a Bose-Einstein condensate that was claimed to be a simulation of Hawking radiation [21]. Similarly, simulations of Hawking radiation of Bose-Einstein condensates by density correlations due to the phonon pairs were given by Fabbri in 2012 [7]. In theory, the Bose Einstein condensate has been proposed as an analogue of a black hole; however, without an event horizon it cannot be a virtual black hole, and cannot be viewed as experimental support for Hawking radiation.

With a lack of evidence following 45 years of international investigations, the questions now arise:

A. Do primordial or micro-black holes exist?
B. Does Hawking radiation exist?

4. Contradictions with Established Science

4.1. Relativistic Event Horizon

As given by the Schwarzschild or Kerr solutions, the general theory of relativity predicts a sufficiently compact mass can deform space-time to form a black hole [23]. A black hole is a region of space-time exhibiting such strong gravitational effects that neither particles nor electromagnetic radiation can escape from the event horizon. General relativity is not concerned with the compression or loss of matter inside the event horizon of a black hole only asserting that neither particles nor light can escape a black hole event horizon.

4.2. Celestial Mechanics and Escape Velocity

In celestial mechanics, escape velocity gives the minimum speed needed for a free object to escape from the gravitational influence of a massive body [24]. For instance, the escape velocity of rockets from the Earth is 11.186 Km/s. The formula for the escape velocity of any celestial object from a mass, M, is:

$$V_{esc} = \sqrt{2GM / R} \qquad (4)$$

The escape velocity from the surface of the event horizon radius R_S (Schwarzschild radius) of a black hole is exactly the speed of light:

$$R_S = 2GM / c^2 \qquad (5)$$

Hence, a black hole or compact star with an event horizon [25] having an escape velocity that is equal to the speed of light, prevents both particles and radiation exiting the Schwarzschild radius.

4.3. Quantum Tunnelling has Zero Transmission Probability through an Event Horizon

Contrary to classical mechanics, where a particle with less energy than a potential barrier will be reflected and not transmitted, quantum tunnelling shows that there is a small probability that a particle with less energy can be transmitted through an energy barrier. However, the transmission probability is dependent upon the energy of the potential barrier and the width of the barrier [26]. Theory requires that mass of the black hole is lost due to Hawking radiation and that quantum tunnelling is the mechanism for mass loss. Please see figure 1.

Inside the event horizon, $r < r_s$, the Schwarzschild equation describing a stationary black hole is:

$$ds^2 = (1 - r_s/r).\, c^2.dt^2 - (1 - r_s/r)^{-1}dr^2 + r^2(d\theta^2+\sin^2\theta.d\varphi^2) \qquad (6)$$

For particles within the event horizon attempting to cross the Schwarzschild radius, r_s :

$r \rightarrow r_s$, and $-(1-r_s/r) \rightarrow 0$ and $-(1-r_s/r)^{-1} \rightarrow \infty$ and so $ds^2 \rightarrow \infty$

The line element ds^2 (c^2dt^2) tends to infinity as $r \rightarrow r_s$, $ds^2 \rightarrow \infty$, and so the arc length, $ds \rightarrow \infty$ (7)

The transmission coefficient or probability, T, [24] for quantum tunnelling through a potential energy barrier, U of width L:

$$T = (16 / (4 + (k_2/k_1)^2)).\, e^{-2k_2 L} \approx e^{-2k_2 L} \qquad (8)$$

Where $k_2 = \sqrt{(2m (U - E))} / \hbar$, $k_1 = \sqrt{(2mE)} / \hbar$,

L is the width of the barrier, m is the mass of the particle, (U - E) is the difference between the particle's kinetic energy and the potential barrier.

E, kinetic energy

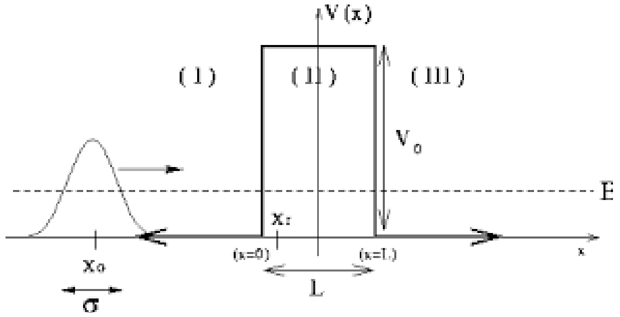

Figure1. Quantum Tunnelling through a Potential Barrier

A. The potential energy barrier, U, of an event horizon:
Energy, E, is force times distance, ds: E = F.ds and ds → ∞ as r → r_s from (7).

➢ Energy tends to infinity, U → ∞, as r → r_s and the potential energy barrier, U, of an event horizon is infinite.

As r → r_s and U → ∞ then ((U - E) → ∞ and from (8) $\kappa_2 \to \infty$ and so T → 0.

➢ The probability of transmission, T, of a particle through an event horizon with infinite potential energy, U, is zero.

B. The width, L, of an event horizon:
As r → r_s the arc length, ds → ∞ from (7) and ds = L and so L → ∞.

As L → ∞ then T → 0 from (8).

A photon and a particle of finite mass both subject to an infinite width would be precluded from quantum tunnelling and escaping an event horizon.

➢ The probability of transmission, T, of any particle through an event horizon with infinite width, L, is zero.

It can be concluded that the probability of transmission via quantum tunnelling of any particle, including a photon, through an event horizon is zero, as the width and the barrier potential energy are infinitely large. The same argument that forbids quantum tunnelling of particles also applies to the Kerr solution for rotating black holes. Hence, Hawking radiation via quantum tunnelling from an event horizon is rendered impossible.

4.4. Firewall Paradox

In curved space-time, a single emission of Hawking radiation involves two mutually entangled particles, according to quantum field theory. The outgoing particle escapes and is emitted as a quantum of Hawking radiation and the infalling particle is accreted in the black hole. The firewall paradox hypothesis indicates that particles are entangled with more than one other particle, but that entanglement is broken the moment it forms. This would create extreme quantities of energy, a firewall at the event horizon [27].

As an outgoing particle must be entangled with all the Hawking radiation the black hole has previously emitted, this phenomenon a principle called „monogamy of entanglement" creates a paradox requiring that the outgoing particle cannot be fully entangled with two independent systems simultaneously, yet the outgoing particle is entangled with both the infalling particle and, independently, with past Hawking radiation.

4.5. Conjectures and Speculations

A comprehensive theoretical study of Hawking radiation has also been given by Helfer in a paper entitled „Do black holes radiate?"[28] According to Helfer, the Hawking hypothesis is conjecture and speculation that relies upon dubious assumptions of quantum gravity. Quantum gravity is an unproven theory because no theory to date has proven successful in describing the general situation where the dynamics of matter, modelled with quantum mechanics, affect the curvature of space-time.

Helfer states *„ordinary physics may be applied to vacuum fluctuations at energy scales increasing exponentially without bound and that quantum gravitational effects may be neglected'*. And continues *„Thus, a definitive theoretical treatment will require an understanding of quantum gravity in at least some regimes, Until then, no compelling theoretical case for or against radiation by black holes is likely to be made.'* Helfer emphasises that that the problems uncovered are whether the correct physical assumptions underlying the mathematics of Hawking radiation are correct.

Helfer argues that „dropping thermal systems into black holes leads to violations of the second law" is probably not really correct as it is not clear whether entropy should refer to the area outside the event horizon or inside the black hole as well [28]. With regard to entropy, Helfer states *„the definition of this (entropy) involves some sort of quantum field theoretic regularisation, and a full understanding of this is yet to come.'*

Similarly, black-hole entropy equation (1) has not been confirmed empirically to date. A controlled calculation of black-hole entropy based on statistical mechanics has been impossible. In 1995, the Bekenstein–Hawking entropy was found to correspond with a super-symmetric black hole in string theory, however, both super-symmetry and string theory are also speculative unproven theories. For the Schwarzschild black hole, no calculation of entropy is possible because the relationship between micro and macro states has not been characterized. The problem remains that black hole entropy and the generalised second law of thermodynamics also remain empirically unverified and speculative.

5. Conclusion

Hawking radiation in the form of anti-matter emission from a black hole event horizon is theoretically possible. However, it is likely that this anti-matter emission will be annihilated in the surrounding space of the black hole and or be swamped by the Cosmic microwave background.

If anti-matter emission occurs from a black hole then the complementary addition of positive mass energy in the form of electrons may increase the mass-energy of a black hole over a time. In either case, whether matter and anti-matter are gravitationally attracted or not, black hole evaporation over a long period of time and its subsequent explosion will not be physically possible.

Due to a lack of evidence following 45 years of the international studies including an 11 year dedicated investigation from the Fermi space telescope, a lack of evidence of its subsequent effects of black hole evaporation and a lack of evidence of micro-black holes or primordial black holes, the Hawking black hole evaporation hypothesis can be viewed as a true negative test result.

Hawking black hole evaporation and explosion is also in contradiction to established sciences:

A. General relativity that asserts neither particles nor light can escape from a black hole event horizon.
B. Celestial mechanics asserts that if the escape velocity is greater than or equal to the speed of light then no particles nor light can escape from an event horizon.
C. The black hole firewall paradox asserts that emitted particles are entangled.
D. Quantum tunnelling transmission probability of zero for any particle through an event horizon renders particle tunnelling from the interior of a black hole impossible.

Hawking radiation is also conjecture:

A. It speculates upon physical assumptions of quantum gravity, a theory as yet also unproven.
B. It speculates on the generalised second law of thermodynamics, a theory unproven to date.

As there has been neither empirical confirmation over a suitably long period of time nor strong theoretical support, the hypothesis of black hole evaporation and subsequent explosion can be viewed to be incorrect.

To quote Karl Popper 1963, Chapter one *Conjectures and Refutations: The Growth of Scientific Knowledge*:

'*But science is one of the very few human activities — perhaps the only one — in which errors are systematically criticized and fairly often, in time, corrected. This is why we can say that, in science, we often learn from our mistakes, and why we can speak clearly and sensibly about making progress there.*'

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