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A5 3 Theoretical Feasibility of a BH-Powered Starship

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Abstract

This paper investigates a theoretical propulsion concept in which the energy source is present in space: a miniature black hole (BH). The spacecraft would harness Hawking radiation emitted by the BH and redirect it opposite to the desired direction of motion, producing thrust without relying on stored fuel. The underlying physics, potential efficiencies, and key engineering challenges of such a "BH starship" are explored.

Introduction

Space travel to other star systems presents one of the greatest technological challenges in modern science. The main difficulty lies in the enormous amount of fuel required to reach interstellar speeds, far beyond what a conventional rocket could carry from Earth.

We explore a speculative propulsion concept in which the energy source is a miniature black hole (BH) already present in space. The spacecraft would harness Hawking radiation emitted by the BH and redirect it opposite to the desired direction of motion, producing thrust without carrying fuel. This study examines the theoretical basis, performance limits, and feasibility of such a "BH starship".

Theory

Hawking (1998) demonstrated that BHs emit thermal radiation due to quantum effects near the event horizon. For simplicity, this analysis considers a non-rotating, uncharged (Schwarzschild) BH. The temperature of the emitted Hawking radiation is given by [1]:

$$T_{\mathrm{H}} = \frac{\hbar c^3}{8\pi G M k_{\mathrm{B}}}. \tag{1}$$

Where T_{H} is the Hawking temperature of the BH, G is the gravitational constant, M is the mass of the BH and k_{B} is the Boltzmann constant. The temperature varies inversely with the BH's mass, meaning that smaller BHs radiate more intensely and at higher photon energies than larger ones.

The total power output of the BH can be estimated by modelling it as a perfect blackbody emitter with surface area $A = 4\pi r_s^2$, where the Schwarzschild radius is defined as

$$r_s = \frac{2GM}{c^2}.$$

Combining Equation 1 with the Stefan–Boltzmann law [2], and using $\sigma = \frac{2\pi^5 k_B^4}{15\,h^3 c^2}$ [3], yields the total radiated power (neglecting small greybody corrections to the ideal blackbody spectrum), assuming unit emissivity for a perfect blackbody:

$$P = \frac{\hbar c^6}{15360\pi G^2 M^2}. \tag{2}$$

Because the power scales as $P \propto 1/M^2$, a decrease in mass causes a rapid increase in luminosity. However, this also leads to a much shorter lifetime. Hawking radiation carries energy away at a rate P. Applying the mass-energy equivalence $E = Mc^2$ shows that the BH mass must decrease according to

$$\dot{M} = -\frac{P}{c^2}. \quad (3)$$

Integrating Equation 3 and combining it with Equation 2 gives a lifetime that scales with the cube of its initial mass,

$$\tau = \frac{5120\pi G^2 M^3}{\hbar c^4}. \quad (4)$$

This relationship highlights the power–stability trade-off: small BHs produce immense power but evaporate quickly, while large BHs are long-lived but emit less.

The propulsion concept considered in this paper assumes that the emitted Hawking radiation could be redirected, using an advanced reflection or conversion mechanism to produce thrust. If a fraction η of the total radiated power can be directed opposite to the desired direction of travel, the resulting thrust is

$$F = \frac{\eta P}{c}. \quad (5)$$

Assuming $\eta = 1$ (an idealised, physically unrealistic efficiency used to establish an upper bound on performance), the total radiated power is entirely converted into thrust. For a spacecraft of mass m_{ship}, the acceleration (a) is therefore, by combining Equation 5 with Newton's second law:

$$a = \frac{F}{m_{\text{ship}}} = \frac{P}{m_{\text{ship}} c}.$$

Rearranging this equation (noting that the total spacecraft mass m_{ship} consists of mass of payload m_{load} + BH mass M)gives a cubic equation with one real physical root for the black-hole mass that satisfies the desired a and m_{load}:

$$aM^3 + a\, m_{\text{ship}} M^2 - \frac{\hbar c^5}{15360\, \pi\, G^2} = 0. \quad (6)$$

To determine the a required to reach a distance d in time t, we assume a symmetric acceleration–deceleration trajectory. In reality, the power radiated, and thus; the a, increases with time as the BH evaporates, but this refinement is beyond the scope of this paper. Assuming instantaneous reversal of thrust halfway through the journey, the constant a required to reach distance d in total time t is

$$a = \frac{4d}{t^2}. \quad (7)$$

Discussion and Calculations

To reach the nearest star system, 4.25 light-years away [4] within 75 years, the required acceleration is $a = 0.0287\ \mathrm{m\,s^{-2}}$ (Equation 7).This time frame is chosen to balance the ambitious nature of interstellar travel with a feasible mission duration. Using Fig.1 and assuming a spacecraft mass of 10^8 kg, this would require a BH of mass 3.16×10^8 kg to generate the necessary thrust. From Equation 4, this BH would evaporate in 84.1 years. After 75 years, it would have shrunk to approximately 1.51×10^8 kg, increasing a to $0.126\ \mathrm{m\,s^{-2}}$, this suggests that, in a more detailed analysis, the point at which the thrust is reversed would occur later than the halfway mark of the journey.

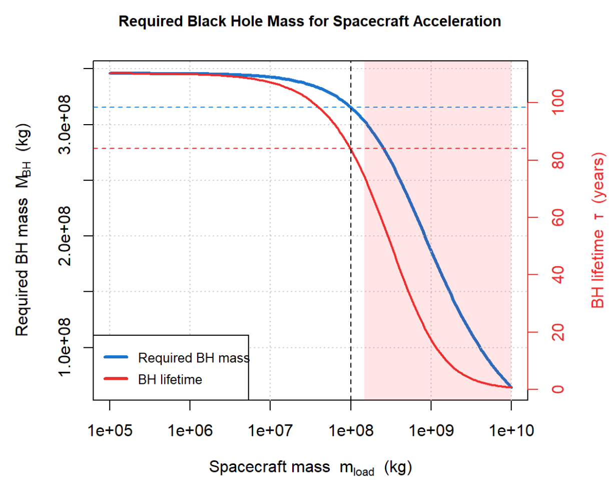

Figure 1: Required BH mass for a 75-year mission with a spacecraft acceleration of $a = 0.0287\ \mathrm{m\,s^{-2}}$, as derived from (Equation 6). The dashed line represents the example payload mass. The right axis shows the BH lifetime, and the shaded region indicates the area where the BH would evaporate before the mission's end.

Conclusion

A 3.16×10^8 kg BH could, in principle, accelerate a 10^8 kg load to interstellar speeds within 75 yr, though redirecting Hawking radiation and maintaining efficiency $\eta \approx 1$ remain formidable challenges. Future research could develop more sophisticated analyses that account for the increasing acceleration as the BH evaporates, explore realistic efficiency limits, and propose viable mechanisms to redirect the Hawking radiation to produce thrust.

References

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[4] Imagine the Universe! (no date), Available at: https://imagine.gsfc.nasa.gov/features/cosmic/nearest_star_info.html. (Accessed 8 Nov 2025)