ILLUMINATION OF A PLANET BY A BLACK-HOLE MOON AS A TECHNOLOGICAL SIGNATURE

Abraham Loeb[1]

[1]*Astronomy Department, Harvard University, 60 Garden St., Cambridge, MA 02138, USA*

ABSTRACT

I show that Hawking radiation from a mini black hole with a mass of $\sim 10^{11}$ g in a low orbit around an otherwise frozen rogue planet, can supply the energy needs of a civilization on the surface of the planet. Maintaining this furnace for more than a few years requires a modest accretion rate of ~ 2 kg s^{-1}. The associated technosignature is detectable as a gamma-ray source occulted by a warm planet every 1-2 hours, with no stellar-mass companion.

1. INTRODUCTION

In this paper, I consider the possibility that an advanced civilization would choose to manufacture a furnace that returns clean energy from the matter fueling it, with a conversion efficiency of mass to energy of nearly 100%, two orders of magnitude above the most efficient nuclear fuel. Once the fuel enters the furnace, it gets consumed and disappears from view. This enclosure of this ideal furnace is the event horizon of a mini black hole.

Advanced civilizations could satisfy their energy needs by processing matter through an accretion disk around a mini black hole that orbits their planet like a moon.

The main technological challenge in producing a mini black hole involves the enormous mass density required to make it. If it is possible to manufacture a mini black hole and keep it as a luminous moon around the planet, then this artificial furnace could replace a star in illuminating and warming a rogue planet that is otherwise frozen and uninhabitable. Rogue (free-floating) planets without a host star to warm them up were recently discovered by gravitational microlensing (Mróz et al. 2020; Sumi et al. 2023; Mróz et al. 2024; Kunimoto et al. 2024; Rektsini & Batista 2024).

For the past half century, cosmologists conjectured that mini black holes might have been produced in the infant Universe, when the radiation energy density was high enough (Carr & Hawking 1974; Carr & Green 2024). It is possible that the dark matter is made of primordial black holes in the mass range $\sim 10^{17}$-10^{22} g (Carr & Kuhnel 2021; Green 2024). Here, we consider a different possibility that a sufficiently advanced technological civilization might have been able to trap a primordial black hole or manufacture a mini black hole in order to satisfy its energy needs.

Stephen Hawking realized in 1974 that a mini black hole would shine on its own, even without an external supply of fuel (Hawking 1974). The associated Hawking radiation is brighter for smaller black holes, causing them to evaporate over a short time. Given the Hawking relations, we identify below the optimal black hole mass for providing the solar energy flux on an Earth-size planet. For simplicity, we focus the discussion on non-spinning (Schwarzschild) black holes.

2. DESIRED PARAMETERS OF THE BLACK HOLE

To obtain specific numbers, consider a mini black hole that circles a rocky planet like the Earth at an altitude of $\sim 1.5 \times 10^3$ km, about a quarter of the Earth's radius. This is commonly called a Low Earth Orbit for artificial satellites and was chosen here to obtain modest energy and mass requirements. Such a black hole would supply the energy flux of 1.4×10^6 ergs s^{-1} cm^{-2} that the Earth is currently receiving from the Sun if its luminosity is $L_\bullet \sim 4 \times 10^{23}$ ergs s$^{-1} = 10^{-10} L_\odot$.

This moon would illuminate the ground under it periodically over an orbital time of about ~ 90 minutes. The duration of the luminous period scales with the orbital radius of the moon to the 1.5 power.

In terms of fundamental constants, the Hawking luminosity is given by,

$$L_\bullet = \frac{\hbar c^6}{15360\pi G^2 M_\bullet^2} = 0.93 \times 10^{-10} \; L_\odot \; \left(\frac{M_\bullet}{10^{11} \text{ g}}\right)^{-2} . \tag{1}$$

The required energy flux at this low-altitude orbit can be supplied by Hawking radiation from a mini black hole with a mass of $M_\bullet = 0.96 \times 10^{11}$ g $(L_\bullet/10^{-10}L_\odot)^{-1/2}$, which is equivalent to the mass of an asteroid with a 40-meter diameter.

The Hawking evaporation time for such a black hole is,

$$t_\bullet = \left(\frac{5120\pi G^2 M_\bullet^3}{1.80083\hbar c^4}\right) = 1.5 \text{ yr} \left(\frac{M_\bullet}{10^{11} \text{ g}}\right)^3 . \tag{2}$$

In order to maintain the operation of the furnace for a period longer than a year, it is necessary to supply it with a modest accretion rate of,

$$\dot{M} = \left(\frac{M_\bullet}{t_\bullet}\right) = 2.2 \; \frac{\text{kg}}{\text{s}} \left(\frac{M_\bullet}{10^{11} \text{ g}}\right)^{-2} , \tag{3}$$

so as to keep its mass constant. This mass supply resembles the deposition of logs in a wood-burning fireplace. The civilization could automate the process by steadily releasing material from a companion satellite, orbiting in the vicinity of the black hole and feeding its accretion disk in a steady state to compensate for its Hawking radiation loss. If the feeding ever stops, the $\sim 10^{11}$ g black hole would evaporate and disappear within $t_\bullet \sim 1.5$ years. In the regime where the black hole accretion rate balances the Hawking mass loss rate, the accretion luminosity would make a small fractional correction to the Hawking luminosity, of order the radiative efficiency with typical values $\lesssim 10\%$.

The Hawking temperature of the mini black hole is given by,

$$T_\bullet = \left(\frac{\hbar c^3}{8\pi k_B G M_\bullet}\right) = 1.2 \times 10^{15} \text{ K} \left(\frac{M_\bullet}{10^{11} \text{ g}}\right)^{-1} , \tag{4}$$

with the peak of the Hawking radiation emitted in γ-rays with an energy of $E_\gamma = 415 \, (M_\bullet/10^{11} \text{ g})^{-1}$ GeV. These photons would be reprocessed by matter in the surrounding accretion disk, as well as the planet's atmosphere and rocky surface, into low-energy radiation and heat that could supply the energy needs of the host civilization.

The Klein-Nishina cross-section for scattering of the emergent radiation on electrons is $\sim 10^{-30}$ cm$^2(E_\gamma/415$ GeV$)^{-1}$ or equivalently $\sim 10^{-6} \, (E_\gamma/415$ GeV$)^{-1}$ of the Thomson cross-section. As a result, the emergent luminosity of $\sim 10^{-10}L_\odot$ is comparable to the effective Eddington limit for infalling matter onto a $\sim 10^{11}$ g black hole. This numerical coincidence allows matter to accrete into the black hole in response to its attractive gravity despite the repulsive radiative force from the Hawking radiation.

The technology to produce a mini black hole of this mass must reach a mass density of,

$$\rho = \left(\frac{3c^3}{32\pi G^3 M_\bullet^2} \right) = 5 \times 10^{60} \ \frac{\text{g}}{\text{cm}^3} \ \left(\frac{M_\bullet}{10^{11} \ \text{g}} \right)^{-2} \ , \tag{5}$$

near its event horizon. Whether such a technological feat was accomplished by an advanced civilization in the Milky-Way galaxy remains to be seen. Gamma-ray and infrared telescopes could search for an anomalous gamma-ray moon occulted every 1-2 hours by a warm, infrared-emitting planet.

3. DETECTION AS A TECHNO-SIGNATURE

If we ever detect a rogue rocky planet which is illuminated by a gamma-ray moon with no stellar-mass companion, we would need to consider the possibility that the source was created (or trapped as a primordial black hole) by a highly-advanced technological civilization. There is no better marker of technological innovation than creating a furnace out of spacetime curvature in the form of a mini black hole.

Currently, there are a large number of startup companies aiming to make compact fusion reactors. A mini black hole would be far more efficient and environmentally friendly.

ACKNOWLEDGEMENTS

REFERENCES

Carr, B., & Kuhnel, F. 2021, arXiv e-prints, arXiv:2110.02821, doi: 10.48550/arXiv.2110.02821

Carr, B. J., & Green, A. M. 2024, arXiv e-prints, arXiv:2406.05736, doi: 10.48550/arXiv.2406.05736

Carr, B. J., & Hawking, S. W. 1974, MNRAS, 168, 399, doi: 10.1093/mnras/168.2.399

Green, A. M. 2024, Nuclear Physics B, 1003, 116494, doi: 10.1016/j.nuclphysb.2024.116494

Hawking, S. W. 1974, Nature, 248, 30, doi: 10.1038/248030a0

Kunimoto, M., DeRocco, W., Smyth, N., & Bryson, S. 2024, arXiv e-prints, arXiv:2404.11666, doi: 10.48550/arXiv.2404.11666

Mróz, P., Ban, M., Marty, P., & Poleski, R. 2024, AJ, 167, 40, doi: 10.3847/1538-3881/ad1106

Mróz, P., Poleski, R., Gould, A., et al. 2020, ApJL, 903, L11, doi: 10.3847/2041-8213/abbfad

Rektsini, N. E., & Batista, V. 2024, arXiv e-prints, arXiv:2407.06689, doi: 10.48550/arXiv.2407.06689

Sumi, T., Koshimoto, N., Bennett, D. P., et al. 2023, AJ, 166, 108, doi: 10.3847/1538-3881/ace688