Black holes as an energy source

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Modern human society faces a serious energy problem. We depend on oil and coal for most of our energy needs, and it is said that these resources will be depleted in a few decades. Furthermore, the use of oil and coal increases the concentration of carbon dioxide in the atmosphere and promotes the greenhouse effect, which leads to global warming, acid rain, abnormal climate, and the destruction of ecosystems.

For this reason, we urgently need to devise an alternative energy source that can replace oil and coal as a major source of energy, and that is also environmentally friendly and sustainable. But it is easy to imagine that if we continue to use resources on Earth, they will one day be depleted. Then, why not look to outer space? For example, solar energy is precisely the kind of energy that is obtained from outer space, albeit less efficient. And, surprisingly, that other celestial body that we have all heard of at least once can be an enormous source of energy, that is, a black hole.

Roughly speaking, a black hole is a celestial body whose gravity is so strong that even the fastest light cannot escape it. And the boundary where the light can escape or not is called the "event horizon". So, those who fall inside it will not be able to communicate with outsiders no matter how hard they try. But a black hole is more than that. General relativity invented by Einstein reveals that black holes have a richer and more interesting structure than we can imagine.

What happens when a black hole rotates? A mysterious region called the "ergo region" emerges outside the event horizon. In that region, no object can come to rest. Even if an infinite force is applied to the object, it cannot come to rest and is forced to flow in the direction of the black hole's rotation. This fact leads to a negative energy state being allowed within the ergo region, which cannot happen under normal circumstances.

We can extract energy from a black hole by taking advantage of the fact that energy can be negative within the ergo region. For example, consider a spacecraft with positive energy entering the ergo region and launching a cannonball into it. Suppose the energy of that cannonball becomes negative due to the rotational effects. Then, considering the law of conservation of energy, the spacecraft will gain that amount of energy. This is called the Penrose process.[1] For example, in the famous movie "Interstellar", which was supervised by theoretical physicists, the Spaceship Endurance was able to escape from the supermassive black hole Gargantua because it used the Penrose process to obtain sufficient escape velocity.

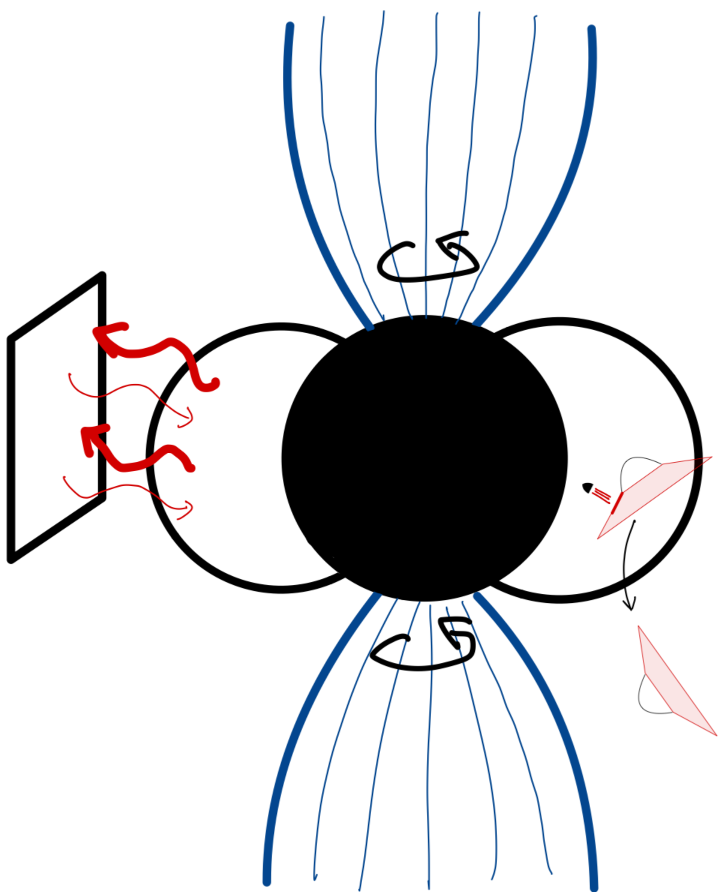
Using a similar principle, when electromagnetic waves are injected into a rotating black hole, electromagnetic waves of a specific frequency are amplified and returned. This is called the super-radiation phenomenon.[2] So, for example, if a large mirror can be successfully placed near a spinning black hole, the electromagnetic waves can be amplified many times over. This energy extraction would be feasible with something like solar panels. Another similar phenomenon is the Blandford Znajek effect, [3] in which rotating energy is extracted by a magnetic field. This effect occurs when a rotating black hole is surrounded by plasma, and this may be a candidate energy source for relativistic jets such as gamma-ray bursts and active galactic nuclei, which are high-energy astrophysical objects. If this is true, one can imagine how great the rotational energy of a black hole would be. This energy is quite enormous, and if we can successfully extract it, future generations may not have to worry about energy depletion. Furthermore, since this energy is extracted in space, it is clean energy for Earth and would not exacerbate environmental problems on Earth.

Even though spinning black holes can be a great source of energy, they have received little attention in modern society. The reason for this is probably the perceived difficulty in achieving what is described below. We must tackle two obstacles to achieve.

First, the observation of black holes is still in its infancy. Assuming that a black hole is formed by self-gravitational evolution from a molecular cloud, we can roughly estimate that there is one black hole in a sphere with a radius of about 20 light-years.[4] However, even the nearest black hole observed today is said to be about 3,000 light-years away. In other words, there is a great possibility that more black holes will be discovered as observation technology improves, and perhaps black holes may exist within our reach. Extracting energy from black holes, as mentioned above, is not an empty dream.

Second, there are still some theoretical issues to be solved regarding indirect evidence such as jets. Theoretical studies and simulations of these phenomena will greatly contribute to the improvement of observations of black holes if they provide more definitive information about the behavior around black holes.

In any case, to be able to utilize black holes as an energy source, it is essential to improve the observational techniques of black holes and promote theoretical studies, which are a bit away from our real lives. Humans have developed enough technology on the ground but are still in the process of expanding into space, so, they are insensitive to the idea of utilizing space. However, looking back on the history of mankind, as can be seen from the history of the energy revolution, basic research must have been the first step behind the development of new technologies. We can only hope that the current basic research on black holes will one-day bear fruit, pioneer new technologies, and solve humanity's energy problems.



References

[1] Penrose, Roger and Floyd, RM, Extraction of rotational energy from a black hole. *Nature Physical Science.* 229, 6, 177-179 (1971).

[2] Ya. B. Zel'dovich, Generation of waves by a rotating body. *JETP Lett.* 14, 180. (1971)
[3] Blandford, Roger D and Znahek, Roman L, Electromagnetic extraction of energy from Kerr black holes. *Monthly Notices of the Royal Astronomical Society.* 179, 3, 433-456. (1977)
[4] Shapiro, Stuart L and Teukolsky, Saul A. Black holes, white dwarfs, and neutron stars: The physics of compact objects. (1983)