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Ray-Tracing Study of Artificial Black Hole in Electromagnetic Field

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Abstract

The artificial black hole has the name "Black Hole", although the size of the "Mini", but any passing electromagnetic wave or light, it is impossible to escape its gravity. Based on the theory of artificial black holes, it is possible to design wave absorbing materials with excellent performance. In this paper analyzes the trajectory equation of light rays in black holes using the Hamilton principle. In the last chapter of the article, the feasibility of the theory in this paper is verified by using Matlab numerical simulation to give ray tracing scenarios under different refractive indices.

Subject Areas

Electromagnetics

Keywords

Artificial Black Hole, Electromagnetic Wave, Hamiltonian Function, Spiral Trajectory

1. Introduction

Black hole is a kind of celestial body with huge density inferred from theory and observation, which usually exists in all galaxies of the universe. In the 1980s, Professor William Anlu of Canada proposed that the performance of sound waves in a fluid is very similar to that of light in a black hole. If the speed of the fluid exceeds the speed of sound, then a "artificial black hole" of sound phenomena can be established in the fluid. With the invention of the Large Hadron Collider, physicists believe that these accelerators are likely to produce high-density materials similar to black holes, and "artificial black holes" may even threaten the safety of the earth [1].

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The particle accelerator, also known as the Large Hadron Collider (LHC), was built by the European Center for Nuclear Research (CERN) in a circular tunnel nearly 27 kilometers long, and is known as the world's largest "black hole factory" device. At 15:30 pm, on September 10, 2008, Beijing Time officially began to operate, becoming the largest particle accelerator facility in the world. Since then, scientists can theoretically produce a black hole in a second.

Each coaxial ring is formed in the form of circuit boards with different structures, and the coaxial rings are connected with each other, so its dielectric constant is very smooth. The outer 40 coaxial rings form the shell, and the inner 20 coaxial rings form the absorber. When the incident electromagnetic wave strikes the equipment, the electromagnetic wave will be induced into the inner coaxial ring and then absorbed. The coaxial ring will convert the absorbed light into heat. "The purpose of the 'artificial black hole' in the laboratory is certainly not to put an all-consuming 'devil' in his pocket. According to Cheng Qiang, the 'artificial black hole' existing in the State Key Laboratory of Millimeter Wave of Southeast University is actually a simulation device, which can absorb electromagnetic waves in the microwave band. In the future, it can also absorb light. But in addition, it can't absorb anything substantial." It only absorbs electromagnetic waves and does not absorb (physical) substances.

In reference [2] [3] [4] [5], they study black holes for the linear hyperbolic equations describing the wave propagation in the moving medium. Such black holes are called artificial since the Lorentz metric associated with the hyperbolic equation does not necessary satisfies the Einstein equations. Artificial black holes also arise when we consider perturbations of the Einstein equations.

Applying absorbent materials to various weapons and equipment and military facilities such as aircraft, missiles, tanks, ships, warehouses, etc., can absorb reconnaissance radio waves and attenuate reflected signals, thus breaking through the defense area of the enemy radar. This is a powerful means of anti-radar reconnaissance and a way to reduce the attack of the weapon system by infrared guided missiles and laser weapons. In addition, absorbing materials are widely used in RFID/NFC, wireless charging and other fields [6] [7] [8] [9] [10].

Currently, the study of ray tracing of artificial black holes in electromagnetic fields has attracted the attention of many researchers both domestically and internationally. Some research teams abroad have made some progress in this area by designing special artificial structures, such as metal nanostructures or dielectric photonic crystals, to control and guide electromagnetic waves, thus simulating the absorption characteristics of black holes. These research findings provide new ideas for the control and manipulation of electromagnetic waves.

However, there are still some issues in the current study of artificial black holes in electromagnetic fields. Firstly, the design and fabrication of artificial black holes require high-precision processing techniques and material processes, which are costly and difficult to manufacture. Secondly, for electromagnetic waves of different frequencies and wavelengths, the absorption effects of artificial black holes may vary and require further optimization in design. Additionally, issues such as energy loss and stability need to be considered in the practical application of artificial black holes, presenting challenges that require urgent solutions in current research. Therefore, further in-depth research is needed in the future to overcome these issues and achieve more stable and efficient applications of artificial black holes in electromagnetic fields.

Therefore, the so-called artificial black hole refers to a special material with specific electromagnetic parameters and distribution. When the light is incident on the surface of this material, the reflection is very small, and most of the energy enters the interior of the material and is absorbed. In this paper, based on the theory of artificial black hole, we design excellent absorbing materials.

2. Hamiltonian Function in Artificial Black Hole

In isotropic nonmagnetic materials, the eikonal equation can be expressed as

$$|\nabla\Phi|^2 = N^2 = \varepsilon. \tag{1}$$

where N is a constant. Different values of N indicate different absorption of light. Without losing generality, we only consider the two-dimensional case, and consider the cylindrical coordinate system, we can get

$$\nabla\Phi = e_r \frac{\partial\Phi}{\partial r} + e_\varphi \frac{\partial\Phi}{r\partial\varphi} = e_r p_r + e_\varphi \frac{p_\varphi}{r}, \tag{2}$$

so the eikonal equation can be expressed as

$$|\nabla\Phi|^2 = p_r^2 + \left(\frac{p_\varphi}{r}\right)^2 = \varepsilon. \tag{3}$$

We can consider establishing a two-dimensional Hamiltonian function as

$$H(r,p) = \frac{1}{2}\left(\frac{p_r^2}{\varepsilon} + \frac{p_\varphi^2}{r^2\varepsilon}\right). \tag{4}$$

At this time, the dielectric constant ε of the artificial light snow black hole satisfies the following equation

$$\varepsilon(r) = \left(\frac{R}{r}\right)^n,\ 0 < r < R, \tag{5}$$

where R is the radius of the optical black hole. In order to study the internal ray trajectory of the artificial black hole more conveniently, without loss of generality, we select a simple circular medium with axisymmetric distribution to study, and the corresponding Hamiltonian function is

$$H = \frac{1}{2}\left(\frac{p_r^2}{\varepsilon(r)} + \frac{p_\varphi^2}{r^2\varepsilon(r)}\right), \tag{6}$$

According to Hamilton's principle, the following four differential equations can be obtained:

$$\frac{\mathrm{d}p_\varphi}{\mathrm{d}t} = 0, \tag{7}$$

$$\frac{\mathrm{d}r}{\mathrm{d}t}=\frac{r^n}{R^n}P_r, \tag{8}$$

$$\frac{\mathrm{d}\varphi}{\mathrm{d}t}=\frac{r^{n-2}}{R^n}P_\varphi, \tag{9}$$

$$\frac{\mathrm{d}p_r}{\mathrm{d}t}=-\frac{nr^{n-1}p_r^2}{2R^n}-\frac{(n-2)r^{n-3}p_\varphi^2}{2R}, \tag{10}$$

Using Equations (7) - (10) and combined with the initial condition when $t = 0$, we can solve the trajectory equation of light rays in the artificial black hole. In general, we can use functions such as ode45 in Matlab to numerically solve the ray trajectory.

Remark 1: The Hamiltonian principle, also known as the principle of least action, is a fundamental principle in classical mechanics. It states that in classical mechanics, the trajectory of a system is the path that minimizes the action. Action describes the properties of a system's motion over a certain period of time and is equal to the integral of the system's Lagrangian function over that time. According to the Hamiltonian principle, the true trajectory of a system among all possible paths is the one that minimizes the action, typically resulting in a minimum value. This principle is widely applied in the analysis and description of classical mechanics and is of great importance for understanding physical phenomena in the natural world.

3. Simulation

We assume that the parallel light is emitted from the position of $x = -3$ and shines on the structure of an artificial black hole with a radius of 3. Light enters the interior of the artificial black hole and is sucked into the center of the black hole. Since the refractive index corresponding to the edge of the black hole is 1 and matches the air, the light at the interface does not deflect. In this paper, the cylindrical coordinate system is adopted, so the initial conditions are analyzed in the following.

Figure 1 shows the geometric relationships involved in the determination of initial conditions [3].

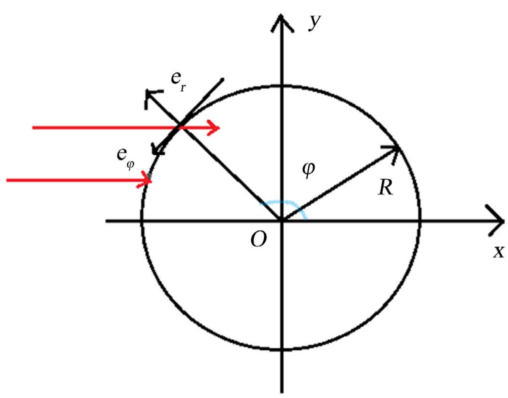

Figure 1. Schematic diagram of initial conditions.

Remark 2: For the sake of analysis, we assume that the parallel light propagates along the plane. In fact, the position from which parallel light is emitted in space can be arbitrary, but it can always be moved through the displacement of the coordinate axis to place the initial emission position of parallel light at a specific location on the coordinate plane.

We assume that the radius of the artificial black hole is *R*, The polar angle corresponding to the incident point is φ, then the initial position is

$$r = R, \tag{11}$$

$$\varphi = \pi + \arctan\left(\frac{y}{x}\right). \tag{12}$$

We use the unit vector in the cylindrical coordinate system and the two ends of Formula (2) to carry out the dot product operation, and consider the property of gradient, we can get

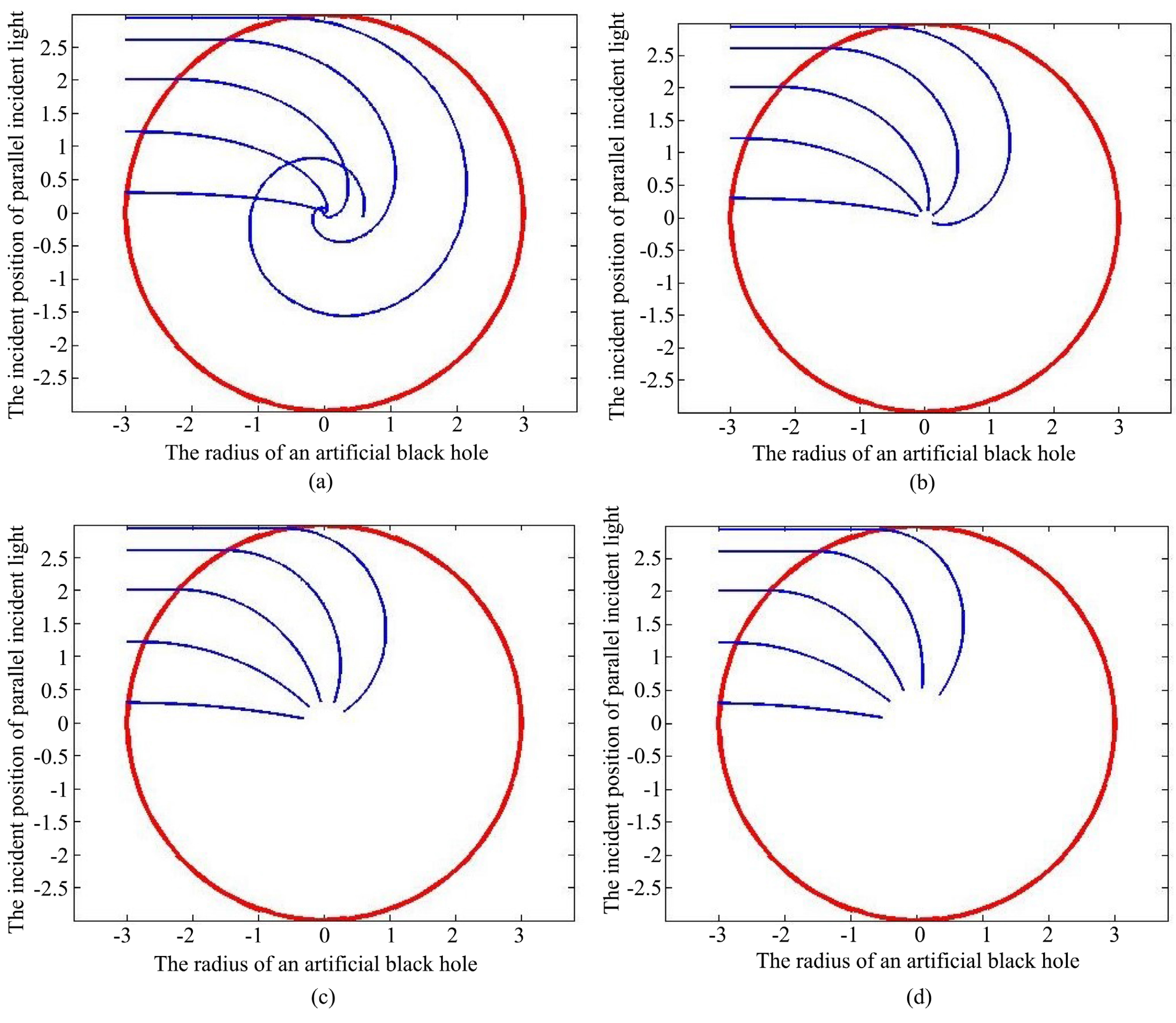

Figure 2. Ray tracing inside an artificial black hole. (a) Refractive index $m = 2$; (b) Refractive index $m = 3$; (c) Refractive index $m = 4$; (d) Refractive index $m = 5$.

$$P_r = e_r \cdot \nabla\Phi = \frac{\partial \Phi}{\partial r}, \tag{13}$$

$$P_\varphi = re_\varphi \cdot \nabla\Phi = \frac{\partial \Phi}{\partial \varphi}. \tag{14}$$

According to the Formula (1) of the eikonal equation, $|\nabla\Phi| = N$ is true, and the direction of the gradient is the direction of the light ray. At the same time, considering that the refractive index at the edge of the black hole is 1 and the radius is *R*, hence

$$P_r = e_r \cdot \nabla\Phi = \cos\varphi, \tag{15}$$

$$P_\varphi = re_\varphi \cdot \nabla\Phi = -R\sin\varphi. \tag{16}$$

Obviously, in the numerical simulation, corresponding to different refractive index, the ray tracing scenarios under different conditions will be obtained.

Without losing generality, we assume that the number of rays is 5. In this paper only gives an example where the refractive index is taken as 2, 3, 4, 5. The red line represents the edge of the artificial black hole, and the blue line represents incident light.

From **Figure 2**, we can see that when the light enters the interior of the artificial black hole, it rotates around the center in a spiral orbit and finally enters the center. Therefore, by arranging the absorbing material at the center of the circle, the light can be introduced into the interior of the artificial black hole and absorbed.

4. Conclusion

The theory of artificial electromagnetic black holes is a hot topic in the field of physics, mathematics and engineering recently. Based on the theory of artificial black holes, this paper studies the Hamiltonian mechanics and canonical equations in black holes. Through the numerical simulation, we can see that the light rays with different refractive indices are absorbed into the interior of the black hole.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Novello, M., Visser, M. and Volovik, G.E. (2002) Artificial Black Holes. World Scientific, London. https://doi.org/10.1142/4861

[2] Leonhardt, U. and Philbin, T.G. (2008) The Case for Artificial Black Holes. *Philosophical Transactions of the Royal Society A*, **366**, 2851-2857. https://doi.org/10.1098/rsta.2008.0072

[3] Eskin, G. (2011) Artificial Black Holes. arXiv:1105.2015. https://doi.org/10.48550/arXiv.1105.2015

[4] Mei, Z.L., Li, Y.E. and Ma, A.N. (2020) Matlab Simulations for Electromagnetic Fields and Microwave Technology. Tsinghua University Press, Beijing.

[5] Liu, W. and Huff, G. (2022) Additive Manufactured Spherical Resonator V-Band Elliptical Waveguide Filter. *Microwave and Optical Technology Letters*, **64**, 265-268. https://doi.org/10.1002/mop.33085

[6] Lu, W., Jin, J.F., Lin, Z., *et al.* (2010) A Simple Design of an Artificial Electromagnetic Black Hole. *Journal of Applied Physics*, **108**, Article ID: 064517. https://doi.org/10.1063/1.3485819

[7] Pelat, A., Gautier, F., Conlon, S.C., *et al.* (2020) The Acoustic Black Hole: A Review of Theory and Applications. *Journal of Sound and Vibration*, **476**, Article ID: 115316. https://doi.org/10.1016/j.jsv.2020.115316

[8] Kumar, S., Datta, D. and Singh, S.K. (2015) Black Hole Algorithm and Its Applications. In: Azar, A. and Vaidyanathan, S., Eds., *Computational Intelligence Applications in Modeling and Control*, Springer, Cham, 147-170. https://doi.org/10.1007/978-3-319-11017-2_7

[9] Hatamlou, A. (2013) Black Hole: A New Heuristic Optimization Approach for Data Clustering. *Information Sciences*, **222**, 175-184. https://doi.org/10.1016/j.ins.2012.08.023

[10] Curtis, M. and Sijacki, D. (2015) Resolving Flows around Black Holes: Numerical Technique and Applications. *Monthly Notices of the Royal Astronomical Society*, **454**, 3445-3463. https://doi.org/10.1093/mnras/stv2246