

Insights sobre singularidades do tipo Kugelblitz implícitos nos trabalhos de Louis de Broglie

Insights on Kugelblitz singularities implicit in Louis de Broglie's works

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Resumo

Neste artigo é proposta uma interpretação complementar para a equação do comprimento de onda de Louis de Broglie, considerando ondas eletromagnéticas teóricas, de altíssima energia. Os desdobramentos conceituais dessa abordagem apontam para a ocorrência de fenômenos gravitacionais que se realizariam na escala de Planck. Considerando esses fenômenos hipotetizados, foi calculado o valor mínimo para o comprimento de onda a partir do qual a transmissão de energia eletromagnética seria viável na normalidade do espaço-tempo. Ondas que apresentassem energia superior a essa condição limítrofe são apresentadas como potenciais formadoras de singularidades não-massivas, formadas apenas por radiação eletromagnética, denominadas *kugelblitze*, ou bolas de luz.

Palavras-chave: Comprimento de onda, buraco-negro, raio de Schwarzschild

Abstract

In this work, I proposed a complementary interpretation of the Louis de Broglie wavelength equation considering theoretical electromagnetic waves with very high energy. The conceptual developments of this approach point to the occurrence of gravitational phenomena that would occur on the Planck scale. Considering these hypothesized phenomena, we calculated the minimum value for the wavelength at which the transmission of electromagnetic energy would be viable in normal space-time. Under this threshold condition, high energetic waves would have the potential to form non-massive singularities called kugelblitze, or balls of light.

Keywords: Wavelength, black hole, Schwarzschild radius

1. Introduction

In the 1920s, the French physicist Louis de Broglie (1892-1987) published a series of papers attempting to integrate the corpuscular and wave descriptions of the nature of light [1, 2, 3]. Among Louis de Broglie's proposals, this article highlights his wavelength equation [4]. According to it, every material body presents an association with a wave phenomenon whose wavelength is inversely proportional to its mass. This understanding was fundamental to Louis de Broglie's conclusions about the wave nature of the electron, for which he was awarded the Nobel Prize in 1929.

The purpose of this work was to out a theoretical exercise establishing a correlation between the Schwarzschild metric [5] and Louis de Broglie's wavelength equation. So, it was possible to derive a limit condition for the relationship between wavelength and mass. In this approach, it was considered the possibility of the formation of gravitational fields on a quantum scale from hypothetical high energetic electromagnetic waves. In 1955, John Archibald Wheeler had already proposed the formation of electromagnetic singularities [6]. Wheeler called these phenomena geons, short for electromagnetic-gravitational entities. However, the original German term "Kugelblitz" is more commonly used in the literature.

This paper is structured as follows: Section 2 gives a historical overview of Louis de Broglie's work, emphasizing the development of his wavelength equation. Section 3 presents the mathematical relationships between Louis de Broglie's and Schwarzschild's equations and their physical implications. Section 4 discusses the feasibility of the high energetic waves hypothesized in this paper occurring.

2. Historical review

At the beginning of the 20th century, the first notions of quantum mechanics were introduced to the scientific community, mainly through the work of Max Planck [7] and Albert Einstein [8]. The understanding that electromagnetic energy flows in a quantized way, i.e., in small discrete units (quanta), led several researchers to question the descriptions already established for some natural phenomena, especially those related to light. In this scenario, the physicist Louis de Broglie presented his first paper in 1922 [1]. In this article, de Broglie presented a new perspective on the nature of light, proposing a corpuscular description based solely on the dynamics of photons. To support his argument, de Broglie referenced Planck's equation [7] (1), which considers frequency, a characteristic of wave phenomena, to highlight the significance of energy in distinguishing between photons.

$$E = hf \quad (1),$$

where the symbol ' h ' denotes Planck's constant, while the symbol ' f ' represents frequency.

In 1923, Louis de Broglie published an article [2] on the dynamics and energy of quanta. He observed that there exists a connection between equation (1) and Einstein's relativistic equation (2) and understood that quanta could have low mass values, on the order of 10^{-54} kilograms, and speeds very close to the speed of light (c).

$$E = mc^2 \quad (2)$$

By combining equations (1) and (2), the correlation $hf = mc^2$ was obtained. From this association, de Broglie deduced that each moving material body is associated with a wave phenomenon. An external observer would perceive this phenomenon as always being in the same phase on the quantum scale, resulting in the perception of a rectilinear displacement, as established by classical mechanics. However, there was a relativistic impediment to this solution: if a quantum were to have a speed very close to the speed of light, the associated wave would have to have a speed equal to or greater than that of light.

In 1924, Louis de Broglie [3] reaffirmed his dual understanding of the nature of light. He used a relativistic approach to describe wave phenomena, proposing the wave characterization in a momentum-energy quadrivector, from which it would be possible to relate the momentum of a particle to the wavelength of the wave associated with that particle. Equation (3) describes this understanding:

$$\lambda = h/p \quad (3),$$

where λ is the wavelength, h is Planck's constant, and p is the momentum of the particle. This equation (3) was rewritten by de Broglie in his Nobel Prize speech in 1929 as follows:

$$\lambda = h/mc \quad (4).$$

Currently, the de Broglie wavelength equation (4) has its application considering the uncertainty principle. This way, Planck's constant (h) is used in its reduced form ($\hbar$), i.e., 1.05×10^{-34} instead of 6.6×10^{-34} . For a broader historical review, including teaching proposals based on Louis de Broglie's original articles, see reference [9].

3. Complementary interpretation of de Broglie's wavelength

Traditionally, we use the Louis de Broglie equation (4) to estimate the wavelength associated with a body of a previously estimated mass. In calculations involving bodies with significant mass, the wavelength values are too small, even lower than the Planck length. They are, therefore, referred to as negligible when describing the physical properties of these bodies. For instance, consider a body with a mass of 1 kilogram. Applying de Broglie's equation (4), we can conclude that the wave associated with this body would have a wavelength equal to 3.5×10^{-43} m. Even in agreement with this result, the present work points to the mathematical conclusion that a theoretical electromagnetic wave, independent of a material body, would have the same amount of energy as an object with a mass of 1 kilogram if it had the same wavelength. This correspondence became explicit when applying Plank's and Einstein's equations (1 and 2) for calculating energy in massive bodies and wave phenomena. Note that when applying equation (1), I used the reduced Planck constant since the wavelength was obtained using equation (4) with this value.

$$E = hf = \hbar \frac{c}{\lambda} = (1,05 \times 10^{-34}) \times \frac{3 \times 10^8 \text{ m/s}}{3,5 \times 10^{-43} \text{ m}} = 9 \times 10^{16} \text{ J} \quad (1)$$

$$E = mc^2 = 1 \text{ kg} \times (3 \times 10^8)^2 \text{ m/s} = 9 \times 10^{16} \text{ J} \quad (2)$$

The equality between these equations supports the understanding that all the known developments for equation (2) are also valid for equation (1), including its effect on space-time. On this topic, Wheller, in 1955, had already considered that high-intensity electromagnetic radiation, combined in small spaces, could form gravitational fields and even singularities called *geons* (or *kugelblitze*) [6]. In this way, the theoretical wave referred to in the previous example, with energy of 9×10^{16} J, would have a gravitational effect equivalent to that of a body with a mass of 1 kilogram, interacting with matter, space-time, and other waves, according to the laws of universal gravitation. Note that this is not about the concept of relativistic mass. According to de Broglie [2], relativistic mass refers to the change in the mass value of a particle as its speed approaches the speed of light. Here, I refer to the amount of energy in electromagnetic waves as the source of gravitational effects.

As expressed in equation (4), the energy of an electromagnetic wave is associated with its frequency (f) and, consequently, its wavelength. Since the other elements of equation (4) are the constants $\hbar$ and c , the wavelength would be the primary descriptor of the amount of energy in wave phenomena. In addition, geometrically, the wavelength is one of the determining elements of the volume of the electric and magnetic fields through which the energy of electromagnetic waves distributes itself. So, we can understand that the energies of electromagnetic waves occupy regions of space delimited by their wavelength. As per Louis de Broglie's equation (4), we can observe that the space decreases as the energy increases. When examining the creation of gravitational fields by high-

energy waves, it may be possible to identify a threshold wavelength at which the resulting gravitational field could become a singularity. We can find this limit value by establishing a correlation between the de Broglie wavelength (4) and the Schwarzschild radius multiplied by two (6). The Schwarzschild radius (5) is a length measurement defined as one of the possible solutions to Einstein's field equations. A massive body compressed into a sphere bounded by a radius less than or equal to its Schwarzschild radius will form a singularity. Integrating the de Broglie and Schwarzschild equations would be a theoretical exercise, bringing relativistic behavior closer to the quantum realm. However, based on this correlation, we can demonstrate mathematically that certain electromagnetic waves have their energy distributed in a space limited by a wavelength shorter than or equal to twice their relative Schwarzschild radius. For this reason, they could become singularities (figure 1).

$$r_s = \frac{2GM}{c^2} \quad (5)$$

$$\frac{\hbar}{mc} = 2 \times \frac{2GM}{c^2} \quad (6)$$

Using correlation (6), we find a mass value of 1.09×10^{-8} kg. The corresponding wavelength is 3.2×10^{-35} m. This length measurement corresponds to the diameter of a body with a mass of 1.09×10^{-8} kg that has reached its Schwarzschild radius. These results indicate that electromagnetic waves with a wavelength less than or equal to 3.2×10^{-35} m could form singularities, given their concentration of energy in such a confined space, equivalent to the diameter determined by the Schwarzschild radius for their amount of energies. Therefore, the measurement 3.2×10^{-35} m would be the zero point on a scale of possible wavelengths. All values below "zero" on this scale would be singularities. We can also conclude that the transmission of energy by electromagnetic radiation would only be feasible at wavelengths greater than 3.2×10^{-35} m. Another evidence for this boundary condition is the temperature of the singularity formed under the conditions. I calculated this temperature based on the equation (7) from reference [10]. It would be of the same order of magnitude as Planck's temperature, as shown in Table 1. Table 2 presents further characteristics of this boundary wave.

Santos, Silva, Gomes, and Lobo in 2020 [11] used the Schwarzschild and de Broglie equations to describe the smallest theoretically possible photon and black hole. These authors set the Planck length as the minimum wavelength value for this theoretical photon. As a result, they described a photon with a Schwarzschild radius (r_s) twice the Planck length. The diameter of this photon, and therefore the singularity it hypothetically creates, would be four times the Planck length. In the present work, the analysis based on wave phenomena shows that the shortest possible wavelength could not be

less than twice the Planck length (Figure 2). This value would also be the minimum diameter of a singularity formed by electromagnetic waves.

$$T = \frac{\hbar c^3}{8\pi G K_B M_b} \quad (7),$$

where G is the universal gravitation constant, K_B is Boltzmann's constant, and M_b is the mass of the singularity.

4. Conclusion

The characteristics of the waves theorized in this work, which have the potential to form singularities, are within the dimensional limits of the Planck scale, mainly length, time (period), and temperature. This condition indicates the possibility of these phenomena occurring within the normality of space-time. However, the energetic conditions that could form waves with such high frequencies are rare in today's universe. Cosmic rays are the most energetic particles known and have a variable energy, with the most energetic records not reaching 10^2 J [12]. As shown in Table 2, for an electromagnetic wave to form a singularity, is required an energy of about 10^8 J or more. In this scenario, the singularities theorized in this paper seem infeasible or unlikely. However, it is relevant to emphasize that there are still limitations in understanding cosmic rays, such as their interstellar or intergalactic origin and the processes that make them so energetic.

However, if we look at the initial conditions of the universe described in the literature, we find an environment favorable to the formation of waves with very high energy values. The high energy density that filled the cosmos one Planck second after its formation [13] could have allowed the formation of wave phenomena with the properties necessary to transform them into singularities, even in abundance. In this hypothesis, the first singularities in the universe would not be those large and massive but those with quantum measures formed by electromagnetic waves. These could have played a fundamental role in the inflationary process, as in the agglomeration of matter that led to the formation of the first galaxies.

The proposal in this work to compare the results of de Broglie's wavelength equation with Schwarzschild's conclusions represents a strategy to stimulate abstract thinking in the understanding of quantum and relativistic theories. Integrating the description of wave phenomena with known relativistic solutions can be relevant in developing a theory that satisfactorily describes physics interactions on both quantum and macroscopic scales. In addition, the results presented in this work could be relevant in developing teaching strategies on particle-wave duality, not only on light but also on singularities.

Table 1: Comparison between Planck scale values and the characteristics of the theoretical wave with a wavelength equal to the corresponding Schwarzschild radius

<i>Planck scale</i>		<i>Boundary wave characteristics</i>	
Planck length	$1,6 \times 10^{-35} \text{ m}$	$3,2 \times 10^{-35} \text{ m}$	Wavelength (λ)
Planck mass	$2,2 \times 10^{-8} \text{ kg}$	$1,09 \times 10^{-8} \text{ kg}$	Equivalent gravitational effect
Planck time	$5,4 \times 10^{-44} \text{ s}$	$1,07 \times 10^{-43} \text{ s}$	Period
Planck energy	$1,95 \times 10^9 \text{ J}$	$9,81 \times 10^8 \text{ J}$	Energy
Planck temperature	$1,4 \times 10^{32} \text{ K}$	$1,12 \times 10^{31} \text{ K}$	Temperature of the singularity formed

Table 2: General characteristics of electromagnetic waves comparing the wavelength with the Schwarzschild radius. Highlighted is the wave with a wavelength equal to the corresponding Schwarzschild radius

<i>Equivalent gravitational effect(kg)</i>	<i>$E=mc^2 \text{ (J)}$</i>	<i>$E=\hbar f \text{ (J)}$</i>	<i>Schwarzschild radius (r_s) (m)</i>	<i>de Broglie's wavelength (m)</i>	<i>$2 \times (r_s)$</i>	<i>Frequency (Hz)</i>	<i>Example</i>
1E+10	9E+26	9E+26	1,47E-17	3,5E-53	2,93E-17	8,57E+60	Theoretical waves
1	9E+16	9E+16	1,47E-27	3,5E-43	2,93E-27	8,57E+50	
0,1	9E+15	9E+15	1,47E-28	3,5E-42	2,93E-28	8,57E+49	
1,09E-08	9,81E+08	9,81E+08	1,60E-35	3,2E-35	3,2E-35	9,35E+42	
9,10E-31	8,19E-14	8,19E-14	1,33E-57	3,85E-13	2,67E-57	7,80E+20	Electron
1,67E-27	1,50E-10	1,50E-10	2,45E-54	2,10E-16	4,90E-54	1,43E+24	Proton
2,20E-40	1,98E-23	1,98E-23	3,23E-67	1,0E-02	6,45E-67	3,00E+10	Radio waves
2,20E-38	1,98E-21	1,98E-21	3,23E-65	1,0E-04	6,45E-65	3,00E+12	Infrared
2,20E-34	1,98E-17	1,98E-17	3,23E-61	1,0E-08	6,45E-61	3,00E+16	Ultraviolet
2,20E-30	1,98E-13	1,98E-13	3,23E-57	1,0E-12	6,45E-57	3,00E+20	X-rays
1,38E-29	1,24E-12	1,24E-12	2,02E-56	1,60E-13	4,03E-56	1,88E+21	Gamma radiation

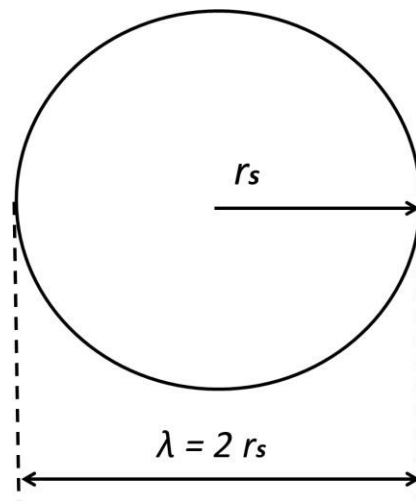


Figure 1: Comparison between a hypothetical body with a mass of 1.09×10^{-8} kg compressed to the volume determined by its Schwarzschild radius (r_s) and the wavelength (λ) of an electromagnetic wave with the same energy value as the body indicated.

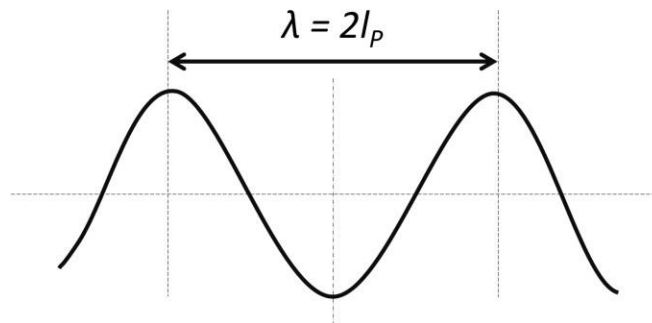


Figure 2: Wavelength equivalent to twice the Planck length (l_p). Characteristic of a boundary electromagnetic wave, theoretically capable of forming a singularity.

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