

Towards a Mechanism Type Structure for Light, Part I: Crucial Verification of how Light Spreads at Large Distances; Experimental Design, Non-wave Results and Consequences for Light, Gravity, Generally for Physics

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Abstract

We recognize that the spreading of light at large distances (the whole space) is the only property which can decide by yes or no if light really behaves physically like waves, while the fit of the waves for describing the diffraction fringes is insufficient for this purpose. Indeed, the fringe space is too limited and hence, brings the possibility of misinterpretation. Hence, the experiment for the direct verification if light is spreading like waves at large distances is necessary in principle, and is crucial. However, very surprisingly and tragically, this direct experiment was totally missing in history. This experiment uses the simplest diffraction case, in which a beam of light falls perpendicularly with its axis on the line and the plane of a straight edge. Practically, this experiment verifies if there is a dependence of the diffracted light at large distances in the geometrical shadow, on the changes in beam thickness traversal to a single straight edge, while the distribution of light along the straight edge remains the same. If this dependence exists, as the wave theory for light fundamentally predicts, then the wave approach to light is physically true. If there is no dependence then light cannot behave physically like waves. This experiment can clearly be developed and performed without any calculation from the wave approach, just by a careful measurement practice. However, for a broader view, we describe in detail wave results for spreading of light at large distance, which illustrate the experiment—what are the spatial points where the measurement must be done to see if the above dependence exists, and which is the big picture for the wave approach. We attempted this experiment for many years, but could not finish it because of the lack of resources to measure at 100 m–500 m. However, we show alternatively that the answer to how light spreads also comes from comparing the well-known wave results for the diffraction on macroscopic holes with relatively recent data for the diffraction on nanoscopic holes. This comparison clearly shows that light does not spread physically like waves, which makes necessary a new, non-wave but periodic structure for light. On this line, we show here the big-picture for developing this non-wave structure, that is a mechanism-type structure for light. With this new structure for light one can see that there is also a missing experiment at the foundation of gravity. Finally, the above alternative answer regarding the spreading of light also makes absolutely necessary to perform the above missing experiment, as a direct way that convinces anybody how light is spreading. The present article will empower big labs to perform this crucial experiment.

Keywords: *Light spreading at large distances; Missing experiment for the wave approach*

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I. Introduction

We recognize here an unsolved fundamental problem for the nature of light. Namely we recognize that the spreading of light at large distances (the whole space) is the only property which can decide by yes or no if light really behaves physically like waves in propagation, while the fit of the waves for describing the diffraction fringes is insufficient for this purpose. Indeed, the fringe space is too limited and hence, brings the possibility of misinterpretation regarding the nature of light. Hence, the experiment for the verification of how light is spreading at large distances is necessary in principle and it is crucial, but it is still missing. This experiment is as follows. A stable laser beam falls perpendicularly with its axis on a straight diffracting edge, where the distribution of light intensity along the edge can be maintained constant, while the distribution of light transversal to the edge can be substantially broadened. For each case of transversal distribution of light, the intensity of the diffracted light is measured in a set of points at large distances in the geometrical shadow. If the results show a dependence of the intensity of light on the beam thickness transversally to the diffracting edge, as the Maxwell equations and the wave diffraction integral for light predict, then the wave theory of light is physically true. If there is no dependence, then light does not spread like the waves do, and a new physical approach is necessary for light, that is a diffraction mechanism that takes place only in the material edges. Hence, this experiment is crucial, and can be done without any wave calculation for defining the measurement points because these points can be found by a simple but systematic practice of light measurements at small and large distances. However, a systematic evaluation of the diffraction integral for this edge diffraction helps defining these points, and helps a better understanding of the wave approach.

The method for seeing the missing fact in a field

Before introducing the measurements of how light is spreading at large distance, we describe here the method necessary for naturally recognizing this missing experiment for light and its results, instead of ignoring them for hundreds of years. Such a method would avoid repeating in the future this case of missing fact for light, and the long-time-ago case of missing fact for heat, namely producing heat by mechanical action. From our lifetime work on light we found that both the case for light and the case for heat happened because the method of broad thinking on the major opposing views in a field, was not used systematically in the university, in society in general. For the case of light, the major opposing views are those on the origin of the diffracted light – as waves both inside and outside of the diffracting edge, or as non-waves only inside the diffracting edge. A serious broad thinking on these opposing views shows to the regular student that there is no verification on how light spreads at large distances, and to recognize that the diffracted light is born only inside the diffracting edge. This recognition makes impossible for light to physically behave like waves in diffraction (because if it did, the diffracted light would also be produced around the diffracting edges). Only by using this broad thinking, we realized that there is a missing experiment at the foundation of light: how light spreads at large distances, as waves or not as waves ? For heat, the opposing views were how the heat is produced in a body—only by its vicinity with a hot body, or both by this vicinity and by a mechanical action on this body. If the student is taught and allowed to practice this broad thinking he/ she will see the missing fact/ experiment, and hence, the theories that are based on a missing fact will not survive/ repeat. On this line of thought, sooner or later this method will become a basic part in the education in science, to grow

scientists who have the big-picture knowledge, in excess to the method for fast thinking for detailed knowledge. This method is also necessary for the society sciences. For instance a broad thinking on the major opposing views in society, namely those of liberals and conservatives, shows quickly that a major and simple system is missing in society/ democracy- the system for growing/ developing common ground based functional and wise broad views, that is for growing the big-picture knowledge.”. In such a system the Constitution requires that a party and a candidate, in order to participate in elections, must prove that they know the method and have worked to grow some common ground/ functional and wise broad views with their counterpart. It would also be a requirement that a non-government organization (as a part of the school system) should control the enforcement of this system for common ground/ functional and wise broad views. **Results:** In Section II we present a detailed description of the crucial experimental setup which is necessary for the measurement of the dependence between the light in the geometrical shadow and the light above the diffracting edge (in the plane of this edge), a dependence that is crucial for the nature of light. Performing this experiment does not necessarily need the wave calculations because the measurement points in the geometrical shadow can be found by a systematic practice. However, such calculations clearly illustrate how the waves generate the above dependence and where to measure. In Section II we use the wave approach to illustrate how the waves intrinsically produce the above dependence of the diffracted light in the geometric shadow, on the wave front above the diffracting edge. For this purpose we use the scalar Rayleigh-Sommerfeld wave diffraction integral in the Fresnel approximation for a Gaussian laser beam. Such a diffraction integral is verified as accurate if the following conditions are satisfied:

- The diffraction aperture must be large as compared with the wavelength
- The diffracted light must be observed relatively far from the aperture
- The laser beam comes from a low power, helium neon laser (a Micro-g Lacoste laser - a high quality He-Ne, 1mW, stable laser) for which it is justified to use a single transverse mode (also called a pure or fundamental mode) Gaussian beam, that is an ideal mode beam

For higher power lasers, would be necessary to use more complex beams. However, since for our experiment, the wave calculations are necessary only as an illustration, that is, not as strictly necessary calculations, it is sufficient to use the single transverse Gaussian beam. We do these calculations to illustrate the wave big picture for the experiment, and to suggest the measurement points at large distance in the geometrical shadow, which also can be found by the simple evaluation of the first Fresnel zone (see Section II) and by a systematic measurement practice.

In section III we show that we designed and attempted this experiment for more than 10 years, with measurements up to 5 m distance in the geometrical shadow, from the diffracting edge. For these distances, we found no -dependence of the diffracted light in the geometrical shadow on the beam thickness above the diffracting edge, which is in accordance with the wave integral prediction. Due to the lack of resources to measure at 100 m–500 m, where the wave approach indicates the existence of such a dependence, we could not finish the experiment. But our documentation here for this experiment will allow that bigger labs develop quickly and finish these measurements.

However, Section III also shows that by using the method reported above, namely the broad thinking on the major opposing view,

we found that alternatively, the proof for how light spreads in general, surprisingly comes by recognizing the real significance of relatively new experimental data existing for the diffraction on nanoscopic holes. This experimental data comes from measurements which analyze the role of the edges in the diffraction on nanoscopic and microscopic holes in nanoscopic walls. We show that the data from these measurements provides a simple case of reduction to absurd for the wave approach to macroscopic holes. This case of reduction to absurd proves/ demonstrates that light has physically a non-wave spreading. This proof makes necessary and important for the physics community to perform the above missing direct experimental verification, as a double-check for this proof. If correct, this proof/ demonstration makes necessary a new, non-wave but periodic, mechanism type structure for light. This situation would be similar but much more important than the case when the heat production by mechanical action was missing and then added in physics by the kinetic theory of heat, instead of the model of the caloric fluid for heat. A new mechanism type structure for light would supplement the current approach to light which is based on the non-mechanism, physically impossible ideas like “light spreads like waves, but nothing oscillates”. In this case, the wave approach could still be used as a formal way in the limited space of the diffraction fringe zones, as a valid way for practical quantitative evaluations.

As a result of the proof presented in Section III, which shows that light does not spread like waves do, in Section IV we suggest the feasibility of a new structure for light, which we call a bi-structure. We also suggest there the consequences of this bi-structure for a new fundamental experiment towards a mechanism-type understanding of gravity. In a second paper we describe in detail this bi-structure, its applications in optics, and its broad consequences in physics.

II. The Experimental Setup and the Measurements

In our straight edge diffraction experiment, **FIG. 1**, a laser beam of light falls with its axis perpendicularly on the sharp edge of a material plate and forms a luminous column on a screen at any distance from the diffracting edge in the direction of the light propagation. This column is perpendicular on the diffracting edge, and the part of this column with fringes is only in the directly illuminated area on the screen, while the non-fringe part is in the geometrical shadow of the diffracting edge.

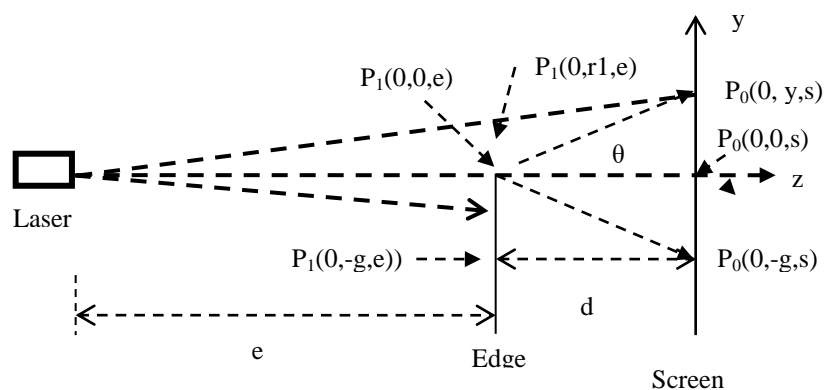


FIG. 1. Single straight Edge diffraction where the angle θ can be positive (directly illuminated area) or negative (geometrical shadow).

In this experiment the intensity of light is measured in the geometrical shadow of the diffracting edge at points P_0 . This experiment verifies systematically if the intensity of the diffracted light in any point in the geometrical shadow, especially at large distances, increases when the thickness of the diffracting beam increases only transversally to the diffracting edge. This dependence is more important than the diffracting fringes because it involves a very large (infinite) volume. Surprisingly, this dependence, although is the most fundamental prediction for understanding the spreading and hence, the nature of light, was not systematically measured yet.

This experiment tests if the Huygens principle, or the wave diffraction integral is valid for the diffracted light in the geometrical shadow that is, if the later depends on the thickness of the beam transversal to the diffracting edge, while maintaining the same distribution of light along the diffraction edge. We answer the following questions. What is the experimental setup? Where to place the diffracting edge? How the experiment can vary this transversal thickness of the beam and maintain the longitudinal distribution of light along the diffracting edge? At what distance from the laser we need to measure the light in the geometrical shadow in order to see if there is a dependence on the beam thickness across the diffracting edge? We answer these questions both by a simple insight, and by the wave calculations with the elliptical Gaussian beam.

The experimental setup

Our experimental setup includes three systems: a highly stable laser with a fine positioning/ orientation system, a fine edge/ slit system with micrometric positioning system, and a detector system: a linear detector - PDF10A, Femtowatt Photoreceiver from Thor, and a two-dimensional camera - the Little Guy beam profiler from Ankrone, with a fine positioning system. Our laser is a Micro-g Lacoste laser-a high quality He-Ne $\lambda=6.32 \times 10^{-4} \text{mm}$, 1mW: with a highly stable in intensity and direction 1mW laser. For this laser the beam of light is described in the wave approach by a Gaussian formula which has the minimum beam radius (waist) $\omega_m=0.3 \text{mm}$ at the exit from the laser, and with a beam divergence $2\theta=1.3 \text{mrad}$ [1].

The measurements compare two basic experimental cases.

Case 1: By placing the diffracting edge at $e=1500 \text{mm}$ from our laser, the beam waist across z axis is

$$\omega_x = \omega_y = \omega_m \sqrt{1 + (e / z_0)^2} \approx 1 \text{mm}, \text{ where } z_0 = \pi \omega_m^2 / \lambda \approx 450 \text{mm}.$$

Case 2: With a cylindrical lens placed between the laser and the diffracting edge, with its axis parallel with the diffracting edge and intersecting the z axis, it is easy to increase as necessary the beam waist along y axis at the diffracting edge, to $\omega_y=3 \text{mm}$ for instance, while maintaining $\omega_x=1 \text{mm}$ along the diffracting edge (x -axis).

A simple insight for the measurement points:

A quick insight for where to measure the diffracted light in the geometrical shadow for these two cases, to see the difference between them, can be obtained by evaluating the radius of the first Fresnel zone on the integration domain of the diffraction integral [2]. It is well known that this Fresnel zone is the main contributor to the value of the diffraction integral for any given point

$P_0(0, g, s)$ in the geometrical shadow. For $d \gg g$ a good approximation of the first Fresnel zone for the point $P_0(0, -g, s)$ is an area in the integration domain of the diffraction integral. This area in integration domain is between the straight diffracting edge that passes through the point $P_1(0, 0, e)$ and the circle with the center in $P_1(0, -g, e)$ and passing through the point $P_1(0, r_l, e)$ in the integration

domain-see **FIG. 1**, where r_1 is defined such that the distance between $P_0(0,-g,s)$ and $P_1(0,r_1,e)$ equals the distance between

$$P_0(0,-g,s) \text{ and } P_1(0,0,e) \text{ plus } \lambda/2: (r_1+g)^2+d^2=(\sqrt{g^2+d^2}+\lambda/2)^2.$$

For $d \gg \lambda$ and $d \gg g$ this means $r_1 \approx -g + \sqrt{g^2 + \lambda d}$. For $P_0(0,-g,s)$ in the geometrical shadow with $g=10$ mm and $d=5$ m, 50 m, 100 m and 500 m, the results for the radius r_1 of the first Fresnel zone is of the order of 0.15 mm, 1.45 mm, 2.77 mm and 10.4 mm respectively. For $g=20$ mm and the same d values, the results for r_1 are 0.08, 0.77, 1.52, and 6.76 respectively. This means that the difference between a case with a beam thickness of 1 mm (Case 1) on the diffracting edge, both longitudinally and transversally to the diffracting edge, and the Case 2 with a beam thicknesses of 1 mm longitudinally and 3 mm transversally to the diffracting edge, can be seen by measurements of the light intensity at points in the geometrical shadow on the lines with $y_0 = -10$ mm and $y_0 = -20$ mm, at distances d in the range 100 m-500 m.

The next sub-section describes our Fortran program Edge diffraction Gaussian beam for numerical wave calculations for the edge diffraction integral. With this program we found the following differences between the light intensities for the two cases above (Case 1 and Case 2):

- Less than 1% for $d=5$ m, $g=10$ mm below z axis, that is in the geometrical shadow
- 5% for $d=50$ m, $g=10$ mm below z axis, that is in the geometrical shadow
- Around 75% for $d=100$ m, $g=10$ mm below z axis, that is in the geometrical shadow
- Around 250% for $d=500$ m, $g=10$ mm below z axis, that is in the geometrical shadow

Therefore, these numerical results show that we need to measure the diffracted light in the geometrical shadow for d in the range from 100 m to 500 m, for g in the range 10-20 mm. If we need to measure deeper in the geometrical shadow (at larger values for g) we will need to measure at larger values for d . We needed a long time to explore by calculations where we need to measure. Initially we were looking at distances d from 5 m to 10 m.

Again, how can be accomplished experimentally the above Case 1 and Case 2? Experimentally, the beam waists for our laser are in the same place $z_{mx} = z_{my} = 0$ mm on the z axis, as described in the Case 1 above. For Case 2, we place a divergent cylindrical lens of a certain focal distance f at a position z_l , before the diffracting edge for Case 1, with the axis of the cylindrical lens parallel with the x axis. Then the beam spreads more along y axis, as if a second beam waist ω_{new} along z axis (smaller than ω_{my} from the Case 1) is created at a distance before the lens, as necessary for the Case 2. By varying the lens position and the focal distance f , we can have an adequate broader light beam transversally to the diffracting edge (but the same distribution of light falling on the diffraction edge along the x axis). This is necessary for finding the measurements with good differences between the Case 1 and Case 2. Hence it is possible to reproduce experimentally the Case 1 and Case 2 above. Certainly the normalization of the beam distribution on the diffracting edge for the two cases is necessary in order that the distribution of light along the diffracting edge (x axis) be the same in the two cases.

Analytical and numerical wave calculations illustrative for the measurement points in the missing experiment:

Our numerical approach is intended to show the wave results for the above cases, Case 1 and Case 2, for the purpose of verifying if the diffracted light in the geometrical shadow at large distances depends on the light above the diffracting edge, or only on the light falling on the diffracting edge. We use the Rayleigh-Sommerfeld (RS) formula for the diffraction integral with integration on the free space outside of the diffracting edges [1]. The RS formula is generally verified experimentally as accurate in the fringe zones for the cases of macroscopic hole and slit diffraction, not too close however to the diffracting edges. In the case of the fringe zones

for the macroscopic edge diffraction some inaccuracies have been identified for the wave approach [3, 4]: The wave approach does not give the right position of the diffracting fringes – they are slightly displaced. However, our interest here lays in the fact that any wave approach shows, through the diffraction integral, that there is a dependence of the diffracted light at large distance in the geometrical shadow, on the wave front above the diffracting edge (see above the discussion for the first Fresnel zone).

By using the RS diffraction integral we developed the necessary analytical formulae and the numerical calculations for the edge diffraction of a Gaussian beam, based on the documentation from Refs [1, 5–15]. Our computer program Edge diffraction Gaussian

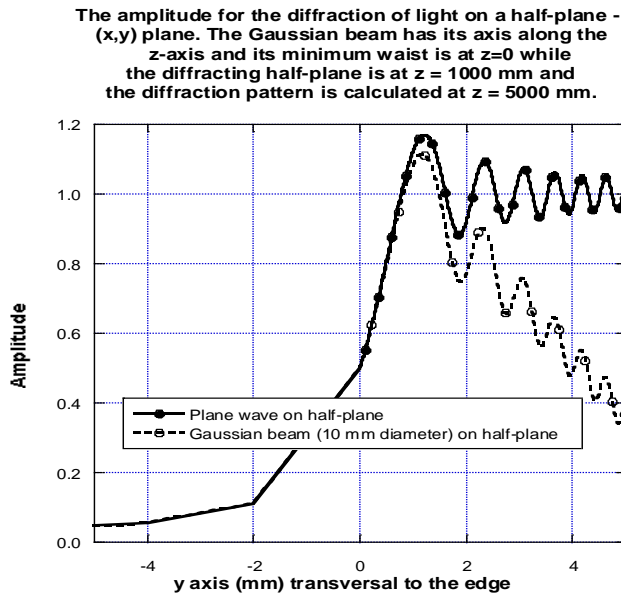


FIG. 2 Testing the program for the diffraction of a Gaussian beam. The diffracted amplitude at 4000 mm behind the diffracting half-plane for a thick (10 mm diameter) Gaussian beam is compared with the standard case of the diffracted amplitude for a plane wave. The comparison shows that the numerical calculations are satisfactory

beam (Fortran) for the numerical calculations of the RS diffraction integral, is tested in **FIG. 2**. This graph compares the results for a thick beam with the results for a plane wave, and these results look reasonable. For those interested in the analytical details we provide a long appendix that describes these analytical calculations, and we can also provide our Fortran program Edge diffraction Gaussian beam.

III. Results

The results from our experiment

Again, due to limited resources of our small lab, we could perform the measurements only at distances up to 5 meters from the diffracting edge. For these distances the differences between the above two cases for the diffracted light were very small, as the wave integral predicts. This means that we could not measure in the range of 100 m to 500 m where the wave approach displays a strong dependence of the diffracted light in the geometrical shadow, on the beam thickness transversal to the diffracting edge. It took a long time, a lifetime for the authors to perform these steps. But this paper, with our work, could be the base for future attempts to verify this dependence. However, we give below the alternative proof that this dependence does not exist.

The alternative experimental proof that light does not spread like the waves do

As described above, the experimental verification of how light spreads at large distances is missing, and hence, nobody can decide with certainty that the wave spreading is the right way for light spreading. In this context, we found that the experimental results from [16-23] are totally useful. These experiments analyze the role of the edges in the diffraction on nanoscopic and microscopic holes in nanoscopic walls. The results display a surprising extraordinary transmission-type of the diffracted light, instead of the regular fringe pattern seen in the cases of macroscopic diffraction of light. The authors rightly conclude that the transmission, that is the spreading of light through the nanoscopic edges, has a major contribution to the diffracted light. And they extend the wave propagation in the nanoscopic walls to include this contribution and successfully describe the experimental results on nanoscopic and microscopic holes.

However, the authors of these measurements did not see or discuss that this important contribution from the edges in the diffraction on nanoscopic holes, brings the following absurd contradiction in the wave approach for the diffraction on macroscopic holes. Indeed, the edges in the macroscopic holes necessarily have a macroscopic surface area with nanoscopic terminal shapes, and hence, according to the above findings, these macroscopic edges necessarily contribute an important part of the diffracted light. Such an important contribution is also supported by the direct observations with the naked eye, from all directions and from all distances, around the illuminated spots on the diffracting edges in the macroscopic case. The brightness of these spots is even bigger than some of the diffraction fringes. This clearly shows that the brightly illuminated spots on the edges are a source of diffracted light both for the directly illuminated area of the diffraction pattern, and for the geometrical shadow area of the diffracted light. However, in the wave approach for the macroscopic holes/ slits/ single edge, the diffracted light is sufficiently described by the diffraction integral applied only on the inner/ empty space of the macroscopic hole that is, without a necessary inclusion of the illuminated spot on the diffracting edge. And what is the contribution from the edges in the wave case? If the wave diffraction integral is extended inside the diffracting edges of the hole, the contribution from these edges to the wave diffraction integral is small as compared with the contribution of the wave front on the inner space of the hole. But this is a direct result of the fact that the waves on the inner space of the hole can produce by themselves the diffraction fringes. This result from the waves is in total contradiction with the above conclusion from the experimental data of [16-23] that the diffracting edges have always an important contribution to the diffracted light. However, this result from the wave approach for the light diffracted inside the edges is used in books and discussions to wrongfully claim that the edges have physically only a small contribution to diffraction. And hence, this result is used not to see evidence for the major role of the edges in diffraction, and the related questions on the nature of light. Based on this contradiction of the standard wave approach with the results from [16-23] we have a clear case of reduction to absurd for the wave approach, and hence, light does not spread as the waves do. This means that in the wave approach, the real problem is replaced by a formal approach valid only in the fringe zones: the fringes are formed mainly by the inherent capability of spreading and interfering of the wave-front which passes through the inner space of the hole.

Again, this clear case of reduction to absurd for the wave diffraction of light shows that the wave approach has a formal (not physical) character for light, and makes necessary and important for the physics community to perform the missing experimental verification of how light spreads at large distances, as a double-check (double to the above case of reduction to absurd for the wave approach). This double-check would convince everybody on the necessity of a new, non-wave but periodic, mechanism type structure for light. We suggest in Section IV, and demonstrate in a separate paper, that this structure is feasible and brings mechanism-type explanations for all the optical phenomena. Again, in this new structure light does not spread like the waves do. Such a change would be similar but much more important than the case when recognizing the heat production by mechanical action made necessary and feasible a mechanism-type model, which is the kinetic theory of heat, instead of the model of the caloric fluid

for heat.

IV. An Overview of the Necessity, Feasibility and Consequences of a Non-wave, Mechanism-type Structure for Light

This Section is intended as an introduction or a broad discussion regarding a mechanism-type approach for the nature of light, starting from a broad thinking on the major opposing views on the origin of the diffracted light. Doing such a broad thinking is necessary in order to consider all the necessary issues, to see the mechanism-type approach that is necessary for light, and in order to see the consequences in physics. We shortly discuss here the feasibility of this mechanism-type approach for light, and we suggest its broad consequences. One consequence is that for gravity there is also a mechanism-type approach/structure, a mechanism which can be verified by performing a new crucial experiment. We shortly describe here this mechanism and crucial experiment for the gravity. The detailed steps towards this new structure for light and its consequence in physics are presented in our separate paper on the structure of light.

The above missing verification of how light is spreading at large distance by a fundamental experiment of edge diffraction, and the above proof that light does not spread as the waves do, form the missing fact at the foundation of the current understanding of light. This is similar with the missing fact long ago at the foundation the old caloric fluid understanding of heat, namely the fact that heat in a body is also produced by mechanical action on this body, not only by the vicinity of this body with a warmer body. Recognizing this missing fact for heat showed the necessity of a new type, mechanism-type understanding for heat. Similarly, the above missing fact for light shows the necessity for a new, non-wave, mechanism-type structure and understanding for light. In fact there is a great deal of evidence that strongly supports a non-wave approach. This evidence includes:

- The current understanding of light is based on non-mechanism, physically impossible ideas like “light spreads like waves, but nothing oscillates”
- The role of the bright spots on the diffracting edges, as the only source for the diffracted light, which is the fundament of the Geometrical Theory of Diffraction (GTD) [24-26]
- In the statistical optics [27, 28] the statistical nature of the diffraction and image formation basically requires a statistical nature for the light beam that is, a discontinuous and random structure. Such a basic property cannot be offered by the continuous structure in the wave approach, but should be intrinsic and obvious in a mechanism-type structure of light

In this non-wave, mechanism-type structure for light there are three fundamental requirements.

- The first fundamental characteristic in this new structure is that light does not spread like the waves do. In this new structure, both the light in the fringe zones and the light at large distance in the geometrical shadow, are essentially an effect of the light originated in the edges. In GTD, the rays of light propagating from the edges are essential for producing the diffraction fringes [24-26]. However, in GTD these rays are still based on the wave approach, which is physically impossible: the waves are essentially spreading and hence, cannot propagate as rays. In the new structure light must have entities which propagate and exert pressure in the propagation direction, and can spread a little around it
- In this new structure, a beam of light consists of trains of random length which move in the beam direction, and are randomly distributed across the beam propagation. These discontinuities along and across the propagation direction are necessary to make possible the statistical effects for a beam of light
- In this new non-wave structure for light, its trains must have a periodicity along the propagation line, and hence, each train carries a periodical momentum along its propagation. However, the length of such train could be limited. A beam of light

with such a structure produces naturally forced oscillations (regular or resonant), photo-effect, pressure, heat and statistical effects when it falls on a surface of matter. Also, when two beams superpose on a surface of matter the interference phenomenon occurs

Based on these three fundamental requirements we explored the feasibility for a new, non-wave but periodic, mechanism-type understanding for light, instead of the current non-mechanism, physically impossible ideas like “light spreads like waves, but nothing oscillates”. The steps towards this new structure for light are presented in our separate paper on the structure of light. There we propose the new structure for light and show that it offers easy, mechanism-type explanations and quantitative descriptions for all the optical phenomena, including the photo-effect. We recognize there that the light phenomena themselves are a clear way to prove the physical existence of a field of finely dispersed matter or dark matter. This is similar with the evidence that the wind phenomena are a solid proof for the existence of the air. However, the case of the finely dispersed/ dark matter is a much bigger case. The finely dispersed matter (FDM or dark matter) is a material field as a basis for the Universe. The FDM in this field is moving in all directions. We propose this new structure for light and call it a bi-structure: one structure in free space that is based on periodic trains of bursts of FDM, and a second structure in condensed matter that is, a structure based on trains of collective electron oscillations. These two structures are in functional relation on the exit and on the entrance surface of condensed matter. At the entrance surface such a train of bursts produces, also by momentum transfer, collective electron oscillations which are absorbed if the surface is non-transparent or propagate if the material is transparent. At the exit surface, the collective electron oscillations act on the field of FDM and throw, also by momentum transfer, in free space trains of bursts of FDM. First, we found that this new structure is perfectly feasible and explains in a mechanism-type way all the phenomena in optics. Second, we suggest that such a new structure for light brings has broad consequences in physics: mechanism-type understandings for gravity, atomism, electromagnetism, and condensed matter. We shortly discuss here the case of FDM for gravity because this case also shows that there is also a missing fundamental experiment that is crucial in physics. The cause for gravity is not an intrinsic property of the matter in each body but is a result of a mechanism based on FDM. Such an intrinsic property would be impossible. Indeed, such an intrinsic gravitational force, of an infinite duration, would mean an infinite energy for any body of matter which is impossible physically. Instead, the mechanism of the attraction between two big bodies and the mechanism of producing heat in a big body in universe are as follows. The FDM that moves in each direction loses some momentum and energy when passing through a big body of material. This naturally leads to more heat produced toward the center of the body because more FDM passes through the center of such a big body. The loss of the energy by FDM is also the basis for producing the gravity when two bodies are present. Indeed, when two bodies are present they are shadowing each other in the flux of FDM passing from one to the other. This shadowing is the cause of a pressure that pushes the two bodies towards each other. This mechanism-type approach simply leads to the law of gravity as we show in our separate paper on the structure of light and its consequences. An experiment that verifies the link between the heating prediction of FDM and gravity is crucially necessary and easily feasible in principle. This experiment is simple, as follows. Given that the temperature increase in the first km of the earth's depth is approximately 25° Celsius, we must build a cylinder of dense earth ground of about 50 m diameter and 200 m height. This huge cylinder needs to be kept in a large storage at a constant temperature on its lateral, bottom and top surfaces. This temperature is verified by lines of thermometers. On the axis of the cylinder a line of thermometers is also necessary. If in time a temperature increase occurs (of about 5° Celsius) on the axis of this cylinder, similar with the temperature increase in the depth in the earth, this will prove that the gravity must be associated with heat production/ energy loss by the FDM.

Therefore, a new, non-wave and mechanism-type structure would offer a great positive change in physics, greatly extending the

positive change brought by the kinetic theory of heat. Therefore, strong discussions are necessary to initiate this path of analysis and development for light and for broad consequences in physics.

V. Conclusion

This paper presents the experimental design of the missing experiment and crucially necessary at the foundation of the wave theory of light: the experiment for the verification if light spreads at large distances as the waves do. We designed and developed the experimental setup, and used it for measurements up to 5m from the diffracting edge, but we could not finish the experiment because of the lack of resources to measure at 100 m–500 m. Our design of the experiment makes easier for a big lab, like the one in Magurele, Romania, to start and repeat this absolutely necessary experiment for convincing everyone how light spreads—as the waves do or not as the waves do. We identified the existing alternative experimental proof that light does not spread like the waves do, as presented in Section III. This alternative proof comes from a series of experiments on the role of the nanoscopic diffracting edges in the diffraction on nanoscopic holes. These experiments show that the nanoscopic edges have a major role in diffraction. However, such nanoscopic edges are also present in a great extent in any diffraction on macroscopic edge/ holes/ slits. But for the latter, the wave approach gives the diffracted light mainly without any contribution from the edges, which is absurd. If so, the wave approach is only a formal approach for diffraction, not a physical one, which is based on the wave capability to spread and interfere. This line of analysis based on the missing experiment at the foundation of light, and on the alternative proof for the negative results from this experiment for the wave spreading of light, leads to extremely important conclusions.

- It makes necessary and important for the physics community to perform the above missing experimental verification, as a double-check that convinces everybody regarding the status of the wave structure of light
- It leads, by a broad thinking, to recognizing other light issues as solid proofs for the non-wave spreading of light.
 - a) The simple naked-eye observations that the origin of the diffracted light in the geometrical shadow of a diffracting edge, is only in the illuminated spot on this edge
 - b) The impossibility of an elastic medium (the ether) as a support for the electromagnetic wave for light. This impossibility is dictated by an impossible high elasticity for this medium, and by the negative results from the MM experiment for the existence of the ether. However, the light waves cannot exist without such a medium, and hence, the conclusion is that the wave approach is non-physical.
 - c) The wave approach has generated along history many non-physical consequences, such as the speed of light in free space is the same in any reference system.
- It makes absolutely necessary a new, non-wave but periodic, mechanism type structure for light. Developing a new, mechanism-type structure for light will be a long process, similar with the case when recognizing and performing the missing experiment for heat (namely the heat production by mechanical action) took a long time

We explored the steps towards such a non-wave but periodic, mechanism-type structure for light based on the concept of finely dispersed matter (FDM) or dark matter. We show in a second paper that this new structure is perfectly feasible and explains in a mechanism-type way all the phenomena in optics and has broad mechanism-type consequences in physics. At the same time, by this new structure, the light becomes the obvious evidence for the existence of the FDM or the dark matter. As a result we suggest that the “dark matter” name should be replaced by “Finely Dispersed Matter (FDM)” or even by “bright matter”. Such steps towards a mechanism-type structure for light are necessary to start/ initiate a strong path of analysis and development for light and other phenomena in physics. We show in detail this path for the case of gravity. For this case this path indicates what is the crucial

experiment that is missing for a mechanism-type understanding of gravity.

VI. Acknowledgement

We acknowledge the important help from Professor Anthony Leggett, Nobel Laureate from UIUC in Urbana-Champaign, USA: His criticism led to improving the content of our work for describing the missing fact at the foundation of the current understanding of light. Also, we acknowledge the help from Dr. Ionel Rata by useful discussions on our ideas for defining the missing experiment for light, and on the math for the propagation of collective longitudinal electron oscillations in condensed matter

VII. Appendix

Analytical and numerical wave calculations illustrative for the missing experiment:

The wave theory of diffraction shows, through the diffraction integral (an expression of the Huygens principle), that all the points above the diffracting edge contribute/ spread diffracted light in the geometrical shadow. We present the predictions of the diffraction integral for the light in the geometrical shadow of a straight diffracting edge. We underline here that in the wave view, all the points around the diffracting edge, not only those in the illuminated spot on the diffracting edge, contribute diffracted light in the geometrical shadow. This presentation also suggests where in geometrical shadow, we can measure the effect of increasing of the beam thickness transversal to the diffracting edge.

We use the Rayleigh-Sommerfeld (RS) formula for the diffraction integral which is simpler than the Fresnel-Kirchhoff formula and accurate at distances in the fringe zones, that is not close to the diffracting edge [29-31]. If U characterizes the electrical potential (a complex number) of the incident beam of light, in the electromagnetic theory of light, then the RS formula states that the electrical potential U at a point P_0 behind a screen with the aperture Σ of **FIG.3**, is given by an integral over the entire area of the aperture, with the elementary area ds [29],

$$U(P_0) = \frac{1}{j\lambda} \iint_{\Sigma} U(P_1) \frac{\exp(-jkr_{01})}{r_{01}} \cos(\vec{n}, \vec{r}_{01}) ds \tag{1}$$

Where $j = \sqrt{-1}$, $k = 2\pi / \lambda$ is the light wavelength of the wave. The other quantities in eq (1) are defined in **FIG.3**. $\cos(\vec{n}, \vec{r}_{01})$ is the cosine of the angle between the directions \vec{n} and \vec{r}_{01} . In this formula one assumes that the values of U at the points P_1 on the surface Σ of the aperture are the same as when the screen and the aperture are not present. Here U could characterize a round or elliptic laser beam, or a plane wave beam [29,31].

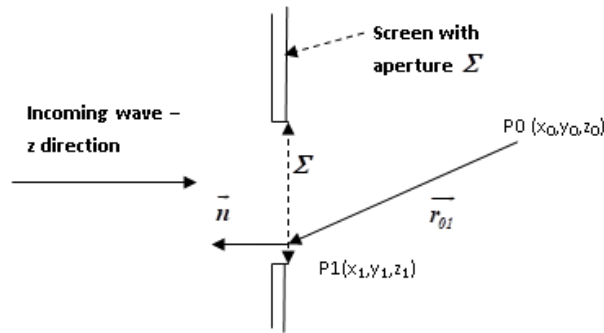


FIG.3 The diffraction of light on an aperture Σ in a non-transparent plate. To calculate the diffracted light by the aperture $U(P_0)$ we can use the Rayleigh-Sommerfeld formula where the electrical potential U is assumed known at point P_1 in the aperture—the value of U given by the Maxwell equations in the absence of the plate

The formula (1) is an expression of the Huygens principle, and says that each point P1 on the wave front Σ contributes a number of $U(P_1) \cos(\vec{n}, \vec{r}_{01})$ spherical waves $\exp(-jkr_{01}) / r_{01}$ towards the point P0. In other words, in the wave theory any point P1 in the aperture Σ contributes to a given point P0, even if this point is in the geometrical shadow, i.e. not in the area directly illuminated by the incident beam of light. In the wave theory of light, the intensity of the optical field at a point P is the square of the modulus of the complex electrical potential U(P),

$$I(P) = |U(P)|^2 \tag{2}$$

Fresnel Approximation: We use the Fresnel approximation for the diffraction integral because its results are clearly valid at points of interest here, starting with points relatively far from the diffracting edge, but not too far from the beam axis [29]. It would be simpler to use the Fraunhofer approximation (and the associated Fourier transform) but this approximation is valid only for too large distances from the diffracting edge – more than 1500 m from the diffracting edge, [29]. Assume that the electrical potential $U(x_1, y_1, z_1)$ on the aperture can be factorized as $U(x_1, y_1, z_1) = F(x_1, z_1)G(y_1, z_1)$. In order to produce a closed form from eq. (1) we need an approximation that allows the exponential to be factorized in terms dependent only on one integration coordinate. According to **FIG. 3**,

$$r_{01} = \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2 + (z_0 - z_1)^2} \tag{3}$$

Generally, we are interested in a diffraction pattern at large z_0 and we assume that $z_{01} = z_0 - z_1$ is much greater than the rest of the difference quantities in eq. (7). In this case,

$$r_{01} = z_{01} \sqrt{1 + (x_0 - x_1)^2 / z_{01}^2 + (y_0 - y_1)^2 / z_{01}^2} \approx z_{01} (1 + (x_0 - x_1)^2 / 2z_{01}^2 + (y_0 - y_1)^2 / 2z_{01}^2) \tag{4}$$

The above assumption is also consistent with assuming $\cos(\vec{n}, \vec{r}_{01}) \cong 1$. Therefore eq. (1) for the electrical potential becomes,

$$U(P_0) = \frac{\exp(-jkz_{01})}{j\lambda z_{01}} \iint_{\Sigma} U(x_1, y_1, z_1) \times \exp(-j \frac{k}{2z_{01}} [(x_0 - x_1)^2 + (y_0 - y_1)^2]) ds$$

$$U(x_0, y_0, z_0) = \frac{\exp(-jkz_{01})}{j\lambda z_{01}} \int dx_1 F(x_1) \exp(-j \frac{k}{2z_{01}} [(x_0 - x_1)^2]) \times \int dy_1 G(y_1) \exp(-j \frac{k}{2z_{01}} [(y_0 - y_1)^2]) \tag{5}$$

This formula is called the Fresnel approximation of eq. (1).

Gaussian beam: According to “the low power beam from helium-neon lasers are closely approximated by a Gaussian beam (also called a pure or fundamental mode beam)” [32]. Indeed, the propagation factor M^2 for such helium-neon lasers, which measure the deviation of the beam propagation from a pure Gaussian beam, is close to 1. The higher the power of the laser, the more complex is mathematical description necessary for the beam. Hence, for our illustrative purpose (not absolutely necessary) of the wave approach for the straight line diffraction, we can use a pure Gaussian beam. An elliptic Gaussian beam is a solution of the Maxwell equations. A Gaussian beam that propagates along the z axis is defined by the following electrical potential [33, 34].

$$U^{laser}(x, y, z) = U_{inc} \frac{\sqrt{\omega_{0x}\omega_{0y}}}{\sqrt{\omega_x(z)\omega_y(z)}} \exp(j[kz + \beta(z)] - x^2 [\frac{1}{\omega_x^2(z)} + \frac{jk}{2R_x(z)}] - y^2 [\frac{1}{\omega_y^2(z)} + \frac{jk}{2R_y(z)}]) \tag{6}$$

Here,

$$r^2 = x^2 + y^2, \quad k = 2\pi / \lambda,$$

$$\begin{aligned}
 \omega_x^2(z) &= \omega_{mx}^2 (1 + (2(z - z_{mx}) / b_x)^2), \\
 \omega_y^2(z) &= \omega_{my}^2 (1 + (2(z - z_{my}) / b_y)^2), \\
 \text{or, } \omega_x^2(z) &= \omega_{mx}^2 (1 + ((z - z_{mx}) / z_{0x})^2) \\
 \omega_y^2(z) &= \omega_{my}^2 (1 + ((z - z_{my}) / z_{0y})^2) \\
 R_x(z) &= (z - z_{mx})(1 + (b_x / (2(z - z_{mx})))^2), \\
 R_y(z) &= (z - z_{my})(1 + (b_y / (2(z - z_{my})))^2), \\
 \beta(z) &= \frac{1}{2} \tan^{-1}(2(z - z_{mx}) / b_x) + \frac{1}{2} \tan^{-1}(2(z - z_{my}) / b_y), \\
 b_x &= 2\pi\omega_{mx}^2 / \lambda, \quad z_{0x} = b_x / 2, \quad b_y = 2\pi\omega_{my}^2 / \lambda, \quad z_{0y} = b_y / 2
 \end{aligned} \tag{7}$$

The quantities ω_{mx} and ω_{my} are the beam minimum waists (ellipse semi-axes) at the positions z_{mx} , z_{my} respectively, along the z axis. ω_{mx} and ω_{my} are the values at which the beam field amplitude $|U|$ decreases by a factor $1/e$ compared to its value on the beam axis. The beam is simply a circular beam along the z axis when $\omega_{mx} = \omega_{my} = \omega_m$, $z_{mx} = z_{my} = z_m$, and hence, when $\omega_x = \omega_y = \omega$. Its minimum waist of ω_m is at z_m .

The diffraction of an elliptic Gaussian beam. Assume that the diffracting half-plane edge/ screen is defined by the conditions $z = z_1$, $y_1 \leq \varepsilon$ and $-\infty < x_1 < \infty$, where ε is positive or negative number to position the half-screen off the axis of the circular Gaussian beam. The position of the screen for the diffraction pattern is considered at $z_0 > 0$. The diffracted light in this case can be derived by using eq. (6) as $U^{laser}(x_1, y_1, z_1) = F(x_1, z_1)G(y_1, z_1)H(z_1)$ in the Fresnel approximation - eq. (5) of the diffraction formula - eq (1). The integration domain will be $-\infty < x_1 < \infty$ and $\varepsilon \leq y_1 \leq y_{max}$. For a plane wave diffraction, “y_{max}” is very large (i.e., ∞). However, y_{max} can be chosen smaller than $\omega_y(z_1)$ for studying how the integration domain influences the diffracted light in a certain point (x_0, y_0, z_0) . In the latter case, the interval (ε, y_{max}) defines a one-dimensional slit. These slit-type and plane wave cases are described by,

$$\begin{aligned}
 U(x_0, y_0, z_0) &= \frac{\exp(-jkz_{01})}{j\lambda z_{01}} U_{inc} \frac{\sqrt{\omega_{mx}\omega_{my}}}{\sqrt{\omega_x(z)\omega_y(z)}} \exp j[kz_1 + \beta(z_1)] \times \int_{-\infty}^{\infty} dx_1 \exp(-x_1^2 [\frac{1}{\omega_x^2(z_1)} + \frac{jk}{2R_x(z_1)}]) \exp(-j \frac{k}{2z_{01}} [(x_0 - x_1)^2]) \\
 &\quad \int_{\varepsilon}^{y_{max}} dy_1 \exp(-y_1^2 [\frac{1}{\omega_y^2(z_1)} + \frac{jk}{2R_y(z_1)}]) \exp(-j \frac{k}{2z_{01}} [(y_0 - y_1)^2])
 \end{aligned} \tag{8}$$

In the plane wave case, y_{max} goes to infinity. And

$$U(x_0, y_0, z_0) = \frac{\exp(jkz_{01})}{j\lambda z_{01}} U_{inc} \frac{\sqrt{\omega_{mx}\omega_{my}}}{\sqrt{\omega_x(z)\omega_y(z)}} \exp j[kz_1 + \beta(z_1)] \times \int_{-\infty}^{\infty} dx_1 \exp(-(a_1x_1^2 + 2b_1x_1 + c_1))$$

$$\times \int_{\varepsilon}^{\infty} dy_1 \exp(-(a_2 y_1^2 + 2b_2 y_1 + c_2)) \tag{9}$$

In eq. (9) the coefficients are defined as follows,

$$\begin{aligned} a_1 &= V_{1x}(z_1) + j(V_{2x}(z_1) + \frac{k}{2z_{01}}) = V_{1x} + j(V_{2x} + \frac{k}{2z_{01}}) \\ a_2 &= V_{1y}(z_1) + j(V_{2y}(z_1) + \frac{k}{2z_{01}}) = V_{1y} + j(V_{2y} + \frac{k}{2z_{01}}), \\ b_1 &= -j \frac{kx_0}{2z_{01}} \quad b_2 = -j \frac{ky_0}{2z_{01}} \\ c_1 &= j \frac{kx_0^2}{2z_{01}} \quad c_2 = j \frac{ky_0^2}{2z_{01}} \end{aligned} \tag{10}$$

Where

$$U(x_0, y_0, z_0) = U_{inc} \times A \times I_1 \times I_2 \tag{11}$$

With

$$A = \frac{\exp(-jkz_{01})}{j\lambda z_{01}} \frac{\sqrt{\omega_{mx}\omega_{my}}}{\sqrt{\omega_x(z)\omega_y(z)}} \exp[j[kz_1 + \beta(z_1)]] \tag{12}$$

According to the integrals in eq. (9) , and based on $erf(\infty) = 1$ and $erf(-\infty) = -1$, are [35],

$$\begin{aligned} I_1 &= \int_{-\infty}^{\infty} dx_1 \exp(-(a_1 x_1^2 + 2b_1 x_1 + c_1)) \\ &= \exp(\frac{b_1^2}{a_1} - c_1) \frac{1}{2} \sqrt{\frac{\pi}{a_1}} erf(\sqrt{a_1} x_1 + \frac{b_1}{\sqrt{a_1}}) \Big|_{-\infty}^{\infty} \\ &= \exp(\frac{b_1^2}{a_1} - c_1) \frac{1}{2} \sqrt{\frac{\pi}{a_1}} \times 2 = \exp(\frac{b_1^2}{a_1} - c_1) \sqrt{\frac{\pi}{a_1}} \end{aligned} \tag{13}$$

Where,

$$\begin{aligned} I_2 &= \int_{\varepsilon}^{y_{max}} dy_1 \exp(-(a_2 y_1^2 + 2b_2 y_1 + c_2)) = \int_{\varepsilon}^{\infty} dy_1 \exp(-(a_2 y_1^2 + 2b_2 y_1 + c_2)) - \int_{y_{max}}^{\infty} dy_1 \exp(-(a_2 y_1^2 + 2b_2 y_1 + c_2)) \\ &= \frac{1}{2} \sqrt{\frac{\pi}{a_2}} \exp(\frac{b_2^2}{a_2} - c_2) erf(\sqrt{a_2} y_1 + \frac{b_2}{\sqrt{a_2}}) \Big|_{\varepsilon}^{\infty} - \frac{1}{2} \sqrt{\frac{\pi}{a_2}} \exp(\frac{b_2^2}{a_2} - c_2) erf(\sqrt{a_2} y_1 + \frac{b_2}{\sqrt{a_2}}) \Big|_{y_{max}}^{\infty} \\ &= \frac{1}{2} \sqrt{\frac{\pi}{a_2}} \exp(\frac{b_2^2}{a_2} - c_2) (1 - erf(\sqrt{a_2} \varepsilon + \frac{b_2}{\sqrt{a_2}})) - \frac{1}{2} \sqrt{\frac{\pi}{a_2}} \exp(\frac{b_2^2}{a_2} - c_2) (1 - erf(\sqrt{a_2} y_{max} + \frac{b_2}{\sqrt{a_2}})) \\ &= \frac{1}{2} \sqrt{\frac{\pi}{a_2}} \exp(\frac{b_2^2}{a_2} - c_2) (cerf(\sqrt{a_2} \varepsilon + \frac{b_2}{\sqrt{a_2}}) - cerf(\sqrt{a_2} y_{max} + \frac{b_2}{\sqrt{a_2}})) \end{aligned} \tag{13'}$$

Where $\text{cerf}(y) = 1 - \text{erf}(y)$.

In order to express these equations in a more computational form let us define

$$\begin{aligned} \cos \varphi_x &= V_{1x} / \sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2} > 0, \\ \sin \varphi_x &= (V_{2x} + k / 2z_{01}) / \sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2} > 0 \\ \cos \varphi_y &= V_{1y} / \sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2} > 0, \\ \sin \varphi_y &= (V_{2y} + k / 2z_{01}) / \sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2} > 0 \end{aligned} \tag{14}$$

Notice that since $\cos \varphi > 0, \sin \varphi > 0$, it follows that $\cos \varphi / 2 > 0, \sin \varphi / 2 > 0$.

Hence we have the following expressions,

$$\begin{aligned} a_1 &= V_{1x} + j(V_{2x} + \frac{k}{2z_{01}}) = \sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2} (\cos \varphi_x + j \sin \varphi_x), \\ \sqrt{a_1} &= \sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}} (\cos \varphi_x / 2 + j \sin \varphi_x / 2) \\ 1/a_1 &= (V_{1x} - j(V_{2x} + k / 2z_{01})) / (V_{1x}^2 + (V_{2x} + k / 2z_{01})^2) = \frac{1}{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}} (\cos \varphi_x - j \sin \varphi_x), \end{aligned} \tag{15}$$

$$\begin{aligned} b_1^2 / a_1 &= \frac{-k^2 x_0^2 / (4z_{01}^2)}{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}} (\cos \varphi_x - j \sin \varphi_x), \\ a_2 &= V_{1y} + j(V_{2y} + \frac{k}{2z_{01}}) = \sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2} (\cos \varphi_y + j \sin \varphi_y), \\ \sqrt{a_2} &= \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} (\cos \varphi_y / 2 + j \sin \varphi_y / 2) \\ 1/a_2 &= (V_{1y} - j(V_{2y} + k / 2z_{01})) / (V_{1y}^2 + (V_{2y} + k / 2z_{01})^2) = \frac{1}{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} (\cos \varphi_y - j \sin \varphi_y) \end{aligned} \tag{16}$$

$$\begin{aligned} b_2^2 / a_2 &= \frac{-k^2 y_0^2 / (4z_{01}^2)}{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} (\cos \varphi_y - j \sin \varphi_y), \\ 1/\sqrt{a_1} &= \frac{1}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}}} (\cos \varphi_x / 2 - j \sin \varphi_x / 2), \\ |\sqrt{\frac{\pi}{a_1}}| &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}}} |\cos \varphi_x / 2 - j \sin \varphi_x / 2| = \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k / 2z_{01})^2}}} \end{aligned} \tag{17}$$

$$\begin{aligned} 1/\sqrt{a_2} &= \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} (\cos \varphi_y / 2 - j \sin \varphi_y / 2), \\ |\sqrt{\frac{\pi}{a_2}}| &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} |\cos \varphi_y / 2 - j \sin \varphi_y / 2| = \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \end{aligned} \tag{18}$$

$$b_2 / \sqrt{a_2} = -j \frac{ky_0}{2z_{01}} \frac{\cos \varphi_y / 2 - j \sin \varphi_y / 2}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} = -\frac{ky_0}{2z_{01}} \frac{\sin \varphi_y / 2 + j \cos \varphi_y / 2}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}}$$

Let us also define

$$u_y + jv_y = \sqrt{a_2} \varepsilon + \frac{b_2}{\sqrt{a_2}} = \varepsilon \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \cos \varphi_y / 2 + j \varepsilon \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \sin \varphi_y / 2 - \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \sin \varphi_y / 2 - j \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \cos \varphi_y / 2 \tag{19}$$

$$p_y + jq_y = \sqrt{a_2} y \max + \frac{b_2}{\sqrt{a_2}} = y \max \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \cos \varphi_y / 2 + jy \max \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \sin \varphi_y / 2 - \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \sin \varphi_y / 2 - j \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \cos \varphi_y / 2 \tag{19'}$$

Hence,

$$u_y = \varepsilon \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \cos \varphi_y / 2 - \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \sin \varphi_y / 2, \tag{20}$$

$$v_y = \varepsilon \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}} \sin \varphi_y / 2 - \frac{ky_0}{2z_{01}} \frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \cos \varphi_y / 2$$

Similar expressions are true for p_y and q_y .

Notice that

$$v_y^2 - u_y^2 = (\varepsilon \sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}})^2 (\sin^2 \varphi_y / 2 - \cos^2 \varphi_y / 2) + \frac{k^2 y_0^2}{4z_{01}^2} \left(\frac{1}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k / 2z_{01})^2}}} \right)^2 (\cos^2 \varphi_y / 2 - \sin^2 \varphi_y / 2)$$

$$= -\varepsilon^2 \sqrt{(V_{1y}^2 + (V_{2y} + k / 2z_{01})^2)} \cos \varphi_y + \frac{k^2 y_0^2}{4z_{01}^2} \frac{1}{\sqrt{(V_{1y}^2 + (V_{2y} + k / 2z_{01})^2)}} \cos \varphi_y \tag{21}$$

$$= -\varepsilon^2 V_{1y} + \frac{k^2 y_0^2}{4z_{01}^2} \frac{V_{1y}}{(V_{1y}^2 + (V_{2y} + k / 2z_{01})^2)}$$

And hence,

$$-\frac{k^2 y_0^2}{4z_{01}^2} \frac{V_{1y}}{(V_{1y}^2 + (V_{2y} + k / 2z_{01})^2)} = u_y^2 - v_y^2 - \varepsilon^2 V_{1y} \tag{22}$$

Similarly,

$$-\frac{k^2 y_0^2}{4z_{01}^2} \frac{V_{1y}}{(V_{1y}^2 + (V_{2y} + k / 2z_{01})^2)} = p_y^2 - q_y^2 - y \max^2 V_{1y} \tag{22'}$$

From eq. (11)

$$|U(x_0, y_0, z_0) / U_{inc}| = |A| \times |I_1| \times |I_2| \tag{23}$$

Where,

$$|A(z_1)| = \frac{\sqrt{\omega_{mx} \omega_{my}}}{\sqrt{\omega_x(z_1) \omega_y(z_1)}} \frac{1}{\lambda z_{01}} \tag{24}$$

Based on eqs. (14), (22) and (22')

$$\begin{aligned}
 |I_1| &= |I_1(x_0)| = |I_1(x_0, z_0, z_1)| = \frac{\sqrt{\pi} |\exp(b_1^2/a_1) - c_1|}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} = \frac{\sqrt{\pi} |\exp(b_1^2/a_1)|}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} \\
 &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} \times \exp\left(\frac{-k^2 x_0^2 / (4z_{01}^2)}{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}} (\cos \varphi_x - j \sin \varphi_x)\right) \\
 &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} \times \exp\left(\frac{-k^2 x_0^2 / (4z_{01}^2)}{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}} \cos \varphi_x\right) \\
 &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} \exp\left(\frac{-V_{1x} k^2 x_0^2 / (4z_{01}^2)}{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}\right) \tag{25}
 \end{aligned}$$

Similarly,

$$\begin{aligned}
 |I_2| &= |I_2(y_0)| = |I_2(y_0, z_0, z_1)| = \frac{1}{2} \frac{\sqrt{\pi} |\exp(b_2^2/a_2 - c_2)|}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \times \left| \operatorname{cerf}\left(\sqrt{a_2} \varepsilon + \frac{b_2}{\sqrt{a_2}}\right) - \operatorname{cerf}\left(\sqrt{a_2} y_{\max} + \frac{b_2}{\sqrt{a_2}}\right) \right| \\
 &= \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \times \exp\left(\frac{-k^2 y_0^2 / (4z_{01}^2)}{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}} (\cos \varphi_y - j \sin \varphi_y)\right) Y \tag{26} \\
 &= \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \left(\exp\left(\frac{-k^2 y_0^2 / (4z_{01}^2)}{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}} \cos \varphi_y\right) Y\right), \\
 &= \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \left(\exp\left(\frac{-V_{1y} k^2 y_0^2 / (4z_{01}^2)}{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}\right) Y\right)
 \end{aligned}$$

Where,

$$Y = |\operatorname{cerf}(u_y + jv_y) - \operatorname{cerf}(p_y + jq_y)| \tag{26'}$$

Therefore,

$$\begin{aligned}
 |I_1| &= \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}}} \exp\left(\frac{-V_{1x} k^2 x_0^2 / (4z_{01}^2)}{V_{1x}^2 + (V_{2x} + k/2z_{01})^2}\right) \tag{27} \\
 |I_2| &= \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \times \left| \exp(-\varepsilon^2 V_{1y}) \exp(u_y^2 - v_y^2) \operatorname{cerf}(u_y + iv_y) \right. \\
 &\quad \left. - \exp(-y_{\max}^2 V_{1y}) \exp(p_y^2 - q_y^2) \operatorname{cerf}(p_y + iq_y) \right| \tag{28}
 \end{aligned}$$

Notice that when y_{max} goes to infinity then,

$$|I_2| = \frac{1}{2} \times \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_{1y}^2 + (V_{2y} + k/2z_{01})^2}}} \exp(-\varepsilon^2 V_{1y}) \left| \exp(u_y^2 - v_y^2) \operatorname{cerf}(u_y + iv_y) \right| \tag{28'}$$

The numerical calculations: The direct calculation of $\operatorname{cerf}(u+jv)$ from eq. (28') is difficult because it leads to multiplying very large numbers with very small numbers which results in very large errors. Rather, the calculation of $\operatorname{cerf}(u+jv)$ can be based on the calculation of the Fadeeva function $w(-v+ju)$ by the following derivation. From Ref. [35] we have,

$$w(z) = \exp(-z^2) \operatorname{cerf}(-jz),$$

$$w(jz) = \exp(z^2) \operatorname{cerf}(z)$$

where $z = u+jv$, or $z = p+jq$

Hence,

$$w(-v + ju) = \exp(u^2 - v^2) \exp(j2uv) \operatorname{cerf}(u + jv) \quad (30)$$

$$w(-q + jp) = \exp(p^2 - q^2) \exp(j2pq) \operatorname{cerf}(p + jq)$$

$$\exp(u^2 - v^2) \operatorname{cerf}(u + jv) = \exp(-j2uv) w(-v + ju)$$

$$\exp(p^2 - q^2) \operatorname{cerf}(p + jq) = \exp(-j2pq) w(-q + jp)$$

Therefore eq. (28) becomes

$$|I_2| = \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_1^2 + (V_2 + k/2z_{01})^2}}} \times |\exp(-\varepsilon^2 V_1) \exp(-j2uv) w(-v + ju) \\ - \exp(-\text{pmax}^2 V_1) \exp(-j2pq) w(-q + jp)| \quad (31)$$

Again, when pmax goes to infinity then,

$$|I_2| = \frac{1}{2} \frac{\sqrt{\pi}}{\sqrt{\sqrt{V_1^2 + (V_2 + k/2z_{01})^2}}} \exp(-\varepsilon^2 V_1) |w(-v + ju)| \quad (31')$$

A Fortran program for eqs. (23–31) : Edge diffraction Gaussian beam: We developed a computer program in Fortran for the calculation of the diffraction integral for a Gaussian beam based on eqs. (23-31). The calculation of the function $w(-v+ju)$ is done with the routine Function $\operatorname{wverf}(z)$ [36-40]. We tested the program in various ways.

- For a perfectly round beam it produces the value of $A(z_1)/2$ for eq. (23) for $(x_0, y_0, z_0) = (0,0,z_0)$ as it should. This means that the light intensity on the beam axis (i.e., the square value of eq. (23)) is $A(z_1)*A(z_1)/4$. The program shows that when ε is a large negative number, that is when there is no diffraction edge in the path of the beam, the program gives for the diffraction integral the values of the Gaussian beam, as it should. Also, when ε is a very large positive number, that is when the Gaussian beam of light is blocked by the diffracting edge, the program gives very small numbers for the diffraction integral, that is no beam passes the diffracting edge.
- The graph in **FIG. 4** compares the results for a thick beam with the results for a plane wave.

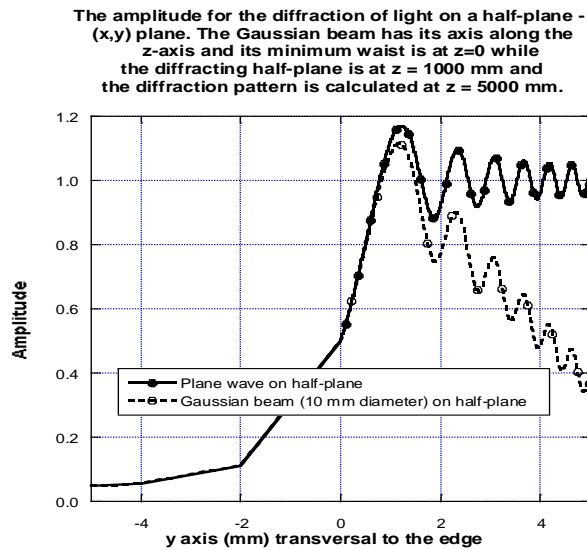


FIG. 4 Testing the program for the diffraction of a Gaussian beam. The diffracted amplitude at 4000 mm behind the diffracting half-plane for a thick (10 mm diameter) Gaussian beam is compared with the standard case of the diffracted amplitude for a plane wave. The comparison shows that the numerical calculations are satisfactory

Calculations of the measurement points for our experiment:

In our experiment a laser beam hits perpendicularly with its axis a straight diffracting edge, and the intensity of light is measured in the geometrical shadow of the diffracting edge. This experiment verifies systematically if the intensity of the diffracted light in any point in the geometrical shadow, especially at large distances, increases when the thickness of the diffracting beam increases transversally to the diffracting edge. Surprisingly, this dependence, although is the most fundamental prediction for understanding the nature of light (more important than the diffracting fringes, for the nature of light) because a very large (infinite) volume, was not systematically measured yet. Our experimental setup includes three systems: a highly stable laser with a fine positioning/ orientation system, a fine edge/ slit system with micrometric positioning system, and a detector system: a linear detector - PDF10A, Femtowatt Photo receiver from Thor, and a two-dimensional camera-the Little Guy beam profiler from Akron, with a fine positioning system. Our laser is a Micro-g Lacoste laser - a high quality He-Ne, 1 mW.

This experiment tests if the Huygens principle, or the wave diffraction integral is valid for the diffracted light in the geometrical shadow that is if the later depends on the thickness of the beam transversal to the diffracting edge, while maintaining the same distribution of light along the diffraction edge. We answer the following questions. How the calculations and the experiment can vary this transversal thickness of the beam and maintain the longitudinal distribution of light along the diffracting edge? At what distance from the laser we need to measure the light in the geometrical shadow in order to see if there is a dependence on the beam thickness across the diffracting edge? By following a systematic measurement, or calculations with the elliptical Gaussian beam, naturally allows answering these questions.

Our Micro-g Lacoste laser is a highly stable in intensity and direction 1mW laser, with a minimum beam radius (waist) $\omega_m = 0.3\text{mm}$ at the exit from the laser, and with a beam divergence 0.65 mrad, polarized beam. The diffracting edge is placed at distances 1500 mm where of eq. (7) becomes proportional with z. For $z_{mx} = z_{my} = 0\text{mm}$ we have $\omega_x = \omega_y = 1\text{mm}$ at $z=1500\text{mm}$, while for $z_{my} = 0\text{mm}$ and $z_{mx} = 3000$ we have $\omega_y = 3\text{mm}$ and $\omega_x = 1\text{mm}$ at $z=4500\text{mm}$.

The laser and the origin of the beam is placed at $z=0$, the plane of the diffracting edge is placed in the semi-plane (x_l, y_l, z_l) where $-\infty < x_l < \infty$, $y_l \leq 0$ with z_l a fixed point beyond z_R . The edge itself extends parallel with the x axis and touches the z axis at z_1 . The points where we calculate or measure the diffracted light are on the line $(0, y_0, z_0)$ with $y_0 < 0$ such that $z_0 - z_1$ is a large distance from the diffracting edge, that is a line parallel with the y axis, at large distance in the geometrical shadow. Below we show that the latter distance needs to be in a range difficult to measure, namely 100 m to 500 m, that is not in the 5 m which is normally accessible.

In the calculations, for a given position of the diffracting edge on the z axis, we compared two cases of traversal thickness but with the same longitudinal (along the diffracting edge) distribution of light. In the first case (case 1), which is the reference case, we use the same position along the beam axis $z_{mx} = z_{my} = 0$ in eq. (7) for the two minimum waists of the Gaussian beam – the one on the x axis (along the diffracting edge) and the one on the y axis (transversal to the diffracting edge). The diffracting edge is placed at the distance $z_1 - z_{mx} = 1.5$ from the beam waists. In the second case (case 2) the position of the minimum waist on the y axis is kept as in the first case while the position of the minimum waist on the x axis is moved forward at larger values of z_{mx} along z axis. At the same time the position z_1 of the diffracting edge is also moved forward, so that the distance $z_1 - z_{mx}$ remains constant, which is the same as in the case 1. As a result of this variation the traversal (y-axis) distribution of the light on the diffracting edge varies. Namely, the traversal thickness of the beam falling on the diffracting edge increases, but the distribution along the diffracting edge is similar and by normalization can be made the same. The comparison of the calculated diffracted light in these two cases characterizes the predicted effect of increasing the beam thickness, transversal to the diffracting edge, on the diffracted light in the geometrical shadow.

The numerical calculations with our Fortran program Edge diffraction Gaussian beam show the following differences between the light intensities for the two cases:

- Less than 1% for $z_0 - z_1 = 5\text{m}$ and y_0 in the range of 10 mm to 25 mm below z axis that is in the geometrical shadow
- 5% for $z_0 - z_1 = 50\text{m}$ and $y_0 = 10\text{mm}$, and 5% for $z_0 - z_1 = 50\text{m}$ and $y_0 = 25\text{mm}$ below z axis that is in the geometrical shadow
- Around 75% for $z_0 - z_1 = 100\text{m}$ and y_0 in the range of 10 mm to 25 mm below z axis that is in the geometrical shadow

Therefore, these numerical results show that we need to measure the diffracted light in the geometrical shadow for $z_0 - z_1$ in the range from 100 m to 500 m, better for $z_0 - z_1$ close to 500 m. We needed a long time to explore by calculations where we need to measure. Initially we were looking at distances $z_0 - z_1$ from 5 m to 10 meters.

Experimentally, the beam waists for our laser are in the same place $z_{mx} = z_{my} = 0\text{mm}$ on the z axis, as used in the Case 1 above. By placing a divergent cylindrical lens of a certain focal distance f at a position z_l , before the diffracting edge for Case 1, with the axis of the cylindrical lens parallel with the x axis. Then the beam spreads more along y axis, as if a second beam waist ω_{new} along z axis (smaller than ω_{my} from the Case 1) is created at the distance d before the lens, as necessary for the Case 2. By varying the position and the focal distance f we can have the same distribution of light falling on the diffraction edge along the x axis, but a broader light beam falls transversally to the diffracting edge. Hence it is possible to reproduce experimentally the Case 1 and Case 2

above. Certainly the normalization of the beam at the diffracting edge for the two cases is necessary in order that the distribution of light falling on the diffracting edge be the same in the two cases.

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