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Light Strands: Visualization of Free Space in Double Slit Diffraction

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Abstract Modern understanding of light has fluctuated between particle and wave theory. The classic double slit experiment provided seemingly conclusive support for wave theory of light with its resultant fringe patterns thought to only be due to wave interference. However, interference junctures of light have never been directly visualized. We investigated the double slit experiment and its fringe pattern through novel techniques of direct visualization of light propagation in the free space after slit exit in order to validate this interference principle. A cloud chamber and gel media were developed to visualize otherwise invisible light pathways. Coherent light was observed in these environments in settings of diffraction, refraction, and reflection. Experimental generation of distinct, isolated light strands after diffraction through double slits were visualized. Discrete light strands, not waves, were noted as light propagated through free space. Light strands were visualized directly creating the pseudo-interference fringe pattern, counter to the concept of wave interference. Novel visualization of light strands supports the particle theory of light and provides an alternative to wave theory. The finding that diffractive fringe patterns and other observations of light can be explained in some situations by the phenomena of discrete radiating strands, not wave interference, may have implications in physics, quantum mechanics, and technology.

Keywords: *light strands, particle wave duality, photons, diffraction, double slit, wave interference*

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1. Introduction

Since early times, civilizations have strived to understand light. Modern theories have equivocated between particle and wave descriptions [1,2]. In the 1600’s, Isaac Newton described the corpuscular or particle theory of light [1]. Huygens, Young and others used experiments with slits, interference patterns, and wave propagation analysis to support the wave nature of light [1,3]. However, Planck, describing spectral radiation, introduced the idea of quanta of energy [4]. Einstein, expounding on this, elucidated the photoelectric effect by utilizing the discrete, particle nature of photons [4]. Schrodinger, Bohr, Heisenberg, de Broglie, and others developed quantum mechanics and probability of wave functions to try to reconcile the dual particle-wave nature of light [2,4,5].

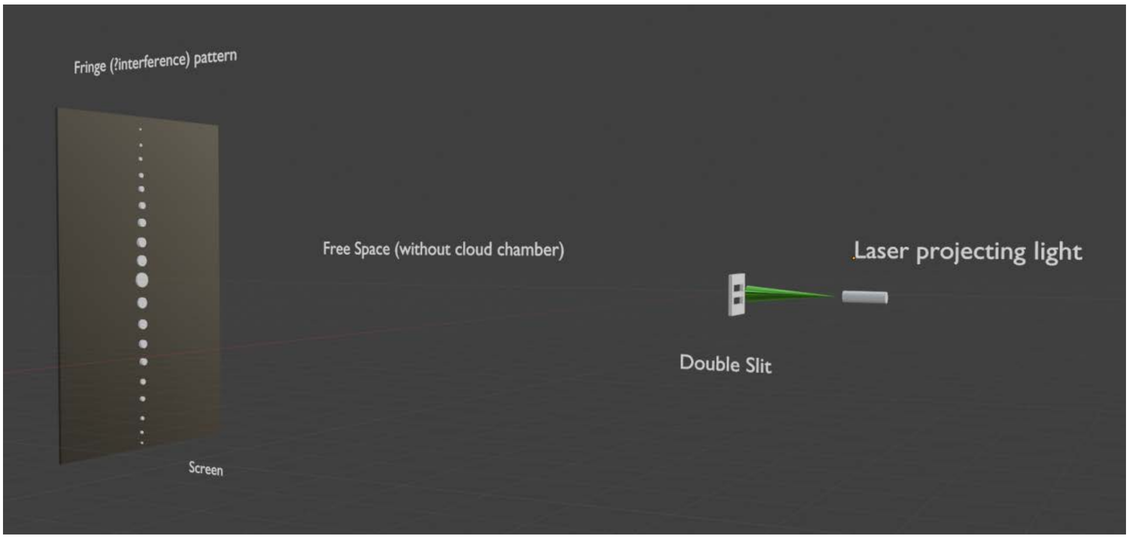

Figure 1. Schematic rendering of Double Slit experiment without cloud chamber

The classic double slit experiment by Young provided strong support for wave theory [7]. The fringe pattern produced by diffracting light through a double slit (Figure 1) has been accepted as indicative of wave interference of light. Based on wave interference patterns with other media, light was assumed to behave similarly. However, interference arrays of light have never been directly visualized. In this paper we investigate the double slit experiment and its fringe pattern through direct visualization of its light propagation in order to validate this interference principle. To our knowledge, no significant study has looked at light behavior after exiting the slit in the intervening free space between the double slit and screen. Employing techniques to directly visualize this trajectory pattern in free space, we revisited the double slit experiment. We report our novel experimental findings on the diffractive interference pattern as well as in refraction and reflection settings.

2. Methods

Double slits obtained from 3B Scientific were used in slide format with slit width of 0.15mm, and spacing of 0.30mm. A coherent light source was obtained with a laser of 532nm wavelength and 5mW output. A cloud chamber environment was created that would detect light pathways while remaining transparent using heated water vapor. This was created in an enclosed room to capture and hold the water vapor and allowed for wide field imaging. A light box was used to contain the water vapor for some images. More focused, macro imaging was obtained with hydrated gelatin. A block of gelatin was placed in the pathway of the slit diffracted light travelling in free space and images were captured. Gelatin allowed viewing of static and finer images compared with shifting water vapor. Water vapor and gelatin media were examined to ensure that the media did not affect or create fringe patterns. Passing laser light, without the double slit diffraction, through the vapor cloud chamber or gelatin did not create any fringe pattern. Photographic images were obtained with Sony NEX-5N mirrorless digital camera with 16.1MP Exmor APS HD CMOS image sensor and Sony E 18-55mm f3.5-5.6 OSS lens.

The layout of the experiment is depicted in Figure 1. The laser source was placed on a stable platform. The double slit slide, held with a clamp, was placed 10cm in front of the laser. Upon projecting the laser light on the double slit, a fringe pattern was noted on the screen. Subsequently, a cloud chamber was formed or gelatin block was placed in the free space between slit and screen. The resulting visualized light output pattern was captured in both environments. Different configurations in addition to the double slit were also used including single slit, circular pinhole,+20D converging lens after the slit, projecting the light output onto a prism, projecting an additional laser on the light output, and applying bar magnets around the light output.

3. Results

Novel visualization of discrete strands of light was evident in free space after exiting the double slit (Figure 2). Photon trajectory as distinct strands was clearly manifest as they traversed the cloud chamber.

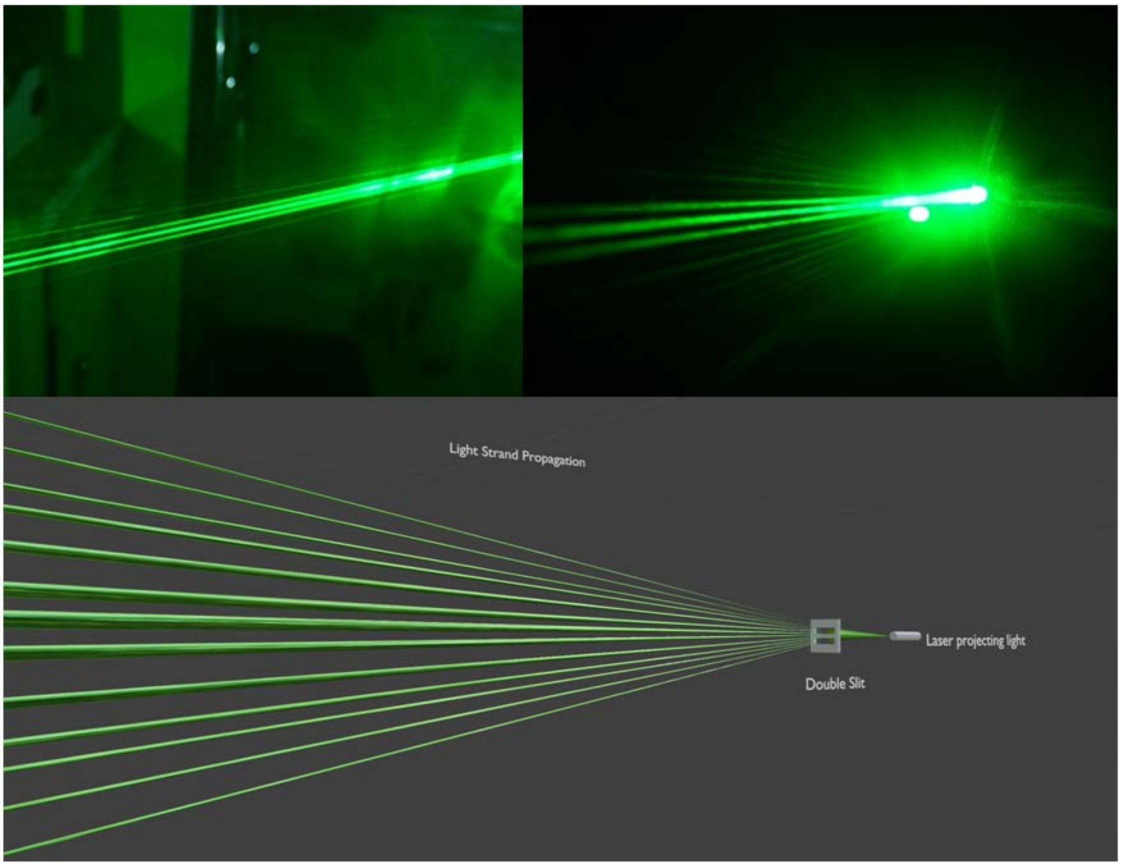

Figure 2. Photo images and schematic rendering of visualized discrete light strands, not waves, streaming from a double slit at regularly spaced intervals and angles

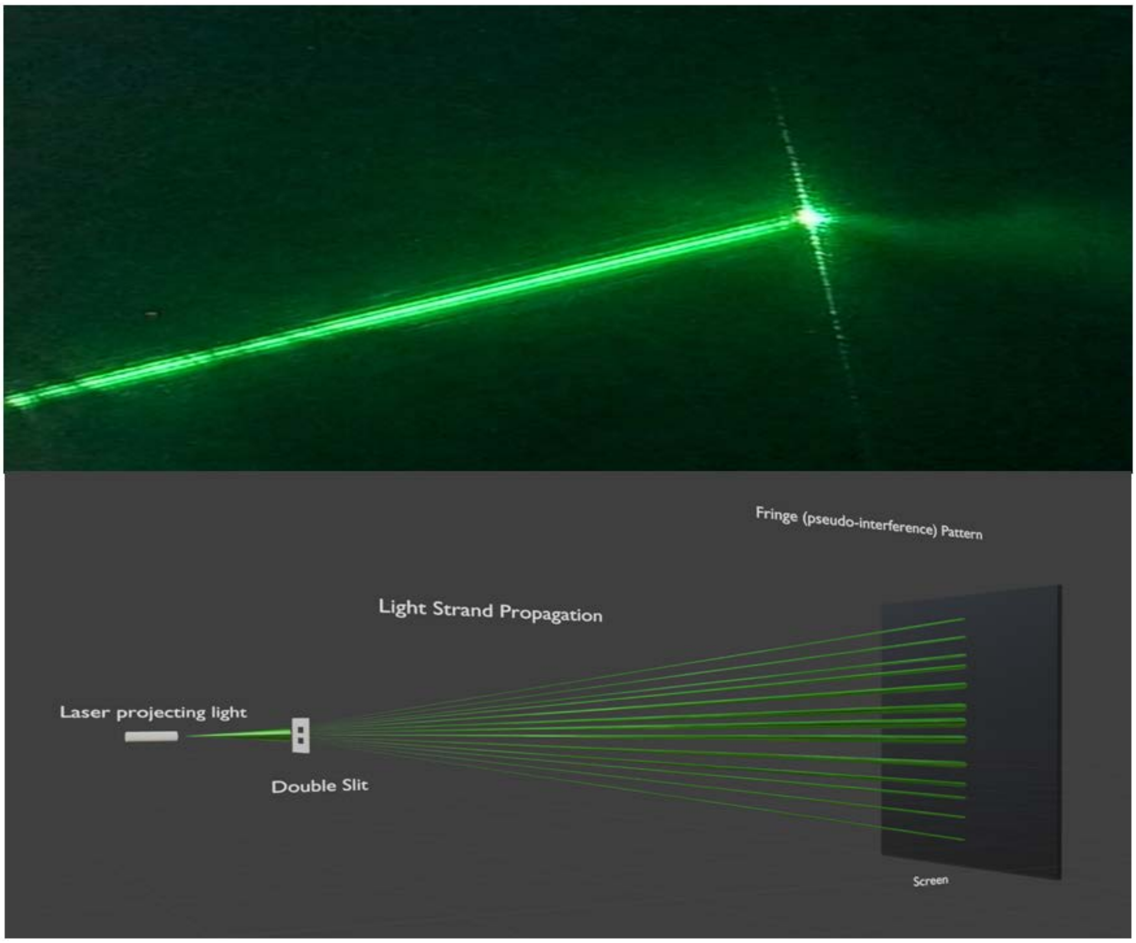

Figure 3. Photo image and schematic rendering of photon strands creating the pseudo-interference fringe pattern

Separation into uniform strands with uniform angles, and clear intervals occurred immediately after exiting the slit. The strands streamed out in a geometric fashion, perpendicular to the slit edge. Strands remained in discrete channels as they collided with the screen and created the characteristic fringe pattern (Figure 3). Separation between strands created the clear intervals. Repeated double slit diffractions resulted in the same visual results.

Strands could also be focally blocked anywhere between slit and screen without effecting other strands. A hollow tube placed around strands did not affect the linear pathway of strands inside or outside the tube. No effect on light strands was noted from water vapor or gelatin media as the fringe pattern did not change in intensity or pattern after the addition of either media. Water vapor nor gelatin media, without the double slit, also did not create light strands with laser light projection.

The further the screen distance is from the slit, the wider the strands and wider the interval between strands (Figure 4 and Figure 5) (Table 1).

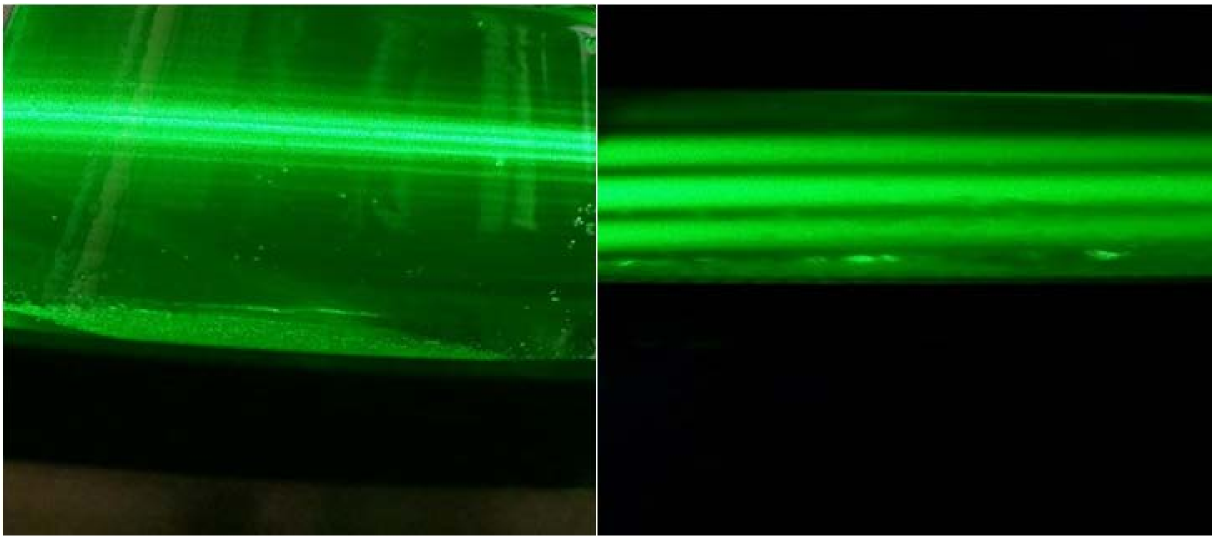

Figure 4. Photon strands traversing gelatin media at 100 cm and 500 cm from slit

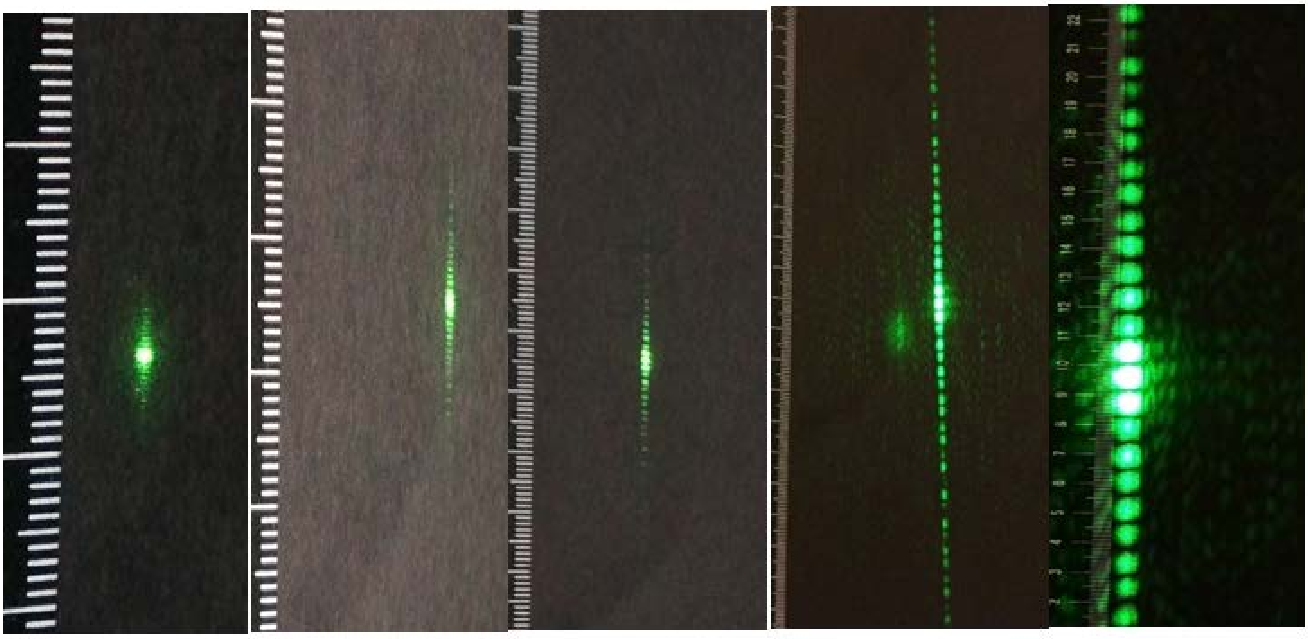

Figure 5. Fringe pattern with increasing distance between slit and screen (10 cm, 40 cm, 80 cm, 250 cm, 500 cm)

Table 1. Fringe Mark (Strand) Width and Clear Interval Width at Increasing Slit Distance

Slit Distance (D)	Mark Width (W)	Mark Angle (Θ)	Calculated Wavelength (λ)	Mark Shape	Interval Width	Interval Angle
(mm)(±.1)	(mm)(±.1)	(Radians)	(nm)		(mm)(±.1)	(Radians)
100	0.3	0.0030	284	Linear	0.15	0.00150
400	0.5	0.0012	681	Linear	0.25	0.00062
800	1	0.0012	681	Oval	0.50	0.00062
2500	4	0.0016	532	Circular	1.0	0.00040
5000	8	0.0016	532	Circular	1.5	0.00030

When graphed, light strands and their clear intervals followed a linear dilation as they propagated in free space (Figure 6 and Figure 7).

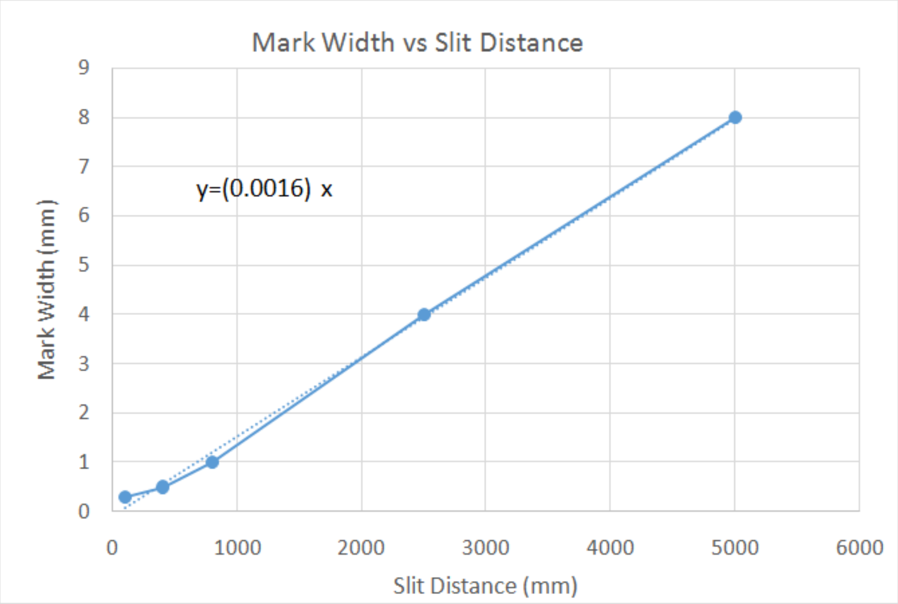

Figure 6. Graph of strand mark width vs slit distance displaying a linear relationship

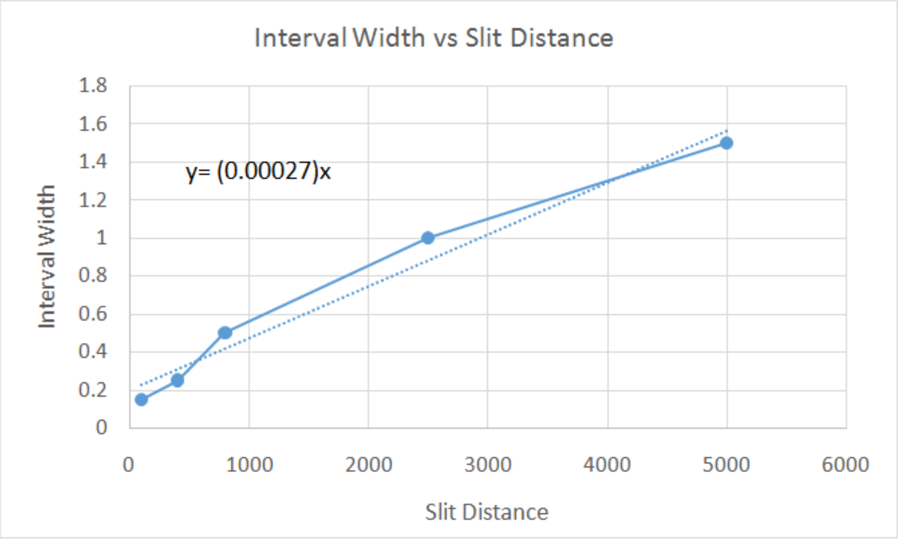

Figure 7. Graph of clear interval width vs slit distance exhibiting a linear relationship

Strands were initially linear in cross section and become circular, the further the distance from the slit (Figure 5). The central strands' intensity was greater than peripheral ones.

A reflection was also noted with light strands travelling from the entrance of the slit to the back wall (Figure 8). This posterior reflection also created strands and a fringe pattern.

In the next investigation, a single slit was employed in place of the double slit. Its trajectory map also resulted in visible strands (Figure 9) causing a fringe pattern as they collided with the screen. Most of the strands coalesced in the center with fewer peripheral strands.

Additionally, a pinhole was substituted for a slit. Its trajectory map revealed streaming concentric sheaths of light (Figure 10). In cross section in free space and as these sheaths impacted the screen, a concentric ring pattern was noted.

Figure 8. Light strands reflecting posteriorly before entering double slit creating its own strands and fringe marks

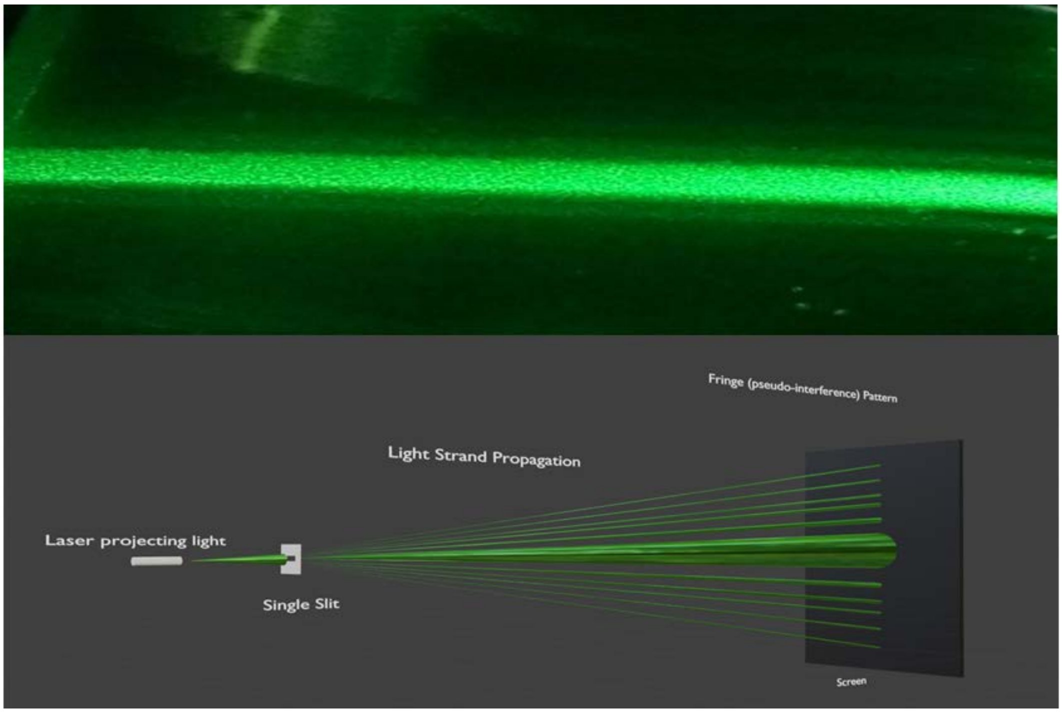

Figure 9. Photo image and schematic rendering of single slit causing characteristic dense central strand and faint peripheral ones

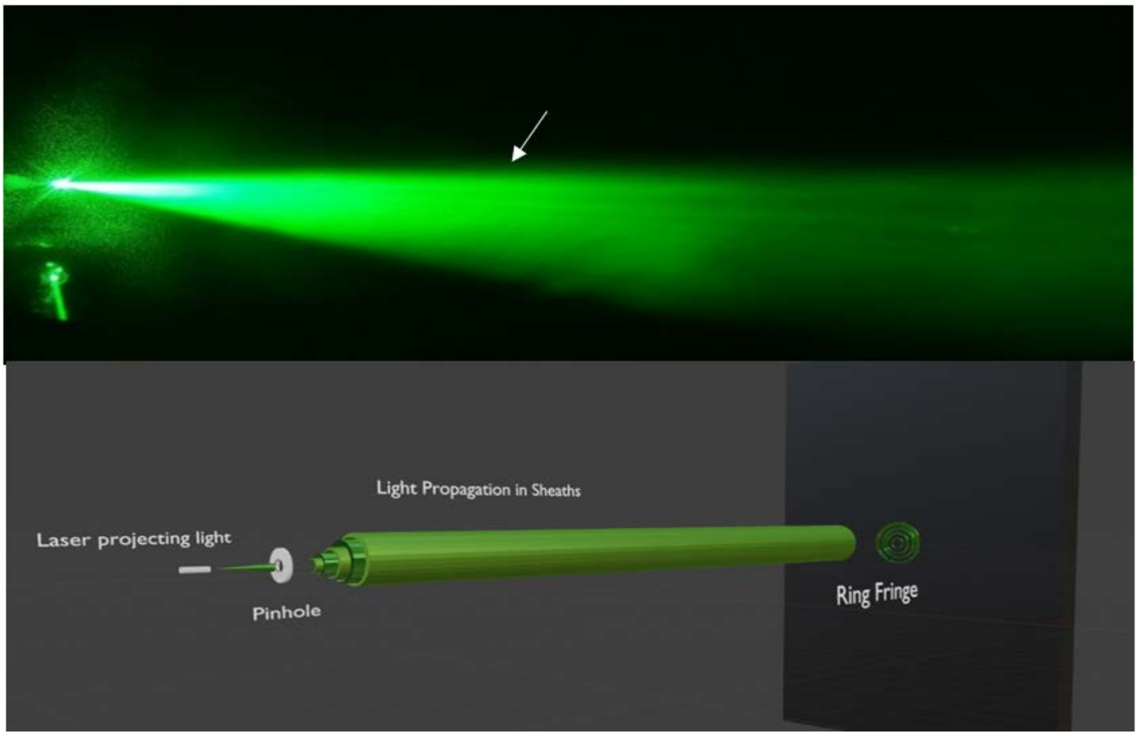

Figure 10. Photo image and schematic rendering of light strands radiating from pinhole in cylindrical sheaths, creating concentric rings in cross section

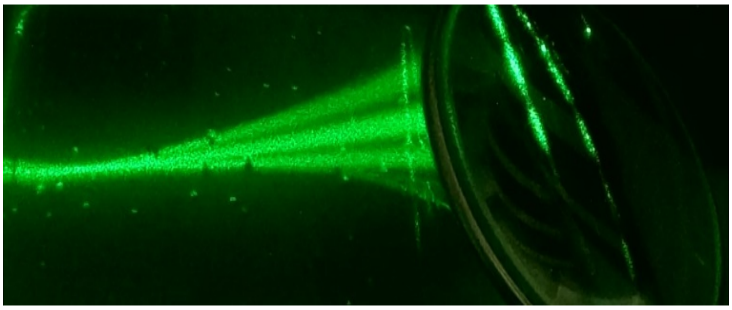

Figure 11. Collapse of fringe pattern upon projection onto +20D lens due to convergence of photon strands

In another investigation, a fringe pattern was projected onto a +20D lens. After traversing the lens, convergence of strands was noted to a point at the lens focal distance (Figure 11).

A prism was placed in the path of the photon strands. The reflected strands displayed the same sharp, fringe pattern.

No discernible changes, movements, or deflections were noted with projecting additional laser light onto the strands. Similarly, magnets did not show any visible effects on light strands with either pole nor with any directional movement.

4. Discussion

Directly observing the phenomena of light strands and its propagation in free space is strong confirmation of its particle nature. The generation of discrete strands with defined borders counters wave theory in this setting. Blurred edges or gradients, which would be consistent with wave interference, were not present as the strands are sharply defined. The immediate splitting into strands upon exiting the slit further opposes wave theory in which interference would occur further away from the slit where expanding waves would have constructive and destructive interference. Focally blocking strands without effecting adjacent strands points to particle behavior. Similarly, isolated strands can traverse through hollow tubes placed anywhere along its path without effecting adjacent strands or its own interaction with the screen. Wave interference would be obstructed by the tube.

We show, for the first time, distinct streaming strands of light traversing free space, striking the screen, and creating the classic fringe pattern. This is visible information countering wave constructive interference as the sole cause for fringe marks in this setting. Furthermore, the clear spaces are not due to wave destructive interference, but are from the separation of discrete strands. These photon trajectory patterns visibly counter longstanding wave interference concepts.

The reflection posteriorly from the slit caused its own fringe pattern. Not having gone through the double slit, this reflection should not have a fringe per wave theory as no constructive or destructive wave interference would have occurred. Particle theory explains it as multiple strands reflecting posteriorly from the slit entrance.

Single slit diffraction also caused a breakup of light into visible strands causing a fringe pattern. This occurred with a single slit where there should be an absence of interfering waves. Most of the strands coalesced in the center with fewer peripheral strands reflecting away, consistent with observed single slit fringe patterns.

Pinhole diffraction created streaming concentric sheaths of light. Having a curved edge, unlike a slit, the circular pinhole reflected strands in concentric halos. As these sheathes collided with the screen, the characteristic concentric ring pattern was created. This ring pattern was also visible in cross section of the strands traversing free space.

Convergence of strands occurs with refraction through a +20D lens. This "collapse" of the fringe pattern is noted with visible convergence of the photon strands. This sharp visible deflection of strands further supports a particle nature of light. It may also offer an explanation for the puzzling collapse of interference patterns noted in some double slit experiments [8,9].

Photon strands can also be reflected and still retain discrete borders. When sent through a prism, the reflected strands continued to display sharp, fringe patterns, which would be consistent with particles.

Light strands prefer to preserve their tight formation as evidenced by the lack of reaction to additional laser light projection onto the strands. There seems to be a resistance to interference from external photons. This may explain the sharp separation of strands exiting from a slit and the corresponding distinct clear spaces of the fringe pattern.

Magnets did not show any significant visible effects on light strands with either pole nor with any directional movement. This is unexpected if light is part of the electromagnetic spectrum, and requires further exploration.

These observations of visible light strands support the particle theory of light. They also counter the model that double slit diffraction patterns of light are only attributable to wave interference. Distinct strand channels, not waves, appear to create the alternating marks. In our schematic diagram (Figure 12) consider the laser beam as being shattered into shards of photons at the periphery where it encounters the slit edges. These photon shards, as they reflect in all directions, appear to quickly re-organize and fuse into evenly separated strands as they stream away from the slits. After traversing free space these strands collide with the screen creating an evenly spaced fringe pattern.

The data shows that strands become more cylindrical with greater distance from the slit. We propose that this round configuration is consistent with particles propagating through the strands in a helical, rotational pattern. Particles traversing along tubular channels would be more symmetrical and stable with a helical rotation. Additionally, linear point particles would scatter in all different directions. Helical, cylindrical propagations are more likely to stay in defined channels, creating the sharp, alternating bright and dark fringe marks

Strands of helical tunneling photons also provide both particle and oscillatory behavior. As strands, light behaves as a particle that travels linearly. With a helical rotation, it displays oscillatory wave-like behavior with rotational phases. Therefore, this model can be described as a hybrid, though different from the traditional descriptions of transverse light waves.

Photons in the same phase of helical rotation, merging and weaving together tightly, may explain the formation of discrete strands. This coupling mechanism relies on a helical rotational phase matching, while photons out of phase would be repulsed away towards another strand, creating the evenly spaced fringe pattern. Tight phase integration of strands may also clarify why light beams do not interfere with each other when their paths cross. Photons tunneling through some materials may also be explained by this tight union that may cross through weaker bonds of some materials. Other attractive or repulsive forces may also be present. Cohesiveness of strands does not seem to be due to charge or magnetism as photons do not have charge nor did the strands respond to magnetic fields.

As light strands radiate in uniform angles and intervals (Table 1) (Figure 13), equations can model the observations.

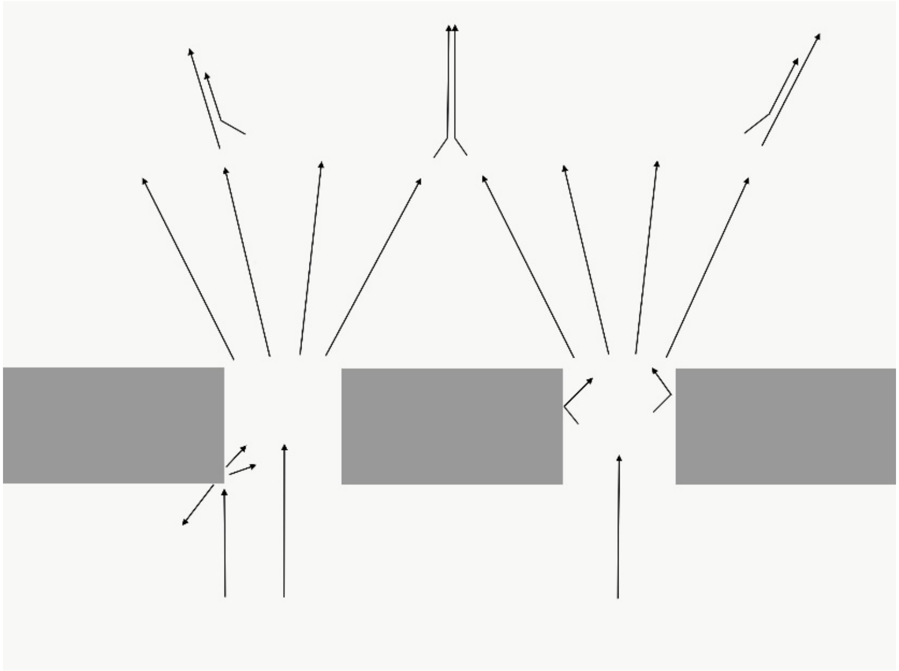

Figure 12. Schematic diagram of photon patterns after slit interaction

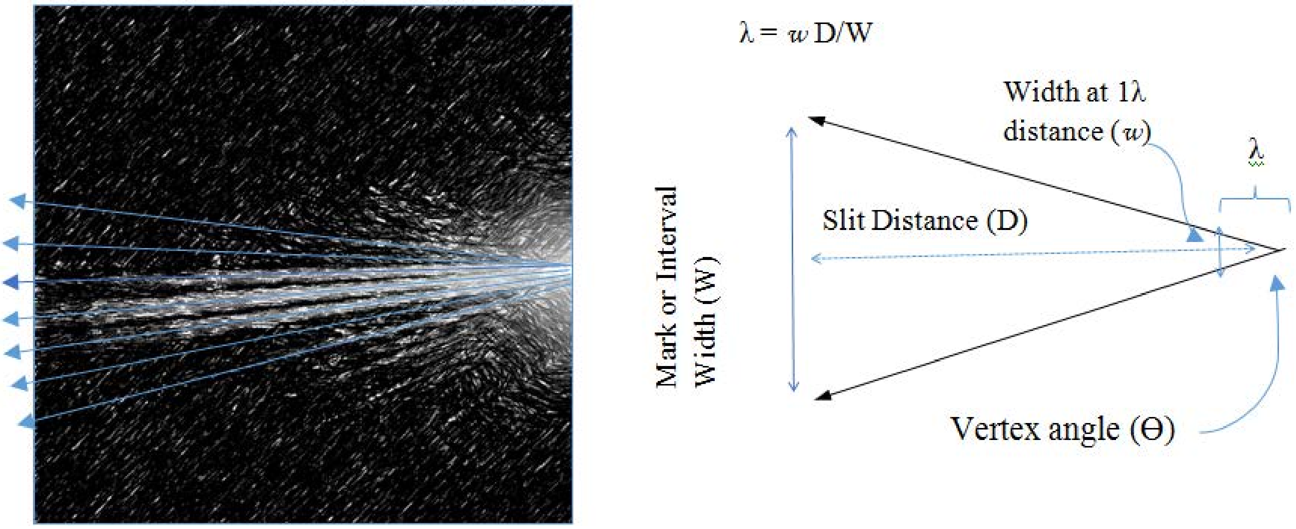

Figure 13. Light strands radiating in regularly spaced intervals and angles, and geometric diagram of single light strand

Geometrical dilation of individual light strands over distance can be described by the linear equation (Figure 6):

$$y = (0.0016)x$$

Dilation of the clear interval can be described with the linear equation (Figure 7):

$$y = (0.00027)x$$

As angles approximate to isosceles triangles, the vertex angle of a strand or clear interval can be calculated using the equation:

$$Vertex\ angle(\Theta) = 2(\arctan((Width/2)/Slit\ Distance))$$

The strand (mark) angle is larger than the clear interval angle, consistent with observed greater geometrical dilation of the light strand over distance.

The single light strand triangle can also be used to calculate the linear wavelength (λ) of the laser (Table 1) (Figure 13). One wavelength will create a smaller similar triangle with base width calculated from the previous linear equation of light strands (w =8.512E-07 at slit distance of 1 λ). As these are similar triangles the following equation can be applied:

$$\lambda / D \ = w/W \ and \ \lambda = w * D/W$$

Using vertex angles it can be written as:

$$\lambda = w/2(Tan(1/2)(\Theta))$$

Discrete strands, which stream in straight lines, explain why ray tracing is an effective way of describing light behavior. Calculations based on wave interference patterns [10] will be less precise in this model. Models using ray diagrams [11], instead of wave geometry to explain their results, remain effective as they are consistent with linear strands. Precision may improve when adapted to photon strand geometry. Interferometers, thought to be displaying interference patterns of waves [10], may be alternatively explained as photo-strand interaction patterns. Similarly, diffraction grating [12] effects may result from photo-strands that are split or reflected apart by slits or grooves. The Fresnel central bright spot [10] may be described as the convergence of strands reflecting from an object's round border to the middle of its shadow.

Light strands not only explain the pseudo- interference pattern of double slits, but also may elucidate how single photons or electrons display pseudo-interference patterns [5,13,14]. Superposition of the same wave passing through both slits, interfering with itself and collapsing as a particle on the screen has a simpler alternative. Single photons or electrons follow these discrete cylindrical channels instead of scattering diffusely, thus creating a pseudo-wave interference fringe. There still is noise on the fringe pattern of single photons with indistinct marks as some photons land in the clear spaces. This would be consistent with single photons generally propagating helically along a set channel but not as steadily as multiple photons travelling together in tight strands.

These findings require us to re-assess the idea, which was supported by Young's original double slit experiment [15], of light as a wave. The fringe pattern is a pseudo-interference pattern and not wave interaction in this setting. Wave functions, being a foundation of modern quantum mechanics [6,14,16], may need to be re-visited to incorporate these findings. Though, accurate in describing some of what we are observing, quantum mechanics is presently a probability model of possible chance outcomes. Conceivably these new findings may help its progression into a model that describes subatomic particles and fields with more certainty. Perhaps photons, electrons, and matter can be described, not as waves, but as focal helical oscillation functions.

5. Conclusion

Particle and wave nature of light has perplexed the scientific community over several centuries. Our novel visualization of discrete light strand behavior in free space encompassing settings of diffraction, refraction, and reflection supports particle theory and provides an alternative to some wave concepts. In particular, the double slit diffraction fringe pattern can visibly be shown to be pseudo-wave interference marks created by distinct light strands, countering a longstanding support for wave concepts in this setting. Further investigation will be required to ascertain outcomes in other varied situations. This novel discovery of photon strands may have implications in physics, quantum mechanics, and technology. With the scientific method, we revise and improve upon traditional ideas with new information. We anticipate that this novel information about photon strand propagation of light will provide a launching point for further discovery.

References

[1] Kuhn KF, Noschese, F., Light. Wave or Particle? In: *Basic Physics*. Ed 3, Wiley, New Jersey, 2020, 227-236.

[2] Carroll, G., *Quantum Physics for Beginners*, Carroll; 2020, 46-112.

[3] Walker J, Halliday, D, Resnick, R., Interference In: *Fundamentals of Physics.* Ed 10, Wiley, New Jersey, 2014, 1048-1055.

[4] Kuhn, KF, Noschese, F., The Quantum Nature of Light. In: *Basic Physics.* Ed 3, Wiley, New Jersey, 2020, 242-245.

[5] Griffiths, DJ, Schroeter, DF., *Introduction to Quantum Mechanics*. Ed 3, Cambridge University Press, Cambridge, 2020, 13-37.

[6] Fiman, N., *Quantum Physics for Beginners,* Gazzoli, 2020, 33-34.

[7] Born, M, Wolf, E., *Principles of Optics*, Cambridge University Press, Cambridge, 1999.

[8] Jacques, V et al., “Experimental Realization of Wheeler’s Delayed-Choice Gedanken Experiment”, *Science*, 315(5814), 966-968, 2007.

[9] Kim Y, Yu R. Kulik SP, Shih, YH, Scully, M., “A Delayed Choice Quantum Eraser”, *Physical Review Letter*, 84(1), 1-5, 2000.

[10] Walker J, Halliday, D, Resnick, R., Diffraction. In: *Fundamentals of Physics.* Ed 10, Wiley, New Jersey, 2014, 1082-1084.

[11] Nave, CR., *Hyperphysics*, Dept. of Physics and Astronomy, Georgia State University, Atlanta, GA, 2017, Available: http://www.hyperphysics.phy-astr.gsu.edu.

[12] Kuhn, KF, Noschese, F., Light as a Wave. In: *Basic Physics.* Ed.3, Wiley, New Jersey, 2020, 302-311.

[13] Frabboni, S et al., “The Young-Feynman Two-slits experiment with single electrons: Build-up of the interference pattern and arrival time distribution using a fast readout pixel detector”, *Ultramicroscopy*., 116, 73-76, 2012.

[14] Feynman, R, Leighton R, Sands, M., *The Feynman Lectures on Physics*. Vol 3, Addison –Wesley, 1965, 1. 1-1.8.

[15] Young, T., “Bakerian Lecture: Experiments and calculations relative to physical optics”, *Philosophical Transactions of the Royal Society*, 94, 1-16, 1804.

[16] Greene, B., *The Elegant Universe*, WW Norton, New York, 1999, 97-109.