An observational study of localized light intensity features under natural environmental conditions

Yelda Davran

Independent Researcher
yeldadavran@gmail.com

Abstract

Although the particle nature of light has long been established through phenomena such as Compton scattering and double-slit experiments, there are relatively few reports of its direct observability under natural environmental conditions. In this work, we report a novel observational phenomenon suggestive of particle-like behavior of light occurring in a natural outdoor setting. The observations were conducted during the winter of 2020 in Ağrı, Türkiye, at an altitude of 1,640 m and ambient temperatures ranging between −10 °C and −20 °C. During afternoon hours, within deeply shadowed regions formed by surrounding buildings, bright, point-like micro-flashes resembling scattered water droplets were observed impinging on the ground and exhibiting multidirectional dispersion. These features were not detected in areas directly exposed to sunlight. It is suggested that the combination of extreme cold climatic conditions, reduced atmospheric pressure associated with high altitude, dark ground surfaces, and strong shadow–contrast conditions contributes to the enhanced visibility of particle-like characteristics of light. The observed micro-flashes are interpreted as a phenomenon in which localized light intensity features become macroscopically distinguishable under specific environmental conditions, representing a rare natural observational instance related to the wave–particle duality of light.

Introduction

Wave–particle duality, which describes light as exhibiting both wave-like and particle-like behaviors, is one of the foundational concepts of modern physics. While the wave aspect of light is comprehensively explained through interference, diffraction, and Maxwell's electromagnetic theory, its particle-related properties were established through landmark experiments such as the photoelectric effect [1] and Compton scattering [2]. These studies demonstrated that light energy exchange can occur in discrete quanta, forming the basis of the photon concept.

Despite this well-established theoretical and experimental framework, observational reports addressing how particle-related aspects of light may manifest under **natural environmental conditions**, outside laboratory-controlled arrangements, remain relatively limited. This gap is particularly noticeable for field observations where atmospheric, thermal, and surface conditions may jointly influence light propagation and visibility.

The present work reports a field-based optical observation conducted during the winter of 2020 in Ağrı, Türkiye, at an altitude of approximately 1,640 m above sea level. The region is characterized by prolonged snow cover, persistent subzero temperatures (−10 °C to −20 °C), frozen ground surfaces, and stable winter atmospheric conditions dominated by Siberian-origin air masses. These conditions provide a distinctive natural environment for examining light–environment interactions.

During sunny afternoon hours in March, while ambient temperatures remained low, extremely small, point-like bright features were observed within deeply shadowed regions formed by surrounding buildings. These features exhibited high localized brightness and appeared to propagate toward the ground, where multidirectional scattering-like behavior was visually discerned upon surface interaction. Notably, such structures were observed exclusively in shadowed regions and were absent on surfaces directly exposed to sunlight.

Rather than proposing a new particle model of light, this study presents a phenomenological account of an unusual optical visibility effect observed under specific environmental constraints. The observations suggest that certain natural conditions may enhance localized light intensity patterns, offering an opportunity to revisit how wave–particle duality–related concepts may be discussed from an observational perspective in real-world environments.

Literature Review

The particle nature of light has been extensively investigated since the early development of modern physics. Einstein’s explanation of the photoelectric effect in 1905 provided one of the first compelling pieces of evidence that light interacts with matter in discrete energy packets. This was followed by the discovery of Compton scattering (Compton, 1923), which demonstrated that light can behave as a particle carrying momentum. Together, these foundational studies led to the establishment of the photon concept and paved the way for the development of quantum electrodynamics.

Despite the clear demonstration of particle-like properties of light in these seminal experiments, nearly all such investigations were conducted under carefully controlled laboratory conditions. These environments allow precise regulation of parameters such as temperature, pressure, background illumination, surface materials, and photon flux. Consequently, while the particle nature of photons can be directly measured in laboratory settings, comparable observations under natural environmental conditions have remained scarce in the literature.

Existing studies do not provide a systematic analysis of environmental variables that may influence photon behavior in natural settings, such as low ambient temperatures, high altitude, pronounced shadow regions, dark surface characteristics, or aerosol density. As a result, the question of whether particle-like behavior of light can become directly observable to the naked eye in natural environments remains largely unanswered.

In recent years, some theoretical works have suggested that under sufficiently low temperature and reduced pressure conditions, particle-like aspects of light–matter interactions may become more pronounced. However, to date, direct observational evidence supporting such phenomena in natural outdoor environments has been lacking.

The present study aims to address this gap by presenting a field-based observation indicating that, under specific natural conditions—particularly in extremely cold, deeply shadowed regions and over dark surfaces—the particle-like characteristics of light may become visibly discernible. In this respect, the work contributes to the limited body of literature on non-laboratory observations of photon behavior.

Methods

The field observation presented in this study was conducted in Ağrı, Türkiye, during mid-March 2020, at an altitude of approximately 1,640 m above sea level, under prolonged low-temperature conditions ranging between −10 °C and −20 °C. At the time of observation, persistent snow cover that had remained unmelted for approximately three months, along with ice formations and continuously frozen surfaces, provided a stable and homogeneous outdoor environment for examining light–environment interactions.

The observation site consisted of a street corridor formed by opposing buildings. This geometry allowed simultaneous monitoring of deeply shadowed regions and areas directly exposed to sunlight, depending on the solar position throughout the day. Temporal variations in shadow geometry were systematically tracked, and the primary observation window was defined as the period between 13:30 and 14:30, when sunlight reached the street surface at a pronounced angle.

During the observation period, regions with varying shadow intensities were comparatively examined. To evaluate light–surface interactions, the physical characteristics of heterogeneous ground surfaces, including stone, gravel, and concrete, were documented. Environmental variables such as ambient temperature, solar incidence angle, surface texture, and shadow profiles generated by building configurations were systematically recorded.

Although photographic and video documentation was initially planned, the extremely small size and very short visibility duration of the observed luminous points prevented conventional camera equipment from achieving sufficient spatial and temporal resolution. In contrast, the human visual system, with its high dynamic range and instantaneous contrast sensitivity, enabled clear visual discrimination of the particle-like luminous points. Consequently, data collection was based on direct visual observation, accompanied by simultaneous manual notes and schematic sketches.

To support the observational analysis, technical diagrams illustrating the geometry of the observation area and the spatial behavior of light were prepared and are presented in the relevant sections (e.g., Fig. 1).

Results

During the field observations, pronounced differences were recorded in both the visibility of particle-like luminous features arising from light–environment interactions and the scattering patterns observed following surface contact. In particular, a systematic distinction was identified between deeply shadowed regions and areas directly exposed to sunlight.

Within dark, deeply shadowed regions not directly reached by sunlight, diamond-bright, needle-sized, droplet-like luminous particles were detected, aligned along closely spaced, parallel linear tracks and progressing sequentially toward the ground in a manner resembling a flow channel.

These particles were observed to:

- emerge at heights of approximately 40–50 cm above the ground,
- propagate briefly through the air before impacting the surface at a distinct angle,
- scatter upon impact predominantly along their direction of incidence, and
- lose visible discernibility again at heights of approximately 40–50 cm above the surface following scattering.

The luminosity carried by the particles exhibited a metallic intensity and a purely white light character. This whiteness suggested that the incident photons propagated without undergoing noticeable refraction or spectral dispersion prior to surface interaction.

The scattering patterns observed immediately after surface contact were consistent with natural diffuse scattering and varied according to surface roughness.

In contrast, no particle-like behavior was observed in regions where sunlight directly illuminated the surface. These areas exhibited only homogeneous brightness, and all particle-like observations remained strictly confined to regions characterized by high shadow density.

Discussion

1. Impact and scattering behavior of the particle-like features

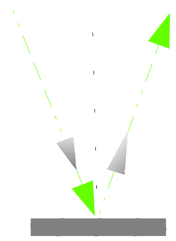

Figure 1. *Schematic illustration showing the angular correspondence between the incidence and scattering directions of two representative particle-like features (indicated by colored arrows) during their interaction with the ground surface.*

The droplet-like bright features observed in this study were found to strike the ground surface at a well-defined angle and to scatter along directions closely correlated with their incidence angles, as schematically illustrated in Fig. 1. At a macroscopic observational level, this behavior gives the **visual impression** of an elastic collision. While surface reflection in classical optics can be described by Fresnel-based models, the observed behavior may also be **qualitatively interpreted** as arising from interactions between incident light and theelectronic structure of surface atoms.

In this context, the observed scattering behavior does not appear to be governed solely by simple geometric reflection conditions. Instead, it may involve microscopic light–matter interaction processes at the surface, **qualitatively analogous** to photon–electron scattering mechanisms discussed in established quantum optics literature [1]. The observation therefore exhibits a scattering character that is **consistent, at an observational level**, with particle-like aspects of light.

2. Influence of surface texture on scattering patterns

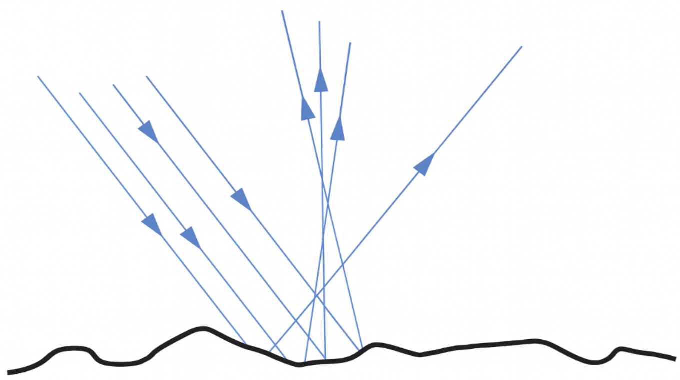

Figure 2. *Schematic representation illustrating how surface roughness leads to increased diversity in post-impact scattering directions.*

The scattering directions and visibility durations of the particle-like features were observed to be sensitive to the micro-textural properties of the ground surface. On rough surfaces, the resulting scattering patterns appeared more diffuse, irregular, and short-lived, whereas on comparatively smoother surfaces, more linear and relatively stable scattering traces became apparent.

This contrast indicates that surface microstructure plays an important role in shaping light–surface interactions, influencing both the angular distribution and the temporal persistence of the scattered features. Accordingly, the observed scattering patterns appear to be determined not only by the properties of the incident light, but also by the physical texture and micro-geometry of the interacting surface.

3. Shadow–contrast conditions required for visibility

The fact that the particle-like features became visible exclusively within dark shadow regions indicates that the observed phenomenon is governed primarily by **local contrast conditions** rather than by absolute illumination intensity. In areas directly exposed to sunlight, no particle-like structures were detected, and the ground surface exhibited only uniform brightness. In contrast, within regions of high shadow density, distinct point-like bright micro-features became clearly discernible.

This distinction suggests that particle-like visibility emerges only when specific brightness–contrast thresholds are satisfied. Furthermore, the confinement of visibility to a limited vertical range, approximately 40–50 cm above the ground surface, implies that the relevant contrast conditions possess both vertical and horizontal components. Visibility therefore appears to depend on the combined geometry of illumination, observation angle, and environmental contrast, rather than solely on the light source itself.

4. Interpretation of the groove-like flow pattern

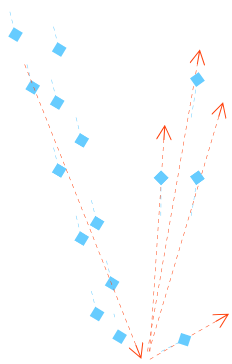

Figure 3. *Schematic illustration showing the alignment of particle-like bright features along parallel trajectories, forming a groove-like flow pattern.*

The alignment of particle-like bright features along successive, nearly parallel trajectories suggests that these structures do not arise as isolated or randomly distributed events. Instead, they form a coherent spatial pattern exhibiting continuity along well-defined directions, particularly within regions shielded from direct solar illumination.

This groove-like flow appearance may be **interpreted observationally** as an indication that, under specific geometric and environmental conditions, light can exhibit a directional, beam-like intensity distribution in natural settings. The combination of low temperature, reduced atmospheric pressure associated with high altitude, and enhanced shadow–contrast conditions is thought to contribute to the macroscopic perceptibility of these otherwise unresolved directional intensity structures. In this sense, the observed flow pattern represents a **qualitative manifestation of organized light intensity visibility**, rather than evidence of a new physical transport mechanism.

5. Localized visibility concentration zones

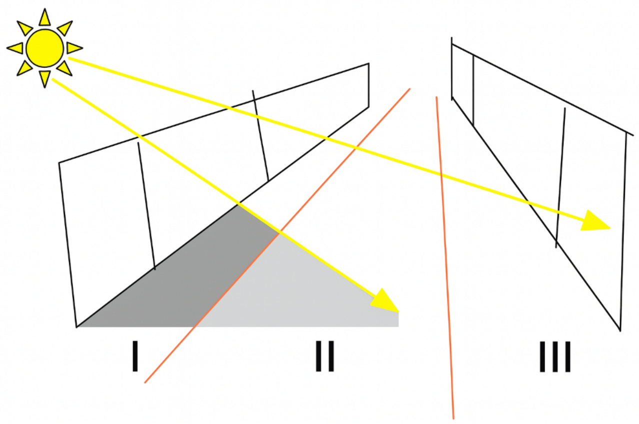

Figure 4. *Schematic of the street-corridor geometry formed by opposing buildings, indicating the solar illumination angle and the resulting graded shadow regions on the ground surface where the reported optical phenomenon becomes observable.*

As depicted in Fig. 4, Region I corresponds to areas of maximum shadow intensity, Region II represents partially shaded transition zones, and Region III denotes regions directly illuminated by sunlight. Observations indicate that the particle-like bright features become most prominent within Region I, where shadow contrast is highest.

This spatial distribution suggests that the phenomenon does not arise from a physical concentration of photon energy, but rather from a **localized enhancement of visibility** enabled by favorable contrast conditions. In other words, the effect reflects not an increase in local energy density, but the selective perceptibility of localized light intensity features under specific environmental and geometric constraints.

6. Possible origins of the droplet-like appearance of the particle-like features

The droplet-like appearance of the observed bright features may be considered within the framework of several **phenomenological interpretations**:

(a) Apparent structure suggestive of gravitational influence

Although the droplet-shaped form may visually evoke gravitational effects, such a macroscopic imprint is not physically expected for individual photons. This suggests that the observed morphology is unlikely to result from a direct mechanical influence, and may instead reflect perceptual or distribution-related characteristics of the observed intensity feature.

(b) Probability distribution interpretation

The observation that the feature appears to originate as a thin linear trace and subsequently develops into a volumetric, droplet-like form may be interpreted not as the localization of a single particle position, but as the visual manifestation of a spatial intensity or probability distribution associated with light propagation within a confined observational region [3]. In this interpretation, the initial thin trace corresponds to lower apparent intensity, while the volumetric region corresponds to enhanced visibility.

(c) Comet-like brightness concentration effect

The high apparent brightness of the moving feature may generate an elongated intensity distribution along its direction of motion, producing a visual effect analogous to the tail-like structures observed in comets. Under this interpretation, the droplet-like shape arises from the spatial distribution of light intensity rather than from a discrete material boundary.

7. Photon packet formation and macroscopic wave–particle visibility

The observed droplet-shaped regions of intense brightness may be associated with the emergence of localized photonic energy concentrations formed under specific environmental conditions. This observation suggests that wave–particle duality may not be confined exclusively to quantum-scale phenomena, but may also become macroscopically perceptible when appropriate external conditions are satisfied.

The key contributing factors appear to be the combined presence of low illumination levels, freezing environmental conditions, reduced atmospheric pressure, and high contrast. Together, these conditions enable photon behavior to manifest in a particle-like visible form. Shadowed environments, in particular, suppress multiple scattering processes, allowing photons to become stably perceptible within a relatively narrow energy band. In contrast, brightly illuminated regions, characterized by broadband photon flux, inhibit the formation of organized visible concentrations.

Within this framework, the observed droplet-like photonic concentration zones may be qualitatively interpreted as an effective macroscopic "potential well" formed within the system [3], with the shadowed regions acting as the primary boundary condition guiding its emergence.

Conclusion

This study presents field-based optical observations indicating the emergence of highly localized bright features under specific natural environmental conditions. The observations show that when low temperature, frozen surfaces, reduced atmospheric pressure, and strong shadow contrast coexist, light propagation within shadowed regions may exhibit unusually concentrated and structured intensity patterns.

The appearance of droplet-like, point-localized brightness features suggests that environmental constraints may suppress multiple scattering processes and allow optical energy to become spatially localized within narrow regions. Such localization is consistent with scenarios in which normally diffuse light becomes selectively discernible due to constrained excitation and propagation conditions.

Additionally, the observed rebound-like scattering behavior upon interaction with ground surfaces may reflect macroscopic signatures of underlying microscopic scattering mechanisms. While classical optical models remain sufficient to describe surface reflection and scattering in general, these observations indicate that, under suitable environmental conditions, such processes may become visually distinguishable at larger scales.

Overall, the findings demonstrate that natural shadowed environments can act as effective optical filters, enhancing localized intensity features and enabling uncommon visibility effects. Rather than challenging established optical theory, this work contributes observational insight into how environmental constraints may influence the macroscopic appearance of light, offering a complementary perspective on wave–particle duality–related concepts in natural settings [4].

References

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4. M. Born and E. Wolf, Principles of Optics (Cambridge University, 1999).