The Dark Side of Light

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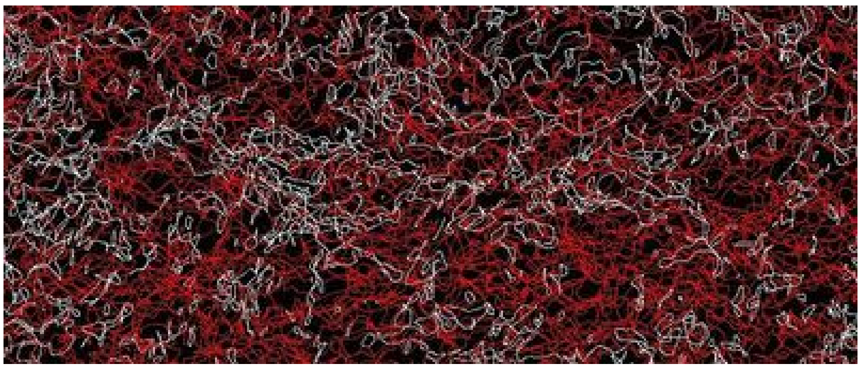

The model of vortex structure in laser speckle. Open vortex lines are in red, while closed vortex loops are in white. Credit: O'Holleran, et al.

Light may not seem very interesting in our everyday lives. But to scientists, light's properties are a constant source of intrigue. The nature of light as both wave and particle, light as the universal speed limit, and the way light interacts with magnetic fields in the atmosphere to form auroras are a just a few examples of light's fascinating behavior.

Recently, researchers from the University of Glasgow and the University of Bristol in the UK have discovered another unusual property of light – or, more accurately, the darkness within light. As the researchers explain, natural light fields are threaded by lines of darkness, which create optical vortices that appear as black points within the light. The group has modeled this phenomenon, and found that the lines of darkness exhibit fractal properties with Brownian (random) characteristics. Further, the characteristics of these optical vortices suggest universal properties, which could help connect different areas of physics.

Many people have noticed the phenomenon of laser speckle, which occurs when coherent, monochromatic laser light bounces off a rough surface, giving the surface a speckled appearance. The black specks are interference patterns generated by a superposition of highly coherent light waves reflected from different points on the rough surface. Sometimes the speckled pattern can even appear to sparkle when the viewer moves relative to the surface.

In a recent issue of *Physical Review Letters*, the UK researchers describe how they developed a model of the superpositions that create the dark optical vortices, using numerical simulations and experiments. In their experiments, they created laser speckle with a 10-mm-diameter helium neon laser beam shining through a screen made of ground glass.

By measuring the superpositions with an interferometer, the scientists could generate a 3D map of the structure of the optical vortices. They found two types of vortices. Infinite vortex lines, which account for about 73% of the dark vortices, percolate entirely through the light beam. The remaining 27% of the vortices form closed loops, which occur when a vortex line returns to its starting point within a small enough area.

When investigating the lines of darkness further, the researchers found that they exhibit scale invariance. In other words, the vortices look the same no matter how much you zoom out – they are fractals. Lead author Kevin O'Holleran of the University of Glasgow said that, while he and his colleagues suspected vortex lines to exhibit fractal properties, they were quite surprised to find that the fractality was of a Brownian nature.

"To find that the vortex lines in light have Brownian characteristics is exciting," O'Holleran told *PhysOrg.com*. "Brownian structures are inherently random, so the coherence of our model was in no way limiting the fractal behavior of the vortex lines. We are looking forward to exploring these properties in more detail. More specifically, we hope to investigate the topological side of random light fields, such as how often vortex lines are knotted or linked."

Interestingly, the researchers noted that these properties of optical vortices (the ratio of vortex lines to loops and their scale invariance) are very similar to the properties of cosmic strings, according to the cosmic string lattice model. The model describes the configuration of cosmic strings in the early universe – the very thin but very dense one-dimensional defects in space-time that could be responsible for the formation of galaxies.

The researchers don't think this similarity is likely to be coincidental. They suggest that these properties could be universal for all optical fields, and they plan to investigate the analogy further.

"The greatest significance [of this study] is the connection to other fields in physics," O'Holleran said. "Universal properties connect fields of research at deeper levels than the exact formulation of each system. Shared fundamental properties or restrictions (like how lines can be embedded in 3D space) result in universal exponents appearing in varied and apparently disconnected fields of research. The fact that vortex lines in light exhibit power laws suggesting universal properties means that these lines are governed by more general laws than wave equations."

More information: O'Holleran, Kevin, Dennis, Mark R., Flossmann, Florian, and Padgett, Miles J. "Fractality of Light's Darkness." *Physical Review Letters* 100, 053902 (2008).