

Multicolored light twists in new knotted ways

ICFO researchers report on the discovery of a new type of optical singularity with the topology of a knot.

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Around age six, we start learning how to tie our shoelaces, making knots that look like ribbons - or possibly more complex forms, if we are a little clumsy. We use knots every day, but the type of knots we generally use are associated with physical objects, things we can touch.

Although it can be hard to image, light can also be shaped in ways that form knotted configurations, whose shape depends on the orbital angular momentum of the light. This parameter is responsible for making the beam of light twist around its own axis, generating different knot shapes, and expanding to a new degree of freedom that can carry valuable information.

Learning and mastering how to generate twisted light - light with orbital angular momentum

- has been a thriving field of study for the past 20 years. Unlike spin angular momentum, which is associated with the polarization of light, orbital angular momentum is associated with its spatial distribution. These two types of angular momentum can also be coupled, which results in a variety of light fields whose polarizations change from point to point.

The behaviour of light also becomes richer when it passes from oscillating at one single frequency (monochromatic light) to vibrating at many different frequencies, which allows the polarization of the light to trace different shapes over time. Combining these polarizations with the spatial variations of light allows even more room for interesting connections, but until now this has been an uncharted frontier.

In a recent study, published in two papers, joint collaborations by ICFO researchers have broken theoretical and experimental ground in this new field, uncovering new types of knots for twisted light and a new type of angular momentum.

In the first paper, published in Nature Photonics, ICFO researchers Emilio Pisanty, Gerard Jimenez Machado, Veronica Vicuna-Hernandez, Antonio Picon and Alessio Celi, led by ICREA Prof. at ICFO Maciej Lewenstein and UPC Prof. at ICFO Juan P. Torres, have designed a beam of light with a polarization state that forms three-lobed trefoils at each point, by combining light of different frequencies, and making the trefoils connect to each other in a way such that the light beam, as a whole, has the shape of a knot. These beams also exhibit a new kind of angular momentum, associated with the unusual symmetry of the beams, which remain unchanged when they're rotated - but only when the polarization is rotated by a specific portion of the rotation in space. This new quantity is termed the torus-knot angular momentum, because of the type of knot in the beams, and the researchers were able to experimentally confirm its presence.

In the second paper, published in Physical Review Letters, ICFO researchers Emilio Pisanty and Antonio Picon, led by ICREA Professor at ICFO Maciej Lewenstein, in collaboration with researchers from the University of Salamanca and from CU Boulder, show that the new type of angular momentum is conserved in interactions. They show, via theoretical simulations, that at extremely high intensities, many photons of light can be combined into single photons with high energy, and that these new, bigger photons carry the combined torus-knot angular momentum of the original, smaller photons.

The results of both studies provide new frameworks and results that advance the study of structured light. On one hand, the researchers were able to find new conservation laws for photons, and how they can combine. On the other, they analyzed the fields that make this possible and showed that they contain a new optical singularity, with a new degree of

freedom that could be used to store valuable information, opening the possibility of using these new topologies of light for future communication applications, among others.