Laser tornado in a synthetic magnetic field

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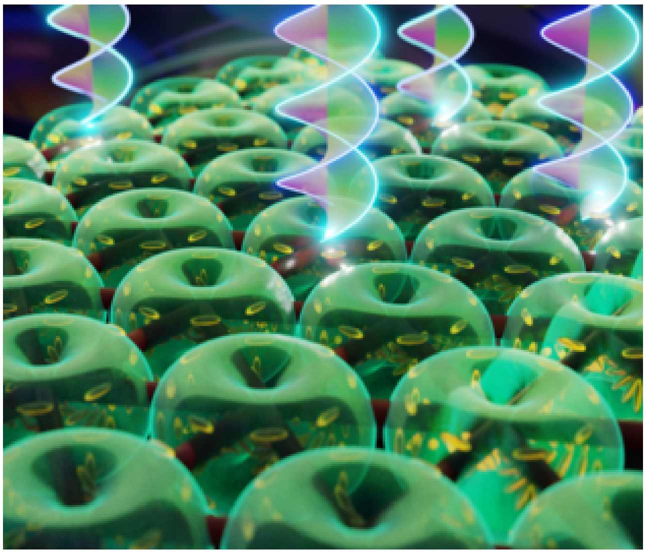
Can light behave like a whirlwind? It turns out it can – and such "optical tornadoes" have now been created in an extremely small structure by scientists from the Faculty of Physics at the University of Warsaw, the Military University of Technology, and the Institut Pascal CNRS at Université Clermont Auvergne. This discovery opens a new pathway for creating miniature light sources with complex structures, potentially enabling the development of simpler and more scalable photonic devices in the future, for applications such as optical communication and quantum technologies.



A network of torons, self-organizing defects in liquid crystals whose internal structure enables the generation of laser light carrying orbital angular momentum (visualisation Marcin Muszyński, Faculty of Physics University of Warsaw).

"Our solution combines several fields of physics, from quantum mechanics, through materials engineering, to optics and solid-state physics," explains Prof. Jacek Szczytko from the Faculty of Physics at the University of Warsaw, the leader of the research group. "The inspiration came from systems known from atomic physics, where electrons can occupy different energy states. In photonics, a similar role is played by optical traps, which confine light instead of electrons." "You can think of it as an optical vortex," says Dr. Marcin Muszyński from the Faculty of Physics at the University of Warsaw and

Department of Physics City College of New York, the first author of the study. “The light wave twists around its axis, and its phase changes in a spiral manner. Moreover, even the polarization – the direction of oscillation of the electric field – begins to rotate.”

Such light structures are highly promising, with potential applications in areas such as quantum communication and the manipulation of microscopic objects. The challenge, however, is that generating them typically requires complex nanostructures or large experimental setups.

The research team took a different approach. “Instead of building complex systems, we used a liquid crystal, a material with properties intermediate between a liquid and a solid. Although it can flow like a liquid, its molecules arrange themselves in an ordered way, maintaining a fixed orientation and relative positions, much like in a crystal,” explains Joanna Mędrzycka, a nanotechnology student at the Faculty of Physics, University of Warsaw, who, together with Dr. Eva Oton from the Military University of Technology, prepared the liquid crystal samples.

In such a structure, defects known as torons can be created. “They can be imagined as tightly twisted spirals, similar to DNA, along which the liquid crystal molecules are arranged. If such a spiral is closed by joining its ends into a ring resembling a doughnut, we obtain a toron,” Mędrzycka explains. “These structures act as microscopic traps for light. A key step was creating an equivalent of a magnetic field for photons. Although light does not respond to magnetic field like electrons do, a similar behavior can be achieved for light by other means.”

– Spatially variable birefringence, that is, the difference in the propagation of different polarizations of light, acts like a synthetic magnetic field,” explains Dr. Piotr Kapuściński of the Faculty of Physics at the University of Warsaw. “We call it ‘synthetic’ because its mathematical description resembles the behavior of a magnetic field, even though physically it isn’t there. As a result, light begins to ‘bend,’ much like electrons moving in cyclotron orbits.” To enhance this effect, the toron was placed inside an optical microcavity—a structure composed of mirrors in which light is repeatedly reflected and remains confined for an extended time. “This makes the field much stronger,” says Dr. Muszyński. “Additionally, we can control the size of the trap, and thus the properties of the light, using an external electric voltage.”

The most important result, however, turned out to be even more surprising. “In typical systems, light carrying orbital angular momentum appears in excited states,” explains Prof. Guillaume Malpuech from Université Clermont Auvergne and CNRS, who, together with Prof. Dmitry Solnyshkov and post-doc Daniil Bobylev, developed the theoretical model of the phenomenon. “For the first time, we managed to obtain this effect in the ground state, i.e., the lowest-energy state. This is significant because the ground state is the most stable and the easiest for energy to accumulate in.”

“This makes it much easier to achieve lasing,” emphasizes Prof. Szczytko. “Light naturally ‘chooses’ this state because it is associated with the lowest losses.” To verify this, the researchers added a laser dye to the system. “We obtained light that not only rotates but also behaves like laser light: it is coherent and has a well-defined energy and emission direction,” says Dr. Marcin Muszyński. “It's interesting that our approach draws inspiration from very advanced theories involving a so-called vectorial charge," adds Prof. Dmitry Solnyshkov "So, in a way, we've managed to make photons behave not even like electrons, but like quarks, the charged particles which make up protons.

"This discovery opens a new pathway for creating miniature light sources with complex structures. “It shows that instead of relying on complex nanotechnology, we can use self-organizing materials,” concludes Prof. Wiktor Piecek from the Military University of Technology. “In the future, this may enable simpler and more scalable photonic devices, for example for optical communication or quantum technologies.”

Faculty of Physics at the University of Warsaw
Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics, the Department of Mathematical Methods in Physics. The research covers almost all areas of modern physics on scales from quantum to cosmological. The Faculty's research and teaching staff consists of over 250 academic teachers. About 1350 students and over 150 doctoral students study at the Faculty of Physics UW. The University of Warsaw is among the 200 best universities in the world, educating in the field of physics according to Shanghai's Global Ranking of Academic Subjects.

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Marcin Muszyński, Daniil Bobylev, Piotr Kapuściński, Przemysław Oliwa, Joanna Mędrzycka, Eva Oton, Rafał Mazur, Przemysław Morawiak, Wiktor Piecek, Przemysław Kula, Dmitry Solnyshkov, Gillaume Malpuech, Jacek Szczytko Ground-state orbital angular momentum lasing from liquid crystal torons embedded in a microcavity, Science Advances 12, eaeb6167 (2026) 13 March 2026
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A network of torons, self-organizing defects in liquid crystals whose internal structure enables the generation of laser light carrying orbital angular momentum (visualisation Marcin Muszyński, Faculty of Physics University of Warsaw).

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