Laser pulses and nanoscale changes yield stable skyrmion bags for advanced spintronics

July 28 2025

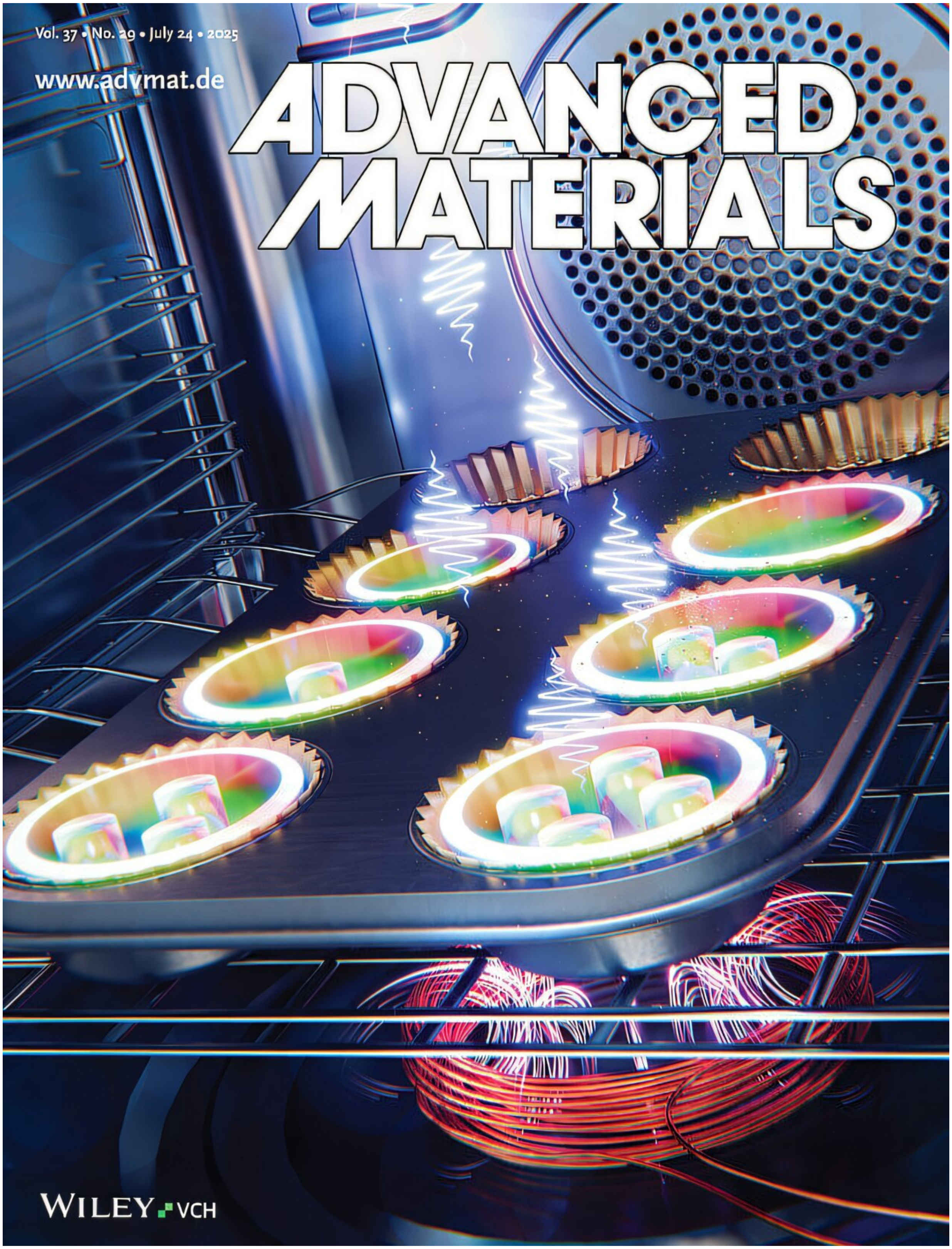

Fig. 1. The formation of skyrmions bags via laser shots is enabled by designing

the anisotropy potential, symbolized in the cover picture of the journal *Advanced Materials* by the muffin tin. Once the recipe is developed, the textures can be readily "baked." Credit: *Advanced Materials* (2025). DOI: 10.1002/adma.202501250

A team of researchers at the Max Born Institute and collaborating institutions has developed a reliable method to create complex magnetic textures, known as skyrmion bags, in thin ferromagnetic films. Skyrmion bags are donut-like, topologically rich spin textures that go beyond the widely studied single skyrmions.

Magnetic skyrmions are nanometer-sized, stable magnetization vortices with promising applications in spintronics and data storage. Their simplest forms have been explored extensively and take on a circular shape where the spins rotate by 180° from the outside to the inside in a thin magnetic film. The spins in the center of the skyrmion, therefore, point to the opposite direction to those outside the skyrmion.

More intricate configurations include the so-called skyrmionium where the spins rotate by 360° and the spins in the skyrmionium's center have the same orientation as those outside, resulting in a ring-like structure. Remarkably, this ring can then be filled with skyrmions again, leading to the target skyrmion for one skyrmion inside the ring and skyrmion bags for multiple skyrmions inside.

While theory has already predicted such higher-order configurations, they have remained difficult to produce in real materials in a controlled way.

In a new study published in *Advanced Materials* (see fig. 1), the research team demonstrates how nanoscale modifications of the magnetic properties of the material, introduced via focused helium-ion beams, can foster the generation of these higher-order textures.

These local anisotropy modifications are designed such that the desired structures can be formed selectively using single ultrafast laser pulses. The resulting magnetic textures with features on the sub-100-nm scale were directly imaged using a high-resolution X-ray microscope equipped with a tailored laser system developed at the Max Born Institute.

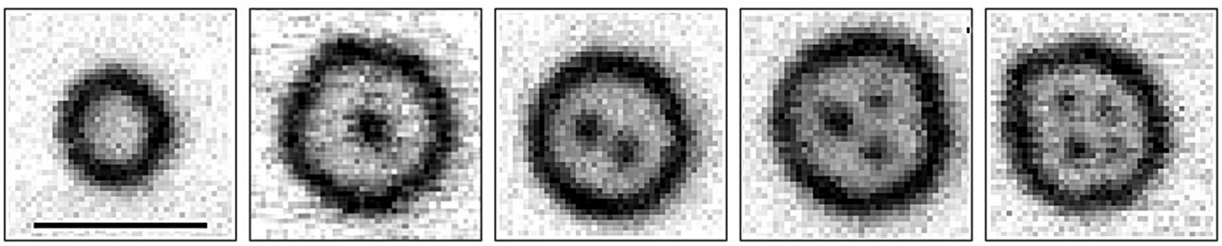

Fig. 2. X-ray microscopy images of the magnetization textures showing the different orders of skyrmion bags, ranging from the empty skyrmionium to a bag filled with four skyrmions. The scale bar is 500 nm. Credit: *Advanced Materials* (2025). DOI: 10.1002/adma.202501250

The researchers demonstrate the generation of a variety of skyrmion bags, from the empty skyrmionium up to bags filled with four skyrmions (see fig. 2). They showed that the skyrmion-bag generation triggered by single laser pulses has a significantly higher success rate compared to a purely magnetic-field-driven approach.

The repeatable, consistent generation of such textures is the key prerequisite for studying the dynamics of higher-order skyrmions in future time-resolved experiments. This work offers a practical route to investigate and utilize complex skyrmion states in thin-film materials, which is an important step toward future spintronic devices that leverage topological control at the nanoscale.

More information: Lisa-Marie Kern et al, Controlled Formation of Skyrmion Bags, *Advanced Materials* (2025). DOI: 10.1002/adma.202501250

Provided by Forschungsverbund Berlin e.V. (FVB)