Physicists find a method to comb the hair of spins

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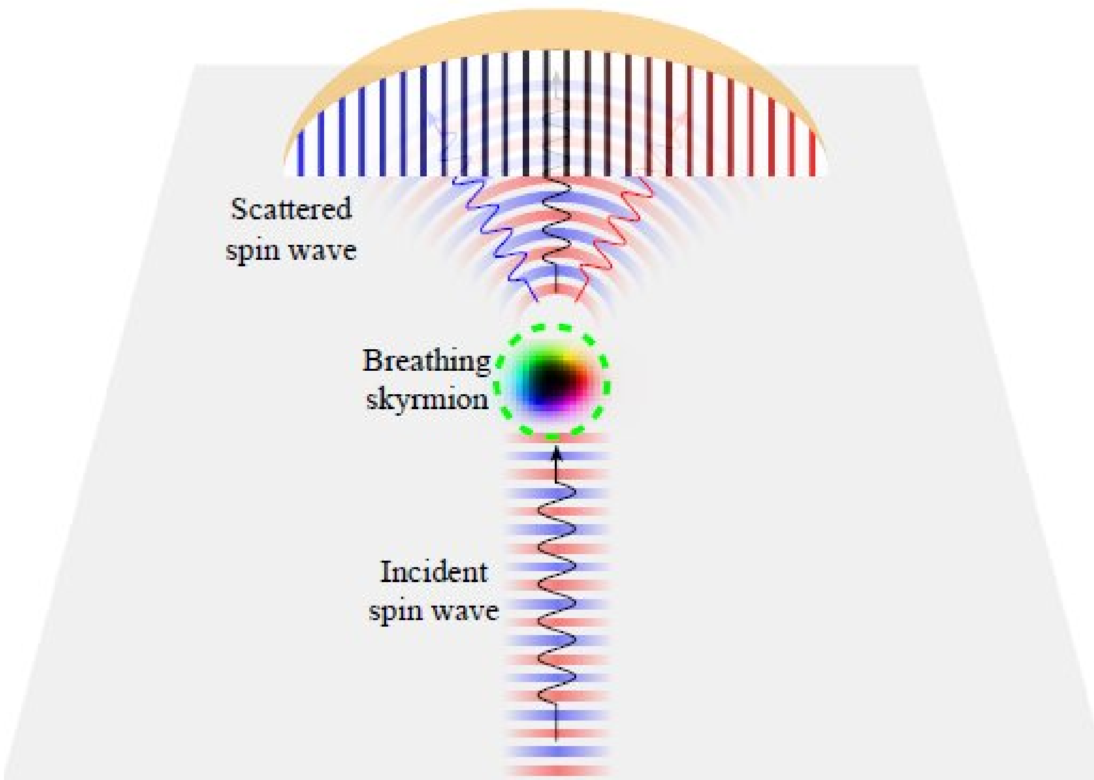

Scheme of a spin-wave frequency comb. A magnetic skyrmion (colored dots) splits an incoming spin-wave into an evenly-spaced comb. Credit: Zhenyu Wang, Huaiyang Yuan and Peng Yan

Similar to the wave of human hair in the wind, spins in a solid can also wave under the influence of external perturbations. Such a wave-like collective motion of spins is called a spin wave. Usually, spin waves with a wide frequency range are superposed and form a wave packet. Recently, physicists have found a method to split spin waves into a comb-like pattern using a curling magnetic structure. Such a spin-wave frequency comb can serve as a ruler to calibrate the wave frequency and allow the detection of complex magnetic textures in a physical system.

The concept of a frequency comb can be traced back to the textbooks of general physics. It is known that an electromagnetic wave bouncing back and forth between two mirror planes can only take discrete frequencies. Each allowable frequency mode represents a standing wave mode between the two mirrors. Based on this principle, scientists have invented a laser source to produce a series of optical pulses, with equal spacing of frequency. This accomplishment has evaluated the high-precession measurement of time and frequency, from atomic clocks in space to frequency rulers in the lab. In 2005, one-half of the Nobel Prize in Physics was awarded to John Hall and Theodor Hänsch "for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique."

Spin waves have many similarities with electromagnetic waves. They can reflect and transmit at the interface of two magnetic media obeying the law of reflection and transmission. It also has particle-like properties, which can condense at low temperatures. However, despite these analogs, it is very challenging to generate a spin-wave frequency comb, because the nonlinearity required to generate it is usually very weak in magnetic systems.

Now, in collaboration with physicists from University of Electronic Science and Technology of China and Utrecht University, we have overcome this challenge by studying spin wave transmission across a magnetic texture, so-called skyrmions (magnetic curling structures with large spin variation in space near the core). Here, we first apply a strong perturbation to excite spin waves remotely. When the spin waves propagate toward and interact with the skyrmion, an internal breathing mode of skyrmions was excited. Due to the strong driving, the incoming spin wave combines with the breathing mode to produce both sum-frequency and difference-frequency modes. A cascade to produce more frequency modes occurs when we increase the driving power. Finally, an evenly spacing spin-wave frequency comb is generated, where the frequency spacing is equal to the breathing mode of skyrmions.

The physical principle of our findings can be extended to other magnetic textures, such as magnetic domain walls, vortices and antiskyrmions. The frequency spacing inside comb can be tuned from the megahertz to the gigahertz regime by both magnetic and electric controls. In the future, we would like to study the applications of this frequency comb as a ruler to calibrate the wave frequency and as a synthesizer to combine the spin-waves over a broad range of spectral frequencies. The spin-wave frequency comb is also potentially useful for detecting magnetic textures. Here, the spin-wave modes inside the frequency comb may interfere when passing through a magnetic texture. By analyzing the interference pattern, we can extract the information of magnetic textures.

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More information: Zhenyu Wang, H. Y. Yuan, Yunshan Cao, Z.-X. Li, Rembert A. Duine, and Peng Yan, Magnonic frequency comb through nonlinear magnon-skyrmion scattering. *Physial Review Letters* 127, 037202 (2021); journals.aps.org/prl/abstract/ … ysRevLett.127.037202

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Huaiyang Yuan has a PhD in physics and currently works as a postdoc in the Institute for Theoretical Physics, Utrecht University, Netherlands. Yuan's research interests are mainly in the field of spintronics and its crossing with quantum information science. Yuan is supported by the funding of Marie-Sklodowska-Curie Individual Fellowship under European Union Horizon 2020 scheme.