A method to determine magnon coherence in solid-state devices

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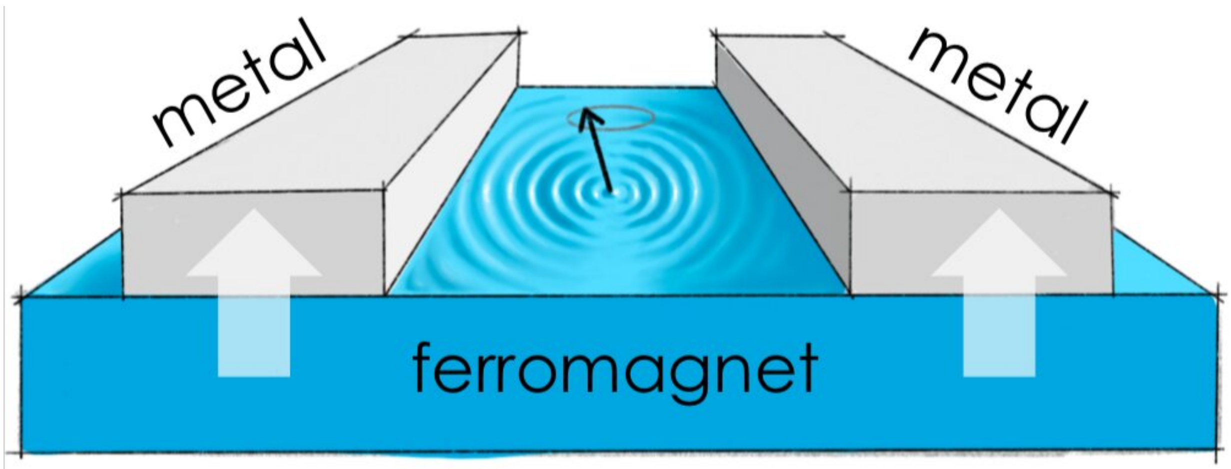


Credit: Scott Bender.

A team of researchers at Utrecht University, the Norwegian University of Science and Technology and the University of Konstanz has recently proposed a new method to determine magnon coherence in solid-state devices. Their study, outlined in a paper published in *Physical Review Letters* , shows that cross-correlations of pure spin currents injected by a ferromagnet into two metal leads normalized by their dc value replicate the behavior of the second-order optical coherence function, referred to as $g^{(2)}$, when magnons are driven far from equilibrium.

"Consider a big room full of people having a party," Akash Kamra, one of the researchers who carried out the study, told Phys.org. "These people can either behave as in a night club, bumping into each other in an uncoordinated way and with chaotic movements, or the party people might be directed by a common host, such as at a wedding party. Such a 'condensed' crowd of people moves swiftly without bumping into each other."

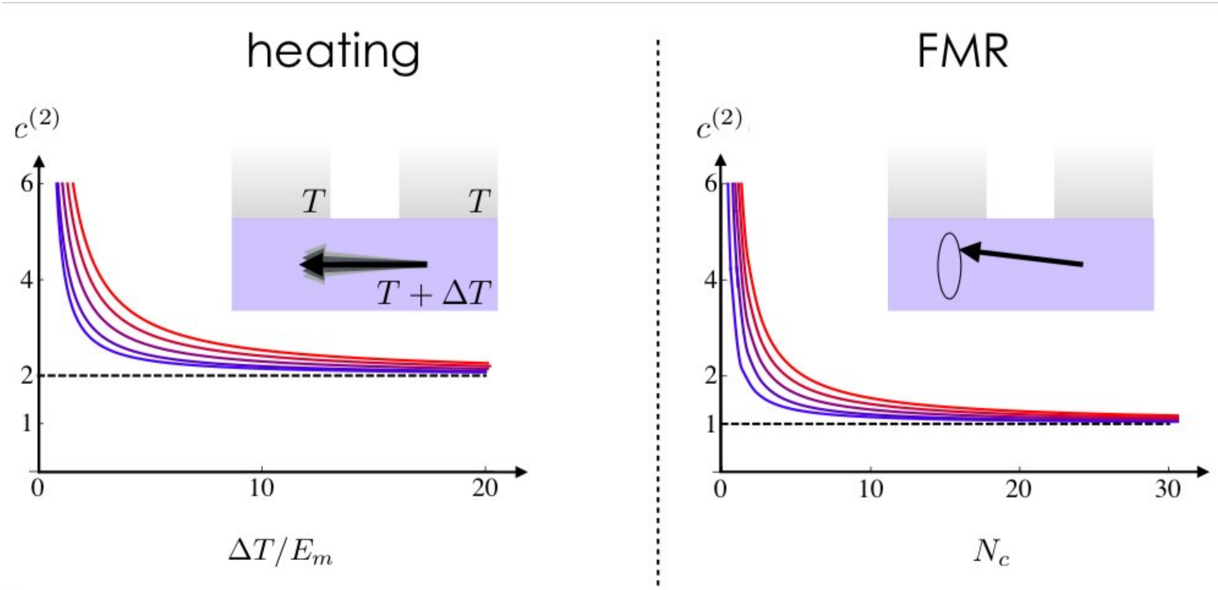
Kamra draws an analogy between the party situations he described and magnons, quantum particles that correspond to a specific decrease in magnetic strength, traveling as a unit through a magnetic substance. In his analogy, an uncoordinated "party" would occur if magnons are in a "thermal" state, while a coordinated one if they are in a "coherent" or "condensed" state. The coordinated movement of guests in the second type of party, on the other hand, would correspond to a superfluid flow, which is a manifestation of a remarkable state of matter: the condensate.

"For several fundamental scientific and technological reasons, the magnon condensate is an intriguing and valuable entity, and the main breakthrough of our paper is that we propose a method to unambiguously detect it," Kamra said.

If one were to open two doors to a big room containing loads of people and keep track of how many people exit the room via each door within a given time window, she would be able to identify what state these people are in. In other words, by comparing statistics of people exiting both doors, one would be able to determine whether the people are behaving in an uncoordinated or coordinated way.

"Remarkably and counter-intuitively, this cannot be achieved with one door," Kamra explained. "This is where the analogy between magnons (the quantum particles of spin waves in magnets) and people necessarily falls short: magnons follow the weird laws of the quantum world and do not obey the rules of our classical, everyday realm."

The work of Kamra and his colleagues was inspired by a classic experiment with photons, the quantum particles that make up light, in which photons from the same [light beam](#) are detected at two different locations. Comparing the statistics of detection times for these photons at two locations allows researchers to attain direct information about the state of the light beam (i.e. identify whether it is thermal or coherent).



Credit: Scott Bender.

"Our goal was to find and propose a similar way of detecting whether a magnon beam is coherent or not," Kamra said. "Dealing with a completely different medium (a magnetic material for magnons as opposed to free space for light), we succeeded in identifying an experimentally feasible way to achieve this magnon-coherence detection via measurement of spin current cross-correlations."

The researchers suggest interfacing a magnetic layer, which hosts magnons, with two distinct nonmagnetic metal leads. The magnons inject spin current into both metal leads, which can be detected via the associated, inverse spin Hall effect-mediated charge current.

"We suggest measuring the dc spin currents into the two leads in addition to the cross-correlation of the two spin currents," Kamra said. "A ratio of the cross-correlation to the product of the two spin currents comes out to be 1 for a perfectly coherent magnon system. When the ratio deviates from 1, it serves as a measure of and allows to quantify the coherence in the magnon system."

The most important finding gathered by Kamra and his colleagues is that the well-established mechanism and method for detecting the coherence of a light beam actually works for completely different quantum particles, such as magnons, as well. When applying this method to magnons, however, one should consider the fact that systems that host these particles are usually very small (less than a millimeter long) compared to light beams, which usually extend over several meters or kilometers.

"Keeping this distinction in mind, we have proposed a method of using spin current cross-correlations for coherence detection," Kamra said. "Our work also demonstrates that the same current cross-correlations idea can be used to measure coherence for the whole range of bosonic excitations, such as phonons and excitons, in solid-state-systems, opening exciting perspectives for multiple research communities."

The findings gathered by the researchers are a significant contribution to quantum magnonics, a field of study that seeks to explore and exploit the quantum nature of magnons. The achievement of such a robust detection of magnon coherence is a major leap forward, as it could pave the way for the development of concepts and devices based on spin supercurrents and superfluidity.

"Our present proposal is simply a first small window into the exciting world of quantum magnonics," Kamra said. "This window shows how to achieve in magnets what has already been achieved with light. We are now working on further exploring the potential of the cross-correlation technique and investigating phenomena that go beyond the standard bosonic properties of light."

More information: Scott A. Bender et al. Spin Current Cross-Correlations as a Probe of Magnon Coherence, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.187701