2016 EPS CMD Europhysics Prize

The Condensed Matter Division of the European Physical Society is proud to announce the award of the 2016 European Physical Society Condensed Matter Division Europhysics Prize to:

Peter Böni, Aleksandr N. Bogdanov, Christian Pfleiderer, Achim Rosch and Ashvin Vishwanath

"for the theoretical prediction, the experimental discovery and the theoretical analysis of a magnetic skyrmion phase in MnSi, a new state of matter."

Discovery of a Skyrmion Phase in MnSi

Initially proposed as a model for hadrons in a mesonic field theory in particle physics, skyrmions have recently been discovered in magnetic systems thus establishing the existence of a new state of matter. Such structures exhibit a topological Hall effect and can be moved by currents much smaller than those required to displace domain walls thus opening the door to applications in data storage. This nomination is in support of an exemplary collaboration of both theoretical and experimental groups on a most intriguing magnetic state of topological nature: a magnetic skyrmion crystal. In the remarkable pioneering studies by the nominees, this state was first proposed theoretically and subsequently discovered by neutron scattering in MnSi and its features have been impressively analyzed theoretically.

Magnetic skyrmions are spin textures on length scales of tens of nanometers that behave like particles. Similar to a vortex in a superconductor, a skyrmion cannot be unwound without creating discontinuities. This topological stability is reflected by a nonzero topological index also known as the skyrmion number.

Prior to the theoretical work by A.N. Bogdanov and co-workers [1, 2], conventional wisdom stated that skyrmions cannot spontaneously form as ground states in magnetic materials. It thus came as a considerable surprise that these authors were able to demonstrate that skyrmion lattices may spontaneously form in noncentrosymmetric magnetic systems if longitudinal fluctuations of the magnetization are facilitated. MnSi was proposed as one of the suitable candidates for such a scenario as it exhibited strong longitudinal magnetization fluctuations and the absence of a centre of inversion may result in a Dzyaloshinskii-Moriya contribution to the Hamiltonian.

Independently of these authors, A. Vishwanath and co-workers [3] theoretically proposed the existence of a "helical spin crystal" in MnSi, motivated by its enigmatic high-pressure phase. These authors also showed that the resulting skyrmion spin crystal can be interpreted as a multimode superposition of helical spin spirals. In subsequent work, Vishwanath and co-author also predicted the existence of a topological Hall effect resulting from a fixed phase relationship of these spin spirals, a phenomenon which has subsequently been verified in Ref. [4].

These theoretical proposals were taken up by a team around C. Pfleiderer, P. Böni, and A. Rosch, building on their respective expertise in transport properties of unconventional phases in MnSi, neutron scattering on noncollinearly ordered magnetic systems, and the provision of visionary theoretical support. Resulting from this combined expertise, the team was able to identify and theoretically explain the novel skyrmion phase in MnSi. The first experimental evidence for the existence of a skyrmion crystal in MnSi was provided by small angle neutron scattering (SANS) [5]. The SANS diffraction pattern was consistent with a hexagonal skyrmion lattice which was interpreted as a triple wavevector state. While prior theoretical work suggested the exclusive stability of a conical helical state in a field, the authors demonstrated within a sophisticated theoretical analysis in Ref. [5] that the thermodynamic fluctuations around the skyrmion crystal were fundamental in stabilizing the observed skyrmion crystal.

While highly suggestive of a skyrmion crystal, the SANS results did not yet unambiguously prove a fixed phase relationship between the spin spirals. To settle this issue, C. Pfleiderer, P. Böni, A. Rosch and co- workers investigated the Hall effect in Ref [4]. The observed Hall resistivity showed an additional contribution, in quantitative agreement with a Berry-phase induced emergent magnetic field originating from the nonvanishing skyrmion number of the topologically nontrivial skyrmion lattice.

Finally, C. Pfleiderer, P. Böni, A. Rosch and co-workers demonstrated that skyrmions can be manipulated similarly to other magnetic topological defects such as domain walls. Applying currents that were more than five orders of magnitude weaker than those used in similar experiments on domain walls, the authors observed a distinct rotation of the skyrmion lattice. This demonstrates the extraordinarily weak pinning of the skyrmion lattice and opens the door to manipulation of skyrmions in related systems.

This unique effort led by this group of theorists and experimentalists has resulted in the identification of a new state of matter that has literally created a “skyrmion-boom” in the condensed matter community. Not only have skyrmions also been identified in a larger class of systems, but also explicit proposals emerged to use skyrmions instead of domain walls for racetrack-type memory technologies. It is testament to the excellent work by P. Böni, A.N. Bogdanov, C. Pfleiderer, A. Rosch, A. Vishwanath that skyrmions have become such an exciting field of current research and they highly deserve the EPS CMD Europhysics Prize 2016.

Publications relevant for this nomination

[1] U.K. Rössler, A.N. Bogdanov, C. Pfleiderer, Spontaneous Skyrmion Ground States in Magnetic Metals, Nature 442, 797 (2006).
[2] A.N. Bogdanov , D.A. Yablonskii, Thermodynamically Stable “Vortices” in Magnetically Ordered Crystals – The Mixed State of Magnets, Sov. Phys. JETP 68, 101 (1989).
[3] B. Binz, A. Vishwanath, V. Aji, Theory of the Helical Spin Crystal: A Candidate for the Partially Ordered State of MnSi, Phys. Rev. Lett. 96, 207202 (2006).
[4] A.Neubauer, C. Pfleiderer, B. Binz, A. Rosch, R. Ritz, P.G. Niklowitz, P. Böni, Topological Hall Effect in the A-Phase of MnSi, Phys. Rev. Lett. 102, 186602 (2009).

[5] S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, P. Böni, Skyrmion Lattice in a Chiral Magnet, Science 323, 915 (2009).
[6] F. Jonietz, S. Mühlbauer, C. Pfleiderer, A. Neubauer, W. Münzer, A. Bauer, T. Adams, R. Georgii, P. Böni, R.A. Duine, K. Everschor, M. Garst, A. Rosch, Spin Transfer Torques in MnSi at Ultralow Current Densities, Science 330, 1648 (2010).

About the Prize

The EPS CMD Europhysics Prize is one Europe's most prestigious prizes in the field of condensed matter physics. It is awarded every 2 years in recognition of recent work by one or more individuals for scientific excellence in the area of condensed matter physics. The Prize has been awarded for the first time in 1975.

About the EPS

The European Physical Society (EPS) was created in 1968 to promote physics in Europe. The EPS now has around 4000 individual members, and brings together 42 national physical societies which themselves represent together over 130,000 physicists.
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