Isolated skyrmions in a ferromagnet: From fundamentals to room temperature applications

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Skyrmions are spin structures with spherical topology. They typically manifest as circular domains in ferromagnets with perpendicular magnetic anisotropy and Dyzaloshinskii-Moriya interaction (DMI). So far, there are two competing theoretical models describing small skyrmions in materials with strong DMI and large skyrmions in materials with strong stray field interactions, respectively. Here, I present a unified theory that describes isolated skyrmions of all sizes with a fully analytical energy function [1]. In particular, this theory includes a term for the stray field interactions that is accurate to 1 % for all skyrmion sizes and film thicknesses. Using this accurate model, I will show that the distinction of stray field skyrmions and DMI skyrmions is justified, but not so the distinction criteria that were previously suggested. I will furthermore show that our model can predict materials with sub-10 nm skyrmions at zero field and room temperature, where those skyrmions can be moved with velocities exceeding 1000 m/s at reasonable current densities of 10^{12} A/m^2, see Figure 1.

Experimentally, I will show that skyrmions can be nucleated by spin-orbit torque current pulses [2]. In contrast to spin-orbit torque switching of uniformly magnetized MRAM cells, skyrmion nucleation does not require any in-plane fields to be applied. The nucleation mechanism is robust, ultra-fast (sub-nanosecond), and extremely easy to implement. I will discuss the mechanism of the skyrmion generation and explain why DMI can replace the need for in-plane fields.

[1] Büttner, F., Lemesh, I. & Beach, G. S. D. Full phase diagram of isolated skyrmions in a ferromagnet. *arXiv:1704.08489* (2017).

[2] Büttner, F. *et al.* Field-free deterministic ultra fast creation of skyrmions by spin orbit torques. *Nature Nanotechnology* **in press** (2017).

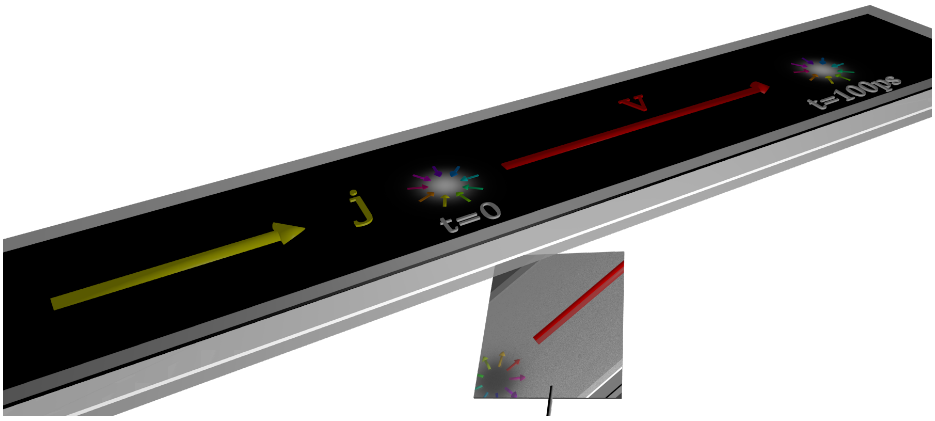

Figure 1 | 10 nm skyrmion moving with 1000 m/s in a synthetic antiferromagnet.