Skyrmion characterization and manipulation via a molecular spin-probe

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Scanning Tunneling Microscopy (STM) stands out as one of the few scanning probe techniques capable of atomic-scale spin detection and magnetic imaging. Our STM group at IPCMS has developed an expertise in this field, with key contributions to areas such as Kondo physics and spin-polarized STM. Of particular note is our pioneering work in quantum magnetometry, as demonstrated in our recent publication in Science [1], where we introduced a molecular magnet as a probe-tip for STM. This innovative technique involves terminating the STM tip with a nickelocene molecule (Nc-tip), which consists of a single Ni atom sandwiched between two cyclopentadienyl rings (C_5H_5) (Fig. 1a). The nickelocene's spin states, which can be precisely monitored via inelastic tunneling current, interact with the sample through an exchange interaction across the vacuum gap, thus enabling sub-angstrom precision in sample spin detection. Our research has demonstrated that the Nc-tip can freely scan surface locations and accurately sense surface magnetism, offering high sensitivity to both spin polarization and magnetization orientation [3].

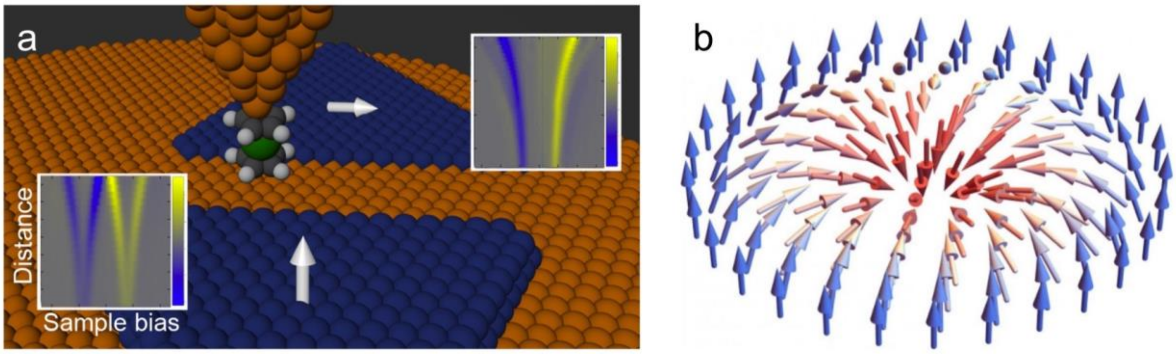

Figure 1: (a) Sketch of a nickelocene terminated tip above nanoscale Co islands on a copper surface. The tip is sensitive to the orientation of the island magnetization. (b) Sketch of a skyrmion. A skyrmion is a vortex-like magnetic structure formed by a unique arrangement of spins that twist in a continuous, spiral pattern. The spins at the core point in one direction, while those at the edge point in the opposite direction.

The PhD will focus on investigating non-collinear magnetic systems, particularly magnetic skyrmions—vortex-like magnetic structures [4] (Fig. 1b). The goal is to use low-temperature STM to characterize and control nanoscale skyrmions in a Fe/Ir(111) magnetic thin film [5]. This research will employ the novel Nc-tip approach, which offers several key advantages over conventional metal tips: i) Atomic-level precision in mapping the spin textures of skyrmions. ii) The ability to create and manipulate skyrmions using the local exchange field and spin-polarized current generated by the Nc-tip, in both tunneling and contact modes. Through this work, we aim to gain a deeper understanding of skyrmion dynamics and their potential use in memory devices. Experiments will be performed in an ultra-high vacuum, low-temperature STM system (1.5 K) housed in a noise-free facility. Additionally, an external magnetic field (≤5 T) perpendicular to the sample surface can be applied.

[1] B. Verlhac et al., Science **366**, 623 (2019)
[2] A. Fétida et al., ACS Nano **18**, 13829 (2024)
[3] R. Wiesendanger, Nature Reviews Materials **1**, 16044 (2016)