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Title: **Artificial van der Waals multiferroics with twisted two-dimensional materials**

Abstract: Twisted van der Waals materials have risen as a powerful platform to engineer artificial quantum matter. Artificial moire heterostructures, in general, display two length scales: the original lattice constant and the emergent moire length. Here we reveal a microscopic mechanism to engineer van der Waals multiferroics from the interplay of non-collinear magnetism and spin–orbit coupling, both in van der Waals monolayers [1,2] and twisted multilayers [3]. First, as a proof of concept and focusing on the recently isolated NiI2 multiferroic monolayer [1], we reveal the origin of the helimagnetic order and the critical role of halide spin-orbit coupling in driving a ferroelectric distortion. We demonstrate that the electronic reconstruction accounting for the ferroelectric order emerges from the interplay of such a non-collinear magnetism and spin-orbit coupling, and we demonstrate how the ferroelectric distortion can be probed experimentally with scanning tunneling spectroscopy [2]. Second, we show the emergence of multiferroic order in twisted chromium trihalide bilayers, an order fully driven by the moiré pattern and absent in aligned multilayers. We show that a spin texture is generated in the moiré supercell of the twisted system as a consequence of the competition between stacking-dependent interlayer magnetic exchange and magnetic anisotropy [3]. An electric polarization arises associated with such a non-collinear magnetic state due to the spin-orbit coupling, leading to the emergence of a local ferroelectric order following the moiré. Among the stochiometric trihalides, our results show that twisted CrBr3 bilayers give rise to the strongest multiferroic order. We further show the emergence of a strong magnetoelectric coupling, which allows the electric generation and control of magnetic skyrmions. Our results put forward van der Waals materials as a powerful platform to engineer artificial multiferroic order and electrically control exotic magnetic textures.

[1] Adolfo O Fumega and Jose L Lado 2022 2D Materials. 9 025010 (2022)

[2] Mohammad Amini, Adolfo O. Fumega, Héctor González-Herrero, Viliam Vaňo, Shawulienu Kezilebieke, Jose L. Lado, Peter Liljeroth, arXiv:2309.11217 (2023)

[3] Adolfo O. Fumega, Jose L. Lado, 2D Matererials 10 025026 (2023)