Orthogonal flows in magnetic active roller suspensions & the emergence of higher order anisotropy

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The Quincke electrohydrodynamic instability drives the steady rotation of a dielectric particle in a weakly conducting fluid under the action of an external DC electric field. Once a critical field strength is exceeded, a spherical particle will rotate steadily with its rotation axis perpendicular to field, or in the vicinity of a surface will roll at a constant speed. Isolated rollers typically perform quasi-linear random walks, with collective motion emerging at sufficient densities[1]. Our system includes an additional degree of freedom using magnetite-doped particles, to observe markedly different dynamics. In the absence of a magnetic field, roller motion is isotropic, executing tight circular trajectories interspersed with brief "runs". Introducing a homogeneous in-plane magnetic field alongside the electric driving, initially (¡ 20 mT) linearises the motion, as the rollers' induced magnetic moment aligns with field, thereby fixing the Quincke rotation axis and breaking isotropy. The resulting in linear anisotropy, which manifests as steady currents perpendicular to the magnetic field is consistent with other work describing coherent uniaxial trajectories[2]. However, as we increase the applied magnetic field beyond 20 mT, we observe a second symmetry breaking by the appearance of an anomalous secondary mode, with rollers travelling parallel to the magnetic field axis resulting in synchronous orthogonal flows. We have constructed a numerical model of anisotropic magnetic susceptibility to capture the emergent dual-anisotropic character of our active system, characterizing the dynamics of our easy magnetic axis in the steady state as stationary during perpendicular motion, acting as a fixed-point attractor, or oscillatory and reminiscent of a limit cycle, during parallel motion. The novelty of our dual-anisotropic active matter system therefore opens the door to a rich phase space of unexplored collective states.

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[1]Bricard et al., *Nature* **503**, 95-98 (2013)
[2]Reyes Garza et al., *Science Advances* **9**, eadh2522 (2023)