

Active Rosensweig Patterns

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Ferrofluids, colloidal dispersions of magnetic nanoparticles, are renowned for pattern formation like few other materials. The Rosensweig instability of a horizontal ferrofluid-air interface in perpendicular magnetic field is especially well known: this instability sets the air-ferrofluid interface into an array of spikes that correspond to a new free energy minimum of the system. However, once the pattern is formed, it does not exhibit any notable thermal or non-equilibrium fluctuations –it is passive. In this work [1], we present an active version of Rosensweig patterns. We realize them experimentally by driving a dispersion of magnetic nanoparticles with an electric field into a non-equilibrium gradient state and by inducing an instability using a magnetic field. The coupling of magnetic forcing and electrically driven convection leads to patterns that can be adjusted from quiescent classic Rosensweig-like behavior (low activity) to highly dynamic ones displaying peak and defect dynamics (high activity). We analyze the results using an active agent-based approach as well as from a continuum perspective. We propose a minimal Swift–Hohenberg type model to capture the essential dynamics of these active patterns. Our results suggest that classic equilibrium systems exhibiting pattern formation can be activated to display considerably more complex dynamic phenomena inspired by living systems.

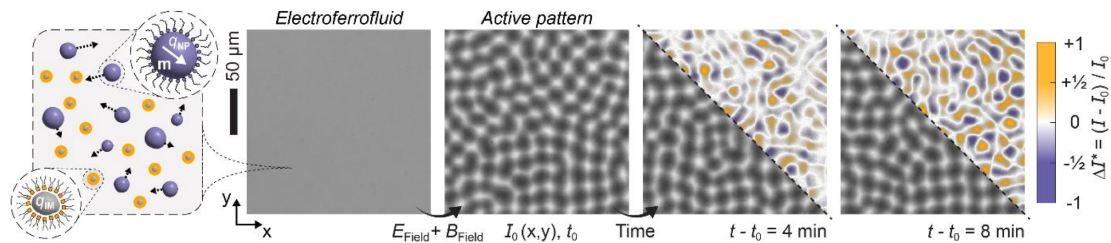


Figure 1: Active patterns of nanoparticle clouds in electroferrofluids [2] made of inverse micelles and magnetic nanoparticles subjected to electric and magnetic fields ($I(x, y)$ = local transmitted light intensity of the microscopy images, dark areas = clouds of nanoparticles).

References

- [1] C. Rigoni et al. *arXiv preprint arXiv:2510.09099* (2025).
- [2] T. Cherian et al. *Sci. Adv.* 7, eabi8990 (2021).

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