# Magnetic noise measurements and demonstration of a field-induced magnetic monopole plasma in artificial spin ice

M. Goryca[1], X. Zhang[2], J. D. Watts[3], C. Nisoli[4], C. Leighton[3], P. E. Schiffer[2], S. A. Crooker[4]

[1] *Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
[2] *Department of Applied Physics, Yale University, New Haven, USA*
[3] *Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, USA*
[4] *National High Magnetic Field Lab, Los Alamos National Laboratory, Los Alamos, USA*

Arrays of interacting nanomagnets known as Artificial Spin Ice (ASI, Fig. 1(a)) have allowed the design of geometrically frustrated exotic collective states not found in natural magnets. A key emergent description of fundamental excitations in ASIs is that of magnetic monopoles – mobile quasiparticles that carry an effective magnetic charge. While the presence of monopoles in ASI has been observed in pioneering imaging measurements, dynamical studies of monopole kinetics, and (especially) the ability to tune continuously through monopole-rich regimes in thermal equilibrium, remain at an early stage.

In this work we use a high-bandwidth magneto-optical noise spectrometer (Fig. 1(c)) to passively "listen" to spontaneous magnetization fluctuations in thermally active ASI lattices under conditions of thermal equilibrium. The noise reveals specific regions in the field-dependent phase diagram (Fig. 1(b),(d)) where the density of mobile monopoles increases well over an order of magnitude, a consequence of the field-tunable tension on the Dirac strings connecting mobile monopoles. Moreover, detailed noise spectra demonstrate that monopole kinetics are minimally correlated (*i.e.*, most diffusive) in this plasma-like regime [1]. Discovery of on-demand monopole regimes with tunable kinetic properties opens the door to new probes of magnetic charge dynamics and provides a new paradigm for studies of magnetricity in artificial magnetic materials [2].

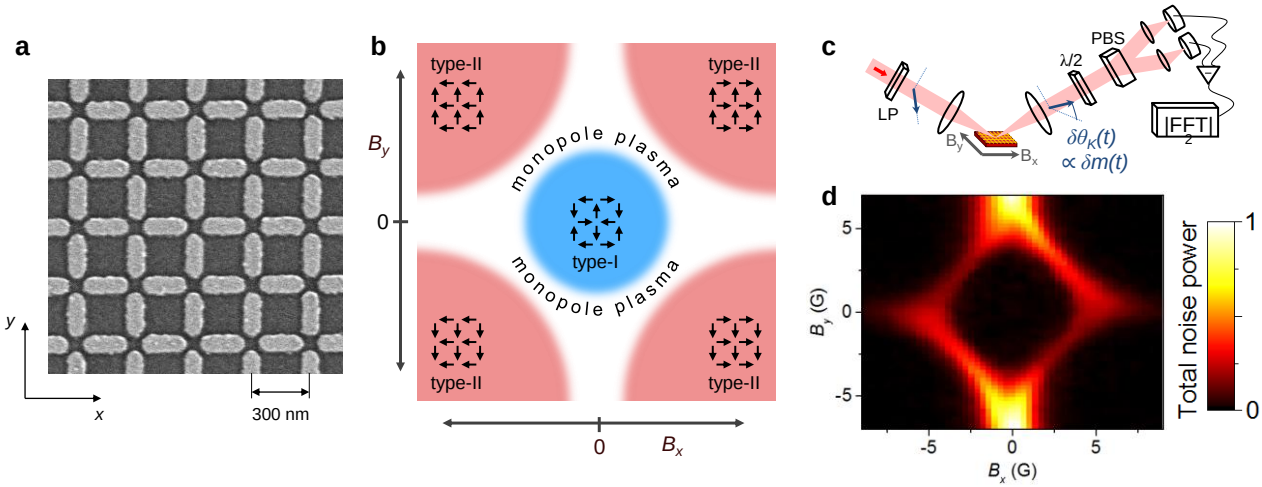


**Fig. 1:** *(a) SEM image of square ASI lattice. (b) Notional field-dependent phase diagram of square ASI. Between antiferromagnetic ordering at small magnetic field (blue) and fully polarized order at large field (red), a monopole-rich regime is expected. (c) Schematic of experimental setup for optical detection of magnetization fluctuations in ASI. (d) Measured map of the total magnetization noise power versus applied in-plane magnetic fields $B_x$ and $B_y$. The diamond-shaped feature indeed reveal a plasma-like regime, with the high density of mobile magnetic monopoles.*

**References:**

[1] M. Goryca, X. Zhang, J. Li, *et al.*, *Phys. Rev. X* **11**, 011042 (2021).
[2] M. Goryca, X. Zhang, J. D. Watts, *et al.*, *Phys. Rev. B* **105**, 094406 (2022).