Supplementary Information
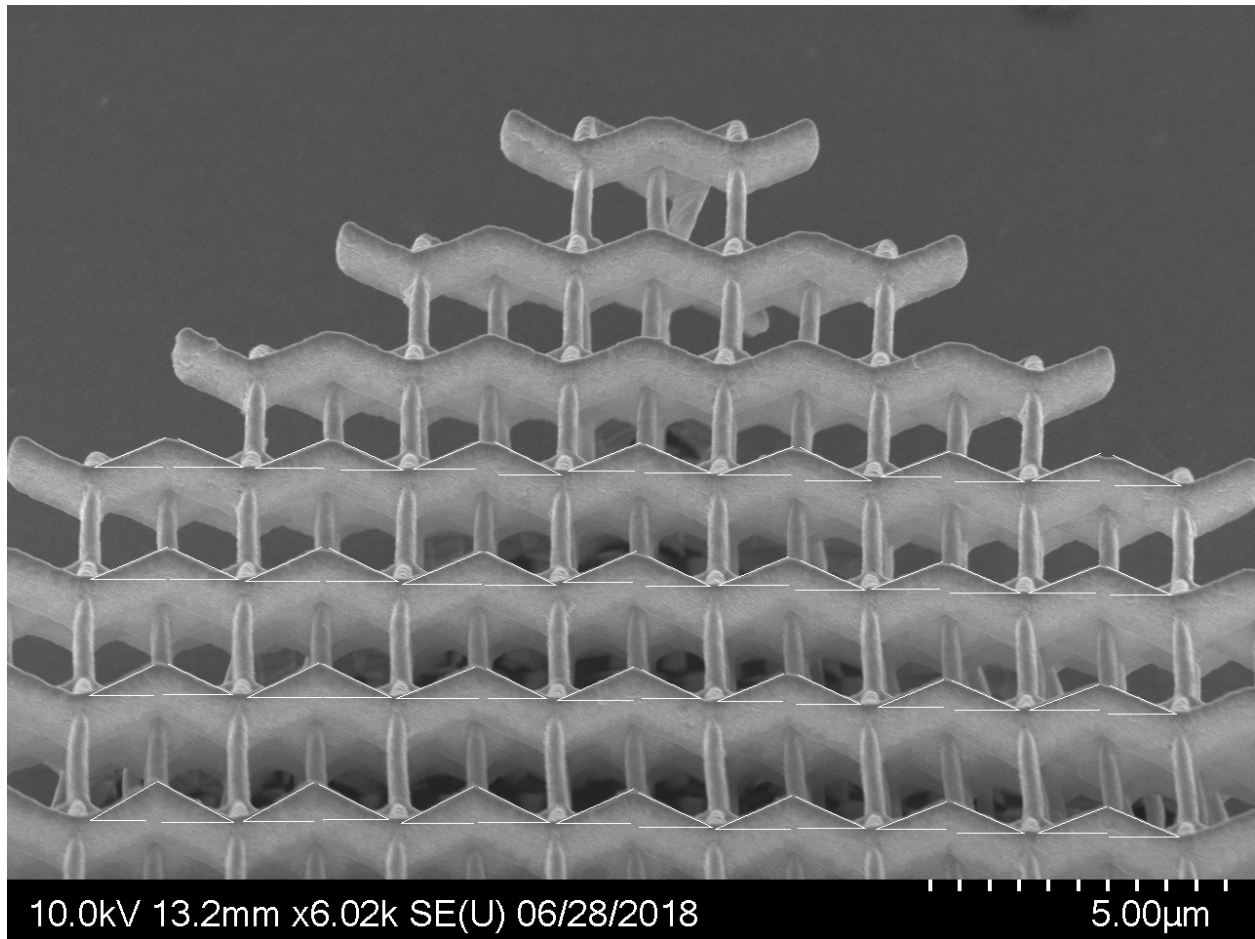
Magnetic Charge Propagation upon a 3D Artificial Spin-ice

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This PDF file includes:
Figs. S1 to S12

10.0kV 13.2mm x6.02k SE(U) 06/28/2018   5.00μm

**Supplementary Fig. 1**: SEM image showing 50 measurements of the angle between the L1 wire long-axis and the substrate plane (θ). A simple calculation was required to transform this measured angle into the actual angle, to account for the 45° tilt present during image acquisition.
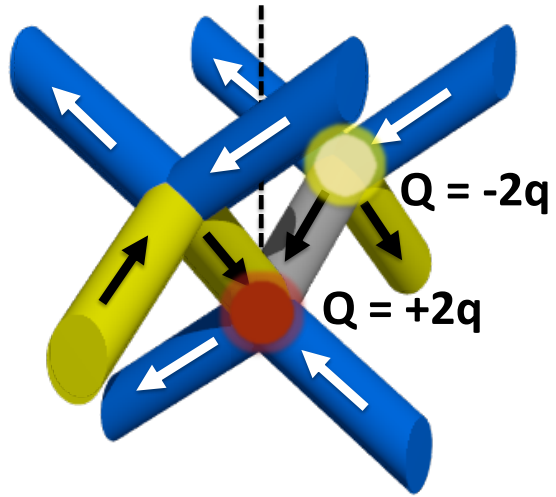
Supplementary Fig. 2: A schematic showing the creation of monopoles upon the L2 sub-lattice.
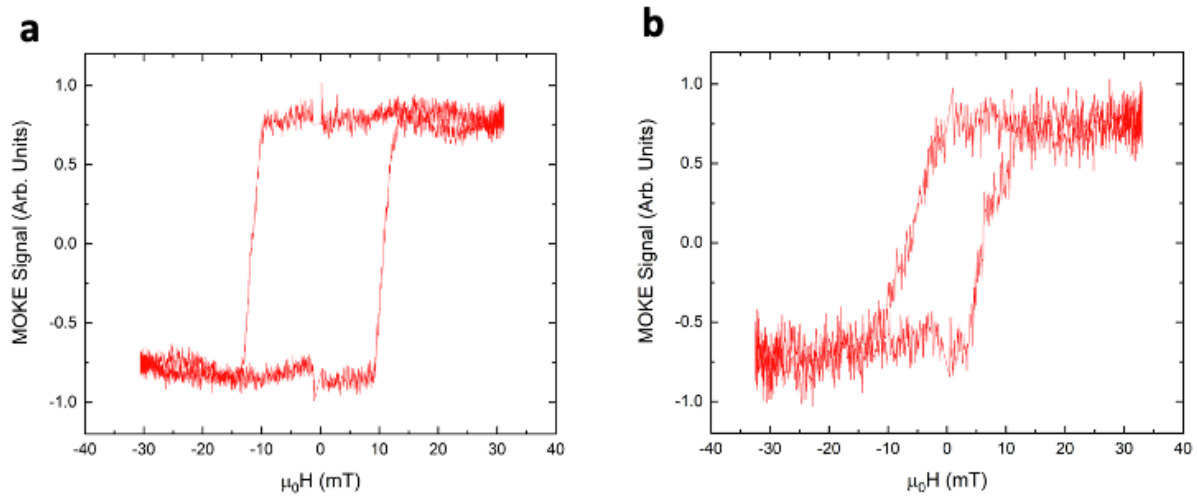
Supplementary Fig. 3: Optical magnetometry with external field applied along projection of **(a)** L1 sub-lattice and **(b)** L2 sub-lattice.
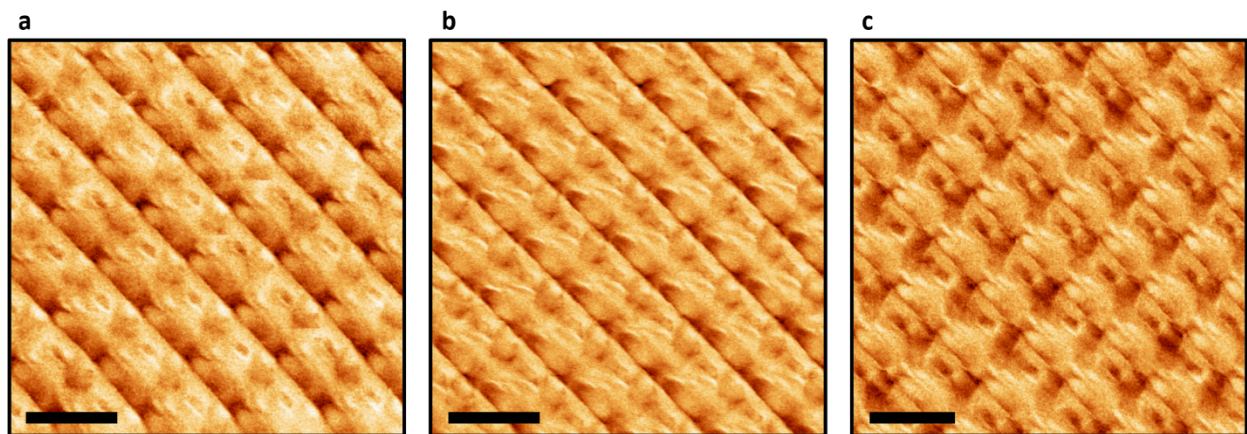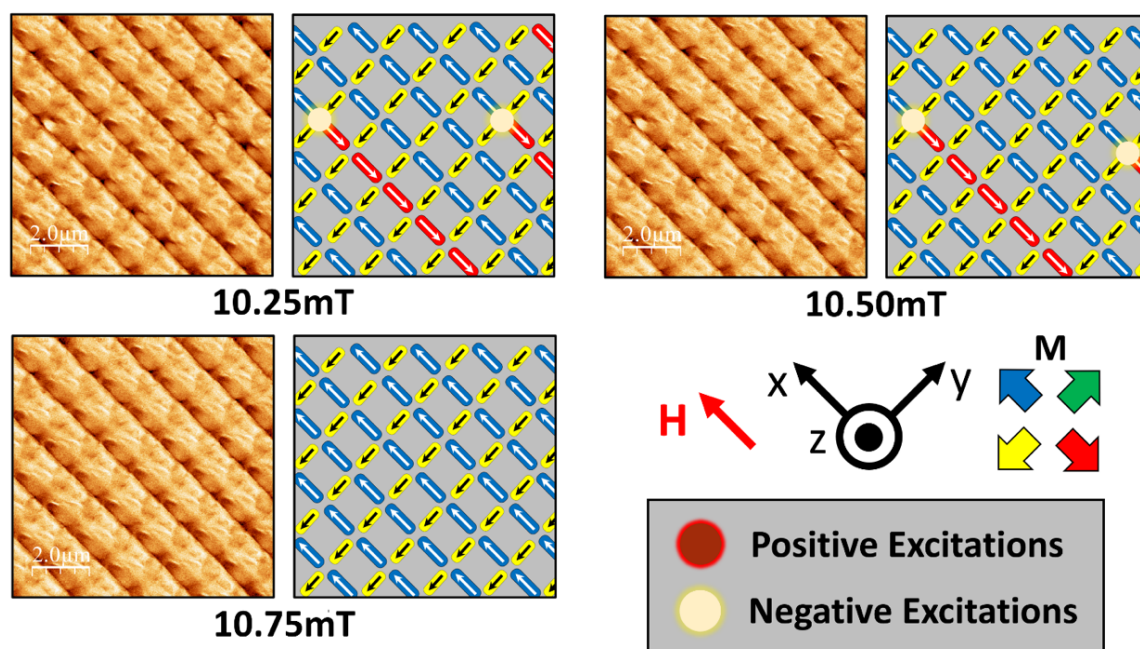
Supplementary Fig. 4: Unmasked MFM images of L1 and L2 saturated states. (a) An MFM image taken at remanence after application of saturating fields along the unit vectors (1,-1,0) and (-1,-1,0). (b) MFM image taken at remanence after a further saturating field is now applied along unit vector (-1,1,0). (c) MFM image taken at remanence after a further saturating field is now applied along unit vectors (1,-1,0) and (1,1,0). See main text for definition of coordinate system. Scale bars are 2μm.
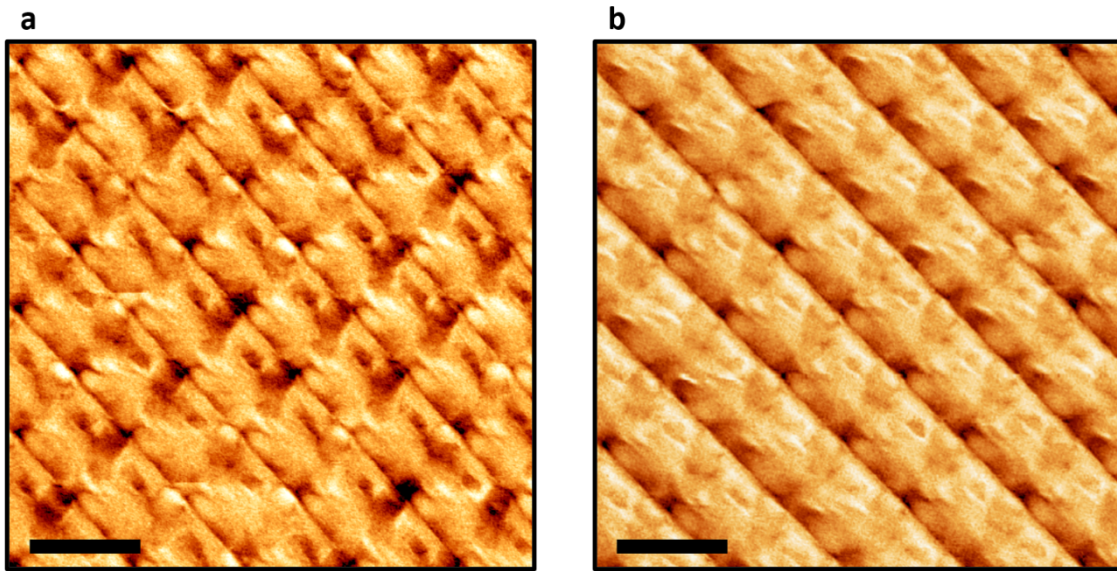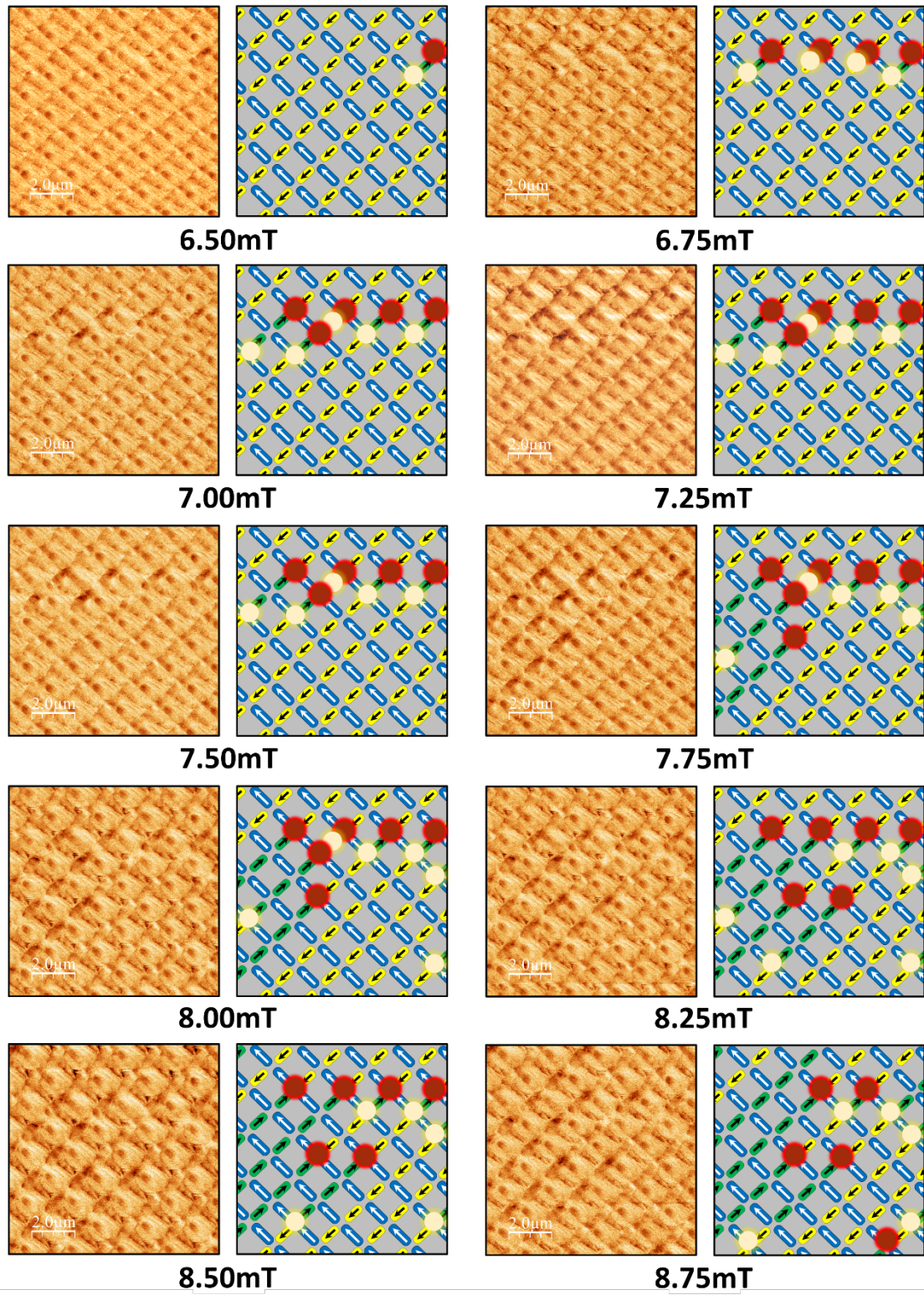
Supplementary Fig. 5: Unmasked MFM images of intermediate L1 and L2 states. (a) MFM image taken at remanence following a saturating field along L2, unit vector (-1,-1,0), and subsequent 8.0mT field applied along (1,1,0). (b) MFM image taken at remanence following a saturating field along L1, the unit vector (1,-1,0), and subsequent 9.5mT field along the unit vector (-1,1,0). See main text for definition of coordinate system.
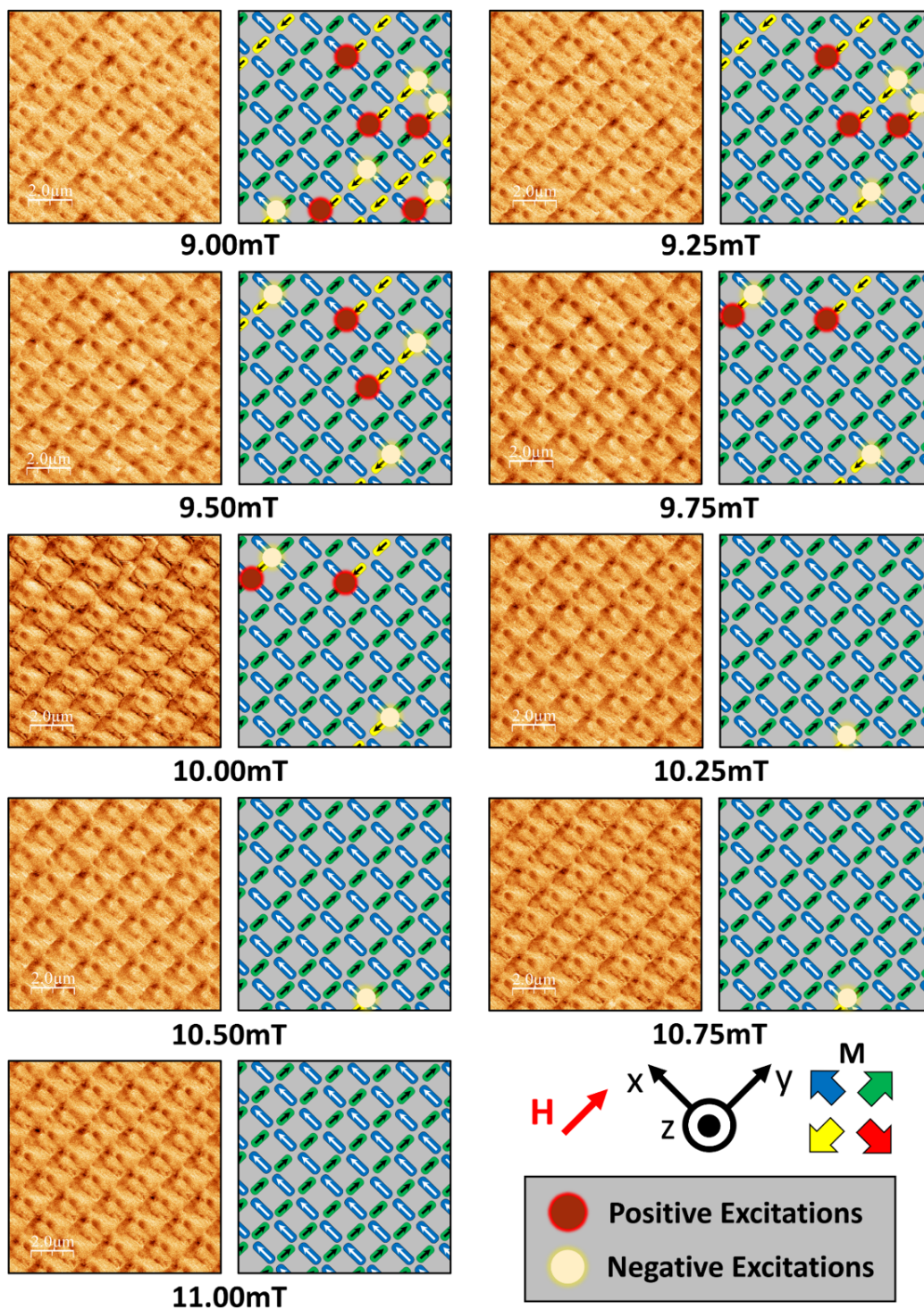
7.50mT

7.75mT

8.00mT

8.25mT

8.50mT

8.75mT

9.00mT

9.50mT

9.75mT

10.00mT
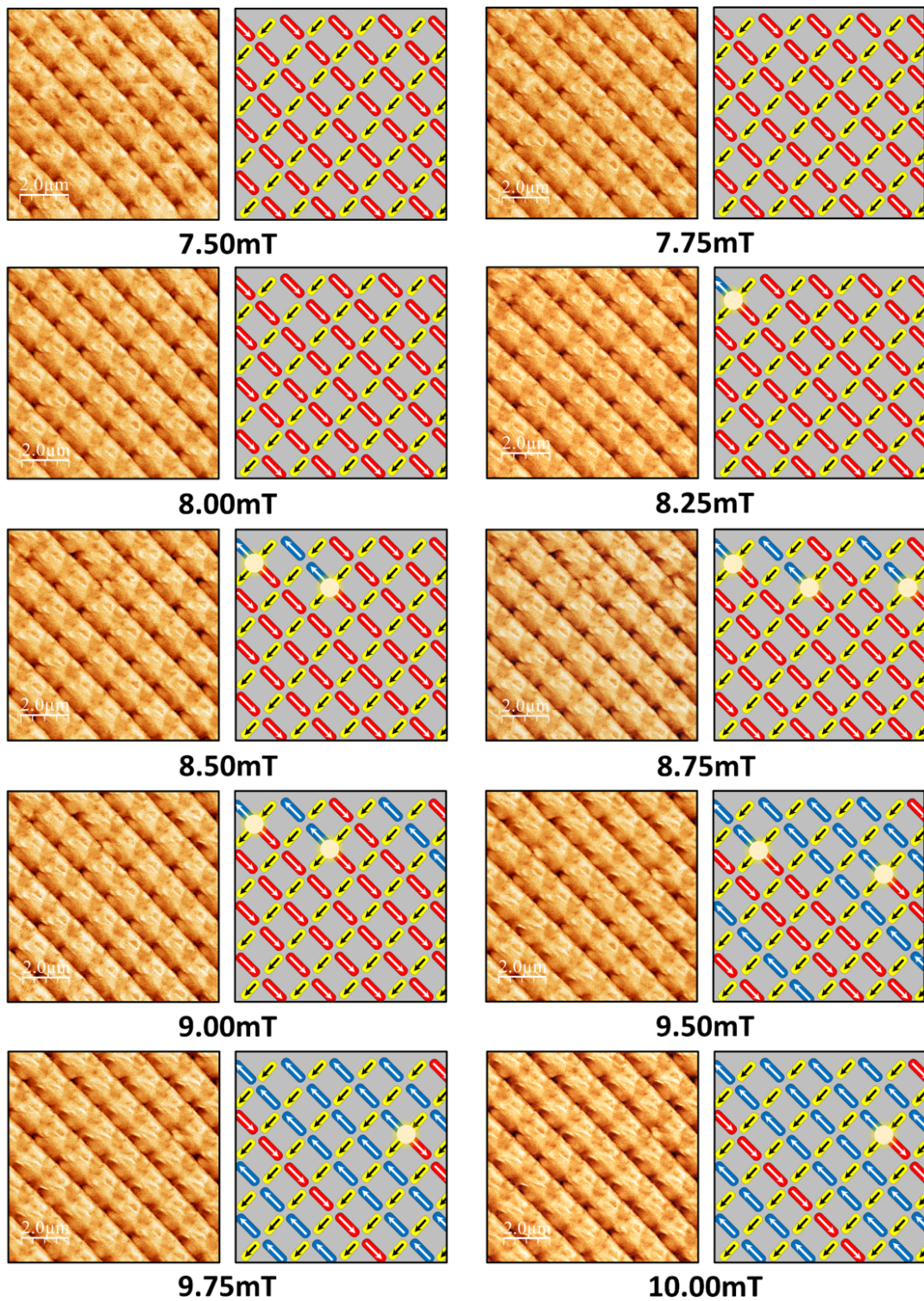
Supplementary Fig. 6: Raw MFM data without masks, L1 switching. All scale bars are 2μm.

10.25mT

10.50mT

10.75mT

H

x

y

z

M

Positive Excitations

Negative Excitations

Supplementary Fig. 6 (continued): Raw MFM data without masks, L1 switching. All scale bars are 2μm.

6.50mT

6.75mT

7.00mT

7.25mT

7.50mT

7.75mT

8.00mT

8.25mT

8.50mT

8.75mT

Supplementary Fig. 7: Raw MFM data without masks, L2 switching. All scale bars are 2µm.

9.00mT

9.25mT

9.50mT

9.75mT

10.00mT

10.25mT

10.50mT

10.75mT

11.00mT

Positive Excitations

Negative Excitations

Supplementary Fig. 7 (continued): Raw MFM data without masks, L2 switching. All scale bars are 2μm.

7.50mT

7.75mT

8.00mT

8.25mT

8.50mT
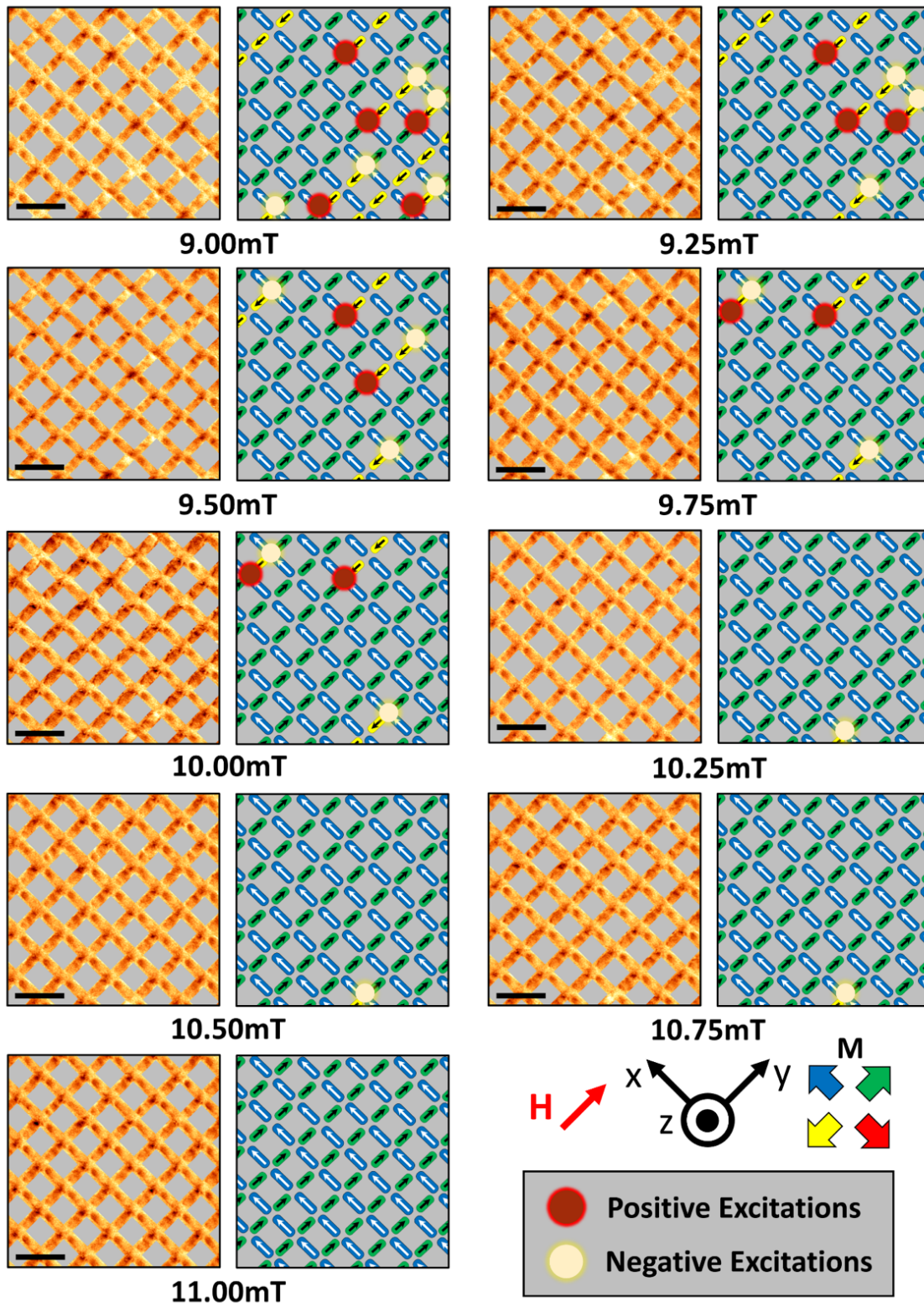
8.75mT

9.00mT

9.50mT

9.75mT

10.00mT
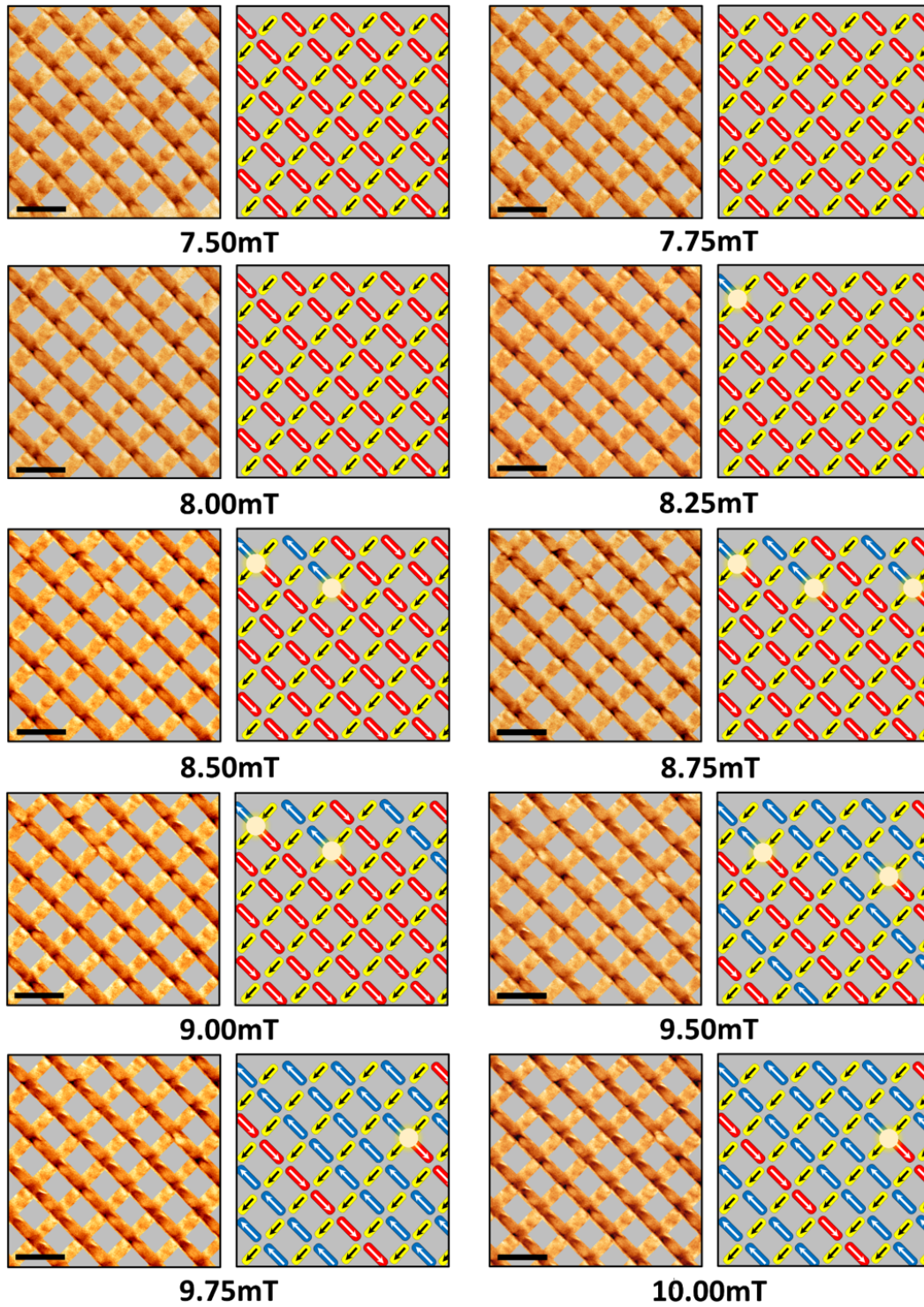
**Supplementary Fig. 8**: Full MFM data with masks, L1 switching. All scale bars are 2µm.
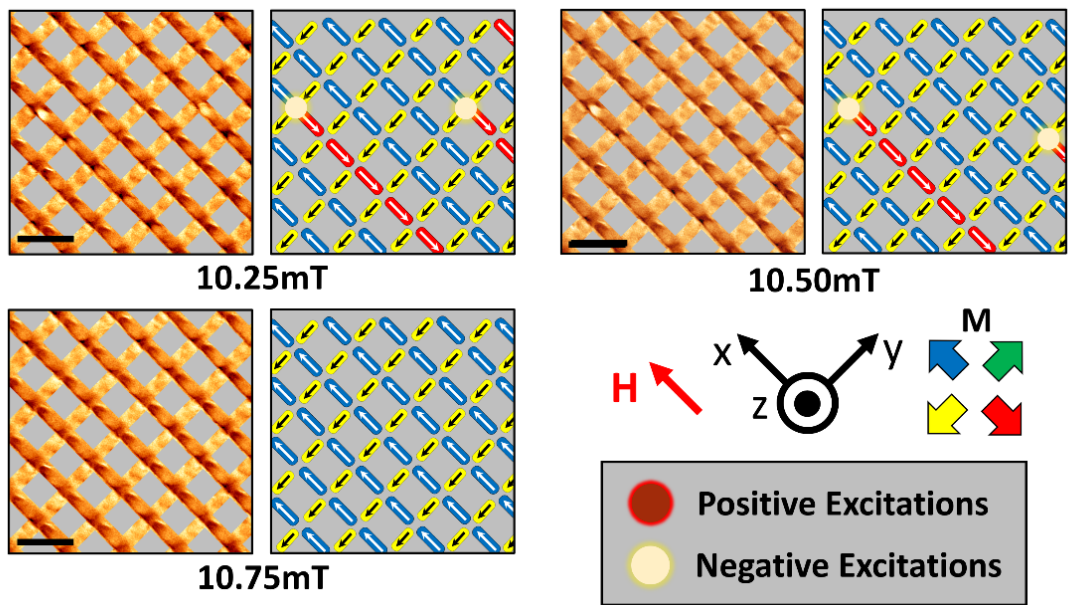
Supplementary Fig. 8 (continued): Full MFM data with masks, L1 switching. All scale bars are 2μm.

6.50mT

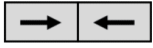**6.75mT**

7.00mT

7.25mT

7.50mT

7.75mT

8.00mT

8.25mT

8.50mT

8.75mT
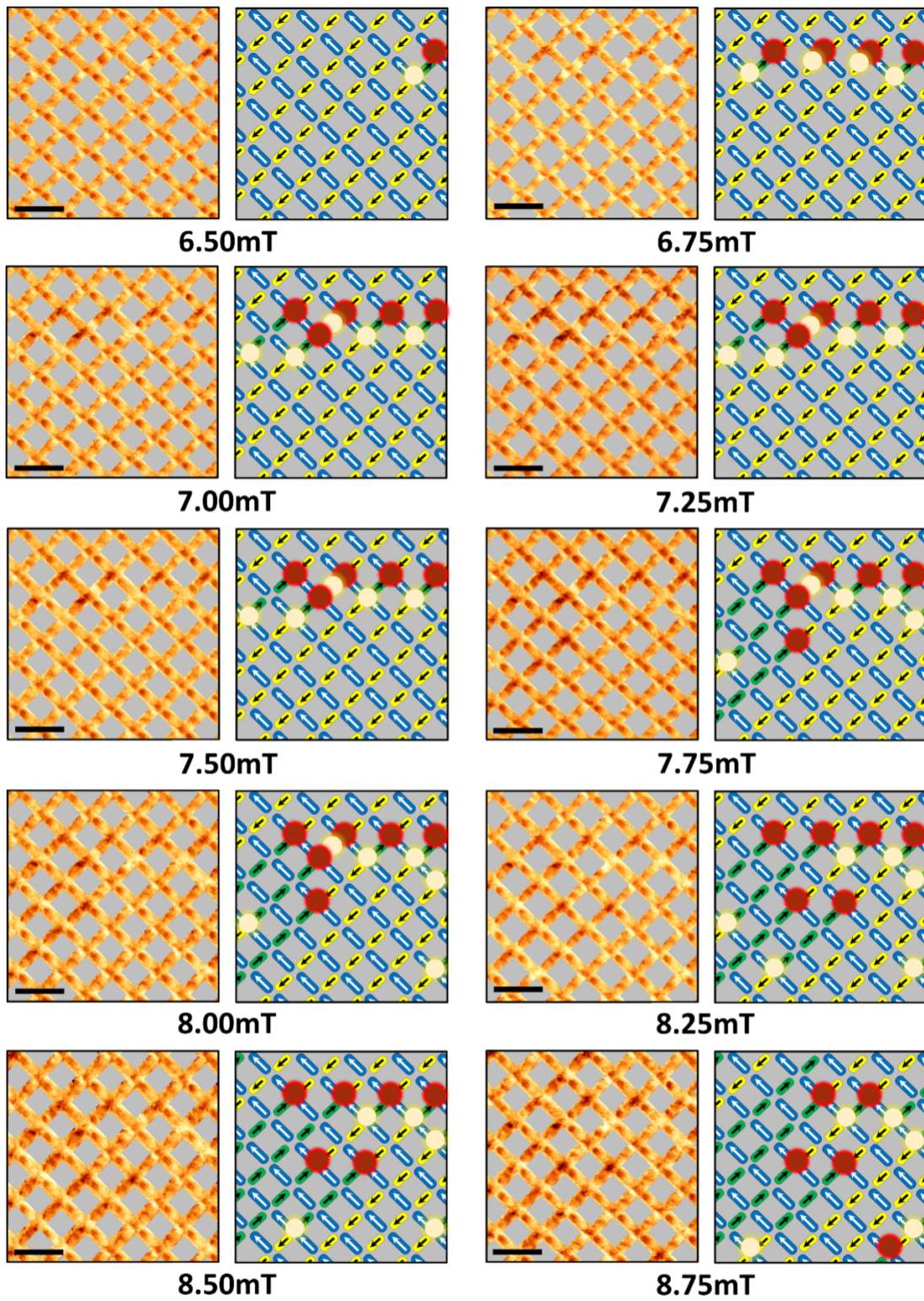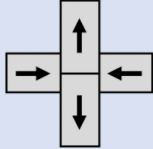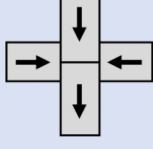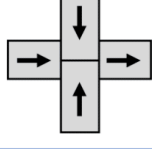
Supplementary Fig. 9: Full MFM data with masks, L2 switching. All scale bars are 2µm.

9.00mT

9.25mT

9.50mT

9.75mT

10.00mT

10.25mT

10.50mT

10.75mT

11.00mT

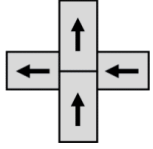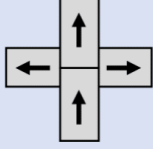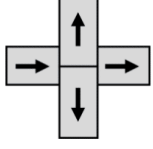**Supplementary Fig. 9 (continued)**: Full MFM data with masks, L2 switching. All scale bars are 2μm.

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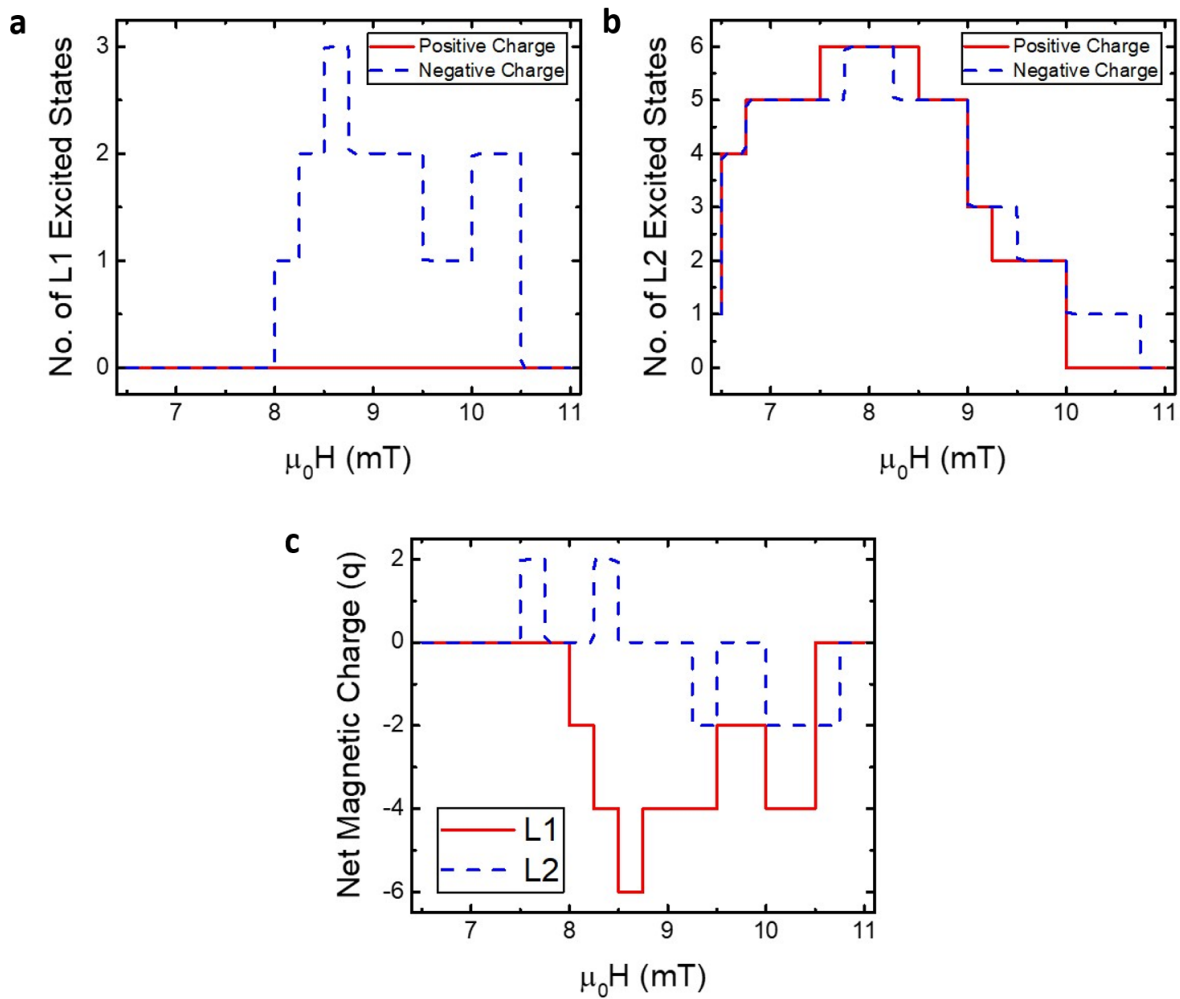
Supplementary Fig. 10: Analysis of MFM reversal datasets. **(a)** Number of monopole-excitations as a function of applied field for the L1 switching. Excitations are separated into $Q = +2q$ (red) and $Q = -2q$ (blue). **(b)** Equivalent plot for observed monopole-excitations during the L2 reversal. **(c)** Net magnetic charge within the measured window during the L1 (red) and L2 (blue) reversals.

Vertex Diagram	Vertex Type	Energy Density (Jm^{-3})
→ →	1-in/1-out	7021
→ ←	2-in	16006
(↑ → ← ↓)	1	8342
(↑ ← ← ↑)	2	7745
(↑ ← → ↑)	3	9907
(↑ → → ↓)	3	11276
(↓ → ← ↓)	3	10447
(↓ → → ↑)	3	11683

Supplementary Fig. 11: Vertex energies as calculated using micromagnetic simulations.
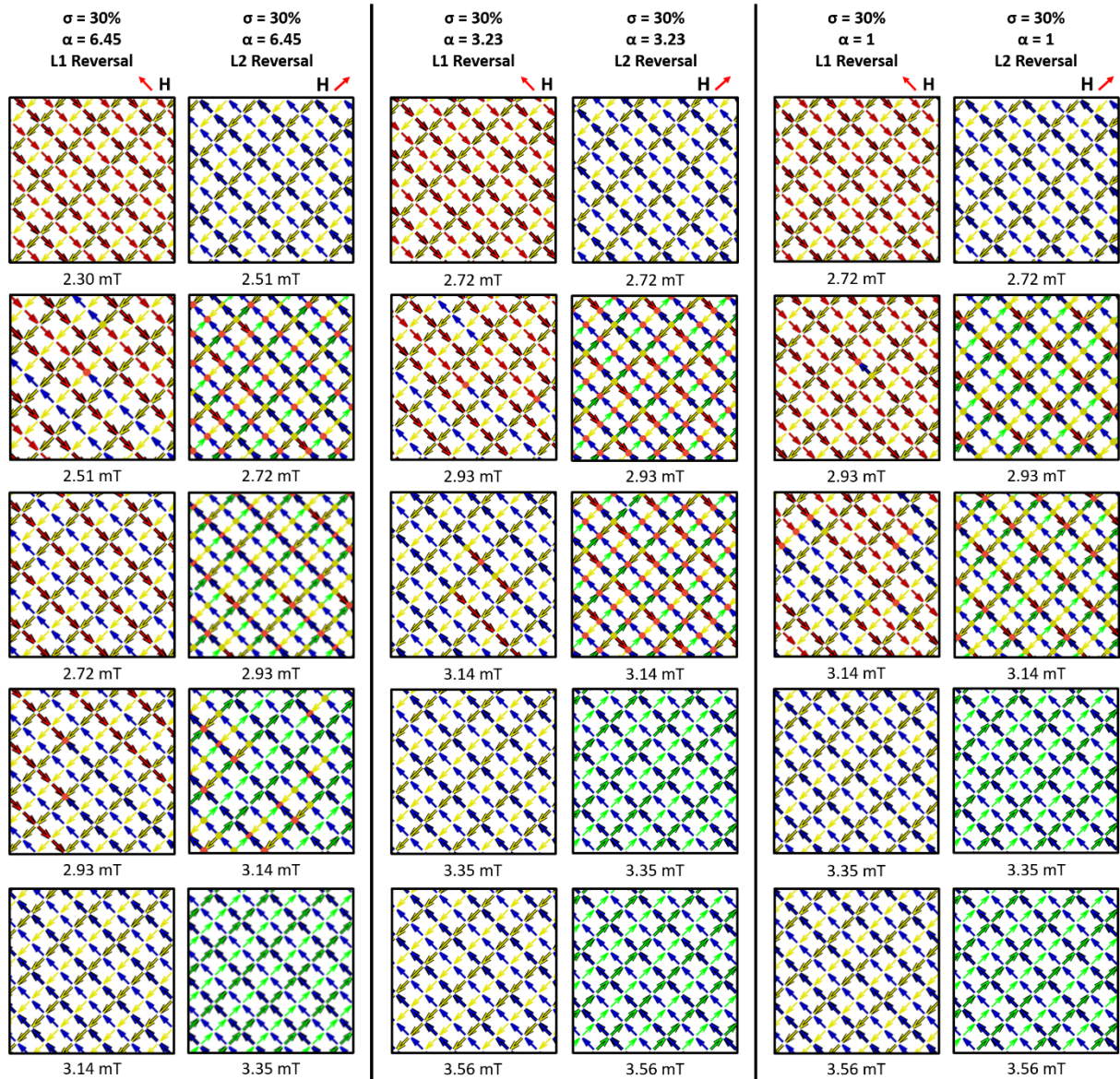
Supplementary Fig. 12: Full Monte-Carlo Simulations with varying surface energetics (α_{ij}). Micromagnetic simulations indicate α_{ij} = 3.23, whereas these Monte-Carlo simulations most closely resemble the experimental results when α_{ij} = 6.45.