Exploring topological effects and frustration in different Artificial Spin Ice geometries

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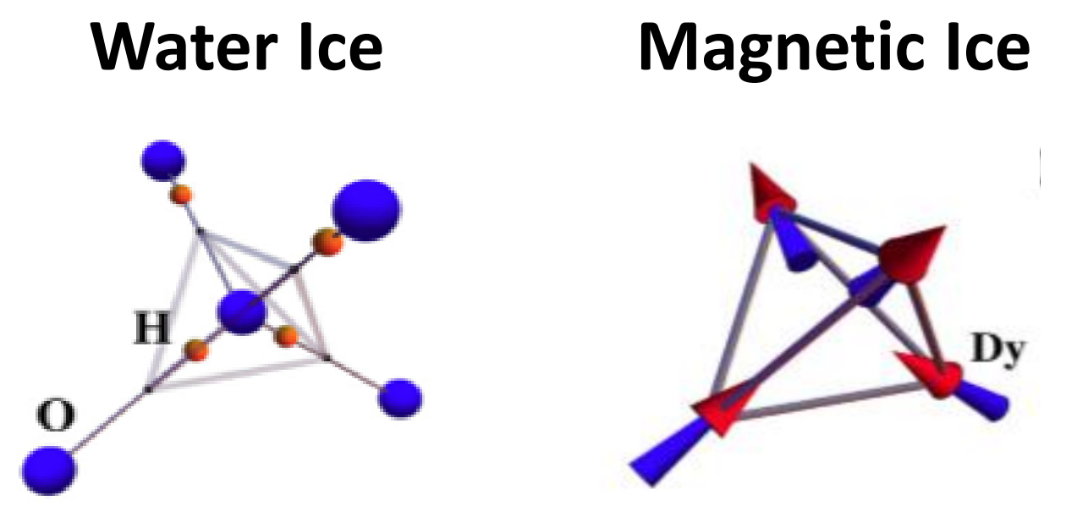
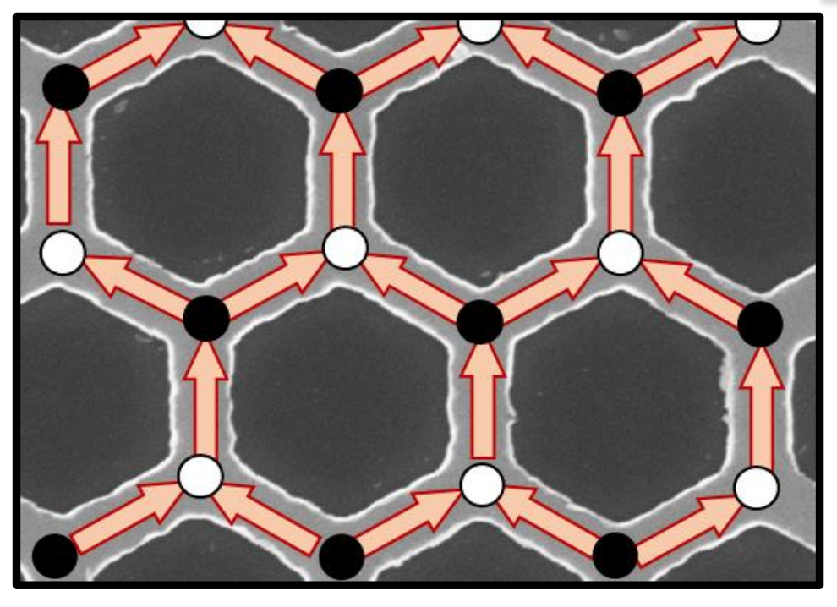
Artificial spin ices (ASIs) are examples of magnetic interacting nanostructures which have opened a way to study topological phenomena such as frustration, emergent magnetic monopoles and phase transitions. Geometric properties of the ASI are key to determine the dynamics of the magnetic charges and the possible energetic configurations, which can also have an influence on the magnetic textures present in these systems. The main goal of this work is to characterize the magnetic properties, spin textures and frustration in ASIs with different geometries and its influence in the formation and ordering of magnetic features. Different geometries of ASI systems had been fabricated by combining nanolithography techniques (optical and electronic lithography) and DC magnetron sputtering. Nanostructures were characterized using different microscopy techniques, magnetic force microscopy (MFM), magnetotransport and micromagnetic simulations.

Frustration[1]



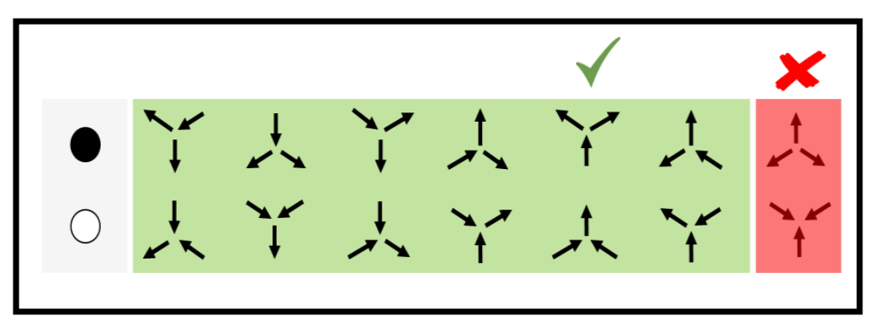
Frustration in a physical system emerges from the impossibility of simultaneously minimizing all interactions.

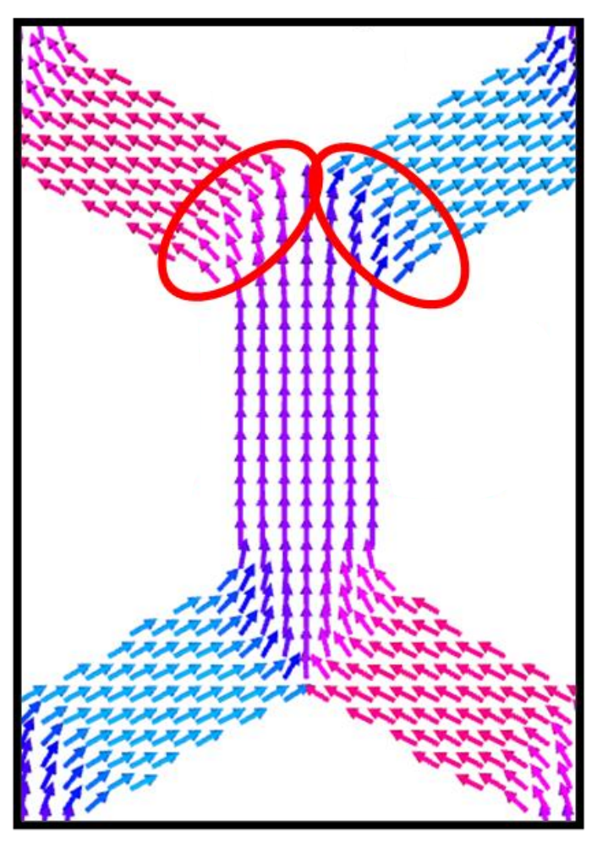
ASI[2,3]



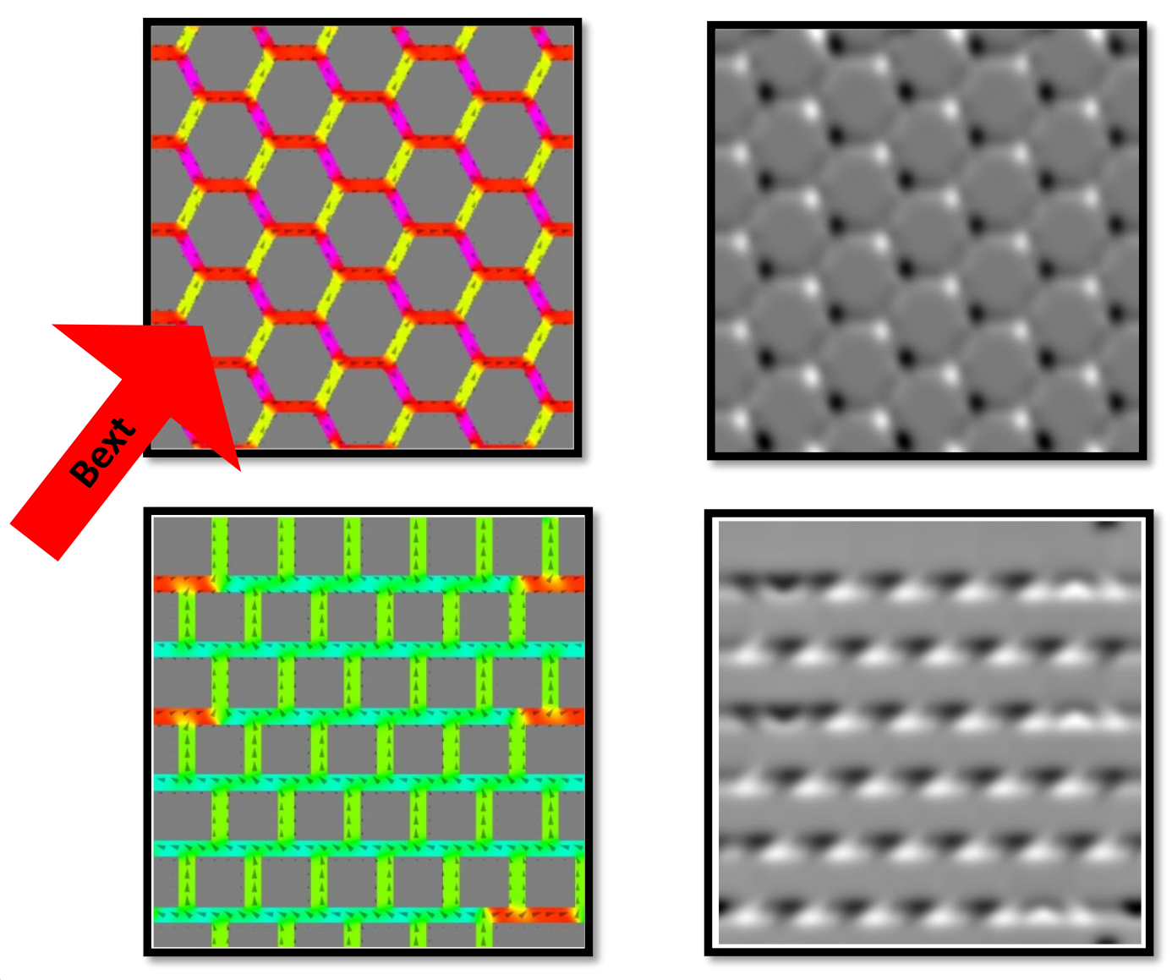
Magnetically interacting nanostructures

Ice Rules
- Charge neutrality
- Different phases





Mumax^3

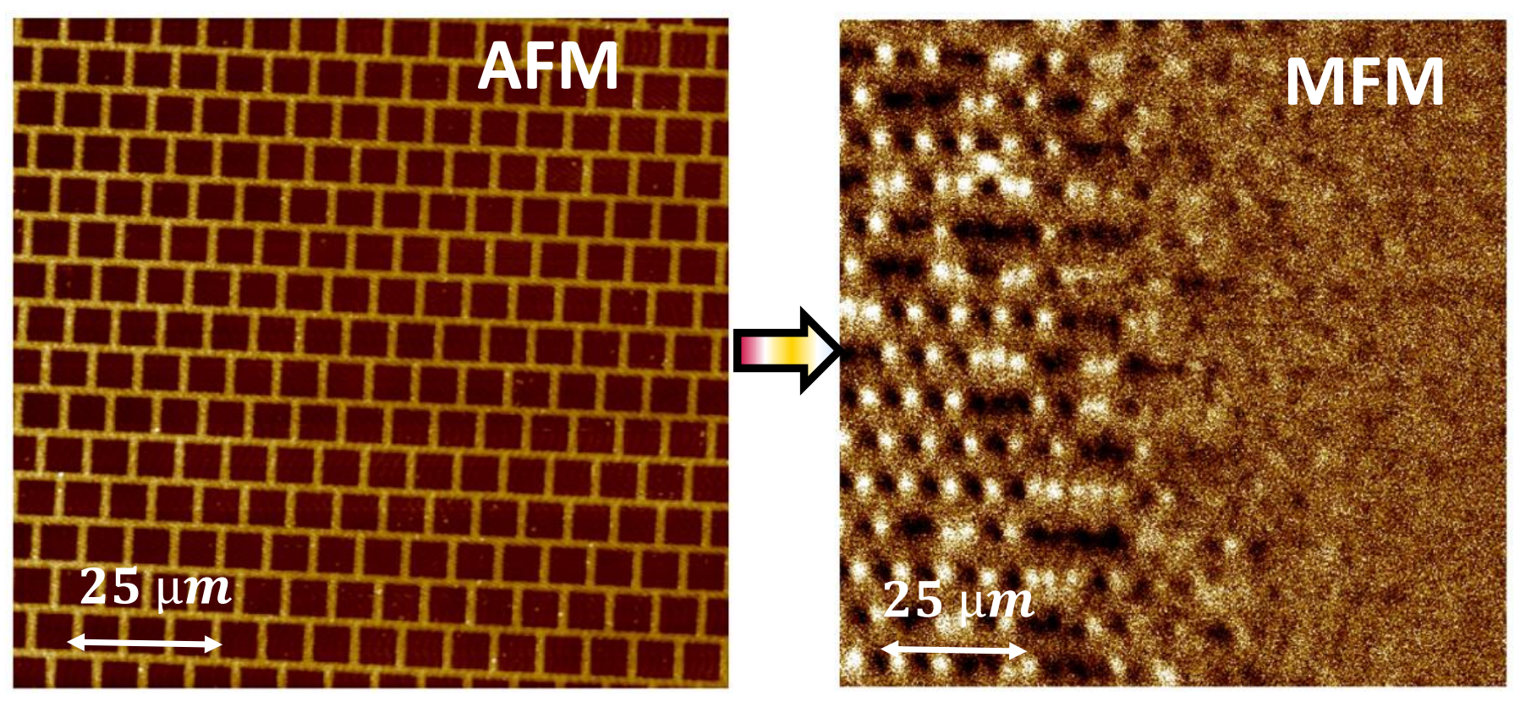


SIMULATIONS:
Same parameters are used with different geometries of ASIs

Co parameters:
$$M_s = 1.4\,x10^6\,Am^{-1}$$
$$A = 3x10^{-11}Jm^{-1}$$
$$K = 0\,Jm^{-3}$$

Square ASI: MFM at Tamb

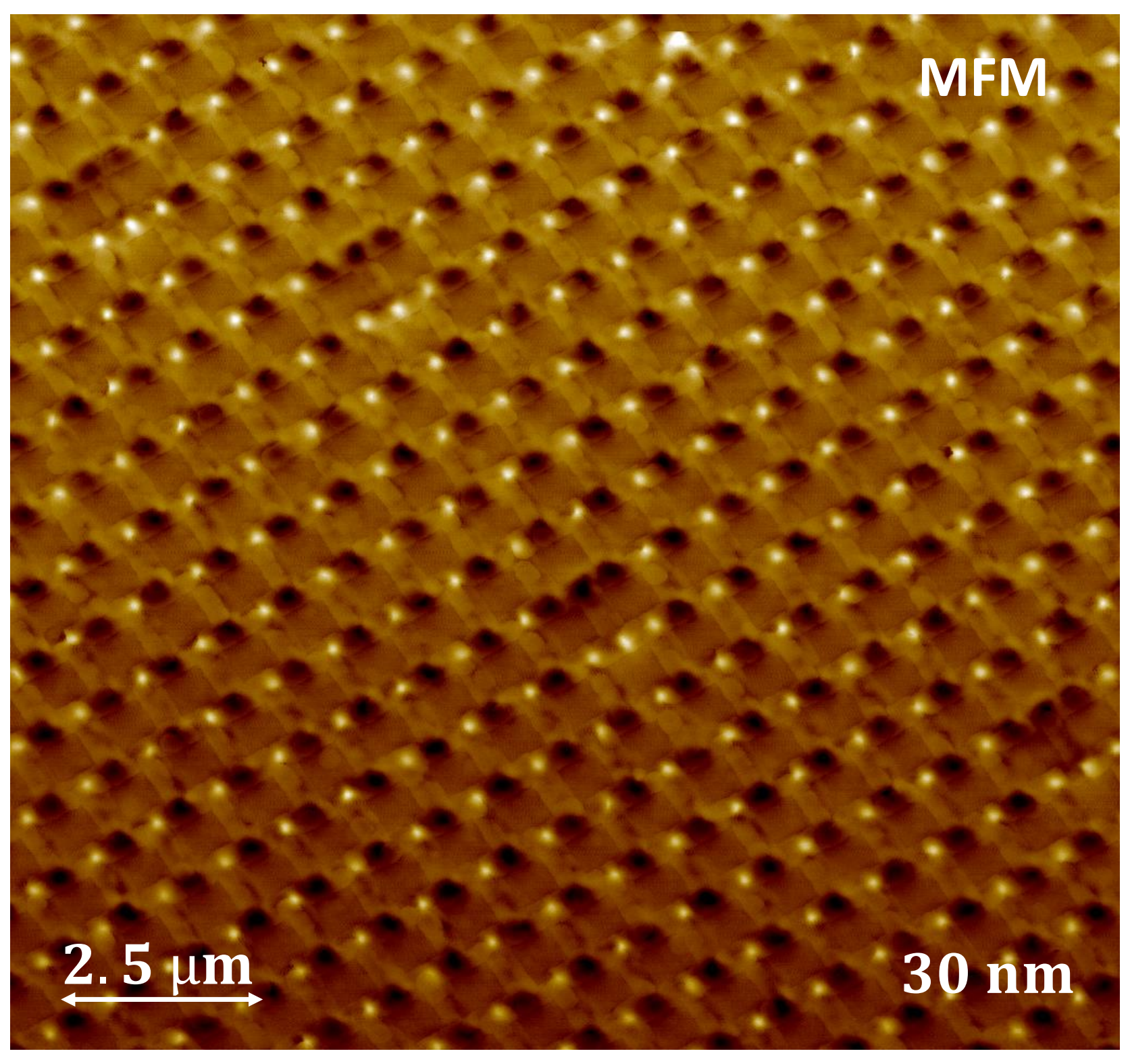
20 x 100 nm of Co



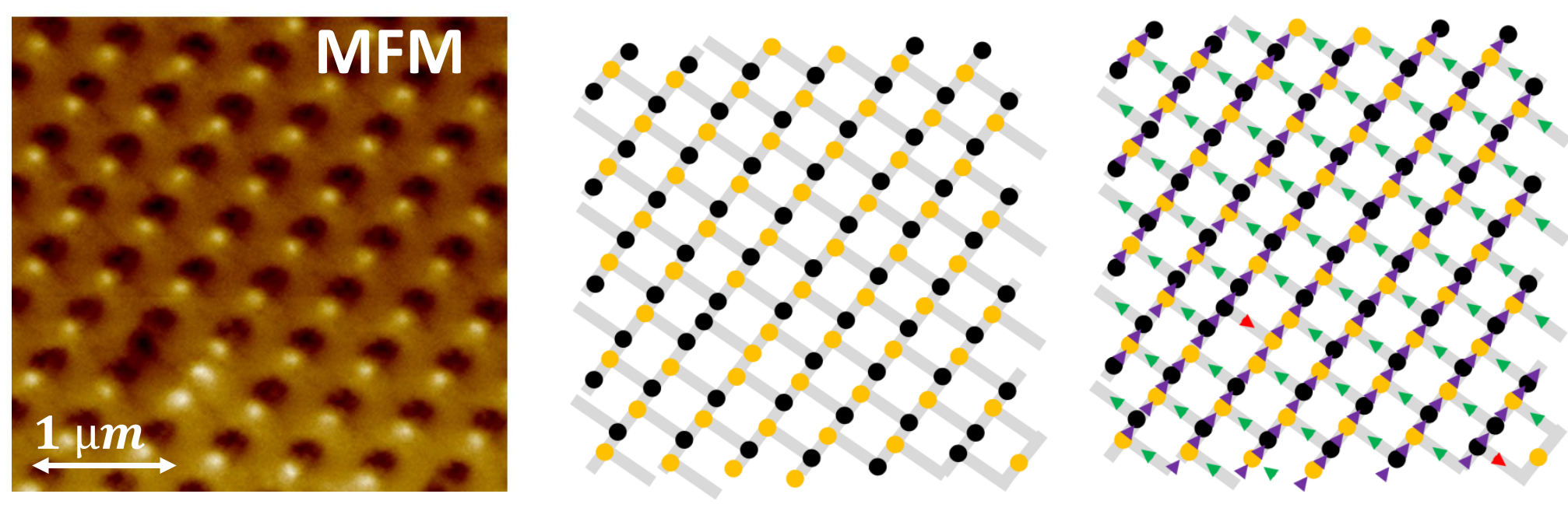
- ☐ Topologically protected magnetic charges in the vertex
- ☐ Same topology as the honeycomb ASI.
- ☐ Charges are maintained on topologically equivalent networks.

Co thickness lower than 15 nm has no topological effects

Magnetic charges at the array vertices

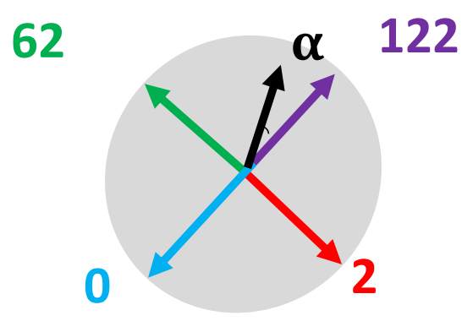


Possible direction of the resulting magnetization:



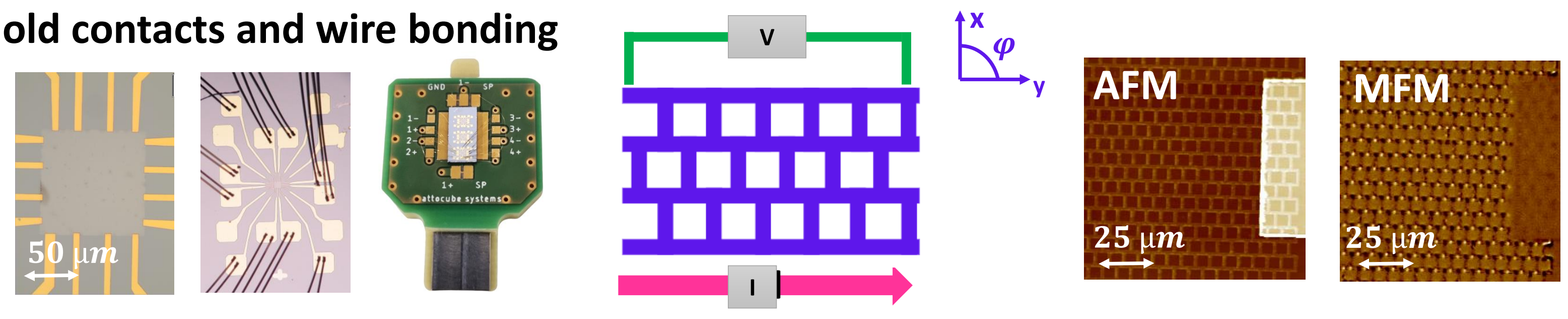
As grown state

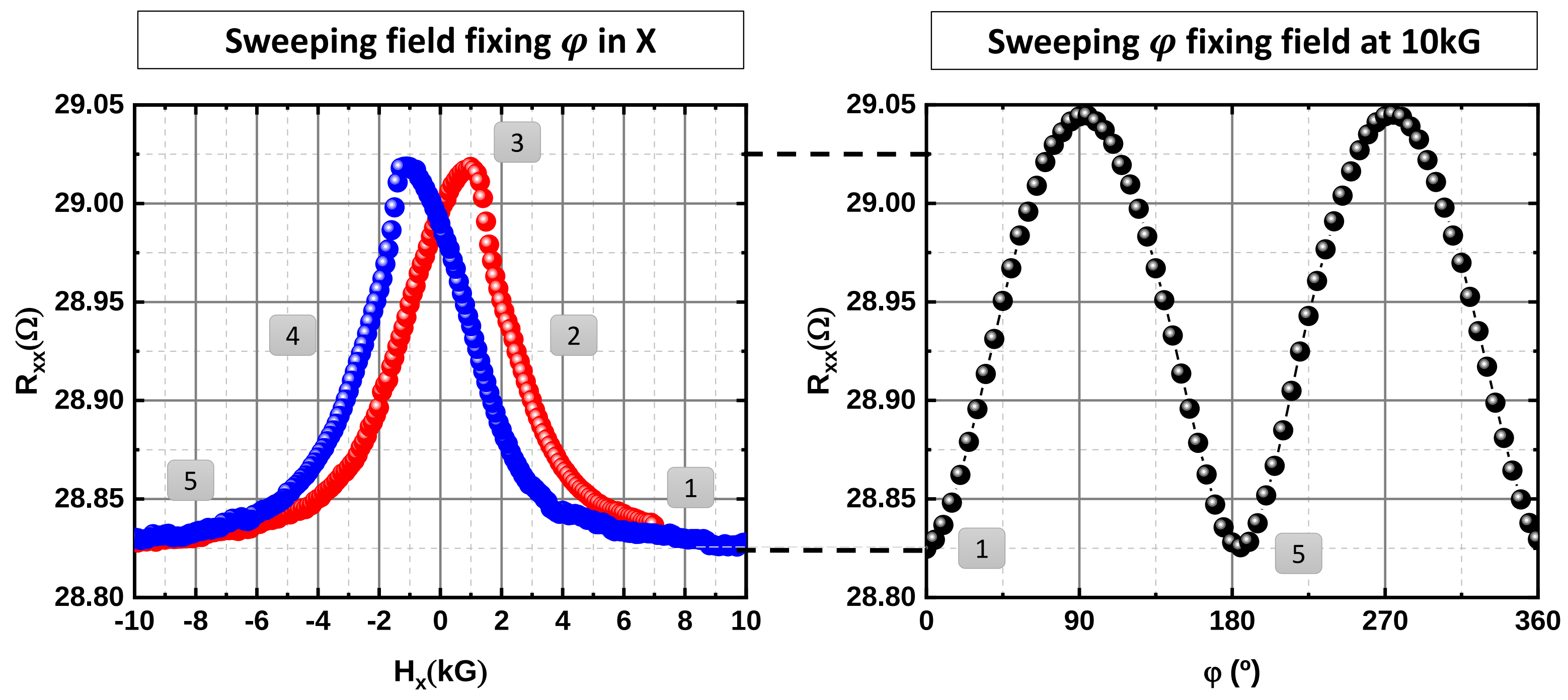
(122-0)x + (62-2)y
122x +60y
$\alpha = 26°$



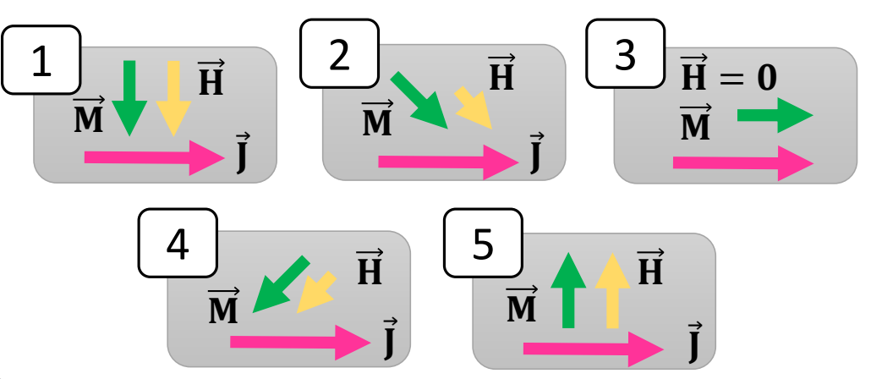
Square ASI: Manetotransport at 4.5K

Gold contacts and wire bonding





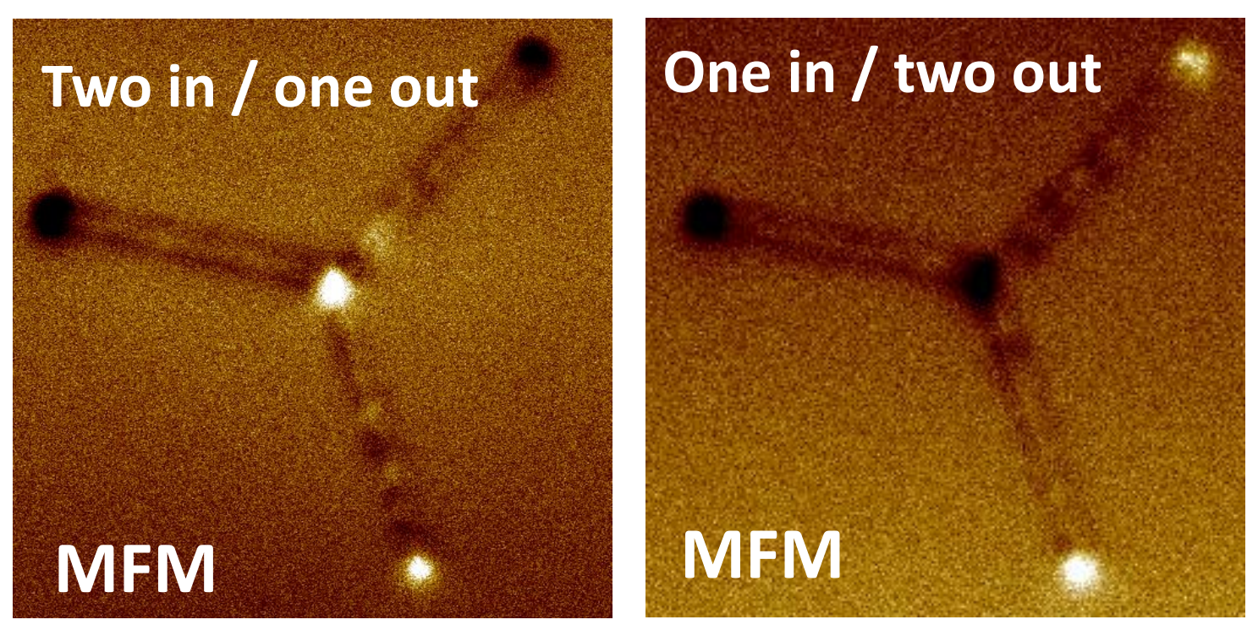
Possible rotation diagram:

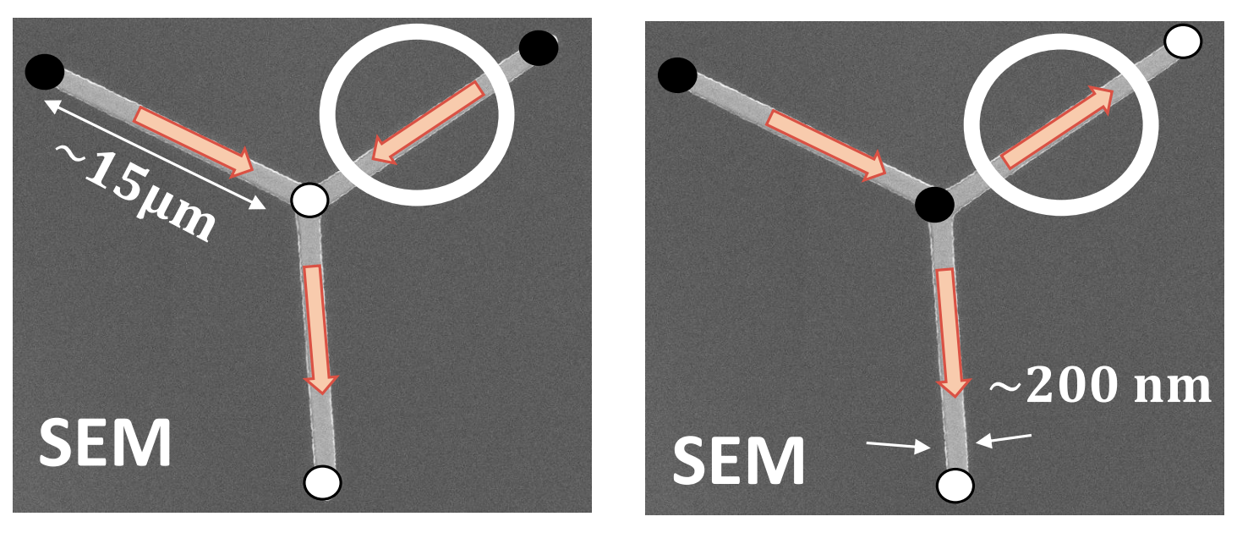


- ☐ Experimental variation in total resistance arising from the formation of Neel walls and topological charges
- ☐ Transport measurements can be used to determine the direction of magnetization with respect to the applied electric current as function of the magnetic field.

Y-Devices based on ASI

Different orientations of magnetic charges in "as grown" state

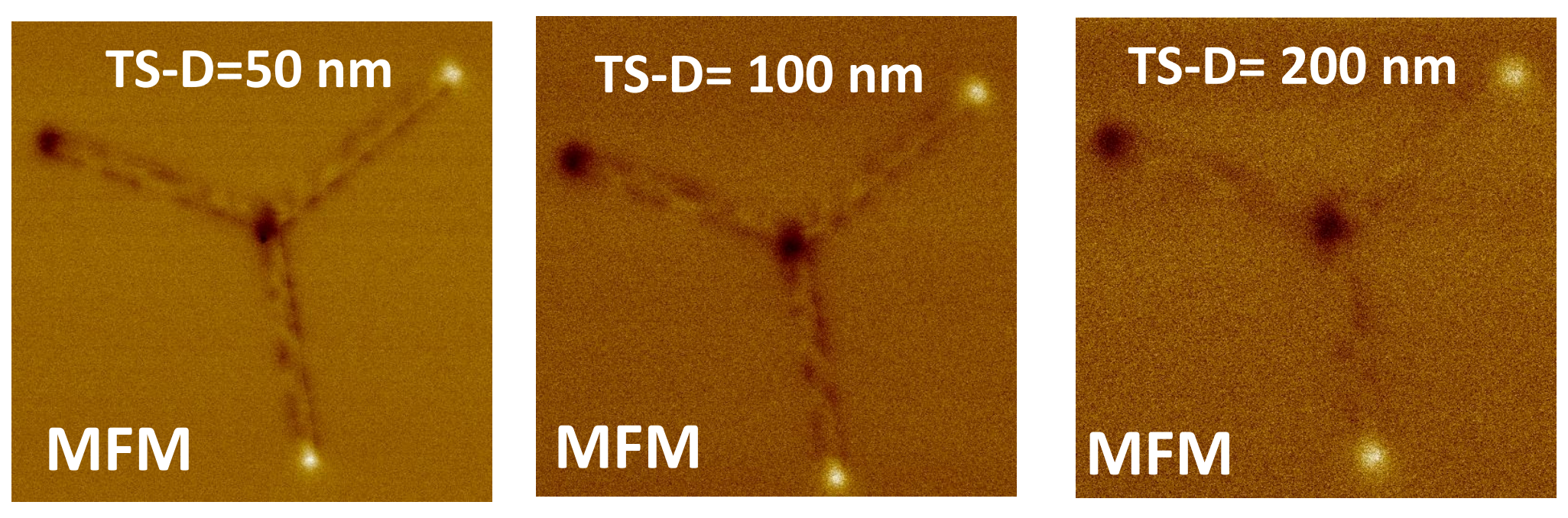




Y-Devices follow the pseudo spin ice rules!!

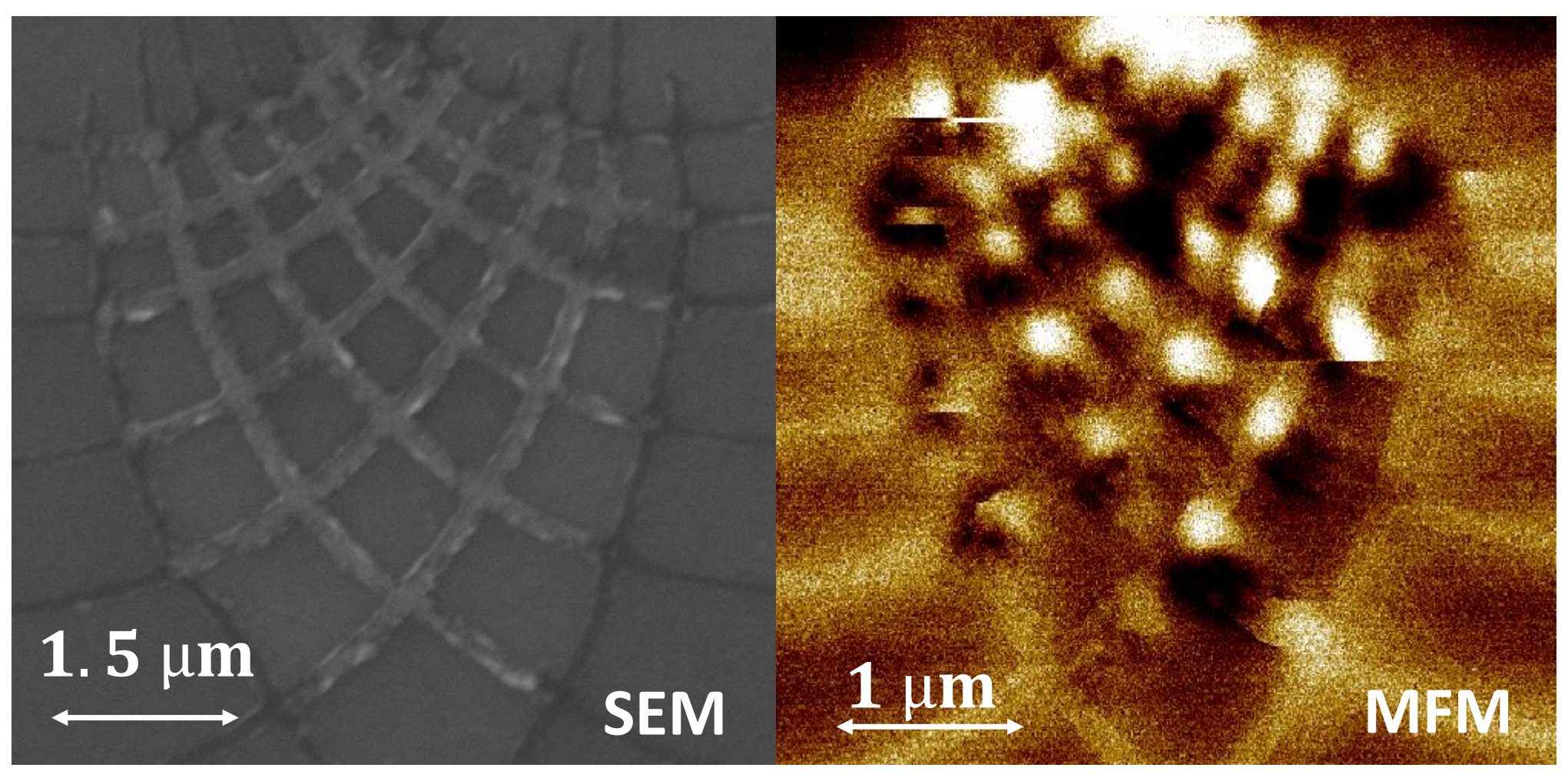
Topologically protected magnetic charges

- ☐ Same topological effects as honeycomb ASI
- ☐ Strong out of plane field. Magnetic charges are visible up to 200 nm high!!
- ☐ Open door for combination of Type II superconductor materials and ASI → Manipulation of SC vortices using new types of devices based on hybrid systems



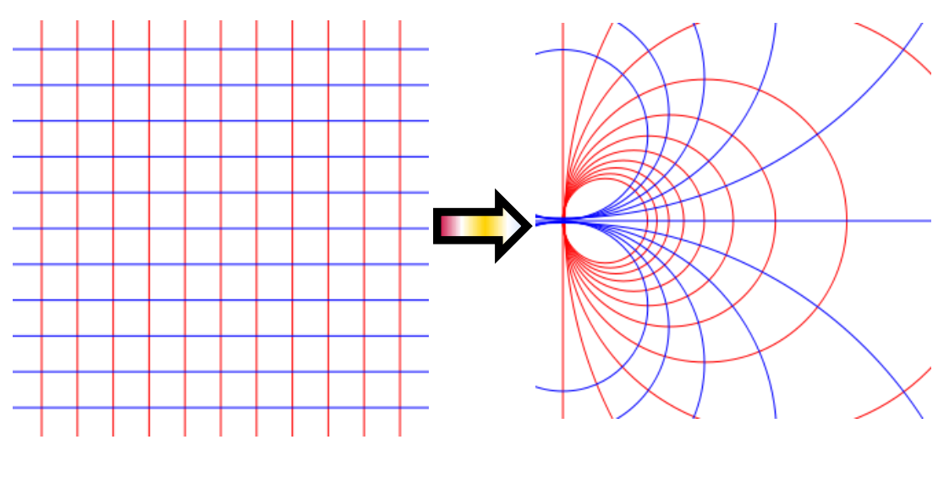
Conformal ASI

- ☐ Is it possible to make artificial spin ices by applying a conformal transformation?
- ☐ Will it maintain the topology of the system?



4 macrospins instead of 3 Now it is a Spin Ice
(no pseudo spin ice like the 3 previous geometries)

Möbius transformation



A coordinate grid prior to a Möbius conformal transformation

The distance between magnetics charges is variable but we still see topology

Next Steps

- ☐ Studying magnetotransport at different temperatures and in different geometries.
- ☐ Exploring the Planar Hall effect in ASIs.
- ☐ Enhancing our understanding of the irreversible magnetization process in the system and improving simulations

References

[1]Nisoli, C. et al.Rev. of Modern Physics 85 (2013)
[2] Tanaka *et al. Phys. Rev. B* 73 (2006)
[3] V. Rollano et al. Nanotechnology 30 (2019)

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