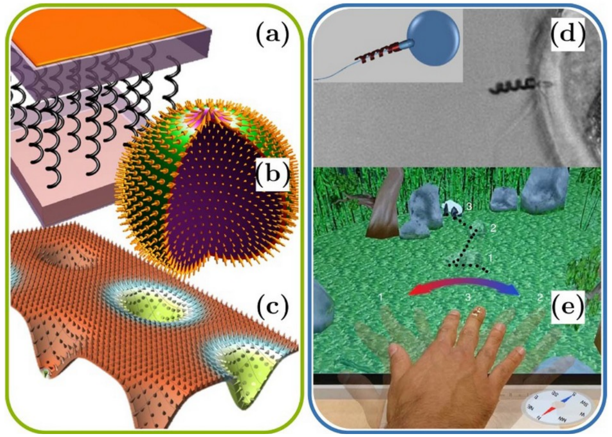
Domain wall tilt and pinning in CrO_x/Co/Pt corrugated strips

Jose A. Fernandez-Roldan, S. Shakeel, M. Quintana, O. Volkov, O. Pylypovskyi, E. S. Oliveros-Mata, C. Abert, D. Suess, F. Kronast, M.-A. Mawass, D. Erb and D. Makarov

Outline

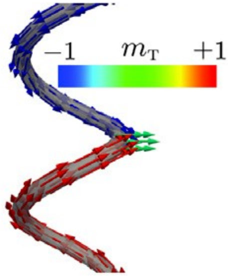
1. Introduction
2. Corrugated samples and PEEM
3. Modelling
4. Conclusions

Curvilinear phenomena and applications

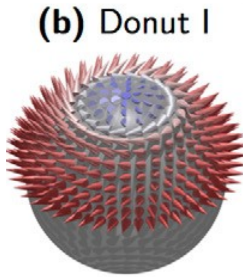


Effects leading to topological patterning

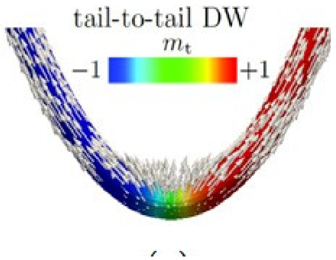
(1) Breaking of inversion and chiral symmetries



(2) Shape-induced patterning

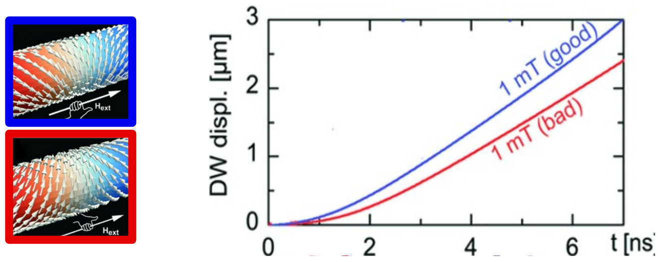


(3) Curvature-induced pinning

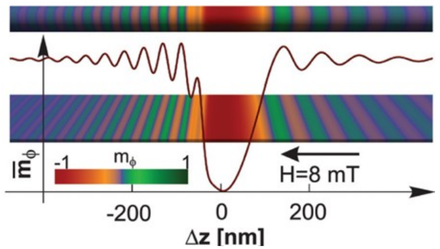


Magnetochiral effects

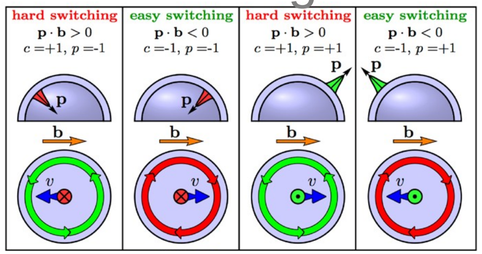
(1) Asymmetric propagation of chiral domain walls



(2) Asymmetric spin wave emission

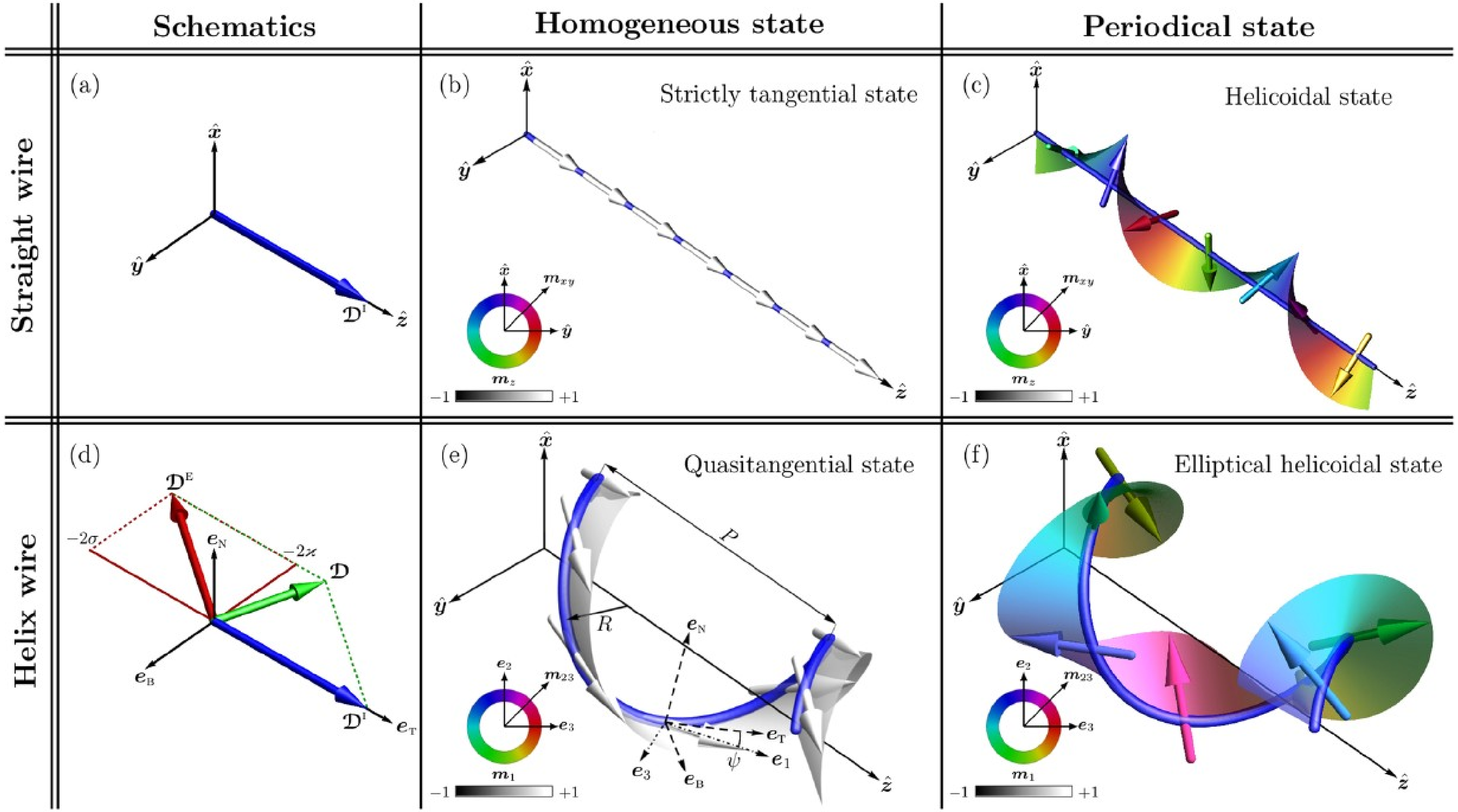


(3) Asymmetric core switching



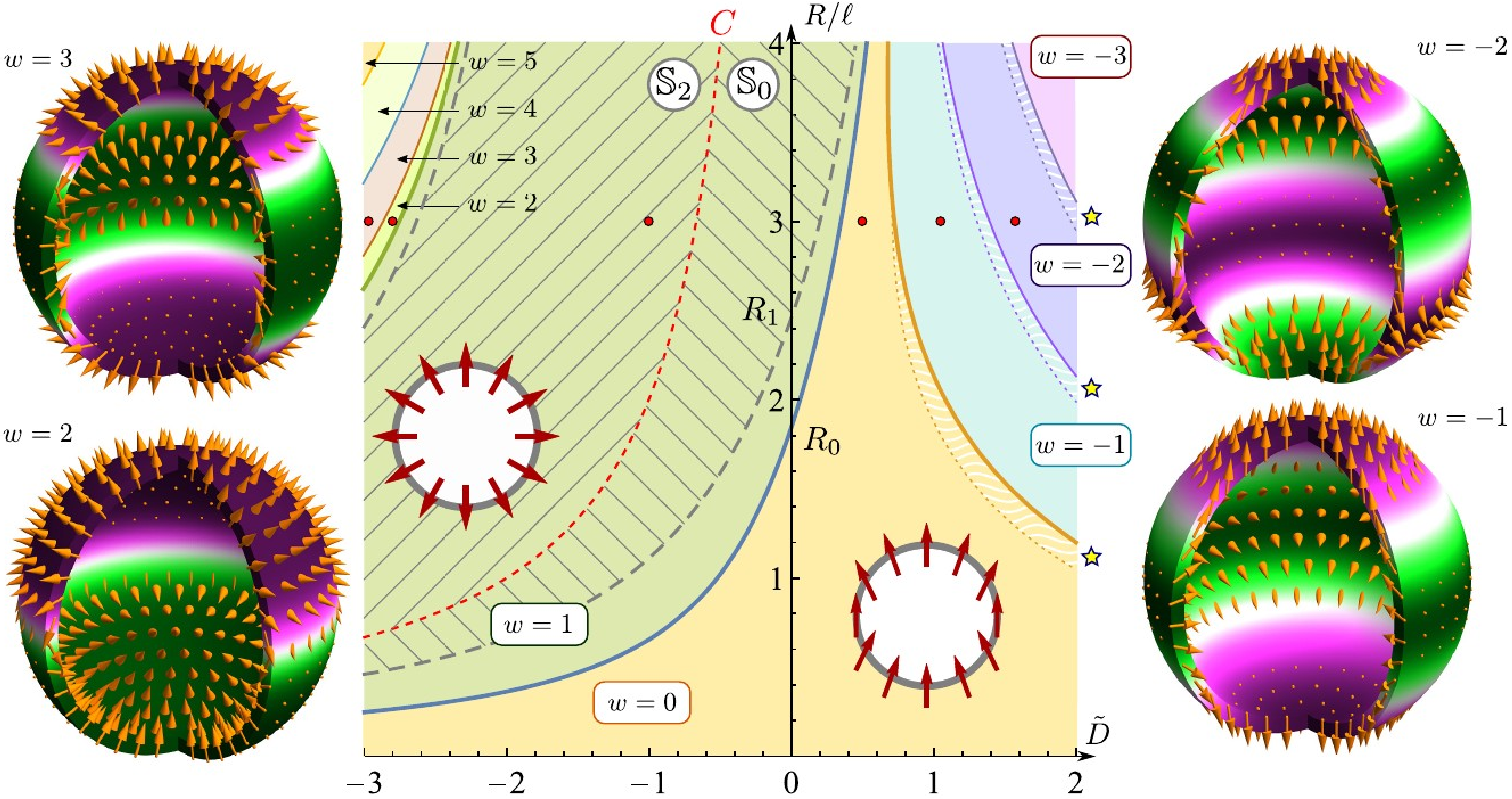
E. Y. Vedmedenko et al., J. Phys. D. Appl. Phys. 53, 453001 (2020).
R. Streubel et al. J. Phys. D. Appl. Phys. 49, 363001 (2016)
R. Hertel, SPIN 3, 1340009 (2013).

Intrinsic + curvature-induced DMI in nanowires



[Volkov et al, Sci. Rep. 8 (2018)]

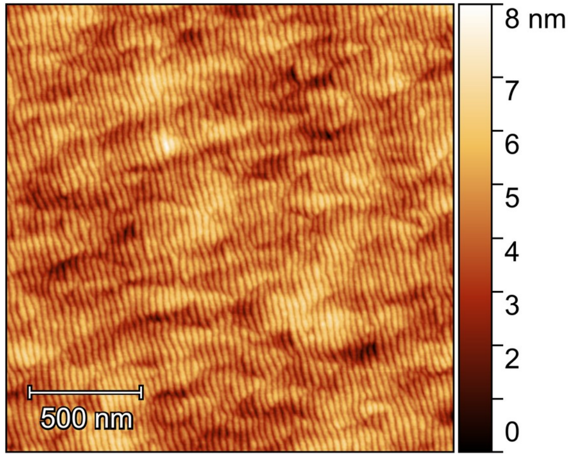
Intrinsic + curvature-induced DMI in shells



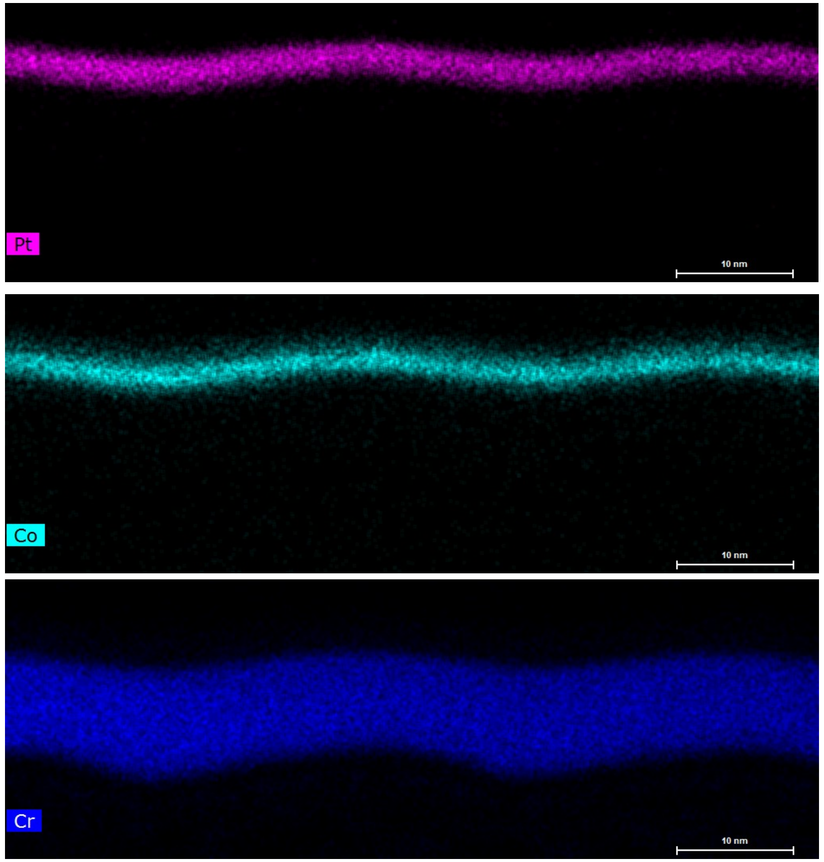
[Kravchuk et al, Phys. Rev. B 94 (2016)]

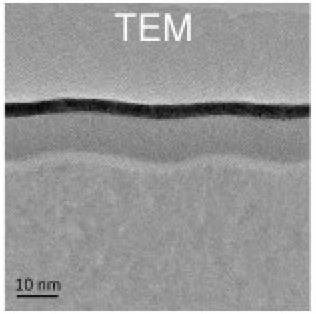
Corrugated Si/CrOx (5nm)/Co(1nm)/Pt (2 nm)

M-07_01



TEM M-07_01





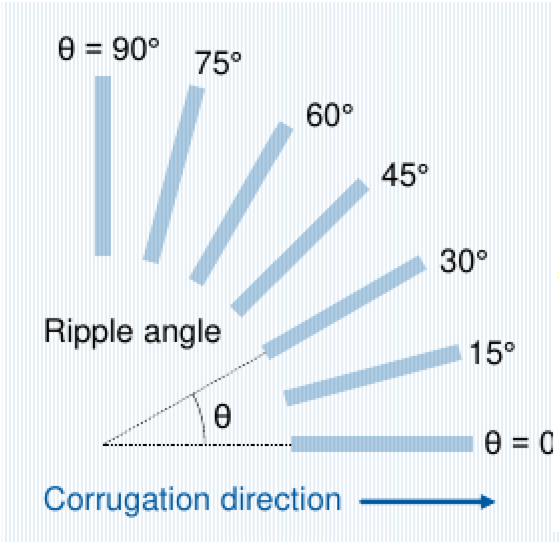
<u>**Si corrugated templates:**</u>
LEI instrument
Ion species: Ar+
Ion energy: 250 eV
Incidence angle: 45°, 48°, 50°

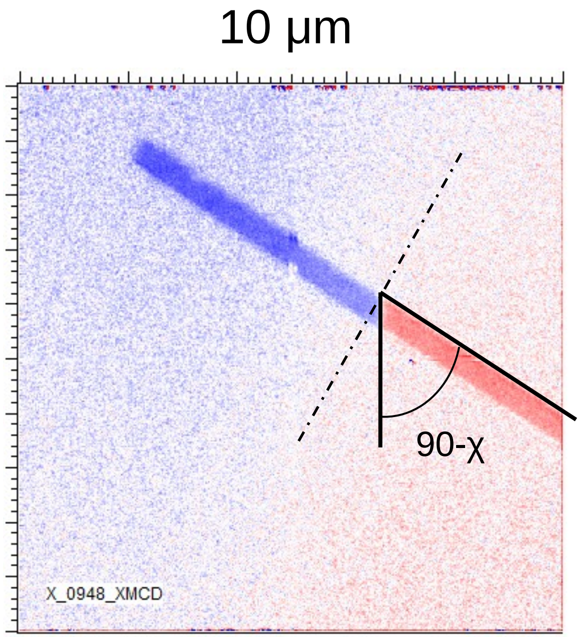
Nom. ion flux: 10^{15} $cm^{-2}s^{-1}$
Nom. ion fluence: 10^{18} cm^{-2}
No heating, with water cooling

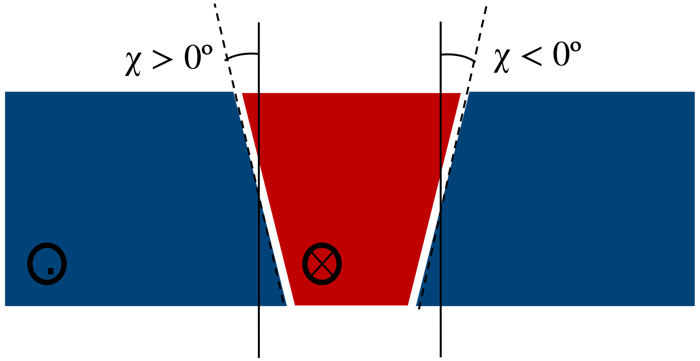
M-07_01: incidence of 45°

Sputter deposition with BESTEC at RT
Ar $8 \cdot 10^{-4}$ mbar
Si/CrOx (5 nm)/Co (1 nm)/Pt (2 nm)
P_{CrOx} = 100 W.
P_{Co} = 75 W.
P_{Pt} = 25 W

PEEM imaging at BESSY







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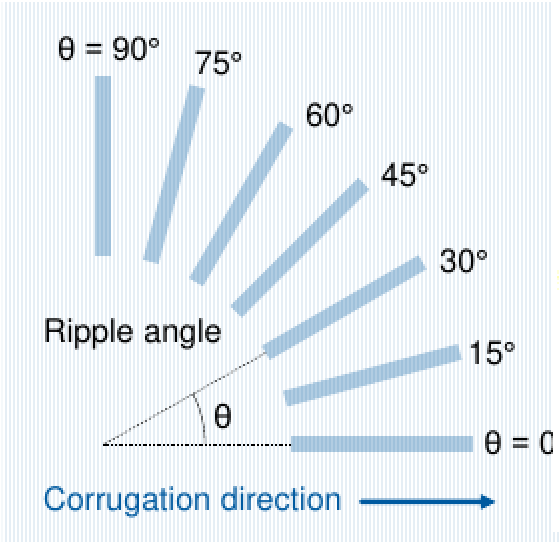
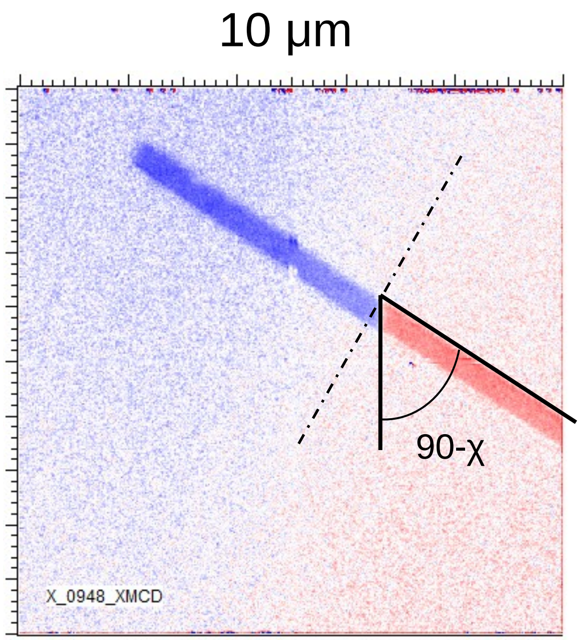
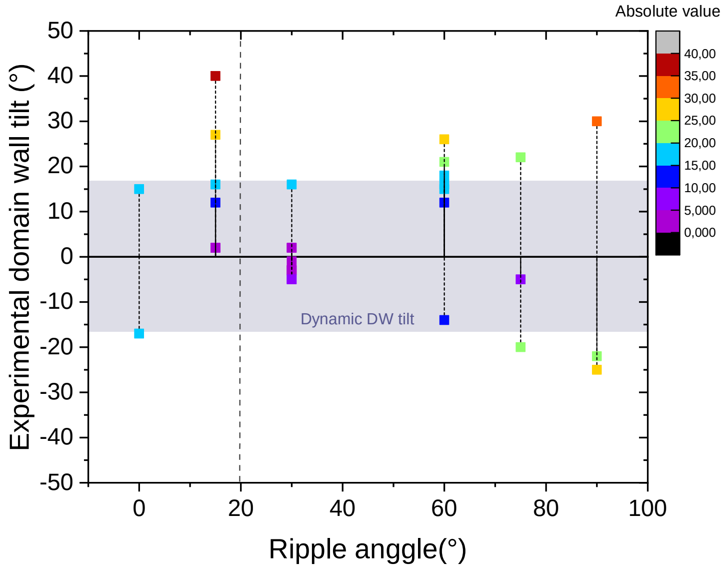


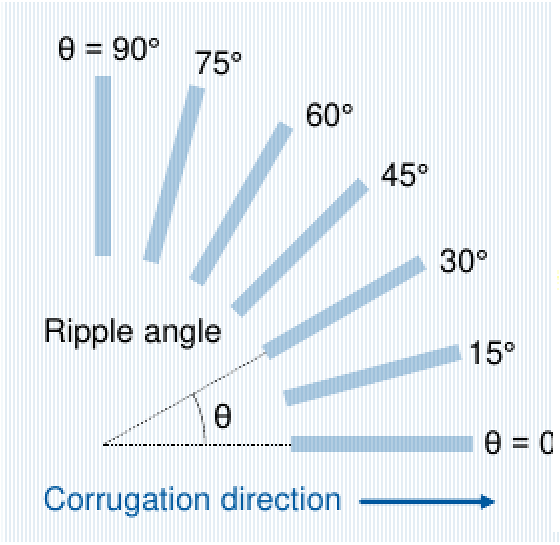


All the experimental values

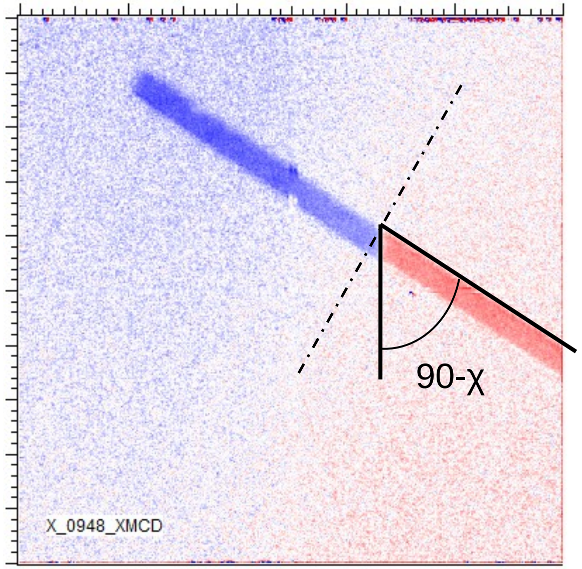


- The stabilization of a dynamic domain wall tilt of the Thiavielle model by means of granular defects explains only the experimental values in the grey region up to a maximum theoretical angle of 16º, according to the model in [O. M. Volkov et al., Phys. Rev. Applied 15, 034038 (2021)].
- However, angles over 16° cannot so be explained by this method. Our goal is to gain insight on the mechanism behind large tilts

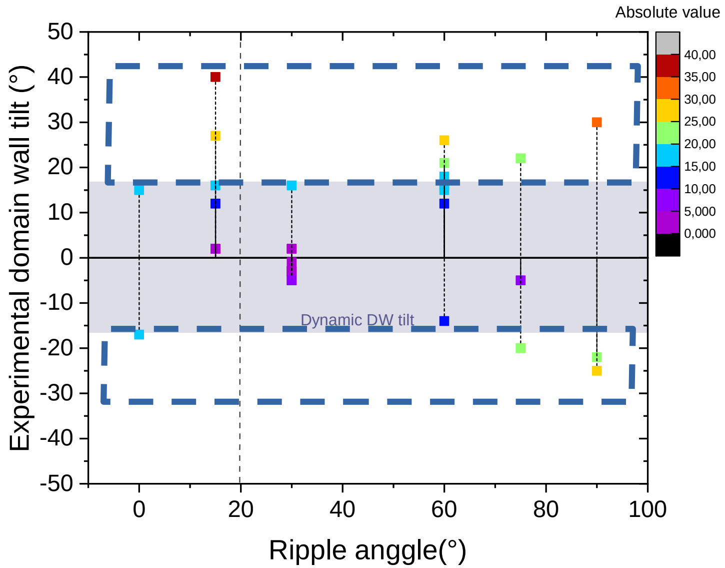
PEEM imaging at BESSY



10 µm



All the experimental values



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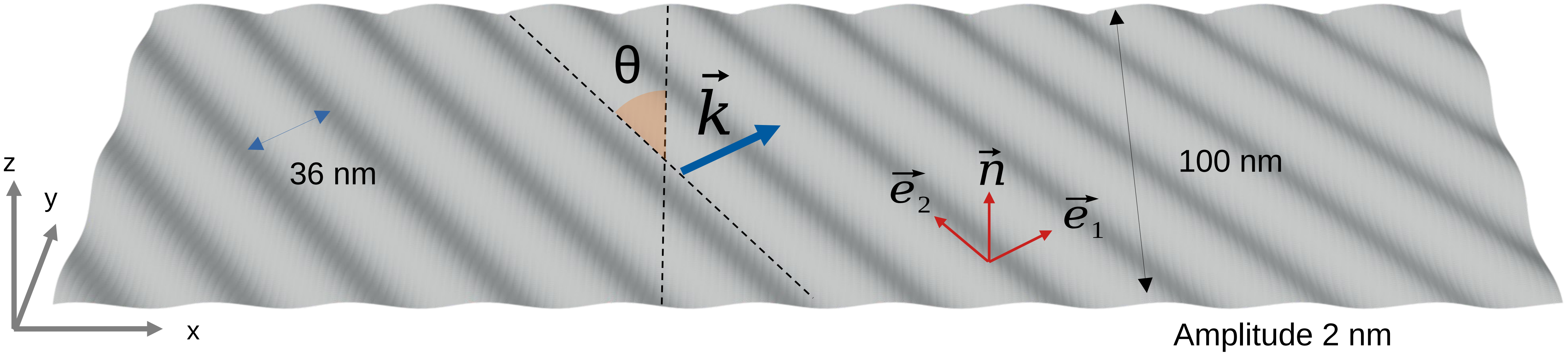
Geometry

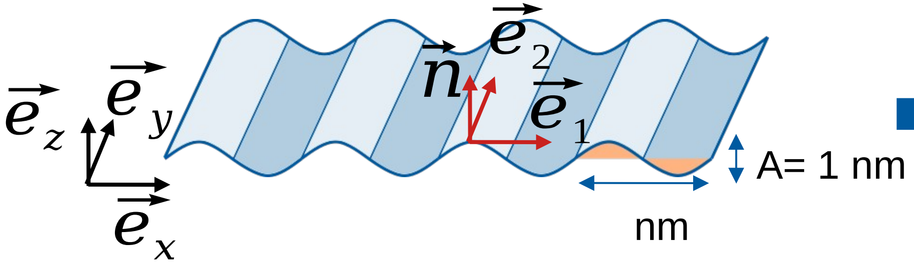
Si/CrOx (5nm)/Co(1nm)/Pt (2 nm)

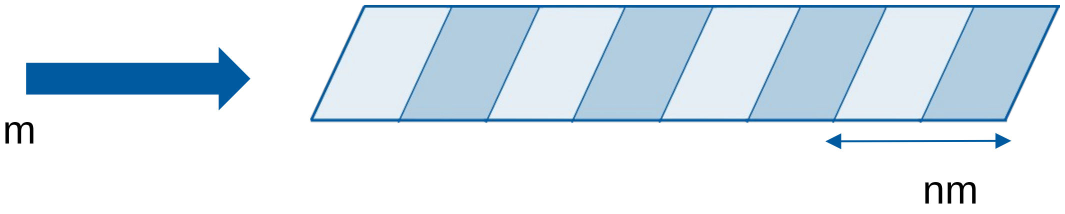


Maximum curvature of k_1=0.061 nm^{-1}

Curvilinear micromagnetic approach

Following a curvilinear approach in mumax3 in a flat stripe with dipolar interaction OFF.





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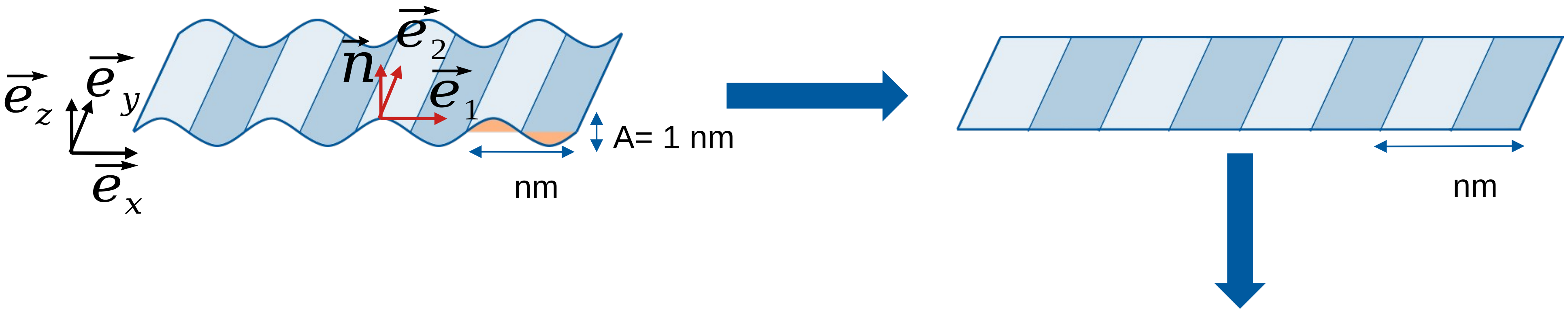


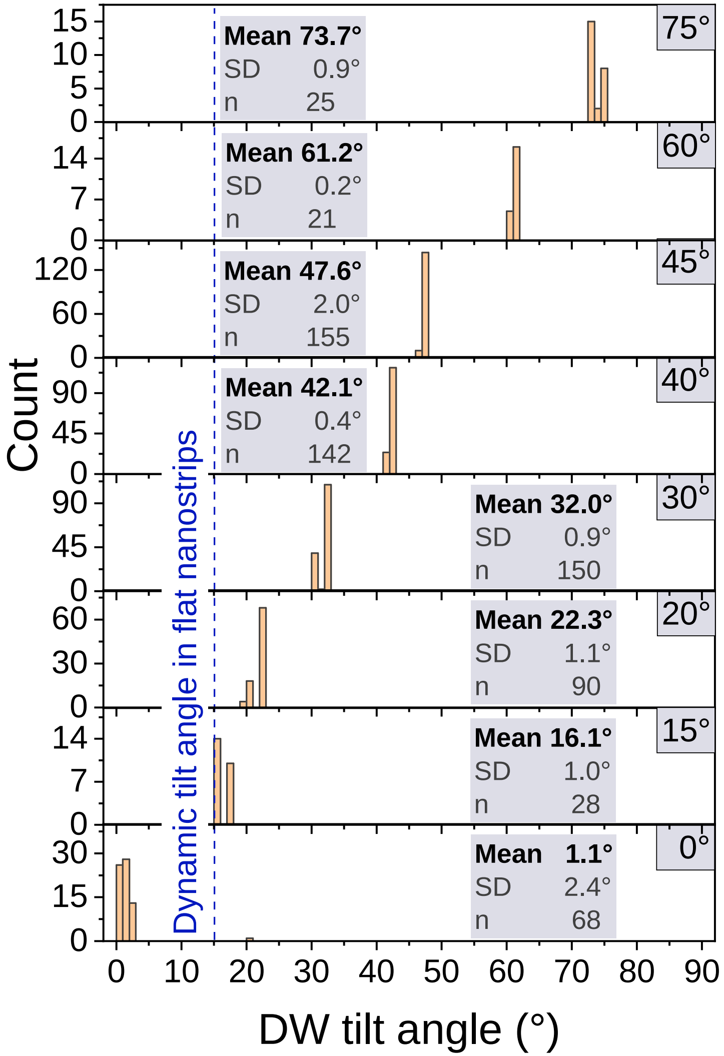
Curvilinear effects emerge as effective anisotropies and an additional exchange-induced DMI,

$$w_{ANIS}^{total} = (-K_{ex} - K_{rip})m_2^2 + (\mathrm{K_{DMI}} - K_3)m_n^2 - K_{1,shape}m_x^2; \qquad w_{DMI}^{ex} = 2A_{ex}k_1\left(m_1\frac{\partial m_n}{\partial x_1} - m_n\frac{\partial m_1}{\partial x_1}\right);$$

where

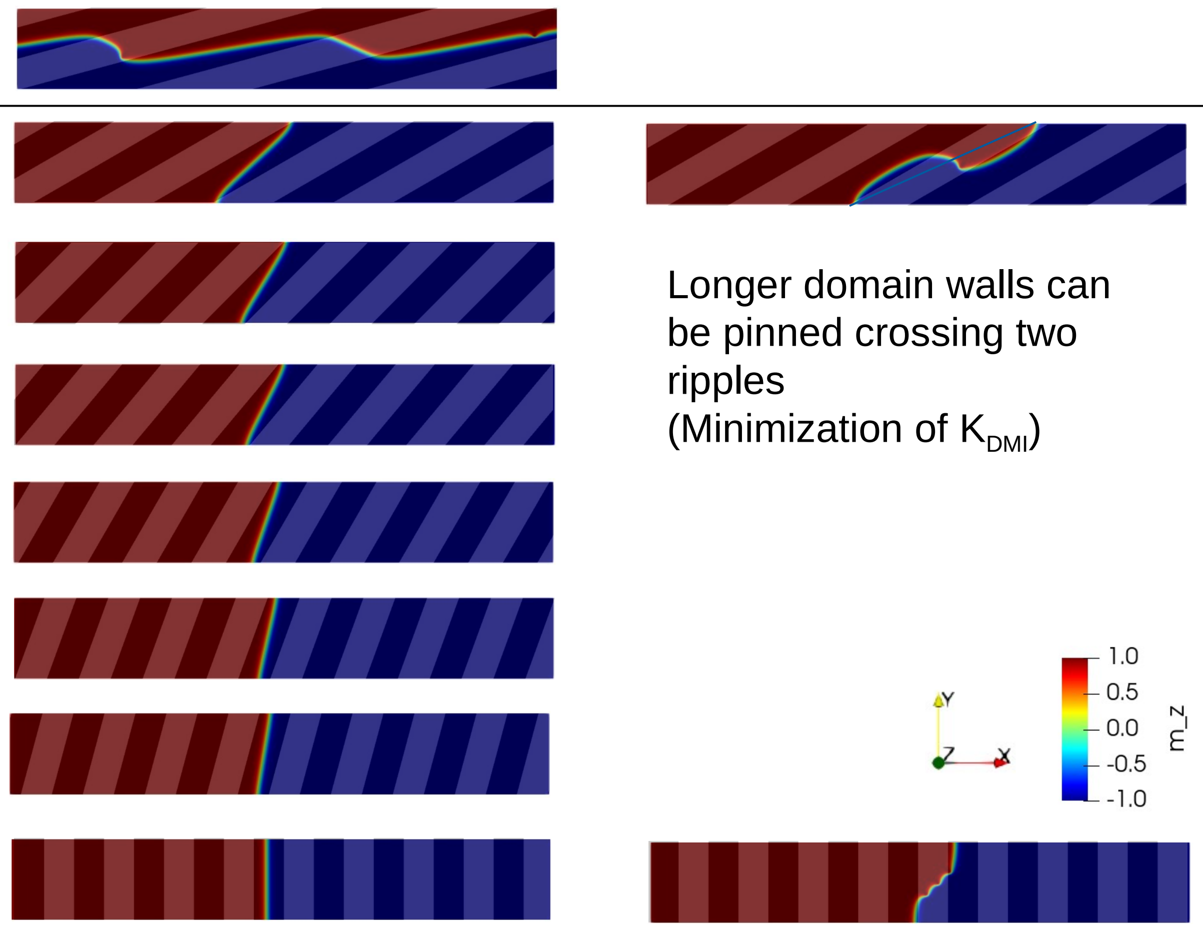
- k_1 is the curvature and A_{ex} the exchange stiffness.
- $K_{ex} = k_1^2 A_{ex}$, and $K_{DMI} = Dk_1$ are the exchange-induced and DMI-induced anisotropies, respectively.
- K_3, $K_{1,shape}$ and K_{rip} are the perpendicular anisotropy, the shape anisotropy and the intra-Ripple dipolar interaction.

Micromagnetic modelling of the Domain wall tilt vs. Ripple angle



DW examples

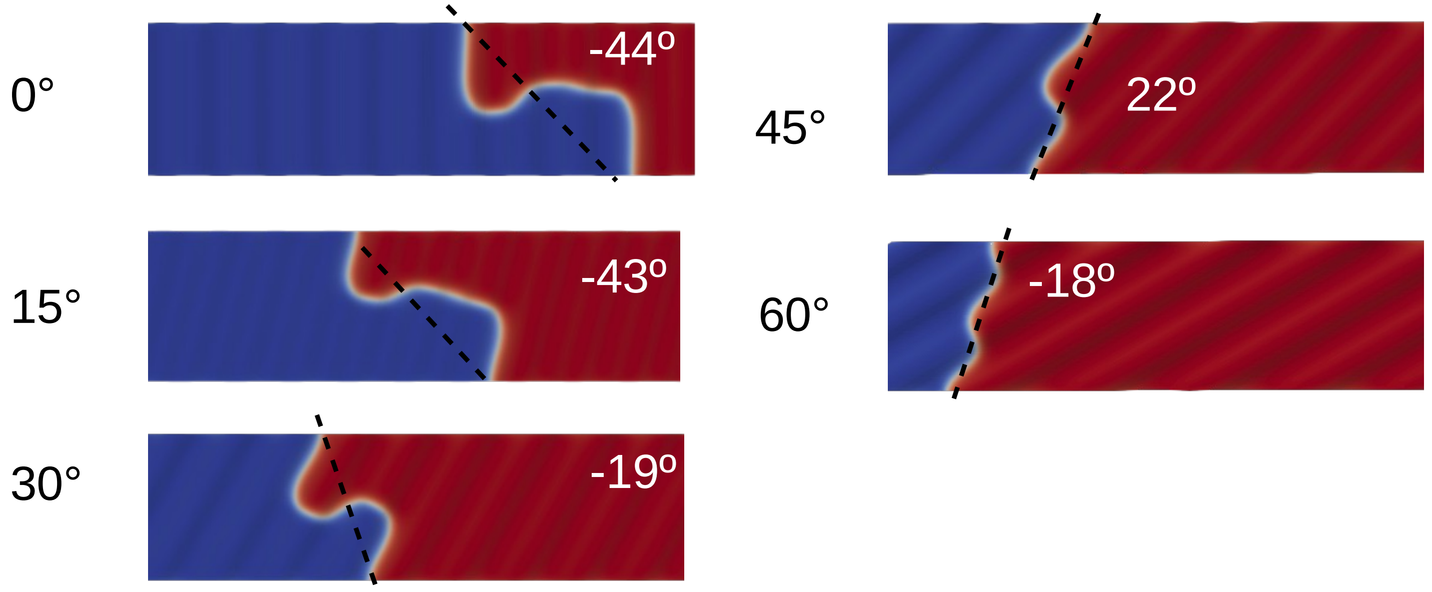
Other tilted domain walls



Longer domain walls can be pinned crossing two ripples
(Minimization of K_{DMI})

The role of intrawire dipolar interaction

Ripple angle **Example**

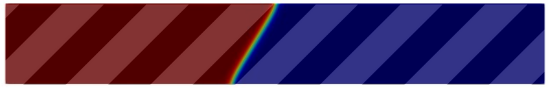


Micromagnetism modelling of domain wall tilts in a truly sinusoidal geometry leads to a complex landscape of domain wall tilts, that requires statistics for understanding the curvilinear mechanism behind.

Curvature effects in magnetostatics: [Sheka et al, Commun. Phys. 3 (2020)]

Conclusions

1. Micromagnetism modelling of domain wall tilts in a corrugated geometry leads to a complex landscape of domain wall tilts, that requires statistics for understanding the mechanism behind.
2. Relevant mechanisms of domain wall pinning:
   - Periodic variations of (intrinsic + curvature induced) DMI.
   - Spatially dependent anisotropic terms stemming from intrinsic DMI
   - Complex energy landscape induced by magnetostatics on ripples.

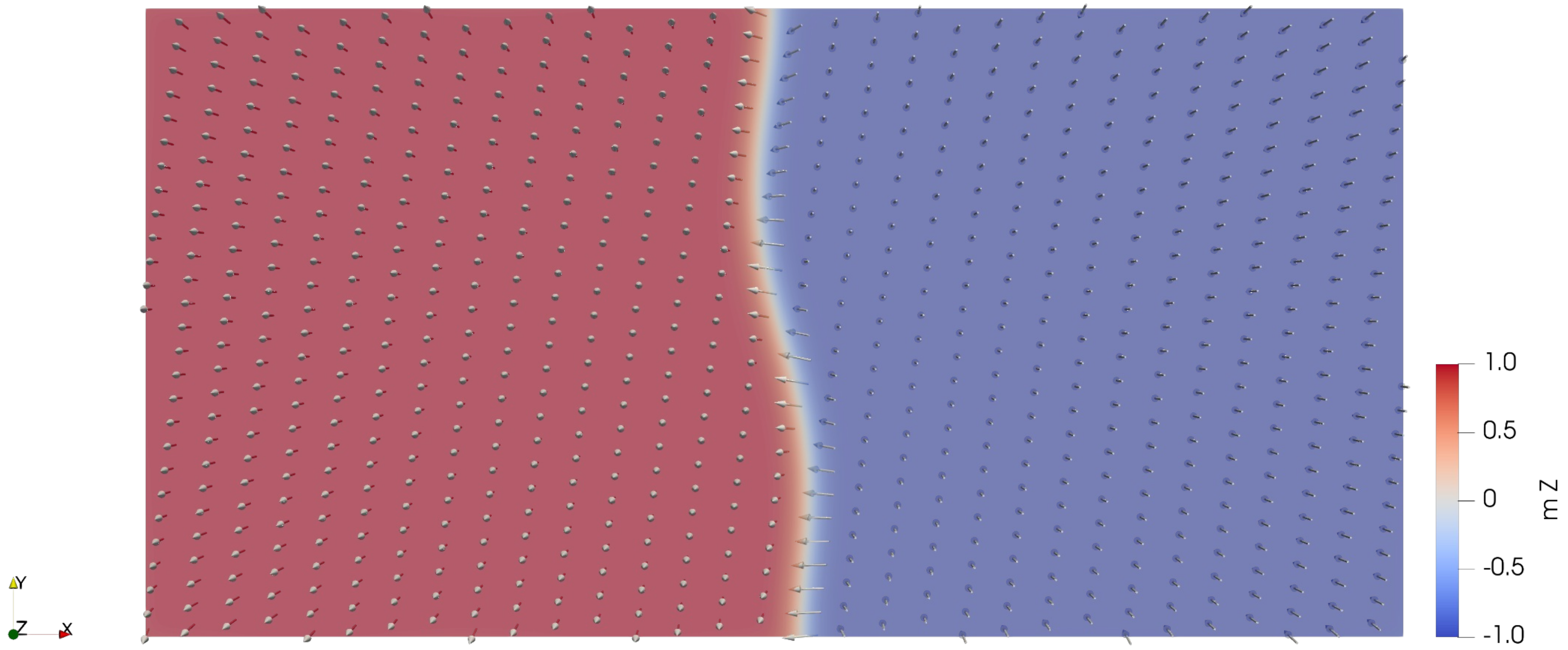


Acknowledgment

Thank you for your attention

Spin Lattice Simulator (SlaSi)

Second approach: Flat stripe with effective interactions



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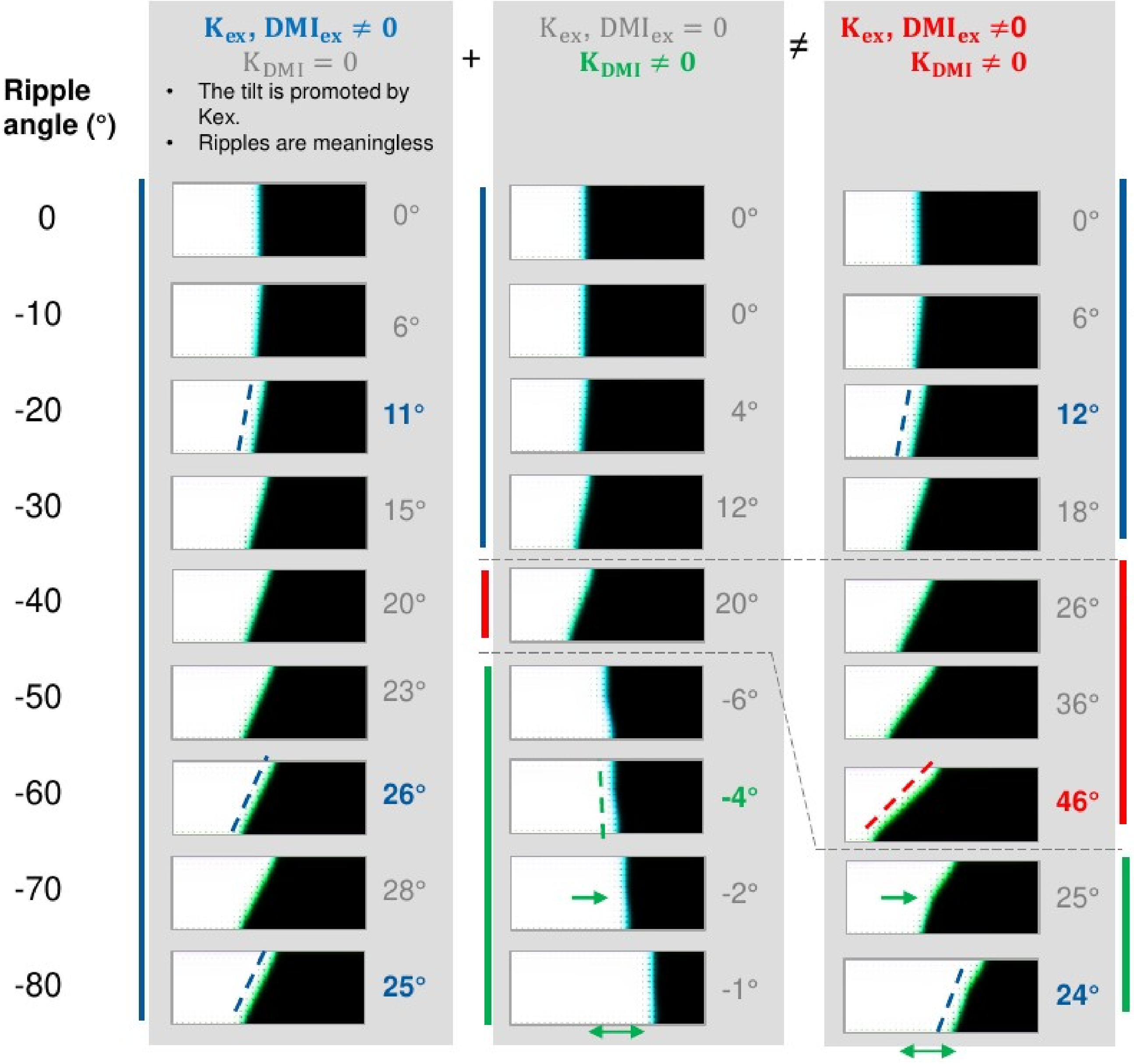


Exchange effects dominate the DW tilt

- $K_{DMI} \neq 0$ sets the pinning site

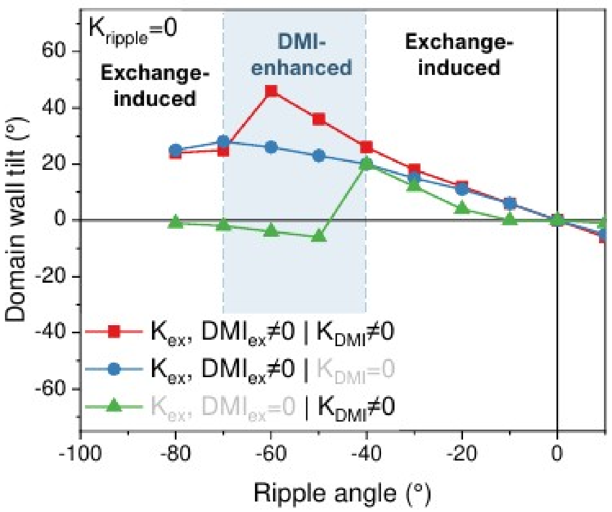
Exchange effects dominate the tilt. However, the DMI effect increases the tilt significantly

- The pinning is induced by $K_{DMI} \neq 0$ at inflexion points
- The DW is contained in a semi-ripple with positive curvature

Exchange effects dominate the DW tilt

- The pinning is induced by $K_{DMI} \neq 0$
- The DW crosses several ripples

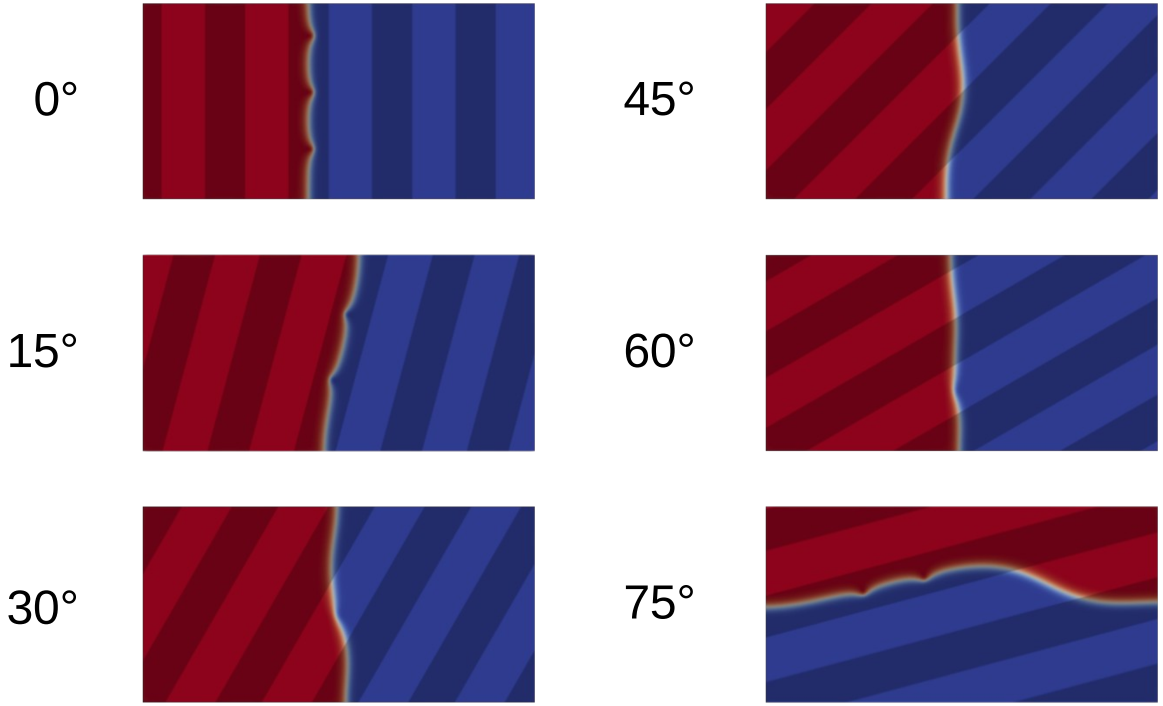
DW tilt vs. Ripple angle



SLaSi

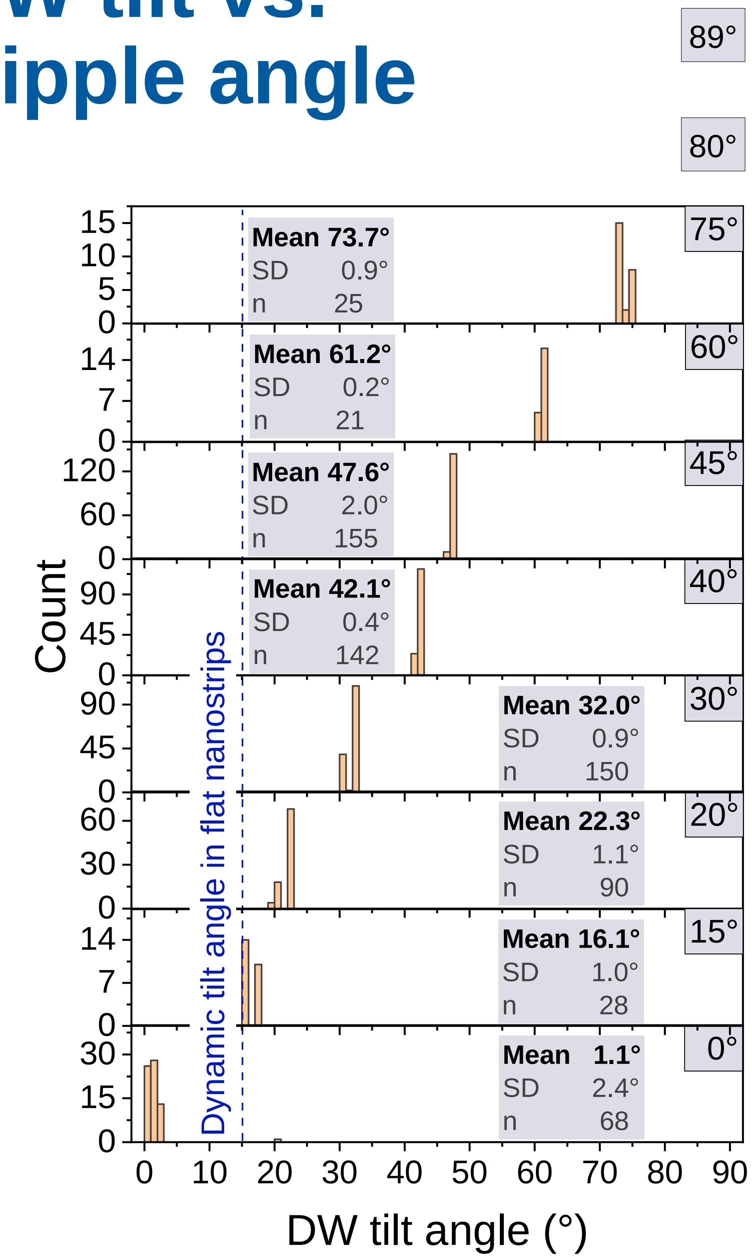
Second approach: A corrugated surface

Example

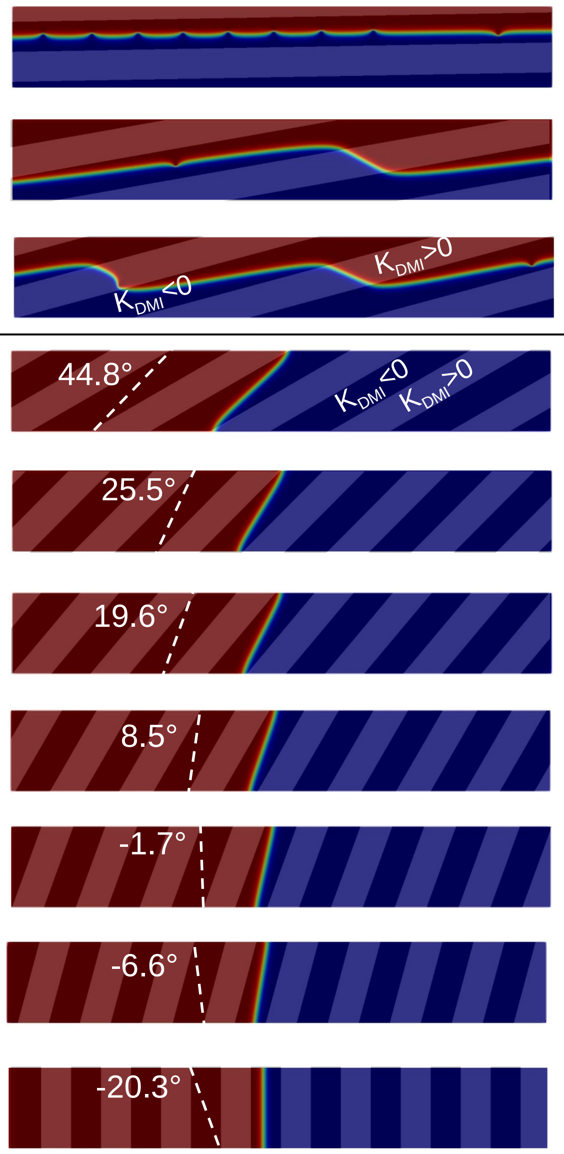


- Following a similar approach, we consider a flat stripe with effective curvilinear interactions and relax the system for different initial domain wall conditions in our home-made Spin Lattice System (SLaSi).
- SLaSi enables customizable interfacial DMI and anisotropies, including spatial gradients.
- SLaSi provides scale-free modelling in units of exchange length

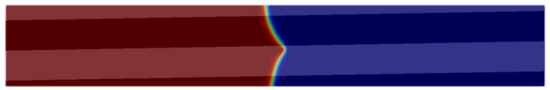
DW tilt vs. Ripple angle



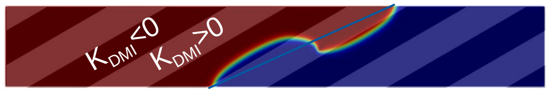
DW examples

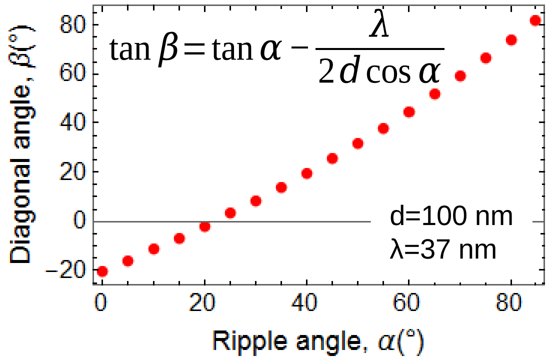


Other tilted domain walls



Long domain walls in the direction fo the ripple (Minimization of K_{DMI})





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