# Magnetostatic coupling between a ferromagnetic stripe and a skyrmion inscribed in a nanodot

Mathieu Moalic[1], Mateusz Zelent[1], and Maciej Krawczyk[1]

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## Introduction

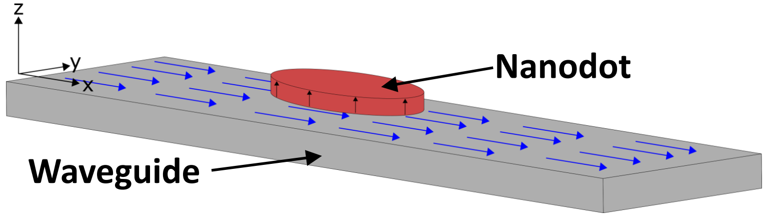


*Figure 1: The waveguide (WG) and the nanodot (ND), separated by a vacuum layer, the system used in micromagnetic simulations.*

- Micromagnetic simulations are used to study the system in Fig (1).
- Variations of the system are also studied for different Dzyaloshinskii-Moriya Interaction (DMI) values or different waveguide shapes

## Demagnetization Field

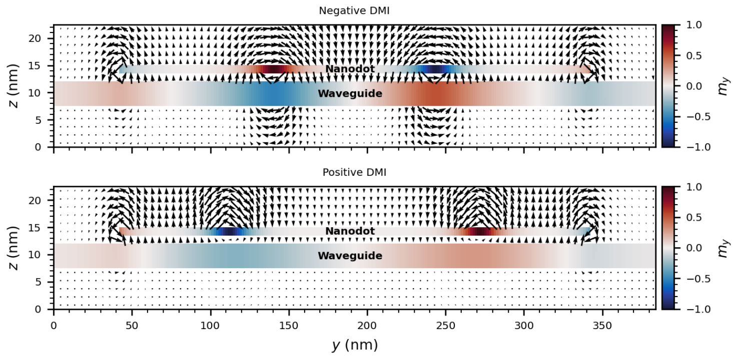


*Figure 2: A cross-section in the middle of the system. The arrows represent the demagnetization field created by the magnetization from the Nanodot and Waveguide.*

- The demagnetization field is the result of the magnetization of the skyrmion
- The field is much stronger on one side of the nanodot than on the other, this is due to the Halbach effect
- We can control this effect by changing the sign of the DMI
- It results in different *imprint* strengths inside the waveguide

## Method

- Simulations using Mumax3 [1]
- The system can function with several combinations of magnetic materials
- The waveguide has to be ferromagnetic and present a low enough damping so that the SWs can propagate over a significant distance, which is why Permalloy is an ideal candidate having one of the lowest Gilbert damping [2]
- The waveguide is magnetically saturated along its length and is separated from the nanodot by a spacer of 1.5 nm
- There are absorbing boundary conditions at its edge both extremities to avoid any kind of back-propagating SWs.
- The nanodot must have a specific geometry and size, as it requires a strong enough interfacial DMI to allow for the formation of a skyrmion
- For this reason, the nanodot is made of Pt/Co/Ir circular layers with a diameter of 300 nm to create a strong shape anisotropy which allows the presence of a metastable state such as a skyrmion in its core.
- The shape of the waveguide is the only variable in the different systems

## Dependence on DMI

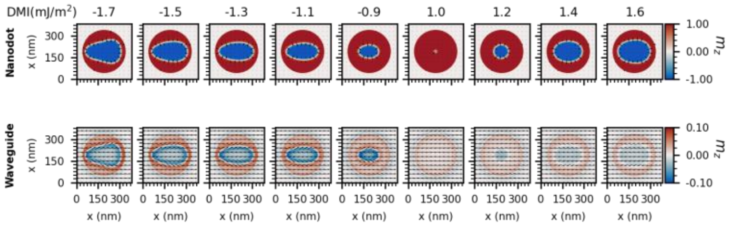


*Figure 3: Skyrmion dependence on the value of the Interfacial Dzyaloshinskii-Moriya interaction in the Nanodot.*

- When relaxing this system, an imprint of the skyrmion is created in the waveguide, meaning the magnetization below the nanodot will deviate from their saturated magnetization along the x axis because of the dipolar coupling with the skyrmion
- Only the range of DMI values for which the skyrmion is stable is shown here.
- For a negative DMI, the shape of the skyrmion is much more elliptic than circular compare to the positive values
- This is due to the much stronger coupling with the waveguide
- For the same reason, the waveguide is greatly affected by the nanodot and its magnetization deviates strongly from its position on the originally saturated *x*-axis

## Dependence on the waveguide shape

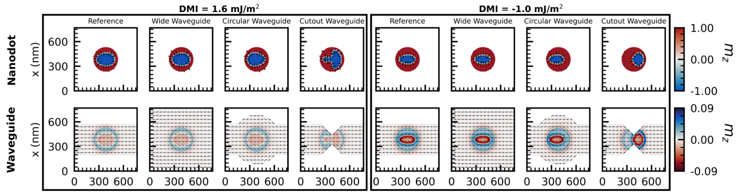


*Figure 4: Skyrmion dependence on the shape of the waveguide with which it is coupled. The comparison is done both with a positive and a negative value of the DMI.*

- Simulations are repeated for 4 shapes of waveguides for both a positive and negative value of the DMI ( 1.6 and -1.0 mJ/m$^2$)
- The wide waveguide has a width of 768 nm which is twice that of the reference with a coupling that is similar
- The circular waveguide has a lot of complexity arising for it's inability to be fully saturated along the *x*-axis
- Magnetization tends to follow along the edge of the waveguide which in the case of the *cut-out* waveguide creates a strong demagnetization field with diagonal directions

## Conclusion

- This static study has shown a great potential for negative DMI skyrmions as the very strong coupling could result in equally strong generated wavelengths
- Alternating the shape of the waveguide is a convenient way to tune the coupling which can give us a very customized system

## References

[1] Vansteenkiste, Arne, et al. "The design and verification of MuMax3." *AIP advances* 4.10 (2014): 107133.
[2]: Zhao, Yuelei, et al. "Experimental investigation of temperature-dependent Gilbert damping in permalloy thin films." Scientific reports 6 (2016): 22890.

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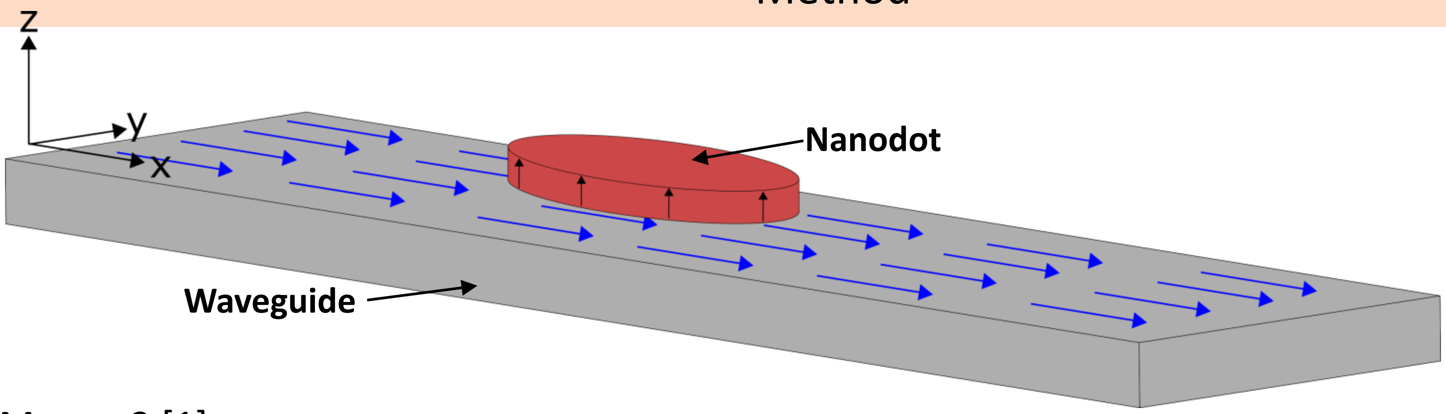


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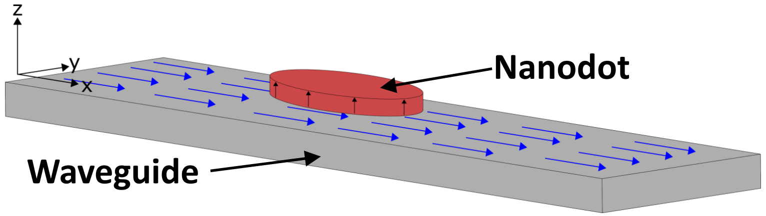


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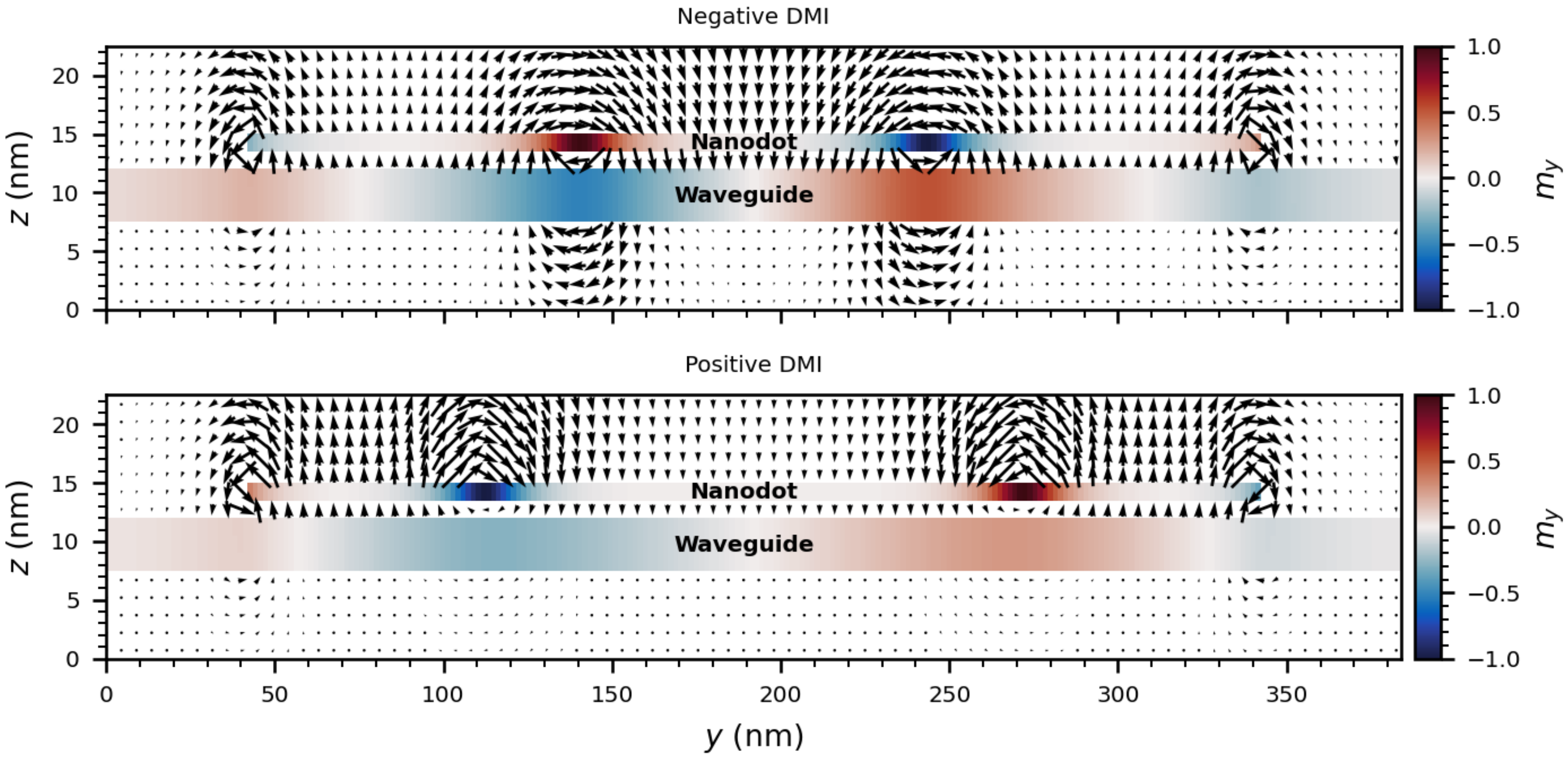

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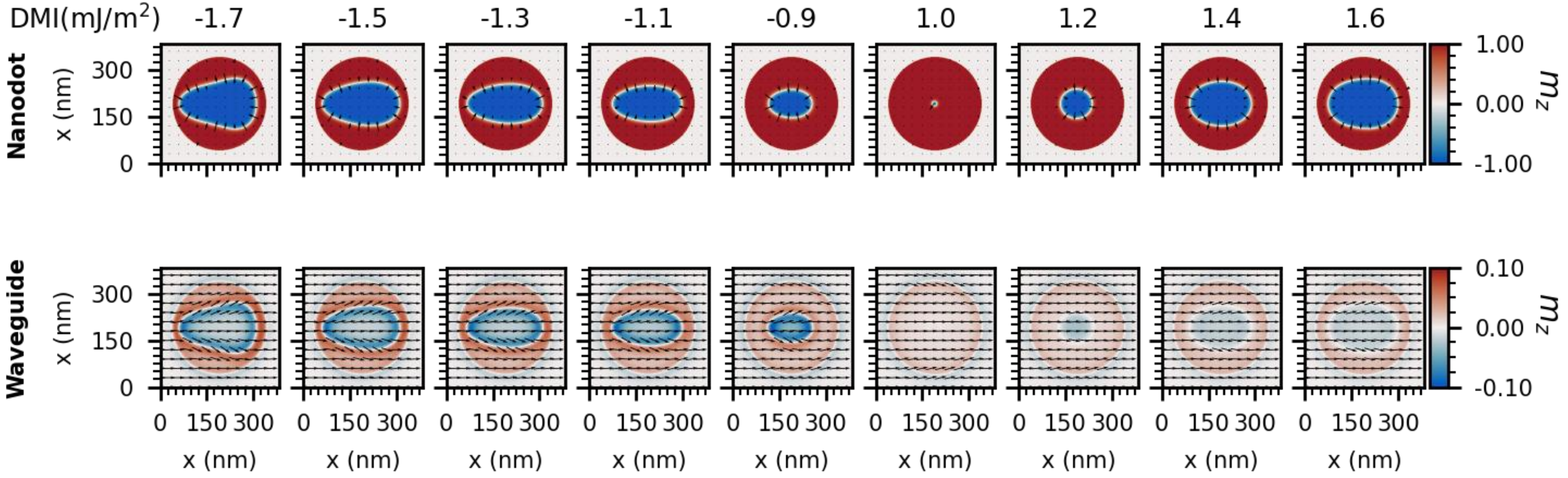


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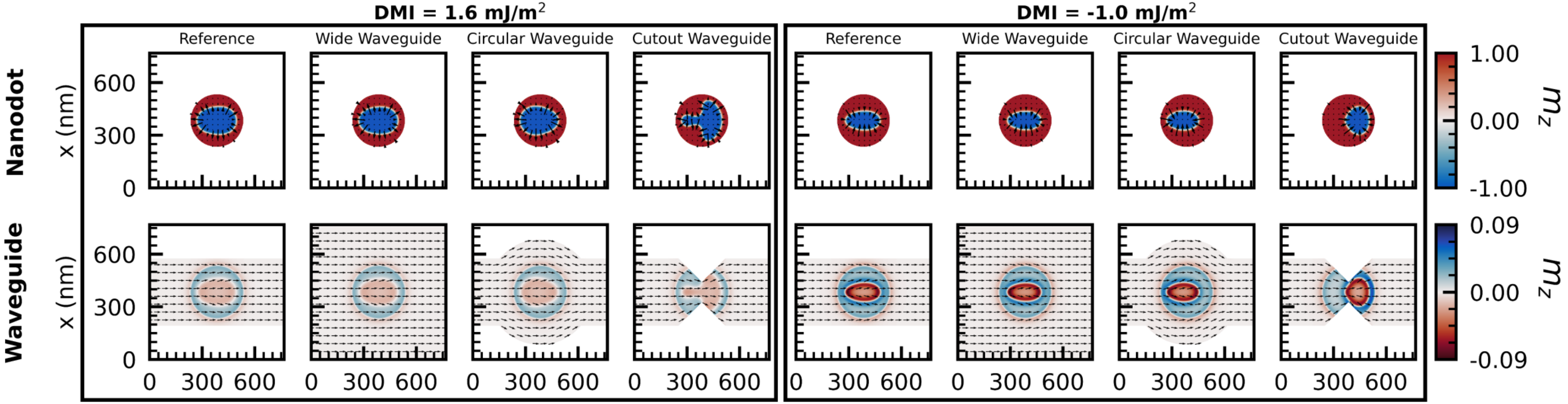


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