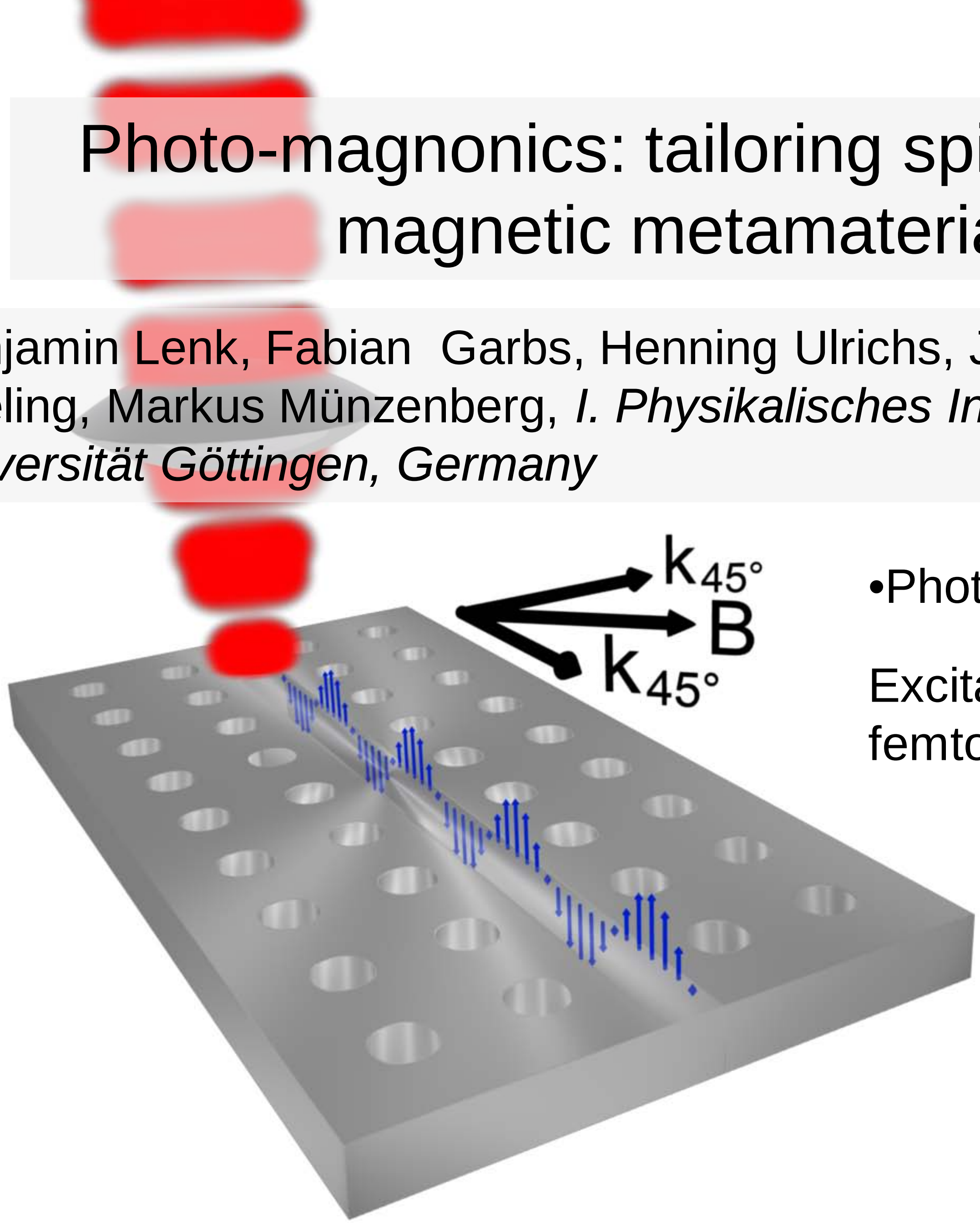
Photo-magnonics: tailoring spin-waves in magnetic metamaterials

Benjamin Lenk, Fabian Garbs, Henning Ulrichs, Jelena Panke, Nils Abeling, Markus Münzenberg, *I. Physikalisches Institut, Georg-August-Universität Göttingen, Germany*

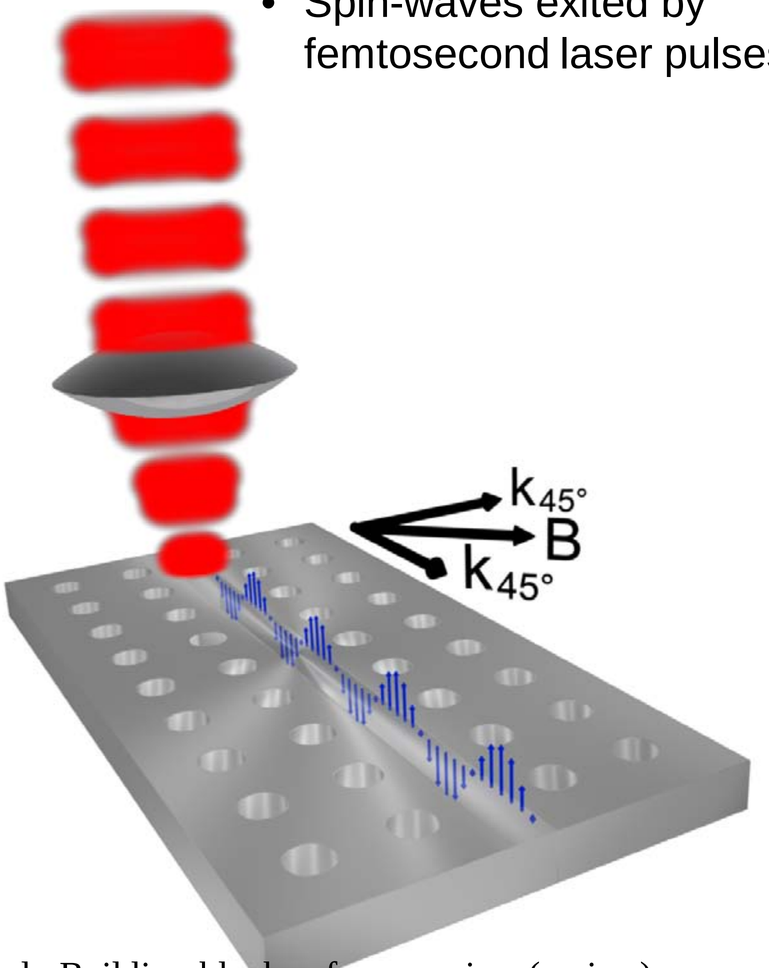


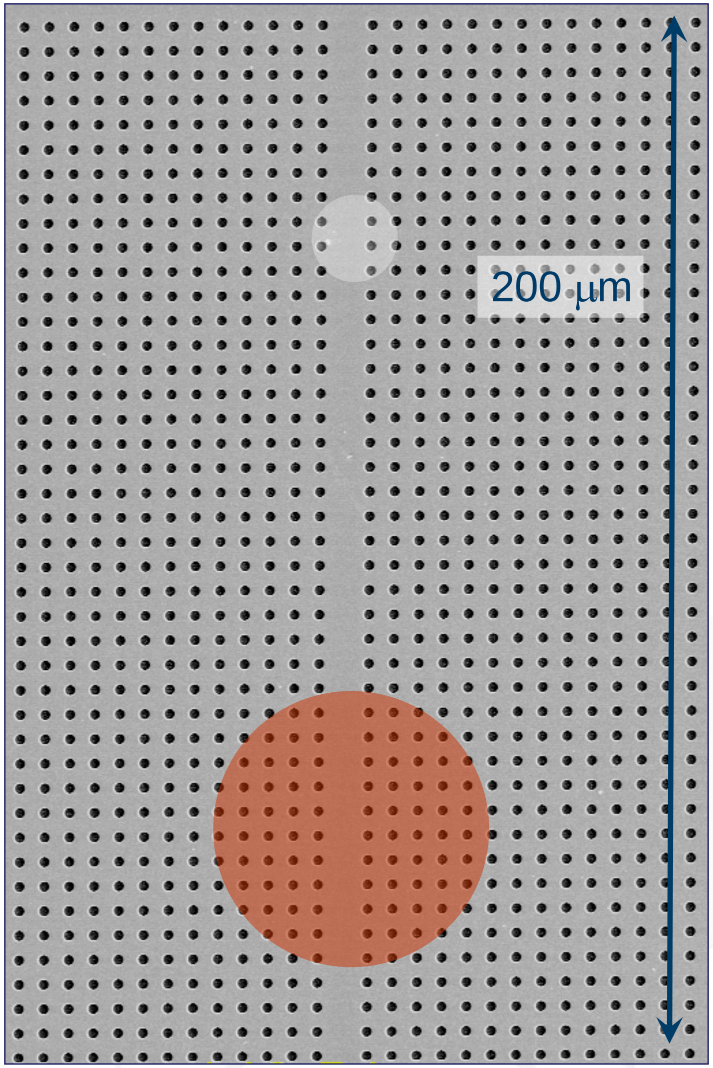
•Photo-magnonics:

Excitation of spin waves by femtosecond laser pulses

Photo-magnonics: magnonic spin-wave guides

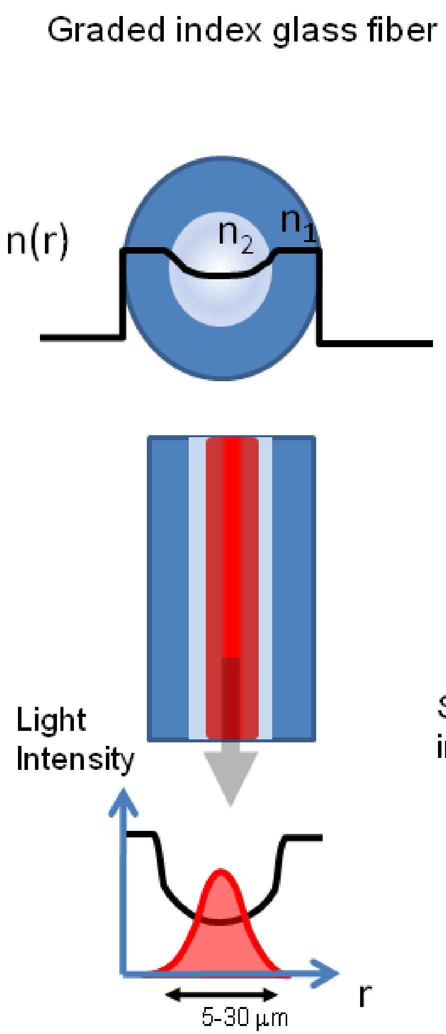
- Spin-waves exited by femtosecond laser pulses

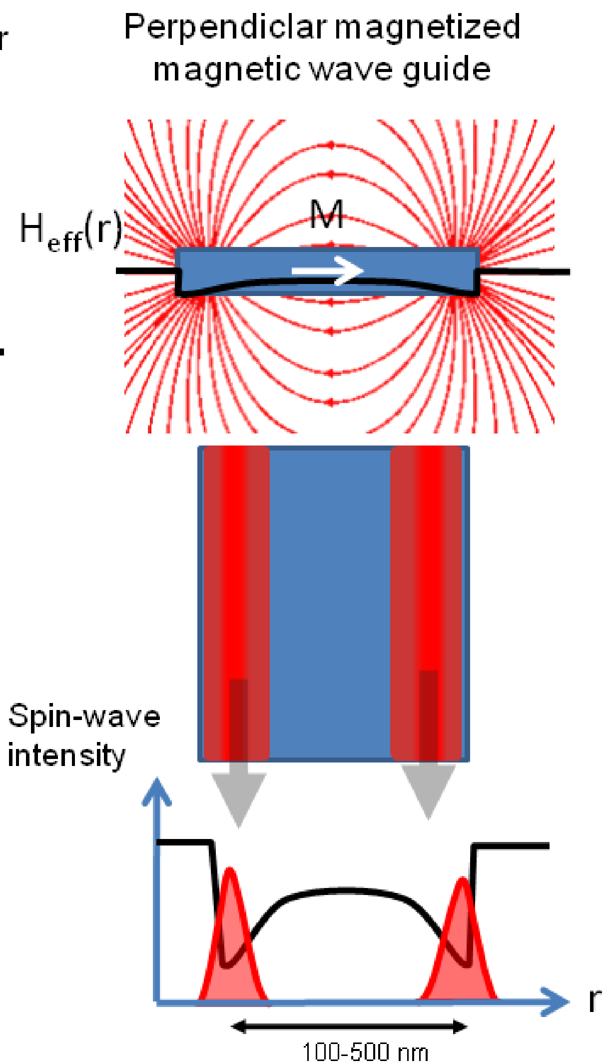


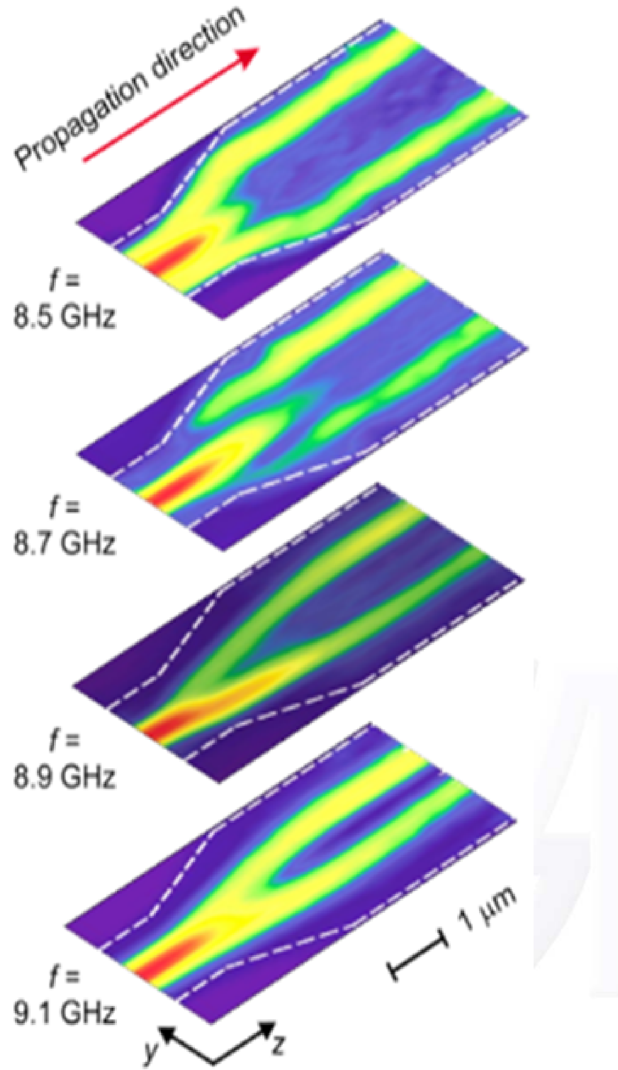


B. Lenk et al., Building blocks of magnonics (review)
Physics Reports, advance online

Optical vs. magnetic wave guide







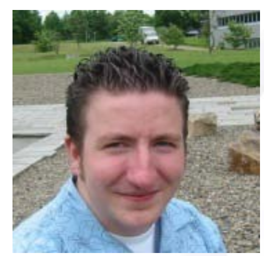
Demidov et al, PRB**79**, 054417 (2009)

People who do the work

Benjamin Lenk

Jakob Walowski

Diploma: Andreas Mann (now EPFL), Henning Ulrichs (now Münster), Fabian Garbs



Marvin Walter

…. + Valdislav Zbarsky

Bachelor students:

Martin Lüttich, Christian Leutenantsmeyer, Jelena Panke, Nils Abeling, Mirco Marahrens, Anissa Zeghuzi

Deutsche Forschungsgemeinschaft DFG

Priority program SpinCaT

einzelnes Atom SFB 602 Kondensierte Materie
mikroskopisch makroskopisch
1nm 1μm

Outline

- Photoexcitation of spin waves
- Spin-wave dispersion:
    - nm length scales – exchange
    - μm length scales – dipole
- Metamaterials basics
- Application
    - Zone boundary Bloch states
    - Spin-wave localization
- Summary

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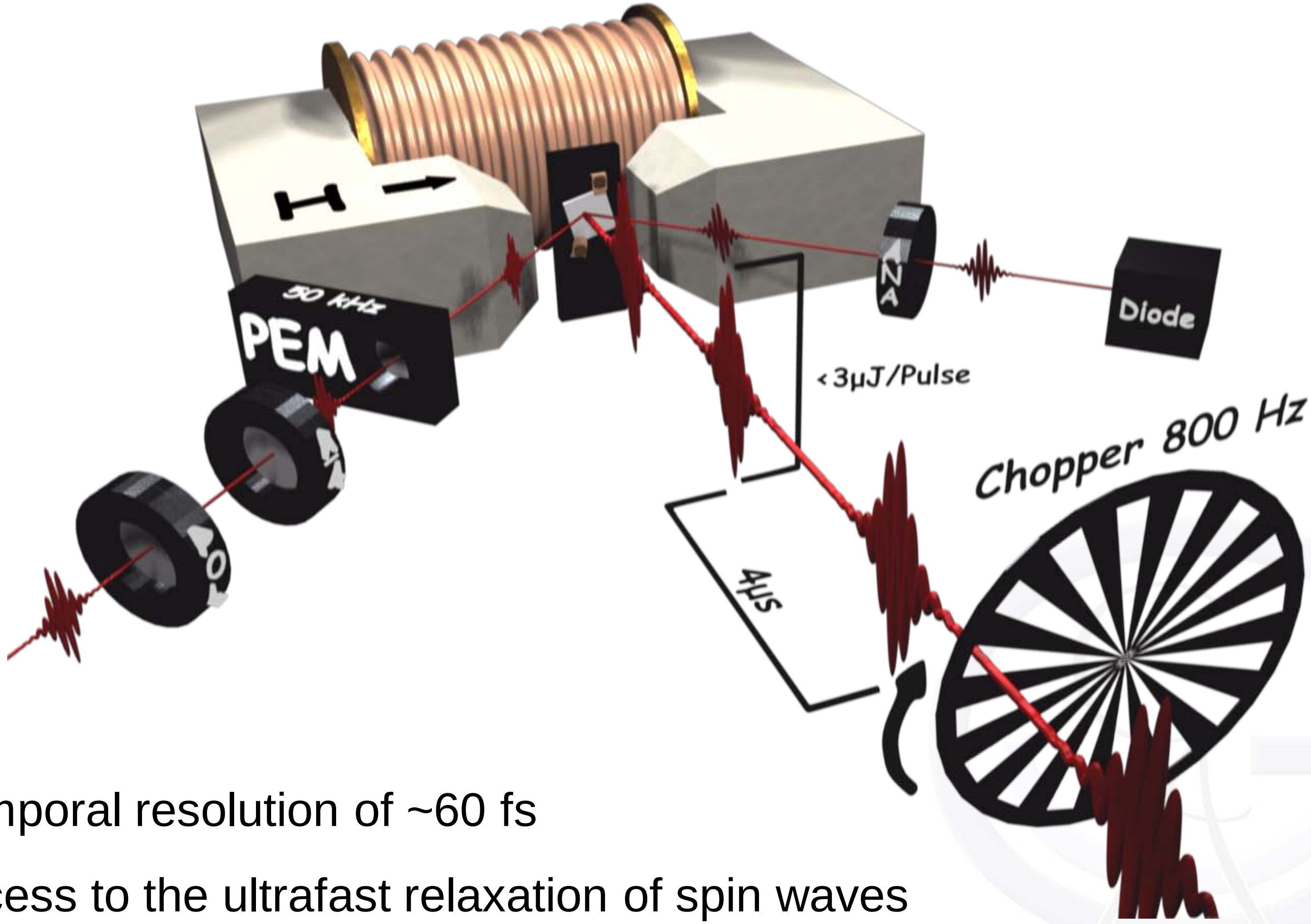
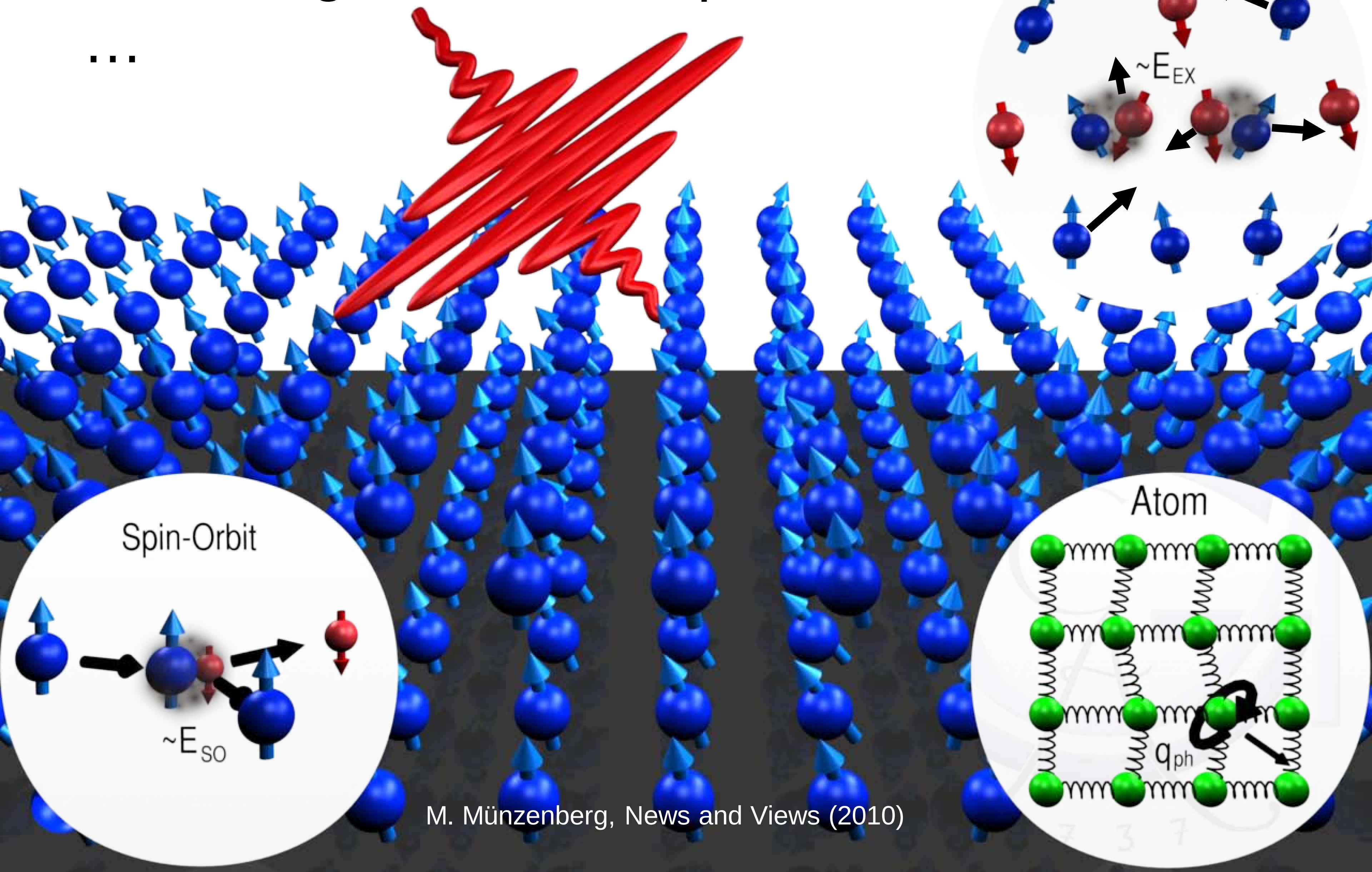
Spin-wave excitation and detection



- Temporal resolution of ~60 fs
- Access to the ultrafast relaxation of spin waves

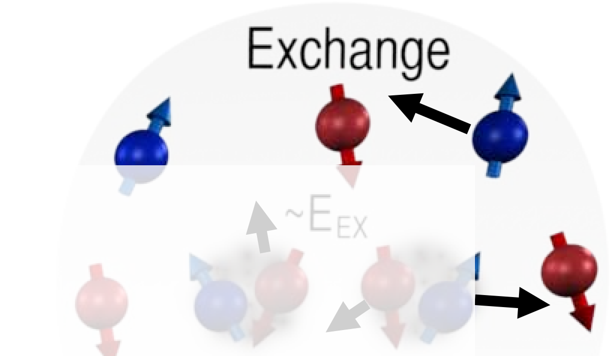
Ferromagnets stirred up

…



M. Münzenberg, News and Views (2010)

Our “milestones” …



Micromagnetism of ultrafast demagnetization:
- U. Atxitia, Phys. Rev. B 81, 174401 (2010).(LLB)
- M. Djordjevic, M. Münzenberg, Phys. Rev. B 75, 012404 (2007).

Spin-scattering mechanisms:
- G. Müller, et al. Nature Materials 8, 56 (2009). (Half Metals)
- J. Walowski, et.al. Phys. Rev. Lett. 100, 246803 (2008). (RE Doping)
- M. Münzenberg, Nature Materials 9, 184 (2010). (News and Views)

Verification of Damon-Eshbach modes all-optically:
B. Lenk et al., Phys. Rev. B 82, 134443 (2010).

New! **Magneto-Seebeck effect in MTJ‘s:**
M. Walter, et al., Nature Materials (2011).

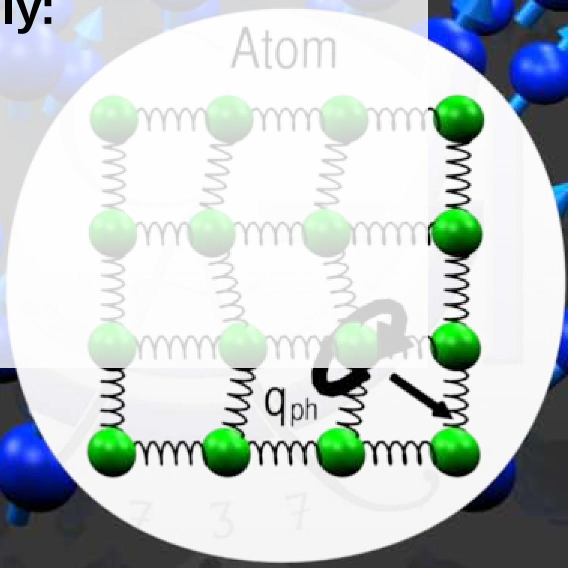
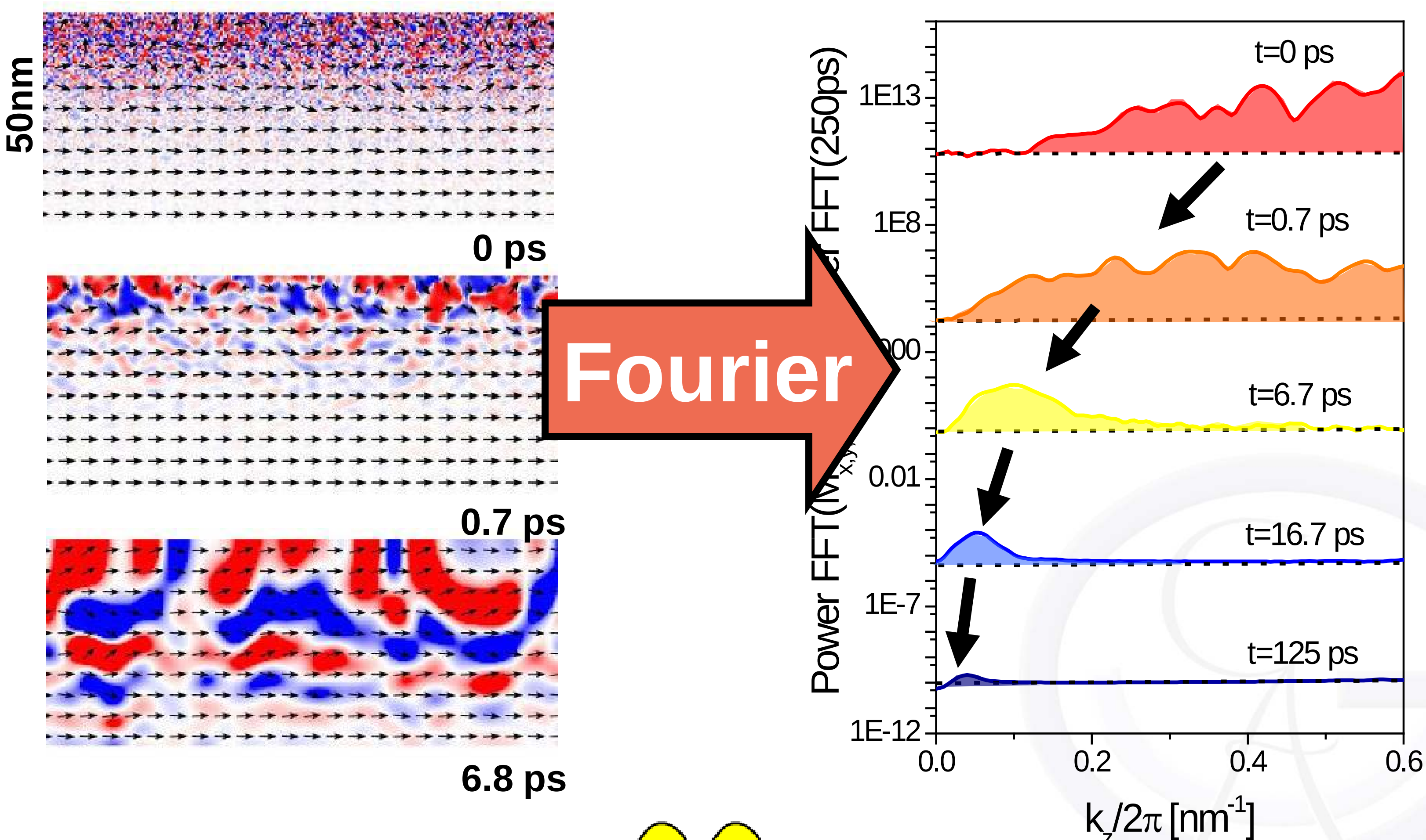


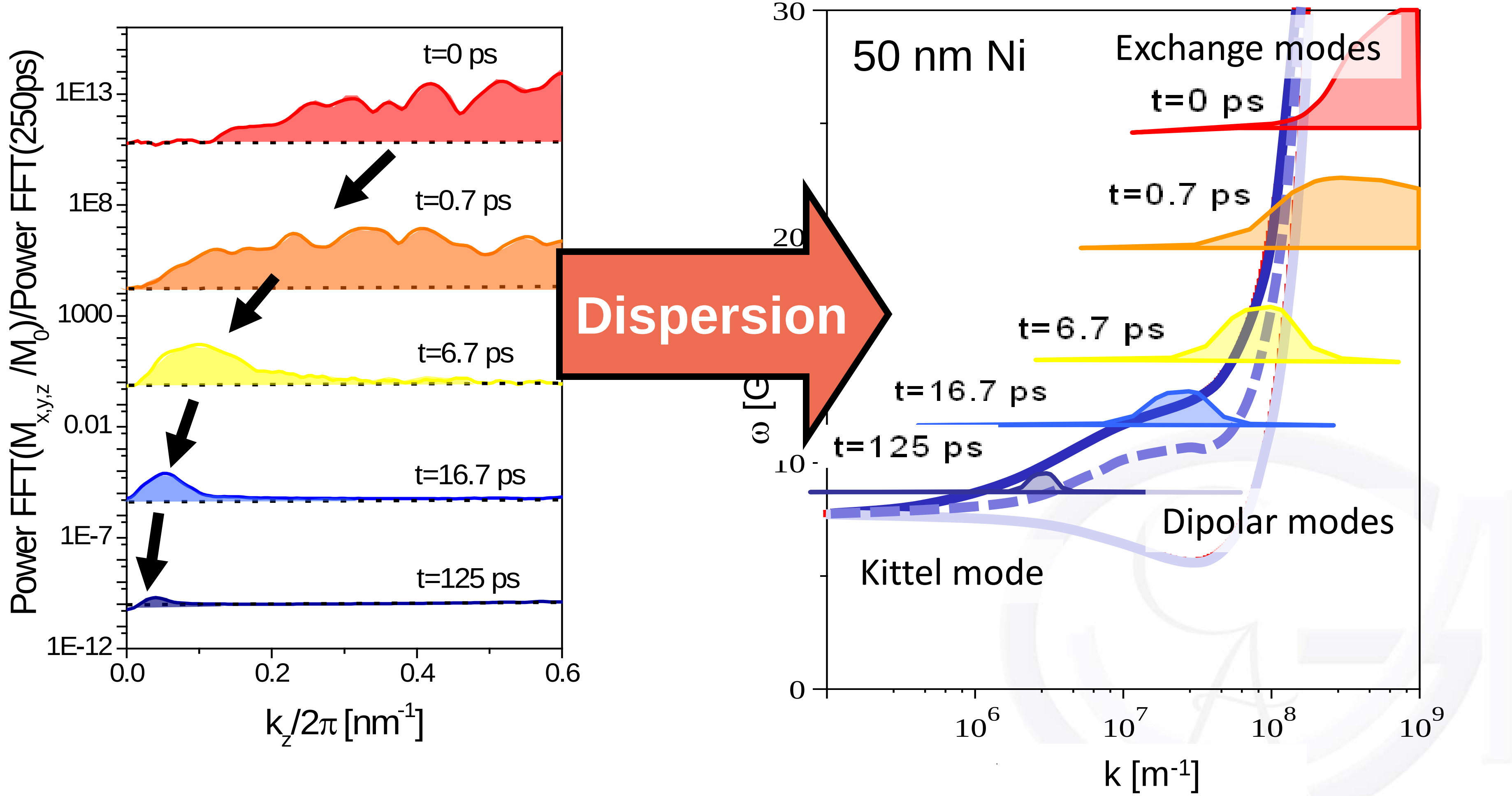
Photo excitation of spin waves: theory



•Micromagnetic simulation

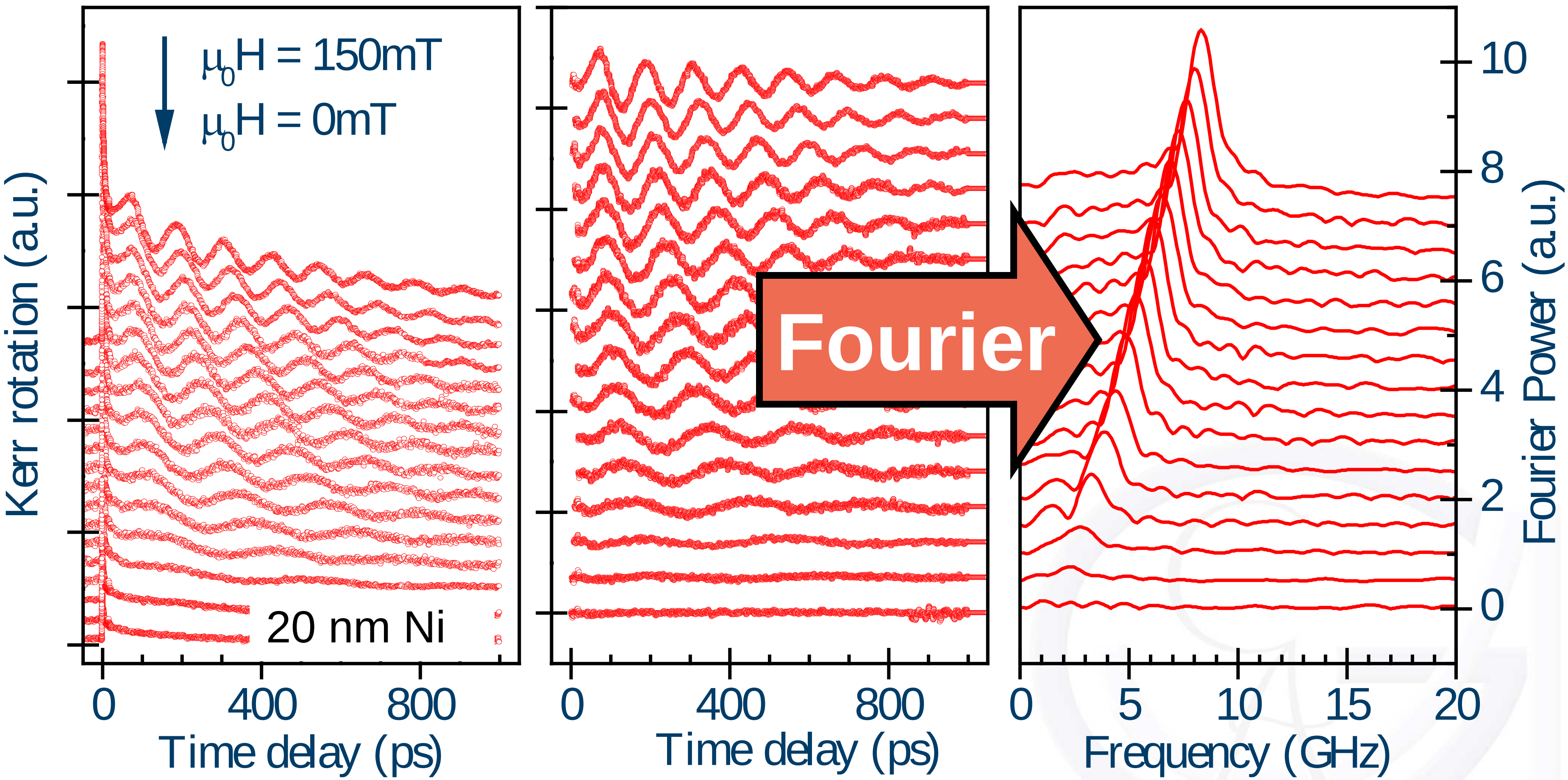
M. Djordjevic, PRB **75**, 012404 (2007)

Photo excitation of spin waves: theory



M. Djordjevic, PRB **75**, 012404 (2007)

Photo excitation: experiment (20 nm Ni)



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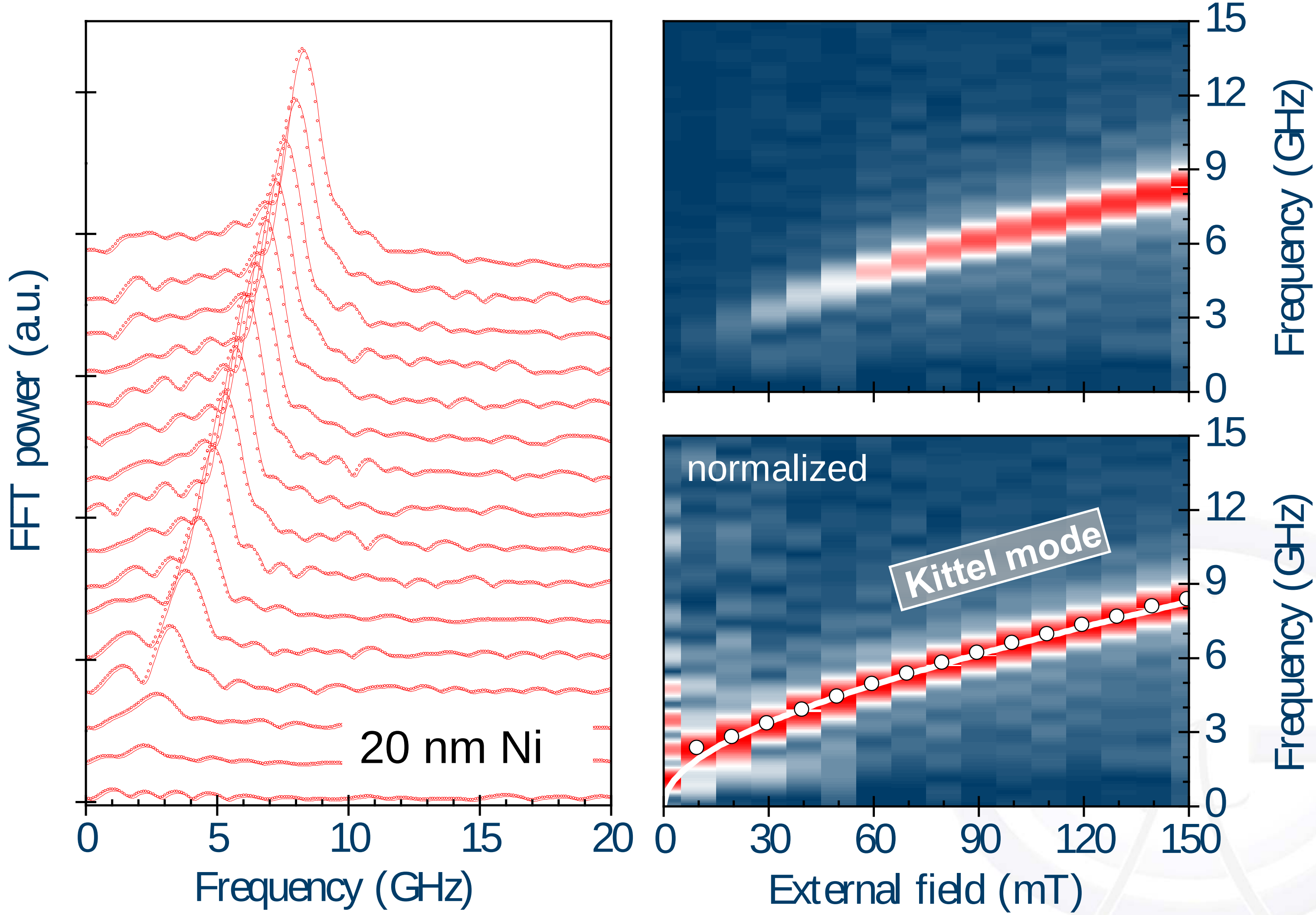

B. Lenk et al., Building blocks of magnonics, Physics Reports, advance online

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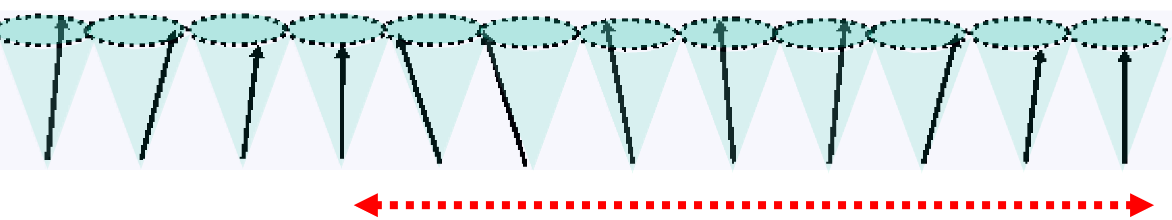
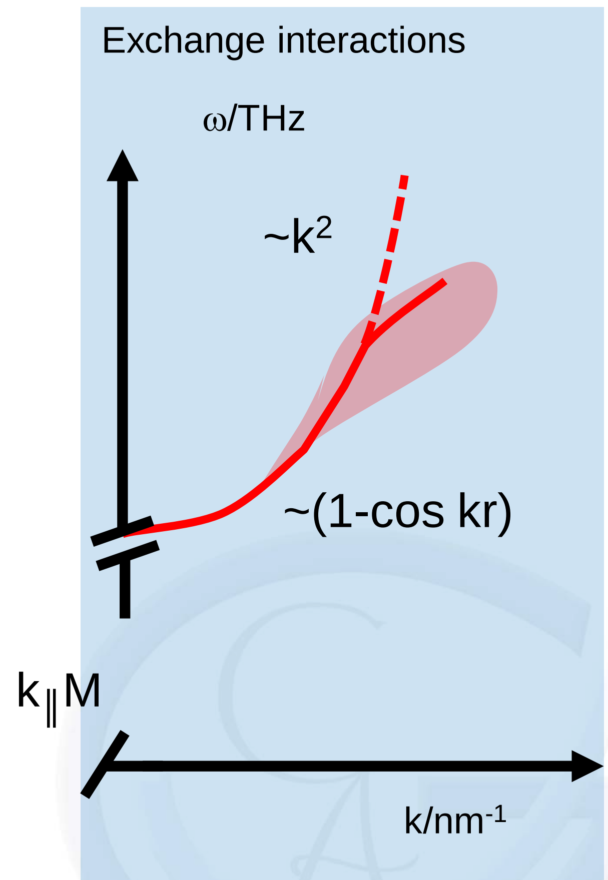
Spin-wave dispersion: exchange and dipolar modes

Dispersion for a Ni film:

- Spin waves from the GHz to THz range



$$\lambda = \frac{2\pi}{q}$$



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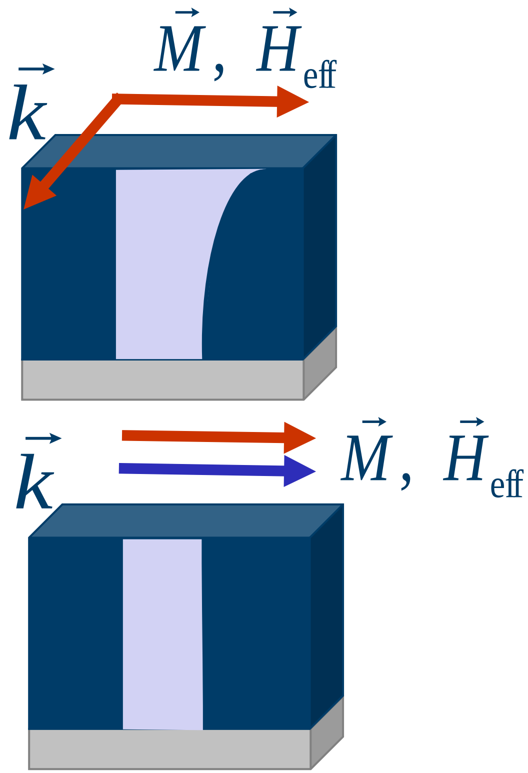

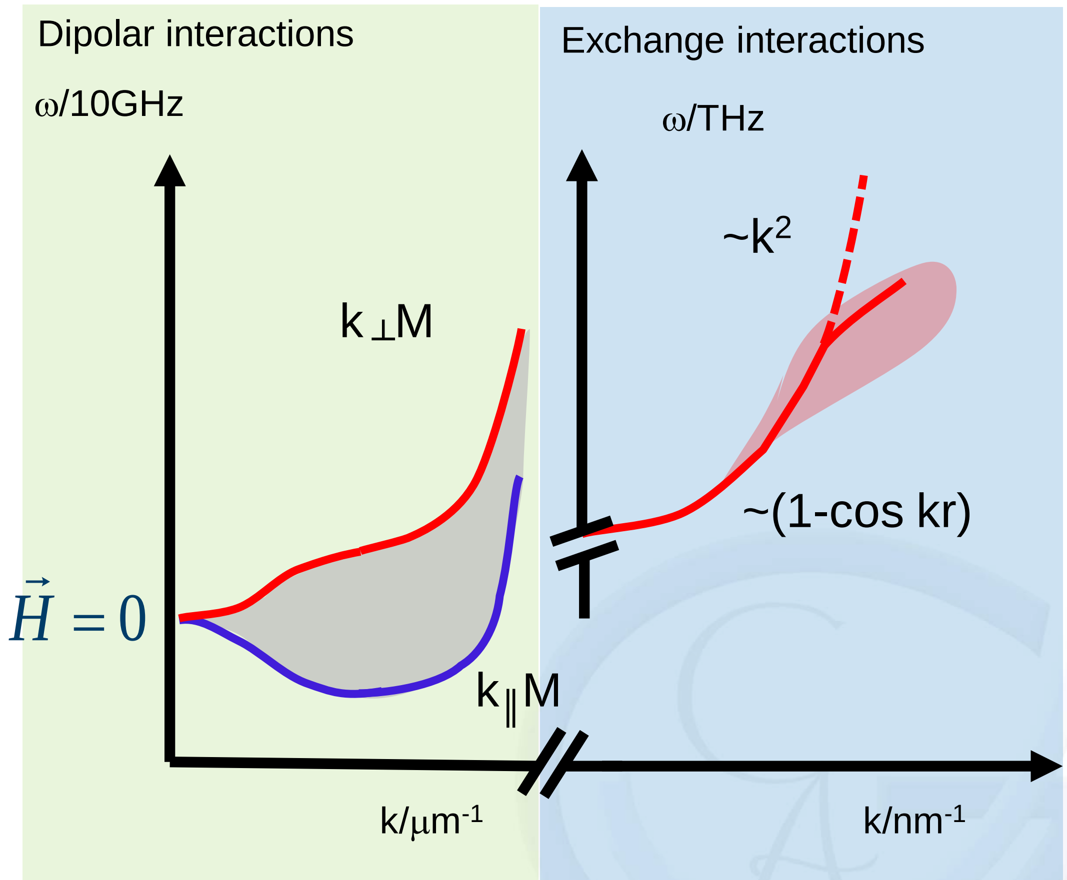

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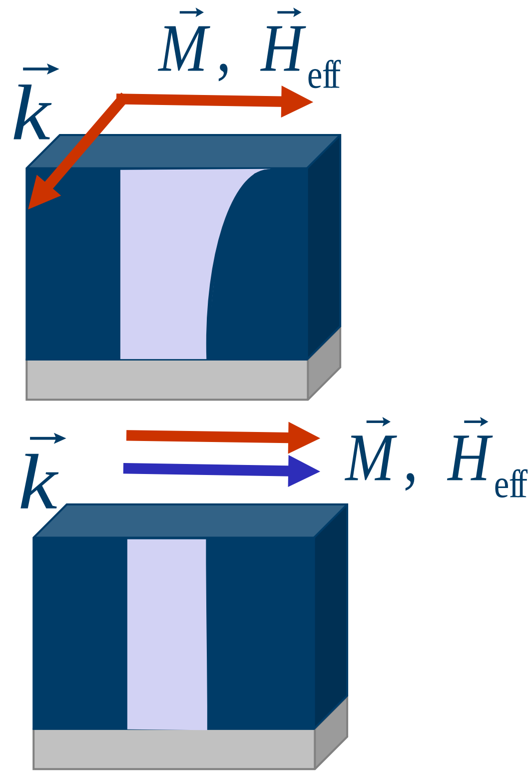

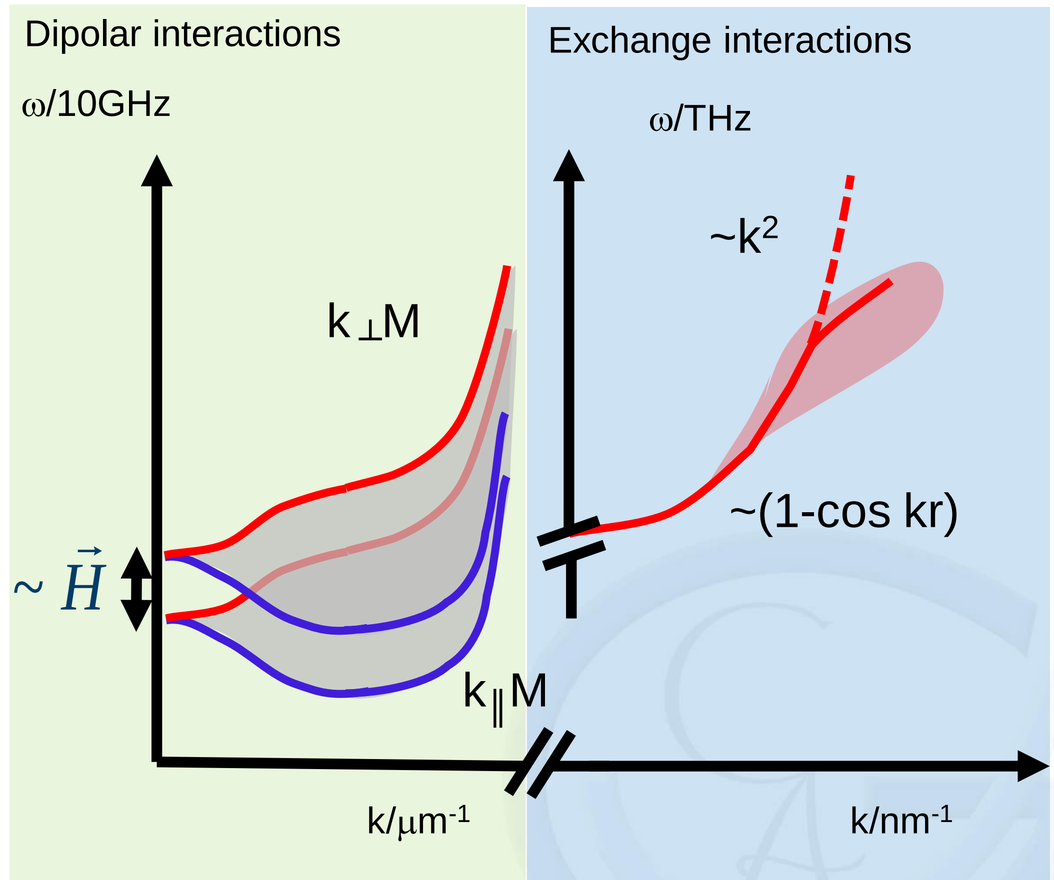

B. Lenk et al., Building blocks of magnonics, Physics Reports, advance online

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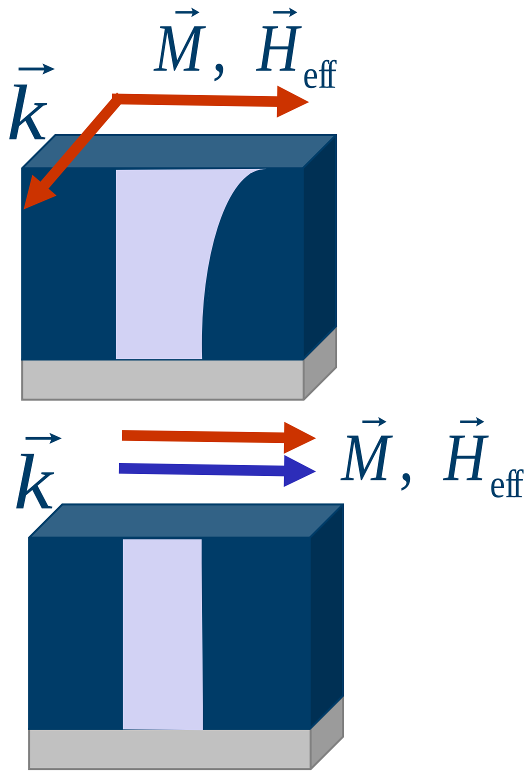

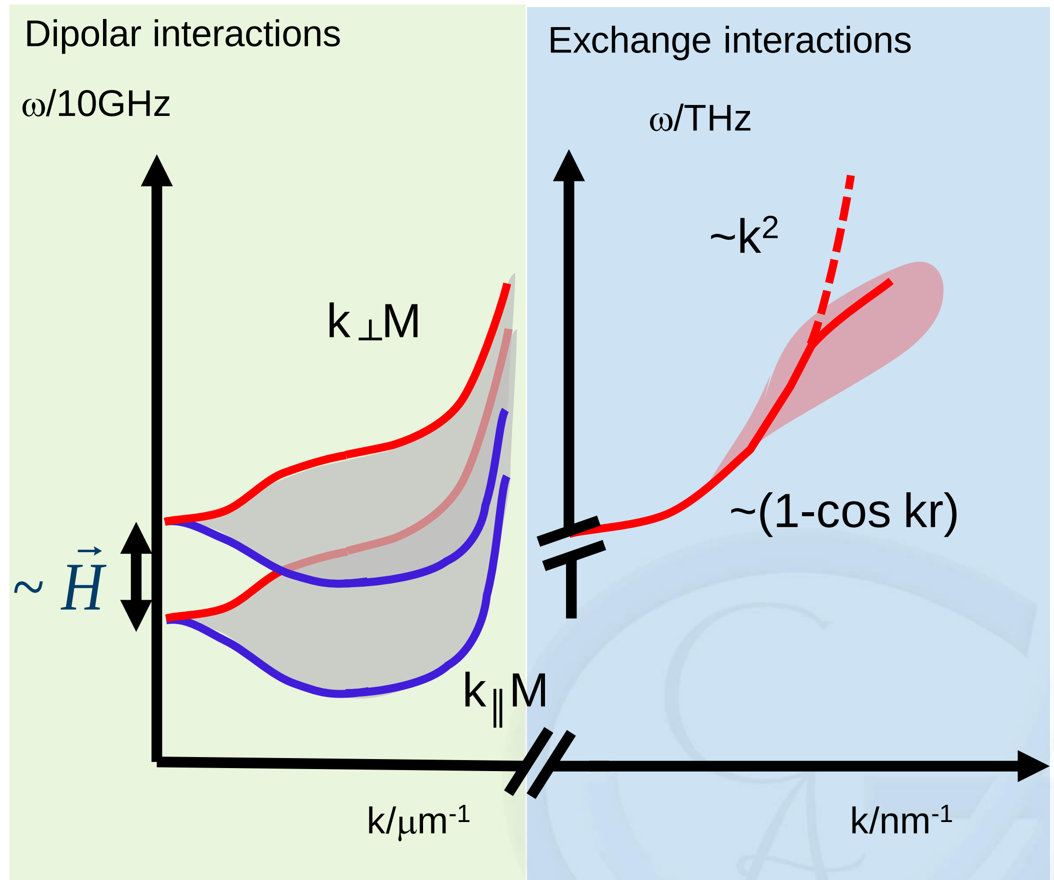

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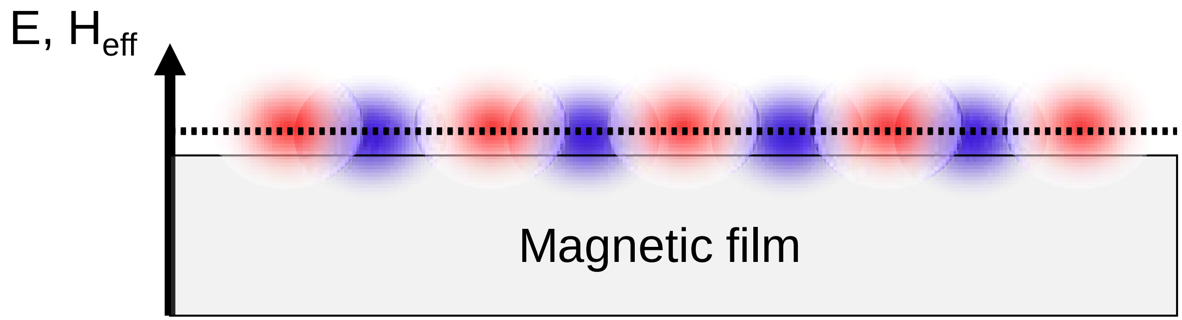
Bloch states for magnons



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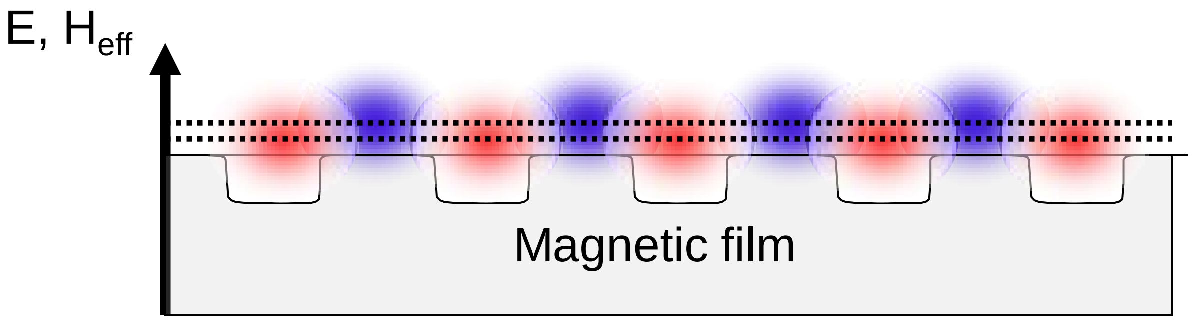

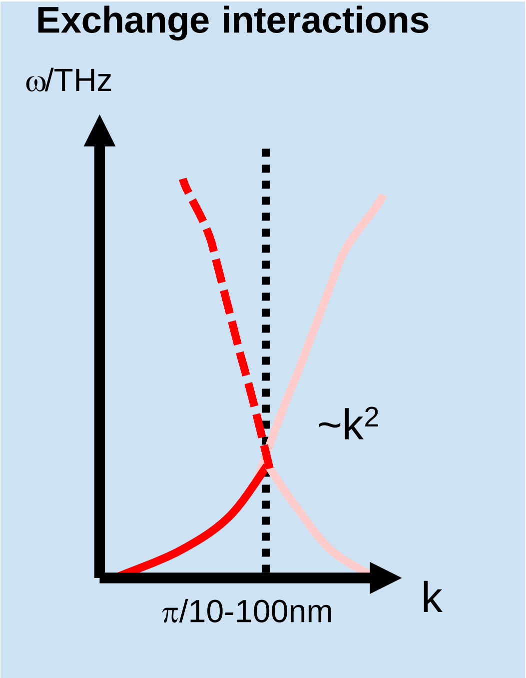

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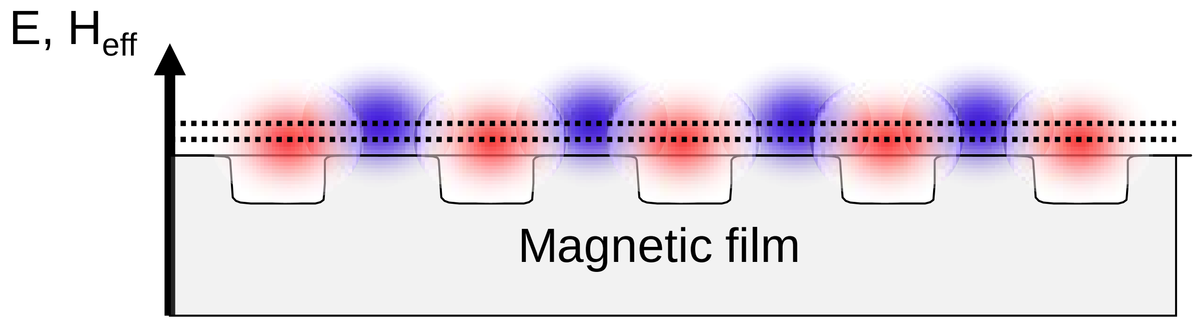
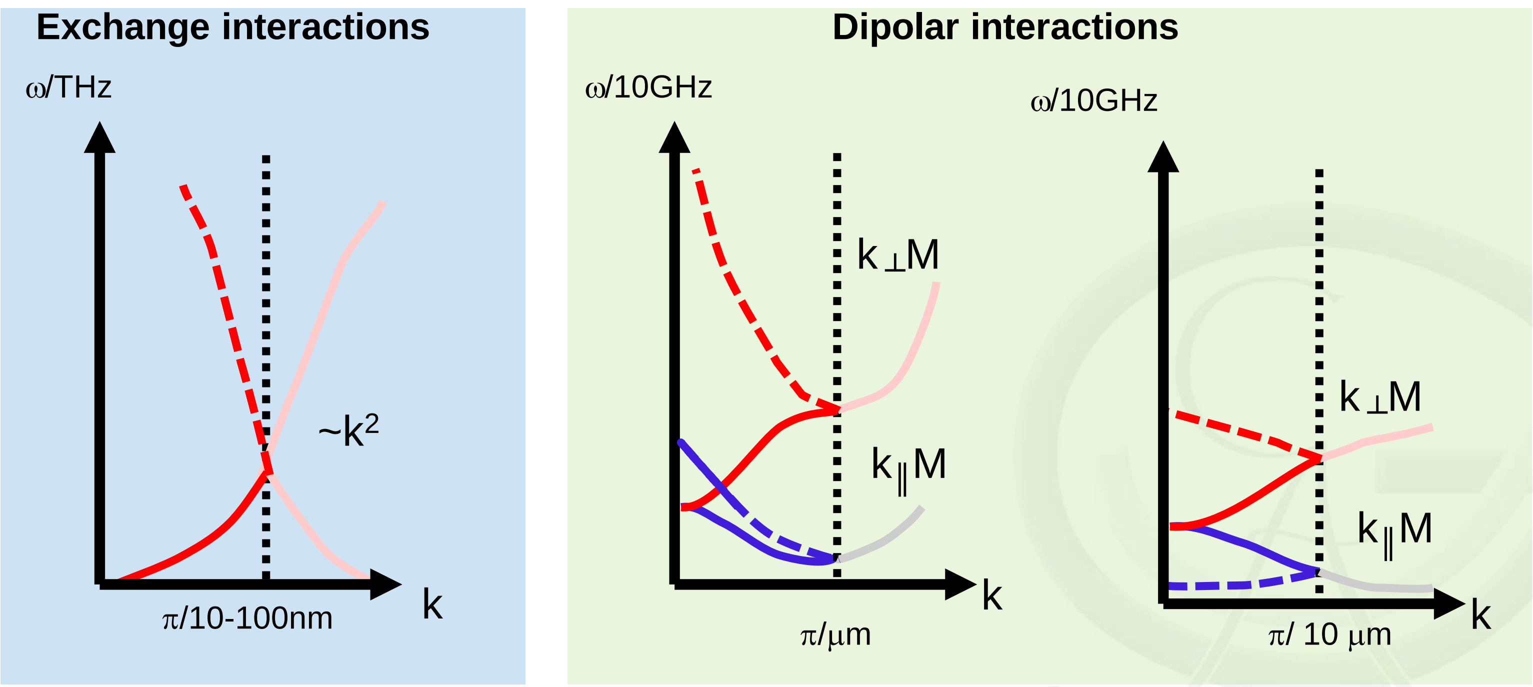
Bloch states for magnons





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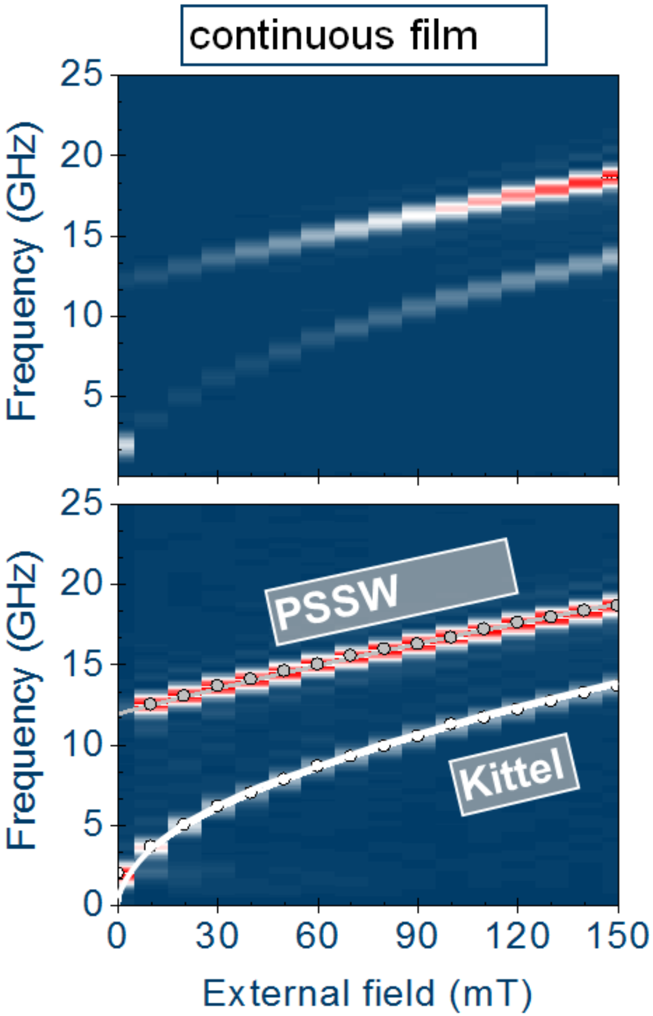
Bloch states in square lattices



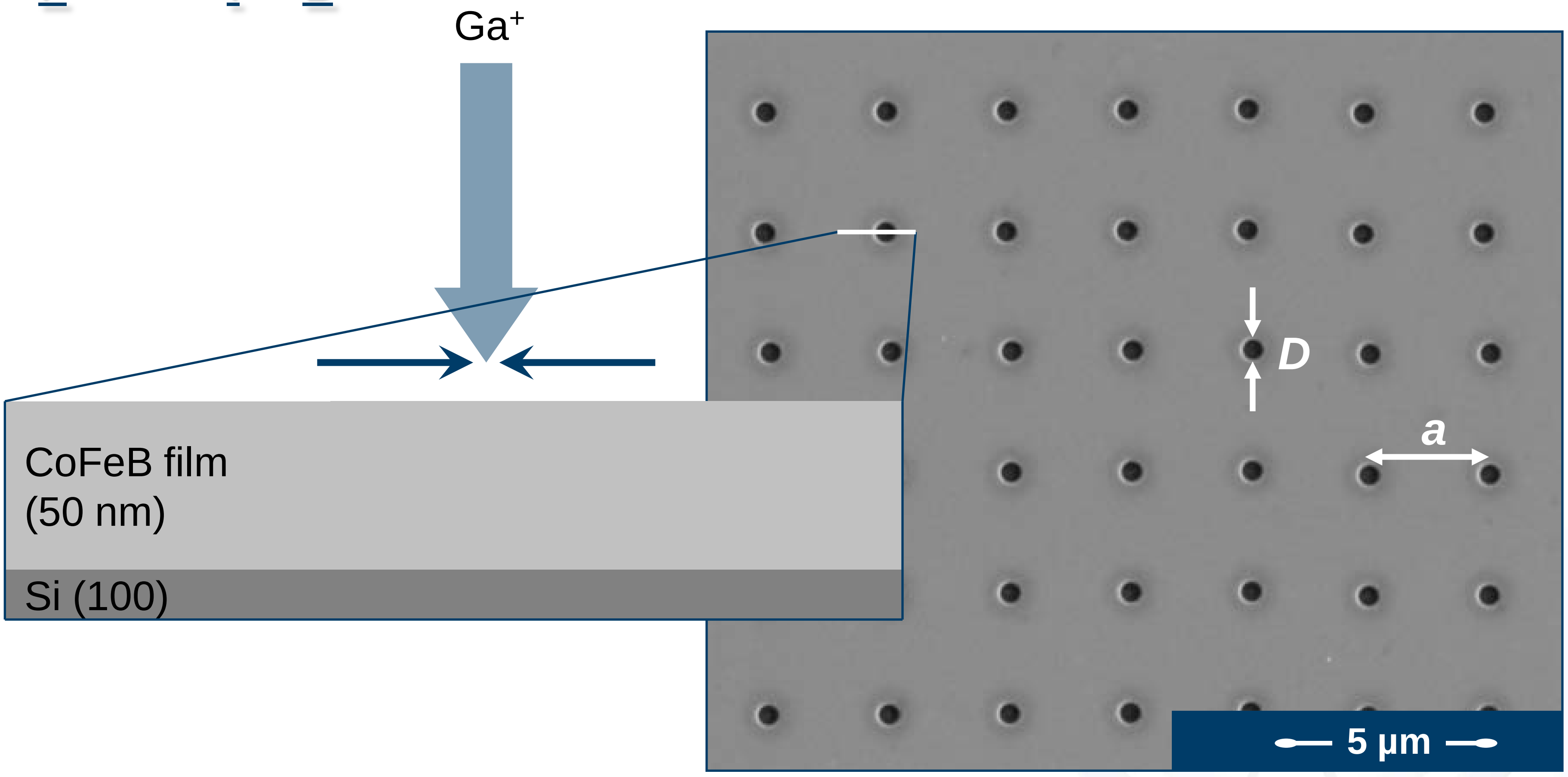
Low damging material

- Line width <<0.5 GHz
- Gilbert damping α=0.006
- Spin-wave propagation length from phase velocity: >100 µm

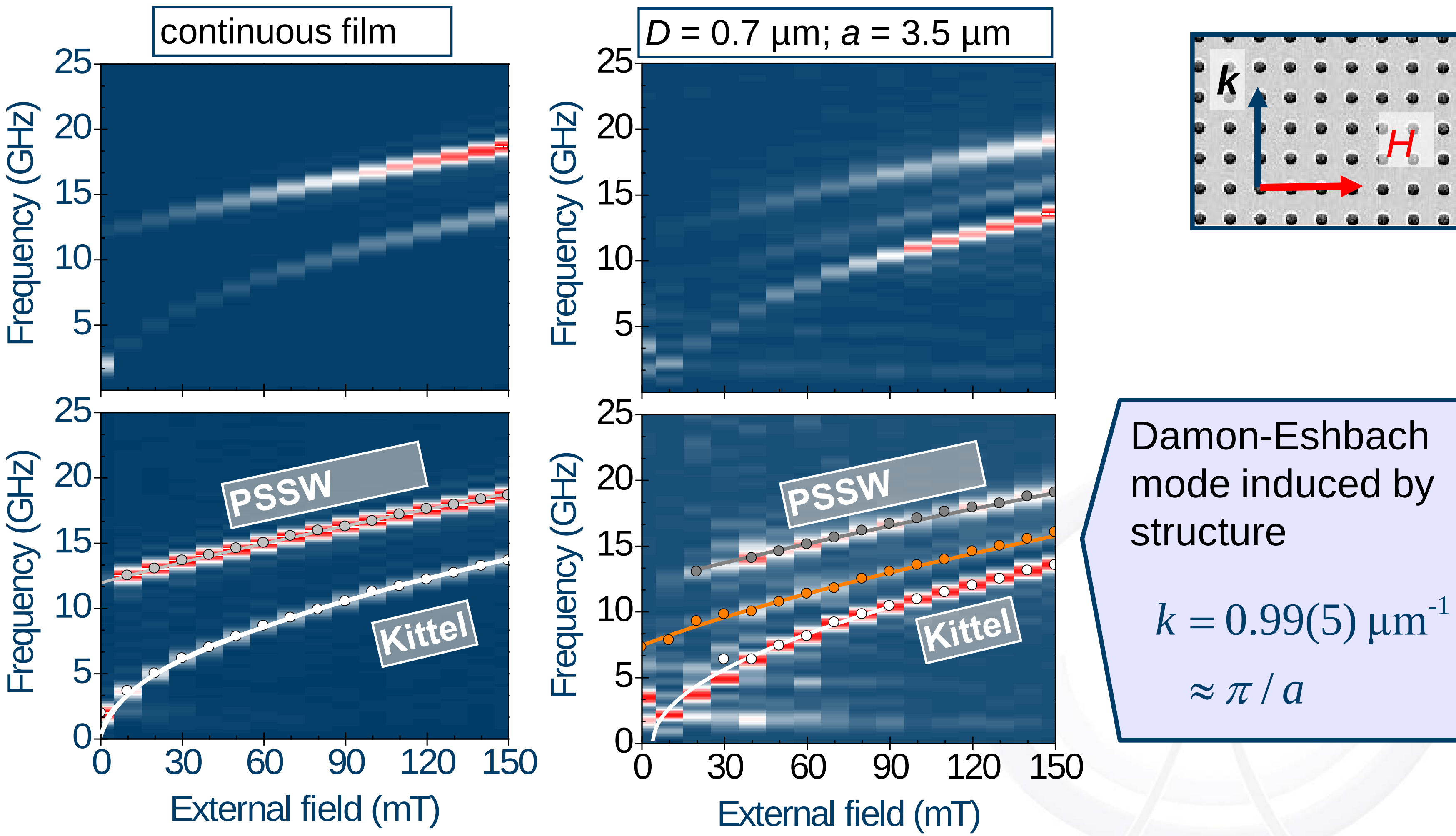
H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

2-Dim magnonic crystal

Focused Ion Beam



Bloch states in square lattices



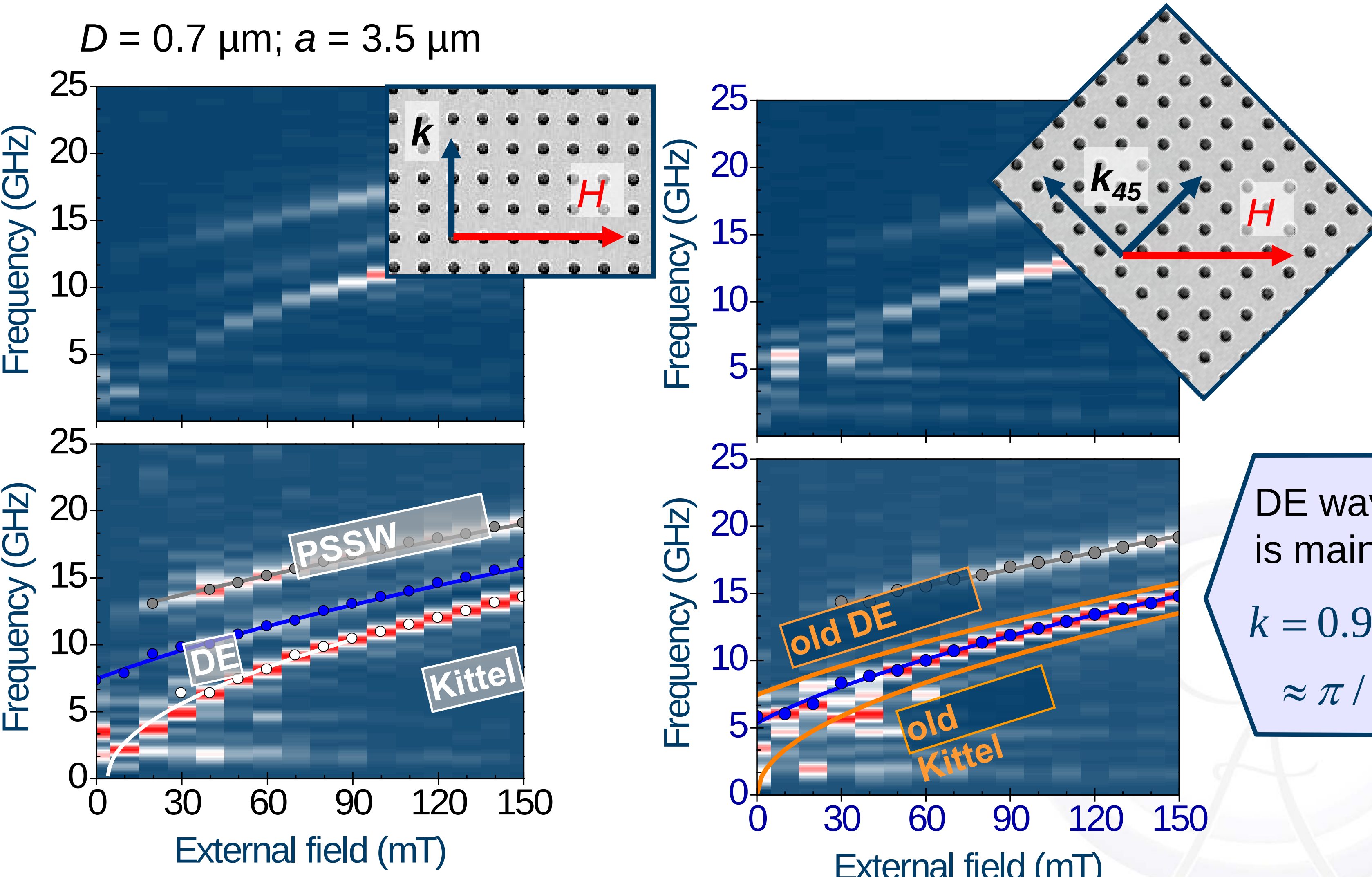
Damon-Eshbach mode induced by structure

$$k = 0.99(5)\ \mu\mathrm{m}^{-1}$$
$$\approx \pi / a$$

H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

Bloch states in square lattices

D = 0.7 µm; a = 3.5 µm



DE wave vector is maintained

$$k = 0.99(5)\ \mu\text{m}^{-1}$$

$$\approx \pi / a$$

H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

Bloch states in square lattices

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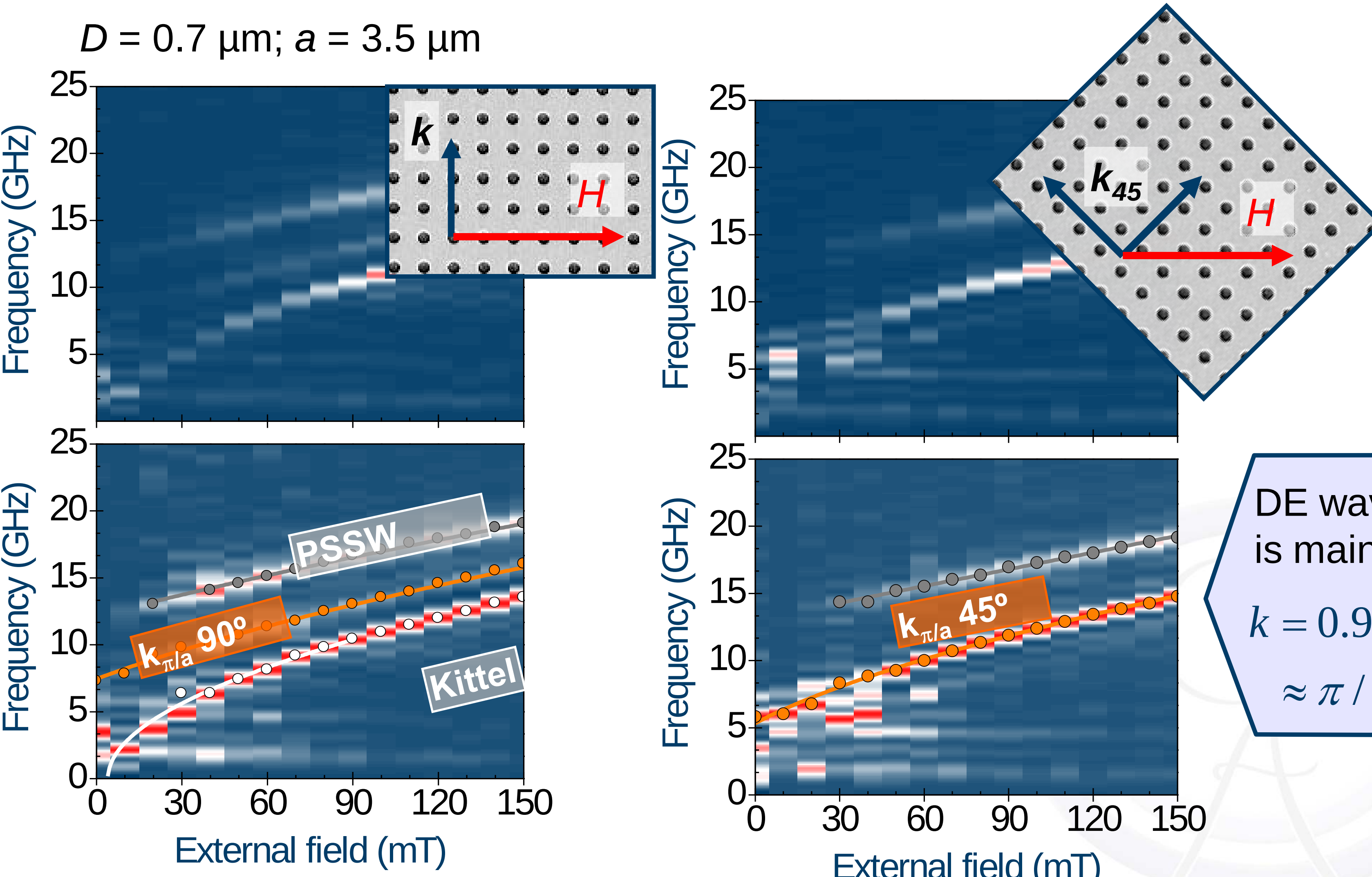

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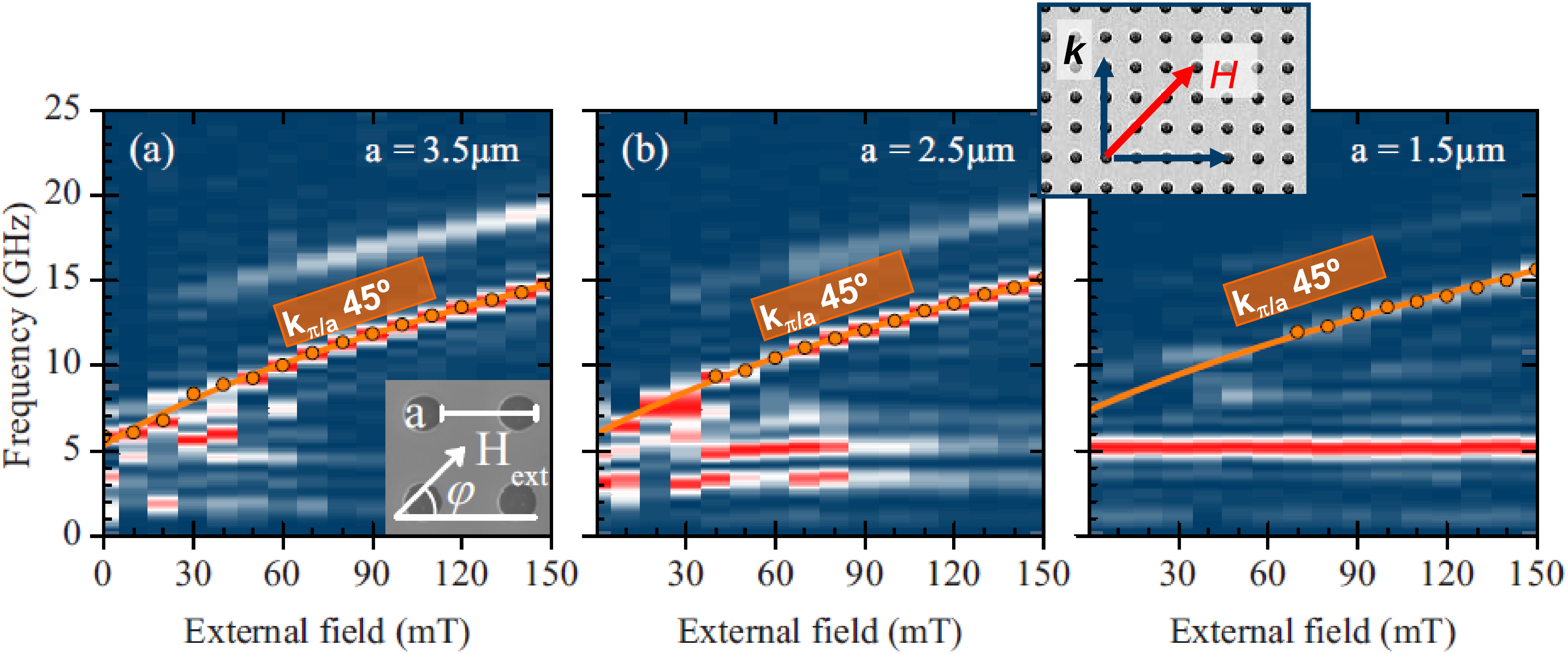
H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

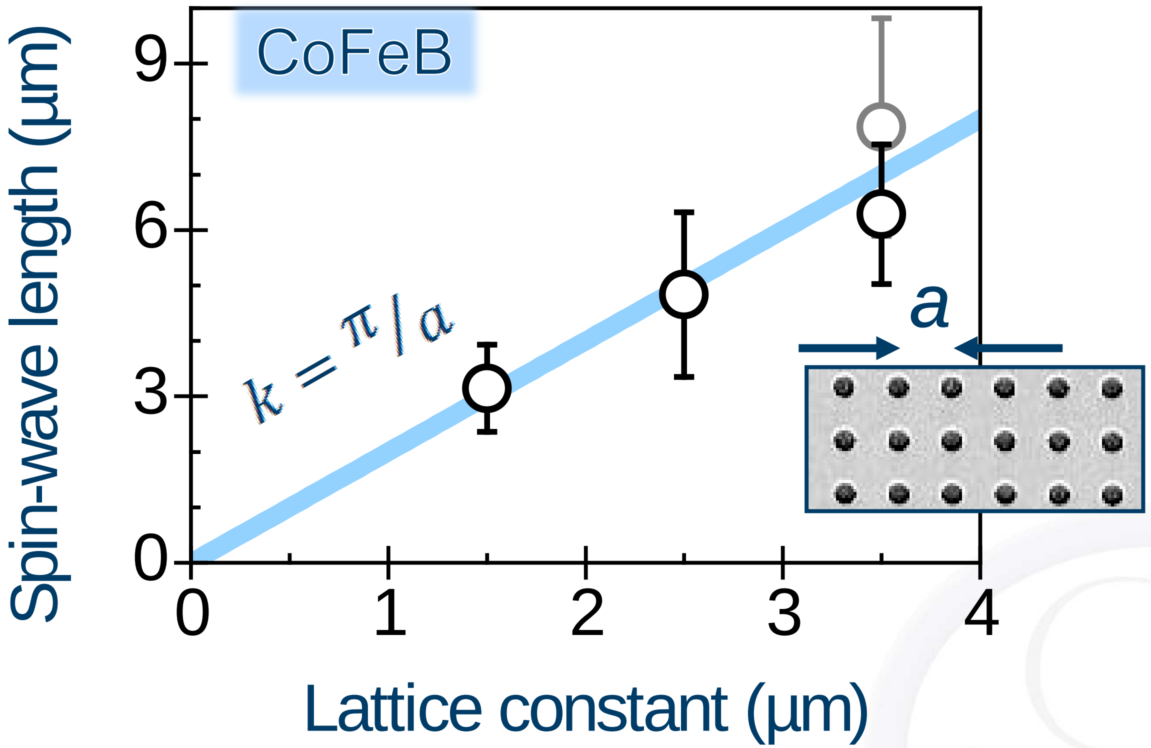
Bloch states at 45° to magnetization [1,0], [0,1]-direction



•Dispersion determined by Bloch states at the BZ boundary

H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

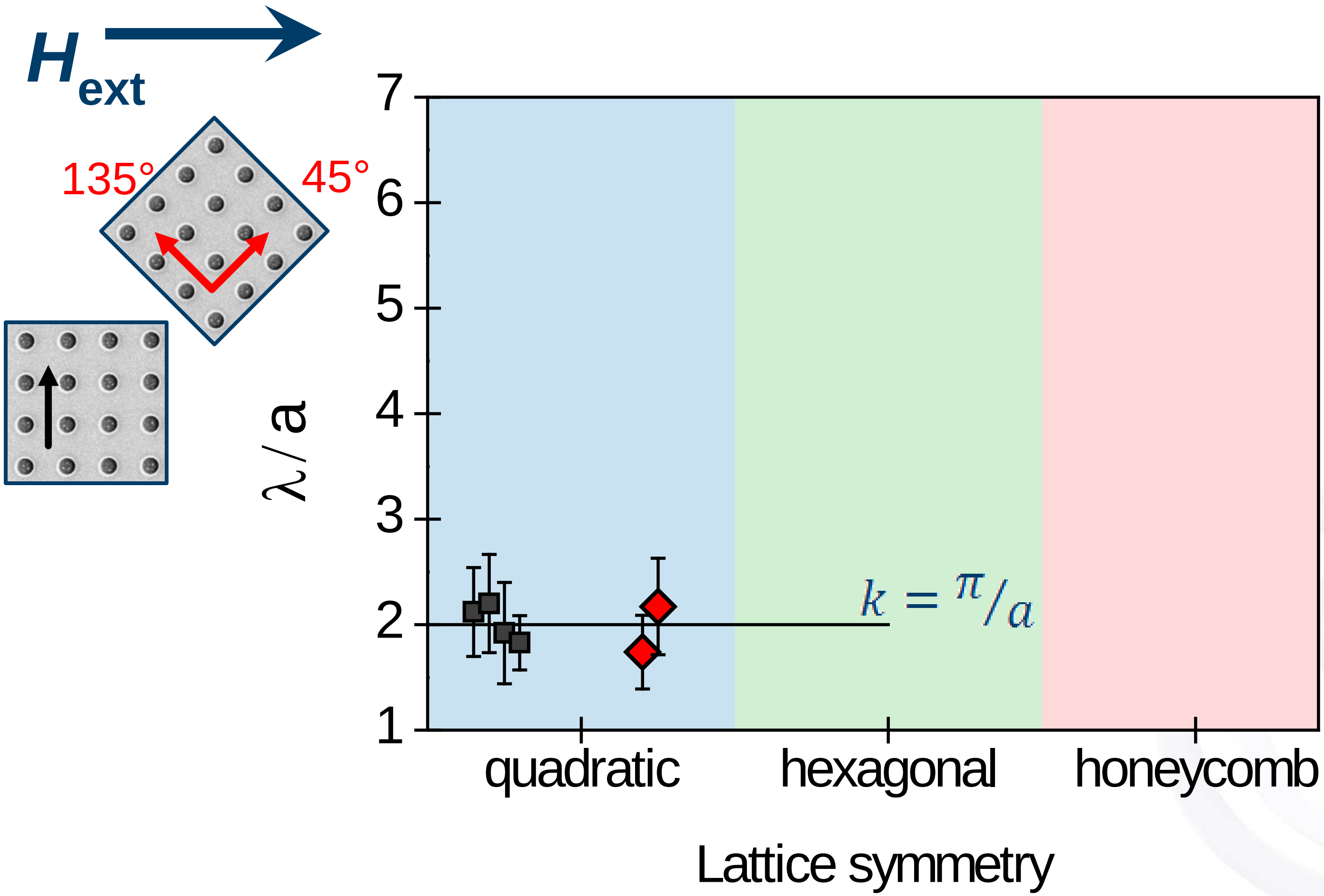
Bloch states in square lattices



•π/a state is dominating for a series with varied a

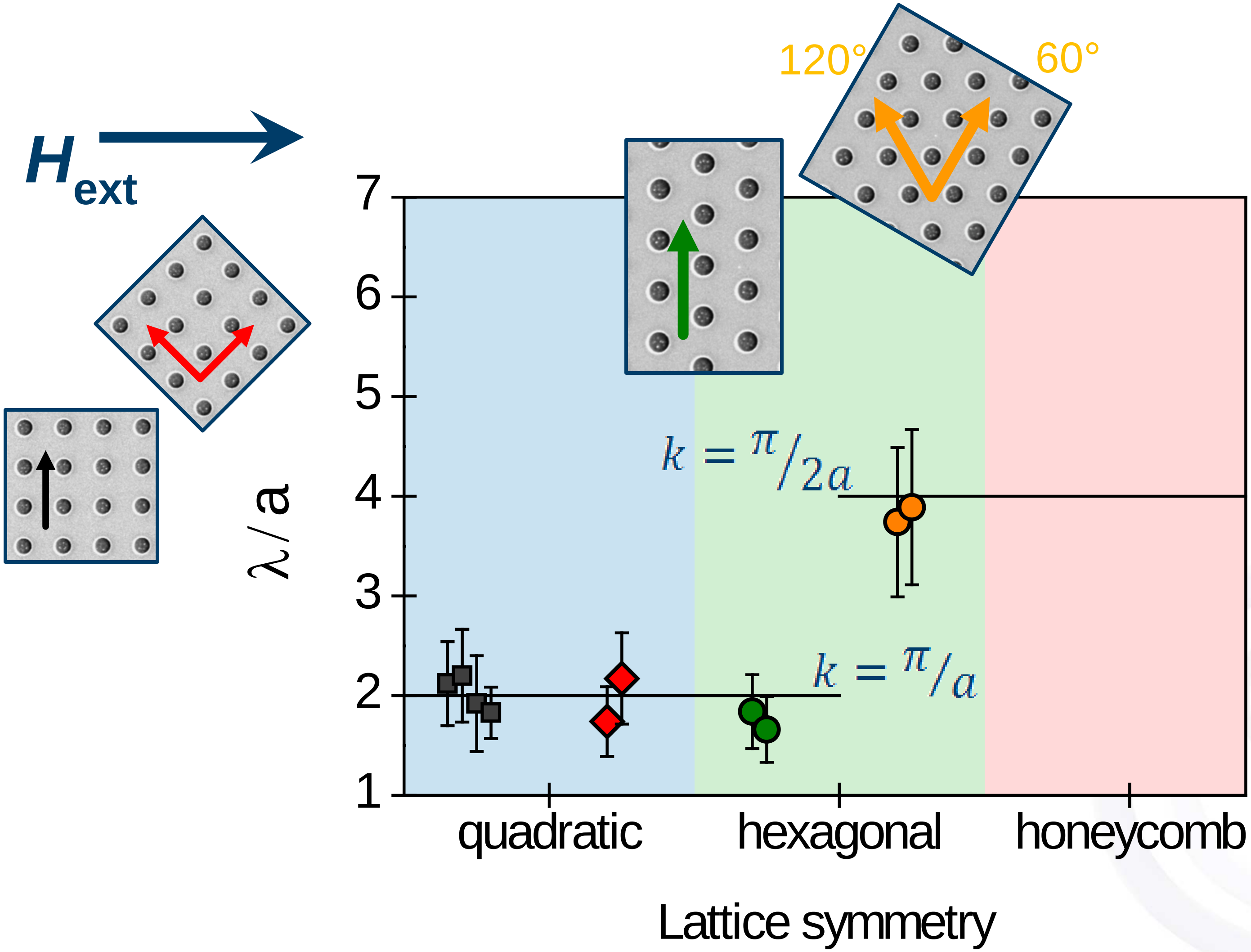
H. Ulrichs et al. , *Appl. Phys. Lett.* ***97***, 092506 (2010)

Bloch states by symmetry



Fabian Garbs, Diploma thesis, Uni Göttingen

Bloch states by symmetry



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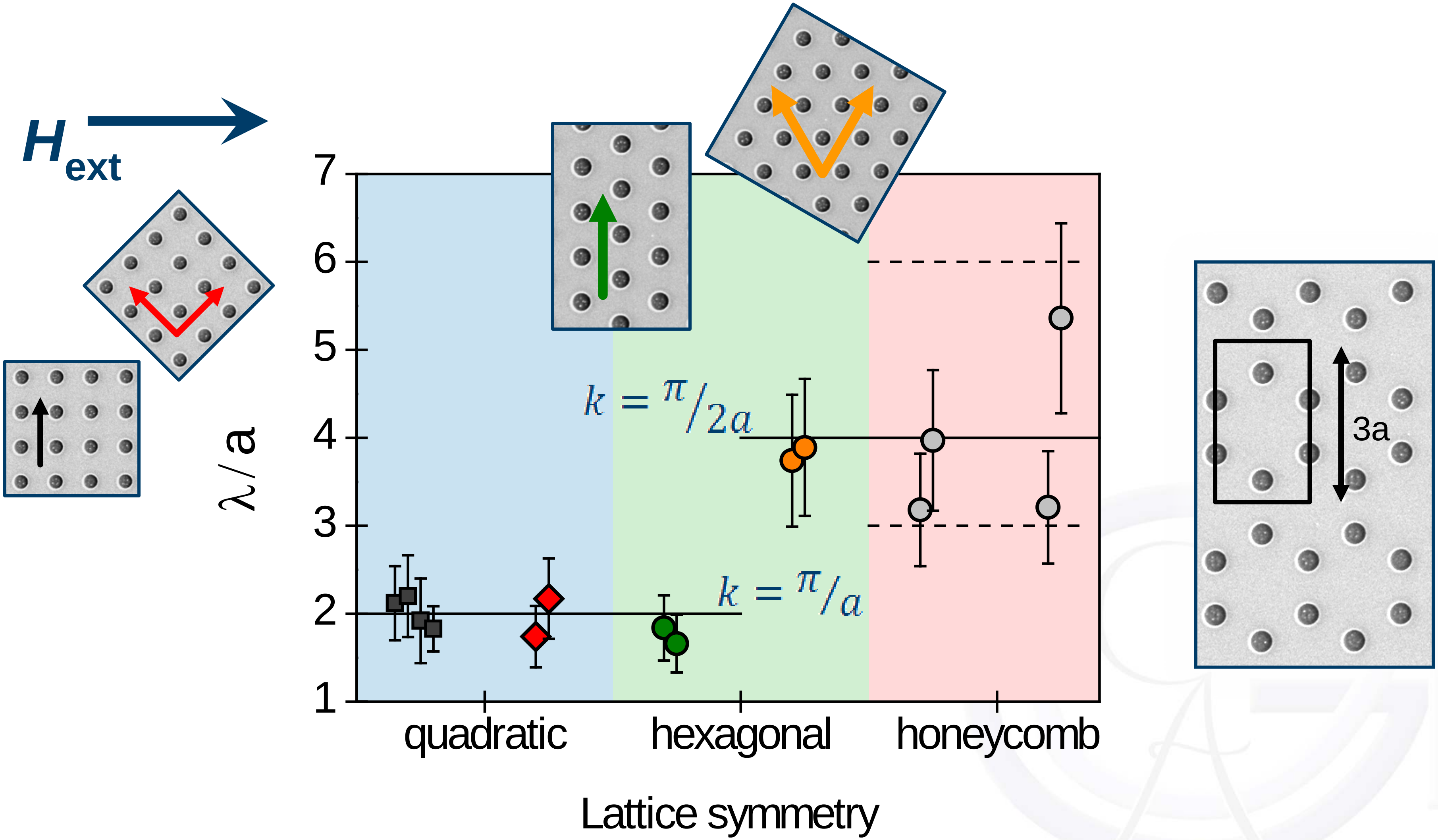

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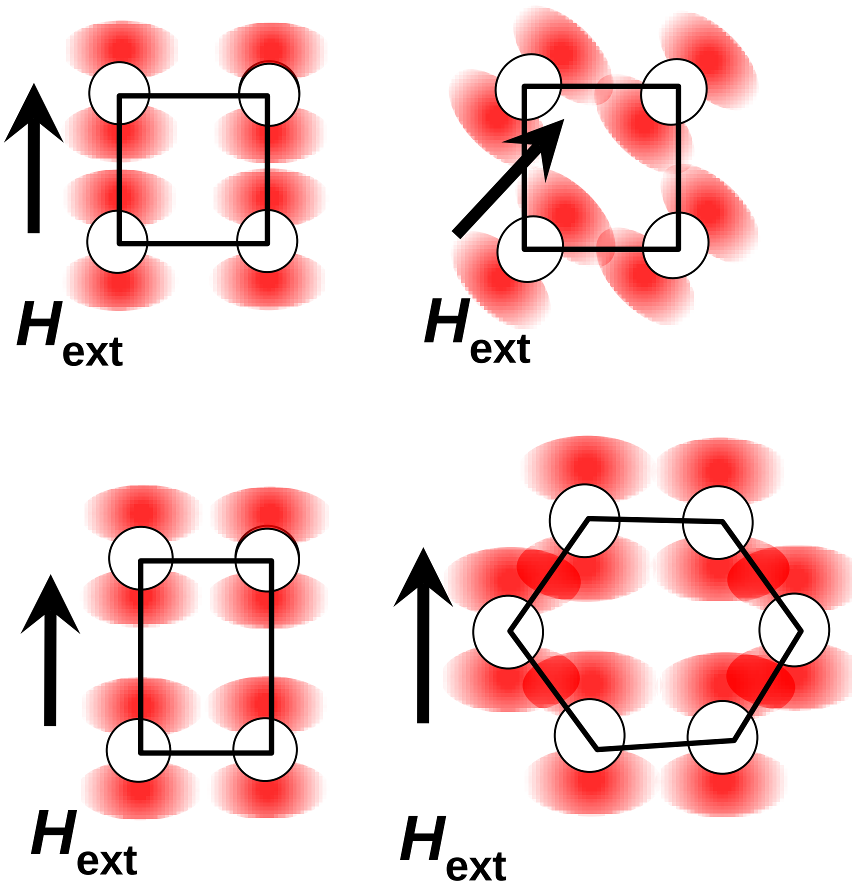
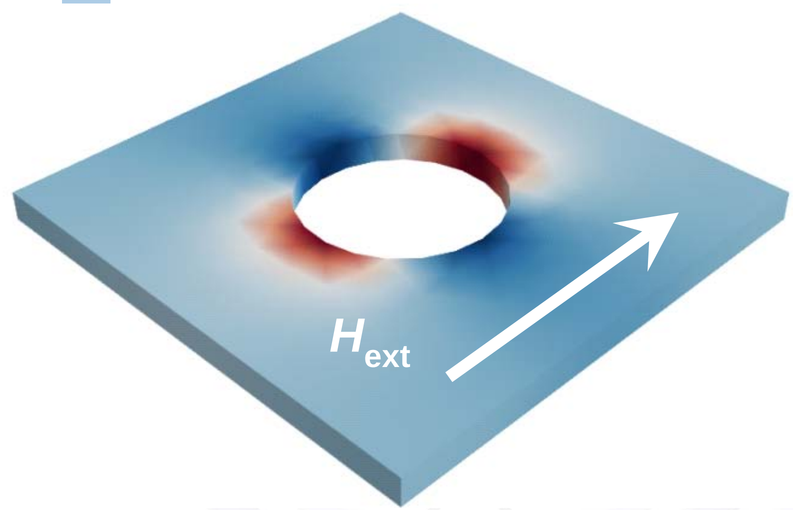
Lattice geometries



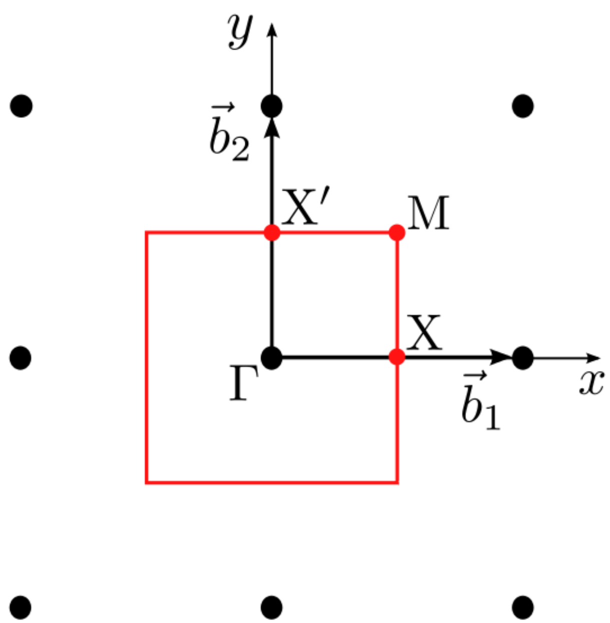
Periodic internal field

- Magnon potential wells and areas of weak disturbance in close proximity

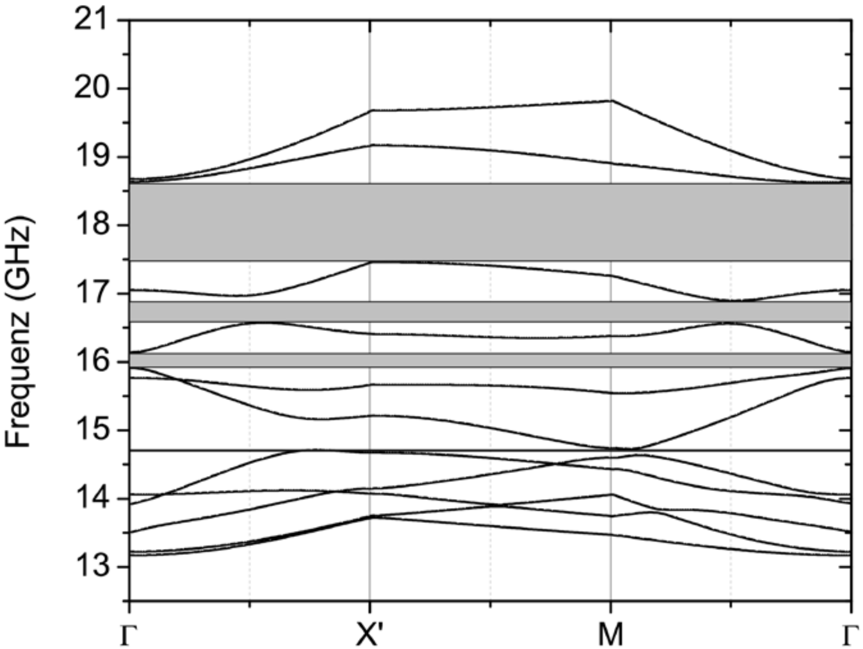


Simulation using *Nmag* by Fischbacher, Fangohr

Square lattice structure – *some theory*



Reciprocal lattice with special points of the first Brillouin-Zone

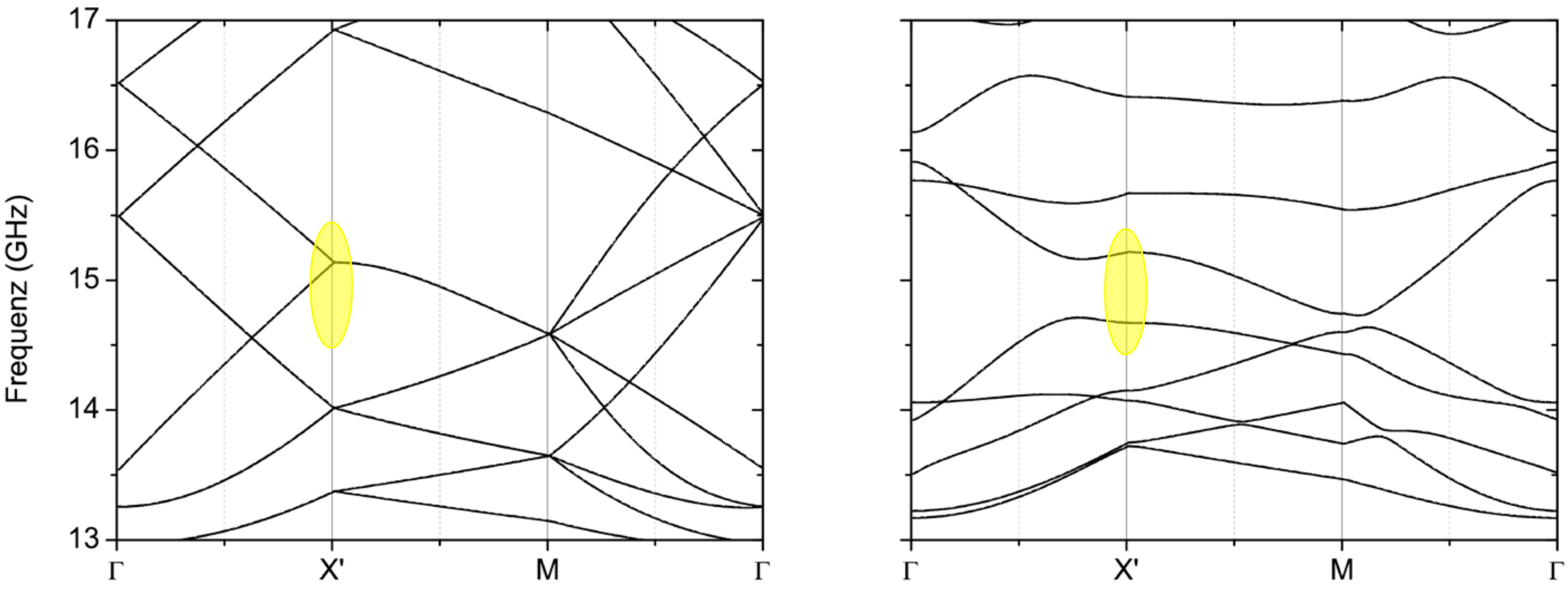


Band structure with a=3.5µm with kS=0.229

Plane wave ansatz from J. O. Vasseur et al., Phys. Rev. B 54, 1043 (1996)

B. Lenk et al., Building blocks of magnonics, Physics Reports, advance online

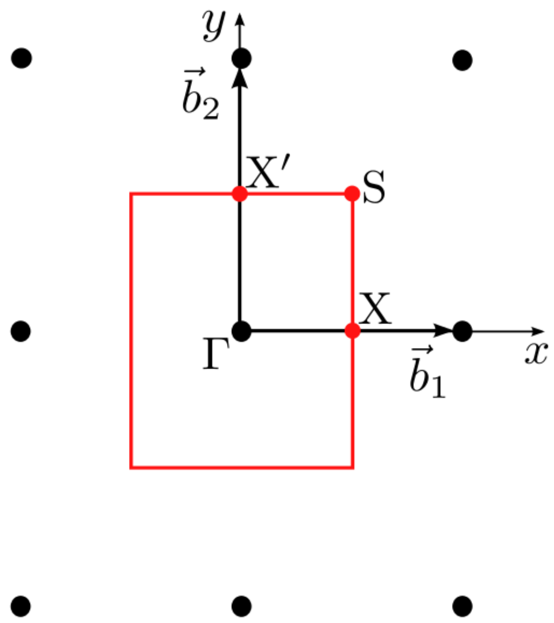
Square lattice structure – *some theory*



Unstructured film

Structured film

Rectangular structure



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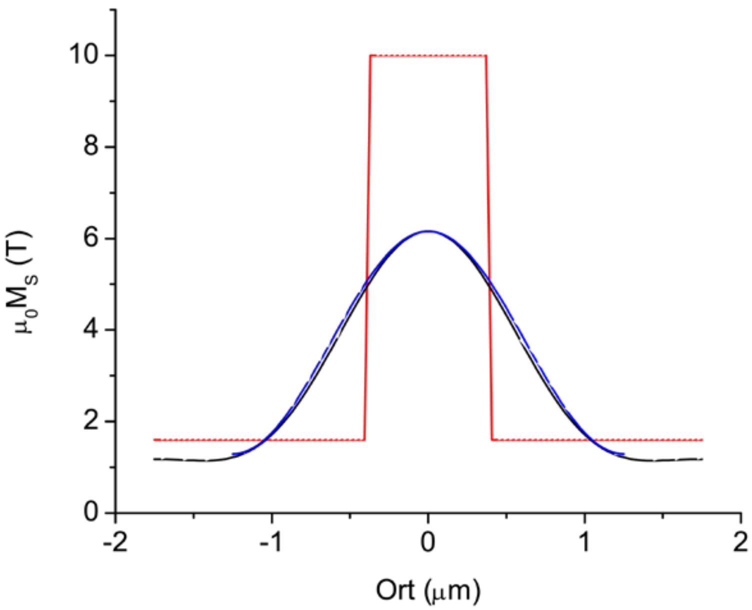
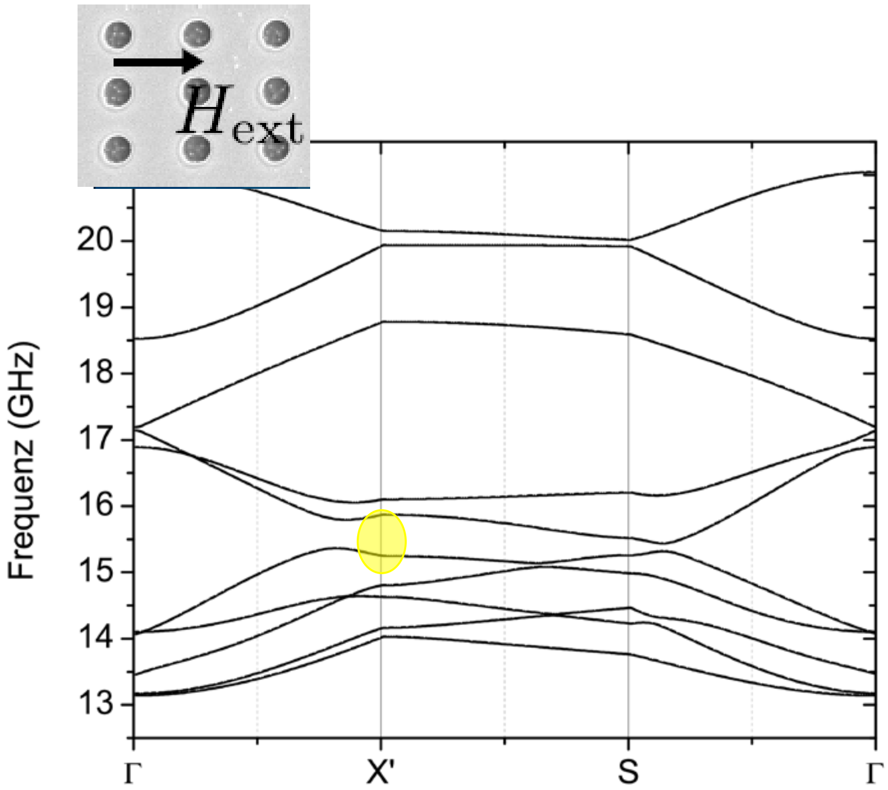
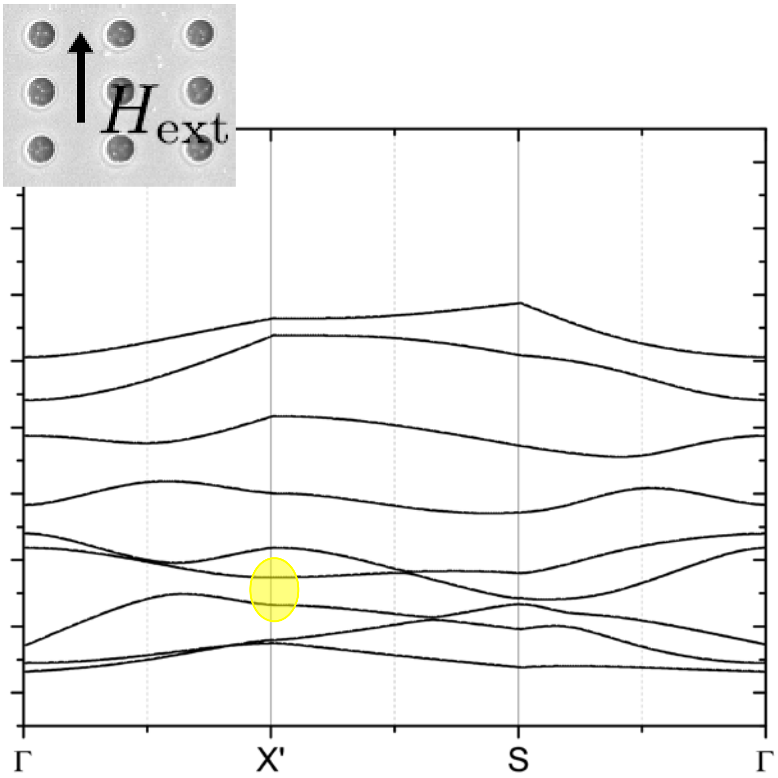


Profiles of simulated antidot for a=3.5μm, R=0.4 μm (11 lattice vectors, kS=0.233)

Rectangular structure



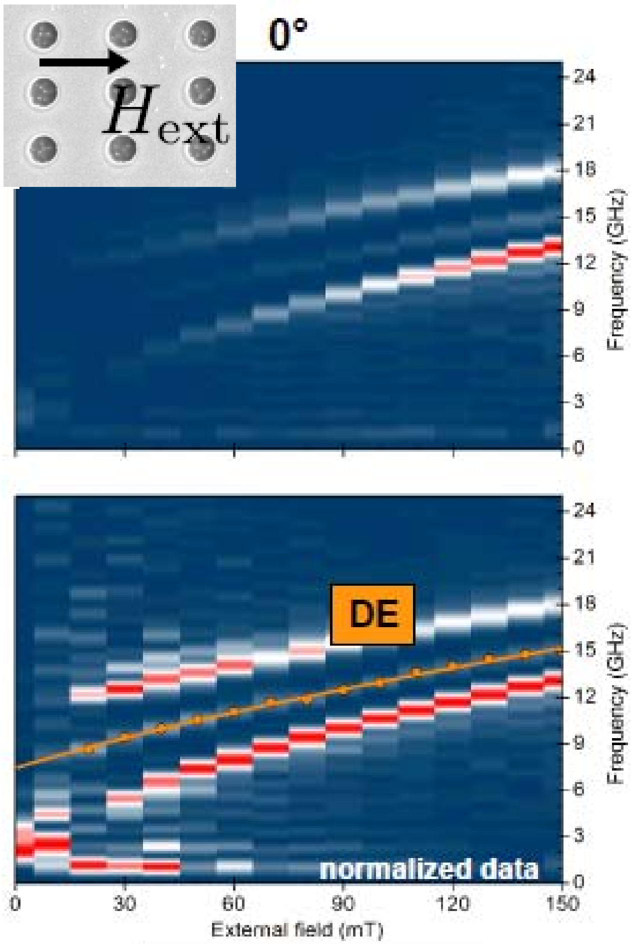
a=3.5μm, b=2.5μm



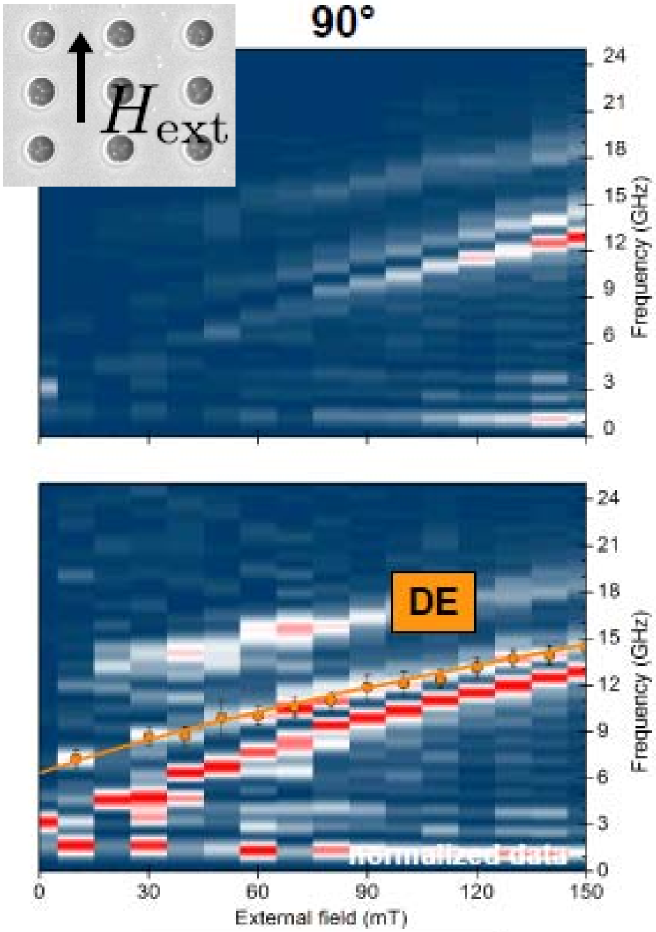
a=2.5μm, b=3.5μm

Rectangular structure

$$a_1 = 3.5\,\mu m, a_2 = 2.5\,\mu m, d = 0.8\,\mu m, f = 5.7\,\%$$



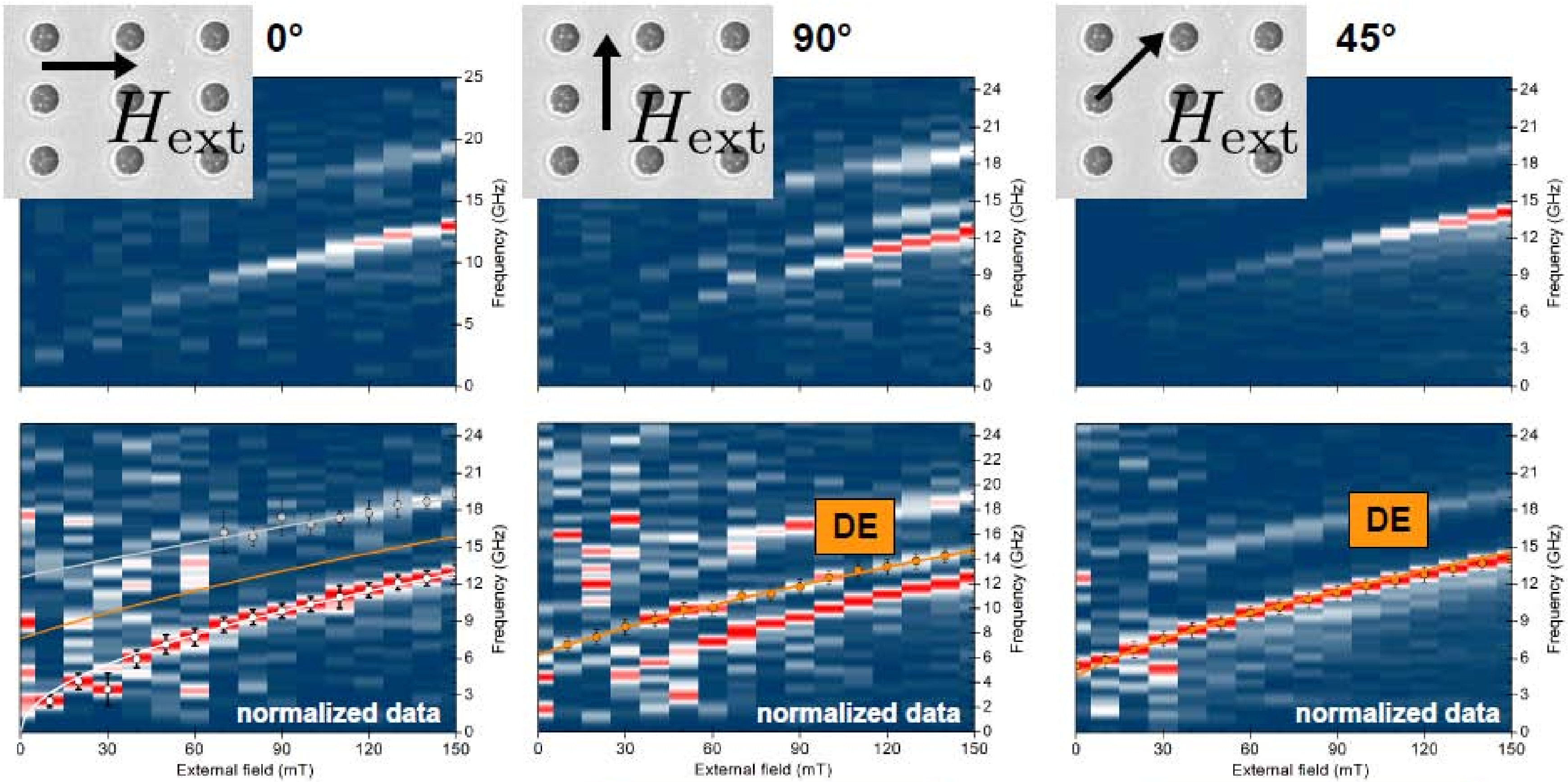
$$\frac{\lambda}{2} = 2.57(7)\,\mu m$$



$$\frac{\lambda}{2} = 3.60(27)\,\mu m$$

Rectangular structure

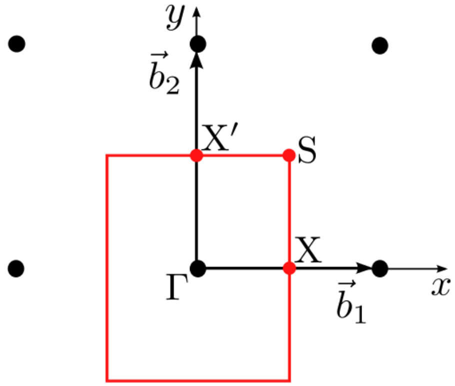
$$a_1 = 3.5\,\mu m, a_2 = 2.5\,\mu m, d = 1.1\,\mu m, f = 12.1\,\%$$

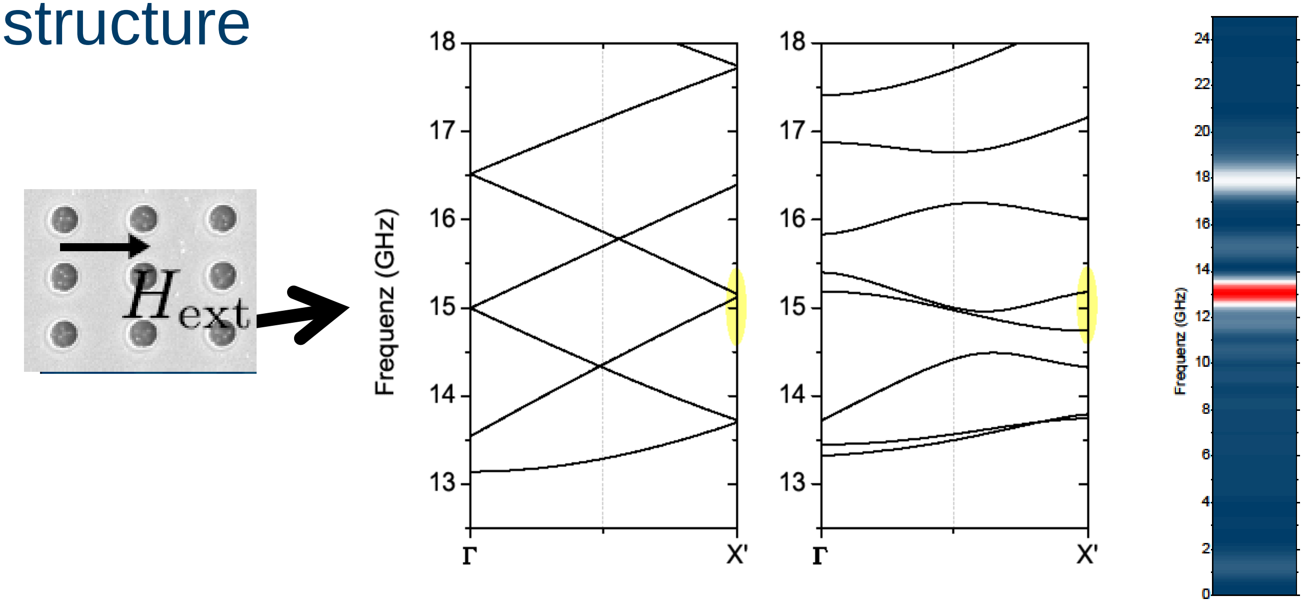


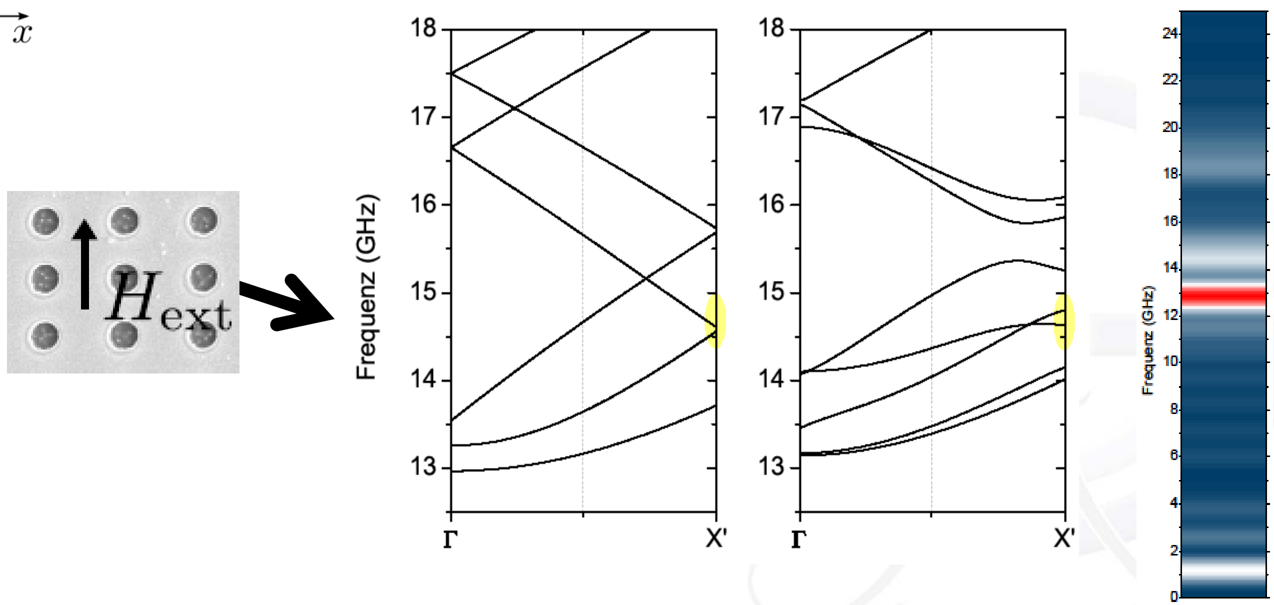
$$\frac{\lambda}{2} = 3.56(27)\,\mu m$$

$$\frac{\lambda}{2} = 3.77(28)\,\mu m$$

Rectangular structure







link

Summary

magnonic metamaterials

- Periodic structures 2D arrays have strong effects on mode structures
- Magnetic metamaterials
- Both collective localized (Ni) and delocalized modes (CoFeB) are observed, “filling fraction”
- Allows to implement magnonic wave guide structures

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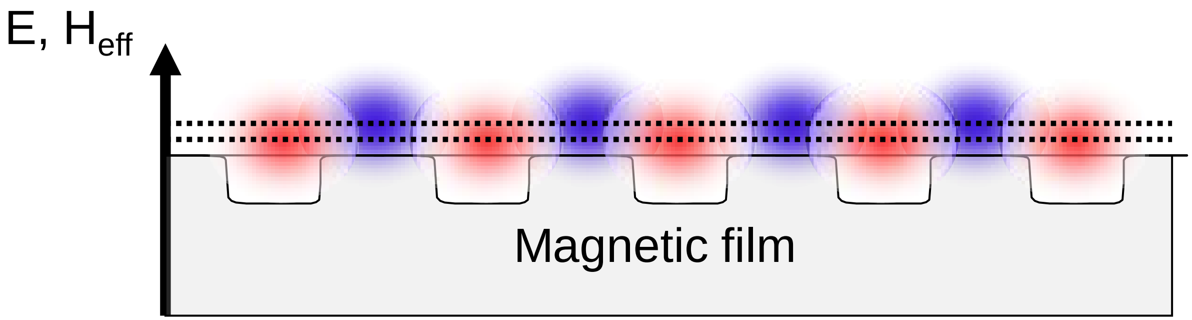
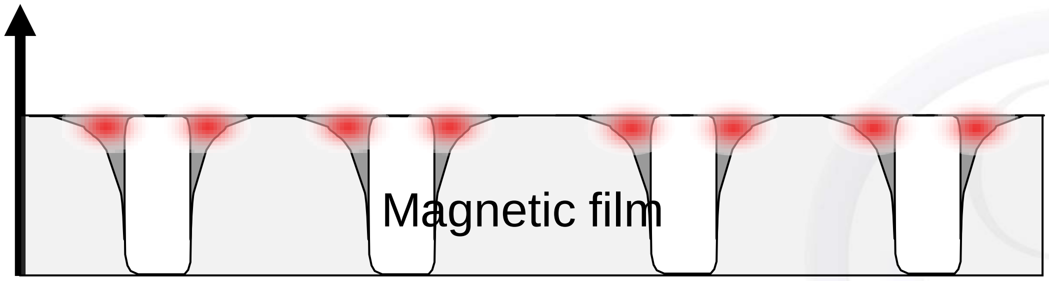
Bloch states for magnons

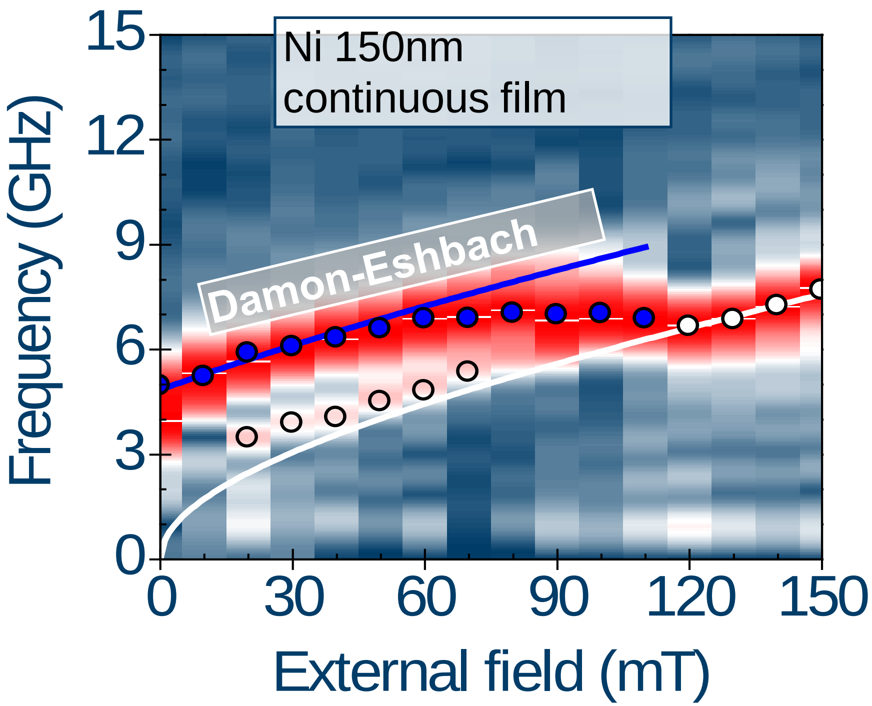


Periodic structures and Bloch states

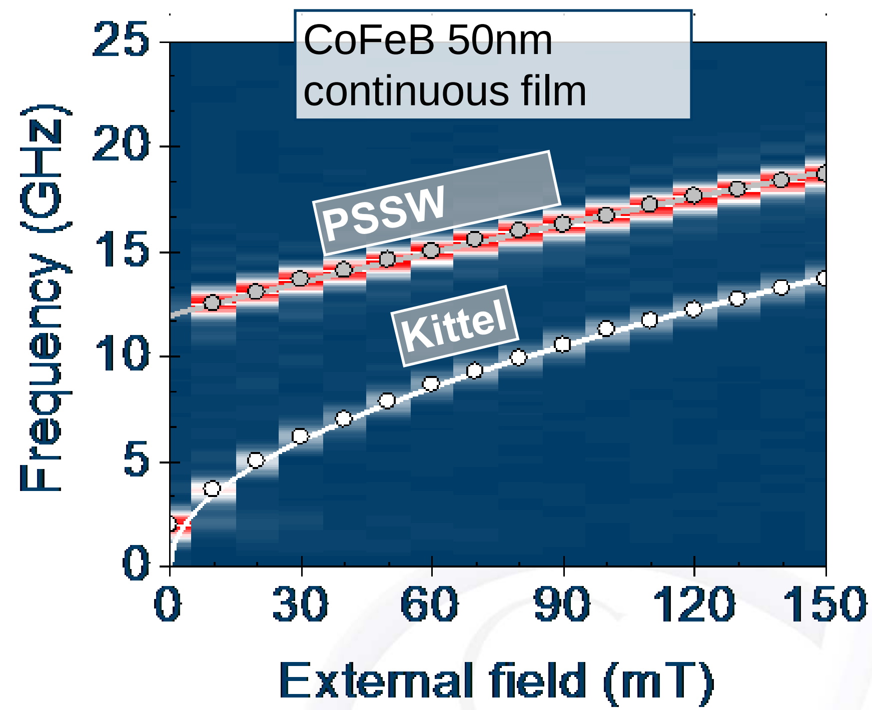


Periodic structures and localized states

From Ni to CoFeB: low damping materials

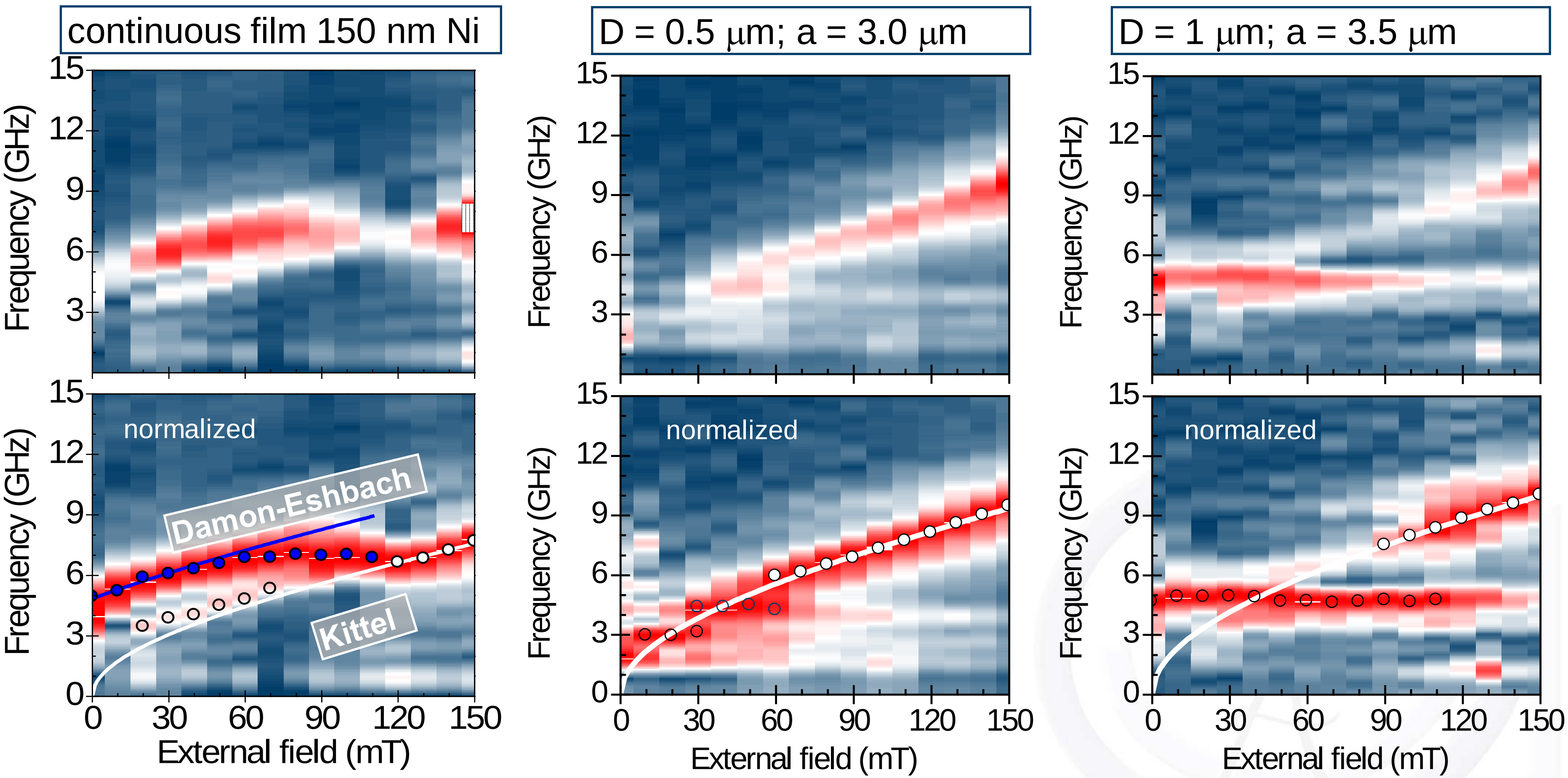


- Gilbert damping α=0.02
- Spin-wave propagation length from phase velocity: ~10 µm



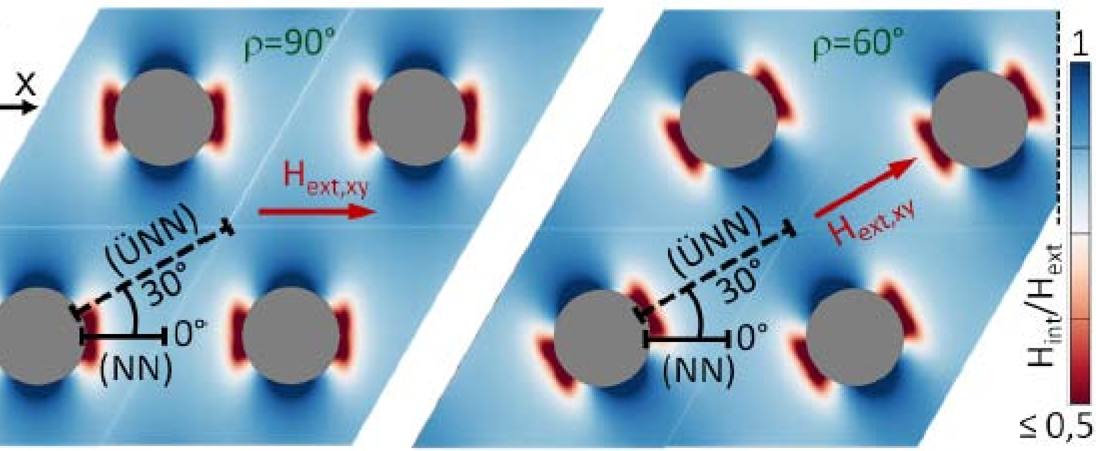
- Gilbert damping α=0.006
- Spin-wave propagation length from phase velocity: >100 µm

2-Dim magnonic crystal: Ni films



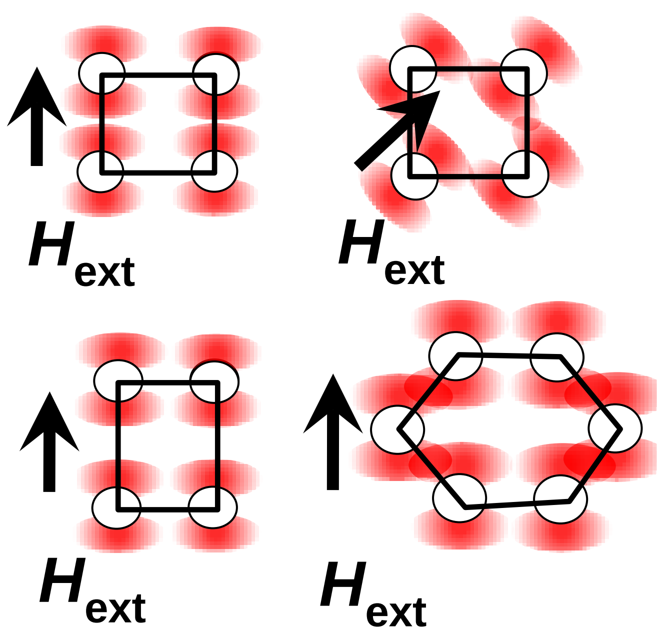
B. Lenk et al., Building blocks of magnonics, Physics Reports, advance online

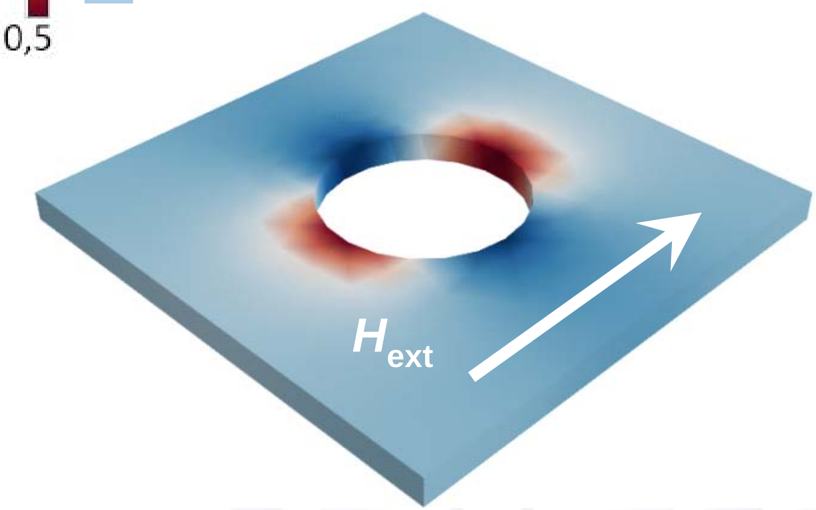
Localized vs. extended modes



Periodic internal field

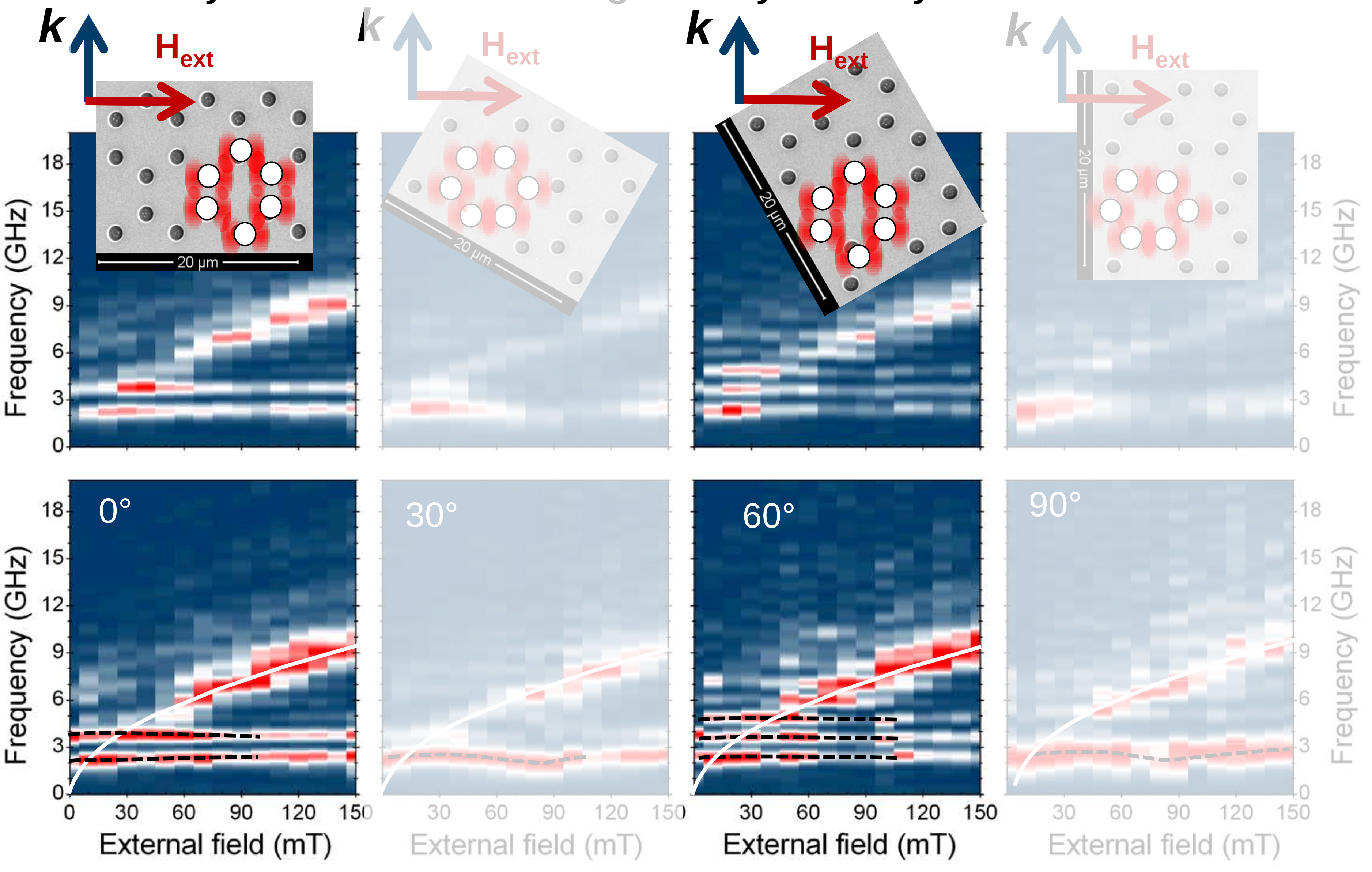
- Magnon potential wells and areas of weak disturbance in close proximity





Simulation using *Nmag* by Fischbacher, Fangohr

Honeycomb lattice: hexagonal symmetry



Honeycomb lattice: hexagonal symmetry