JSSP

Joint School on Spin Physics

SFB / TRR 173 + 227

Apolda 2021

ABSTRACT BOOKLET

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Ultrafast Spin Dynamics

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The conference is fully organized by a collaboration of PhD students of the TRR173 and the TRR227.

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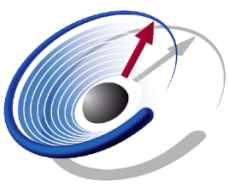

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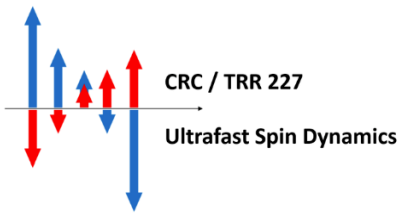

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Ultrafast Response Functions

Sangeeta Sharma[1]

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Ultrafast magnetization dynamics induced by femtosecond laser pulses is a rapidly developing research field. This is due to the vast increase in speed that such processes offer over traditional methods of magnetic manipulation. Due to short timescales and the push towards smaller lengthscales, the problem is intrinsically quantum-mechanical and thus challenging to understand and predict. In this regard, both theory and experiment must work together in order to comprehensively understand the problem. However, it has been difficult for theory and experiments of work in tandem in the field due to the fact that the experimental observables are often indirect measurements of those that are simulated; experiments rely on spectroscopy to study transient magnetization dynamics. In theoretical work on femtomagnetism on the the other hand, the fundamental quantity calculated is the dynamics of the spin magnetic moment itself [1-4,7,8,9].

The ability to measure and calculate the same physical quantity thus forms the cornerstone of the vital collaboration between theory and experiment, and I will discuss recent work where we have *ab-initio* calculated the real time response functions of L-edge and M-edge semi-core states during spin dynamics, demonstrating both good quantitative agreement with experiment [5,6] but also showing how theory can actually predict new phenomena and guide new experiments.

References:

[1] Dewhurst et al. Nano Lett. 18, 1842, (2018)

[2] Elliott et al. Scientific Reports 6, 38911 (2016)

[3] Shokeen et al. Phys. Rev. Lett. 119, 107203 (2017)

[4] Chen et al. Phys. Rev. Lett. 122, 067202 (2019)

[5] Willems et al. Nat. Comm. 11, 1 (2020)

[6] Dewhurst et al. Phys. Rev. Lett. 124, 077203 (2020)

[7] Hofherr et al. Sci. Advs. 6, eaay8717 (2020)

[8] Siegrist et al. Nature 571, 240 (2019)

[9] Golias et al. Phys. Rev. Lett. 126, 107202 (2021)

Spectrally resolving ultrafast magnetization dynamics using XUV light: Exchange scattering. superdiffusive spin transport, optically induced intersite spin transfer and beyond

Daniel Steil[1]

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In my presentation, I will highlight the opportunities of using XUV-light as a spectrally resolved probe in ultrafast spin dynamics. Starting from the observation of exchange scattering in NiFe-alloys [1], I will discuss the examples of the experimental verification of superdiffusive spin currents in metallic trilayer systems [2,3], and the recent discovery of optically induced intersite spin transfer (OISTR). OISTR describes the fastest possible manipulation of spins by light [4,5] and has been experimentally verified by several groups by now [6-12]. Beyond OISTR, spectrally distinct spin dynamics in nonequilibrium have recently been observed [13,14] even in single-element magnets. I will try to complement this topic by discussing some of our own recent experimental data.

References

[1] S. Mathias et al., Proc. Natl. Acad. Sci. **109**, 4792 (2012)
[2] D. Rudolf et al., Nat. Commun. **3**, 1037 (2012)
[3] E. Turgut et al., Phys. Rev. Lett. **110**, 197201 (2013)
[4] P. Elliott et al., Sci. Rep. **6**, 38911 (2016)
[5] J. K. Dewhurst et al., Nano Lett. **18**, 1842 (2018)
[6] F. Siegrist et al., Nature **571**, 240 (2019)
[7] M. Hofherr et al., Sci. Adv. **6**, eaay8717 (2020)
[8] P. Tengdin et al., Sci. Adv. **6**, eaaz1100 (2020)
[9] D. Steil et al., Phys. Rev. Research **2**, 023199 (2020)
[10] F. Willems et al., Nat. Commun. **11**, 871 (2020)
[11] C. von Korff Schmiesing et al., Appl. Sci. 10, 7580 (2020)
[12] E. Golias et al., Phys. Rev. Lett. **126**, 107202 (2021)
[13] K. Yao et al., Phys. Rev. B. **102**, 100405(R), 2020
[14] M. Hennes et al, Appl. Sci. **11**, 325 (2020)

Massively parallel atomistic simulations of complex magnets

Richard Evans[1]

[1]Department of Physics, University of York, Heslington, York, YO10 5DD, UK

Magnetic materials are increasingly complicated, especially for applications in green energy, data storage and spintronics. Atomistic models provide deep insight into the behaviour of nanoscale magnetic devices. In this talk I will introduce atomistic spin models and their theoretical framework and their parallel implementation enabling large scale calculations on thousands of processor cores. I will discuss their extension to complex magnetic materials that enable a quantitatively accurate model of the temperature dependent properties of NdFeB permanent magnets. Atomistic models have been instrumental in understanding ultrafast magnetization dynamics and I will present recent results on domain formation and heat induced switching of ferrimagnetic metals. Finally I will present recent results on 2D magnetic materials and the absence of universality in temperature scaling of magnetic properties as well as predicting the existence of unusual magnetization dynamics including field driven domain walls in 2D antiferromagnets and ultrafast magnetic solitons.

References

[1] Dewhurst et al. Nano Lett. 18, 1842, (2018)

[2] Elliott et al. Scientific Reports 6, 38911 (2016)

[3] Shokeen et al. Phys. Rev. Lett. 119, 107203 (2017)

[4] Chen et al. Phys. Rev. Lett. 122, 067202 (2019)

[5] Willems et al. Nat. Comm. 11, 1 (2020)

[6] Dewhurst et al. Phys. Rev. Lett. 124, 077203 (2020)

[7] Hofherr et al. Sci. Advs. 6, eaay8717 (2020)

[8] Siegrist et al. Nature 571, 240 (2019)

[9] Golias et al. Phys. Rev. Lett. 126, 107202 (2021)

Probing ultrafast spin transport with terahertz electromagnetic pulses

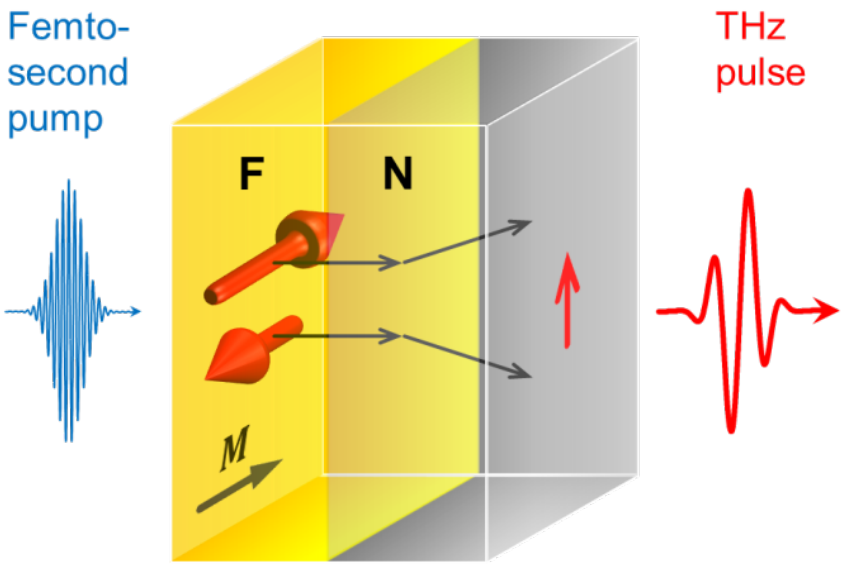
Tobias Kampfrath[1]

[1]Freie Universität Berlin and Fritz Haber Institute of the Max Planck Society

To take advantage of the electron spin in future electronics, spin angular momentum needs to be transported and detected. Electric fields and temperature gradients have been shown to efficiently drive spin transport at megahertz and gigahertz frequencies. However, to probe the initial elementary steps that lead to the formation of spin currents, we need to launch and measure transport on much faster, that is, on femtosecond time scales. This goal is achieved by employing ultrashort optical and terahertz electromagnetic pulses in conjunction with spin-orbit coupling. We obtain new insights into important spintronic phenomena such as spin-caloric transport [1], spin-to-charge-current conversion [2] and anisotropic magnetoresistance [3]. Interesting photonic applications such as the generation of ultrashort terahertz electromagnetic pulses also emerge [4].

References

[1] S.M. Rouzegar *et al*., arXiv:2103.11710 (2021)
[2] Gueckstock *et al*., Advanced Materials 2006281 (2021)
[3] Nadvorník *et al*., Physical Review X **11**, 021030 (2021)
[4] Seifert *et al*., Nature Photon. **10**, 483 (2016); Fülöp *et al*., Advanced Optical Materials 1900681 (2019)



Quantum Engineering of Magnonic States in Layered Ferromagnets

Khalil Zakeri[1]

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Magnons are the representative quasiparticles of spin excitations in a magnetically ordered solid. In single-element bulk ferromagnets, one expects to observe a single exchange-dominated magnon band dispersing along all possible directions of the Brillouin zone. The magnonic bandwidth can exceed several hundreds of terahertz. In contrary, in atomically designed ultrathin ferromagnetic films and multilayers the quantum confinement permits the existence of multiple magnon modes, which shall exhibit an in-plane momentum. However, how such magnonic bands are formed in layered structures and what is the origin of different magnonic states is not fully understood yet.

We present our recent experimental results on the observation and investigation of terahertz confined magnon modes in various ferromagnetic layered structures. We discuss how one may tune the properties of these confined magnon modes and achieve entirely different in-plane magnon dispersions, characterized by positive and negative group velocities. Comparing the results to those calculated based on linear-response time-dependent density functional theory, we comment on the physical mechanism behind the decay of these magnonic states [1].

Next, we will unravel the origin of the observed bands and bring the topic of magnonic surface and interface states in layered ferromagnets into discussion. We provide experimental examples of synthetic layered structures, supporting our discussions and show that the magnonic surface and interface states can be tailored in artificially fabricated layered structures. We demonstrate that the magnonic surface or interface states may show peculiar features, including “standing” or “ultrafast” states [2].

Finally, we will propose a method for quantum engineering of the magnonic band structure and will demonstrate the possibility of designing an atomic scale terahertz magnonic crystal [3].

[1] Kh. Zakeri, A. Hjelt, I. V. Maznichenko, P. Buczek, and A. Ernst, Phys. Rev. Lett. **126**, 177203 (2021).

[2] Kh. Zakeri, H. J. Qin and A. Ernst, Commun. Phys. **4**, 18 (2021). DOI: 10.1038/s42005-021-00521-7.

[3] H. J. Qin, S. Tsurkan, A. Ernst and Kh. Zakeri, Phys. Rev. Lett. **123**, 257202 (2019).

Seeing or listening: magnetoelastic effects in antiferromagnetic textures

Olena Gomonay[1]

[1]INSPIRE Group, Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany

Antiferromagnets are considered as prospective materials for spintronic applications as they could be effectively manipulated with the electrical and optical pulses, and also show magnetic dynamics and low susceptibility to the external magnetic field. The mechanisms involved into control and manipulation of antiferromagnetic states were usually related with the current- or laser-induced spin-torques. However, recent experiments demonstrated that heating and heat-induced strains that follow current and laser pulses can produce similar or even stronger effects on the magnetic dynamics. In this presentation we consider behaviour of antiferromagnetic textures in presence of inhomogeneous strain fields of different origin. In particular, we discuss the magnetoelastic mechanism that is responsible for formation of the domain structure, magnetoelastic pinning of the domain walls, and thermo-magnetoelastic mechanism of current-induced switching.

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2	Hassan	Al-Hamdo	Magnetization Dynamics in ferromagnetic/antiferromagnetic hybrids
3	Ahmed	Alhassanat	Element-specific magnetic properties of mixed 3d-4f metallacrowns
4	Tim	Amrhein	Optical control of 4f orbital state in rare-earth metals
5	Sanjay	Ashok	Ultrafast demagnetization dynamics including spin-, charge- and heat- transport
6	Chowdhury	Shadman Awsaf	Laser induced demagnetization of [Co/Pt]n samples.
7	Tomás	Périé de Barros	Impact of electron correlation on the light-induced demagnetization
8	Benedikt	Baumann	UHV in-situ preparation techniques of multi-spin molecules
9	Sven	Becker	Electrical detection of the spin reorientation transition in antiferromagnetic TmFeO3 thin films and single crystals by spin Hall magnetoresistance
10	Michael	Berger	Spin-Resolved Quantum Scars
11	Mona Manjaree	Bhukta	Direct Imaging of Chiral Domain Walls and Néel-Type Skyrmionium in Ferrimagnetic Alloys using SEMPA
12	Jan	Böhnke	Ultrafast dynamics of direct and indirect excitation pathways of the topologically protected surface states on Sb2Te3
13	Lukas	Bolz	Infrared spectroscopy on multi-spin carrying metallacrown molecules
14	Satya Prakash	Bommanaboyena	Strongly exchange coupled Mn2Au/Ni81Fe19 bilayers for antiferromagnetic spintronics
15	Martin	Borchert	Bringing the particle accelerator to the lab
16	Oliver	Busch	Anomalous and spin Hall effect in chiral antiferromagnets Mn3X (X = Ir, Sn, ...)
17	Bikash	Das Mohapatra	Investigation of electromagnetic and electrical response of Spintronic THz Emitters by micropatterning and manipulation of stack geometry
18	Felix	Dusabirane	Electron-magnon scattering dynamics in a two-band model
19	Peter	Elliott	Insights into spin dynamics from ab-initio simulations

Poster Session 1B

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21	Sumit	Ghosh	Ultrafast optical generation of antiferromagnetic spin spirals and underlying electronic interactions
22	Oliver	Gückstock	Terahertz spin-to-charge conversion by interfacial skew scattering in magnetic metal bilayers
23	Luca	Haag	Optically Induced Electron Dynamics in Graphene
24	Tobias	Held	Density-Dependent Electron-Phonon Coupling in Multiband Systems
25	Anna	Hellenes	Giant and tunneling magnetoresistance in unconventional collinear antiferromagnets with non-relativistic spin-momentum locking
26	Paul	Herrgen	Optical manipulation of the antiferromagnetic order in a Pt/NiO bilayer system by ultrafast energy transfer
27	Katharina	Hilgert	Electron Dynamics of intercalated Graphene Layers on Nickel
28	Jonas	Hoefer	Disentangling the Ultrafast Magnetization Dynamics in Magnet/Non-Magnet Bilayer Systems
29	Albert	Hönemann	Edelstein effect and spin-orbit torque in ferromagnetic/ nonmagnetic multilayers
30	Wolfgang	Hoppe	Investigation of laser-induced ultrafast current pulses in nanolayered, metallic material systems up to the THz regime
31	Rahil	Hosseinifar	Magnetic imaging study of magnetic toggle switching in GdFe thin films induced by femtosecond laser pulses
32	Denis	Iagodkin	Time-resolved photocurrent towards spin resolution
33	Rodrigo	Jaeschke Ubiergo	Spin transport in Altermagnets
34	Fabian	Kammerbauer	Search for current-induced interlayer DMI in synthetic antiferromagnets
35	Robin	Kamrla	Photoemission and double photoemission spectroscopy on SrTiO3 and SrRuO3 with MHz high-order harmonics
36	Ross	Knapman	Current-Induced H-Shaped Skyrmion Creation and Their Dynamics in the Helical Phase
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39	Akira	Lentfert	Combined tr-MOKE, BLS and THz-radiation setup for the investigation of THz spin-wave modes and their contribution to the ultrafast demagnetization process
40	Christian	Lotze	A THz Scanning Tunneling Microscope - Going Ultrafast with Atomic Resolution
41	Jake	Love	Audio Recognition with Skyrmion Reservoir Computing
42	Maximilian	Mattern	Laser-induced metamagnetic phase transition of FeRh studied by a combined UXRD and MOKE experiment
43	Hendrik	Meer	Direct Imaging of Current-Induced Antiferromagnetic Switching Revealing a Pure Thermomagnetoelastic Switching Mechanism in NiO
44	Martin	Mitkov	Excitonic states and exciton dynamics in organic semiconductors
45	Gizem	Ozcan	Elastoconductivity in Altermagnets
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47	Henrike	Probst	Ultrafast element-resolved magnetization dynamics using a fiber- laser-driven high-harmonic generation light source
48	David	Reiss	Theory of spin-Hall magnetoresistance in the AC (THz) regime
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55	Benjamin	Schwager	Coupled electronic charge and spin dynamics on curved spaces
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57	Martin	Stiehl	Wavelength dependency in ultrafast magnetization dynamics of Ni
58	Abolfazl	Tavakoli	Ferro and ferrimagnetic switching dynamics due to exchange scattering
59	Tim	Titze	Ultrafast Spectroscopy of La0.7Sr0.3MnO3/La2CoMnO6 Superlattices
60	Jorge	Torres	X-ray absorption spectroscopy of spin-crossover molecules and analysis by means of AI methods
61	Sergey	Trishin	Moire tuning of spin excitations: Individual Fe atoms on MoS2/Au(111)
62	Markus	Ühlein	Implementation of the electronic non-equilibrium in the two- temperature model
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64	Christopher	Weiß	K-space investigation on structured monocrystalline silver flakes
65	Huijuan	Xiao	The role of magnon-phonon hybridization in the lifetime broadening of surface states in rare-earth metals
66	Kelvin	Yao	All-optical switching on the nanometer scale excited and probed with femtosecond extreme ultraviolet pulses
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68	Xinwei	Zheng	Ultrafast magnetization dynamics in Fe at the BZ edge studied by tr-ARPES
69	Gregor	Zinke	Influence of a non-magnetic substrate on optically induced transport in a ferromagnetic alloy

Magnetic Coupling in $Y_3Fe_5O_{12}/Gd_3Fe_5O_{12}$ Heterostructures

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Ferrimagnetic $Y_3Fe_5O_{12}$ (YIG) is the prototypical material for studying magnonic properties due to its exceptionally low damping. By substituting the yttrium with rare earth elements that have a net magnetic moment, we can introduce an additional spin degree of freedom [1]. Here, we study the magnetic coupling in epitaxial $Y_3Fe_5O_{12}/Gd_3Fe_5O_{12}$ (YIG/GIG) heterostructures grown by pulsed laser deposition. From bulk sensitive magnetometry and surface sensitive spin Seebeck effect and spin Hall magnetoresistance measurements, we determine the alignment of the heterostructure magnetization as a function temperature and external magnetic field. The ferromagnetic coupling between the Fe sublattices of YIG and GIG dominates the overall behavior of the heterostructures. Because of the temperature-dependent gadolinium moment, a magnetic compensation point of the total bilayer system can be identified. This compensation point shifts to lower temperatures with increasing YIG thickness due the parallel alignment of the iron moments. We show that we can control the magnetic properties of the heterostructures by tuning the thickness of the individual layers, opening up a large playground for magnonic devices based on coupled magnetic insulators. These devices could potentially control the magnon transport analogously to electron transport in giant magnetoresistive devices [2].

References:

[1] A. B. Harris; Phys. Rev. **132**, 2398 (1963).

[2] H. Wu, L. Huang, C. Fang, B. S. Yang, C. H. Wan, G. Q. Yu, J. F. Feng, H. X. Wei, and X. F. Han; Phys. Rev. Lett. **120**, 097205 (2018).

Magnetization Dynamics in ferromagnetic/antiferromagnetic hybrids

Hassan Al-Hamdo[1], Vitaliy Vasyuchka[1], Philipp Pirro[1], Moritz Ruhwedel[1], Martin Jourdan[2], Mathias Kläui[2] , Yaryna Lytvynenko[2] and Mathias Weiler[1]

[1]Fachbereich Physik, Technische Universität Kaiserslautern
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Ferromagnets and antiferromagnets feature qualitatively different magnetization dynamics. While ferromagnetic magnons are typically gapless at zero external magnetic field, antiferromagnetic magnons have THz frequency. Thus, spin dynamics of ferro/antiferromagnetic bilayer systems are expected to host excitations of hybrid character.

We study magnetization dynamics of a Mn2Au/NiFe thin film bilayer system. This system allows us to control the Mn2Au Néel vector orientation with moderate in-plane external magnetic fields < 100 mT [1]. Mn2Au furthermore shows strong spin-orbit torque efficiency [2] making this system intriguing for all-electrical control of magnetization direction. We vary the NiFe thickness to study the effect of the Mn2Au/NiFe interface on NiFe spin dynamics.

Our Broadband Ferromagnetic resonance (BBFMR) and Brillouin light scattering (BLS) experiments reveal that interfacial exchange coupling causes an increase in the resonance frequency of NiFe. This increase is inversely proportional to the thickness of the NiFe layer. The NiFe resonance frequency and the spectral weight of the NiFe perpendicular standing spin waves (PSSWs) depend on the orientation of the external magnetic field in the film plane (see Figure 1), which is attributed to a uniaxial in-plane anisotropy of the Mn2Au film. We furthermore observe a hysteretic behavior of two distinct uniform-mode NiFe resonances that accompanies the switching of the Mn2Au Néel vector direction. From our BLS measurements we extract the influence of the Mn2Au/NiFe interface on the NiFe spin wave dispersion.

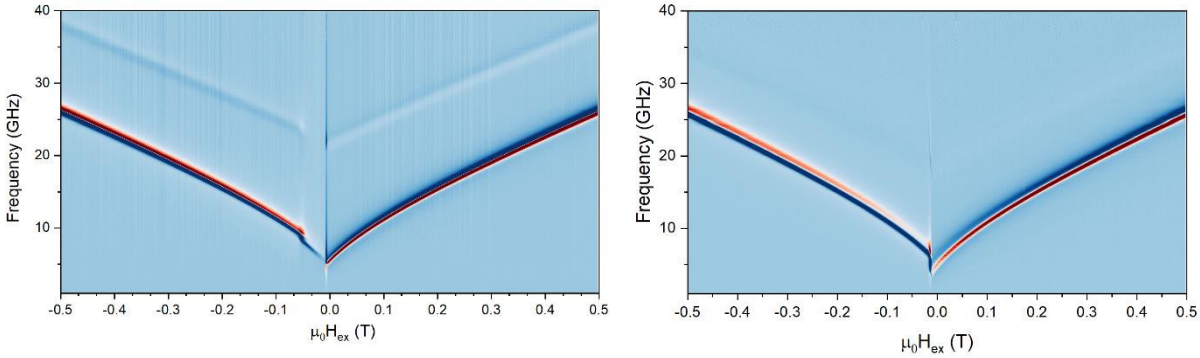

Figure1: BBFMR measurements of Mn2Au/NiFe(30nm). a) the measurement was performed in α orientation (α is an assumed orientation), where the NiFe FMR and PSSW are visible. b) shows the orientation α+90°, where the PSSW disappeared and switching fields changed.

References:

[1] Bommanaboyena et al., arXiv 2106.02333 (2021)

[2] Bodnar et al., Nature Communications 9, 348 (2018)

Element-specific magnetic properties of mixed 3*d*-4*f* metallacrowns

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Single molecule magnets comprising rare earth metals are of high interest due to the unquenched orbital moments of the rare earth ions that result in a large energy barrier for magnetization reversal. We investigate the magnetic properties of polynuclear 3*d*-4*f* 15-MC-5 metallacrowns using x-ray magnetic circular dichroism of powder samples at a temperature of 7 K in a magnetic field of 7 T. The magnetic moments of the 3*d* transition metal Ni(II) ions are coupled antiferromagnetically to each other and contribute only little to the total molecular moment. The spin and orbital moments of the rare earth ions are unexpectedly smaller than the ionic values resulting from Hund's rules because of a finite magnetic anisotropy along the molecules axis. Considering an energy functional including magnetic anisotropy and Zeeman energy the powder average reveals a magnetic anisotropy of 28 meV (340 K) in the case of Dy(III) and 7 meV (85 K) in the case of Tb(III). The spin moments agree with the ionic value when the expectation values of the dipole operator are considered. [1]

Another 3*d*-4*f* double-decker metallacrown molecules have been investigated.[2] The double decker metallacrowns comprise of one rare earth Gd(III) or Tb(III) ion embedded between two squared scaffolds of four Ni(II) ions. The sum rules results in unusual increase of Ni(II) moments when get dissolved in methanol solvent. This has been attributed to a spin crossover from a low to high spin state due to a change of coordination Ni ions. Charge transfer multiplet calculations confirmed this claim.

References:

[1] A. Alhassanat, C. Gamer *et al*; *Phys. Rev. B*, 064428, **98** (2018)

[2] A. Alhassanat, L. Völker *et al*; *Jour. Phys. Z*, 98765, **32** (2012)

Optical control of 4f orbital state in rare-earth metals

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High density magnetic storage devices base on materials with large magneto crystalline anisotropy (MCA) that needs to be overcome by laser heating above the Curie temperature to enable bit writing [1]. In a time-resolved X-ray absorption experiment at the European XFEL we found that the MCA itself can be manipulated on fs time scales by an optical stimulus [2]. In 4f rare-earth metals the magnetic moment and high MCA stems from the 4f system that is not directly accessible with optical wavelengths. We show, however, that the direct excitation of 5d electrons drives 4f-5d inelastic electron scattering and 4f-5d electron transfer, initiating orbital excitations in the 4f shell that change the MCA tremendously. Besides the technological relevance of such handle on MCA, 4f electronic excitations directly alter exchange and electron-phonon coupling and thus contribute to a more fundamental understanding of non-equilibrium dynamics.

References:
[1] Challener W. et al. *Nature Photon 3*, 220-224 (2009).
[2] arXiv:2106.09999

Influence of a non-magnetic substrate on optically induced transport in a ferromagnetic alloy

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Optical manipulation of magnetic materials on extremely short, sub-100fs timescales can be achieved either by generation and injection of optically induced (ballistic) spin currents or by direct excitation of the spin system, for instance by the optically induced spin transfer (OISTR) effect as shown in [1, 2].

In this work, we aim to reveal the mutual interplay of these spin transfer effects on ultrafast timescales. Therefore, we investigate the ultrafast demagnetization of a thin Fe20Ni80 alloy on a non-magnetic Au substrate and how it is influenced by the spin-dependent charge transport into the Au substrate.

As an element-resolved probe of the spin dynamics, we employ time resolved Kerr spectroscopy with fs-XUV radiation in transversal geometry to disentangle the spectroscopic signatures of the OISTR and ballistic spin transport in this material. Our results will be compared to the magnetization dynamics of a Fe20Ni80 film on an insulating substrate.

References:

[1] Dewhurst et al.; *Nano Lett.*, 18, 3, 1842–1848, (2018)

[2] Hofherr et al.; *Sci. Adv.*, 6(3), eaay8717 (2020)

Ultrafast demagnetization dynamics including spin-, charge- and heat- transport.

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Ultrafast Demagnetization of metallic ferromagnets induced by femtosecond laser is usually studied in homogeneously heated thick films. In such cases, due to absence of temperature and density gradients within the material, there are no heat- or charge-currents. For thicker magnetic metals, the heating is not uniform and spin-, charge- and heat-transport contribute to ultrafast de- and re- magnetization. Here we study the role of spin-resolved charge and heat transport in ultrafast demagnetization of thick magnetic metal using the thermodynamic μT-model [1] and obtain spatial and temporal evolution of magnetization. We also study the role of transport for the relation between quenching and quenching time. Further, we analyze the different transport mechanisms and their contributions to measurable quantities.

References:

[1] B. Y. Mueller and B. Rethfeld, Phys. Rev. B 90, 144420 (2014)

Laser induced demagnetization of $[Co/Pt]_n$ samples.

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Pt atoms at the interface of Co/Pt multilayers cause strong and localized d-orbital hybridization in Co which induces an increased perpendicular orbital moment in Co atoms [1]. As a result, Co/Pt films exhibit high perpendicular anisotropy. Large coercivity along with high anisotropy has unfolded many application possibilities of Co/Pt layers in magnetic memories [2] and spintronic devices [3]. Despite several studies on ultrafast demagnetization of Co/Pt samples, investigating various parameters involved like sample structure [4, 5], laser fluence and magnetic field [6], a complete picture of the underlying magnetization dynamics is still unclear. Exploiting the magneto-optical Kerr effect (MOKE) as a femtosecond probe for the temporal evolution of magnetization, we explore the temporal behavior of the exchange bias effect, due to direct coupling, for Co/Pt films. Different repetitions of the ferromagnetic Co/Pt multilayers were grown on different antiferromagnetic layers namely, manganese iridium (MnIr) and manganese platinum (MnPt). Using our self-assembled TR-MOKE setup, we try to observe the effects when we pump a system comprised of a multilayer ferromagnetic with high spin-orbit coupling (Co/Pt) combined with an AFM (MnIr) and (MnPt). The investigation targets several questions like, does the AFM order change the observed magnetization times compared to Co/Pt? What happens if we swap Ir and Pt? Does the AFM order influence spin transport?

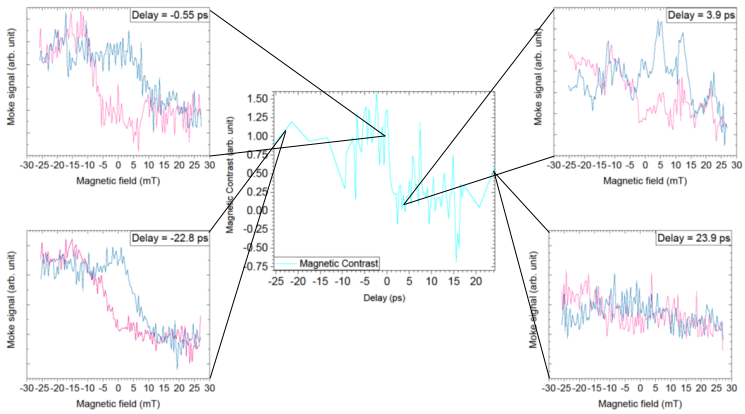

Fig.1: Hysteresis at different pump-probe time delays of femtosecond demagnetization of [Co (5.2 Å)/Pt(10 Å)]/MnPt(30 Å) at 20.37 mJ/cm^2 pump fluence. The magnetic contrast is normalized by the average value at negative delay times.

References:

[1] A. Barman et al., *J. Appl. Phys*., 09D102, **101**, (2007)

[2] R. Sbiaa et al., *Phys. Status SolidiRRL*, 413,**5**, (2011)

[3] P. Matthes et al., *IEEE Trans. Magn*., 1,**51**, (2015).

[4] N. Bergeard et al., *Phys. Rev. Lett*., **117**, 147203 (2016).

[5] A. Bonda et al., *J. Magn.Magn. Mater*., 166702, **505**, (2020).

[6] N. Moisan et al., *Sci. Rep*., 4658, **4**, (2014).

Impact of electron correlation on the light-induced demagnetization of elemental ferromagnetic metals

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The local spin-density approximation (LSDA) is known to describe poorly the electronic structure of 3d transition metals, yet most density-functional-based ab-initio studies of ultrafast demagnetization rely on it. One way to account for Coulomb correlations among the localized d electrons and go beyond LSDA is to include the effective correlation energy (or Hubbard) U. In this poster I present the results of simulations with the real-space TDDFT code Octopus [1] with different values of Hubbard U and show also how the various laser parameters, such as pulse duration or intensity, change the magnetization dynamics.

References:

[1] Andrade, D. Strubbe, U. De Giovannini, A. H.Larsen, M. J. T. Oliveira, J. AlberdiRodriguez, A. Varas,I. Theophilou, N. Helbig, M.J. Verstraete, L. Stella,F. Nogueira, A.

[2] Aspuru-Guzik, A. Castro, M. A. L. Marques, and A. Rubio, Phys. Chem. Chem. Phys 17, 31371 (2015)

Infrared spectroscopy on multi-spin carrying metallacrown molecules

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Multi-spin carrying metallacrown complexes are a promising platform for the development of new spintronic applications [1,2]. Of particular interest in this infrared spectroscopic study on metallacrowns are $\{\mathrm{Cr(III)}(\mu_2-\mathrm{piv})_3[9-\mathrm{MC}_{\mathrm{Cr(III)N(shi)}}-3](\mathrm{morph})_3\}\mathrm{MeOH}$, $(\mathrm{HNEt_3})_2\{\mathrm{Cu(II)}[12-\mathrm{MC}_{\mathrm{Cu(II)N(shi)}}-4]\}$ and $\{\mathrm{Cu(II)(DMF)_2Cl_2}[12-\mathrm{MC}_{\mathrm{Fe(III)N(shi)}}-4](\mathrm{DMF})_4\}\cdot 2\mathrm{DMF}$. Their magnetic properties and therefore potential use as single molecular magnets are characterized by an axial magnetic anisotropy, their high spin ground state, and their energy barrier to magnetization reversal and thus a resulting long relaxation time.

For possible applications and devices molecules need to be deposited on surfaces. At the interface, possible reactions might have a critical influence on the resulting systems or even cause the molecule to decompose. Therefore, it is essential to check the molecular structure and molecular integrity afterwards. One method of investigation is infrared spectroscopy. The wavelength-, or frequency-dependent absorption of infrared radiation by excitation of molecular vibration modes is individually unique to each molecular structure and can be used to accurately identify substances.

The building blocks of the metallacrowns do not form covalent bonds to an unreactive silica surface during the adsorption process. Nevertheless, the metallacrowns stay intact. The respective coordination bonds between the building blocks can be observed in the IR spectra. This fact can be exploited for the qualitative evaluation of the infrared spectra. The observed absorption bands in the spectra of both the metallacrowns and the uncoordinated building blocks are brought into accordance with the adsorbed metallacrowns. Differences and shifts are then identified, defining unique features for intact metallacrowns. The results of this investigation can be used in future experiments using different preparation methods, including in-situ preparation within the ultra-high vacuum to demonstrate the presence and intactness of the metallacrowns.

References:

[1] P. Happ, E. Rentschler, *Dalton transactions* (Cambridge, England: 2003) 43, 15308 (2014)
[2] A. Lüpke, L.M. Carrella, E. Rentschler, *Chemistry – A European Journal* 27, 4283 (2021)

Strongly exchange coupled $Mn_2Au/Ni_{81}Fe_{19}$ bilayers for antiferromagnetic spintronics

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Mn_2Au is a metallic, collinear antiferromagnet (AFM) which possesses the requisite crystallographic symmetry to enable the manipulation of its magnetic order via current induced Néel spin-orbit torques [1,2]. In this work, we demonstrate an exceptionally strong exchange coupling of epitaxial Mn_2Au films with very thin Permalloy ($Ni_{81}Fe_{19}$) layers [3]. We demonstrate the perfect imprinting of the AFM domain pattern of Mn_2Au on the Permalloy overlayer, which is attributed to a specific atomic termination of the Mn_2Au(001) layer at the interface. Ferromagnetic hysteresis loops of exchange coupled Py layers with a thickness of 2 nm show a large coercive field of 0.5 T. This is found to arise from a joint rotation of both the AFM Néel vector and the magnetization of the FM layer. These results unlock novel possibilities for the readout of next generation spintronics devices based on antiferromagnets.

References:

[1] J. Železný et al. Phys. Rev. Lett. **113**, 157201 (2014).
[2] S. Yu. Bodnar et al. Nat. Commun. **9**, 348 (2018).
[3] S.P. Bommanaboyena et al, arXiv:2106.02333 (2021)

Electrical detection of the spin reorientation transition in antiferromagnetic $TmFeO_3$ thin films and single crystals by spin Hall magnetoresistance

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TmFeO3 (TFO) is a canted antiferromagnet that undergoes a spin reorientation transition (SRT) with temperature between 82 and 94 K in single crystals[1]. In this temperature region, the Néel vector continuously rotates from the crystallographic *c*-axis (Γ_2, below 82 K) to the *a*-axis (Γ_4, above 94 K). The SRT allows for a temperature control of distinct antiferromagnetic states without the need for a magnetic field, making it apt for applications working at terahertz frequencies.

Here, we investigate both TFO thin films[2] and single crystals using the all-electrical spin Hall magnetoresistance (SMR)[3]. The surface-sensitive technique allows for the determination of the magnetic state of the whole sample. We further observe an additional contribution to the transverse resistivity, possibly arising from the Dzyaloshinskii–Moriya interaction (DMI) at the TFO/Pt interface.

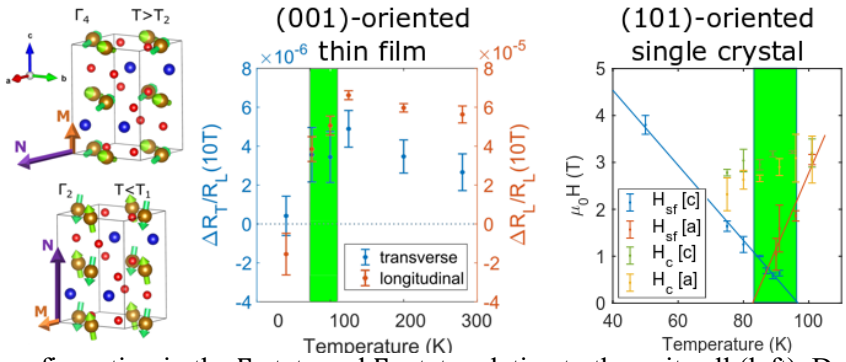

Fig.1: Magnetic configuration in the $\Gamma_4$state and Γ_4 state relative to the unit cell (left). Detection of the SRT by SMR in (001)-oriented TFO thin films (middle) by transverse (R_T) and longitudinal resistivity (R_L) and in (101) single crystals (right) by the determination of the spin flop field via R_L.

References:

[1] J.A. Leake, G. Shirane, J.P. Remeika.; *Solid State Commun*, **6**, 15 (1968)

[2] **S. Becker**, A. Ross, R. Lebrun, L. Baldrati, S. Ding, F. Schreiber, F. Maccherozzi, D. Backes, M. Kläui, and G. Jakob; *Phys. Rev. B* **103**, 024423 (2021)

[3] H. Nakayama, M. Althammer, Y.-T. Chen, K. Uchida, Y. Kajiwara, D. Kikuchi, T. Ohtani, S. Geprägs, M. Opel, S. Takahashi, R. Gross, G. E. W. Bauer, S. T. B. Goennenwein, and E. Saitoh; *Phys. Rev. Lett.* **110**, 206601 (2013)

THz spin dynamics in antiferromagnetic Mn2Au driven by Néel spin-orbit torque

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In antiferromagnets, the intrinsic terahertz (THz) magnon resonances are expected to enable pathways to high-speed spin information processing. In antiferromagnetic CuMnAs and Mn_2Au, switching of the Néel vector has been demonstrated by using pulsed electrical currents and free-space THz pulses [1-3]. The switching was attributed to the Néel spin-orbit torque (NSOT), which is proportional to the current. However, the underlying spin dynamics have not been observed on ultrafast timescales. Here, we employ a THz-pump optical-probe setup to investigate perturbative spin dynamics in Mn_2Au thin films. The direction of the Néel vector was prealigned via spin-flop transition in a high magnetic field (60 T) [4]. We observe a signal that depends linearly on the driving THz field and is in frequency and symmetry consistent with NSOT-driven spin dynamics. The spin motion corresponds to a strongly damped magnon with frequency of 0.6 THz, suggesting that NSOT allows for spin control via ultrafast currents in Mn2Au.

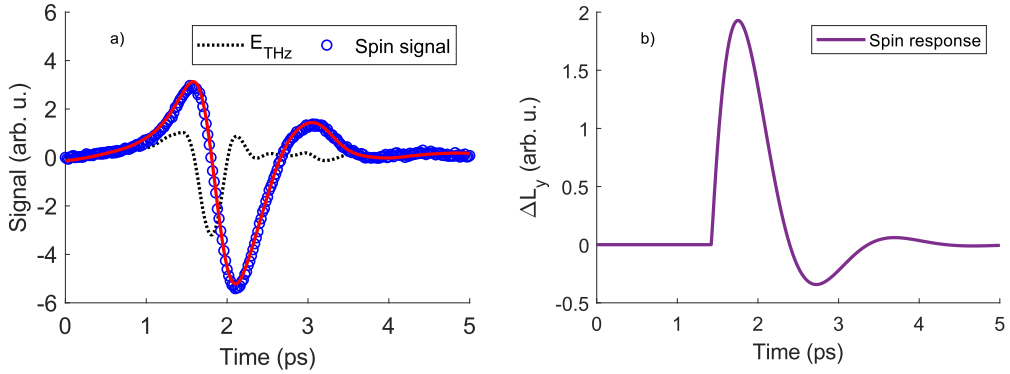

Fig.1: a) THz-induced spin signal from Mn2Au. Black-dotted line shows electric field of the driving THz pulse. Blue circles: Magneto-optical signal generated by perturbed spins. Red line: Fitted signal by convolution of E_{THz} with damped-oscillatory spin response (see b)) b) Damped oscillation of in-plane Néel vector (Spin response) extracted from a). The frequency corresponds to $f_0 = 0.59$ THz with strong damping.

References:

[1] P. Wadley et al., Science 351, 587-590 (2016)
[2] K. Olejnik et al., Sci. Adv. 4, eaar3566 (2018)
[3] S. Yu. Bodnar et al., Nat. Comm. 9, 348 (2018)
[4] A. Sapozhnik at al., Phys. Rev. B 97, 134429 (2018)

Spin-Resolved Quantum Scars

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Quantum scars refer to an enhanced localization of the probability density of isolated wavefunctions along closed periodic trajectories of the corresponding classical system.[1] They are discussed for numerous confined pure and impurity-doped electronic and acoustic systems. We studied the influence of the spin on quantum scarring for a two-dimensional electron gas subjected to a confining potential, an external magnetic field, and a Rashba-type spin-orbit coupling.[2] The coupling of pure and doped quantum systems can lead to increased density of scars within the wavefunction spectrum. Calculating the high energy spectrum for each spin channel and corresponding states, as well as employing statistical methods known for the spinless case, we showed that spin-dependent scarring occurs in a spin-coupled electronic system. Scars can be spin mixed or spin polarized and may be detected via transport measurements or spin-polarized scanning tunneling spectroscopy.

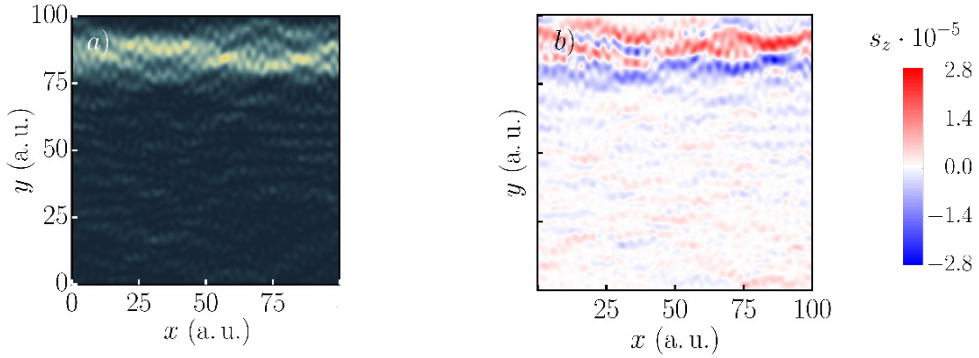

Fig.1: Charge density (a) and z-component of spin (b) for a rectangular system with a periodic boundary in x-direction.[2]

References:

[1] Heller E. J.: *Phys. Rev. Lett.*, 1515, **53** (1984)

[2] Berger M., Schulz D., Berakdar J.: Nanomaterials, 1258, **11** (2021)

Direct Imaging of Chiral Domain Walls and Néel-Type Skyrmionium in Ferrimagnetic Alloys using SEMPA

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Magnetic skyrmions[1] are twisted spin configuration, which could be stabilized by various interaction like Dzyaloshinskii-Moriya interaction[2-3], frustration exchange interaction, dipolar coupling etc. However, skyrmion shows a finite skyrmion Hall angle when driven by current in ferromagnetic material due to its topological nature[4]. Skyrmions in antiferromagnet or compensated ferrimagnets could suppress this effect owing to an overall zero topological charge.

In this study, we investigate the chirality of spin textures in a ferrimagnet namely GdFeCo by imaging the spin structure of the D using scanning electron microscopy with polarization analysis (SEMPA).

SEMPA is a powerful surface sensitive imaging techniques that uses the secondary spin polarized electrons emitted from a ferromagnetic material and determine the chiral character of out-of-plane magnetized spin textures. We observed that the domain wall spin textures exhibit a pure Néel-type homochirality that is consistent over a large temperature range and also reported the first direct observation of pure Néel-type skyrmionium in ferrimagnetic materials [Figure 1][6]. Our work unlocks the future possibilities of making/designing of skyrmionics devices in ferrimagnet.

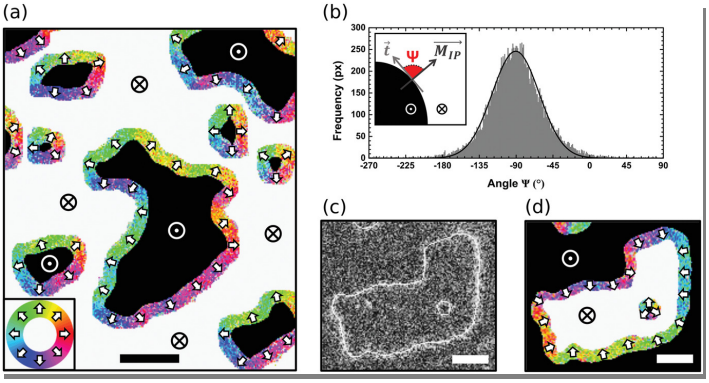

Figure 1: Determination of the magnetization direction inside the DW of different ferrimagnetic chiral spin textures. a) The direction of the in-plane magnetization in the DW is displayed, as defined by the color wheel in the bottom left corner of the image. Scale bar in a): 1 µm. b) Distribution of the direction of the in-plane magnetization in the DW with respect to the local tangent at RT: angle Ψ (see inset where a clockwise angle is defined as negative following the usual convention). A Gaussian fit indicates a central value around −90°. c) Absolute in-plane magnetization intensity with the DW skeleton displayed in white and d) direction of the in-plane magnetization in the DW of a ferrimagnetic skyrmionium at 320 K. Scale bars in c,d): 500 nm. Extracted from [6].

References:

[1] T. H. R. Skyrme, Nucl. Phys. 31, 556 (1962).

[2] I. Dzyaloshinskii, J. Phys. Chem. Solids **4**, 241 (1958).

[3] T. Moriya, Phys. Rev. **120**, 91 (1960).

[4] K. Litzius *et al.*, Nat. Phys. **13**, 170 (2017).

[5] Y. Hirata *et al.*, Nat. Nanotechnol. **14**, 232 (2019).

[6] B. Seng *et al.*, Adv. Funct. Mater., 202102307 (2021).

Ultrafast dynamics of direct and indirect excitation pathways of the topologically protected surface state on Sb_2Te_3

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Dirac cone like topologically protected surface states (TSS) have attracted high interest for spintronic applications due to their specific spin texture in momentum space and the long electron mean free path because of reduced scattering phase space. Optical control of electric currents at the surface of topological insulators has been discussed controversially [1, 2, 3, 4].

We investigated the role of direct and indirect population channels of the TSS on Sb_2Te_3 in 2D momentum space by time-and angle-resolved two-photon photoemission spectroscopy. Excitation with 1.55 eV photons leads to an initially anisotropic population of the Dirac cone depending on the helicity of the excitation pulse. This circular dichroism however predominantly exhibits a 3-fold symmetry, which reflects the symmetry group of the bulk material but does not correspond to a macroscopic current in the TSS. We investigated in detail the dependence of the different symmetry components on the sample's azimuthal orientation. Using a polar Fourier analysis on the observed dichroic images, we were able to extract the different frequency and phase contributions leading to the dichroic patterns. Since the photon energy exceeds the bulk band gap, the optical excitation creates also a significant electron population in the conduction band, which relaxes towards the band minimum on the timescale of few 100 fs. On the same timescale electrons scattered from the conduction band dominate the population in the TSS so that the anisotropy decays rapidly.

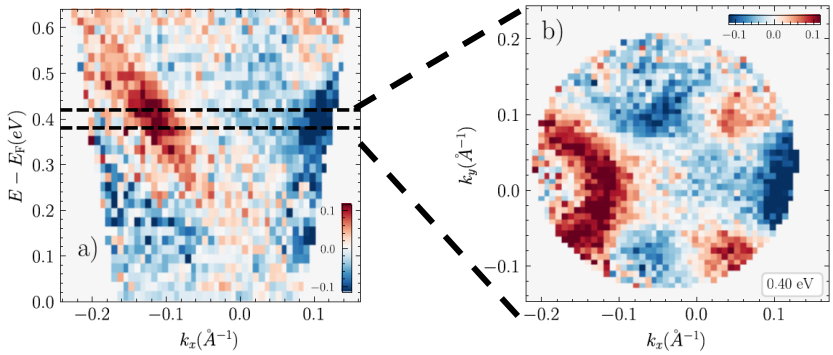

Fig.1: **(a)** Dichroic image (E vs. k_x) cut along k_y direction showing a strong asymmetry (up to 10 %) at an energy of 0.4 eV corresponding to the warped TSS region**. (b)** 2D momentum map at the energy of highest dichroic contrast reveals the 3-fold crystal symmetry together with a 2-fold anisotropy

References:

[1] J. McIver, D Hsieh, H Steinberg et al., *Nature Nanotechnology. 7*, 96-100 (2012)

[2] J. Sánchez-Barriga, E. Golias, A. Varykhalov et al., *Physical Review B 93,* 155426 (2016)

[3] A.S. Ketterl, S. Otto, M. Bastian et al., *Physical Review B 98*, 155406 (2018)

[4] J. Güdde and U. Höfer, *Phys. Status Soldi B*, 2000521, 258 (2020)

Bringing the particle accelerator to the lab.

Tabletop resonant soft X-ray scattering and circular dichroism

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Time- & element-resolved resonant magnetic (soft) X-ray scattering (RMXS) is a powerful tool for accessing the spatially-resolved and element-specific spin dynamics in (antiferro-) magnetic materials[1].

On the other hand, element-resolved magnetic circular dichroism (XMCD) is a powerful tool for accessing the spin dynamics in ferromagnetic materials[2].

So far, the application of these photon-demanding techniques were limited to large-scale facilities.

Here, we present the development of a lab-based instrument providing sufficient photon flux up to from 50 to 1500 eV photon energy, covering the soft-X-ray resonances of transition (e.g. Fe, Ni, Co) and rare-earth metals (eg. Gd, Tb, Dy, Ho).

Our setup features tunability in energy- and reciprocal-space in combination with sub-10 ps temporal resolution exploiting the broadband emission of a laser-driven plasma X-ray source, which is monochromatised to <1 eV bandwidth by a reflection zone plate for RSXS experiments (Fig.1a, 1b) .

Alternatively the randomly polarised light can be circularly polarised via an absorptive foil, allowing for single-shot broadband XMCD and even scattering experiments(Fig.1c, 1d) .

Our development lays the foundation for laser-driven RSXS and XMCD to study ultrafast ordering phenomena of charges, spins, and orbitals.

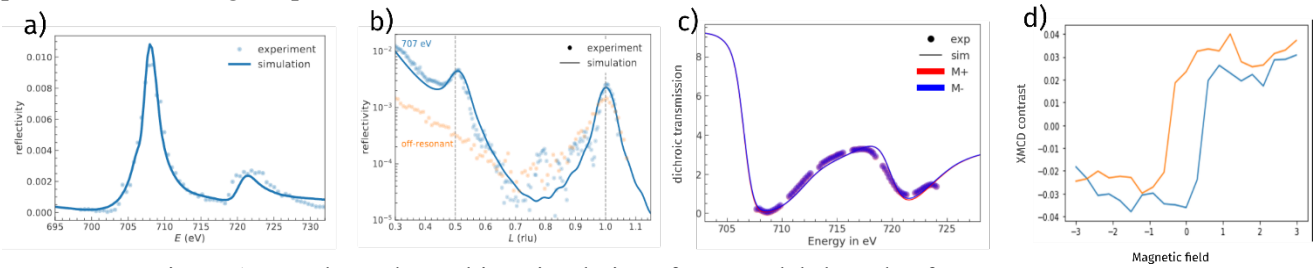

Figure 1: Results and matching simulations from our lab-based soft X-ray source

RSXS:

a) Reflection spectrum from antiferromagnetic Fe|Cr Superlattices
b) On- (707eV) & off- (690 eV) resonant magnetic scattering

XMCD:

c) Dichroic magnetic single-shot transmission spectrum
d) Hysteresis loop at 707 eV (Fe L3 edge)

References:

[1] D.Schick and M.Borchert, J.Braenzel, H.Stiel, J.Tümmler, D.Bürgler, A.Firsov, C.v. Korff Schmising, B.Pfau, and Stefan Eisebitt; *Optica*, 2021, (Accepted), https://doi.org/10.1364/OPTICA.435522

[2] M.Borchert, D.Schick, C.v. Korff Schmising, B.Pfau, D. Engel, and Stefan Eisebitt; 2021, (In Prep.)

Anomalous and spin Hall effect in chiral antiferromagnets Mn_3X (X=Ir, Sn, …)

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Recently, antiferromagnets (AFMs) gained attention due to their unique transport properties. Large anomalous Hall effects (AHEs) have been measured in the non-collinear kagome AFMs Mn_3Sn [1] and Mn_3Ge [2] and large spin Hall effects (SHEs) were predicted in such compensated Mn_3X systems [3].

We discuss the intrinsic contributions to both Hall effects of kagome AFMs via tight-binding calculations. We describe a microscopic mechanism for the occurrence of the AHE: within this model, spin-orbit coupling (SOC) is equivalent to an out-of-plane tilting of the magnetic texture [4]. Thus, the AHE can be interpreted as a topological Hall effect generated by the opening angle of the virtually tilted texture. Besides, we find that the main contribution to the SHE in Mn_3X is a pure spin current originating from the non-collinear magnetic texture and it occurs even without SOC when the AHE is absent [5]. In addition to that, SOC gives rise to the AHE and reduces the SHE effectively which gives rise to spin-polarized currents.

Therefore, non-collinear kagome AFMs have the potential for applications in spintronic devices where they might be utilizable as alternative generators for spin currents and spin-polarized currents in analogy to collinear AFMs and ferromagnets, respectively (cf. Fig. 1).

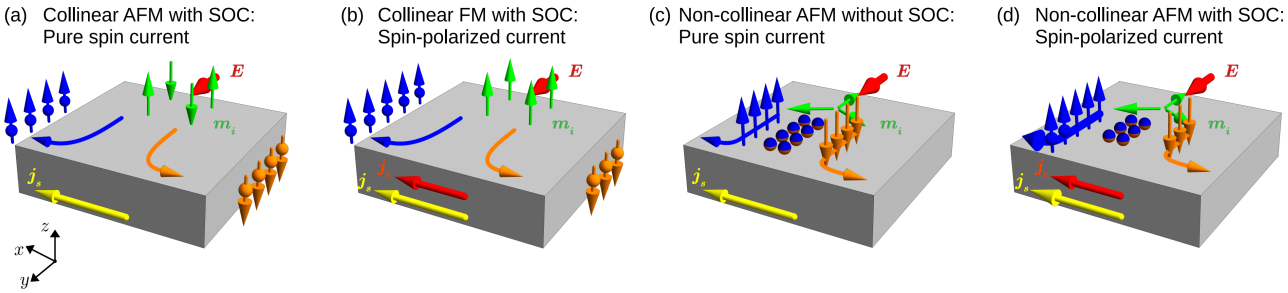

Fig.1: Overview of spin currents and spin-polarized currents in different magnetic systems as described in the panels [5]. Green arrows represent the magnetic texture $\{\boldsymbol{m}_i\}$. Electrons are distinguished according to their spin (blue: up, orange: down). Spin currents $\boldsymbol{j}_s$ (yellow) and charge currents $\boldsymbol{j}_c$ (red) are indicated by thin arrows as a transverse response to an applied electric field $\boldsymbol{E}$ (thick red arrows).

References:

[1] S. Nakatsuji, N. Kiyohara, T. Higo; *Nature (London)*, 212, **527** (2015)

[2] A. K. Nayak *et al.*; *Science Advances*, e1501870, **2** (2016)

[3] Y. Zhang *et al.*; *New Journal of Physics*, 073028, **20** (2018)

[4] O. Busch, B. Göbel, I. Mertig; *Physical Review Research*, 033112, **2** (2020)

[5] O. Busch, B. Göbel, I. Mertig; *Physical Review B*, submitted (2021)

Investigation of electromagnetic and electrical response of Spintronic THz Emitters by micropatterning and manipulation of stack geometry

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As Ultrafast Spintronics is fast gaining interest, it is relevant to investigate various devices to generate signal in THz regime. Various studies have shown the generation of ultrafast transverse charge current from spin current by the Inverse Spin Hall Effect resulting in THz electromagnetic pulses. We have investigated ultrafast electromagnetic response from THz emitters which are patterned into micron and sub-micron sized squares and rectangles. These emitters show an emission spectrum which is different than for large area reference emitters. We suggest that the confinement[1] results in local charge accumulation that creates additional currents that counteract the initial inverse spin Hall effect. We also investigate various ferromagnetic heterostructures to generate electrical response when they are illuminated with fs-laser pulse. Pulse magnitude and polarity can be manipulated by using different relative magnetization directions of the different ferromagnetic components in the stacks. The electrical response was measured using a 50 GHz sampling oscilloscope. All the structures were fabricated using Sputter deposition and e-beam lithography.

References:

[1] Z. Jin et al., "Terahertz Radiation Modulated by Confinement of Picosecond Current Based on Patterned Ferromagnetic Heterostructures ", Phys. Stat. Sol. 13, 1900057 (2019).

Imaging and phase-locking of non-linear spin waves

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Non-linear processes are a key feature in the emerging field of spin-wave based information processing. Non-linear phenomena allow converting uniform spin-wave excitations into propagating modes at different frequencies. Recently, the existence of non-linear magnons at half-integer multiples of the driving frequency has been predicted for $Ni_{80}Fe_{20}$ at low bias fields [1]. However, it is an open question under which conditions such non-linear spin waves emerge coherently and how to manipulate them in device structures. Here, we demonstrate a modified time-resolved microscopy approach for coherent imaging of the parametrically generated non-linear spin waves [2]. The spatially resolved observation of parametrically generated magnons in $Ni_{80}Fe_{20}$ elements allows to directly visualize their wave vectors (see Fig. 1). In addition, we demonstrate injection locking of the generated non-linear magnons. These results provide unprecedented insight into non-linear spin-wave processes and open new possibilities for applications such as spin wave sources and amplifiers.

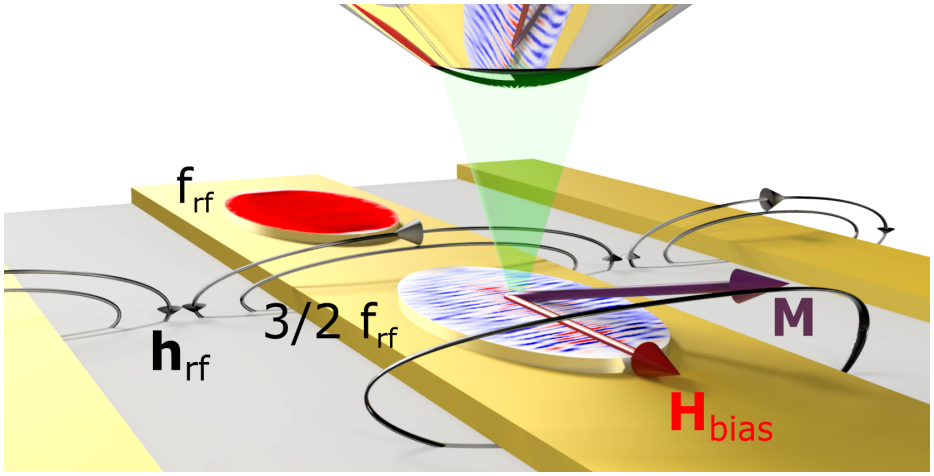

Fig.1: Magneto-optical imaging of non-linear magnetization dynamics at low bias fields in $Ni_{80}Fe_{20}$ microstructures simultaneously obtained at the driving frequency and half-integer multiples.

References:

[1] Bauer, H. G., *et al.*, Nat. Comm., **6**, 8274 (2015)
[2] Dreyer, R., *et al.*, PRM, **5**, 064411 (2021)

Electron-magnon scattering dynamics in a two-band model

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While a variety of incoherent and coherent electronic scattering mechanism are still being discussed in connection with ultrafast demagnetization dynamics, the fingerprint of magnons has so far been mainly been treated with quasi-static approximations, where magnons are included via constrained DFT calculations [1]. Here, we use a simpler model system of parabolic bands split by a Stoner exchange term to investigate electronic dynamics and under the influence of electron-electron and electron-magnon scattering processes [2]. Electron-electron and electron-magnon scattering are treated at the level of Boltzmann scattering integrals, where the magnons are treated as a bosonic bath, and the optical excitation process is assumed to be instantaneous. We discuss a numerical scheme that achieves excellent carrier-density conservation, which is needed for an accurate description of the dynamics. An example of the computed dynamics for the dynamical distribution functions $n_{k\sigma}(t)$. We discuss how the scattering dynamics depend on the magnon temperature, coupling exchange constant and exchange spin splitting energy.

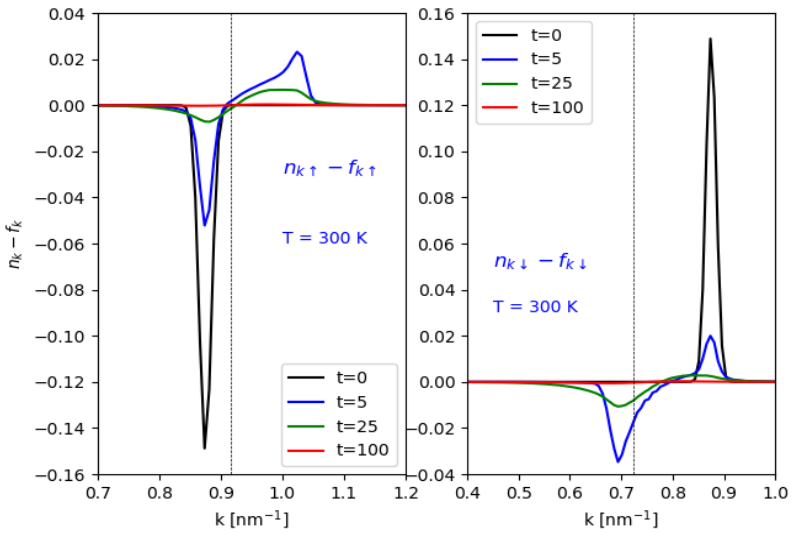

Fig.1: Relaxation dynamics for up and down spins for instantaneous excitation of carriers in the down-spin channel under the influence of electron-magnon scattering. The equilibrium electronic Fermi-Dirac distributions are denoted by $f_{k\sigma}$.

References:

[1] Turgut, E.et al.; *Phys. Rev. B*, 220408(R), **94** (1968)

[2] White R. M. and Woolsey, R. B.; *Phys. Rev.*, 908, **176** (1968)

Magnetic Coupling in Ferrimagnetic Bilayers

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With growing demands for faster and more energy efficient information technology, the utilization of magnons as information carriers is envisioned to be a major step forward [1]. To successfully develop magnon based devices, there are several requirements for the applied materials to meet. The insulating ferrimagnet Yttrium Iron Garnet ($Y_3Fe_5O_{12}$, YIG) and other garnets are good candidates with an outstanding low damping and large magnon propagation length [1].

Here, we investigate heterostructures of YIG and the insulating ferrimagnet Gadolinium Iron Garnet ($Gd_3Fe_5O_{12}$, GIG) [3, 4] grown by pulsed laser deposition. In contrast to YIG, the Gadolinium replaces the non-magnetic Yttrium and adds with its magnetic moment to the net magnetization of GIG. In heterostructures of YIG/GIG, we observe a ferromagnetic coupling between the Fe sublattices of the two layers leading to complex behavior in response to external magnetic fields and a nontrivial temperature dependence [2].

This observation is supported by measurements of the bulk sensitive SQUID magnetometry (Fig. 1) and surface sensitive spin Hall magnetoresistance [5, 6] and spin Seebeck effect measurements [6, 7].

The coupled bilayer shows a critical temperature at which its total magnetization is fully compensated. We show that the relative thickness of the YIG and GIG layers can be used to tune this critical temperature. So, we can control the magnetic properties to tune magnonic spin current propagation and magnonic properties and could help to switch magnon transport analogously to the giant magnetoresistance effect [8].

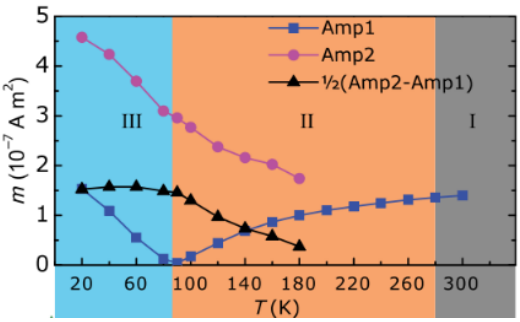

Fig.1: Temperature dependent SQUID magnetometry measurements of a YIG (36 nm)/GIG (30 nm) bilayer. There are three regions of interest, above the compensation temperature of pure GIG (I), below the compensation temperature of the bilayer (III) and in-between (II) [2].

References:

[1] A. Chumak, V. I. Vasyuchka, A. Serga et al., Nat. Phys, Vol. 11, p. 453–461 (2015)

[2] S. Becker, Z. Ren, F. Fuhrmann et al., Phys. Rev. Appl., 16, 014047 (2021)

[3] A. Brooks Harris, Phys. Rev. 132, 2398 (1963)

[4] T. Yamagishi, J. Awaka,Y. Kawashima et al., Philos. Mag. 85,1819 (2005)

[5] H. Nakayama, M. Althammer, Y.-T. Chen et al., Phys. Rev. Lett.110, 206601 (2013)

[6] M. U. Fayaz, M. S. Saleem, Y. Gu et al., J. Appl. Phys.126, 183901 (2019)

[7] J. Cramer, E.-J. Guo, S. Geprägs et al., Nano Lett.17, 3334 (2017)

[8] J. Cramer, F. Fuhrmann, U. Ritzmann et al., Nat. Commun. 9, 1089 (2018)

Ultrafast optical generation of antiferromagnetic spin spirals and underlying electronic interactions

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Recent experimental demonstration of ultrafast generation skyrmions [1] is one of the most profound landmarks in the field of optical manipulation of magnetic order. However the theoretical understanding of the underlying physics is still under mist. Most of the theoretical understanding is based on the magnetization dynamics which completely ignores the electronic interactions and miss the crucial channels of energy transfer from laser to the magnetic system. More advanced time dependent DFT based approaches are quite successful in explaining the ultrafast demagnetization, however, due to the high computational demand, they are limited within orders of 100fs and thus can't capture the slow magnetization dynamics happening after picoseconds. In this presentation we present a unified approach which creates a bridge between the two approaches [2]. By combining quantum evolution of states with classical magnetization dynamics we are able to capture the fast electronic interactions playing governing role in the first 50-100fs after being hit by the laser as well as the slow magnetization process that survives for several picoseconds leading to a steady chiral formation. We are able to identify the emergent chiral interaction behind the chiral formation and also able to estimate the lifetime. We show how the final chiral formation can be controlled by tuning the laser parameter as well as by material parameters which agrees well with the experimental finding. Our results shows that this chiral formation is intrinsically different from the thermally excited magnetization dynamics which is widely used to explain ultrafast demagnetisation.

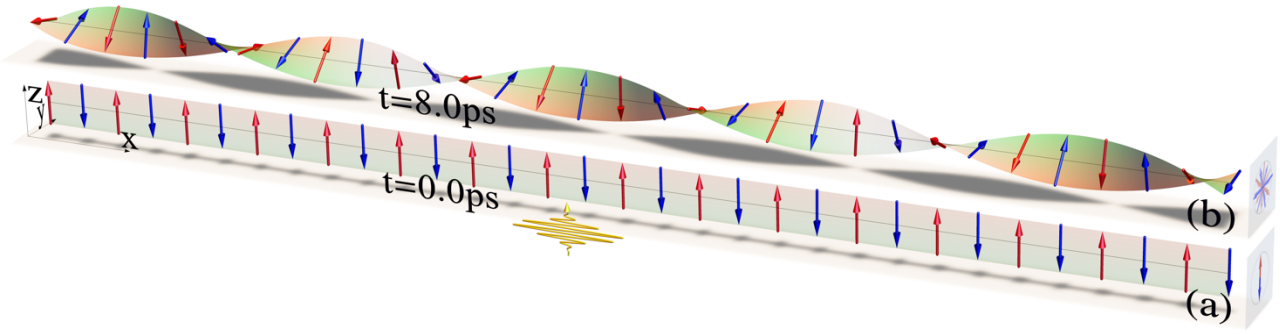

Fig.1: Formation of antiferromagnetic spin spiral with laser [2].

References:

[1] F. Büttner *et al.*, *Nat. Mater.*, vol. 20, no. 1, pp. 30–37, 2021.
[2] S. Ghosh *et al.*, *arXiv*, no. 2011.01670, pp. 1–5, 2020. http://arxiv.org/abs/2011.01670

Terahertz spin-to-charge conversion by interfacial skew scattering in magnetic metal bilayers

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An efficient spin-to-charge current conversion (S2C) is important for the detection and generation of spin currents in spin-based electronics [1]. Interfaces of heterostructures are known to have a marked impact on this process [2]. Here, we study ultrafast S2C at interfaces by terahertz (THz) emission spectroscopy [3-4] in a model system: F|N bilayers consisting of thin metal films of a ferromagnetic layer F and nonmagnetic layer N with strong and weak spin-orbit coupling (SOC). Varying the interface composition allows us to drastically change the amplitude and even invert the polarity of the THz charge current that is induced by S2C close to the interface. Remarkably, when N is a material with weak SOC, we find a dominant interface contribution to the ultrafast S2C. Symmetry arguments and first-principles calculations strongly suggest that the interfacial S2C arises from skew scattering of spin-polarized electrons at interface imperfections. Our results pave the towards designing S2C by interfacial skew scattering.

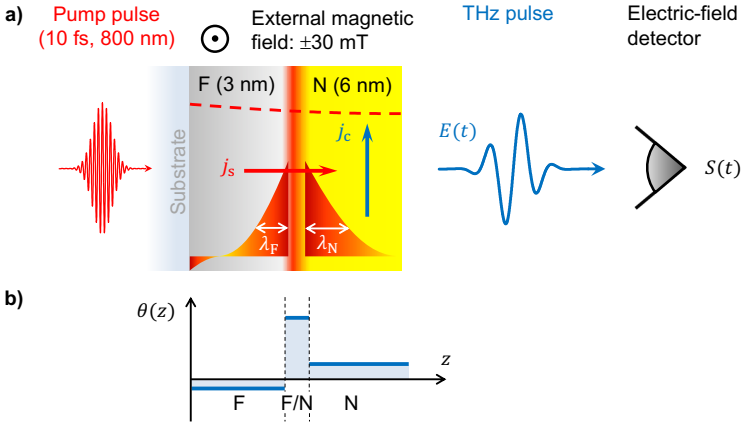

Fig.1: Photoinduced spin transport and spin-to-charge current conversion (S2C) in F|N bilayers.

References:

[1] F. Hellman *et al.*, Rev. Mod. Phys. 89,025006 (2017)
[2] M.B. Jungfleisch *et al.*, Phys. Rev. Lett. 121, 086801 (2018)
[3] T. Kampfrath *et al.*, Nature Nanotech. 8, 256 (2013)
[4] T. Seifert *et al.*, Nature Phot. 10, 483 (2016)

Optically Induced Electron Dynamics in Graphene

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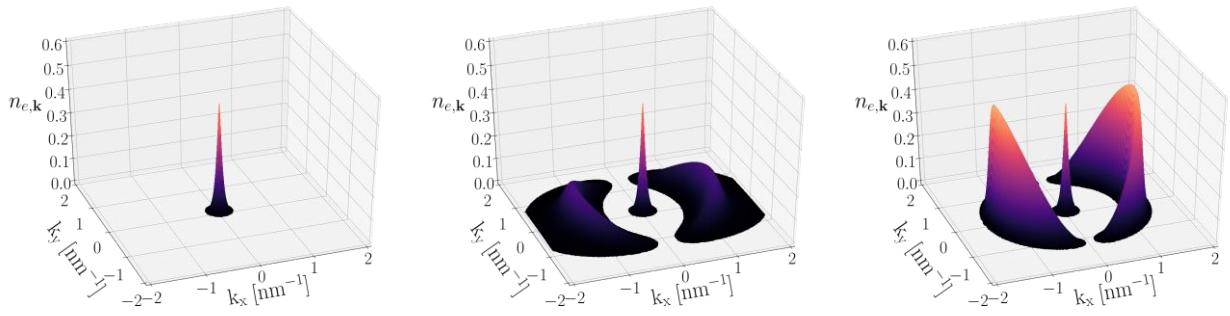
We investigate the fundamental processes concerning the optical excitation of graphene, following the basic approach developed in a series of papers by the research group of Malic and Knorr [1,2]. To this end, we calculate the bandstructure as well as the optical matrix elements using a tight-binding approach and study the excited electron dynamics numerically for a variety of parameters. The theoretical basis of the approach are the Semiconductor-Bloch-Equations, which allow us to study the excitation on ultrashort time scales in a microscopic fashion. By neglecting the electron-electronscattering and electron-phonon-scattering we investigate the occurrence of anisotropic excitations in graphene as well as the role of multi-photon-processes. Finally, we extend our model to describe the scattering dynamics by using a relaxation-time ansatz.



(a) t = -30 fs (b) t = 0 fs (c) t = 30 fs

Fig.1: Example of the anisotropic optical excitation of graphene around the K point of the Brillouin zone without scattering. The graph shows the occupation number in the valence band (a) before the excitation (b) during the excitation and (c) after the excitation with a laserpulse [3].

References:

[1] Ermin Malic and Andreas Knorr; “Graphene and Carbon Nanotubes. Ultrafast Relaxation Dynamics and Optics”, WILEY-VCH Verlag GmbH (2013)

[2] Torben Winzer; "Ultrafast Carrier Relaxation Dynamics in Graphene“, Dissertation, TU Berlin (2013)

[3] Luca Haag; "Theoretische Aspekte der optisch induzierten Elektronendynamik in Graphen“, Bachelorarbeit, TU Kaiserslautern (2021)

Density-Dependent Electron-Phonon Coupling in Multiband Systems

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When a solid is irradiated with a short-pulsed laser within the visible spectrum, the energy is almost entirely absorbed by the electrons while the lattice remains cold. The subsequent energy flow between electrons and phonons is commonly described by the electron-phonon coupling parameter, a central parameter in the Two-Temperature Model and most other temperature-based models.

This coupling parameter depends on a multitude of variables as reinforced by recent results. The most commonly considered dependence is the one on the electron temperature.

In this work we aim to see how the density distribution between different electronic subsystems affects the coupling parameter in combination with the electronic temperature.

For the different electron subsystems we distinguish between orbital types in gold and spins in magnetic nickel. The results show that the total coupling strongly depends on the density distribution for gold, while for nickel the influence is mostly compensated within both bands.

Giant and tunneling magnetoresistance in unconventional collinear antiferromagnets with non-relativistic spin-momentum locking

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When the electrical switching of an antiferromagnet (AF) was observed experimentally, it opened opportunities to research memories that are 1000 times faster than the conventional ferromagnetic (FM) ones[1]. So far, however, identifying AF counterparts of robust FM read-out mechanisms, such as giant magnetoresistance (GMR)[2], has been elusive due to the absence of spin polarised states and currents in conventional AFs. Recently, researchers delimited a previously overlooked class of unconventional AFs with nonrelativistic spin-momentum locking and spin-polarization[3]. Here we present our conceptualization of unprecedented AF GMR and TMR effects based on this spin-momentum locking[4,5]. We obtain magnetoresistance signals reaching the order of ~100%, not only in tight-binding toy models but also in density functional theory calculations of realistic material candidates such as RuO_2[5].

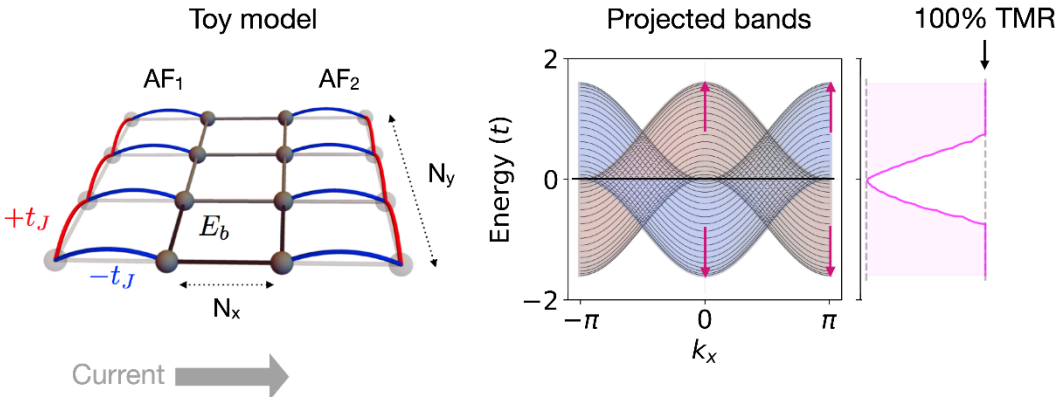

Fig.1: We obtain 100% TMR (right) for a toy model (left, middle) with the unconventional AF as leads (AF_1 and AF_2, with alternating nearest-neighbour hopping $\pm t_J \sigma_z$ in spin space), separated by a tunnel barrier (dark gray, onsite energy E_b, hopping t_b). AF_2 is the free layer where we switch the sign of t_J.

References:
[1] P. Wadley et al.; *Science, 351, 6273, 2* (2016)
[2] Claude Chappert, Albert Fert et al.; *Nature Materials, 6, 11* (2007)
[3] Libor Šmejkal, Jairo Sinova, Tomas Jungwirth; *arXiv:2105.05820*
[4] Libor Šmejkal, Anna Birk Hellenes et al.; *arXiv:2103.12664*
[5] Ding-Fu Shao, Shu-Hui Zhang et al.; *arXiv:2103.09219*

Optical manipulation of the antiferromagnetic order in a Pt/NiO bilayer system by ultrafast energy transfer

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Antiferromagnets are highly promising materials for future spintronic devices due to their strong resilience against external magnetic fields and their high frequency magnon modes. These modes can be found in the THz regime and enable the fast manipulation of antiferromagnetic materials on the sub-nanosecond to picosecond timescale.

In this contribution, we aim to go beyond these timescales and explore the sub-picosecond magnetization dynamics of the antiferromagnet NiO after strong optical excitation with fs light pulses. NiO is a prototypical antiferromagnetic insulator with a band gap of 4.3eV and a Néel-Temperature of 523K. The antiferromagnetic order of the NiO samples is monitored on ultrafast timescales using the magneto-optical birefringence of NiO in a pump-probe setup.

Here, we will present our results for two sample systems: (i) a thin NiO film and (ii) a Pt/NiO bilayer structures. For optical excitation with 1.5eV photon, no changes of the antiferromagnetic order can be observed for the bare NiO film. In contrast, we find a clear reduction of the magnetic order parameter for the Pt/NiO bilayer systems on sub-picosecond timescales despite the large band gap of NiO. Our observations are discussed in the framework of an extended muT model. This allows us to conclude that the ultrafast loss of antiferromagnetic order in the Pt/NiO bilayer system is mediated by a highly efficient energy transfer between the hot electrons in Pt and the NiO spin system.

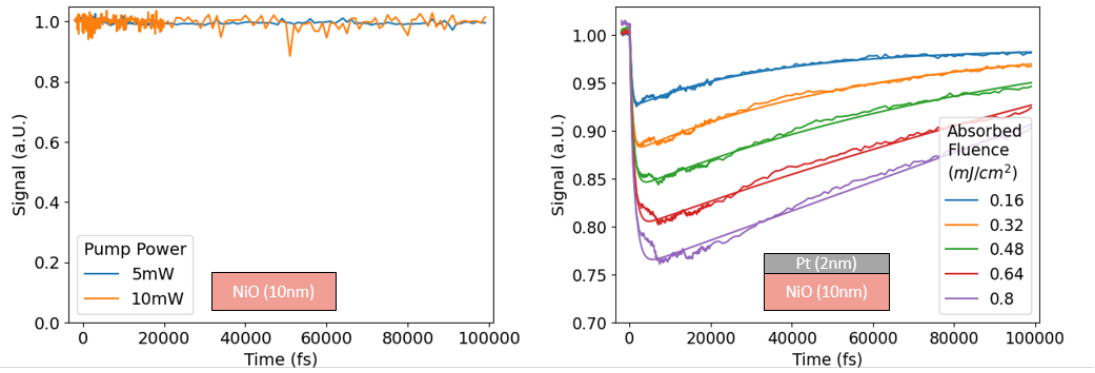

Fig.1: Fluence-dependent magnetic response of (i) a thin NiO film and (ii) a Pt/NiO bilayer after optical excitation with 1.5eV photons.

Electron Dynamics of intercalated Graphene Layers on Nickel

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One of the great challenges in information technology is to develop novel concepts and materials for the realization of active functional units on ever-smaller length scales. This challenge can be tackled by employing the unique electronic and optical properties of graphene and other 2D materials. However, their extraordinary properties are often severely altered on surfaces due to their strong chemical interaction with the substrate material [1, 2].

On this poster we present our approach to restore and design the electronic properties of graphene on a Ni(111) surface by intercalation of lead or dysprosium atoms. The electronic band structure of graphene on Ni(111) prior and after the interaction of Pb and Dy is monitored by angle resolved photoelectron spectroscopy (ARPES) with extreme ultra violet (XUV) radiation. On the highly reactive Ni(111) surface, the linear dispersion of the Dirac cone of the freestanding graphene sheet is completely suppressed by the strong graphene-surface interaction. This changes significantly after the intercalation of Pb. The band structure of the graphene/Pb/Ni(111) multilayer systems reveals again the linear dispersion of the Dirac cone with its Dirac point located at the Fermi energy. The latter resembles the behavior in free-standing graphene. Our findings hence set the stage for exploring the ultrafast spin-dependent charge carrier dynamics in a quasi-free-standing graphene layer on a ferromagnetic surface.

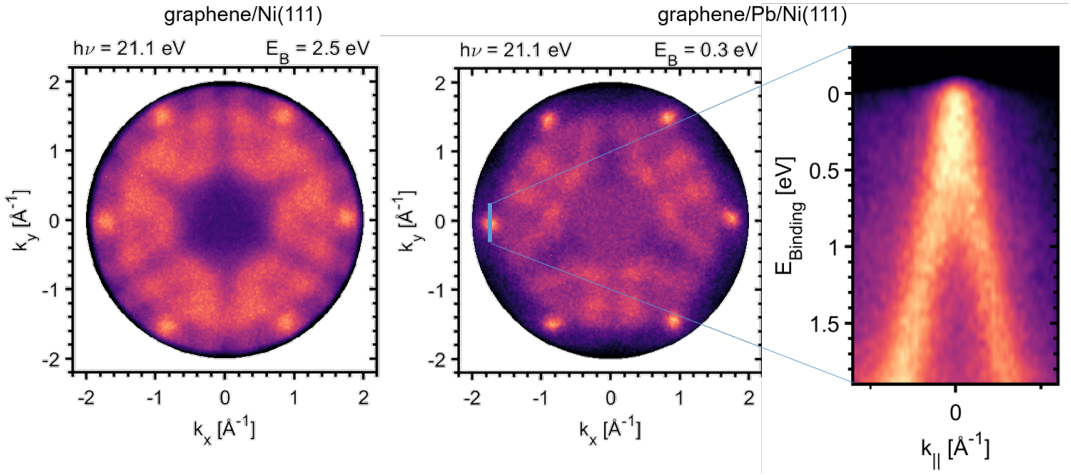

Fig.1: Bandstructure changes of graphene/Ni(111) heterostructure after intercalation of Pb atoms.

References:

[1] P. Sutter et al., Nano Lett. 2009, 9, 7, 2654–2660

[2] A. Varykhalov et al., Phys. Rev. Lett. 101, 157601

Disentangling the Ultrafast Magnetization Dynamics in Magnet/Non-Magnet Bilayer Systems

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In the last 20 years, different all-optical techniques based on the magneto-optical Kerr effect (MOKE) were employed to study the ultrafast magnetization dynamics of magnetic thin films, alloys and multilayer structures. While conventional time-resolved MOKE studies provided the insights into the microscopic mechanisms governing the loss of magnetic order in simple materials, time-resolved MOKE experiments with fs-XUV radiation provided a detailed understanding of the element specific magnetization dynamics of multi-compound materials.

The most recent progress in time-resolved MOKE experiments is the implementation of the so-called C-MOKE approach. It takes advantage of the complex nature of the material specific Kerr response to disentangle the magnetization dynamics of magnetic/non-magnetic multilayer structures. A crucial ingredient for the separation of the magnetization dynamics of all layers is, however, the precise value of the Kerr response of the transiently spin-polarized non-magnetic layers that is often only available from theory.

Here we present a new strategy to experimentally determine the Kerr response of a transiently magnetized gold layer in a Permalloy (Py)/gold (Au) heterostructure after optical excitation. This allows us to disentangle the layer specific magnetization dynamics of both materials and thus to discuss the spin transport across the Py/Au interface.

Edelstein effect and spin-orbit torque in ferromagnetic/ nonmagnetic multilayers

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Transport phenomena caused by spin-orbit coupling such as spin Hall effect (SHE) and anomalous Hall effect (AHE) are highly relevant topics of current research. In ferromagnetic/nonmagnetic heterostructures, the interplay of spin-orbit interaction and broken inversion symmetry causes new phenomena like Edelstein effect and spin-orbit torques.

We use a first principles approach based on a fully relativistic *tight binding* Korringa-Kohn-Rostoker method to determine the electronic structure [1] and solve the linearised Boltzmann equation to describe the electronic transport [2]. We apply these methods to a Co/Cu superlattice with magnetisation perpendicular to the interface as well as with magnetisation parallel to the interface with different substitutional impurities delta-distributed within the individual atomic layers [3].

We investigate the Edelstein effect induced spin density as well as the spin-orbit torque on the magnetisation of the multilayers. By analysing the spatial distribution of the spin density and of the spin-orbit torque, we highlight a close connection between the non-equilibrium spin density and the spin-orbit torque.

Furthermore, we consider the AHE-induced charge current as well as the SHE-induced spin current perpendicular and parallel to the interface and compared it to the values of the underlying bulk systems. In the investigated Co/Cu multilayers, the SHE as well as the AHE are more efficient in Co/Co multilayers with magnetisation parallel to the Co/Cu interface and initial charge current flowing perpendicular to the interface than in Co/Cu multilayers with magnetisation perpendicular to the interface and initial charge current flowing parallel to the interface.

References:

[1] Gradhand M., Czerner M., Fedorov D. V., Zahn P., Yavorsky B. Y., Szunyogh L., and Mertig I.; *Physical Review B* **80**, 224413 (2009)

[2] Gradhand M., Fedorov D. V., Zahn P., and Mertig I.; *Physical Review Letters* **104**, 186403 (2010)

[3] Hönemann A., Herschbach C., Fedorov D. V., Gradhand M., and Mertig I.; *Phyiscal Review B* **99**, 024420 (2019)

Investigation of laser-induced ultrafast current pulses in nanolayered, metallic material systems up to the THz regime

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Illuminating a nanometer thin metallic bilayer consisting of ferromagnetic (FM) and a non-magnetic layer (NM) with an intense femtosecond laser pulse launches an ultrafast spin current from the FM into the NM via the spin-dependent Seebeck effect (SDSE). There it is converted into a transverse, in-plane charge current by the inverse spin Hall-effect (ISHE) [1] where it can either measured directly, electrically via a coplanar air probe connected to a fast sampling oscilloscope [2] or via electrooptic sampling (EOS). The oscilloscope approach allows a quick characterization of thin films up to the GHz regime. In contrast the EOS extends to the THz regime and can not only be used to capture the emerging current on its actual timescale but also to look at its propagation inside a waveguide. Both techniques are applied on different materials systems including simple FM|HM bilayers, gradient samples and bilayers with thin interlayers [3].

References:

[1] T. Seifert, T. Kampfrath et al. *Nature Photon.*, 10, 483 - 488 (2016)

[2] W. Hoppe, J. Weber, S. Tirpanci, O. Gückstock, T. Kampfrath and G. Woltersdorf *ACS Appl. Nano Mater.*, 4, **7,** 7454–7460 (2021)

[3] Wahada A., Parkin S. S. P. et al.*Nat. Commun.*, submitted (Sept. 2021)

Search for current-induced interlayer DMI in synthetic antiferromagnets

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The exchange interaction underlies all spintronic devices. This interaction has two counterparts – the symmetric and antisymmetric part. The symmetric term governs the ferro- and antiferromagnetism where the antisymmetric, which has recently gained interest, promotes topologically non-trivial chiral spin textures that promise new magnetic devices. Synthetic antiferromagnets can display an antisymmetric interlayer exchange interaction due to symmetry breaking within the sample plane [1, 2]. This effect provides an additional handle to engineer magnetic structures and could enable three-dimensional topological structures such as hopfions.

Additionally, there have been reports that a current can induce a change in the antisymmetric exchange interaction [3]. Thus, we have observed the current effect on the antisymmetric interlayer exchange interaction by employing anomalous Hall effect measurements with an additional applied in-plane fields. In order to quantify the current dependence of the antisymmetric interlayer exchange interaction, an interlayer DMI field is introduced as a measure of quantification in which a consistent current dependence is observed. Therefore we have observed the possibility to control the antisymmetric interlayer exchange interaction by current opening possibilities to engineer three dimensional spin structures.

References:

[1] D.-S. Han, K. Lee *et al., Nature Materials* **18**, 703-708 (2019)
[2] A. Fernández.-Pacheco *et al., Nature Materials* **18,** 679-684 (2019)
[3] G. V. Karnad et al., Phys. Rev. Lett. 97, 100405 (2018)

Photoemission and double photoemission spectroscopy on $SrTiO_3$ and $SrRuO_3$ with MHz high-order harmonics

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Photoelectron spectroscopy (PES) has provided deep insights into the electronic structure of solids. However, correlation effects can only be addressed indirectly. To observe such phenomena directly, double photoemission (DPE) spectroscopy is able to detect pairs of correlated photoelectrons that are emitted upon absorption of a single photon [1].

In this contribution we present PES and DPE data for the two perovskite surfaces, $SrTiO_3$ (001) and $SrRuO_3$ (001), obtained by a laboratory high-order harmonic (HHG) light source at $h\nu$ =25 and 30 eV operating at MHz repetition rates. Well-ordered TiO_2-terminated $SrTiO_3$(001) surfaces have been prepared by etching, whereas $SrRuO_3$(001) surfaces have been prepared by UHV cleaving.

A photoemission onset at E_B = 3.4 eV is found for $SrTiO_3$(001), whereas $SrRuO_3$(001) reveals metallic behavior. In strong contrast, we find DPE onsets for emission of correlated photoelectrons at a pair binding energy of 5.4 eV from $SrTiO_3$(001) and 2.2 eV from $SrRuO_3$(001), both independent of the individual single-electron energies. The DPE data will be compared to data for

Ag(001) [2], indicating the presence of a strong electron-electron interaction in $SrTiO_3$(001) and $SrRuO_3$(001).

References:

[1] J. Berakdar et al., Phys. Rev. Lett.81 (1998)

[2] A. Trützschler et al., Phys. Rev. Lett.118 (2017)

Bend Don't Break. Strain Incompatibility in Antiferromagnetic Systems

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Antiferromagnets (AFMs) have shown their potential in the use of active spintronics elements as they are faster and more stable than the FMs in recent devices. However, their lack of a magnetization brings up the challenge to manipulate their magnetic state. Recent studies suggested that the magnetoelastic coupling can be used for this task [1]. Thus, it is essential to understand how the strains from deformations in the AFM and the Néel vector interact. The interactions in elasticity are long ranged, which then also applies to the magnetoelastic interactions. Therefore, the coupling influences the domain structure of the AFM, similar to the demagnetization in FMs. The strains produced in different domains may be physically inconsistent (incompatible) at the domain wall in between and would lead to cracks in the crystal. To compensate this incompatibility new strains emerge and increase the energy. Thus, multidomain configurations without incompatibilities usually correspond to minimal energy. The dependence of the incompatibility with respect to the explicit domain structure is therefore an important factor in the formation of AFM domains.
This talk will introduce the concept of incompatibility from a mathematical and physical perspective. It will be shown how to compute the additional strains originating from the incompatibility. As an example, the previous concepts will be applied to a tetragonal AFM to show how the energy of a single magnetic domain wall changes with respect to the orientation of the domain wall in the crystal.

References:
[1] Meer H. et al; *Nano Lett.*, **21.1** (2020)

Localizing Magnetic Skyrmion Nucleation

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Magnetic skyrmions are vortex-like topological quasiparticles that are stabilized in out-of-plane magnetized multilayer structures providing a high Dzyaloshinskii-Moriya interaction (DMI).

During the last decade, research on magnetic skyrmions attracted interest from scientific and industrial research communities due to the skyrmion's fascinating and emerging properties from its topological charge. The topology provides a certain stability and allows to manipulate skyrmions with spin-polarized currents. The magnetic skyrmion has therefore been envisioned as information carrier in future data storage technology [1-2]. In recent years, great advances have been reported in generating, annihilating and shifting skyrmions via spin-orbit torque from spin-polarized currents [35]. Optical nucleation with single laser pulses is a purely thermal process and offers a possibly faster and more energy-efficient alternative to create magnetic skyrmions [6-7]. While the underlying mechanisms of current-induced and laser-induced nucleation of skyrmions are different, both methods suffer from a certain stochasticity in the spatial distribution of the skyrmions nucleated [7]. However, in view of a scientific and practical application of magnetic skyrmions, a controllable localization of the skyrmion's nucleation site is typically required.

With the tailored implantation of He^+-ions to pre-define artificial pinning sites, we employ an elegant way to locally alter the perpendicular magnetic anisotropy (PMA) on the nanometer scale without changing the topography of the multilayer [8]. Just recently, we have demonstrated the controlled and reproducible skyrmion nucleation and motion in our magnetic multilayers.

Nanopatterning of a tailored magnetic anisotropy landscape using He^+-ions thus transforms the skyrmion nucleation into a controllable and deterministic process – a prerequisite for any fundamental or applied use of these topological structures.

References:

[1] Fert et al., *Nature Nanotech* **8,** 152–156 (2013).
[2] Tomasello et al., *Sci Rep* **4,** 6784 (2014).
[3] Caretta et al., *Nature Nanotech* **13,** 1154–1160 (2018).
[4] Woo et al., *Nat Electron* **1,** 288–296 (2018).
[5] Büttner et al., *Nature Nanotech* **12,** 1040–1044 (2017).
[6] Je et al., *Nano Lett.* 2018, 18, 11, 7362–7371.
[7] Büttner et al., *Nat. Mater.* **20,** 30–37 (2021).
[8] Deinhart et al., *Beilstein J. Nanotechnol.* **2021,** *12,* 304–318.

Current-Induced H-Shaped Skyrmion Creation and Their Dynamics in the Helical Phase

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A promising application of magnetic skyrmions is in racetrack memory devices. [1] While efforts focussing on encoding information in these topological magnetic objects have initially been concentrated on the use of ferromagnetic racetracks, previous work suggested the use of helimagnets to be superior. [2] In helimagnets, skyrmions consisting of a bound pair of meron ends that form a H-shaped structure are energetically preferred over the usual whirlpool-like structures found in ferromagnets. The helices naturally confine the H-shaped topological magnetic structures to quasi-1D channels, mitigating the skyrmion Hall effect. Additionally, they allow for high-speed skyrmion motion. Inspired by previous works where skyrmions are created through the interplay of spin-polarized currents and magnetic impurities, [3] we develop an all-electrical method to controllably produce and manipulate skyrmions in the helical background, see Fig. 1. We analyse the stability and current-driven motion of these skyrmions with in-plane uniaxial anisotropy fixing the orientation of the helices. [4]

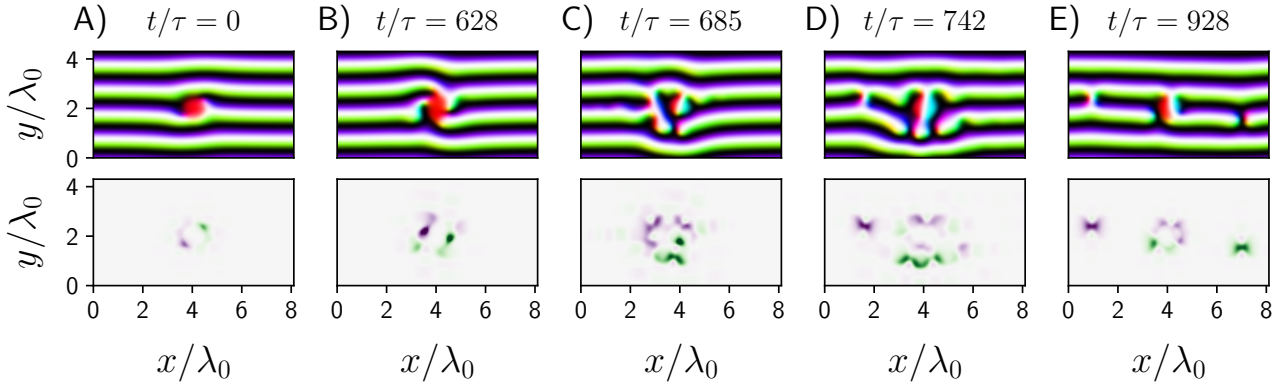

Fig.1: Shedding of H-shaped skyrmions from an impurity under the application of a spin-polarised current.[4]

References:

[1] Fert, A et. al., *Nat. Nanotechnol.*, 152-156, **8**(3) (2013).
[2] Müller, J. et.al., *Phys. Rev. Lett.*, 137201, **119**(13) (2017).
[3] Everschor-Sitte, K. et. al., *New J. Phys.*, 092001, **19**(9) (2017).
[4] Knapman, R. et. al., *J. Phys. D: Appl. Phys.*, 404003, **54**(40) (2021).

Manipulating spin dynamics in TMDs under uniform strain and proximity coupling

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Optical control and manipulation of the coupled spin/valley degrees of freedom in transition metal dichalcogenides (TMDs) are crucial for their applications in information processing. Here, we develop two different approaches to manipulate spins in TMDs. First, we use a type-II TMD heterostructure MoS_2–$MoSe_2$ to optically generate the spin/valley-polarized currents of electrons and holes across the interface. We find spin-conserving ultrafast tunneling of carriers for both tunneling directions across the interface, however, with dramatically different depolarization rates for electrons and holes, ~30 and <1 ns^{-1}, respectively. These results establish the long-lived hole spins as the robust information carriers [1]. Second, we apply a controlled mechanical strain to manipulate the excitons in a suspended monolayer WSe_2 membrane. A uniform strain "brightens" a normally dark excitonic state associated with TMD defects. We probe unconventional spin/valley signatures of these states and a robust valley polarization up to room temperature. Our work establishes new ways to manipulate, control, and transfer the spin/valley information in TMDs.

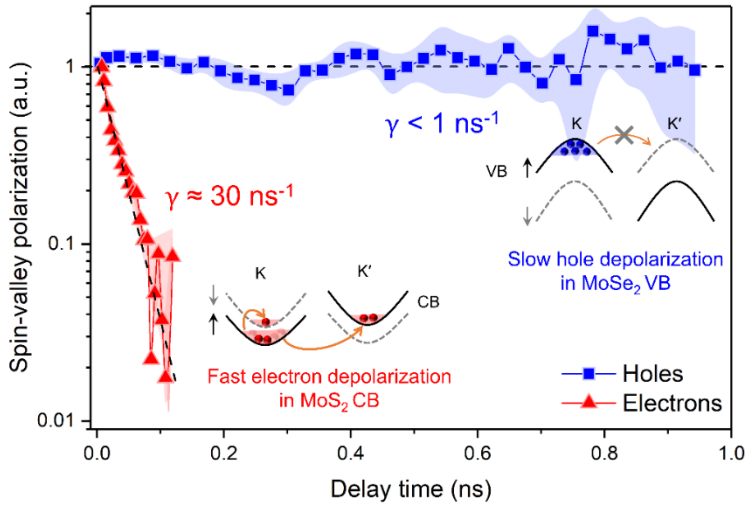

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Fig.1: Spin/valley polarization dynamics of the tunneled electrons and holes across the MoS_2-$MoSe_2$ heterostructure interface [1].

References:

[1] Kumar, A.; Yagodkin, D.; Stetzuhn, N.; Kovalchuk, S.; Melnikov, A; Elliott, P.; Sharma, S.; Gahl, C.; Bolotin, K. I.; *Nano Letters* **2021** 21 (17), 7123-7130.

Simulation of the ultrafast magneto optical response in Co from experimental data

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We study the magneto-optical response of a Co system in the resonant X-ray regime to an ultrashort laser excitation using X-ray reflectivity measurements employing circular polarization. The observed signals for opposing sample magnetization are investigated in detail and information about the electronic and magnetic state is obtained by looking at the sum and difference of the detected reflectivity. The observed electronic and magnetic signal response show different response times, caused by a transient shift of the resonance edge [1,2]. The signals are simulated considering changes due to electronic excitation and by inhomogeneous X-ray scattering considering layer resolved strain [3,4]. The experimental curves are only reproduced when considering a shift of the resonance energy.

In time-resolved studies the magnetization of the system is usually probed over time at a specific electronic excitation, i.e, at a limited energy bandwidth. Following the time evolution of the signal we can link the observation to the relative change of the temporal magnetic state of the system, however, we do not know whether our observation can be directly correlated with the absolute magnetic state of the system. Therefore, an important question that we must answer, and is often taken for granted, is: can we extract qualitative information about the magnetic state of a system out-of-equilibrium using a limited energy window of the full electronic spectrum?

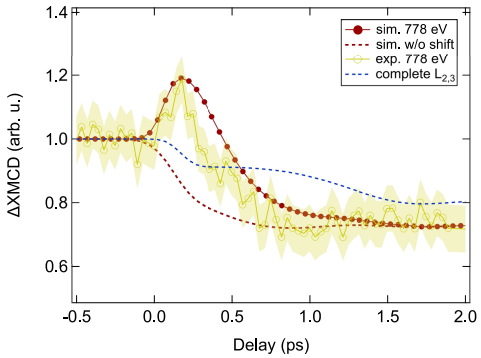

Fig.1: Normalized change in the observed dichroism in a Co sample. The data (yellow squares) is only reproduced by the simulation (dark red dots) when a shift of the resonance edge is considered. The fits without introducing a shift of the resonance either on the full spectrum (blue) or with a narrow energy window (light red) fail to reproduce the data.

References:

[1] C. Stamm et al., *Nature Mat.* 740-743, **6**, (2007)

[2] C. Stamm et al., *Phys. Rev. B.*, 104425, **81** (2010)

[3] S. Macke and E. Goering, *Jour. Phys. Condens. Mat.*, 363201, **26**, (2014)

[4] D. Schick et al., *Computer Physics Communications*, 651, **185** (2014)

Nanopatterning of room-temperature localized excitons in MoS_2

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We demonstrate a simple approach to pattern a novel localized excitonic state in monolayer MoS_2[1]. We raster an electron beam over pristine monolayer MoS_2 with a resolution down to 20 nm. In the exposed areas we observe new narrow (1 meV) peaks near 1.72 eV in the photoluminescence (PL) spectrum. We investigate the nature of the state responsible for the peaks using scanning transmission electron and atomic force microscopies, PL, and electron energy loss spectroscopies, and by examining the response of the state to nanomechanical cleaning. All these techniques indicate that the state is not associated with structural defects in MoS_2, as commonly assumed for irradiation-induced states, and results neither from strain nor from local dielectric screening. Instead, we suggest that this state is a charge transfer exciton associated with the organic substance deposited onto the MoS_2 during the e-beam exposure. We show that this new state is well-resolved, easy-to-generate via conventional electron beam lithography, and its emission is visible at room temperature. It can be used to study localized excitons, to enable chemical sensing, and to generate new many-body excitonic states.

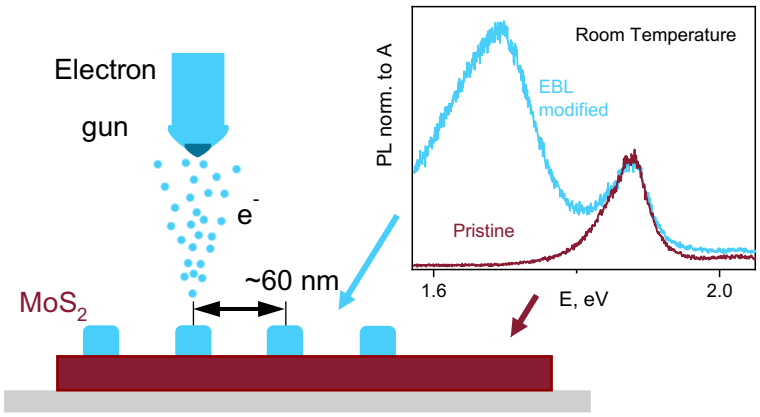

Fig.1: Local focused electron beam exposure of monolayer MoS_2 results in a new peak at 1.7 eV in photoluminescence from the exposed areas (inset).

References:

[1] Yagodkin. D et.al. *arXiv:2105.13711*

Combined tr-MOKE, BLS and THz-radiation setup for the investigation of THz spin-wave modes and their contribution to the ultrafast demagnetization process

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The ultrafast loss of magnetic order in different materials induced by optical pulses has been studied intensively in the last decades since its discovery in ferromagnetic nickel [1]. Meanwhile, many explanations for the underlying interaction of the coupled electron, spin, and phonon systems and the angular momentum transfer were proposed [2,3]. In the spin system, the magnetization dynamics can be described using single-particle excitations in form of Stoner excitations, and collective excitations in form of spin waves in the THz-regime [4]. However, in magnonics, spin waves in this frequency range are less studied due to the lack of adequate magnon sources, as an excitation with conventional methods, such as microstrip antennas, is not possible and instead has to rely on optical excitations. Recent works reported the detection of the Kaplan-Kittel exchange resonance mode in the ferrimagnet yttrium-iron garnet by applying optical stimuli [5]. Therefore, we propose a combined setup of all-optical time-resolved pump-probe spectroscopy based on the magneto-optical Kerr effect (tr-MOKE) and Brillouin light scattering (BLS) spectroscopy to realize the simultaneous detection of ultrafast magnetization dynamics and the THz spin-wave spectrum, including coherent and incoherent excitations. By that, we may get a clearer picture of the spin-wave dynamics near the Stoner continuum and the decaying process of Stoner excitations into spin waves. Furthermore, the additional THz-radiation setup enables the resonant pumping of spin waves in the THz regime with a single-cycle THz-pump pulse, which allows the investigation of antiferromagnetic spin-wave modes in ferrimagnets and antiferromagnets and also in ultrathin samples.

References:

[1] E. Beaurepaire et al., Phys. Rev. Lett., 4250, **76** (1996)
[2] C. Dornes et.al, Nature, 209, **565** (2019)
[3] M. Battiato et al., Phys. Rev. Lett., 027203, **105** (2010)
[4] E. Turgut et al., Phys. Rev. B, 220408, **94** (2016)
[5] W.-H. Hsu et al., Phys. Rev. B, 174432, **102** (2020)

A THz Scanning Tunneling Microscope - Going Ultrafast with Atomic Resolution

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Within the framework of the CRC TRR 227 we have set up a THz-based ultrafast pump-probe experiment, that will allow us to investigate ultrafast processes on the atomic scale [1]. Therefore, we couple ultrashort VIS/IR and THz pulses into the junction of a low temperature (<10K) scanning tunneling microscope.
We measure THz gated photocurrents as proposed in [2, 3] and find THz pulses inside the STM allow for a time resolution of about 550 fs. Within the tunneling regime the effect of THz induced transient bias voltages on features with non-linear I-V characteristics, we can estimate the THz electric field amplitude in the STM junction to reach some 100 mV. Also here, we find from sending two time delayed THz pulses, again, a confirmation of above's possible time resolution.

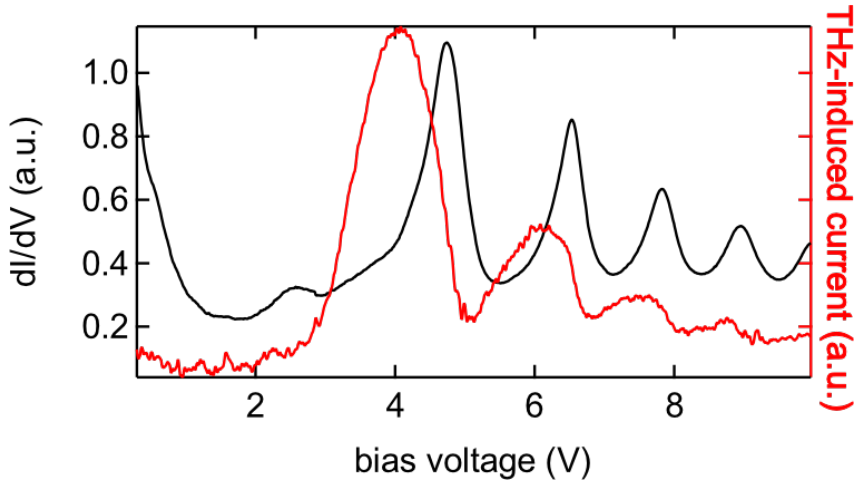

Fig.1: Differential conductance spectrum (constant current dI/dV, black) showing the field emission resonances of a Ag(111) sample measured with a Ag tip. THz-induced current (red line) measured with a chopper at 834 Hz, laser repetition rate 40 MHz. The peak position of the THz signal is shifted by 800 mV to lower bias voltage compared to the dI/dV signal.

References:

[1] T. L. Cocker, D. Peller, P. Yu, J. Repp & R. Huber: *Nature* **539**, 263 (2016)
[2] S. Yoshida et al.: *ACS Photonics* **6**, 1356 (2019)
[3] M. Müller, N. M. Sabanés, T. Kampfrath, and M. Wolf: *ACS Photonics* **7**, 2046 (2020)

Audio Recognition with Skyrmion Reservoir Computing

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Physical reservoir computing is a computational architecture that enables temporal pattern recognition to be performed directly in physical matter [2]. By exciting dynamical systems with temporal input data, we can create nonlinear mappings from the original input to a high dimensional latent space allowing for classification and regression. The use of physical matter leads the way towards energy-efficient devices capable of solving machine learning problems without building a modular system from millions of interconnected synapses. Through micro-magnetic simulations, we show an implementation of the reservoir computing model using electrically excited magnetic textures [3]. We demonstrate the performance of our reservoir model by using it to solve a multi-dimensional classification problem, audio recognition, to a high degree of accuracy. These results argue that skyrmion magnetic textures are a competitive substrate for reservoir computing due to the quality of the results shown and the low power properties of magnetic texture reservoirs. In the future, we aim to extend our model to use multiple reservoirs of different timescales connected in a sequential hierarchy, with the goal of processing information over a more extensive range of timescales.

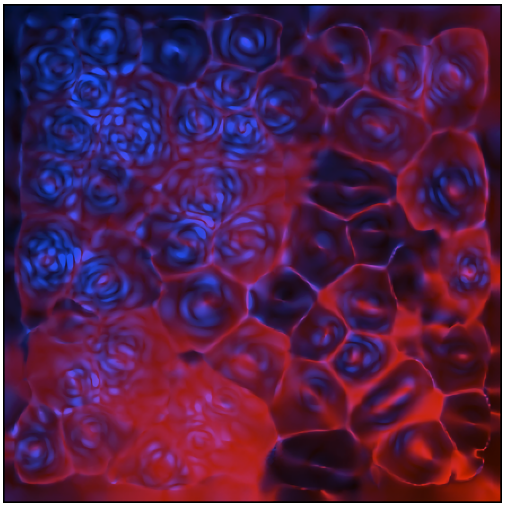

Fig.1: Spatial Representation of Nonlinearity (red) and Memory (blue) in a Skyrmion reservoir [2].

References:

[1] Love, Jake, et al. "Task Agnostic Metrics for Reservoir Computing." arXiv preprint arXiv:2108.01512 (2021).

[2] Tanaka, Gouhei, et al. "Recent advances in physical reservoir computing: A review." Neural Networks 115 (2019): 100-123.

[3] Pinna, Daniele, George Bourianoff, and Karin Everschor-Sitte. "Reservoir computing with random skyrmion textures." Physical Review Applied 14.5 (2020): 054020.

Laser-induced metamagnetic phase transition of FeRh studied by a combined UXRD and MOKE experiment

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We use time-resolved X-ray diffraction (UXRD) and magneto-optical Kerr effect (MOKE) to study the laser-induced metamagnetic phase transition in FeRh. FeRh undergoes a first-order phase transition from an antiferromagnetic to a ferromagnetic phase upon heating above ~360K. The phase transition is accompanied by a gigantic (~0.7%) expansion. The increased lattice constant of the ferromagnetic phase provides access to the ferro- and antiferromagnetic volume fraction through the phase transition using X-ray diffraction. The UXRD measurements access the time-dependent ferromagnetic volume fraction independent of the orientation of the magnetic moment of different domains. In contrast, MOKE is sensitive to different orientations of the magnetization of the arising ferromagnetic order. With our combined UXRD and MOKE experiment under identical experimental conditions we quantitatively investigate the nucleation, growth and coalescence of the ferromagnetic domains upon laser-excitation.

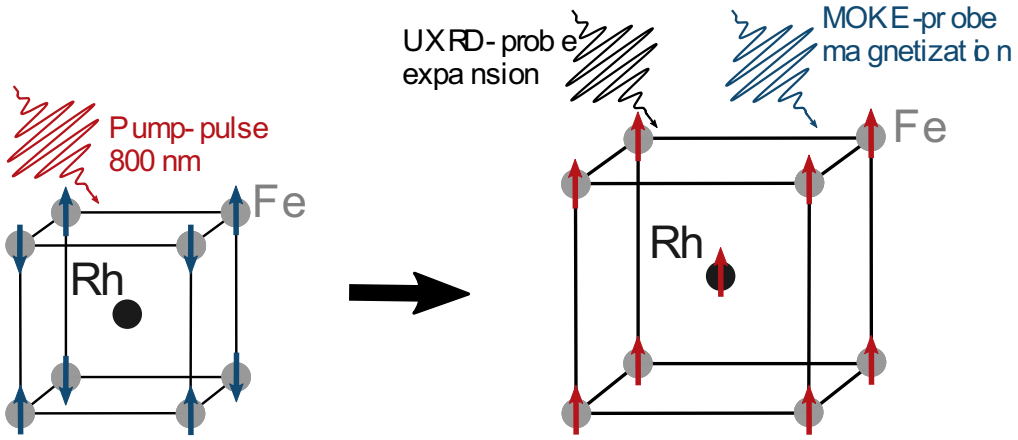

Fig.1: Schematic sketch of the laser-induced metamagnetic phase transition of FeRh changing the magnetic order (arrows) and the lattice constant probed by MOKE and UXRD, respectively.

Direct Imaging of Current-Induced Antiferromagnetic Switching Revealing a Pure Thermomagnetoelastic Switching Mechanism in NiO

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It has been established that current pulses through an adjacent heavy metal layer can induce a reorientation of the antiferromagnetic ordering in insulating AFMs. However, various switching mechanisms have been proposed, such as spin-orbit torque (SOT) switching [1] and thermomagnetoelastic switching [2,3]. Recent investigations have shown that one needs to distinguish between nonmagnetic and magnetic signals when reading-out the orientation of the antiferromagnetic order $\boldsymbol{n}$ electrically [4]. Here, we directly image the current-induced switching of Pt/NiO bilayers by concurrent birefringence microscopy of the antiferromagnetic domains [5]. We investigate the underlying switching mechanism, finding that the pulsing with current density **j** leads to different switching directions of **n** depending on the device and pulsing geometry, contrary to the expectations for a SOT-based switching mechanism. A single current pulse can lead to the formation of different domains with opposite final states $\boldsymbol{n}\|\boldsymbol{j}$ or $\boldsymbol{n}\perp\boldsymbol{j}$. We can attribute such reversal to thermomagnetoelastic switching processes, as the simulated current-induced heat and strain profiles in the respective devices favor different switching final states. Combined with electrical measurements of the spin Hall magnetoresistance, we can now reconcile previously conflicting reports of the final state of the switching in different device geometries. Finally, we achieve reversible non-contact thermomagnetoelastic switching in regions where no current flows, and therefore in the absence of contributions from spin-transfer and spin-orbit torque mechanisms [6].

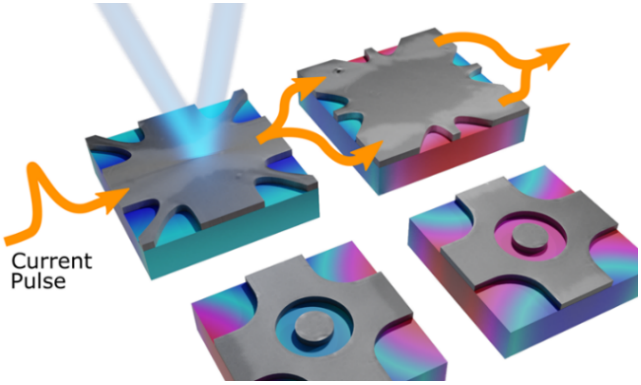

Fig.1: Direct imaging of current-induced antiferromagnetic switching in different devices [6].

References:

[1] O. Amin et al., *Appl. Phys. Lett.* 117, 010501 (2020)

[2] P. Zhang et al., *Phys. Rev. Lett.* 123, 247206 (2019)

[3] L. Baldrati et al., *Phys. Rev. Lett.* 125, 077201 (2020)

[4] A. Churikova et al., *Appl. Phys. Lett.* 116, 02241 (2020)

[5] F. Schreiber et al., *Appl. Phys. Lett.* 117, 082401 (2020)

[6] Meer, H. et al., *Nano Lett.* 21, 114 (2021)

Orbital magnetic moment of magnons

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It is commonly accepted that magnons—collective excitations in a magnetically ordered system— carry a spin of $1\hbar$ or, phrased differently, a magnetic moment of $g\mu_B$. In this talk, I demonstrate that magnons carry magnetic moment beyond their spin magnetic moment. Our rigorous quantum theory uncovers a magnonic orbital magnetic moment brought about by spin-orbit coupling. We apply our theory to two paradigmatic systems where the notion of orbital moments manifests itself in novel fundamental physics rather than just quantitative differences. In a coplanar antiferromagnet on the two-dimensional kagome lattice the orbital magnetic moment gives rise to an orbital magnetization. While the spin magnetization is oriented in the kagome plane, the orbital magnetization also has a finite out-of-plane component leading to "orbital weak ferromagnetism." The insulating collinear pyrochlore ferromagnet $Lu_2V_2O_7$ exhibits a "magnonic orbital Nernst effects," i. e. transversal currents of orbital magnetic moment induced by a temperature gradient. The orbital magnetization and the orbital Nernst effect in magnetic insulators are two signatures of the orbital magnetic moment of magnons.

Plasmonic and Magnetic Dichroism Imaging of Magnetic Surfaces in Photoemission Electron Microscopy

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Over the last decades, the rapid progress in the ultrafast optical manipulation of magnetic materials has opened the development of several new experimental and theoretical methods for the investigation and control of spin and magnetization dynamics. Supported by the "Collaborative Research Center TRR-227 Ultrafast Spin Dynamics" we investigate magnetic thin films and nanostructures on nanometer-femtosecond scales with a newly-designed experimental setup. Our approach is to combine state-of-the-art time-resolved photoemission electron microscopy (PEEM) with several special excitation methods, such as circular dichroism imaging, normal incidence excitation or back-side pumping via a tunable femtosecond fiber laser system [1]. Here, we report on two dichroism imaging techniques, namely magnetic circular dichroism (MCD) and the recently discovered plasmonic dichroism. The first is used to image and manipulate magnetic domains of ferromagnetic and possibly antiferromagnetic surfaces. The second was successfully used to image propagating surface plasmon polaritons (SPPs) on a ferromagnetic material in threshold photoemission for the first time [2]. This finding extends experimental observation and investigation of SPPs to materials with high plasma frequency and larger damping. Specifically, it enables studies of magnetic materials within the exciting field of magnetoplasmonics [3].

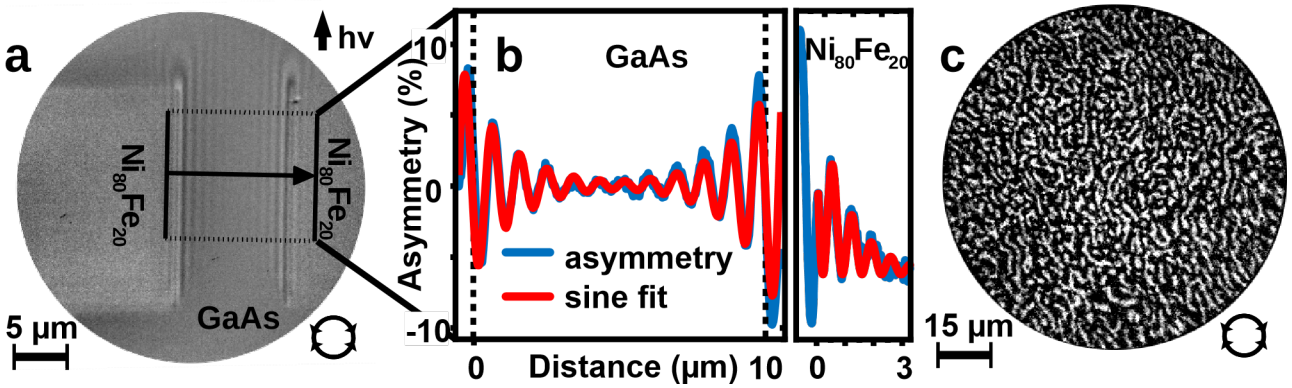

Fig.1a, b: Femtosecond laser PEEM image (30 fs, 1.23 MHz repetition rate, 3.32 eV) with circular dichroism contrast of $Ni_{80}Fe_{20}$ microstructures on GaAs revealing propagating SPPs [1].
Fig.1c: MCD PEEM image of ~12 monolayers Ni on Cu(100) revealing magnetic domains.

References:

[1] http://www.trr227.de/Projects/area_A/A0_6_/index.html

[2] Paleschke M., Chiang C.-T., Brandt L., *et al., New J. Phys.* 093006, **23** (2021).

[3] Armelles G., Cebollada A., García-Martín A., and González M. U., *Adv. Opt. Mat*. **1**, 10–35 (2013).

Opto-electrical imaging of spin polarization

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Generation, manipulation and detection of the spin polarization is the basis of modern spintronics. In recent years, the focus has shifted towards detecting spin current without the need of ferromagnetic material. However, direct optical detection of spin accumulation is more challenging in metals compared to semiconductors. We exploit the magnetic circular dichroism (MCD) effect to image magnetic texture in microscale magnetic metallic wire structures opto-electrically. This is accomplished by illuminating magnetized samples with circular polarization modulated laser light and measuring the helicity dependent photoconductivity (HDP) simultaneously in a spatially resolved manner. In addition to imaging magnetic domain structures, the result allows to link magnetic dichroism with detected HDP voltage. In contrasts to other recently developed opto-electrical magnetic domain imaging methods that requires materials exhibiting a sizable anomalous Nernst effect or spin Seebeck effect [1-3], the method developed here relies only on out-of-plane spin polarization and MCD effect. This implies that it can be used to image magnetic textures and spin polarization in much wider range of materials. In particular, detecting spin Hall effect (SHE) induced spin polarization at the edges of non-magnetic metallic wires is of immense interest. HDP measurement provides us a possibility to directly detect SHE induced spin polarization, allowing to study spin to charge conversion effects more efficiently. In this talk, results of opto-electrical imaging of magnetic domain structures, and a detailed study of detecting SHE induced spin accumulation at sample edges of non-magnetic wires via HDP measurements will be presented.

References:

[1] Janda, T. et al. Magneto-Seebeck microscopy of domain switching in collinear antiferromagnet CuMnAs. Physical Review Materials 4, 094413 (2020).

[2] Reichlova, H. et al. Imaging and writing magnetic domains in the non-collinear antiferromagnet Mn3Sn. Nature communications 10, 5459 (2019).

[3] Weiler, M. et al. Local Charge and Spin Currents in Magnetothermal Landscapes. Physical 2 Review Letter 108, 106602 (2012)

Orbital angular momentum of light

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It is widely known that circularly polarized light carries a spin angular momentum (SAM) of $S = \pm 1\hbar$ per photon. This was first proposed by J. H. Poynting in 1909 [1] and proven experimentally by R. A. Beth in 1936 [2]. More than 50 years later, L. Allen et al. demonstrated in 1992 that light **can** also carry an orbital angular momentum (OAM) $L = l\hbar$ with $l \in \mathbb{Z}$ per photon if it has an azimuthal phase [3].

Since then, the OAM of light has become an active field of research that has brought forward a variety of applications. Examples are an additional degree of freedom for data transmission, the trapping and rotating of particles in optical tweezers, and logic operations at the single-photon level.

In my talk, I will explain the underlying physical mechanisms of light with OAM, present different methods for its creation, and showcase a few selected applications in detail.

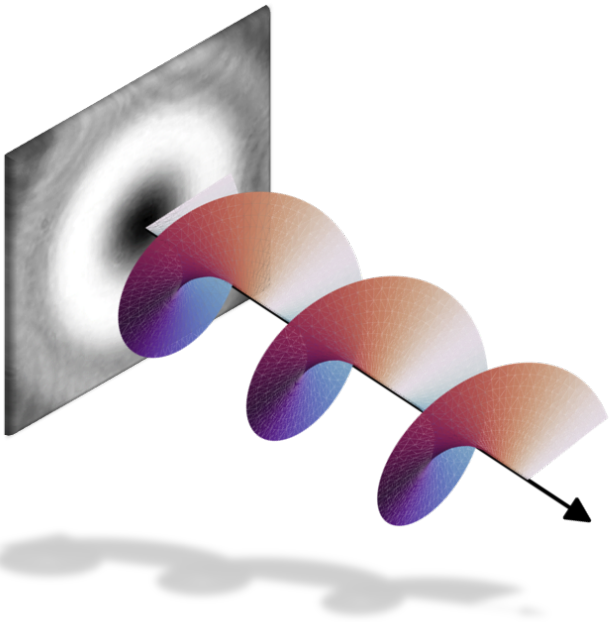

Fig.1: Beam profile and spiral phase of light with orbital angular momentum (OAM).

References:

[1] Poynting J. H.; *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 560-567, **82** (1909)

[2] Beth R. A.; *Phys. Rev.*, 115-125, **50** (1936)

[3] Allen, L., Beijersbergen, M. W., Spreeuw, R. J. C. and Woerdman, J. P.; *Phys. Rev. A*, 8185-8189, **45** (1936)

Ultrafast element-resolved magnetization dynamics using a fiber-laser-driven high-harmonic generation light source

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In the last few decades enormous progress has been made in the field of magneto-optical spectroscopy, uncovering numerous effects in ultrafast demagnetization, including the observation of femtosecond spin currents and optically induced spin transfer [1-3]. Despite these advances little is known about the magnetization dynamics of complex magnetic systems such as alloys, strongly correlated electron systems and their heterostructures. For a microscopic understanding of ultrafast magnetism in complex systems, an element-specific probe of the magnetic subsystems is necessary [3, 4].

Our experimental setup makes use of the transverse magneto-optical Kerr effect in the extreme ultraviolet spectral range. The high-harmonic beamline is based on a fiber laser amplifier system with a repetition rate between 100 and 300 kHz, covering a photon energy range of 30-72 eV. The setup is equipped with a strong electromagnet and a cryostat, allowing measurements between 10 K and 420 K using magnetic fields up to 0.86 T.

We illustrate the capabilities of our new setup by showing temperature- and time-dependent magnetization measurements with elemental resolution. The possibility to investigate complex magnetic systems with excellent signal-to-noise ratio is demonstrated by the measurement of the ferromagnetic phase transition of double perovskite La_2NiMnO_6 and distinct ultrafast magnetization dynamics of iron and nickel in the $Fe_{19}Ni_{81}$ alloy (see fig. 1) [5].

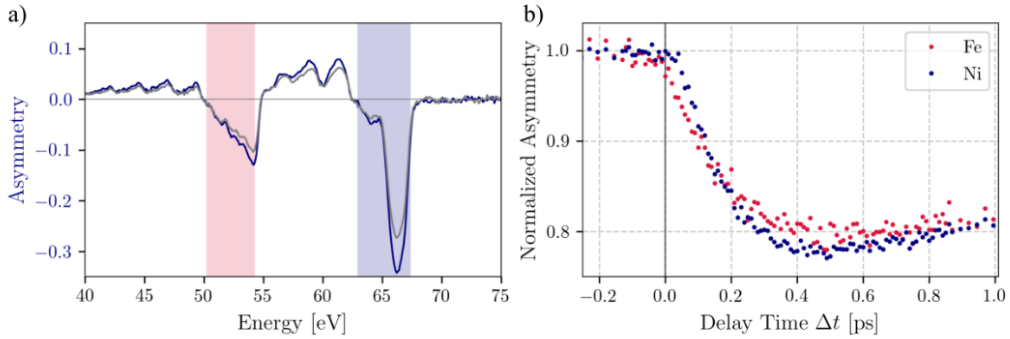

Fig.1: a) Magnetic asymmetry of $Fe_{19}Ni_{81}$. b) Demagnetization traces of Fe and Ni averaged over the depicted energy intervals in a).

References:

[1] M. Battiato et al., Phys. Rev. Lett. **105,** 027203 (2010)

[2] Rudolf et al., Nature Communications **3**, 1037 (2012); Turgut et al., Phys. Rev. Lett. **110**, 197201 (2013)

[3] M. Hofherr et al, Sci. Adv. **6**, eaay8717 (2020)

[4] S. Mathias et al., PNAS **108**, 4792 (2012)

[5] Möller et al., Rev. Sci. Instr. **92**, 065107 (2021)

Theory of spin-Hall magnetoresistance in the AC (THz) regime

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In bilayers of a normal metal (N) with strong spin-Hall effect (SHE) and a ferromagnet (F), the conductivity of N depends on the magnetization direction of F — an effect known as spin-Hall magnetoresistance (SMR). We present a theory of the SMR for driving frequencies up to the THz regime [1]. The SMR signal can be split into two parts: the longitudinal one has a systematic frequency dependence in the GHz regime; the transversal contribution has pronounced singularities at the spin-wave frequencies of F — making it a potential tool for all-electric magnon-spectroscopy —, but otherwise only a weak frequency dependence for common materials. These features can be found in the total SMR signal, see Fig. 1 below.

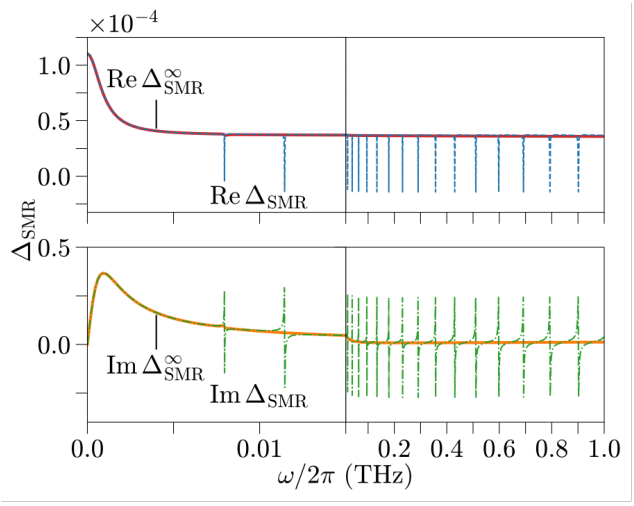

Fig.1: SMR signal for a YIG|Pt bilayer [1].

References:

[1] D. A. Reiss, T. Kampfrath, and P. W. Brouwer; *Phys. Rev. B* **104**, 024415 (2021)

Laser-induced terahertz spin transport in magnetic nanostructures arises from the same force as ultrafast demagnetization

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Laser-induced terahertz spin transport (TST) and ultrafast demagnetization (UDM) are central phenomena in femtomagnetism and terahertz spintronics. Here, we use broadband terahertz emission spectroscopy to reliably measure both processes in one setup. We find that the rate of UDM of a single ferromagnetic metal film F (Fig.1a) has the same time evolution as the flux of TST from F into an adjacent normal-metal layer N (Fig.1b). This remarkable agreement shows that UDM and TST are driven by the same force, which is a generalized spin voltage that is defined for arbitrary, nonthermal electron distributions (Fig1. c&d). We also conclude that contributions due to a possible temperature difference between F and N are negligible and that the spin-current amplitude can, in principle, be increased by one order of magnitude.

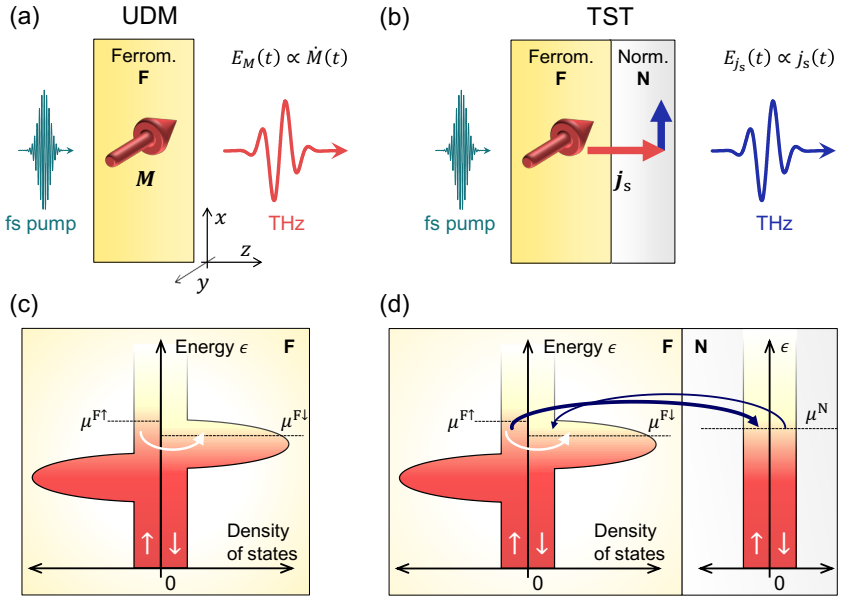

Fig.1: UDM vs TST [1].

References:

[1] Rouzegar, R., et al. arXiv preprint arXiv:2103.11710 (2021).

Ultrafast charge carrier dynamics in low-dimensional heterostructures

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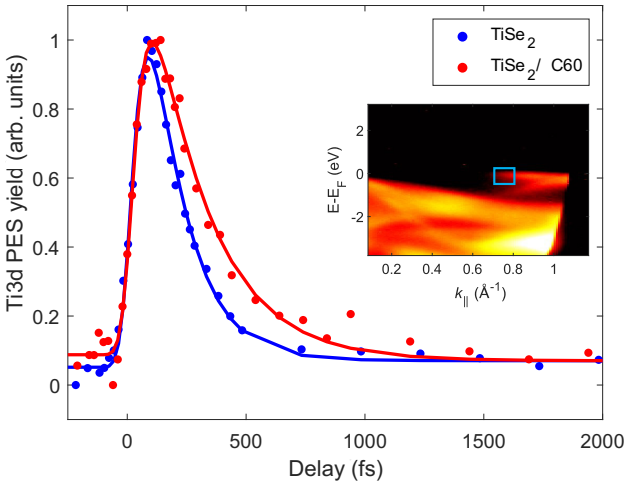
One of the most crucial challenges in the field of 2D van der Waals materials is to devise new approaches to design their electronic and optical properties on the nanoscale. For transition metal dichalcogenides (TMDCs), this is mainly achieved by the formation of 2D heterostructures with either other TMDCs or 2D honeycomb materials. While this approach was already successfully employed to tune the interfacial properties of 2D heterostructures, it still reveals limitations in the tunability of the interfacial energy level alignment as well as in the lateral dimensions of the heterostructures.

In this contribution, we introduce an alternative route to functionalize the properties of TMDCs by the adsorption of molecular materials. As exemplary case, we focus on a heterostructure of the TMDC crystal 1*T*-$TiSe_2$ and the fullerene molecule C_{60}. Both were selected due to their intriguing properties. On the one hand, $TiSe_2$ undergoes a transition from a narrow-gap semiconducting normal phase into a charge density wave (CDW-) phase with a smaller band gap below a critical temperature which can be quenched again by optical excitation [1,2]. On the other hand, the excited state dynamics of C_{60} is dominated by charge transfer excitons that can transiently manipulate the energy level alignment of the surrounding material [3].



Here, we employ fs optical-pump XUV-probe tr-ARPES to uncover modifications of the optically induced dynamics of $TiSe_2$ after the adsorption of organic molecules. After evaporation of a sub-monolayer C_{60} on top of the $TiSe_2$ surface, we find a substantially larger relaxation time of the hot carriers compared to the bare $TiSe_2$ crystal. We will discuss these findings in the light of the interfacial density of states as well as of a possible interplay of the molecular states with the TMDC bands.

Fig.1: Partial spectral yield (blue box) of the Ti 3d band of $TiSe_2$ and of the C_{60}/$TiSe_2$ heterostructure during the transient CDW-quenching after optical excitation with ultrashort laser pulses

References:

[1] Rohwer T., *et al.*; *Nature,* **471,** 490, (2011)

[2] Mathias S., *et al.*; *Nature Communications,* **1**, 12902, (2016)

[3] Stadtmüller B. *et al.*; *Nature Communications,* **10**, 1470 (2019)

Coupling of Yu-Shiba-Rusinov states on $NbSe_2$

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Unpaired adatom spins on superconductors interact with the Cooper pairs of the substrate and induce so called Yu-Shiba-Rusinov (YSR) states inside the superconducting gap. In structures containing more than one adatom the YSR states of the individual atoms may overlap and couple. Here, we investigate Fe atoms on 2*H*-$NbSe_2$ which exhibit several YSR states with partly large spatial extent. Additionally, superconductivity coexists with a charge density wave (CDW) in 2*H*-$NbSe_2$. As the CDW is incommensurate with the lattice, atoms adsorbed in identical hollow sites of the crystal can be found at various positions with respect to the CDW. This causes variations in both energy and symmetry of the YSR resonances. We arrange the Fe atoms using the tip of a scanning tunneling microscope and investigate the resulting structures by means of scanning tunneling microscopy and spectroscopy.

Hidden current-induced spin and orbital torques in bulk Fe_3GeTe_2 from first-principles

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Within the field of spintronics, the two dimensional (2D) van der Waals (vdW) material Fe_3GeTe_2 has been in the spotlight in the last few years for displaying exciting characteristics such as being a potential nodal line semimetal [1], a material for highly efficient spin orbit torque switching [2] and having the ability to exhibit skyrmion formation [3]. In a recent collaboration [4] we found that spin orbit torques (SOTs) were observed in bulk Fe_3GeTe_2. Using first principles methods, we calculated the current-induced bulk spin and orbital torques and found that due to bulk Fe_3GeTe_2's global inversion symmetry, a zero overall bulk SOT is observed. Despite this, when investigating the layer resolved torkance its overall magnitude was nonzero and of comparable magnitude to the experimental signal. Here, we aim to discuss in more detail the microscopic origins of the layer resolved 'hidden' torkance by investigating the spin and orbital textures present on the Fermi surface and making a connection to the rich valley physics present within this material. Furthermore, we compare our work to the analytic expressions of the torkance from Johansen, Ø., *et al* [5] and show that the comparison is in good agreement with their work. From these considerations we aim to provide insights into how, in combination with other mechanisms, the hidden current-induced SOT could give rise to a tangible signal in experiment.

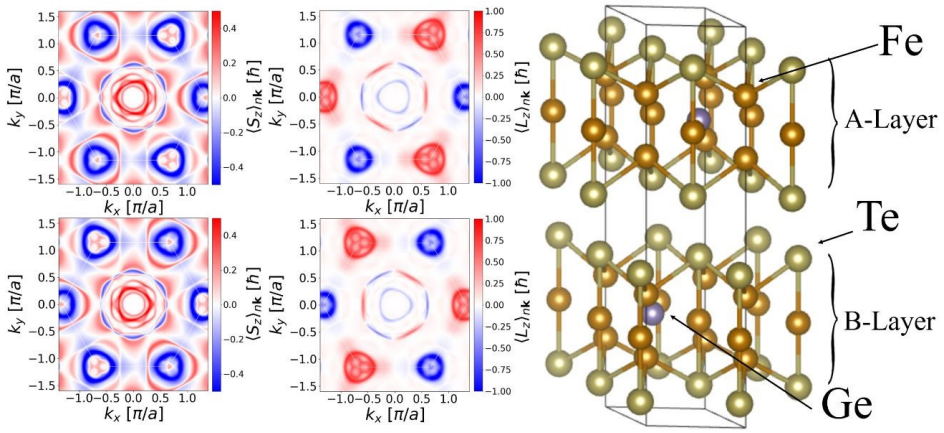

Fig.1: a) Layer resolved spin and orbital textures on the Fermi surface. b) Crystal structure of Fe_3GeTe_2. The crystal consists of two distinct layers, A and B, which are highlighted as the top and bottom layers respectively.

References:

[1] Kim, K., *et al*; Nat. Mater. 794, **17** (2018)

[2]Alghamdi, M., *et al*; Nano Lett. 4400, **19** (2019)

[3] Ding B., *et al*; Nano Lett. 868, **20** (2020)

[4] Martin, F., *et al*; arXiv:2107.09420

[5] Johansen, Ø., *et al*; Phys. Rev. Lett. 217203, **122** (2019)

Nanostructured spintronic emitters for polarization-textured thz fields

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Spintronic THz emitters (STEs) rely on spin current acceleration or decay, which results in a burst of broadband THz emission. They offer a new route to both THz optics as well as ultrafast magnetism by relating radiation characteristics to specific spin excitations [1,2]. Here, we present some microscopic architectures forming metastructures of STEs, that allow for molding the vectorial focal distribution with the phase of the orbital part of the emitted THz fields. By appropriate material engineering, combined micromagnetic and photonic simulations allocate the possibility of generating structured electromagnetic fields, for example, broadband azimuthally and radially polarized beams.

The magnetization distribution within the metastructure is decisive for the properties of the near field region, exhibiting subwavelength features prevalent at a distance of fewer than 10 microns.

Generally, higher degrees of distinct spatial structure are assessed with respect to the number and geometry of these STEs.

It is worked out how the fields may be tuned concerning certain magnetoelectric contributions.

The results point towards a new type of engineered STEs for the generation of structured broadband THz fields, with possible application in the fields of optoelectronics, optics, and ultrafast magnetism.

References:

[1] Kampfrath T., Tanaka K. and Nelson K. A.; *Nature Photonics*, 680-690, **7** (2013)

[2] Papaioannou E. T., Beigang R.; *Nanophotonics*, 1243-1257, **10** (2021)

Coupled electronic charge and spin dynamics on curved spaces

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Geometry has an effect on the quantum dynamics of particles confined within quantum dots (smooth submanifolds of Euclidean space). The effect is especially important for lower-dimensional structures, like curves and surfaces, as it can then be expressed in analytical form in, for instance, the Schrödinger equation [1]. Physically, this situation may be represented by a nearly-free electron gas like that forming out on the curved interfaces of nanofabricated GaAs semiconductor heterostructures. This work presents the influence of geometry and topology on the internal electronic charge and spin dynamics of nanostructures. Among these lie the spatial inhomogeneity of the equilibrium probability and spin densities, the appearance of new spin-orbit coupling mechanisms [2], as well as modifications to the effects triggered by irradiated electromagnetic fields.

References:

[1] R.C.T. da Costa; *Phys. Rev. A*, 1932, **23** (1981)

[2] G.-H. Liang, Y.-L. Wang, M.-Y. Lai *et al.*; *Phys Rev. A*, 062112, **98** (2018)

Control of transport effects in magnetic heterostructures by wavelength modulation

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Existing experimental and theoretical studies of ultrafast demagnetization in ferromagnets rely mostly on only one fixed wavelength to excite the sample. However, recent experiments indicate that the dynamics of the demagnetization and remagnetization process of magnetic bi- and multilayer structures depend on the wavelength of the exciting laser pulse [1, 2].

In this contribution, we extend the temperature-based μT-model to describe the ultrafast magnetization dynamics of magnetic/non-magnetic bilayer systems. Our theoretical model relies on realistic densities of states of both materials and includes energy and spin transfer at the interface. Additionally, the model takes into account layer- and photon energy-dependent absorption of the pump pulses in the multilayer system.

For the exemplary case of a thin nickel layer on a gold substrate, we find a faster and larger loss of the magnetic order of Ni when increasing the wavelength from 360 nm to 800 nm. Our theoretical predictions are confirmed by time-resolved magneto-optical Kerr effect experiments. This allows us to discuss the influence of energy and spin transfer processes for the photon energy dependent magnetization dynamics of magnetic bi- and multilayer structures.

References:

[1] V. Cardin et al.; *Phys. Rev. B*, 054430, **101** (2020)

[2] U. Bierbrauer et al.; *JOP: Cond. Mat.*, 244002, **29** (2017)

Wide-field magneto-optical microscope to access quantitative magnetization dynamics with femtosecond temporal and submicrometer spatial resolution

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We introduce a wide-field magneto-optical microscope to probe magnetization dynamics with femtosecond temporal and sub-micrometer spatial resolution. We carefully calibrate the non-linear dependency between the magnetization of the sample and the detected light intensity by determining the absolute values of the magneto-optical polarization rotation. With that, an analytical transfer function is defined to directly map the recorded intensity to the corresponding magnetization, which results in significantly reduced acquisition times and relaxed computational requirements. The performance of the instrument is characterized by probing the magnetic alloptical switching dynamics of GdFe in a pump–probe experiment. The high spatial resolution of the microscope allows for accurately subdividing the laser-excited area into different fluence-regions in order to capture the strongly non-linear magnetization dynamics as a function of the optical pump intensity in a single measurement.

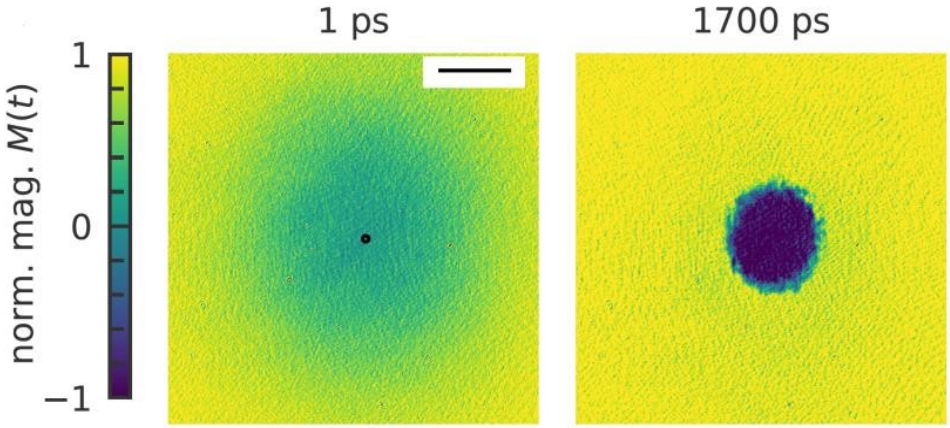

Fig.1: Magnetization of the GdFe sample at different delays after optical excitation. The small black circle in the first image (1 ps) marks the integration area with a size of about 0.2 mJm^{-2} for the timeresolved transient shown in panel.

Wavelength dependency in ultrafast magnetization dynamics of Ni

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We revisit the problem of the influence of optical excitation conditions on ultrafast magnetization dynamics. Combining a theoretical analysis of the excitation and electron dynamics with time-resolved magneto-optical Kerr effect (tr-MOKE) studies we attempt to uncover the role played by the different pump-photon energies for ultrafast demagnetization in thin Ni films (10nm). In the experiment, we use the insulating substrate MgO to exclude transport effects and focus on the intrinsic magnetic dynamics. In our theoretical approach, we calculate the absorption and energy-resolved carrier distribution for different pump wavelengths by a Fermi's Golden Rule approach including ab-initio band structure data. The incoherent electron dynamics after optical excitation is described by the μ-T model.

We compare the magnetization dynamics for a fixed absorbed energy, both in experiment and theory. The calculations show that one obtains rather different minority and majority carrier distributions for pump photon energies in the range from 0.5eV to 2.5eV. In contrast, we find identical tr-MOKE traces for optically excited Ni films for all corresponding pump photon energies. The shape and fluence dependence of these photon energy dependent tr-MOKE traces can be described well by our theoretical model, which is based on an electronic quasi-equilibrium assumption. Our observations suggest a negligible influence of the details of the excited hot-carrier distributions on the ultrafast demagnetization. Rather, the photon energy dependence of ultrafast demagnetization of Ni seems to be dominated by the deposited energy and quasi-thermal behavior of the electron system.

Ferro and *ferri*magnetic switching dynamics due to exchange scattering

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Magnetization switching dynamics in multi-sublattice ferrimagnets with itinerant electronic states have been known and studied for about a decade. The consensus is that the exchange interaction plays the most important role together with the influence of spin-orbit coupling. We discuss here a microscopic description of the dynamics of itinerant electrons that underlies magnetization dynamics on ultrashort timescales in an exchange-coupled magnetic model system [1]. We treat the exchange interaction in the band structure at mean-field level and the exchange scattering between the sublattices in the form of scattering integrals. Spin-orbit coupling can be included explicitly or via an effective spin-flip rate. Assuming an instantaneous excitation we can then describe the complete demagnetization and remagnetization at short and long times, respectively, as the interplay of *incoherent scattering processes*. At short timescales, we find that the incoherent scattering processes due to a ferromagnetic exchange interaction lead to dynamics that are qualitatively similar to those obtained from a time-dependent DFT calculation, where this mainly coherent effect has been called optical inter-site spin transfer (OISTR) [2].

We also revisit our earlier results for a *ferri*magnetic coupling of the sublattices, and show that the asymmetry in the magnetization dynamics leading to a transient-ferromagnetic like state [3,4] can be explained by exchange scattering instead of different magnetization relaxation times of the sublattices.

References:

[1] Baral, A. and Schneider, H. C.; *Phys. Rev. B*, 100402(R), **91** (2015)

[2] Hofherr, M, et al.; *Sci. Adv.*, eaay8717, **6** (2020)

[3] Mentink, J. H., et al.; *Phys. Rev. Lett.*, 057202, **108** (2012)

[4] Ostler, T. A., et al.; *Nat. Comm.*, 666, **3**, (2012)

Ultrafast Spectroscopy of $La_{0.7}Sr_{0.3}MnO_3/La_2CoMnO_6$ Superlattices

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We have studied photoinduced spin dynamics of a $La_{0.7}Sr_{0.3}MnO_3/La_2CoMnO_6$ $[(LSMO)_{12}/(LMCO)_{12}]_8$ superlattice (SL) using time-resolved transient reflectivity and magneto-optical Kerr effect (MOKE). Static studies [1] (see Fig.1) revealed an antiferromagnetic (AFM) coupling between the two adjacent ferromagnetic (FM) layers, i.e. LSMO (T_{C1}=350K) and LMCO (T_{C2}=230K) for temperatures $T \leq T_{C2}$. A moderate external field (H~10kOe) destroys the AFM coupling leading to a FM coupling of the spins in the LSMO/LMCO bilayers.

We have observed complex spin dynamics strongly influenced by the temperature- and field-dependent magnetic state of the SL. For the FM coupled LSMO/LMCO layers (H=10kOe) our MOKE data revealed a relatively fast demagnetization on a 10ps-timescale which is followed by a much slower remagnetization within hundreds of picoseconds. Remarkably, when the AFM coupling sets in for $200K \leq T \leq T_{C2}$ and $H \leq 1kOe$ (see Fig.1) the demagnetization time significantly increases up to about 200ps. For even lower temperatures T<200K within the AFM coupling regime complex magnetization dynamics are observed with an apparent sample magnetization on longer timescales. Finite-Difference Time-Domain (FDTD) simulations [2] of the single layers are performed to explain the observed dynamics of the SL. Our data show a possibility to control the magnetic state and spin dynamics of the SL by applied magnetic fields.

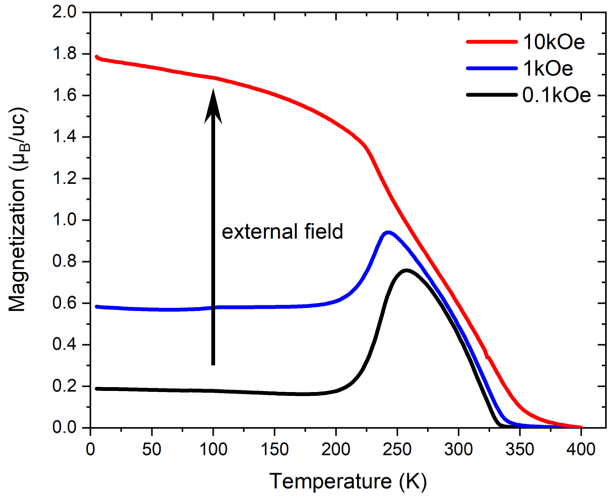

Fig.1: Temperature-dependent magnetization of the LSMO/LMCO superlattice for different applied fields [1].

References:

[1] Weimer I.; Bachelor's thesis (2020)

[2] Ulrichs H., Meyer D. and Müller M.; *AIP Conf. Proc.*, 040004, **1763** (2016)

X-ray absorption spectroscopy of spin-crossover molecules and analysis by means of AI methods

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Spin crossover molecules (SCM) were deposited on a substrate of graphite by thermal evaporation in ultra-high vacuum and characterized by x-ray absorption spectroscopy (XAS). After light irradiation or by a temperature change, the SCM can change their spin state between high-spin (HS) and lowspin (LS). An ensemble of SCM can also exhibit a mixture of both spin states. The two spin states lead to distinctly different XAS at the Fe $L_{2,3}$ edge.

Different coverages of the SCM $[Fe\{(pz)(pypz)\}_2]$[1] were irradiated green light at low temperatures, which leads to a conversion from LS to HS. This phenomenon in general is called light-induced excited spin state trapping (LIESST)[2]. Saturation of the HS content was observed after 10 minutes for 1.2 monolayers (ML), while less than 1 minute was required for 0.9 ML with a flux density of $4.2(8) \times 10^{14}$ photons s^{-1} mm^{-2}. With the same fluence, the saturation time of a 0.7 ML and for the bulk phase on indium, was measured.

The analysis of XAS spectra in terms of HS/LS composition of an ensemble of molecules requires reference spectra with a known composition. As an outlook, a method to evaluate the composition from XAS spectra of an unknown SCM species based on a principal-component analysis to reduce the dimensionality of the signals, in form of 2D images, followed by a comparison by means of a convolutional neural network algorithm is suggested.

References:

[1] S. Ossinger, et. al.; *Inorg. Chem. 2020, 59, 12, 7966–7979*

[2] L. Kipgen et. al. ; NATURE COMMUNICATIONS (2018) 9:2984

Moire tuning of spin excitations: Individual Fe atoms on MoS2/Au(111)

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Magnetic adatoms have been studied on various surfaces in regard to stabilizing, controlling and manipulating single quantum spins. Here, we study single iron atoms adsorbed on a single layer of molybdenum disulfide (MoS_2) on a Au(111) crystal. MoS_2 has been recently reported as a well-suited system for decoupling molecules. We show that we can tune the coupling strength between the individual Fe atoms and the substrate, by making use of the moire structure of the MoS_2 islands. The different coupling strengths are manifested as varying spectroscopic fingerprints, ranging from pure spin excitations (weak coupling to the surface) to Kondo resonances (strong coupling to the surface). Moreover, we see spatial variations of those excitations over one atom, which result from the formation of Fe-S hybrid states, despite the inert nature of the substrate. In conclusion, our work establishes MoS_2 as a tuning layer for quantum spin properties. This tuning can be realized very continuously.

Implementation of the electronic non-equilibrium in the two-temperature model

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We investigate a temperature-based model, called extended two-temperature model (eTTM), that describes the electronic non-equilibrium after ultrashort laser excitation. We discuss improvements in comparison to published versions of this model [1, 2]. We also compare results of the eTTM with results of the well-known two-temperature model (TTM) [3]. We see a delayed increase of the electronic temperature calculated with the eTTM. The observation of the dynamics of high-energy electrons shows the influence of non-equilibrium electrons and thus the advantage of the eTTM over the TTM in comparison to the experiment [4]. Furthermore, we find a good correspondence in the absorption of photons in comparison to the kinetic description using a Boltzmann collision term [5].

References:

[1] Carpene E.; *Phys. Rev. B*, 024301, **74** (2006)
[2] Tsibidis G.D.; *Appl. Phys. A*, 311, **124** (2018)
[3] Anisimov S.I., Kapeliovich B.L., Perel'man T.L.; *Sov. Phys. JETP*, 375, **39** (1974)
[4] Beyazit Y., *et al.*; *Phys. Rev. Lett.*, 076803, **125** (2020)
[5] Mueller B.Y., Rethfeld B.; *Phys. Rev. B*, 035139, **87** (2013)

Lockdown: Pinning and Hysteresis Effects in Antiferromagnetic-Ferromagnetic Heterosystems

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Experimental results on $Mn_2Au/Ni_{80}Fe_{20}$ have shown that a strong exchange coupling of the antiferromagnetic (AFM) Néel vector and the ferromagnetic (FM) magnetization facilitates control of the FM state by external fields with local pinning by the presence of the AFM layer. The domain structure is exactly mapped between the AFM and the FM part and, therefore, allows for indirect imaging of the AFM domain structure [1]. Exchange coupling between the AFM and the FM layers is modelled by an effective space-dependent FM anisotropy, that causes a domain wall (DW) to be present in the FM system [3]. The explicit space-dependence breaks the translational invariance. As a result, the DW in the FM part of the bilayer system is pinned by the position of the DW in the AFM part. The pinning force was determined to scale linearly with the interlayer coupling strength. Hysteresis effects of single domain states in the FM part of the bilayer system were simulated. It was found, that the AFM layer alters the FM switching by inducing anisotropic behaviour. The FM coercive field scales inversely proportional with the applied field strength and the thickness of the FM layer [3].

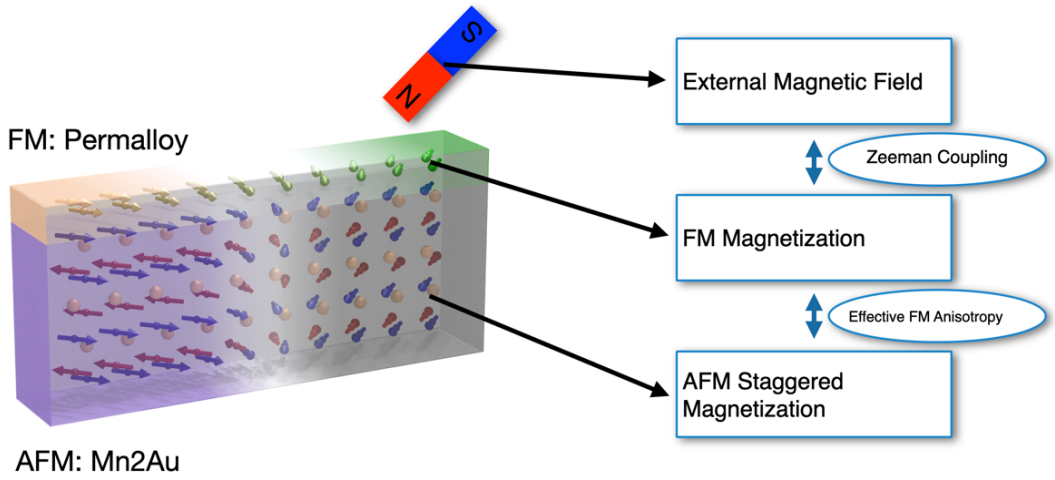

Fig.1: Effective exchange coupling in an AFM-FM heterosystem [2].

References:

[1] S. P. Bommanaboyena et al., arXiv:2106.02333

[2] Figure adapted from Dr. Sarah Jenkins

[3] T. Wagner, Interface Effects in Chiral Magnetic Structures and Antiferromagnetic- Ferromagnetic Heterosystems, Master Thesis, JGU Mainz

Manipulation of ultrafast spin current transmission by insertion of MgO ultrathin layers

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Ferromagnet/heavy metal bilayers represent a central building block for spintronic devices where the magnetization of the ferromagnet can be controlled by spin currents generated in the heavy metal. The efficiency of spin current generation is paramount. Equally important is the efficient transfer of this spin current across the ferromagnet/heavy metal interface. By utilizing ultrafast optical laser excitation, a spin current pulse is generated in the bilayer and converted in the heavy metal into a charge current radiating into the THz regime rendering this system an efficient spintronic THz emitter[1]. Using this technique with Ta as a heavy metal, we demonstrate that the spin current is partially transmitted through the interface while this effect is absent in Pt. Through calculations, we demonstrate that this is due to orbital hybridization which reduces the magnetic moment at the interface in the former case causing also significant spin memory loss. By inserting ultrathin MgO layers in between, the transmission is recovered and the spin current is suppressed after four monolayers of MgO. We further show that by stacking spintronic emitters separated by MgO layers, the on-chip THz signal is significantly increased compared to the radiative signal.

References:

[1] Seifert et. al., *Nature Photonics* 10, 483 (2016)

Spin- and time-resolved momentum microscopy: a powerful tool for imaging optically excited carrier dynamics

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In recent years the development of smaller sizes, faster-operating speed and lower power consumption devices was a main focus in the solid-state community. Especially in the field of 2D material heterostructures more and more material combinations with exotic properties are predicted, grown and studied [1].

The device-relevant functionality of these systems is rooted in the ultrafast charge carrier dynamics within and in between their multilayer structures. Therefore, investigating such dynamics is crucial for application-oriented material research. In this context, spin- and time-resolved momentum microscopy with femtosecond light sources has been proven to be a powerful technique to investigate ultrafast optically induced carrier dynamics in solid-state systems.

This talk will introduce photoelectron microscopy and give an overview of the possibilities such setups can provide for monitoring charge carrier dynamics at surfaces and interfaces. We will present exemplary momentum space images from single metallic crystals such as Cu (111) surfaces, as well as more complex materials like WSe_2, measured with a time-of-flight PEEM, an ARPES setup as well as a NanoESCA. The implementation of spin- and time-resolution will be discussed as well as the possibility for a “complete” photoemission experiment.

References:

[1] C. Gong and X. Zhang: *Science*, **363**, 706 (2019)

Hot electron scattering with exchange effects

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The dynamics of electrons on ultrashort timescales after ultrafast optical excitation is influenced by a variety of mechanisms. Here, we focus on a microscopic description of electronic scattering with magnons. There exist two viewpoints on this problem: One is an exchange Coulomb matrix element with Stoner split d-bands [2] and the other a formal T-matrix contributions to the electronic self energy of Bloch electron states, see Fig. 1 for an illustration. In the latter approach the T-matrix is nevertheless computed using localized Wannier functions. [1] We compare the two approaches concerning the inclusion of screening properties and the role played by the Bethe-Salpeter equation. Going beyond the existing quasi-equilibrium results for electronic lifetimes [1,2], we derive a dynamical equation for electrons in Bloch bands including T-matrix contributions, which allow us to study electron-magnon and electron-electron (Stoner) scattering dynamics without explicitly introducing magnon operators or an additional "spin system" with a parametrized exchange interaction with the itinerant electrons.

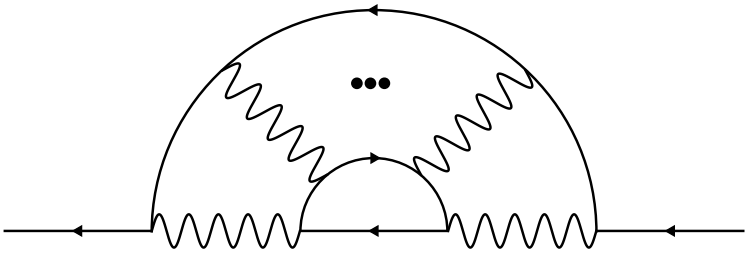

Fig.1: T-Matrix [2].

References:

[1] M. C. T. D. Müller, S. Blügel and C. Friedrich; *Phys. Rev. B*, 045130, **100** (2019)

[2] J. Hong and D. L. Mills; *Phys. Rev. B*, 5589, **62** (2000)

K-space investigation on structured monocrystalline silver flakes

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Surface plasmon polaritons (SPPs) are coherent electromagnetic excitations propagating along the interface of a metal and a dielectric. Due to a momentum mismatch between free-space light and SPPs their excitation requires structures like for example a slit or a grating.

In our research, we investigate SPPs on monocrystalline silver flakes on a silicon substrate fabricated by a self-assembling top-down process [1]. By using a focused ion beam (FIB), the flakes are structured with segmented Archimedean spirals (so-called plasmonic vortex generators). The plasmons excited at these structures with circularly polarized light carry an orbital angular momentum (OAM) of $l = m + s$ where m is the order of the spiral and $s = \pm 1$ is the spin of the illumination [2, 3]. Fig. 1 presents a time-resolved photoemission electron microscope (PEEM) snapshot of a plasmonic-vortex generator with $m = 10$ upon right-handed circularly polarized light ($s = -1$) illumination. Our aim is to study the momentum space signature of plasmon-induced hot electrons created in such vortices.

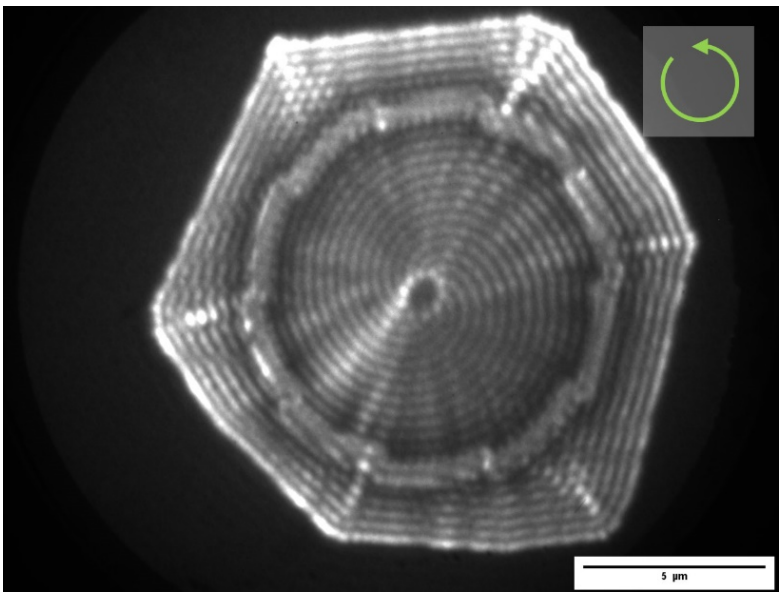

Fig.1: Real-space PEEM image of SPPs with OAM on a structured silver flake using right-handed circularly polarized light (green arrow).

References:

[1] Schörner, C., Adhikari, S. and Lippitz, M.; *Nano Lett.*, 3238, **19** (2019)

[2] Kim, H., Park, J., Cho, S.-W., Lee, S.-Y., Kang, M. and Lee, B.; *Nano Lett.*, 529, **10** (2010)

[3] Spektor, G., Kilbane, D., Mahro, A. K., Frank, B., Ristok, S., Gal, L., Kahl, P., Podbiel, D.,Mathias, S., Giessen, H., Meyer zu Heringdorf, F.-J., Orenstein, M. and Aeschlimann, M.; *Science*, 1187, **355** (2017)

The role of magnon-phonon hybridization in the lifetime broadening of surface states in rare-earth metals

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Magnons and phonons are elementary excitations of spin and lattice systems that can form a hybrid quasiparticle in the presence of strong magnetoelastic coupling. Here we use spin-, angle-, and energy-resolved photoemission spectroscopy to show that magnon-phonon hybridization plays an important role for the relaxation of the electron surface-state in Tb, opening both majority and minority spin channels in electron-phonon scattering. This is attributed to the strong 4f spin-orbit coupling, as evidenced by a comparison of the lifetime broadening in the occupied surface states of Gd and Tb. Both ferromagnetic metals have a comparable valence electronic structure, but the magnetocrystalline anisotropy is much stronger in Tb as compared to Gd. Consequently, in Gd electron-phonon and electron-magnon scatterings lead to spin-dependent photohole relaxation rates. Unlike in Gd, the lifetime broadening of the occupied surface state in Tb is only weakly spin dependent and the mass enhancement parameter λ is twice the spin-averaged value of Gd. This difference in phase space is explained by the intimate coupling of phonons and magnons to form magnon polarons, which opens both minority and majority spin bands as decay channels.

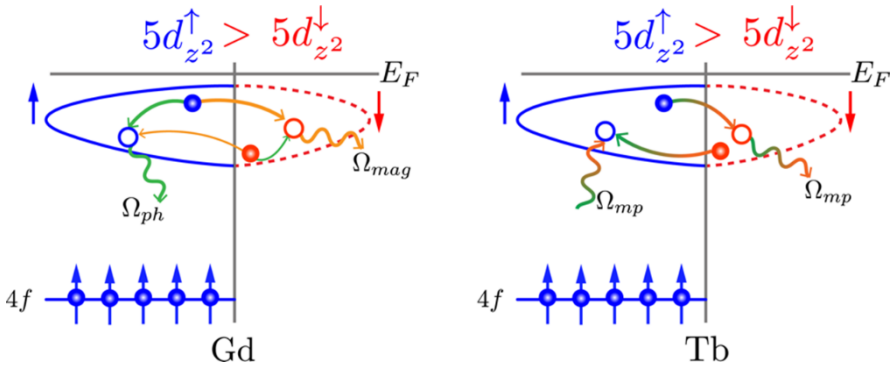

Fig. 1: Scattering process sketch of Gd (left) and Tb (right).

References:

[1] Bo Liu., Huijuan Xiao. and Martin Weinelt., etc; *Phys. Rev. B* 104, **024434** (2021)

Oscillating kinetic energy of the photoemitted electrons in tr-ARPES

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We observed an oscillatory modulation of the kinetic energy of photoelectrons before time delay zero when measuring dynamics of electronic band structures on the surface of Fe (110) in time- and angle-resolved photoelectron spectroscopy with XUV photons. Such oscillations have been observed on the surface state of Gd [1]. They described the oscillations with a ponderomotive acceleration of the emitted photoelectrons in a transient grating formed by the interference between the incident and reflected parts of the pump pulse. The oscillations during temporal overlap between pump and probe pulses may have an impact on ultrafast dynamics at short positive delays. We extended the ponderomotive acceleration model to study the impact, which is dependent on the phase shift between incoming and reflected infrared light.

References:

[1] Bovensiepen et al., Phys. Rev. B, 79, 045415 (2009)

All-optical switching on the nanometer scale excited and probed with femtosecond extreme ultraviolet pulses

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Ultrafast control of magnetization on the nanometer length scale, in particular all-optical switching (AOS), is key to putting ultrafast magnetism on the path towards future technological application in data storage technology. However, magnetization manipulation with light on this length scale is challenging due to the wavelength limitations of optical light. Here, we show AOS on the nanometer scale by interfering two extreme ultraviolet (XUV) pulses from a free electron laser (FEL) at the FERMI facilities, exciting transient magnetization gratings (TMG) with periods of 87 nm and perform resonant diffraction from the TMG at the Gd N-edge, probing the magnetic excitation in a GdFe alloy. By examining the simultaneously recorded first and second order diffraction and by performing reference real-space measurements on a wide-field magneto-optical microscope, we can conclusively demonstrate AOS on the nanometer scale.

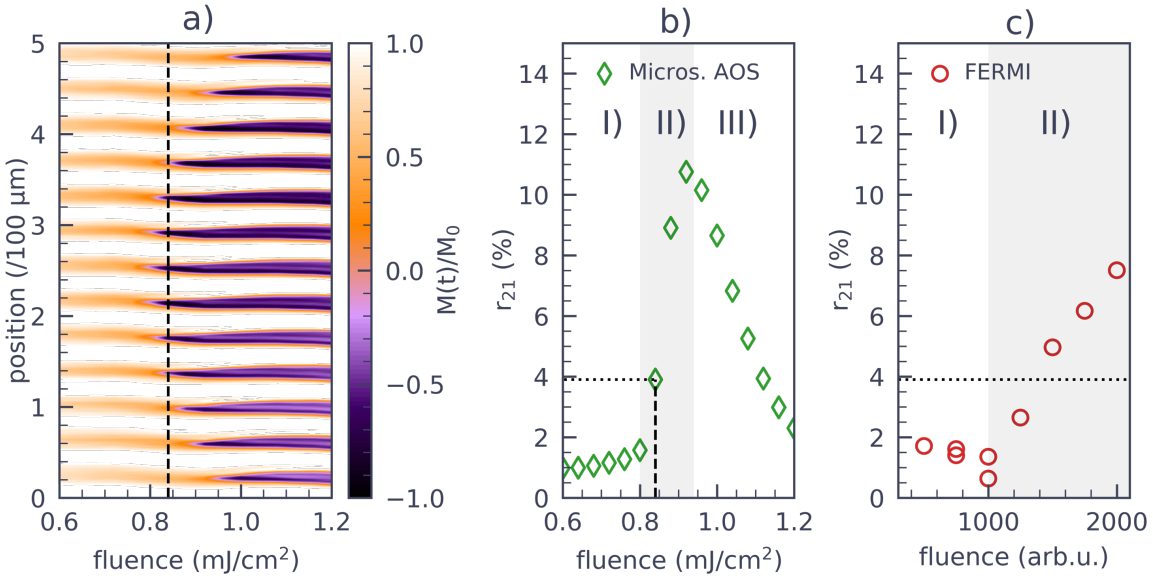

Fig. 1 a) Lineouts of cropped real-space images as a function of pumping fluence (each of the two pump beams) at a delay of 50 ps. b) Ratio r21 between the 2nd and 1st order as a function of the pump fluence, by the Fourier transform of the real-space images, where the vertical dashed lines indicates the switching fluence and the dotted horizontal line reveals the corresponding switching value r21 and c) from the diffraction experiment at FERMI at a delay of 50 ps. The horizontal dotted line indicates the asymmetry above which we expect AOS.

Magnetization dynamics in ferromagnetic multilayers

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Thin film heterostructures consisting of several magnetically ordered layers are a promising platform for magnon spintronics because they can host complex magnetic textures, hybrid spin dynamics and spin torques [1,2].

We have investigated the magnetization dynamics of qualitatively different purely metallic ferromagnetic thin film multilayers systems using broadband ferromagnetic resonance (FMR) and microfocused frequency-resolved magneto-optic Kerr effect (μFR-MOKE) at room temperature. With FMR, we find that the anisotropy of all-metallic systems based on Pt/CoFe/Ir multilayers can be tuned from $\mu_0 M_{\mathrm{eff}} \approx 300$ mT to $\mu_0 M_{\mathrm{eff}} \approx 0$ by varying the number of multilayer repeats without affecting magnetic damping. We extract the spinwave dispersion using μFR-MOKE and find μm scale spinwave propagation lengths and group velocities in the order of 10 km/s. We investigate the hybrid spin dynamics in metallic ferromagnetic in-plane anisotropy/perpendicular magnetic anisotropy systems based on [Co/Ni]/Cu/CoFeB thin film multilayers.

References:

[1] Klingler *et al*., Phys. Rev. Lett. **120**, 127201 (2018)

[2] Flacke *et al*., arXiv:2102.11117 (2021)