UNIVERSITÄT GREIFSWALD
Wissen lockt. Seit 1456

Attosecond Spintronics

Light wave dynamics driving attosecond coherent spins and topological systems

Markus Münzenberg

F. Siegrist *et al*., Light-wave dynamic control of magnetism,
Nature **571**, 240–244 (2019)

Florian Siegrist, **Martin Schultze**, TU Graz/ MPQ Garching
Sangeeta Sharma, MBI Berlin/ MPI Halle

Collaborations

@spintronicsHGW

Attosecond spin dynamics:

Florian Siegrist, Martin Schultze, TU Graz/ MPQ Garching

Sangeeta Sharma, MBI Berlin, MPI Halle

THz emitter:

J. Nötzold, S. Mährlein, Lukas Braun, Tobias Kampfrath, *Fritz Haber Institute*

Marco Battiato, Pablo Maldonado, Peter Oppeneer, *Uppsala University*

F. Freimuth, Y. Mokrousov, S. Blügel, *FZ Jülich*

Mathias Kläui, *Mainz University*

All-optical writing:

Pablo Nieves, Oksana Chubykalo-Fesenko,
CSIC, Madrid

J. McCord, C. Müller, *Kiel University*

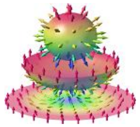
Tiffany Santos,
Western Digital Cooperation San Jose

Uli Nowak, Denise Hinzke, *Konstanz University*

Deutsche Forschungsgemeinschaft
DFG

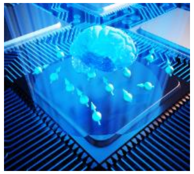
SPP 1666

Priority program
Topologische
Isolatoren



Priority program
Skyrmionics

HORIZON 2020



FET Open SpinAge

ZENTREN FÜR
INNOVATIONSKOMPETENZ
UNTERNEHMEN REGION
Die BMBF-Innovationsinitiative Neue Länder

Bundesministerium
für Bildung
und Forschung

META ZIK PlasMark

DAAD

Contributions

@spintronicsHGW

Ulrike Martens

Nina Meyer

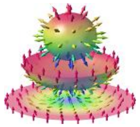
Jakob Walowski

Christian Denker

Deutsche Forschungsgemeinschaft
DFG

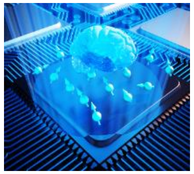
SPP 1666

Priority program
Topologische
Isolatoren



Priority program
Skyrmionics

HORIZON
2020



FET Open SpinAge

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und Forschung

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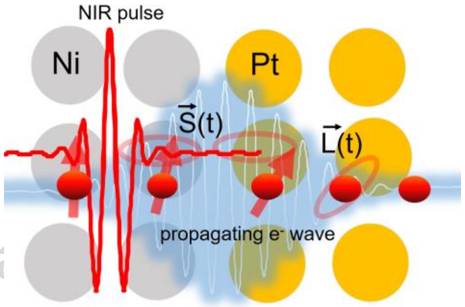
DAAD

Outline

- A coherent attosecond spintronics?
- The nature of femtosecond spin dynamics
- THz spintronic emitter – *noncoherent*
- *Topological Insulators*
- Lightwave electronics - *coherent*
- Summary

Outline



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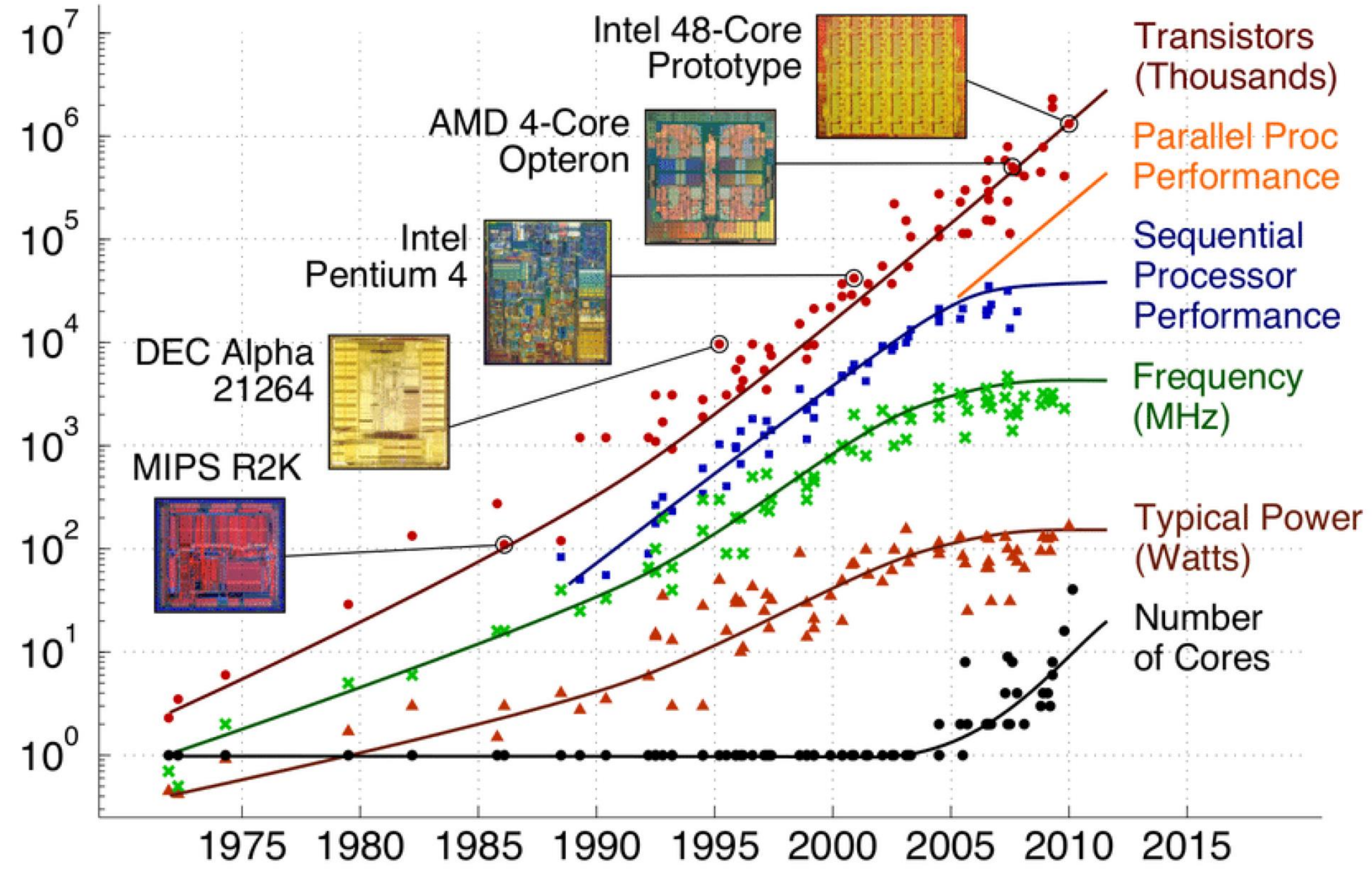
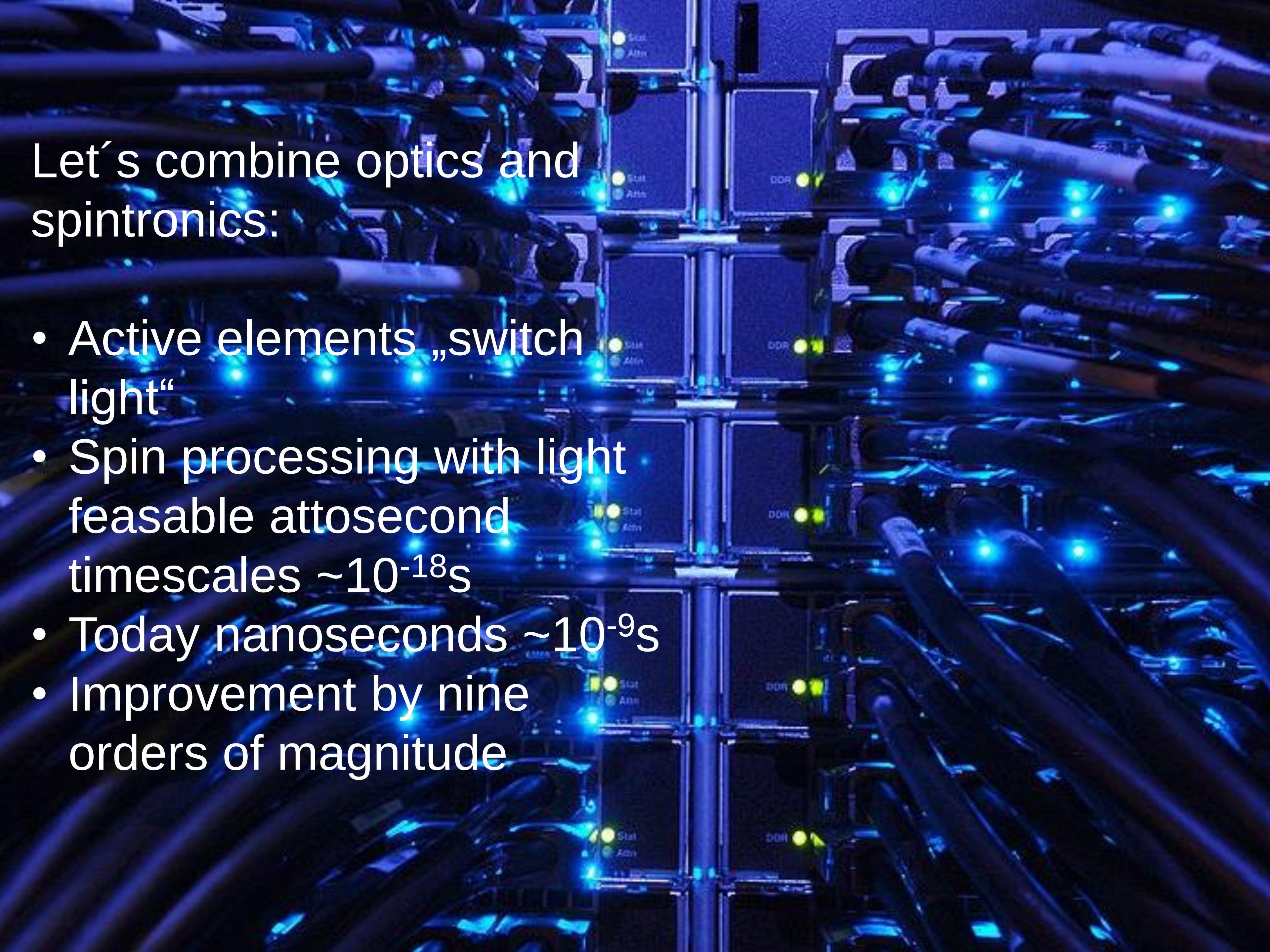
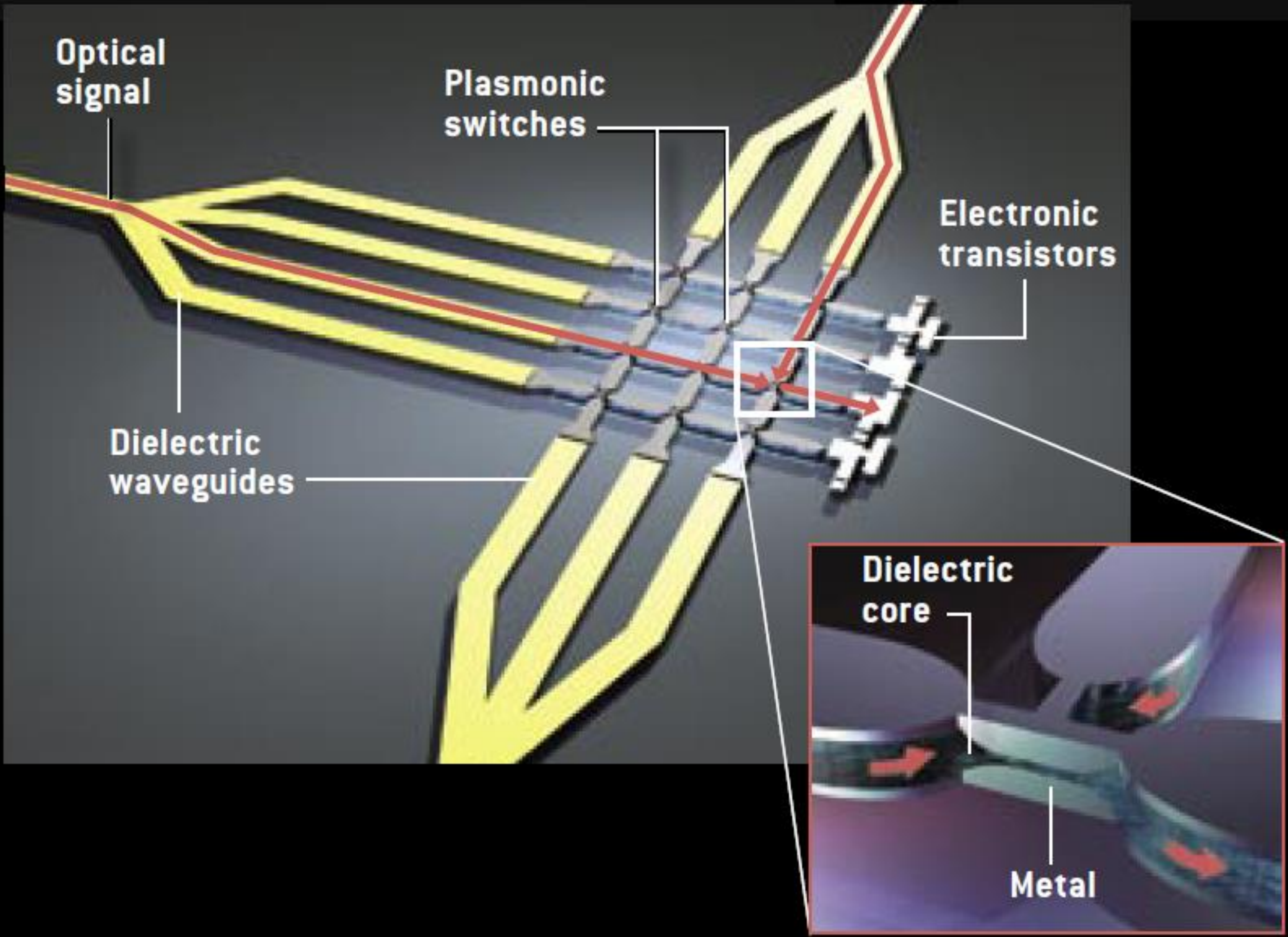

Intel 48-Core Prototype
AMD 4-Core Opteron
Intel Pentium 4
DEC Alpha 21264
MIPS R2K
Transistors (Thousands)
Parallel Proc Performance
Sequential Processor Performance
Frequency (MHz)
Typical Power (Watts)
Number of Cores
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1975
1980
1985
1990
1995
2000
2005
2010
2015



Let´s combine optics and spintronics:

- Active elements „switch light“
- Spin processing with light feasable attosecond timescales ~10^{-18}s
- Today nanoseconds ~10^{-9}s
- Improvement by nine orders of magnitude

Squeeze light: plasmonics

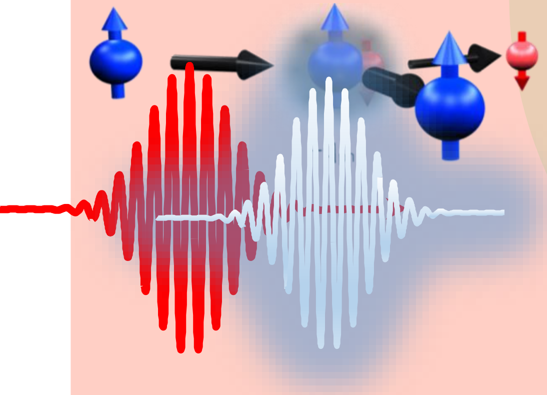


Scientific American (2007)

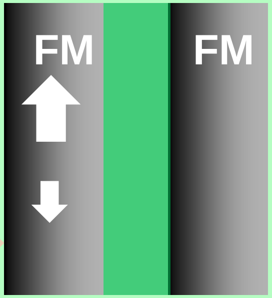
Novel spintronic Photonic THz applications

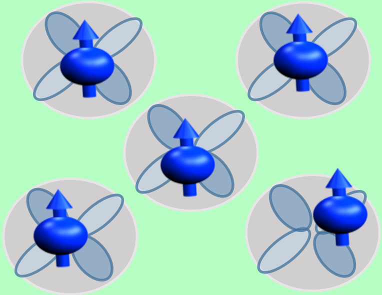
Photonics

Attosecond
coherent
clocking



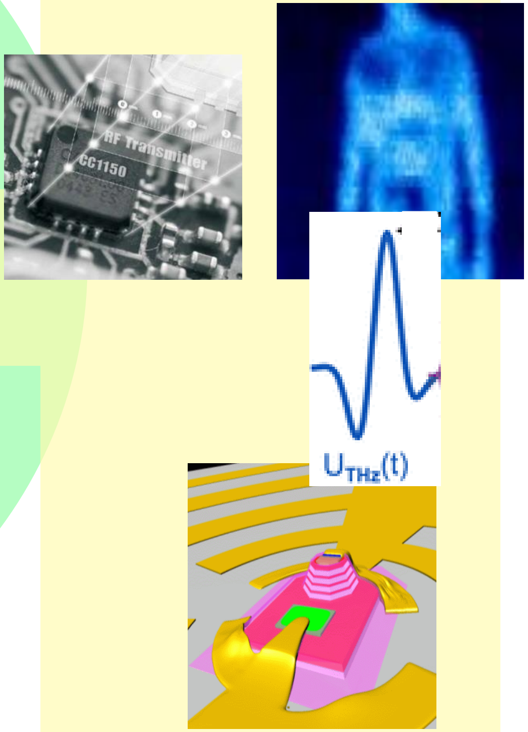
Spintronics



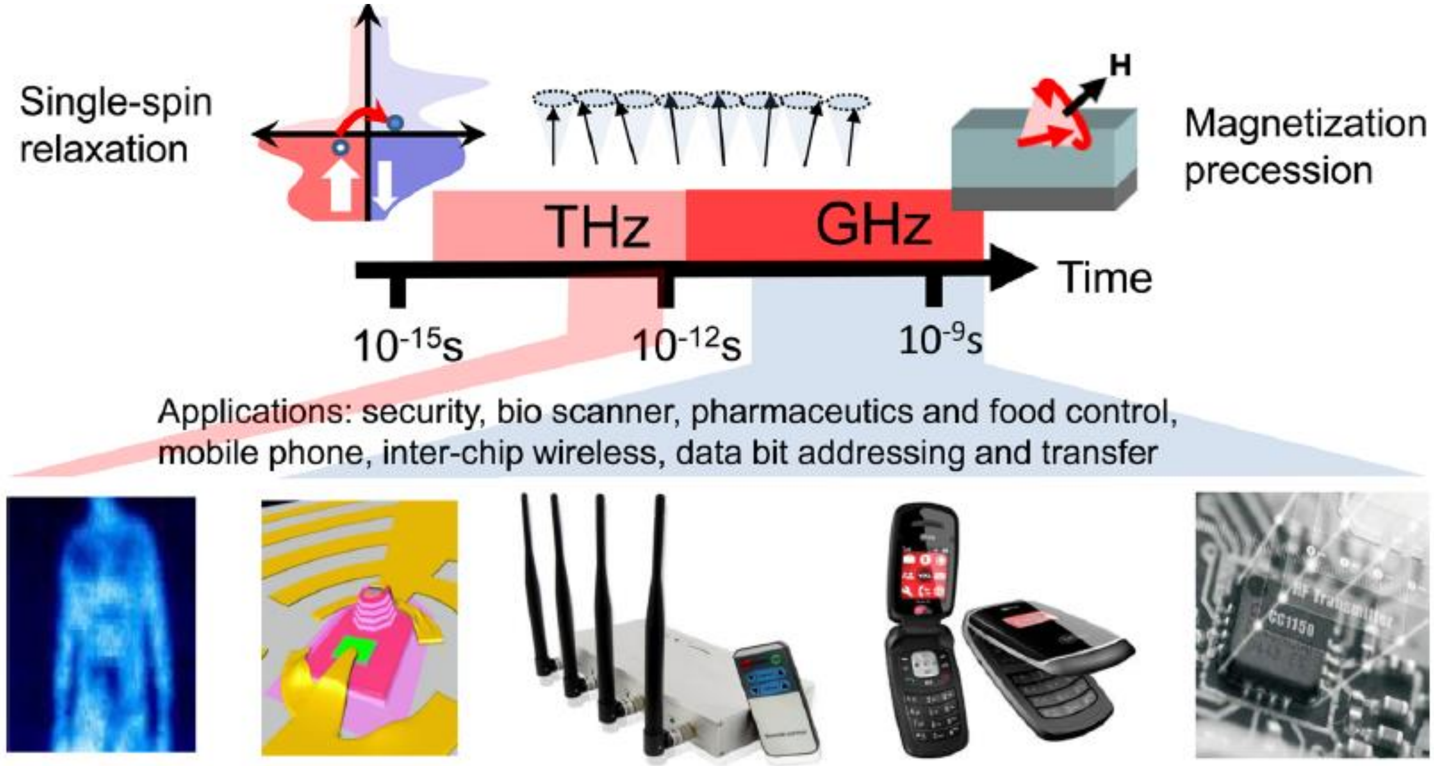


Electronics

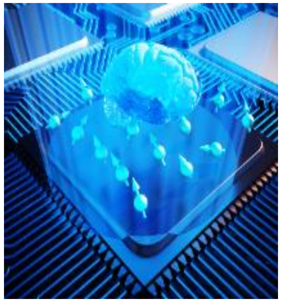
THz applications



Novel spintronic THz applications



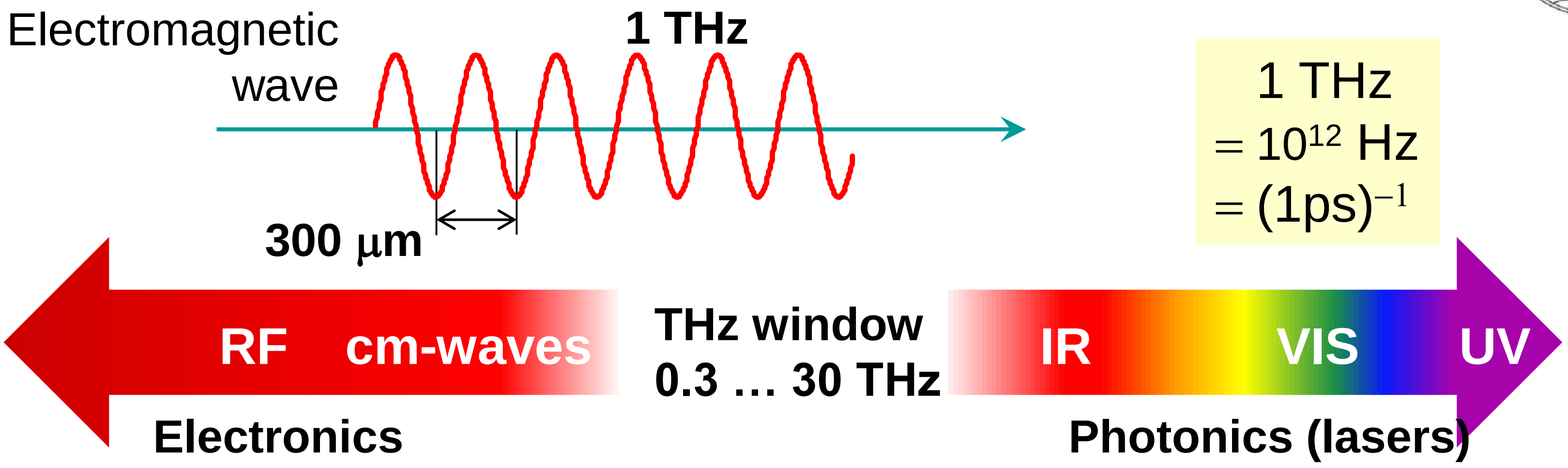
Brain inspired computing - SOT oscillators addressed in plasmonic chips



FET Open SpinAge

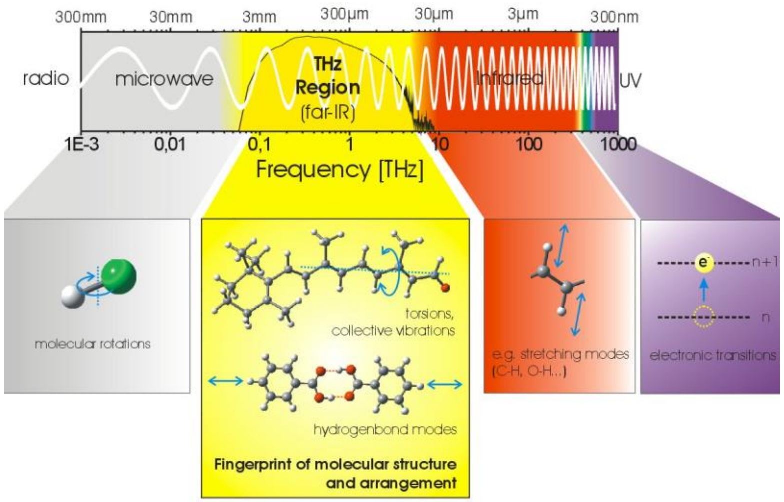
Communicationand data frequencies:
3G and LTE: 0.7 to 2.6 GHz 5G: 24.25 – 27.5 GHz
6G reaches THz frequency: > 95 GHz to 3 THz range

Novel spintronic THz applications

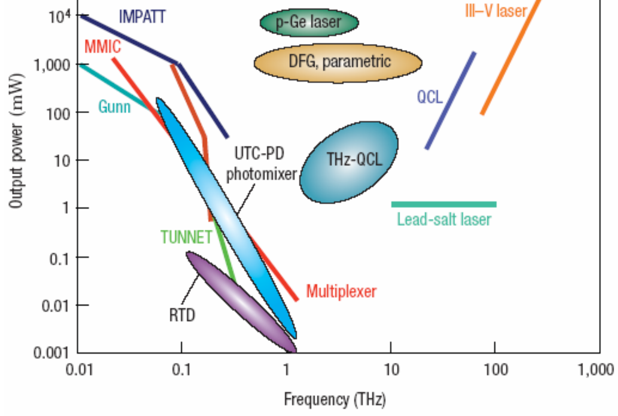


1 THz
$= 10^{12}$ Hz
$= (1\text{ps})^{-1}$

Biophysical and medical sensing



Novel THz sources bridge the THz gap



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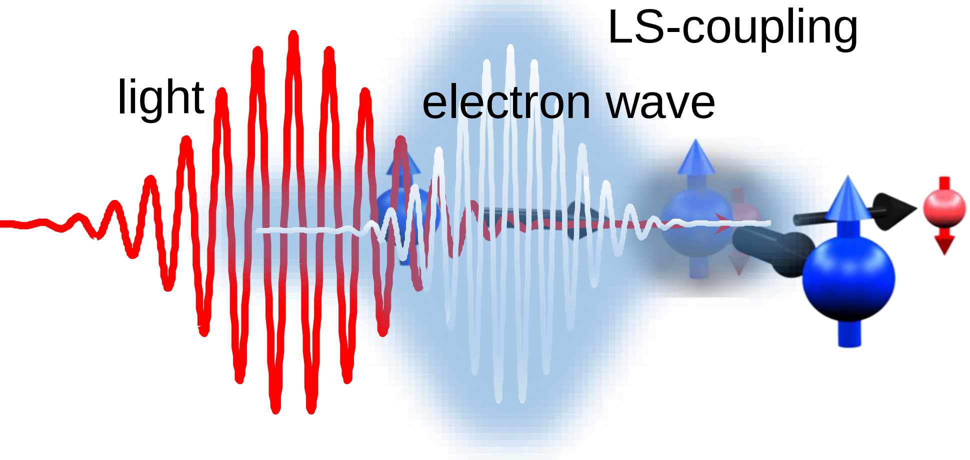
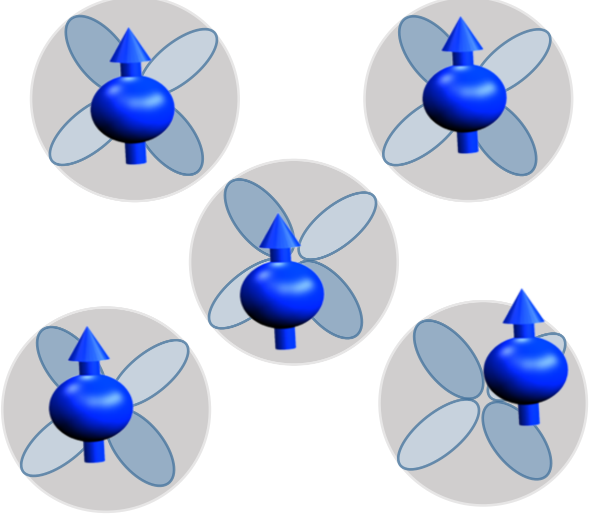
A coherent attosecond spintronics?

Excitation



Five atoms, evolution of $\left\langle \Delta S^z \right\rangle$?



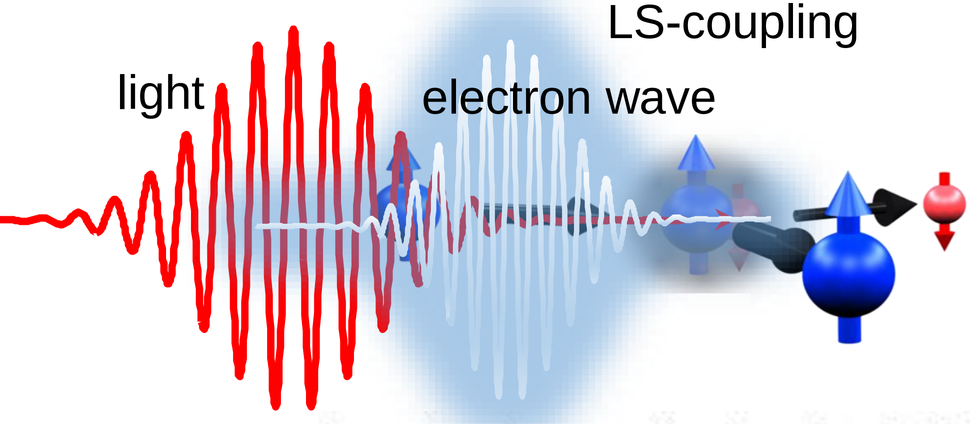
Key to understanding of spin dynamics on atto- to femtosecond timescales (1 as to 10 fs) ab-initio:

Timeresolved Density Functional Theory (trDFT)

Wolfgang Hübner, Gouping Zhang, Hardy Gross, Sangeeta Sharma, Stefano Sanvito …

A coherent attosecond spintronics?

Excitation

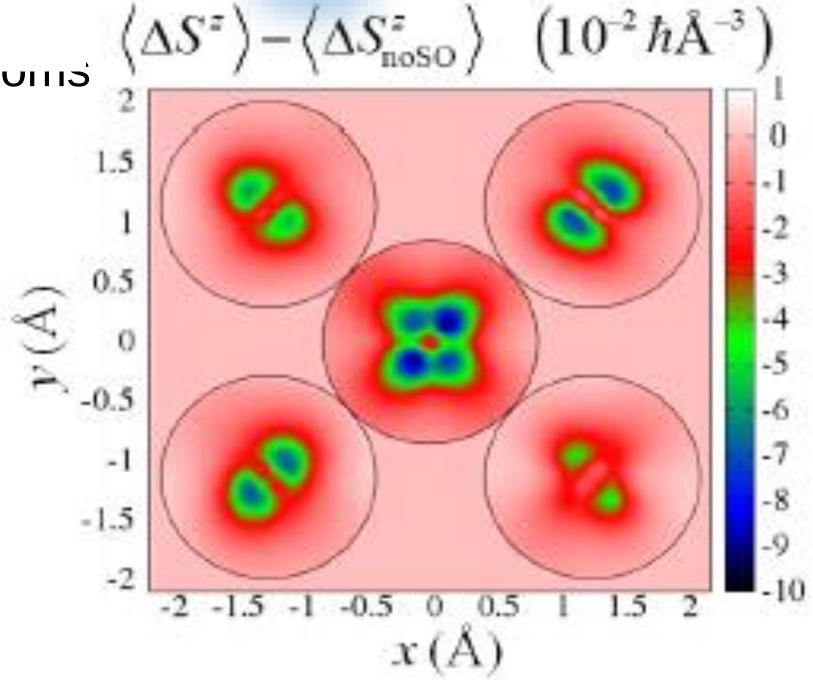


LS-coupling

light

electron wave

Five atoms



$\langle \Delta S^z \rangle - \langle \Delta S^z_{\mathrm{noSO}} \rangle \quad (10^{-2}\,\hbar \text{Å}^{-3})$

J. Simoni, et al. Phys. Rev. B 95, 024412 (2017)

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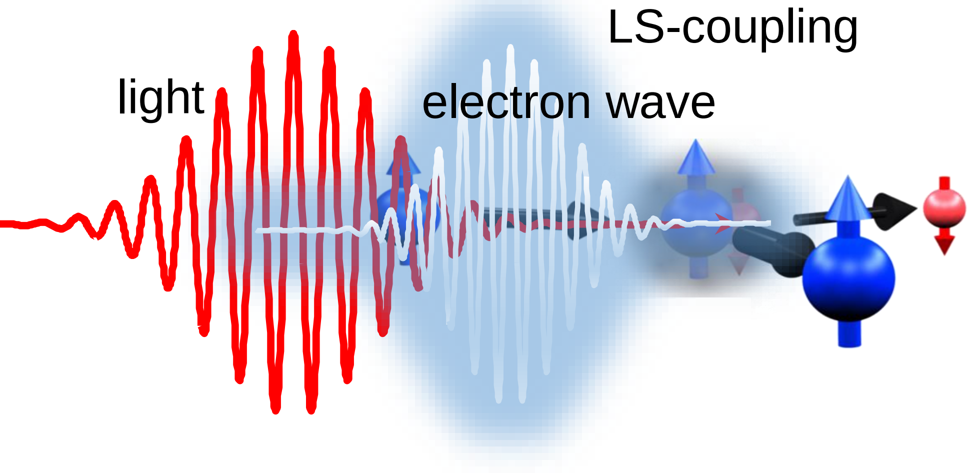
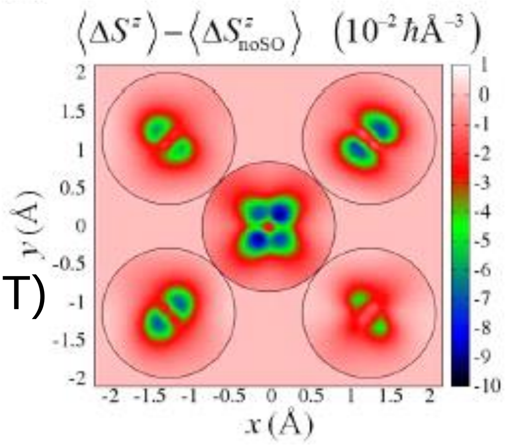
LS-couping results in evolution of the magnetization on attosecond timescales in the atom´s shell

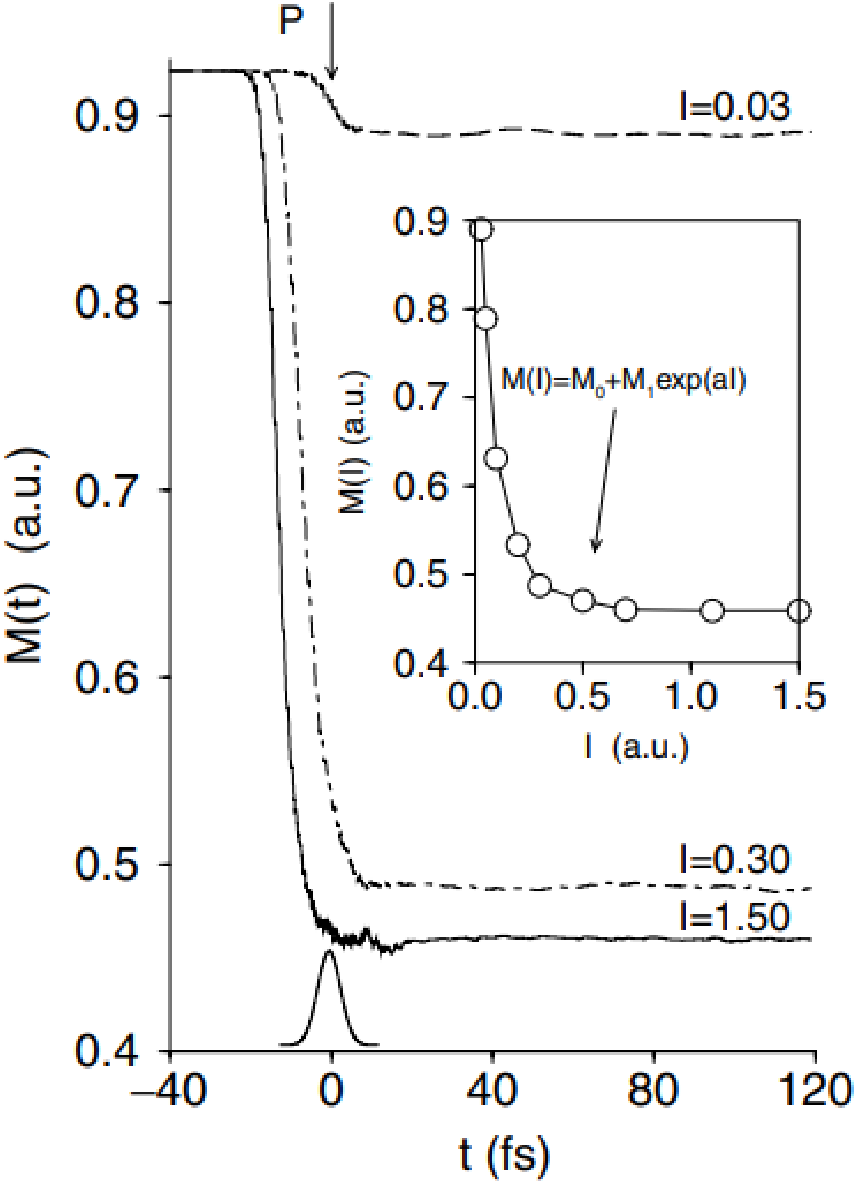
A coherent attosecond spintronics?

Excitation



Time dependent density functional theory (trDFT)

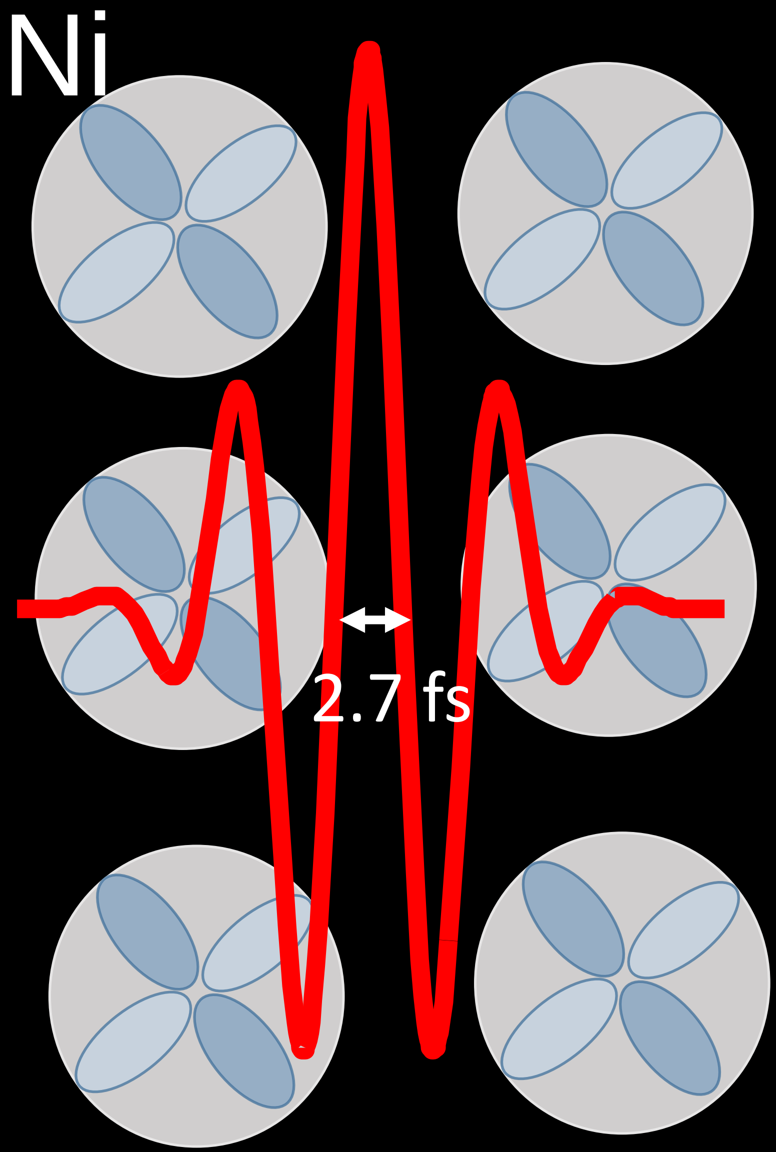


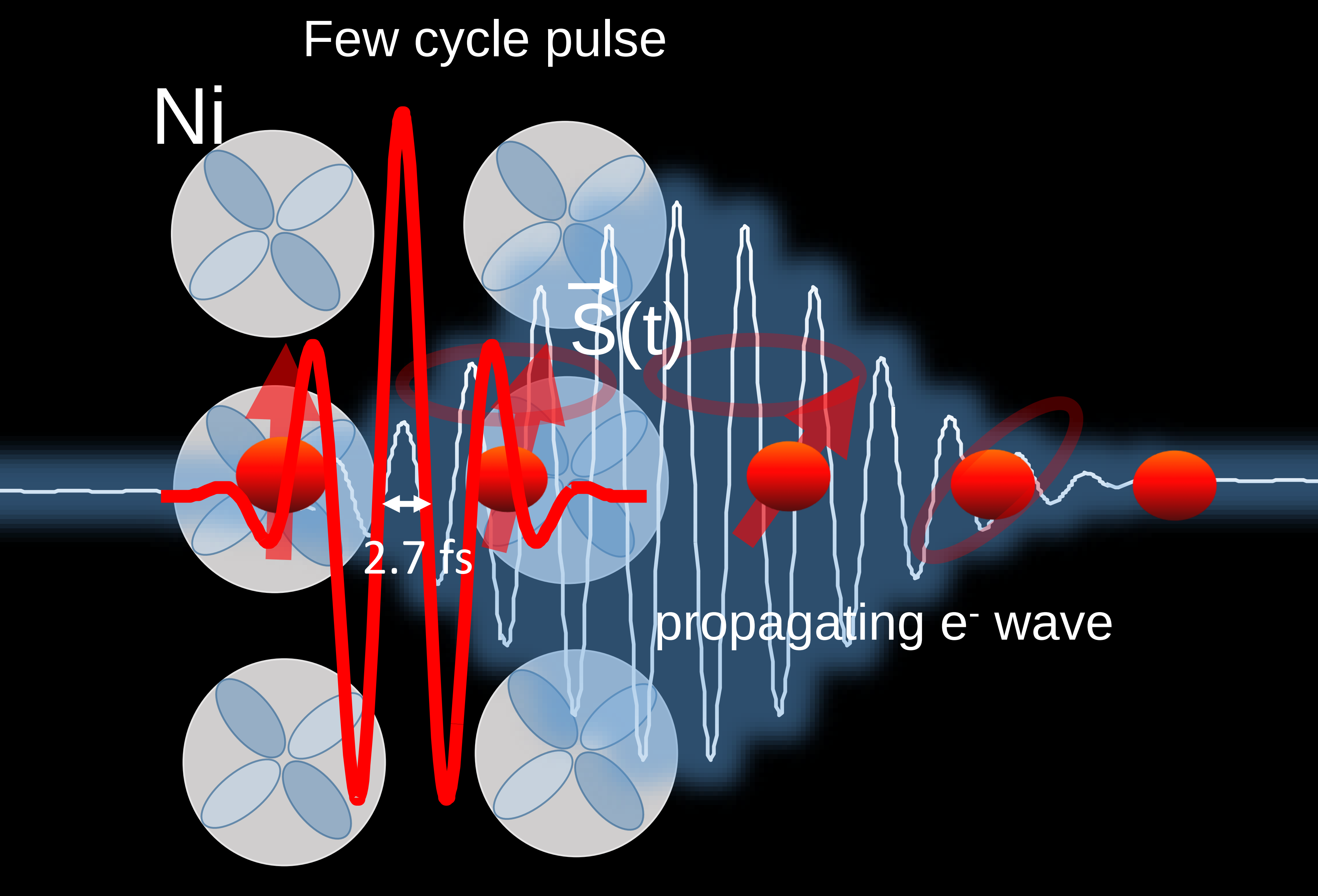


LS-couping results in evolution of the magnetization on attosecond timescales

G. Zang, W. Hübner Phys. Rev. Lett 2000

Few cycle pulse





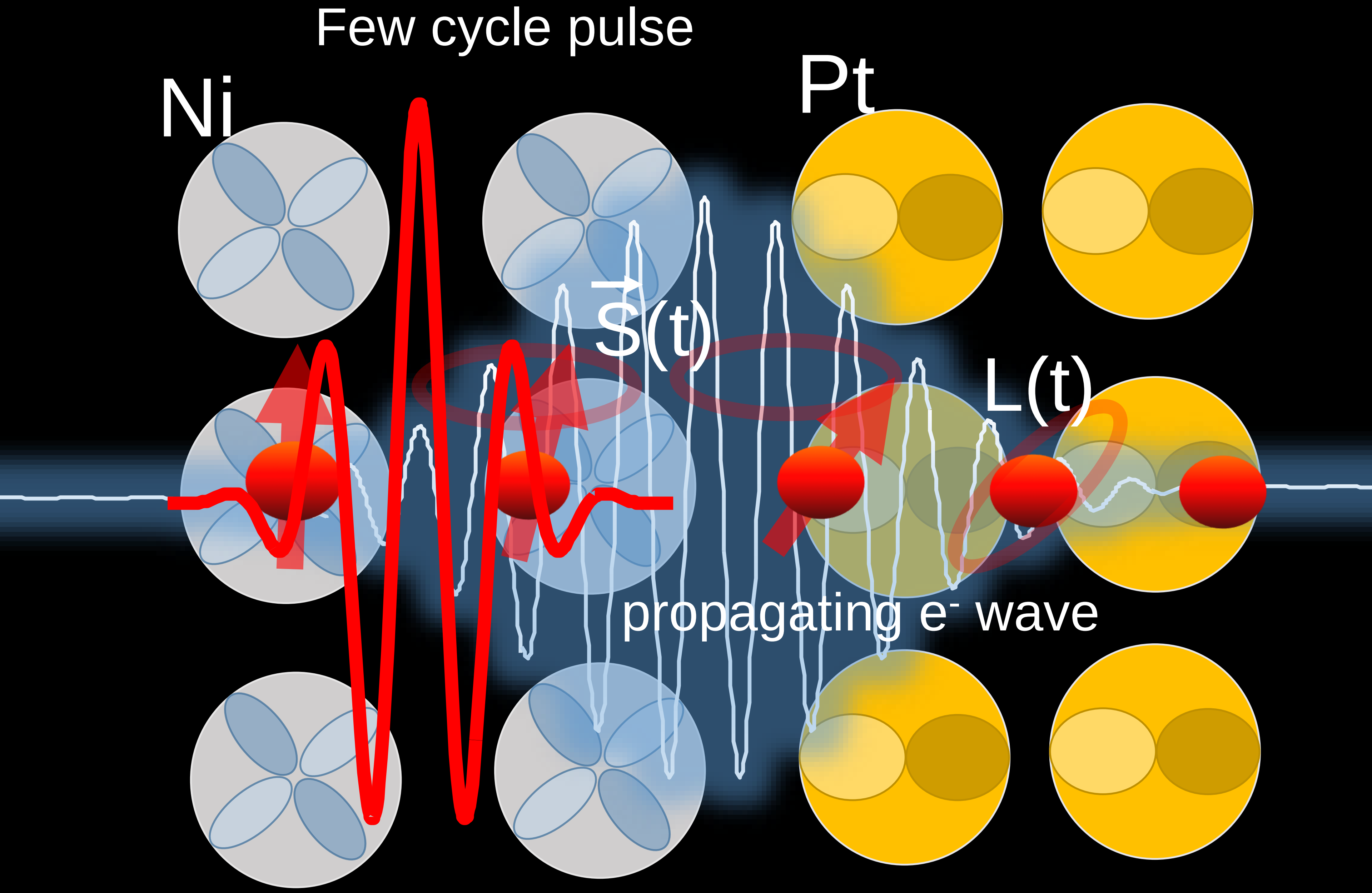
Few cycle pulse

Ni

$\vec{S}(t)$

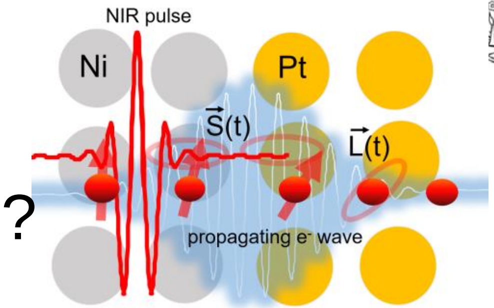
2.7 fs

propagating e^{-} wave



Attosecond Coherent Spintronics

Outline



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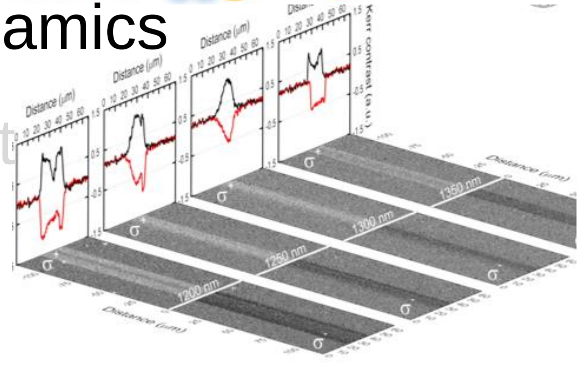
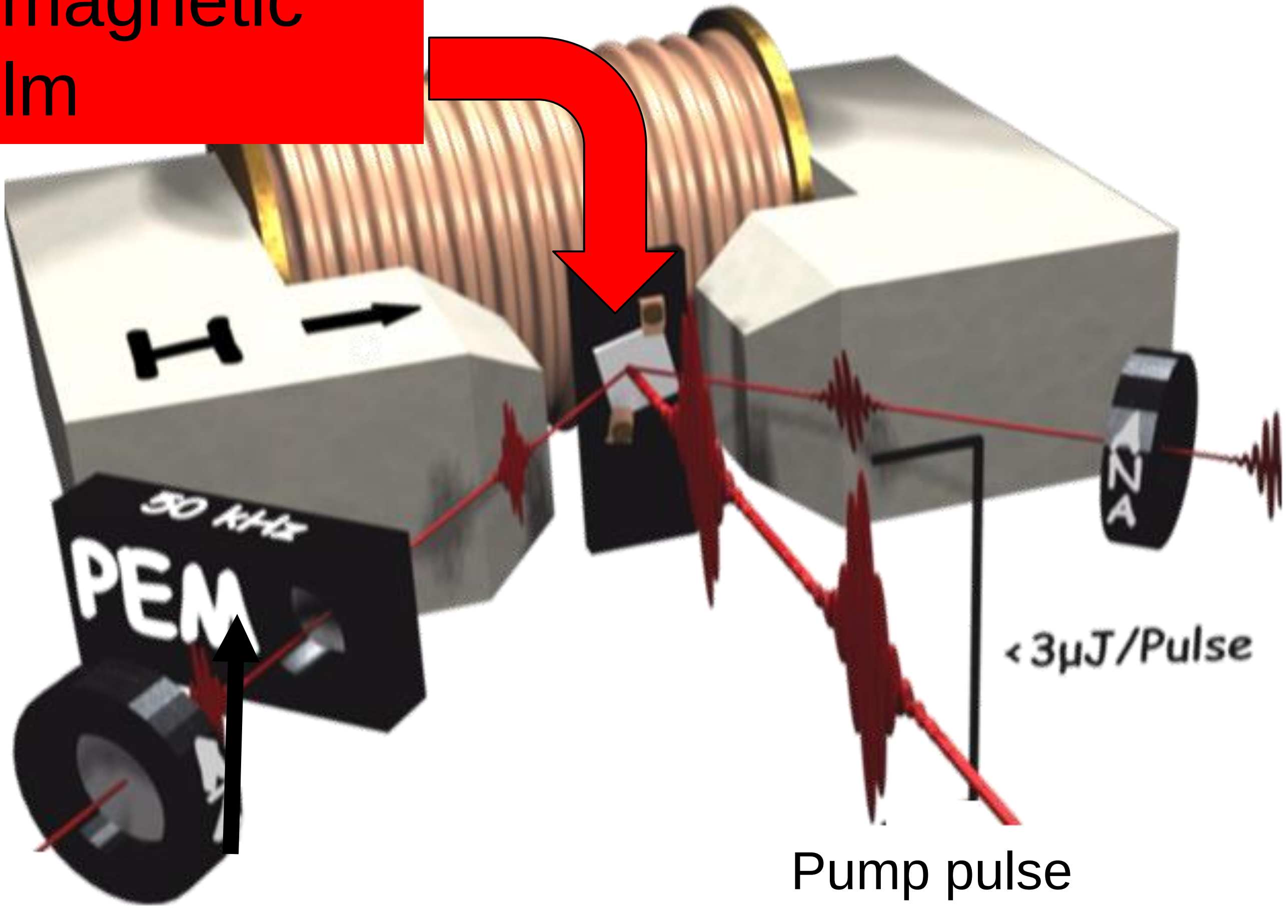


Femtosecond pump-probe

Ferromagnetic thin film



Polarization modulation

Signal ~ M(t)

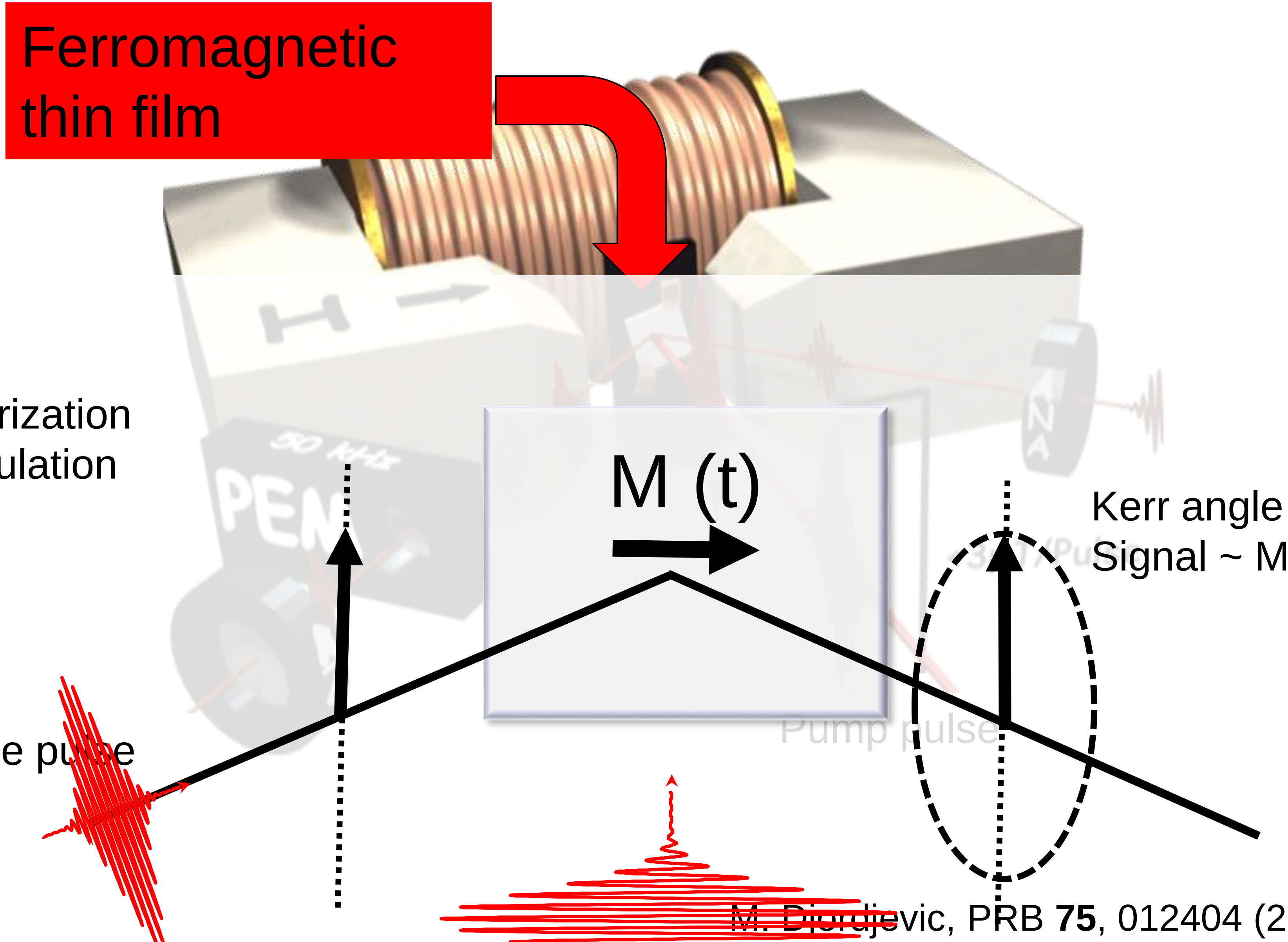
Probe pulse

Pump pulse

- Access to ultrafast the relaxation (40 fs, λ=800nm)

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

Femtosecond pump-probe



Ferromagnetic thin film

Polarization modulation

M (t)

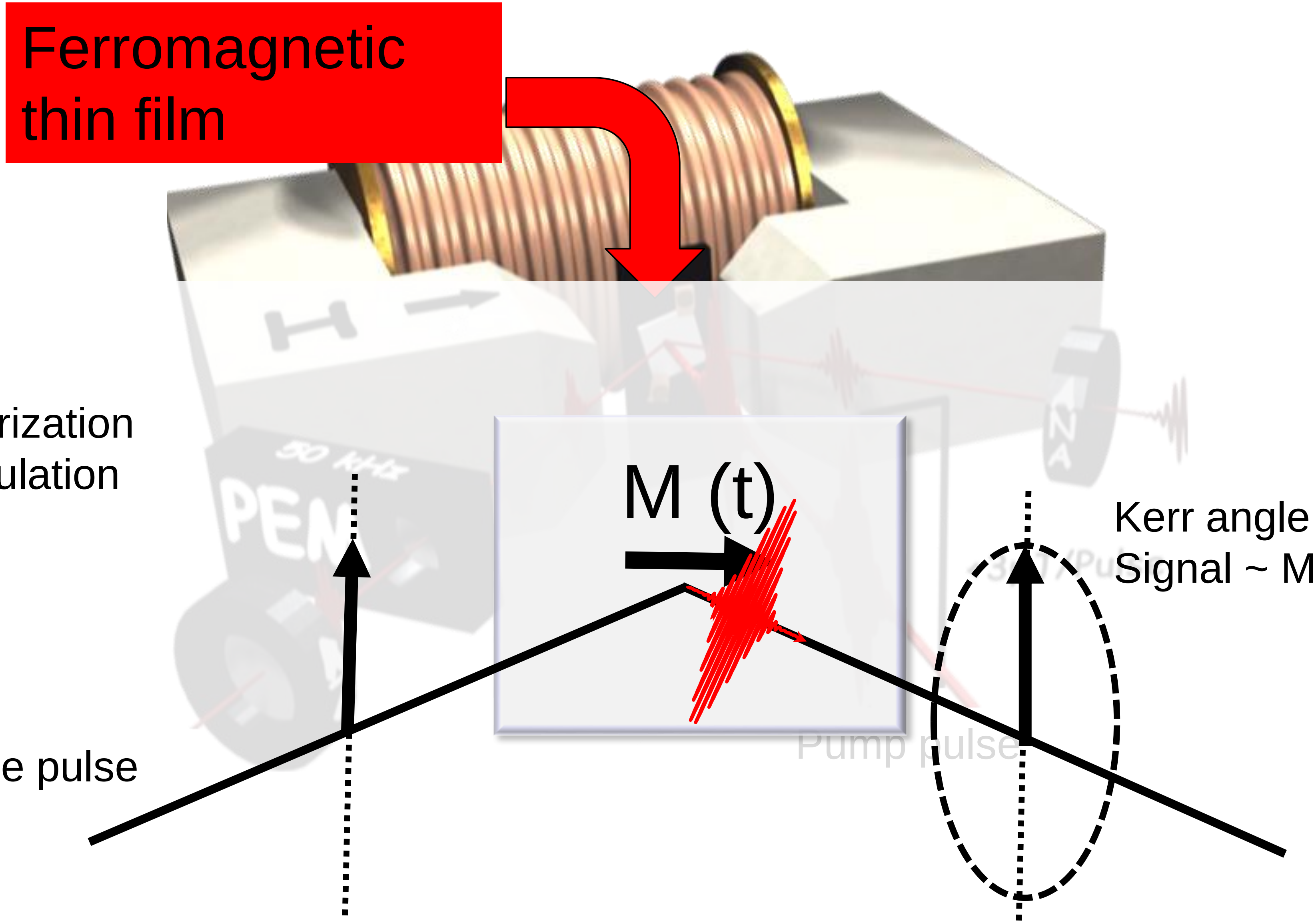
Kerr angle
Signal ~ M(t)

Probe pulse

Pump pulse

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

Femtosecond pump-probe



Ferromagnetic thin film

Polarization modulation

M (t)

Kerr angle Signal ~ M(t)

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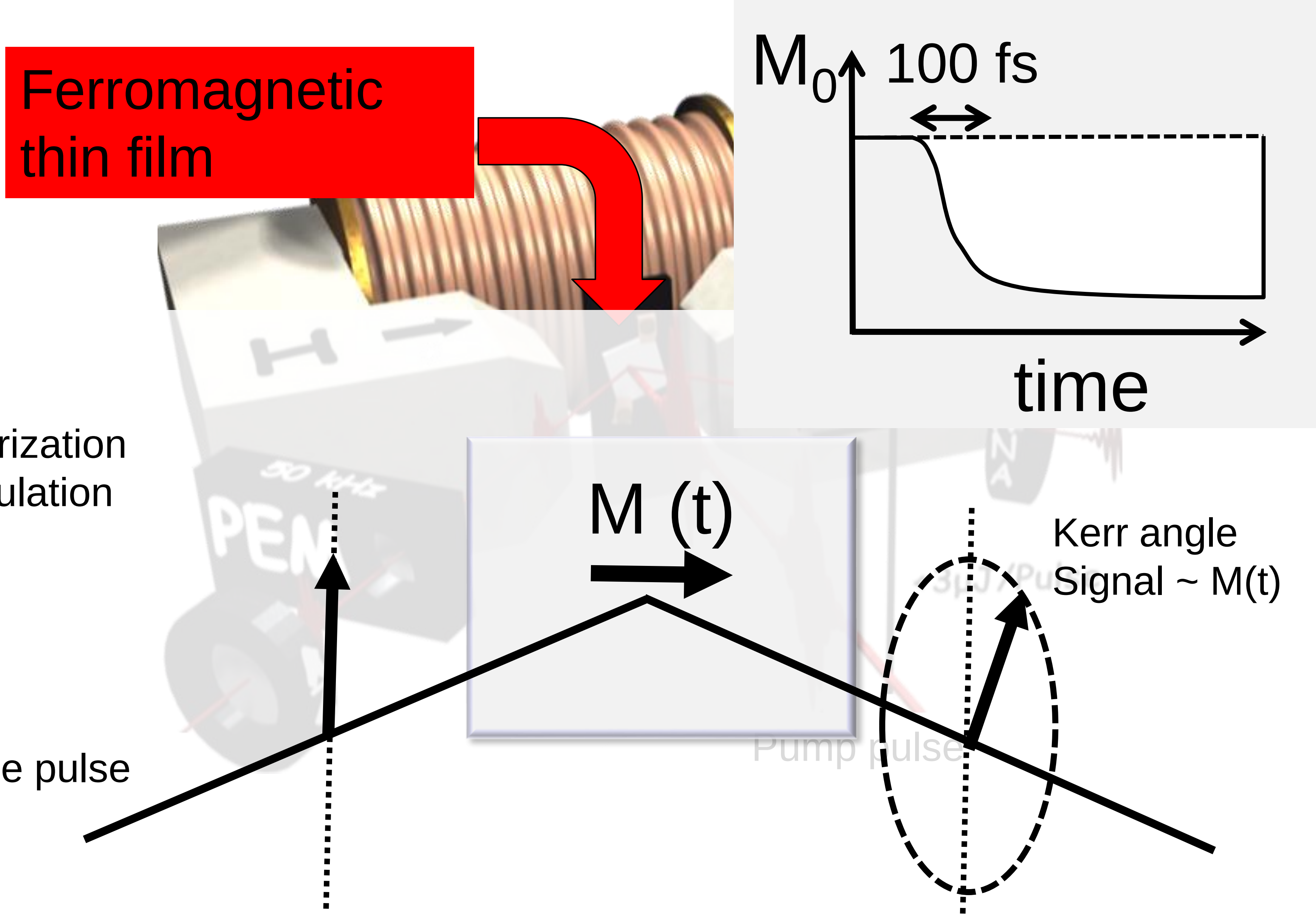

Ferromagnetic thin film

Polarization modulation

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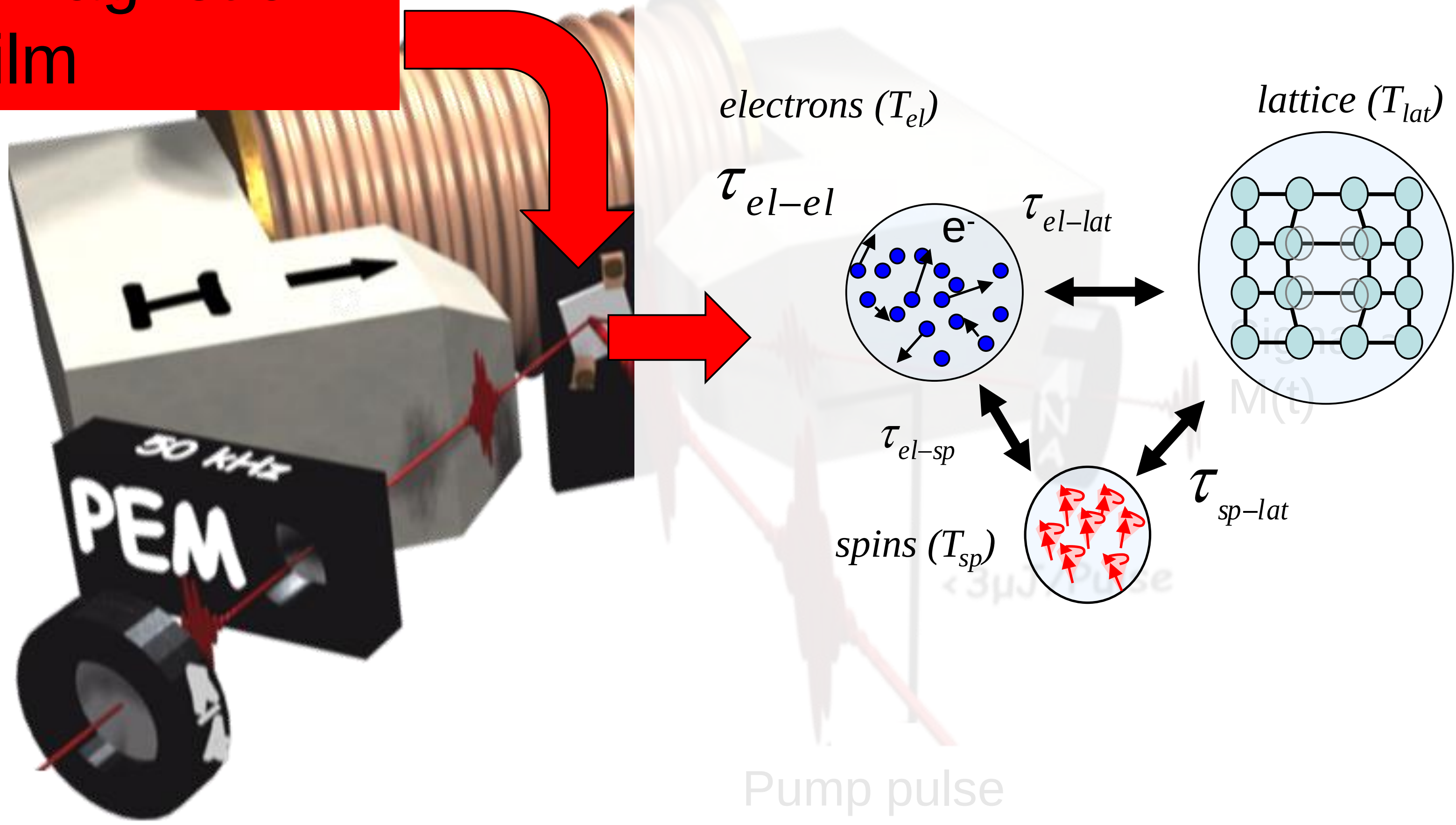

Polarization modulation

Probe pulse

Pump pulse

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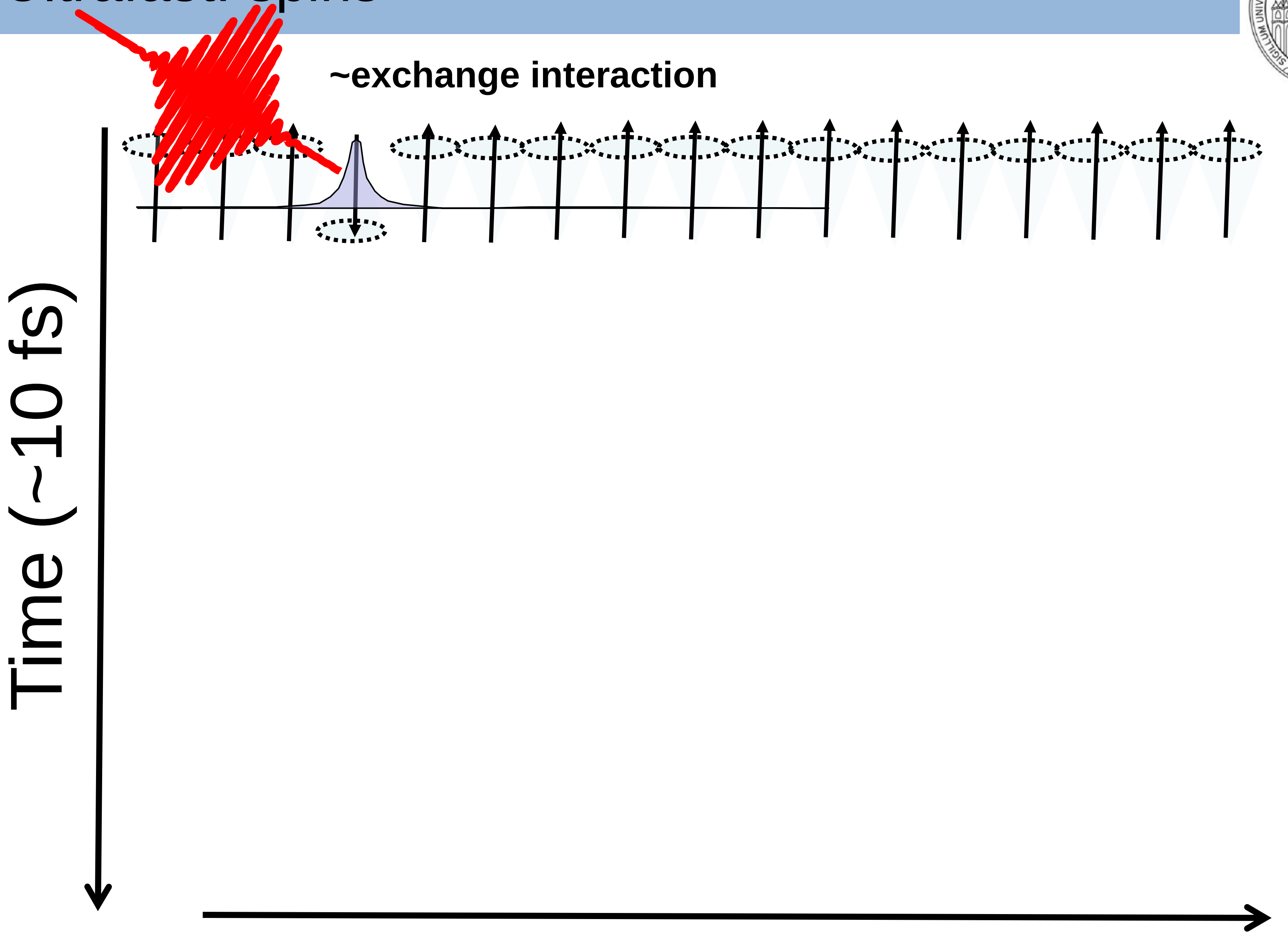
Ultrafast: spins

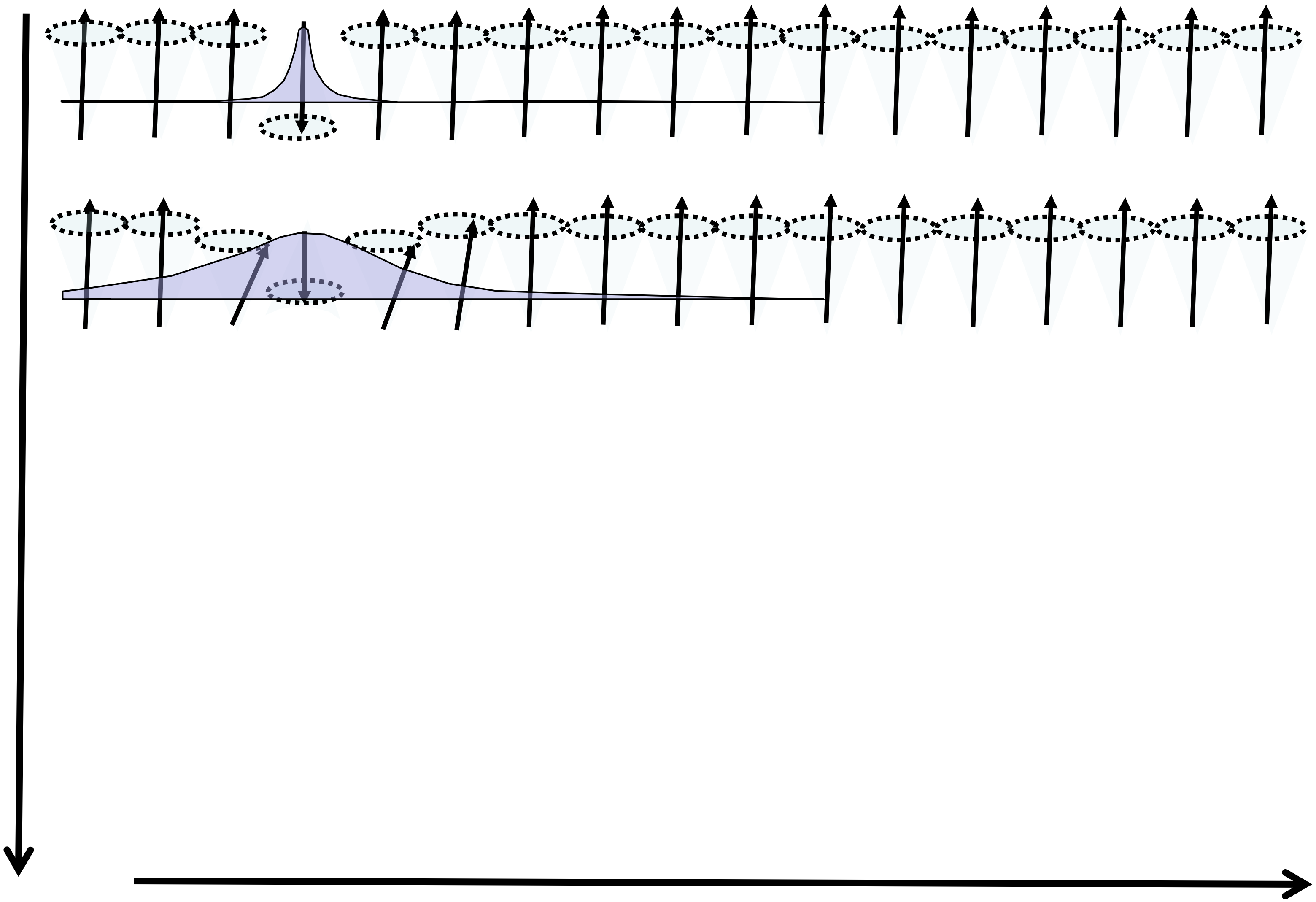


Length (~nm)

M. Münzenberg, Ultrafast
Magnetism I, Proceedings (2015)

Ultrafast: spins

~exchange interaction

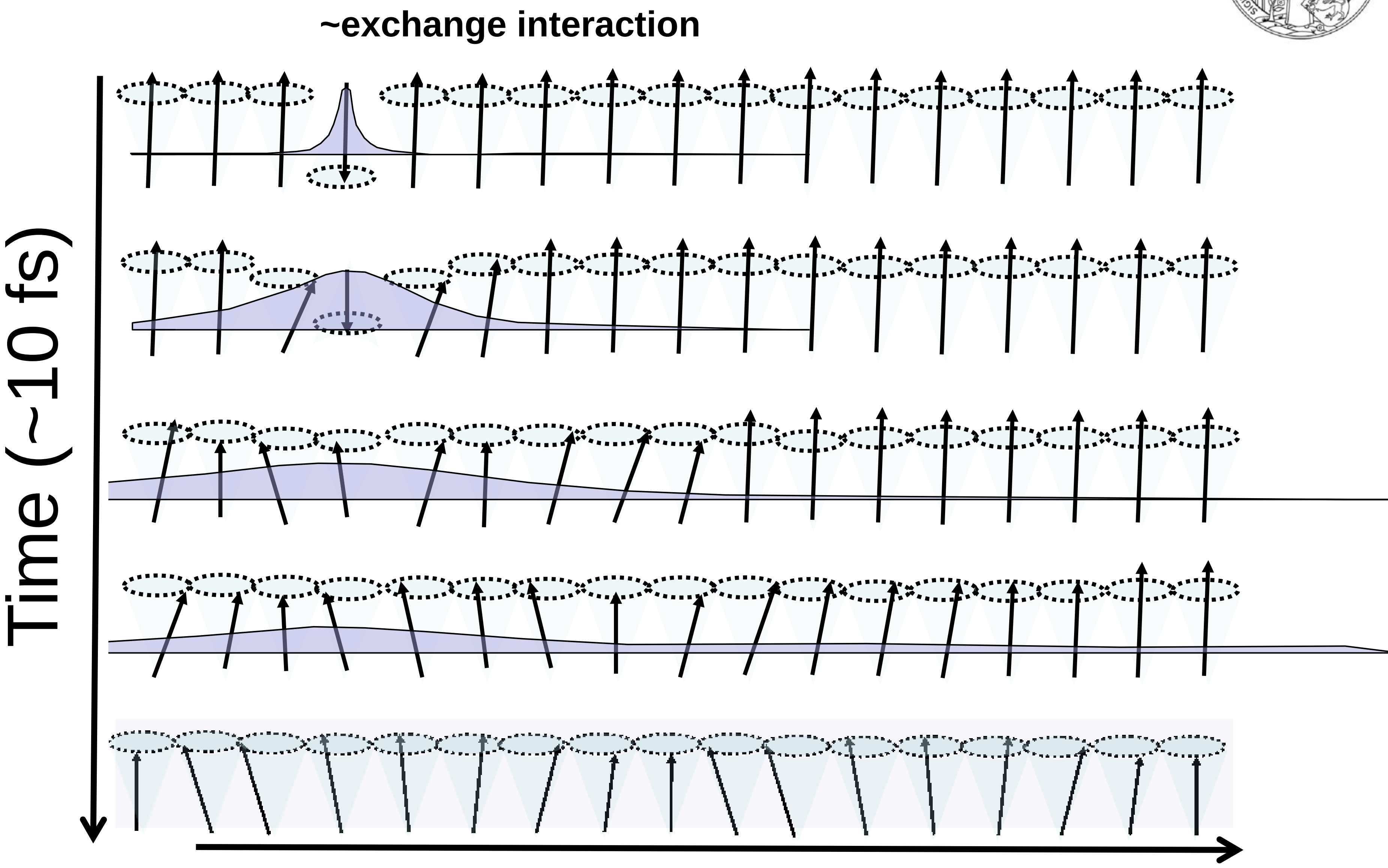


Time (~10 fs)

Length (~nm)

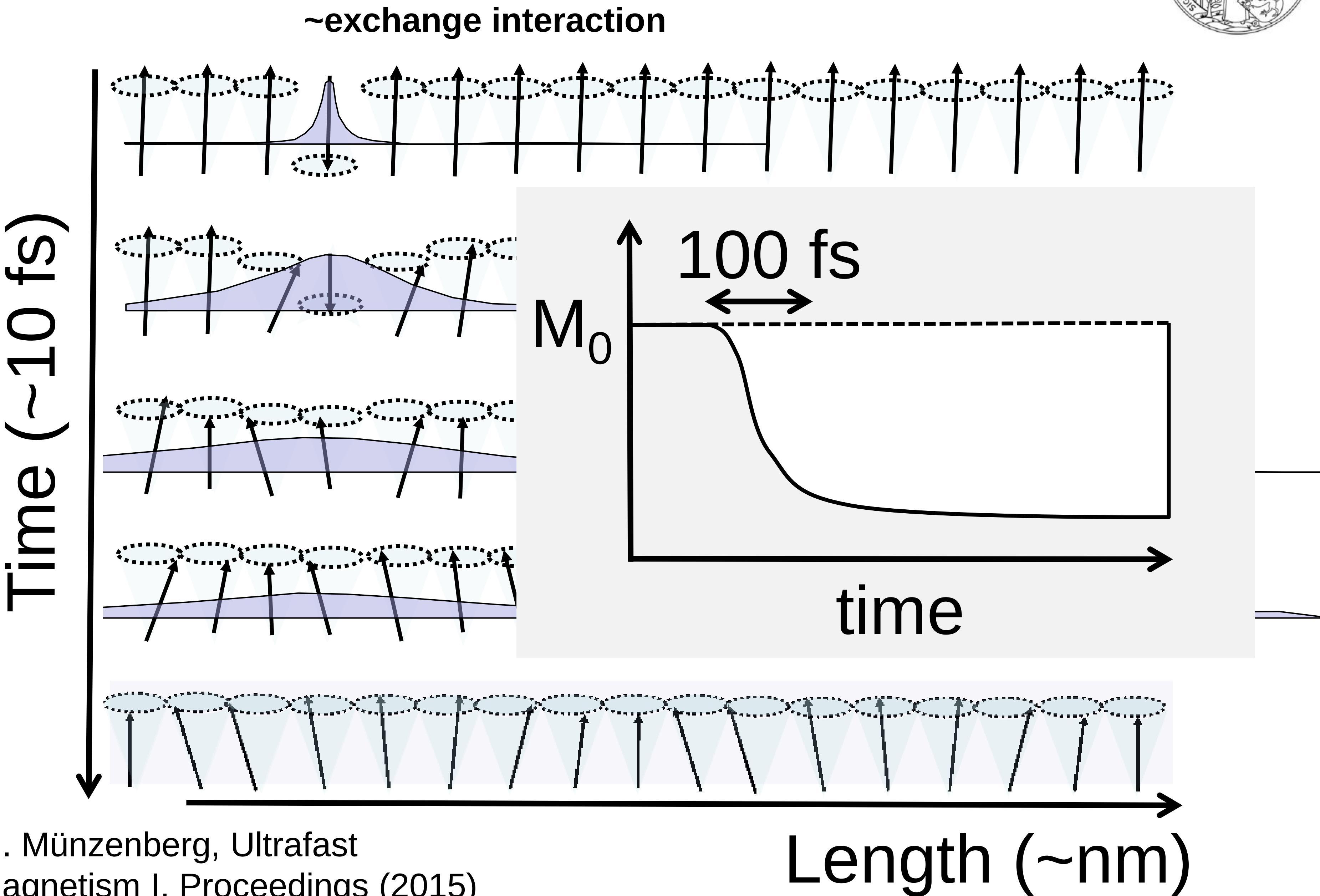
M. Münzenberg, Ultrafast
Magnetism I, Proceedings (2015)

Ultrafast: spins



M. Münzenberg, Ultrafast
Magnetism I, Proceedings (2015)

Ultrafast: spins

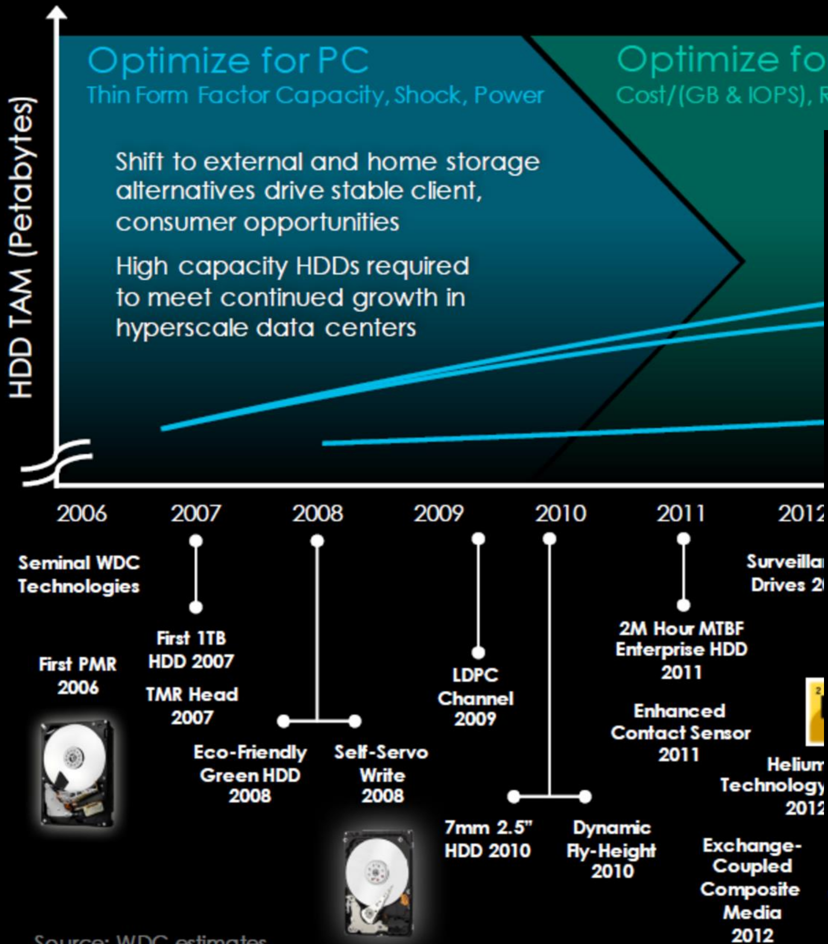


M. Münzenberg, Ultrafast Magnetism I, Proceedings (2015)

- Hard disc at fs speed

Interior of a hard disc

Rich Variety of Solutions for the World's Data Storage Needs



Optimize for PC
Thin Form Factor Capacity, Shock, Power

Optimize for Enterprise
Cost/(GB & IOPS), Reliability, Features

Optimize for Cloud
TCO/(GB & IOPS), QoS, Longevity

Shift to external and home storage alternatives drive stable client, consumer opportunities

High capacity HDDs required to meet continued growth in hyperscale data centers

Seminal WDC Technologies

First PMR 2006

First 1TB HDD 2007

TMR Head 2007

Eco-Friendly Green HDD 2008

Self-Servo Write 2008

LDPC Channel 2009

7mm 2.5" HDD 2010

Dynamic Fly-Height 2010

2M Hour MTBF Enterprise HDD 2011

Enhanced Contact Sensor 2011

Surveilla Drives 2

Heliu Technolog 201

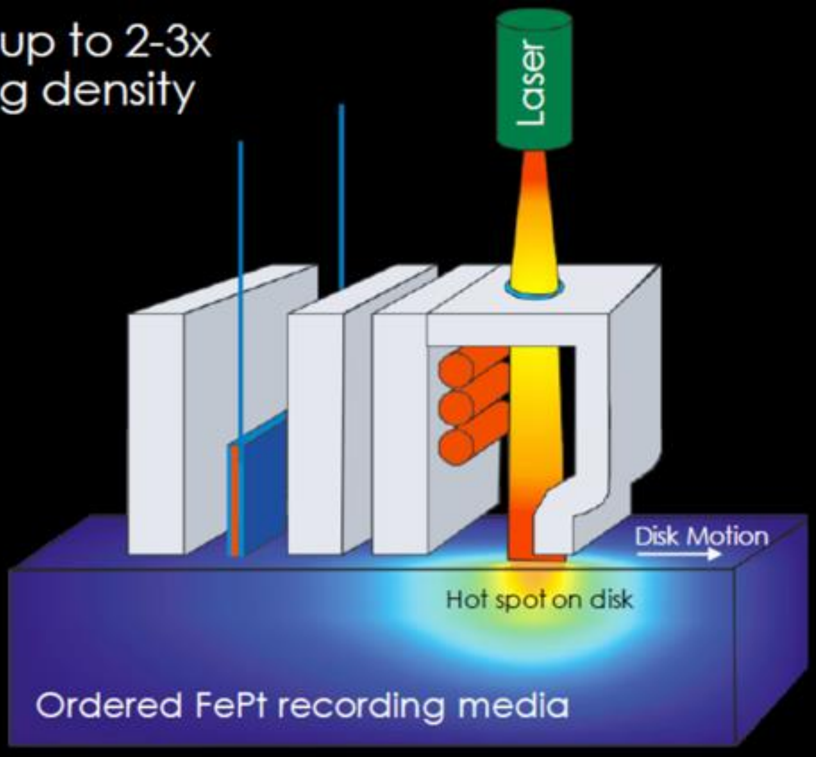
Exchange-Coupled Composite Media 2012

Enterprise 2013

2013 Hybrid Drive 2013

Logical Head Depopulation

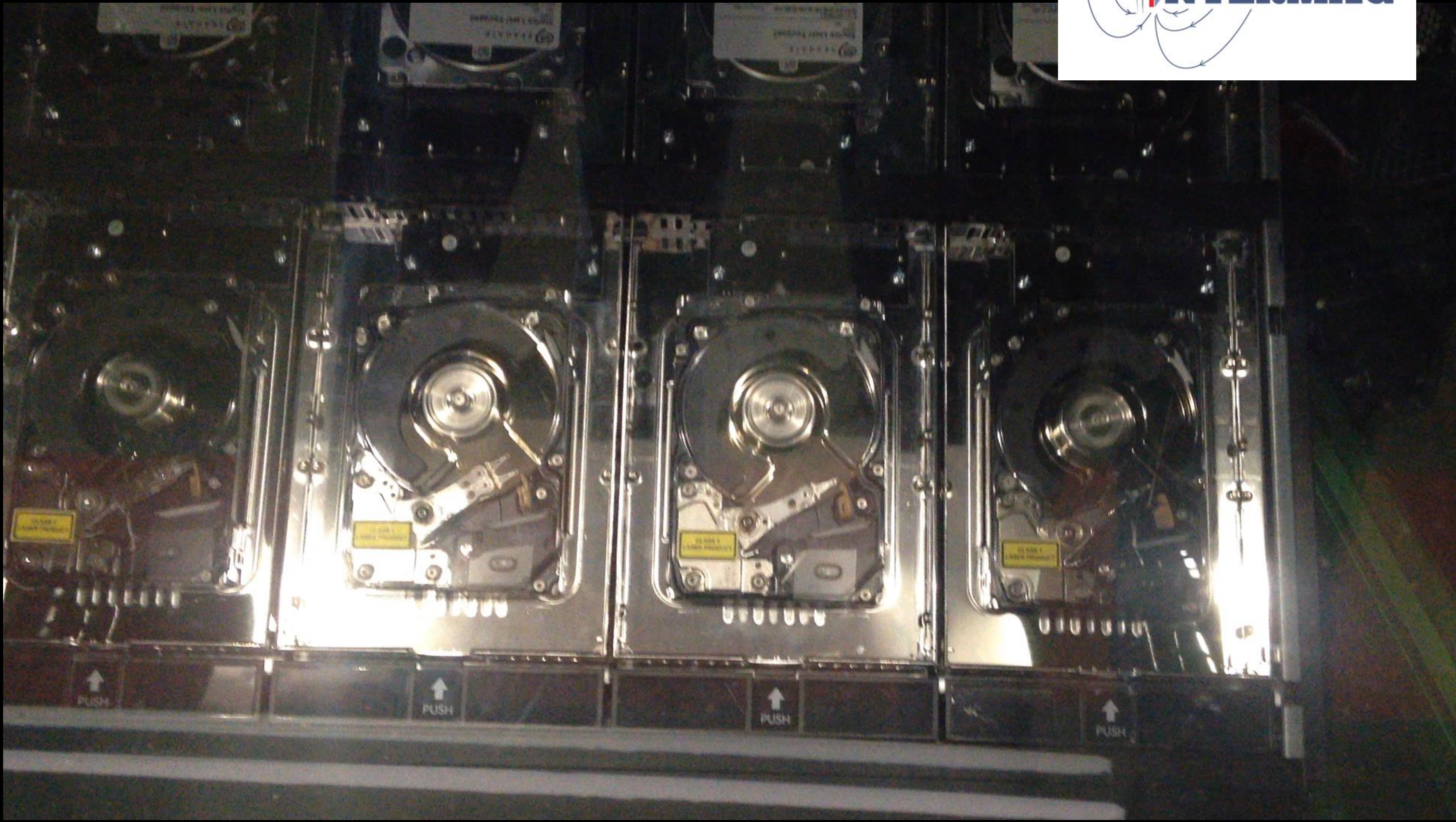
- Enables up to 2-3x recording density



Source: WDC estimates

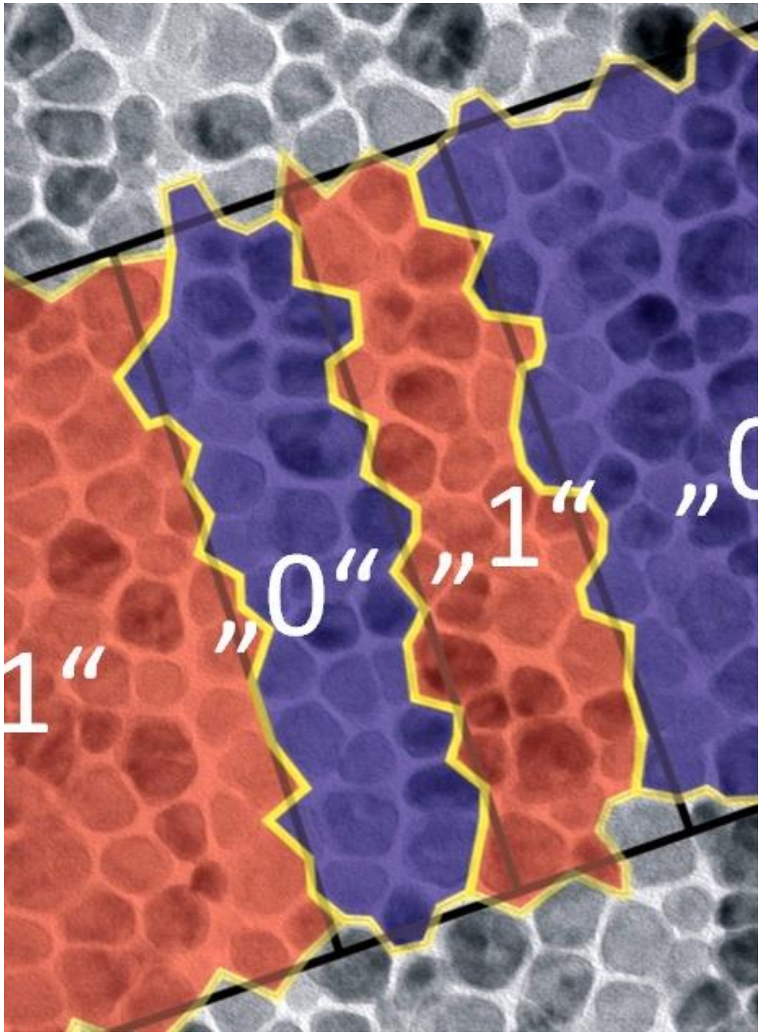
Live demonstration HAMR Seagate server at Intermag Dublin

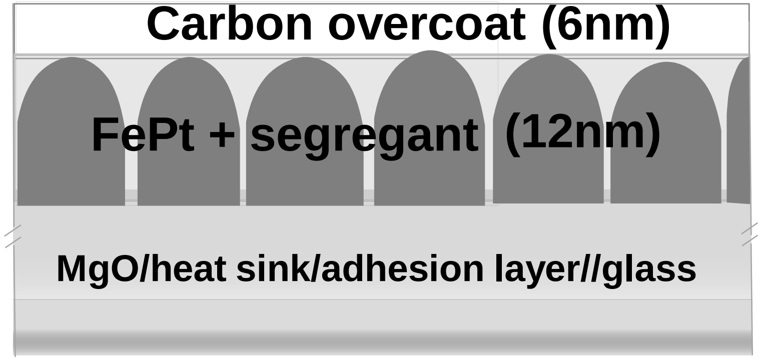
Dublin 2017
INTERMAG



Hard disc at ultrafast speed

Western Digital Corporation HAMR media, H_C= 4T at room temperature

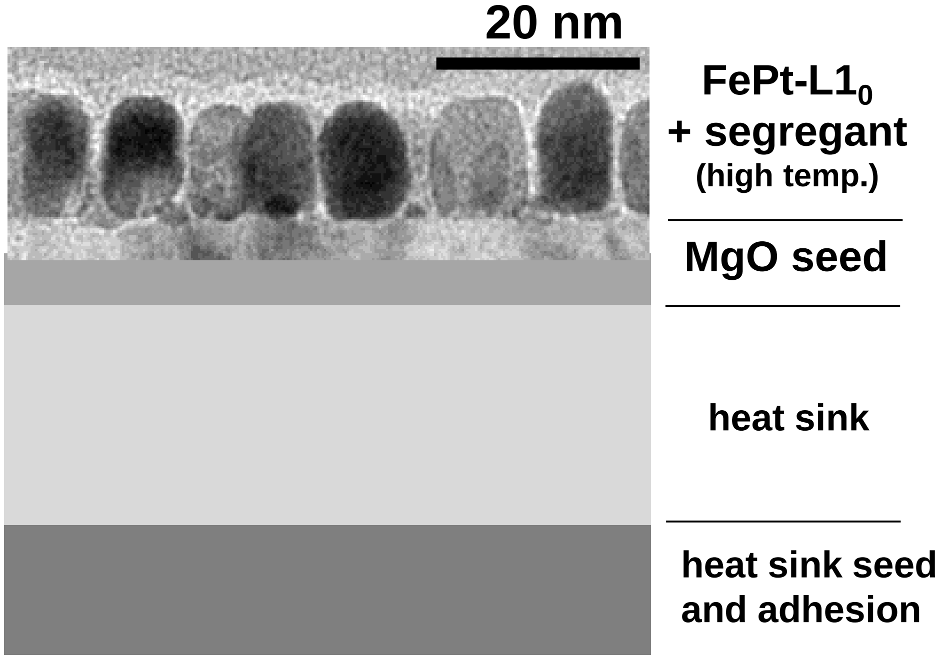




Carbon overcoat (6nm)

FePt + segregant (12nm)

MgO/heat sink/adhesion layer//glass



20 nm

FePt-L1$_0$ + segregant (high temp.)

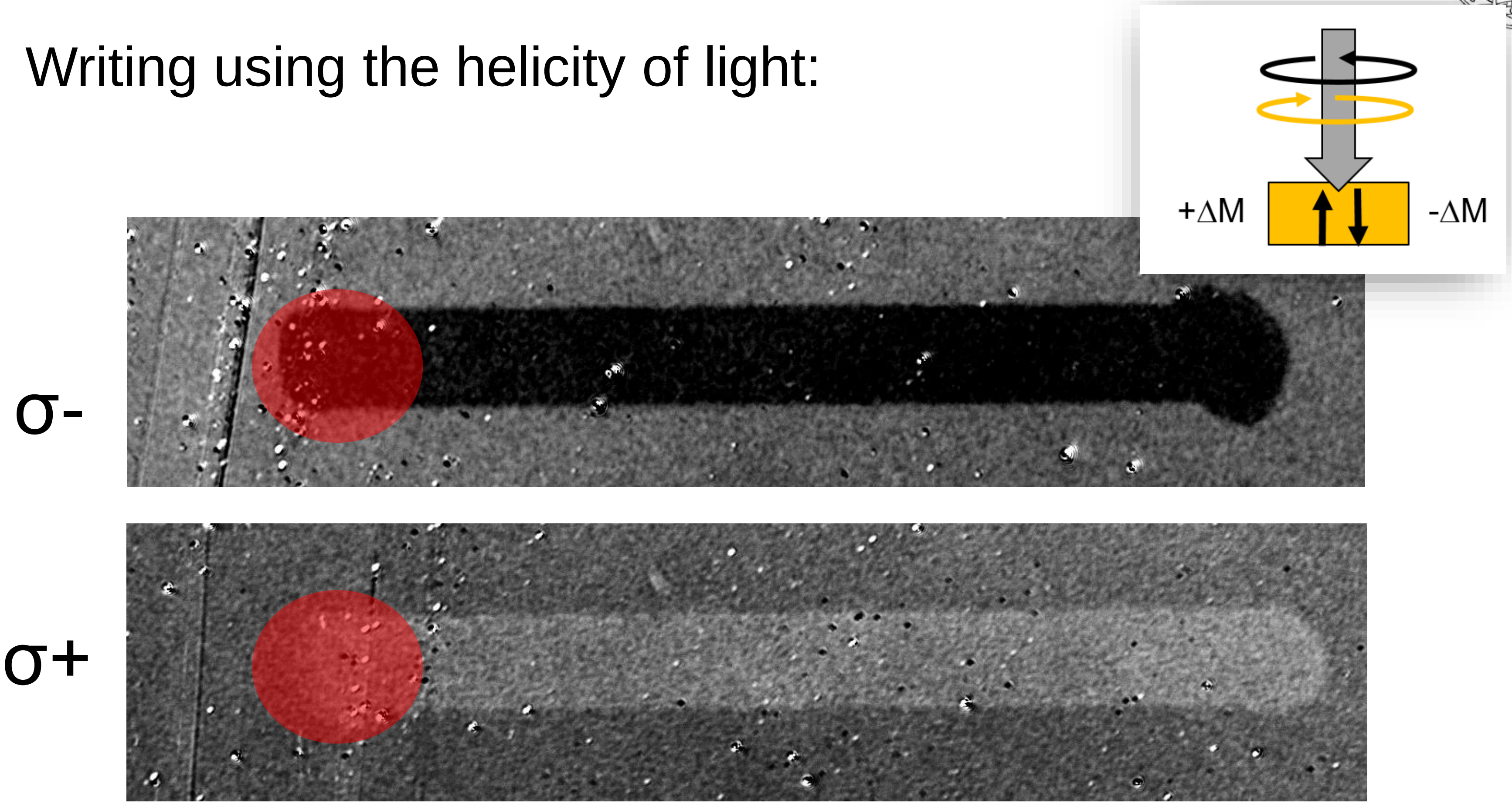
MgO seed

heat sink

heat sink seed and adhesion

FePt optical writing a storage media

Writing using the helicity of light:



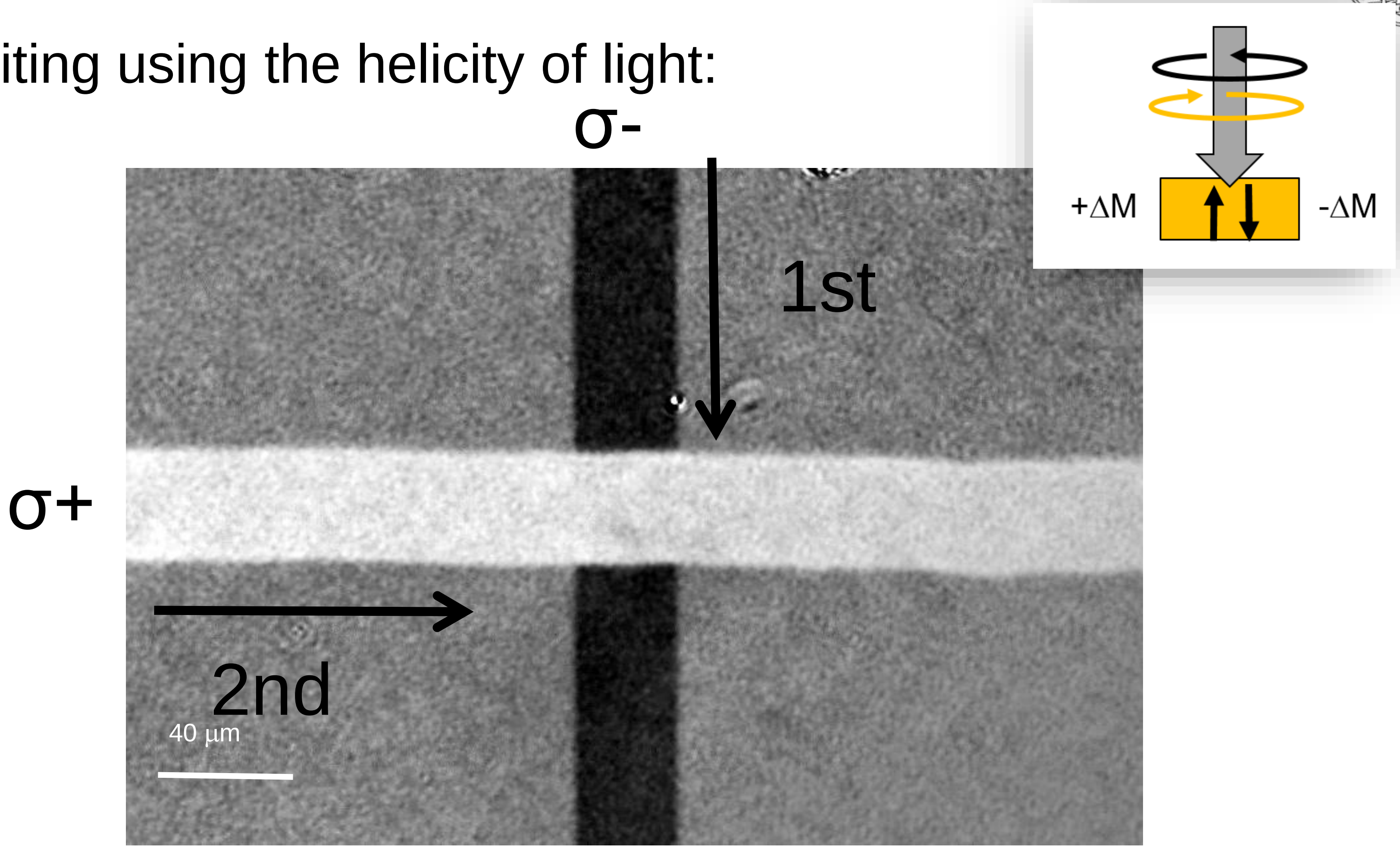
12.7 mJ/cm^2 (10 mW)

Magneto-optical contrast (Kerr microscopy)
FePt (AgCu) granular recording media

R. John, P. M. Oppeneer, U. Nowak, and M. Münzenberg, Sci. Rep. 7, 4114 (2017)

FePt optical writing a storage media

Writing using the helicity of light:

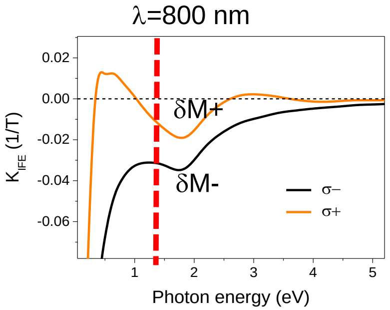


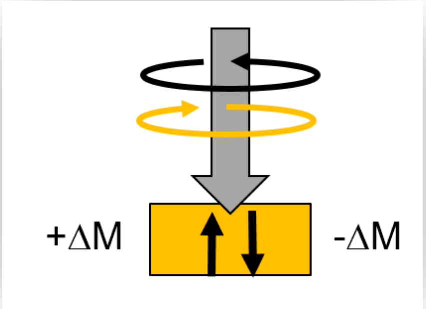
10 mW
Beamwaist 15 µm

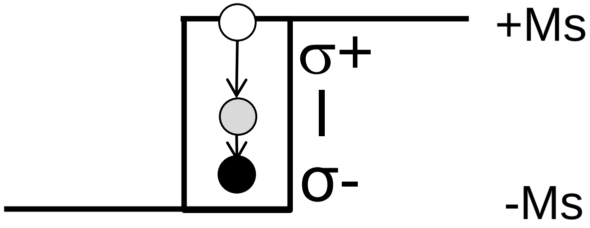
FePt (AgCu) granular recording media

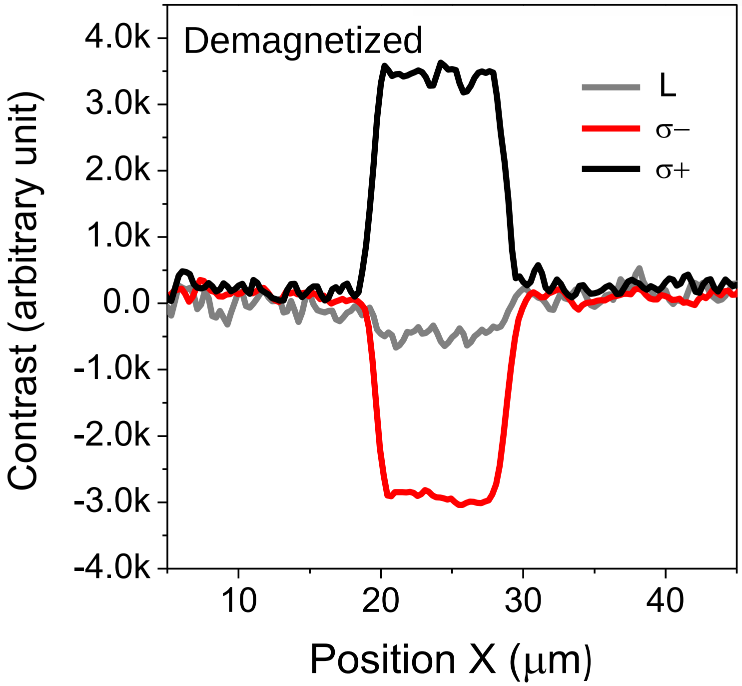
FePt optical writing a storage media

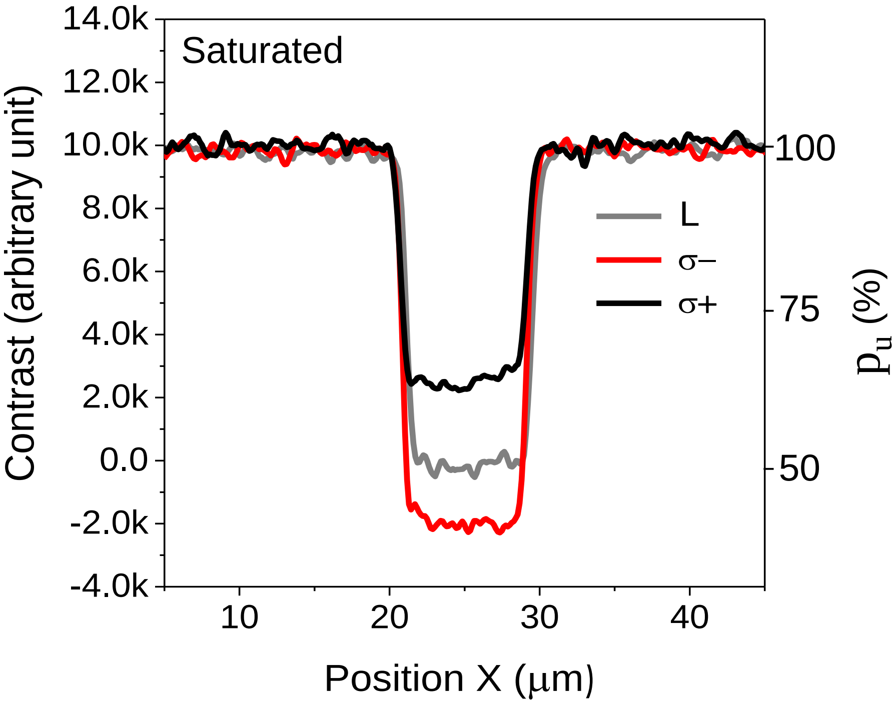
Starting with magnetization 100% Ms, saturated case:









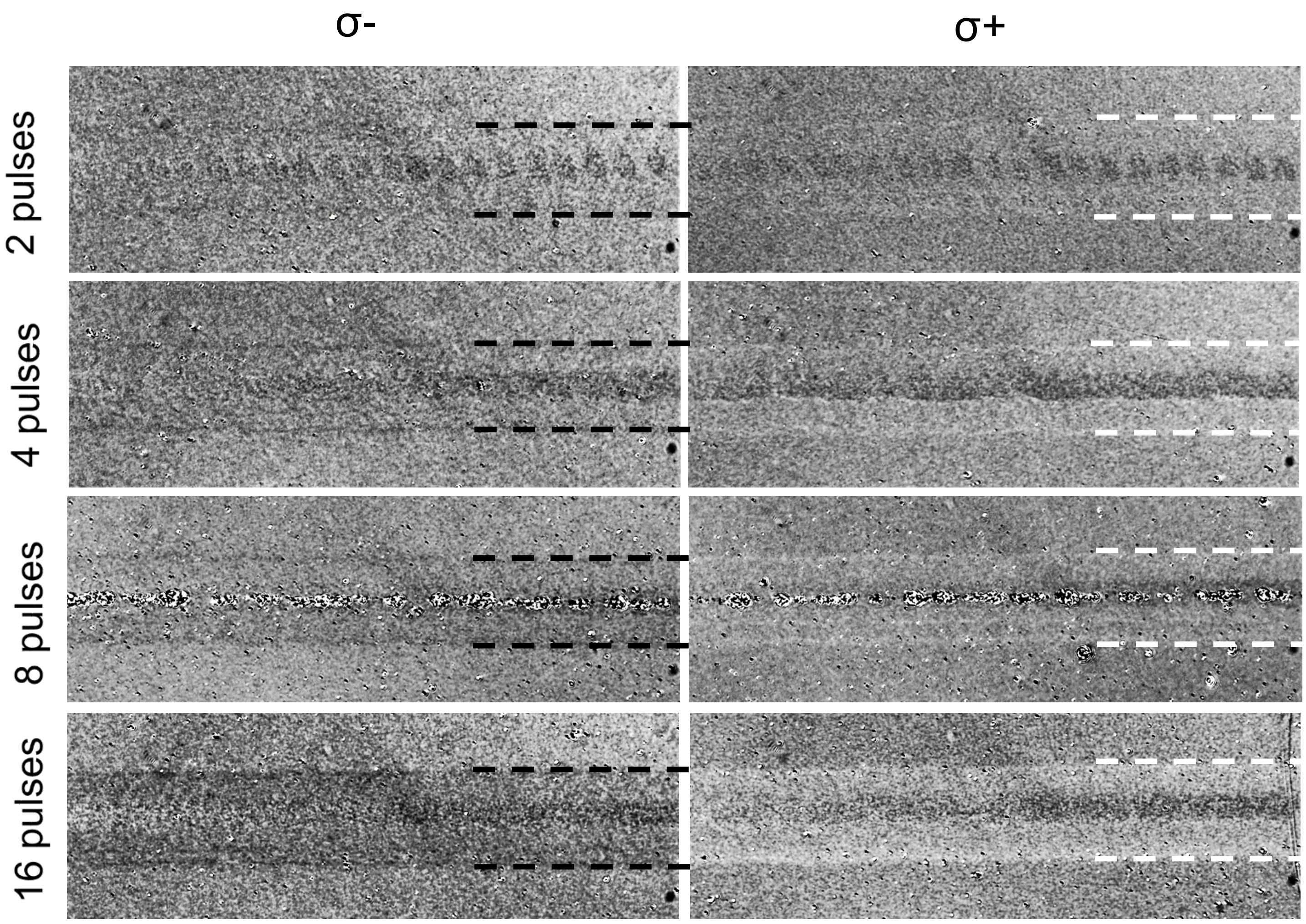


No full writing! What is the mechanism?

15 mW (13.2 mJ/cm^2 per pulse)

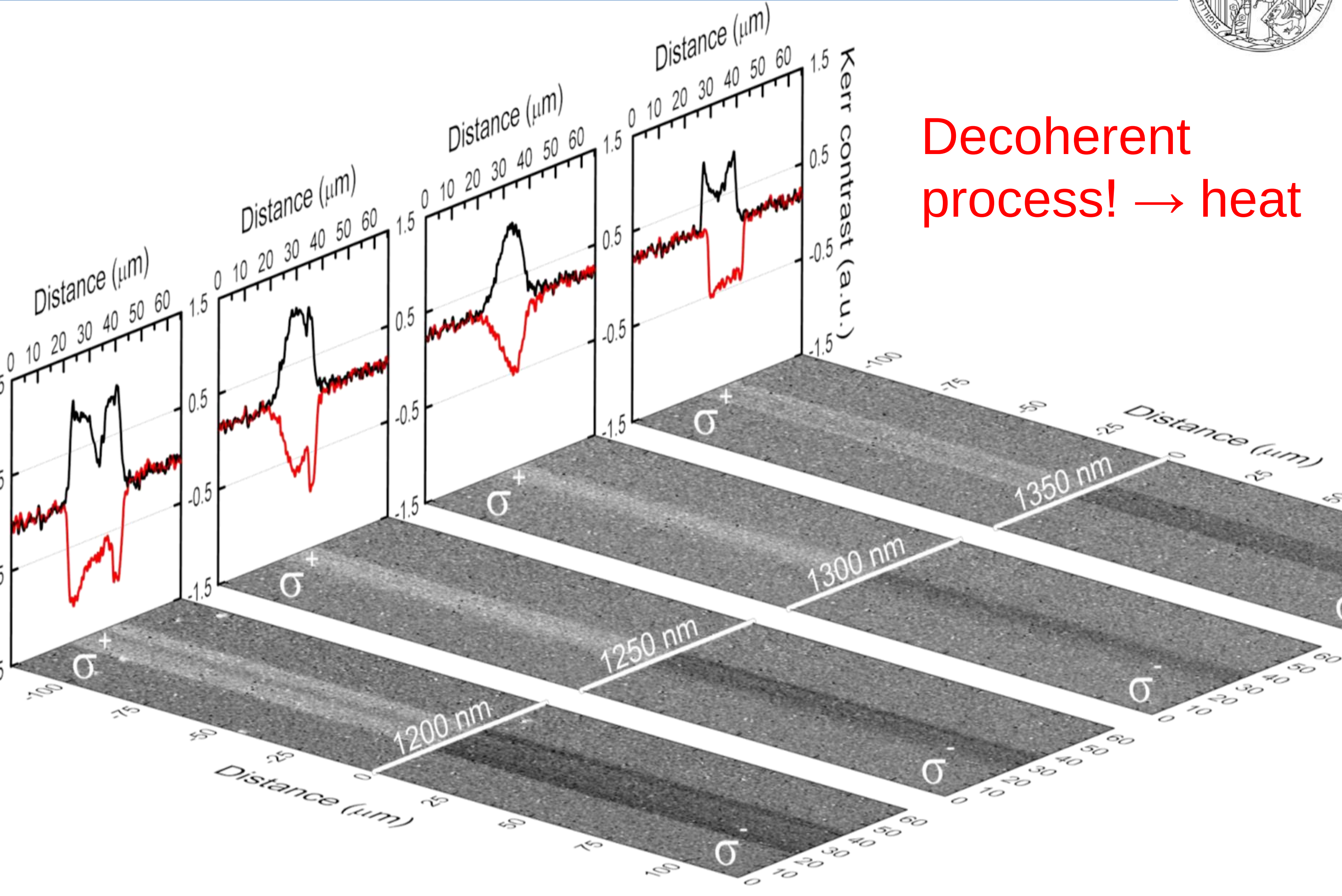
FePt optical writing a storage media

- FePt (AgCu) granular recording media: single/ multiple pulse writing



5 mW (30 mJ/cm^2 per pulse)

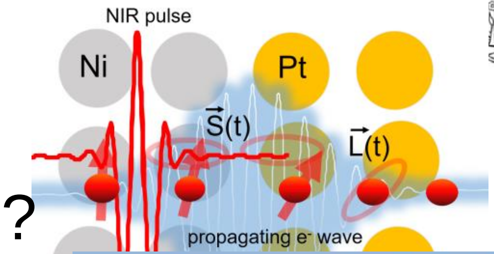
FePt optical writing a storage media

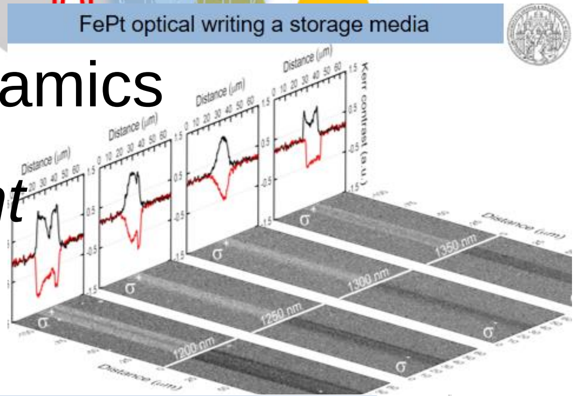


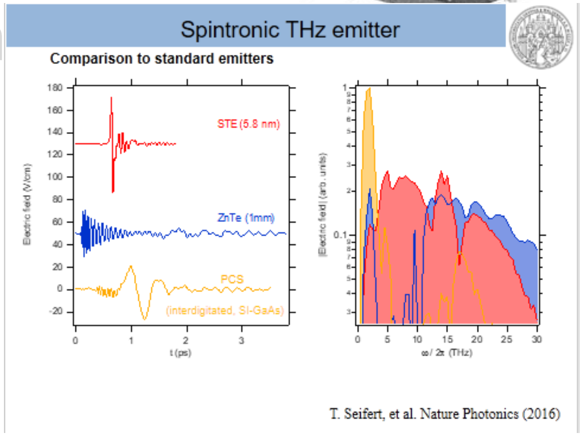
Decoherent process! → heat

Outline

- A coherent attosecond spintronics?
- The nature of femtosecond spin dynamics
- THz spintronic emitter – *noncoherent*
- Topological Insulators
- Lightwave electronics - coheren
- Summary



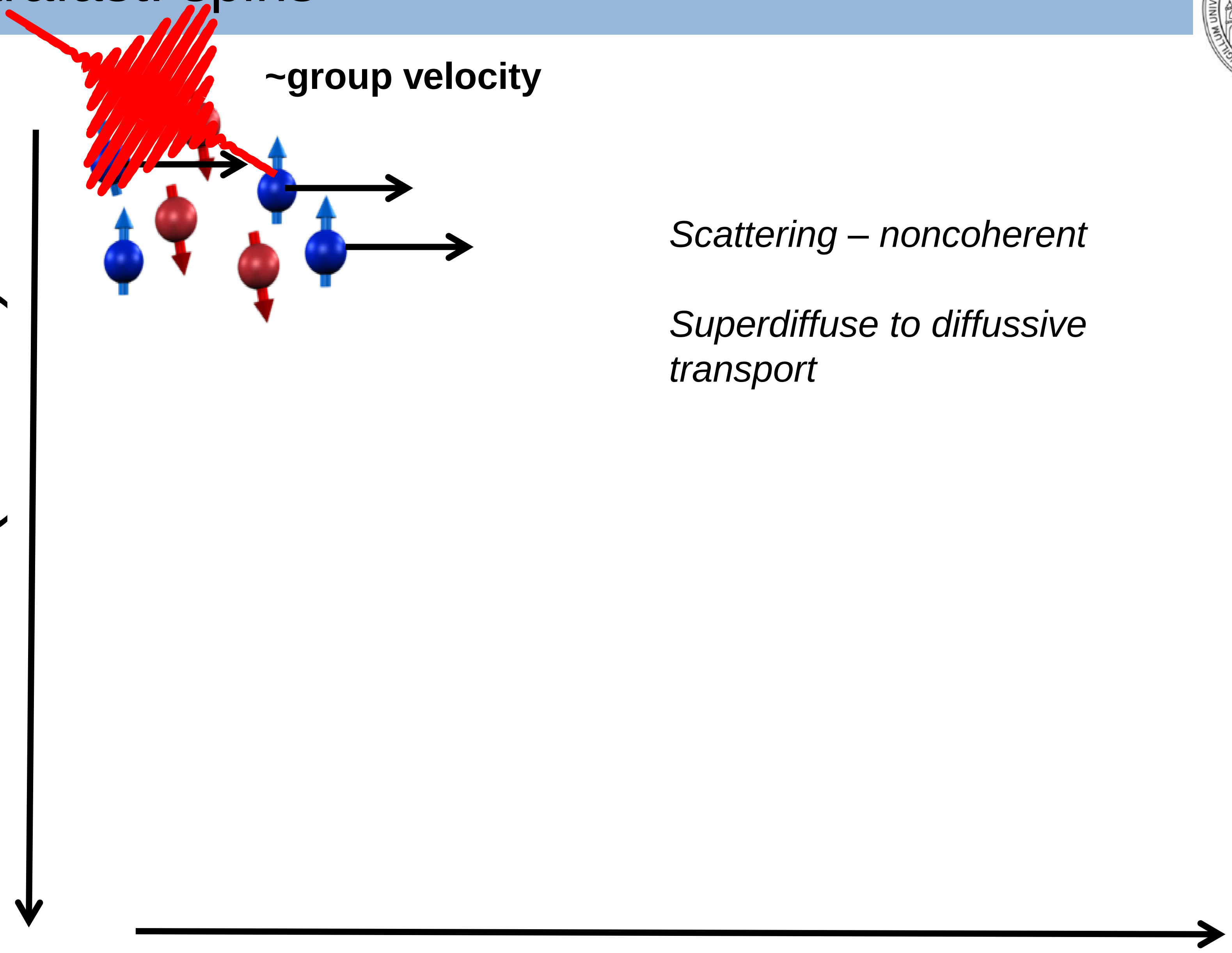

FePt optical writing a storage media


Spintronic THz emitter

Comparison to standard emitters

T. Seifert, et al. Nature Photonics (2016)

Ultrafast: spins



~group velocity

Scattering – noncoherent

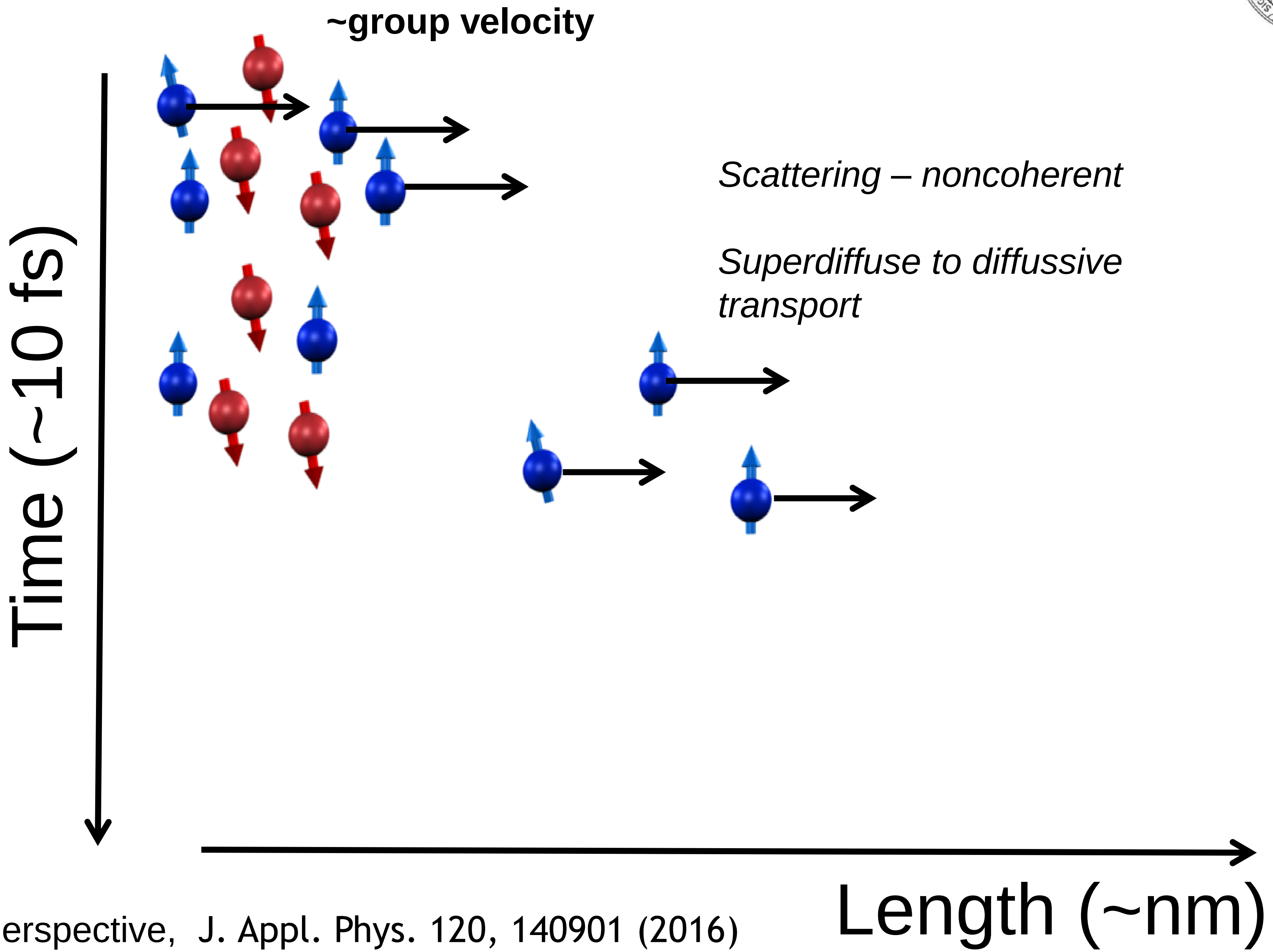
Superdiffuse to diffussive transport

Time (~10 fs)

Length (~nm)

Perspective, J. Appl. Phys. 120, 140901 (2016)

Ultrafast: spins

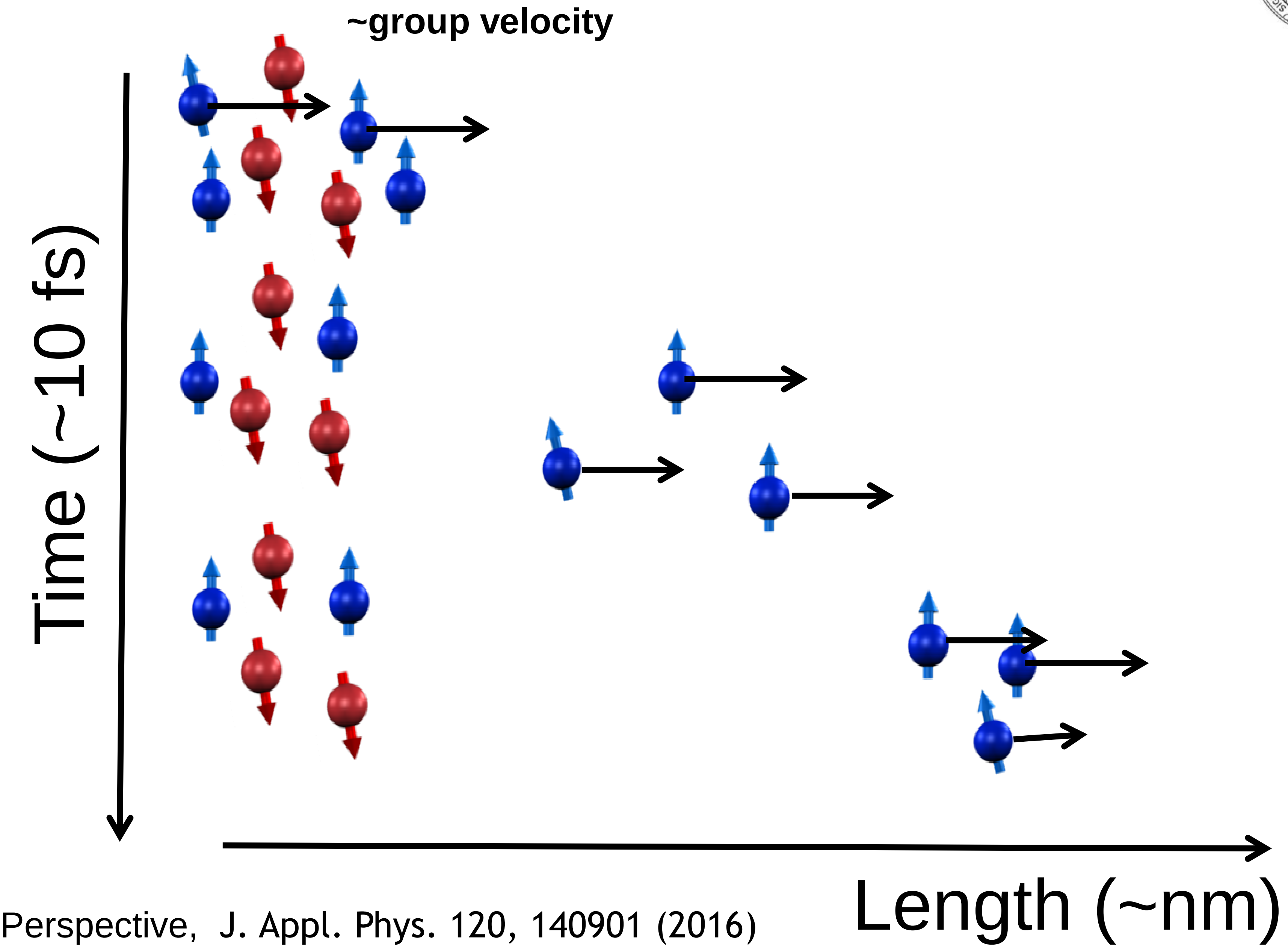


Scattering – noncoherent

Superdiffuse to diffussive transport

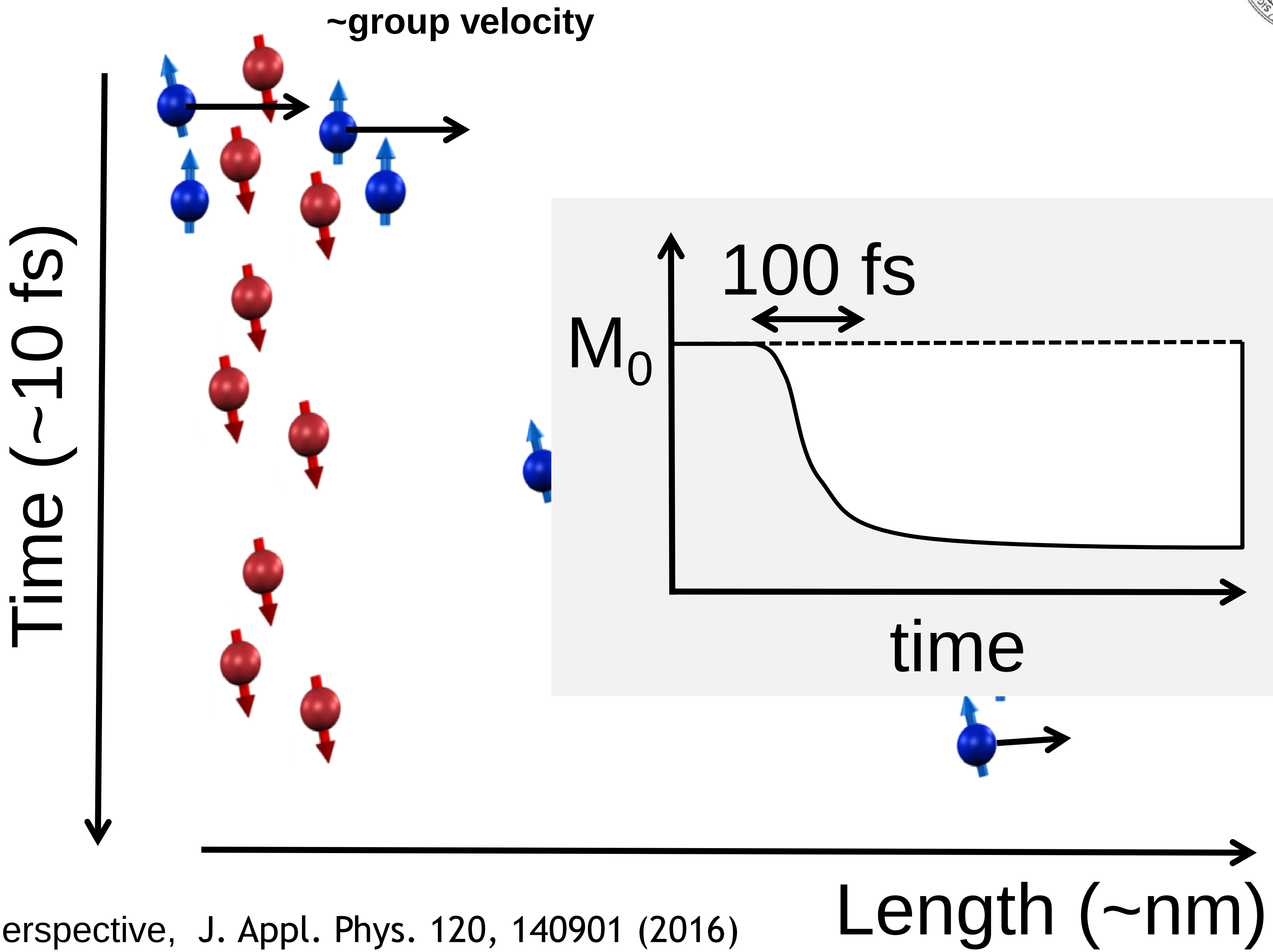
Perspective, J. Appl. Phys. 120, 140901 (2016)

Ultrafast: spins



Perspective, J. Appl. Phys. 120, 140901 (2016)

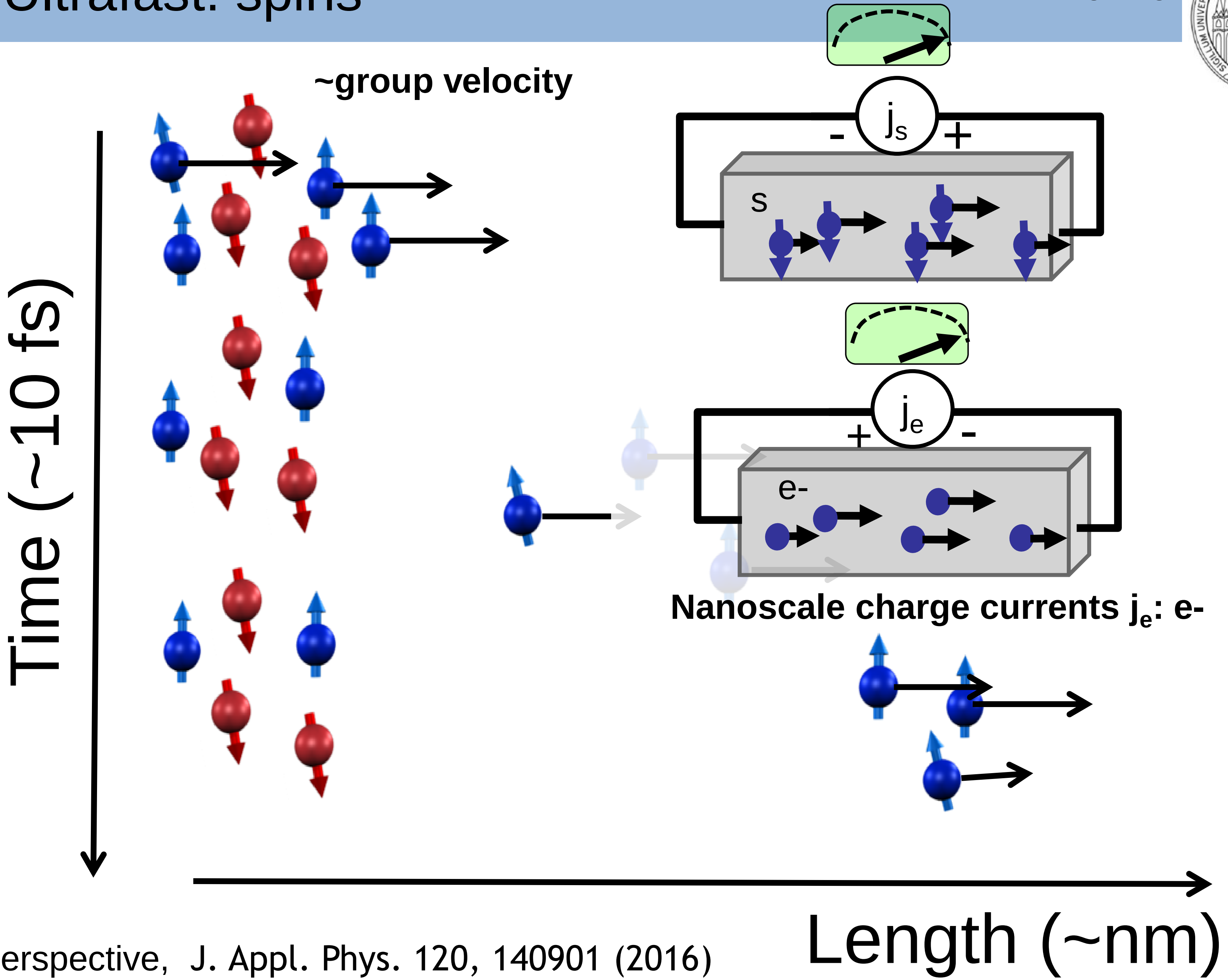
Ultrafast: spins



Perspective, J. Appl. Phys. 120, 140901 (2016)

Ultrafast: spins

Nanoscale spin currents j_s: m_s



~group velocity

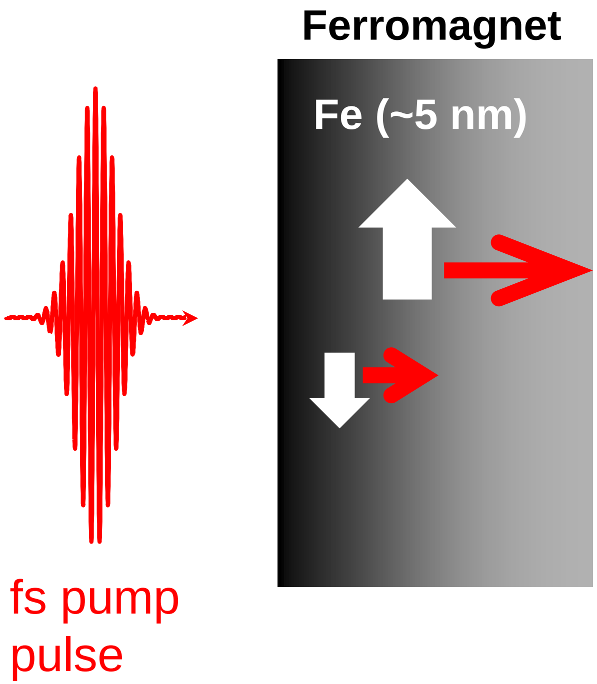
Nanoscale charge currents j_e: e-

Time (~10 fs)

Length (~nm)

Perspective, J. Appl. Phys. 120, 140901 (2016)

Spintronic THz emitter



Pump pulse excites $\uparrow$ and $\downarrow$ electrons

$\uparrow$: d $\rightarrow$ sp bands $\Rightarrow$ become fast

$\downarrow$: d $\rightarrow$ d bands $\Rightarrow$ stay slow

Oppeneer *et al.*, PRL (2010)

$\Rightarrow$ Pump launches spin-polarized current

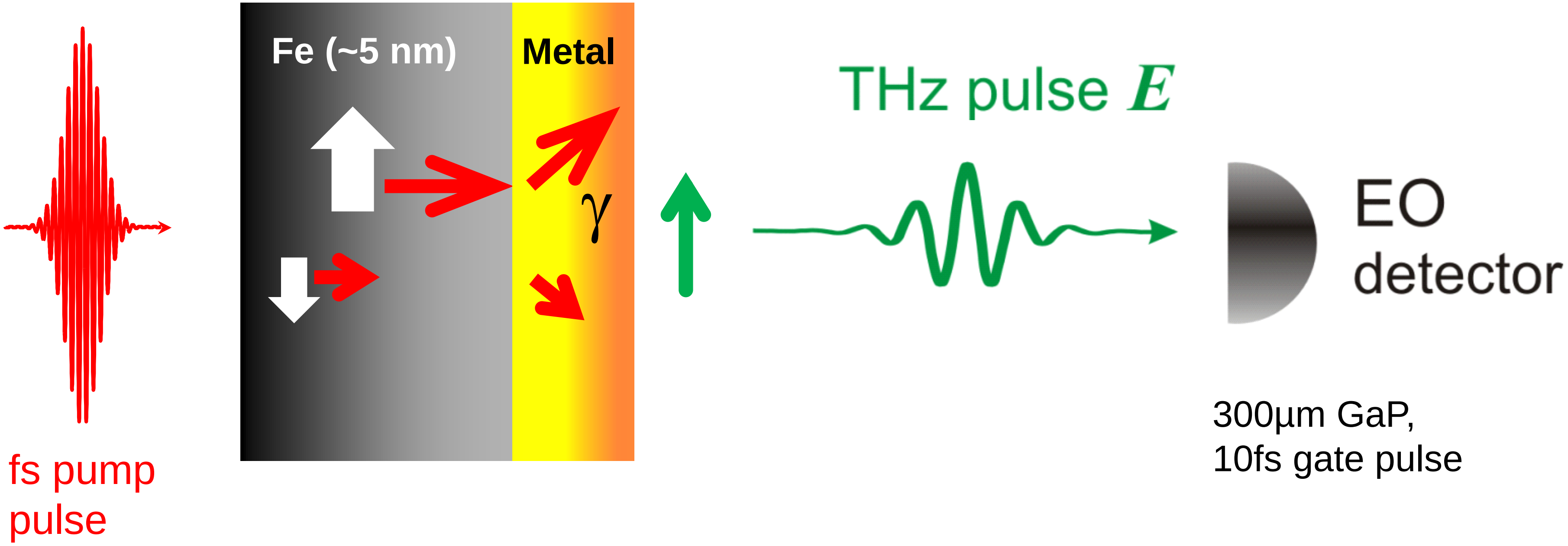
Melnikov *et al.*, PRL (2011)
Rudolf *et al.*, NatComm (2012)
Turgut *et al.*, PRL (2013)

How to detect the spin current?

Idea: convert spin current into charge current

Nature Nanotech. 8, 256 (2013).

Spintronic THz emitter



300µm GaP,
10fs gate pulse

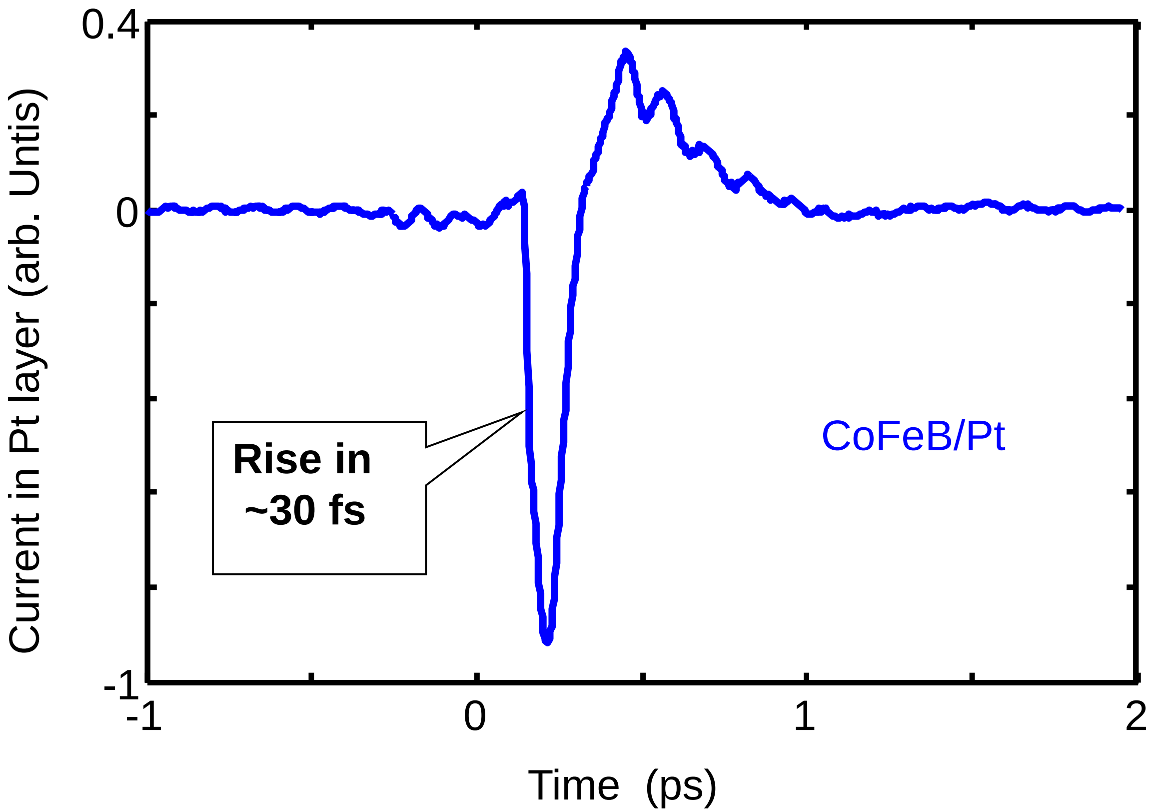
⇒ Measure THz emission from photoexcited FM/NM bilayers

Note: just used a pulsed laser oscillator (10 fs, 80 MHz)

Kampfrath, Battiato, Oppeneer, Wolf, Freimuth, Mokrousov, Münzenberg *et al*., Nature Nanotech. 8, 256 (2013)

Spintronic THz emitter

THz Pt sheet current



Reveals spin transport dynamics with 10 fs resolution

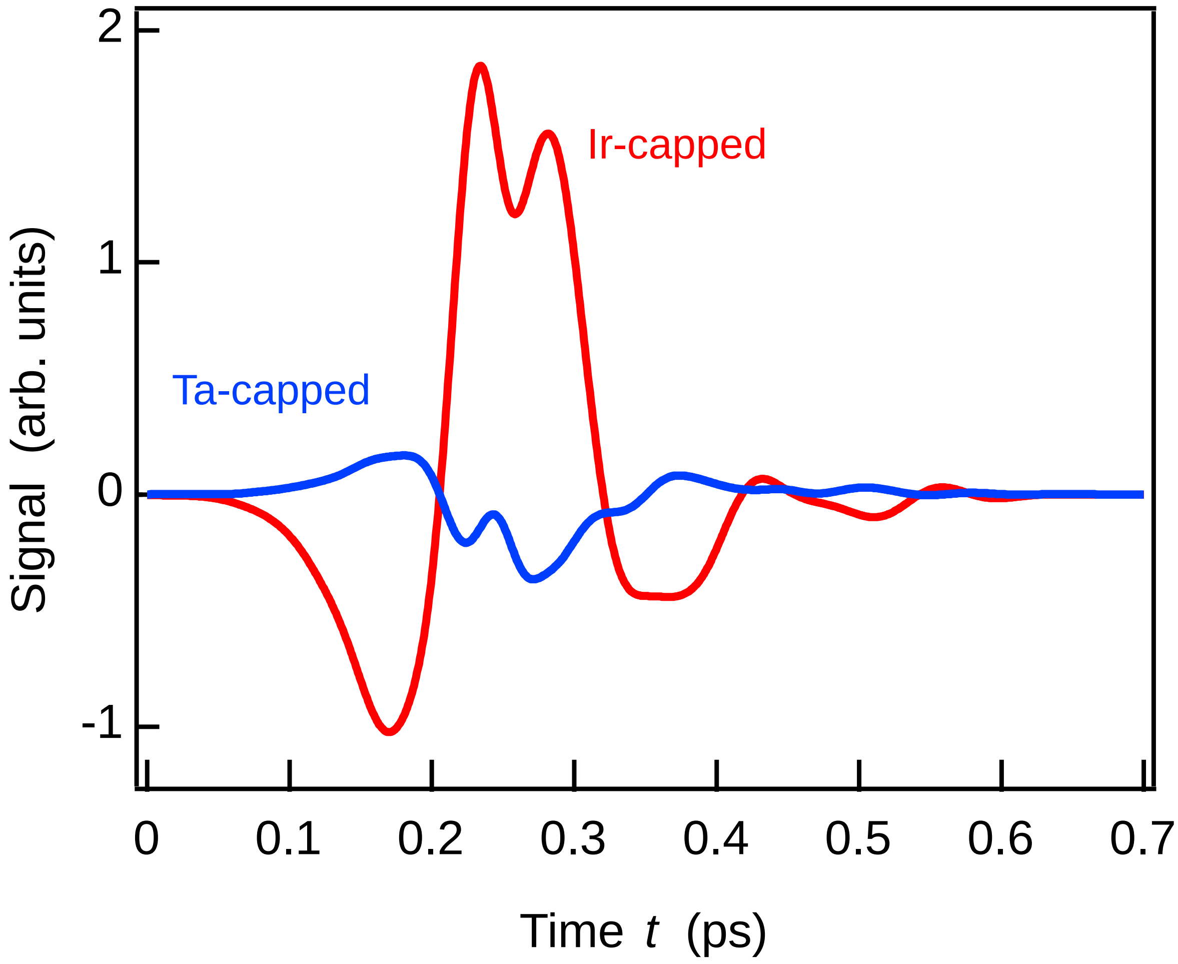
Spintronic THz emitter

Idea:

Vary nonmagnetic cap layer

Ta vs Ir:

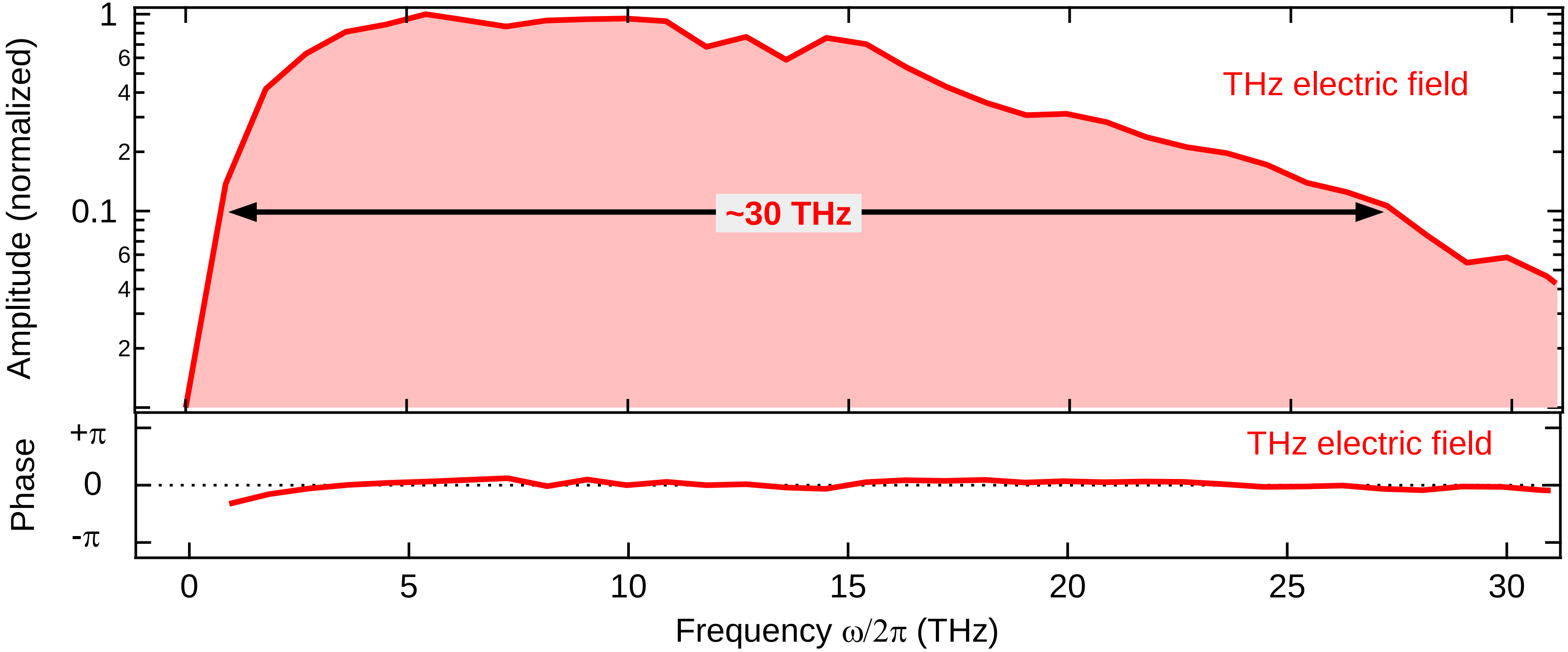
Opposite spin Hall angles, Ir larger



Behavior consistent with ISHE scenario?

Spintronic THz emitter

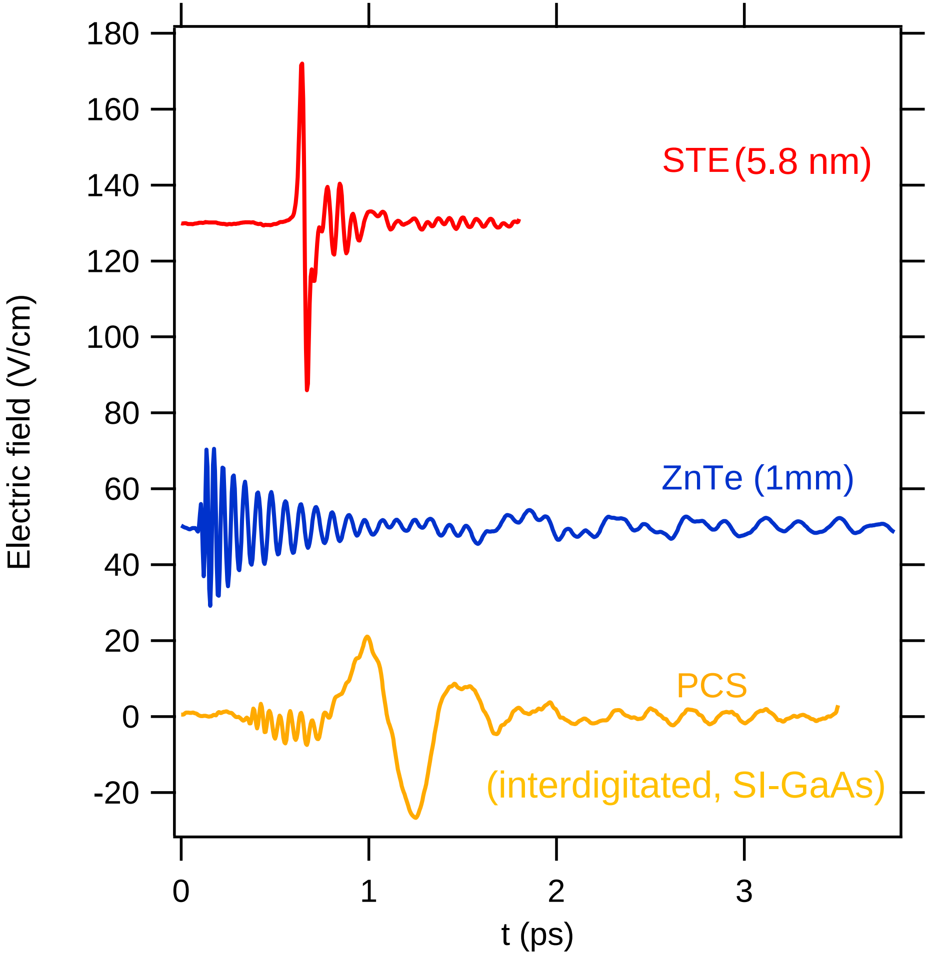
Fourier transform of time-domain data yields spectrum



Gap-free emission from 1-30 THz

Spintronic THz emitter

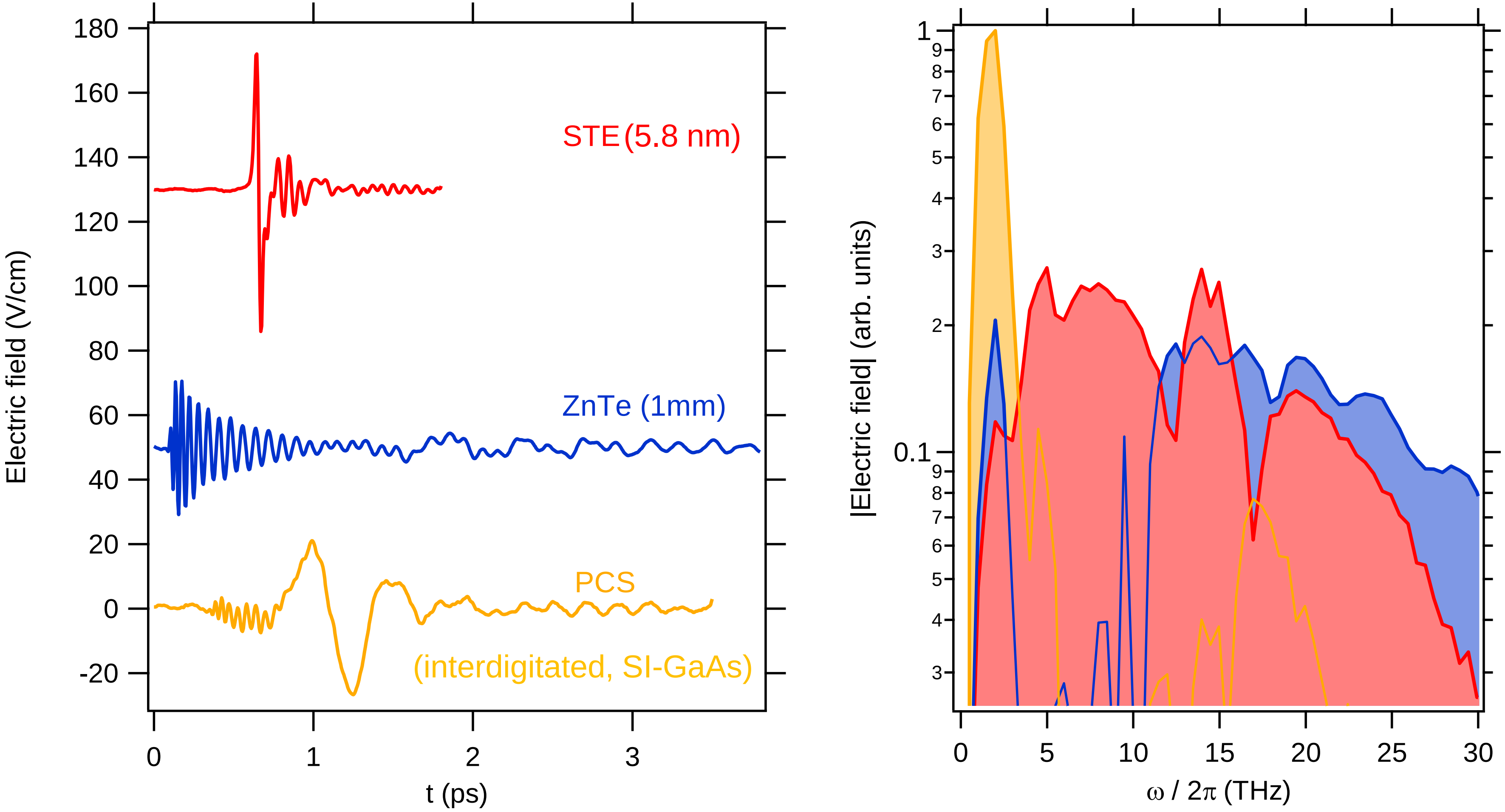
Comparison to standard emitters



T. Seifert, et al. Nature Photonics (2016)

Spintronic THz emitter

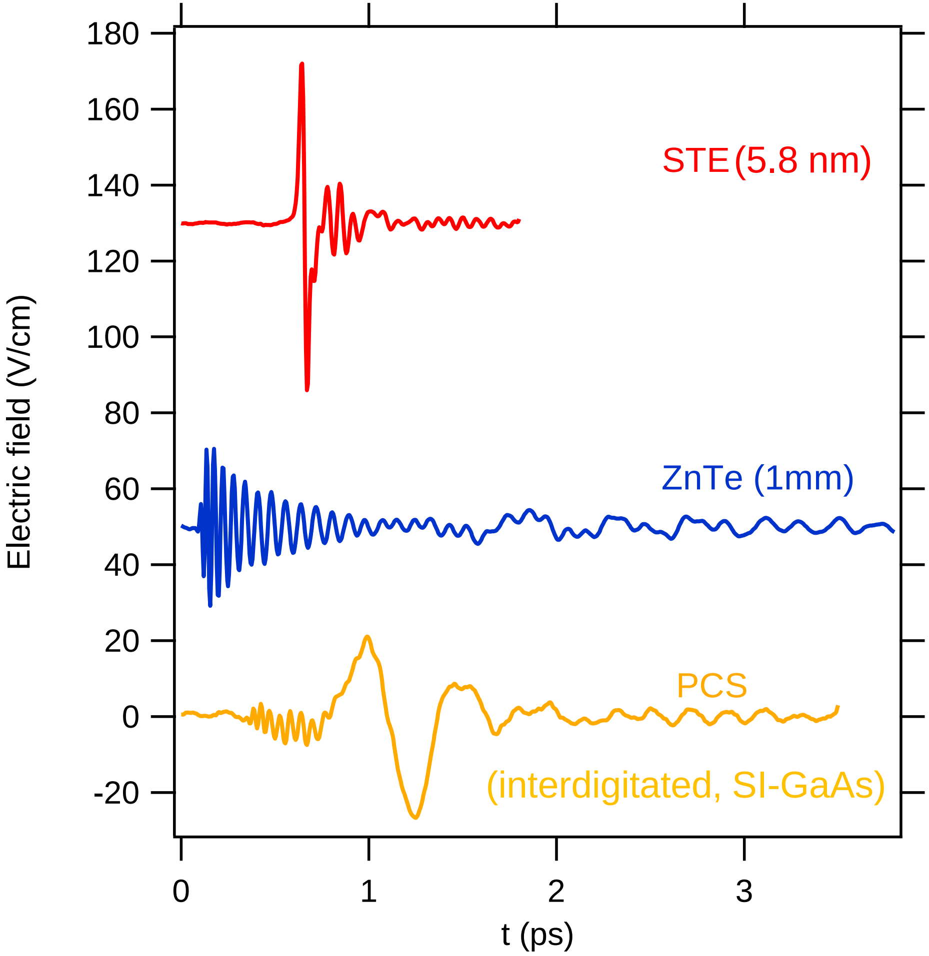
Comparison to standard emitters

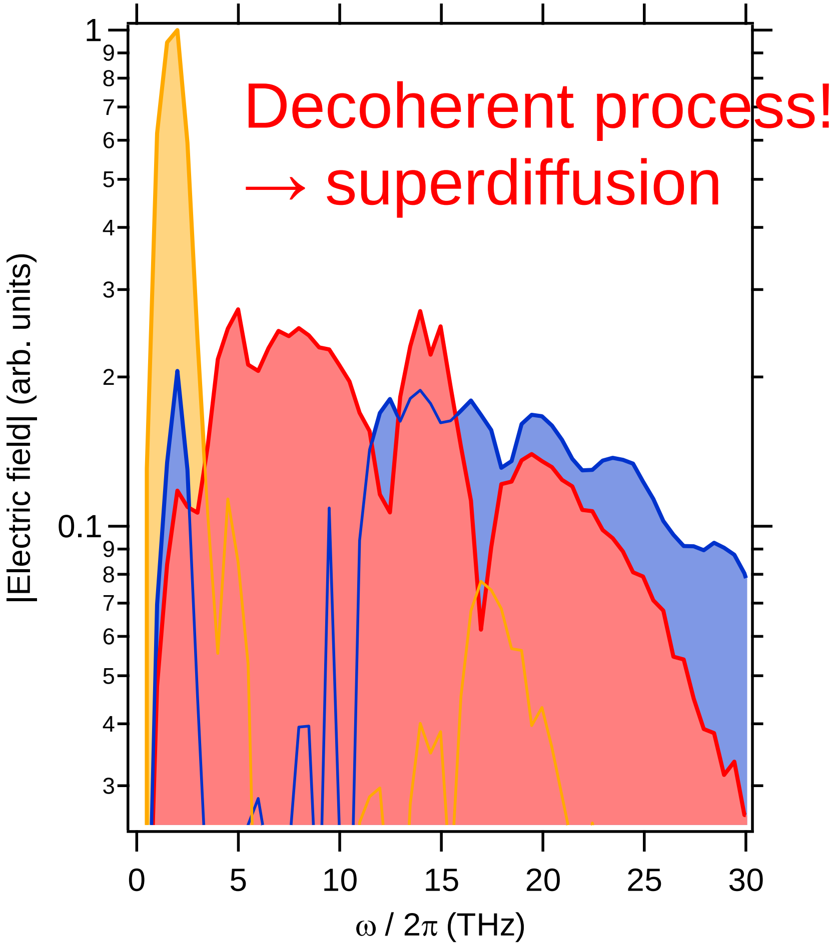


T. Seifert, et al. Nature Photonics (2016)

Spintronic THz emitter

Comparison to standard emitters




Decoherent process!

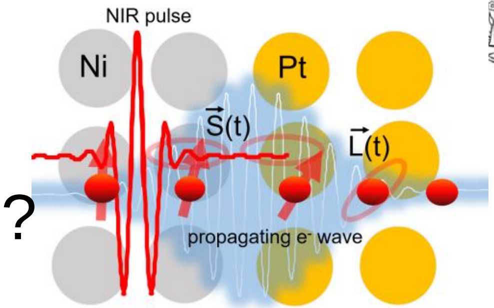
→ superdiffusion

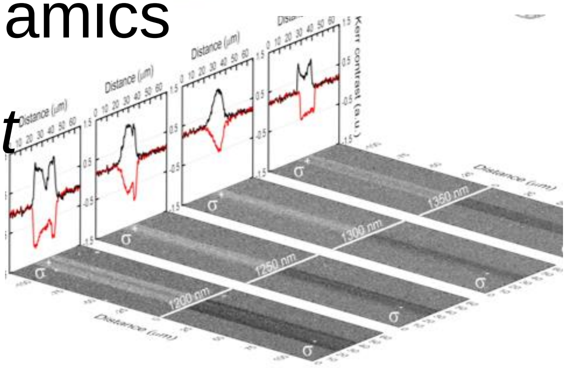
Spintronic metalic emitter outperforms standard emitters over large frequency intervals

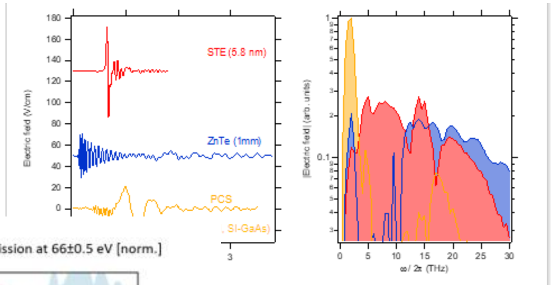
Robust, low cost, scalable, easy to handle and flexible

Outline

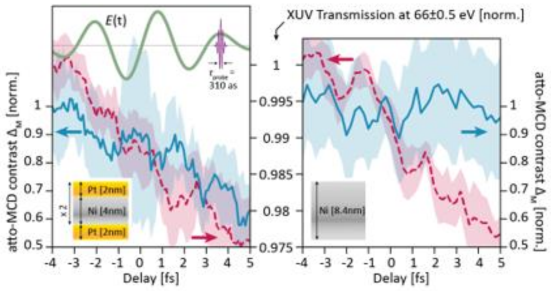
- A coherent attosecond spintronics?
- The nature of femtosecond spin dynamics
- THz spintronic emitter - *noncoherent*
- Topological Insulators
- Lightwave electronics - coherent
- Summary







T. Seifert, et al. Nature Photonics (2016)

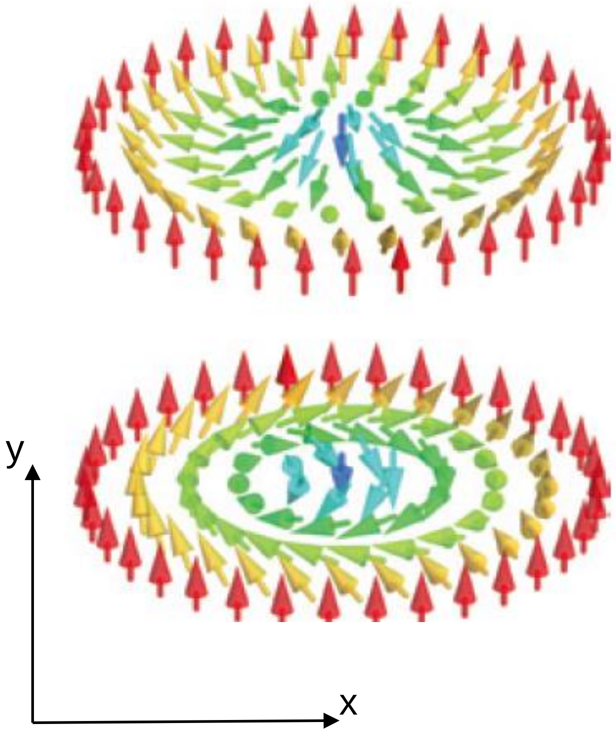


F. Siegrist *et al.*, Light-wave dynamic control of magnetism,
Nature **571**, 240–244 (2019)

Topological matter

Skyrmions

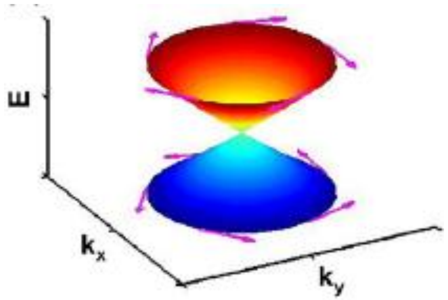
Real space x, y

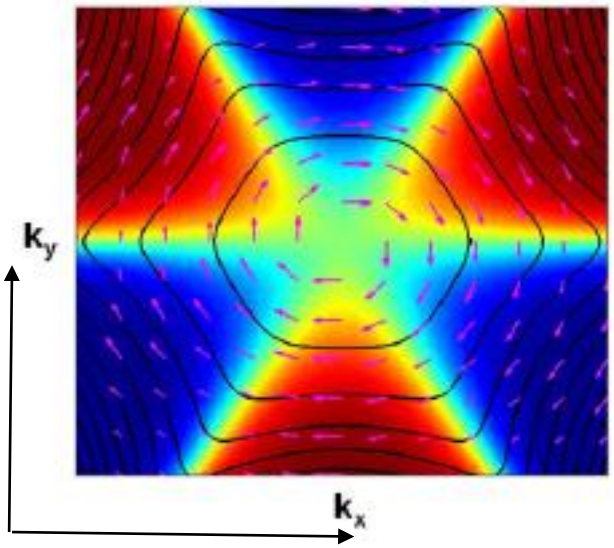


From A. Fert, V. Cros, and J. Sampaio, Nat. Nano. 8, 152–156 (2013)

Topological Insulators

Reciprocal space k_x, k_y



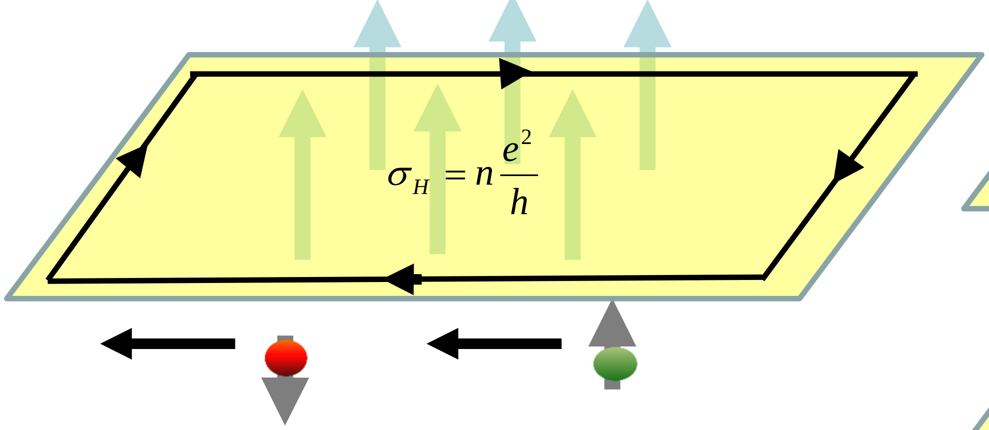


Nature Phys. 5 (2009) 438-42
Phys. Rev B 82 (2010) 045122

Topological matter

Large B field

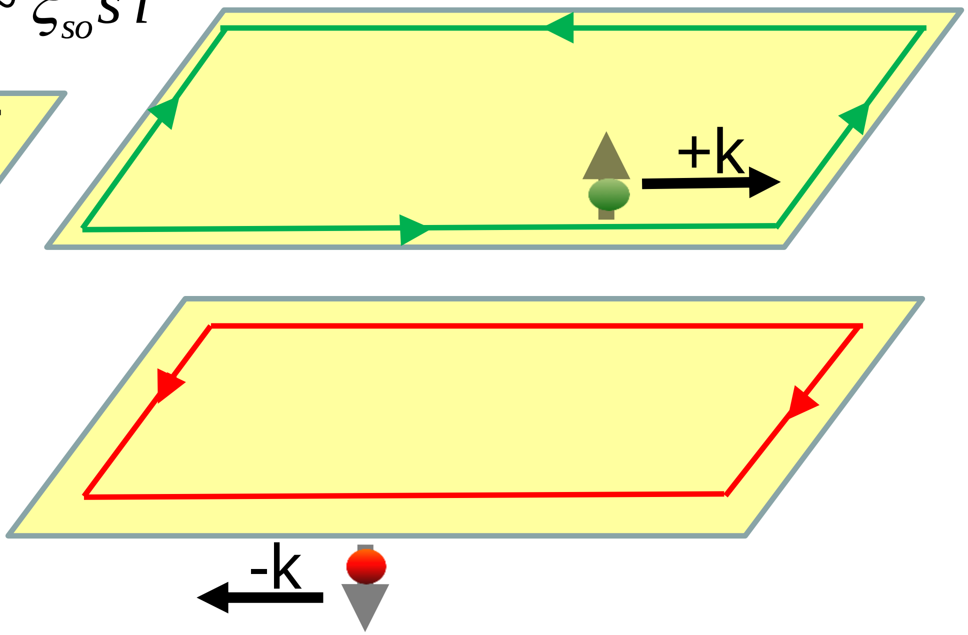
$$E \sim \vec{s}\,\vec{B}$$



$$\sigma_H = n\frac{e^2}{h}$$

Internal spin-orbit field

$$E \sim \xi_{so}\,\vec{s}\,\vec{l}$$



Cyclotron resonance, in 2D materials quantum Hall effect and edge states

Large spin-orbit coupling leads to cyclotron orbit

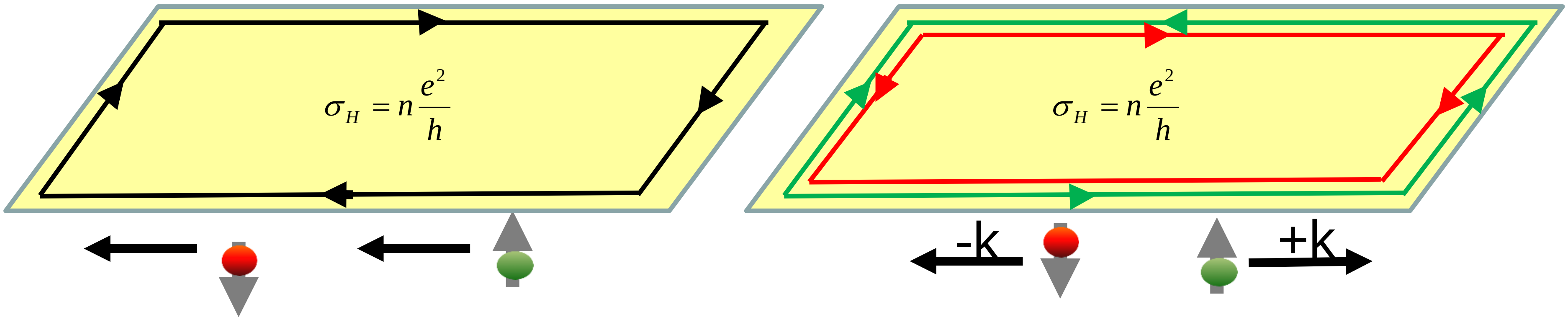
Topological matter

Large B field

$$E \sim \vec{s}\,\vec{B}$$

Internal spin-orbit field

$$E \sim \xi_{so}\,\vec{s}\,\vec{l}$$



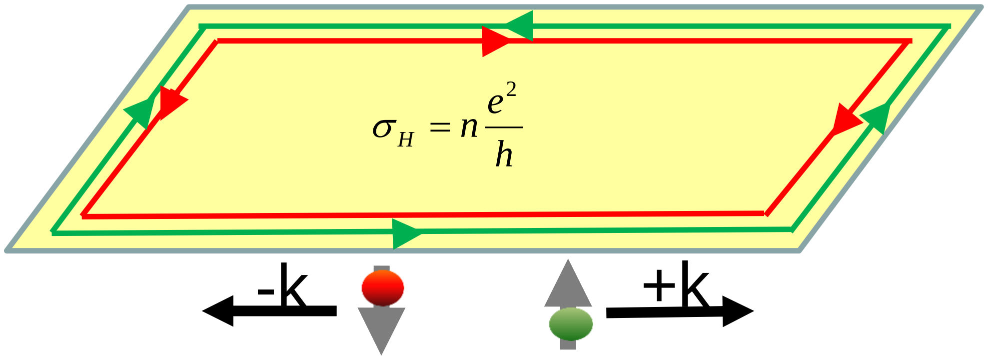
Quantum Hall effect and edge states

Spin-momentum locking, spin polarized edge states

Topological matter

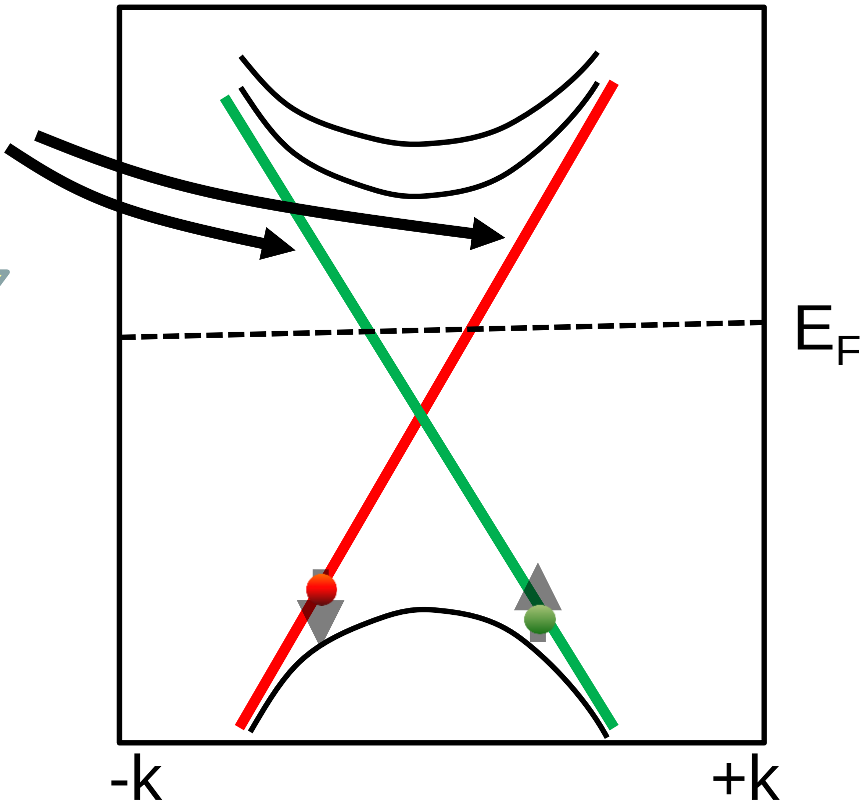
Topological insulator

$$E \sim \xi_{so} \vec{s}\,\vec{l}$$


$$\sigma_H = n\frac{e^2}{h}$$

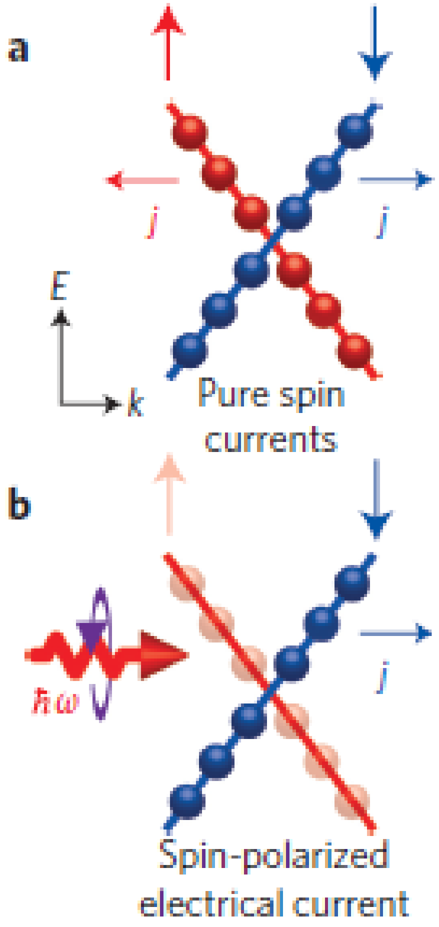
Schematic bands

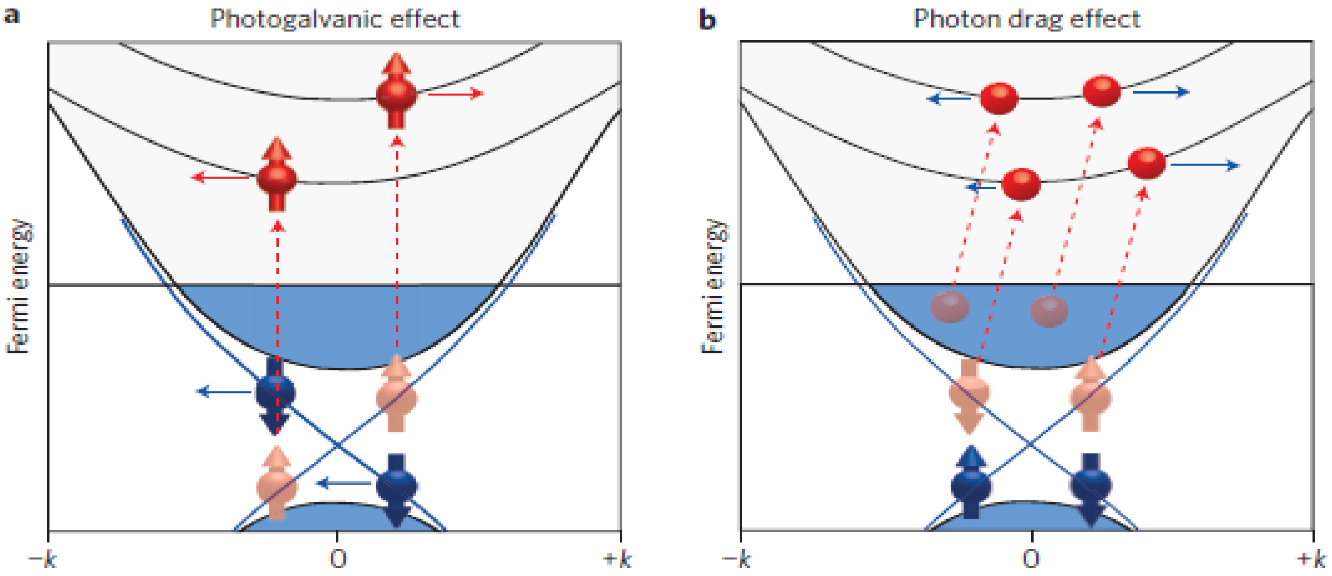
Surface states



- Spin-momentum locking of the surface state
- Generation of spin currents driven by light

Photoinduced currents in topological insulators



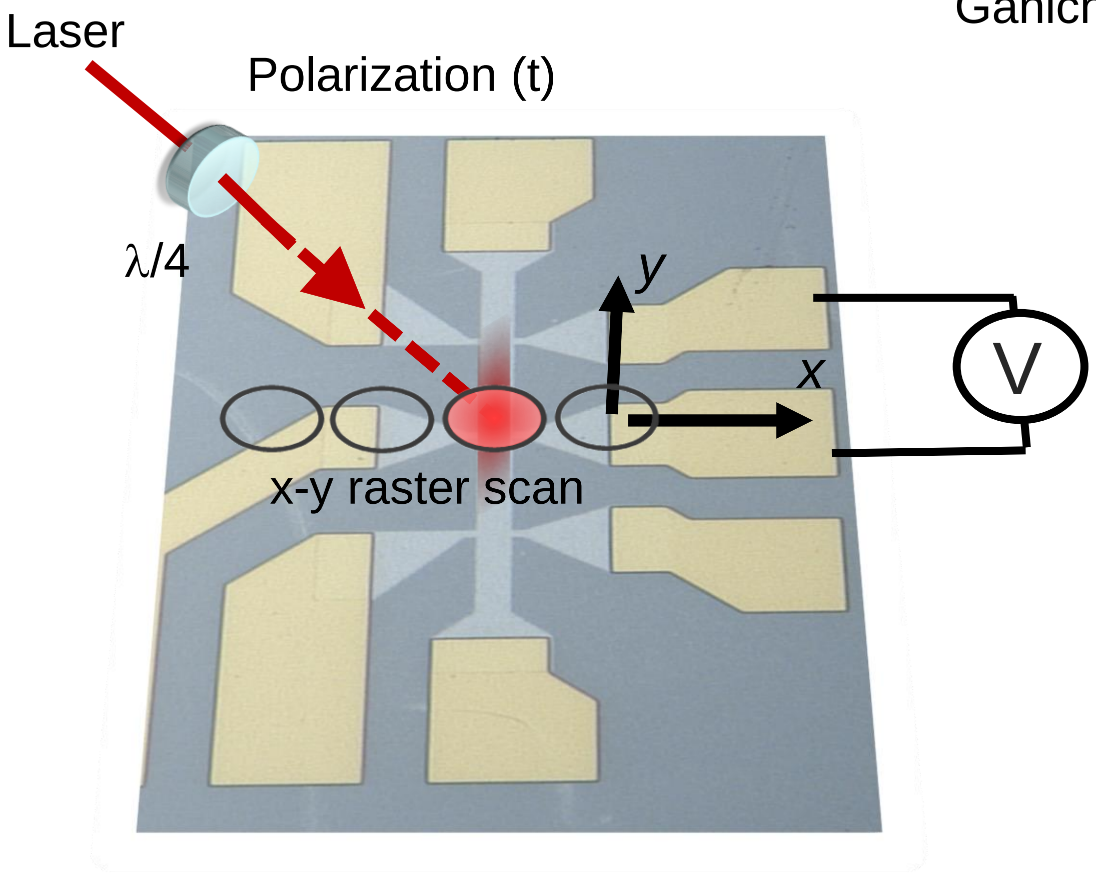


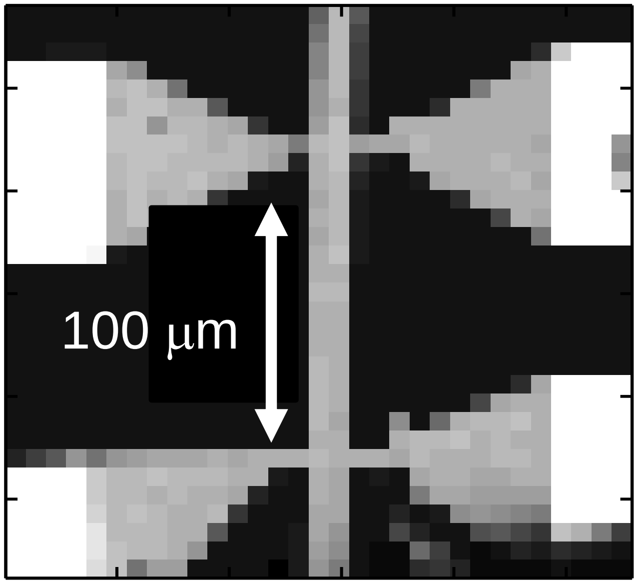
[1] *Control over topological insulator photocurrents with light polarization;* **J. W. McIver, D. Hsieh, H. Steinberg, P. Jarillo-Herrero and N. Gedik;** NATURE NANOTECHNOLOGY LETTERS: DOI: 10.1038/NNANO.2011.214

Photoinduced currents in topological insulators

- Circular photogalvanic effect

J. W. McIver, et al. Nature Nano.(2011).
Ganichev et al. Nature (2002).



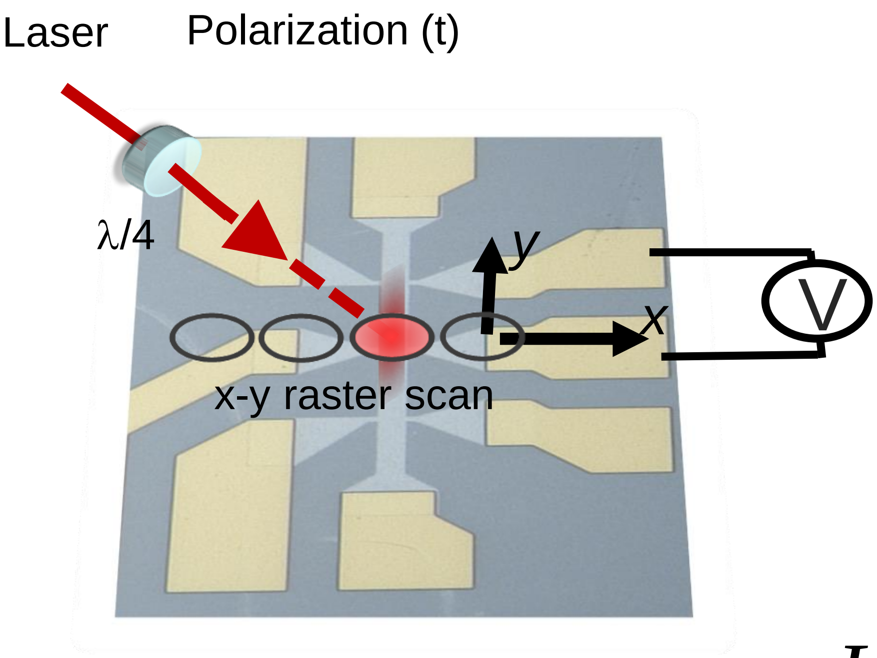


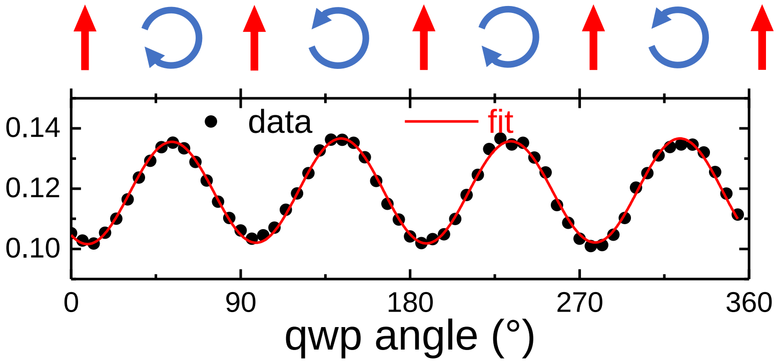
Reflectivity map
scan area

- 3D topological insulator intrinsic doping, 16 nm $(Bi_{0.57}Sb_{0.43})_2Te_3$)

Topological matter

- Circular photogalvanic effect C, thermovoltage D





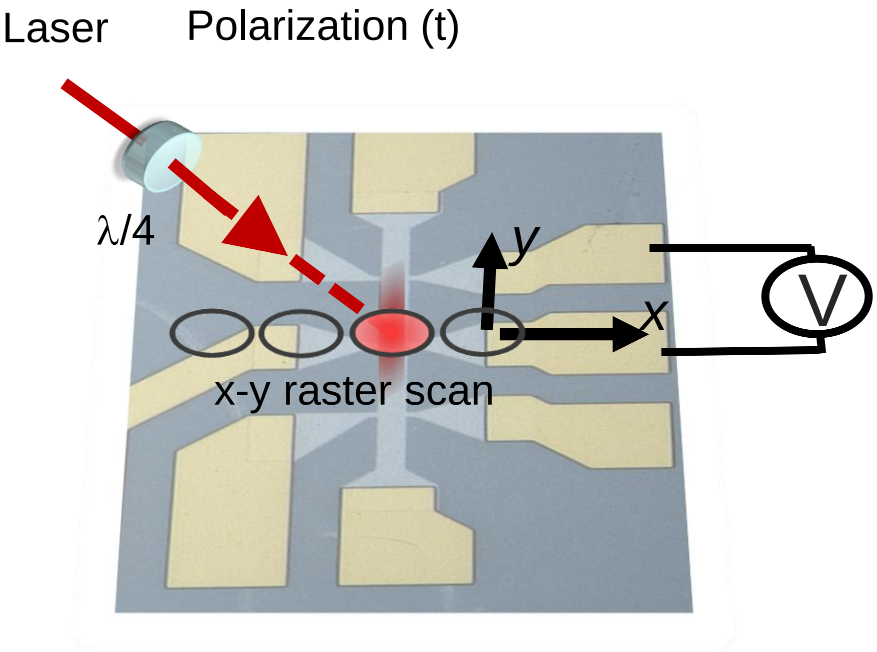
Ganichev model (θ=pump helicity):

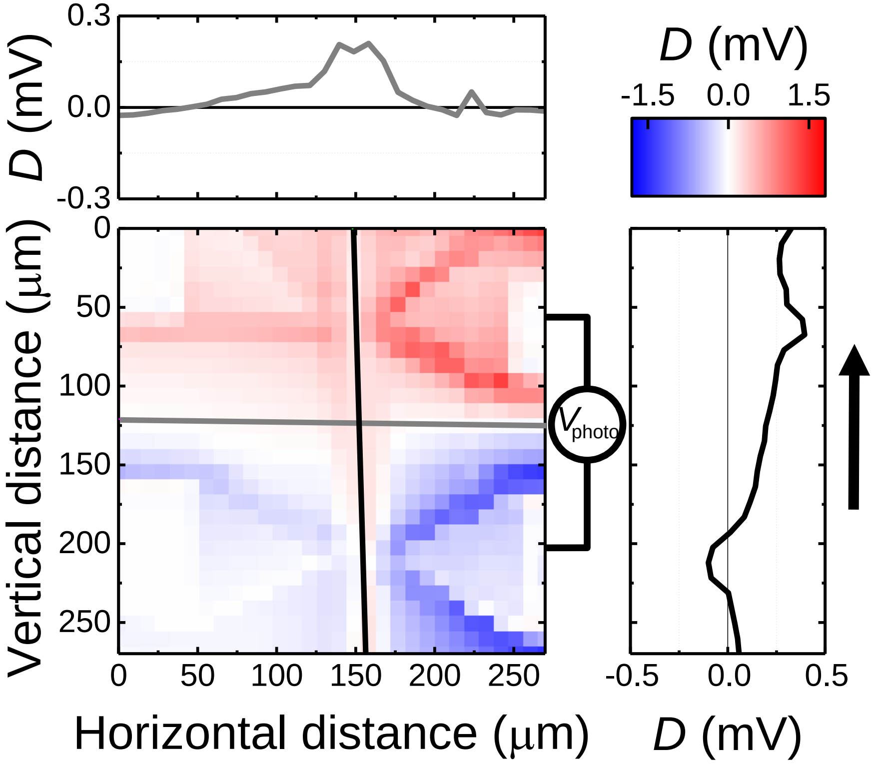
$$U(\theta)=\underbrace{C\sin(2\theta)+L_1\sin(4\theta)}_{\text{Photoinduced currents}}\underbrace{+L_2\cos(4\theta)+D}_{\text{Seebeck effects (thermal)}}$$

Separation of the different contributions.

Topological matter

- Circular photogalvanic effect C, thermovoltage D



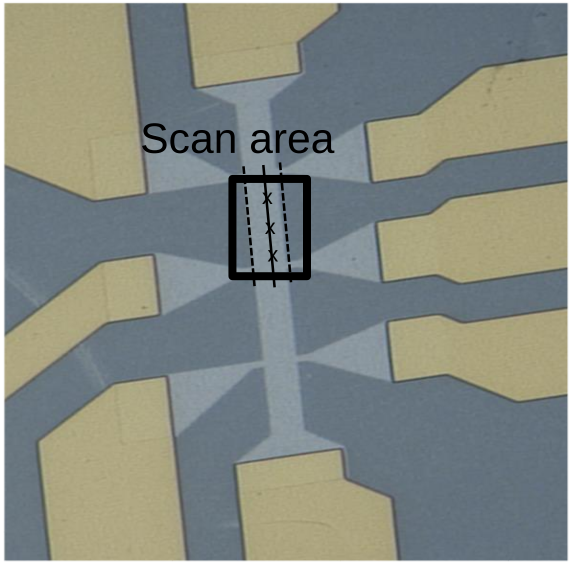


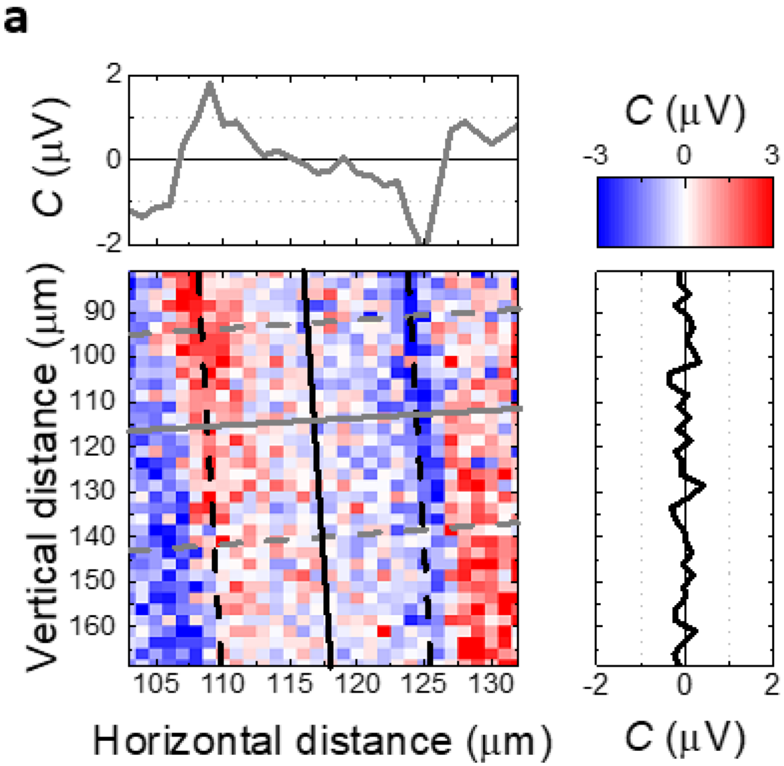
- 3D topological insulator intrinsic doping, 16 nm $(Bi_{0.57}Sb_{0.43})_2Te_3$)

Topological matter

- Circular photogalvanic effect C, thermovoltage D

Detail: Hall bar





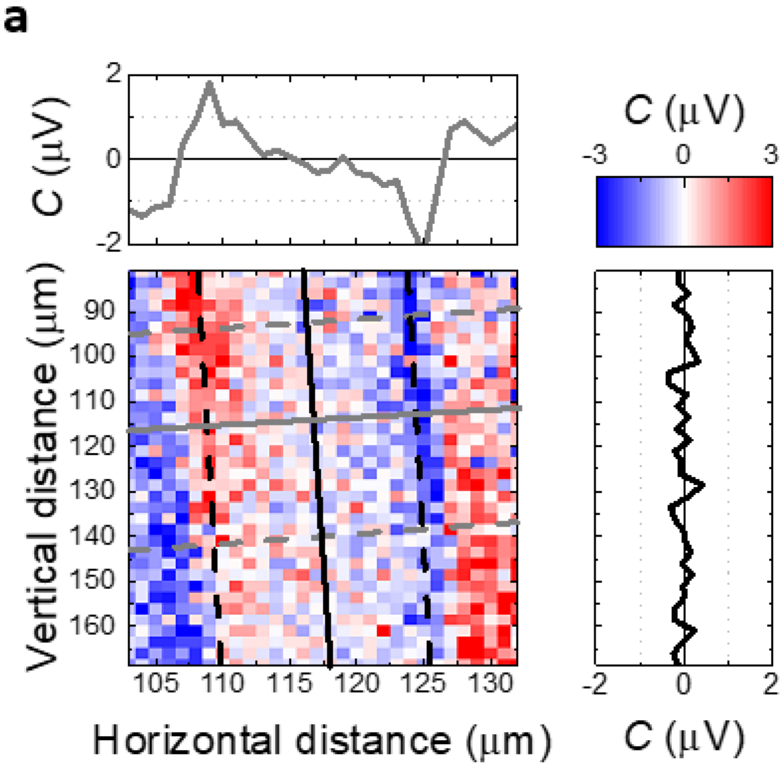
- Spin accumulation by Spin-Nernst effect

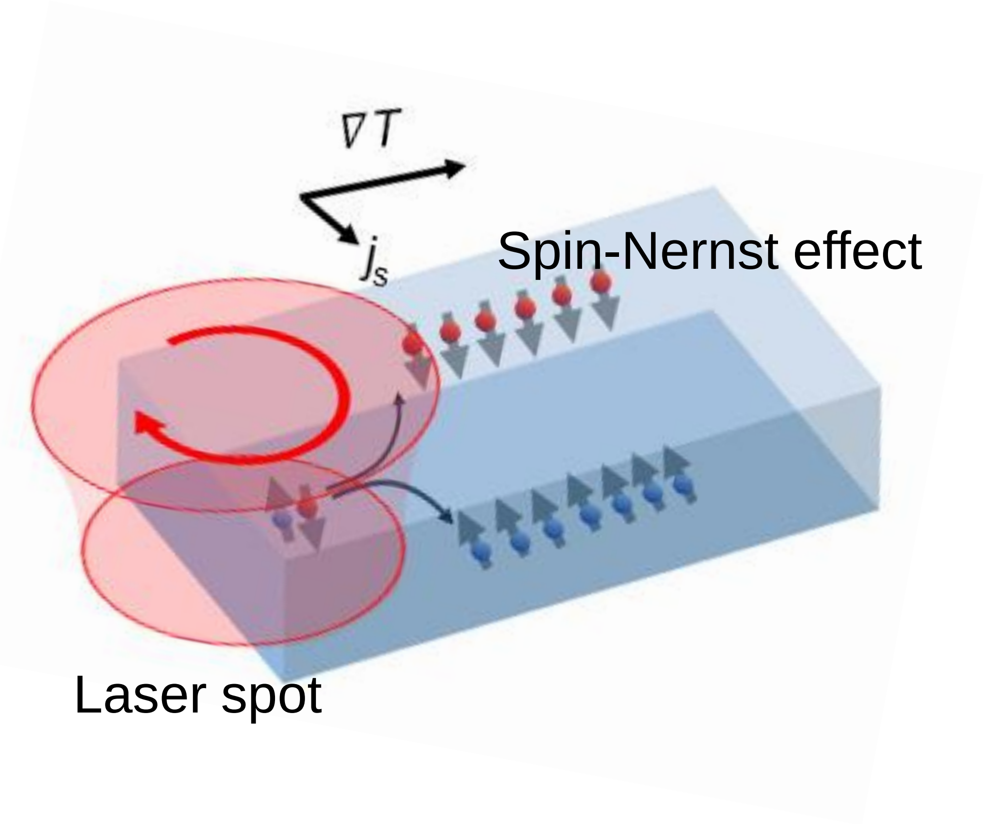
T. Schumann et al. arXiv 1810.12799

Topological matter

- Circular photogalvanic effect C, thermovoltage D

Detail: Hall bar





Spin-Nernst effect

Laser spot

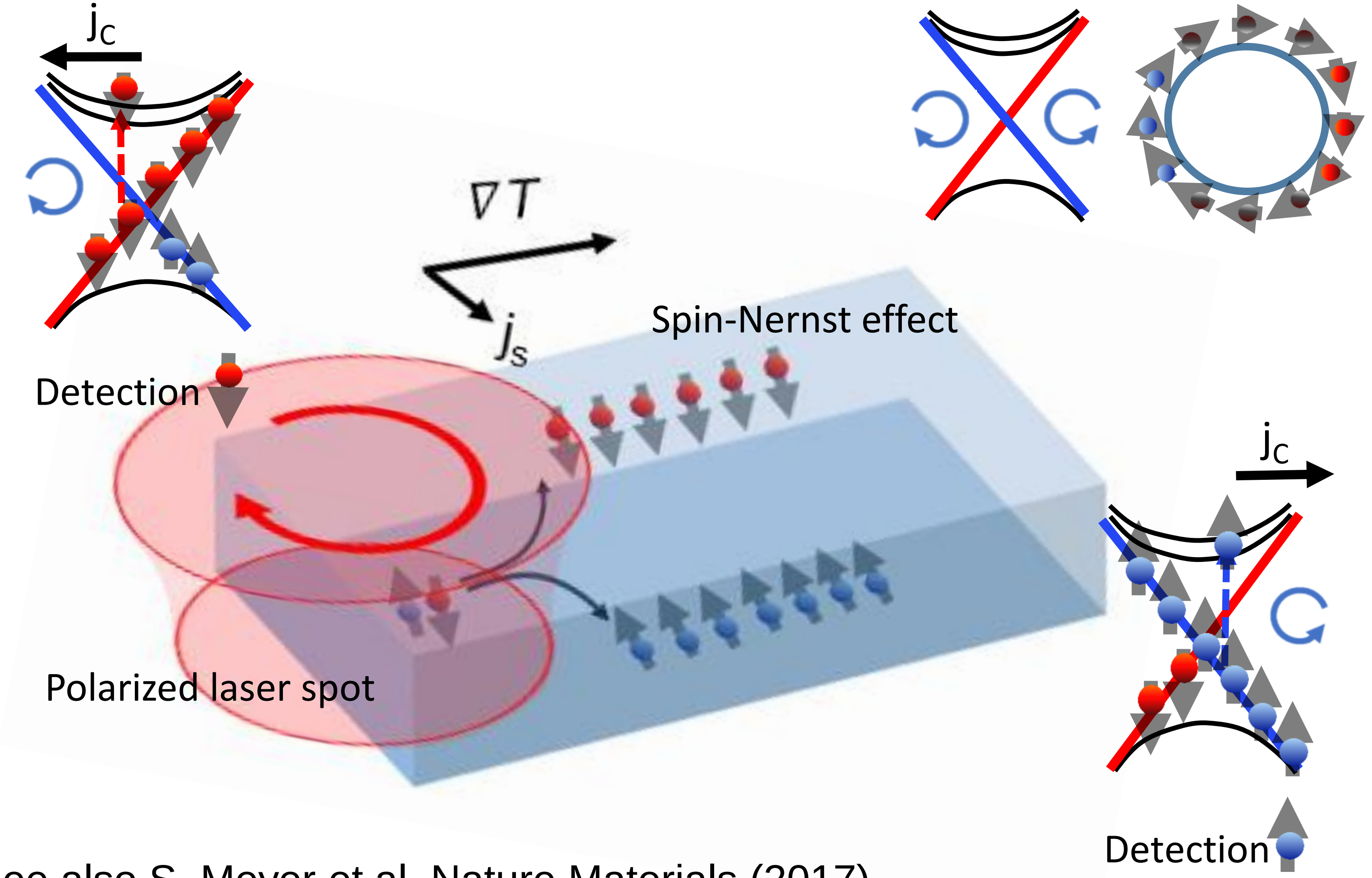
- Spin accumulation by Spin-Nernst effect

T. Schumann et al. arXiv 1810.12799

Topological matter

Spin-orbit driven spin-accumulation

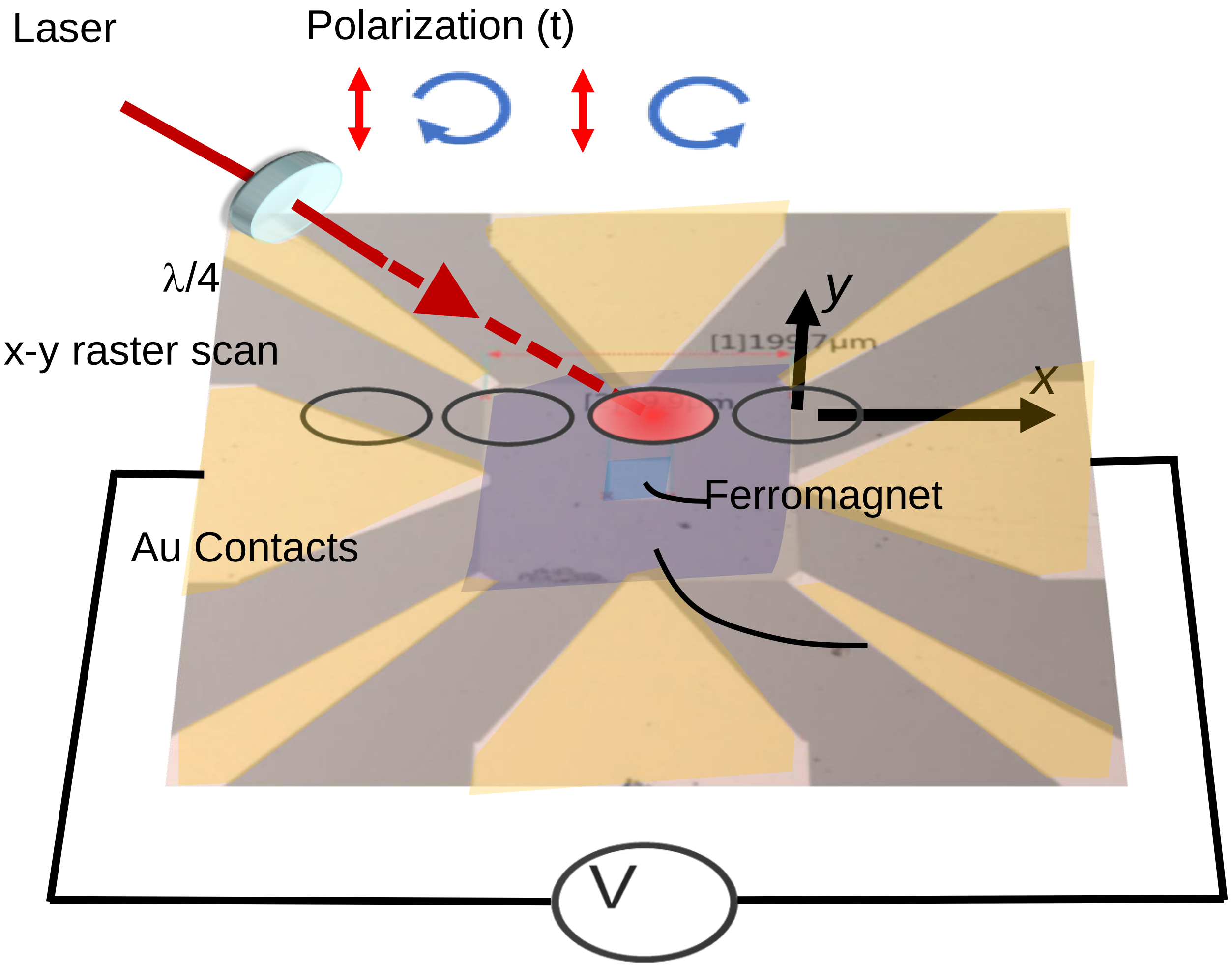
Spin-sensitive detection by photo-current blocking

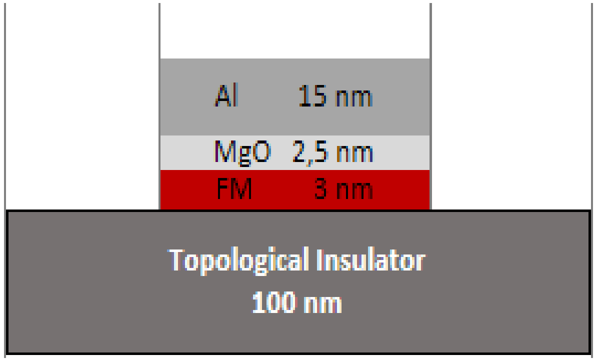


See also S. Meyer et al. Nature Materials (2017).

Topological matter

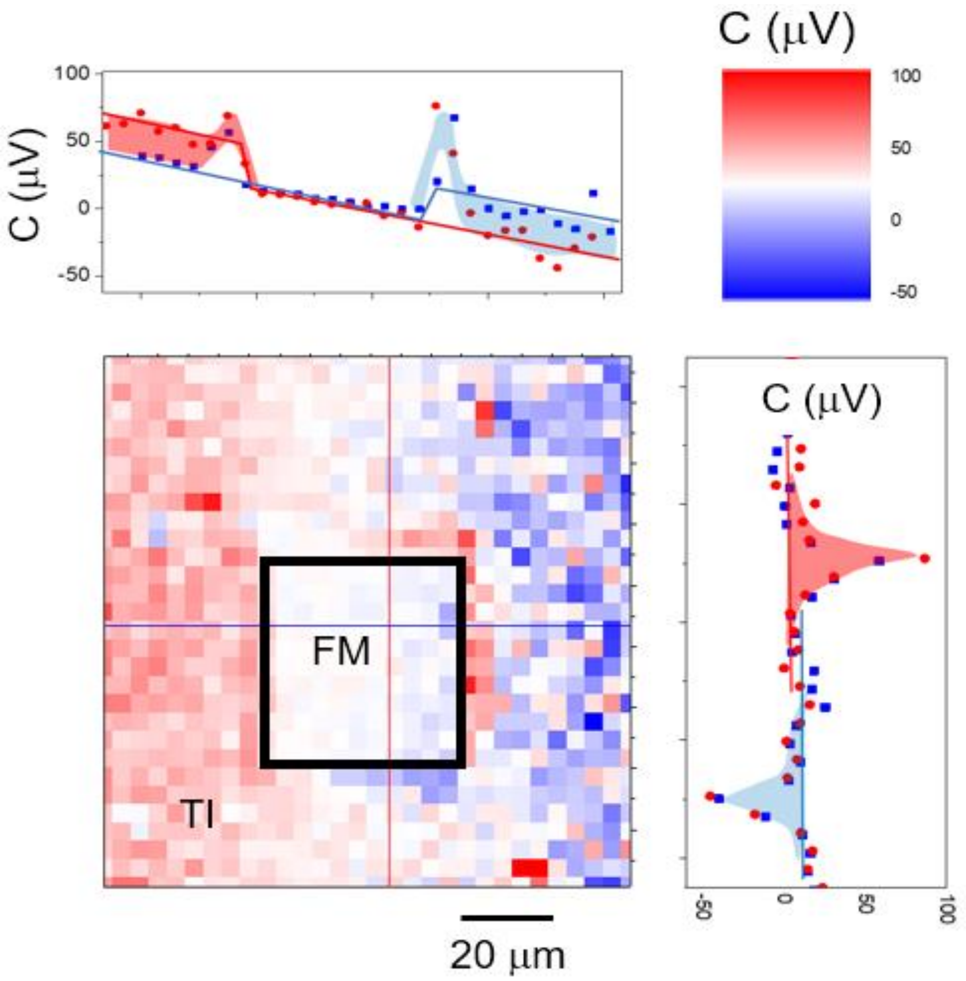
Ferromagnet/ Topological insulator hybrid structures



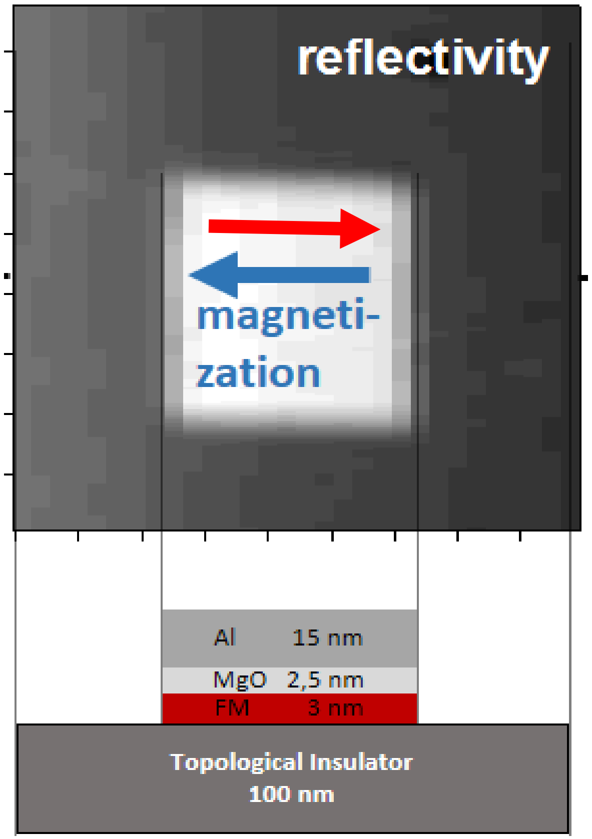


Topological matter

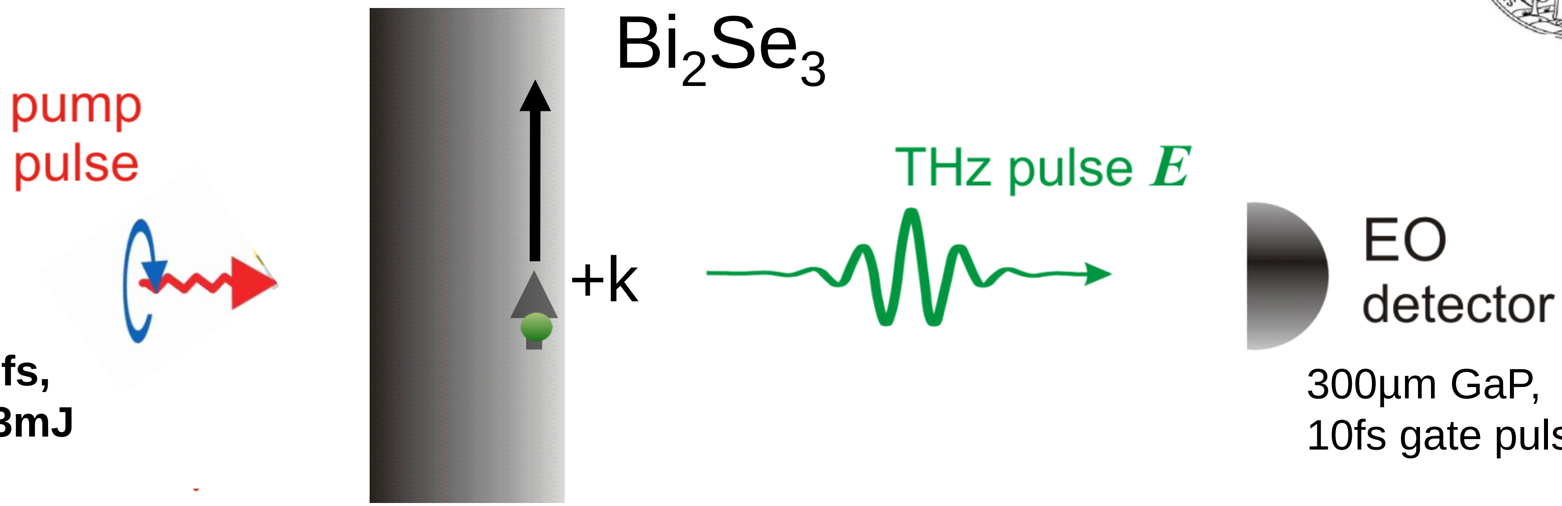
- Circular photogalvanic effect C with ferromagnetic structure



B= +- 31mT



Spins driven in Topological Insulators



Bi_2Se_3

pump pulse

20fs, 0.3mJ

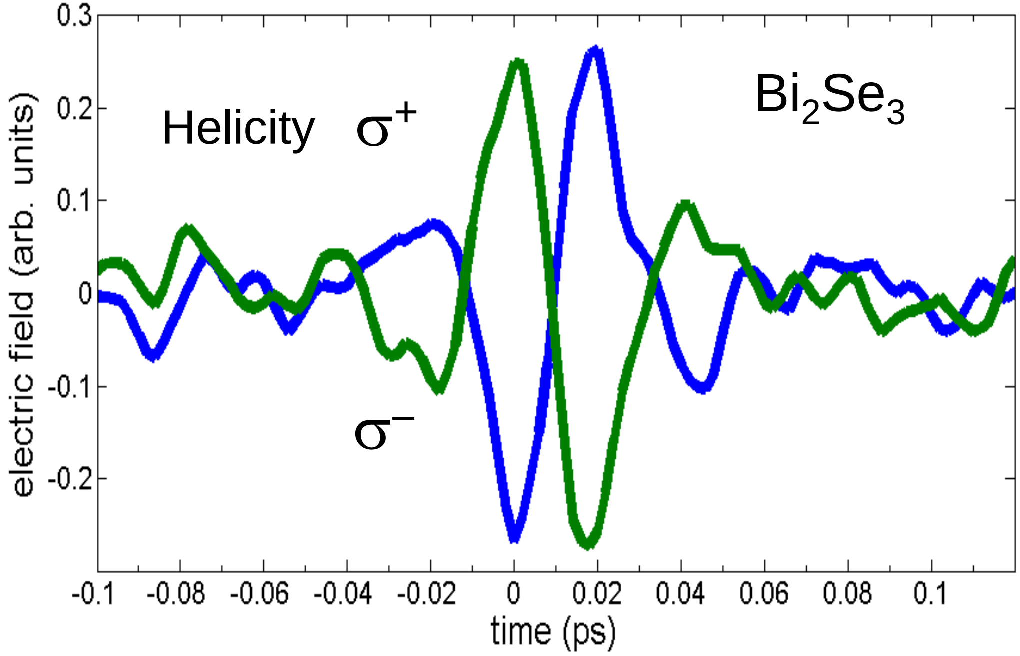
+k

THz pulse $\boldsymbol{E}$

EO detector

300µm GaP, 10fs gate pulse

“Ultrafast amperemeter”



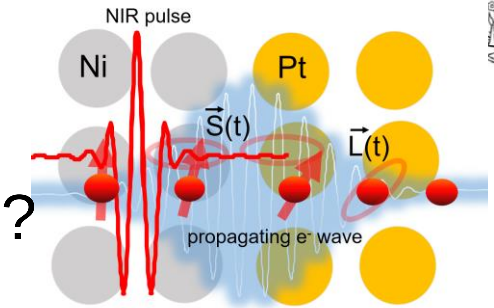
- THz emission is polarization dependent

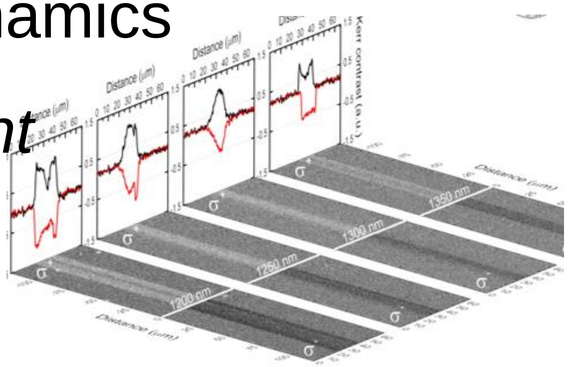
- Full story here:

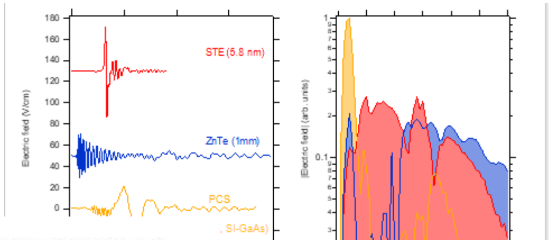
L. Braun, et al., Nature Comm. 7, 13259 (2016).

Outline

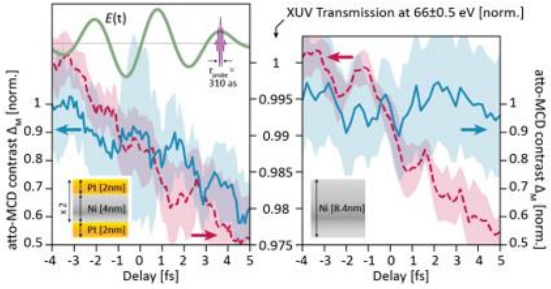
- A coherent attosecond spintronics?
- The nature of femtosecond spin dynamics
- THz spintronic emitter – *noncoherent*
- Topological Insulators
- Lightwave electronics - *coherent*
- Summary





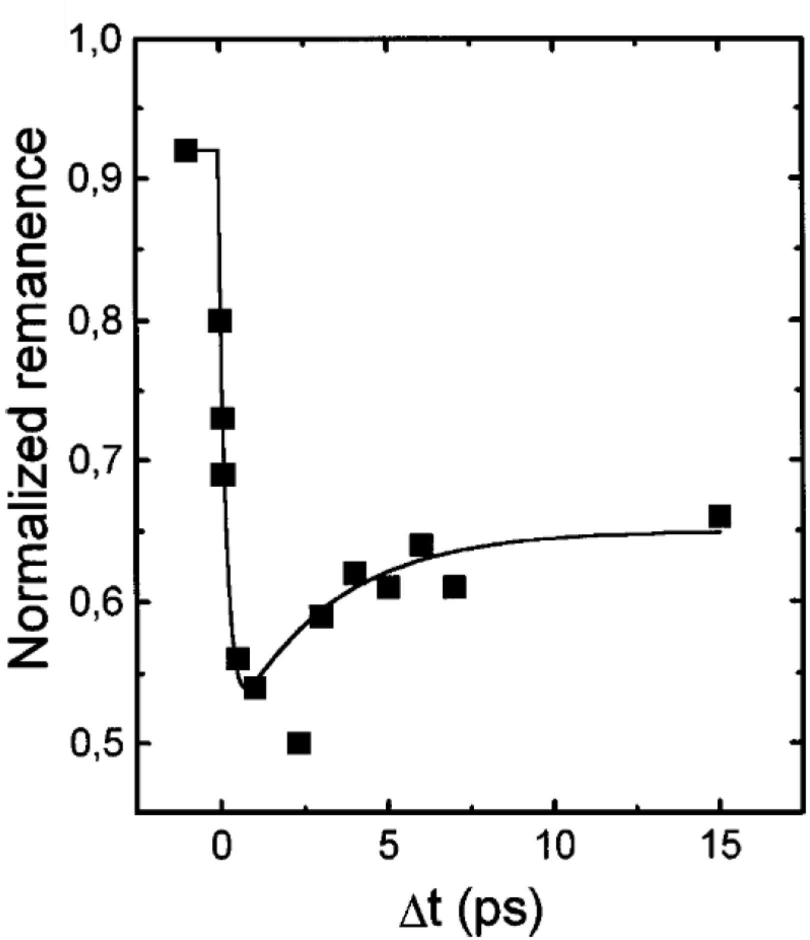


T. Seifert, et al. Nature Photonics (2016)



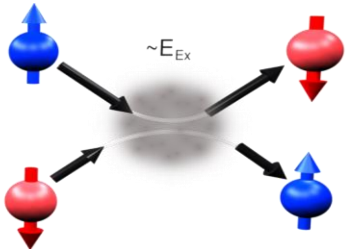
F. Siegrist *et al.*, Light-wave dynamic control of magnetism, Nature **571**, 240–244 (2019)

Lightwave Spintronics – Attosecond dynamics

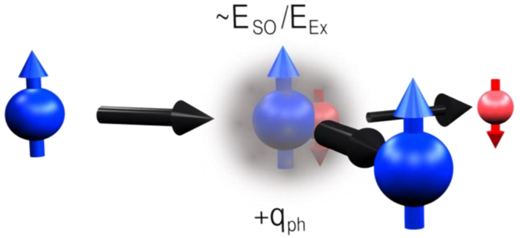


Laser-induced **demagnetization**

Beaurepaire et al. PRL 76, 4250 (1996)

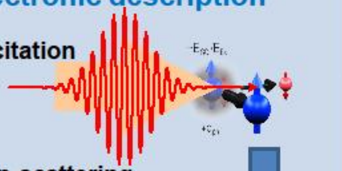


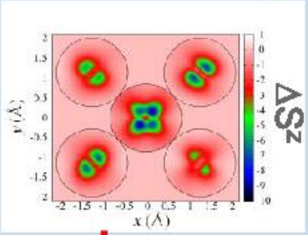
Metal	Exchange	Spin-orbit
Fe	52 fs	50 fs
Co	80 fs	52 fs
Ni	380 fs	48 fs



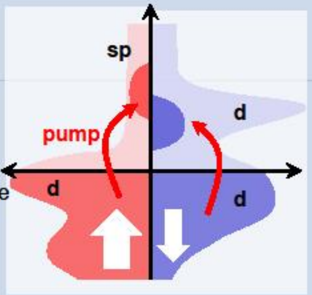
Family tree of models for ultrafast spin dynamics

Electronic description



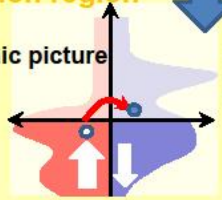


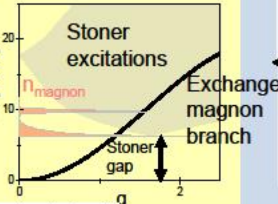
Time dependent density functional theory (TDDFT)



Transition region

Electronic picture

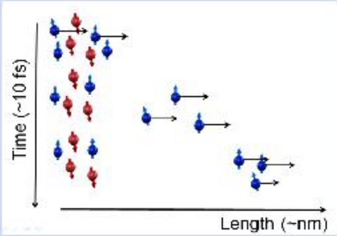




Exchange magnon branch

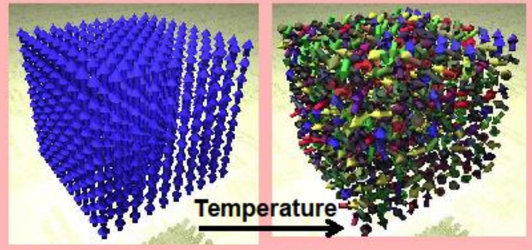
Spin picture

Spin diffusion

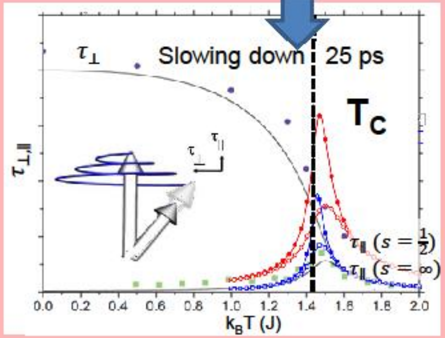


Spin projected description

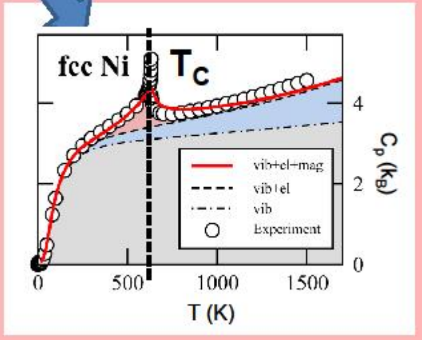
Thermal spin ensemble: atomistic



Landau-Lifshitz Bloch and M3TM



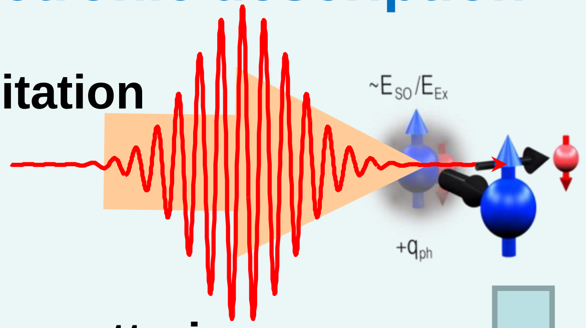
Specific heat picture



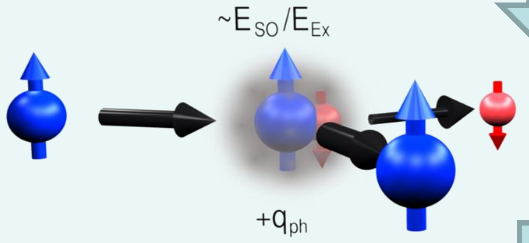
Family tree of models for ultrafast spin dynamics

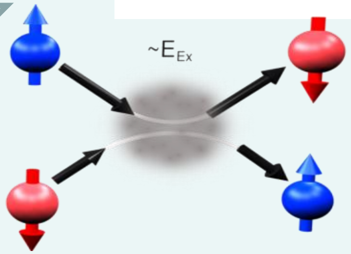
Electronic description

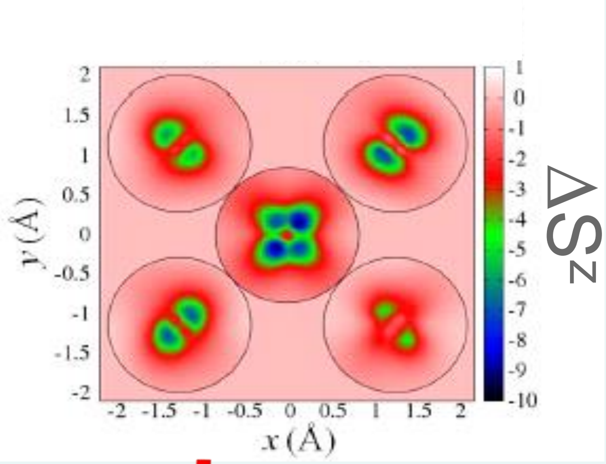
Excitation



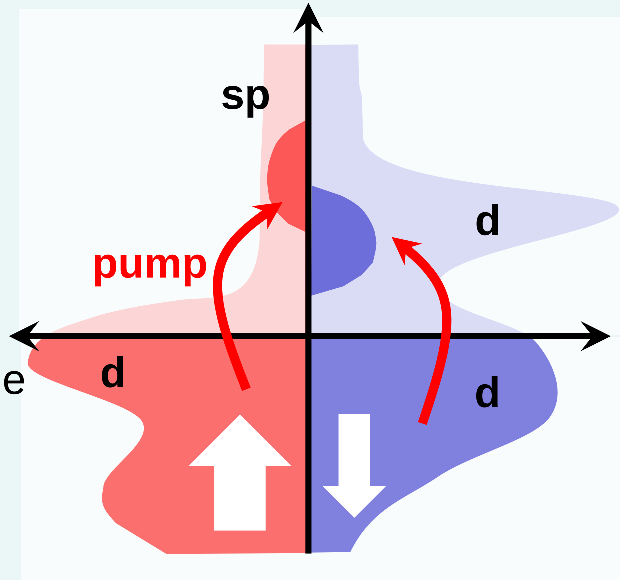
Spin-scattering





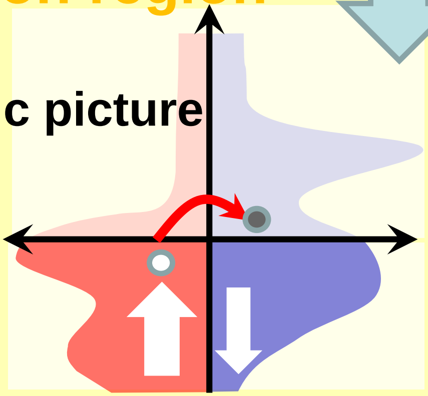


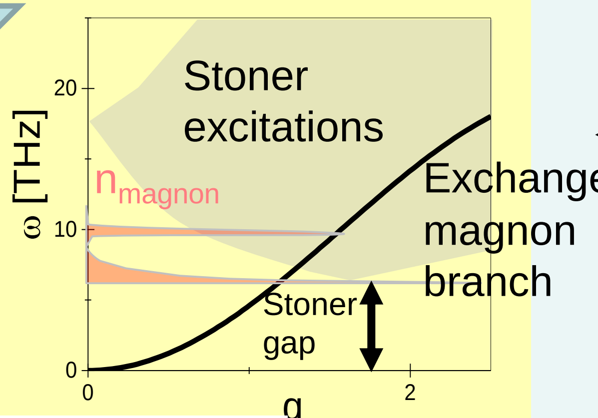
Time dependent density functional theory (TDDFT)



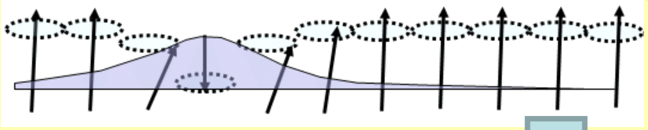
Transition region

Electronic picture



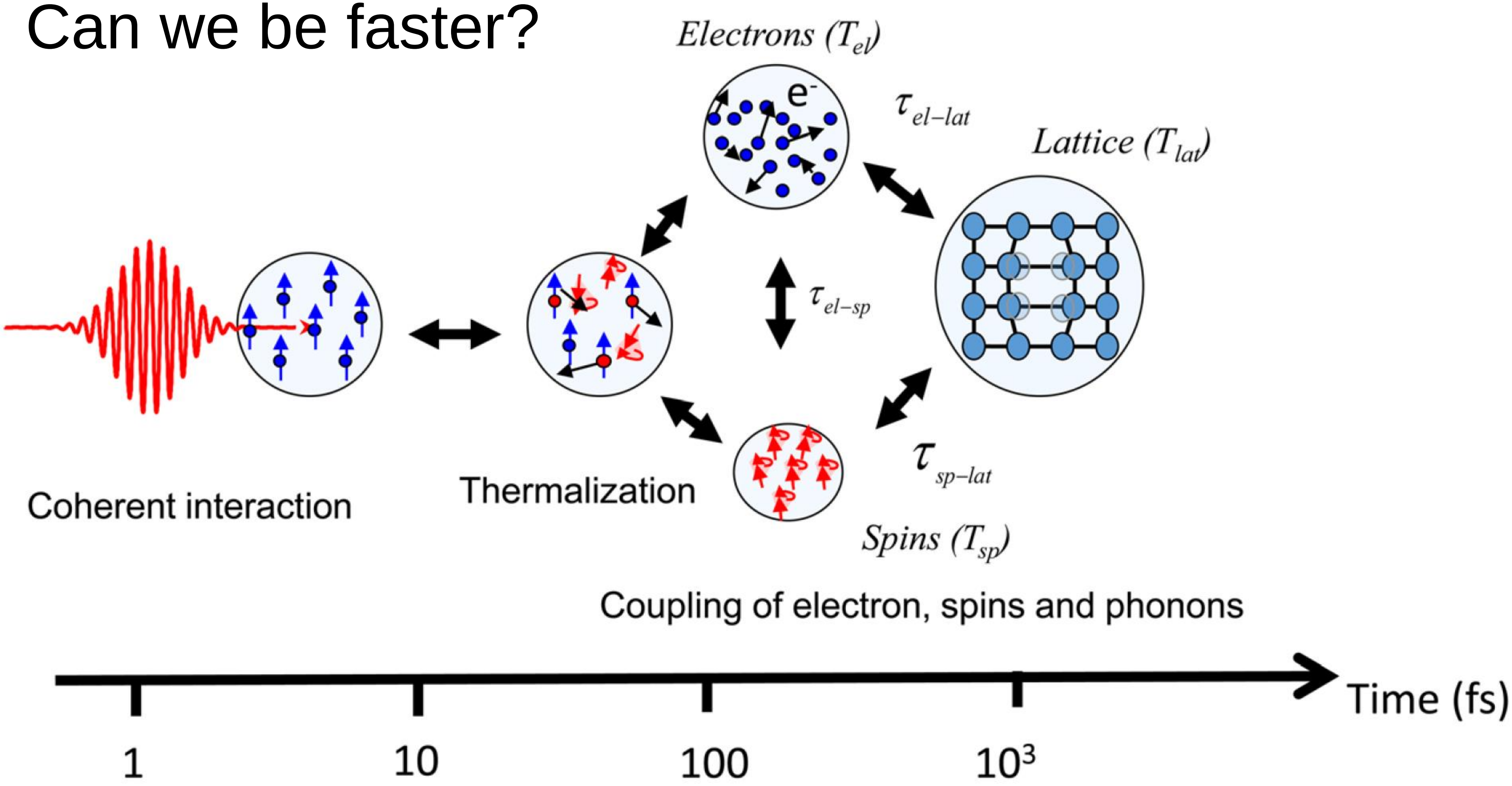


Spin picture



Lightwave Spintronics – Attosecond dynamics

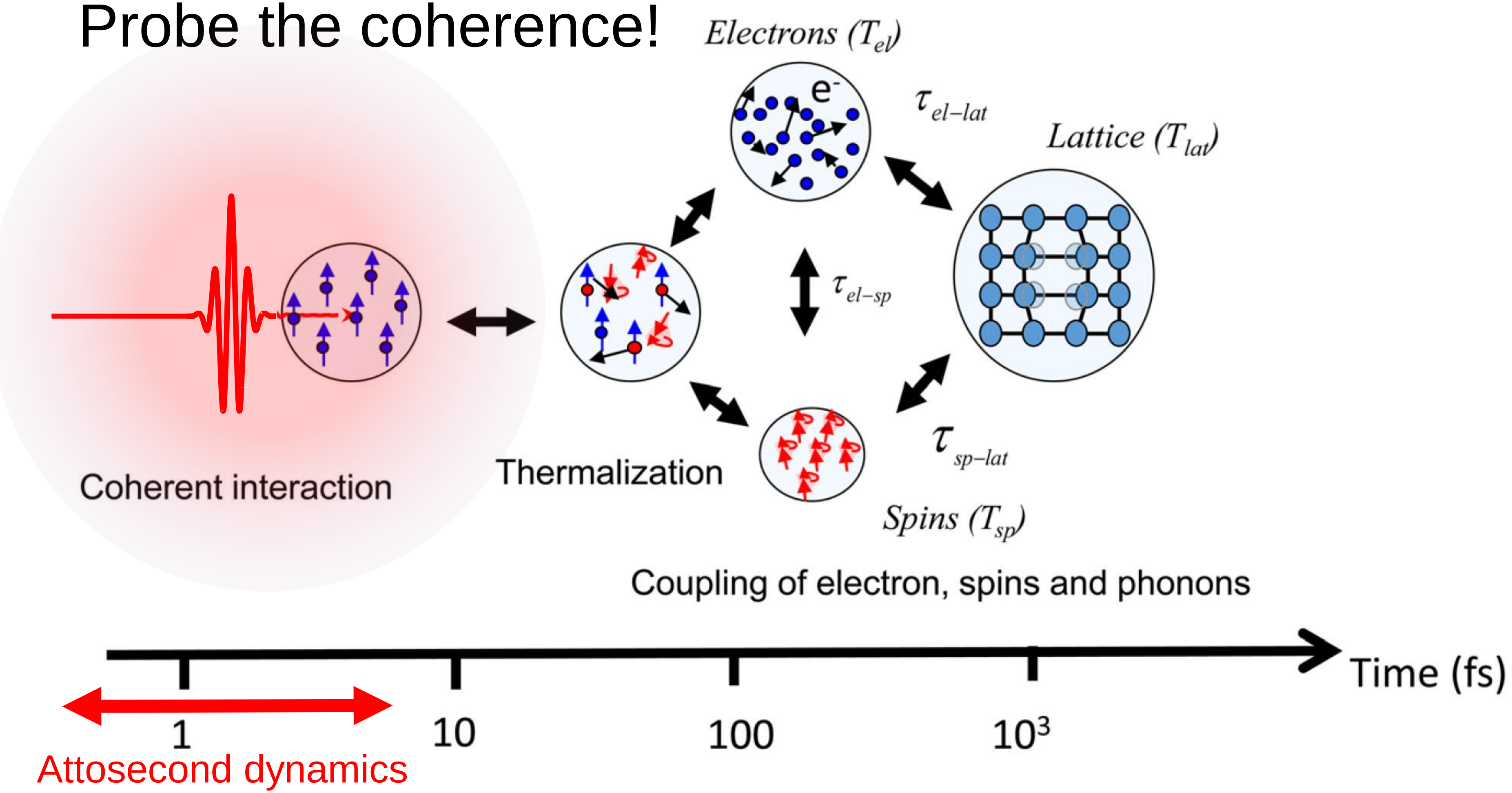
Can we be faster?



Perspective, J. Appl. Phys. 120, 140901 (2016)

Lightwave Spintronics – Attosecond dynamics

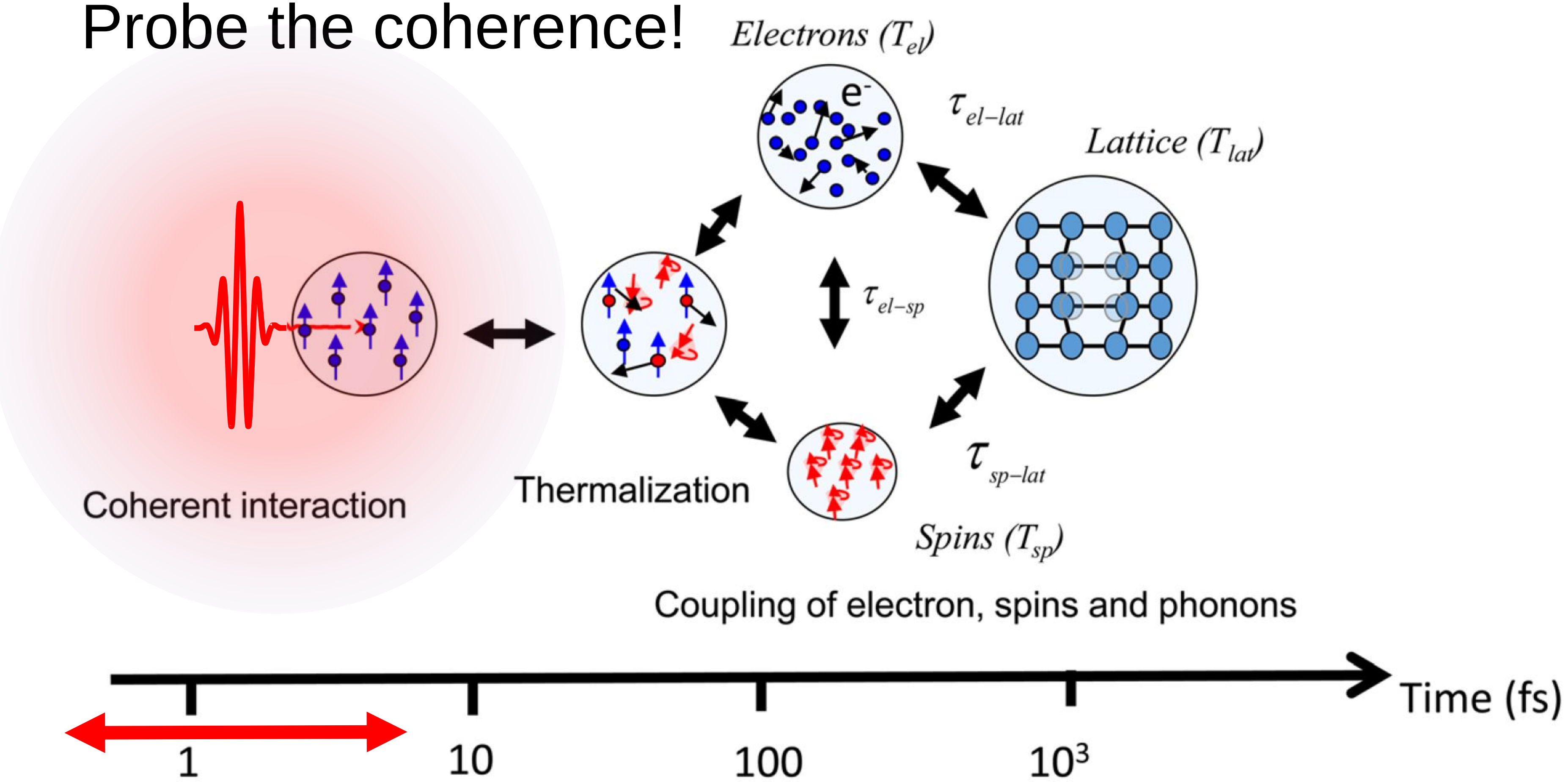
Probe the coherence!



Perspective, J. Appl. Phys. 120, 140901 (2016)

Lightwave Spintronics – Attosecond dynamics

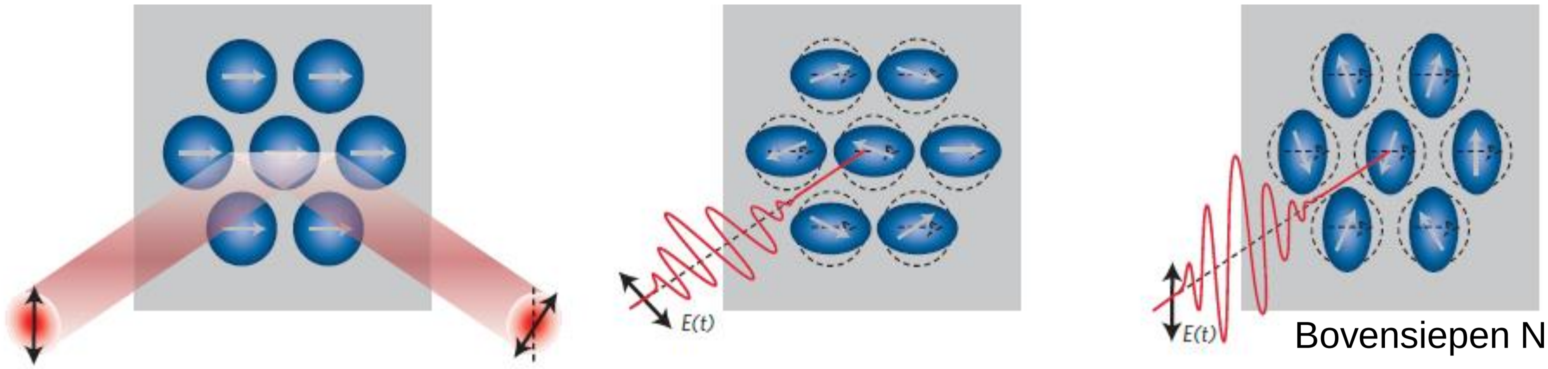
Probe the coherence!



Attosecond dynamics

Perspective, J. Appl. Phys. 120, 140901 (2016)

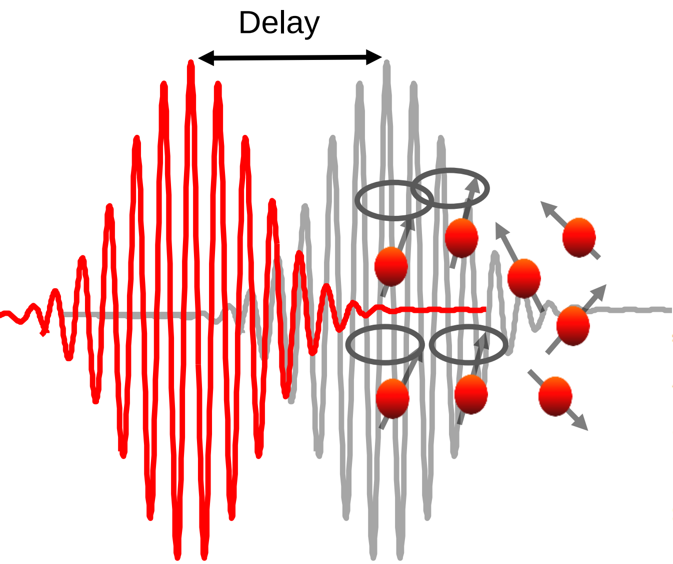
Going sub- femtosecond: coherent effects

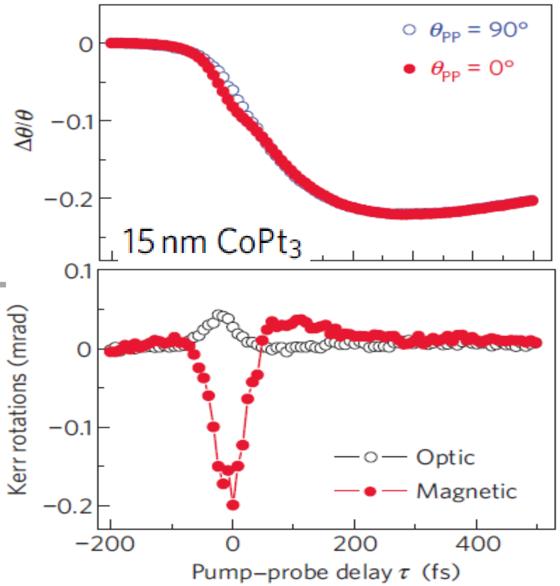


Bovensiepen Nat. Phys.

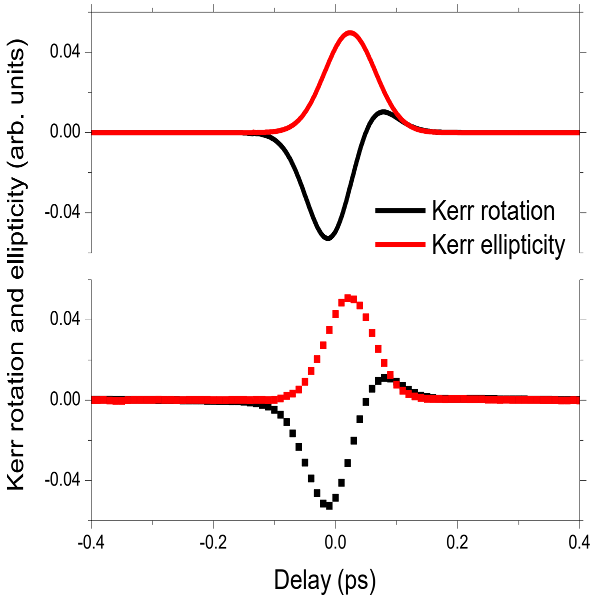
Laser cycle driven: ferromagnet CoPt$_3$

Topological insulator (Bi$_{0.57}$Sb$_{0.43}$)$_2$Te$_3$





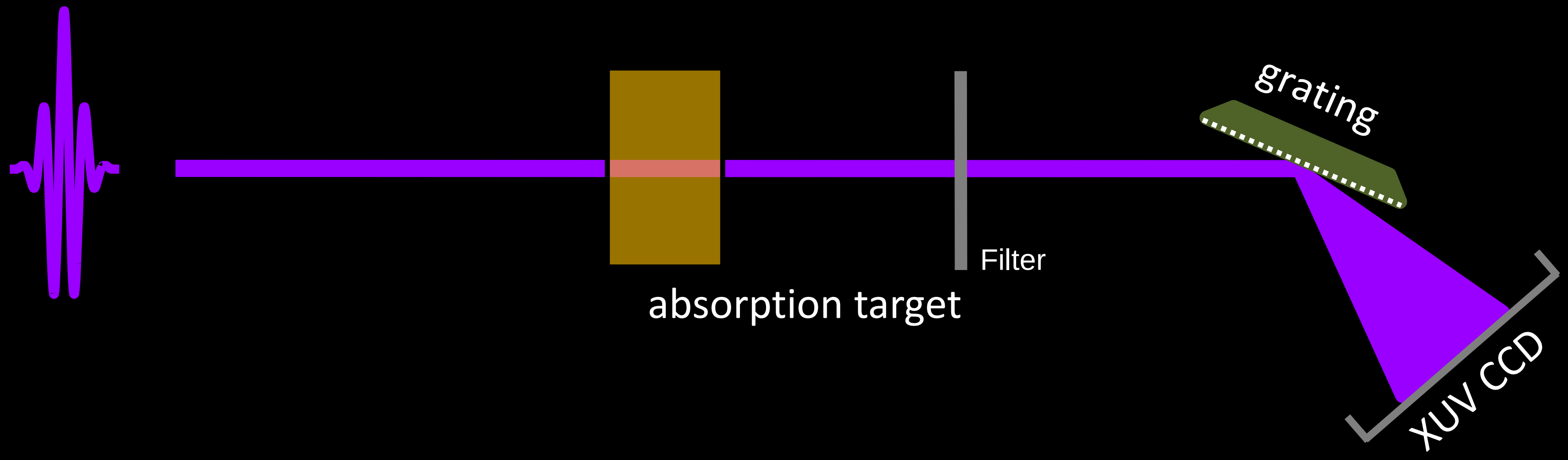
Bigot et al. Nat. Phys.

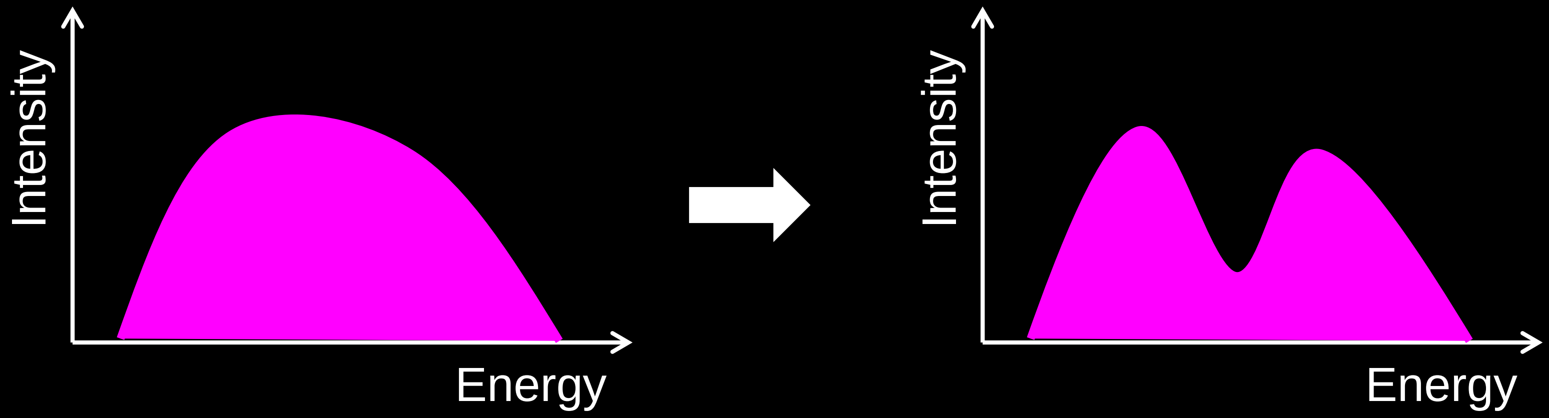


Boschini et al. Sci. Rep.

Lightwave Spintronics – Attosecond dynamics

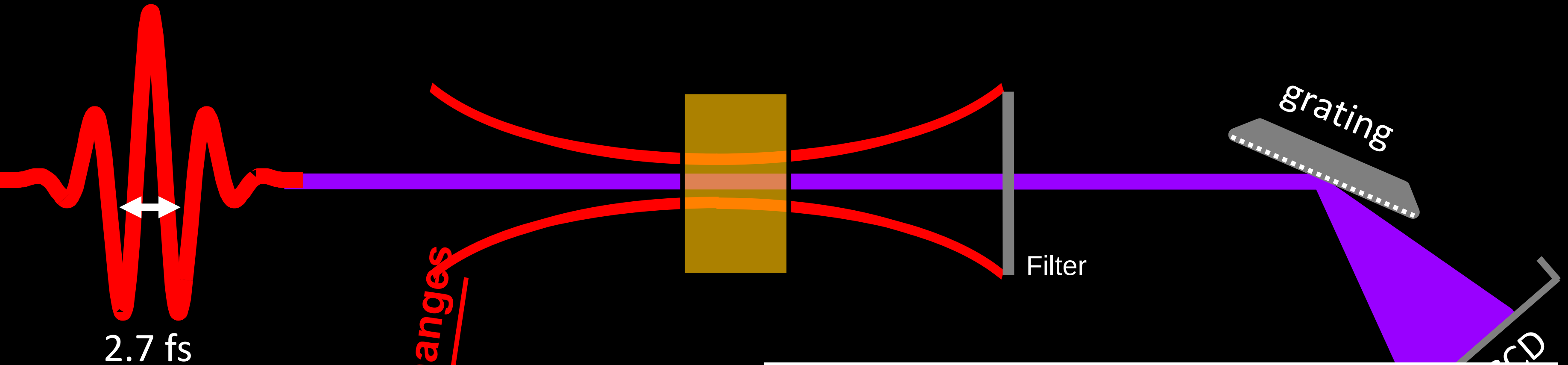
100-300 Attoseconds

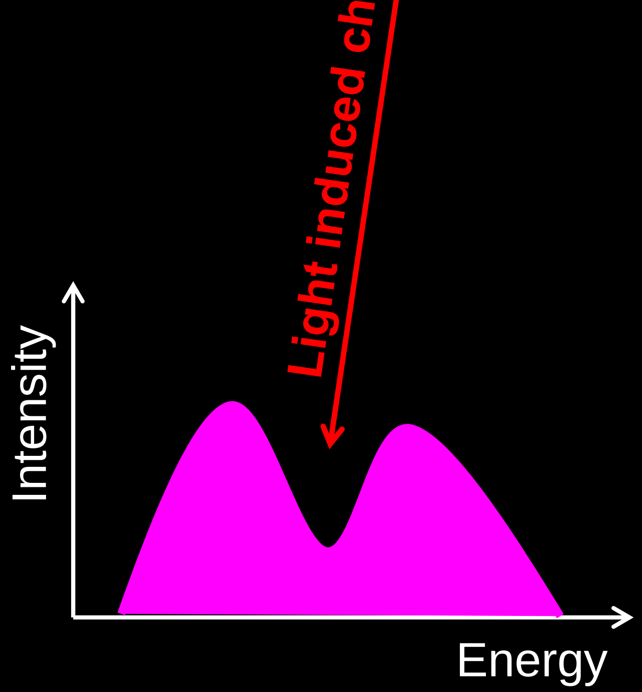


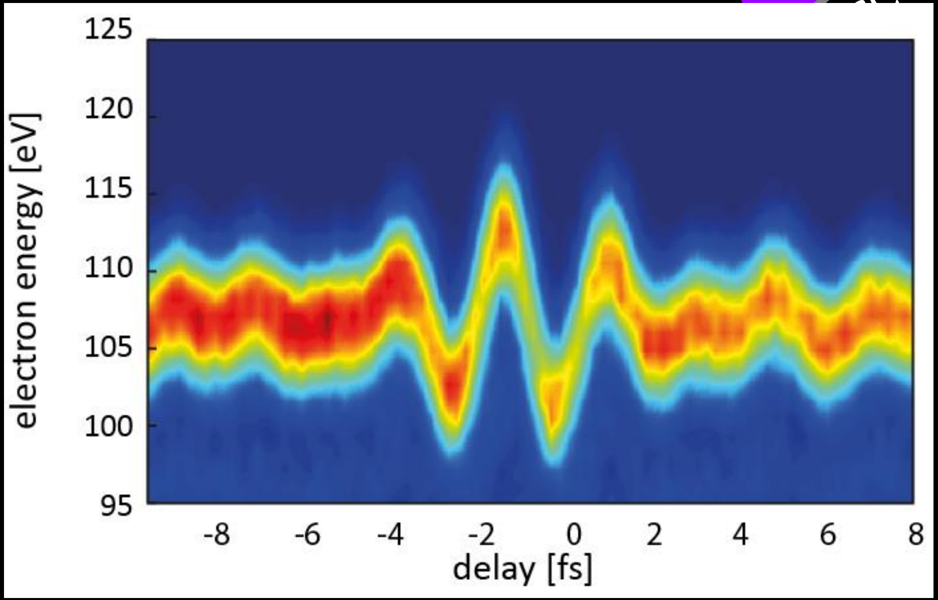


Lightwave Spintronics – Attosecond dynamics

Few cycle light pulse, Pump



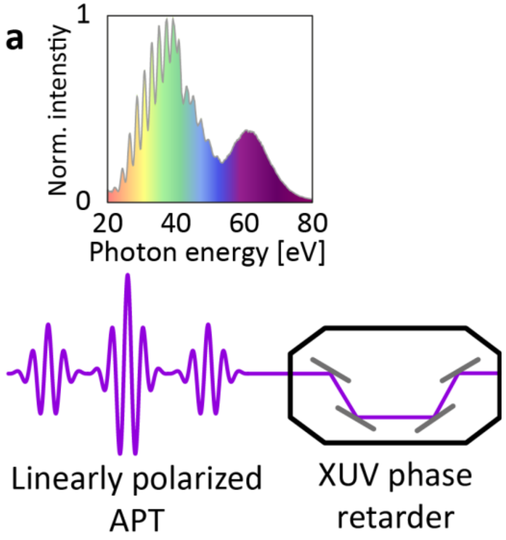


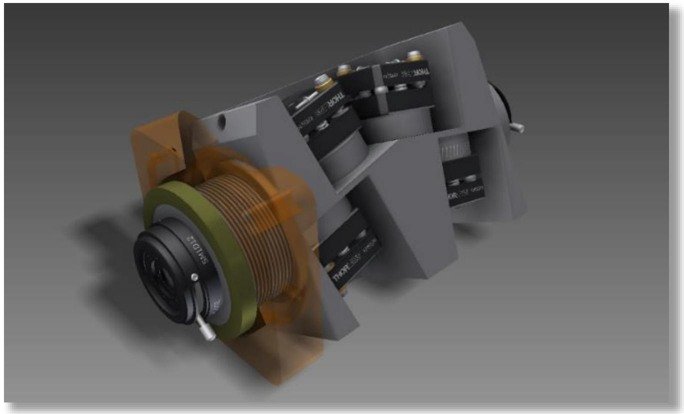


Time resolved coherent excitations
Attosecond resolution

Lightwave Spintronics – Attosecond dynamics

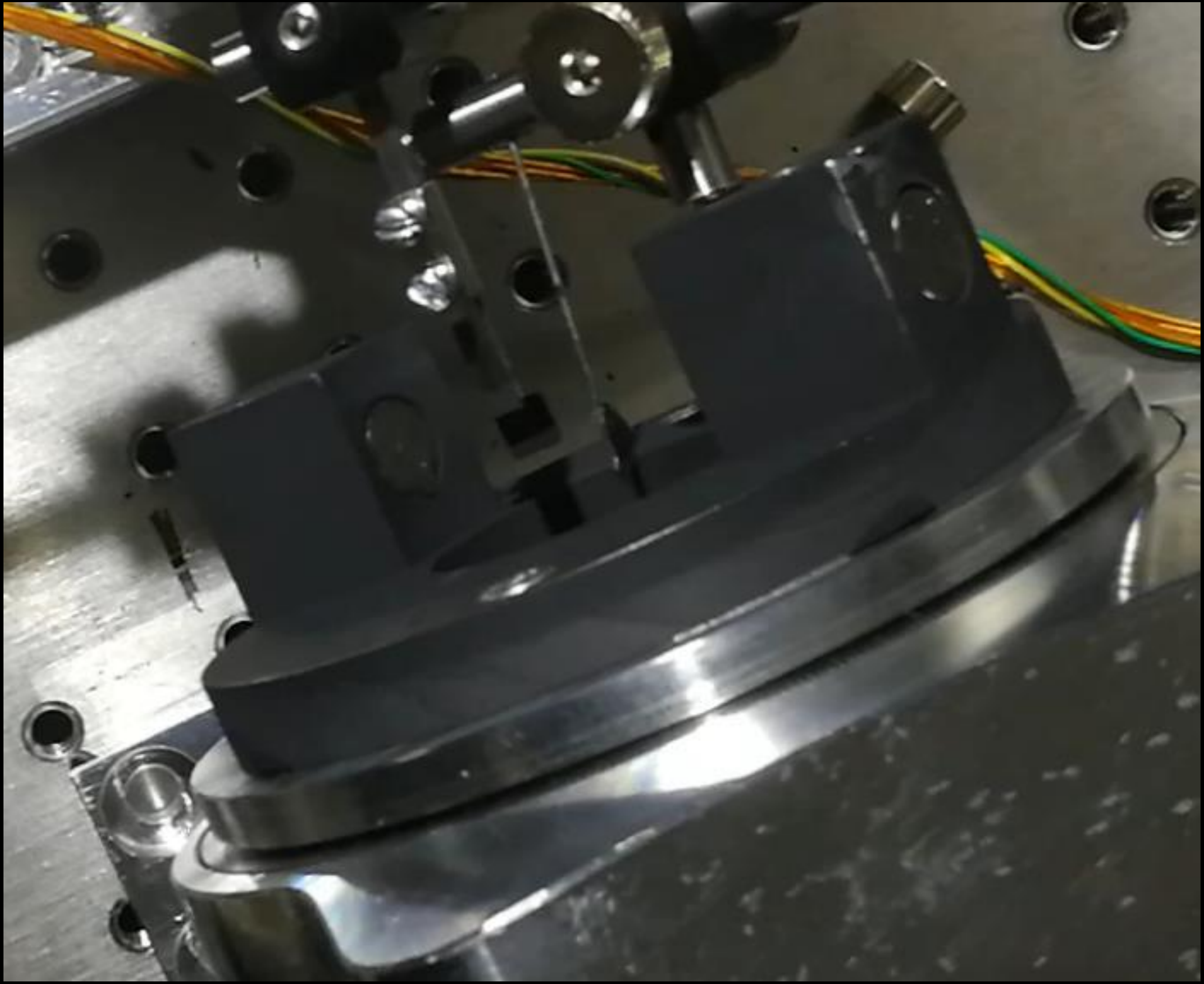
For ferromagnets we need attosecond x-ray dichroism:





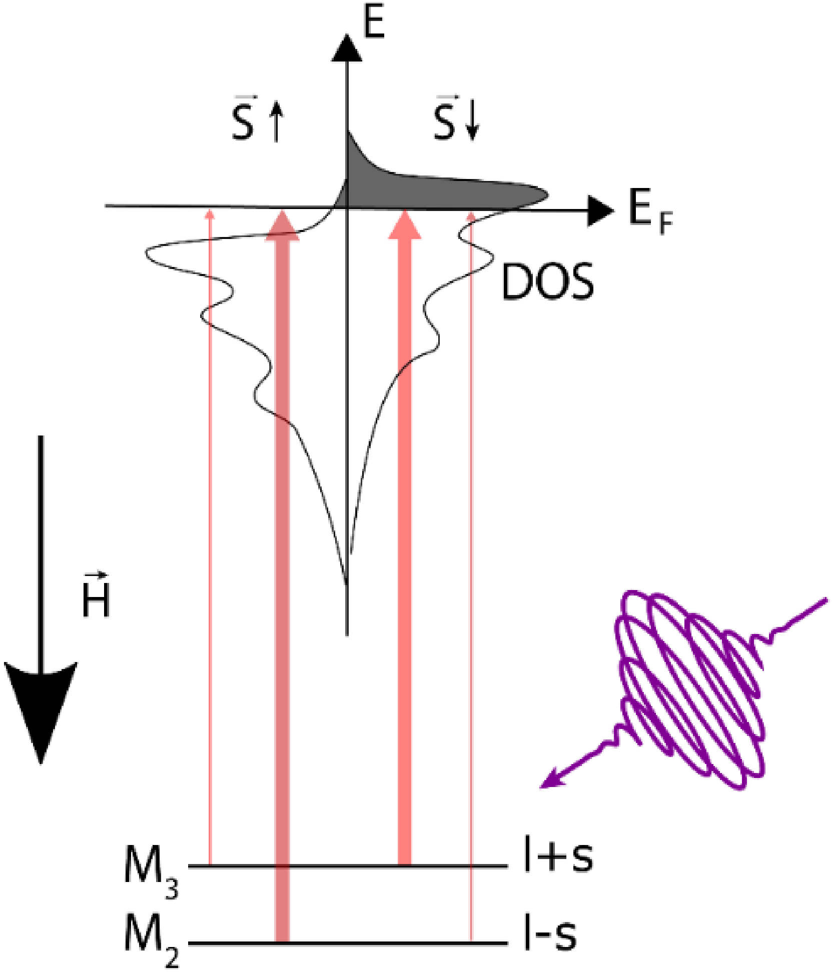
Mirror based Quarter Wave Plate (QWP)

Attoseconds:
Martin Schultze, TU Graz



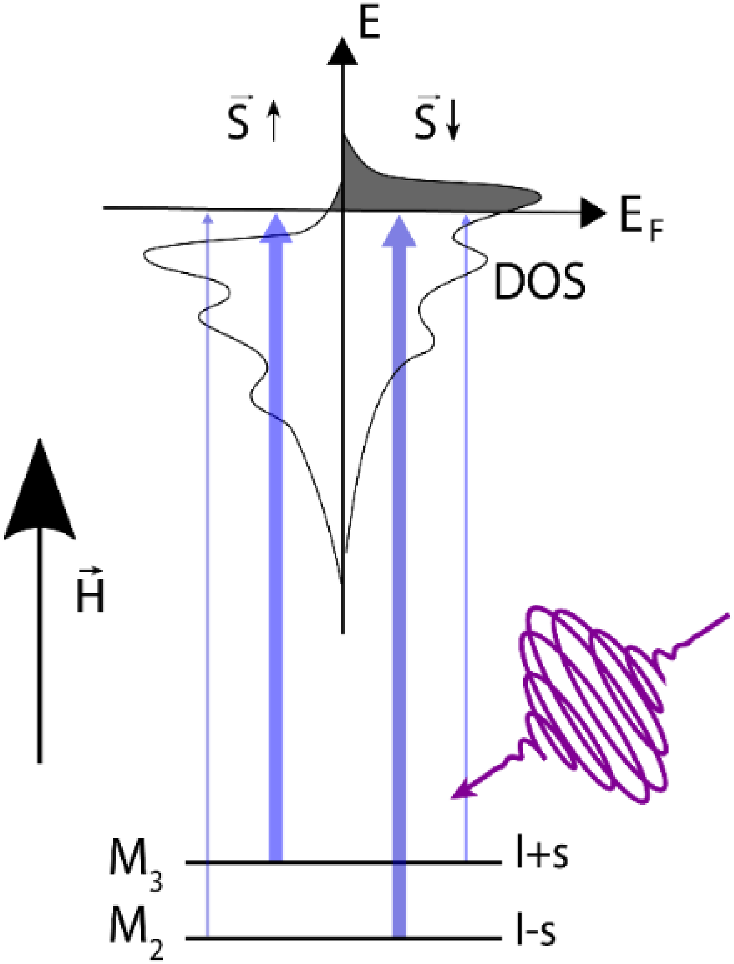
Lightwave Spintronics – Attosecond dynamics

Ni $M_{2,3}$ edge



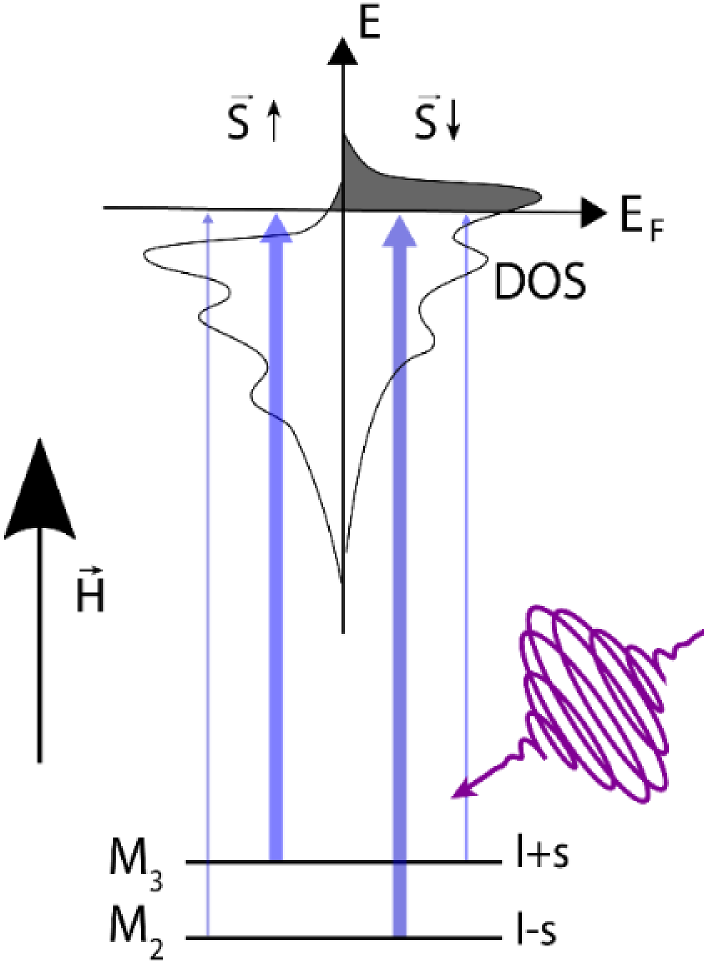
Lightwave Spintronics – Attosecond dynamics

Ni $M_{2,3}$ edge

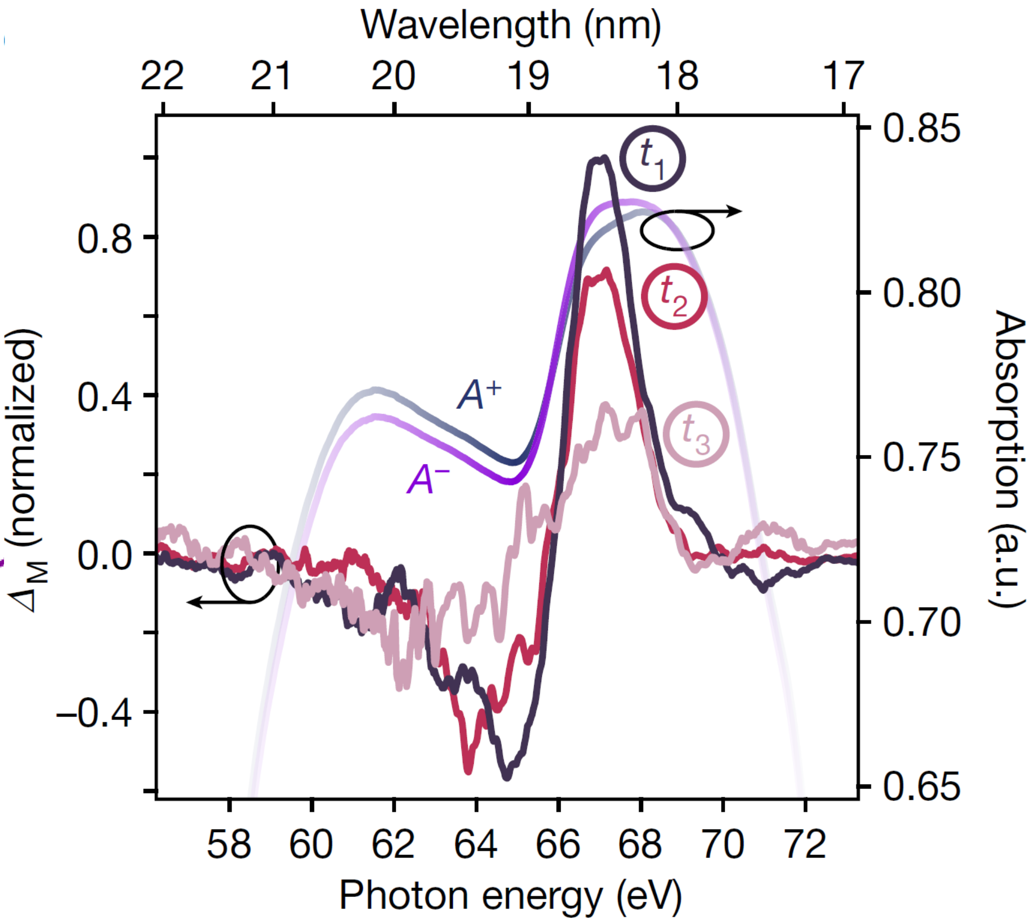


Lightwave Spintronics – Attosecond dynamics

Ni $M_{2,3}$ edge

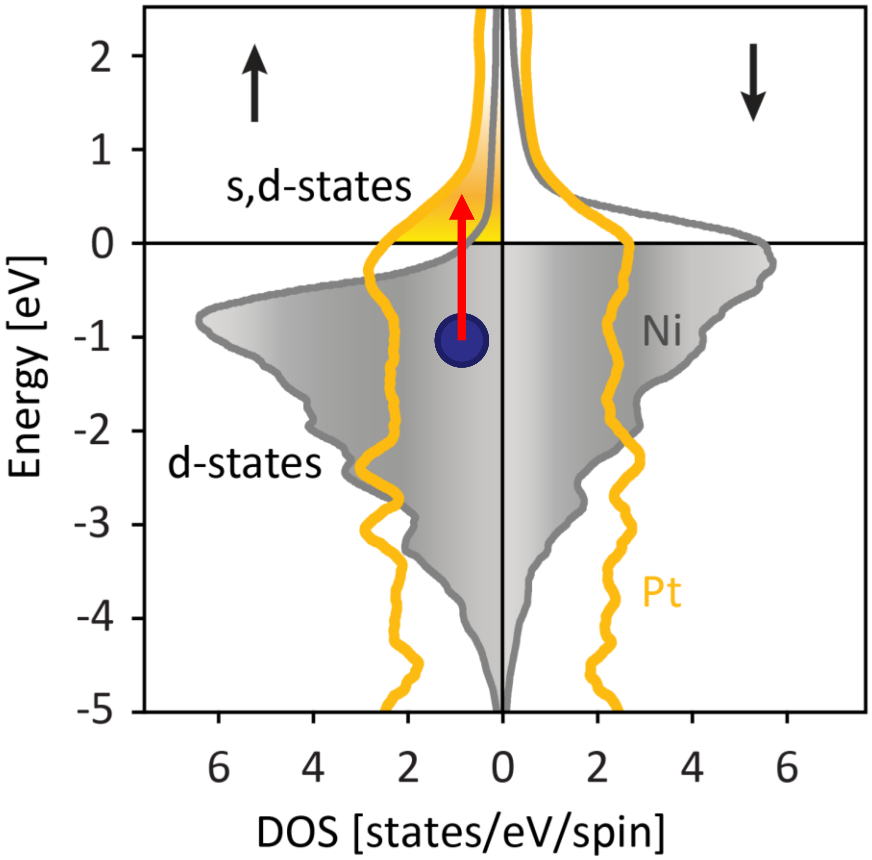


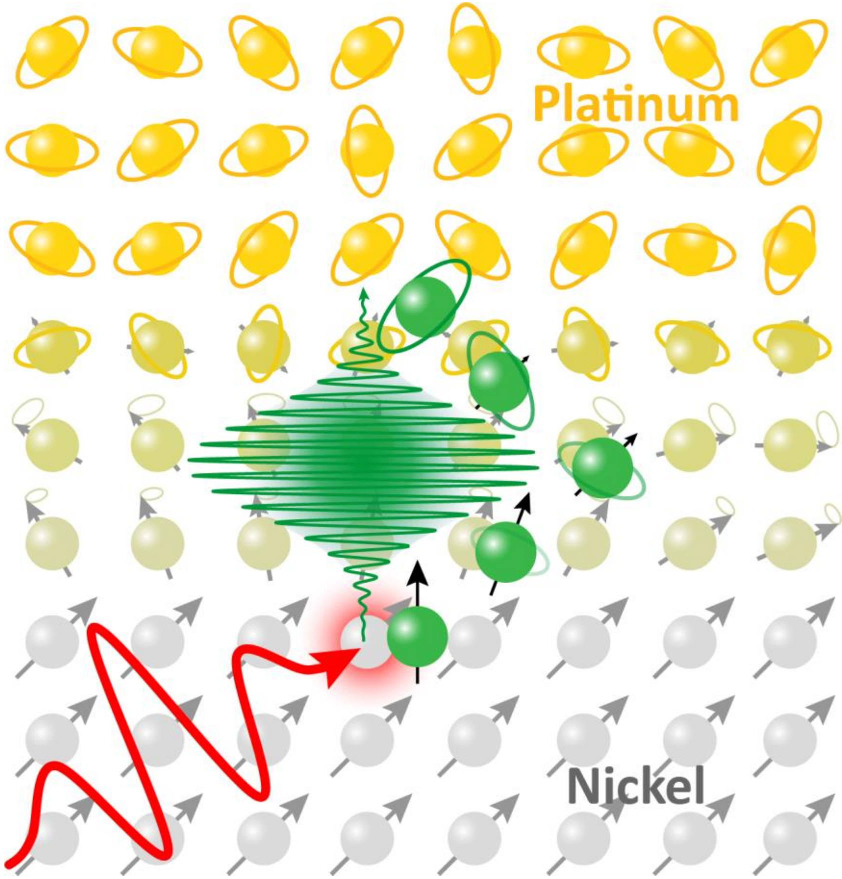
XMCD for different delay t_1, t_2, t_3



Lightwave Spintronics – Attosecond dynamics

Optically Induced Spin Transfer (OISTR):
coherent spin motion



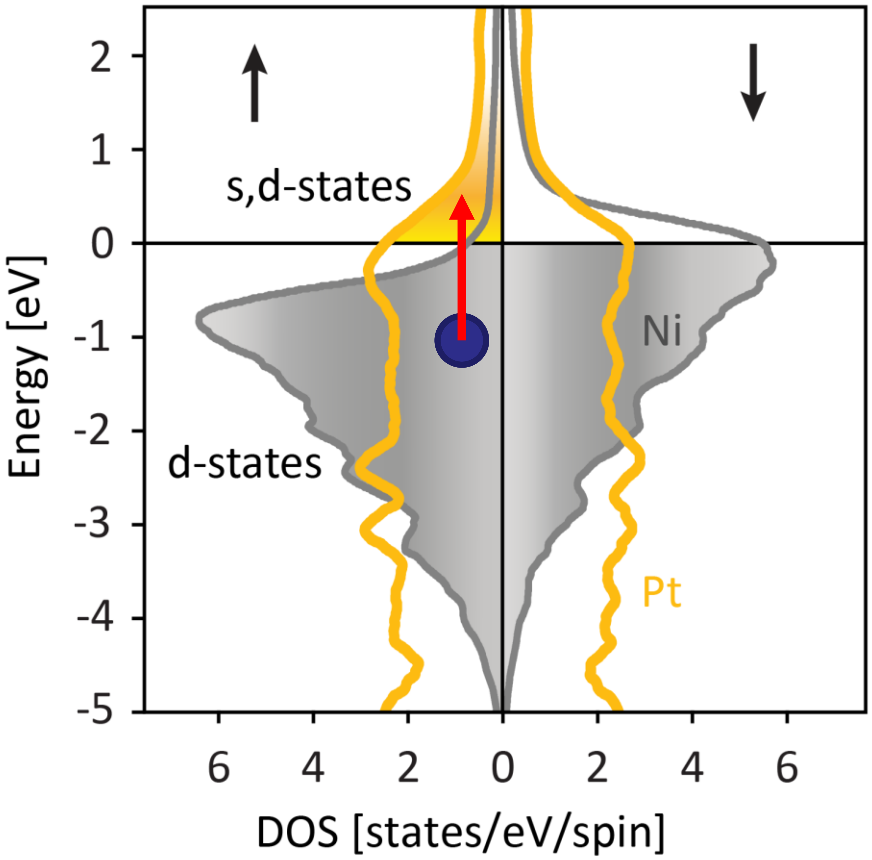


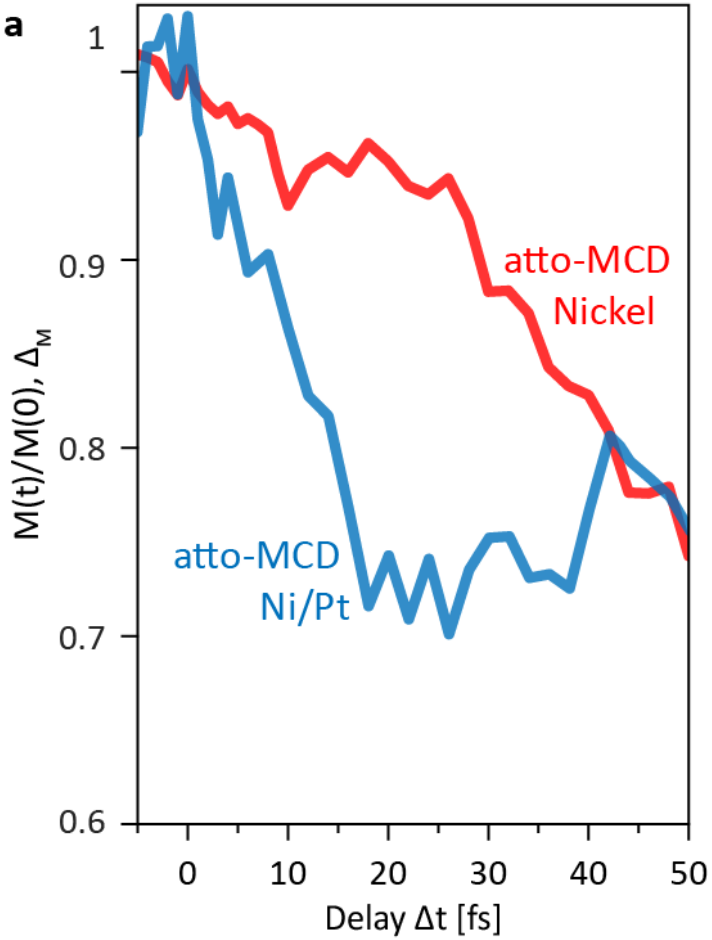
F. Siegrist *et al*., Light-wave dynamic control of magnetism,
Nature **571**, 240–244 (2019)

Lightwave Spintronics – Attosecond dynamics

Optically Induced Spin Transfer (OISTR):
prediced ab-initio by time resolved DFT

Ab-initio theory by trDFT:
Sangeeta Sharma MBI Berlin





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Nature **571**, 240–244 (2019)

Fluence NIR = 2 × 10^{12} W cm^{-2}

Lightwave Spintronics – Attosecond dynamics

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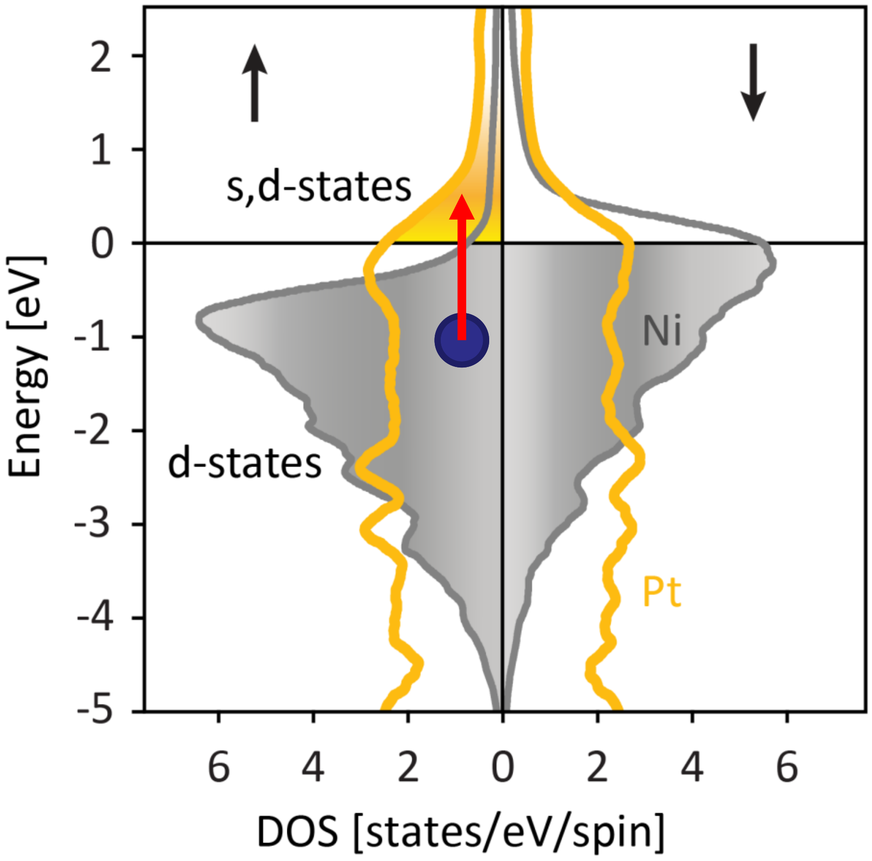

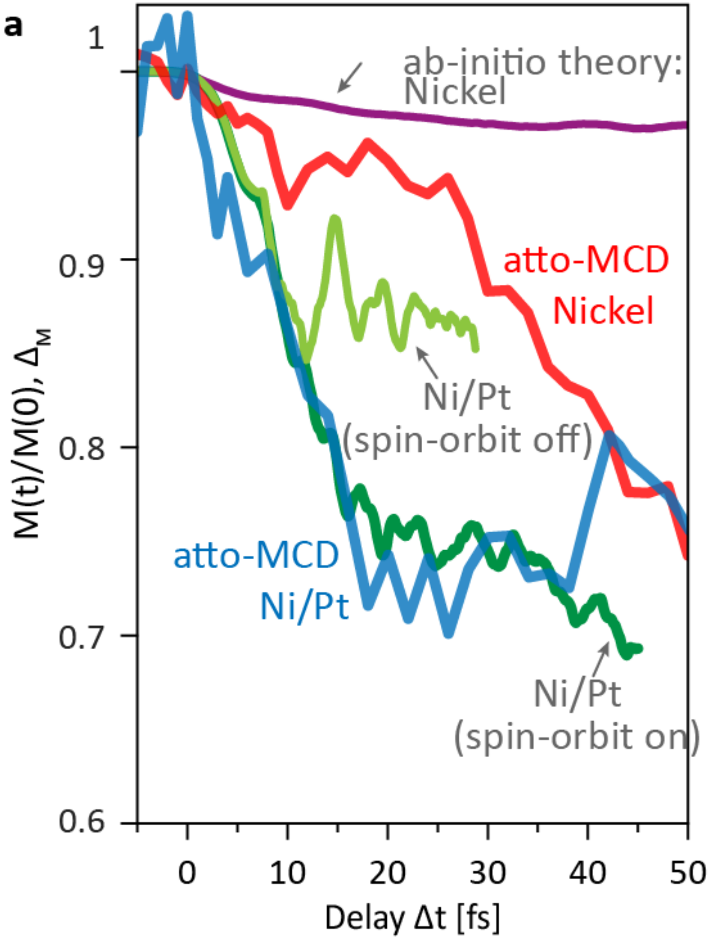

F. Siegrist *et al.*, Light-wave dynamic control of magnetism,
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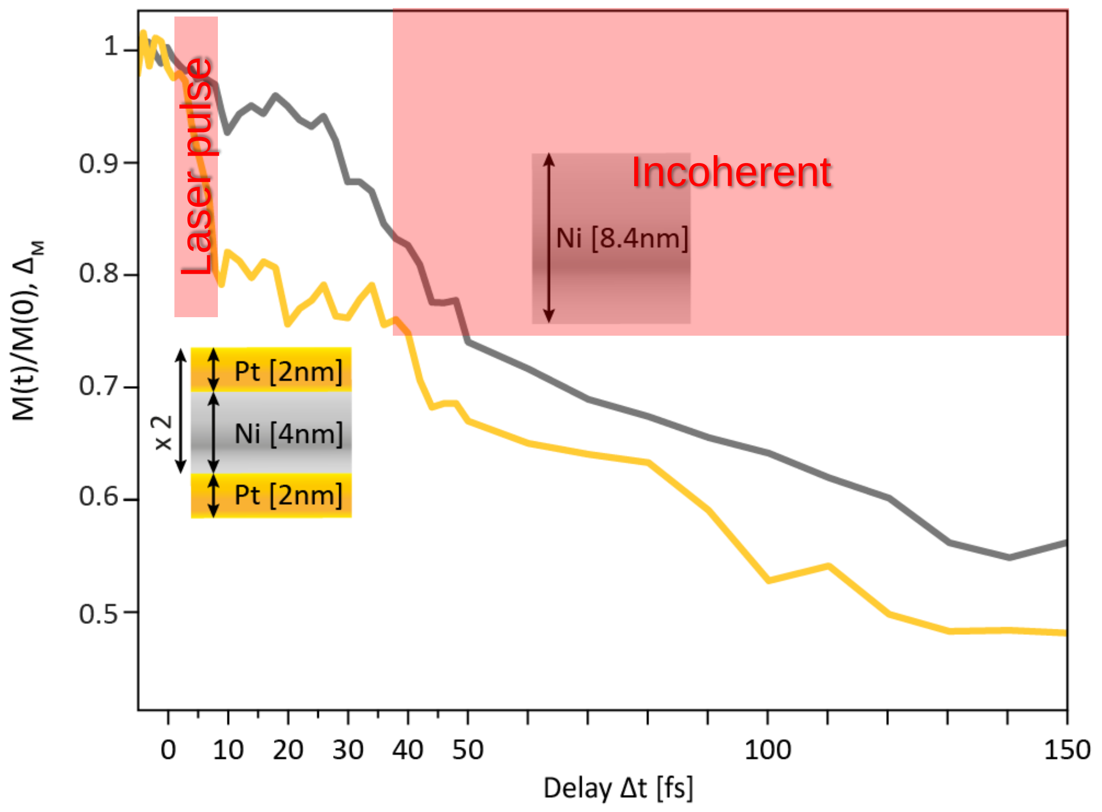
Fluence NIR = 2×10^{12} W cm^{-2}

TU Graz –

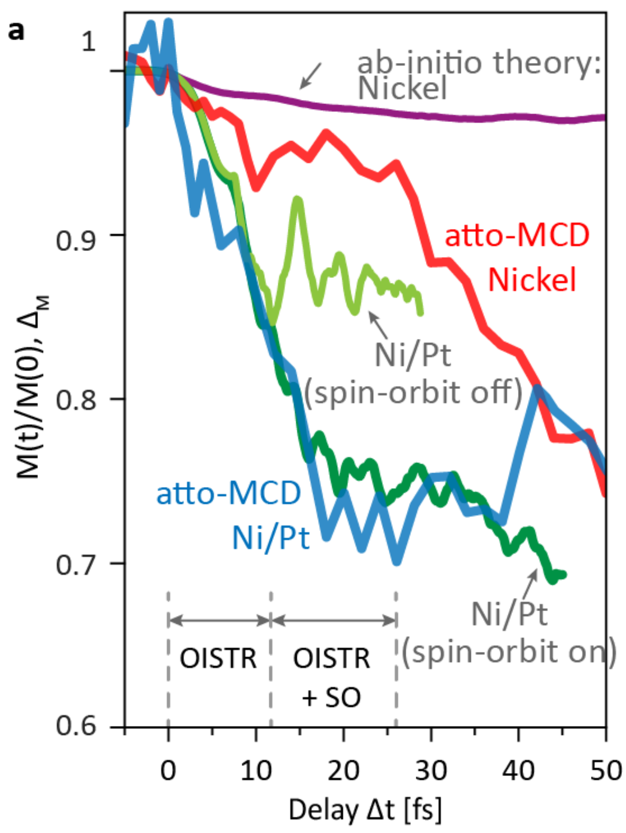
Lightwave Spintronics – Attosecond dynamics

Optically Induced Spin Transfer (OISTR): prediced ab-initio by time resolved DFT

Experiment



Theory

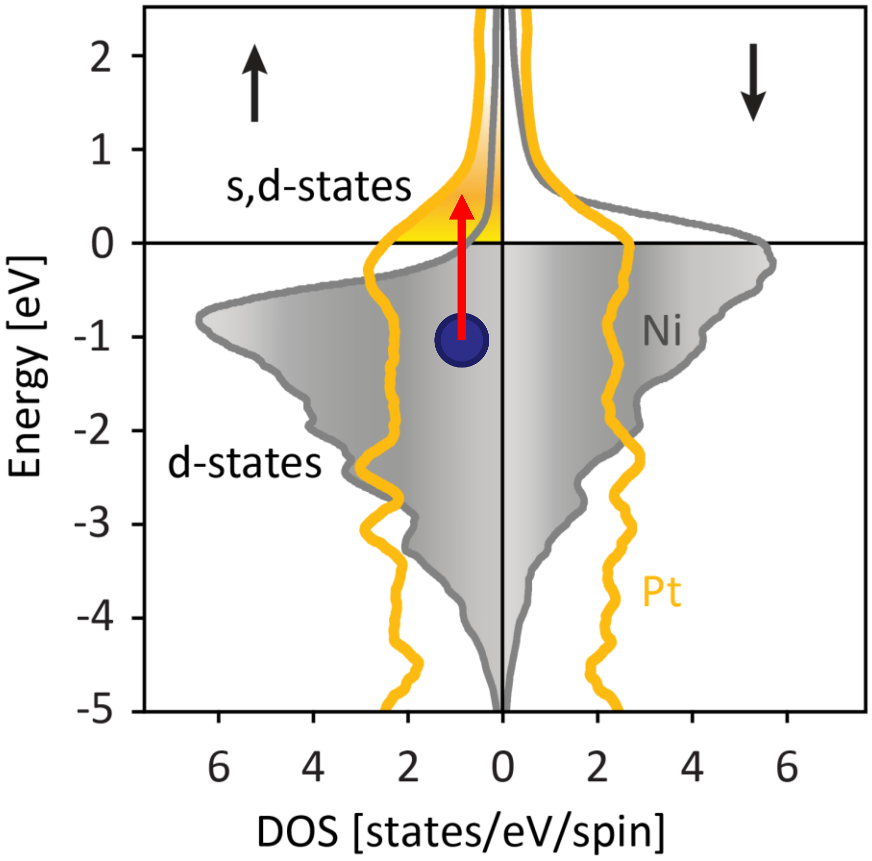


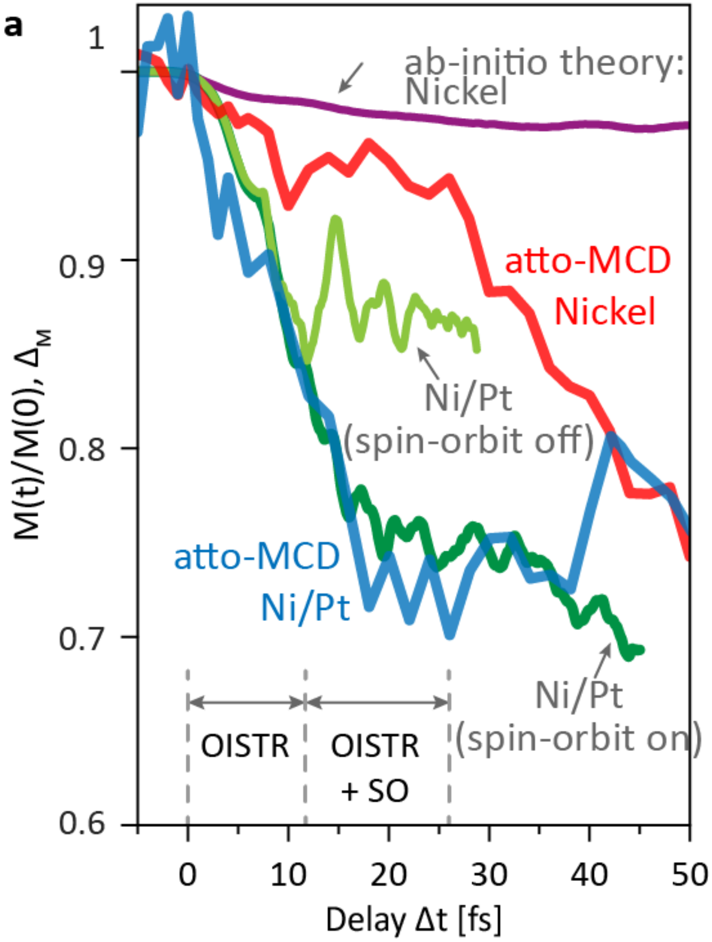
F. Siegrist *et al*., Light-wave dynamic control of magnetism, Nature **571**, 240–244 (2019)

Lightwave Spintronics – Attosecond dynamics

Optically Induced Spin Transfer (OISTR): prediced ab-initio by time resolved DFT

Ab-initio theory by trDFT:
Sangeeta Sharma MBI Berlin



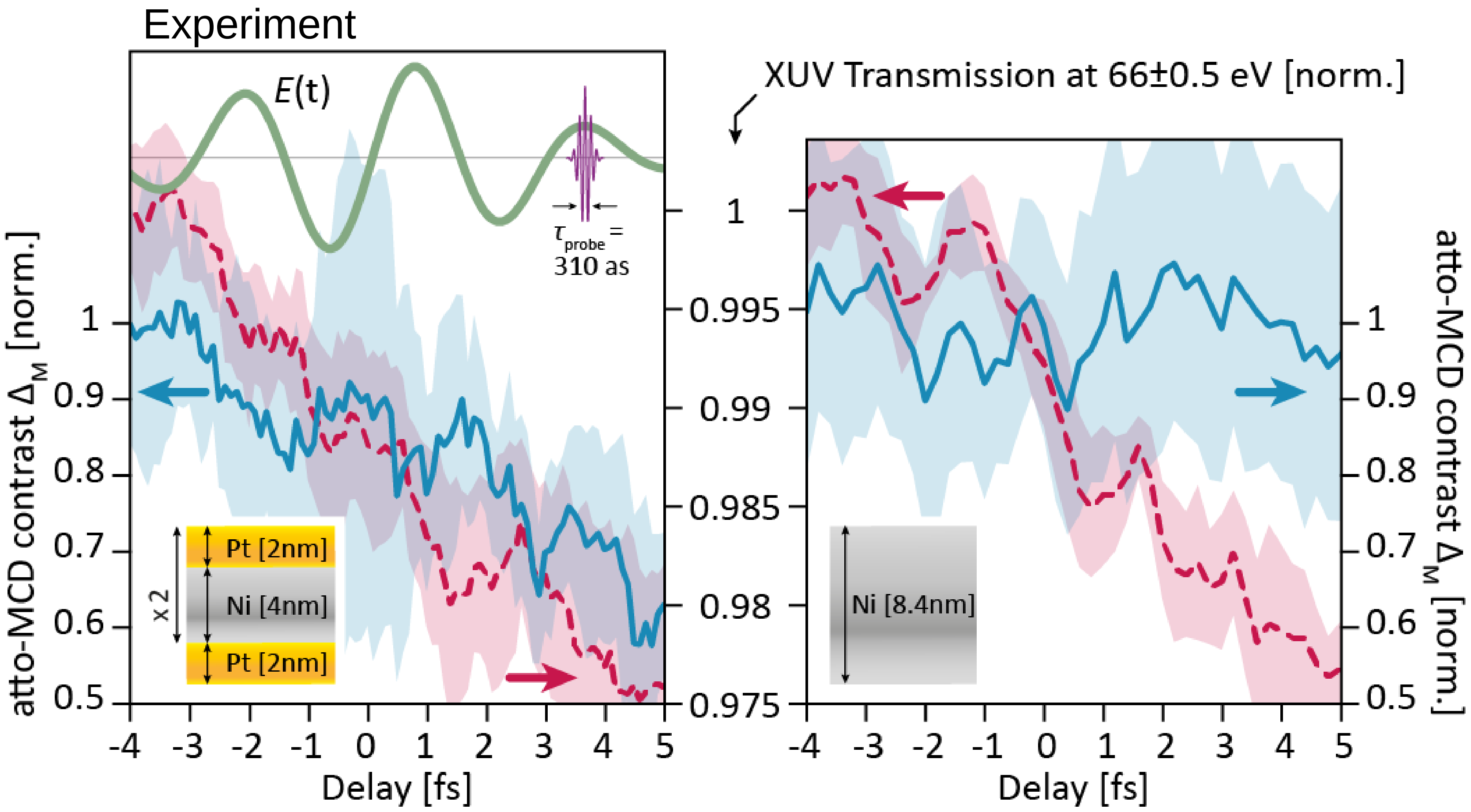


F. Siegrist *et al.*, Light-wave dynamic control of magnetism, Nature **571**, 240–244 (2019)

Fluence NIR = 2 × 10^{12} W cm^{-2}

Lightwave Spintronics – Attosecond dynamics

Few fs step like decay with Pt interface (resolution 310 as)



Fluence NIR = 4 × 10^{12} W cm^{-2}

F. Siegrist *et al.*, Light-wave dynamic control of magnetism,
Nature **571**, 240–244 (2019)

Collaborations

@spintronicsHGW

Attosecond spin dynamics:

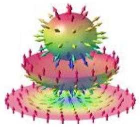
Florian Siegrist, Julia Gessner, Marcus Ossiander, Martin Schultze, Technical University Graz/ Max-Planck-Institute für Quantum Optics, Munich

J. Dewhurst, Sangeeta Sharma, Max-Born-Institute, Berlin, Max-Planck-Institut for Microstructure Physics, Halle

Deutsche Forschungsgemeinschaft
DFG

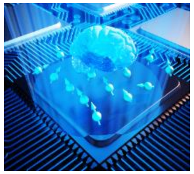
SPP 1666

Priority program Topologische Isolatoren



Priority program Skyrmionics

HORIZON 2020



FET Open SpinAge

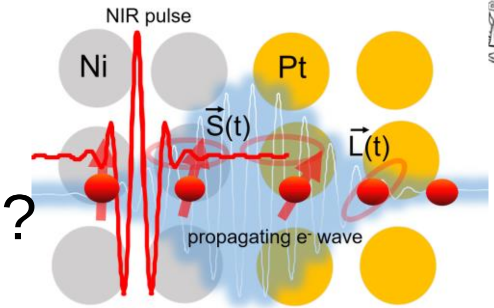
ZENTREN FÜR INNOVATIONSKOMPETENZ
UNTERNEHMEN REGION
Die BMBF-Innovationsinitiative Neue Länder

Bundesministerium für Bildung und Forschung

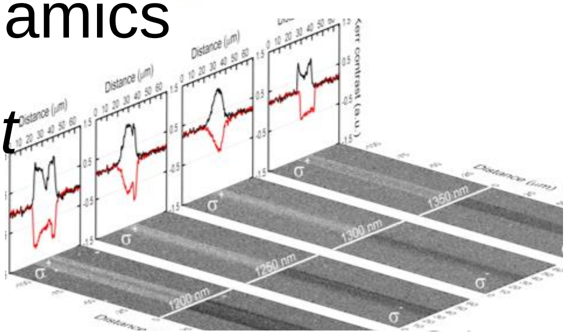
META ZIK PlasMark

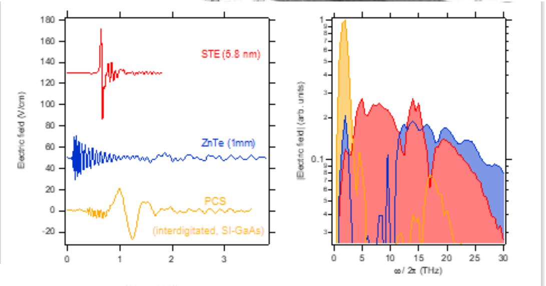
DAAD

Outline

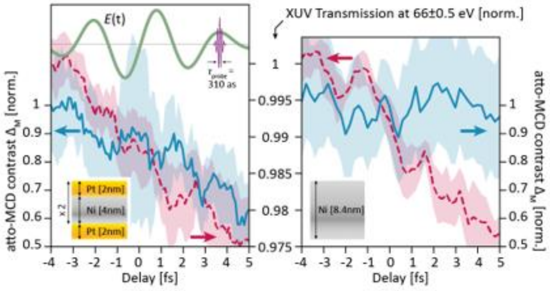


- A coherent attosecond spintronics?
- The nature of femtosecond spin dynamics
- THz spintronic emitter - *noncoherent*
- Lightwave electronics - *coherent*
- Summary





T. Seifert, et al. Nature Photonics (2016)



F. Siegrist *et al.*, Light-wave dynamic control of magnetism, Nature **571**, 240–244 (2019)

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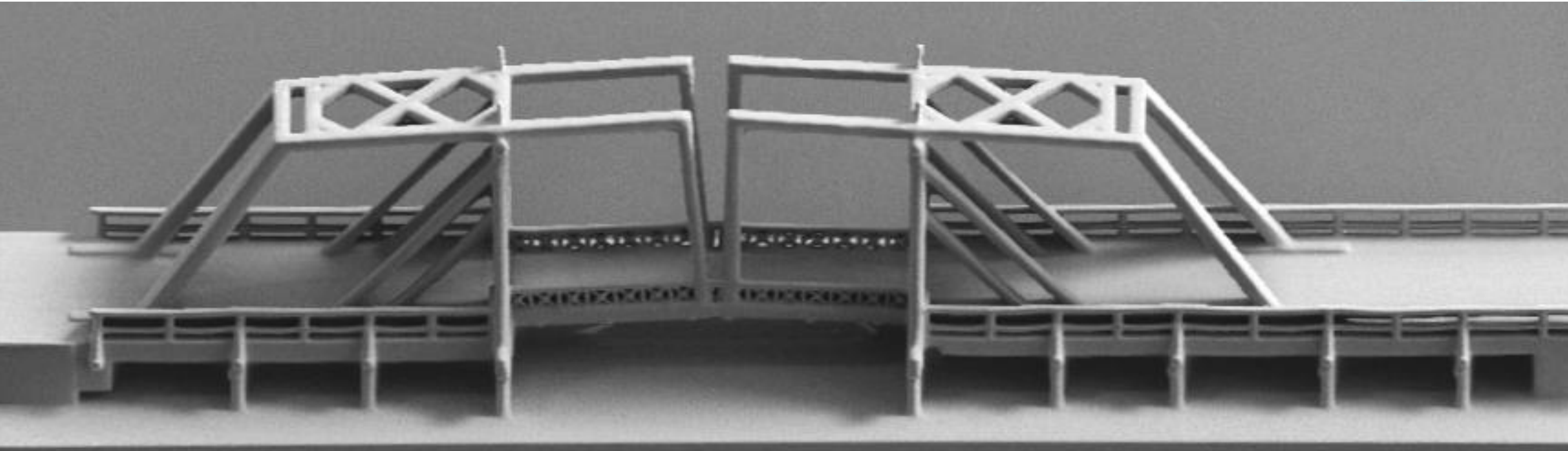
Das Beste am Norden

UNIVERSITÄT GREIFSWALD
Wissen lockt. Seit 1456



See NDR feature on our new labs: Nordmagazin or http://www.physik.uni-greifswald.de/aktuelles.html @spintronicsHGW