Towards coherent control of quantum materials

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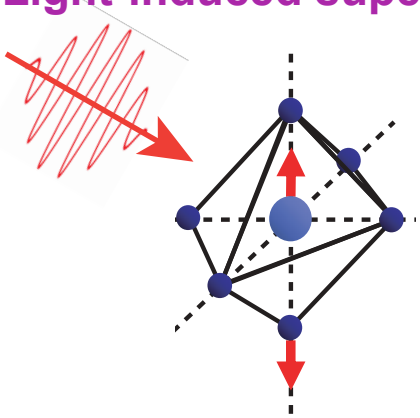
Olof Karis, Patrik Thurström, Oscar Grånäs, Olle Eriksson UU
Martin Beye DESY
Johan Mentink Radboud University

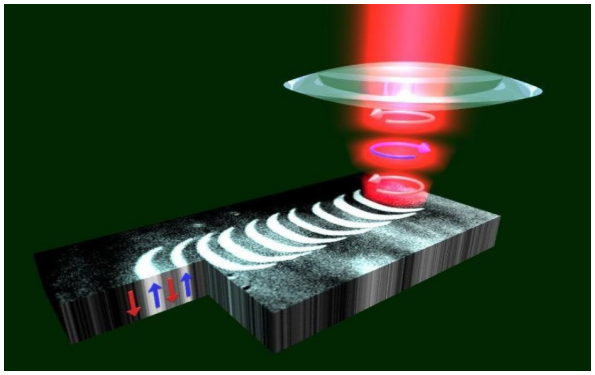
Photonic control of materials' functionality

Light-induced superconductivity

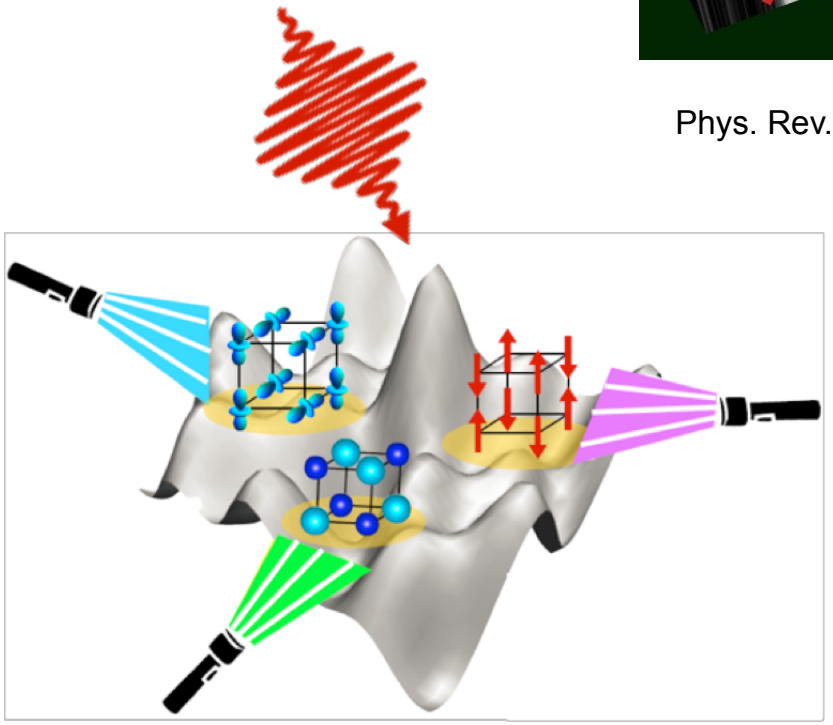


Fausti, et al.
Science **331**, 189 (2011)

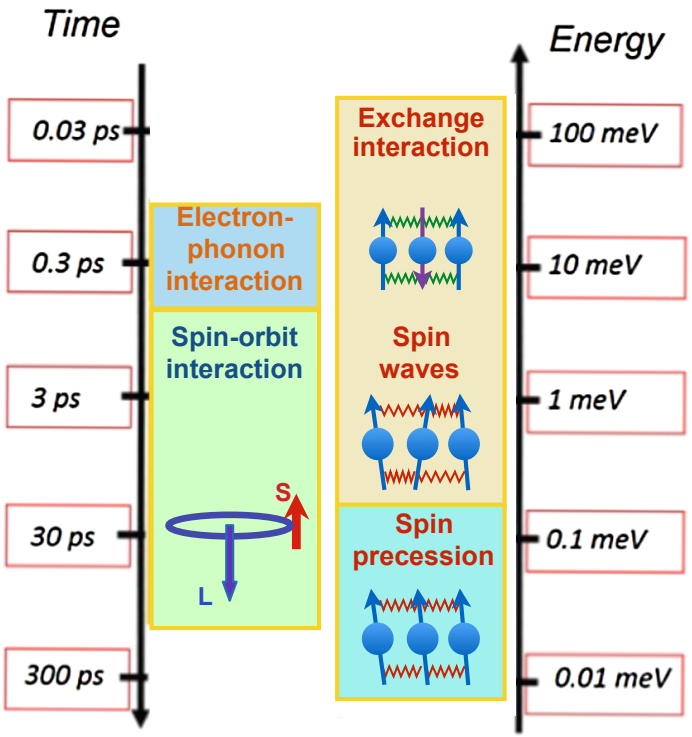
Magnetic switching with light



Stanciu, et al
Phys. Rev. Lett. **99**, 047601 (2007)

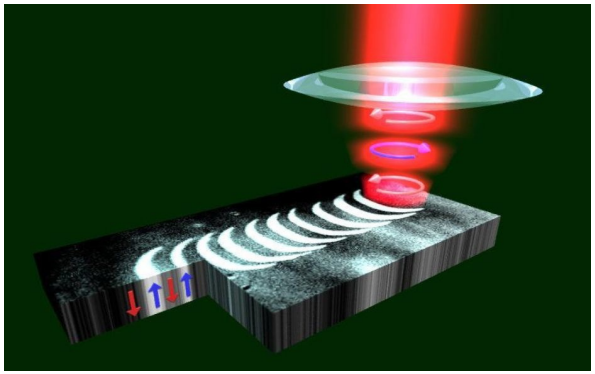


Can we modify electronic interactions?

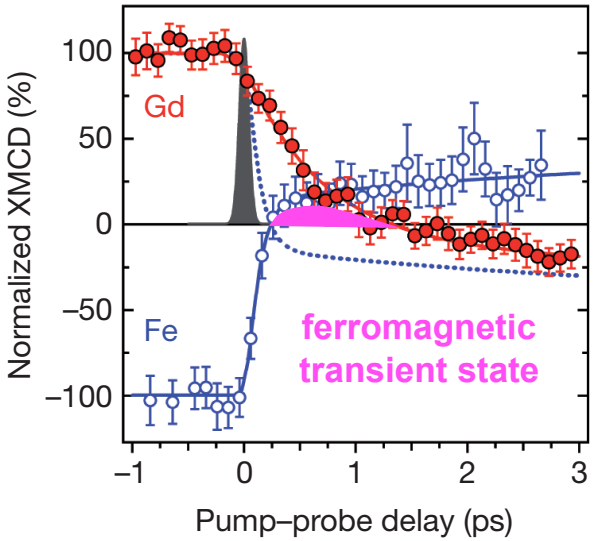


Hellman, et al., Rev. Mod. Phys. **89**, 025006 (2017)

Magnetic switching with light

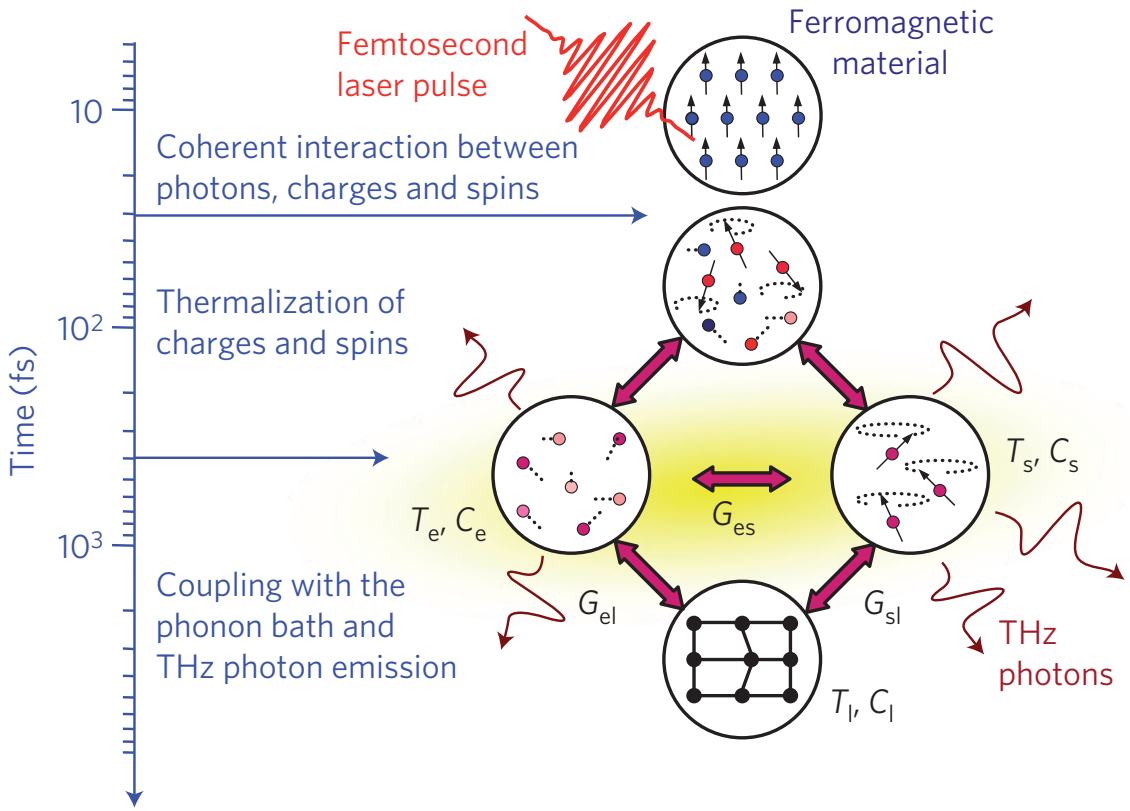


Stanciu, et al
Phys. Rev. Lett. **99**, 047601 (2007)



I. Radu, et al., Nature **472**, 205 (2011)

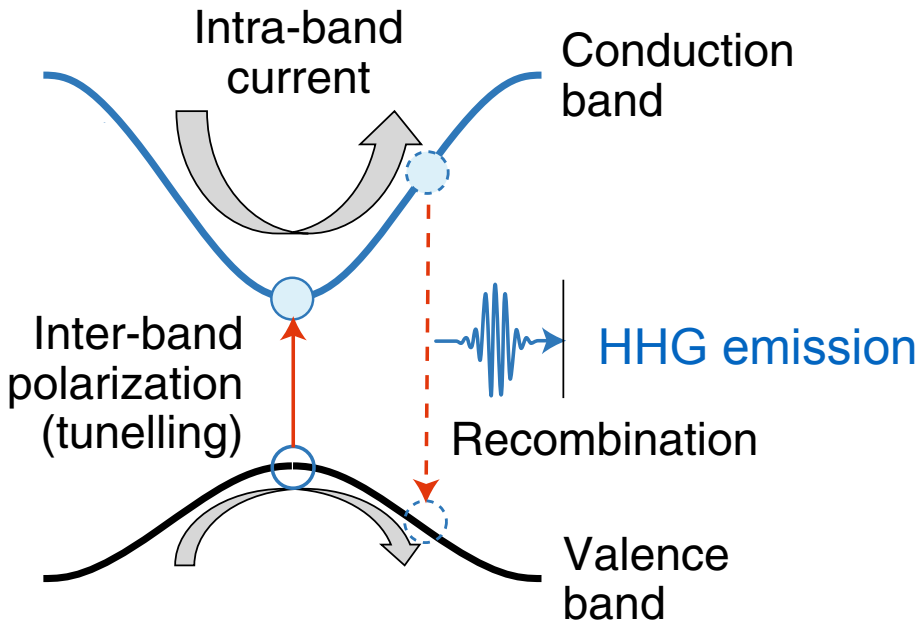
Can we coherently control electronic interactions?



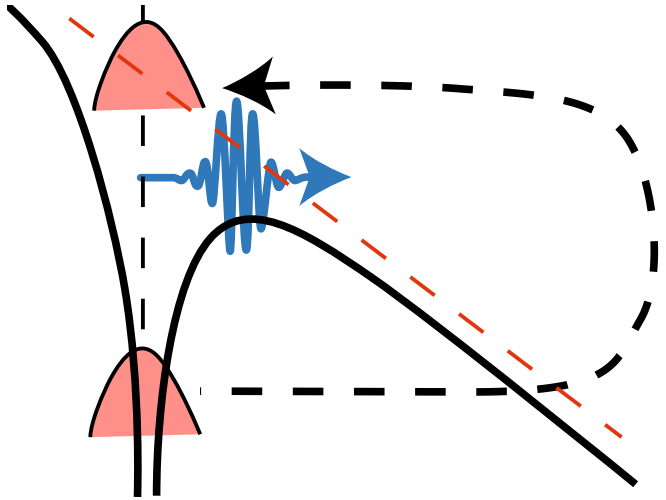
Bigot, Vomir, Beaurepaire,
Nature Physics **5**, 515 (2009)

Can we coherently control electronic interactions?

High-harmonic generation in solids



momentum space

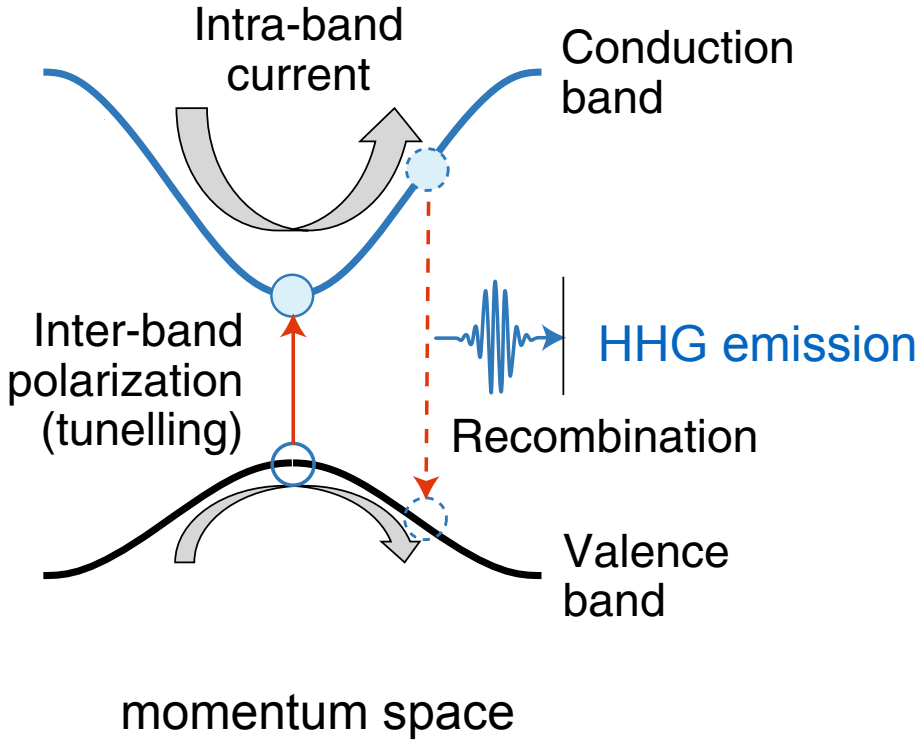


real space

Ghimire, Reis, Nature Physics **15**, 10 (2019)

Can we coherently control electronic interactions?

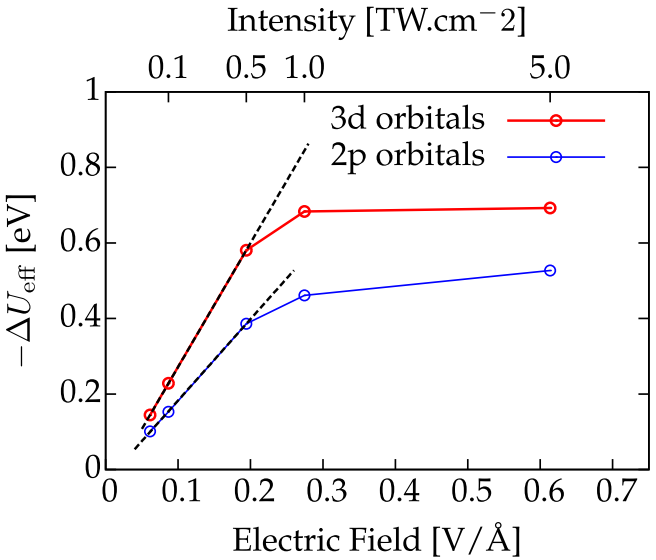
High-harmonic generation in solids



Ghimire, Reis, Nature Physics **15**, 10 (2019)

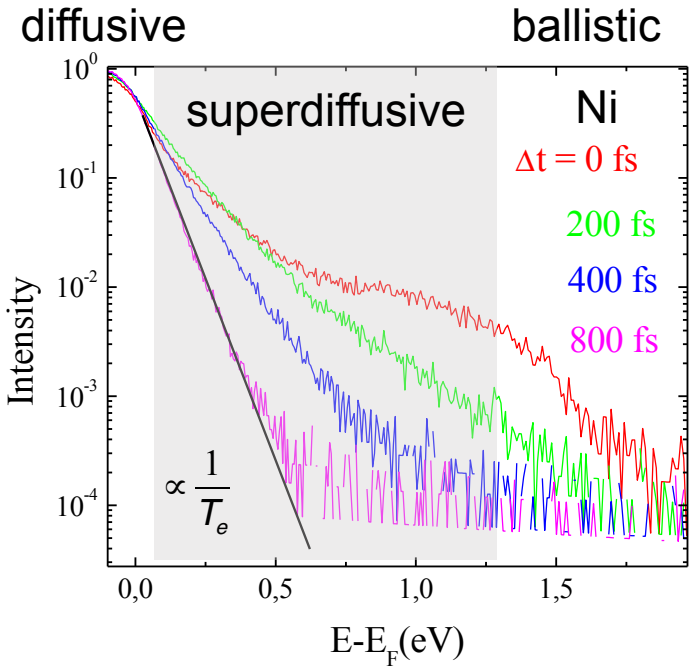
Field-induced manipulation of electron correlations in NiO

Calculated for 40 fs laser pulse @ hv = 0.43 eV

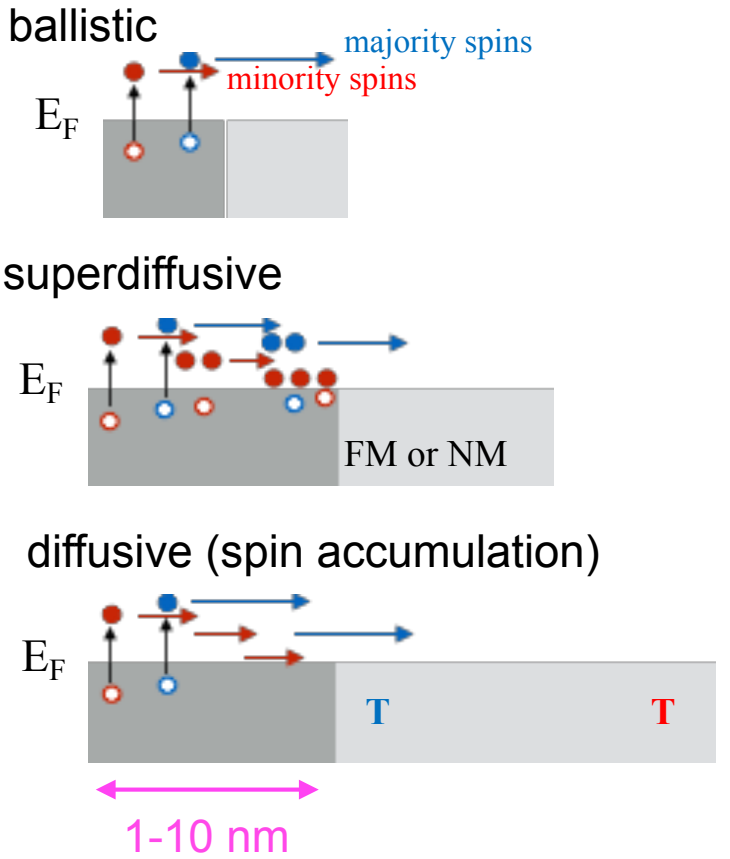


N. Tancogne-Dejean, M. A. Sentef, A. Rubio,
Phys. Rev. Lett. **121**, 097402 (2018)

What inhibits/promotes coherent excitation?



Rhie, Durr, Eberhardt,
Phys. Rev. Lett. **90**, 247201 (2003)



Hellman, et al., Rev. Mod. Phys. **89**, 025006 (2017)

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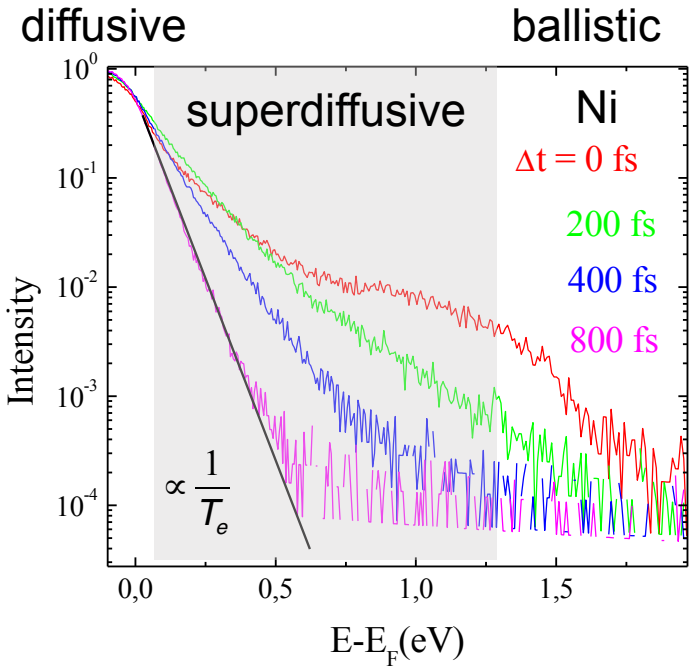
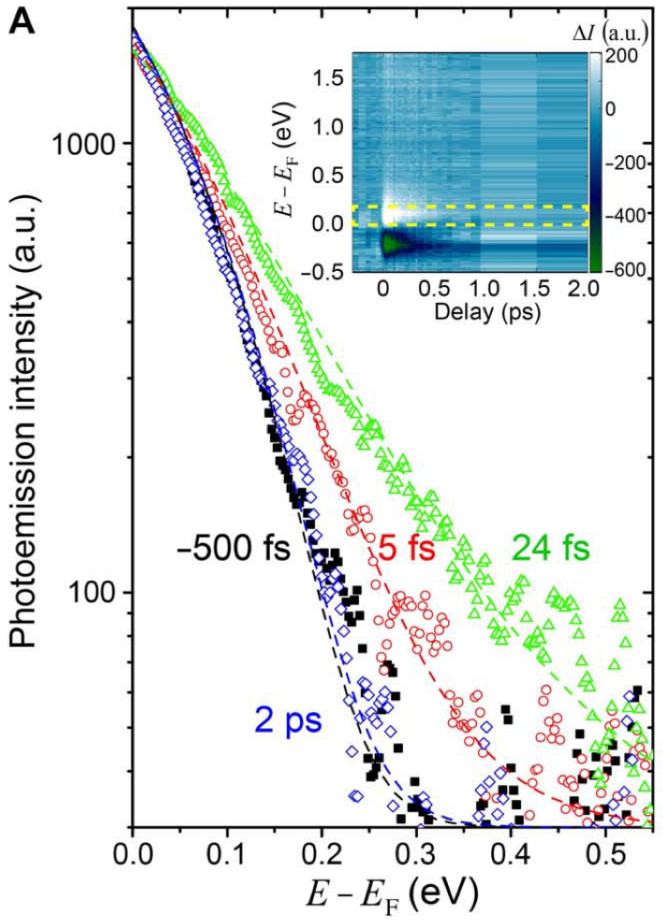


Rhie, Durr, Eberhardt,
Phys. Rev. Lett. **90**, 247201 (2003)

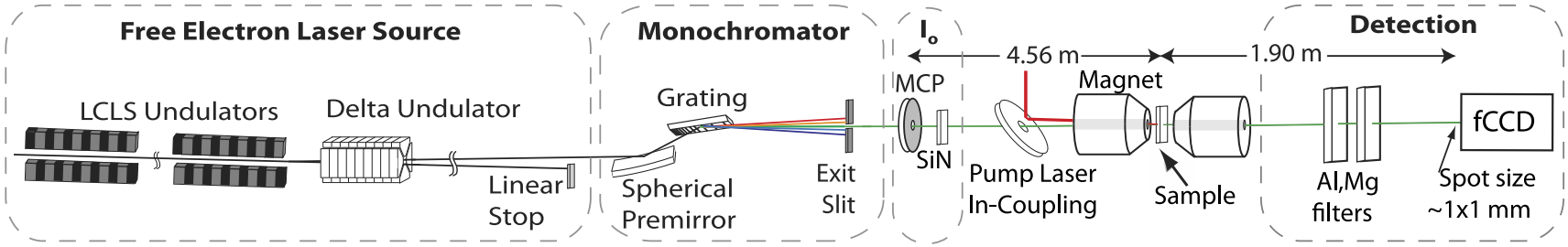
Electronic scattering is fast

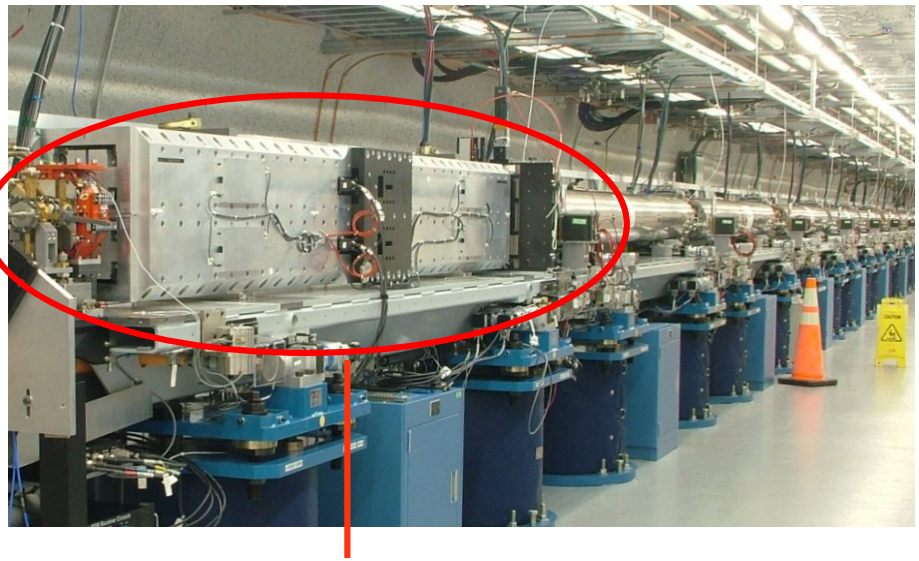


Tengdin, et al., Sci. Adv. **4**, 9744 (2018)

Short pulses are required to achieve coherence

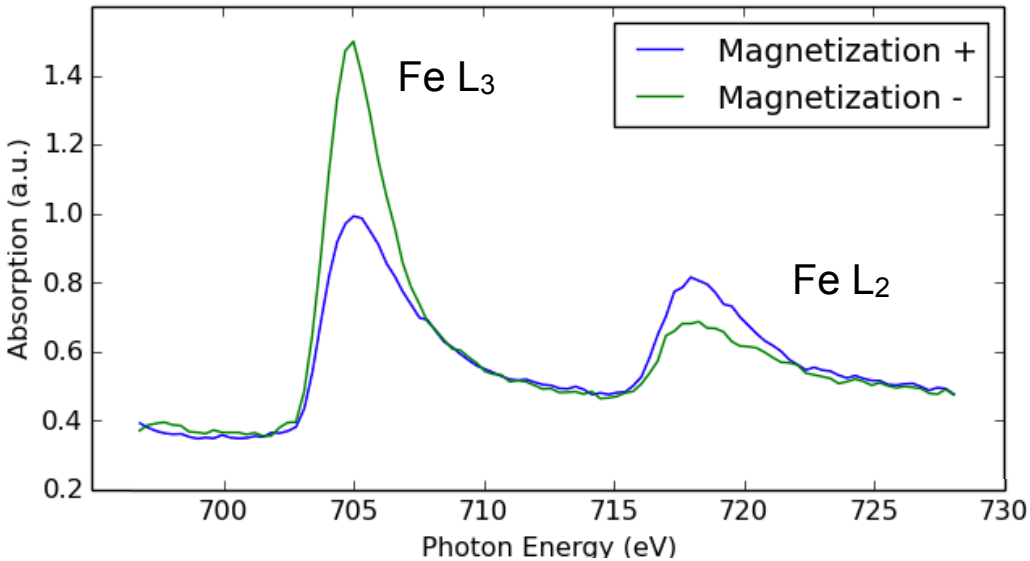
The conventional way to study magnetization dynamics





new 3.2m “Delta” undulator

Lutman, et al. Nature Photonics **10**, 468 (2016)

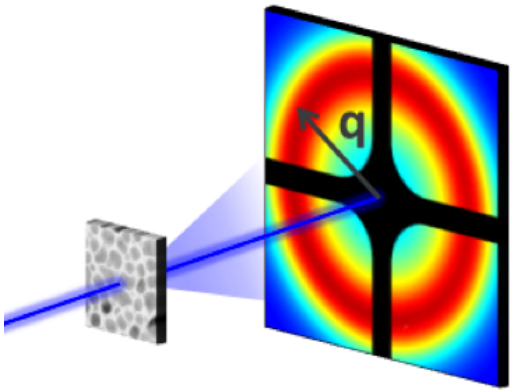


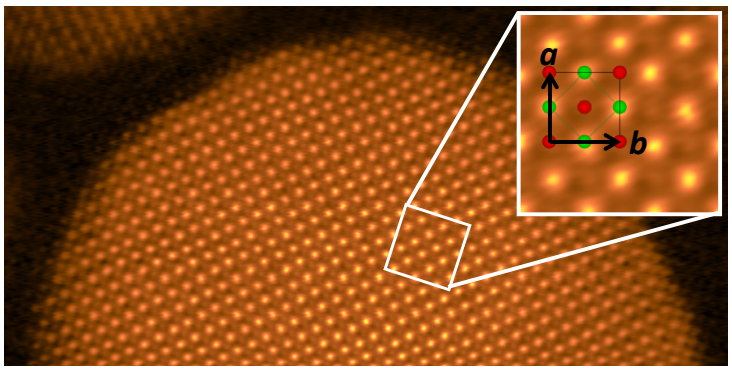
Higley, et al. Rev. Sci. Instrum. **87**, 033110 (2016)

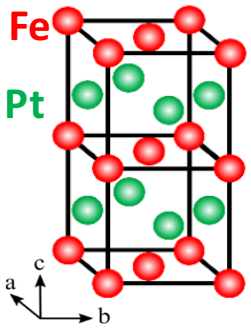
Preserving high (attosecond) time resolution requires broadband pulses and energy analysis after the sample

Why x-rays from XFELs?
It enables femtosecond nanomagnetism

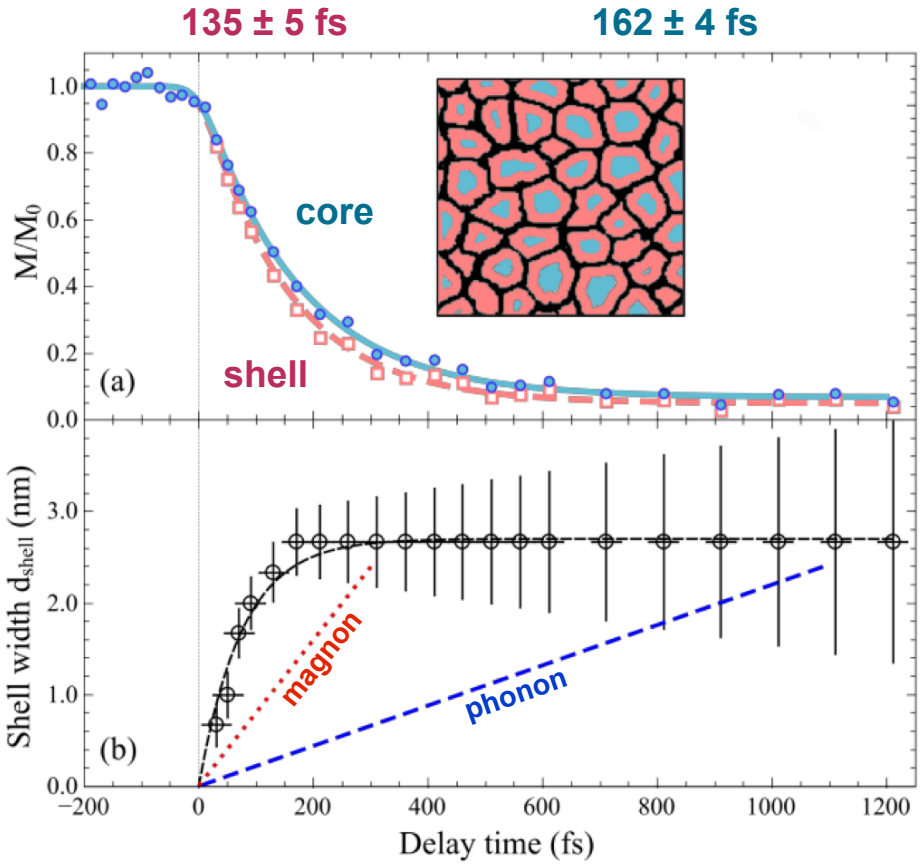
Separate scattering from FePt core & shell







Reid, et al., Nature Commun. **9**, 388 (2018)

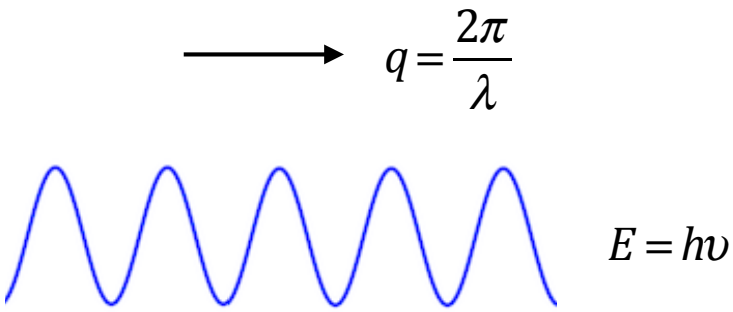


shell width increases at electronic speed

Granitzka, et al. (unpublished); arXiv: 1903.08287

Why x-rays from XFELs?
It enables detection of non-equilibrium quasiparticle dynamics

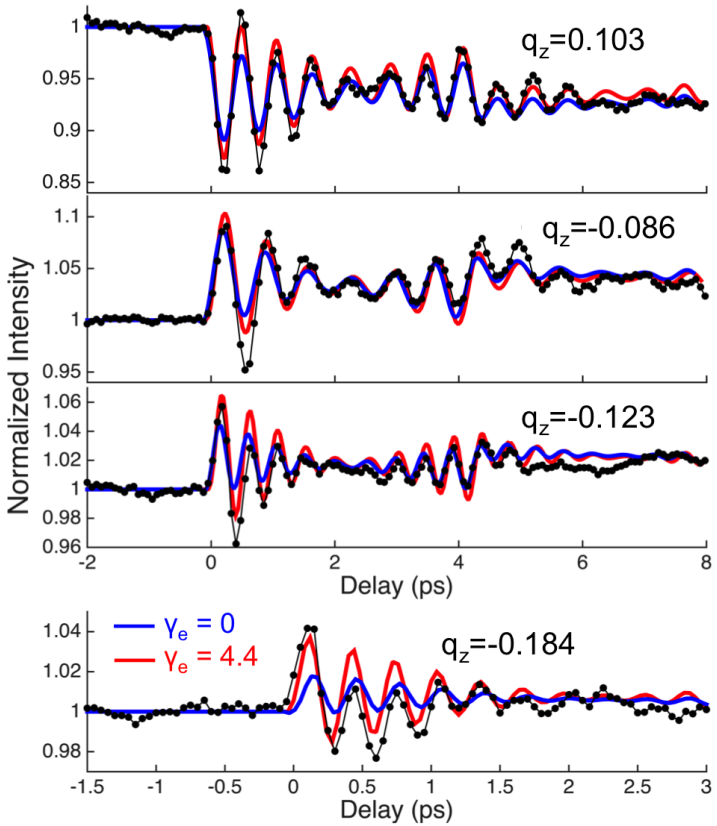
phonons **spin-waves**

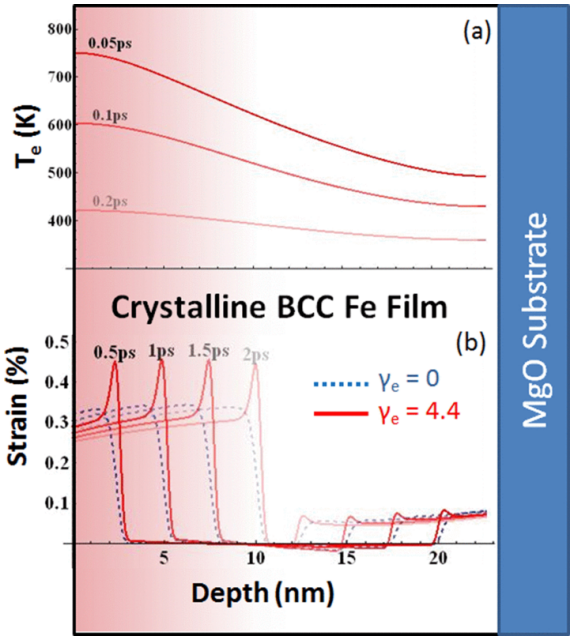


quasi-elastic scattering in the time domain

Coherent phonons in Fe/MgO(001)

Probe temporal evolution of diffuse scatter near [011] Bragg peak



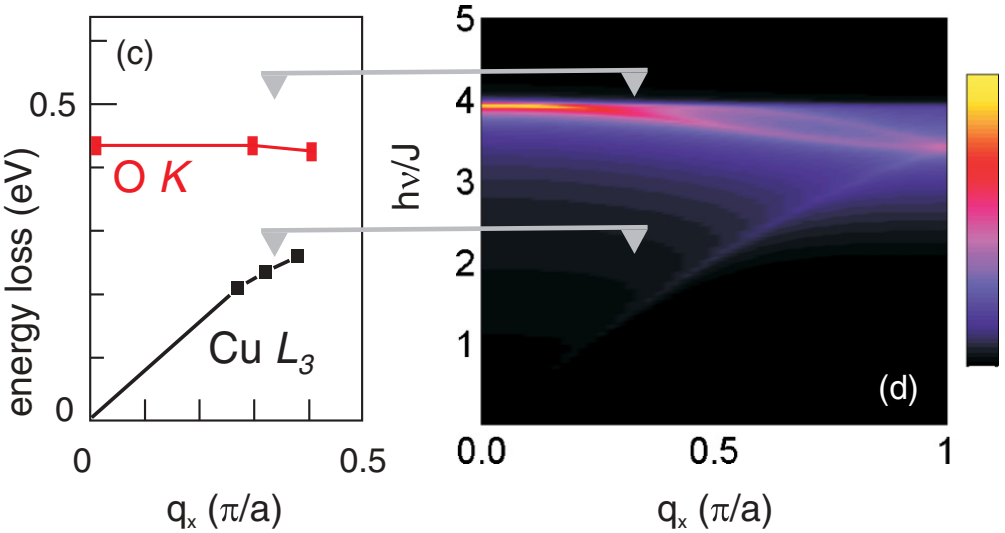


We need to include non-equilibrium electronic stress

Henighan, et al. Phys. Rev. B **93**, 220301(R) (2016)

Coherent spin waves in antiferromagnets

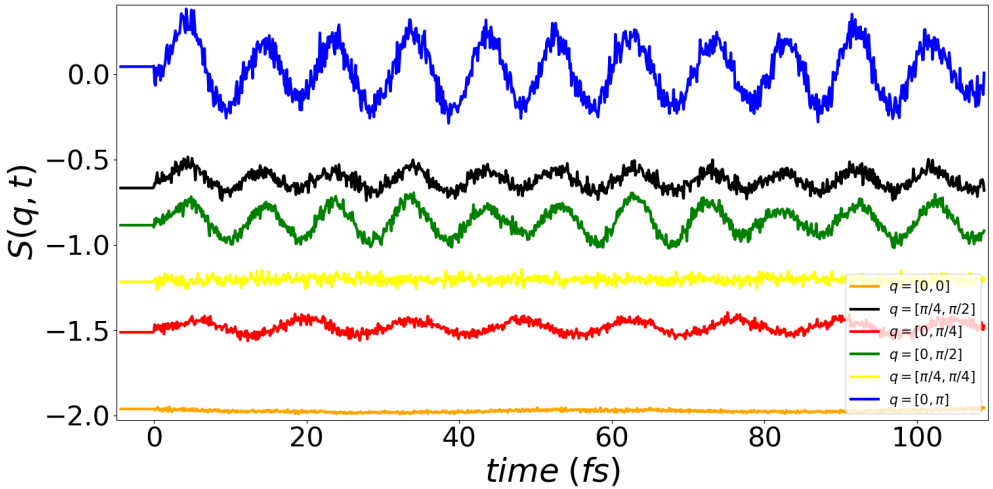
Bimagnons in $LaCuO_4$ seen with RIXS

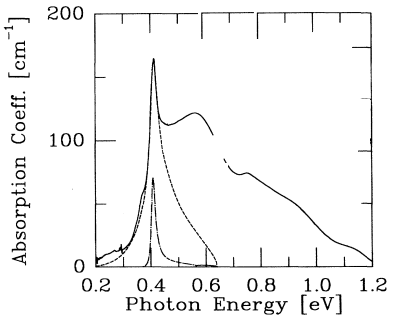


Bisogni, et al. Phys. Rev. B **85**, 214527 (2012)

... and in the time domain

Fabiani, Mentink (unpublished); arXiv:1903.08482

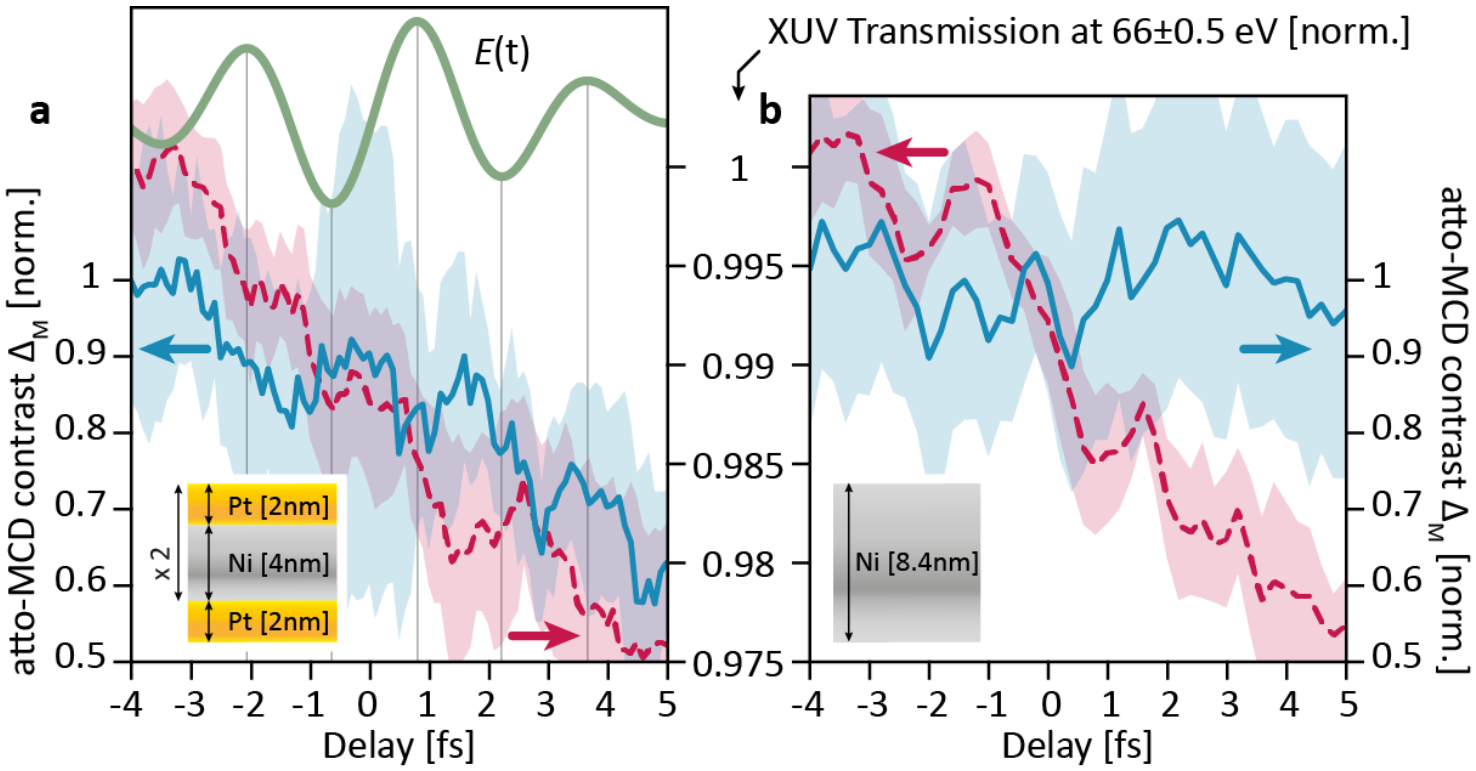




J. Lorenzana, G. A. Sawatzky,
Phys. Rev. Lett. **74**, 1876 (1995).

Field-driven ‘Petaherz Spintronics’ in Ni films

Ultrafast intersite spin transfer processes could provide a universal mechanism for coherent spin wave excitation

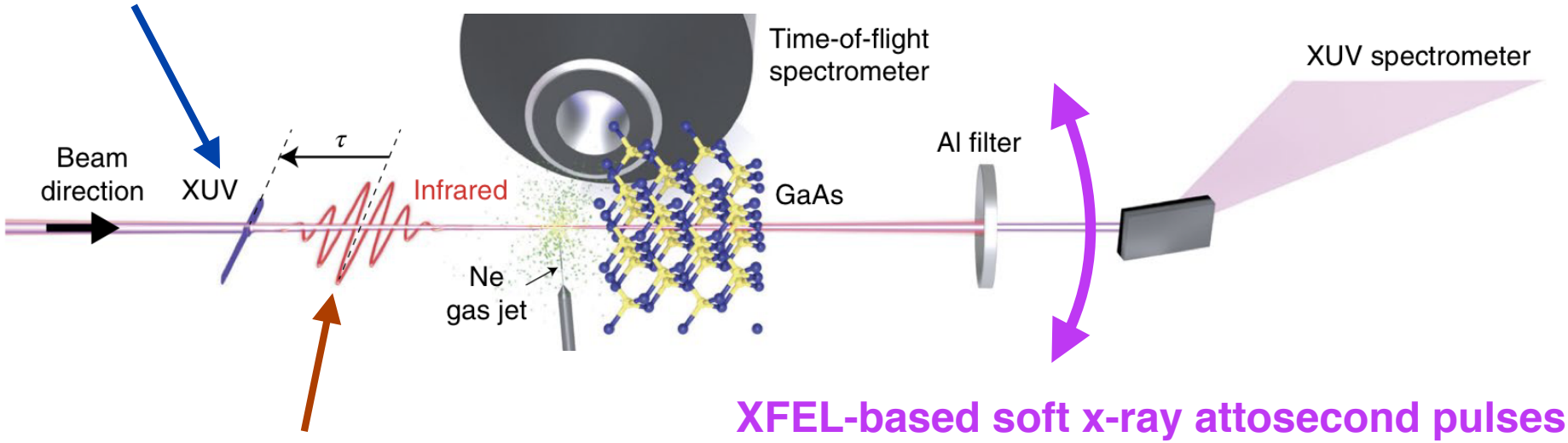


Segrist, et al. (unpublished); arXiv: 1812.07420

How do we detect coherent (spin wave) excitations?

We need to borrow ideas from laser-based attosecond spectroscopy

variable-polarization attosecond soft x-ray pulse



'single-cycle' pump pulse

XFEL-based soft x-ray attosecond pulses enable wavevector-resolved detention of coherent (spin wave) excitations

Schlaepfer, et al. Nature Physics **14**, 560 (2018)