Light-Driven Control of Spin-Wave Damping in an Antiferromagnet

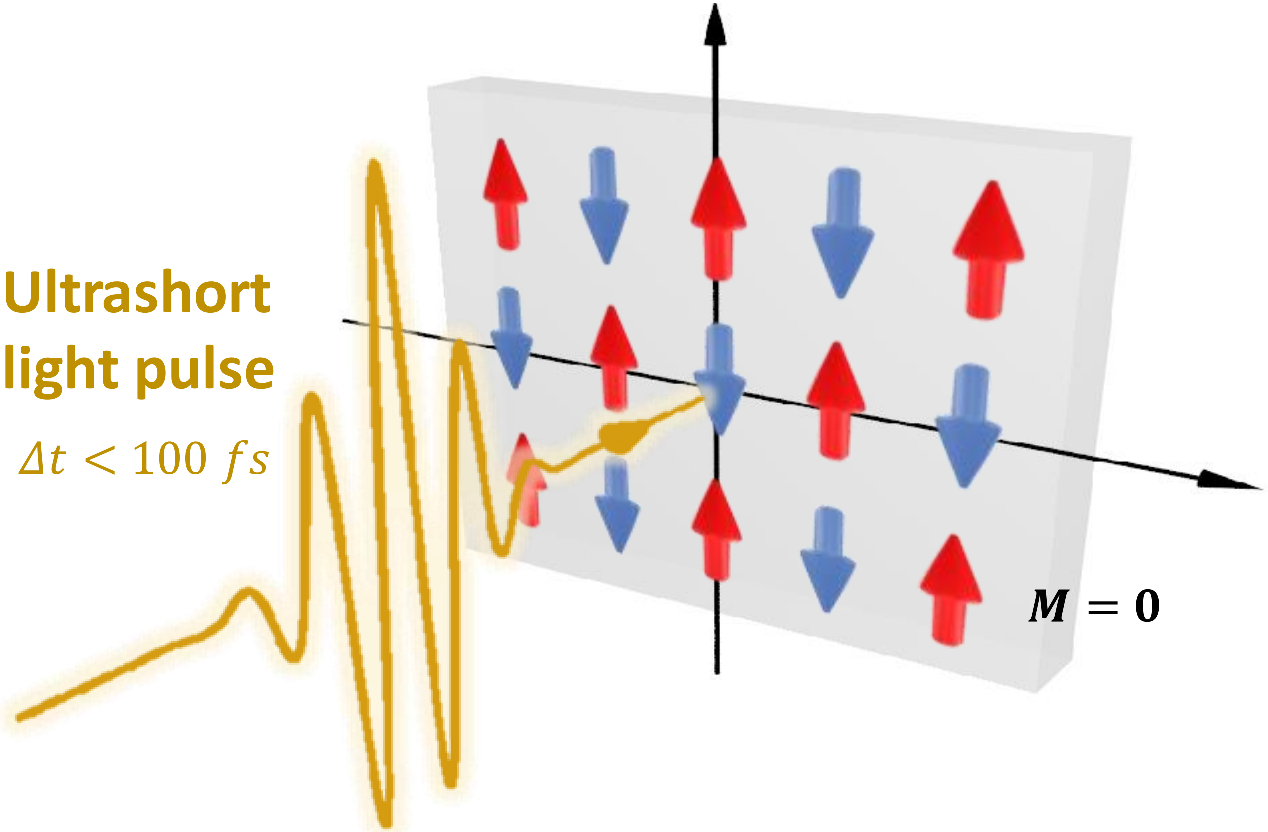
Viktoriia Radovskaia

Radboud University, Nijmegen

Light-driven spin precessions in Antiferromagnets

Ultrashort light pulse

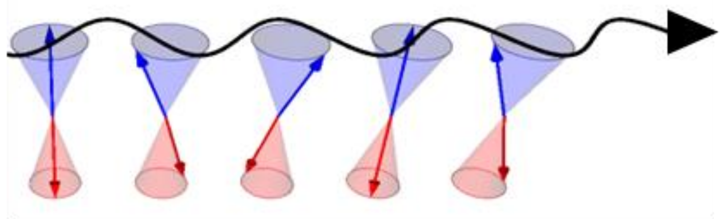
$\Delta t < 100\ fs$



Optomagnetic field

$(\Delta\omega > 10\ THz)$

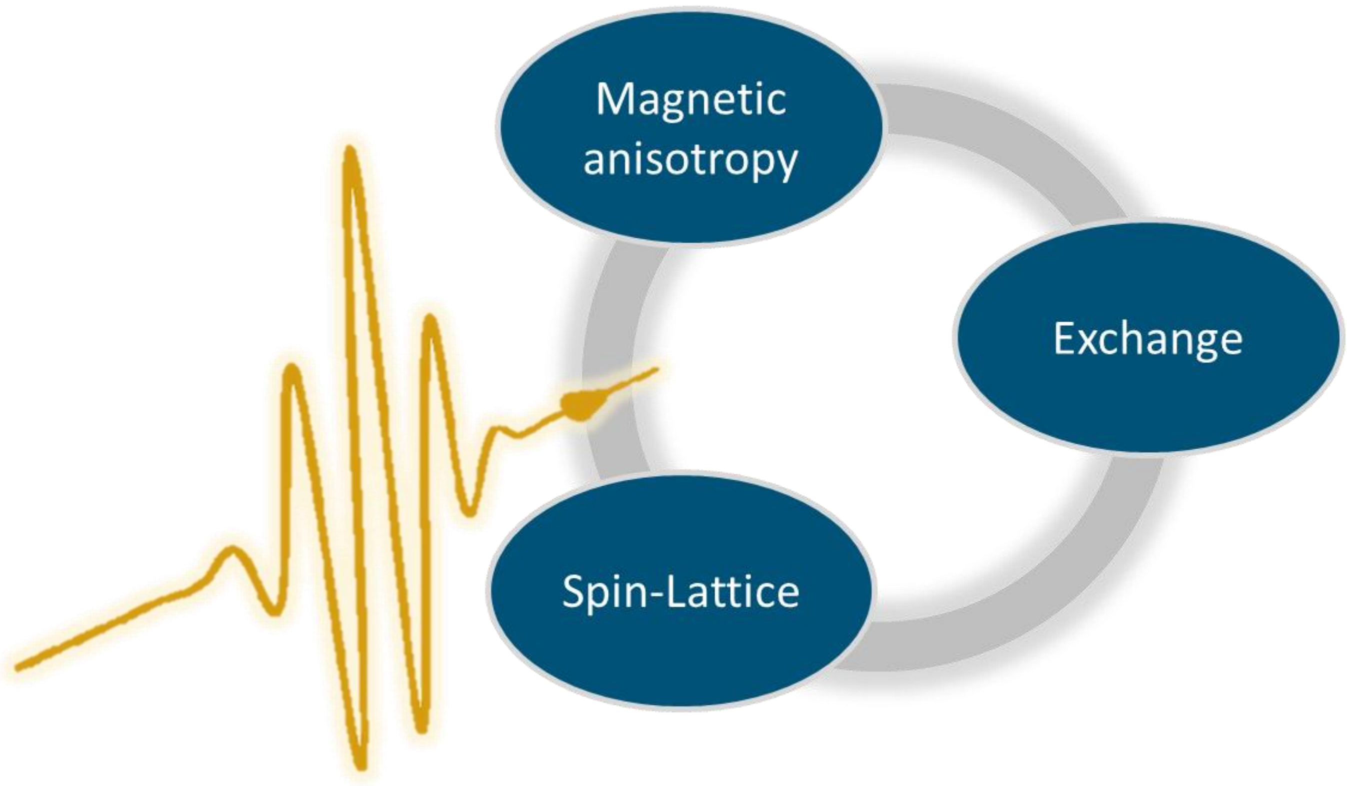
Antiferromagnetic magnonics

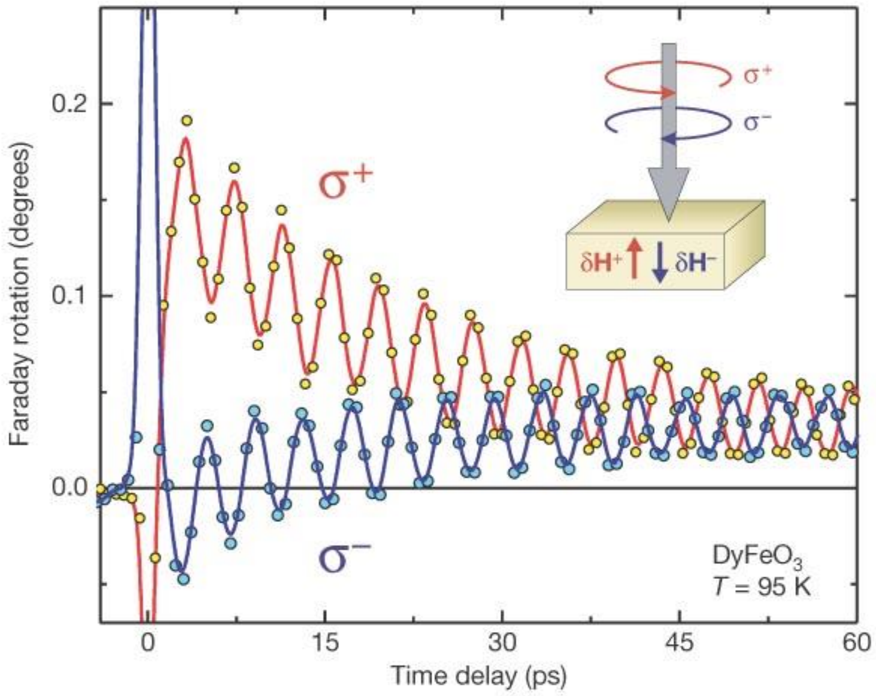


- High frequencies *(> 1 THz)*
- High group velocities *(> 10 km/s)*
- Non-dispersive propagation

Hortensius, J.R., et. al. Nat. Phys. 17, 1001–1006 (2021)
*Madami, M. et al. Nature Nanotech **6**, 635–638 (2011)*
*Afanasiev, D. et al. Nat. Mater. **20**, 607–611 (2021)*
*Němec, P. et al. Nature Phys **14**, 229–241 (2018)*

Dynamic control of spin-wave properties





E. A. Mashkovich, et.al. Science 374, 1608–1611 (2021)
Mikhaylovskiy, R.,et al. Nat Commun 6, 8190 (2015)
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Kimel, A., et al. Nature 435, 655–657 (2005)
Afanasiev D, et. al.. Nat. Mater. 20, 607–611 (2021)
Qiu, JX., et al. Nat. Mater. 22, 583–590 (2023)
D. Bossini, et. al. ACS Photonics 2016 3 (8), 1385-1400

It's possible to control:

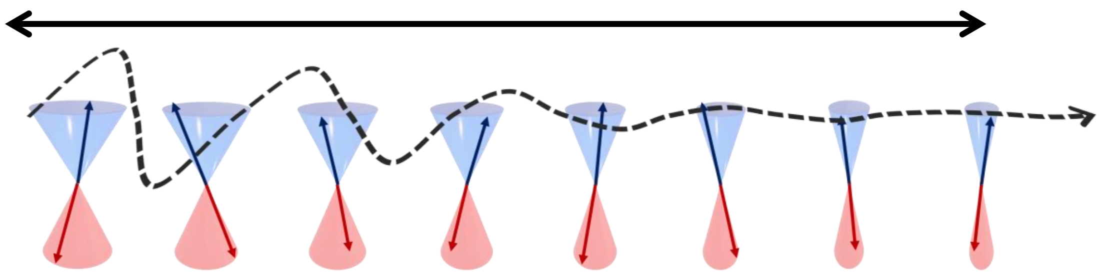
- Phase
- Amplitude
- Frequency
- Lifetime (damping α)

Importance of the spin-wave damping: low and high

Propagation:

- a lifetime: τ_{coh}
- a propagation length: l_{coh}

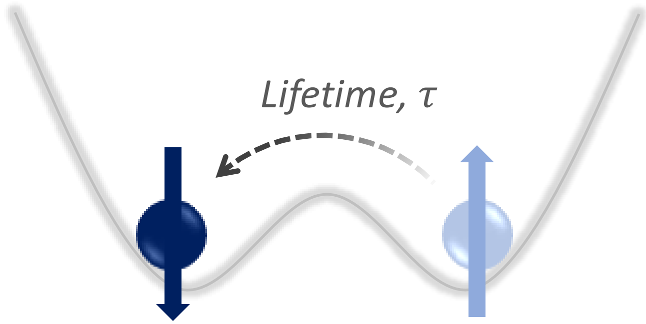
$$l_{coh} = v\tau_{coh}$$



Switching:

- $\tau = (\Delta\omega)^{-1} \sim (\alpha / f_0)^{-1}$

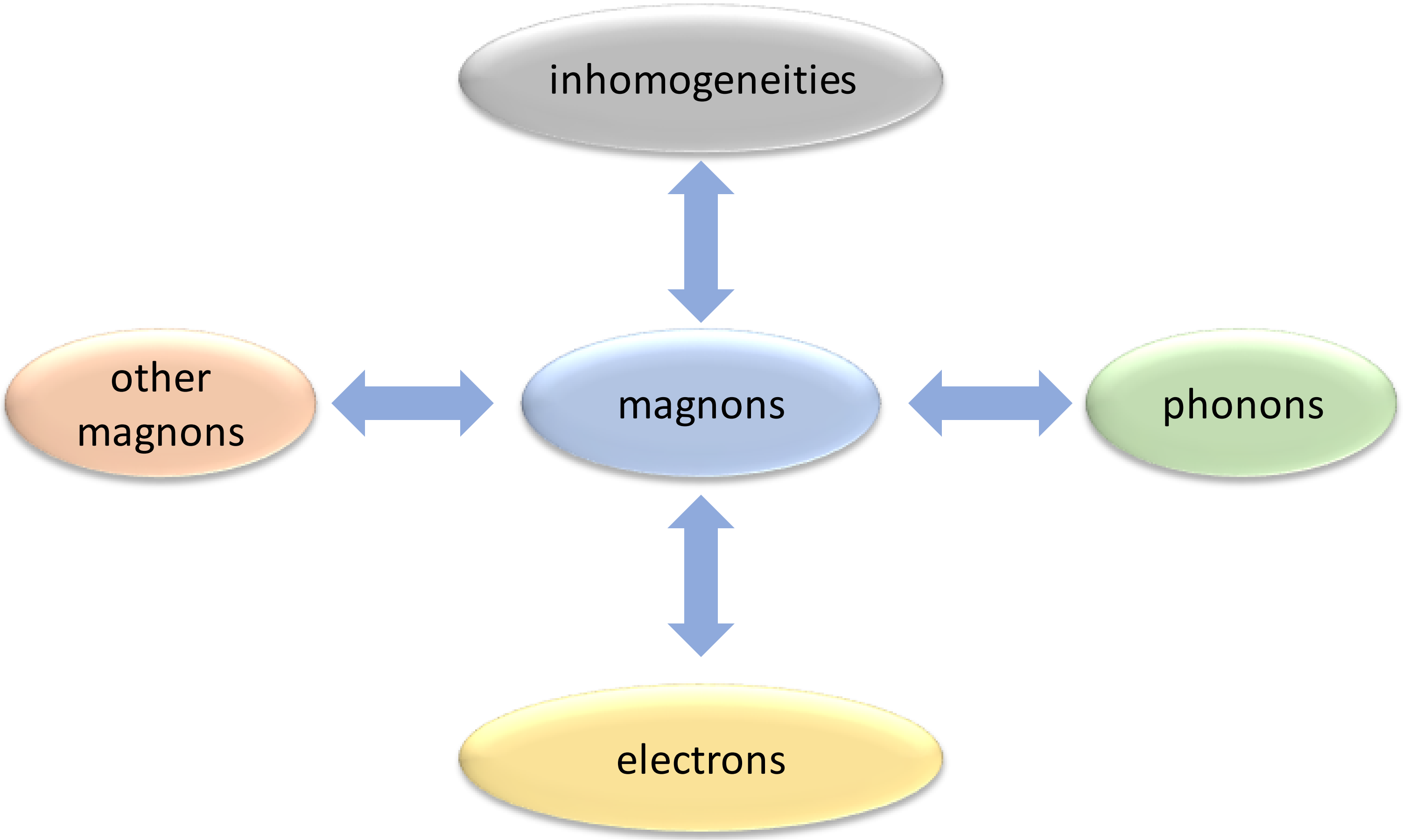
α – damping parameter
f_0 – frequency



Low damping:
for long-living coherent precessions

High damping:
for reliable switching of the system

Origin of the spin-wave damping

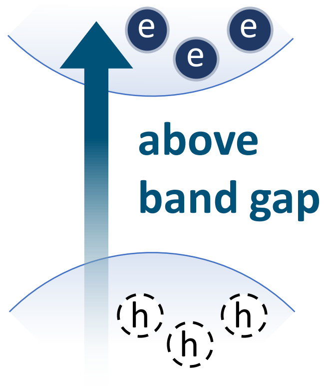


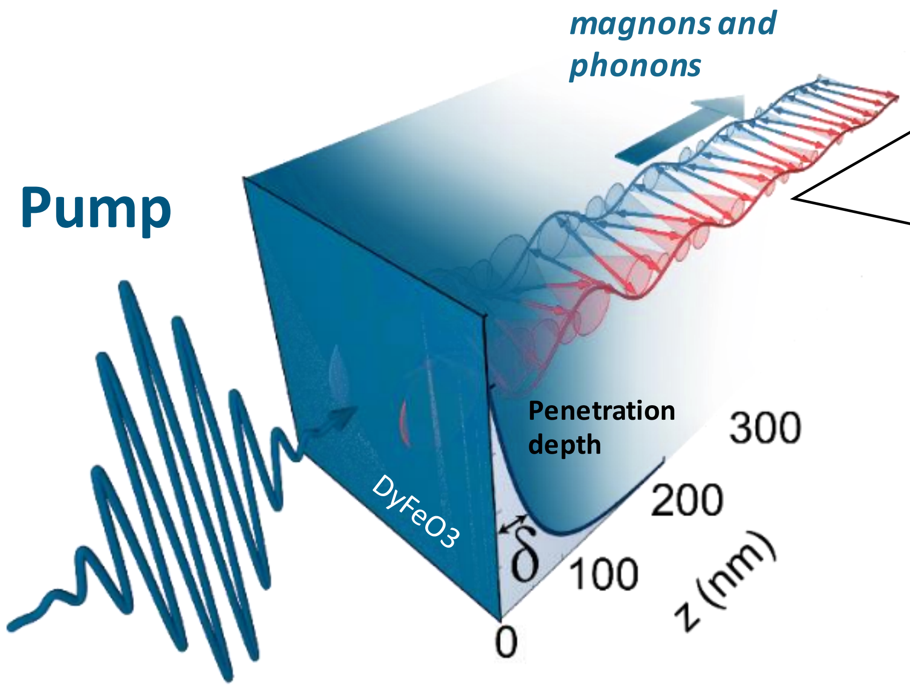
- two-magnon scattering
- three/four magnon interaction
- magnon-phonon scattering
- electron-magnon scattering

P. Pirro et. al. Nat. Rev. Mater. ***6,*** *1114–1135 (2021)*
M.M.H. Polash et.al. J. Mater. Chem. C, 2020,8, 4049-4057

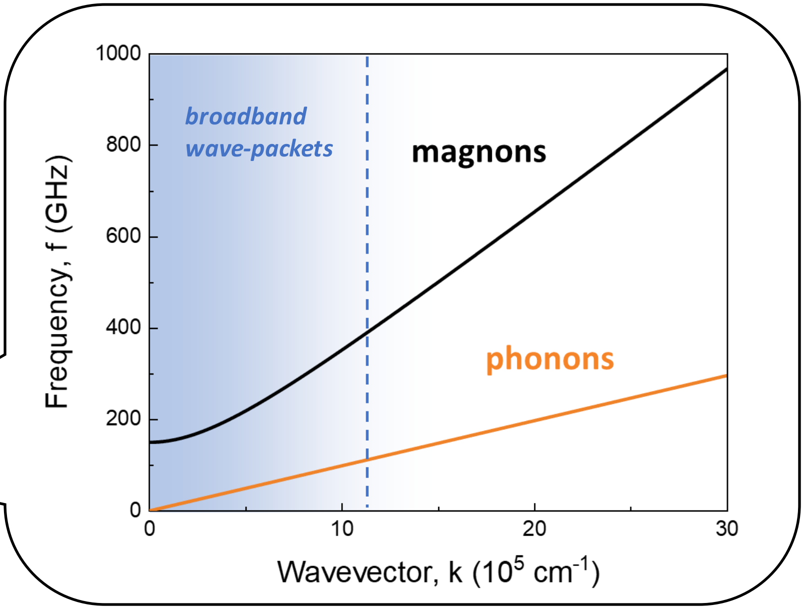
Damping is a many-body interaction process!

Many body magnon scattering platform with ultrashort laser pulses





Ultrashort laser pulse
(above band gap)

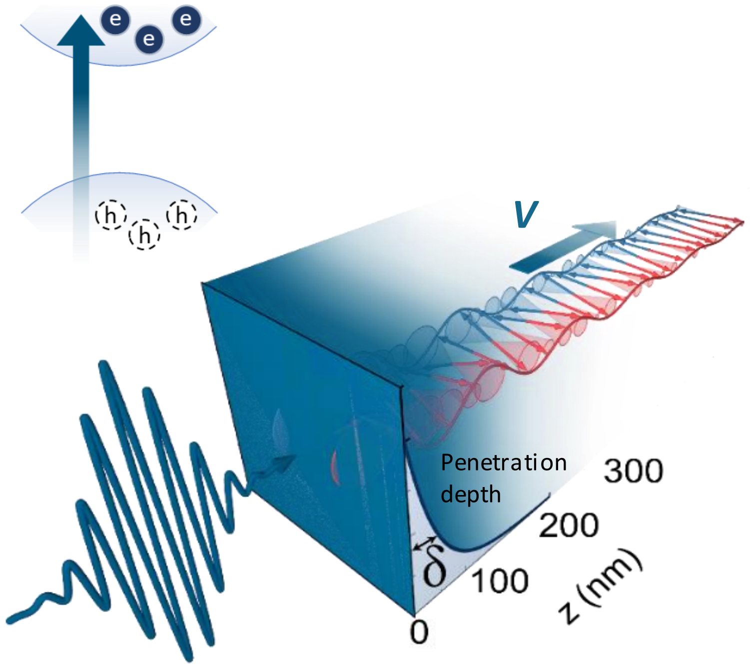


One can excite:

- electron-hole pairs
- magnons
- phonons

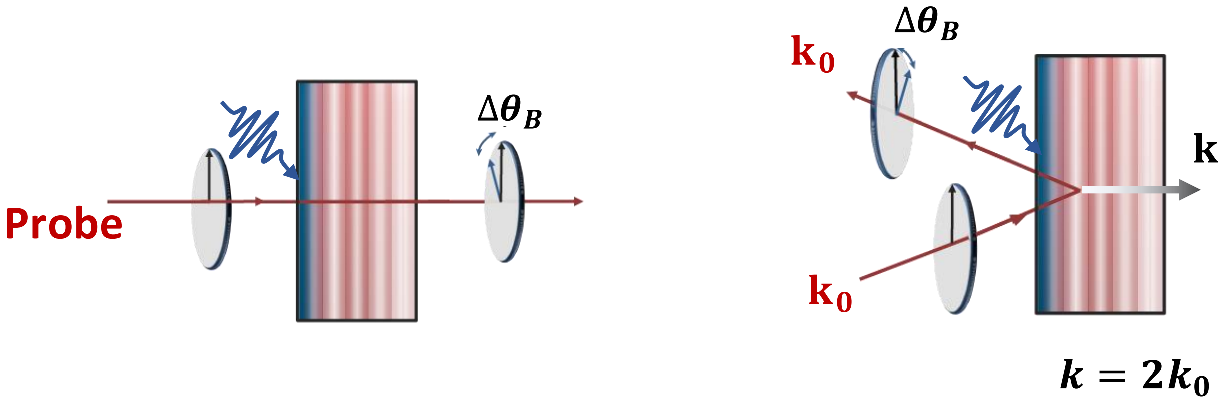
Hortensius, J.R., et al. Nat. Phys. **17**, 1001–1006 (2021).

Detection of uniform and propagating excitations



Ultrashort laser pulse
(to create many-body excitation)

Birefringence of light, $\Delta\theta_B$



Transmission: $k = 0$

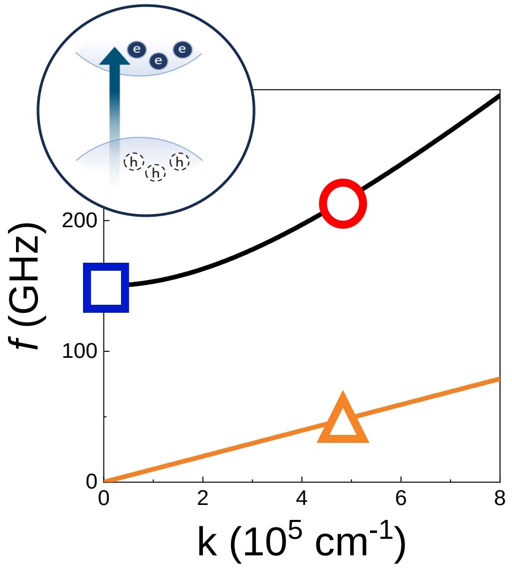
- *uniform magnon*

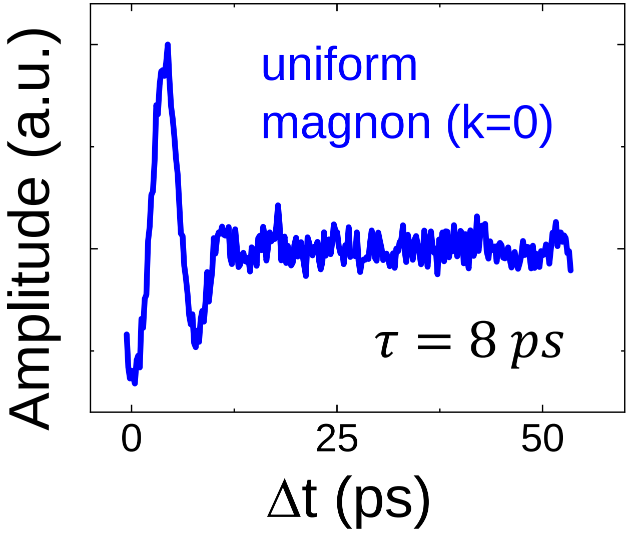
Reflection: $k \neq 0$

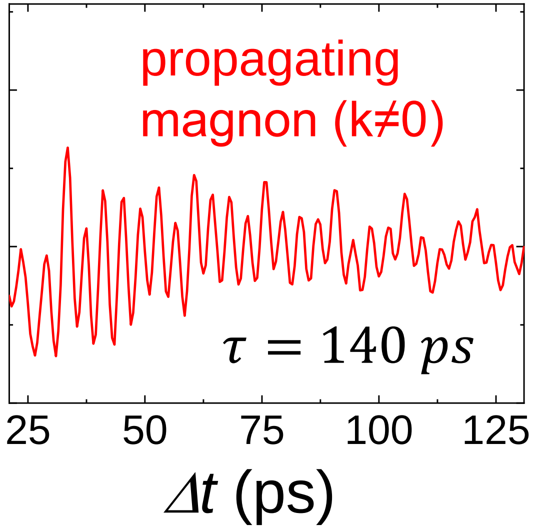
- *propagating magnons*
- *propagating phonons*

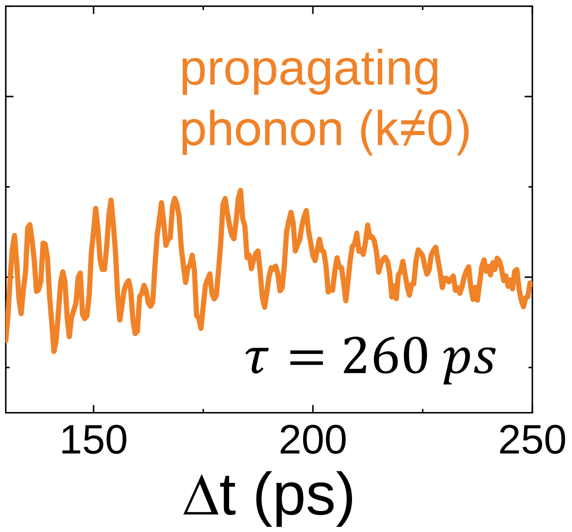
Hortensius, J.R., et al. Nat. Phys. **17**, 1001–1006 (2021).

Magnon&Phonon excitation in a time domain

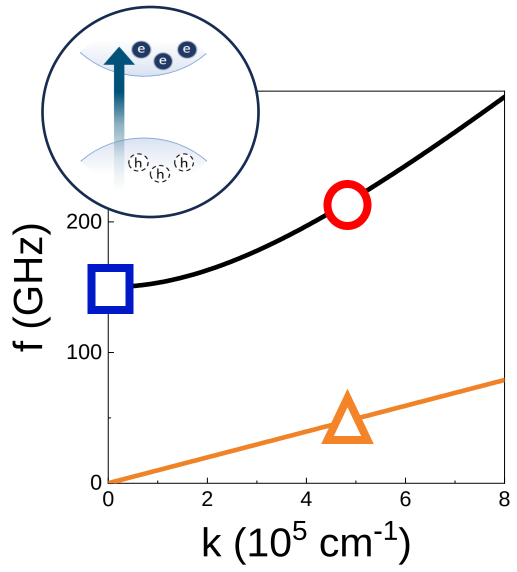


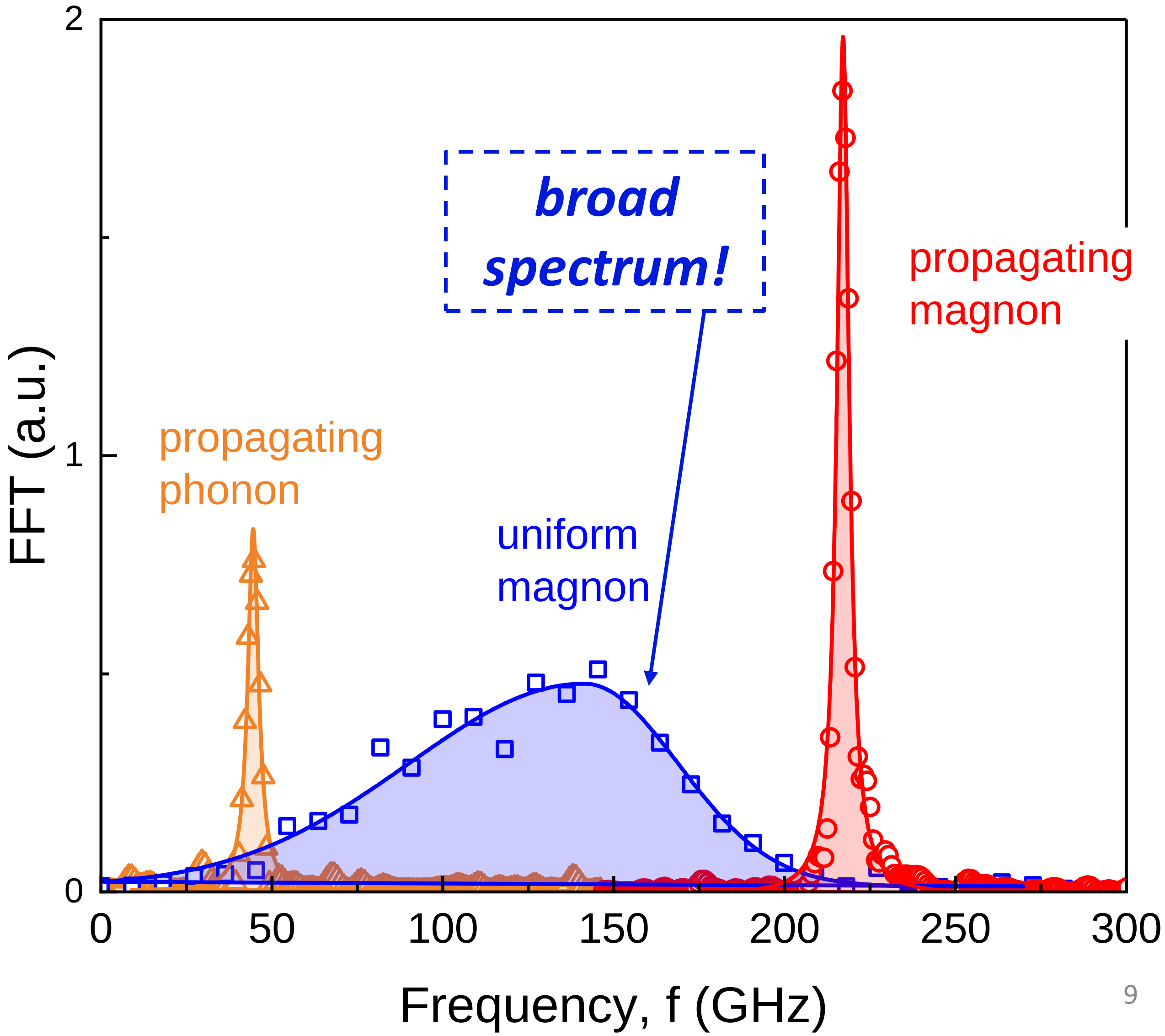






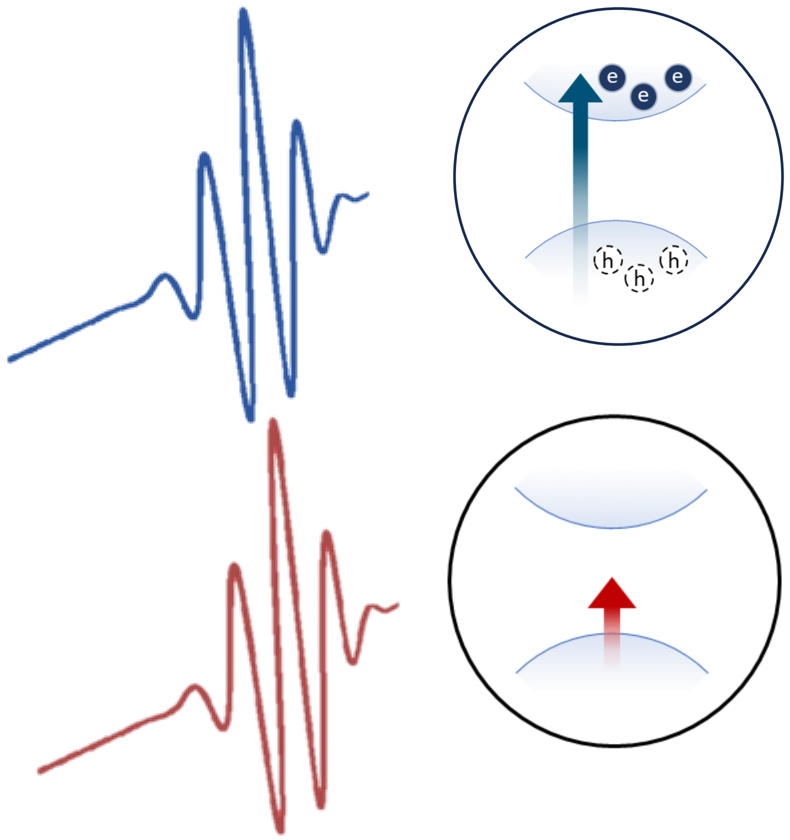
Giant damping of k=0 magnon

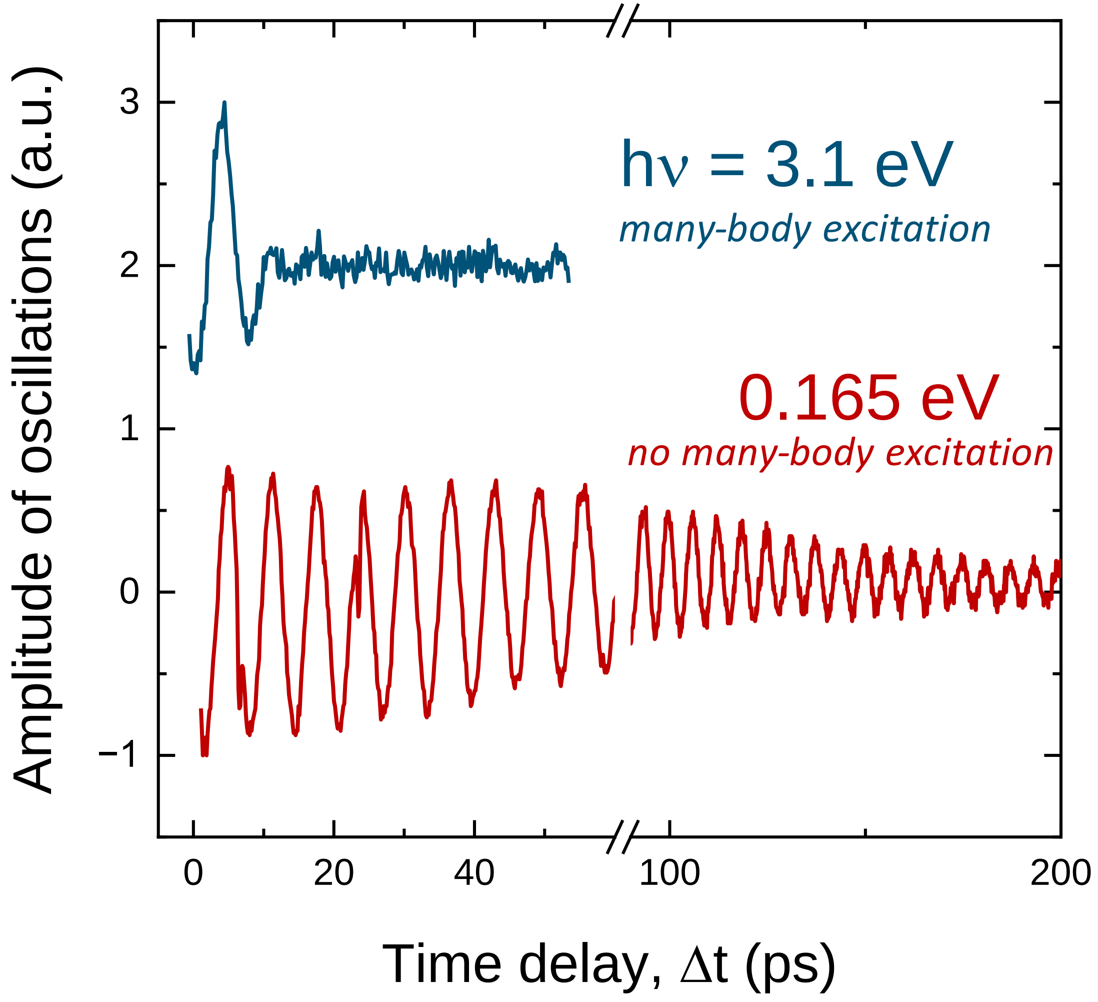




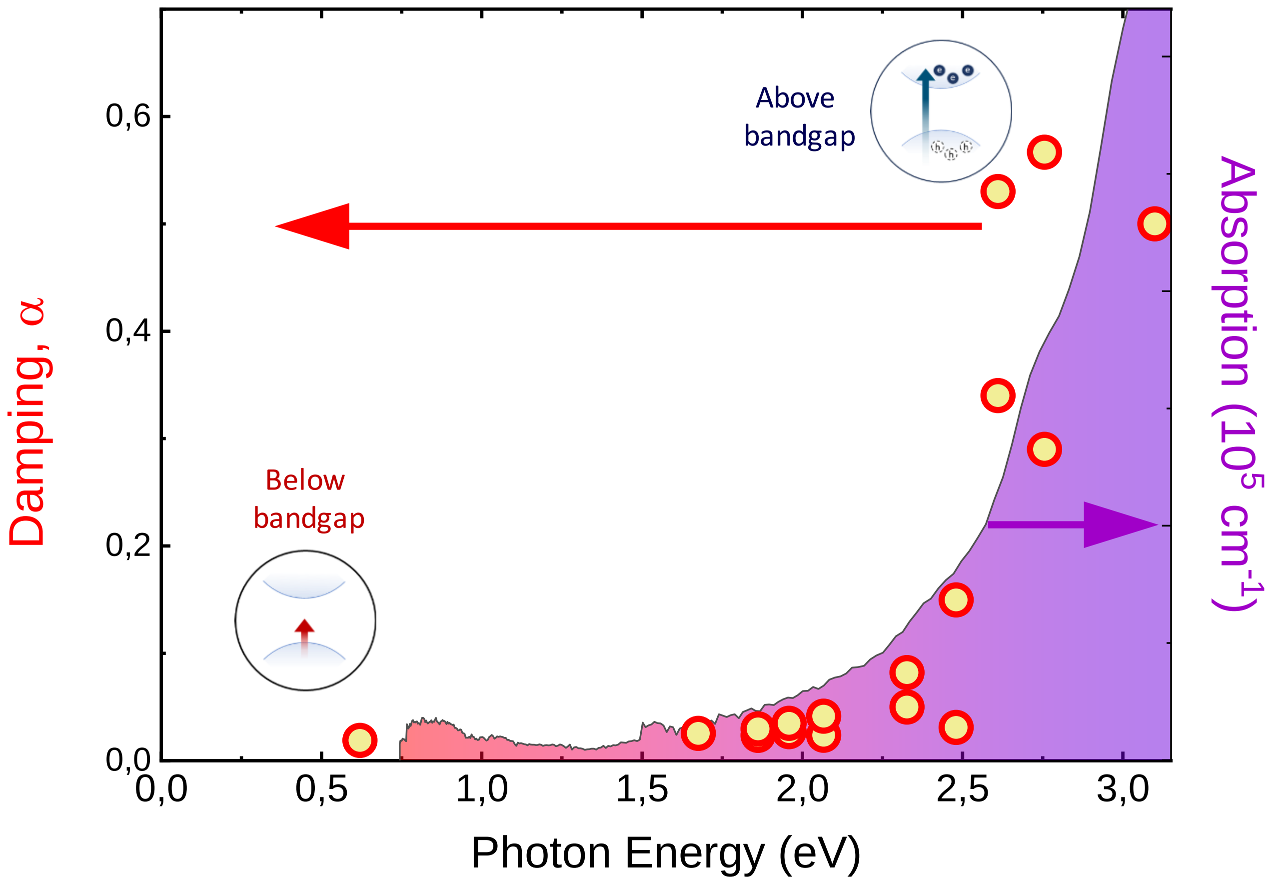
the uniform spin precession is significantly damped!

Control of damping of uniform spin precession by the pump photon energy



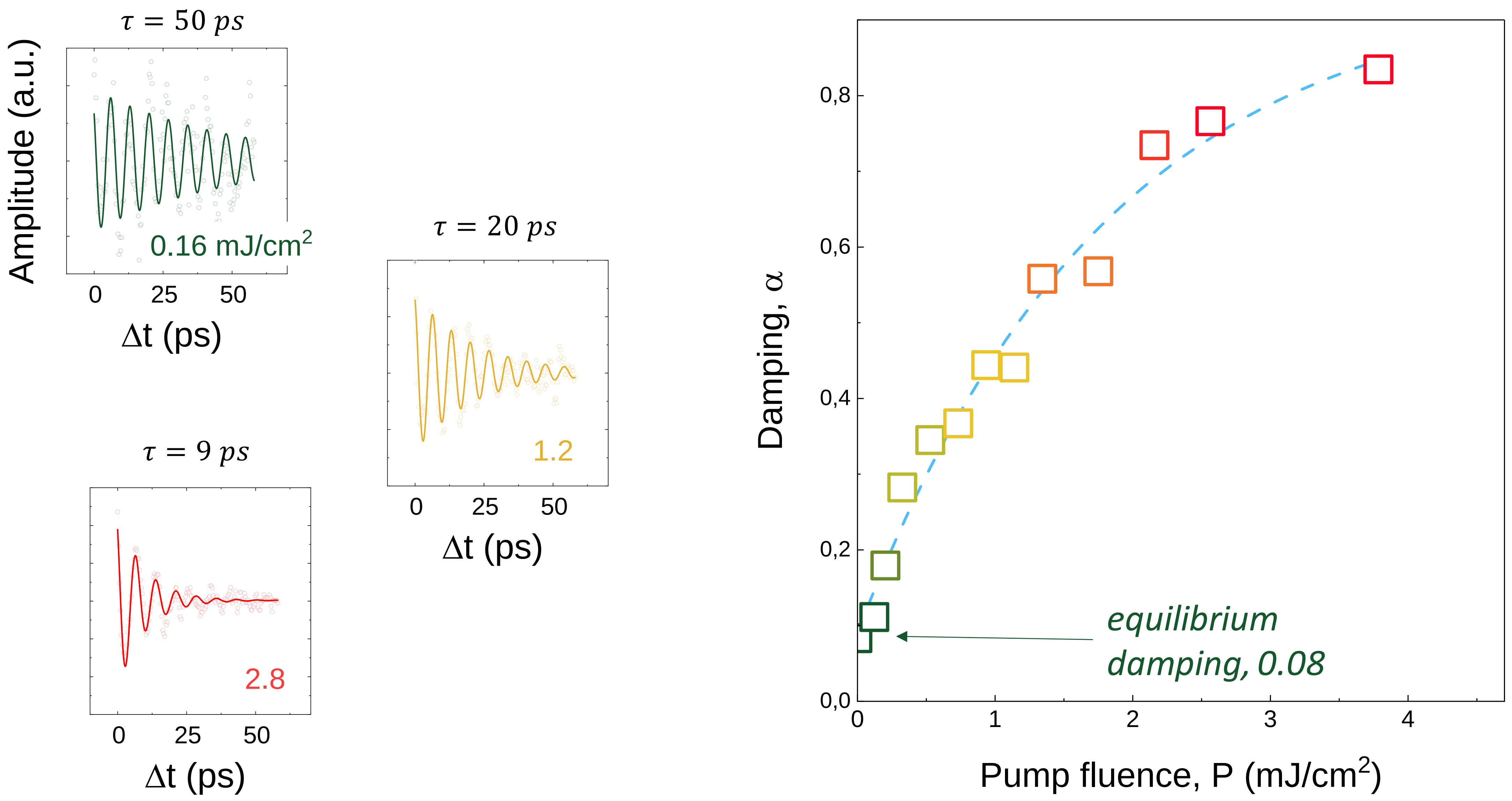


Coherent spin-waves with on-demand damping

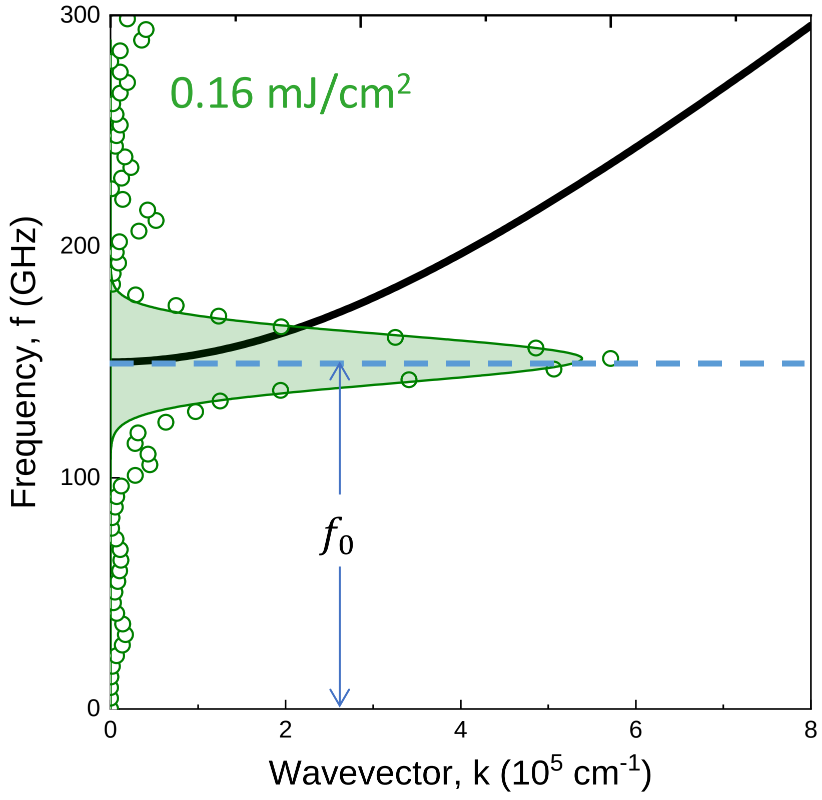


Stronger confinement *higher density* → **More quasiparticles** *more collisions* → **Higher damping**

Coherent spin-waves with on-demand damping

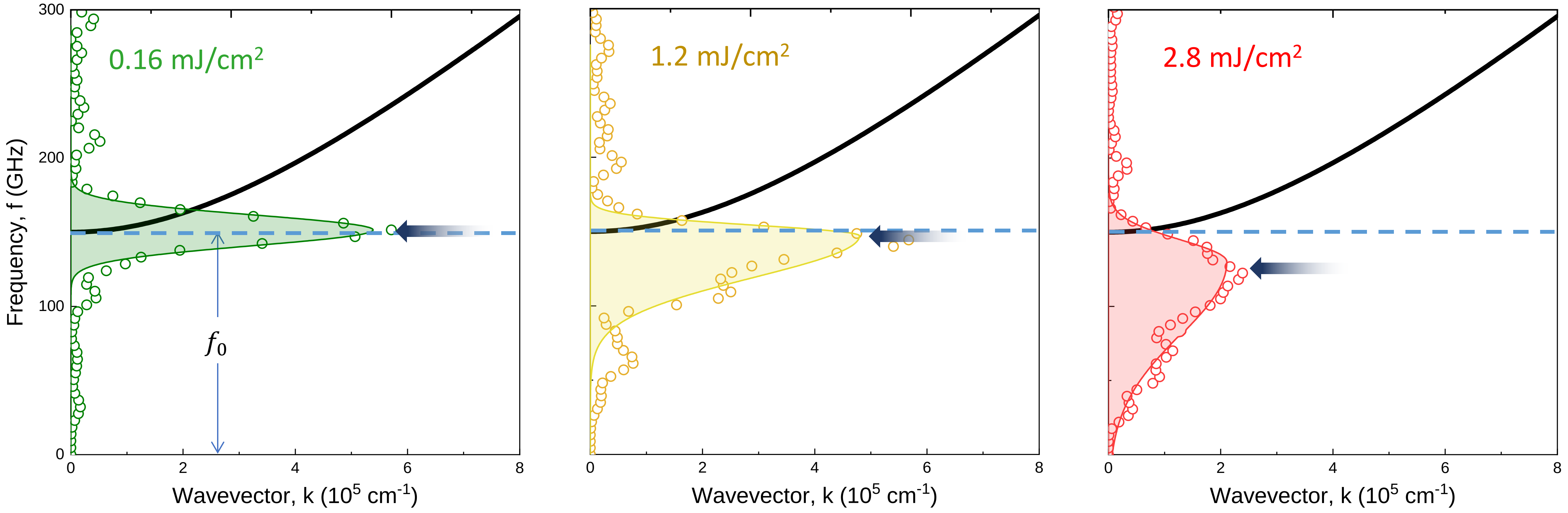


Asymmetric spectral weight transfer

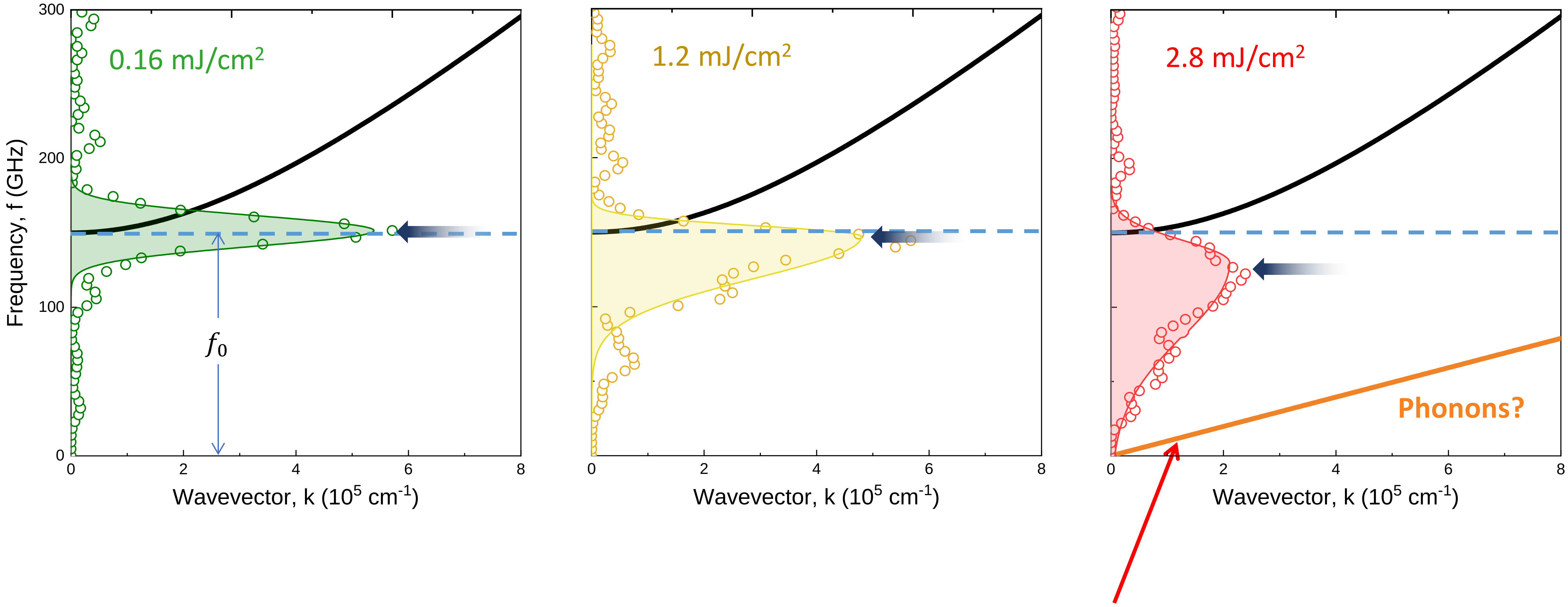


- $f_{magn} = \sqrt{f_o^2 + (vk\,)^2}$
- f_0 - spin-wave gap

Asymmetric spectral weight transfer

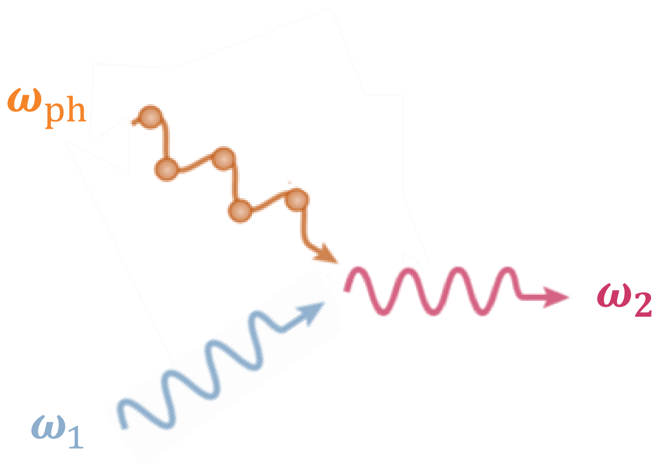


Asymmetric spectral weight transfer



Towards low-energy excitations!

Magnon-phonon scattering scenario

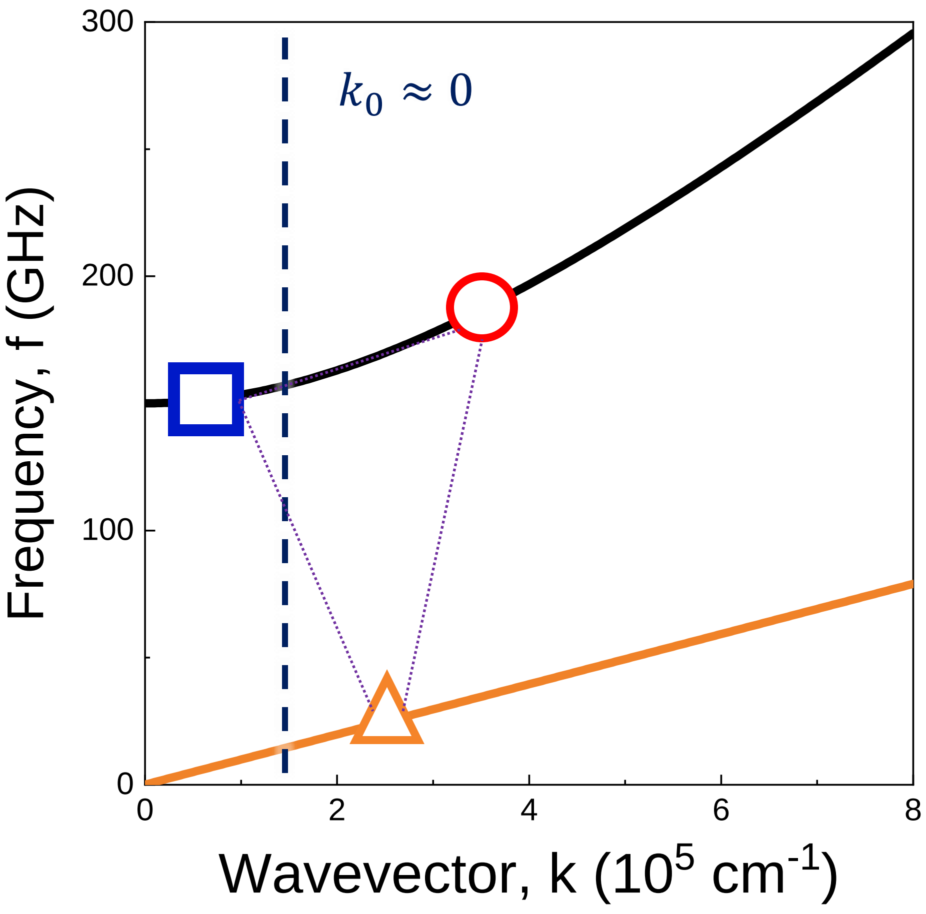


Conservation of momentum and energy:

$$k_1 + k_{ph} = k_2$$
$$\omega_1 + \omega_{ph} = \omega_2$$

Fulfilled only if:

$$k_1 \leq k_0 = 1.54 * 10^5 cm^{-1}$$



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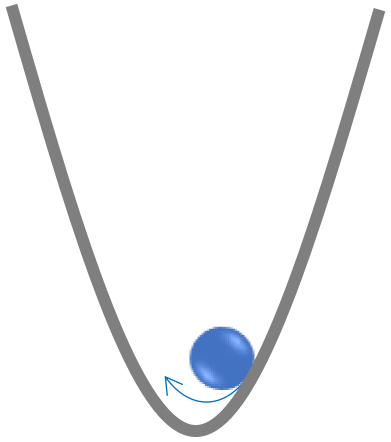
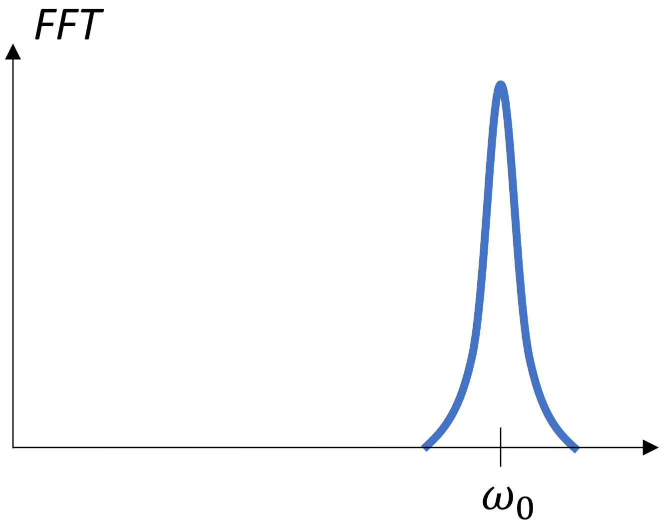
High-amplitude induced nonlinearity

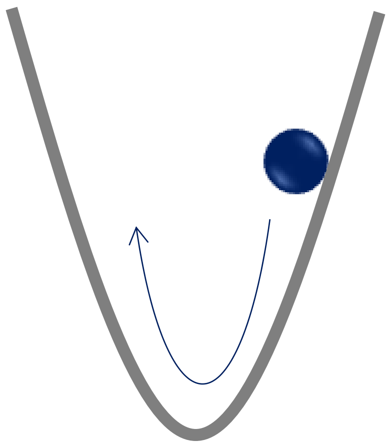
a) Low amplitude

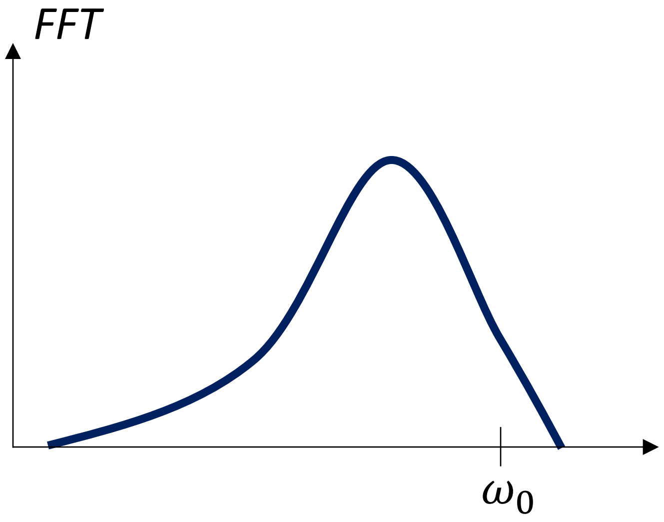




narrow FFT peak at equilibrium frequency

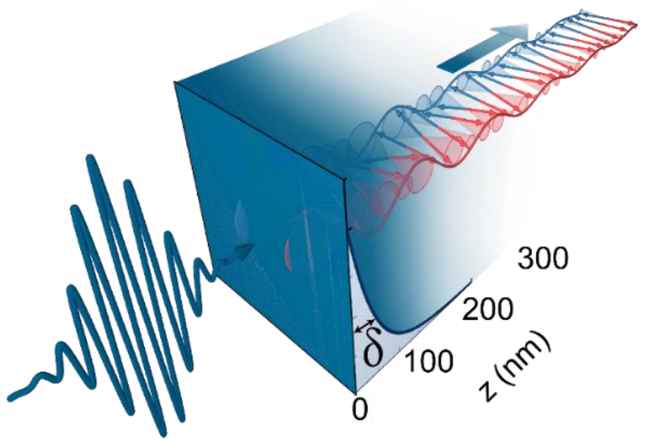
b) High amplitude

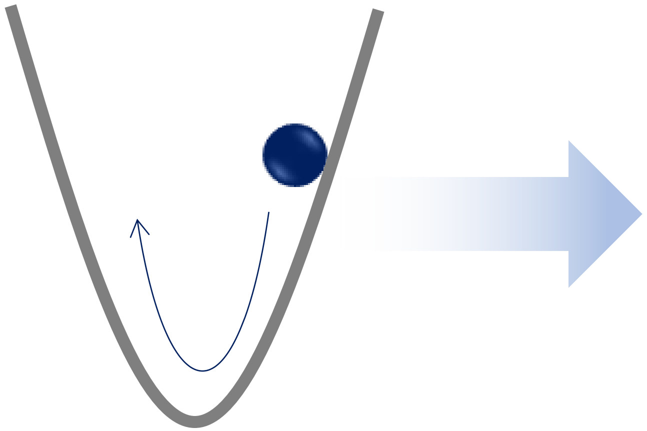


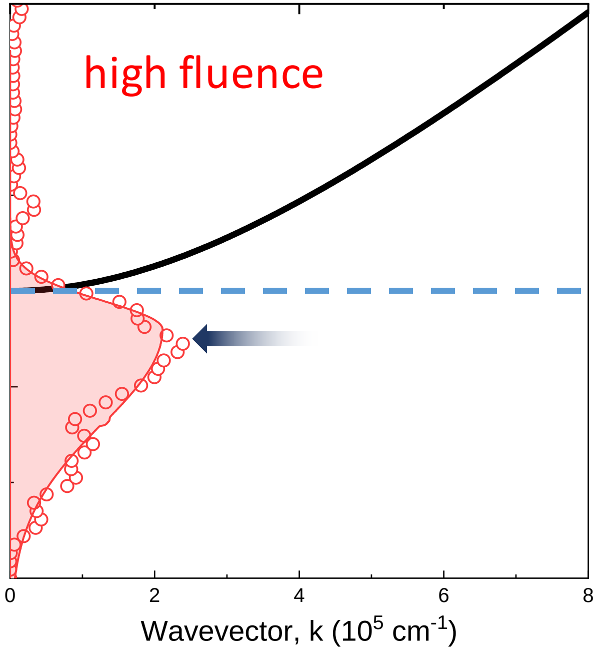


broadened red-shifted FFT peak

High-amplitude induced nonlinearity



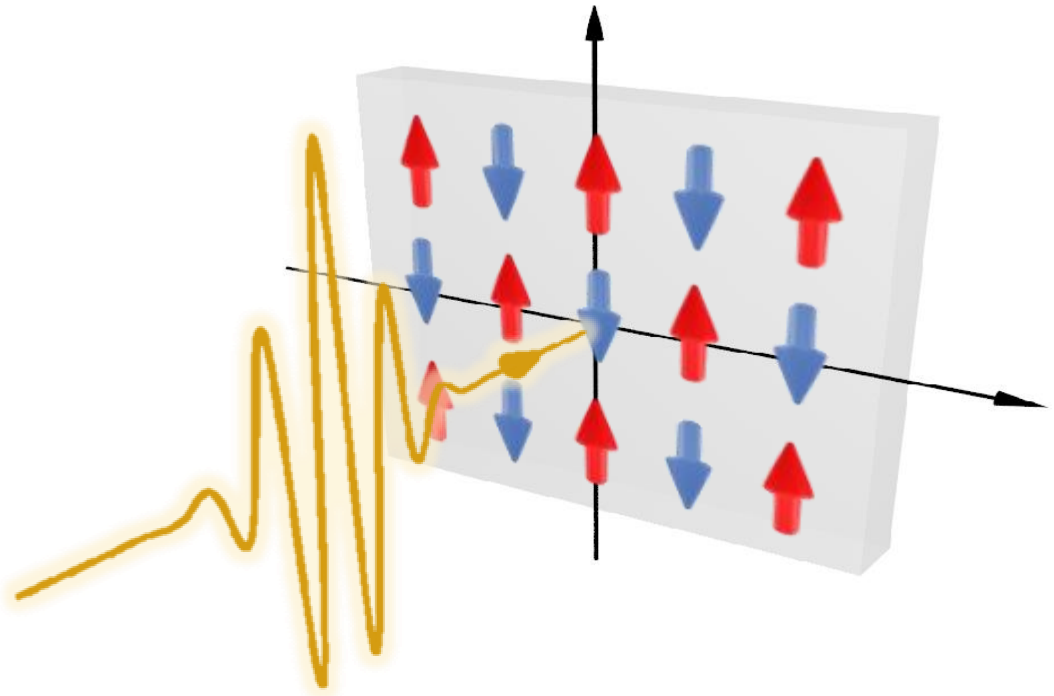




All the light fluence is absorbed in a narrow skin-depth layer ~ 50 nm !!!

~ 30 deg spin deflection

Conclusions



- An ultrashort optical excitation of insulating antiferromagnets may lead to a broadband population of quasiparticles with many-body interaction (e.g electron-hole pairs, magnons, phonons)

- In AFM DyFeO3, the many-body optical excitation manifests as a giant renormalization of the damping of uniform spin precession.

Optical excitation of spin-waves with a damping on-demand!

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erc "ASTRAL"

QuMat


Thank you for your attention!