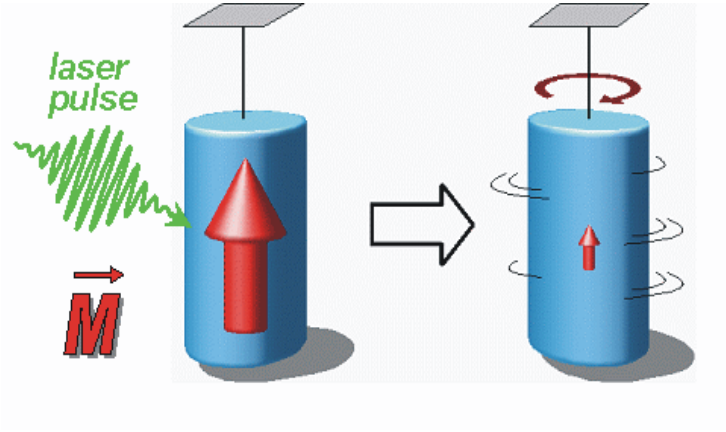
The X-Ray View of Femtosecond Magnetism

Hermann A. Dürr

SLAC National Accelerator Laboratory



PULSE SIMES

The X-Ray View of Femtosecond Magnetism

Hermann A. Dürr

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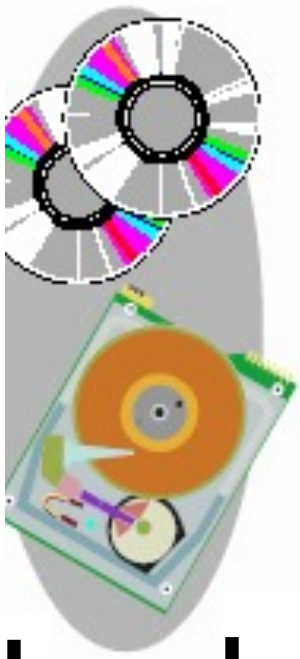
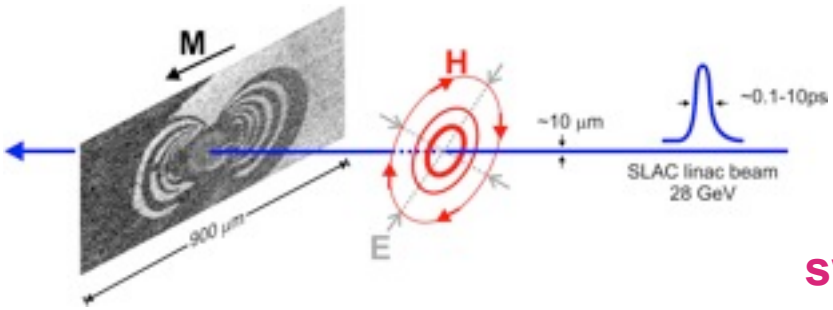
- observe the importance of the lattice
- understand spin-orbit fluctuations
- control the exchange interaction

Ultrafast Dynamics in Magnetic Materials

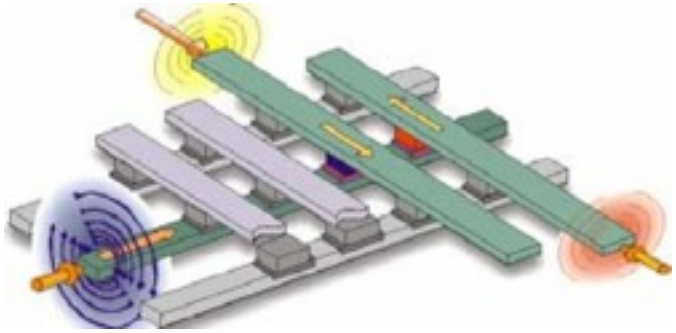
retention time in data storage

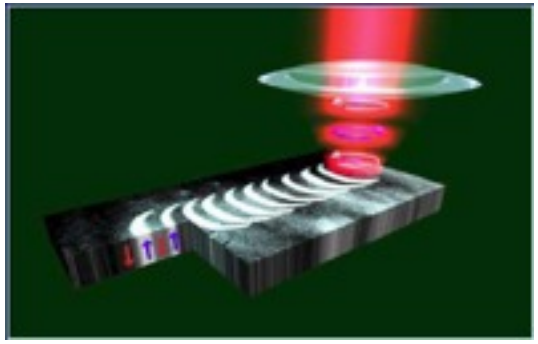


switching by fields



switching by light



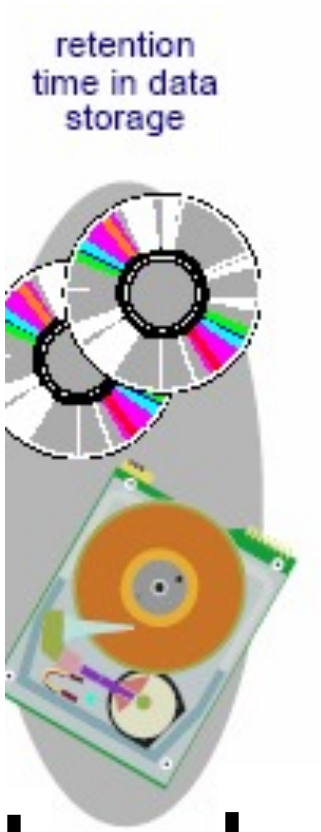


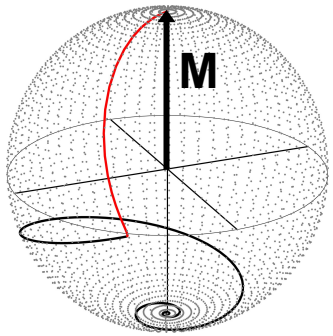
10^9 10^8 10^{-9} 10^{-12} 10^{-15}

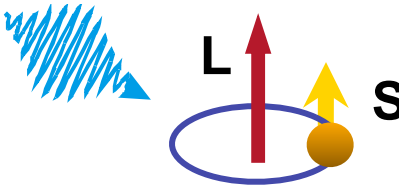
time (s)

H. A. Dürr, Complexity 2010

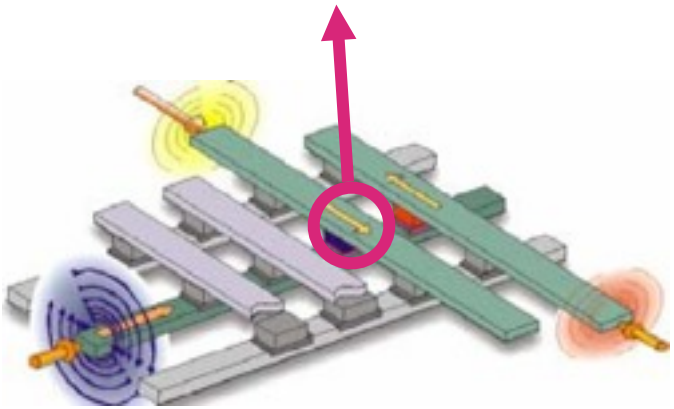
Ultrafast Dynamics in Magnetic Materials

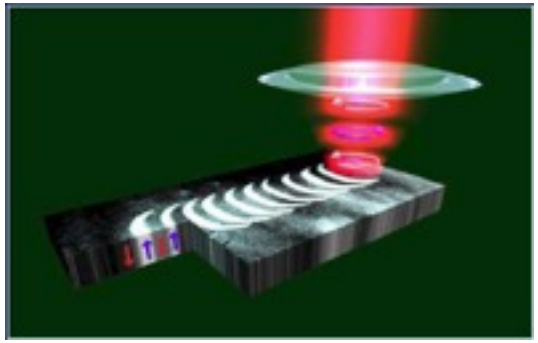


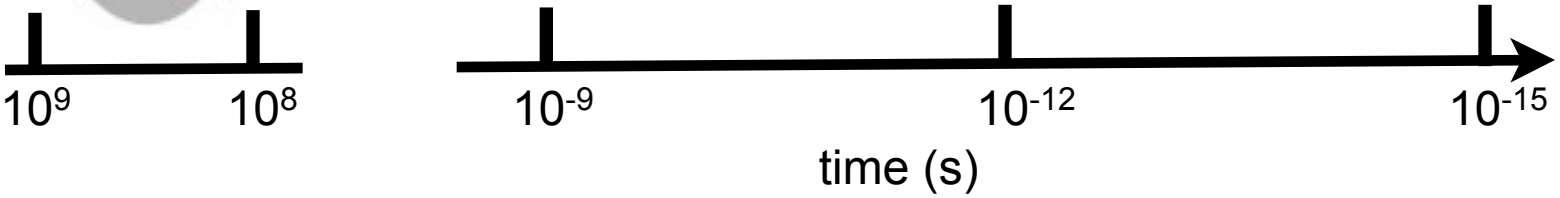




ultrafast angular momentum transfer





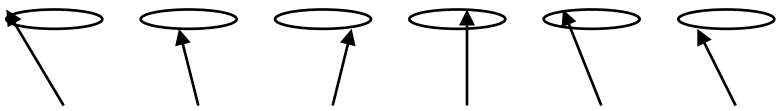


ultrafast timescales require nanoscale dimensions

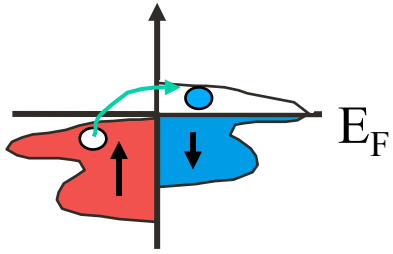
H. A. Dürr, Complexity 2010

Complexity in Magnetic Materials

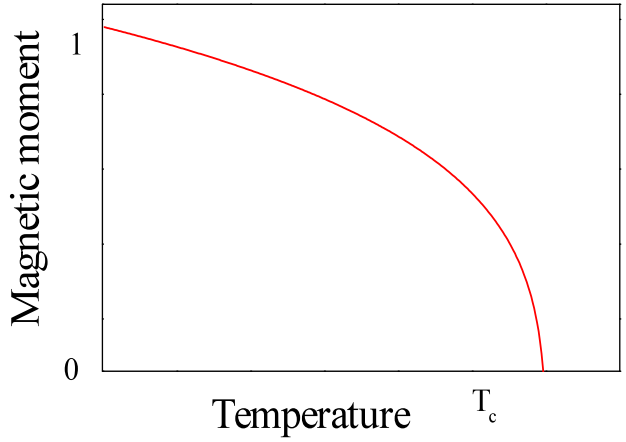
magnon excitations



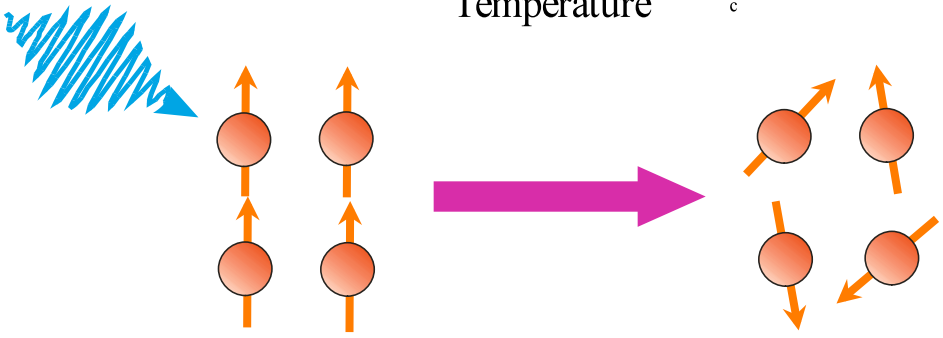
Stoner excitations



fluctuations on all length & time scales @ T_C



coupling to the lattice is usually neglected near equilibrium !



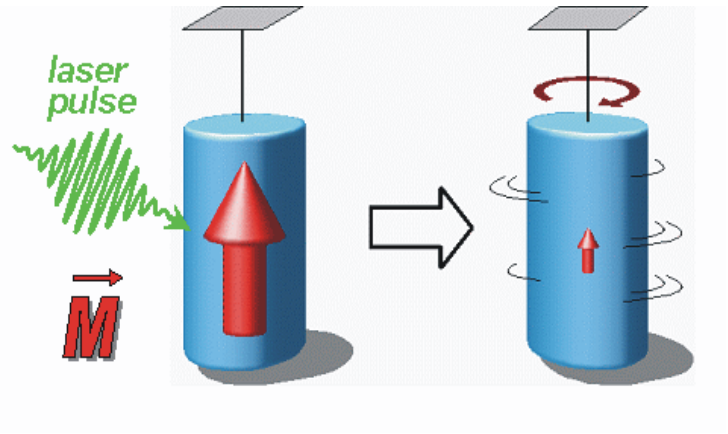
here we cannot do this anymore

H. A. Dürr, Complexity 2010

We need to consider angular momentum dynamics

conserve total angular momentum

$$J = S_e + L_e + L(\text{lattice}) + L(\text{photon})$$



ultrafast Einstein – de Haas effect ?

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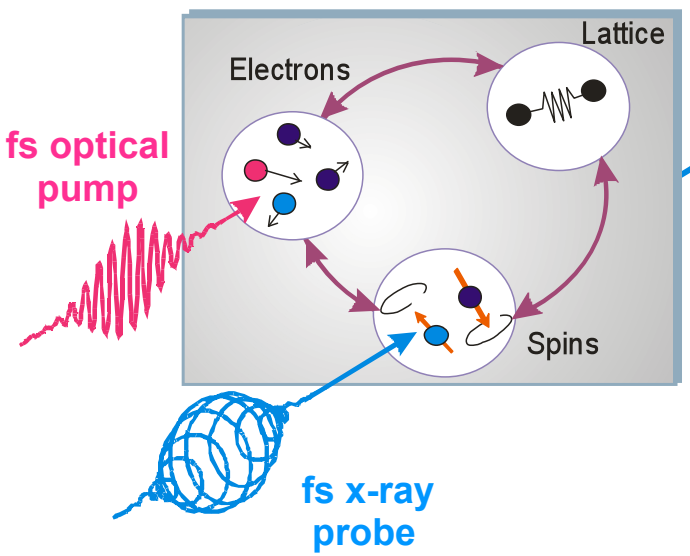
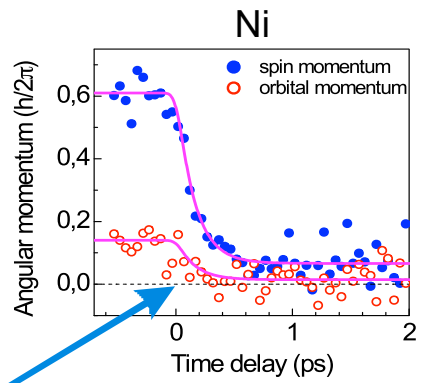
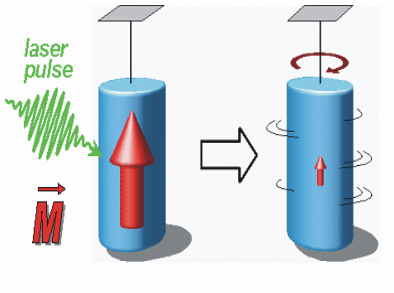
How do we do it ?

conserve total angular momentum

$J = S_e + L_e + L(\text{lattice})$







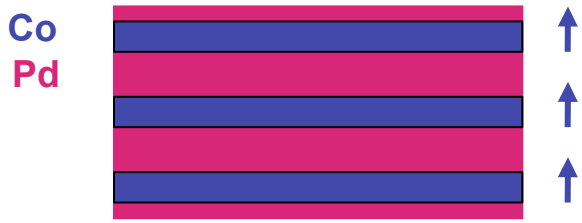
There must be an ultrafast Einstein - de Haas effect

But how does it work so fast ?

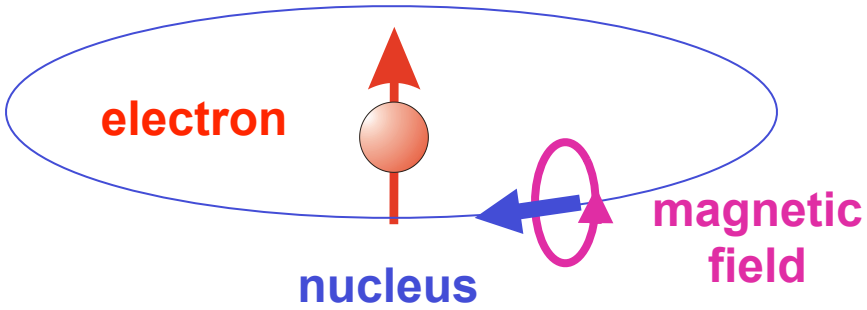
We need to probe the lattice !

Stamm, Dürr, et al., Nature Materials **6**, 740 (2007);
Stamm, Dürr, et al., PRB **81**, 104425 (2010)

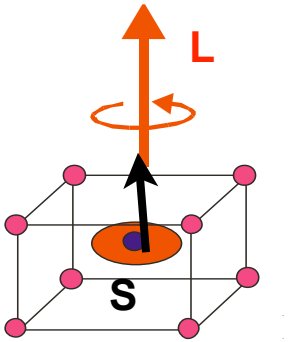
Femtosecond Control of Magnetic Anisotropy



$E \sim -\xi \langle \mathbf{L} \cdot \mathbf{S} \rangle$



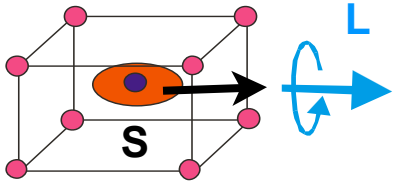
easy axis



L > L

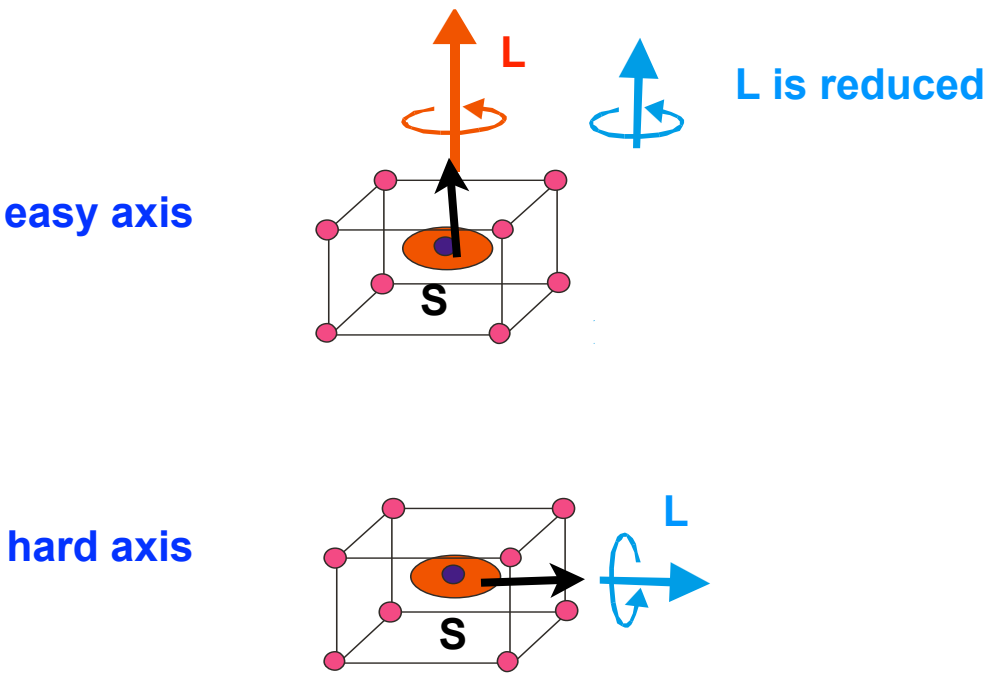
H.A. Dürr, G. van der Laan,
Phys. Rev. B **54**, R760 (1996).

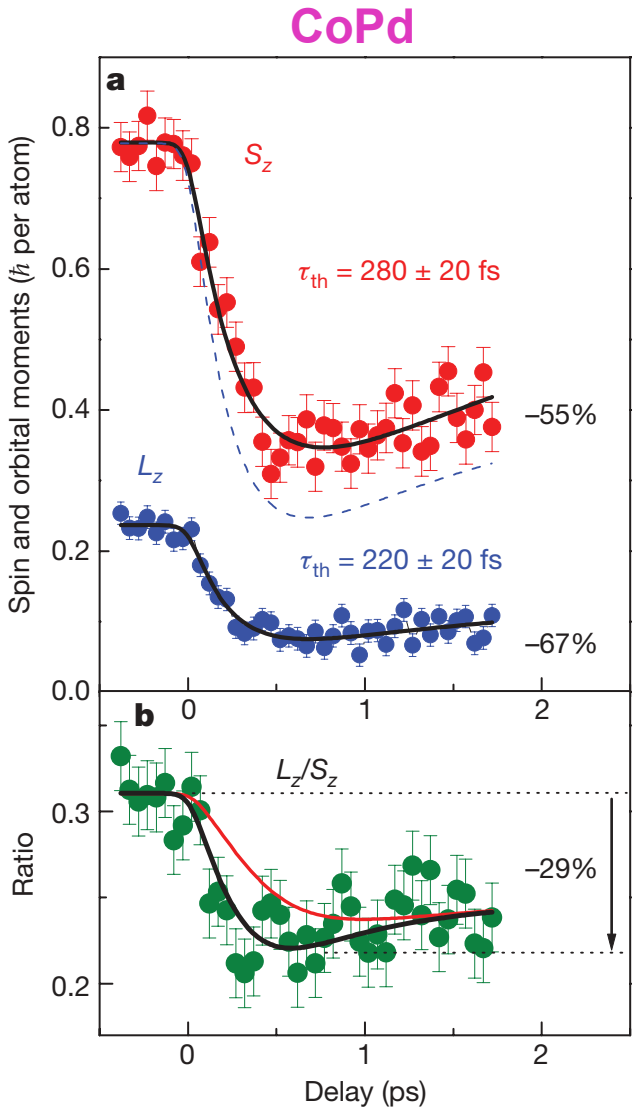
hard axis



Femtosecond Control of Magnetic Anisotropy

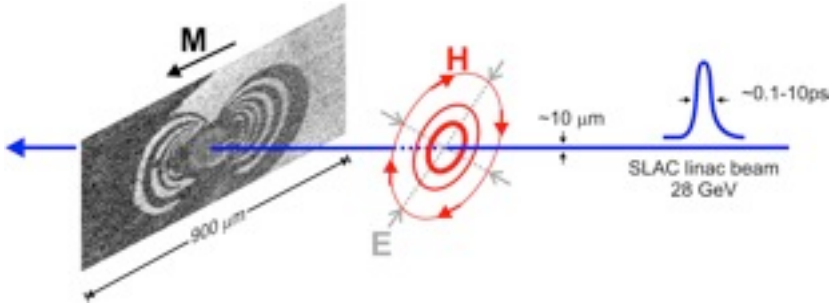
Orbital moment precedes spin moment





C. Boeglin, E. Beaurepaire, V. Halté, V. Lopez-Flores, C. Stamm, N. Pontius, H. A. Dürr, .J.-Y. Bigot, Nature **465**, 458 (2010)

THz Control of Magnetic Anisotropy ?

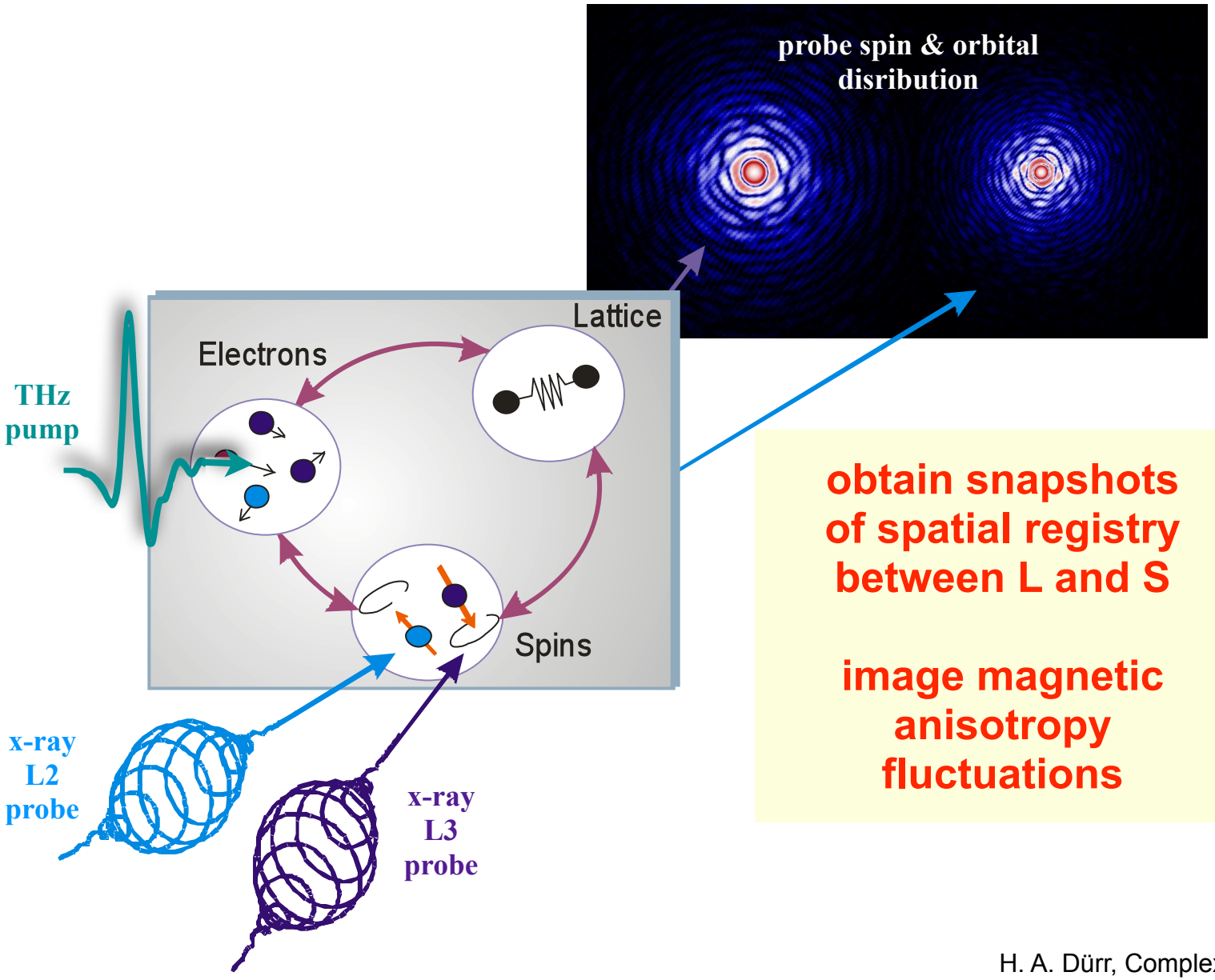


S.J. Gamble et. al., Electric field induced magnetic anisotropy in a ferromagnet, PRL 102, 217201 (2009)

It is possible without sample heating !

But how ?

Femtosecond Two-Color X-Ray Holography



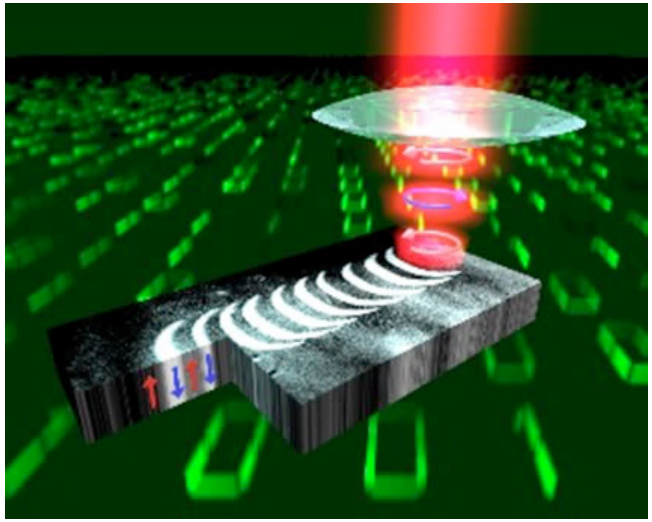
obtain snapshots of spatial registry between L and S

image magnetic anisotropy fluctuations

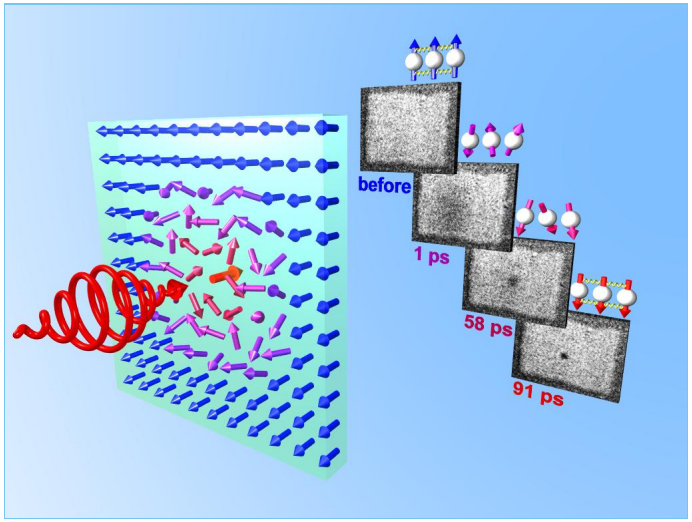
H. A. Dürr, Complexity 2010

Femtosecond Control of Exchange Coupling
All Optical Switching

Stanciu, et al, PRL **99**, 047601 (2007)



Vahaplar, et al, PRL **103**, 117201 (2009)



it happens on the nanoscale!

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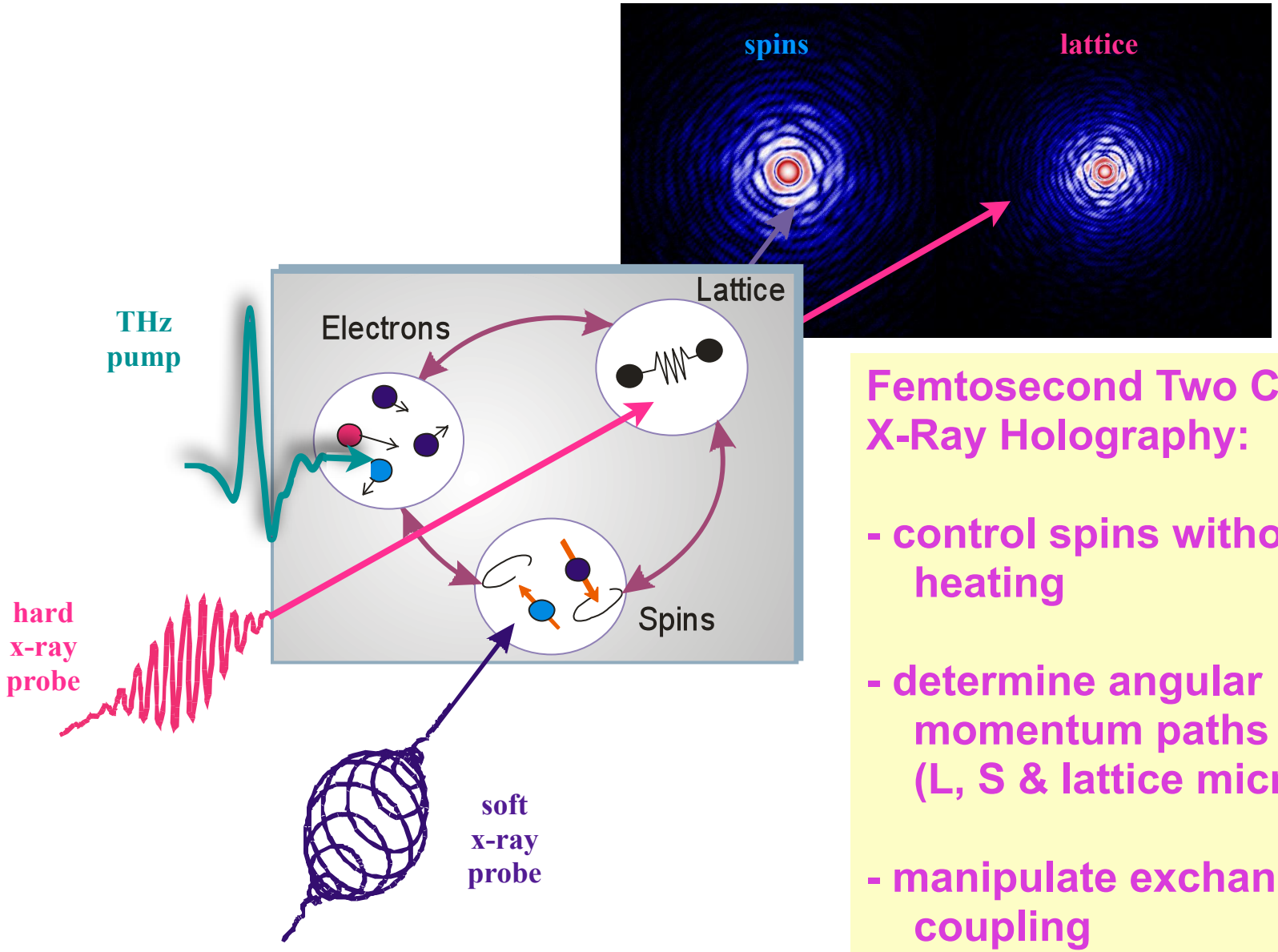
The Ultimate Femtosecond X-Ray Experiment

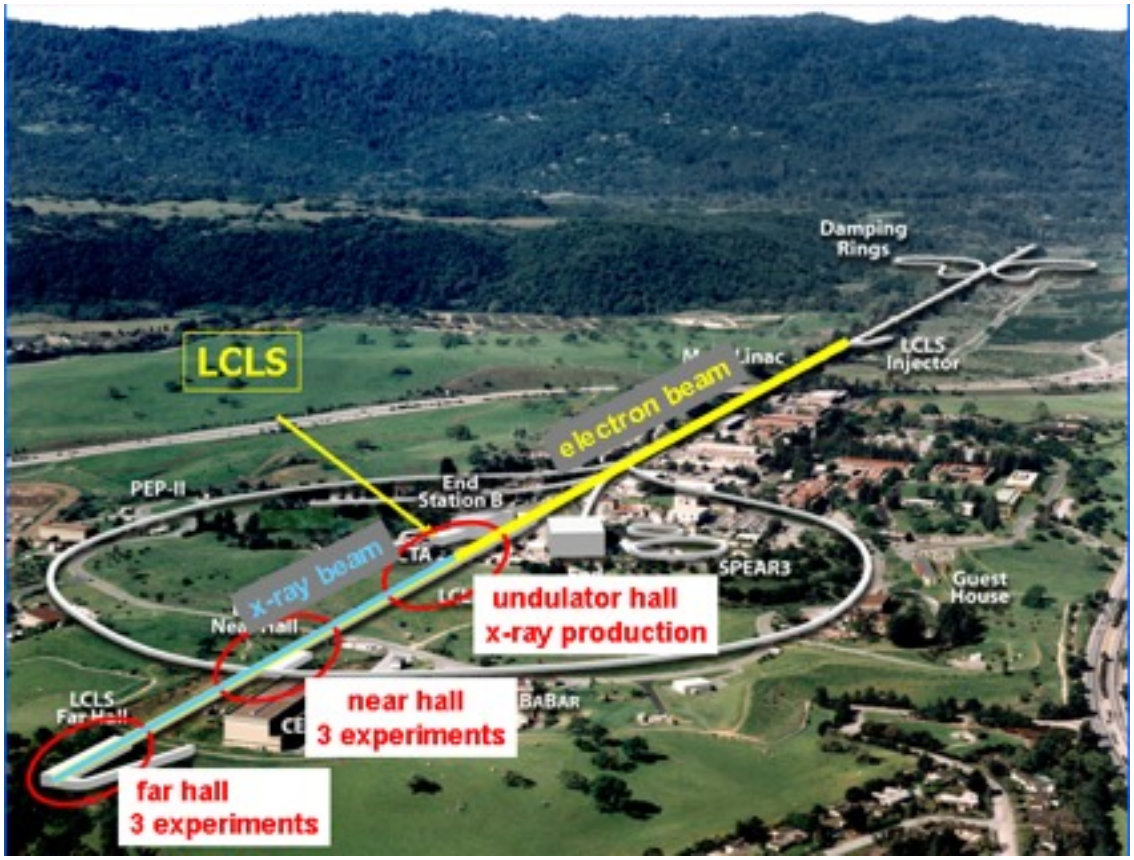


Femtosecond Two Color X-Ray Holography:

- control spins without heating
- determine angular momentum paths (L, S & lattice microscopy)
- manipulate exchange coupling

H. A. Dürr, Complexity 2010

We are on the way ...



- Lasing down to 500 eV
- Short pulse mode <10fs