WHY ARE SPIN WAVE EXCITATIONS ALL IMPORTANT IN NANOSCALE MAGNETISM ?

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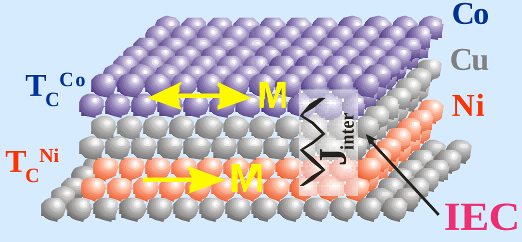
1. Element specific magnetizations and T_C's in trilayers.
2. Interlayer exchange coupling and its T-dependence.
3. Gilbert damping versus magnon-magnon scattering.



A whole variety of experiments on nanoscale magnets are available nowadays. Unfortunately many of the data are analyzed using theoretical *static mean field (MF) model*, e. g. by assuming only magnetostatic interactions of multilayers, static exchange interaction, or static interlayer exchange coupling (IEC), etc. We will show that such a mean field ansatz is insufficient for nanoscale magnetism. 3 cases will be discussed to demonstrate the importance of *higher order spin-spin correlations* in low dimensional magnets.

Spin-Spin correlation function $\frac{\partial}{\partial t}\langle\langle S_i^+ S_j^- \rangle\rangle \rightarrow$

$$S_i^z S_j^+ \approx \langle S_i^z \rangle S_j^+ - \langle S_i^- S_i^+ \rangle S_j^+ - \langle S_i^- S_j^+ \rangle S_i^+ + \cdots$$

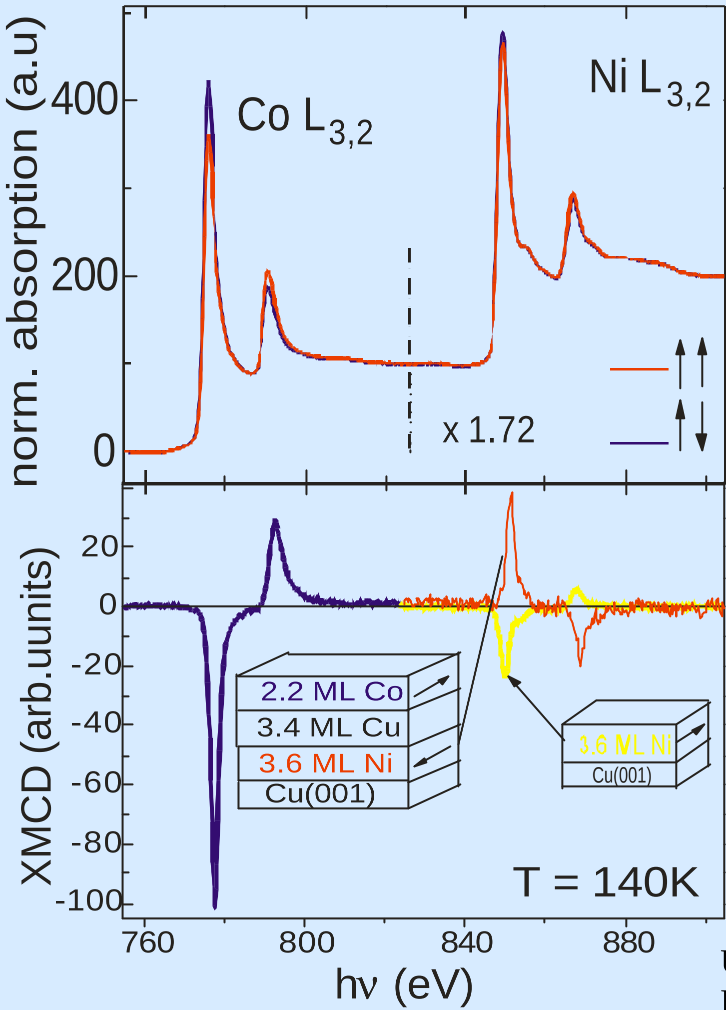
$\longleftarrow$ RPA $\longrightarrow$

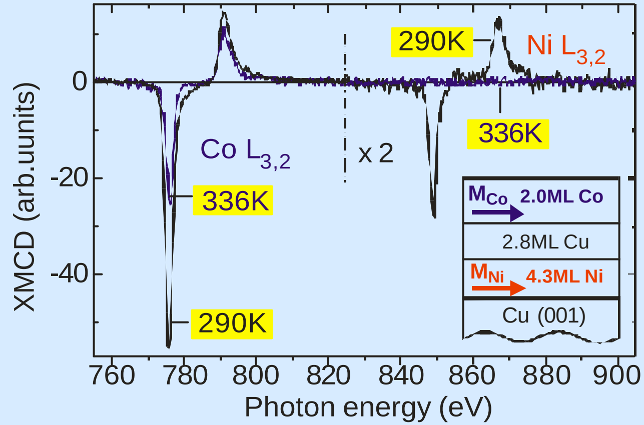
The damping of spin motions in ultrathin films: Is the Landau–Lifschitz–Gilbert phenomenology applicable?☆

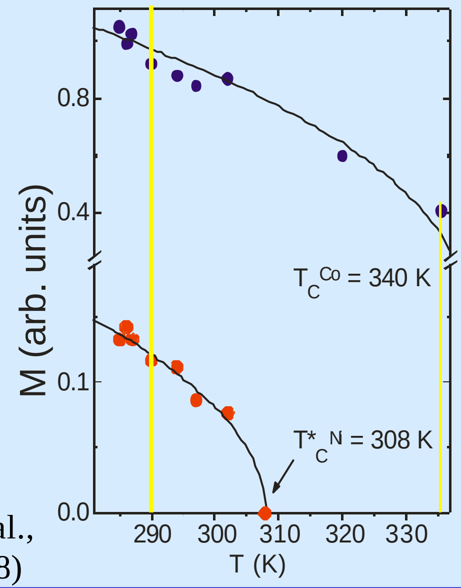
D.L. Mills[a,*], Rodrigo Arias[b]

Physica B **384**, 147 (2006)

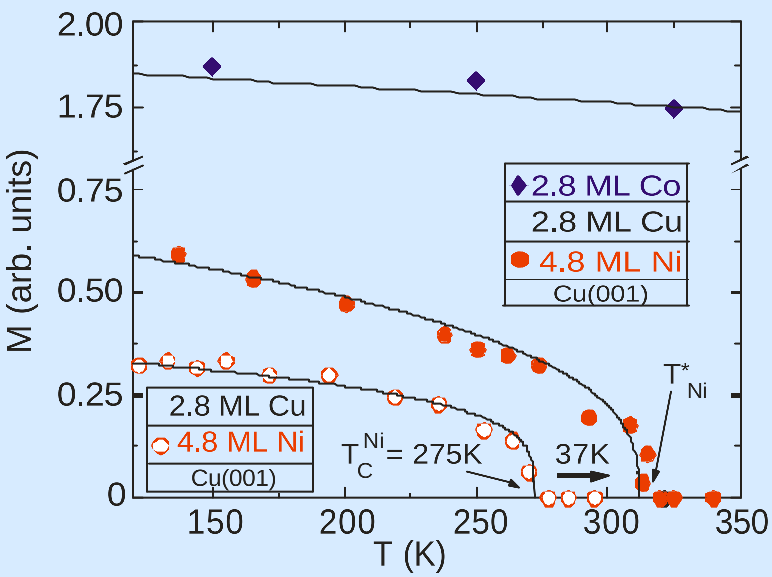
1. Element specific magnetizations and T_C's in trilayers.



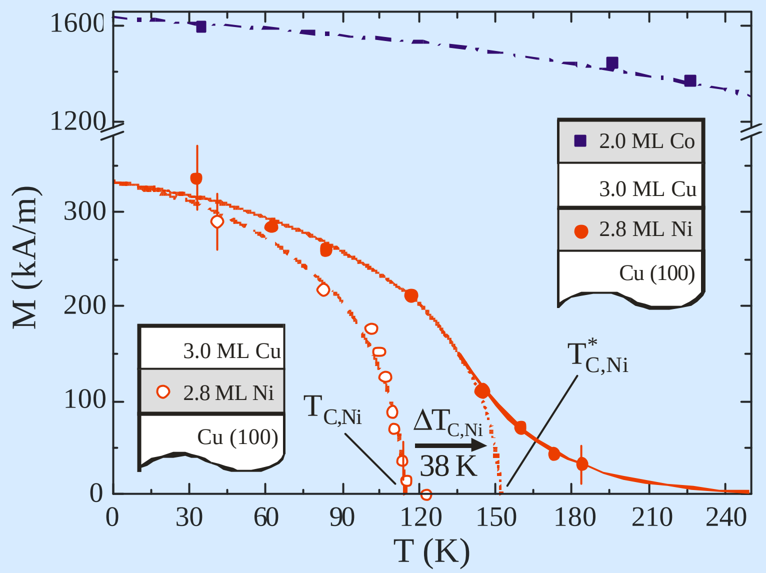




U. Bovensiepen et al.,
PRL **81**, 2368 (1998)



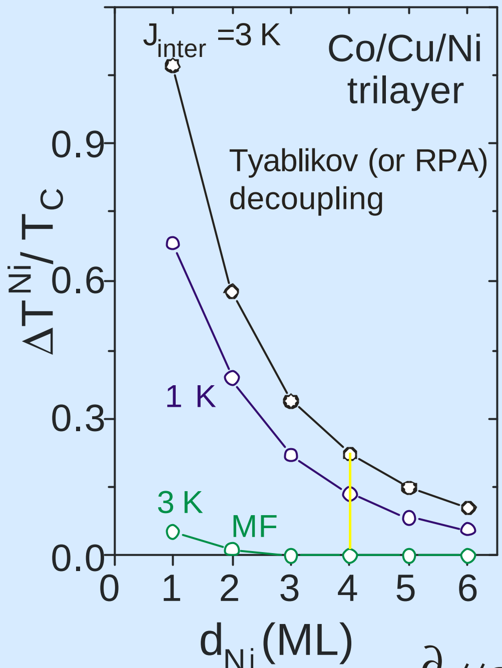
P. Poulopoulos, K. B., Lecture Notes in Physics **580**, 283 (2001)



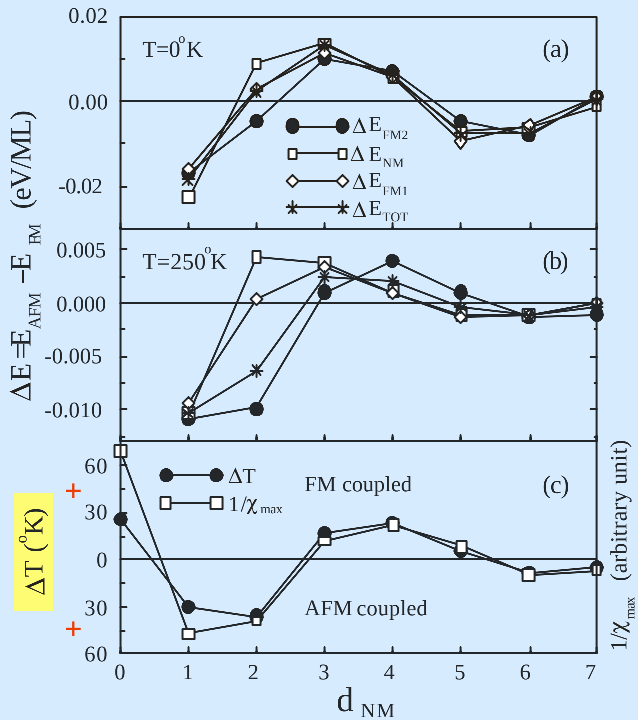
A. Scherz et al. PRB **65**, 24411 (2005)

Enhanced spin fluctuations in 2D (theory)

P. Jensen et al. PRB **60**, R14994 (1999)



J.H. Wu et al. J. Phys.: Condens. Matter **12** (2000) 2847



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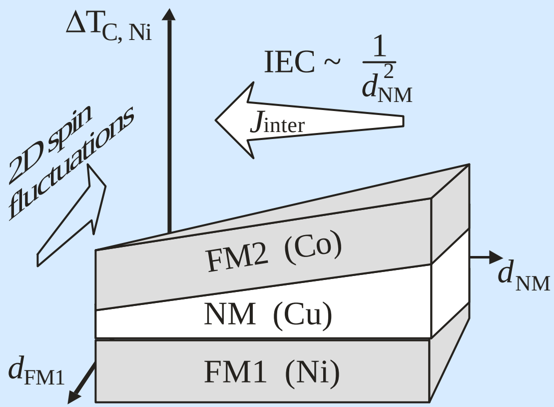
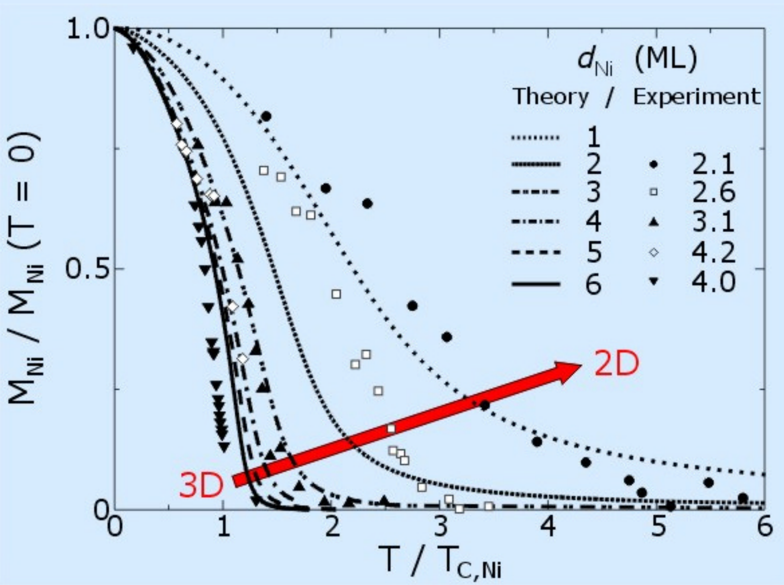
← RPA →

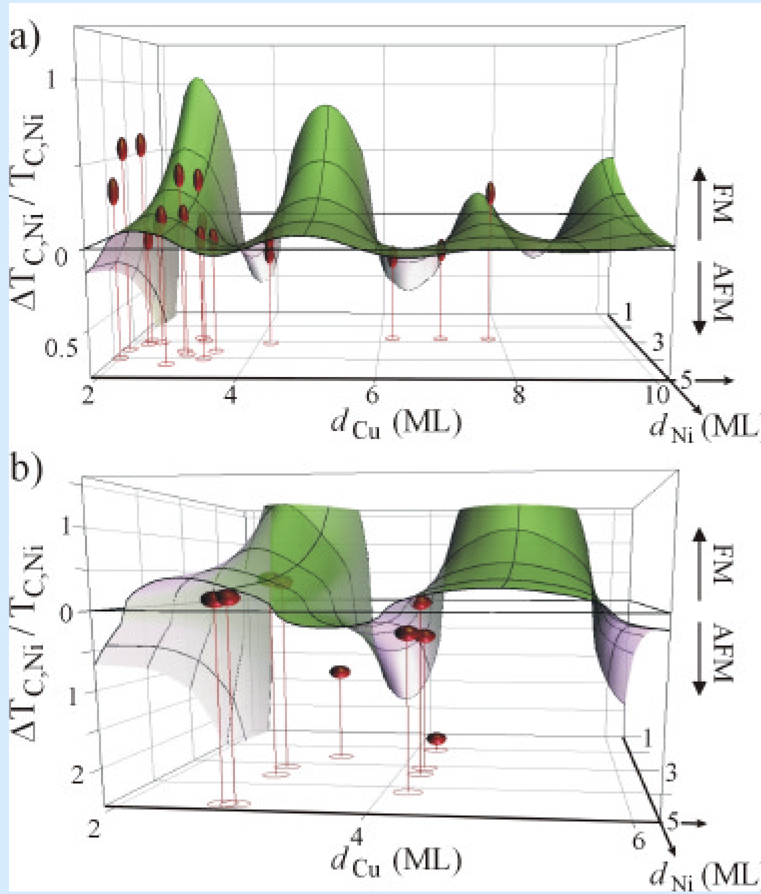
$\langle S_i^z \rangle S_j^+$, mean field ansatz (Stoner model) is insufficient to describe spin dynamics at interfaces of nanostructures

Single band Hubbard model:
Simple Hartree-Fock (Stoner) ansatz is insufficient
Higher order correlations are needed to explain T_C-shift

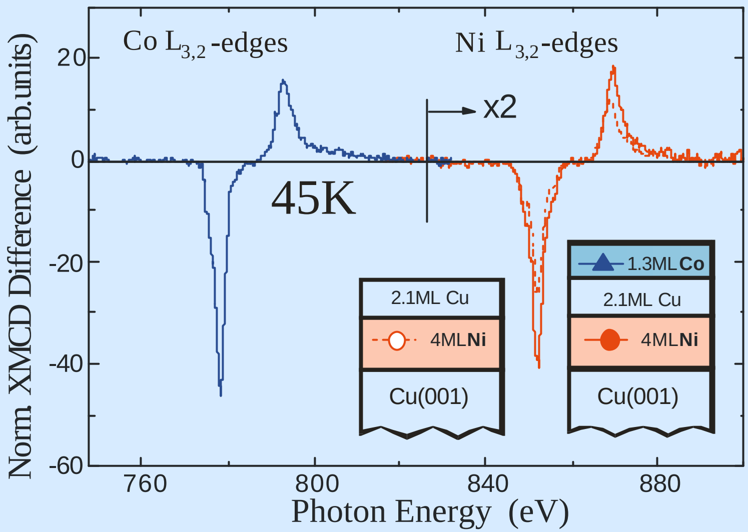
Evidence for giant spin fluctuations (A. Scherz et al. PRB **72**, 54447 (2005))

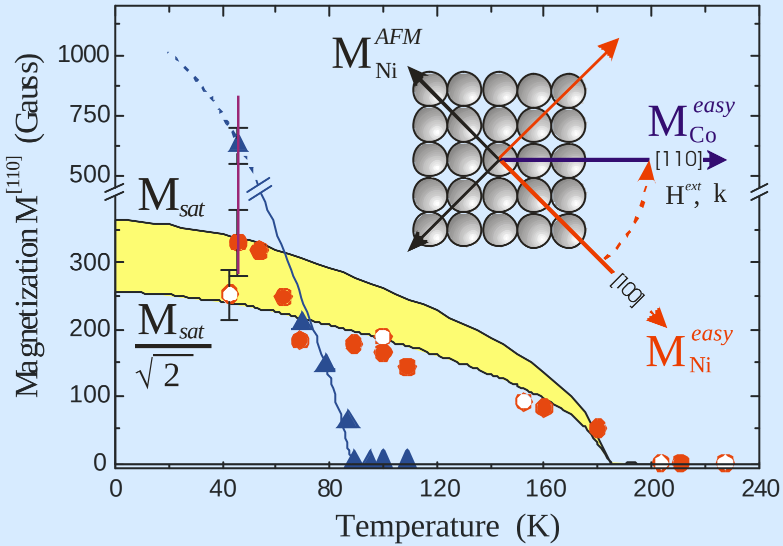






Crossover of $M_{Co}(T)$ and $M_{Ni}(T)$

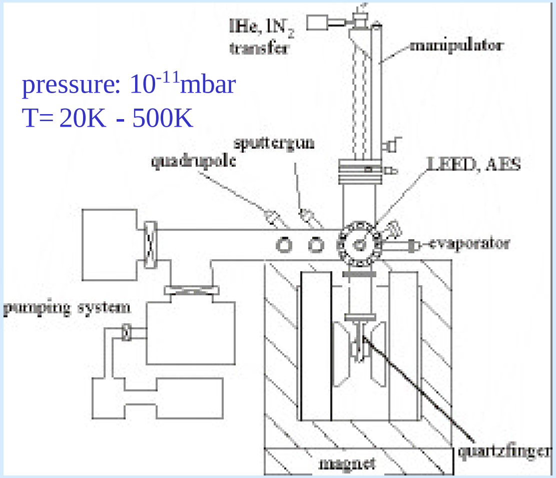


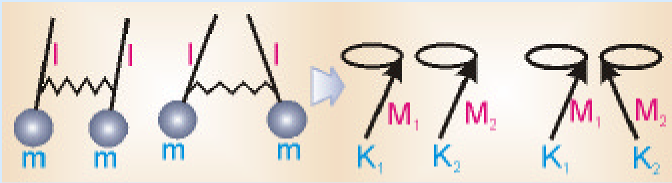


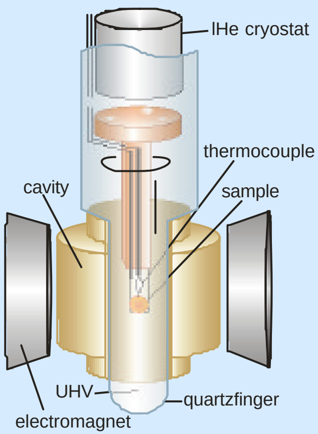
Two order parameter of T_C^{Ni} and T_C^{Co}
A further reduction in symmetry happens at T_c^{low}

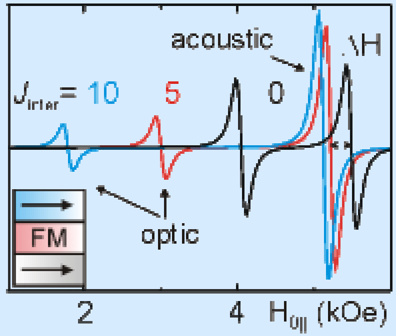
A. Scherz et al. J. Synchrotron Rad. **8**, 472 (2001)

2. IEC in coupled films measured withUHV-FMR

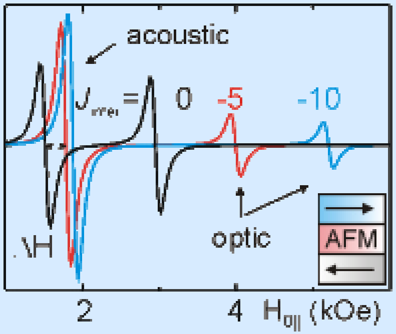




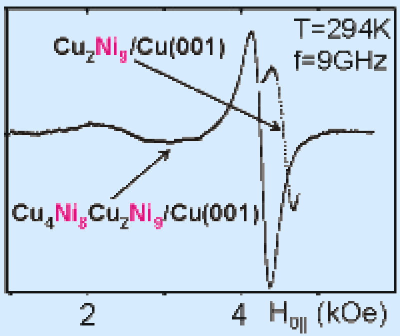




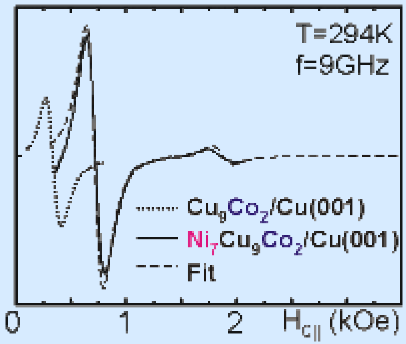
theory



FMR



exp.



J. Lindner, K. B. Topical Rev., J. Phys. Condens. Matter **15**, R193-R232 (2003)

Interlayer exchange coupling and its T-dependence.

P. Bruno, PRB **52**, 411 (1995)

$$J_{inter} = J_{inter,0} \left[\frac{T/T_0}{\sinh(T/T_0)} \right] \qquad T_0 = \hbar v_F / 2\pi k_B d$$

N.S. Almeida et al. PRL **75**, 733 (1995)

$$J_{inter} = J_{inter,0} \left[1-(T/T_C)^{3/2} \right]$$

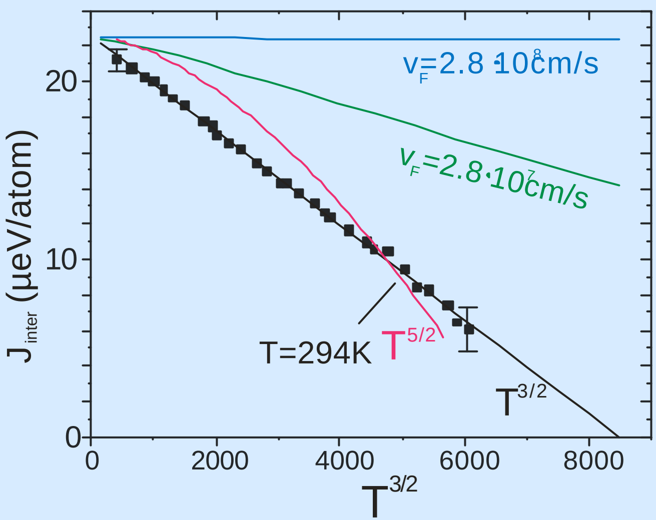
$Ni_7Cu_9Co_2/Cu(001)$

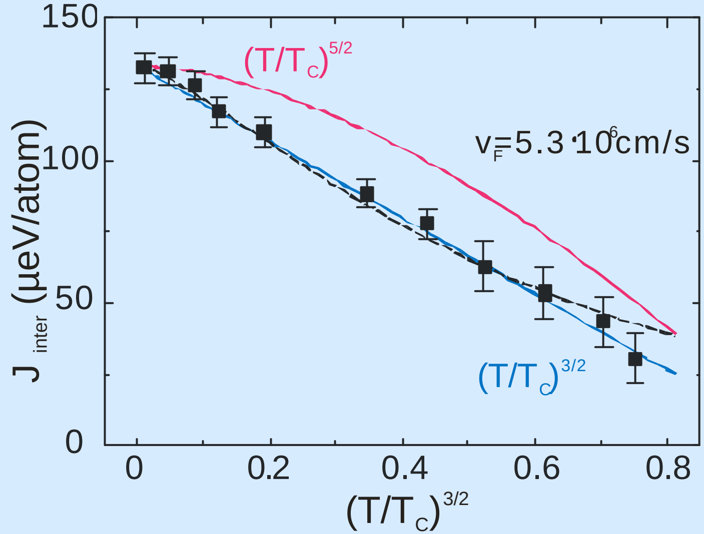
T=55K - 332K

J. Lindner et al.
PRL **88**, 167206 (2002)

$(Fe_2V_5)_{50}$

T=15K - 252K, T_C=305K

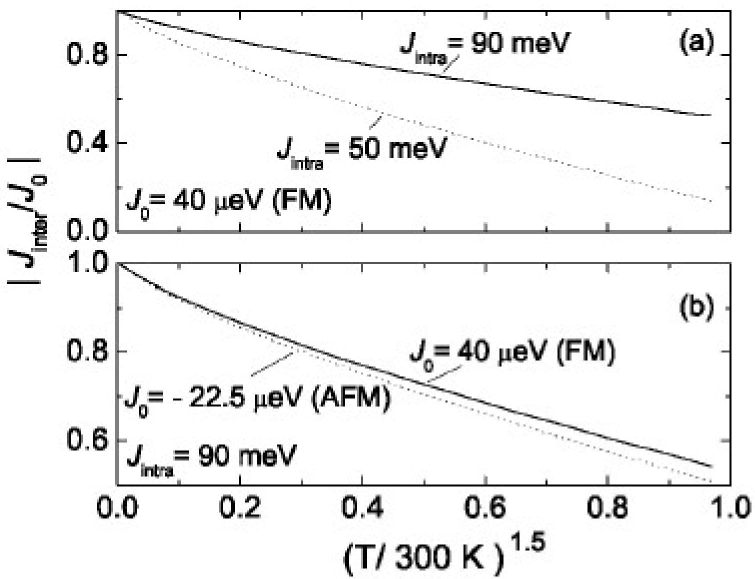


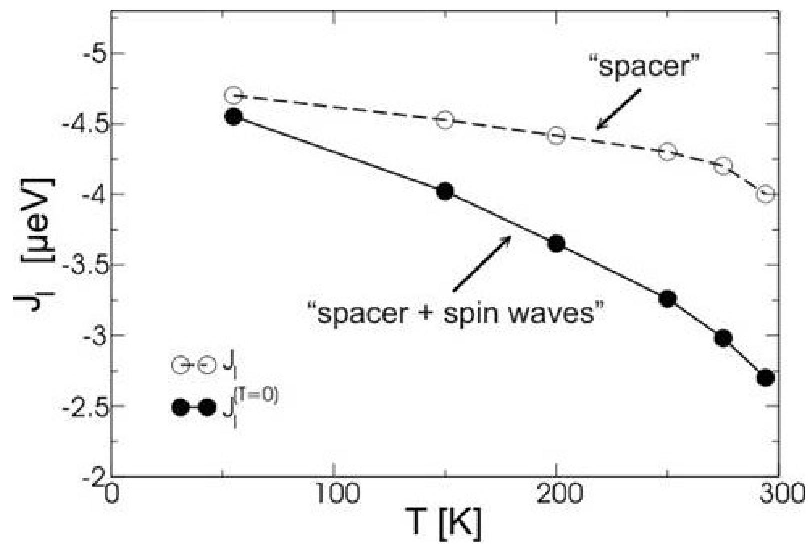


S. Schwieger, W. Nolting, PRB **69**, 224413 (2004)

All contributions due to the spacer, interface and magnetic layers, nevertheless give an effective power law dependence on the temperature:

$$J(T) \approx 1 - AT^n, \quad n \approx 1.5 \qquad (1)$$



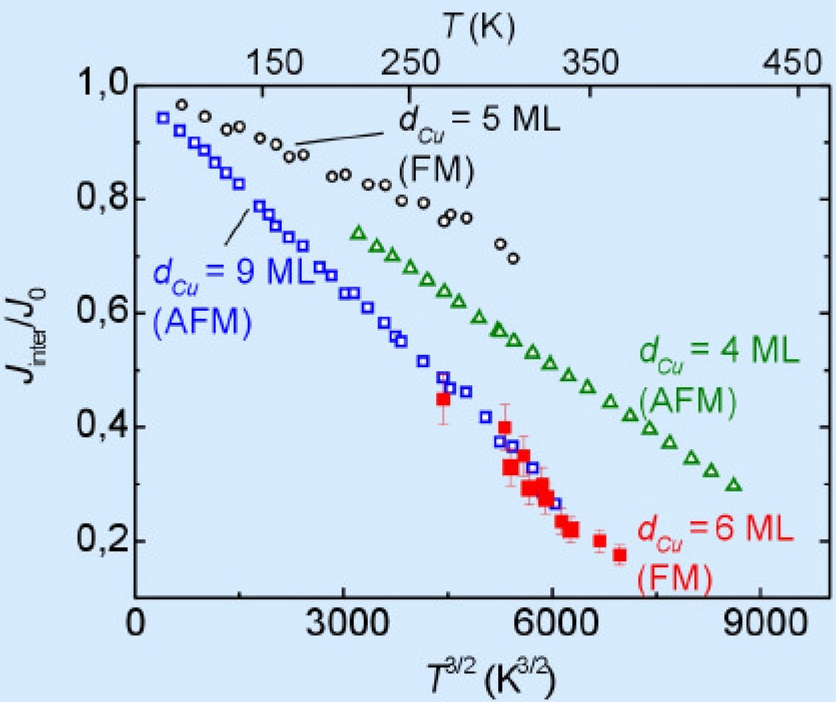


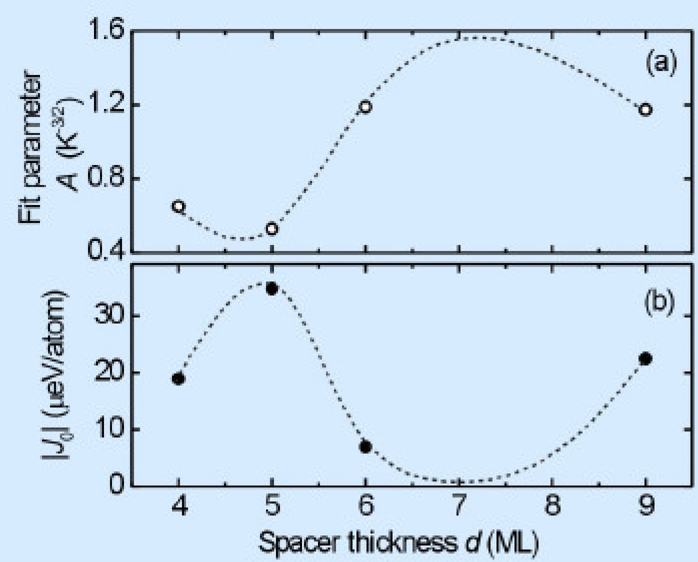
The dominant role of thermal magnon excitation in the temperature dependence of the interlayer exchange coupling: experimental verification

S. S. Kalarickal,* X. Y. Xu,† K. Lenz, W. Kuch, and K. Baberschke‡
Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany
(Dated: March 20, 2007)

PRB (2007) in print

$J(T) \approx 1 - AT^n$, with $n \approx 1.5$



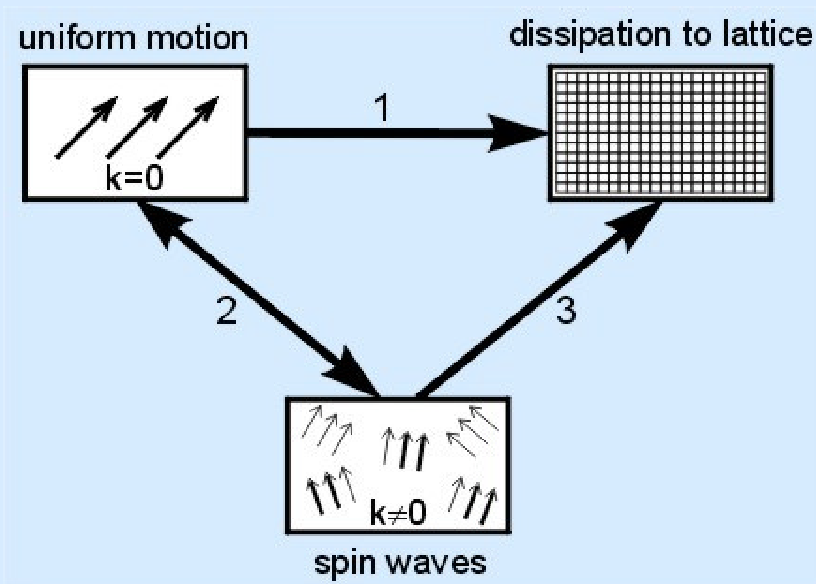


3. Gilbert damping versus magnon-magnon scattering.

1834 IEEE TRANSACTIONS ON MAGNETICS, VOL. 34, NO. 4, JULY 1998

THEORY OF THE MAGNETIC DAMPING CONSTANT

Harry Suhl
Department of Physics, and Center for Magnetic Recording Research, Mail Code 0319,
University of California-San Diego, La Jolla, CA 92093-0319.



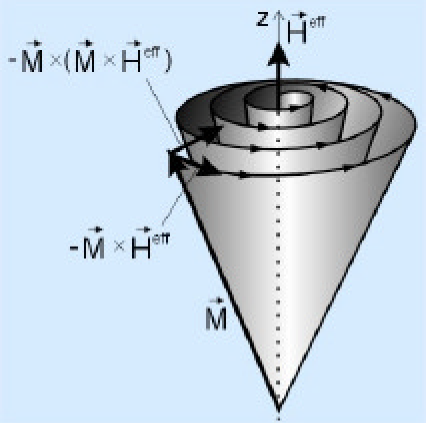
Landau-Lifshitz-Gilbert equation(1935)

$$\frac{\mathrm{d}\mathbf{m}}{\mathrm{d}t} = -g\ \mathbf{m}\times\mathbf{H}_{\mathrm{eff}} + a\ \mathbf{m}\times\frac{\mathrm{d}\mathbf{m}}{\mathrm{d}t}$$

$$T \sim \frac{1}{aw}$$

Gilbert damping

|M|=const.



Bloch-Bloembergen Equation (1956)

$$\frac{\mathrm{d}m_z}{\mathrm{d}t} = -g\,(\,\mathbf{m}\times\mathbf{H}_{\mathrm{eff}}\,)_z - \frac{m_z - M_S}{T_1}$$

spin-lattice relaxation

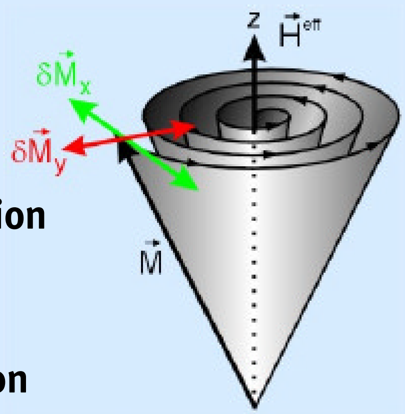
(longitudinal)

$$\frac{\mathrm{d}m_{x,y}}{\mathrm{d}t} = -g\,(\,\mathbf{m}\times\mathbf{H}_{\mathrm{eff}}\,)_{x,y} - \frac{m_{x,y}}{T_2}$$

spin-spin relaxation

(transverse)

M_z=const.



FMR Linewidth - Damping

Landau-Lifshitz-Gilbert-Equation

$$\frac{1}{\gamma}\frac{\partial M}{\partial t} = -(M\times H_{eff}) + \frac{G}{\gamma M_S^2}\left(M\times\frac{\partial M}{\partial t}\right)$$

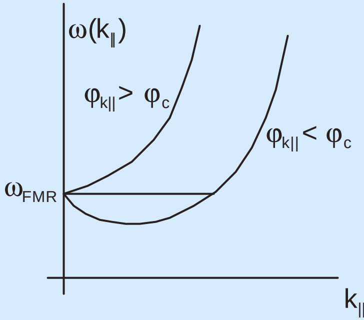
viscous damping,
energy dissipation

Gilbert-damping ~ω

$$\Delta H^{Gil}(\omega) = \frac{G}{\gamma^2 M_S}\,\omega$$

2-magnon-scattering

R. Arias, and D.L. Mills, *Phys. Rev. B* ***60****, 7395 (1999);*
D.L. Mills and S.M. Rezende in
‘*Spin Dynamics in Confined Magnetic Structures* ‘,
edt. by B. Hillebrands and K. Ounadjela, Springer Verlag



$$\Delta H^{2Mag}(\omega) = \Gamma \arcsin\sqrt{\frac{[\omega^2+(\omega_0/2)^2]^{1/2} - \omega_0/2}{[\omega^2+(\omega_0/2)^2]^{1/2} + \omega_0/2}}$$

$\omega_0 = \gamma(2K_{2\perp} - 4\pi M_S)$, $\gamma = (\mu_B/h)g$
$K_{2\perp}$ - uniaxial anisotropy constant
M_S - saturation magnetization

- Gilbert damping contribution:
- linear in frequency
- two-magnon excitations (thin films): non-linear frequency dependence

$$\Delta H_{2-\mathrm{magnon}}(w) = \Gamma \arcsin\sqrt{\frac{\sqrt{w^2+(w_0/2)^2}-w_0/2}{\sqrt{w^2+(w_0/2)^2}+w_0/2}}$$

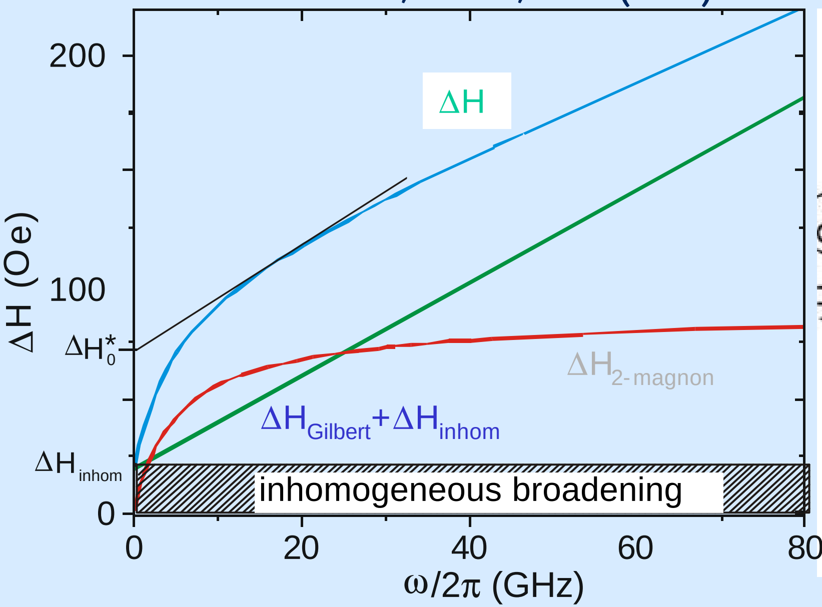
with $w_0 = gM_{\mathrm{eff}}$

real relaxation – no inhomogeneous broadening

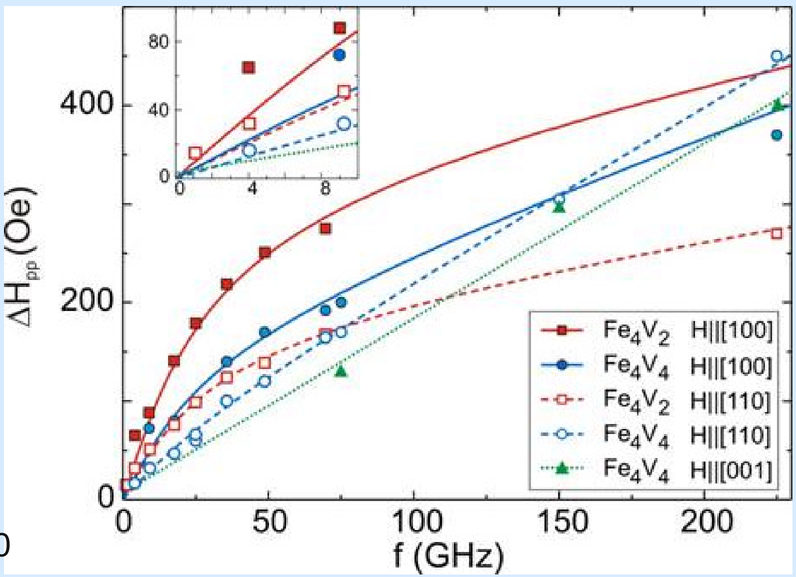
two-magnon damping dominates Gilbert damping by two orders of magnitude:

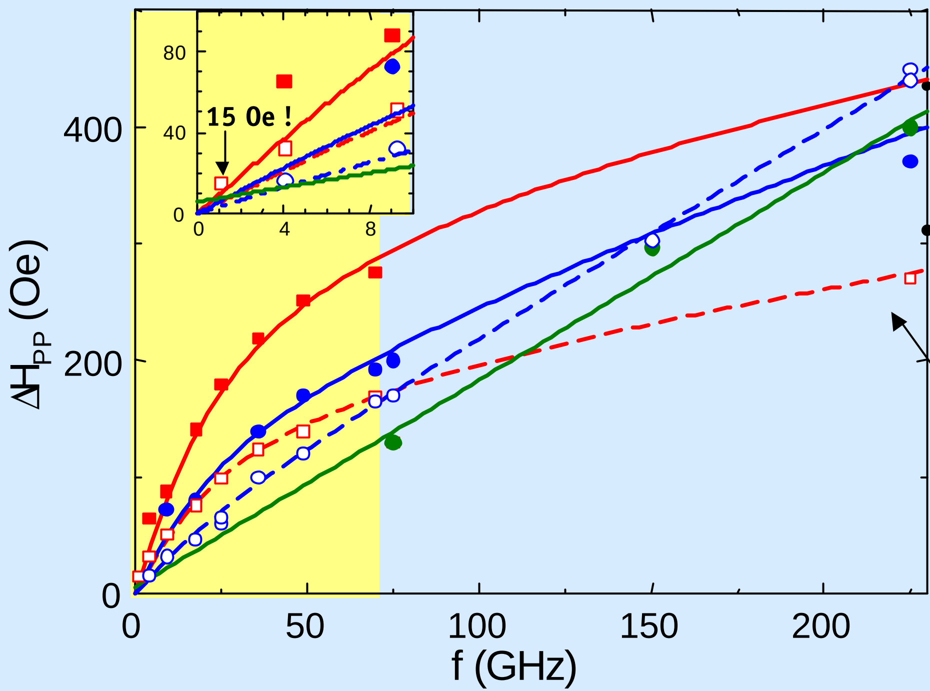
$1/T_2 \sim 10^9\ s^{-1}$ vs. $1/T_1 \sim 10^7\ s^{-1}$

R. Arias et al., PRB 60, 7395 (1999)



K. Lenz et al., PRB 73, 144424 (2006)





two-magnon scattering observed in Fe/V superlattices –

*J. Lindner et al., PRB **68**, 060102(R) (2003)*

HF FMR *K. Lenz et al. PRB **73,** 144424 (2006)*

	Γ (kOe)	γ·Γ (10^8 s^{-1})	G (10^8 s^{-1})	α (10^{-3})	ΔH_0 (Oe)
■ Fe_4V_2 ; H||[100]	0.270	50.0	0.26	1.26	0
● Fe_4V_4 ; H||[100]	0.139	26.1	0.45	2.59	0
□ Fe_4V_2 ; H||[110]	0.150	27.9	0.22	1.06	0
○ Fe_4V_4 ; H||[110]	0.045	8.4	0.77	4.44	0
● Fe_4V_4 ; H||[001]	0	0	0.76	4.38	5.8

- **recent publications with similar results:**
  - Pd/Fe on GaAs(001) – network of misfit dislocations *G. Woltersdorf et al. PRB **69**, 184417 (2004)*
  - NiMnSb films on InGaAs/InP *B. Heinrich et al. JAP **95**, 7462 (2004)*

Conclusion

Higher order spin-spin correlations are important to explain the magnetism of nanostructures.

In most cases a *mean field model* is insufficient.

A phenomenological effective *Gilbert damping parameter* gives very little insight into the microscopic relaxation mechanism.

It seems to be more instructive to separate scattering mechanisms within the magnetic subsystem from the dissipative scattering into the thermal bath;

Todays advanced experiments and analysis result in:

G ≈ isotropic and Γ anisotropic.

Acknowledgement

BESSY-crew: H. Wende, C. Sorg, A. Scherz, J. Luo, X. Xu

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R. Wu, D.L. Mills, UCI; P. Jensen + K.H. Bennemann, FUB; W. Nolting, HUB

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