Nanostructured magnetic materials for high density storage applications

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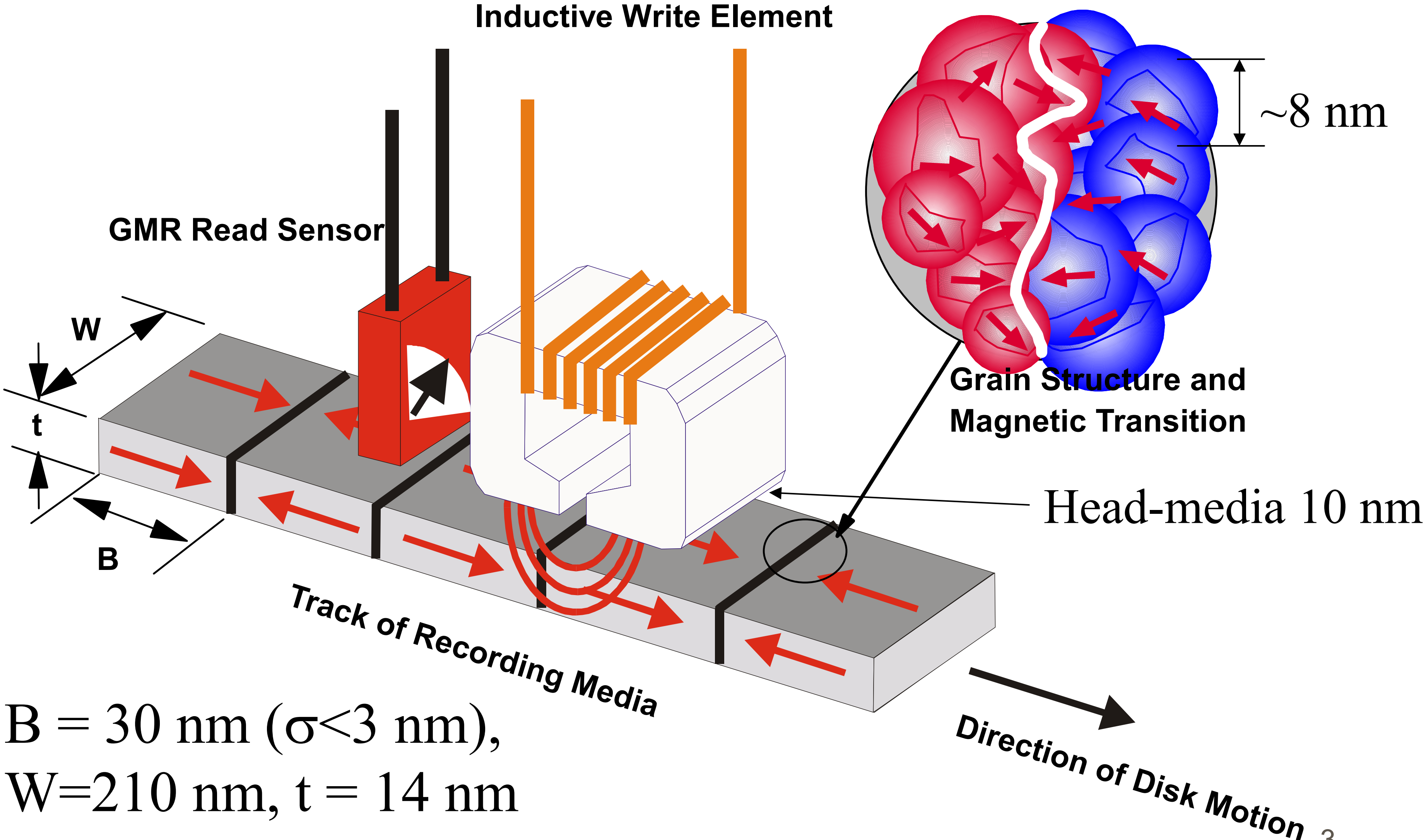
Nanostructured magnetic materials for high density storage applications

- Advanced recording media
  - Intro and issues
  - Opportunities for magnetic x-ray techniques
  - Inter- and intra-layer magnetic correlations

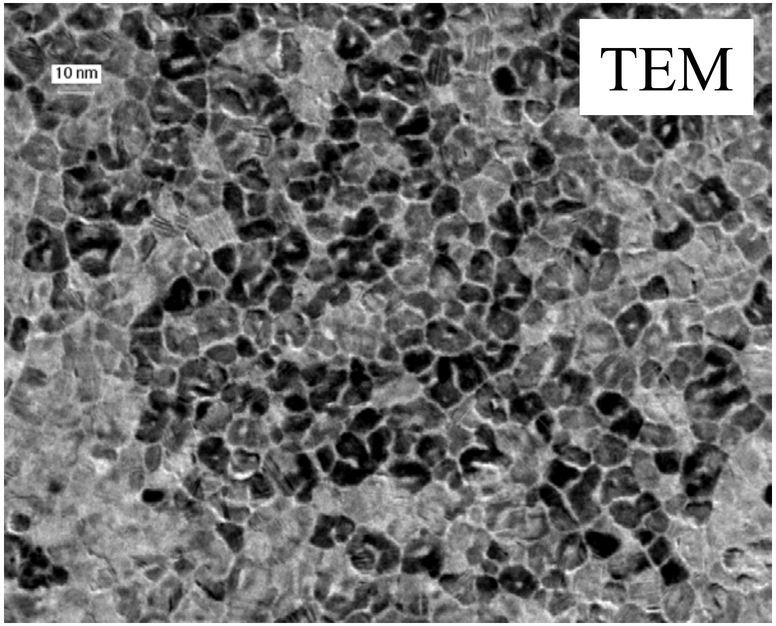
Magnetic recording components



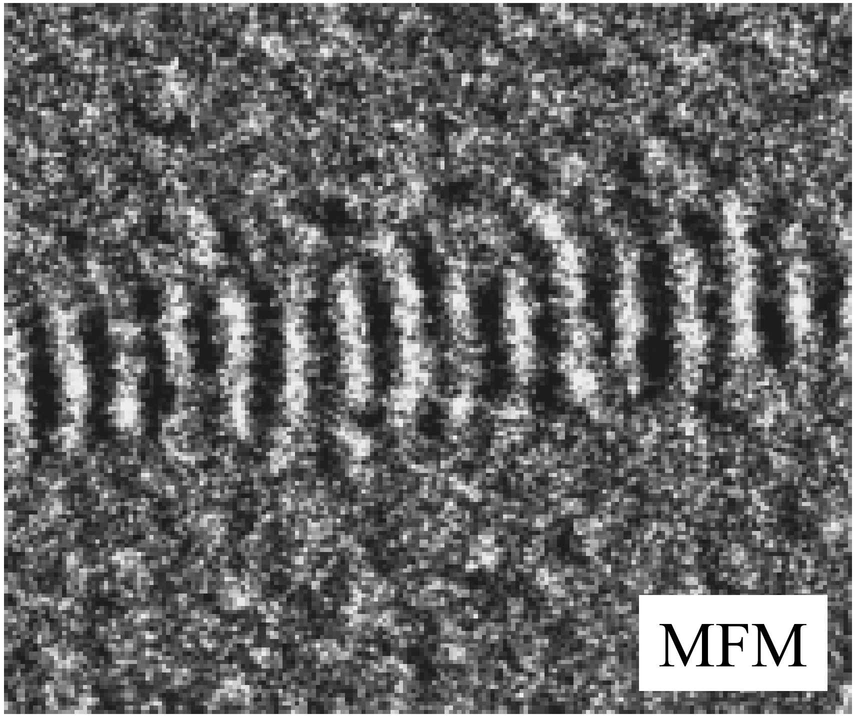
B = 30 nm (σ<3 nm),
W=210 nm, t = 14 nm

Media: TEM and MFM images

CoPtCrB alloy



100 nm <D> = 8.5 nm



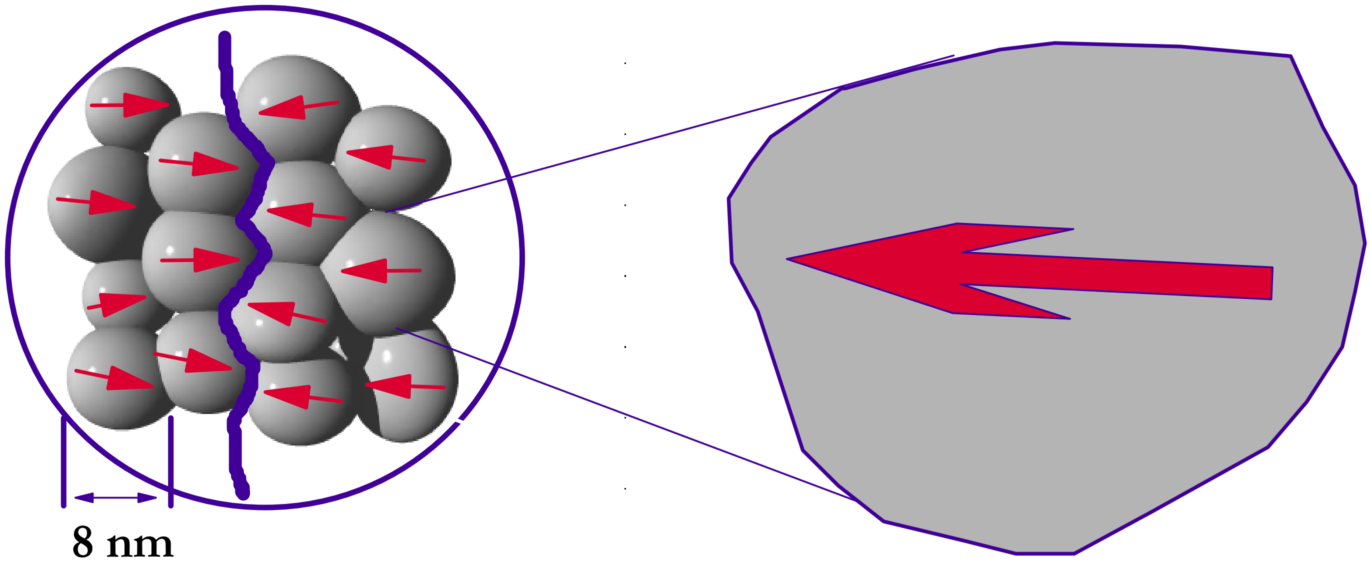
1000 nm

Eames, et al.
U. of Minn.

$SNR \propto \sqrt{N}$ # grains/bit

2x reduction in bit size/year

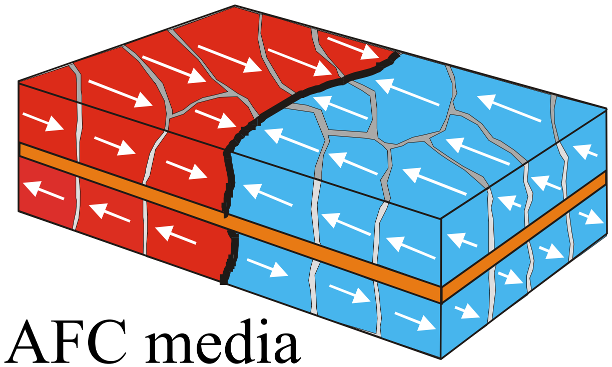
Superparamagnetic limit



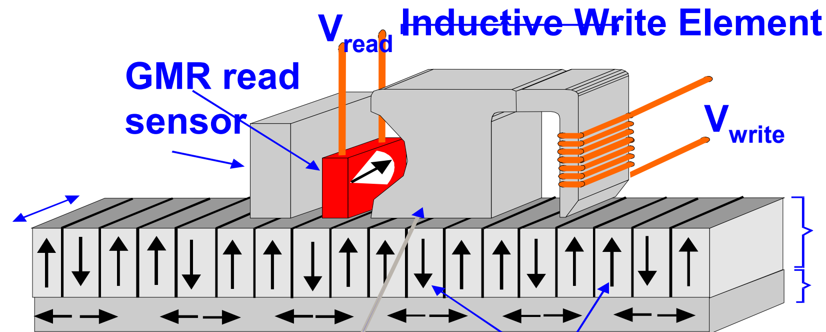
$$\textit{Particle energy } E = K_U V > 55\ k_B T$$

$$\textit{Particle coercivity } H_C = K_U/M < H_{head}$$

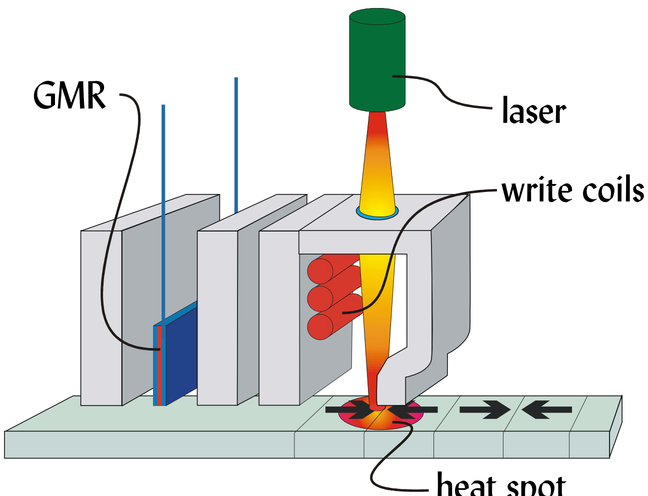
Advanced media and systems



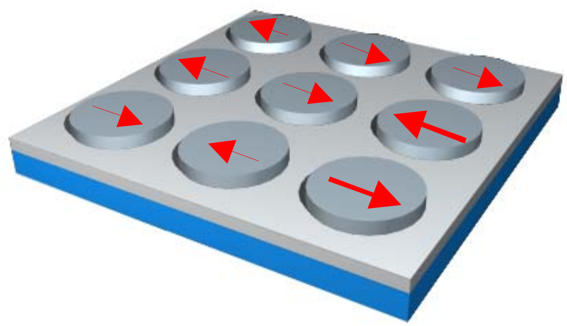
AFC media



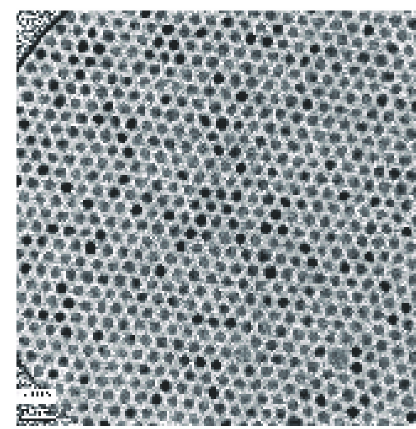
Perpendicular recording



Thermal assisted recording



patterned media



self-organized media

Moser et al., J. Phys. D: Appl. Phys. **35**, R157 (2002)

Magnetic nanostructures

- Want to link structure and magnetism
  - atomic depth resolution
  - <10 nm lateral resolution
  - <ns temporal resolution
- Want intra- and inter-layer correlations

Soft x-ray techniques

- 3d-transition metal L-edges 2p → 3d transitions (550-900)
- rare-earth M-edges 3d → 4f transitions (800-1600 eV)
- $\lambda = 1 - 2$ nm
- tuning energy gives element specificity
- tuning polarization gives magnetic specificity

Small-angle scattering

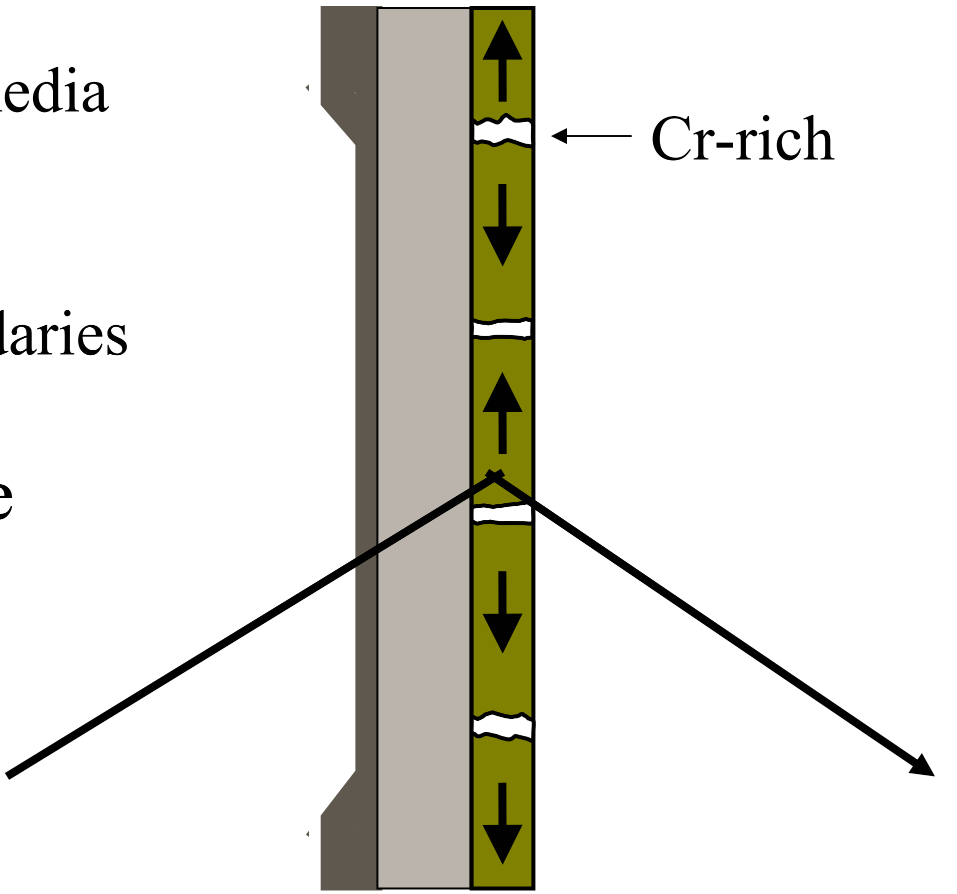
e.g. longitudinal recording media

Scattering at the Cr-edge

enhances grain boundaries

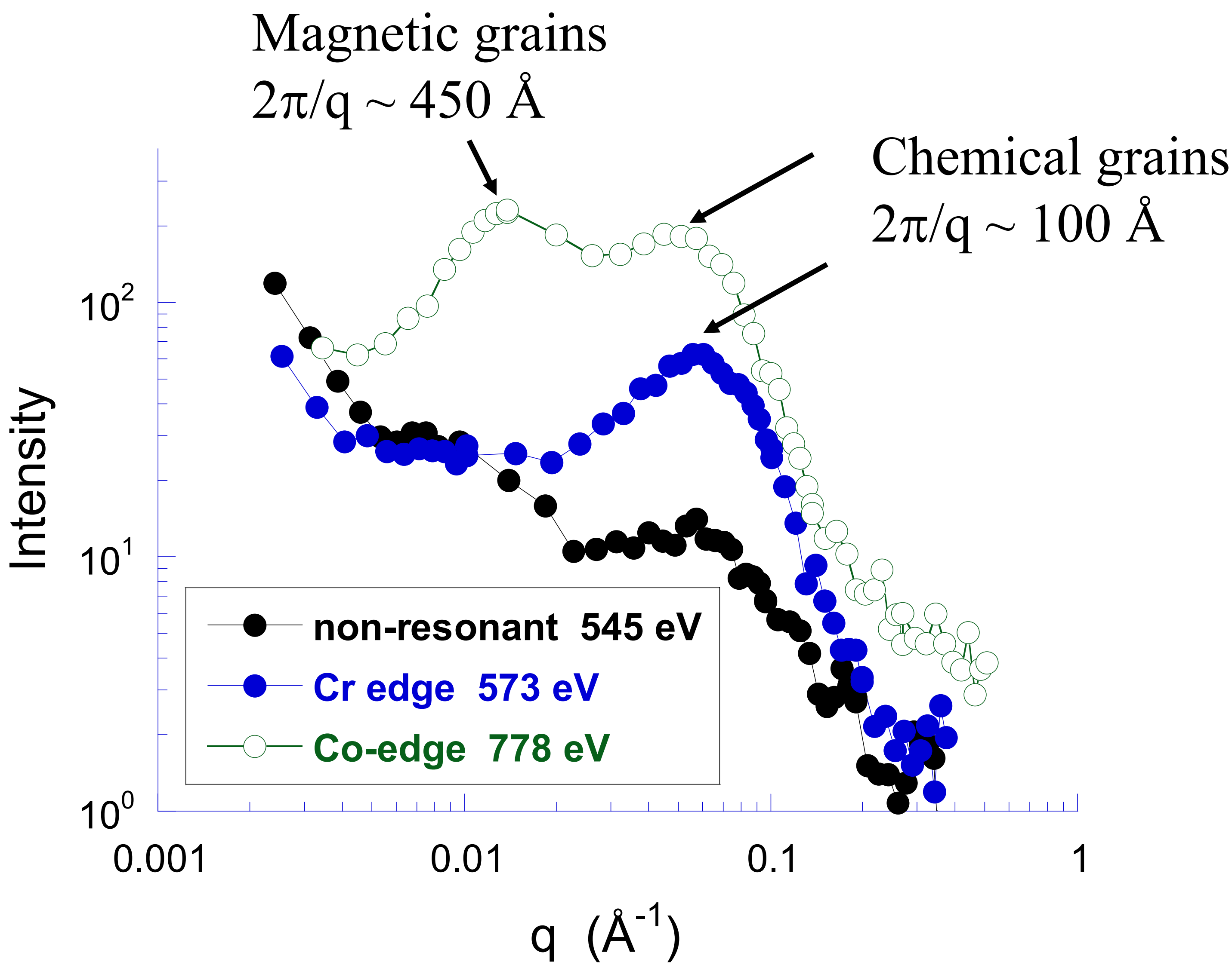
Scattering at the Co-edge

enhances grain and magnetic scattering

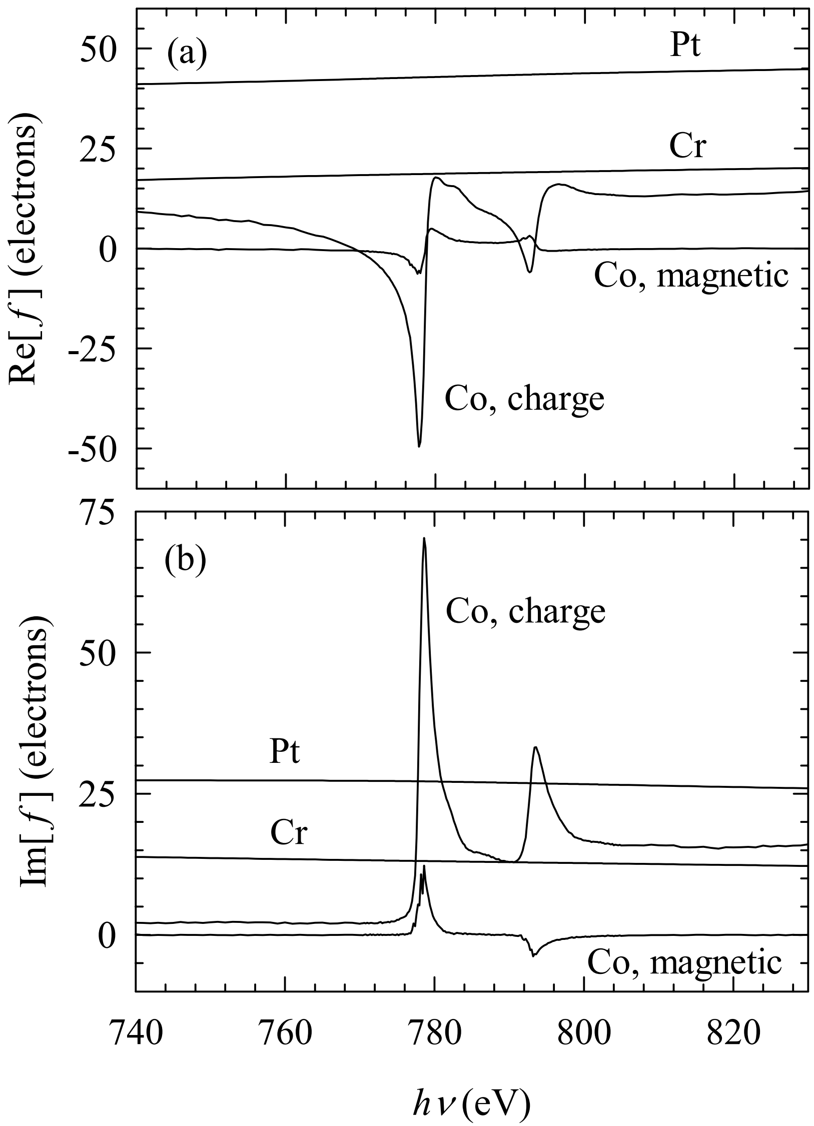


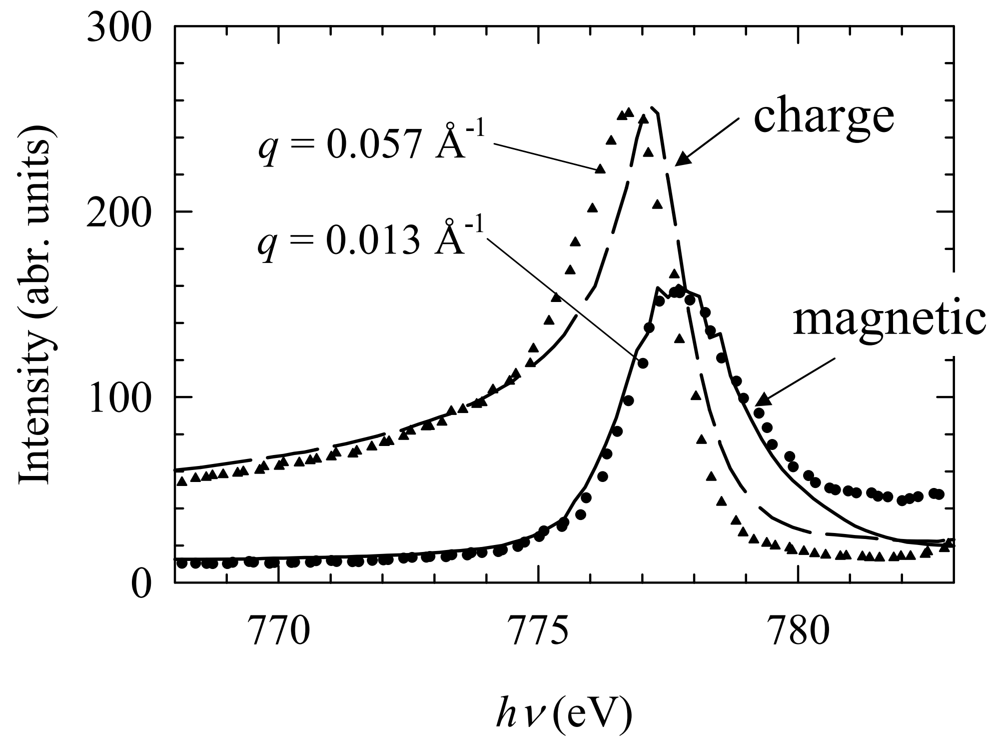
Kortright *et al*., Phys. Rev. B **64**, 092401 (2001).
Hellwig *et al*., Appl. Phys. Lett. **80**, 1234 (2002).

CoPtCr scattering



Energy dependence





Energy scans separate charge and magnetic scattering

Magnetic + charge scattering

$$I_{\pm} = |f_c s_c \pm f_m s_m|^2$$

Assumptions:
- small θ
- $\mathbf{k} \parallel \mathbf{M}$

$$\mathbf{I}_{+} \propto \mathbf{f}_{\mathbf{c}}^{2}\mathbf{s}_{\mathbf{cc}} + \mathbf{f}_{\mathbf{m}}^{2}\mathbf{s}_{\mathbf{mm}} + 2\,\mathrm{Re}[\mathbf{f}_{\mathbf{c}}^{*}\mathbf{f}_{\mathbf{m}}]\mathbf{s}_{\mathbf{cm}}$$

$$\mathbf{I}_{+} + \mathbf{I}_{-} \propto \mathbf{f}_{\mathbf{c}}^{2}\mathbf{s}_{\mathbf{cc}} + \mathbf{f}_{\mathbf{m}}^{2}\mathbf{s}_{\mathbf{mm}}$$

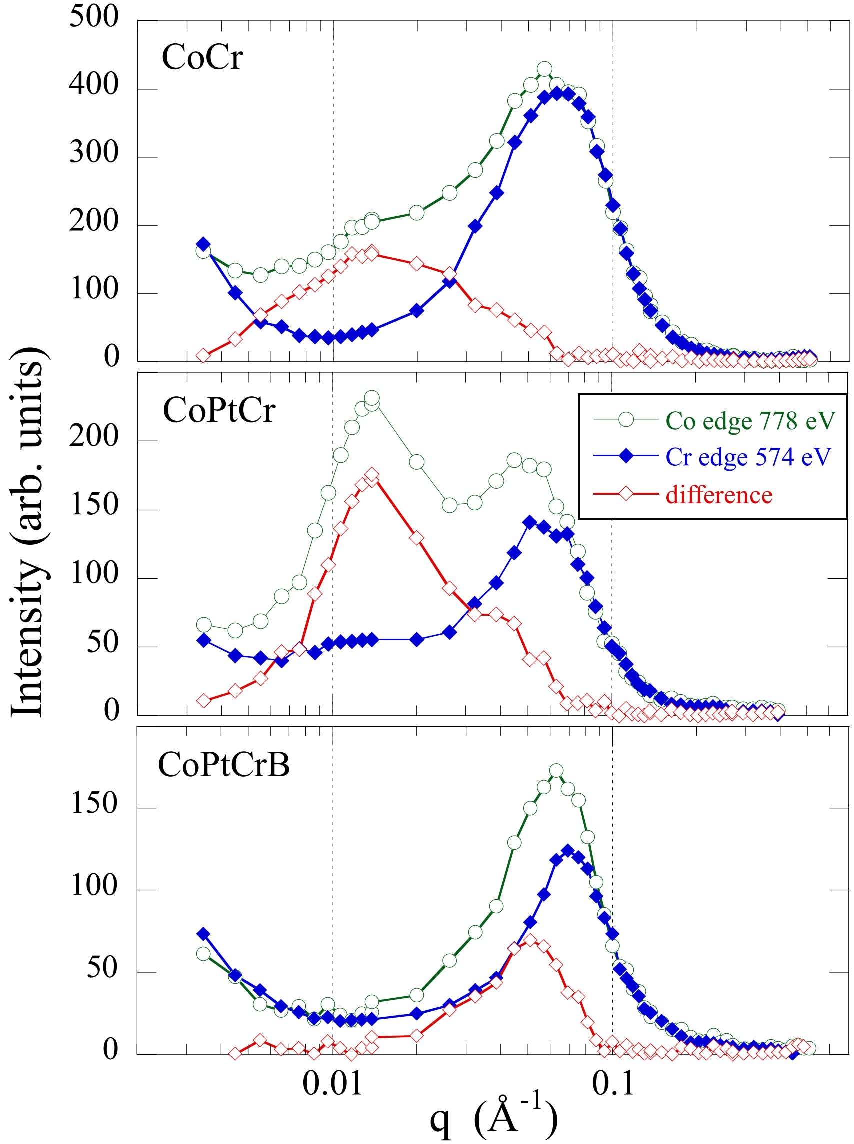
linear
pure magnetic *plus* pure charge

$$\mathbf{I}_{+} - \mathbf{I}_{-} \propto \mathrm{Re}[\mathbf{f}_{\mathbf{c}}^{*}\mathbf{f}_{\mathbf{m}}]\mathbf{s}_{\mathbf{cm}}$$

magnetic-charge cross term

see also: Osgood *et al*. JAP **85**, 4619 (1999)

Effect of B



Chemical / Magnetic

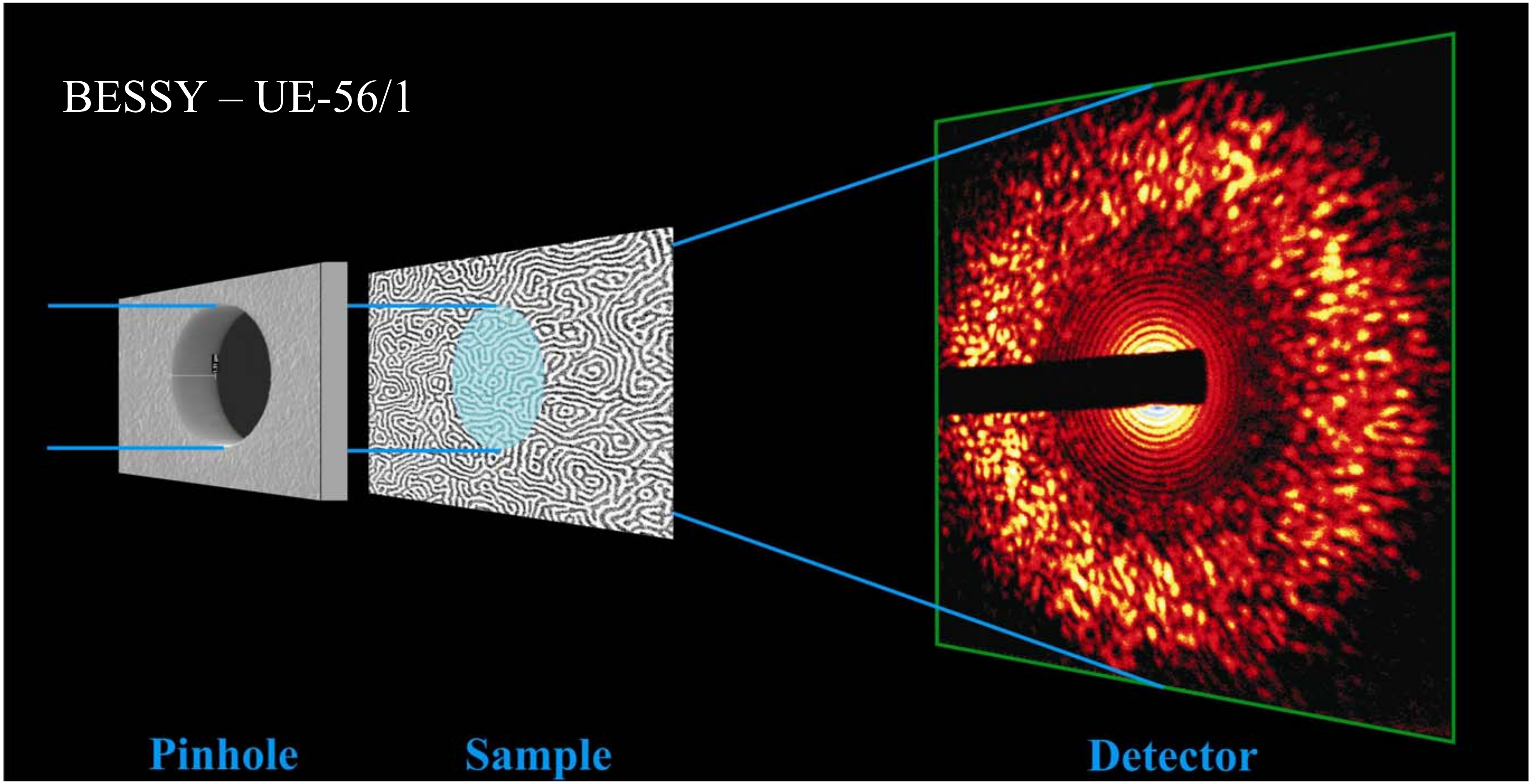
95Å / 420Å

105Å / 450Å

88Å / ~120Å

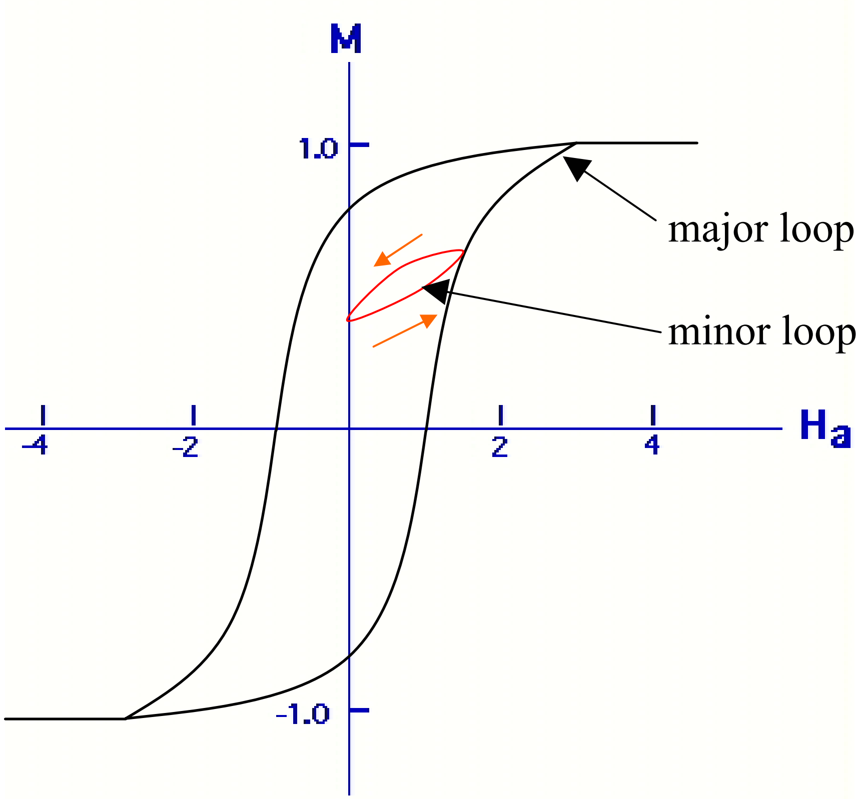
Hellwig *et al*, Appl. Phys. Lett **80**, 1234 (2002).

Coherent scattering



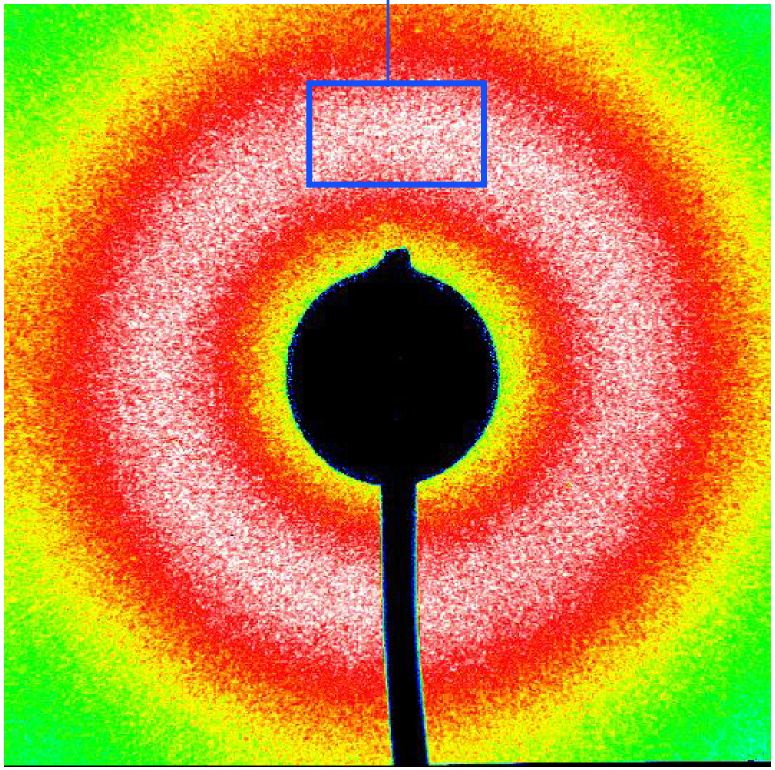
S. Eisebitt et al., Phys. Rev. B **68**, 104419 (2003).

Microscopic return point memory



Cross correlation of speckle patterns

I(x, y) * I'(x, y)

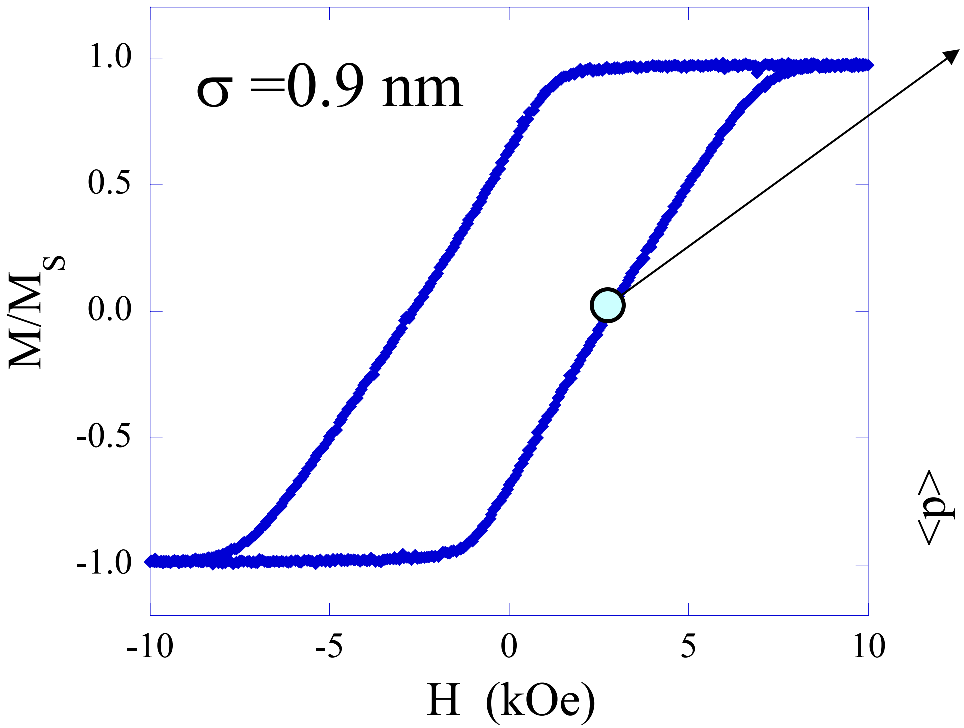


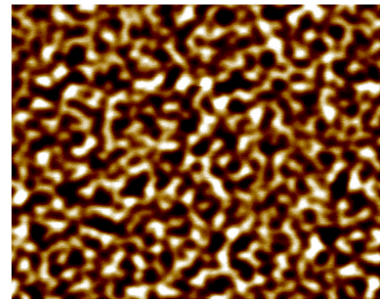
ALS, beamline 9 U. Oregon, U. Washington, LBL, Hitachi

Pierce *et al.*, Phys. Rev. Lett., **90**, 175502 (2003).

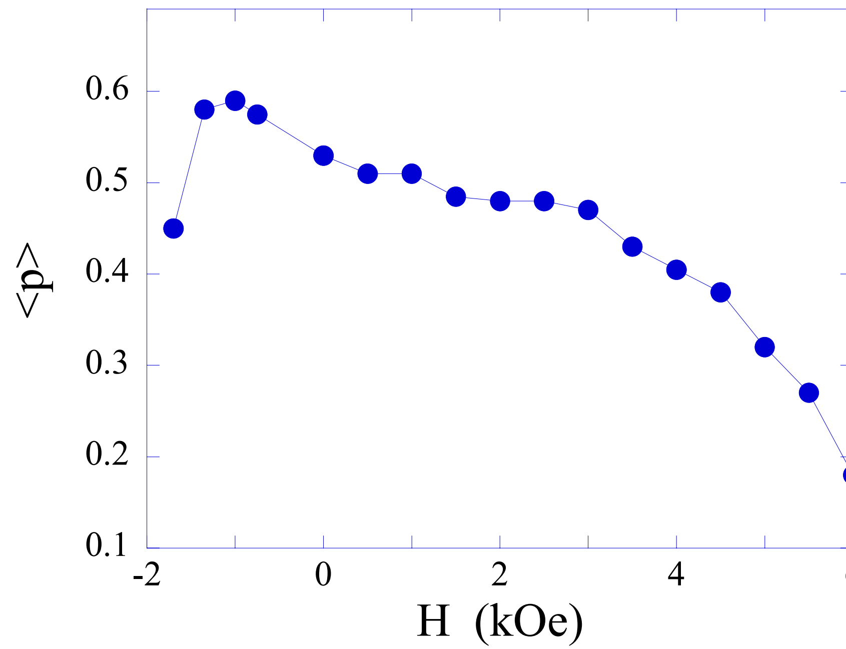
Microscopic rpm

Rough Co/Pt multilayer





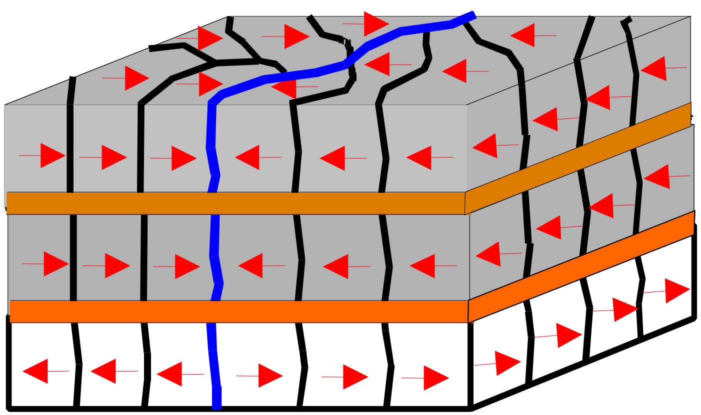
finite
microscopic rpm
on the major loop



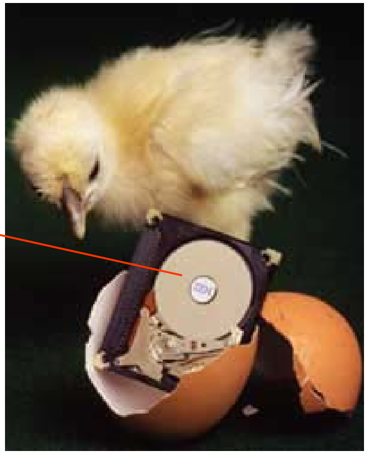
Pierce *et al*., Phys. Rev. Lett., **90**, 175502 (2003).

Inter-layer correlations

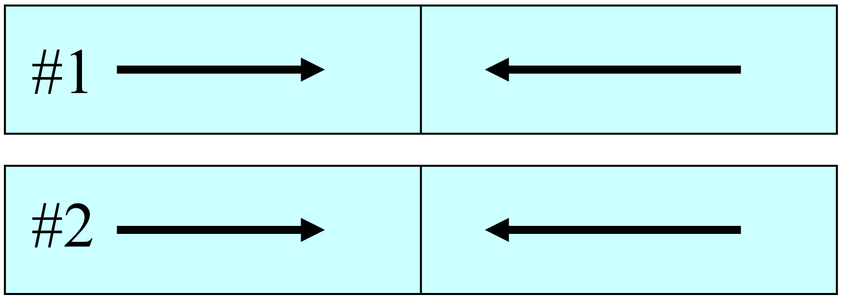
- Magnetic correlations in multilayer systems
    - Laminated media
    - Antiferromagnetically-coupled media



4 Gbyte



SNR in two layer systems



Signal = S_1 , Noise = N_1

Signal = S_2 , Noise = N_2

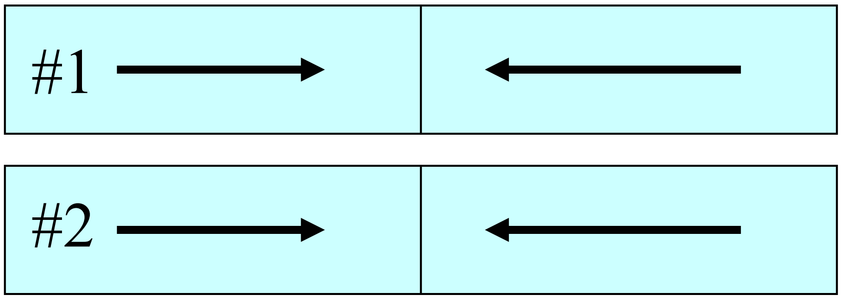
$$S = S_1 + S_2$$

$$N^2 = N_1^{\,2} + N_2^{\,2} + 2\mathbf{c}*N_1*N_1$$

c = 1 correlated noise: $N = N_1 + N_2$

SNR of the composite is the same as the individual layer

SNR in two layer systems



Signal = S_1 , Noise = N_1

Signal = S_2 , Noise = N_2

$$S = S_1 + S_2$$

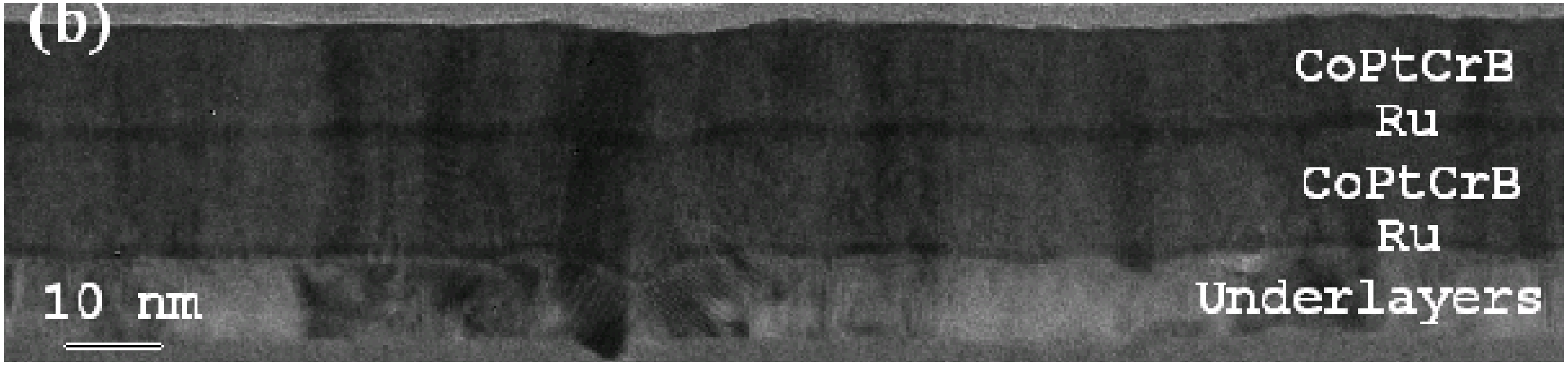
$$N^2 = N_1^{\,2} + N_2^{\,2} + 2\mathbf{c} * N_1 * N_1$$

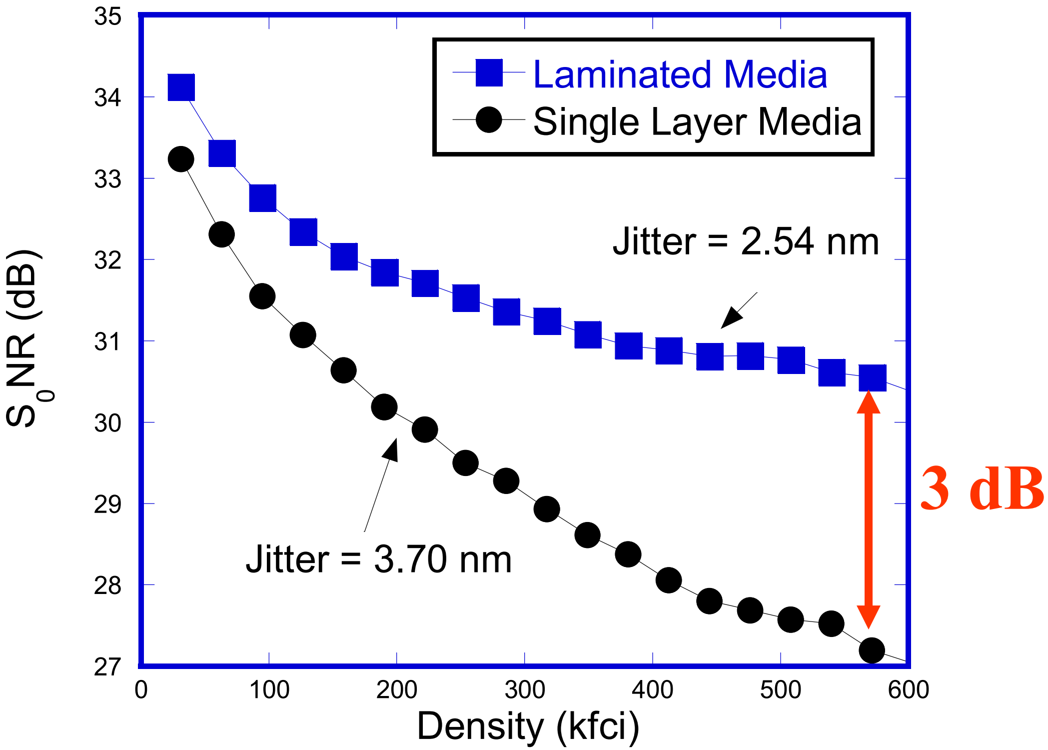
c = 0 uncorrelated noise: $N = \sqrt{}(N_1^{\,2} + N_2^{\,2})$

laminated media

SNR improves 3 dB over the individual layer

SNR in two layer systems

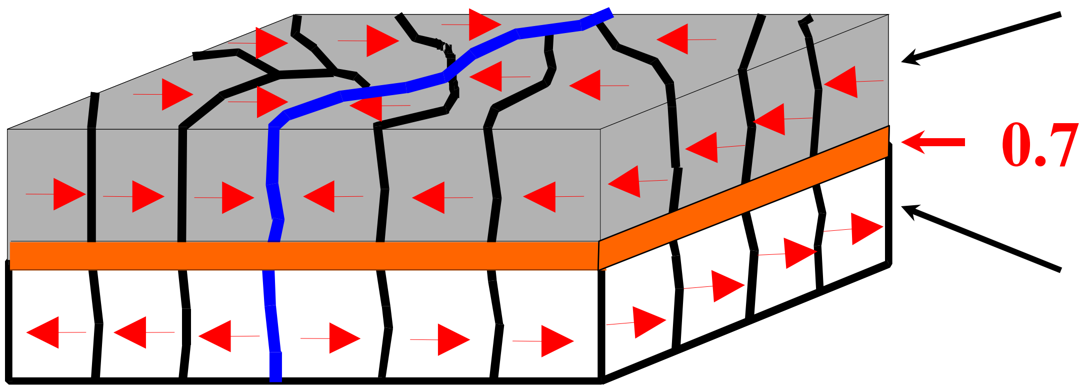




Microstructure is correlated

SNR improvement is density dependent

Inter-layer behavior

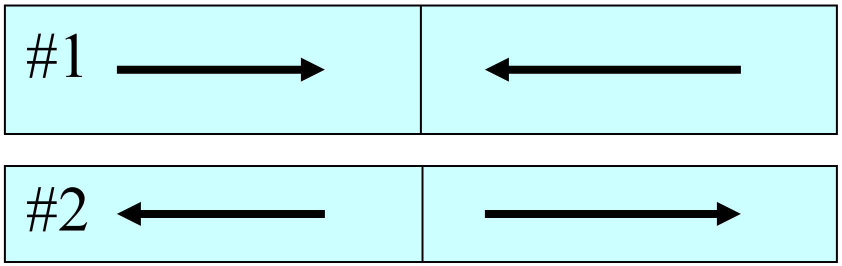


$$Mrt \sim Mrt_1 - Mrt_2$$

$$K_U V_{SL} < K_U V_1 < K_U V_{eff} < K_U V_1 + K_U V_2$$

Fullerton *et al*., Appl. Phys. Lett. **77**, 3806 (2000).
Abarra *et al*., Appl. Phys. Lett. **77**, 2581 (2000).

SNR in two layer systems



Signal = S_1 , Noise = N_1

Signal = S_2 , Noise = N_2

$S = S_1 - S_2$

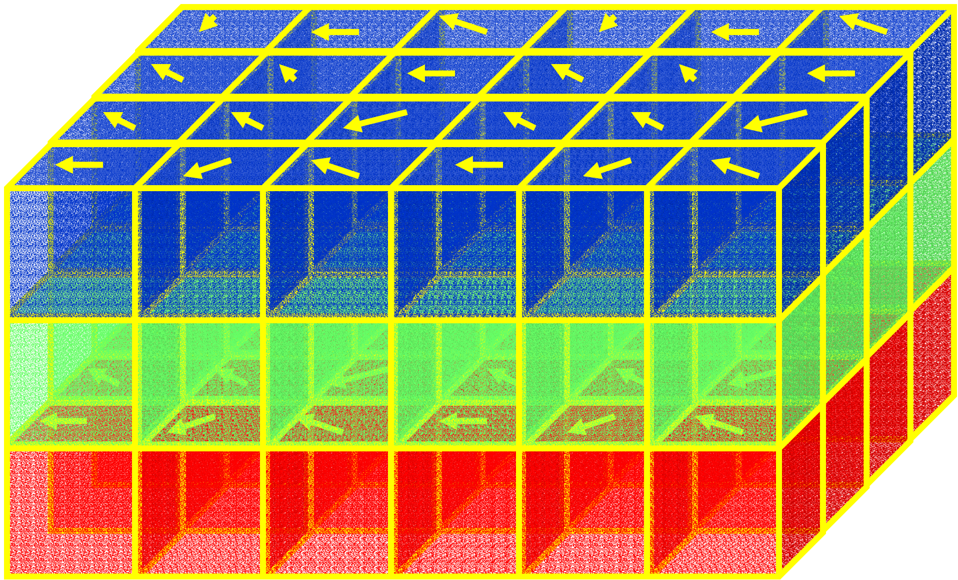
c = -1 anticorrelated noise: $N = N_1 - N_2$

$SNR_1 = SNR_2$ then composite $SNR = SNR_1$

$SNR_2 < SNR_1$ then composite $SNR > SNR_1$

subtract more noise than signal

simple micromagnetic model

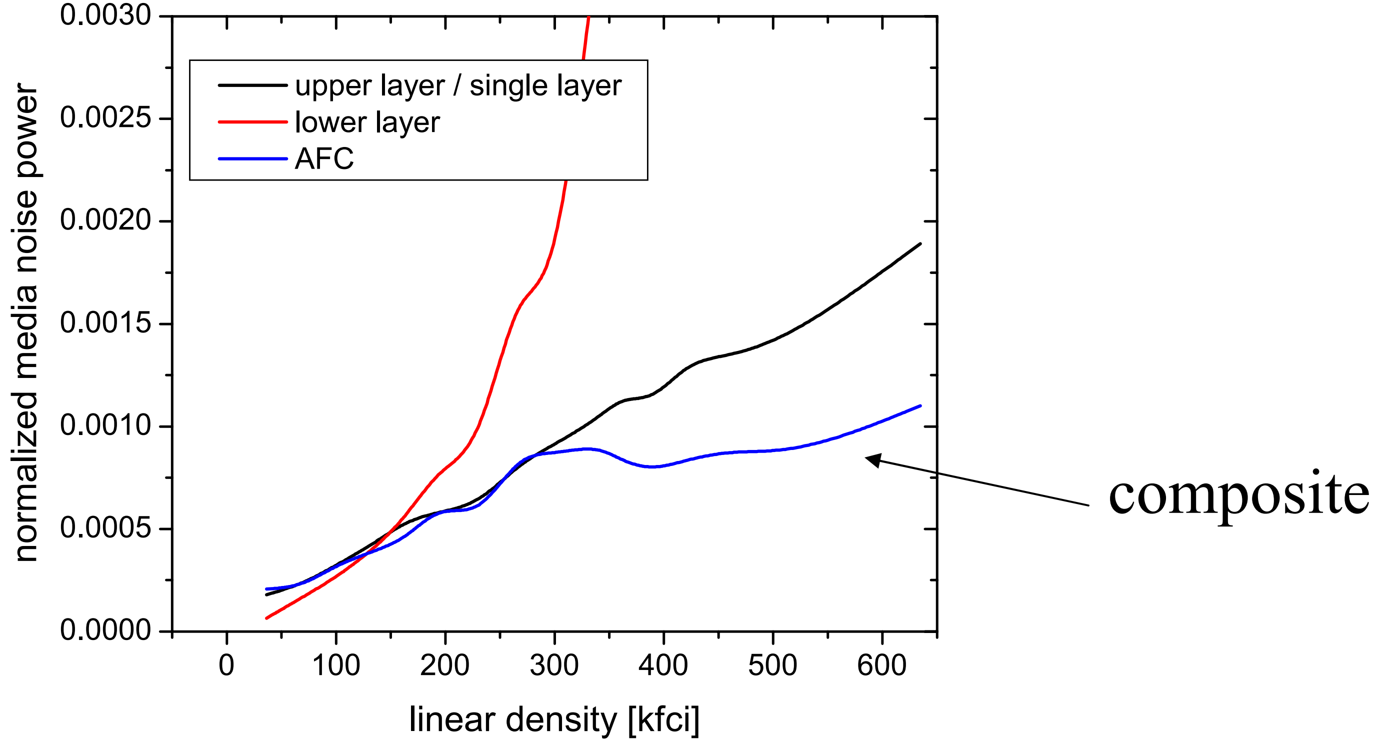


LL has 20% of the moment of UL

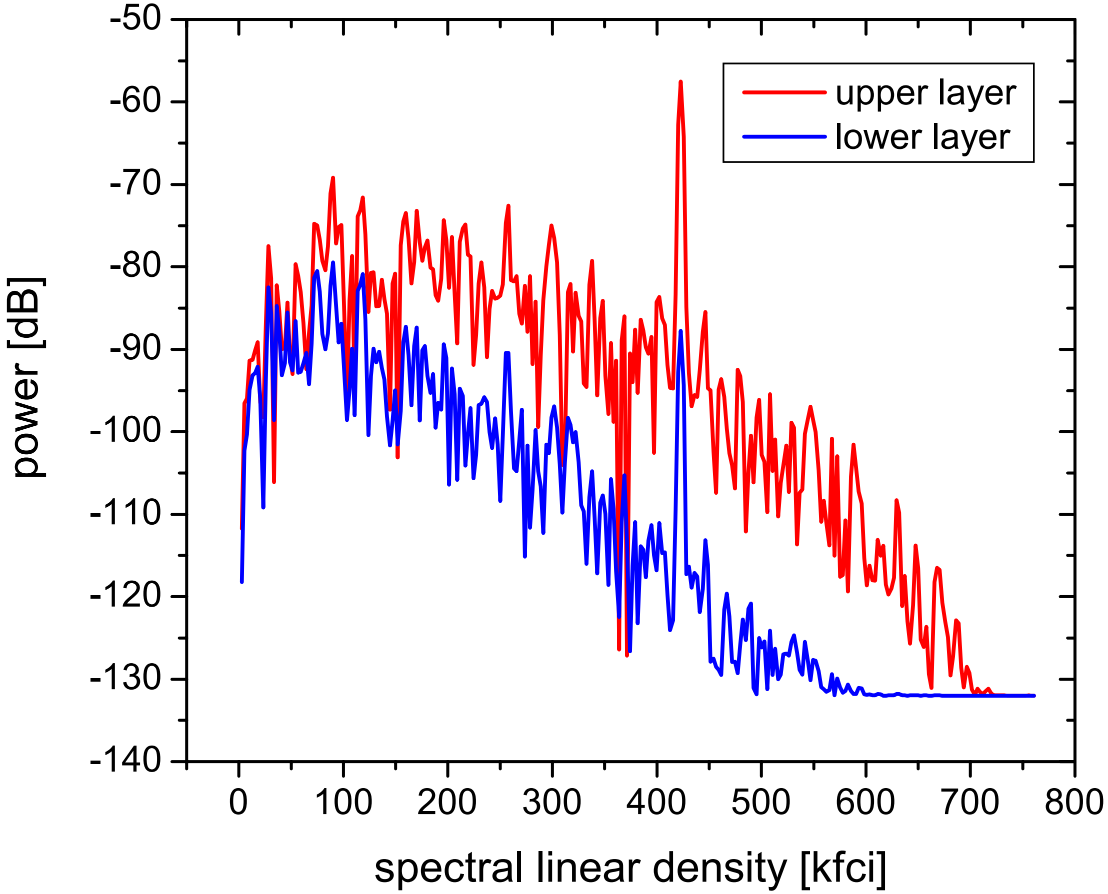
Put transition in the upper layer and let the lower layer relax

Increase the intergranular exchange in the lower layer

Calculated normalized media noise



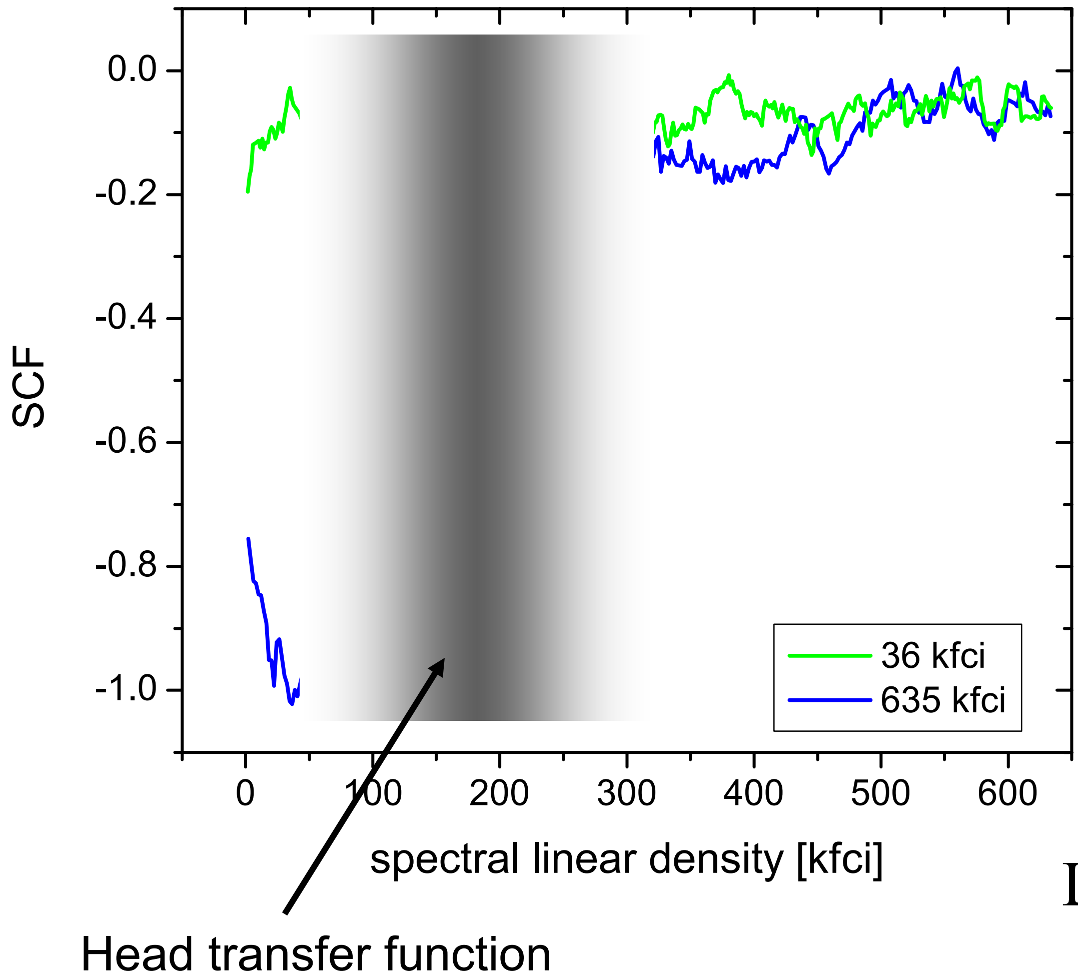
Calculated noise spectra



- Upper layer spectrum:
  - conventional spectrum
- Lower layer spectrum:
  - rolls off much faster

- Lower layer produces more noise at low densities than upper layer

Spectral correlation function (SCF)



- Consider phase

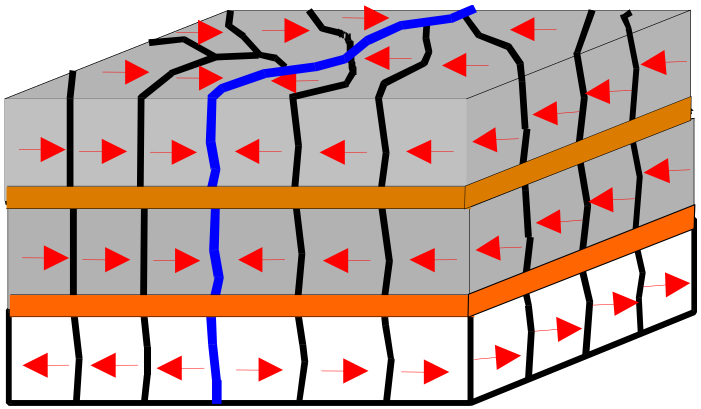
$$\mathrm{SCF} = \frac{\mathrm{fft}(LL)\cdot \mathrm{fft}(UL)^*}{|\mathrm{fft}(UL)|^2}$$

- $MrT_{LL} = 0.2 * MrT_{UL}$
- -1 ~ complete compensation

LL acts as a low-pass filter

Conclusions

- New nano-structured materials are needed for continued growth of storage densities
  - Multilayer media is one pathway



- Desired functionality requires characterization and control of intra- and inter-layer correlations
  - Correlations are frequency and density dependent