Quantitative FORC Analysis: Mean Field Theory and Local Cluster Corrections

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Magnetizing Arrays - Ridge

$H_{tot}=H+\alpha M(H)$ $\alpha>0$

$P(H_k^{min})$ unmatched (min)

$H_{dn}^{min}=-H_K^{min}-\alpha M_S$

$H_{up}^{min}=H_K^{min}-\alpha M_S$

Low H_C end shifted by

$\Delta H_B=\alpha M_S$ $\Delta H_C=0$

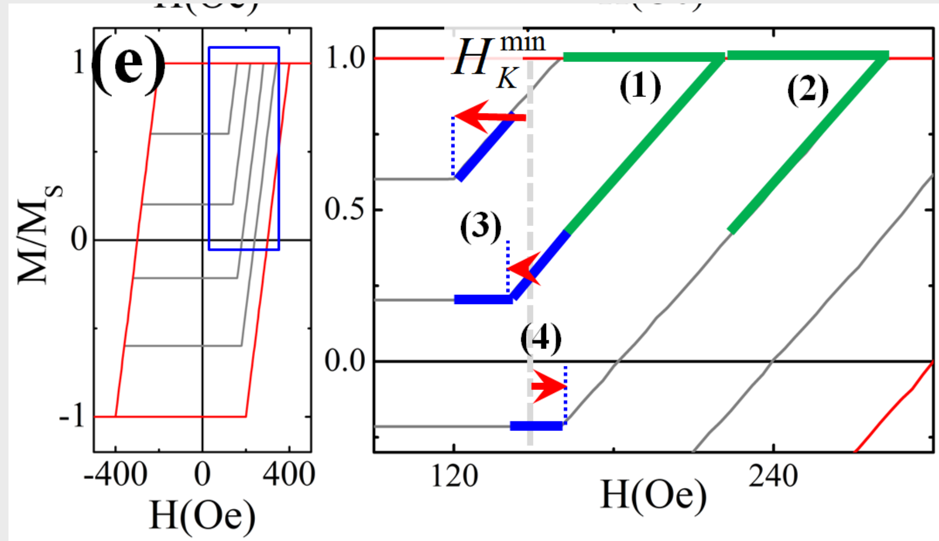
$P(H_k^{max})$ unmatched (max)

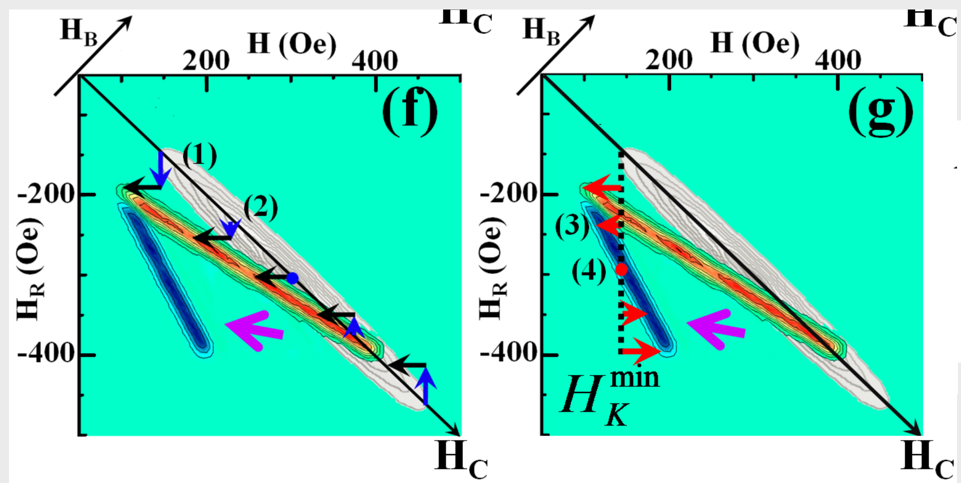
$H_{dn}^{max}=-H_K^{max}+\alpha M_S$

$H_{up}^{max}=H_K^{max}-\alpha M_S$

High H_C end shifted by

$\Delta H_B=0$ $\Delta H_C=\alpha M_S$

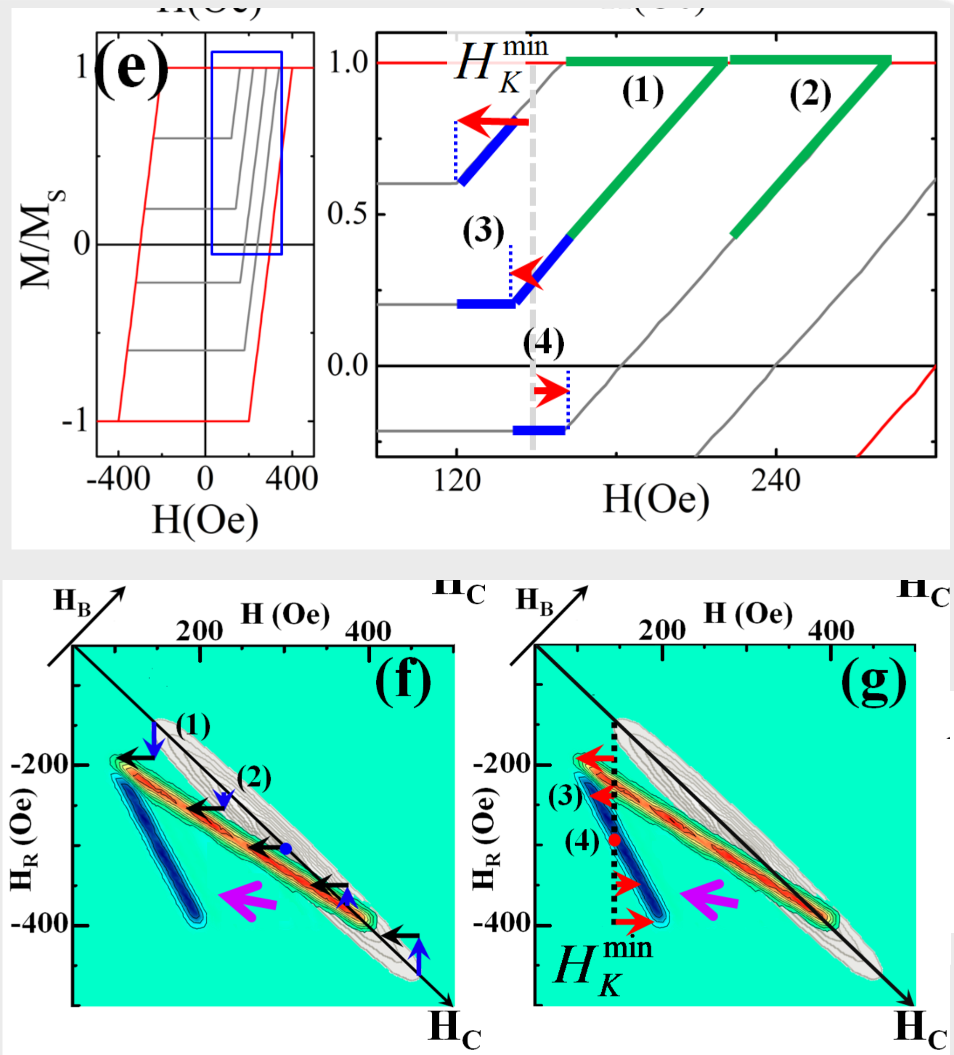




Magnetizing Arrays - Ridge

Ridge: unmatched last flip

1. Min H_K end shift H_B<0
2. Max H_K end stay H_B=0
3. Ridge length decreases
4. Edge ?
5. Negative feature



Magnetizing Arrays - Edge

Edge:

$H_{tot}=H+\alpha M(H)$ $\alpha>0$

$P(H_k^{min})$ up unmatched (3-4)

top:

$H=H_K^{min}-\alpha M_S$, $H_R=-H_K^{min}-\alpha M_S$

bottom

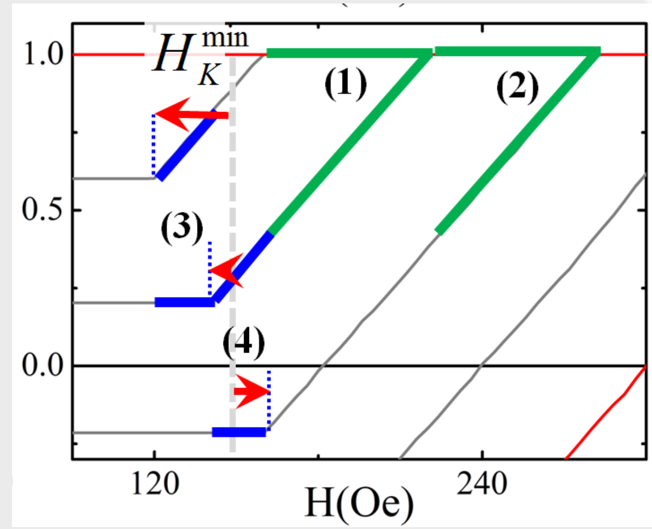
$H=H_K^{min}+\alpha M_S$, $H_R=-H_K^{max}+\alpha M_S$

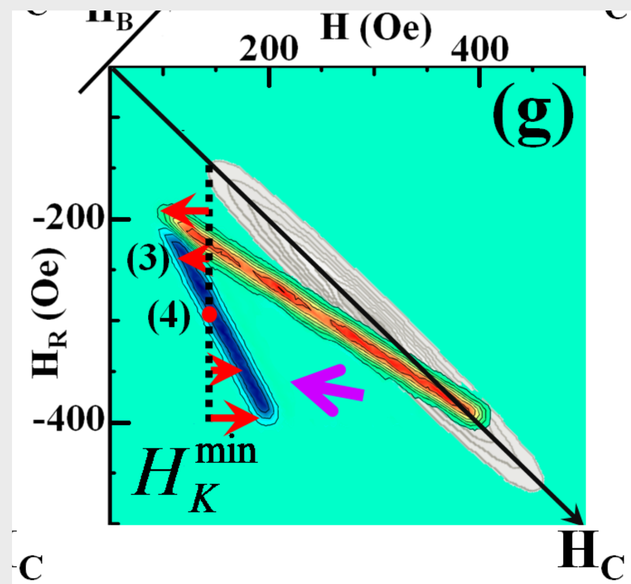
top:

$H_C=H_K^{min}$, $H_B=-\alpha M_S$

bottom:

$H_C=(H_K^{min}+H_K^{max})/2$, $H_B=\alpha M_S+(H_K^{min}-H_K^{max})/2)$





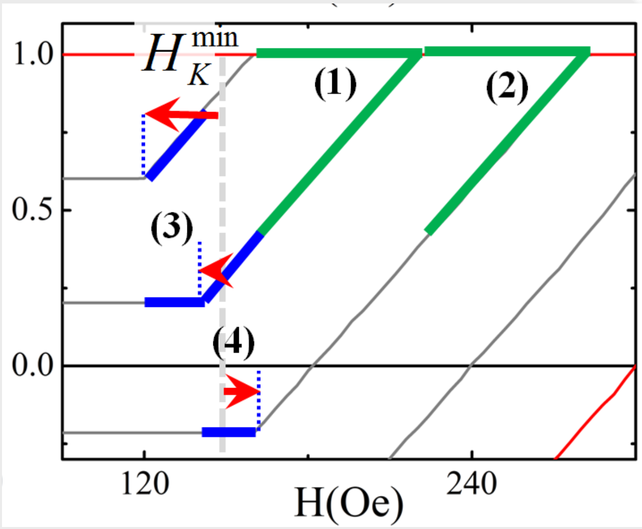
Magnetizing Arrays - Edge

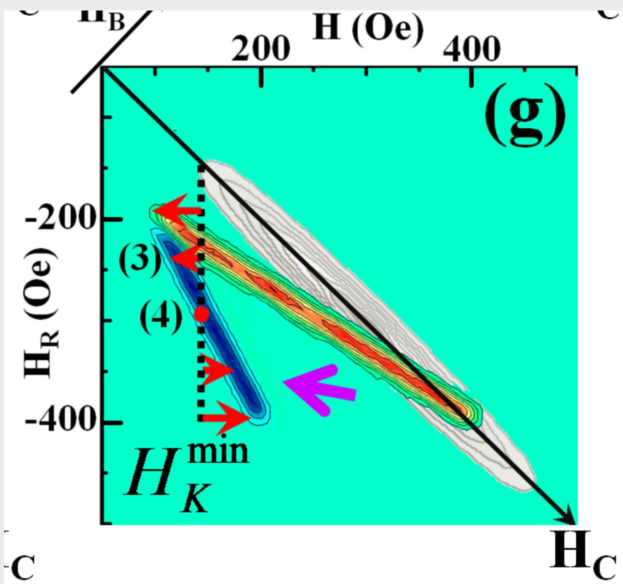
Edge: unmatched first flip

1. Min H_K end shift H_B<0
2. Max H_K end stay H_B=0
3. Ridge length decreases
4. Edge: no positive edge
5. Edge already generates

   bent-in negative feature

   (low H_K region)

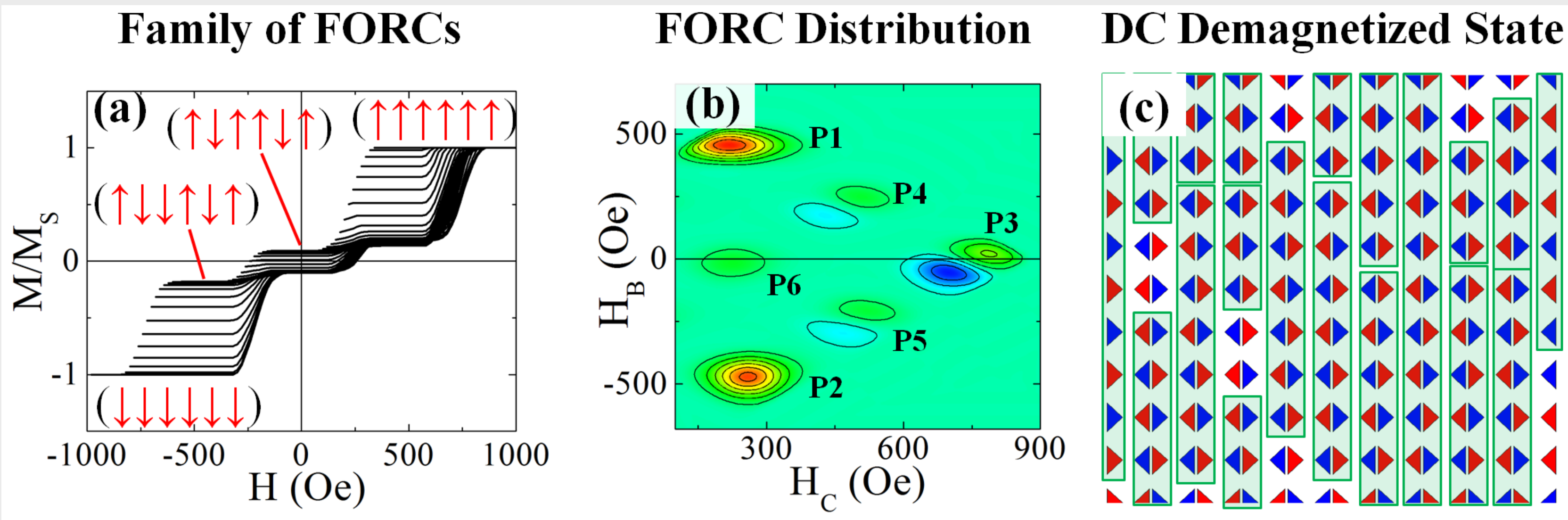




Beyond Mean Field – Demagnetizing Arrays Nearest Neighbor Interaction

Experimentally, the ridge is segmented:

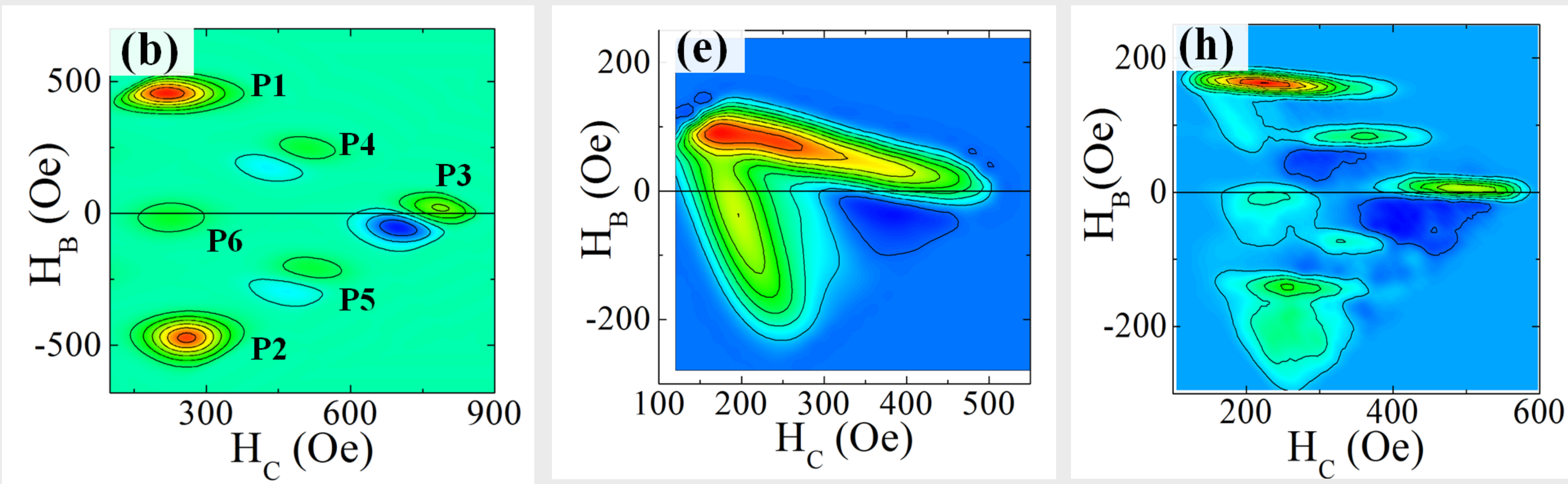
Account for it by including nearest neighbor non-mean field terms



Three primary peaks, three secondary peaks

Beyond Mean Field – Demagnetizing Arrays Nearest Neighbor Interaction

Nearest Neighbor only	Mean field only	Mean field + Nearest Neighbor



Beyond Mean Field – Demagnetizing Arrays
Nearest Neighbor Interaction

(D1) positive saturation → checkerboard (↑ ↑ ↑ → ↑ ↓ ↑ : H_{int}=2$H_{n.n.}$)

(D2) checkerboard → negative saturation (↓ ↑ ↓ → ↓ ↓ ↓ : H_{int}= -2$H_{n.n.}$)

(D3) frust. checkerboard → frust. checkerboard (↓ ↑ ↑ → ↓ ↓ ↑ : H_{int}=0)

(U1) checkerboard → positive saturation (↑ ↓ ↑ → ↑ ↑ ↑ : H_{int}=2$H_{n.n.}$),

(U2) negative saturation → checkerboard (↓ ↓ ↓ → ↓ ↑ ↓ : H_{int}= -2$H_{n.n.}$)

(U3) frust. checkerboard → frust. checkerboard (↓ ↓ ↑ → ↓ ↑ ↑ : H_{int}=0)

peak P1 at (H_C=H_K, H_B=+2$H_{n.n.}$): FORC with the D1 and U1 flips

peak P2 at (H_C=H_K, H_B=-2$H_{n.n.}$): FORC with the D2 and U2 flips

peak P3 at (H_C=H_K+2$H_{n.n.}$, H_B=0): FORC with the D2 and U1 flips

Peaks strong: flips through energetically favored intermediate state

P1/P2: flips from saturation into checkerboard - demagnetizing interactions

P3: flip from checkerboard into saturation

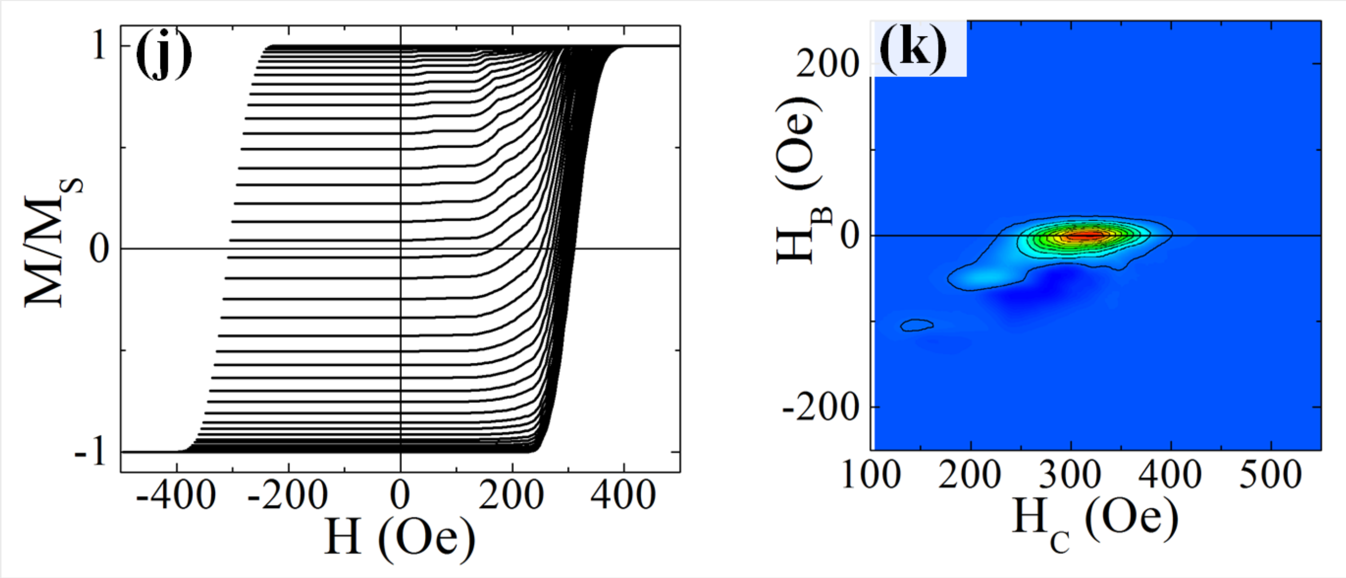
Beyond Mean Field – Magnetizing Arrays
Nearest Neighbor Interaction

Experimentally, the ridge is not segmented:

Even when nearest neighbor terms are included:

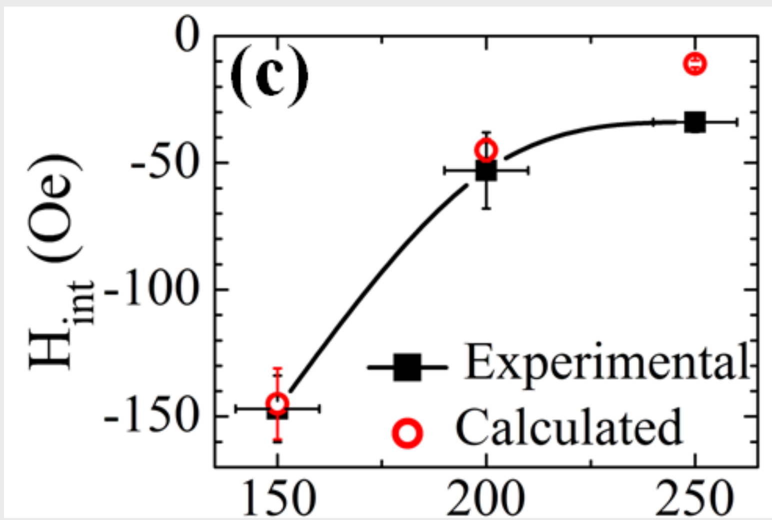
No energy minimizing intermediate state:

The flipping dipole further destabilizes other dipoles: avalanche

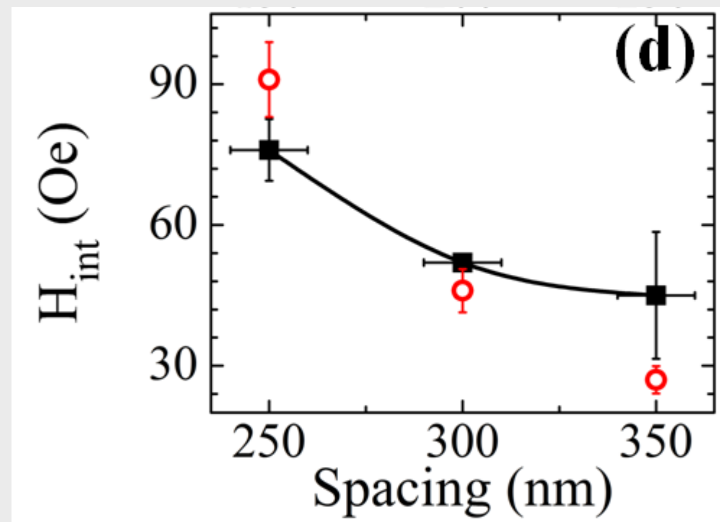


Simulations vs. Experiment: Mean Field plus Nearest Neighbor

Demagnetizing



Magnetizing



Using known material parameters, mean field + nearest neighbor calculation quantitatively reproduced

- experimental FORC
- interaction fields

Mean Field FORC for Hard Soft Composites

Two dipole arrays

Different coercivity distributions

Coupled by:

- they both experience total mean field
- coupled by nearest neighbor interaction H_{ex}