Finite-Temperature Micromagnetic Simulations of Magnetization Reversal

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Micromagnetics

Precession of classical moments

$$\frac{dS}{dt} = \frac{\gamma_0}{1+\alpha^2} S \times \left\{ H - \alpha \left(S \times H \right) \right\}$$

Coupled through inhomogeneous field

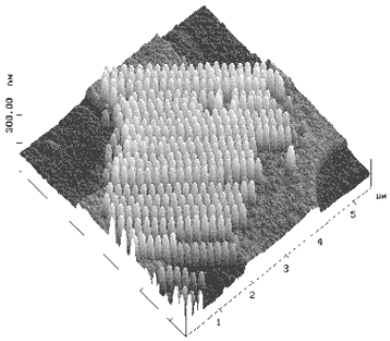
$$H_i = H_{ex,i} + H_{dd,i} + H_{zm,i} + H_{th,i}$$

Thermal field (Fluctuation-dissipation)

$$\left\langle H_{n,i,\mu} \cdot H_{n,j,\nu} \right\rangle = \frac{2\alpha k_B T}{\gamma_0 M_S V} \delta(t-t') \delta_{i,j} \delta_{\mu,\nu}$$

Nanoscale Single-domain Magnets

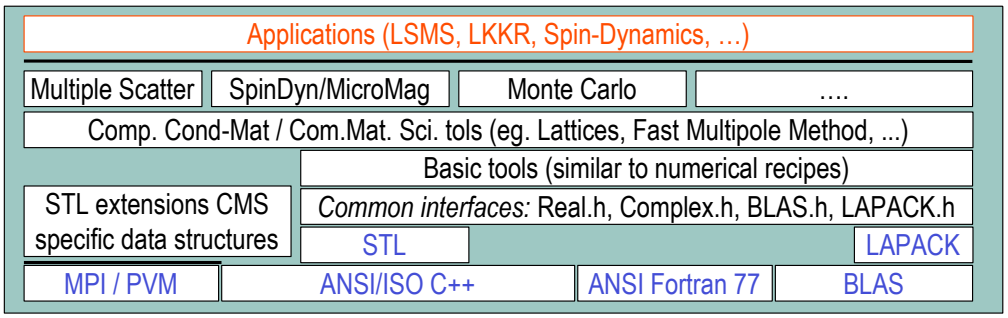
STM-assisted Chemical Vapor Deposition
Awschalom, von Molnar, and coworkers



Parameters match those of bulk iron
M_s = 1700 emu/cm^3
l_{ex} = 3.6 nm
dt = 0.85 fs
α=0.1

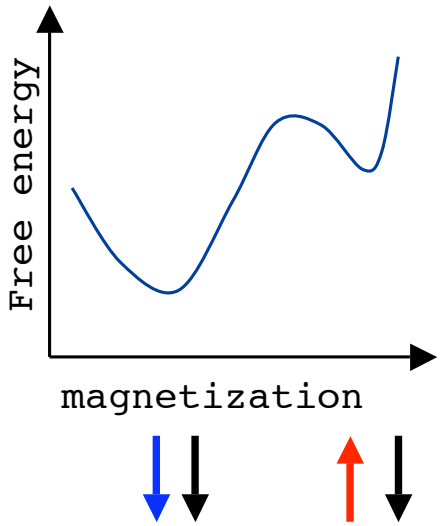
Ψ-Mag tool set

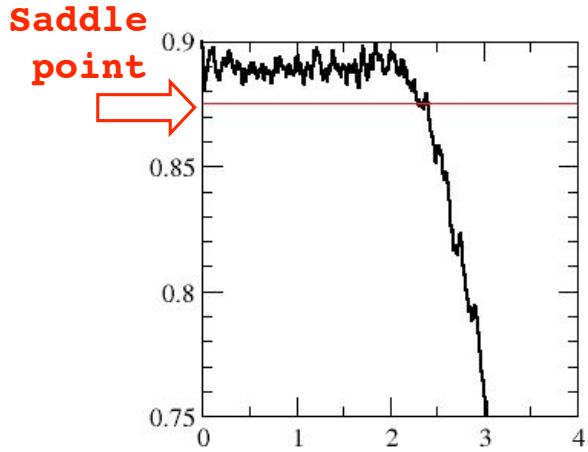
- **Library for computational magnetism**
- **Common data structures & algorithms**
- **Fast Multipole Method**



Conceptual organization of the ψ-Mag tool set (black) along with the application layer (orange) and support layer (blue).

Metastable reversal



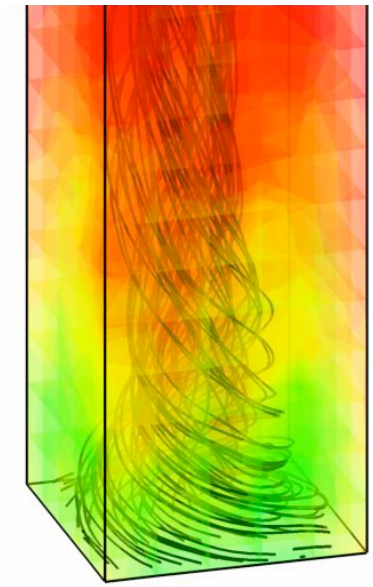


H_0 = 1125 Oe

T = 15 K

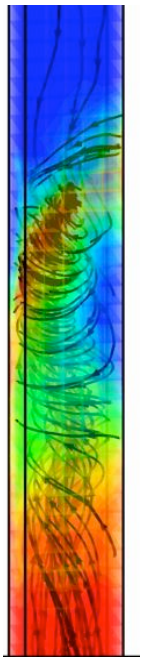
End Caps

Metastable vortex



Saddle-point vortex

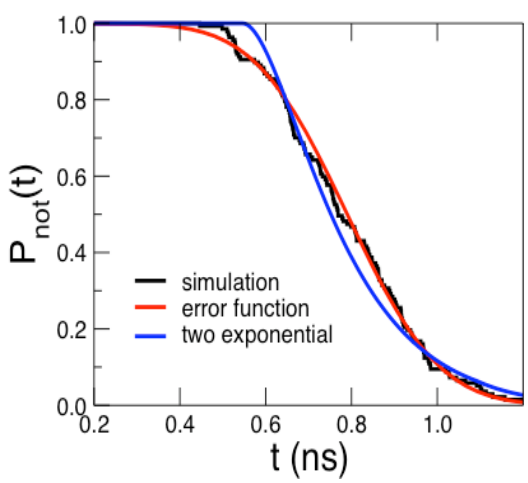
Reversal Dynamics



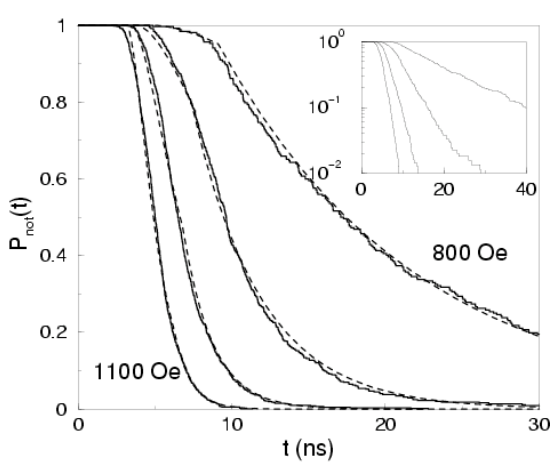
6x6x90, 15K, 1125Oe, 0deg,
run-d-040120

Probability of not switching

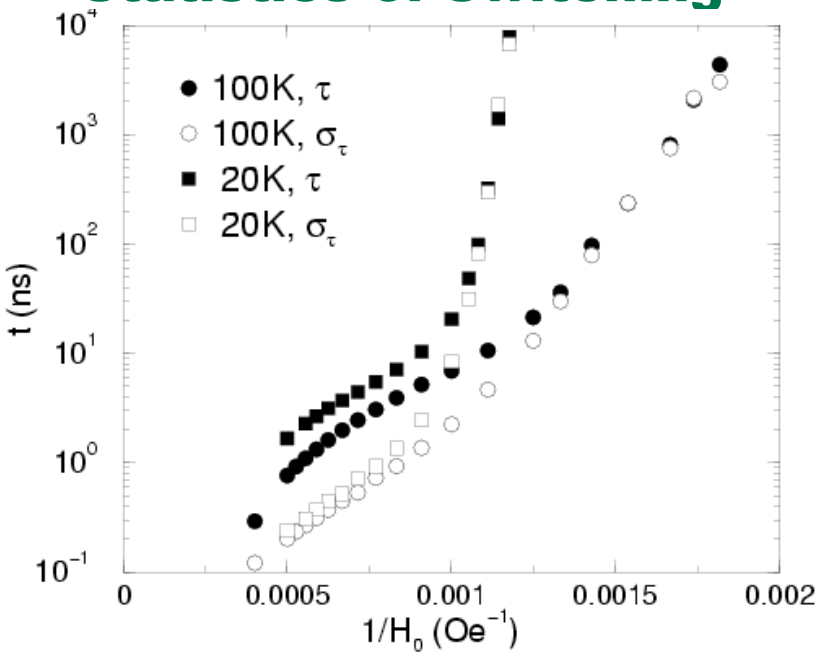
3d Model



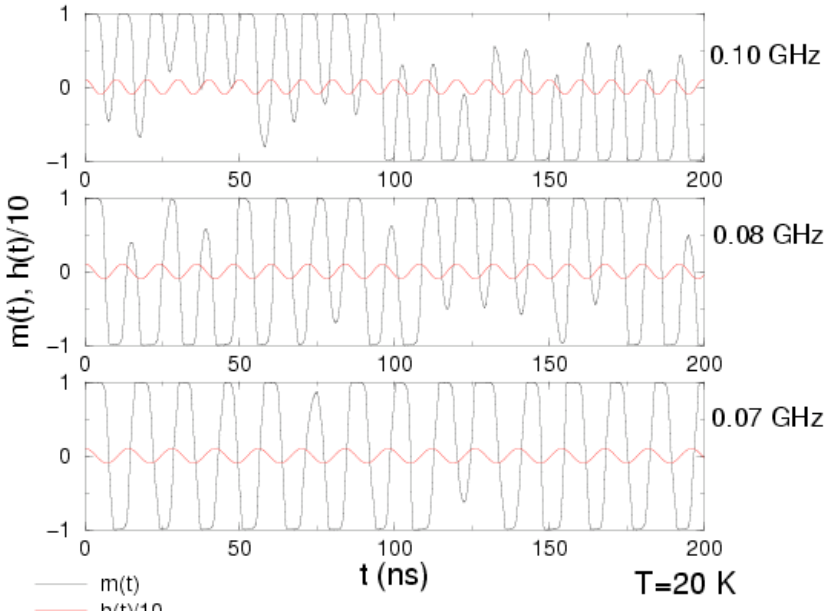
1d Model



Statistics of Switching

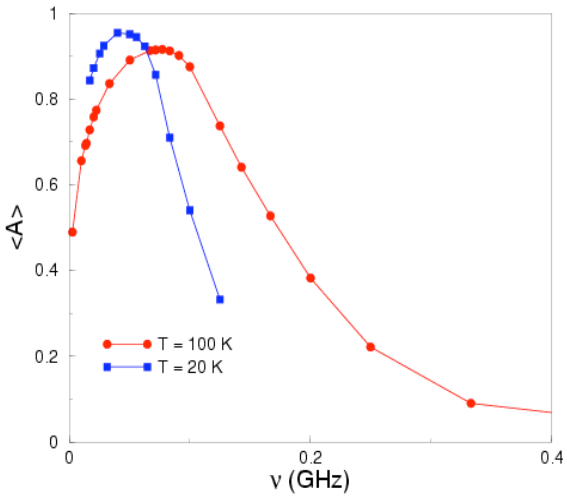


Competition of time scales

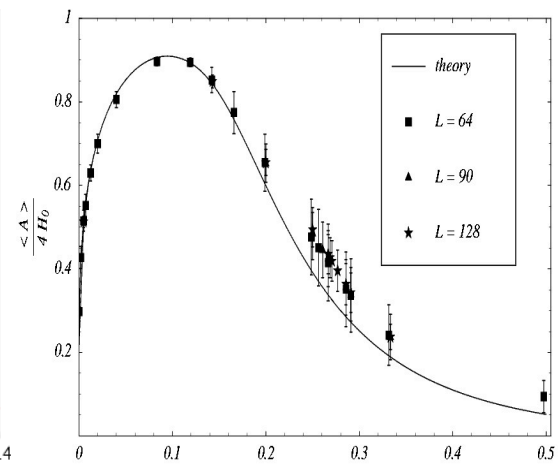


Resonance

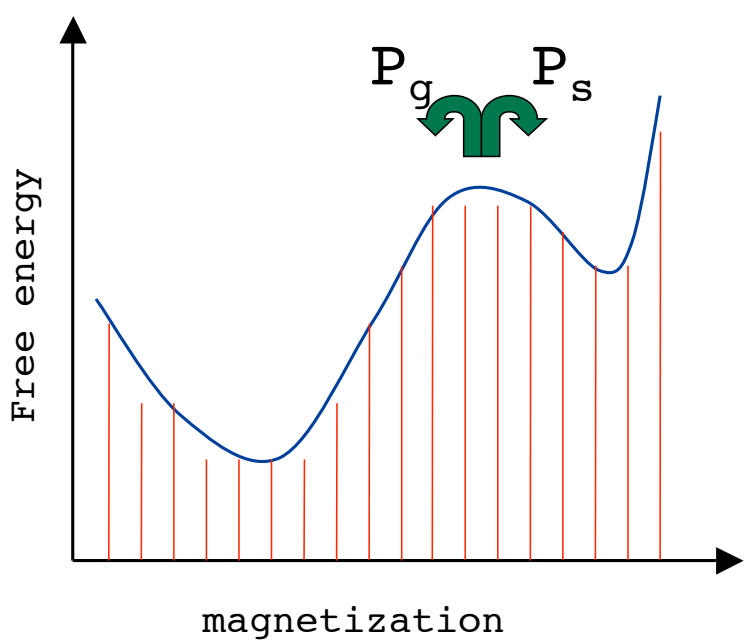
Micromagnetics



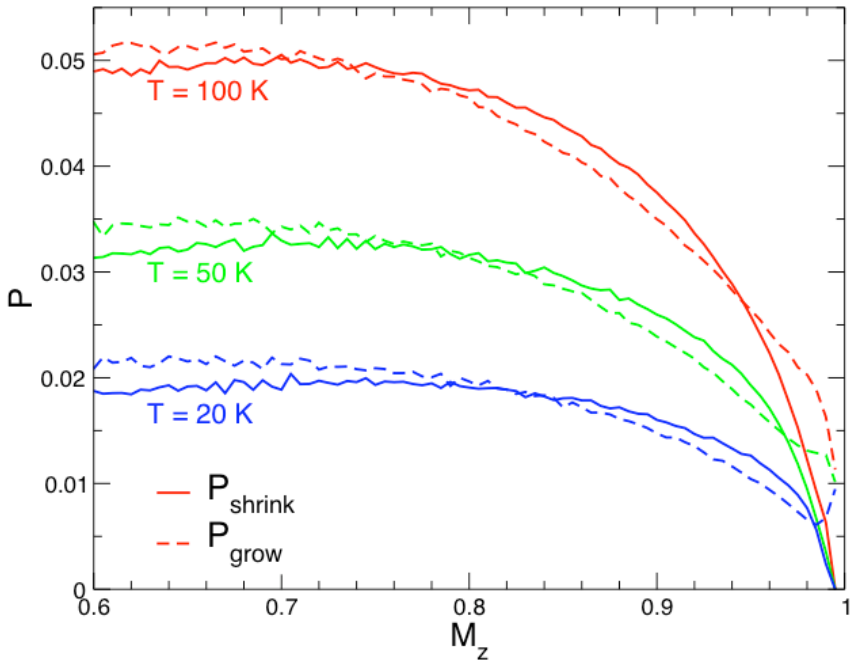
Kinetic Ising Model



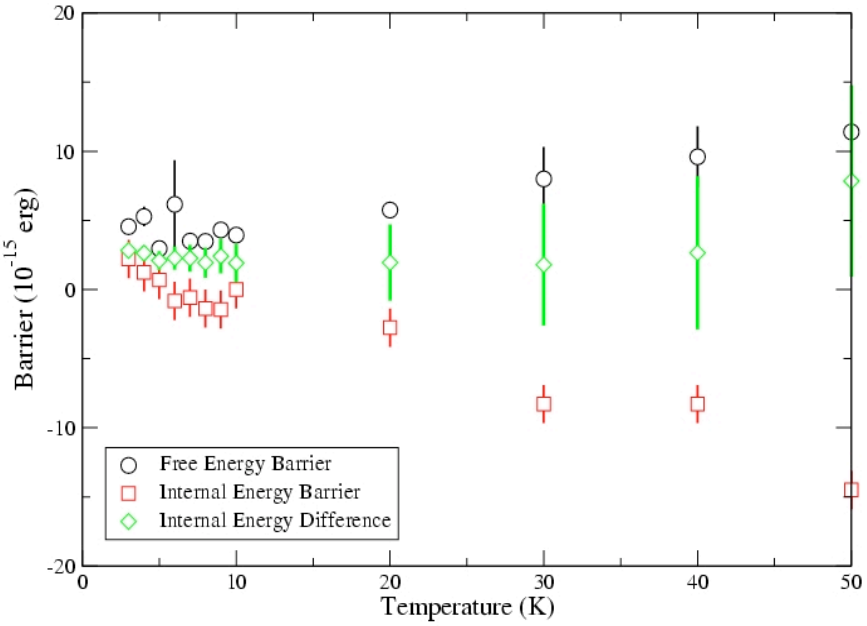
Projective Dynamics



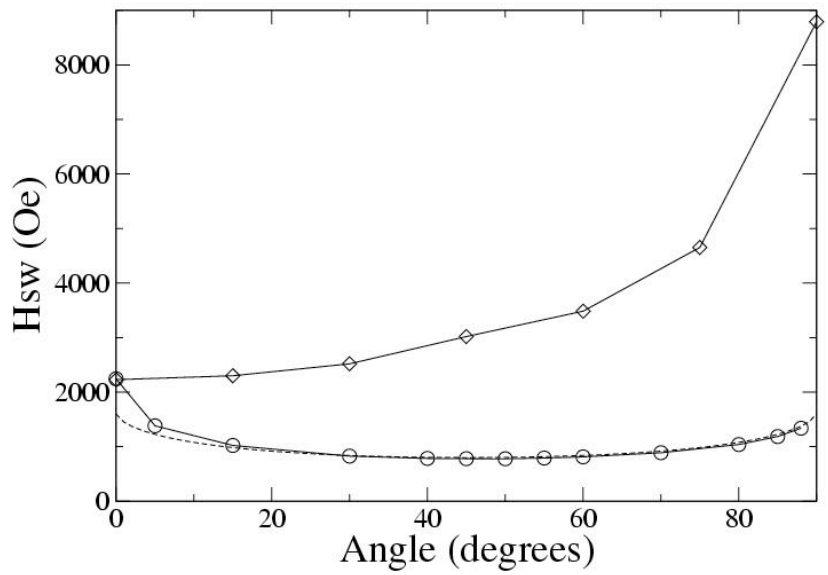
Measure Free Energy Extrema



Estimate Barriers

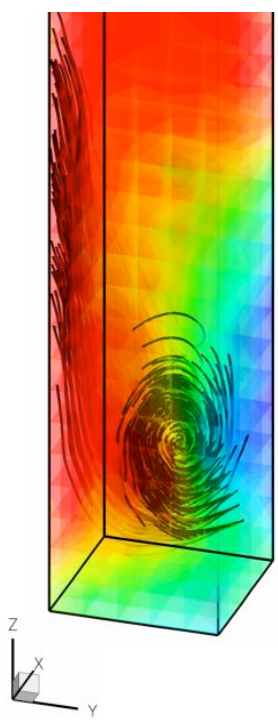


Misaligned Field



Experiment: Li, et al, JAP 93, 7912 (2003)

75° Reversal



6x6x90, 15K, 3175Oe, 75deg,
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Summary

- Micromagnetics at nonzero temperatures
- Single-domain nanoscale magnets
- Decay of the metastable states
- Competition of nucleation and growth timescales
- Misaligned Fields

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