Magnetic Particle Imaging with a Cantilever Detector

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NIST

Submitted PRL

Outline

- Experimental Setup
- Raw Data
- Theory
- Results
- Future plans

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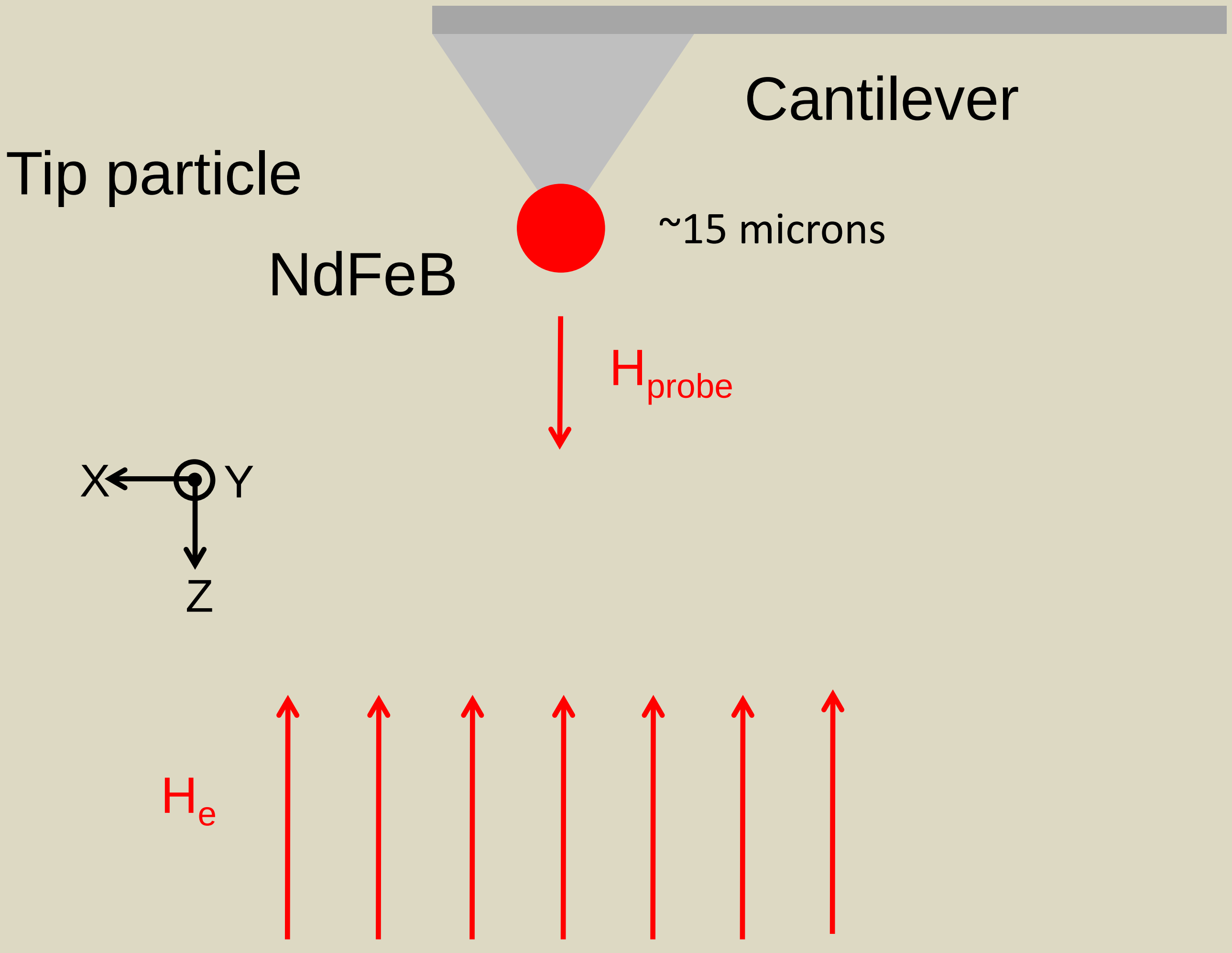
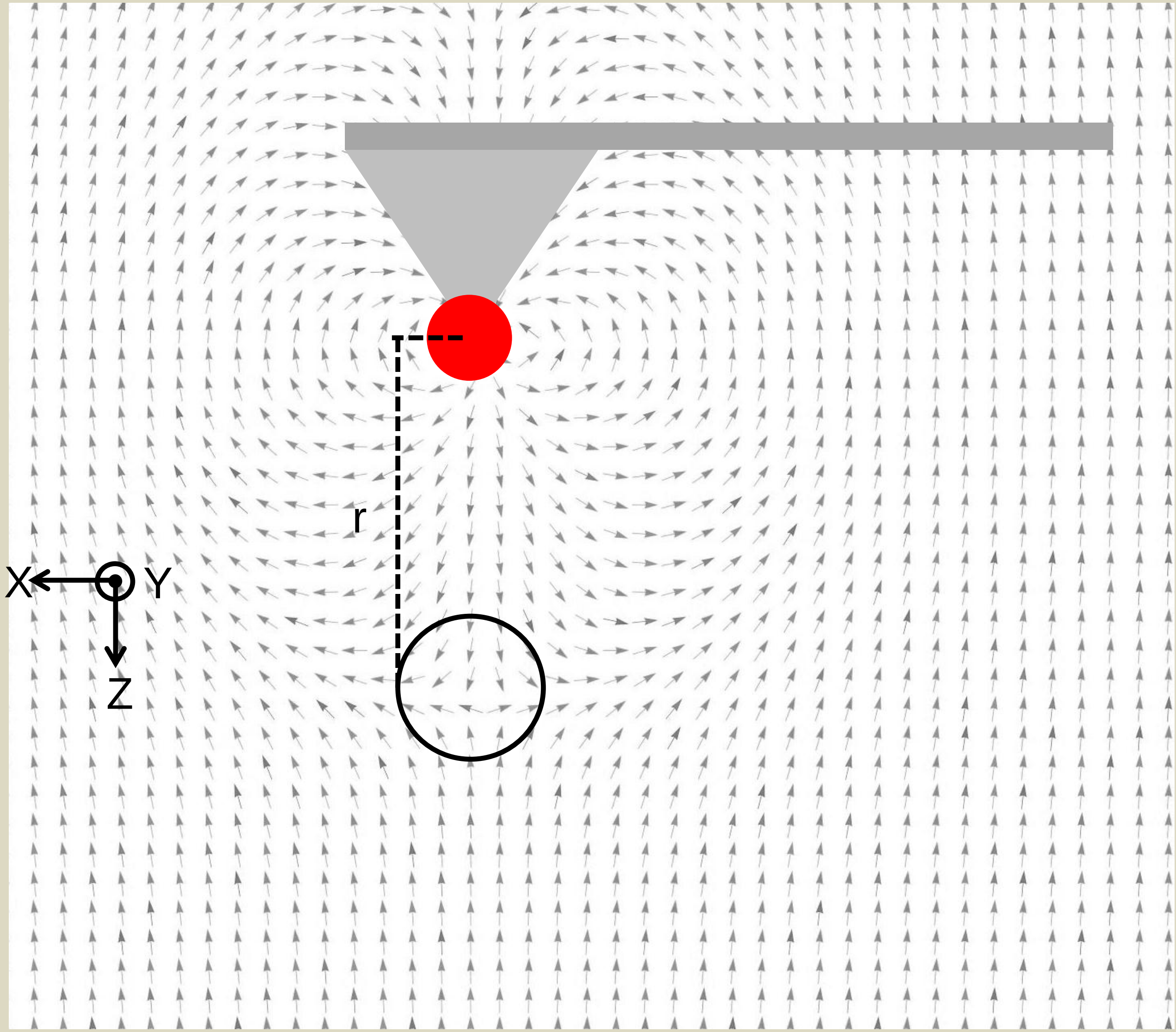
Cantilever Detection Configuration



Field Configuration



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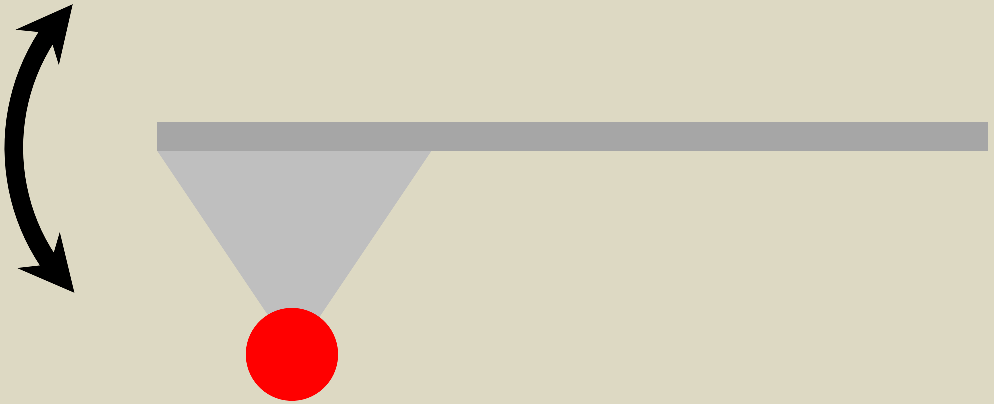
Measurement



Vibrate the Cantilever at $f_0/2$

Detect at f_0

We measure the 2nd Derivative of the Force

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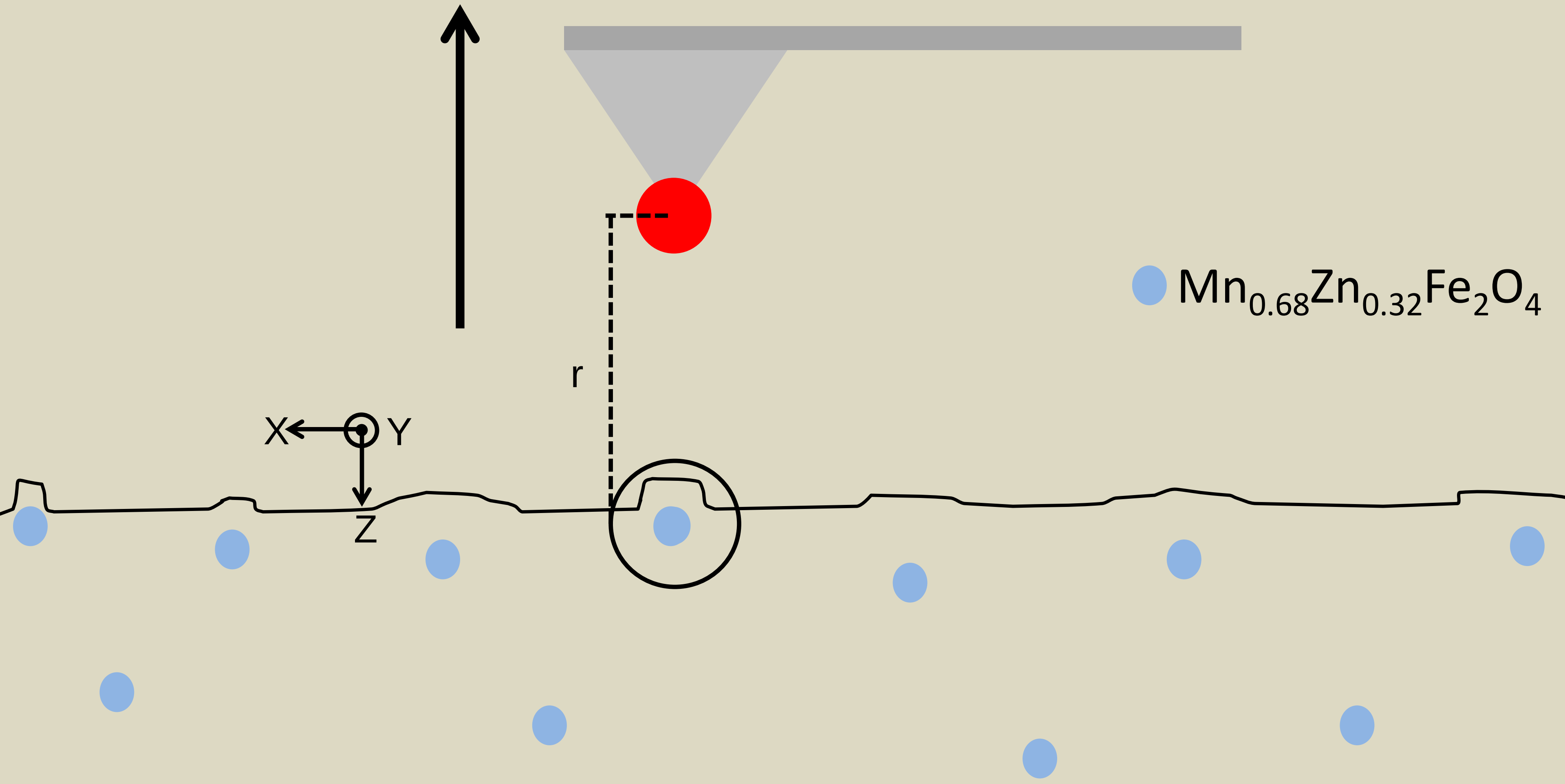
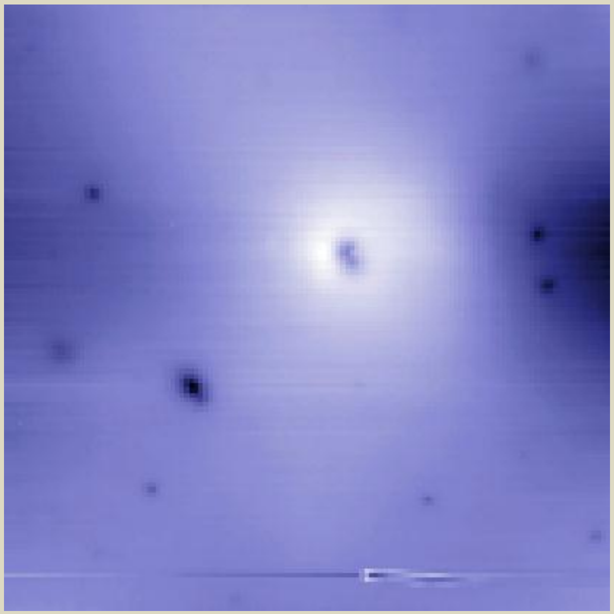
Measurement



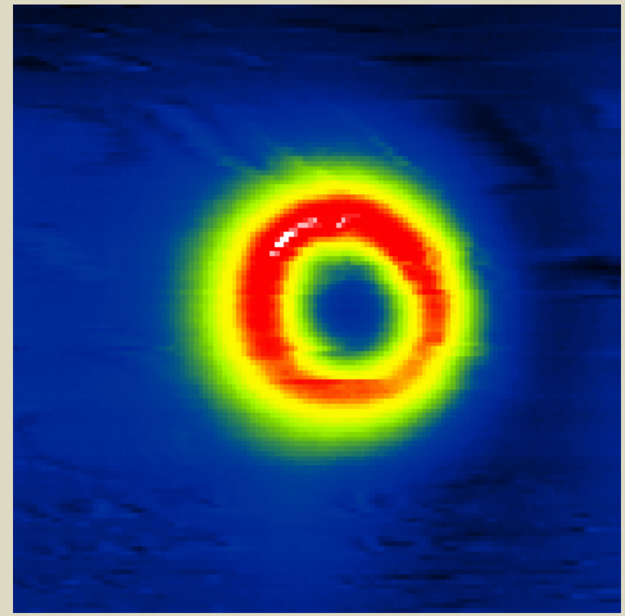
Signal as a Function of Lift Height

Topograph



0 nm 400 nm

2nd Harmonic



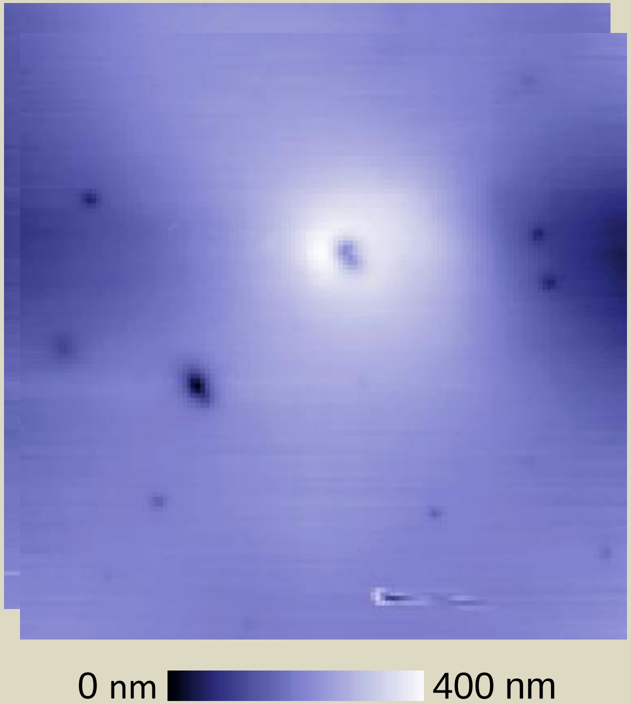
0.1 V 0.2 V

0.19 T
32 X 32 μm

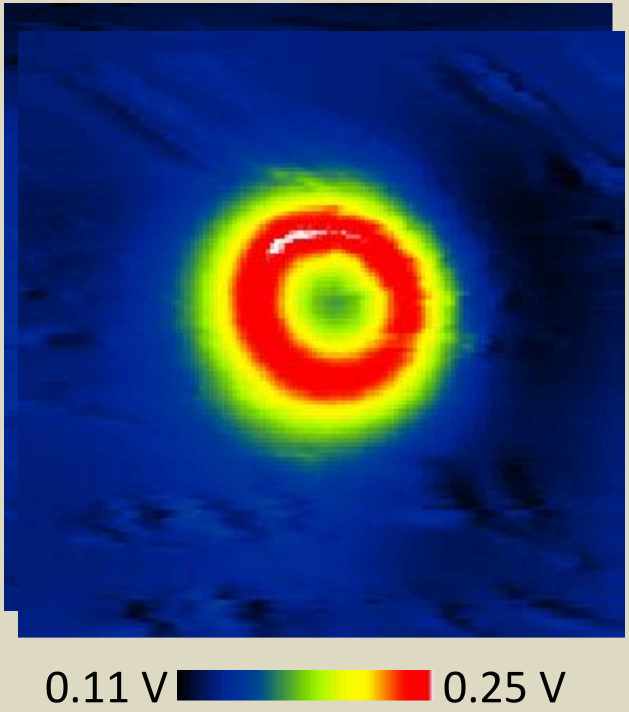
500 nm

Signal as a Function of Lift Height

Topograph



2nd Harmonic

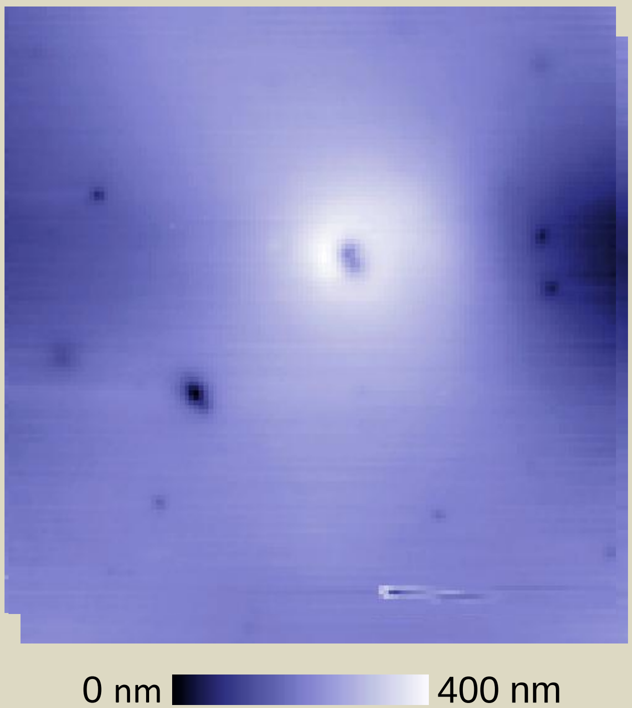


0.19 T
32 X 32 μm

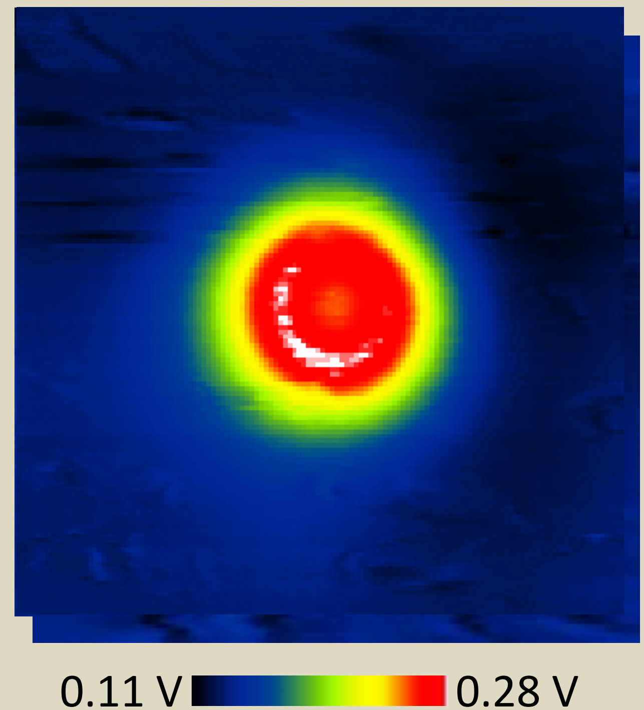
1000 nm

Signal as a Function of Lift Height

Topograph



2nd Harmonic

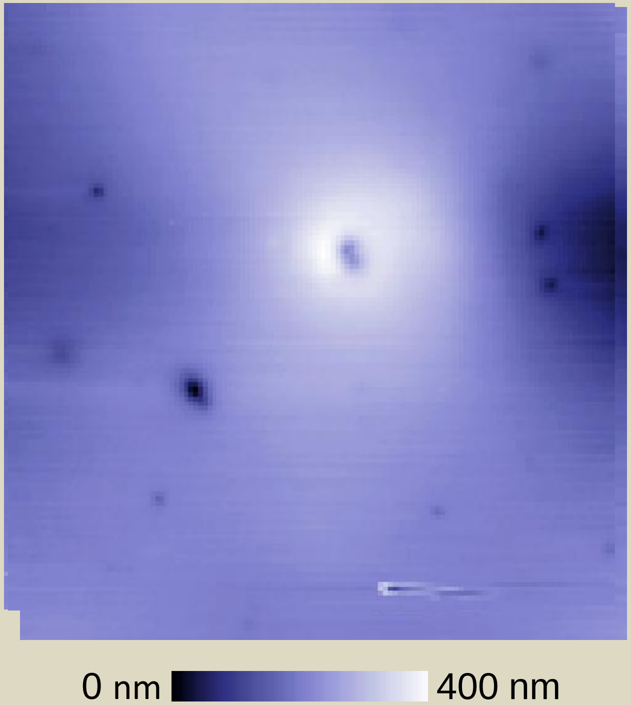


0.19 T
32 X 32 μm

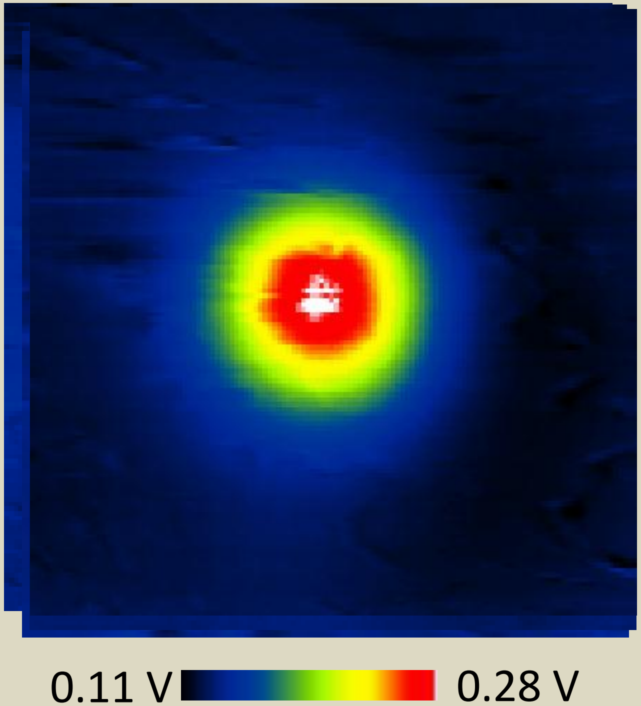
1500 nm

Signal as a Function of Lift Height

Topograph



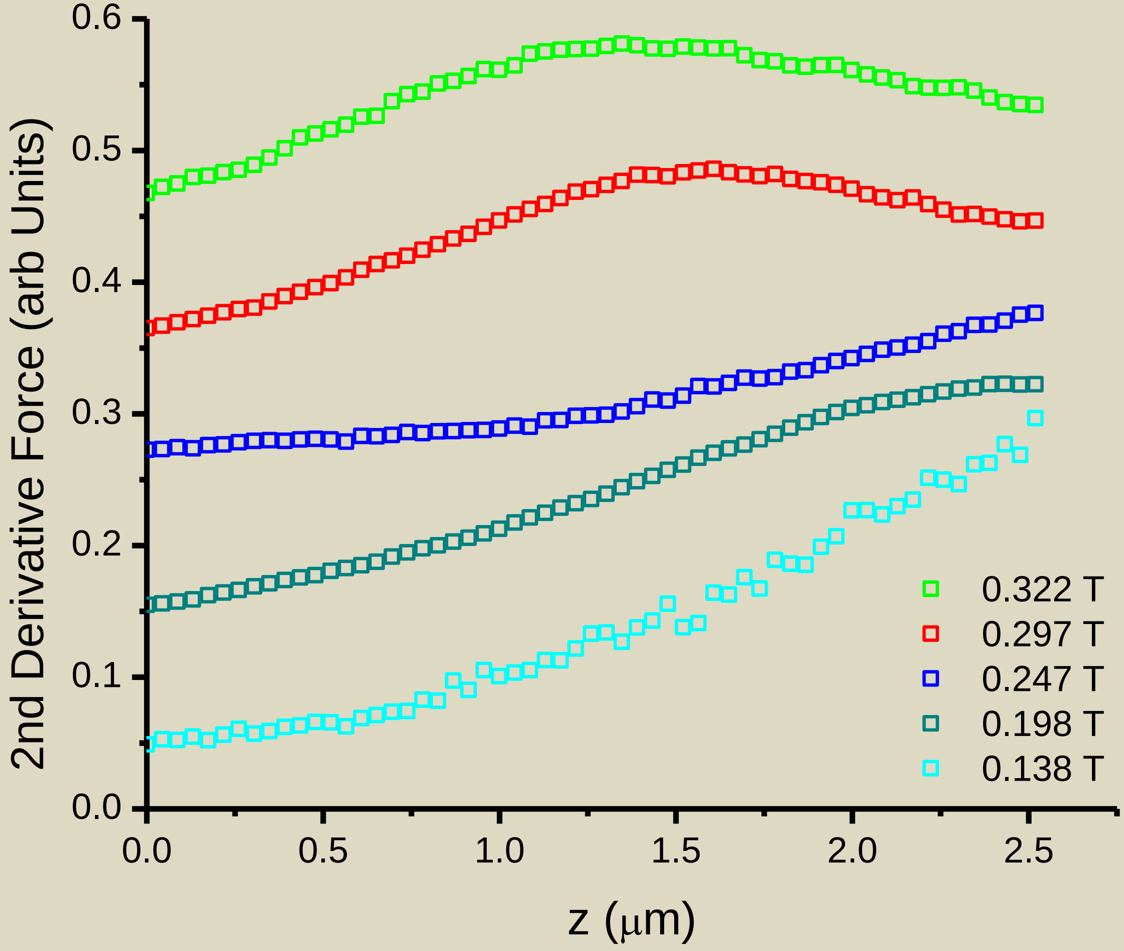
2nd Harmonic



0.19 T
32 X 32 μm

2500 nm

Extracting fitable data



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Theory

Dipole in an external field

$$H_z(z) = -H_e + \frac{\mu_0}{4\pi}\frac{2m_t}{(z^3)}$$

m_t=moment of the tip

m_p=moment of the particle

Gives a Force of:

$$F(z) = \frac{d}{dz}\frac{\mu_0}{4\pi}(m_p(H_z)\cdot(H_z+H_e))$$

$$= -\frac{\mu_0}{4\pi}\left(\frac{6m_t m_p(H_z)}{z^4} - \frac{12{m_t}^2{m_p}'(H_z)}{z^7}\right)$$

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Theory/Model

Mixture of harmonics -> Need model m(H)

Langevin model:

$$M = N \cdot g \cdot J \cdot \mu_B \cdot B_J \left[\frac{g \cdot J \cdot \mu_B \cdot \mu_0 \cdot H}{k_B \cdot T} \right]$$

Where B_J is the Brillouin function, g is the Lande splitting factor, and J is total angular momentum

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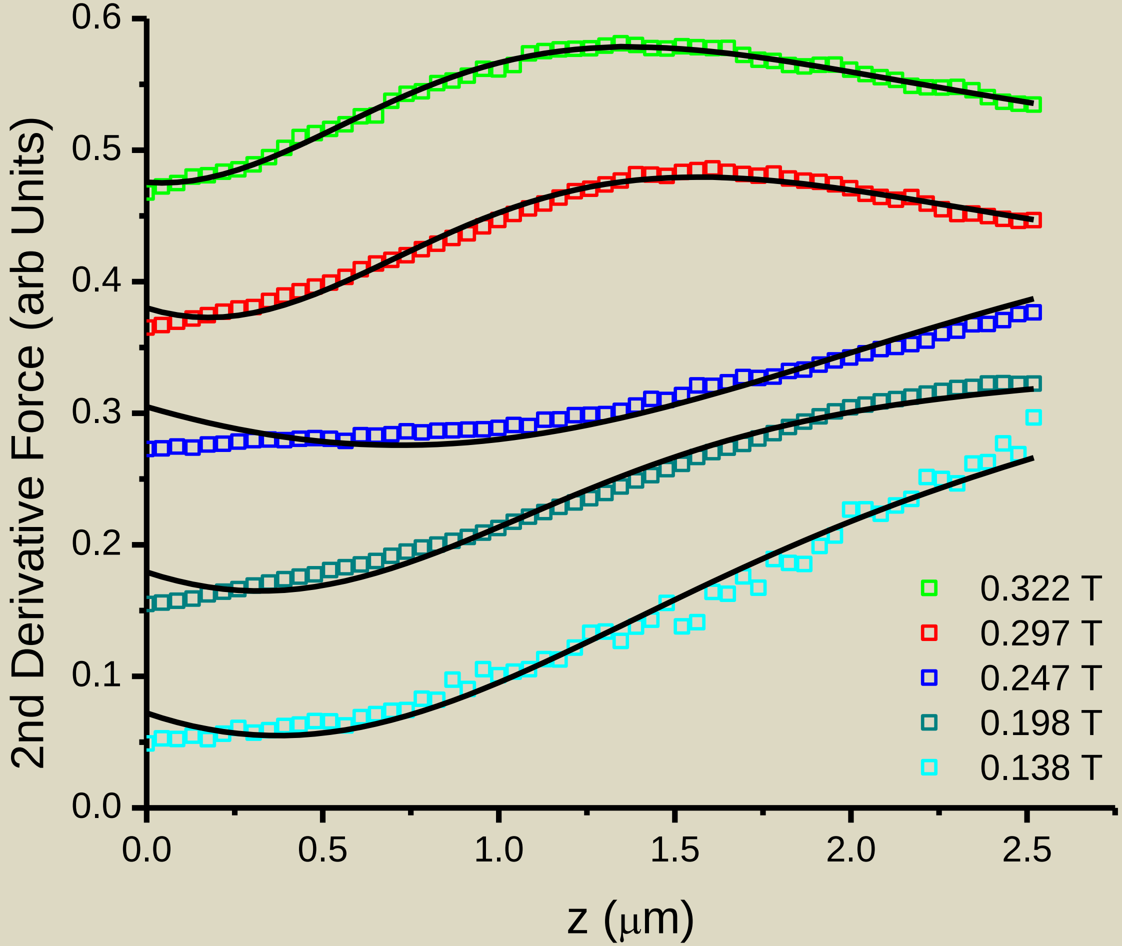
Fitting



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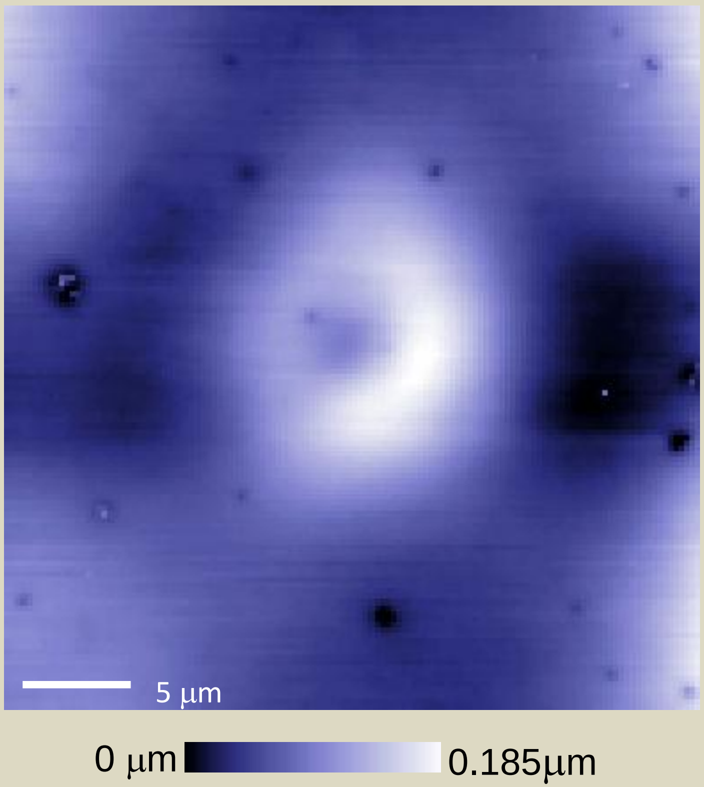
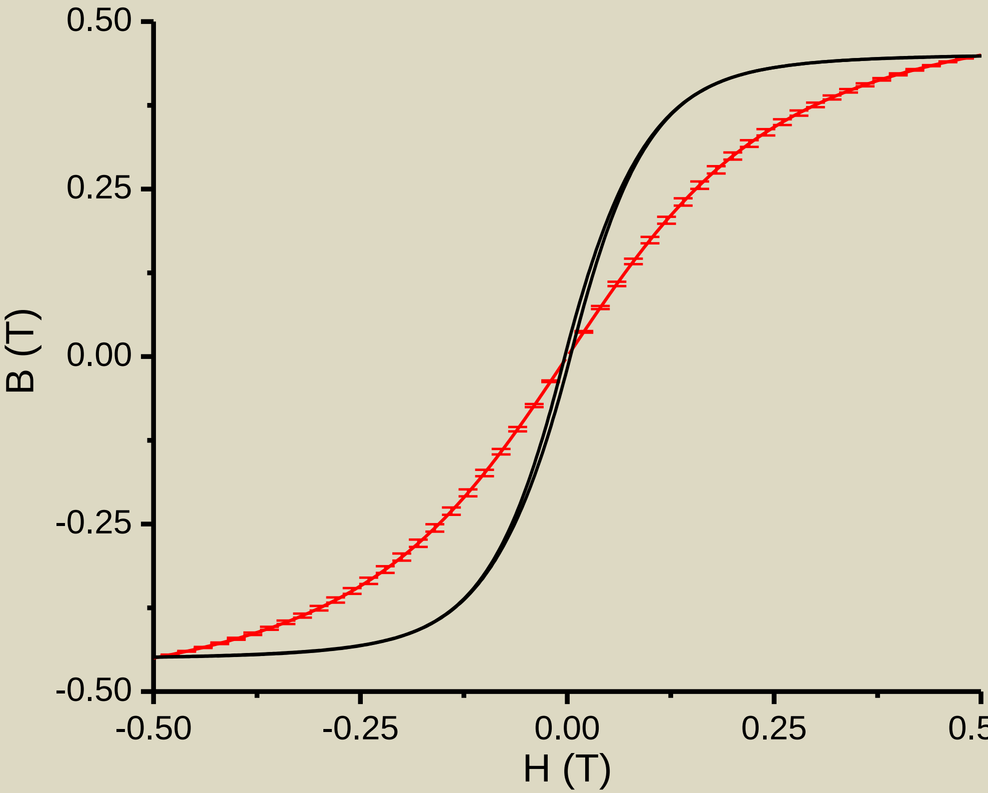
Extracted m-H curve





Demagnetization factor of 0.54

Ellipsoid cluster

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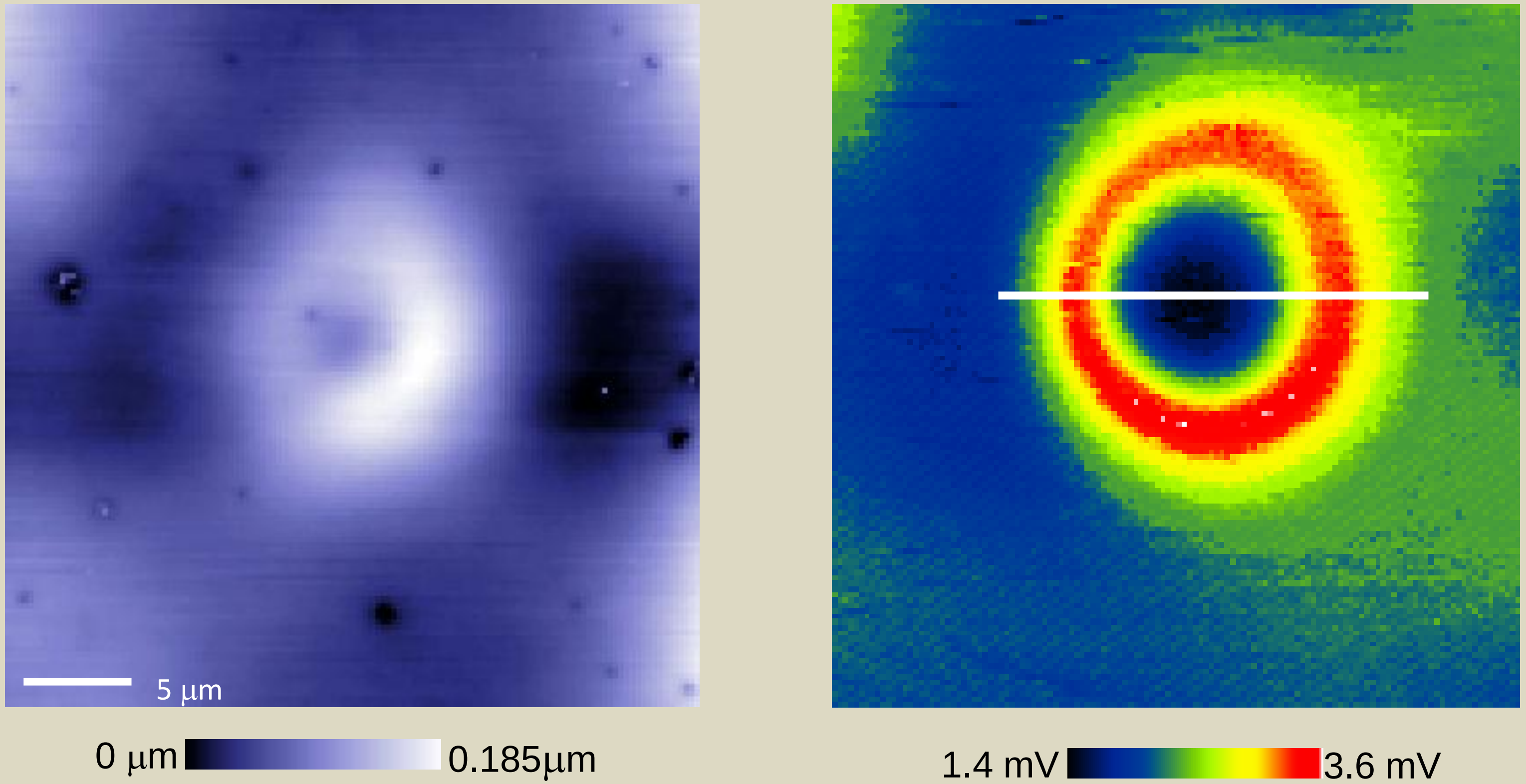
2D slices of the data compared to theory



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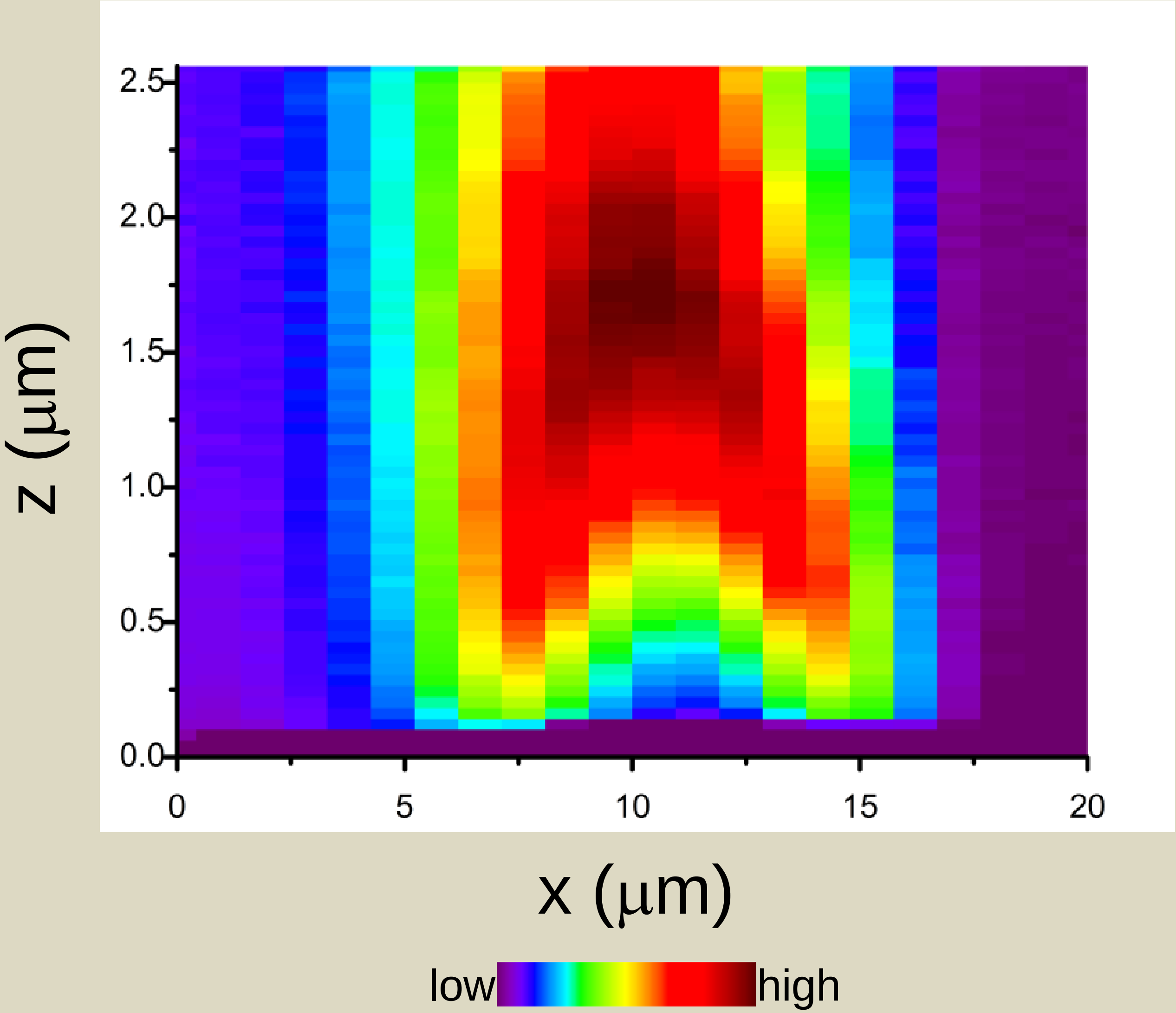
2D Data Slice



H_e = 0.322 T

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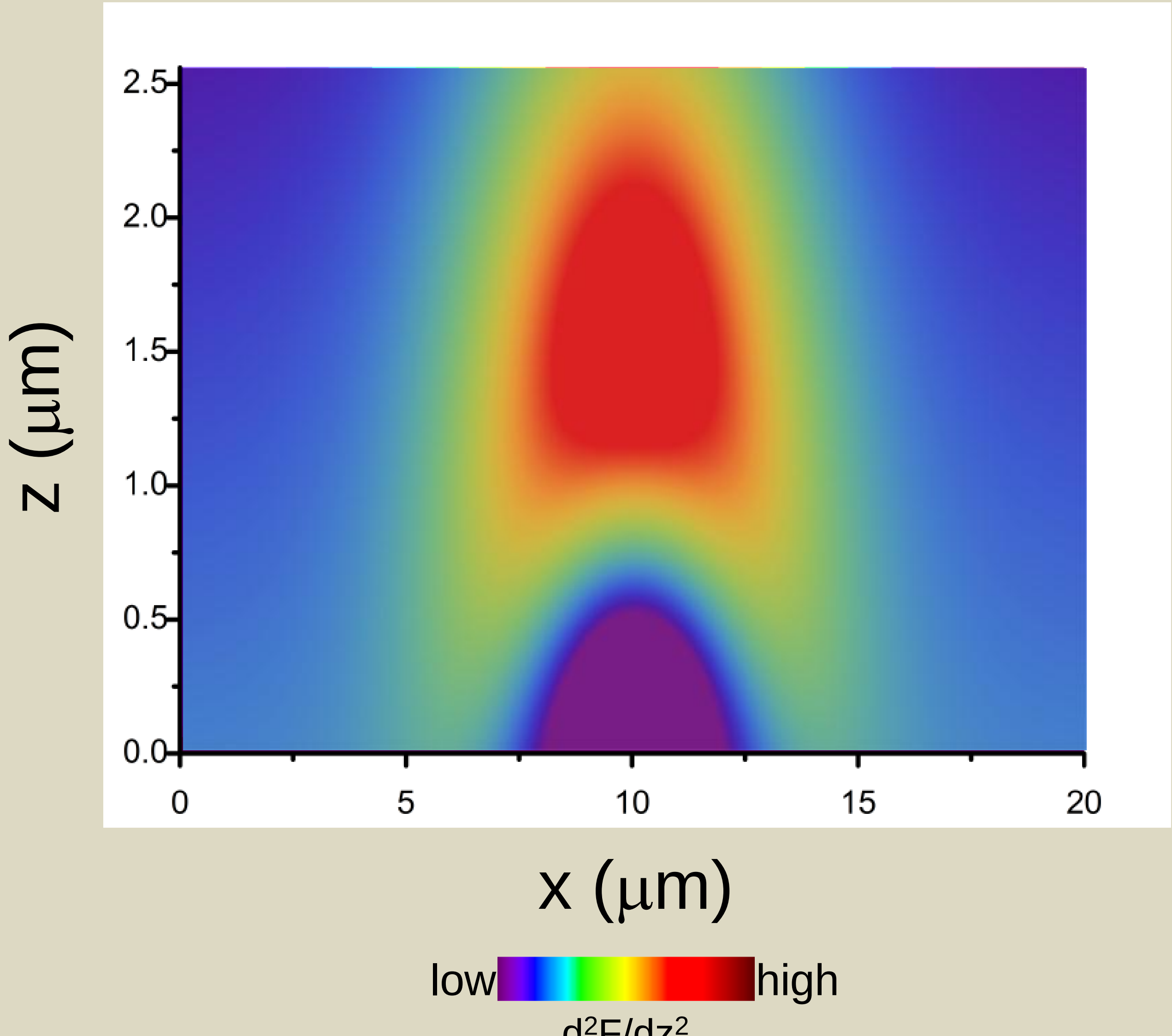
2D Theory Slice



H_e = 0.322 T

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Conclusions

- We can measure and extract m-H curves, position of particles
- Can be done at fixed H_e or as a function of H_e
- With calibration can extract magnetic moment of sample
- Full 2D fitting will enable better single data set fits

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Future Plans

- Calibration
- Smaller scales, vacuum
- Applications

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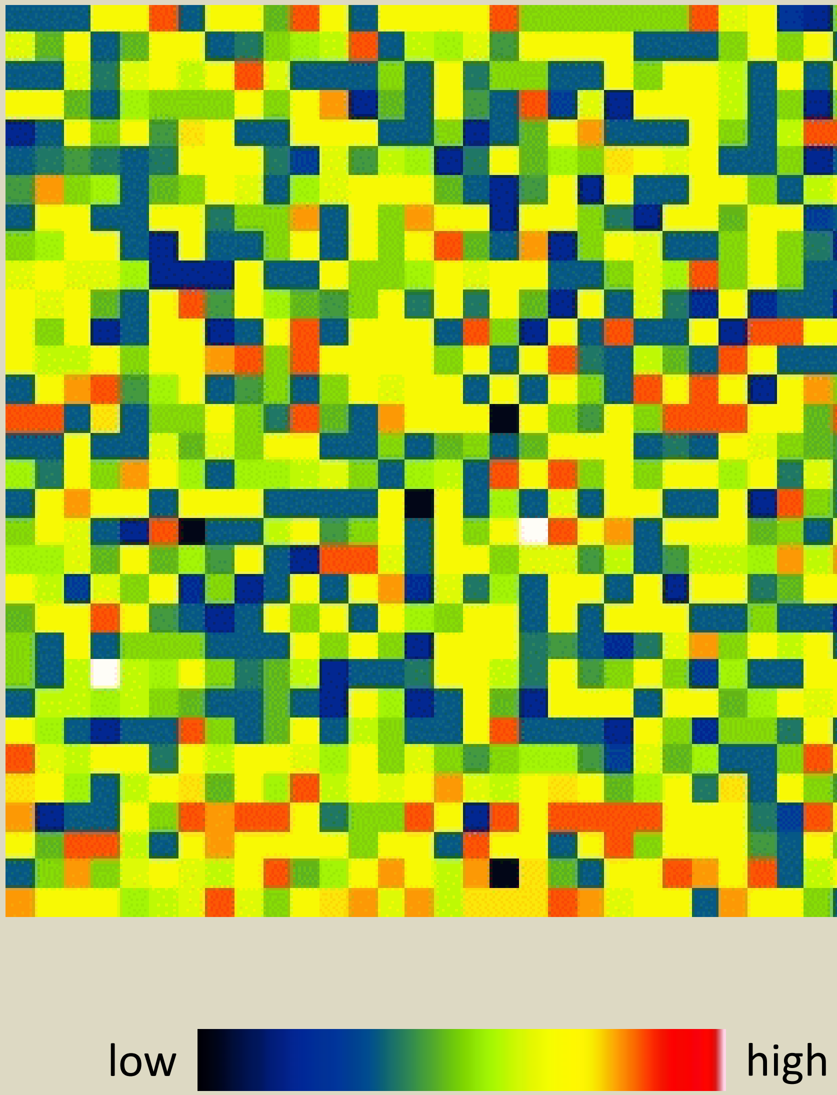
END

3D Data Sets



0.322 T

32 X 32 μm

0-2.56 μm

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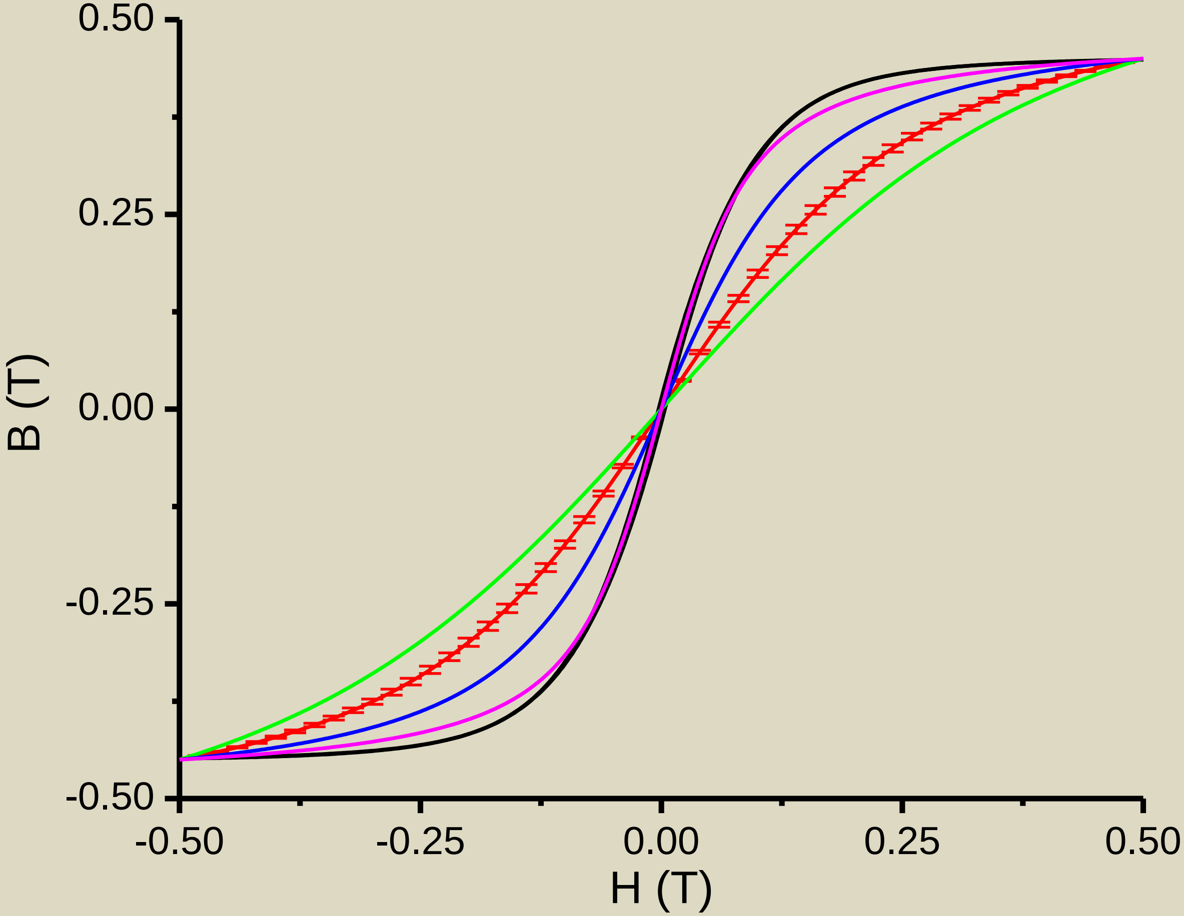
Problems and issues

- Setup has large background due to small permanent magnet
- Temperature Drift
- Optical Interference
- Lack of a defined, easy to make calibration setup

Demag Statistics

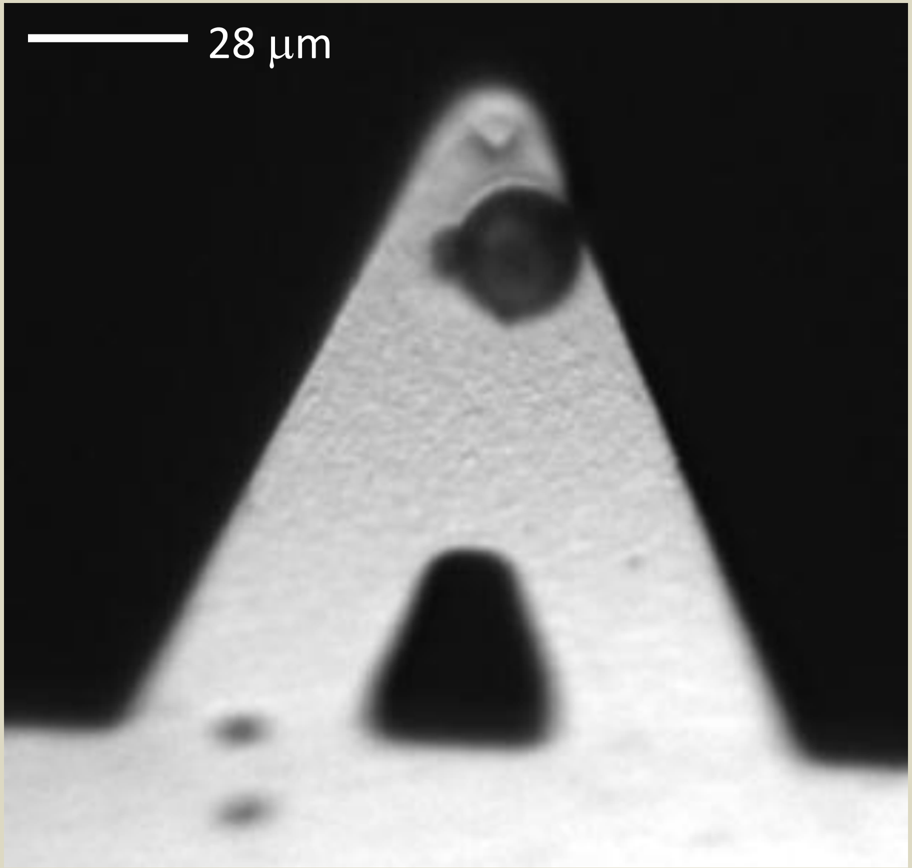


Blue, Green, Pink three more particles measured

Working on processing more now

Biased towards larger particles, bigger signal, more change in the 2.56 μm throw of the AFM

Tip Construction and Characterization



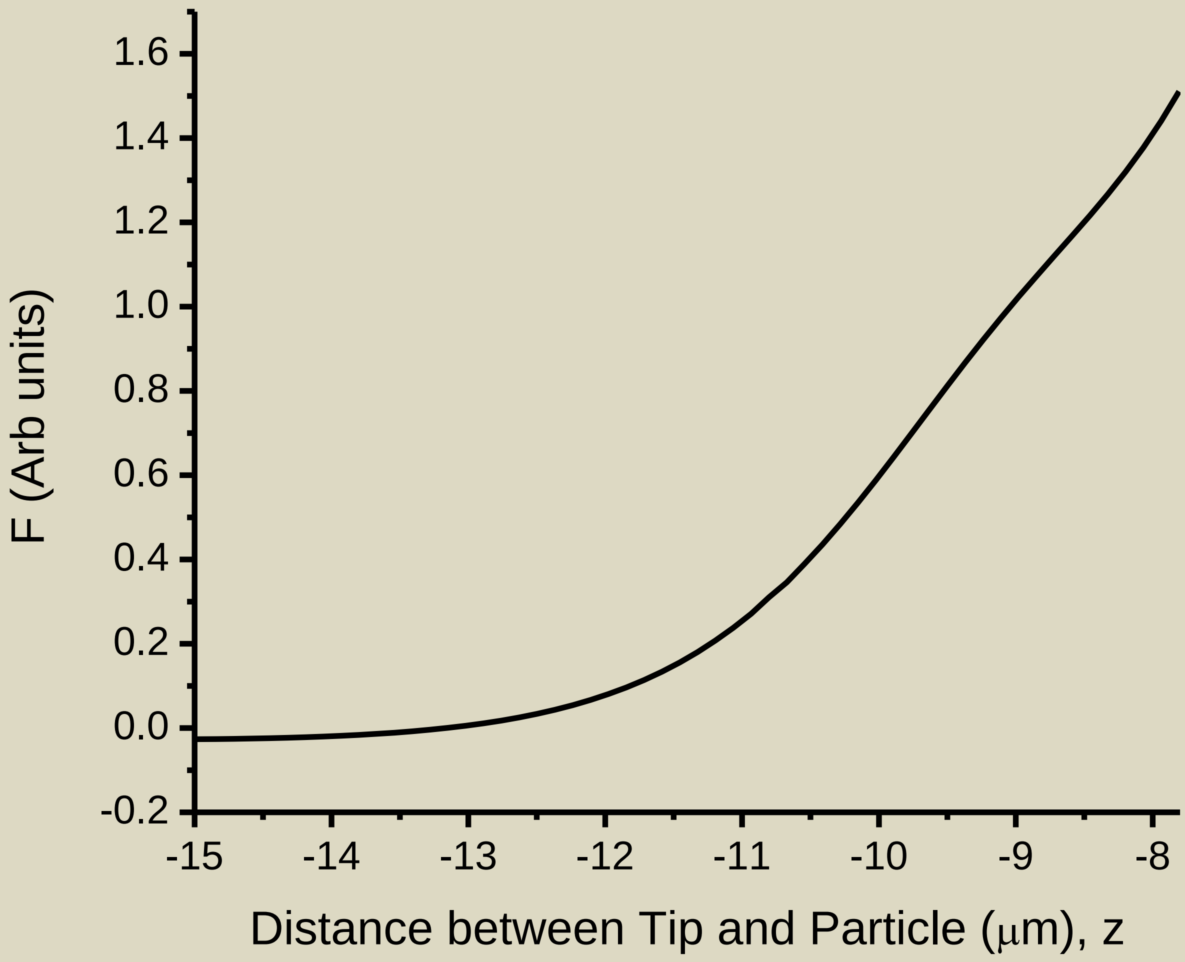
Commercial SiN tips

NdFeB 5-50 mm spheres

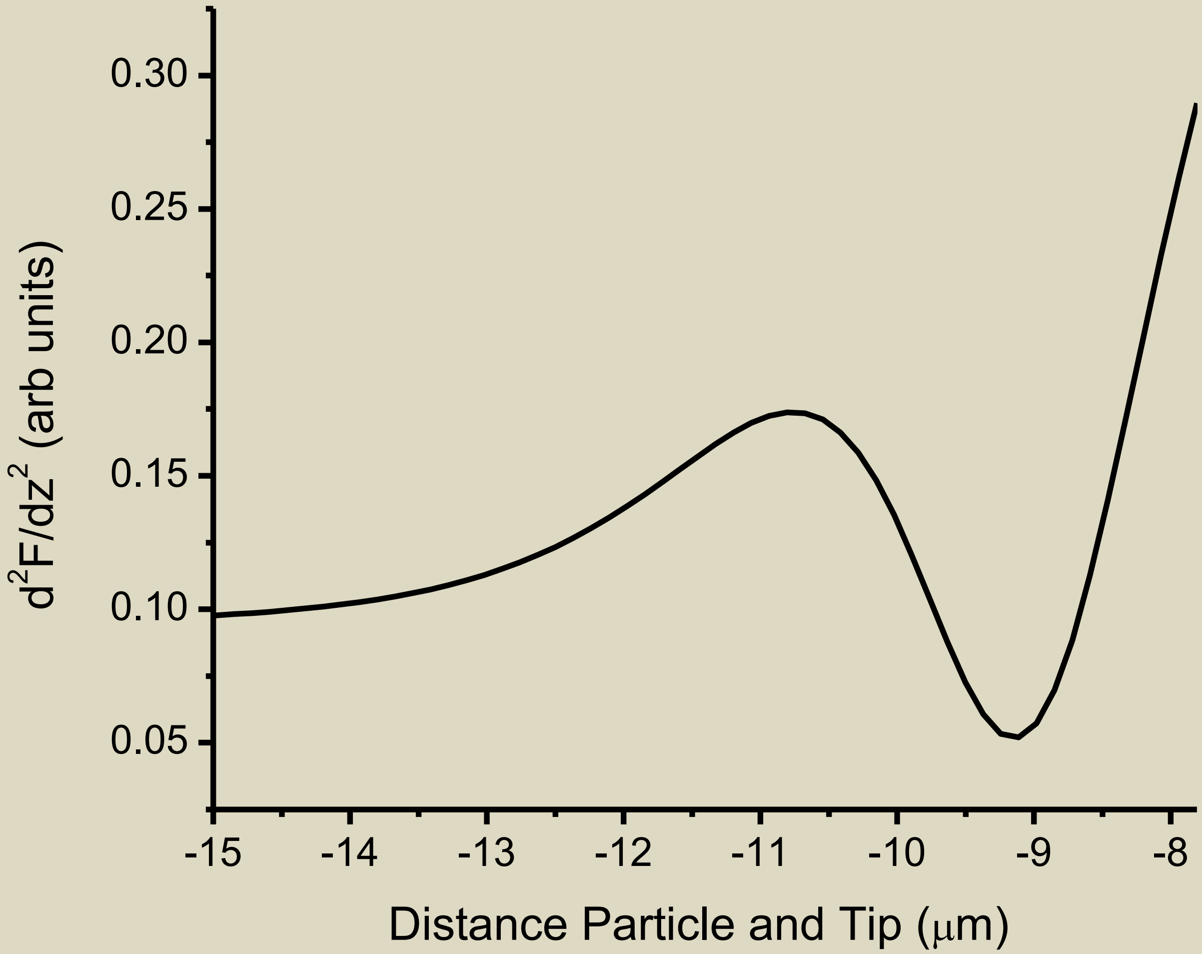
Magnetized in 3 Tesla field

Resonance $f_0 \sim 80$ kHz

Theory: Force



Theory: 2nd Derivative Force



Theory

We measure the 2nd Harmonic, or Derivative of the force

$$\frac{\partial^2 F}{\partial z^2}(z) = -\frac{\mu_0}{4\pi}\frac{120 m_t m_p(H_z)}{z^6}$$

$$-\frac{\mu_0}{4\pi}\frac{1104 {m_t}^2 {m_p}'(H_z)}{z^9}$$

$$-\frac{\mu_0}{4\pi}\frac{1512 {m_t}^3 {m_p}''(H_z)}{z^{12}}$$

$$-\frac{\mu_0}{4\pi}\frac{432 {m_t}^4 {m_p}^{(3)}(H_z)}{z^{15}}$$