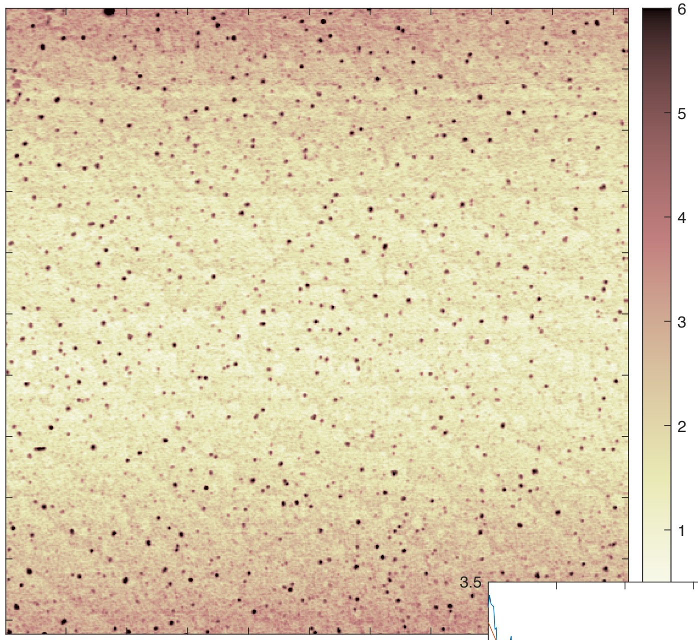
NiO nanoparticle in-phase susceptibility calculation

2021/03/18

Ruby Shi

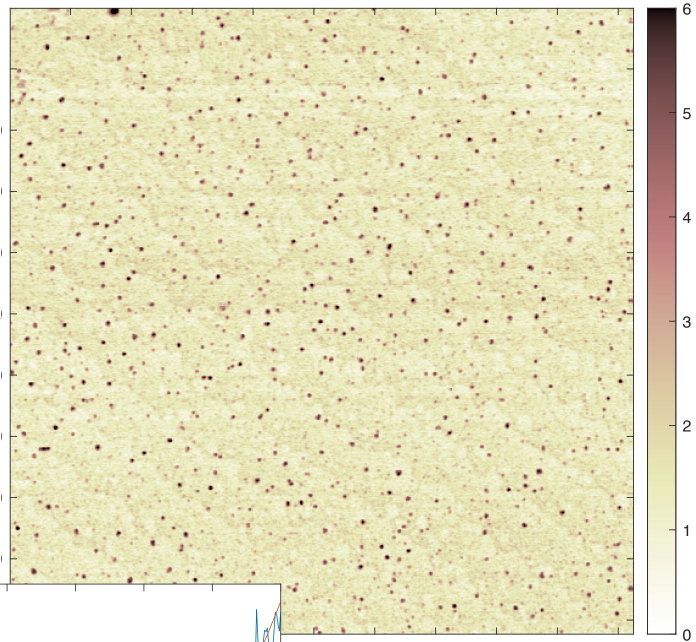
AFM image processing - 1

Raw AFM data



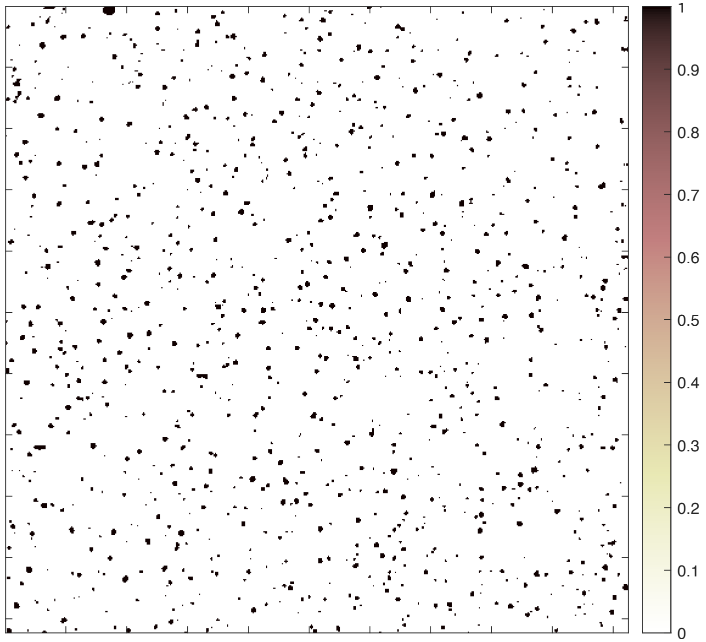
Background subtraction

BG subtracted AFM

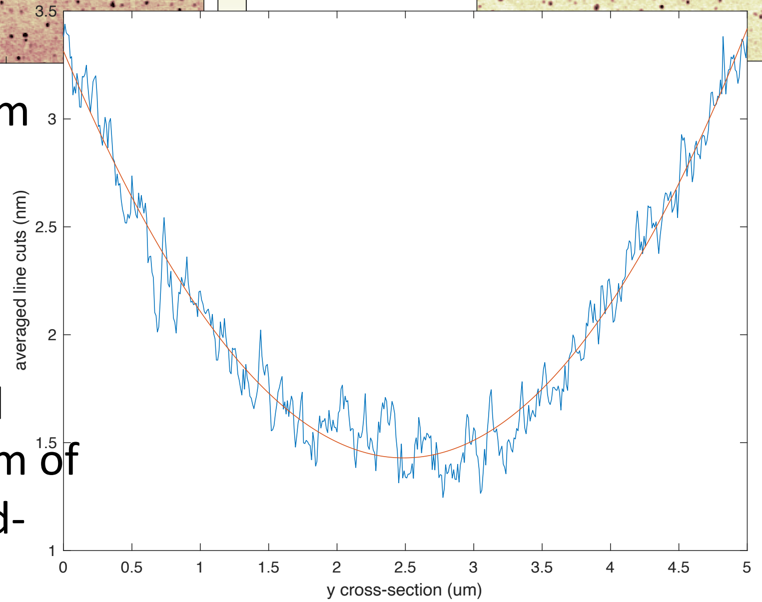


Threshold 2.5nm

Binary AFM



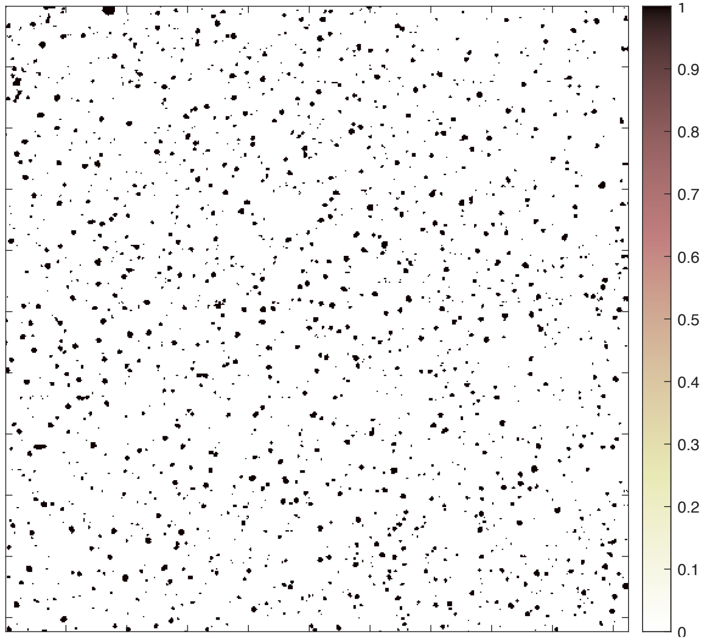
La-sample, 5um * 5um
Color-bar 0 – 6nm



Without any physical interpretation, fit sum of all y line cuts to a 3rd-order polynomial

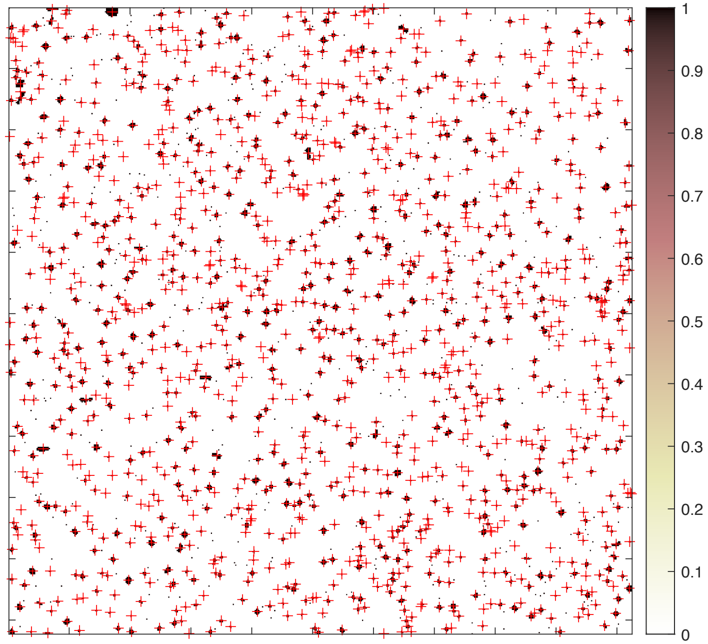
AFM image processing - 2

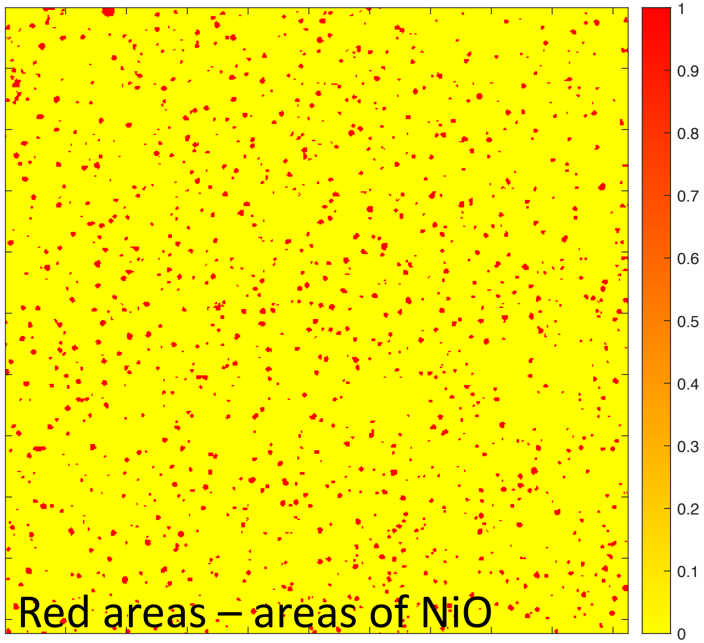
Binary AFM



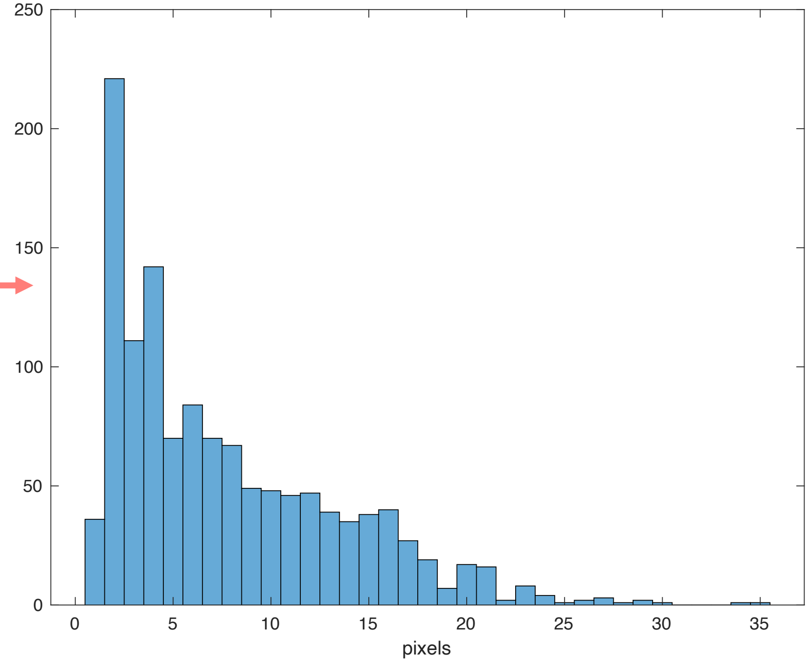
Use *connected component* object in MATLAB to identify NiO nano particles

Red crosses – centers of NiO



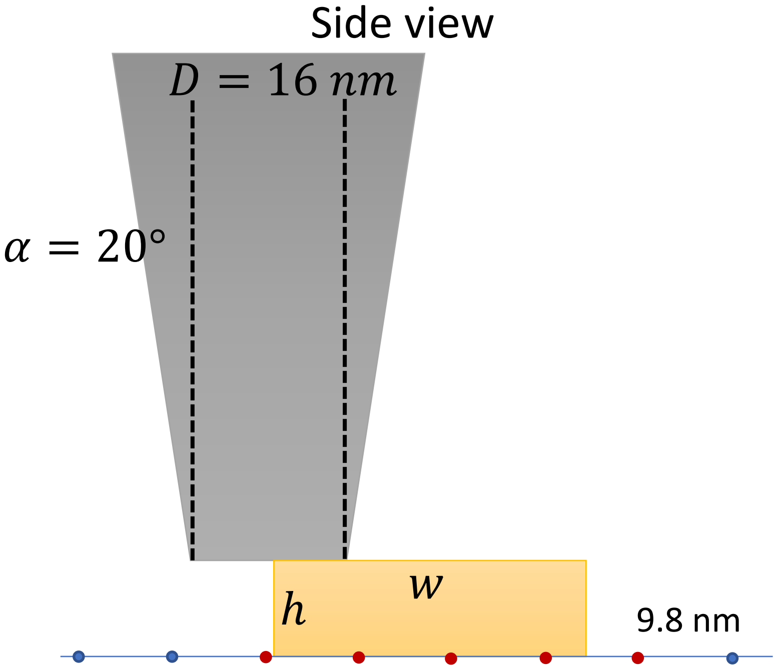


Red areas – areas of NiO



2D area histogram of NiO in number of pixels

AFM image processing - 3



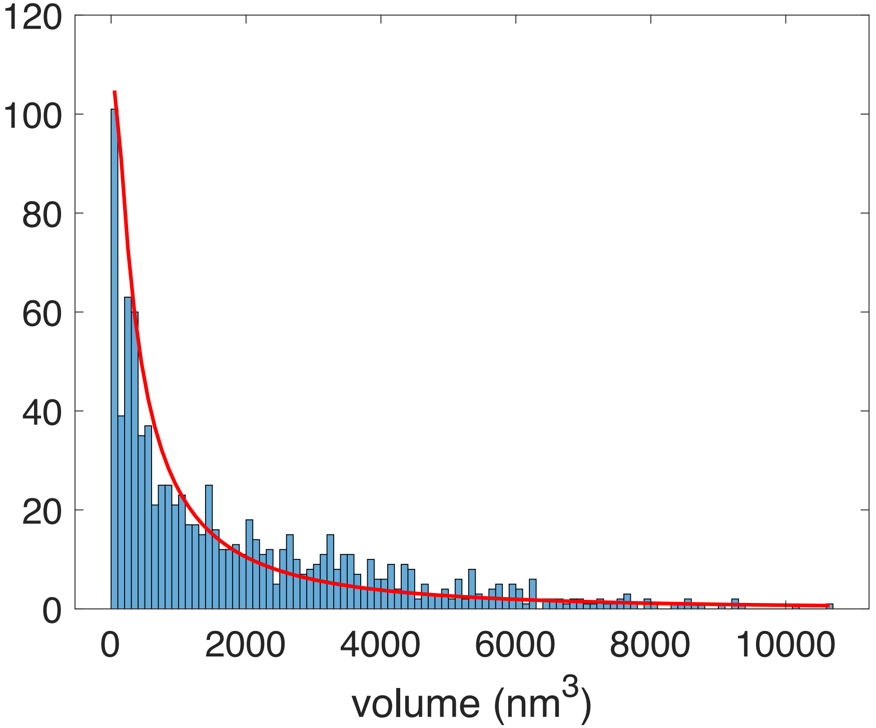
$$w_{actual} = w_{measured} - D$$

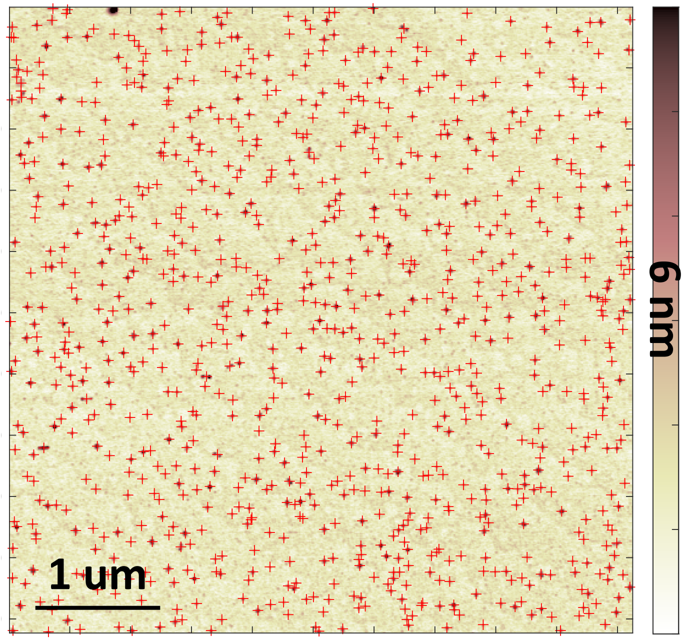
dots – AFM steps, 9.8 nm
Red dots – where a grain is detected
So here actual pixel is 3

The actual width is decided as
Pixels – a random number either 1 or 2

TIP : [HQ:NSC15/AL BS]

Eventual results





Fitted to log-normal distribution with
$\mu = 6.74(.14)\ , \sigma = 1.62(.1)$

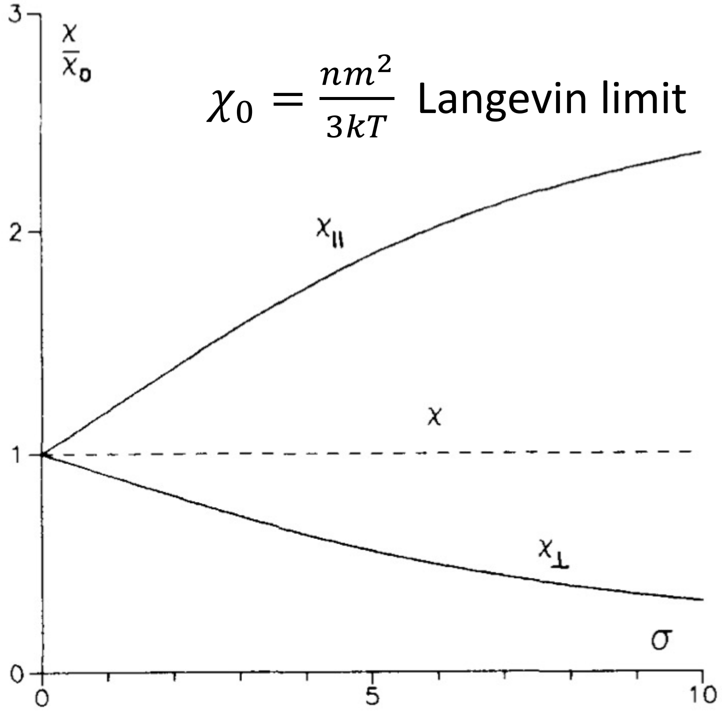
χ' calculation

K anisotropy constant ~ $3e5\ erg/cm^3$
V nanoparticle volume ~ $100\ nm^3$
$\sigma = KV/k_BT$ a scaling constant

$$\chi_{\parallel} = \frac{nm^2}{kT}\frac{R'}{R}, \qquad R(\sigma) = \int_0^1 e^{\sigma x^2} dx.$$

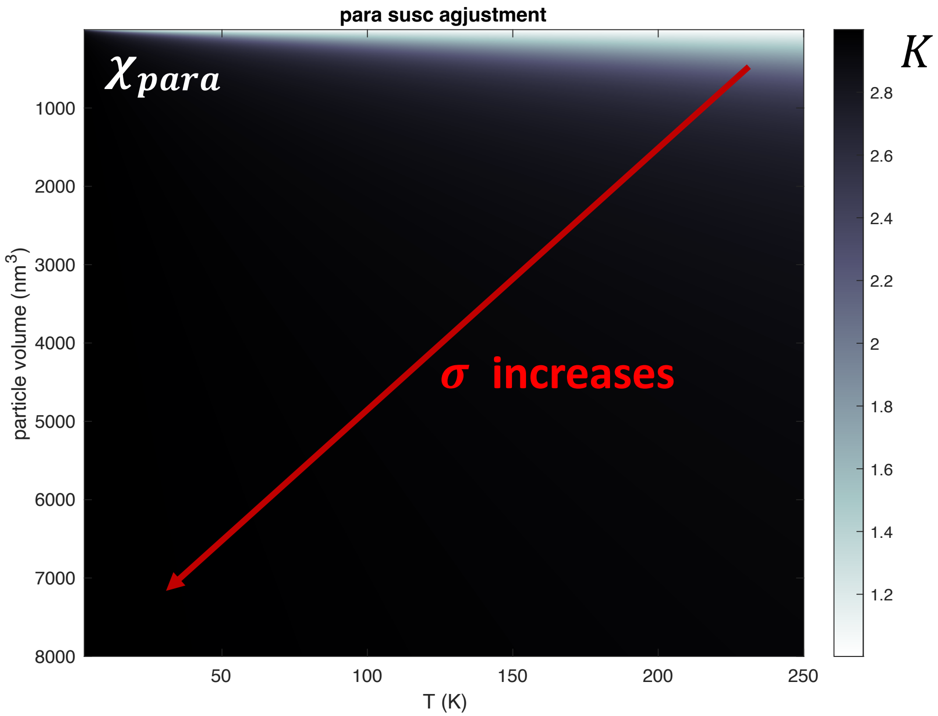
$$\chi_{\perp} = \frac{nm^2}{kT}\frac{R - R'}{2R}.$$

$\chi_0 = \frac{nm^2}{3kT}$ Langevin limit

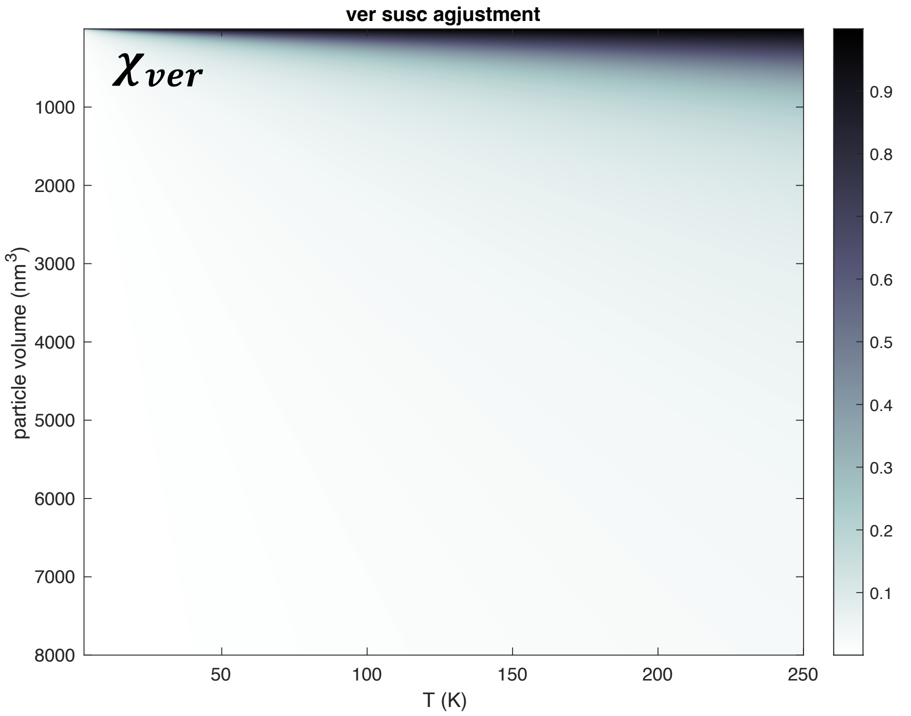


Step 1: get longitudinal and transverse static susceptibility

M. I. Shliomis and V. I. Stepanov, J. Magn. Magn. Mater. **122**, 176 (1993).



$K = 2.5 erg/cm^3$



σ-dependence of my calculation agrees with theory paper

χ' calculation

The dynamic susceptibility is described as

$$\chi = \tfrac{1}{3}\left[\chi_{\parallel}(1+i\omega\tau_{\parallel})^{-1} + 2\chi_{\perp}(1+i\omega\tau_{\perp})^{-1}\right]$$

$$\tau_{\parallel}^{-1} = \tau_l^{-1} + \tau_B^{-1}, \quad \tau_{\perp}^{-1} = \tau_t^{-1} + \tau_B^{-1},$$

where

Some relaxation time of solvent, dropped

$$\tau_l = \tau_D \begin{cases} (1+2S)/(1-S) & \text{at } \sigma \le 2; \\ (\sqrt{\pi}/2)\sigma^{-3/2}e^{\sigma} & \text{at } \sigma \ge 2; \end{cases}$$

$$\tau_t = 2\tau_D \frac{1-S}{2+S} \quad \text{for all } \sigma.$$

Longitudinal relaxation time is also Neel time

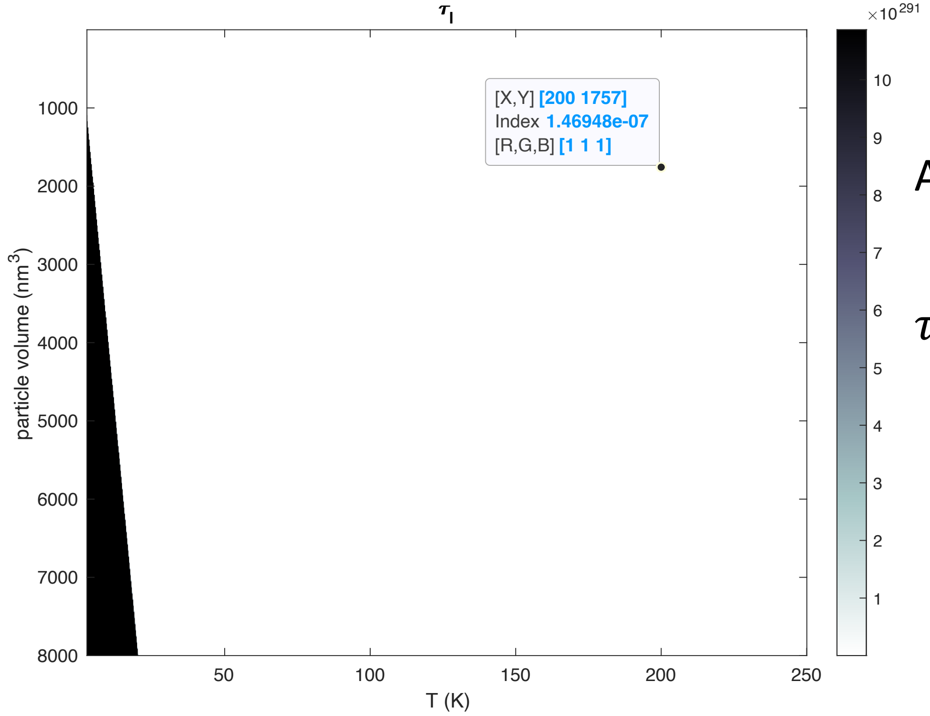
$$\tau_l = \tau_N = \tau_0 \exp\left(\frac{KV}{k_b T}\right) = \tau_0 \exp(\sigma)$$

Step 2: get switching time dependence

So eventually, I used

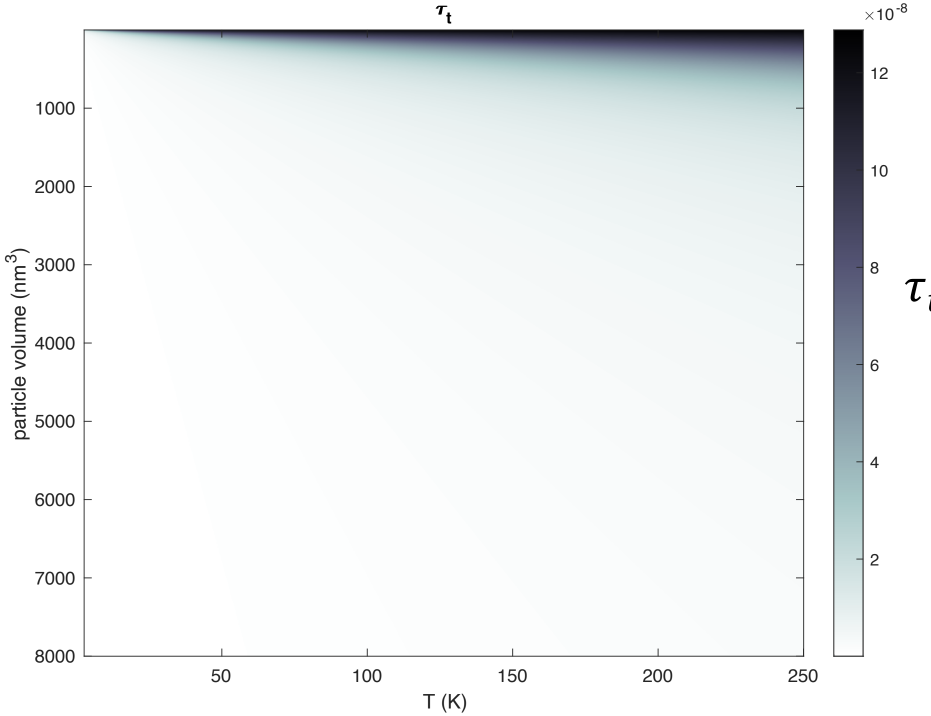
$$\tau_l = \tau_0 \exp(\sigma), \tau_0 = 1e-12\ s$$

$$\tau_t = 2\tau_D \frac{1-S}{1+S}, \tau_D = 1e-7\ s$$



As σ increases…

τ_l grows exponentially



τ_t drops to 0

χ' calculation

$$\chi = \tfrac{1}{3}\left[\chi_{\parallel}(1 + i\omega\tau_{\parallel})^{-1} + 2\chi_{\perp}(1 + i\omega\tau_{\perp})^{-1}\right]$$

Step 3: take real and imaginary part of χ

Sanity check:
What is the blocking temp for 500 nm^3 nano-particles?

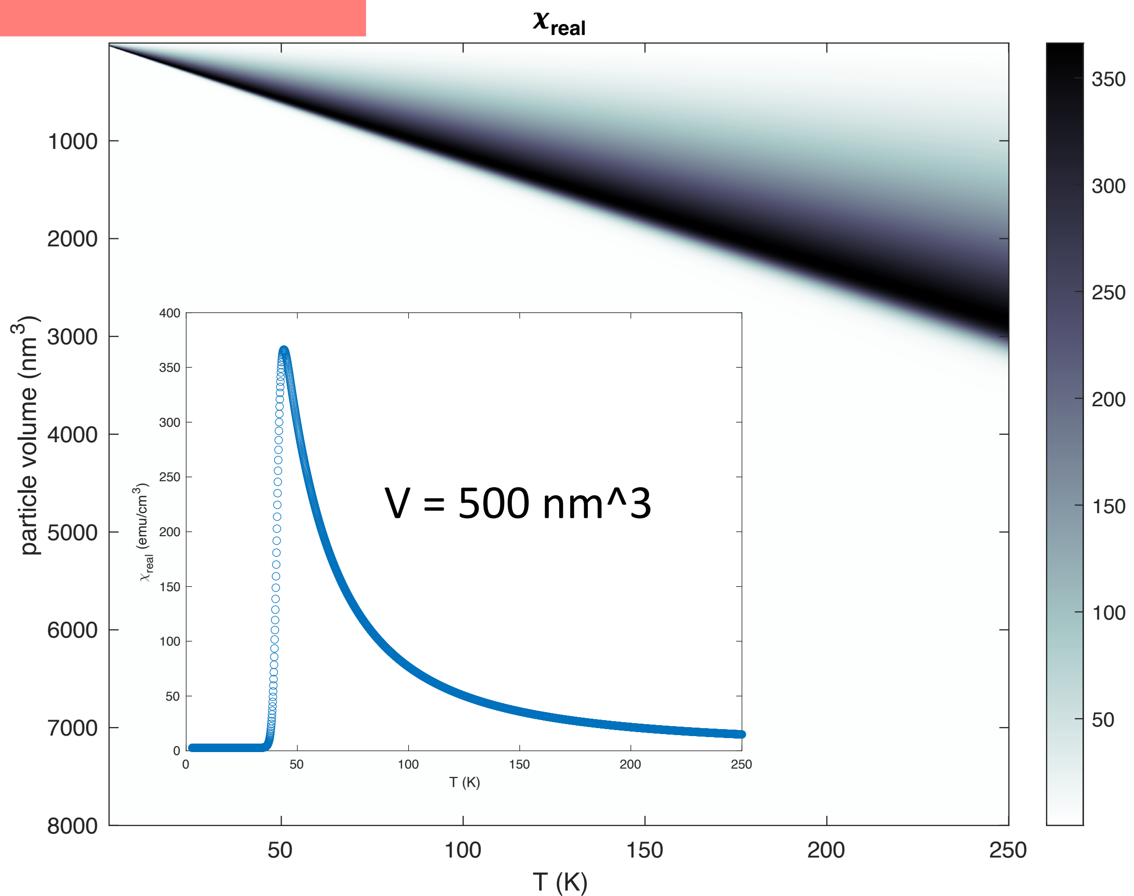
$$T_B = \frac{KV}{k_B \ln(\tau_m/\tau_0)}$$

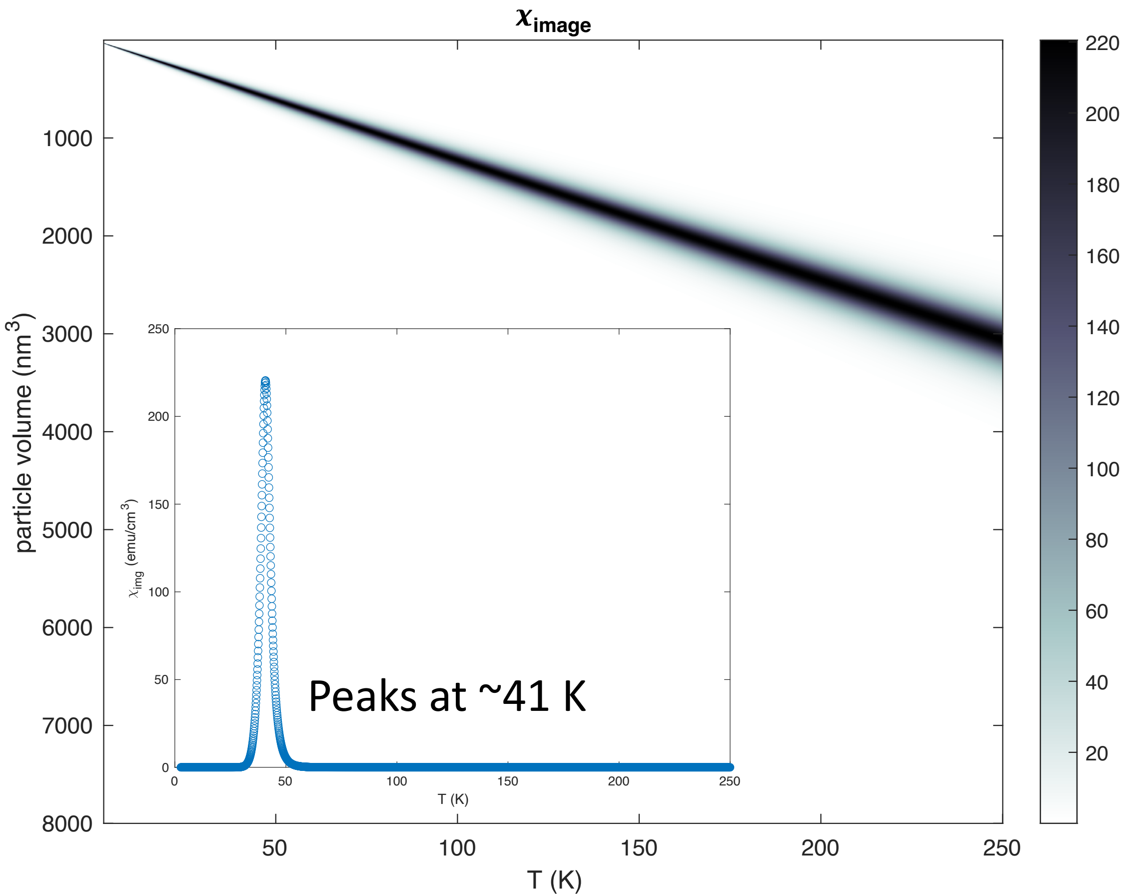
$$K = 2.5\ erg/cm^3$$

$$\tau_m = \frac{1}{1223\ Hz} \longrightarrow T_B = 45\ K$$

$$\tau_0 = 1e - 12\ s$$

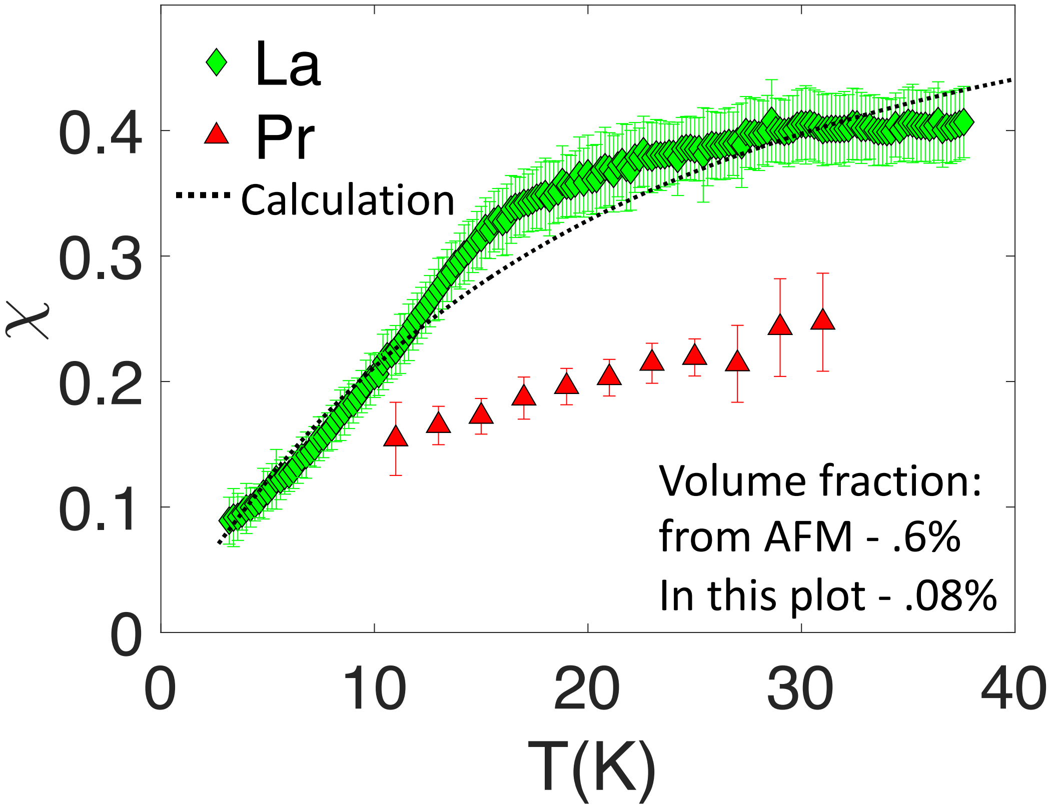
Agrees reasonably well with plot





χ' calculation

Step 4: apply probability distribution

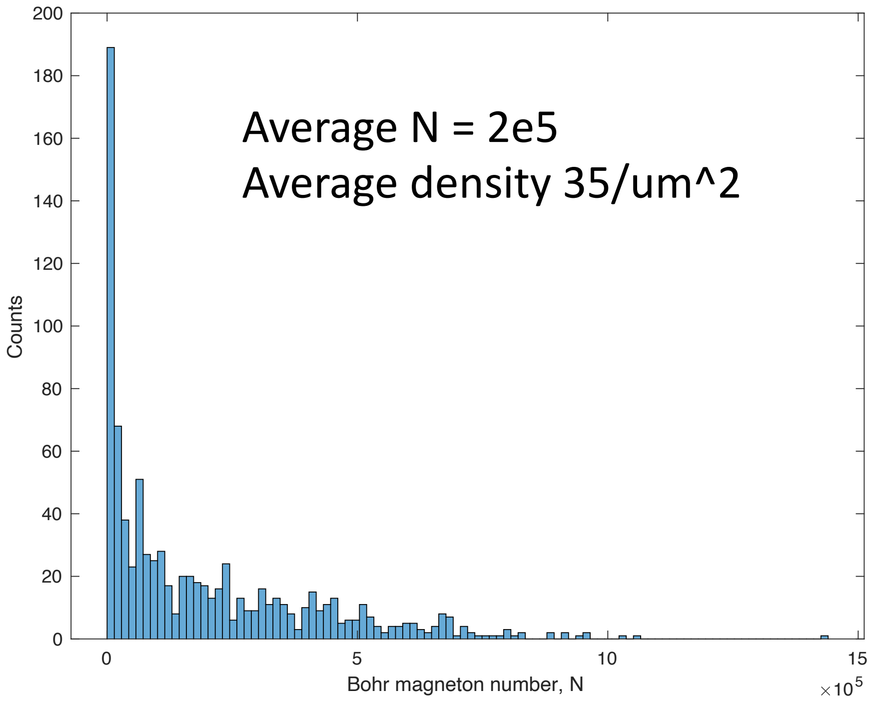


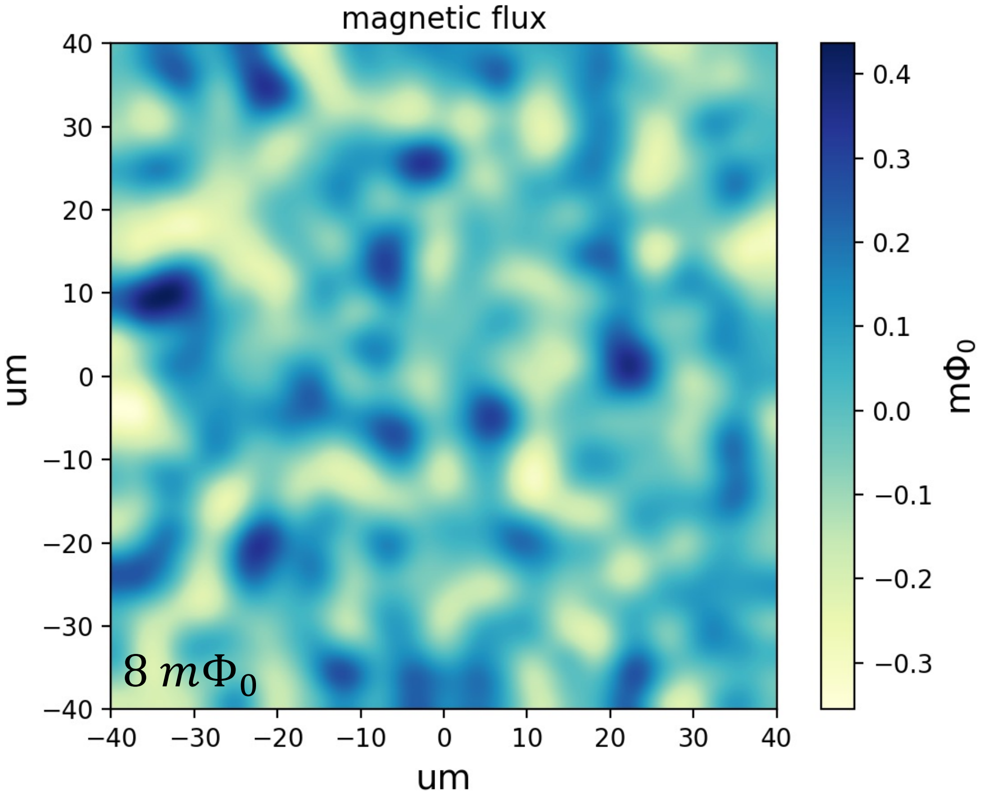
Calculated result captures the trend of data but not flattening near 15 K
-> could get some flattening if twisting the fitted log- normal distribution a tiny bit

Sources of error:

- Incorrect counting of nanoparticle volume from AFM
- Big nanoparticles are not single-domain
- Nanoparticles are not non-interacting

Magnetic background





- This simulation result agrees really well with data
- If I used the real distribution, than the average, the simulated signal should be greater
- Hence sources of error from last slide, such as bigger nano particles have multi domains, can still hold