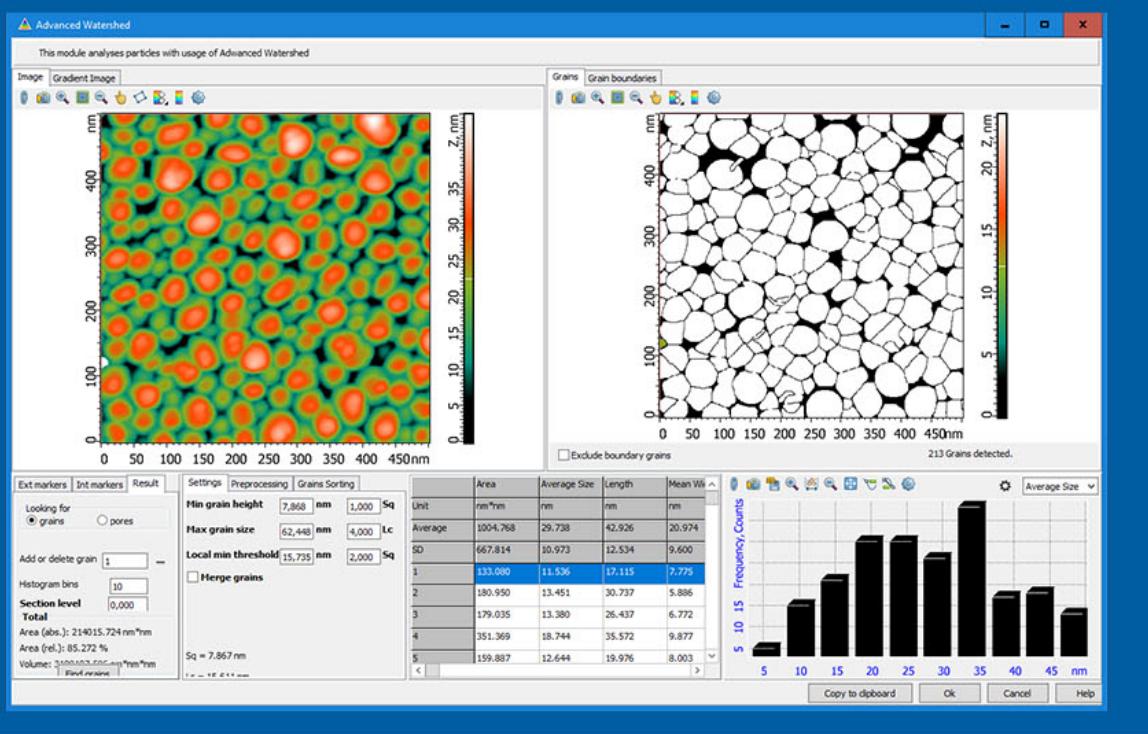


Image Processing and Analysis in Scanning Probe Microscopy: Key Aspects and Recipes

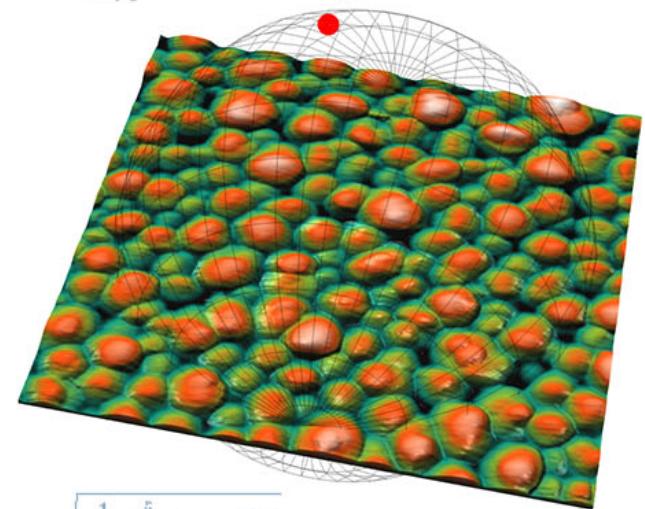
$$r_{x,y} = \frac{\sum (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \cdot \sqrt{\sum (y_i - \bar{y})^2}}$$

$$F = \frac{\max(D_1; D_2)}{\min(D_1; D_2)}, \quad df_1 = n_{\max} - 1, \quad df_2 = n_{\min} - 1$$

$$r_{xy-z} = \frac{r_{xy} - r_{xz} \cdot r_{yz}}{\sqrt{(1-r_{xz}^2)(1-r_{yz}^2)}}$$



$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i = \frac{(X_1 + X_2 + X_3 + \dots + X_n)}{n}$$



$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2}$$

$$t = \sqrt{\frac{n_1 \cdot n_2 \cdot (n_1 + n_2 - 2) (\bar{x} - \bar{y})^2}{(\sum (x_i - \bar{x})^2 + \sum (y_i - \bar{y})^2) (n_1 + n_2)}}$$

Stanislav I. Leesment, Ph.D
May 15th 2019

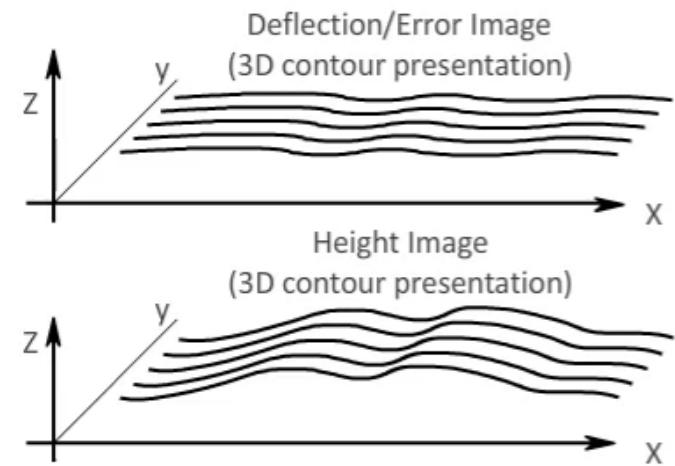
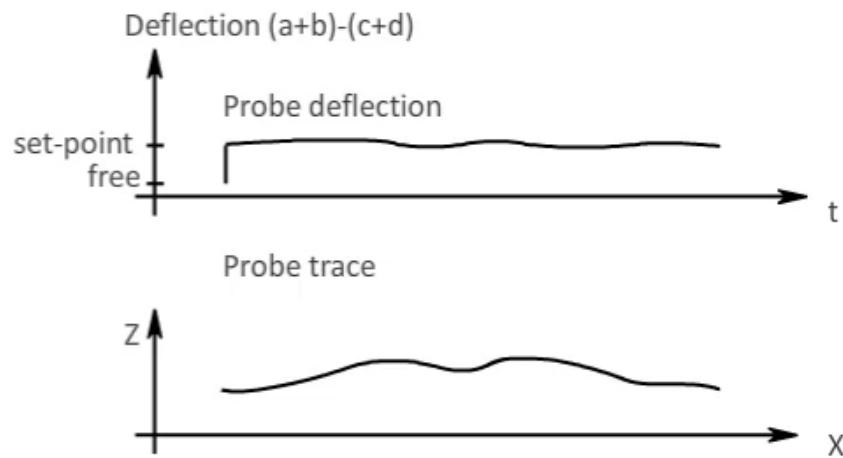
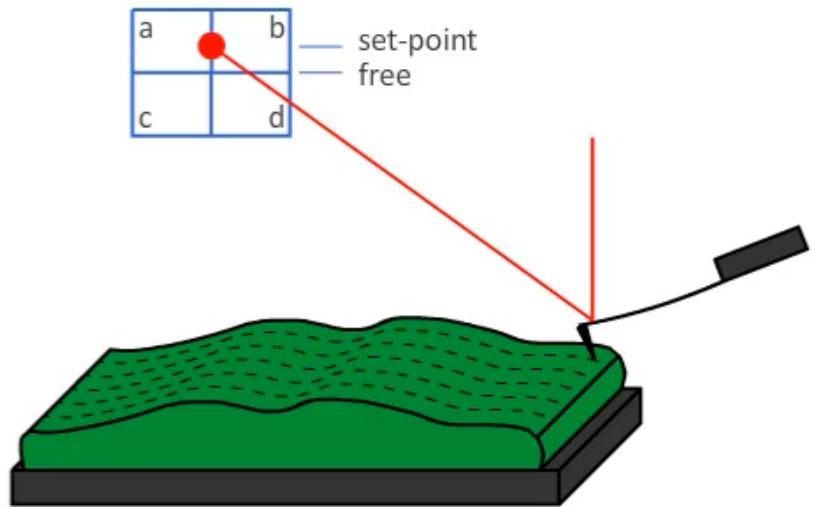
Webinar Summary

- 1. Introduction. Overall principles**
- 2. Flattening: surface and interline**
- 3. Image Reconstruction**
- 4. Images representation**
- 5. Image Analysis**

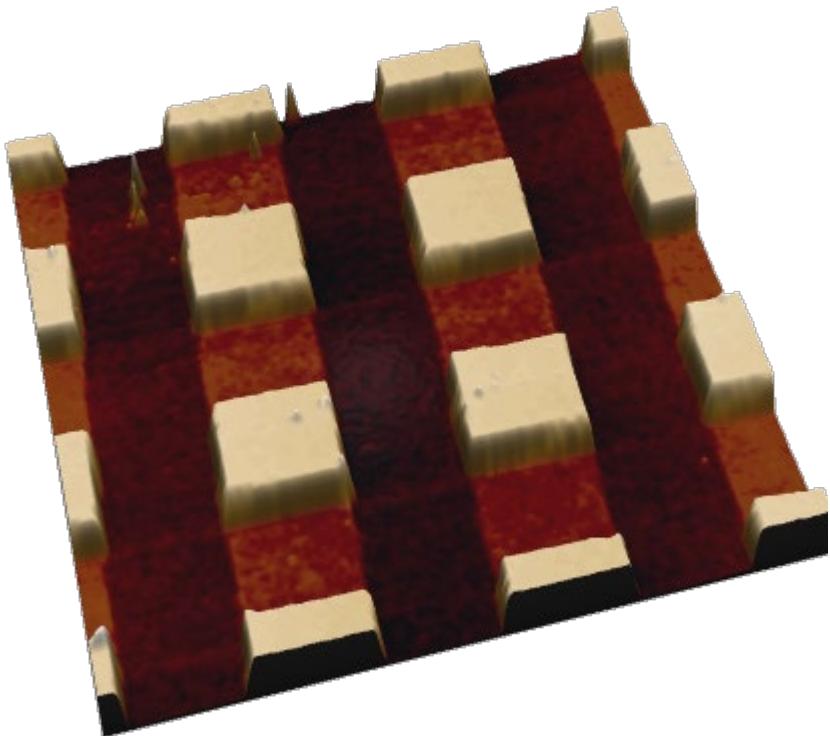
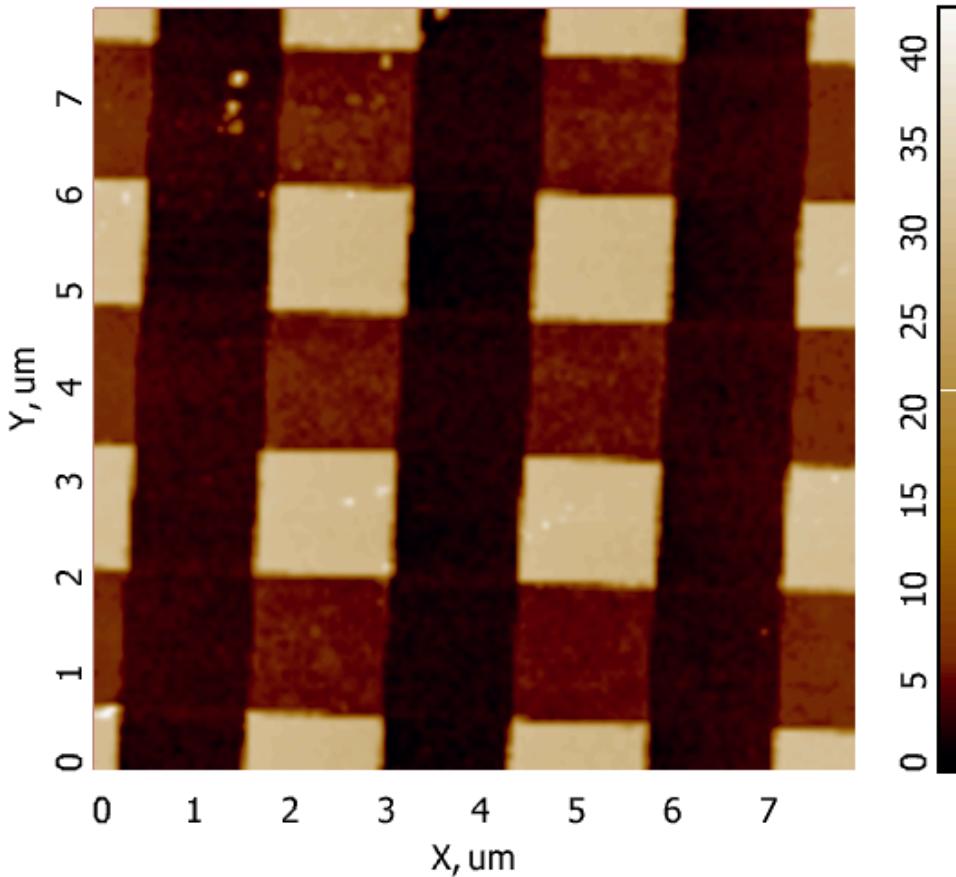
How AFM Images are Acquired?



How AFM Images are Acquired?

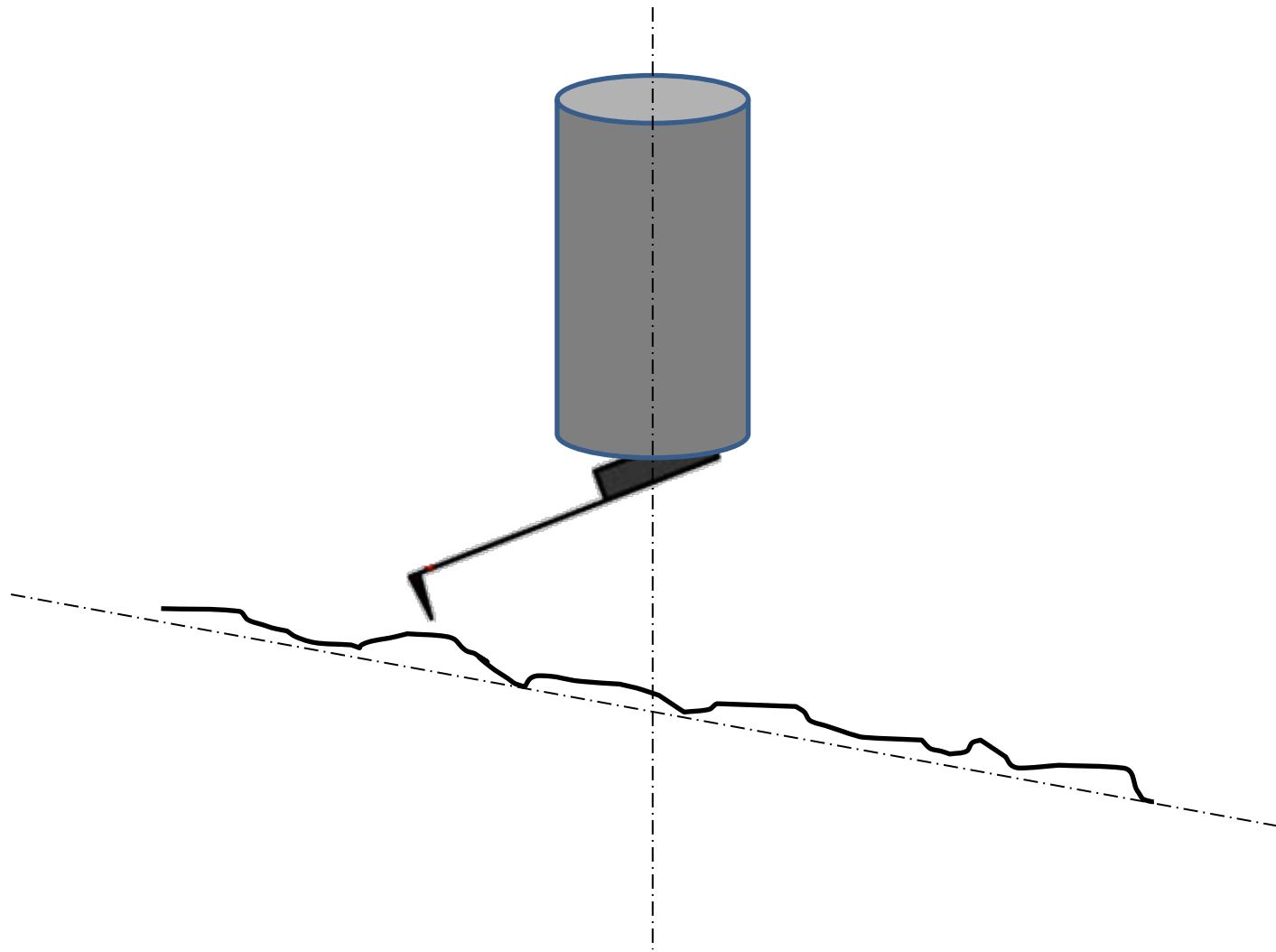


What Does AFM Image Mean

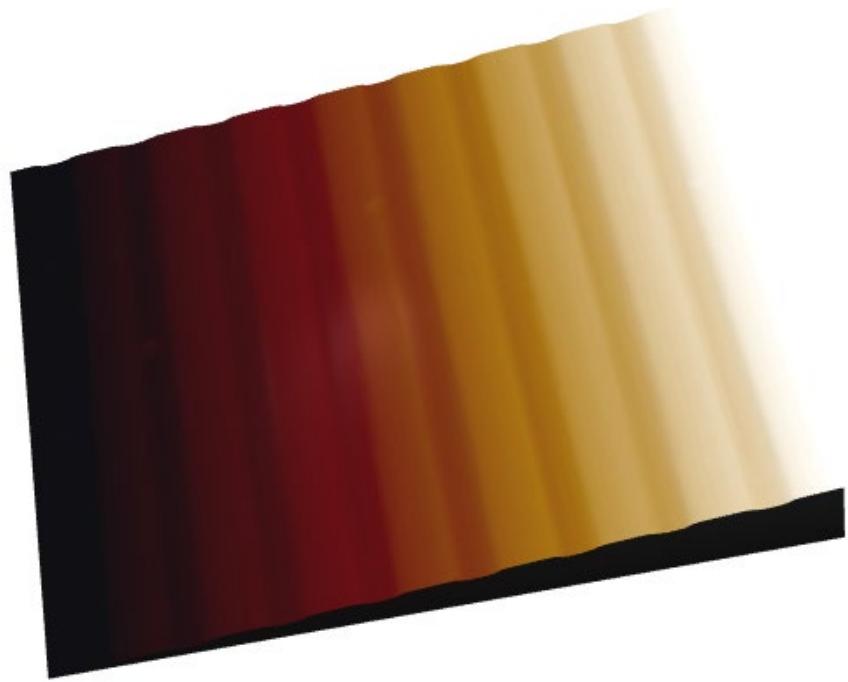
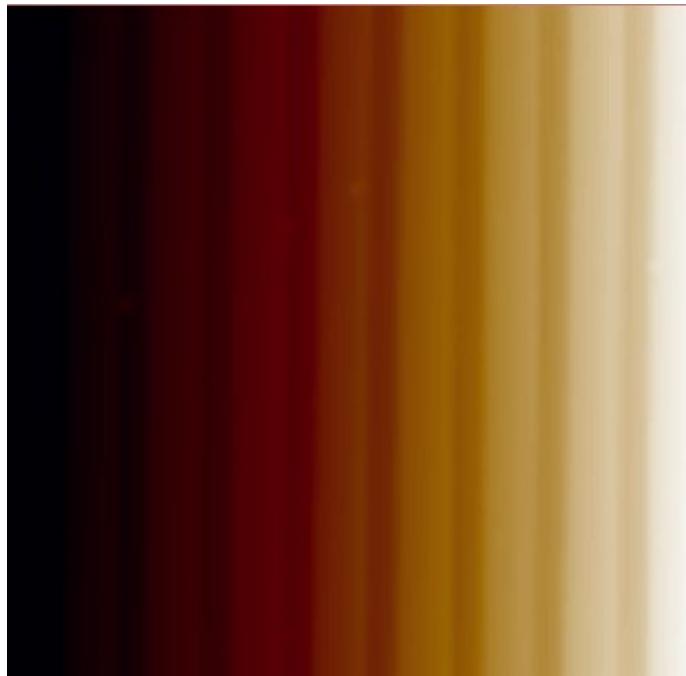


Flattening

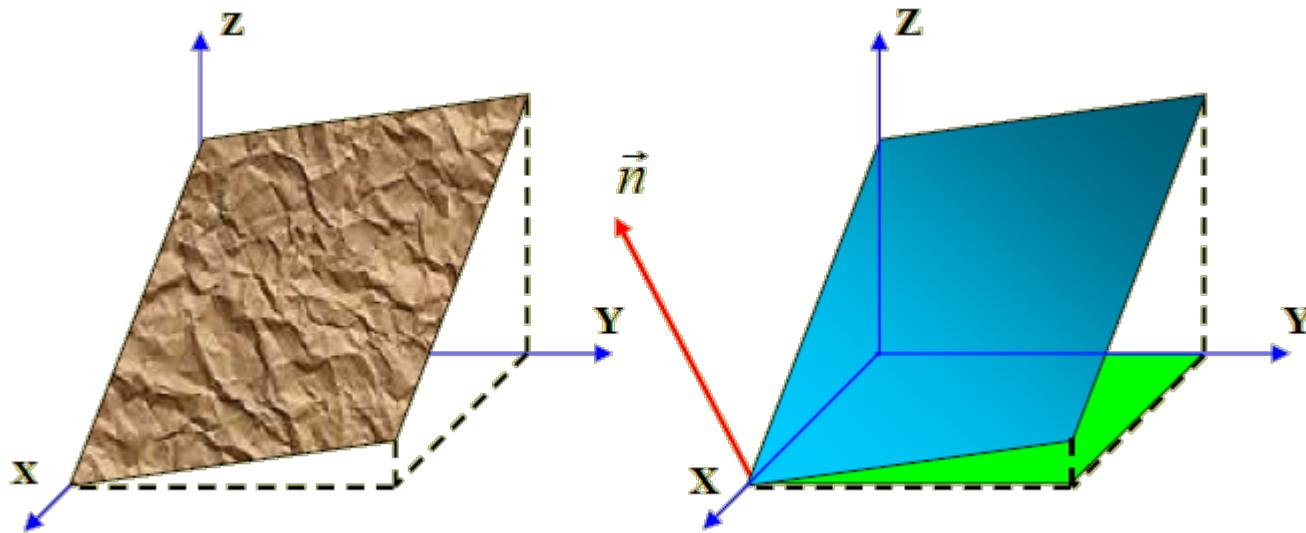
Surface Slope



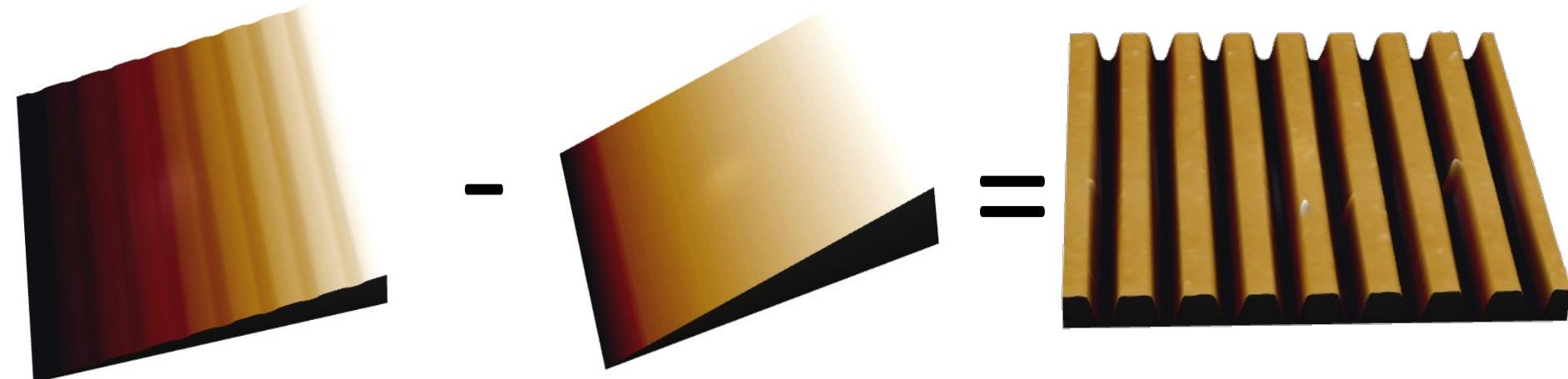
Surface Slope



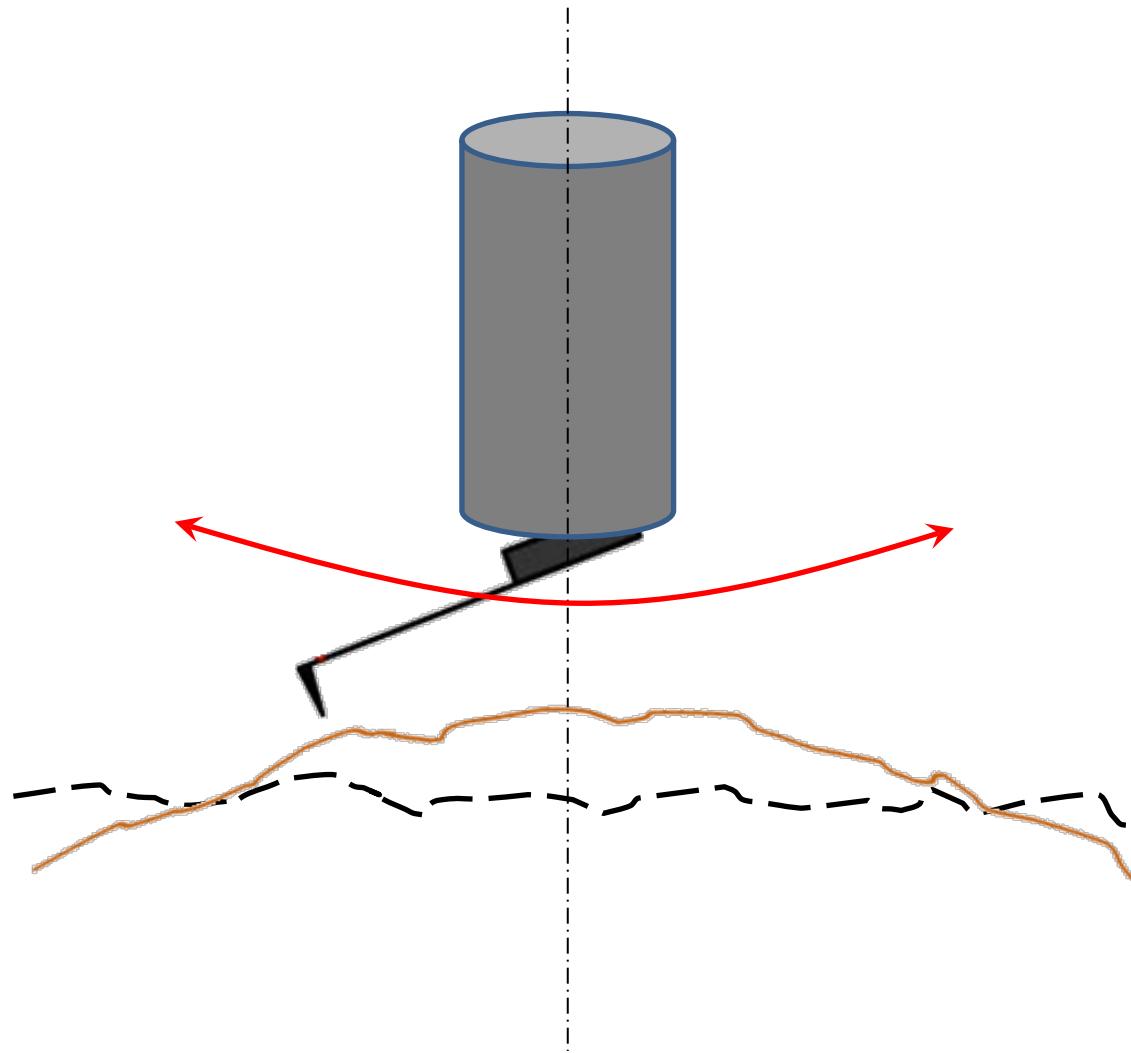
Slope Subtraction



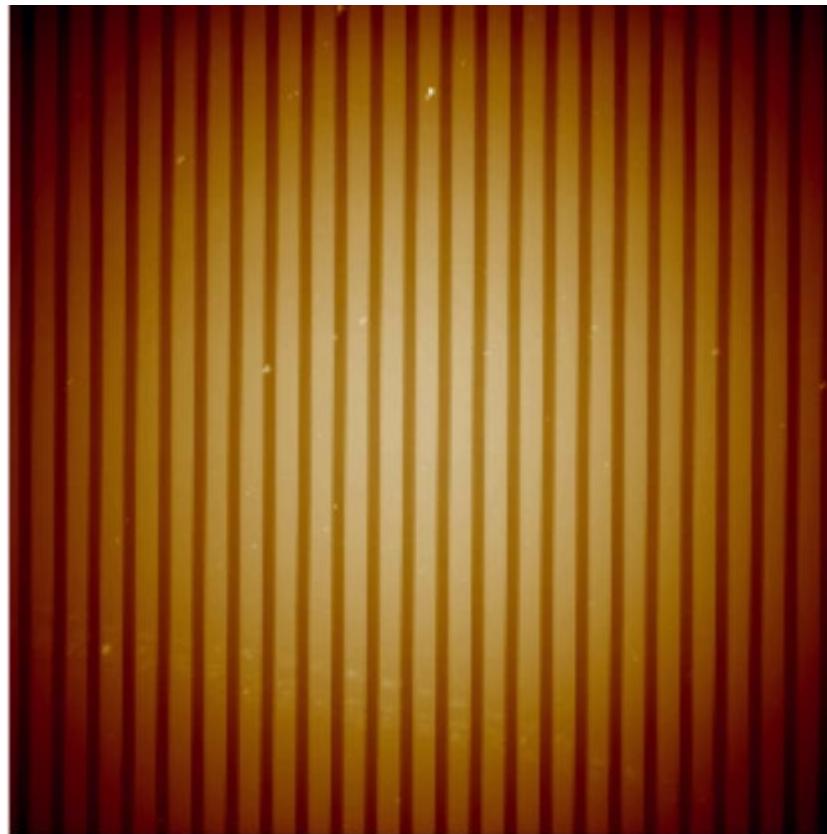
$$Ax + By + Cz + D = 0$$



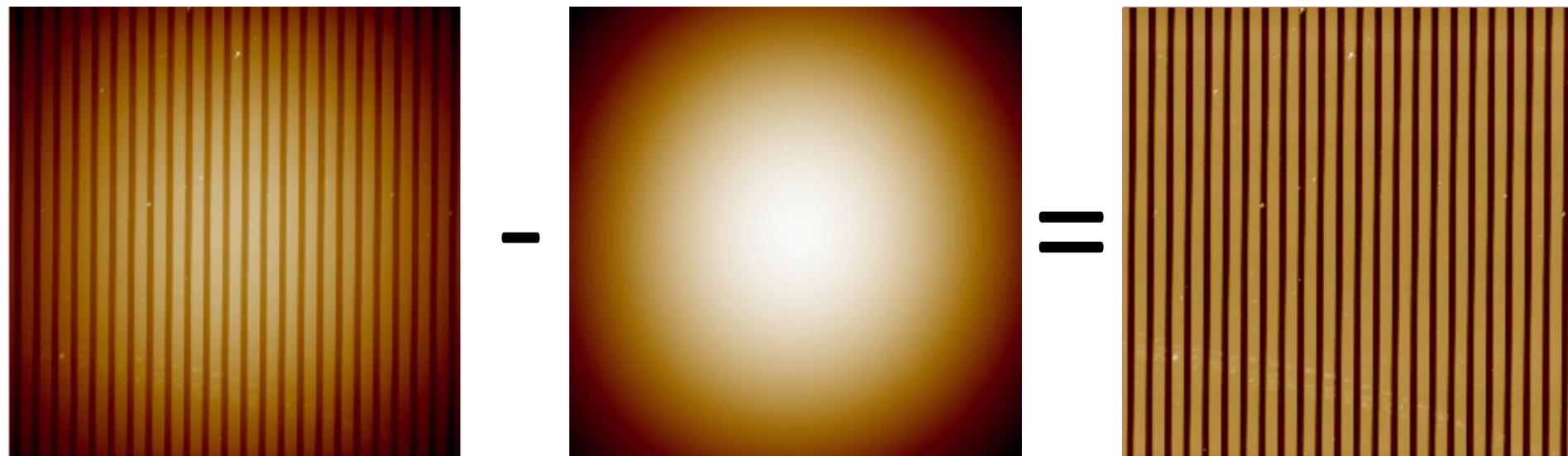
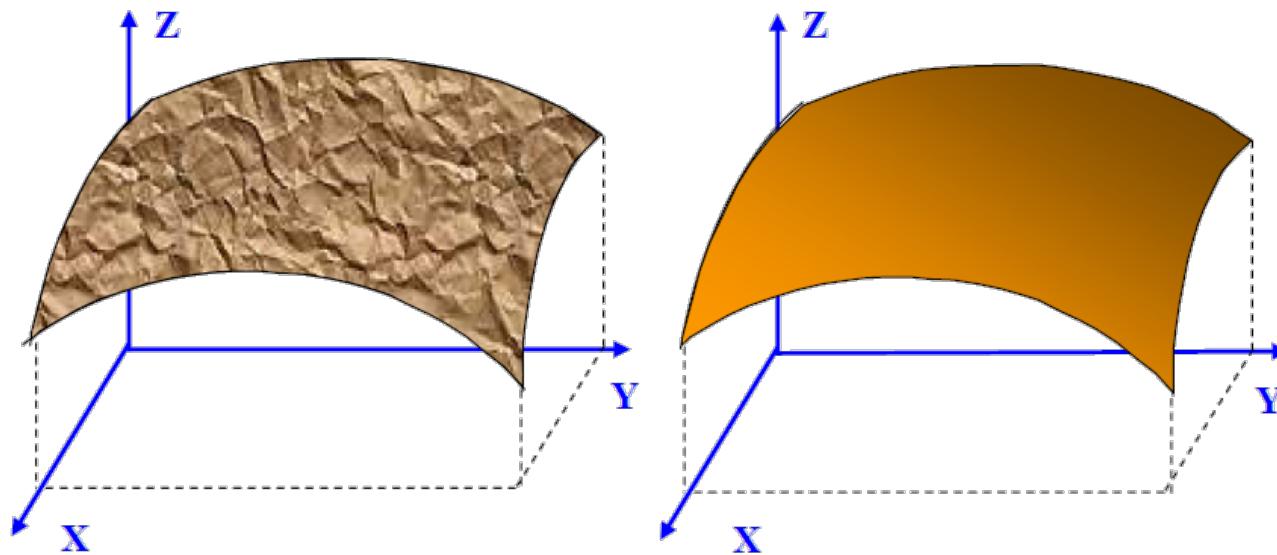
Bow



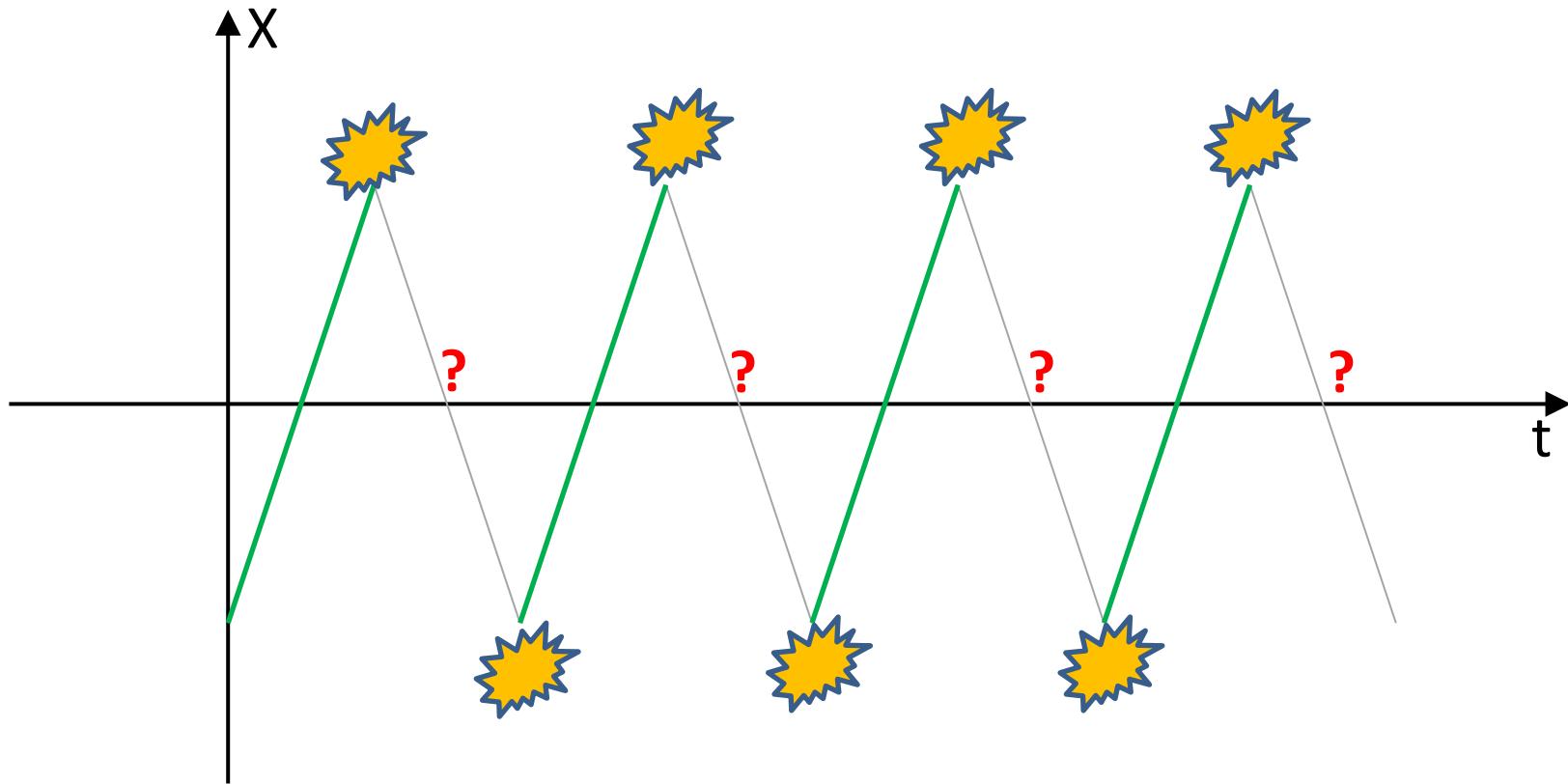
Bow



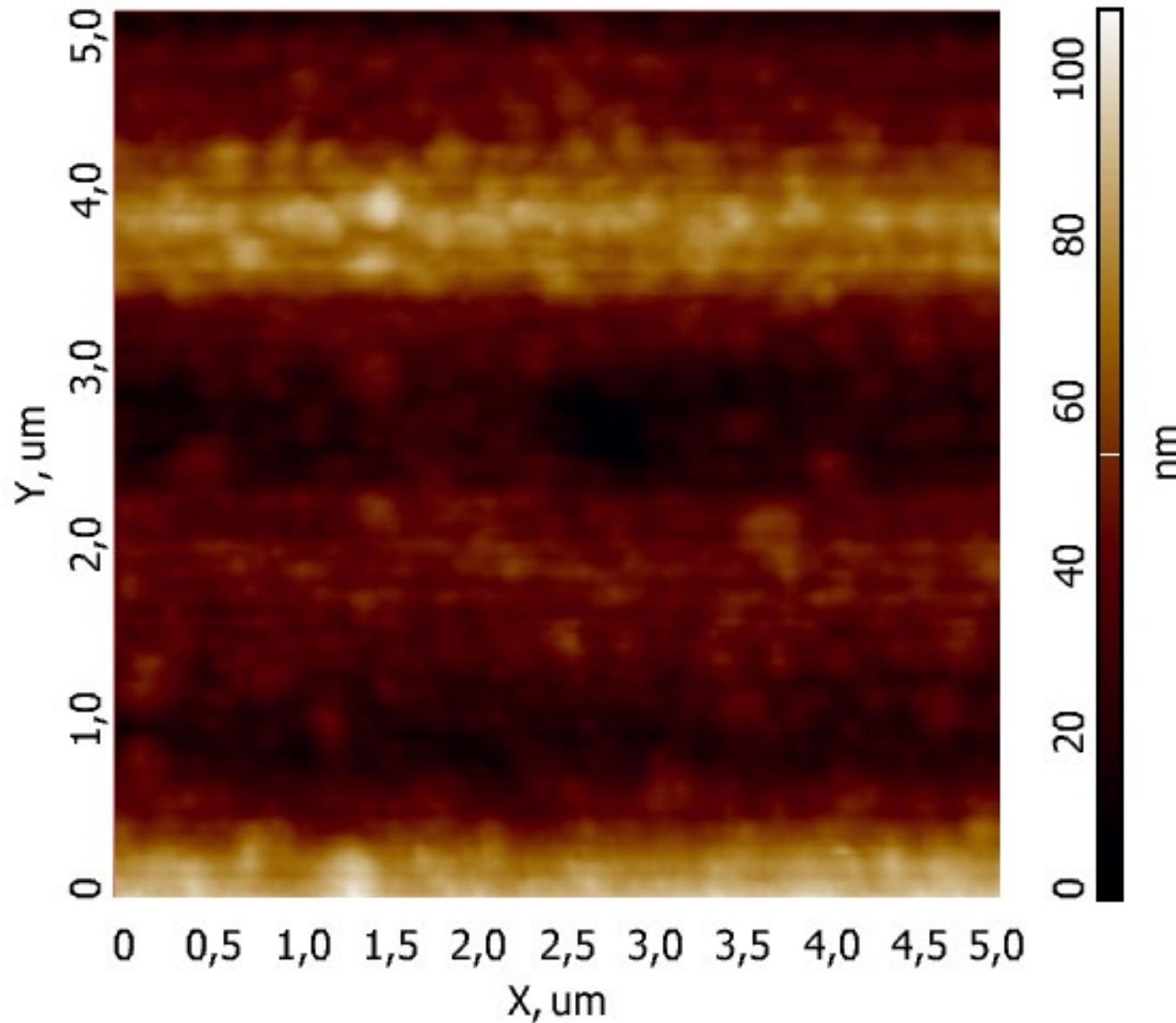
2-nd Order Subtraction



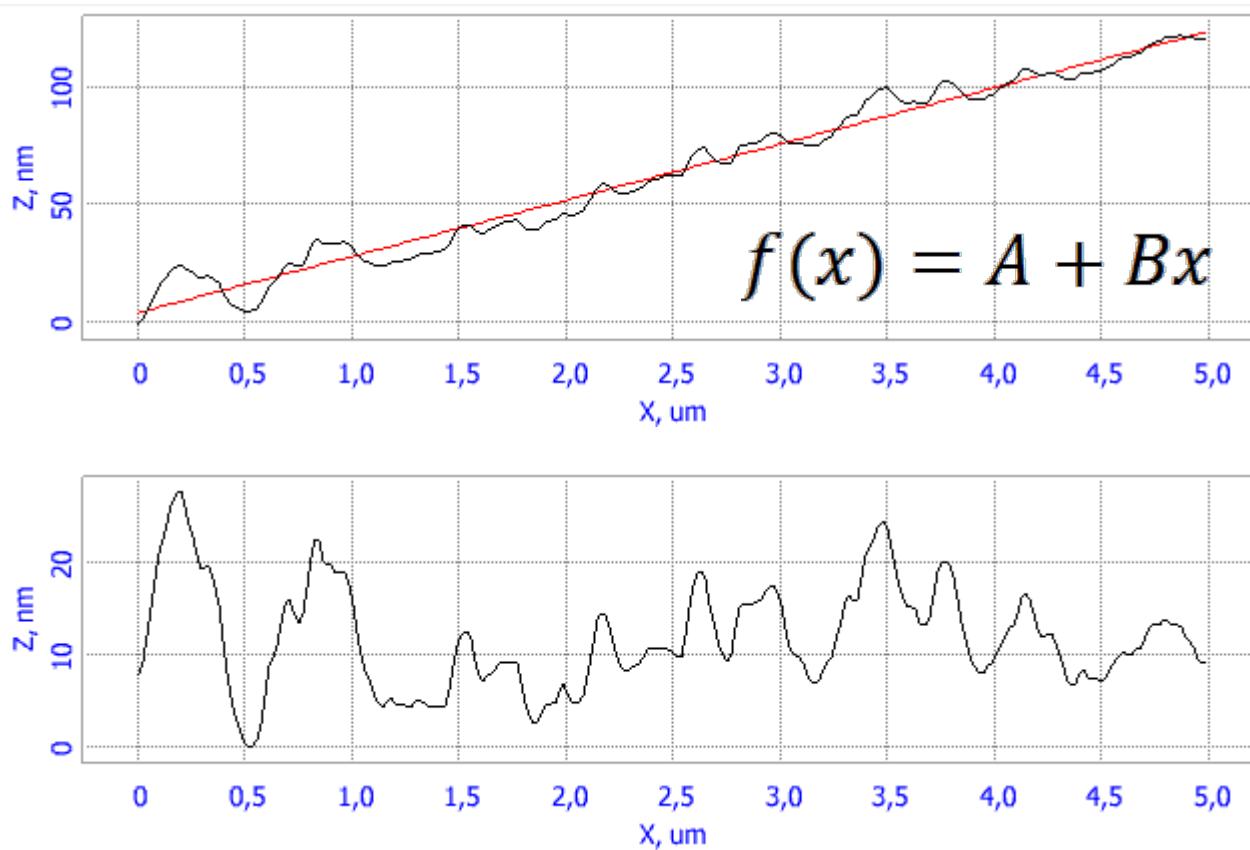
Interline Jumps



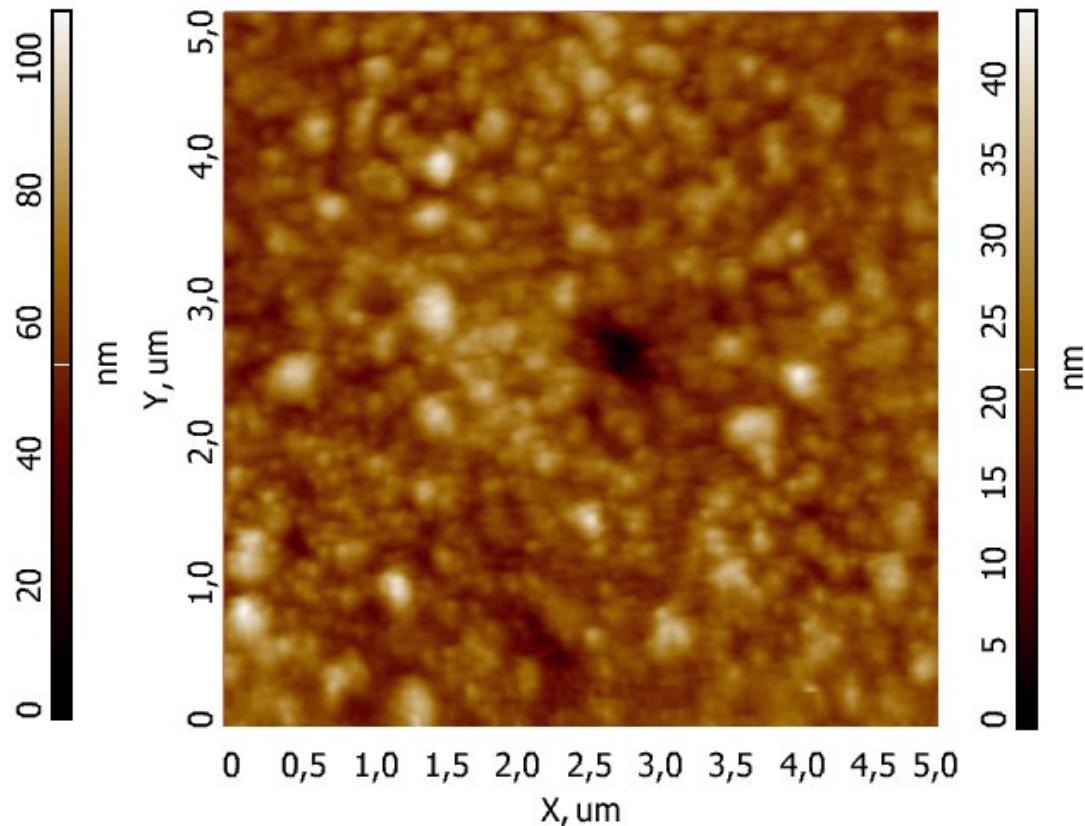
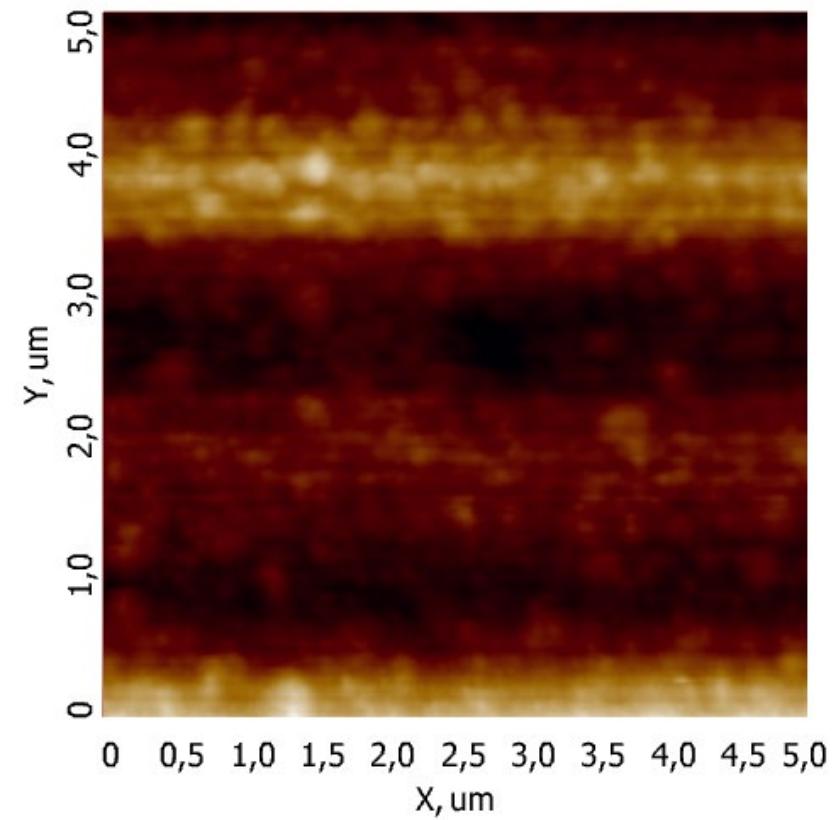
Interline Jumps



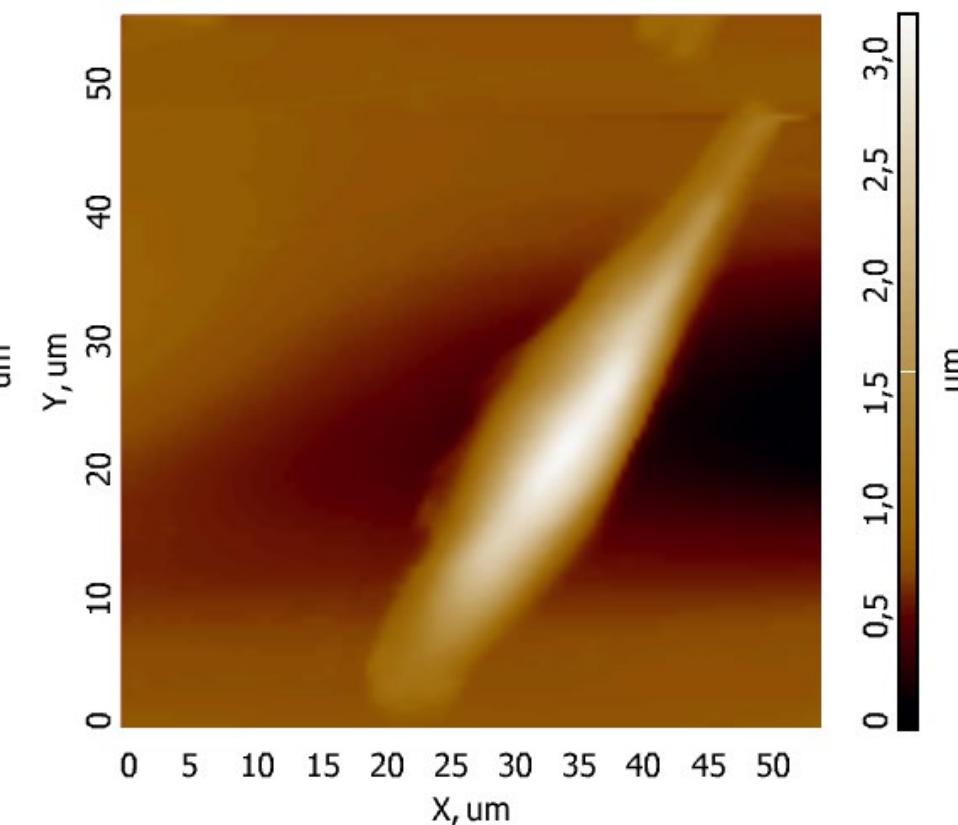
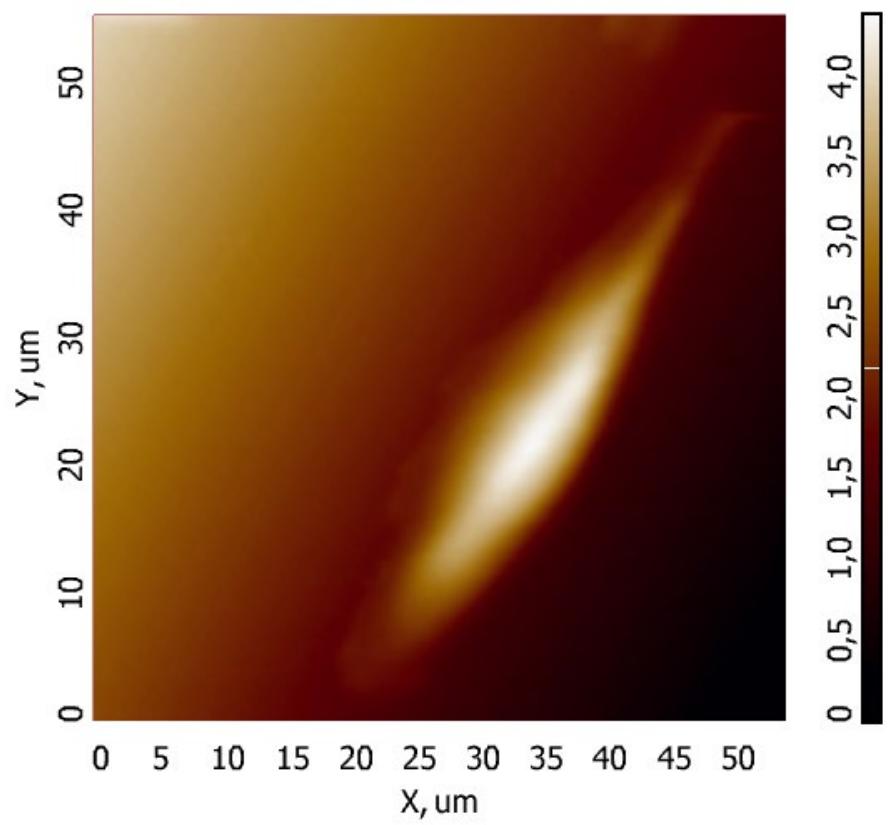
Linear Fitting



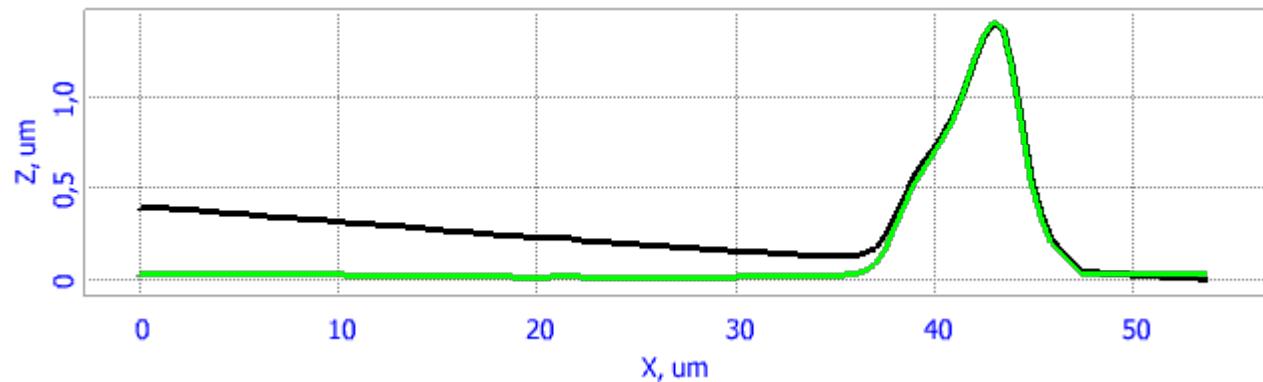
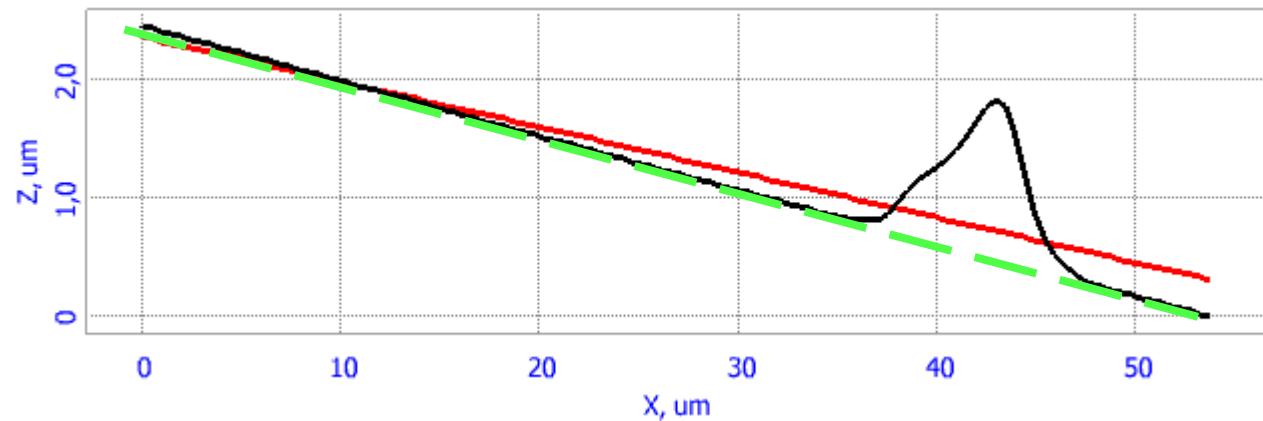
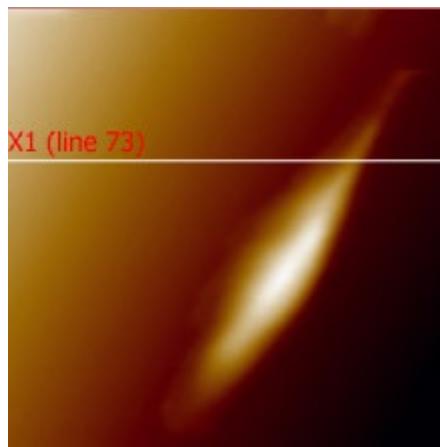
Linear Fitting



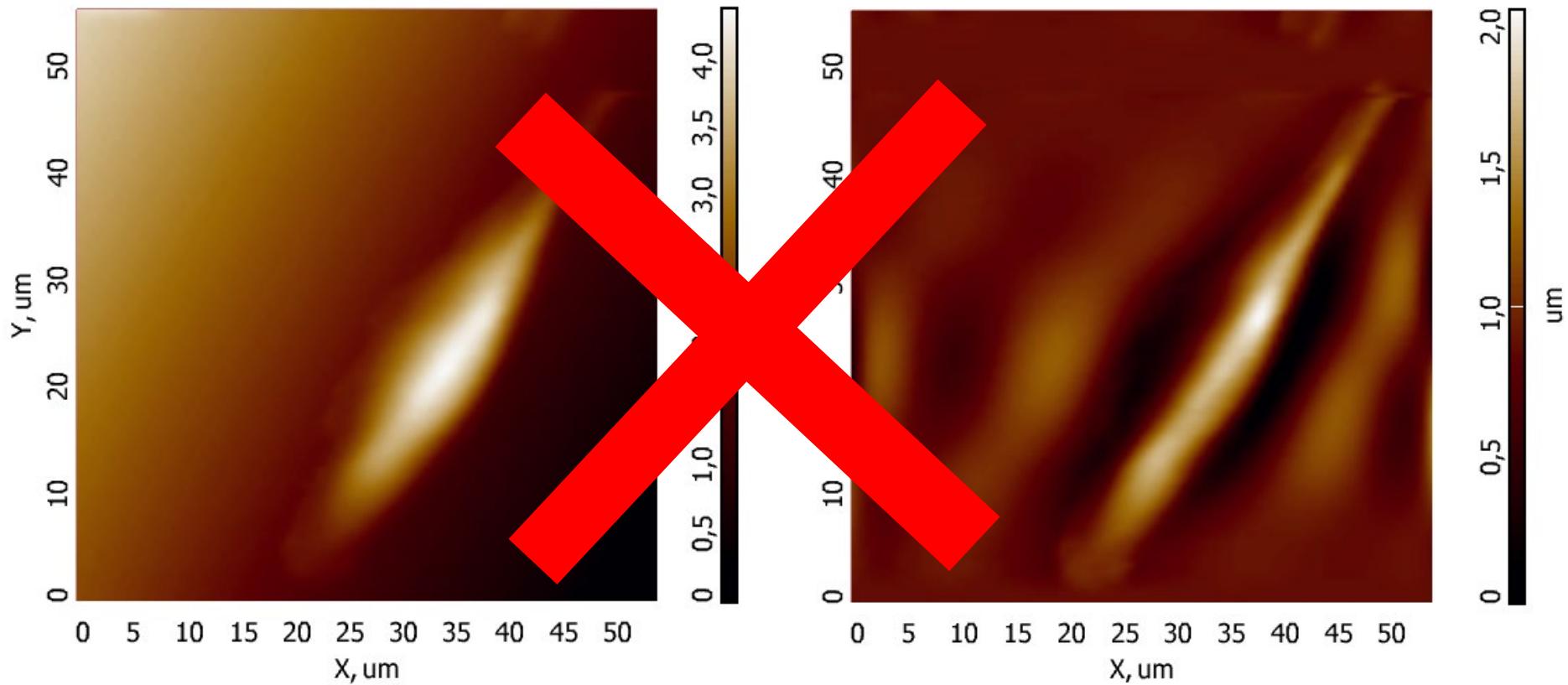
High Objects on Flat Substrate



High Objects on Flat Substrate



Too High Order



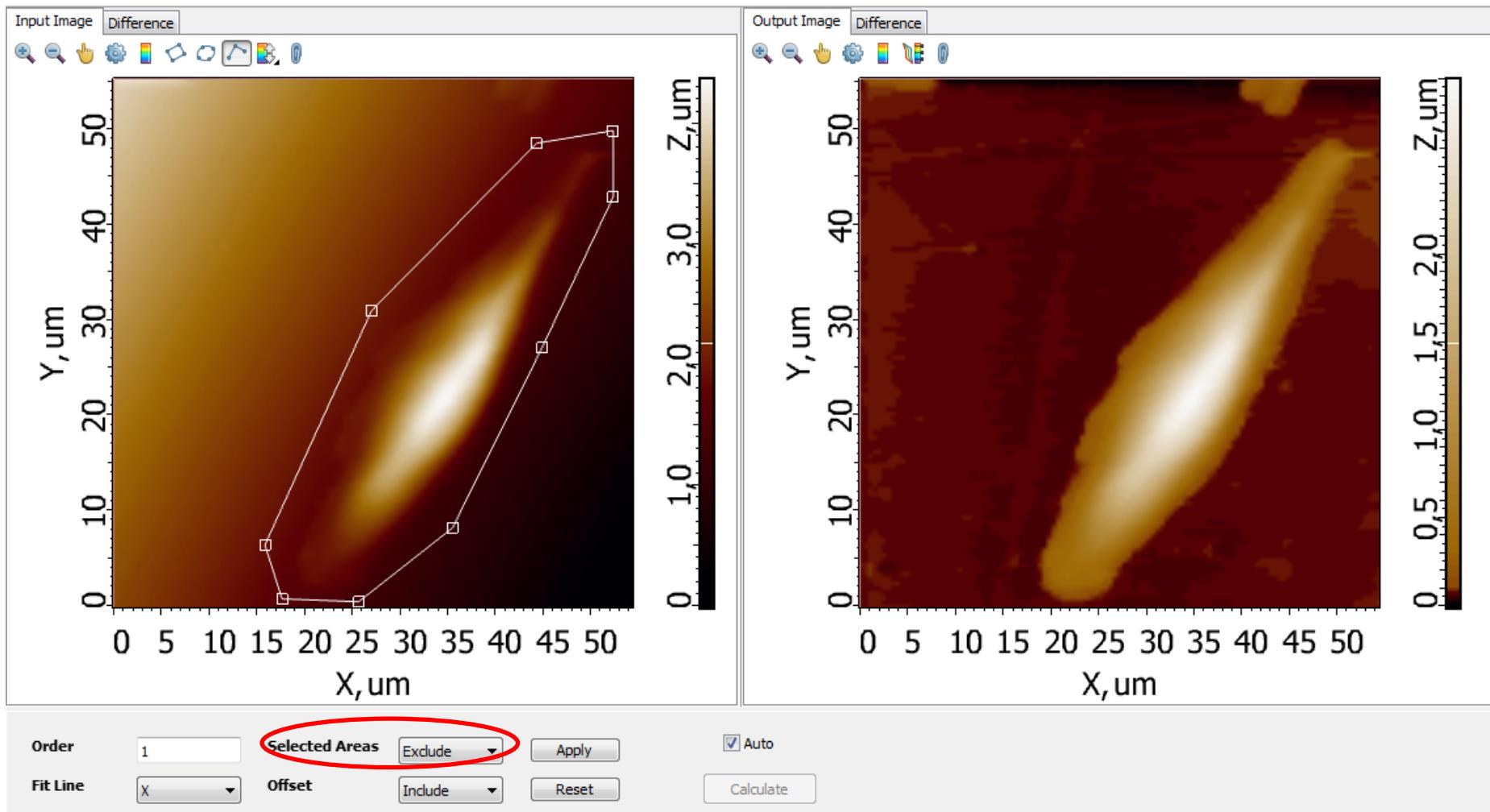
$$f(x) = A + Bx + Cx^2 + Dx^3 + Ex^4 + Fx^5 + Gx^6 + Hx^7$$

Too High Order

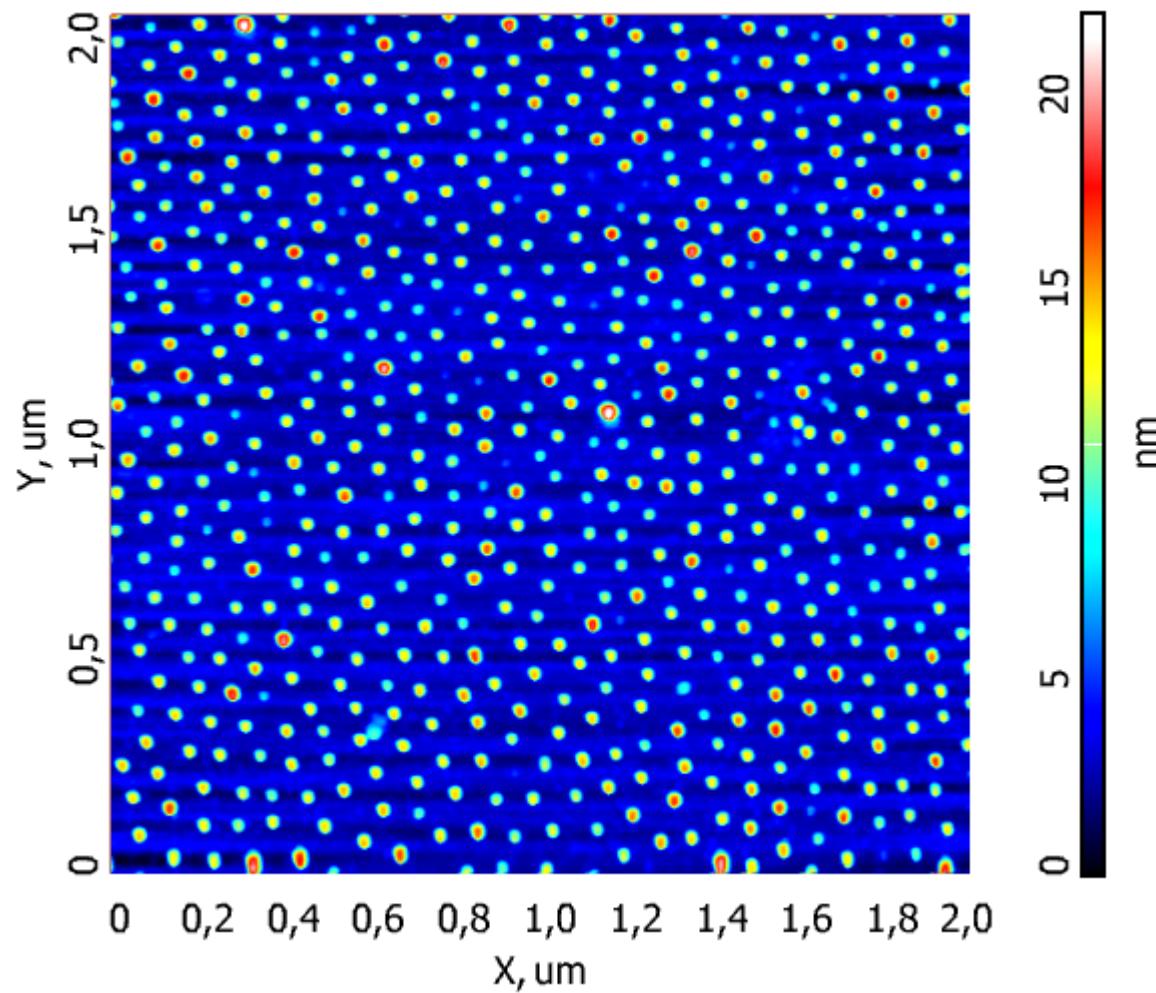
YOU CAN NOT JUST PUBLISH SCAN

WITH 7-TH ORDER FIT

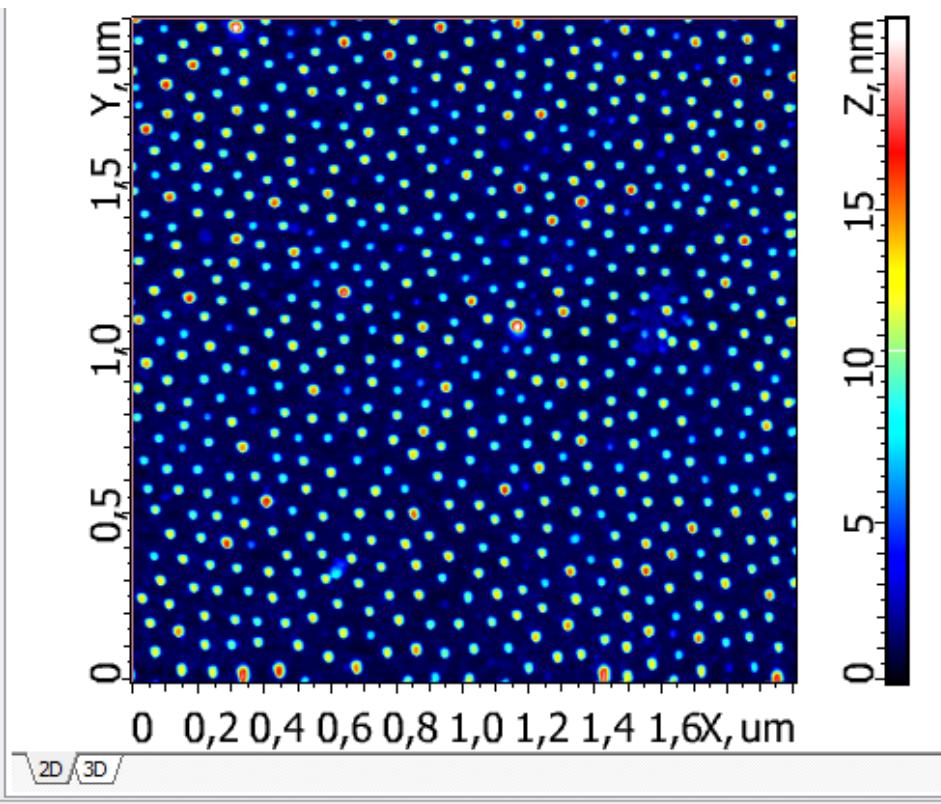
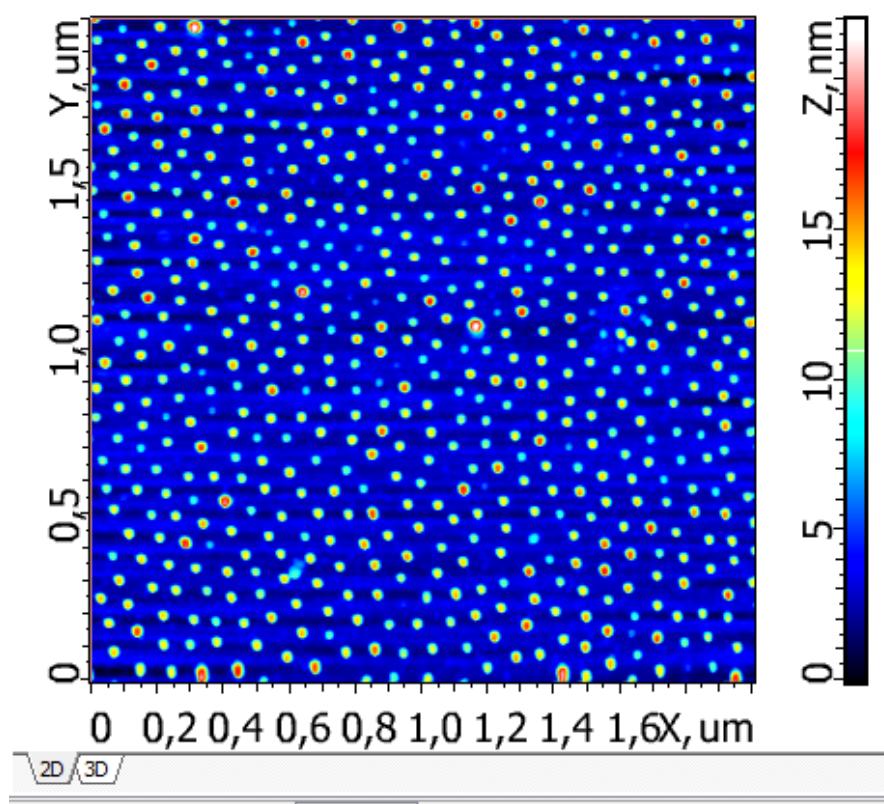
Fit Lines by Area



Numerous Objects



Fit Lines by Histogram



Interline Surface 3 Points Histogram Paths Sphere

Z Min 0,88 Polynomial order 2 Auto

Z Max 5,08 Direction X Y

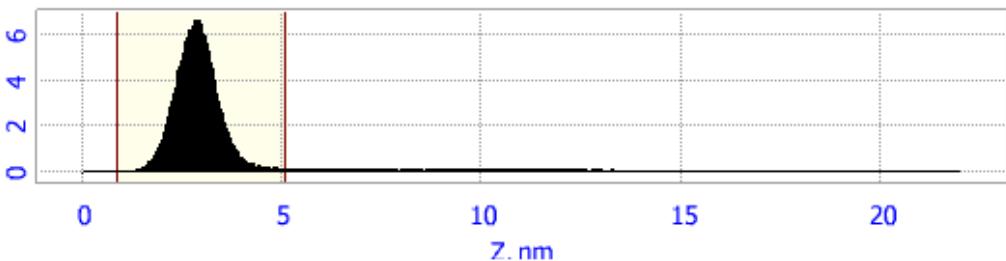
Interline

Surface

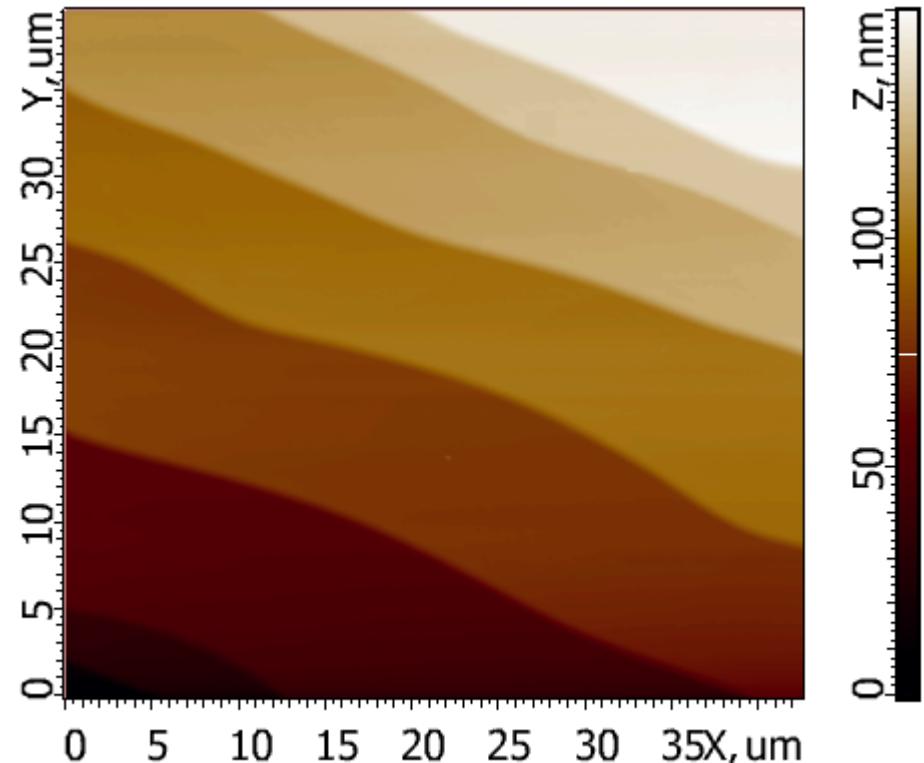
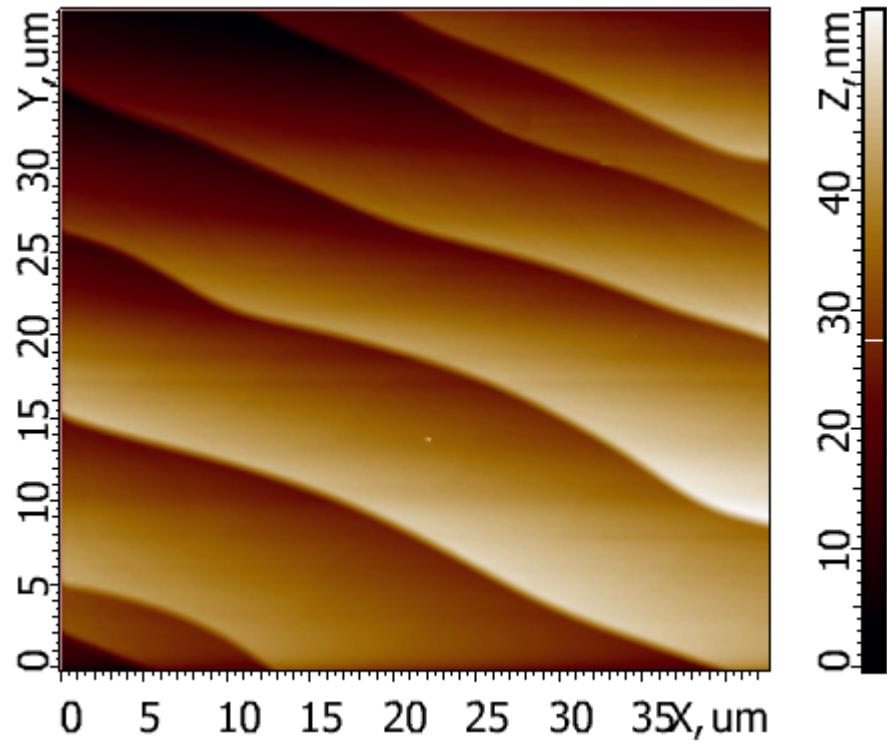
ROI
Include

Order

1



Facet Leveling



$$\nabla f(x) \rightarrow \min$$

Leveling Module GUI (Leveling->Leveling)

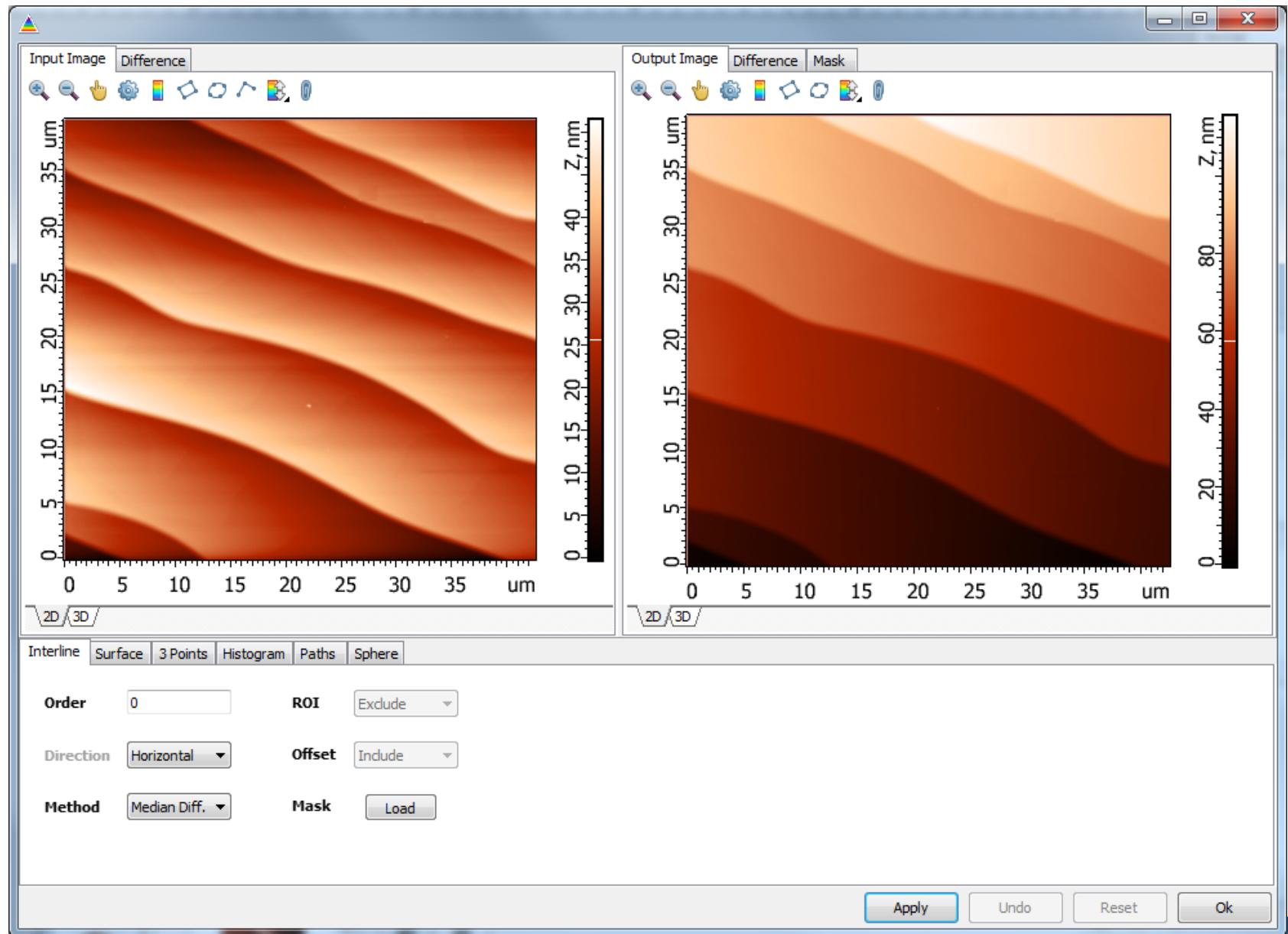
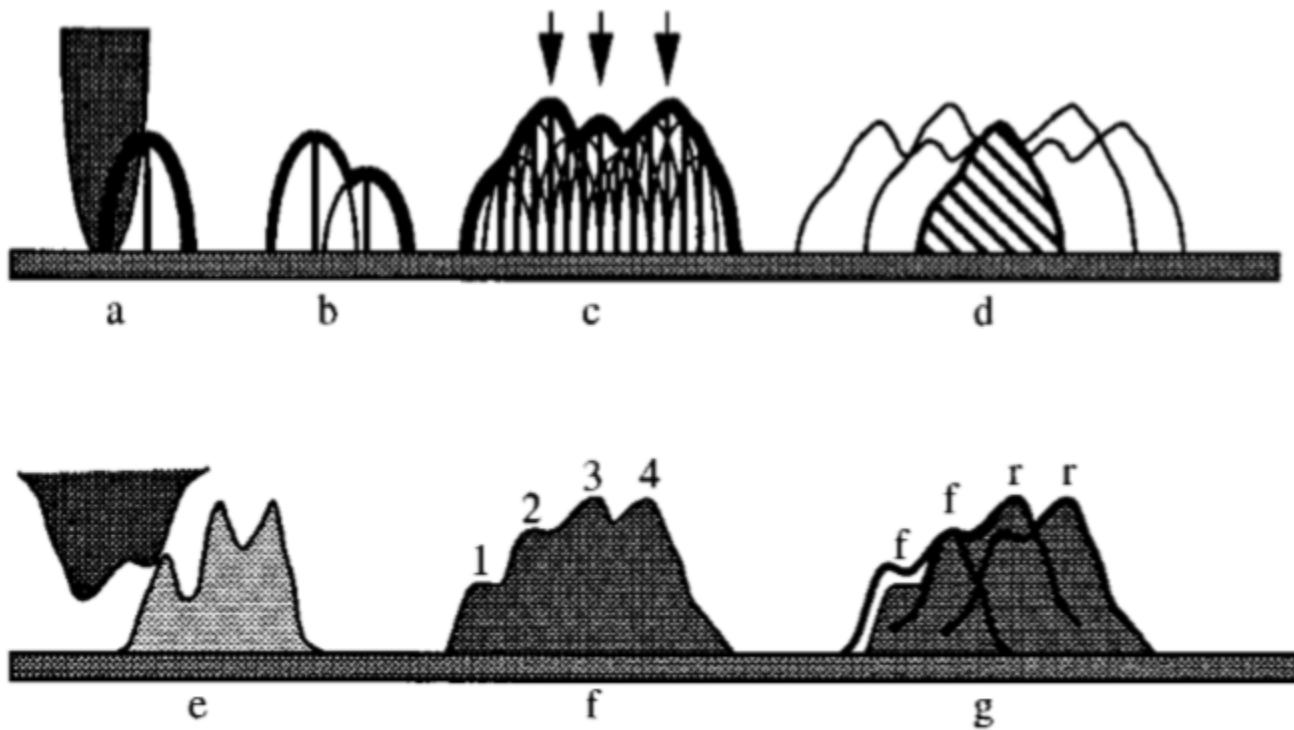


Image Reconstruction

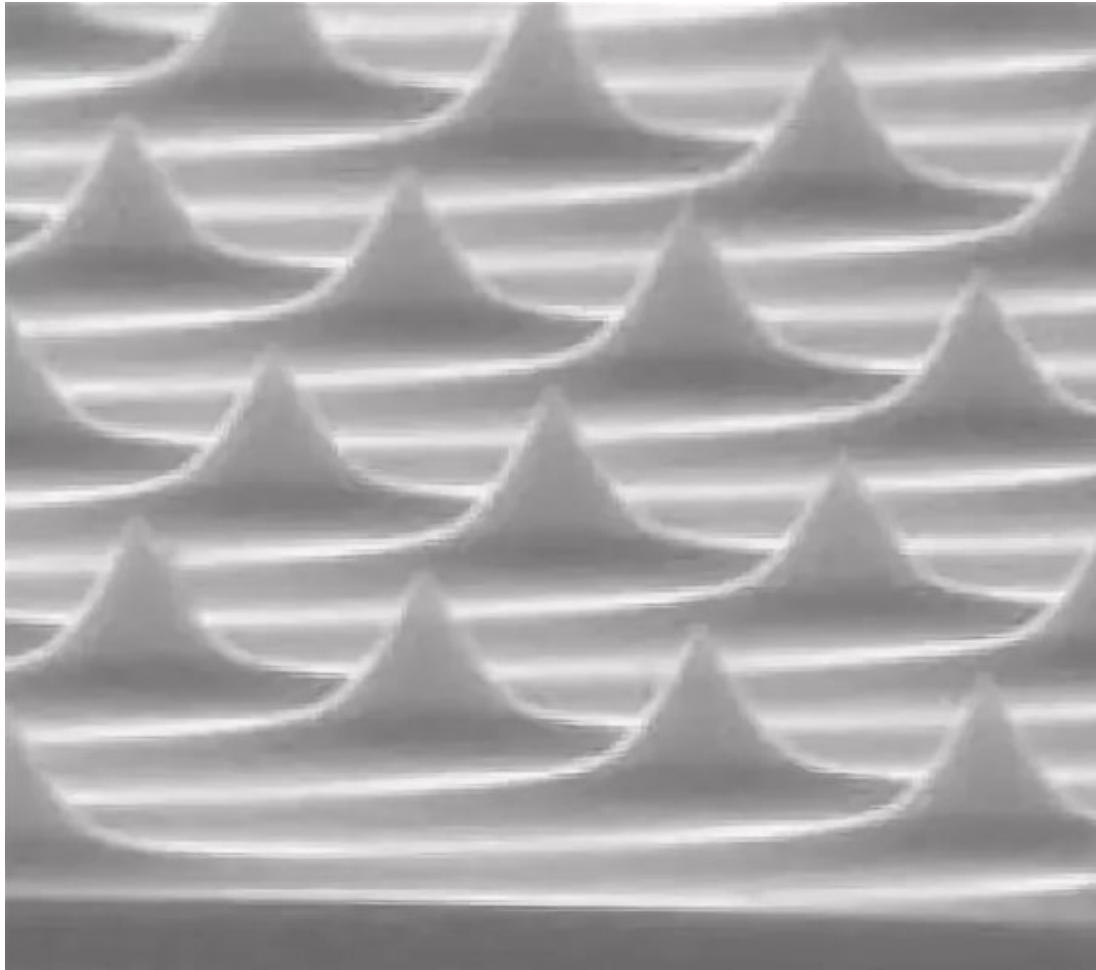
Deconvolution

Deconvolution

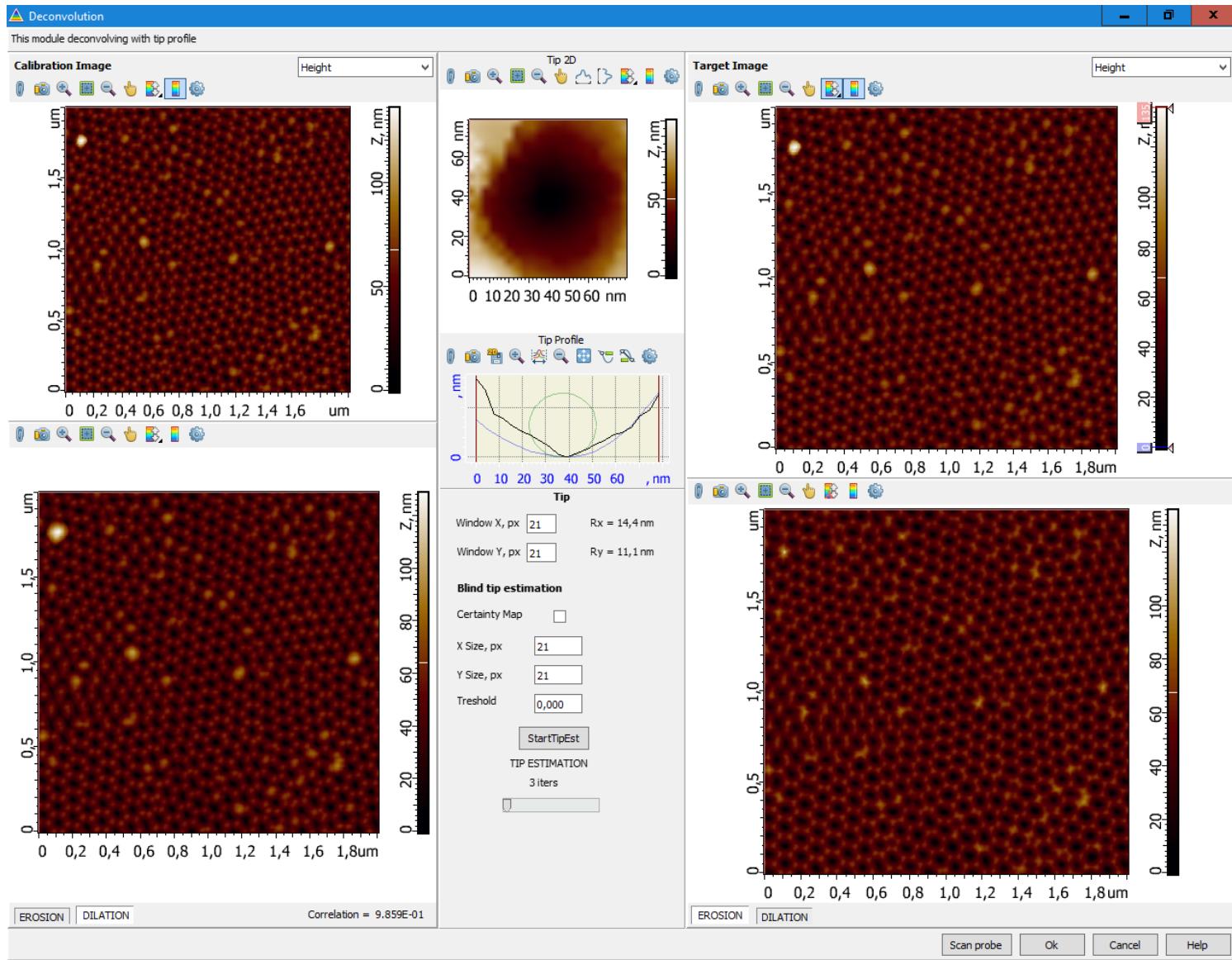


P.M.Williams, K.M.Shakesheff et al. - "Blind reconstruction of scanning probe image data". // J. Vac. Sci. Technol. B 14 (2) p. 1557-1562 (1996).

Deconvolution



Deconvolution



GTransform™

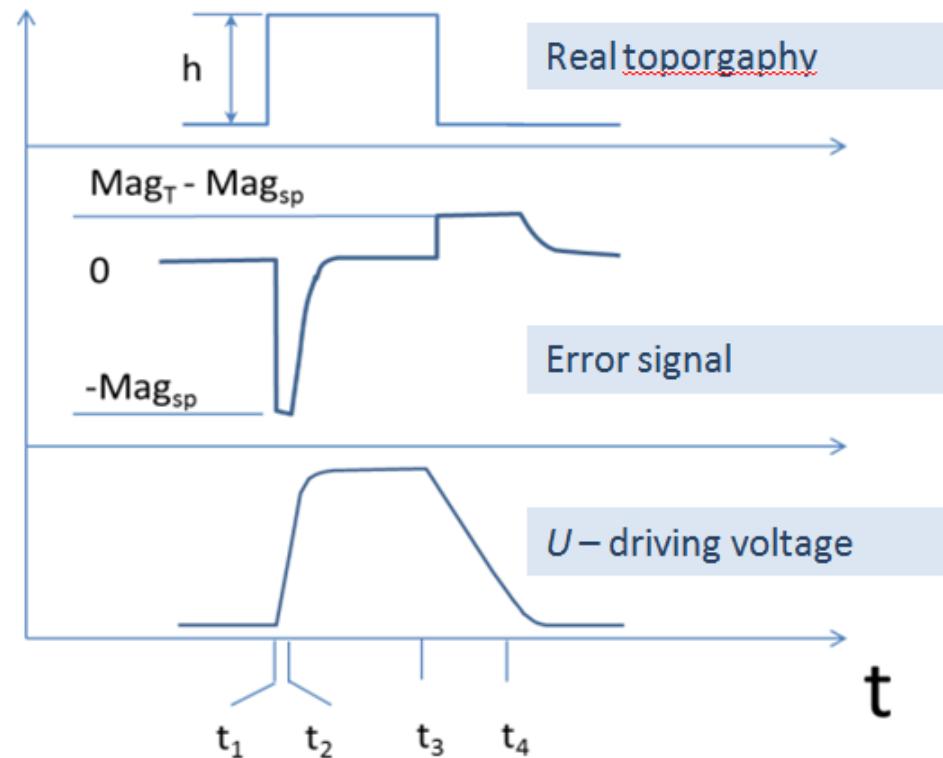
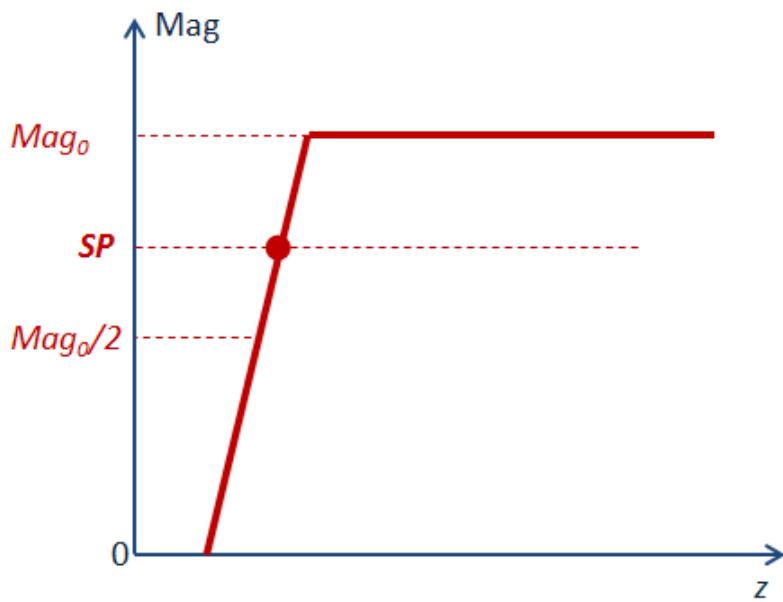
(Genuine Transformation)

Parachuting effect in tapping mode AFM

$$-SP \leq \varepsilon \leq Mag_0 - SP$$

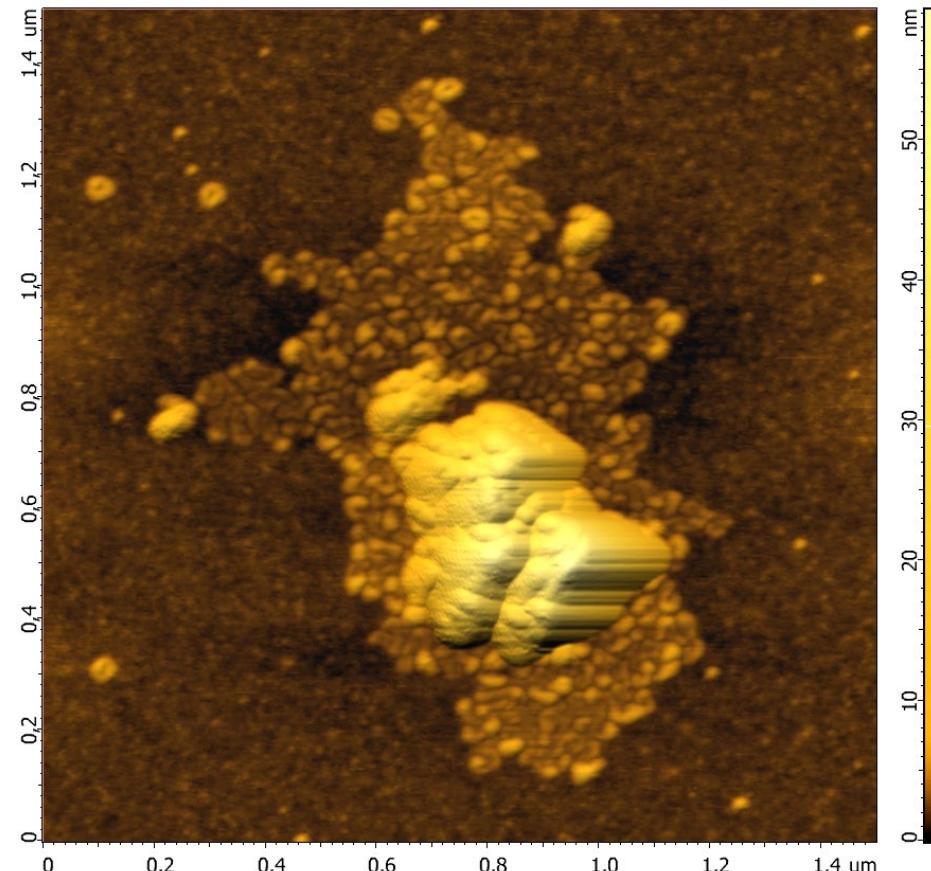
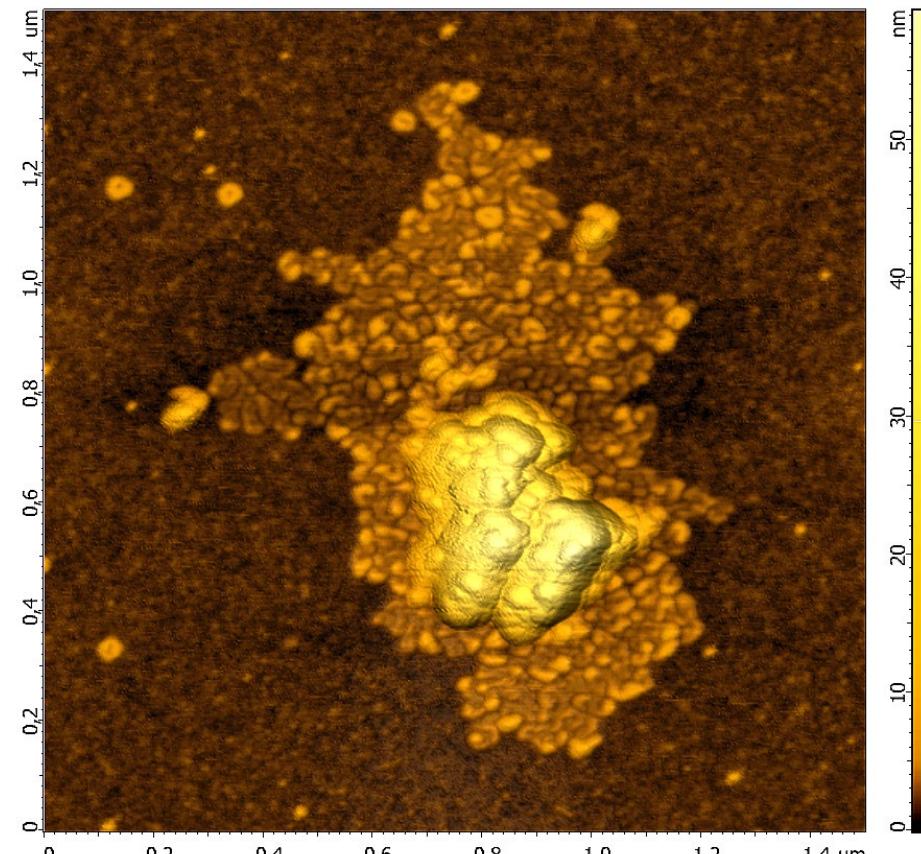
$$\frac{dU}{dt} = k_i \cdot \varepsilon = k_i(Mag_0 - SP)$$

$$U = k_i(Mag_0 - SP) \cdot t + U_0 \quad t_3 < t < t_4$$

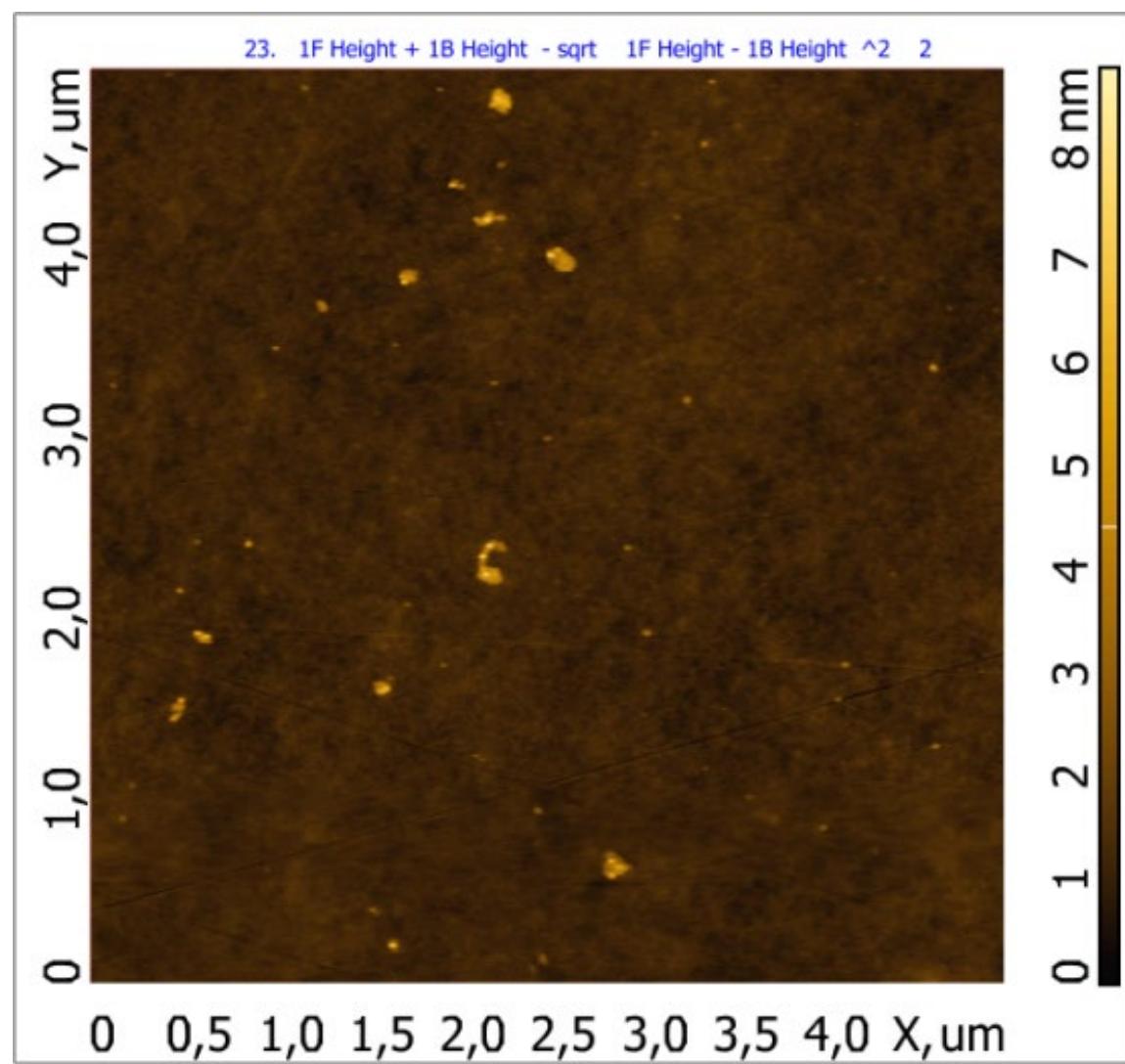
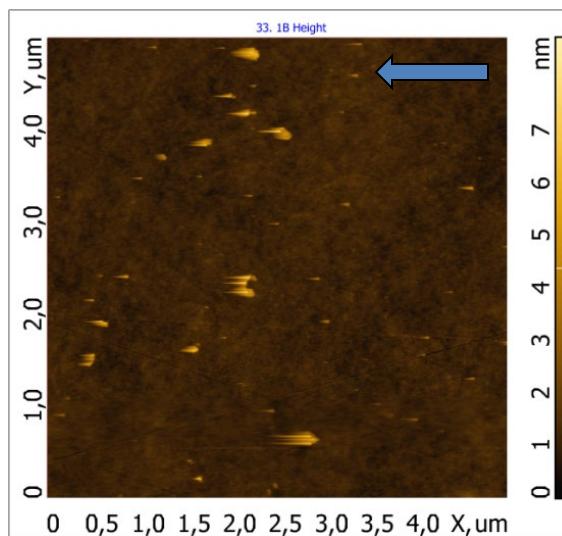
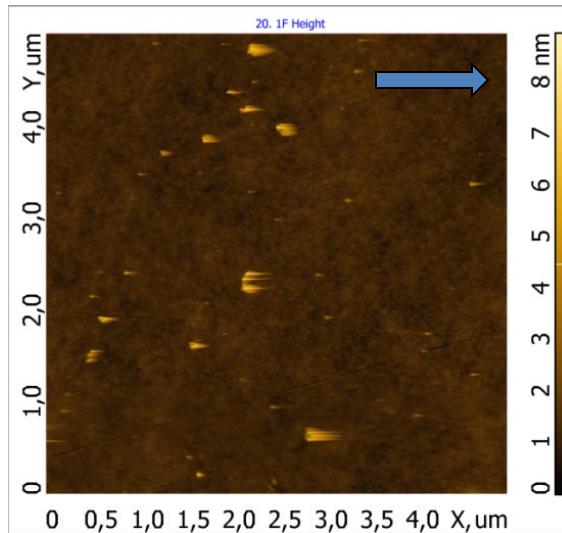


Ref.: T. Ando, "Control Techniques in High-Speed Atomic Force Microscopy," ACC: 3194-3200, 2008

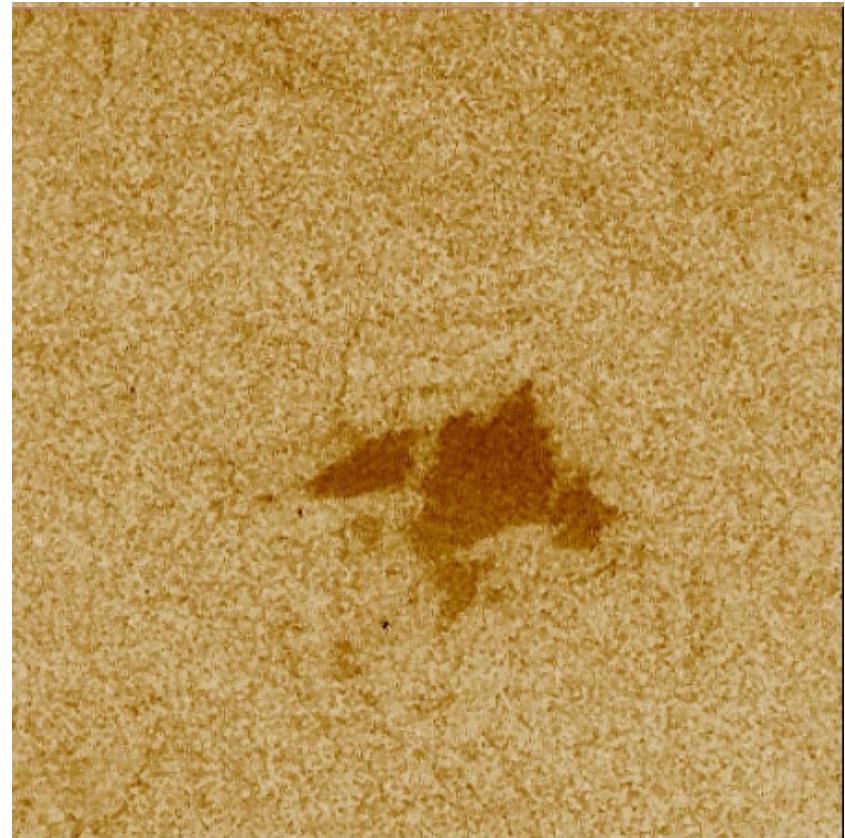
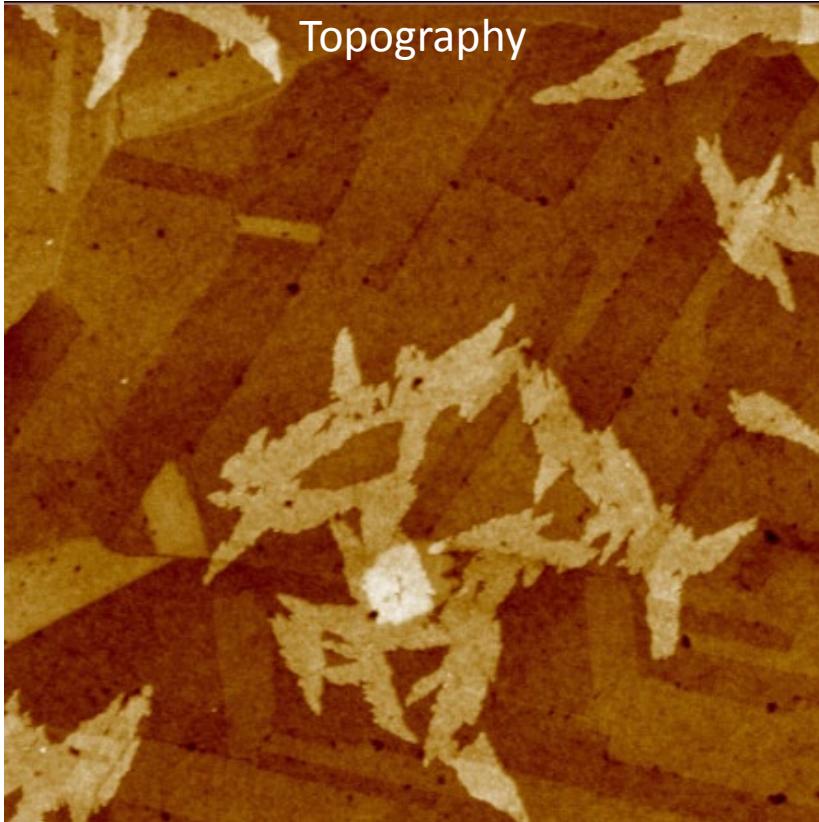
Parachuting



GTransform™ for Topography



GTransform™ for Phase channel



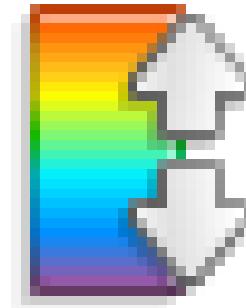
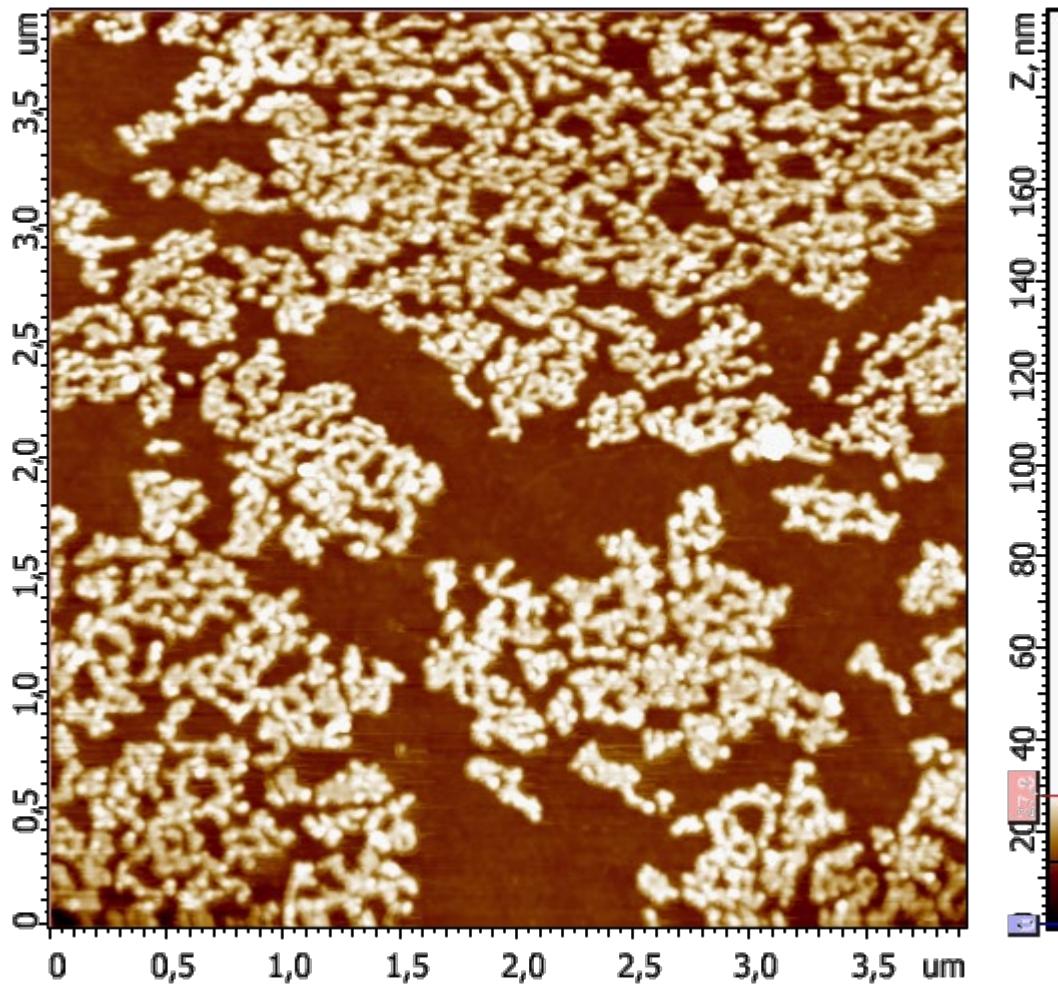
- Probe current
- Lateral force
- Mechanical properties
- etc...

AFM Images Representation

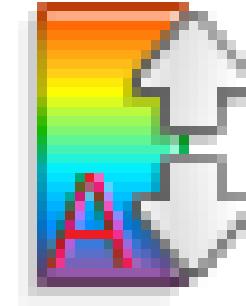
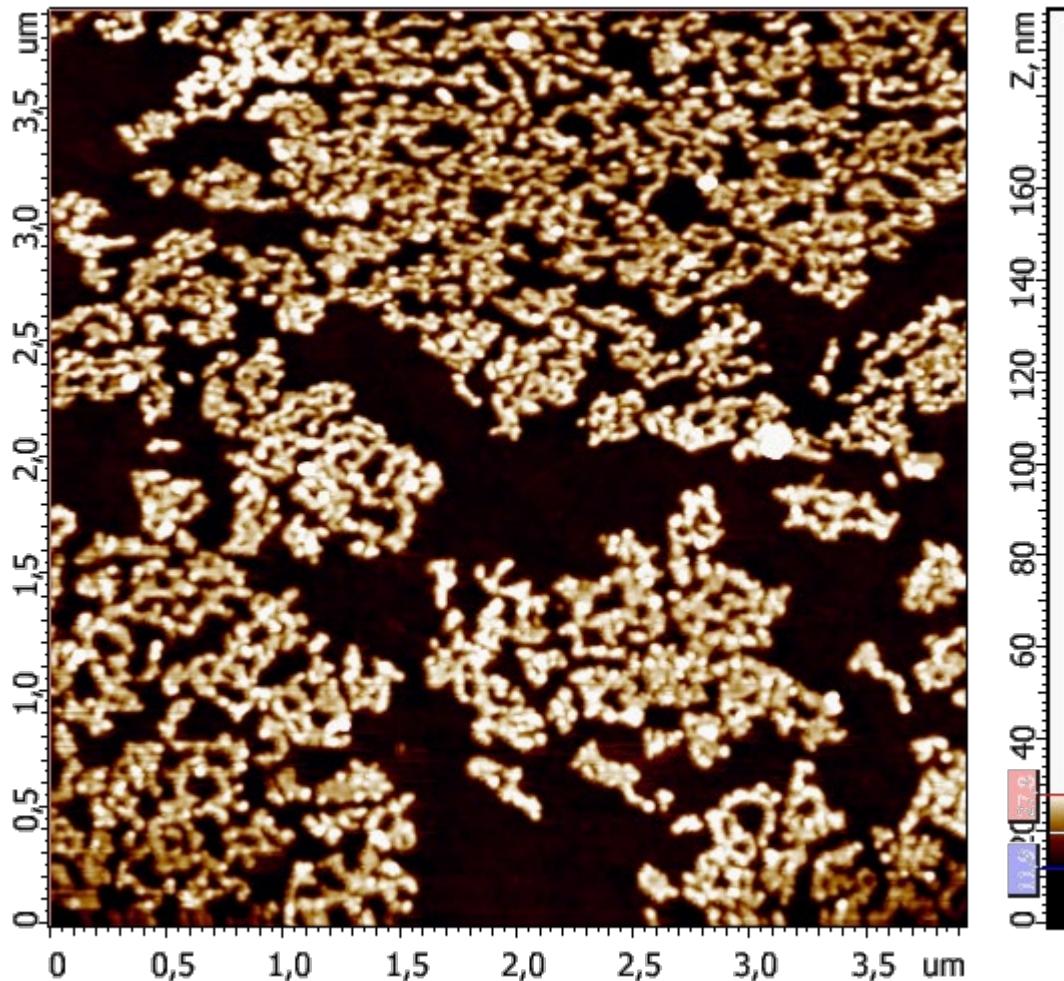
Main Principle



Coloration Modes: Min-Max

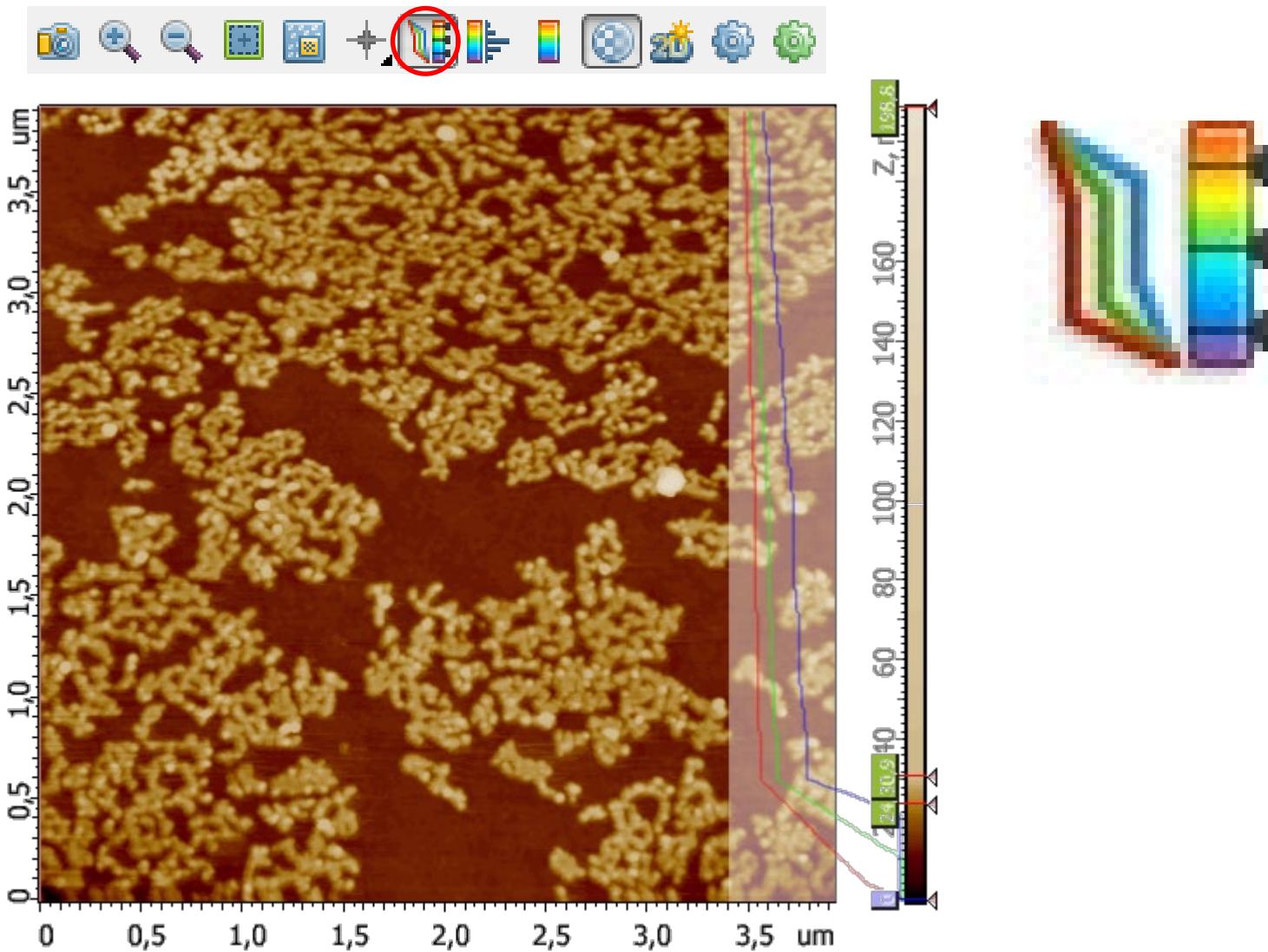


Coloration Modes: Auto

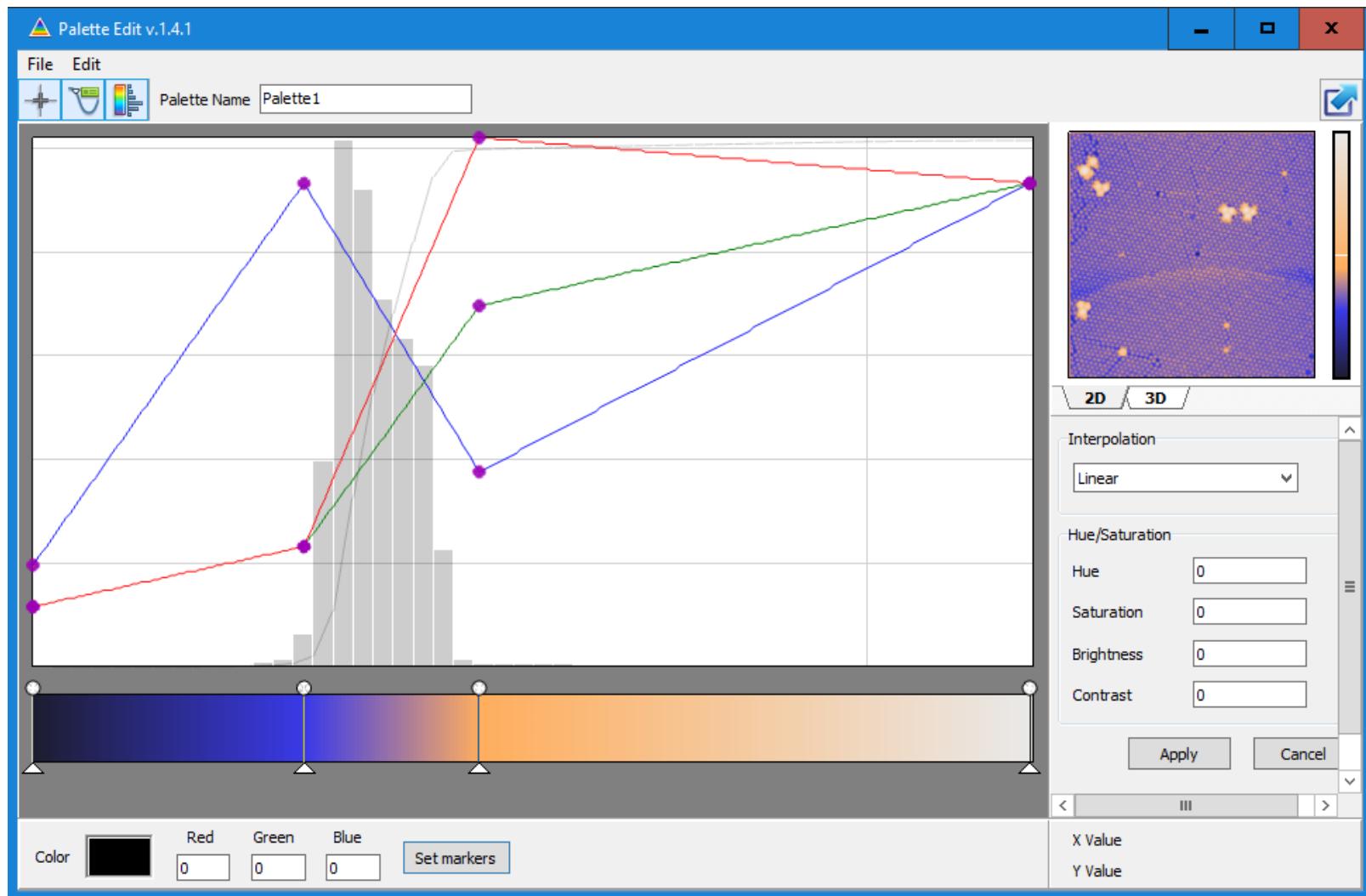


Settings-> 2D Settings -> Axes -> Histogram -> Auto Coloration Percent

Coloration Modes: Nonlinear

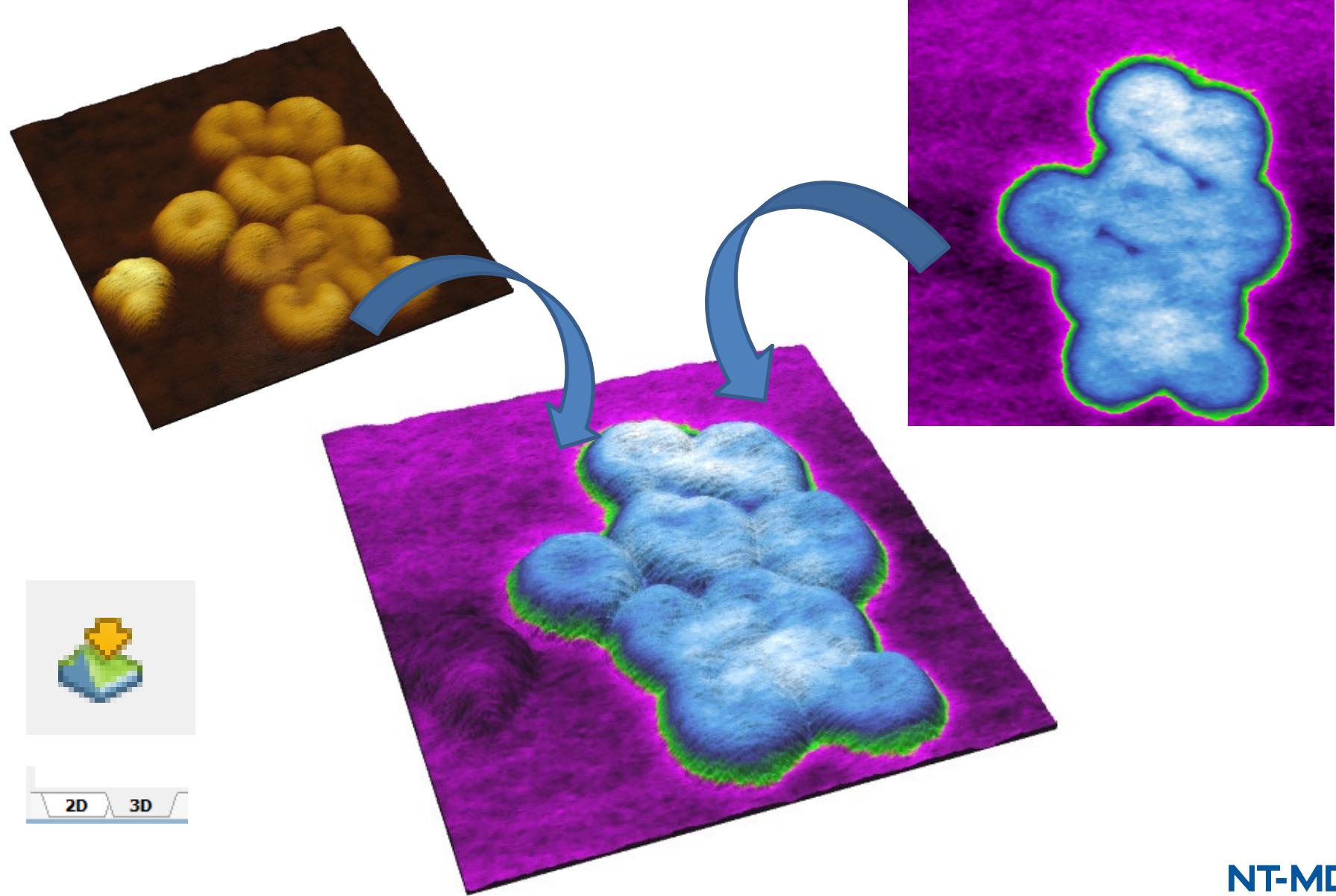


Palette Editor

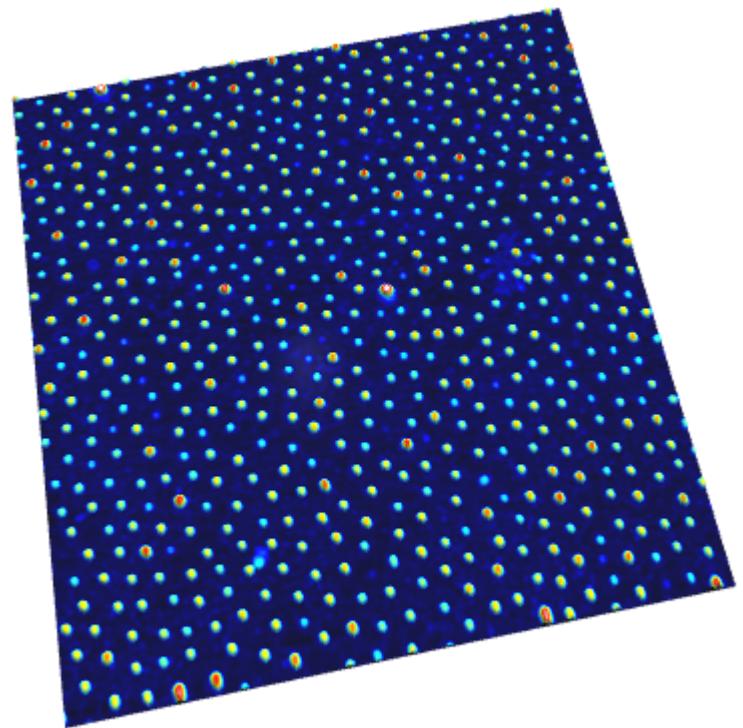
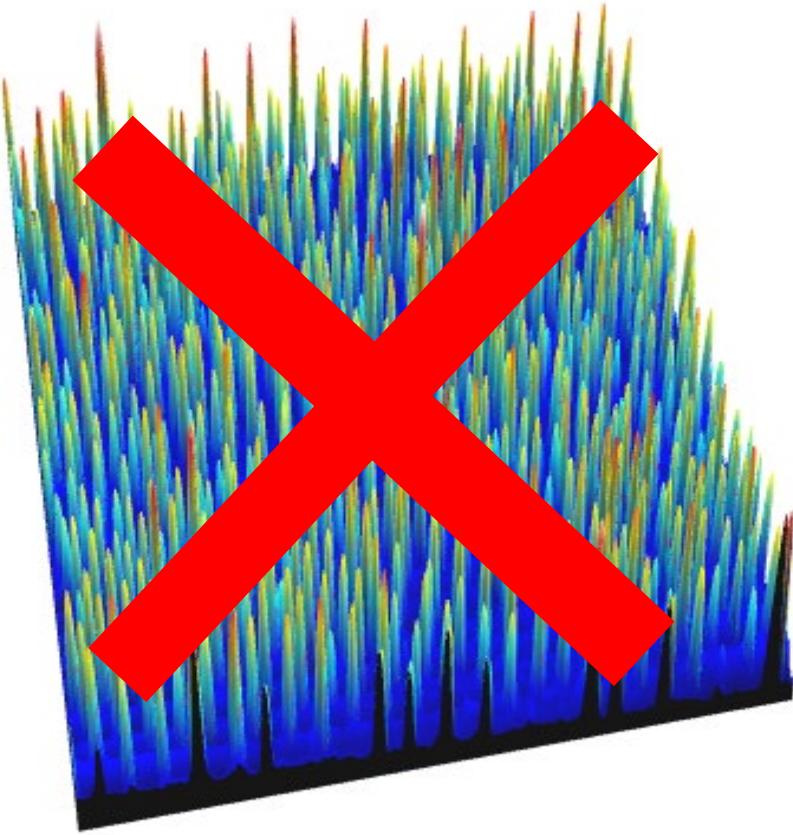


Tools -> Palette Editor

Texture Overlay



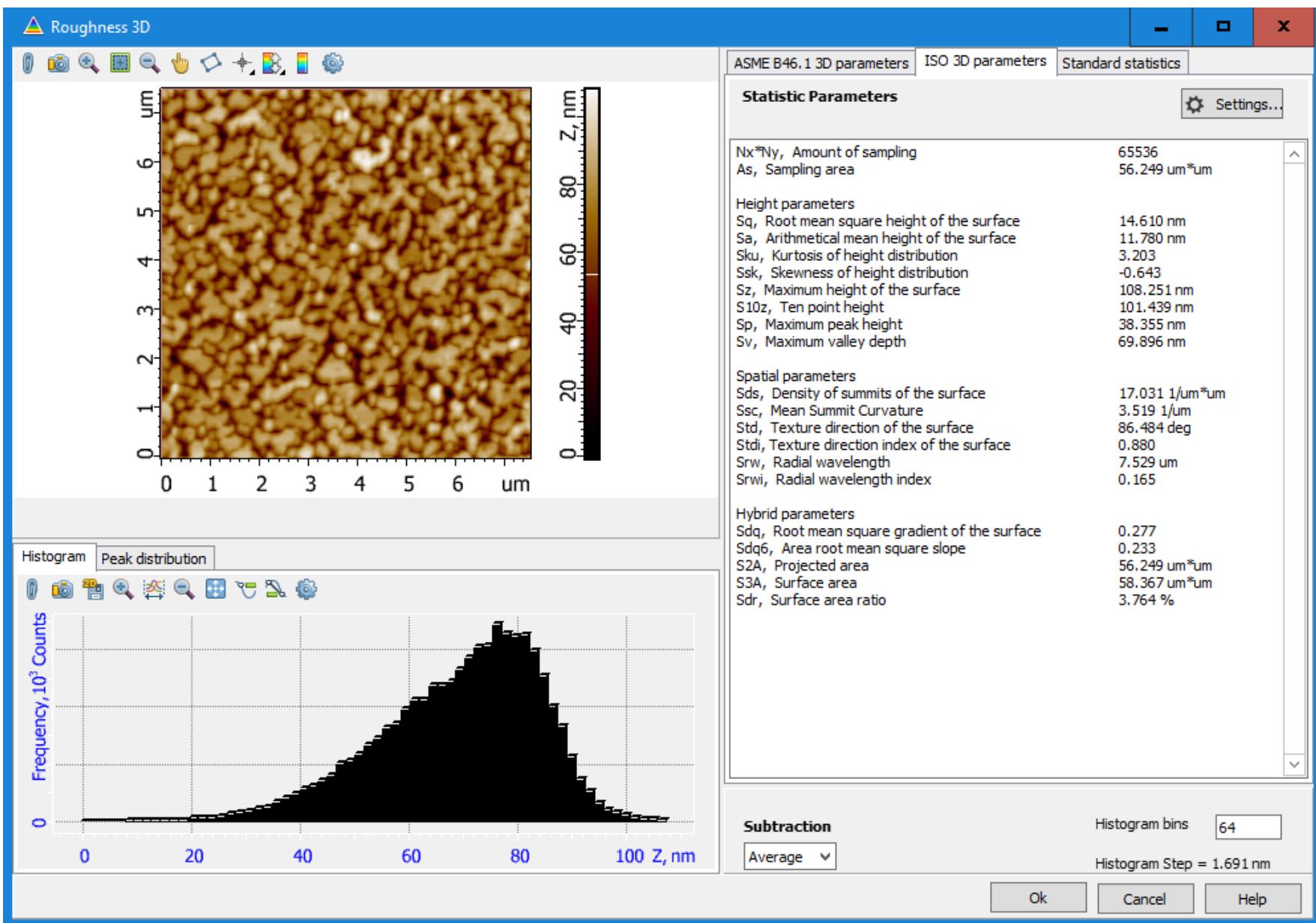
3D



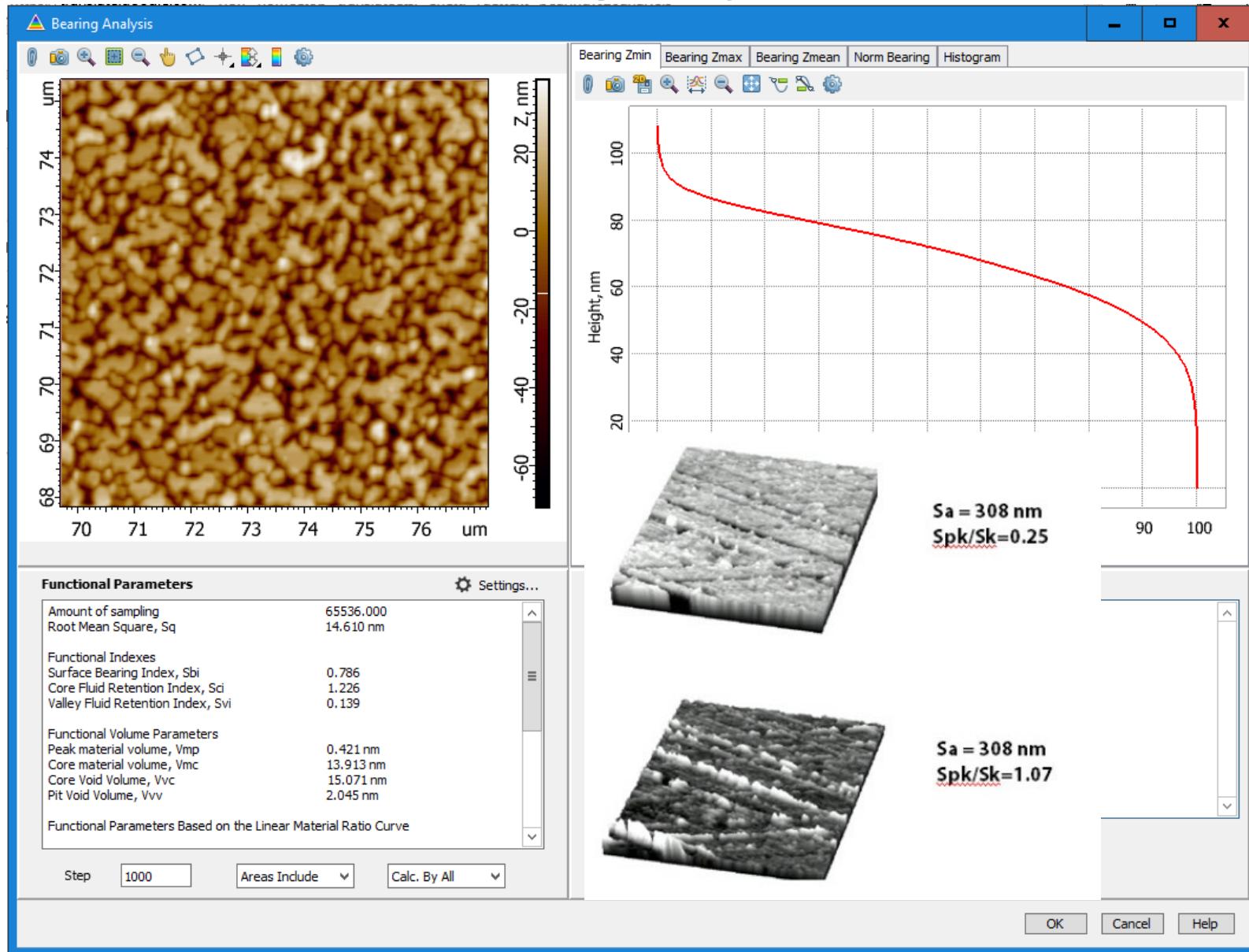
Data Analysis

Statistical Analysis

Roughness 3D Statistics



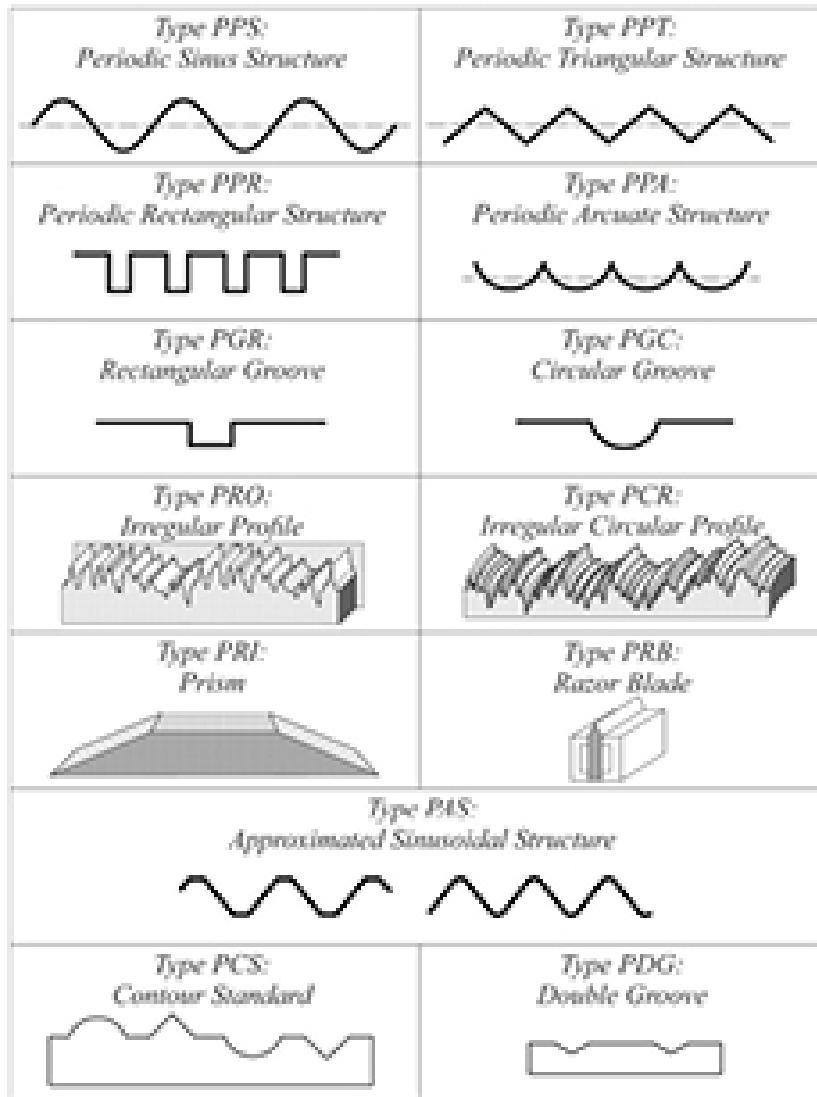
Bearing Analysis



https://www.michmet.com/3d_s_functional_parameters.htm

Nanoroughness parameters

Profile Material Measures of ISO 25178-70

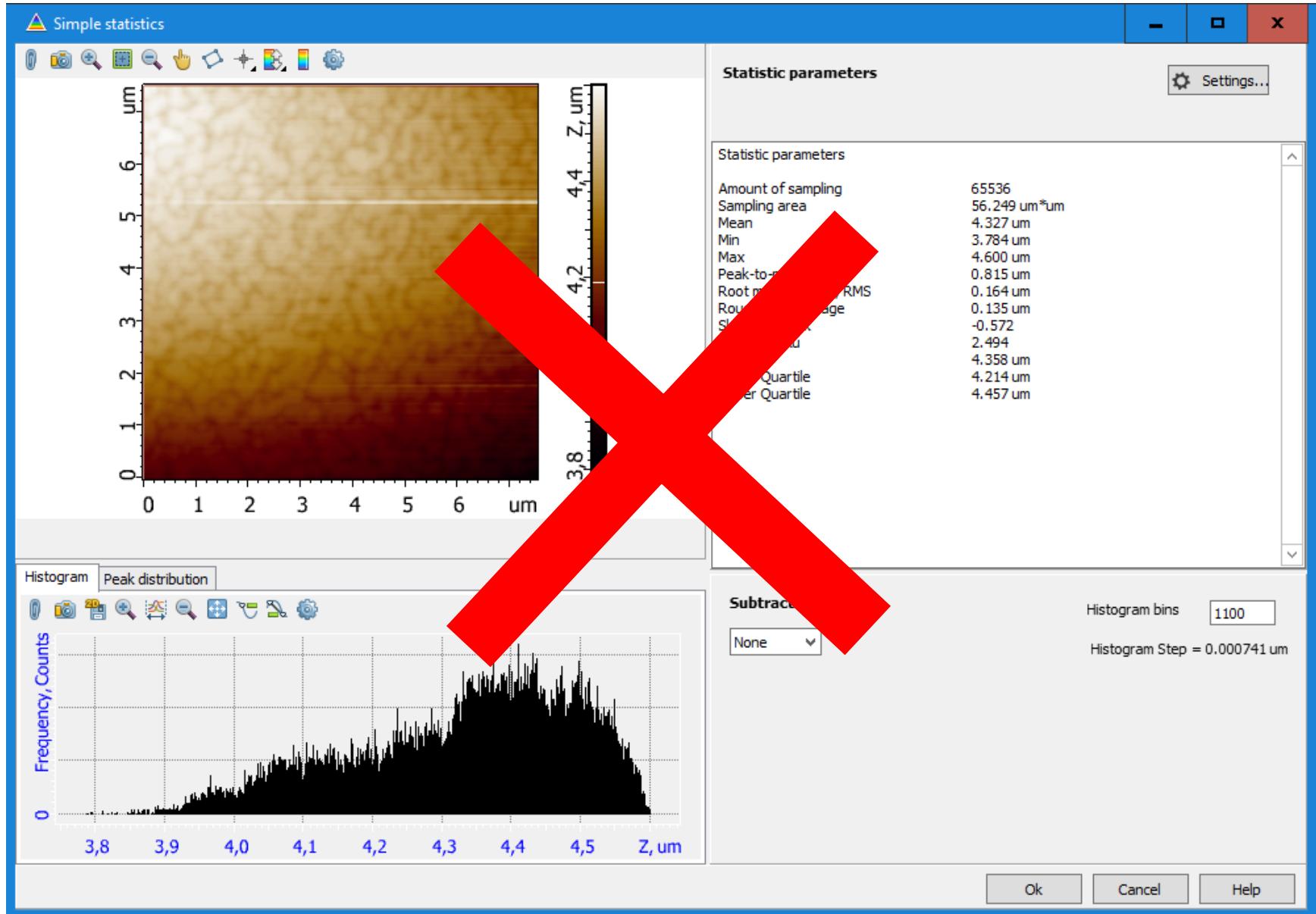


3D:
ASME B46.1
ISO 25178

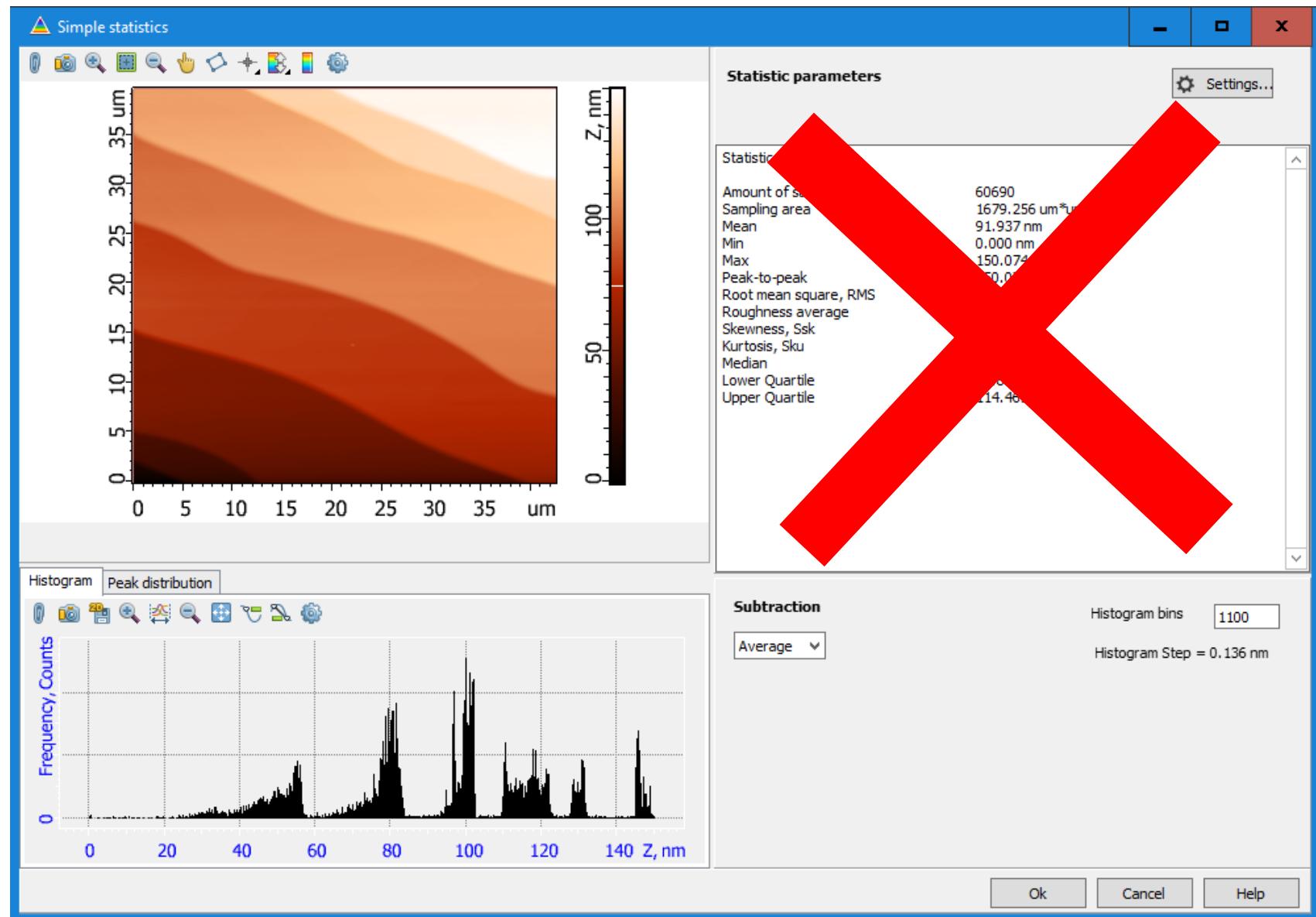
2D:
ГОСТ 25142
ASME B46.1
ISO 4287

ISO 25178-70 2014 Geometrical product specification (GPS),
Surface texture: Areal, Part 70: Material measures

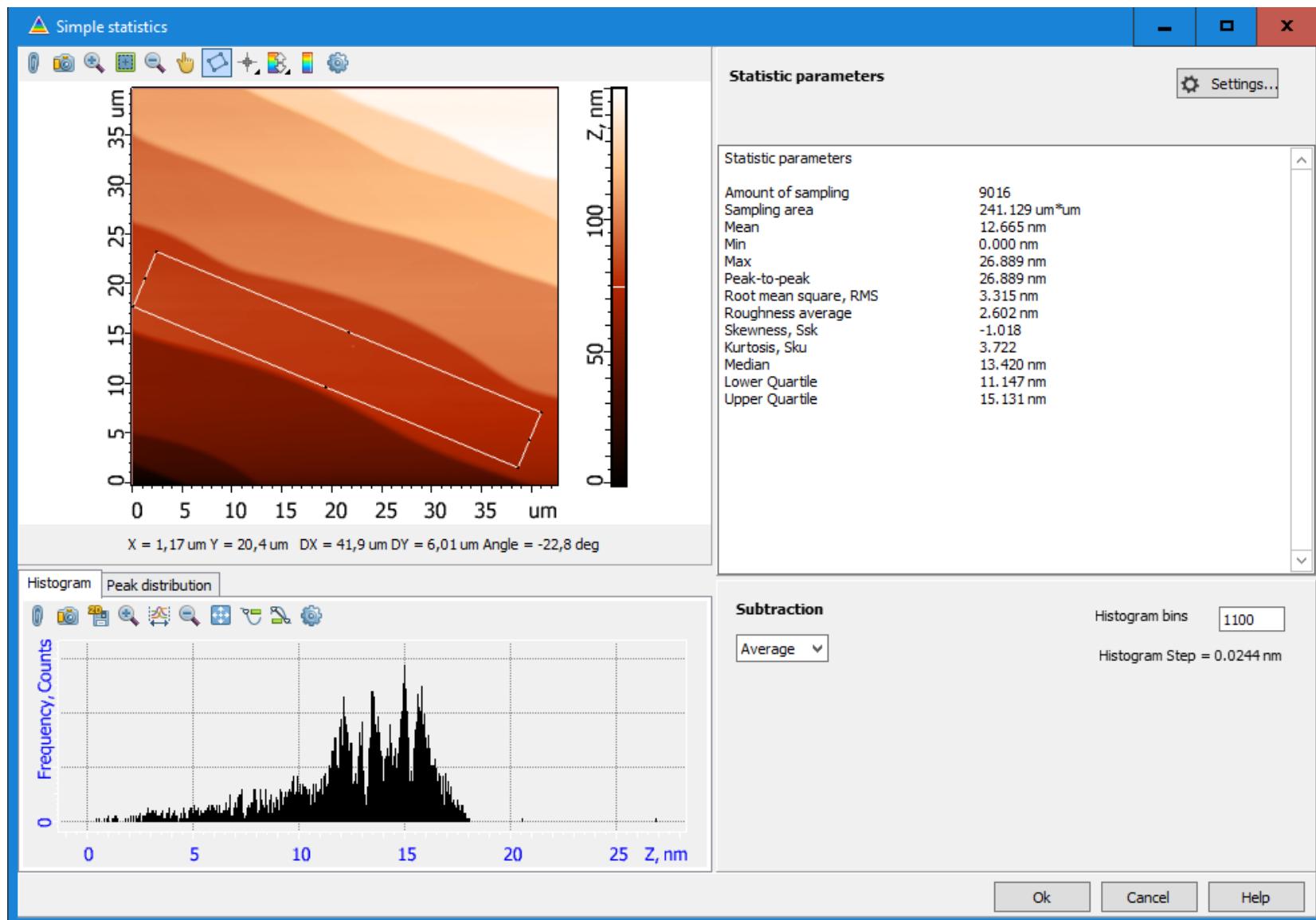
Image should be correctly prepared for analysis



Statistical models are applicable to single-mode distributions

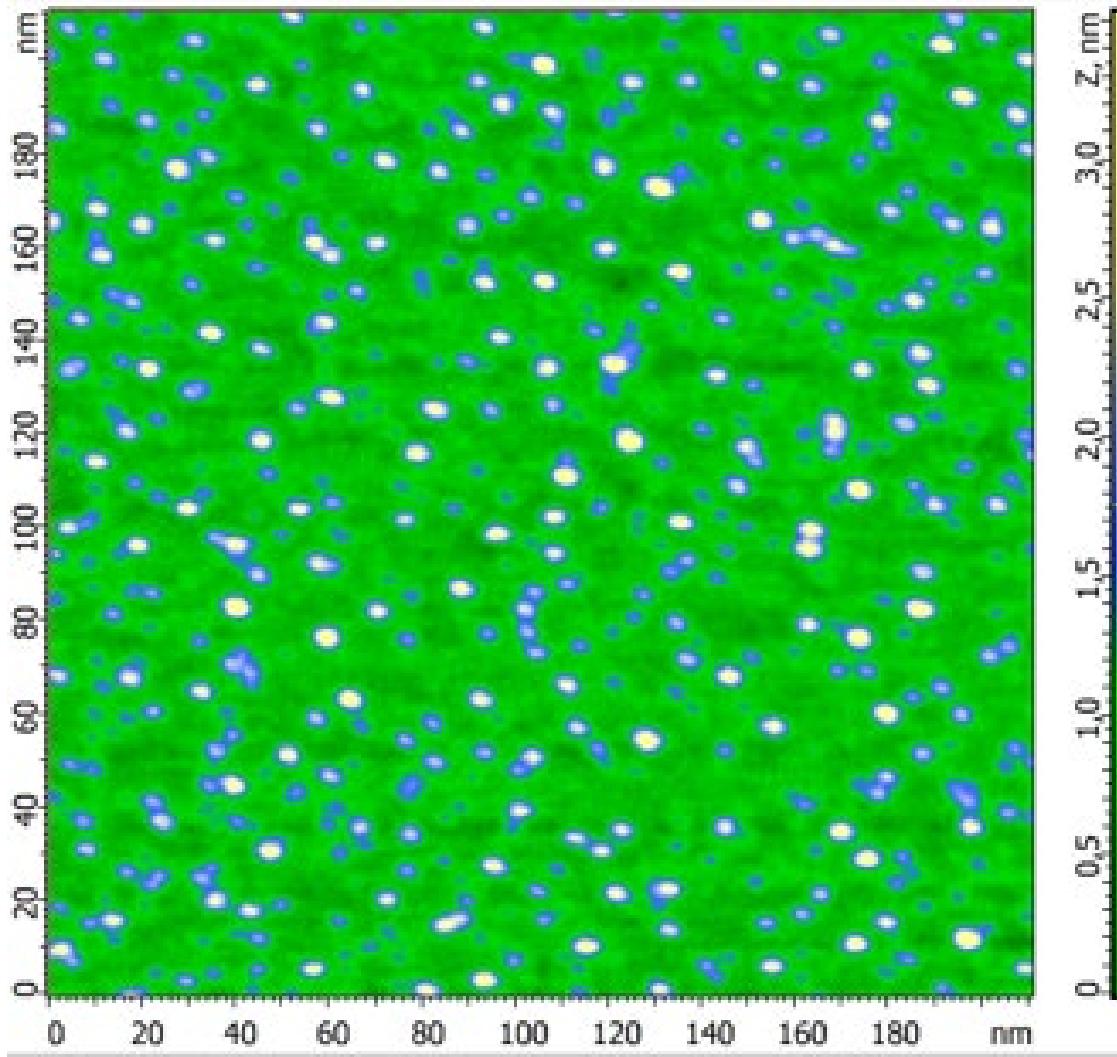


Statistical Analysis by Area

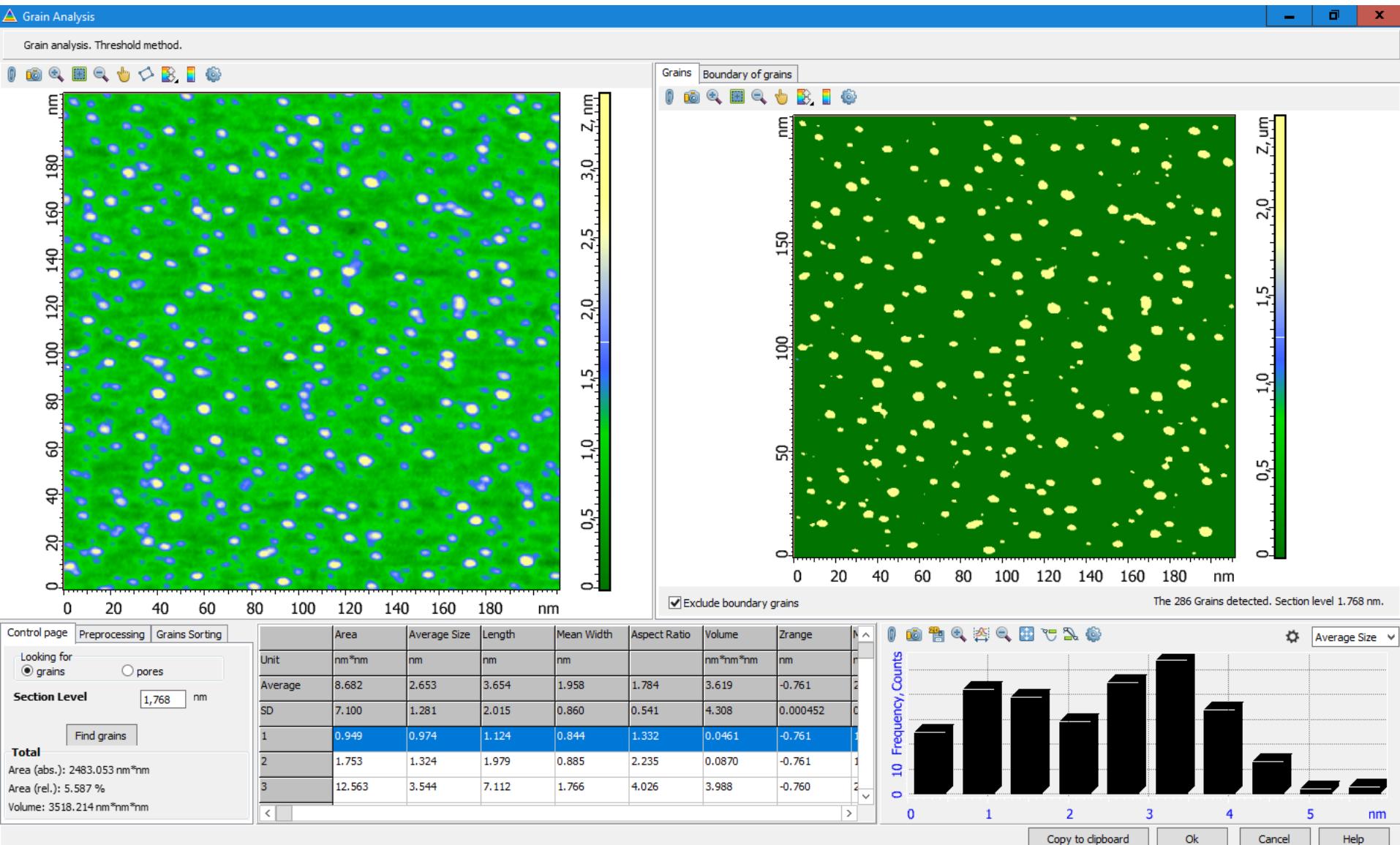


Particle Analysis

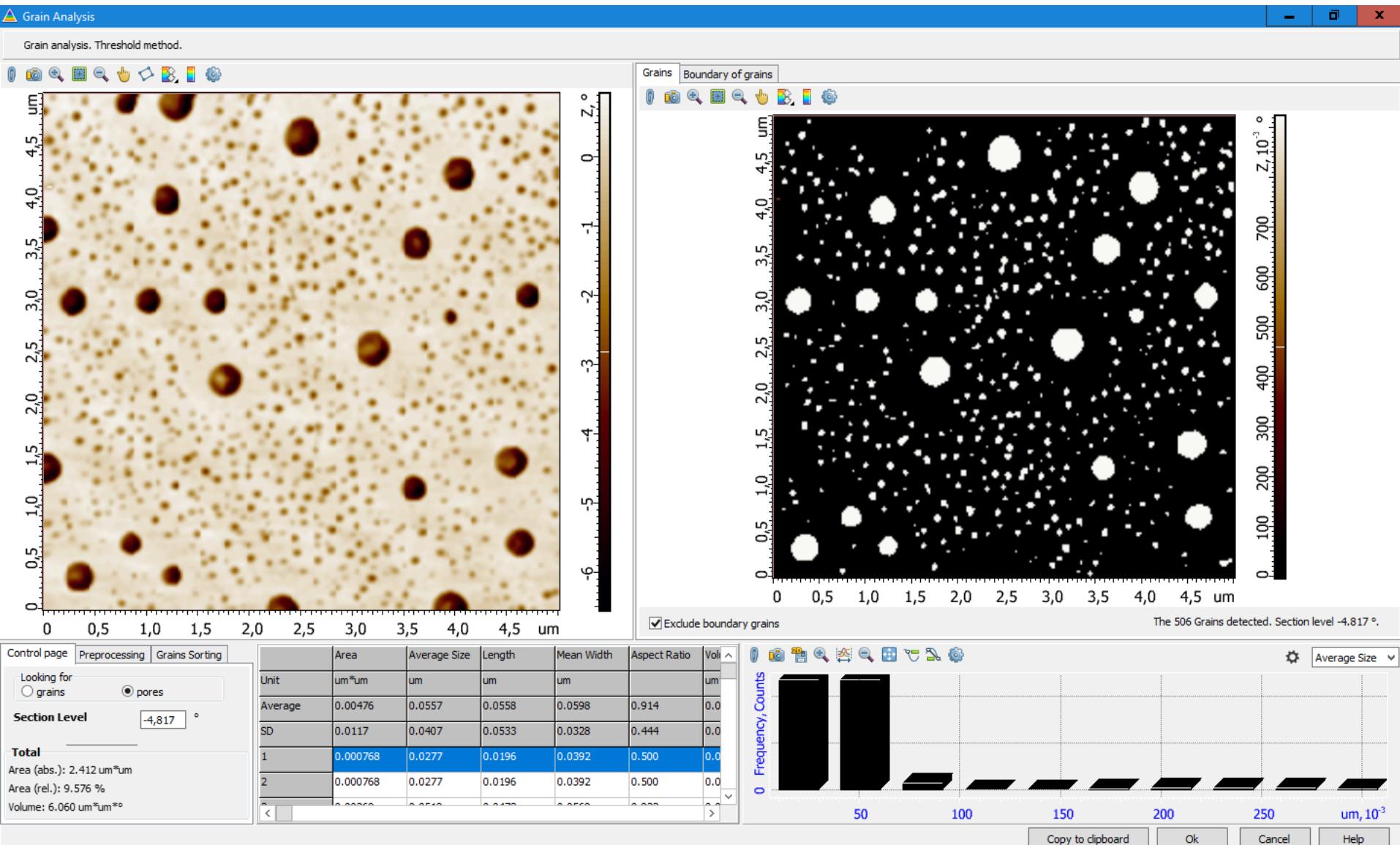
How many particles?



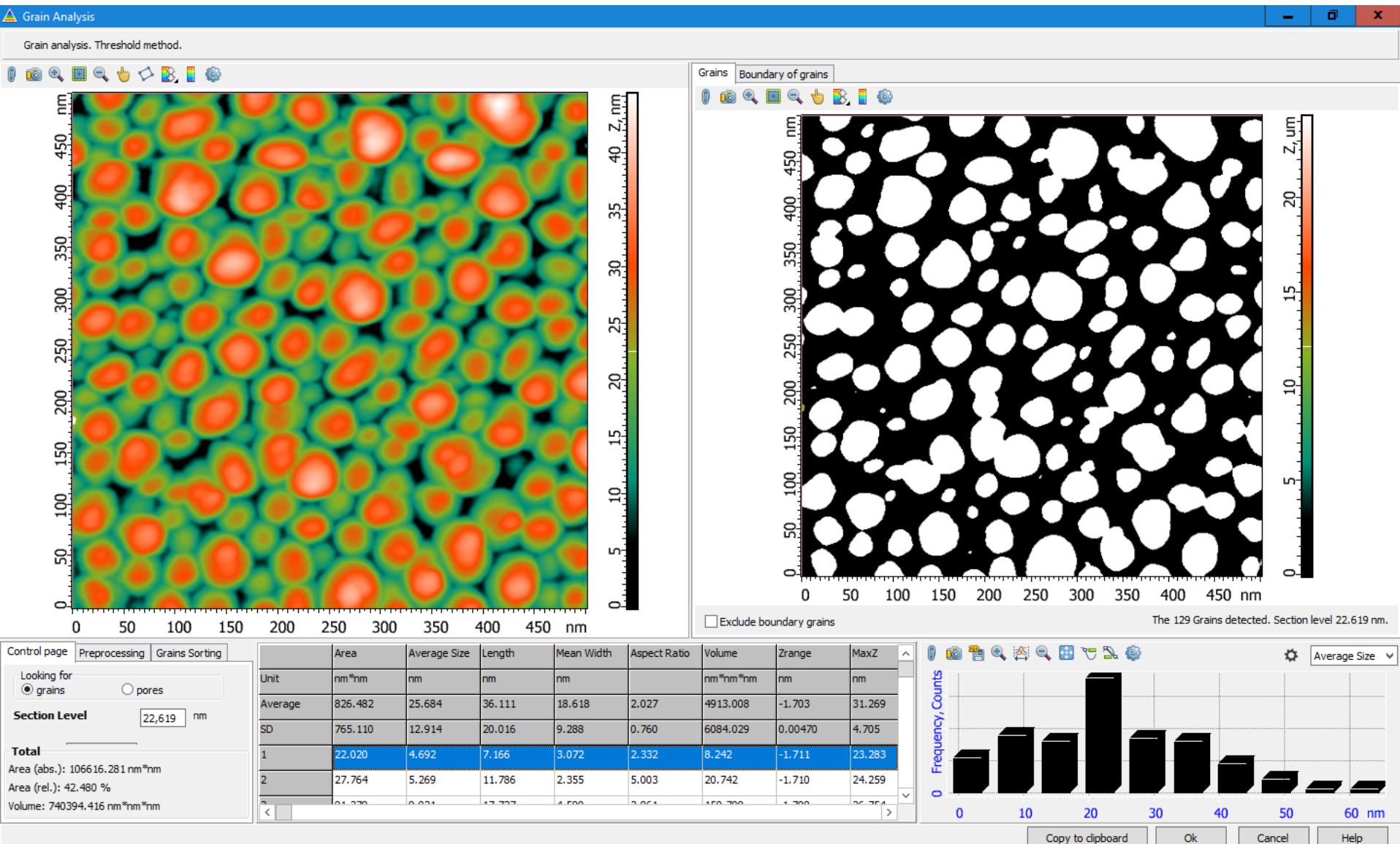
Threshold



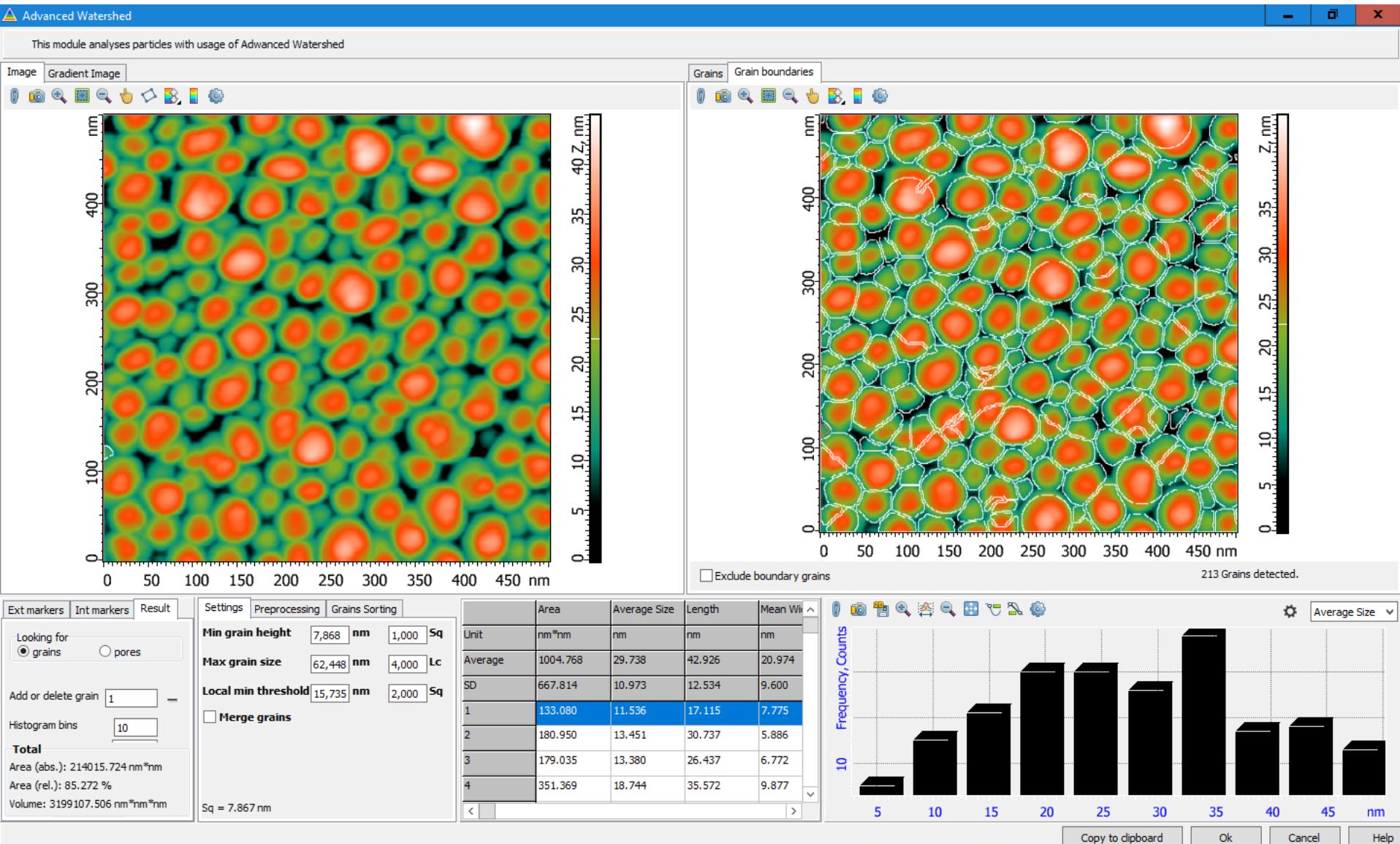
Pores



Threshold



Advanced Watershed



Summary

1. Try different approaches
2. Use a priori information (flat substrate should be flat)
3. Save Trace and Retrace channels for GTransform™
4. Image should be informative
5. Don't use analysis methods blindly. This can affect your scientific reputation

Acknowledgements

Dr. Sergei Magonov
Dr. Raluka Gavrila
Dr. Oksana Karban
Dr. Valery Kuryavy
Dr. Viktor Novak

Dr. Yuri Bobrov
Anton Podstrelov
Sergey Nesterov
Arseny Kalinin
Andrey Gruzdev

Literature used:

Mironov V.L., Fundamentals of Scanning Probe Microscopy (2004)

Gonzales R.C., Woods R.E. Digital Image Processing. 2 ed. PH, 2001.

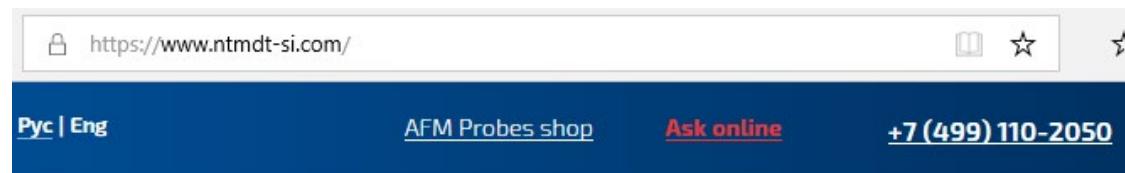
ISO 25178-70 2014 Geometrical product specification (GPS), Surface texture: Areal, Part 70: Material measures

P.M.Williams, K.M.Shakesheff et al. - "Blind reconstruction of scanning probe image data". // J. Vac. Sci. Technol. B 14 (2) p. 1557-1562 (1996)

Ref.: T. Ando, "Control Techniques in High-Speed Atomic Force Microscopy" ACC: 3194-3200, 2008

https://www.michmet.com/3d_s_functional_parameters.htm

Find out more at www.ntmdt-si.com



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