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Integrated modelling approaches for tribological interfaces

DJE interpretation: New ideas and developments for improved modelling

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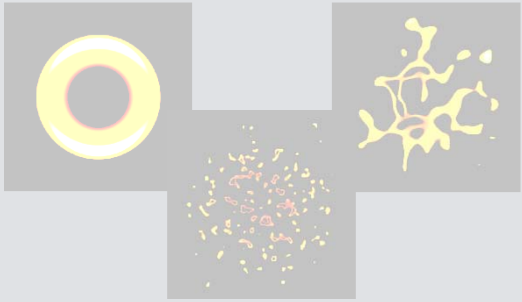
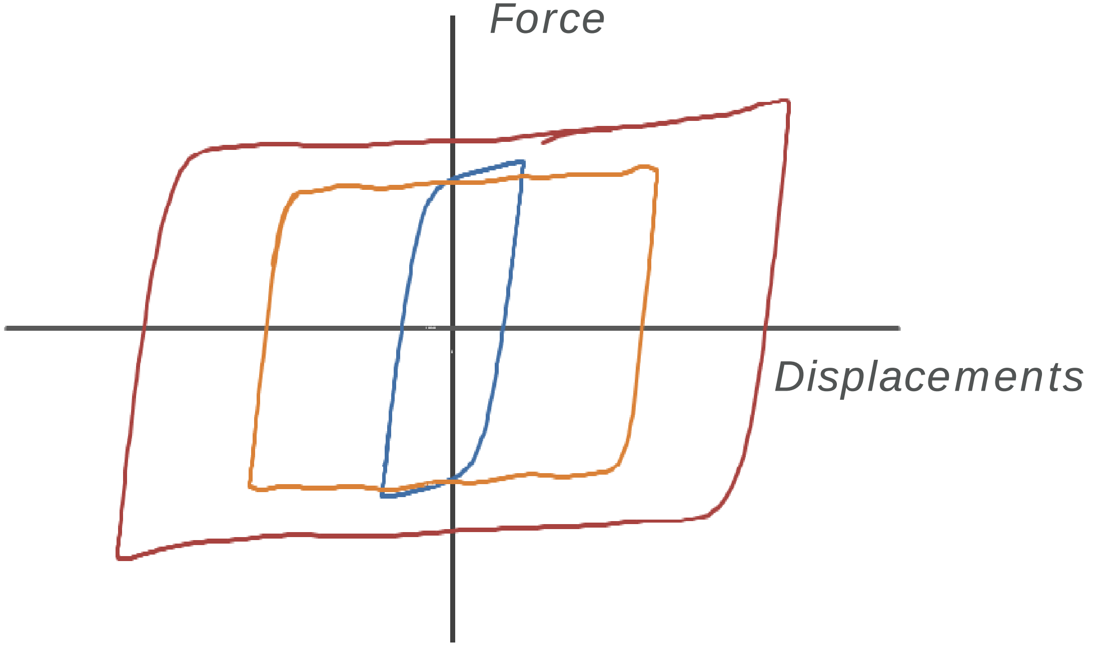
Background 1 – The continuum side



- Frictional hysteresis loops recorded for reciprocating sliding of representative samples of material
- Friction coefficient and tangential contact stiffness obtained from hysteresis trace
- Difficult to predict friction, but…
  - Are results scalable?
  - Can initial curvature (stiffness due to partial slip) be predicted?
  - Can energy dissipation be predicted?



- **Focusing on surface roughness effects**
- **Interested primarily in energy dissipation and tangential contact stiffness**

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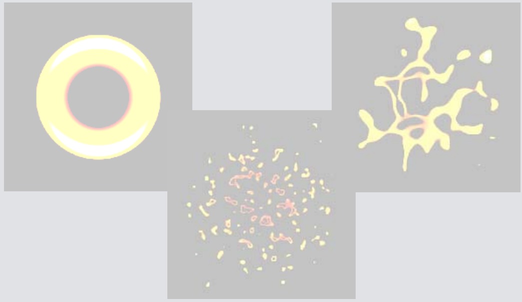

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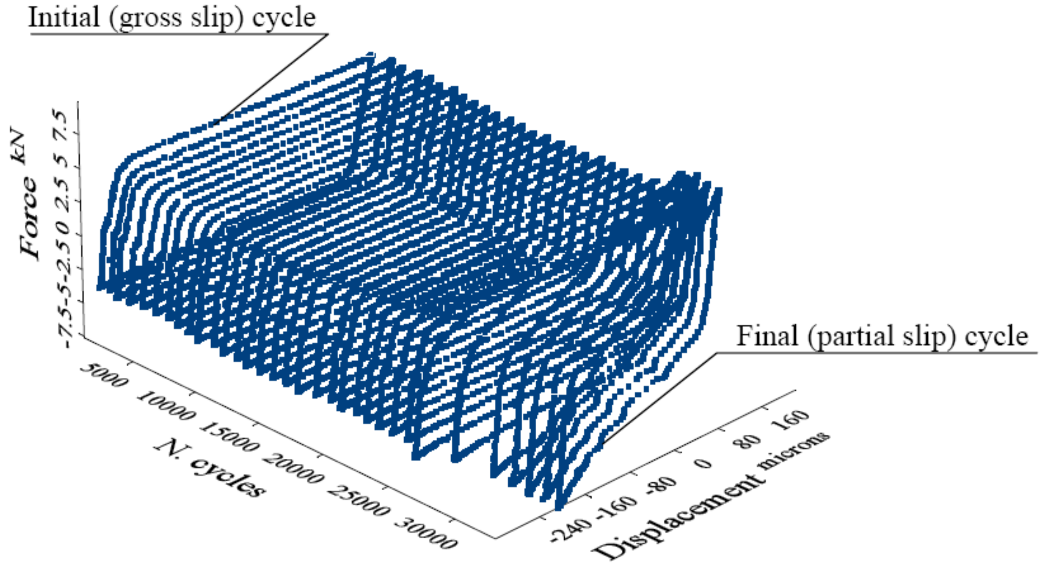
- What about history and evolution ???



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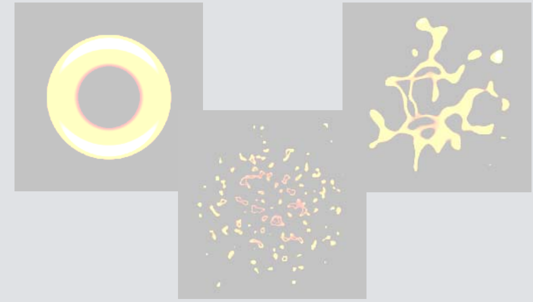
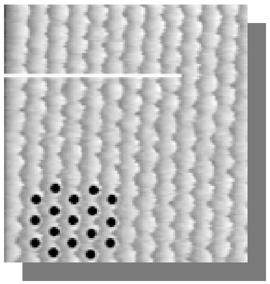
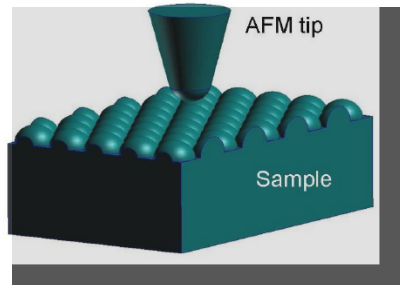
Background 2 – Bridging scales

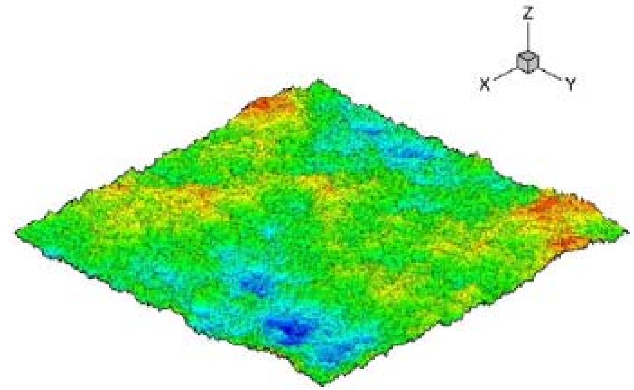




Carpick et al., JOM 2004

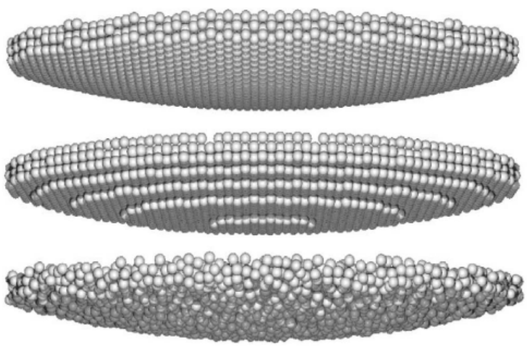


AFM supporters 1990's-



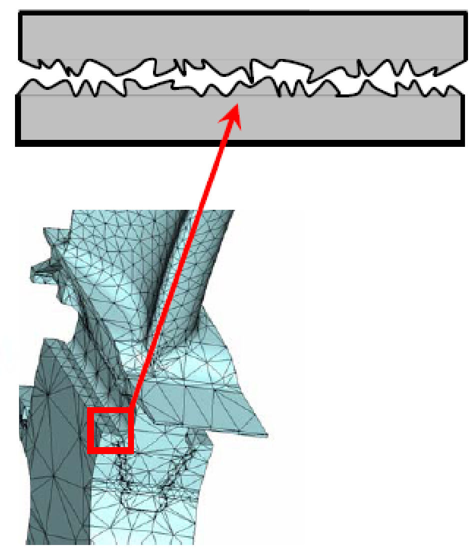
Hyun and Robbins, JMPS 2005

3D nano- or micro-scale contacts

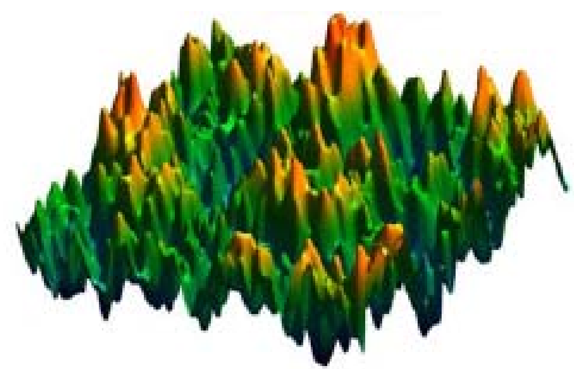


Luan and Robbins, Nature 2005

3D macro-scale contacts

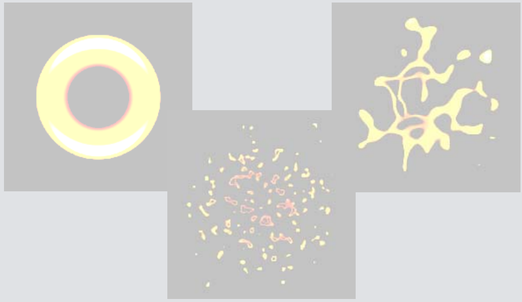


Petrov et al., ASME 2004



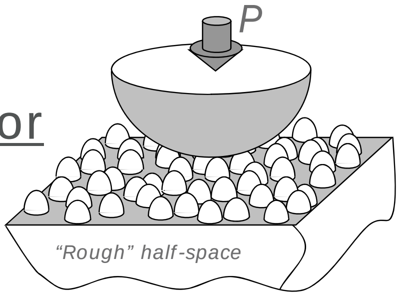
Ciavarella et al., JMPS 2006

Where does continuum brake down? Is it question of size or models?

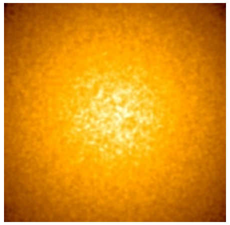


Effect of roughness (Method)

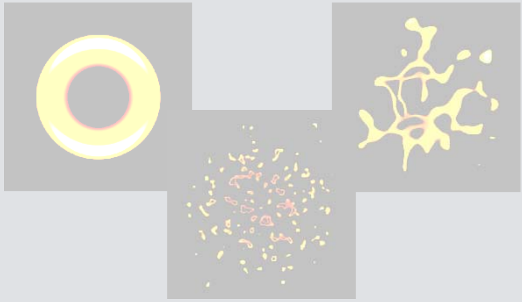
Rough surfaces contact analysis



- Uses either real roughness from optical profilometry or randomised surfaces
- Using Multilevel Multi-integration method (Bradt & Lubrecht; Venner & Lubrecht)

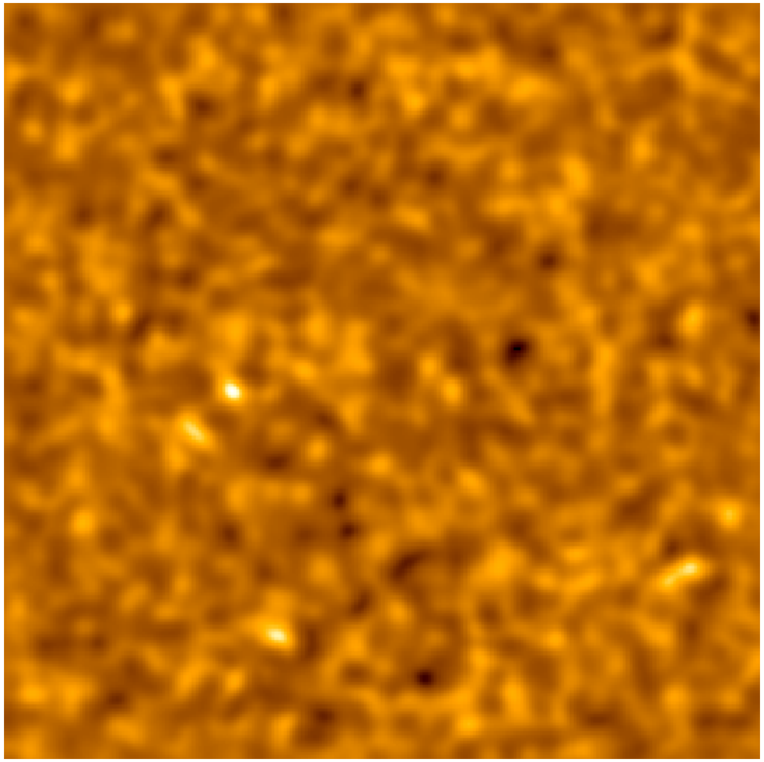


- Coarser grids allow long range influences to pass through Jacobi relaxation process faster, and faster solution
- Good for memory usage; critical for future work on experimental comparison with real surfaces requiring very large grid sizes
- Ciavarella / Jäger method for obtaining partial slip tractions
- Limitations: linear elastic, half-space and Coulomb's friction



Rough surface generation

- Rough surfaces generated using moving average method to control correlation length
- Template surfaces generated
- Rescaled to give different RMS
- Translated using Johnson curves to give different skewness and kurtosis
- Ensures asperity location remains same and reduces scatter



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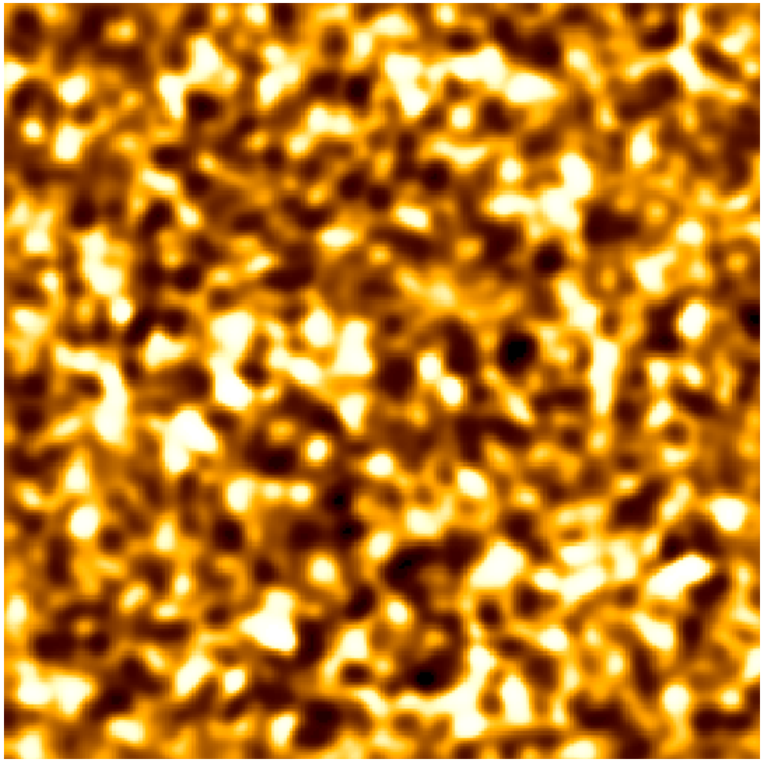

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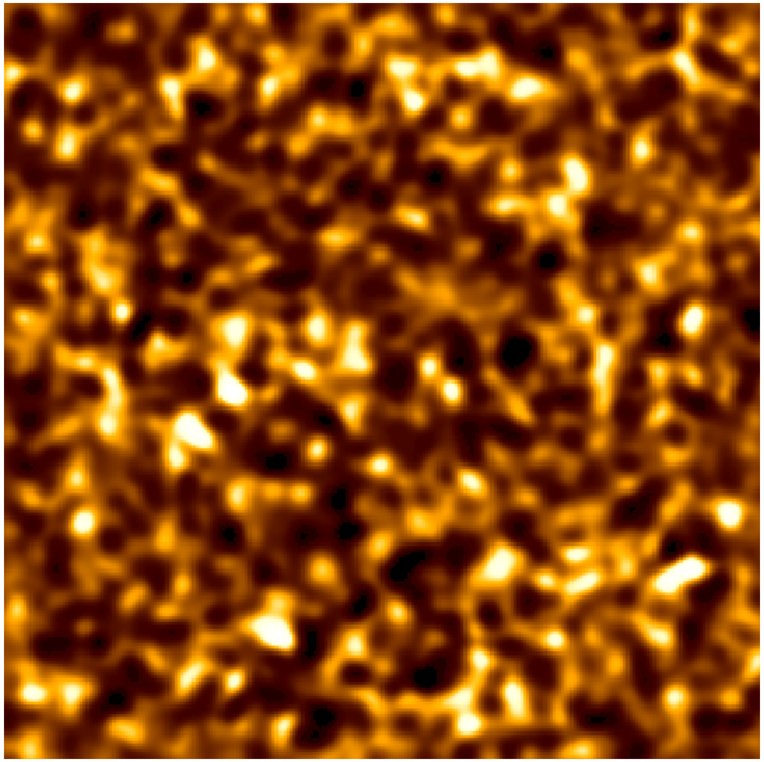
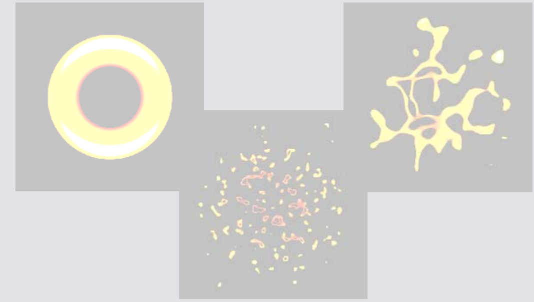
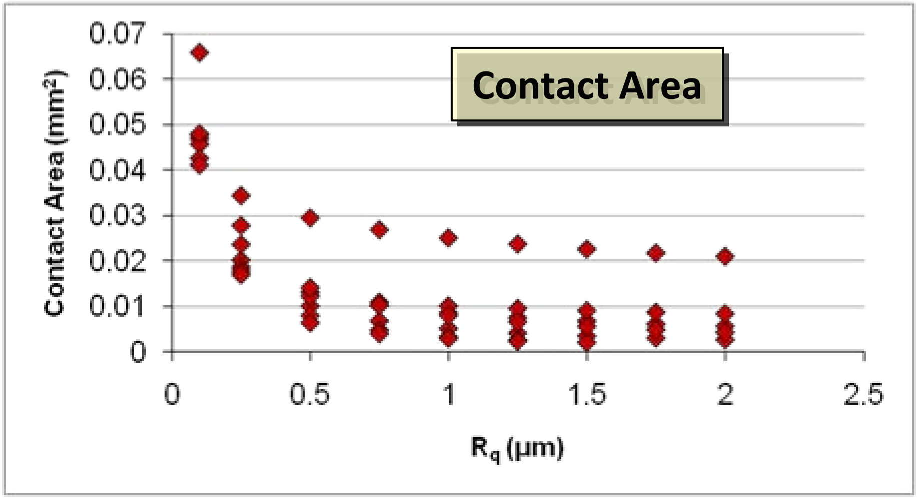
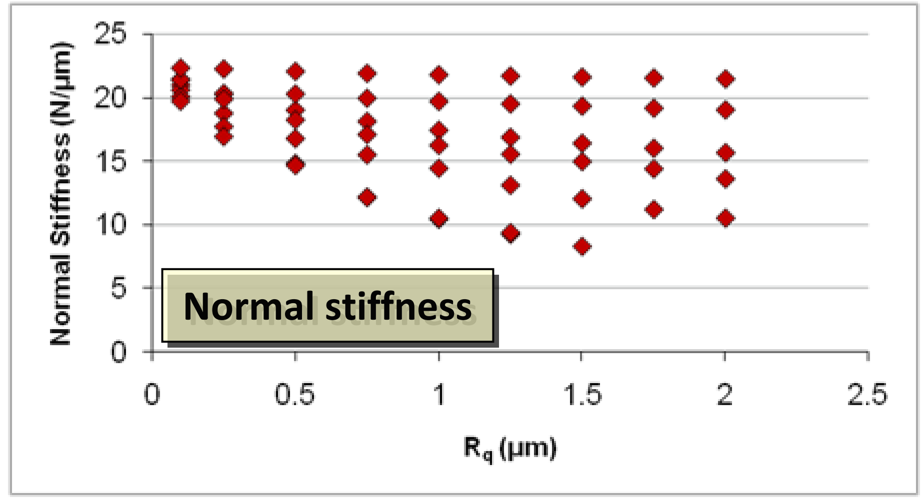
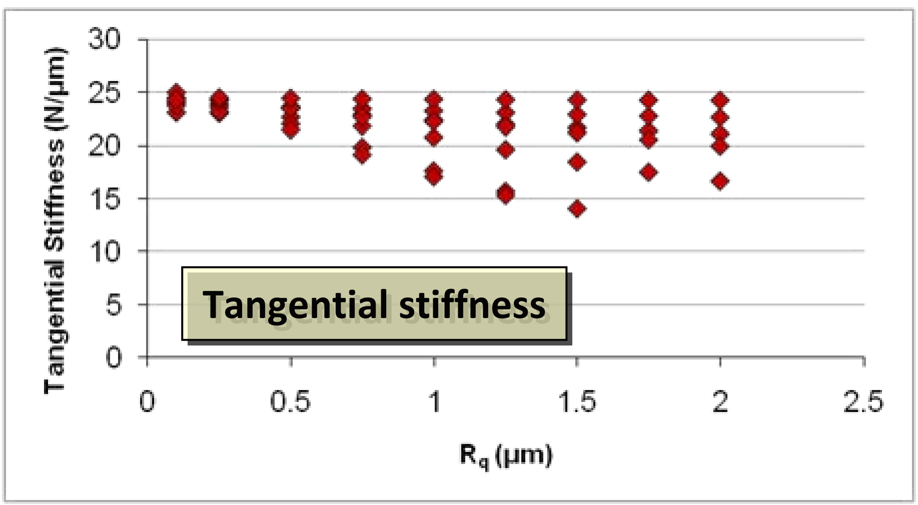


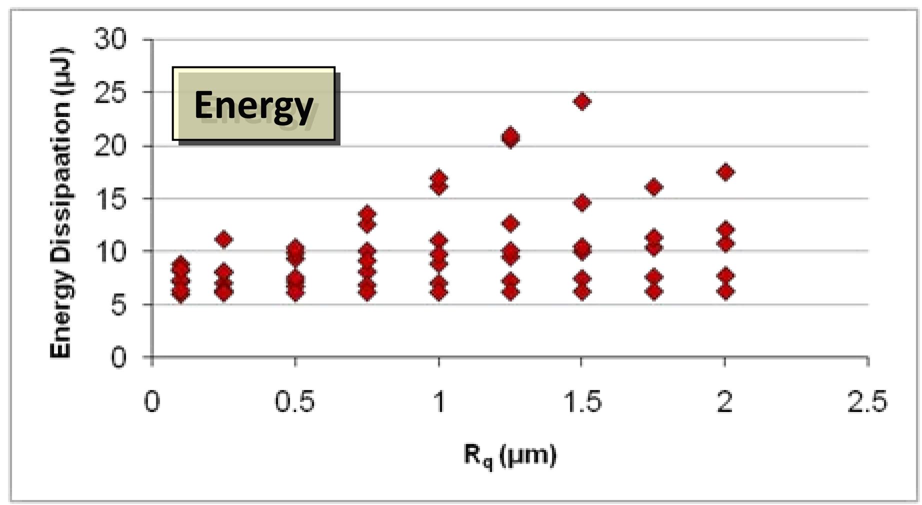


Influence of roughness

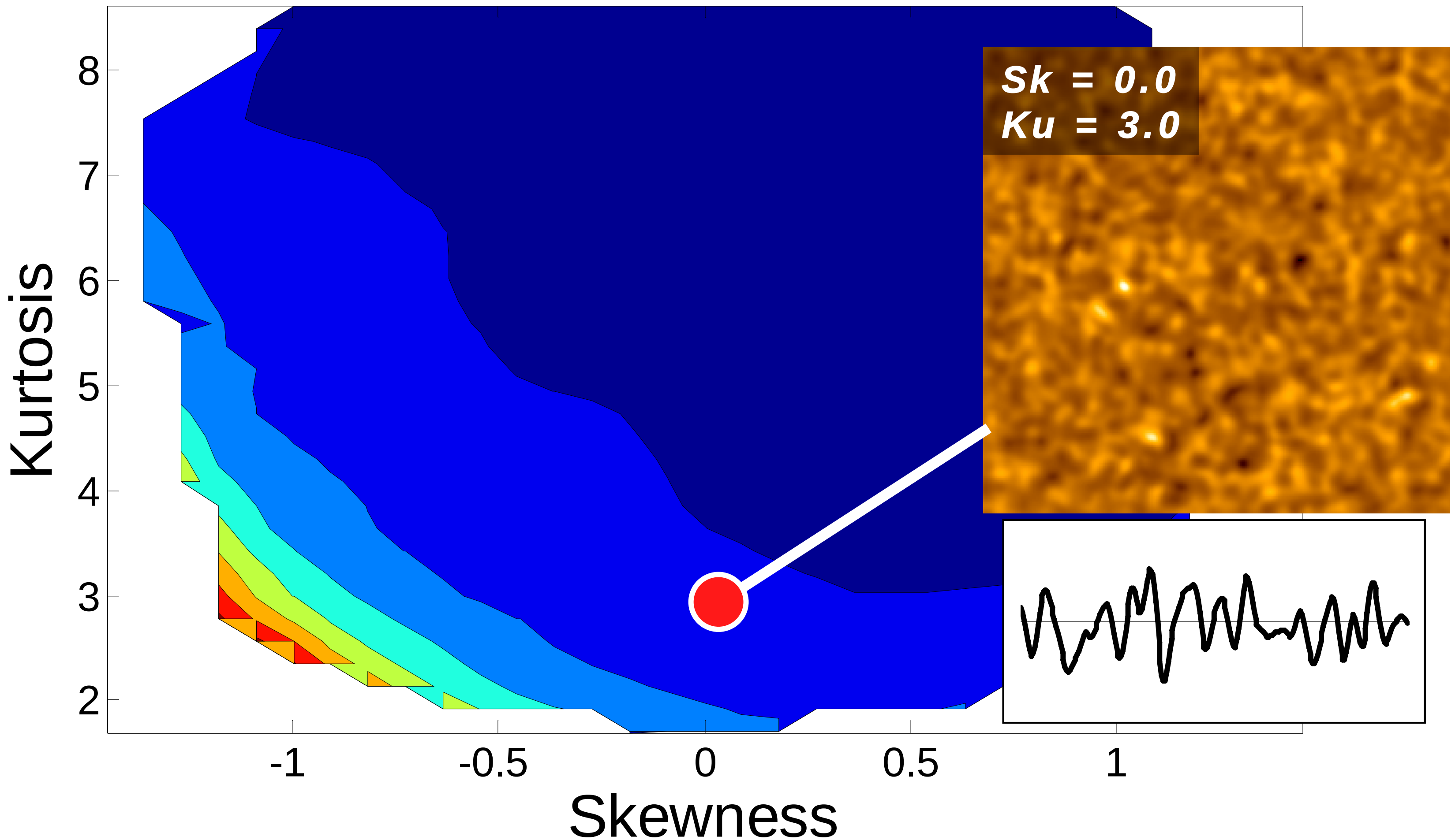








Surface forms – Sk / Ku



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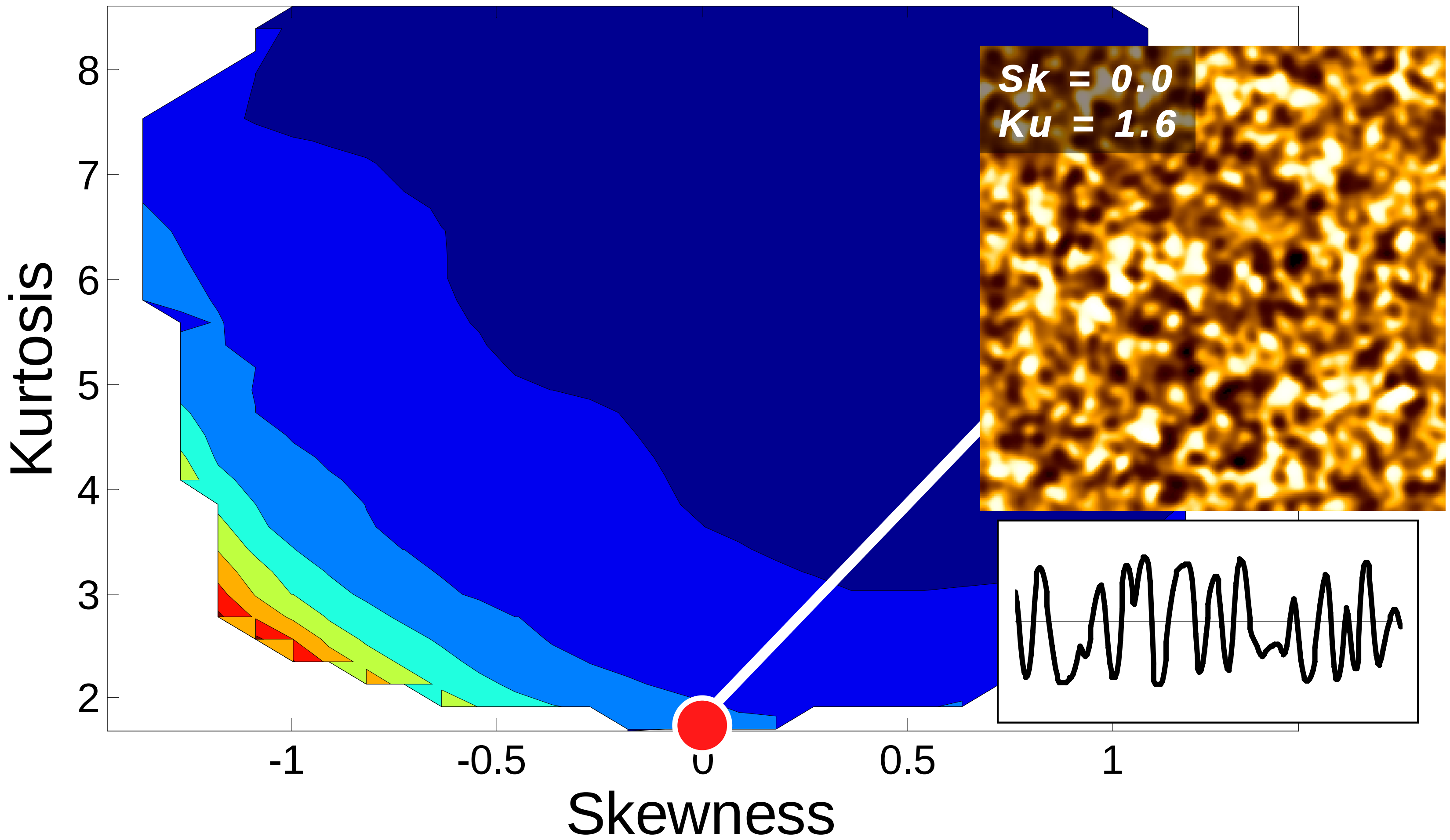

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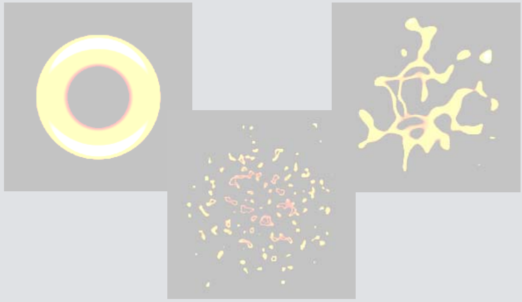

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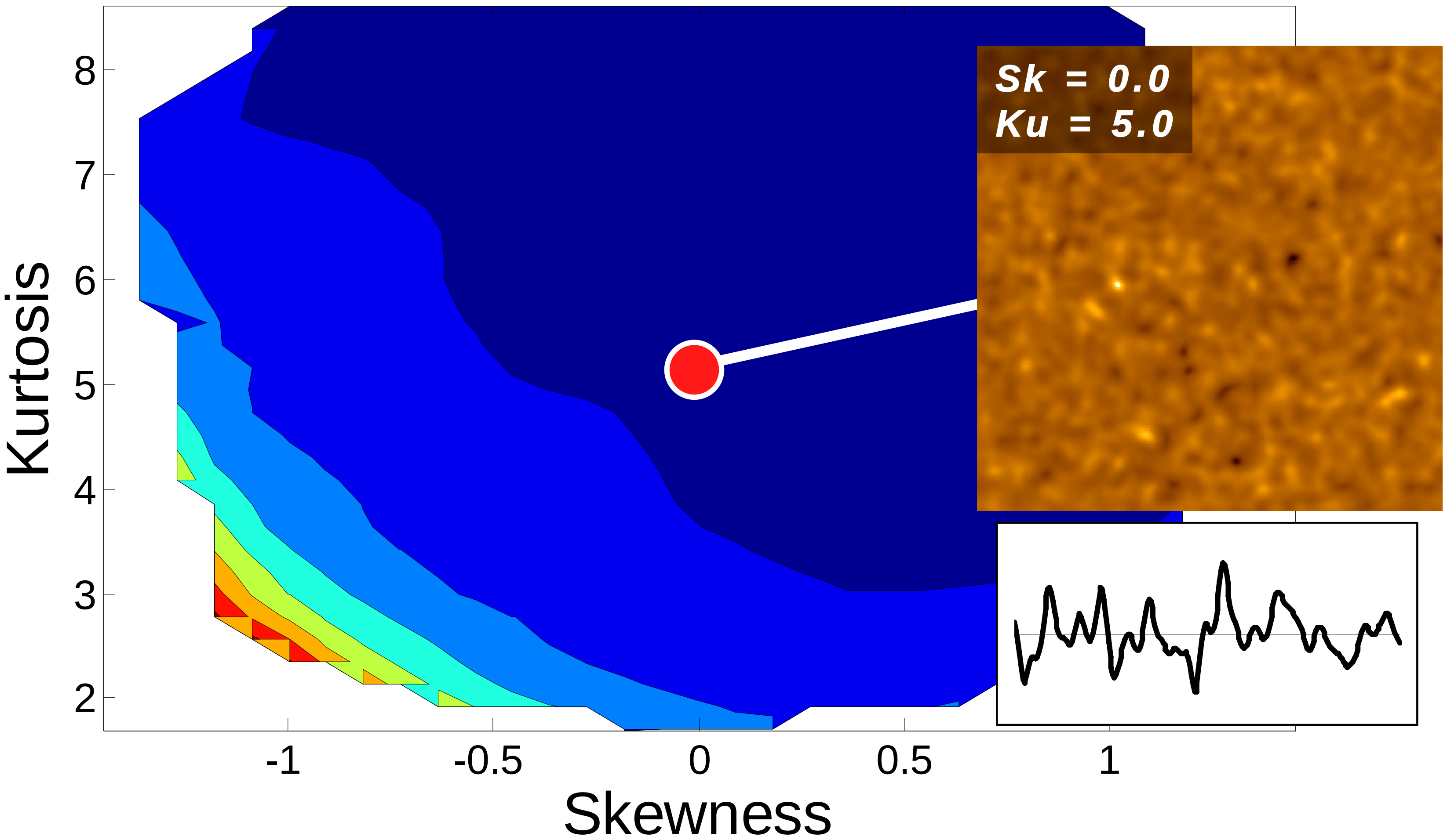

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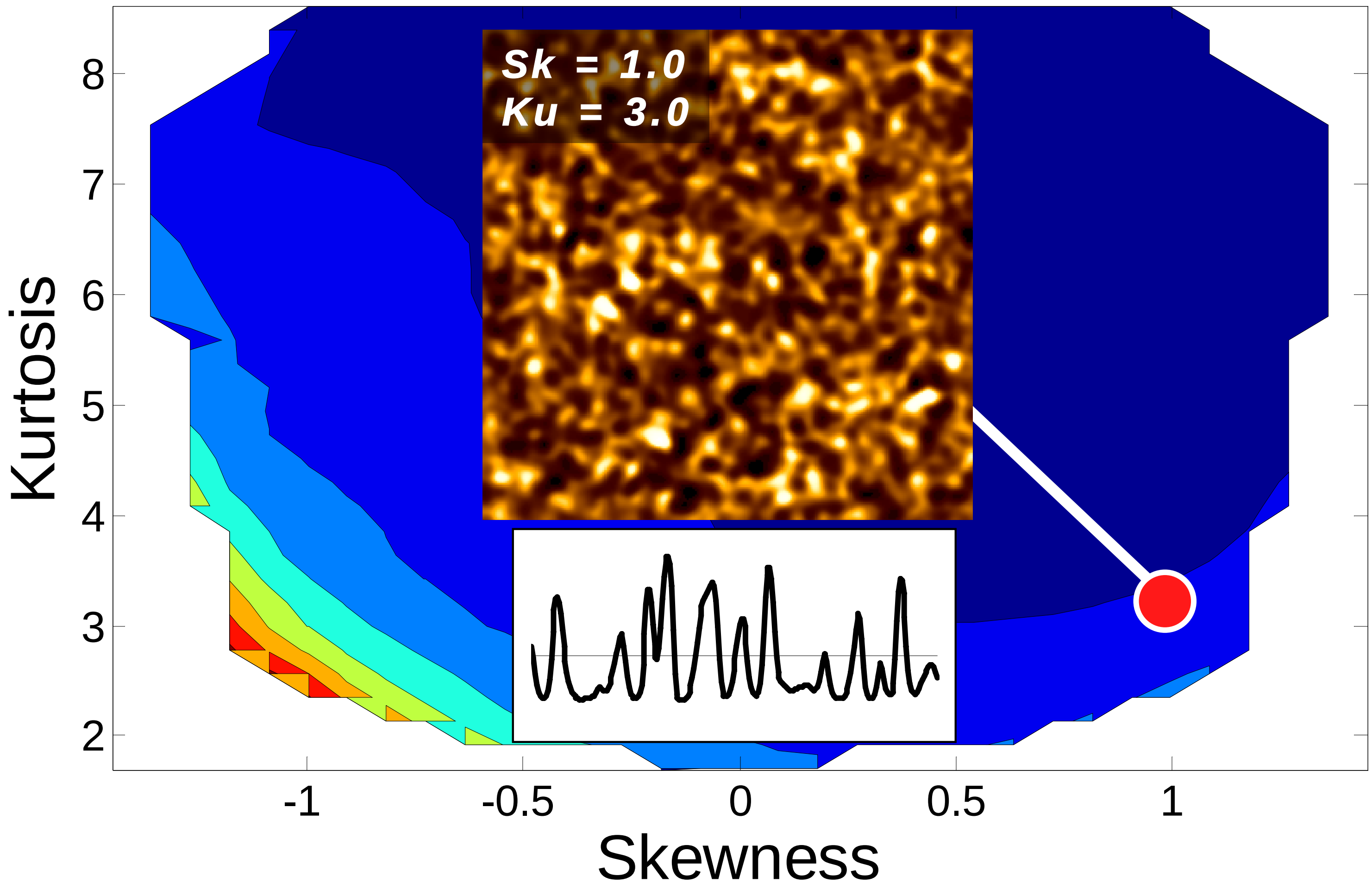

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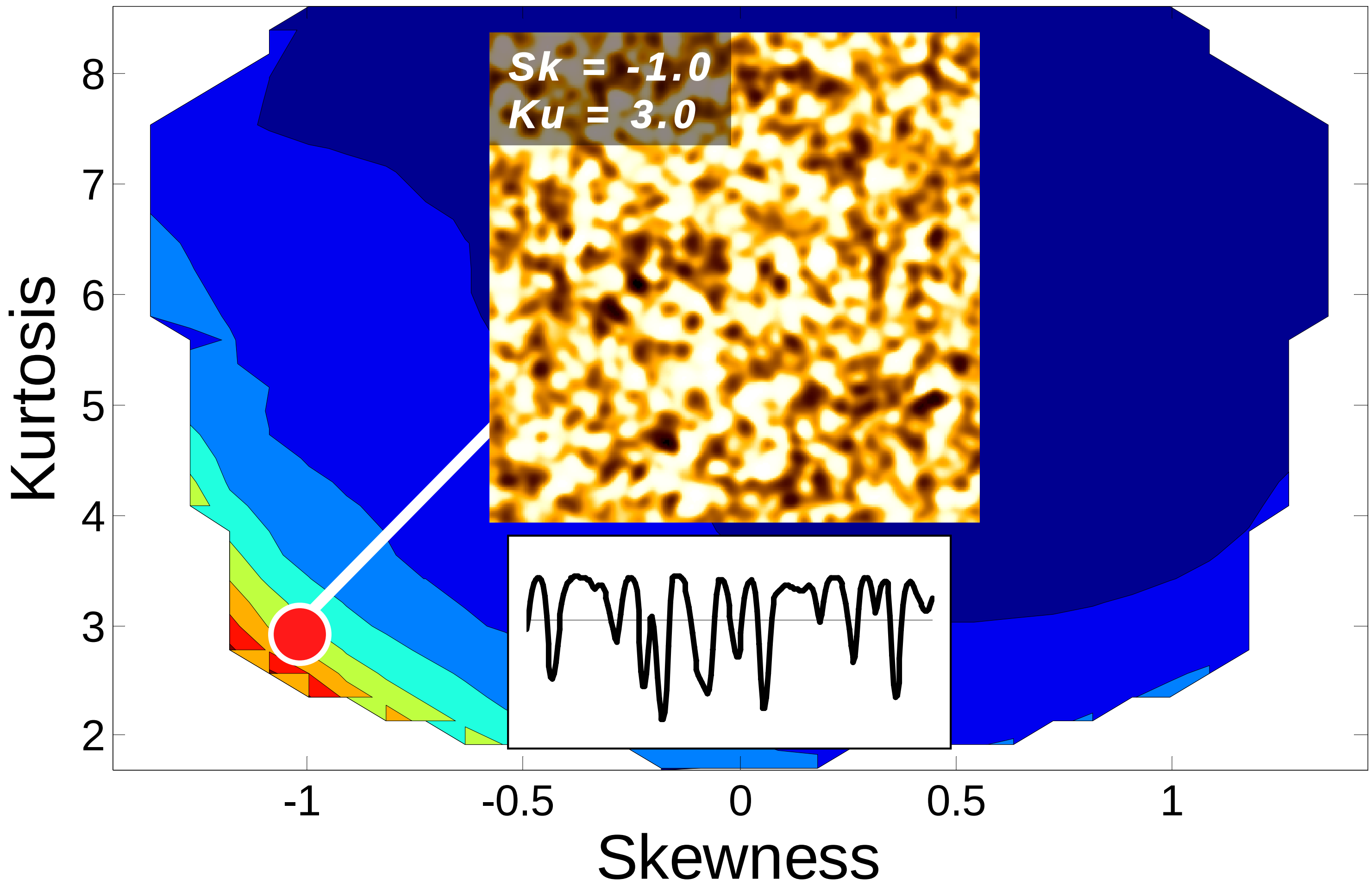

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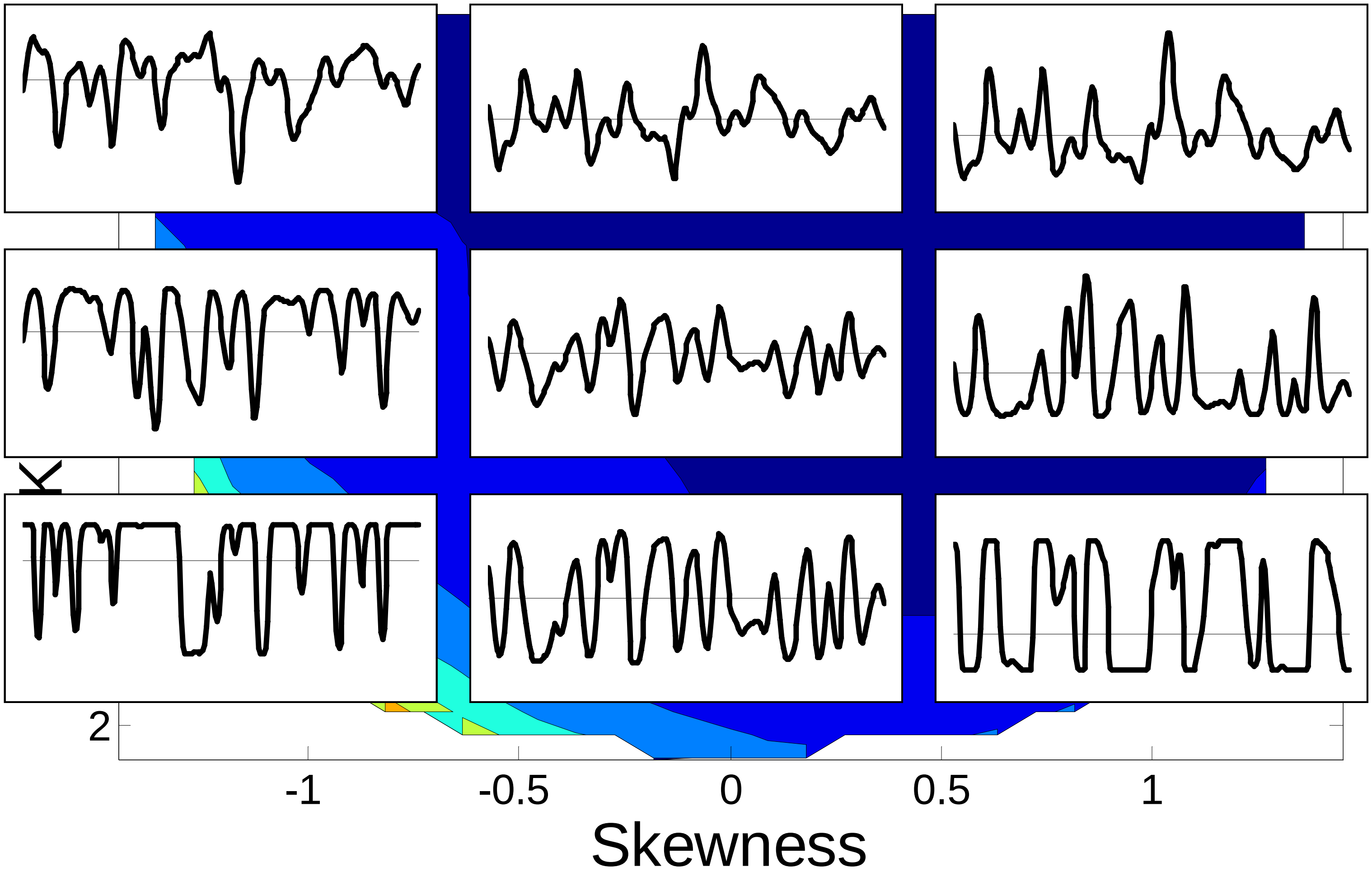
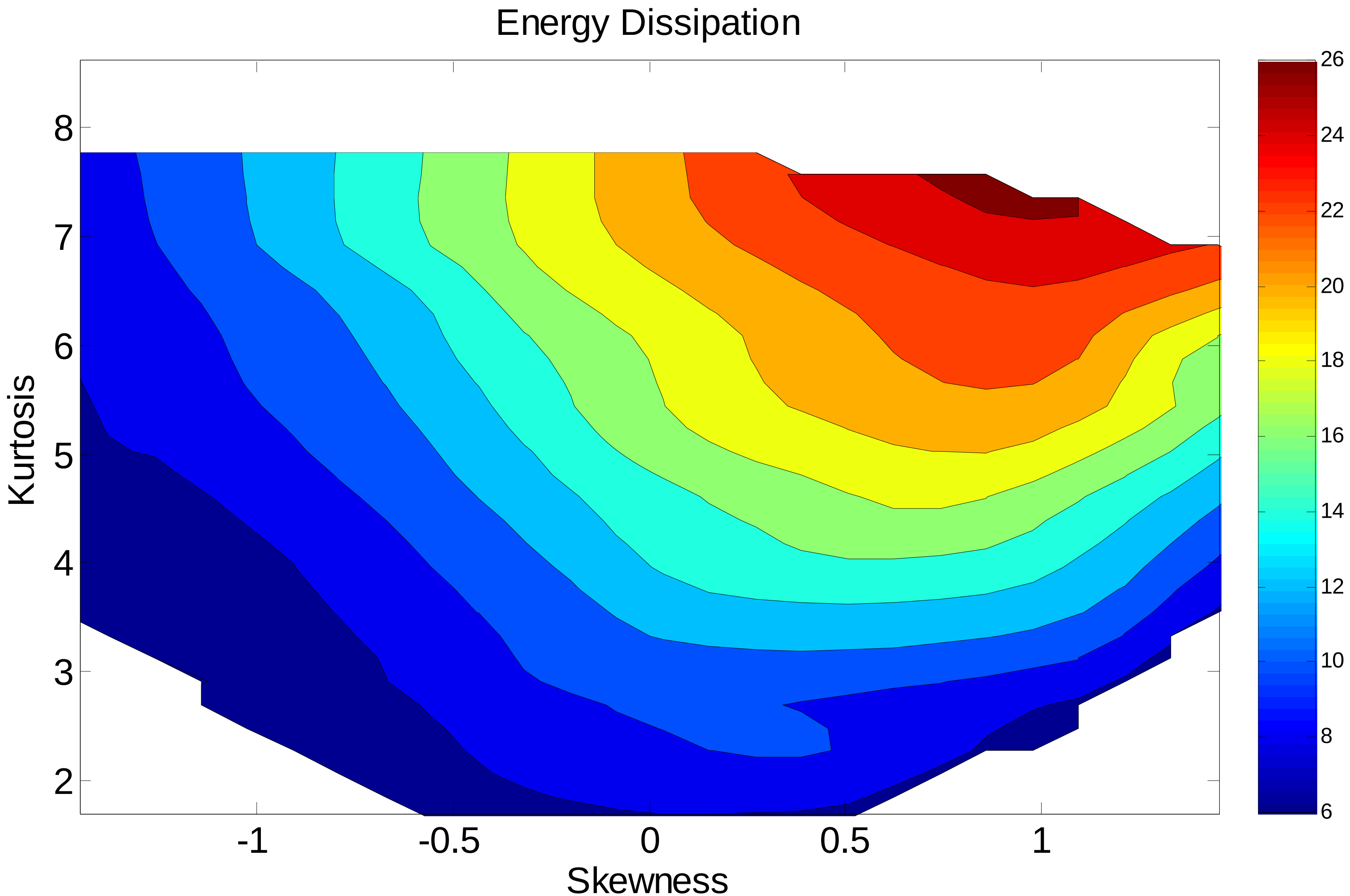


Influence of roughness

CL=10
RMS = 1
Q/fP = 0.8



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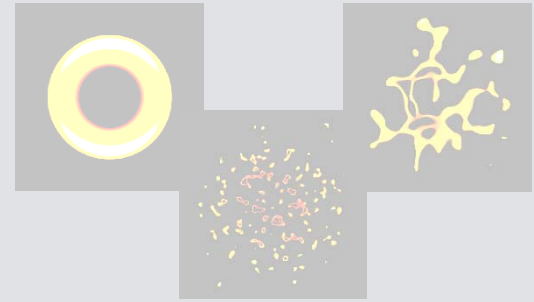
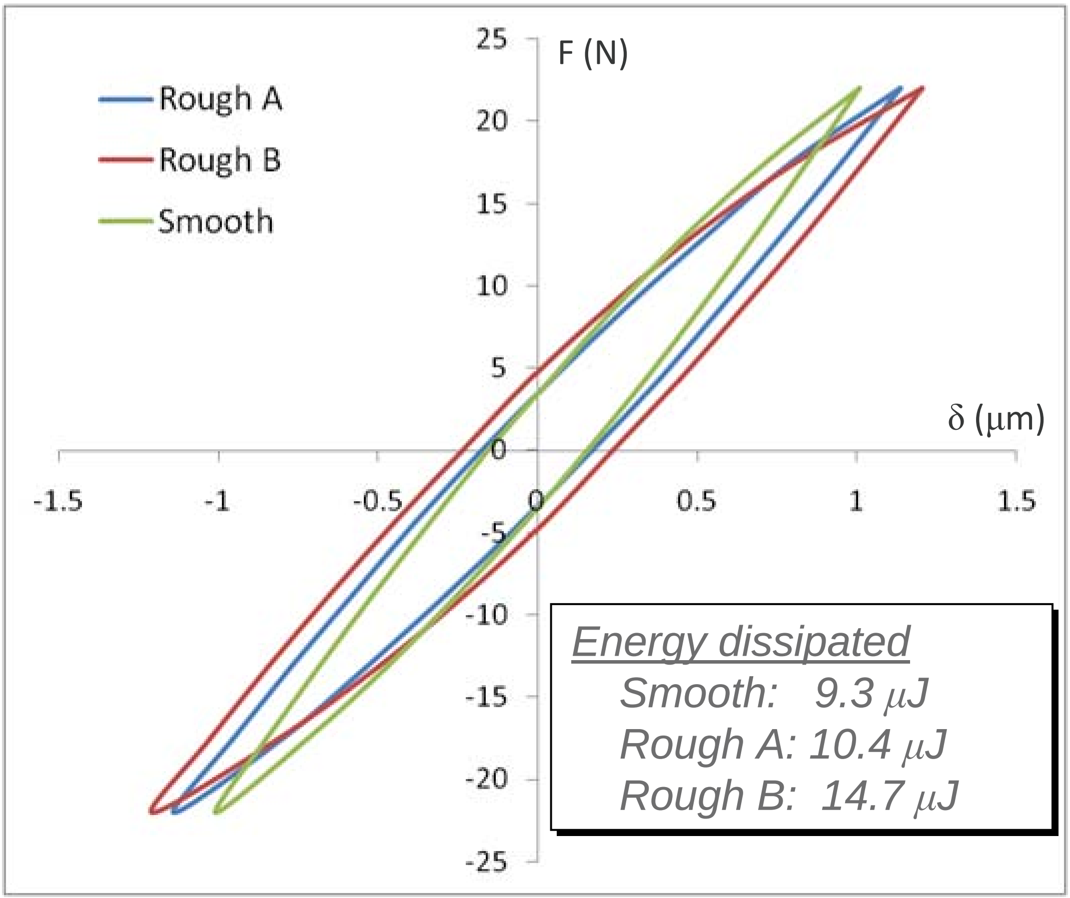


Energy Dissipation in Partial Slip

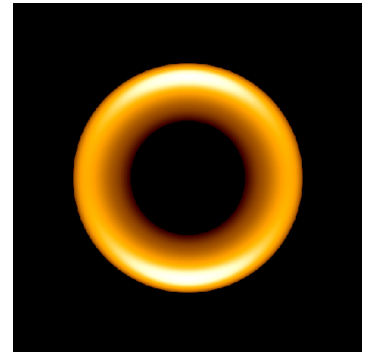


Energy dissipated

Smooth: 9.3 μJ

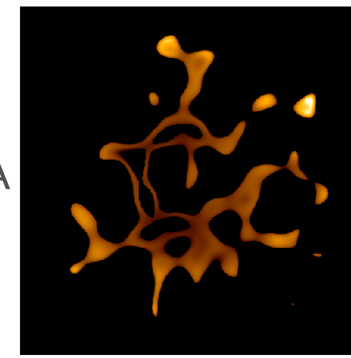
Rough A: 10.4 μJ

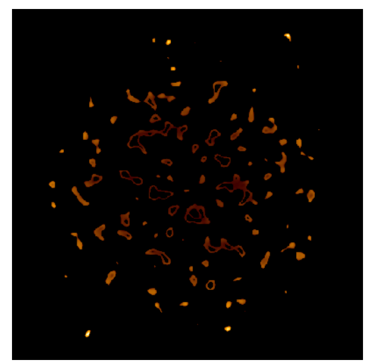
Rough B: 14.7 μJ



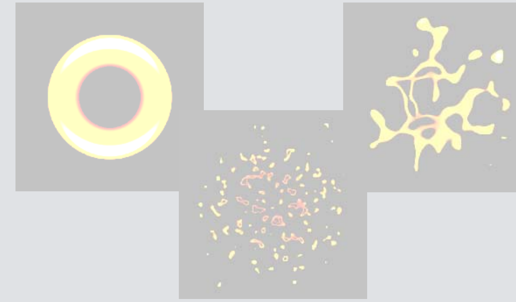
Smooth

Rough A





Rough B

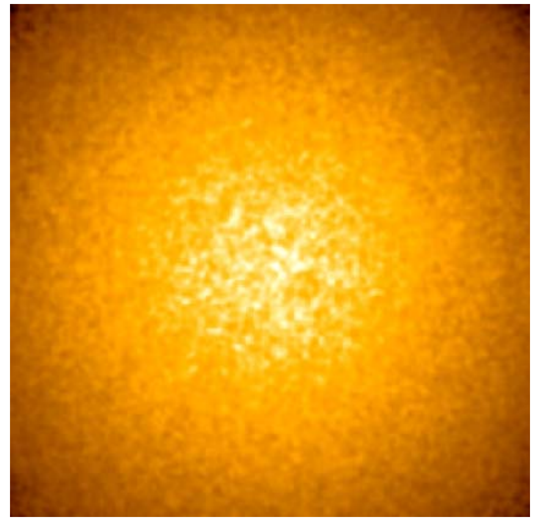


Asperity interaction (two rough surfaces)

RMS 0.2μm

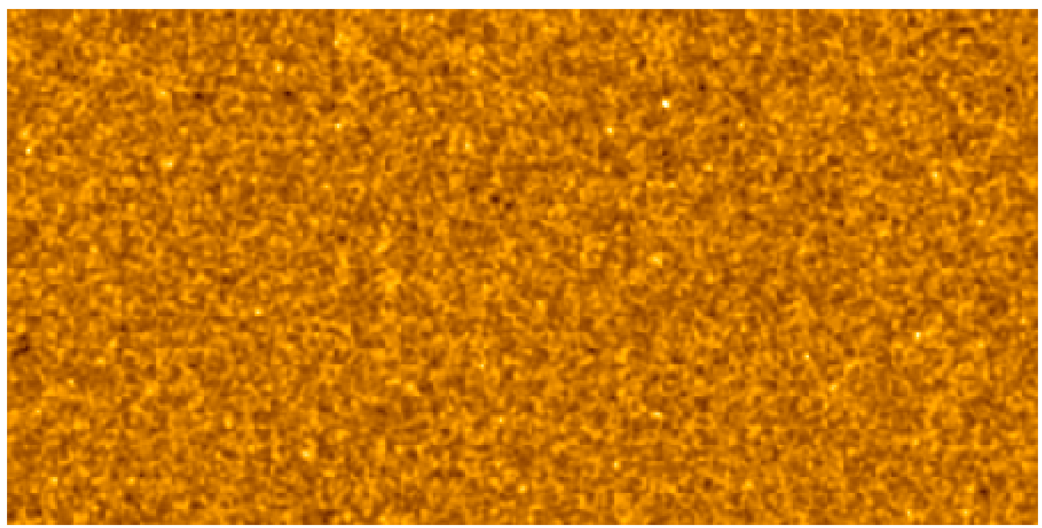
Top surface Rad 10mm

Load 50N



Top surface

Bottom surface



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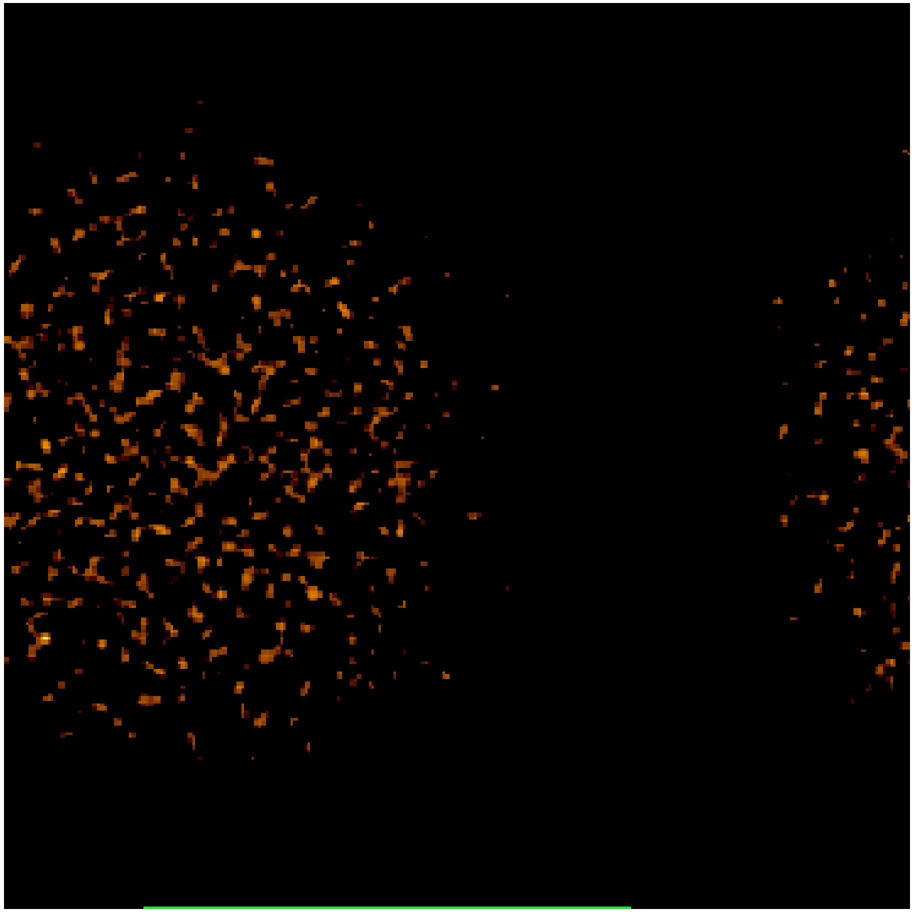
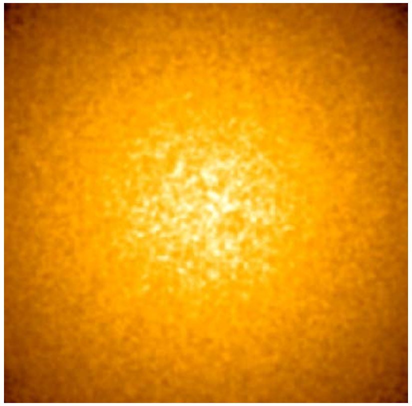
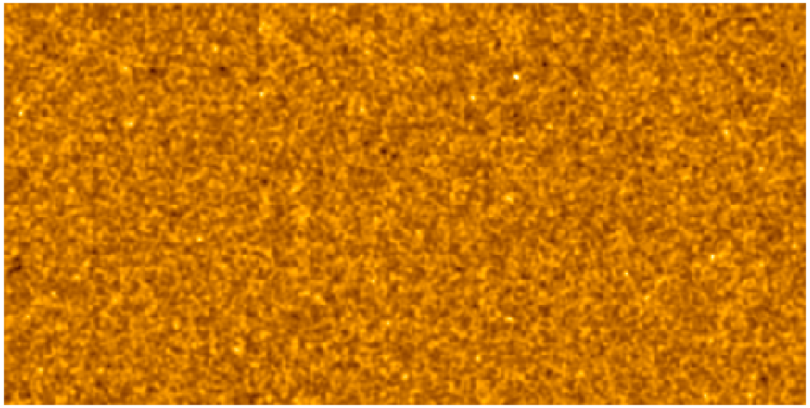






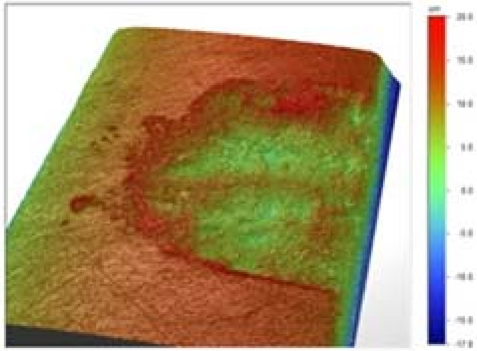
Experimental surface analysis

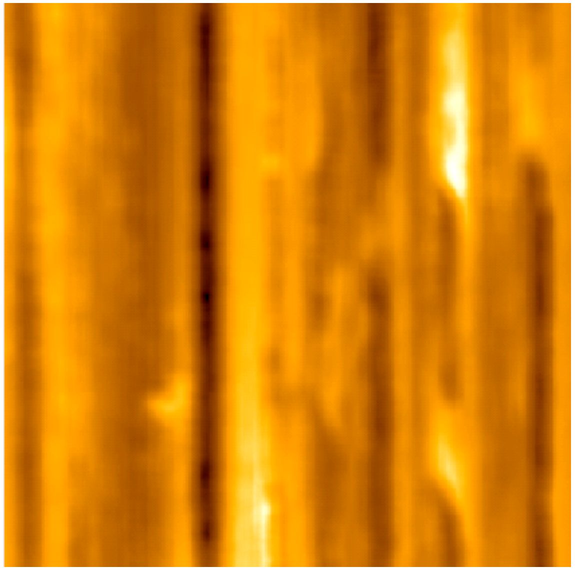
Small section of a Nickel sample, profiled edges

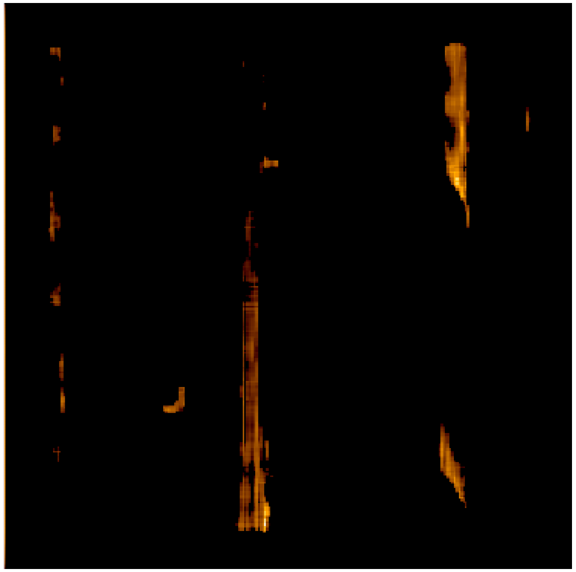
Raw data could not be solved – contact on 2 nodes

Low pass filter applied to remove spikes

Normal load solved satisfactorily







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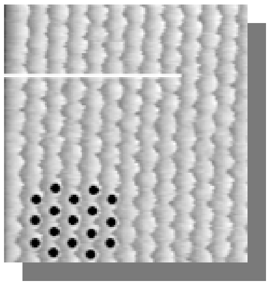
Open questions 1

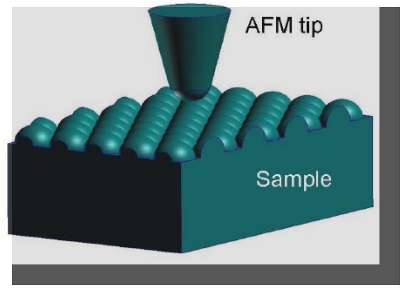
How can we make sure that our models are a close representation of the real components?

How do we extract the processes and the parameters which characterise the behaviour of our assemblies? (very strong link to well characterised experiments)

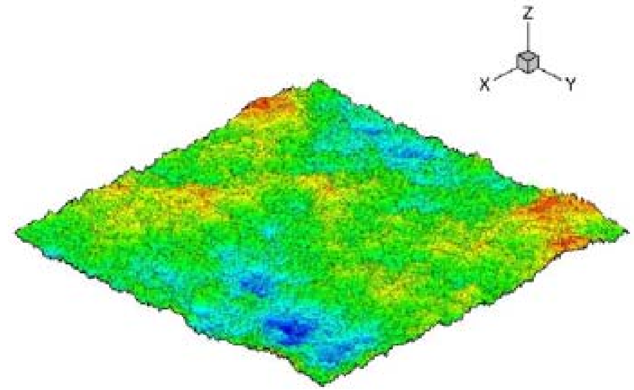
Background 2 – Bridging scales



Carpick et al., JOM 2004



AFM supporters 1990's-



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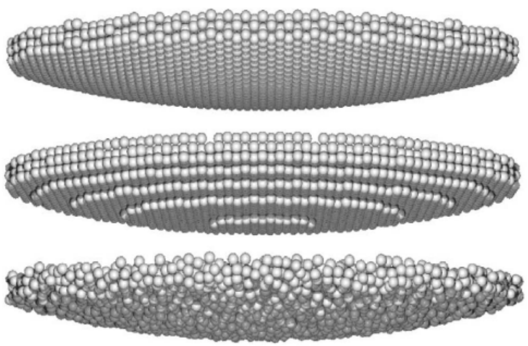

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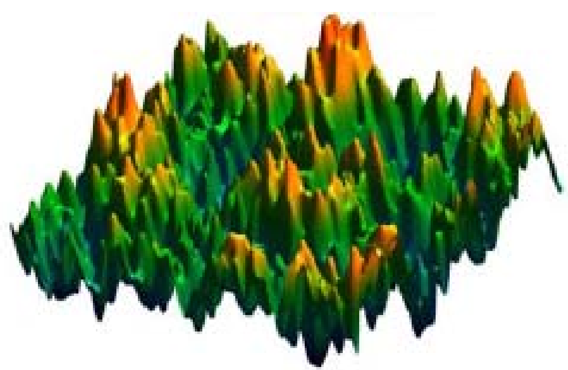
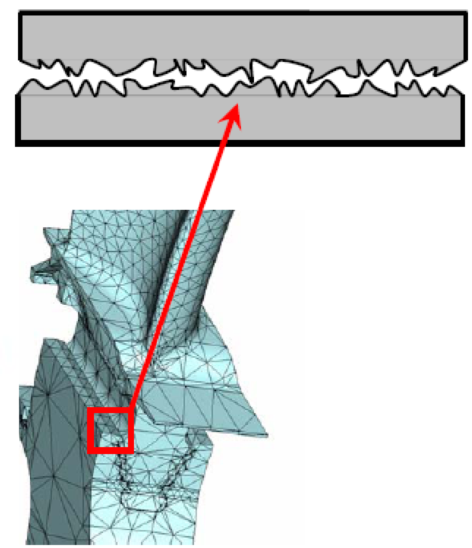
3D macro-scale contacts



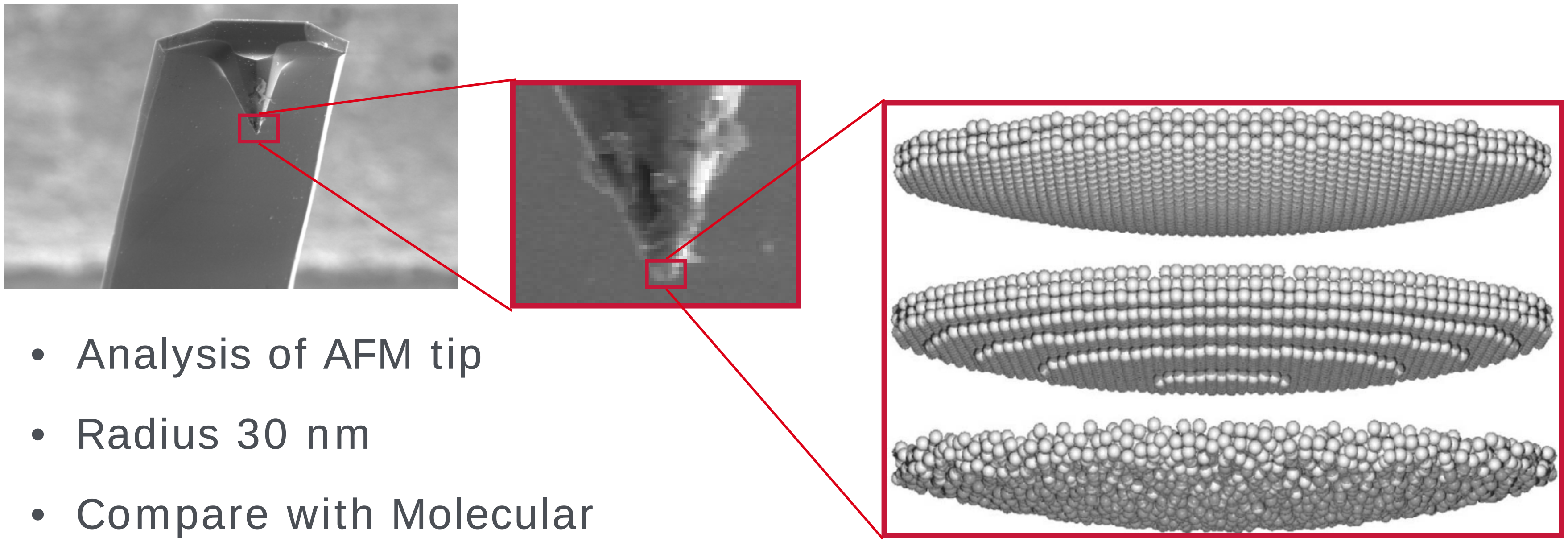
Ciavarella et al., JMPS 2006



Petrov et al., ASME 2004

Where does continuum brake down? Is it question of size or models?

Which Model When? (AFM tip analyses)



- Analysis of AFM tip
- Radius 30 nm
- Compare with Molecular Dynamics Simulations of Luan & Robbins 2006
- Suitability of continuum approach at molecular level
- Surfaces generated using hard sphere model of atoms

B. Luan and M.O. Robbins, 2006, “Contact of single asperities with varying adhesion: Comparing continuum mechanics to atomistic simulations”, Physical Review E 74, 026111

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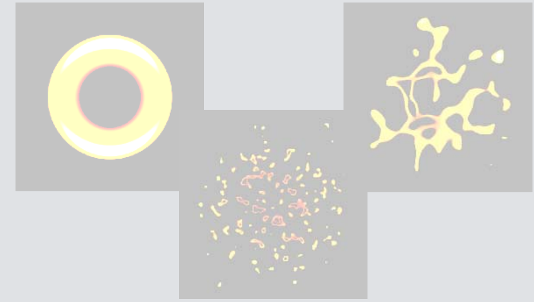
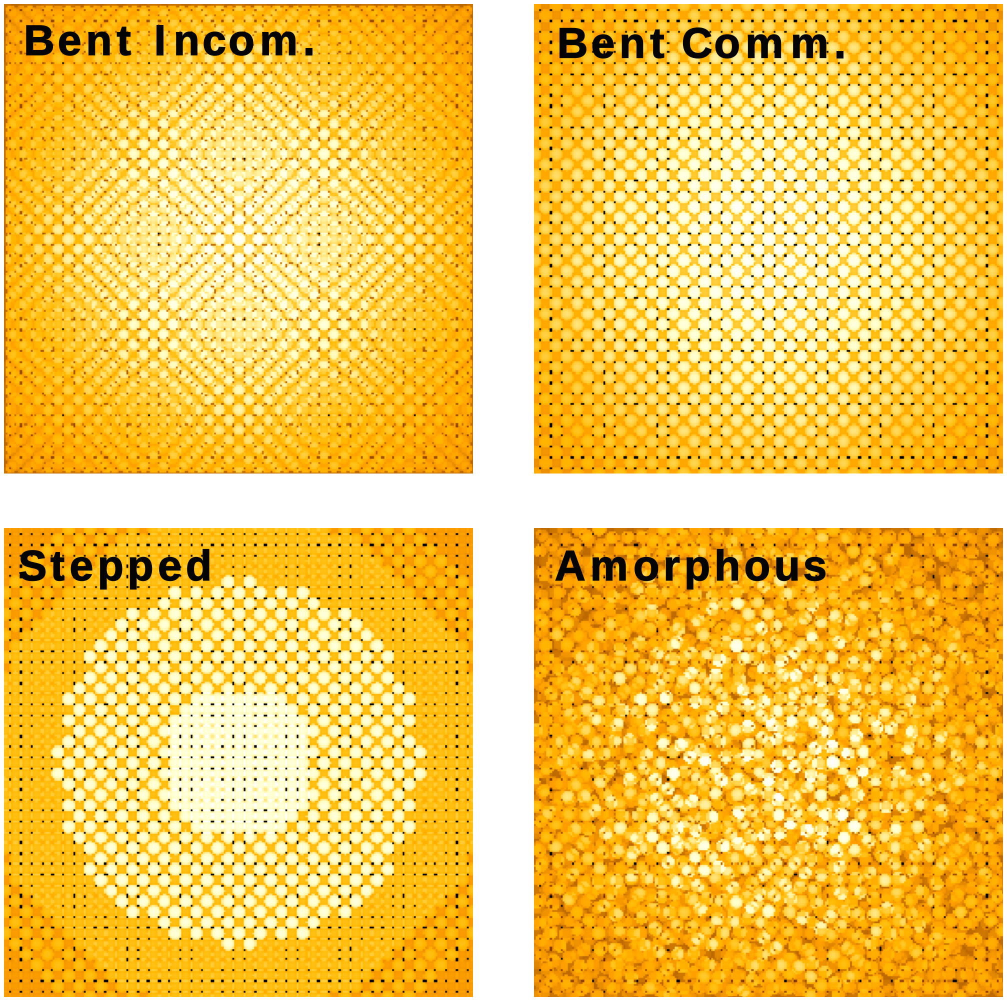
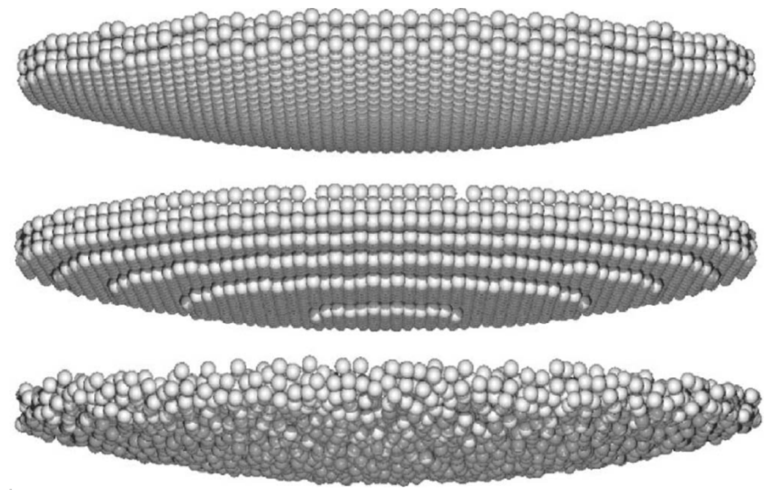
AFM tip profiles





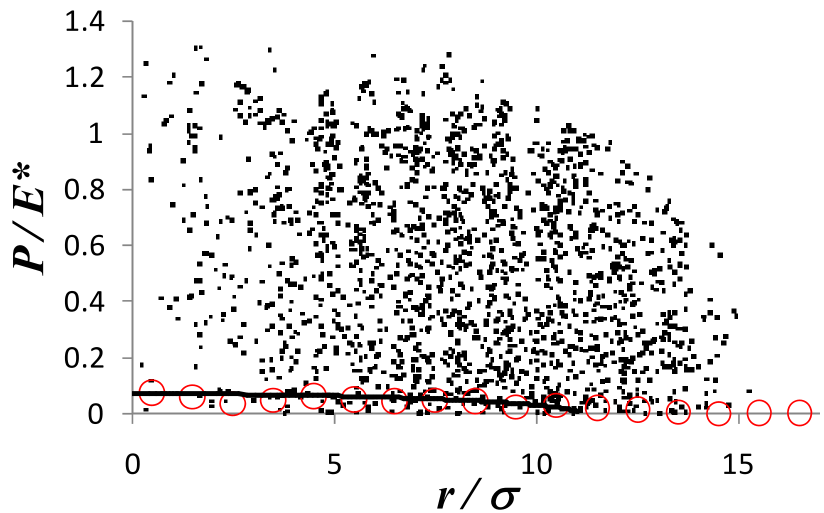


Molecular model

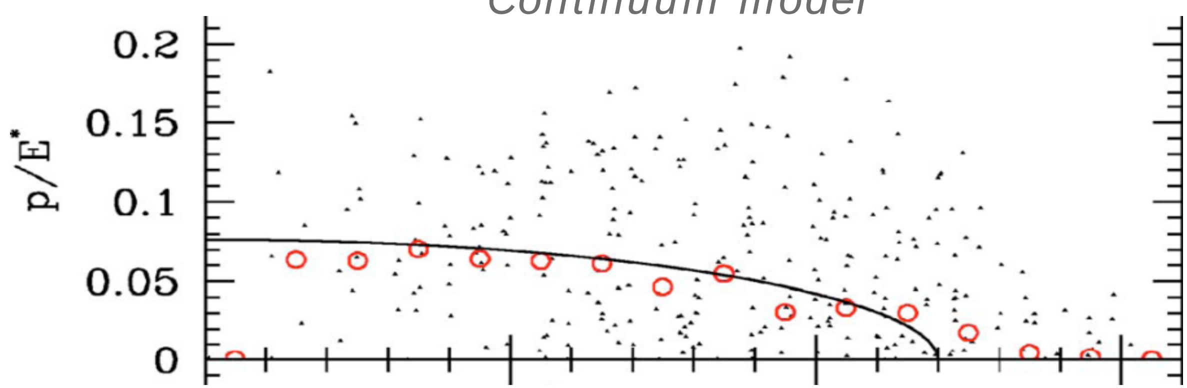
Surface model

AFM tip results – Contact pressures

Amorphous Tip



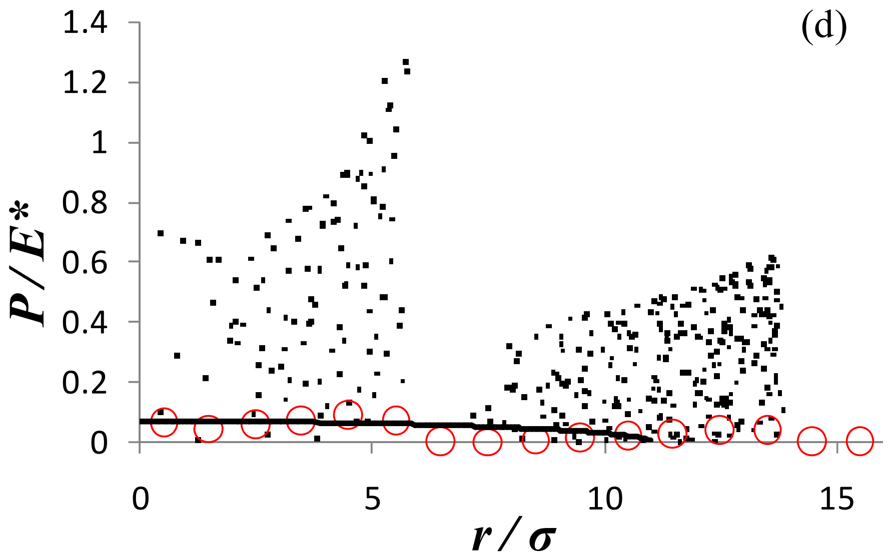
Continuum model



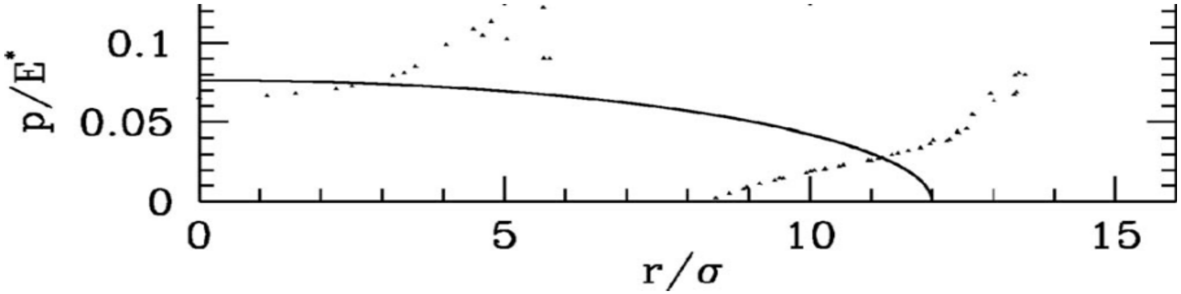
Molecular Dynamics

AFM tip results – Contact pressures

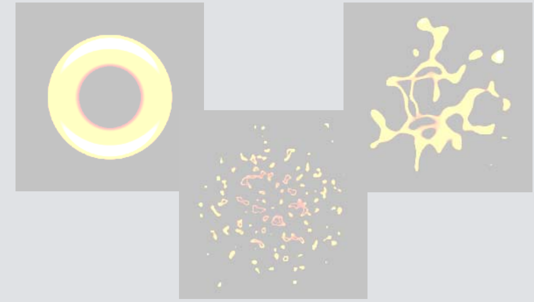
Stepped Tip



Continuum model



Molecular Dynamics



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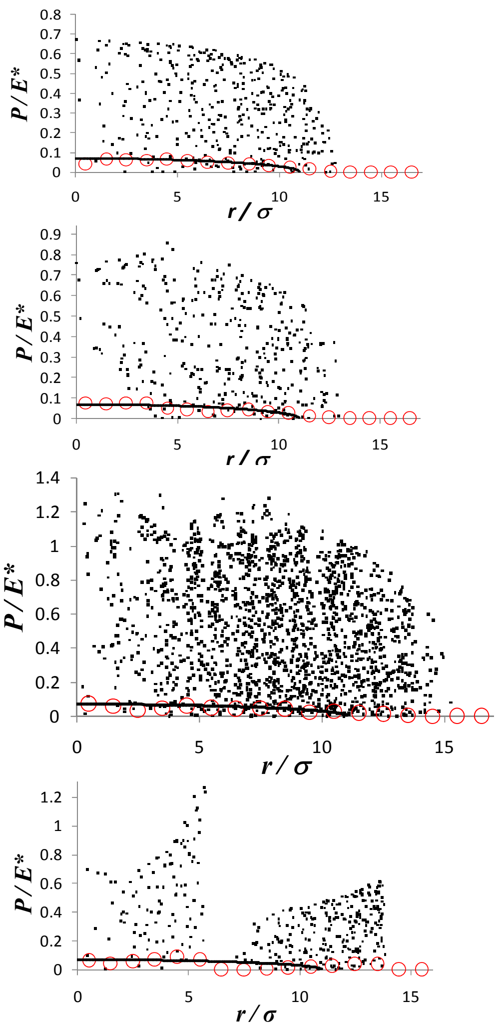


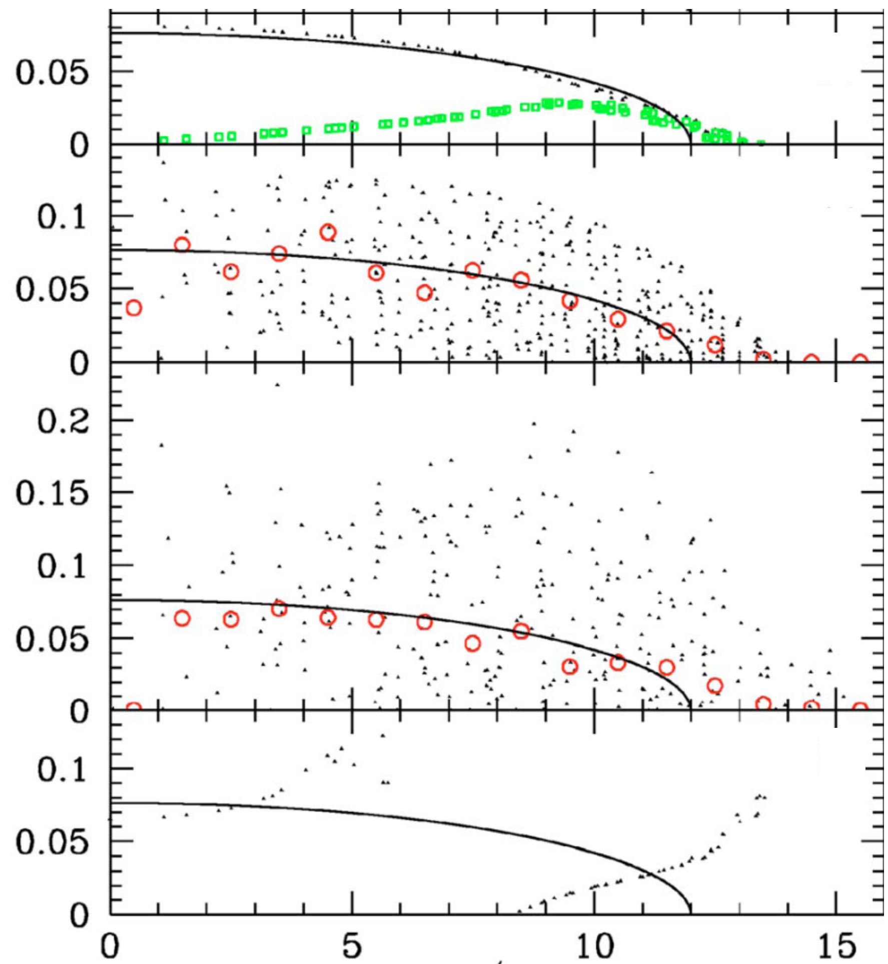
Continuum model

Bent Comm.

Bent Incomm.

Amorphous

Stepped



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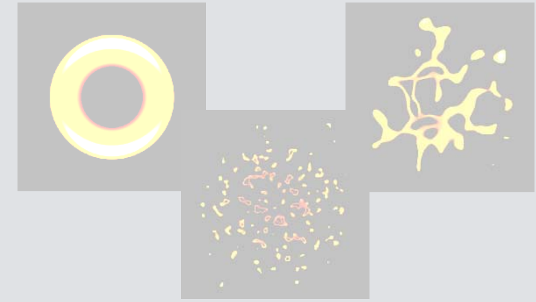
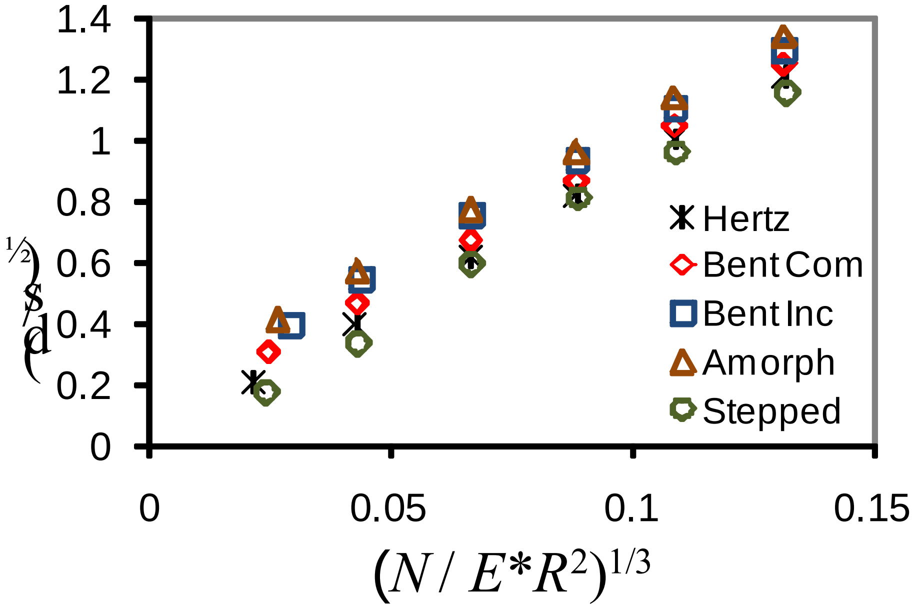
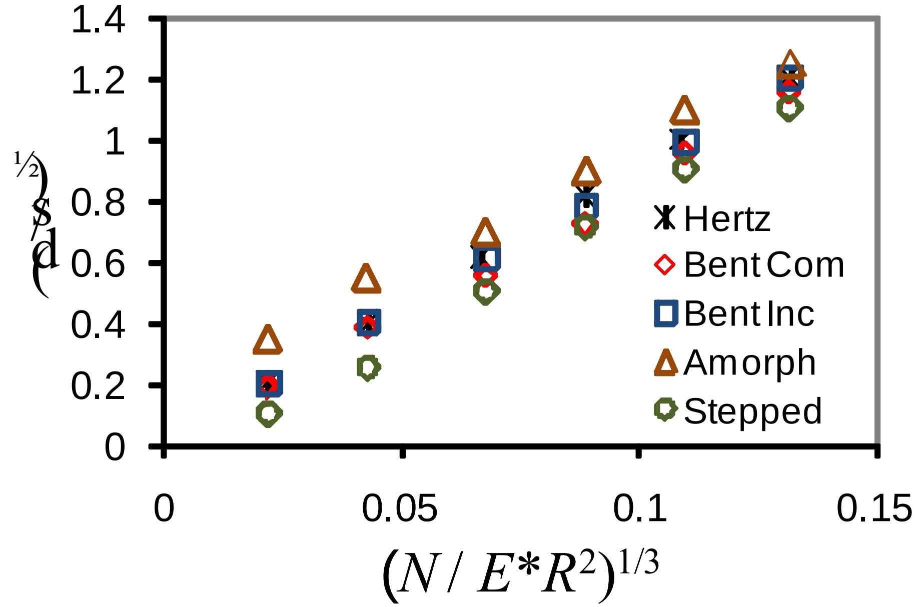


AFM tip results – Approach



Continuum model



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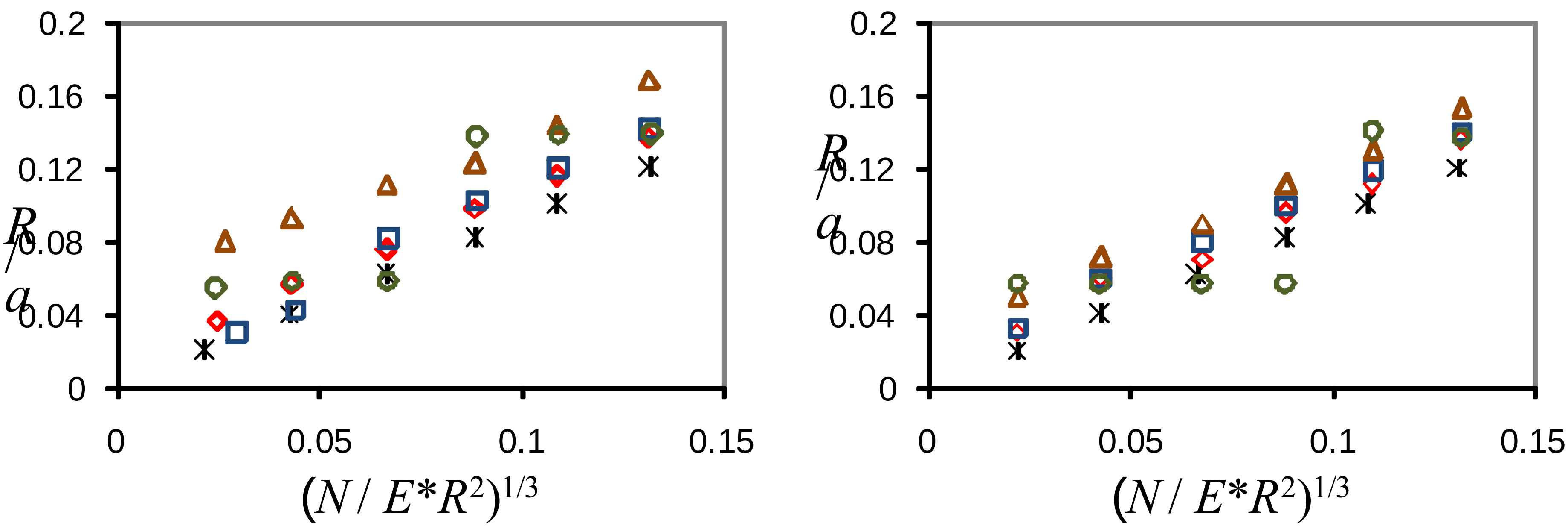
AFM tip results – Contact area



Continuum model

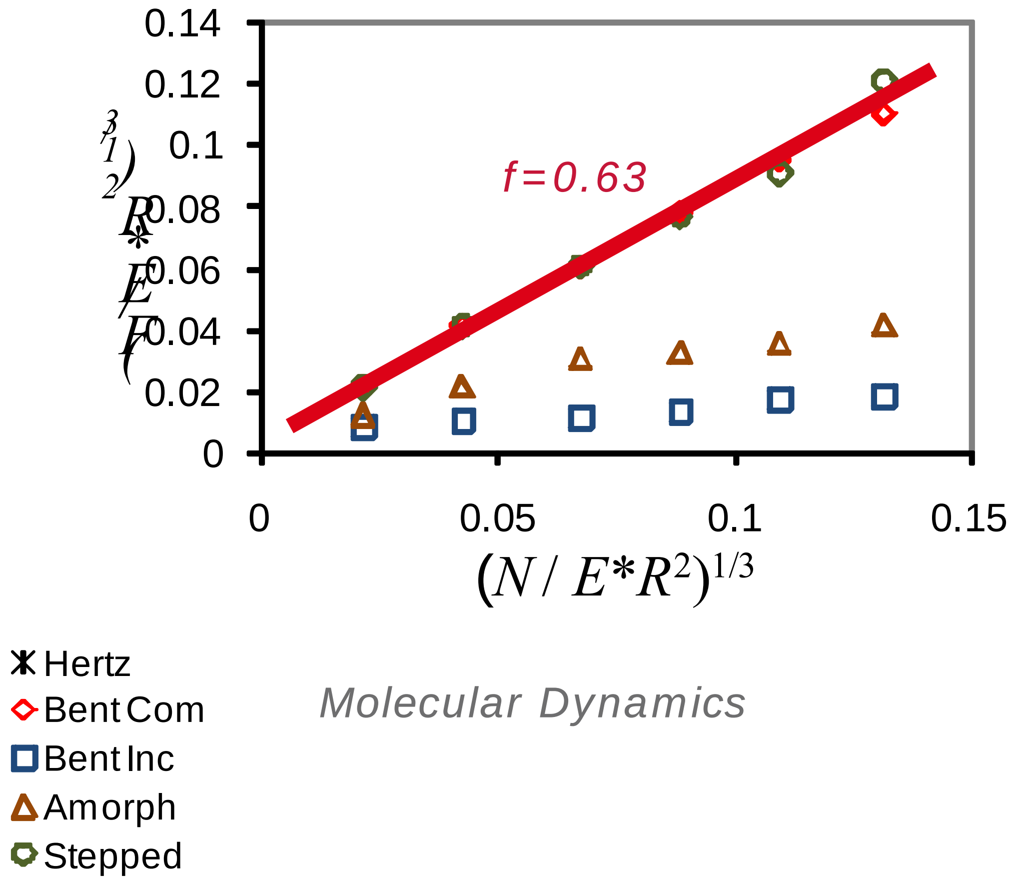
Molecular Dynamics

AFM tip results – Friction force

?

Not Available
Friction coefficient assigned

Continuum model



Molecular Dynamics

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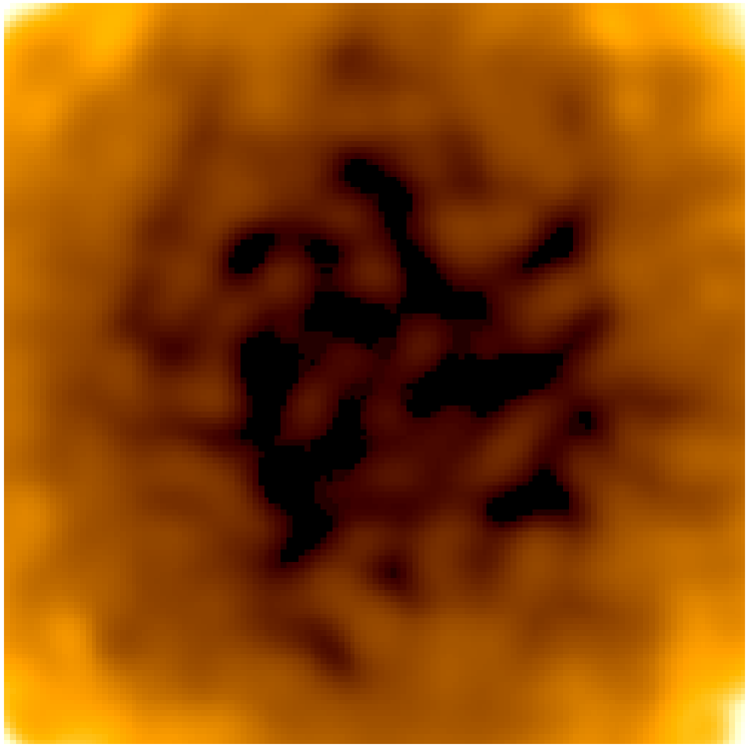
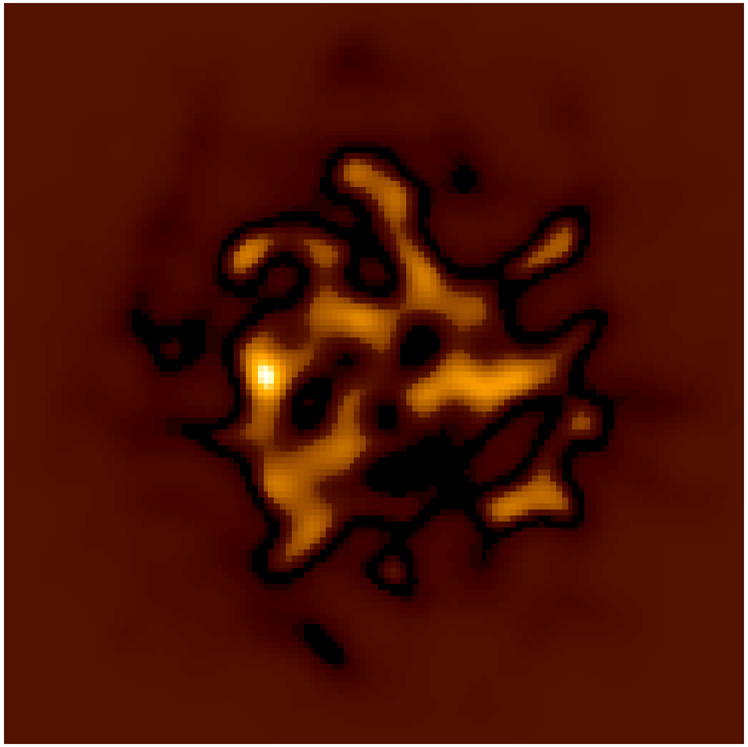
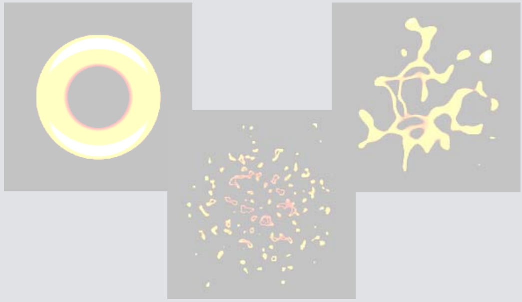
Adhesion – Rough surface (v. small scale)

Surface Separation



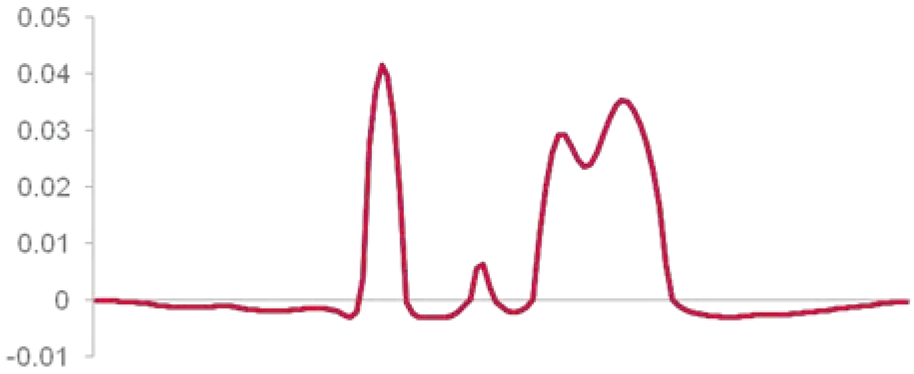
Pressures



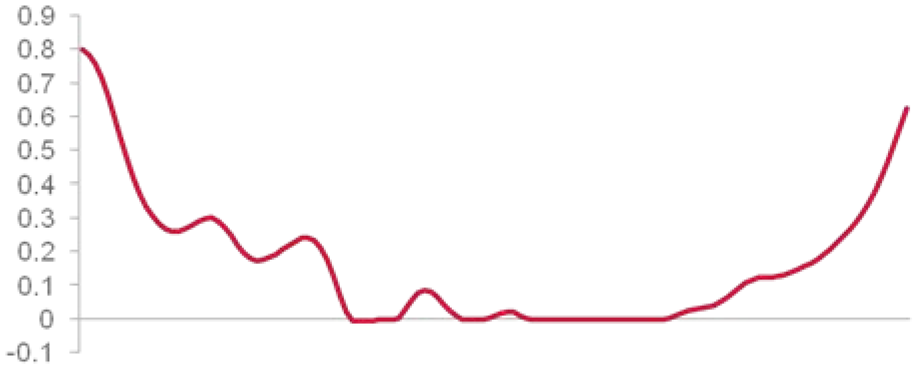


Adhesion – Rough surface (v. small scale)

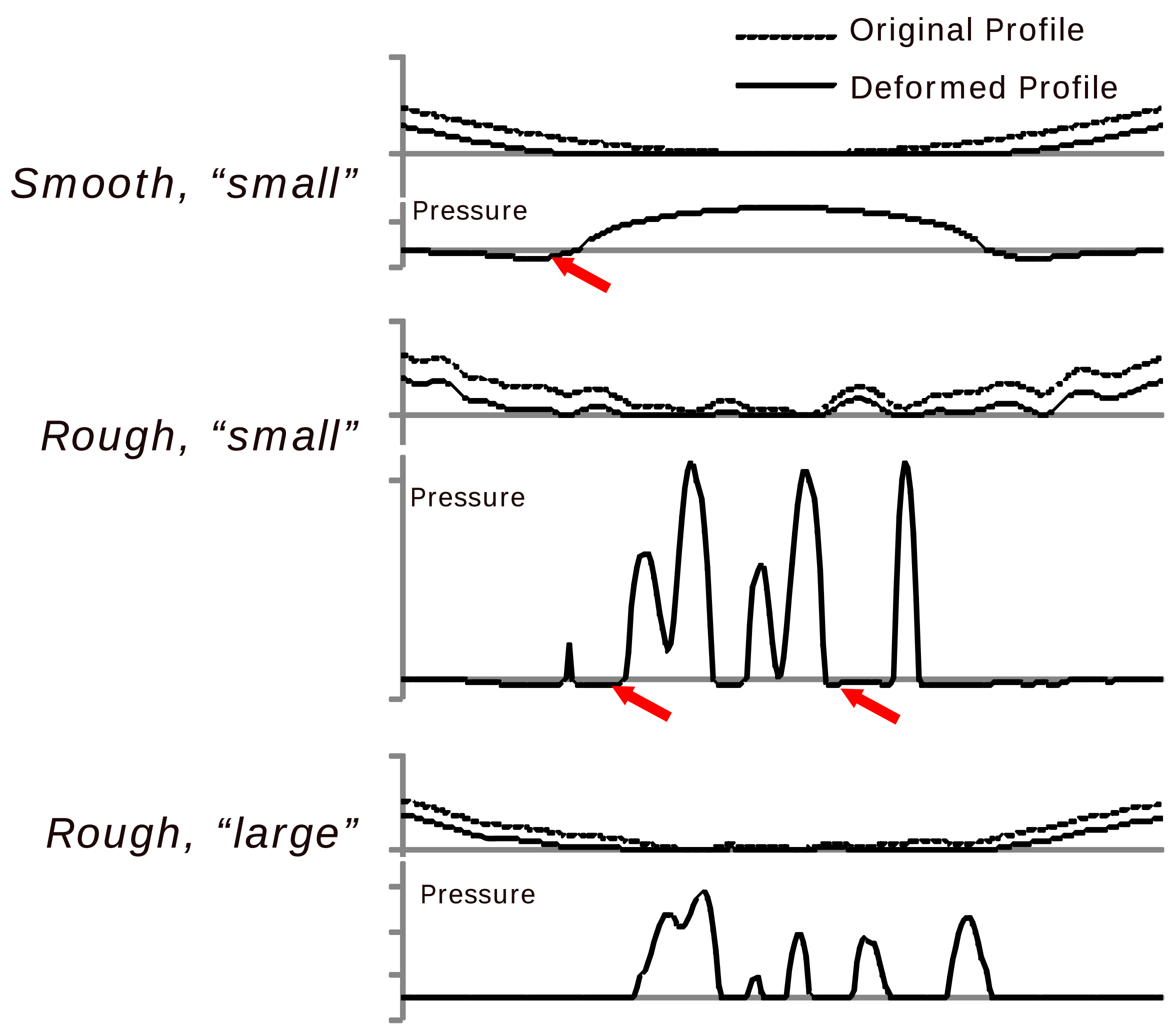
Pressures

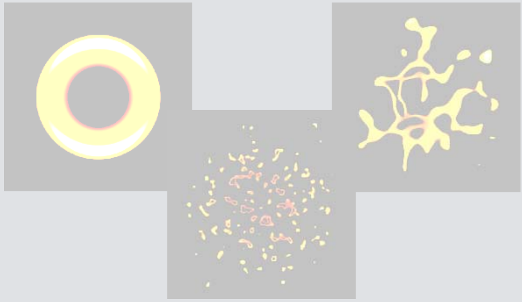


Surface Separation



Adhesion – Effect of scale and roughness





Open questions 2

How do we define the limits of applicability of a model in terms of length- and time-scales

If we could define a modelling framework for the future of joint mechanics modelling, shall we consider the two-way coupling between different scales or shall we just use the information at the lower scales to generate constitutive laws for our continuum descriptions?

Many-scales interactions: strategy

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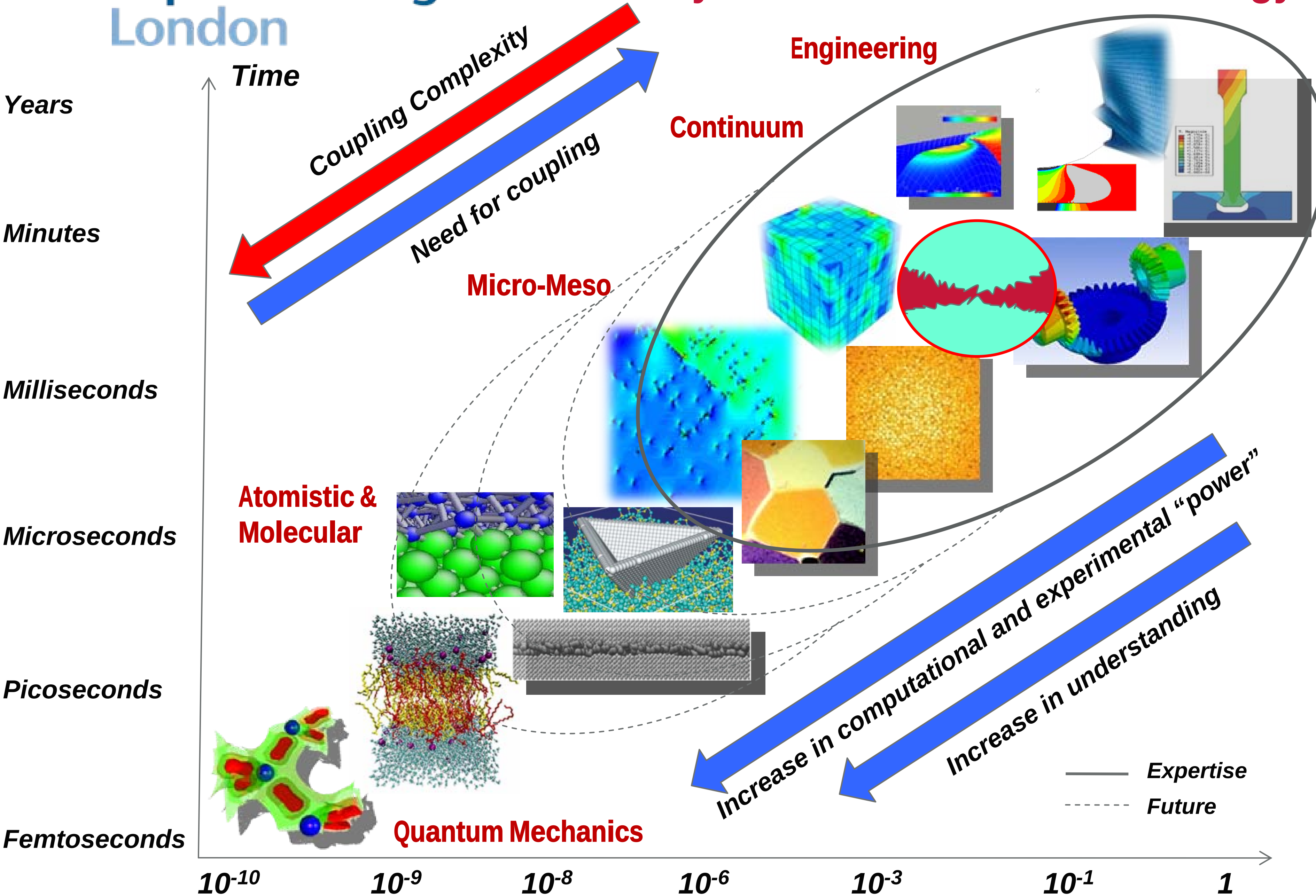

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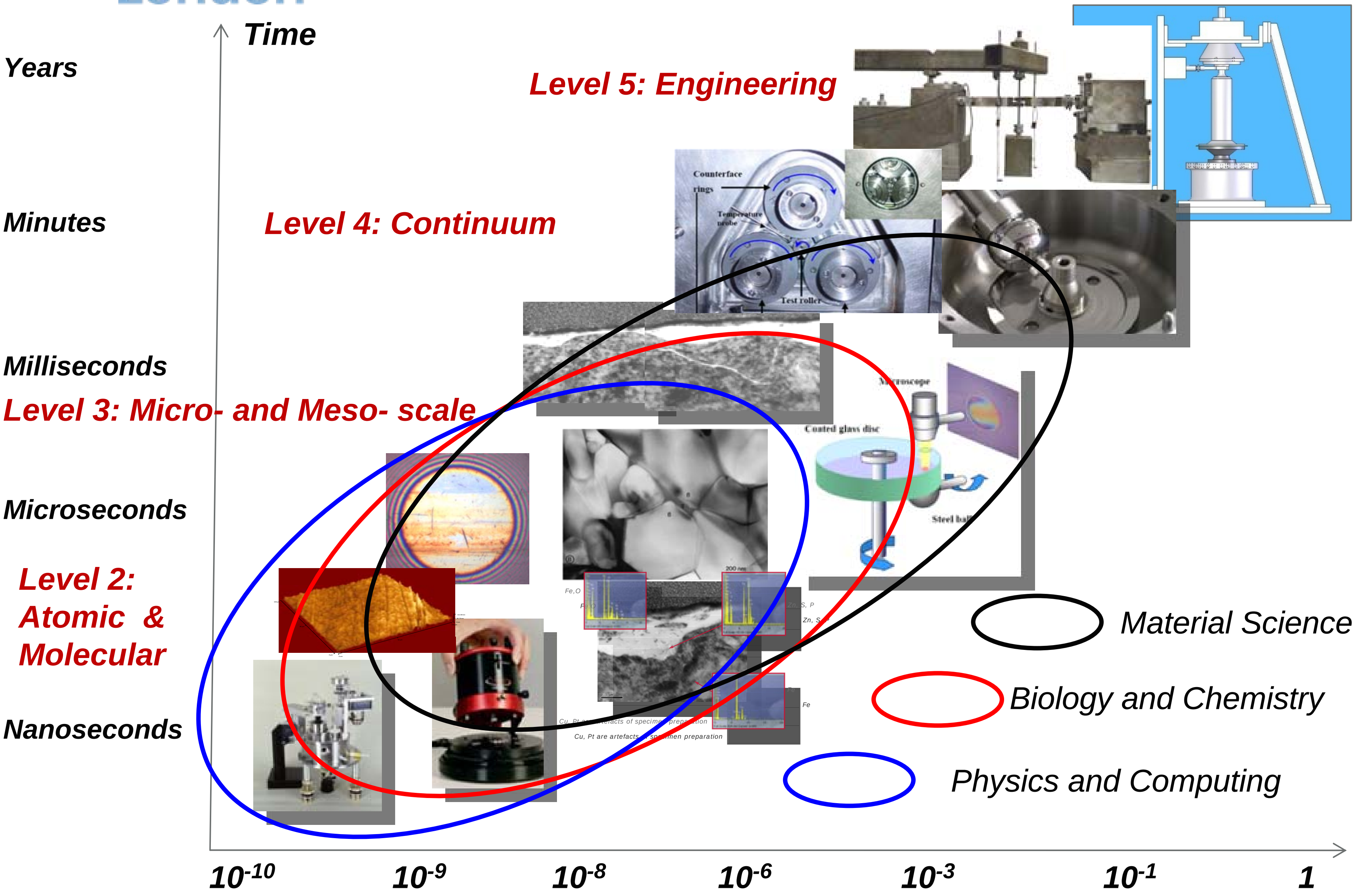
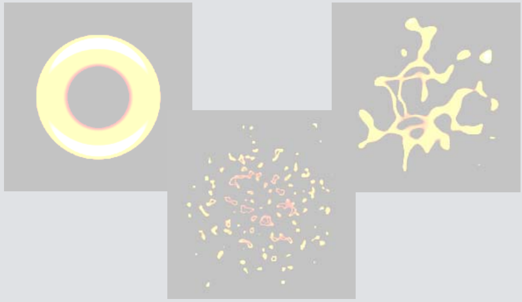
Many-scales / Many-disciplines





Modelling Framework