Quantifying Surface Interactions Using a Multilens JKR Approach

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Surface Interactions

- Biological Systems
- Colloidal dispersions
- Adhesives

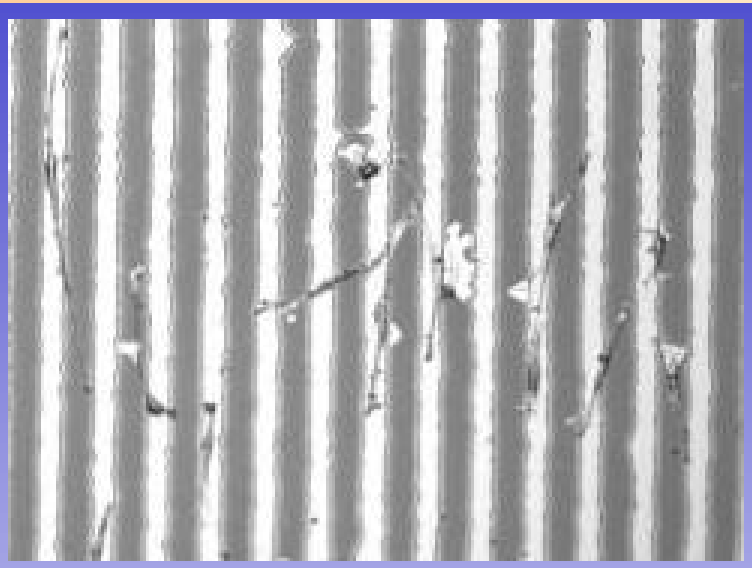
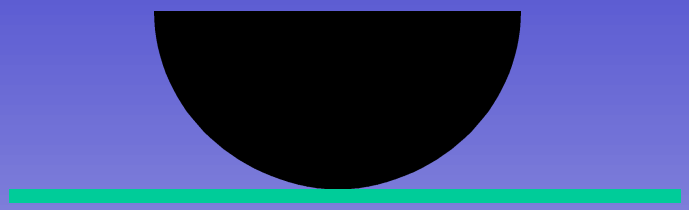


Photo Courtesy of Sharon Kennedy, Polymers Division, NIST

Experimental Techniques



Spherical Probe (JKR)

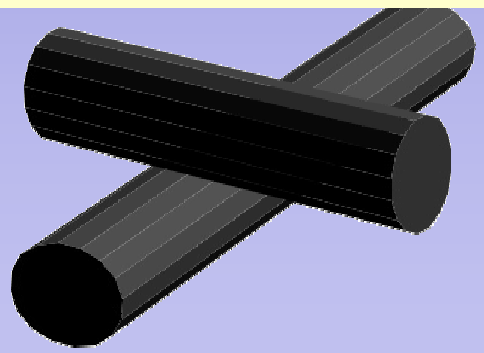
$P \sim 10^{-3} - 10^{-1}$ N

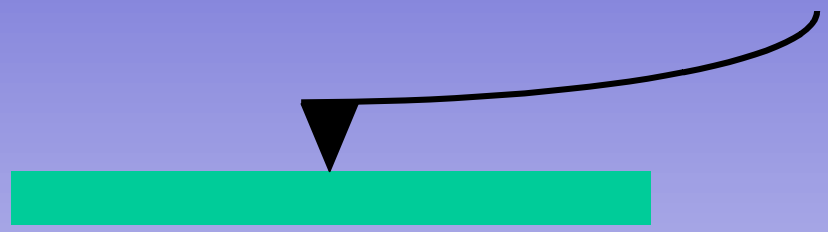
$a \sim 10^{-4} – 10^{-3}$ m

Surface Forces Apparatus

$P \sim 10^{-6} - 10^{-3}$ N

$a \sim 10^{-5} – 10^{-3}$ m





AFM

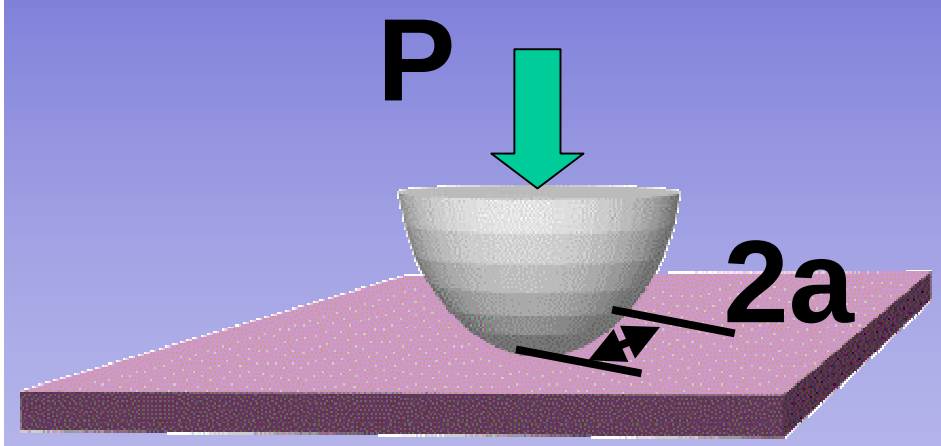
$P \sim 10^{-9}$ N

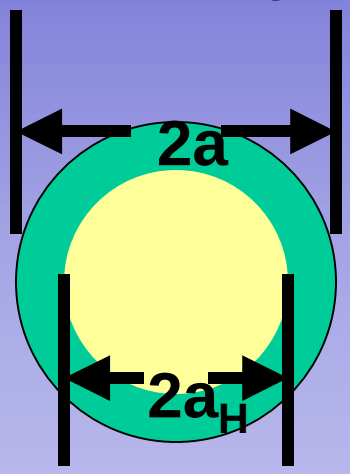
$a \sim 10^{-8} – 10^{-7}$ m

Theory of Johnson, Kendall, and Roberts (JKR)

General Idea

$$a_H^3 = \frac{9RP}{16E}$$





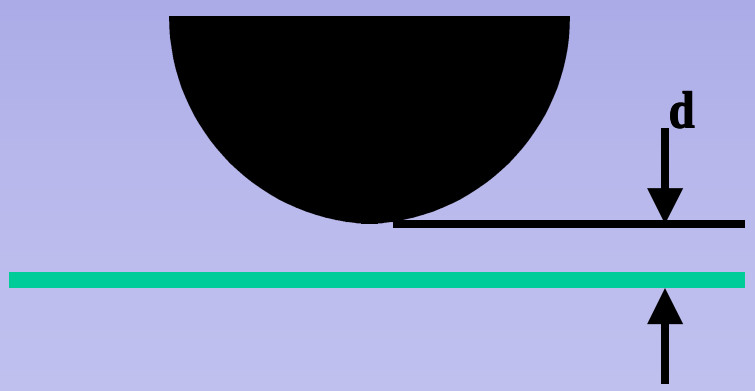
JKR Equation $\rightarrow$ $$a^3 = \frac{9R}{16E}\left[P + 3\pi GR + \sqrt{6GRP + (3\pi GR)^2}\right]$$

“Jump” Into Contact

JKR “Zero Force” contact radius

$$a_o = \left(\frac{27 \pi R^2 G}{8E} \right)^{1/3}$$

For soft, elastic solids, G is defined by thermodynamic work of adhesion.



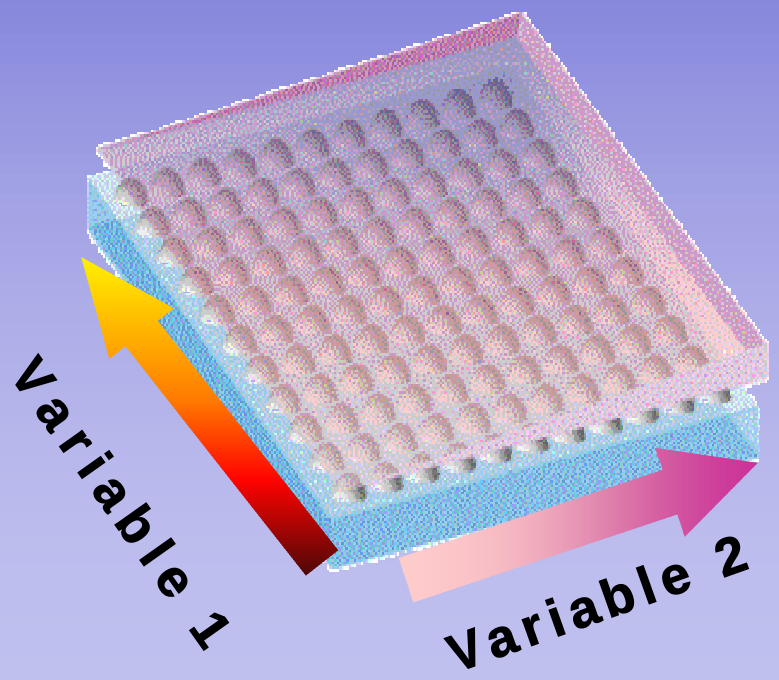
$\delta_{critical} = \delta$ at “jump” into contact

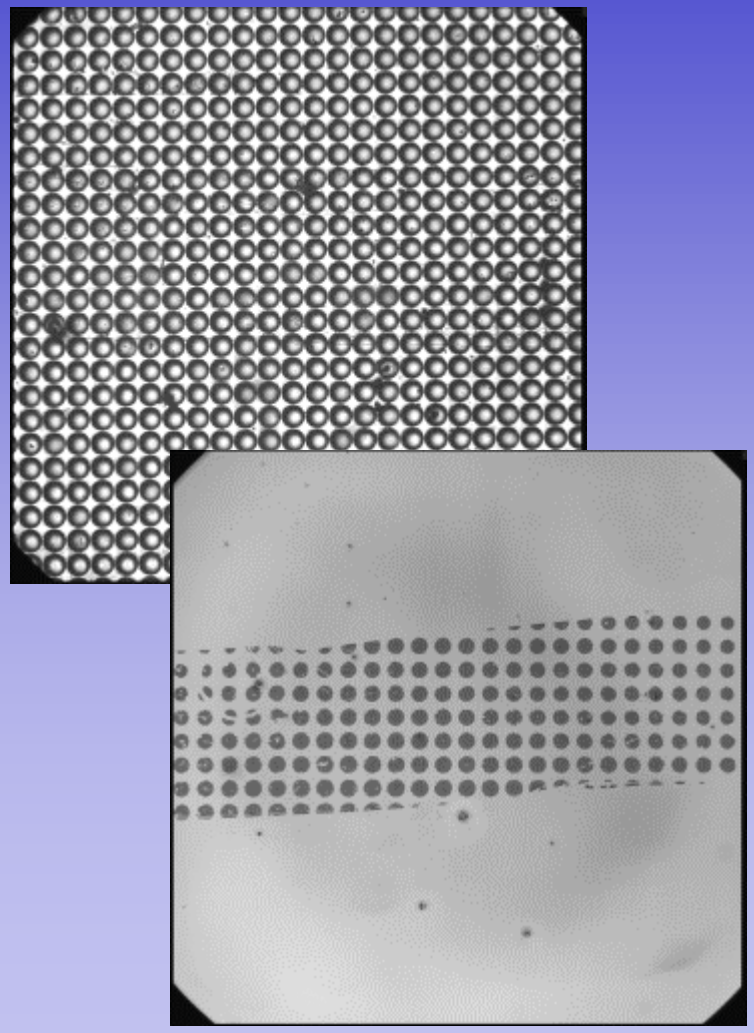
Defined by balance of surface and elastic restoring forces

MultiLens Contact Technique

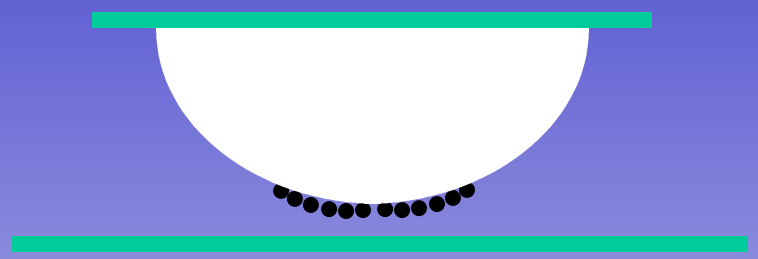
Combinatorial Measurements

- Investigate Multivariable Environments
- High-Throughput data collection



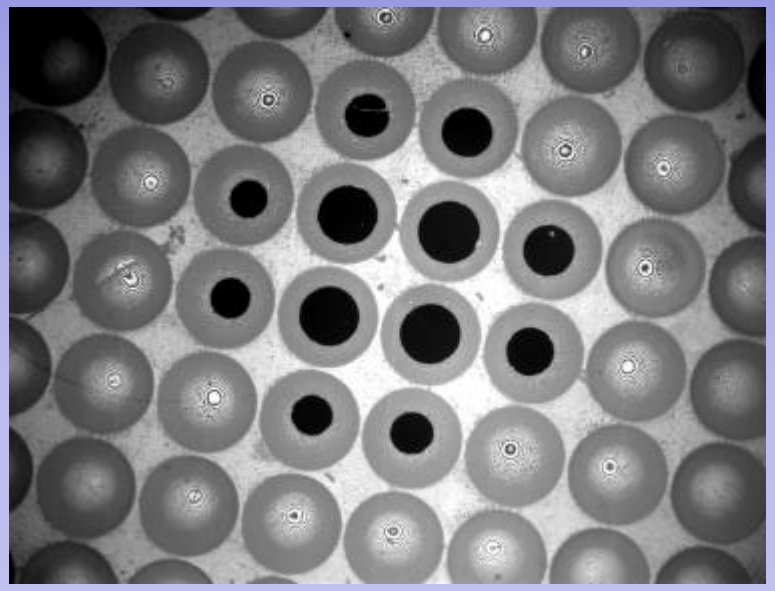


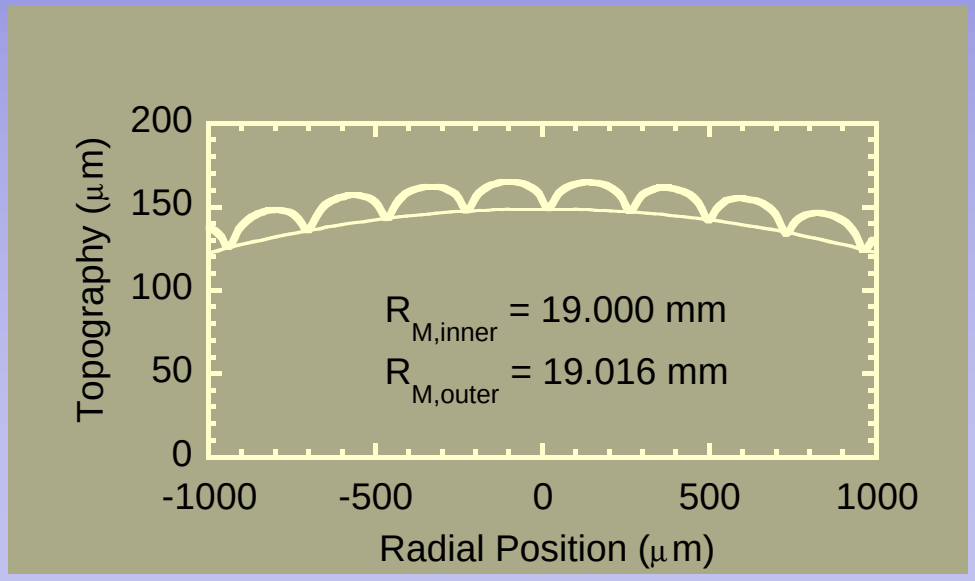
MultiLens Contact Technique



Advantages of Multilens Contact

- Maximize sensitivity and visualize contact
- Investigate effects of roughness on surface interactions
- Investigate dynamics of surface attraction and separation





Materials

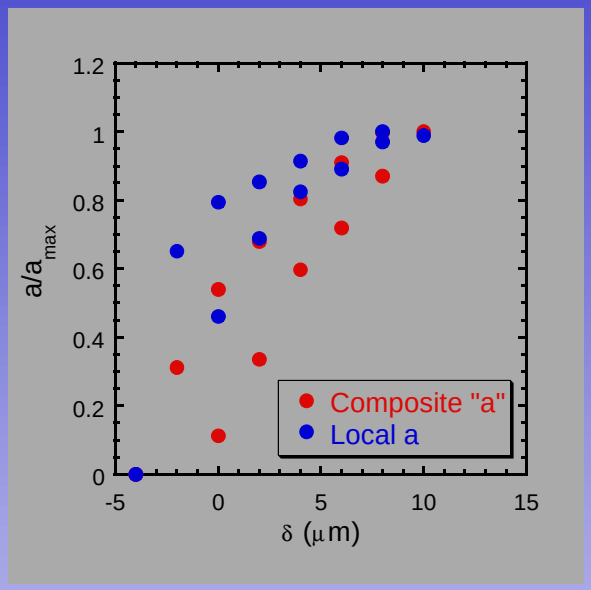
Lens Arrays

- Crosslinked Polydimethylsiloxane (PDMS)
- E = 1.0 Mpa
- $\gamma \sim 20$ mJ/m^2

Substrates

- Bare glass slide (ozone cleaned)
  - $\gamma = 67$ mJ/m^2
- n-octyl dimethylchlorosilane coated glass slide
  - $\gamma = 28$ mJ/m^2
- Fluorinated glass slide
  - $\gamma = 10$ mJ/m^2

Multilens Contact

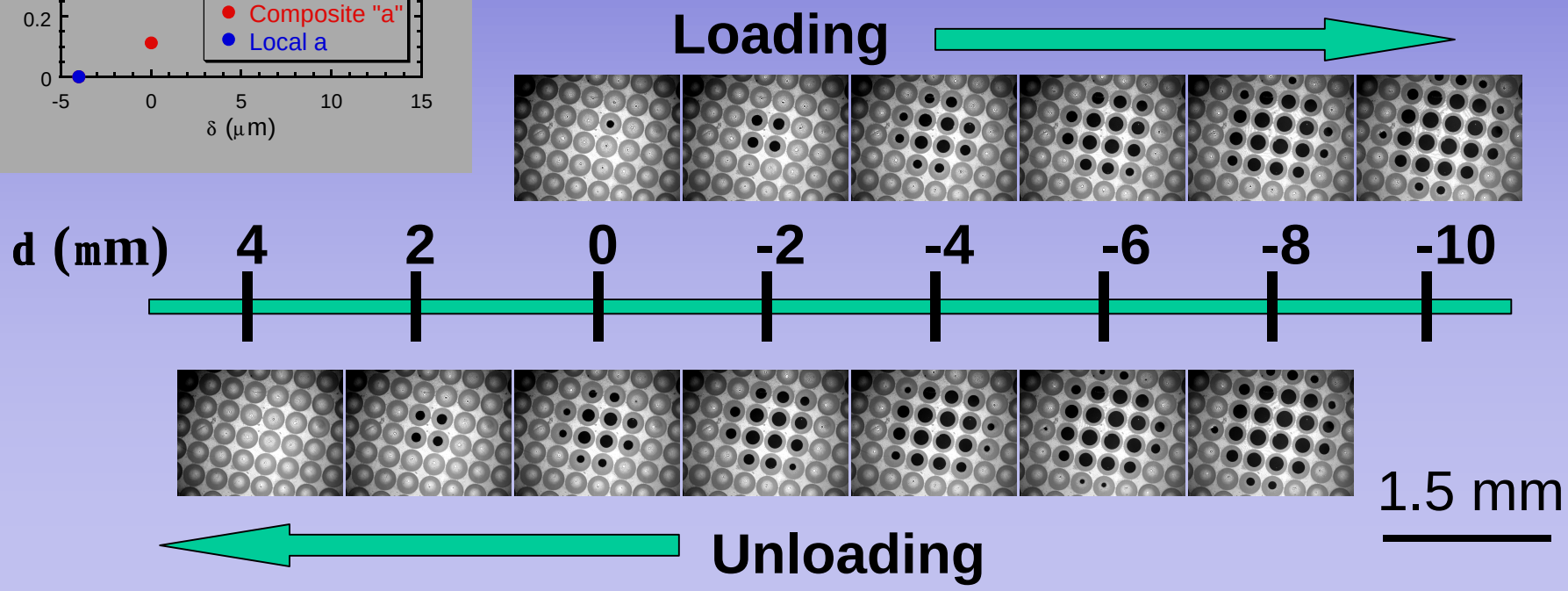


Substrate: n-octyl dimethylchlorosilane

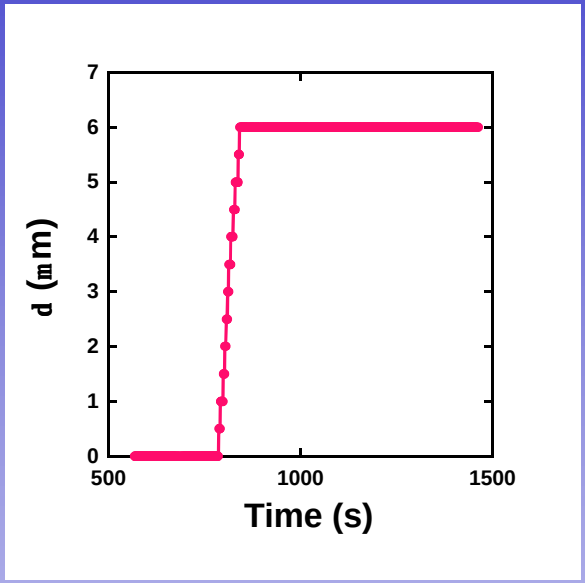
R_{macro} = 19.0 mm $V_{crosshead}$ = 100 nm/s

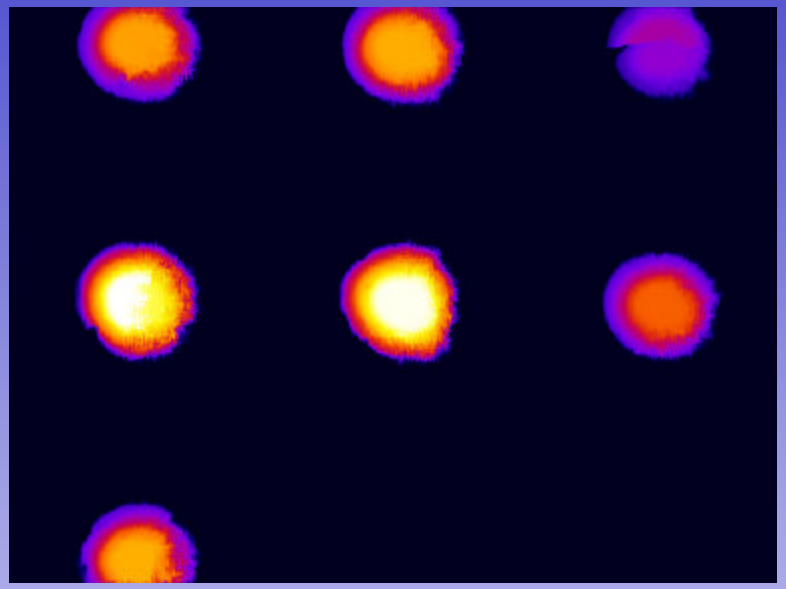
R_{micro} = 0.62 mm E = 1.0 Mpa

Relative mLens height varies by ~ 1 mm



Multilens Contact



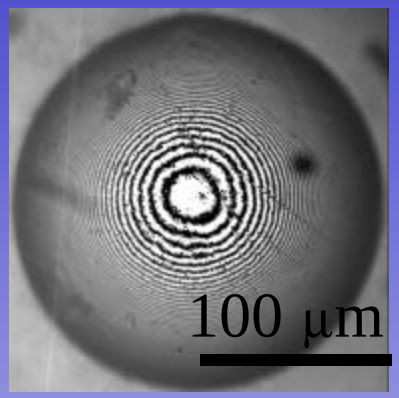


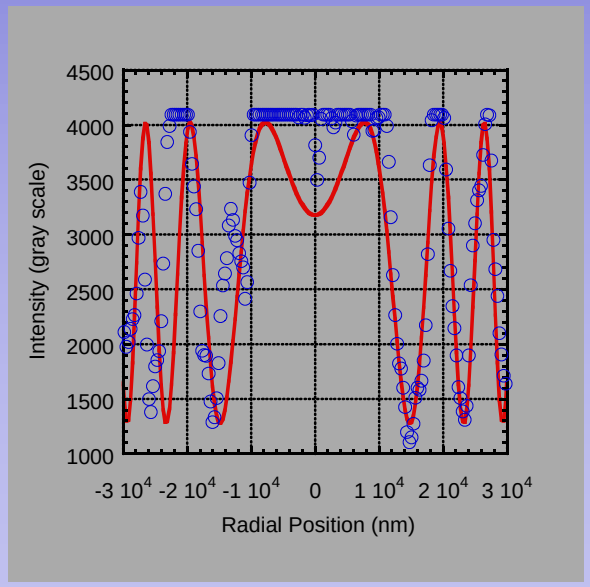
R_{macro} ~ 200 mm --- relative height difference is 100 nm between microlenses

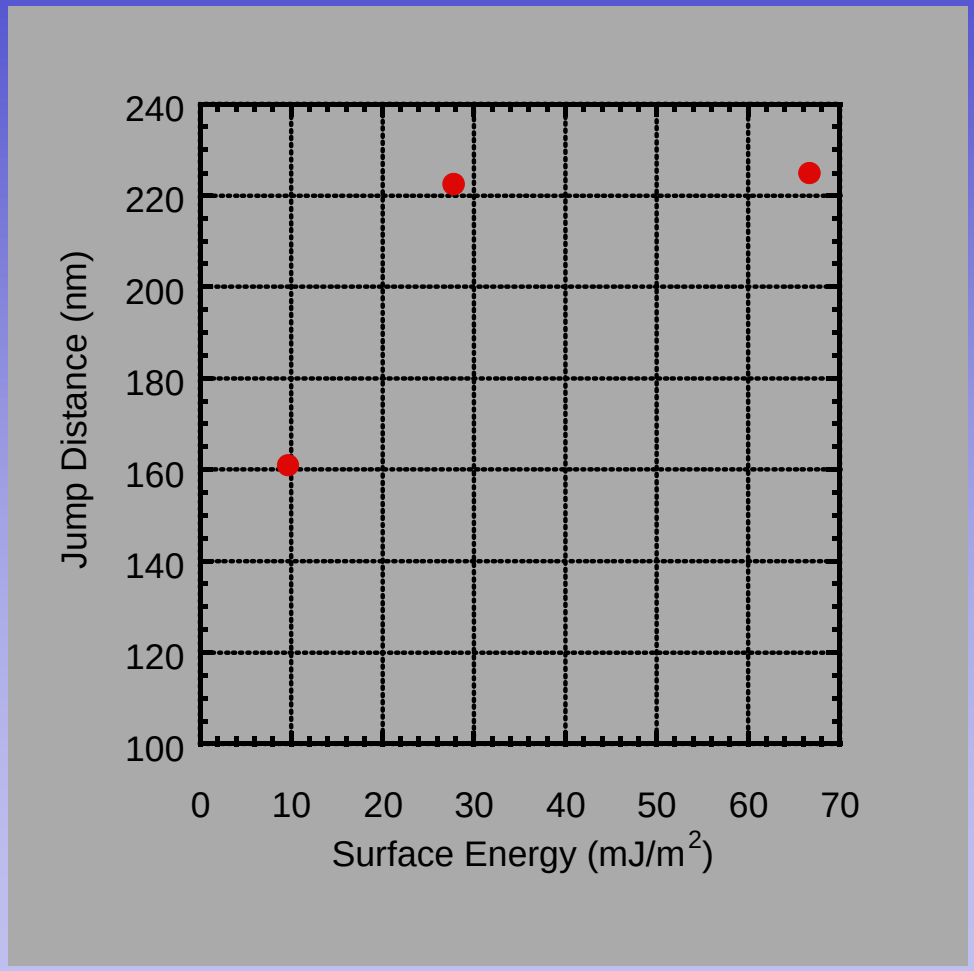
By designing curvature of macrolens, we create natural gradient to bracket $\delta_{critical}$ ~ 100 nm

Quantifying Jump Distance

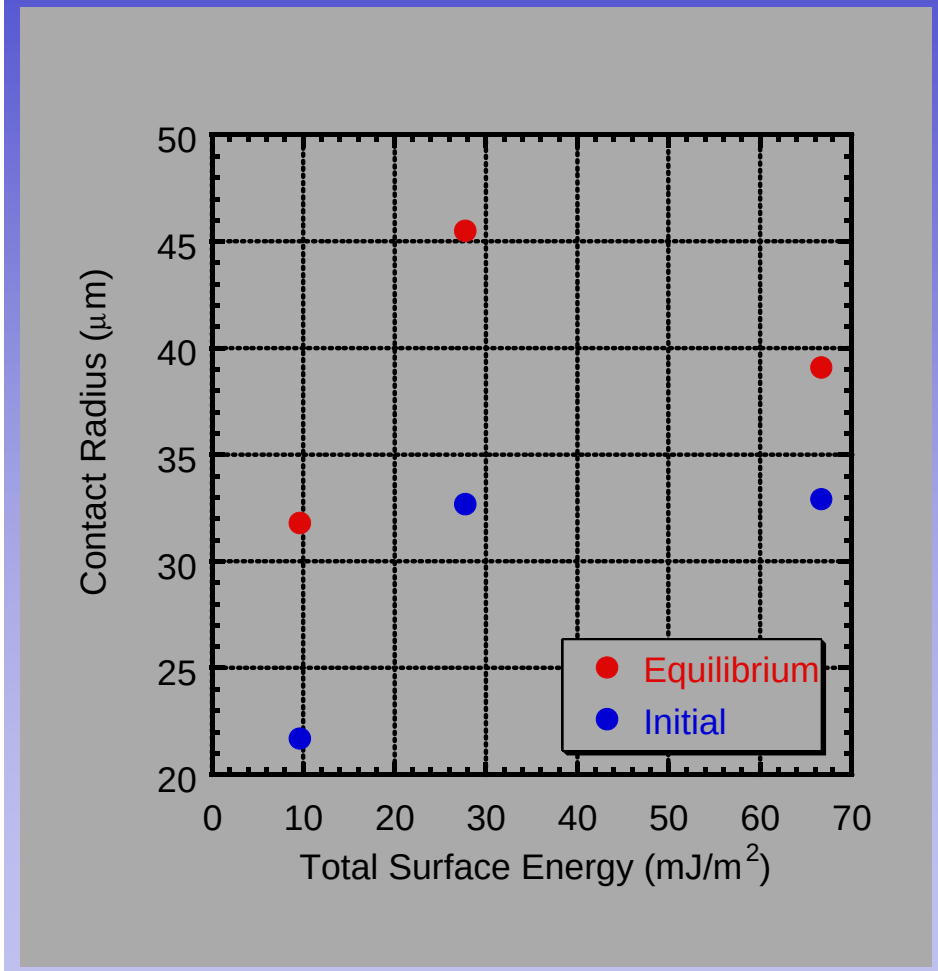
Approach substrate at 4 nm/s

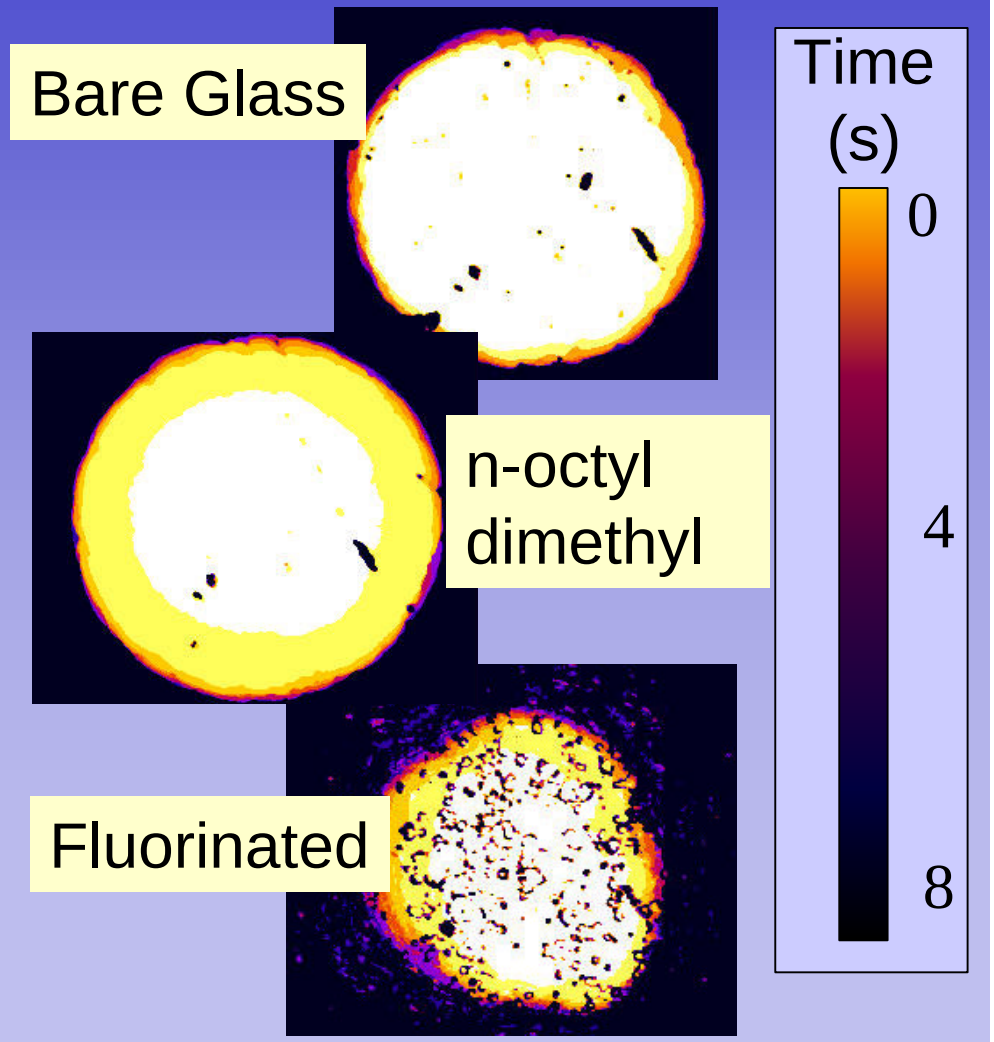






Dynamics of Contact





Force and Energy

Substrate	$g_{substrate}$ (mJ/m^2)	$G_{PDMS/Substrate}$ (mJ/m^2)
Bare glass	66	15
n-octyl dimethyl	27	23
Fluorinated	10	8

$$G = g_1 + g_2 - g_{12}$$

Substrate	Pull-in Force (mN)	Pull-in Stress (MPa)
Bare glass	20	5.8×10^{-3}
n-octyl dimethyl	20	5.8×10^{-3}
Fluorinated	9	6.3×10^{-3}

$$C = \frac{3}{8Ea} = \frac{\P d}{\P P}$$

$$P = \frac{8Ead_{critical}}{3}$$

Summary

- Multilens contact experiments open the doors to new explorations (I.e. roughness, heterogeneities, dynamics)

- Surface interactions extend over 100's of nanometers

Acknowledgements

Dr. Anthony Bur
Dr. Michael Fasolka
Dr. Chris Stafford

National Research Council
NIST