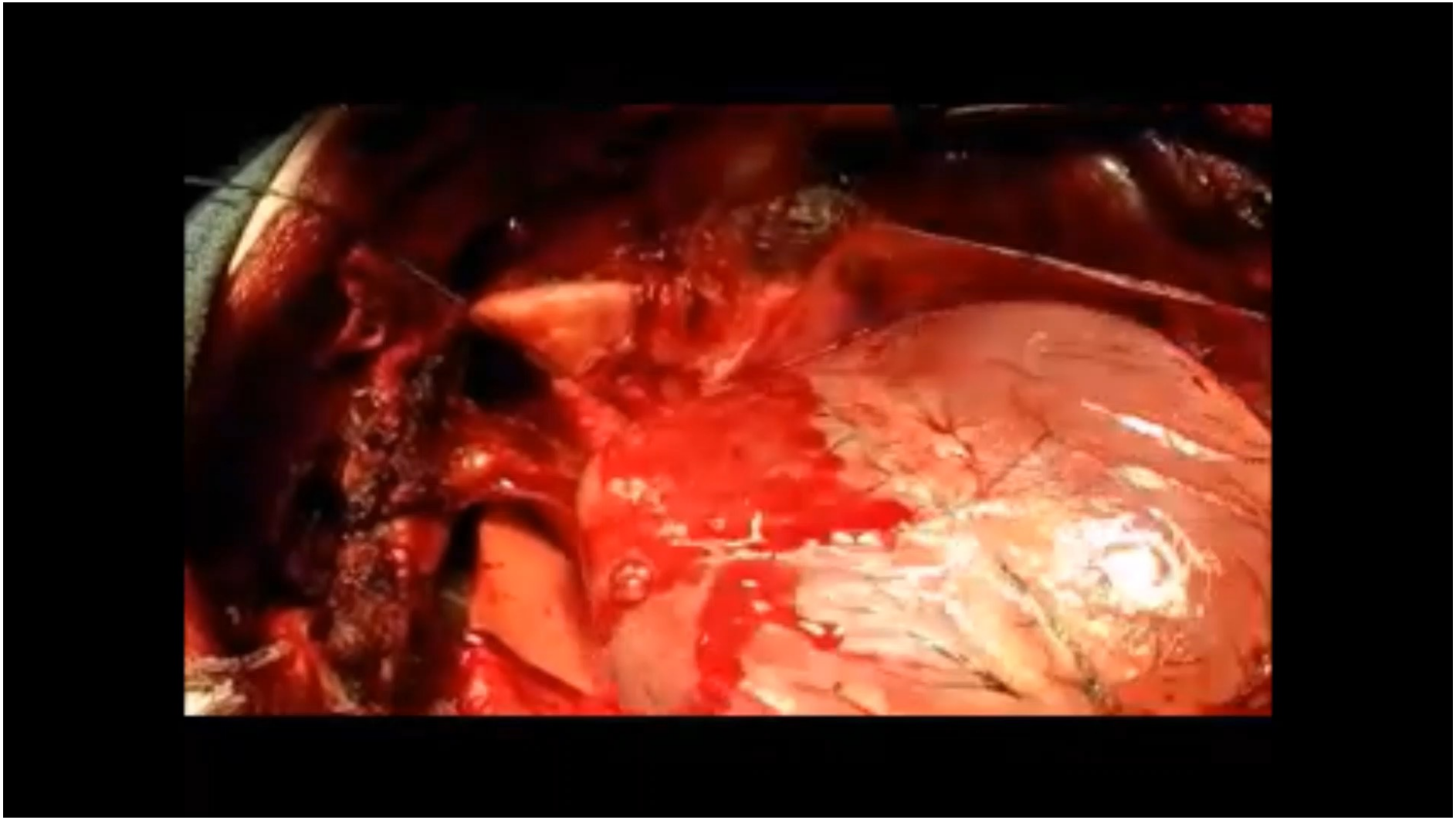
Measuring the Interface Traction during Peel Test of Adhesive Tapes

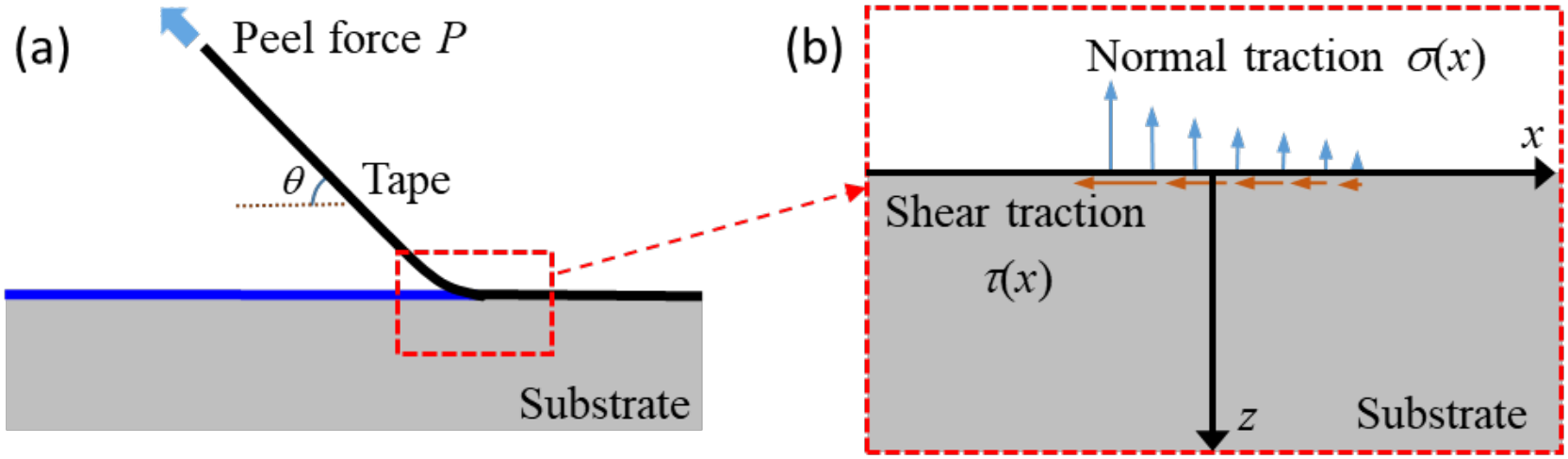
3M x Nonlinear Mechanics Lab

Motivation

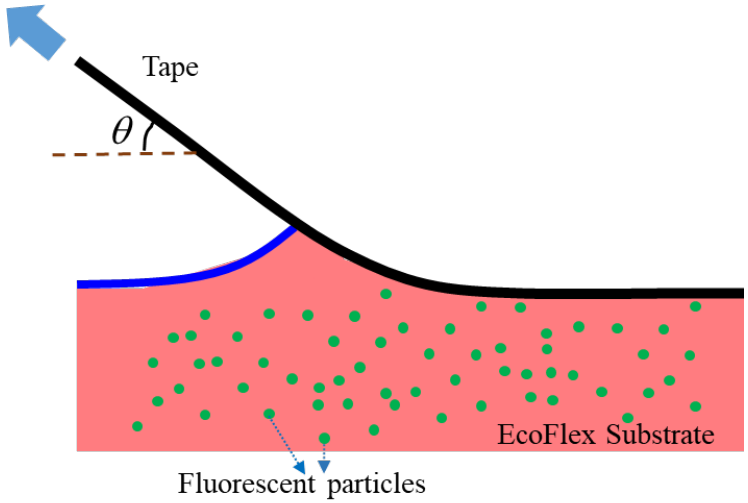


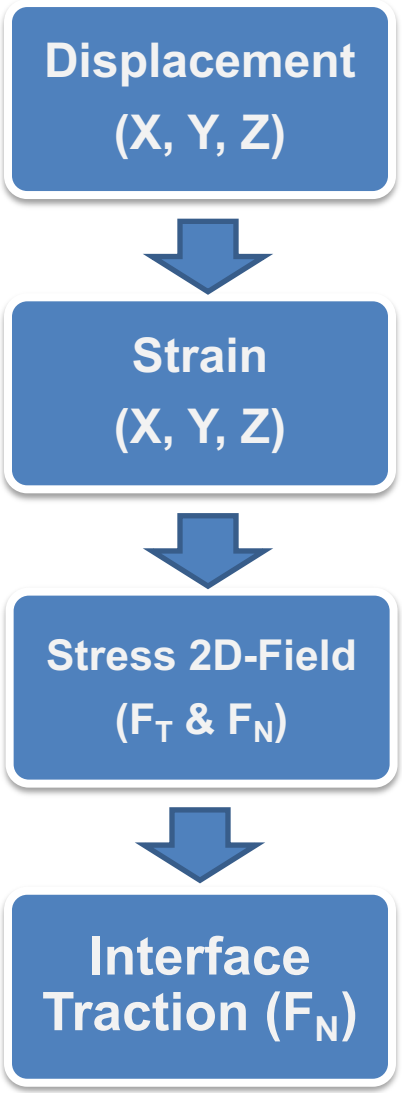
Jianyu Li, et. al, Tough adhesives for diverse wet surfaces, ***Science***, 357, 6349, 378-381 (2017).

Theory

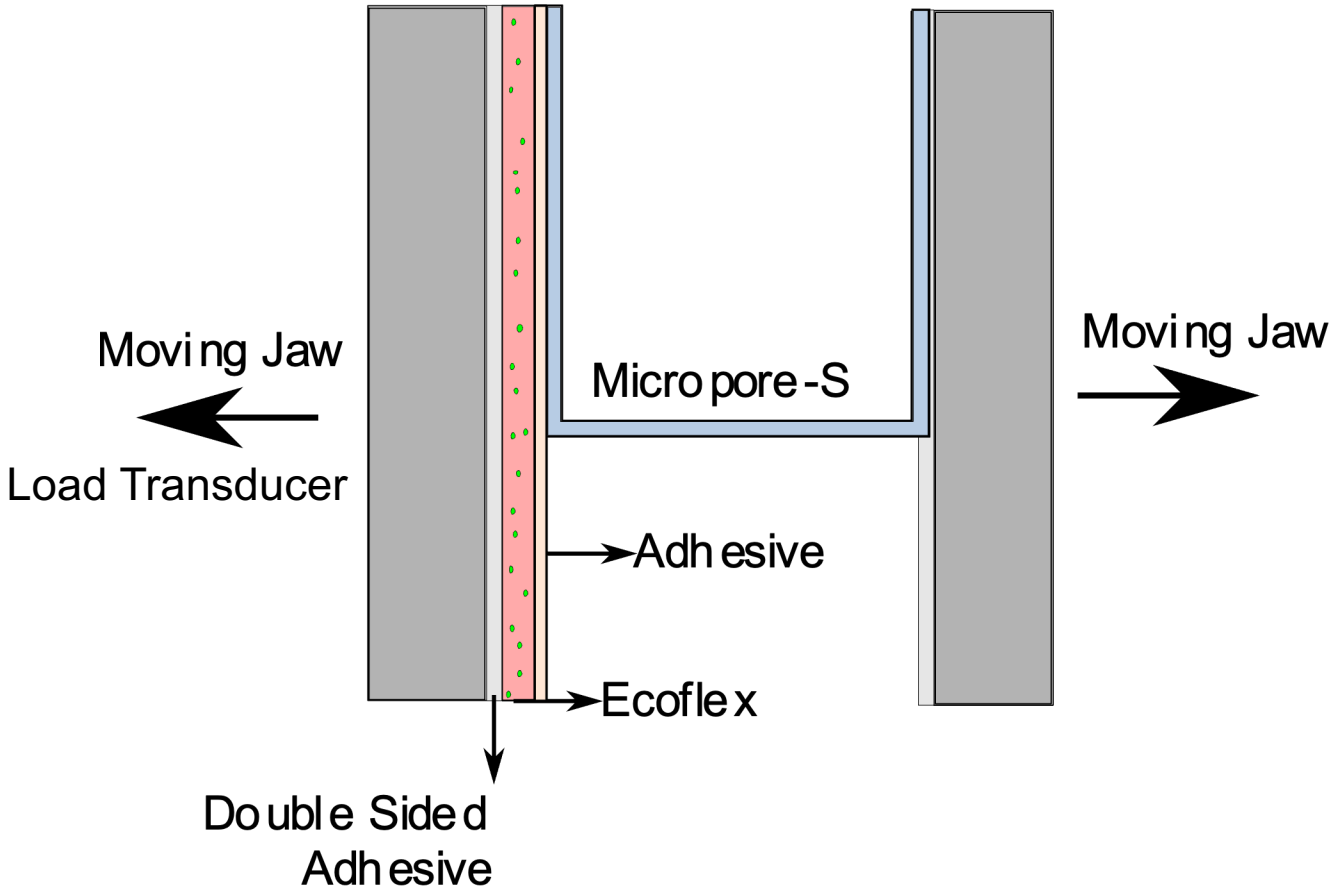

(a)
Peel force P
θ
Tape
Substrate
(b)
Normal traction $\sigma(x)$
x
Shear traction
$\tau(x)$
z
Substrate

Methodology

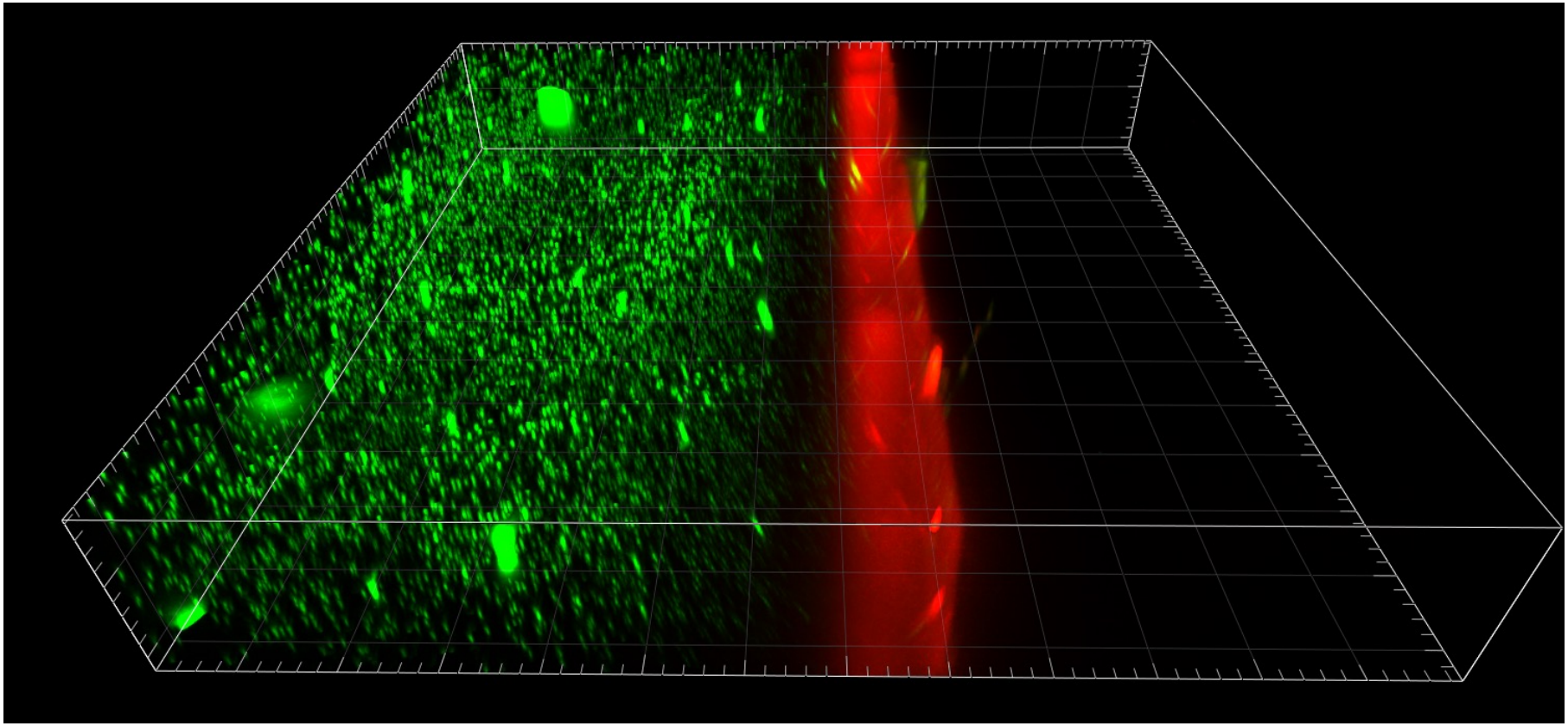




Experimental Setup



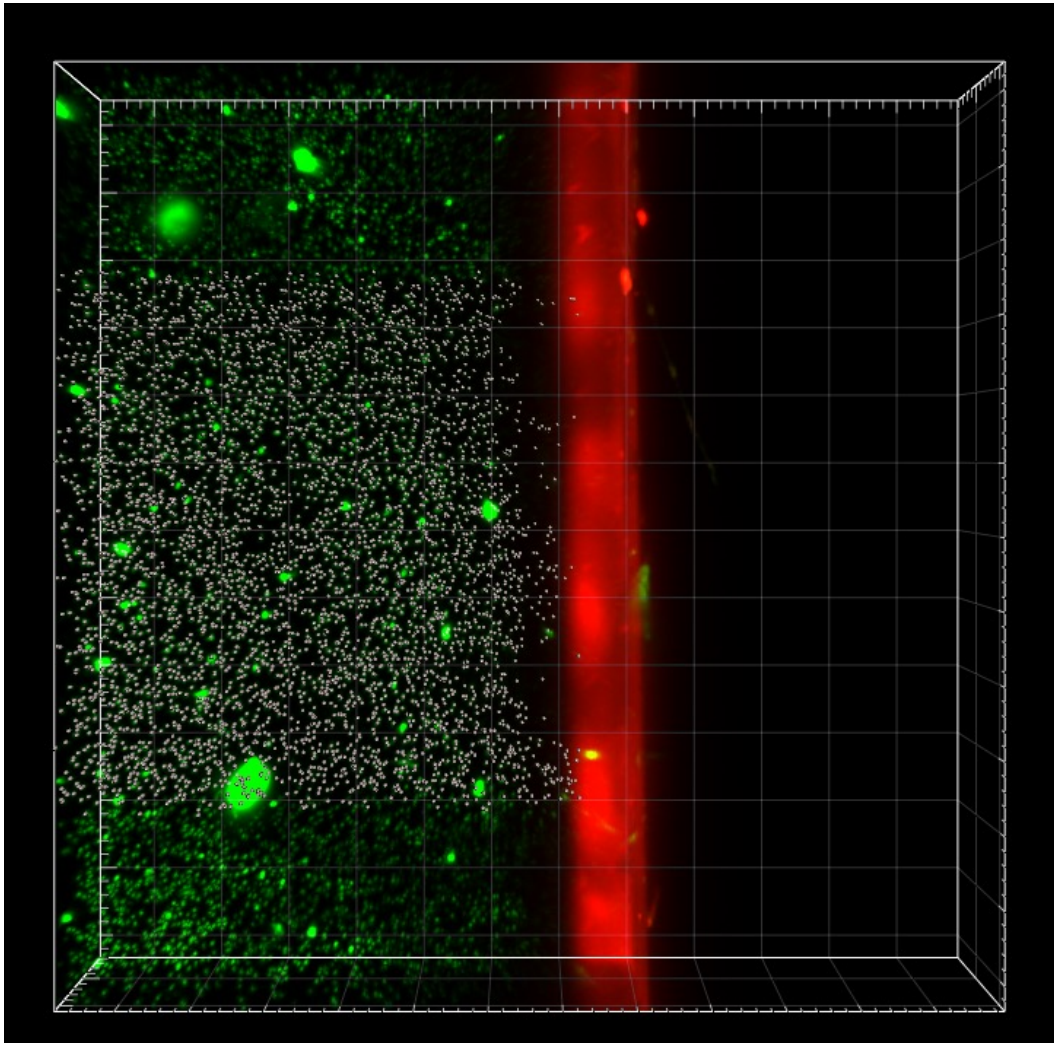
Confocal Microscope Results



$1000\mu m \times 1000\mu m \times 100\mu m$

$x \qquad y \qquad z$

Confocal Microscope Results



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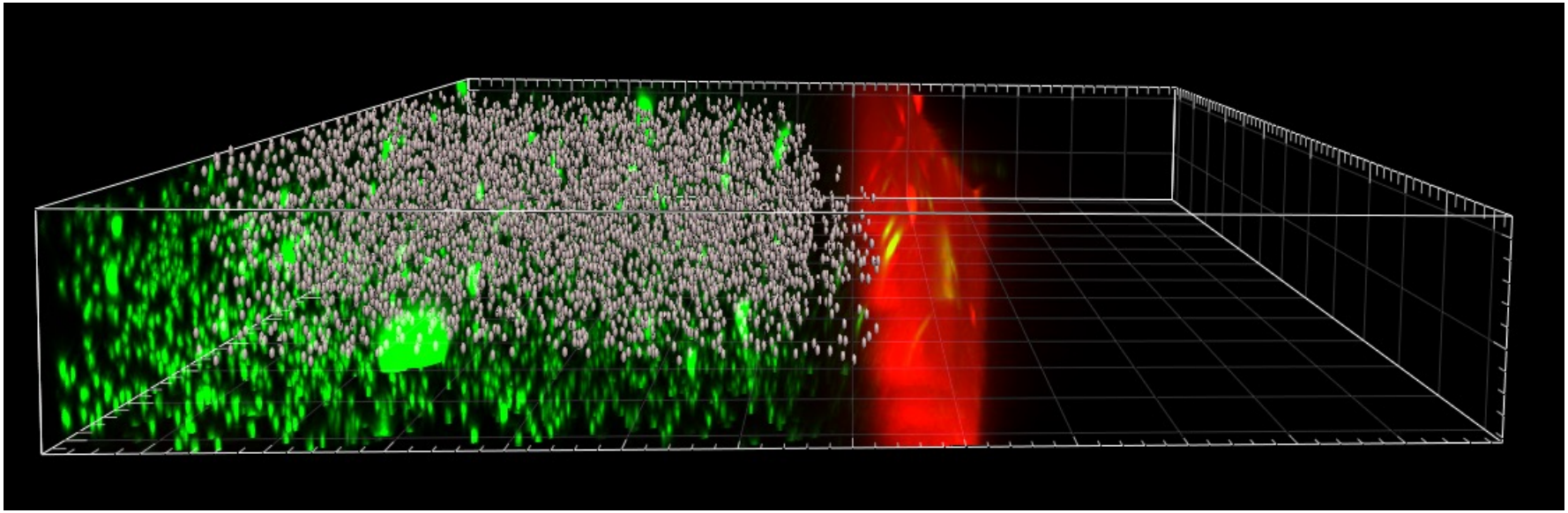
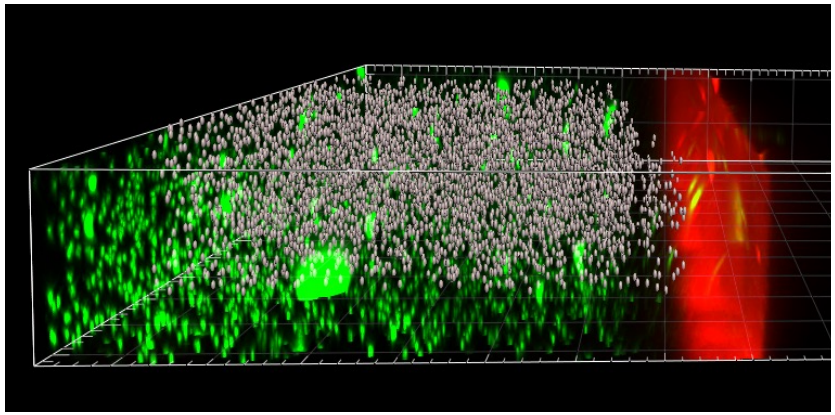


Data Processing

Tracer Particle Displacement Methods

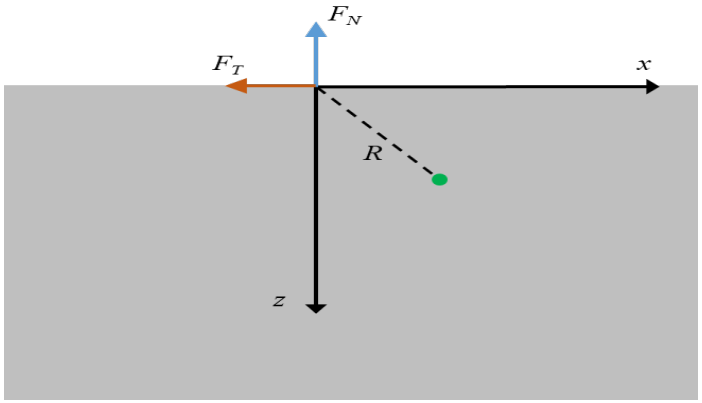
- IMARIS
- Traction Force Microscopy (TFM)



Peel Front Displacement Field

Force acting on surface of infinite half-space

- **Boussinesq–Cerruti solution (3D)**
- **Flamant solution (2D)**



Bower, A.F., 2012, *Applied Mechanics of Solids*, CRC press.

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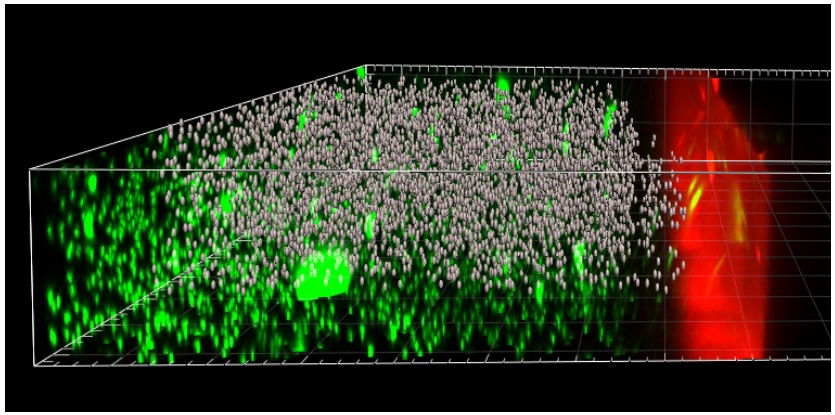

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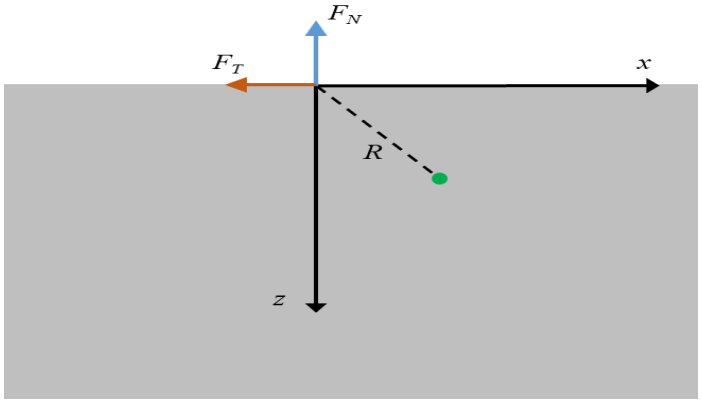

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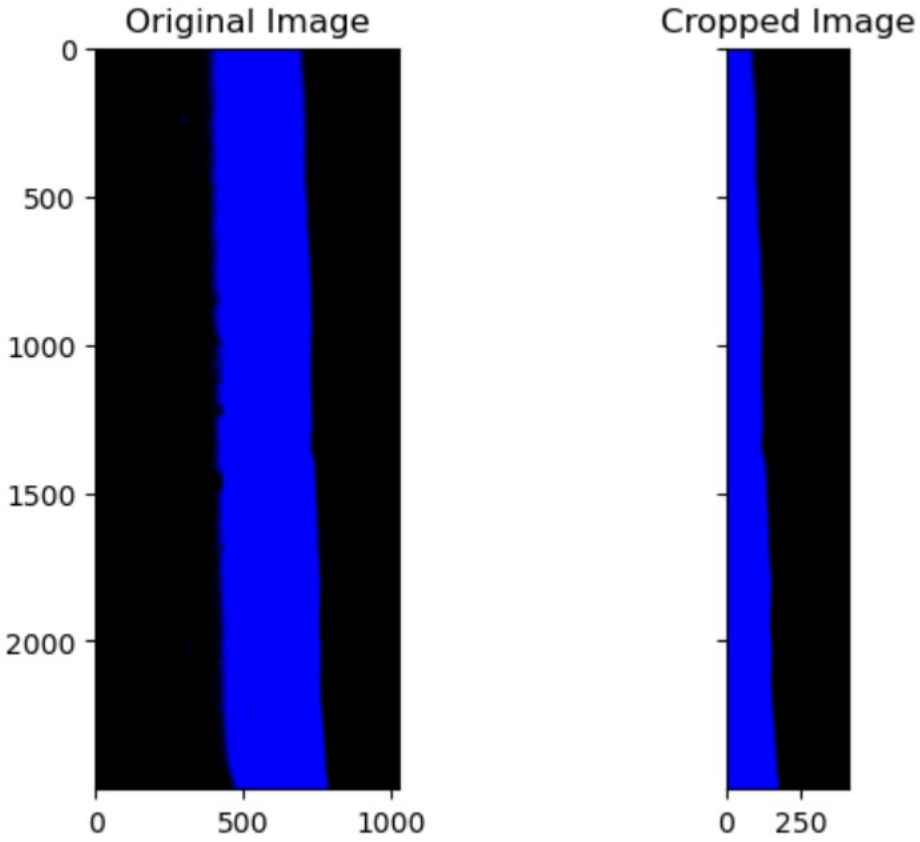
Red Channel (2D) – Rhodamine-β

Image manipulation



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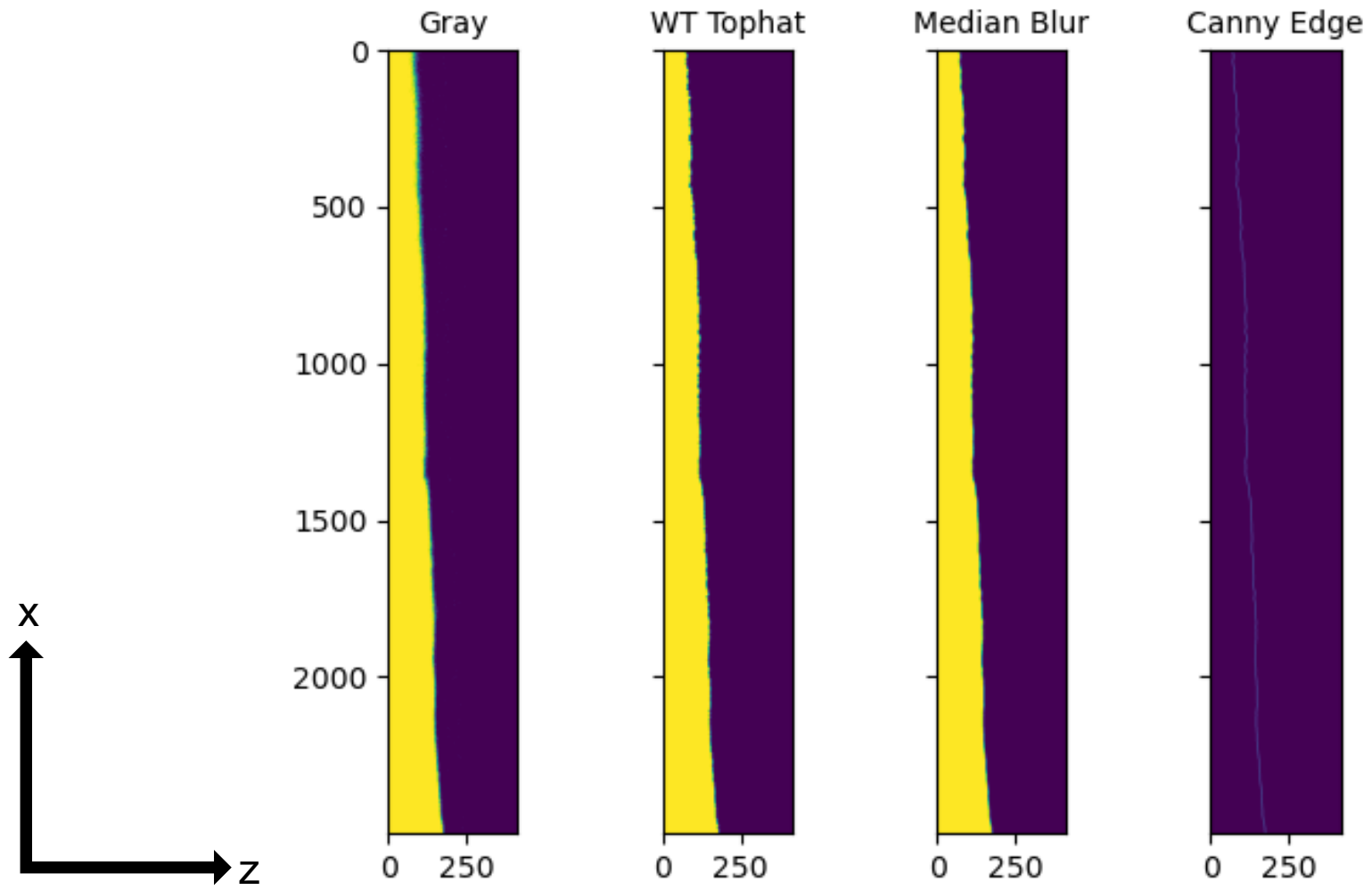


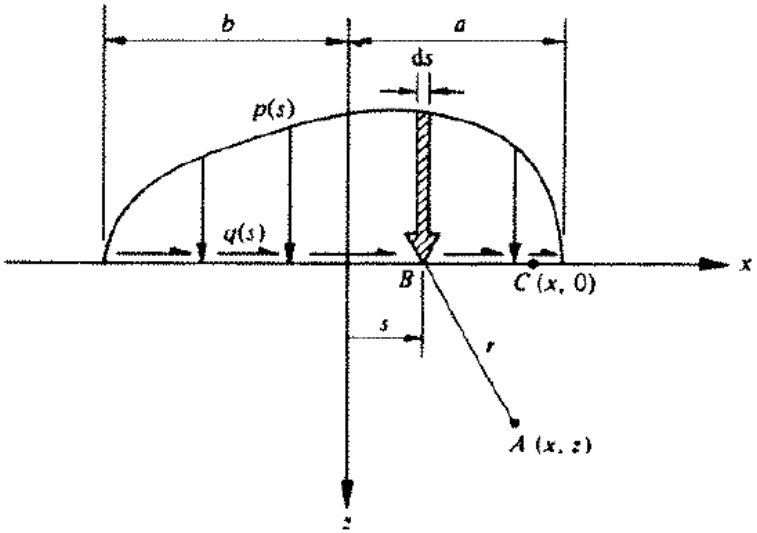
Method 2: Peel Front Displacement Field

Boussinesq-Cerruti solution

$$u_z(x, y=0, z) = -\frac{3}{4\pi E}\int_{-b/2}^{b/2}\int_{a_1}^{a_2}\sigma(x')\frac{2z^2 + y'^2 + (x-x')^2}{\left[(x-x')^2 + y'^2 + z^2\right]^{3/2}} + \tau(x')\frac{(x-x')z}{\left[(x-x')^2 + y'^2 + z^2\right]^{3/2}}\,dx'dy'$$

Flamant solution

$$\frac{\partial \overline{u_z}}{\partial \bar{x}} = -\frac{2(1-\nu^2)}{\pi E}\int_a^b \frac{p\,(\bar{s})}{\bar{x}-\bar{s}}\,ds + \frac{(1-2\nu)(1+\nu)}{E}q(x)$$



- Bower, A.F., *Applied Mechanics of Solids*, CRC press, 2012.
- Johnson, Kenneth Lester. Contact Mechanics. Cambridge Univ. Press, 2003.

Method 2: Peel Front Displacement Field

Boussinesq-Cerruti solution – Symmetric about b (width)

$$u_z(x, y=0, z) = -\frac{3}{4\pi E}\int_{-b/2}^{b/2}\int_{a_1}^{a_2}\sigma(x')\frac{2z^2 + y'^2 + (x-x')^2}{\left[(x-x')^2 + y'^2 + z^2\right]^{3/2}} + \tau(x')\frac{(x-x')z}{\left[(x-x')^2 + y'^2 + z^2\right]^{3/2}}\,dx'dy'$$

0

Flamant solution – Plain strain condition

$$\frac{\partial \overline{u_z}}{\partial \bar{x}} = -\frac{2(1-\nu^2)}{\pi E}\int_a^b \frac{p(\bar{s})}{\bar{x}-\bar{s}}\,ds + \frac{(1-2\nu)(1+\nu)}{E}q(x)$$

0

Assumption: No tangential forces for both solutions

Flamant solution – Simple form

$$\frac{\partial \overline{u_z}}{\partial \bar{x}} = -\frac{2(1-\nu^2)}{\pi E}\int_a^b \frac{p(\bar{s})}{\bar{x}-\bar{s}}\,ds$$

$$f(\bar{x}) \quad = \quad -c \quad \int_{s=0}^{s=1} \frac{p(\bar{s})}{\bar{x}-\bar{s}}\,ds$$

Evaluated from experiment data

Constant (Material dep.)

Integrate and solve for p(s)

Methods to solve:

- Discretize and solve the system of equations
- Laplace Transform

Flamant solution – Discretization

$$\frac{\partial \overline{u_z}}{\partial \bar{x}} = -\frac{2(1-\nu^2)}{\pi E}\int_a^b \frac{p(\bar{s})}{\bar{x}-\bar{s}}\,ds$$

$$f(\bar{x}) \quad = \quad -c \int_{s=0}^{s=1} \frac{p(\bar{s})}{\bar{x}-\bar{s}}\,ds$$

$$b \quad = \quad A \quad x$$

$$\begin{bmatrix} f(x_1) \\ \vdots \\ \vdots \\ f(x_N) \end{bmatrix} = \begin{bmatrix} (x_1,s_1) & \cdots & (x_1,s_N) \\ \vdots & & \vdots \\ \vdots & \ddots & \vdots \\ (x_N,s_1) & \cdots & (x_N,s_N) \end{bmatrix} \times \begin{bmatrix} p(s_1) \\ \vdots \\ \vdots \\ p(s_N) \end{bmatrix}$$

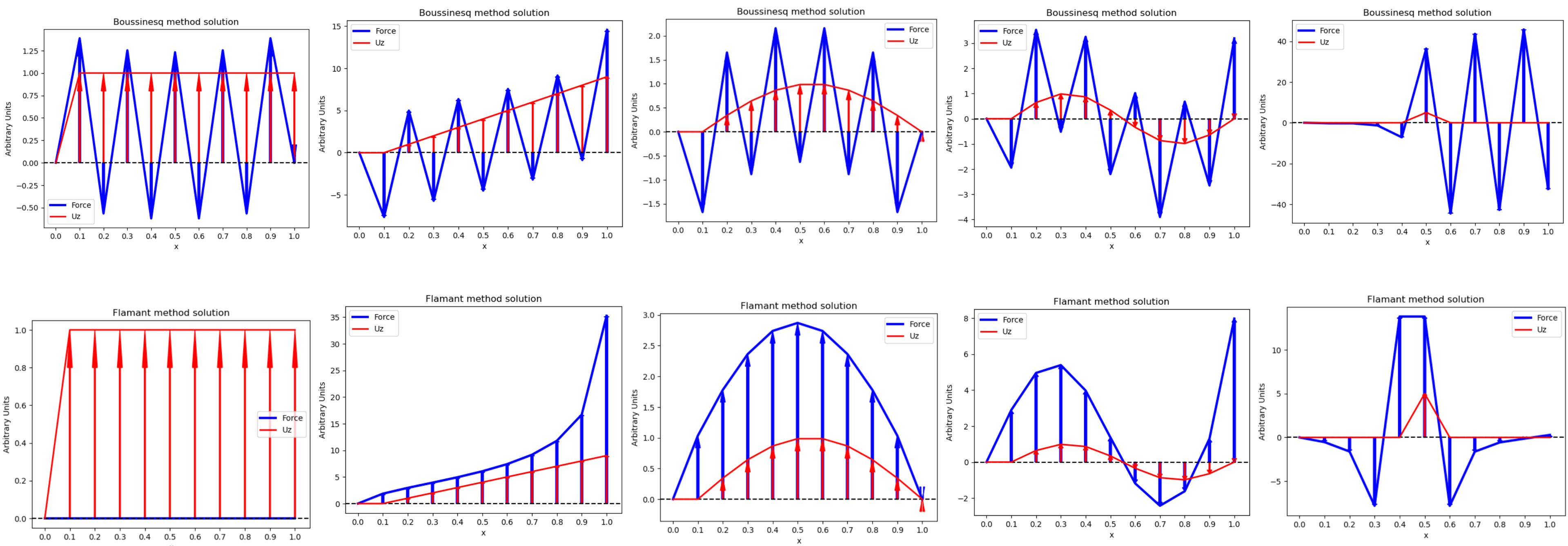
$$x = A^{-1}b$$

Results – “test” displacement scenarios

Legend:

--- : Input displacement

--- : Calc. force



Uniform displacement

Steady-increasing displacement

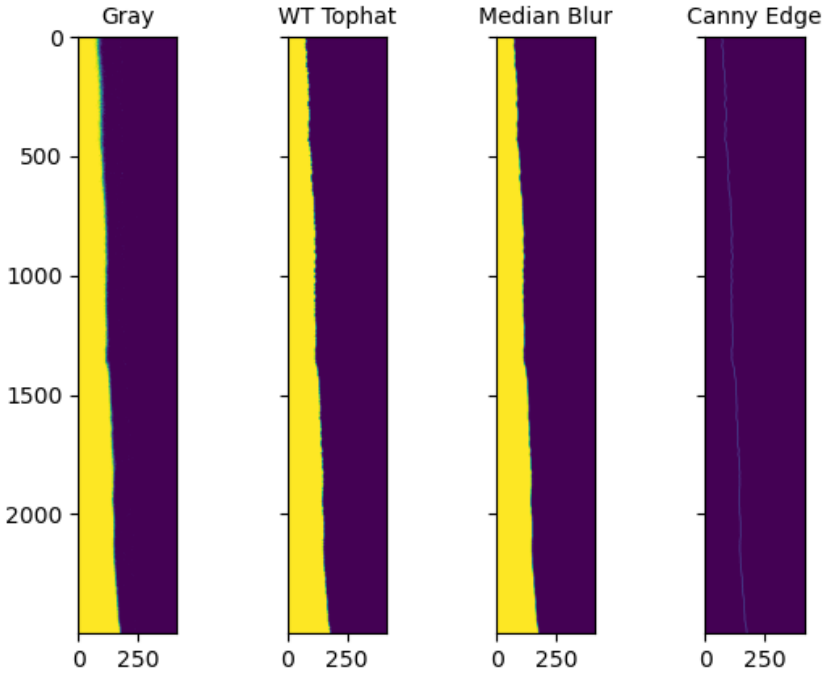
sin (0,pi)

sin (0,2pi)

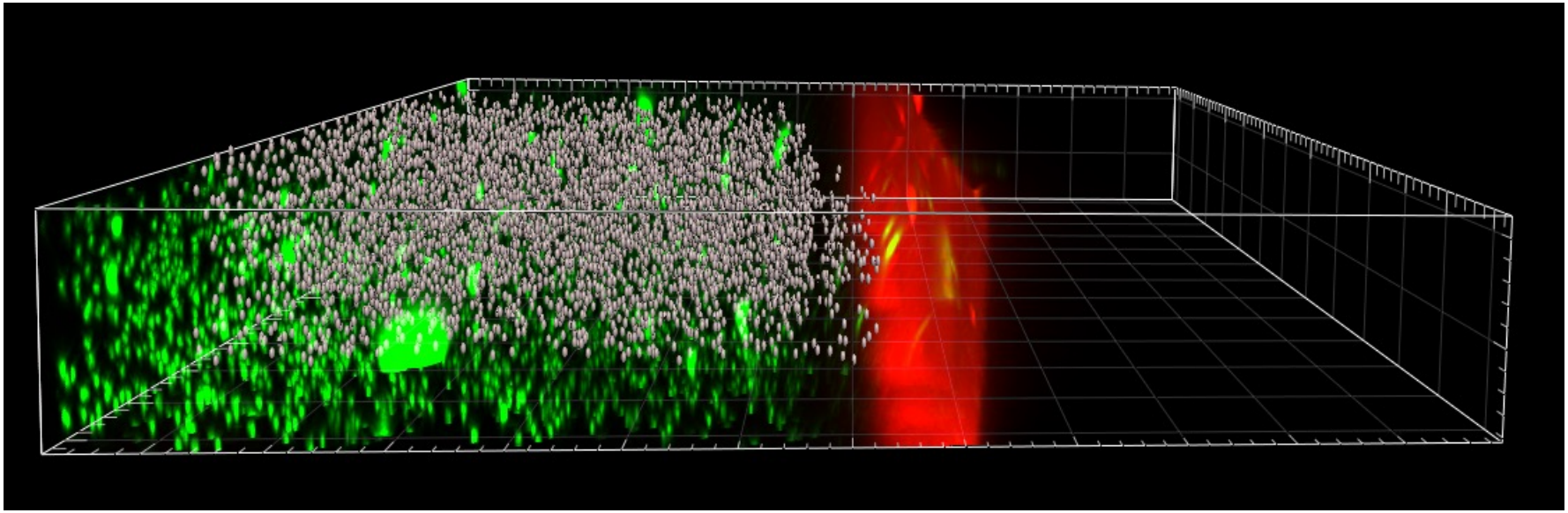
Point disp. @ 0.5

Next Steps:

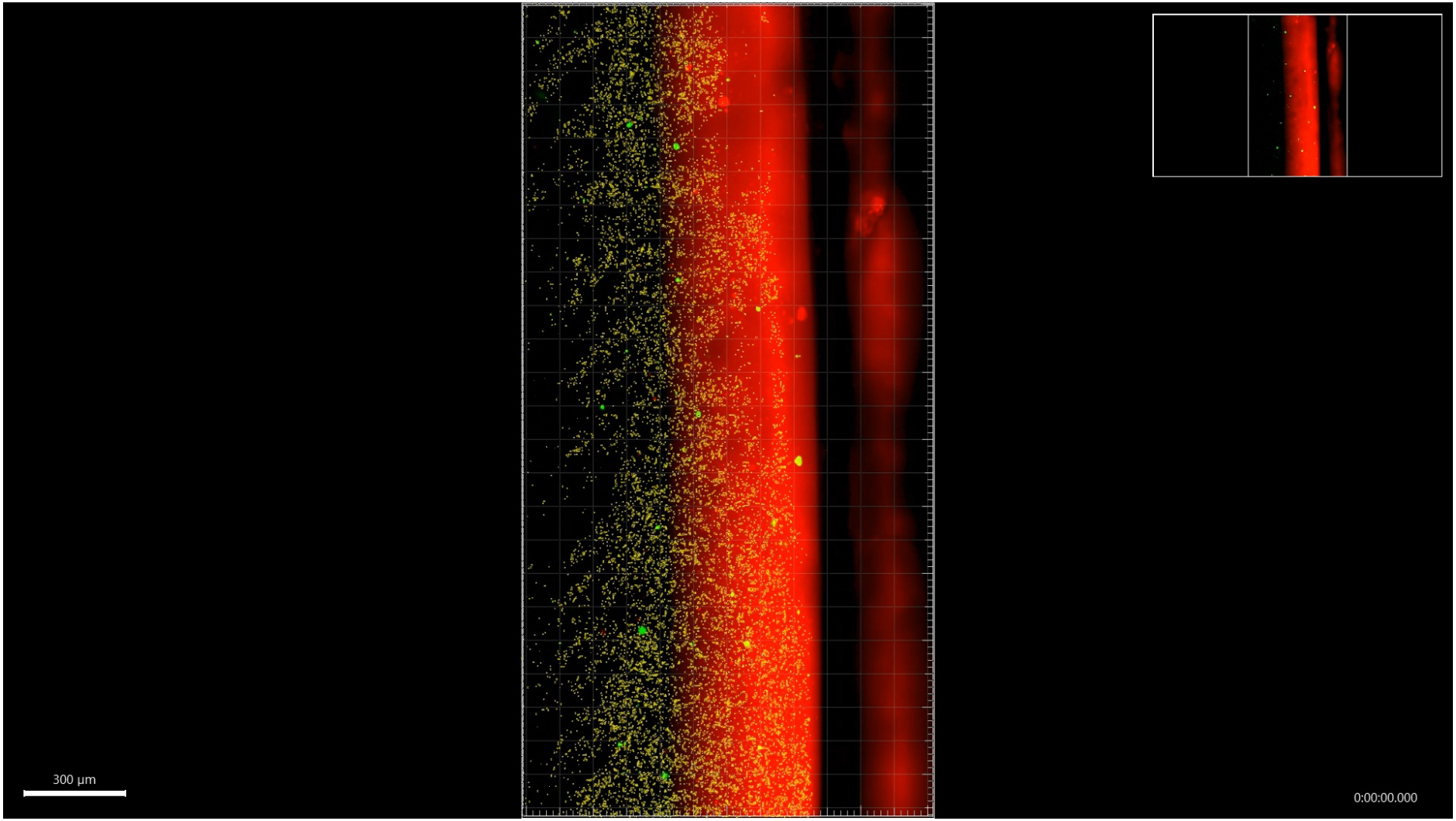
- Verify code again
- Implement boundary conditions
- Verify results using ABAQUS or other simulation software
- More testing (with more nodes)
- Apply method to experiment values



Method 1: Tracer Particle Method



Results



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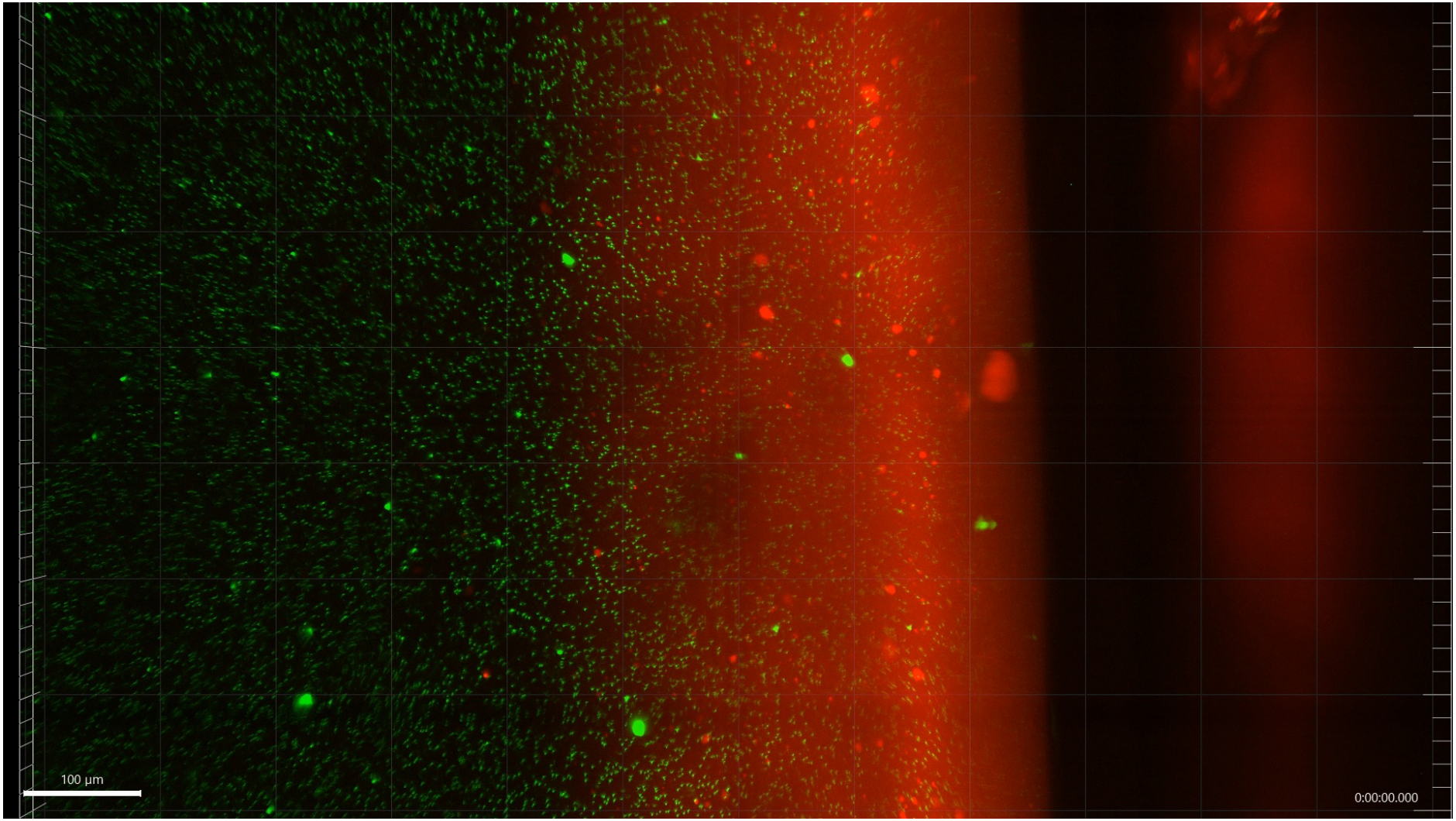
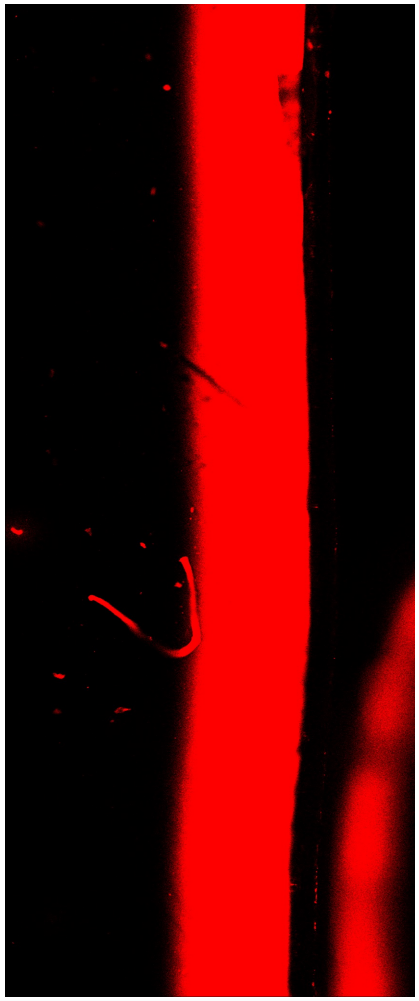
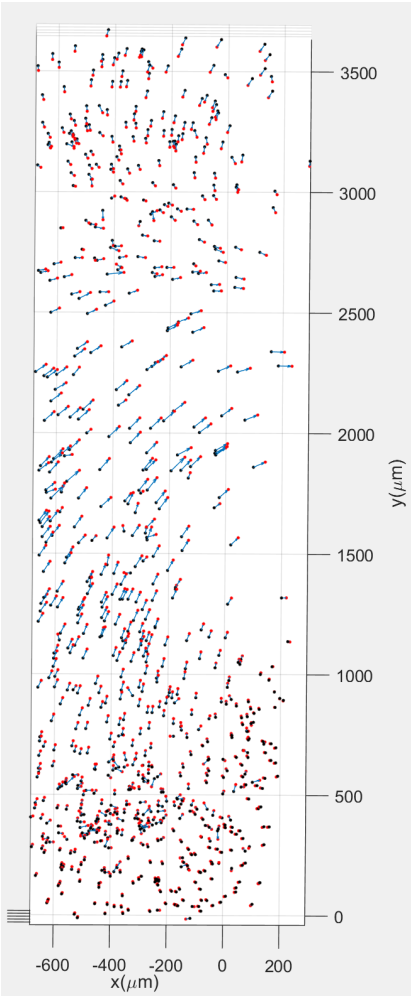


25th Timepoint – ux

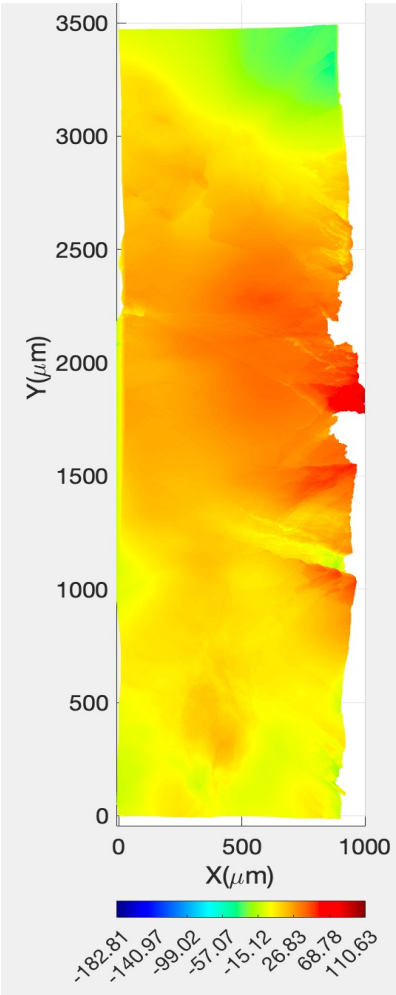
Red channel Image



IMARIS Quiver Plot



Interpolation Result



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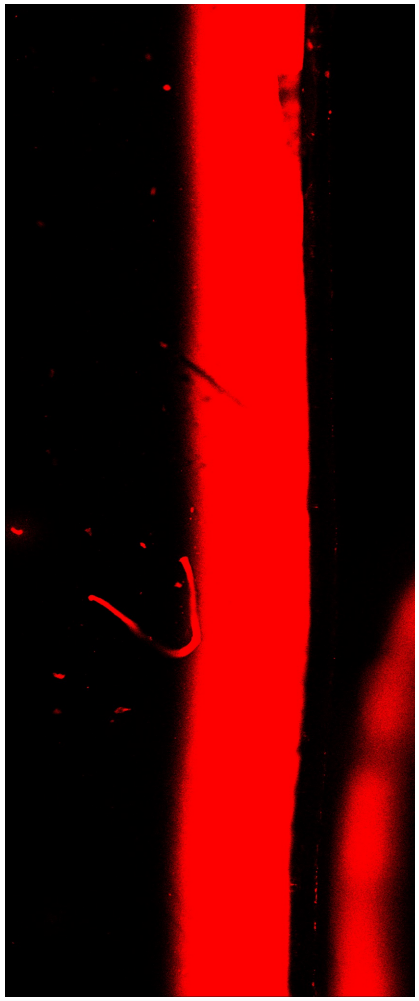

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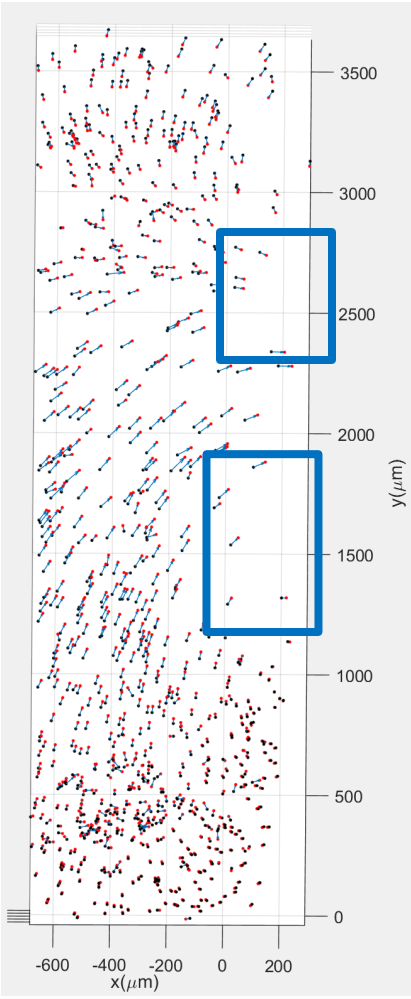

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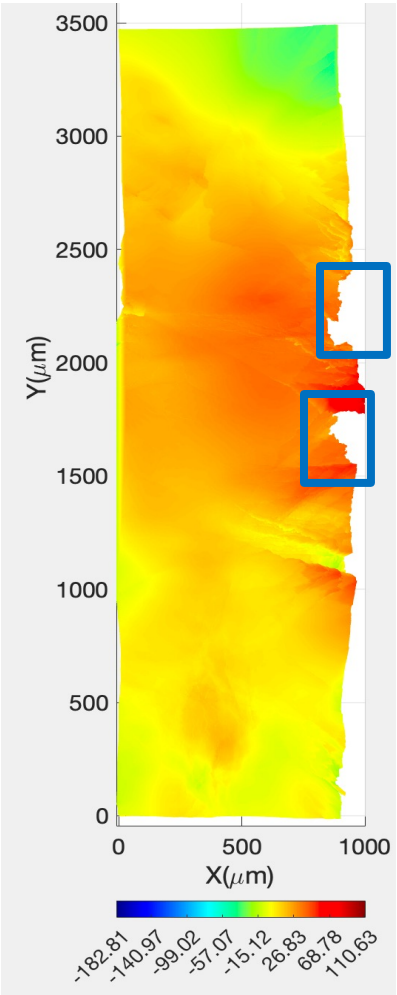

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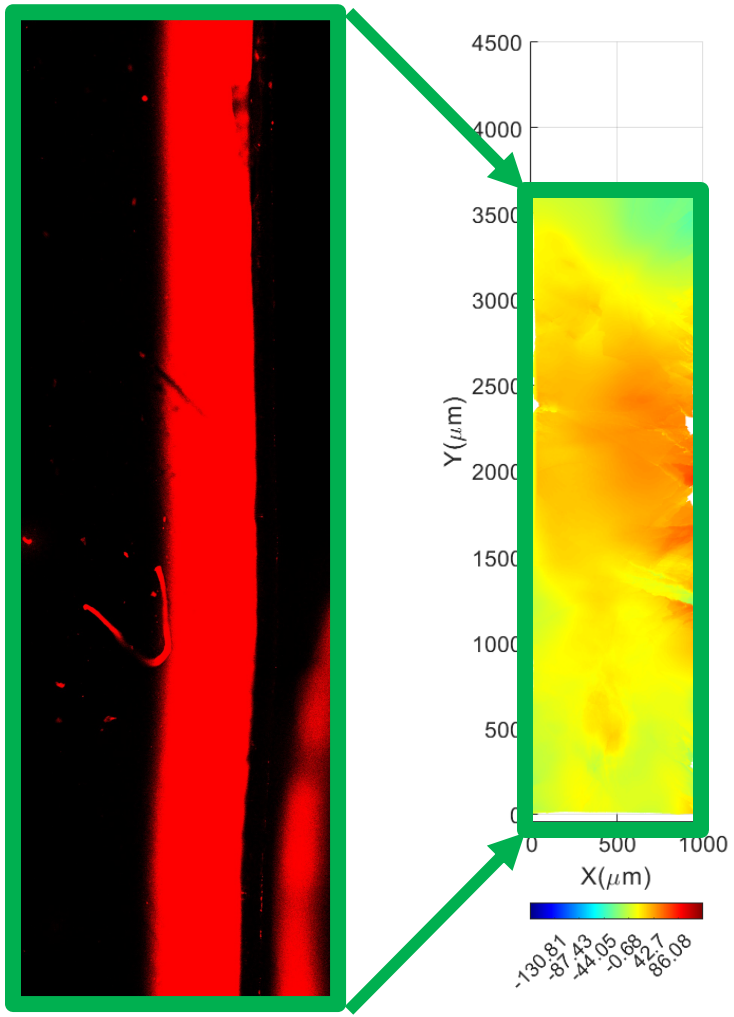
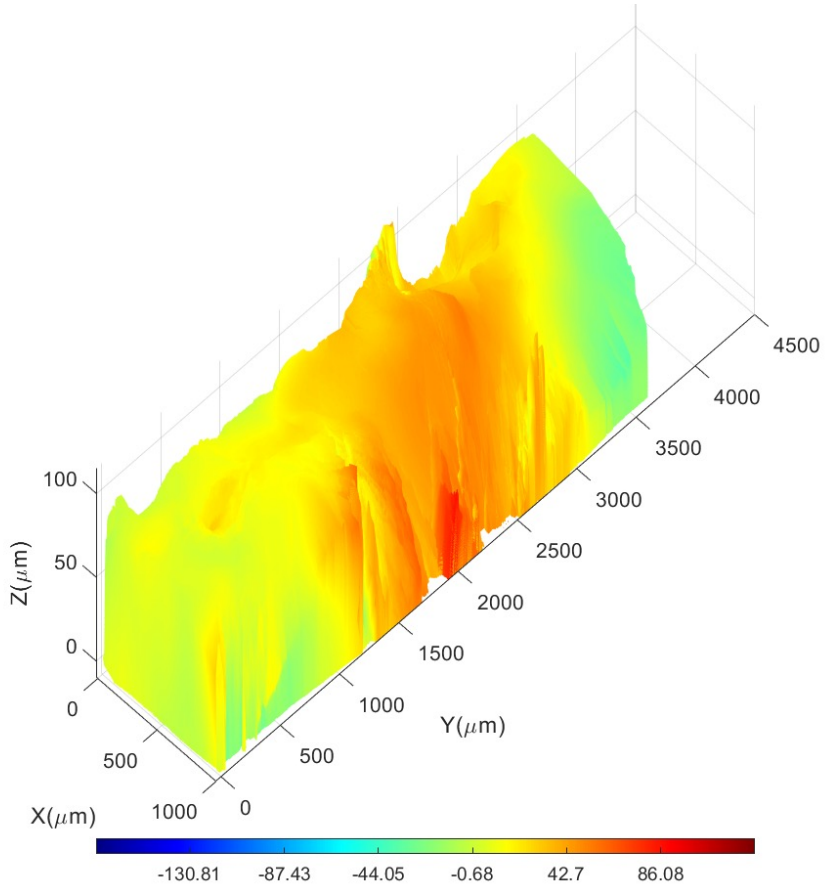
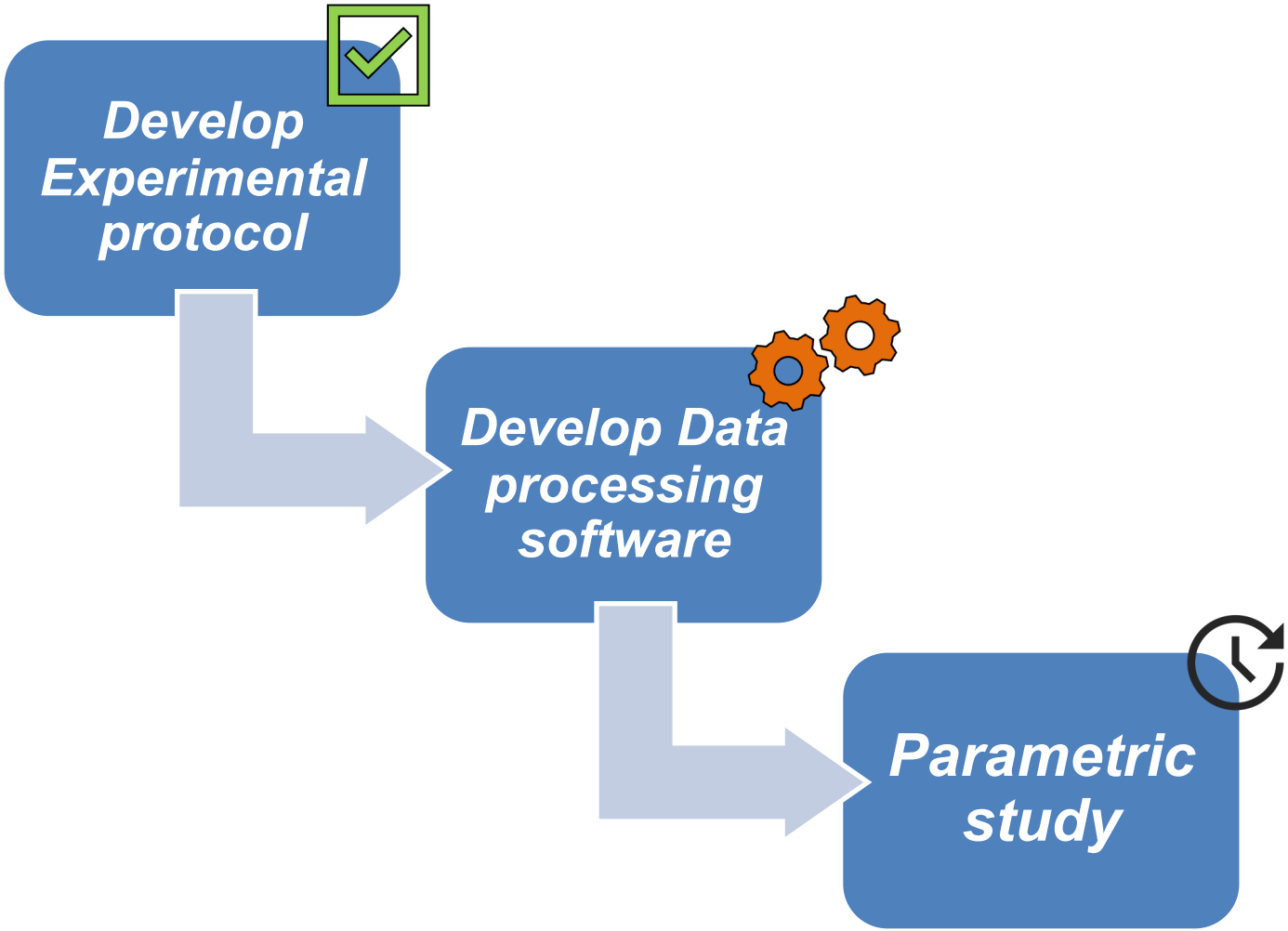




- Current grid size : 950X3550X100

Next Steps?


Develop Experimental protocol
Develop Data processing software
Parametric study

Acknowledgements

- **Advisor:**
  - Dr. Rong Long

- **Non-Linear Mechnics Lab (NML):**
  - Salil Rabade (PhD candidate)
  - Guillaume Lostec (PhD candidate)

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  - Dr. Ryan Birringer
  - Dr. Jonathan Kemling
  - Dr. Dylan Cosgrove

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  - Rentschler Research Group