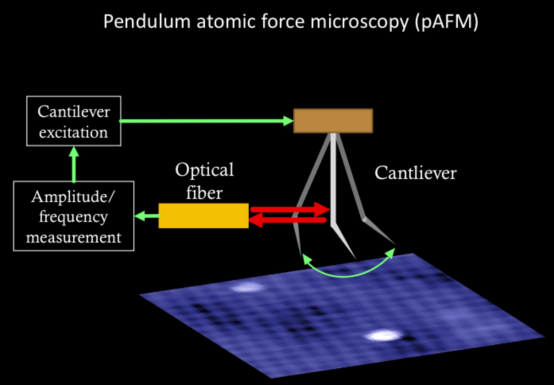
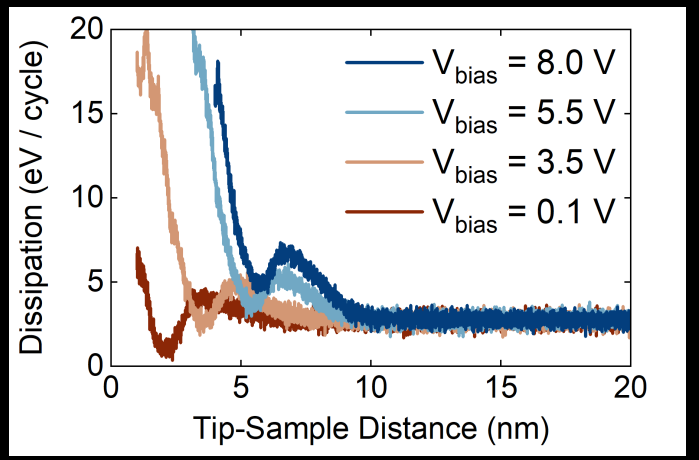
p-AFM for Imaging Fluctuation Dynamics in Correlated Quantum Materials at mK Temperatures

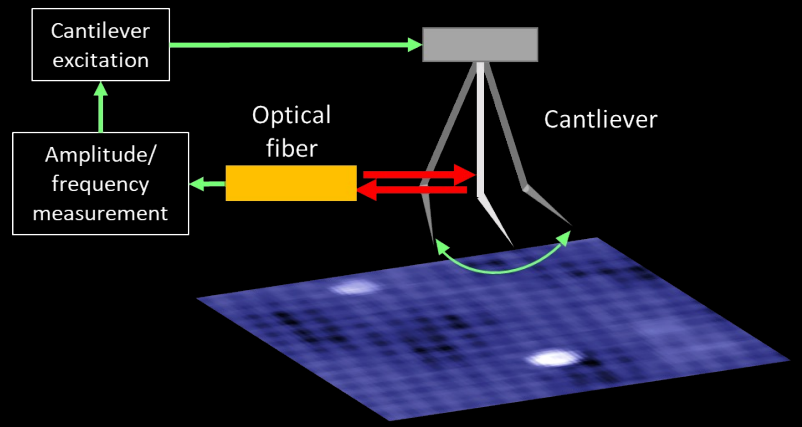
Aaron Coe, Benjamin November, Federico Maccago, Stefan Ulrich, Jennifer Hoffman



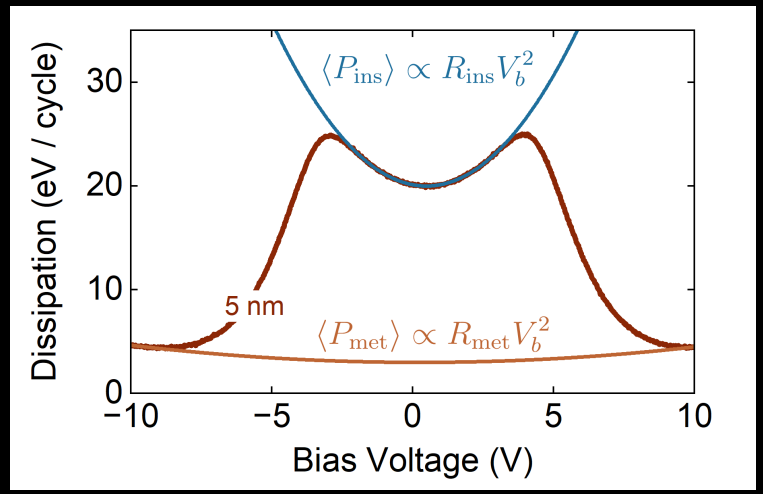


Outline

Pendulum Atomic Force Microscope (pAFM)



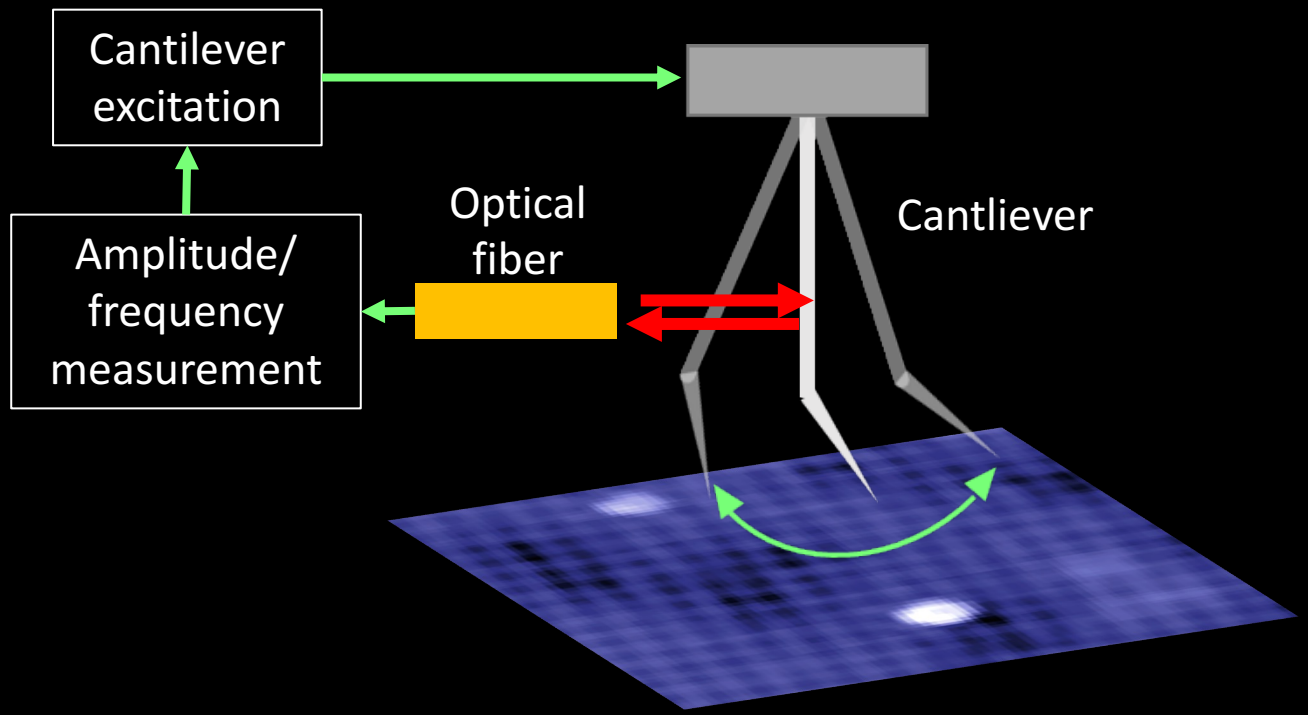
Dissipation measurements in VO_2



pAFM construction and experimental motivations

pAFM enables ultra-sensitive dissipation measurements

Pendulum atomic force microscopy (pAFM)



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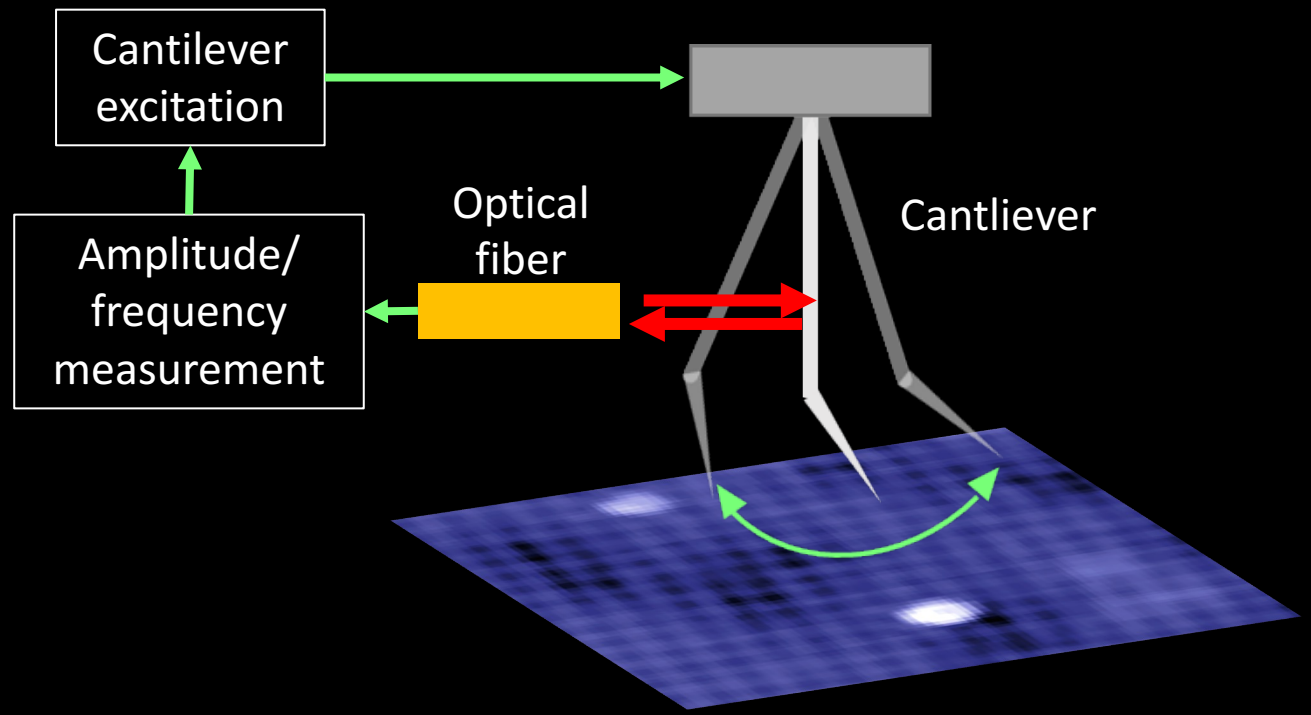
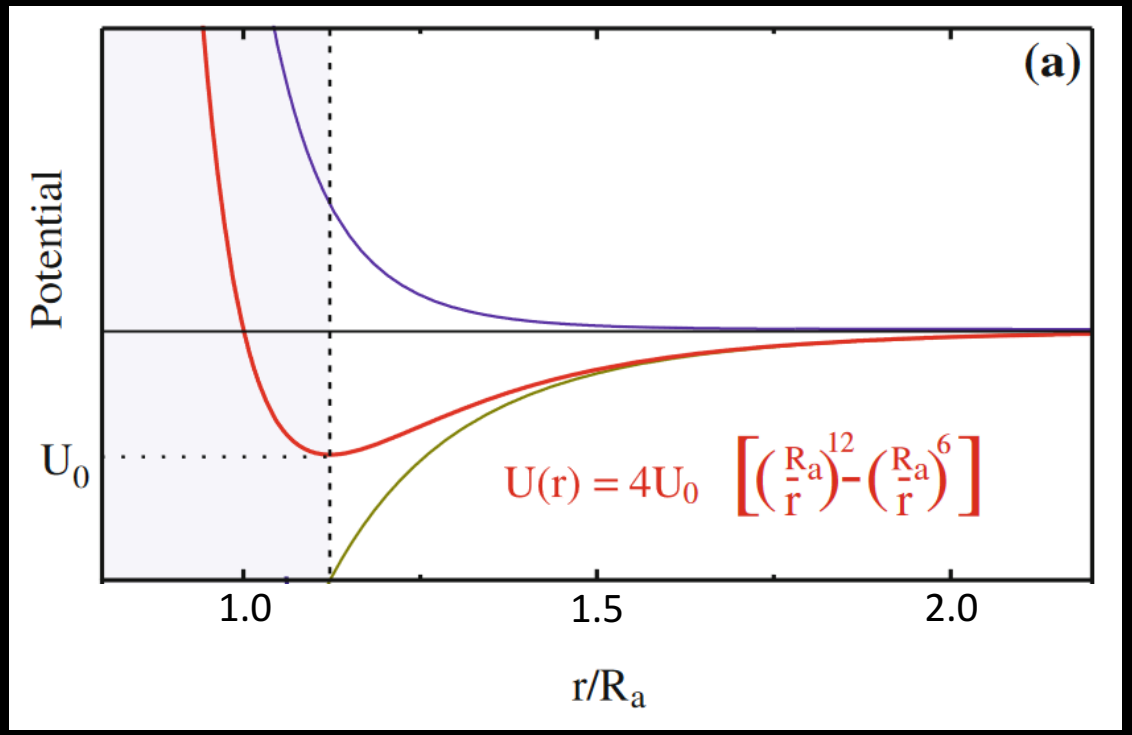
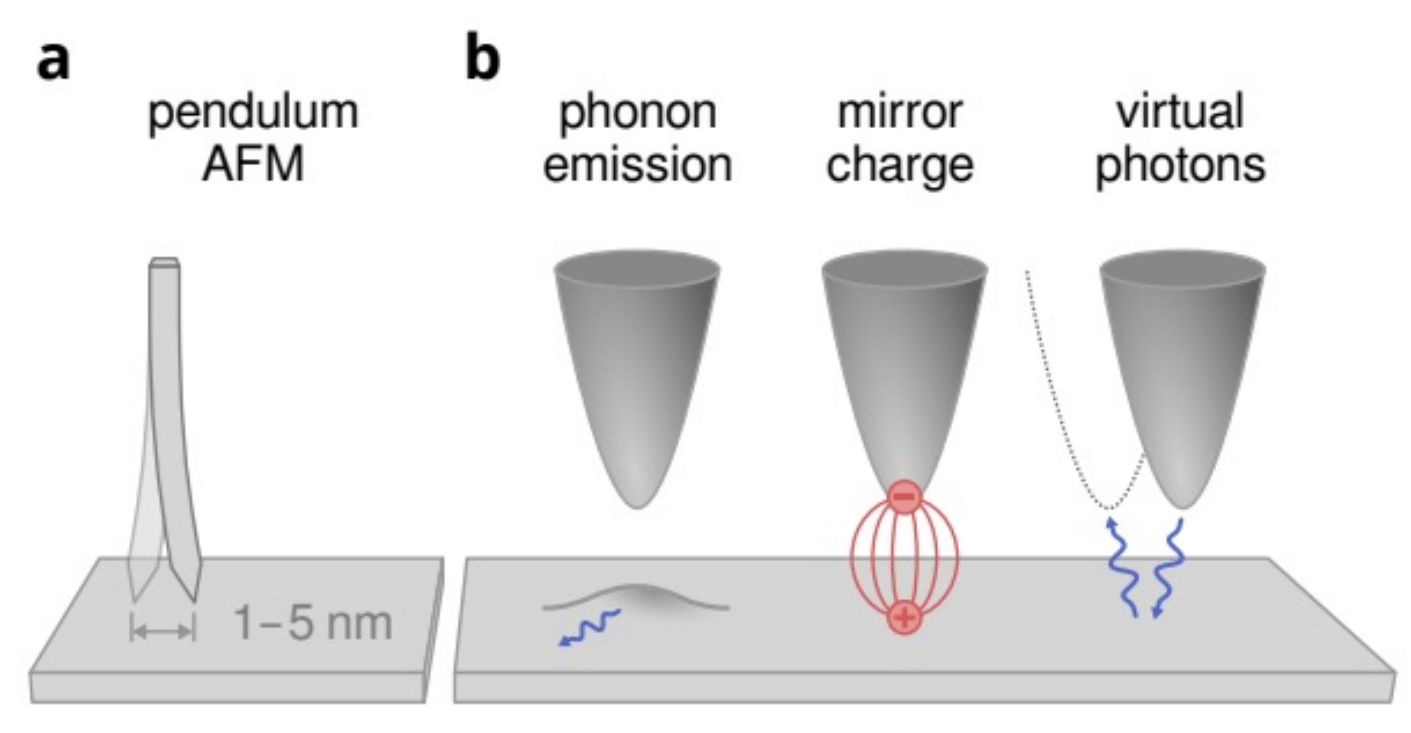




Voigtlander, B. *Springer* (2016).

pAFM enables ultra-sensitive dissipation measurements

Several dissipation channels



Kisiel, M., et. al. *Nat Commun* **9,** 2946 (2018)

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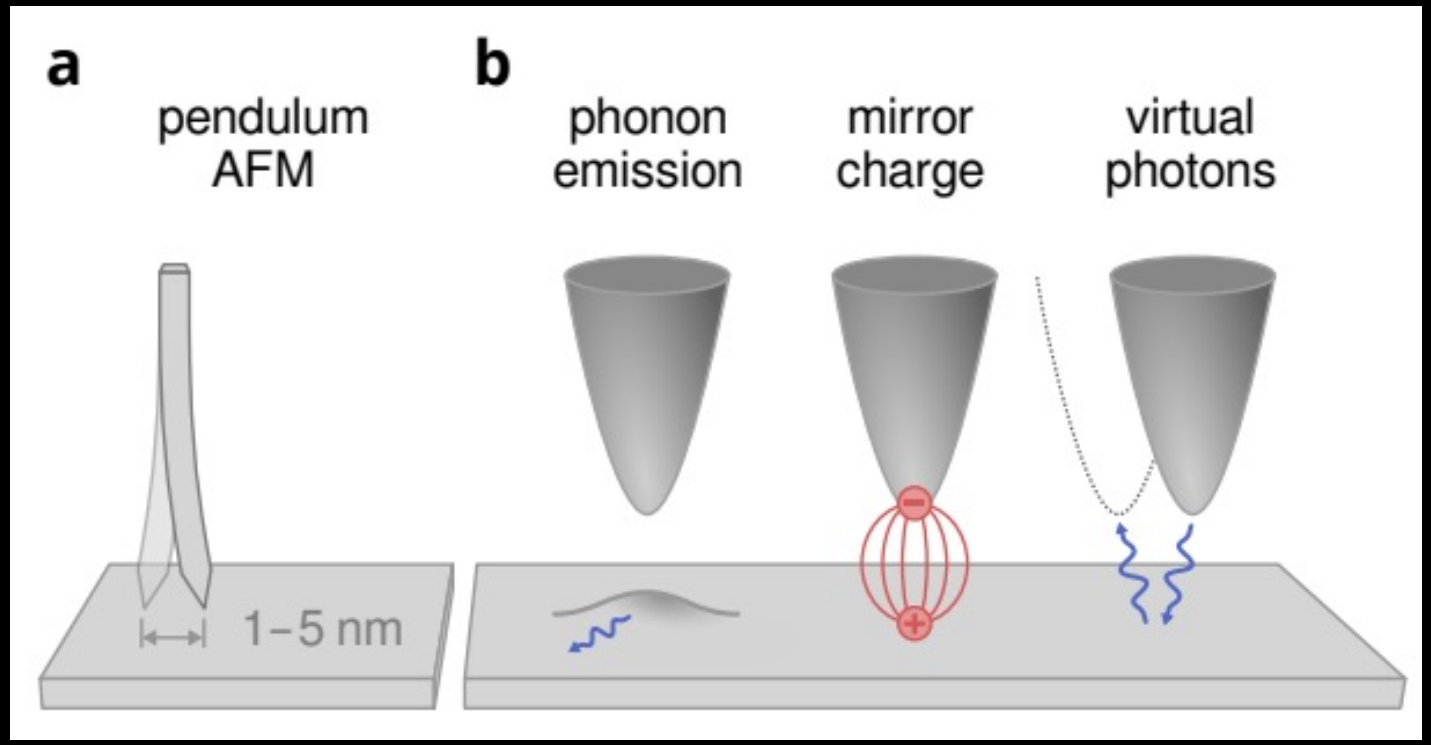

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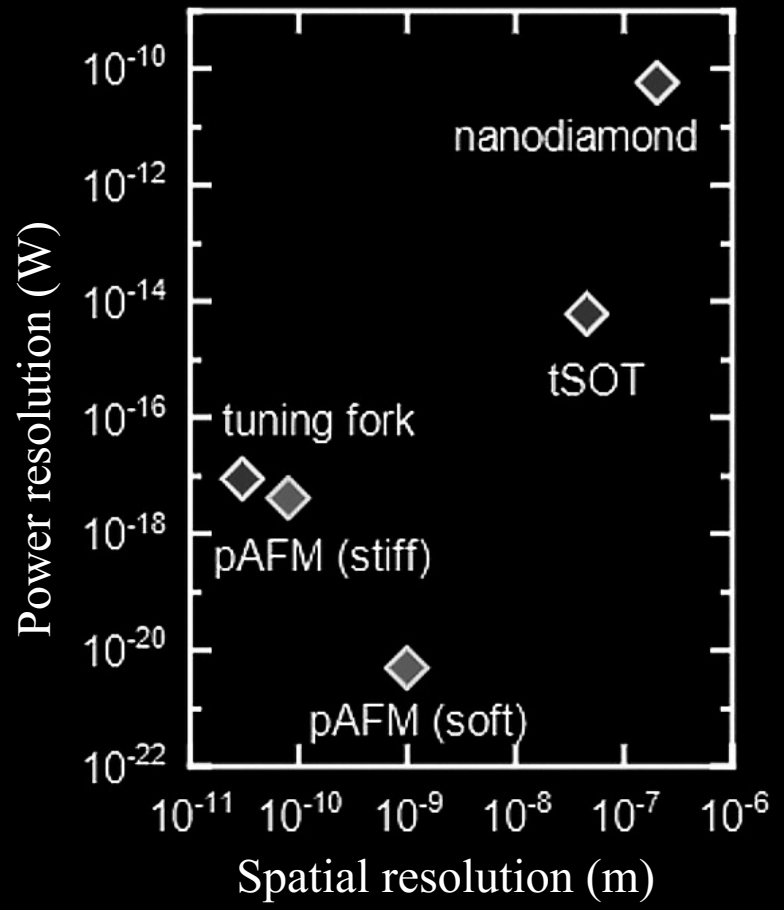
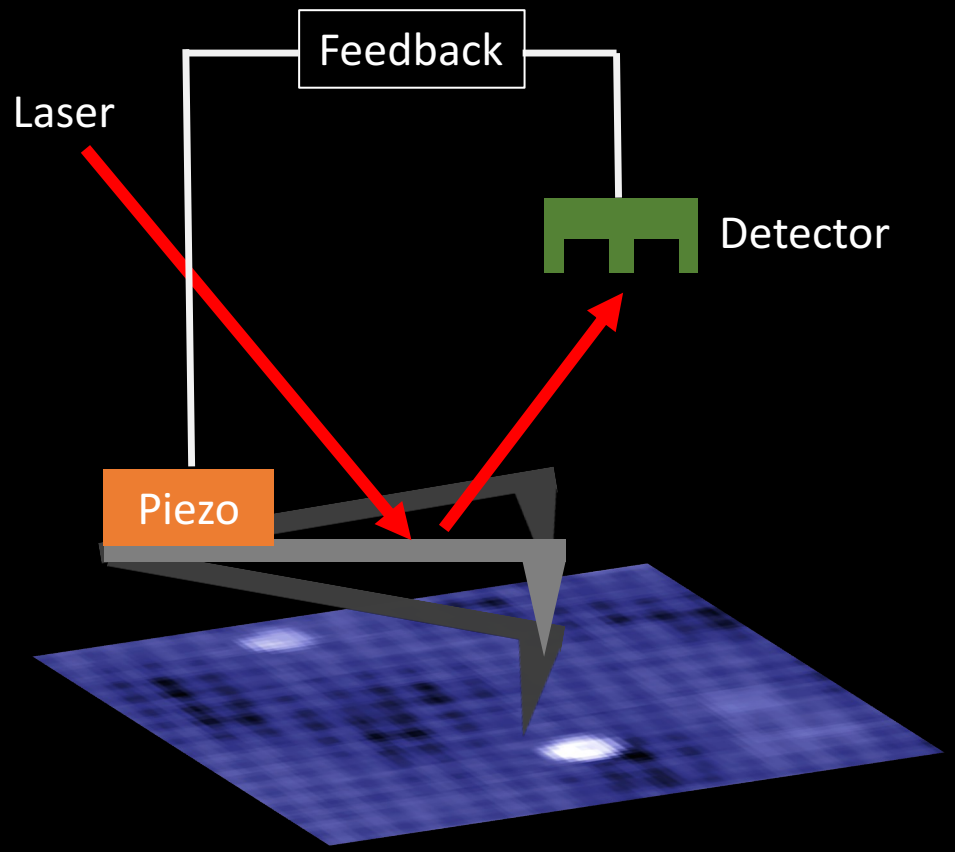


Halbertal, D., M. *et al. Nature* **539**, 407-410 (2016).
Kisiel, M., *et al. Nat Commun.* **9**, 2946 (2018).
Figure by Jason Hoffman

Horizontal AFM is not optimal for dissipation



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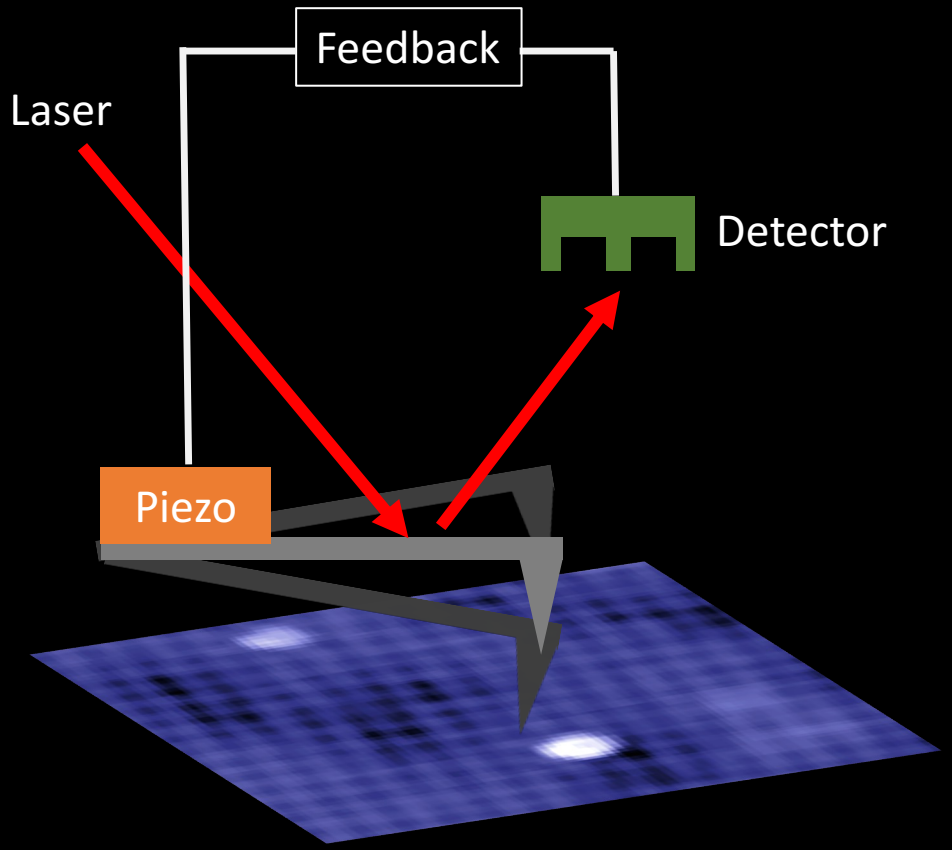
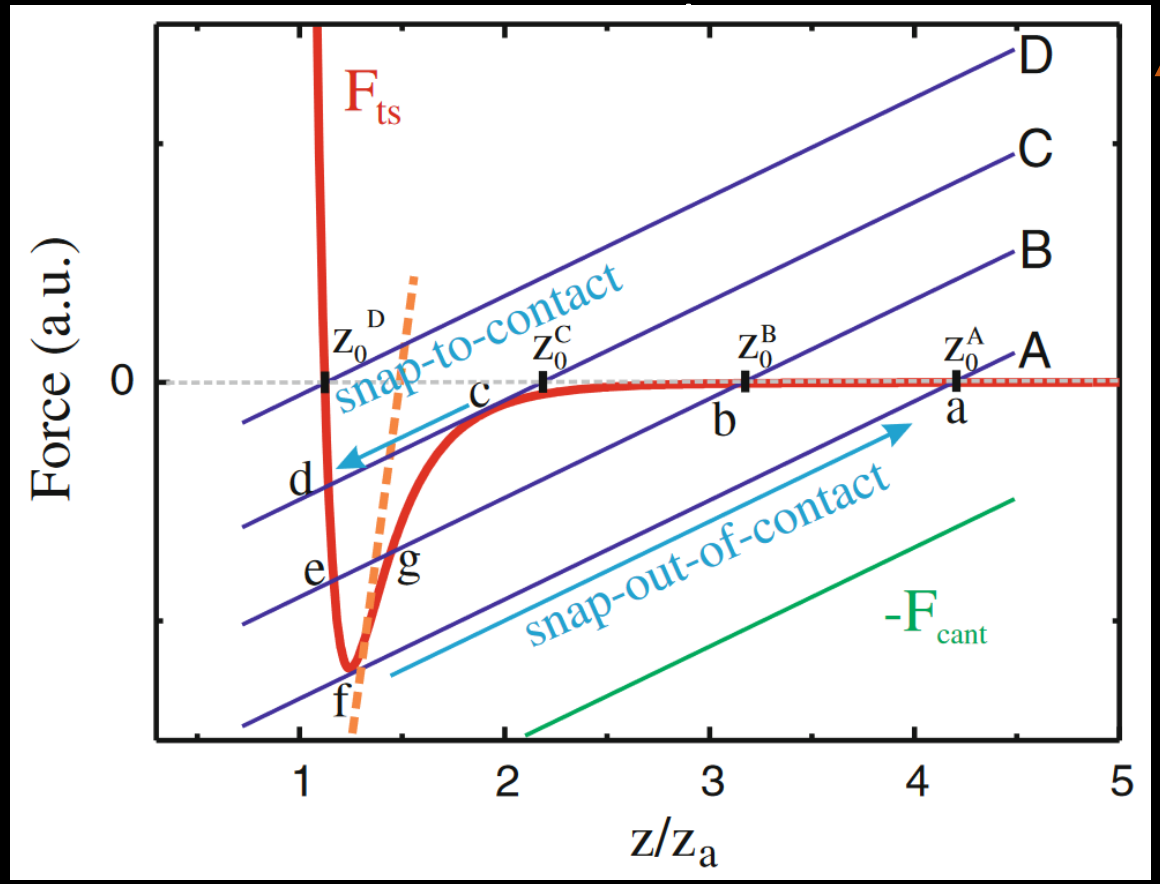


Cantilever can be trapped in a low energy



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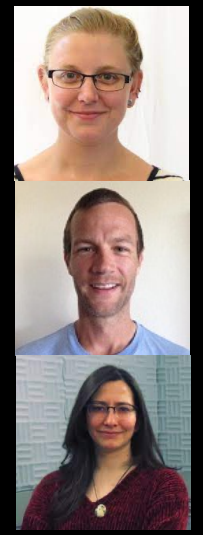
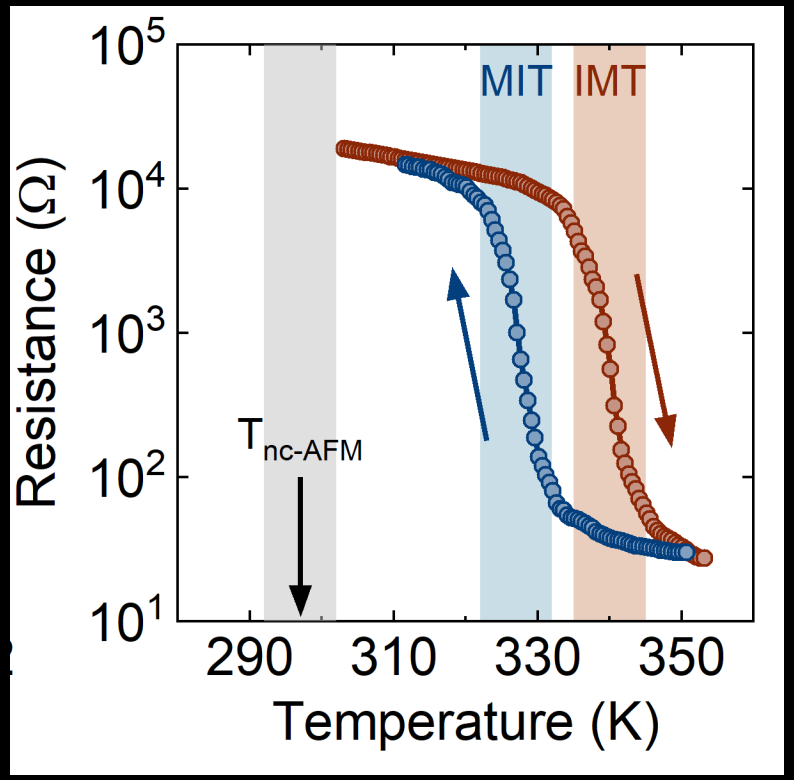
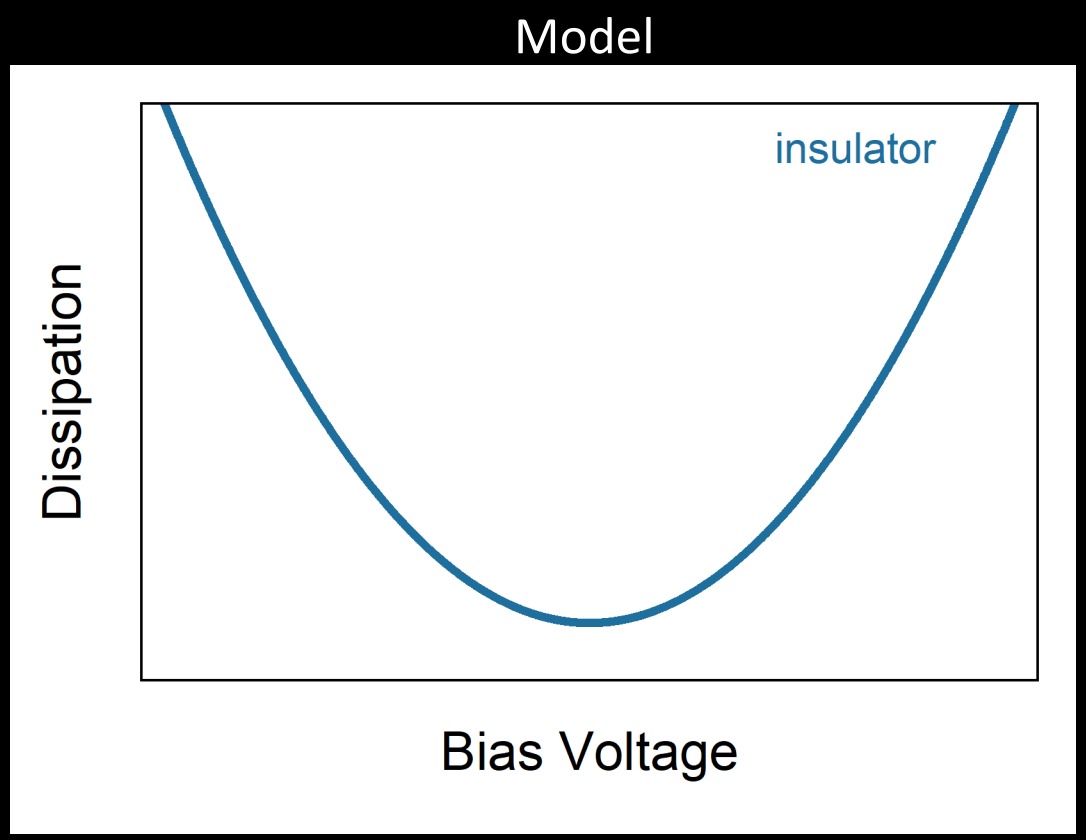
The two things to know about VO_2





- VO_2 undergoes an insulator-to-metal transition around 340 K
- The insulator-to-metal transition can be triggered by a voltage

Dissipation insulator-to-metal transition signature

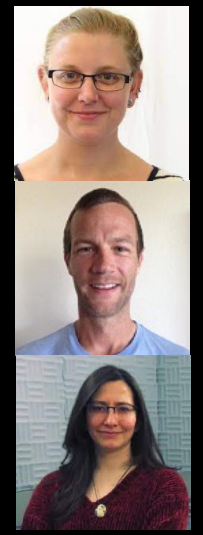


More charge ⟷ Less charge ⟷ More charge

$$\langle P_{\text{Joule}} \rangle \propto \frac{RV_b^2}{d^2}$$

Vary bias

Fix distance



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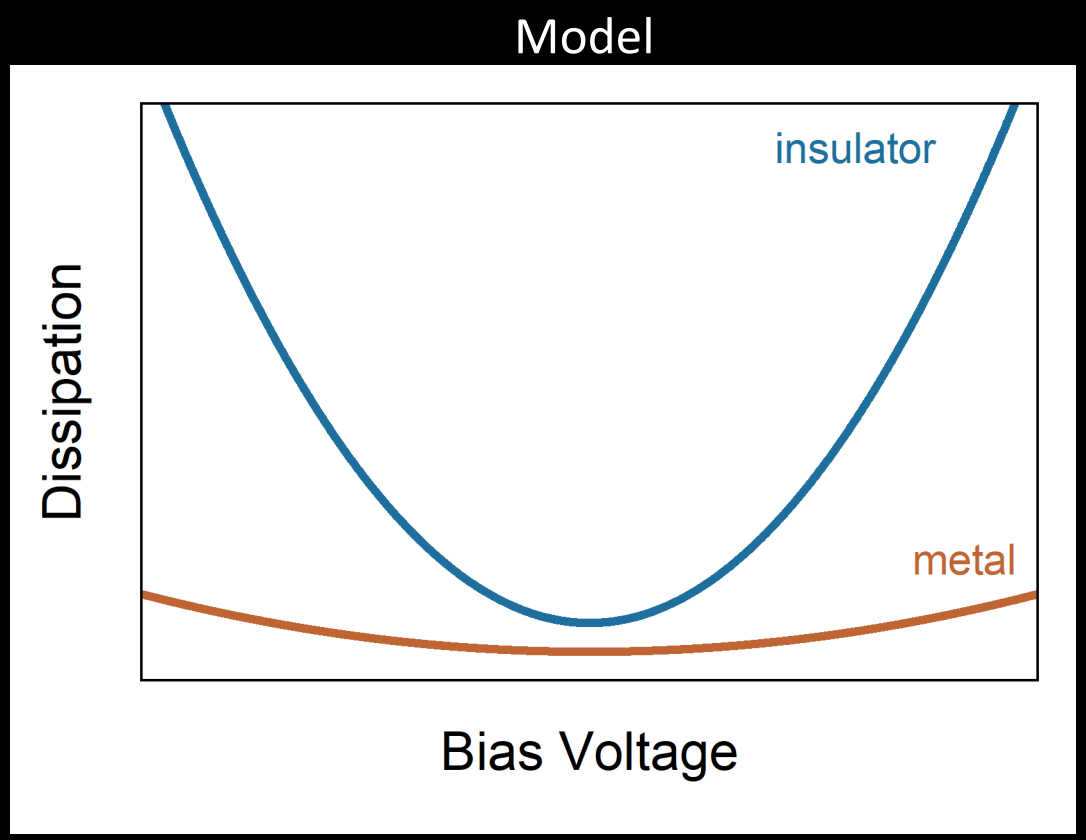

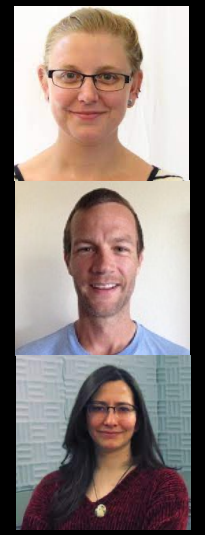

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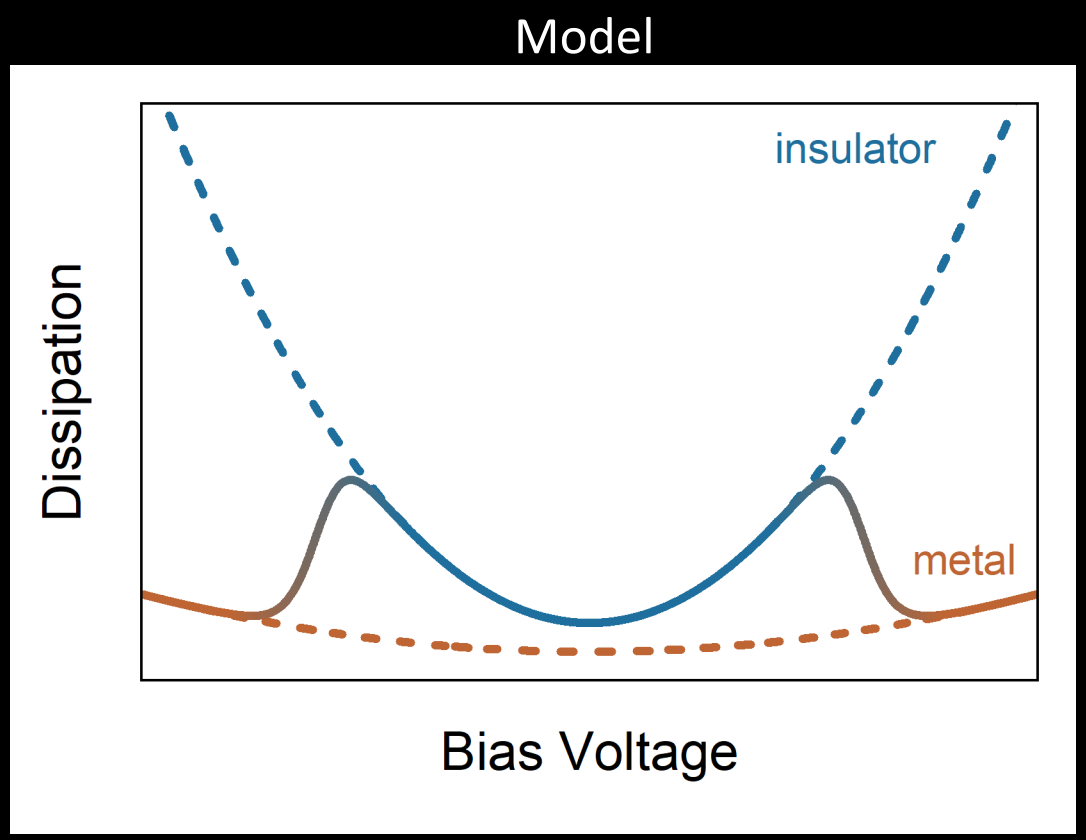

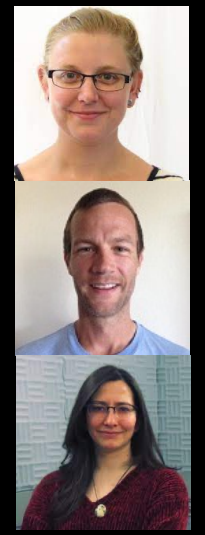

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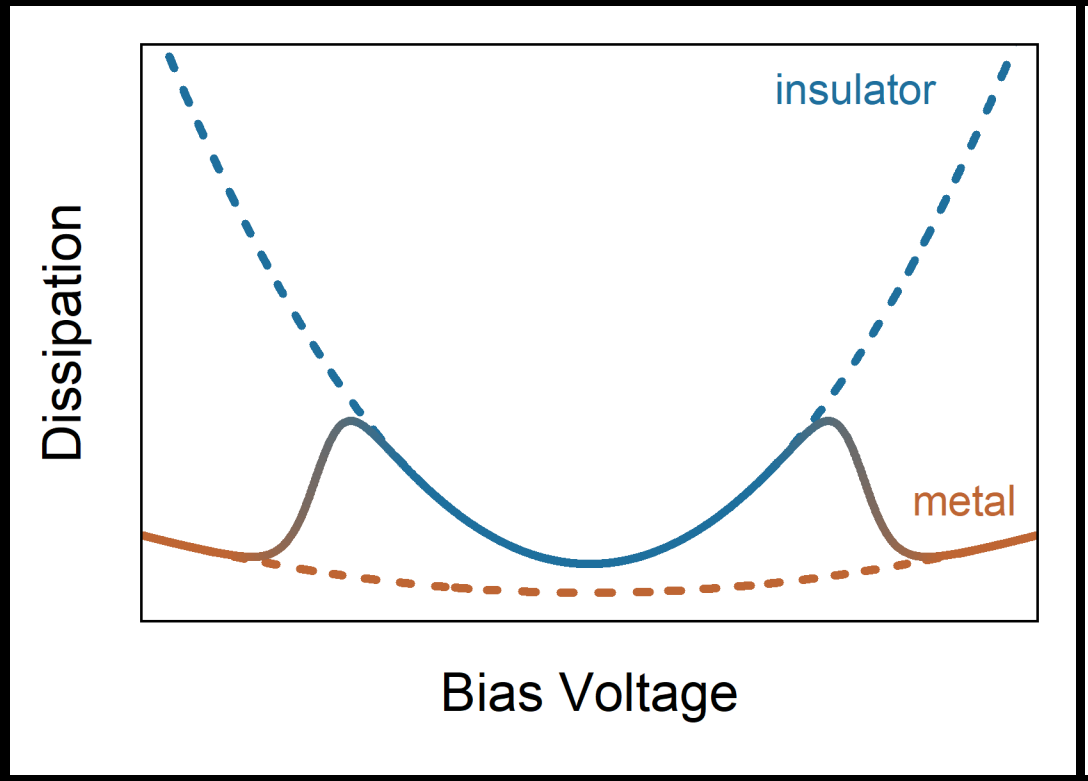
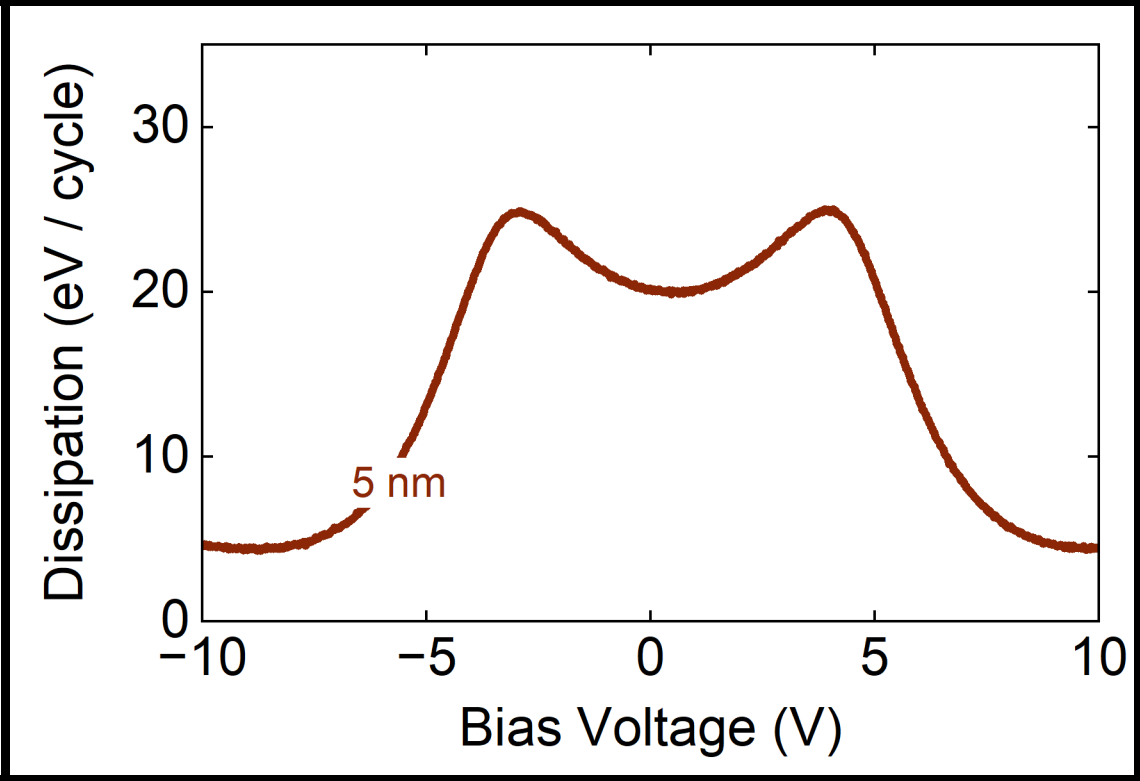
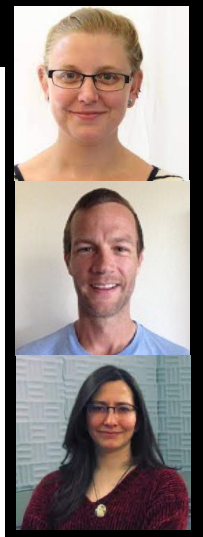
Model



Real





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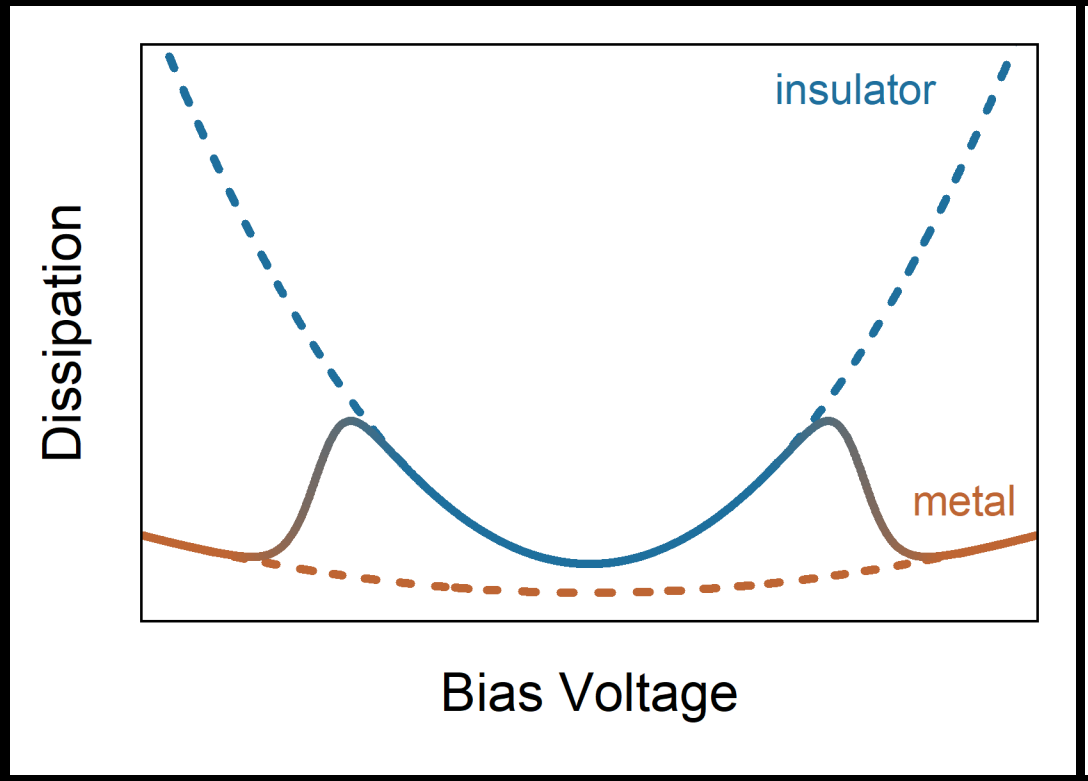

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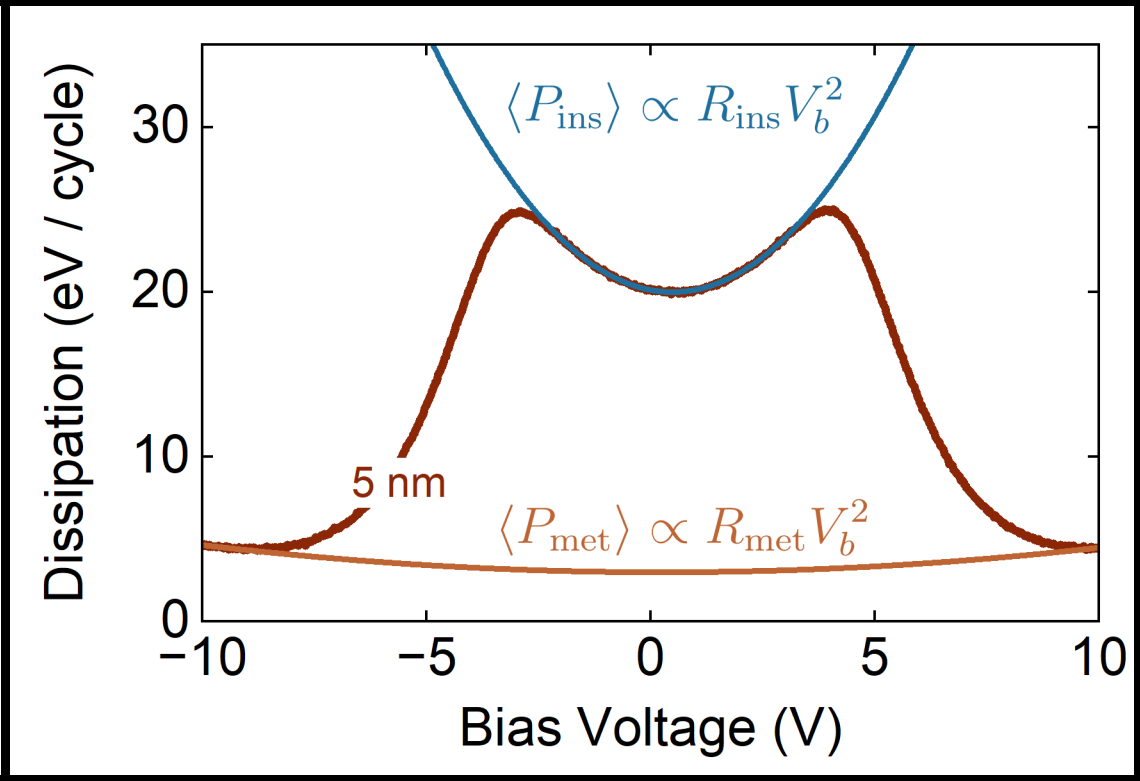

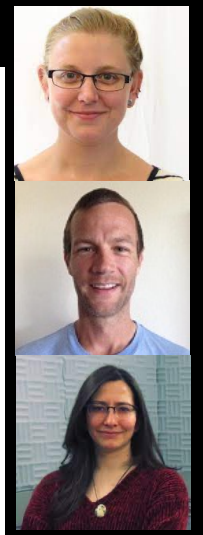

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Vary bias

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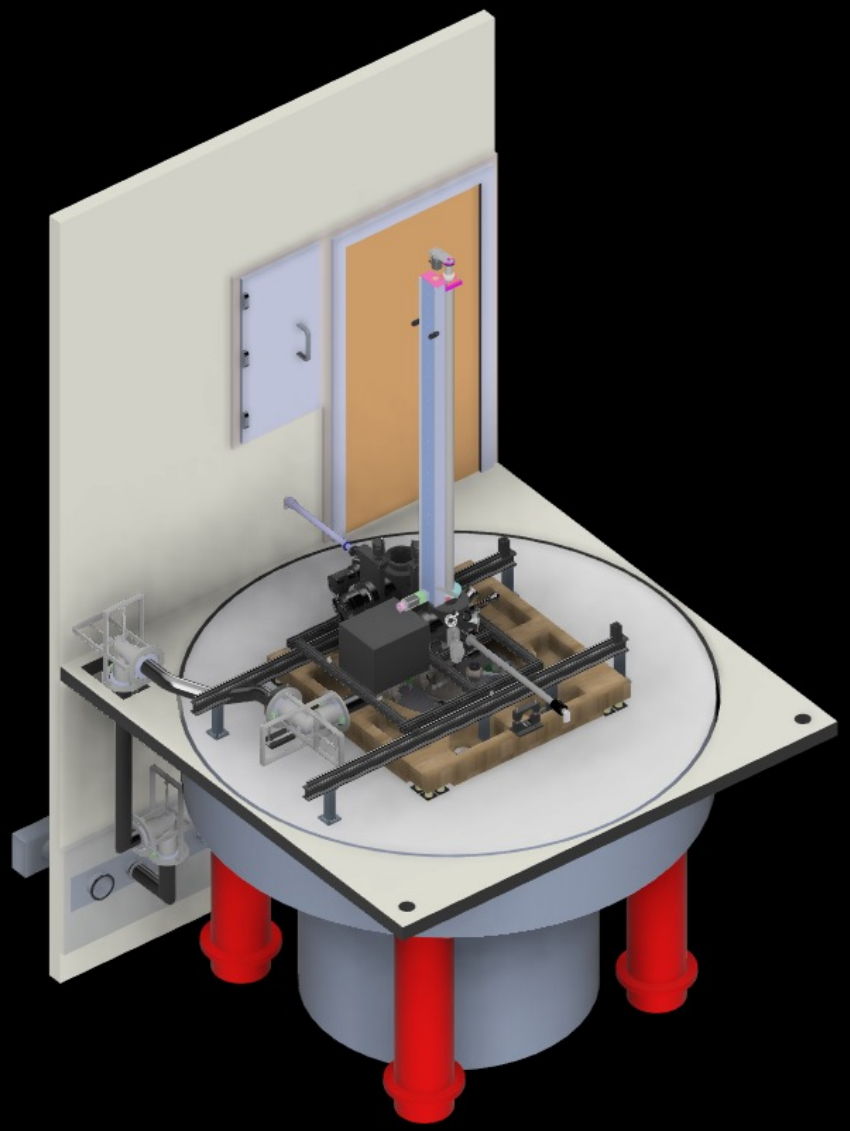
Built ultra-quiet room for microscope



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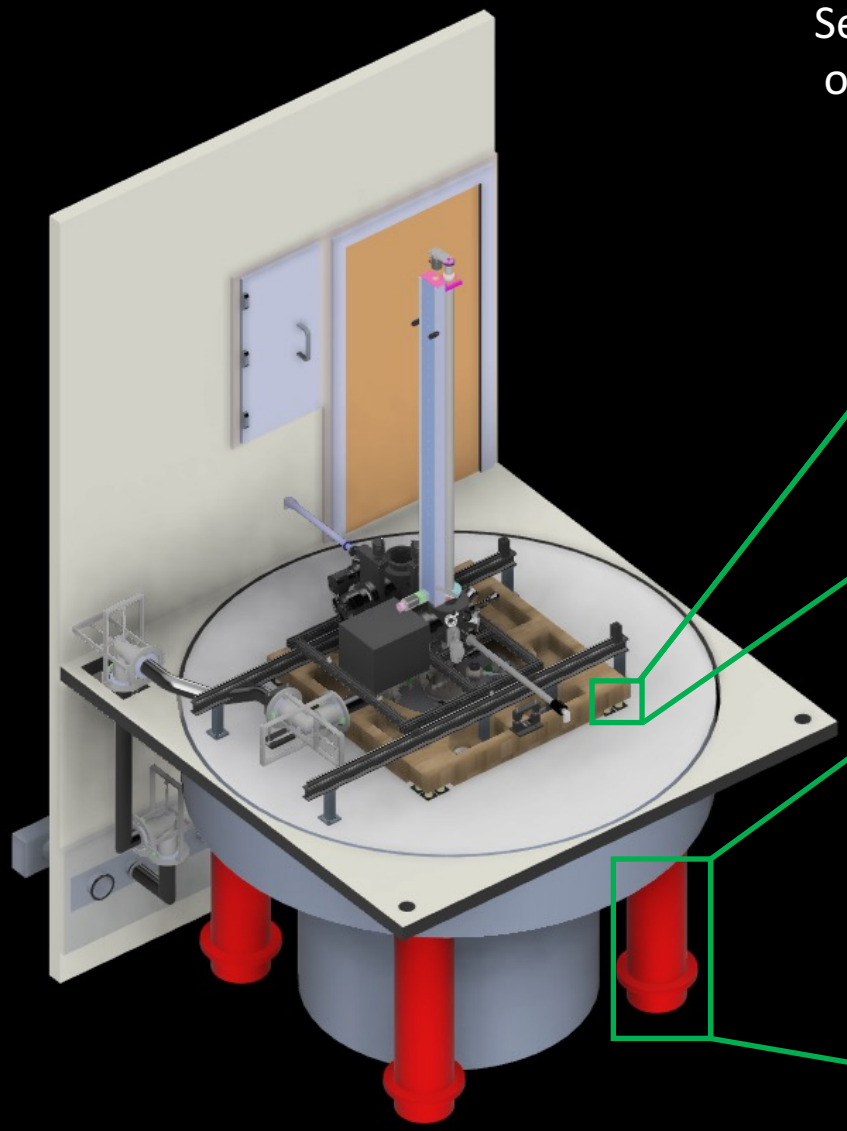
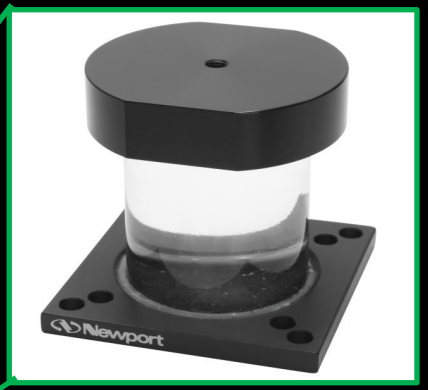


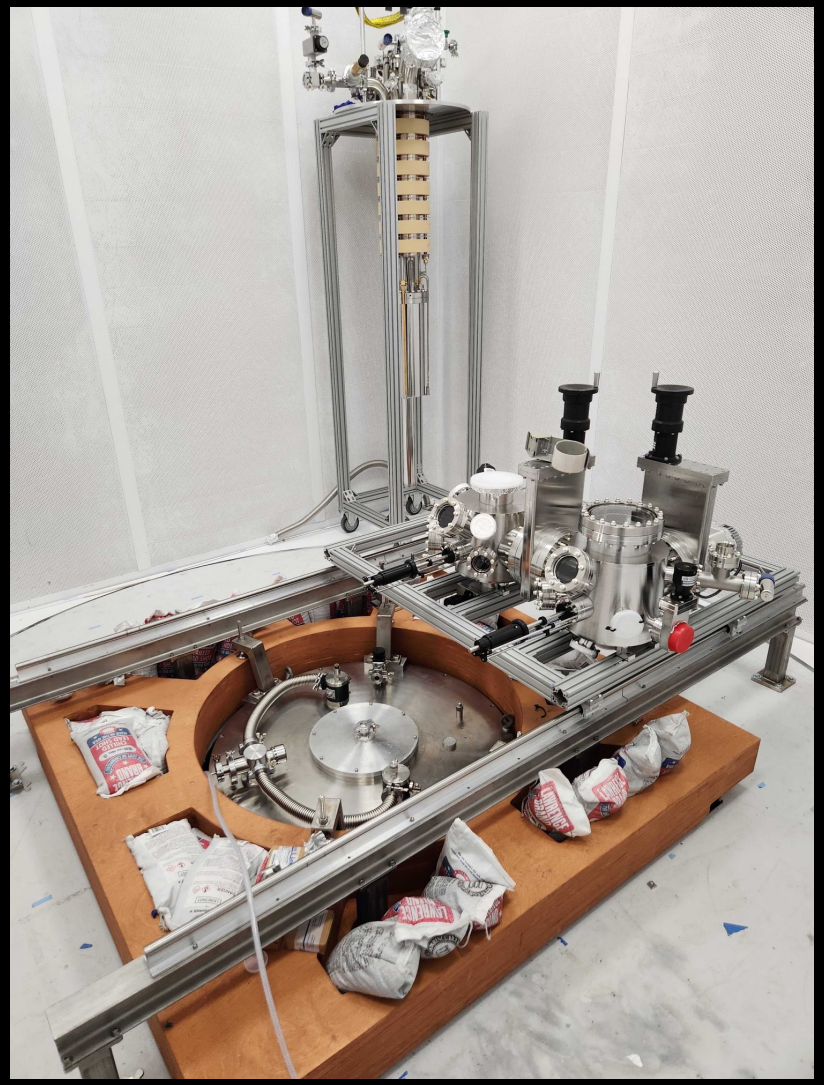
Second stage of vibration isolation:



First stage of vibration isolation:

10 mK base temperature system with 14 T magnet

Ultra-quiet room built for system



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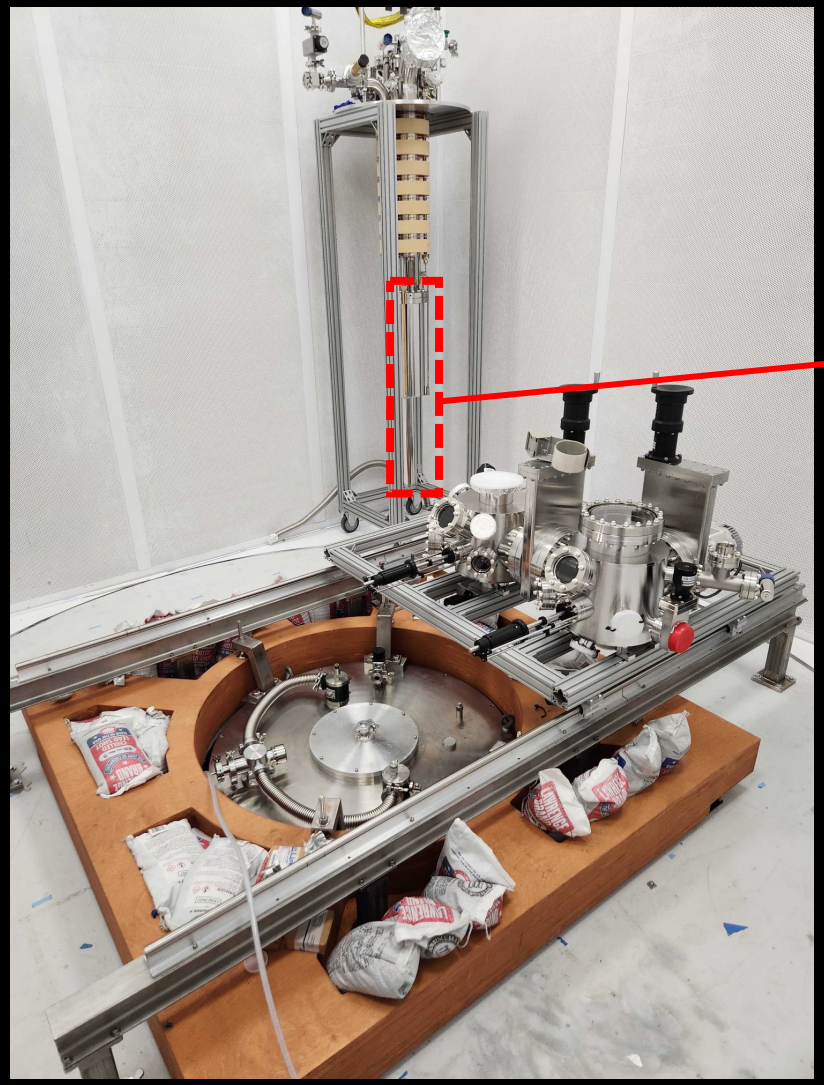
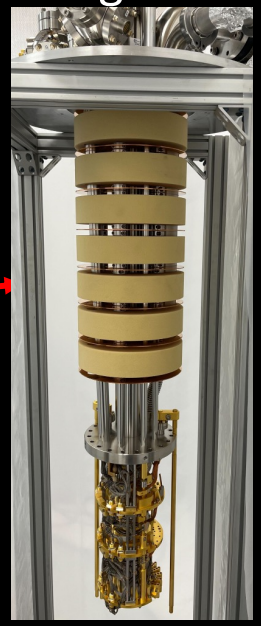
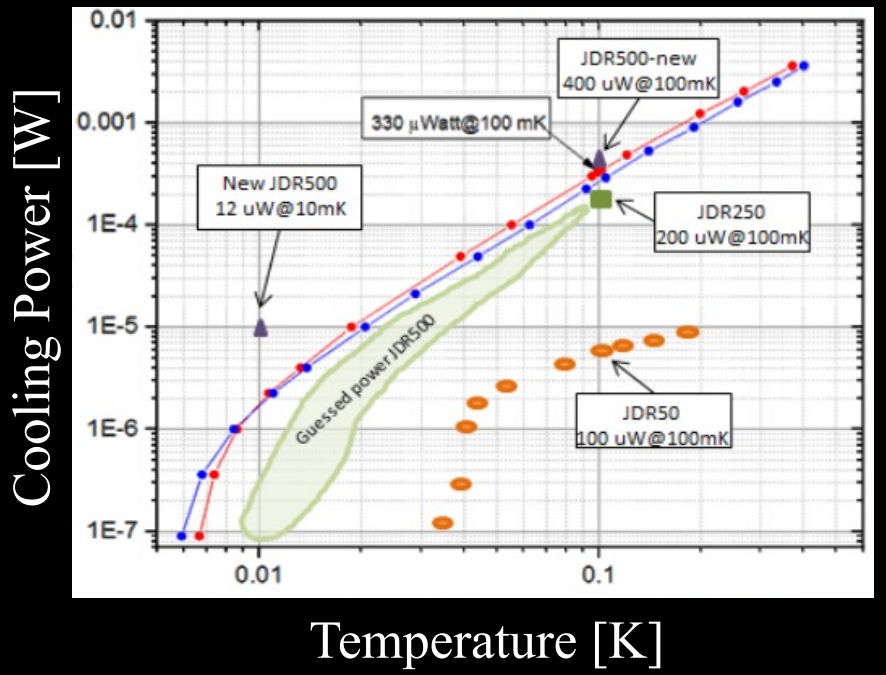


9 mK base temperature dilution refrigerator



Cooling power (JDR500)



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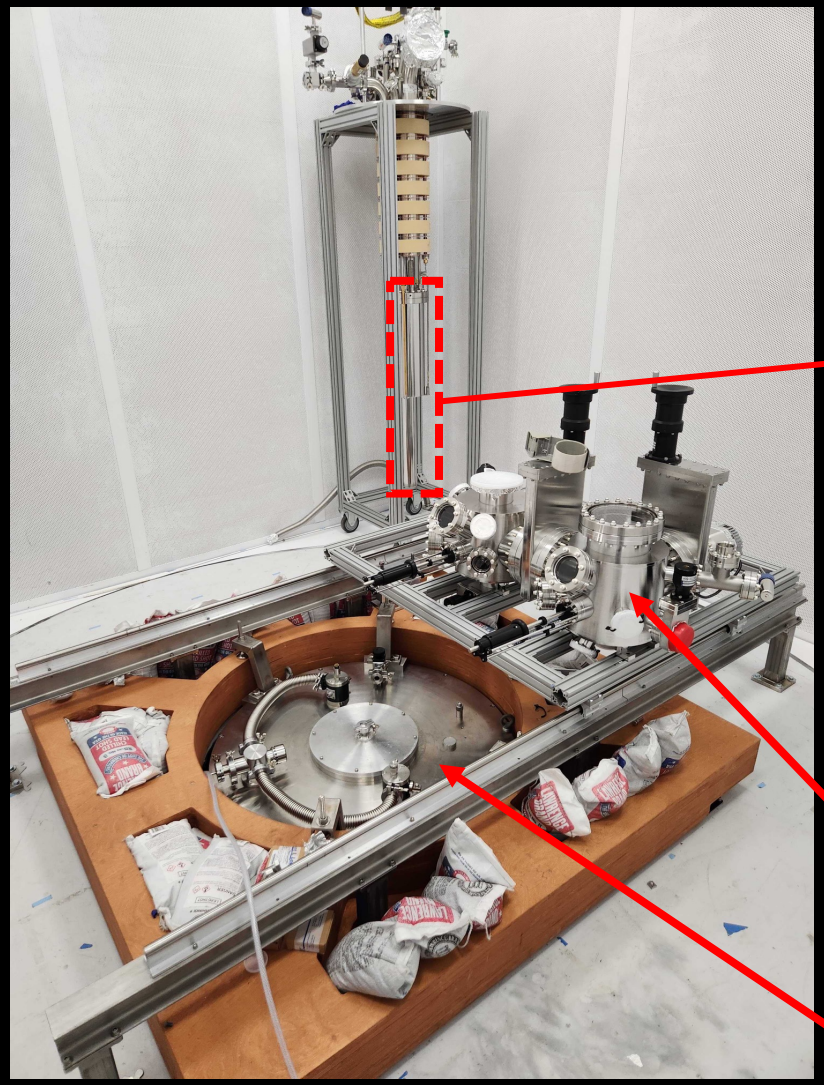

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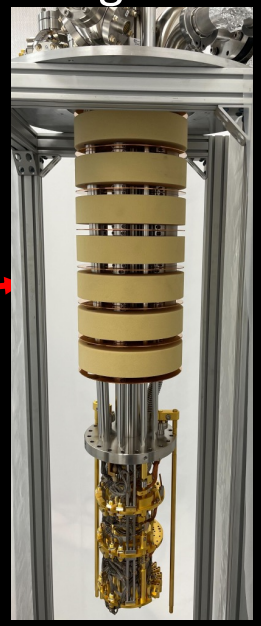
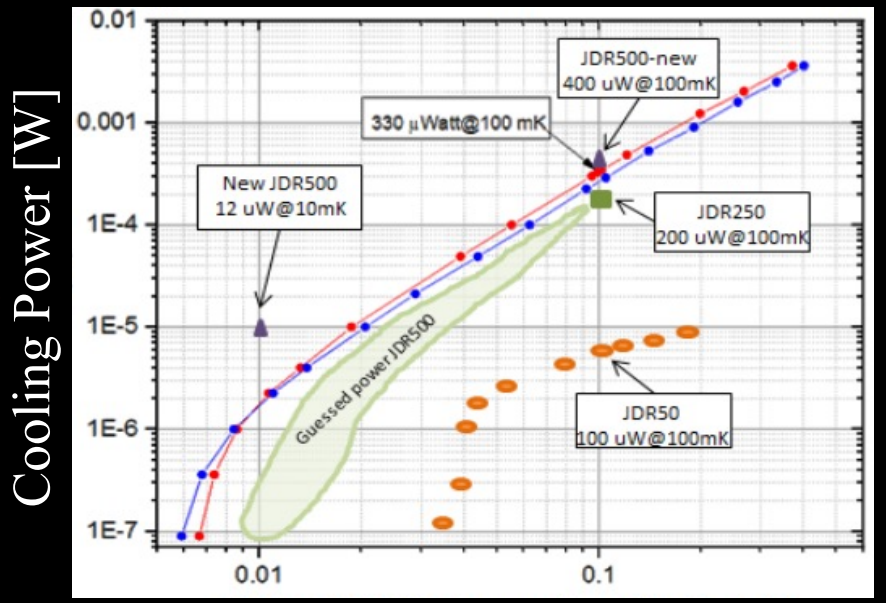


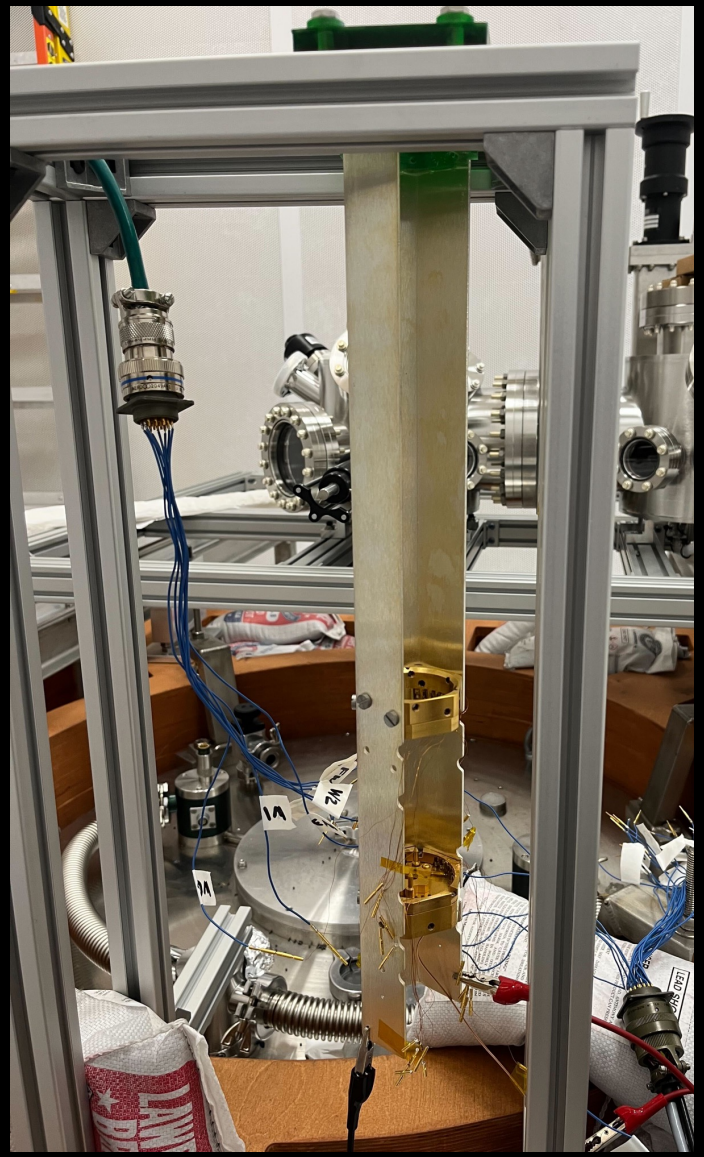
Movable UHV system with sample/probe storage and preparation chamber

14 Tesla superconducting magnet within Dewar

Cooling power (JDR500)



Microscope enables a variety of measurements



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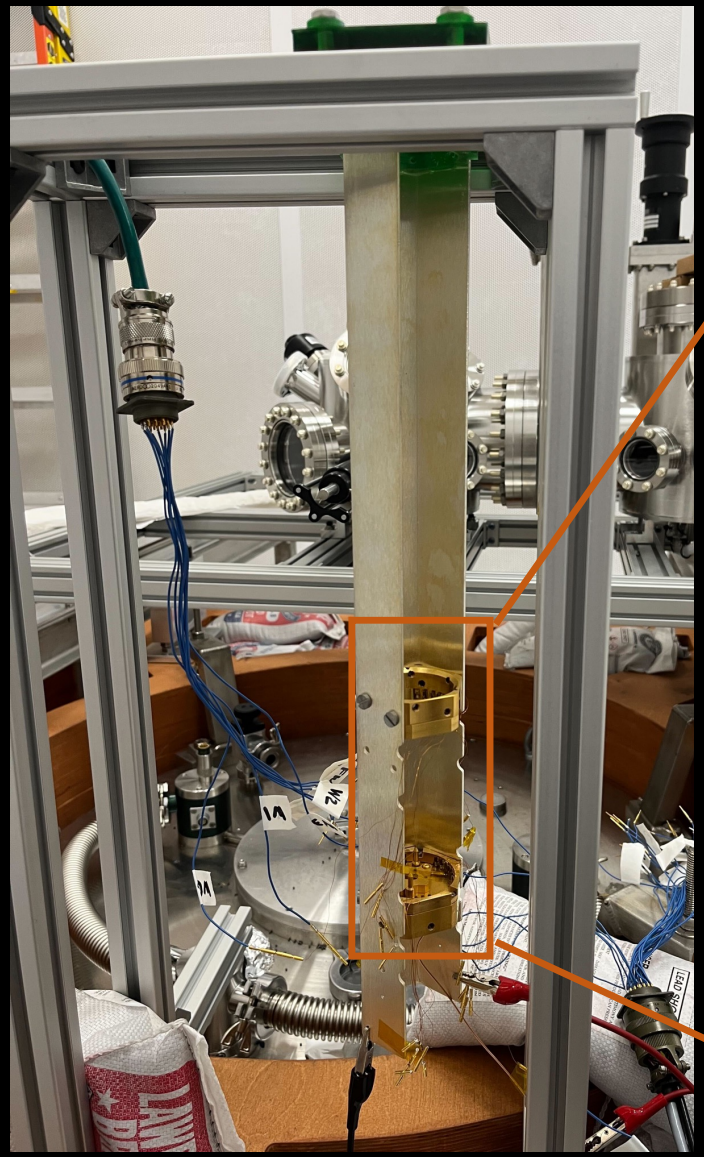

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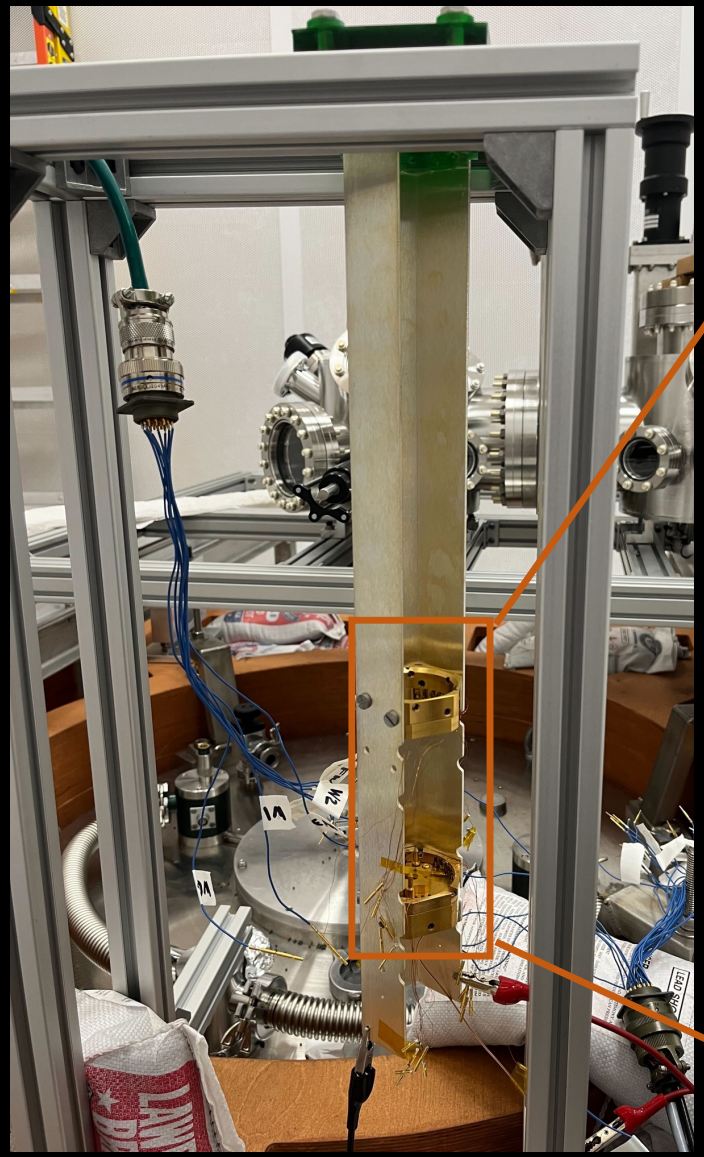
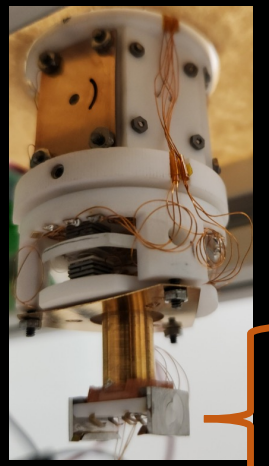
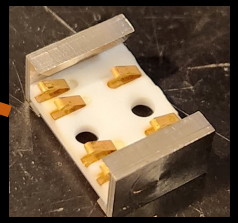


3-axis positioner

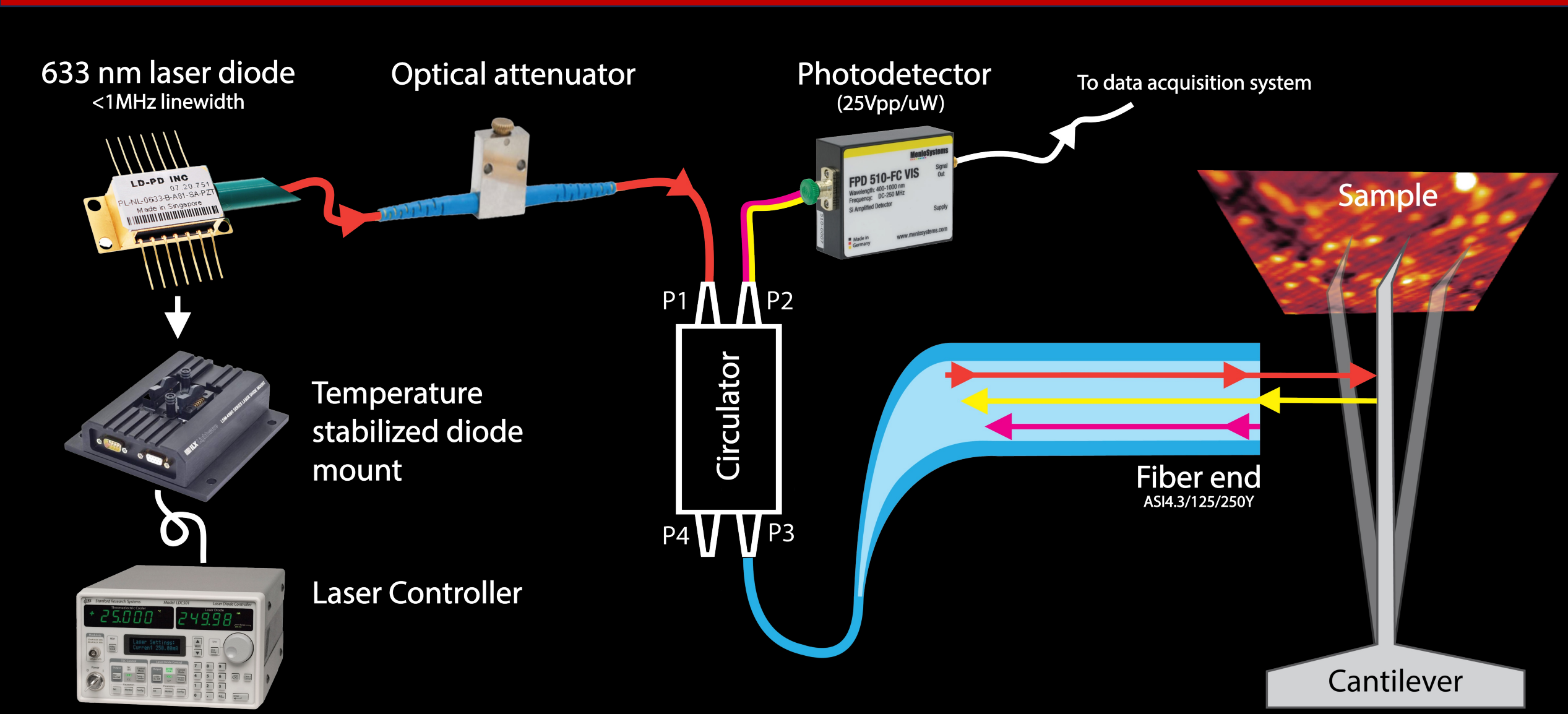


6 contact sample holder

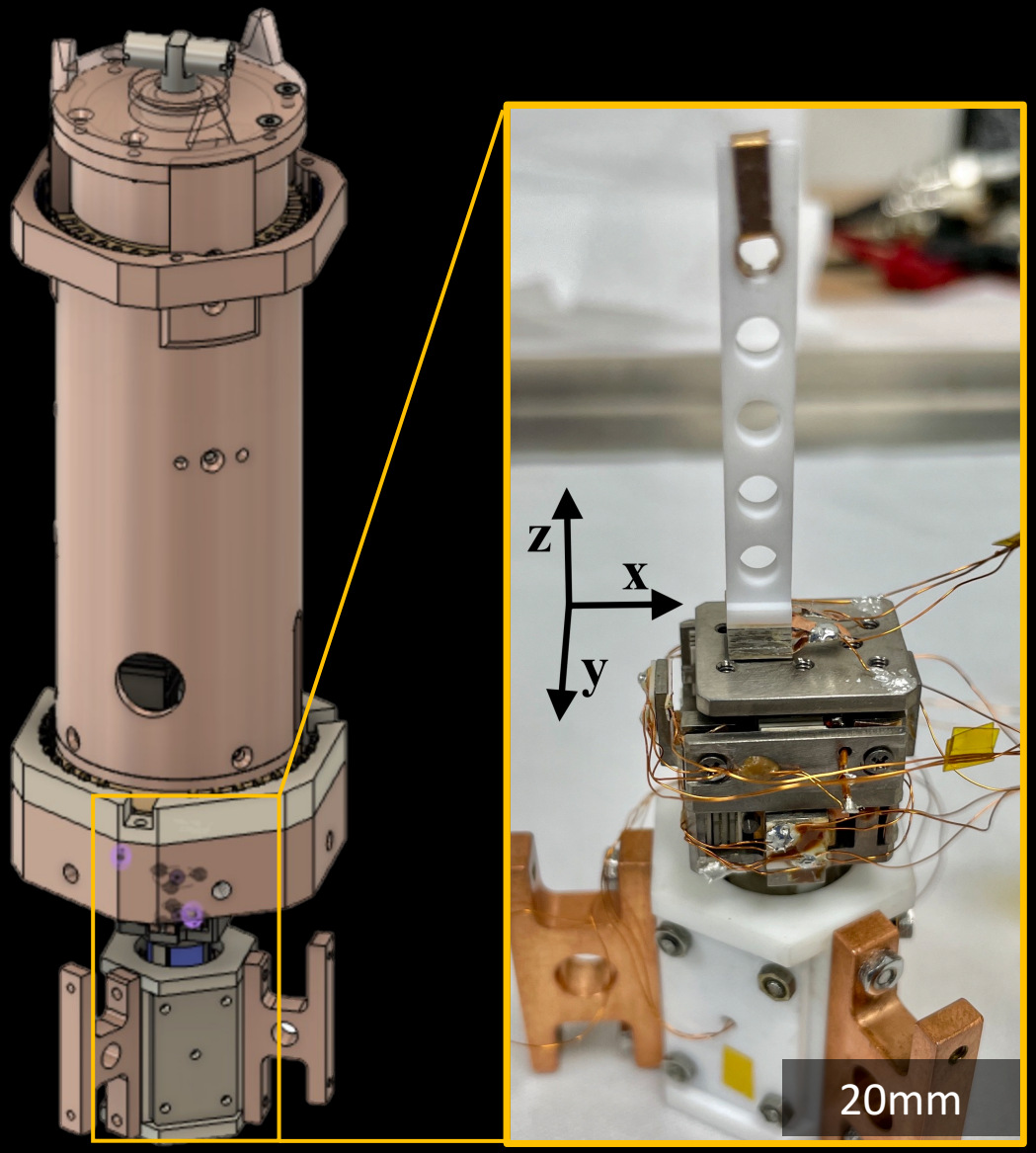


Multi-contact probe holder

Use interferometer to detect cantilever oscillations



Built custom positioning system to align fiber



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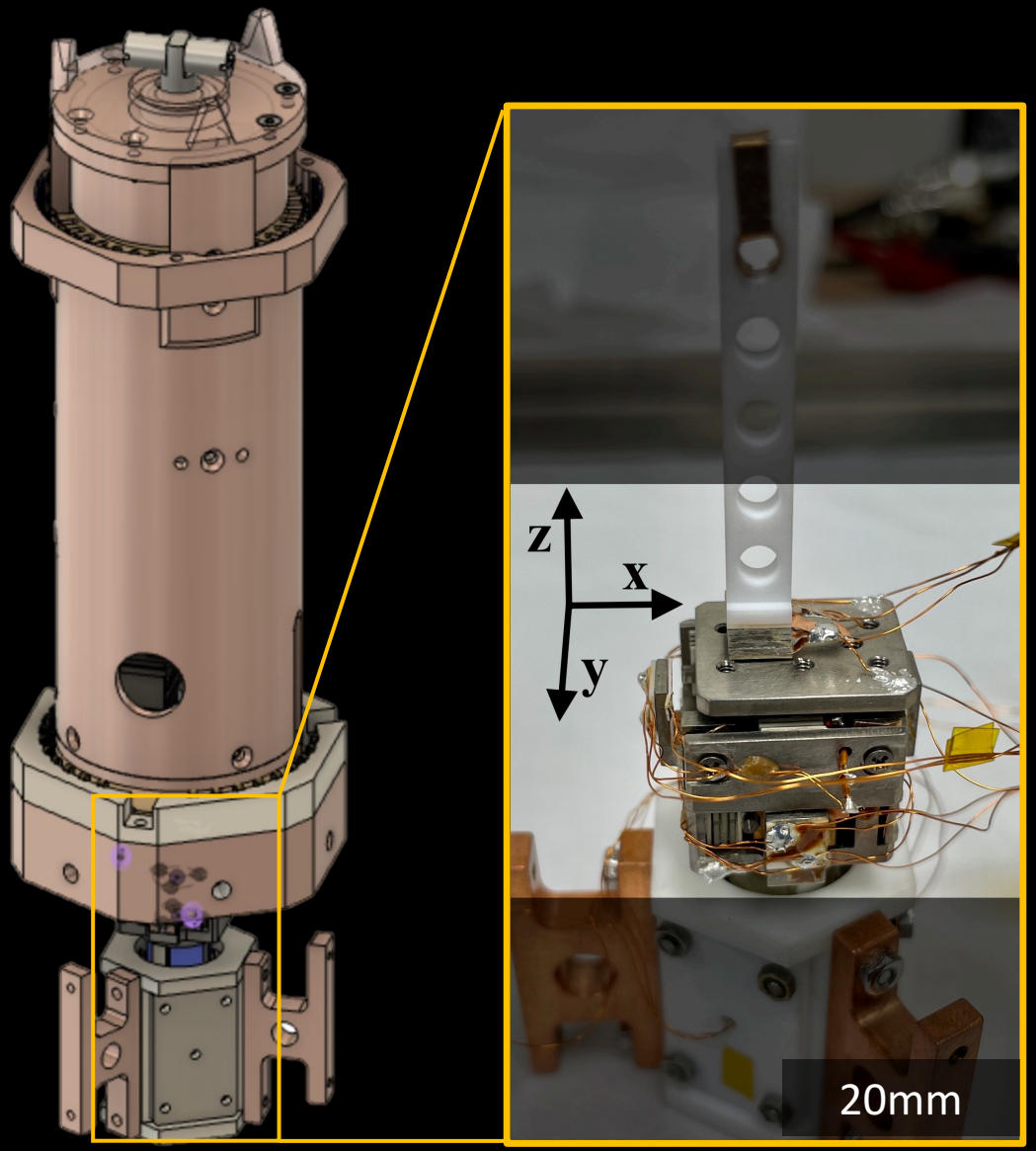
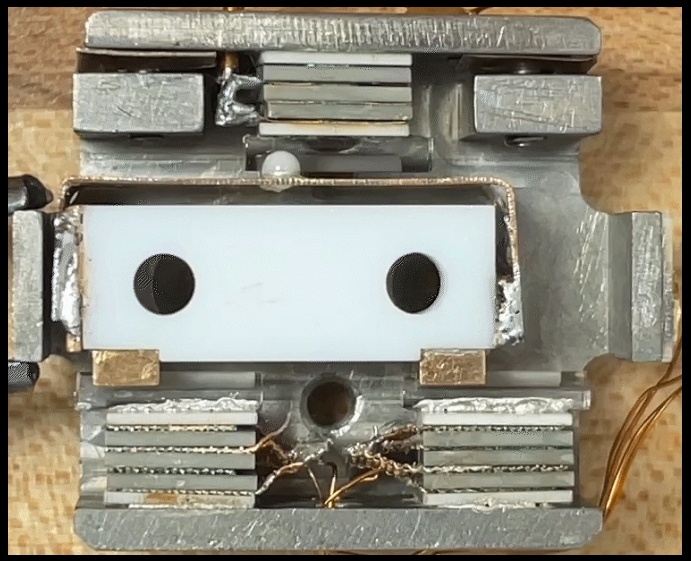
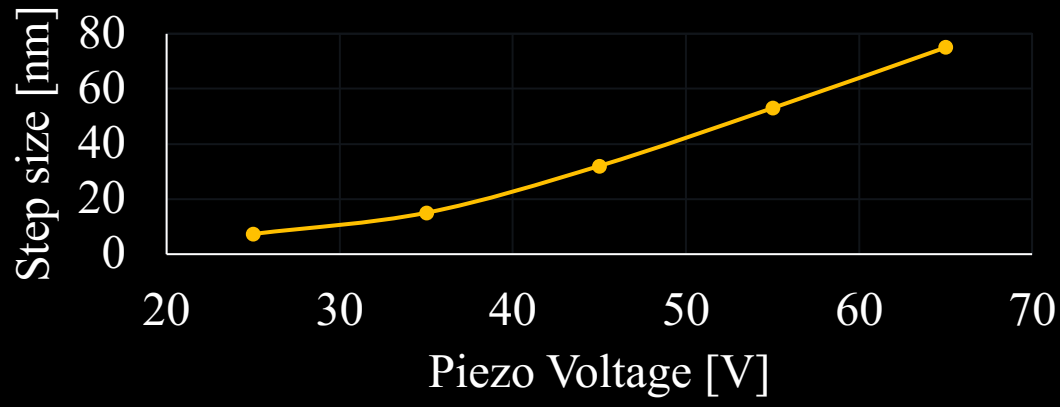


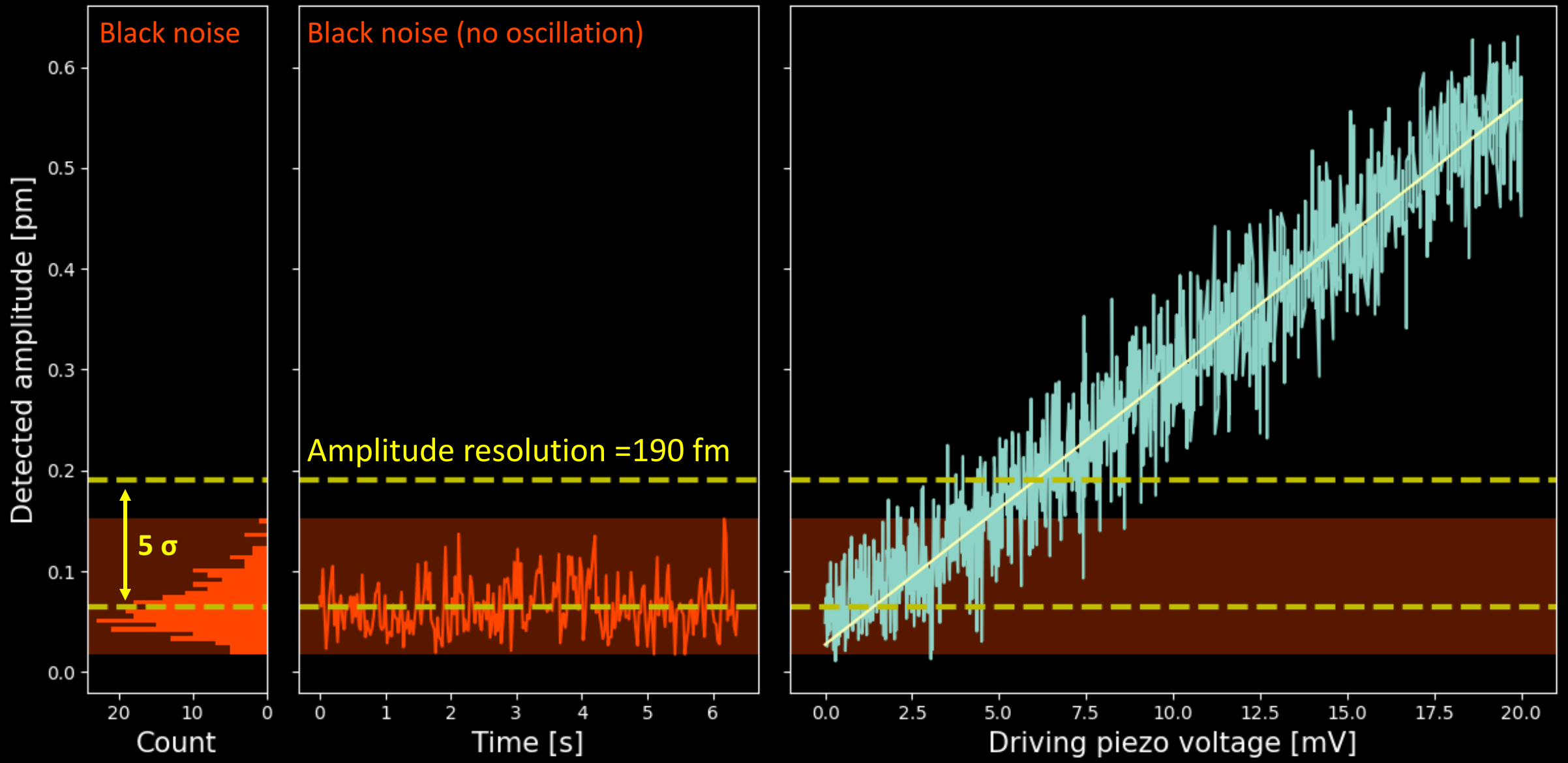
X walker moving at 40V, 2kHz voltage, room temperature



Piezo walker average step size vs piezo ramp voltage



Ultimate oscillation resolution of 190 fm at RT



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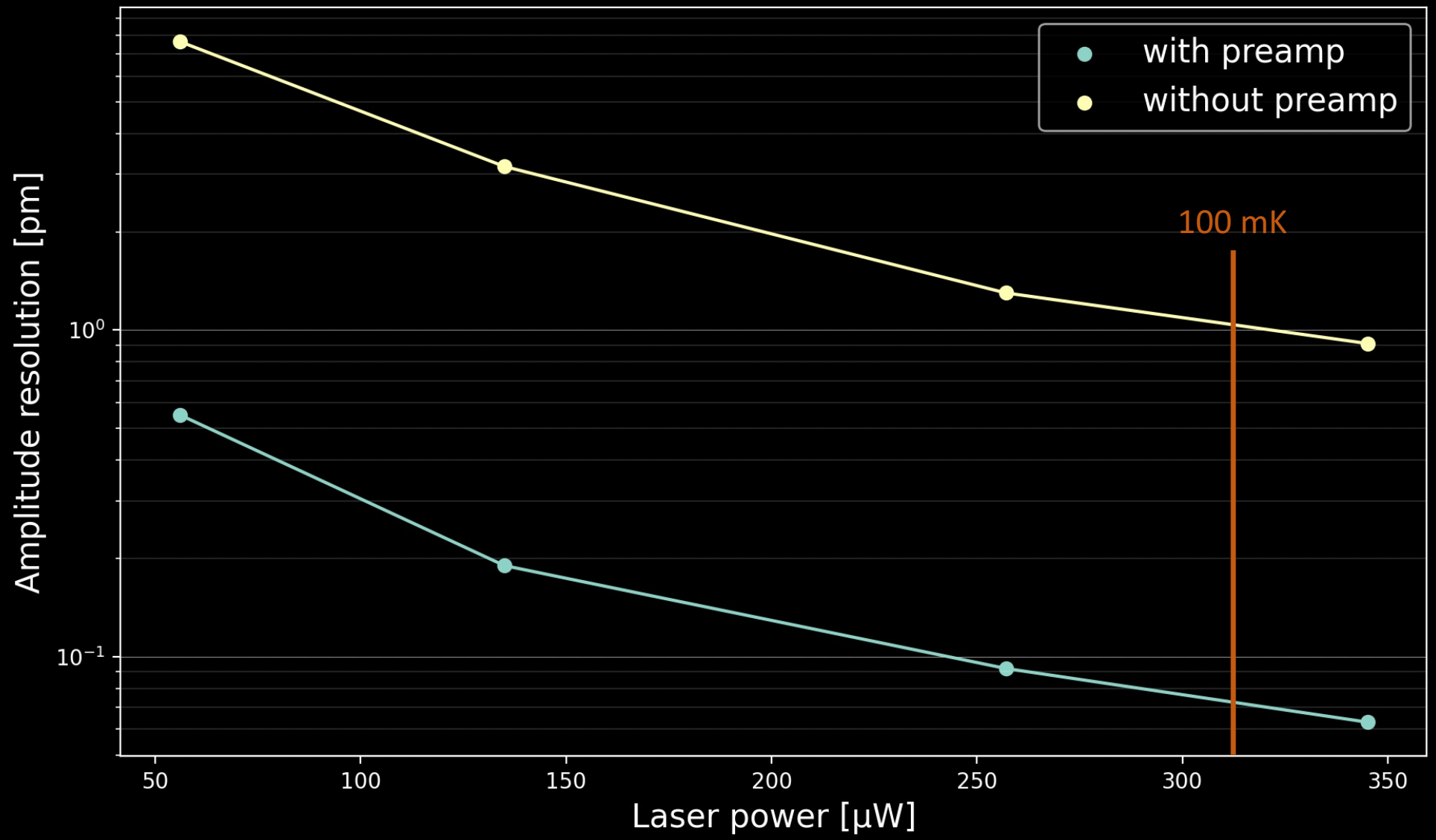
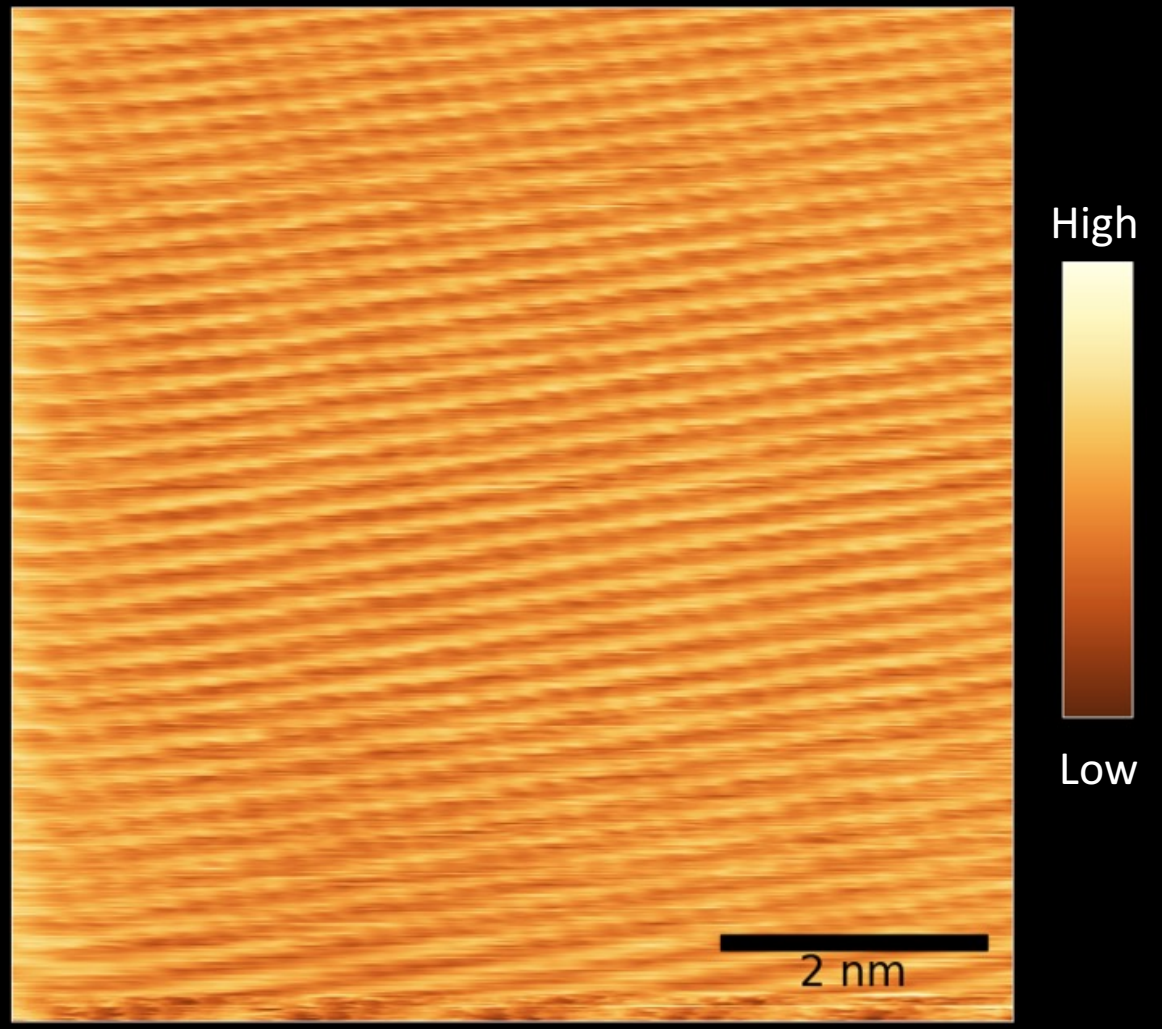


Achieved atomic resolution with STM

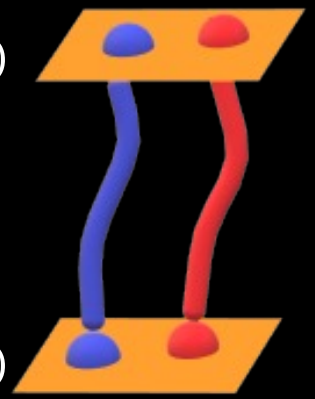
- Currently testing microscope at room temperature
- Achieved atomic resolution with STM
- Now focusing on p-AFM at room temperature



Majoranas as a new platform for quantum computing

Use system where information is topologically protected

$\psi_i(x_1, x_2, \ldots x_N)$



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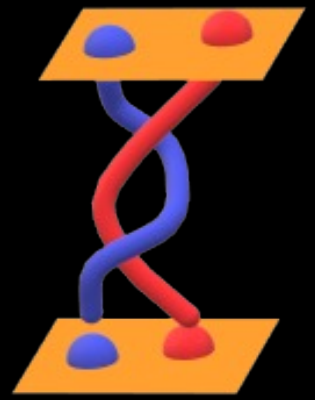

$\psi_j(x_2, x_1, \ldots x_N)$

$\psi_i(x_1, x_2, \ldots x_N)$

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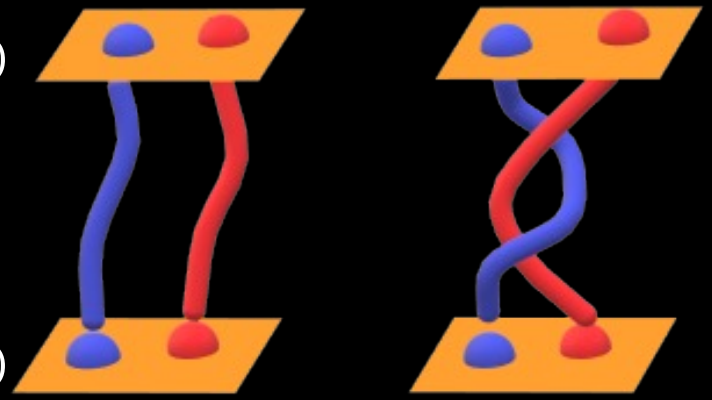

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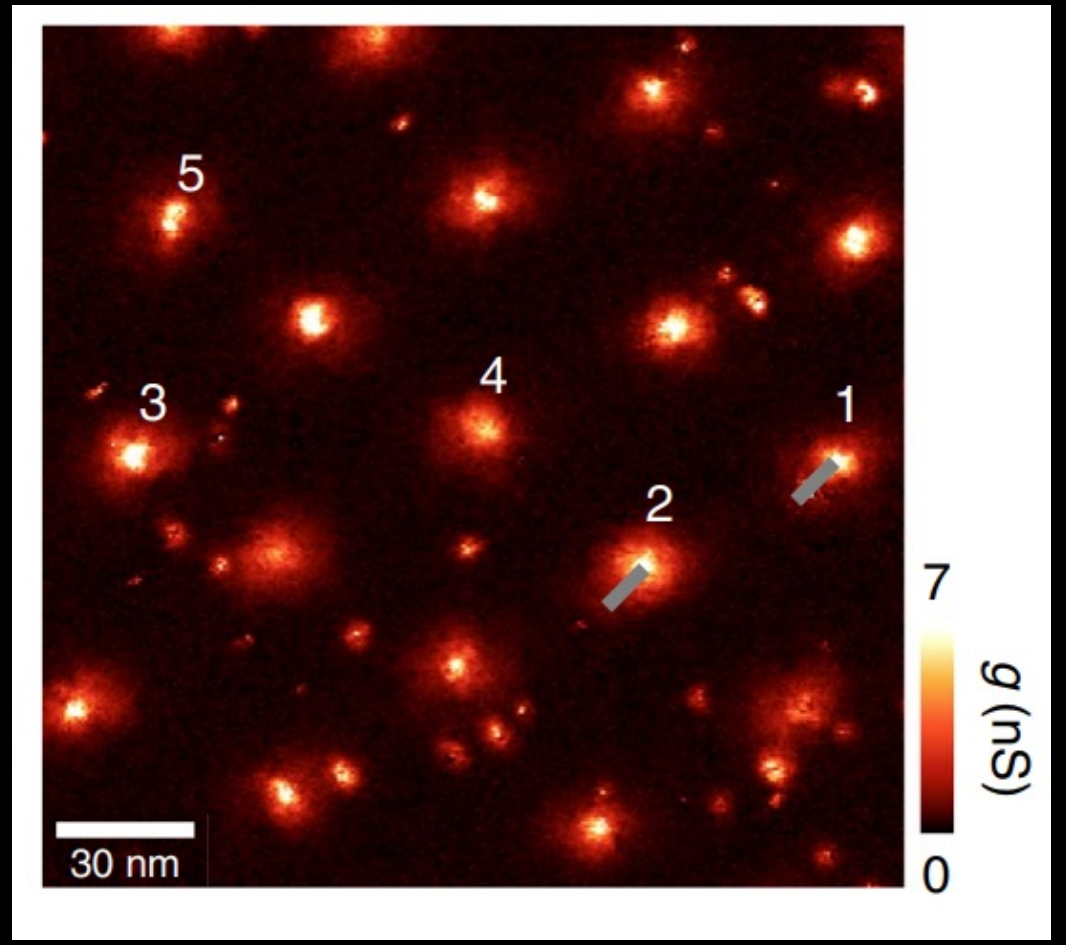
$\psi_i(x_1, x_2, \ldots x_N)$

$FeTe_{1-x}Se_x$



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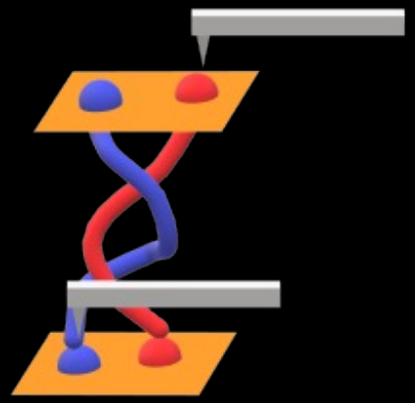
Study motion and dissipation phenomena of MBS

MFM manipulation



Study motion and dissipation phenomena of MBS

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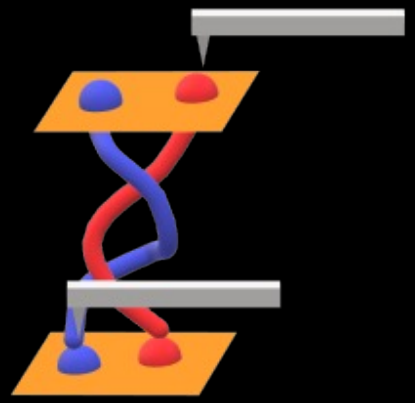
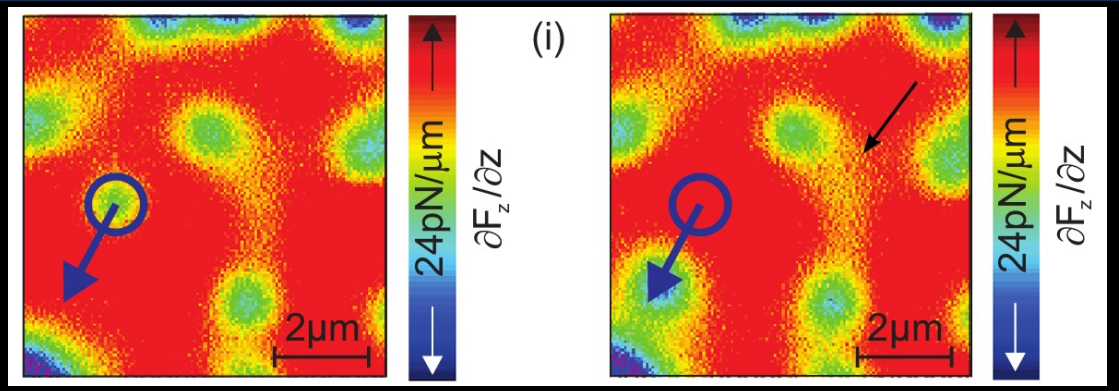
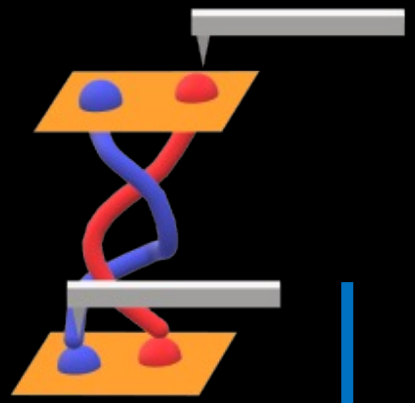




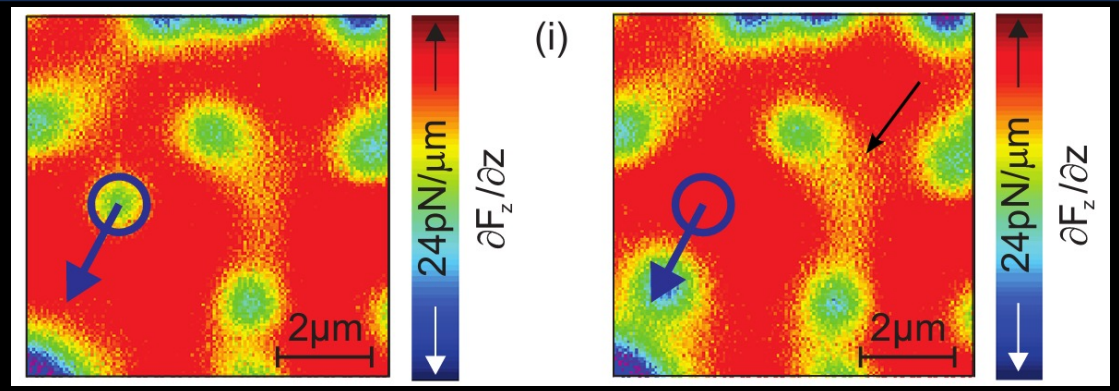
Study motion and dissipation phenomena of MBS

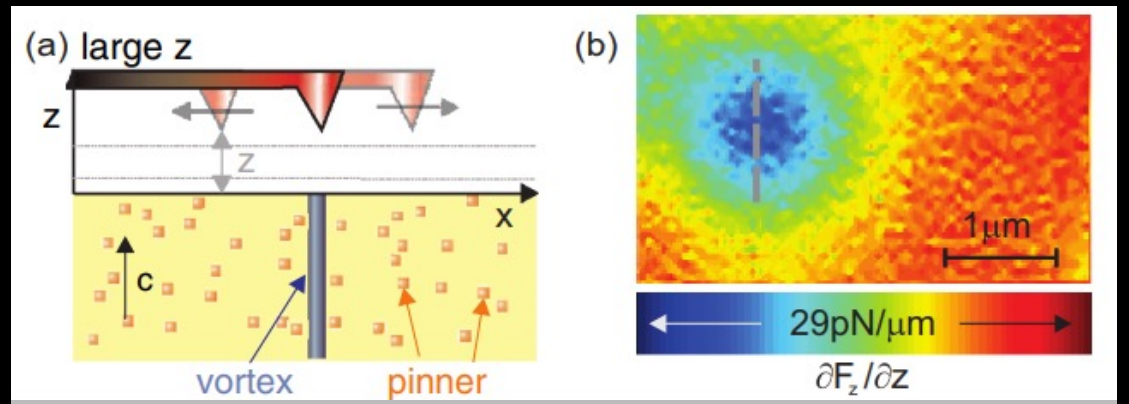
MFM manipulation



Decrease Distance

Increase Force





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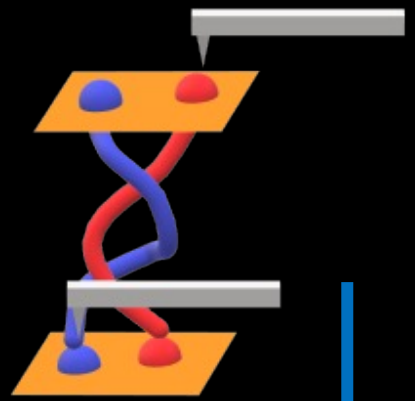
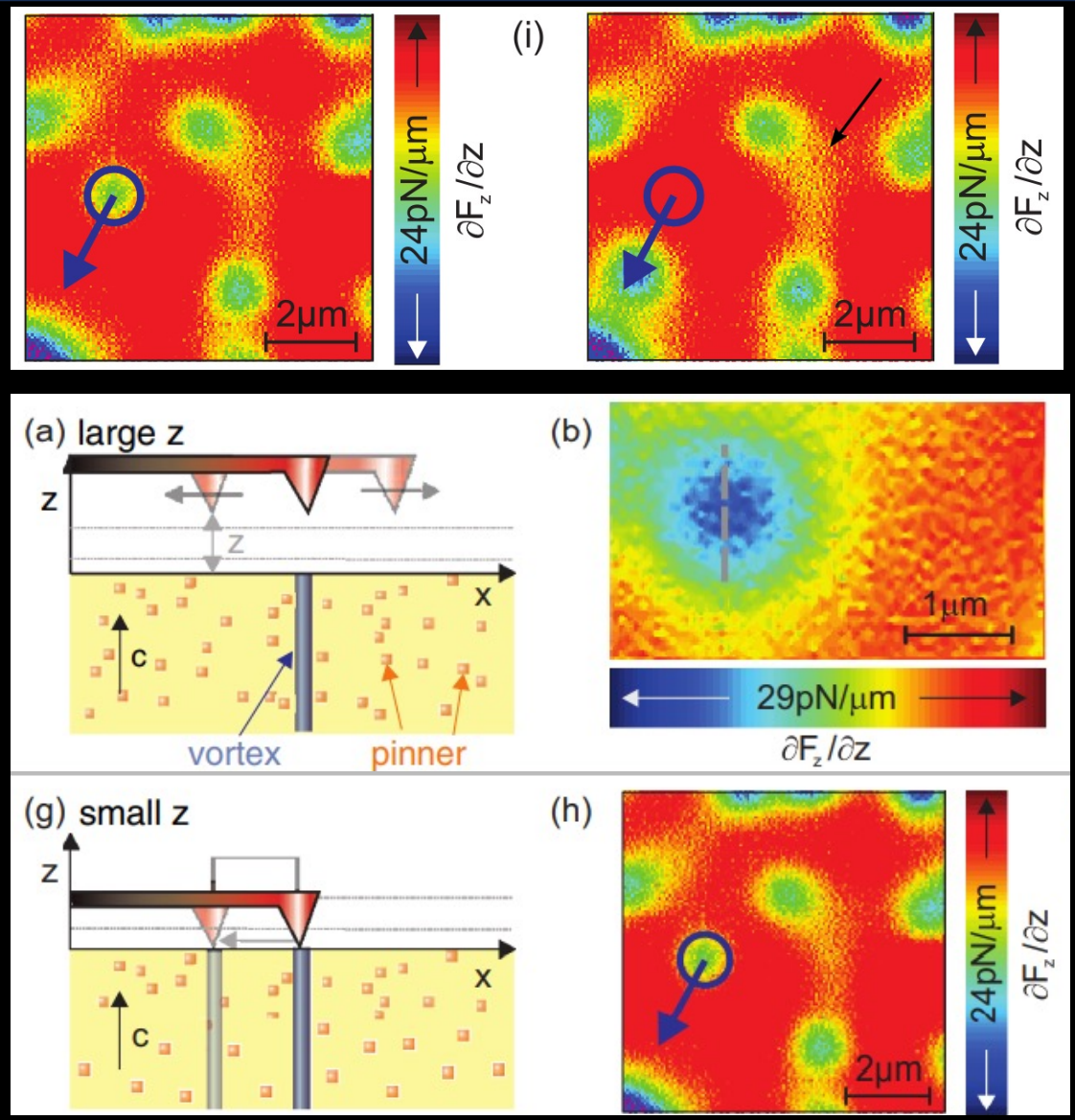
Study motion and dissipation phenomena of MBS

MFM manipulation



Decrease Distance

Increase Force



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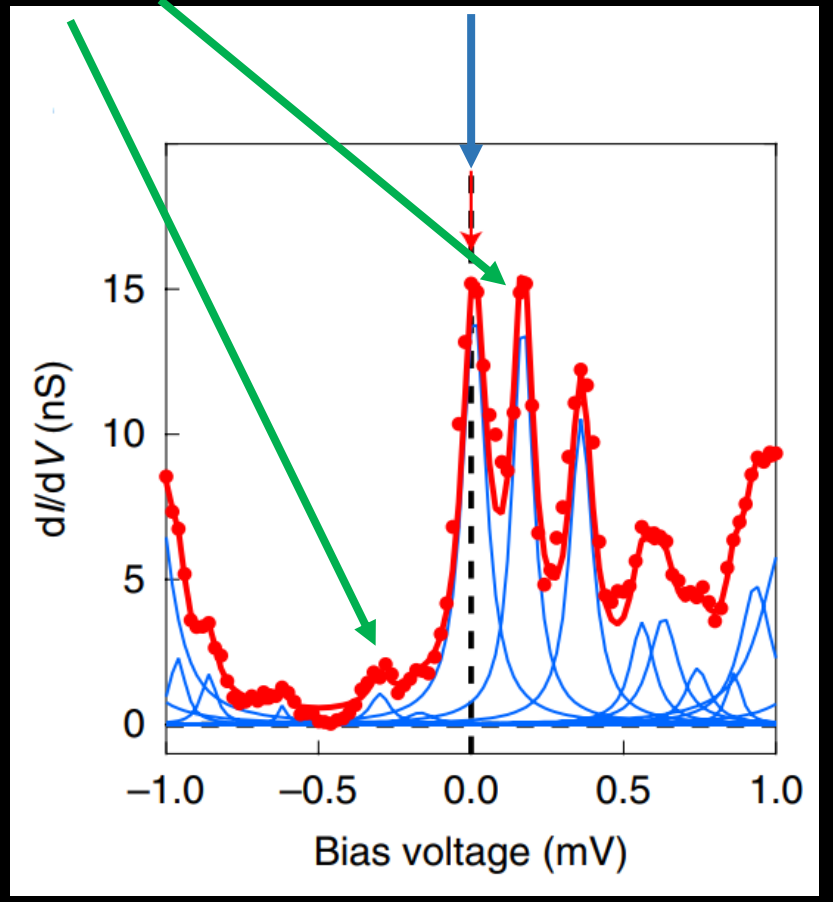
Caroli–de Gennes–Matricon (CdGM) bound states

Zero bias conductance peak (ZBCP)



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Conclusion

- pAFM enables ultra-sensitive dissipative measurements
- We are finishing construction of a new microscope to use this technique in quantum systems