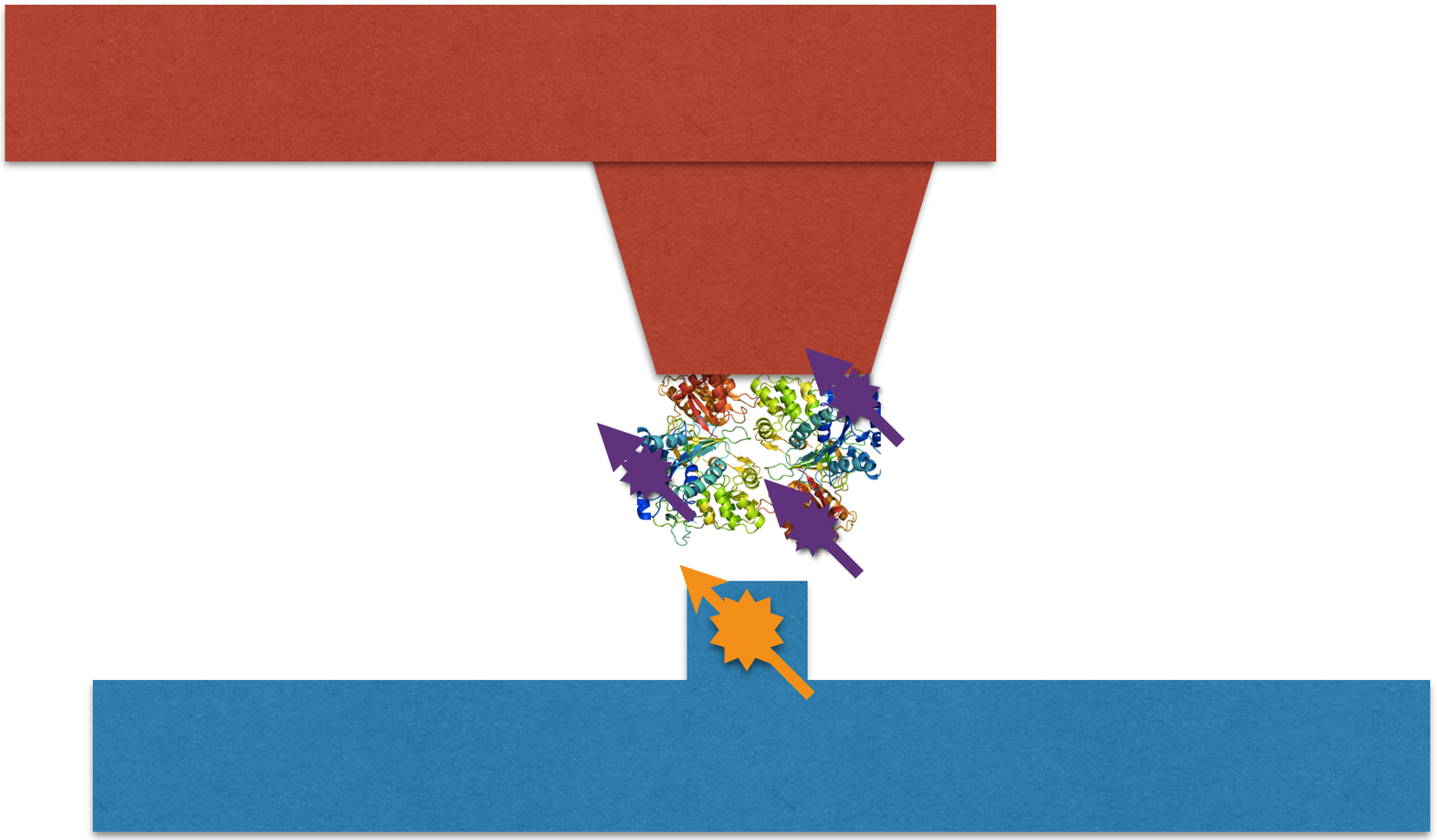
An ultrastable scanning probe microscope for imaging single spins with diamond nitrogen vacancy centers



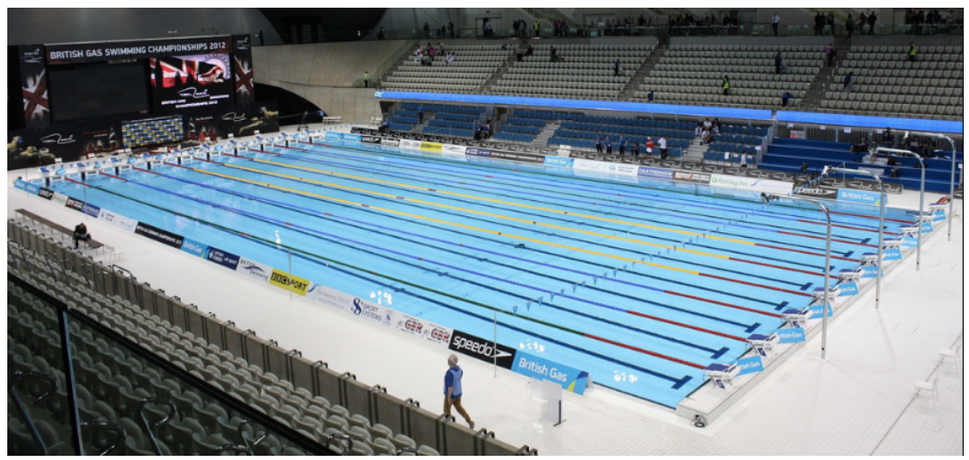
Dolev Bluvstein

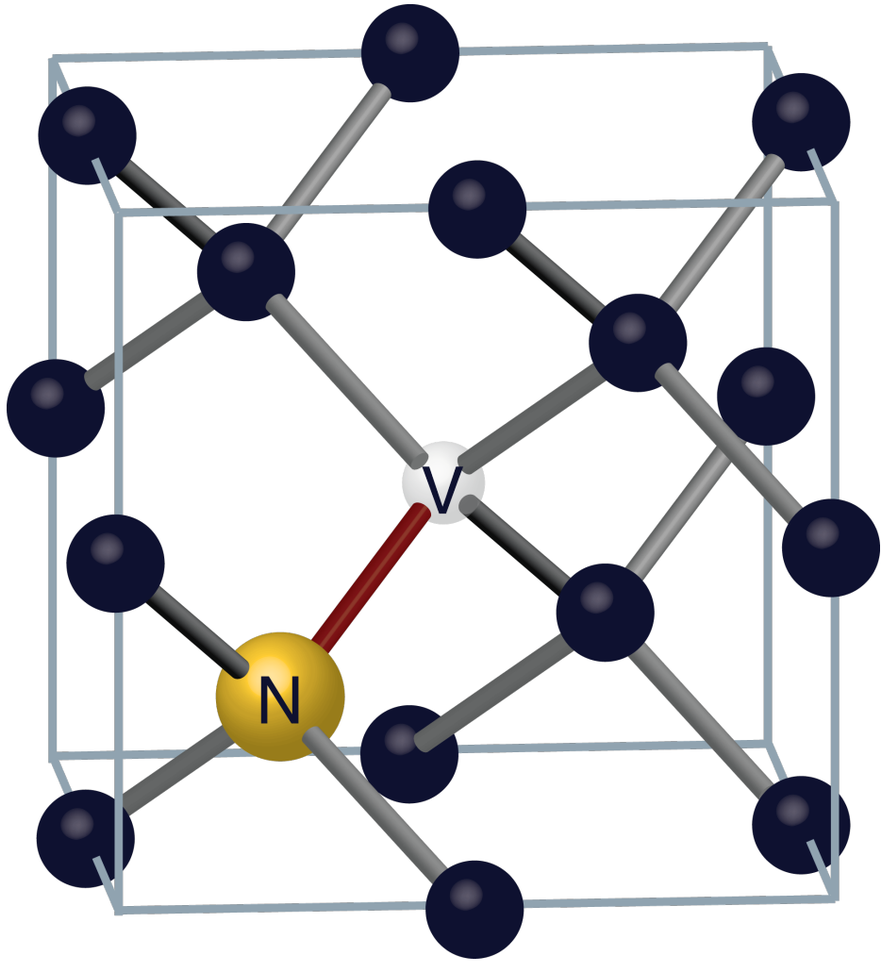
Jayich Group

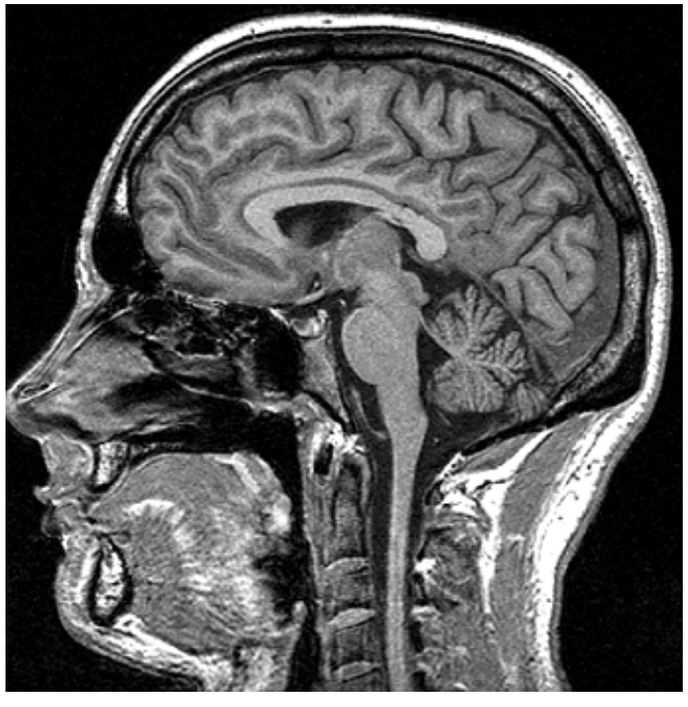
The Nitrogen Vacancy center: a promising frontier

MRI → **NV**

1 trillion nm^3 → **5 nm^3**







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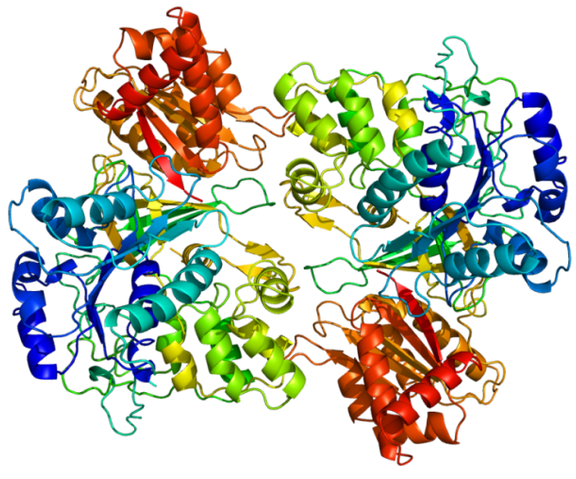
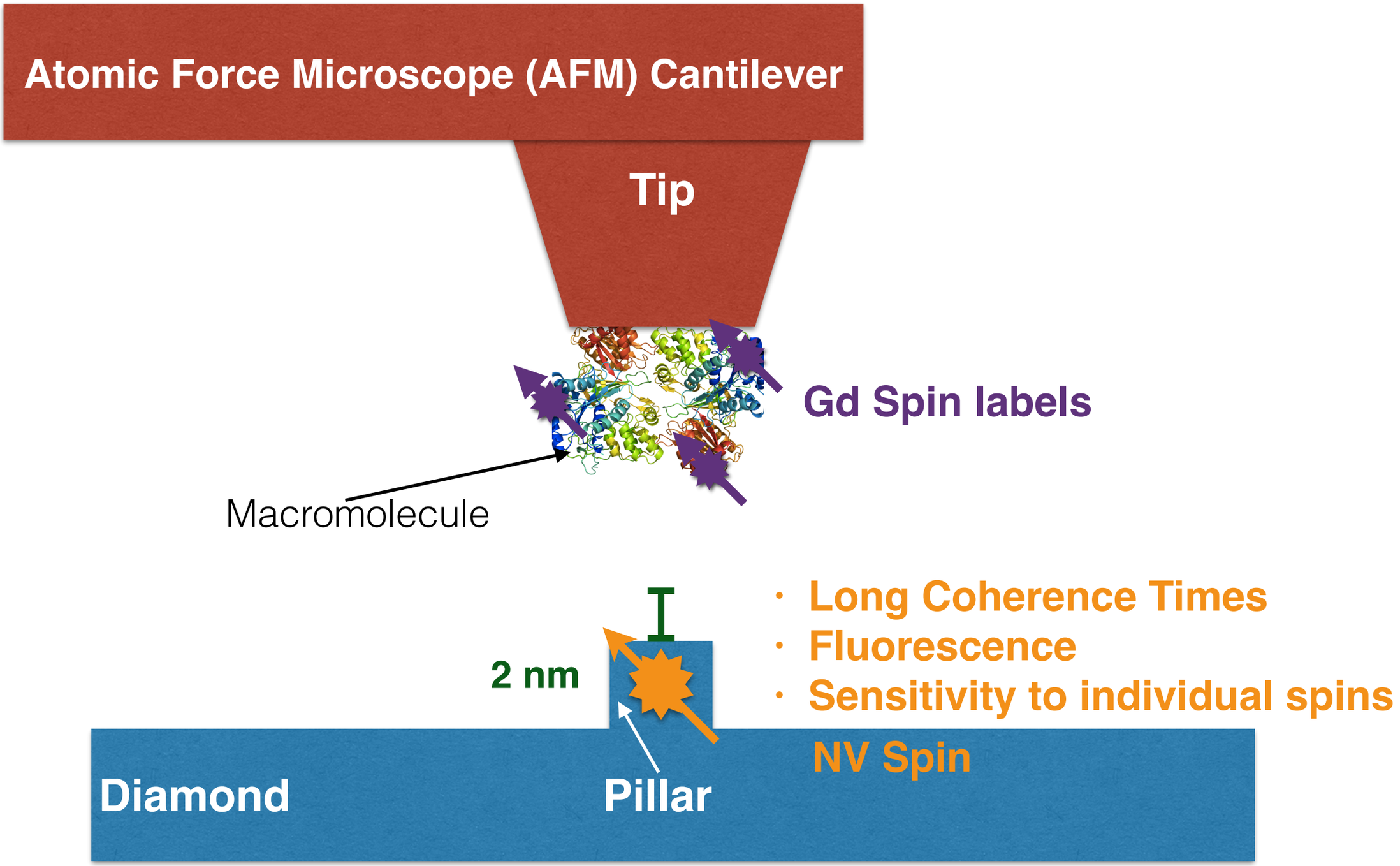


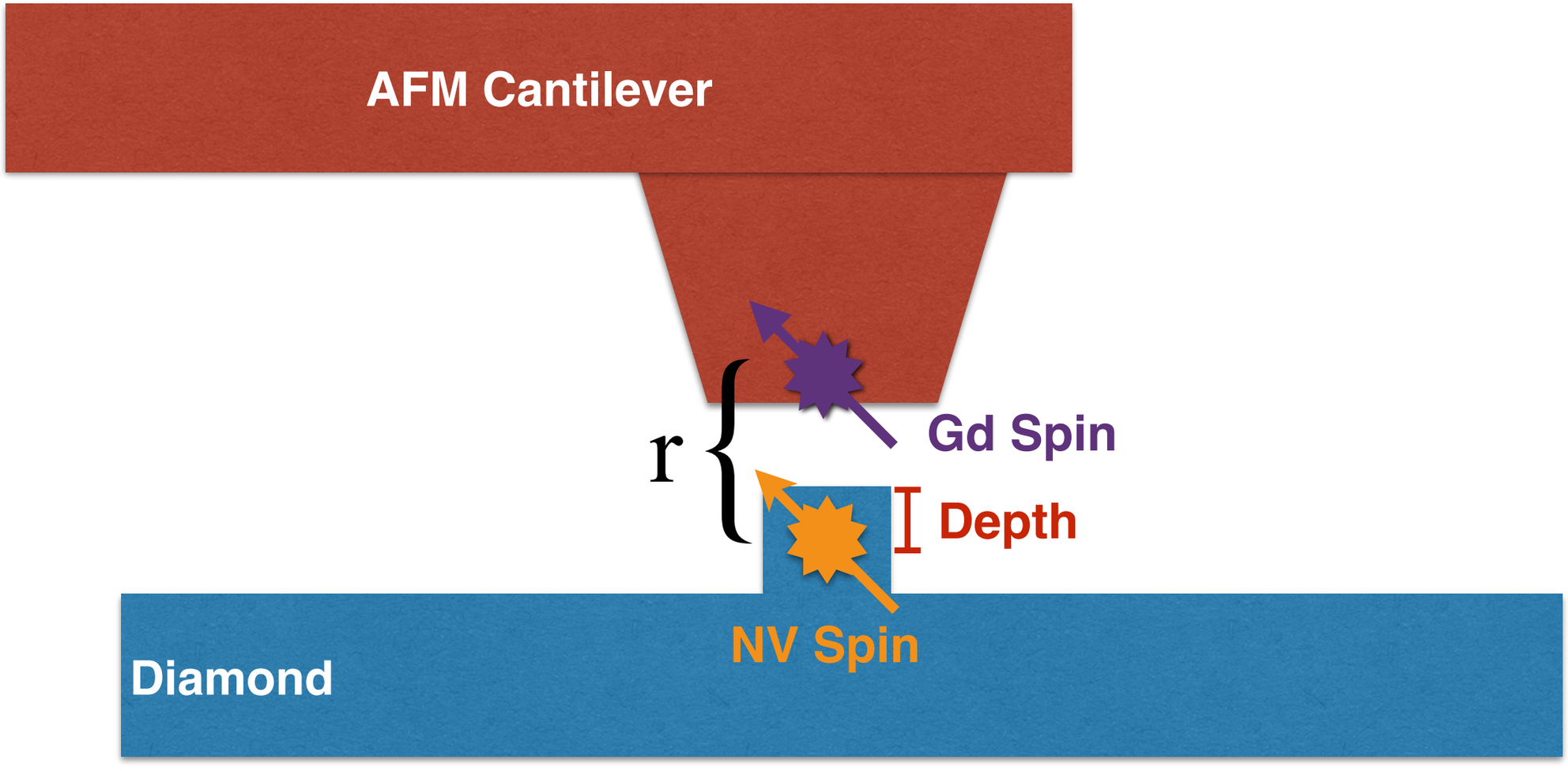
The Nitrogen Vacancy center as a powerful sensor



Many challenges to overcome

Interaction Strength $\propto \frac{1}{r^3}$

Problems: ☐ Drift ☐ Tilt ☐ NV Depth



MilliKelvin stability is critical

Drift

- 1 nm drift per milliKelvin
- Temp-regulated lab fluctuates 100s of mK in minutes

	1 nm drift (1 mK)	20 nm drift (20 mK)
Signal Strength (arbitrary units):	**500**	**1**
Best Case Measuring Time:	**0.01 sec**	**42 minutes**

Achieving temperature stability with feedback loop

Drift

Microscopy Setup

Sensitive thermistor
(temperature dependent resistor)

Homemade Heaters
(resistance wire)

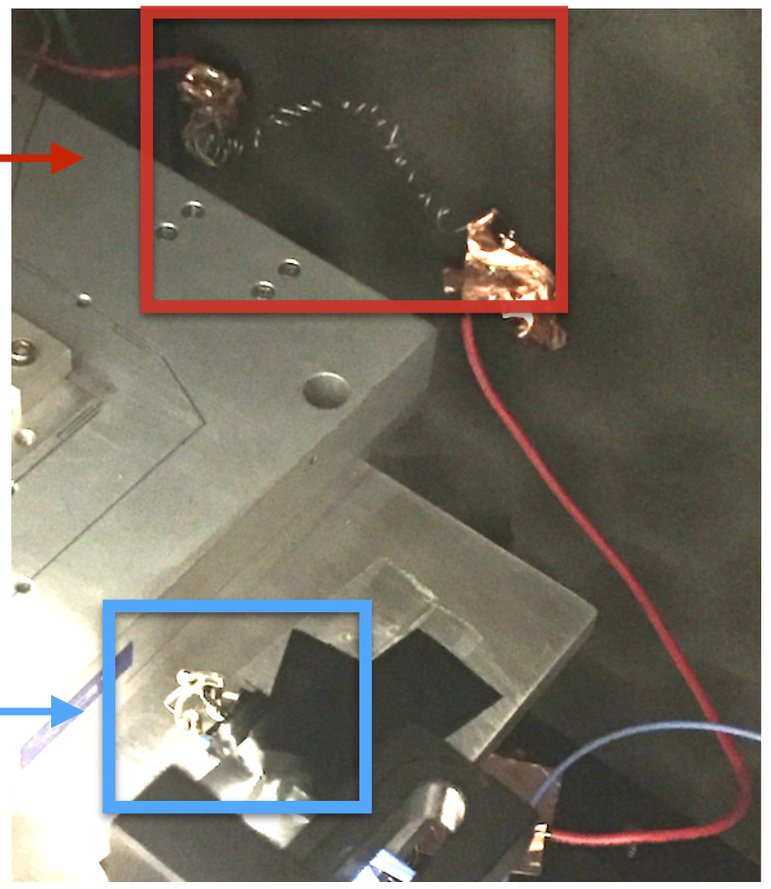
Insulation

D-to-A current amplifier circuit

Raspberry Pi computer

Multimeter/ Current Source

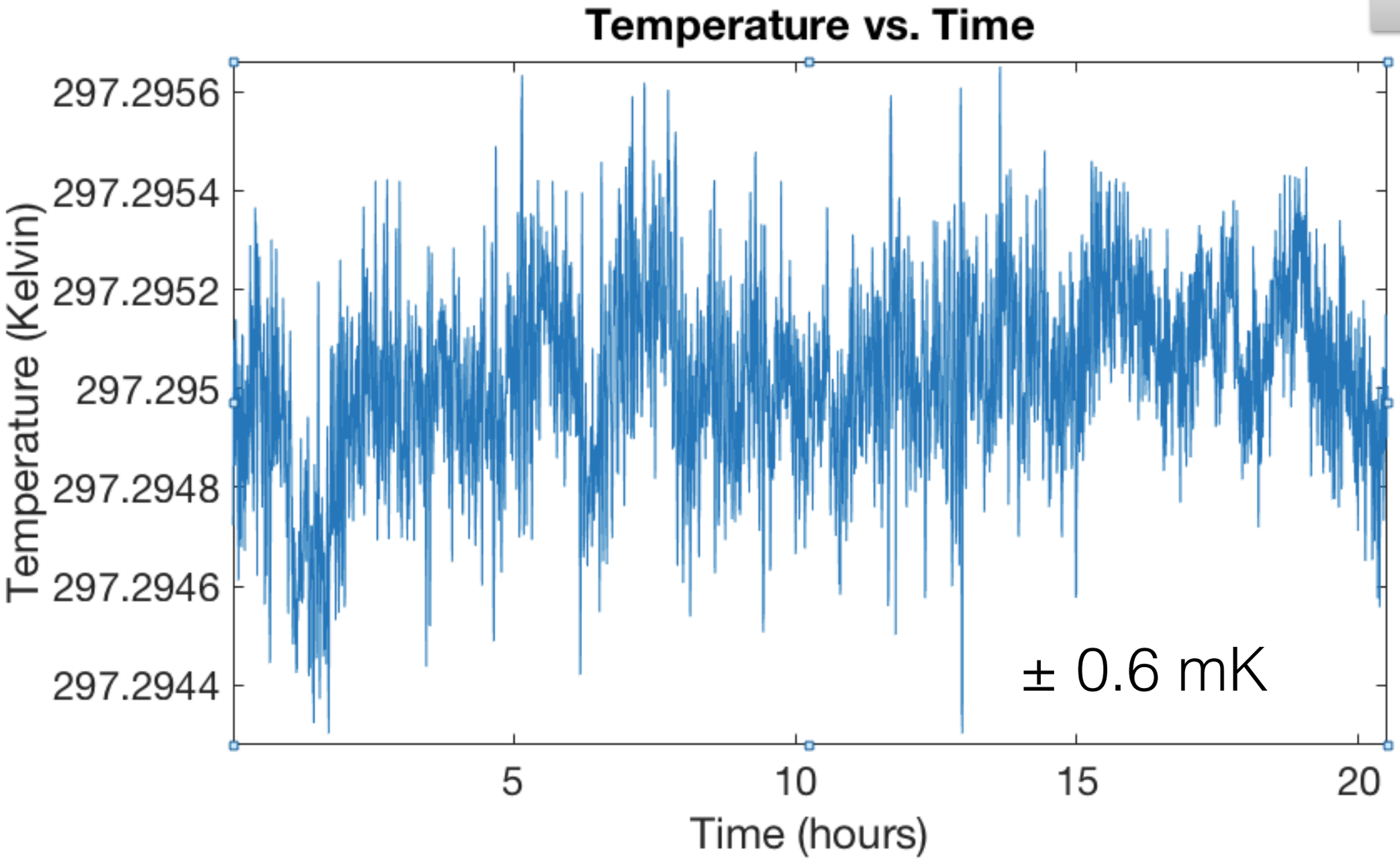
One of Homemade Heaters



Sensitive thermistor

Temperature drift eradicated with sub-milliKelvin stability

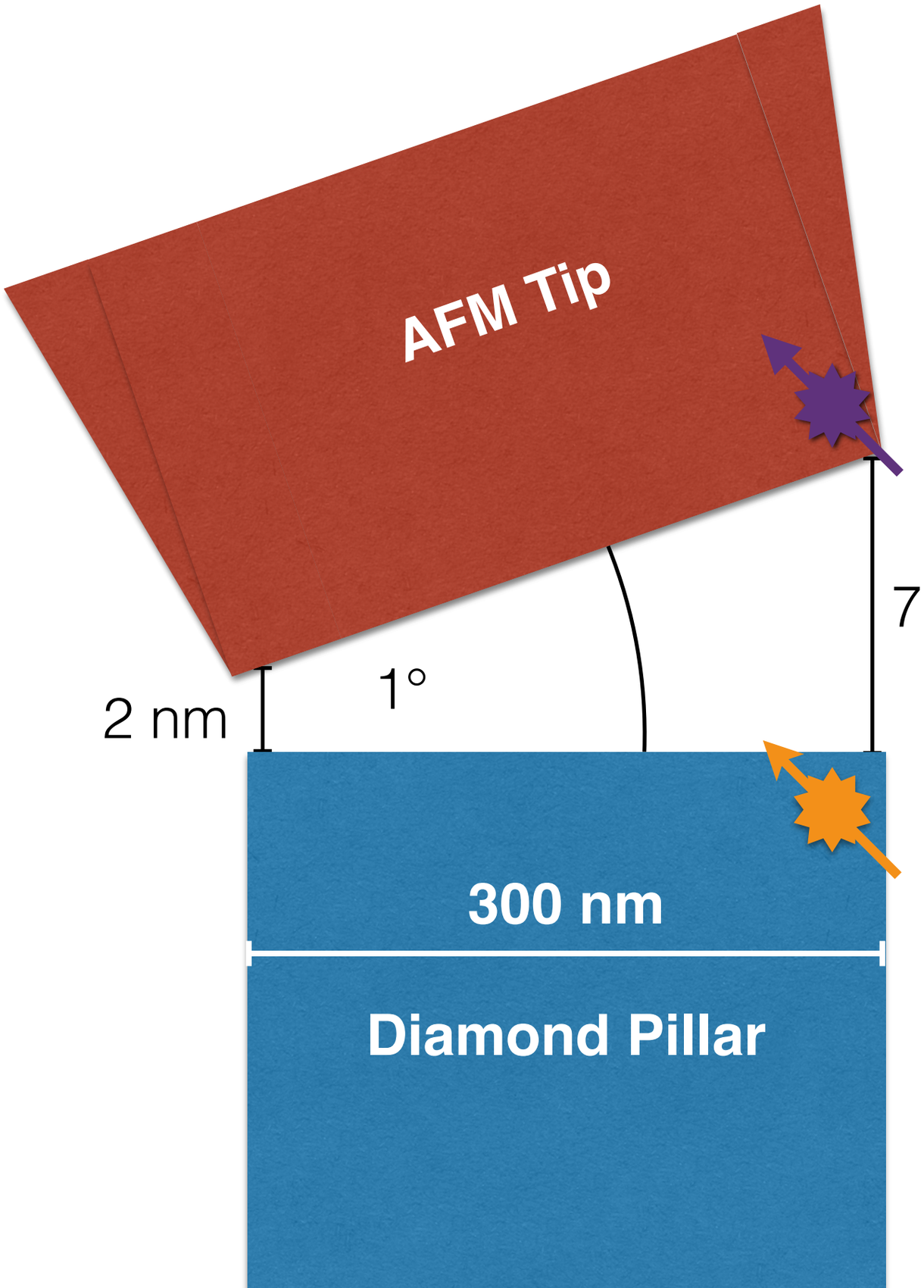
Drift



Problems: ☑ Drift ☐ Tilt ☐ NV Depth

Tilt drastically affects NV-Gd separation

Tilt

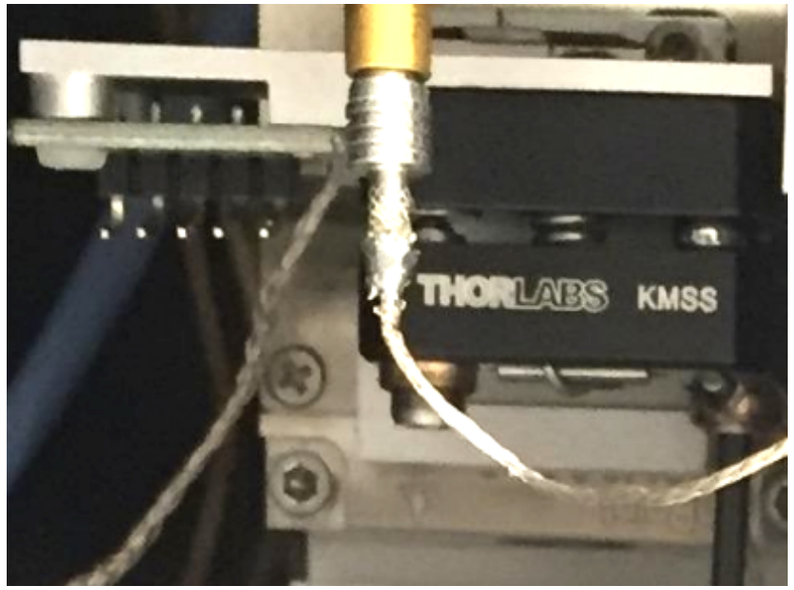


Just 1° in θ and Φ compared to no tilt:

- Up to 7nm extra separation
- Up to 12x weaker interaction

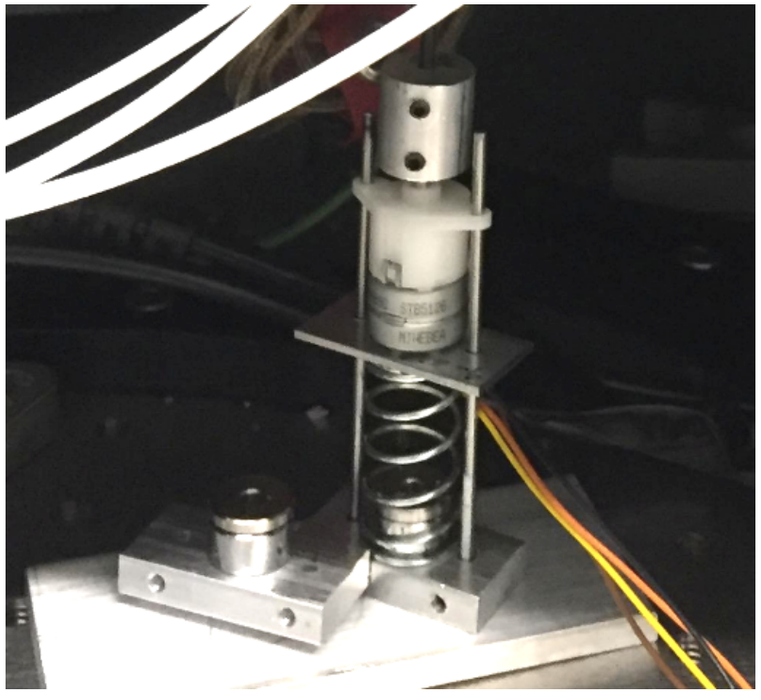
Fine Adjustment of AFM tip tilt

Tilt



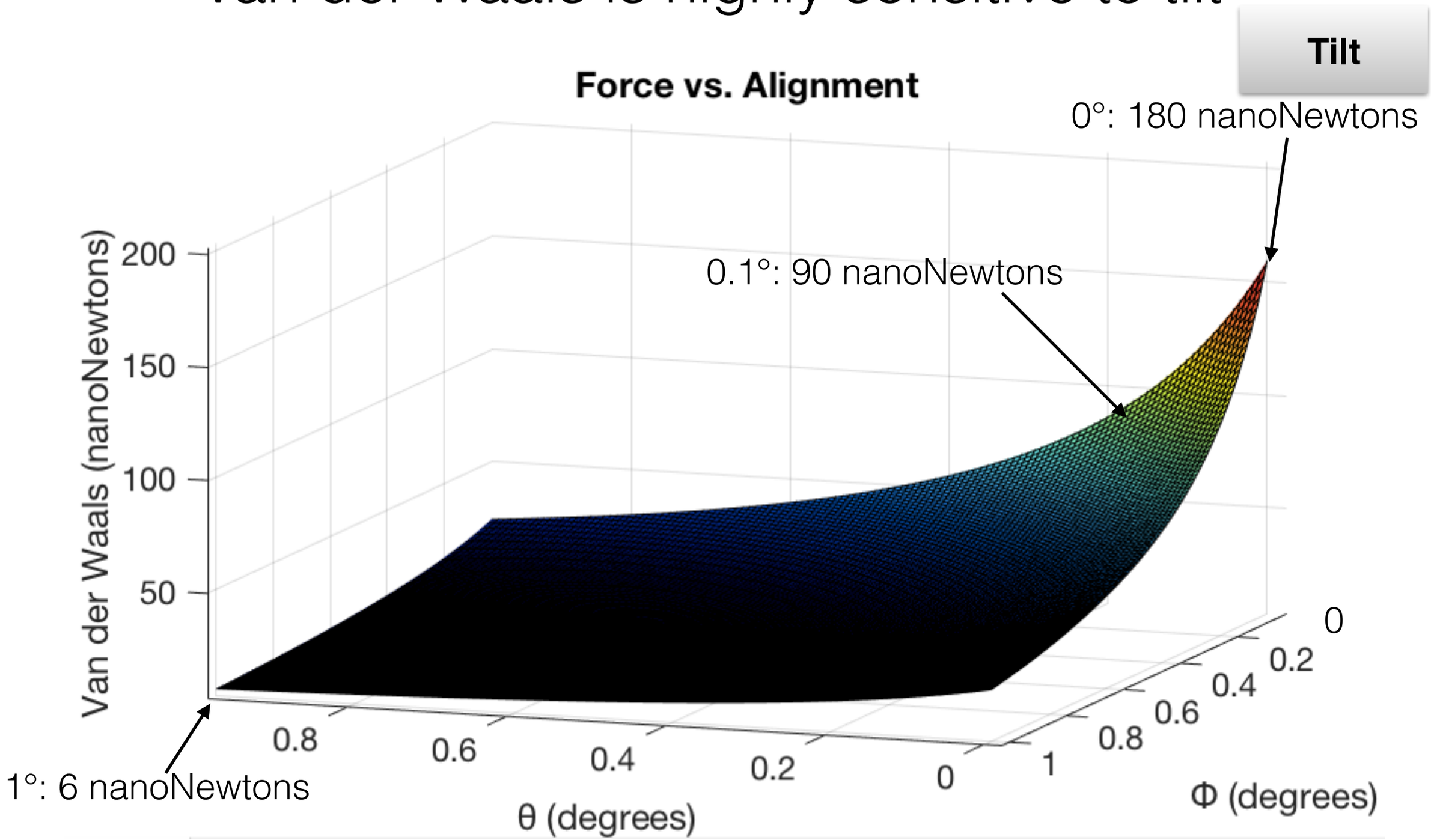
Fine Adjustment Tilt Stage

Spring loaded stepper motor



- **Angular adjustment resolution: 0.007°**

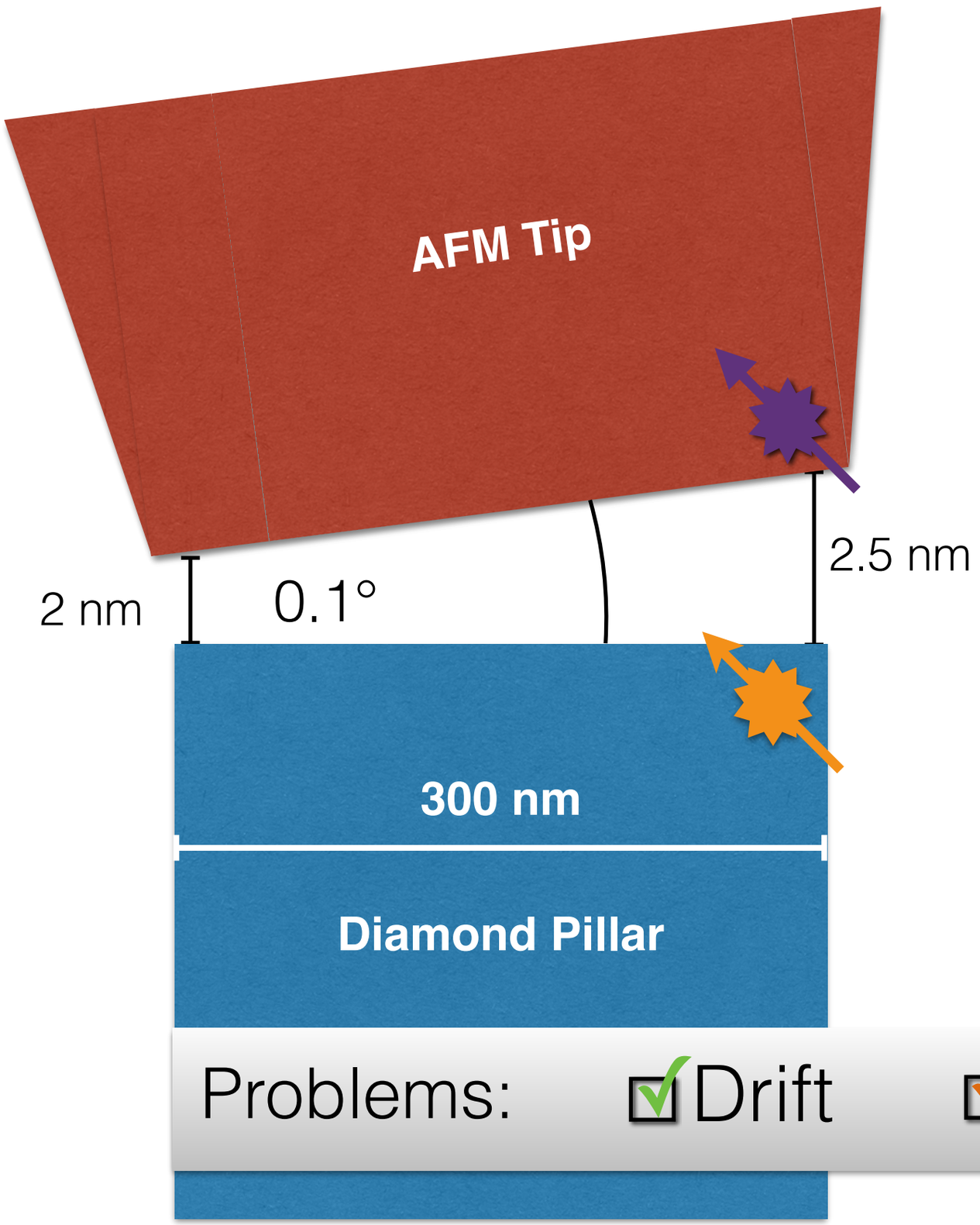
Van der Waals is highly sensitive to tilt



- AFMs can detect and resolve nanoNewtons

Fine tilt adjustment to control and minimize separation

Tilt

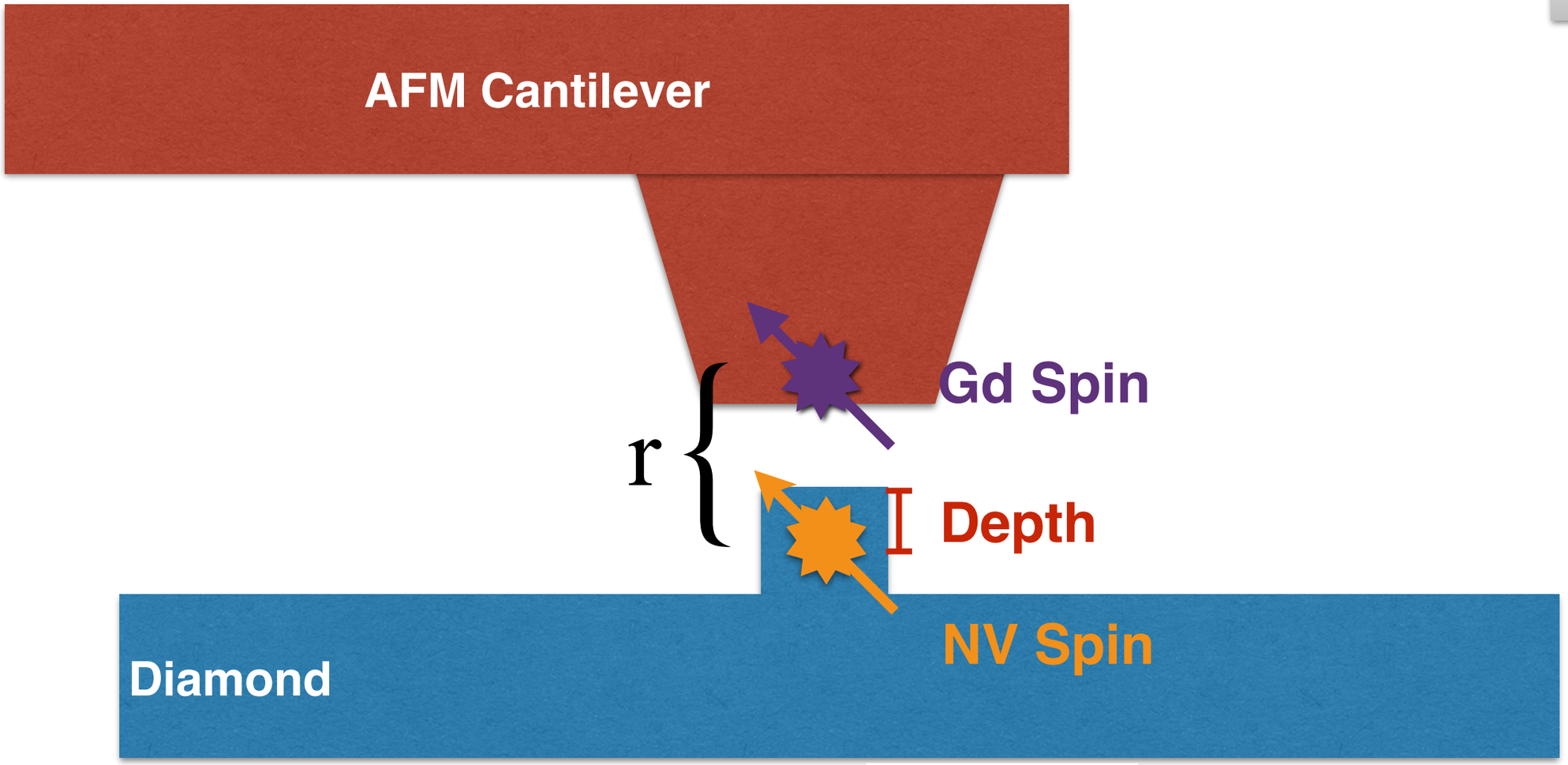


Negligible effects on NV-Gd interaction

Problems: ☑ Drift ☑ Tilt ☐ NV Depth

Extremely Challenging to determine NV Depth

NV Depth

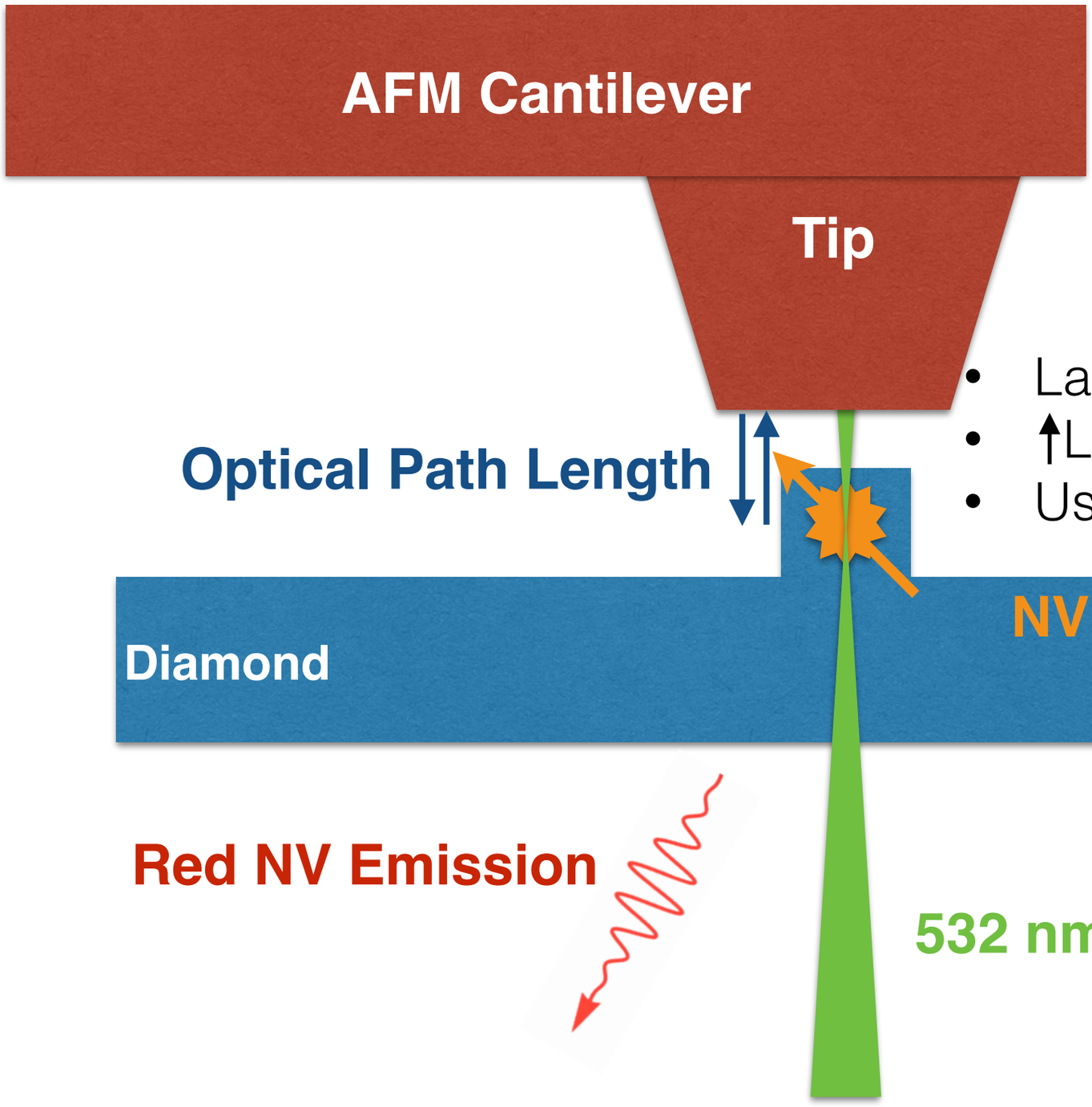


$$\text{Interaction Strength} \propto \frac{1}{r^3}$$

- Currently ± 4 nm in depth, 2-9 nm
- Aim for ± 1 nm

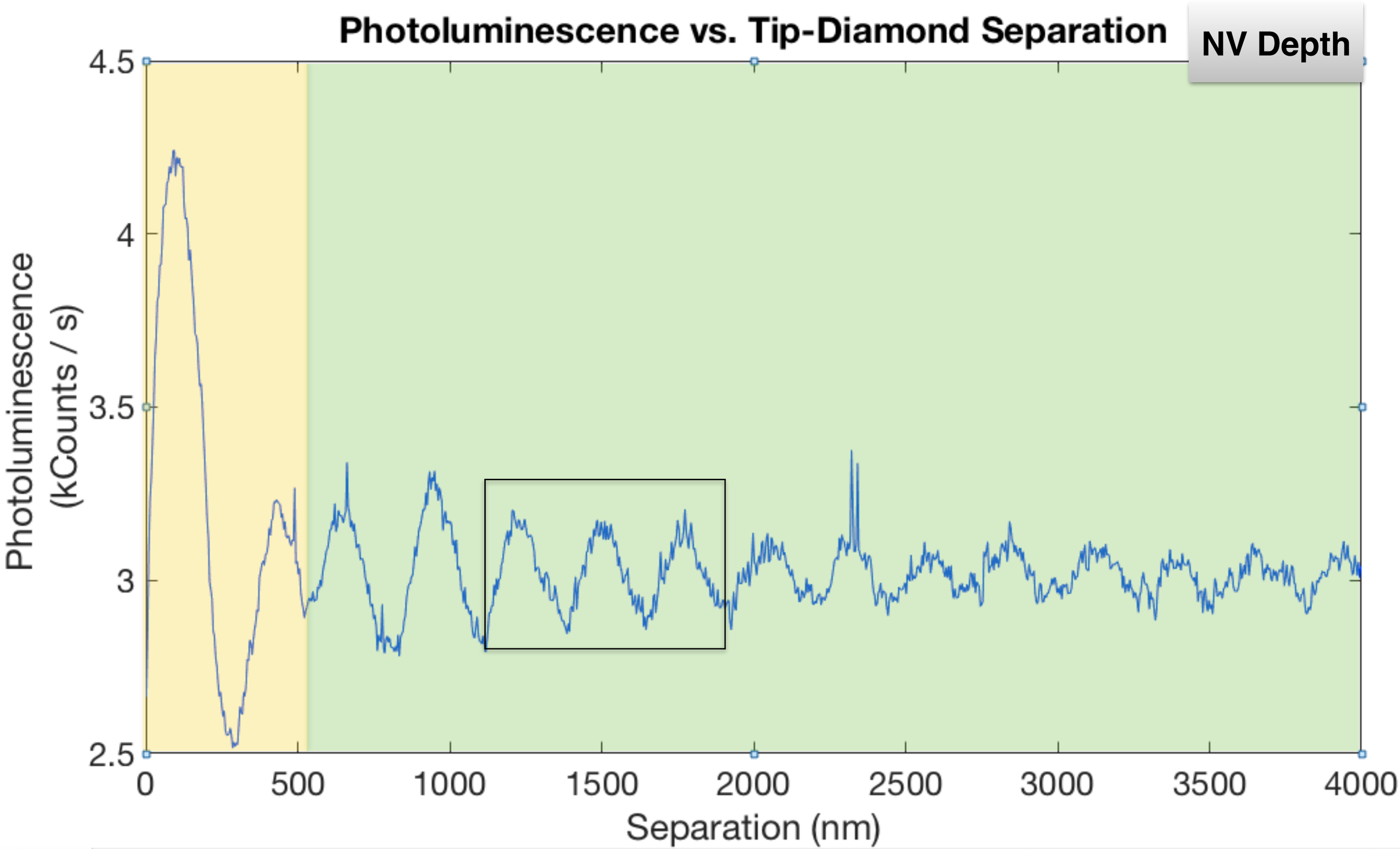
Excitation and Fluorescence of NV Center

NV Depth



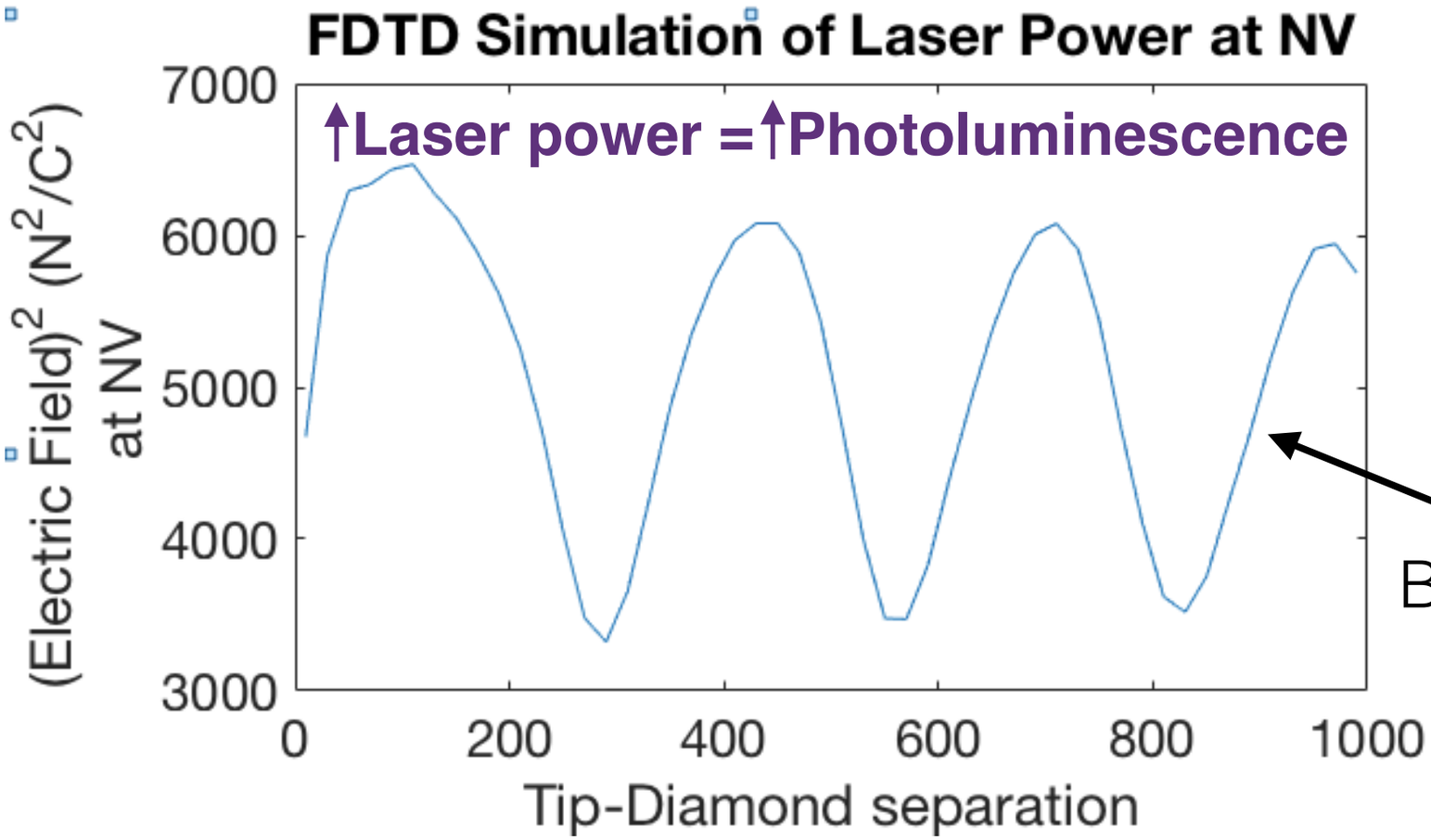
- Laser can reflect back
- ↑Laser power = ↑Photoluminescence
- Use **Optical Path Length**?

Optical signatures of tip-diamond separation

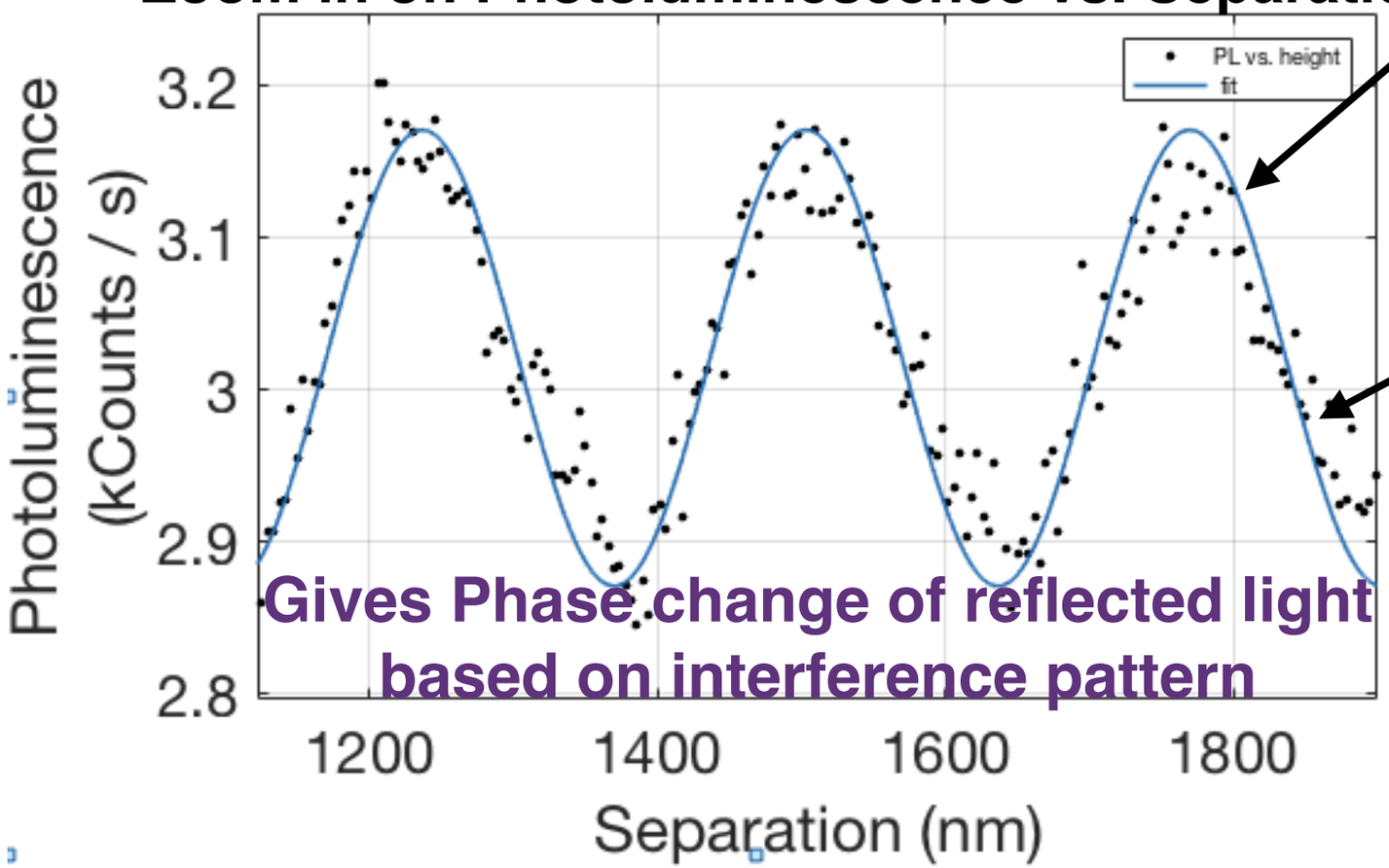


Purcell Effect, Dielectric Environment Change, NV-self interference, **laser self-interference**

NV Depth



Both Oscillations' frequencies match predicted interference frequency



Uncertainty in phase of fit corresponds to ± 4 nm in **Optical Path Length**

Gives Phase change of reflected light based on interference pattern

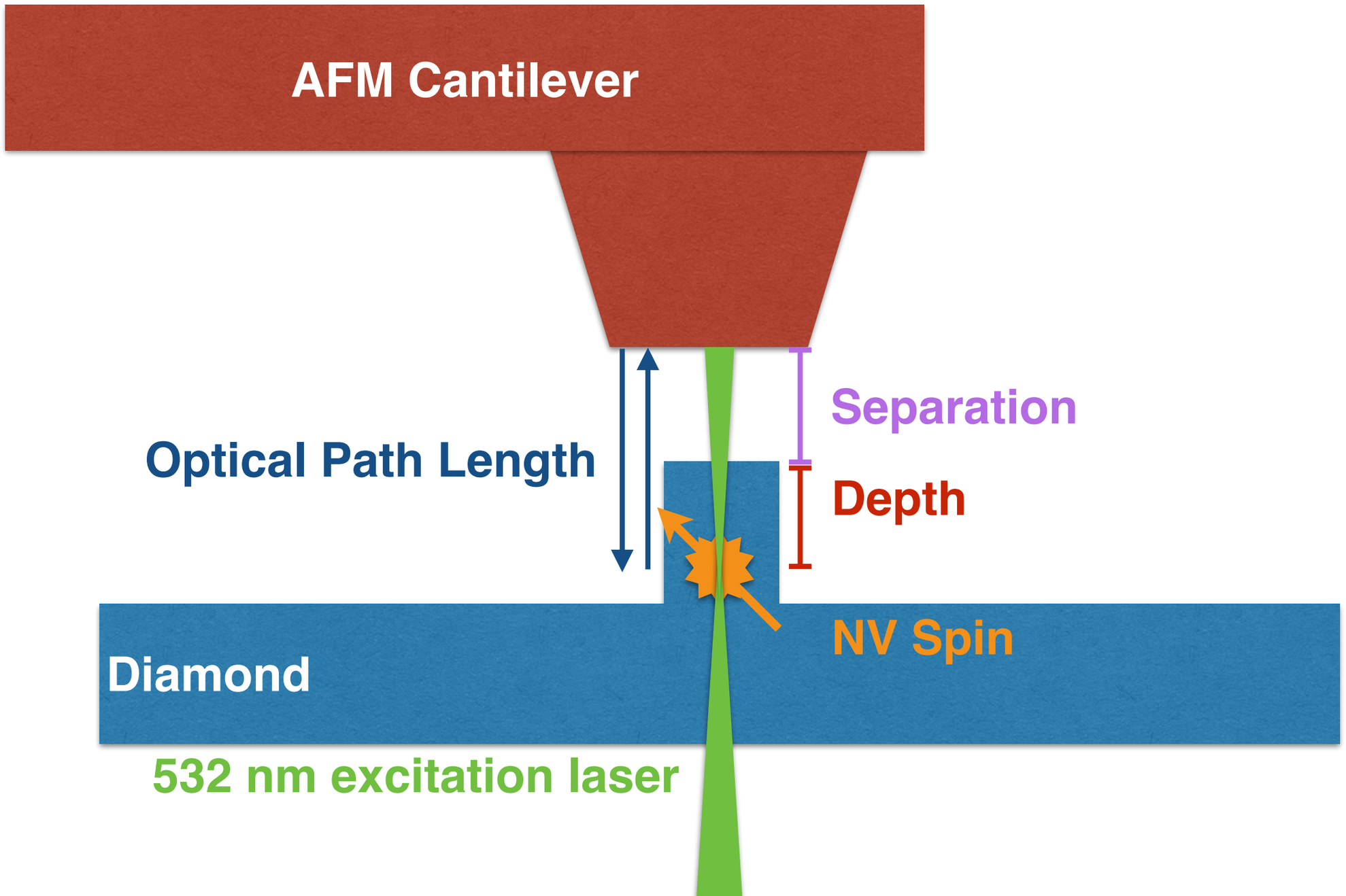
Using laser self-interference to determine NV depth

NV Depth

Diamond Index of Refraction = 2.4

Optical Path Length = 2∗**Separation** + 2∗2.4∗**Depth**

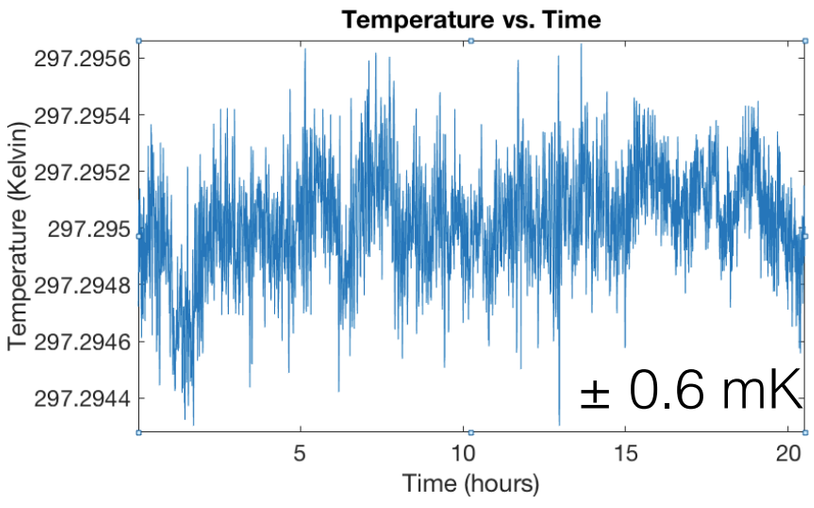
± 4 nm in **Optical Path Length**; ± 1 nm in **Separation** ⟶ ± 1.25 nm in NV **Depth**

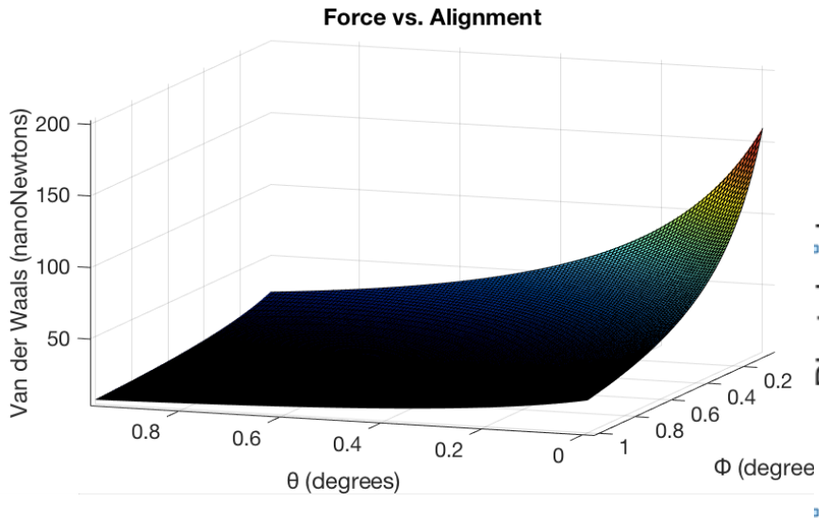


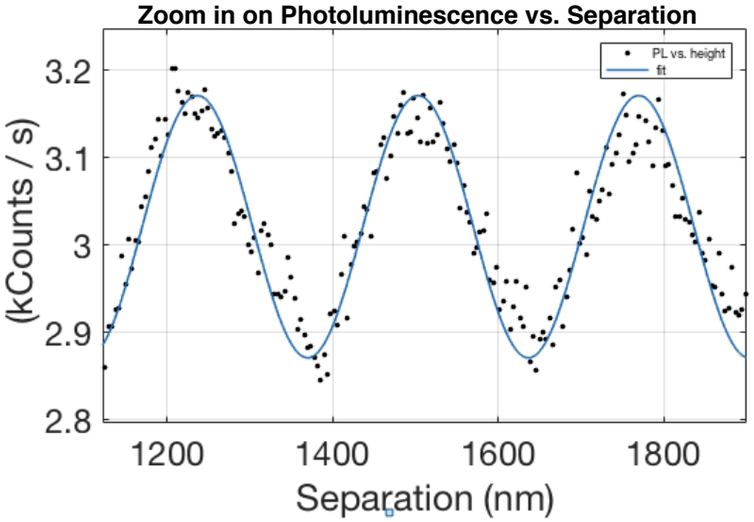
Conclusions and Future Work

Problems: ☑ Drift ☑ Tilt ☐ NV Depth

..Almost!







Acknowledgements

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