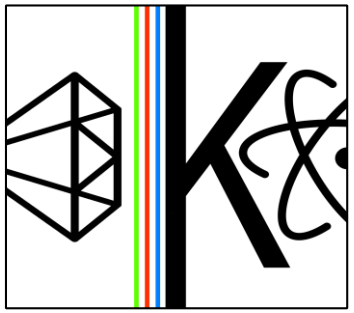
Nanoscale metrology with nitrogen vacancy centers in diamond

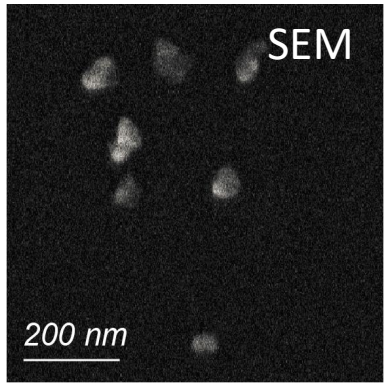
Aedan Gardill



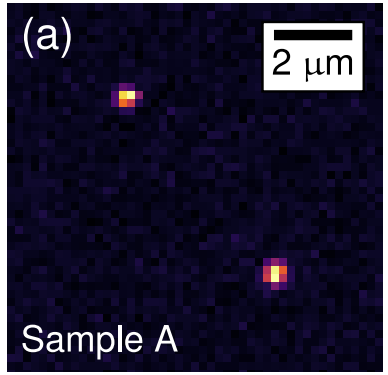
Outline

Metrology with nitrogen vacancy centers

Electric field noise in nanodiamonds



Ultimate limits to coherence and sensitivity



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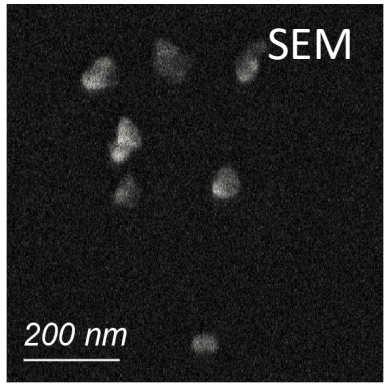

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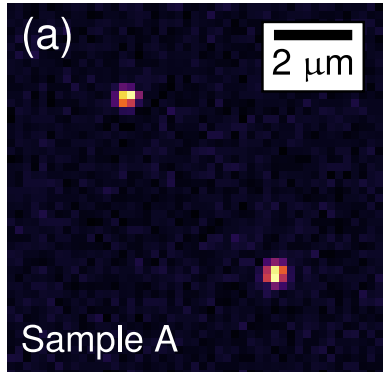
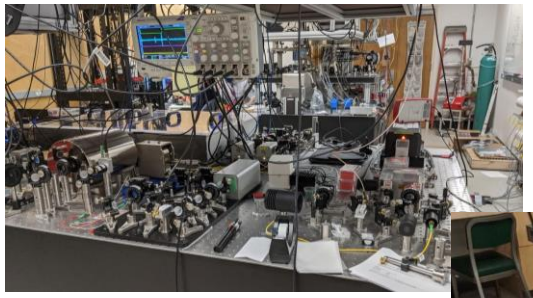
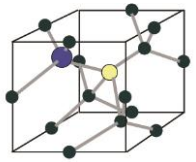


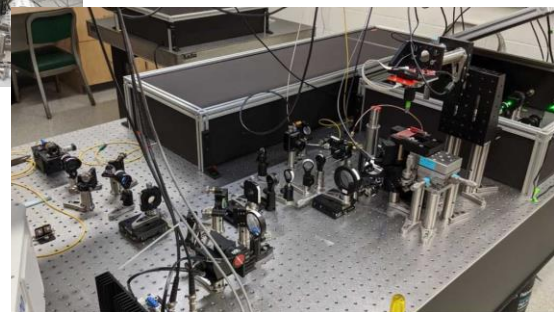
Metrology with solid state defects



Lab manipulating atoms

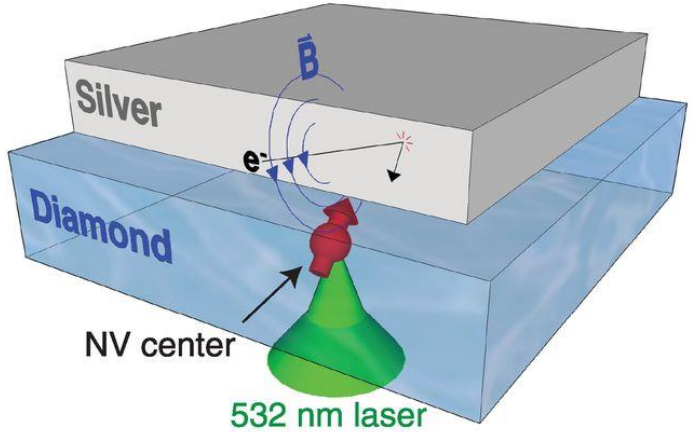


No need for trapping or cooling!

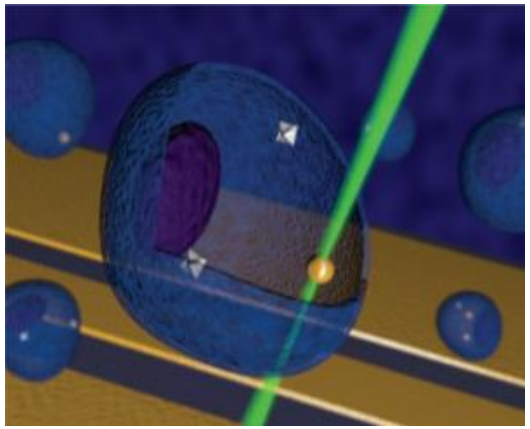


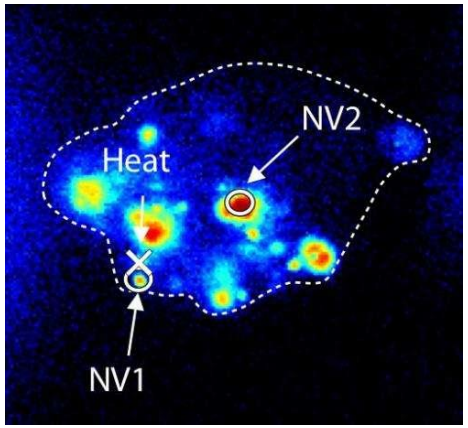
Our lab

Sample placed flush against the defect's bulk material



Often perform measurements in ambient conditions





S. Kolkowitz *et al.*, "Probing Johnson noise and ballistic transport in normal metals with a single-spin qubit" Science (2015)
G. Kucsko *et al.*, "Nanometre-scale thermometry in a living cell" Nature (2013)

Nitrogen vacancy (NV) centers in diamond

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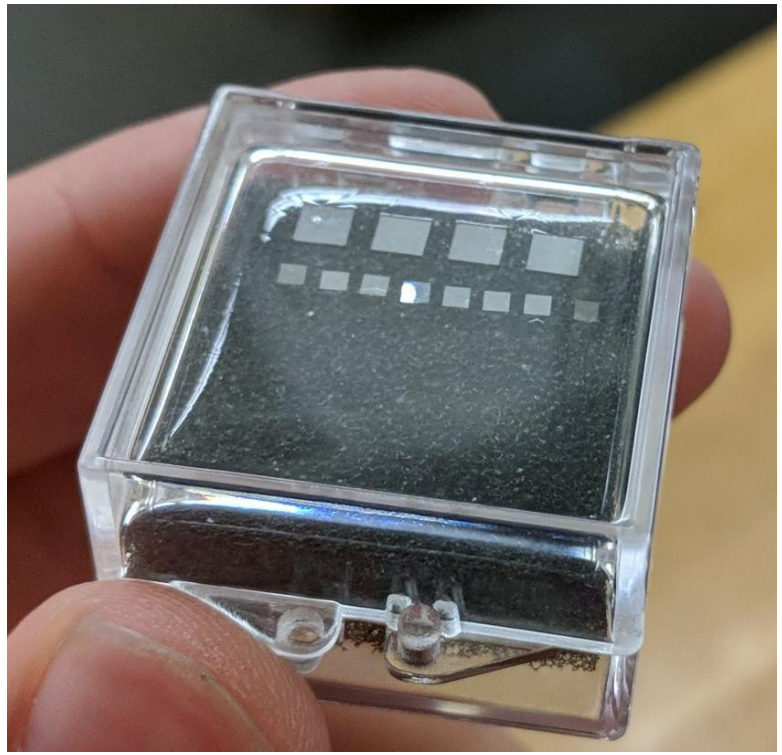
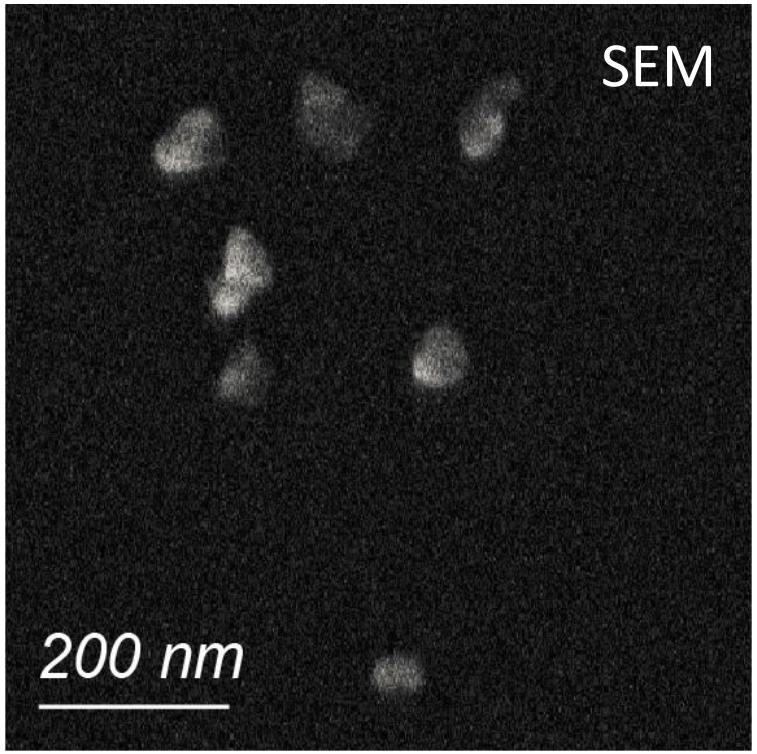
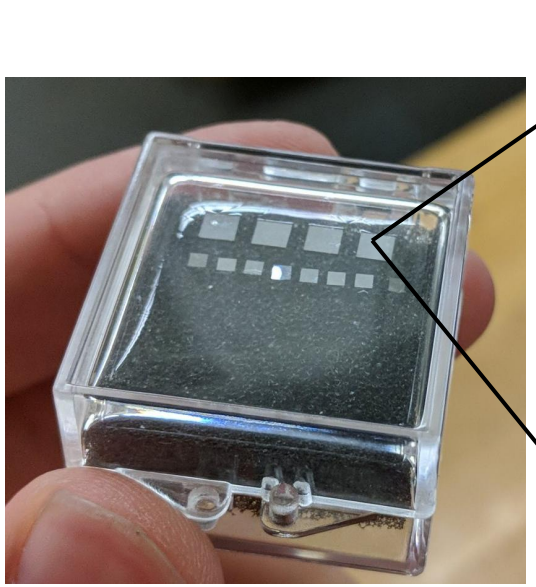


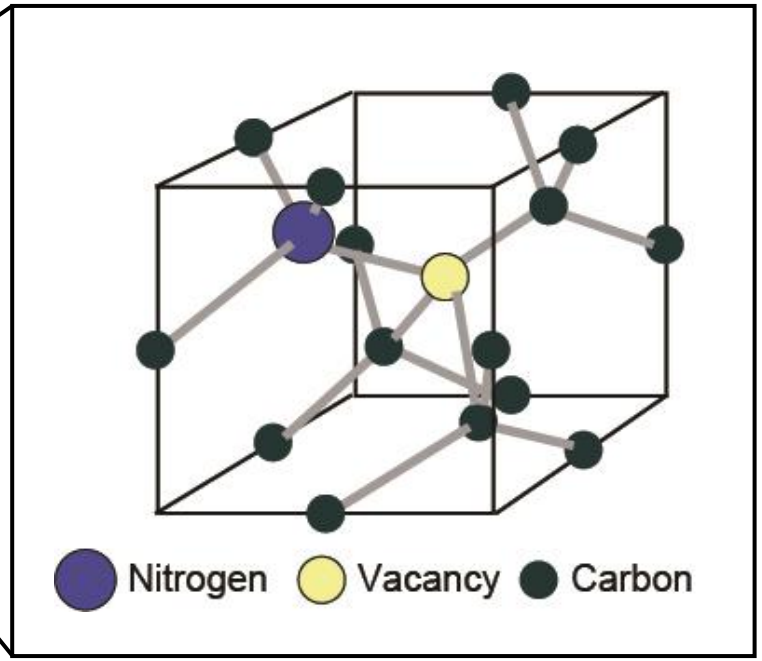
Bulk diamonds



Nanodiamonds

Nitrogen vacancy (NV) centers in diamond





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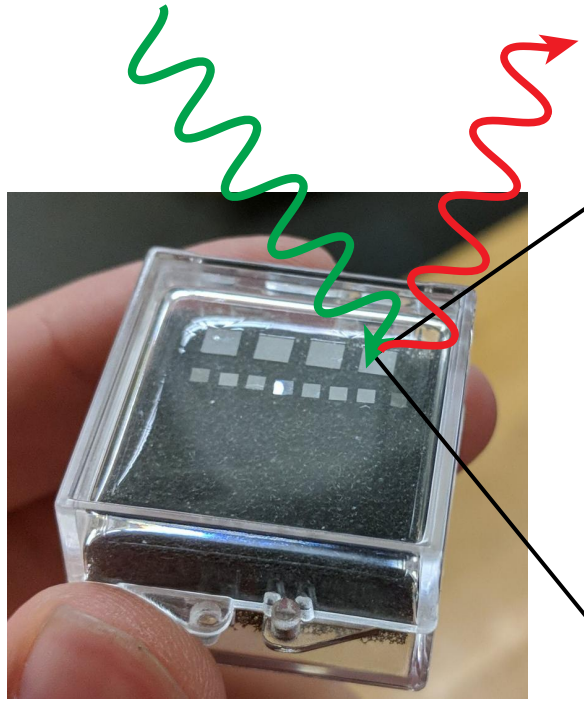
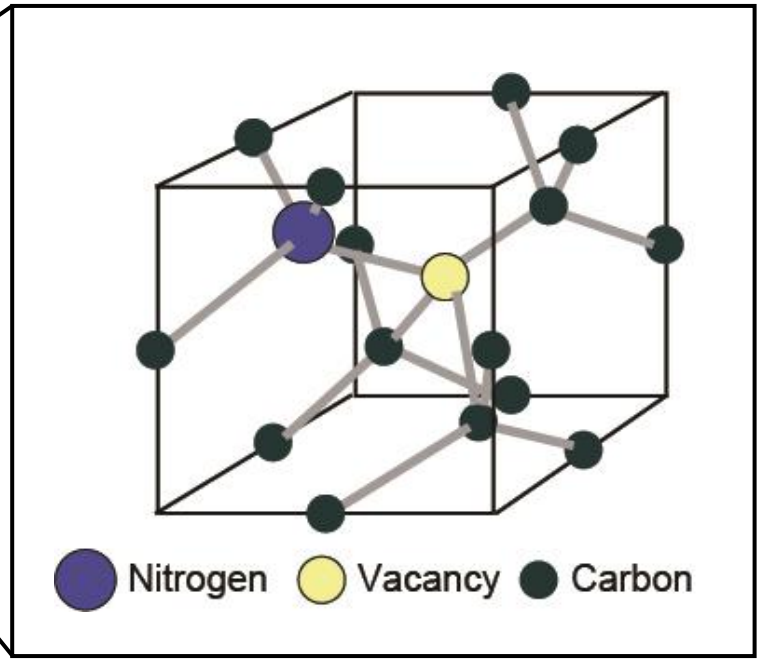
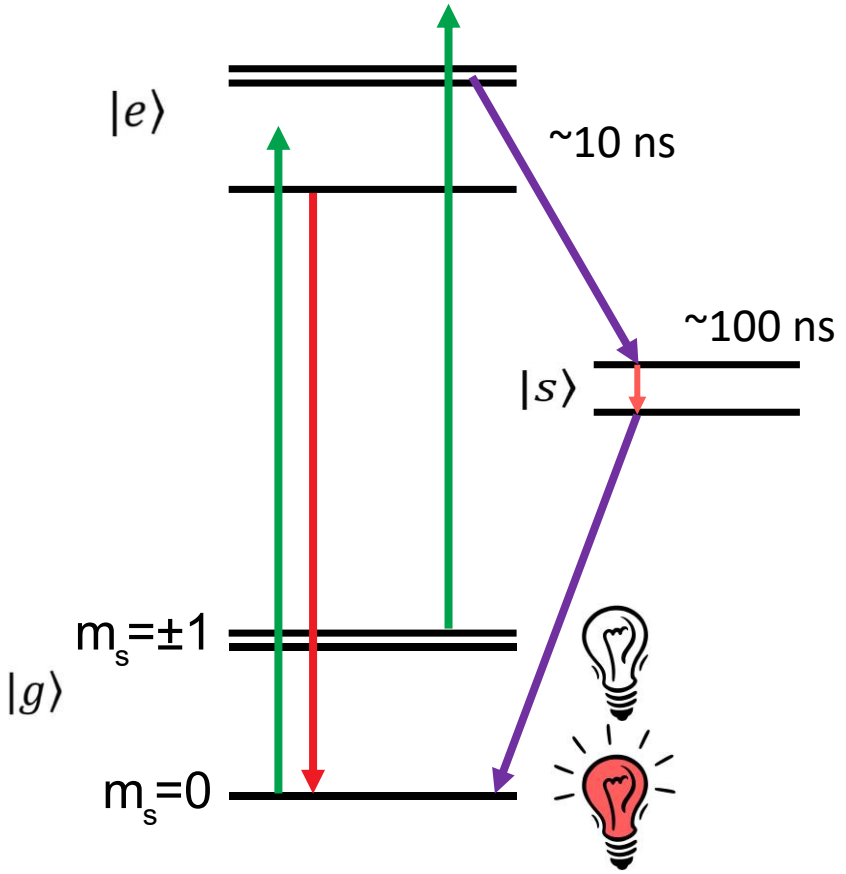
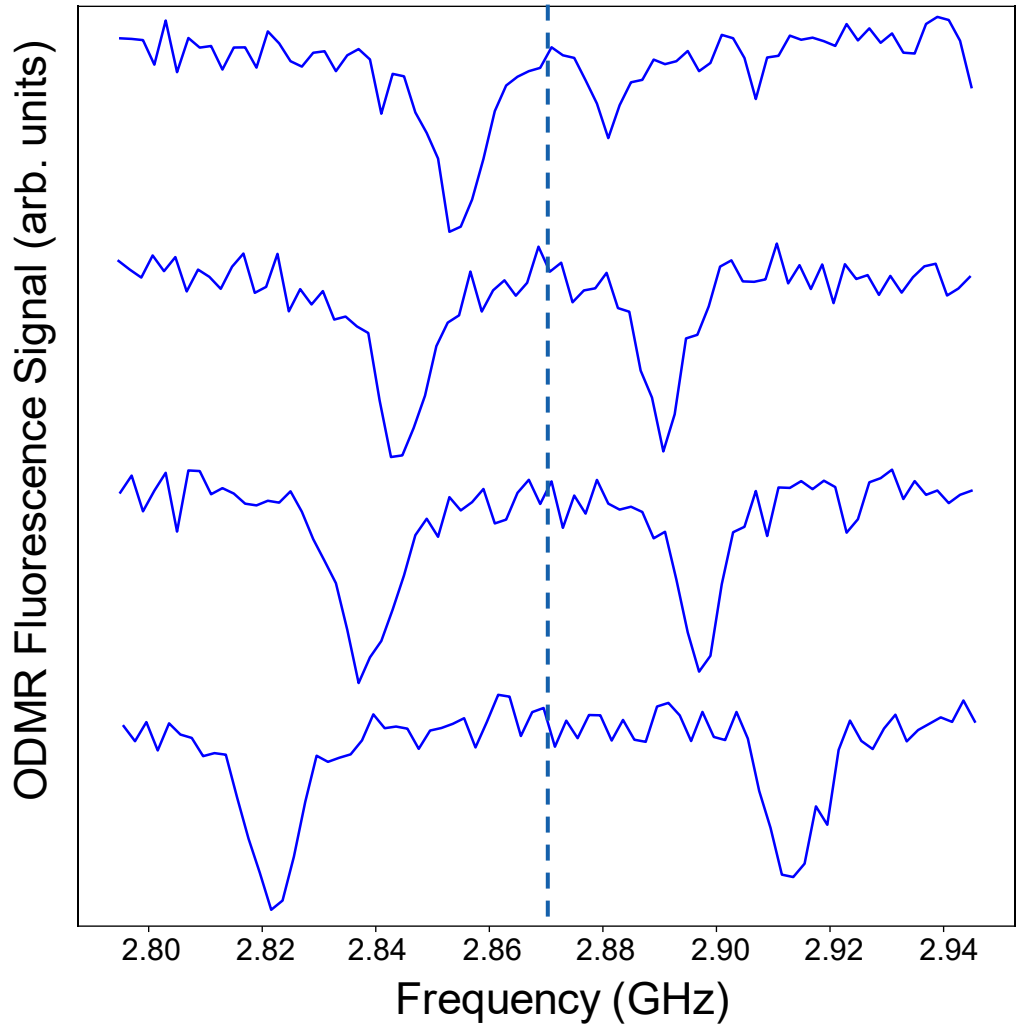
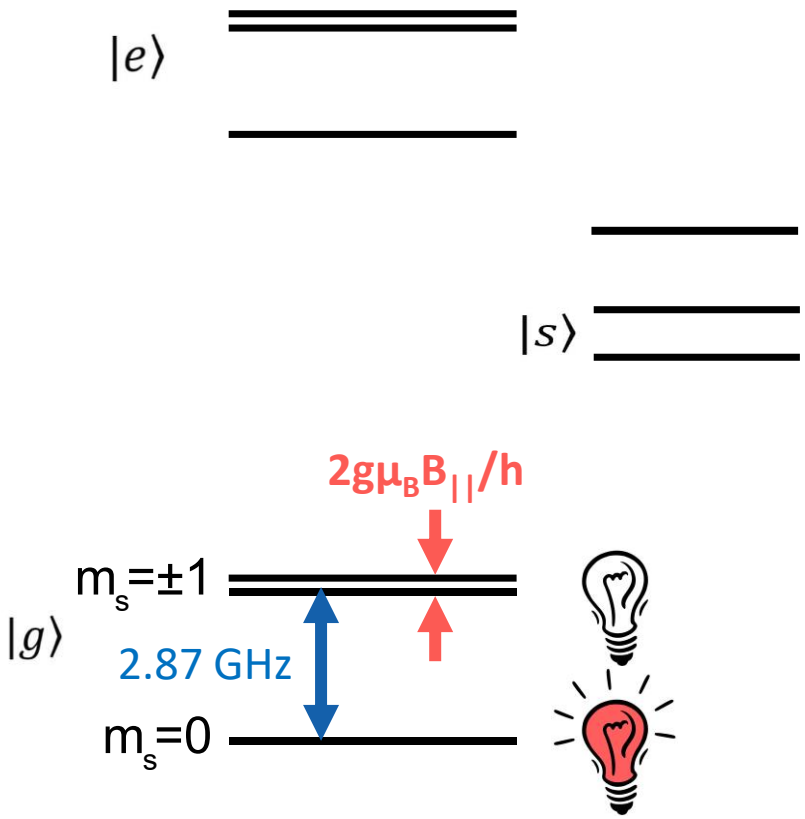




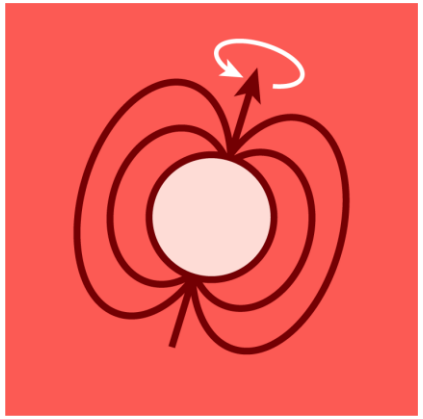


Nitrogen vacancy (NV) centers in diamond

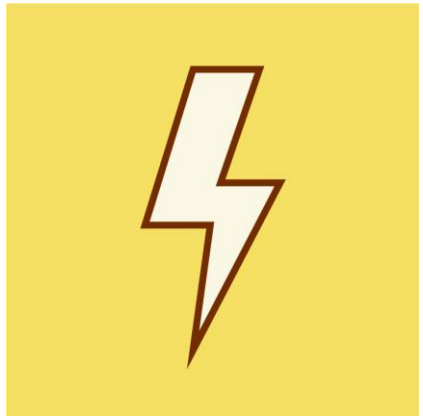




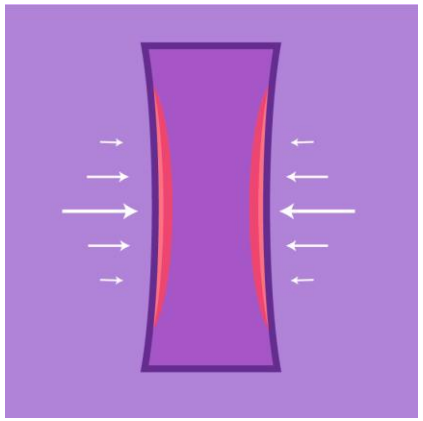
Nitrogen vacancy (NV) centers in diamond



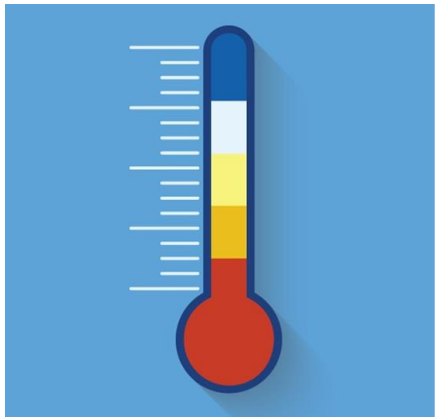
Magnetic fields



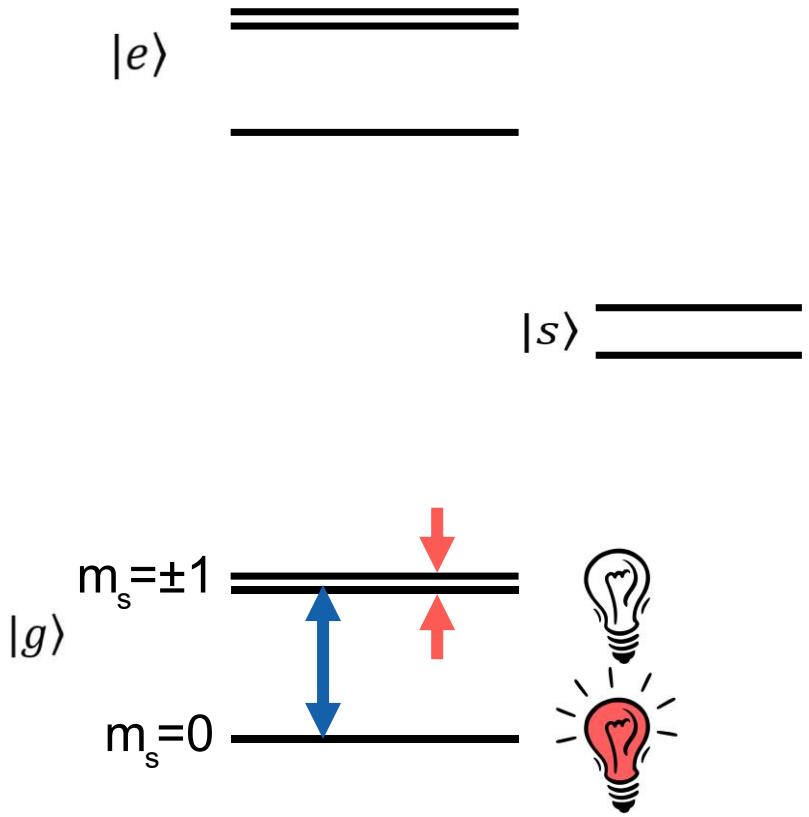
Electric fields



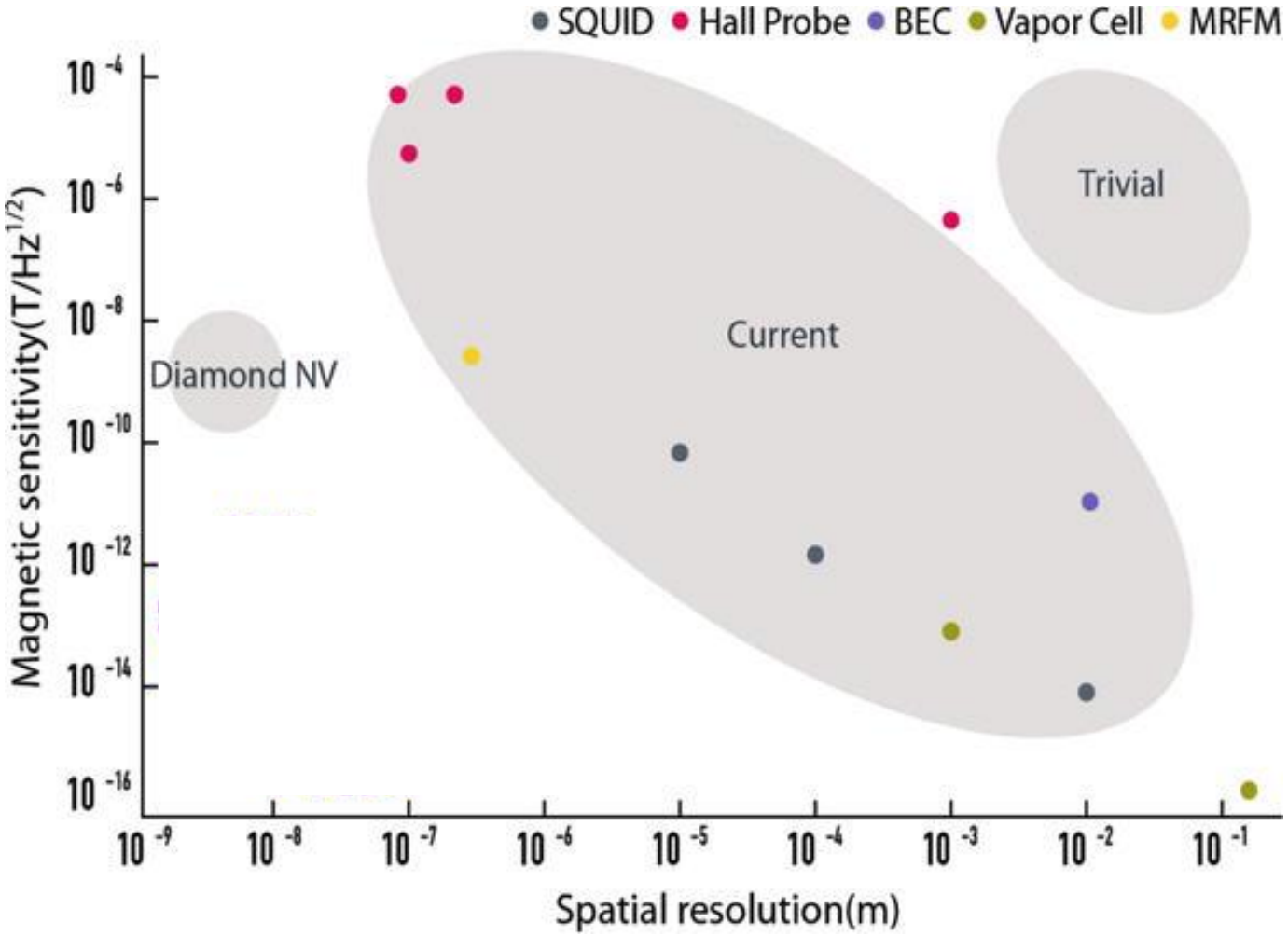
Strain



Temperature



Nanoscale metrology with NV centers



M. Lee *et al., Magnetometers - Fundamentals and Applications of Magnetism* (2020)

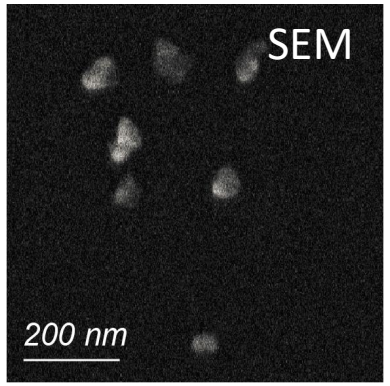
Goal: use NVs to measure local surface noise

- Superconducting qubits
- Quantum dots
- Other novel materials

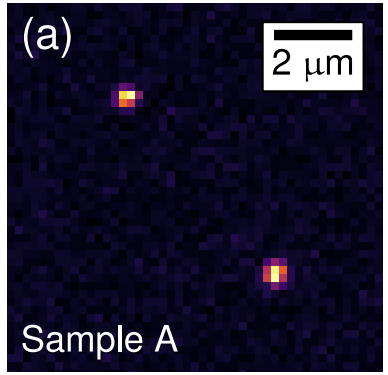
Outline

Metrology with nitrogen vacancy centers

Electric field noise in nanodiamonds

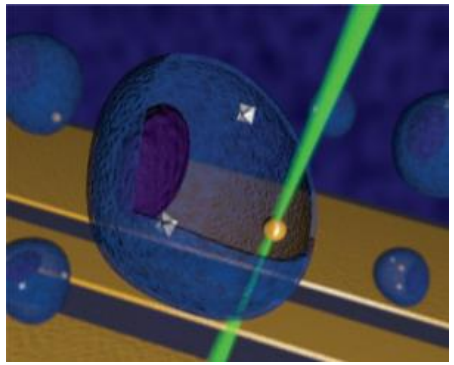


Ultimate limits to coherence and sensitivity



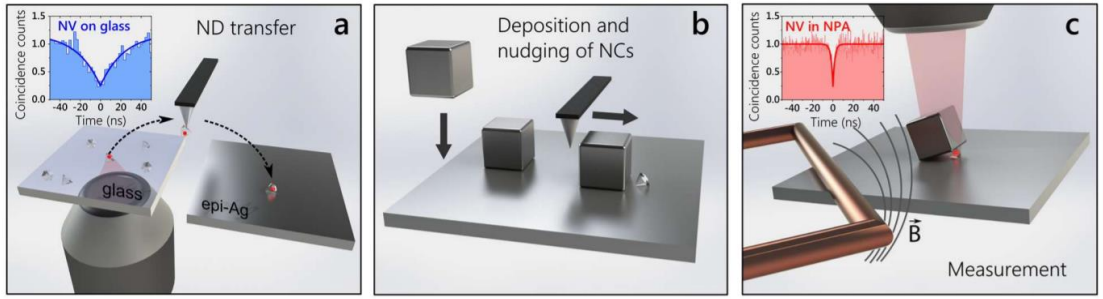
NVs in Nanodiamond

Inserted in living cells



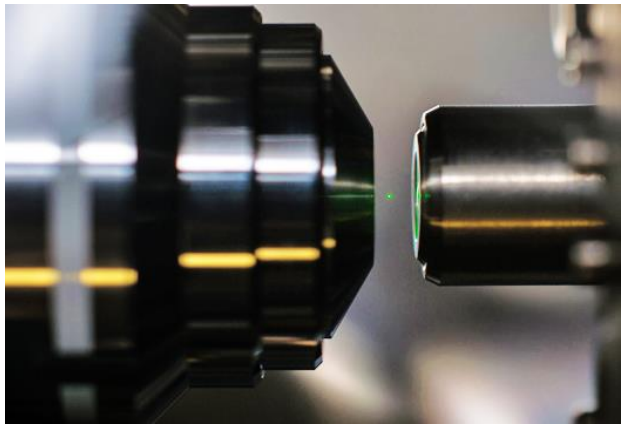
G. Kucsko *et al.,* "Nanometre-scale thermometry in a living cell" Nature (2013)

Deterministically placed on surfaces



S. I. Bogdanov *et al.,* "Deterministic integration of single nitrogen-vacancy centers into nanopatch antennas" arXiv (2019)

Optically levitated

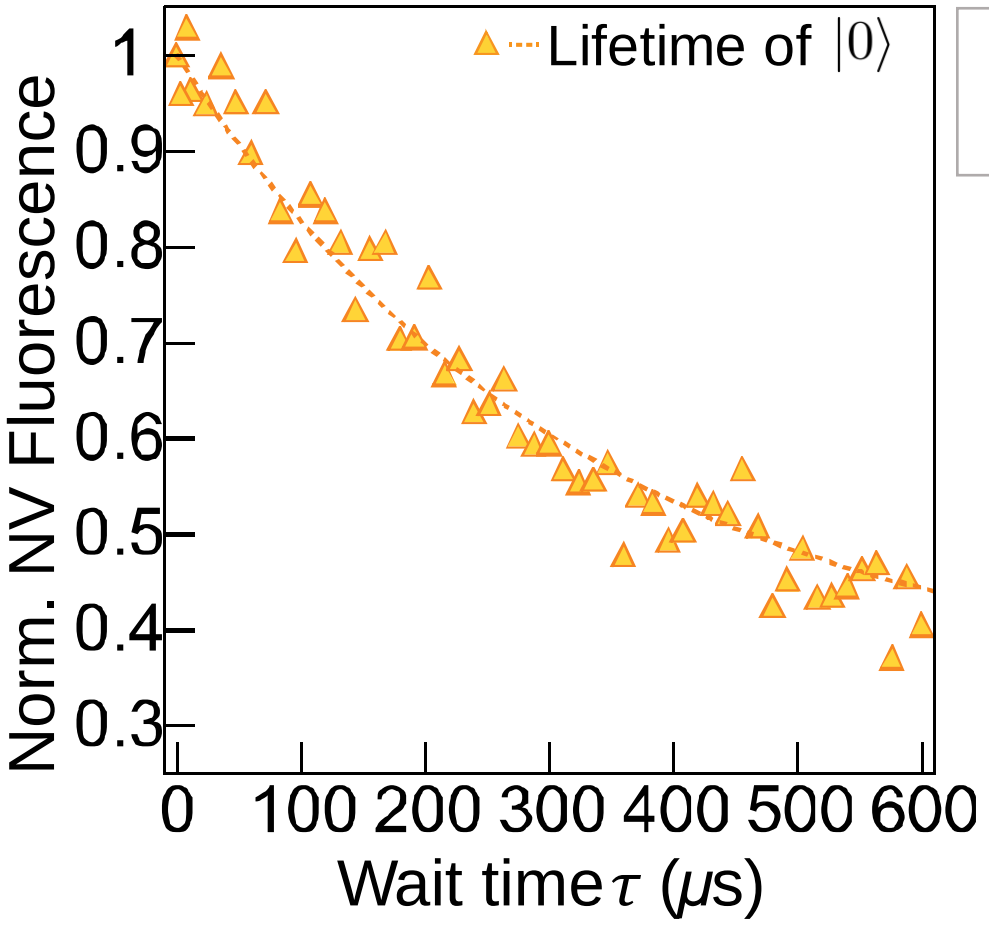


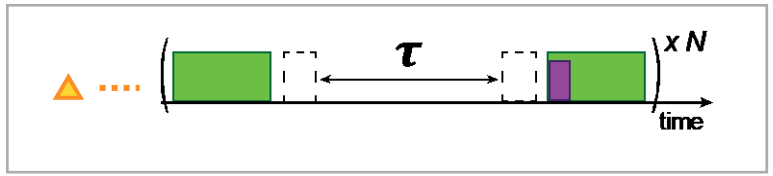
"Researchers use laser to levitate glowing nanodiamonds in vacuum" J. Fenster, University of Rochester (2015)

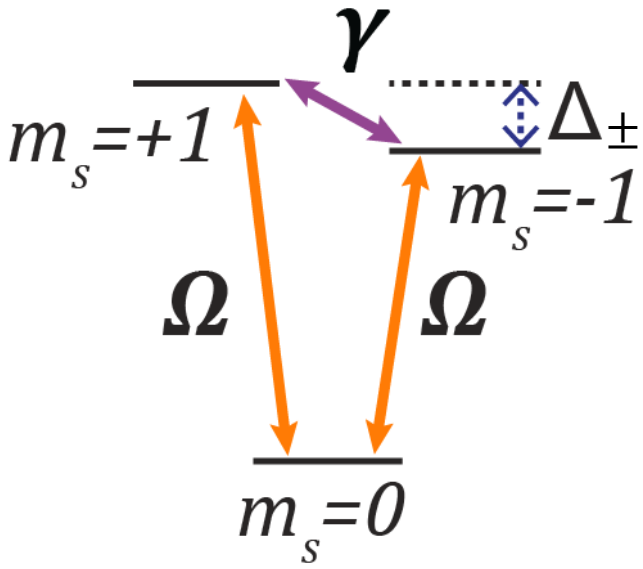
One main obstacle…

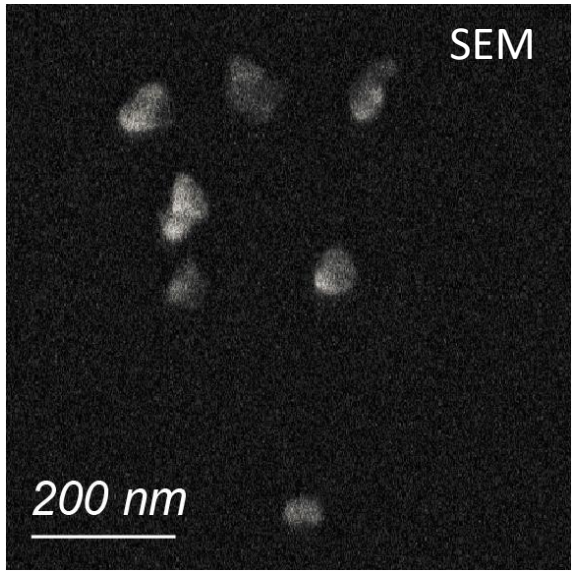
Very poor coherence time

Lifetime of state $m_s = 0$

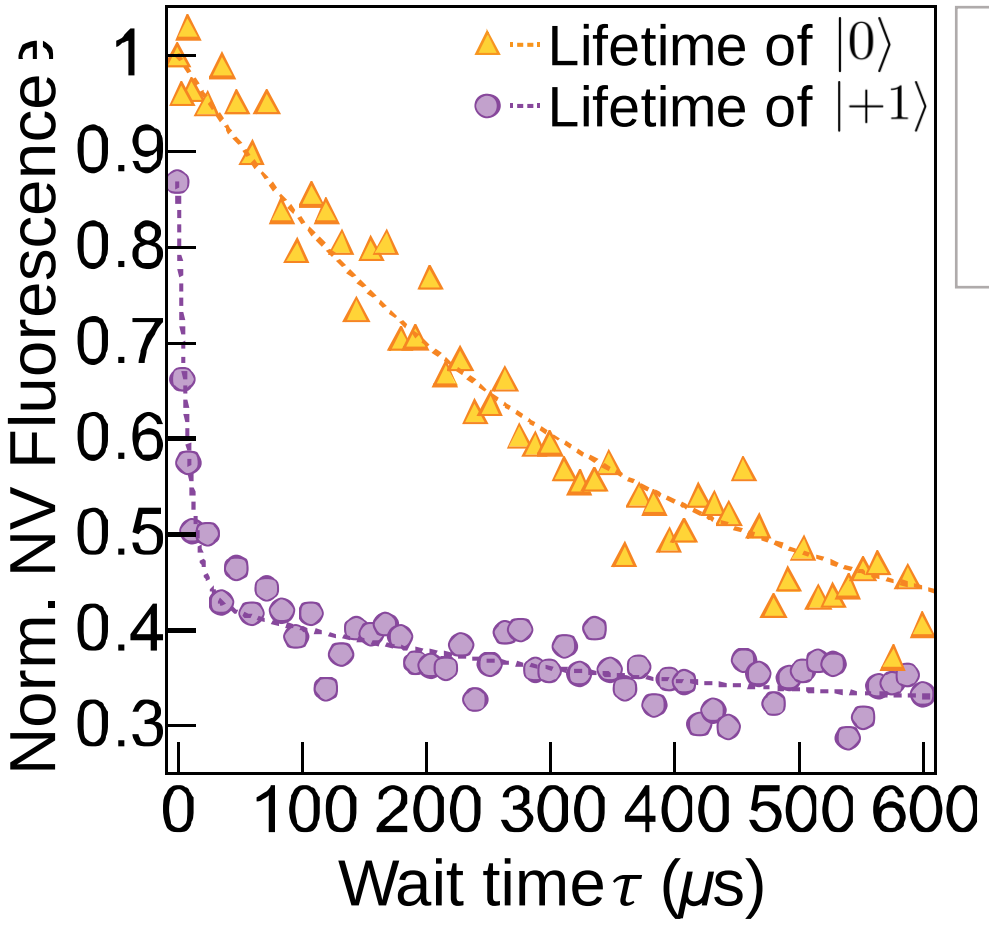


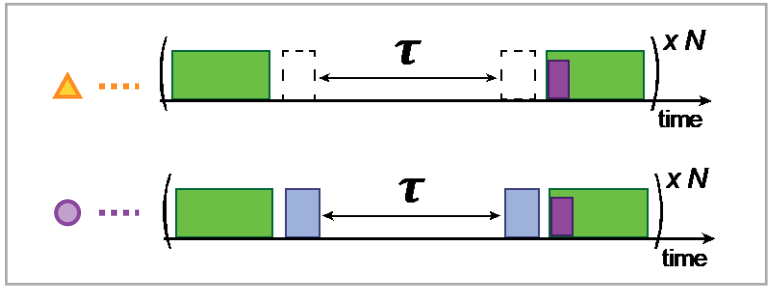


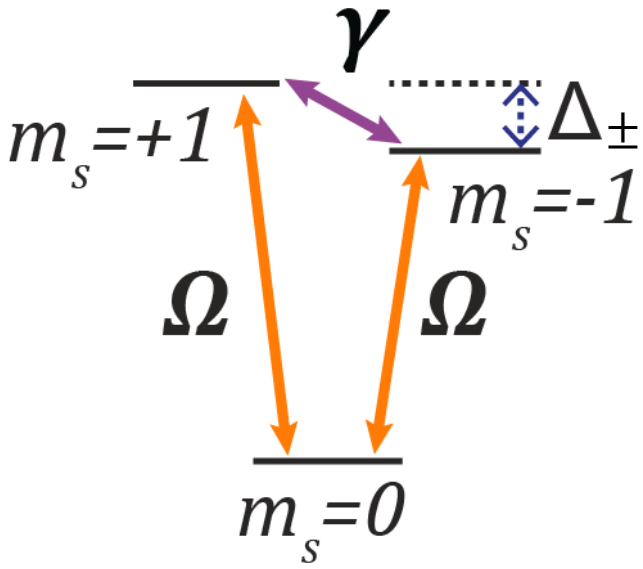


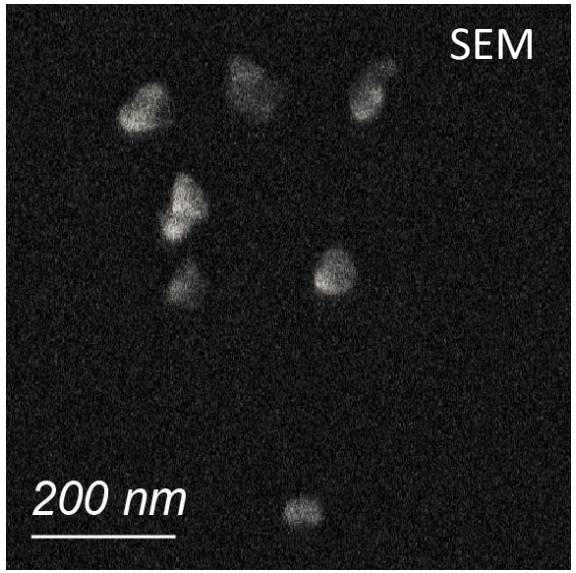


Lifetime of state $m_s = +1$



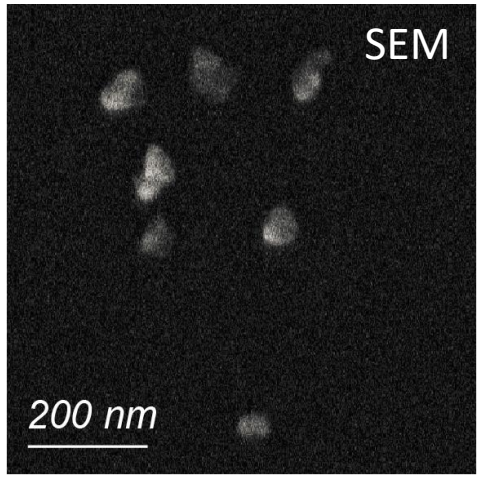


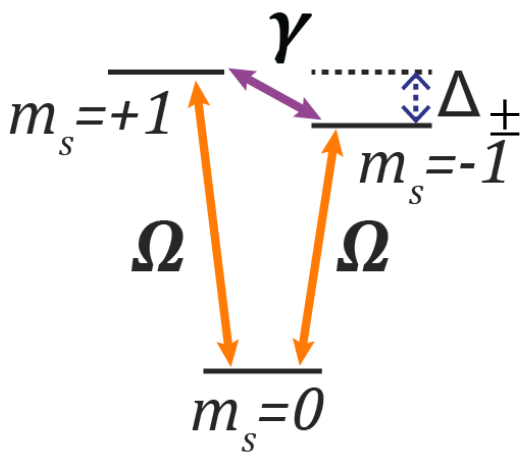


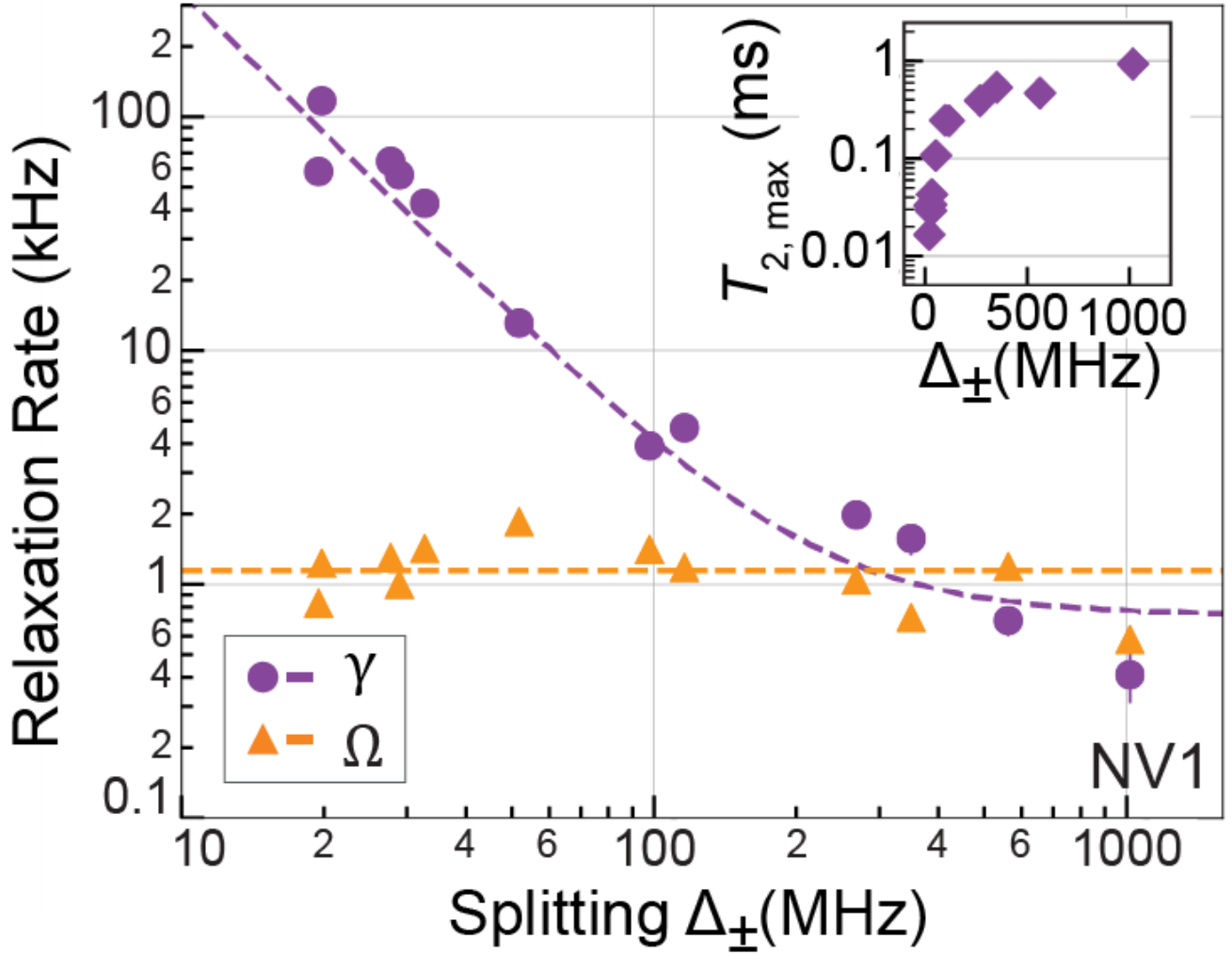


A. Gardill *et al.*, "Fast relaxation on qutrit transitions of nitrogen-vacancy centers in nanodiamonds" Phys. Rev. Applied (2020)

Measurements of γ and Ω







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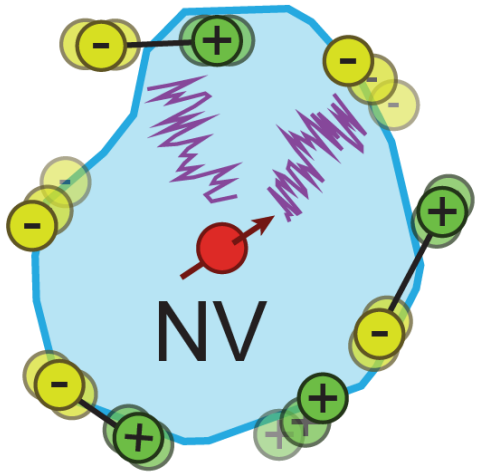
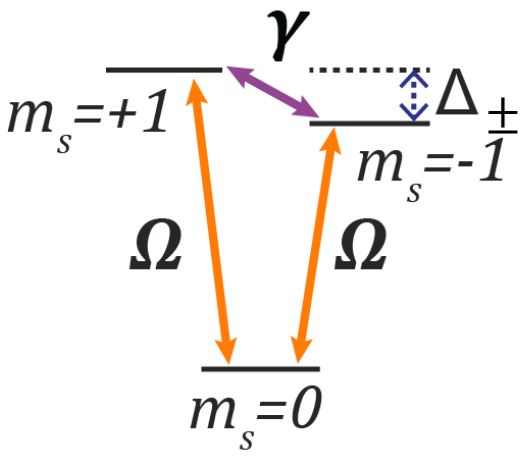
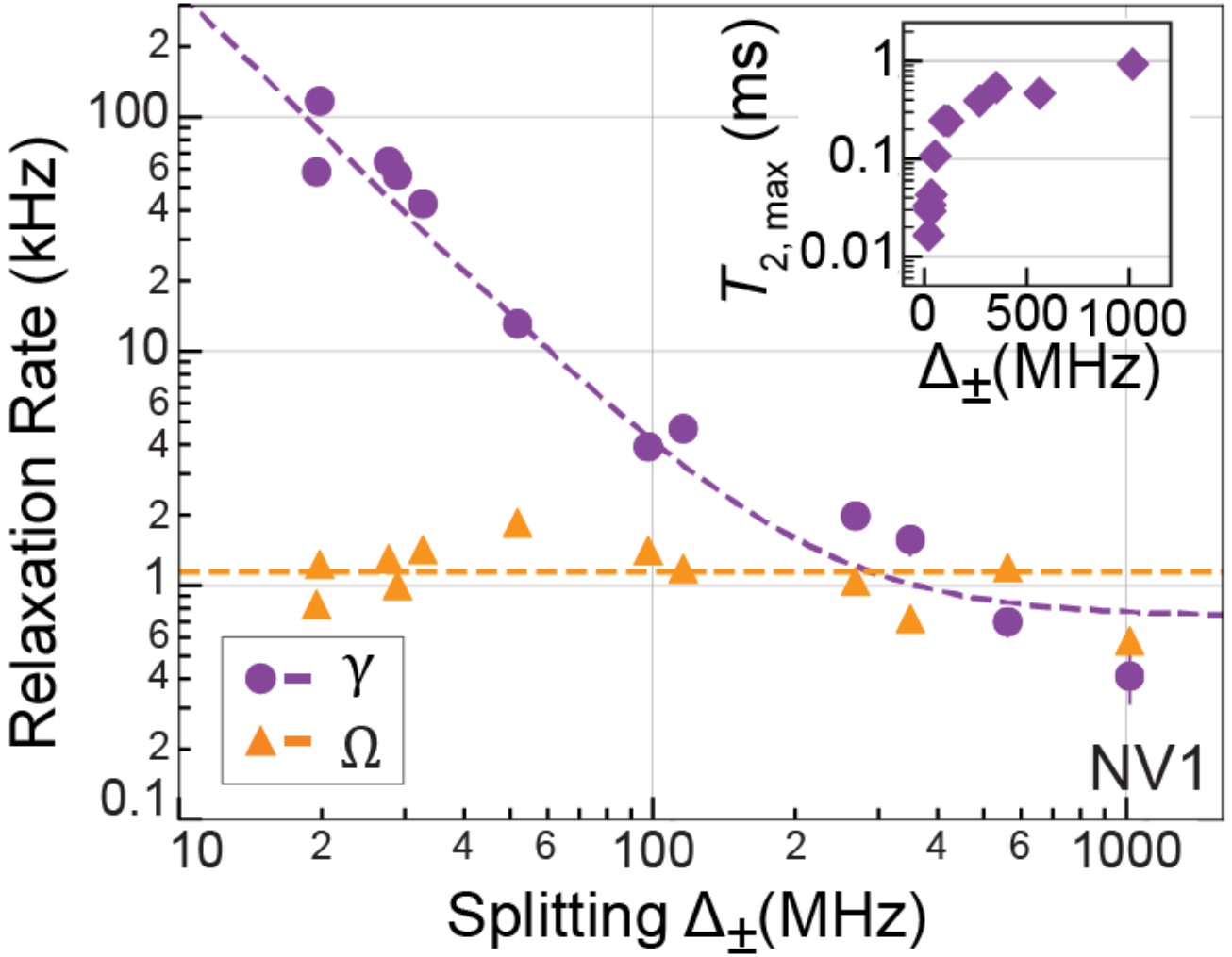
Electric field noise in nanodiamonds







A. Gardill *et al.*, "Fast relaxation on qutrit transitions of nitrogen-vacancy centers in nanodiamonds" Phys. Rev. Applied (2020)

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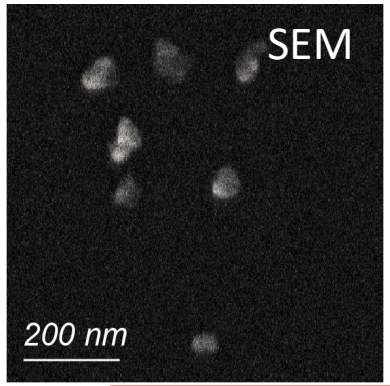
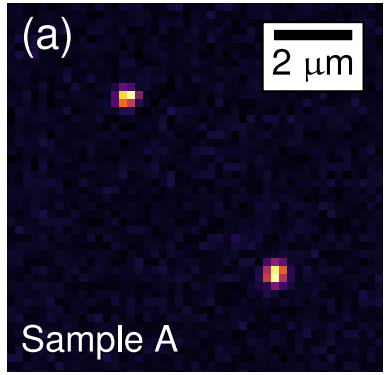
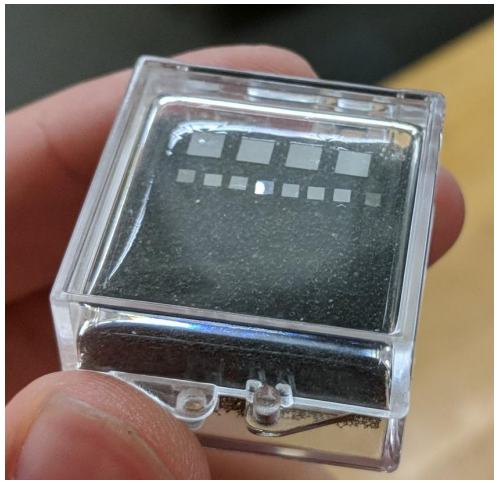
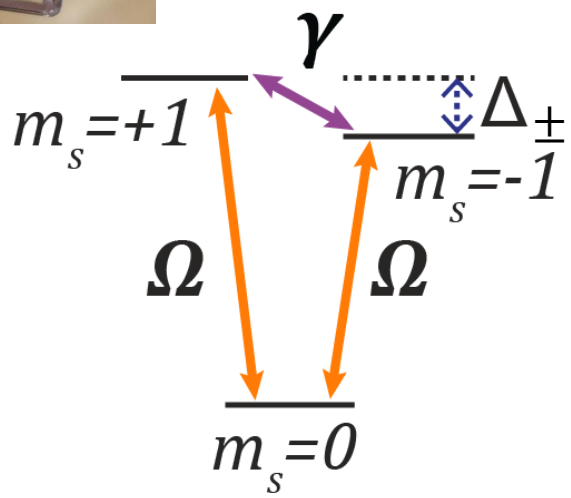


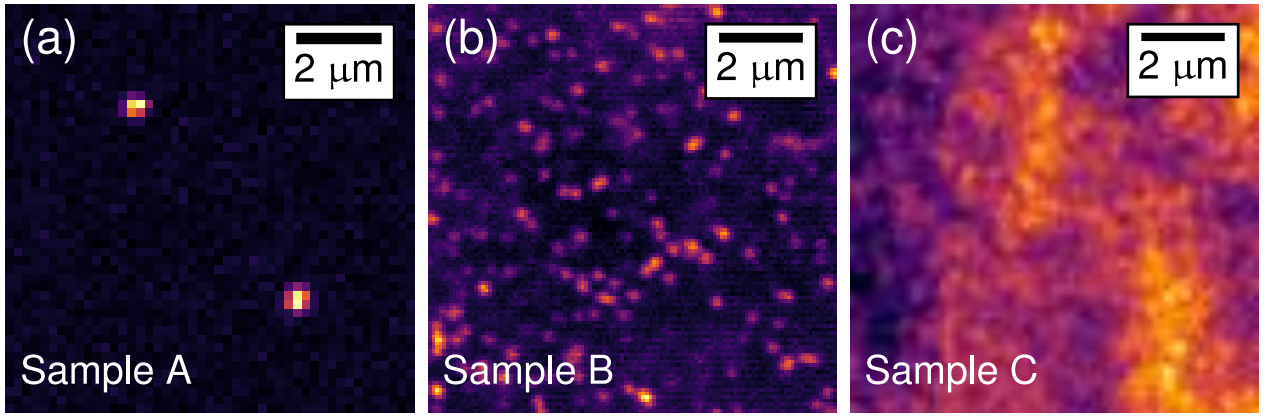
Ultimate limits to coherence and sensitivity

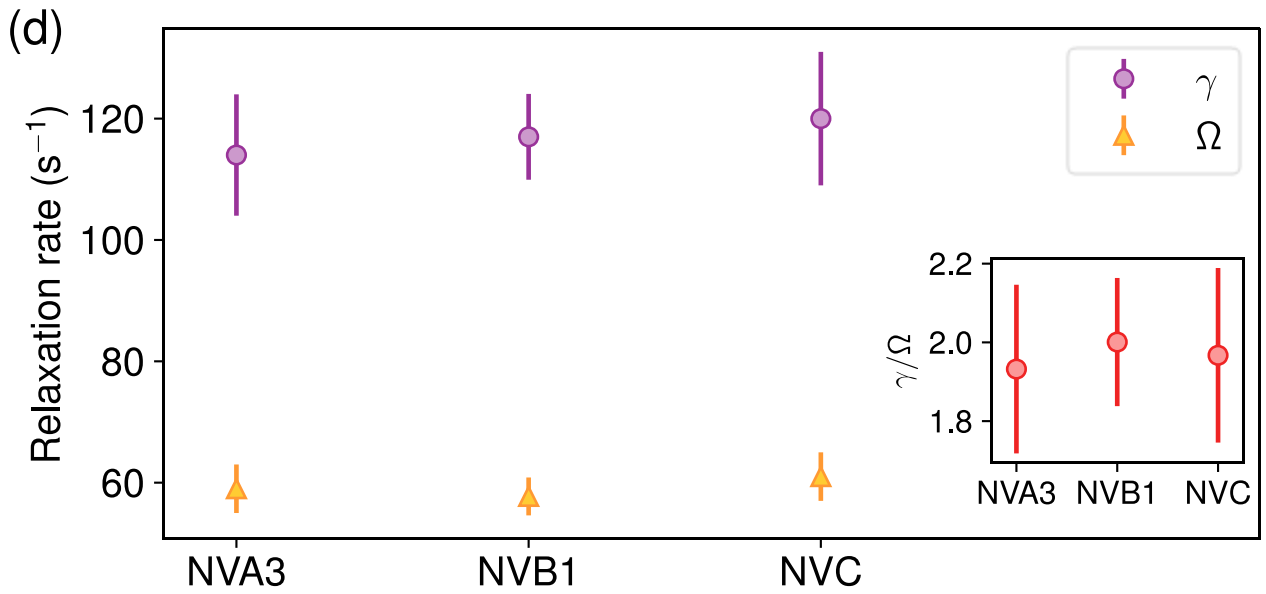


Relaxation rates of native NV in bulk diamond



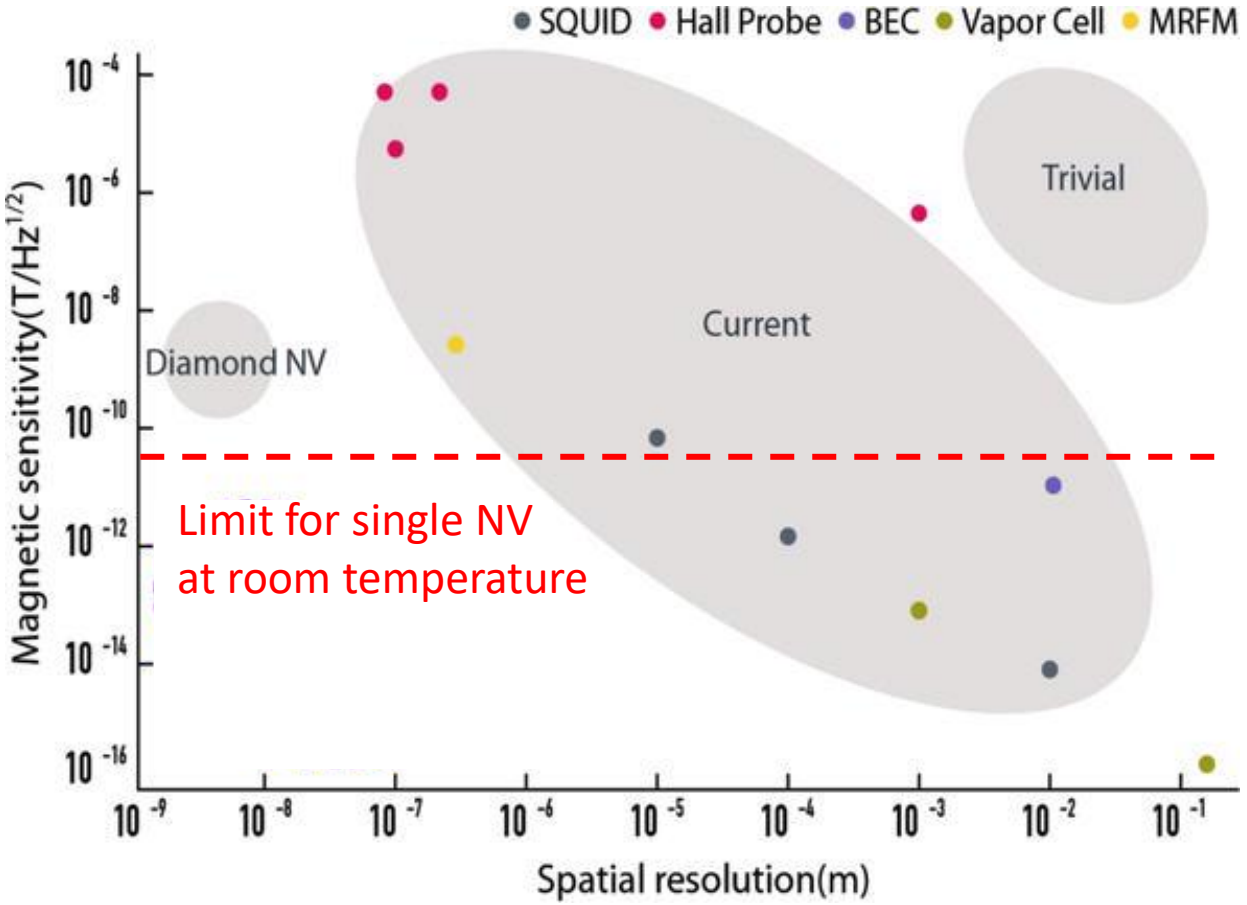




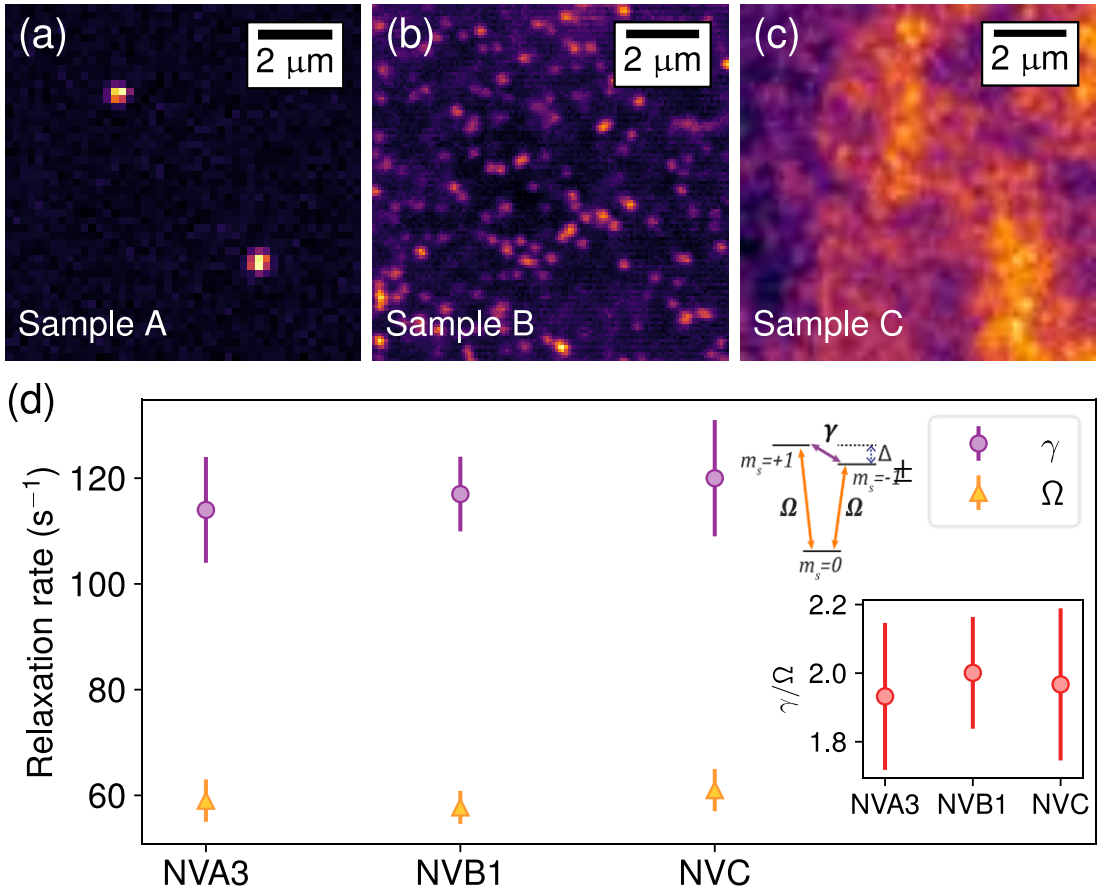


M.C. Cambria, A. Gardill, *et al.*, "State-dependent phonon-limited spin relaxation of nitrogen-vacancy centers", arXiv (2020)

State dependent relaxation in bulk diamond

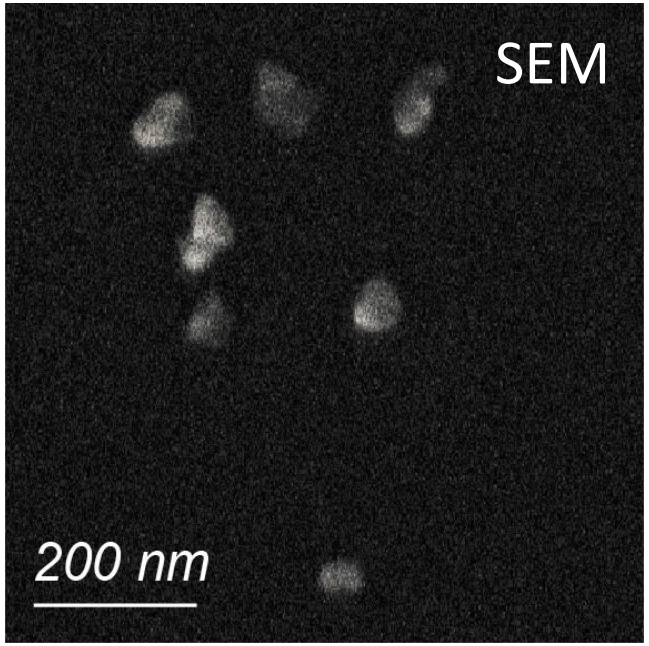


M. Lee *et al., Magnetometers - Fundamentals and Applications of Magnetism* (2020)

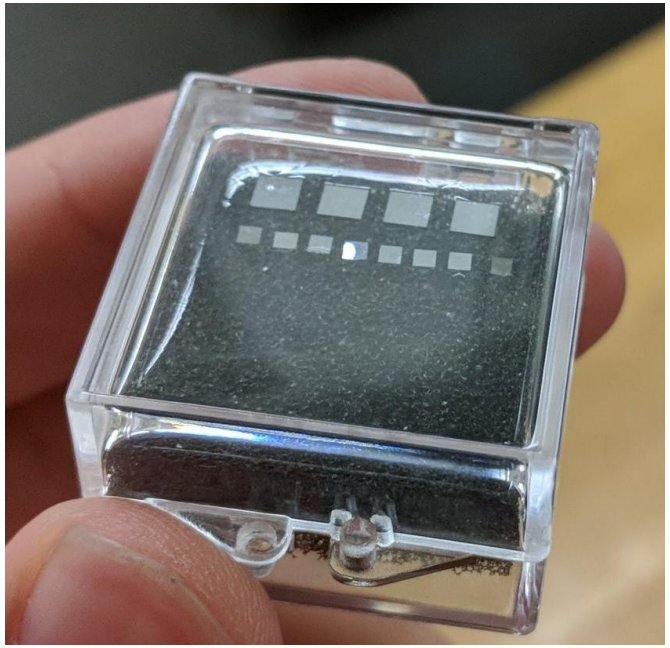


Conclusions

- Electric field noise in nanodiamonds
- Larger magnetic field mitigate electric field noise



- Phonon-limited relaxation of NVs
- Ultimate limit to NV sensitivity at room temperature



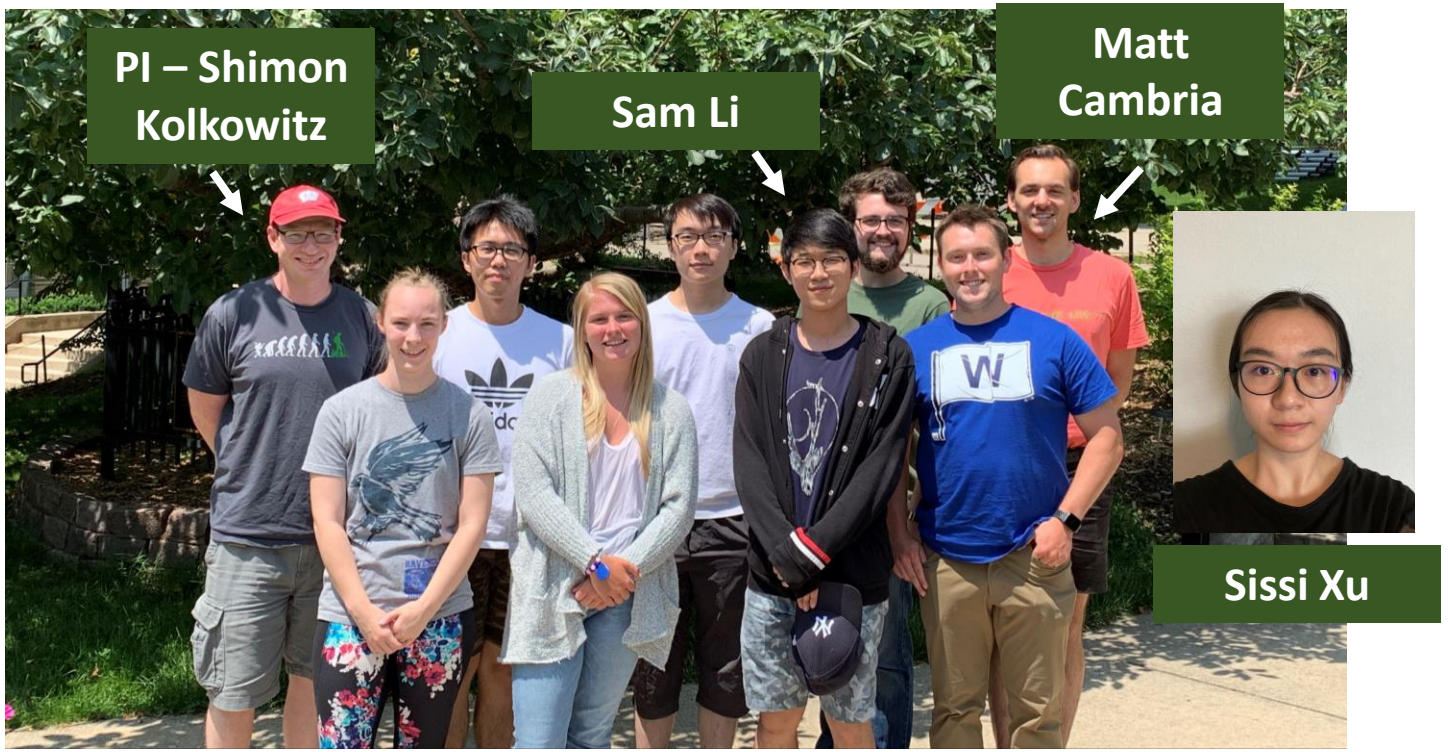
Looking forward

- Continue to investigate electric field noise in nanodiamonds
- Understand origin of phonon-limited relaxation in bulk diamond – temperature

- **Nanoscale measurements on surface noise of other materials – superconducting qubits, quantum dots**

Our cryostat!

Acknowledgements and funding



Kolkowitz Lab

The work was supported by the grant DE-SC0020313 funded by the U.S. Department of Energy, Office of Science