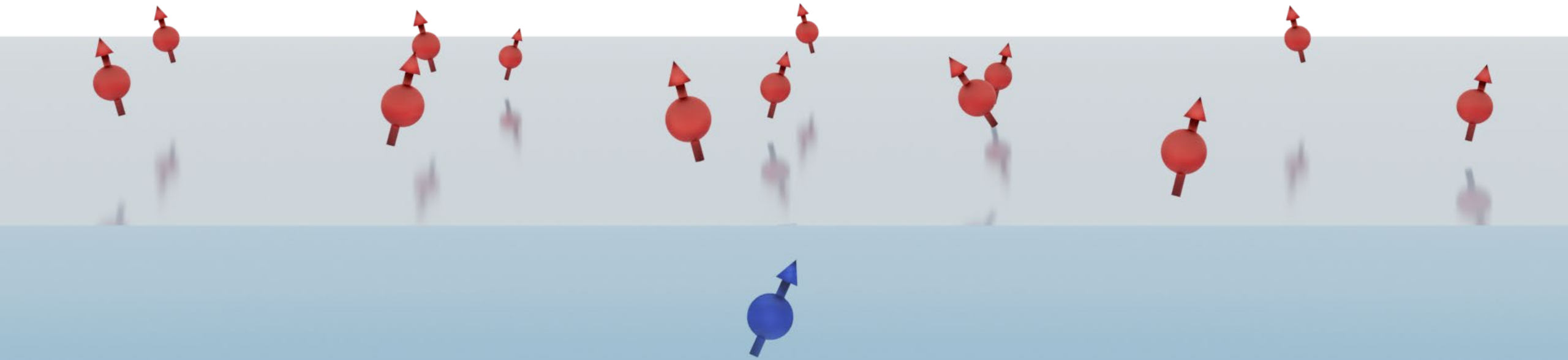
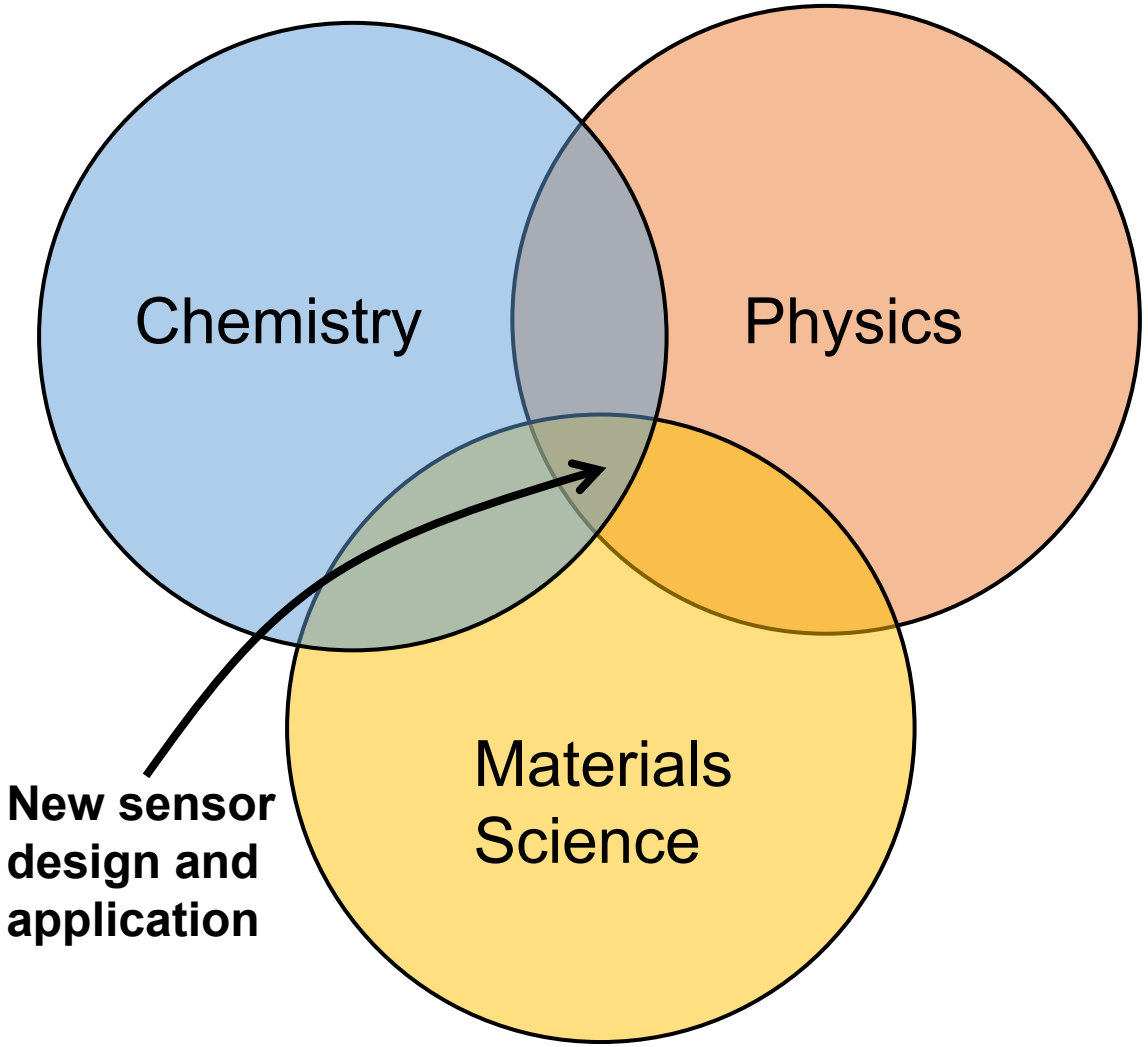
# **Shining light on single spins:** making defects in diamond useful

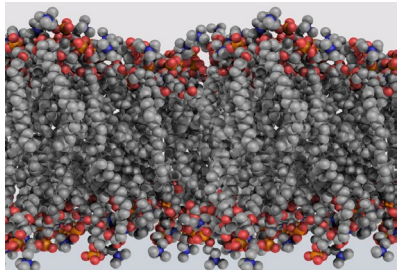


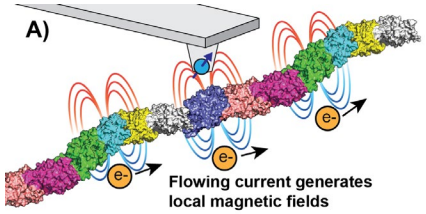
Paul Stevenson
Department of Physics

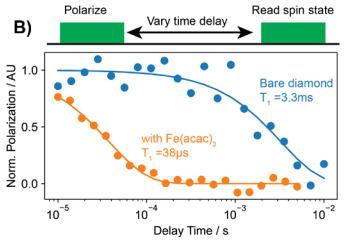
# Research in the Stevenson Group



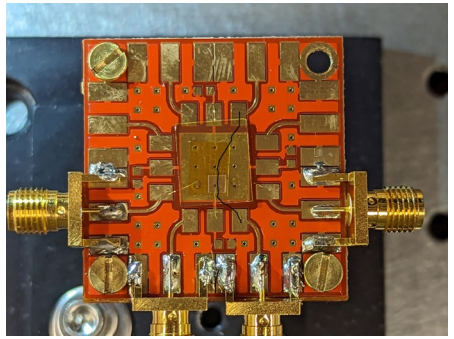

## Chemical & Biological Dynamics

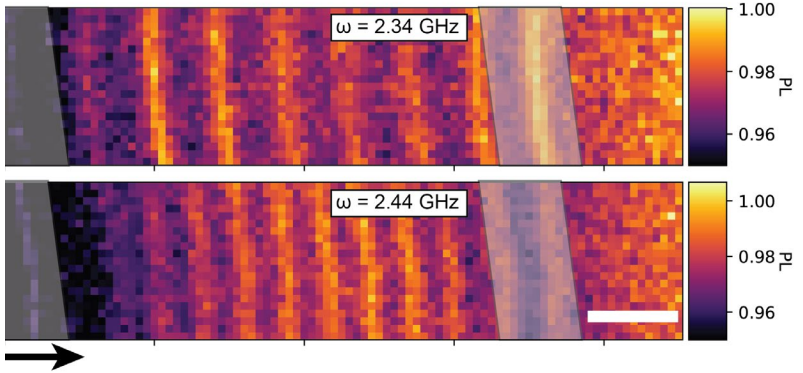




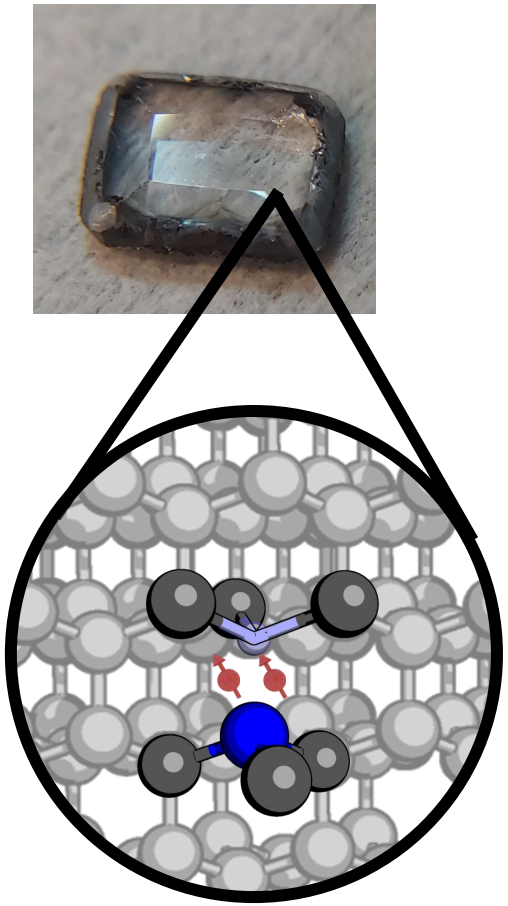




## Magnetic Materials



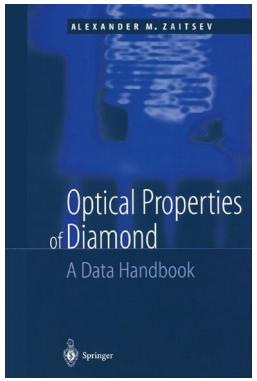


# The NV center: a nanoscale sensor



Nitrogen Vacancy defect in diamond

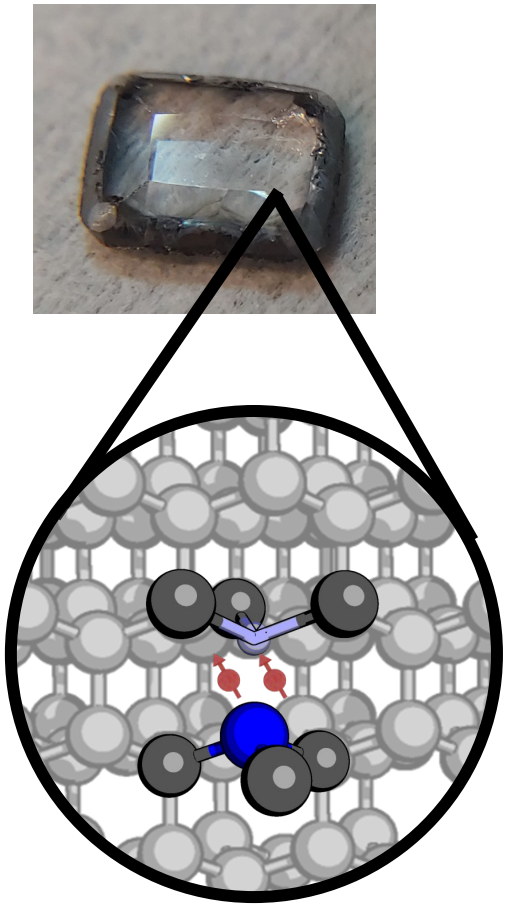
One of *many* different types of defects that can form in diamond




**Colors in diamonds come from impurities**

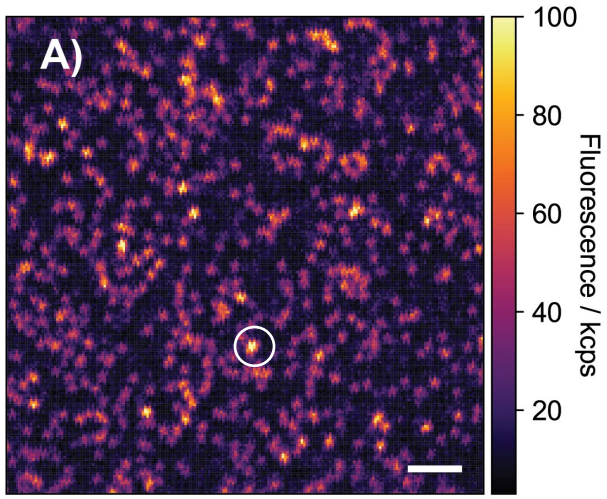
# The NV Center: a nanoscale sensor



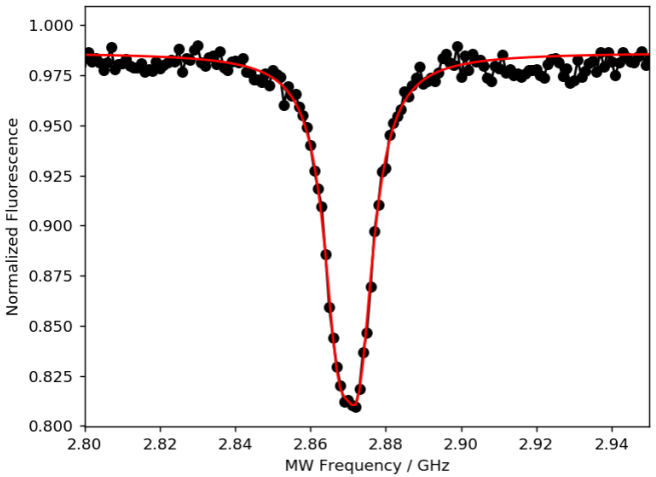
Nitrogen Vacancy defect in diamond

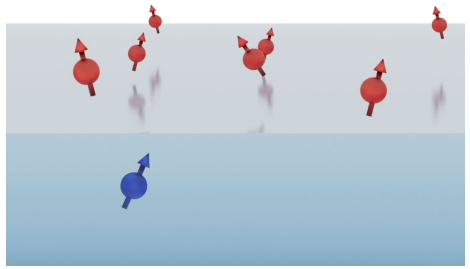
The NV center is special because:

**It's fluorescent**



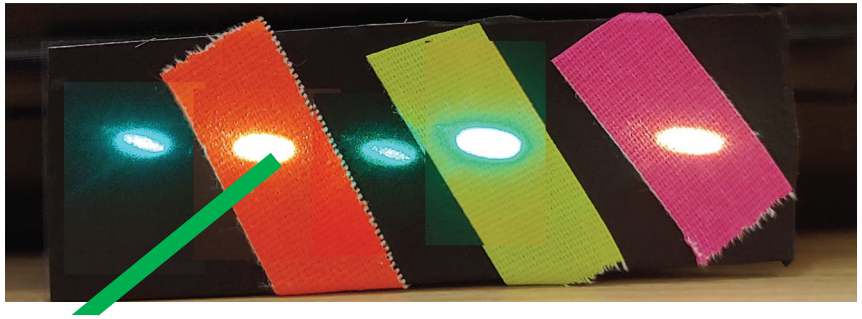

**…and the fluorescence depends on magnetic field**

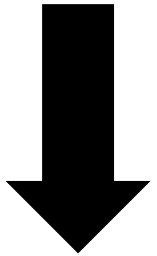


**… and it only reports on the environment in a ~10nm range**

# Fluorescence





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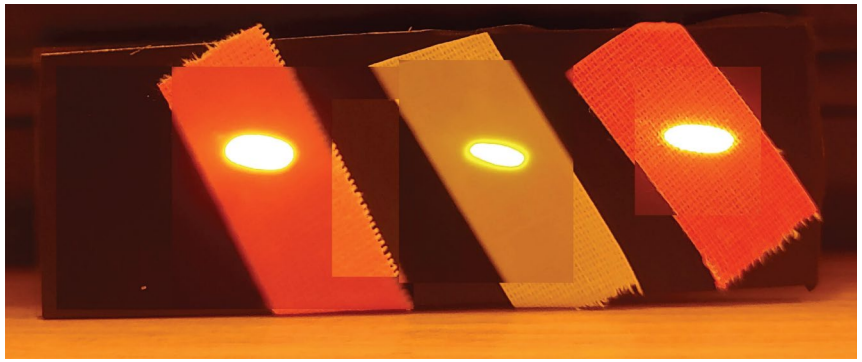
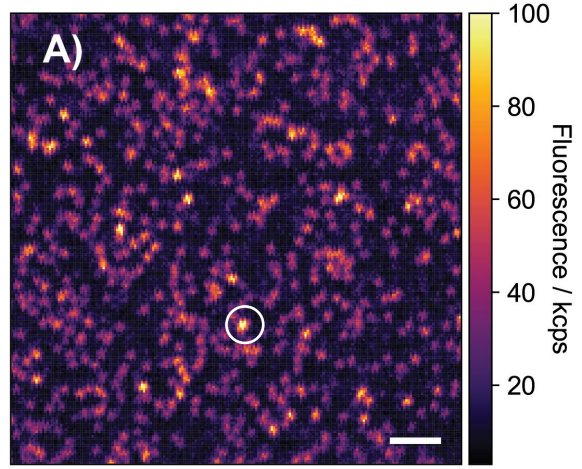


Green light in

Red light out

**Same thing happens in diamond:** green light goes in, and red light comes out if there's a nitrogen-vacancy center

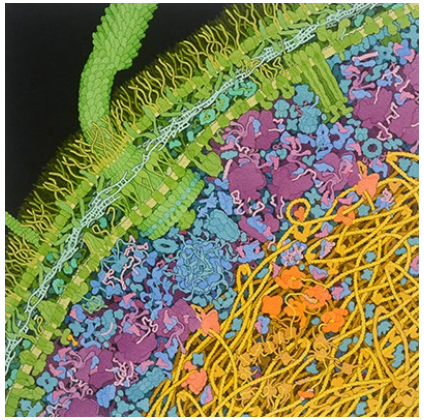
Fluorescence microscopes are **very** sensitive – each spot is an individual NV center



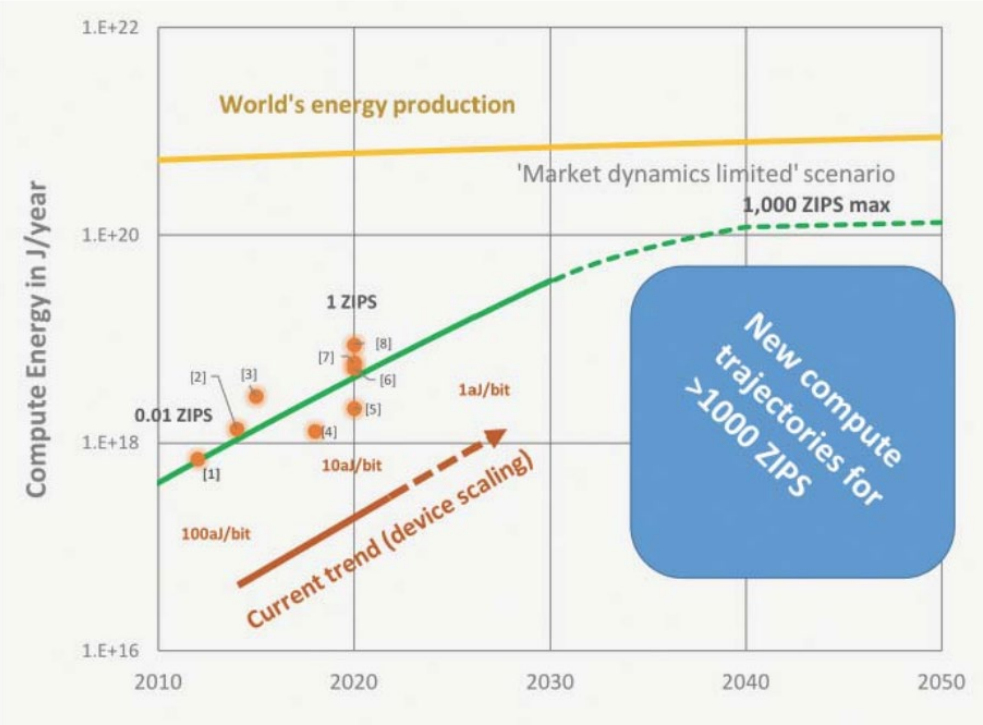
# What can we sense with a diamond defect?

**Magnetic materials**


**Chemical & Biological Dynamics**

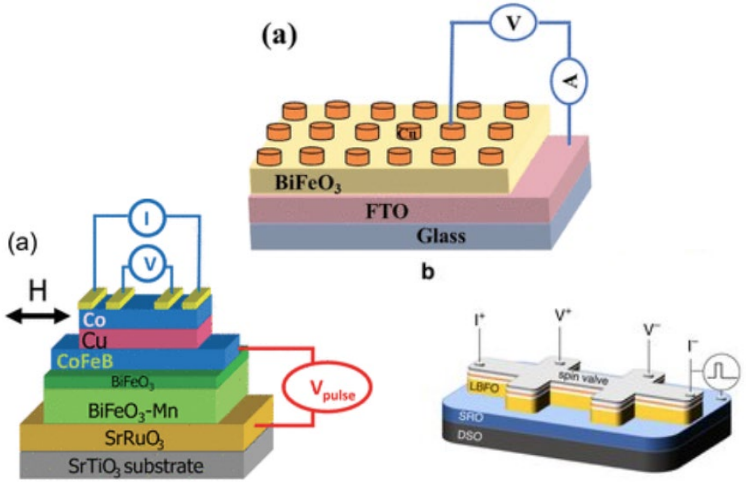


# Why magnetic materials?



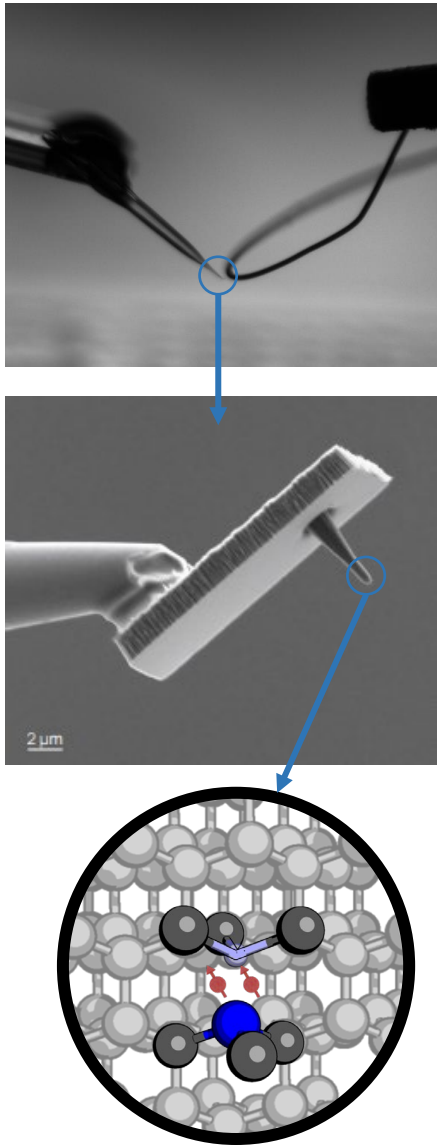

**Computing capabilities will be limited by available energy by 2040 with current device architectures**

Next-gen low-power device designs can utilize magnetism as a new resource…

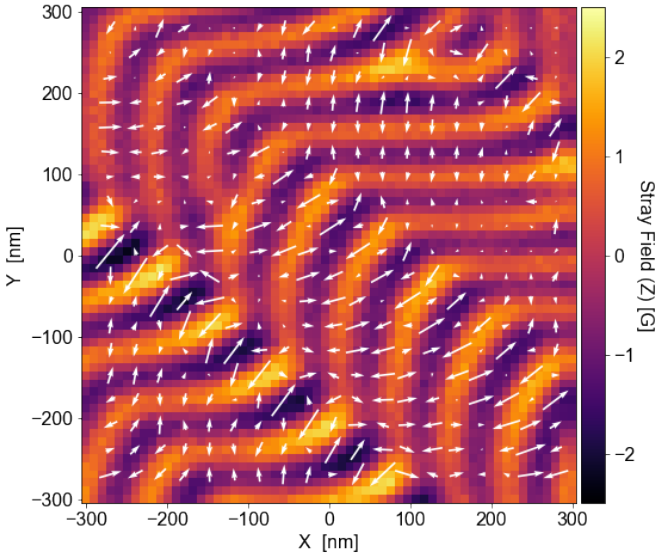


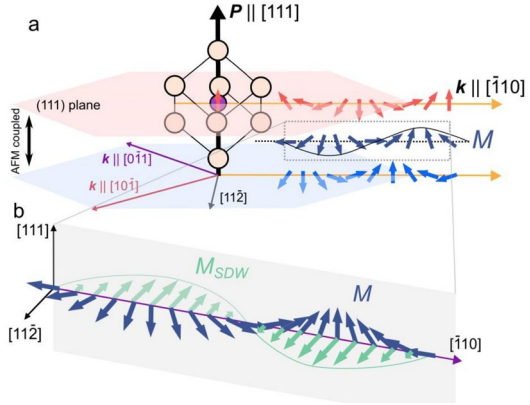

**…but we need to understand how the magnetic dipoles order and interact with other parts of the system**

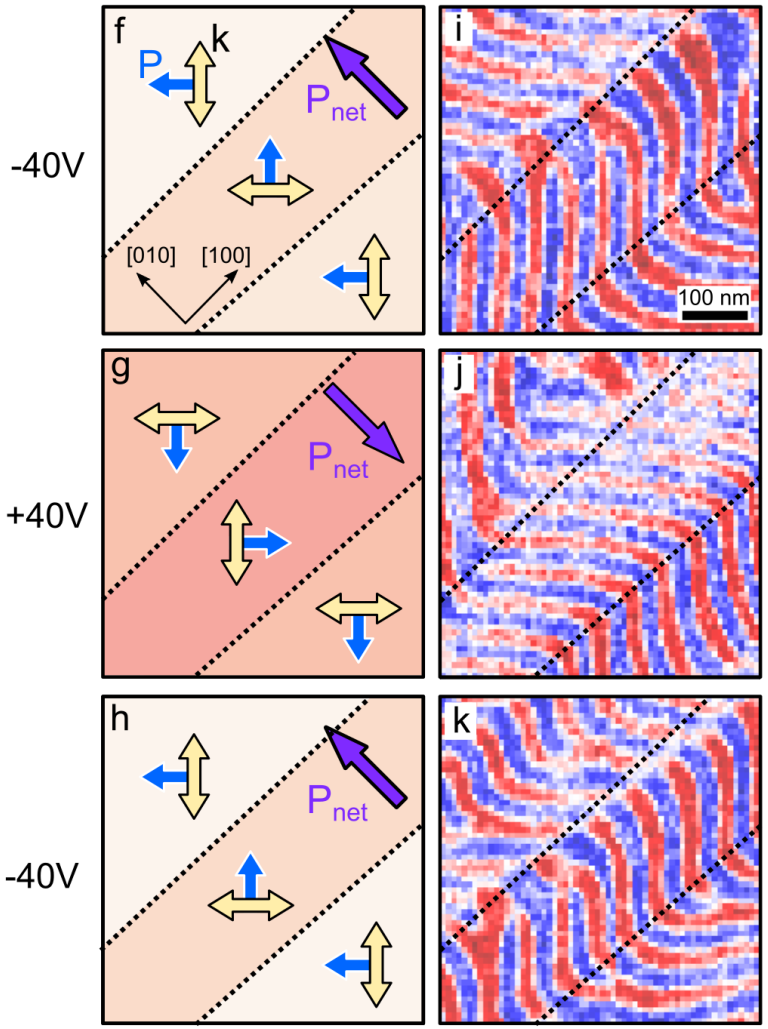
# Sensing magnetic materials




Scanning tip imaging reveals sub-100nm features in **$BiFeO_3$** from complex magnetic texture

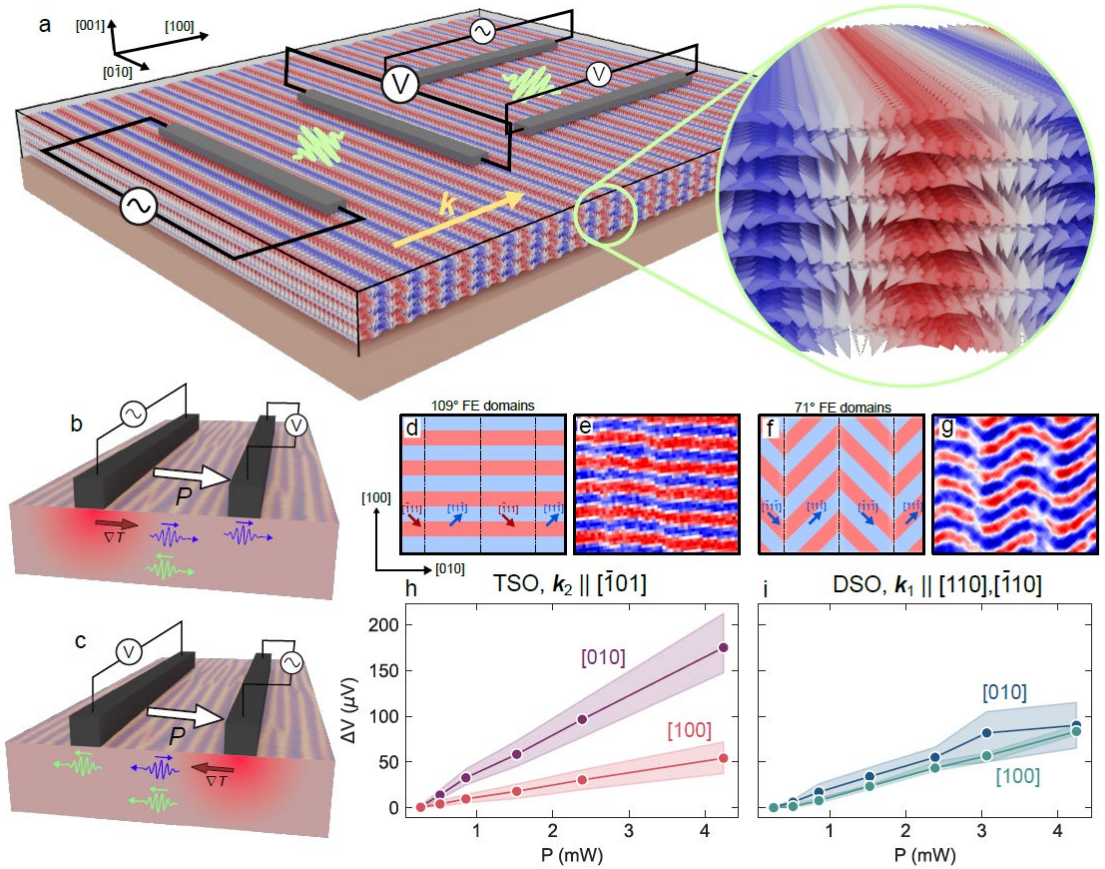


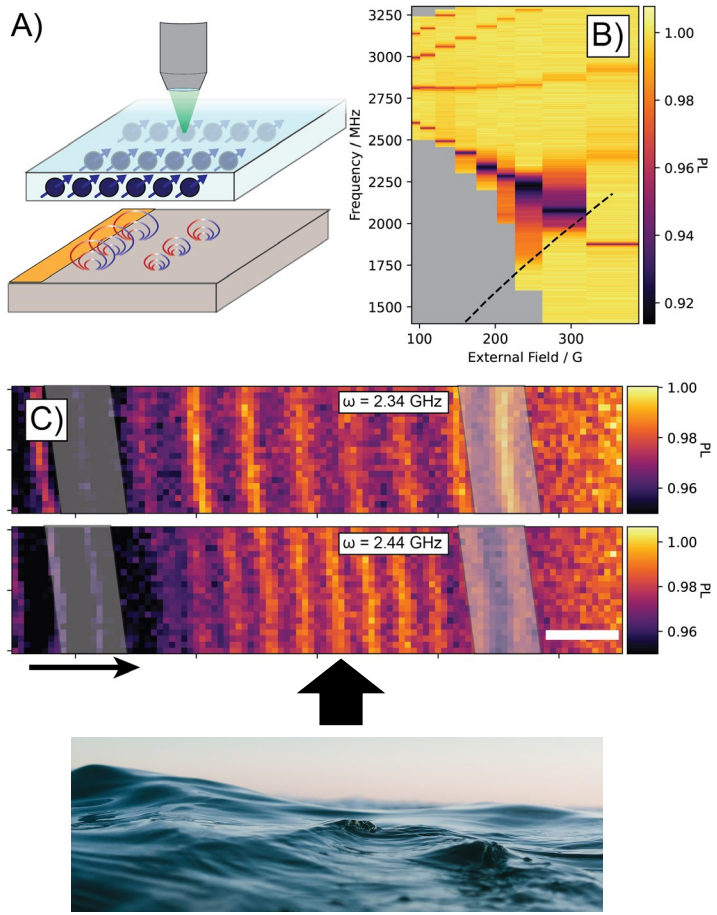

**First direct observation of electric-field control of magnetic structure**

# Sensing magnetic materials




Imaging magnetic materials allows us to explain why energy transport depends on direction

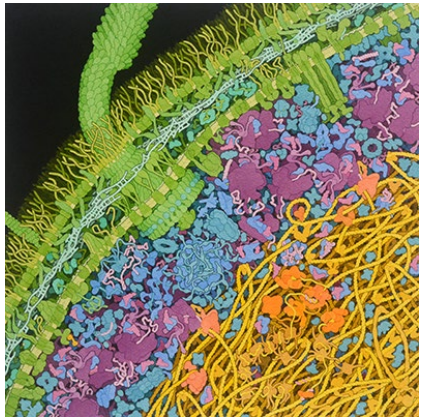
We can also *directly* image the flow of energy in some systems



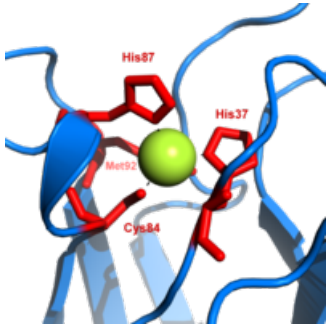
# What can we sense with a diamond defect?

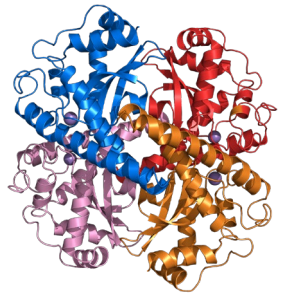
**Magnetic materials**

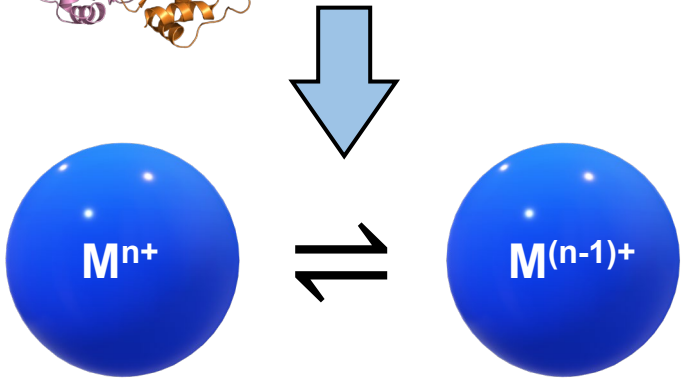

**Chemical & Biological Dynamics**



# Sensing chemical dynamics

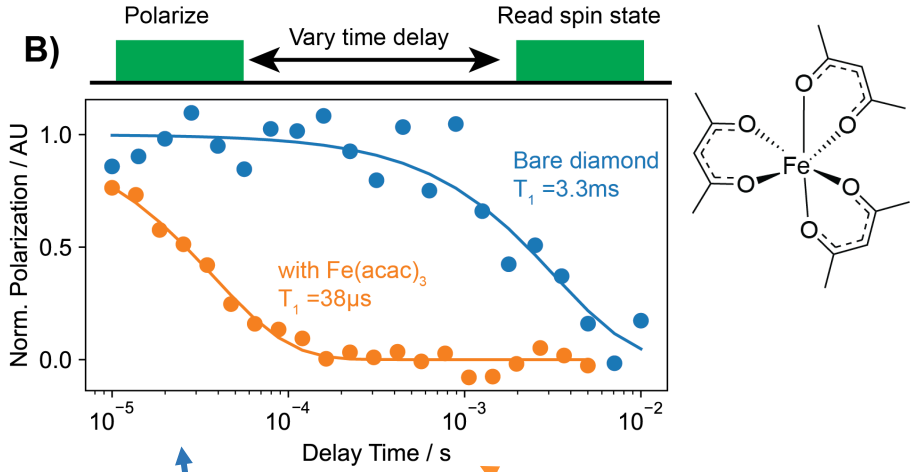


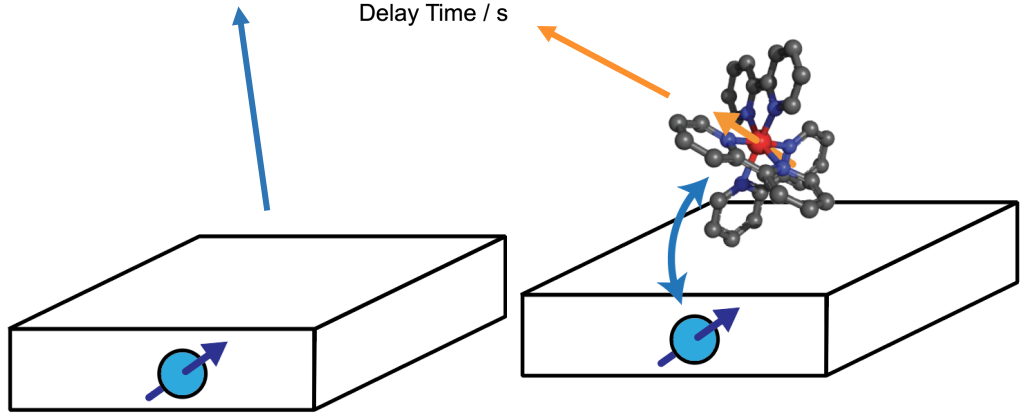






Many chemical reactions are just adding/removing an electron: **changes the magnetic state of the atoms!**

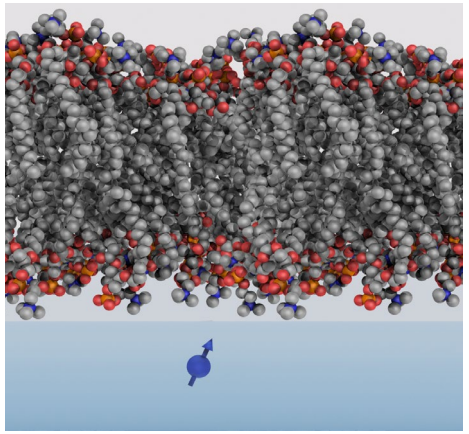
We can read out the presence of <100 molecules using NV centers in diamond



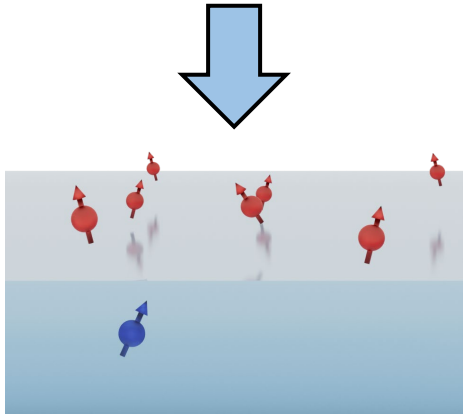



# Sensing biophysical dynamics

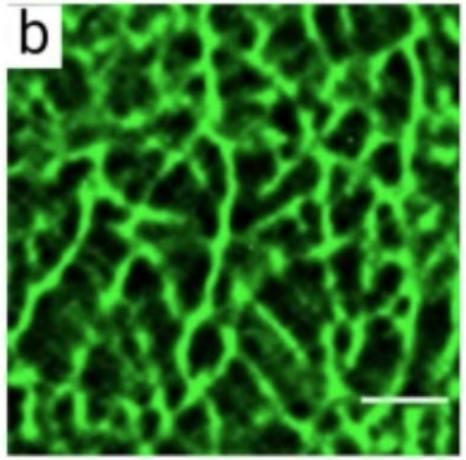
10nm



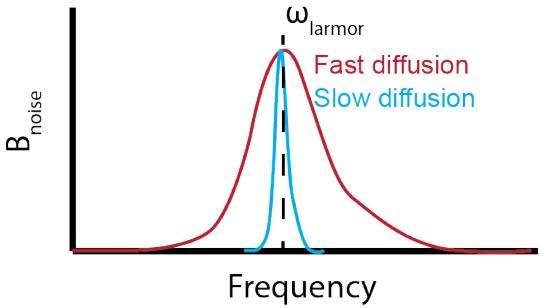
Membrane filled with CH groups



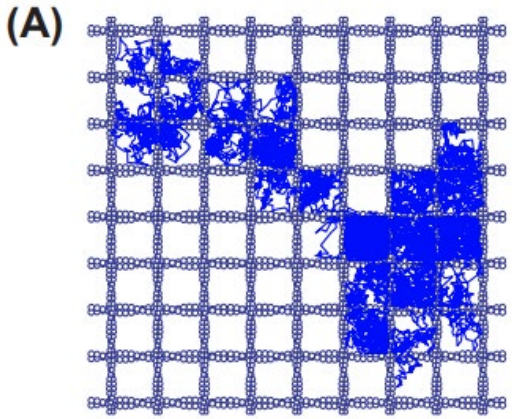
Mobile bath of protons

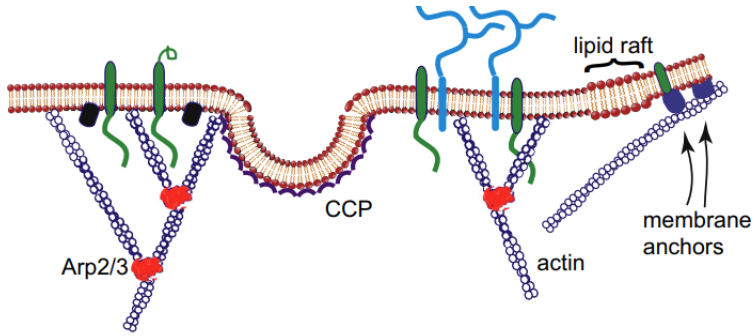



Motion is encoded in the spectrum we measure




Actin-defined compartments give rise to complex diffusion behaviors



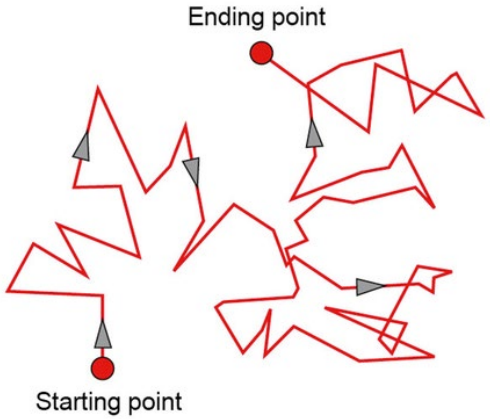



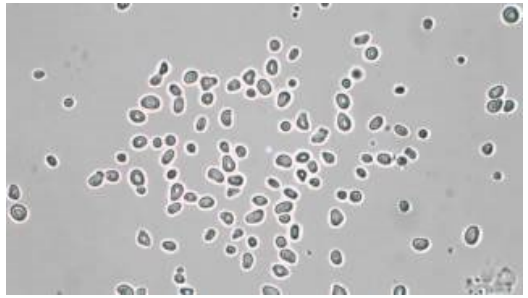

We need new techniques to observe behaviors <100nm

# Translational vs rotational dynamics

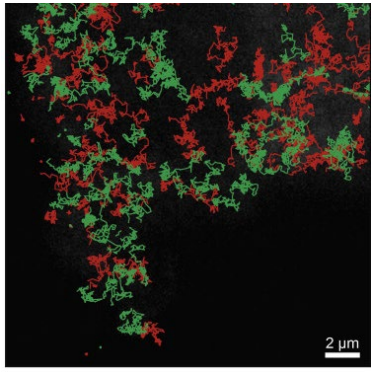
Motion in x, y, z: track the motion of individual particles

**Any microscope will do (more or less…)**



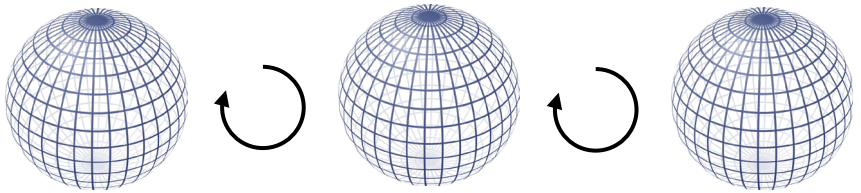



From pollen…

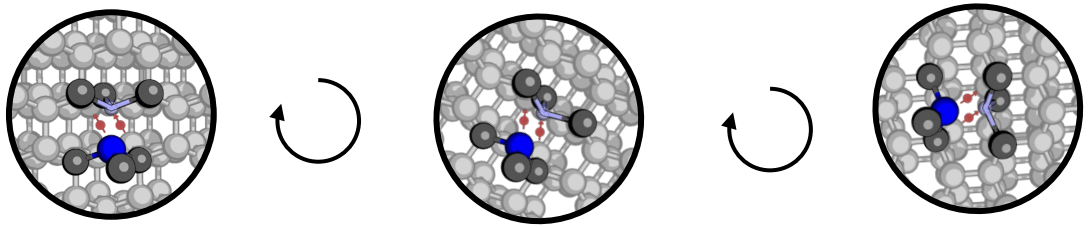



… to single molecules

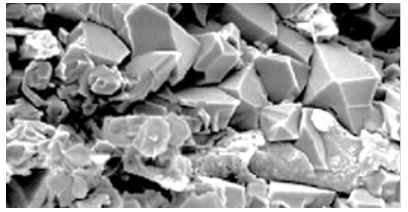
**Rotation?**



**NV centers don't stay the same if we rotate them!**



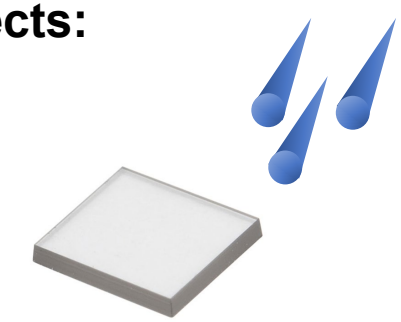
Nanodiamonds allow us to locally probe the freedom to rotate

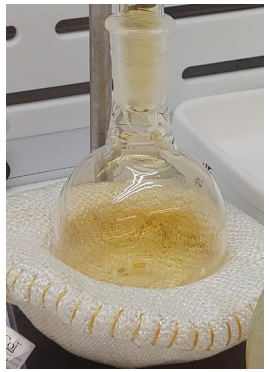


# NV centers in practice

## Making defects:

Implant ultra-pure diamond

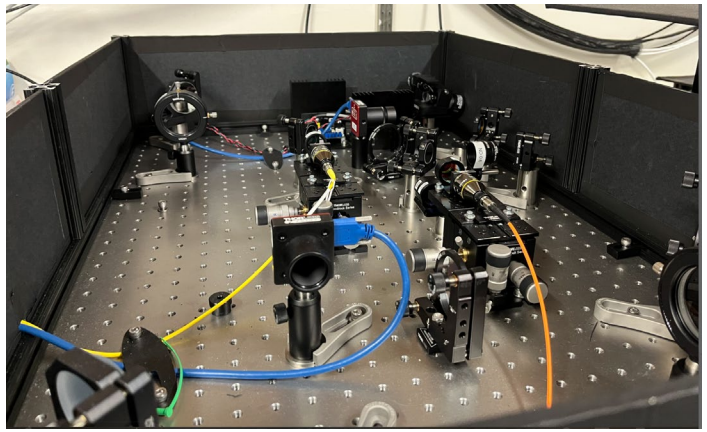


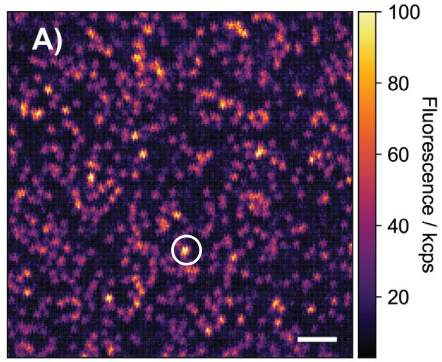


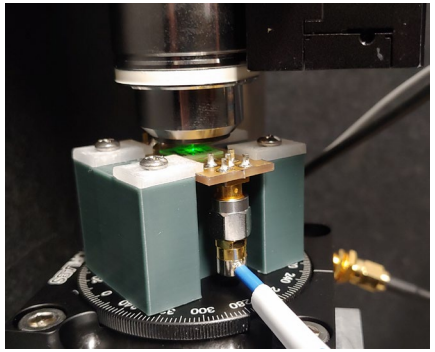
Clean in boiling acid to remove any contaminants

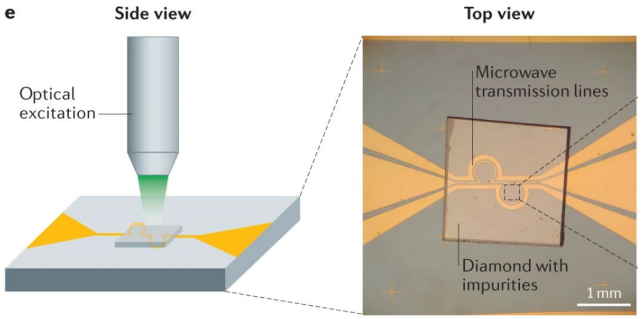
Heat to >1000C to undo damage

## Measuring defects:

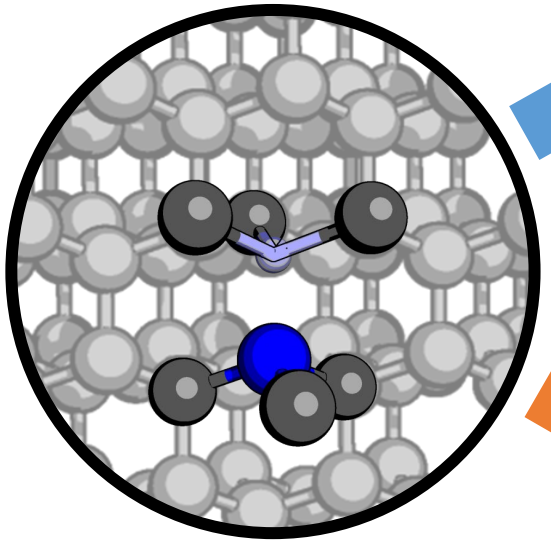


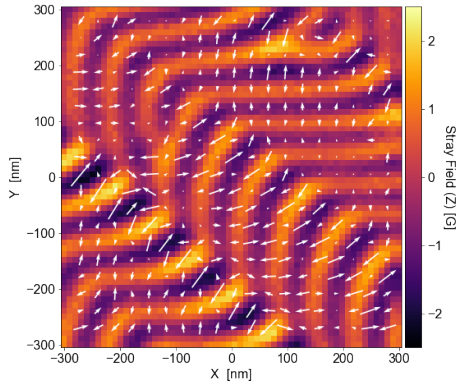


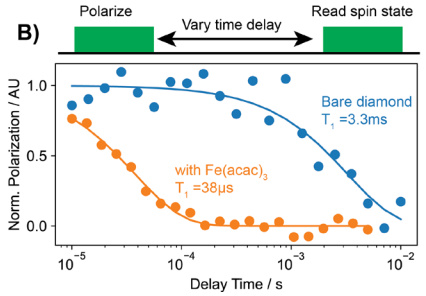



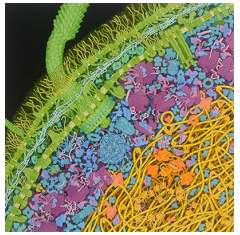


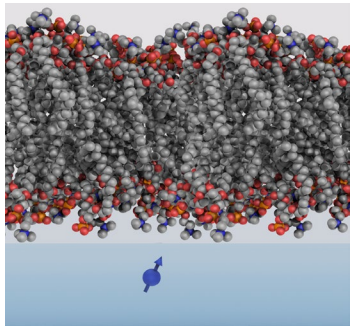
## Magnetic materials







## Chemistry and biophysics

## Graduate Students

Nathaniel Beaver

Nicole Voce

## The lab: