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Diamond crystal stress imaging using nitrogen-vacancy centers in diamond

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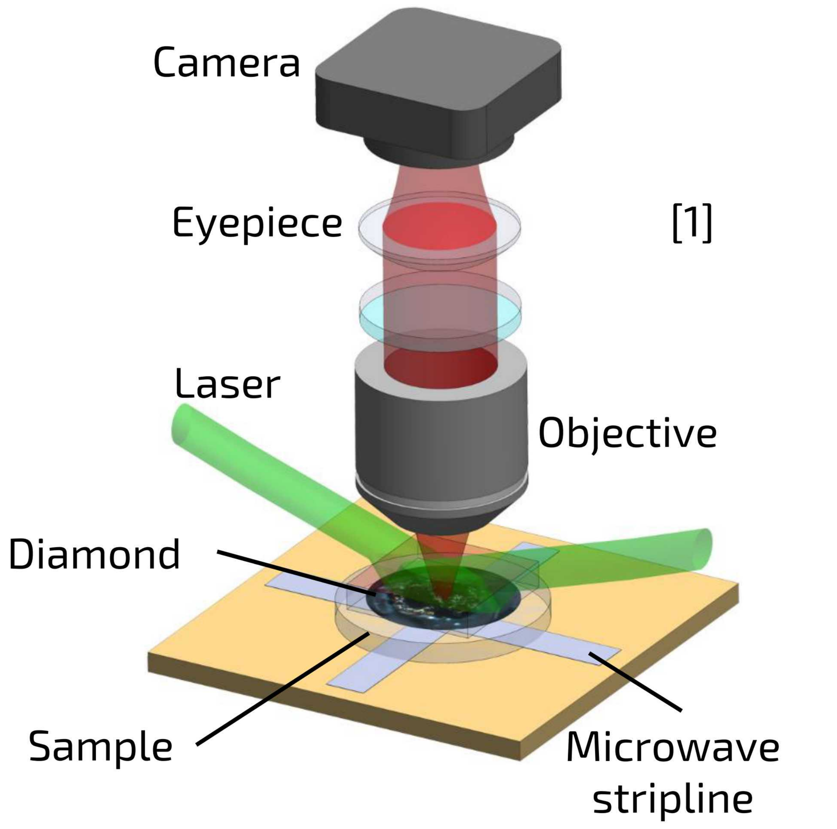
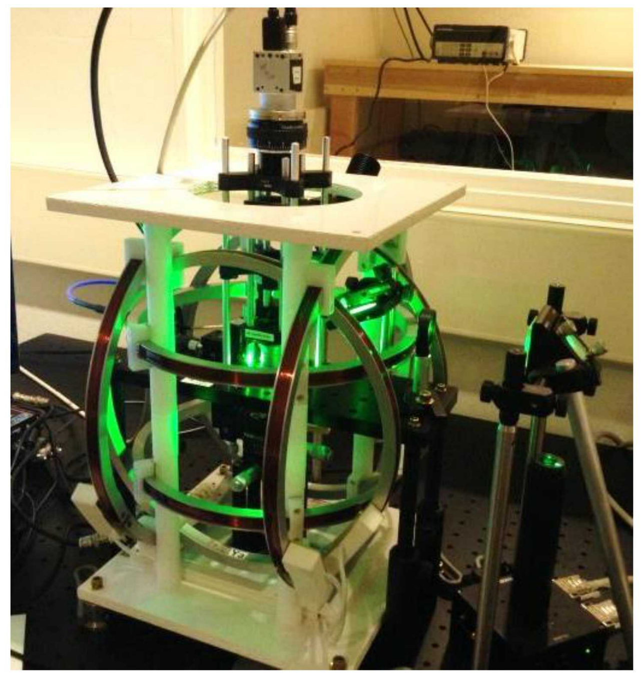
Summary

- We use nitrogen-vacancy (NV) color centers in diamond for magnetic microscopy



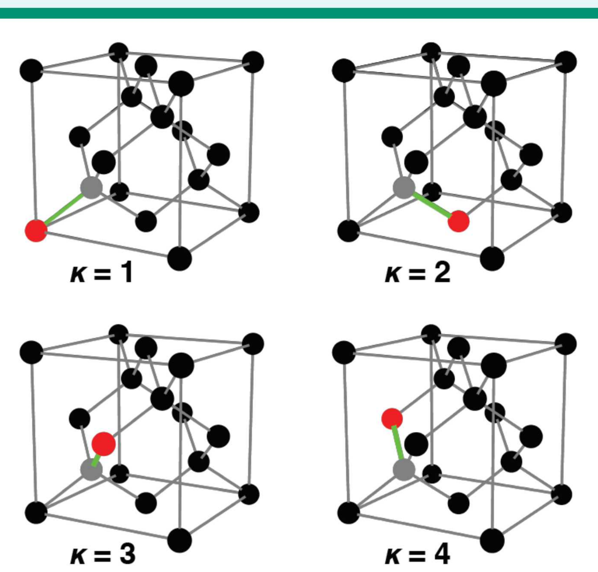


- Diamond crystal stress inhomogeneity can complicate NV magnetometry
- Goals:
  - Map the diamond stress tensors
  - Study natural strain defects
  - Understand their effects on NV magnetic imaging

Stress contribution to NV Hamiltonian [2-5]

For each NV orientation:

$$H_\kappa = (D + M_{z,\kappa})\, S_{z,\kappa}^2 + \gamma \vec{B}\cdot\vec{S}_\kappa + \cancel{M_{x,\kappa}\left(S_{y,\kappa}^2 - S_{x,\kappa}^2\right)} + \cancel{M_{y,\kappa}\left(S_{x,\kappa}S_{y,\kappa} + S_{y,\kappa}S_{x,\kappa}\right)} + \cancel{N_{x,\kappa}\left(S_{x,\kappa}S_{z,\kappa} + S_{z,\kappa}S_{x,\kappa}\right)} + \cancel{N_{y,\kappa}\left(S_{y,\kappa}S_{z,\kappa} + S_{z,\kappa}S_{y,\kappa}\right)}$$



Stress tensor for $\kappa = 1$

$$\begin{pmatrix} \sigma_{XX} & \sigma_{XY} & \sigma_{XZ} \\ \sigma_{XY} & \sigma_{YY} & \sigma_{YZ} \\ \sigma_{XZ} & \sigma_{YZ} & \sigma_{ZZ} \end{pmatrix} \Longrightarrow \quad M_{z,1} = a_1\sigma_{\mathrm{diag}} + 2a_2\left[\sigma_{XY} + \sigma_{XZ} + \sigma_{YZ}\right], \text{ where}$$

$$\sigma_{\mathrm{diag}} \equiv \sigma_{XX} + \sigma_{YY} + \sigma_{ZZ}$$

$$\{a_1, a_2\} = \{4.86, -3.7\}\ \mathrm{MHz/GPa}$$

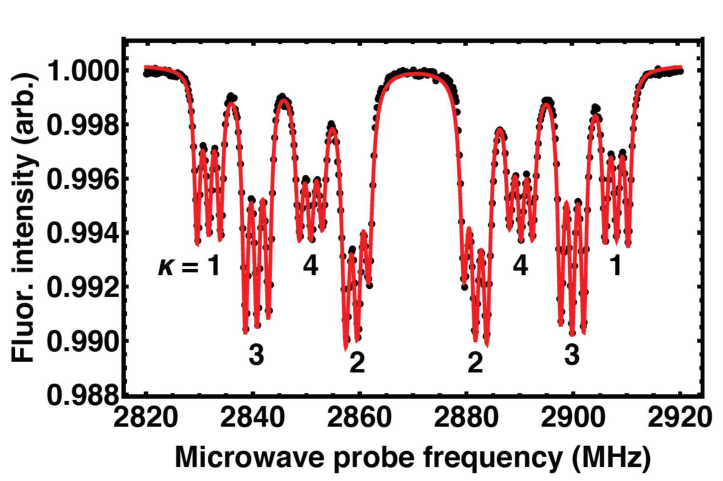
Repeat for each κ and solve:

$$\sigma_{\mathrm{diag}} = \frac{1}{4a_1}\left[M_{z,1} + M_{z,2} + M_{z,3} + M_{z,4}\right]$$

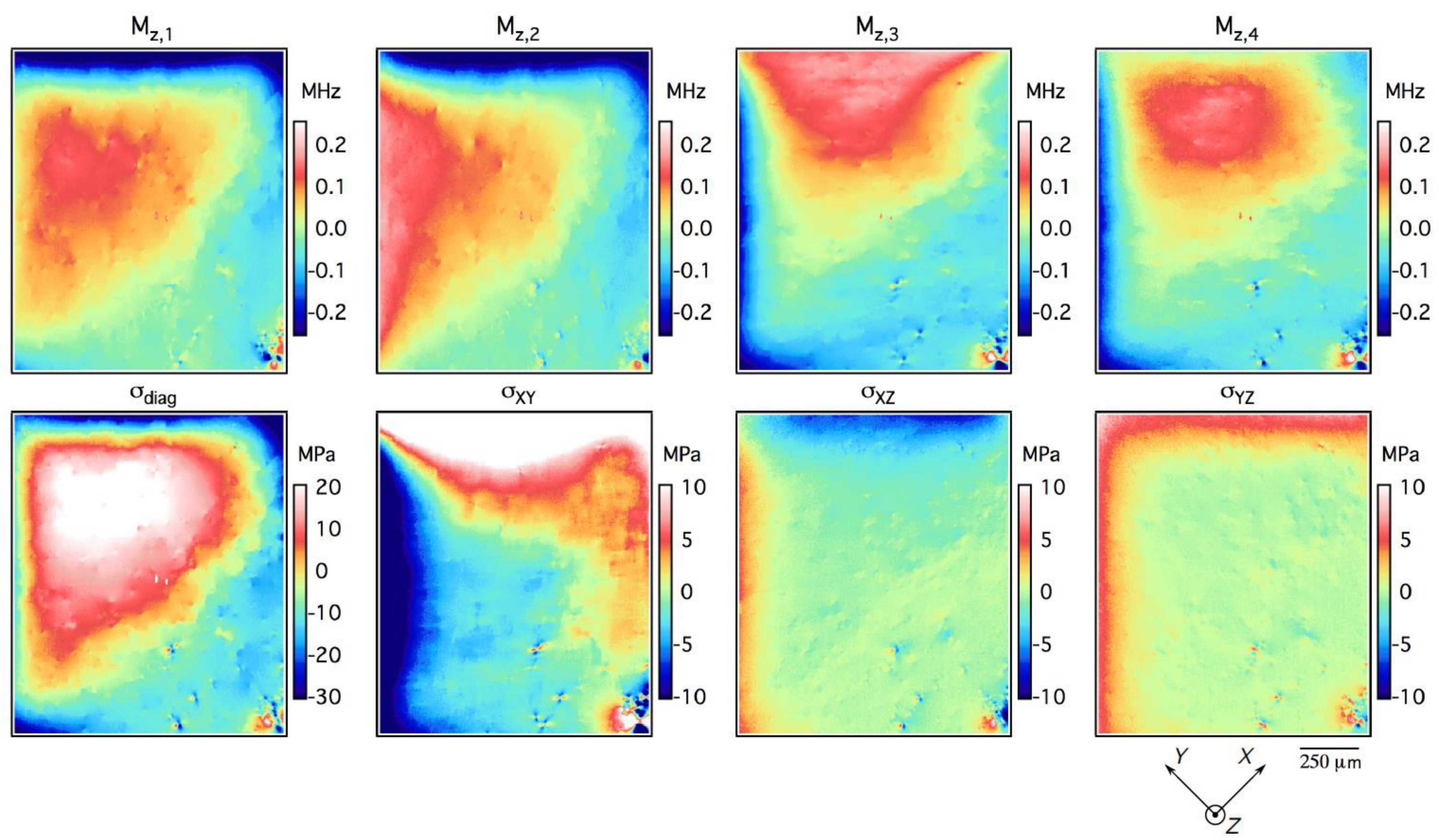
$$\sigma_{XY} = \frac{1}{8a_2}\left[M_{z,1} + M_{z,2} - M_{z,3} - M_{z,4}\right]$$

$$\sigma_{XZ} = \frac{1}{8a_2}\left[M_{z,1} - M_{z,2} + M_{z,3} - M_{z,4}\right]$$

$$\sigma_{YZ} = \frac{1}{8a_2}\left[M_{z,1} - M_{z,2} - M_{z,3} + M_{z,4}\right]$$



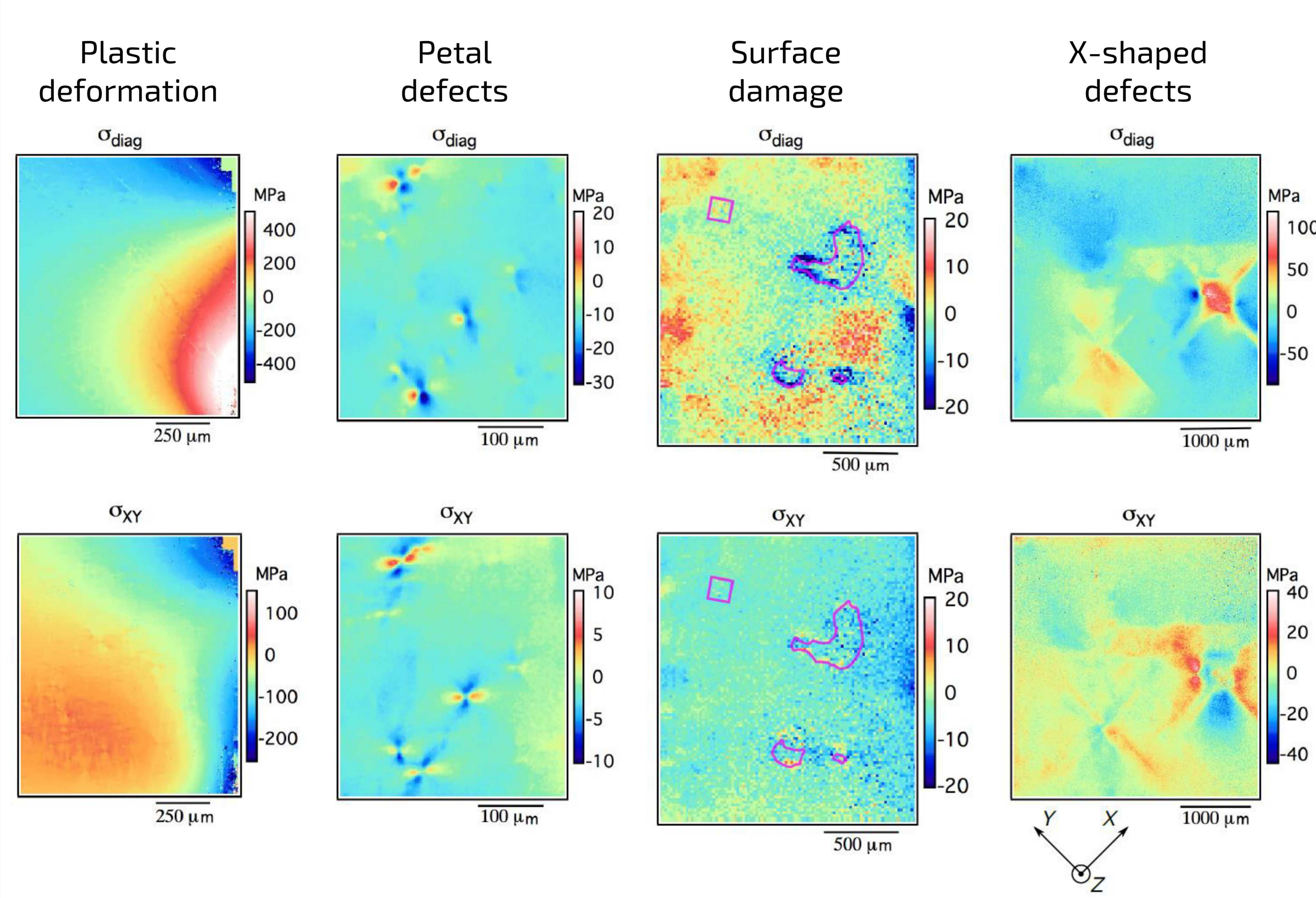
Sample stress tensor reconstruction



- Homogeneous M_z is better for magnetic imaging
- Stress maps indicate diamond growth problems
- Usually get more stress in σ_{diag} and σ_{XY}

Strain feature survey

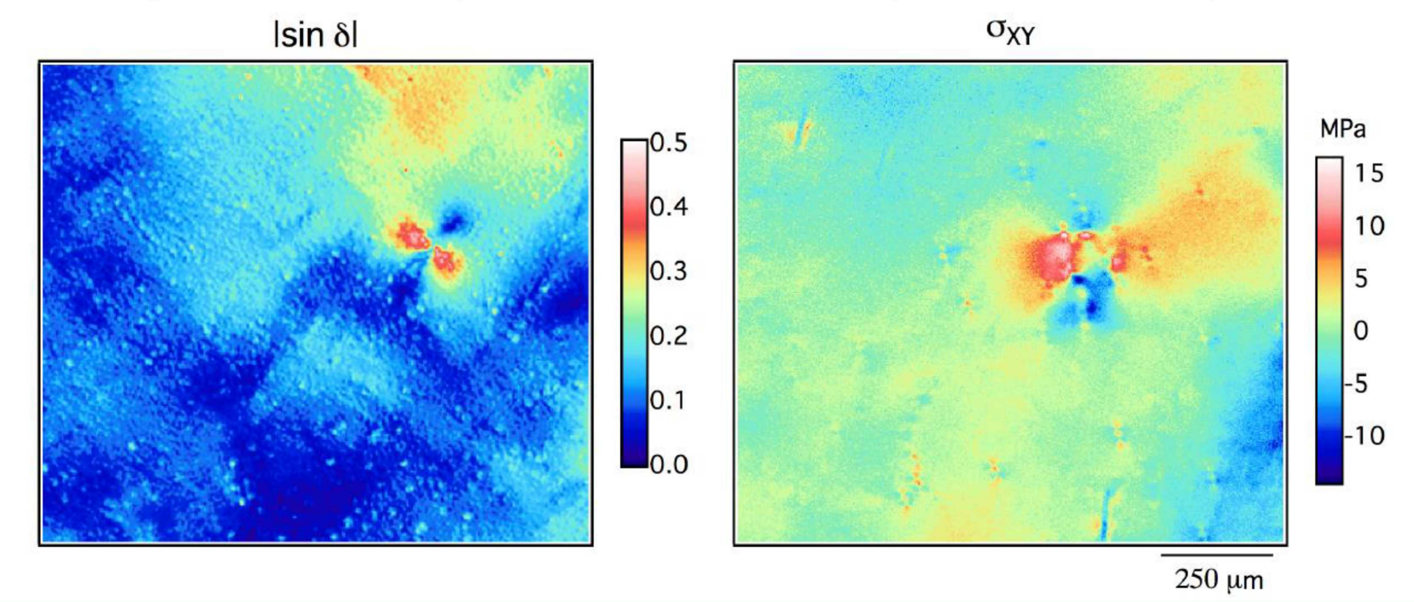
- Strain from edges, corners, lattice dislocations, and surface damage



Comparison to birefringence imaging

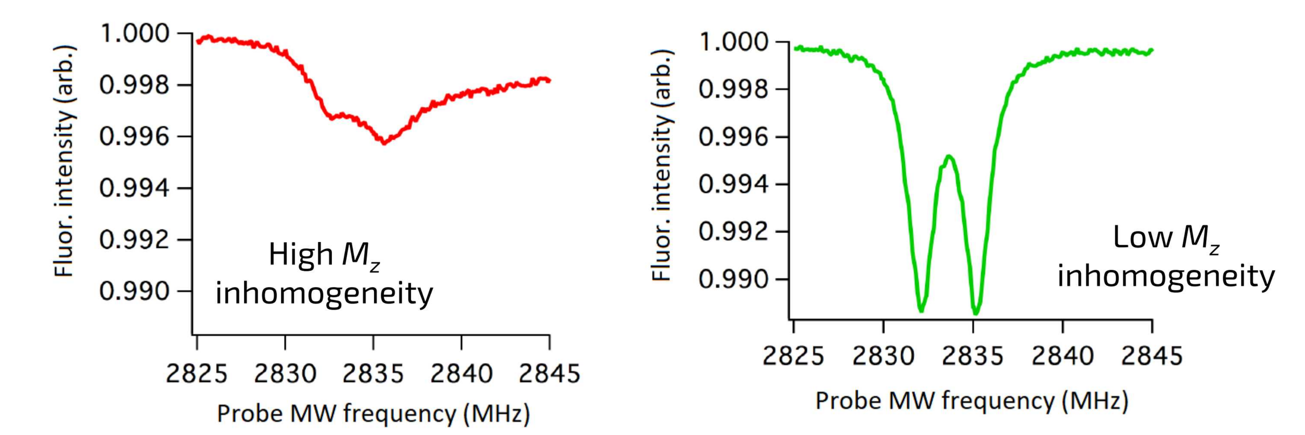
Birefringence:
- \+ Works for transparent materials
- \+ Easier setup & faster measurement
- \- Integrate through diamond slab
- \- Phase ambiguity if δ > π
- \- Nontrivial stress extraction
- \- Birefringence in other optics

NVs:
- \- Need stress-dependent defects
- \- NV magnetic imager needed
- \+ Measure in NV layer only
- \+ No upper bound on stress*
- \+ Easy M_z to stress conversion
- \- Temperature stability

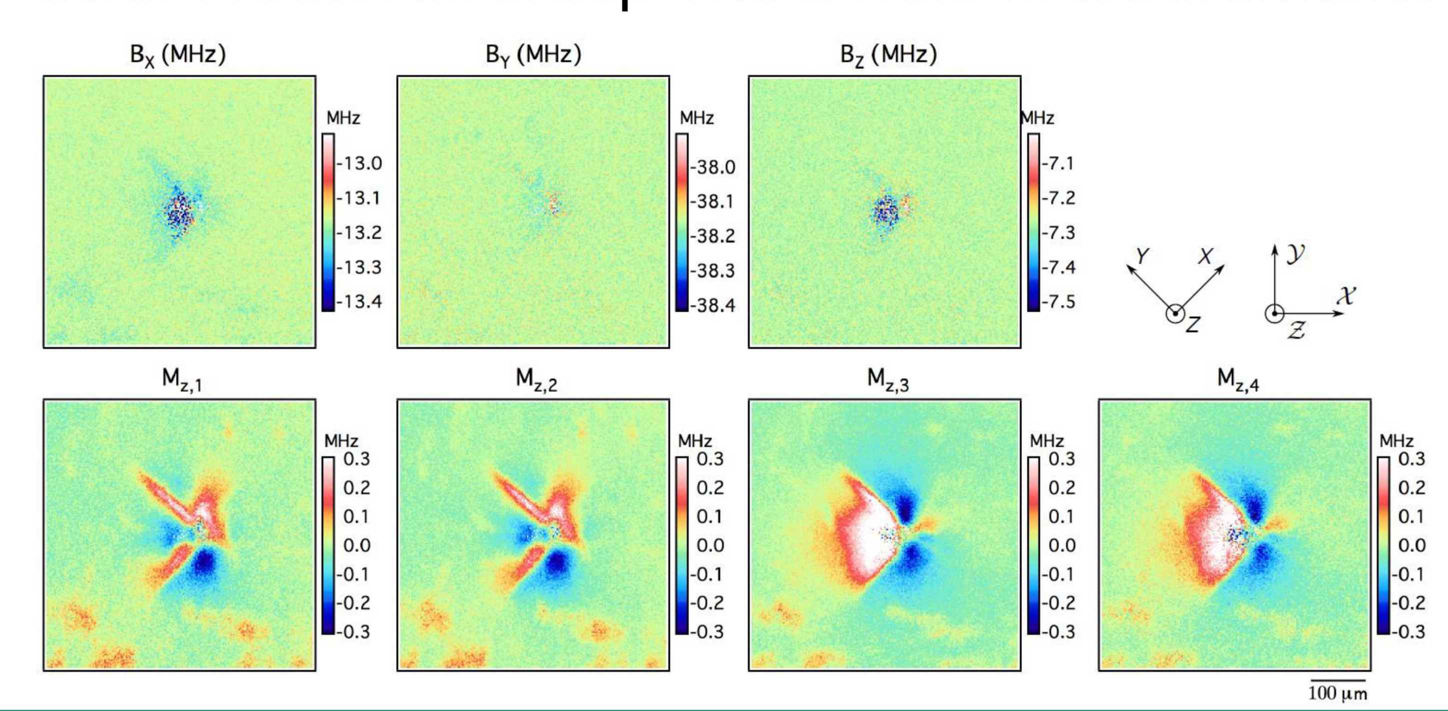


M_z inhomogeneity complicates magnetic imaging

- Single-pixel stress spoils NV T_2^* and contrast [6]



- Strain features creep into B field measurements



References

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