Postdoc Research

Optically Pumped Solid State Quantum Magnetometers for Space Application

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Background

- detection of planetary and local magnetic fields
- information about existing, active or erstwhile geodynamos
- insights to inner structures
  - subsurface oceans
  - mining survey (ores)
- solar wind monitoring

scalar magnetometer (strength of field)
&
vector magnetometer (direction of field)

Objectives

- diamond, silicon carbide (SiC) and hexagonal boron nitride (hBN) host a variety of optically accessible spin-active quantum centers
- excellent coherent properties at ambient conditions ("qubit at room temperature")
- Energy level structure of defects highly sensitive to magnetic fields due to Zeeman splitting

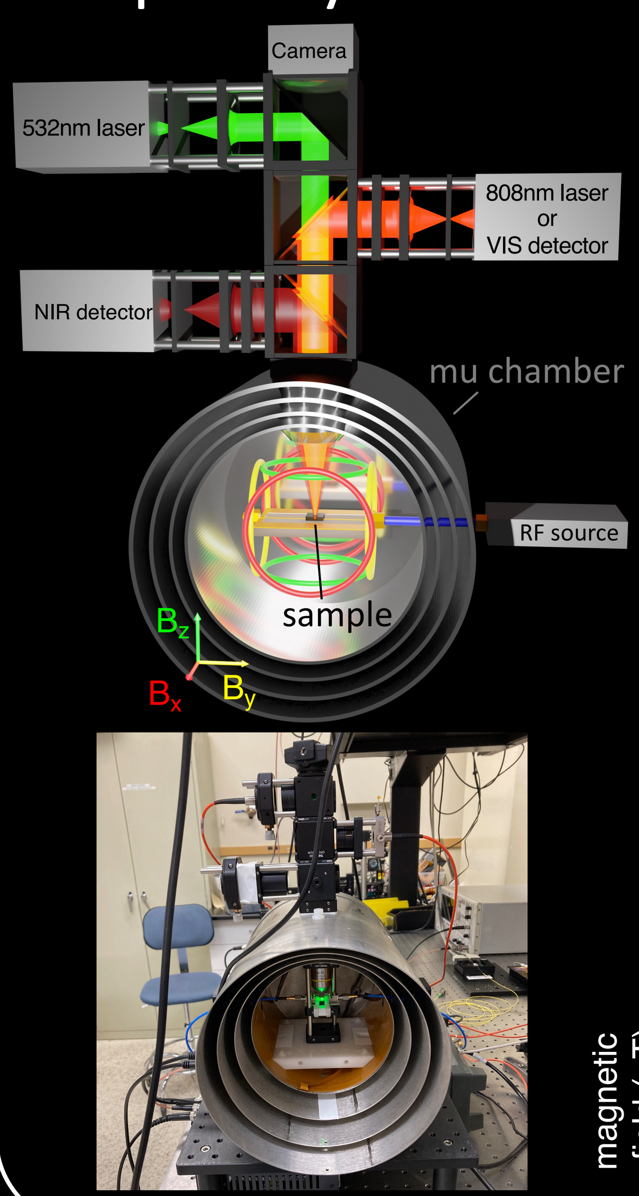
⇒ **robust quantum magnetometer at room temperature**

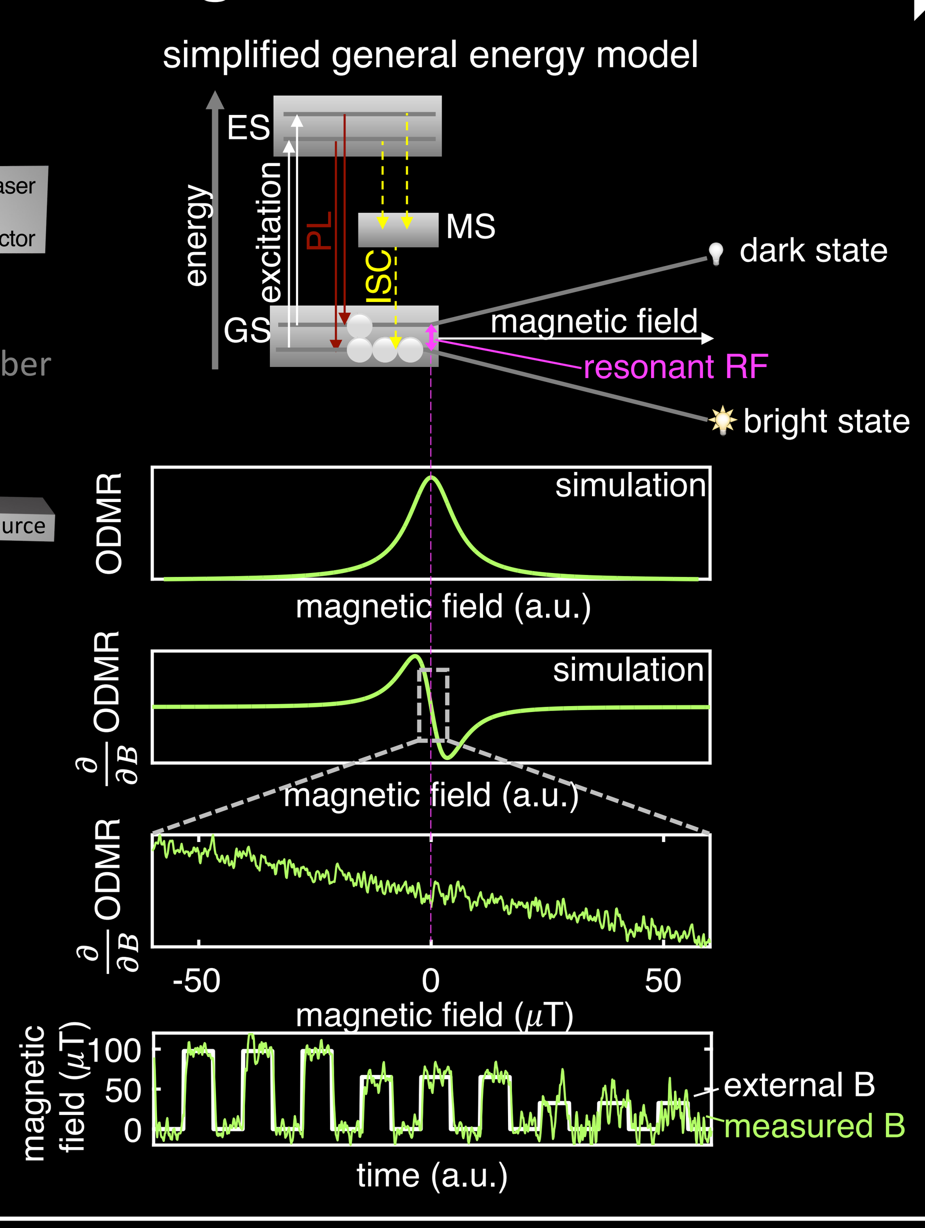
Benefits to NASA/JPL

- ✓ extremely small (multiple sensors on spacecraft)
- ✓ rad-hard sensor
- ✓ lightweight
- ✓ optional self-calibration
- ✓ no gas leaking (⟷ optically pumped ^{4}He)
- ✓ only 1 coil per direction instead of 3 (⟷ fluxgate)

Approach and Results

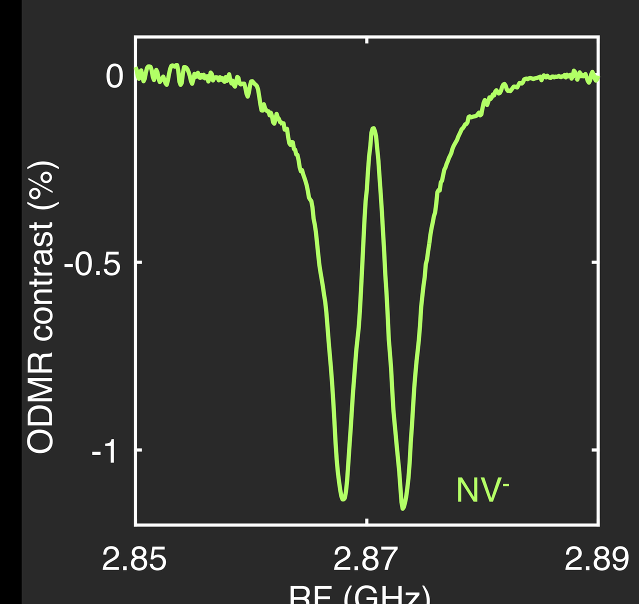
Optically Detected Magnetic Resonance ➡ Development of sample-agnostic setup to study all potential spin-defects





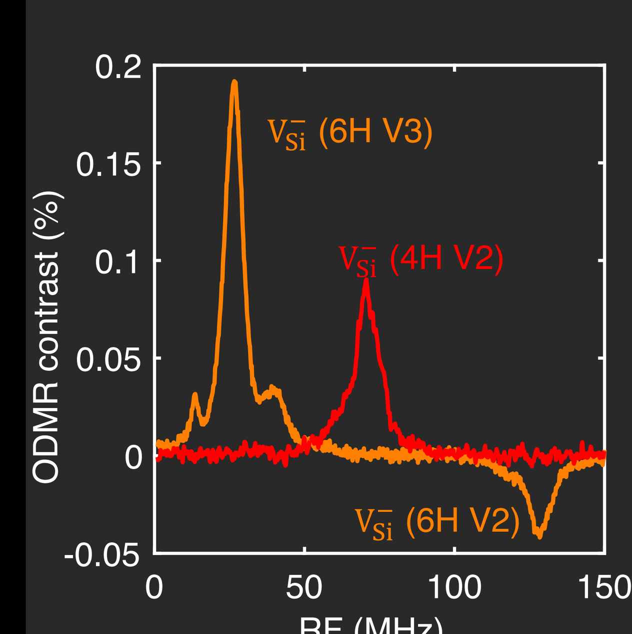
NV^- in diamond

- high ODMR contrast (1-10%)
- narrow peaks
- complex spectrum due to different defect orientations
- high frequencies required (2.87 GHz)



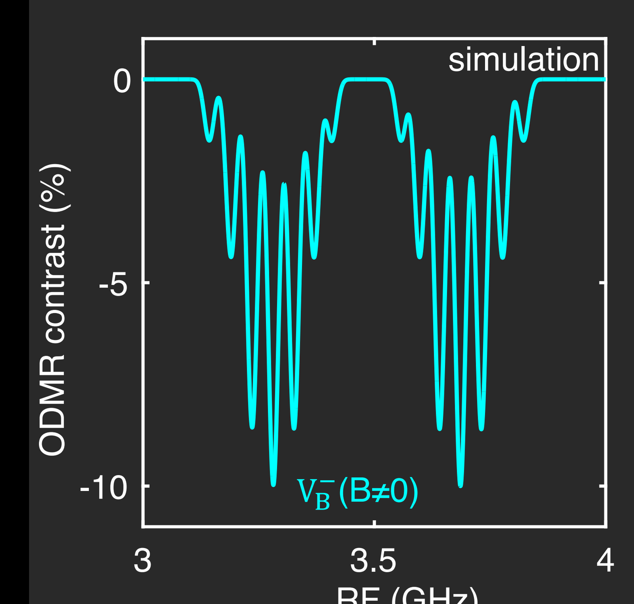
V_{Si}^- in 4H/6H SiC

- low ODMR contrast (0.1-0.2%)
- narrow peaks
- simple spectrum with only one defect orientation ($\vec{c}$-axis)
- low frequencies required (70MHz)



V_B^- in hBN

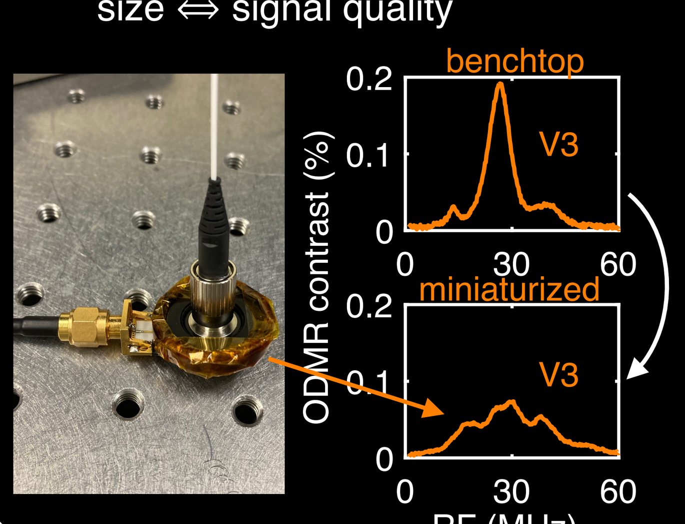
- high ODMR contrast (10-50%)
- broad peaks
- simple spectrum with only one defect orientation ($\vec{c}$-axis)
- high frequencies required (3.5GHz)



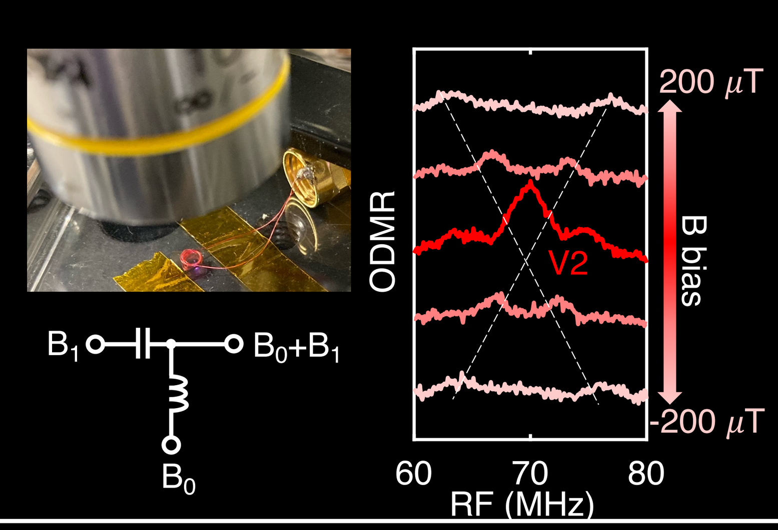
Future Work

Further miniaturization steps (ongoing process…):

- Miniaturized sensor head: size ⟺ signal quality

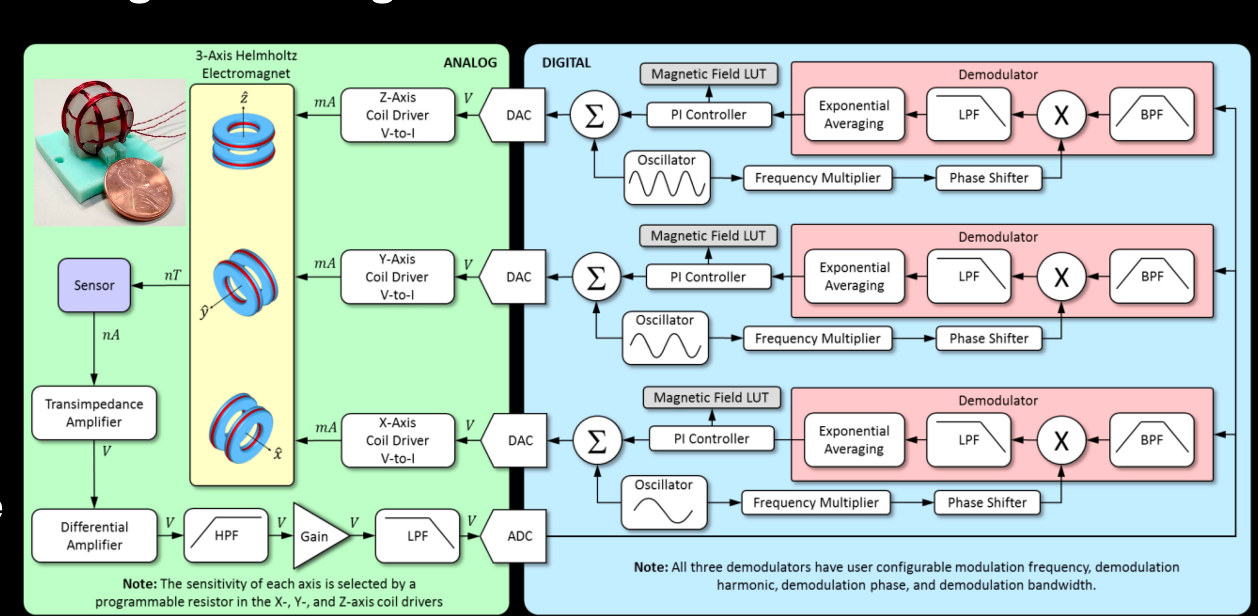


- Miniaturized bias coils: same coil for RF excitation and bias field



➡ Future vector mode based on SiC Mag EDMR magnetometer

- use resonance condition as starting point
- when detuning of energy levels occurs: apply compensation field to bring resonance back to zero
- different modulation frequencies in each direction reveals magnetic field contribution of each direction
- compatible with heritage hardware based on EDMR (electrically detected magnetic resonance)



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Publications:

H. Kraus et al. Magnetic Field and Temperature Sensing with Atomic-Scale Spin Defects in Silicon Carbide *Sci. Rep.* 4, 5303 (2014)

C. Cochrane et al. Vectorized Magnetometer for Space Applications *Sci. Rep.* 6, 37077 (2016)

A. Gottscholl et al. Spin defects in hBN as promising temperature, pressure and magnetic field quantum sensors *Nat. Commun.*12 (1), 4480 (2021)

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