Investigation of radiation damage centers in highly isotopically enriched ^{28}Si as potential single spin qubits accessible via spin/photon coupling

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CAP Congress, SFU, June 2019

The electron and nuclear spins of shallow donors in ^{28}Si are recognized as exceptional qubit candidates - long T_1 and T_2 high fidelity preparation, control and readout, and operations using single donors has been demonstrated (UNSW).

Science AAAS

Quantum Information Storage for over 180 s Using Donor Spins in a ^{28}Si "Semiconductor Vacuum"
M. Steger *et al.*
Science **336**, 1280 (2012);

Science AAAS

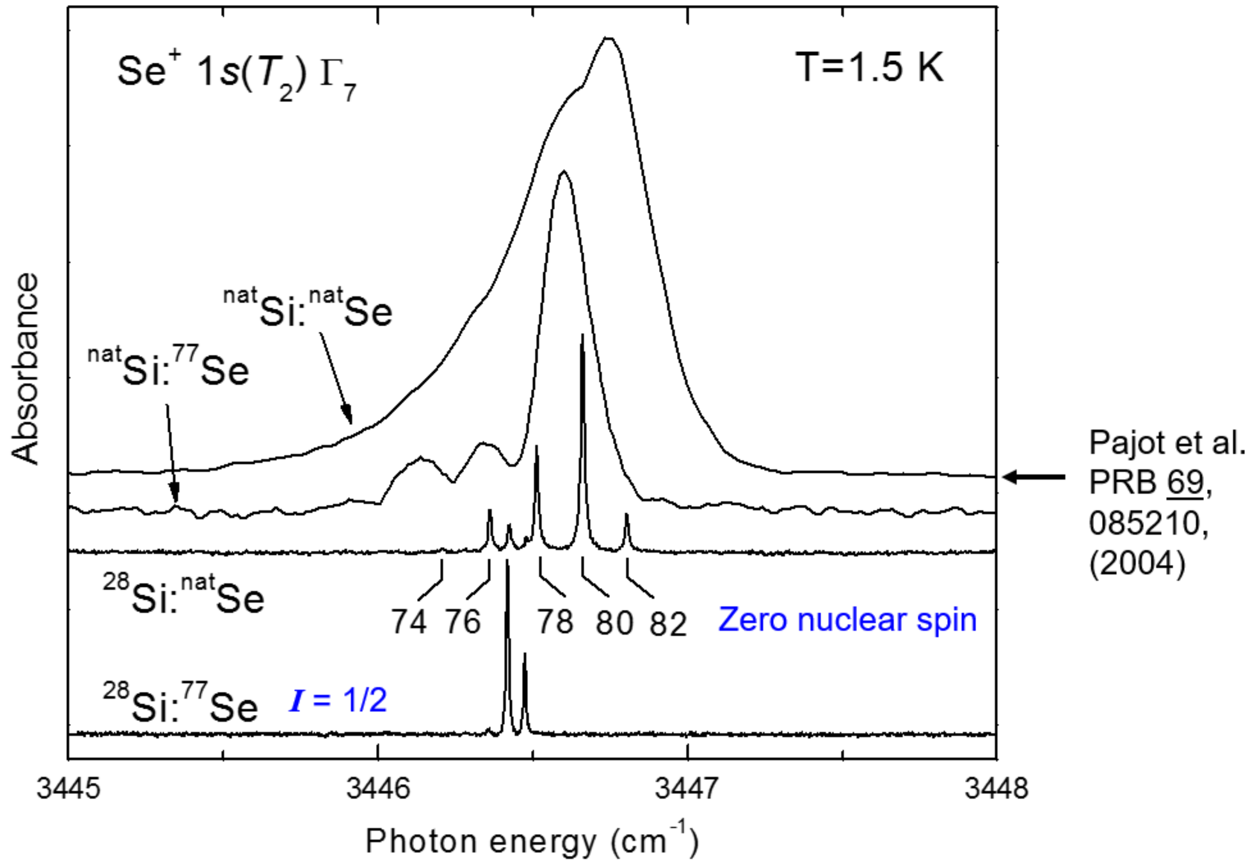
Room-Temperature Quantum Bit Storage Exceeding 39 Minutes Using Ionized Donors in Silicon-28
Kamyar Saeedi *et al.*
Science **342**, 830 (2013);

Compatibility with Si technology is a huge plus…

BUT – how do we perform operations between these qubits, or move the quantum information around? (original ideas involved atomically exact donor placement)

Another possible donor qubit in silicon…

Deep Double Donor Absorption (Phys. Rev. B **80**, 115204 (2009))



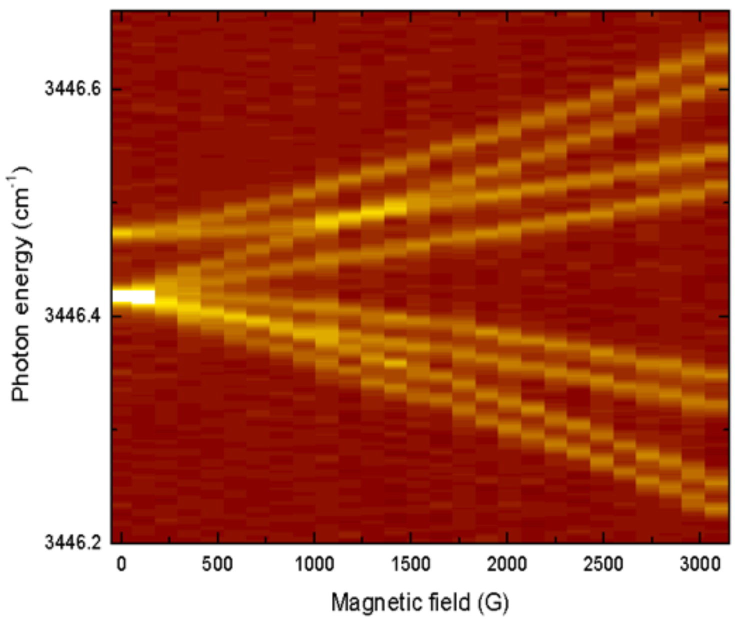
Chalcogens in Si are analogues of the He atom (2 electrons)

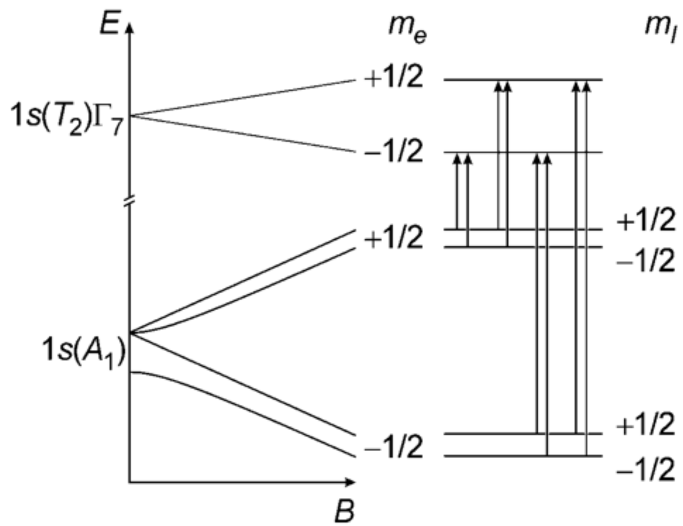
Only ^{77}Se has a nonzero nuclear spin and a hyperfine splitting

A different optical handle on electron/nuclear spin qubits in ^{28}Si (not involving bound excitons)

$^{77}Se^{+}$ has a large hyperfine splitting,
long nuclear spin coherence time, >2 sec

1.66 GHz

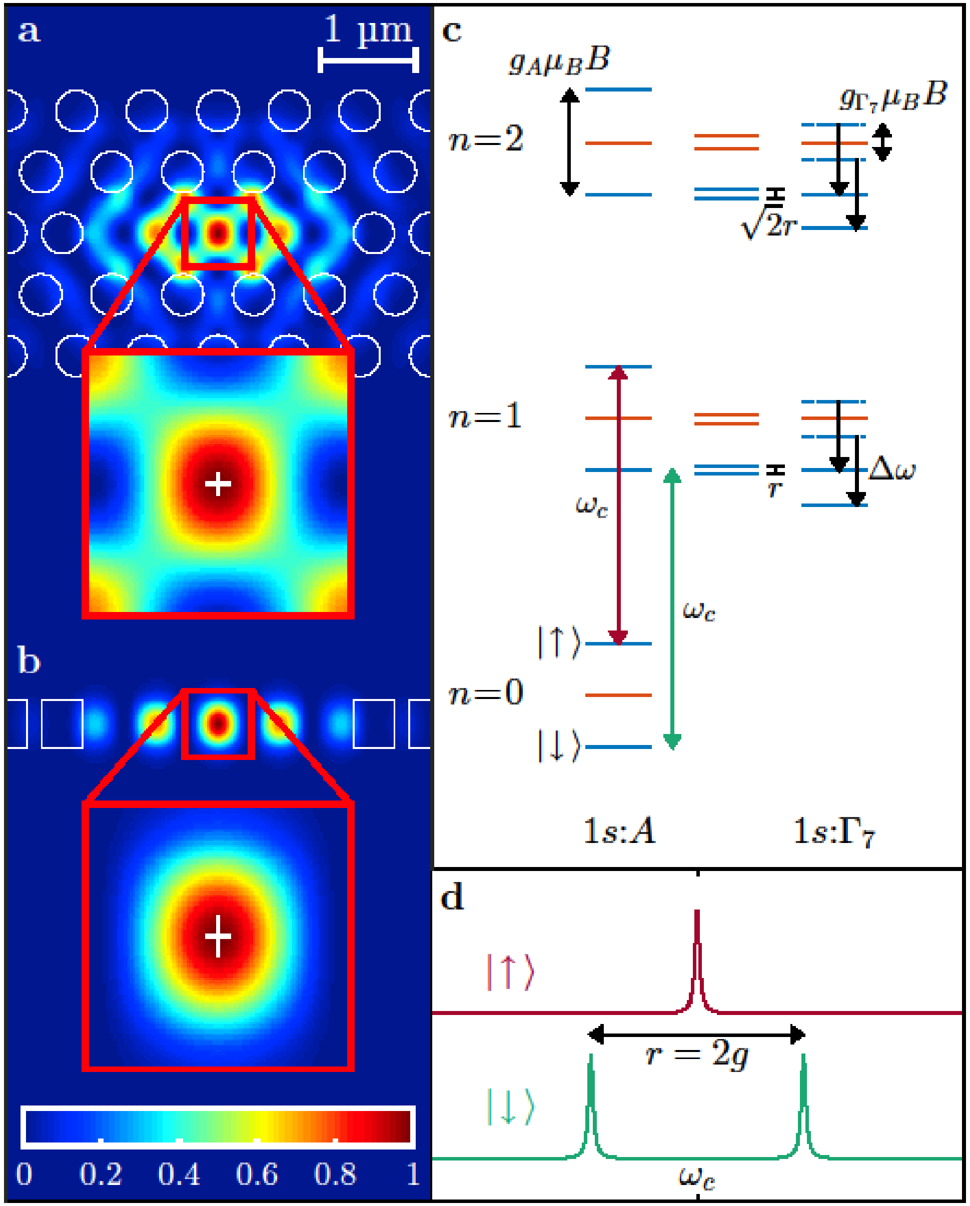




Chalcogens in Si may have advantages as qubits…..

There is still the problem of how to perform operations between qubits, and move quantum information around

Se transitions are strong compared to D^0X, use c-QED for spin/photon conversion (Stephanie Simmons)



SILICON QUANTUM LEAP PROJECT

- Integrated silicon photonics is well-developed at ~1.5 μ (Lukas Chrostowski, UBC) High Q resonators at 1.5 μ
- Very high QE, low dark count integrated supercon. single photon detectors (Jeff Young, UBC)
- Strong coupling c-QED should be possible
- This would allow remote coupling, less need for precise donor placement
- Need to shift and test designs for 2.9 μm

Admittedly, working at 2.9 microns has its drawbacks:

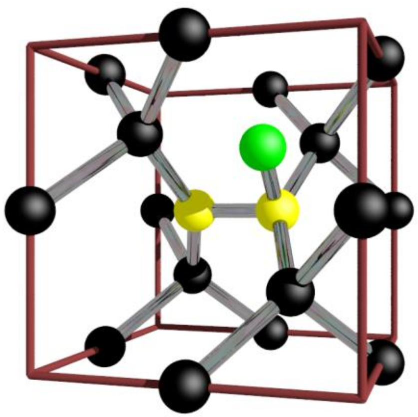
- Fibers
- Optics
- Sources
- Single photon detectors
- Room temp black body
- Extending silicon photonics

Radiation damage centers (color centers) as qubits

- Diamond – NV center
  - SiV center
- SiC – divacancy and other damage centers
  - cheaper than diamond, wafers available, but…
- Si – radiation damage centers studied for over 50 years
  - many are in the 1.3 to 1.55 μ telecom bands
  - bright, high QE, isoelectronic bound exciton-like
  - almost no effort to examine them as qubits, some recent work on possibility of single-photon emitters
- **^{28}Si – let's reexamine some of these Si centers!**

T center (bare center has e⁻ spin ½)

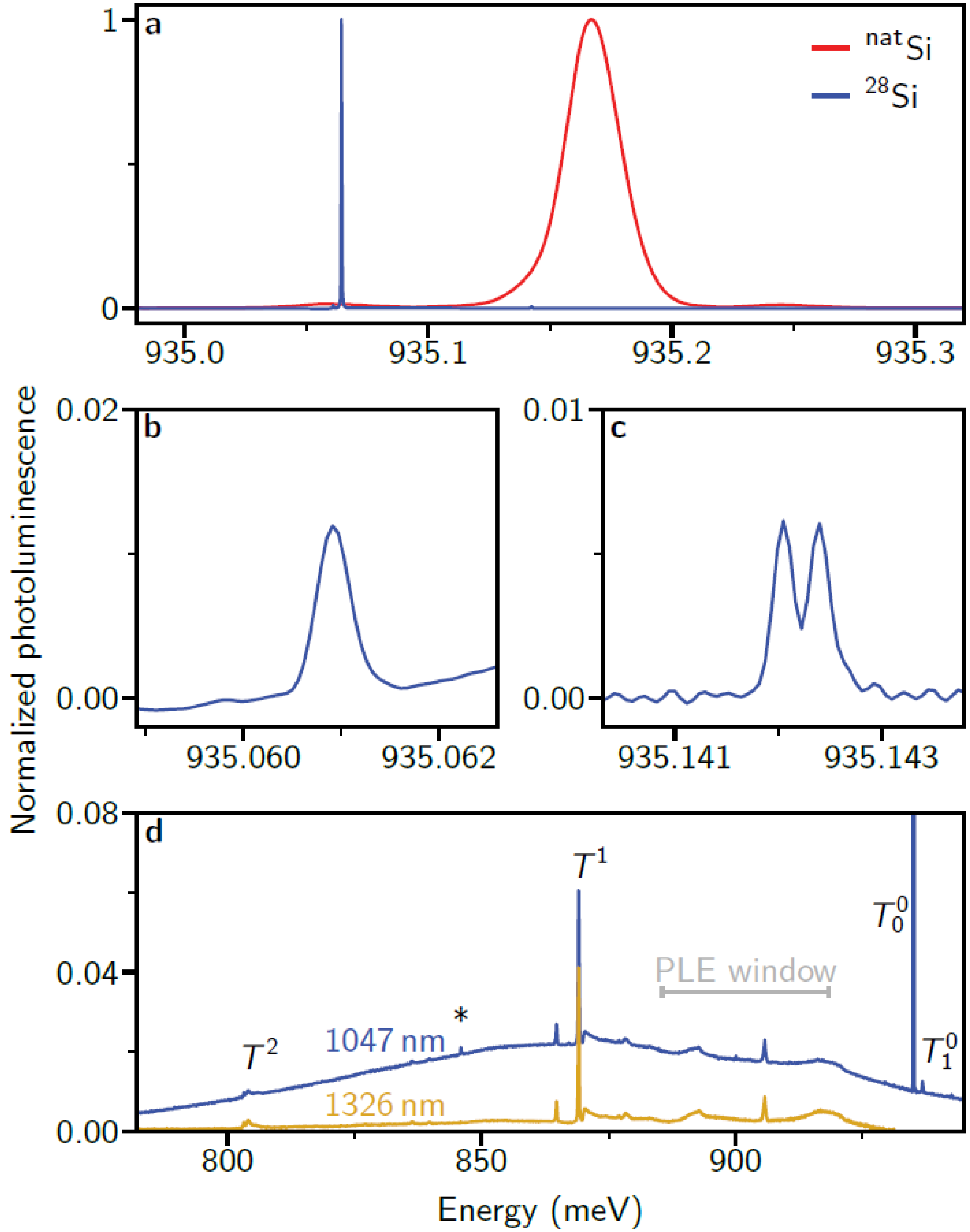
Most damage centers (C, G, W) have no spin in their ground state.
Conflicting T models; happily, we find that it is paramagnetic



C. Chartrand

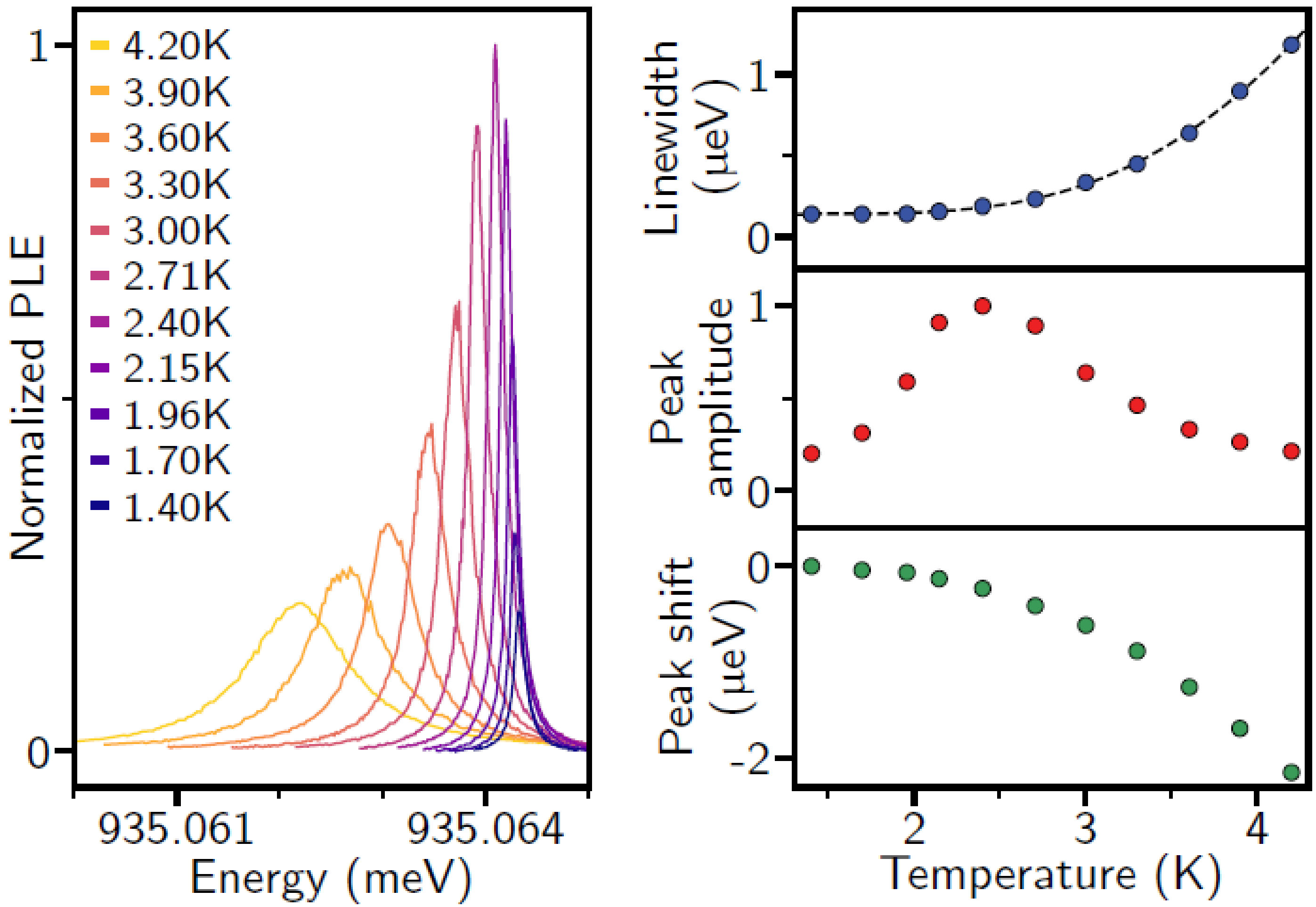
Irradiation 320 kGy → Anneal 440C

	Se	T centre
Energy (nm)	2902	1326
Linewidth (MHz)	~30	~30
ZPL fraction (%)	16(1)	24(2)
Radiative lifetime (us)	0.90(7)	7(1)
Dipole moment (D)	1.98(8)	0.27(3)
Efficiency (%)	0.80(9)	14(4)
T_1 (s)	14400	> 30
T_2 (s)	2.14(4)	1.1(1)
cavity Q	1.5e4	7.4e4

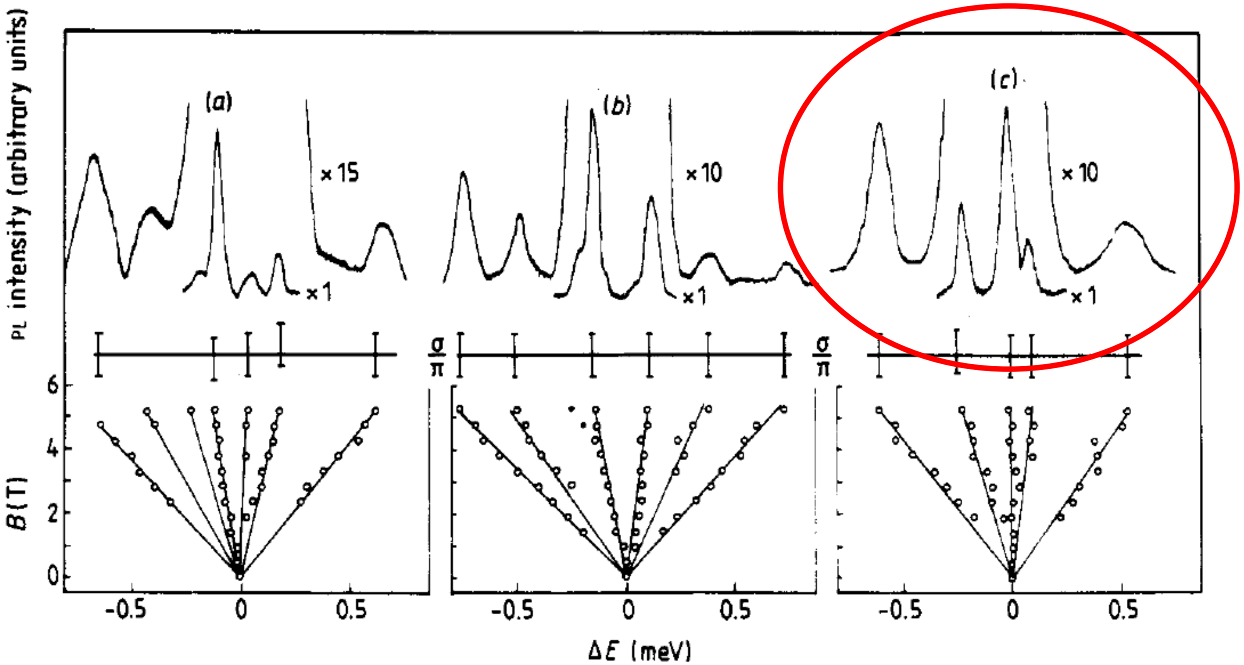


Nearby excited state-valence band splitting

At 4.2 K T has significant homogeneous broadening due to transitions to the low-lying excited state

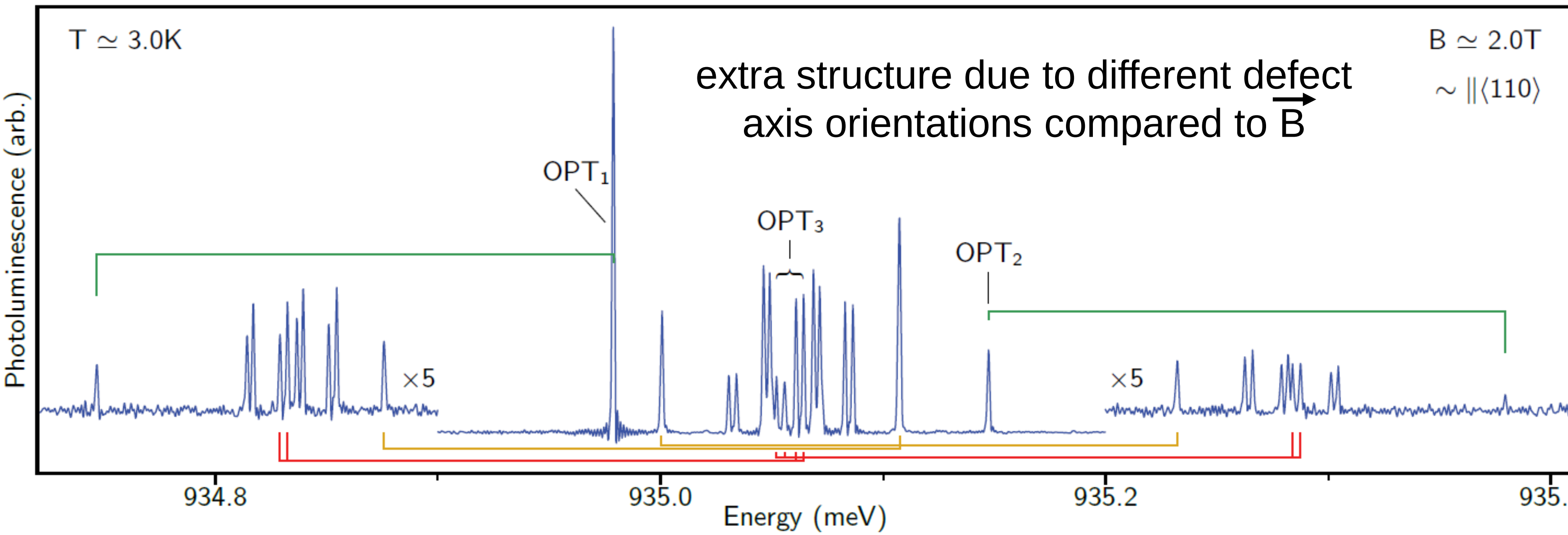


T PL gets weaker at low temperature where inhomogeneous broadening becomes larger than homogeneous, implying a zero field splitting

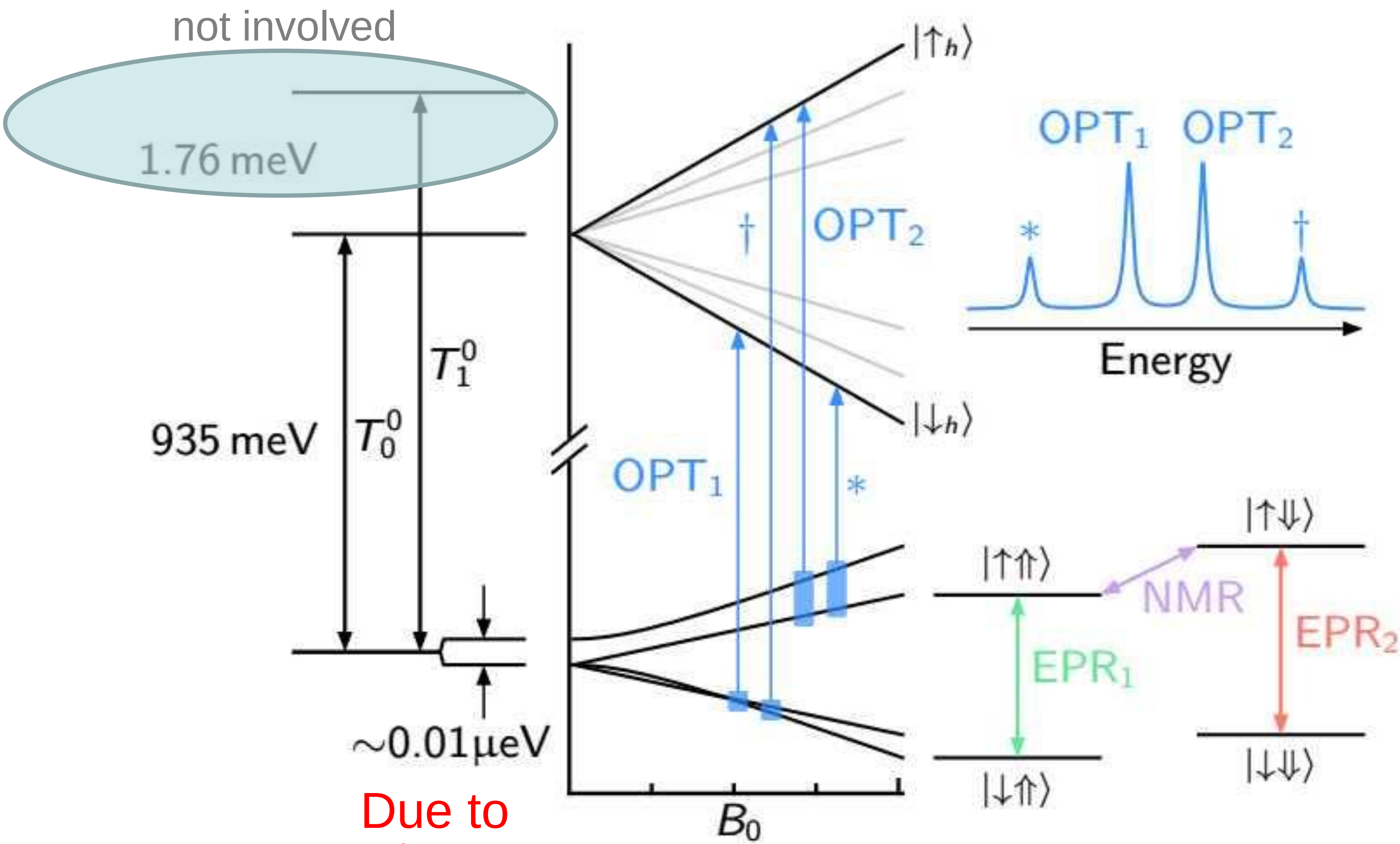


Best Zeeman spectrum in natural Si

E. Irion et al., J. Phys. C: Solid State Physics 18, 5069 (1985)



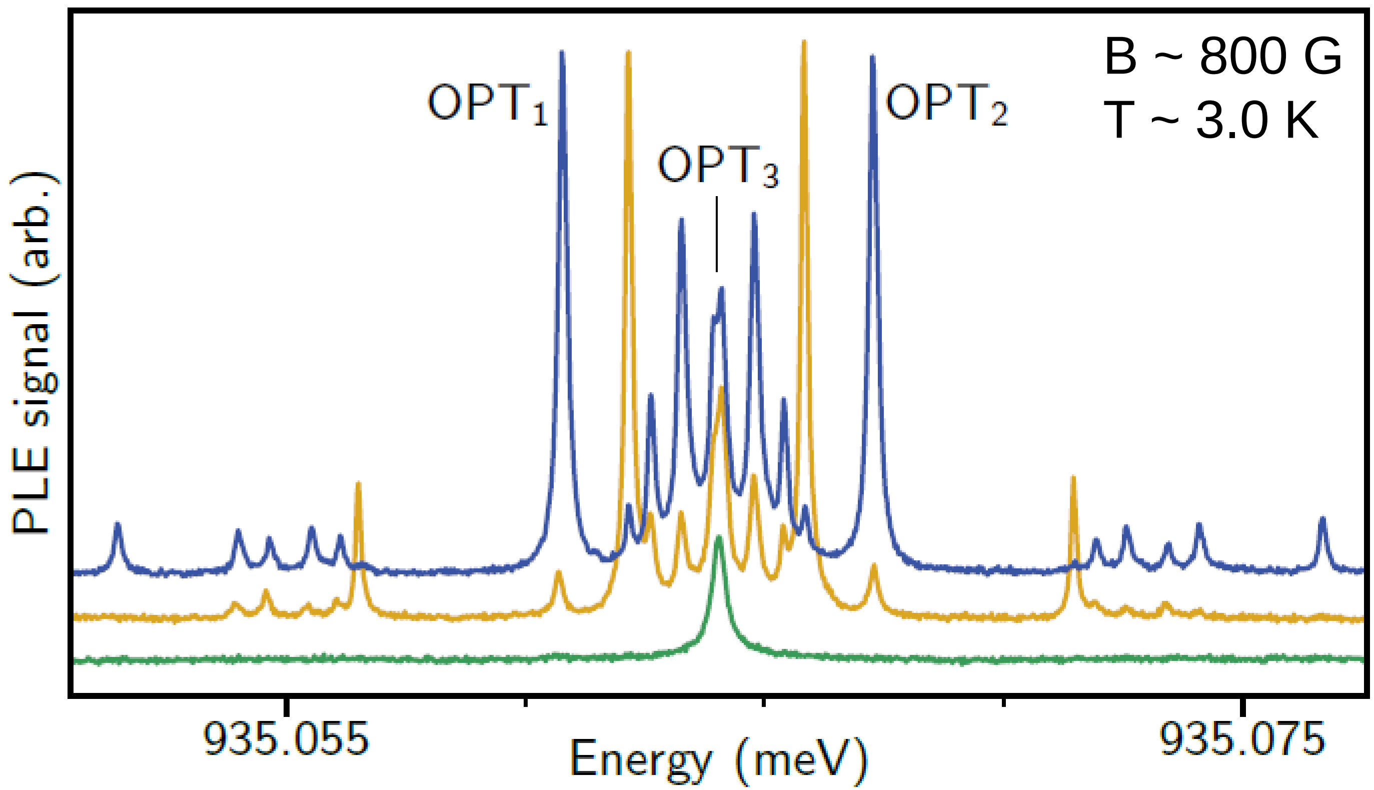
The Zeeman transitions are very similar to D^0X



Due to ^{1}H !

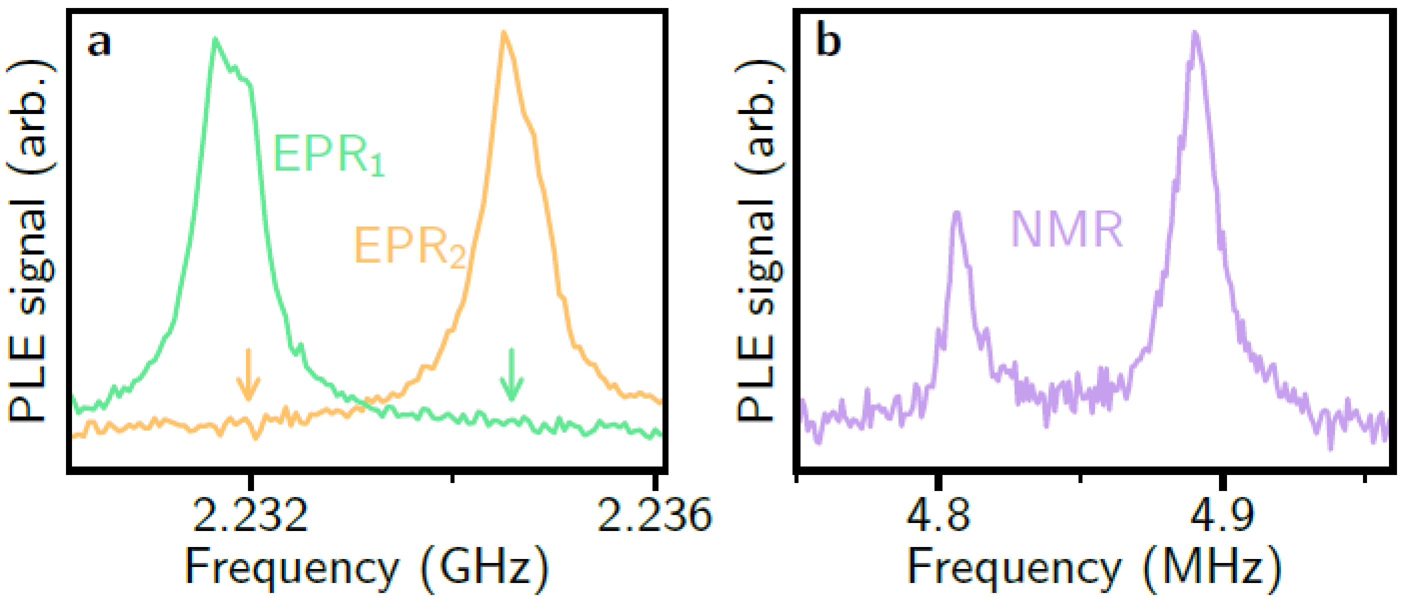
exaggerated hyperfine splittings

PLE signal for different RF pumping frequencies

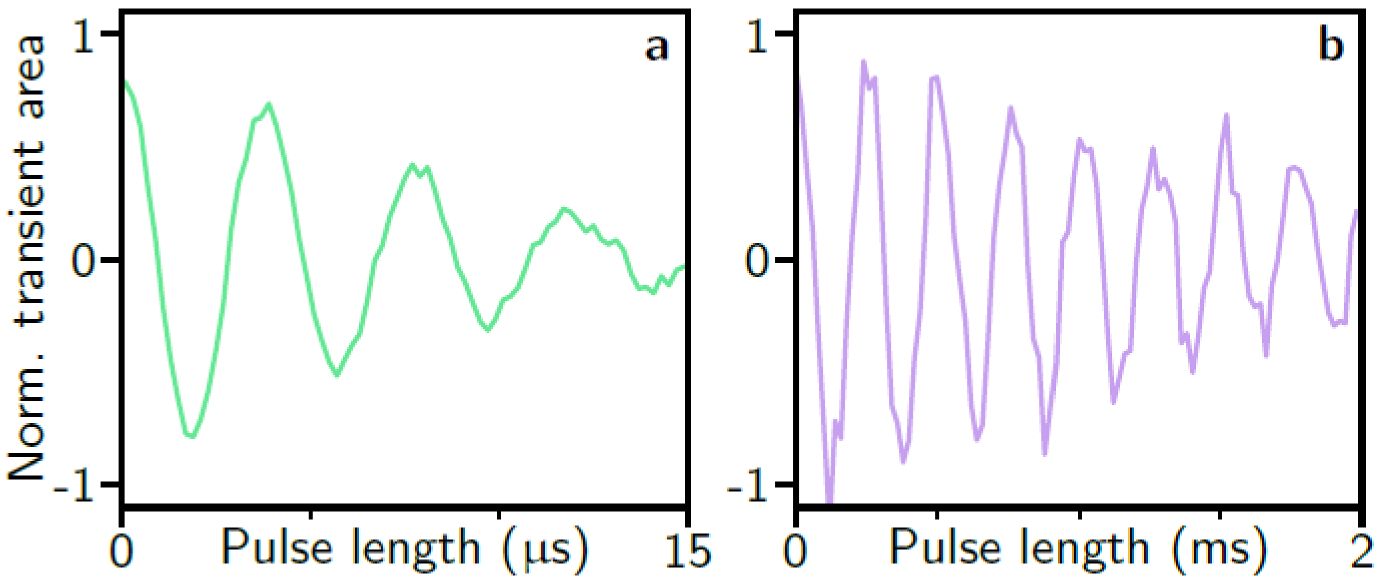


Pumping with tunable single frequency laser, PLE detected on phonon sideband

EPR and NMR resonances when monitoring OPT1 line

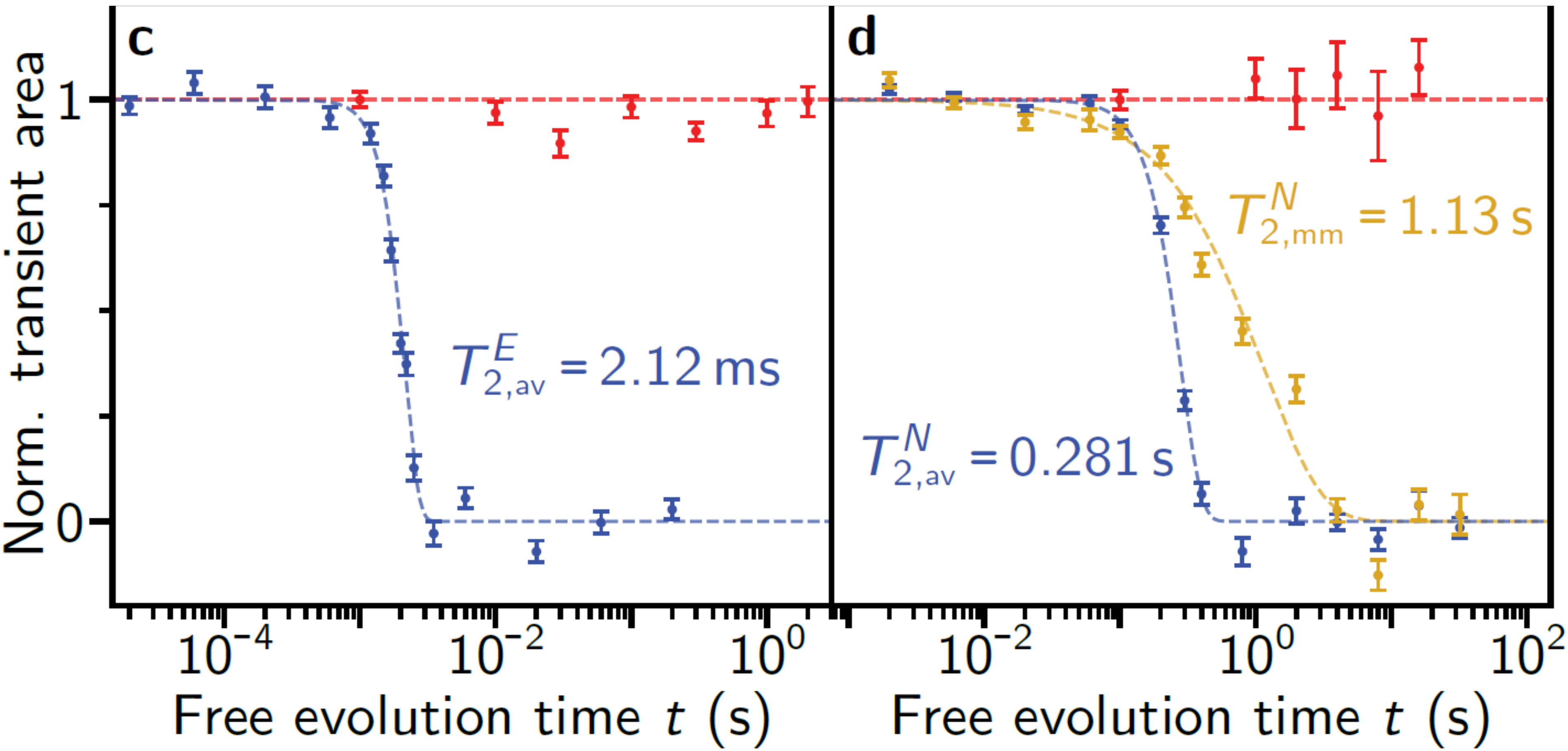


EPR and NMR Rabi sequences



electron T_1 and T_2

nuclear T_1 and T_2



SFU

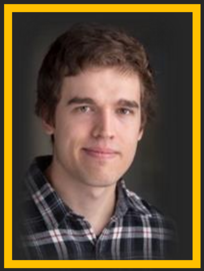
Thank you!







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