Diamond color centers for quantum technologies

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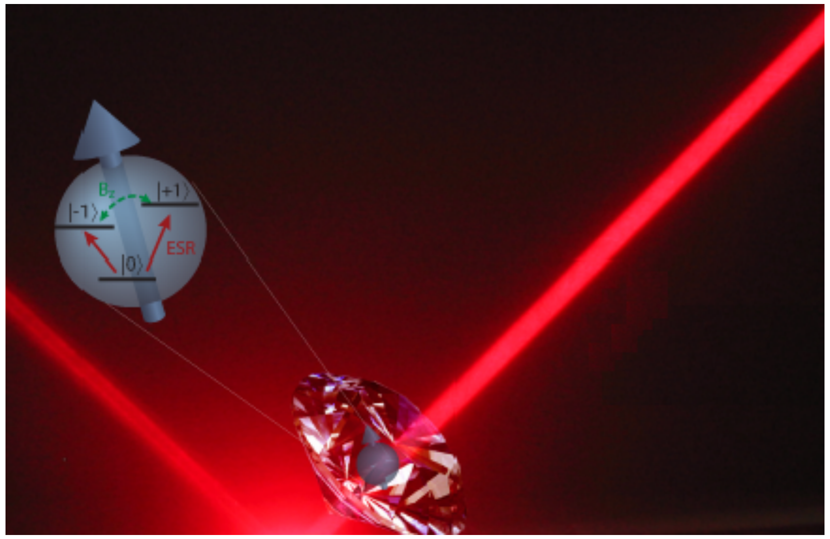
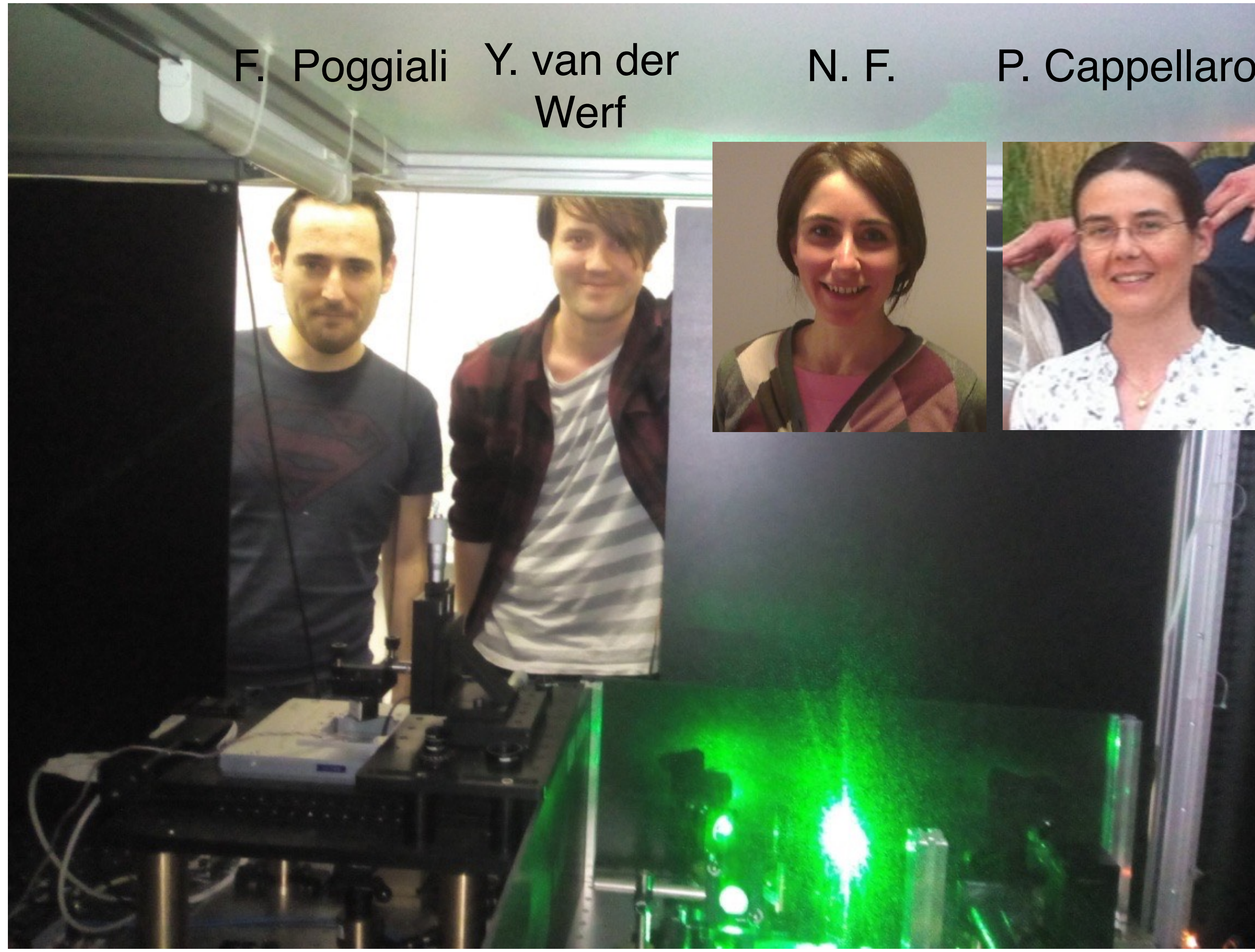


Area della ricerca CNR, Pisa
January 25, 2017

lens
European Laboratory for Non-Linear Spectroscopy



INRiM

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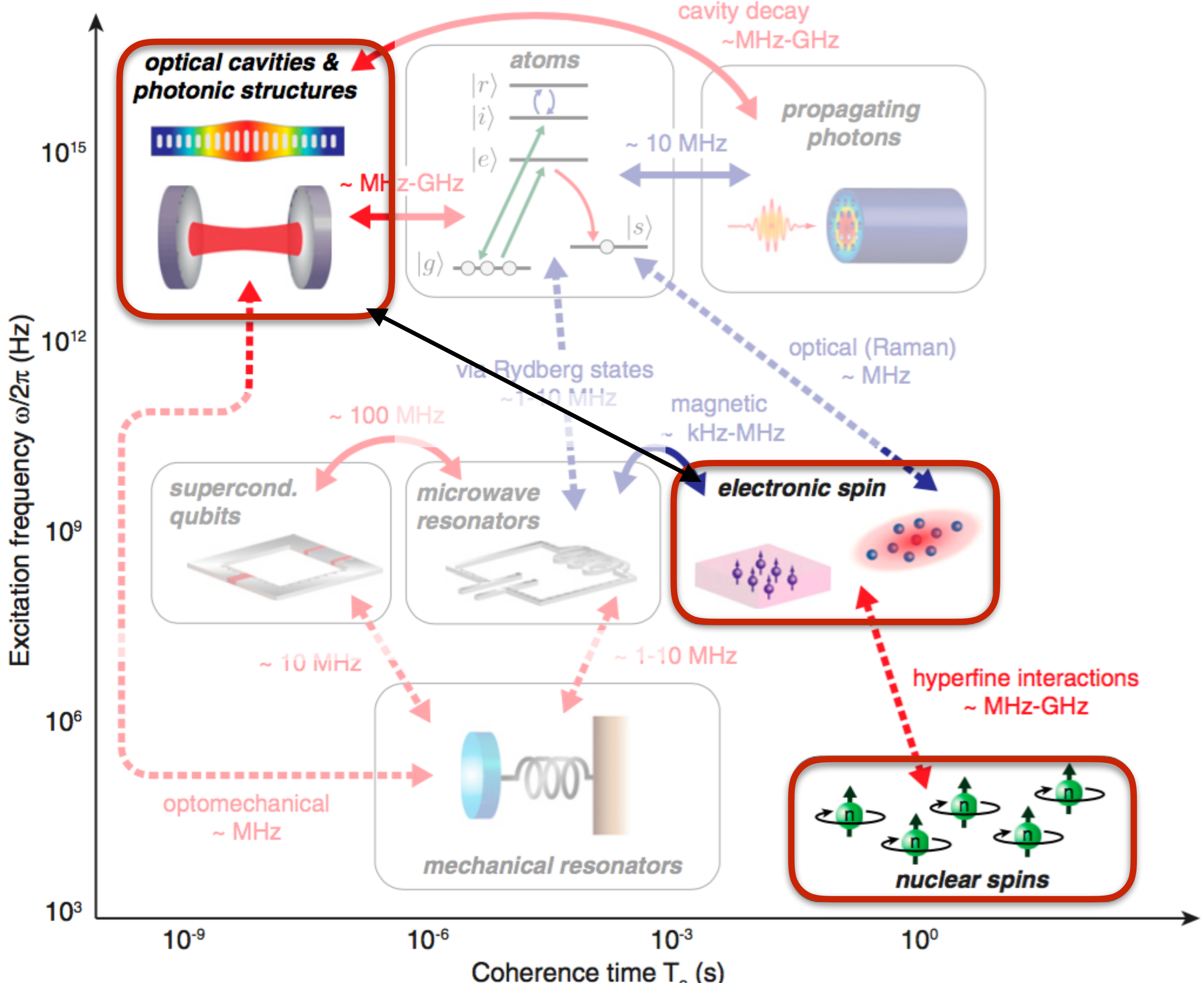
erc
Quantum Enhanced Sensors with Single-Spins
Q-SEnS^2
Laserlab Europe

quantum | information processing
communication
sensing

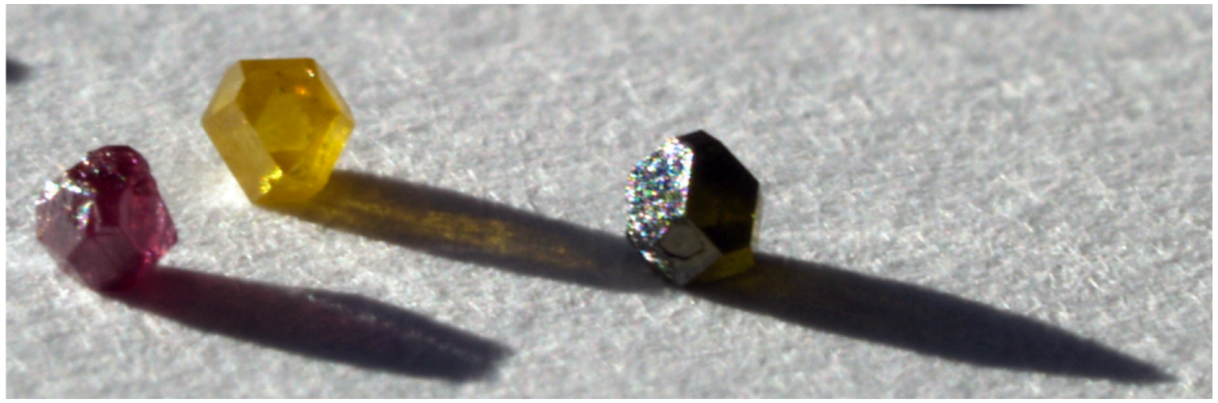


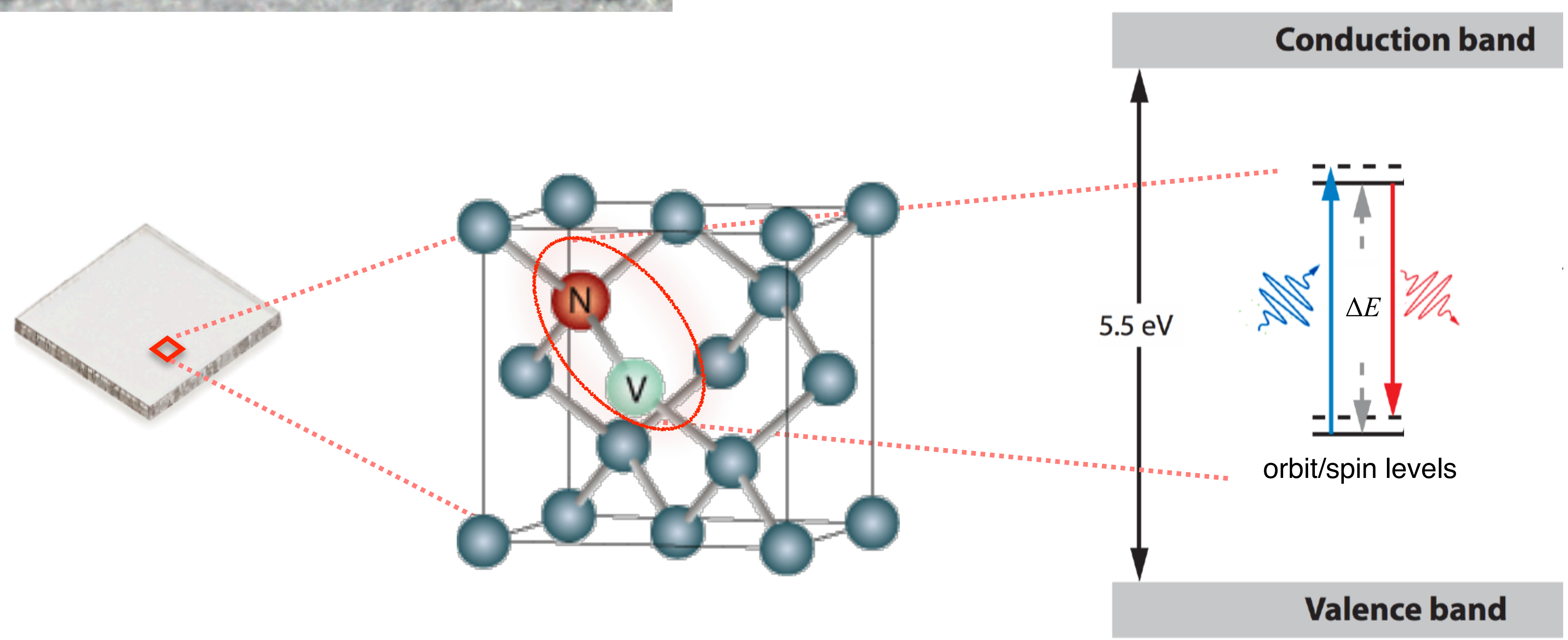
Kurizki et al., PNAS 2015

hybrid quantum systems

Our exp. platform: color centers in diamond

Color centers in diamond

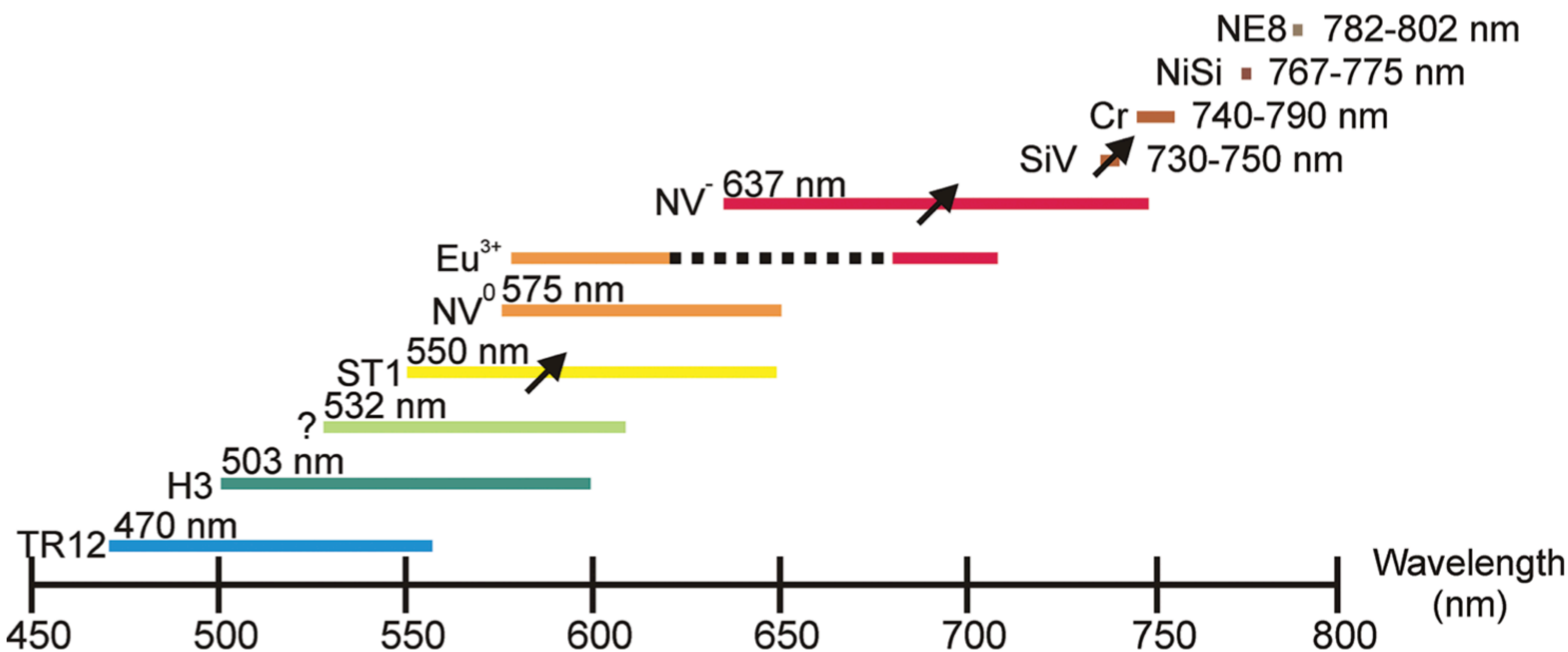




- isolated defects (artificial atoms)
  - robust optical interface
  - localized spin with long coherence times

Color centers in diamond

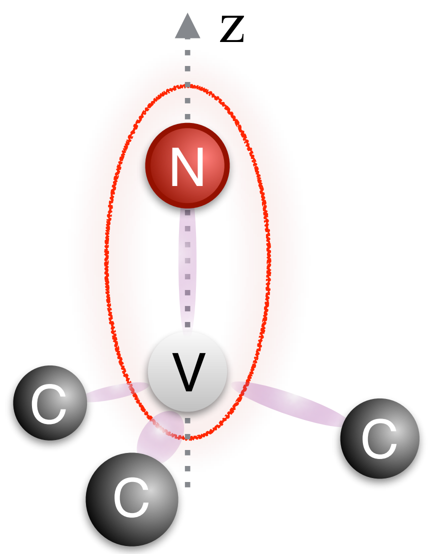
Spectral map of diamond color centers



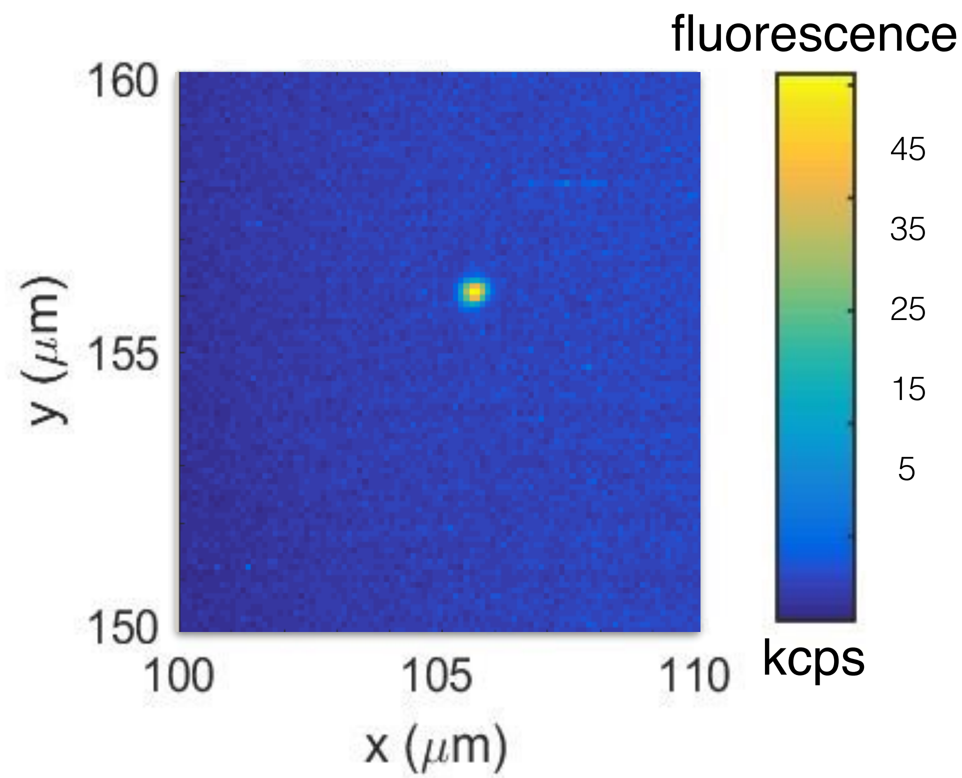
I. Aharonovich and E. Neu, Adv. Optical Mater. (2014)

Spin manipulation of single centers demonstrated for NV, SiV, GeV

NV center

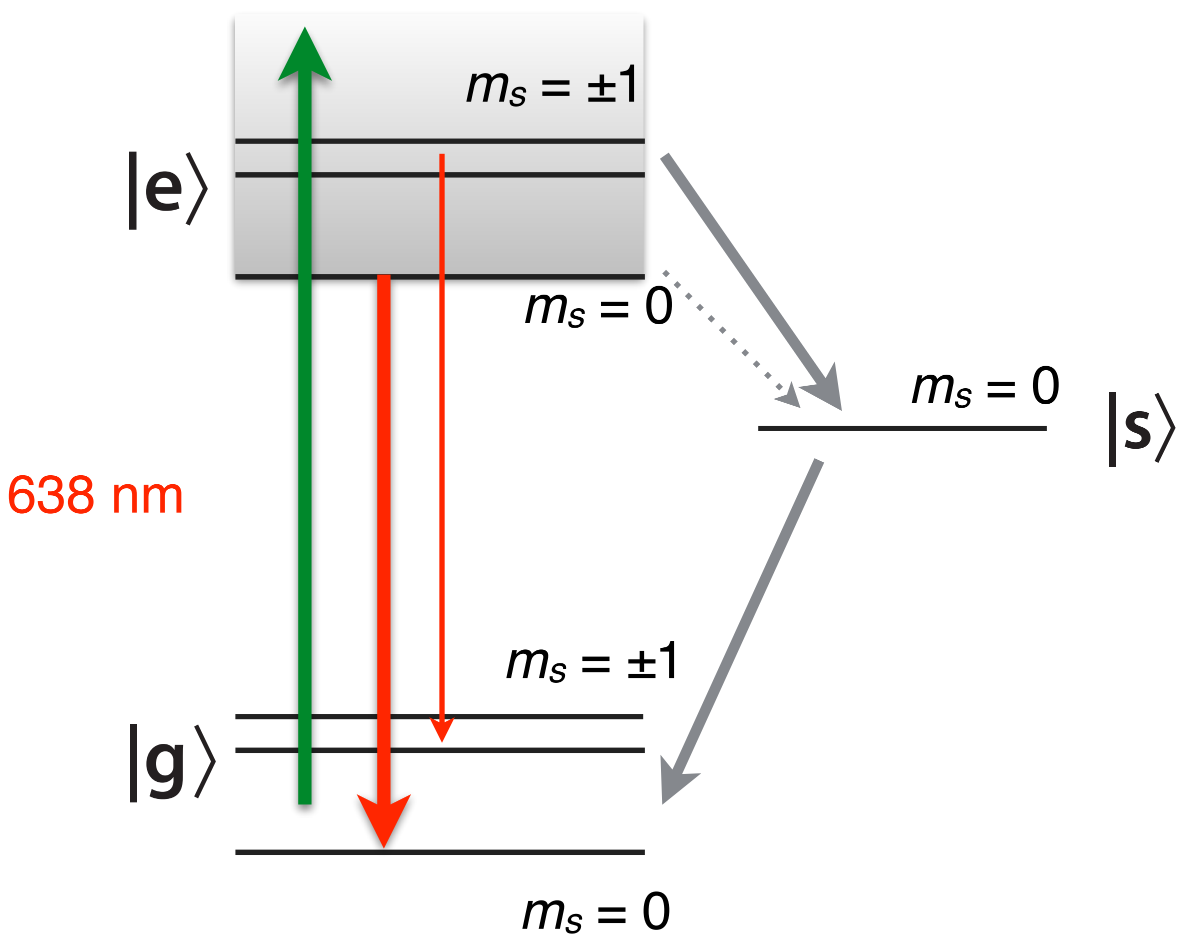


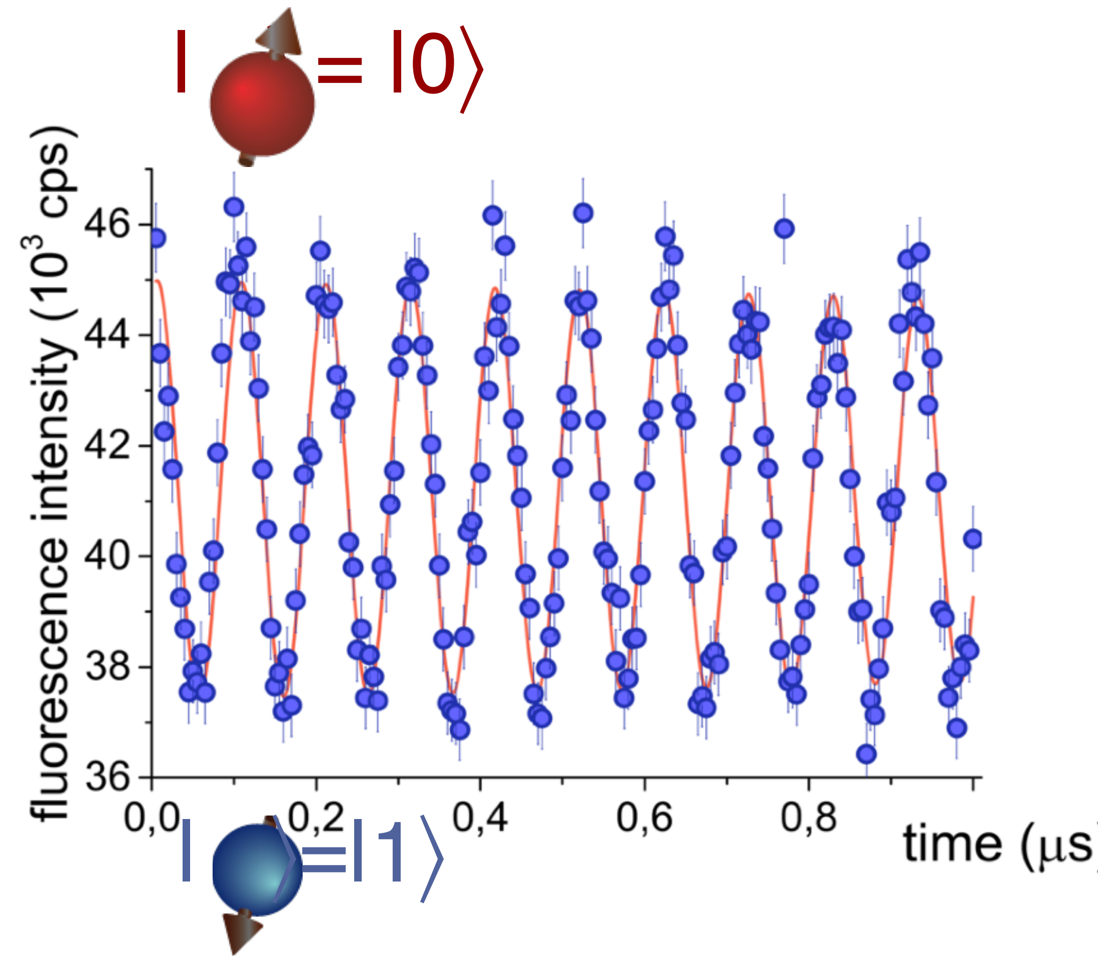
C_{3v} symmetry



Isolated defect in diamond with electronic spin S = 1

NV center

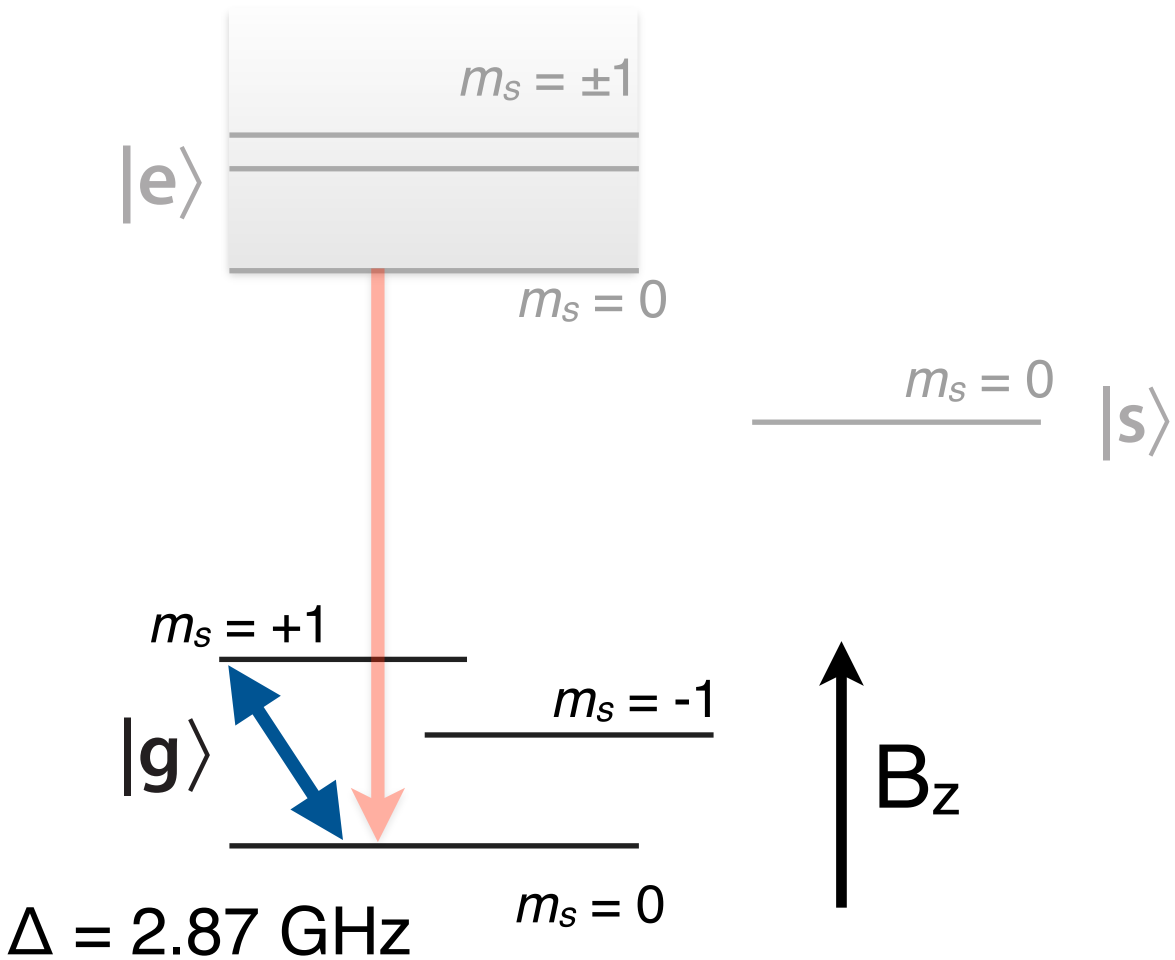




Isolated defect in diamond with electronic spin S = 1

- optical initialization and read-out
- spin manipulation with magnetic resonance tools
- long coherence time @ room temp. (ms)

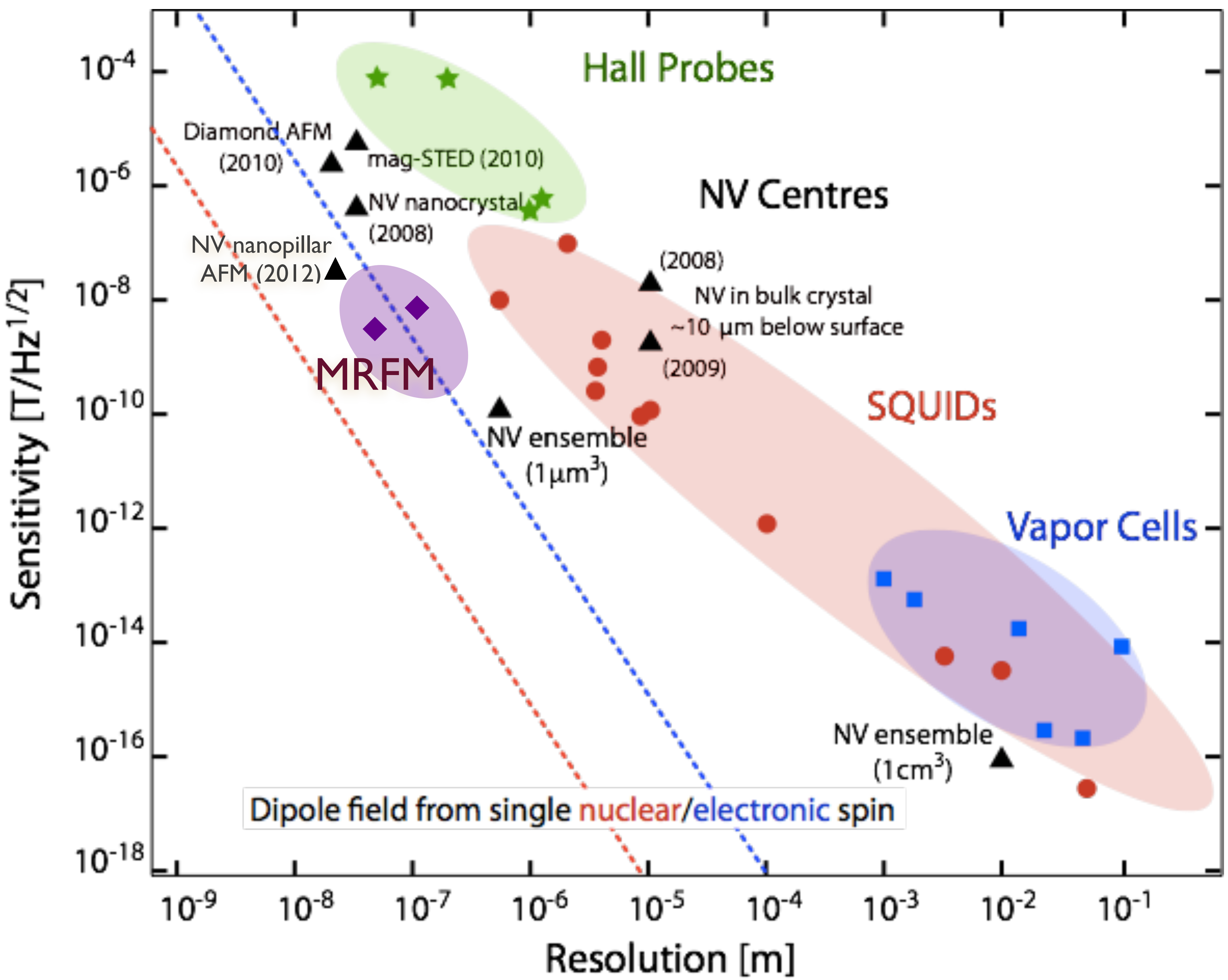
Single-spin NV magnetometer



Magnetic-field sensing by
monitoring Zeeman frequency shift

$$H_Z \sim \gamma_e \, \mathbf{S} \cdot \mathbf{B}$$

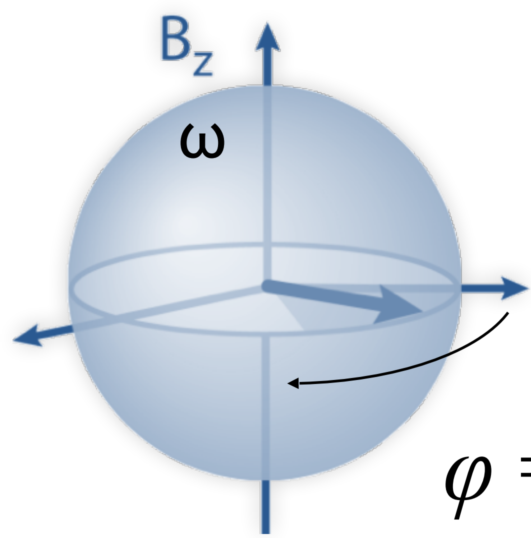
- diamond magnetometer offers an excellent **combination of sensitivity and spatial resolution**



- also, **biocompatible** and working at **room temperature**

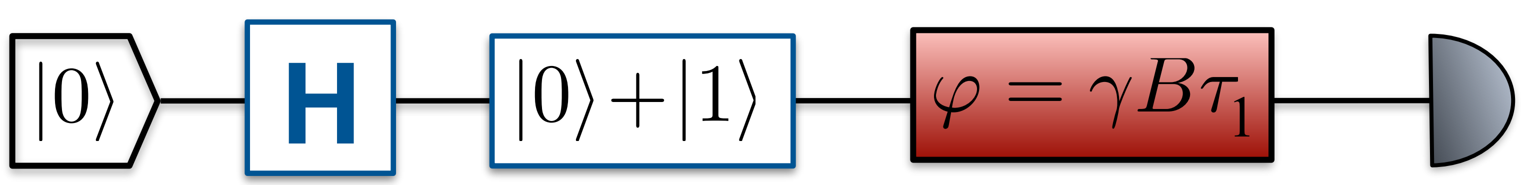
Single-spin NV magnetometer

Detection via Ramsey-type experiment



$$H_Z \sim \gamma_e \, \mathbf{S} \cdot \mathbf{B}$$

$$\varphi = \gamma_e \, B \, \tau_1$$



$$\frac{1}{\sqrt{2}}(|0\rangle + e^{i\phi(\tau_1)}|1\rangle)$$

$$\Delta B = \frac{1}{\gamma\sqrt{\tau T n}}$$

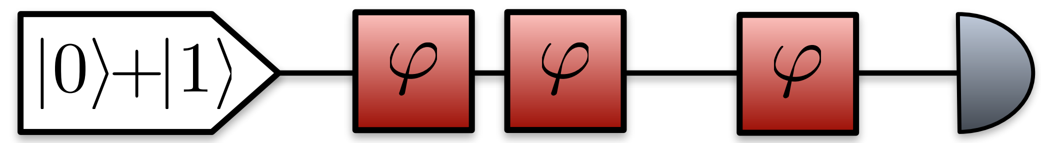
Interrogation time limited by decoherence

$\tau_1 < T_2^*$

For improving sensitivity

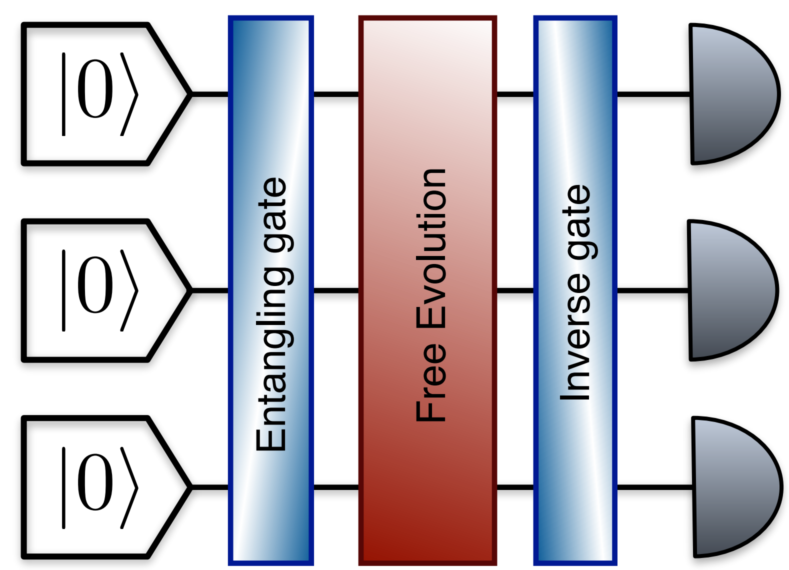
- Longer interrogation times (control schemes)

$$\Delta B = \frac{1}{\gamma T \sqrt{n}}$$

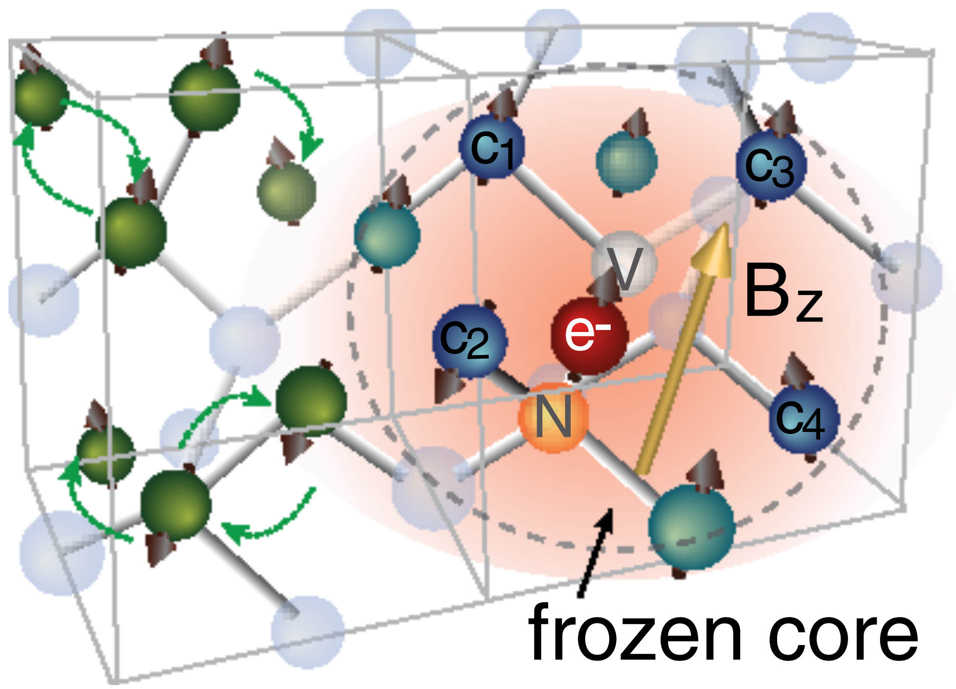


- Entangled states

$$\Delta B = \frac{1}{\gamma n \sqrt{\tau T}}$$

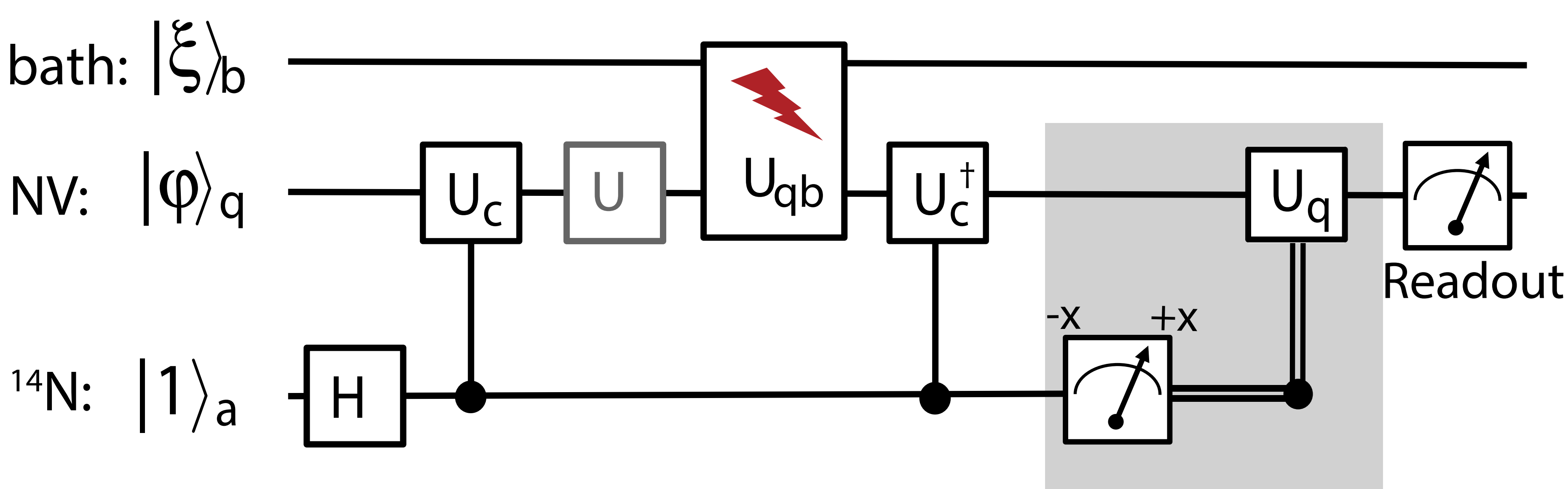


The NV environment can be a resource



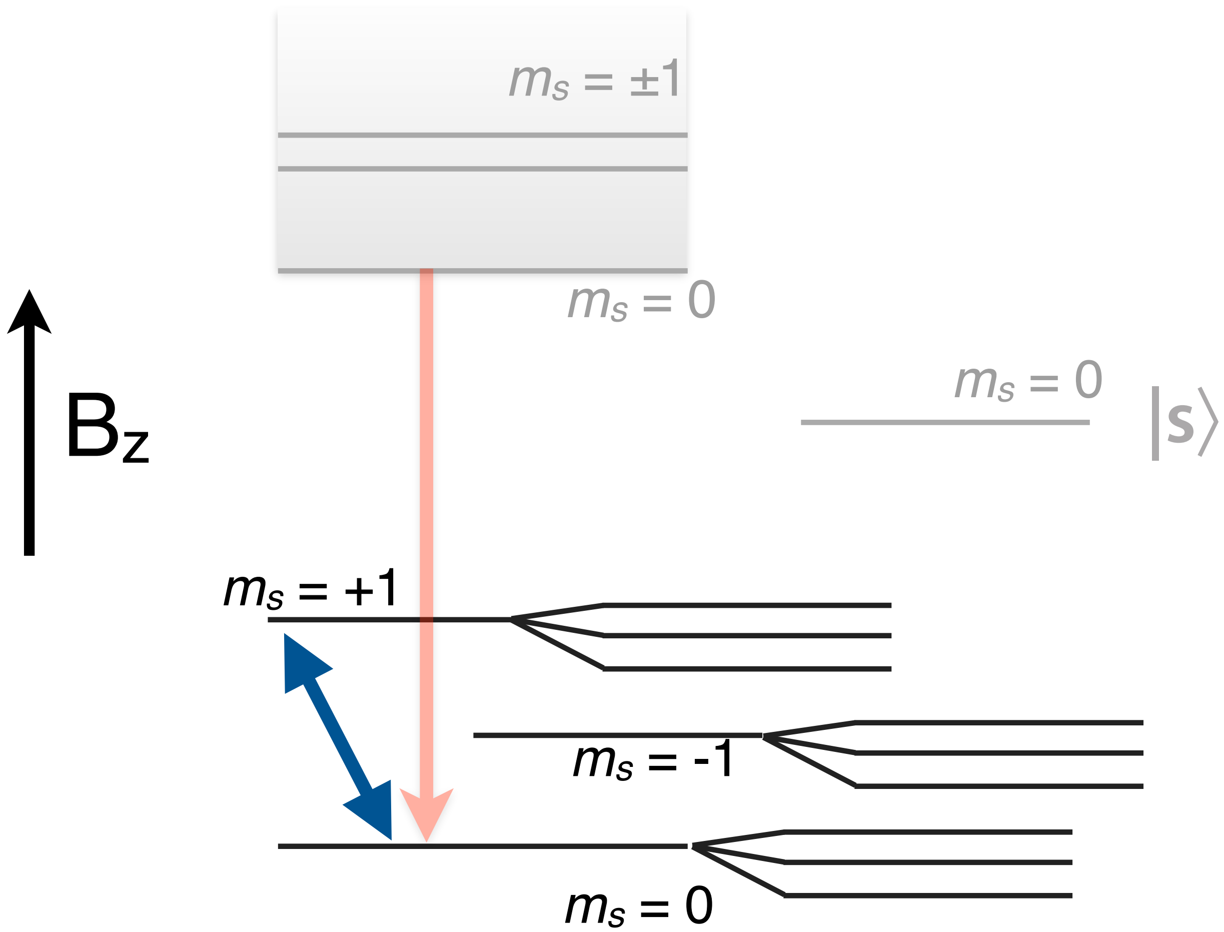
The closest nuclear spins can be used as ancillary qubits of the NV electronic spin

(hyperfine interaction)



Cappellaro et al., Phys. Rev. Lett. 102, 210502 (2009)

The NV-^{14}N two-spin system



$$H_{hf} = \mathbf{S} \cdot \mathbf{A} \cdot \mathbf{I}$$

^{14}N: spin I = 1

Requirements:

- initialize the nuclear spin in a highly polarized (pure) state
- precise knowledge of the interaction

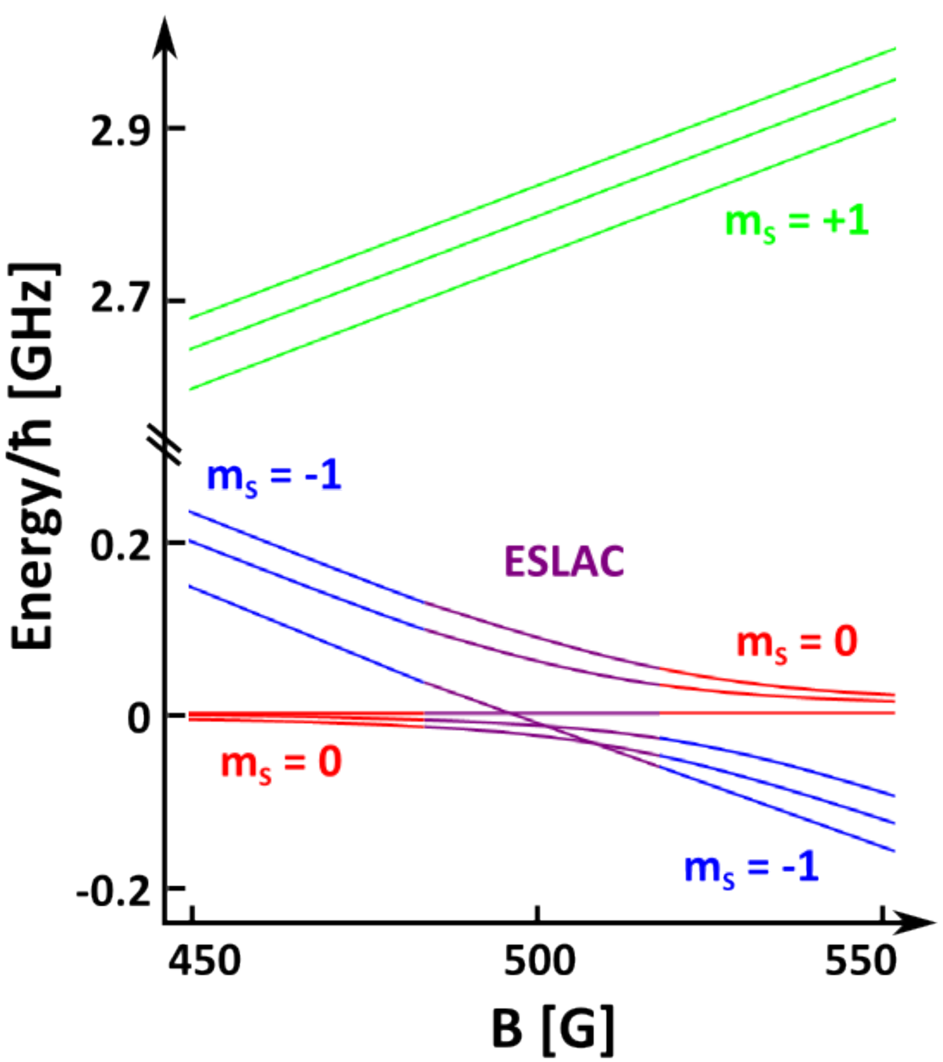
To obtain Nuclear spin polarization

- optical initialization of the electronic spin
- transverse hyperfine coupling mixes electronic and nuclear spin in the excited state

→ energy-conserving exchange of polarization by spin flip-flop:

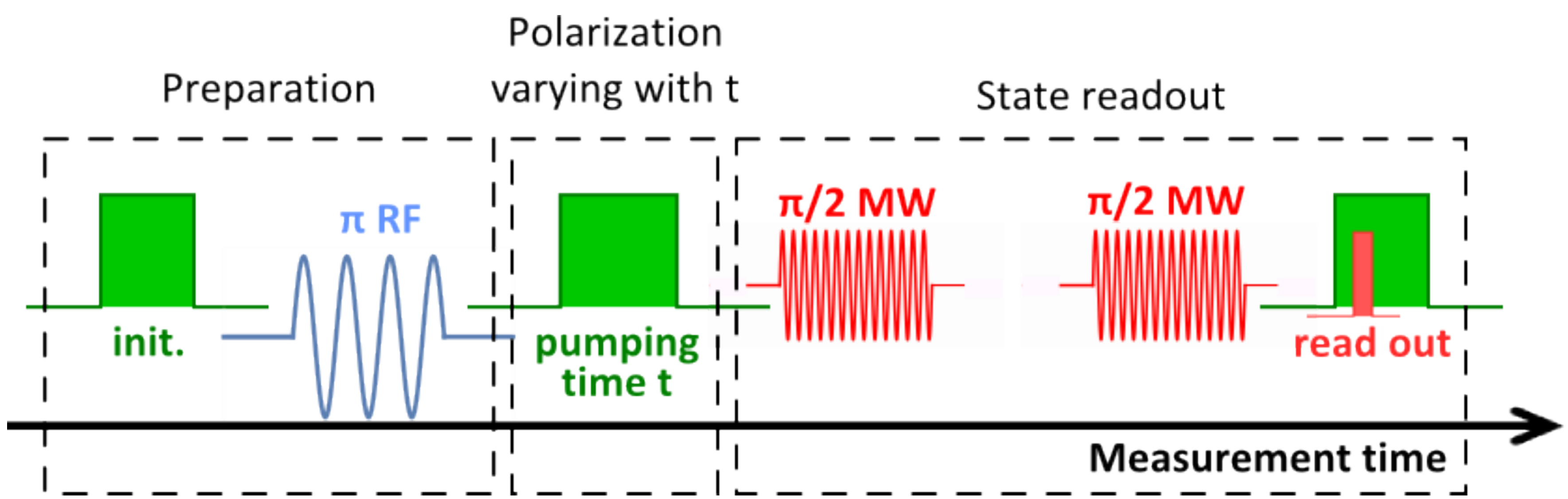
$$H_{\perp}{}^{es} = C_{\perp}(S_x I_x + S_y I_y)$$

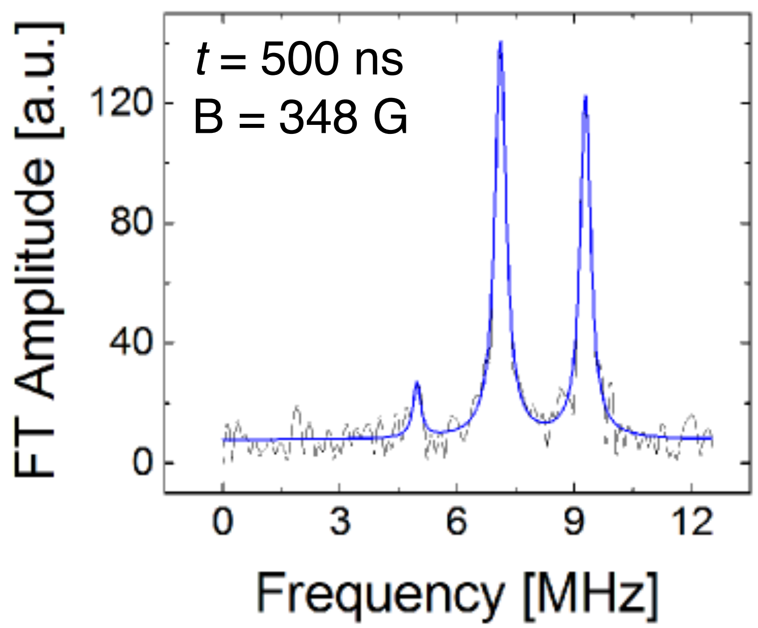
final state $|0, +1\rangle_g$

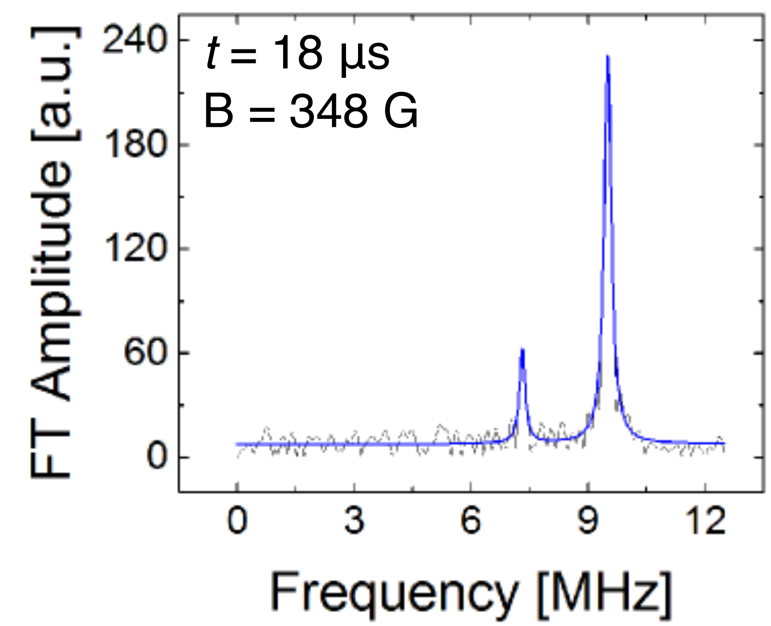


Problem: no exp. meas. of $C_{\perp}$ due to short excited state lifetime (~ 10ns)

Nuclear spin polarization: dynamical measurements

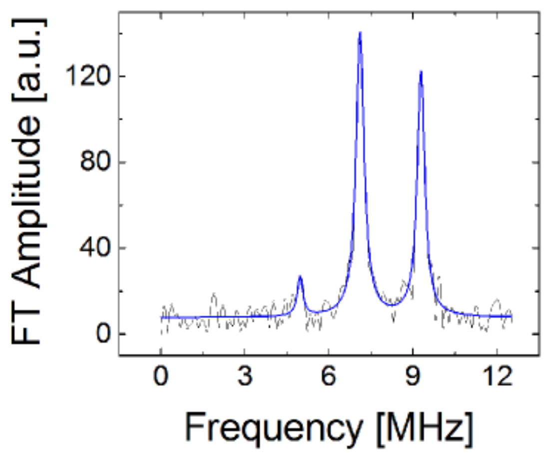




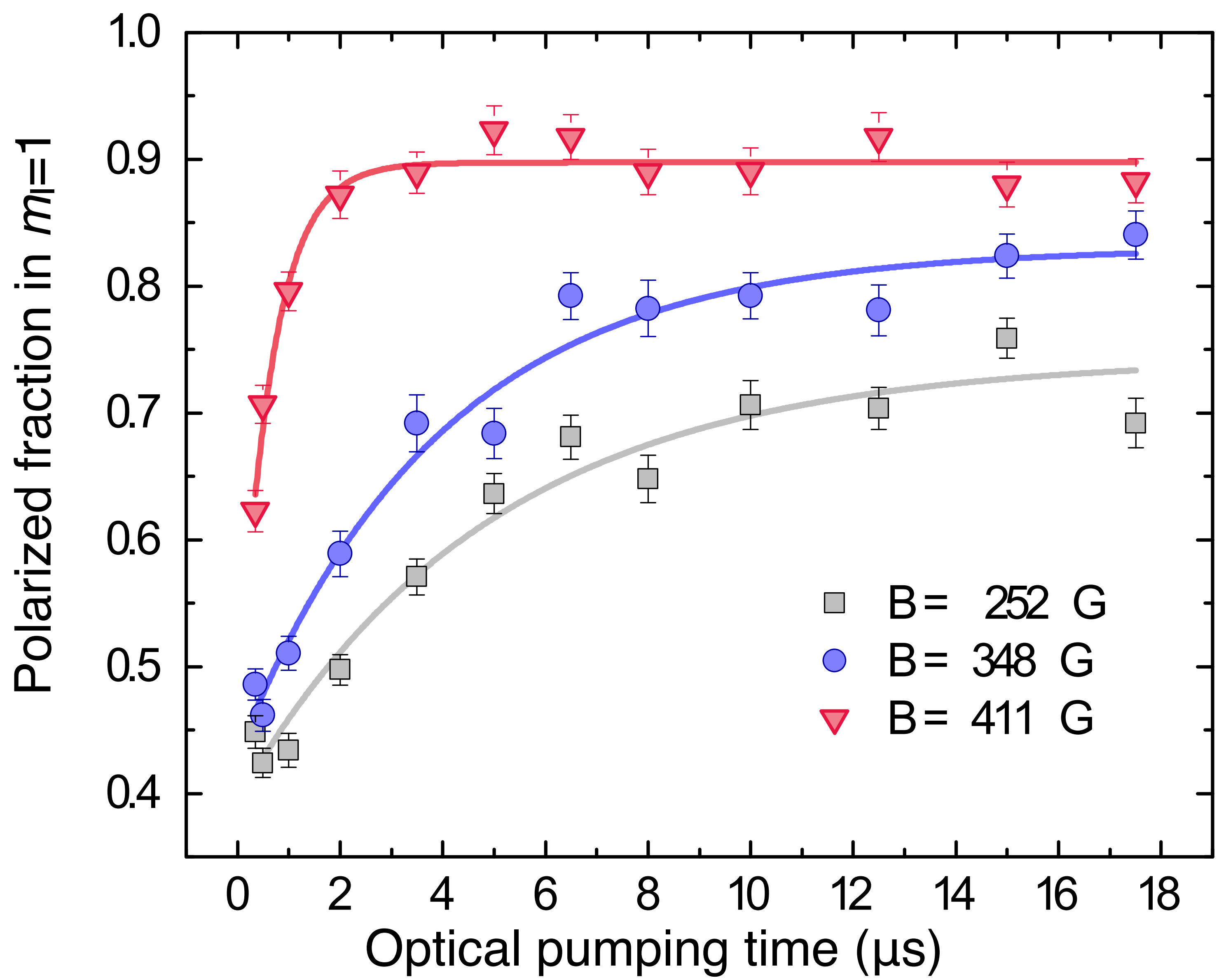


F. Poggiali, P. Cappellaro, N. Fabbri, arXiv:1612.04783

Nuclear spin polarization: dynamical measurements



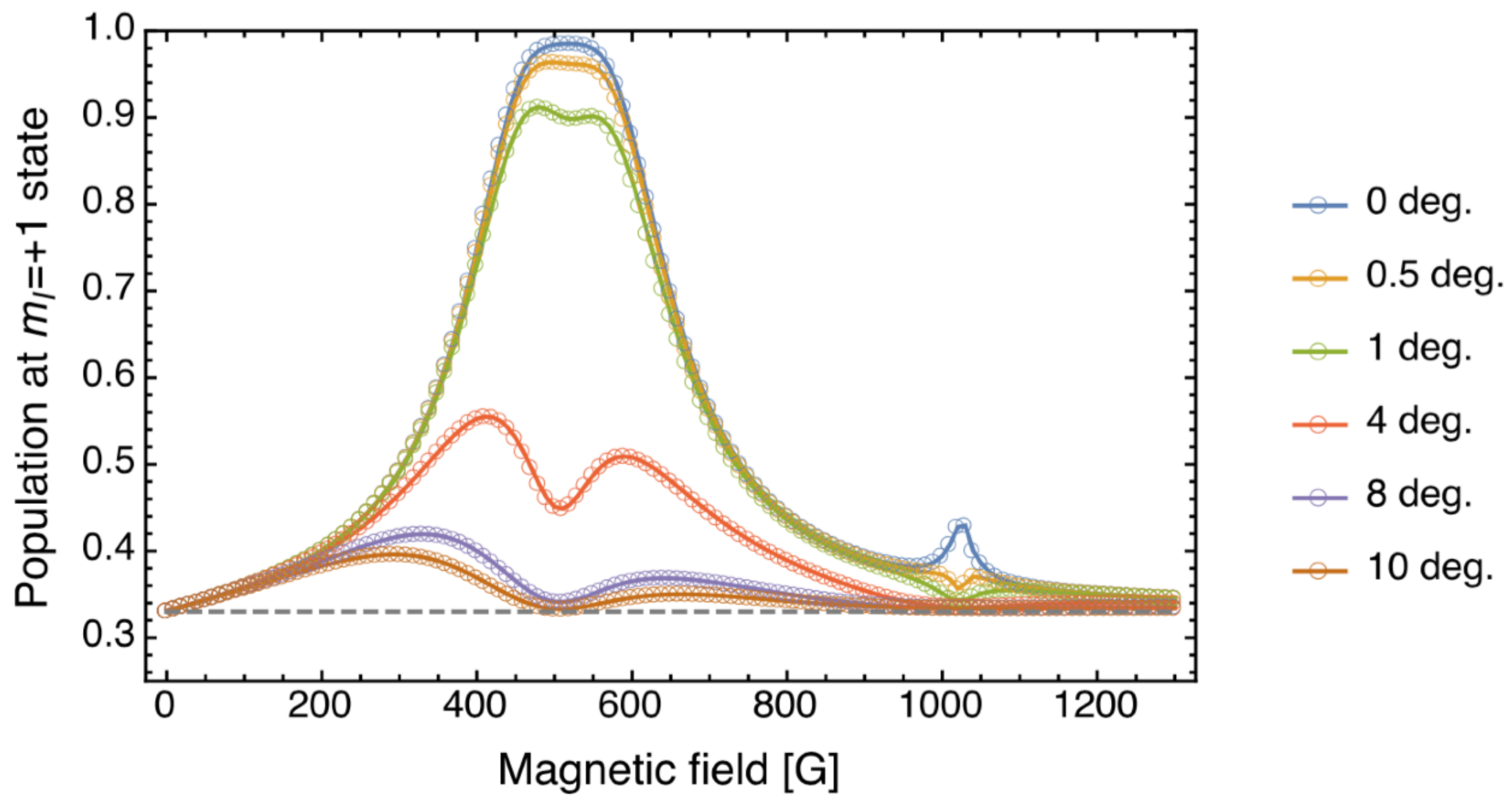
$$P_i = \frac{I(\nu_i)}{\sum_j I(\nu_j)}$$



F. Poggiali, P. Cappellaro, N. Fabbri, arXiv:1612.04783

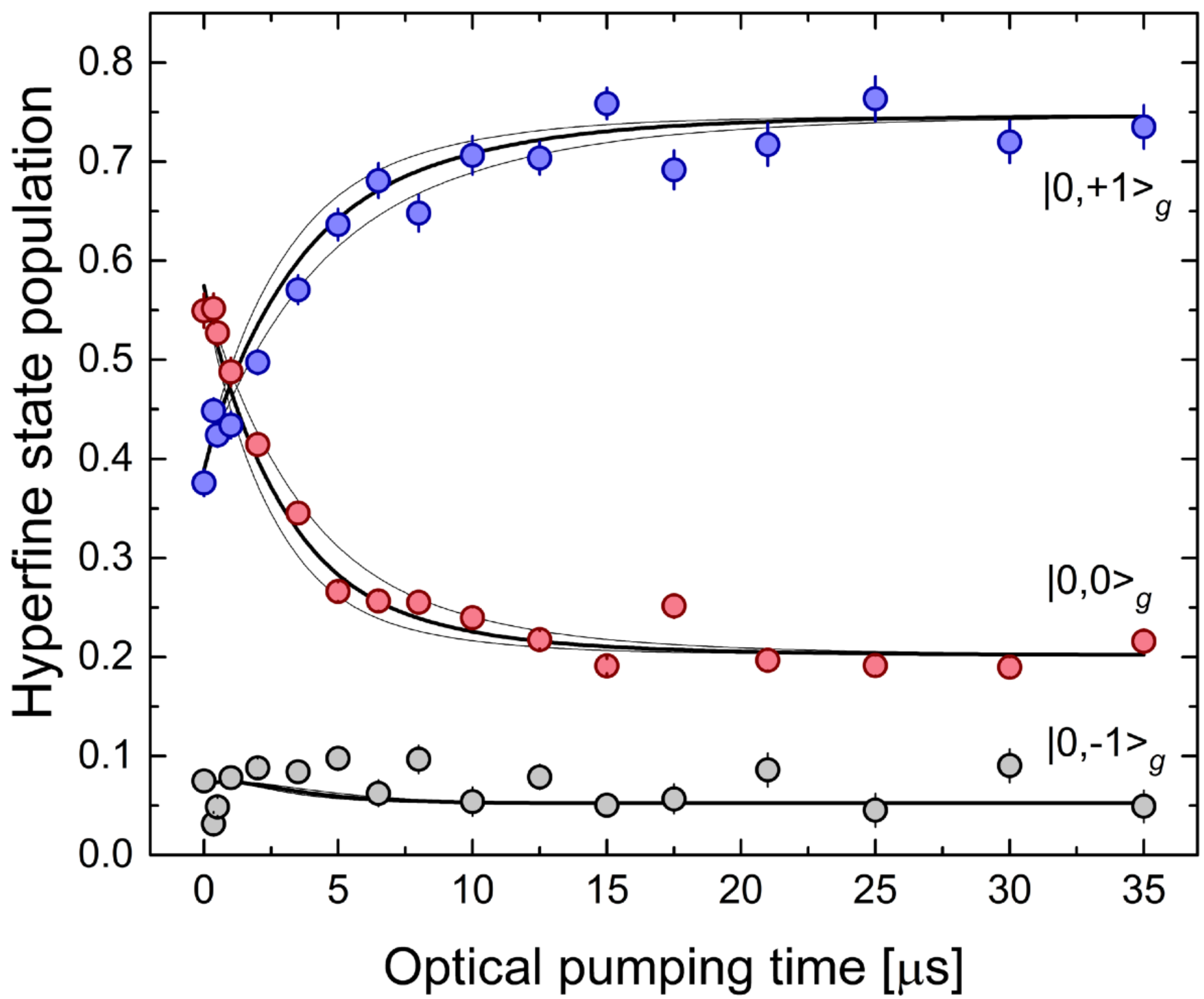
simulate the time evolution of the 2-spin system with Liouville eq.

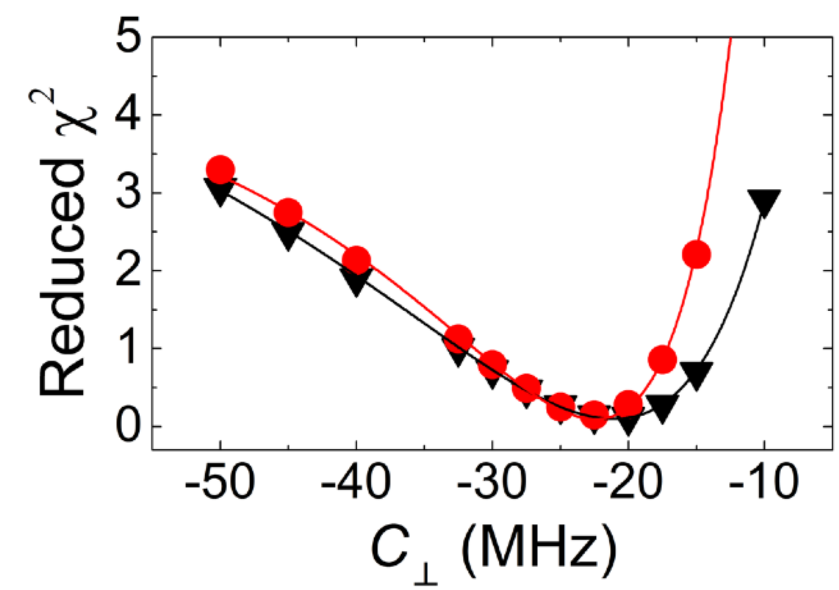
$$\frac{d}{dt}\rho = -\frac{i}{\hbar}[\mathbf{H}, \rho] + \hat{L}[\rho]$$



F. Poggiali, P. Cappellaro, N. Fabbri, arXiv:1612.04783

The timescale of the polarization in $|0,+1\rangle_g$ crucially depends on the excited-state transverse hyperfine interaction $C_\perp$





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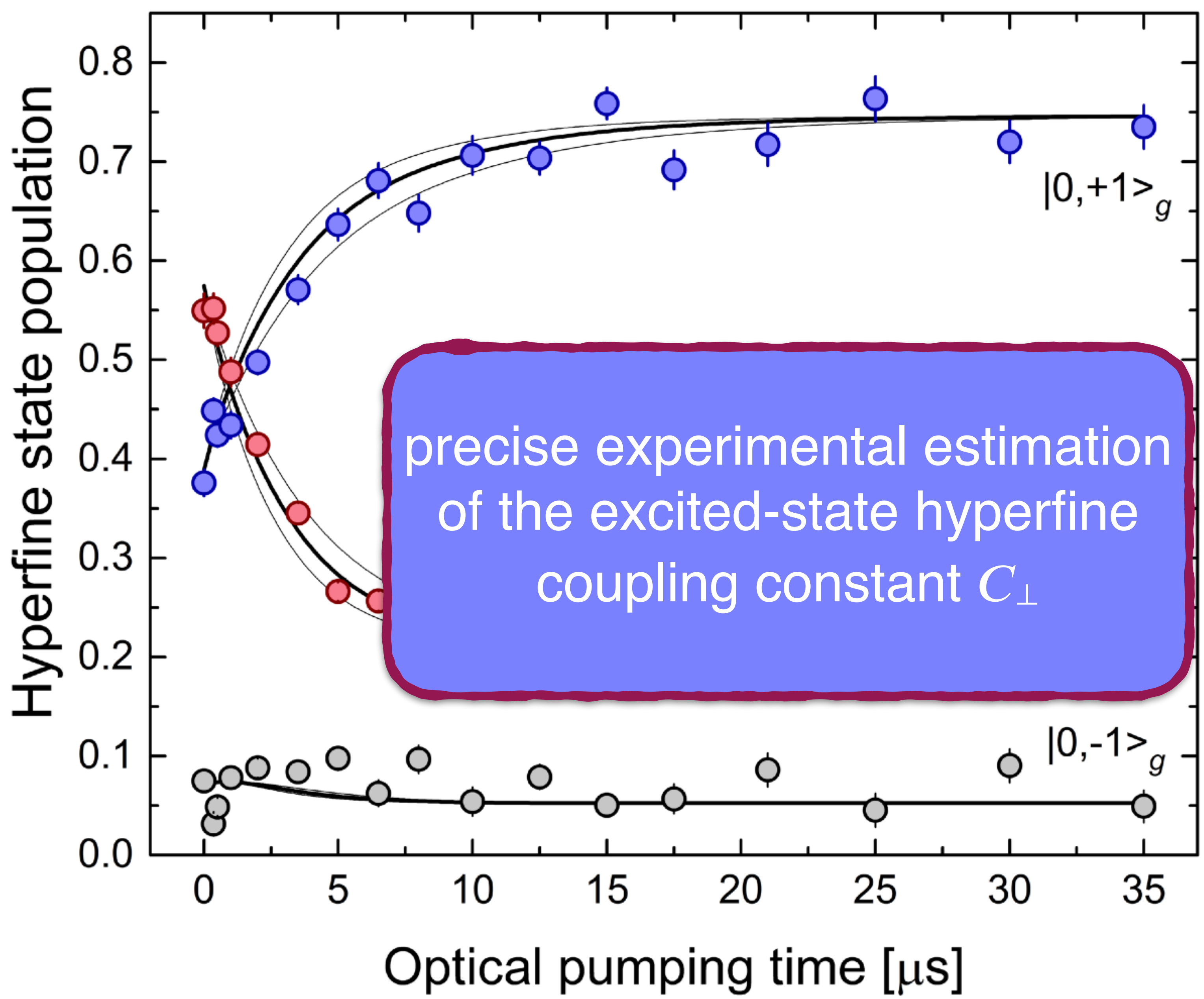
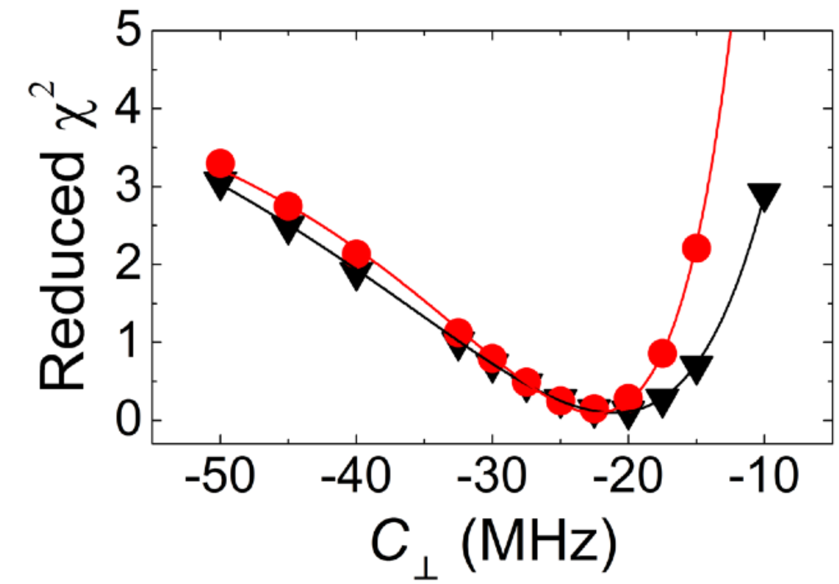
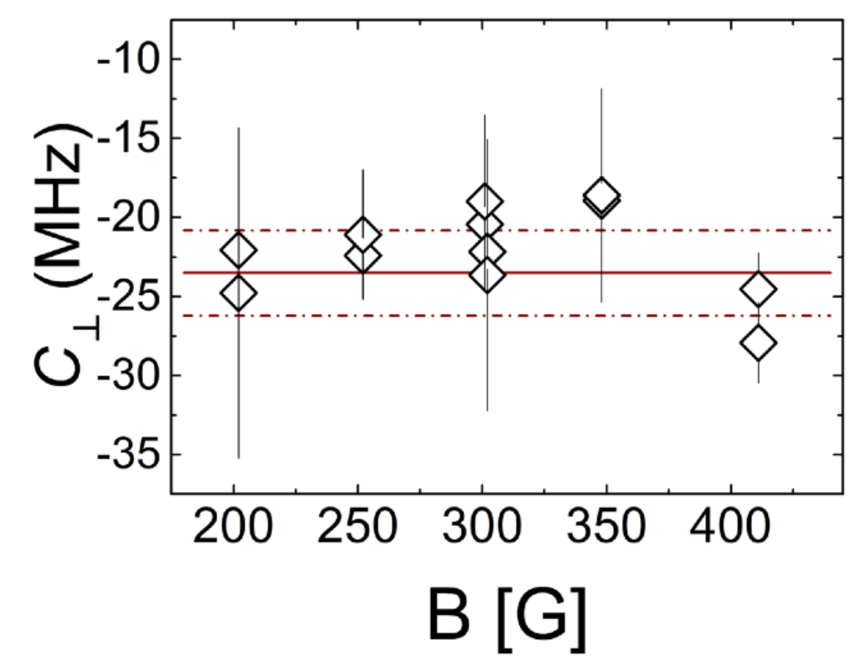


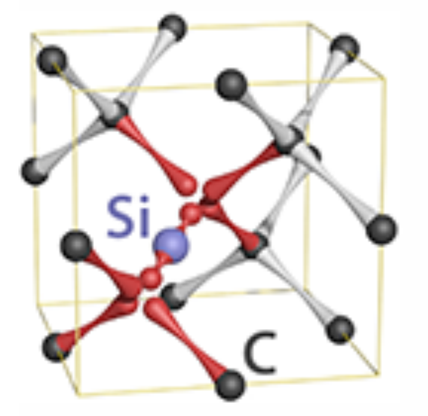




F. Poggiali, P. Cappellaro, N. Fabbri, arXiv:1612.04783

SiV center

- Inversion symmetric potential:
  - narrow line @ room temp. (1 nm)
  - 70% brunching ratio for ZPL
  - weak coupling with host matrix
  - low inhomogeneous broadening (1 GHz)
  - high photostability
- Single SiV centers both in nDiamonds and in bulk
- Short excited-state lifetime
- 150 MHz ZPL @ cryo temp.

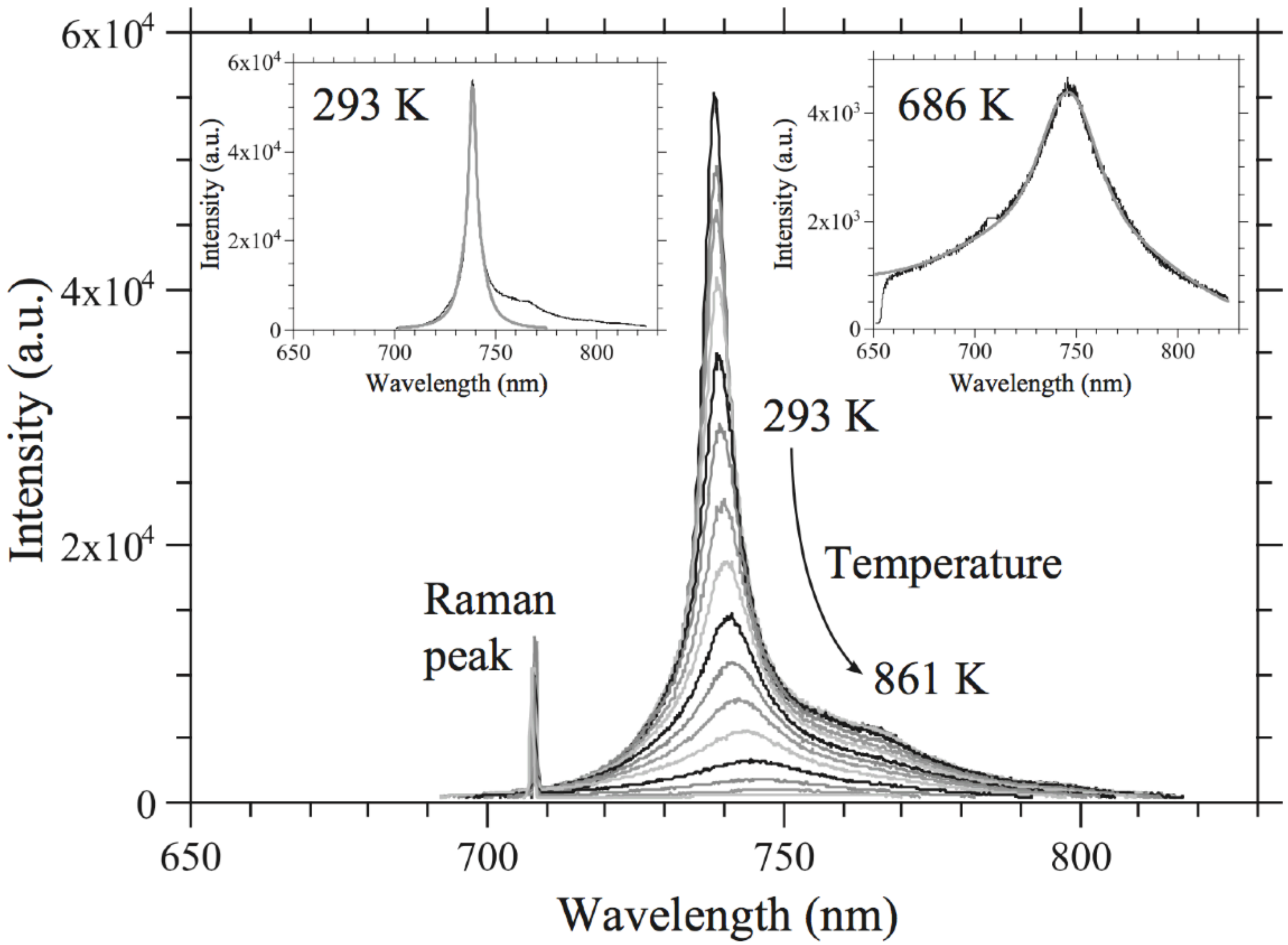


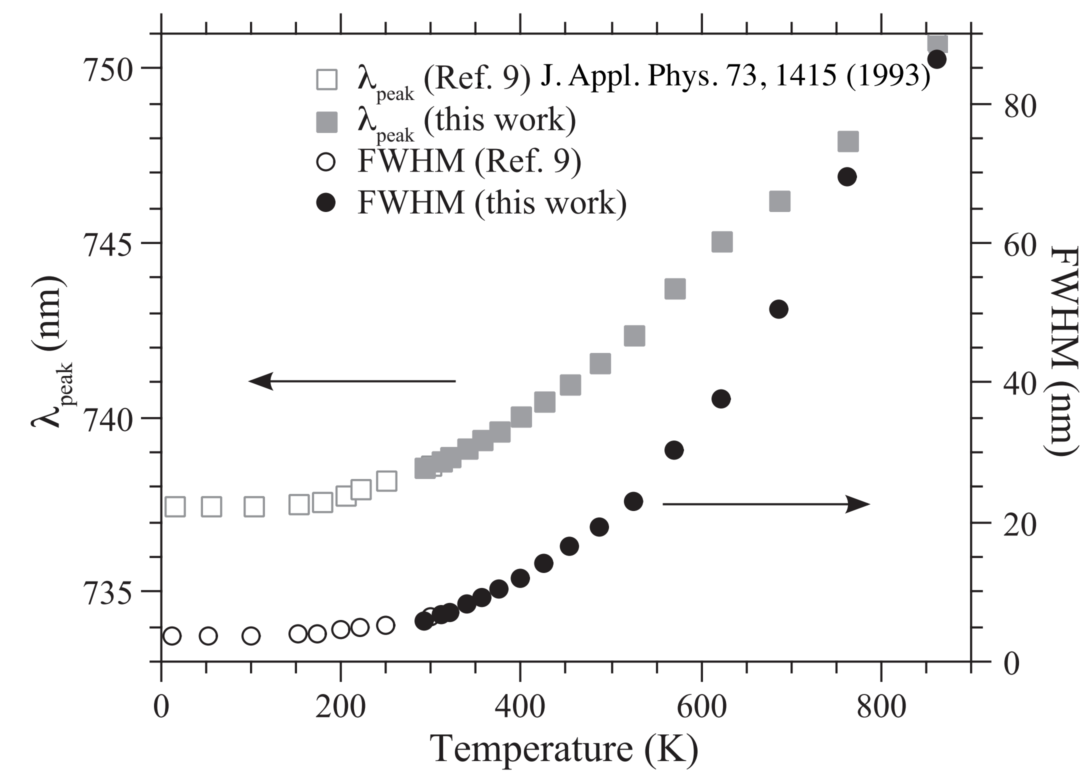
→ good candidate as stable single-photon sources for QC

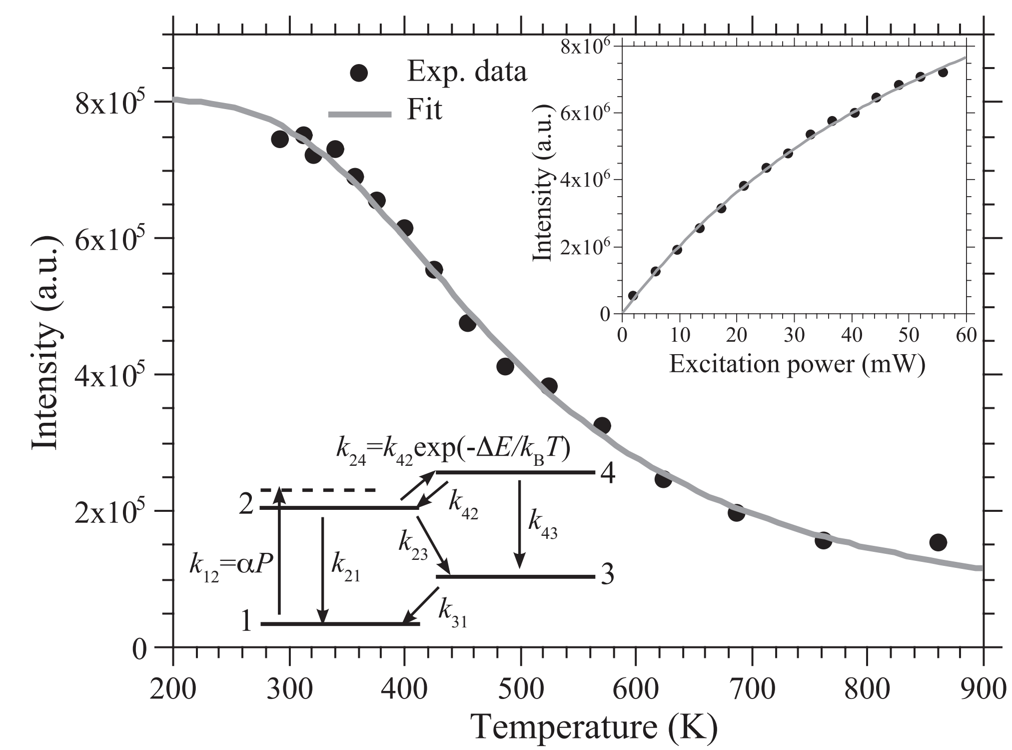
A. Sipahigil et al., PRL 113, 113602 (2014)

Photophysics of SiV center: Temperature effect

High temperature regime for electrical pumping







Collaboration with Univ. Siegen

S. Lagomarsino, F. Gorelli, M. Santoro, N. F. et al., AIP ADVANCES 5, 127117 (2015)

Thanks for your attention!