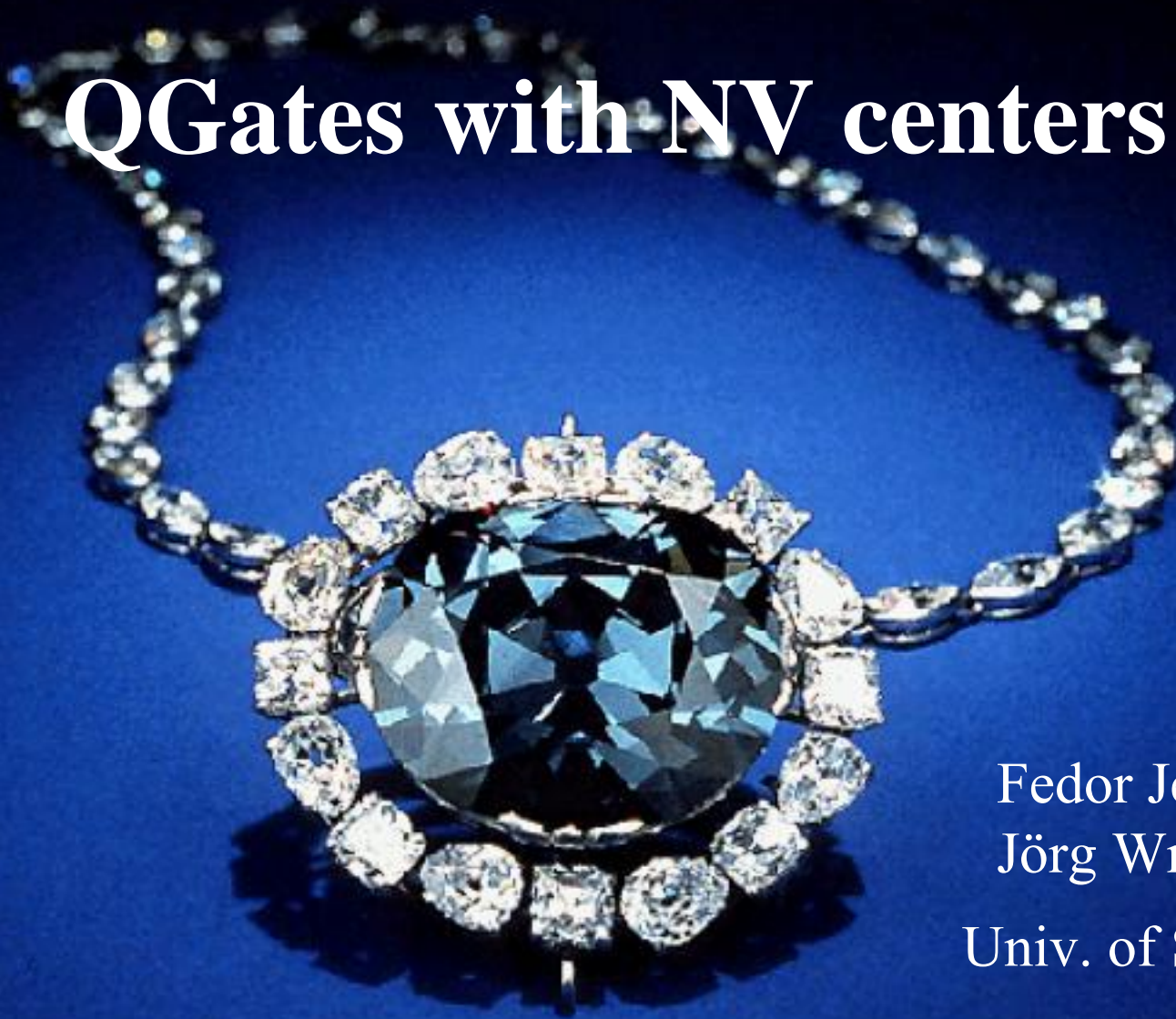
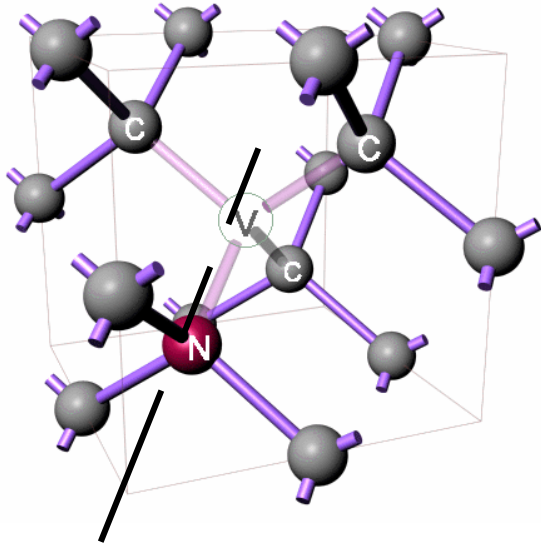


QGates with NV centers



Fedor Jelezko,
Jörg Wrachtrup
Univ. of Stuttgart

The NV-center in diamond

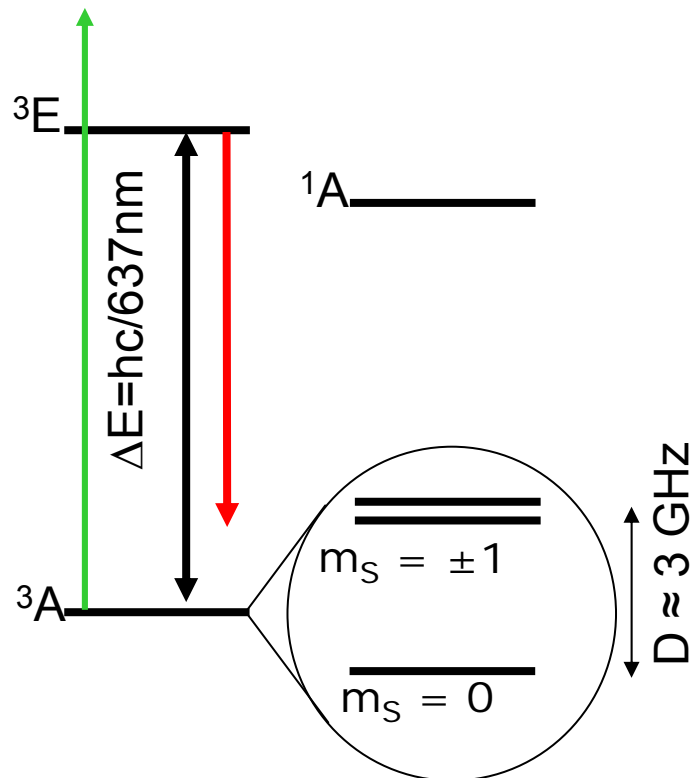


structure

- **Nitrogen Vacancy center** in diamond lattice (^{15}N isotope)
- C_{3v} -symmetry
- photostable

energy levels

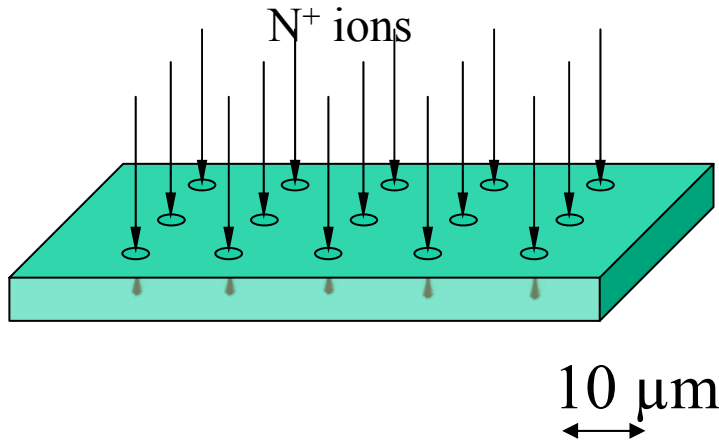
- triplet ground state ($D = 2.88$ GHz)
- strong optical dipole transition
- spin polarization by optical excitation ($m_s=0$)
- spin sublevels encoded in fluorescence intensity ($m_s = 0$ high, $m_s = \pm 1$ low)



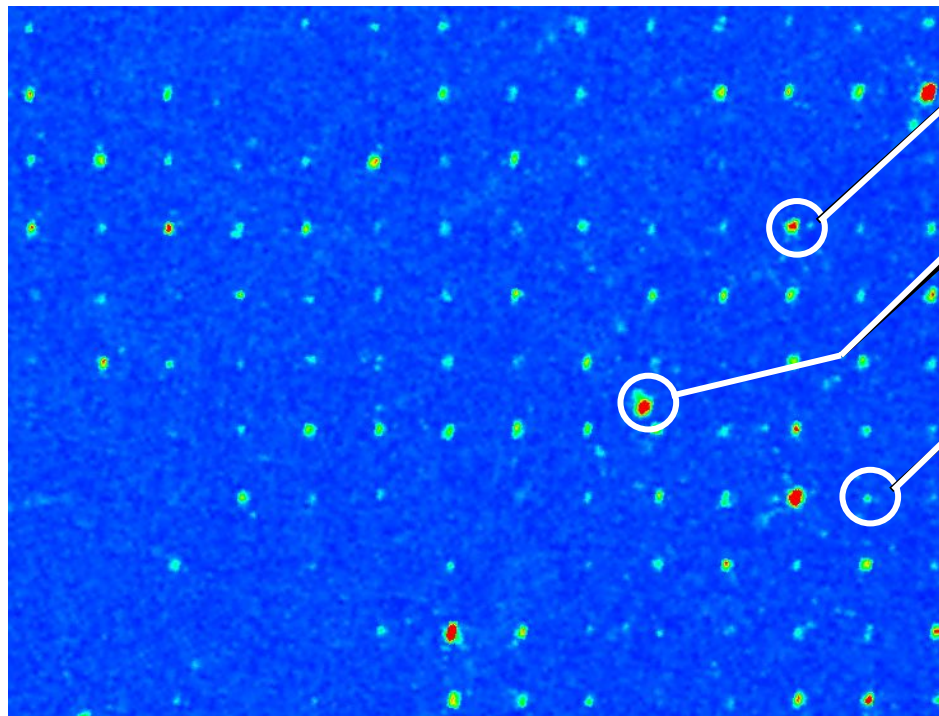
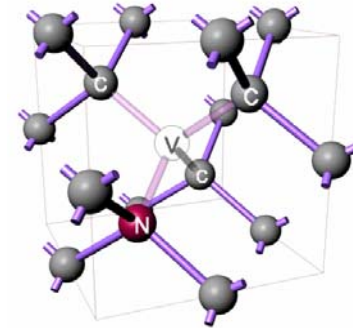
Single N-V centers implantation

Meijer, J. et al. APL 87, 261909 (2005).

Rabeau, J. R. et al. APL 88, 023113 (2006)



cond-mat/0505063



two defects

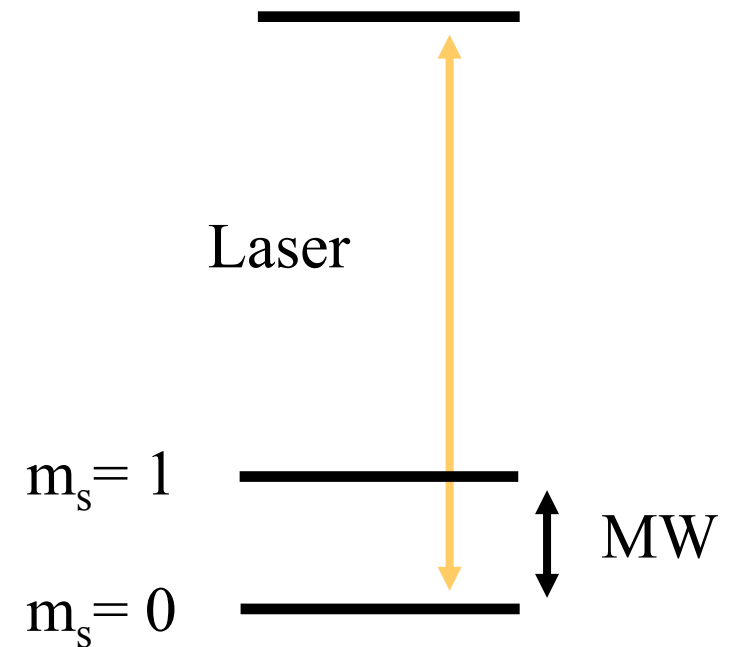
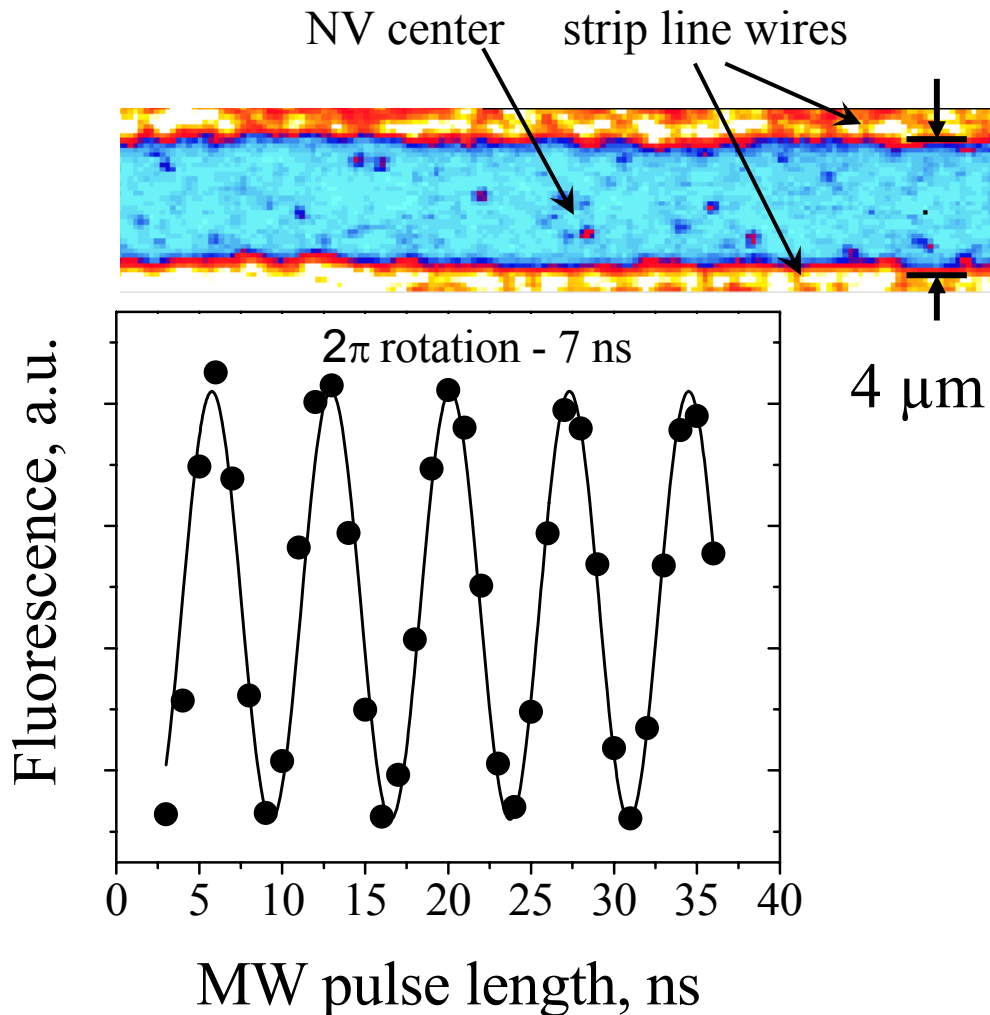
three defects

single defect

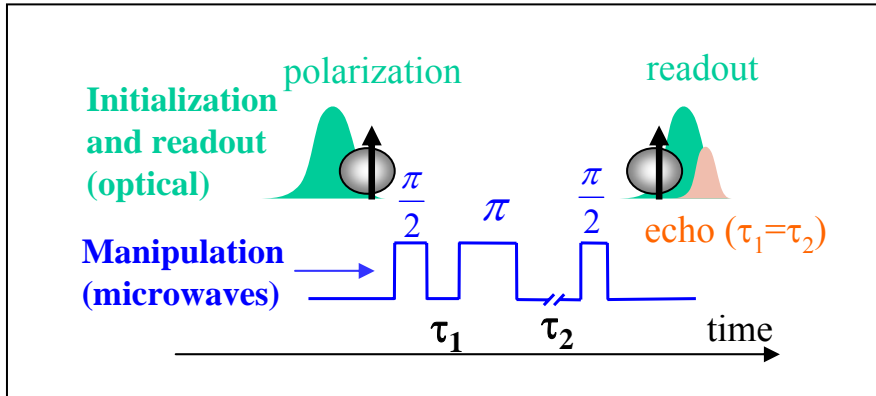
Rabi oscillations of a single spin

Spin-selective photon scattering allows optical detection of spin

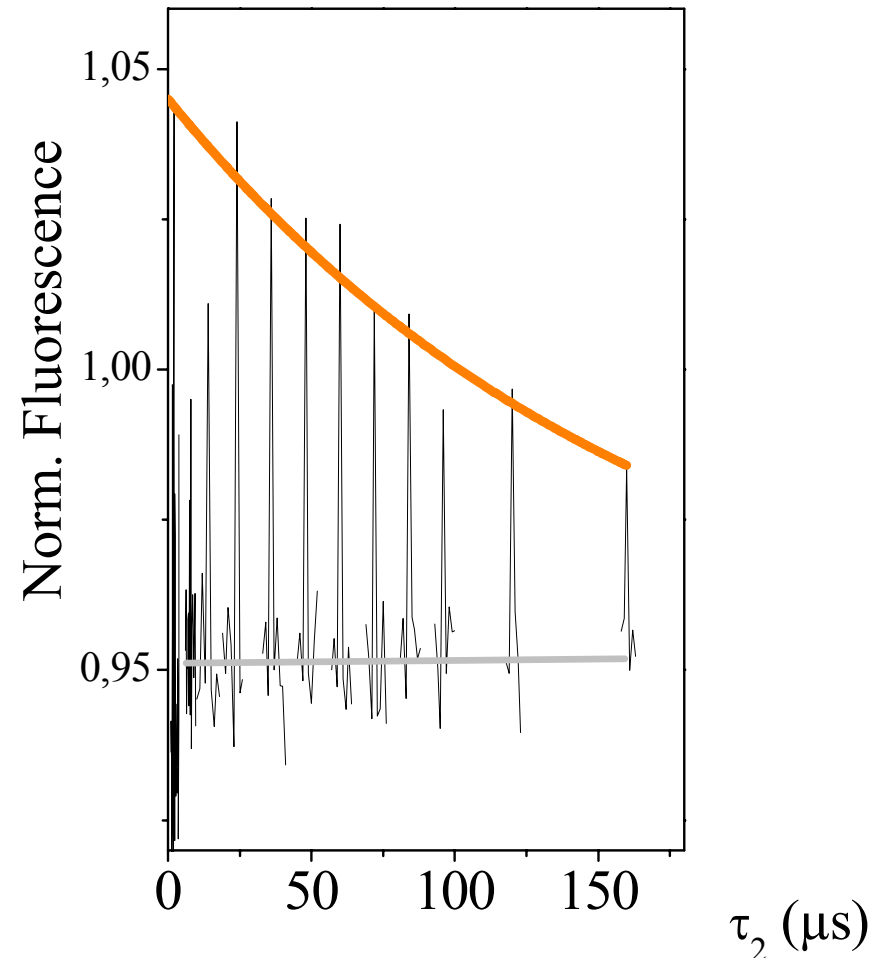
Jelezko et al. PRL **92**, 076401 (2004)



Hahn echo decay of single N-V center in IIa type diamond T=300K



$T_2 = 0.35$ ms, T = 300 K



Mechanism:

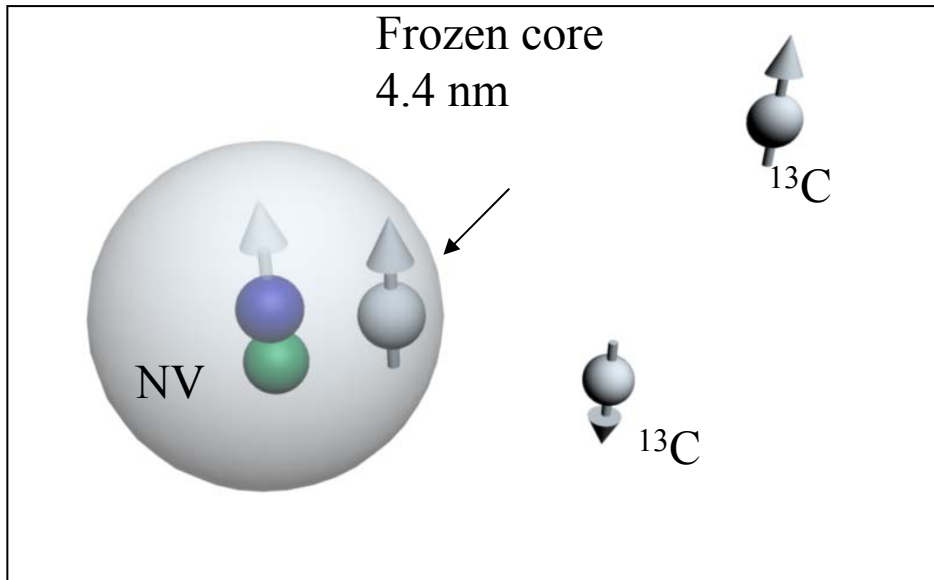
Dipolar coupling of NV spin to other „impurity“ spins in the lattice.

Mostly: N

$$H_D = \frac{\mu_{NV}\mu_N}{r^3} - \frac{3(\mu_{NV}r)(\mu_Nr)}{r^5}$$

$$H_D = \dots + S_{NV}^+ S_n^- + \dots$$

Decoherence



Dipolar coupling of NV spin
Mostly: ^{13}C

$$H_D = \frac{\mu_{\text{NV}}\mu_{^{13}\text{C}}}{r^3} - \frac{3(\mu_{\text{NV}}r)(\mu_{^{13}\text{C}}r)}{r^5}$$

Childress et al., Science 2006

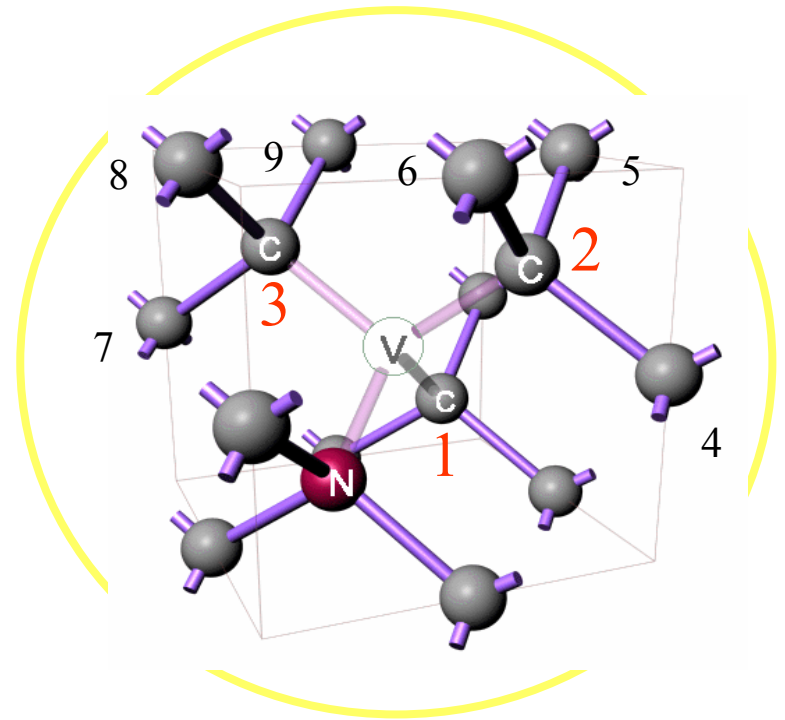
Nuclei: Hyperfine coupling to ^{13}C

$$H = g_e \beta_e \hat{B} \hat{S} + \hat{S} D \hat{S} + \hat{S} A_i \hat{I}_i + g_{ni} \beta_n \hat{I}_i \hat{B}$$

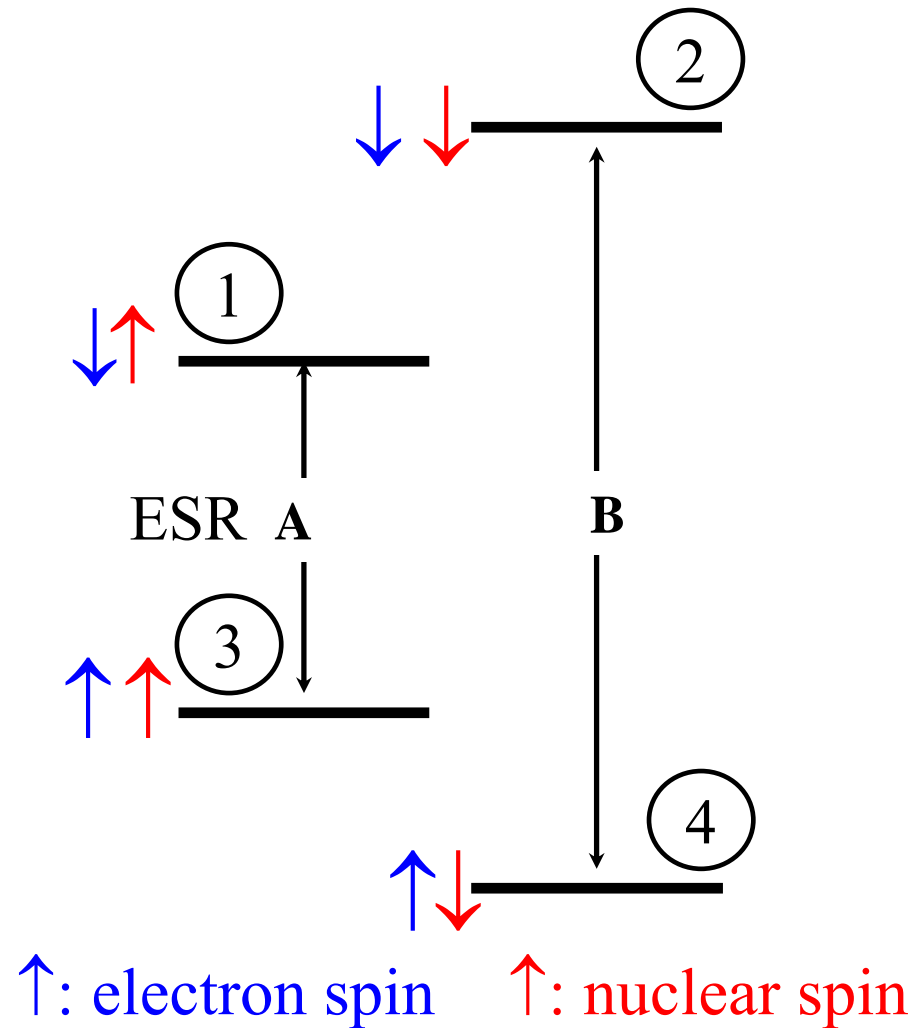
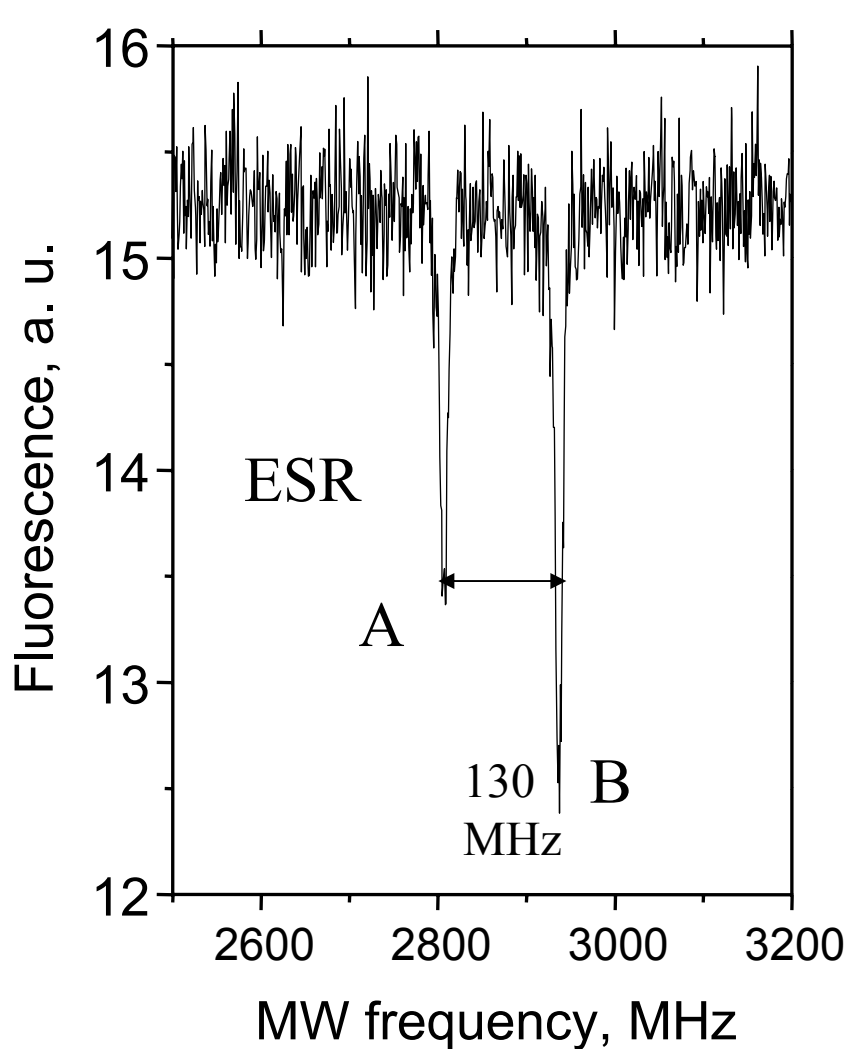
Hyperfine splitting

$$A_{1,2,3} = 130 \text{ MHz}$$

$$A_{4,5,6} = 15 \text{ MHz}$$

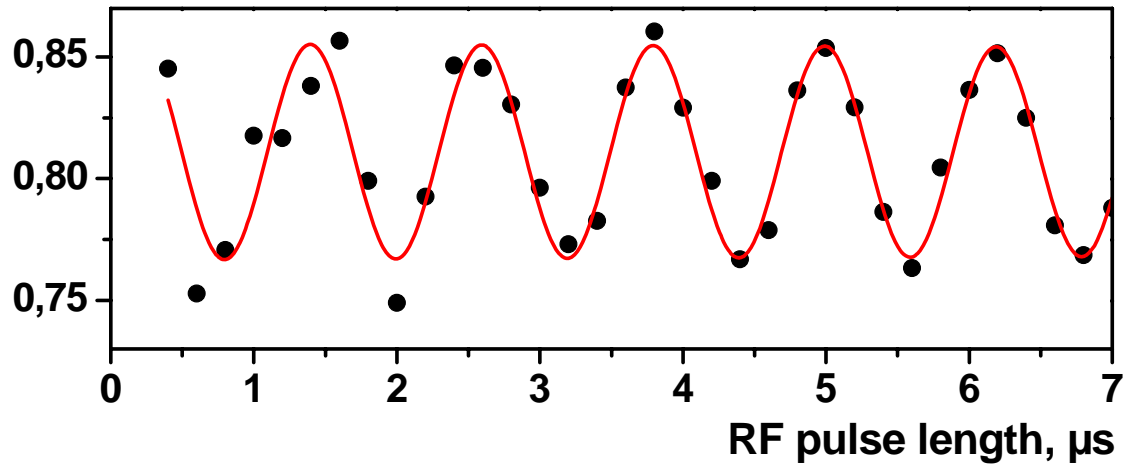
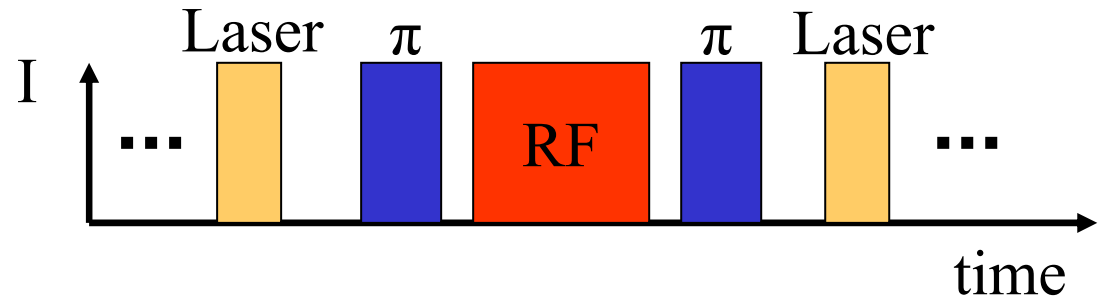
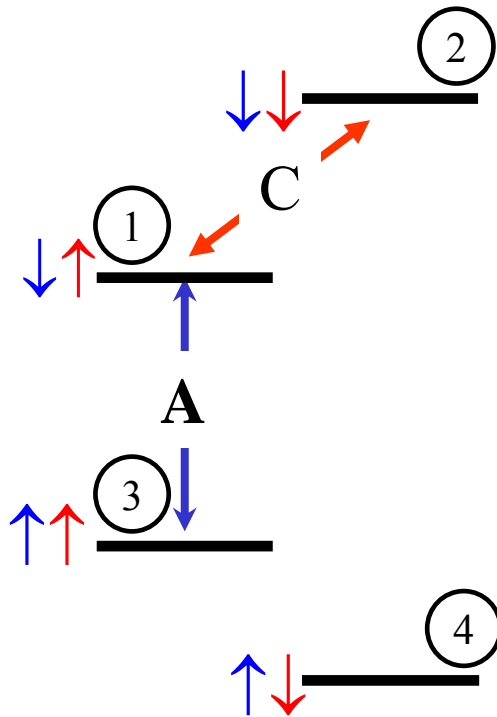


Coupling to single ^{13}C nuclei: ESR and ENDOR spectra



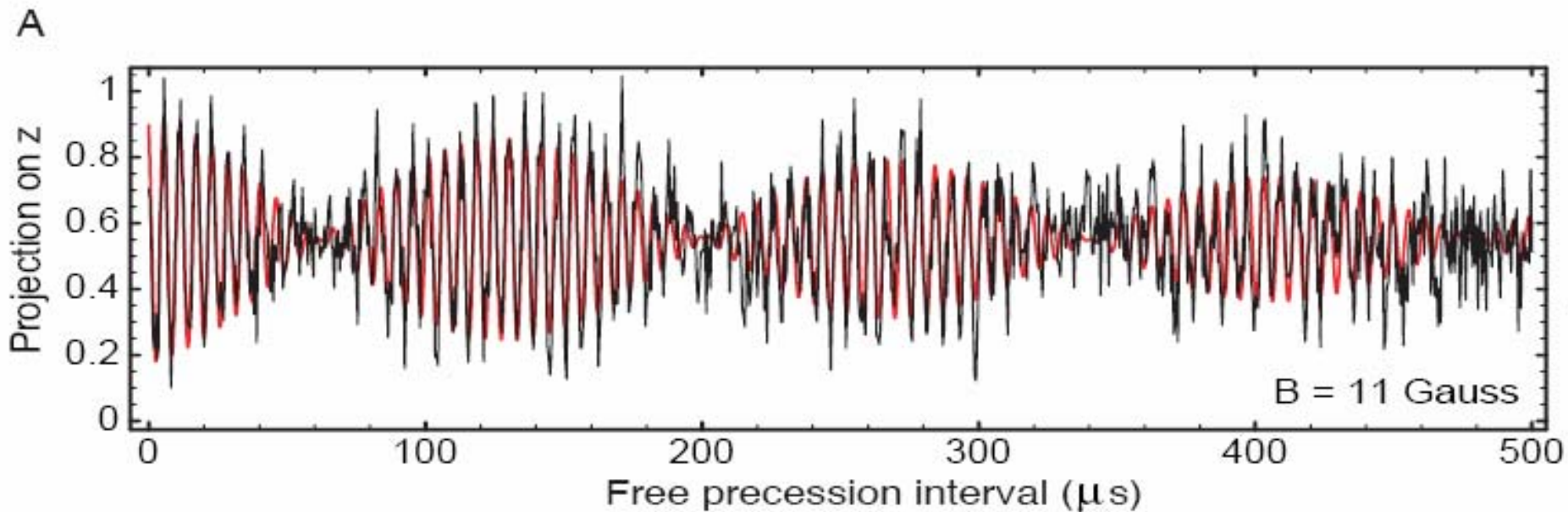
Rabi nutations of a single ^{13}C spin

(average over 10^5 cycles)



\uparrow : electron spin \uparrow : nuclear spin

Ramsey fringes on single ^{13}C nuclear spin

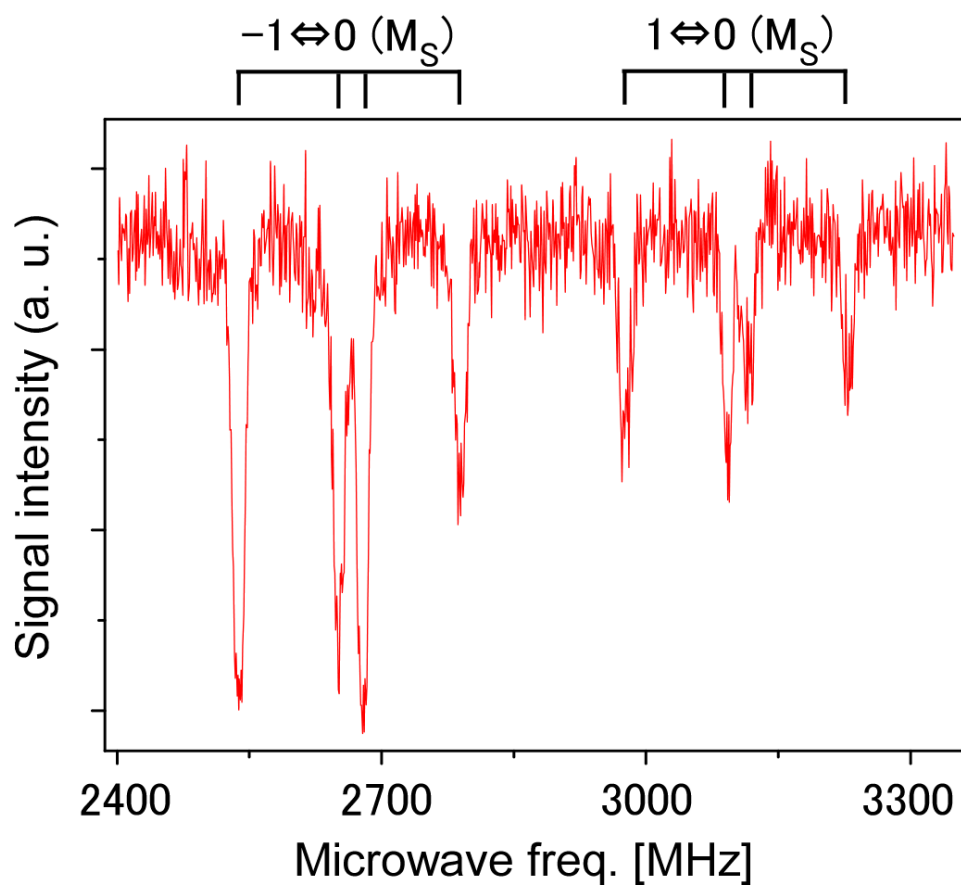


Gurudev M. Dutt et al., submitted

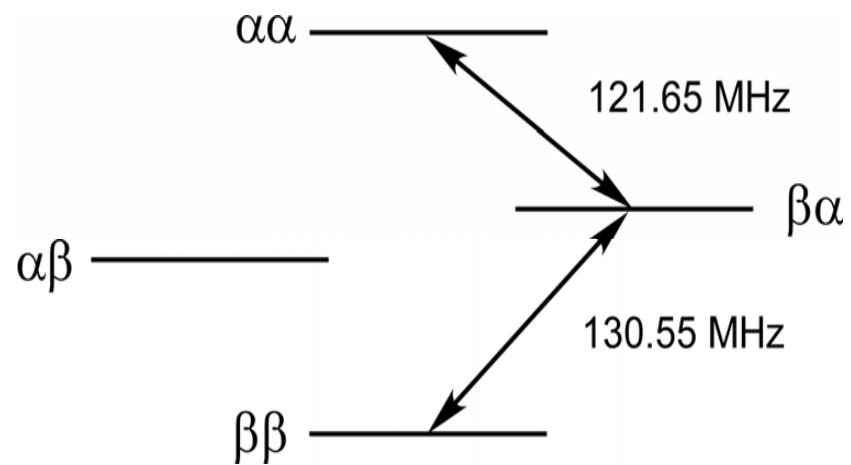
$$T_2^* (\text{FID}) = 0.5 \text{ ms}$$

$$T_2 (\text{echo}) > 40 \text{ ms}$$

Observation of 2 ^{13}C in 1st shell

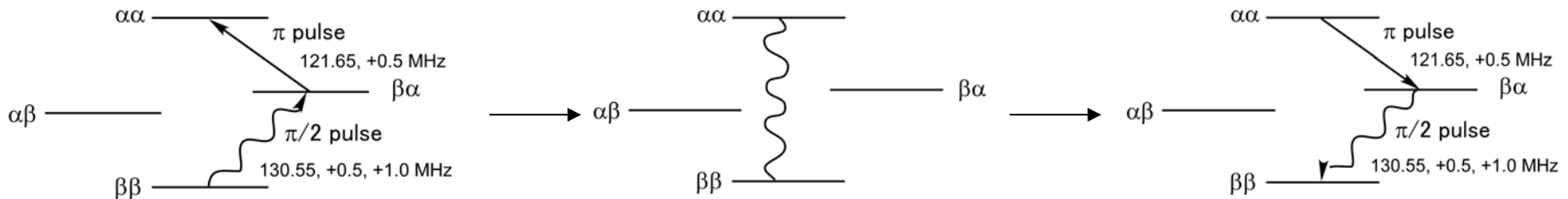


8.4% c^{13} enriched diamond



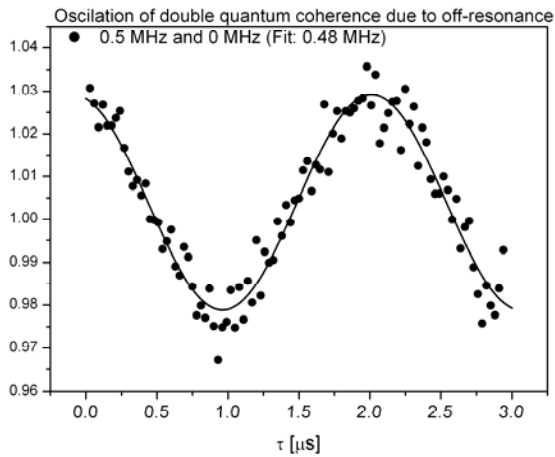
Double quantum coherence of 2 nuclear spins (two ^{13}C in the first shell)

$$\pi(\text{MW}) - \pi/2(\text{rf1}) - \pi(\text{rf2}) - \tau - \pi(\text{rf2}) - \pi/2(\text{rf1}) - \pi(\text{MW})$$



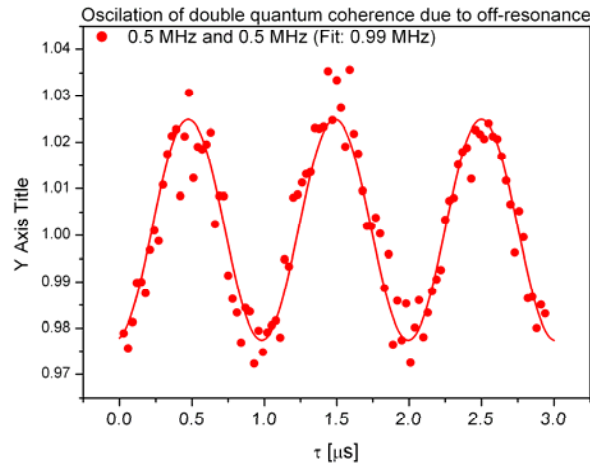
Phase shift by detuning (Off resonance)

rf1: 0 MHz, rf2: 0.5 MHz



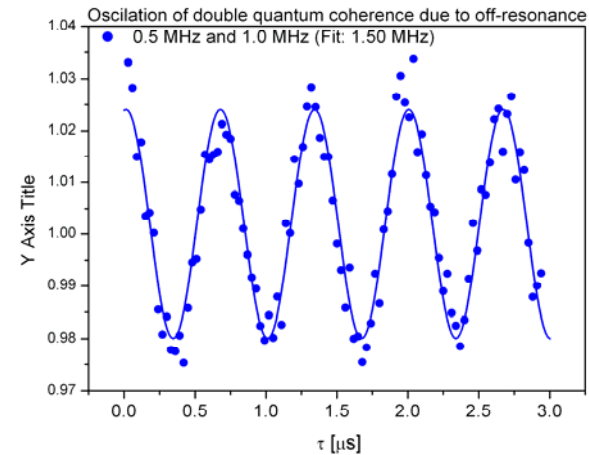
Fitted curve: 0.48 MHz

rf1: 0.5 MHz, rf2: 0.5 MHz



Fitted curve: 0.99 MHz

rf1: 1 MHz, rf2: 0.5 MHz

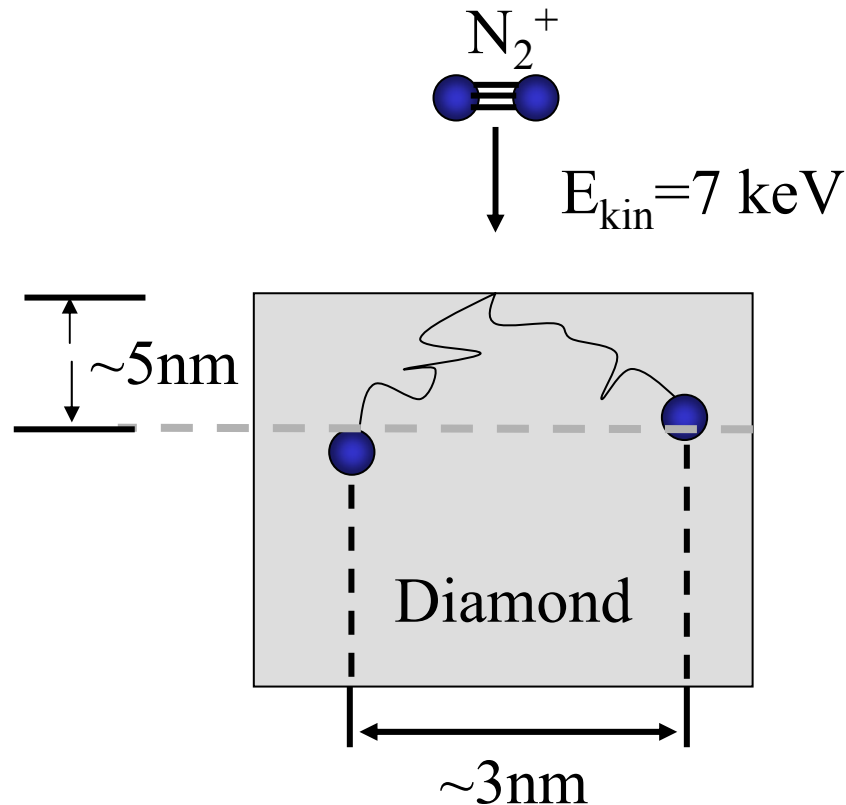


Fitted curve: 1.50 MHz

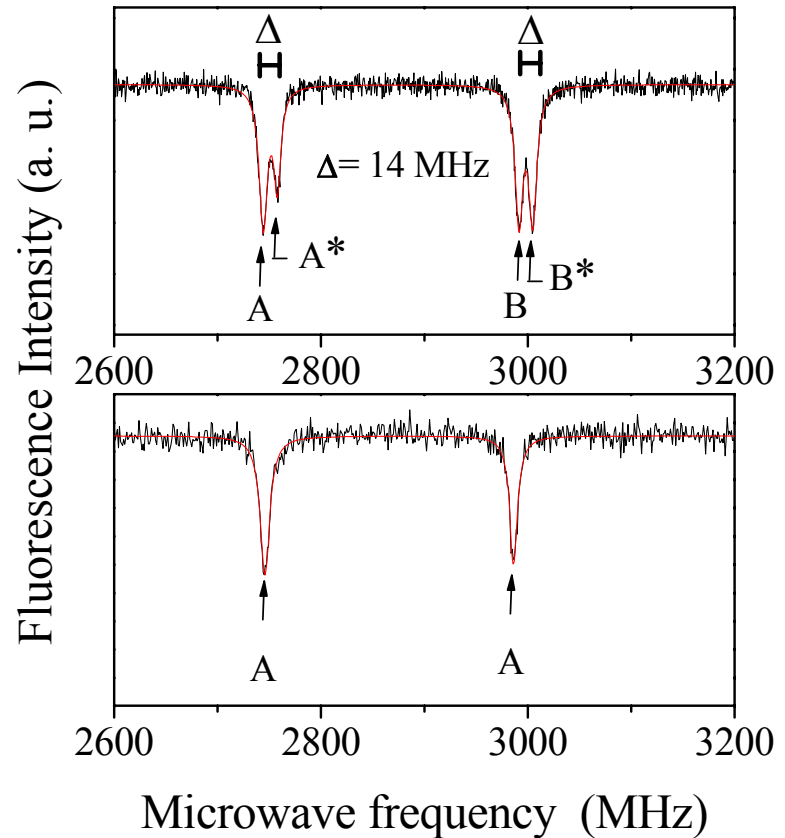
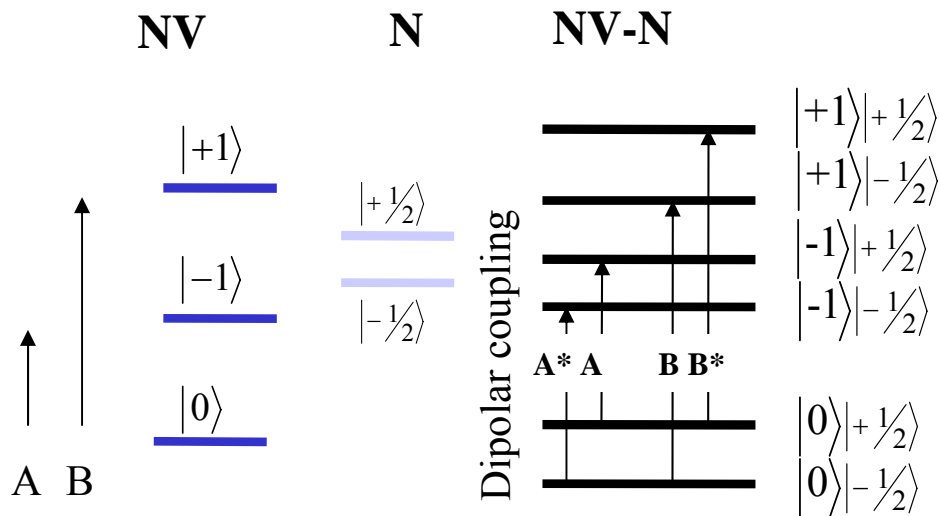
Proof of double quantum coherence (entangled state)

Coupling between electron spins: Implantation of N₂ molecules

Gaebel, T., et al Nature Physics, v. 2, p. 408-413
(2006)



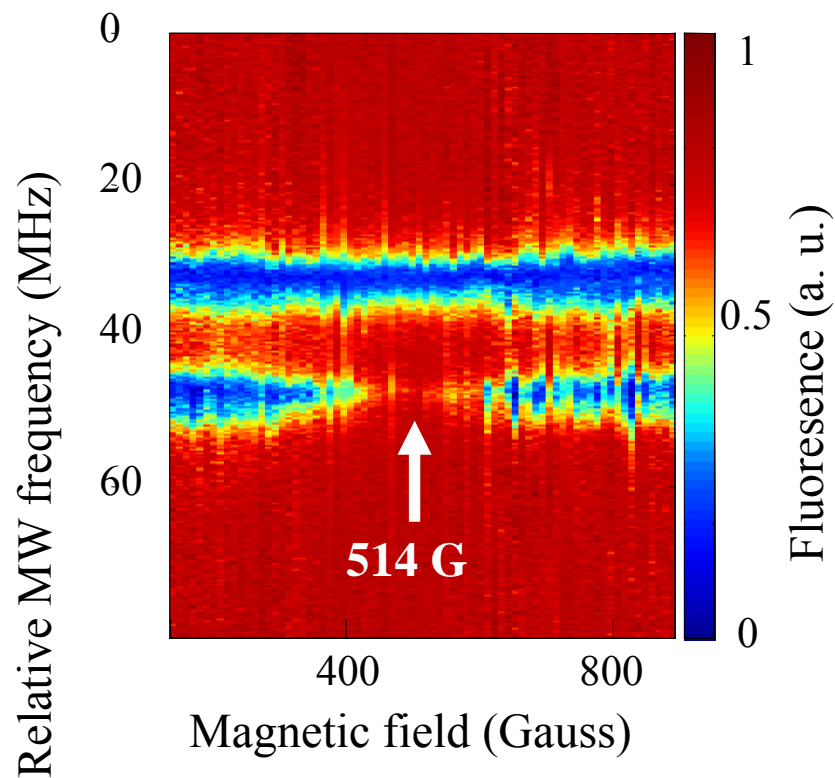
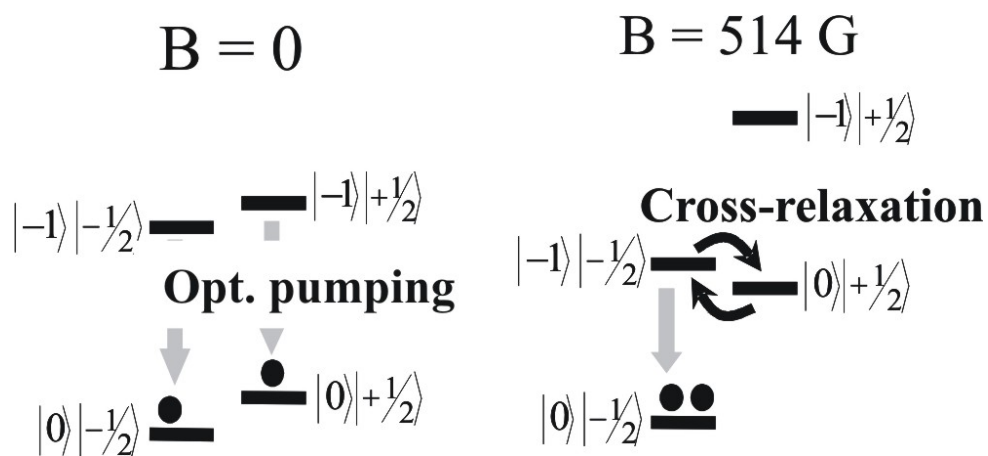
Coupling between two e⁻ spins



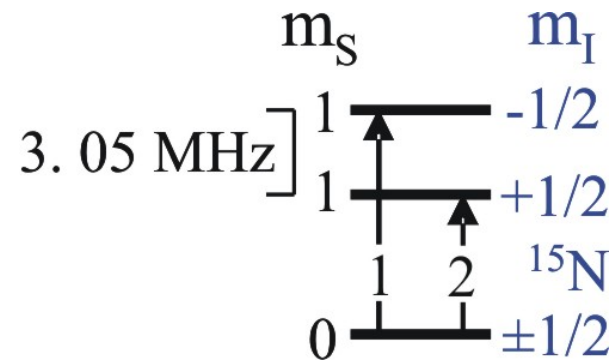
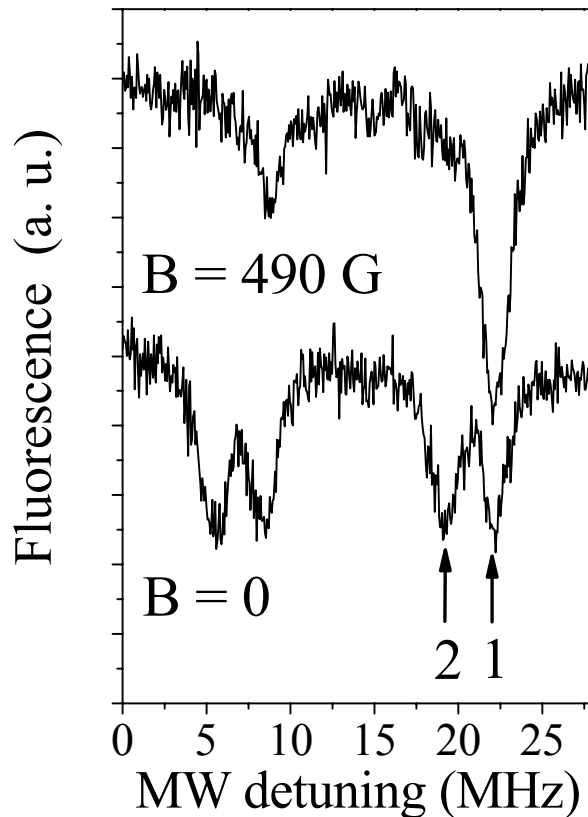
Gaebel, T., et al Nature Physics, v. 2, p. 408-413

Hanson et al. PRL 2006

Polarization transfer



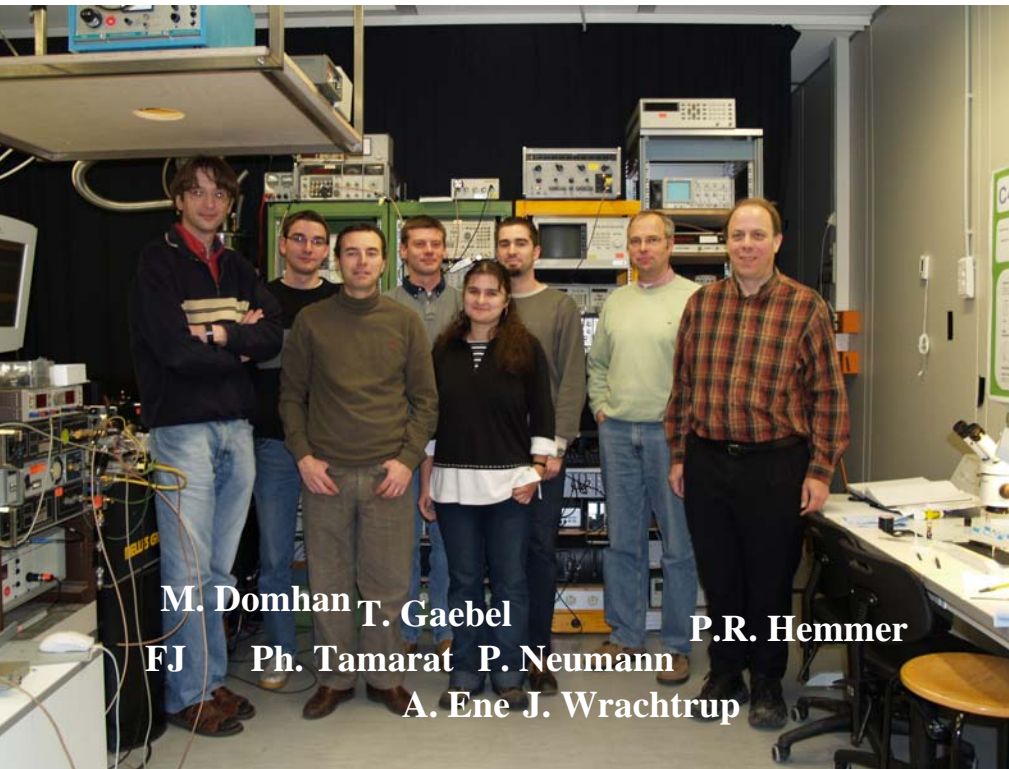
Polarization transfer from electron to nuclear spin



three-spin flip-flop

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J. Twamley, J. Rabeau (Sydney)

QAP, EQUIND



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