Theory & Simulation

Jaynes-Cummings model [1]

$$\mathcal{H} = \underbrace{\hbar\omega_0\hat{s}_z + \hbar\omega_d\hat{a}^\dagger\hat{a}}_{\mathcal{H}_0} + \underbrace{\lambda\hat{s}_x\left(\hat{a}+\hat{a}^\dagger\right)}_{\mathcal{V}_{\text{int}}}$$

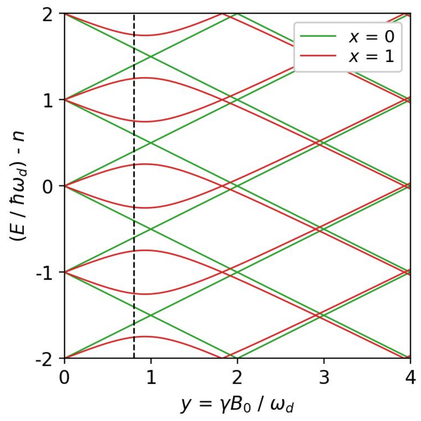
$$\frac{\mathcal{H}}{\hbar\omega_d} = \frac{y}{2}\hat{\sigma}_z + \hat{a}^\dagger\hat{a} + \frac{x}{4\sqrt{\bar{n}}}\hat{\sigma}_x\left(\hat{a}+\hat{a}^\dagger\right)$$

dressing parameters

$$x \equiv \frac{\gamma B_d}{\omega_d} \qquad y \equiv \frac{\gamma B_0}{\omega_d} = \frac{\omega_0}{\omega_d}$$

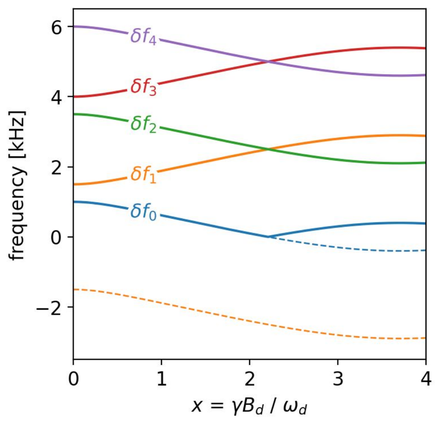
coupling

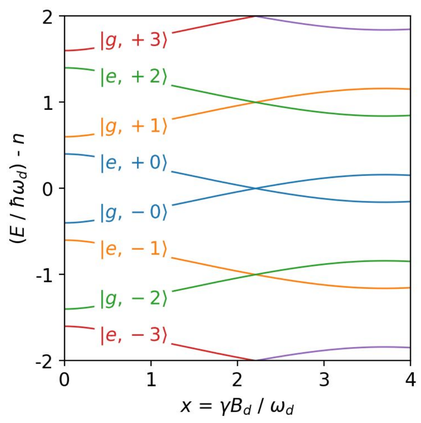
$$\lambda = \frac{\gamma B_d}{2\sqrt{\bar{n}}}$$



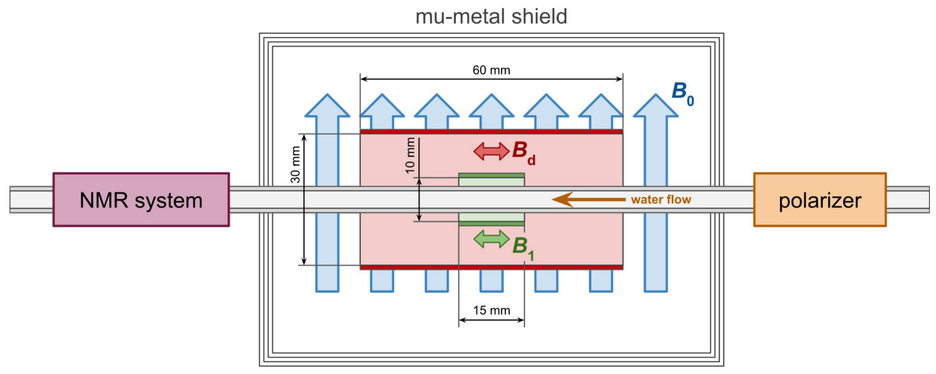
Jaynes-Cummings (10x10)-matrix representation

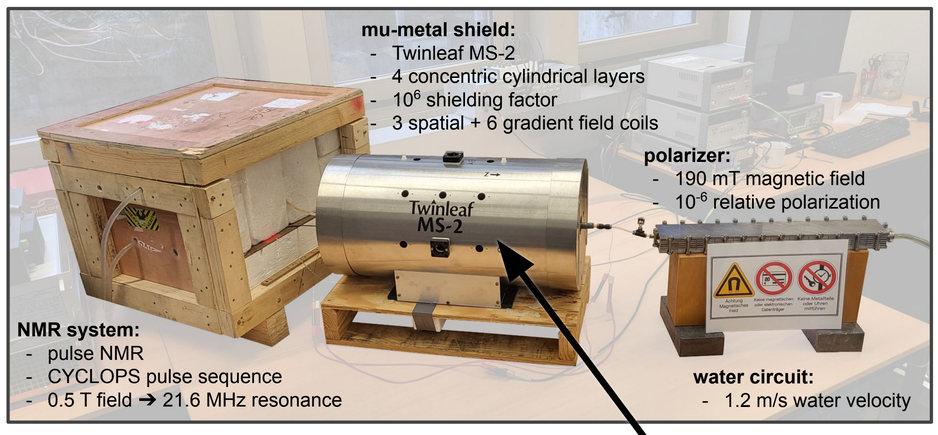
$$\mathcal{H} = \begin{pmatrix}
n+2+\frac{y}{2} & 0 & 0 & \frac{x}{4} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & n+2-\frac{y}{2} & \frac{x}{4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{x}{4} & n+1+\frac{y}{2} & 0 & 0 & \frac{x}{4} & 0 & 0 & 0 & 0 \\
\frac{x}{4} & 0 & 0 & n+1-\frac{y}{2} & \frac{x}{4} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{x}{4} & n+\frac{y}{2} & 0 & 0 & \frac{x}{4} & 0 & 0 \\
0 & 0 & \frac{x}{4} & 0 & 0 & n-\frac{y}{2} & \frac{x}{4} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{x}{4} & n-1+\frac{y}{2} & 0 & 0 & \frac{x}{4} \\
0 & 0 & 0 & 0 & \frac{x}{4} & 0 & 0 & n-1-\frac{y}{2} & \frac{x}{4} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{x}{4} & n-2+\frac{y}{2} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{x}{4} & 0 & 0 & n-2-\frac{y}{2}
\end{pmatrix}$$

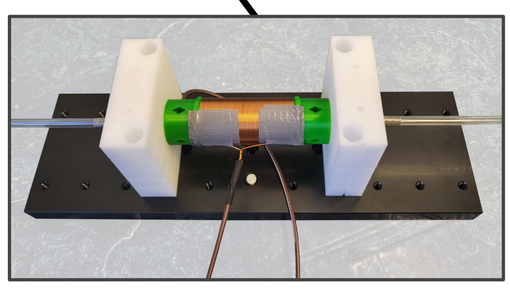




Experimental Setup [2]







spin-flip coil:
- N_1 = 16
- D_1 = 10 mm
- L_1 = 15 mm

dressing coil:
- N_d = 69
- D_d = 30 mm
- L_d = 60 mm

Dressed Spin States of Protons in Water

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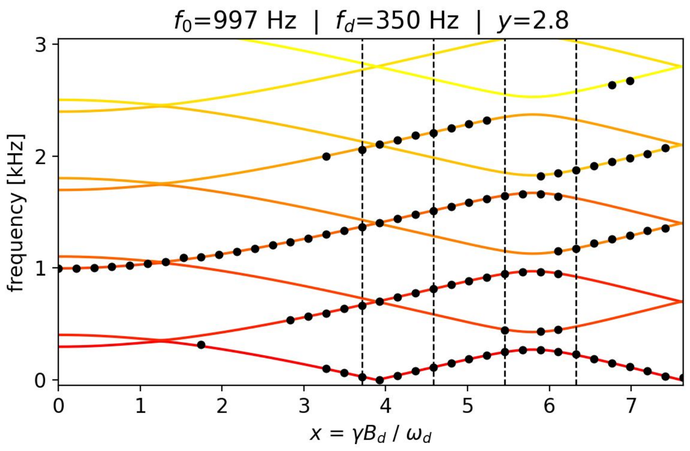
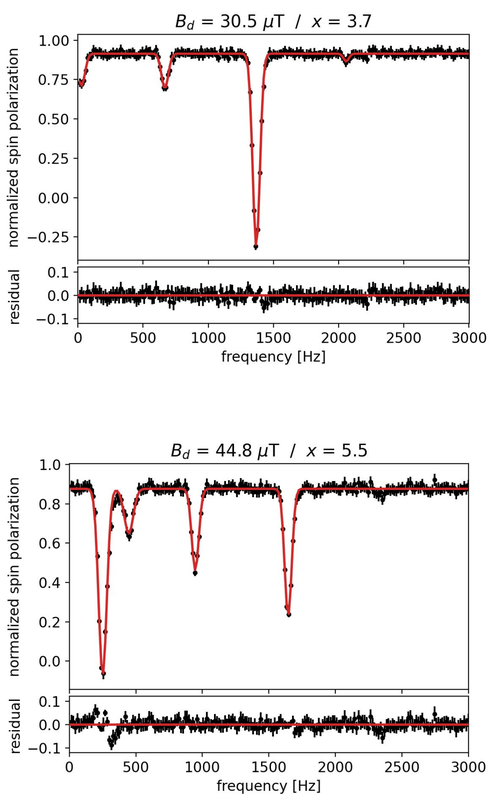
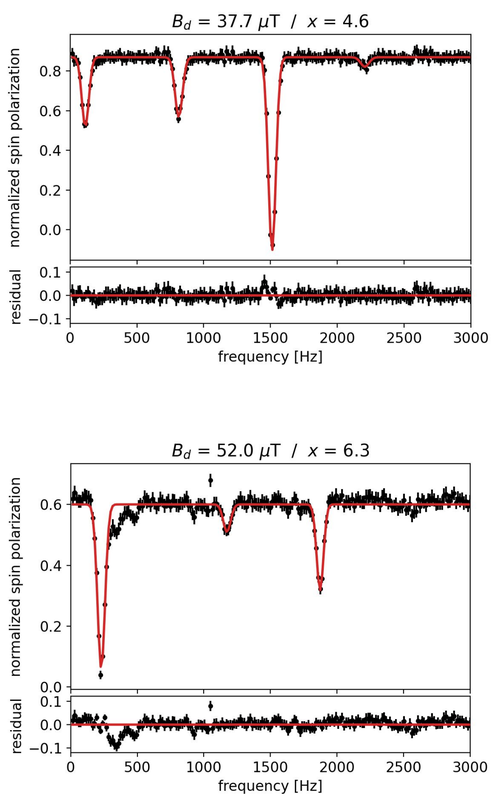
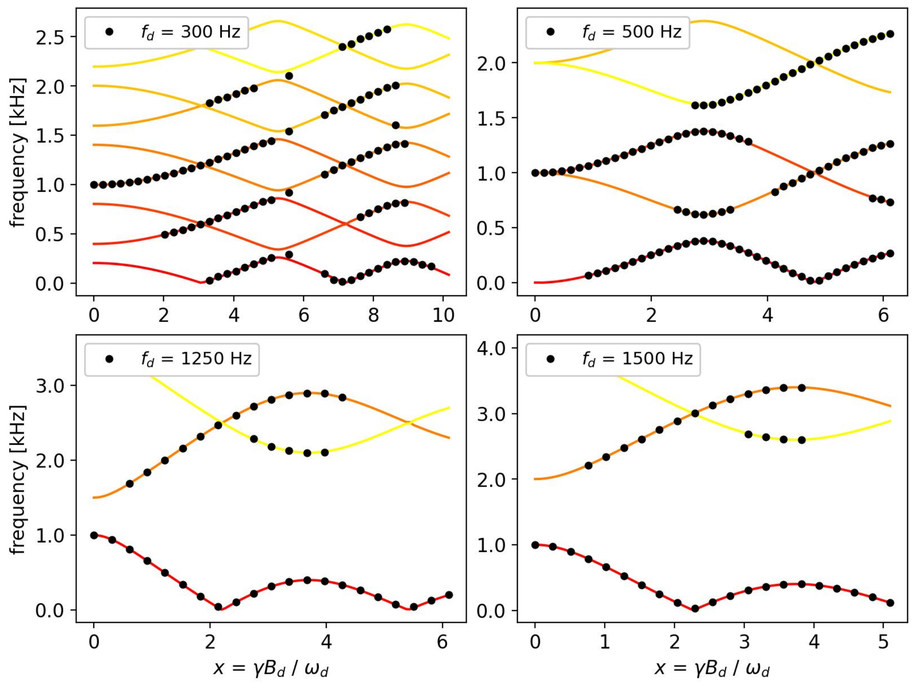
Resonances

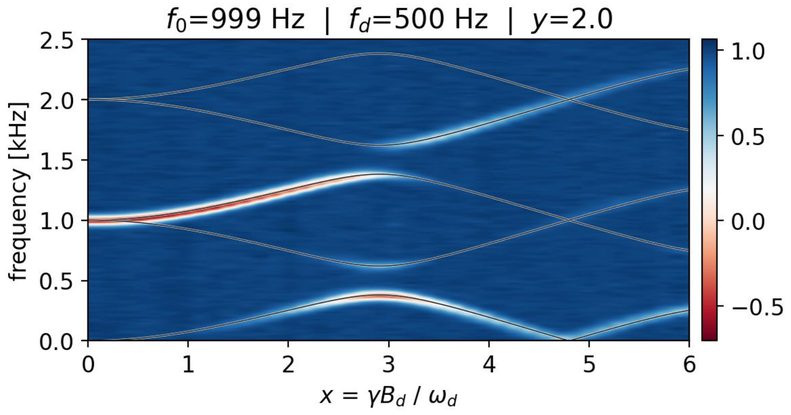






Energy Levels





[1] Jaynes, E. T. & Cummings, F. W.
Comparison of quantum and semiclassical radiation theories with application to the beam maser.
Proc. IEEE **51**, 89–109 (1963).

[2] Schulthess, I. et al.
A Ramsey apparatus for proton spins in flowing water.
J. Magn. Reson. **353**, 107496 (2023).

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