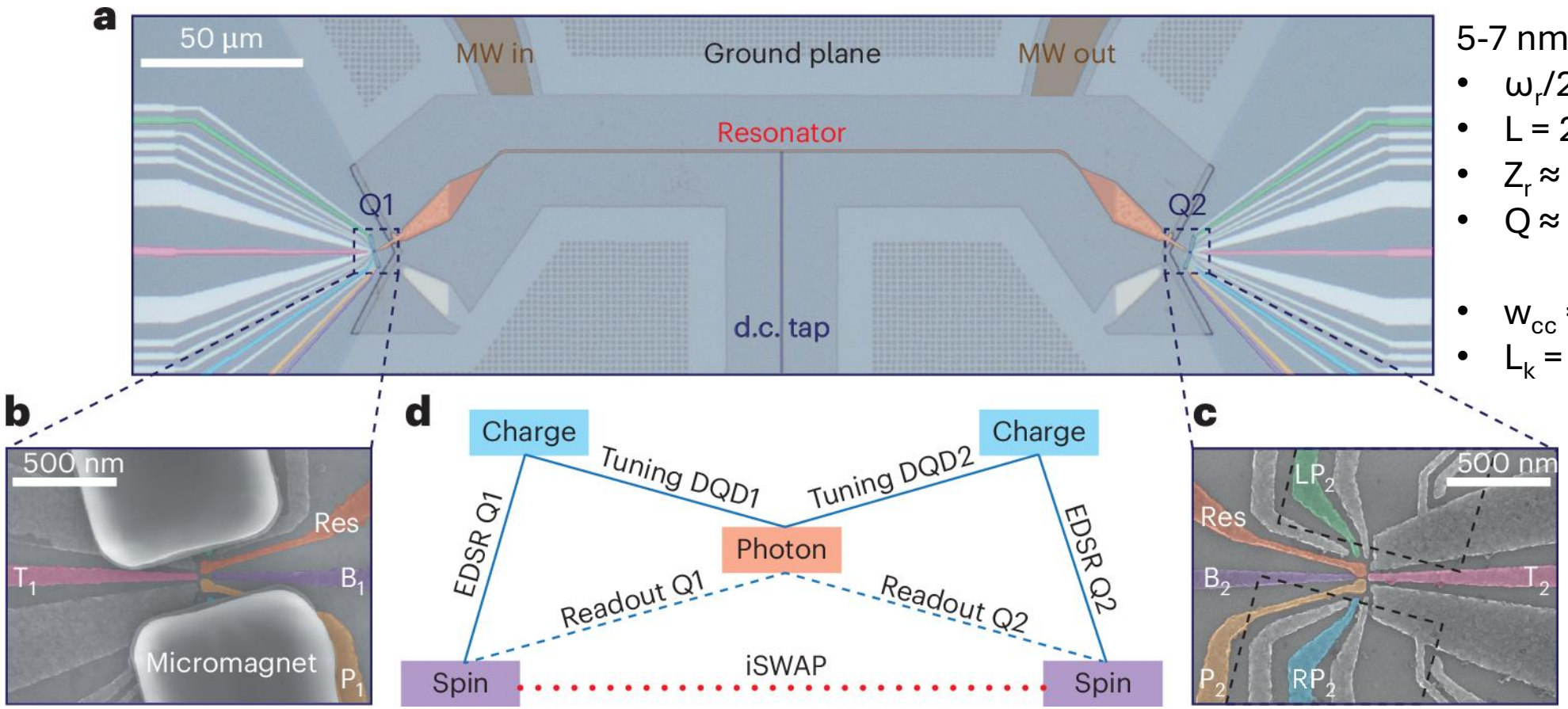
Cavity-mediated iSWAP oscillations between distant spins

By Jurgen Dijkema, Xiao Xue, Patrick Harvey-Collard, Maximilian Rimbach-Russ, Sander L. de Snoo, Guoji Zheng, Amir Sammak, Giordano Scappucci & Lieven M. K. Vandersypen

Presented by Ilja N. Meijer

Dot-resonator-dot device



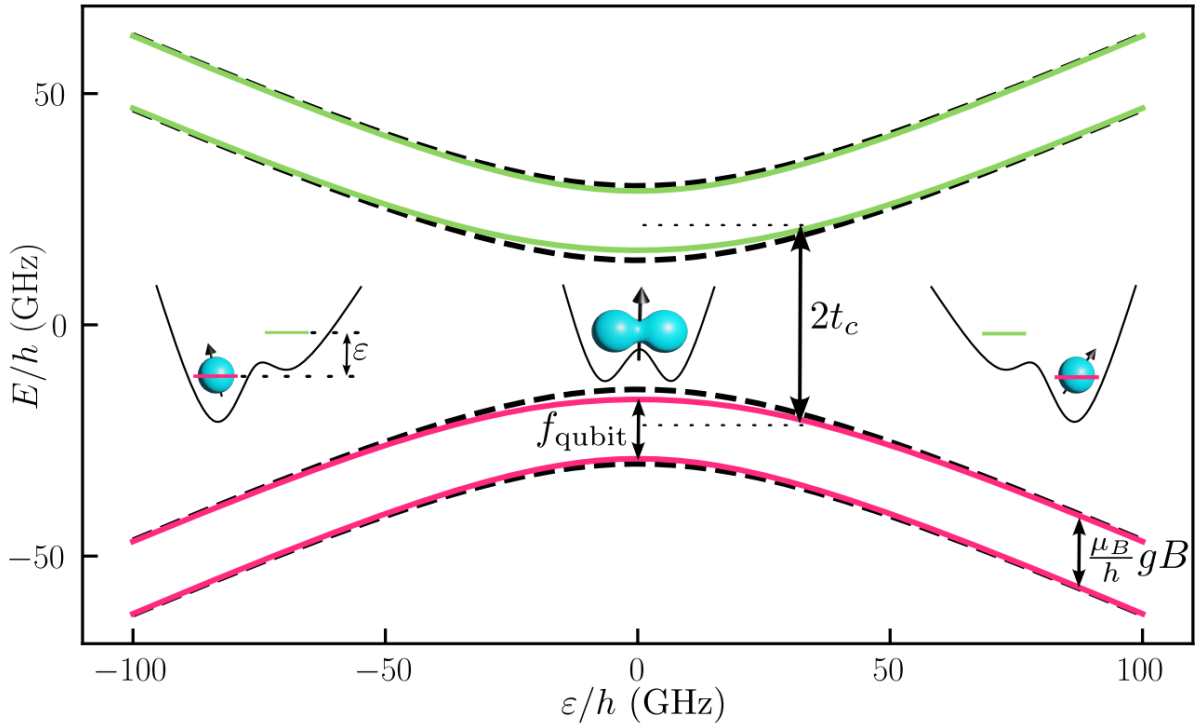
5-7 nm NbTiN resonator:

- $\omega_r/2\pi$ = 6.916 GHz
- L = 250 um
- $Z_r \approx 3.0$ kΩ
- Q ≈ 3800 (undercoupled)

- w_{cc} = 170 nm
- L_k = 140 pH/□

Dijkema, J., Xue, X., Harvey-Collard, P. *et al.* Cavity-mediated iSWAP oscillations between distant spins. *Nat. Phys.* **21**, 168–174 (2025).

Flopping-Mode (FM) Qubits



- Single excess charge in double dot
- Finite magnetic Field
- Large Electric Dipole

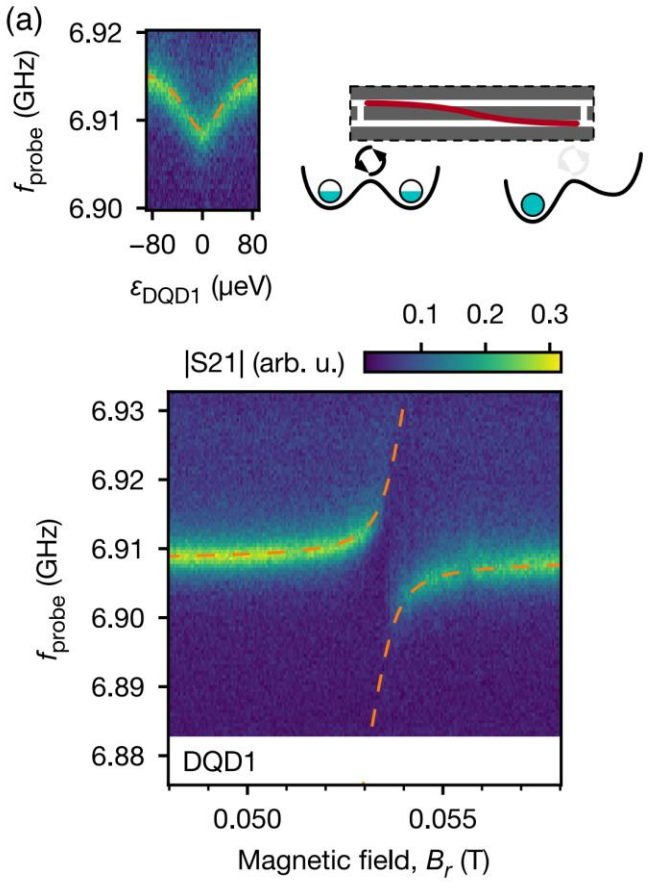
$$2J = g_{s,1} g_{s,2} \left(\frac{1}{\Delta_{2s,1}} + \frac{1}{\Delta_{2s,2}} \right)$$

$$g_s \approx g_c \frac{g_e \mu_B \Delta B_\perp}{4(2t_c - \hbar\omega_r)}$$

With $g_c \propto \alpha_c V_{zpf}$

Noirot, L. et.al. Coherence of a hole spin flopping-mode qubit in a circuit quantum electrodynamics environment. arXiv:2503.10788 (2025).

Resonant spin-photon-spin coupling



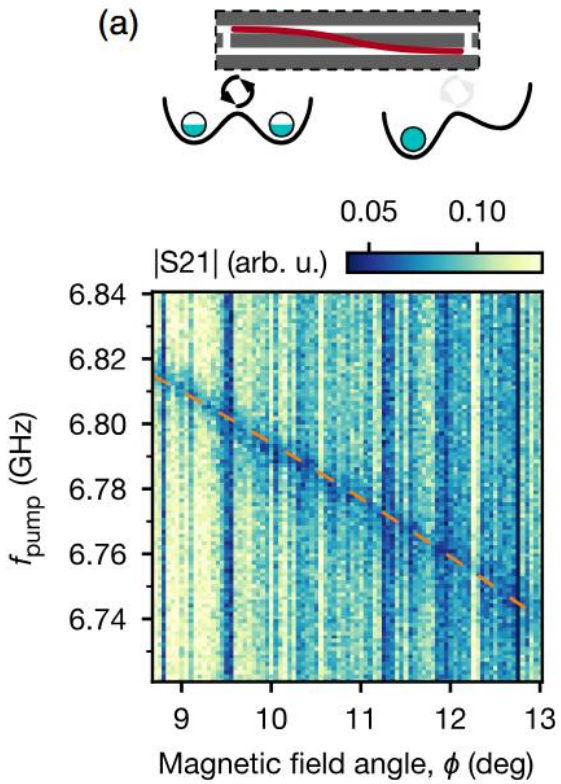
$g_s^1/2\pi = 11.8$ MHz
$g_s^2/2\pi = 11.0$ MHz

$g_s^{12}/2\pi = 16.2$ MHz

$\Gamma_s/2\pi < 6$ MHz

Harvey-Collard, P., Dijkema, J. *et al.* Coherent Spin-Spin Coupling Mediated by Virtual Microwave Photons. Phys. Rev. X 12, 021026 (2022)

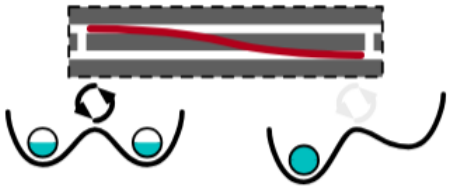
Spin-spin coupling via virtual photons

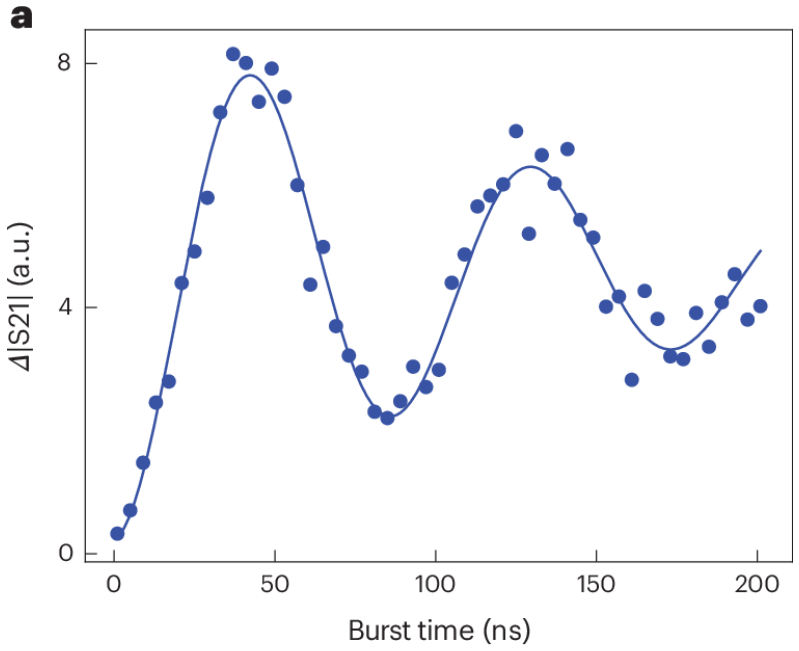


$2J/2\pi$ =19.0 MHz

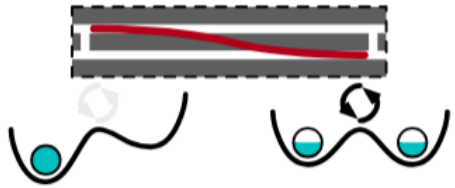
Harvey-Collard, P., Dijkema, J. *et al.* Coherent Spin-Spin Coupling Mediated by Virtual Microwave Photons. Phys. Rev. X 12, 021026 (2022)

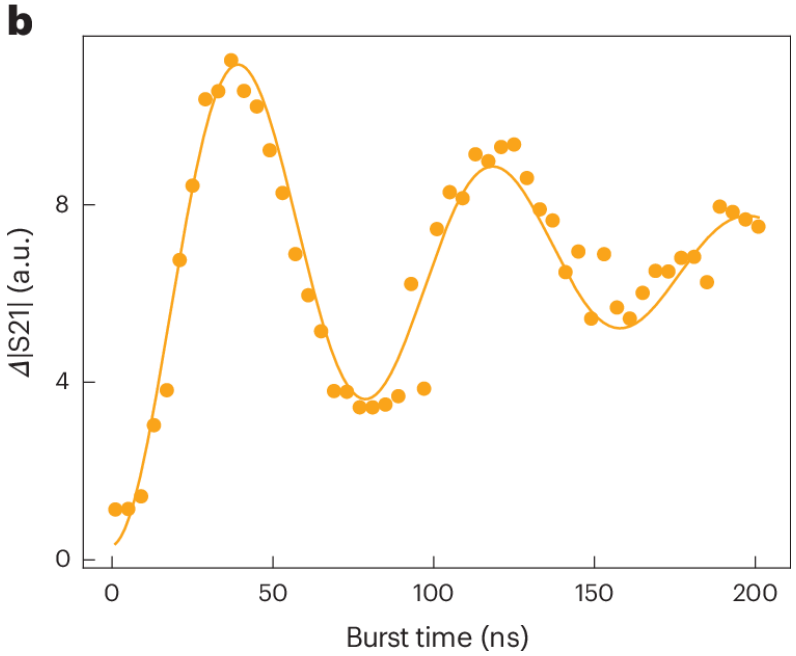
Rabi oscillations in flopping mode





T_2^{Rabi}: 100 ns, T_2^* : 60-80 ns, T_1: 200-260 ns

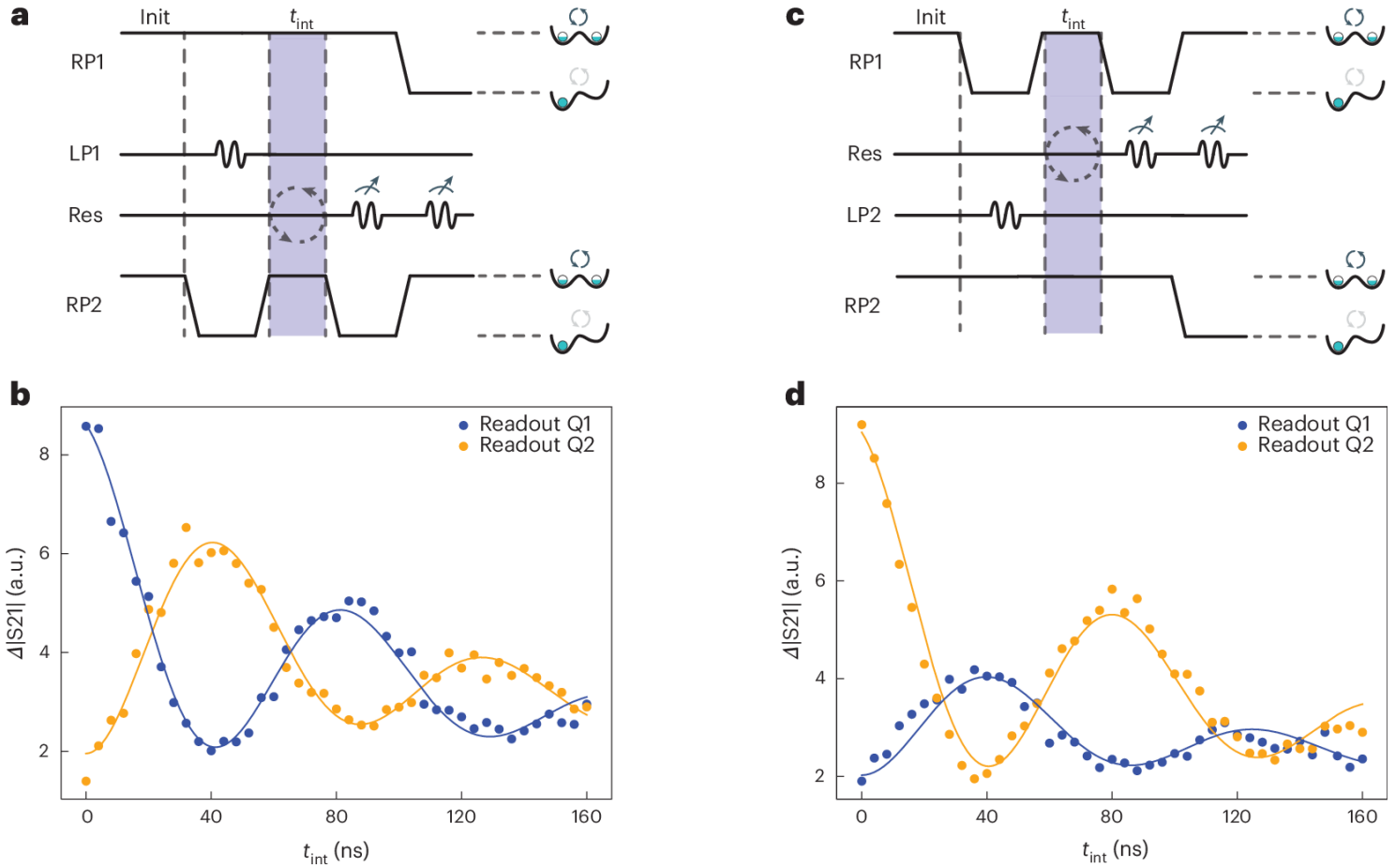




T_2^{Rabi} : 120 ns , T_2^* : 40-60 ns, T_1: 100-130 ns

Dijkema, J., Xue, X., Harvey-Collard, P. *et al.* Cavity-mediated iSWAP oscillations between distant spins. *Nat. Phys.* **21**, 168–174 (2025).

iSWAP oscillations between two distant spin qubits.



$2J/2\pi = 11.6 \pm 0.2$ MHz
Coupling time = 21 ns
$F_{entangle} = 83.1\%$

Asymmetric damping:

- Different T_1
- Different dispersive shift

Dijkema, J., Xue, X., Harvey-Collard, P. *et al.* Cavity-mediated iSWAP oscillations between distant spins. *Nat. Phys.* **21**, 168–174 (2025).

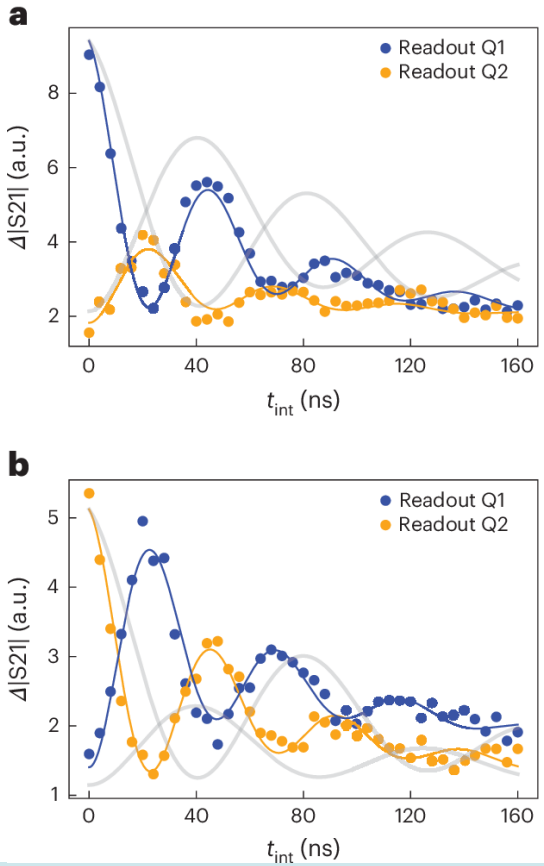
Control of iSWAP oscillations

$$2J = g_{s,1} g_{s,2} \left(\frac{1}{\Delta_{2s,1}} + \frac{1}{\Delta_{2s,2}} \right)$$

$$g_s \approx g_c \frac{g_e \mu_B \Delta B_\perp}{4(2t_c - \hbar\omega_r)}$$

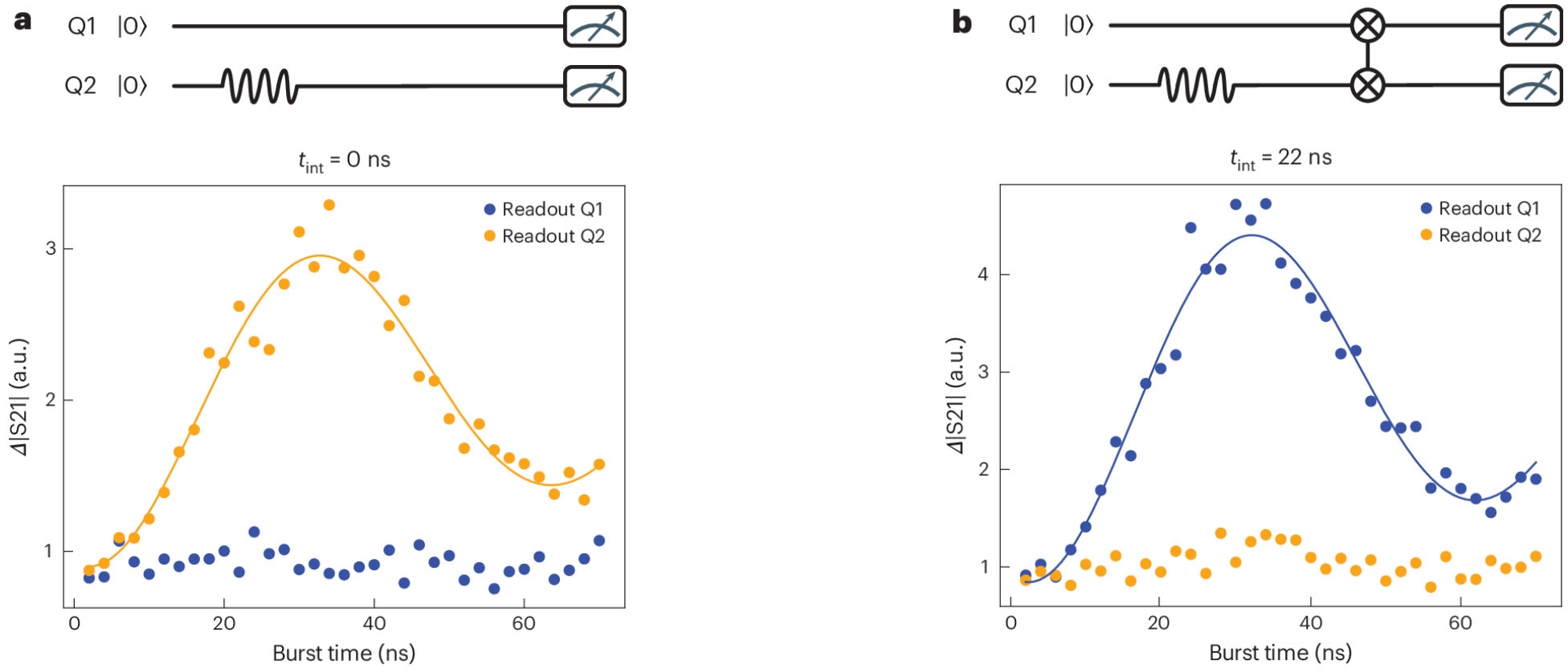
Decrease t_c:

$2J/2\pi$ = 21.4 MHz



Dijkema, J., Xue, X., Harvey-Collard, P. *et al.* Cavity-mediated iSWAP oscillations between distant spins. *Nat. Phys.* **21**, 168–174 (2025).

Swapped Rabi-cycle experiment



Dijkema, J., Xue, X., Harvey-Collard, P. *et al.* Cavity-mediated iSWAP oscillations between distant spins. *Nat. Phys.* **21**, 168–174 (2025).

Conclusion

- Achieved coherent Spin-Spin Coupling without real photons
- Observation and control of iSWAP oscillations between distant spin qubits