Dissipative Control of Chirality in Quantum Spin Systems

Young Research Leaders Group Workshop:

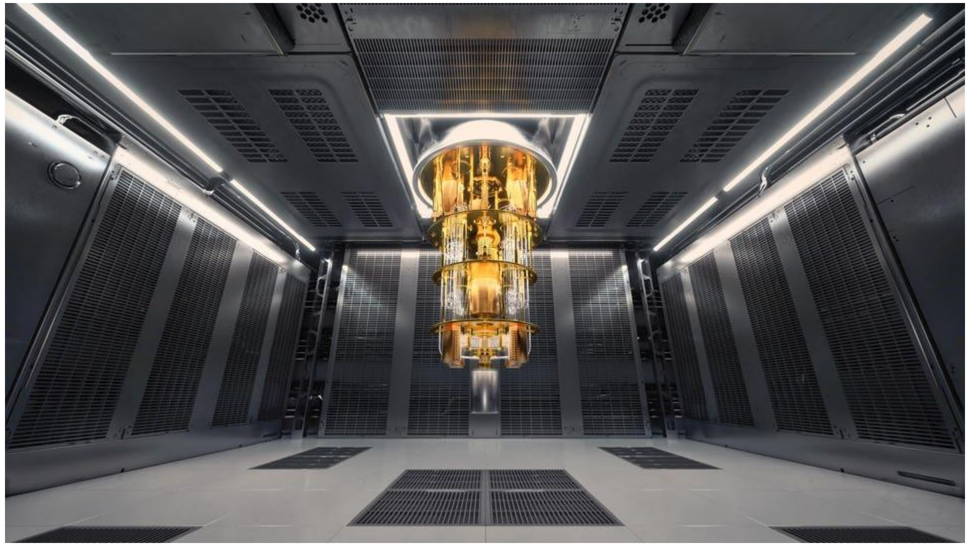
Transport and transfer of angular momentum: magnons, chiral phonons and beyond

11.06.2026

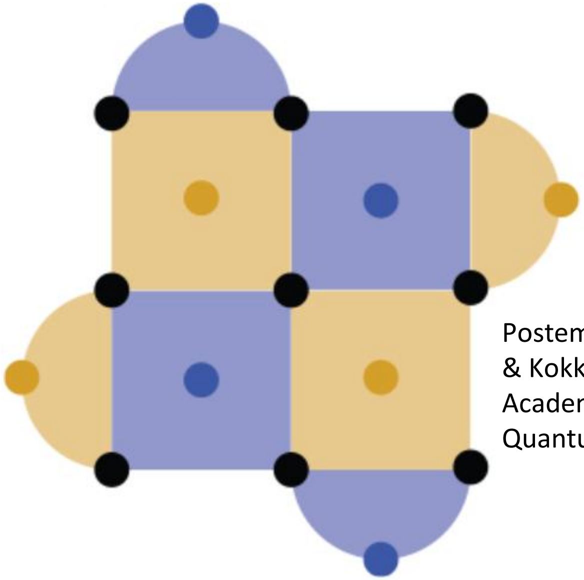
Even Thingstad

Zou, Bosco, Thingstad, Klinovaja & Loss, PRL 132 (2024)
Driessen, Zou, Thingstad, Klinovaja & Loss, arXiv: 2506.20466 (2025)

Quantum computation



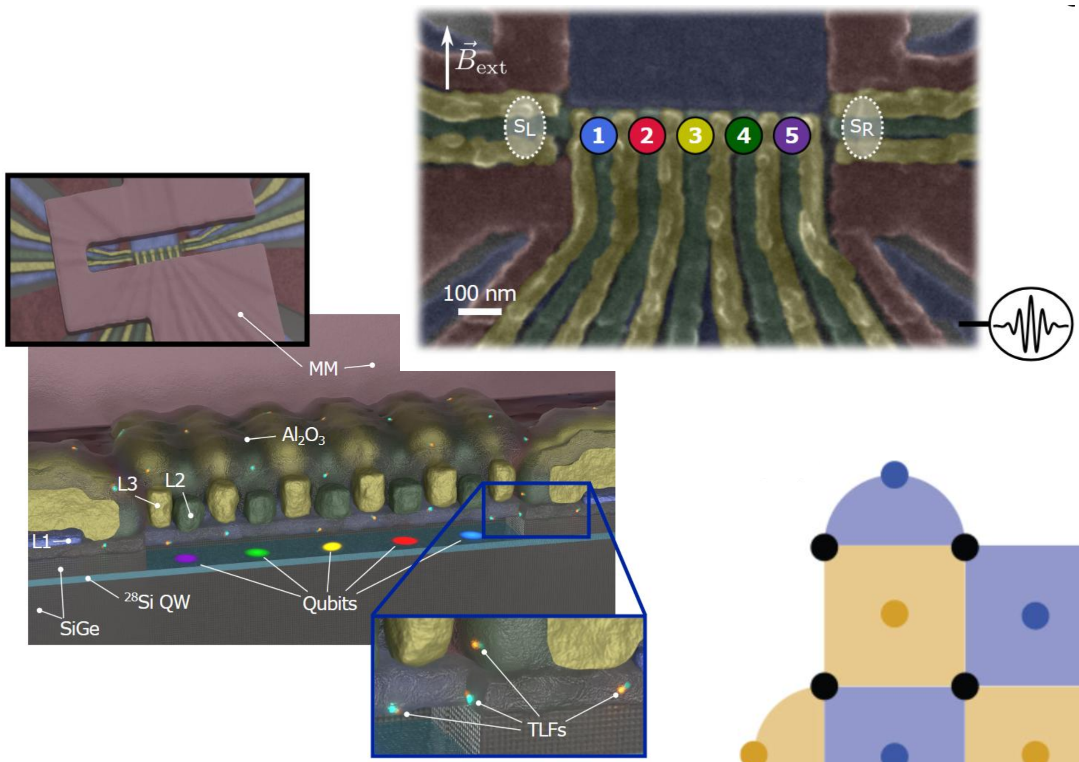
IBM

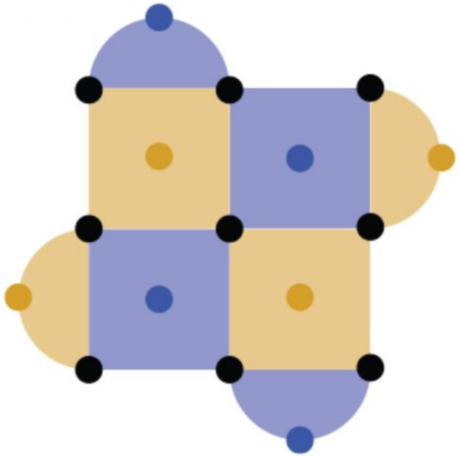


Postema & Kokkelmans, Academia Quantum (2024)

Rotated surface code

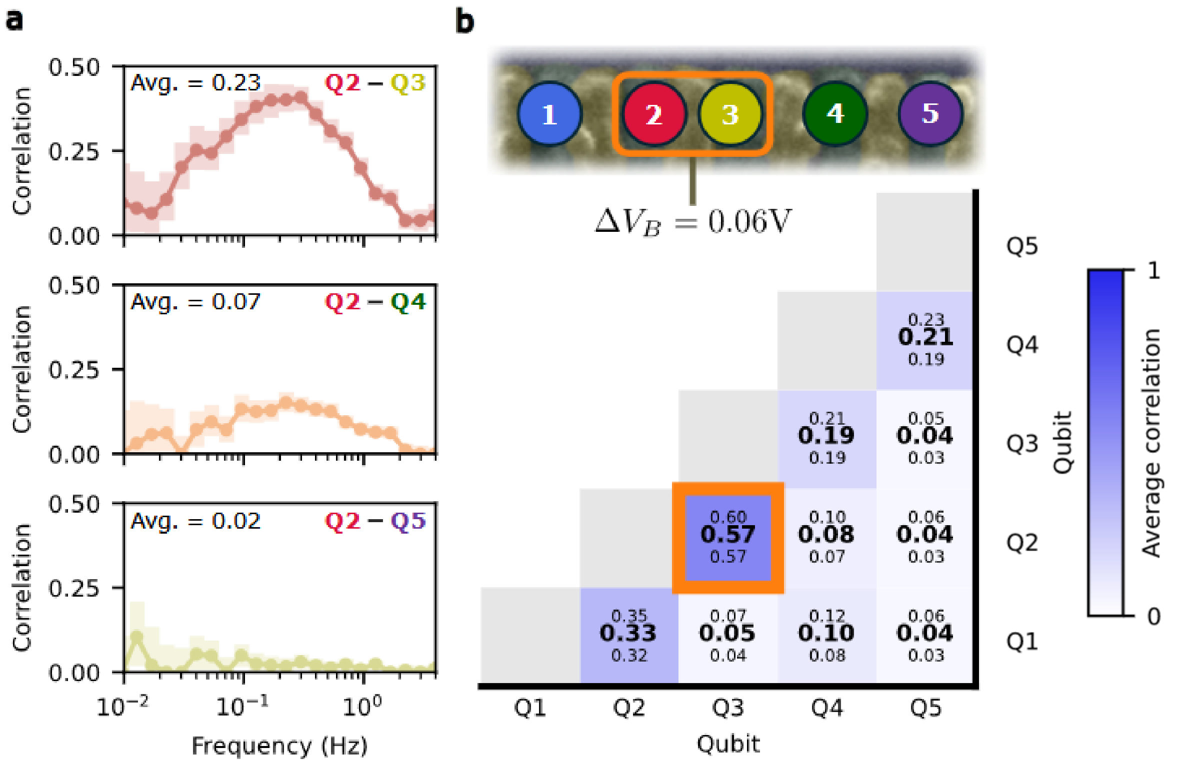
Spatially correlated noise



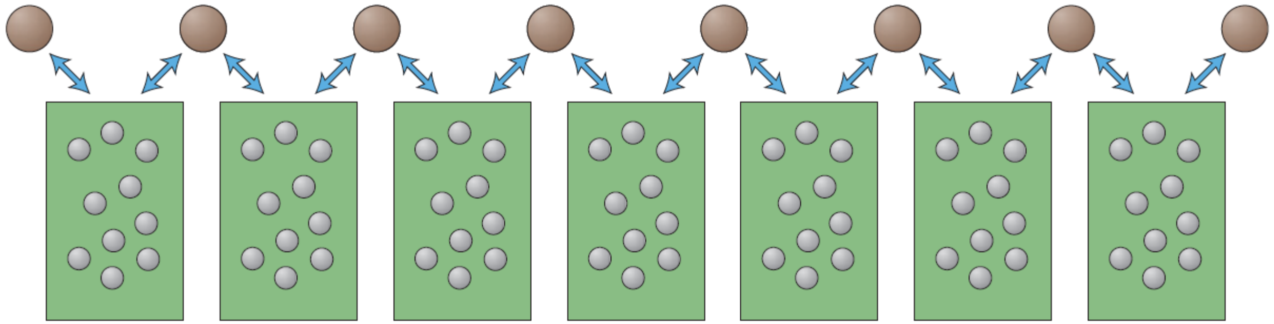


Postema & Kokkelmans,
Academia Quantum (2024)

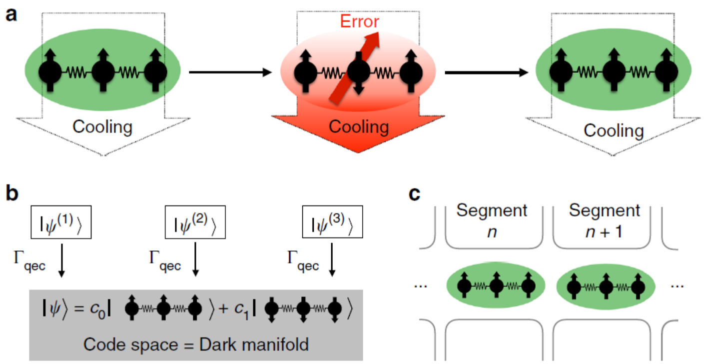
Rojas-Arias *et al.*, arXiv:2603.03051 (2026)



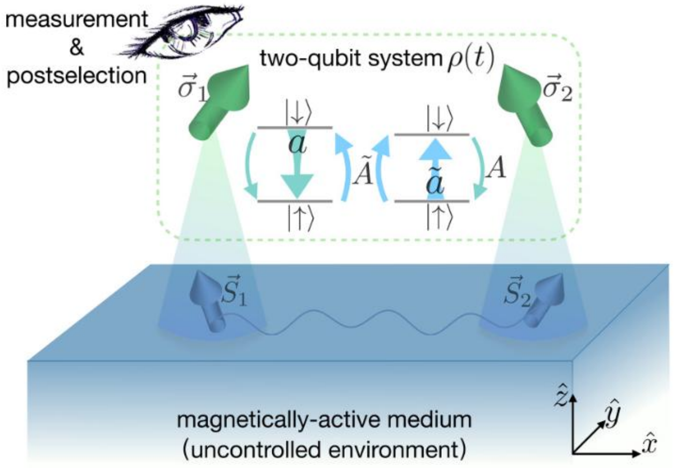
Can dissipation be used as a resource?



Verstraete *et al.*, Nat. Phys. (2009)

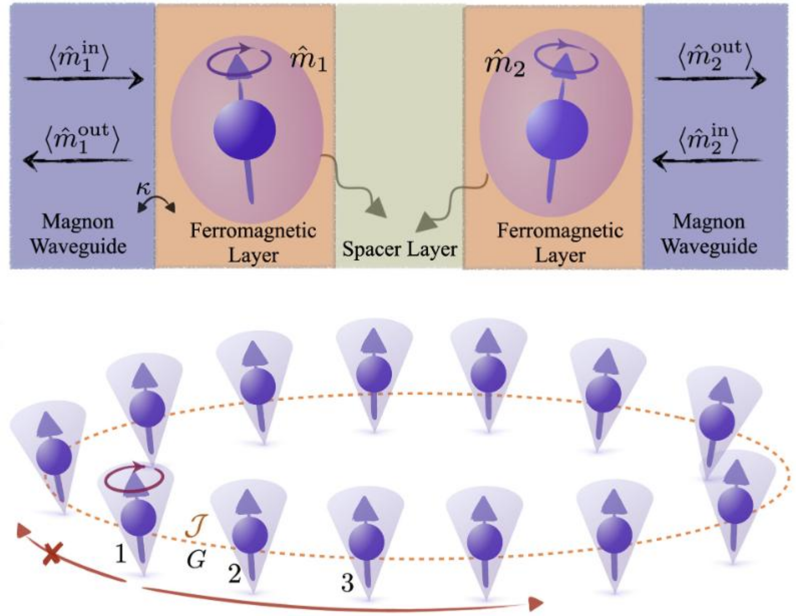


Reiter *et al.*, Nat. Comm. (2017)

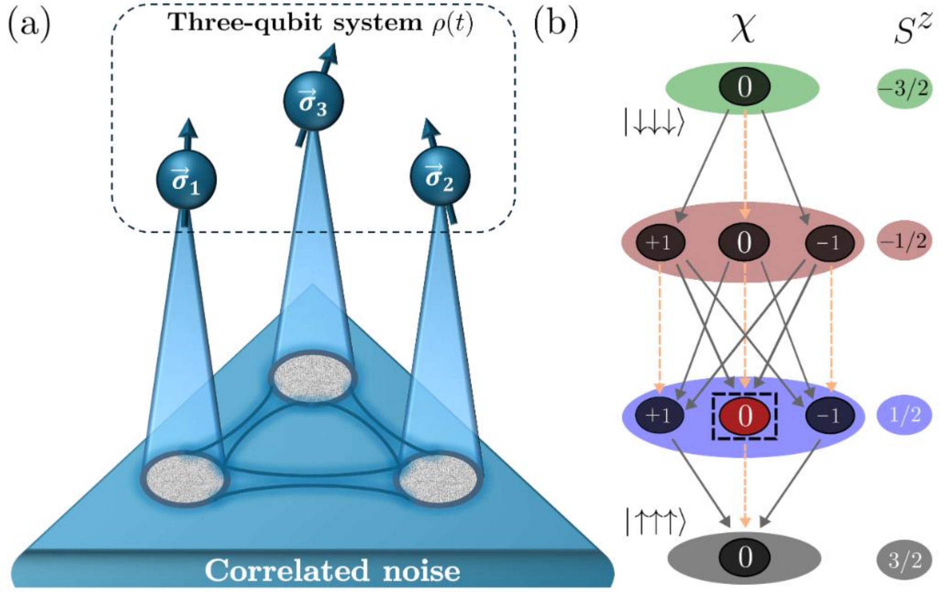


Zou *et al.*, PRB 106 (2022)

- Preparing quantum states
- Memory stabilization
- Error correction



Dissipative Spin-Wave Diode and Nonreciprocal Magnonic Amplifier
Zou, Bosco, Thingstad, Klinovaja & Loss, PRL 132 (2024)



Robust Tripartite Entanglement Generation via Correlated Noise in Spin Qubits
Driessen, Zou, Thingstad, Klinovaja & Loss, arXiv:2506.20466 (2025)

Spin-wave diode

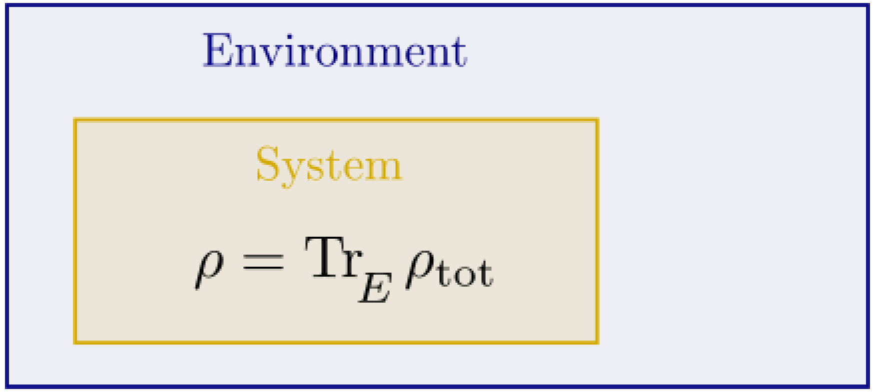
Entanglement generation

Theoretical framework: Lindblad master equation

$$H = H_S + H_E + H_{\mathrm{SE}}$$

$$H_S = -\frac{\Delta}{2}\sum_{i=1}^{3}\sigma_i^z$$

$$H_{\mathrm{SE}} = \lambda\sum_{i=1}^{3}(\sigma_i^+ \otimes E_i^- + \sigma_i^- \otimes E_i^+)$$

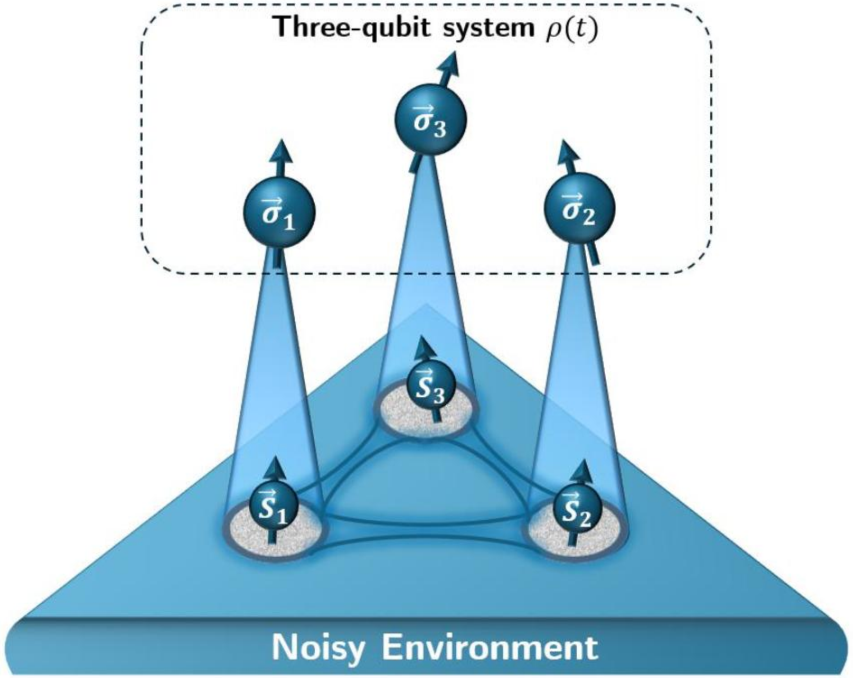


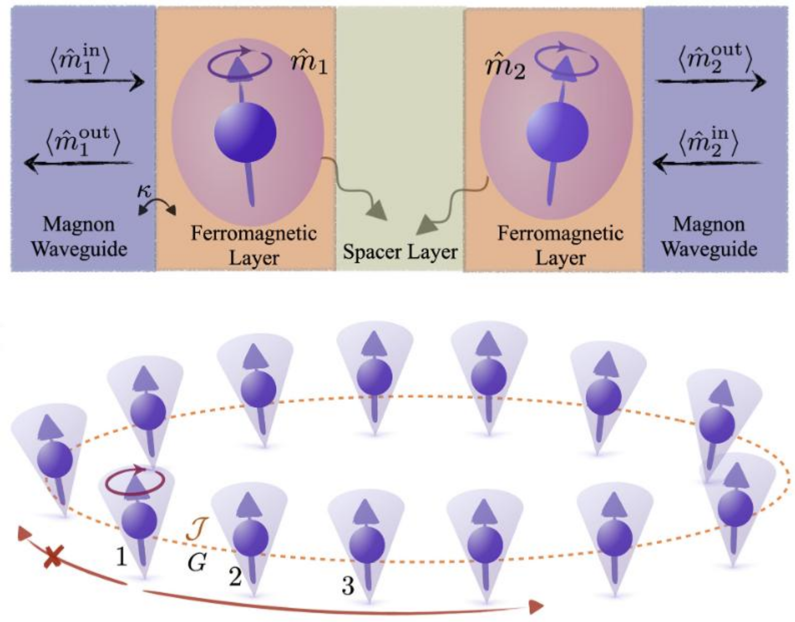
ρ_{tot}

$$\frac{d\rho_{\mathrm{tot}}}{dt} = -i[H_S + H_E + H_{SE}, \rho]$$

$$\Downarrow \quad \tau_E \ll \tau_S$$

$$\frac{d\rho}{dt} = -i[H_S + H_{\mathrm{eff}}, \rho] + \sum_{\mu}\gamma_\mu\left(L_\mu \rho L_\mu^\dagger - \frac{1}{2}\{L_\mu^\dagger L_\mu, \rho\}\right)$$

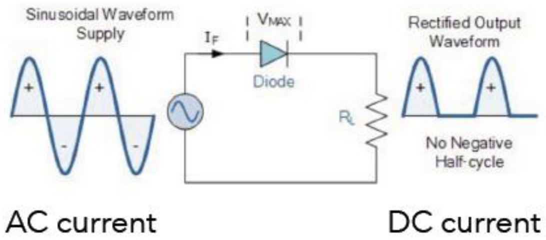




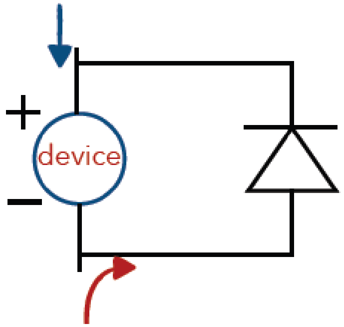
Dissipative Spin-Wave Diode and Nonreciprocal Magnonic Amplifier
Zou, Bosco, Thingstad, Klinovaja & Loss, PRL 132 (2024)

Spin-wave diode

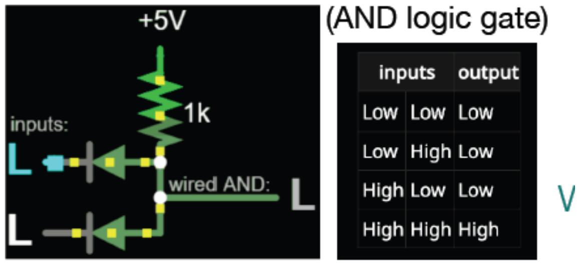
Diodes



Rectifier

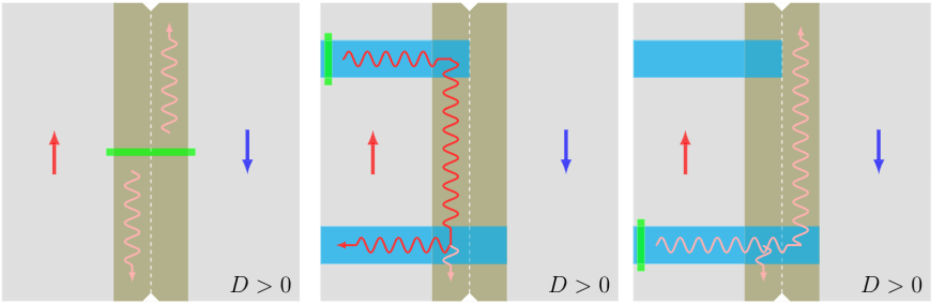


Circuit protection



Logic gates

Lan *et al.*, PRX (2015)

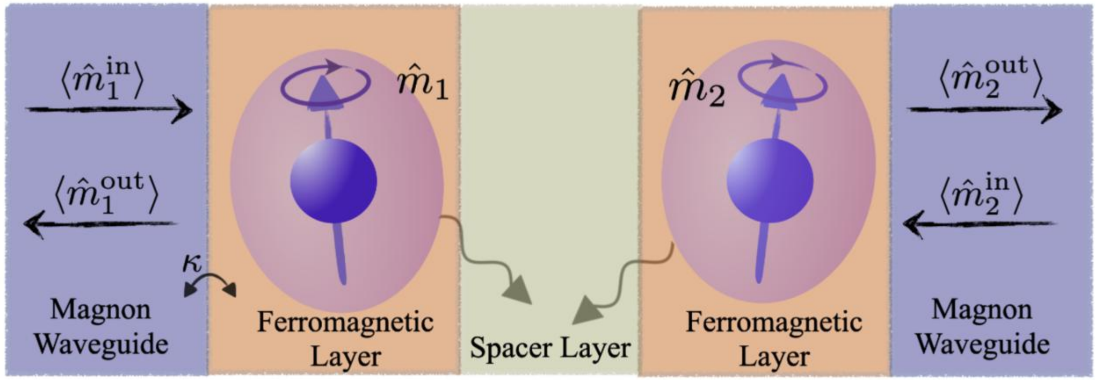


(b) Domain wall with DMI (c) Diode - forward direction (d) Diode - reverse direction

Spin wave diode?

Model system

$$\hat{H} = \hat{H}_M + \hat{H}_E + \hat{H}_{ME} \qquad \hat{H}_M = \hbar\Omega \sum_{i=1}^{2} \hat{m}_i^\dagger \hat{m}_i \qquad \hat{H}_{ME} = \sum_{i=1}^{2} \left(\hat{m}_i^\dagger \hat{E}_i^- + \hat{m}_i \hat{E}_i^+ \right)$$



$$\frac{\mathrm{d}}{\mathrm{d}t}\hat{\rho} = -\frac{i}{\hbar}[\hat{H}_M + \hat{H}_C, \hat{\rho}] + \sum_{k,j=1,2} \mathcal{L}_{kj}^{\downarrow}\hat{\rho},$$

$$\hat{H}_C = J\hat{m}_1^\dagger \hat{m}_2 + J^* \hat{m}_2^\dagger \hat{m}_1$$

$$\mathcal{L}_{kj}^{\downarrow}\hat{\rho} = \gamma_{kj}^{\downarrow}\left[\hat{m}_j \hat{\rho} \hat{m}_k^\dagger - \frac{1}{2}\left\{\hat{m}_k^\dagger \hat{m}_j, \hat{\rho}\right\}\right]$$

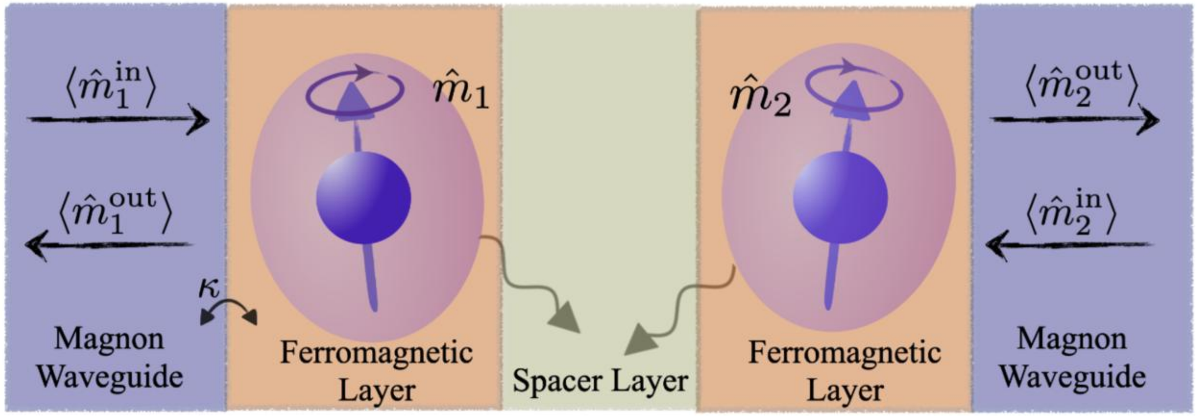
$$J = -\frac{i}{2\hbar}\int_{-\infty}^{\infty} dt\, e^{i\Omega t}\,\mathrm{sgn}(t)\left\langle \left[\hat{E}_1^-(t), \hat{E}_2^+\right]\right\rangle \qquad \gamma_{ij}^{\downarrow} = \frac{1}{\hbar^2}\int_{-\infty}^{\infty} dt\, e^{i\Omega t}\left\langle \hat{E}_i^-(t)\hat{E}_j^+\right\rangle$$

$$\hat{H}_C = J\hat{m}_1^\dagger \hat{m}_2 + J^* \hat{m}_2^\dagger \hat{m}_1$$

Spin-wave diode

$$\langle \hat{m}_i \rangle = \frac{1}{\sqrt{2S}} \left\langle \hat{S}_i^x - i\hat{S}_i^y \right\rangle$$

$$i\frac{d}{dt}\begin{pmatrix} \langle \hat{m}_1 \rangle \\ \langle \hat{m}_2 \rangle \end{pmatrix} = \begin{pmatrix} \Omega - i\gamma/2 & J/\hbar \cancel{- iG^*}/2 \\ J^*/\hbar - iG/2 & \Omega - i\gamma/2 \end{pmatrix} \begin{pmatrix} \langle \hat{m}_1 \rangle \\ \langle \hat{m}_2 \rangle \end{pmatrix}$$



$$\begin{pmatrix} \gamma_{11}^{\downarrow} & \gamma_{12}^{\downarrow} \\ \gamma_{21}^{\downarrow} & \gamma_{22}^{\downarrow} \end{pmatrix} = \begin{pmatrix} \gamma & G^* \\ G & \gamma \end{pmatrix}$$

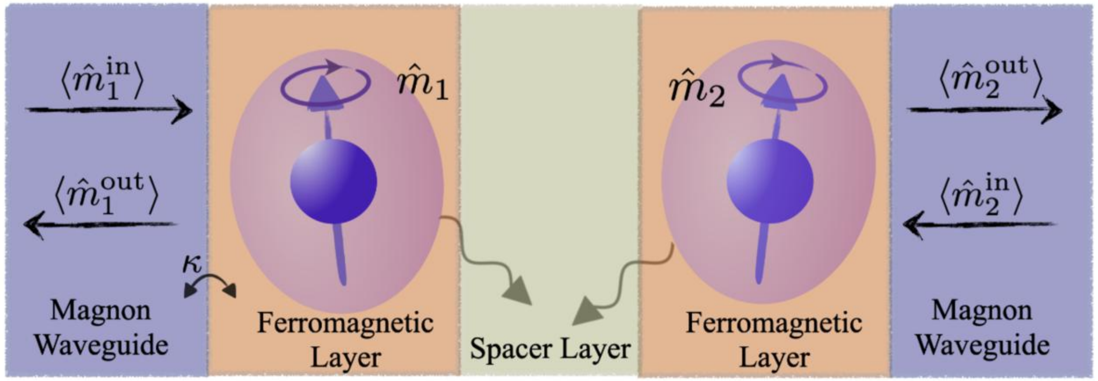
$$J/\hbar = iG^*/2$$

Diode condition

$$J = |J|e^{i\Phi} = J_{\text{exch}} + iJ_{\text{DMI}}$$

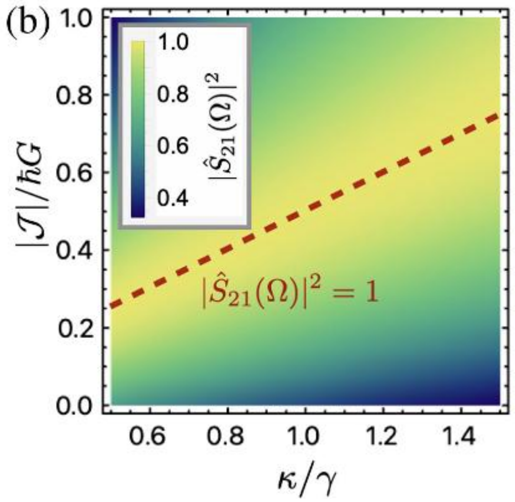
Spin-wave diode

$$\begin{pmatrix} \langle \hat{m}_{1,\mathrm{out}} \rangle \\ \langle \hat{m}_{2,\mathrm{out}} \rangle \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} \langle \hat{m}_{1,\mathrm{in}} \rangle \\ \langle \hat{m}_{2,\mathrm{in}} \rangle \end{pmatrix}$$

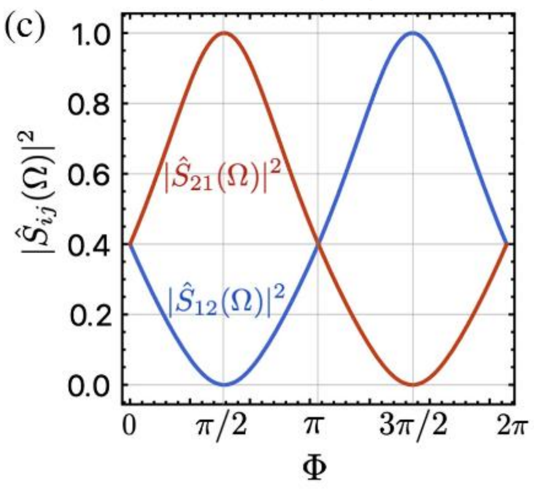


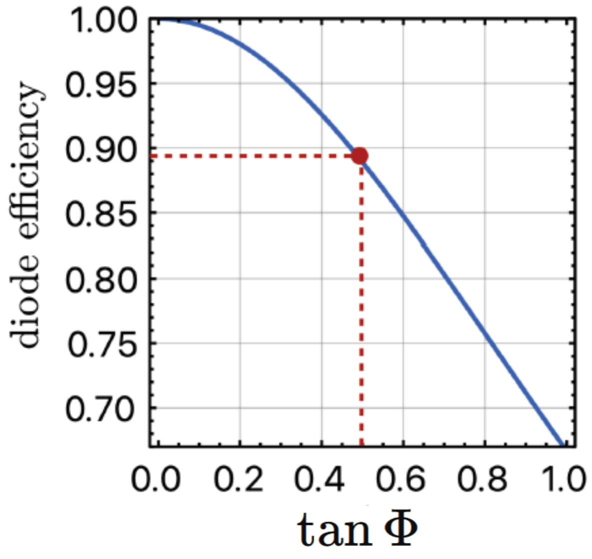
$$S(\Omega) = 1 - i\kappa(\Omega - \mathcal{H})^{-1} = \begin{pmatrix} \frac{\gamma-\kappa}{\gamma+\kappa} & 0 \\ \frac{4\kappa G}{(\gamma+\kappa)^2} & \frac{\gamma-\kappa}{\gamma+\kappa} \end{pmatrix}$$

$$J/\hbar = iG^*/2$$



$J = |\mathcal{J}|e^{i\Phi}$



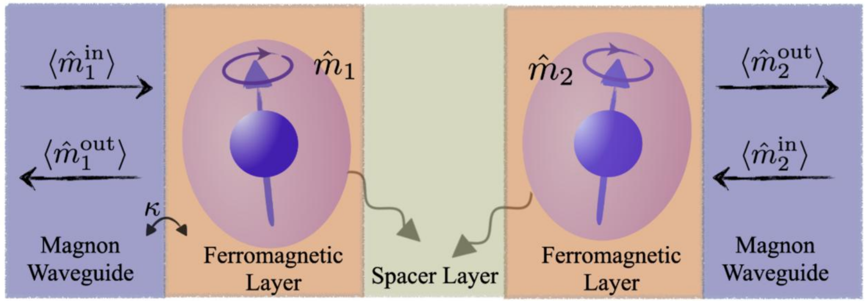


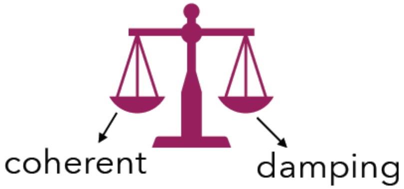
diode efficiency:

$$\frac{|S_{21}|^2 - |S_{12}|^2}{|S_{21}|^2 + |S_{12}|^2}$$

Only DMI

DMI = Exch.

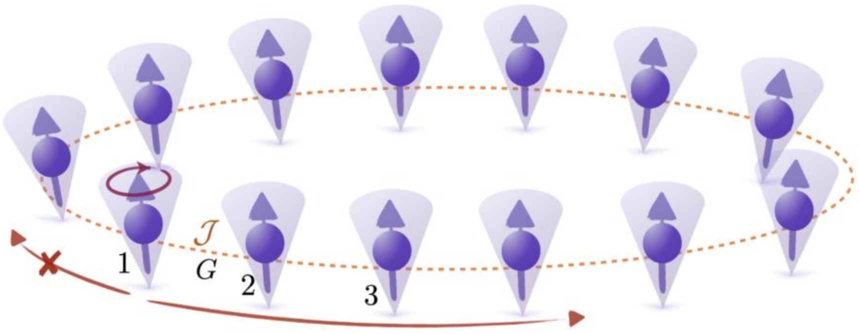




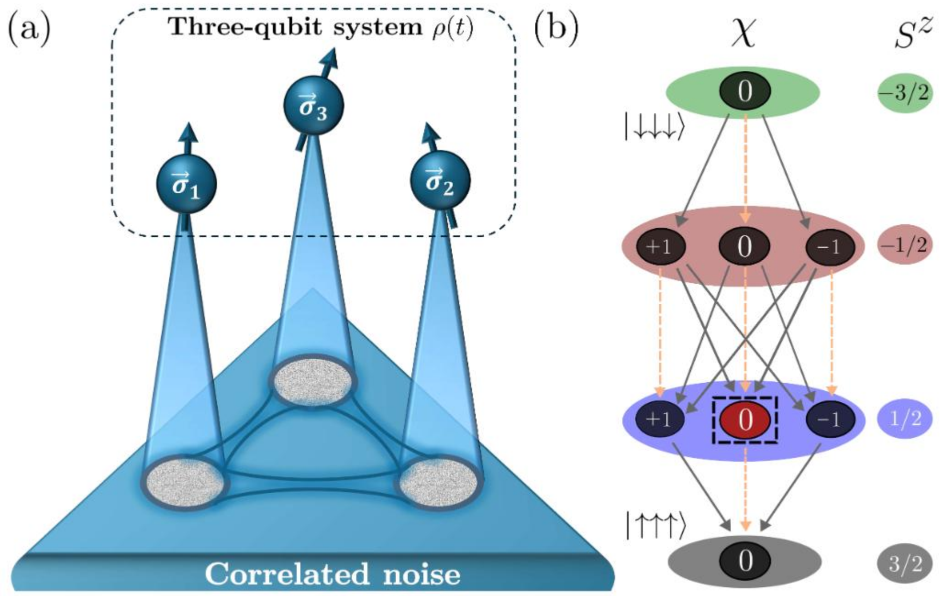
+

DMI > Exchange

$$J/\hbar = iG^*/2$$



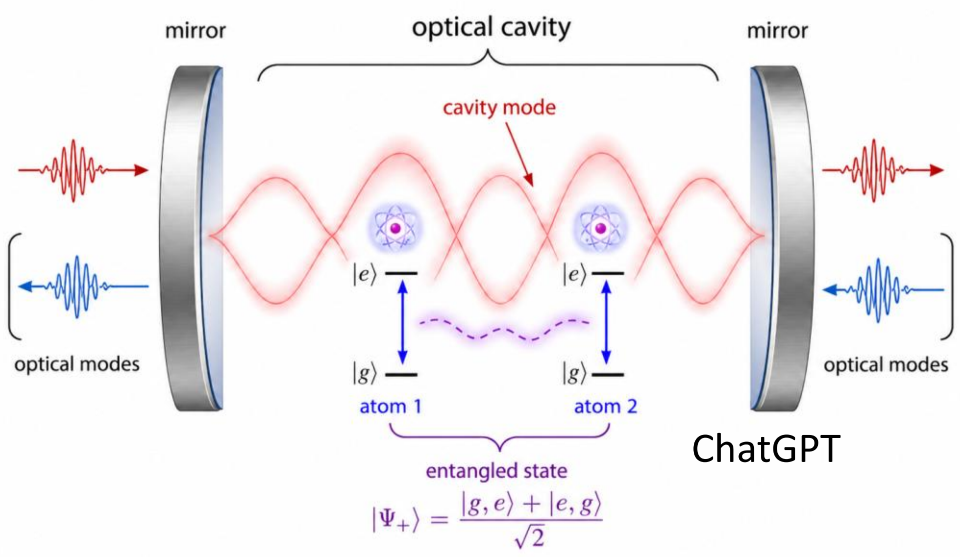
Spin wave diode!



Robust Tripartite Entanglement Generation via Correlated Noise in Spin Qubits
Driessen, Zou, Thingstad, Klinovaja & Loss, arXiv:2506.20466 (2025)

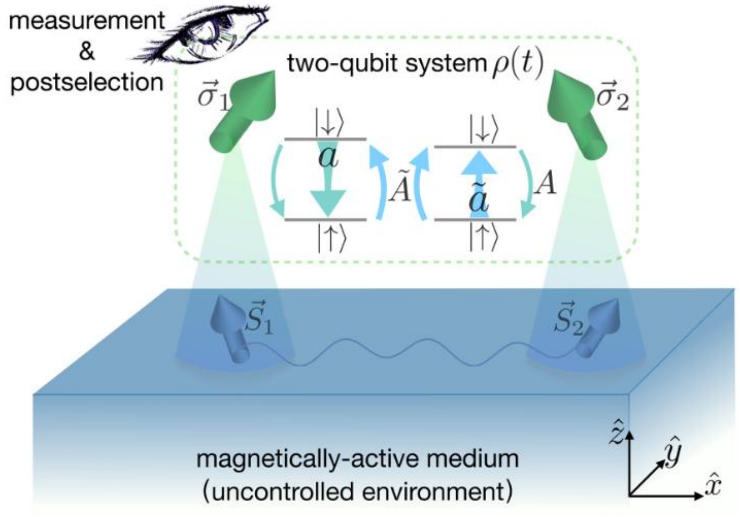
Entanglement generation

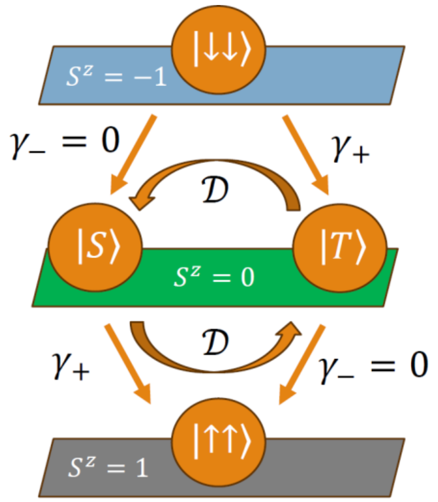
Two qubits



ChatGPT

Kastoryano *et al.*, PRL 106 (2011)





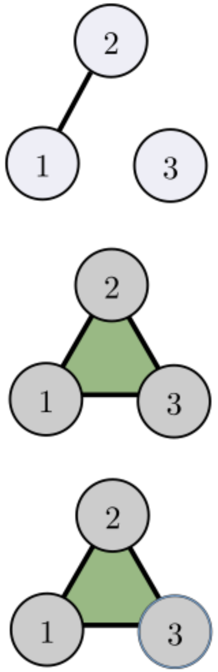
Zou *et al.*, PRB 106 (2022)

Multipartite entanglement

$$|\psi_{\text{bisep}}\rangle = \frac{1}{\sqrt{2}}(|\uparrow\uparrow\downarrow\rangle + |\downarrow\downarrow\downarrow\rangle)$$

$$|GHZ\rangle = \frac{1}{\sqrt{2}}(|\uparrow\uparrow\uparrow\rangle + |\downarrow\downarrow\downarrow\rangle)$$

$$|W_3\rangle = \frac{1}{\sqrt{3}}(|\uparrow\downarrow\downarrow\rangle + |\downarrow\uparrow\downarrow\rangle + |\downarrow\downarrow\uparrow\rangle)$$



Eigenvalues of ρ^{T_j}

$$\mathcal{N}_{123} = \sqrt[3]{\mathcal{N}_{[1]23}\mathcal{N}_{1[2]3}\mathcal{N}_{12[3]}} \qquad \mathcal{N}_{[j]kl} = 2\sum_i |\min\{0, \lambda_i^{T_j}\}|$$

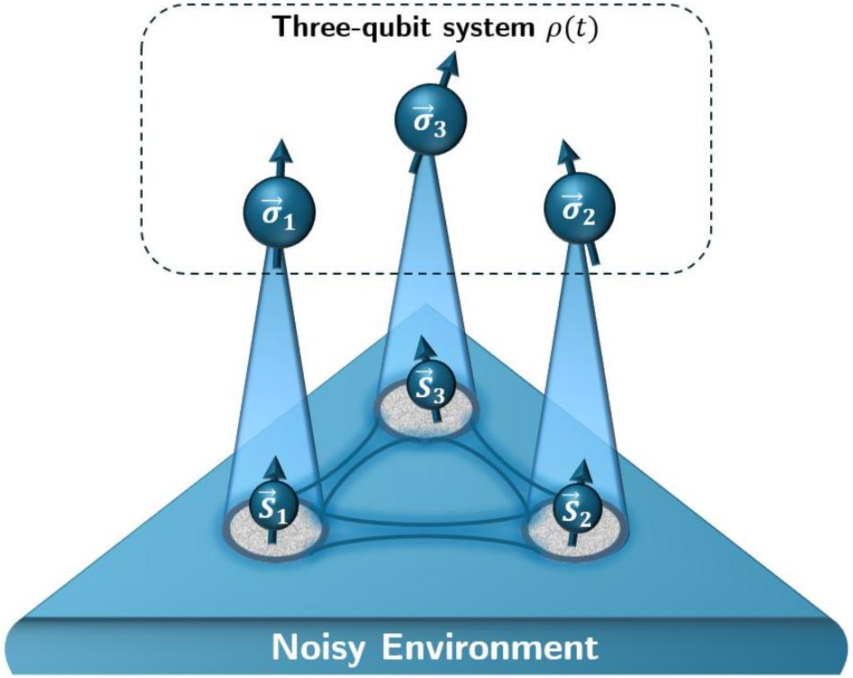
Model system

$$H = H_S + H_E + H_{\mathrm{SE}}$$

$$H_S = -\frac{\Delta}{2}\sum_{i=1}^{3}\sigma_i^z$$

$$H_{\mathrm{SE}} = \lambda\sum_{i=1}^{3}(\sigma_i^+ \otimes E_i^- + \sigma_i^- \otimes E_i^+)$$

H_E unspecified



Lindblad master equation

$$\frac{d\rho}{dt} = -\frac{i}{\hbar}[H_S + H_{\text{eff}}, \rho] + \mathcal{L}[\rho]$$

$$H_{\text{eff}} = \frac{1}{2}\sum_i [\mathcal{J}_\perp(\sigma_i^x\sigma_{i+1}^x + \sigma_i^y\sigma_{i+1}^y) + D\hat{z}\cdot\vec{\sigma}_i \times \vec{\sigma}_{i+1}]$$

$$\mathcal{L}[\rho] = \sum_{ij}\gamma_{ij}\left(\mathcal{O}_j\rho\mathcal{O}_i^\dagger - \frac{1}{2}\{\mathcal{O}_i^\dagger\mathcal{O}_j, \rho\}\right) + \sum_{ij}\tilde{\gamma}_{ij}\left(\tilde{\mathcal{O}}_j\rho\tilde{\mathcal{O}}_i^\dagger - \frac{1}{2}\{\tilde{\mathcal{O}}_i^\dagger\tilde{\mathcal{O}}_j, \rho\}\right)$$

$$[\gamma_{ij}] = \begin{pmatrix} a & A & A^* \\ A^* & a & A \\ A & A^* & a \end{pmatrix}$$

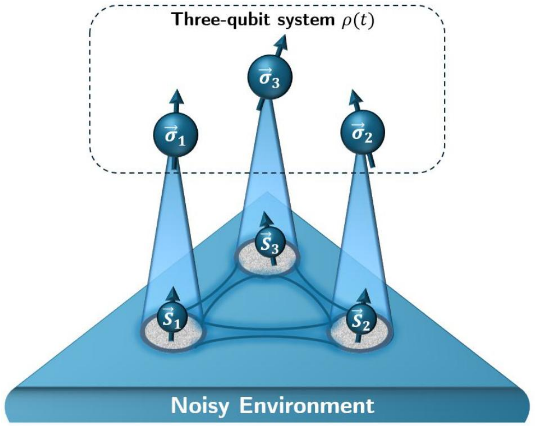
$$\mathcal{O}_i \in \{\sigma_1^+, \sigma_2^+, \sigma_3^+\}$$

$$\tilde{\mathcal{O}}_i \in \{\sigma_1^-, \sigma_2^-, \sigma_3^-\}$$

$$\gamma_{ij} = \frac{\lambda^2}{\hbar^2}S_{ij}(\Delta) = \frac{\lambda^2}{\hbar^2}\int_{-\infty}^{\infty} dt\, e^{i\Delta t}\langle E_i^+(t)E_j^-\rangle$$

$$\mathcal{J}_\perp^{\alpha\beta} = \frac{\lambda^2}{4}\left[G^A_{E_\beta^+E_\alpha^-}(\Delta) + G^R_{E_\beta^+E_\alpha^-}(\Delta) + G^A_{E_\alpha^+E_\beta^-}(\Delta) + G^R_{E_\alpha^+E_\beta^-}(\Delta)\right]$$

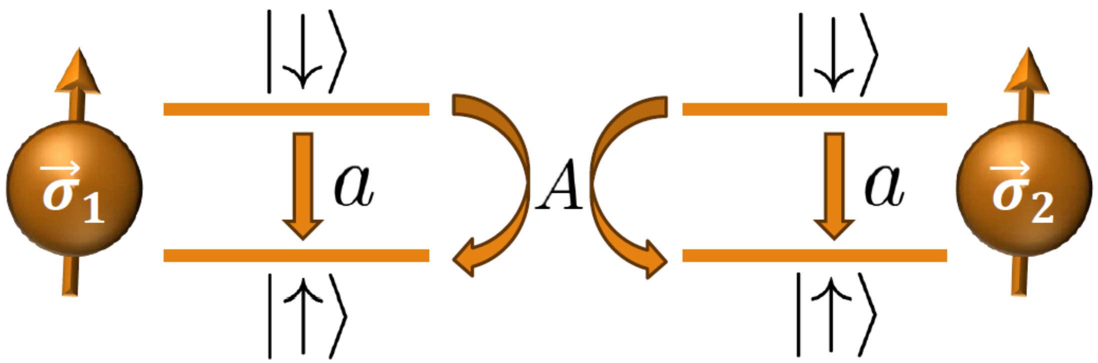
$$D^{\alpha\beta} = -i\frac{\lambda^2}{4}\left[G^A_{E_\beta^+E_\alpha^-}(\Delta) + G^R_{E_\beta^+E_\alpha^-}(\Delta) - G^A_{E_\alpha^+E_\beta^-}(\Delta) - G^R_{E_\alpha^+E_\beta^-}(\Delta)\right]$$

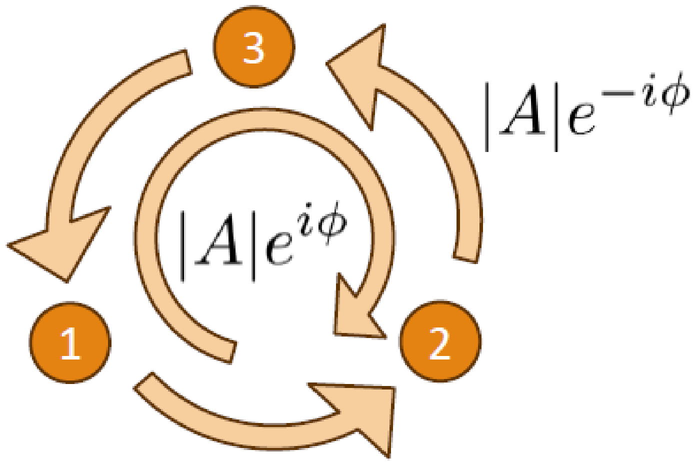


Dissipation

$$\mathcal{L}[\rho] = \sum_{ij} \gamma_{ij} \left(\mathcal{O}_j \rho \mathcal{O}_i^\dagger - \frac{1}{2} \{ \mathcal{O}_i^\dagger \mathcal{O}_j, \rho \} \right)$$

$$[\gamma_{ij}] = \begin{pmatrix} a & A & A^* \\ A^* & a & A \\ A & A^* & a \end{pmatrix}$$





Hilbert space representation

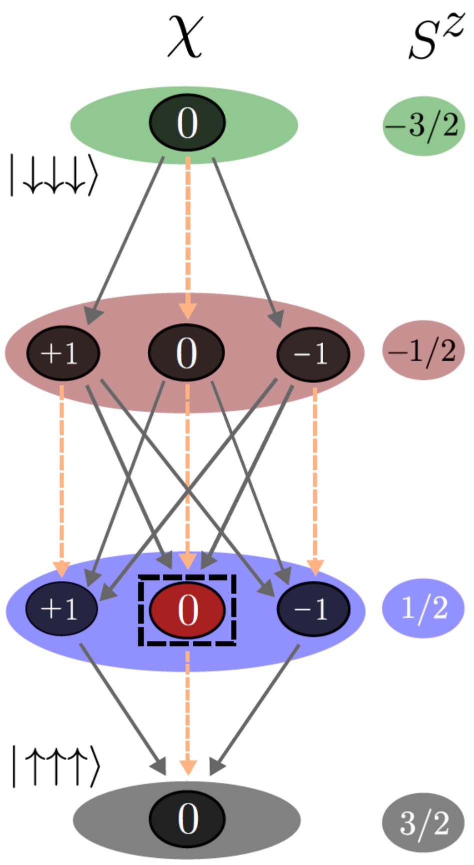
$|\uparrow\uparrow\uparrow\rangle$

$|\uparrow\uparrow\downarrow\rangle, |\uparrow\downarrow\uparrow\rangle, |\downarrow\uparrow\uparrow\rangle$

$|\uparrow\downarrow\downarrow\rangle, |\downarrow\uparrow\downarrow\rangle, |\downarrow\downarrow\uparrow\rangle$

$|\downarrow\downarrow\downarrow\rangle$

$$H_S = -\frac{\Delta}{2}\sum_{i=1}^{3}\sigma_i^z$$



$$S^z = \frac{1}{2}\sum_i \sigma_i^z \qquad \hat{\chi} = \frac{1}{2\sqrt{3}}\vec{\sigma}_1 \cdot \vec{\sigma}_2 \times \vec{\sigma}_3$$

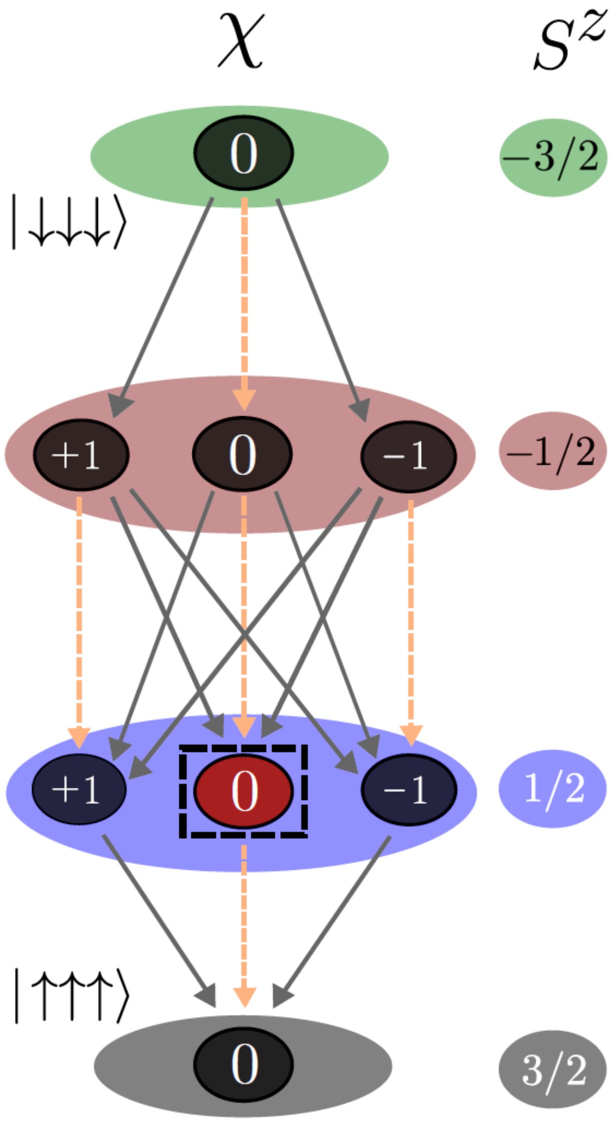
$$\eta = \exp(2\pi i/3)$$

$$\left|S^z = \tfrac{1}{2}, \chi\right\rangle = \frac{1}{\sqrt{3}}\left(\eta^{-\chi}|\uparrow\uparrow\downarrow\rangle + \eta^{\chi}|\uparrow\downarrow\uparrow\rangle + |\downarrow\uparrow\uparrow\rangle\right)$$

$$J_k = \sqrt{\gamma_k(a, A)}\left(\eta^k\sigma_1^+ + \eta^{-k}\sigma_2^+ + \sigma_3^+\right)$$

$$\mathcal{L}[\rho] = \sum_k J_k \rho J_k^\dagger - (1/2)\{J_k^\dagger J_k, \rho\}$$

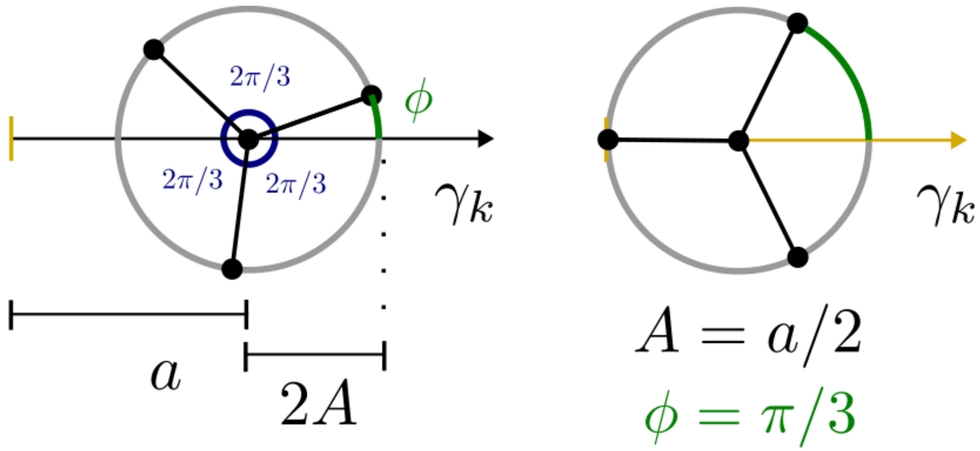
$$\gamma_k(a, A) = \frac{1}{3}\left[a + 2|A|\cos\left(\phi + 2\pi k/3\right)\right]$$



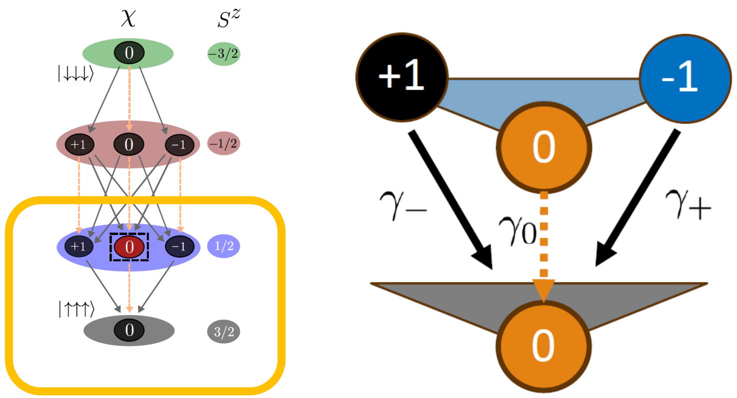
$$S^z = \frac{1}{2}\sum_i \sigma_i^z \qquad \hat{\chi} = \frac{1}{2\sqrt{3}}\vec{\sigma}_1 \cdot \vec{\sigma}_2 \times \vec{\sigma}_3$$

$$J_k|S^z,\chi\rangle \propto |S^z+1,\chi+k\rangle$$

$$\gamma_k(a, A) = \frac{1}{3}\left[a + 2|A|\cos\left(\phi + 2\pi k/3\right)\right]$$



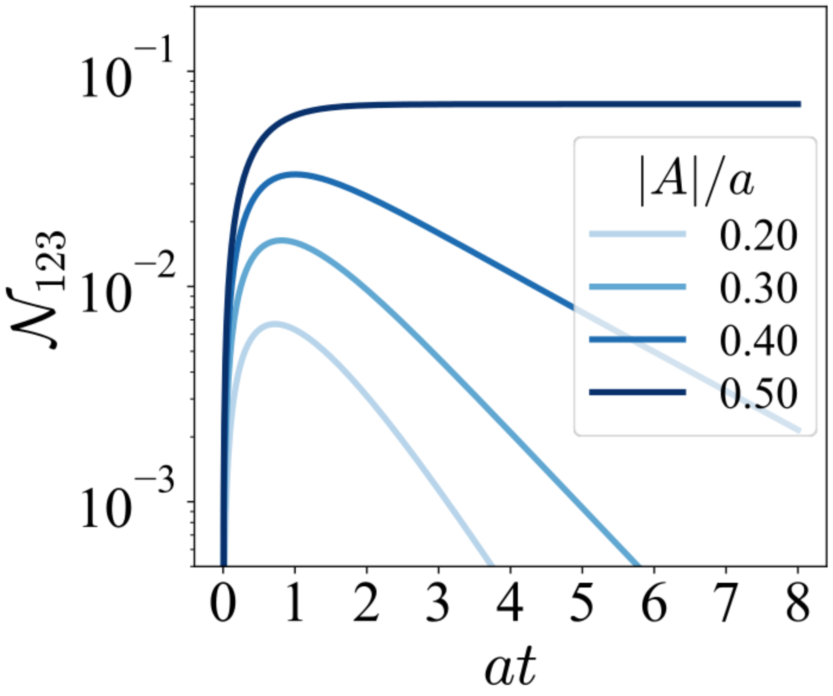
Results: Entanglement generation



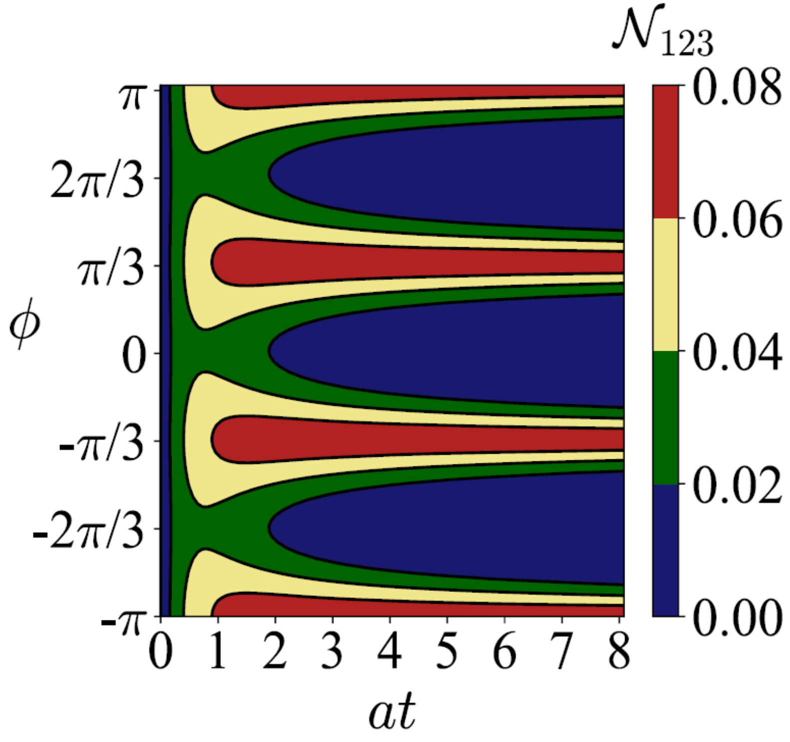
$$\frac{\gamma_0}{a} = 1 + \cos(\phi)$$

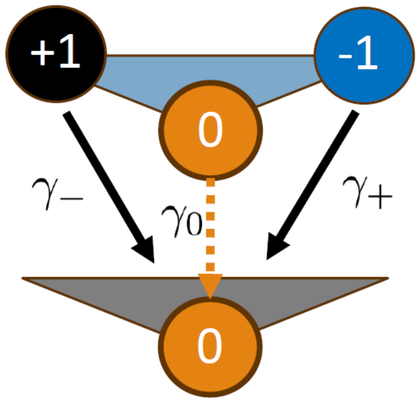
$$\frac{\gamma_+}{a} = 1 + \cos\left(\phi + \frac{2\pi}{3}\right)$$

$$\frac{\gamma_-}{a} = 1 + \cos\left(\phi - \frac{2\pi}{3}\right)$$



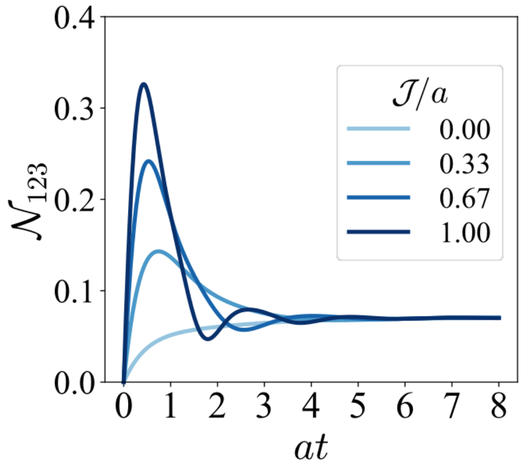
$\mathcal{J} = 0$





$$\rho(t=0) = |\uparrow\downarrow\downarrow\rangle = \sum_{\chi\in\{-1,0,1\}} |-1/2,\chi\rangle$$

$$\rho(t\to\infty) = \frac{1}{3}|W\rangle\langle W| + \frac{2}{3}|\downarrow\downarrow\downarrow\rangle\langle\downarrow\downarrow\downarrow|$$



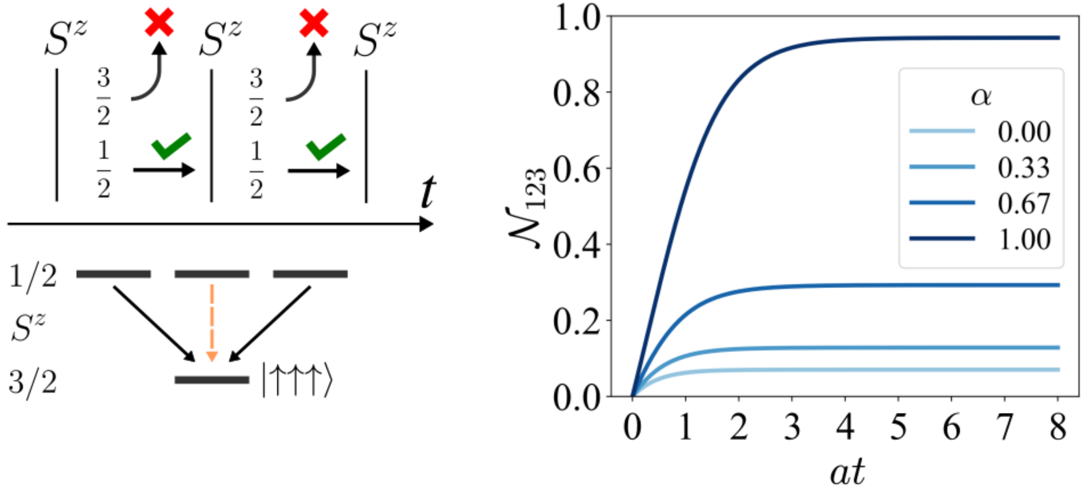
$$\rho(t\to\infty) = \mathcal{F}|\mathrm{W}\rangle\langle\mathrm{W}| + (1-\mathcal{F})|\uparrow\uparrow\uparrow\rangle\langle\uparrow\uparrow\uparrow|$$

$$\mathcal{N}_{123}(\mathcal{F}) = \sqrt{(\mathcal{N}_{123}^{\mathrm{W}}\mathcal{F})^2 + (1-\mathcal{F})^2} - (1-\mathcal{F}) \qquad \mathcal{N}_{123}^{\mathrm{W}} = 2\sqrt{2}/3 \approx 0.94$$

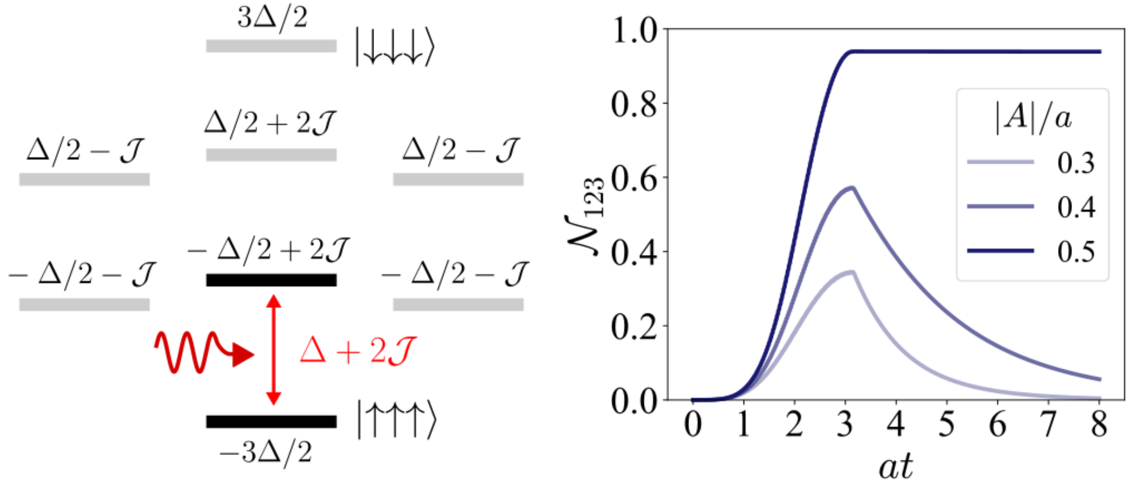
$$\mathcal{F} = 1 \quad \Rightarrow \quad \mathcal{N}_{123} \approx 0.94$$

$$\mathcal{F} = 1/3 \quad \Rightarrow \quad \mathcal{N}_{123} \approx 0.07$$

Enhancing the fidelity

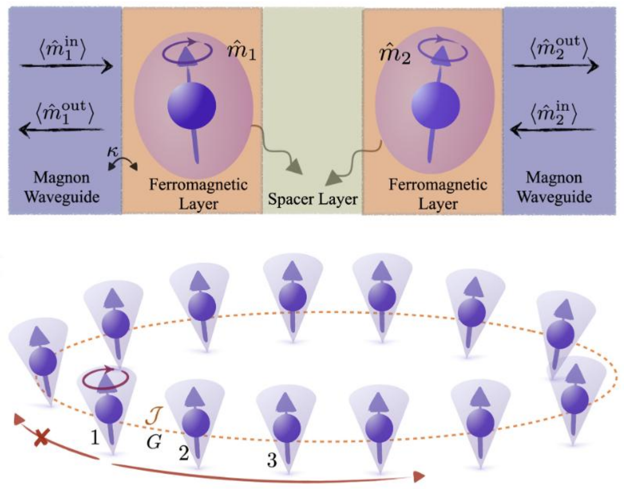


Post-selection

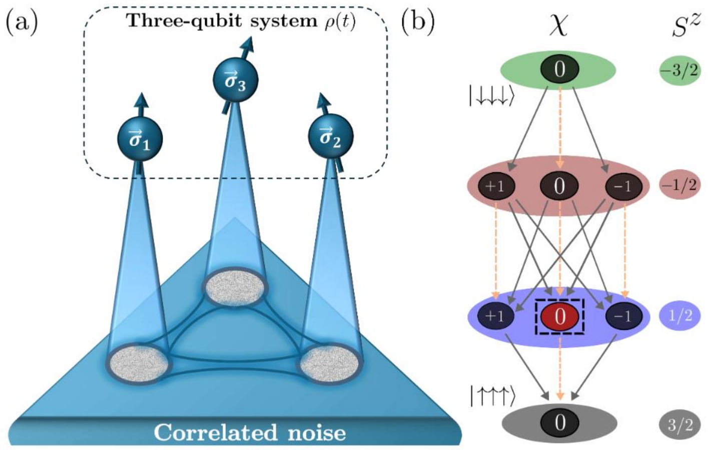


Driving

Conclusion: Dissipative control of chirality in spin systems



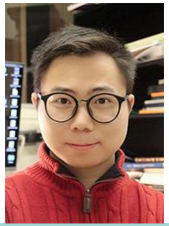
Zou, Bosco, Thingstad, Klinovaja & Loss
PRL 132 (2024)



Driessen, Zou, Thingstad, Klinovaja & Loss
arXiv:2506.20466 (2025)

Swiss National Science Foundation

NCCR SPIN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