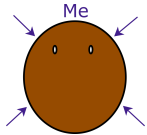
Quantum Tomography of Magnons using Brillouin Light Scattering

Phys. Rev. B 110, 014416 (2024)



Sanchar Sharma

Silvia Viola Kusminskiy

Victor ASV Bittencourt

IFIMAC
CONDENSED MATTER PHYSICS CENTER

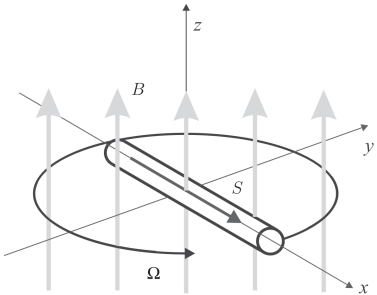
RWTH AACHEN UNIVERSITY

Université de Strasbourg

"la Caixa" Foundation

What can quantum magnonics offer?

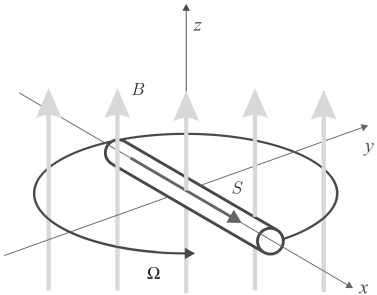
Magnetic Field sensing



Kimball et al. PRL 2016

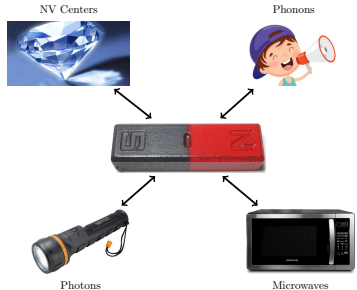
What can quantum magnonics offer?

Magnetic Field sensing



Kimball et al. PRL 2016

Quantum Transduction

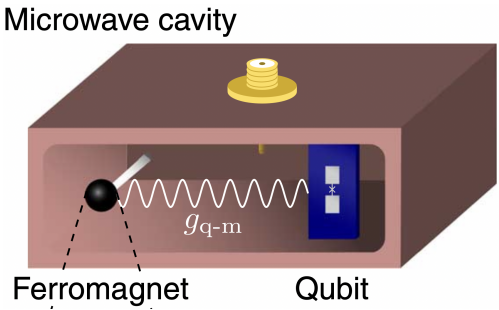


Are magnons even quantum?

Single magnon detection

Are magnons even quantum?

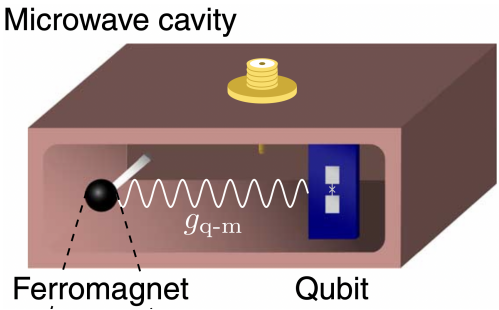
Single magnon detection



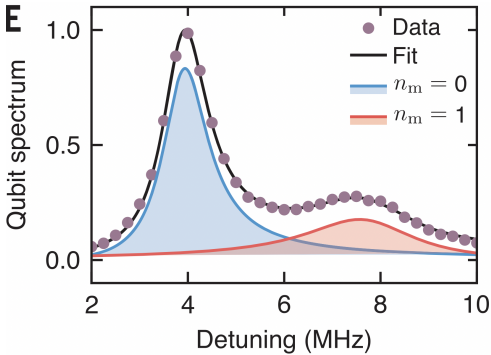
Lachance-Quirion et al.
Sci. Adv. 2017

Are magnons even quantum?

Single magnon detection



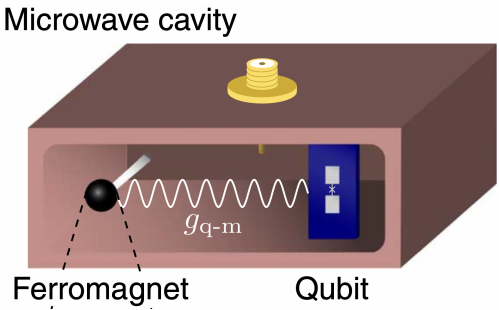
Lachance-Quirion et al.
Sci. Adv. 2017



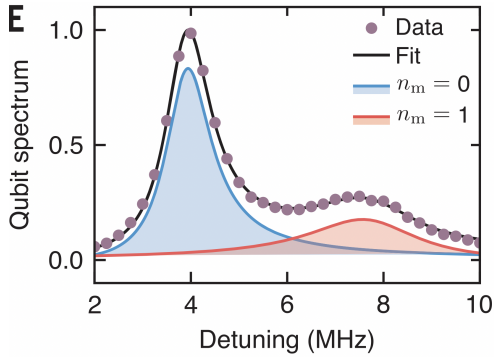
Lachance-Quirion et al.
Science 2020

Are magnons even quantum?

Single magnon detection



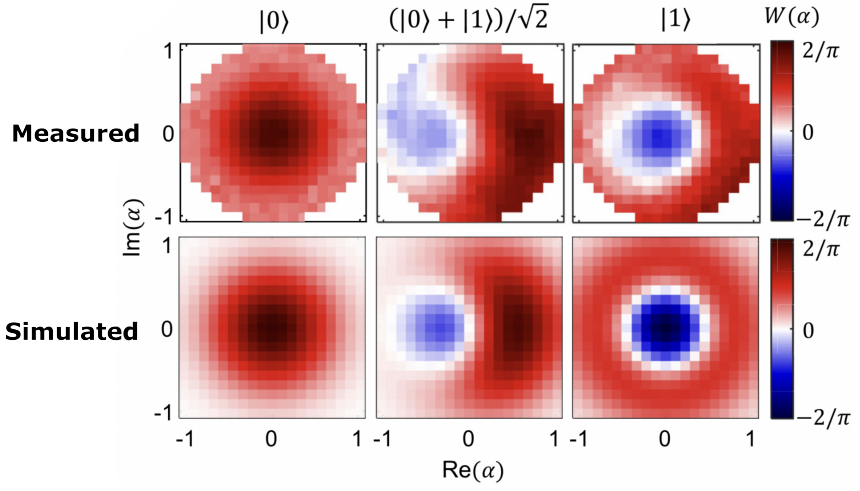
Lachance-Quirion et al.
Sci. Adv. 2017



Lachance-Quirion et al.
Science 2020

Evidence of quantization!

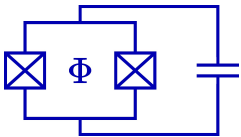
Single magnon Fock state



Xu et al. PRL 130, 193603 (2023)

But why go optical?

But why go optical?



Extremely sensitive

Bad scalability

Additional passive dissipation

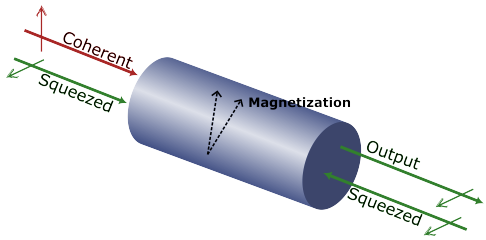
Moderate sensitivity

Size independent

Controllable coupling

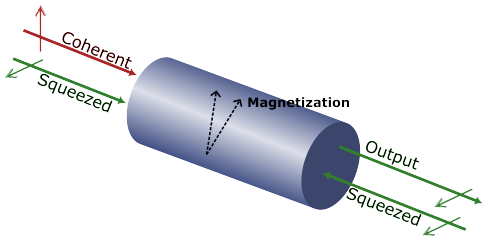
Signal-to-Noise Ratio

"Shut up and calculate" – David Mermin



Signal-to-Noise Ratio

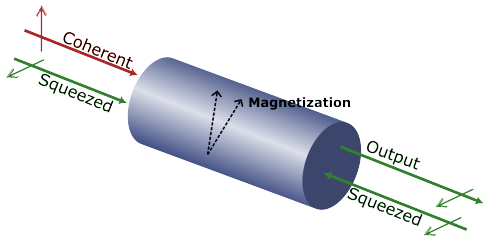
"Shut up and calculate" – David Mermin



$$\hat{a}_{\text{out}} = \cos\theta\,\hat{a}_{\text{noise}} + \sin\theta\,\hat{m}_{\text{signal}}$$

Signal-to-Noise Ratio

"Shut up and calculate" – David Mermin

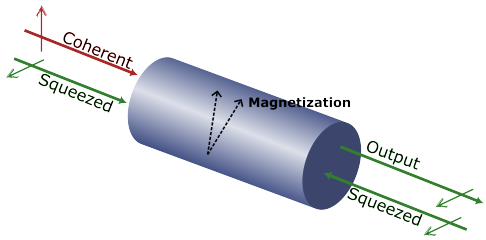


$$\hat{a}_{\mathrm{out}} = \cos\theta\,\hat{a}_{\mathrm{noise}} + \sin\theta\,\hat{m}_{\mathrm{signal}}$$

$$\theta \propto \underbrace{\frac{\Theta}{\sqrt{\omega_{\mathrm{opt}}}}}_{\text{Coupling}} \times \underbrace{\sqrt{\frac{\mu_B}{M_s}}}_{\substack{\text{Vacuum} \\ \text{Fluctuations}}} \times \underbrace{\sqrt{\frac{C_V \rho_{\mathrm{den}}}{\alpha_{\mathrm{abs}}}}}_{\substack{\text{Optical} \\ \text{Power}}}$$

Signal-to-Noise Ratio

"Shut up and calculate" – David Mermin

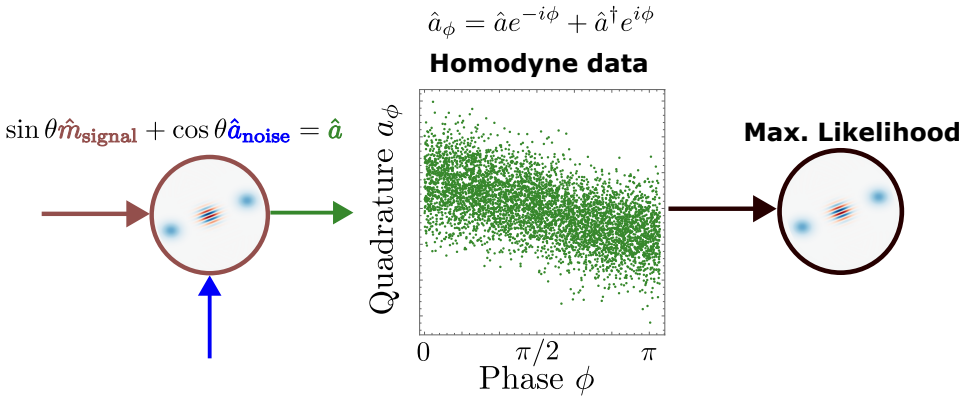


$$\hat{a}_{\mathrm{out}} = \cos\theta\,\hat{a}_{\mathrm{noise}} + \sin\theta\,\hat{m}_{\mathrm{signal}}$$

$$\theta \propto \underbrace{\frac{\Theta}{\sqrt{\omega_{\mathrm{opt}}}}}_{\text{Coupling}} \times \underbrace{\sqrt{\frac{\mu_B}{M_s}}}_{\text{Fluctuations}} \times \underbrace{\sqrt{\frac{C_V \rho_{\mathrm{den}}}{\alpha_{\mathrm{abs}}}}}_{\text{Optical Power}} \sim 0.2(\mathrm{YIG})$$

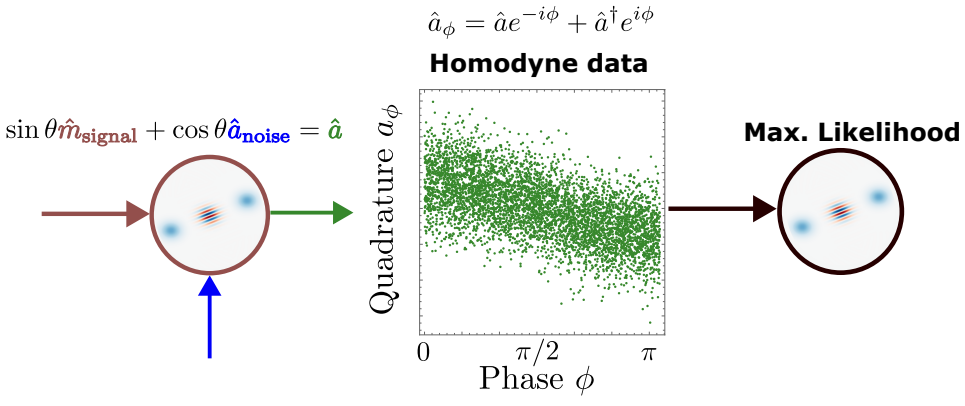
From photons to magnons

Maximum likelihood estimate



From photons to magnons

Maximum likelihood estimate

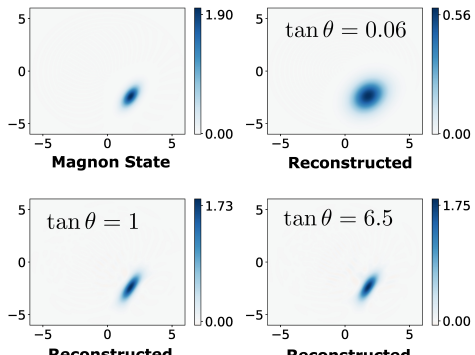


Maximize product of $\text{prob}(a_\phi) = \text{Tr}\left[\hat{\rho}_{\text{mag}}\hat{P}(a_\phi)\right]$

Gaussian state

Can classical states be reconstructed?

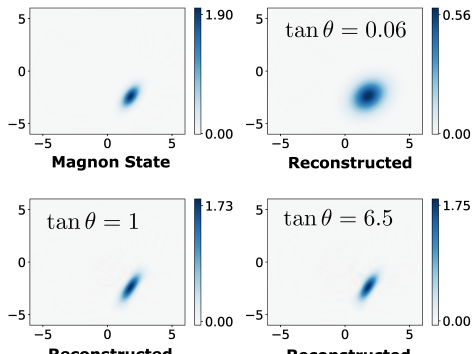
$$\hat{a}_{\text{out}} = \cos\theta \hat{a}_{\text{noise}} + \sin\theta \hat{m}_{\text{signal}}, \quad \theta_{\text{YIG}} < 0.2$$



Gaussian state

Can classical states be reconstructed?

$$\hat{a}_{\mathrm{out}} = \cos\theta\,\hat{a}_{\mathrm{noise}} + \sin\theta\,\hat{m}_{\mathrm{signal}}, \quad \theta_{\mathrm{YIG}} < 0.2$$

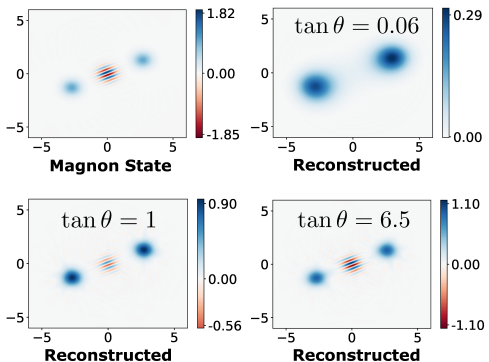


Limited by Hilbert space cut-off!

Cat state

Can quantum information be extracted?

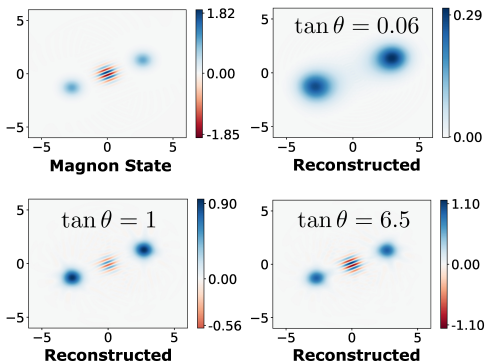
$$\hat{a}_{\text{out}} = \cos\theta \hat{a}_{\text{noise}} + \sin\theta \hat{m}_{\text{signal}}, \quad \theta_{\text{YIG}} < 0.2$$



Cat state

Can quantum information be extracted?

$$\hat{a}_{\text{out}} = \cos\theta \hat{a}_{\text{noise}} + \sin\theta \hat{m}_{\text{signal}}, \quad \theta_{\text{YIG}} < 0.2$$



Limited by number of data points, $N_{\text{data}} = 10^4$

Conclusion

- Estimate magnon density matrix from statistics of scattered photons using maximum likelihood principle.
- 'Classical information' can be reconstructed with a high accuracy!
- 'Quantum Superposition' can likely be inferred with some improvements:

Phys. Rev. B 110, 014416 (2024)

sancharsharma.com

Conclusion

- Estimate magnon density matrix from statistics of scattered photons using maximum likelihood principle.
- 'Classical information' can be reconstructed with a high accuracy!
- 'Quantum Superposition' can likely be inferred with some improvements:

Improve SNR

- Heat sink
- Better parameter tuning

Reconstruction algorithm

- Compact representations of density matrix
- Improved recursion

Phys. Rev. B 110, 014416 (2024)

sancharsharma.com

Upcoming Workshop: WE-Heraeus-Seminar

Quantum Magnonics

January 31 – February 5, 2027

Physikzentrum Bad Honnef, Germany

Topics

- Hybrid quantum systems
- Cavity magnonics
- Nonlinear magnonics
- Magnetic materials

Organizers

- Sanchar S. (Madrid)
- V. Bittencourt (Mexico City)
- H. Huebl (Garching)

Applications Welcome!