Quantum-Enhanced Optical lattice Clock

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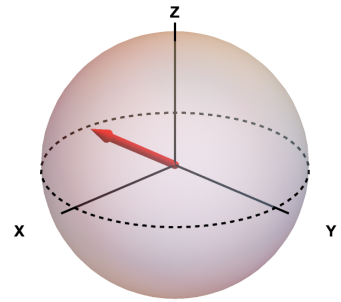
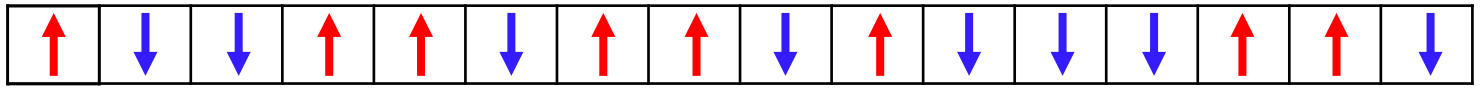
Outline

- Entanglement-Enhanced Optical Clock Phase Measurement
  - *Nature*, 588, 414 (2020)

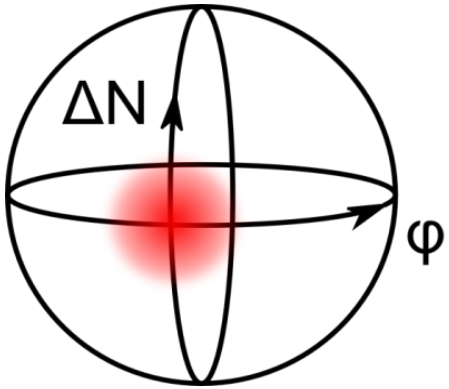
- Time-Reversal-Based Quantum Metrology
  - ArXiv: 2106.03754 (2021)

Quantum Projection Noise



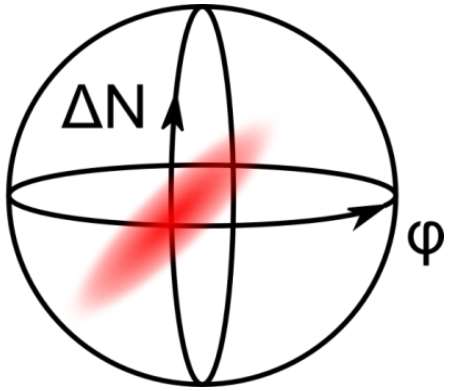


$$\sigma^2 = p(1-p)/\mathrm{N}$$



$$\frac{\sigma_z}{S} \cdot \frac{\sigma_y}{S} \geq \frac{1}{2S} = \frac{1}{N}$$

$$\frac{\sigma_z}{S} = \frac{\sigma_y}{S} = \sqrt{\frac{1}{2S}} = \frac{1}{\sqrt{N}}$$

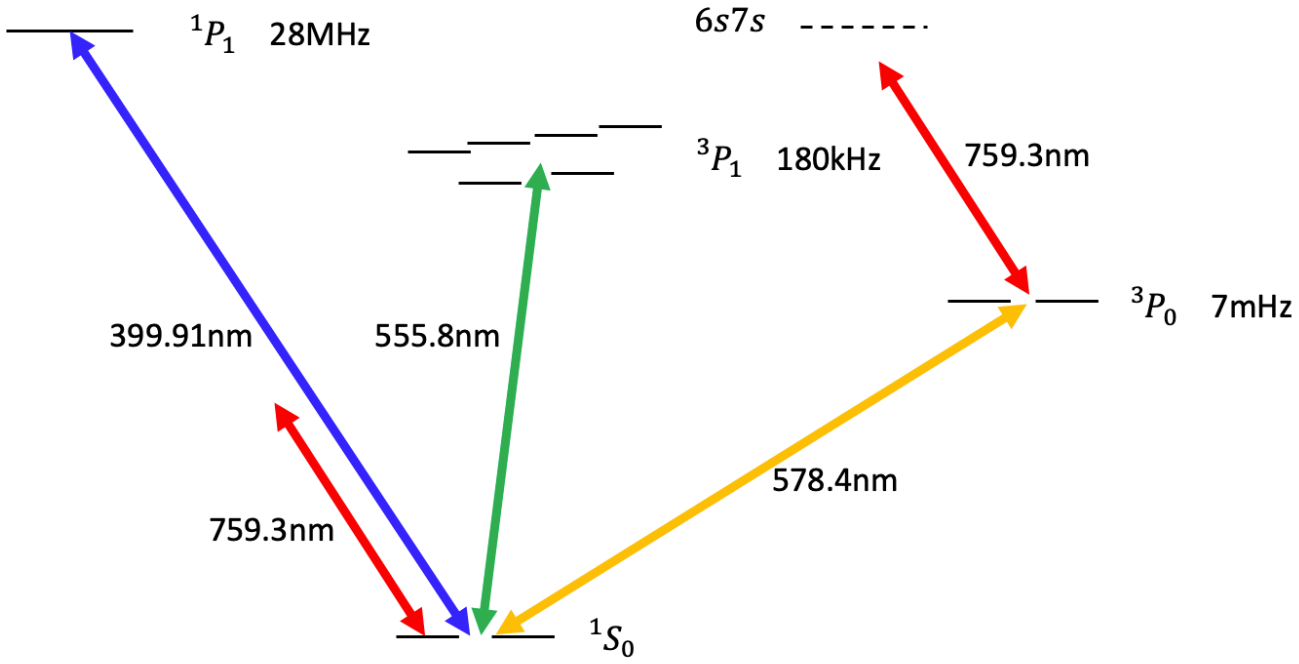


Standard Quantum Limit (SQL)

$$\sigma_{SQL} = \frac{1}{2\pi f_0 C \sqrt{N} T_{Ramsey}} \sqrt{\frac{T_{Ramsey} + T_{preparation}}{\tau}}$$

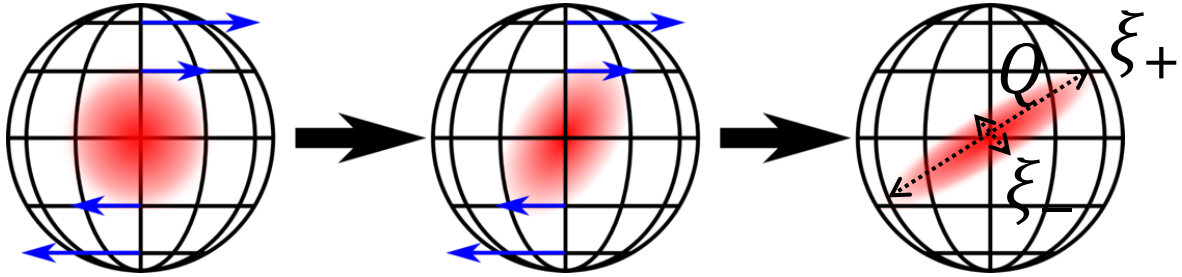
Phys. Rev. Lett. 82, 23 (1999)

Entanglement on Optical Clock Transition

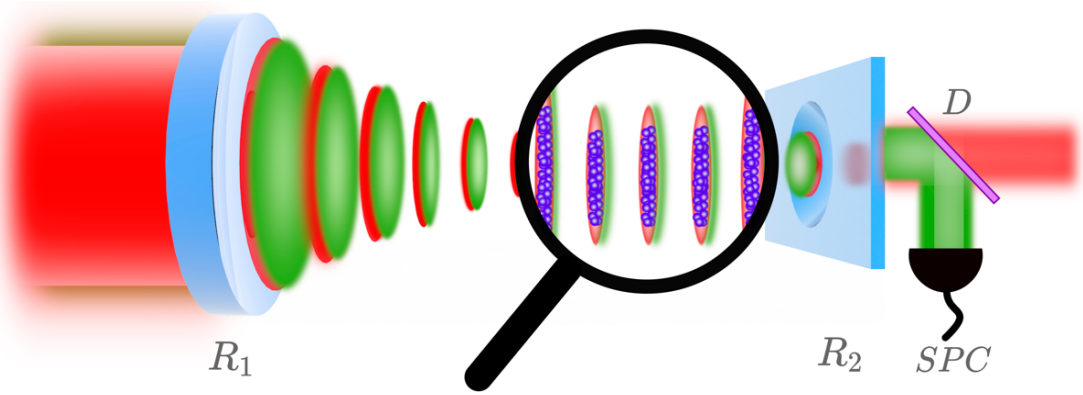


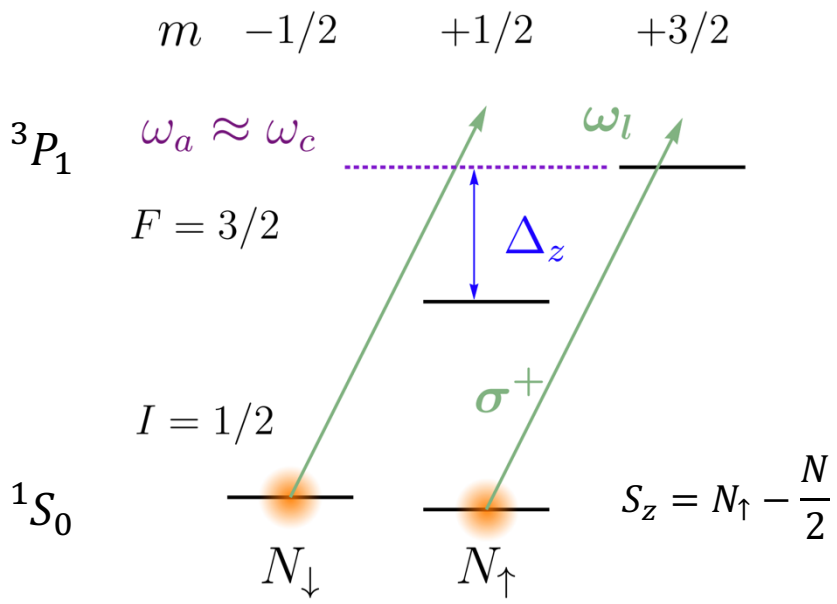
One Axis Twisting Hamiltonian

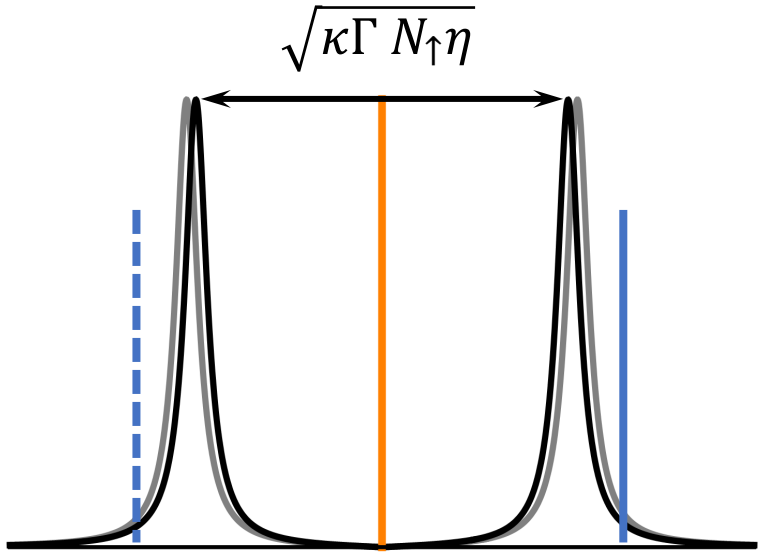
$$H = \hbar\chi S_z^2 = (\hbar\chi S_z)S_z$$



Cavity Feedback Squeezing







Cooperativity $\eta = \frac{4g^2}{\kappa\Gamma} = \frac{24\mathcal{F}}{\pi k^2 w^2}$

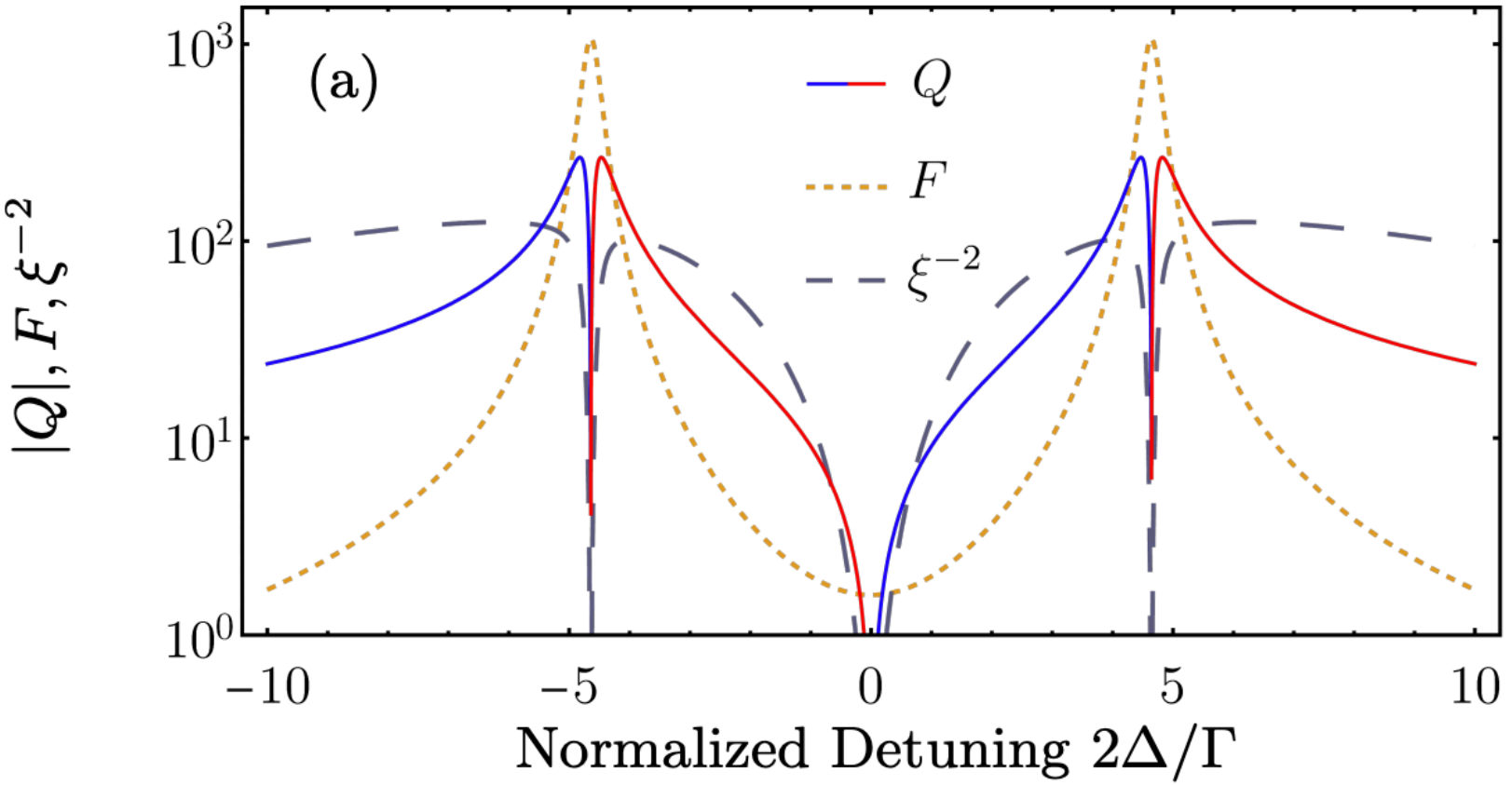
Hamiltonian $H = \hbar\mu B S_z + N_\uparrow \frac{c^\dagger c g^2}{\Delta}$

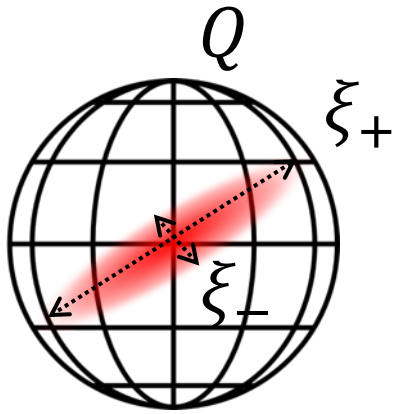
$= \hbar\mu B S_z + (S + S_z)\frac{c^\dagger c[Sz] g^2}{\Delta}$

$= aS_z + \chi S_z^2$

$a' S_z - \chi S_z^2$

Theoretical simulation



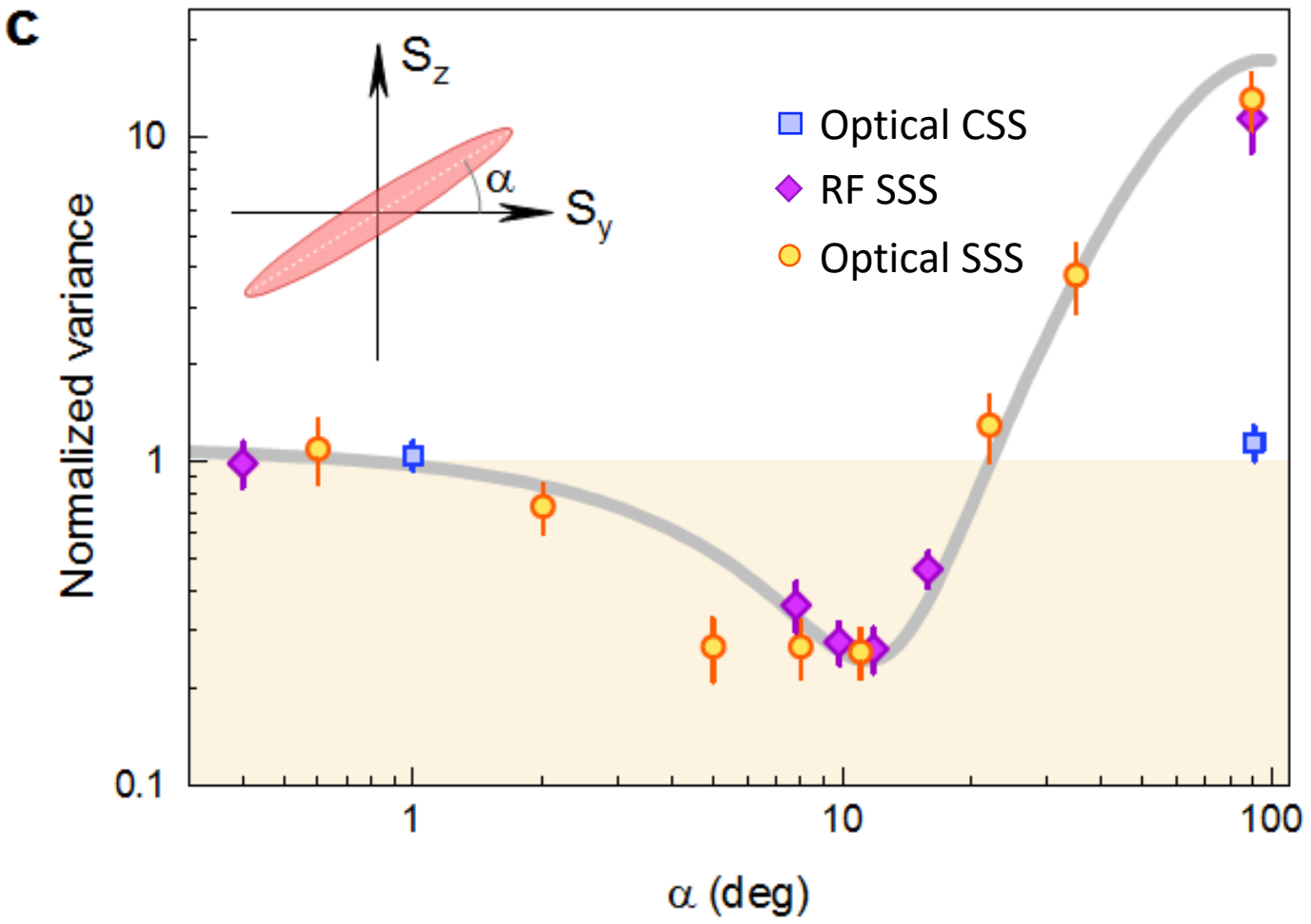


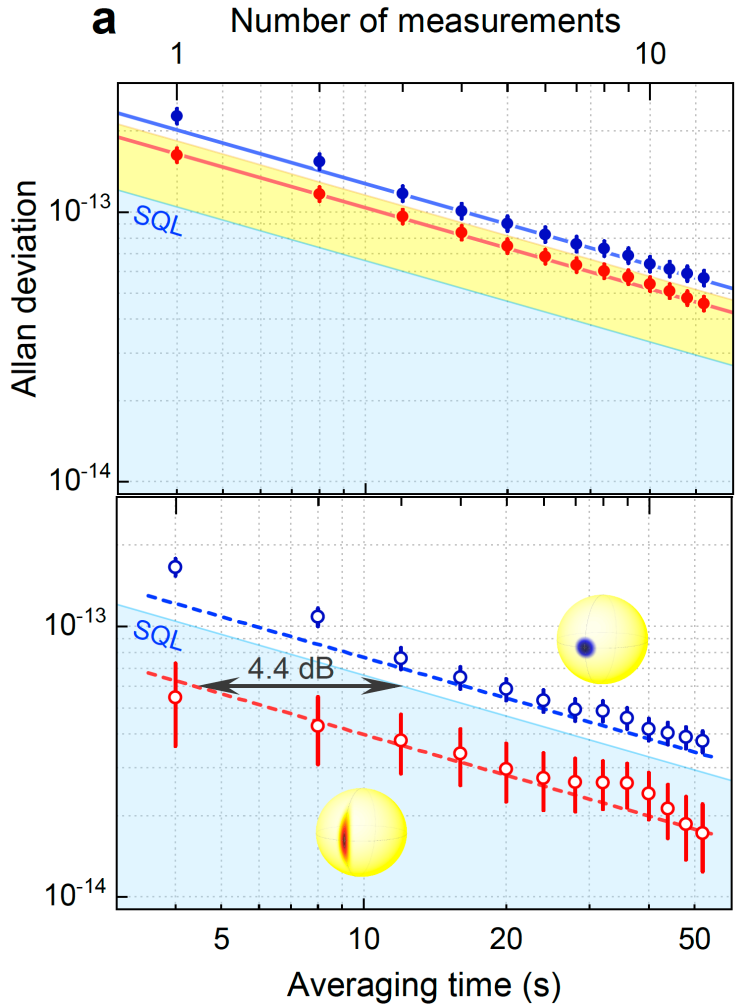
$\xi^2 = \xi_-^2/C\text{^}2$

$F = \xi_-^2 \xi_+^2 - 1$

arXiv 2106.13234 (2021)

Entanglement on Optical Clock Transition



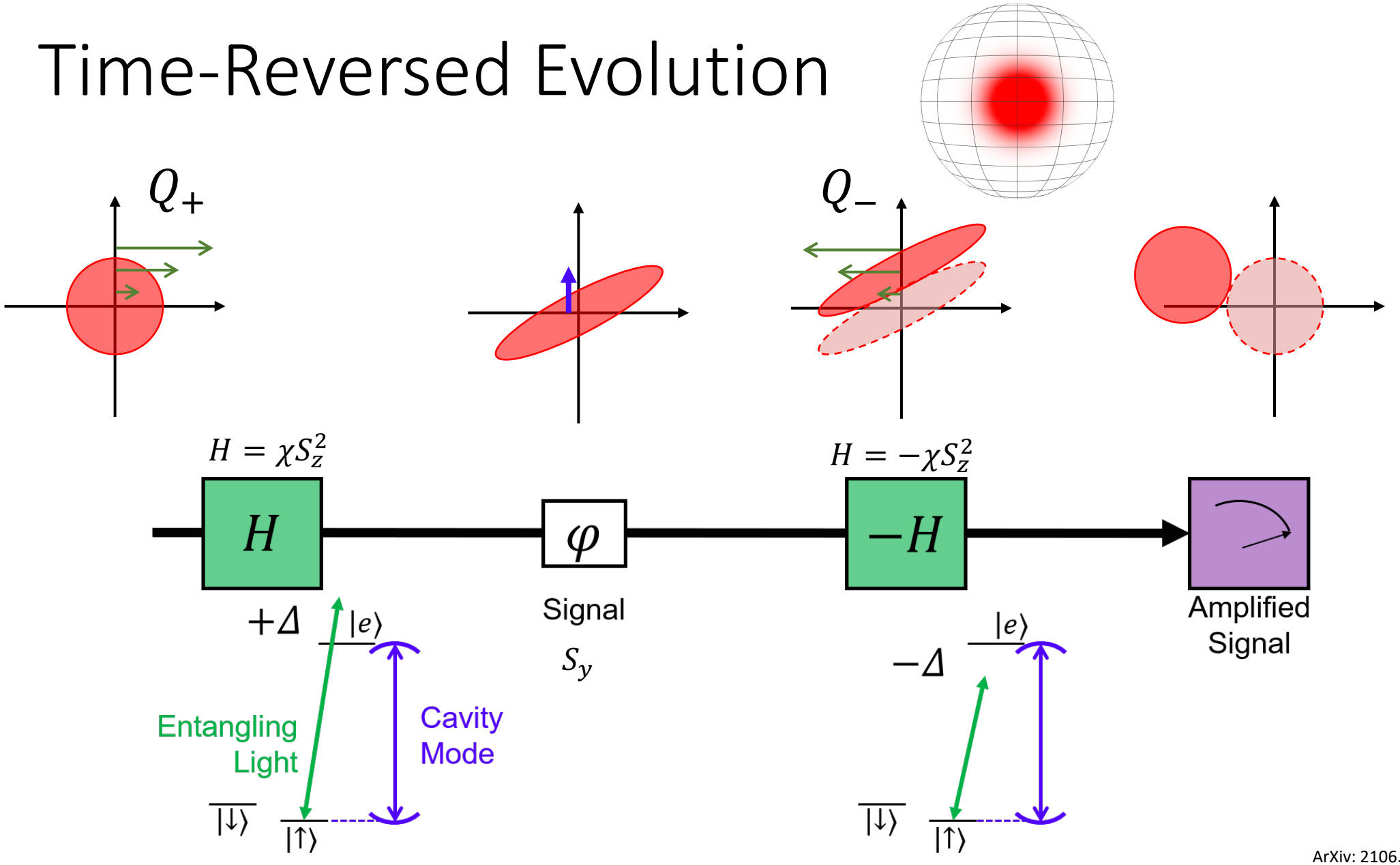


Nature, 588, 414 (2020)

Time-Reversal-Based Quantum Metrology with Many-Body Entangled States

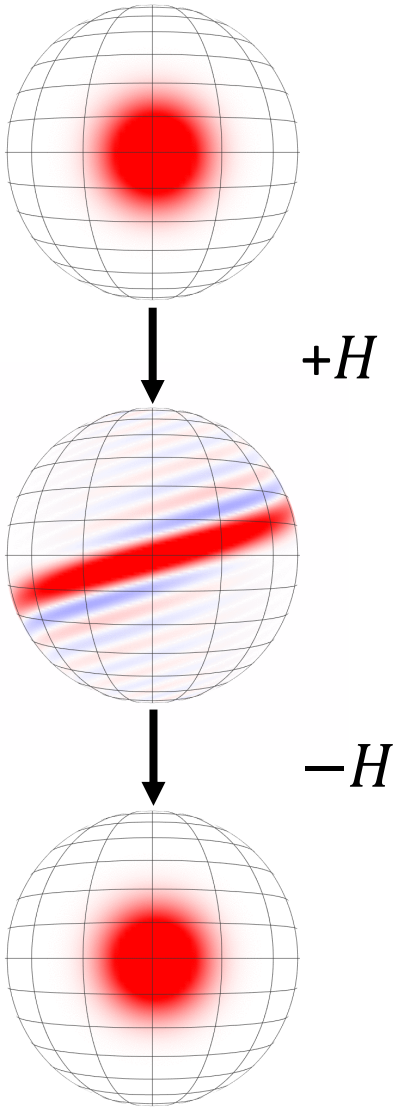
ArXiv: 2106.03754 (2021)

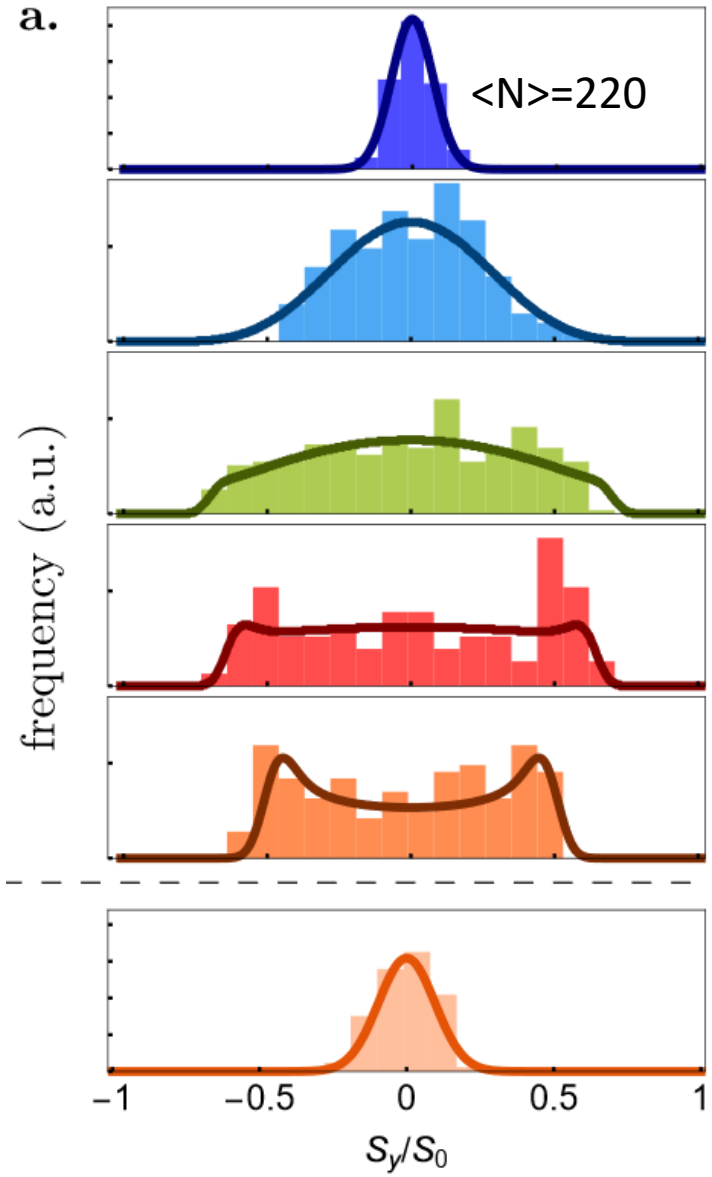
Time-Reversed Evolution



ArXiv: 2106.03754 (2021)

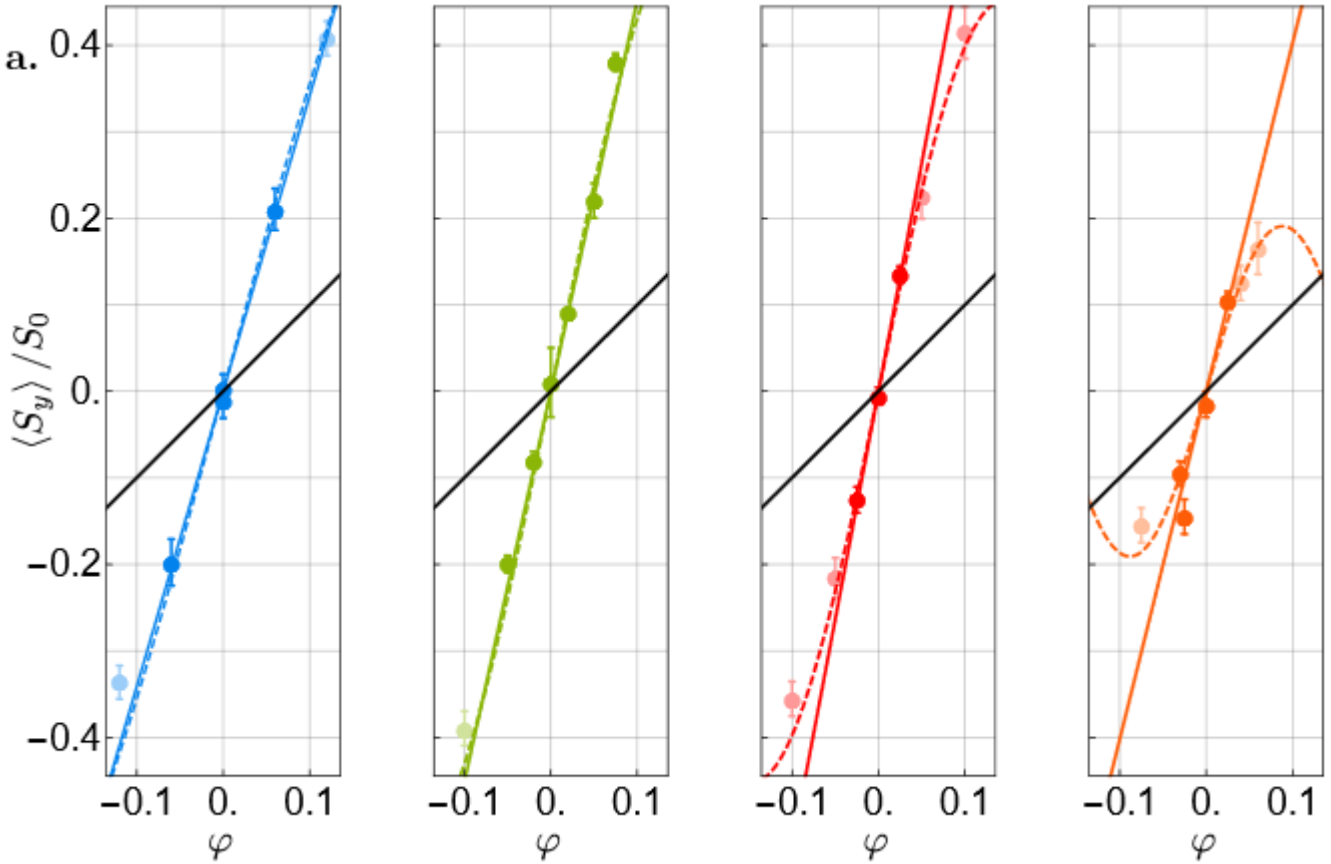
Backward Evolution

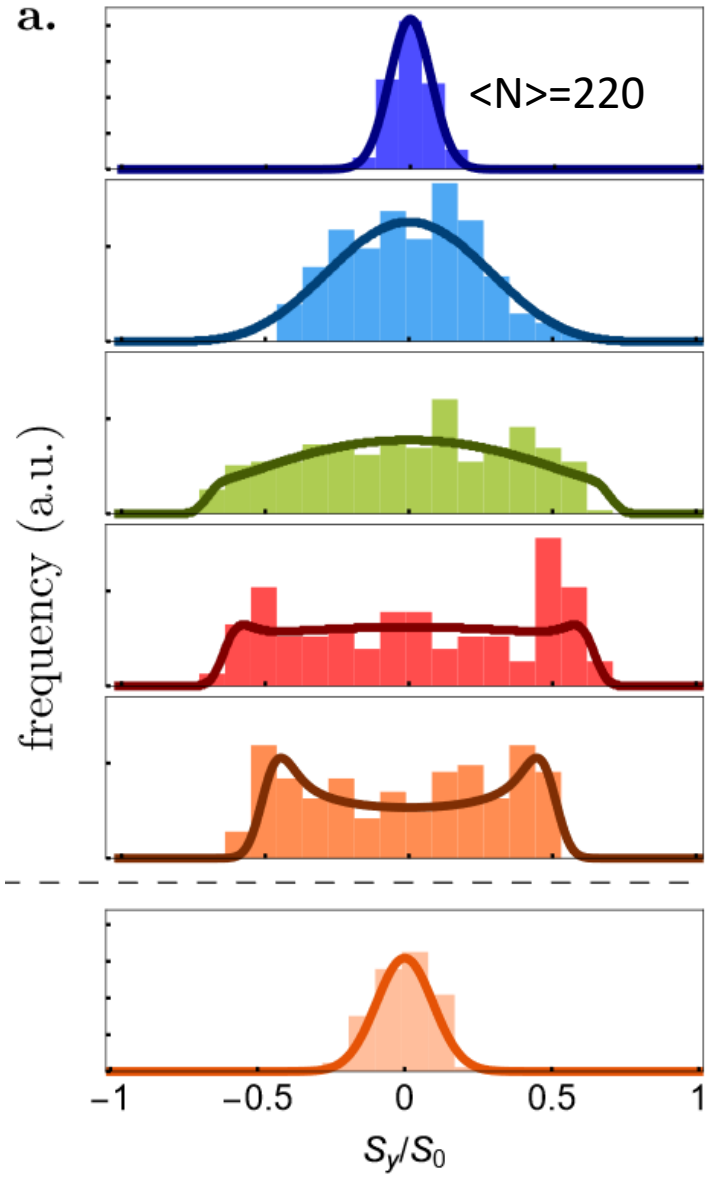




ArXiv: 2106.03754 (2021)

Signal Amplification





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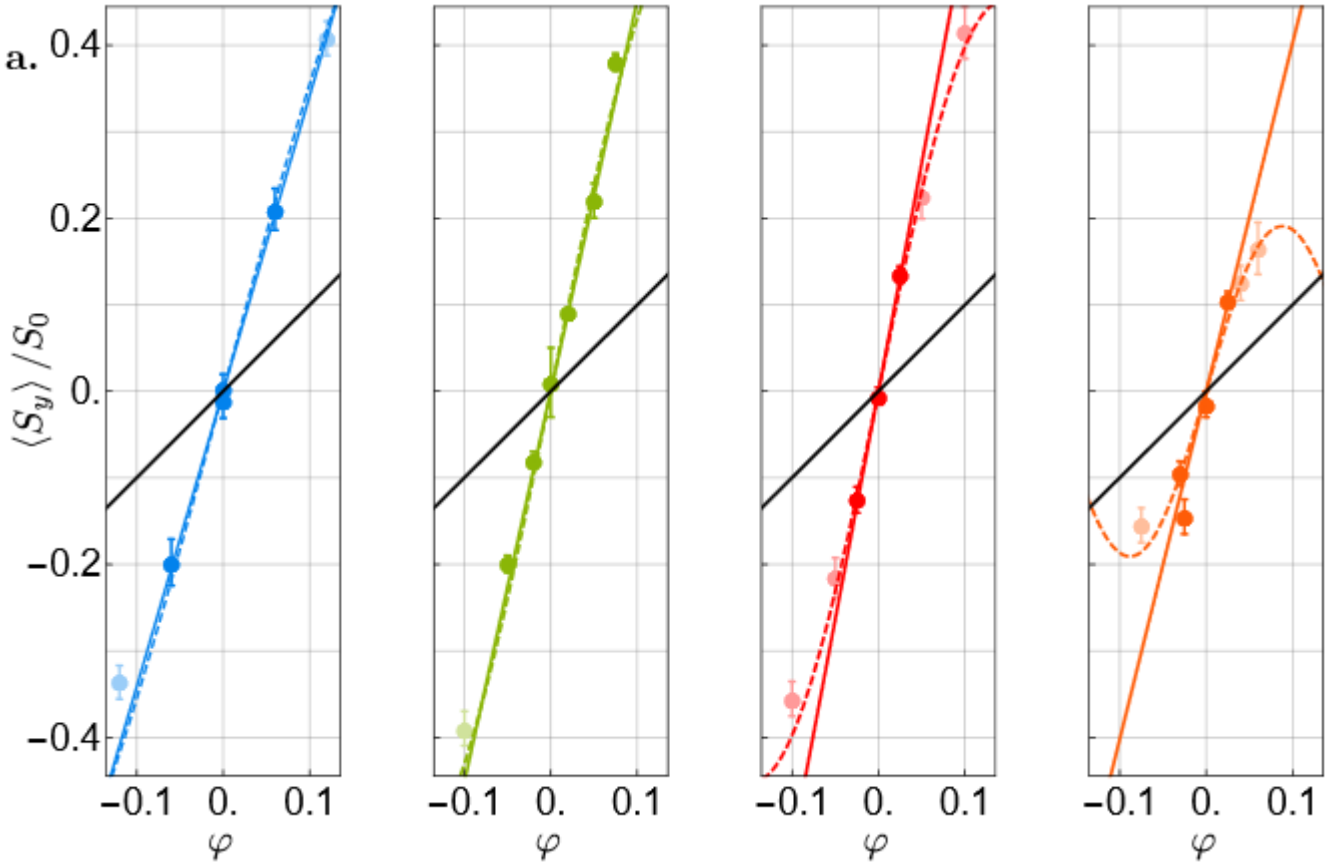

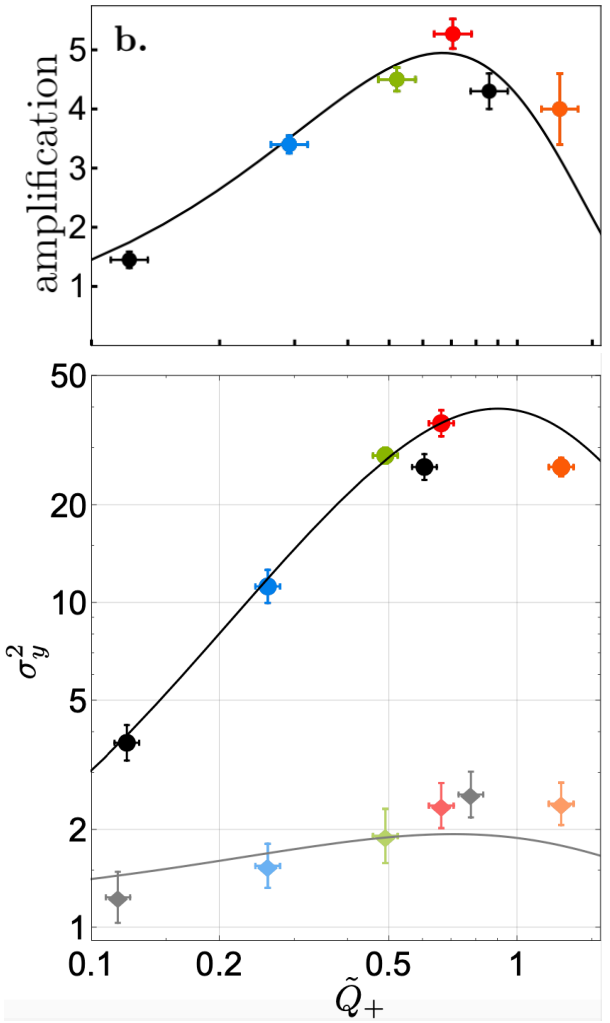

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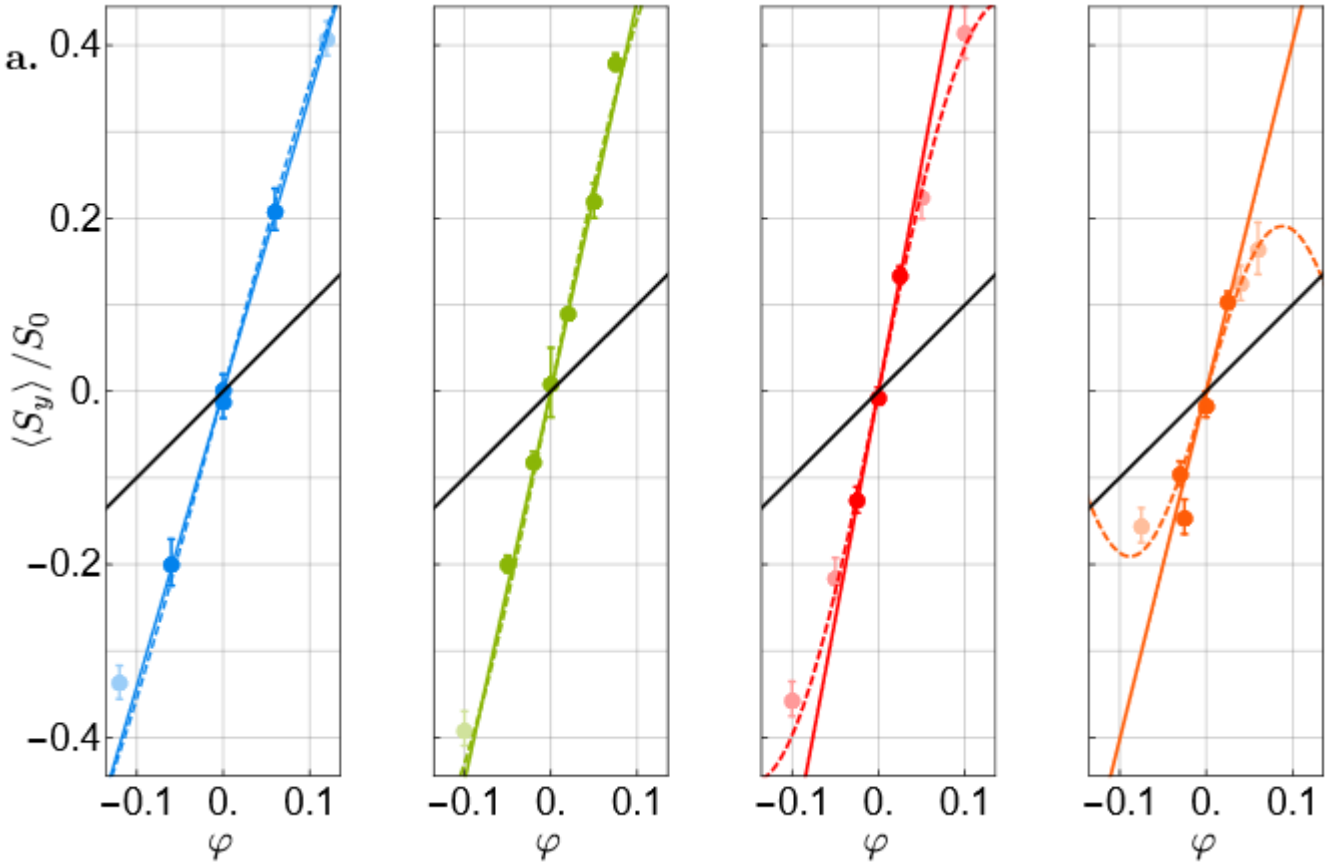

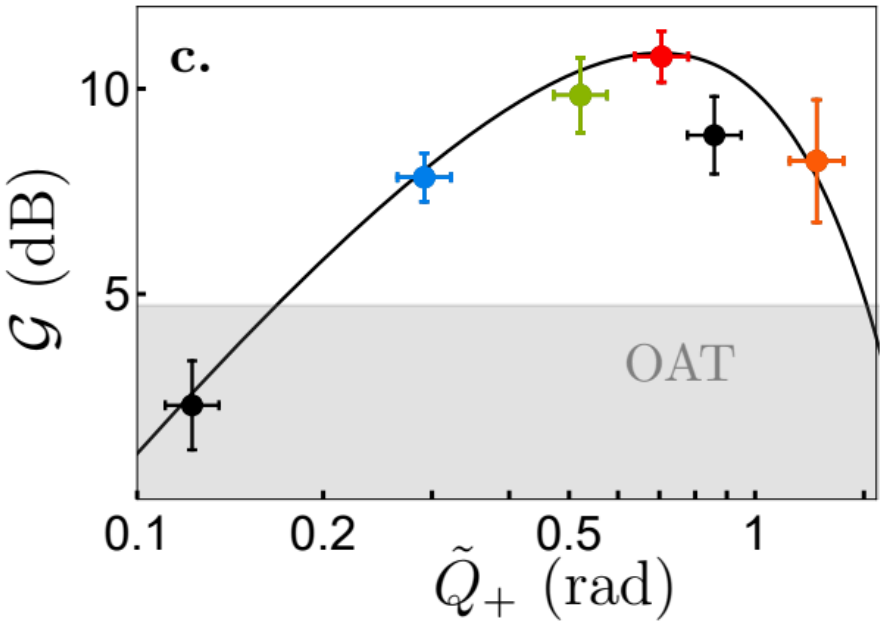

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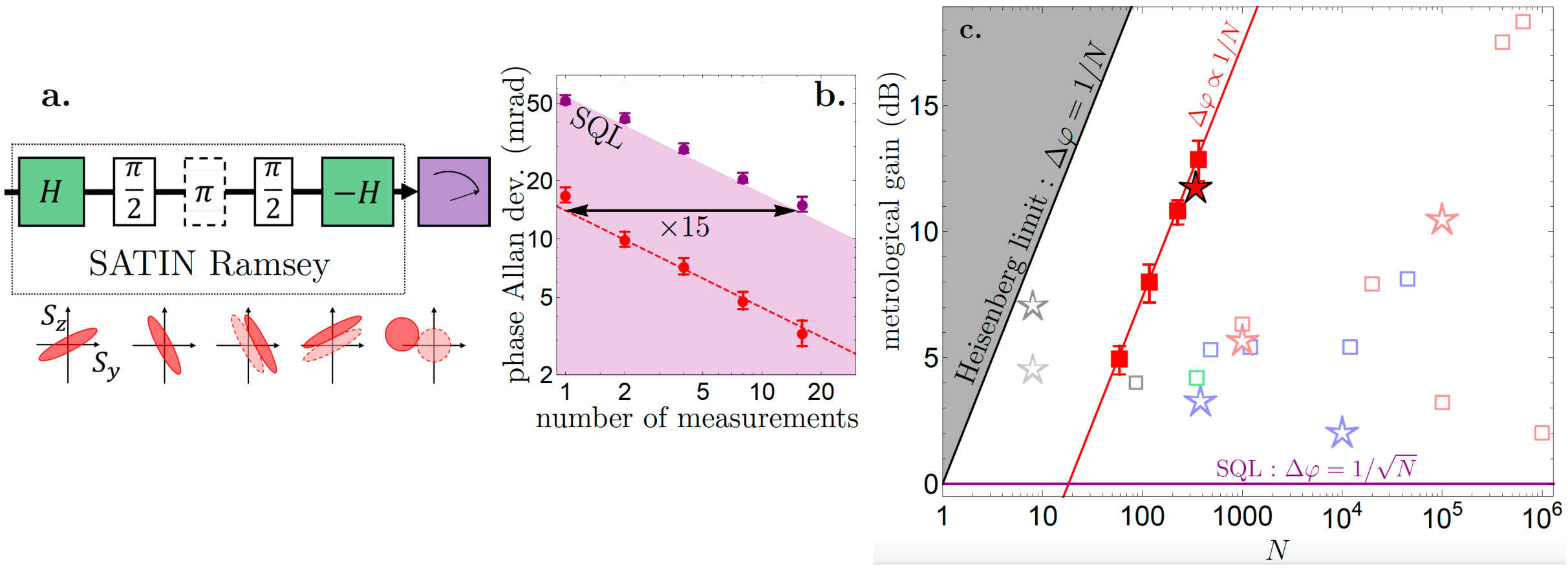
Quantum-Enhancement



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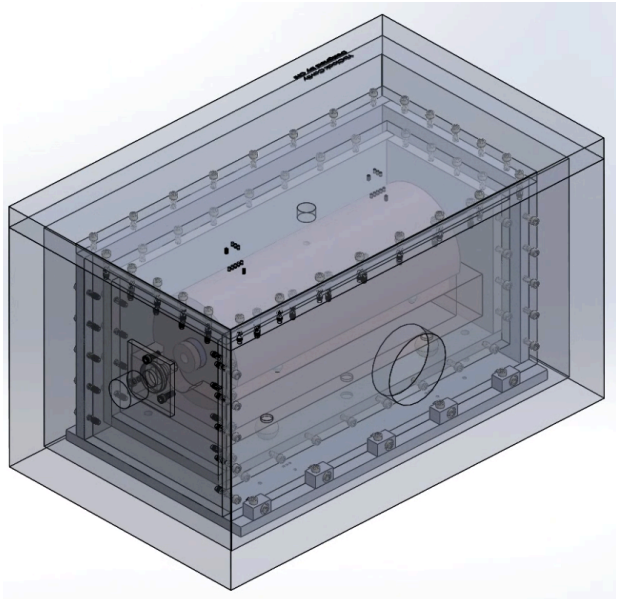
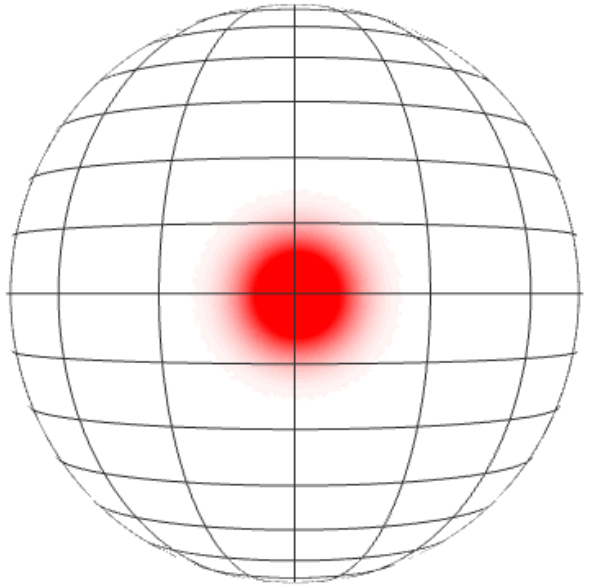
Conclusion and Outlook

- Quantum entanglement on optical clock transition.
- 15x quantum improvement with time-reversed quantum metrology.

- Improve clock laser coherence
- Squeezing-while-rotating
- Multi-ensemble clocks.



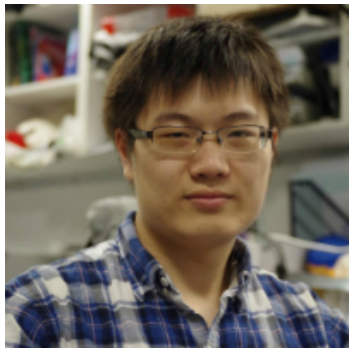


Current Members

Vladan Vuletić, PI

Edwin Pedrozo, Postdoc

Simone Colombo, Postdoc



Chi Shu, Grad. St.

Questions and discussion

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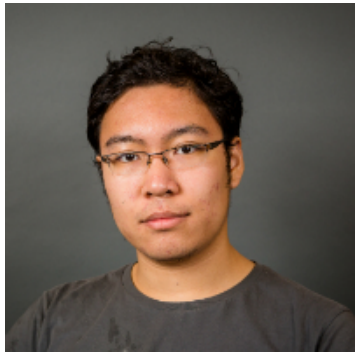

Zeyang Li, Grad. St.

Enrique Mendez, Grad. St.

Former lab members:

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Megan Yamoah
Ozge Ozel
Tailin Wu
Sophie Weber
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Harry Zhou
David Levonian
Grace Zhang
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QinQin Yu
André Heinz
Daisuke Akamatsu
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