Progress Towards Quantum Enhanced Atomic Gravimetry

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Department of Industry, Science and Resources

Australian Government
Australian Research Council

Atomic Gravimetry

de-Broglie wavelength:

$$\lambda = \frac{2\pi\hbar}{p}$$

$$\downarrow$$

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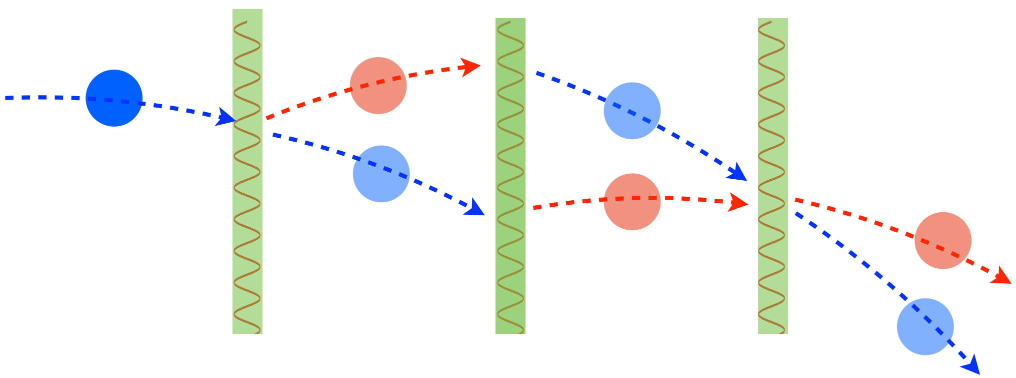
↓

Interferometry with atoms



$\frac{\pi}{2}$ π $\frac{\pi}{2}$

Atomic Gravimetry

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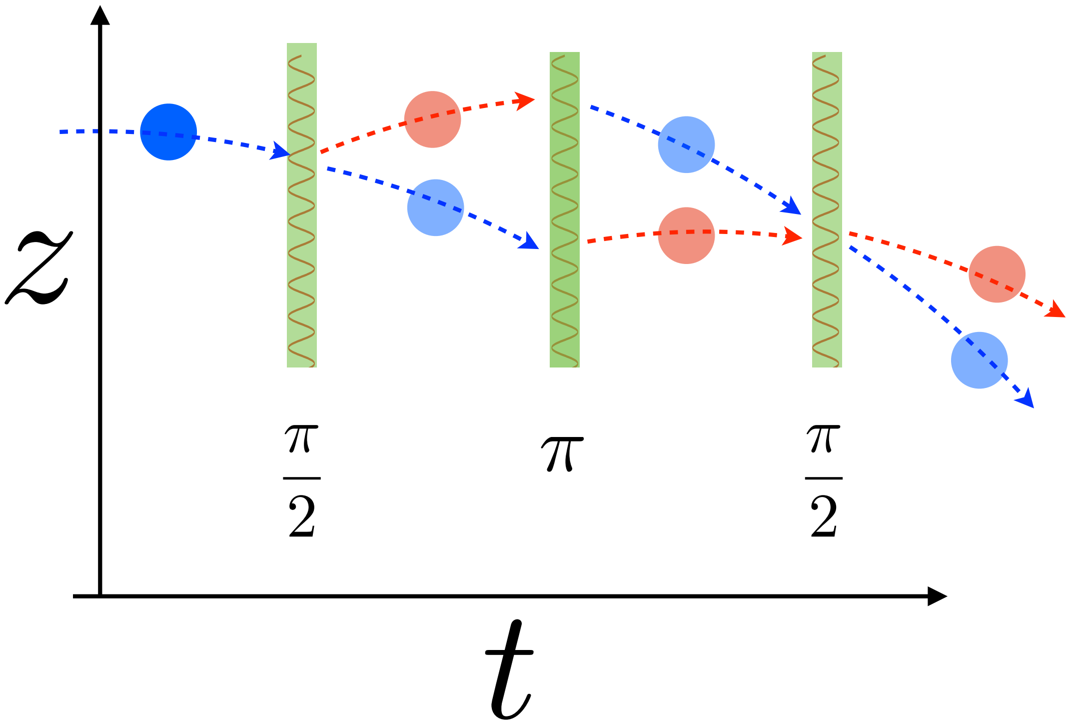

Allows for very precise measurements of gravity

$$\Delta g = \frac{1}{kT^2}\frac{1}{\sqrt{N}}$$

Question:

What is g (in SI units)?

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$$g = 9.8 \text{ m/s}^2$$

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$$g = 9.7959938810(19)\ \mathrm{m/s^2}$$

Question:

What is g (in SI units)?

Latitude

Density (Rocks)

Moon

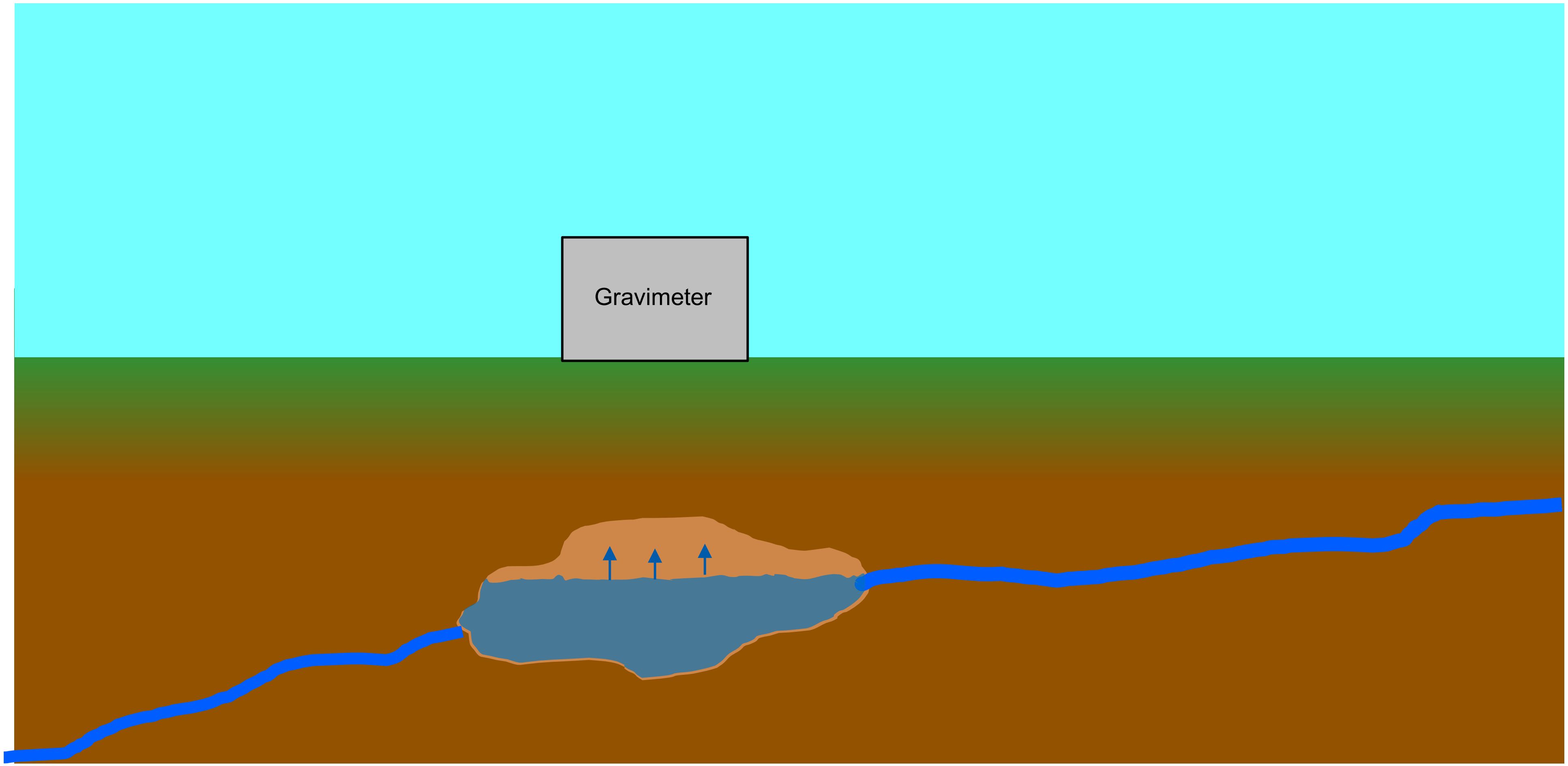
Hydrology

$$g = 9.7959938810(19)\ \mathrm{m/s^2}$$

Altitude

People, Chairs

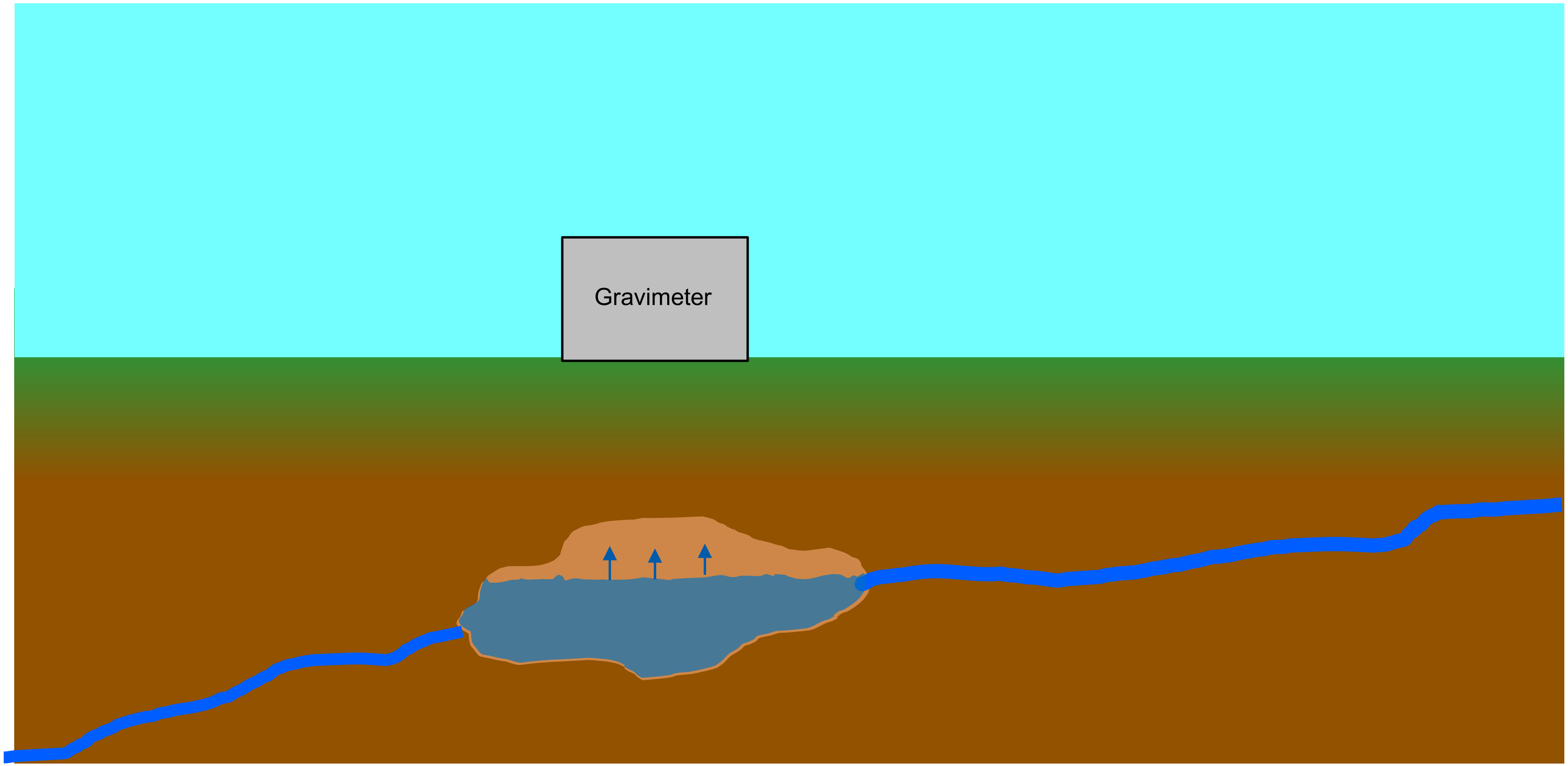
Applications: Gravimetry



Samuel Legge, John Close

Applications: Gravimetry

30% of water in NSW is missing!



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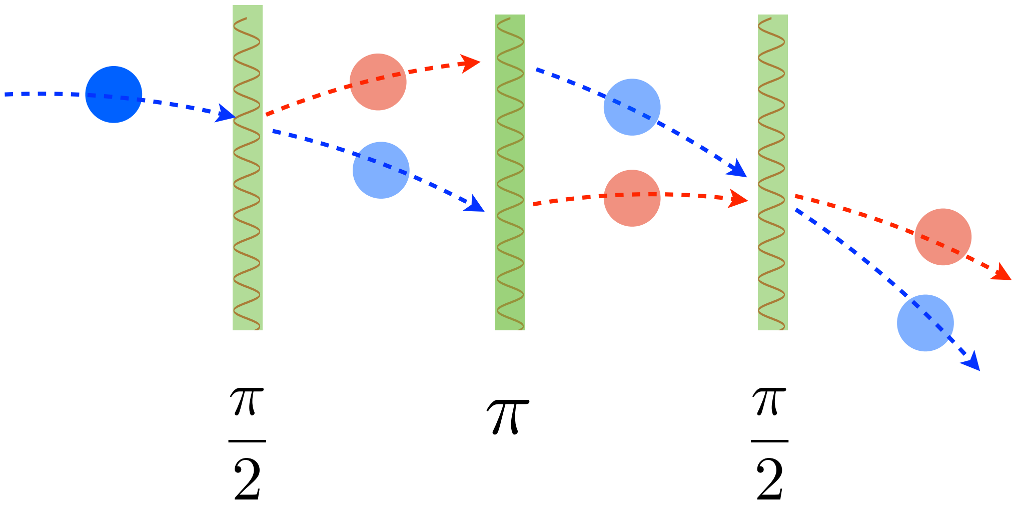
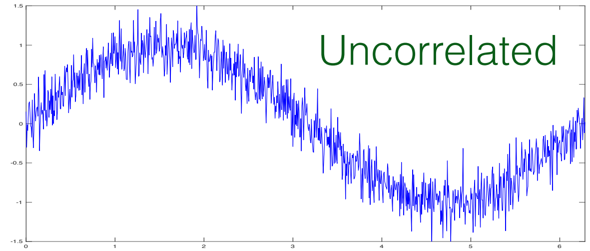
Quantum Entanglement

Increased precision and bandwidth through quantum entanglement





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Uncorrelated atoms (Shot-noise limit)

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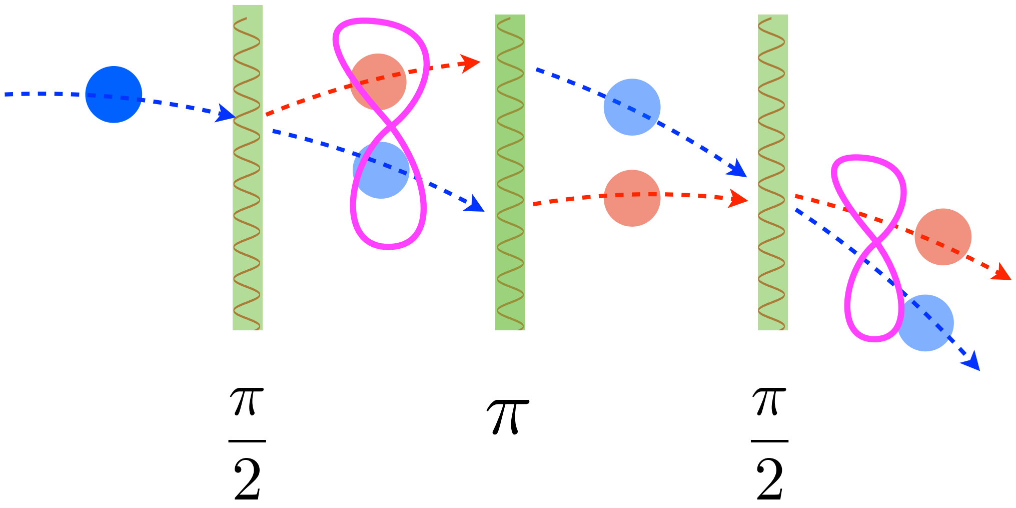

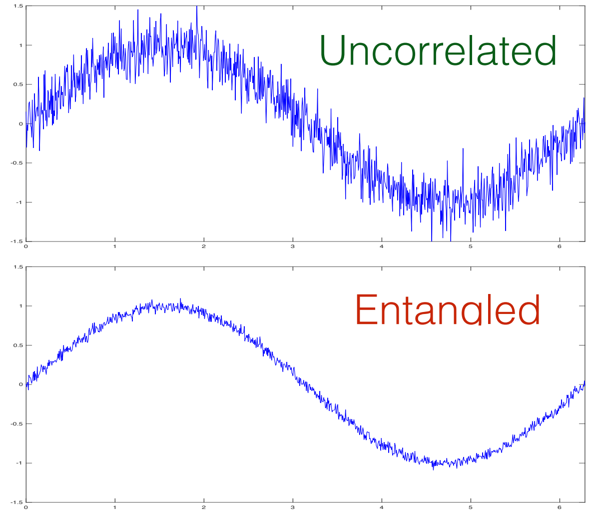

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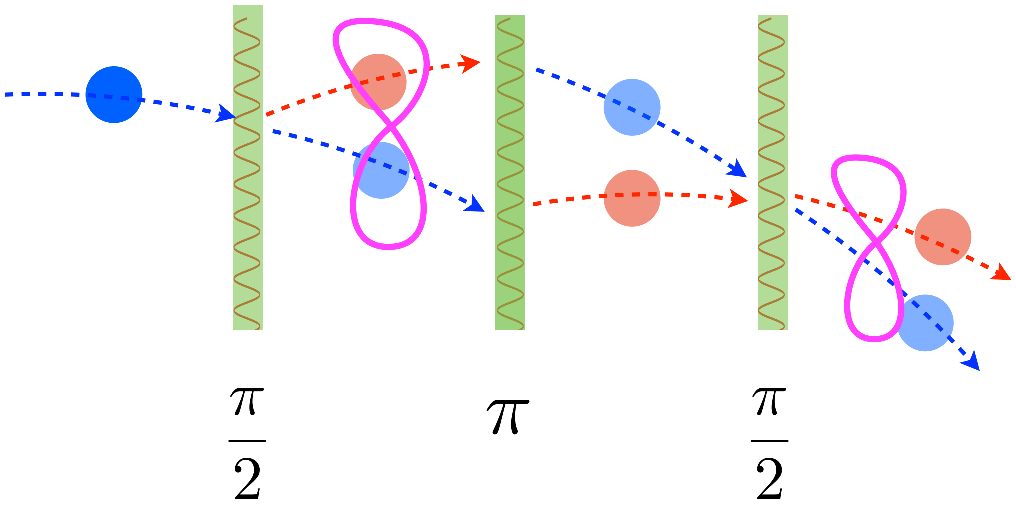

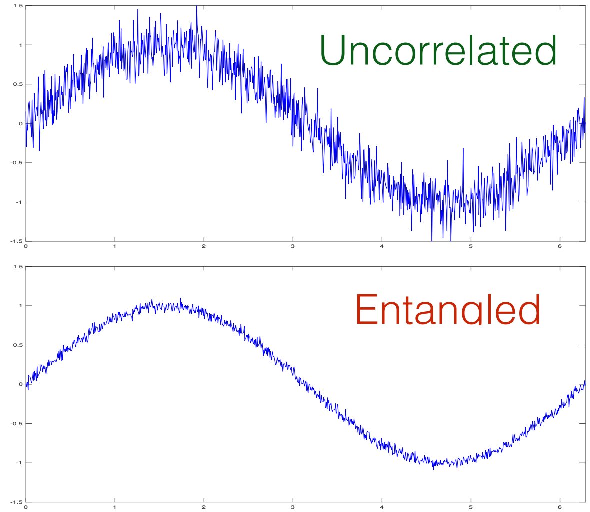

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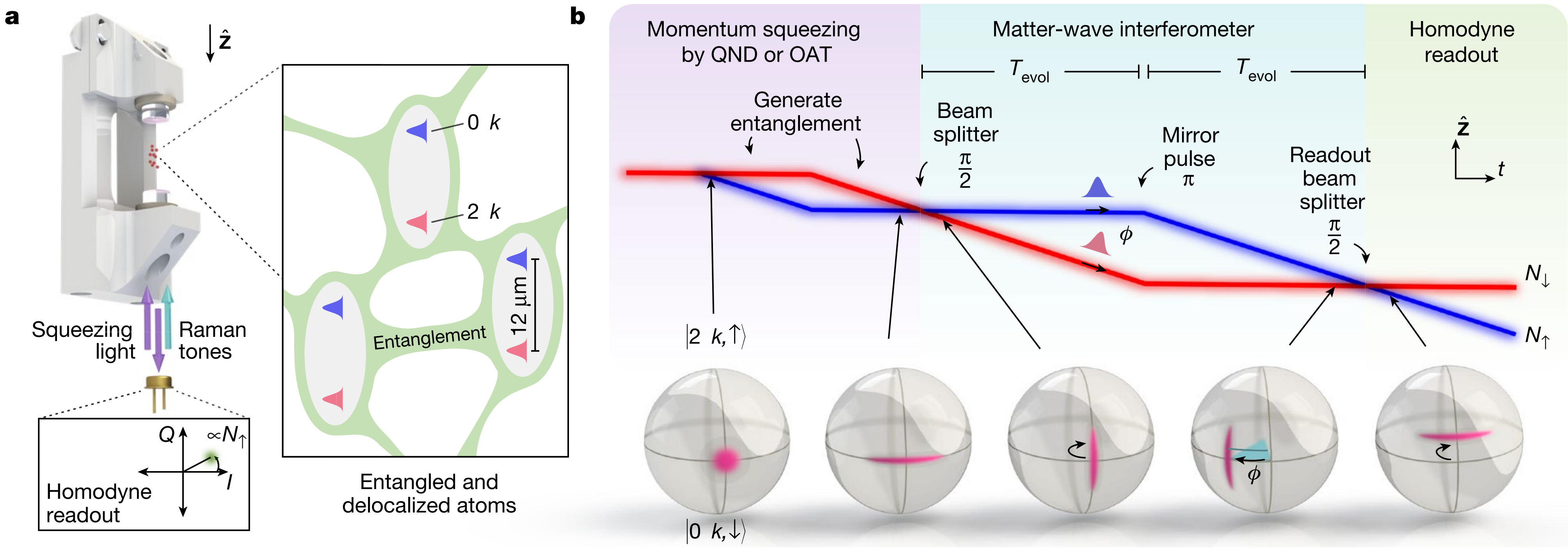
$N = 10^6$ 1000 times more sensitive!



Graham P. Greve, Chengyi Luo, Baochen Wu & James K. Thompson, Nature 610, 472 (2022)

T = 0.7 ms (short)

Requires optical cavity

One-Axis Twisting in BEC

$$\hat{H} = \sum_{i,j=a,b} \frac{U_{ij}}{2} \int \hat{\psi}_i^\dagger(\mathbf{r})\hat{\psi}_j^\dagger(\mathbf{r})\hat{\psi}_i(\mathbf{r})\hat{\psi}_j(\mathbf{r})\, d^3\mathbf{r} \quad \rightarrow \hbar\chi \hat{J}_z^2$$

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- Causes entanglement between relative number and relative-phase degrees of freedom

$$|\Psi\rangle = \sum_n C_{n_a,n_b}|n_a, n_b\rangle \rightarrow \sum_n C_{n_a,n_b}|n_a, n_b\rangle e^{-it\chi(n_a-n_b)^2}$$

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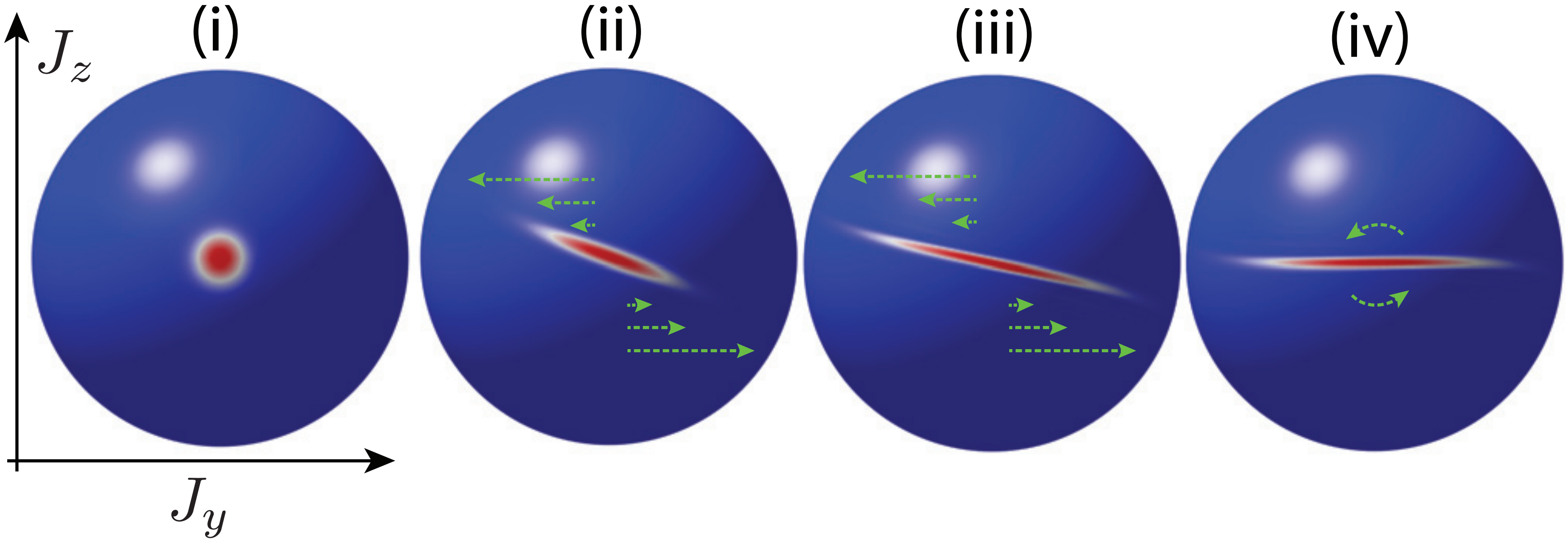

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$$\chi = \frac{U_{aa}}{\hbar} \int |\phi_a(\mathbf{r})|^4 \; d^3\mathbf{r} + \frac{U_{bb}}{\hbar} \int |\phi_b(\mathbf{r})|^4 \; d^3\mathbf{r} - 2\frac{U_{ab}}{\hbar} \int |\phi_a(\mathbf{r})|^2 \, |\phi_b(\mathbf{r})|^2 \; d^3\mathbf{r} \qquad \approx 0$$

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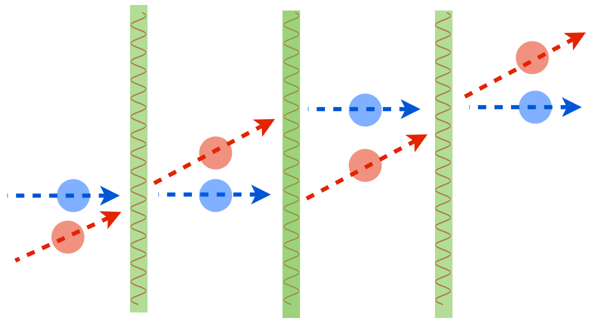
- Methods demonstrated so far don't results in two well-defined momentum modes



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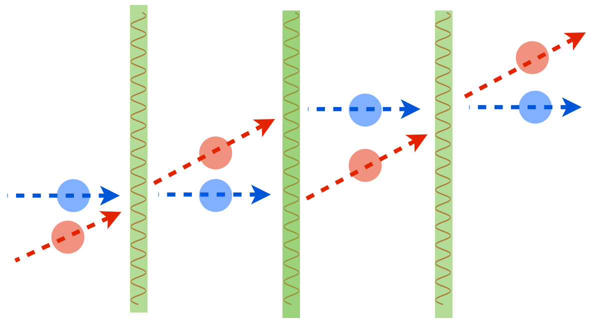

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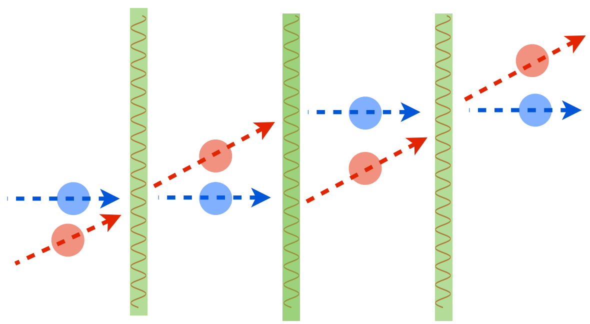

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Not compatible with atomic gravimetry

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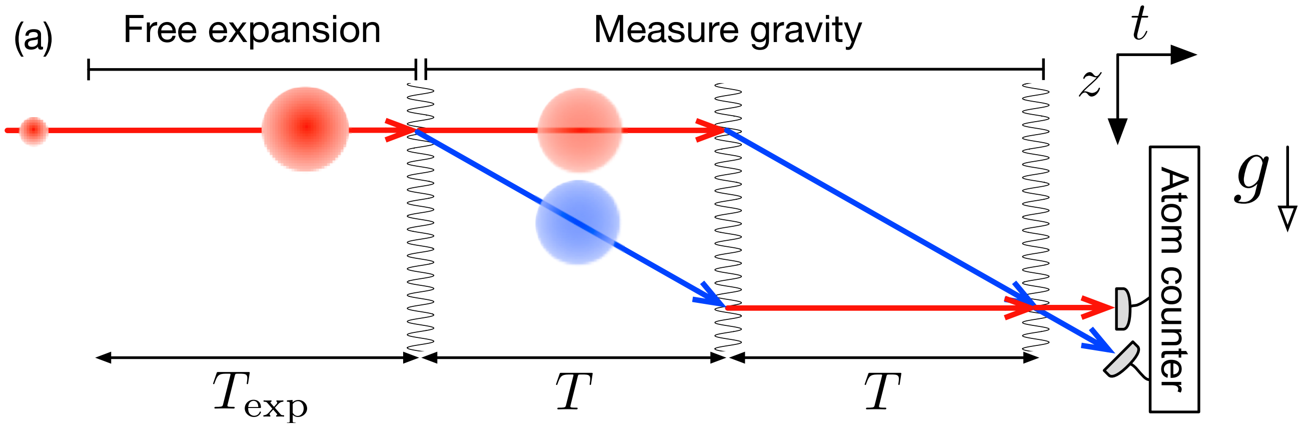

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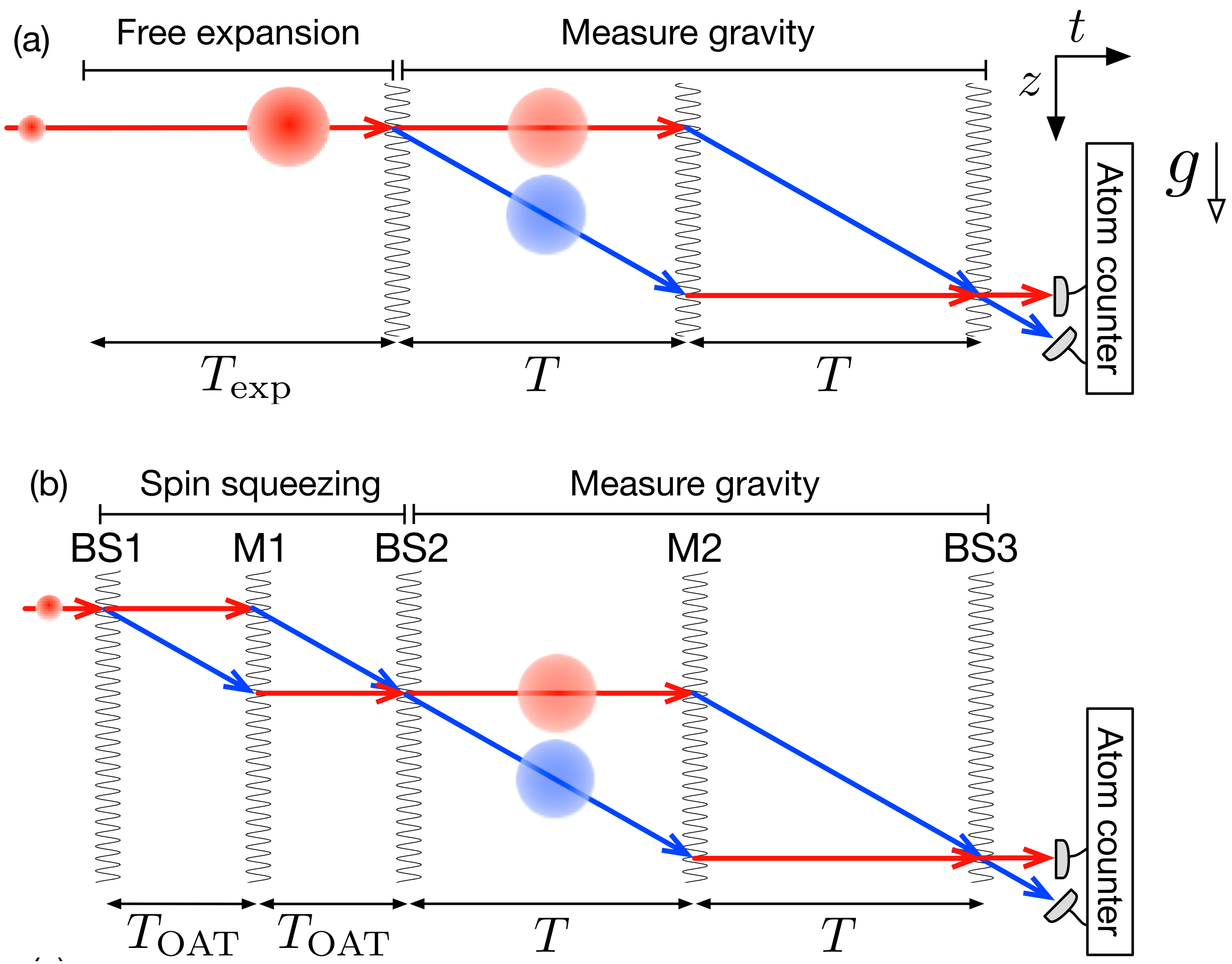

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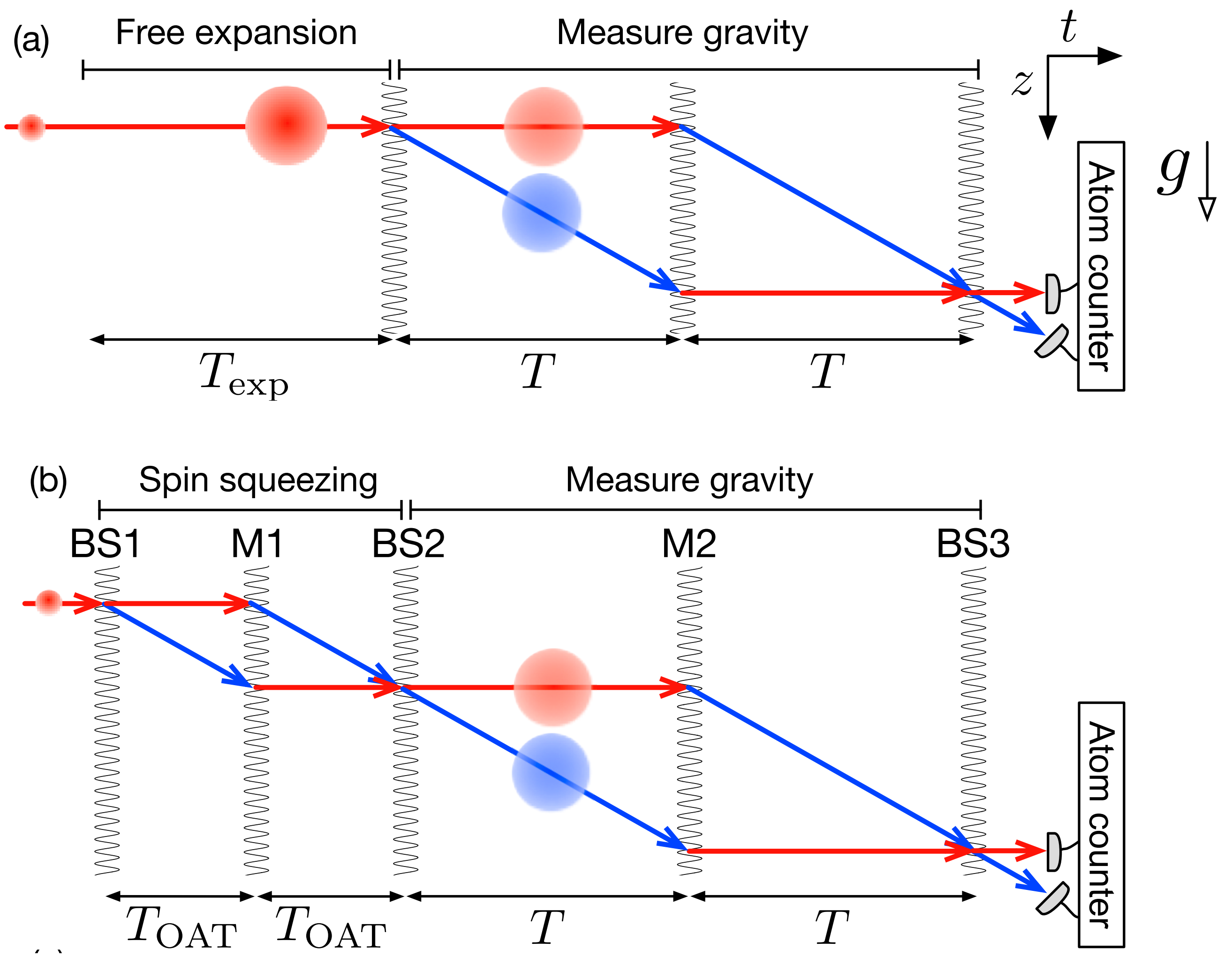

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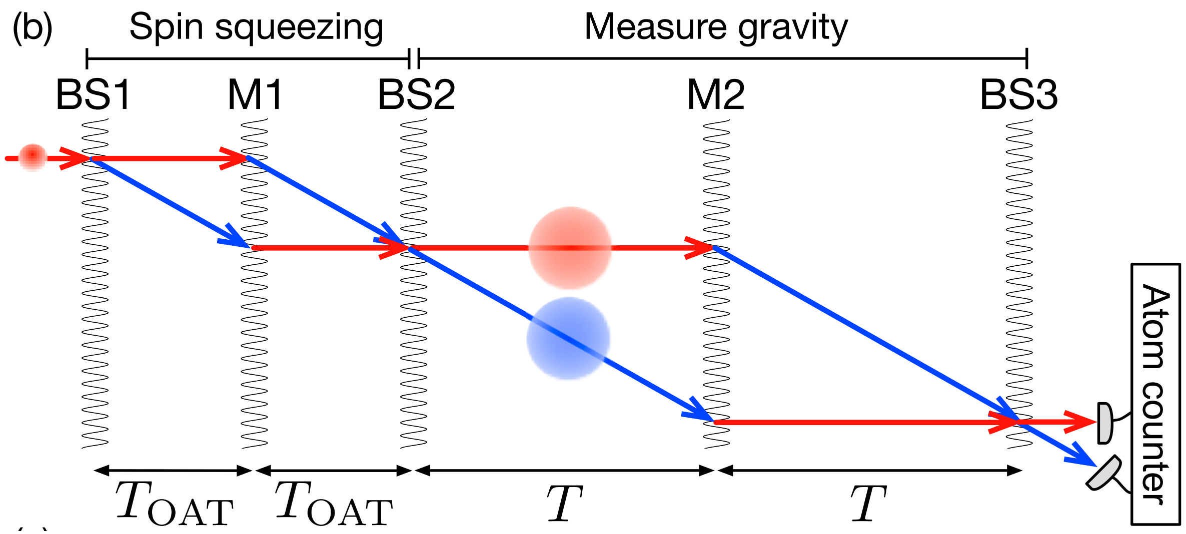
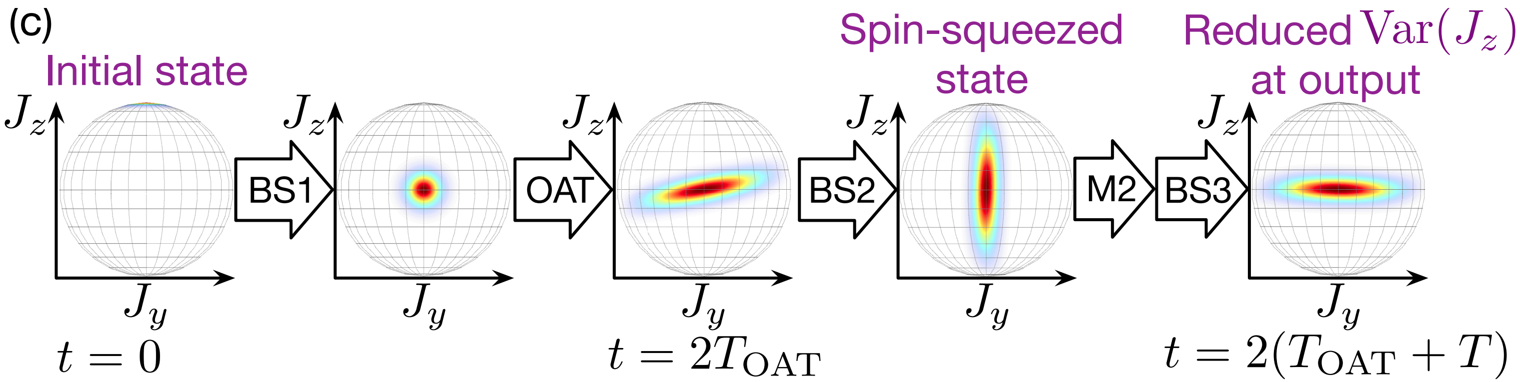
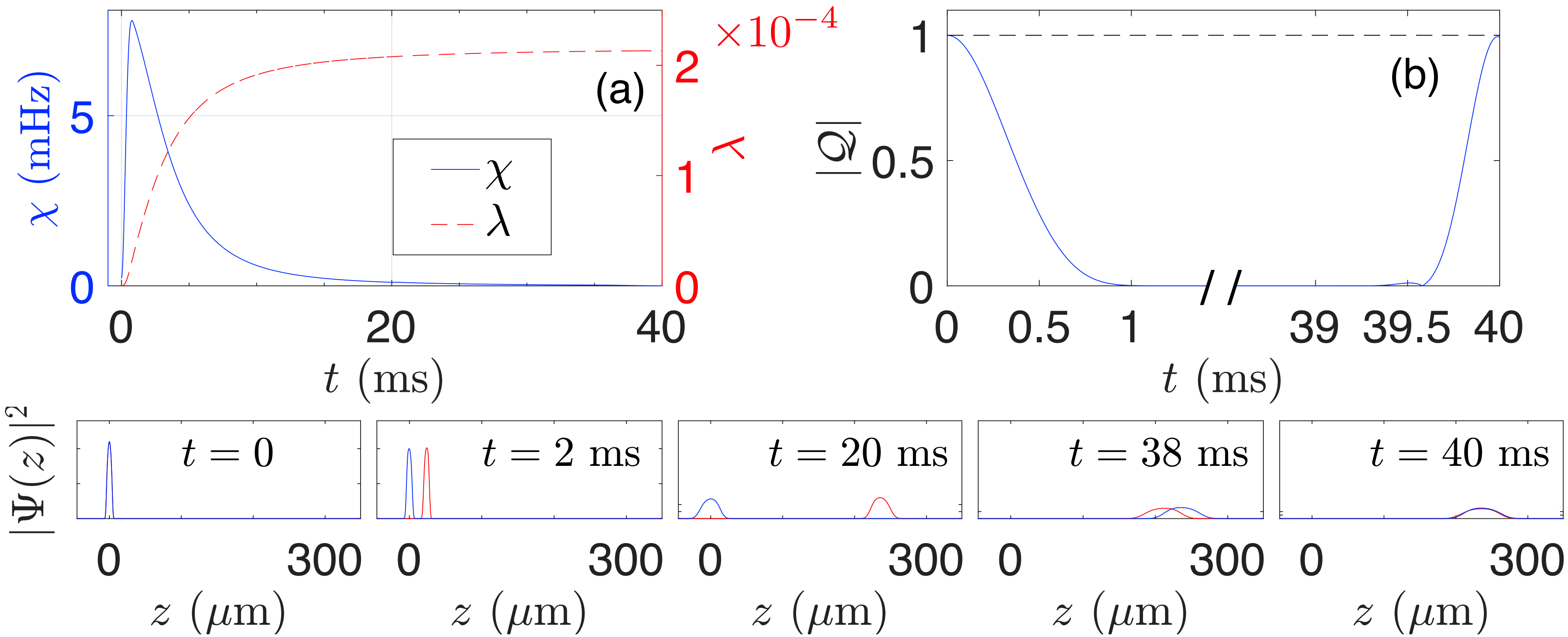




SS Szigeti, SP Nolan, JD Close, SA Haine, PRL **125** 100402 (2020)

GPE simulation:



Quantum Field Simulation:

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- Looks like GPE + noise. Includes quantum correlations

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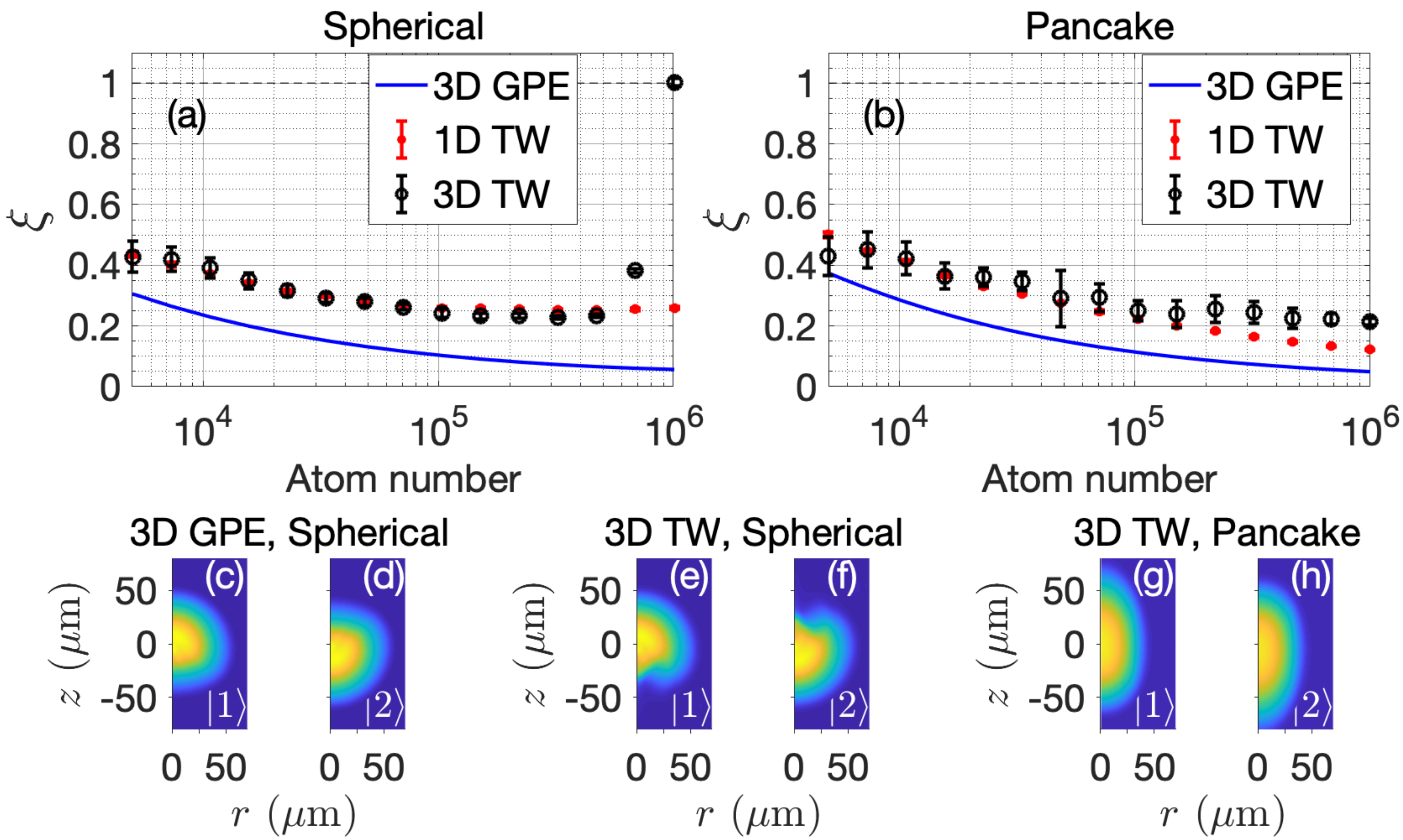
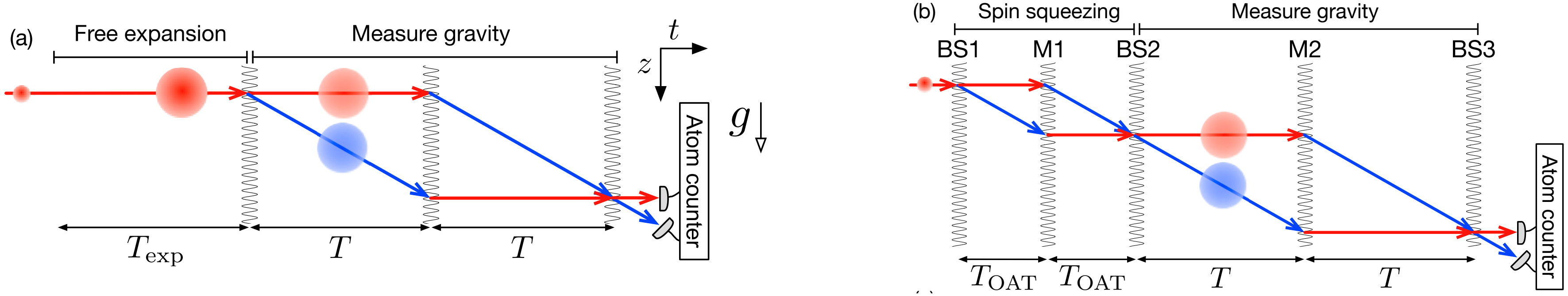
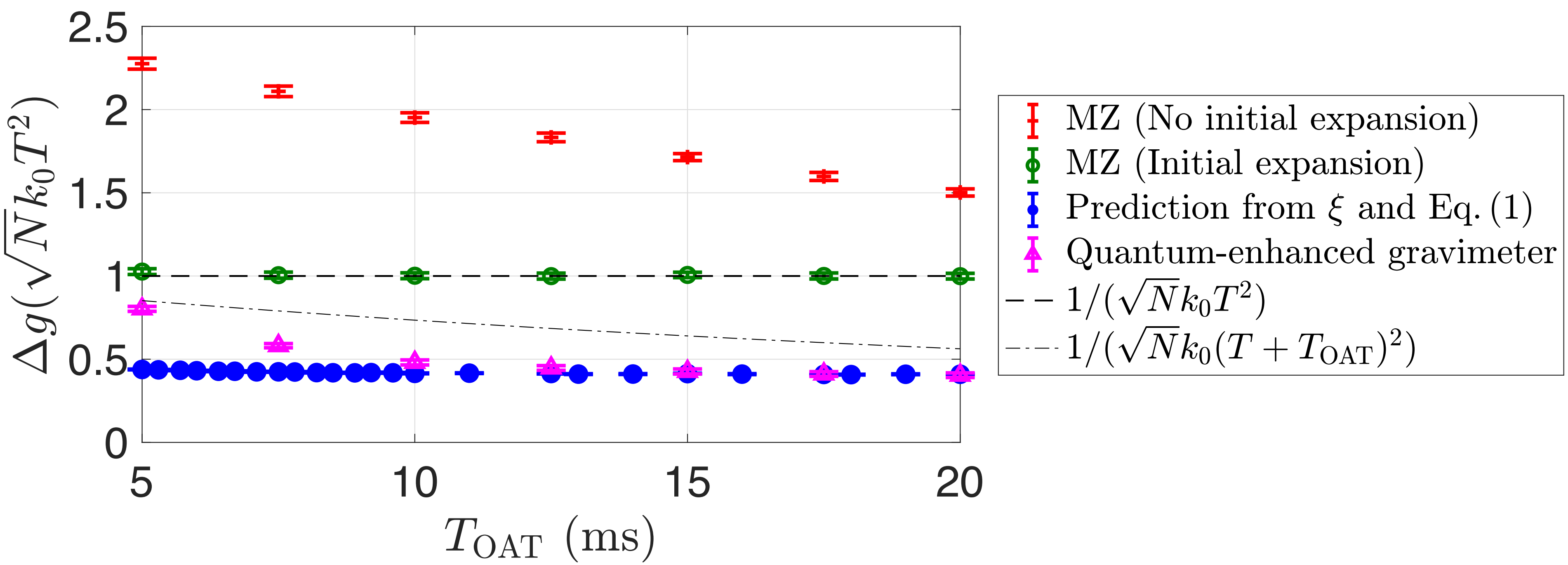


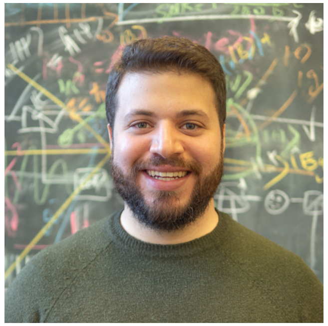
Is this actually better than not squeezing?

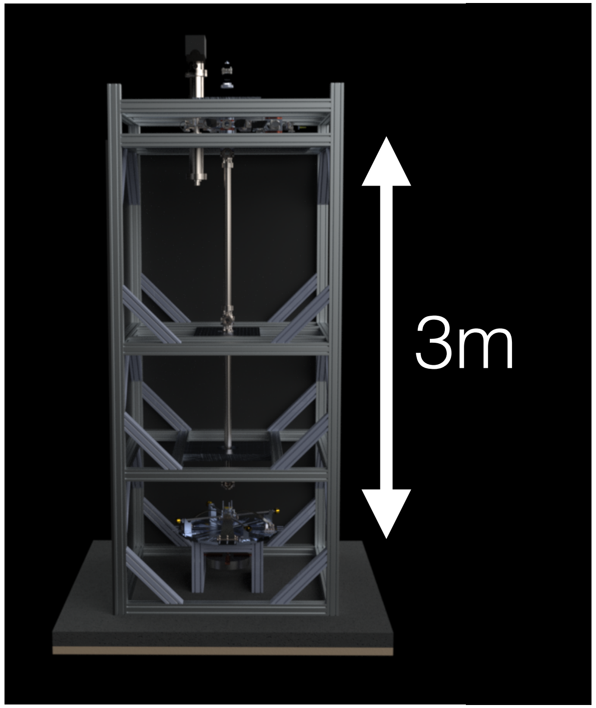




S Szigeti, S Nolan, J Close, and S Haine
Phys. Rev. Lett. **125**, 100402 – Published 3 September 2020

Time to start building





Australian Government
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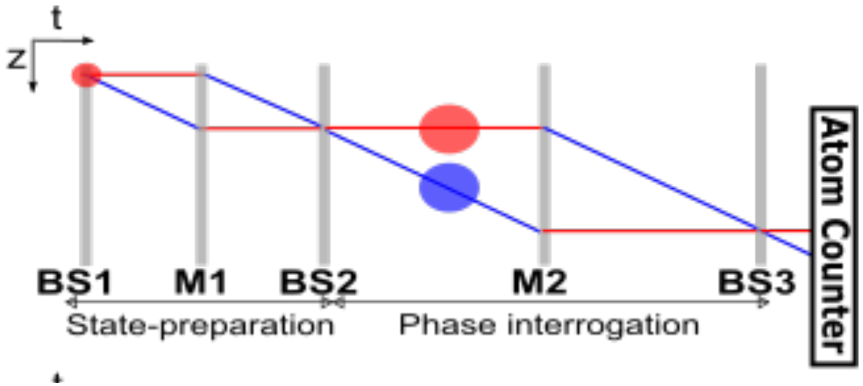
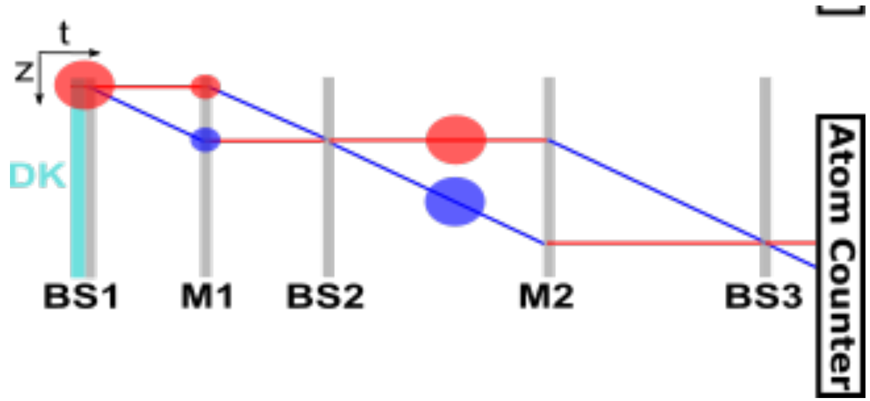
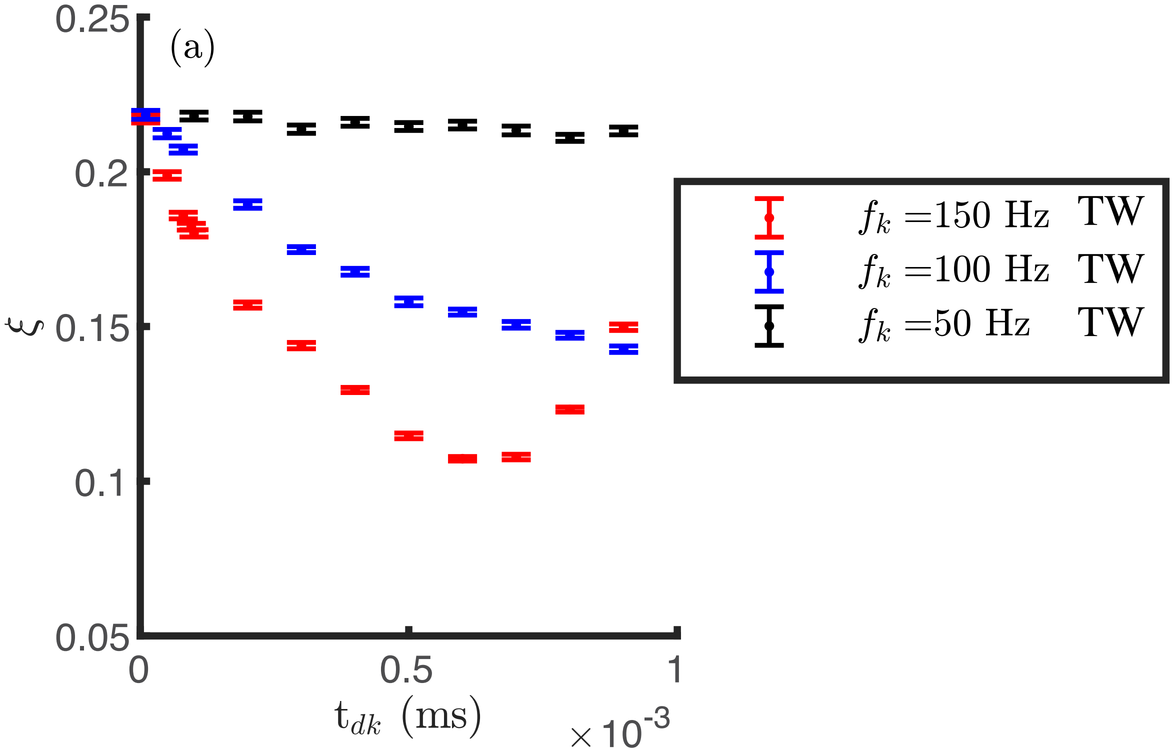
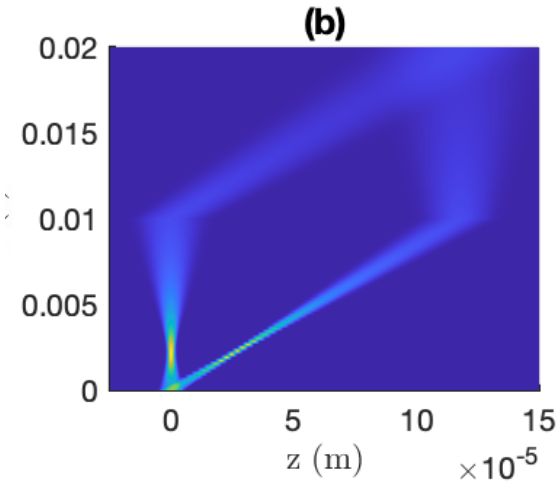
Delta-Kick scheme



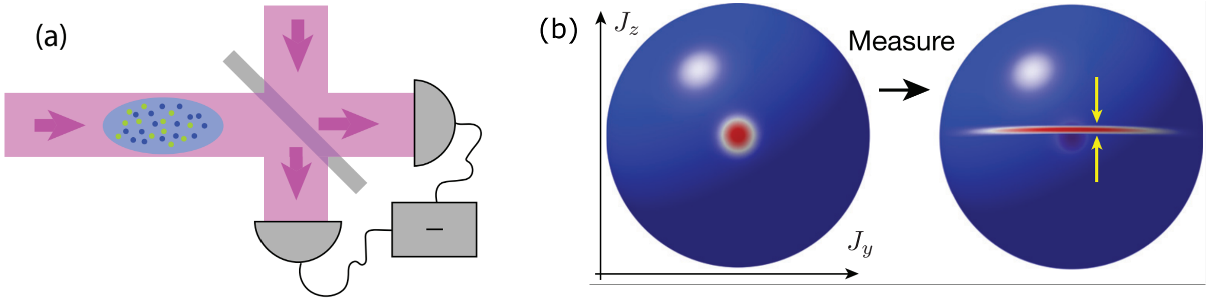






(credit: Karandeep Gill)

QND + OAT:



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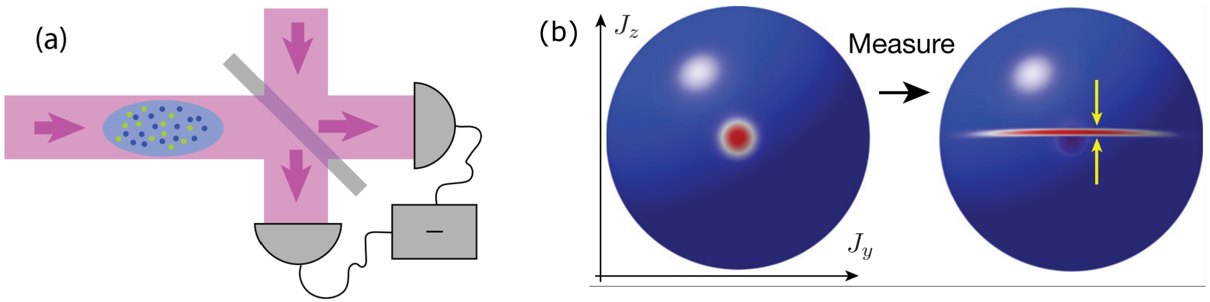

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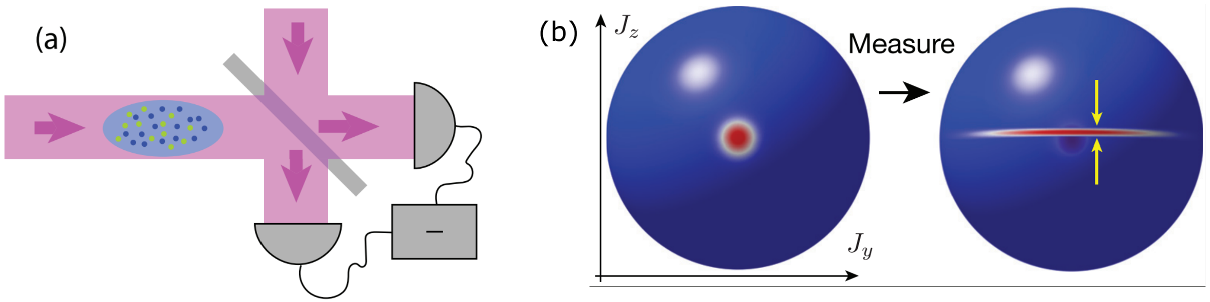

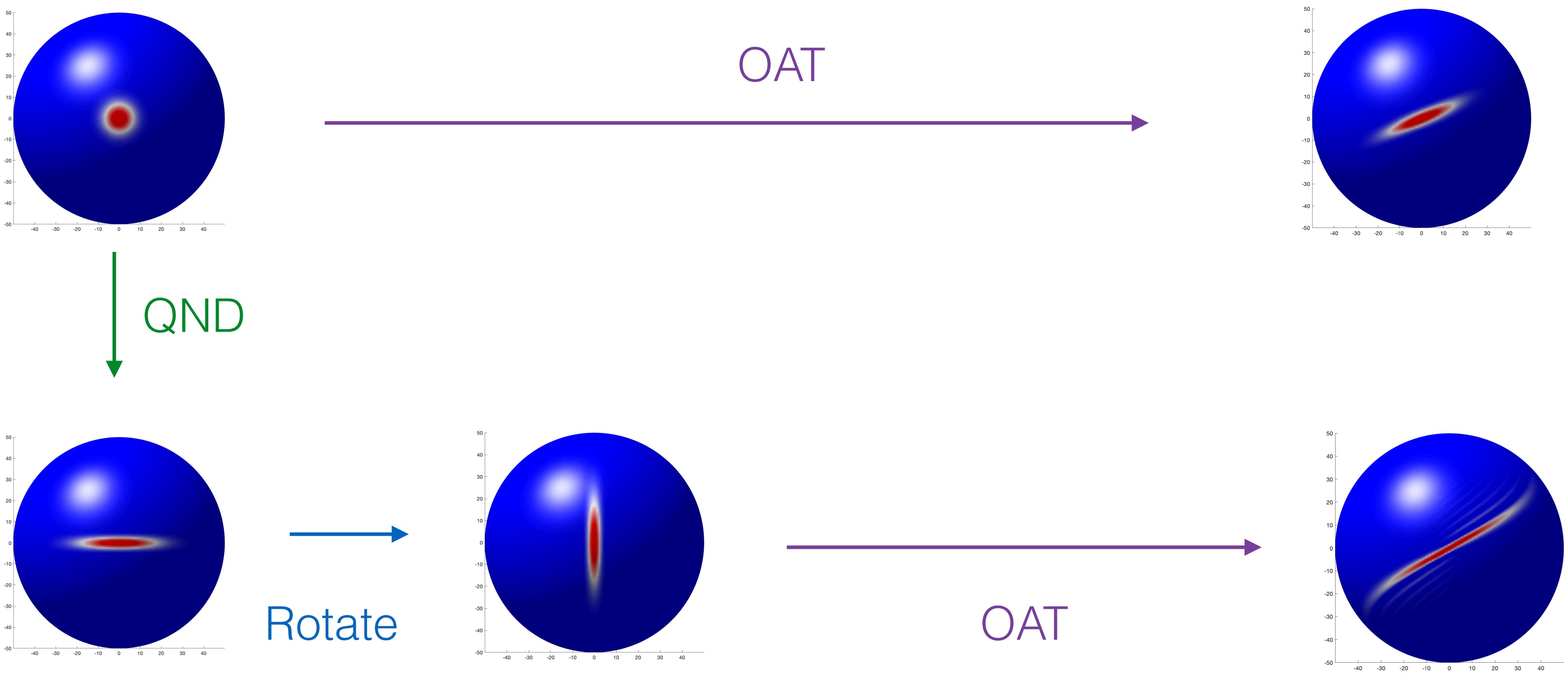

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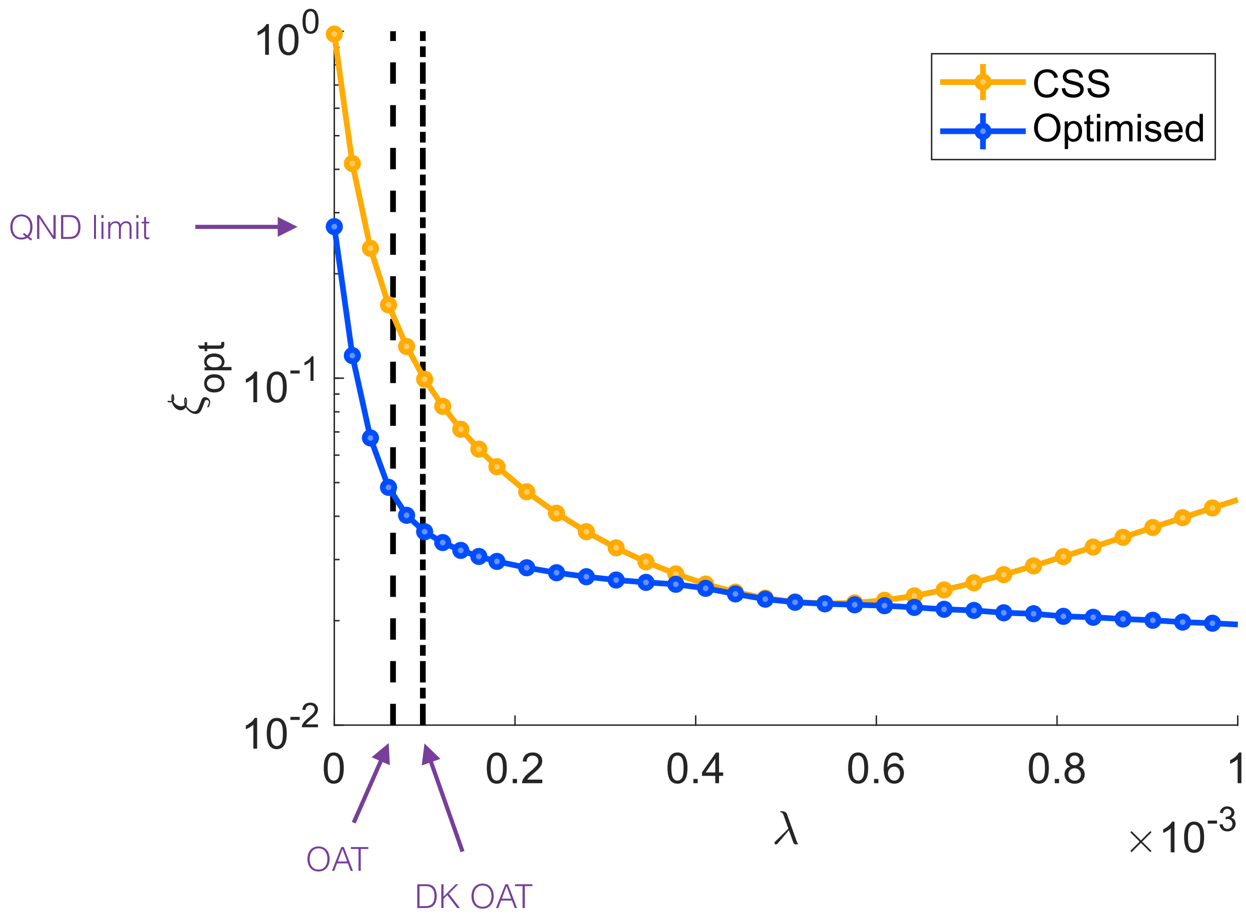

(credit: Liam Fuderer)

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