

Towards broadband quantum noise reduction in GWIs using an atomic noise eater.

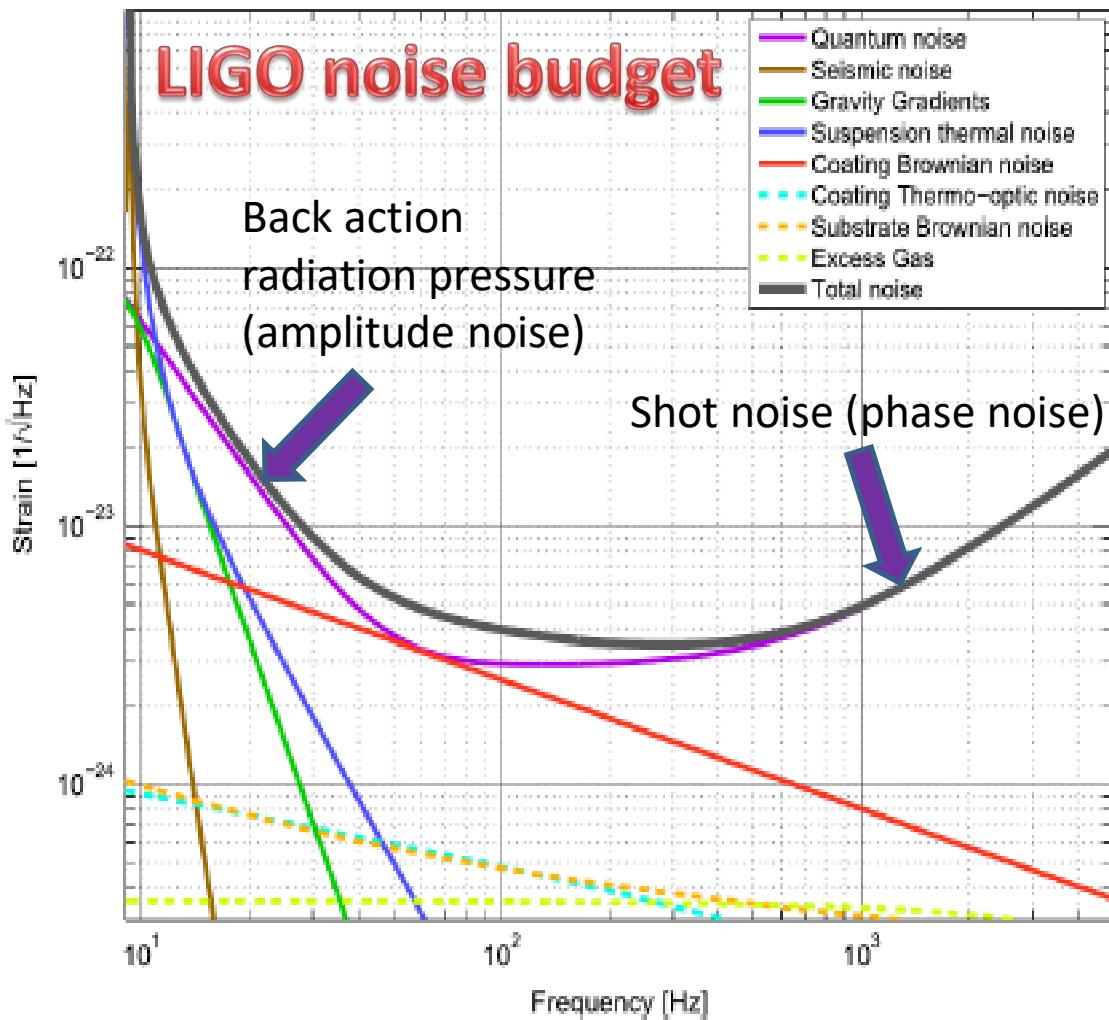
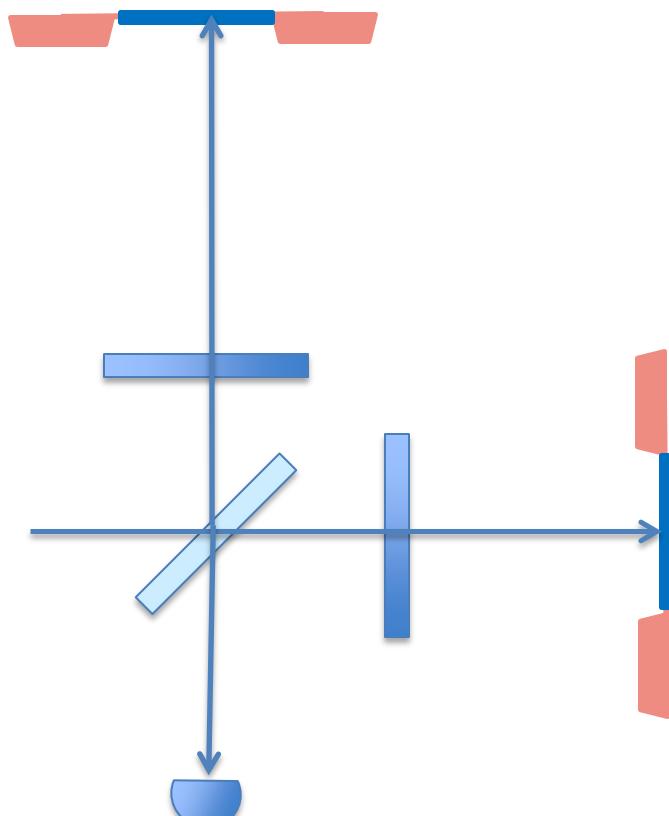
Eugene Polzik

Niels Bohr Institute

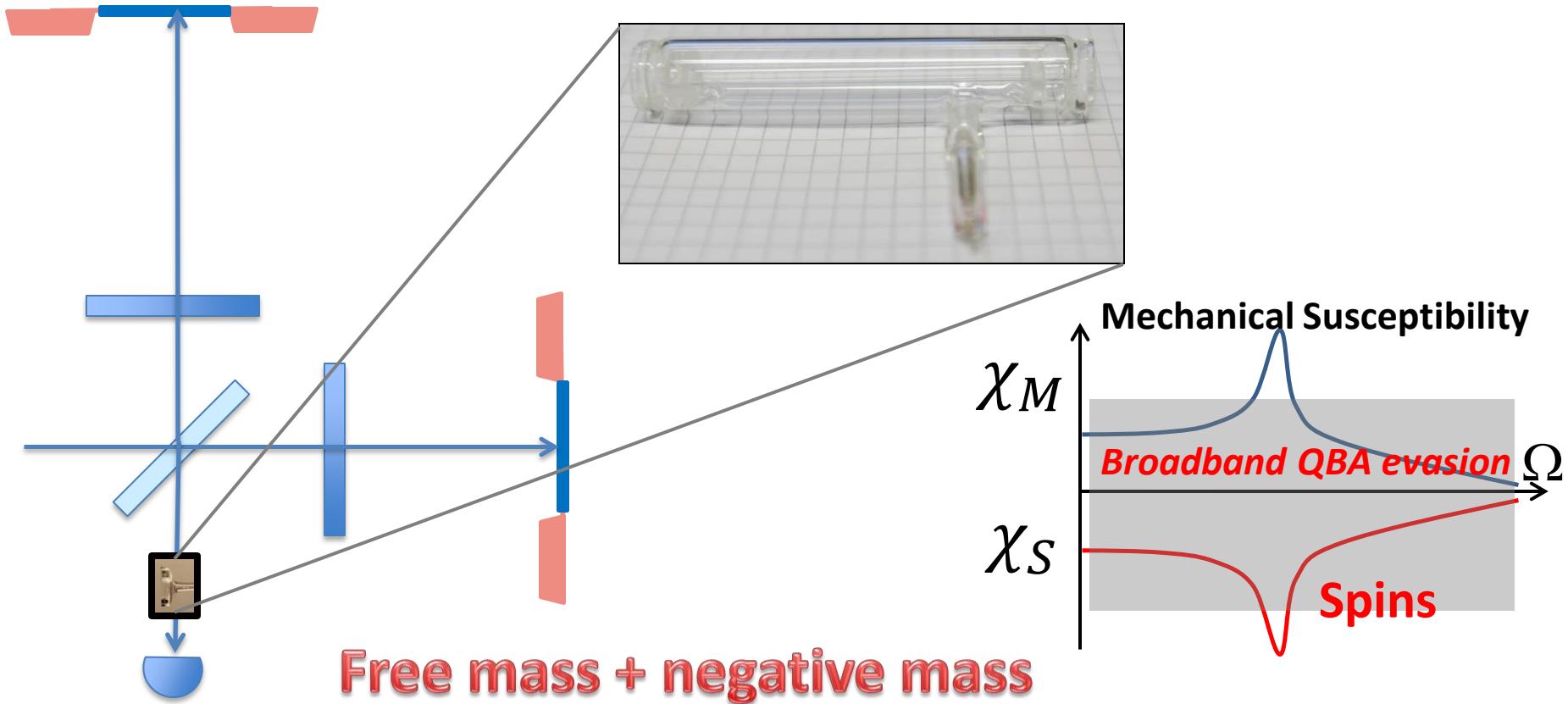


Villum
Foundation

GWD BEYOND SQL WITH NEGATIVE MASS SPINS



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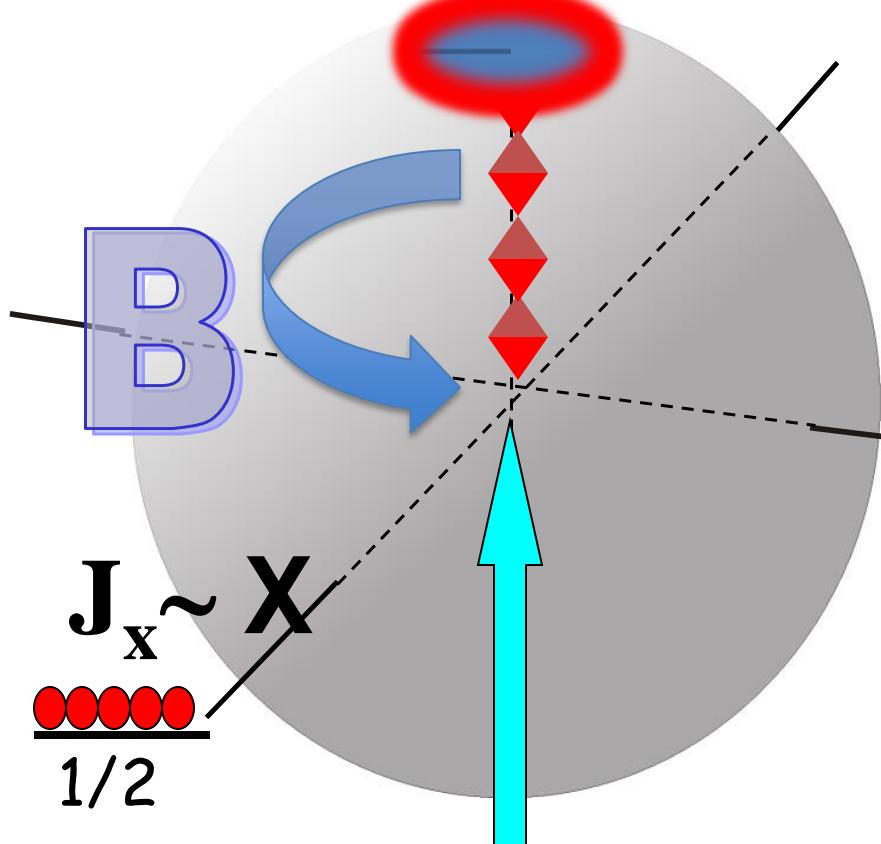
$$X_-(t) = X(t) - X_0(t) = X - X_0 + \frac{Pt}{m} - \frac{P_0 t}{-m} = X_- + \frac{P_+ t}{m}$$

$$[\hat{X}_-, \hat{P}_+] = 0 \Rightarrow \Delta X_- \Delta P_+ \geq 0 \Rightarrow [\Delta X_-(t)]^2 \geq 0 \quad (\text{EPR})$$

Spin ensemble = positive/negative mass oscillator

$$[\hat{J}_x, \hat{J}_y] = iJ_z$$

$$J_z|$$

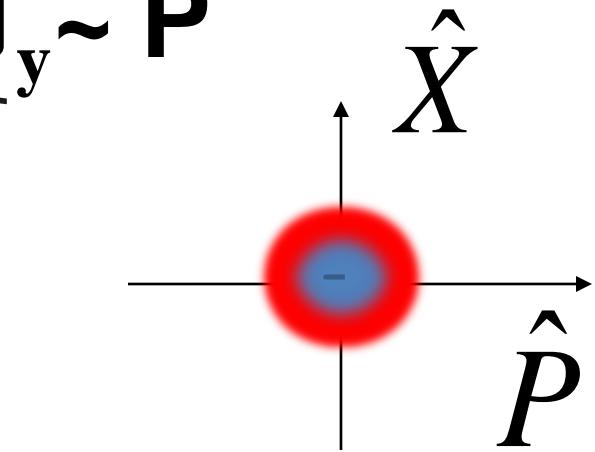


$\overline{-1/2}$

$$J = \sum_{i=1}^N j_i$$

Negative mass oscillator

$$J_y \sim P$$

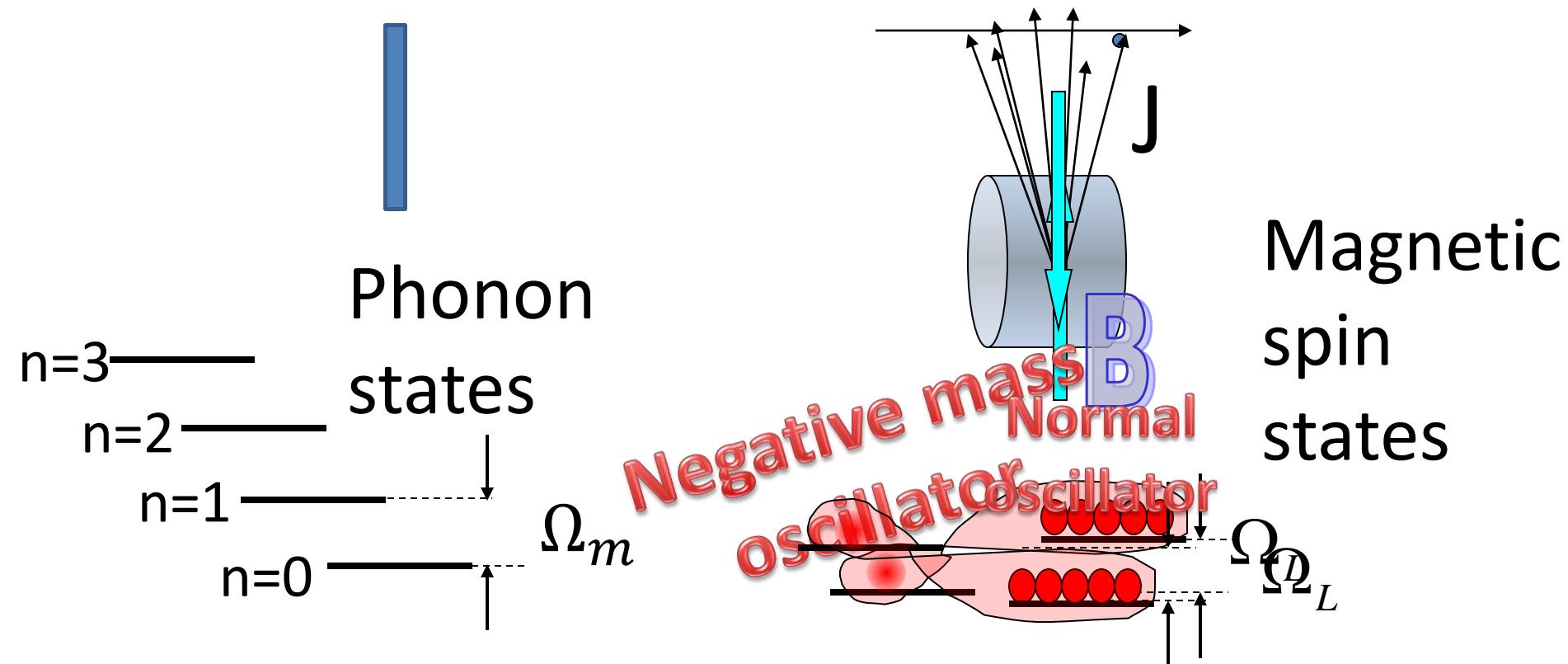


$$[\hat{X}, \hat{P}] = i$$

Holstein-Primakoff

Quantum back-action-evading measurement of motion in a negative mass reference frame

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Quantum back action free measurement of motion

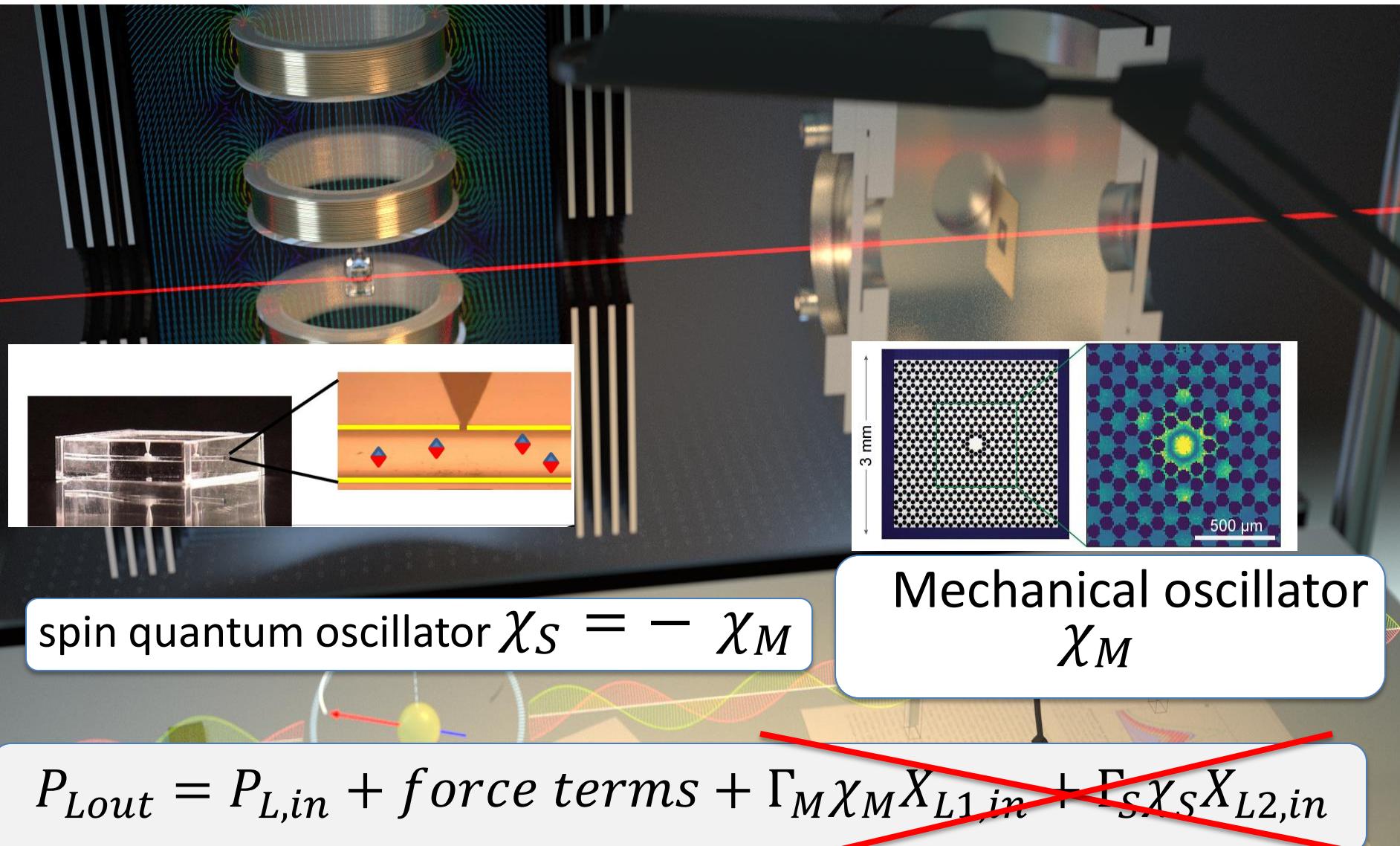
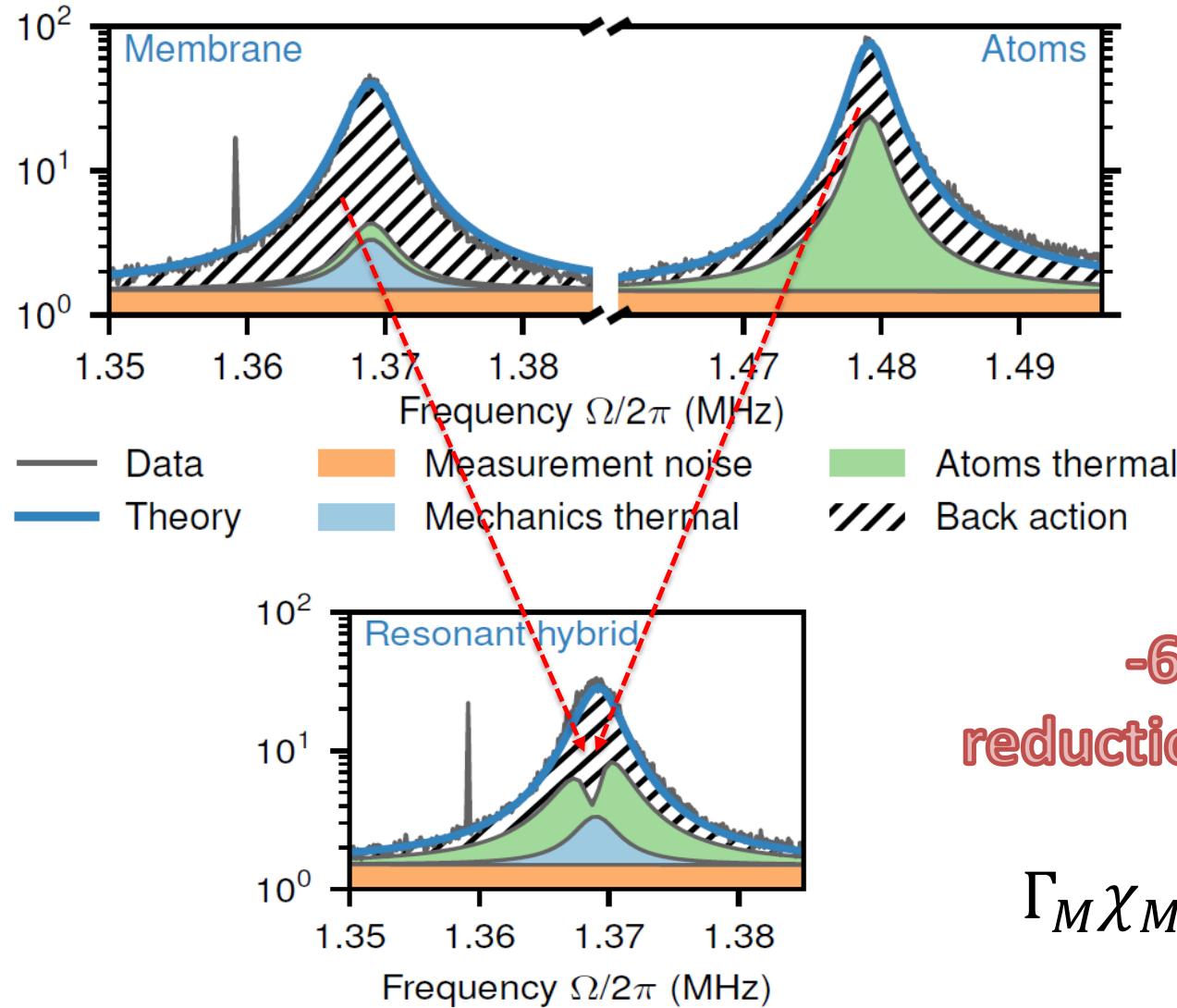


Image credit

Bastian Leonhardt Strube and Mads Vadsholt

Cancellation of Quantum backaction noise in negative mass reference frame



-6 dB
reduction of QBA

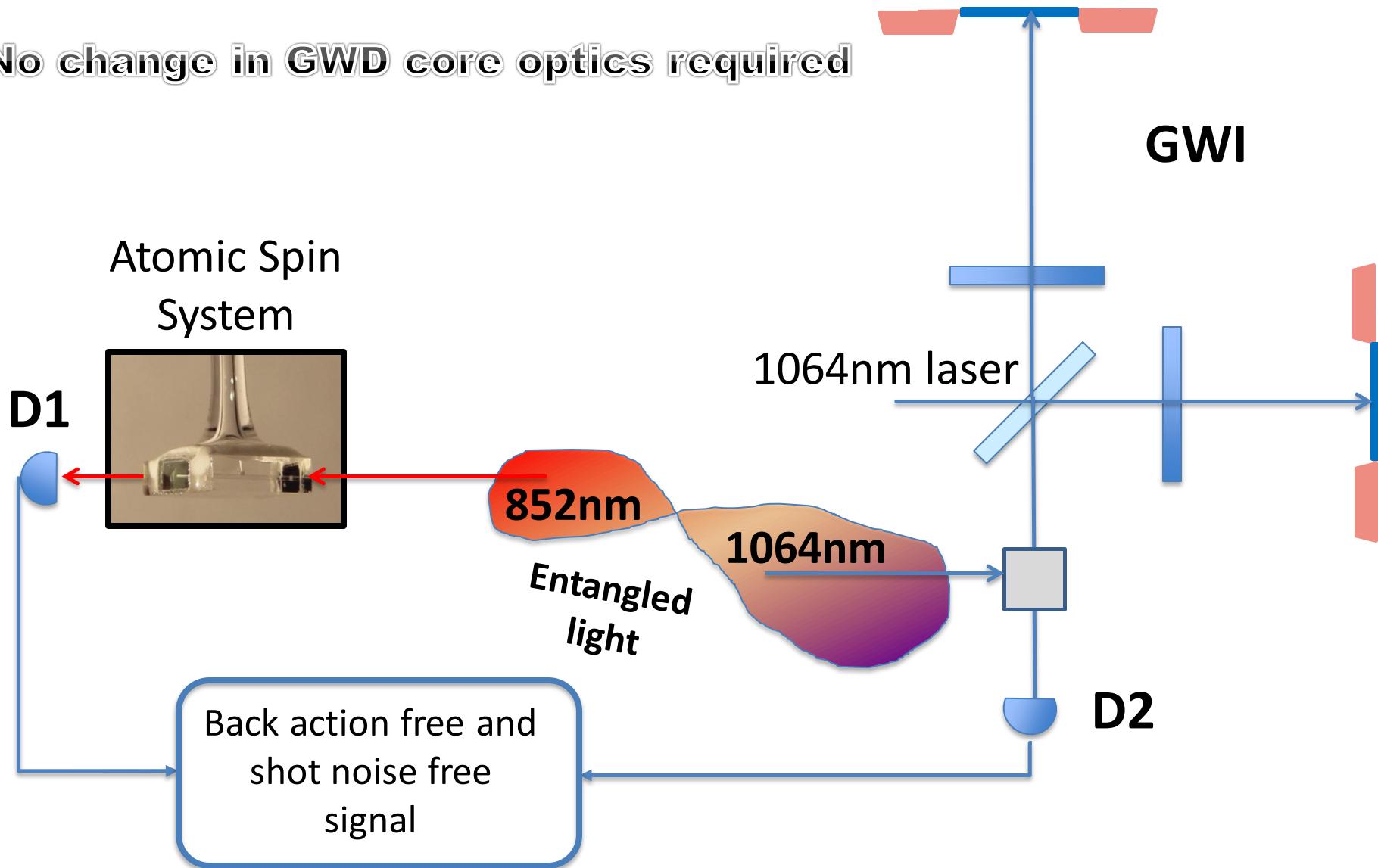
$$\Gamma_M \chi_M = -\Gamma_S \chi_S$$

$P_{Lout} = P_{L,in} + \text{force terms} + \Gamma_M \chi_M X_{L1,in} + \Gamma_S \chi_S X_{L2,in}$

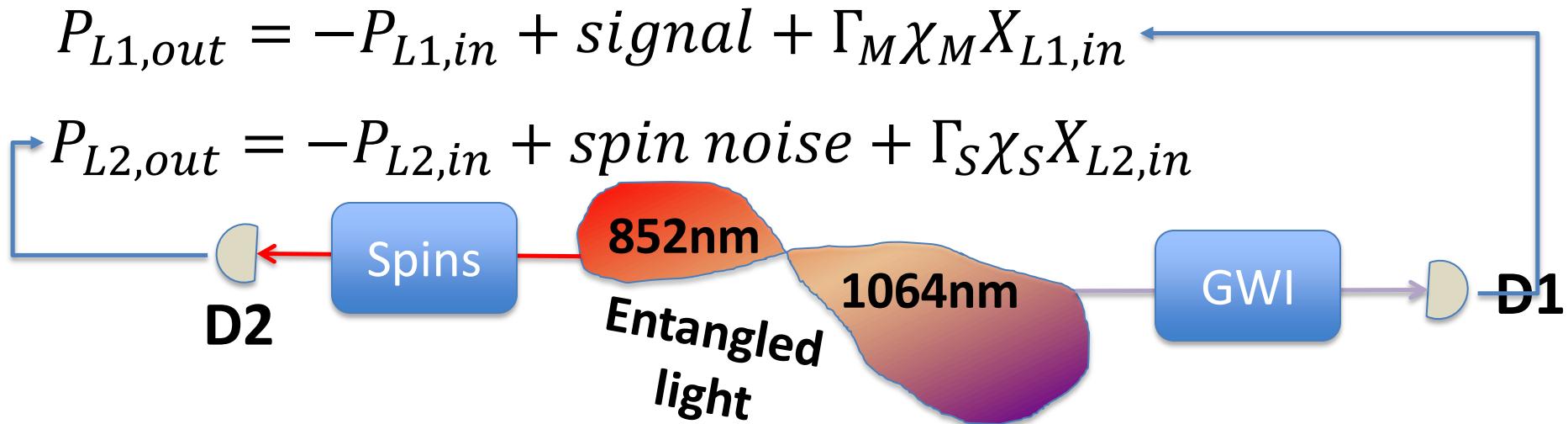
F. Khalili and E.S.P. *Quantum back action evading detection of gravitational waves in a negative mass reference frame*. PRL July 2018

E. Zeuthen, E.S.P., F. Khalili. *Gravitational wave detection beyond the standard quantum limit using a negative-mass spin system and virtual rigidity*. PRD, 100, 062004 (2019).

No change in GWD core optics required



Probing the hybrid system with EPR entangled light modes



$$P_{L1,out} - P_{L2,out} = -P_{L1,in} + P_{L2,in} + force\ terms \\ + \Gamma_M \chi_M X_{L1,in} - \Gamma_S \chi_S X_{L2,in}$$

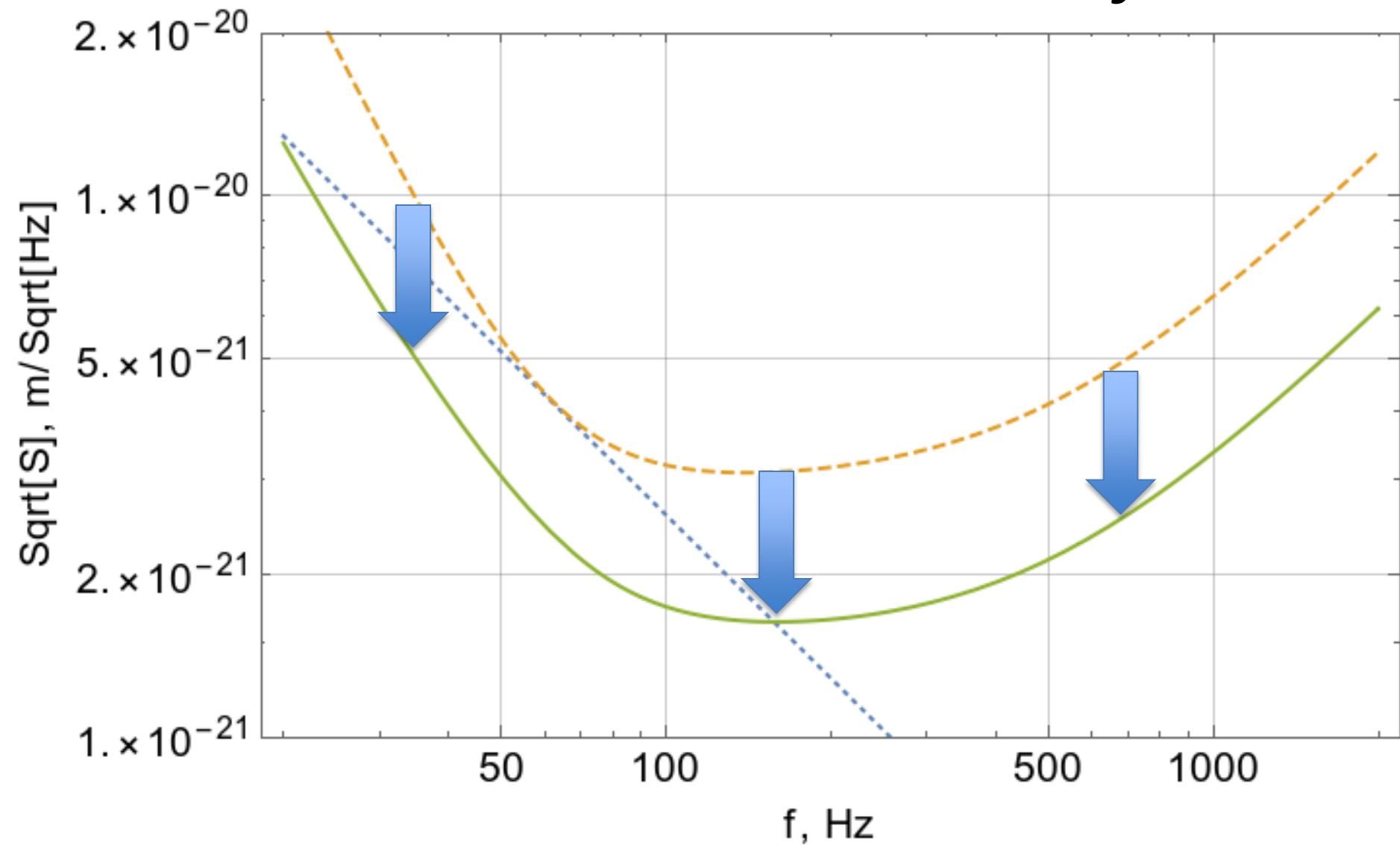
$$\Gamma_S \chi_S = -\Gamma_M \chi_M$$

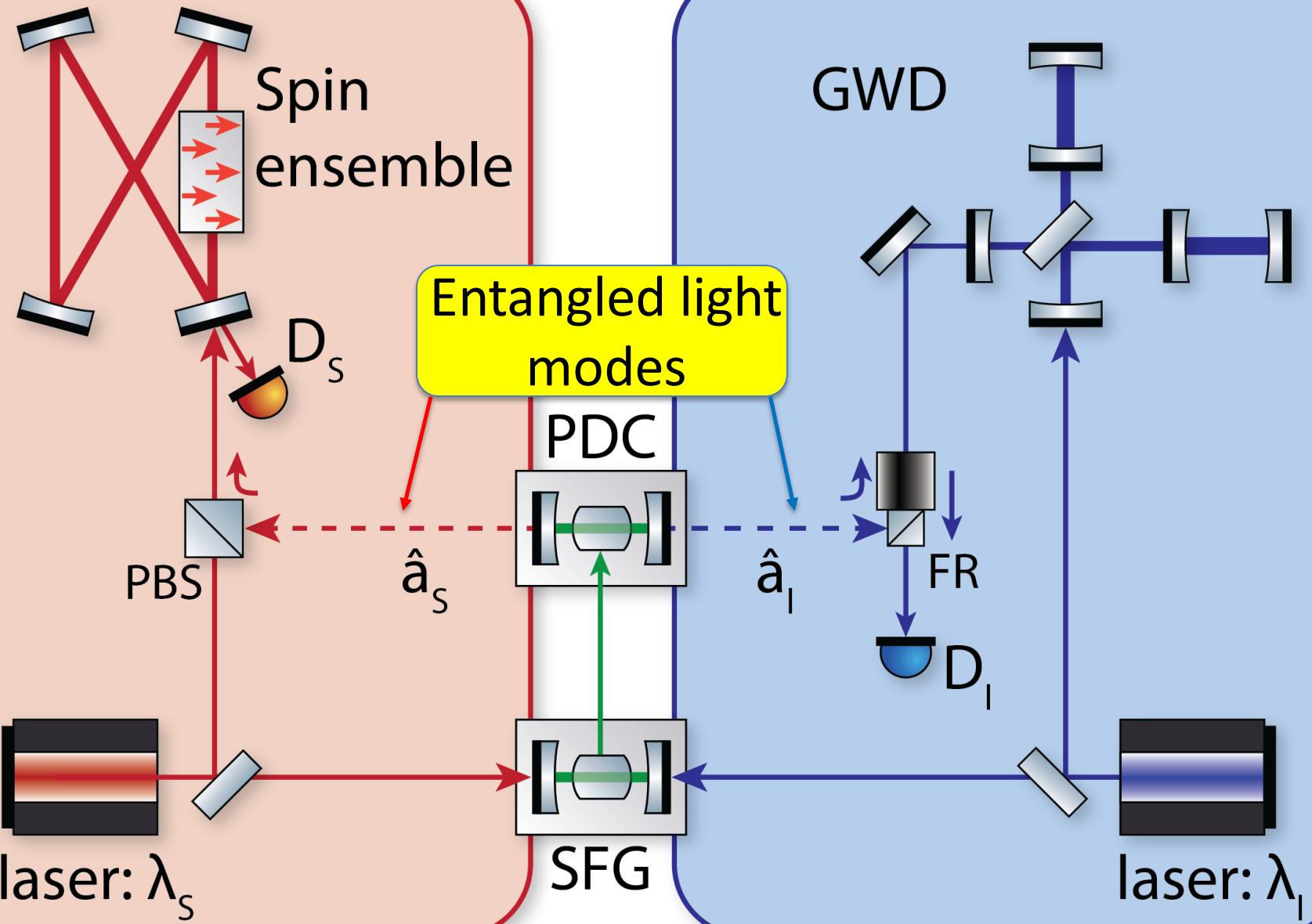
$$(P_{L1,in} - P_{L2,in})^2 = e^{-2r}$$

$$(X_{L1,in} + X_{L2,in})^2 = e^{-2r}$$

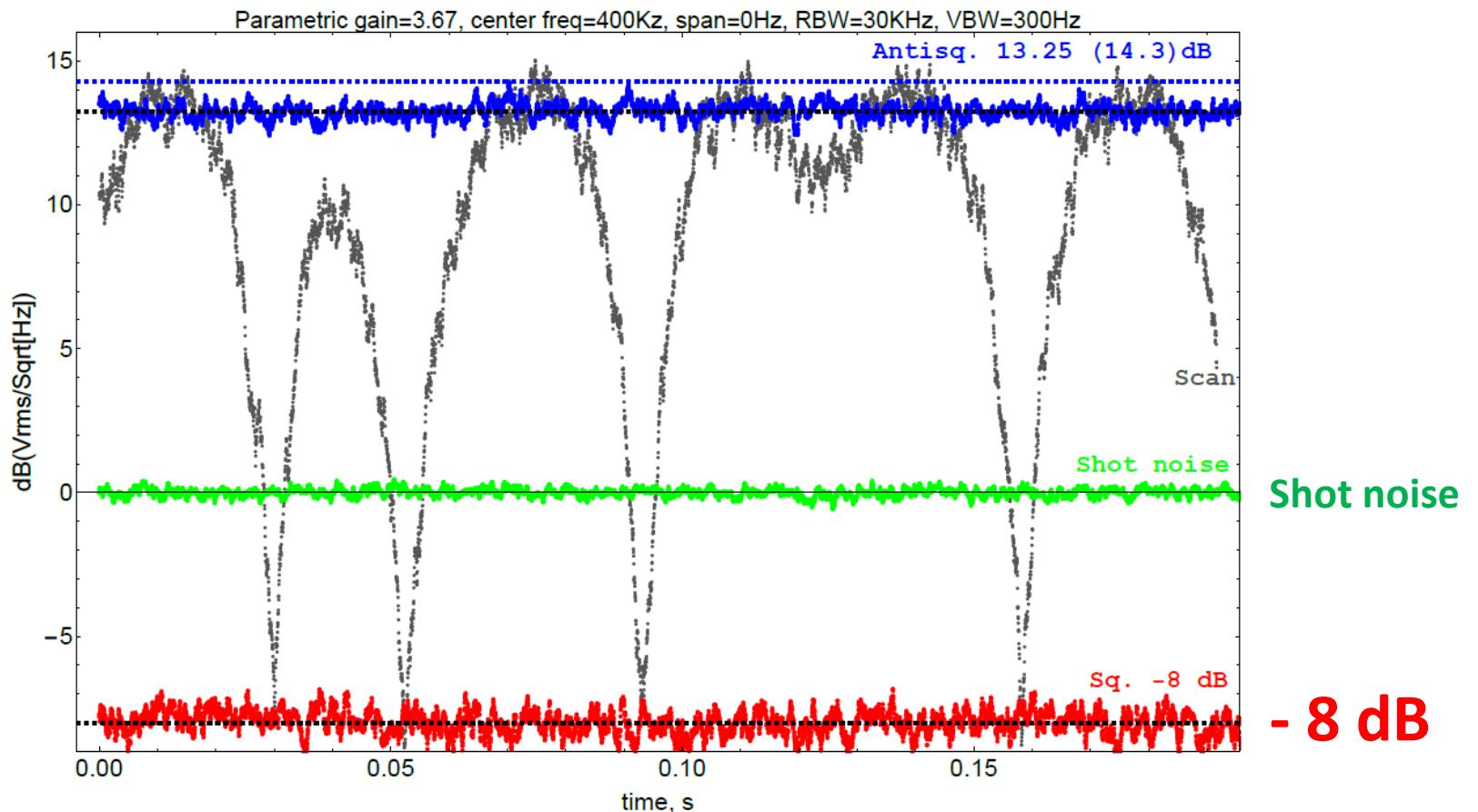
$$P_{L1,out} - P_{L2,out} \Rightarrow force\ terms$$

Simulation for LIGO



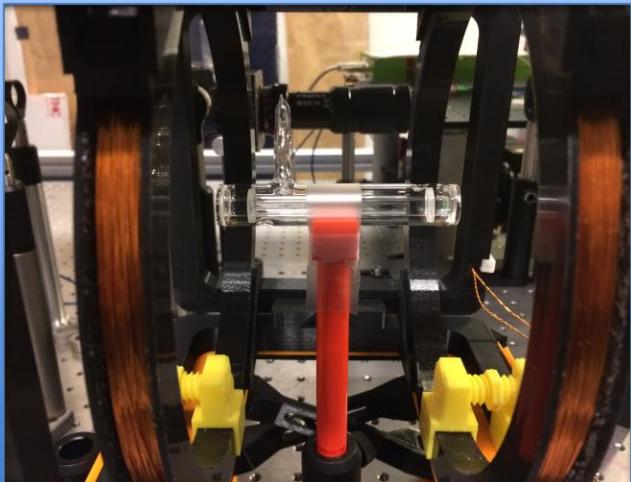


Two color entanglement between 1064nm and 852nm modes



- 8 dB

Shot noise



Valeriy Noviko

Tulio Brasil

We'll keep you posted ☺