Quantum assisted enhancement of optical magnetometer with squeezed vacuum in hot Rb vapor

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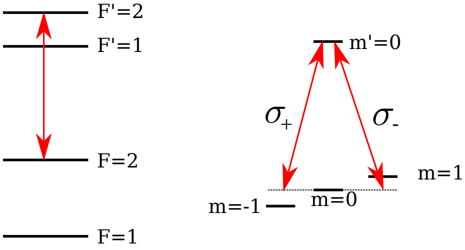
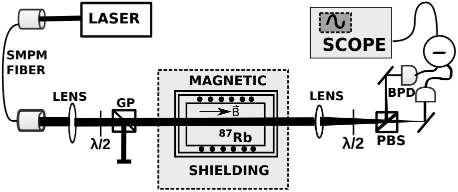
DAMOP

Optical magnetometer and non linear Faraday effect

^{87}Rb D_1 line





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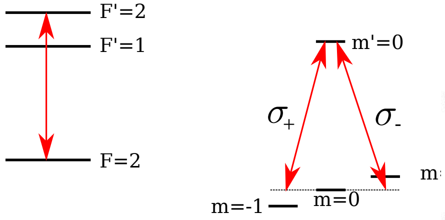
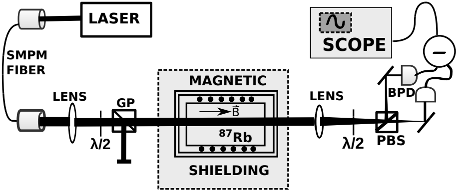
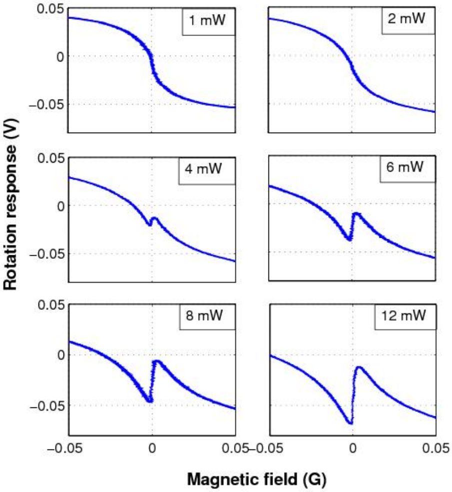
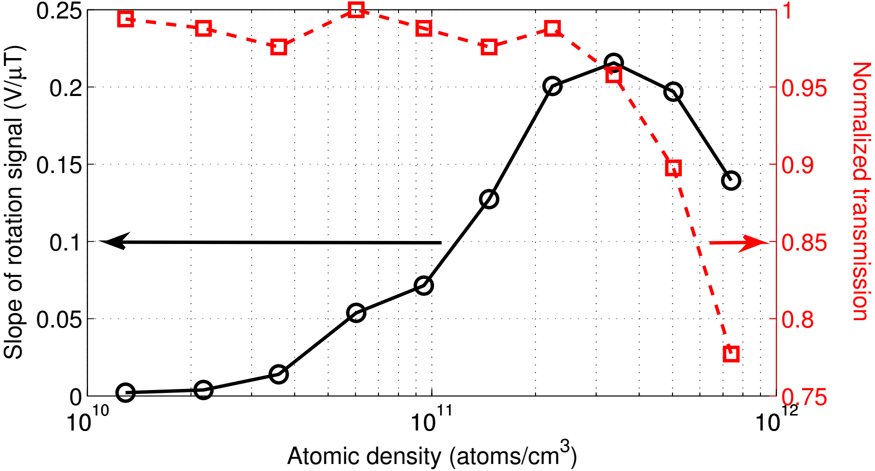


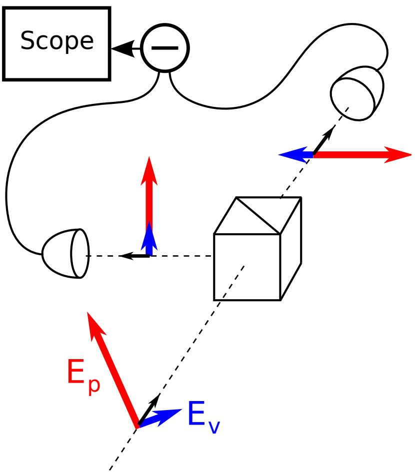




Magnetometer response vs atomic density



Shot noise limit of the magnetometer



$$S \sim E_p E_v$$

$$< \Delta S > \sim E_p < \Delta E_v >$$

Heisenberg uncertainty principle and its optics equivalent

Heisenberg uncertainty principle

$\Delta p \Delta x \geq \hbar/2$

The more precisely the POSITION is determined, the less precisely the MOMENTUM is known, and vice versa

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The more precisely the PHASE is determined, the less precisely the AMPLITUDE is known, and vice versa

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Optics equivalent strict definition

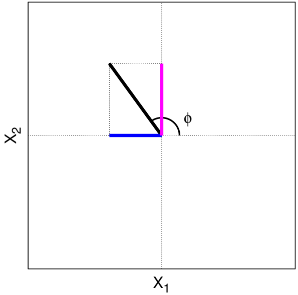
$\Delta X_1 \Delta X_2 \geq 1/4$

Transition from classical to quantum field

Classical analog

- Field amplitude a
- Field real part $X_1 = (a^* + a)/2$
- Field imaginary part $X_2 = i(a^* - a)/2$

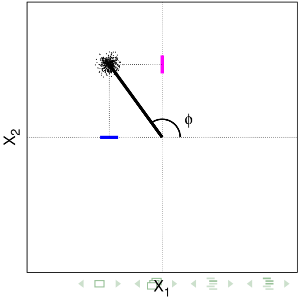
$$E(\phi) \;=\; |a|e^{-i\phi} = X_1 + iX_2$$



Quantum approach

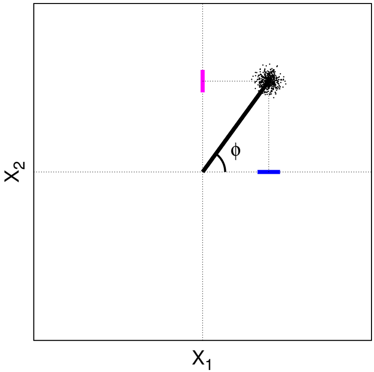
- Field operator $\hat{a}$
- Amplitude quadrature $\hat{X}_1 = (\hat{a}^\dagger + \hat{a})/2$
- Phase quadrature $\hat{X}_2 = i(\hat{a}^\dagger - \hat{a})/2$

$$\hat{E}(\phi) \;=\; \hat{X}_1 + i\hat{X}_2$$

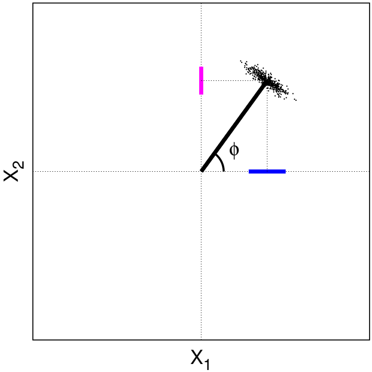


Minimum uncertainty (coherent) states

Coherent state



Squeezed state



$$\Delta X_1 \Delta X_2 \geq 1/4$$

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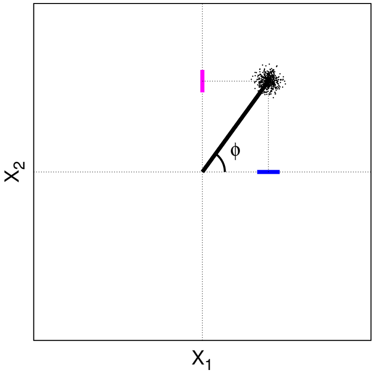
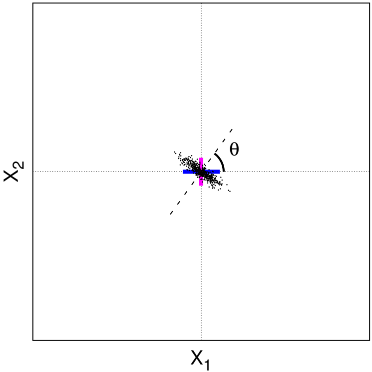
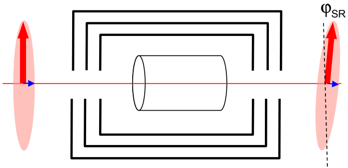


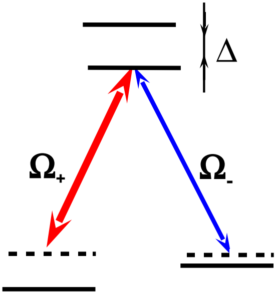
Squeezed state



$$\Delta X_1 \Delta X_2 \geq 1/4$$

Self-rotation of elliptical polarization in atomic medium

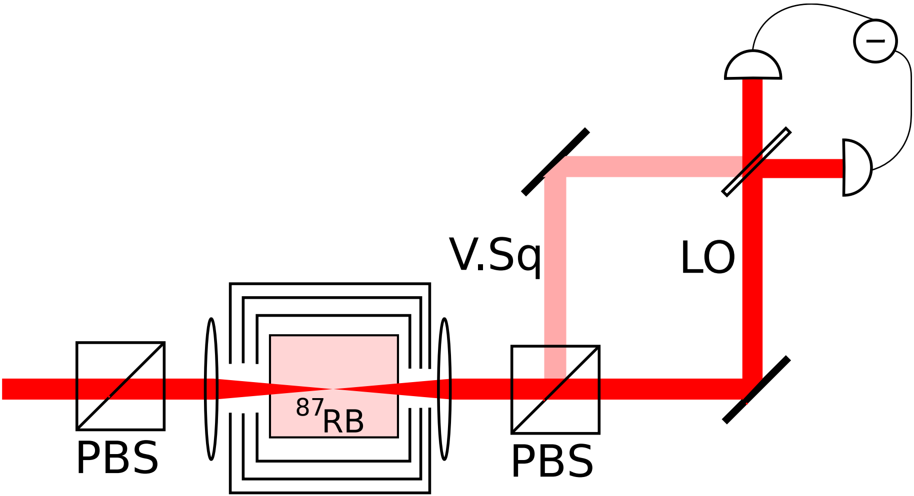




A.B. Matsko et al., PRA 66, 043815 (2002): theoretically prediction of 4-6 dB noise suppression

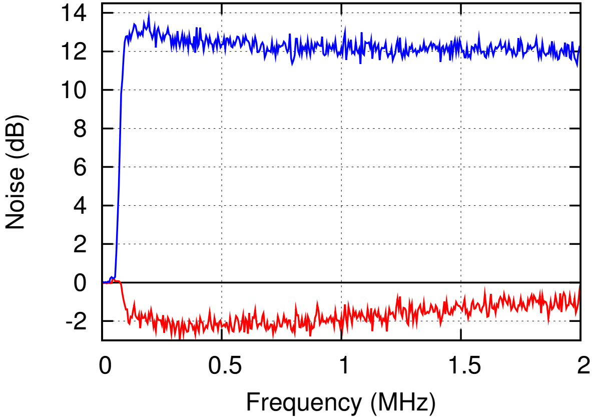
$$a_{out} = a_{in} + \frac{igL}{2}(a_{in}^{\dagger} - a_{in}) \quad (1)$$

Setup



Maximally squeezed spectrum with ^{87}Rb

W&M team. ^{87}Rb $F_g = 2 \rightarrow F_e = 2$, laser power 7 mW, T=65° C



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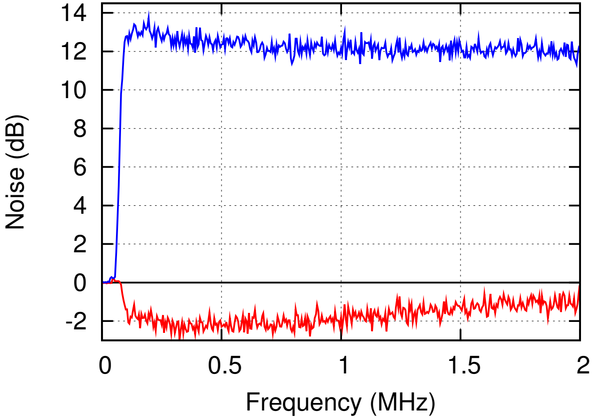
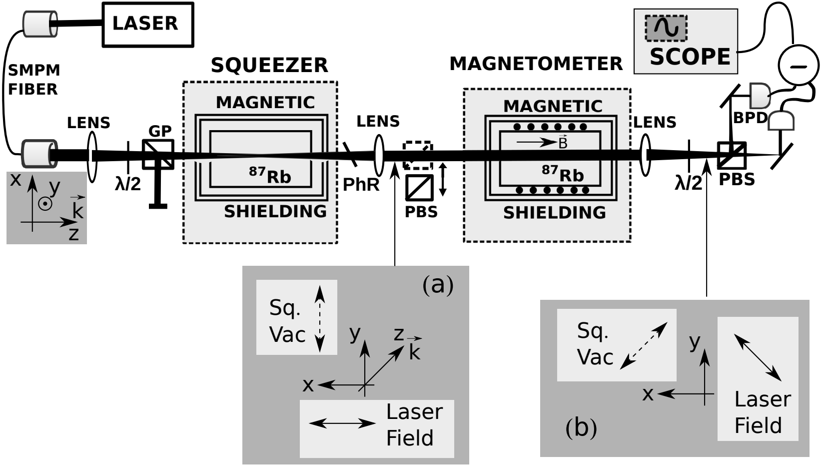


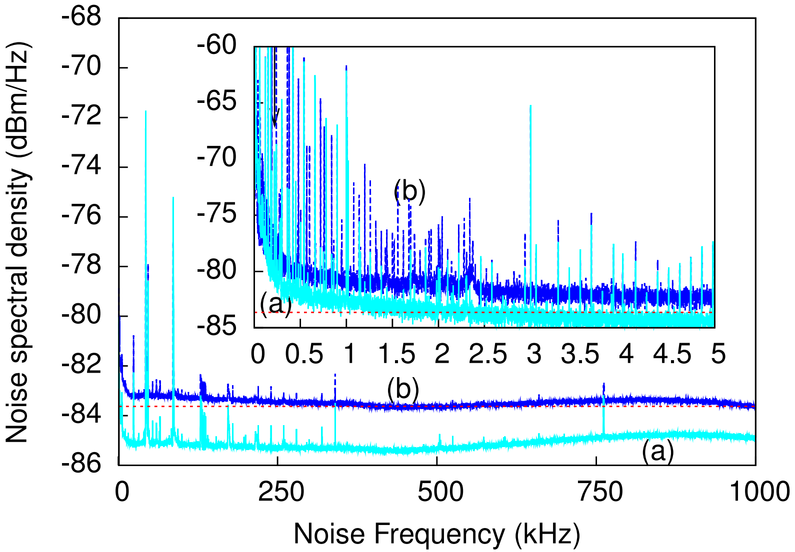
Lezama et.al report 3 dB squeezing in similar setup
Phys. Rev. A 84, 033851 (2011)

Squeezed enhanced magnetometer setup

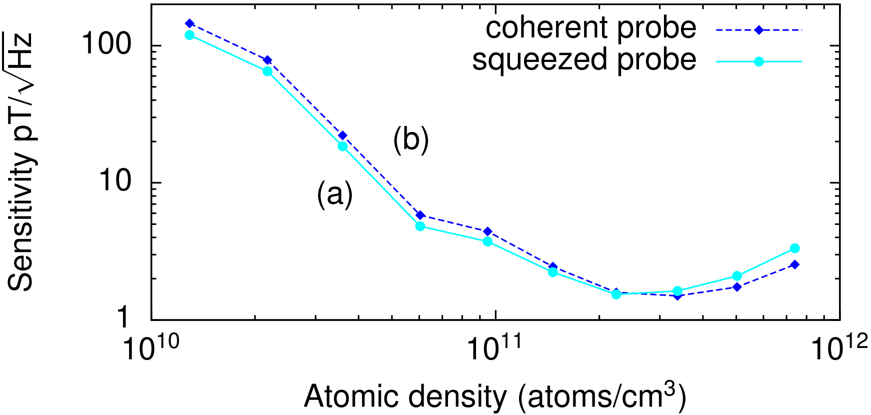


Note: Squeezed enhanced magnetometer was first demonstrated by Wolfgramm *et. al* Phys. Rev. Lett, **105**, 053601, 2010.

Magnetometer noise floor improvements

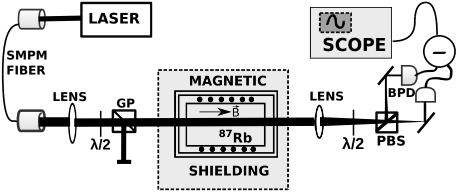


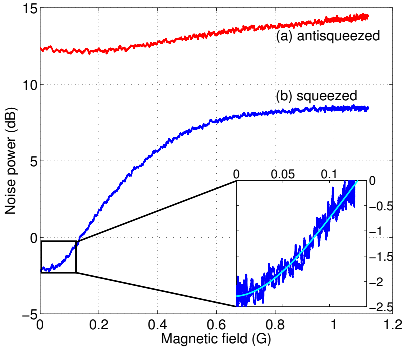
Magnetometer sensitivity vs atomic density



Squeezing vs magnetic field

Spectrum analyzer settings: Central frequency = 1 MHz, VBW = 3 MHz, RBW = 100 kHz





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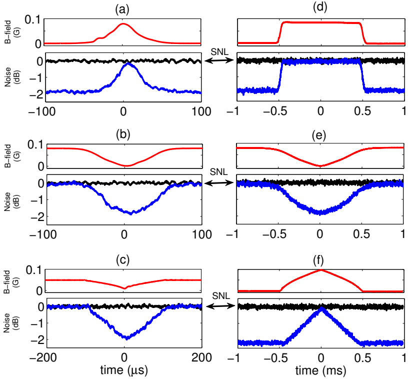

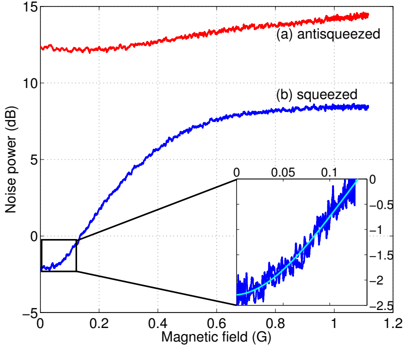

People

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Robinjeet Singh, LSU

Eugeniy Mikhailov, W&M

Jonathan P. Dowling, LSU

Summary

- We demonstrate fully atomic squeezed enhanced magnetometer
- Magnetometer noise floor lowered in the range from several kHz to several MHz
- Demonstrated sensitivity as low as 1 pT/$\sqrt{\text{Hz}}$ in our particular setup

For more details:

- Travis Horrom, Robinjeet Singh, Jonathan P. Dowling, Eugeniy E. Mikhailov, "Quantum Enhanced Magnetometer with Low Frequency Squeezing", **arXiv**:1202.3831, (2012).
- Q1.00079: about noise propagation in dense media

Magnetometer noise suppression vs atomic density