

Improving squeezed vacuum generation in hot Rb vapor with multi-pass configuration

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R. Nicholas Lanning, Zhihao Xiao, Jonathan P. Dowling²

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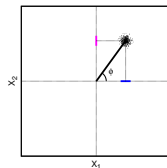
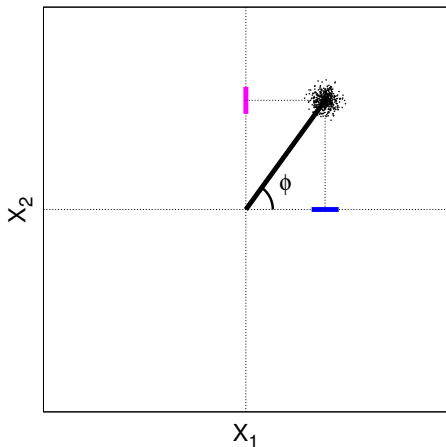
LOUISIANA STATE UNIVERSITY

LPHYS, 19 July 2017

Squeezed quantum states zoo

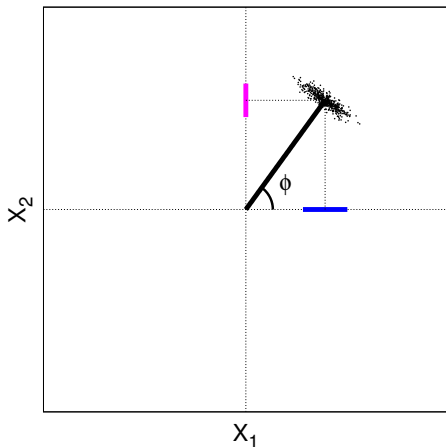
$$\hat{E}(\phi) = \hat{X}_1 + i\hat{X}_2$$
$$\hat{X}_1 = (\hat{a}^\dagger + \hat{a})/2; \hat{X}_2 = i(\hat{a}^\dagger - \hat{a})/2$$

Unsqueezed
coherent

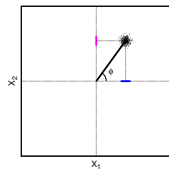


Squeezed quantum states zoo

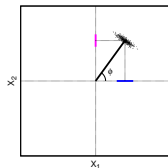
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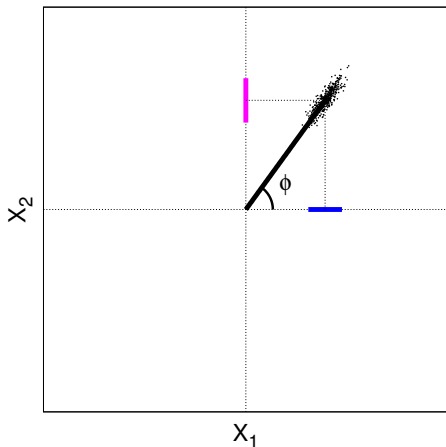


Amplitude
squeezed

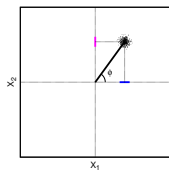


Squeezed quantum states zoo

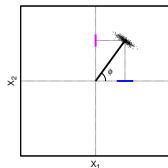
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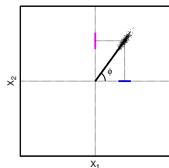
Unsqueezed
coherent



Amplitude
squeezed

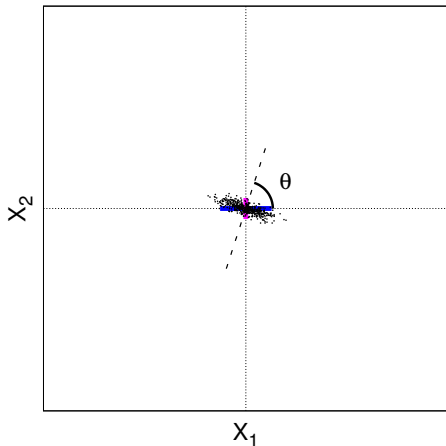


Phase
squeezed

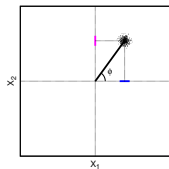


Squeezed quantum states zoo

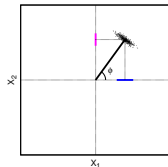
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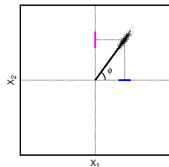
Unsqueezed
coherent



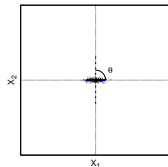
Amplitude
squeezed



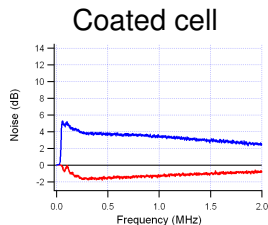
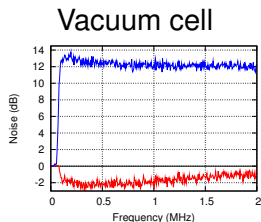
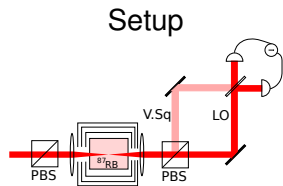
Phase
squeezed



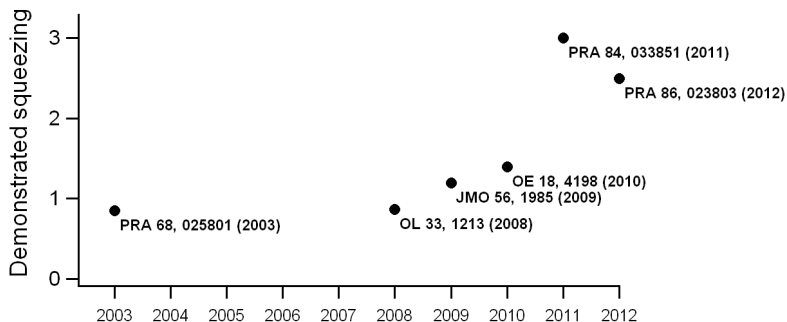
Vacuum
squeezed



Polarization self-rotation (PSR) squeezing

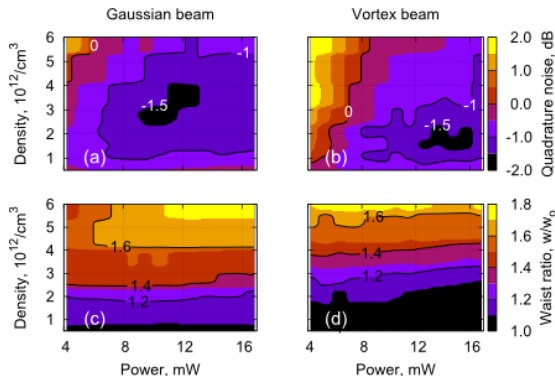
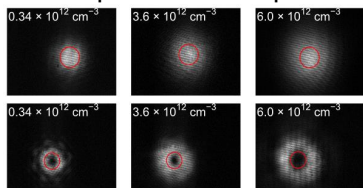


A.B. Misko et al., PRA 66, 043815 (2002): theoretically prediction of 4-6 dB noise suppression



Self-focusing and squeezing relationship

Output beam shapes



Beam expansion caused by self-defocusing seems to be decoupled from measured squeezing amount variation.

Mi Zhang, Joseph Sultanis, Irina Novikova, and Eugeniy E. Mikhailov, "Generating squeezed vacuum field with nonzero orbital angular momentum with atomic ensembles", *Optics Letters*, Vol. 38, Issue 22, pp. 4833-4836 (2013)

$$dI = -NI\alpha dz$$

Beer-Lambert law

$$dI = -NI\alpha dz$$

$$I = I_0 \exp(-\tau)$$

where τ is optical depth

$$\tau = \alpha NL$$

Beer-Lambert law

$$dI = -NI\alpha dz$$

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where τ is optical depth

$$\tau = \alpha NL$$

Will we get equivalent result for the following cases?

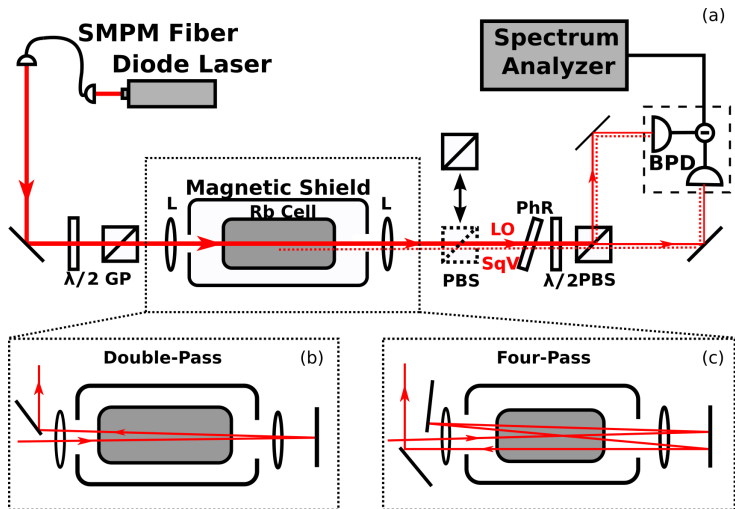
double the medium length

$$\tau = \alpha N(2L)$$

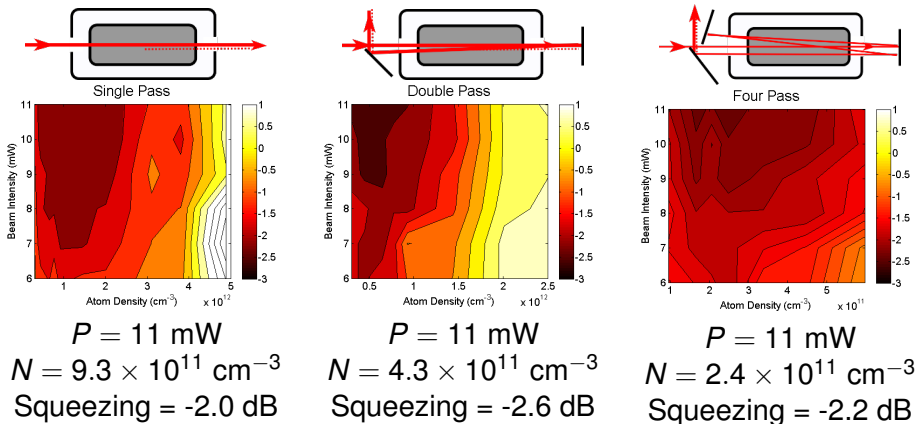
double the medium density

$$\tau = \alpha(2N)L$$

Multipass setup



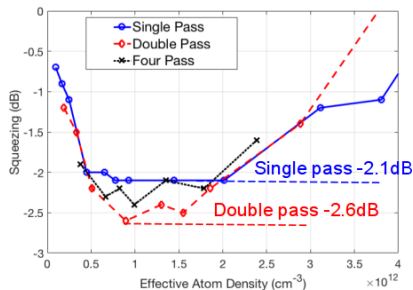
Optical depth dependence



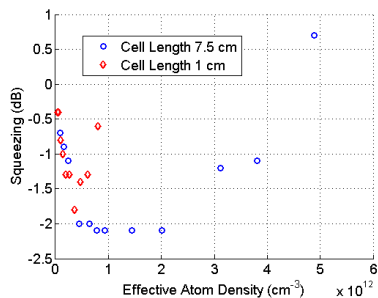
Mi Zhang, Melissa A. Guidry, R. Nicholas Lanning, Zhihao Xiao, Jonathan P. Dowling, Irina Novikova, Eugeny E. Mikhailov, "Multi-pass configuration for Improved Squeezed Vacuum Generation in Hot Rb Vapor", arXiv:1705.02914.

Squeezing vs effective optical depth

Long cell

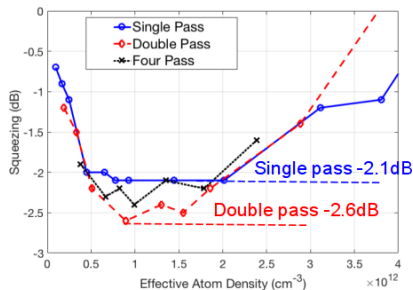


Long vs short cell

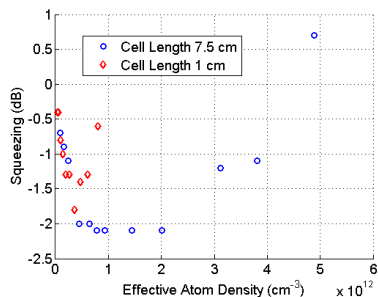


Squeezing vs effective optical depth

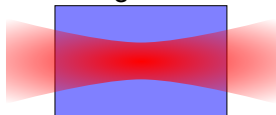
Long cell



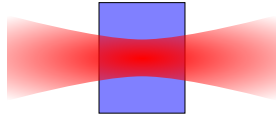
Long vs short cell



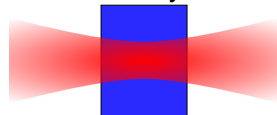
Cell length doubled



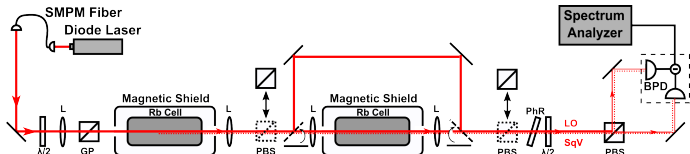
Reference



Atomic density doubled

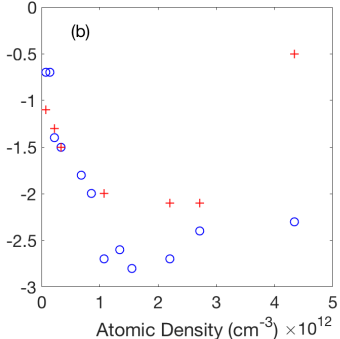
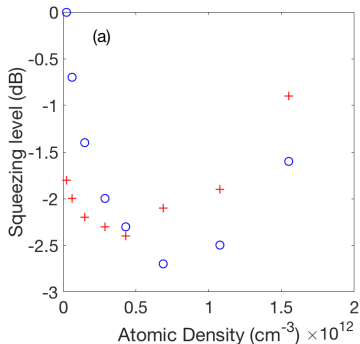


Double cell setup: atomic density optimization



+: combined squeezing
1st cell atomic density
 $N_1 = 9.3 \times 10^{11} \text{ cm}^{-3}$

o: the first cell squeezing filtered
1st cell atomic density
 $N_1 = 4.3 \times 10^{11} \text{ cm}^{-3}$



Double cell setup: position optimization

atomic densities:

$$N_1 = 4.3 \times 10^{11} \text{ cm}^{-3}$$

$$N_2 = 4.3 \times 10^{11} \text{ cm}^{-3}$$

atomic densities:

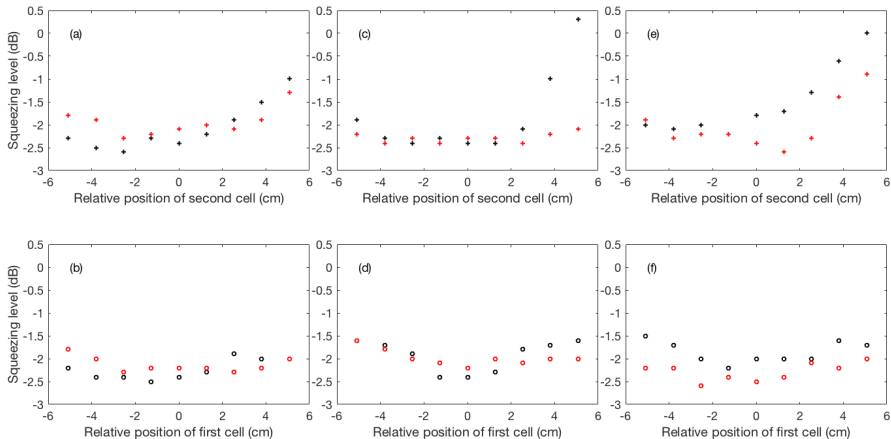
$$N_1 = 4.3 \times 10^{11} \text{ cm}^{-3}$$

$$N_2 = 9.3 \times 10^{11} \text{ cm}^{-3}$$

atomic densities:

$$N_1 = 9.3 \times 10^{11} \text{ cm}^{-3}$$

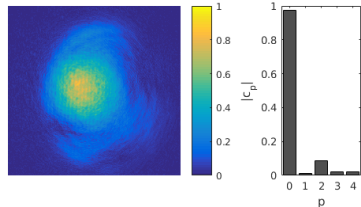
$$N_2 = 9.3 \times 10^{11} \text{ cm}^{-3}$$



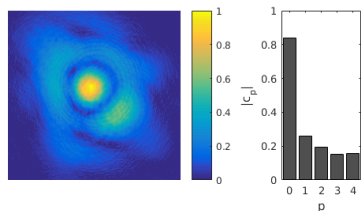
+/: combined squeezing; +/: the first cell squeezing filtered

Multimode pump output

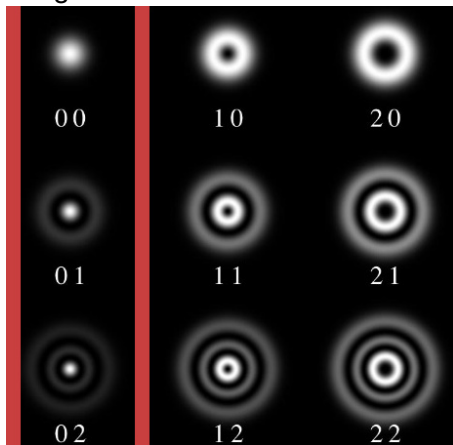
T=26 °C



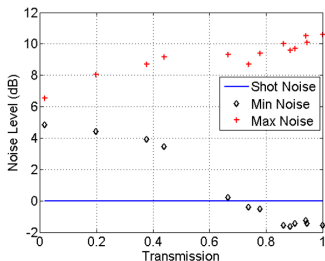
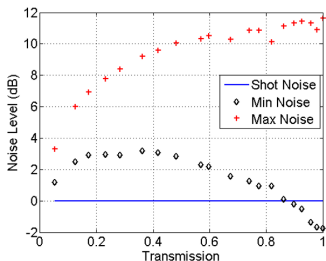
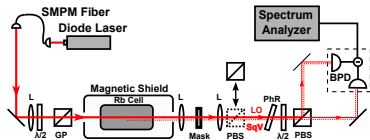
T=91 °C



Laguerre-Gaussian modes basis



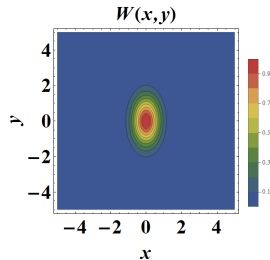
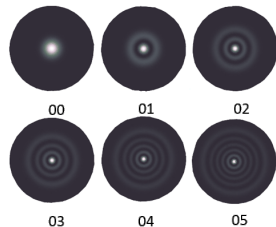
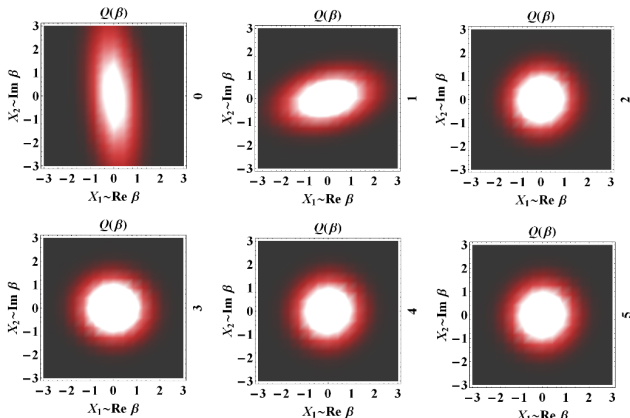
Multimode squeezing



Zhihao Xiao, R. Nicholas Lanning, Mi Zhang, Irina Novikova, Eugeny E. Mikhailov, Jonathan P. Dowling, "Why a hole is like a beam splitter—a general diffraction theory for multimode quantum states of light", arXiv:1703.03818, (2017)

Multimode squeezing decomposition

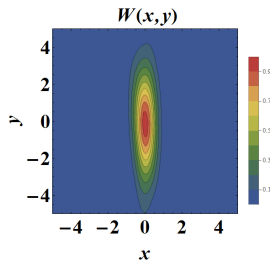
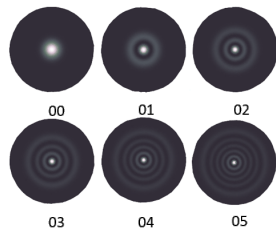
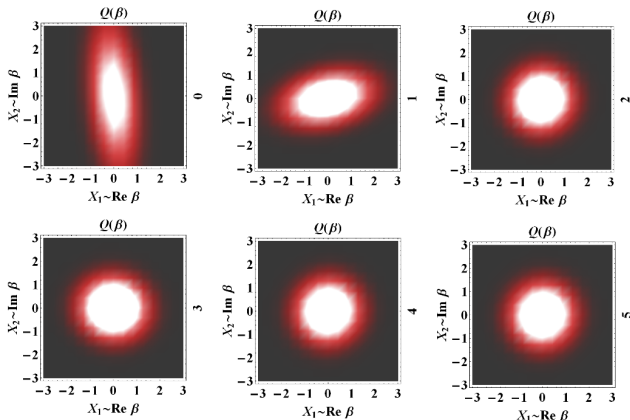
$$\hat{S}(\xi) = \exp \left[\sum_{l,p} \frac{1}{2} (\xi_{l,p}^* \hat{a}_{l,p}^2 - \xi_{l,p} \hat{a}_{l,p}^{\dagger 2}) \right]$$



Mi Zhang, R. Nicholas Lanning, Zhihao Xiao, Jonathan P. Dowling, Irina Novikova, Eugeny E. Mikhailov, "Spatial multimode structure of atom-generated squeezed light", Phys. Rev. A, 93, 013853, (2016).

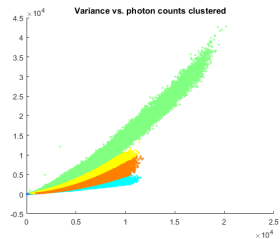
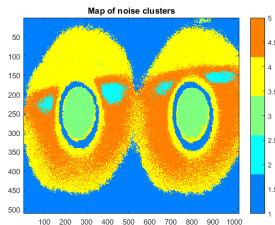
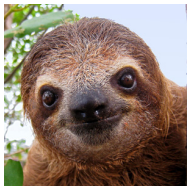
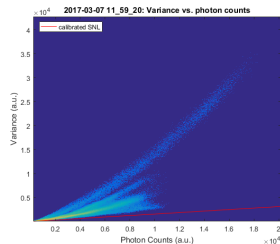
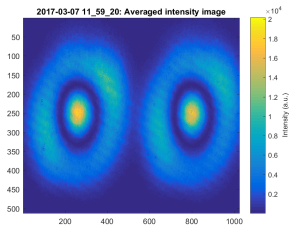
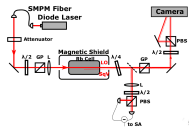
Multimode squeezing decomposition

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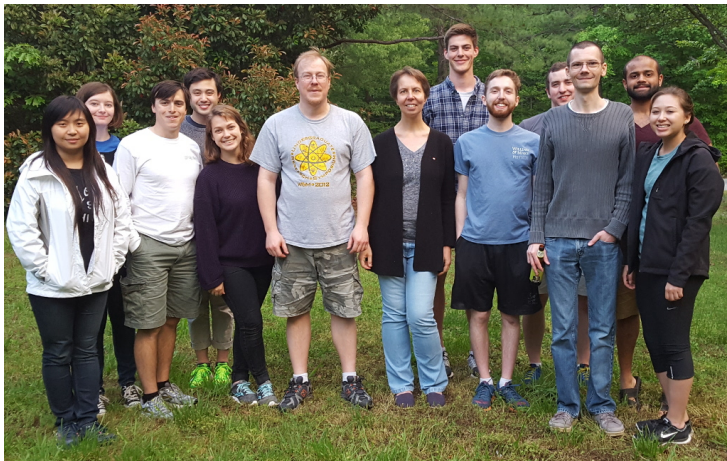
Mi Zhang, R. Nicholas Lanning, Zhihao Xiao, Jonathan P. Dowling, Irina Novikova, Eugeny E. Mikhailov, "Spatial multimode structure of atom-generated squeezed light", Phys. Rev. A, 93, 013853, (2016).

Quantum imaging effort: from owl to sloth



People

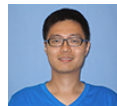
WM: Mi Zhang, Melissa A. Guidry, Irina Novikova



LSU:
R. Nicholas
Lanning



Zihao Xiao



Jonathan P.
Dowling



- We were able to improve squeezing by multipass configuration
- Our squeezed state is a set of competing multimodes
- We are working on quantum modes extraction and imaging

Financial support by AFOSR, ARO, and NSF.