# Generation of squeezed vacuum with hot and ultra-cold Rb atoms

Eugeniy E. Mikhailov, Travis Horrom, Irina Novikova[1]
Salim Balik[2], Arturo Lezama[3], Mark Havey[2]

[1]The College of William & Mary, USA
[2]Old Dominion University, USA
[3]Instituto de Física, Uruguay

January 5, 2011
PQE

# People


Left to right: Arturo Lezama, Eugeniy Mikhailov, Mark Havey, Salim Balik, Travis Horrom, and Irina Novikova

# Heisenberg uncertainty principle

## Optics equivalent

$\Delta\phi\Delta N \geq 1$
The more precisely the PHASE is determined, the less precisely the AMPLITUDE is known, and vice versa

## Optics equivalent strict definition

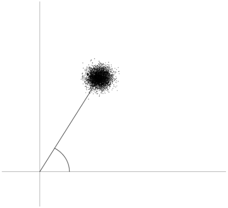
$\left\langle \Delta X_1^2 \right\rangle \left\langle \Delta X_2^2 \right\rangle \geq 1$

$$X_1 = \frac{a + a^\dagger}{\sqrt{2}}$$

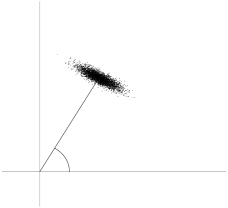
$$X_2 = \frac{a - a^\dagger}{\sqrt{2}i}$$

# Coherent states of light

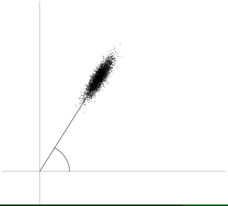
unsqueezed



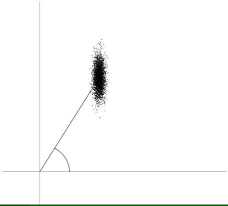
amplitude-squeezed



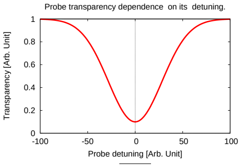
phase-squeezed

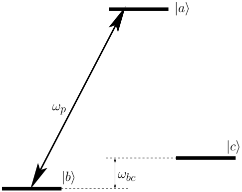


angle-squeezed



# Quantum memory with atomic ensembles



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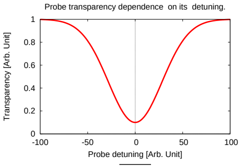


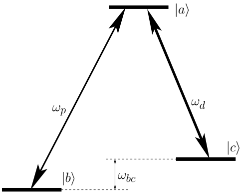


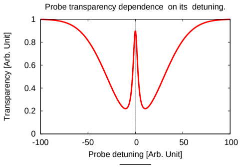

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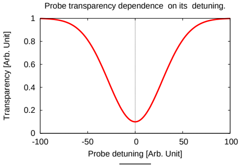
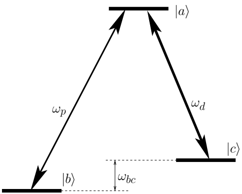
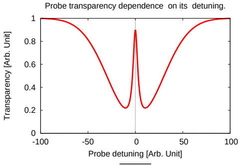
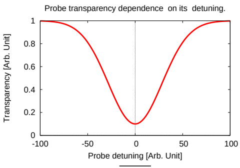


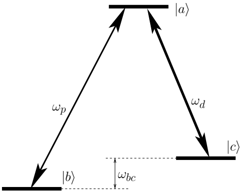



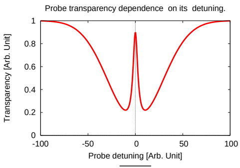




Storage and retrieval

# Quantum memory with atomic ensembles



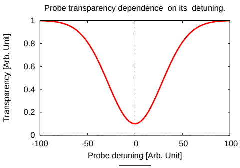



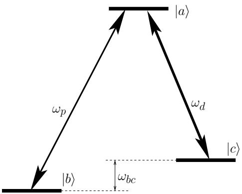



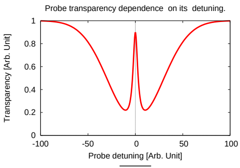

Storage and retrieval

- single photon

# Quantum memory with atomic ensembles




Storage and retrieval

- single photon
- squeezed state (Furusawa and Lvovsky PRL **100** 2008)

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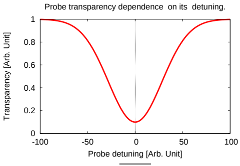


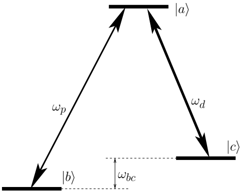


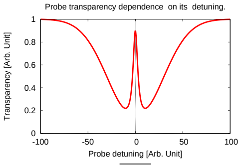


Storage and retrieval

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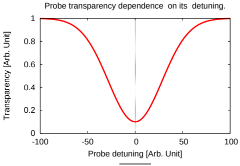
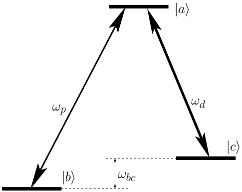
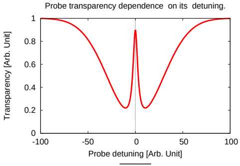
Squeezed state requirements for a quantum memory probe

# Quantum memory with atomic ensembles



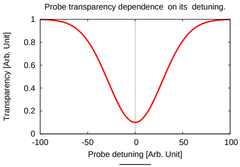

Storage and retrieval

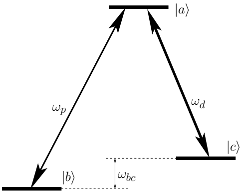
- single photon
- squeezed state (Furusawa and Lvovsky PRL **100** 2008)

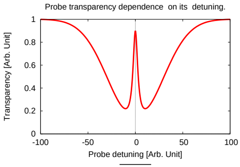
Squeezed state requirements for a quantum memory probe

- squeezing carrier at atomic wavelength (780nm, 795nm)
- squeezing within narrow resonance window at frequencies($<$100kHz)

# Quantum memory with atomic ensembles

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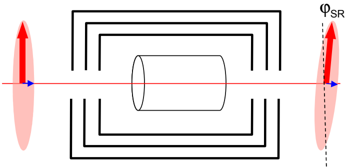
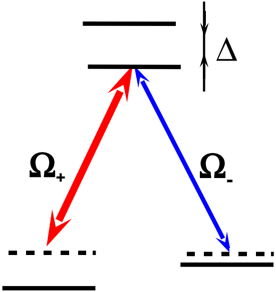
Traditional nonlinear crystal based squeezers are capable of it, but they are extremely technically challenging especially at short wave length.

# 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

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

# Will something so simple work?

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- Yes! J. Ries, B. Brezger, and A. I. Lvovsky, Experimental vacuum squeezing in rubidium vapor via self-rotation, PRA **68**, 025801 (2003).
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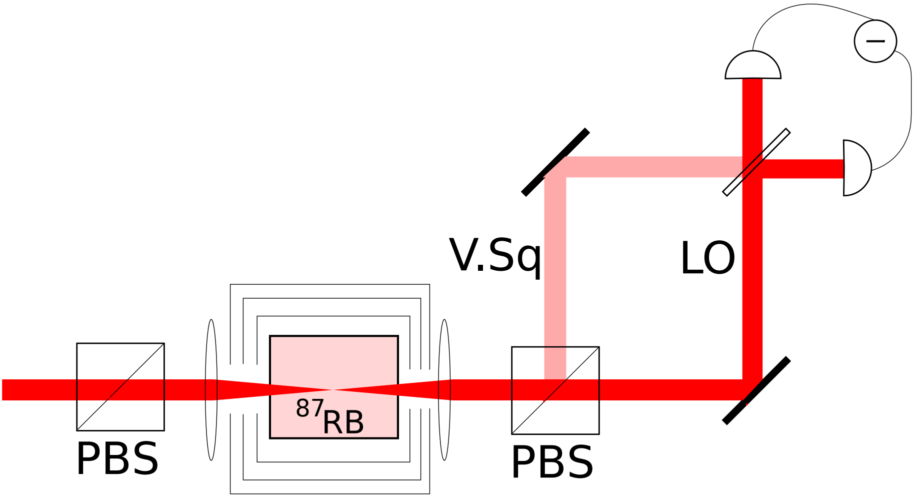
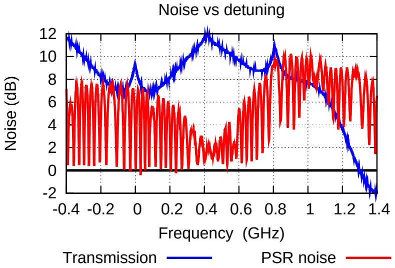
- Definitely Eugeniy E. Mikhailov et al. Optics Letters, Issue 11, **33**, 1213-1215, (2008).
- Definitely Eugeniy E. Mikhailov et al. JMO , Issues 18&19, **56**, 1985-1992, (2009).
- Definitely Philippe Grangier et al. Optics Express, **18**, Issue 5, pp. 4198-4205 (2010)
  - 1.4 dB of squeezing

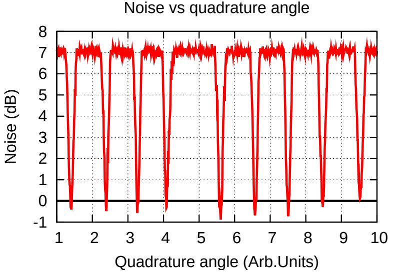
# Setup



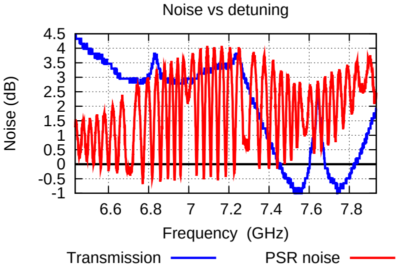
# Noise contrast vs detuning in hot $^{87}$Rb vacuum cell

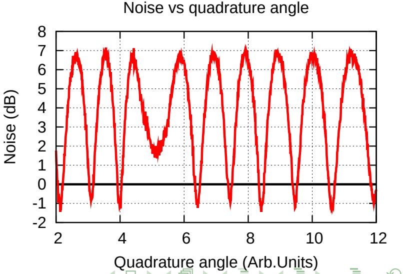
$F_g = 2 \rightarrow F_e = 1, 2$




$F_g = 1 \rightarrow F_e = 1, 2$

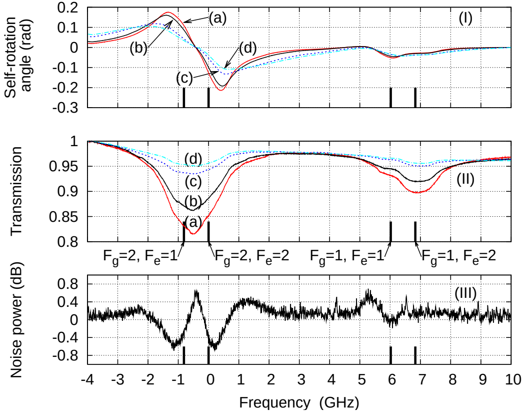


# Squeezing vs detuning in $^{87}$Rb at 795 nm

$^{87}$Rb cell + 2.5Torr Ne

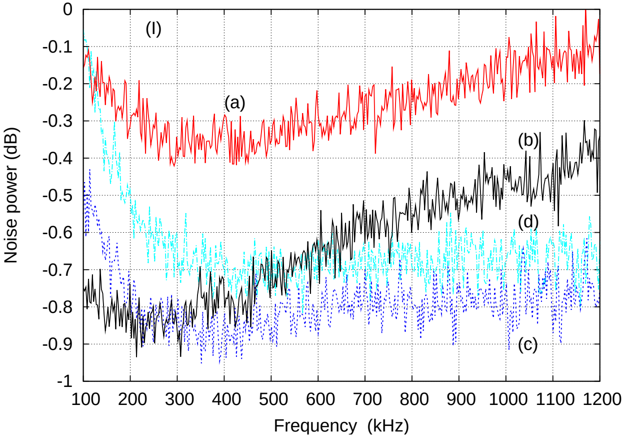
(a) P=1.0 mW, (b) P=1.5 mW, (c) P=4.2 mW, (d) P=6.6 mW



# Low frequency squeezing vs noise sidebands frequency in $^{87}$Rb at 795 nm

$^{87}$Rb cell + 2.5Torr Ne, T=63.3°C

(a) P=1.0 mW, (b) P=1.5 mW, (c) P=4.2 mW, (d) P=6.6 mW



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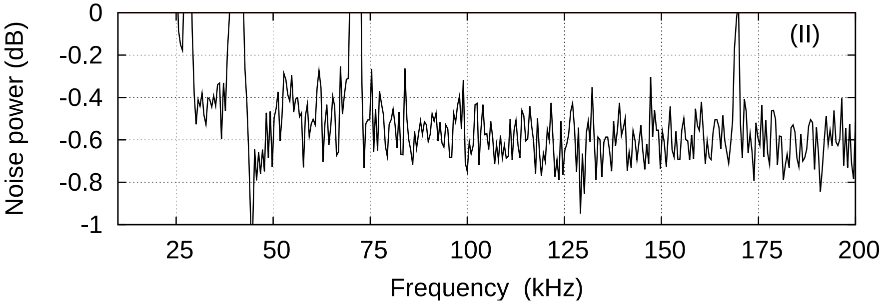
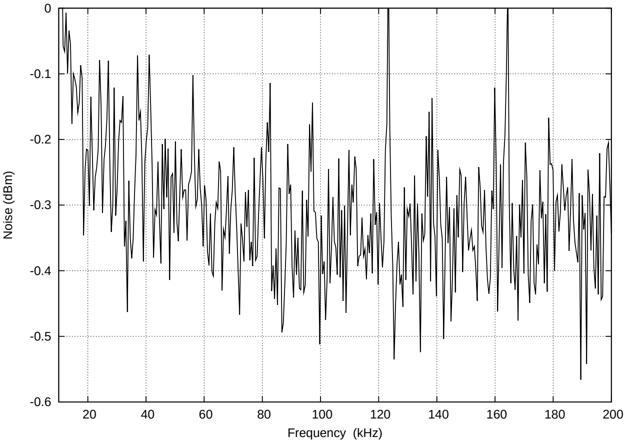



Eugeniy E. Mikhailov, Irina Novikova: Optics Letters, Issue 11, 33, 1213-1215, (2008).

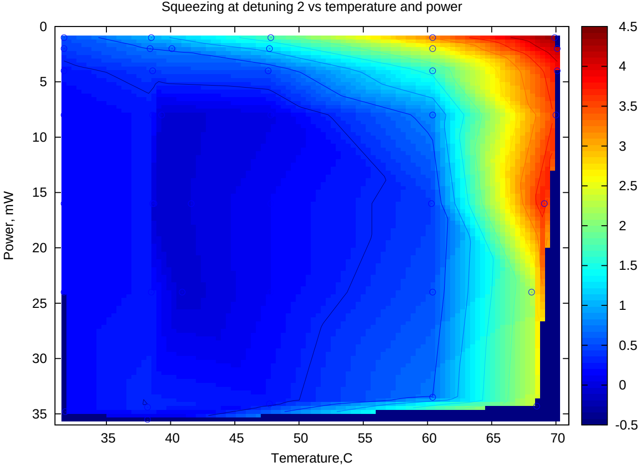
# Low frequency squeezing vs noise sidebands frequency in $^{87}$Rb at 795 nm

$^{87}$Rb cell + 5Torr Ne, T=63.3°C
P=0.5 mW



# Excess noise and the source of the controversy

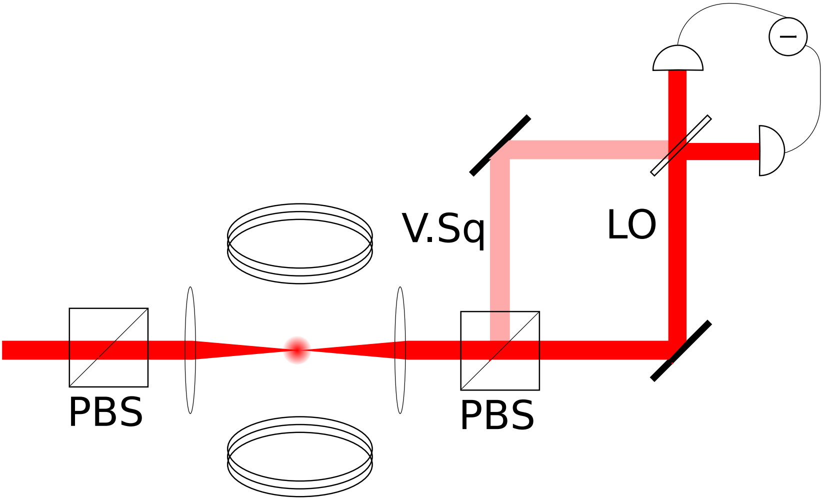
No buffer gas near $F_g = 2 \rightarrow F_e = 2$ transition



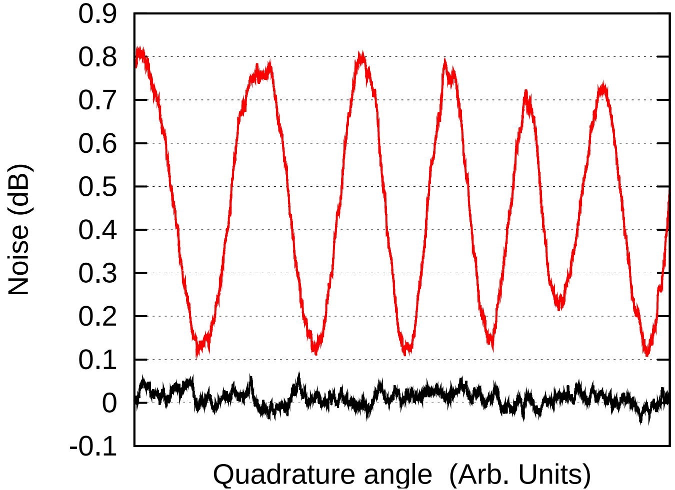

Squeezing occurs in the rather narrow parameters space

# MOT squeezer

T = 200 $\mu$K, N = 2 $\times$ $10^{10}$ 1/cm$^3$, OD = 5, beam size = 0.1 mm



# Noise contrast in MOT with $^{87}$Rb $F_g = 2 \rightarrow F_e = 1$



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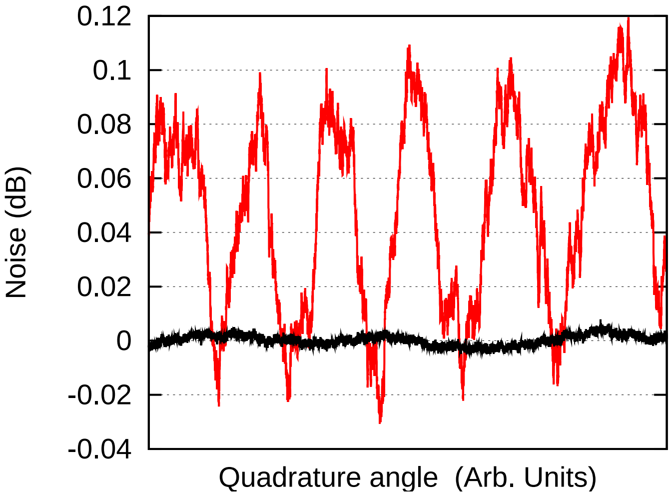
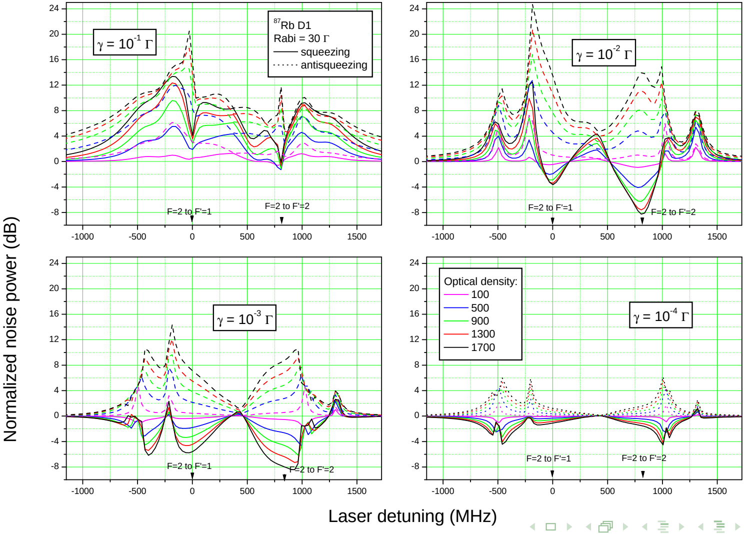


# Theoretical prediction for MOT squeezing with $^{87}$Rb

$F_g = 2 \rightarrow F_e = 1, 2$ high optical density is very important



# Summary

- Self-rotation based squeezing is possible in hot and ultra-cold $^{87}$Rb vapor
- Squeezing is generated in the range from 10 kHz to several MHz
- Such vacuum squeezing is suitable for atomic quantum memory tests

Advantages of the PSR squeezing

- Requires very little optical power (< 100 mW)
- Generated at atomic transition wavelength
- Potentially can be generated at any wavelength where the suitable transition exists
  - think blue or even ultraviolet