Polarisation Self-Rotation Squeezing - Progress Report

M. T. L. Hsu, A. Peng, M. Johnsson, J. J. Hope, C. C. Harb, H.-A. Bachor and P. K. Lam

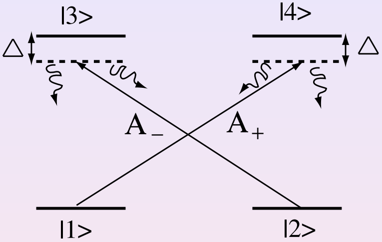
ARC COE Quantum-Atom Optics
ANU Faculties Node

Overview

- AIM - To generate squeezed light at Rb lines.
- SQUEEZING @ ATOMIC λ'S
  - OPO squeezing @ Cs $\sim$ 3dB (H.J. Kimble's group)
  - MOT squeezing @ Cs $\sim$ 2.5dB (E. Giacobino's group)
  - Waveguide PPLN squeezing @ Rb $\sim$ 1dB (M. Kozuma's group)
  - Vapour cell squeezing @ Rb $\sim$ 1dB (A. Lvovsky's group[1])
- METHOD
  - Polarisation self-rotation effect[2] in Rb atoms.
  - Examine theory of self-rotation - 4-level atom[3].
- RESULTS

[1]Ries *et al* PRA 68, 025801 (2003)
[2]Matsko *et al* PRA 66, 043815 (2002)
[3]Josse *et al* JOB 5, S513 (2003)

4-Level Atom



- Model 4-level atom interacting with linearly polarised light

$$\hat{H}_{\text{int}} = \hbar N\Big(\triangle\hat{\sigma}_{33} + \triangle\hat{\sigma}_{44} + g(\hat{A}_{+}\hat{\sigma}_{41} + \hat{A}_{-}\hat{\sigma}_{32} + \text{H.C.})\Big)$$

where g = atom-light coupling constant.

- Derive equations of motion.
  - Include spontaneous emission γ and Langevin terms $\hat{F}_{\mu\nu}$.

Semi-Classical Predictions

- Solve equations of motion to obtain complex susceptibility.
- Consider an almost linearly polarised light in the x-axis with small ellipticity $\sin\epsilon \simeq \epsilon$.
- Obtain absorption by taking the sum of real parts of susceptibility for $\langle\hat{A}_+\rangle$ and $\langle\hat{A}_-\rangle$ fields.

$$\text{Absorption} = C\frac{\gamma}{\gamma^2 + \triangle^2}$$

- Obtain phase change (rotation) by taking difference of imaginary parts of susceptibility

$$\triangle\theta = C'\frac{\triangle}{\gamma^2 + \triangle^2}\epsilon$$

- C and C' dependent on γ, g, N, L.

Semi-Classical Predictions

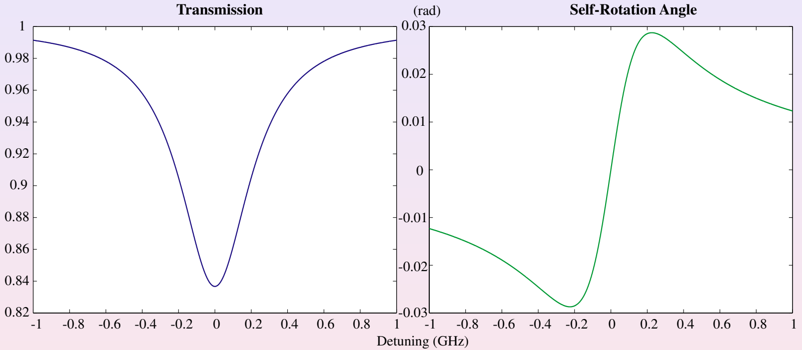


Figure: Parameters used: $\gamma \sim$ 7MHz, Atomic density $\sim 10^{18}/\mathrm{m}^3$, Optical density $\sim$ 10mW/mm^2, $\lambda = 780$nm, Input beam ellipticity 10mrad, Length of cell 5cm.

Quantum Prediction

- Define quantum Stokes operators.

$$\hat{S}_0 = \hat{A}_x^\dagger \hat{A}_x + \hat{A}_y^\dagger \hat{A}_y$$
$$\hat{S}_1 = \hat{A}_x^\dagger \hat{A}_x - \hat{A}_y^\dagger \hat{A}_y$$
$$\hat{S}_2 = \hat{A}_x^\dagger \hat{A}_y + \hat{A}_y^\dagger \hat{A}_x$$
$$\hat{S}_3 = i(\hat{A}_y^\dagger \hat{A}_x - \hat{A}_x^\dagger \hat{A}_y)$$

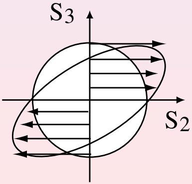
- Write field operators in terms of Stokes operators and Fourier transform to frequency domain.

$$\frac{\partial \delta \tilde{S}_2}{\partial z} = \mathcal{D}(\omega)\delta \tilde{S}_2 + \mathcal{K}(\omega)\delta \tilde{S}_3 + \tilde{\mathcal{F}}$$

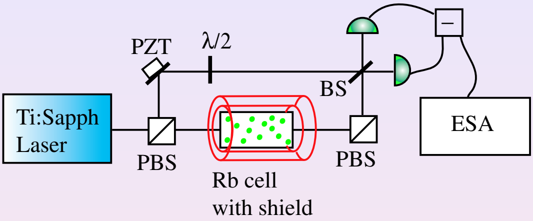
where in steady state $\mathcal{K}(0) = C'$ (i.e. classical self-rotation parameter)

Qualitative Description

- Due to small ellipticity - resolve into L-circular and R-circular polarisation components.
- Undergo different refractive indices in atomic media - different optical power.
- Consider noise component of optical field - intensity dependent phase change $\mathcal{K}(\omega)$.
- As S_3 intensity increases, get larger mapping of S_2.
- Result - shearing of phase space.



Experimental Layout



- Send in linearly polarised light into Rb vapour cell (heated, B-shielded).
- Measure orthogonal polarisation component (i.e. vacuum field) of output beam (squeezing predicted in orthogonal polarisation).
- Use homodyne detection - measure at certain frequency using ESA.

Self-rotation Results

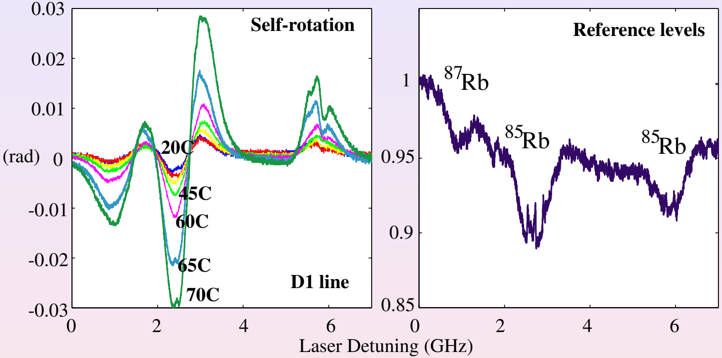


Figure: Input beam $\sim 12.5\text{mW/mm}^2$, Ellipticity $\sim$ 7mrad, D1 line.

- Asymmetry possibly due to presence of two isotopes as well as multi-level structure.

Self-rotation Results

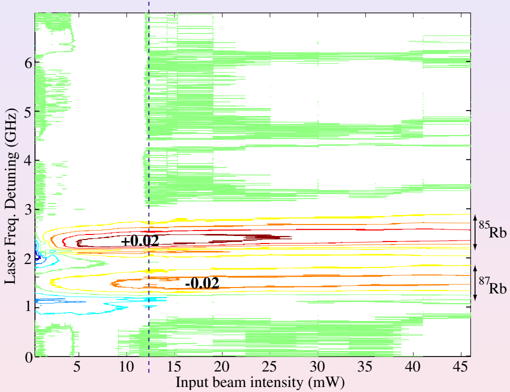


Figure: Contour plot of self-rotation vs beam intensity and laser detuning. Ellipticity ∼ 7mrad, D2 line, Beam area ∼ 1mm^2.

Phase Noise Measurement

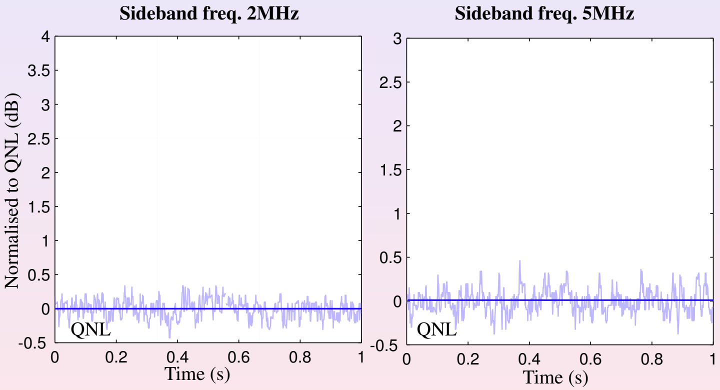
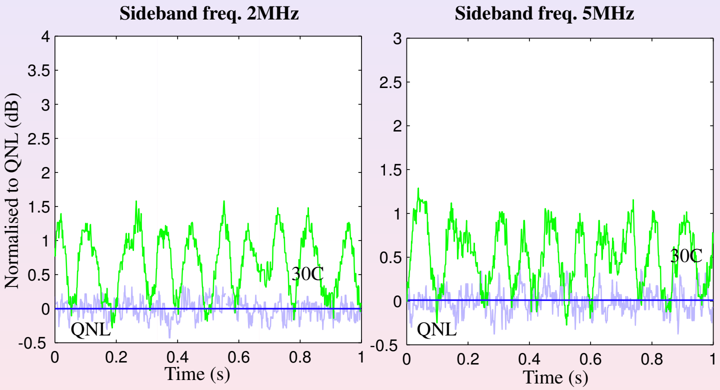


Figure: Input beam $\sim 10\text{mW}/\text{mm}^2$, D2 line.

Phase Noise Measurement



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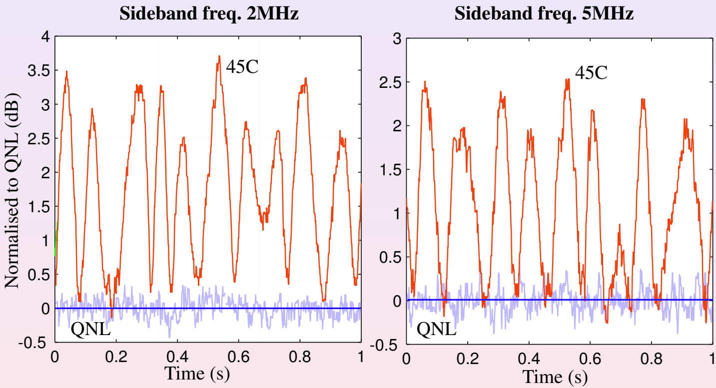
Phase Noise Measurement



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Phase Noise Measurement

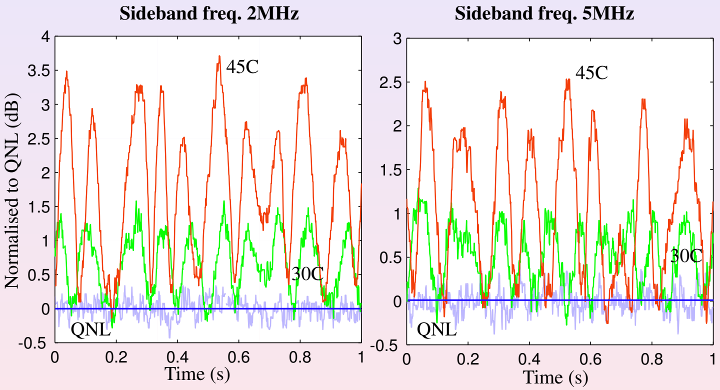

Figure: Input beam $\sim 10\text{mW}/\text{mm}^2$, D2 line.

Analysis

- Observe self-rotation consistent with Lvovsky's results.
- Do not observe any squeezing at detection sideband frequencies of 1 to 10MHz.
- Two possible reasons:
  - Isotopic purity of atomic medium. From theory, get self-rotation across $\sim$ 1GHz detuning.
  - 4-level approximation valid for multi-level structure Rb atoms?
- Same observations reported by Paris group (Dantan, Bramati, Pinard)[4].

[4] Personal correspondence.

Future Directions

- Obtain and use an isotopically pure ^{87}Rb cell (in process).
- Model real atomic level structure to (hopefully) predict: - Classical self-rotation signals (i.e. good values, asymmetry). - Squeezing from a multi-level structure atom.