Polarisation Self-Rotation Squeezing - Progress Report


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Overview

**Aim** - To generate squeezed light at Rb lines.

**Squeezing @ Atomic λ’s**
- OPO squeezing @ Cs ~ 3dB (H.J. Kimble’s group)
- MOT squeezing @ Cs ~ 2.5dB (E. Giacobino’s group)
- Waveguide PPLN squeezing @ Rb ~ 1dB (M. Kozuma’s group)
- Vapour cell squeezing @ Rb ~ 1dB (A. Lvovsky’s group)

**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)
Model 4-level atom interacting with linearly polarised light

\[ \hat{H}_{\text{int}} = \hbar N \left( \Delta \hat{\sigma}_{33} + \Delta \hat{\sigma}_{44} + g (\hat{A}_+ \hat{\sigma}_{41} + \hat{A}_- \hat{\sigma}_{32} + \text{H.C.}) \right) \]

where \( g = \) atom-light coupling constant.

Derive equations of motion.
- Include spontaneous emission \( \gamma \) 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 $\sin \epsilon \approx \epsilon$.
- Obtain absorption by taking the sum of real parts of susceptibility for $\langle \hat{A}_+ \rangle$ and $\langle \hat{A}_- \rangle$ fields.

\[
\text{Absorption} = C \frac{\gamma}{\gamma^2 + \Delta^2}
\]

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

\[
\Delta \theta = C' \frac{\Delta}{\gamma^2 + \Delta^2} \epsilon
\]

- $C$ and $C'$ dependent on $\gamma$, $g$, $N$, $L$. 
Figure: Parameters used: $\gamma \sim 7\text{MHz}$, Atomic density $\sim 10^{18}/\text{m}^3$, Optical density $\sim 10\text{mW/mm}^2$, $\lambda = 780\text{nm}$, 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.

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

where in steady state \(K(0) = C'\) (i.e. classical self-rotation parameter)
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.
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 \( \sim 7 \text{mrad} \), 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 $\sim 7\text{mrad}$, D2 line, Beam area $\sim 1\text{mm}^2$. 
Phase Noise Measurement

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

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**Figure:** Input beam \( \sim 10 \text{mW/mm}^2 \), D2 line.
Phase Noise Measurement

Figure: Input beam $\sim 10\text{mW/mm}^2$, D2 line.
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 $\sim 1$GHz detuning.
- 4-level approximation valid for multi-level structure Rb atoms?

Same observations reported by Paris group (Dantan, Bramati, Pinard)\(^4\).

\(^4\)Personal correspondence.
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.