Noise Suppression via Light Squeezing

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Final Talk, W&M REU 2008

Implication of Uncertainty Principle for Light

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

Everyone's favorite uncertainty relation.

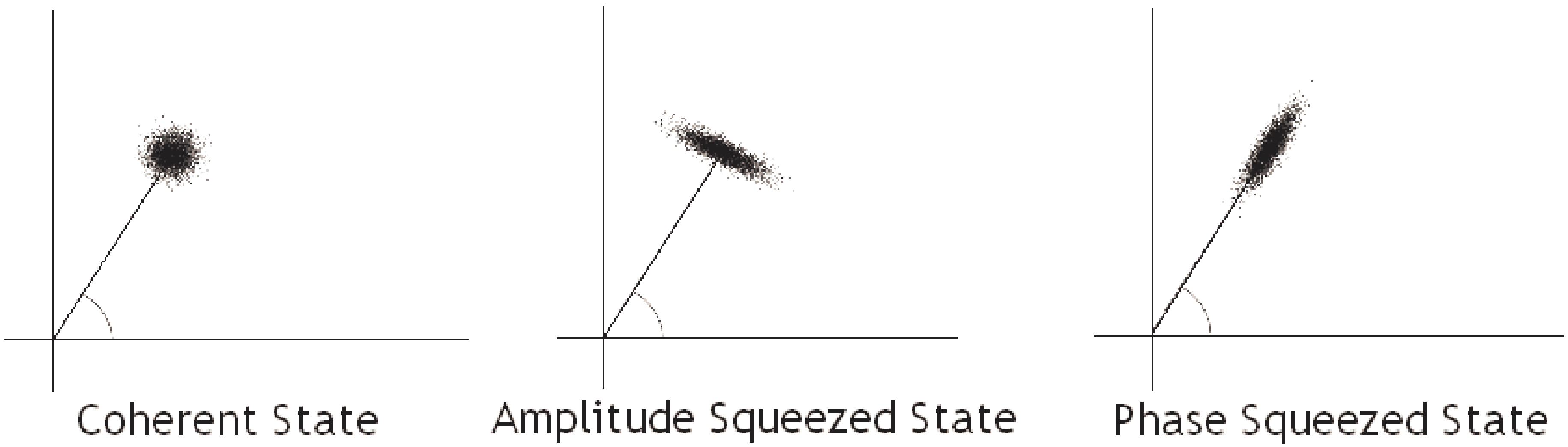
Implication of Uncertainty Principle for Light

$$(\Delta A)(\Delta \phi) \geq 1$$

The more precisely the amplitude is known, the more uncertainty there is in the phase, and vice versa

➔ Fundamental Quantum Noise Limit

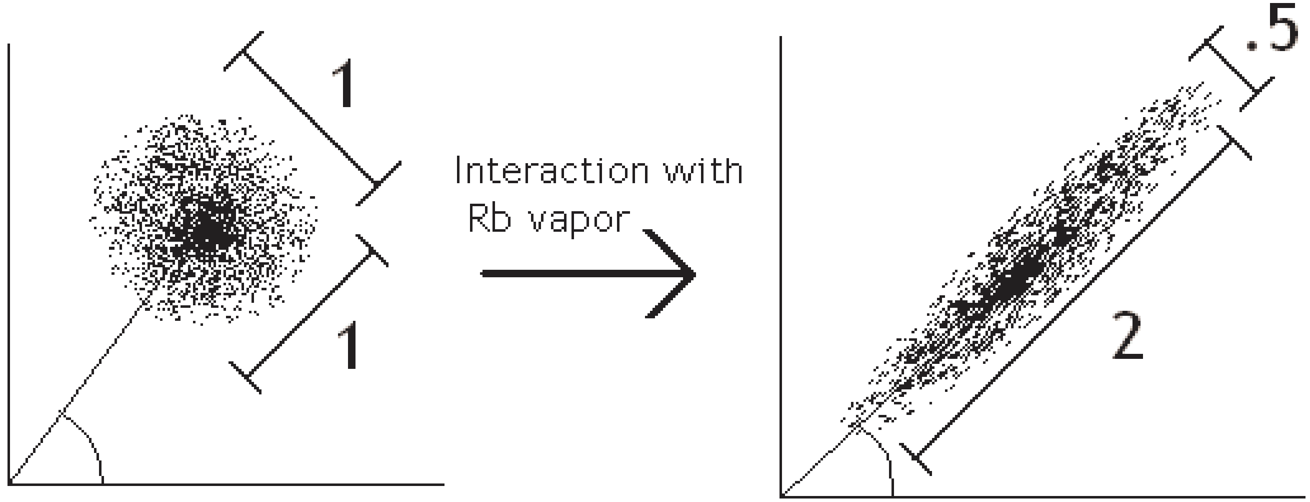
Squeezed light has suppressed noise



- Laser light has equal uncertainty in amplitude and phase
- Squeezed states have less uncertainty in either amplitude or phase (and more in the other)

What do we measure?

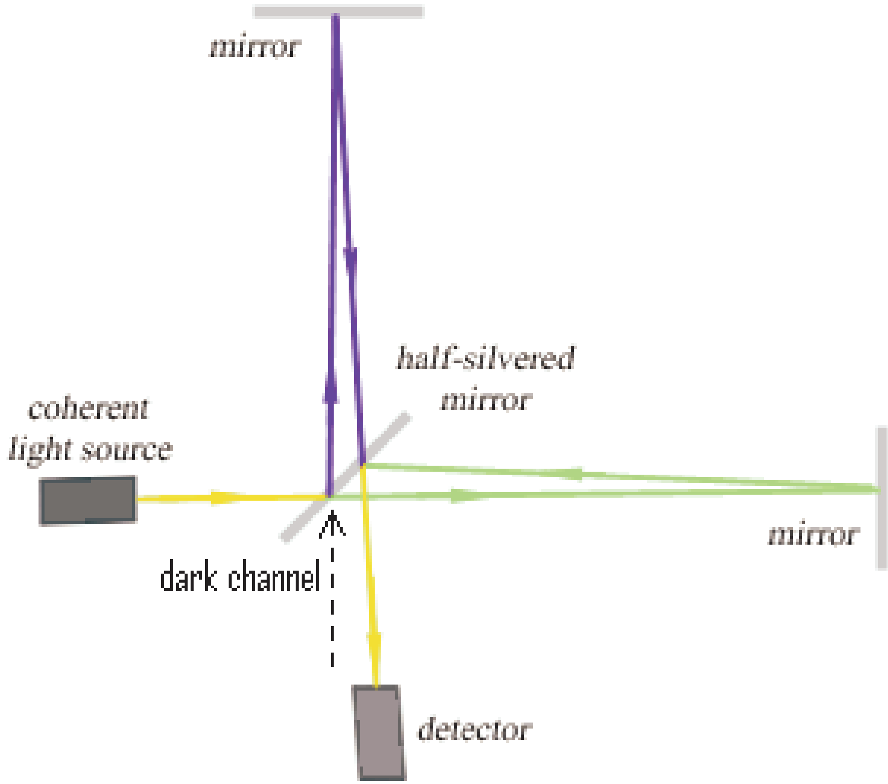
$$Squeezed\,Noise(dB) = 10*\log\left(\frac{Smaller\,Uncertainty}{Coherent\,State\,Uncertainty}\right)$$



$$Squeezed\,Noise = 10*\log\left(\frac{.5}{1}\right) \approx 10*(-.3) = -3\,dB$$

Suppressed noise has applications

- Interferometry
  - Phase sensitive detection
    - Benefit from phase squeezed light

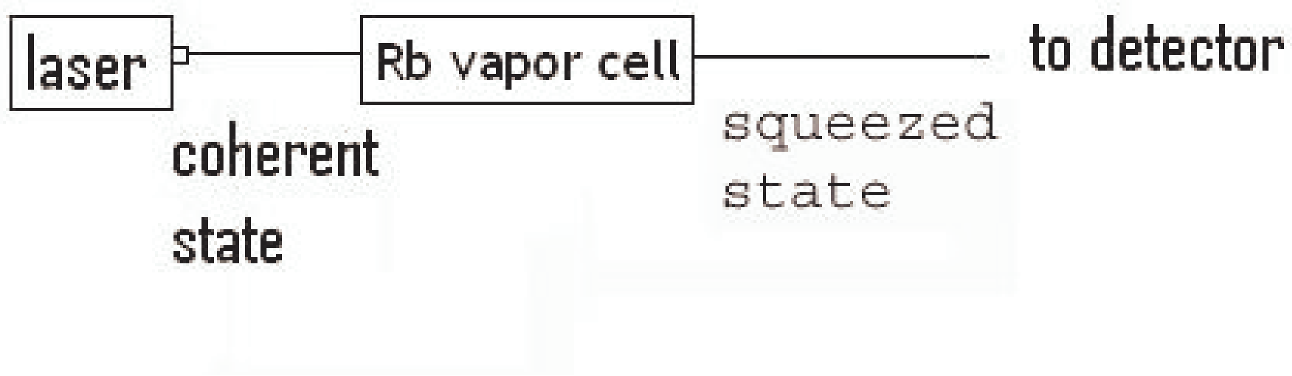


- Quantum Information
  - Benefit from squeezed light at atomic transition frequencies

Squeezing Methods

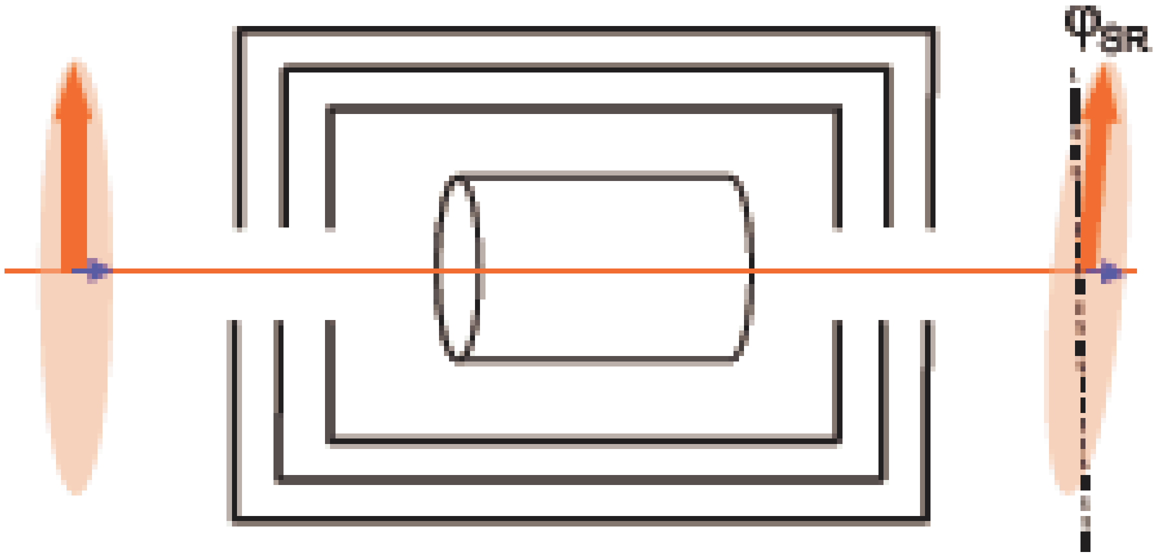
- Crystal based squeezing
  - Proven method to produce squeezing at a wide variety of frequencies
  - Two problems:
    - Crystals become absorptive at UV wavelengths
    - Crystal based systems are complex and technically challenging

- Interaction with atomic Rb vapor creates squeezed state



What Theory Predicts

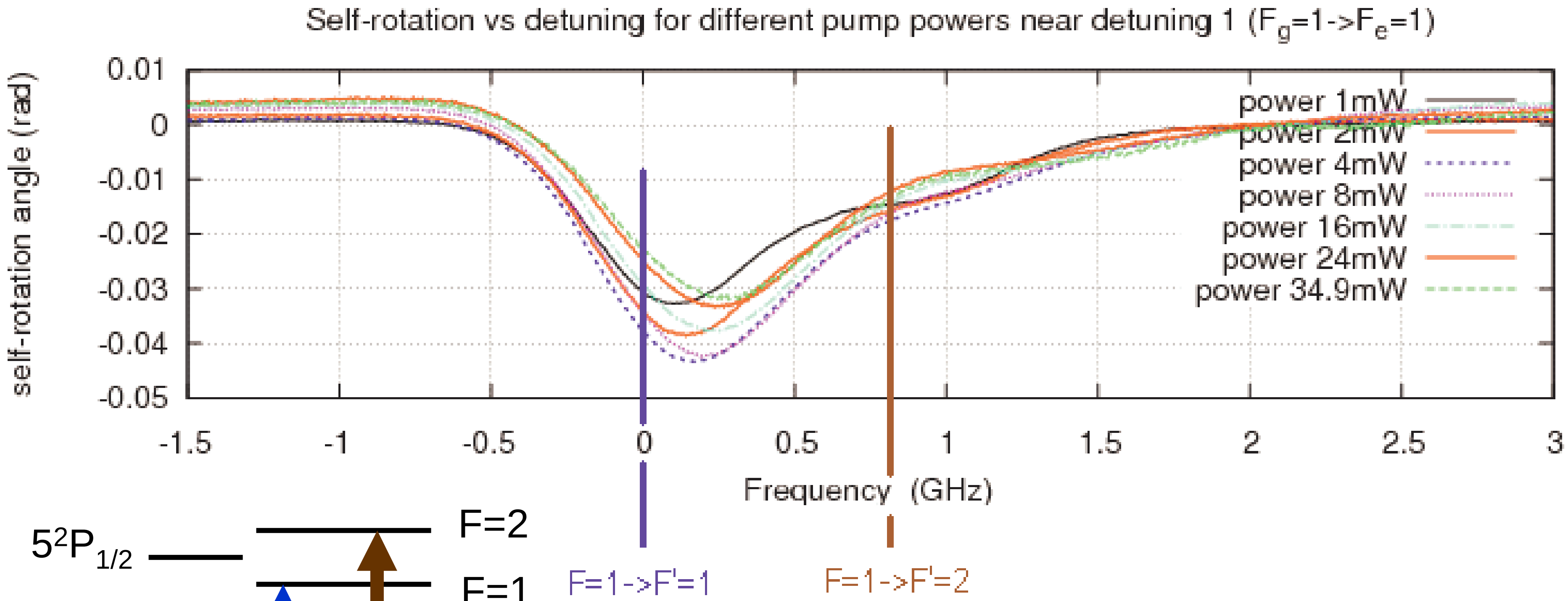
Polarization Self Rotation

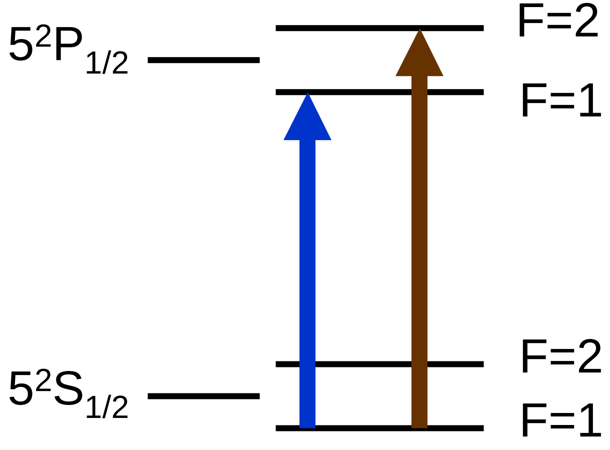


- Theory predicts that amount of noise suppression increases with the self-rotation angle

A.B. Matsko et al., PRA 66, 043815 (2002)

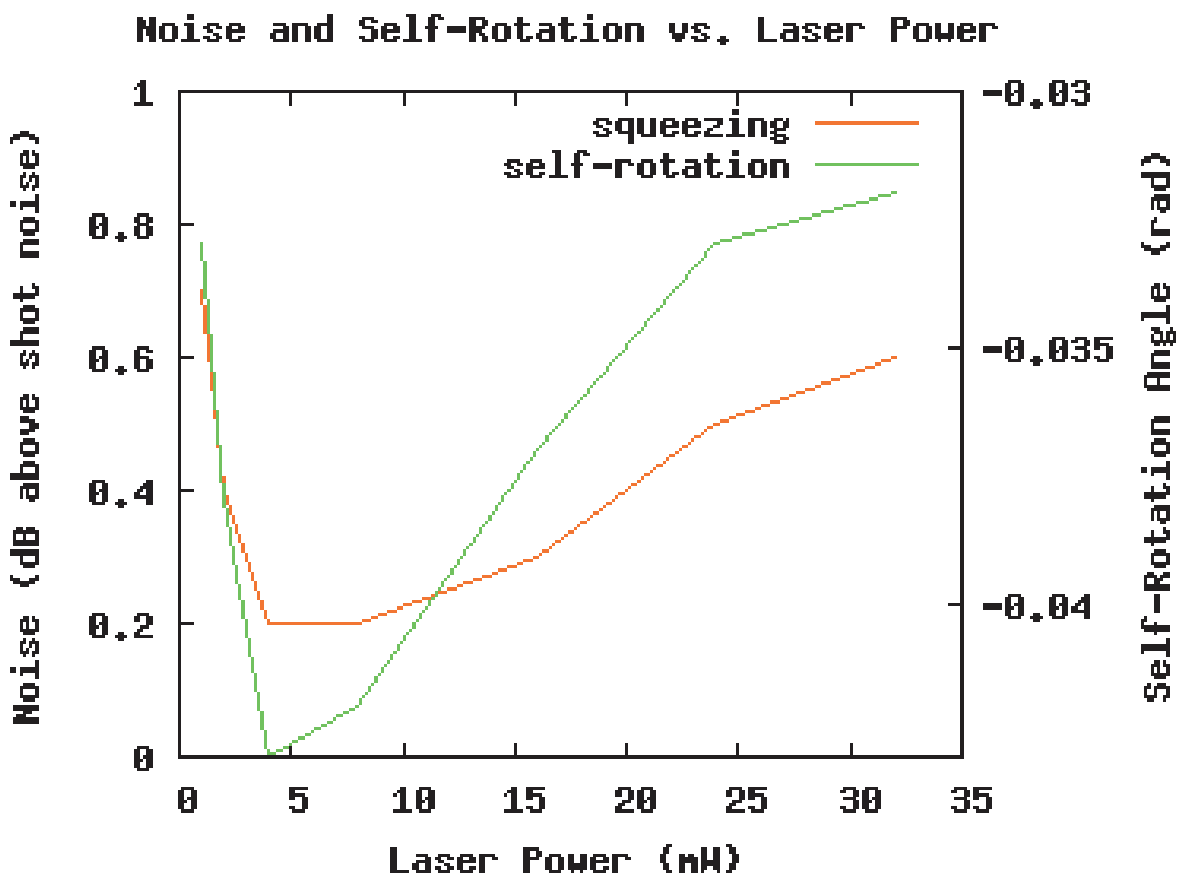
Self Rotation Results

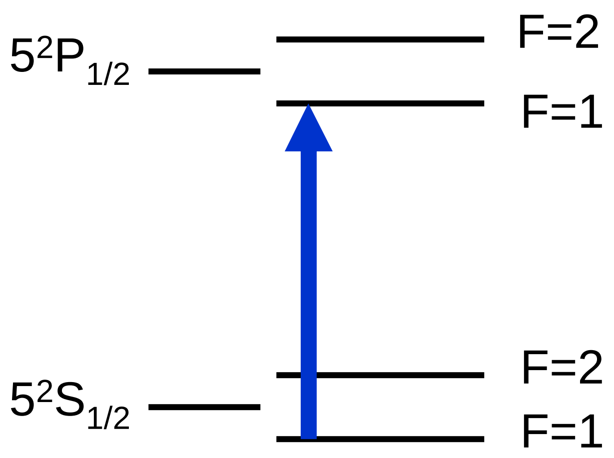




Self-rotation is largest for the F=1→F’=1 resonance and for incident laser powers of about 4 to 8 mW

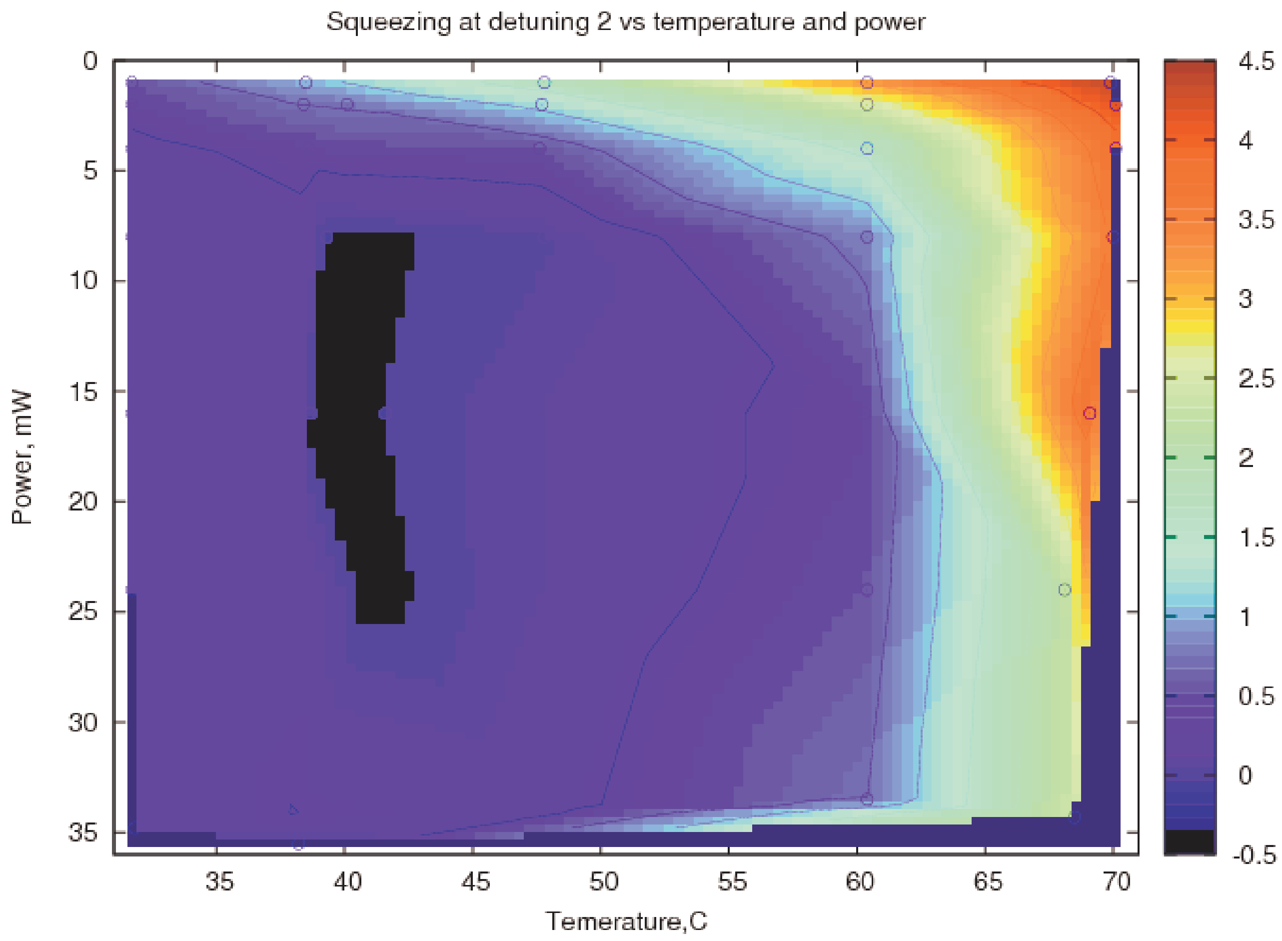
Squeezing Results, I

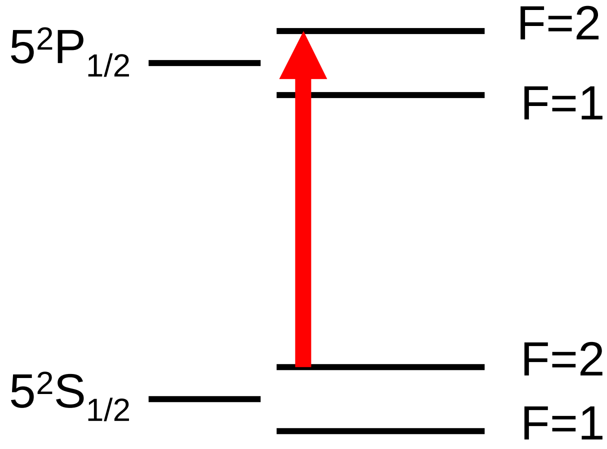




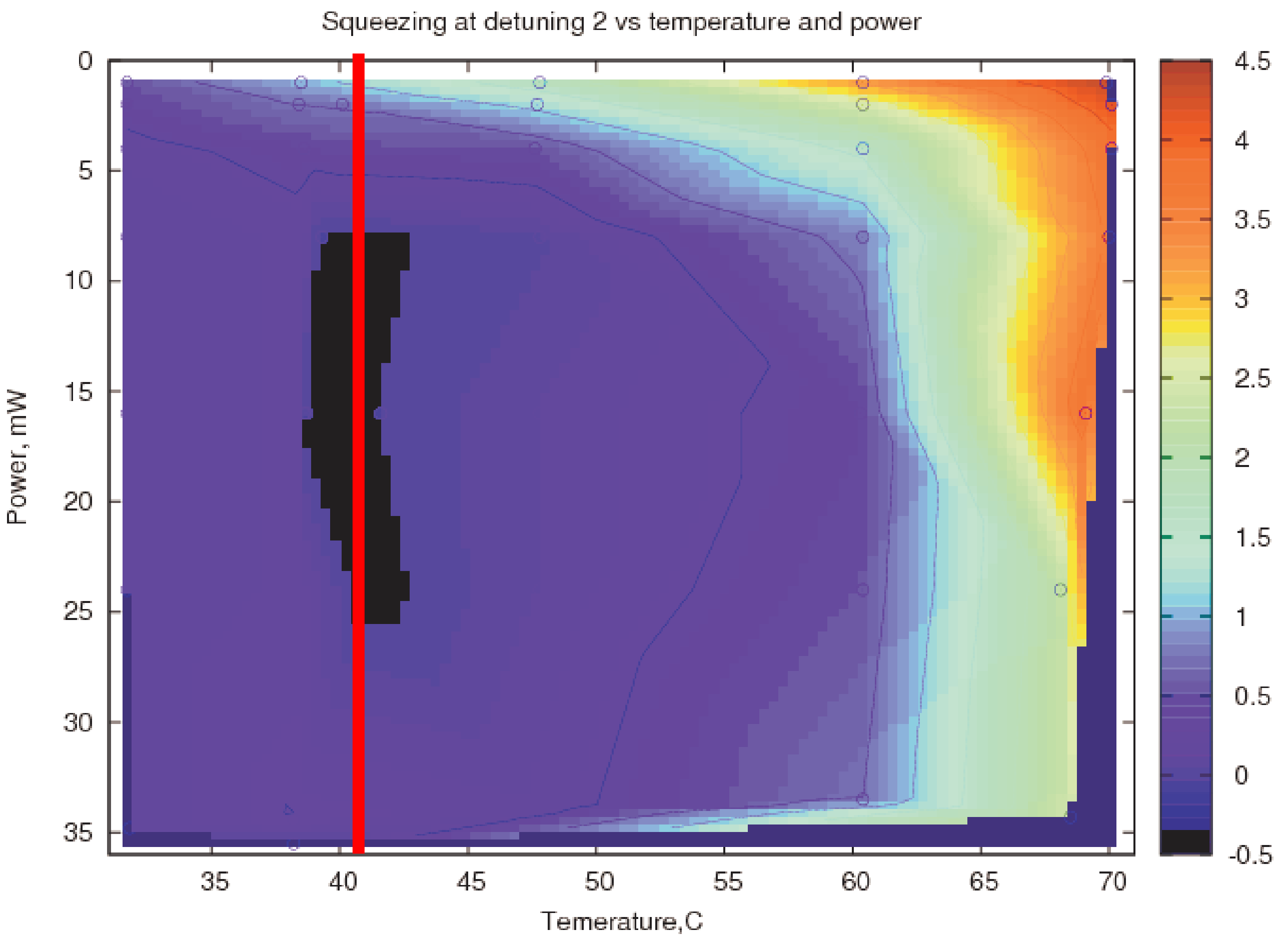
- Optimum laser power is around 4-8 mW, as predicted by self rotation vs. power

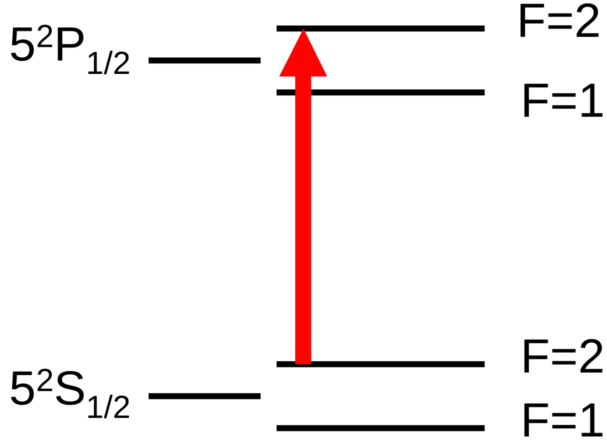
Squeezing Results, II



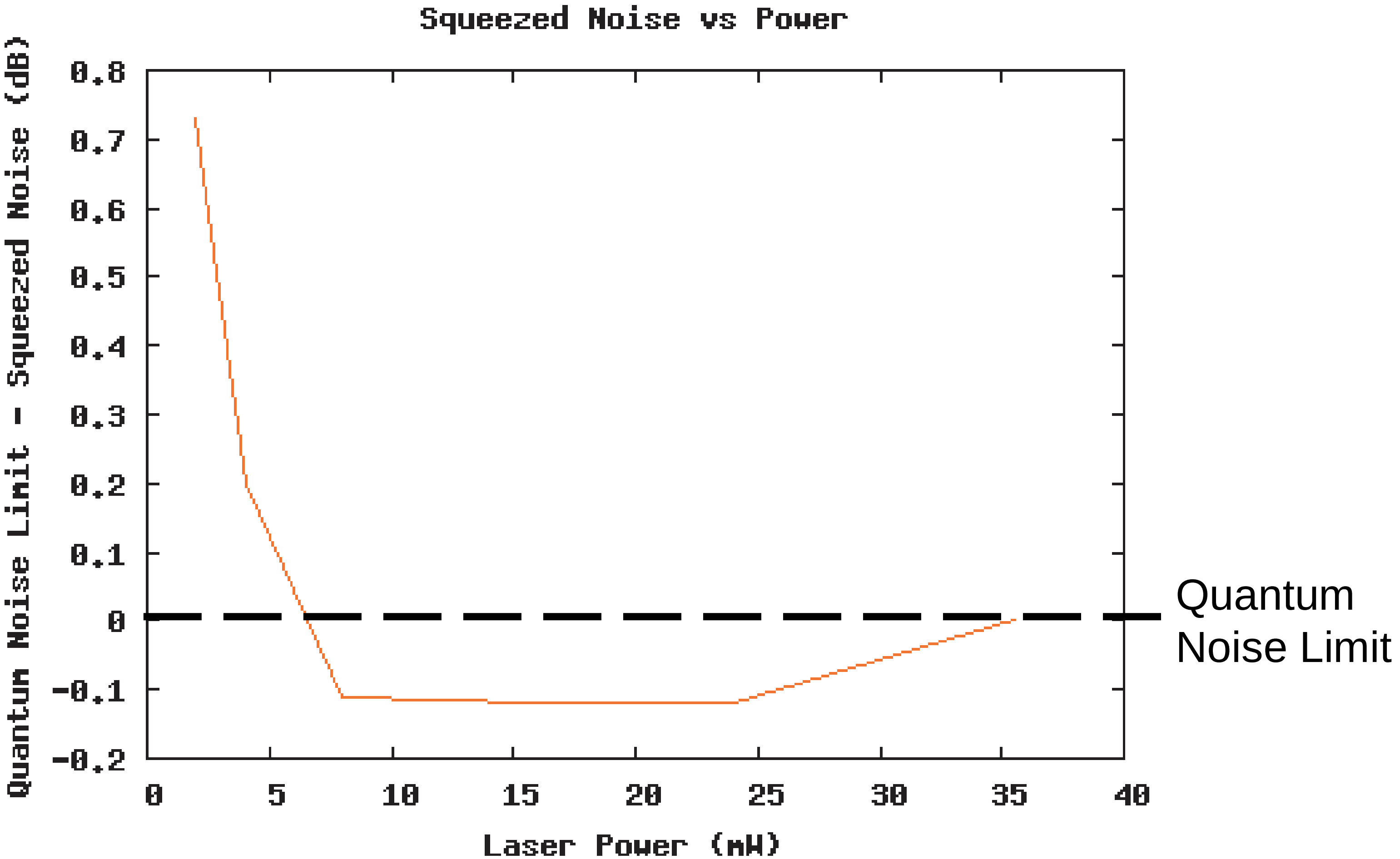


Squeezing Results, II



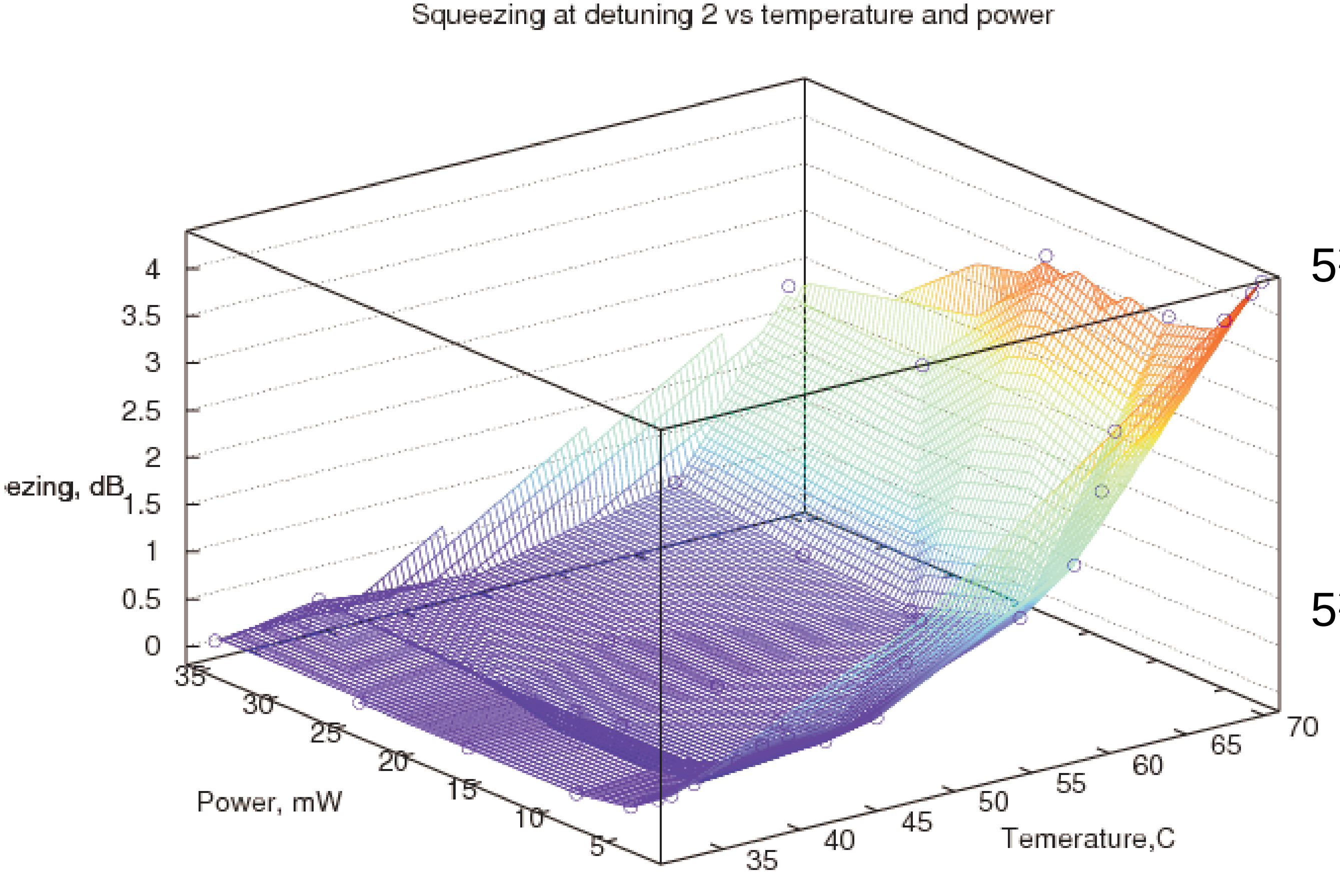


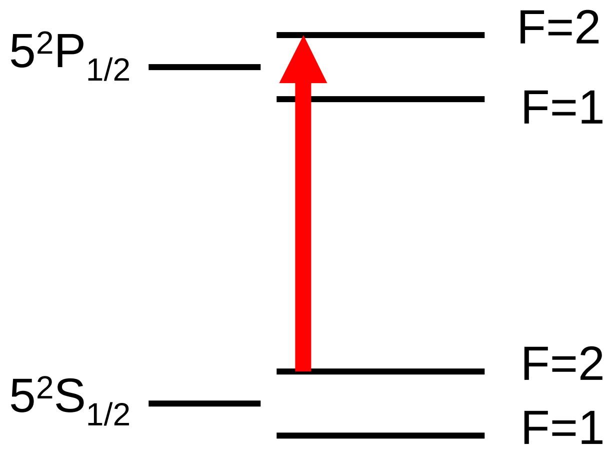
Squeezing Results, III



Noise is suppressed below the quantum noise limit for powers between 8mW and 24mW

Squeezing Results, III





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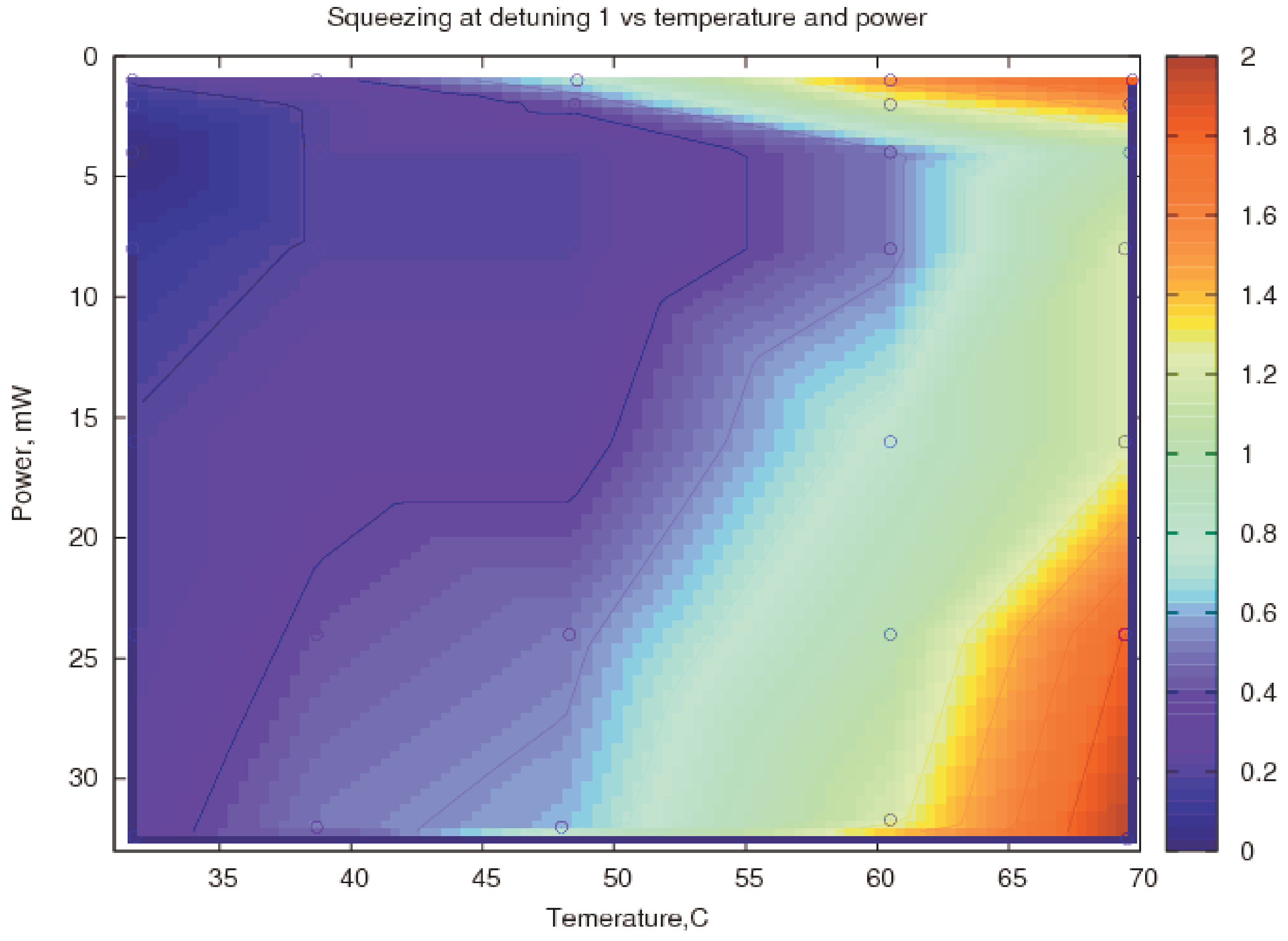

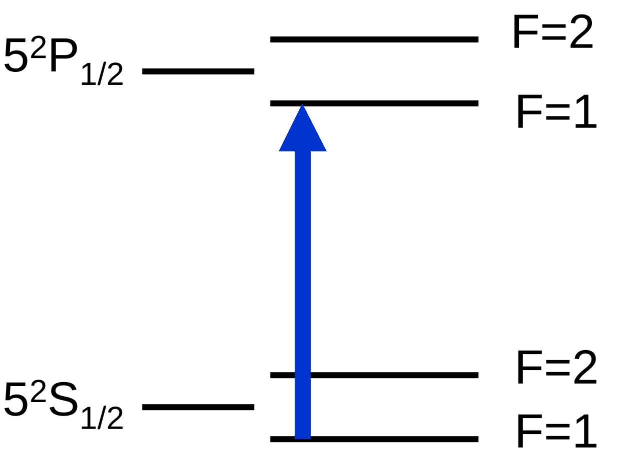

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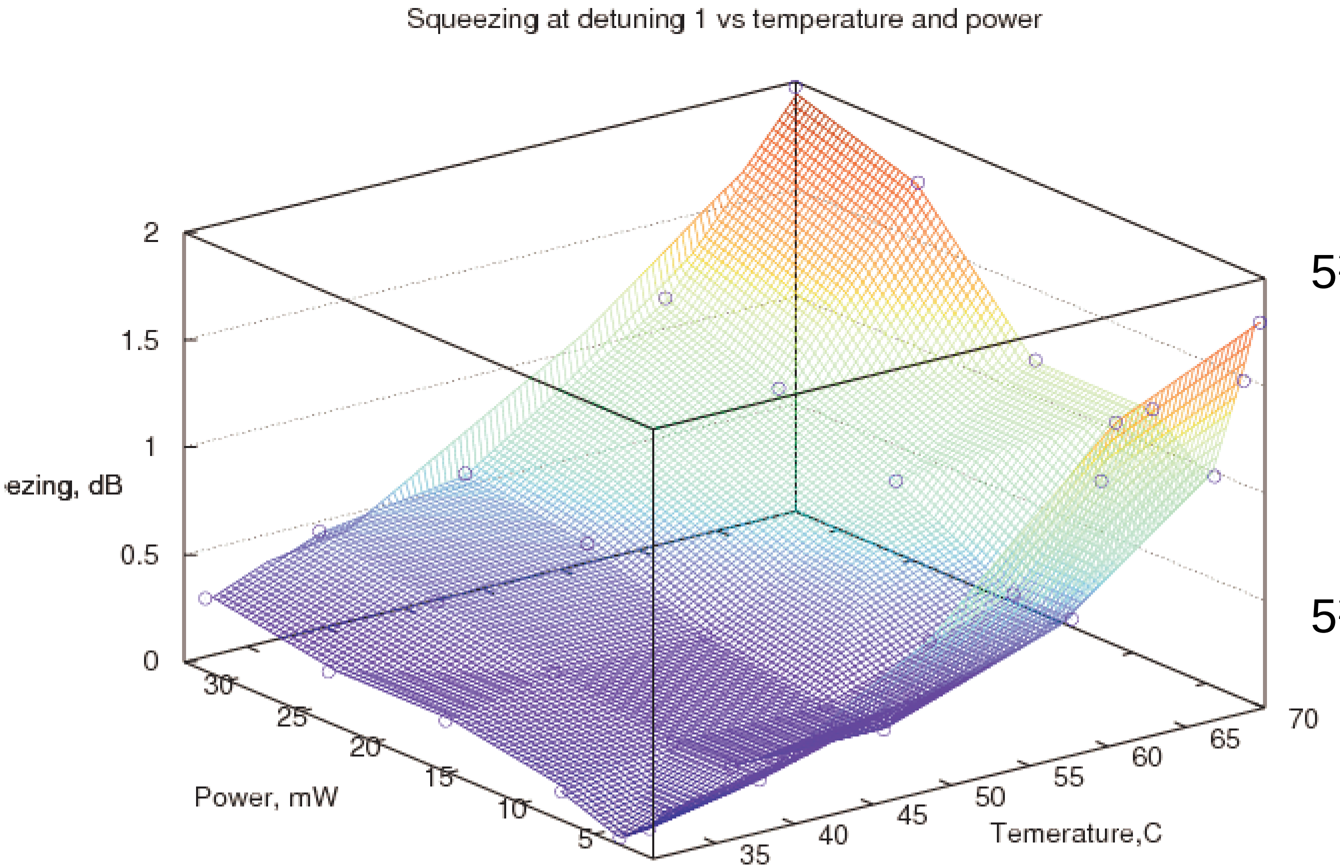
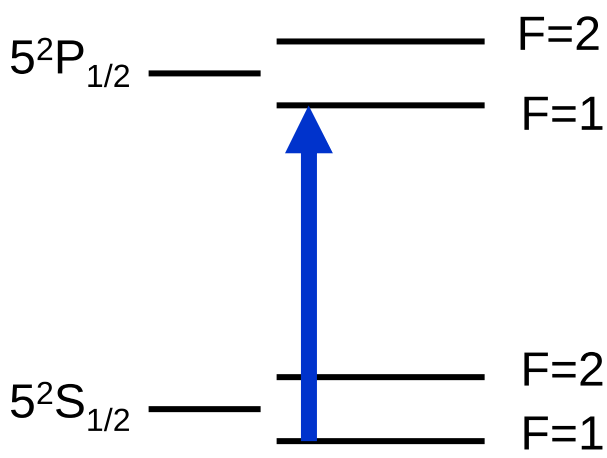
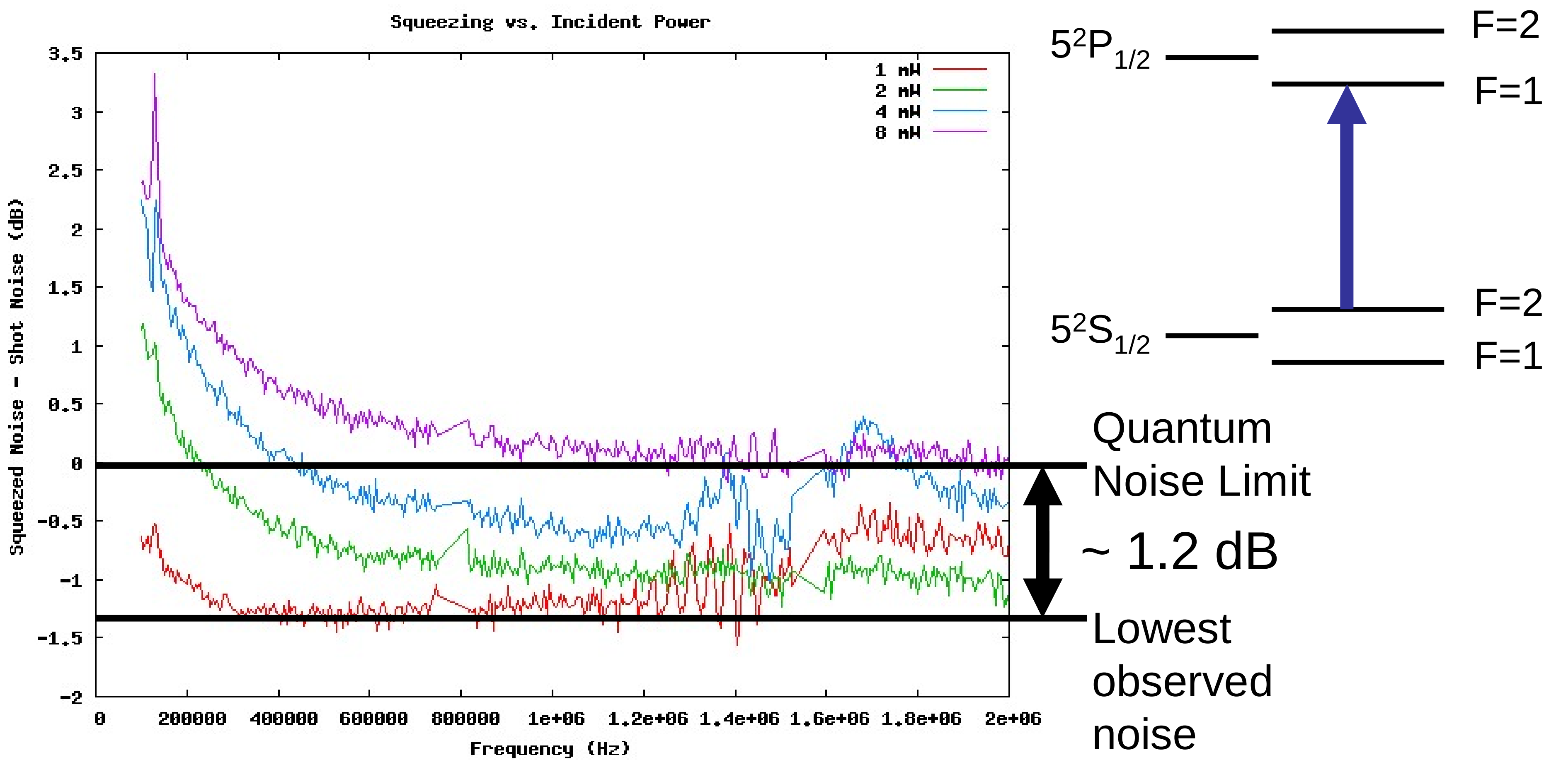




Record Atomic Squeezing



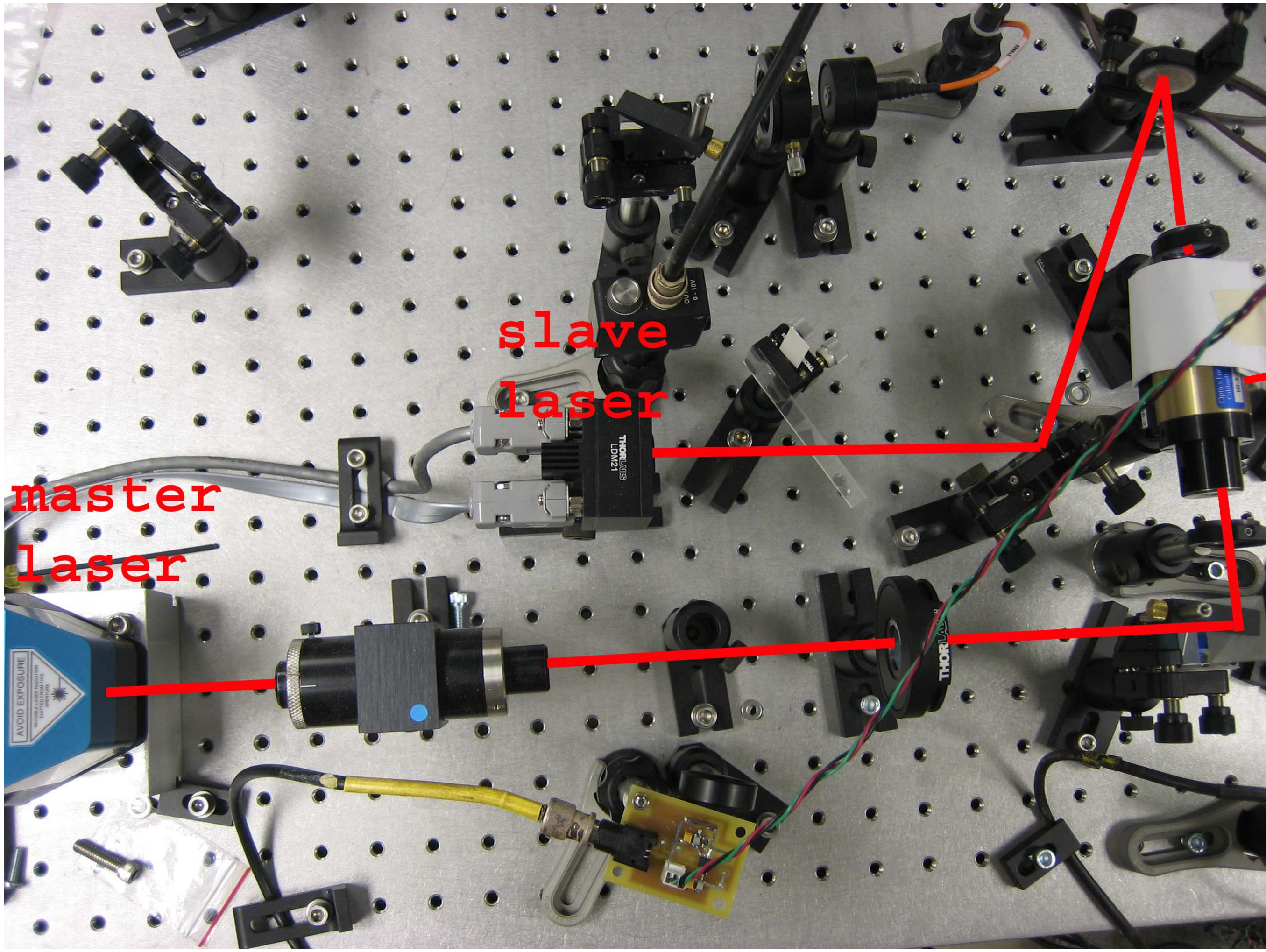
Controversy

- A. B. Matsko, et al.: “This might work”
  - Propose PSR as squeezing method (2002)
- J. Ries, et al.: “Yes!”
  - observe .85 dB of squeezing (2003)
- M. T. L. Hsu, et al.: “No!”
  - Atomic noise overwhelms PSR squeezing (2006)
- A. Lezama, et al.: “Maybe so. . .”
  - Theory paper suggests squeezing should be able to overcome atomic noise (2008)

Conclusions

- large parameter space ➔ inconsistent results in different groups
  - Parameters: laser power, beam diameter, temperature, magnetic field, Rb cell type, Rb resonance used
- squeezing in atomic vapor does occur
  - may be a viable option for applications if degree of noise suppression can be increased

Injection Locking



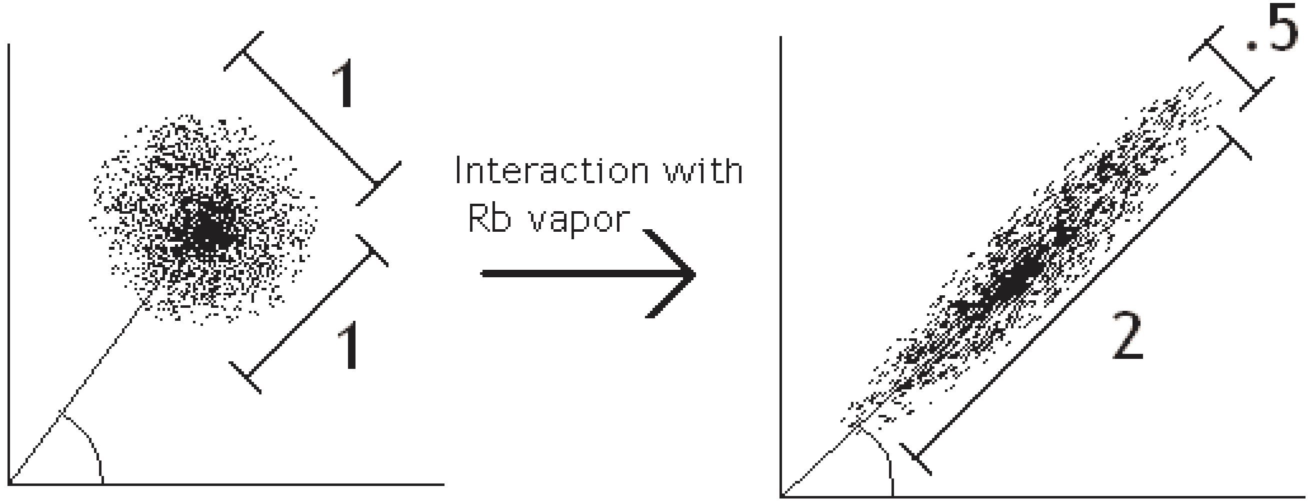
output
to Rb cell

Master: 6 mW

Slave: 40 mW

Squeezing Results, II

$$Squeezed\,Noise(dB) = 10*\log\left(\frac{Smaller\,Uncertainty}{Coherent\,State\,Uncertainty}\right)$$



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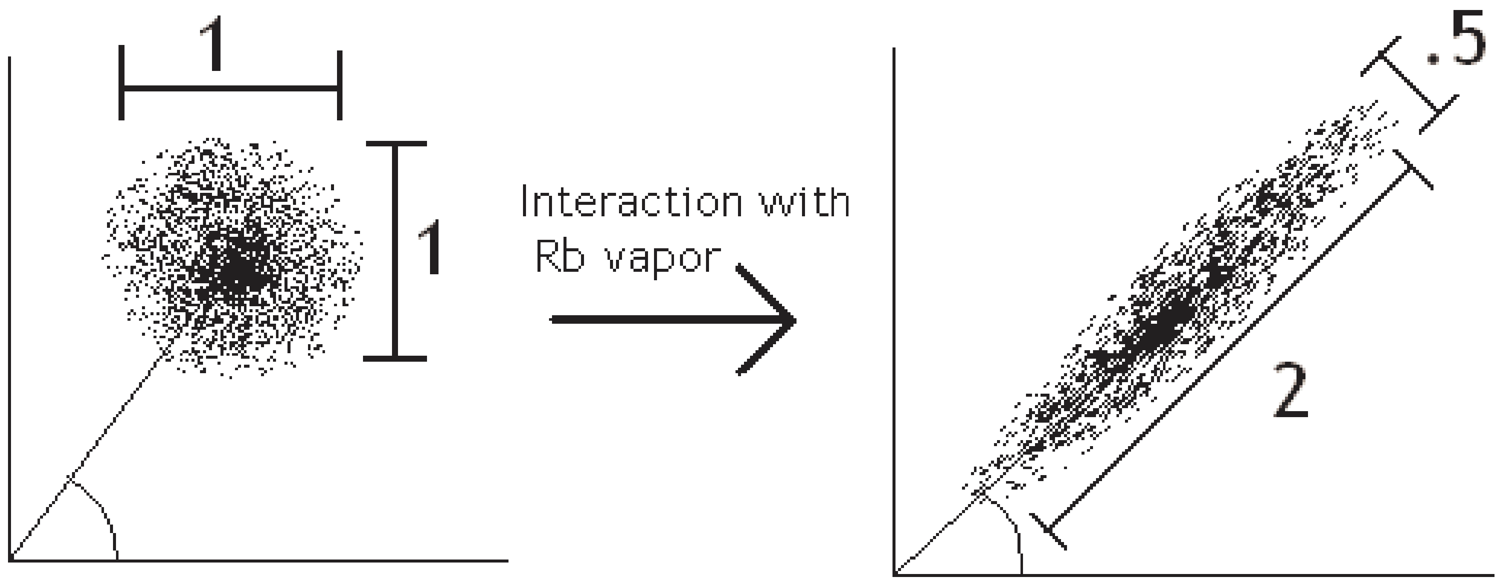
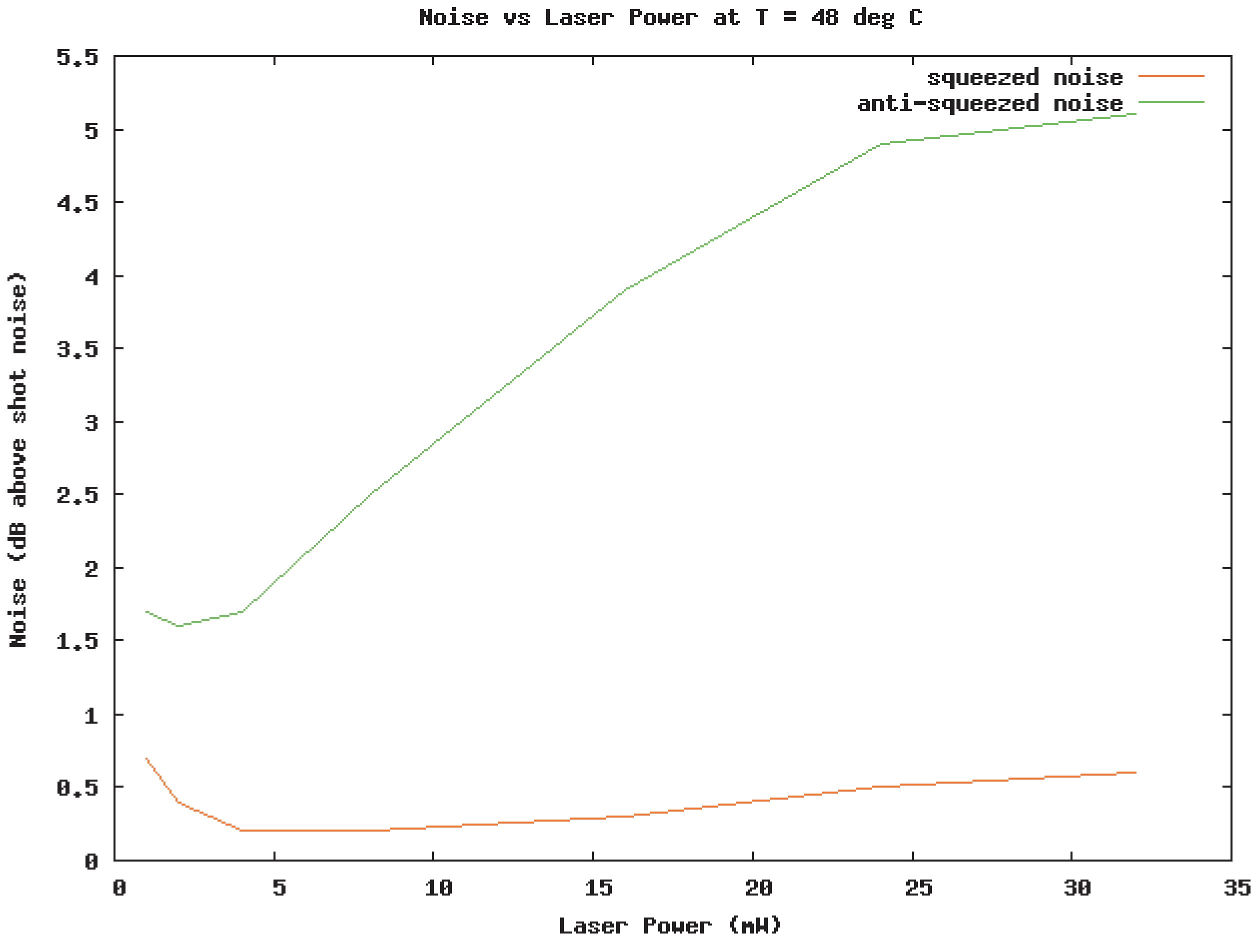
What Theory Predicts, II



- Amount of Squeezing = Amount of Anti-squeezing
  - i.e. the amount of noise suppression in phase, for example, should be equal to the amount of increased noise in the amplitude

Squeezing Results, II



There is some atomic noise that is not accounted for in this theory that pushes the squeezed and anti-squeezed noise above the quantum noise limit.