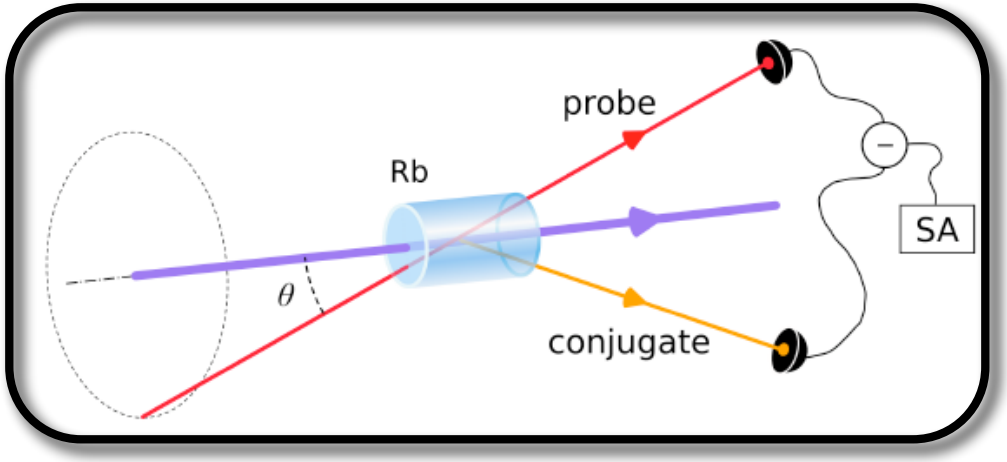
Strongly squeezed light from four-wave mixing in hot Rb vapor



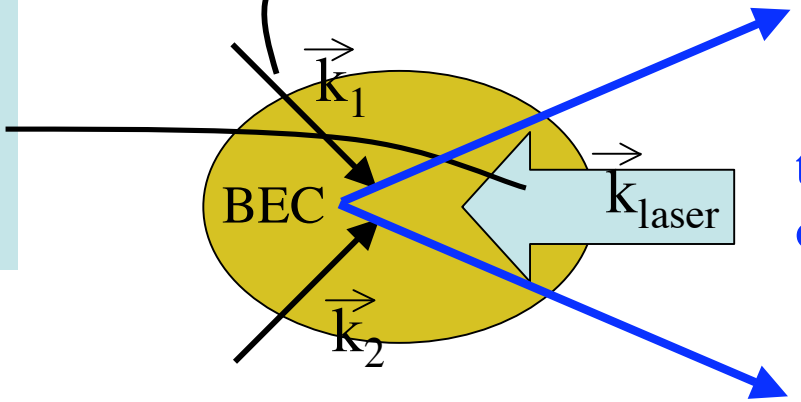
NIST, Gaithersburg, MD
and
Joint Quantum Institute
UMD/NIST

Paul Lett,
Colin McCormick (HSC),
Vincent Boyer,
Alberto Marino,
Ennio Arimondo (Pisa)

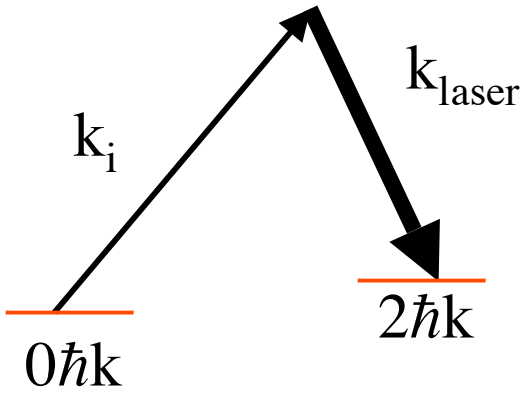
Producing correlated atoms from correlated photons

"dress" the atoms in the BEC with the "downward-going" frequency of a Raman transition

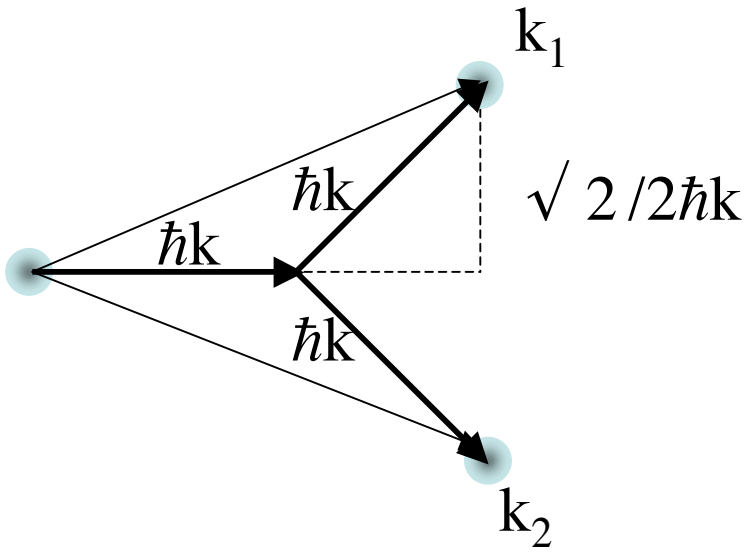
drive the "upward-going" transition with correlated photon beams



twin beams of atoms out



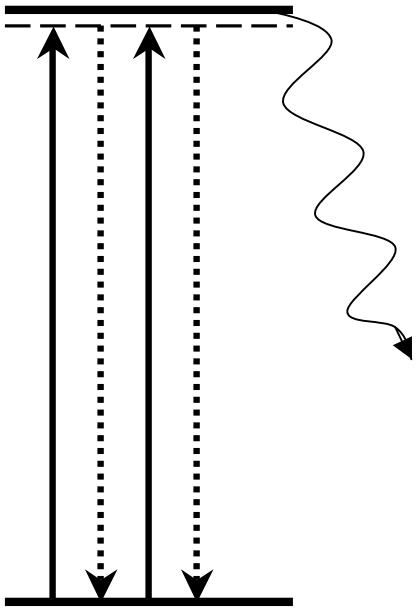
Raman transition



P. Lett, J. Mod Opt. 51, 1817 (2004)

4WM - with a difference

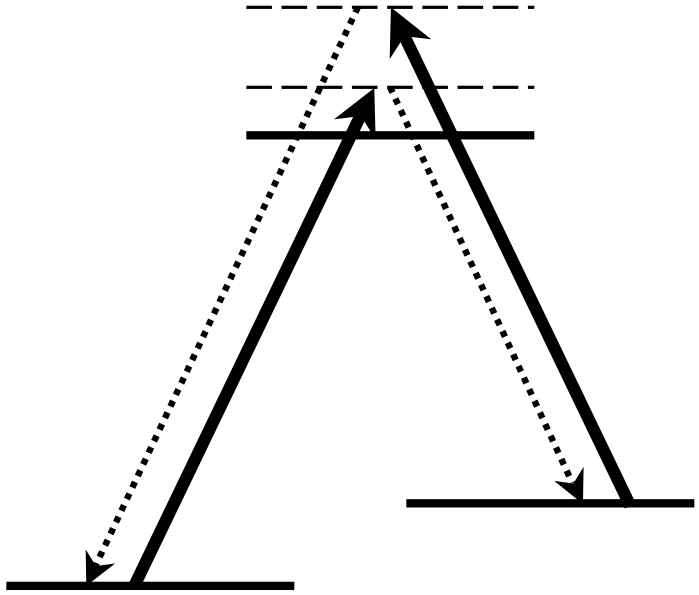
the old way:
a near-resonant, 2-level system



4WM based on
ground-excited coherences
and ensuing absorption and
spontaneous emission noise

Slusher, et al., 1985

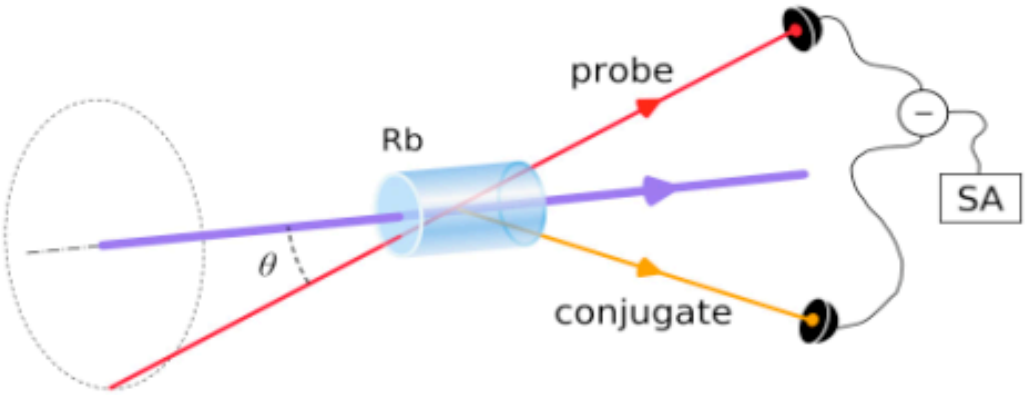
the new way:
an off-resonant, 4 - level system



4WM based on
ground-ground coherences
reduces these noise sources

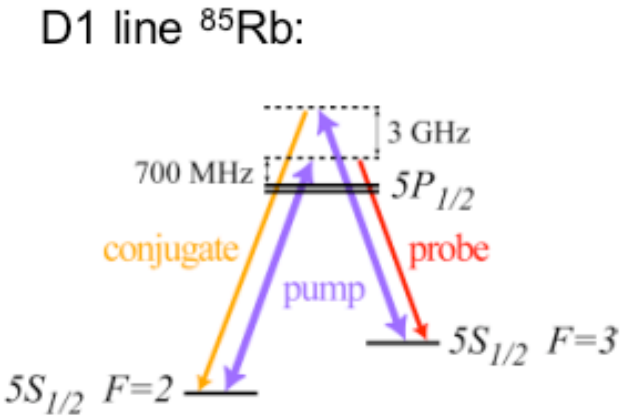
Harris, Lukin, Vuletic...

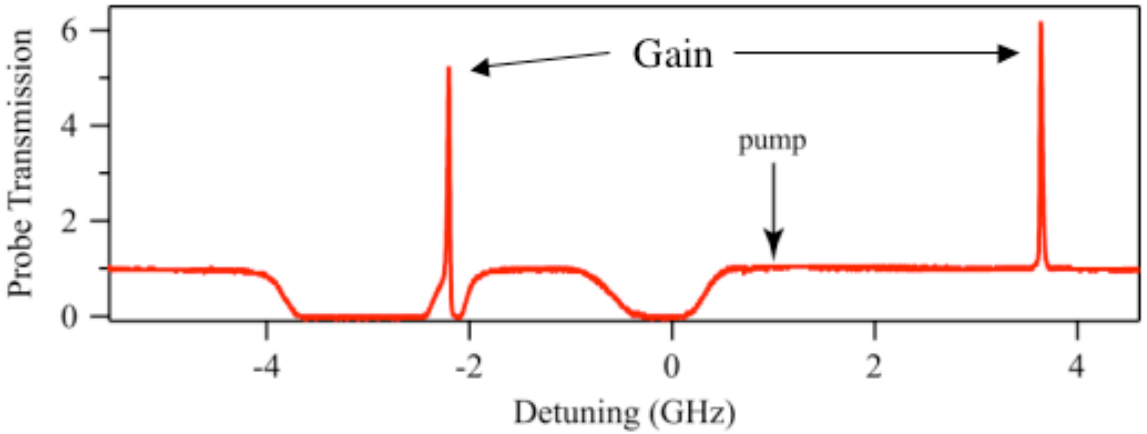
Experimental scheme



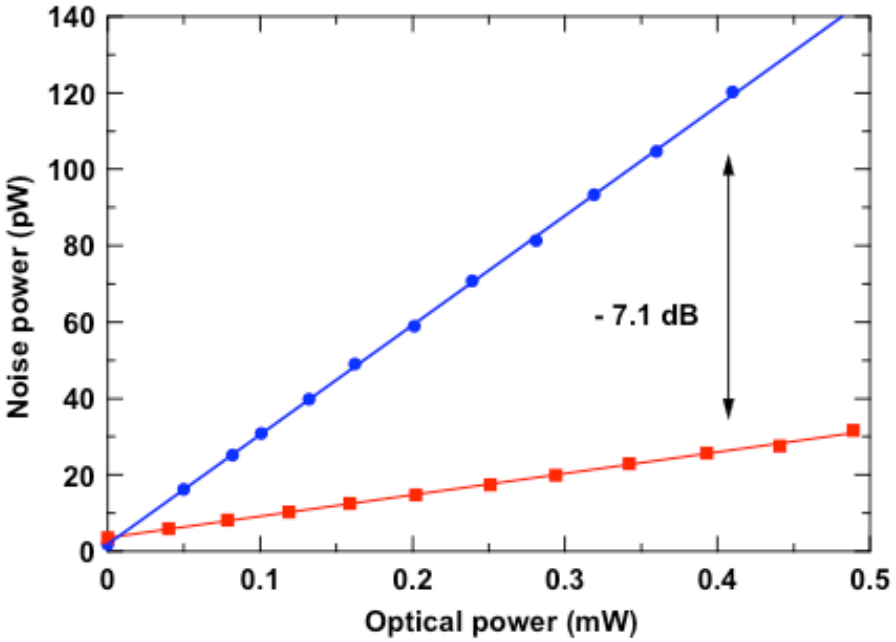
pump ~ 3-400 mW
probe ~ 10-100 μW
cell ~ 12 mm, AR coated
Gain ~ 6
θ ~ 0.5 degrees

probe and conjugate polarization orthogonal to pump



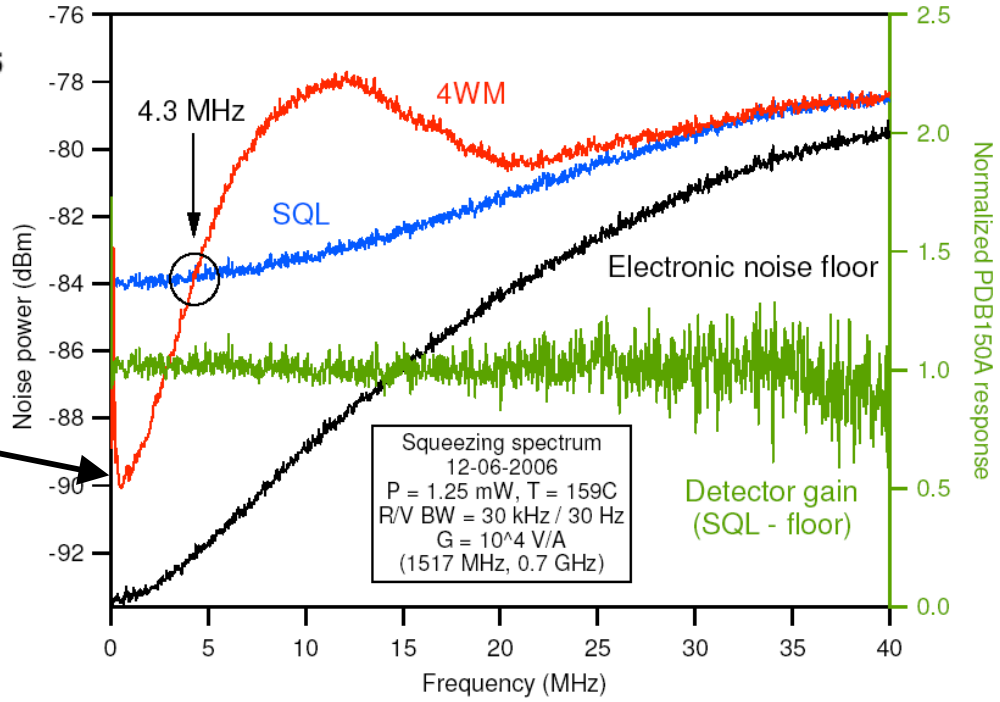


intensity-difference squeezing

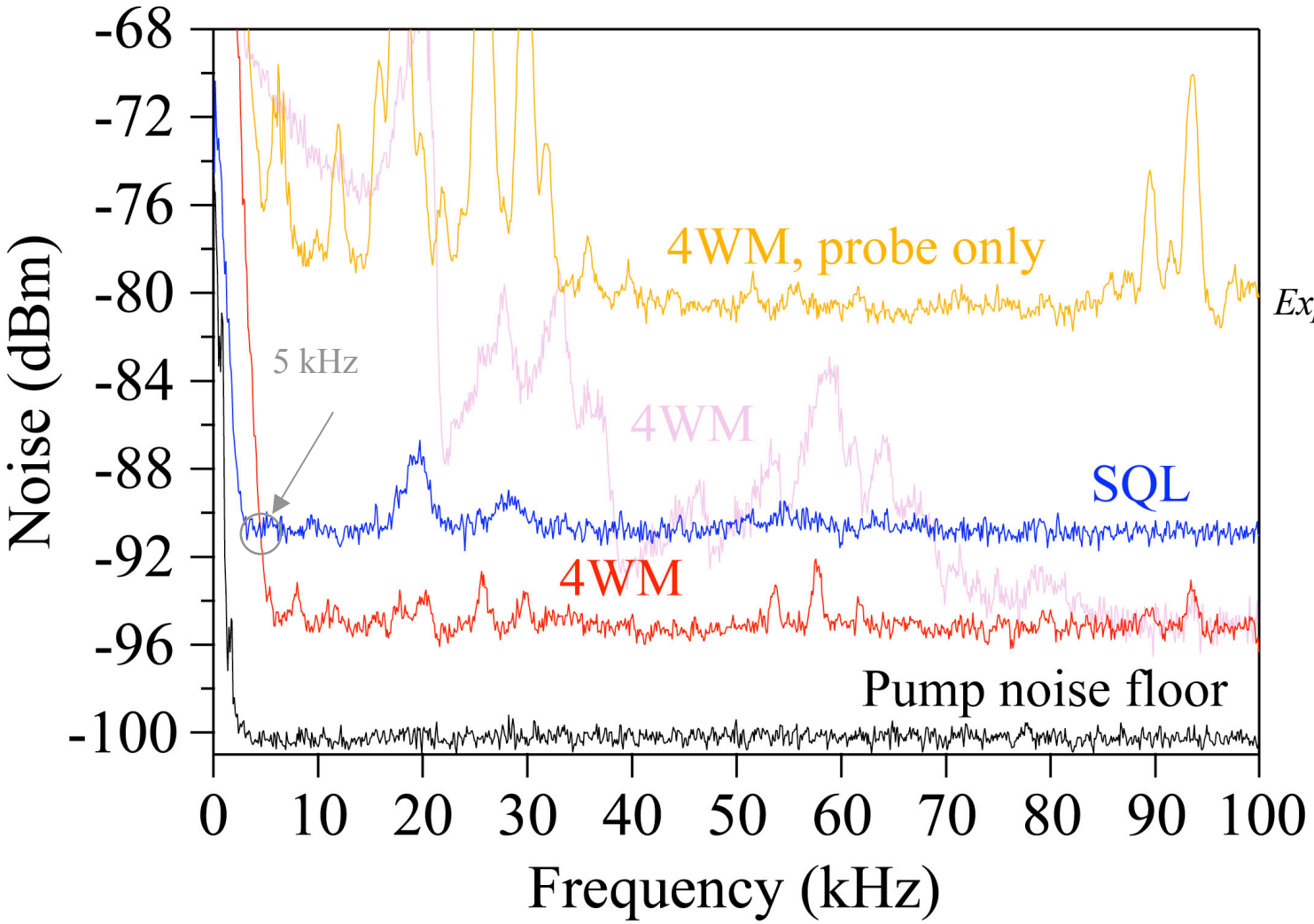


We infer 10.2 dB (between -9.4 and -10.9 dB) of squeezing at the source. (from uncertainties and limited by seed light and small gain)

We have seen up to -7.1 dB at 1 MHz



Low-Frequency Detail

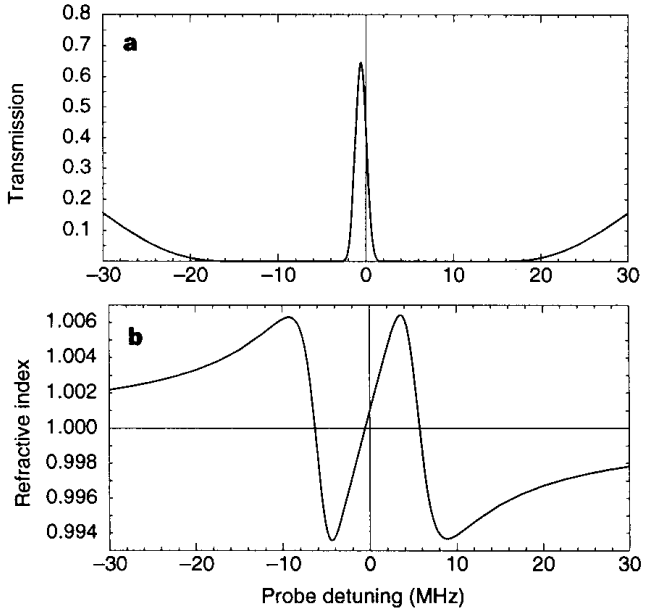


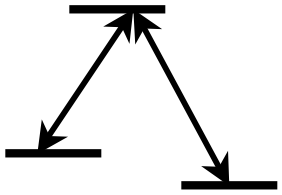
Experimental parameters:

Probe = 41 μW
Conjugate = 39 μW
RBW = 1 kHz
VBW = 3 Hz

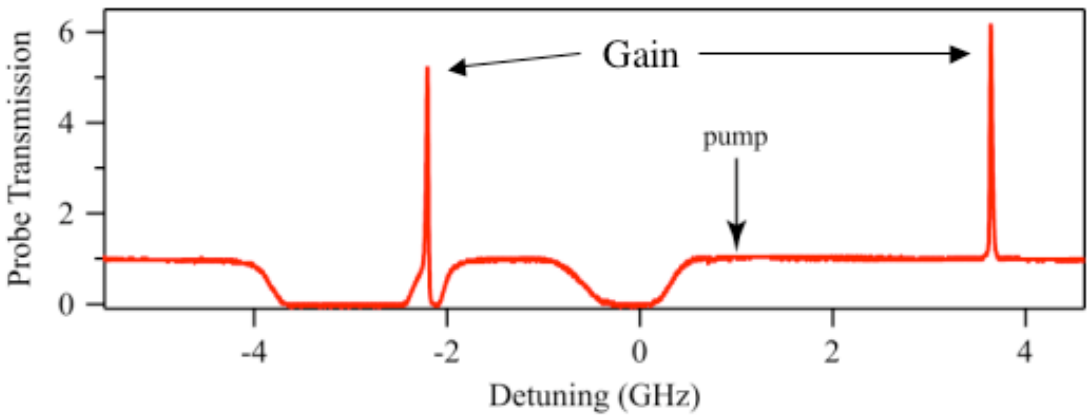
Low-frequency noise limited by noise of input laser.

Slow Light



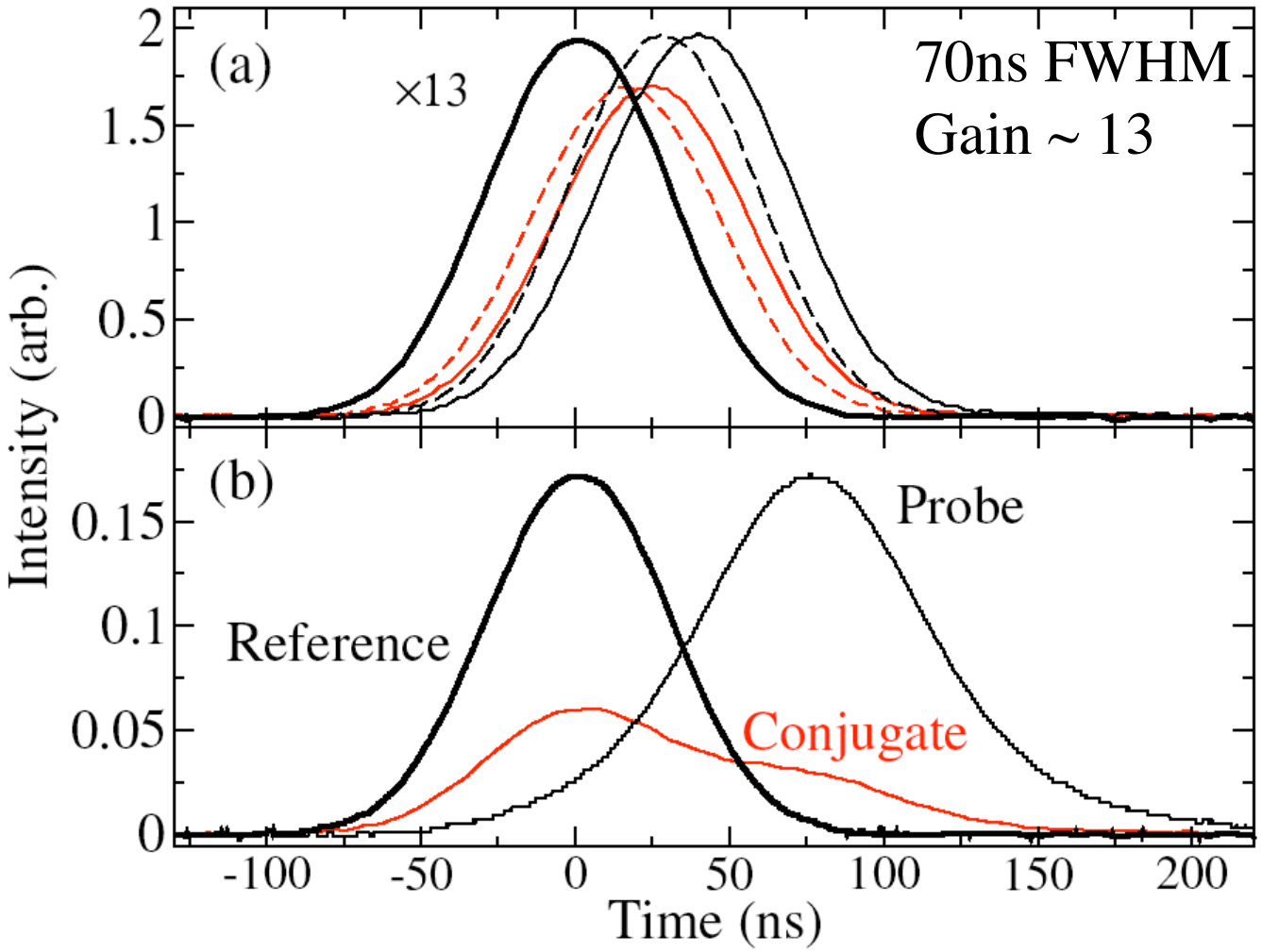


EIT (less loss) spectrum with associated dispersion



gain features imply dispersion and slow light as well

pulse delay

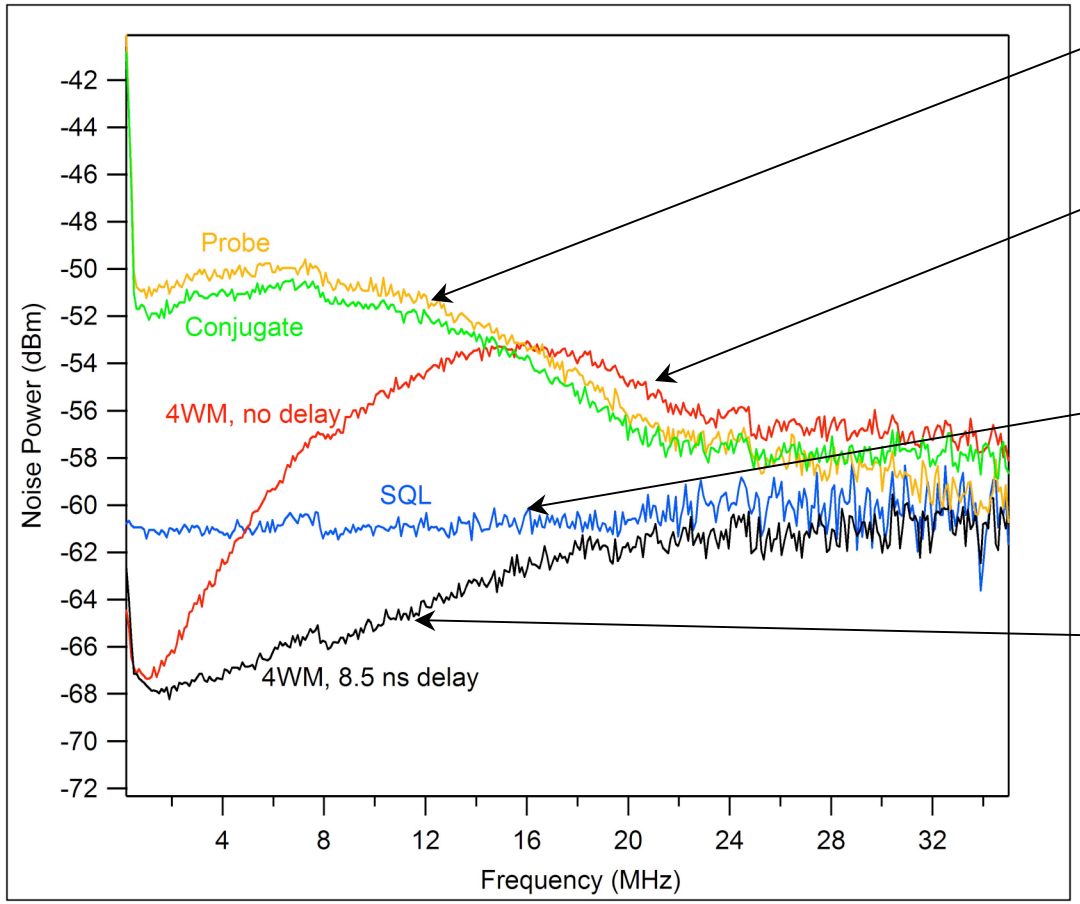


δ=10 MHz
300 mW pump
10% broadening

δ=22 MHz
250 mW pump
5% broadening

pulse breakup when detuned closer to Raman absorption dip

Squeezing with a delay



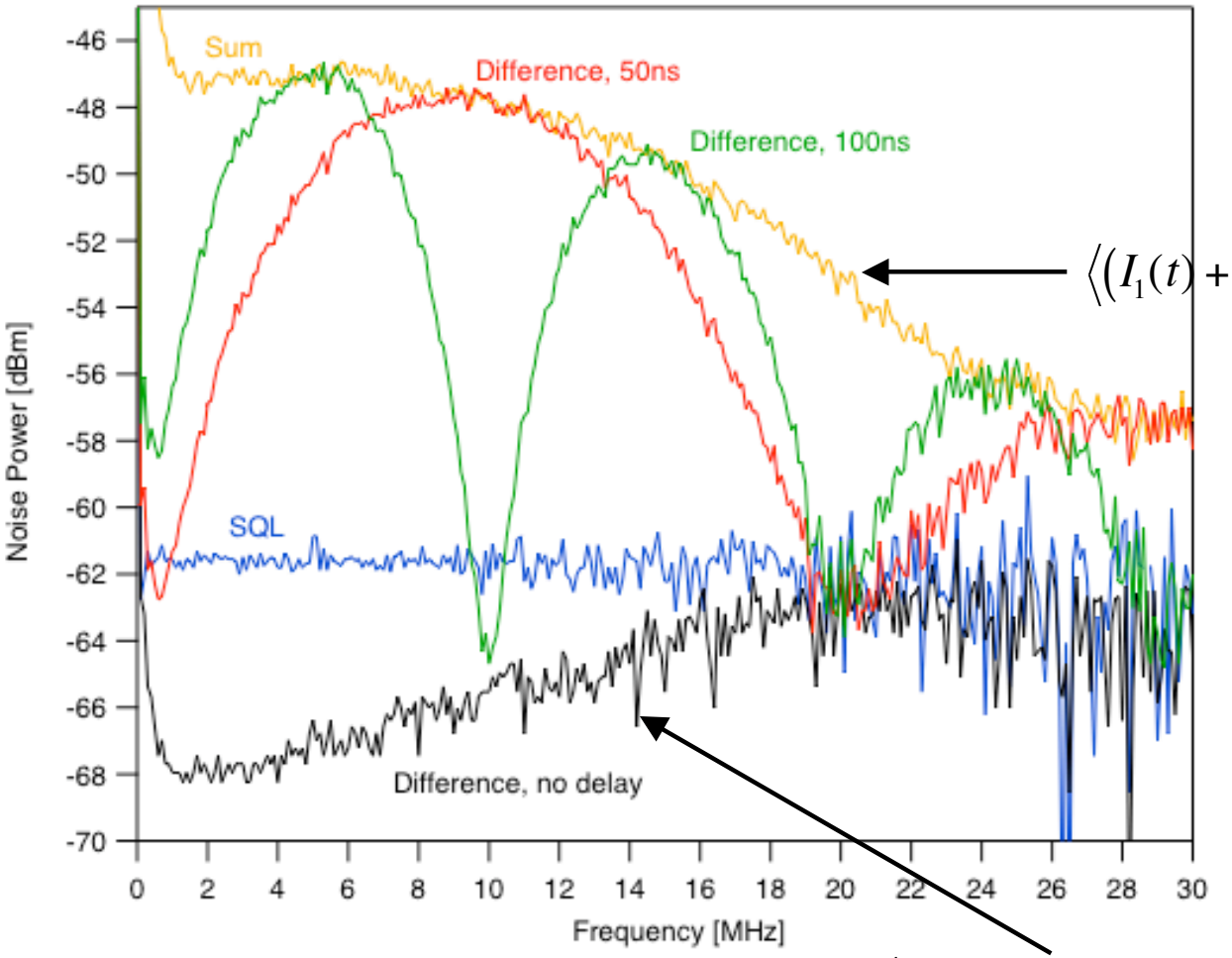
single beam noise

“default” from the 4WM cell

shot noise limit

“optimal” delay to remove differential slow-light delay (8.5 ns)

Squeezing with more delay



bounds are set by the Fourier transforms of:

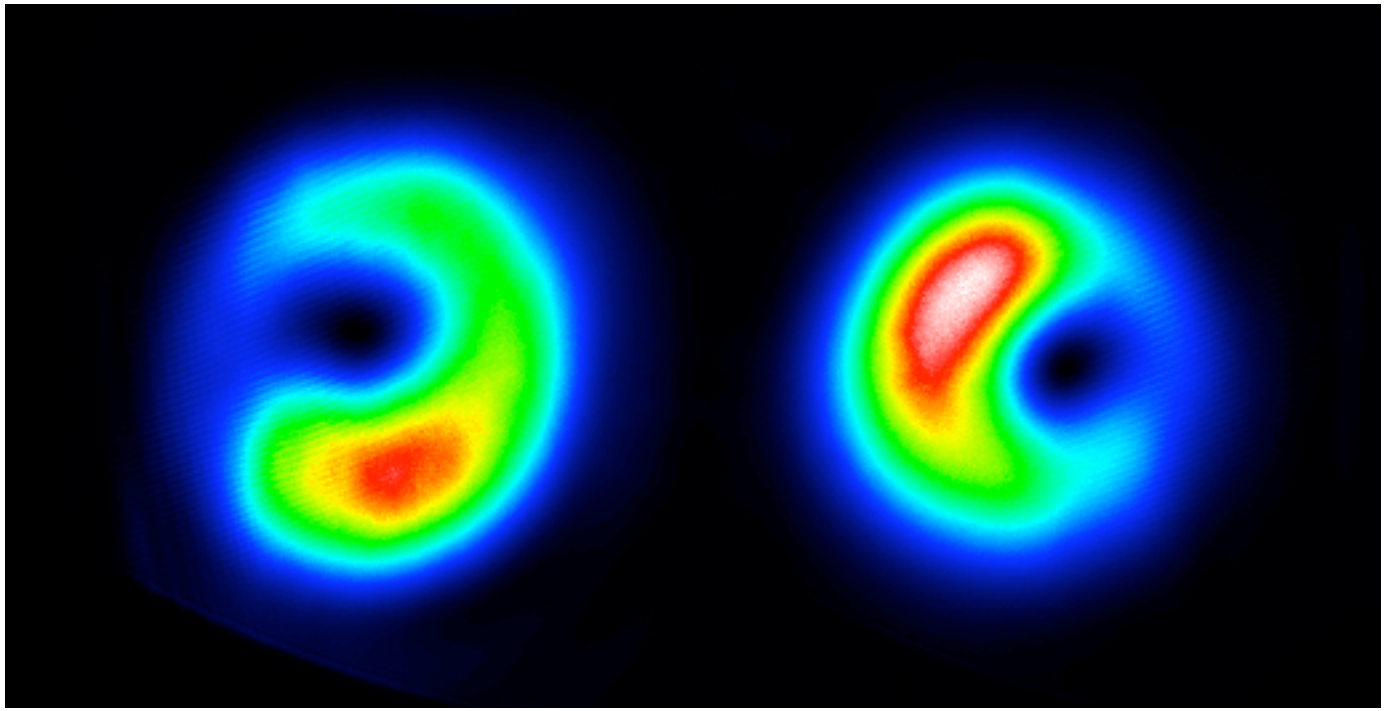
$$\left\langle \left(I_1(t)+I_2(t)\right)\left(I_1(t+\tau)+I_2(t+\tau)\right)\right\rangle$$

(where these are evaluated at the "optimal delay")

see: S. Mashida and Y. Yamamoto, Opt. Lett. 14, 1045 (1989)

$$\left\langle \left(I_1(t)-I_2(t)\right)\left(I_1(t+\tau)-I_2(t+\tau)\right)\right\rangle$$

Squeezing of multi-spatial-mode beams



Laguerre-Gauss ℓ=1 beams with orbital angular momentum (almost)

-7 dB of squeezing measured (between entire beams)

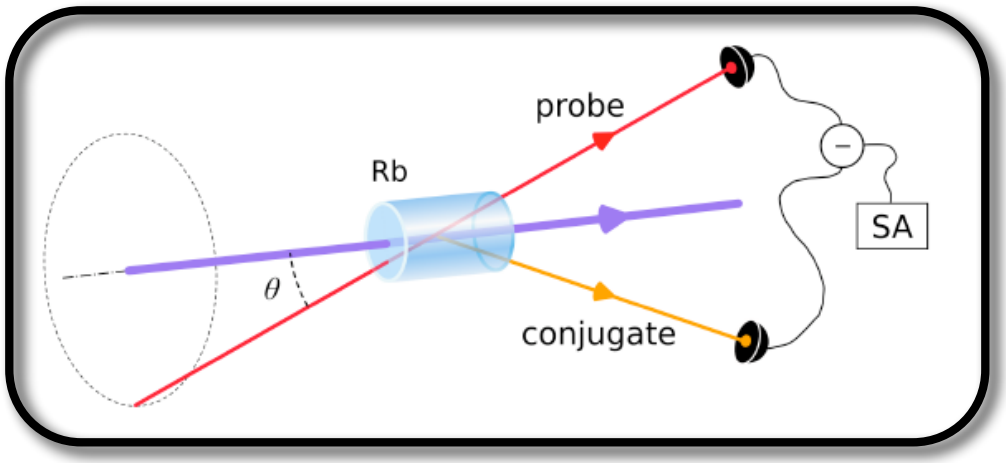
First squeezing of "relative orbital angular momentum?"

(is this useful?)

Summary

A four wave mixing source of squeezed light for image processing and interferometry

a simple system, tuned to Rb atoms for atom optics!



- 2-level vs. 4-level
- single-pass gain, no cavity
- intensity-difference squeezing
- (phase-sum squeezing)
- low frequency squeezing
- slow light
- pulse locking
- effect of delay on squeezing spectrum
- squeezing of Laguerre-Gauss spatial modes
- continuous-variable EPR source

Opt. Lett. **32**,178 (2007), + quant-phys 0703173 and 0703111