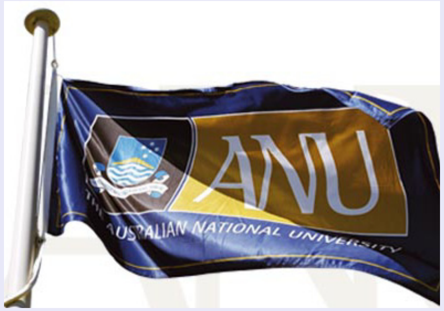
The ANU Atom Laser

Cristina Figl



The ANU BEC group

ACQAO

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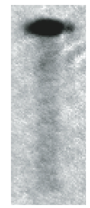
Alexander von Humboldt Stiftung / Foundation

Craig Savage
Laurent Longchambon

Outline

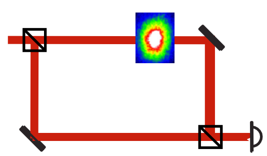
Motivation



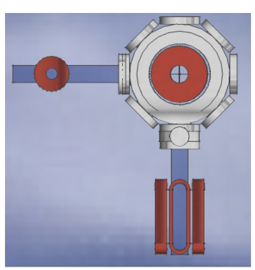
Continuous
Raman atom laser

Properties of an atom laser:

- fluctuations and flux
- beam profile
- linewidth



Detector for minimally
destructive detection of BEC



Outlook

Motivation

<u>advantages of (optical) laser:</u>

coherent

monochromatic

collimated

intense

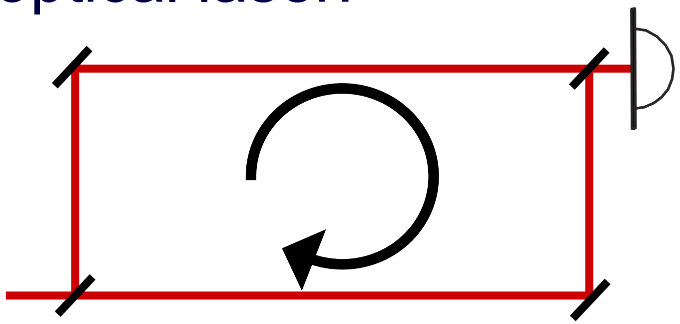
... but not noisy!
(quantum noise limited)

Example for application of optical laser:

laser gyroscope

Atoms have mass

⇨ higher sensitivity

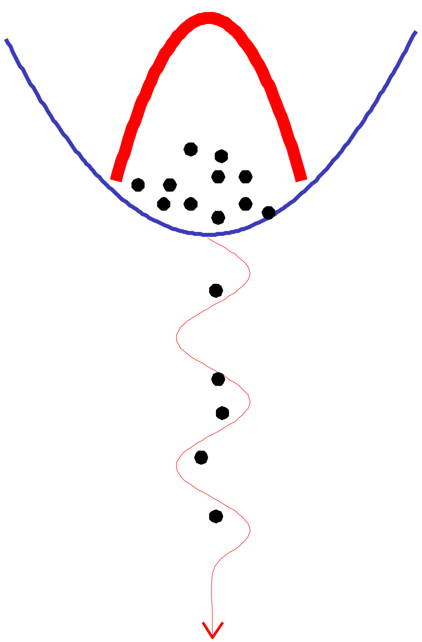


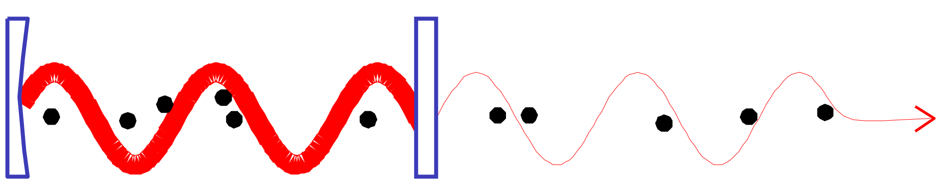
Motivation

properties of atom laser:

- ✓ coherent
- monochromatic
- collimated
- intense

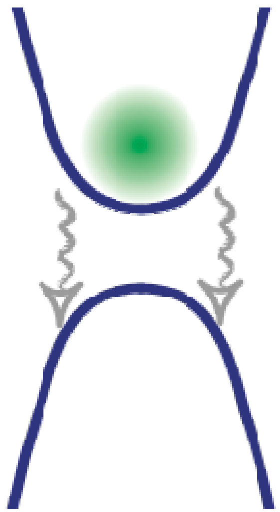
M.R.Andrews et al., Science, 275, 637 (1997
M. Köhl et al., PRL 82, 3008 (2001)
A. Öttl et al. PRL 95, 090404 (2005)





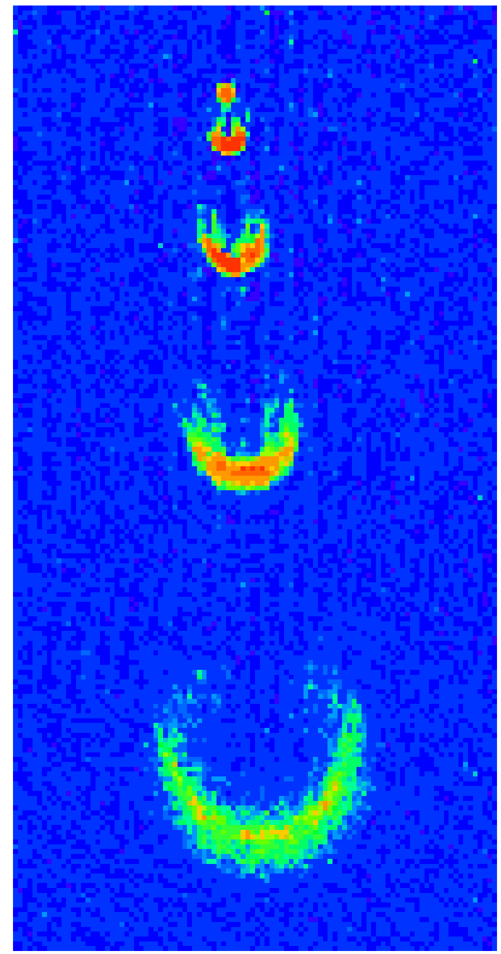
Producing the atom laser

Couple trapped state
to untrapped state.



with rf field

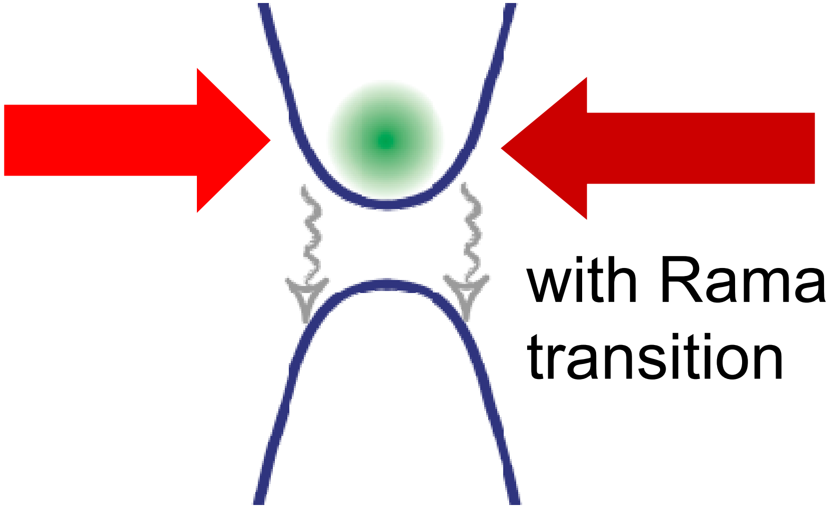
rf atom laser



Ketterle et al., MIT (1997)

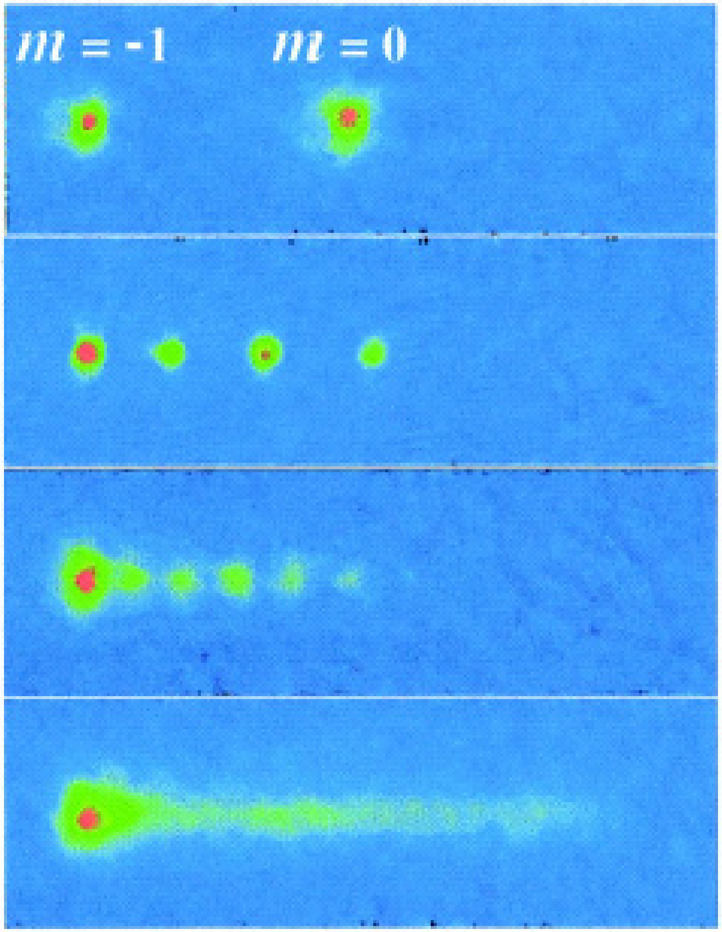
Producing the atom laser

Couple trapped state
to untrapped state.



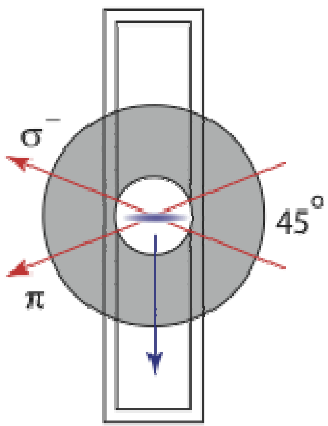
with Raman
transition

pulsed Raman atom laser

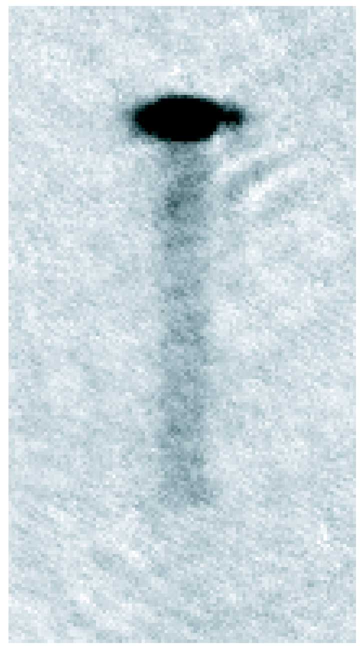


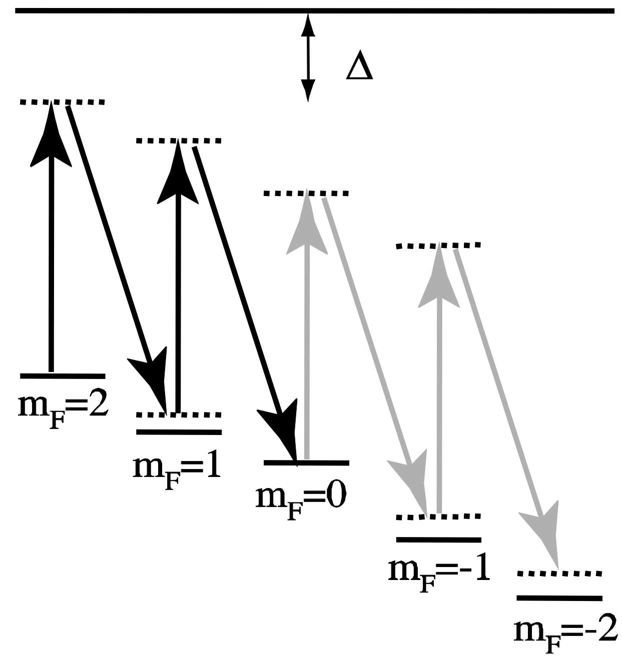
Philips et al., NIST (1999)

The first continuous Raman atom laser



8.5 ms
8 mW/cm²
Δ = 300 GHz

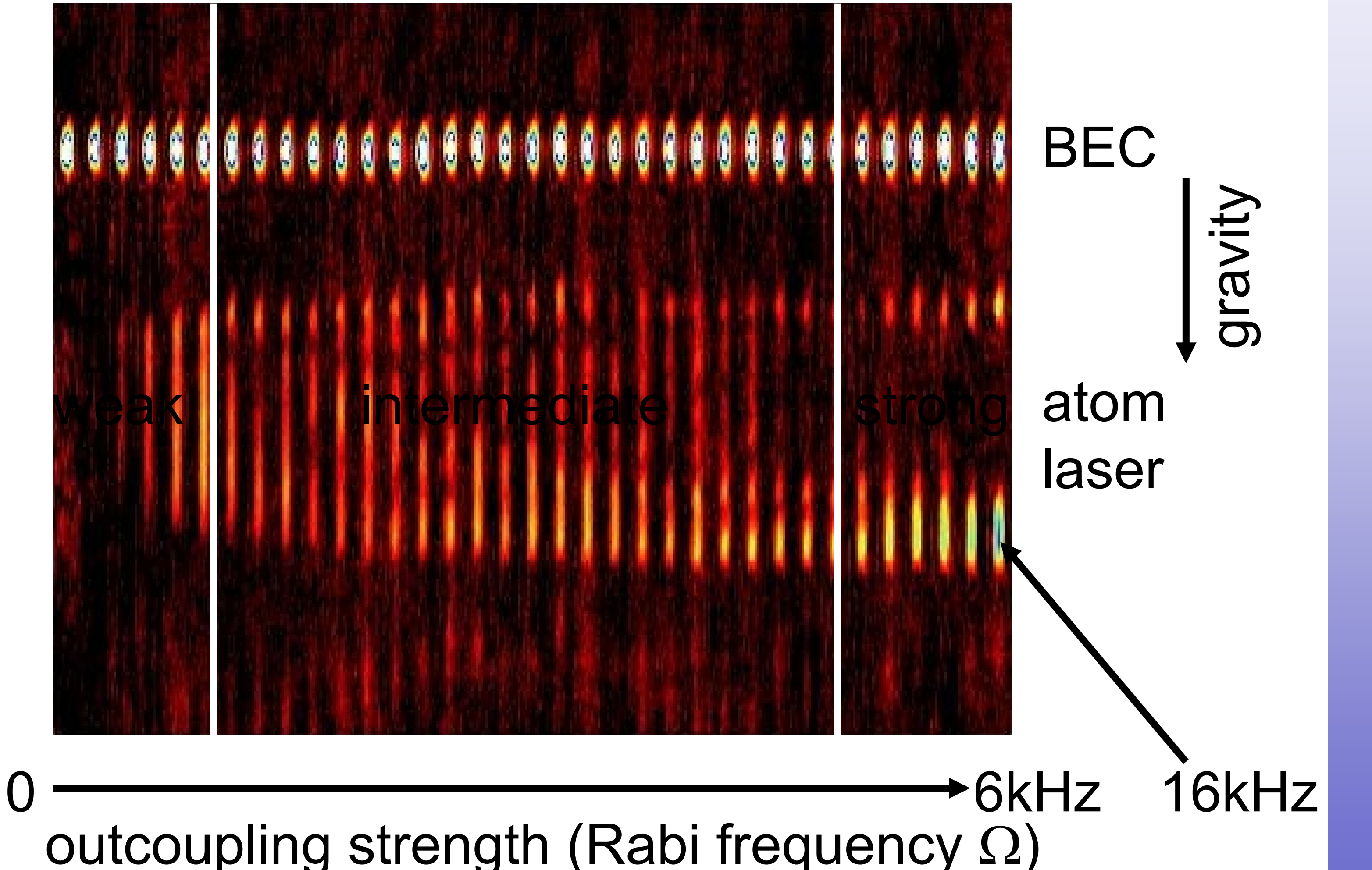




^{87}Rb condensates of 10^5 atoms; $\omega_\rho/2\pi = 260$ Hz; $\omega_z/2\pi = 20$ Hz; $B_0 = 0.25$ G
Low power magnetic trap (140W):
fluctuations in magnetic bias field below 1 mG

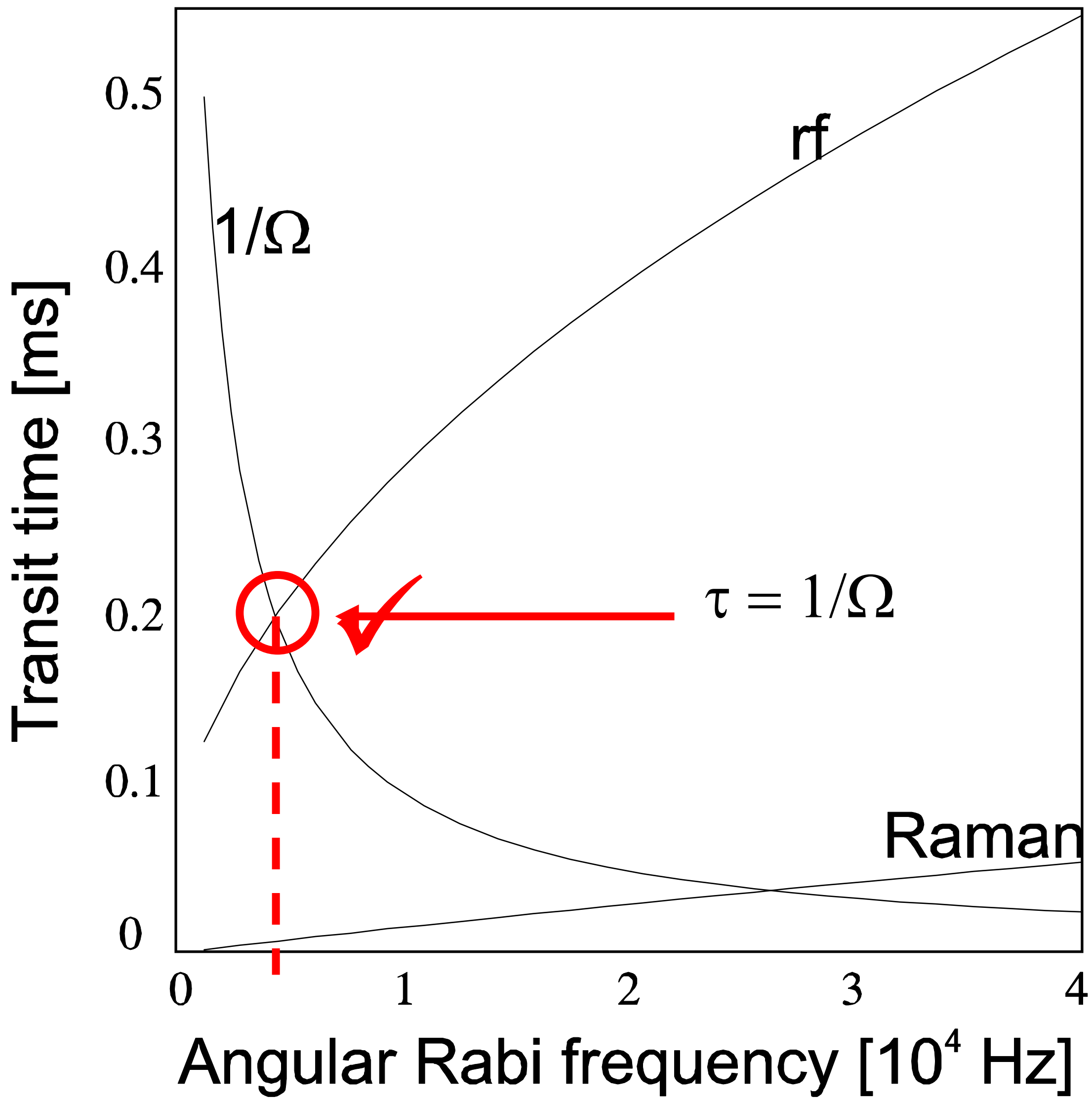
N. Robins et al., cond-mat/0509462 (2005).

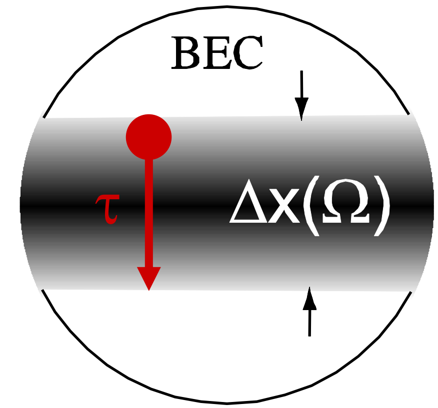
Fluctuations and shut-down: rf outcoupling



N. Robins et al., Phys. Rev. A, 72, 031606 (R) (2005).

Flux limit

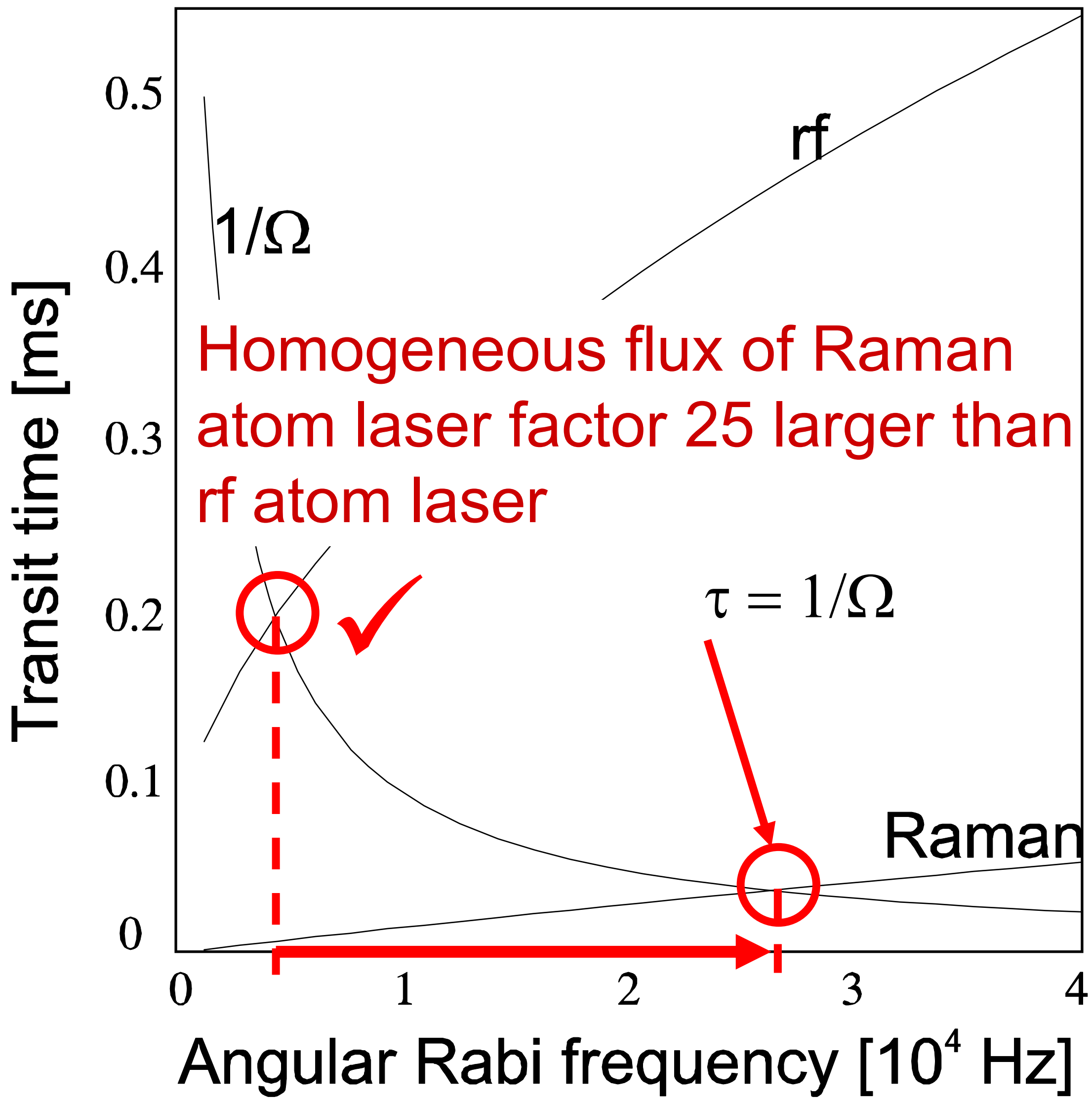


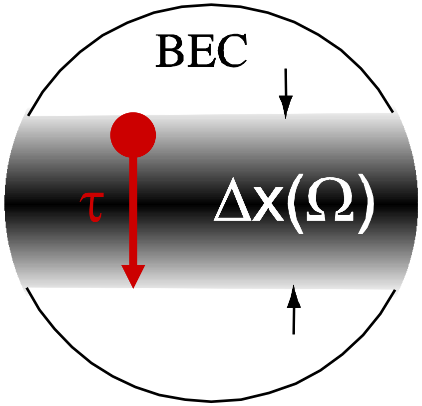


- ► Outcoupling region and outcoupling probability given by Ω
- ► boundary for strong outcoupling for $\tau = 1/\Omega$

⇨ prediction for flux

Flux limit





- ▶ Outcoupling region and outcoupling probability given by Ω
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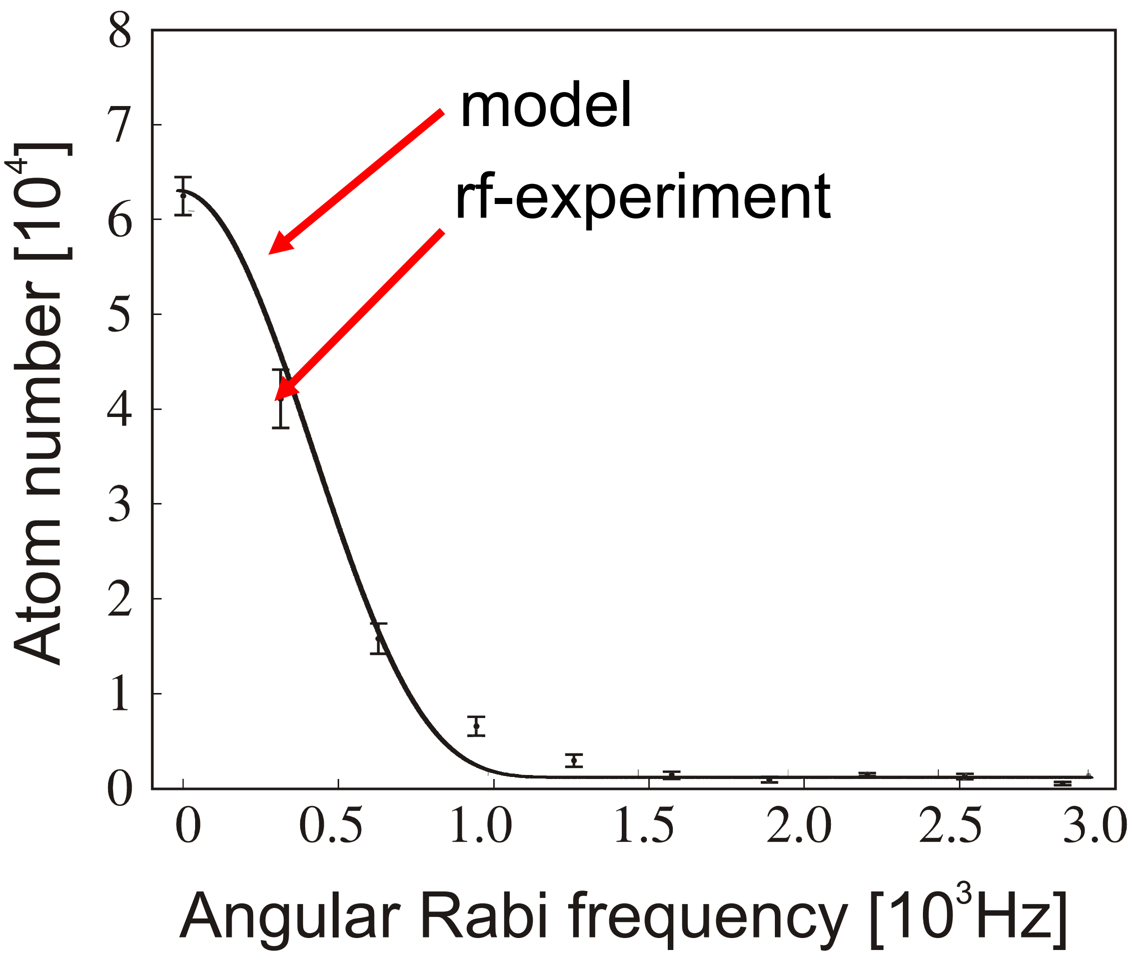
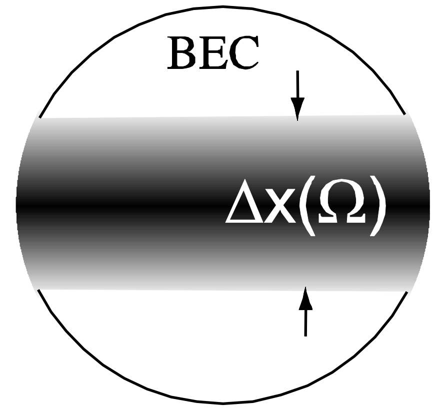
⇨ prediction for flux

Prediction for flux ✓





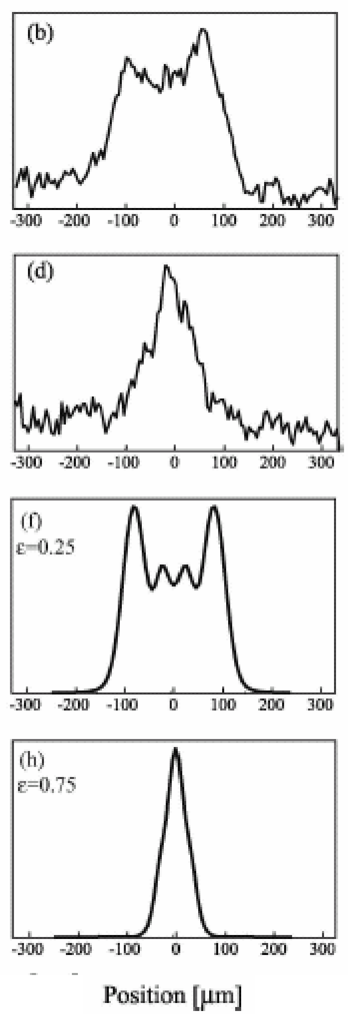
max. achievable flux (Rb)

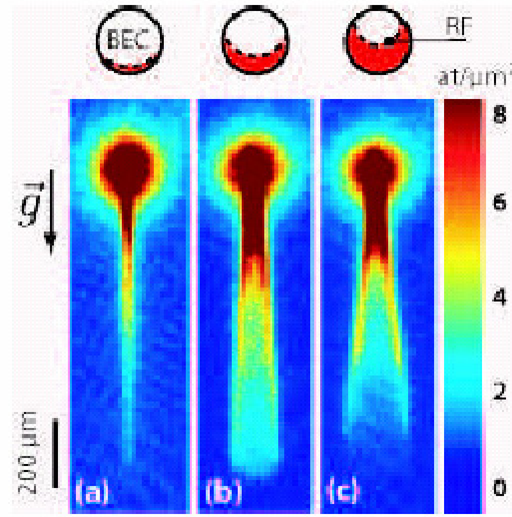
rf:
1.4 x 10^8 atoms/s

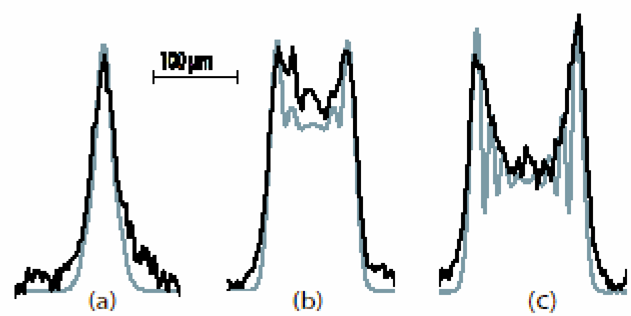
Raman:
4.2 x 10^9 atoms/s

similar measurements: I. Bloch et al., PRL 82, 3008 (1999).

Beam profile and divergence



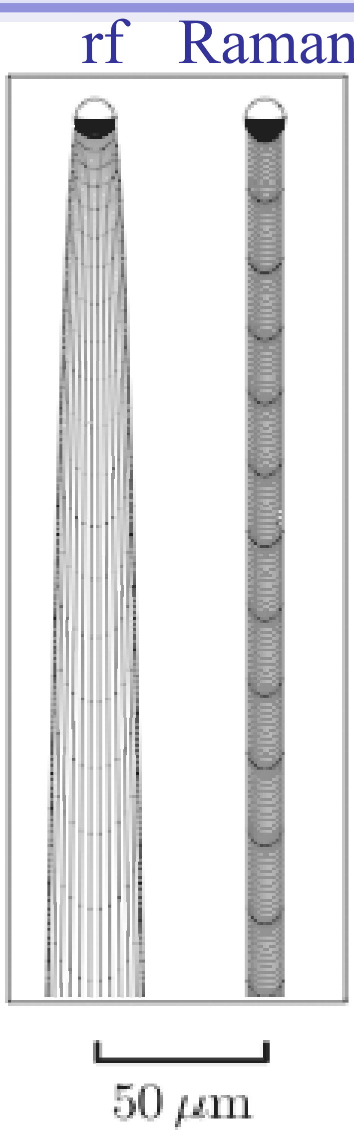


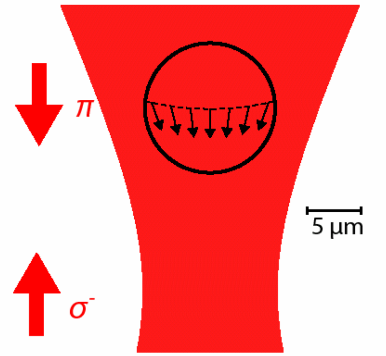


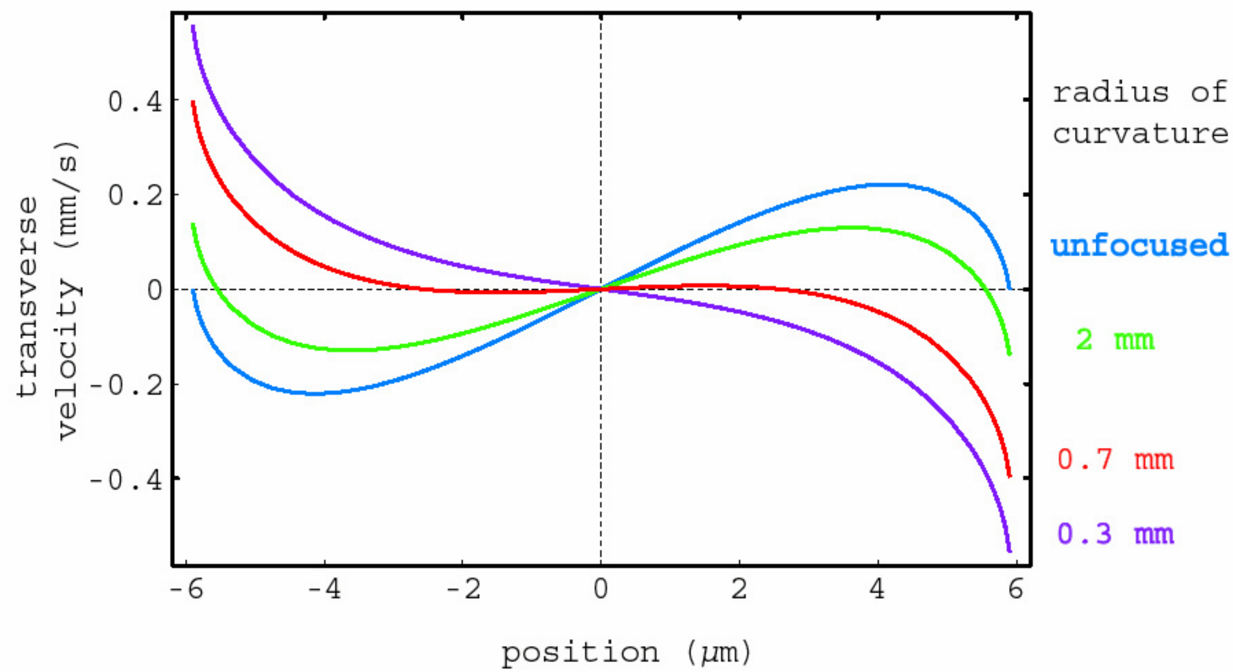
M. Köhl et al., cond-mat/0508778 (2005).

J.-F. Riou et al., PRL, accepted (2006)

Beam profile and divergence







Linewidth (work in progress)

► GPE: Fourier limited (pulse duration)

BUT: chirp due to drift in chemical potential

AND: there must be a limit due to atom number fluctuations (of magnitude $\sqrt{N}$) which turn into energy fluctuations

► Currently using truncated Wigner method for stochastic calculations

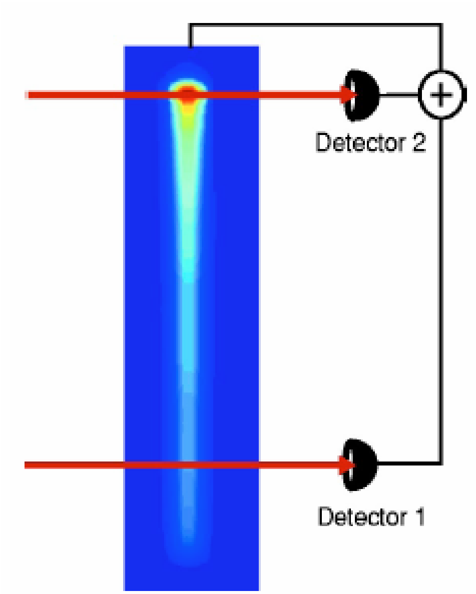
► expect:

$$\Delta E = \mu\left(N + \sqrt{N}\right) - \mu\left(N - \sqrt{N}\right)$$

$$= \frac{m\omega^2}{2}\left(\frac{6\pi N\hbar^2 a}{m^2\omega^2}\right)^{2/3}$$

Detection

Why?



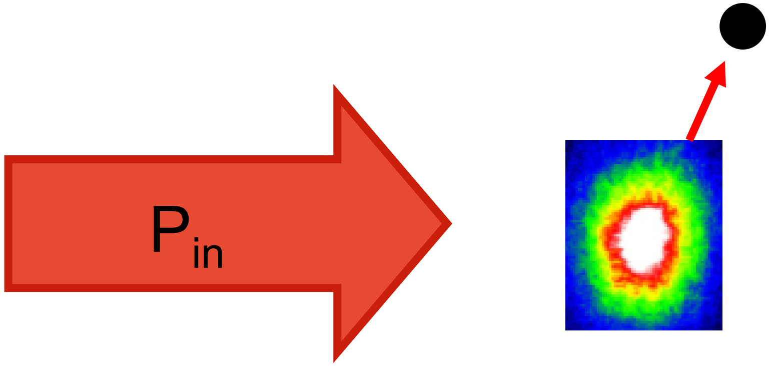
Measure BEC density

- ✓ nondestructively
- ✓ high bandwidth (DC to MHz)
- ✓ real time
- ✓ shot-noise limited

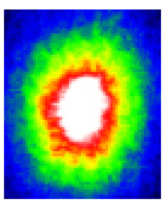
to implement feedback

Detection

Restriction of optical detection



each absorbed photon leads to loss of one atom



10^5 atoms

lifetime 1s

10^5 photons/s = 26 fW

shot noise limited, fixed absorption, optically thick:
measure phase with strong LO

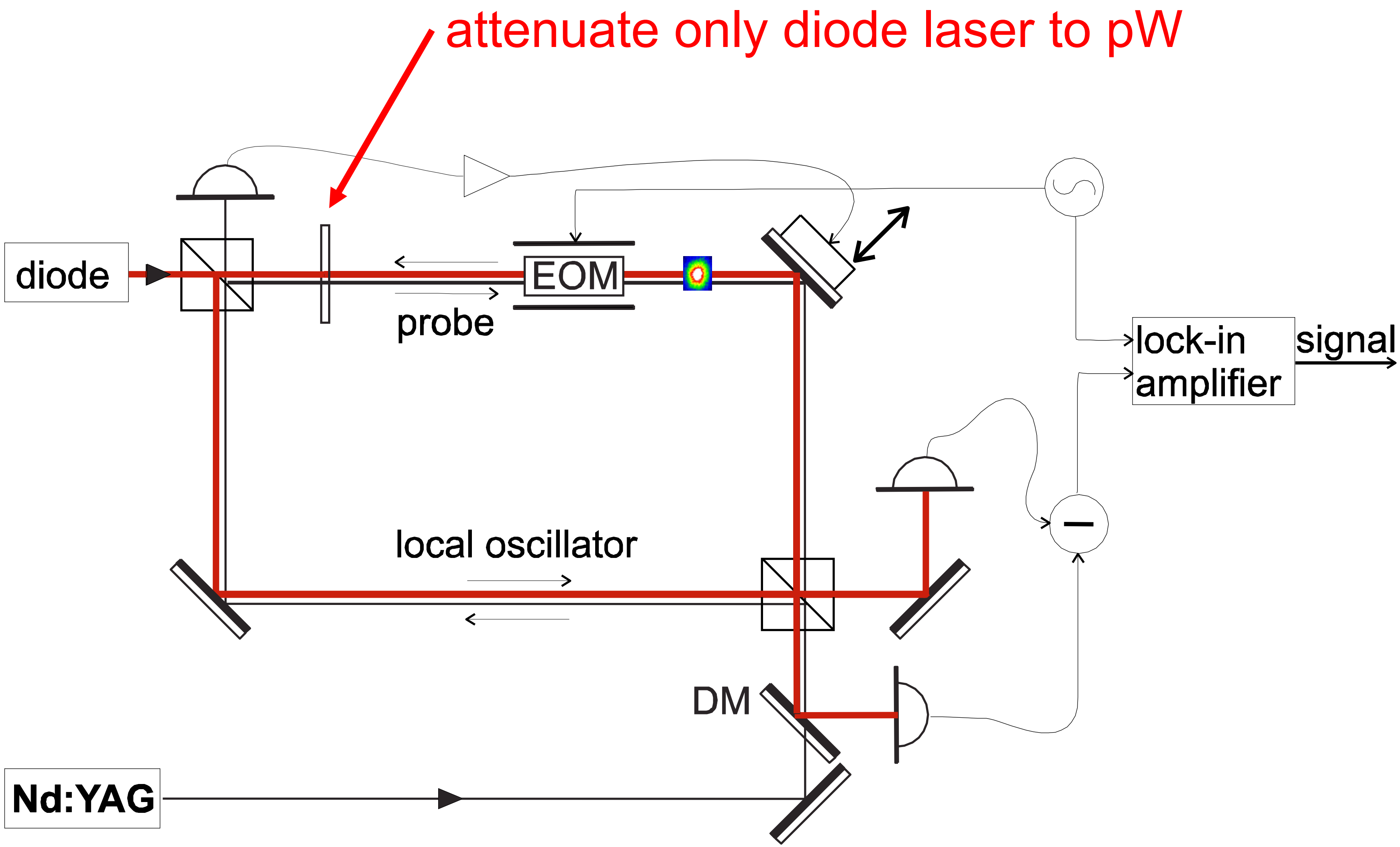
SNR independent of detuning, but given by absorption, optical depth and detection bandwidth

J. Lye et al., Phys. Rev. A **67,** 043609 (2003)

Andrews et al., Science **84** 273 (1996)

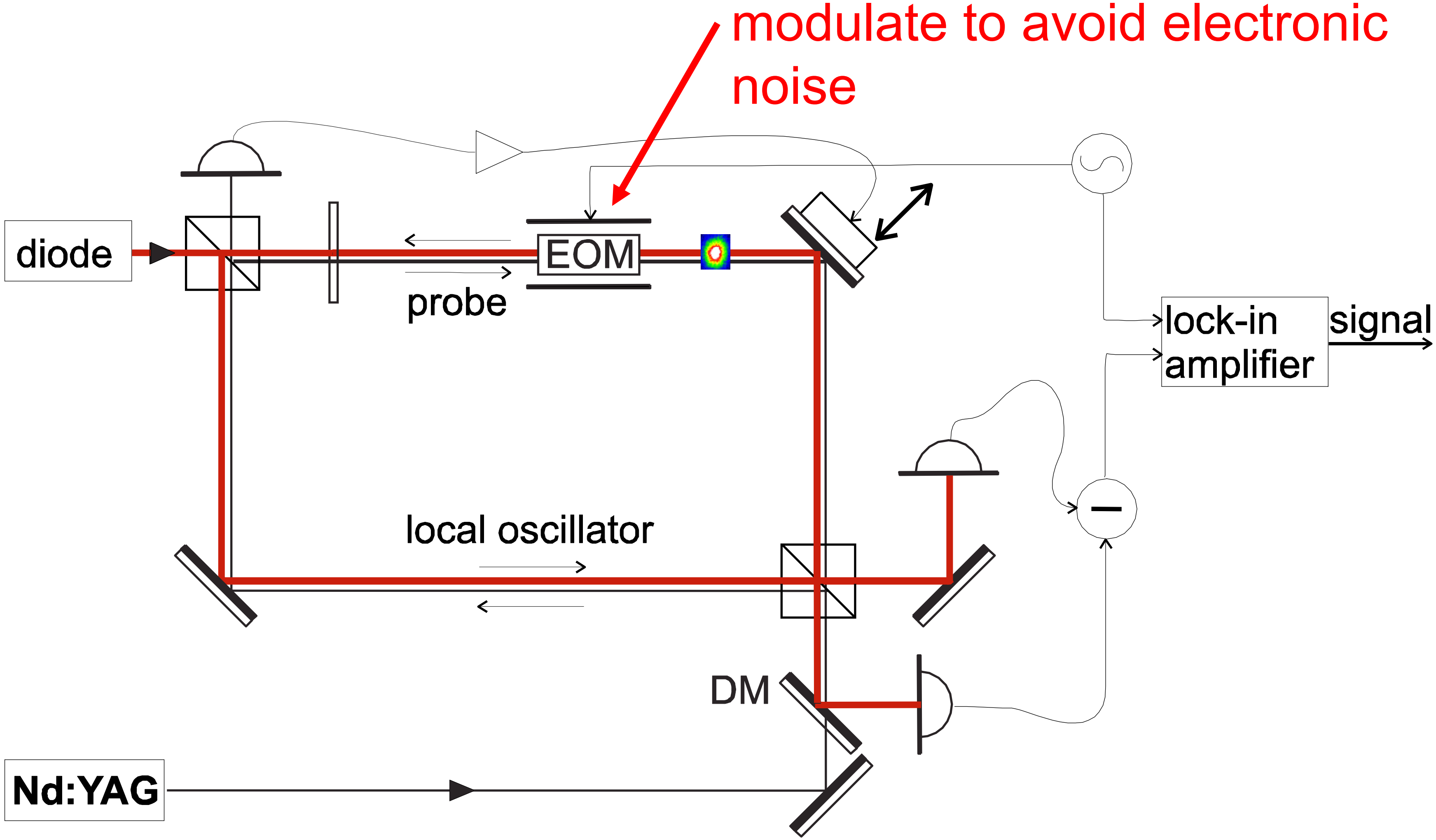
Oblak et al., Phys. Rev. A **71** 043807 (2005)

Detection

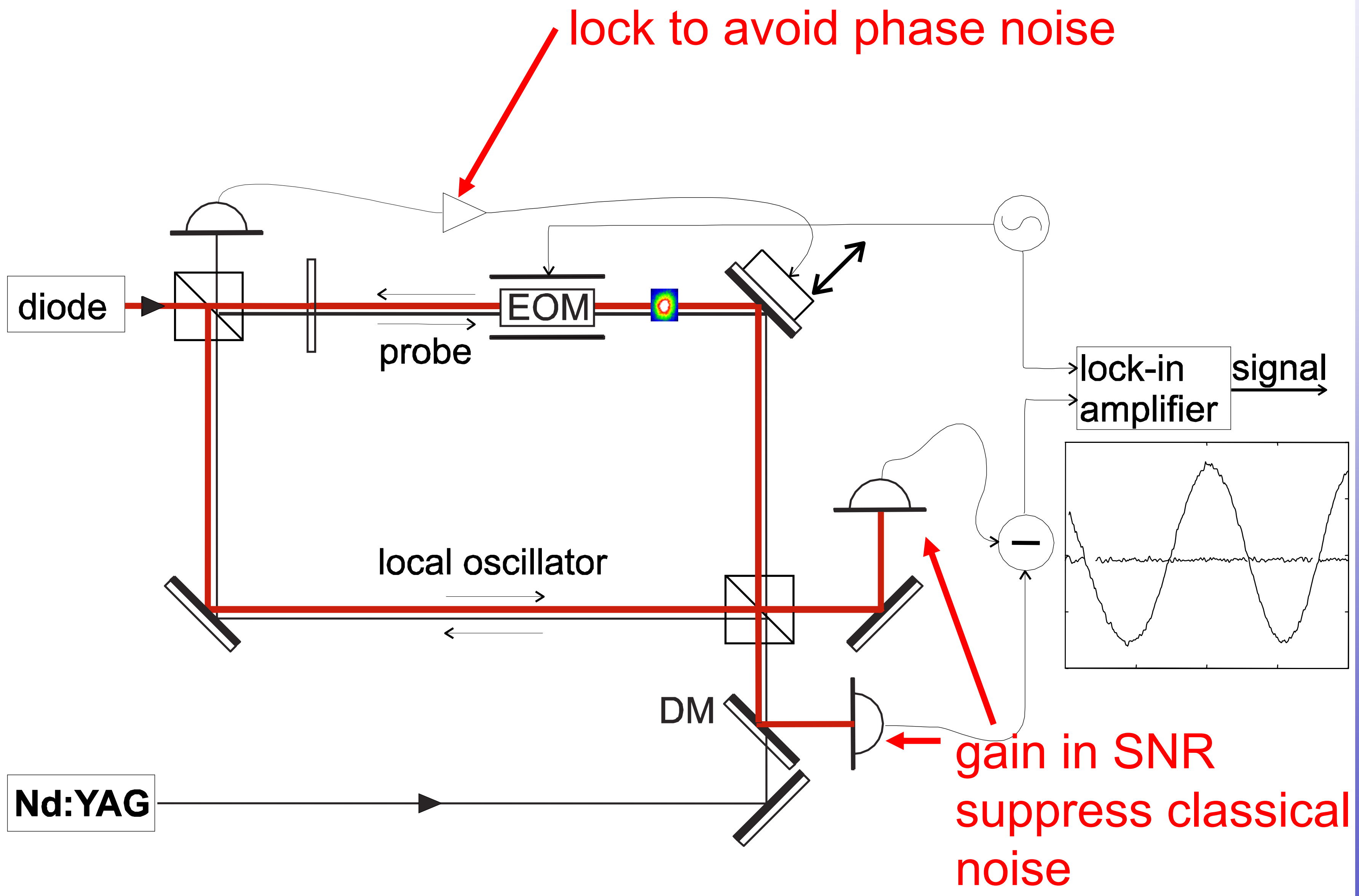


attenuate only diode laser to pW
diode
EOM
probe
lock-in
amplifier
signal
local oscillator
DM
Nd:YAG

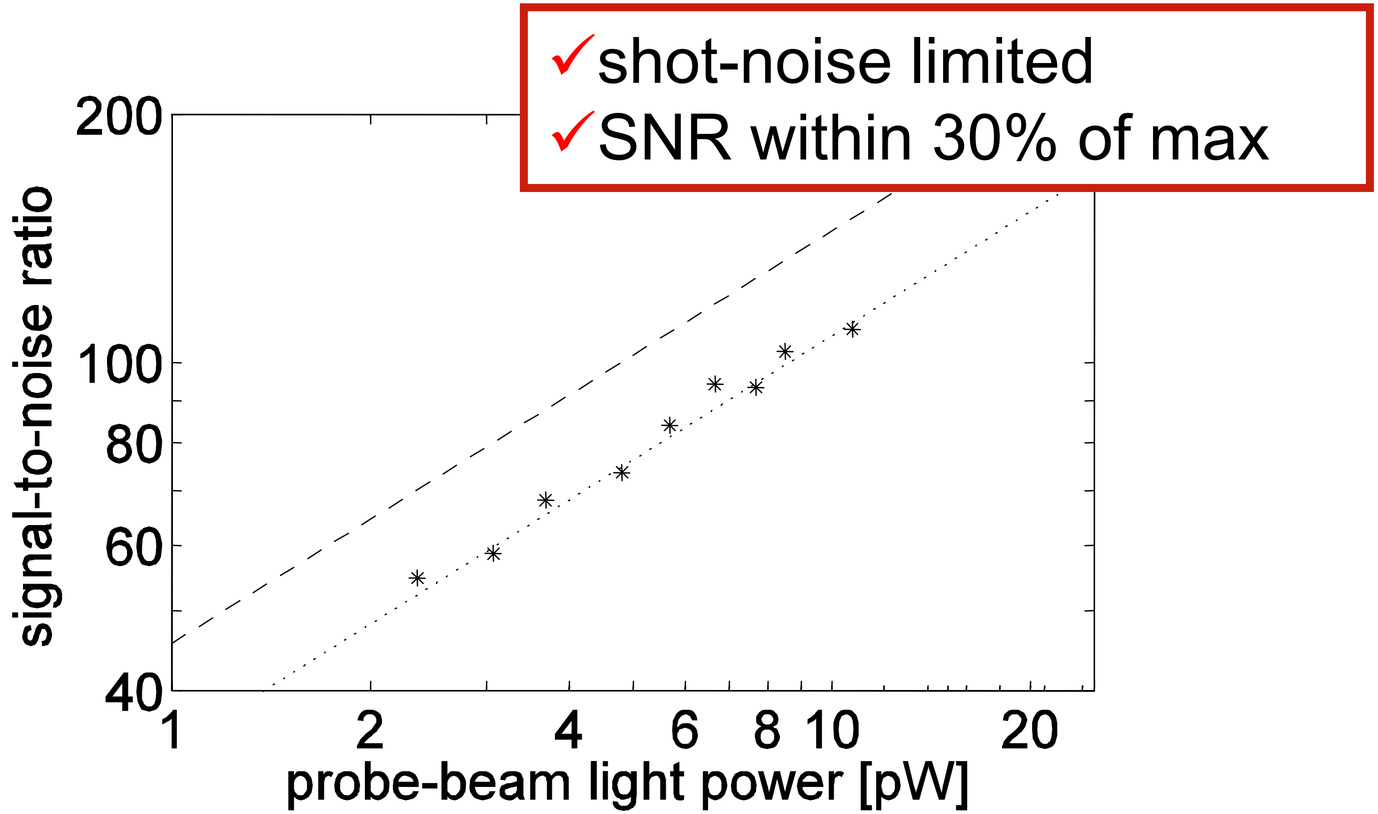
Detection


modulate to avoid electronic noise
diode
EOM
probe
lock-in amplifier
signal
local oscillator
DM
Nd:YAG

Detection

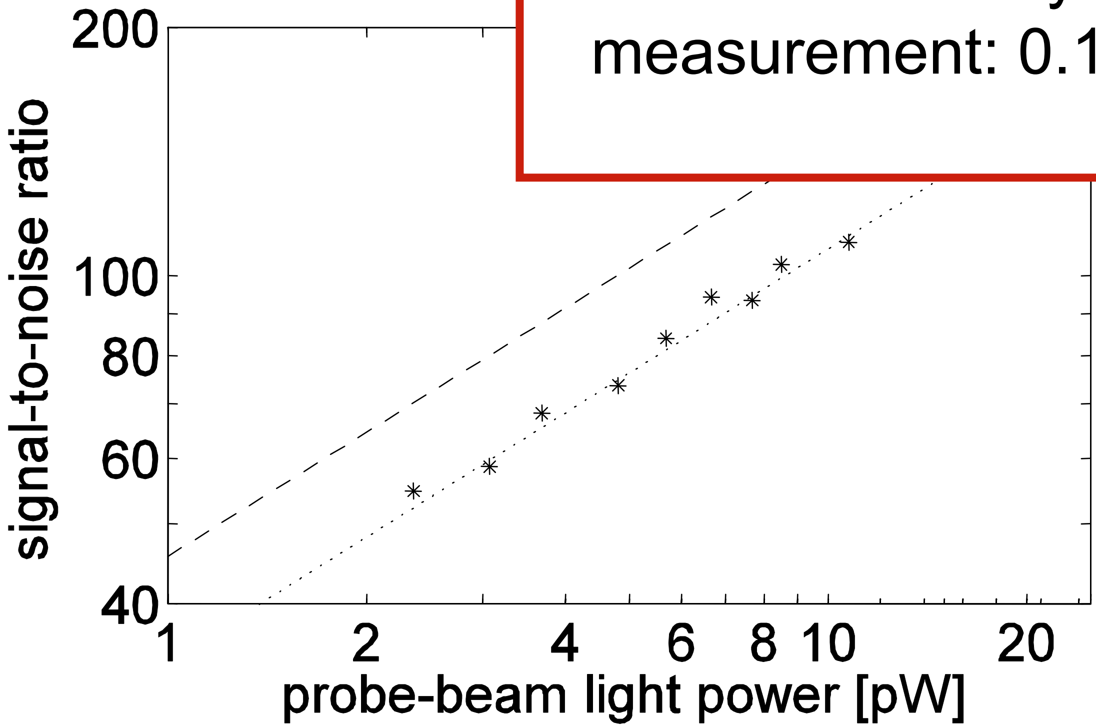

lock to avoid phase noise
diode
EOM
probe
lock-in
amplifier
signal
local oscillator
DM
Nd:YAG
gain in SNR
suppress classical
noise

Detection



$$\text{signal} \propto \sqrt{P_P P_{LO}} \qquad \text{noise} \propto \sqrt{P_{LO}} \qquad \text{SNR} \propto \sqrt{P_p}$$

Detection



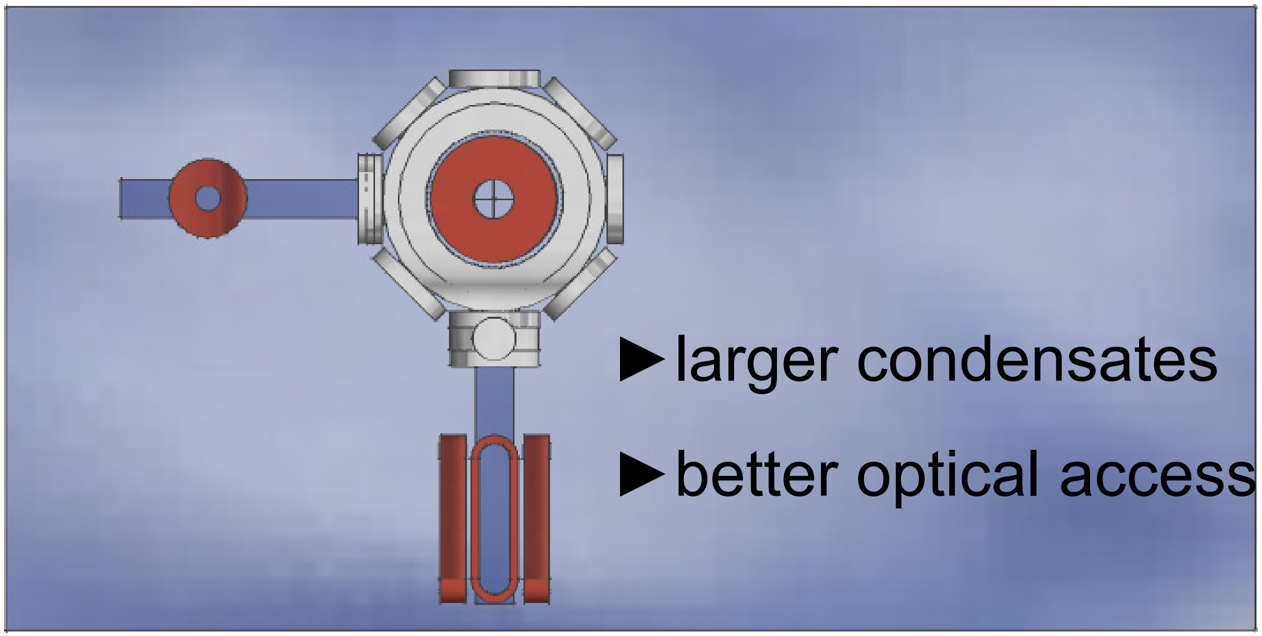
inferred sensitivity for BEC measurement: 0.1%/√Hz

C. Figl et al., Appl. Opt., accepted (2006).

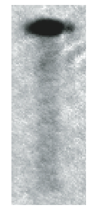
Future work

- Quantitative Raman laser study
- Steps towards a pumped atom laser
- Squeezed atom laser
- single atom detection
- Implementation of interferometric detection

New machine

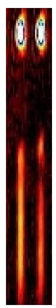


~~Outline~~ Summary

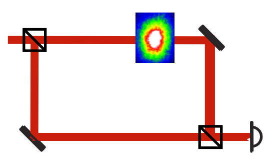


<u>Raman laser offers:</u>

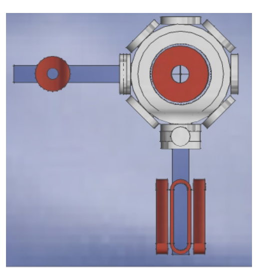
- ▶ Higher flux
- ▶ Lower divergence
- ▶ Shaping of beam profile



- ▶ model for outcoupling
- ▶ beam profile
- ▶ linewidth



Minimally destructive detector for BEC



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