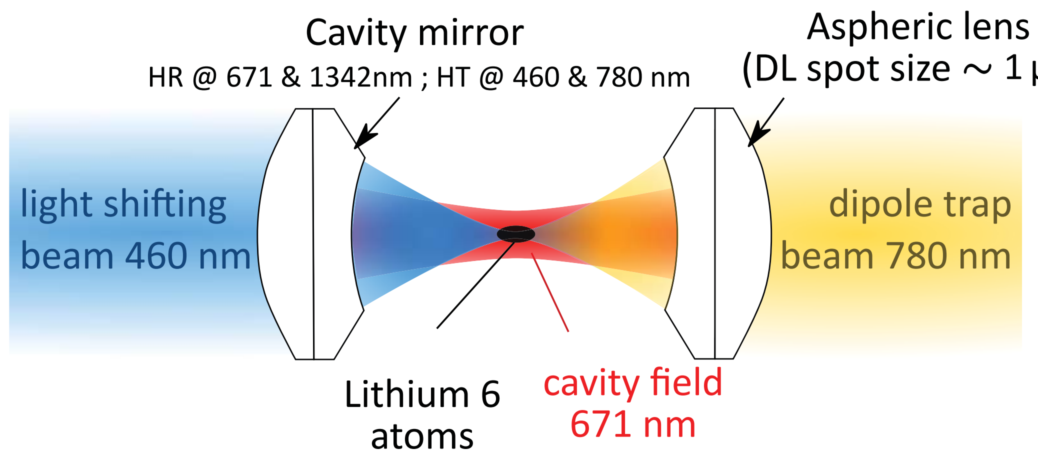
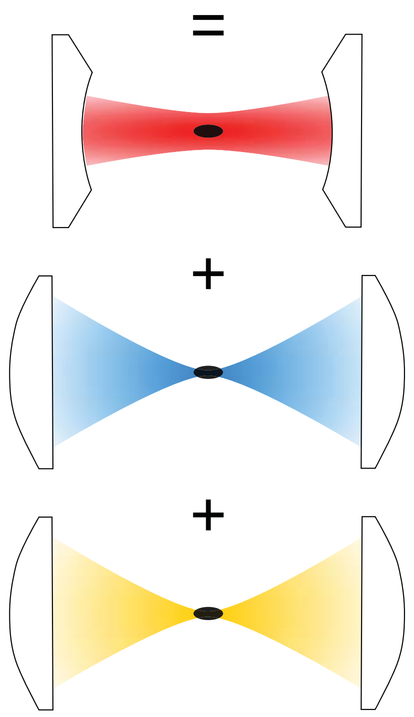
Cavity-Enhanced Microscope for Cold Atoms

T. Cantat-Moltrecht, N. Sauerwein, N. Reiter & J.-P. Brantut

LQG, EPFL, Lausanne, Switzerland

Working Principle of Microscope





Dispersive atom-cavity coupling

Cavity light phase-shifted by $\delta\phi \propto g^2/\Delta$

⇒ dispersive measurement of atom number

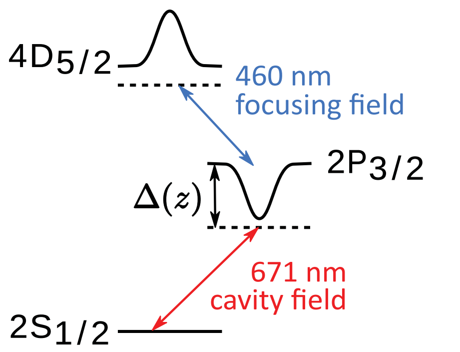
Focusing beam

- 460 nm laser beam focused to < 1 µm
- red detuned from $2P_{3/2}$ - $4D_{5/2}$ transition

⇒ light shifts the $2P_{3/2}$ excited state by $\delta \propto I$

Micro dipole trap

- 780 nm laser beam focused to 1.3 µm
- trapping frequency ~650 kHz for 100 mW
- automatically aligned to cavity center



Spatial control of atom-cavity coupling

At the 460 nm beam focal point, D2 transition is light-shifted closer to cavity resonance

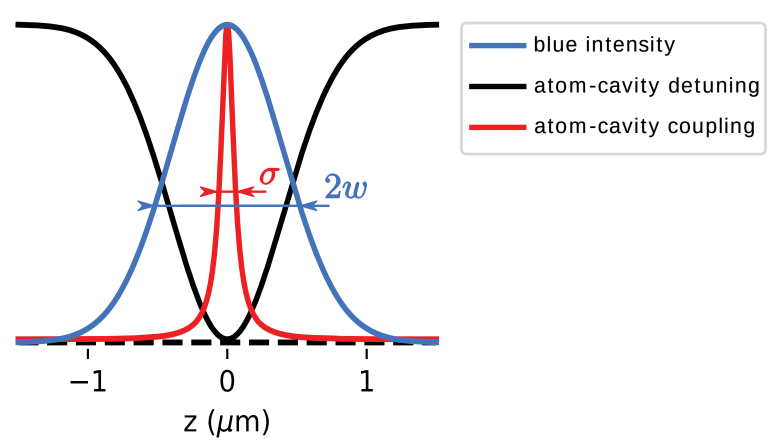
⇒ local enhancement of atom-cavity coupling

Super-resolution effect

non-linearity in atom-cavity coupling

⇒ resolution enhancement $\frac{\sigma}{2w} \sim \sqrt{\frac{\Delta(z_\infty)}{\Delta(z=0)}}$

up to a factor >10 is expected



The Cavity-Microscope : high finesse & high NA

Cavity design

- High-finesse
- Close to concentric

⇒ Strong atom-cav. coupling

Wavelength	671 nm	1342 nm
Cav. length	25.895 mm (2R − 105 µm)	
Mode waist	13.3 µm	18.8 µm
Finesse	17 950	59 300
$\kappa/2\pi$	322.5 kHz	97.7 kHz
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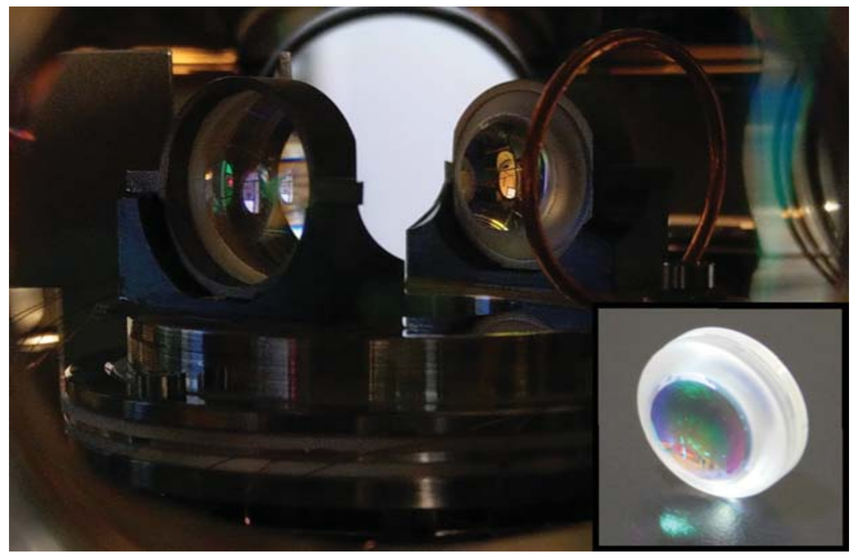

Lens design

Wavelength	460 nm	780 nm
DL beam waist	0.61 µm	1.03 µm

- **High NA = 0.37**
- Optically contacted assembly

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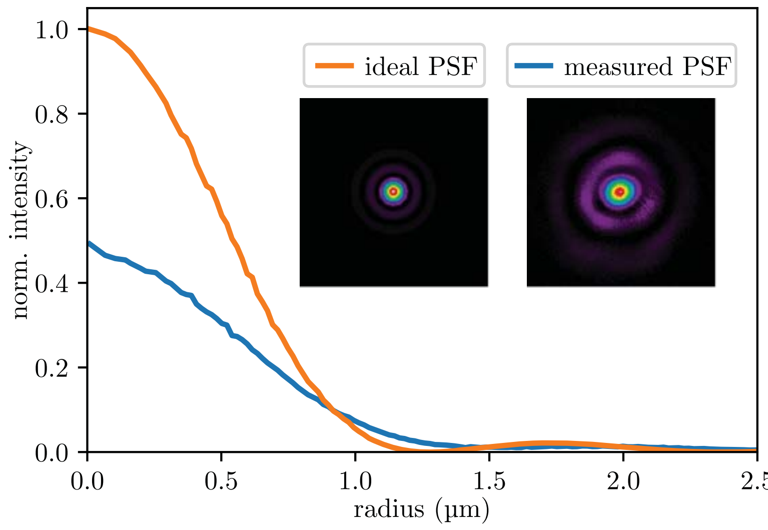
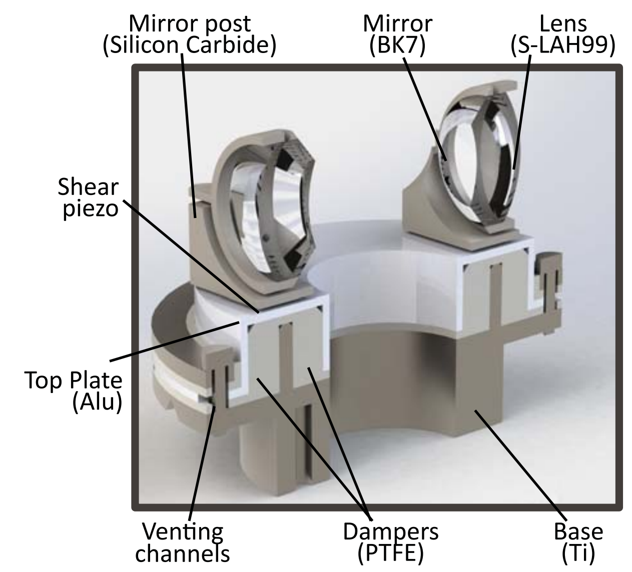
Aberrations lead to Strehl ratio of < 0.5

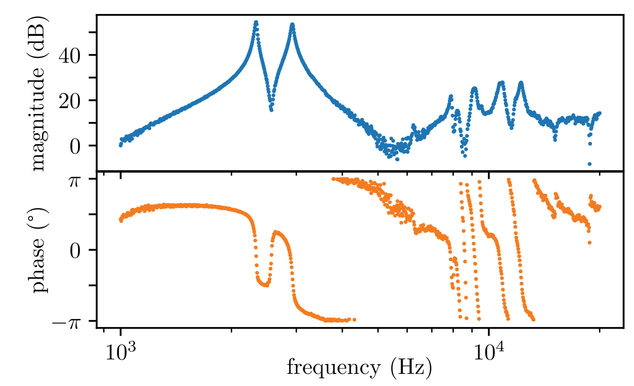
=> wavefront correction necessary for DL operation



Cavity holder design

- Combine strongly damping and high specific stiffness materials
- Non-magnetic and UHV compatible





Measured mechanical response

Laser system

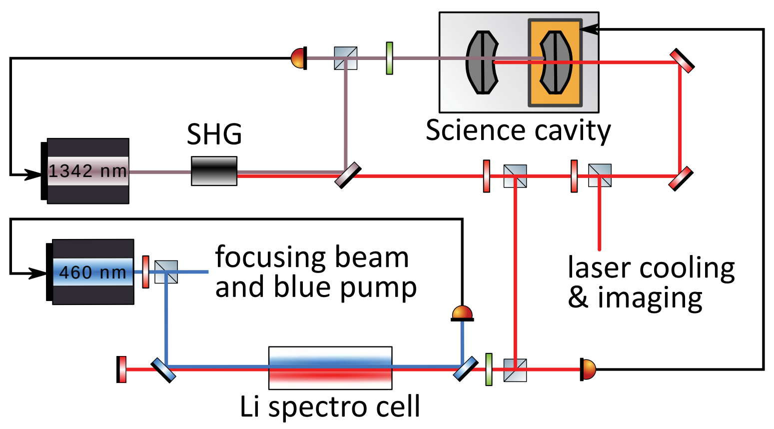
Frequency-doubled system

1342 nm:
(Diode + Raman fiber amp):

- Science cavity lock
- Intra-cavity ODT
- 671 nm generation

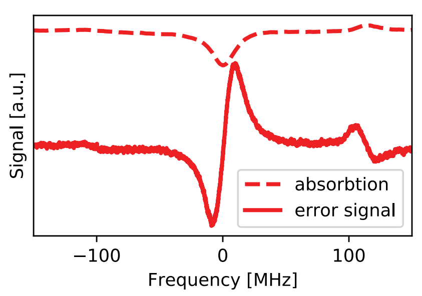
671 nm:

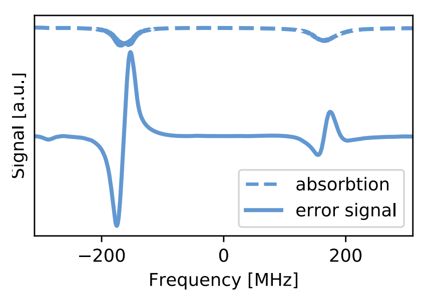
- Laser cooling
- Cavity probe
- Atom imaging



Two-photon spectroscopy

- Saturated absorption spectroscopy for 670 nm
- single-pass absoprtion spectroscopy for 460 nm





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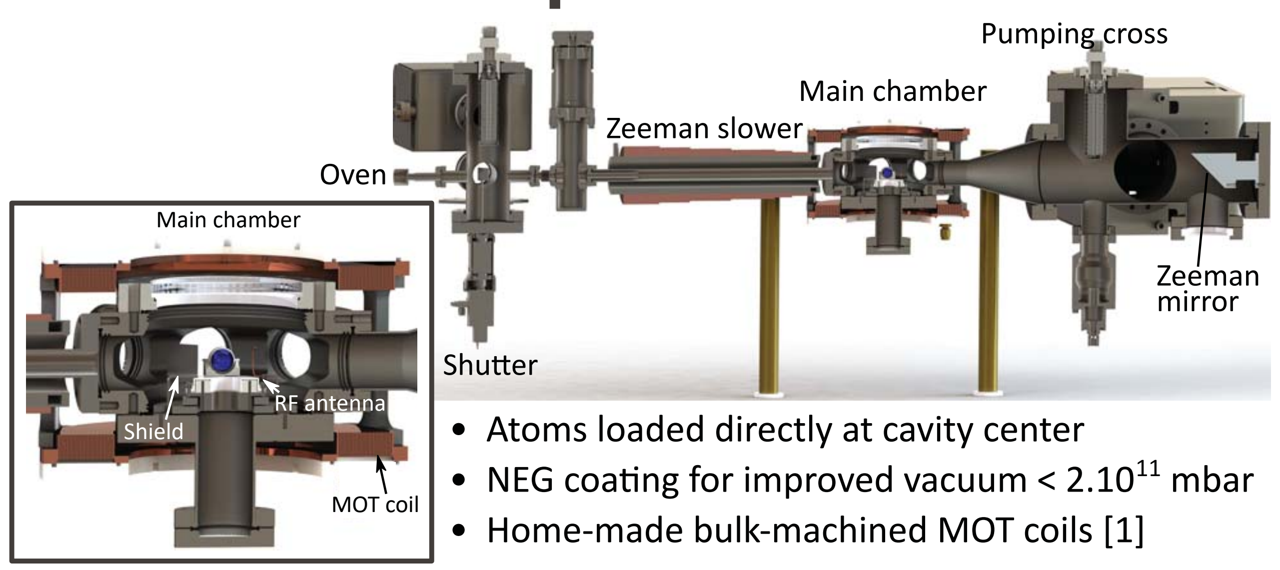
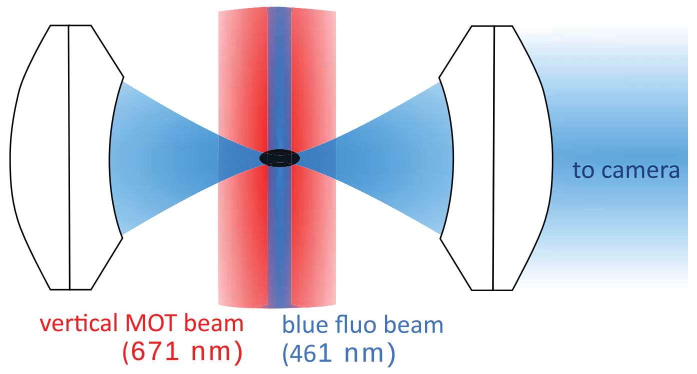
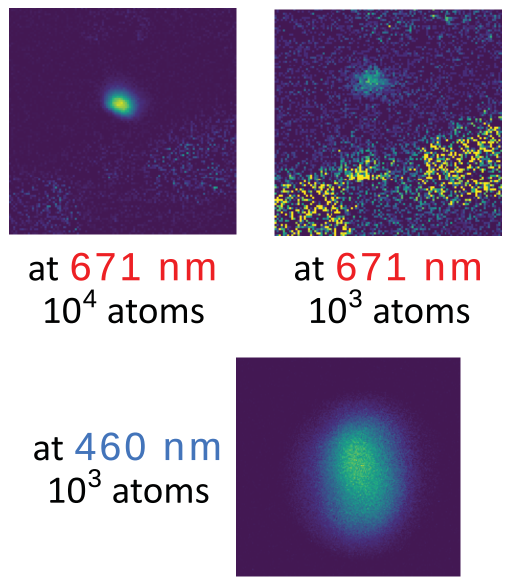


- Atoms loaded directly at cavity center
- NEG coating for improved vacuum < 2.10^{11} mbar
- Home-made bulk-machined MOT coils [1]

Two-colour MOT fluo imaging

- narrow 461 nm beam co-propagating with vertical MOT beam and retro-reflected
- MOT effect at 461 nm
- high collection efficiency at 461nm through "cavity-lens"





[1] K. Roux et al., SciPost Phys. 6, 048 (2019)

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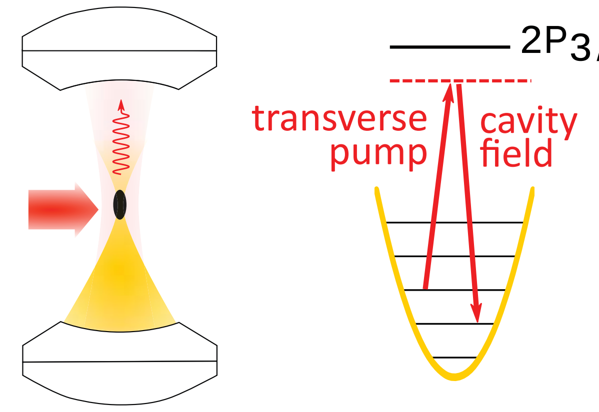

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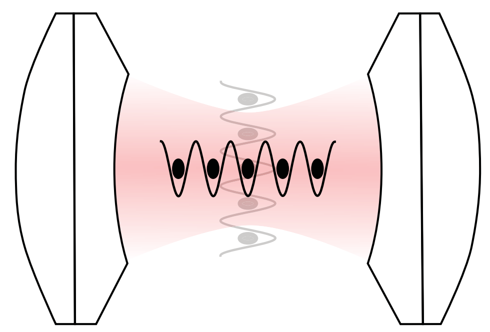

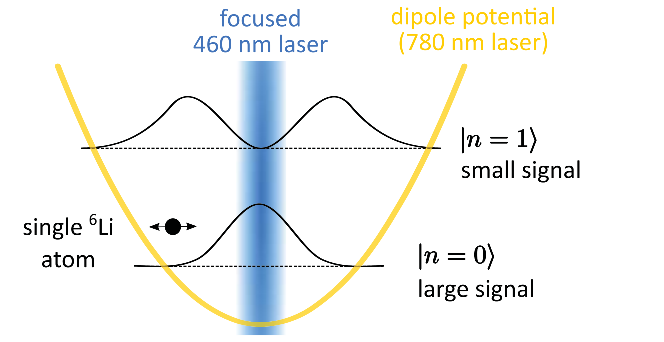

Wavefunction microscope [5]

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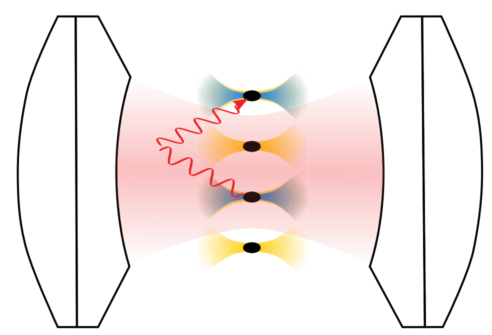

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Fonds National Suisse de la Recherche Scientifique
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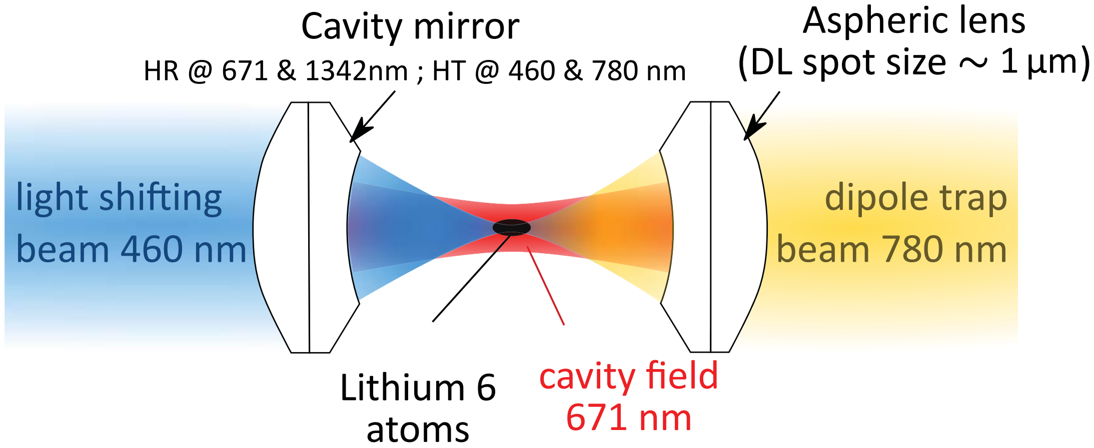

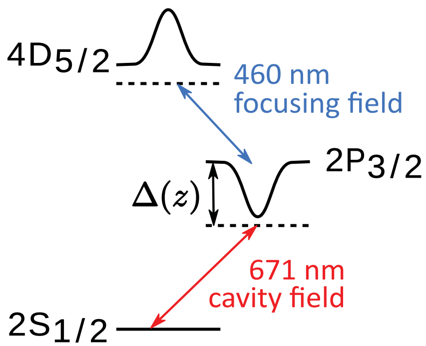

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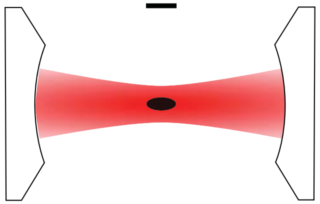

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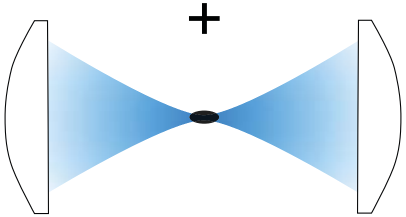

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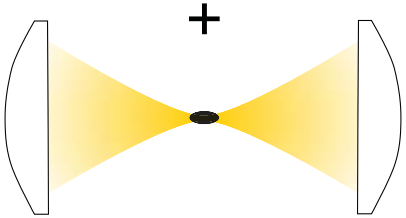

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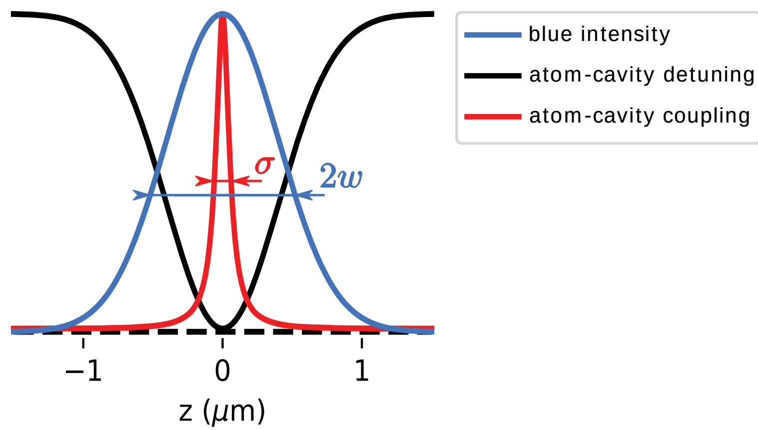

SANDOZ-FONDATION DE FAMILLE
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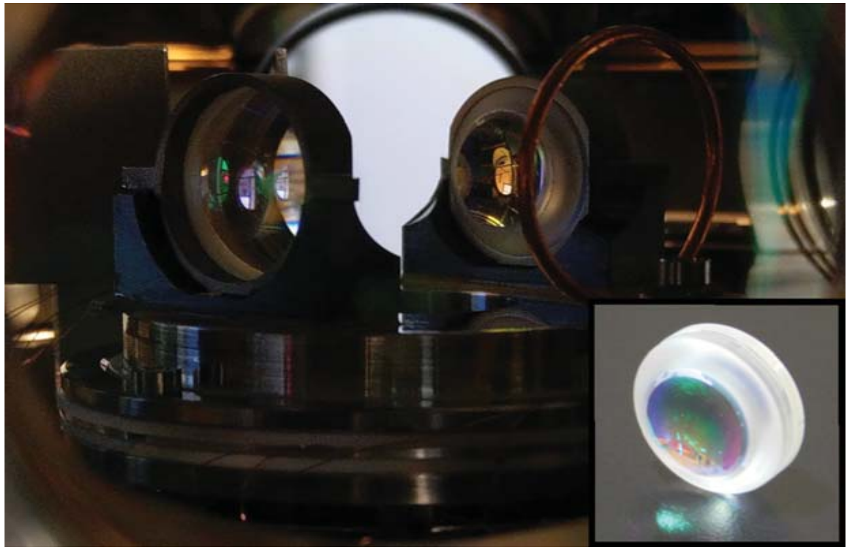

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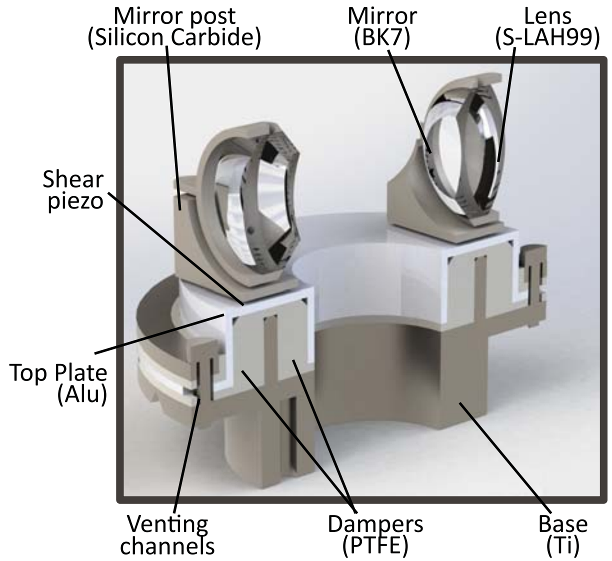

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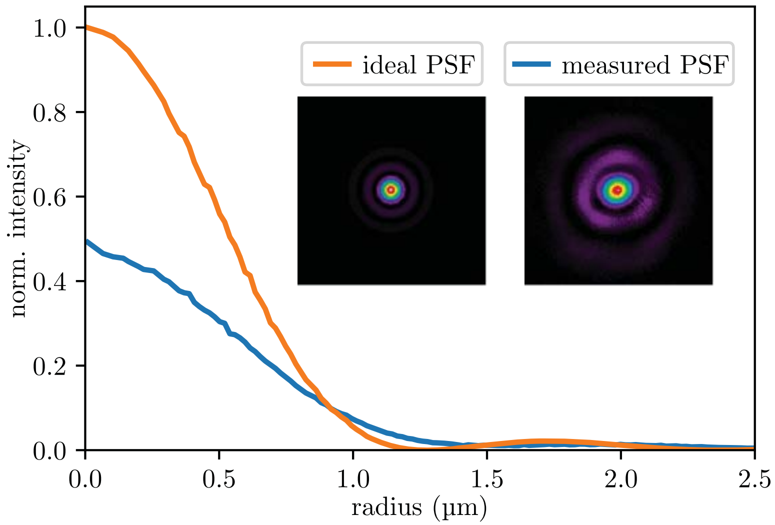

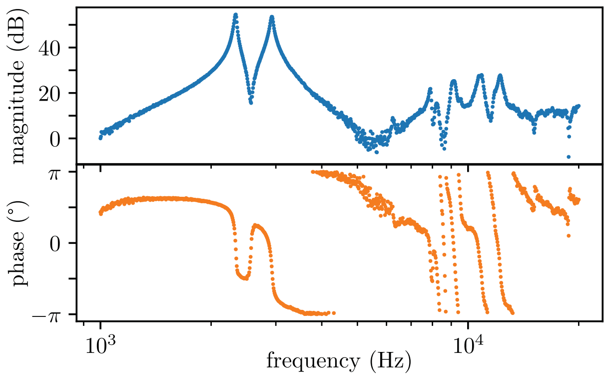

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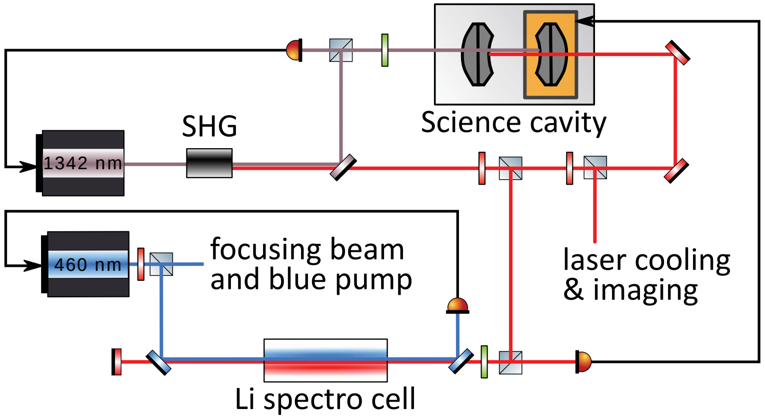

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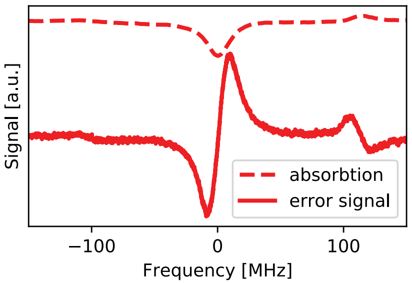

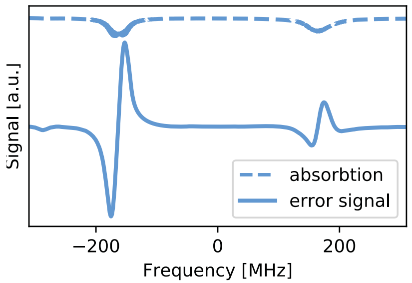

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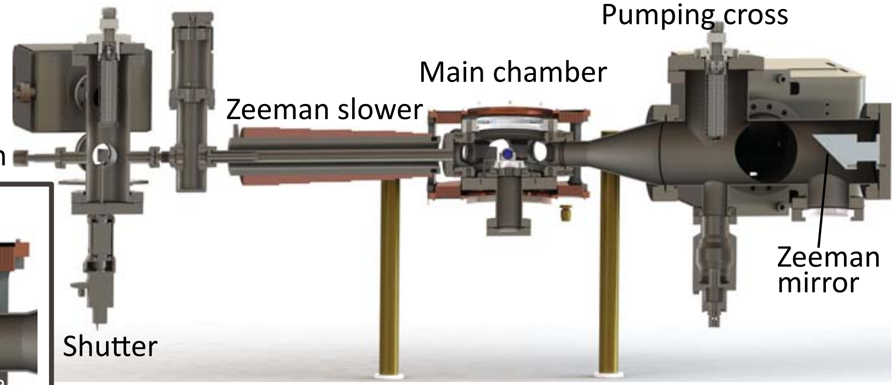

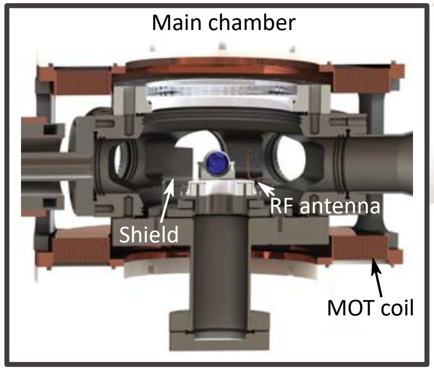

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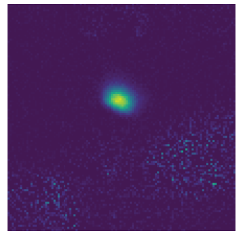

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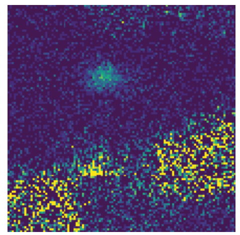
10^4 atoms



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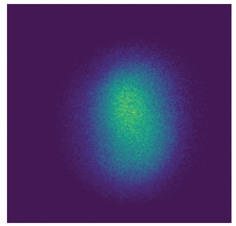

at 460 nm
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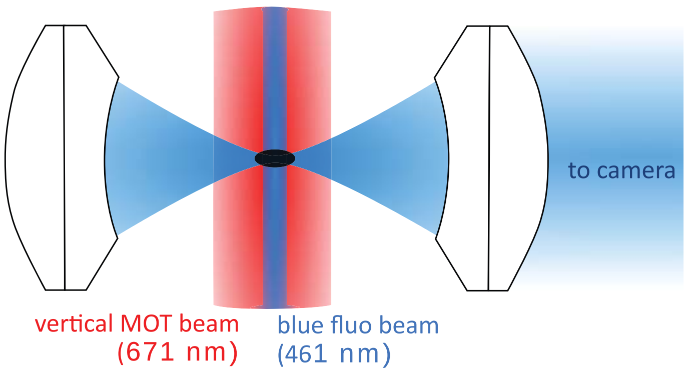

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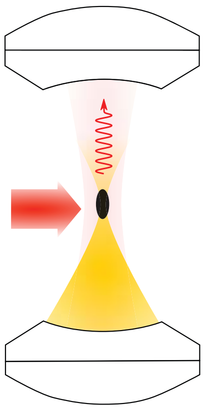

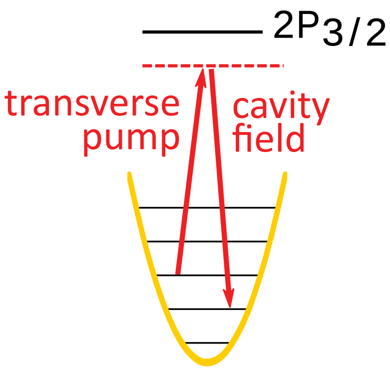

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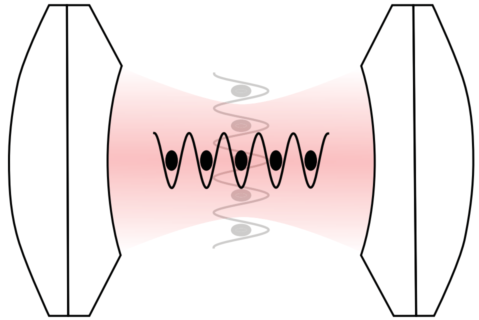

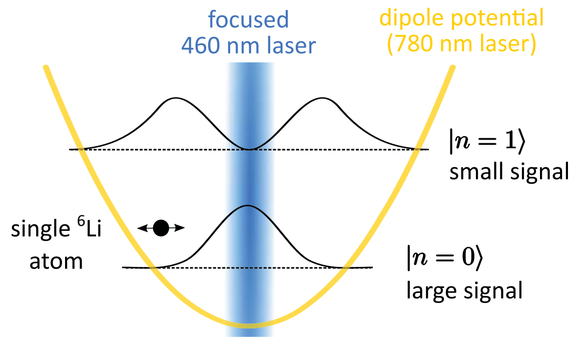

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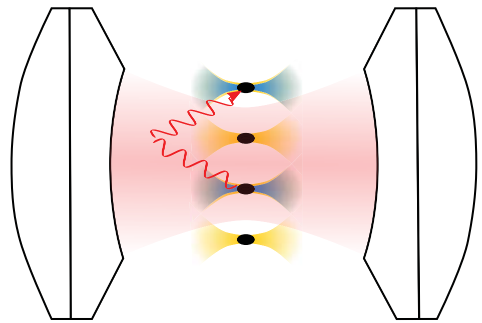

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