Manipulation of cold atoms with the MuQuans laser system

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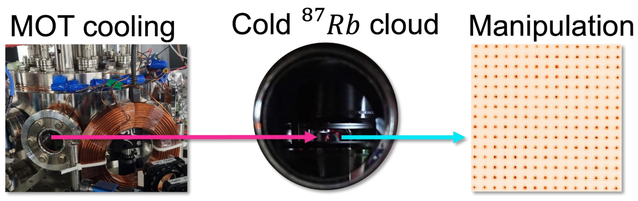
moonshot Goal 6 大森 PM
大規模・高コヒーレンスな動的原子アレー型・誤り耐性量子コンピュータ

Introduction

Motivations

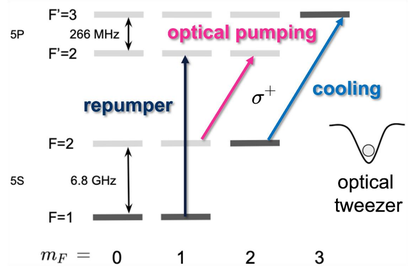
- Atom cooling and trapping
  - Qubit state preparation
  - Non-destructive imaging (NDI)
- Single atoms in array of tweezers
  - Ultrafast regime
  - Rydberg excitation

MOT cooling → Cold ^{87}Rb cloud → Manipulation



Laser beams

- Cooling on F=2 → F'=3
- Optical pumping on F=2 → F'=2 along with a repumper on F=1 → F'=2



Set up overview

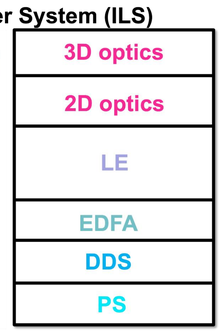
Before

Unstable, bulky, fragile, messy technology

After

Metkham (1m57)

The ILS780-216 MuQuans laser from iXblue



Rack overview

- Precise control of the laser amplitude, phase, absolute frequency with fast tunability
- Based on C-band fibered telecom optical components

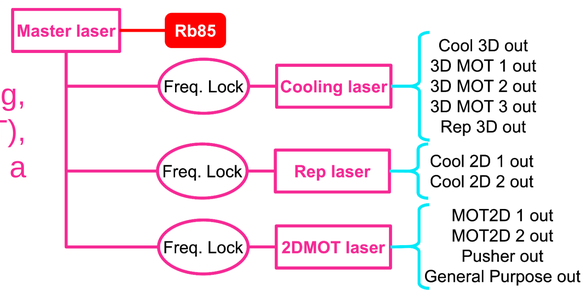
Robust and reliable technology

Inside the MuQuans Laser

Configuration

- 4 independent frequency-stabilized laser heads operating at 780 nm

3 slave lasers (Cooling, Rep, and 2DMOT), frequency-locked to a master laser



11 outputs emitting at 780 nm with a maximum power of 320 mW

Laser architecture developed for atom cooling and trapping

- Optical characteristics

Operating wavelength	780.23 nm
Output power	300 mW per laser head
Power stability	1% rms over 1 hour
Linewidth	< 200 kHz FWHM
Tunability range	Up to 1 GHz
Sweeping rate	250 MHz/ms typ.
Polarization	Linear, PER>20 dB
Beam quality	TEM_{00} M2<1.1
Rise/fall time	< 1 μs

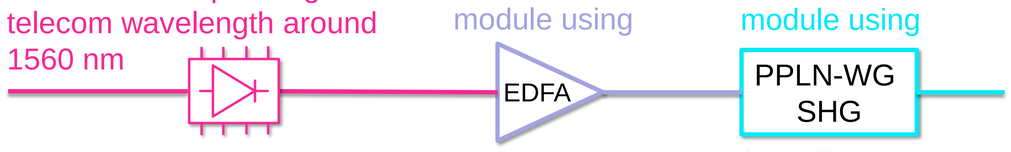
- Electrical characteristics

Supply voltage	100-110 V
Supply frequency	50-60 Hz
Electrical power consumption	< 250 W
Current	< 4 A
Air cooling	

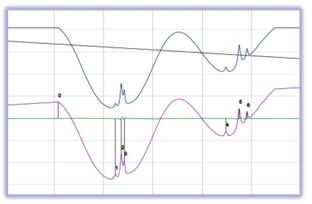
Fibered telecom optical components

780 nm wavelength generation with

- Seed module operating at telecom wavelength around 1560 nm
- Amplification module using EDFA (Erbium-Doped Fiber Amplifier)
- Frequency doubling module using PPLN-WG SHG (Periodically Poled Lithium Niobate)



- Frequency-stabilization module
  - Master laser locked on Rb85 using saturated absorption spectroscopy
  - Beat notes sent to PLL with reference frequencies provided by the DDS rack

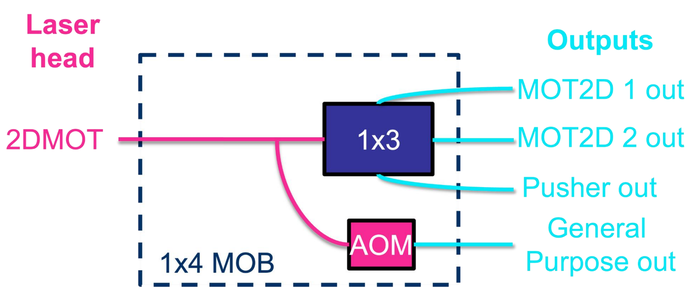


Saturated absorption spectroscopy

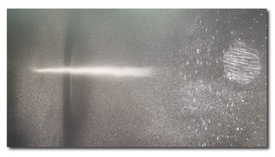
Only suitable for ^{87}Rb, but not for other cold-atom experiments due to the limited wavelength range of Er-doped technology

Implementation

Micro optical bench



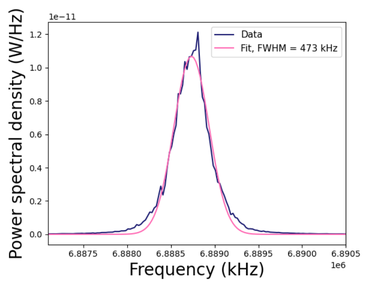
- Ex.: 2DMOT beams



- Designed with iXblue to match our experiments

Laser linewidth

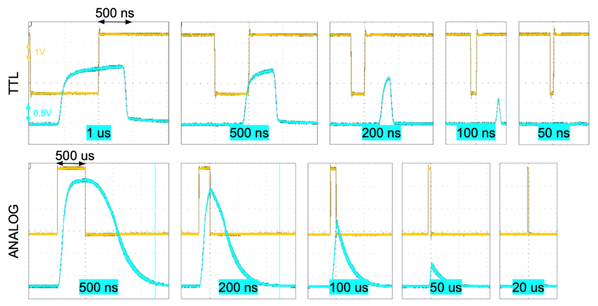
- Linewidth estimated from a beat note between two different laser outputs
- Phase coherence between two beams to drive Raman transitions
- Linewidth FWHM = 473 kHz



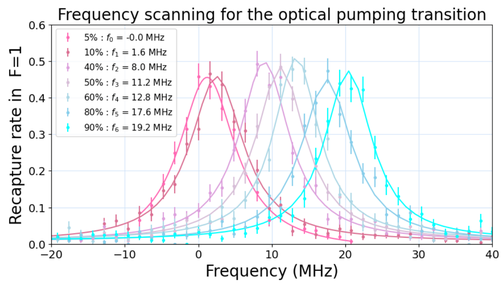
Tunability

Intensity modulation

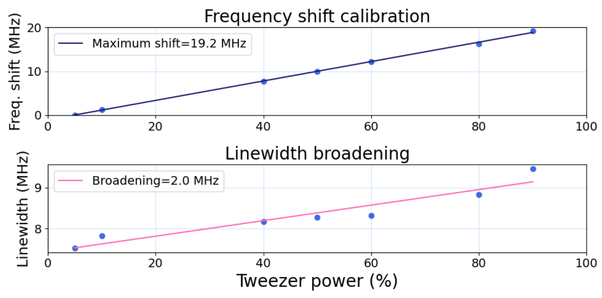
- MuQuans AOM as power modulators and active switches
- TTL output with faster response time (~100 ns) than analog output (~1 ms)
- Extinction ratio : 57.8 dBm



Frequency tunability



- Optical pumping transition F=2 → F'=2
- Regime of ~1 scattering event



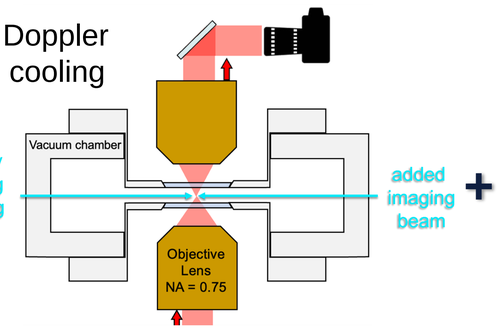
- Trap inhomogeneity
- Not a perfect single-photon scattering event

Towards NDI

Set up

NDI : Non-destructive imaging

- Doppler cooling



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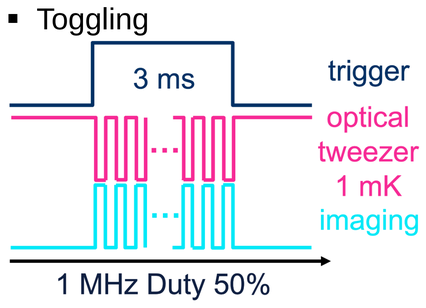
- Toggling



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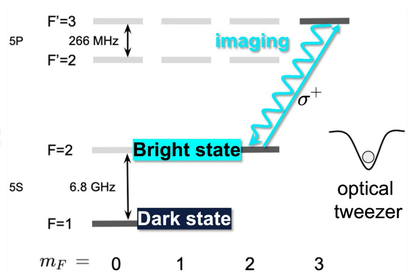
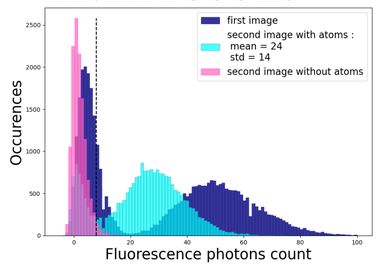
- Fluorescence measurement



Main results



- 10 ms preparation in F=2
- 3 ms toggling
- Threshold : 8 fluorescence photons
- 1 atom detection fidelity : 94%

Conclusion

Abilities

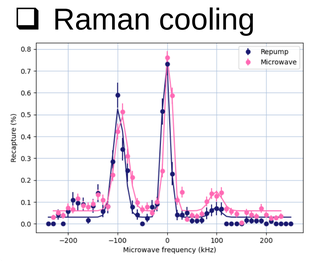
- ✓ Dedicated system to atom cooling, state preparation and, measurement
- ✓ Cold atoms manipulation (Ex.: non-destructive imaging)

Advantages

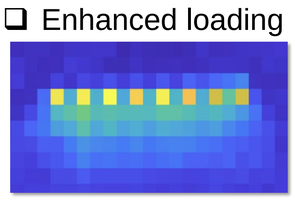
- ✓ Tunability frequency range up to 1 GHz
- ✓ Sideband generation
- ✓ Fast beam extinction and power modulation
- ✓ All diode lasers are phase-locked to the same master laser
- ✓ Laser head power splitting with independent power control

Outlooks

- ❑ Raman cooling

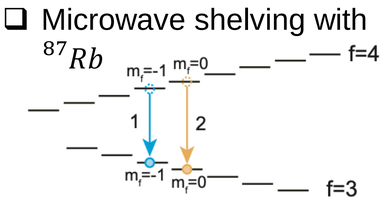


- ❑ Enhanced loading



Aliyu *et al.*, PhysRevResearch.3.043059

- ❑ Microwave shelving with ^{87}Rb



Graham *et al.*, arXiv:*2303.10051*