# Non-destructive state-selective imaging of cold Rubidium atoms with a compact and integrated laser system


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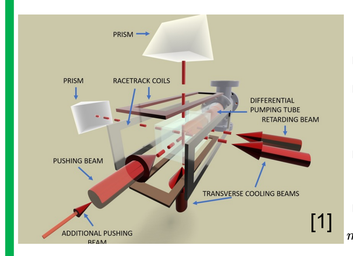
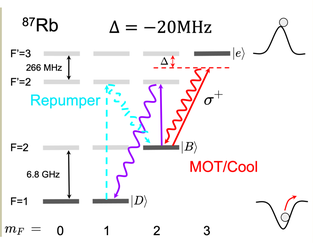
moonshot Goal 6 大森 PM
大規模・高コヒーレンスな動的原子アレー型・誤り耐性量子コンピュータ


## Introduction

### Non-destructive imaging

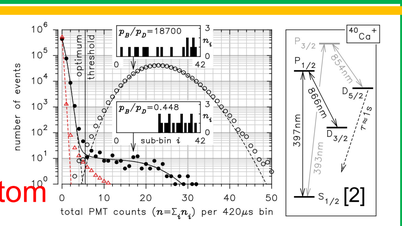
i.e) MOT/Cooling with repumper[1]
- No trapped atom loss
- ✓ Doppler cooling and trapping




- Depumping to unintended ground state

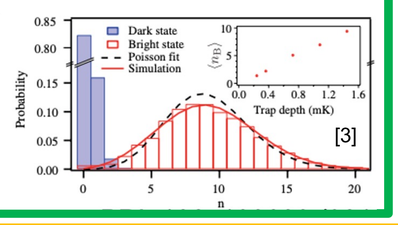
i.e) Ion trap[2]
- Closed transition cycle
- ✓ Trap depth ~ 1000K
- ✓ $10^6$ cycles → 99.99%




↓ Application to neutral atom

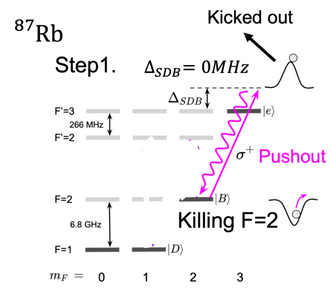
i.e) Tweezers array[3,4,5]
- Pulsed deep trap and tweezers
- ✓ Trap depth = 0.5K~10K
- ✓ Trap numbers 5~225
- ✓ $10^4$ cycles
- ✓ Fidelity : 98.6~99.6%
- ✓ Atom loss : 0.8~1.4%
- ✓ Depumping : 0.1~4%

$^{87}$Rb[3,4], $^{6}$Li[6], $^{133}$Cs[5,7]




### State-selective imaging

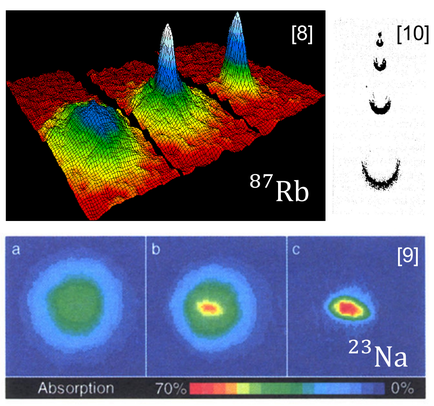
i.e) Tweezers array
- Imaging atoms in selected state
- ✓ "Pushout" measurement
  → Killing other states at first
  → Whole measurement




- Loss of atoms in other states

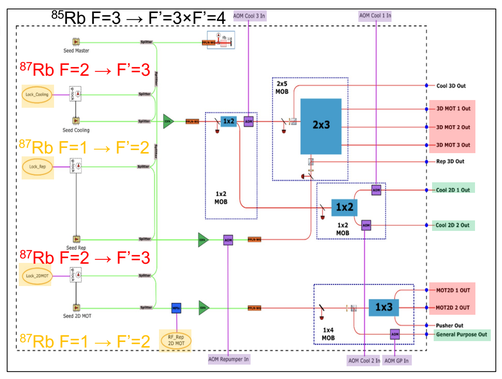
### Non-state-selective & destructive imaging

i.e) TOF absorption method[8,9,10]
- ✓ BEC(Bose-Einstein condensation)



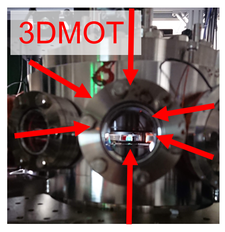

## Experimental Setup

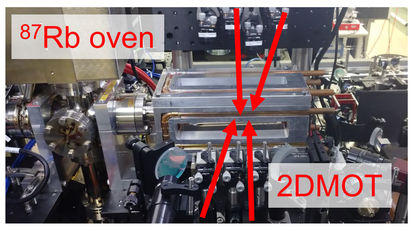
### MuQuans laser system

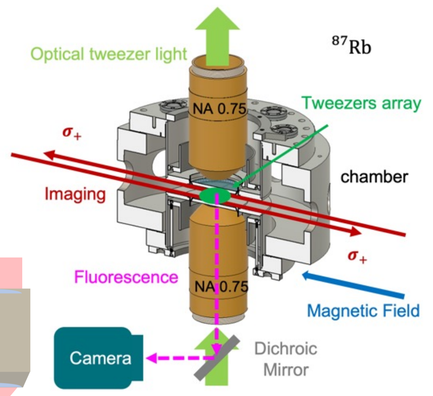


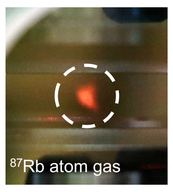

- ✓ Laser wavelength : 780nm
- ✓ Total power : 350mW
- ✓ Atom species : $^{87}$Rb
- ✓ 3 laser line & 4 wavelength
- ✓ 11 outputs (5 AOM input)
  - 3DMOT ×3
  - 2DMOT ×2
  - Evaluation ×3
  - Option with AOM ×3

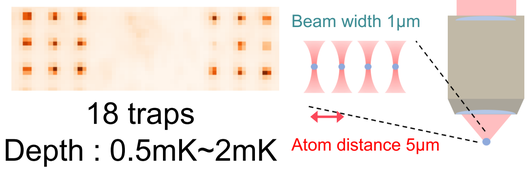
### MOT & Optical tweezer in chamber

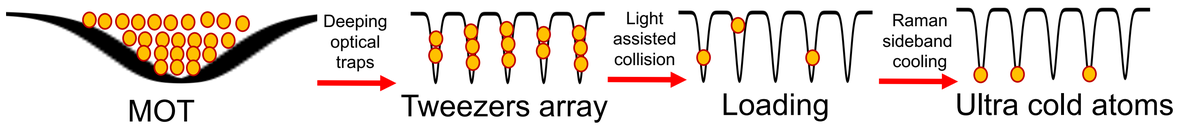


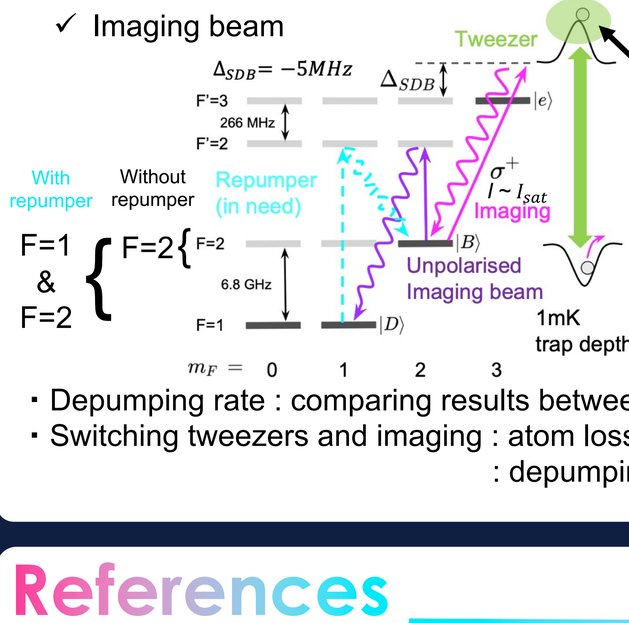



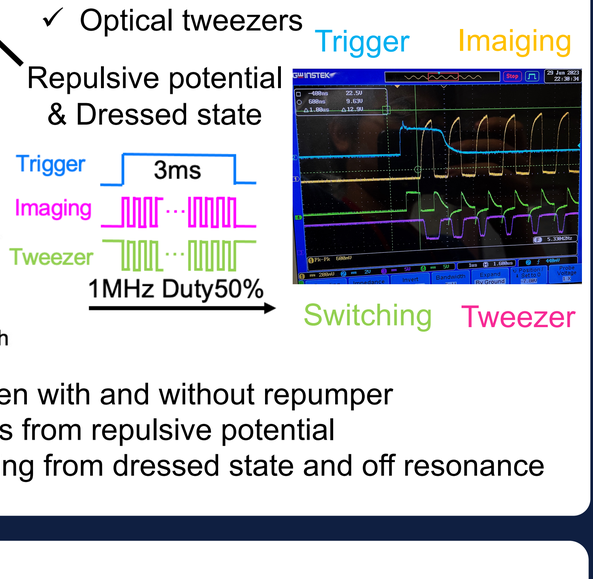




### Pulsed imaging beam[4] & optical tweezers

- ✓ Imaging beam
- ✓ Optical tweezers



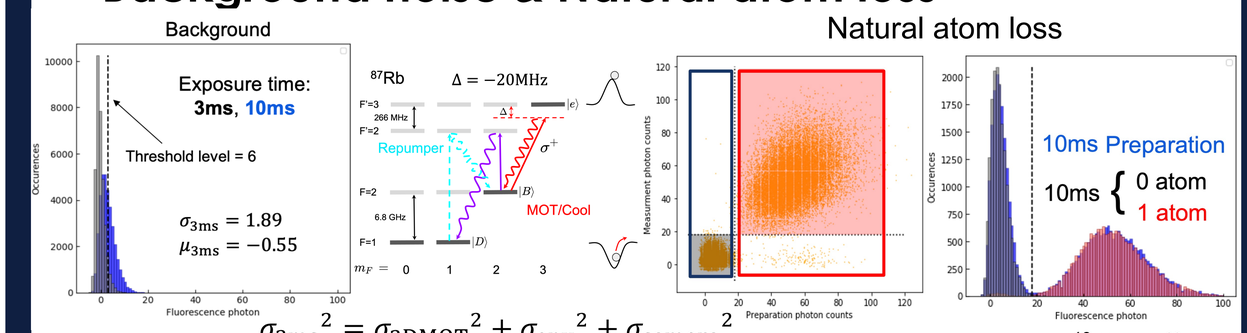

Repulsive potential & Dressed state




- Depumping rate : comparing results between with and without repumper
- Switching tweezers and imaging : atom loss from repulsive potential
  : depumping from dressed state and off resonance

## Experimental Result

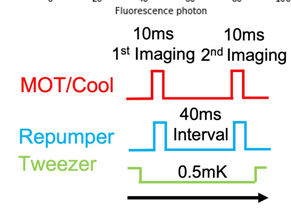
### Background noise & Natural atom loss



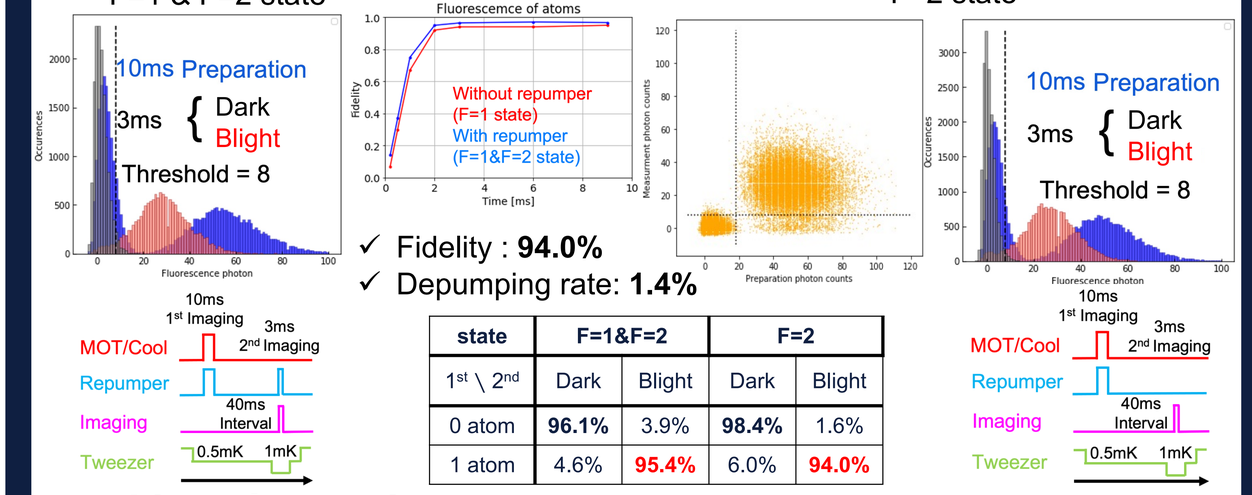

$$\sigma_{3ms}^2 = \sigma_{2DMOT}^2 + \sigma_{env}^2 + \sigma_{camera}^2$$

Camera noise : $\sigma_{camera} = 1.01$
Environment light : $\sigma_{env} = 0.87$
2DMOT leak : $\sigma_{2DMOT} = 1.34$

| 1st \ 2nd | 0 atom | 1 atom |
|---|---|---|
| 0 atom | **99.7%** | 0.3% |
| 1 atom | 1.2% | **98.8%** |



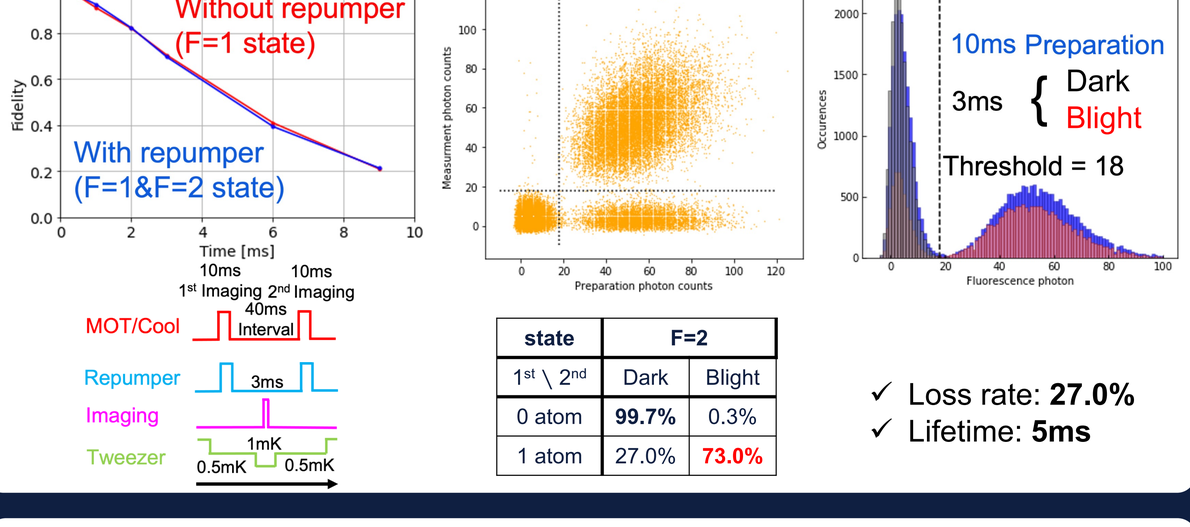

### Fidelity & Depumping rate




- ✓ Fidelity : **94.0%**
- ✓ Depumping rate: **1.4%**

| state | F=1&F=2 | | F=2 | |
|---|---|---|---|---|
| 1st \ 2nd | Dark | Blight | Dark | Blight |
| 0 atom | **96.1%** | 3.9% | **98.4%** | 1.6% |
| 1 atom | 4.6% | **95.4%** | 6.0% | **94.0%** |

### Atom loss rate




| state | F=2 | |
|---|---|---|
| 1st \ 2nd | Dark | Blight |
| 0 atom | **99.7%** | 0.3% |
| 1 atom | 27.0% | **73.0%** |

- ✓ Loss rate: **27.0%**
- ✓ Lifetime: **5ms**

## References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[11] M. Martinez-Dorantes et al, Phys. Rev. A **97**, 023410 (2018)


## Conclusion & Outlook

- ✓ 1 atom detection fidelity : 94%
- ✓ Depumping rate to F=1 state : 1.4%
- ✓ Atom loss rate : 27%

} 18 tweezers (1mK depth)

Improvement plans
- Installing porro prism to enlarge fluorescence[11]
- Automatic purification of polarization and power
- Optimization of tweezer pulsing delay
- Optimization of ROIs and weighting
- Reduction of background noise

Future plans
- Microwave shelving[7]
- Mid-circuit measurement[7]
- Quantum gate experiments
- Raman sideband cooling during imaging