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

Towards high-fidelity ultrafast excitation of atoms to Rydberg states

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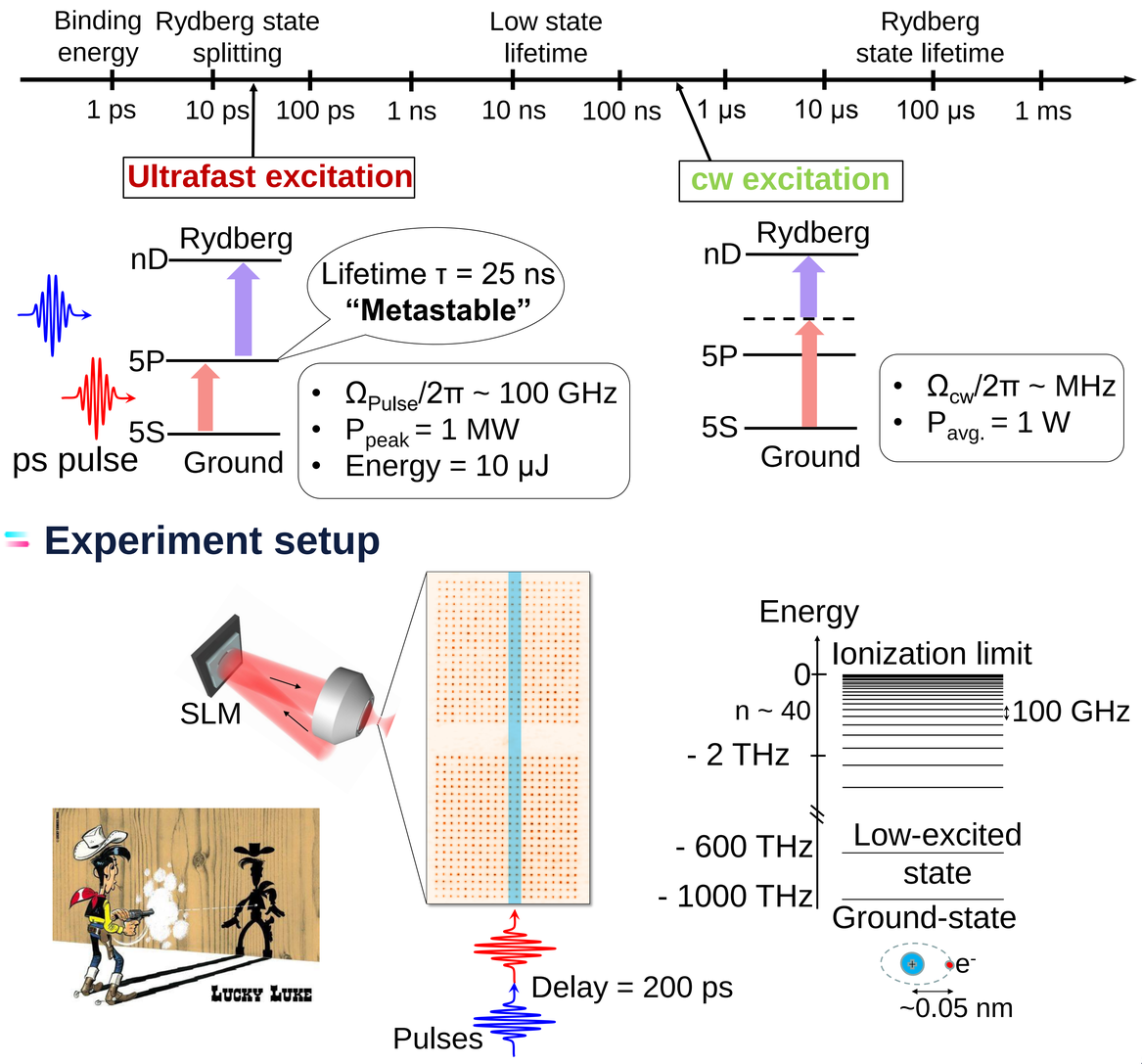
Introduction

My goal is to excite atoms to Rydberg states in 10 ps, as fast as possible, with an efficiency of more than 90 %. This has never been achieved on such ultrafast timescale so far. I learn to use pulse lasers, non linear optics and spectral shaping to achieve this goal.

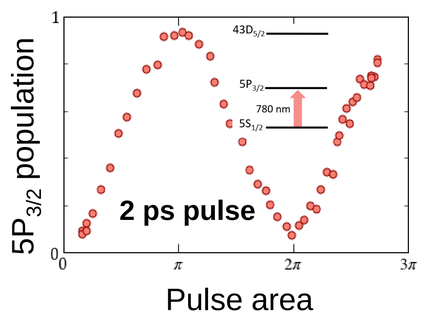
Rydberg atom

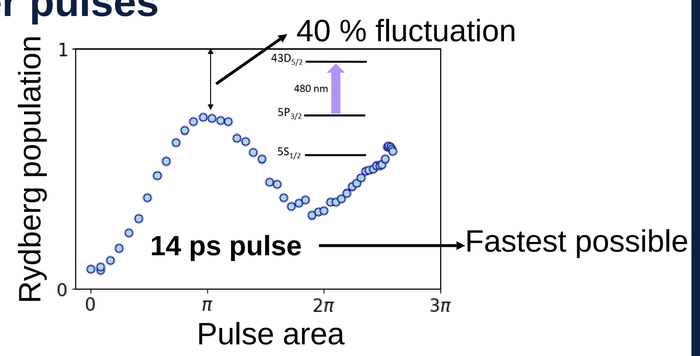


Experiment setup

Ultrafast Rabi oscillation

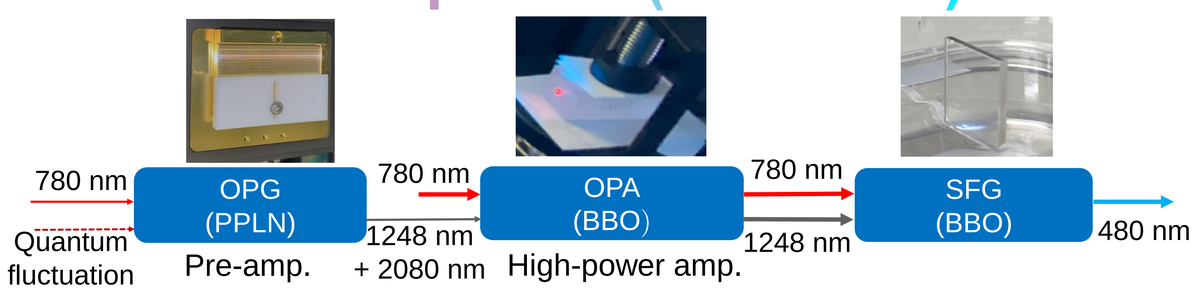
Rabi oscillation with laser pulses

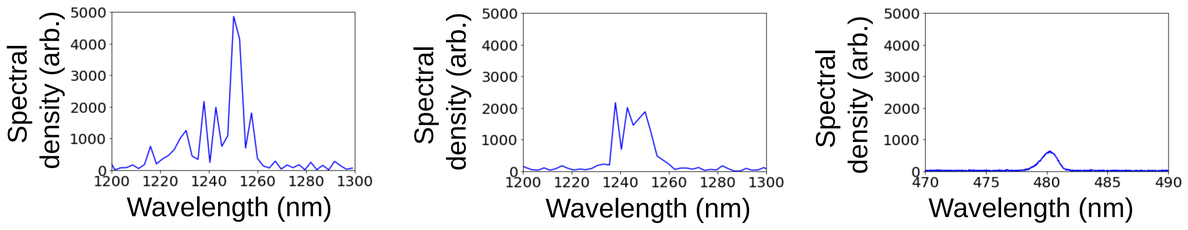




- Excite >95 % atoms from $|5S\rangle$ to $|5P\rangle$ and successfully bring 75% atoms from $|5P\rangle$ to $|43D\rangle$.
- Pulse-to-pulse fluctuations of 480 nm laser originate from OPG process using BBO crystal.

480 nm laser pulses (version 2)



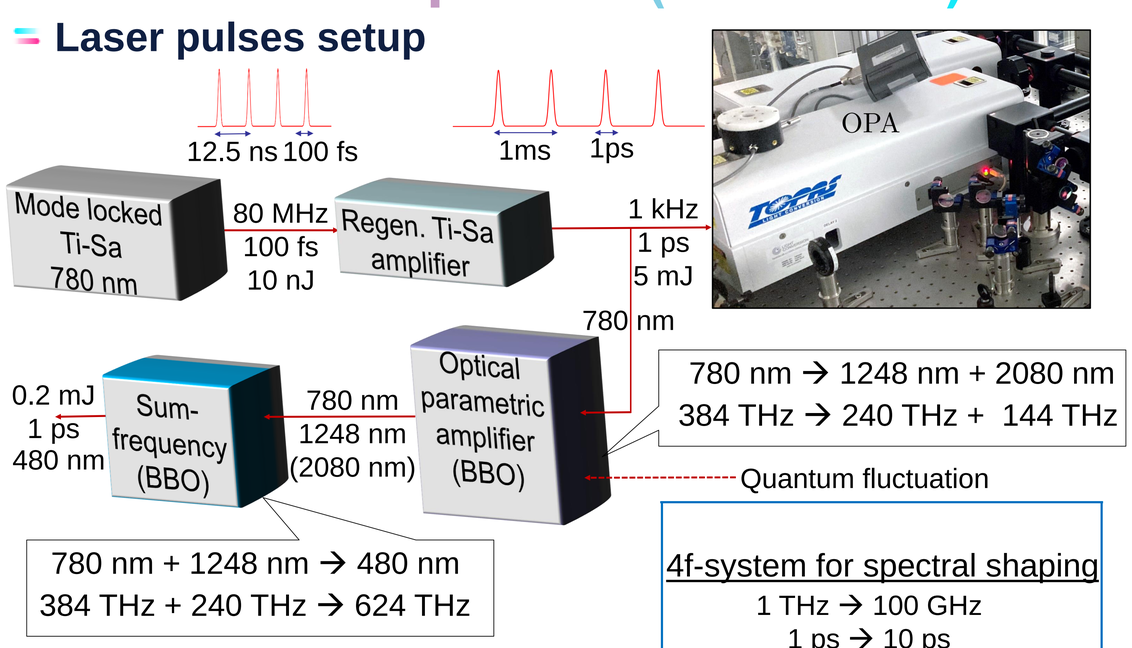


PPLN	BBO
Quasi-phase matching	Birefringence phase matching
d_{eff} = 14 pm/V ✓	d_{eff} = 2 pm/V

- Pulse-to-pulse power fluctuations decreases from 40% to 10% after 4f-system.

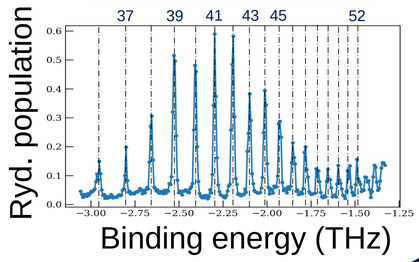
480 nm laser pulses (version 1)

Laser pulses setup

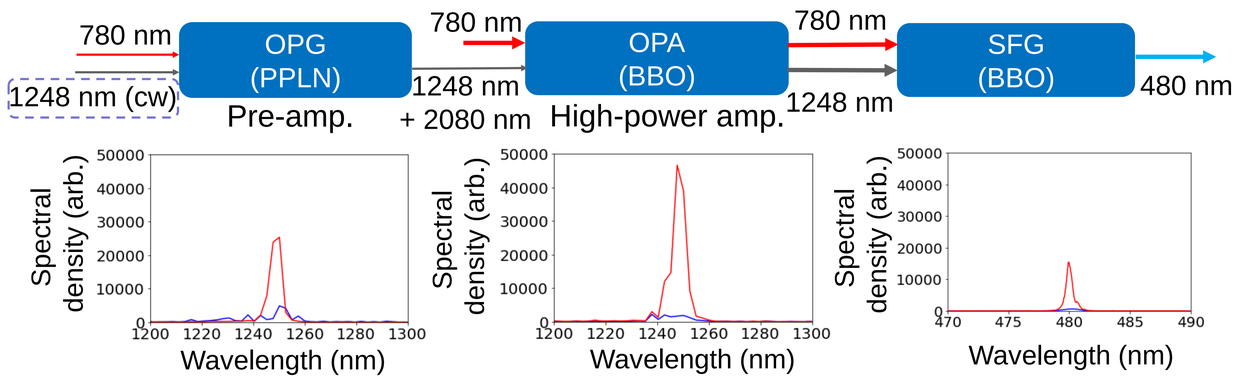


- OPA amplifies quantum fluctuation.
- Same BBO crystal is used for two-stage amplification (pre-amp. / high-power amp.)
- 4f-system reduce pulse bandwidth from 1 THz to 100 GHz and resolve Rydberg spectrum.

Rydberg spectrum



480 nm laser pulses (version 3)



- Amplification of coherent state by adding injection seeding.
- Generate nearly Fourier-transform limited pulses.
- We can further reduce pulse-to-pulse power fluctuations from 10% to 5%.

Future plan

Implementation of high fidelity ultrafast controlled-Z gate

[Y. Chew *et al*., Nature Photonics **16**, 724 (2022)]

- Improve the fidelity of Rydberg excitation scheme via homemade system of laser pulses.
- Further reduction of the spread of the wavefunction by preparing squeezed motional state of the atom.

Ultrafast many-body electron dynamics in tweezer system

[M. Mizoguchi *et al*., PRL **124**, 253201 (2020),
V. Bharti *et al.*, arXiv2201.09590 (2022)]