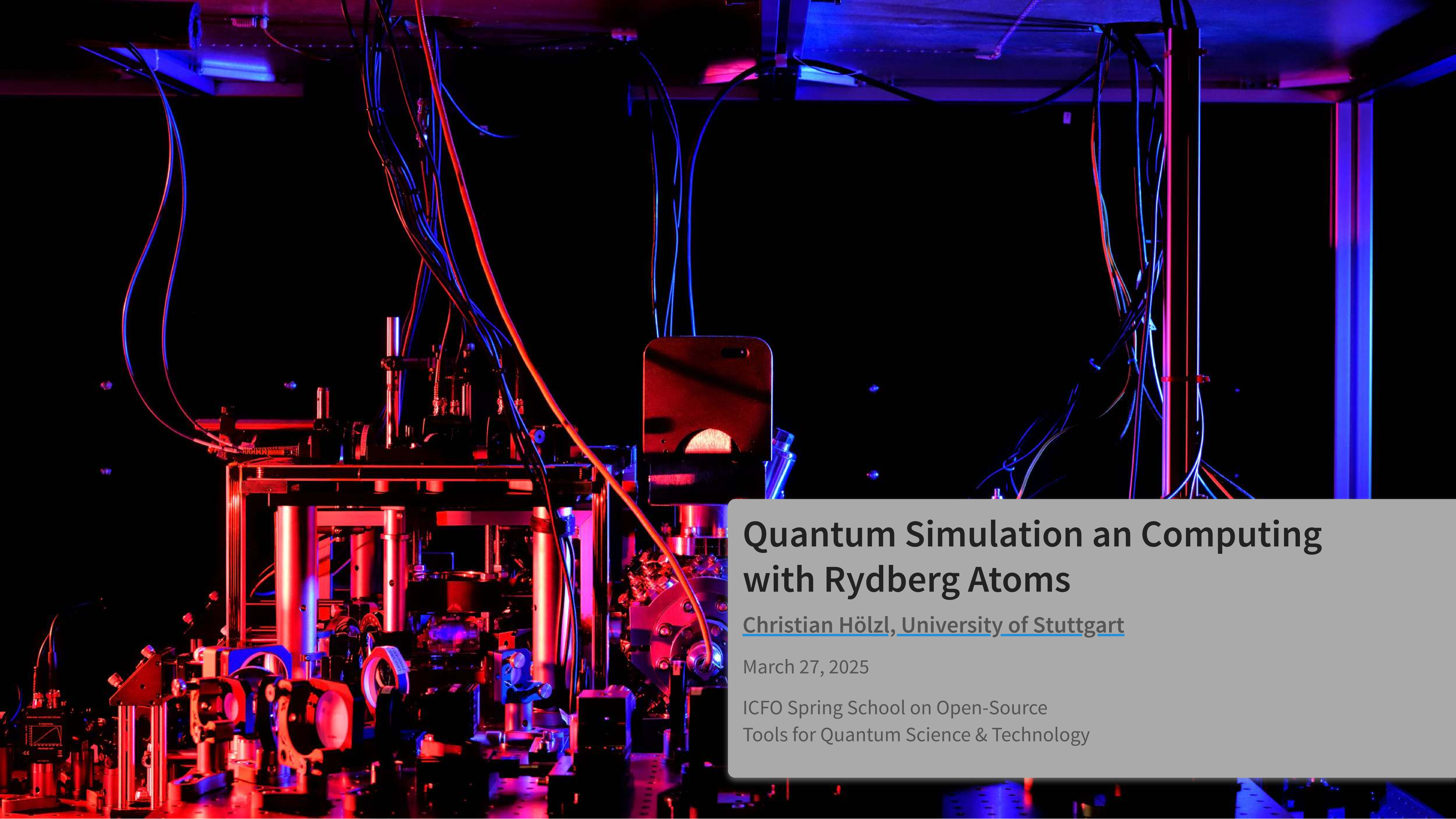


Quantum Simulation an Computing with Rydberg Atoms

Christian Hölzl, University of Stuttgart

March 27, 2025

ICFO Spring School on Open-Source
Tools for Quantum Science & Technology

https://cloud.pi5.physik.uni-stuttgart.de/
index.php/s/Bi7TdTDdrMNiNWW

PDF Slides

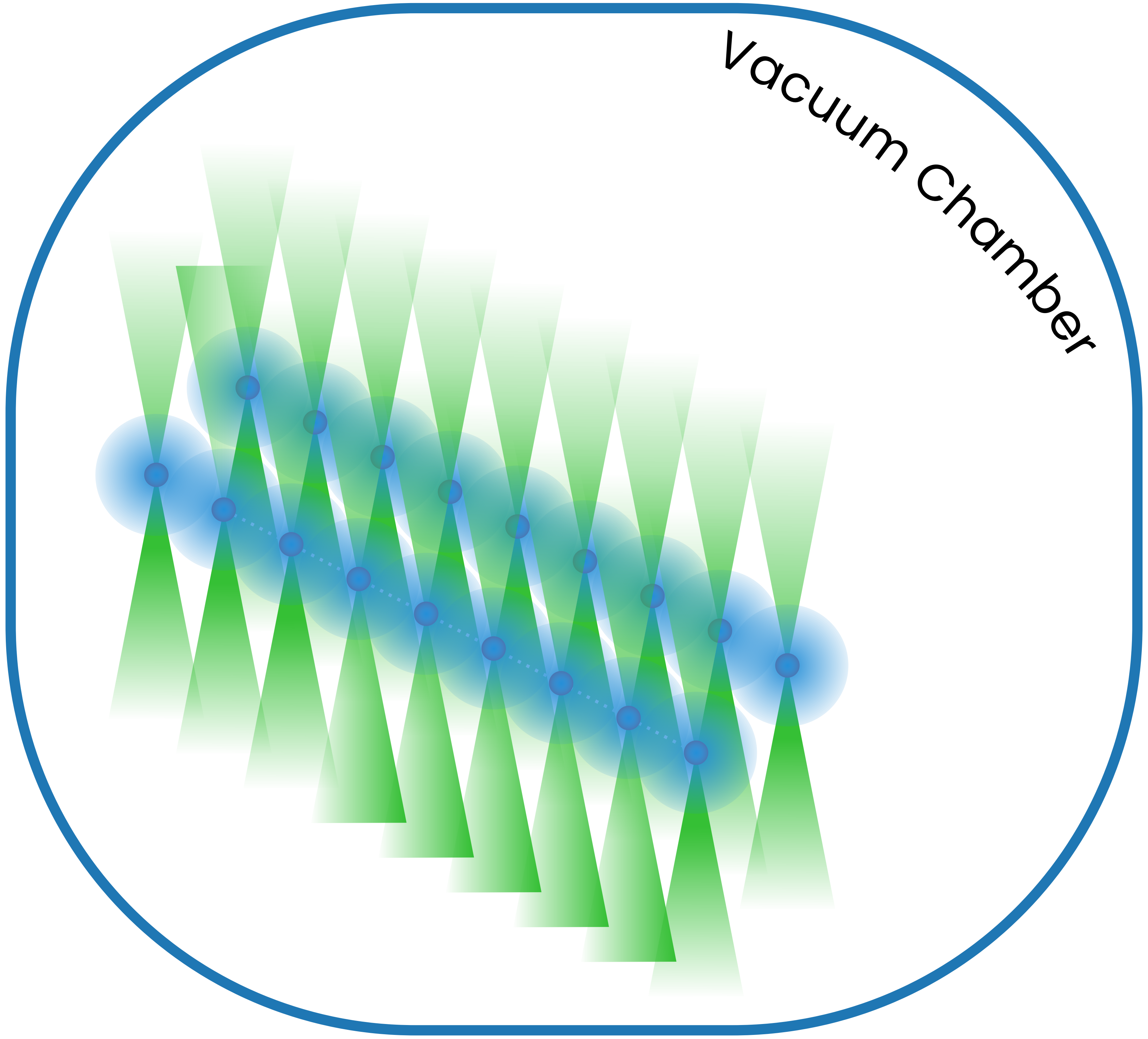
https://slides-icfo-9a3e60.gitlab.io/

Online Slides

Why Tweezer-Trapped Ultracold Atoms?

?

- Fundamentally Identical
- Isolated and Coherent Qubits
  In the electronic levels
- Wireless Gates
  Realized fully optical
  Rydberg Interactions
- Highly Scalable
  >5000 qubits demonstrated
- Flexible (Dynamic) Connectivity



Quantum Simulation with Rydberg Tweezer Arrays

- How do Tweezers work?
- What are Rydberg atoms?
- Why are Rydberg atoms cool?
- How do they interact?
- What can they simulate?

Circular Rydberg States

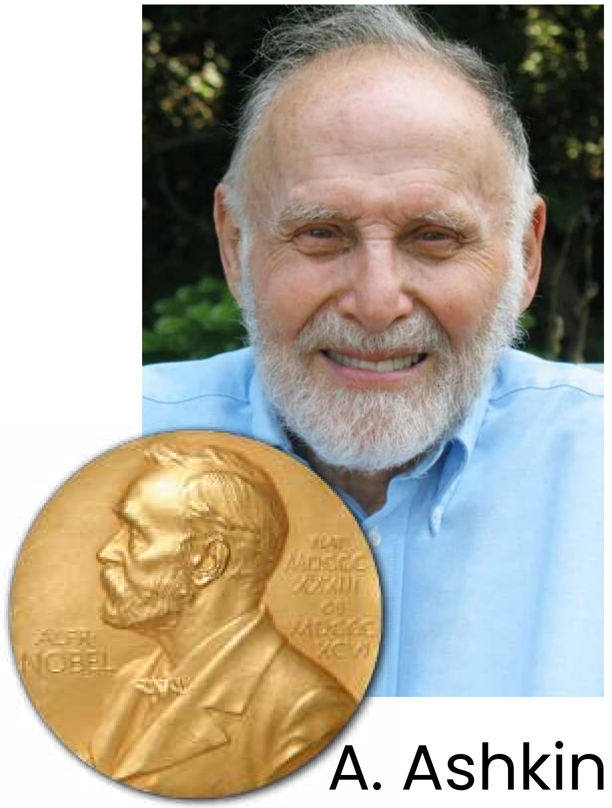
- What are CRS?
- Why are CRS interesting for quantum simulation?
- What is the state of the art?
- How can we prepare CRS?
- Brand new data from our lab!

Controling Neutral Atom Quantum Hardware

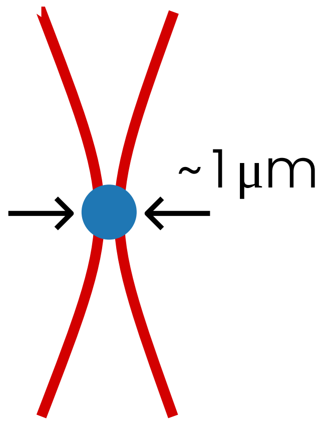
- What are the hardware requirements?
- How can FOSS help in controling quantum hardware?
- How does an example experiment code look?

What are Optical Tweezers?

Original Idea



A. Ashkin



Light pressure traps dielectric objects in highly focused beams

Atoms are **polarizable by light**

➡ Experience a **intensity dependent force**

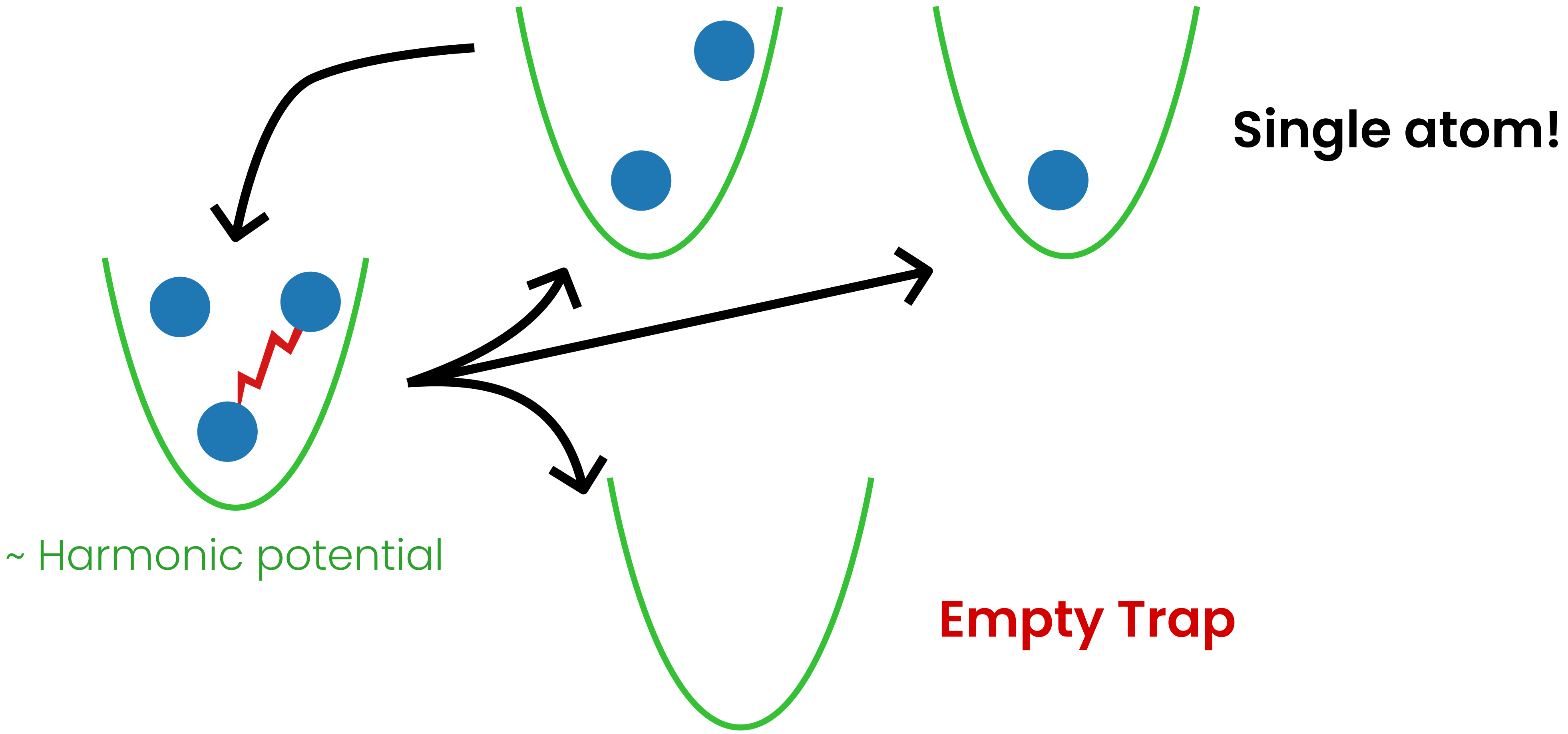
➡ Can also be **trapped**

$$U_{\text{dip}} = -\frac{1}{2\varepsilon_0 c}\,\text{Re}(\alpha) I$$

Laser intensity

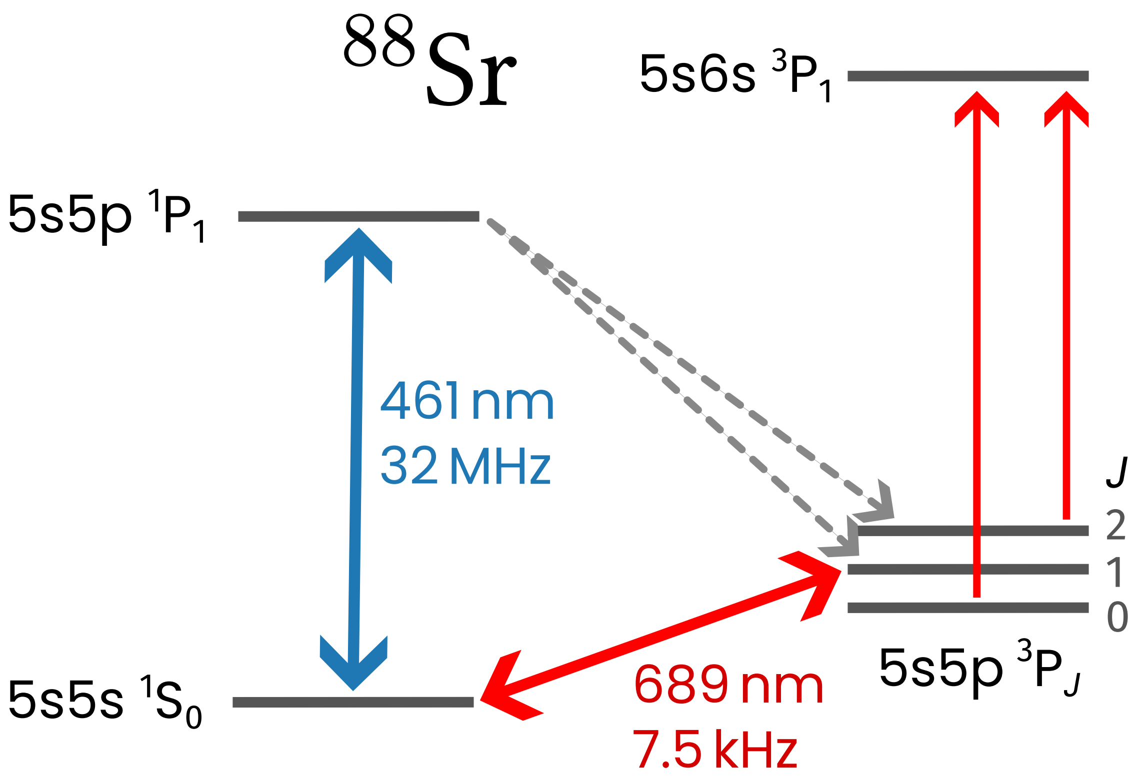
Atom polarizability

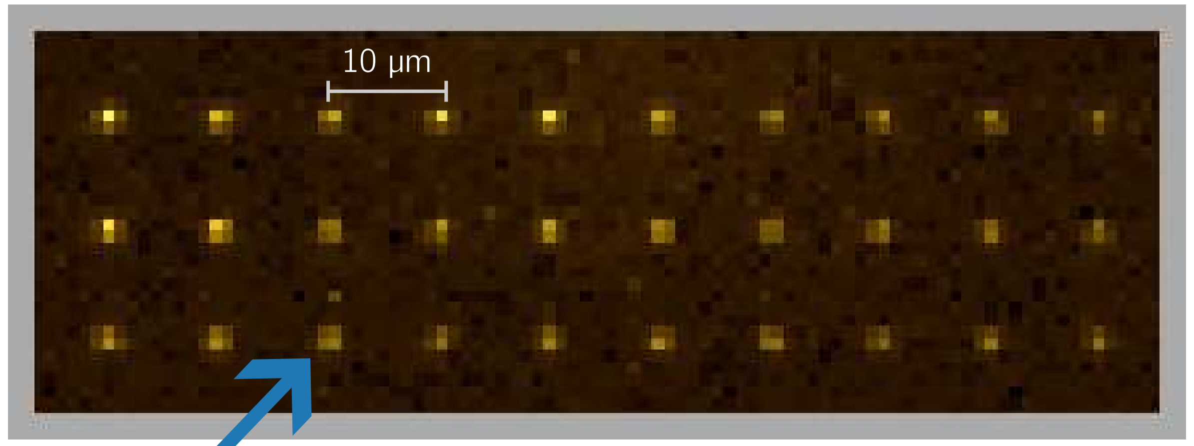
1. Prepare cold Atoms (see previous talks)
2. "Parity Projection" by **light-assisted collisions**



How to Create Defect Free Arrays?

Single Atom Imaging

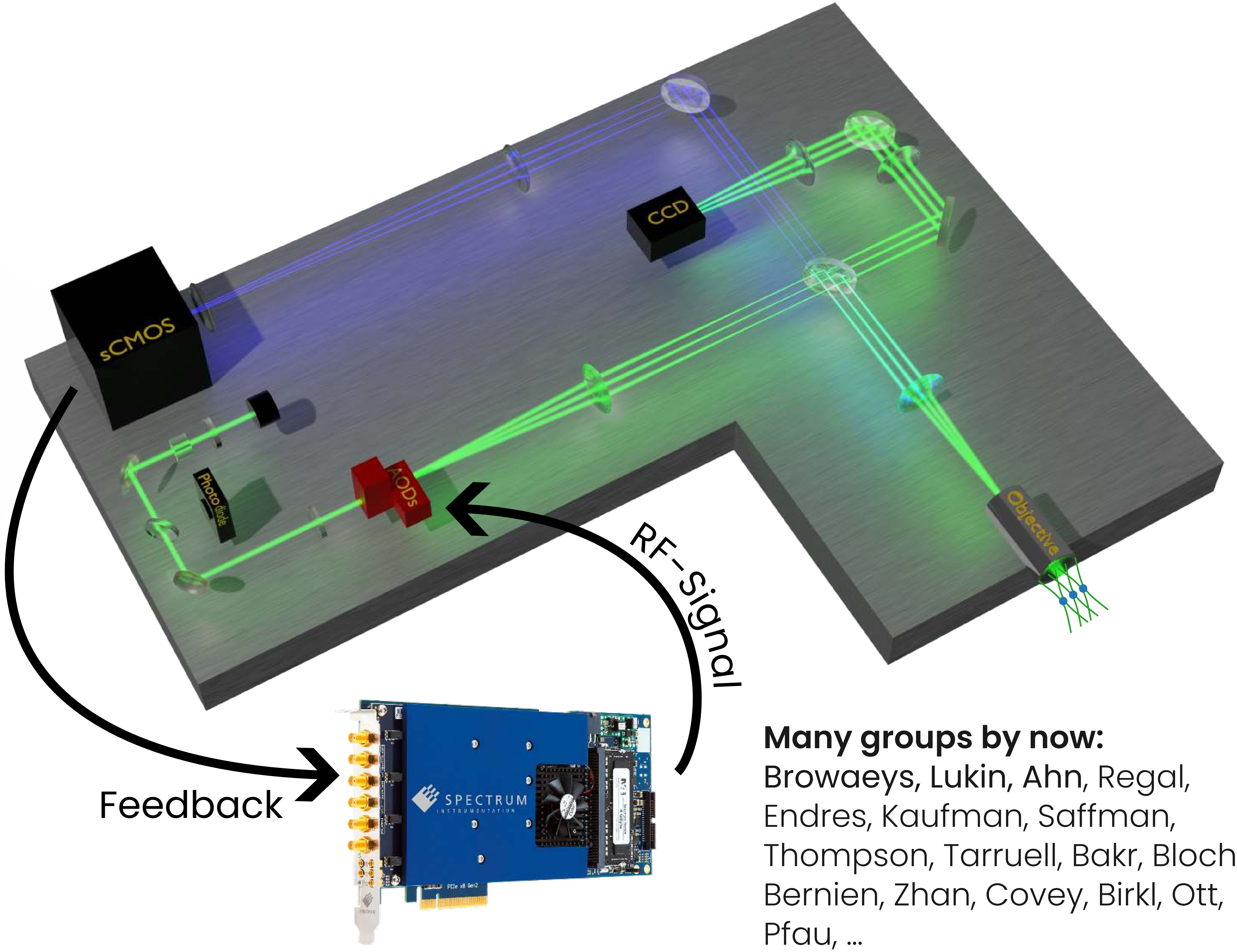




Single Atom

?

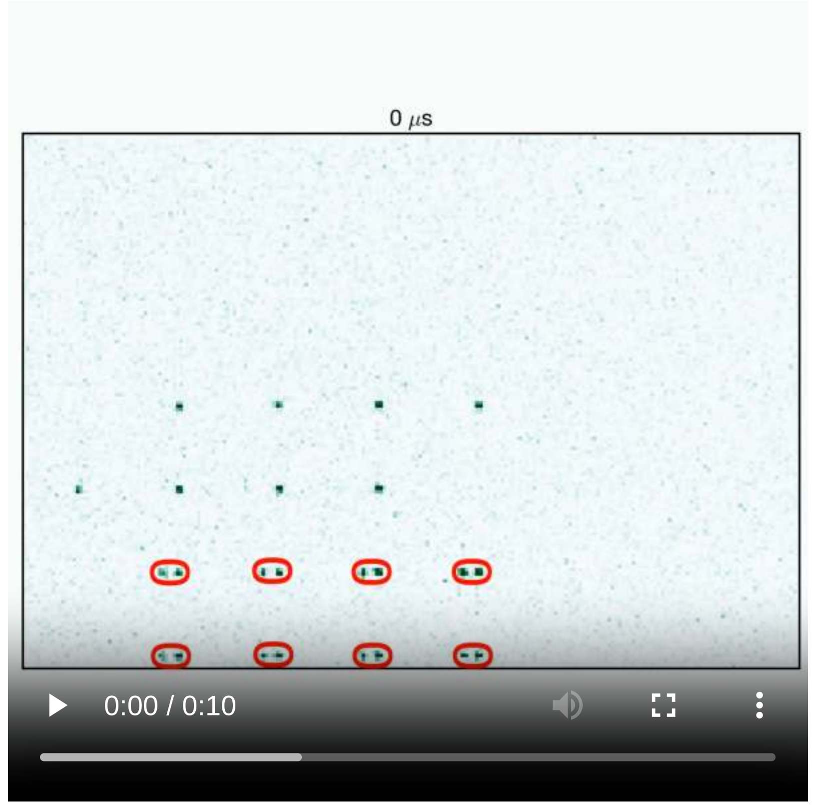
One of the first array experiments: Endres *et al.*, Science. 354, 1024-1027 (2016)



Many groups by now:
Browaeys, Lukin, Ahn, Regal, Endres, Kaufman, Saffman, Thompson, Tarruell, Bakr, Bloch, Bernien, Zhan, Covey, Birkl, Ott, Pfau, ...

Tweezer Arrays are Extremely flexible

Mid-Circuit Shuttling

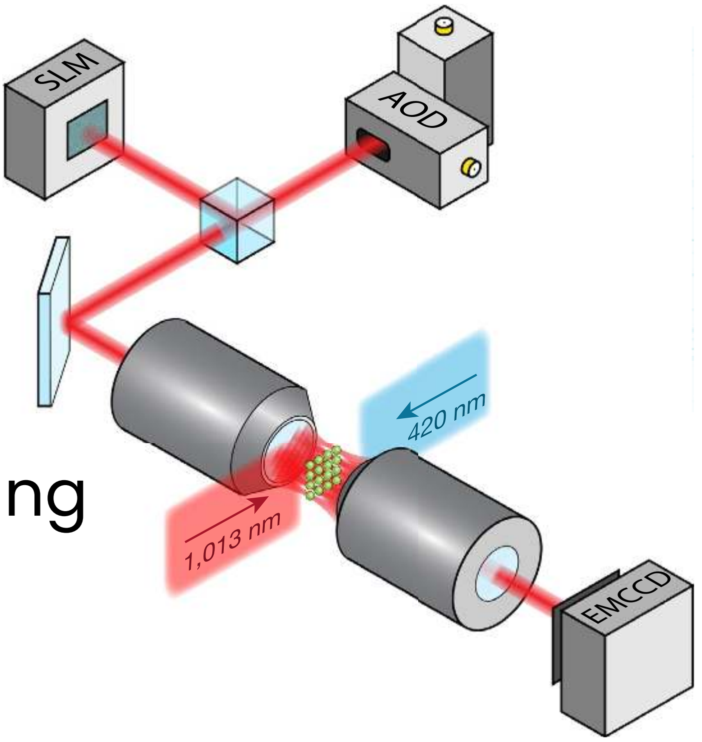


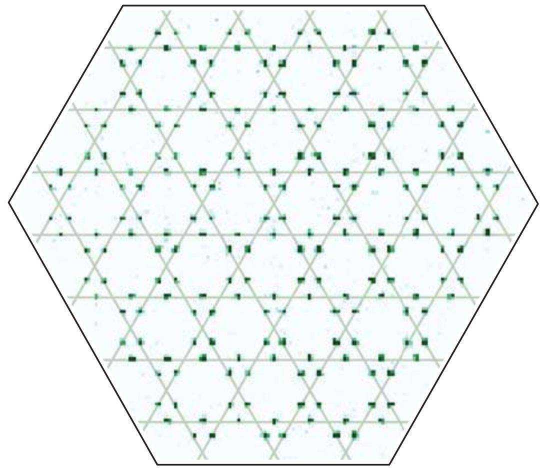
- **Toric code** "error correction"
- **Dynamic connectivity** allows a plethora of new techniques

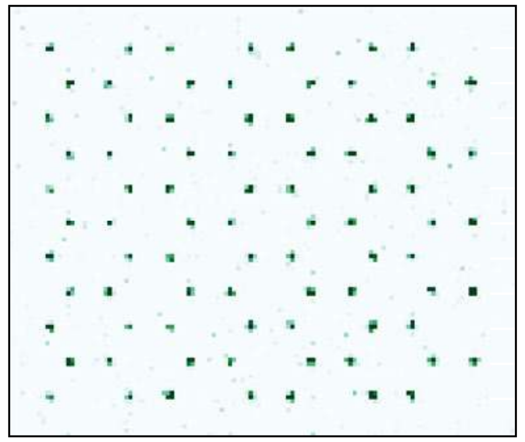
Bluvstein *et al.*, Nature 604, 451–456 (2022)

SLMs: Arbitrary Geometries

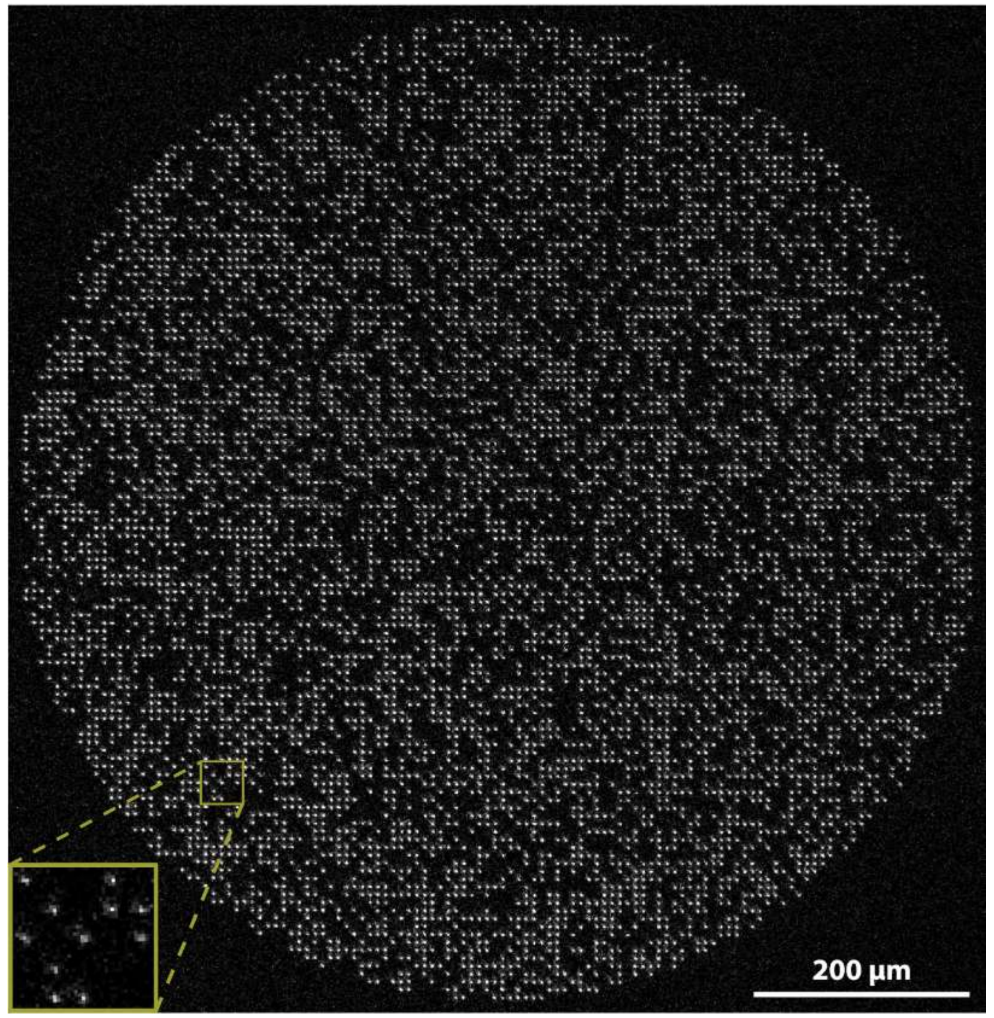
- Spatial Light Modulator
- Slow (Hz)
  ➡ AOD for moving/sorting







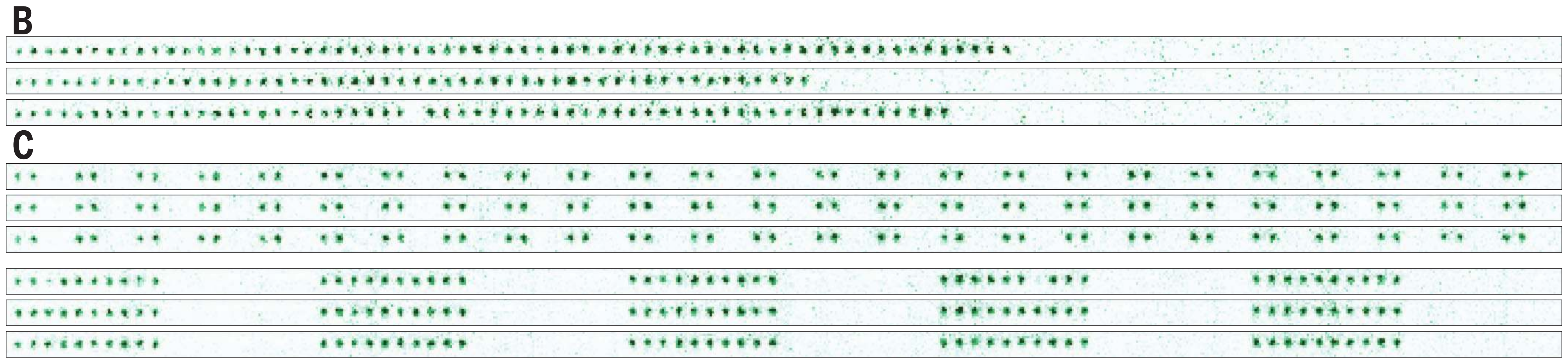
Ebadi *et al.*, Nature 595, 227–232 (2021)
Semeghini *et al.*, Science 374, 1242-1247 (2021)



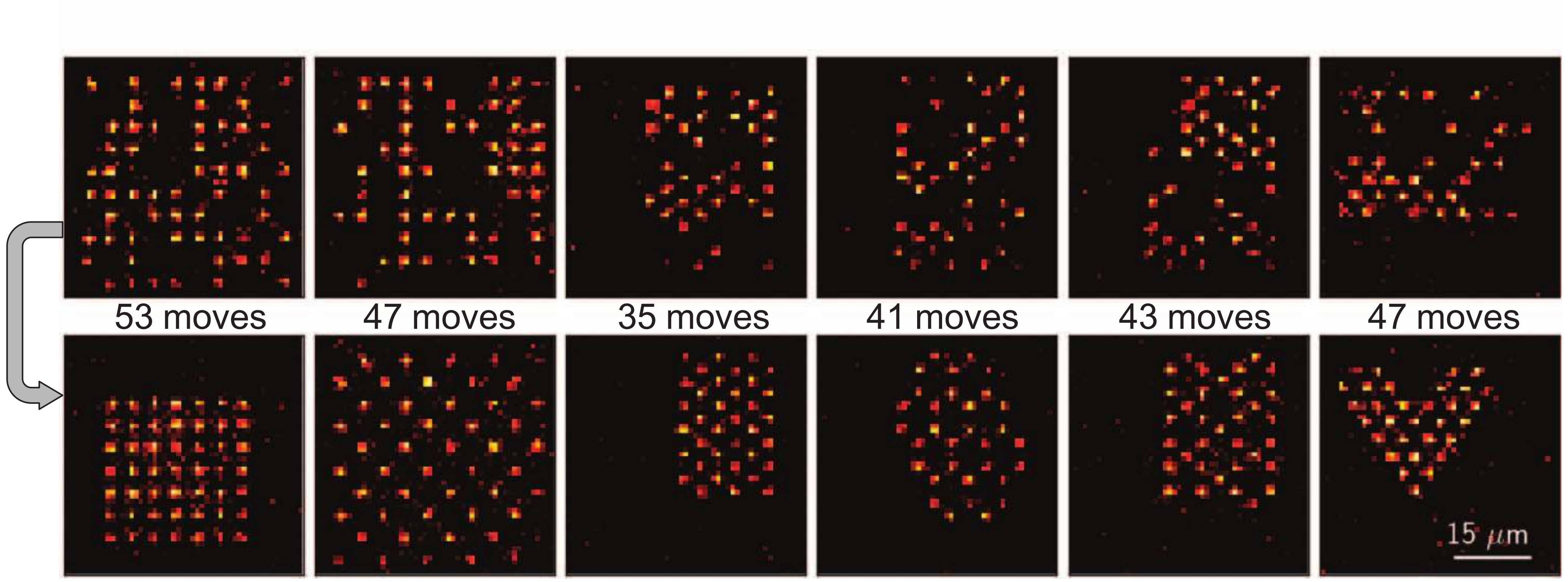
Manetsch et al., arXiv:2403.120213 (2024)

Current size record:
6100 sites

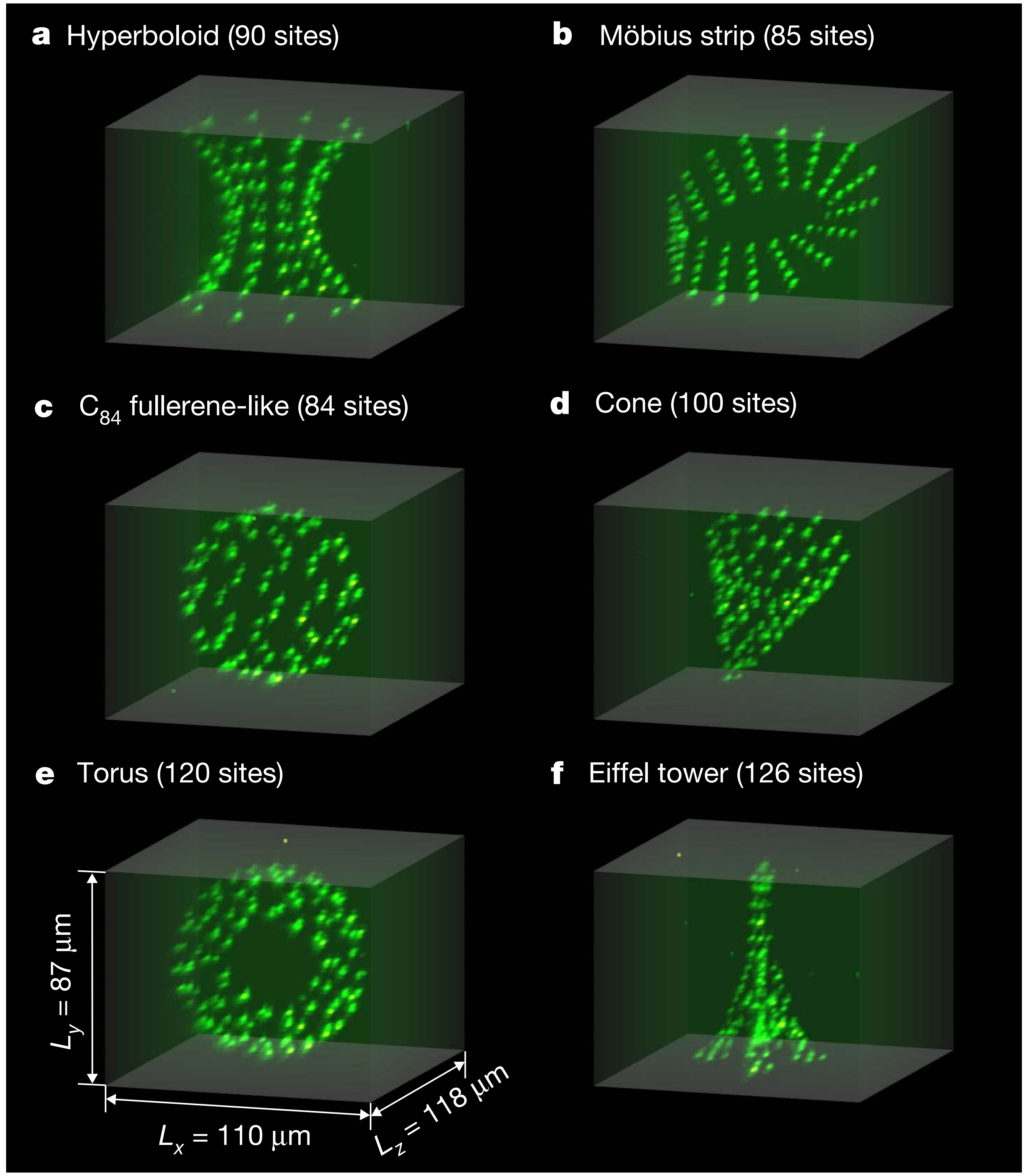
Arbitrary Dimensions



Endres *et al.*, Science. 354, 1024-1027 (2016)



Barredo *et al.*, Science. 354, 1021-1023 (2016)

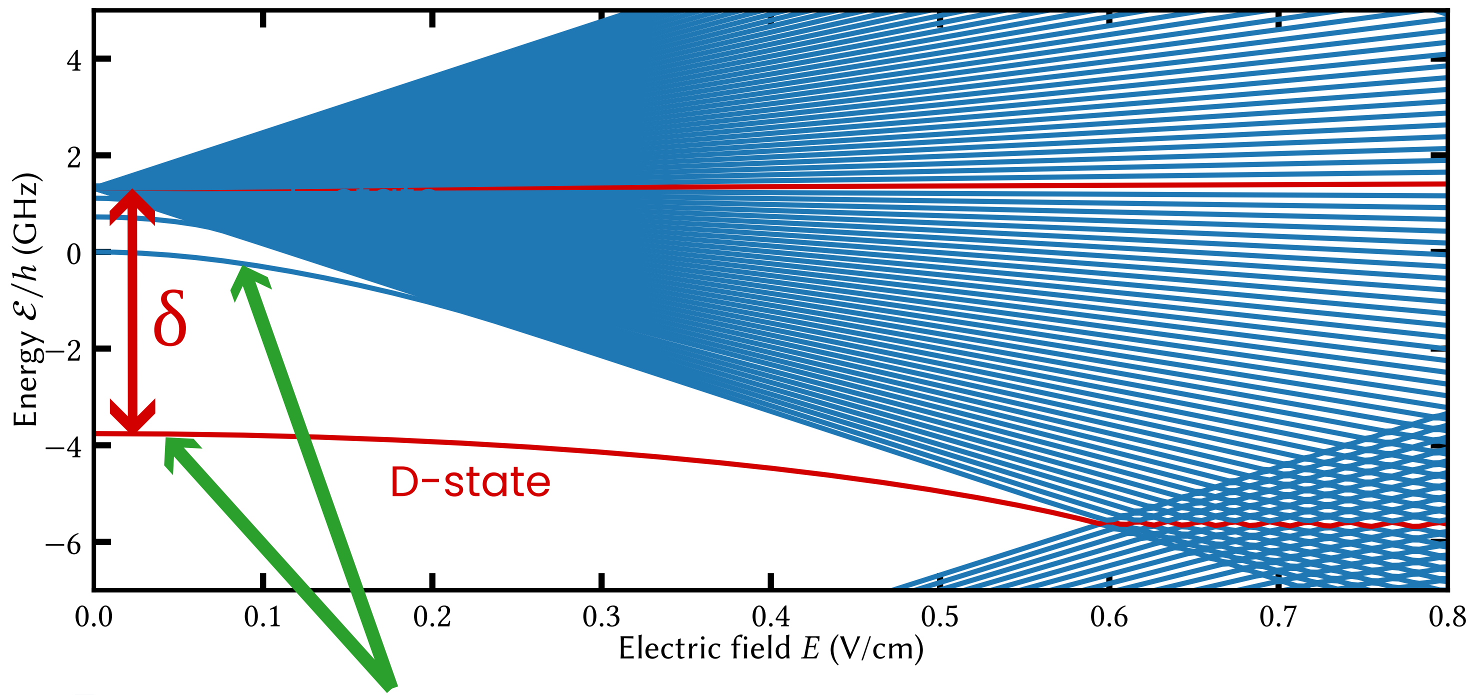


Barredo *et al.*, Nature. 561, 79–82 (2018)

How to Work with Rydberg Atoms?

- Highly excited levels with **n>40**
- Description **like H-Atom**, correction via **quantum defect δ**

$$E_n = -\frac{Rhc}{(n-\delta_l)^2}$$

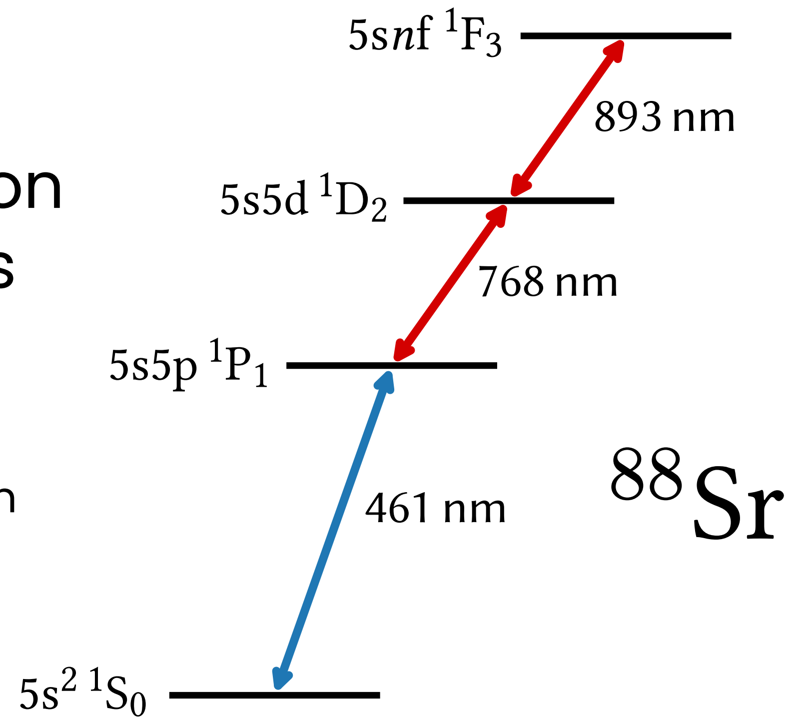


- l-dependence: core overlap decreases with increasing n

Creation

- Laser excitation with 1-3 lasers

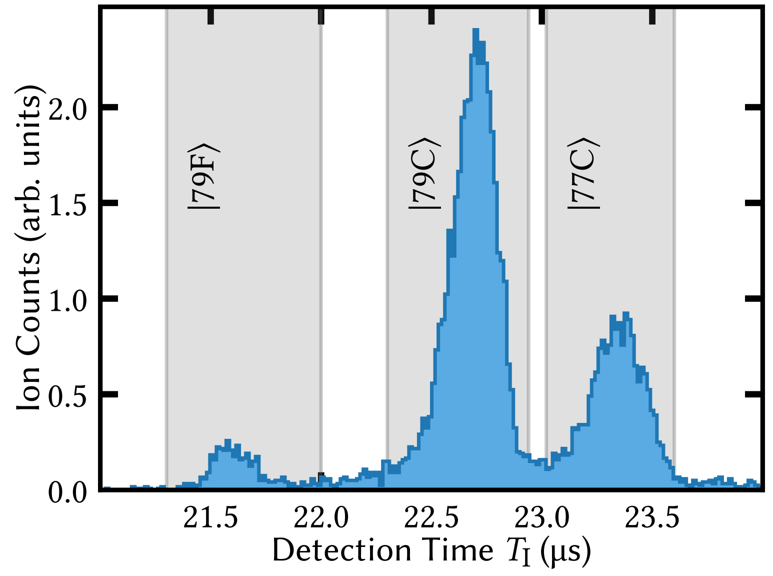
In the following we will simplify it to a transition with **Rabi Frequency** Ω



Detection

- State selective field ionization

Gallagher, Rydberg Atoms. Camb. Univ. Press (1994)



- Loss or Anzilla detection schemes

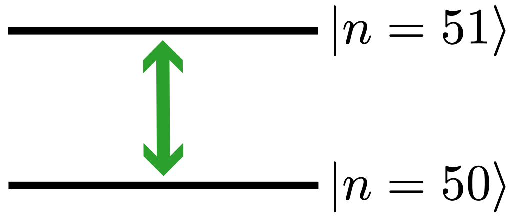
Madjarov *et al.*, Nat. Phys. 16, 857–861 (2020)

Why are Rydberg Atoms Cool?

- Properties described by **scaling laws**
- Rydberg Orbit $\langle r \rangle = \frac{1}{2}(3n^2 - l(l+1)) \propto n^2$

  $\langle r \rangle_{n=100} \approx 1\,\mu\mathrm{m}$
- Spontaneous Lifetime $\tau \propto n^3$

  $\tau_{n=100} \approx 500\,\mu\mathrm{s}$
- Transition Dipole Moment



$d \approx 2500 e a_0$

Strong coupling to EM-Field

➡ **Single photon** sensitivity

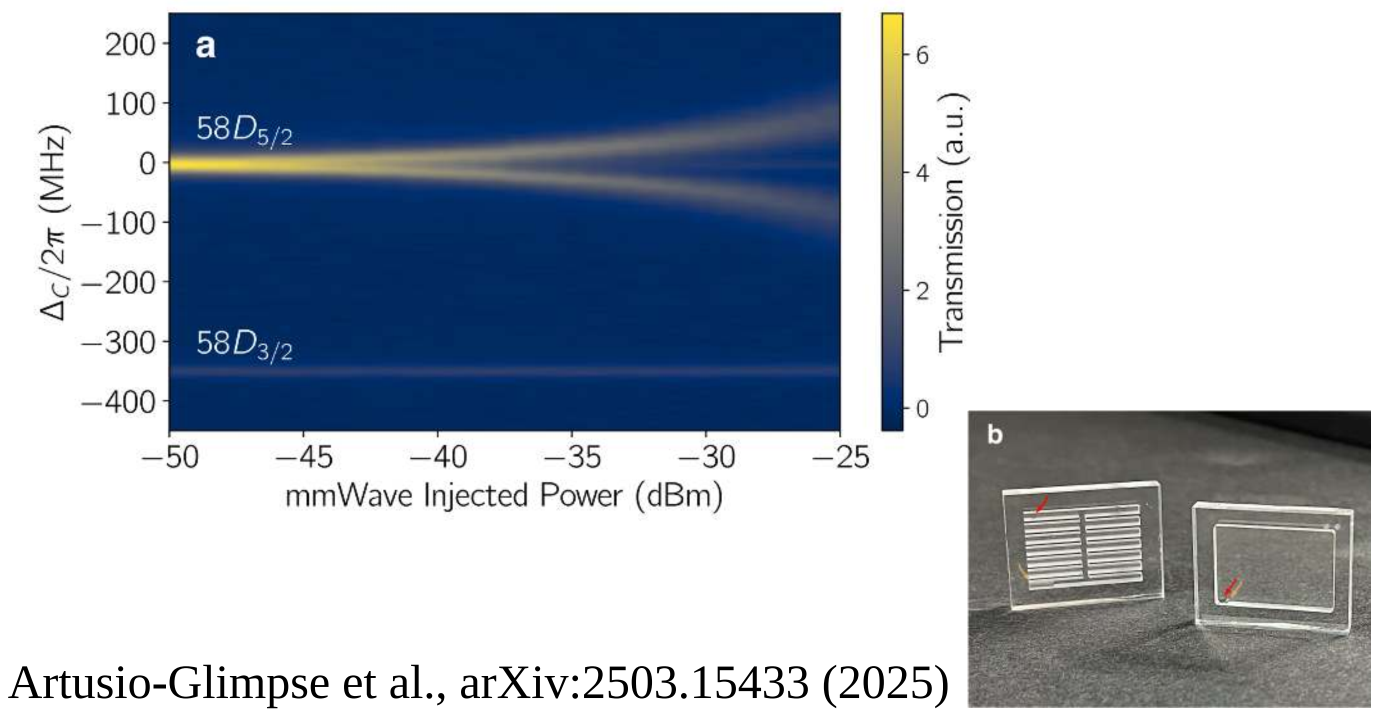
Raimond, Brune and Haroche, Rev. Mod. Phys 73, 565 (2001)

➡ **MHz** Rabi frequencies

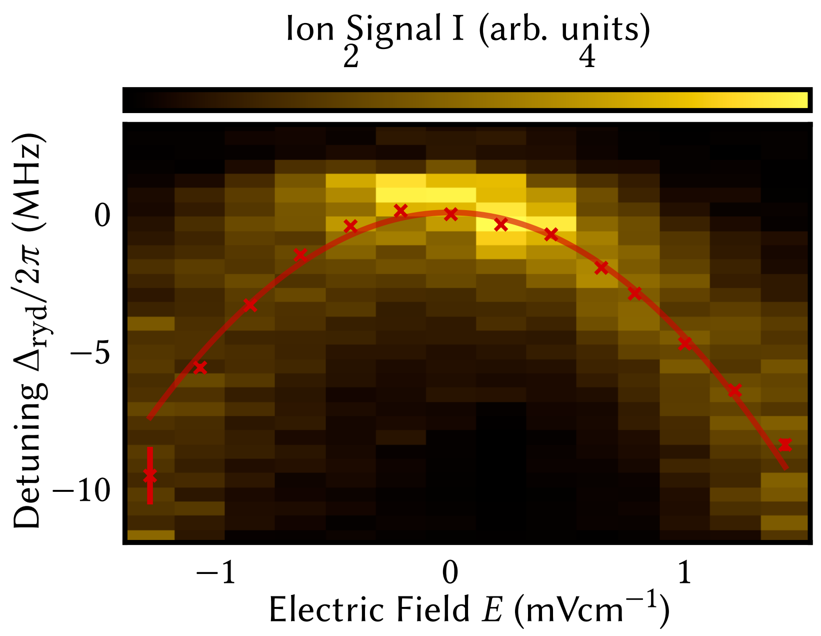
- Polarizability $\alpha \propto n^7$

Extremely sensitive to electric fields

Löw *et al.*, J. Phys. B. 45, 113001 (2012)



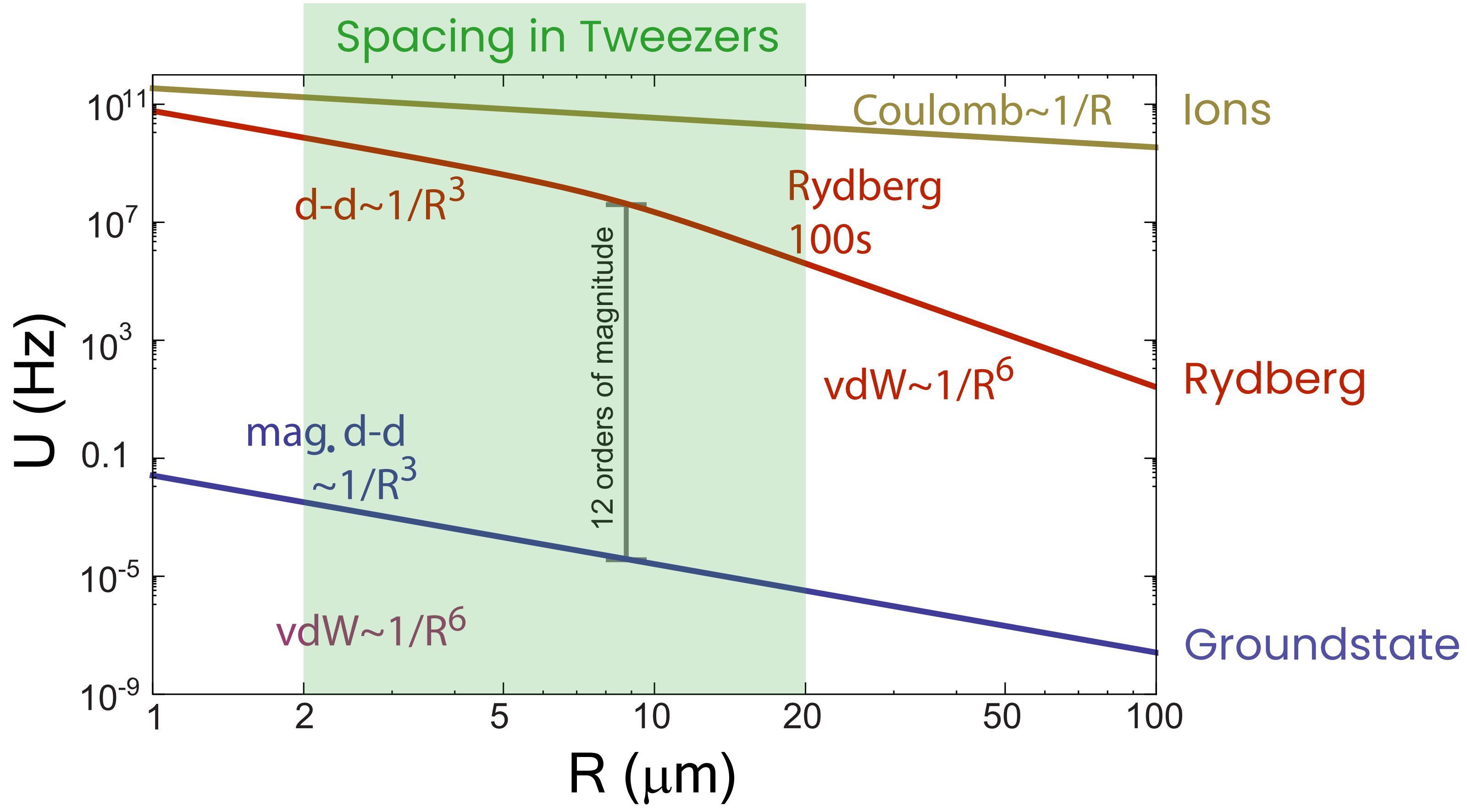
Artusio-Glimpse et al., arXiv:2503.15433 (2025)



212P: MHz lineshift with $\Delta E < 1\,\mathrm{mVcm}^{-1}$

How do Rydberg Atoms Interact?

- Strong and long range van der Waals interaction $V \propto \frac{n^{11}}{R^6}$
- With long lifetimes $\approx 10^5$ interaction cycles



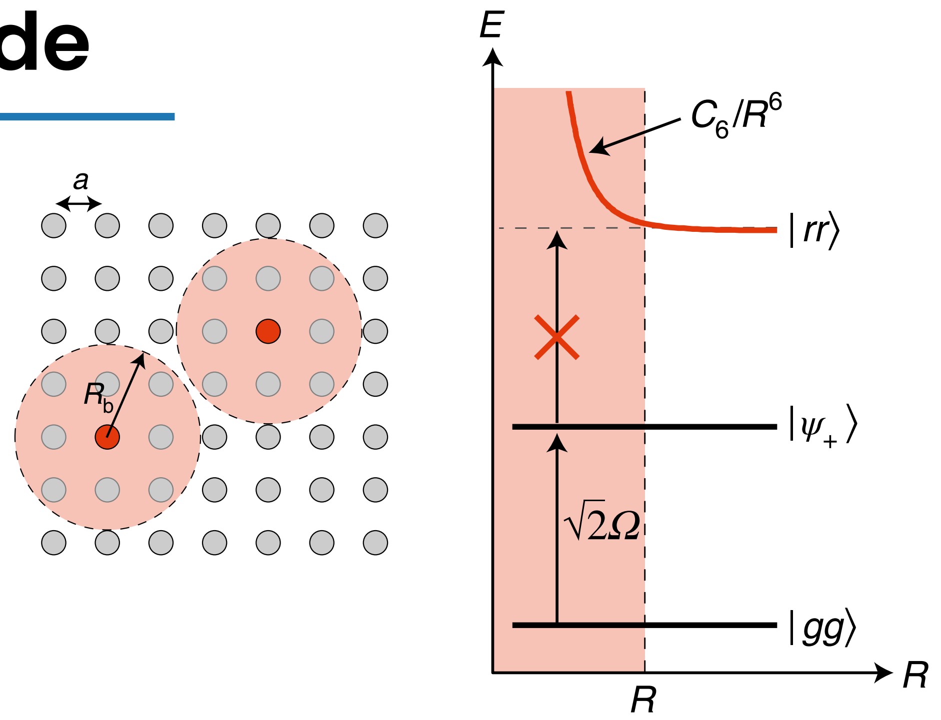
Saffman *et al.*, Rev. Mod. Phys. 82, 2313 (2010)

Rydberg Blockade

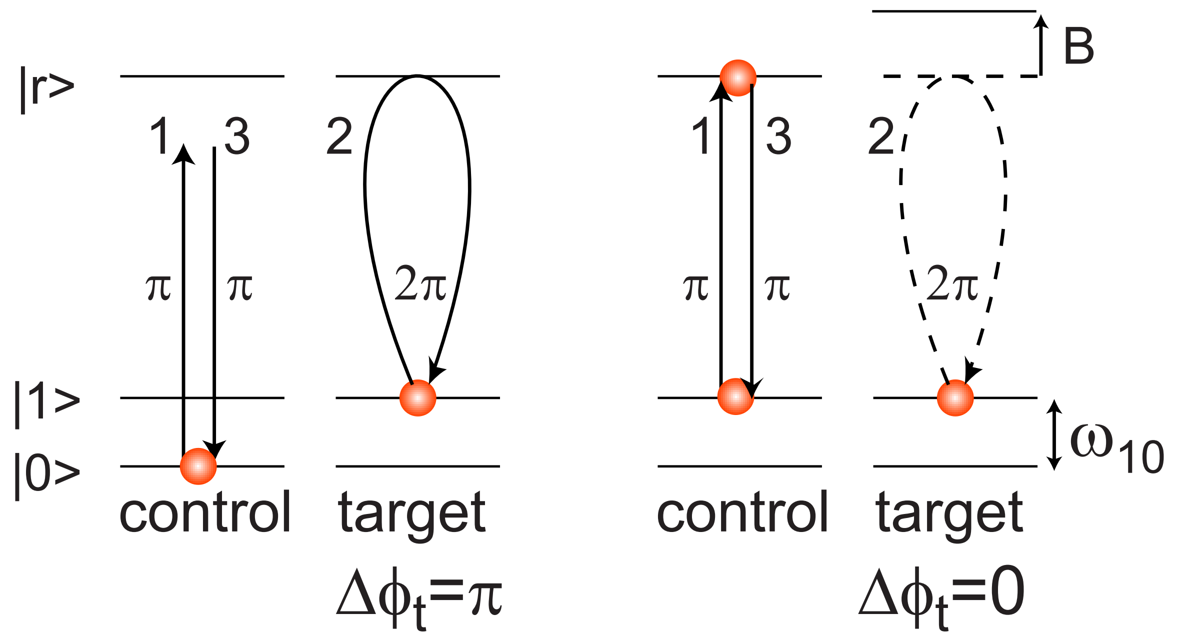
Urban *et al.*,
Nat. Phys. 5, 110–114 (2009)

Browayes *et al.*,
Nat. Phys. 16, 132–142 (2020)

Extremely robust!

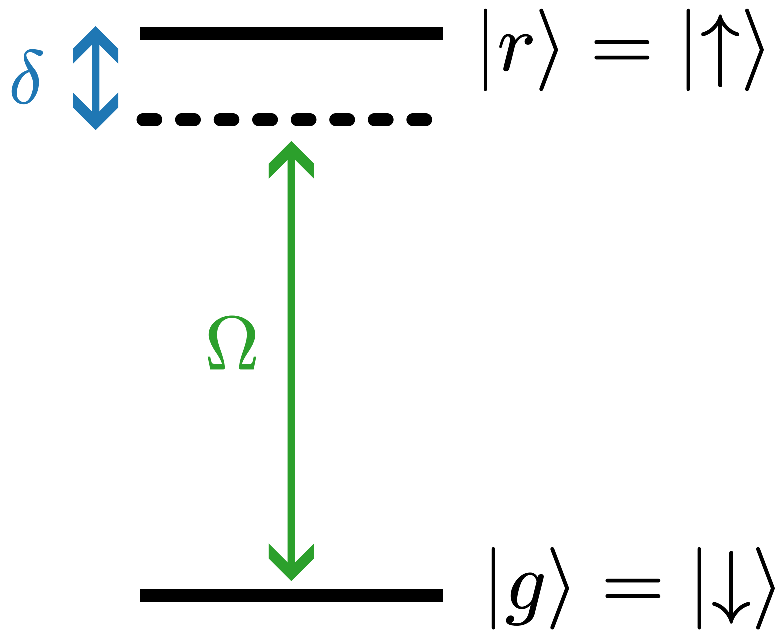


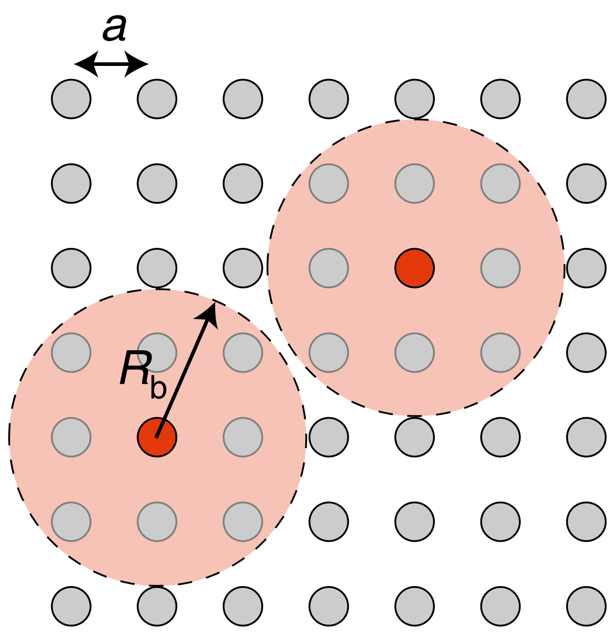
Controled Phase Gate



Saffman *et al.*, Rev. Mod. Phys. 82, 2313 (2010)

Simulation of Ising Hamiltonians





$$H = \frac{1}{2}\Omega(t)\sum_i \sigma_x^{(i)} - \sum_i \delta(t) n_i + \sum_{i<j} V_{i,j} n_i n_j$$

Drive Detuning Interaction

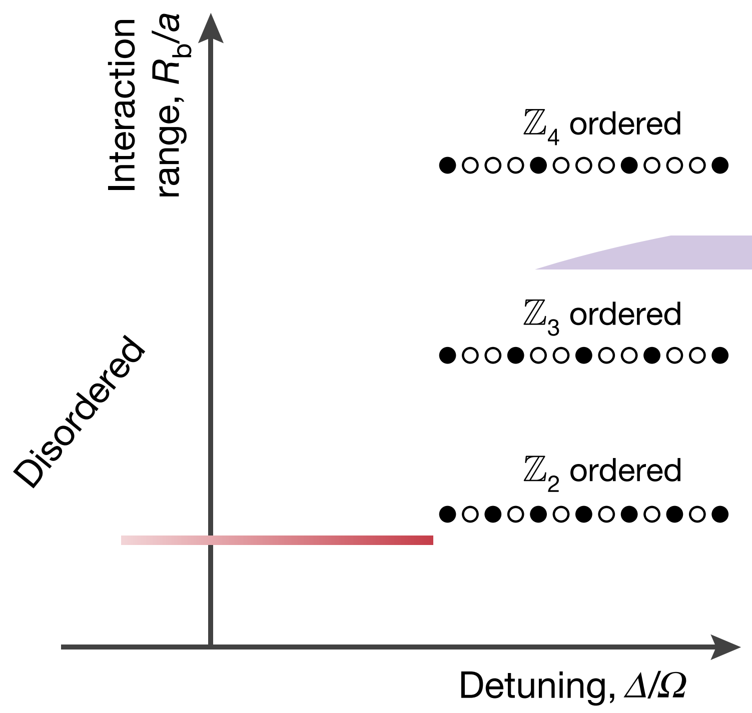
$$n_i = \frac{\sigma_z^{(i)} + 1}{2}$$

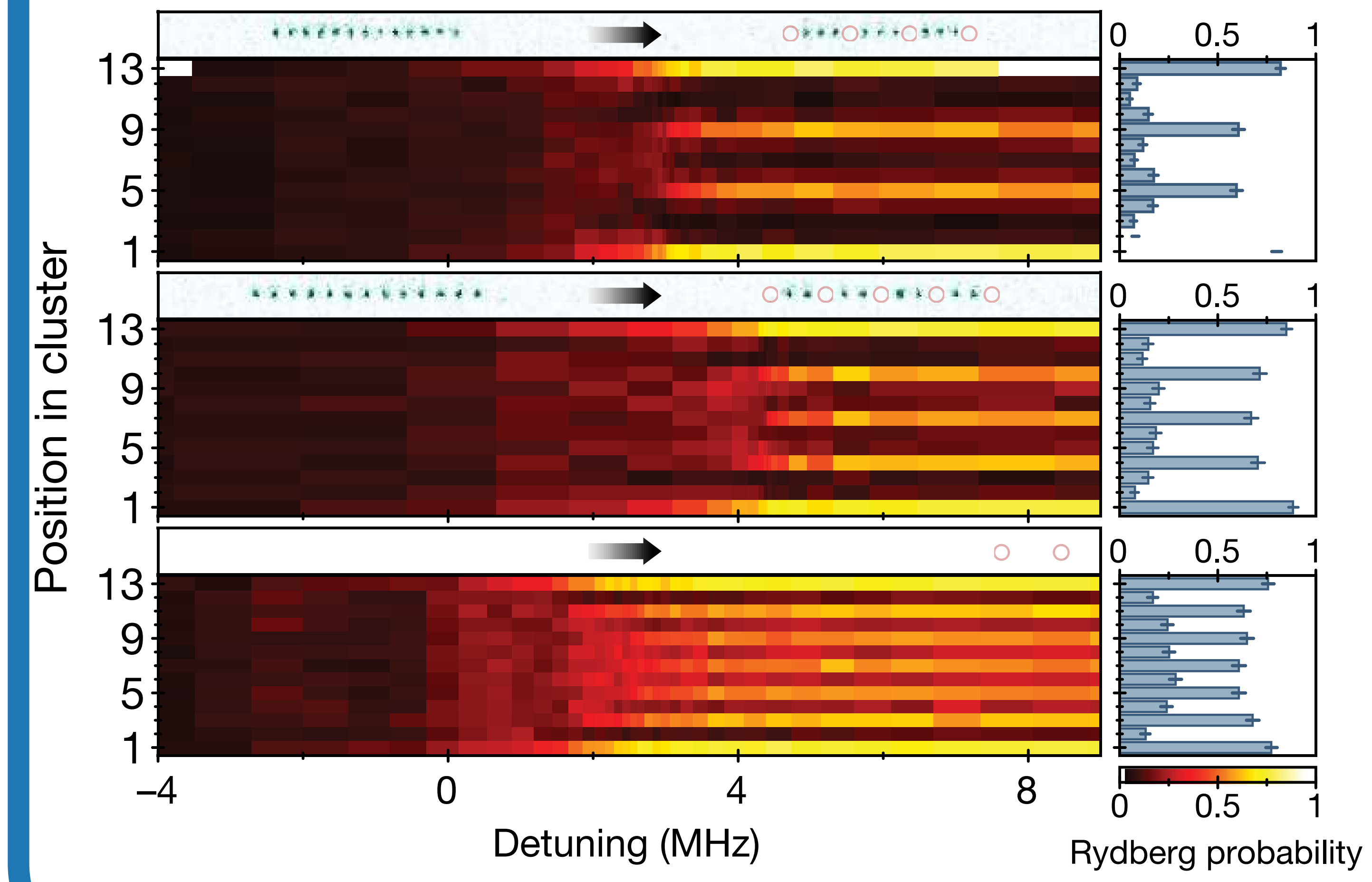
Quantum Ising Model

with transverse Field $B_\perp \propto \Omega$

and with longitudinal Field $B_\parallel \propto -\delta$

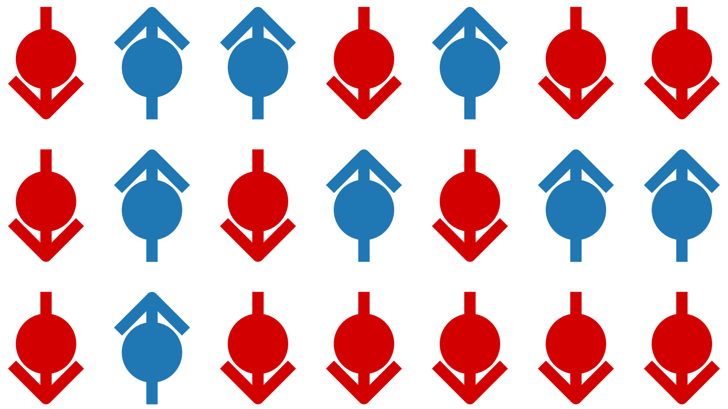
Example of Quench Dynamics





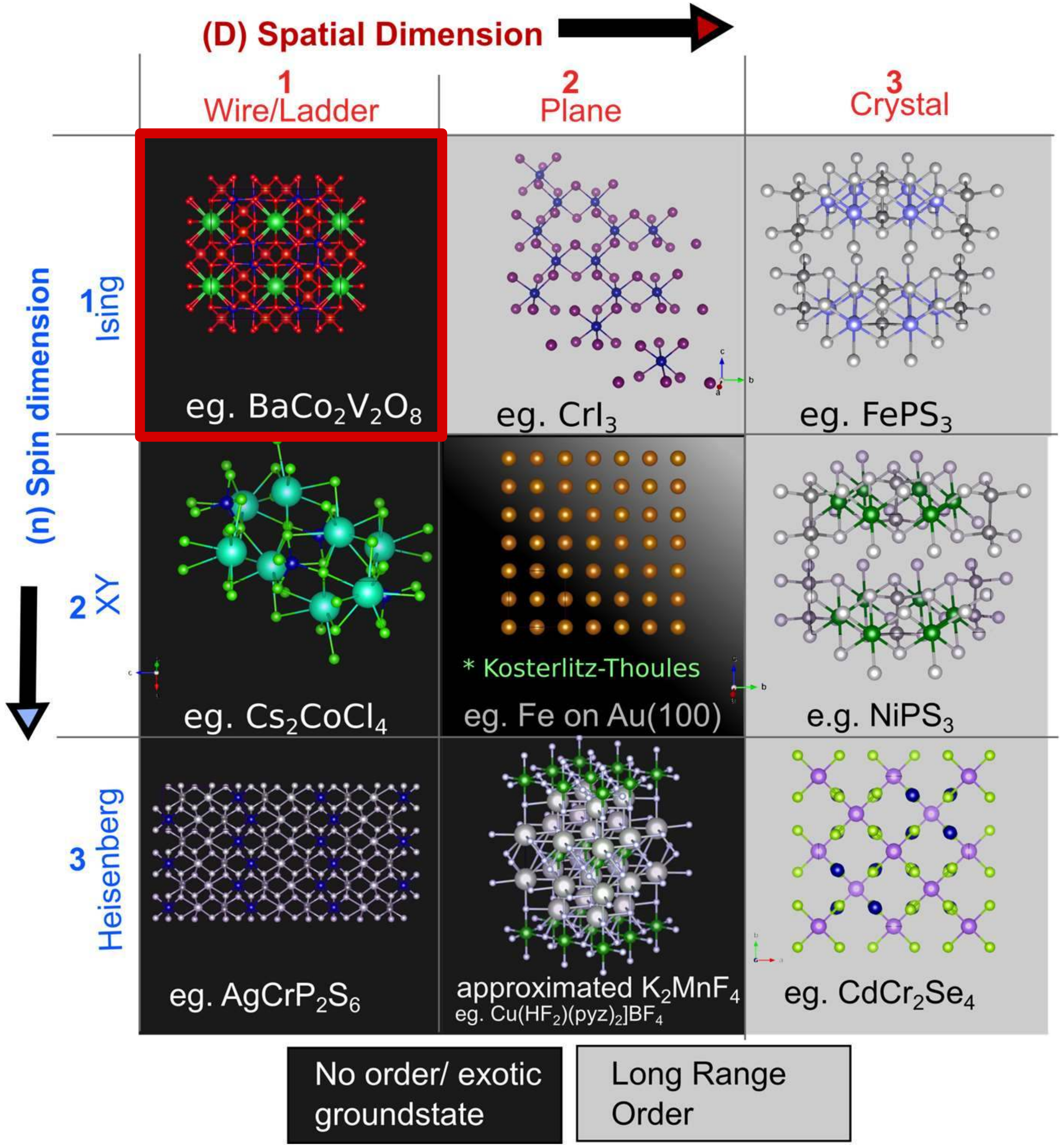
Bernien *et al.*, Nature 551, 579–584 (2017)

Spin Models - Interesting Many-Body Systems



- Lattice spin models are a **generic systems** to study **many-body phenomena** like
  - Quantum phase transitions
  - Out-of-equilibrium phenomena
  - Topology
- Important in hard to control systems like
  - Quantum magnetism
  - Excitation transport (photosynthesis,...)

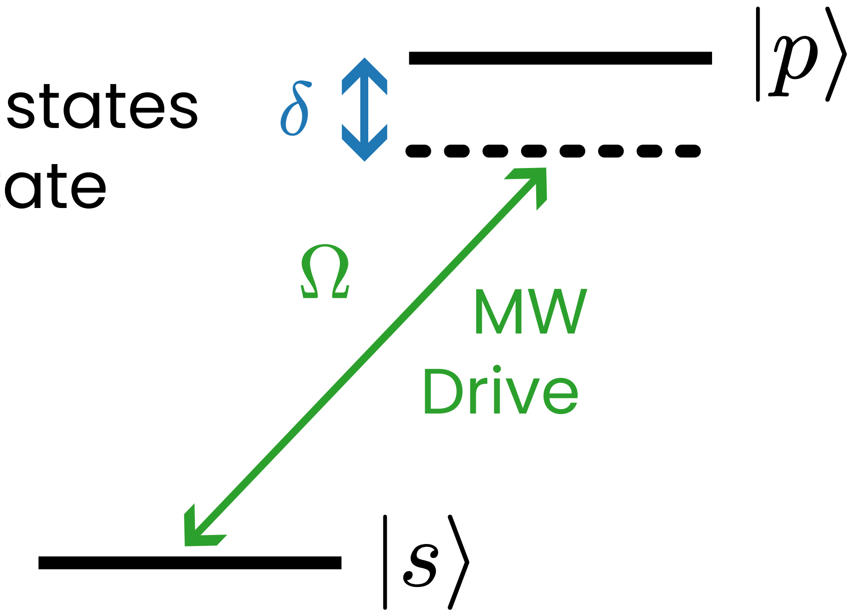
Emulate these systems with well controllable Rydberg arrays

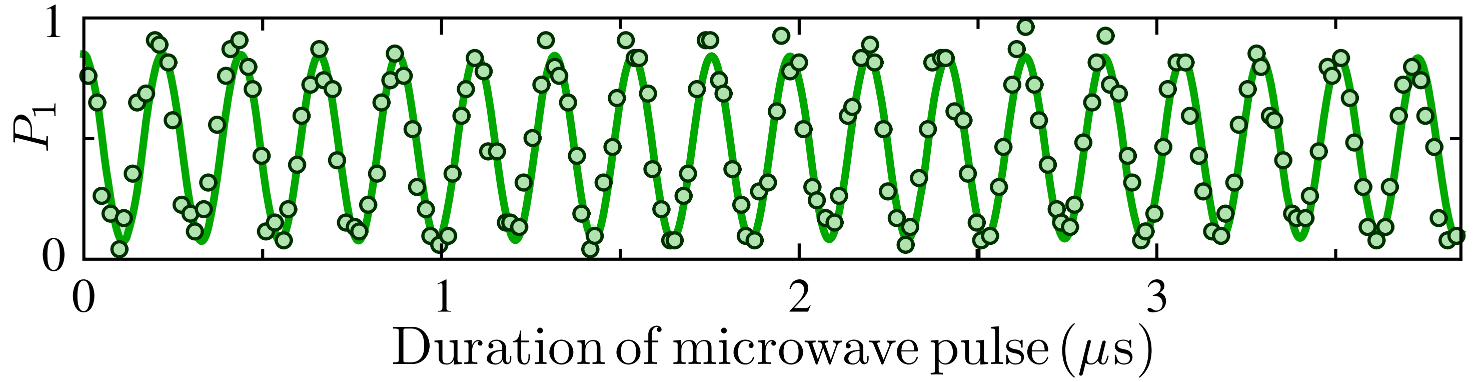


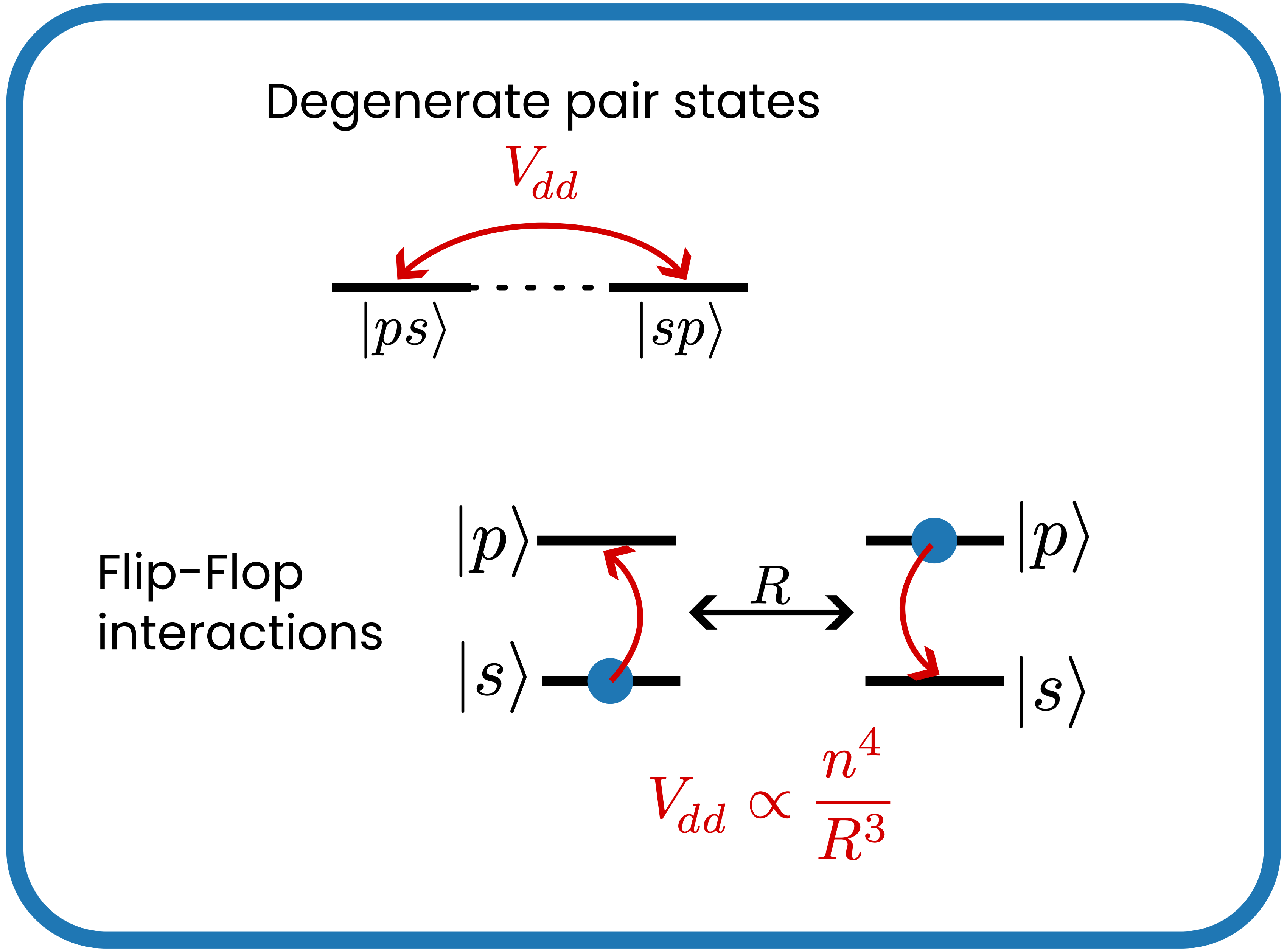
arXiv:2406.13206 (2025)

Simulation of Dipole Hamiltonians

Two **different** Rydberg states
For example **S** and **P** state







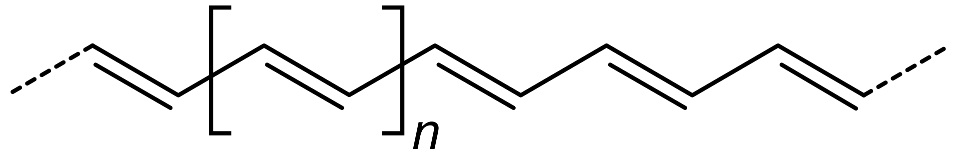
$$H = \frac{1}{2}\Omega(t)\sum_i \sigma_x^{(i)} - \sum_i \delta(t)\sigma_z^{(i)} + \sum_{i\neq j} V_{dd}^{(i,j)}\left(\sigma_+^{(i)}\sigma_-^{(j)} + \sigma_-^{(i)}\sigma_+^{(j)}\right)$$

Heisenberg XY-Hamiltonian

Barredo *et al.*, PRL 114, 113002 (2015)
de Léséleuc *et al.*, Science 365, 775-780 (2019)

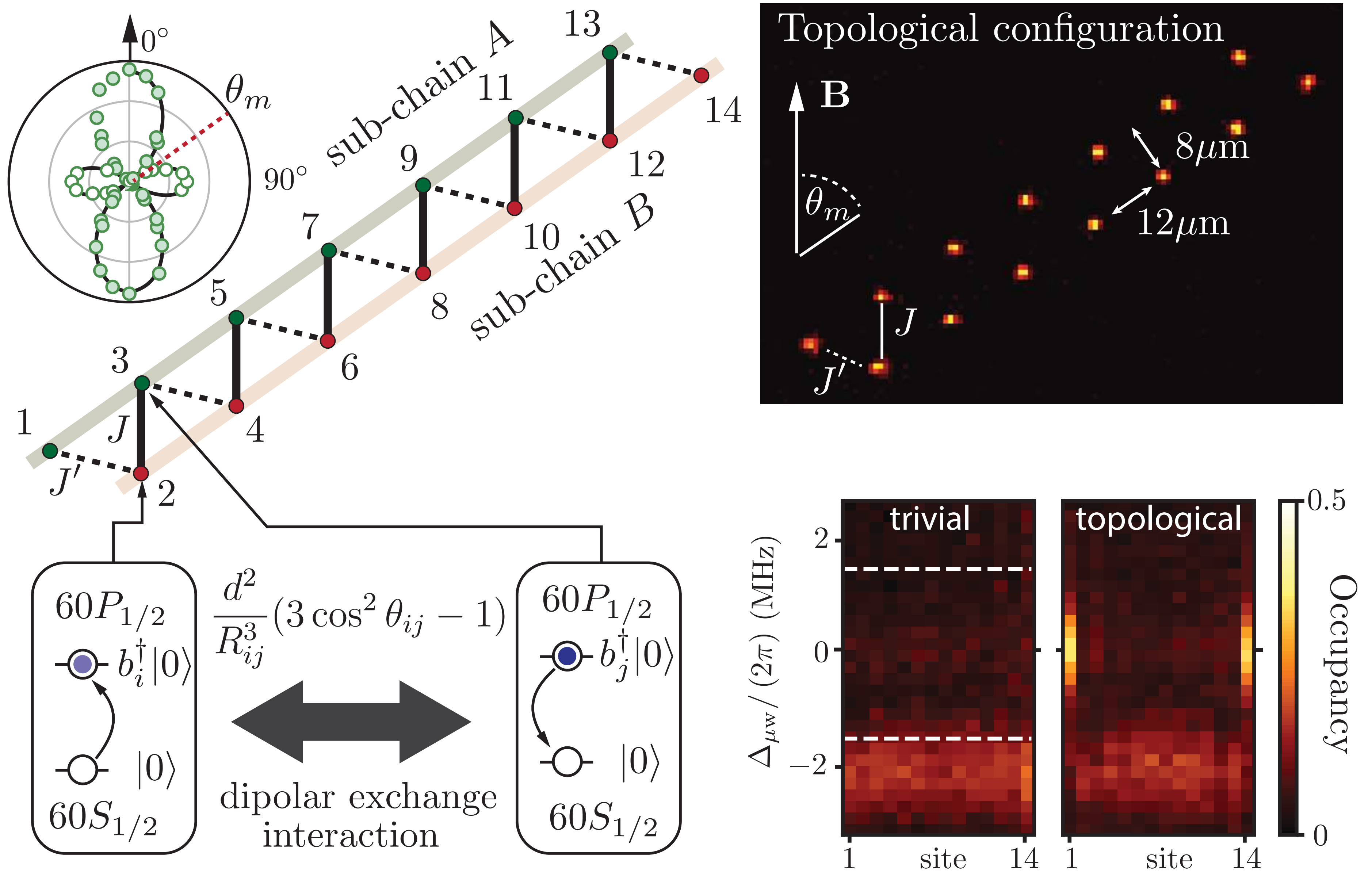
The Su-Schrieffer-Heeger (SSH) Model

Electronic transport in polyacetylene



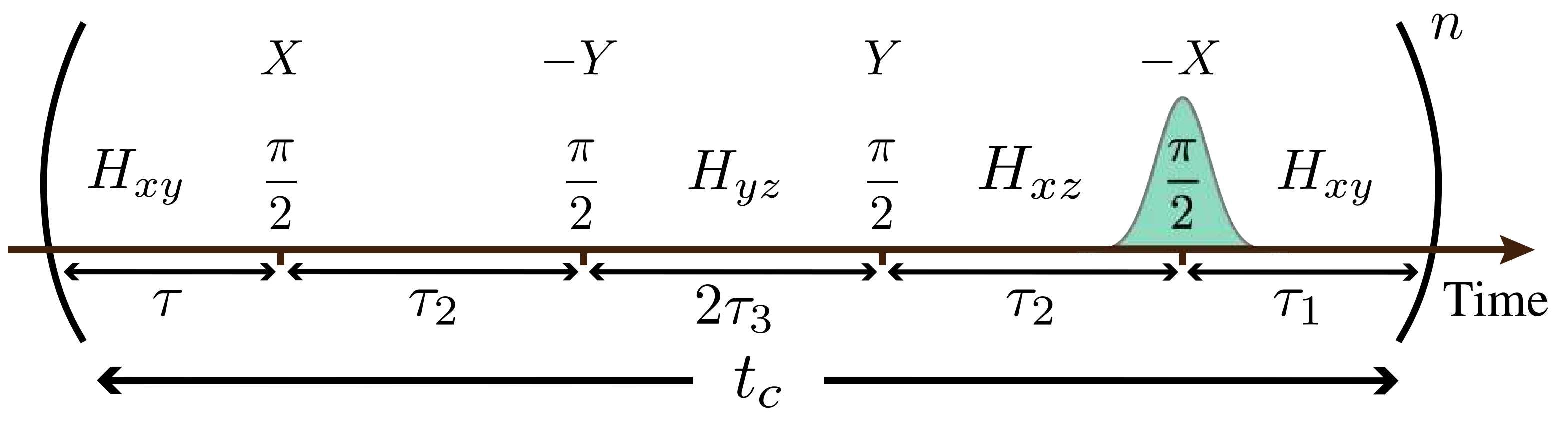
Su, Schrieffer, Heeger, PRL 42, 1698 (1979)

- Simple example of **topological** order
- $J > J'$ **Dimerization**
- **Magic angle**: $J'' = 0$
- Mapping of **electron position** on **Rydberg excitation**



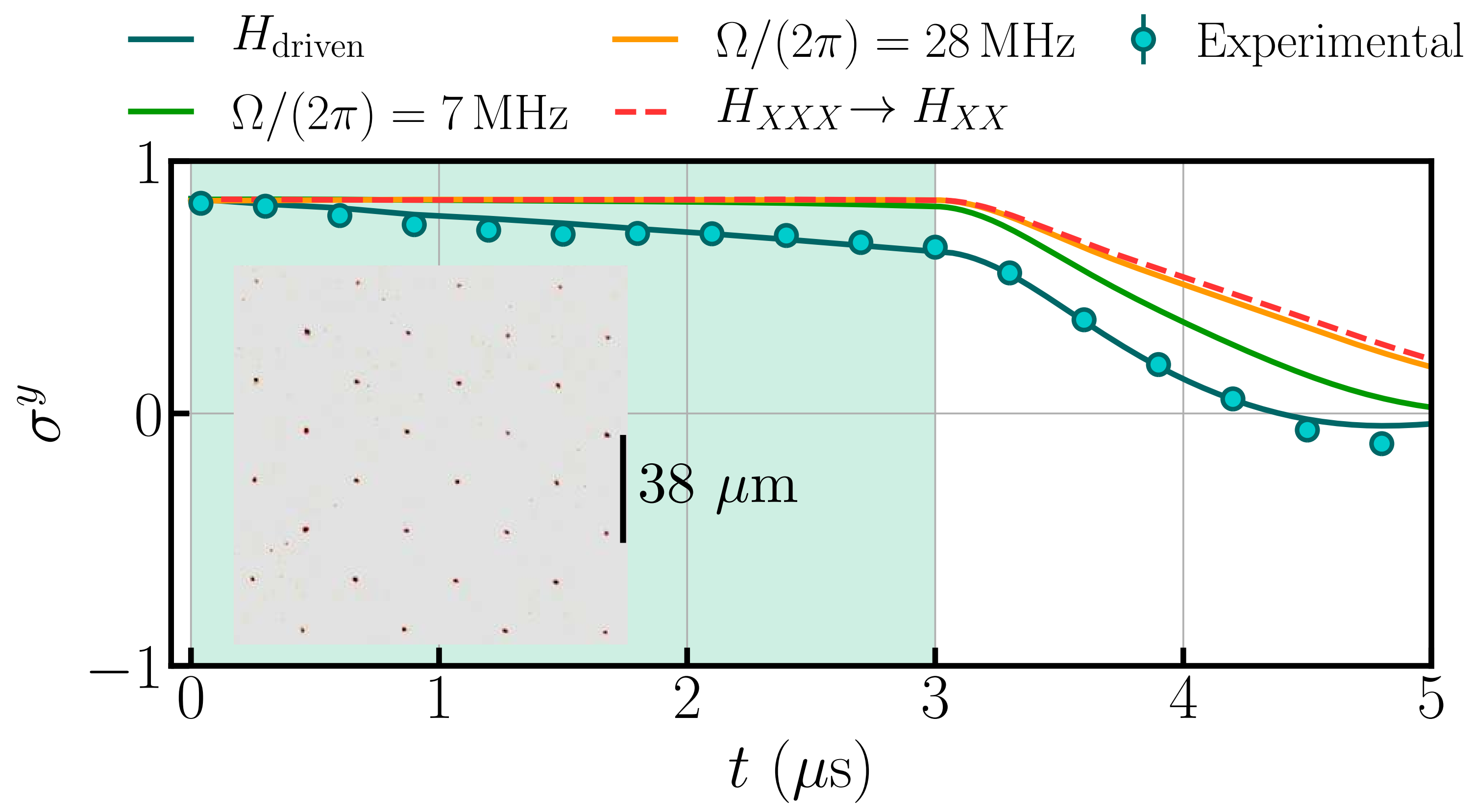
de Léséleuc *et al.*, Science 365, 775-780 (2019)

Engineering Many-Body Hamiltonians: Floquet Engineering



Fast, periodic MW pulses $V_{dd}t_c \ll 1$

$$H_F = \frac{1}{t_c}\int_0^{t_c} H(t)\mathrm{d}t$$



Freezing of magnetization:
Signature of XXX Heisenberg model
(magnetization is conserved)

$$H_F = 2\sum_{i\neq j} V_{dd}^{(i,j)}\left(\frac{\tau_1+\tau_2}{t_c}\sigma_x^{(i)}\sigma_x^{(j)} + \frac{\tau_1+\tau_3}{t_c}\sigma_y^{(i)}\sigma_y^{(j)} + \frac{\tau_2+\tau_3}{t_c}\sigma_z^{(i)}\sigma_z^{(j)}\right)$$

Programmable XYZ Hamiltonians

Scholl et al., PRX Quantum 3, 020303 (2022)

Engineering Many-Body Hamiltonians: Rydberg Dressing

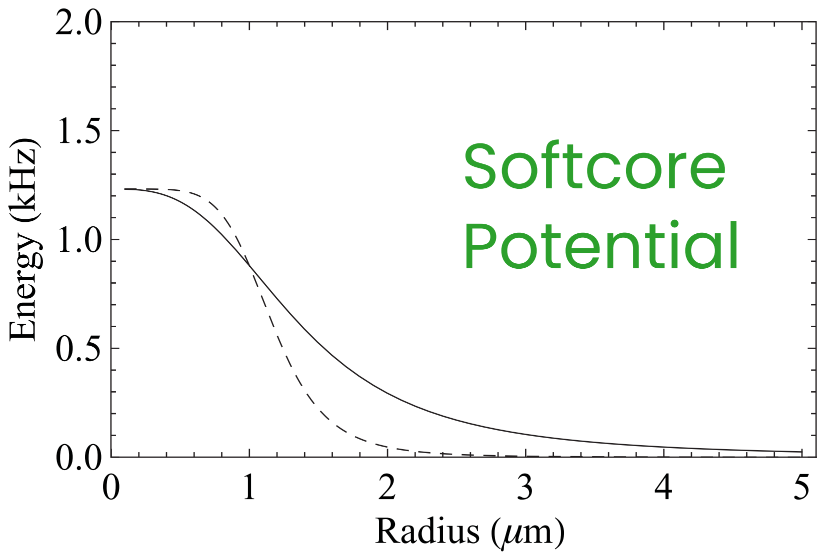
Idea

Atom in $|g\rangle$: **No intersite** interaction
Atom in $|r\rangle$: **Short Lifetime**

Admix Rydberg state to ground state

$$|g'\rangle \approx |g\rangle + \frac{\Omega}{\delta}|r\rangle$$

Pupillo *et al.*, PRL. 104, 223002 (2010)



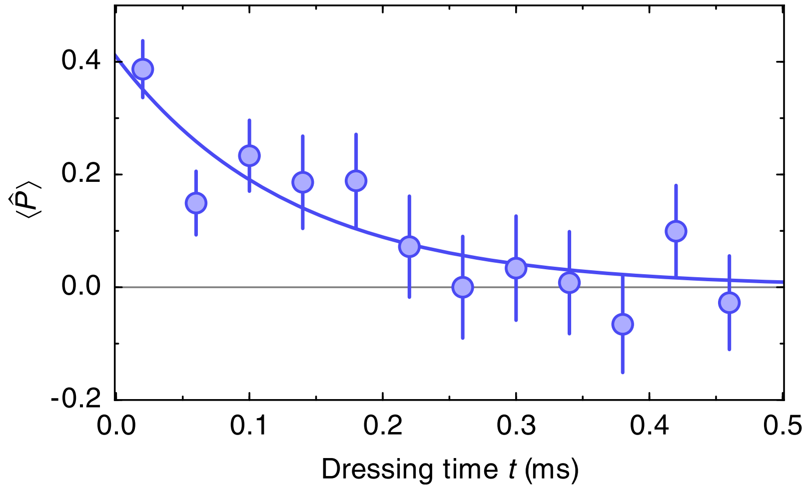
Johnson and Rolston, PRA. 82, 033412 (2010)

Tunable **XYZ** Hamiltonians
Steinert *et al.*, PRL. 130, 243001 (2023)

Spin **Squeezing**
Hines *et al.*, PRL. 131, 063401 (2023)

Problem

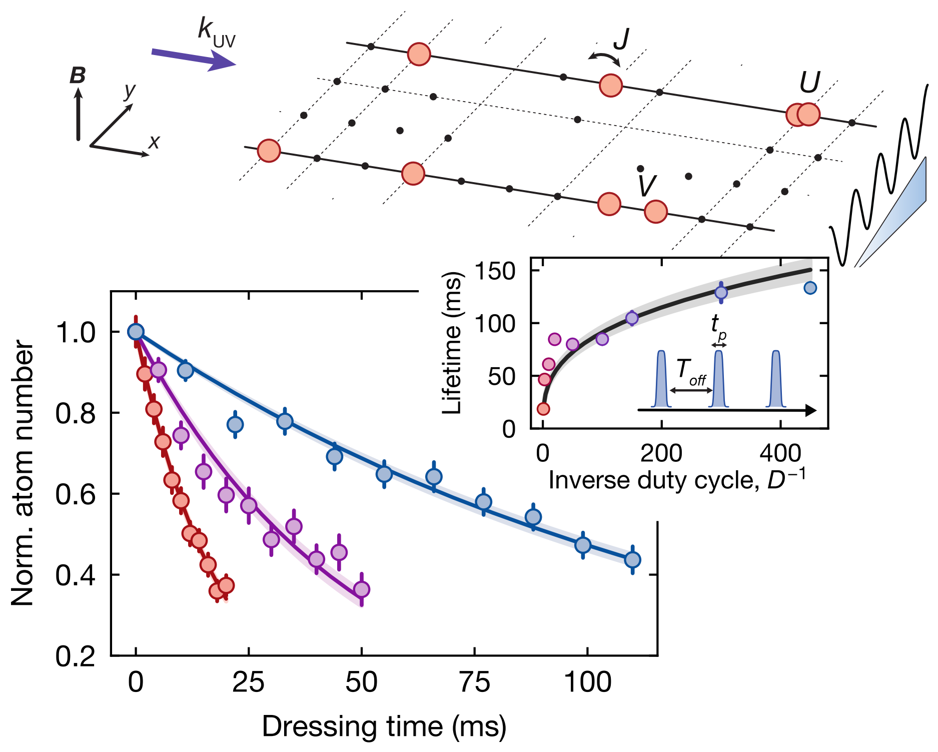
BBR triggers **avalanche decay**
➡ μs short **lifetimes**



Zeiher *et al.*, PRX. 7, 041063 (2017)

Breakthrough

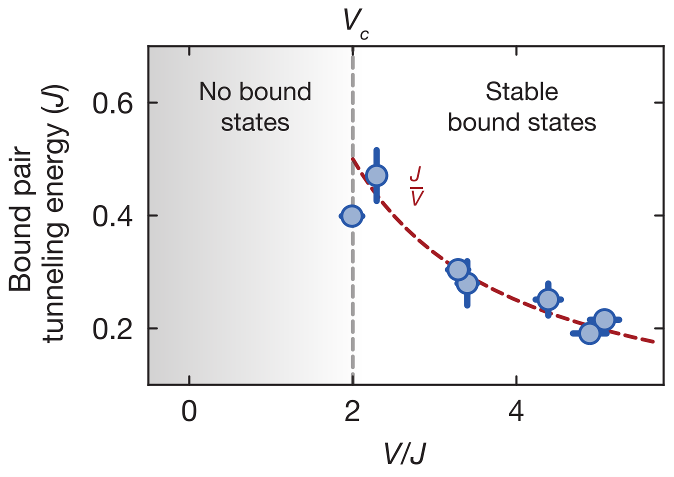
Stroboscopic Rydberg Dressing

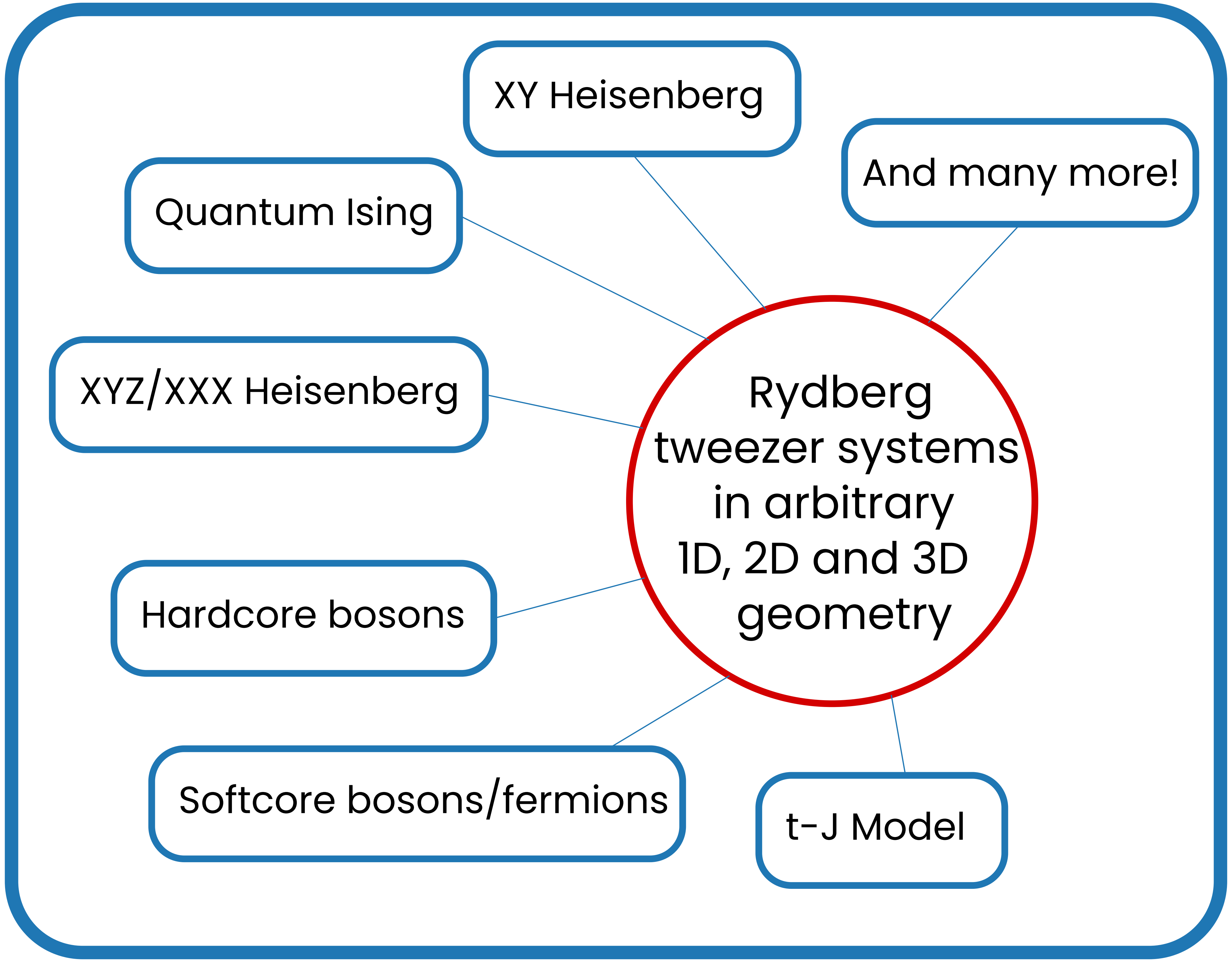


extended Bose Hubbard model

$$H = -J\sum_{i\neq j}\hat{a}_i^\dagger \hat{a}_j + \frac{U}{2}\sum_i \hat{n}_i(\hat{n}_i - 1) + V\sum_i \hat{n}_i\hat{n}_{i+1}$$

Weckesser *et al.*, arXiv:2405.20128 (2024)





Rydberg tweezer systems in arbitrary 1D, 2D and 3D geometry

- XY Heisenberg
- Quantum Ising
- And many more!
- XYZ/XXX Heisenberg
- Hardcore bosons
- Softcore bosons/fermions
- t-J Model

QC/QS Startups

Pasqal

planqc

|QuEra>

atom computing

Infleqtion

Quantum Simulation with Rydberg Tweezer Arrays

- How do Tweezers work?
- What are Rydberg atoms?
- Why are Rydberg atoms cool?
- How do they interact?
- What can they simulate?

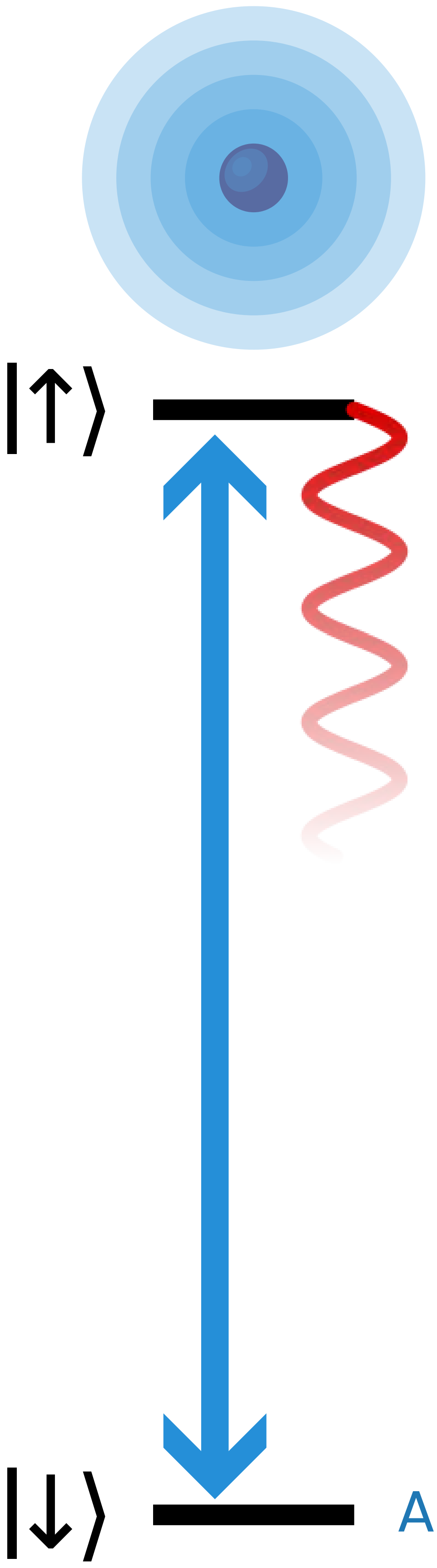
Circular Rydberg States

- What are CRS?
- Why are CRS interesting for quantum simulation?
- What is the state of the art?
- How can we prepare CRS?
- Brand new data from our lab!

Controling Neutral Atom Quantum Hardware

- What are the hardware requirements?
- How can FOSS help in controling quantum hardware?
- How does an example experiment code look?

Fundamental Lifetime Limits?



Low-Angular Momentum Rydberg State

e.g. Scholl *et al.*, Nature 595, 233–238 (2021)

Atomic Groundstate

Optical allowed transitions into (near) ground states

- Spontaneous decay rate

$\sim 1\,000$ THz

$$\frac{2\omega^3}{3\varepsilon_0 c^3 h}\,|\langle\downarrow|d|\uparrow\rangle|^2 \propto n^3$$

$\propto n^{-1.5}$

- Lifetime

$$\tau(n=100) \approx 500\,\mu\mathrm{s}$$

Examples

- Error-Budget of a Rydberg controled-phase gate

	Bell state infidelity		Average gate infidelity	
	0 μK	1.5 μK	0 μK	1.5 μK
Rydberg decay	0.092%	0.092%	0.074%	0.074%
Photon recoil	0.008%	0.011%	0.006%	0.009%
VdW force	0.001%	0.001%	0.001%	0.001%
Summed	0.101%	0.105%	0.081%	0.084%
Full simulation	0.101%		0.081%	

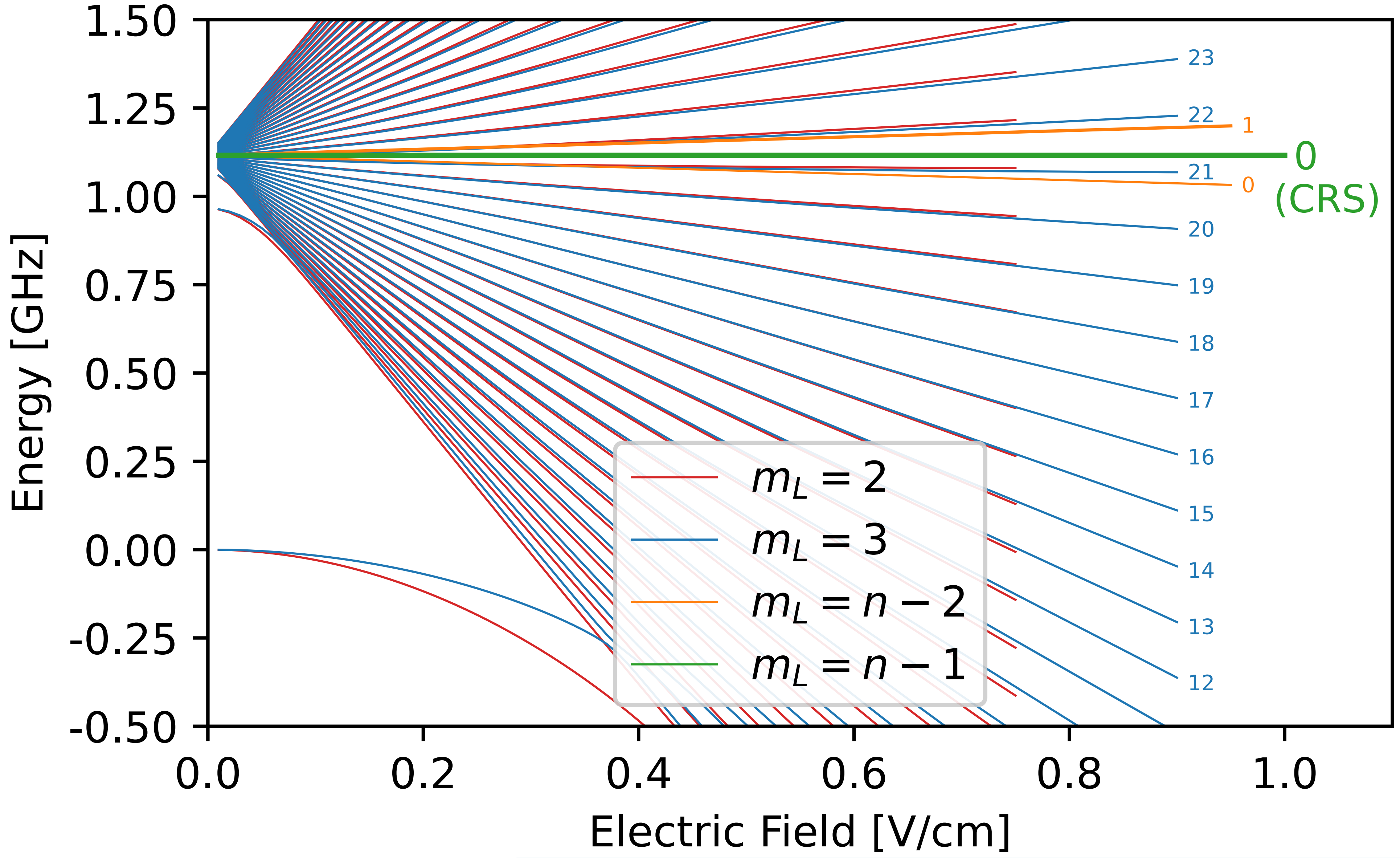
Pagano *et al.*, PRR 4, 033019 (2022)

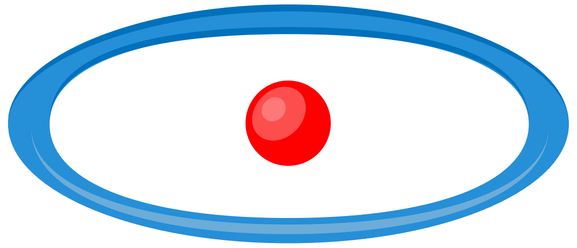
- Adiabatic state preparation limited by Rydberg lifetime
- True groundstates still ellusive

Ebadi *et al.*, Nature 595, 227–232 (2021)

What is a Circular Rydberg State?

?





- Maximum angular momentum

$$l = m_l = n - 1$$

- No linear Stark shift

No Optical allowed transitions into (near) ground states

- Spontaneous decay rate

$$\underbrace{\frac{2\omega^3}{3\varepsilon_0 c^3 h}}_{} \left|\langle d\rangle\right|^2 \propto n^5$$

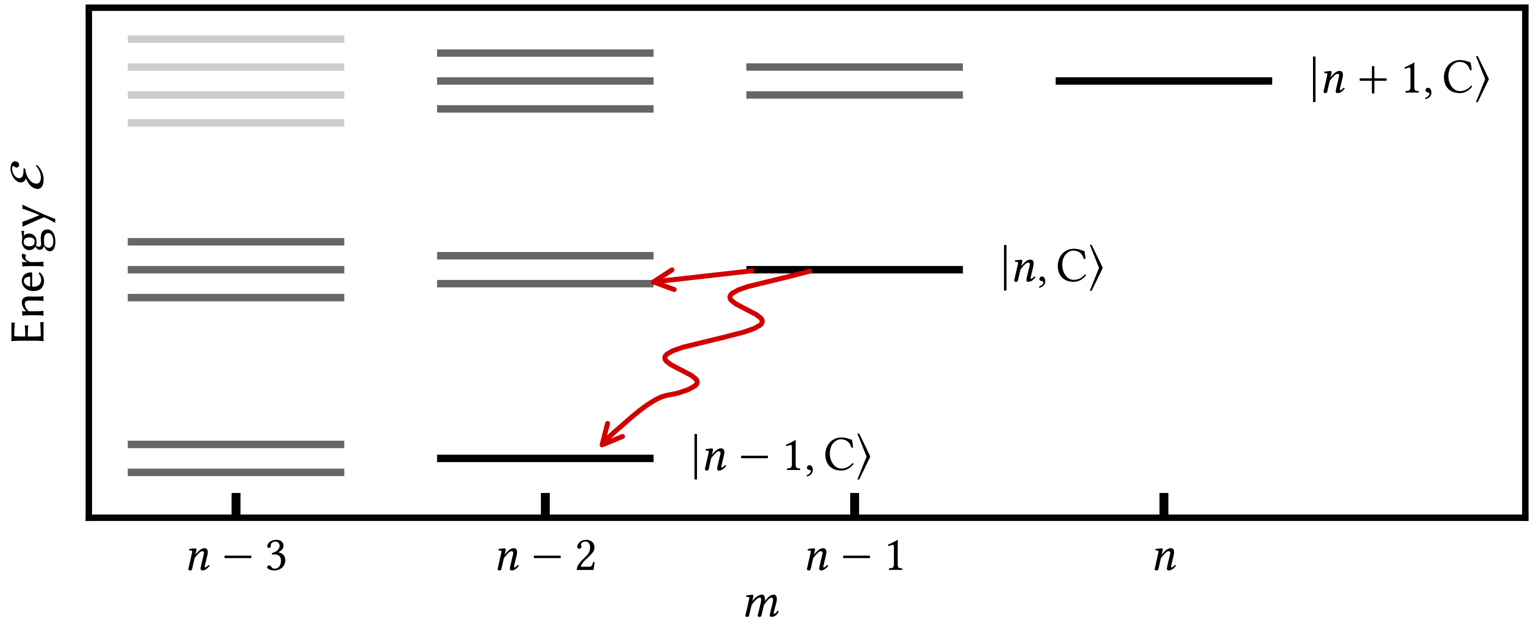
$\propto n^{-3} \sim 10\,\mathrm{GHz}$

$\propto n^2$

- Spontaneous Lifetime

$$\tau(n = 100) \approx 930\,\mathrm{ms}$$

1000 times longer than low-l!

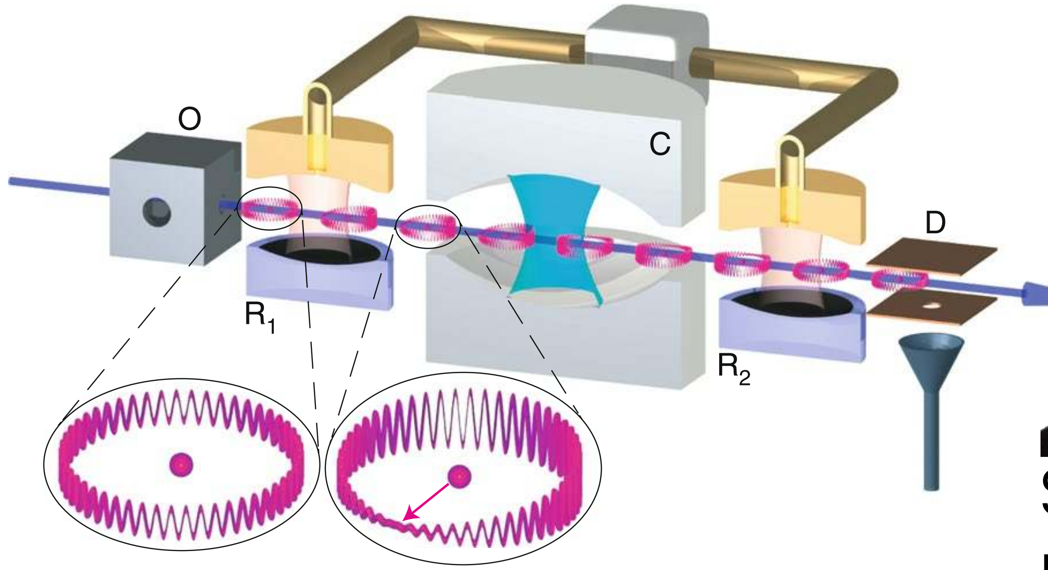


The History of Circular Rydberg States

Pre-Trapping Era

- First mention of "Circular" states:

  Hulet and Daniel Kleppner, PRL 51, 1430 (1983)
- Atomic beam experiments
- Cavity QED



Haroche *et al.*, Nat. Phys. 16, 243–246 (2020)

S. Haroche
Nobel Prize 2012

Raimond, Brune and Haroche,
Rev. Mod. Phys 73, 565 (2001)

- Experiments with CRS mainly by Paris group

Quantum Tech Era

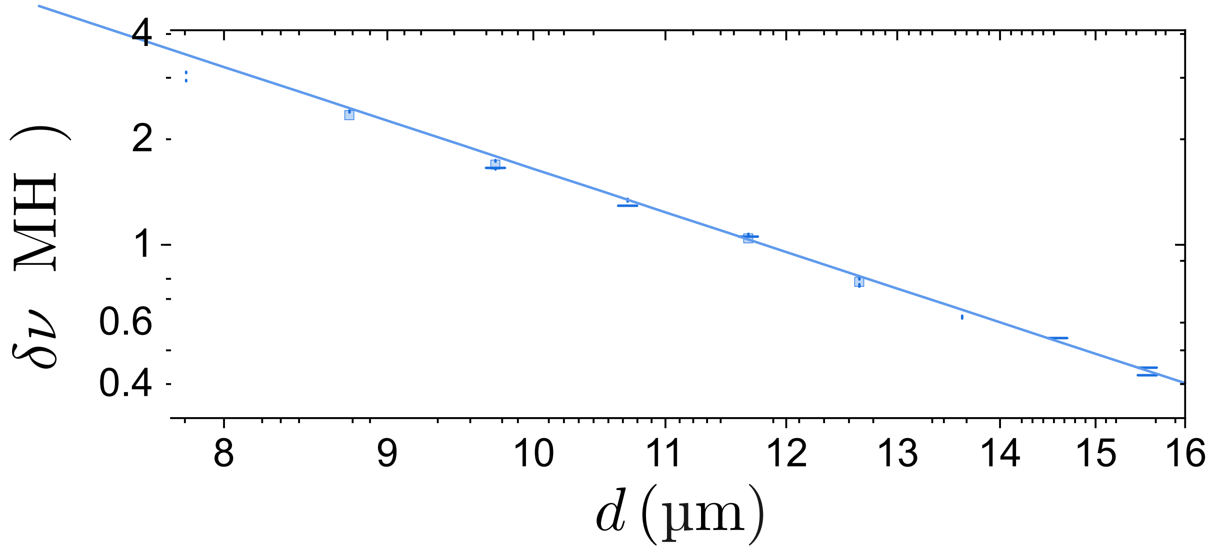
- Proposals for quantum

  simulation: Nguyen *et al.*, PRX 8, 011032 (2018)

  computing: Cohen *et al.*, PRX Quantum 2, 030322 (2021)
- First optical trapping:

  Cortiñas *et al.*, PRL 124, 123201 (2020)
- Array of interacting CRS:

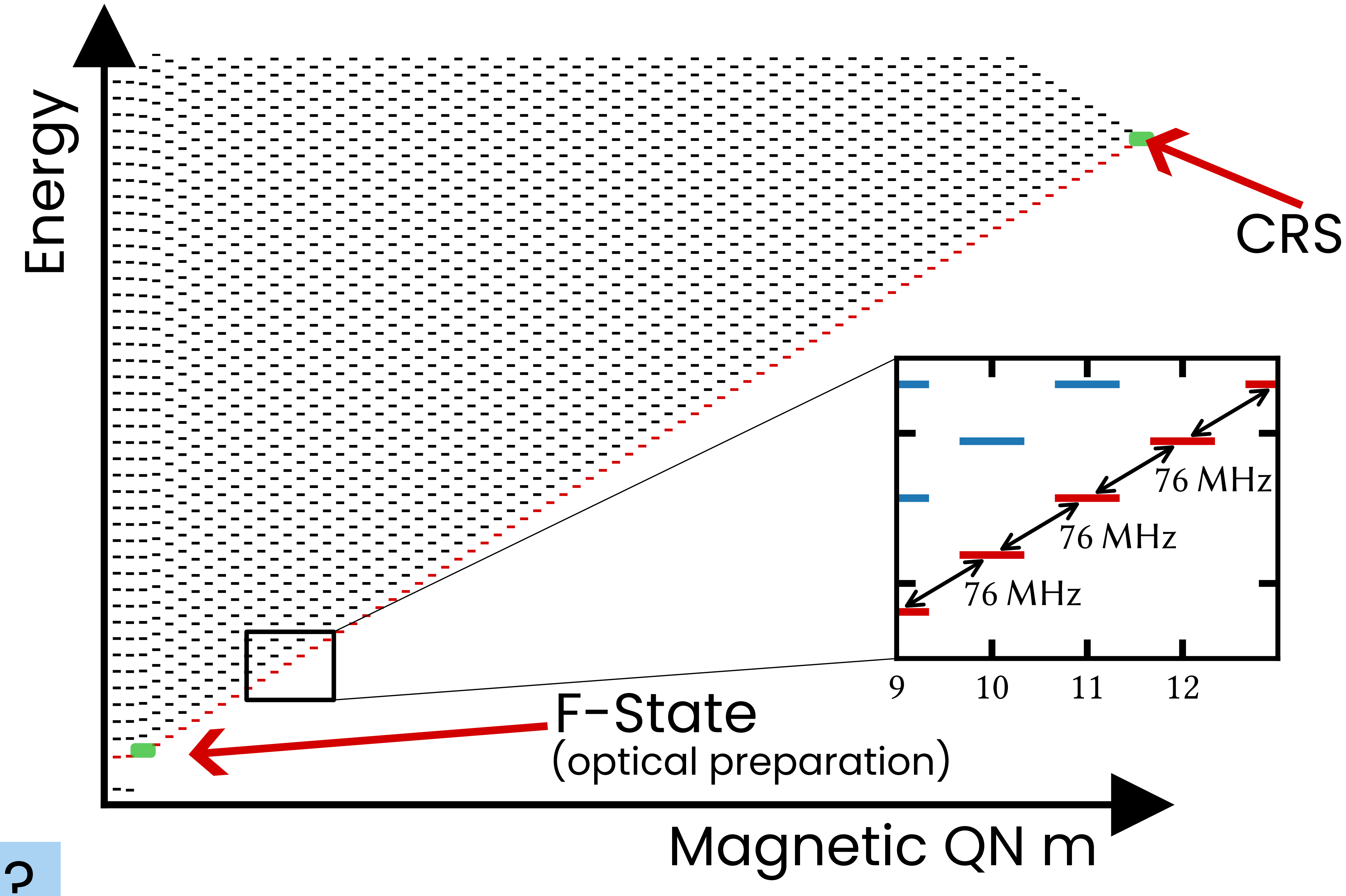
  Méhaignerie *et al.*, arXiv:2407.04109 (2024)



MHz dipole-dipole interaction with $\frac{1}{d^3}$

Many groups start to work with CRS now!

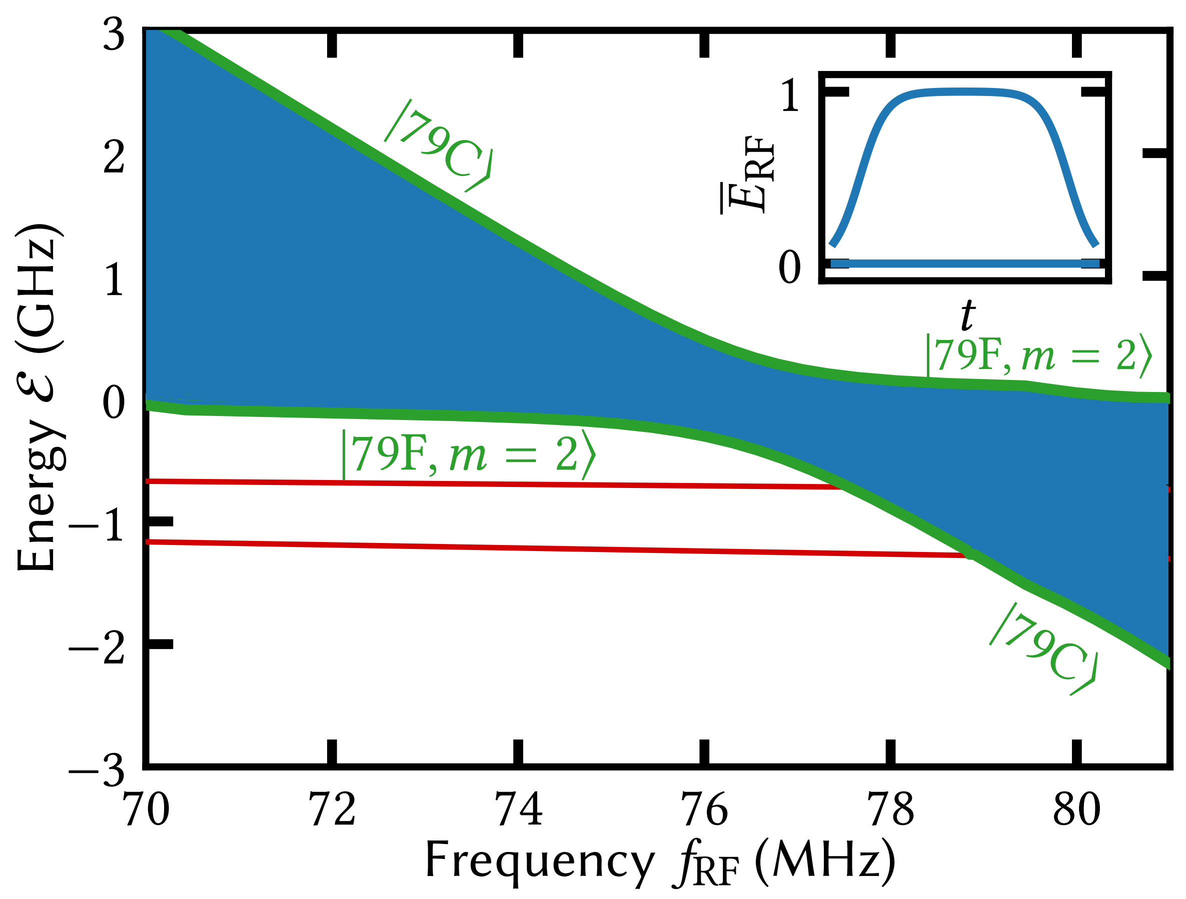
How to prepare CRS?



CRS

F-State
(optical preparation)

Adiabatic Rapid Passage

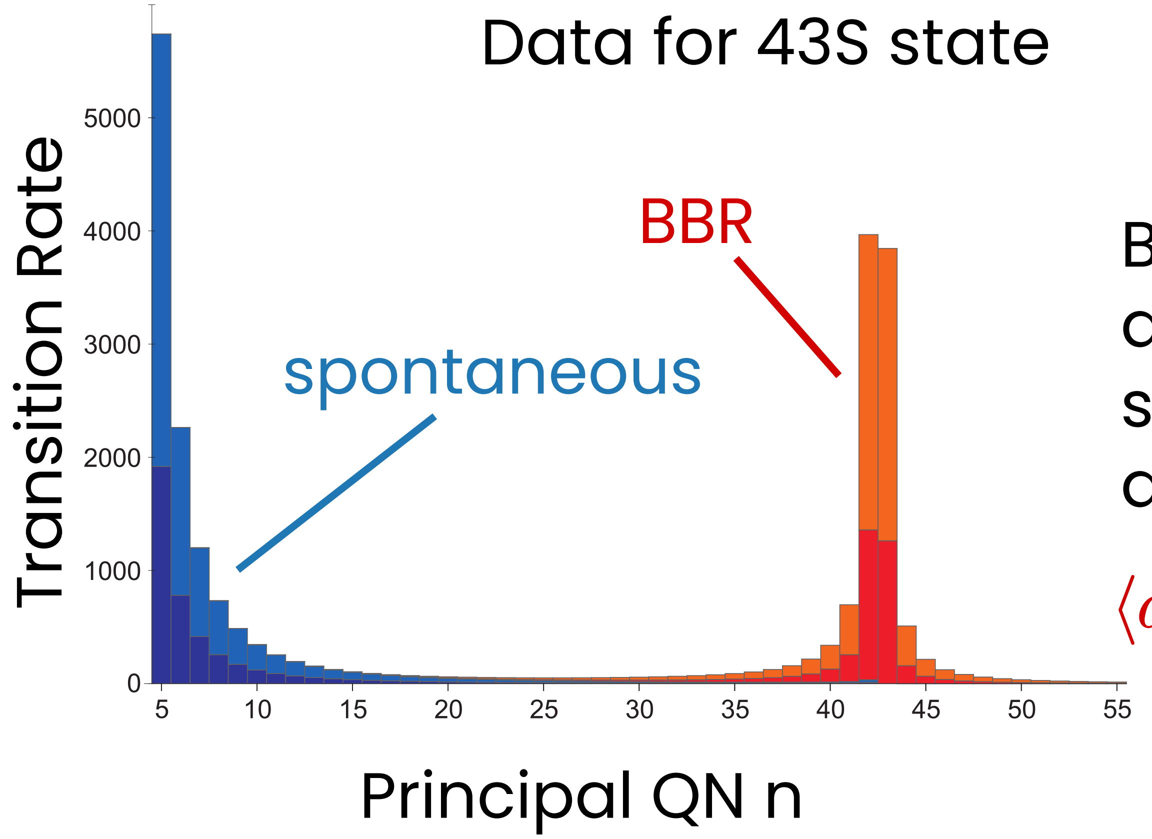


Traverse avoided crossing of RF-drive coupled levels adiabatically

C.H. *et al.*, PRX 14, 021024 (2024)
Teixeira *et al.*, PRL 125, 263001 (2020)
Hulet *et al.*, PRL 51, 1430 (1983)

?

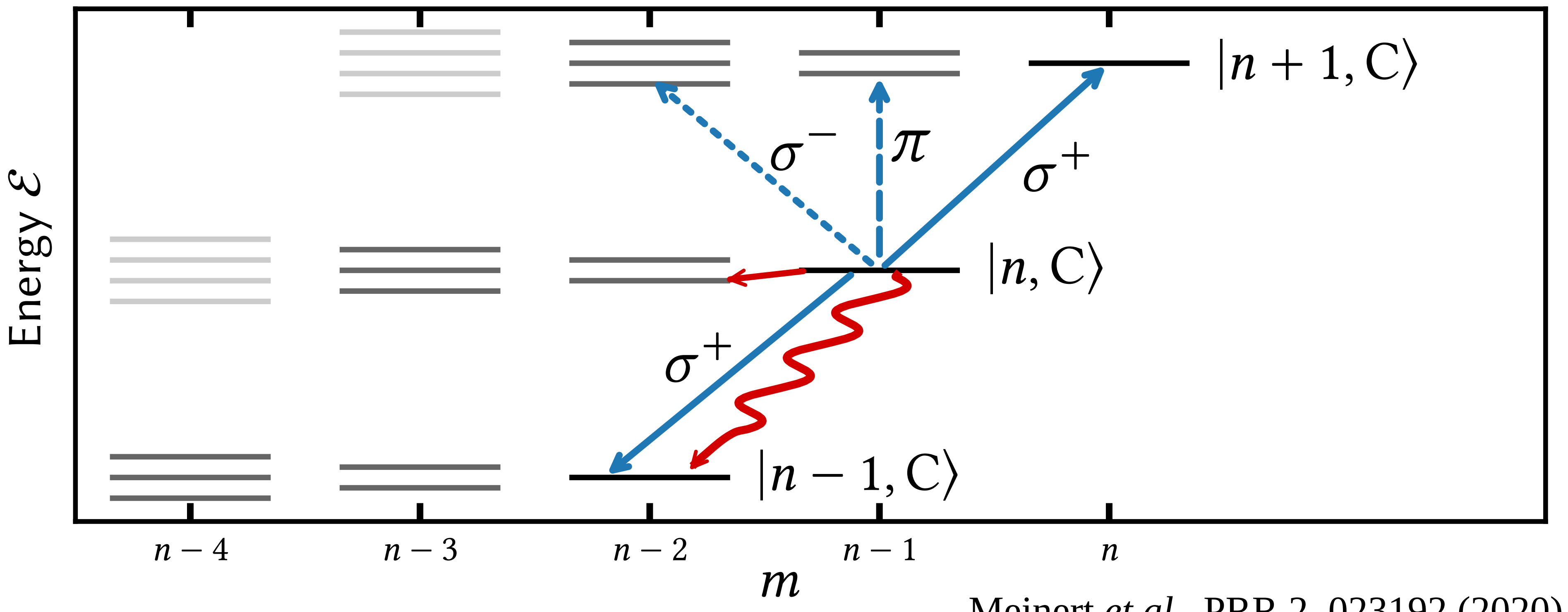
The Issue with the Black-Body-Radiation



BBR decay dominates over spontaneous decay for $n > 50$

$\langle d \rangle \propto n^2$

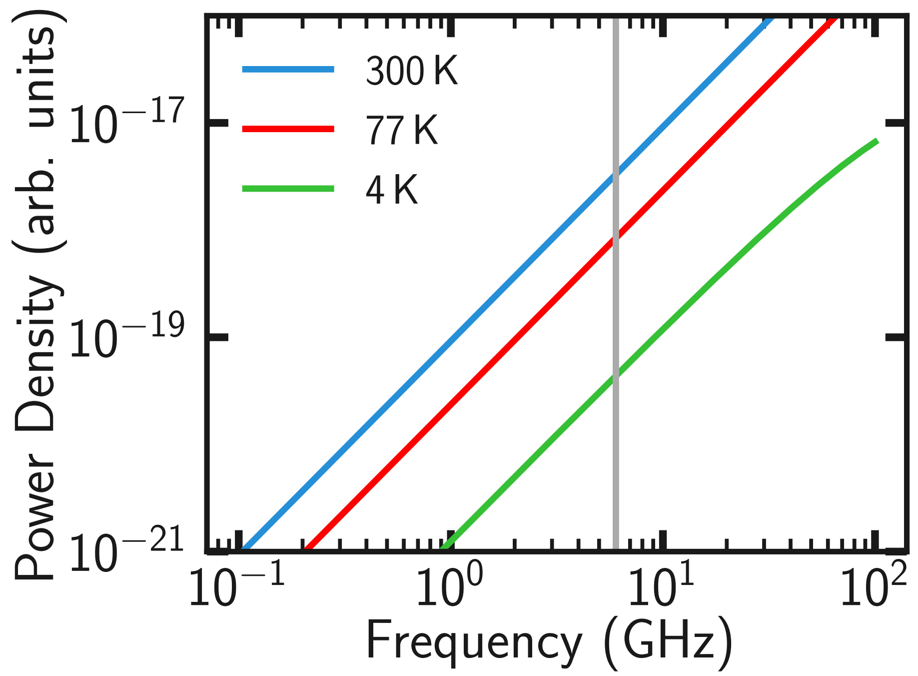
Löw *et al.*, J. Phys. B. 45, 113001 (2012)



Meinert *et al.*, PRR 2, 023192 (2020)

Solution Cryo?

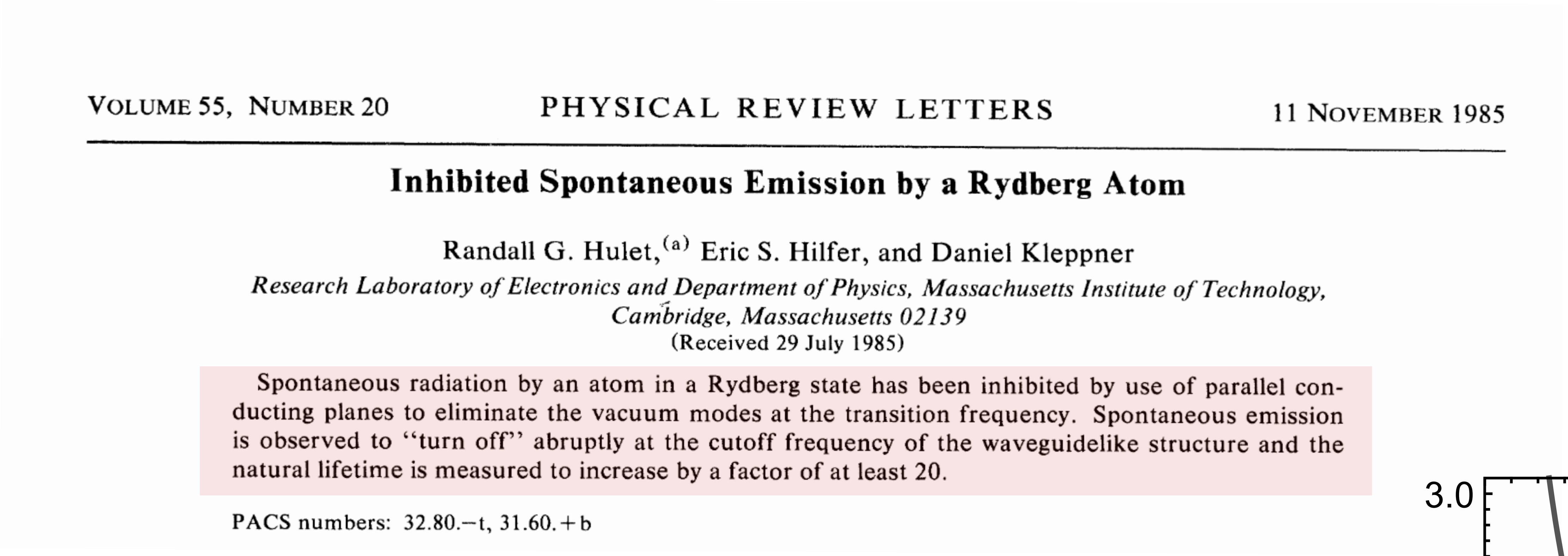
- BBR mode density is reduced at low temperature



- Almost all CRS experiments in cryo

?

What If We Don't Want a Cryo?



VOLUME 55, NUMBER 20 PHYSICAL REVIEW LETTERS 11 NOVEMBER 1985

Inhibited Spontaneous Emission by a Rydberg Atom

Randall G. Hulet,[a] Eric S. Hilfer, and Daniel Kleppner
Research Laboratory of Electronics and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

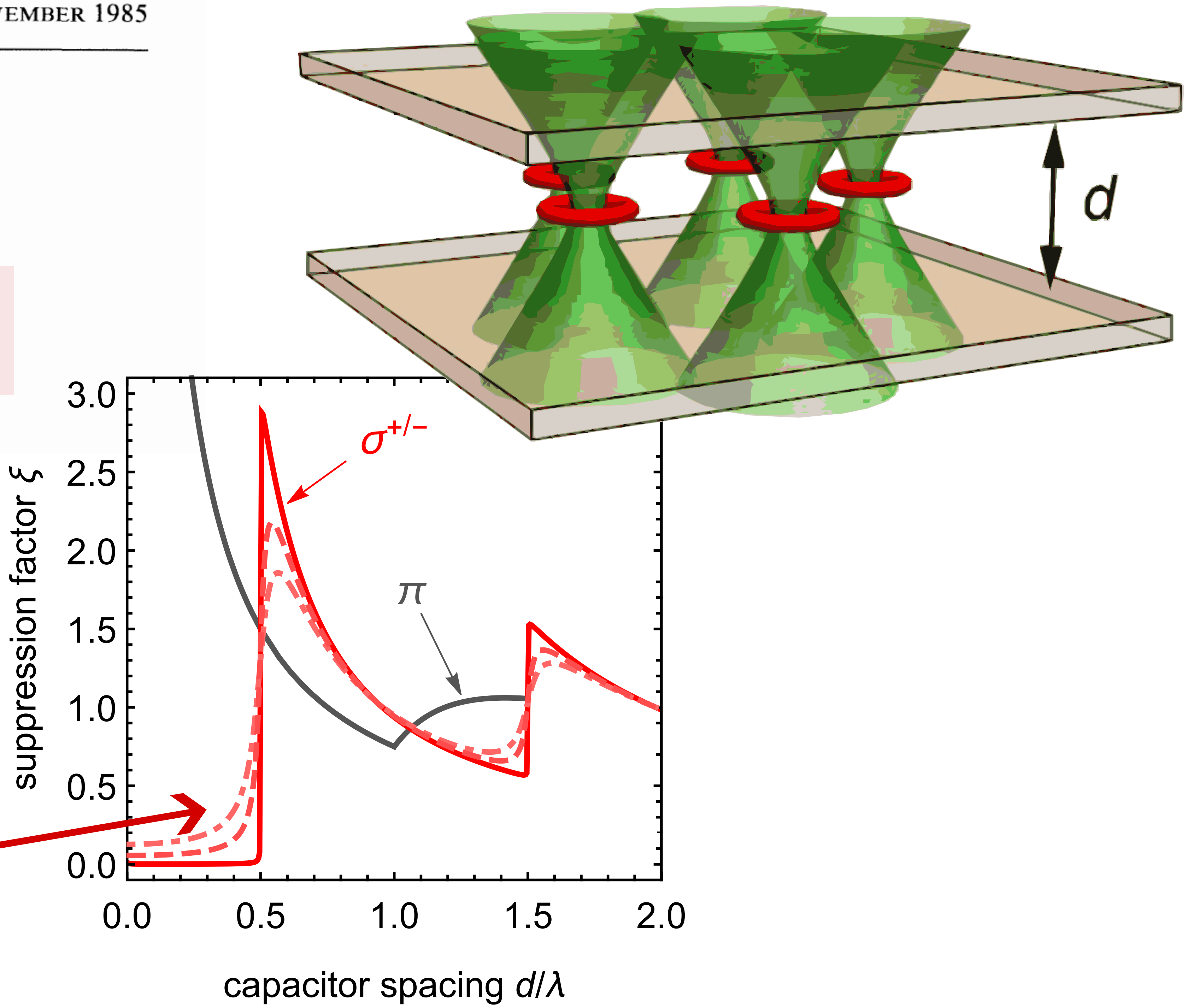
(Received 29 July 1985)

Spontaneous radiation by an atom in a Rydberg state has been inhibited by use of parallel conducting planes to eliminate the vacuum modes at the transition frequency. Spontaneous emission is observed to "turn off" abruptly at the cutoff frequency of the waveguidelike structure and the natural lifetime is measured to increase by a factor of at least 20.

PACS numbers: 32.80.−t, 31.60.+b

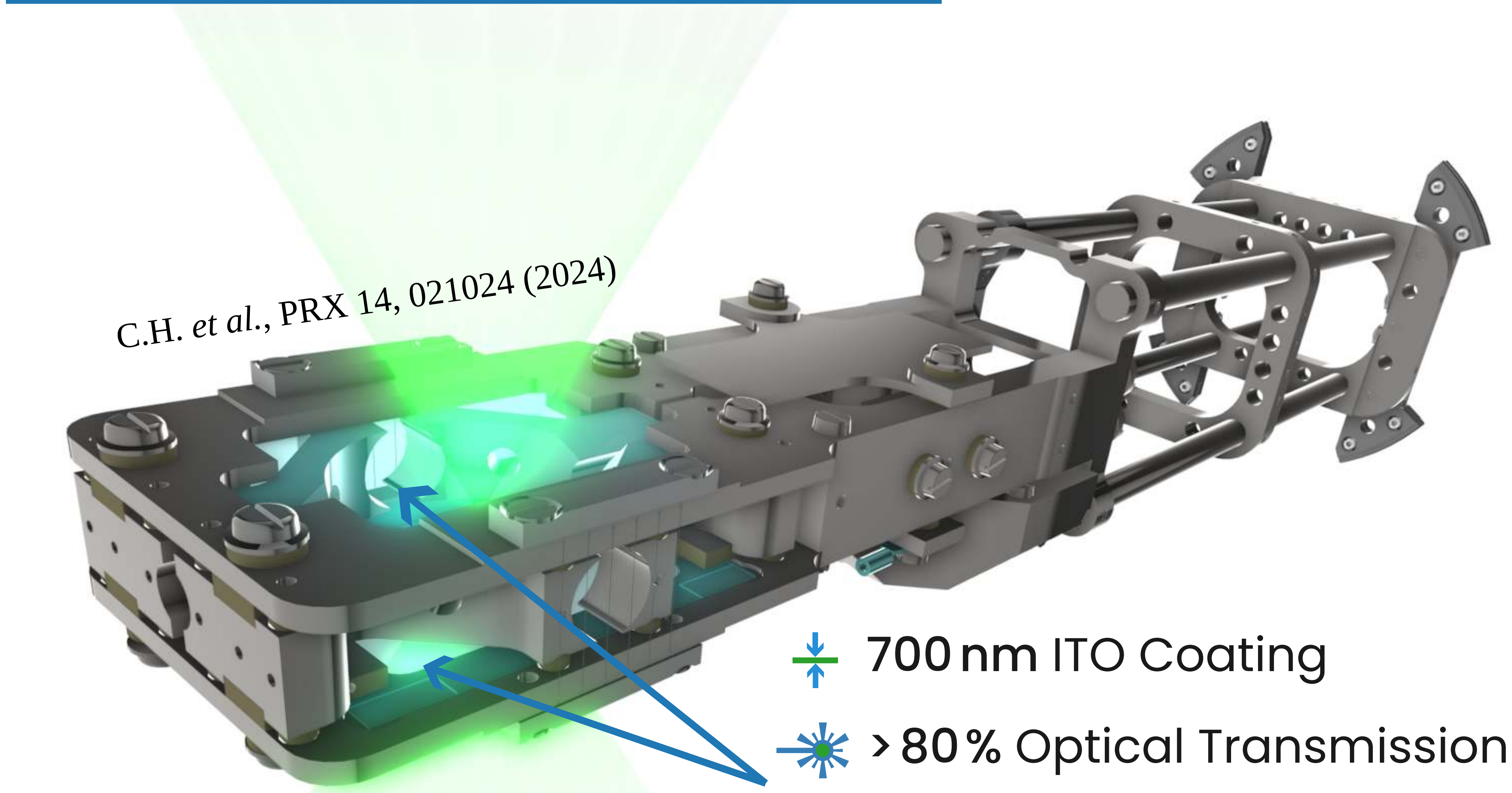
$$\xi^{\sigma^\pm} = 1 + 3\,\mathrm{Im}\sum_{n=1}^{\infty}(-r)^n\left(\frac{\lambda}{2\pi n d} + i\frac{\lambda^2}{(2\pi n d)^2} - \frac{\lambda^3}{(2\pi n d)^3}\right)e^{in2\pi\frac{d}{\lambda}}$$

Suppression factor smoothes out with decreasing reflectivity r



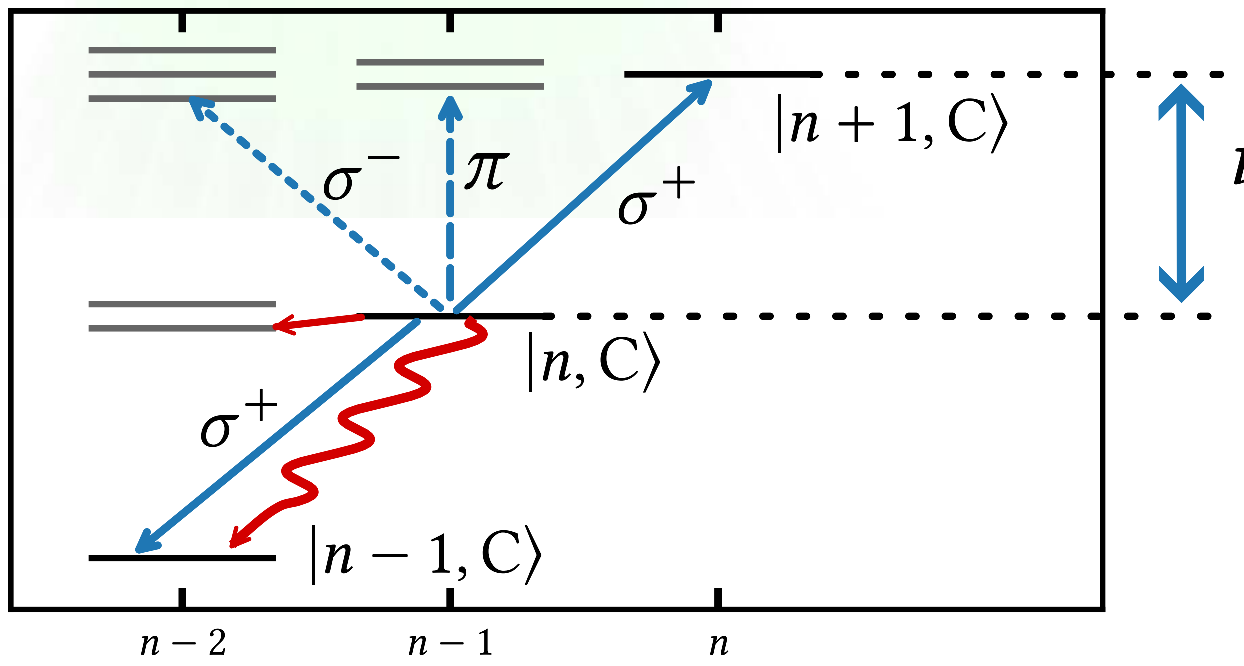
Meinert *et al.*, PRR 2, 023192 (2020)
Wu *et al.*, PRL 130, 023202 (2023)

Our Quantum Processor: Cavity



C.H. *et al.*, PRX 14, 021024 (2024)

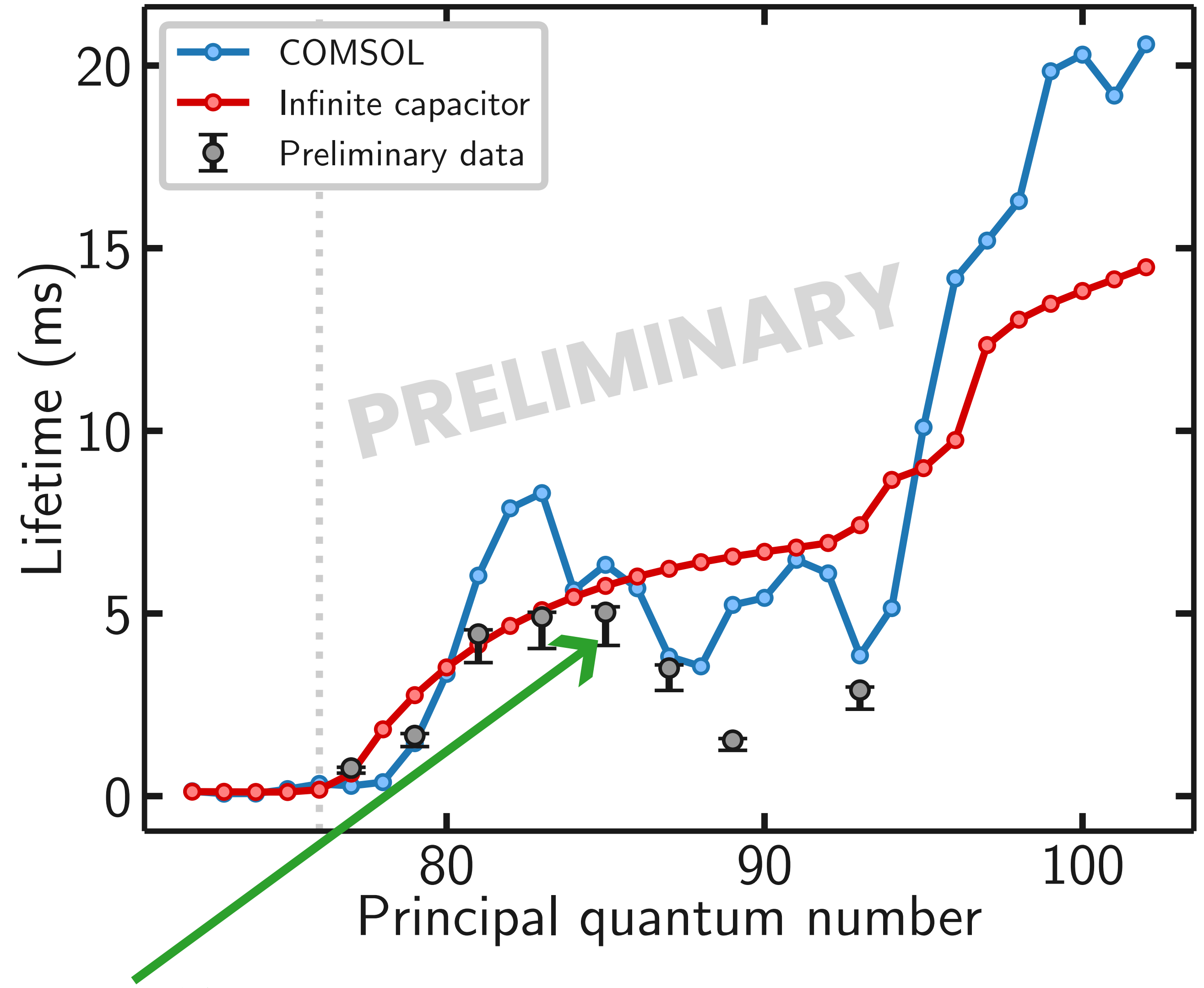
- 700 nm ITO Coating
- > 80 % Optical Transmission
- > 94 % Microwave Reflection



$\nu \propto n^{-3}$

longer wavelength for increasing n

For n=100: $\lambda \approx 3\,\mathrm{cm}$



$\tau \sim 5\,\mathrm{ms}$

Previous Records from Paris (beam):

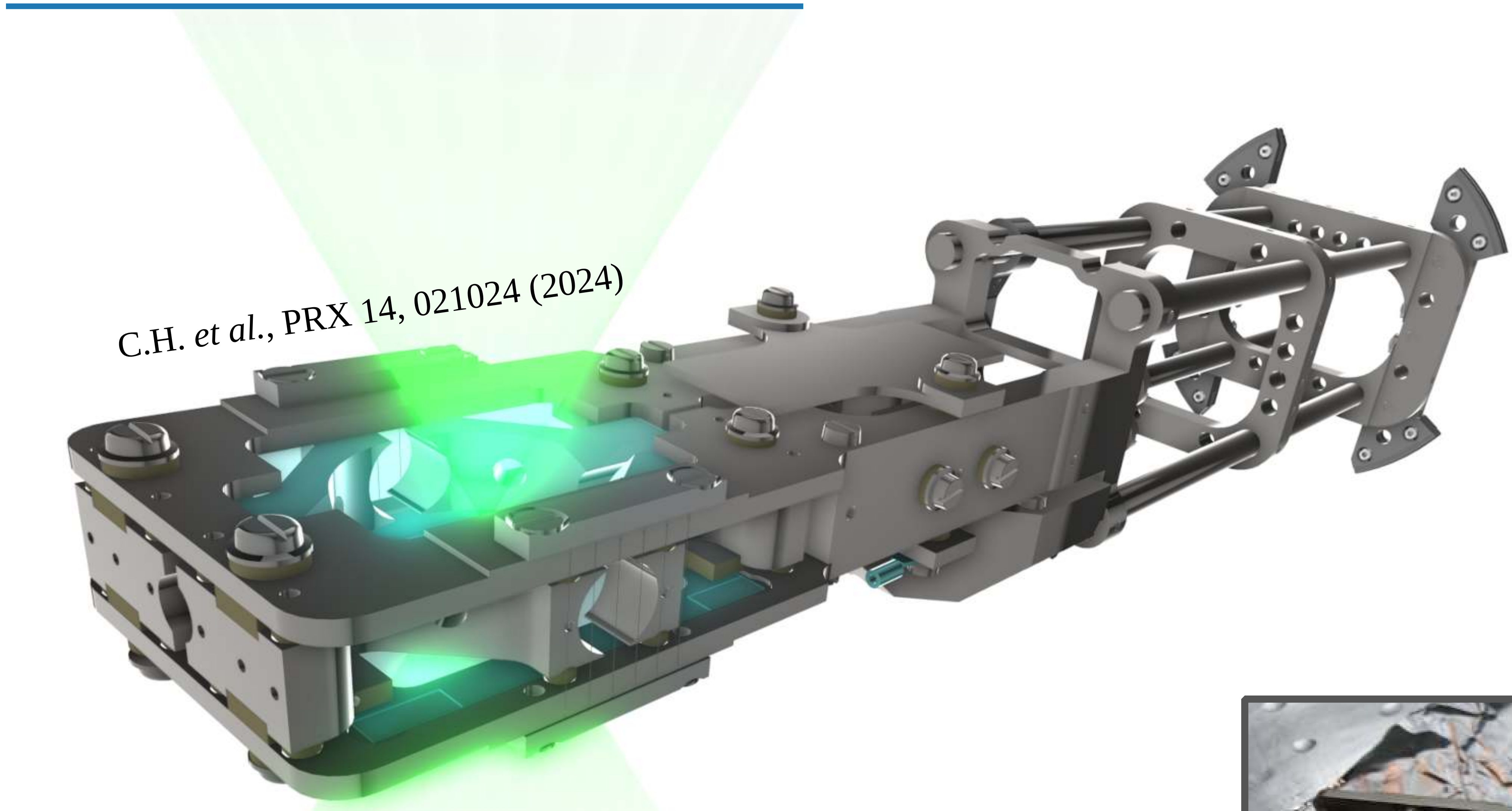
Rb, n=60: 1.1 ms

Wu *et al.*, PRL 130, 023202 (2023)

Rb, n=52, Cryogenic: 3.7 ms

Cantat-Moltrecht et al., PRR 2, 22032 (2020)

Our Quantum Processor

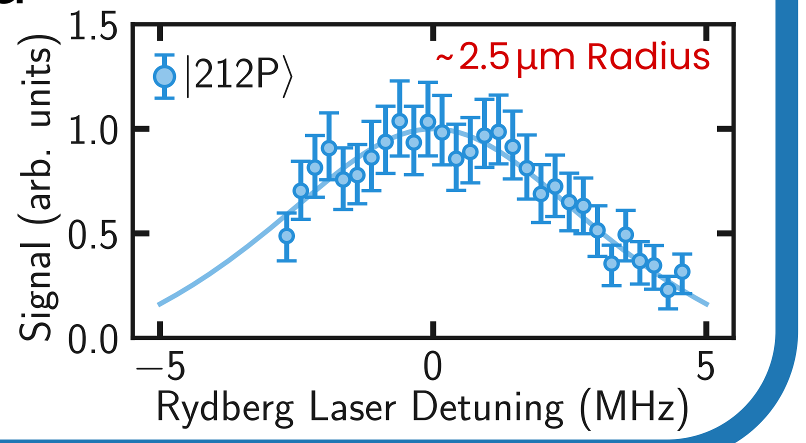

C.H. *et al.*, PRX 14, 021024 (2024)

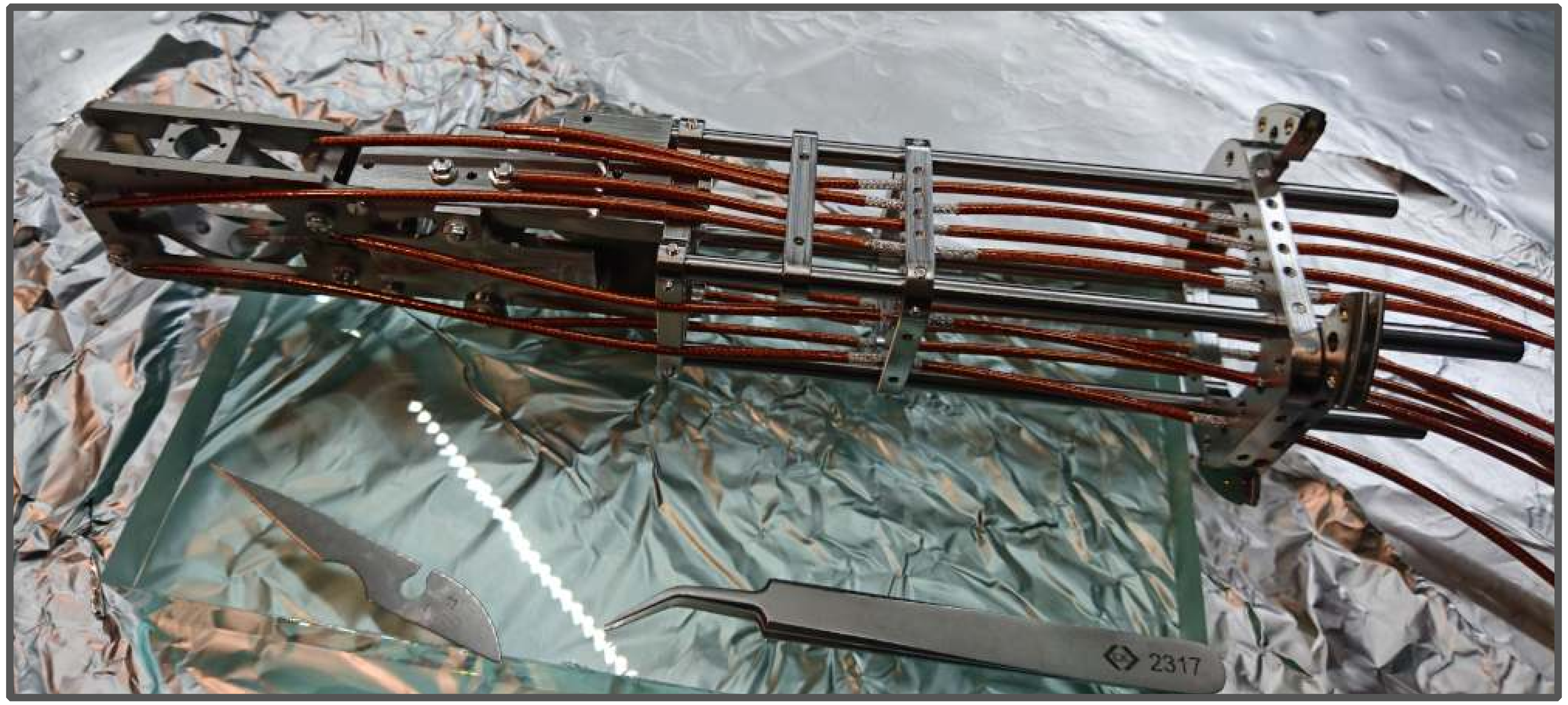
Field Stability

- Rydberg states are sensitive to E-fields
- High-NA access glass cells: Charge patches
- Full shielding required
  - Field stability

    $< 50\,\mu\mathrm{V\,cm^{-1}}$

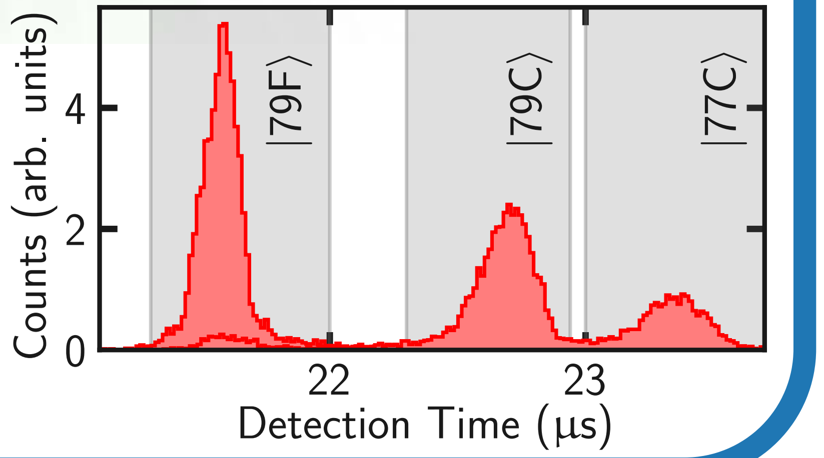
?



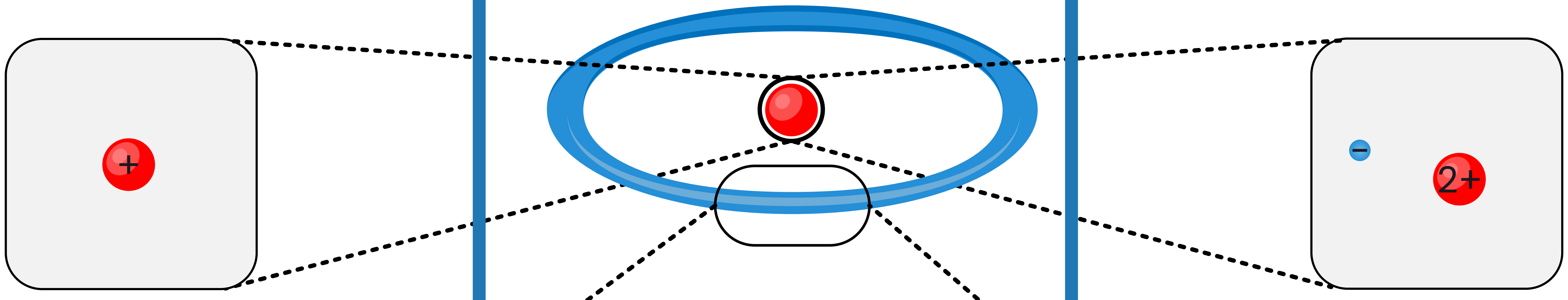


Detection

- State Selective Field Ionization
- Integrated ion detector (MCP)



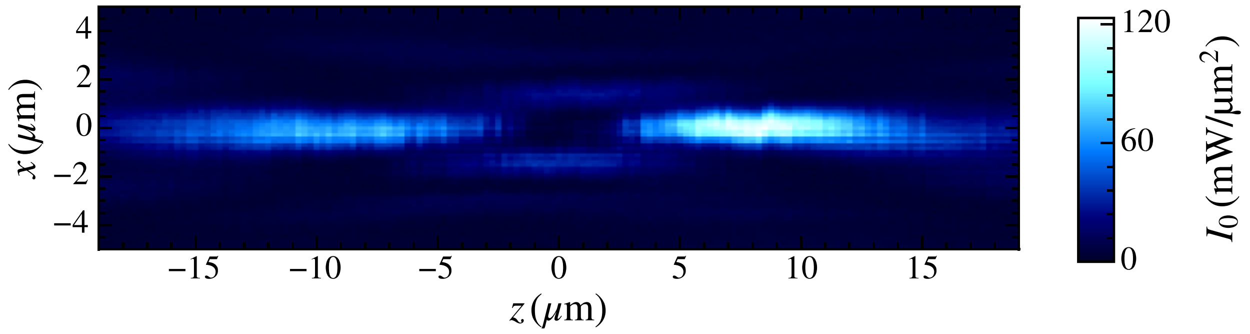
Combining Alkaline Earth and CRS



Alkali Atoms

- Workhorse: Rubidium
- Core has no optical transitions
- No easy trapping in Gaussian beams

Bottle Beam Traps:



Barredo *et al.*, PRL 124, 023201 (2020)

- Rydberg electron experiences ponderomotive force

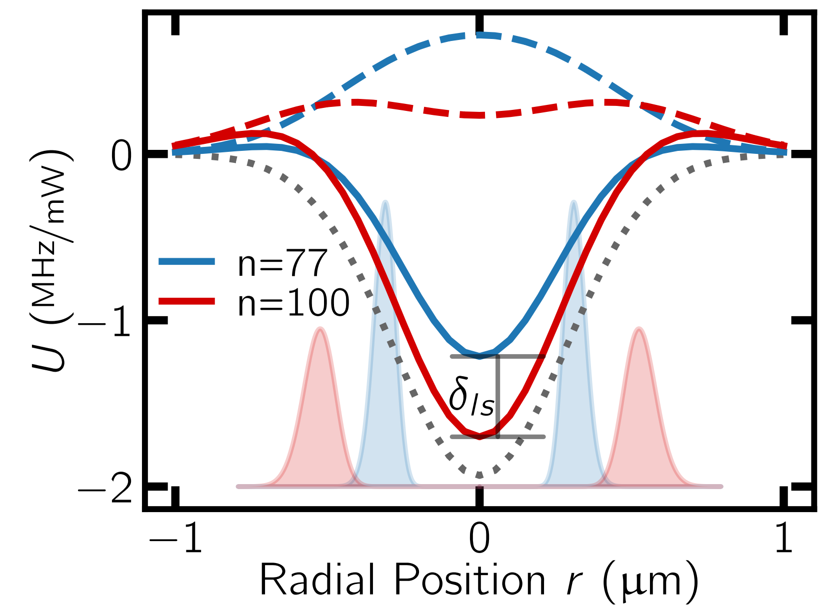
$$U_{\text{pond}} = -\frac{e^2}{m_e \omega^2}\,|E|^2$$

Always Repulsive!

Divalent Atoms

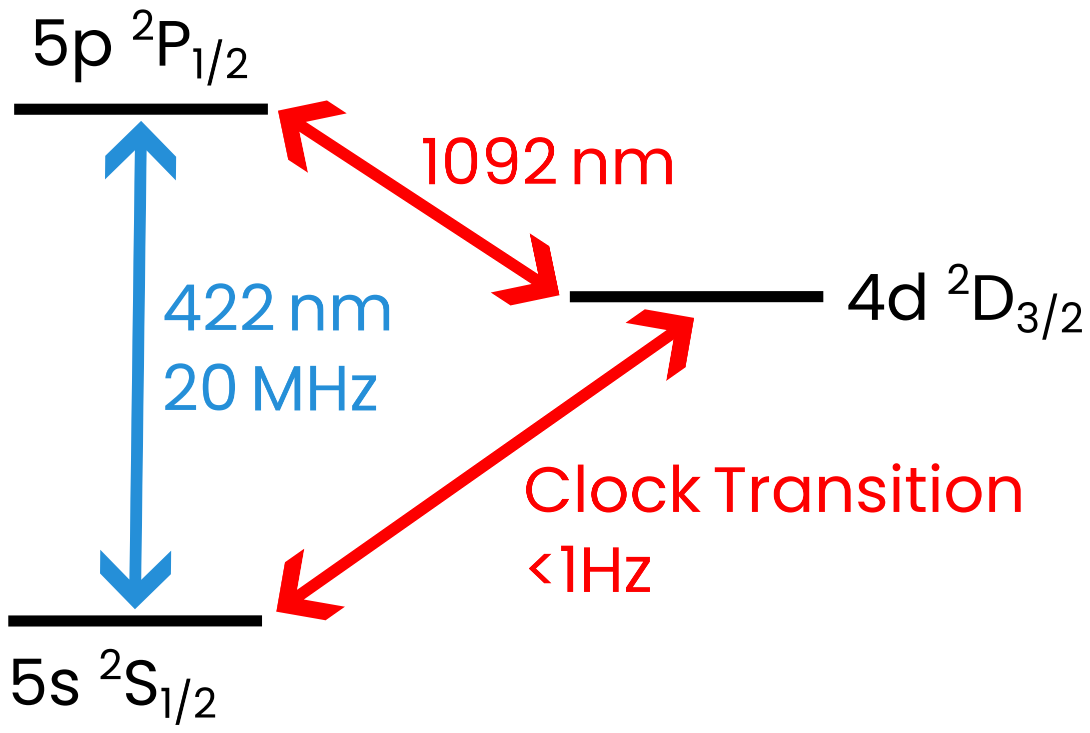
Alkaline-Earth Atoms (Ca, Sr, Ba),Yb

- Core has optical transitions
- Trapping in Gaussian beams



C.H. *et al.*, PRX 14, 021024 (2024)

Using the Core Electron?


5p $^2P_{1/2}$

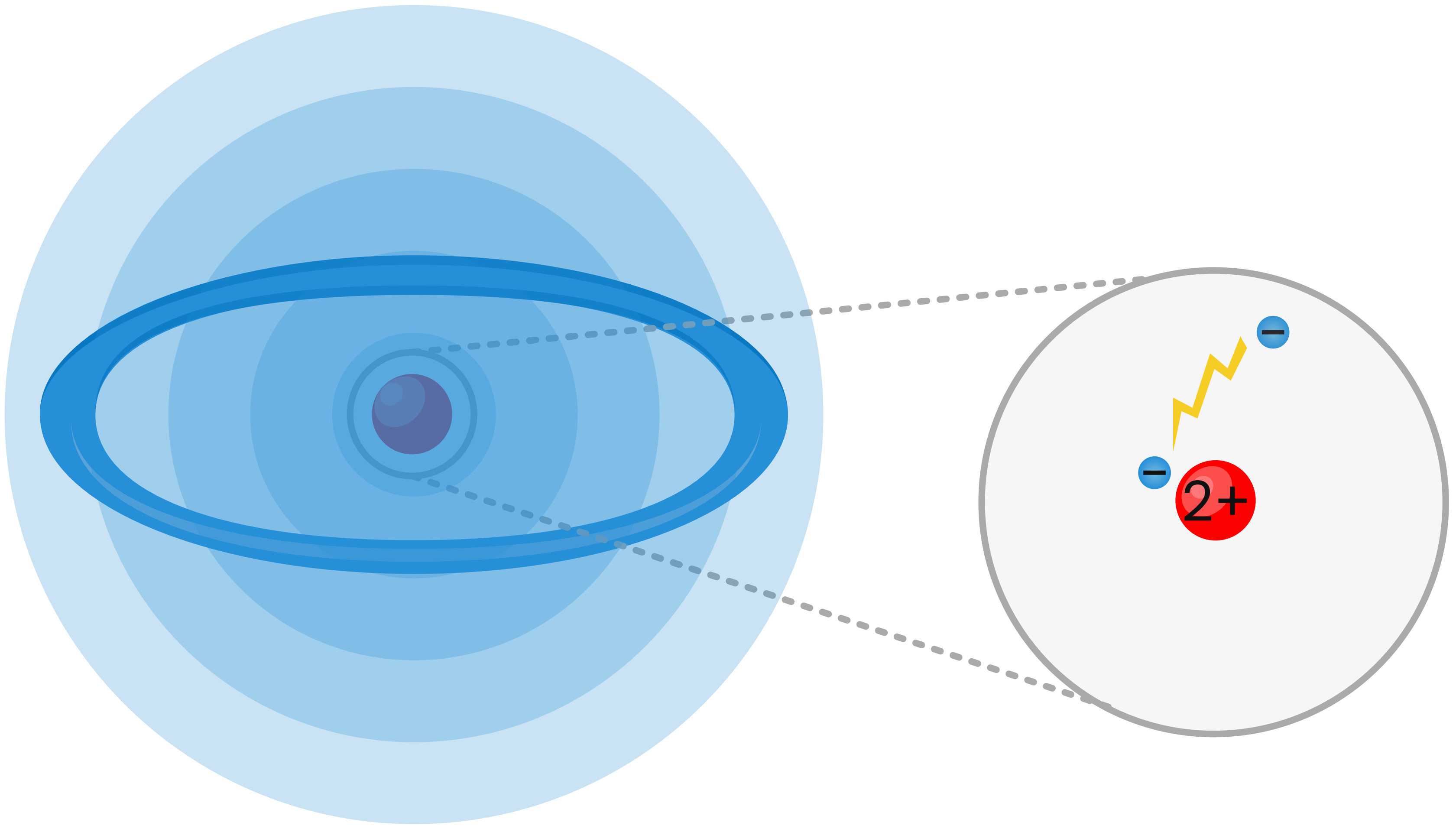
1092 nm

4d $^2D_{3/2}$

422 nm
20 MHz

Clock Transition
<1Hz

5s $^2S_{1/2}$



Autoionization Rate

$$R \propto n^{-3} l^{-5}$$

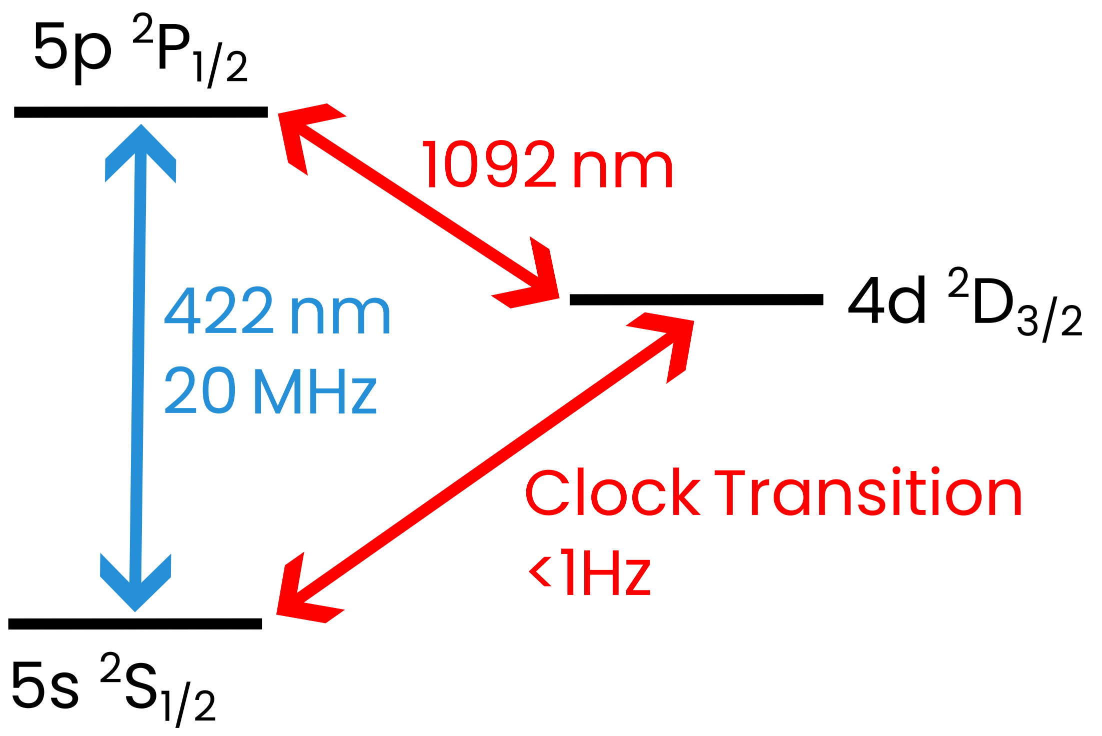
$$R(79F) \approx 3.5\,\mathrm{GHz}$$

$$R(79C) \approx 1\,\mathrm{Hz}$$

Fields *et al.*, PRL 97, 013429 (2018)

With **CRS**, optical core transitions can be addressed **without autoionization**

Using the Core Electron!



Optical Cooling and Imaging

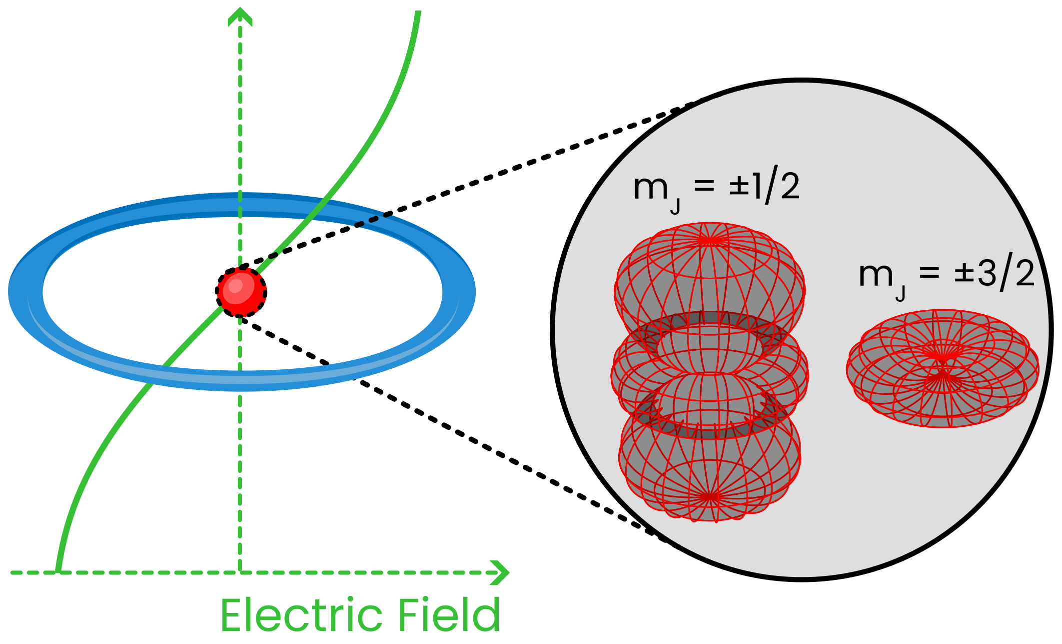
- First experimental demonstration slowing a beam of CRS

  Lachaud *et al.*, PRL 133, 123202 (2024)

- Transfer methods established in experiments with trapped ions to tweezer platform

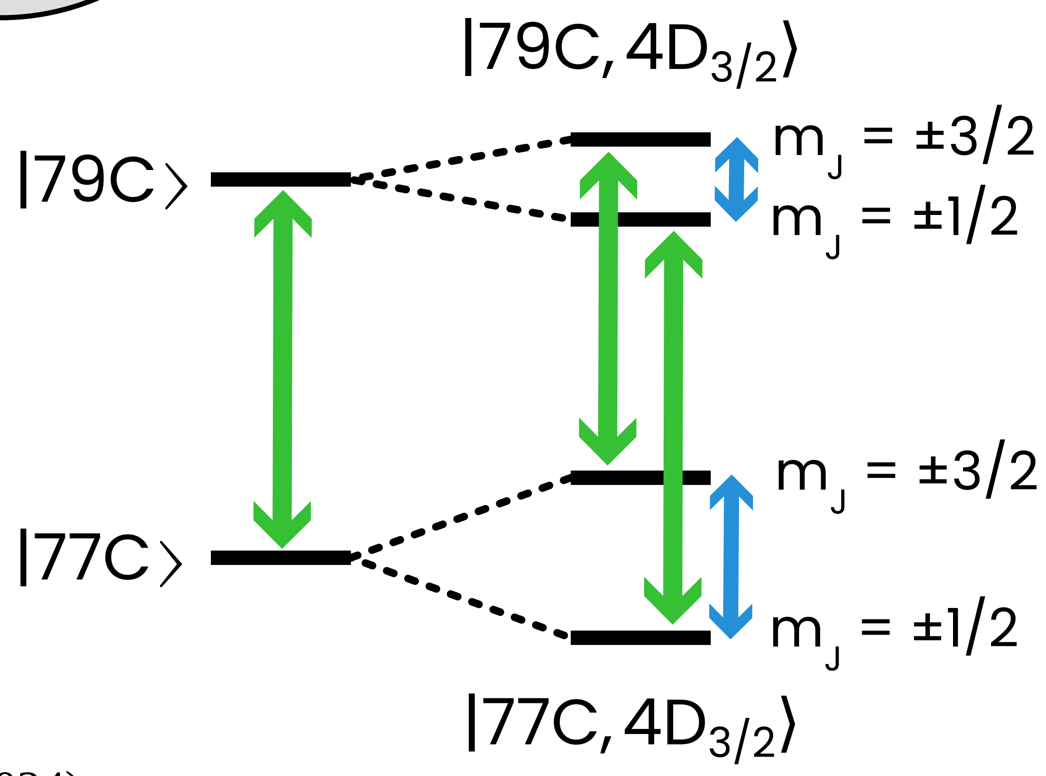
Coherent Control

- No local CRS control possible with microwave



4d $^2D_{3/2}$ state quadrupole moment interacts with electric field gradient of CRS electron

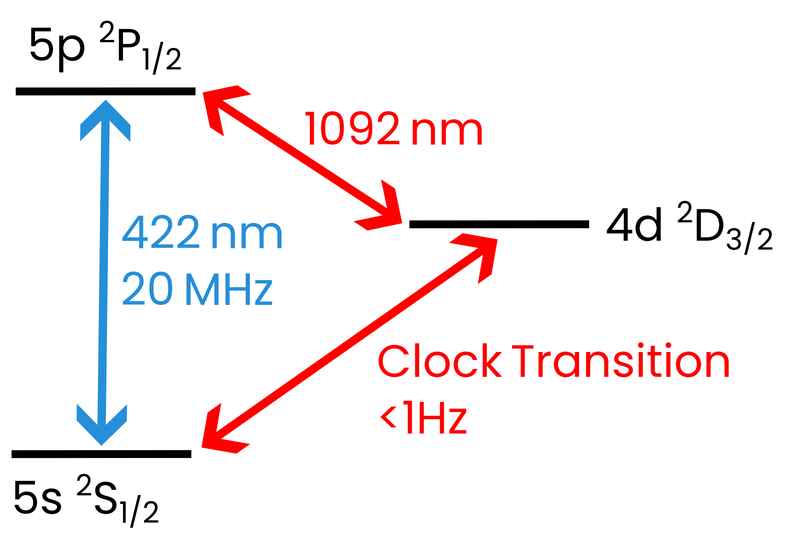
Optically switch interaction shift on CRS qubit transition



- Possible local control

Wirth, C.H. *et al.*, PRL 133, 123403 (2024)
Muni *et al.*, Nat. Phys. 18, 502–505 (2022)

Excursion: Measuring the small Shift

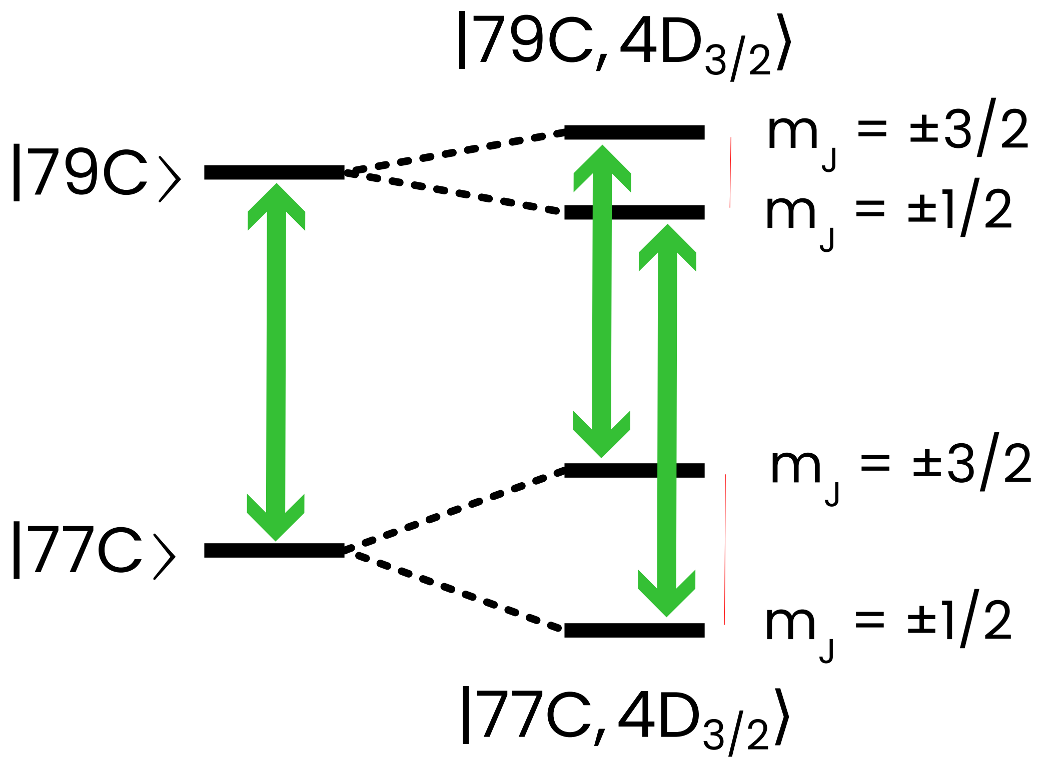


Challenge: Interaction <5kHz for n=79

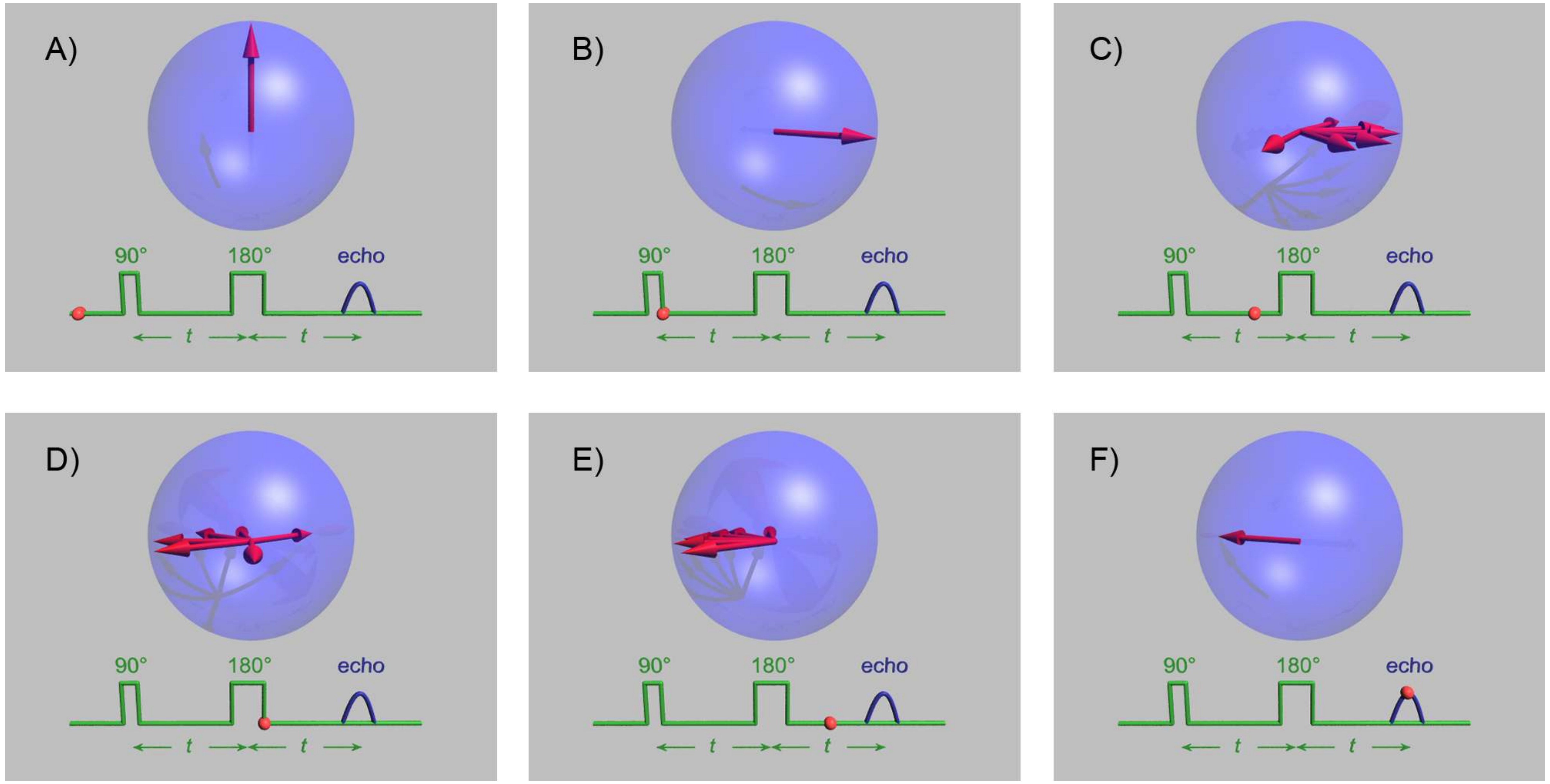
➡ >200μS **coherence time** required

Solution: Spin-Echo measurement

➡ **Slow noise** (including shot-to-shot, B-Field) cancels

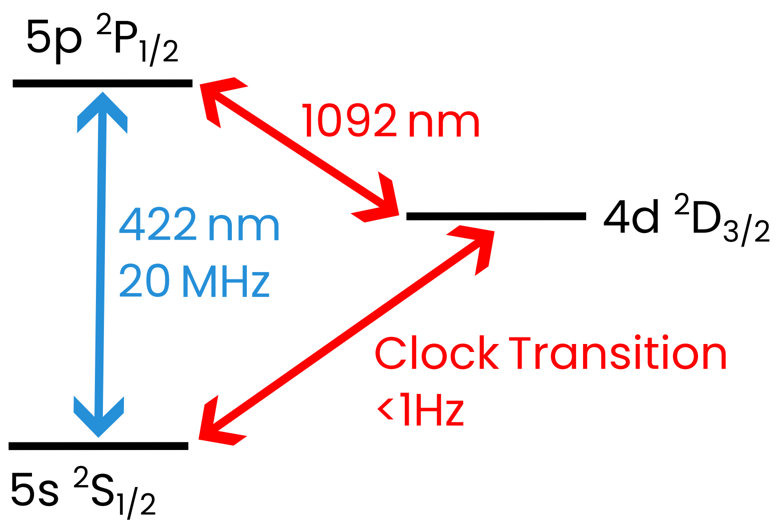


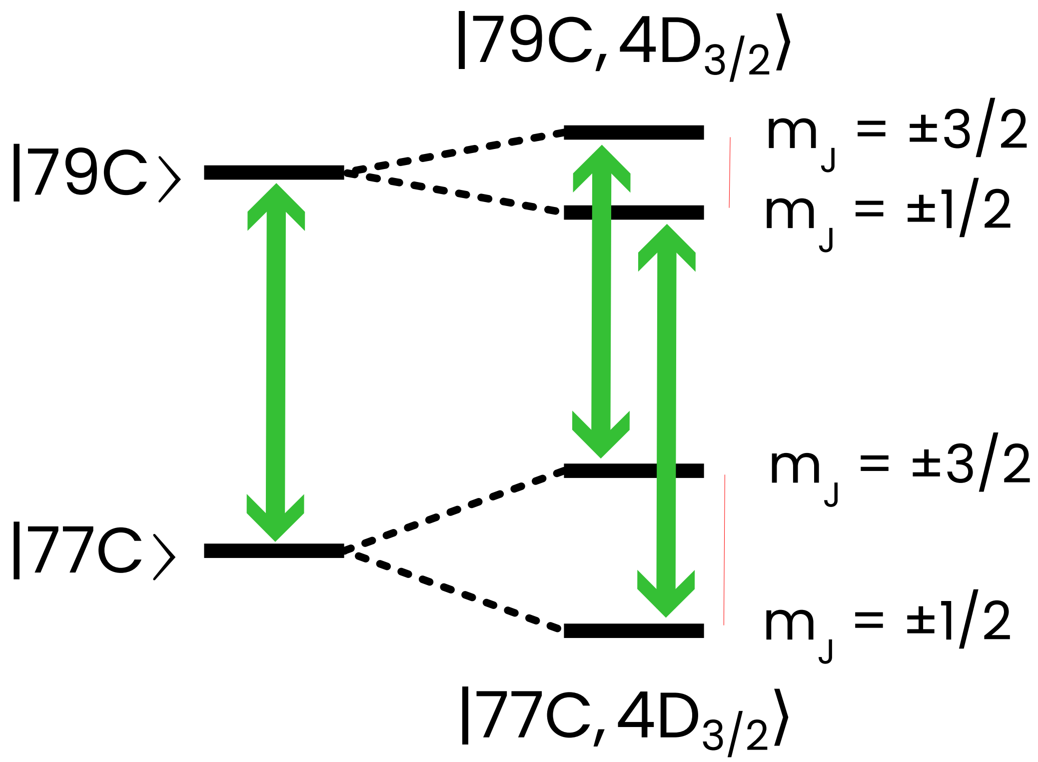
Wirth, C.H. *et al.*, PRL 133, 123403 (2024)

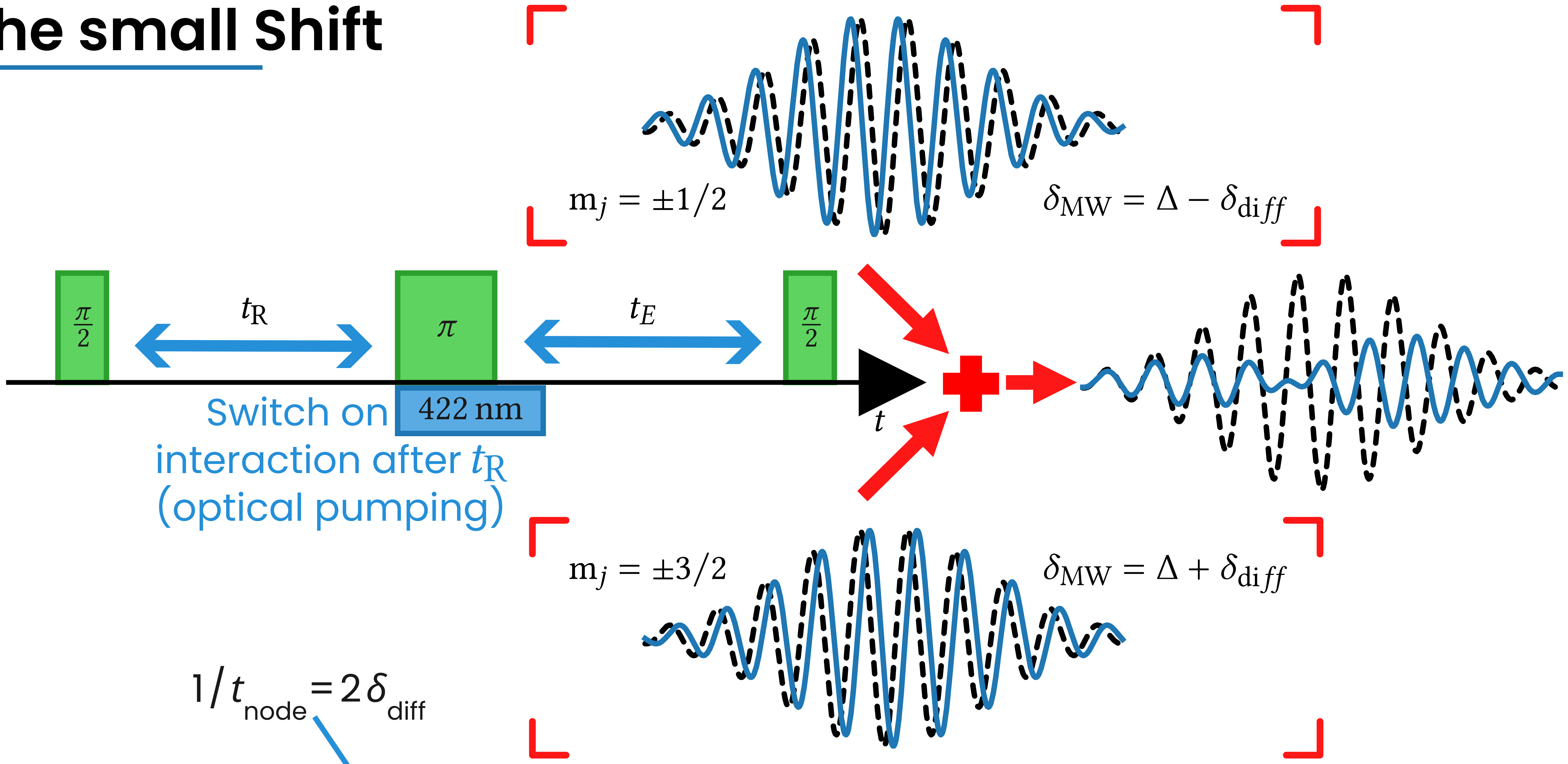


By Gavin W Morley - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15380381

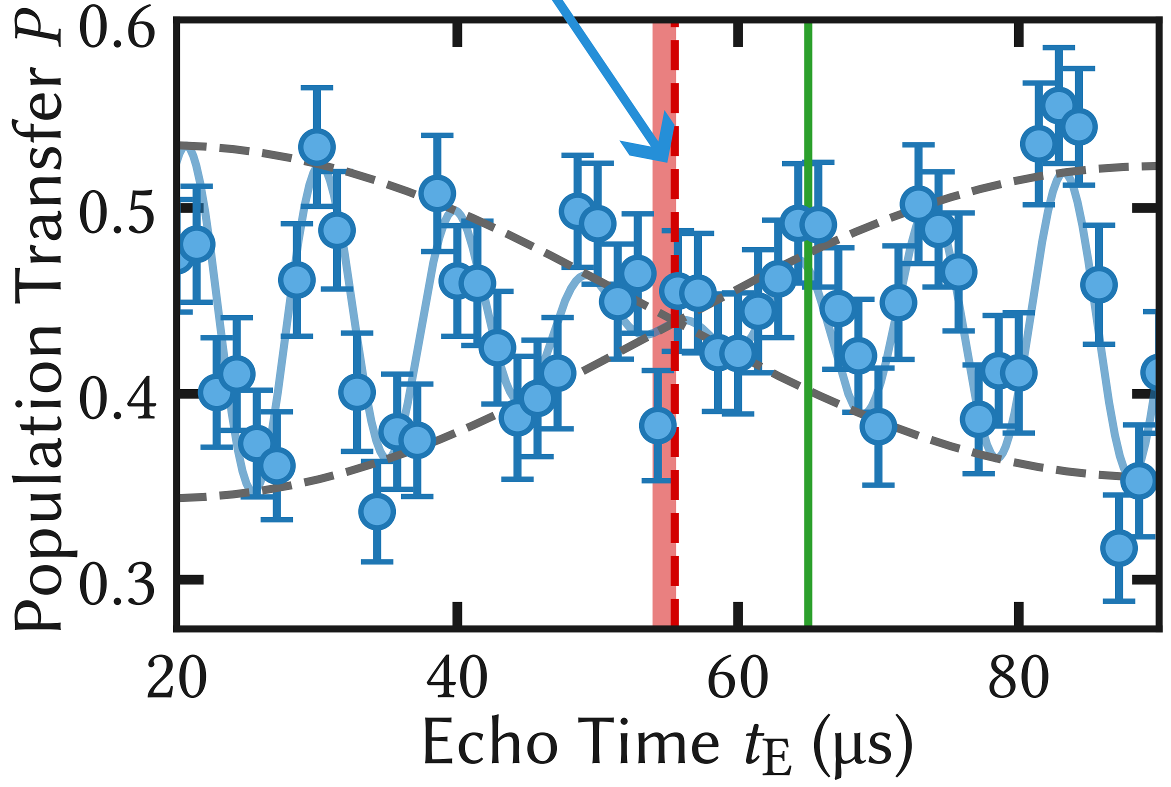
Excursion: Measuring the small Shift







Switch on 422 nm interaction after t_R (optical pumping)



$\delta_{diff} = 4.51(7)$ kHz

Small interaction accessible due to long lifetime and tweezer-trapping

Wirth, C.H. *et al.*, PRL 133, 123403 (2024)

Outlook

New Concepts

Cooling of CRS

using the second electron

see also L. Lachaud et al., PRL **133**, 123202 (2024)

Non-Destructive Readout

Fluorescence Detection

using the second electron

Local Addressing

Using the second electron

or using the ponderomotive Potential

Simulating With CRS

Hamiltonian Implementation

Ising, Heisenberg, XXZ,...

Adiabatic State Preparation

Spin Liquids, ...

Synthetic Dimensions

Encoded in different CRS

Dynamic Reconfigurability

Shuttling of CRS

Quantum Simulation with Rydberg Tweezer Arrays

- How do Tweezers work?
- What are Rydberg atoms?
- Why are Rydberg atoms cool?
- How do they interact?
- What can they simulate?

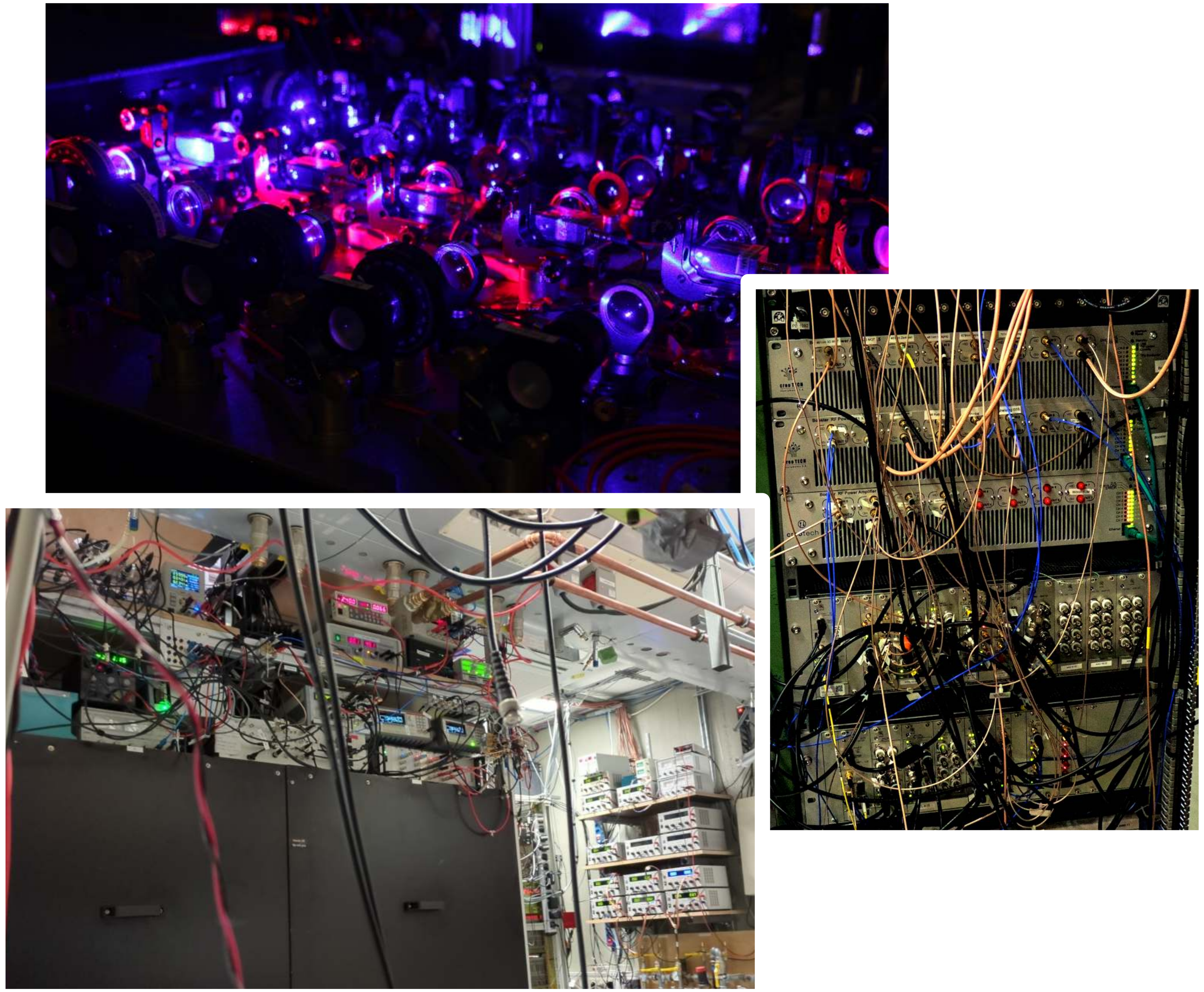
Circular Rydberg States

- What are CRS?
- Why are CRS interesting for quantum simulation?
- What is the state of the art?
- How can we prepare CRS?
- Brand new data from our lab!

Controling Neutral Atom Quantum Hardware

- What are the hardware requirements?
- How can FOSS help in controling quantum hardware?
- How does an example experiment code look?

How to Control A Cold Atoms Lab



Requirements

?

- Nanosecond time resolution
- Control over highly specialized devices (wavemeters, ultra-stable current sources, …)
- Fast repetetition rates (<500ms)
- Scalability

FOSS Solutions Available: ARTIQ labscript …

- 24/7 and unsupervised operation
  - Environmental monitoring and feedback
- Easy to use/understand
- Easy expandable by scientists

Typically a problem in labs
But FOSS can help us!

Atomiq - A FOSS Quantum Control Hardware Orchestrator

atomiq

gitlab.com/atomiq-project

- Build on top of ARTIQ
- Focussed on usability and scalability
- Zenoh protocol for decentralized device comunication

Realtime Hardware

- Seamless integration into ARTIQ
- Support for other systems (planned)

Non-Realtime Devices

- Cameras, Oscilloscopes, ...
- Decentralized pub/sub and remote object integration

heros

Data Sources/Sinks

- Easy integration of databases and exisiting infrastructure

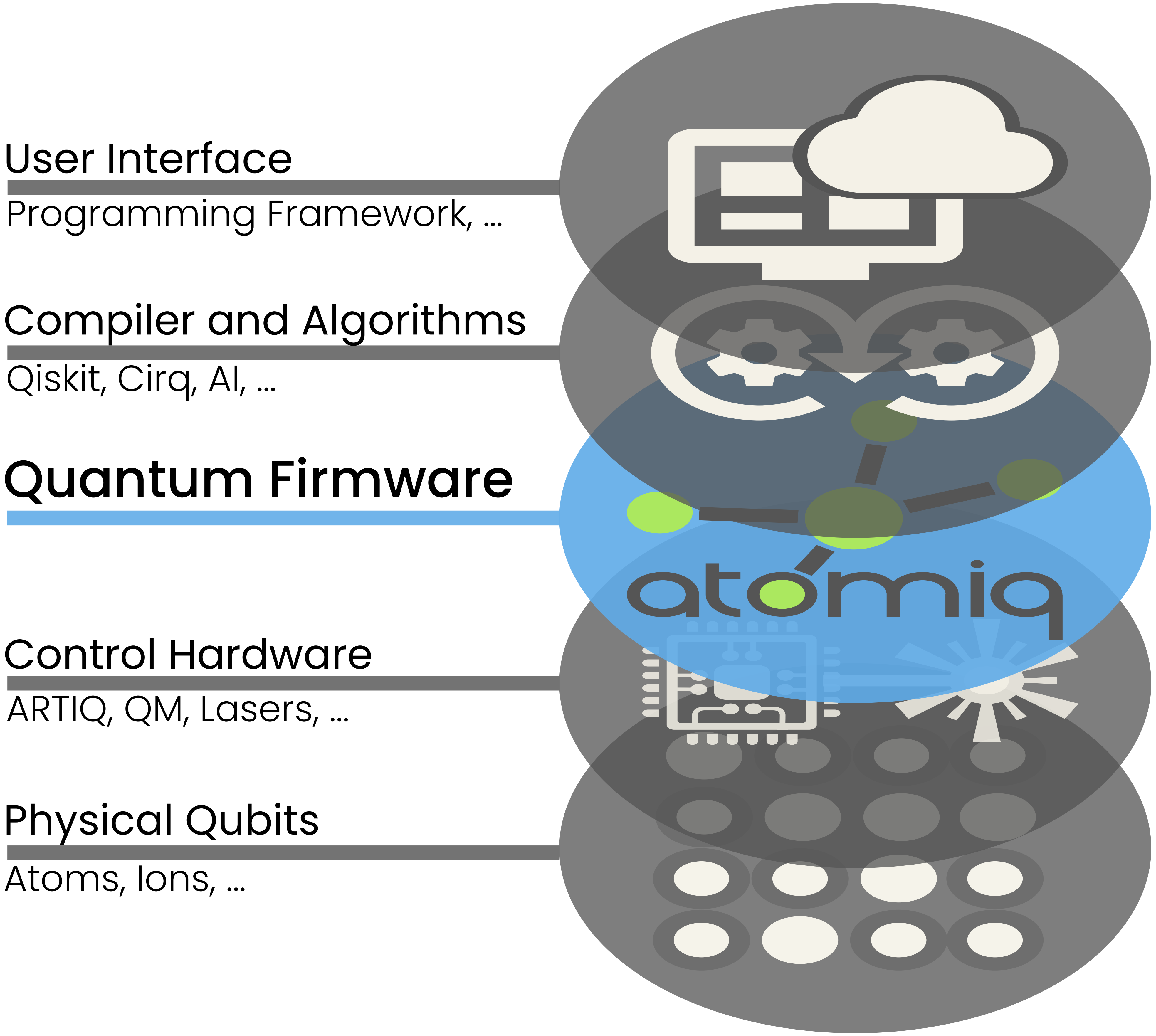
Thomas Niederprüm

Suthep Pomjaksilp

C.H.

RPTU Rheinland-Pfälzische Technische Universität Kaiserslautern Landau

Universität Stuttgart



User Interface

Programming Framework, ...

Compiler and Algorithms

Qiskit, Cirq, AI, ...

Quantum Firmware

Control Hardware

ARTIQ, QM, Lasers, ...

Physical Qubits

Atoms, Ions, ...

An Example Experiment

```python

class MyExperiment(AtomiqExperiment):
    """
    Load and image a magneto optical trap
    """
    components = ["laser_cooler", "mot_coils"]

    arguments = {
        "mot_cooler_det": {"default": -12, "unit": "MHz"},
        "mot_cooler_power": {"default": 30., "unit": "mW"},
        "mot_loading_time": {"default": 200, "unit": "ms"}
    }

    blocks = [Imaging]

    @kernel
    def prestep(self, point):
        self.laser_cooler.set_power(point.mot_cooler_power)
        self.laser_cooler.set_detuning(point.mot_cooler_det)

    @kernel
    def step(self, point):
        self.laser_cooler.on()
        delay(point.mot_loading_time)
        self.Imaging.take_image(point)
        self.laser_cooler.off()
        delay(5*ms)
        self.Imaging.take_image(point)

```

```python

class Imaging(AtomiqBlock):

    components = ["camera", "laser_imaging"]

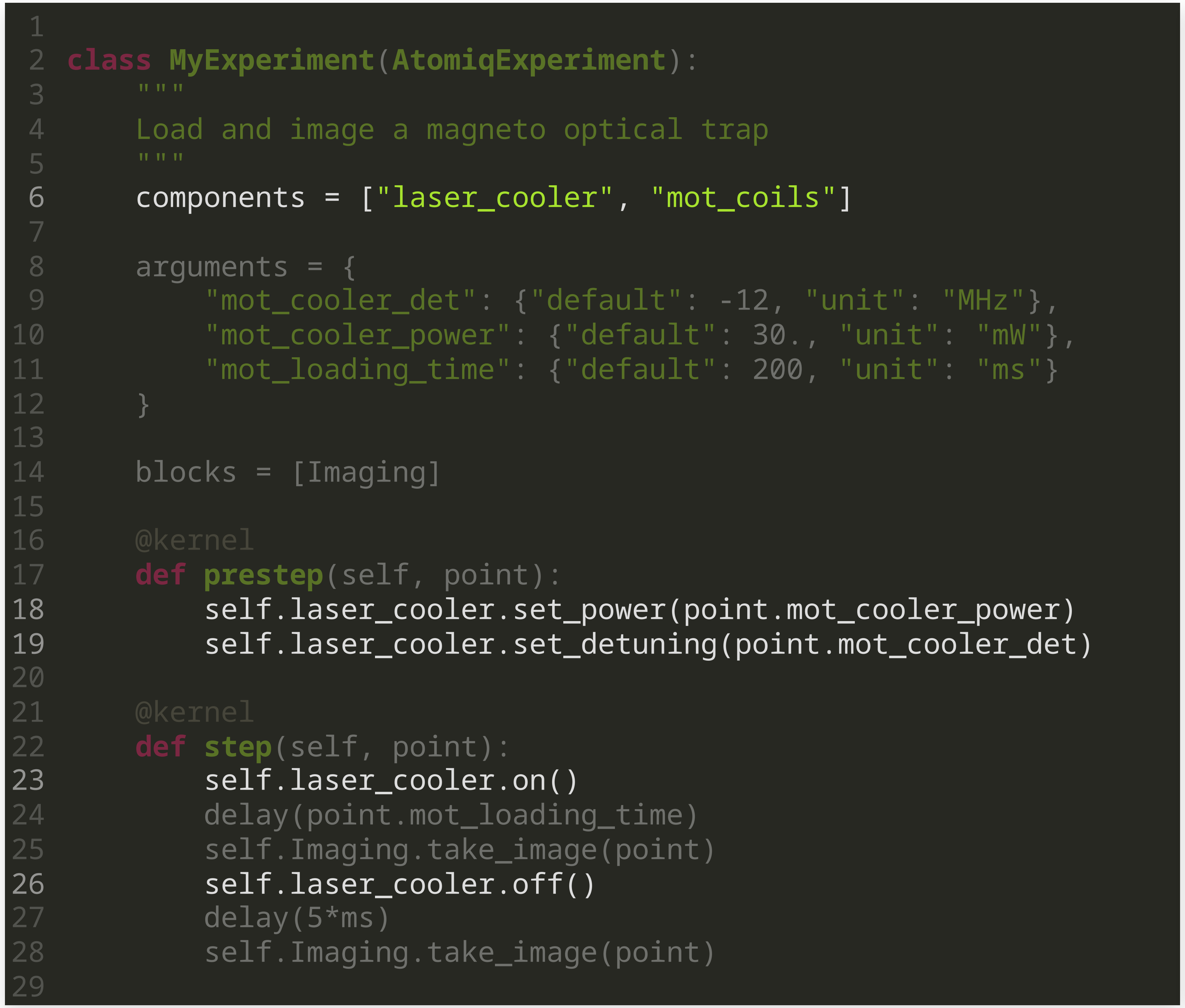
    arguments = {
        "exposure_time": {"default": 100., "unit": "us"},
        "imaging_det": {"default": 0., "unit": "MHz"},
        "imaging_power": {"default": 0.2, "unit": "mW"},
    }


    def prerun(self):
        def printer(payload):
            print(payload)
        self.camera.new_data.connect(printer)

    @kernel
    def prestep(self, point):
        self.laser_imaging.set_power(point.imaging_power)
        self.laser_imaging.set_detuning(point.imaging_det)

    @kernel
    def take_image(self, point):
        self.camera.trigger()
        self.image_aom.on()
        delay(point.exposure_time)
        self.image_aom.off()
```

An Example Experiment



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        delay(point.mot_loading_time)
        self.Imaging.take_image(point)
        self.laser_cooler.off()
        delay(5*ms)
        self.Imaging.take_image(point)

```

```python

# Lasers
components.update({
    "laser_cooler": {
        "classname": "SUServoModulatedLaser",
        "arguments": {
            "laser_source": "&ls_cooler",
            "photodiode": "&pd_cooler",
            "modulator": "&aom_cooler",
            "default_ki": -1.0e4,
            "default_kp": -1.0
        }
    }
})


# Photodiodes
components.update({
    "pd_cooler": {
        "classname": "CalibratedPhotodiode",
        "arguments": {
            "adc_channel": "&input_adc_cooler",
            "calibration": "&cal_pd"
        }
    }
})

# Calibrations
components.update({
```

CiRQus

C.H.
Moritz Berngruber
Aaron Götzelmann
Einius Pultinevicius
Armin Humic

Marius Thomas
Nicklas Kaltenecker
Florian Meinert
Tilman Pfau

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Rydberg Quantum Computers &
Simulators made in Stuttgart

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