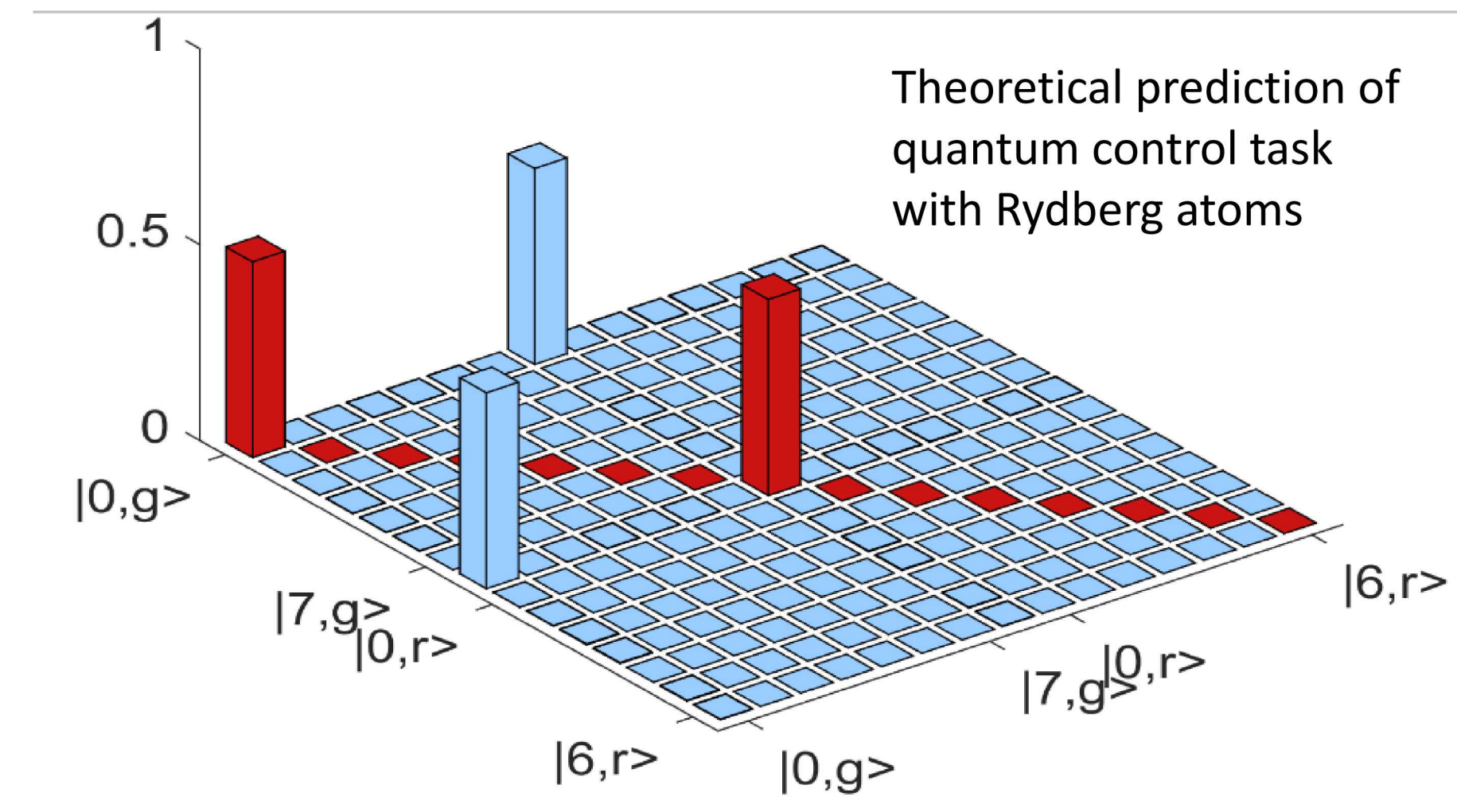
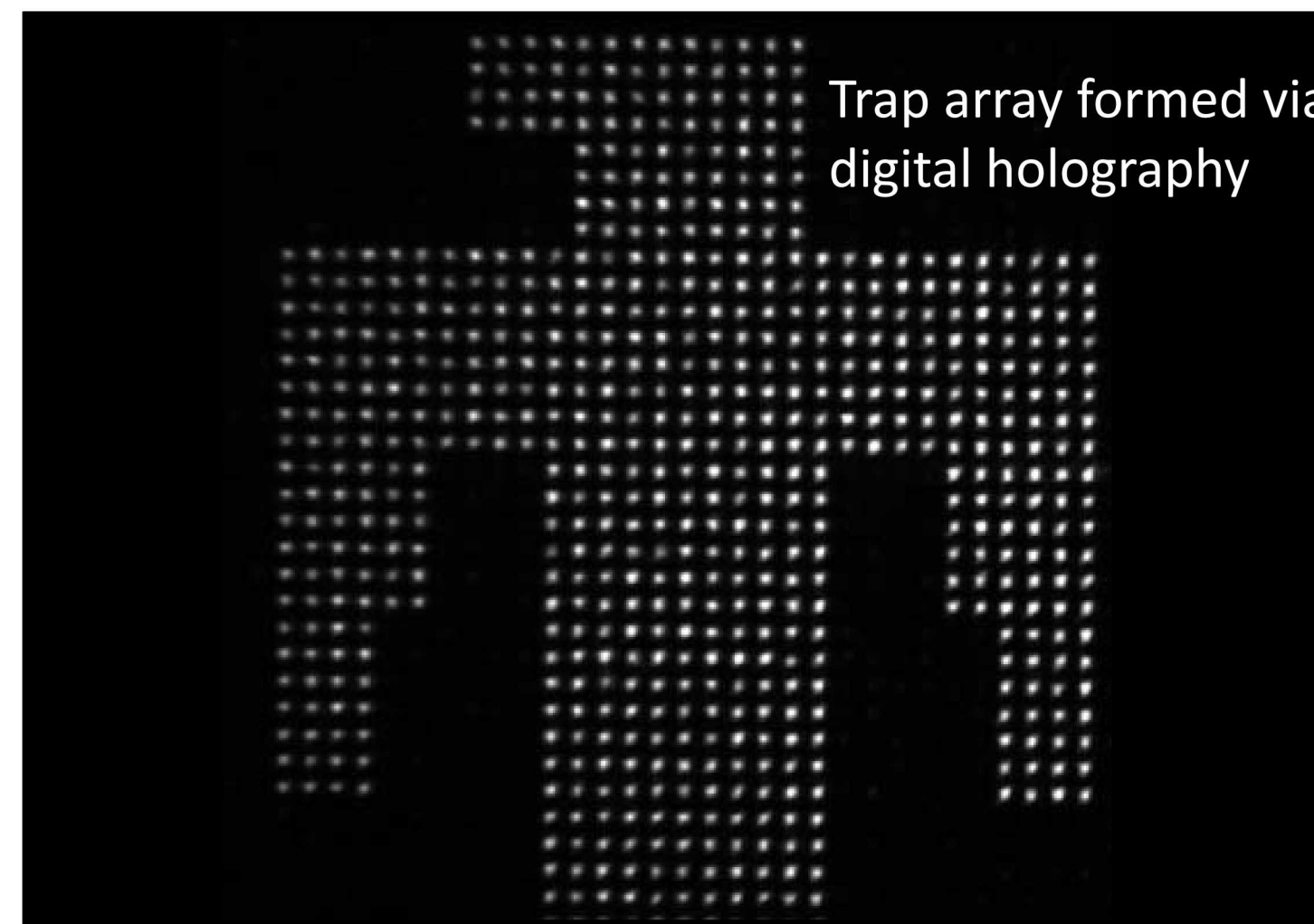
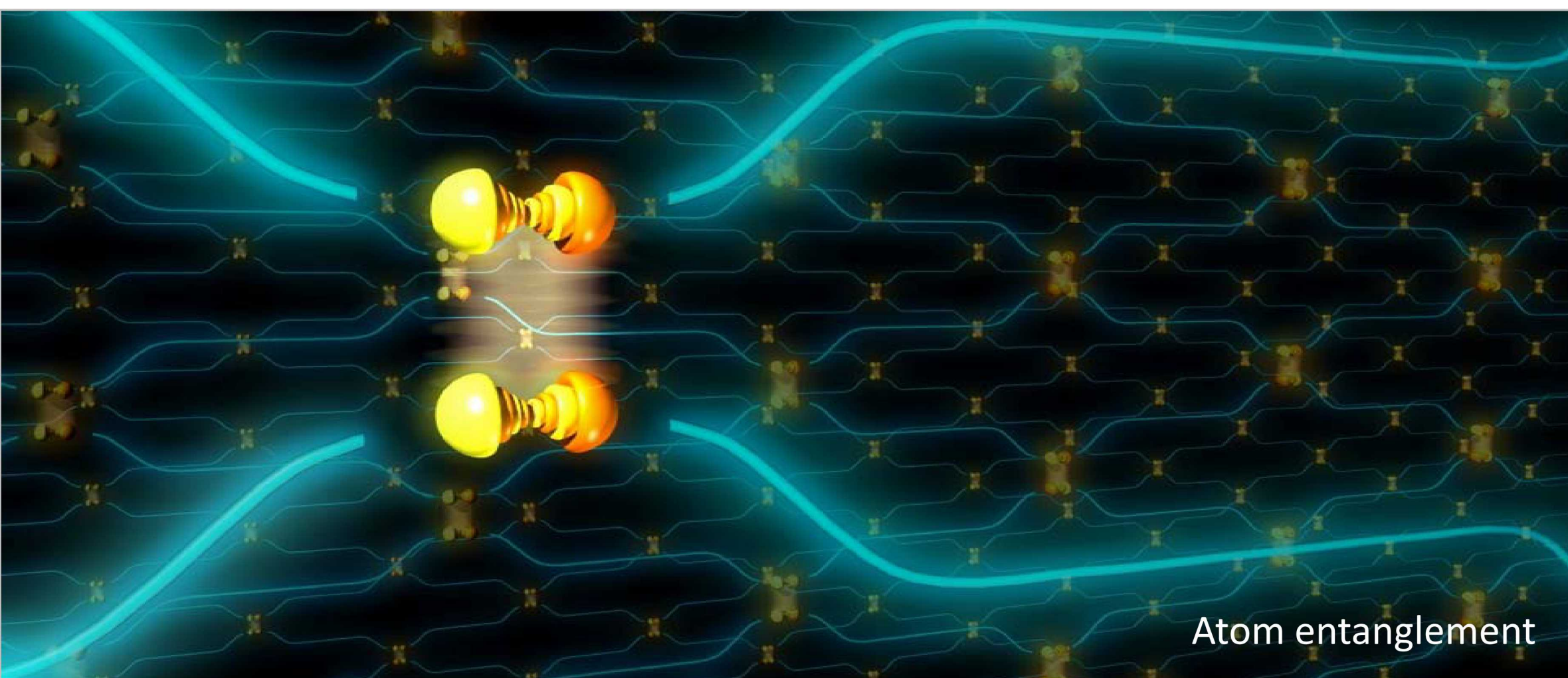


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# Quantum Science with Ultracold Rydberg Atoms

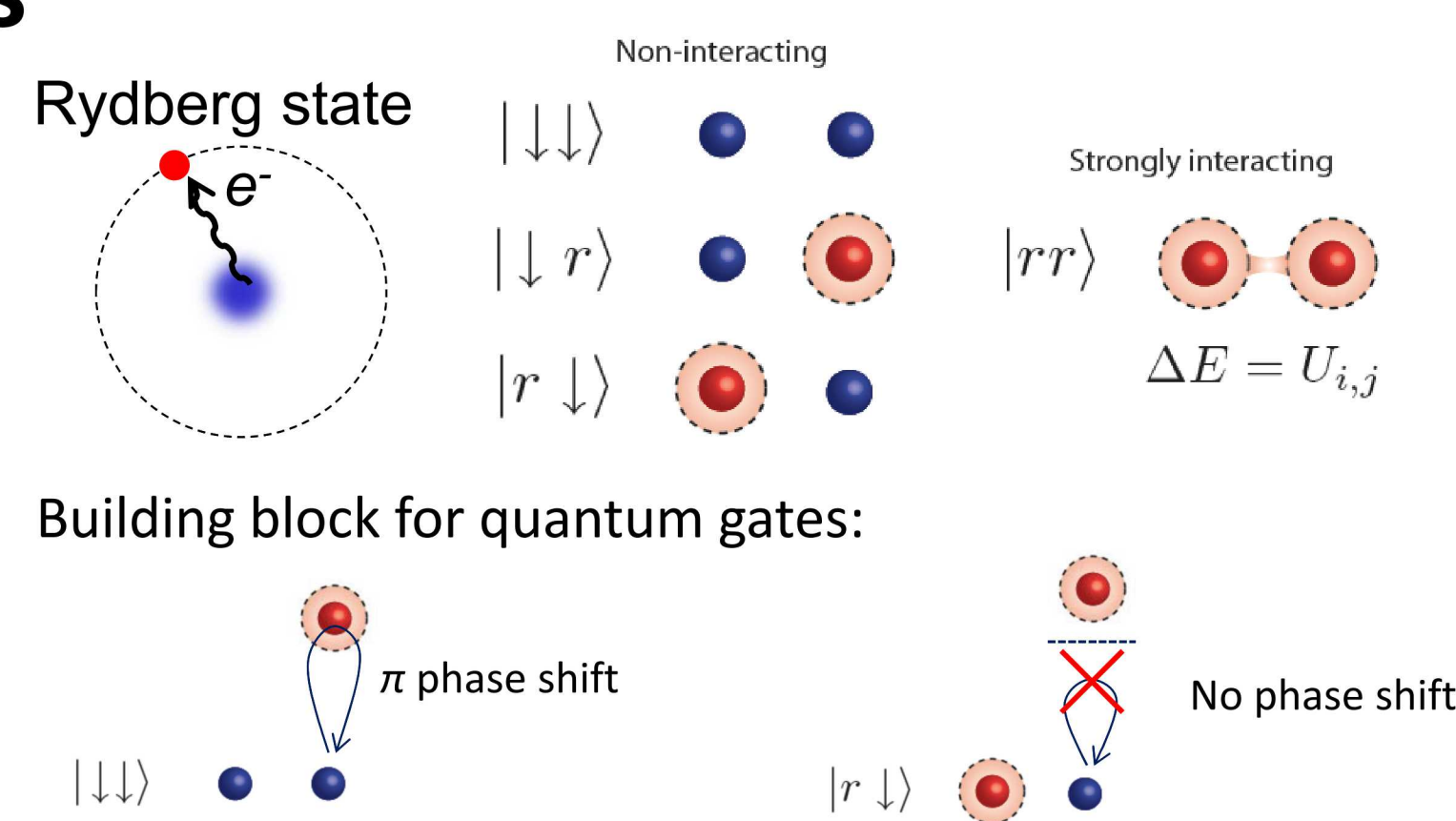
Michael J. Martin, Jongmin Lee, Yuan-Yu Jau, Ivan H. Deutsch, and Grant W. Biedermann

## Abstract

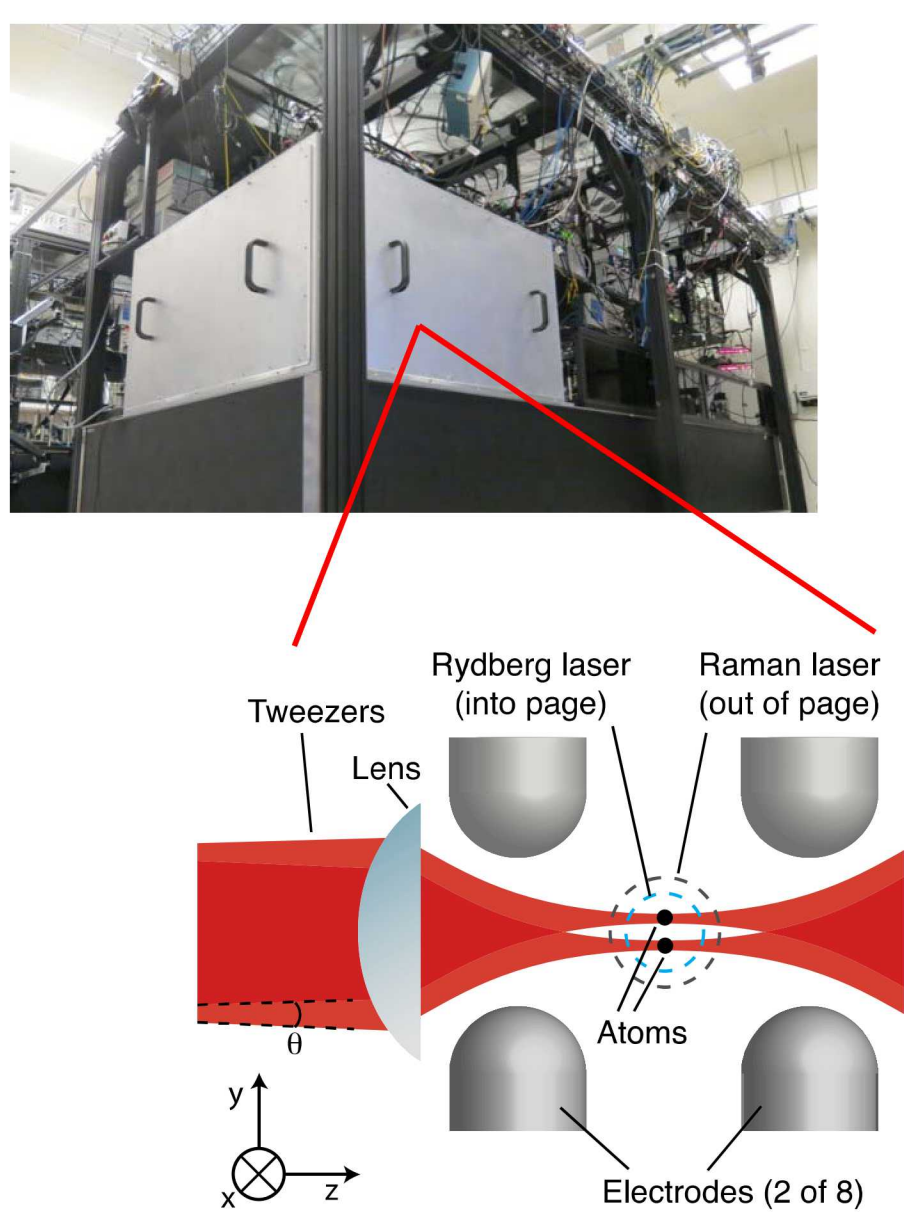
Neutral atom-based qubits are highly scalable and controllable. Furthermore, with optical excitation of high-lying, strongly interacting Rydberg states, one can achieve on-demand, laser-controlled interactions for quantum logic operations. We present studies of entangling operations from a two-atom system employing single ultracold cesium atoms that interact via single-photon laser coupling to a Rydberg level. We also present work towards larger-scale systems employing reconfigurable traps formed via digital holography.

## Rydberg atom interactions

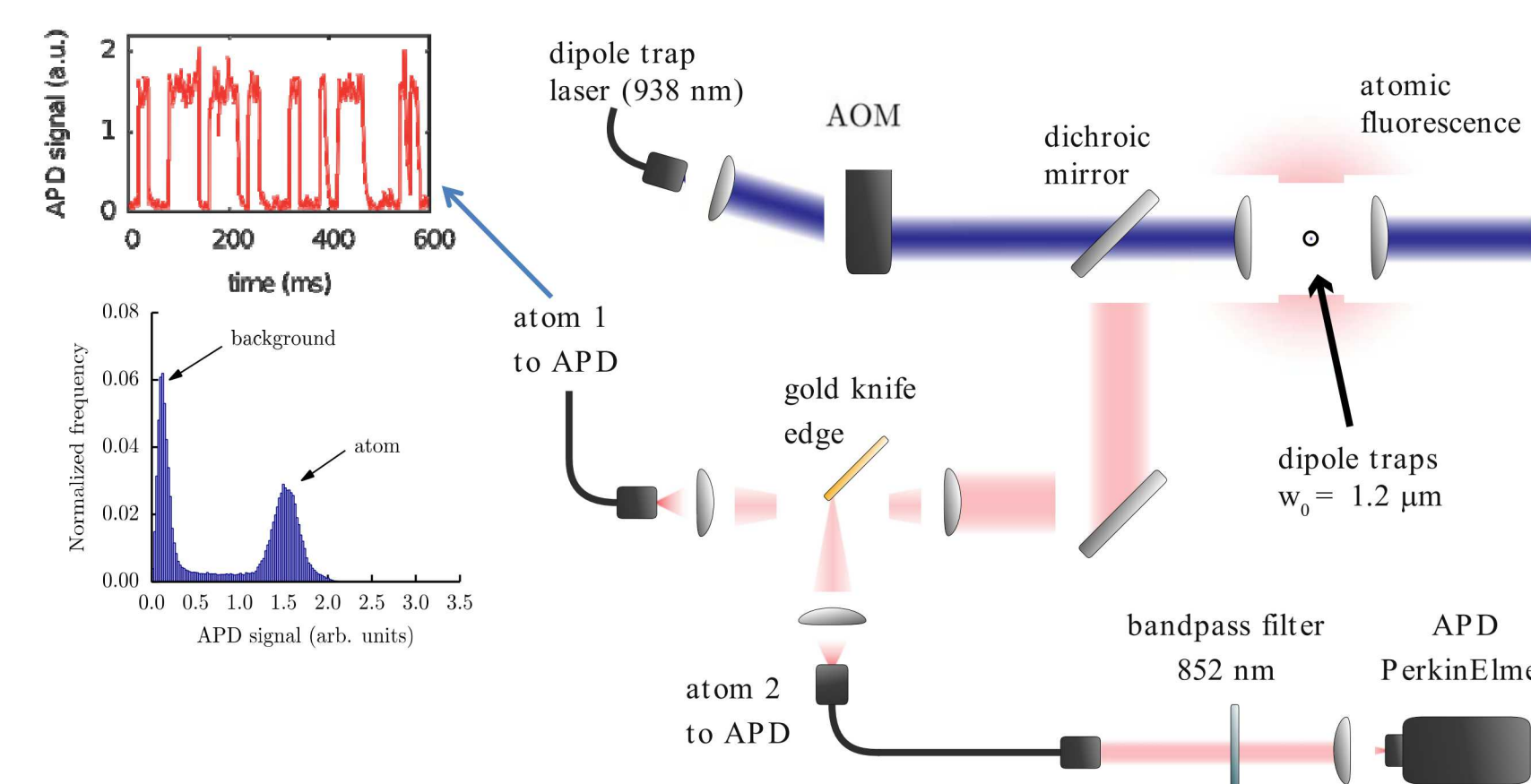
- High principal quantum number ( $n \gg 10$ ).
- Atom exhibits “exaggerated” properties: huge polarizability, size, and van der Waals interaction



## Apparatus

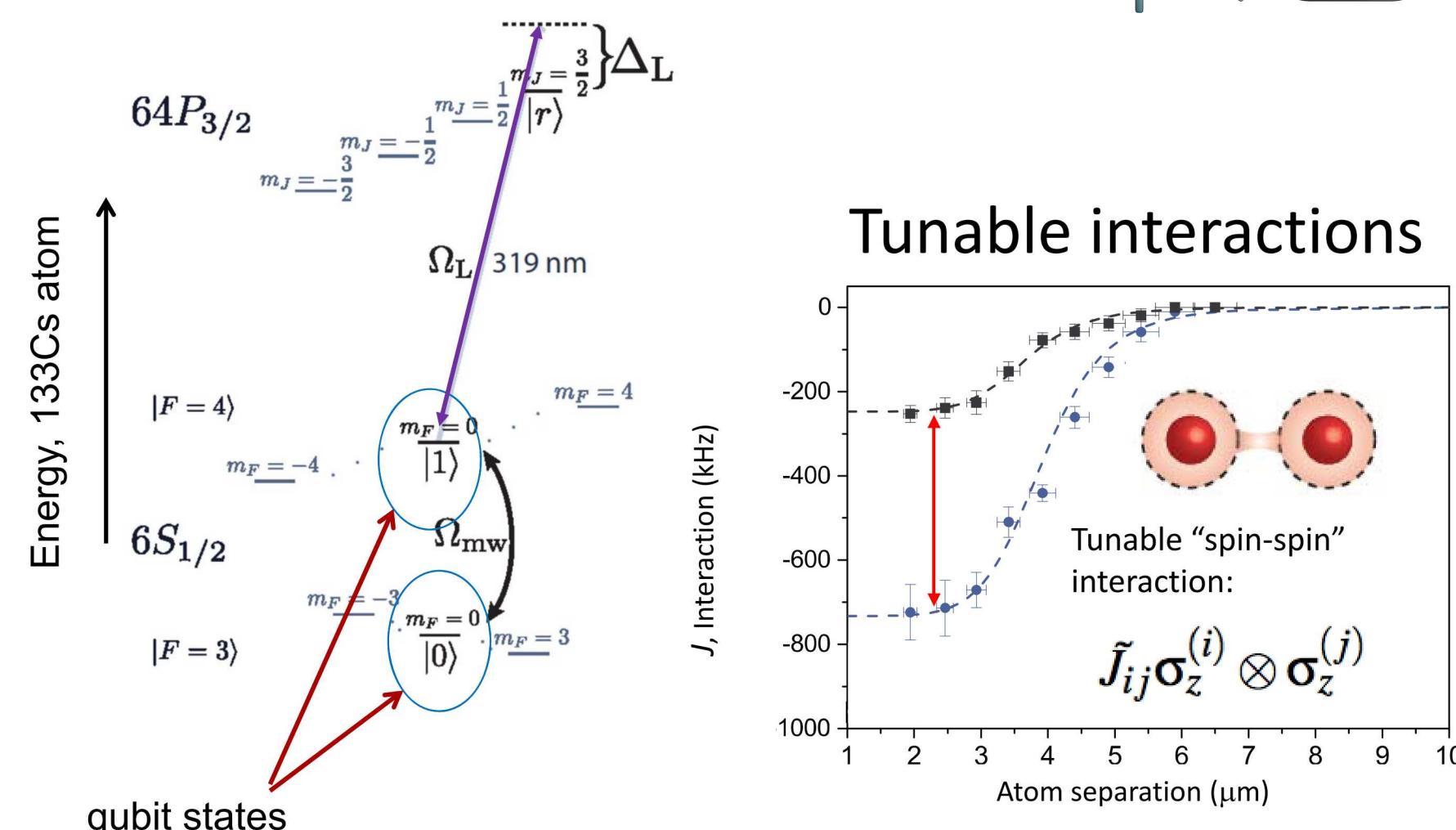


Neutral atom-based qubits are highly scalable and controllable. Furthermore, with optical excitation of high-lying, strongly interacting Rydberg states, one can achieve on-demand,



## Rydberg dressing

- Encode qubit in clock states of Cs.
- Admix Rydberg atom character via Laser dressing at 318 nm.
- Dressed potential is tunable and exhibits “soft”-core potential for increased homogeneity.



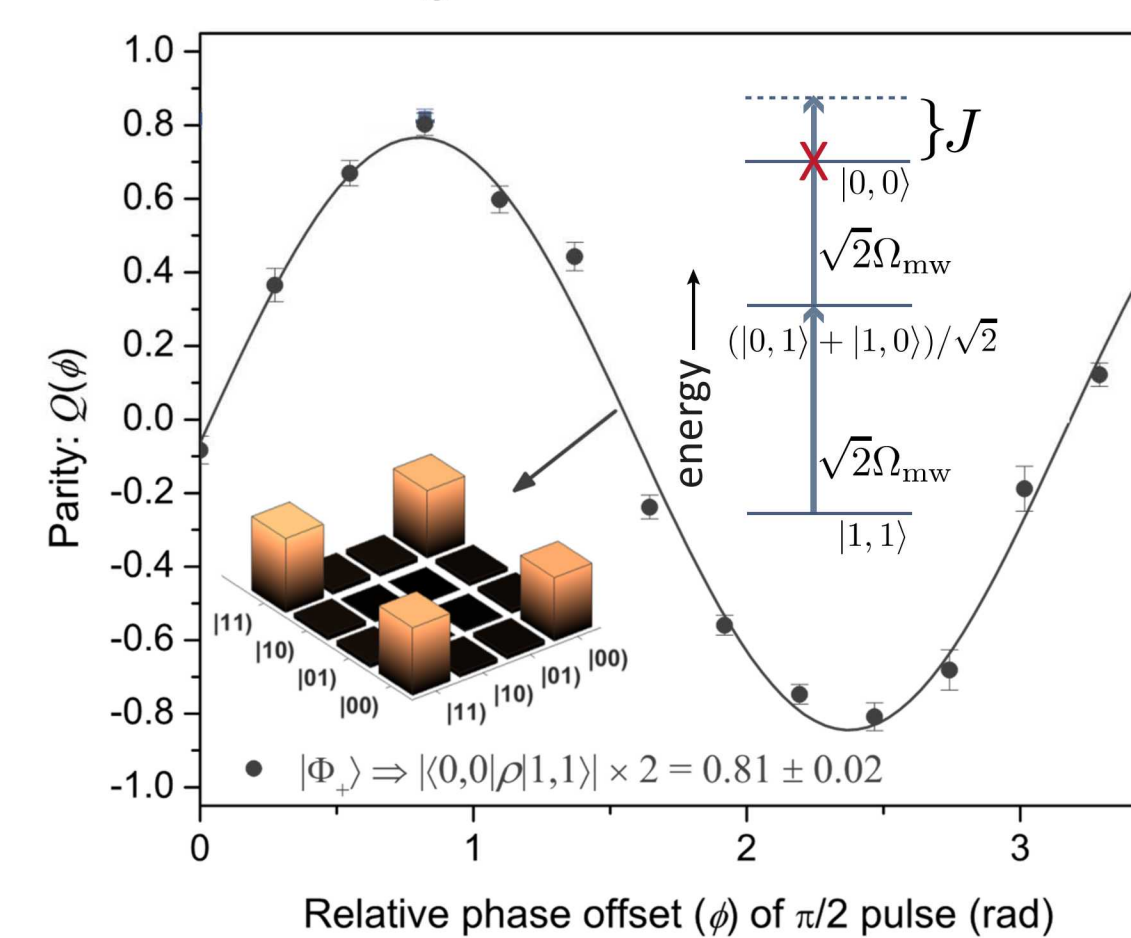
Y.-Y. Jau *et al.*, Nat. Phys. **12**, 71-74 (2016)

## Entanglement Studies

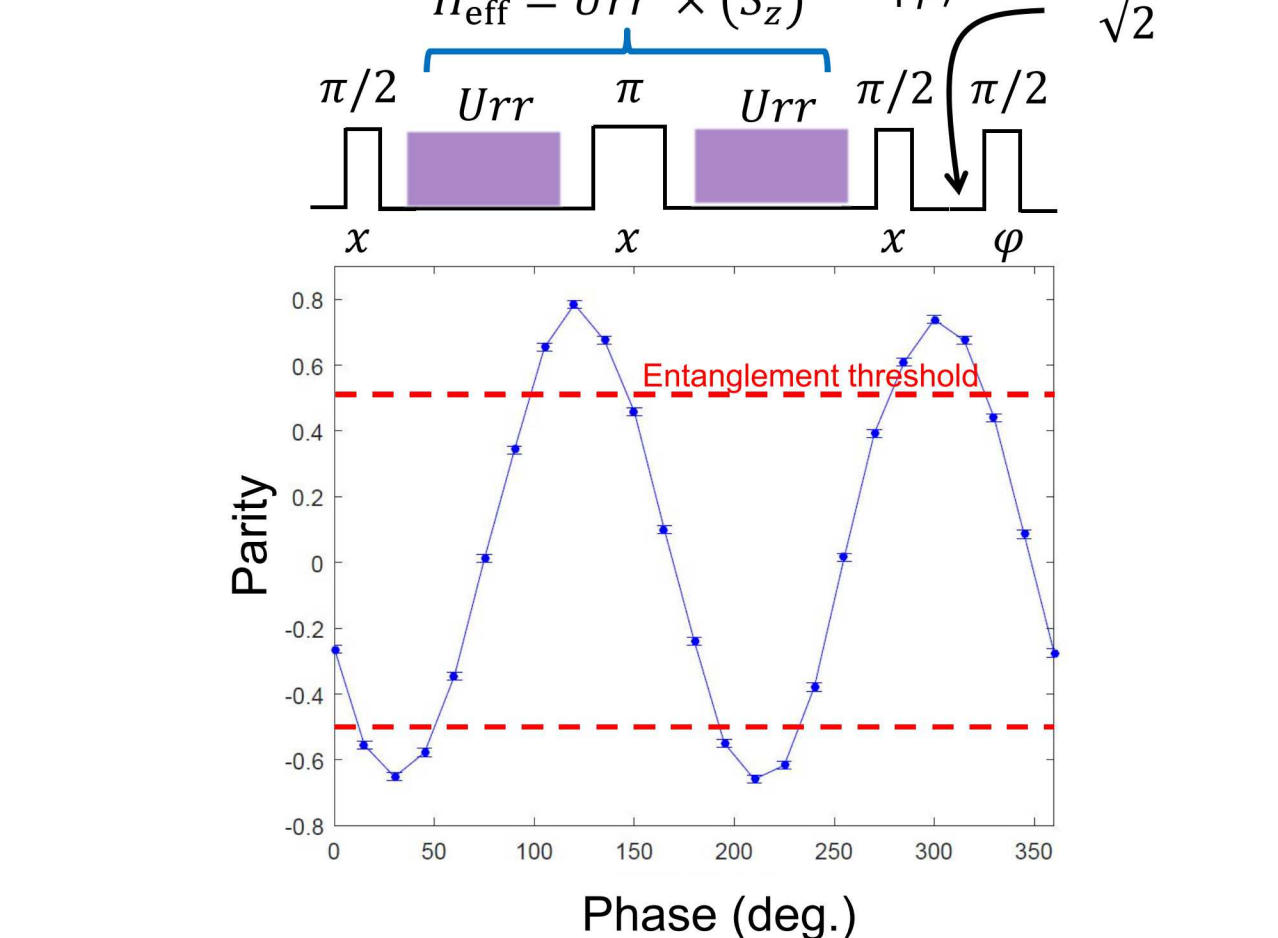
We have demonstrated entanglement between two atoms via blockade and via a controlled phase (CPHASE) gate approach. Both utilize the Rydberg dressing approach.

- Blockade: Prepare two-atom Bell state via nonlinear spectrum.
- CPHASE: Nonlinear interaction enables multi-atom entanglement to develop from product states. Requires *control* of interaction.

### Blockade gate



### CPHASE gate



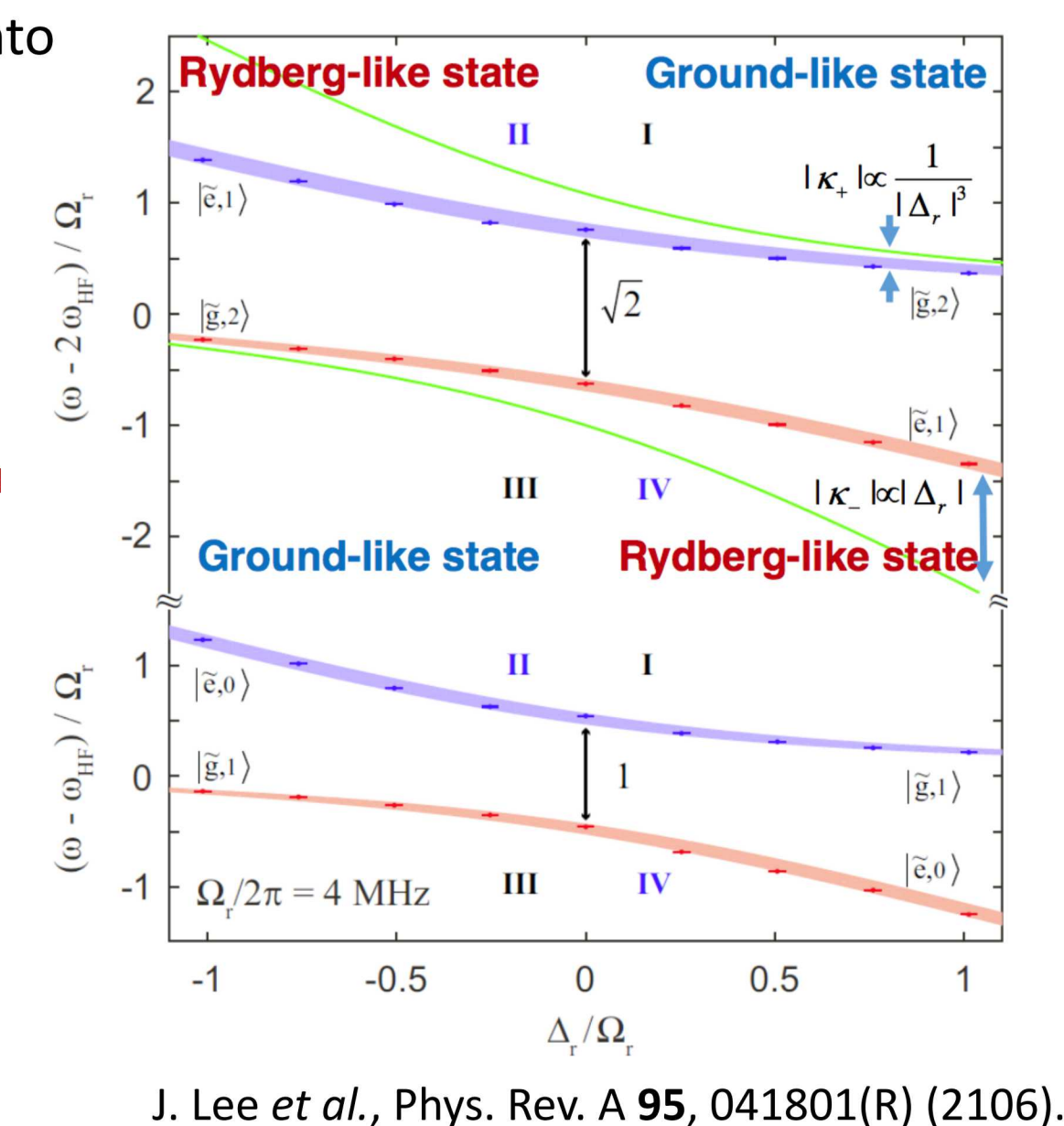
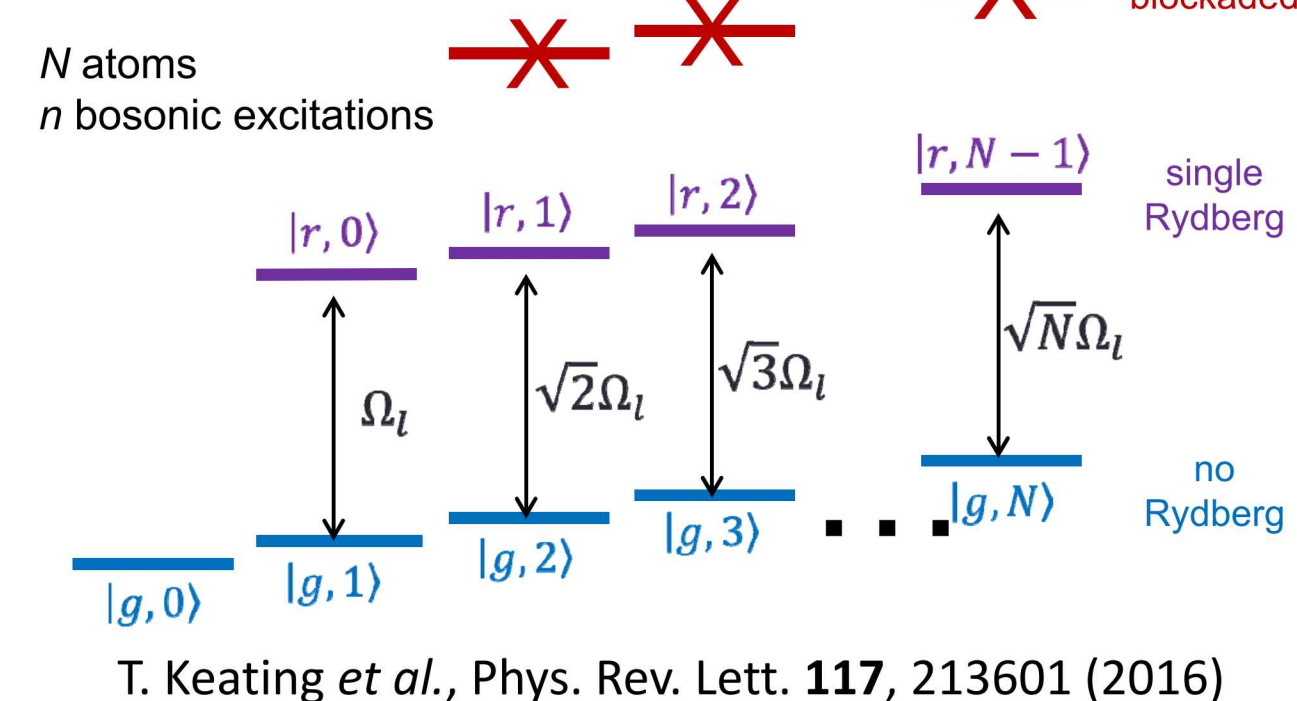
## Jaynes-Cummings ladder

- Multi-atom Rydberg-dressed systems map onto the Jaynes-Cummings model of cavity QED.
- Such a system is amenable to control via strategies developed for cavity QED.

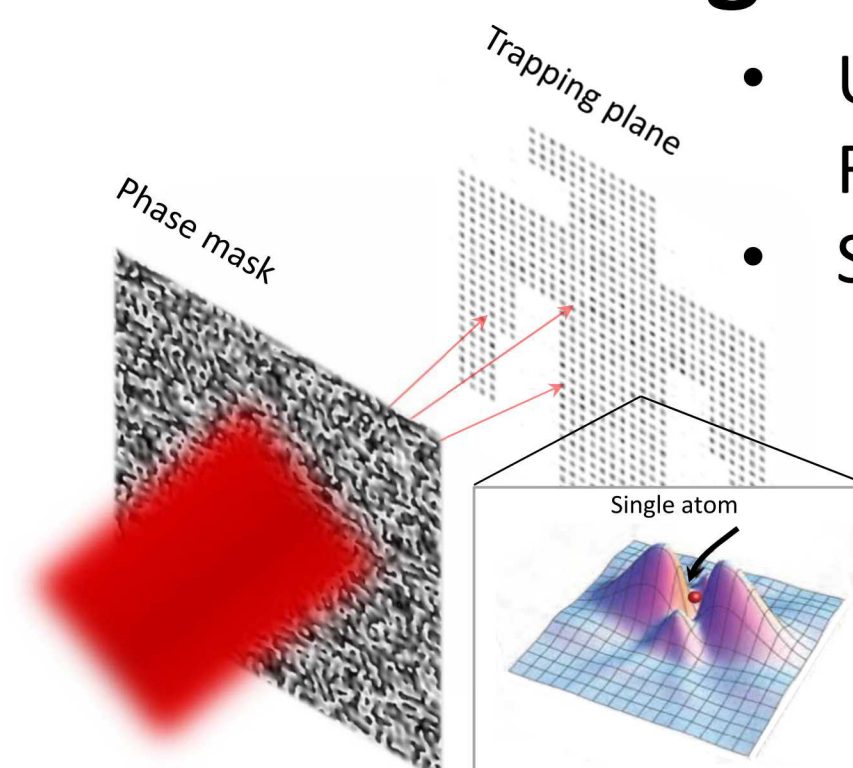
### notation

$$|g, n\rangle \equiv \text{Sym.}(|0\rangle^{\otimes n-1} |1\rangle \otimes |n\rangle)$$

$$|r, n\rangle \equiv \text{Sym.}(|r\rangle \otimes |0\rangle^{\otimes n-1} |1\rangle \otimes |n\rangle)$$



## Towards larger systems



- Utilize digital holography to create configurable arrays of Rydberg-dressed neutral atoms.
- Scale existing neutral atom quantum information efforts.
- Enable creation of large-scale entangled states.
- Create geometries that can simulate interesting, physically-relevant, models of quantum magnetism.

