Ultrafast infrared spectroscopy with single molecular ions

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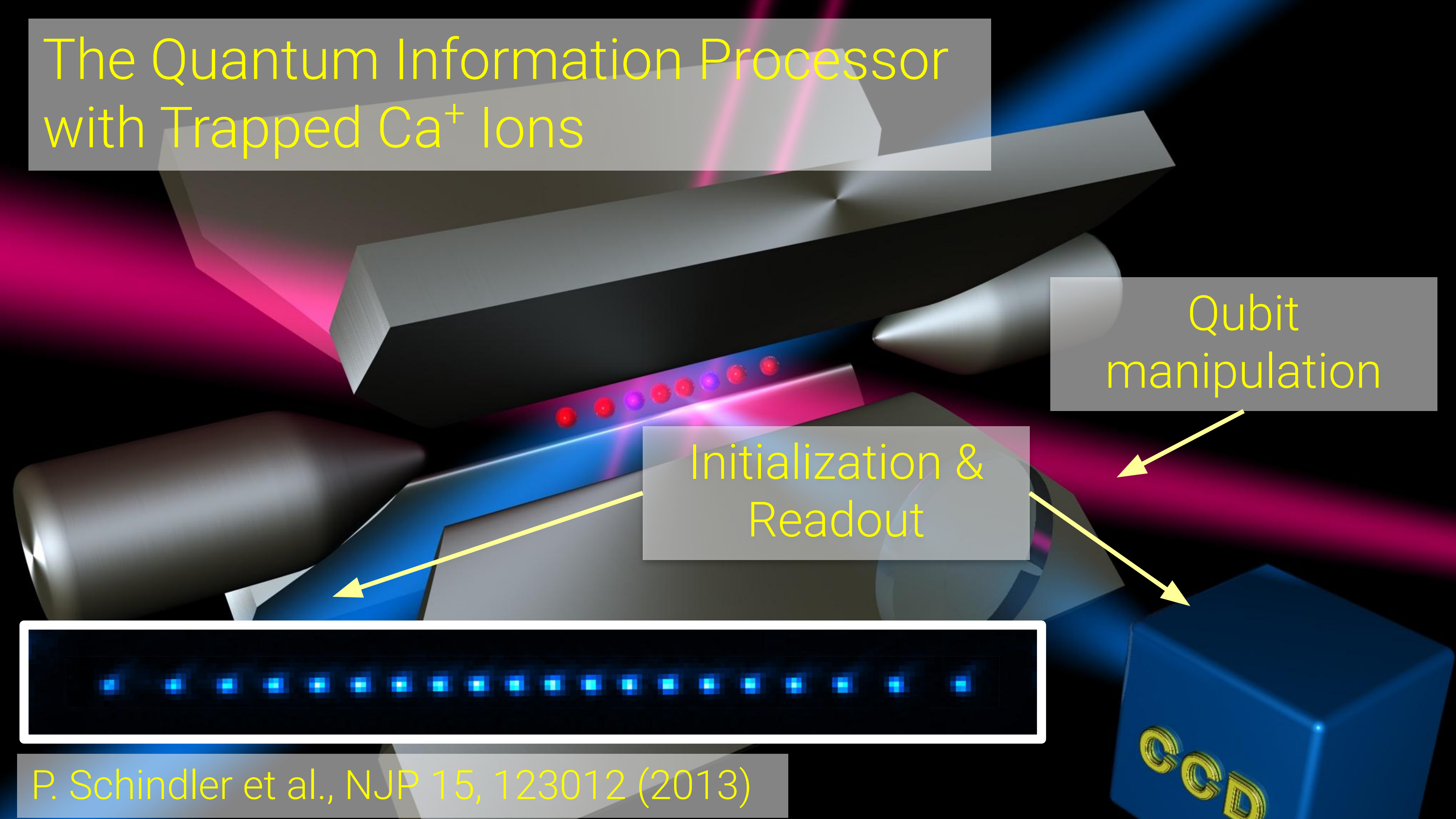
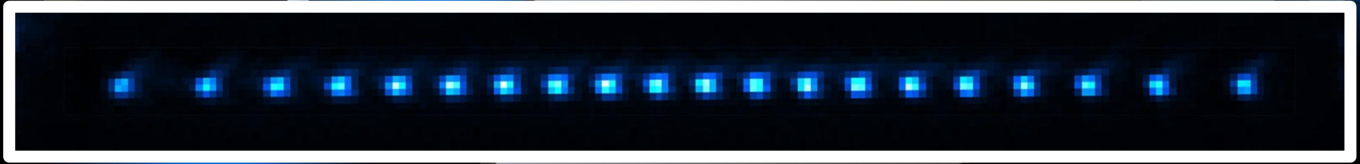

The Quantum Information Processor with Trapped Ca+ Ions
Qubit manipulation
Initialization & Readout
CCD
P. Schindler et al., NJP 15, 123012 (2013)

The Quantum Information Processor with Trapped Ca^+ Ions

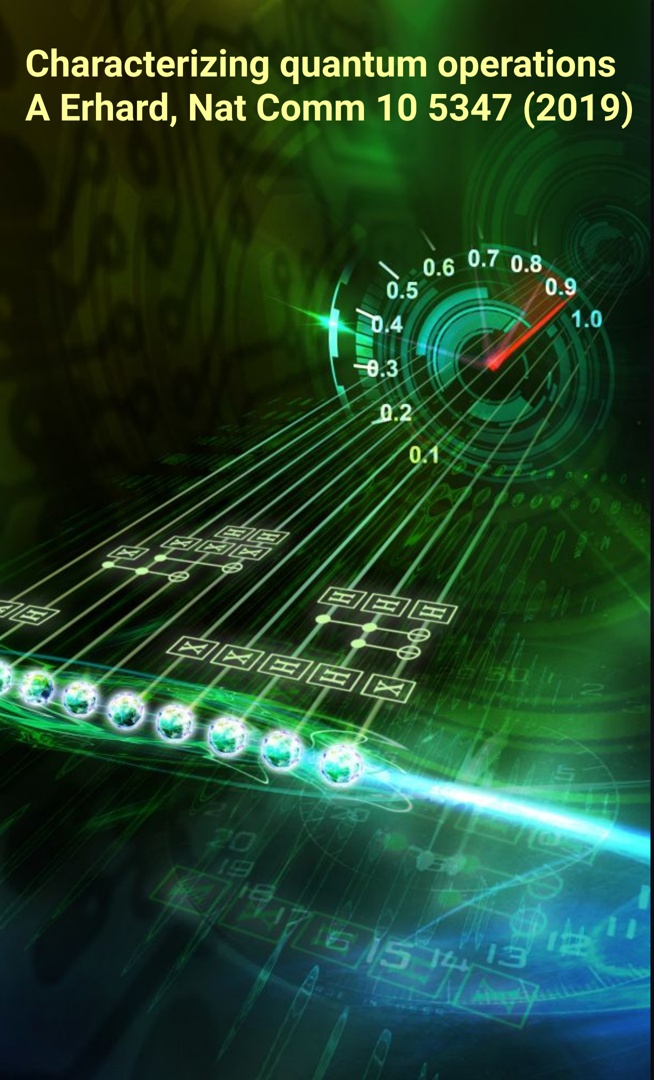
T_2 > 100ms - T_{gate} = 10µs

Error rate < 1%

Limited by imperfections in control fields

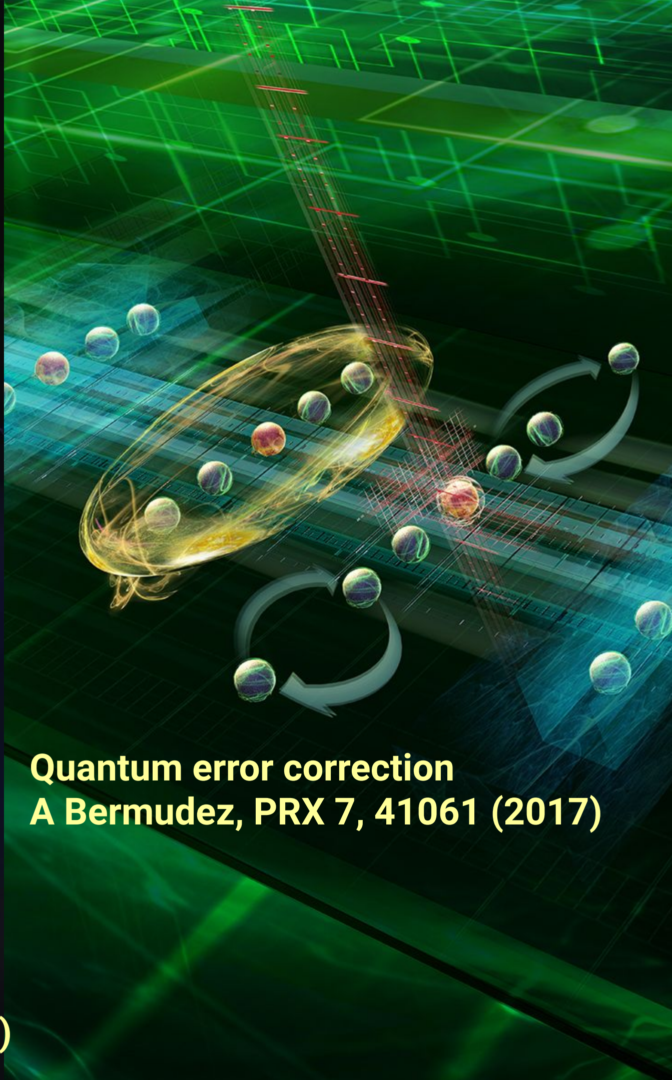


P. Schindler et al., NJP 15, 123012 (2013)



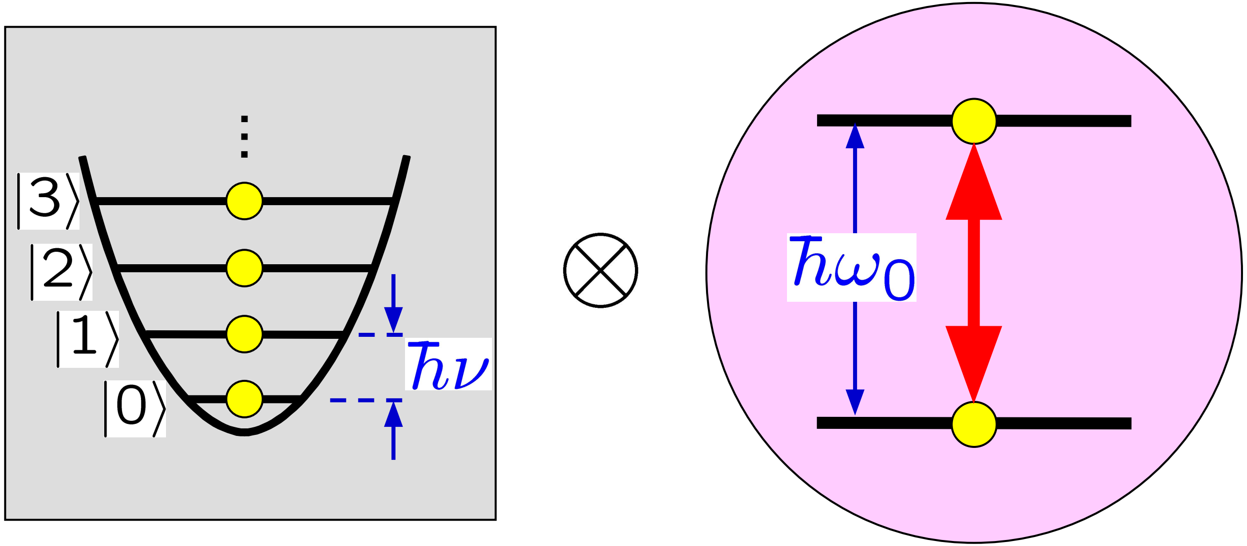
Characterizing quantum operations
A Erhard, Nat Comm 10 5347 (2019)

Simulation of high energy physics
E. Martinez, Nature 534, 516 (2016)



Quantum error correction
A Bermudez, PRX 7, 41061 (2017)

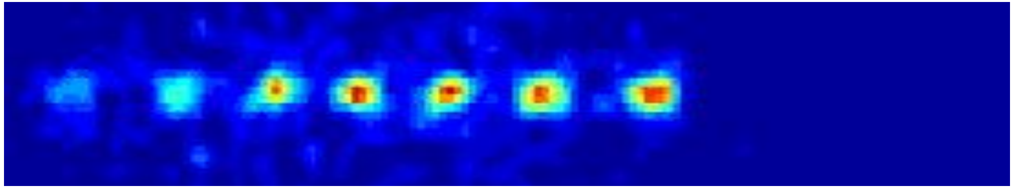
Ion traps for quantum information processing



Ion motion ⊗ Electronic state

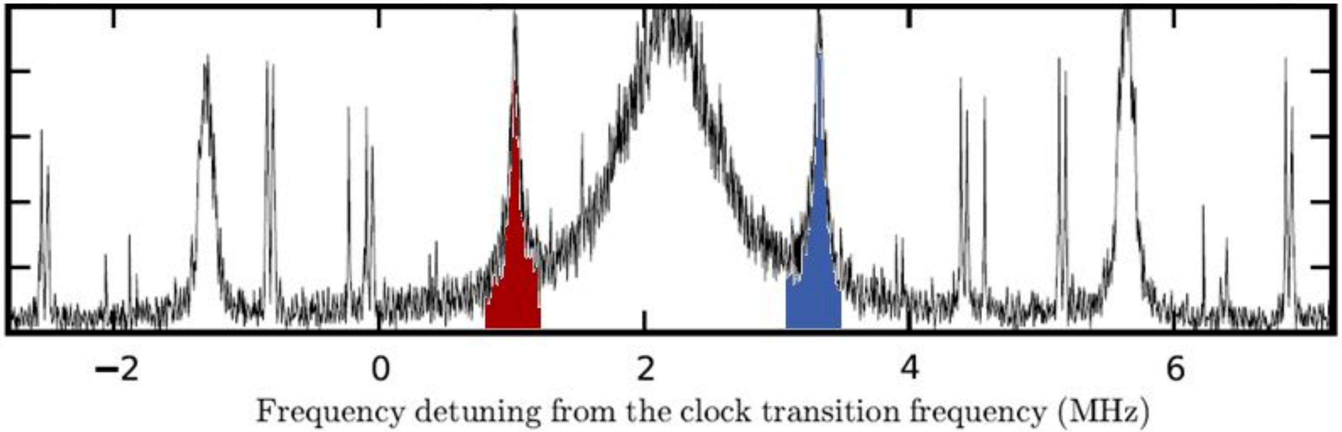
$$|D_{5/2}\rangle \equiv |\uparrow\rangle \equiv |\mathbf{0}\rangle$$

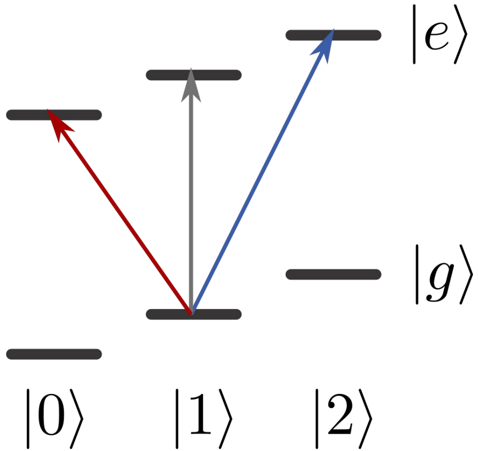
$$|S_{1/2}\rangle \equiv |\downarrow\rangle \equiv |\mathbf{1}\rangle$$



Quantum bus to mediate interactions

Coupling to the quantum bus





Carrier transition: No change of motional mode
Red sideband: Reduce phonon number by one
Blue sideband: Increase phonon number by one

Conditional operations on electronic states depending on the motional state

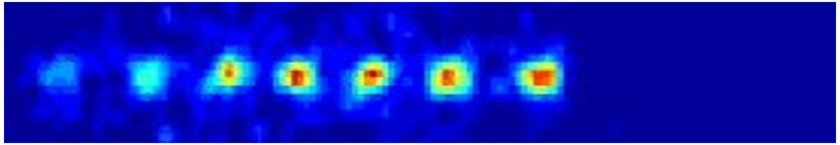
What about molecules?

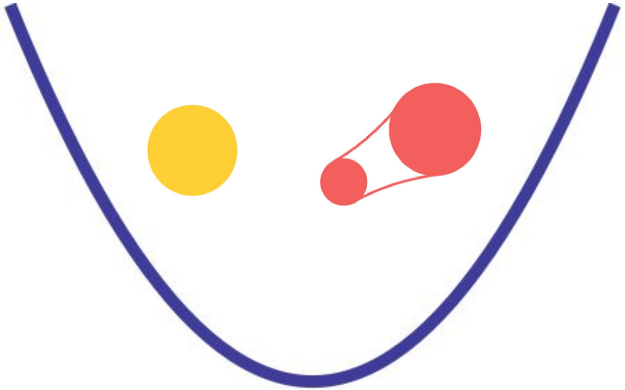
Sympathetic cooling of external degree of freedom to the ground state

Quantum Logic Spectroscopy of internal degrees of freedom:

Use quantum logic techniques to prepare and read-out molecular state.

Manipulate motional mode depending on molecular state





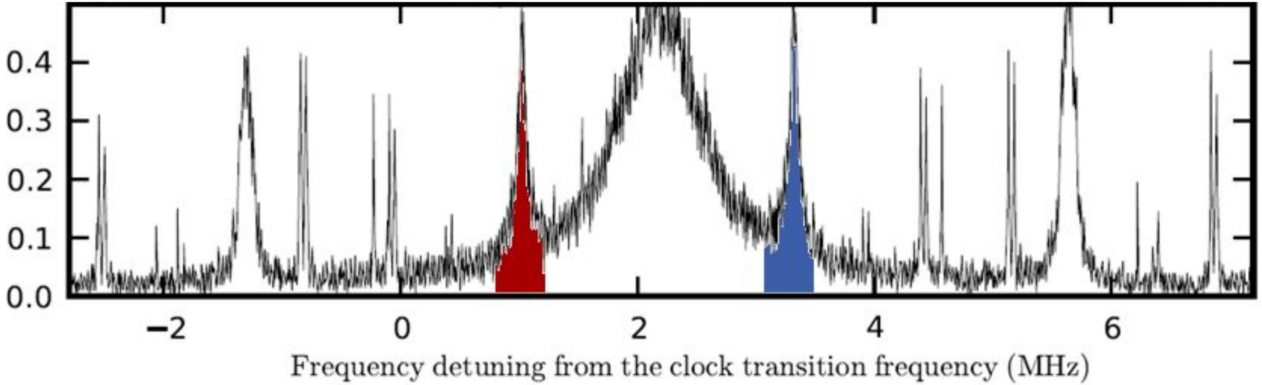
P. Schmidt et al., Science 309, 749 (2005)

C. Chou et al, Nature 545, 203 (2017)

F. Wolf et al, Nature 530, 457 (2016)

M. Sinhal et al, arXiv 1910.11600 (2019)

Time domain methods?

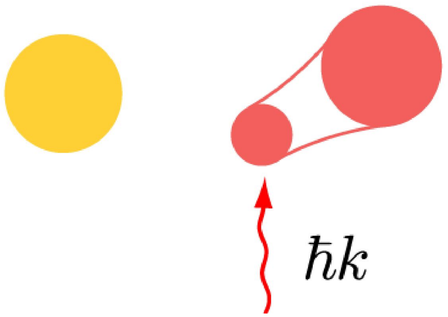


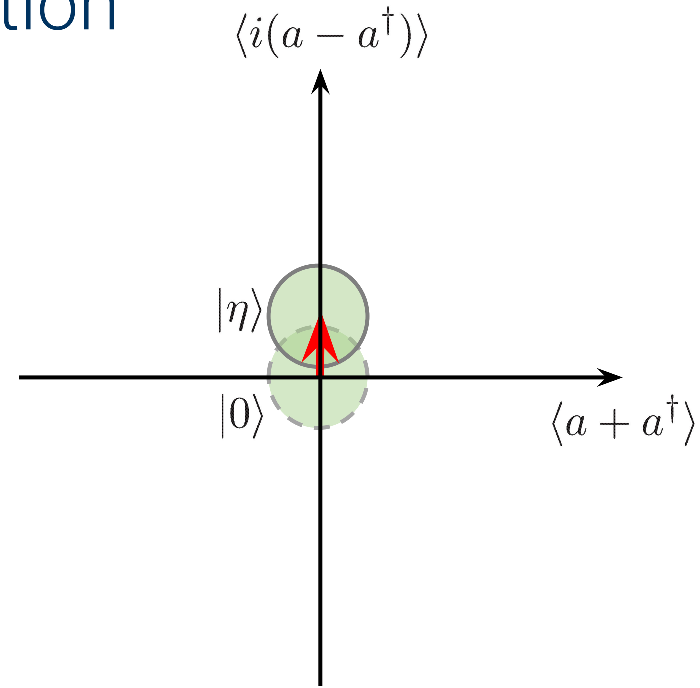
The motional frequency limits the speed of the interaction to several microseconds

The motional state can be manipulated faster than its oscillating frequency!

J. J. Garcia-Ripoll, PRL 91, 157901 (2003)

A kick from single photon absorption



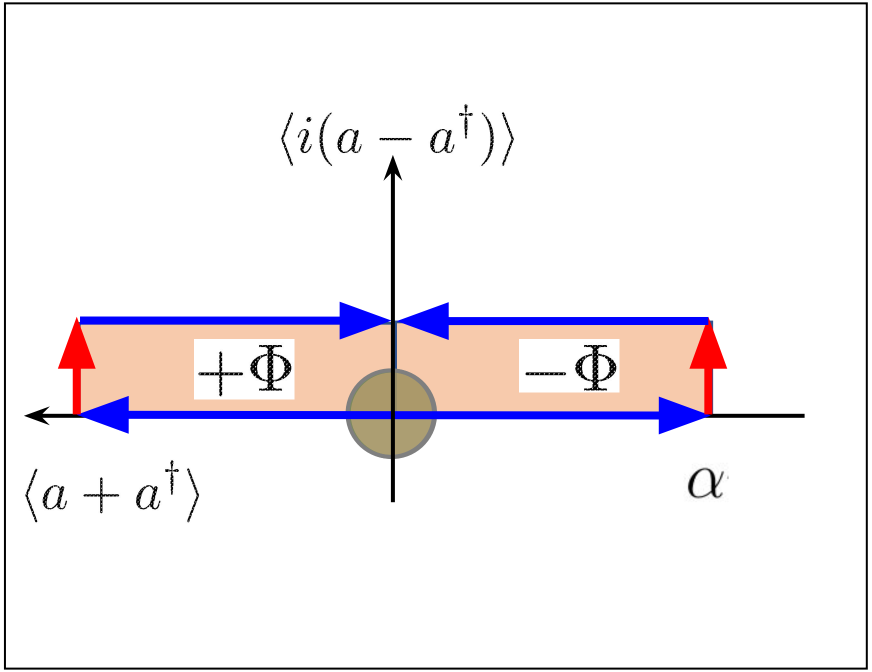


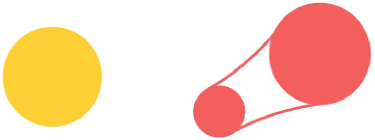
Detection probability for a ground-state cooled ion:

$$p = 1 - |\langle 0|\hat{D}(\eta)|0\rangle|^2 \approx \eta^2 \qquad \eta \ll 1$$

C. Hempel. Nat. Photon. 7, 630 (2013)

Enhanced single photon detection scheme





1 Create cat state

2 Absorption on molecule

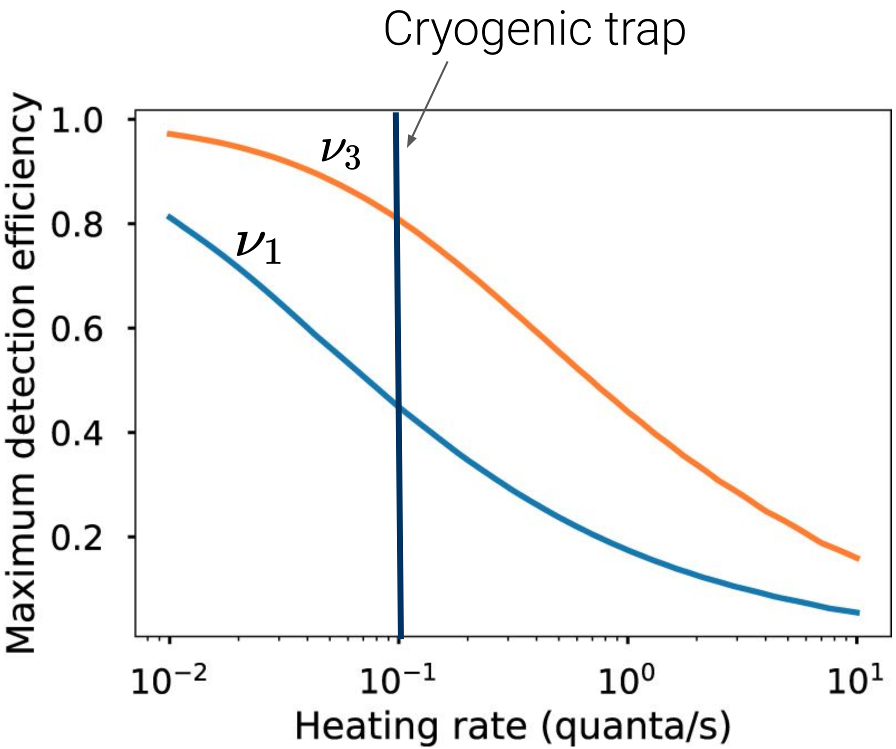
3 Recombine cat state

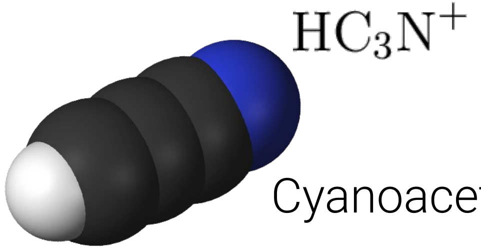
4 Measure geometric phase

$$p_{det} = \sin(2\alpha\eta)^2$$

C. Hempel. Nat. Photon. 7, 630 (2013)

Expected detection efficiency



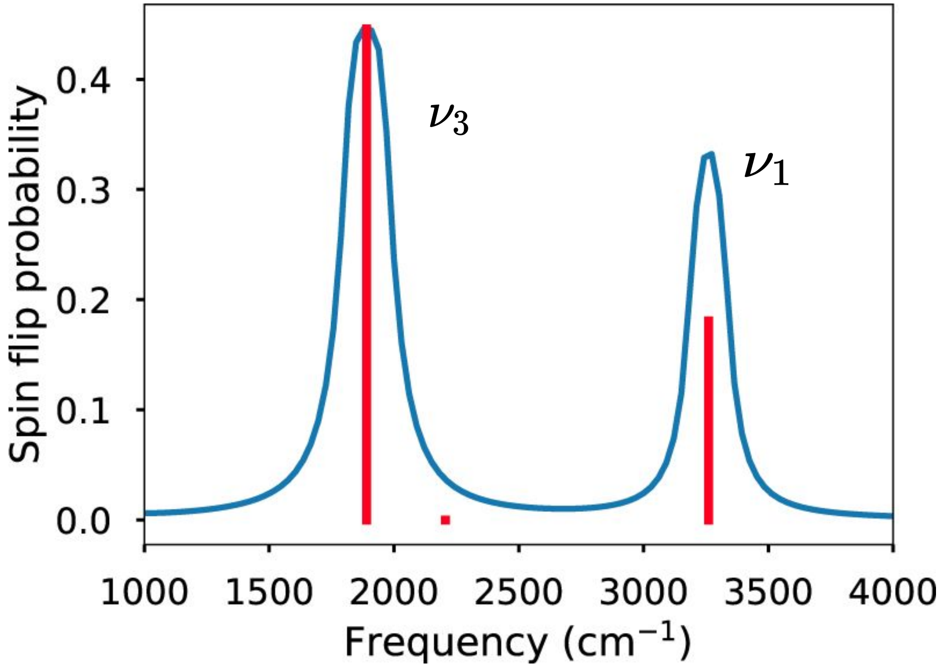


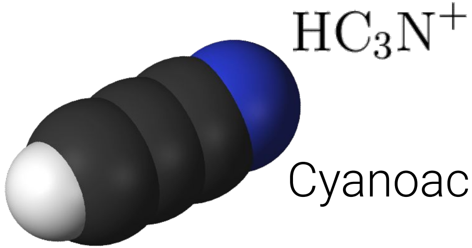
Cyanoacetylene cation

Mode	Frequency (cm^{-1})
*v*1	**3259** (213)
*v*2	2206 (2)
*v*3	**1890** (334)
*v*4	911 (7)

Z. Dai et al, JCP 143, 054301 (2015)
A Desrier et al, JCP 145, 234310 (2016)
P. Schindler, NJP 21 083025 (2019)

Single pulse spectrum





Mode	Frequency (cm^{-1})
v1	**3259** (213)
v2	2206 (2)
v3	**1890** (334)
v4	911 (7)

Single-pulse, single-photon absorption spectroscopy

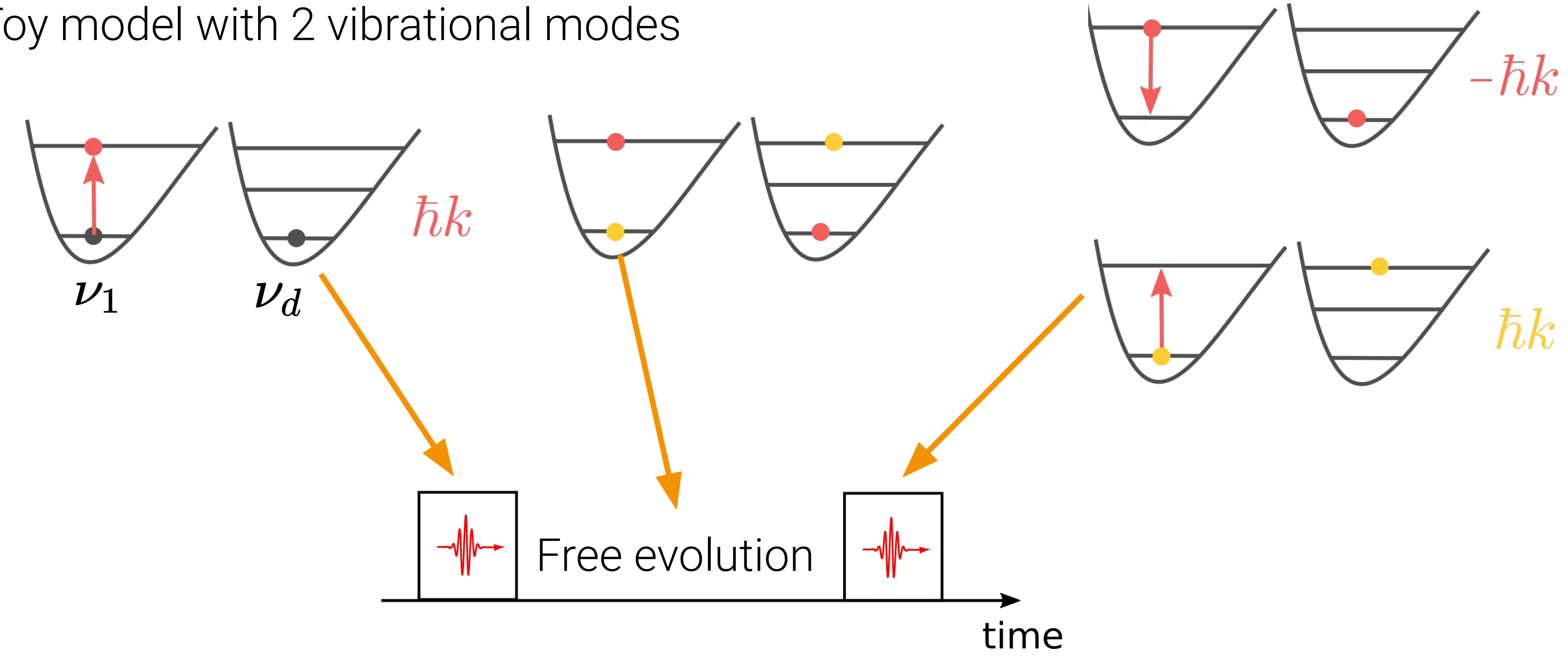
Z. Dai et al, JCP 143, 054301 (2015)

A Desrier et al, JCP 145, 234310 (2016)

P. Schindler, NJP 21 083025 (2019)

Pump - Probe spectroscopy

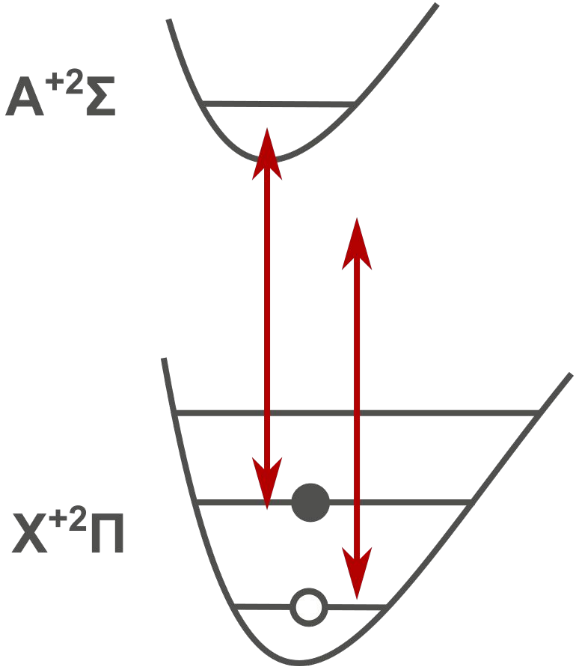
Toy model with 2 vibrational modes



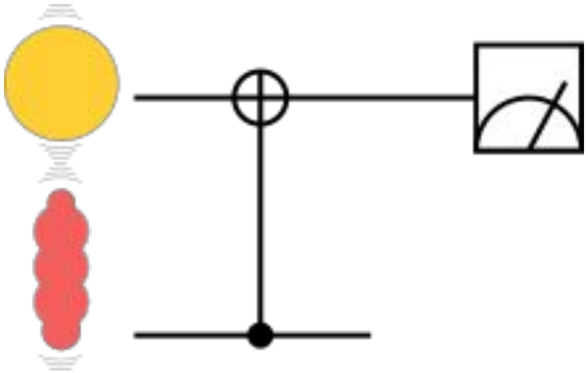
Measure the total recoil of multi-pulse sequence

P. Schindler, NJP 21 083025 (2019)

Optical dipole force



"Optical tweezer" with a force depending on vibrational quantum number

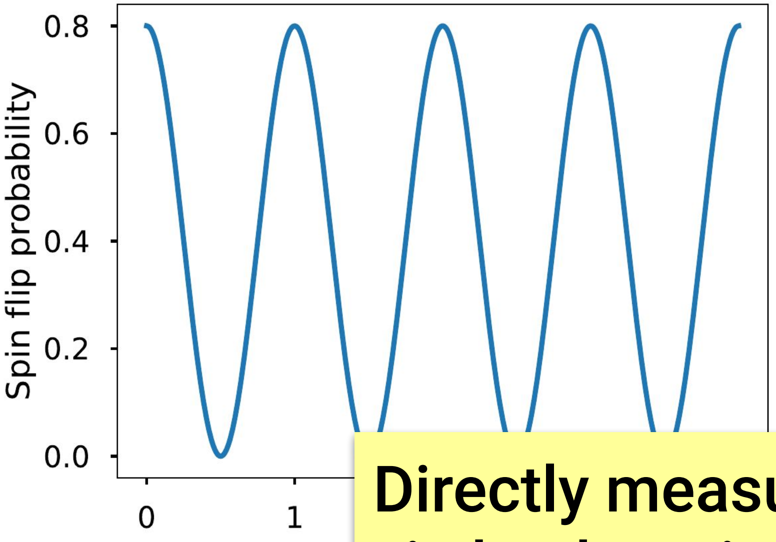


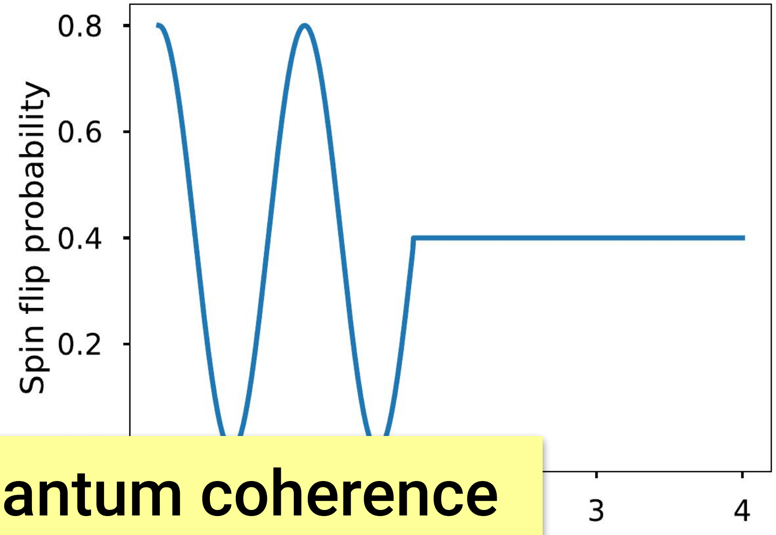
Corresponds to non-demolition measurement of vibrational population

F. Wolf et al, Nature 530, 457 (2016)

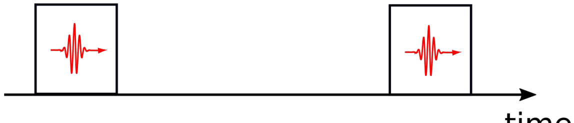
M. Sinhal et al, arXiv 1910.11600

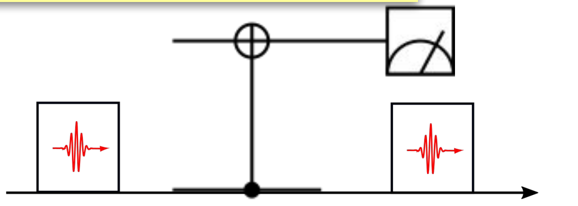
Quantum non demolition measurement

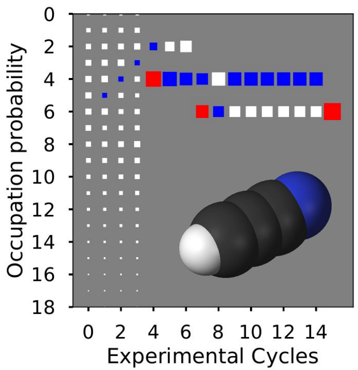




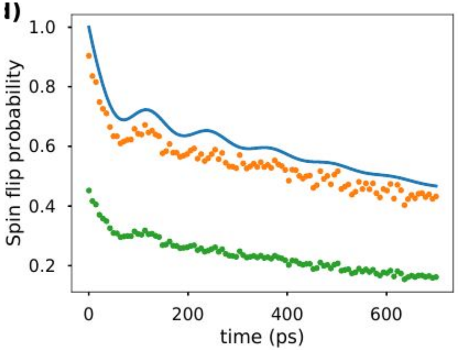
Directly measure quantum coherence via back-action of the measurement



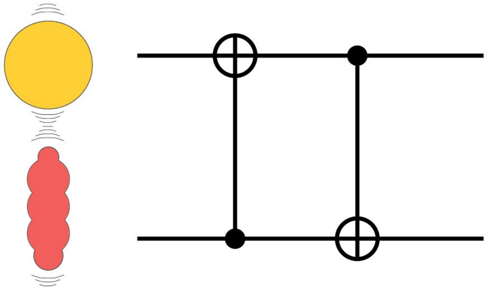




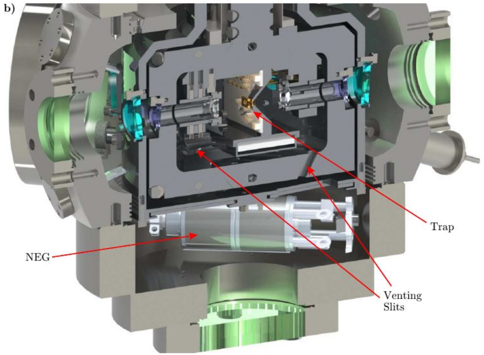
State preparation of polyatomic molecules



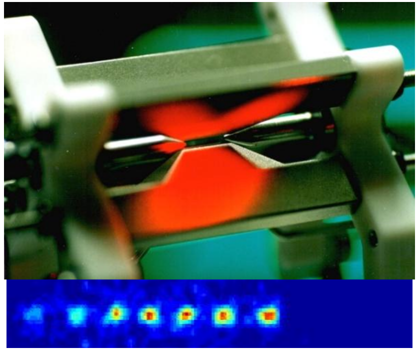
Characterize quantum dynamics in molecules



Molecule powered quantum information processing
Talk 15:40 R. de Vivie-Riedle



Experimental implementation



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