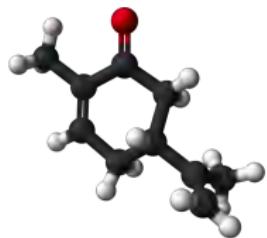
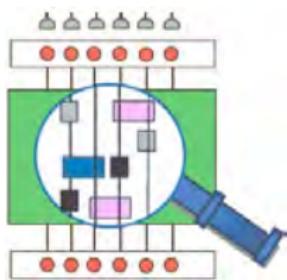


Training Schrödinger's Cat: Quantum Control in Molecular Physics and Quantum Information Science



Christiane Koch



last year so many things were different . . .

last year so many things were different ...

U N I K A S S E L
V E R S I T Ä T



Freie Universität Berlin



quantum control

— the superposition principle at work —

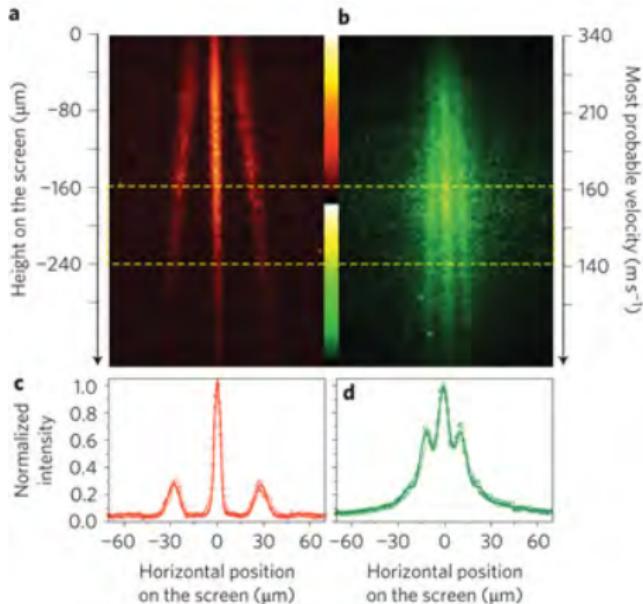
quantum control

— the superposition principle at work —

quantum mechanics:

a molecule

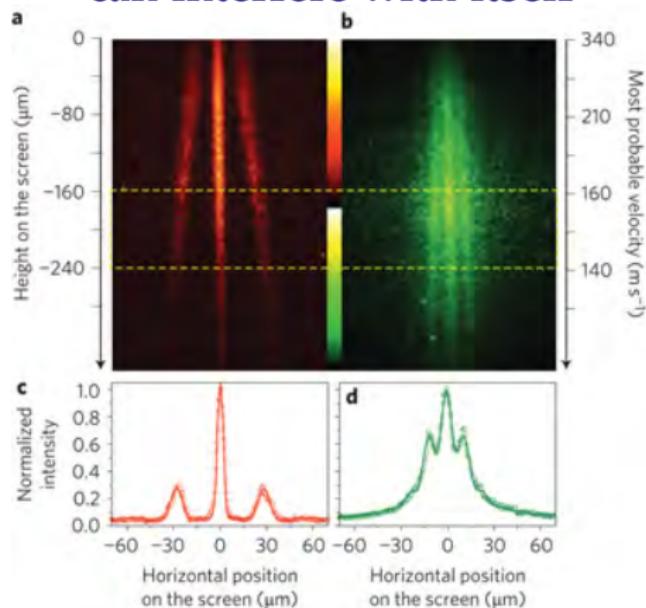
can interfere with itself



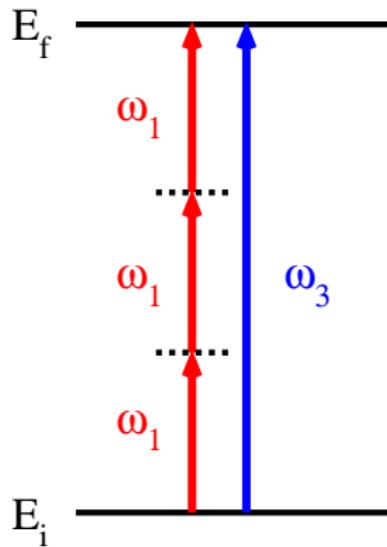
quantum control

— the superposition principle at work —

quantum mechanics:
a molecule
can interfere with itself



quantum control:
build interferences at will
using external fields



quantum optimal control

quantum optimal control

current applications

(laser) control of
atoms & molecules

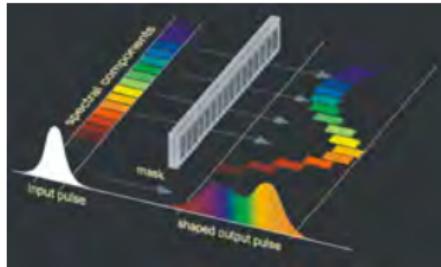
NMR

quantum
information

quantum optimal control

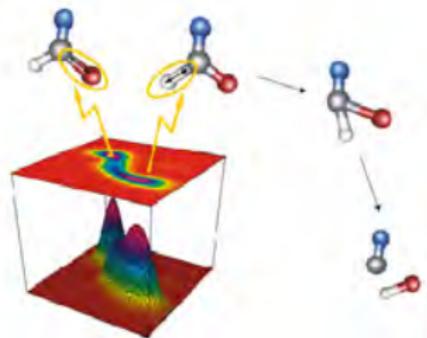
current applications

(laser) control of
atoms & molecules



NMR

quantum
information

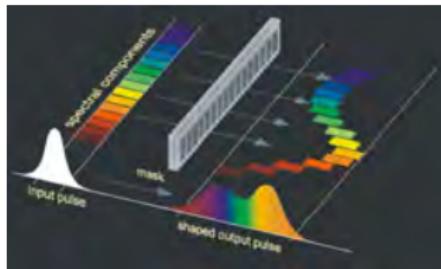


courtesy: R. de Vivie-Riedle

quantum optimal control

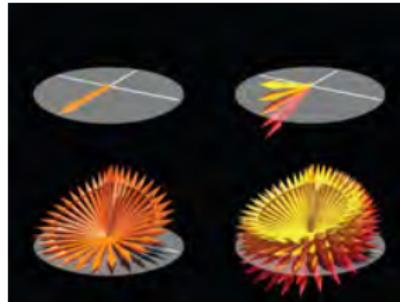
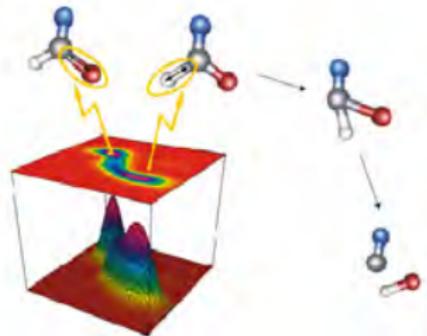
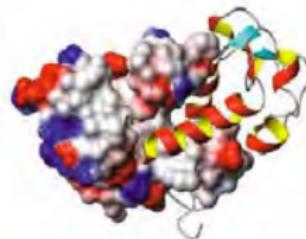
current applications

(laser) control of
atoms & molecules



NMR

quantum
information



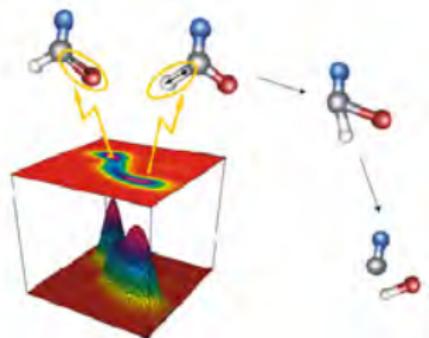
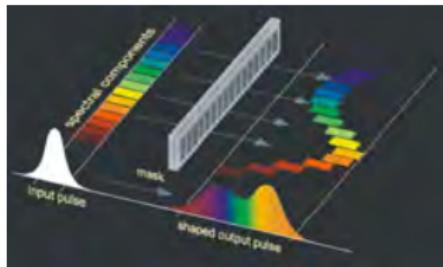
courtesy: R. de Vivie-Riedle

courtesy: S. Glaser

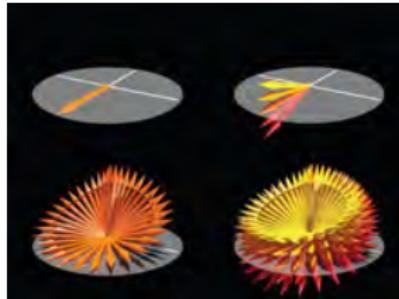
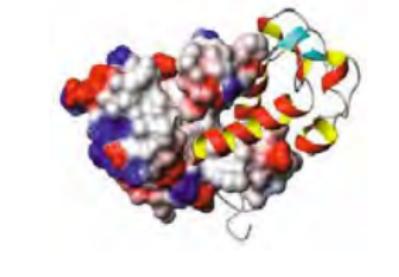
quantum optimal control

current applications

(laser) control of atoms & molecules

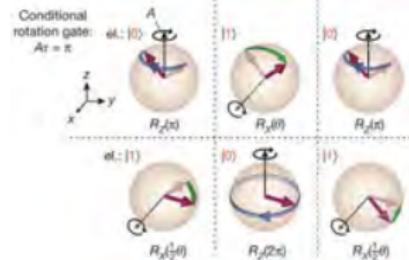
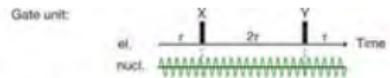
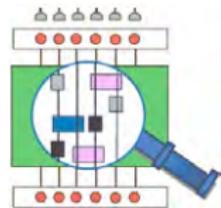


NMR



courtesy: S. Glaser

quantum information



courtesy: F. Jelezko

courtesy: R. de Vivie-Riedle

quantum optimal control

determining the fields that build interferences at will

Glaser et al., Eur. Phys. J. D 69, 279 (2015)

define the objective :

$$\text{GOAL} \equiv \|\langle \varphi_{\text{ini}} | \hat{\mathbf{U}}^+(T, 0; \epsilon) | \varphi_{\text{target}} \rangle\|^2 = -J_T$$

as a functional of the external field ϵ

quantum optimal control

determining the fields that build interferences at will

Glaser et al., Eur. Phys. J. D 69, 279 (2015)

define the objective :

$$\text{GOAL} \equiv \|\langle \varphi_{\text{ini}} | \hat{\mathbf{U}}^+(T, 0; \epsilon) | \varphi_{\text{target}} \rangle\|^2 = -J_T$$

as a functional of the external field ϵ

include additional constraints:

$$J = J_T + \int_0^T J_t(\epsilon, \varphi) dt$$

quantum optimal control

determining the fields that build interferences at will

Glaser et al., Eur. Phys. J. D 69, 279 (2015)

define the objective :

$$\text{GOAL} \equiv \|\langle \varphi_{\text{ini}} | \hat{\mathbf{U}}^+(T, 0; \epsilon) | \varphi_{\text{target}} \rangle\|^2 = -J_T$$

as a functional of the external field ϵ

include additional constraints:

$$J = J_T + \int_0^T J_t(\epsilon, \varphi) dt$$

optimize J by demanding:

$$\partial_\epsilon J = 0 \quad \partial_{\varphi(t)} J = 0 \quad \partial_\epsilon^2 J > 0$$

$$|\varphi(t)\rangle = \hat{\mathbf{U}}(t, 0; \epsilon) |\varphi_{\text{ini}}\rangle \quad \hat{\mathbf{H}} = \hat{\mathbf{H}}_0 + \epsilon(t) \hat{\mathbf{H}}_1$$

or by searching for best parametrization of $\epsilon(t)$

quantum optimal control

determining the fields that build interferences at will

Glaser et al., Eur. Phys. J. D 69, 279 (2015)

define the objective :

$$\text{GOAL} \equiv \|\langle \varphi_{\text{ini}} | \hat{\mathbf{U}}^+(T, 0; \epsilon) | \varphi_{\text{target}} \rangle\|^2 = -J_T$$

as a functional of the external field ϵ

include additional constraints:

$$J = J_T + \int_0^T J_t(\epsilon, \varphi) dt$$

optimize J by demanding:

$$\partial_\epsilon J = 0 \quad \partial_{\varphi(t)} J = 0 \quad \partial_\epsilon^2 J > 0$$

$$|\varphi(t)\rangle = \hat{\mathbf{U}}(t, 0; \epsilon) |\varphi_{\text{ini}}\rangle \quad \hat{\mathbf{H}} = \hat{\mathbf{H}}_0 + \epsilon(t) \hat{\mathbf{H}}_1$$

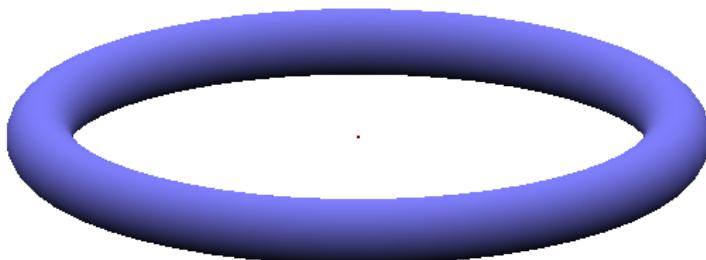
or by searching for best parametrization of $\epsilon(t)$

'easily' generalized to open quantum systems, target operations,
expectation values, or other properties

an example

a first control problem

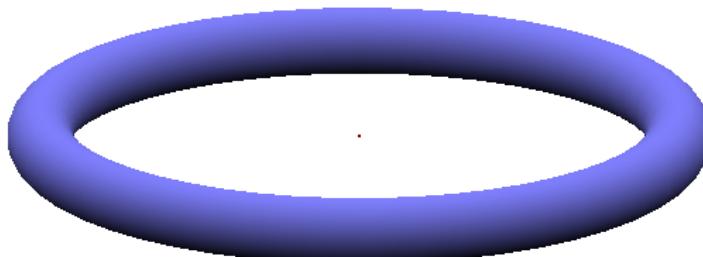
fast & accurate preparation of circular state



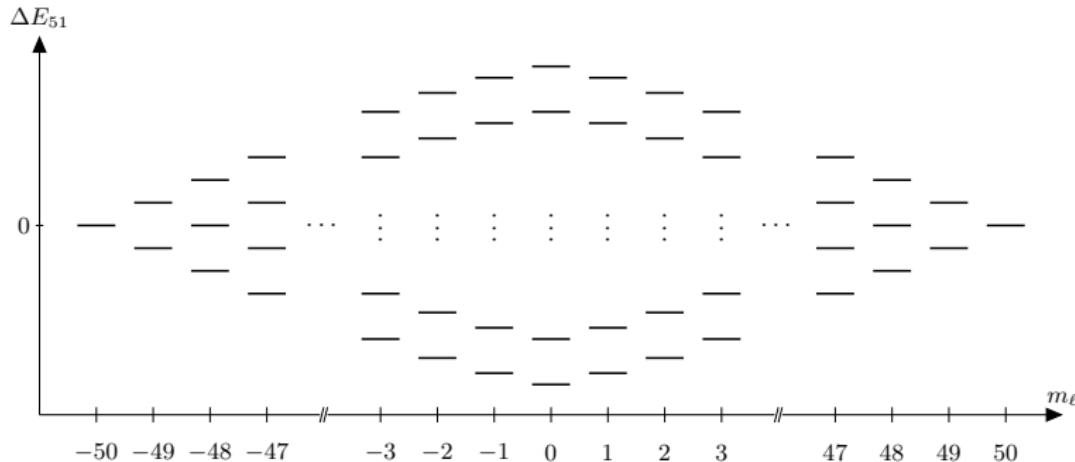
Rb valence electron in
 $|n, (l), m_l^{\max} \rangle$

a first control problem

fast & accurate preparation of circular state

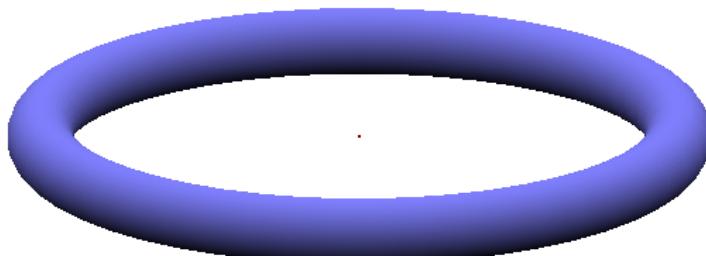


Rb valence electron in
 $|n, (l), m_l^{\max} \rangle$

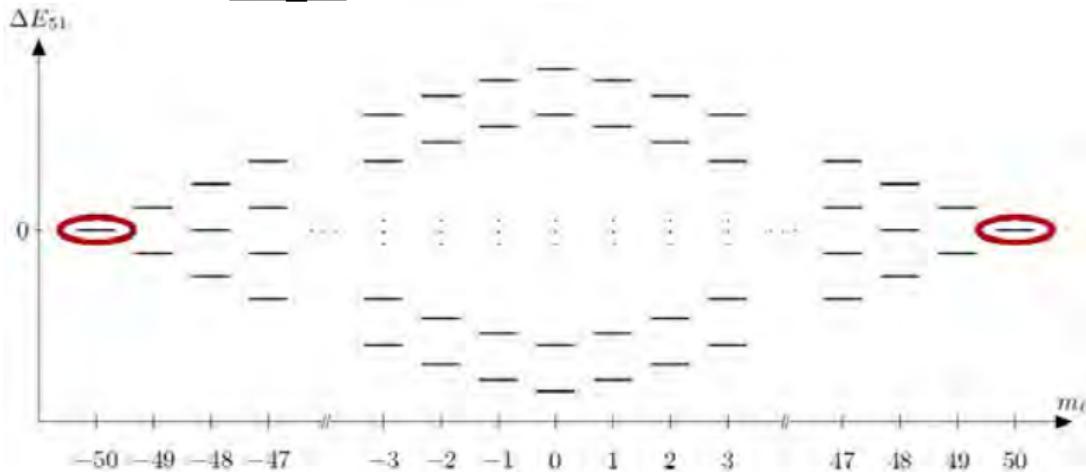


control problem

fast & accurate preparation of circular state



Rb valence electron in
 $|n, (l), m_l^{\max} \rangle$



preparation of circular state why?

preparation of circular state

why?

- super long lifetime
 - ↪ qu sensing ↪ cavity QED
 - ↪ qu interfaces ↪ qu computing

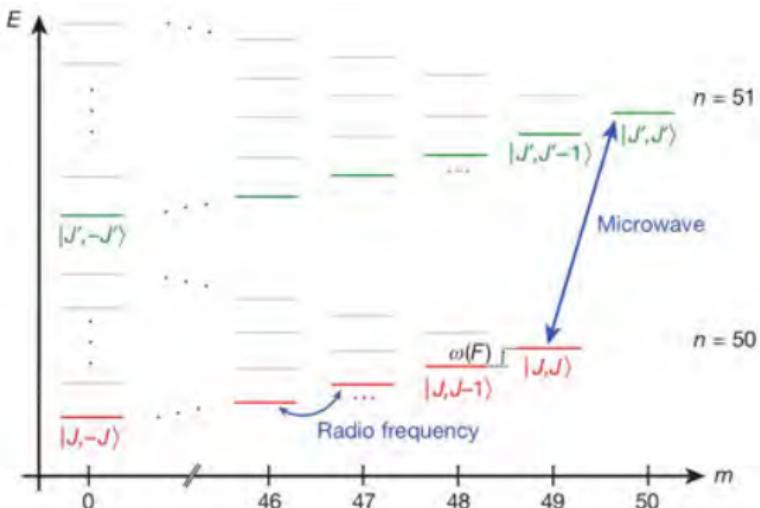
preparation of circular state

LETTER

A sensitive electrometer based on a Rydberg atom
in a Schrödinger-cat state
Albert Ertler^a, Eva-Katharina Überschöf^b, Dennis Giese^c, Siegfried Hofer^c, Stein-Marcus Strohmaier^c, Michael Birnbaum^c,
^aQuantum Optics

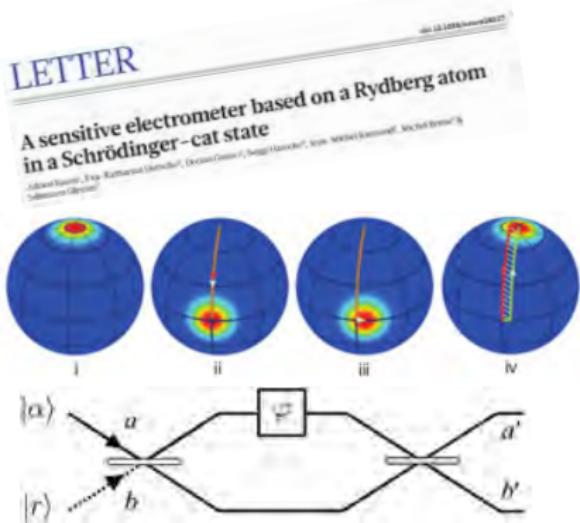
why?

- super long lifetime
- ↪ qu sensing ↪ cavity QED
- ↪ qu interfaces ↪ qu computing



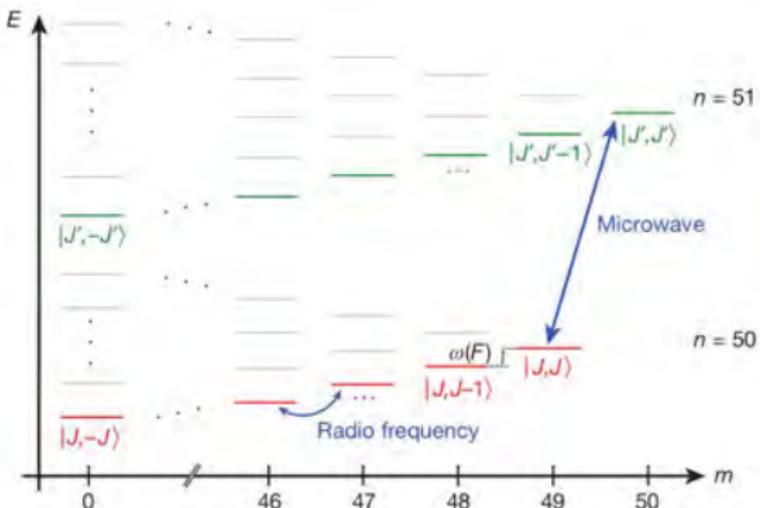
preparation of circular state

LETTER



why?

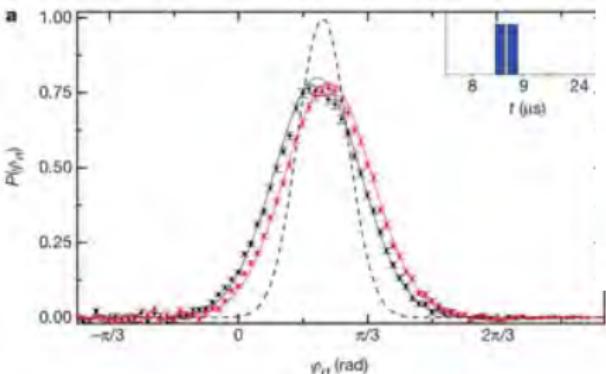
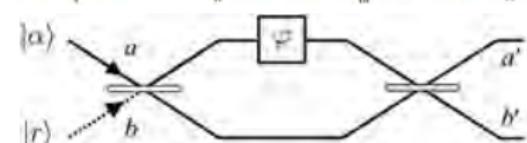
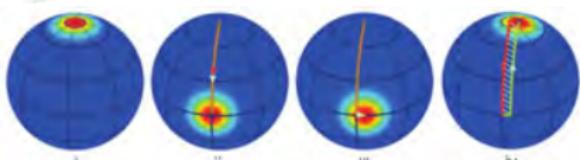
- super long lifetime
- ↪ qu sensing ↪ cavity QED
- ↪ qu interfaces ↪ qu computing



preparation of circular state

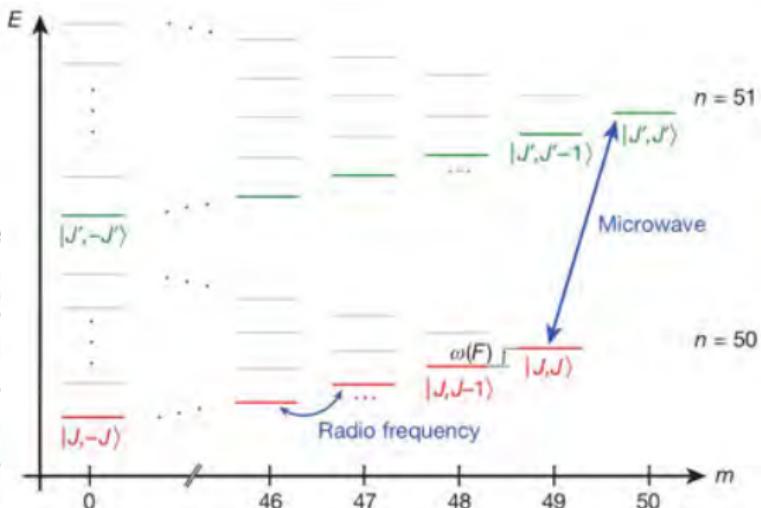
LETTER

A sensitive electrometer based on a Rydberg atom in a Schrödinger-cat state
Robert Kaiser, Eva-Pia Katherina Überschöll, Dennis Göttsche, Siegfried Hoferer, Leon-Michael Krennwein, Michael Birnbaum
Submitted (July 2013); accepted (November 2013)



why?

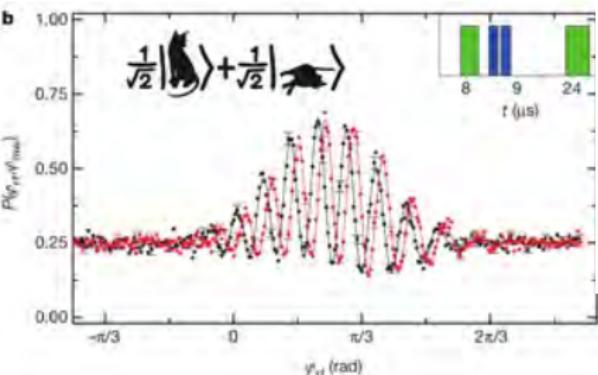
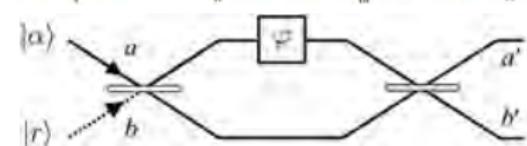
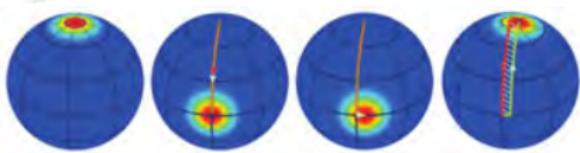
- super long lifetime
- ↪ qu sensing ↪ cavity QED
- ↪ qu interfaces ↪ qu computing



preparation of circular state

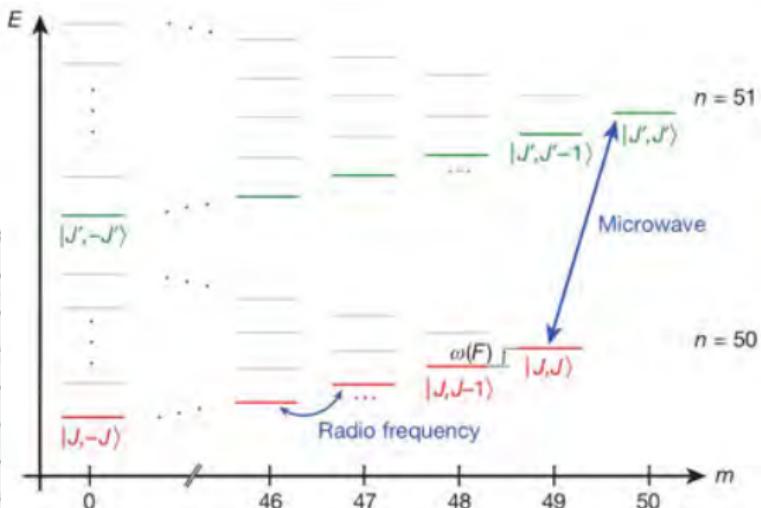
LETTER

doi:10.1088/1367-263X/2007/9
A sensitive electrometer based on a Rydberg atom
in a Schrödinger-cat state
Robert Kaiser, Eva-Pia Katherina Überschöll, Dennis Gericke, Siegfried Hoferer, Stein-Wilhelm Steensgaard, Michael Birnbaum,
Sörensen (Garching)



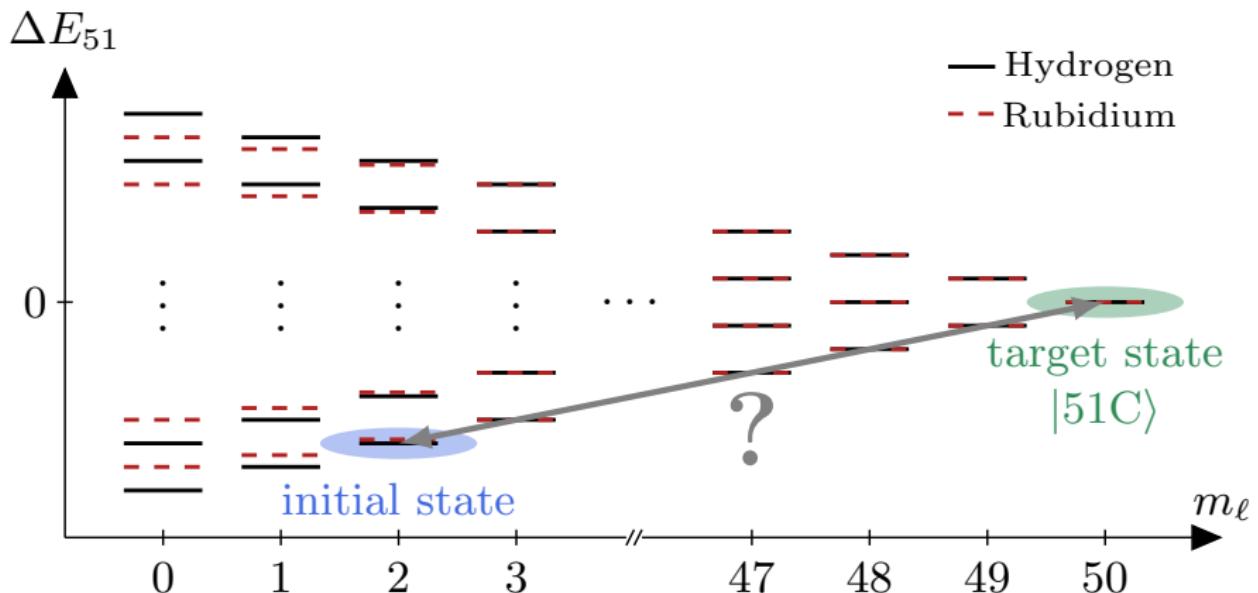
why?

- super long lifetime
- ↪ qu sensing ↪ cavity QED
- ↪ qu interfaces ↪ qu computing



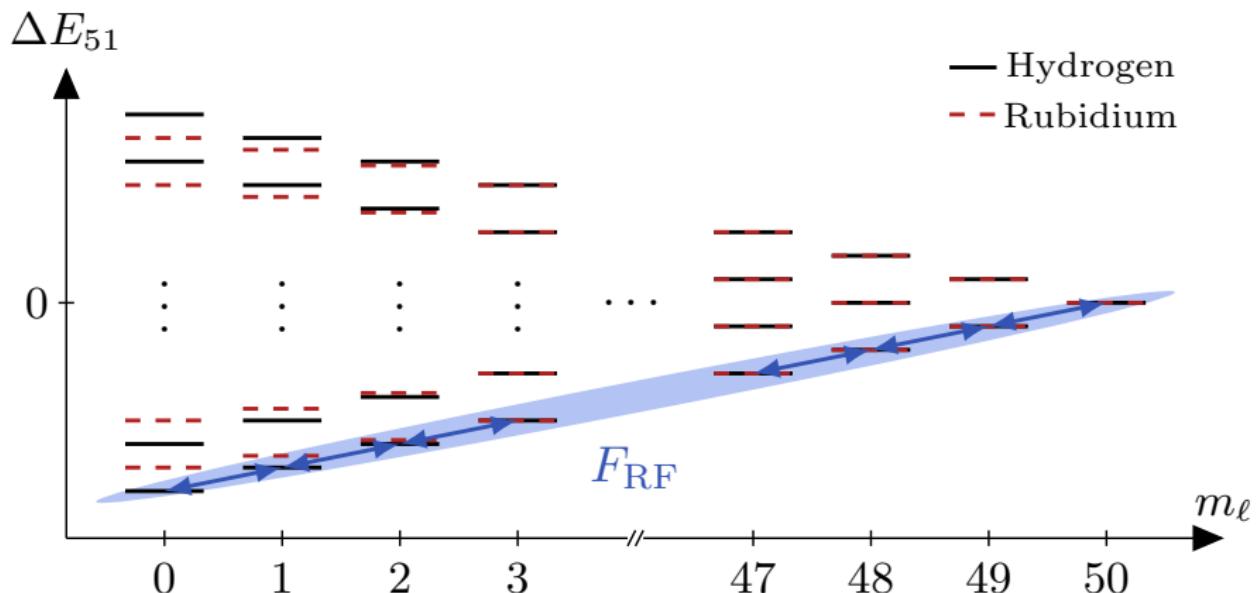
preparation of circular state

after laser excitation, use RF drive: π -pulse



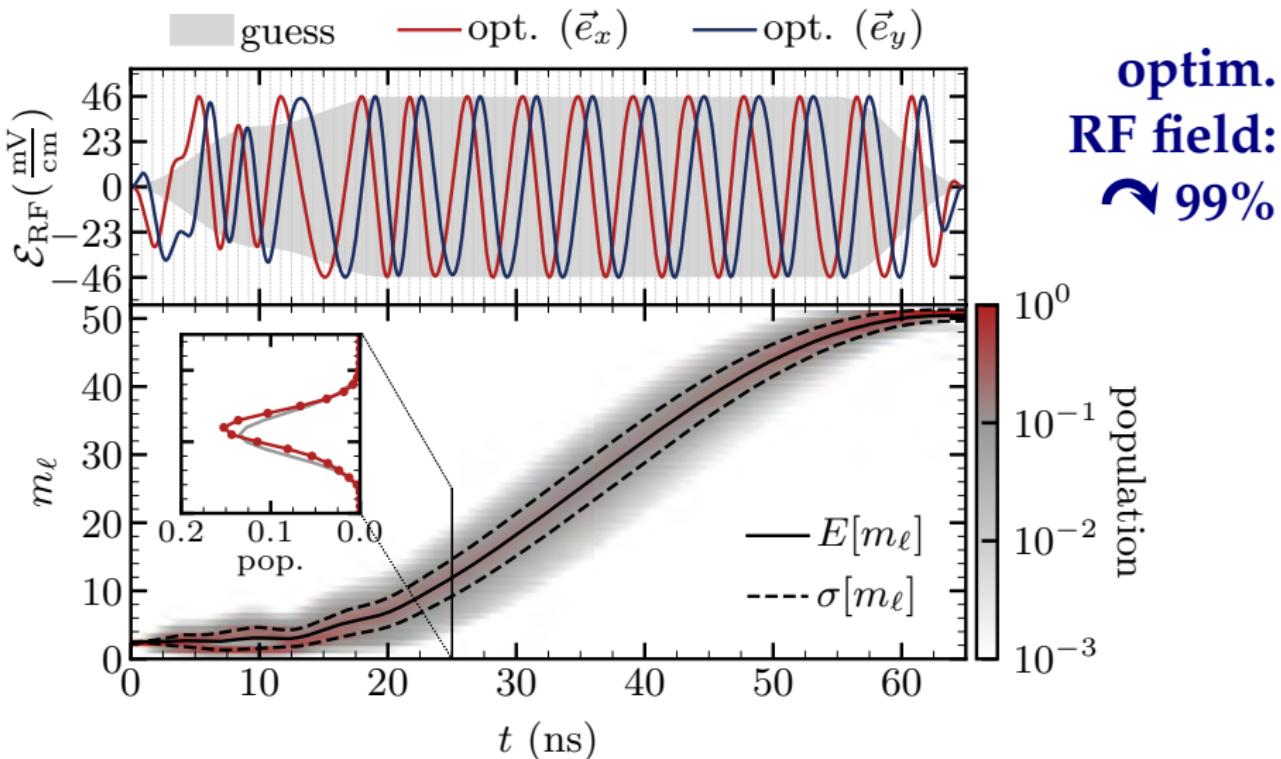
preparation of circular state

problem for speed up:
larger amplitudes drive unwanted transitions to lower m_ℓ



preparation of circular state

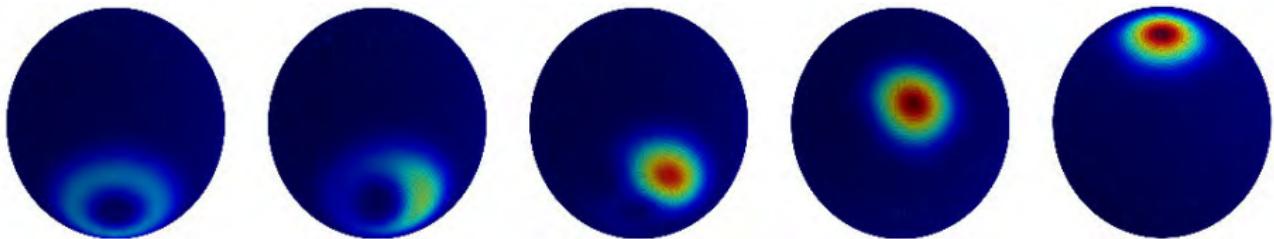
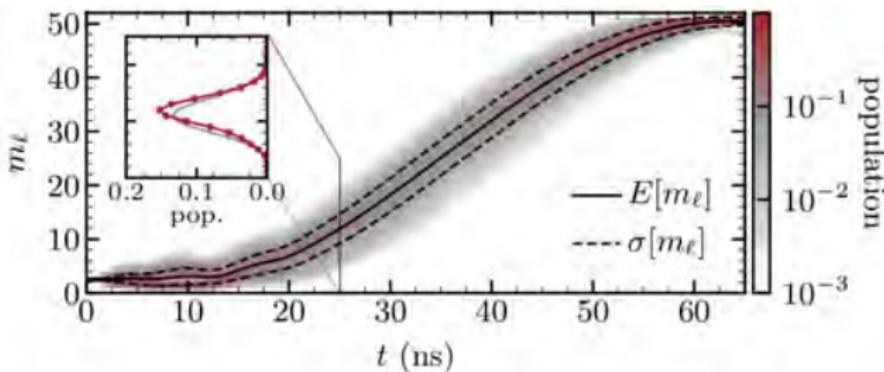
optimization: fast & accurate state transfer



preparation of circular state

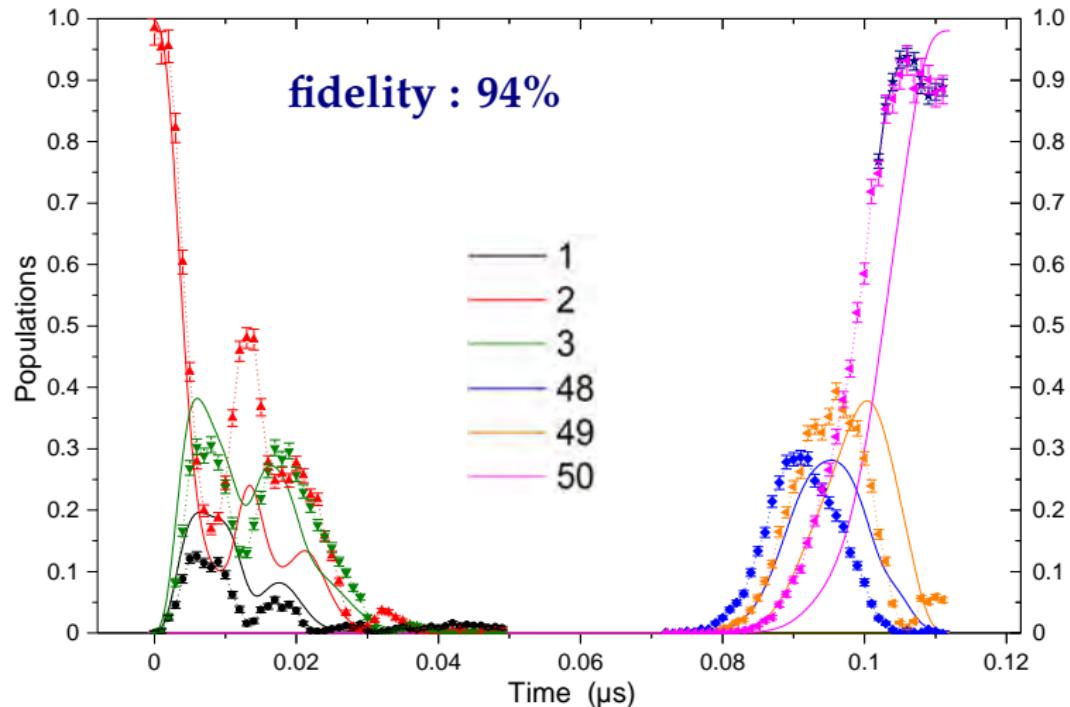
Patsch, Reich, Raimond, Brune, Gleyzes, CPK, Phys Rev A 97, 053418 (2018)

how does the optimized RF pulse work ?



optimized pulse in experiment @ ENS Paris

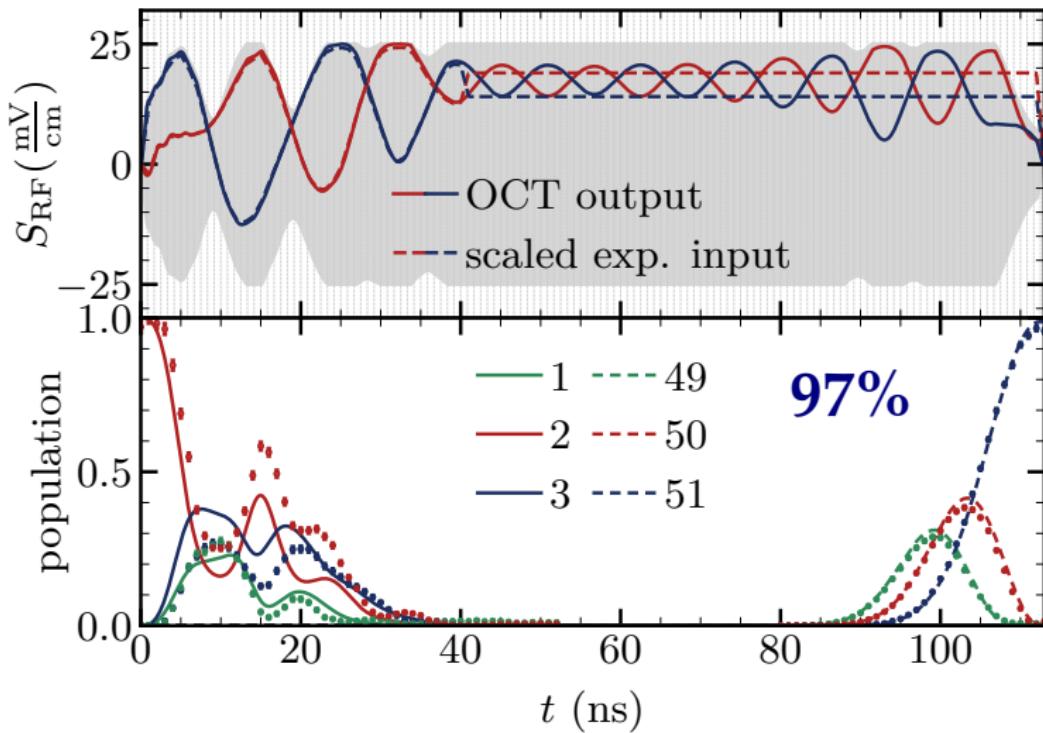
using theoretical pulse as is



optimized pulse in experiment

Larrouy, Patsch, Richaud, Raimond, Brune, CPK, Gleyzes, Phys Rev X 10, 021058 (2020)

improved calibration & simplified pulse



a more challenging target

Larrouy, Patsch, Richaud, Raimond, Brune, CPK, Gleyzes, Phys Rev X 10, 021058 (2020)

superposition of $|m_l = 1\rangle$ and $|m_l = m_l^{max}\rangle$ no known protocol!

a more challenging target

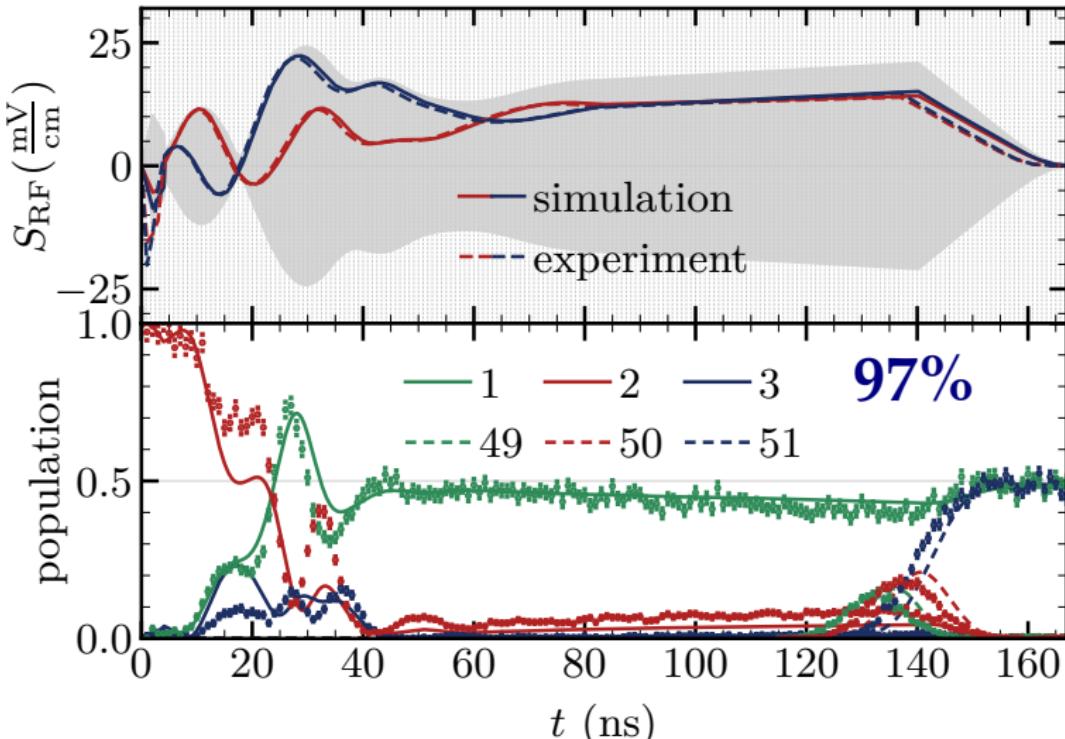
Larrouy, Patsch, Richaud, Raimond, Brune, CPK, Gleyzes, Phys Rev X 10, 021058 (2020)

superposition of $|m_l = 1\rangle$ and $|m_l = m_l^{max}\rangle$ no known protocol!
but we can “train Schrödinger’s cat”

a more challenging target

Larrouy, Patsch, Richaud, Raimond, Brune, CPK, Gleyzes, Phys Rev X 10, 021058 (2020)

superposition of $|m_l = 1\rangle$ and $|m_l = m_l^{max}\rangle$ no known protocol!
but we can “train Schrödinger’s cat”



optimal control for dissipative generation of entanglement

driven dissipative evolution

— quantum reservoir engineering —

$$\partial_t \rho = \mathcal{L}(\rho) = -i[H, \rho]_- + \mathcal{L}_D(\rho)$$

$$\text{steady state} \quad \longleftrightarrow \quad \partial_t \rho = 0$$

dissipation as friend, not foe

driven dissipative evolution

— quantum reservoir engineering —

$$\partial_t \rho = \mathcal{L}(\rho) = -i[H, \rho]_- + \mathcal{L}_D(\rho)$$

$$\text{steady state} \quad \longleftrightarrow \quad \partial_t \rho = 0$$

dissipation as friend, not foe

use external fields + unidirectional evolution due
to \mathcal{L}_D to create non-trivial steady state

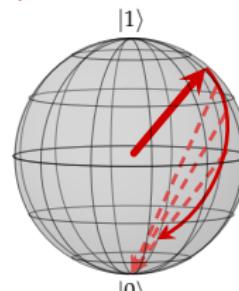
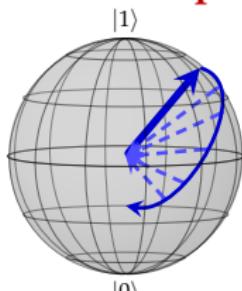
driven dissipative evolution

— quantum reservoir engineering —

$$\partial_t \rho = \mathcal{L}(\rho) = -i[H, \rho]_- + \mathcal{L}_D(\rho)$$

$$\text{steady state} \quad \longleftrightarrow \quad \partial_t \rho = 0$$

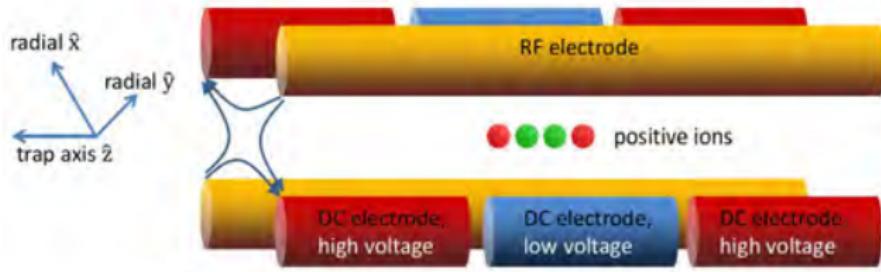
dissipation as friend, not foe



use external fields + unidirectional evolution due
to \mathcal{L}_D to create non-trivial steady state

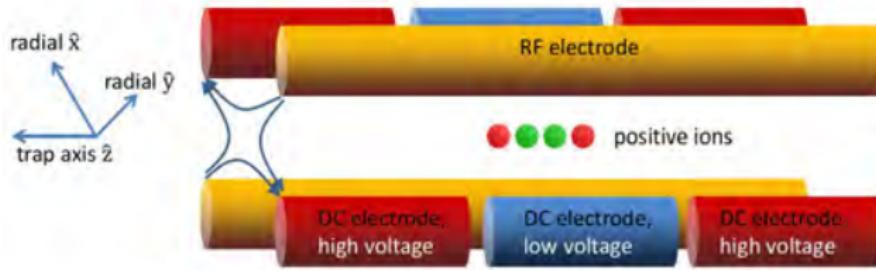
Boulder experiment

Lin, Gaebler, Reiter, Tan, Bowler, Sorensen, Leibfried, Wineland, *Nature* 504, 415 (2013)



Boulder experiment

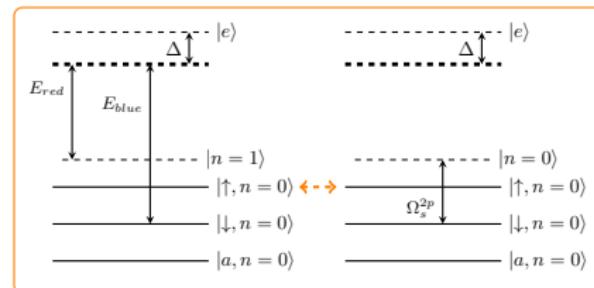
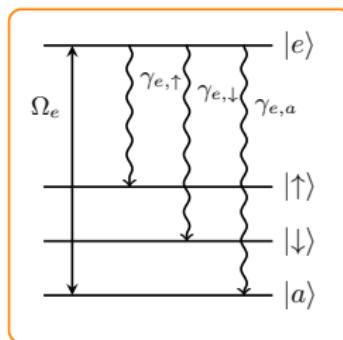
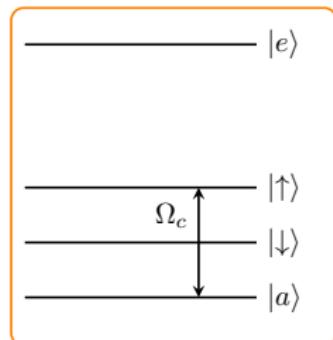
Lin, Gaebler, Reiter, Tan, Bowler, Sorensen, Leibfried, Wineland, Nature 504, 415 (2013)



microwave

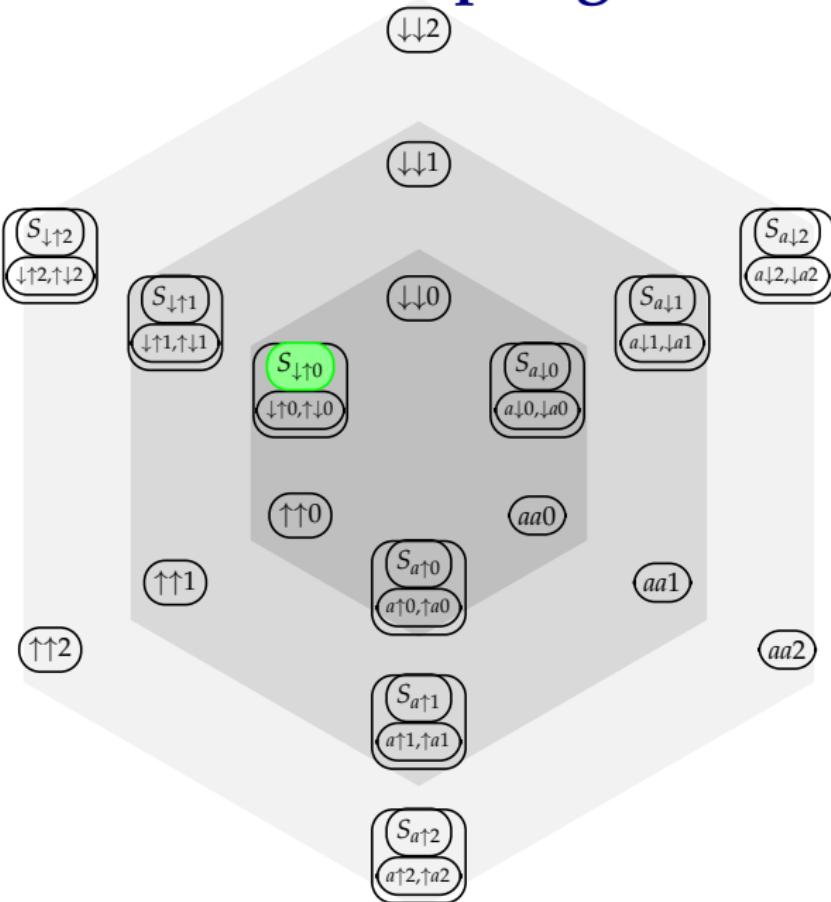
repump

sideband



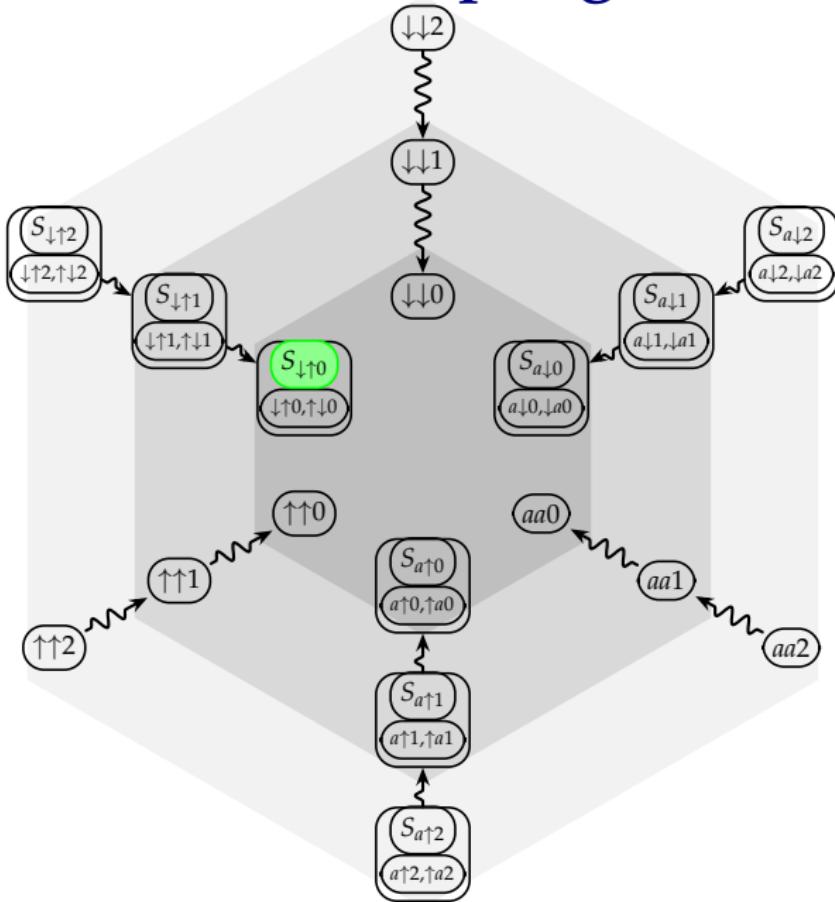
plus laser cooling on Mg^+

coherent couplings & incoherent decays



population flow
for entanglement
generation

coherent couplings & incoherent decays



population flow
for entanglement
generation

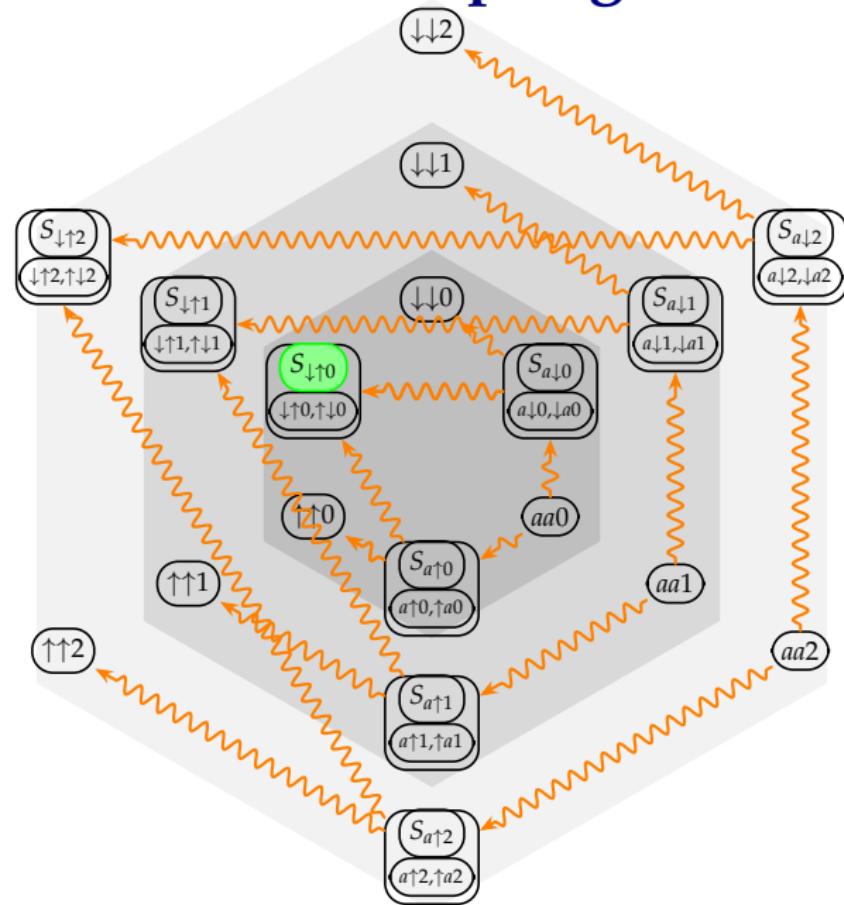
~~~~> laser cooling

~~~~> repump

↔ microwave

←→ sideband

coherent couplings & incoherent decays



population flow for entanglement generation

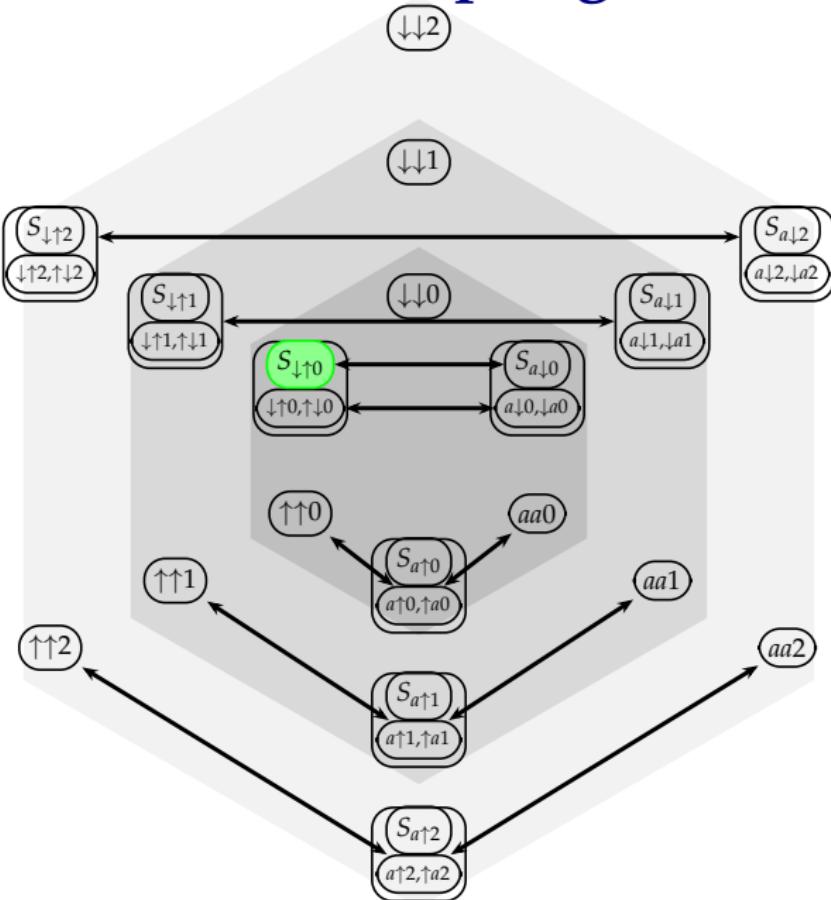
→ laser cooling

→ repump

↔ microwave

\longleftrightarrow sideband

coherent couplings & incoherent decays



population flow
for entanglement
generation

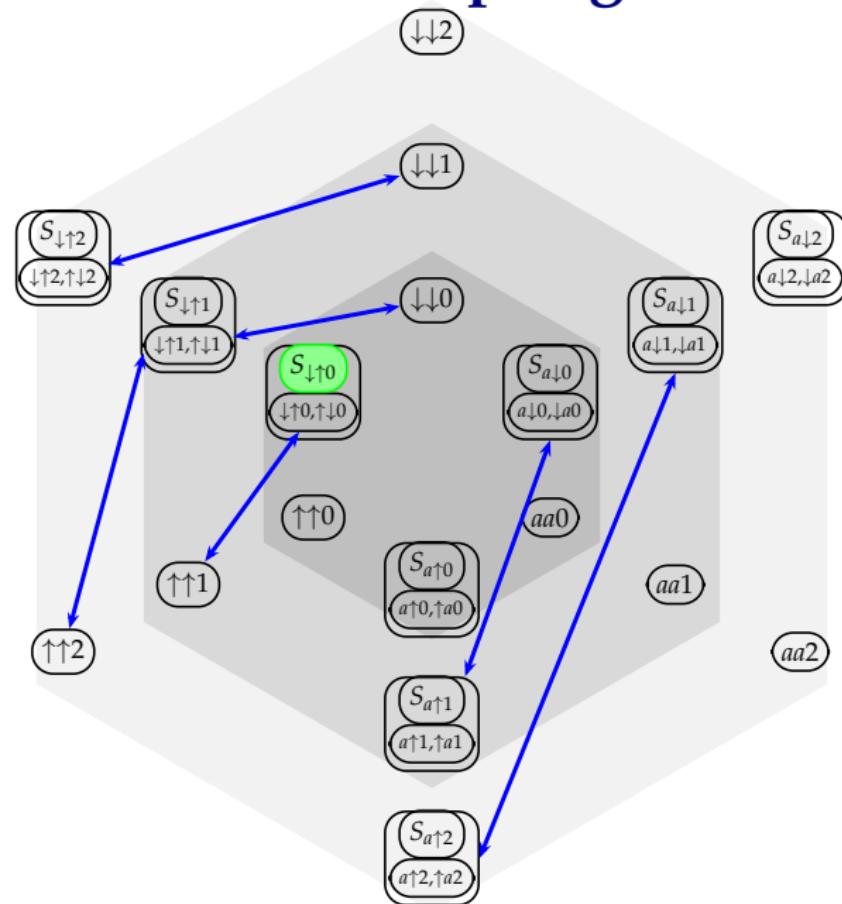
~~~~> laser cooling

~~~~> repump

↔ microwave

←→ sideband

coherent couplings & incoherent decays



population flow for entanglement generation

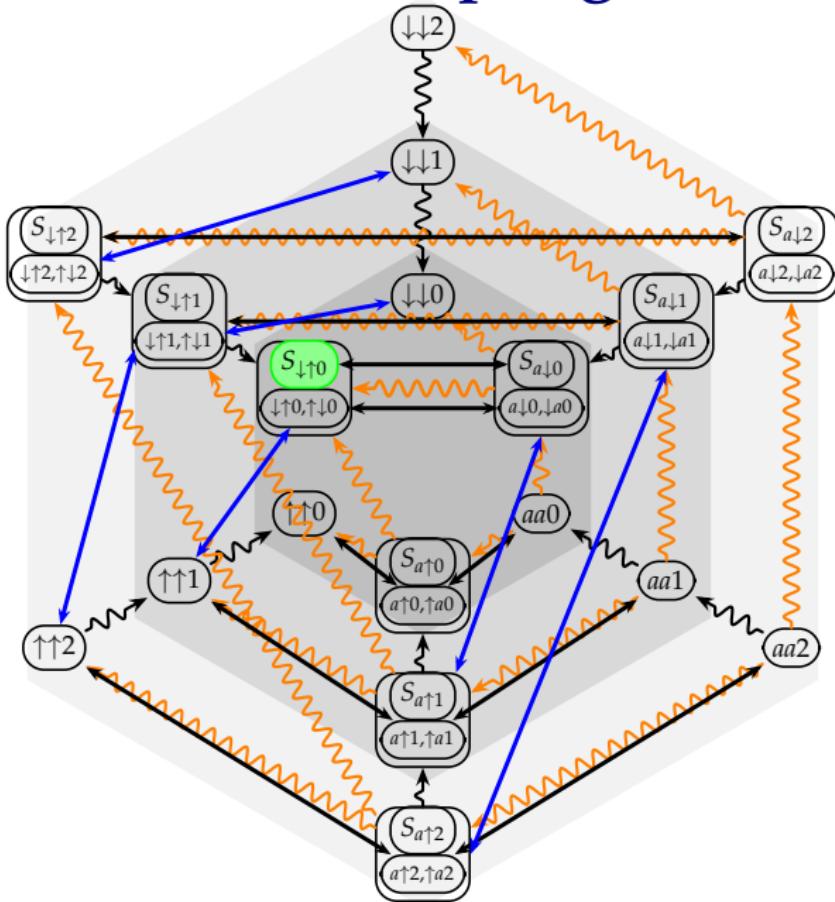
→ laser cooling

→ repump

↔ microwave

\longleftrightarrow sideband

coherent couplings & incoherent decays



population flow
for entanglement
generation

~~~~~ laser cooling

~~~~~ repump

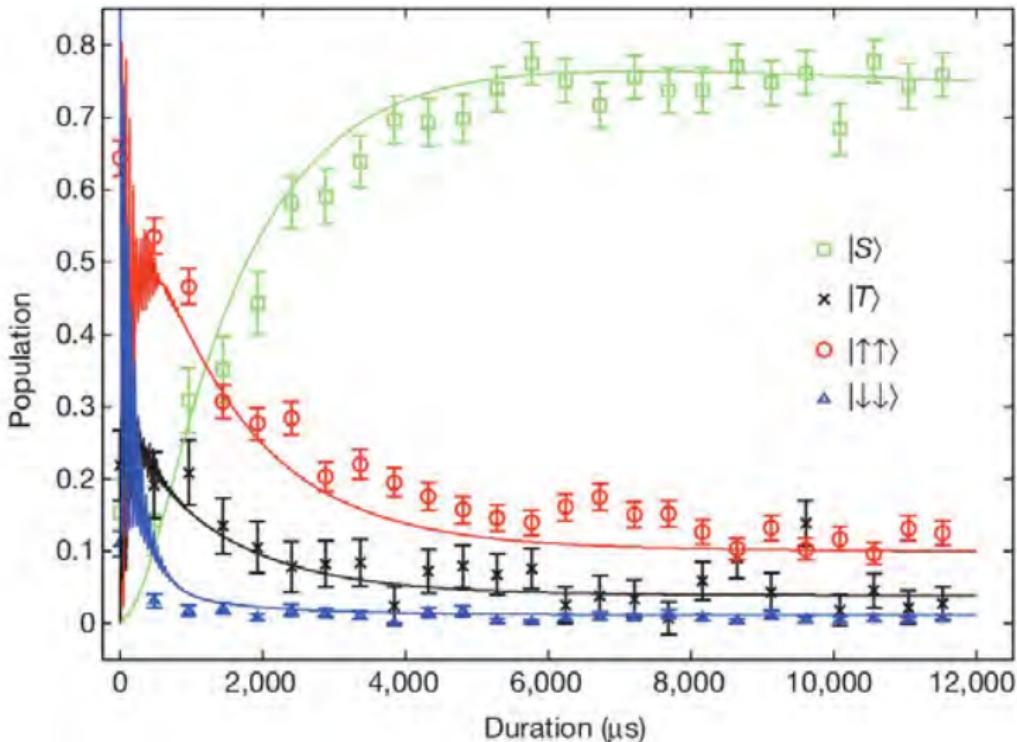
↔ microwave

→ sideband

entanglement generation

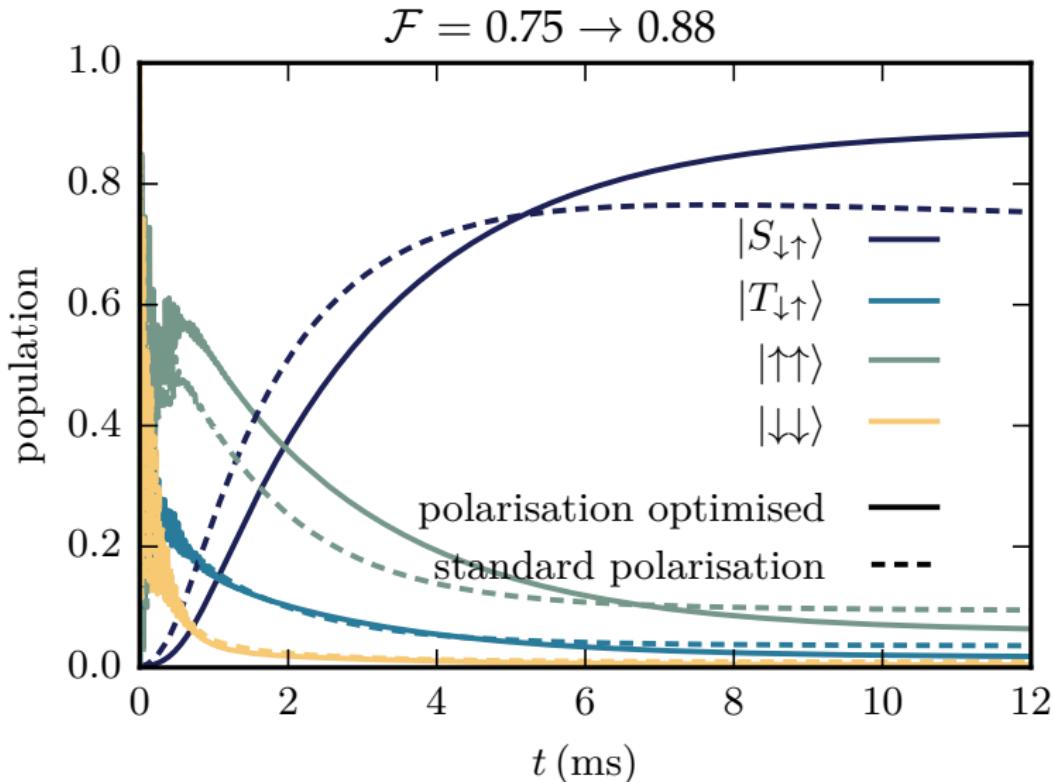
Lin, Gaebler, Reiter, Tan, Bowler, Sorensen, Leibfried, Wineland, *Nature* 504, 415 (2013)

all fields continuously on : $\mathcal{F} = 0.75$

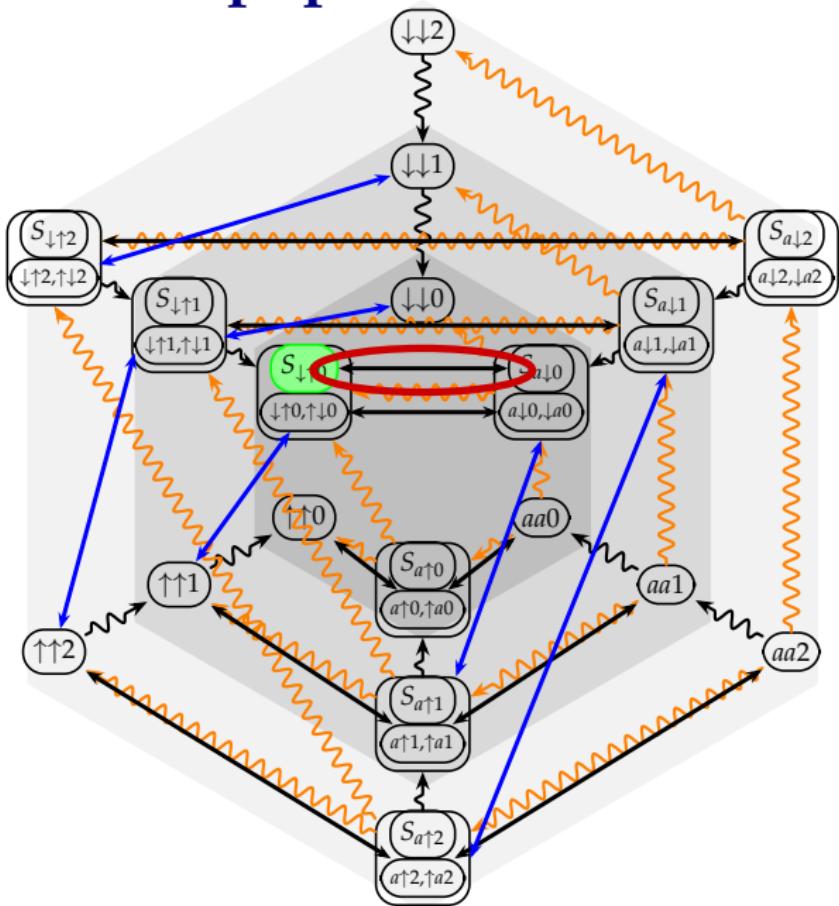


with optimized parameters

Horn, Reiter, Lin, Leibfried, CPK, New J Phys 20, 123010 (2018)

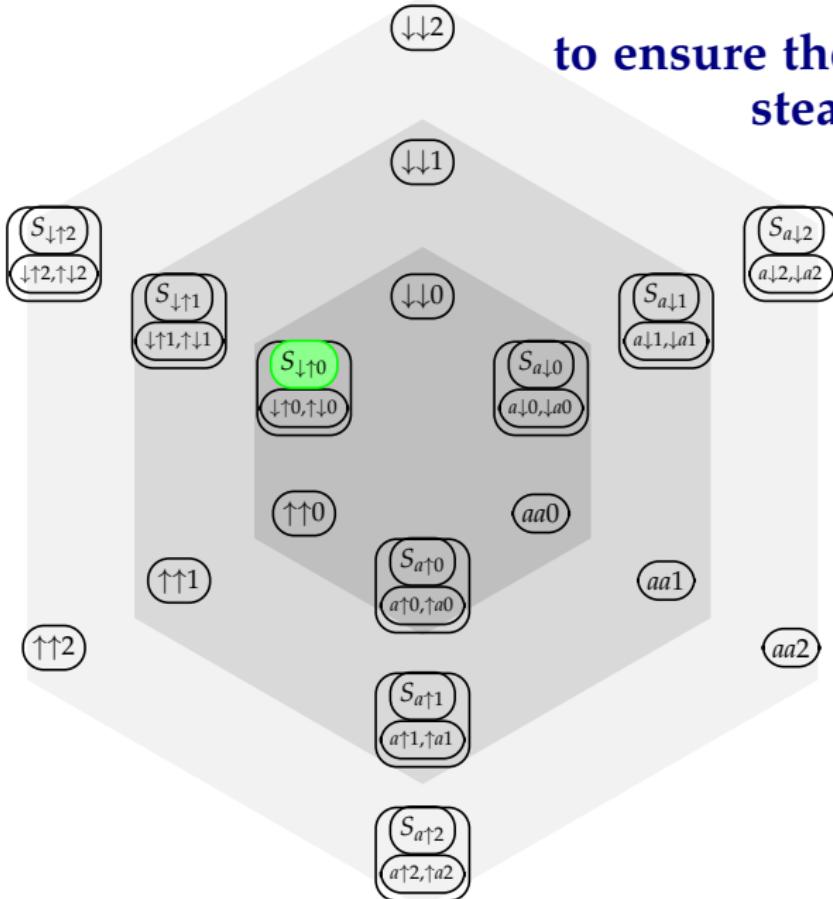


population flow



quantum optimal control

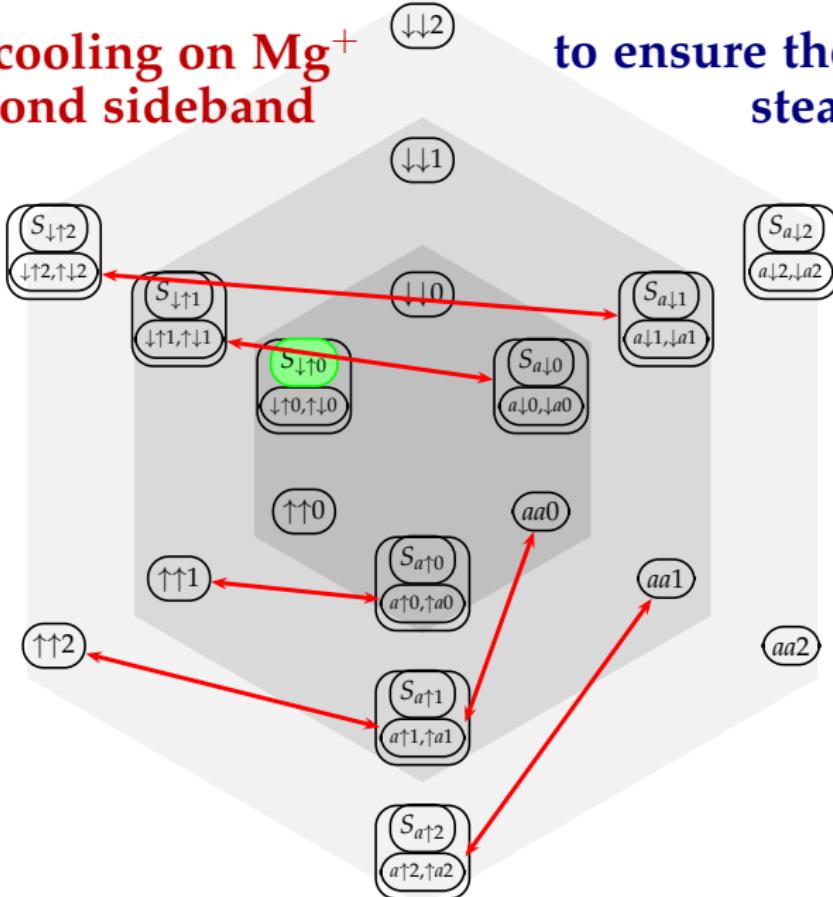
to ensure the proper
steady state



quantum optimal control

replace cooling on Mg^+
by second sideband

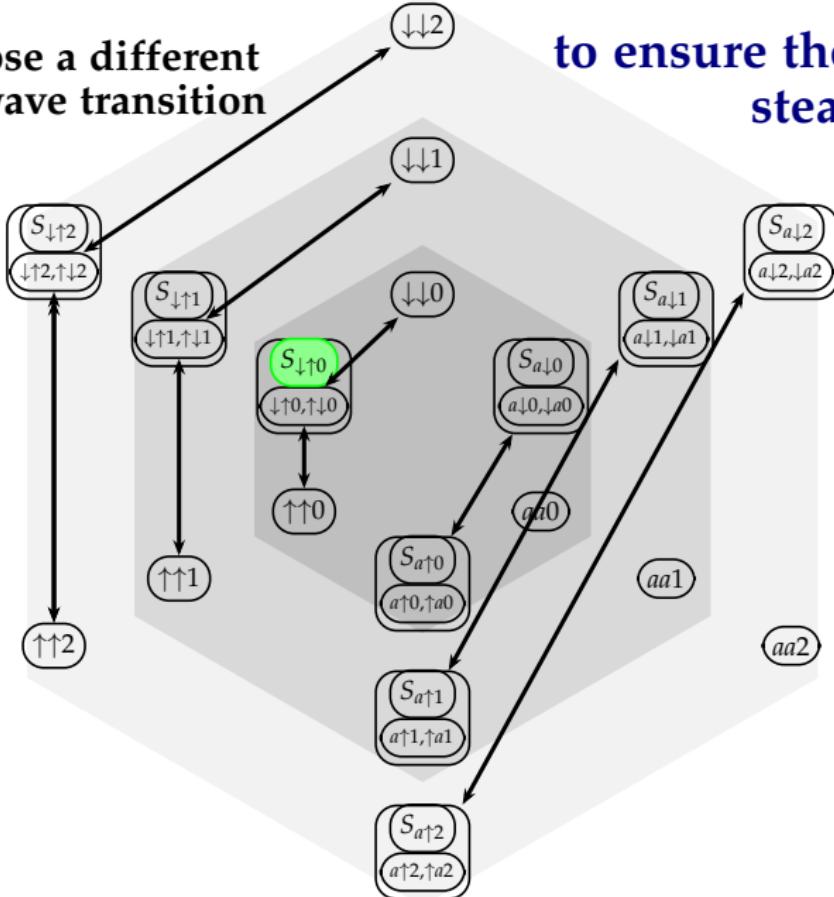
to ensure the proper
steady state



quantum optimal control

choose a different
microwave transition

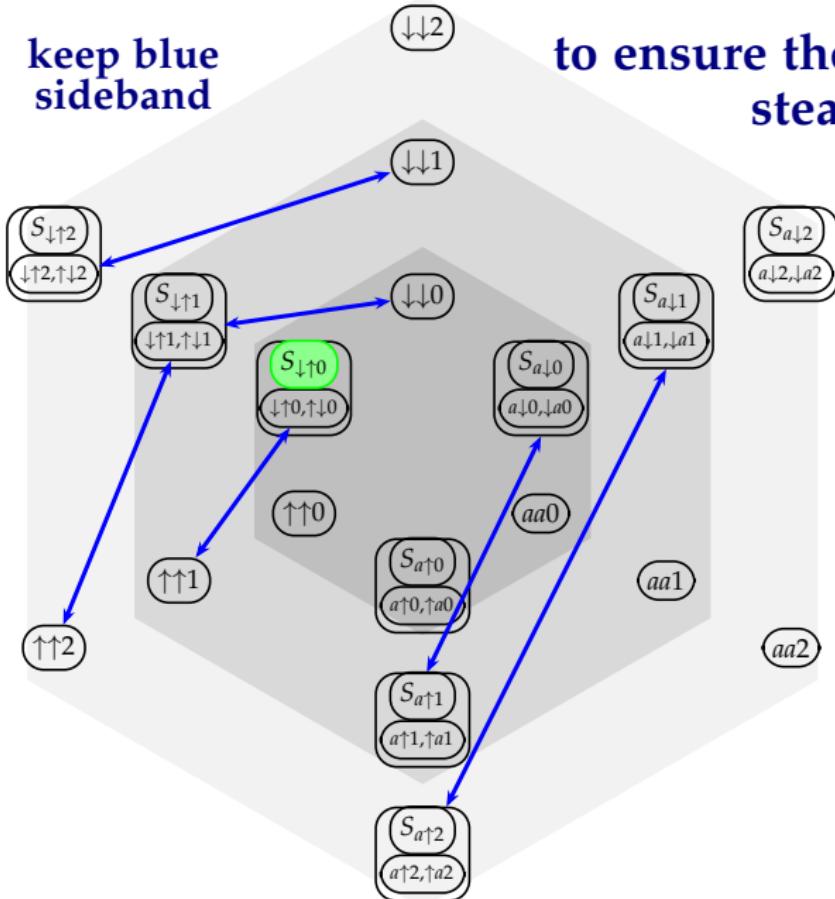
to ensure the proper
steady state



quantum optimal control

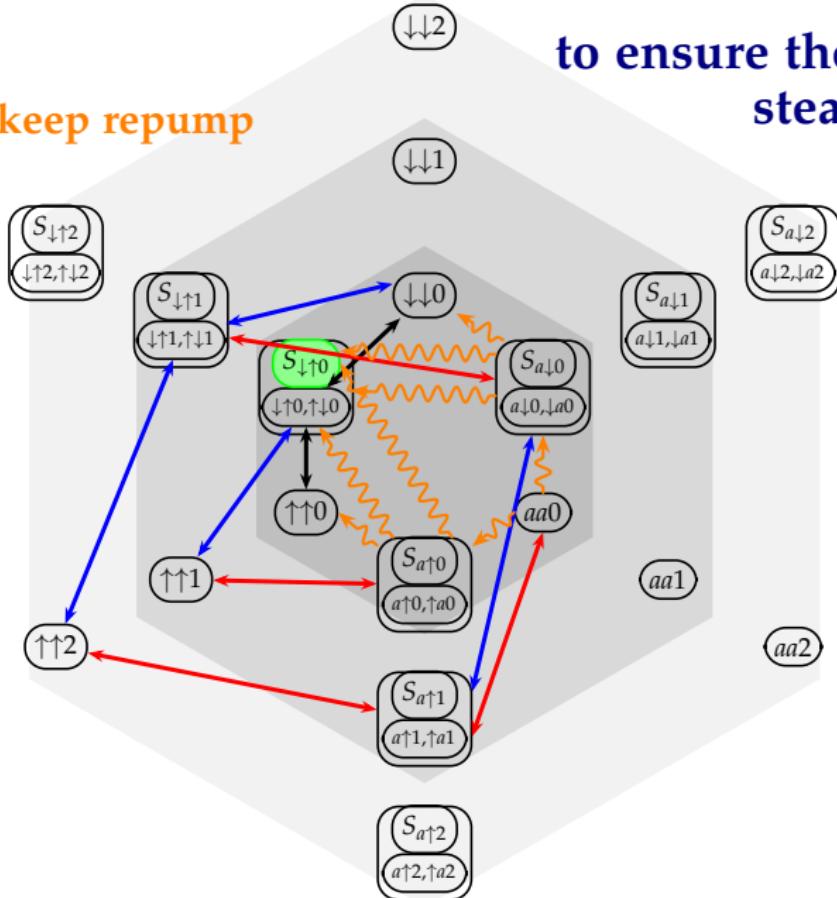
keep blue
sideband

to ensure the proper
steady state



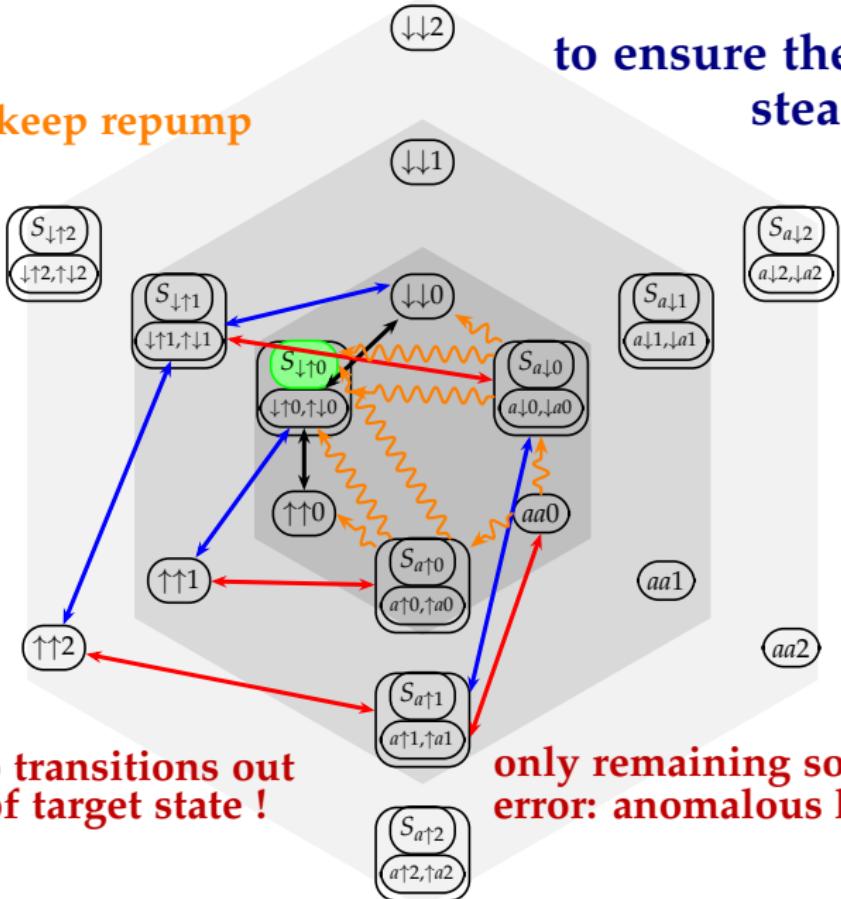
quantum optimal control

keep repump
to ensure the proper steady state



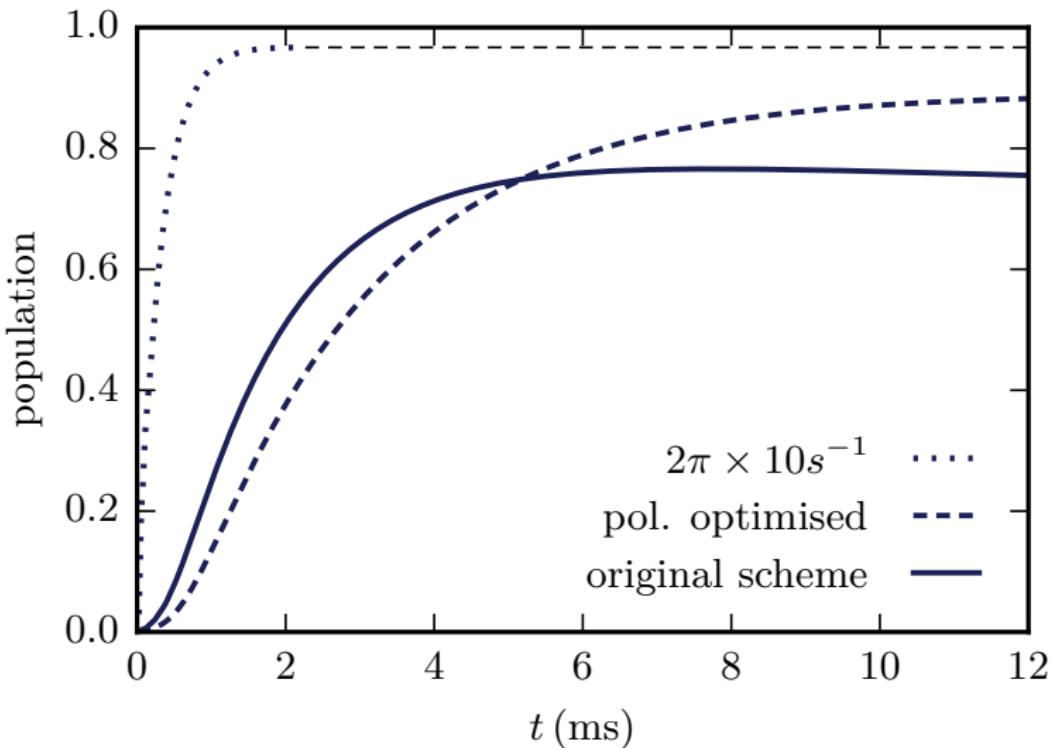
quantum optimal control

keep repump to ensure the proper steady state



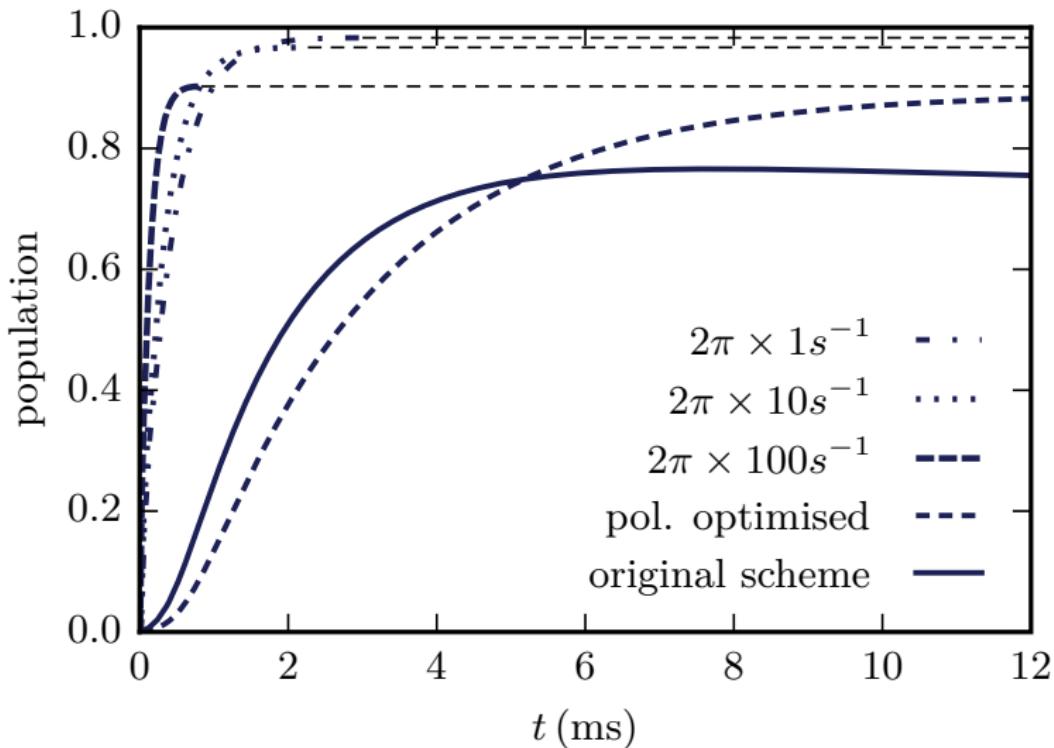
comparison

two sidebands vs original scheme



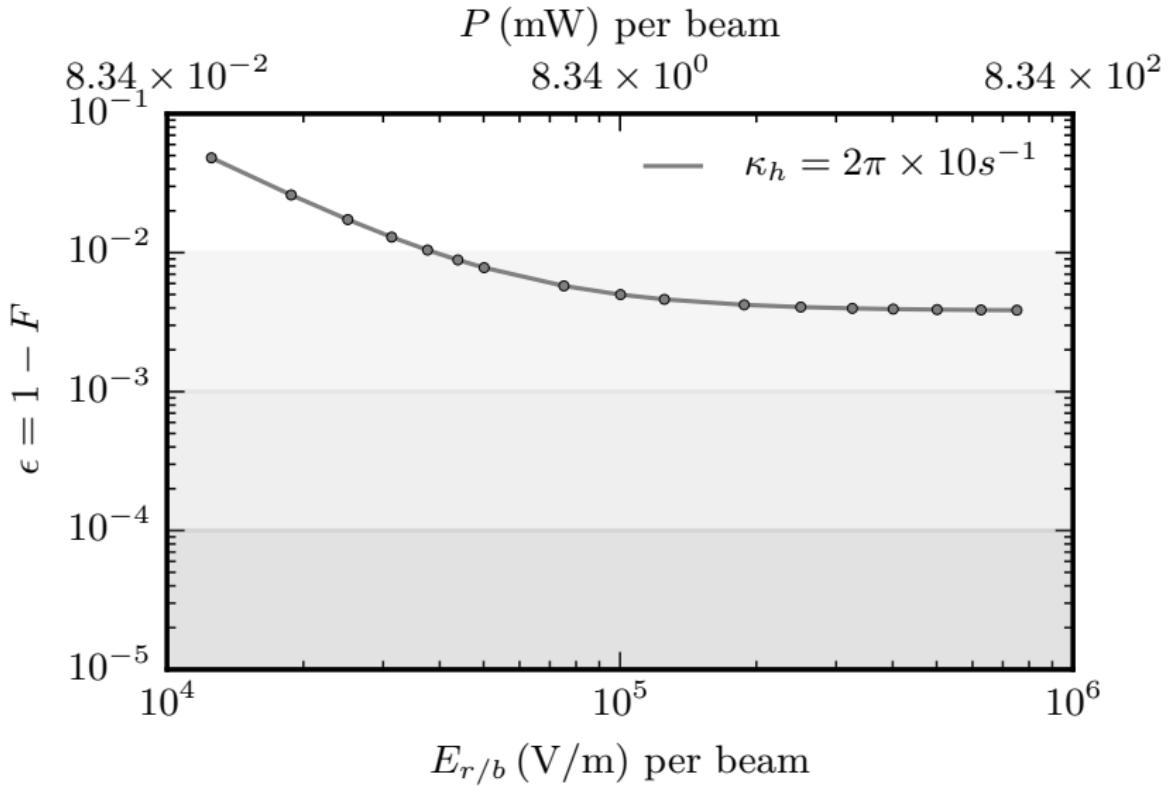
comparison

two sidebands vs original scheme



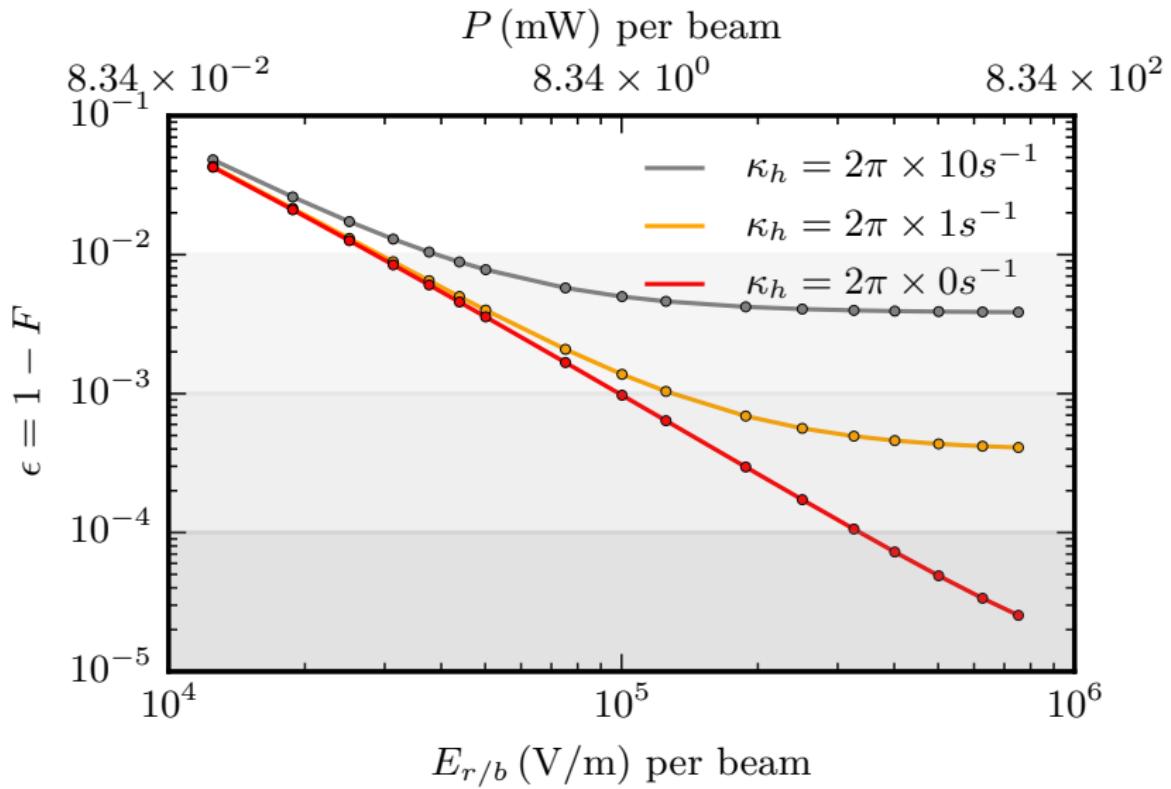
ultimately attainable error

Horn, Reiter, Lin, Leibfried, CPK, New J Phys 20, 123010 (2018)



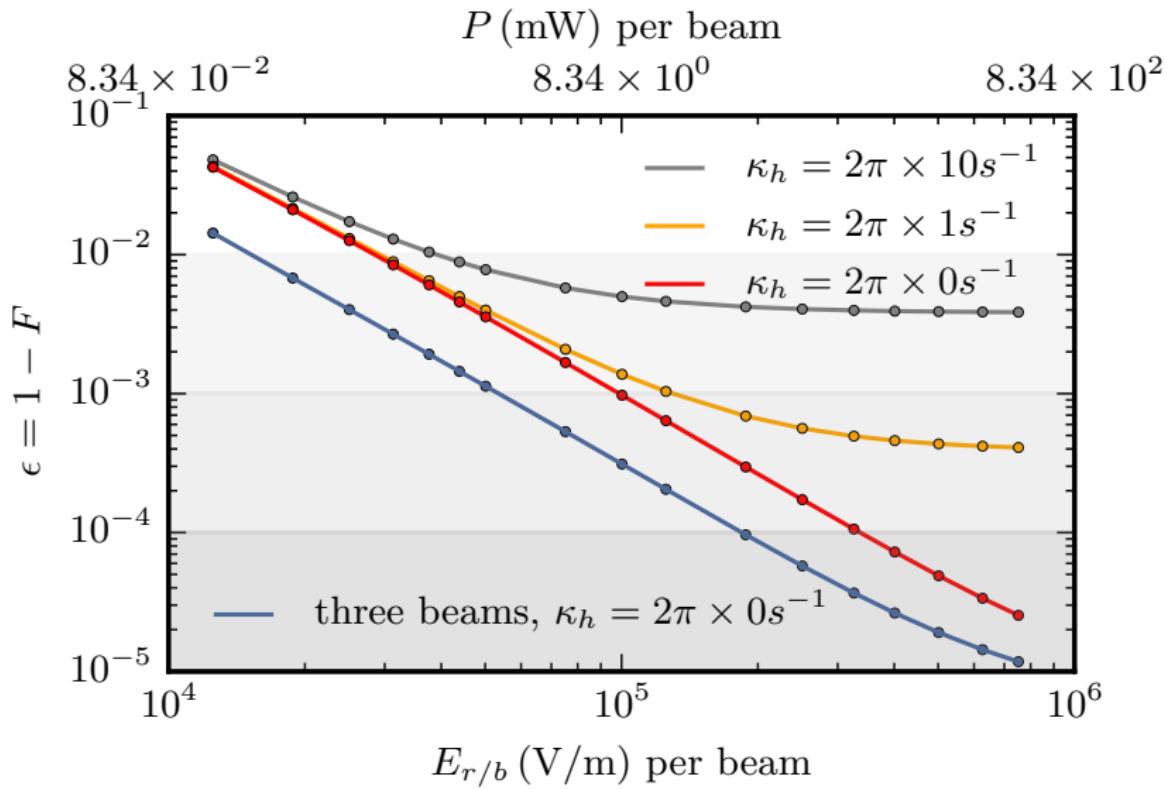
ultimately attainable error

Horn, Reiter, Lin, Leibfried, CPK, New J Phys 20, 123010 (2018)

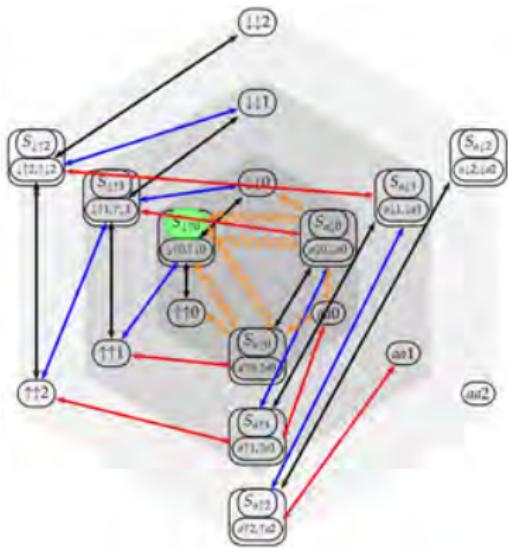


ultimately attainable error

Horn, Reiter, Lin, Leibfried, CPK, New J Phys 20, 123010 (2018)

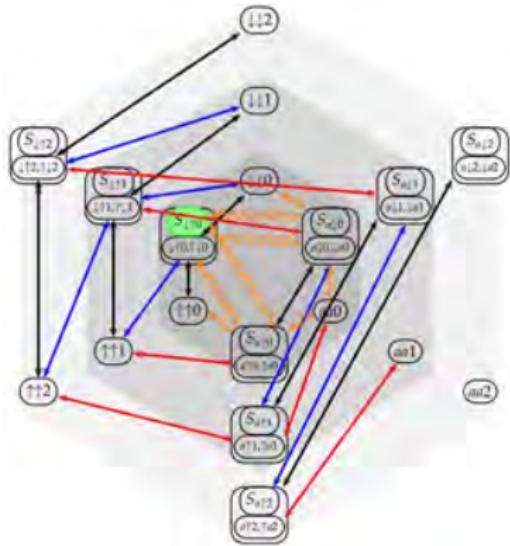


which fields are needed to reach a control target?

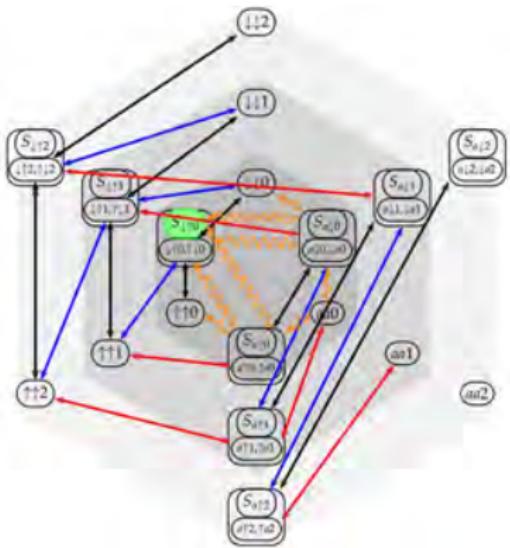


which fields are needed to reach
a control target?

is there a systematic way
to find out?



which fields are needed to reach
a control target?

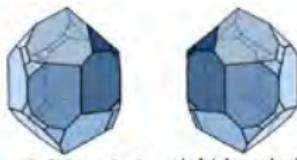
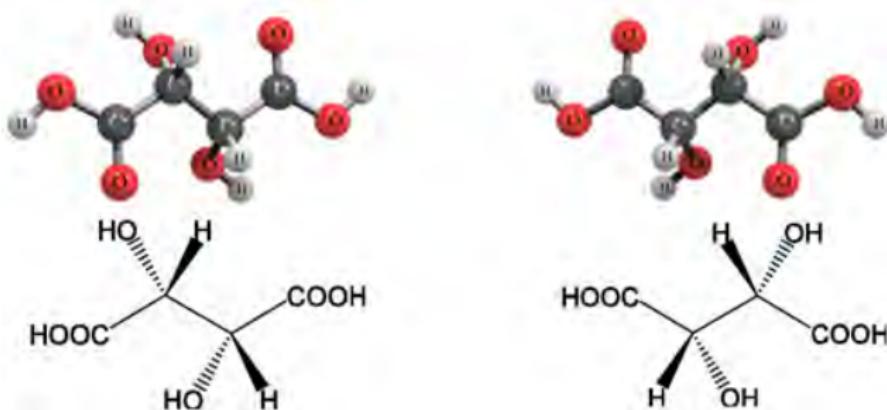


is there a systematic way
to find out?

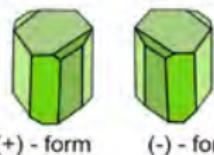
what chiral molecules
can teach us about
quantum control

chiral molecules

chirality = handedness

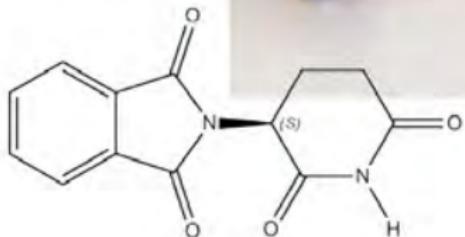


left-handed right-handed

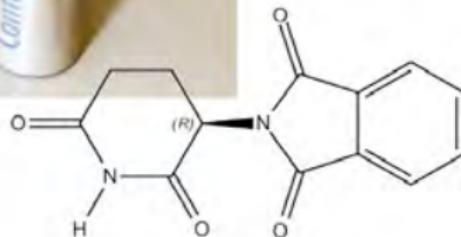


(+)-form (-)-form

chirality in pharmacology

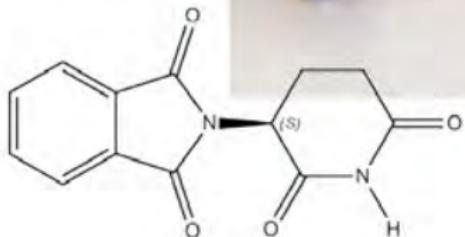


(S)-(-)-Thalidomid

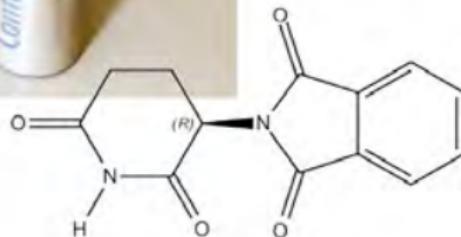


(R)-(+)-Thalidomid

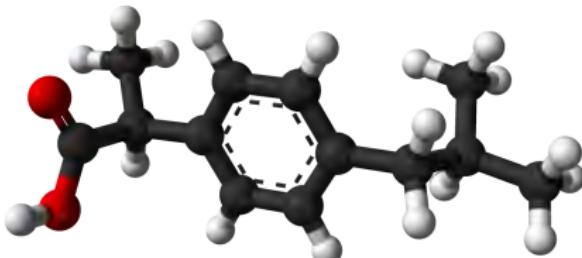
chirality in pharmacology



(S)-(-)-Thalidomid



(R)-(+)-Thalidomid



(S)-ibuprofen

separate enantiomers with electric fields?

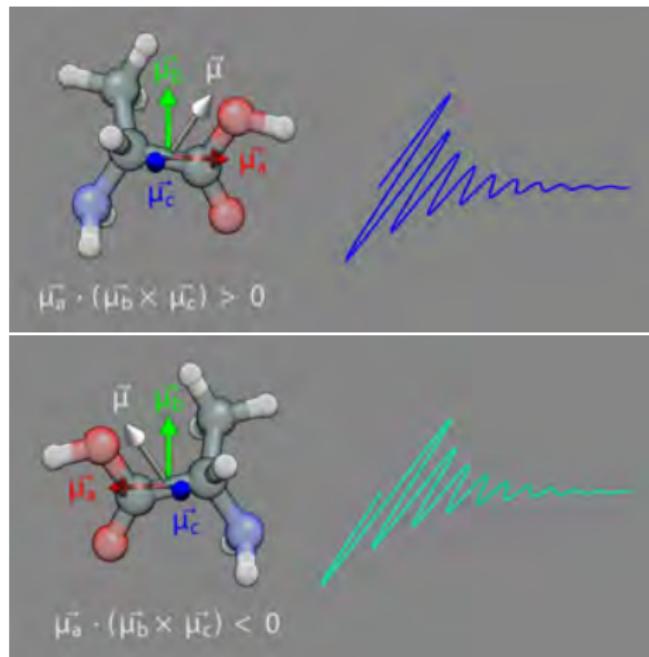
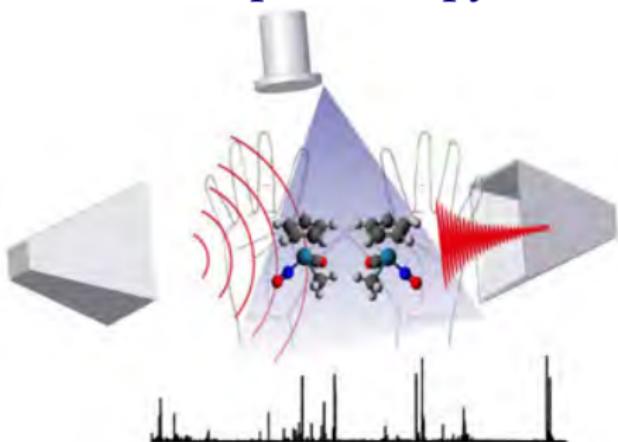
separate enantiomers with electric fields?

can we distinguish left/right-handed molecules with el. fields?

separate enantiomers with electric fields?

can we distinguish left/right-handed molecules with el. fields?

yes! with three-wave mixing
microwave spectroscopy

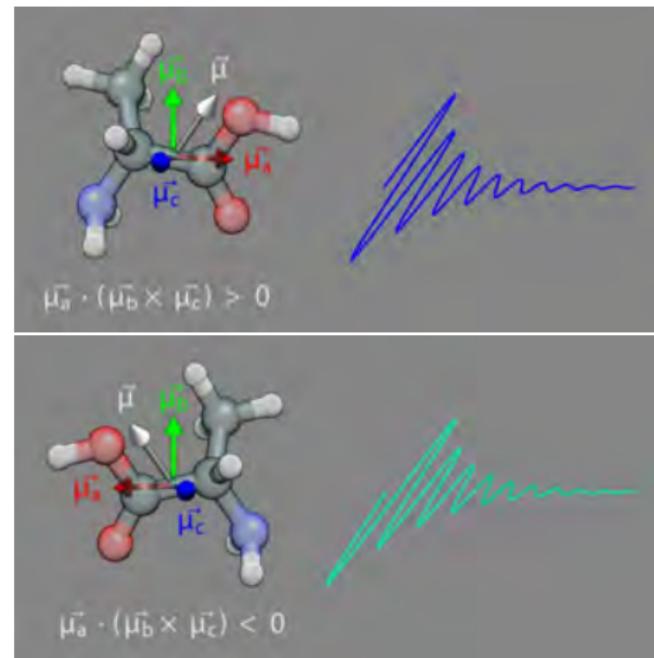
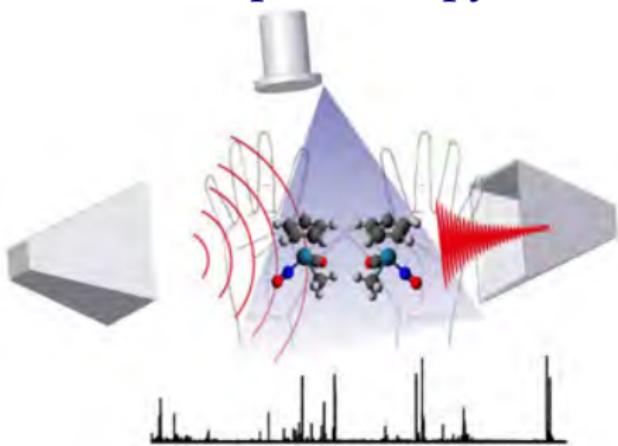


Patterson, Schnell, Doyle, *Nature* 497, 475 (2013)

separate enantiomers with electric fields?

can we distinguish left/right-handed molecules with el. fields?

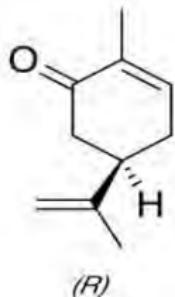
yes! with three-wave mixing
microwave spectroscopy



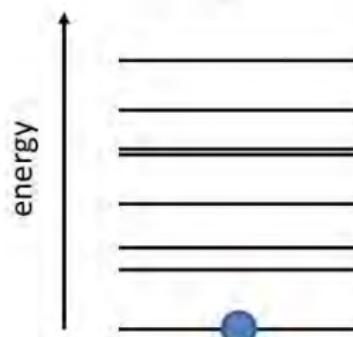
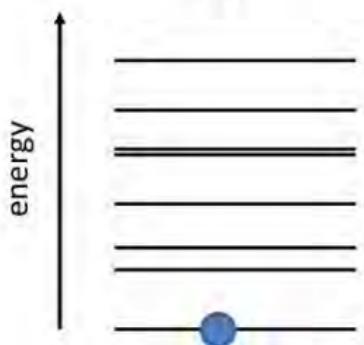
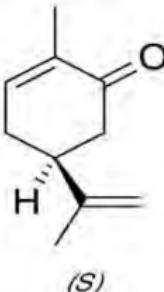
Patterson, Schnell, Doyle, *Nature* 497, 475 (2013)

This works for randomly oriented molecules and requires
only electric-dipole transitions !

enantiomer-selective excitation ?

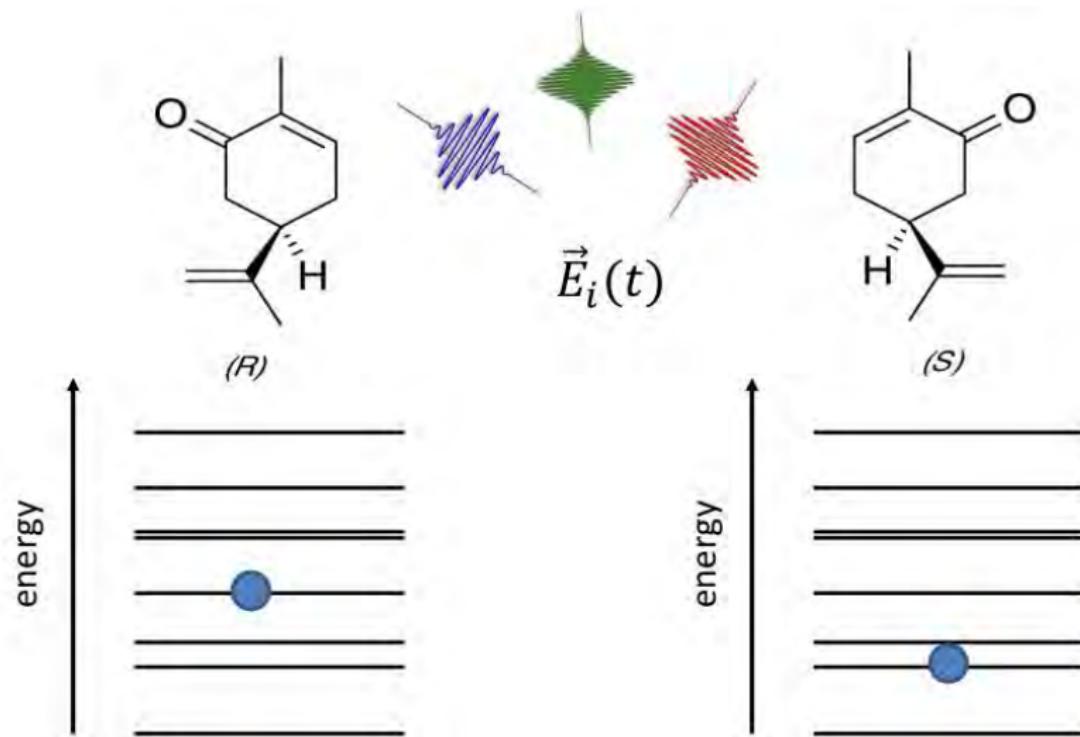


carvone



enantiomers have identical spectra
except for parity violation-related energy shifts

enantiomer-selective excitation !



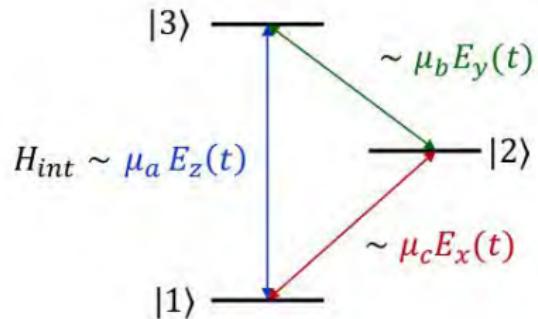
enantiomer-selective excitation !

$$\boldsymbol{\mu} = \begin{pmatrix} \mu_a \\ \mu_b \\ \mu_c \end{pmatrix}$$

$$\mu_a^{(S)} = \mu_a^{(R)}$$

$$\mu_b^{(S)} = \mu_b^{(R)}$$

$$\boxed{\mu_c^{(S)} = -\mu_c^{(R)}}$$



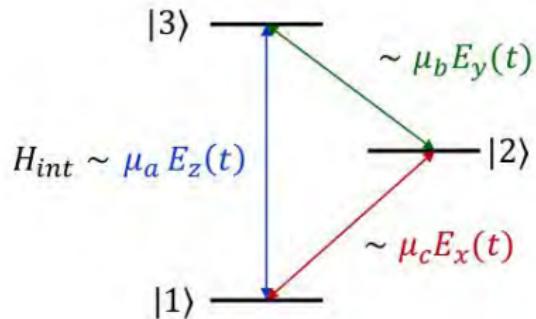
enantiomer-selective excitation !

$$\boldsymbol{\mu} = \begin{pmatrix} \mu_a \\ \mu_b \\ \mu_c \end{pmatrix}$$

$$\mu_a^{(S)} = \mu_a^{(R)}$$

$$\mu_b^{(S)} = \mu_b^{(R)}$$

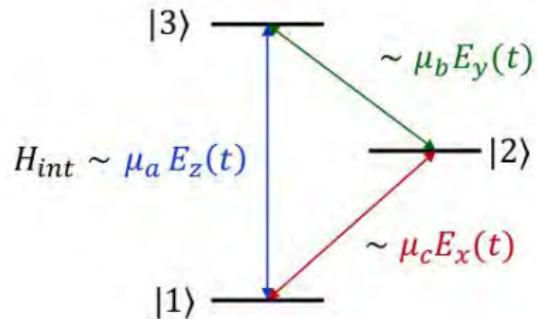
$$\boxed{\mu_c^{(S)} = -\mu_c^{(R)}}$$



- two excitation pathways from $|0\rangle$ to $|2\rangle$
- constructive vs destructive interference

enantiomer-selective excitation !

$$\boldsymbol{\mu} = \begin{pmatrix} \mu_a \\ \mu_b \\ \mu_c \end{pmatrix}$$
$$\mu_a^{(S)} = \mu_a^{(R)}$$
$$\mu_b^{(S)} = \mu_b^{(R)}$$
$$\boxed{\mu_c^{(S)} = -\mu_c^{(R)}}$$

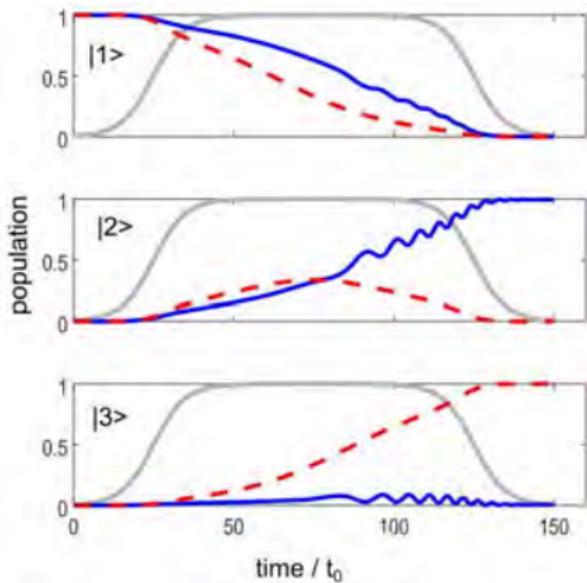


- two excitation pathways from $|0\rangle$ to $|2\rangle$
- constructive vs destructive interference

enantiomer-selective excitation and it doesn't even matter how exactly you do it

Leibscher, Giesen, CPK, J Chem Phys 151, 014302 (2019)

adiabatic ($\Phi = 0$)

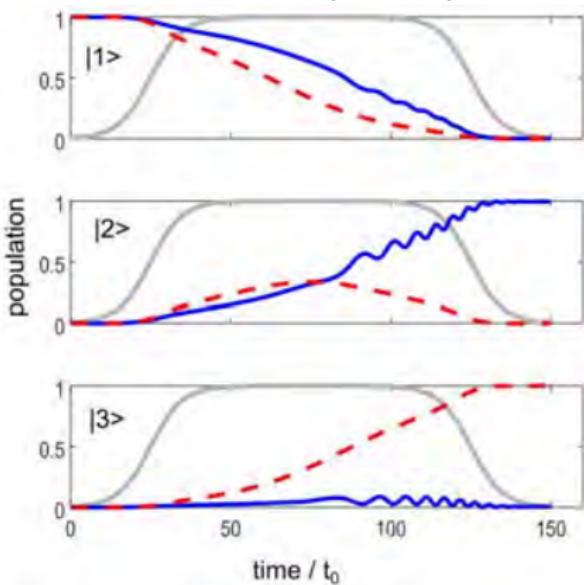


but you do need
three mutually orthogonal polarization directions

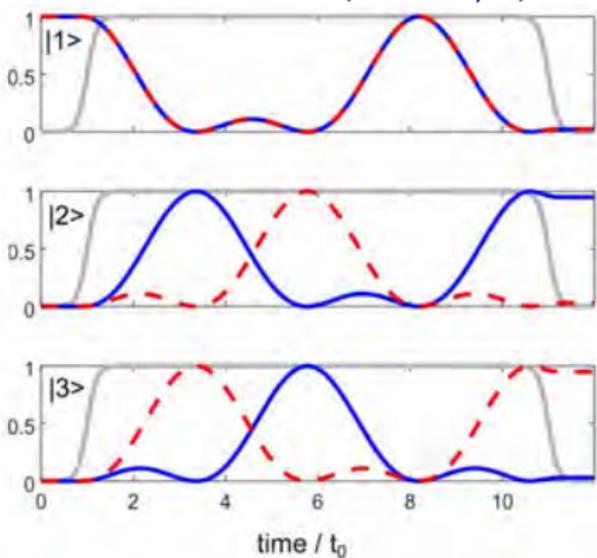
enantiomer-selective excitation and it doesn't even matter how exactly you do it

Leibscher, Giesen, CPK, J Chem Phys 151, 014302 (2019)

adiabatic ($\Phi = 0$)



nonadiabatic ($\Phi = \pi/2$)

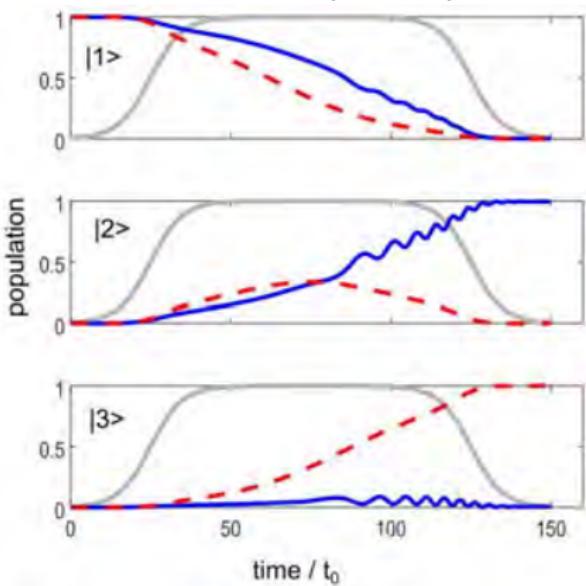


but you do need
three mutually orthogonal polarization directions

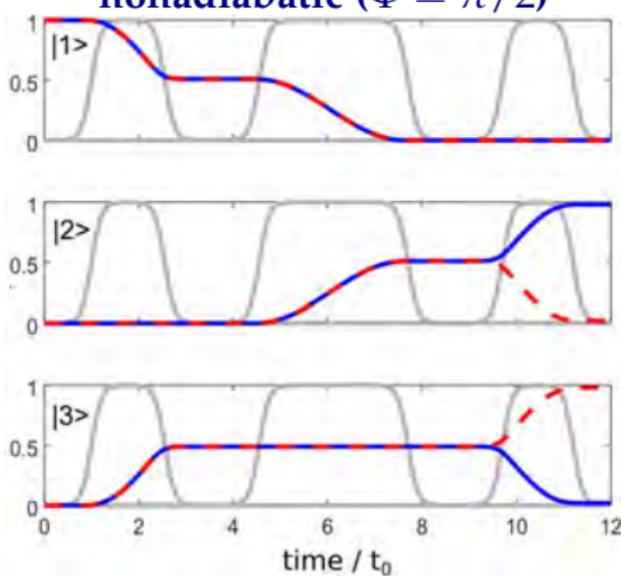
enantiomer-selective excitation and it doesn't even matter how exactly you do it

Leibscher, Giesen, CPK, J Chem Phys 151, 014302 (2019)

adiabatic ($\Phi = 0$)



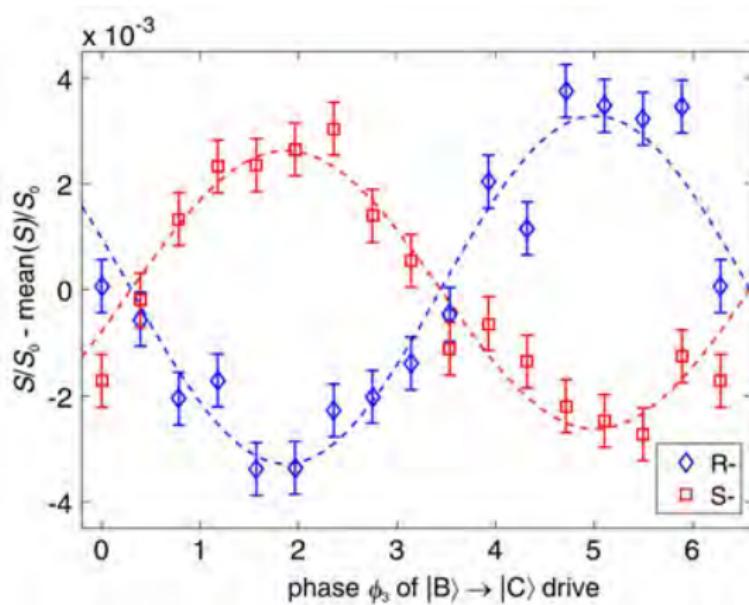
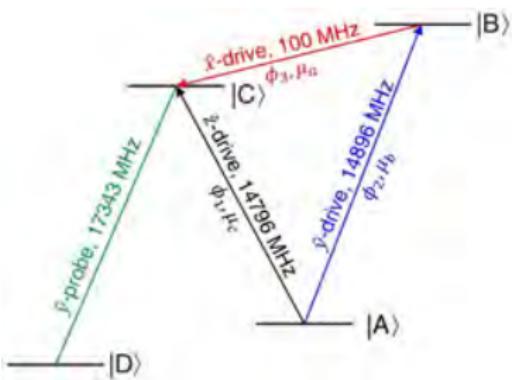
nonadiabatic ($\Phi = \pi/2$)



but you do need
three mutually orthogonal polarization directions

enantiomer-specific state transfer a first step towards separating enantiomers

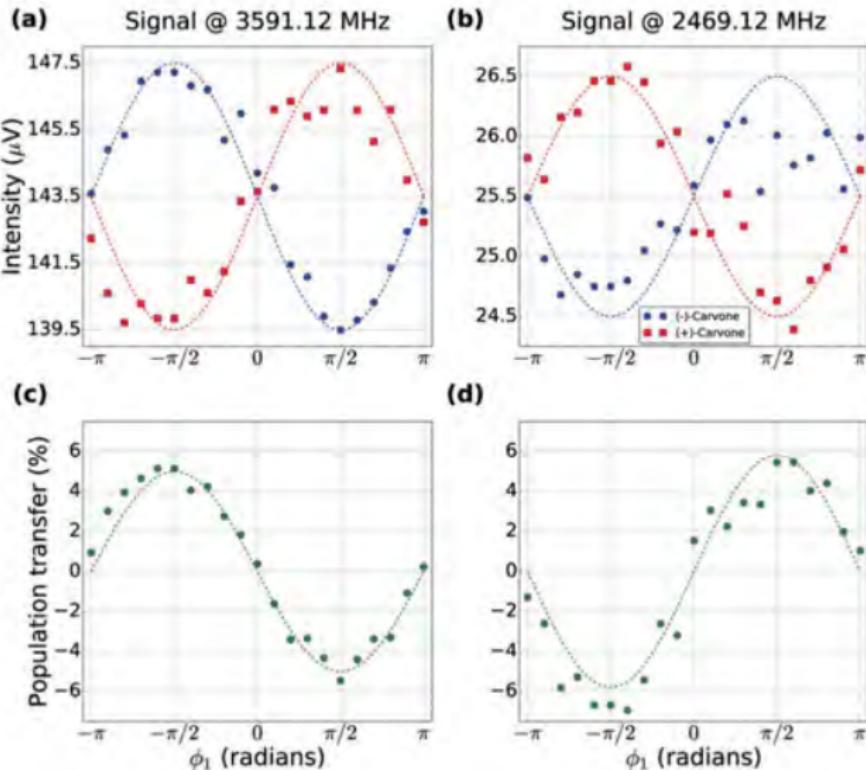
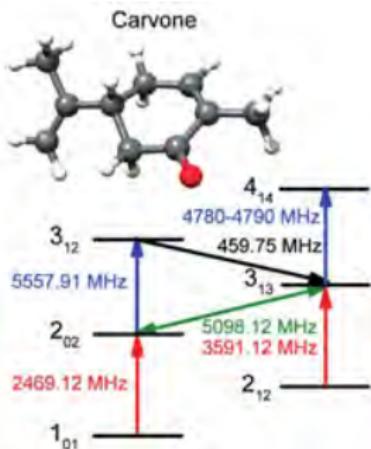
Eibenberger, Patterson, Doyle, Phys Rev Lett 118, 123002 (2017)



enantiomer-specific state transfer

so far limited by temperature and (!) M-degeneracy

Perez, Steber, Domingos, Krin, Schmitz, Schnell, *Angewandte Chemie* 56, 12512 (2017)

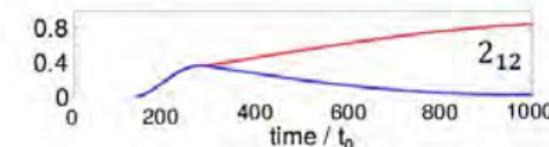
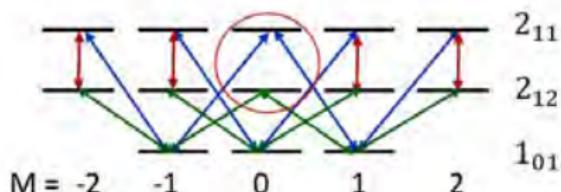


what's the problem ?

M-degeneracy

temperature

Initial states: 1_{01}

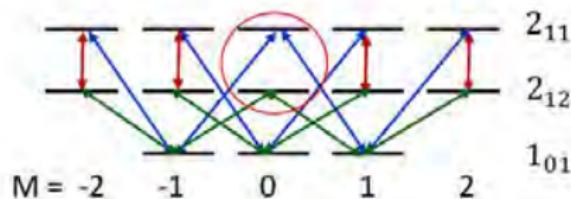


loss due to forbidden transition

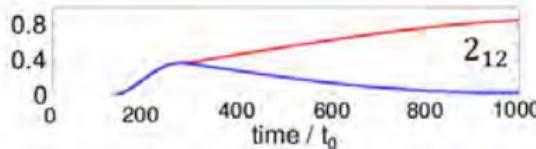
what's the problem ?

M-degeneracy

Initial states: 1_{01}



population

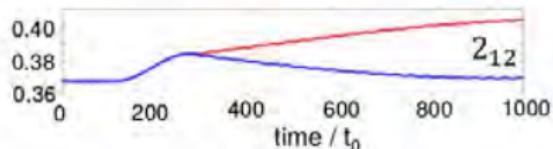
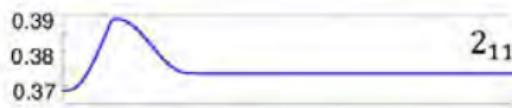
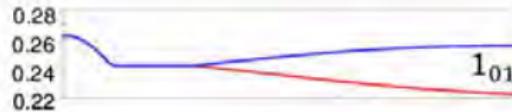


loss due to forbidden transition

temperature

Thermal distribution 1K

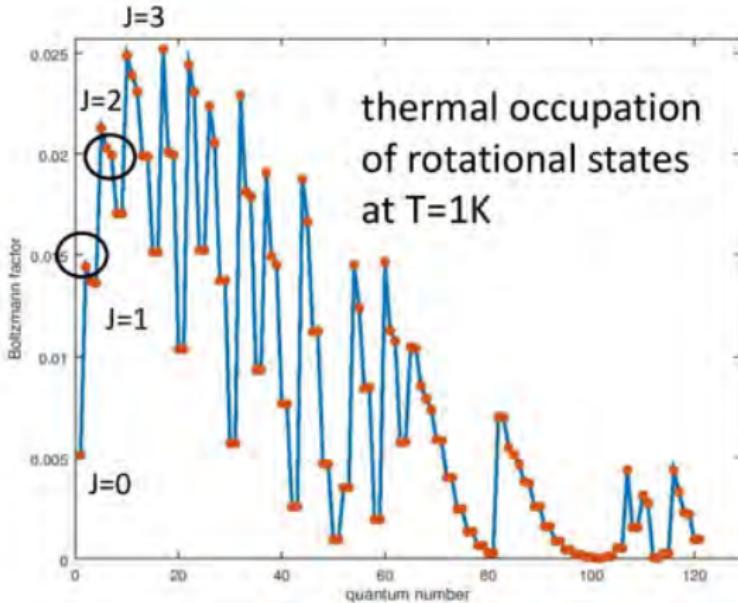
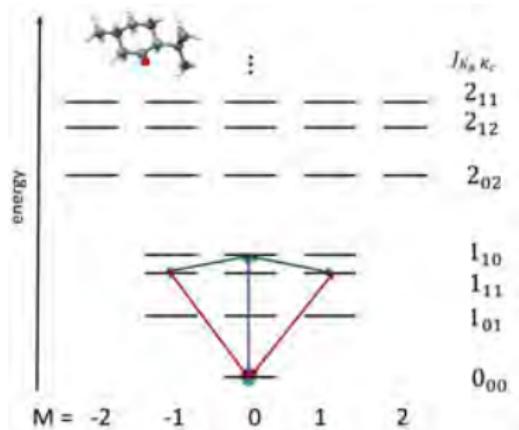
all states are initially populated



approx 3% selectivity

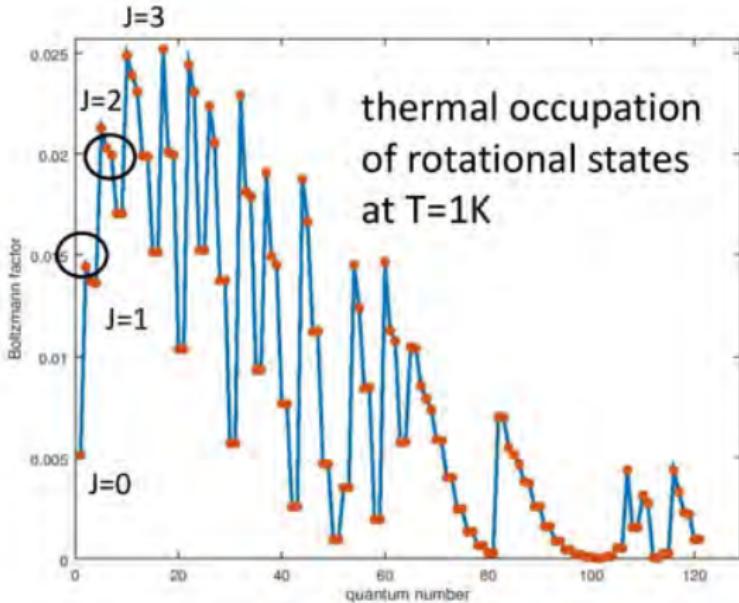
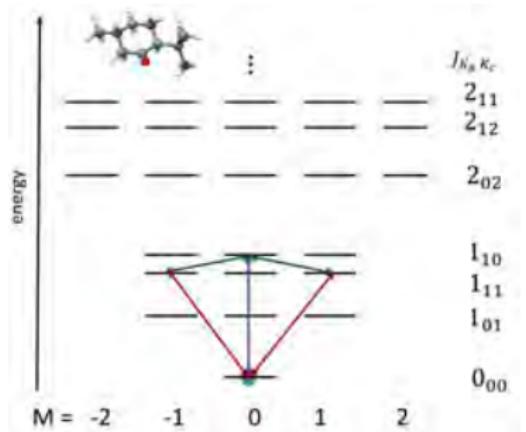
problem of temperature

example of menthone



problem of temperature

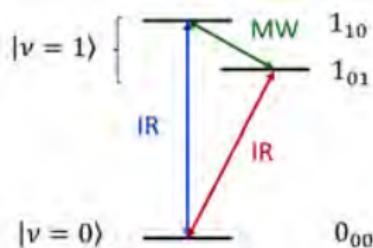
example of menthone



↪ use thermally unpopulated states !

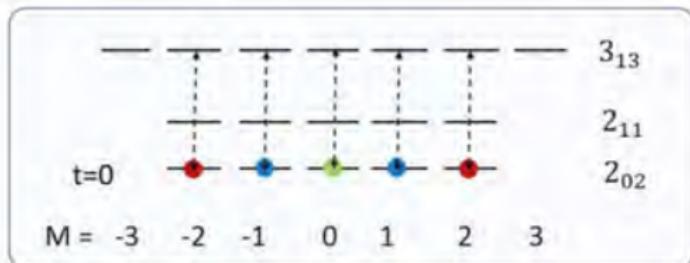
e.g. vibrationally excited states

Leibscher, Giesen, CPK, J Chem Phys 151, 014302 (2019)

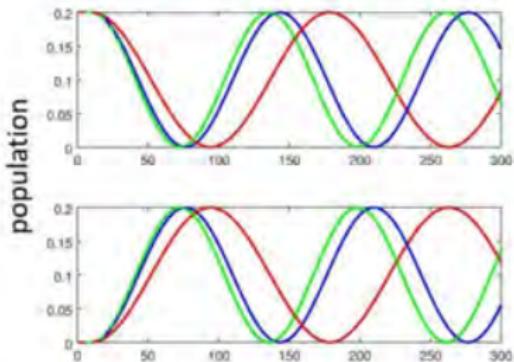


problem of M -degeneracy
controllability of degenerate levels ?

problem of M -degeneracy controllability of degenerate levels ?



- Different Rabi-frequencies
- Forbidden transitions
- Multiple transitions



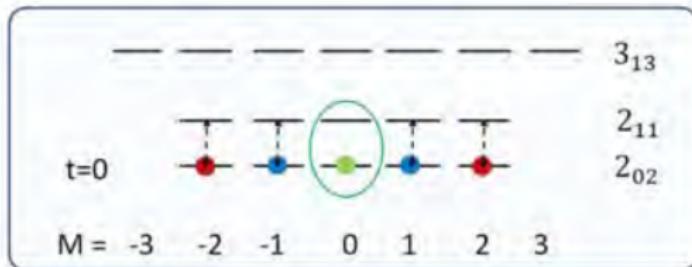
$$\langle J'', K'', M'' | D_{MK}^1 | J', K', M' \rangle$$

$$= \sqrt{2J'' + 1} \sqrt{2J' + 1} (-1)^{M'' + K''}$$

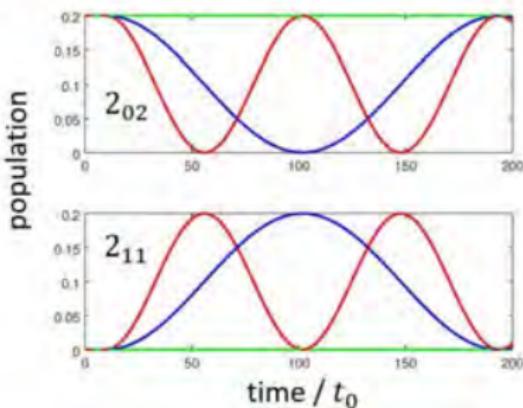
$$\times \begin{pmatrix} J' & 1 & J'' \\ M' & M & -M'' \end{pmatrix} \begin{pmatrix} J' & 1 & J'' \\ K' & K & -K'' \end{pmatrix}$$

Transition matrix elements depend on M

problem of M -degeneracy controllability of degenerate levels ?



- Different Rabi-frequencies
- **Forbidden transitions**
- Multiple transitions



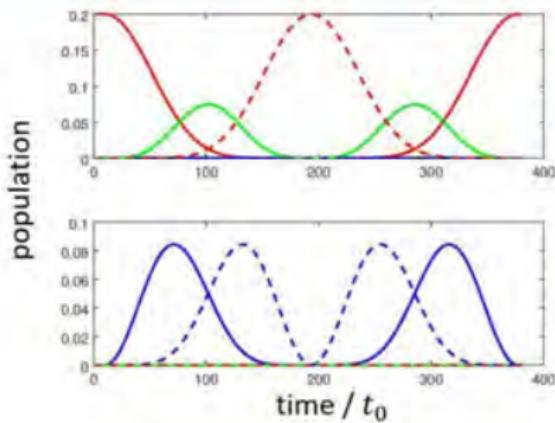
$$\Delta J = 0$$

Transitions between states with $M=0$ are forbidden

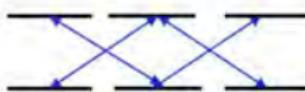
problem of M -degeneracy controllability of degenerate levels ?



- Different Rabi-frequencies
- Forbidden transitions
- Multiple transitions

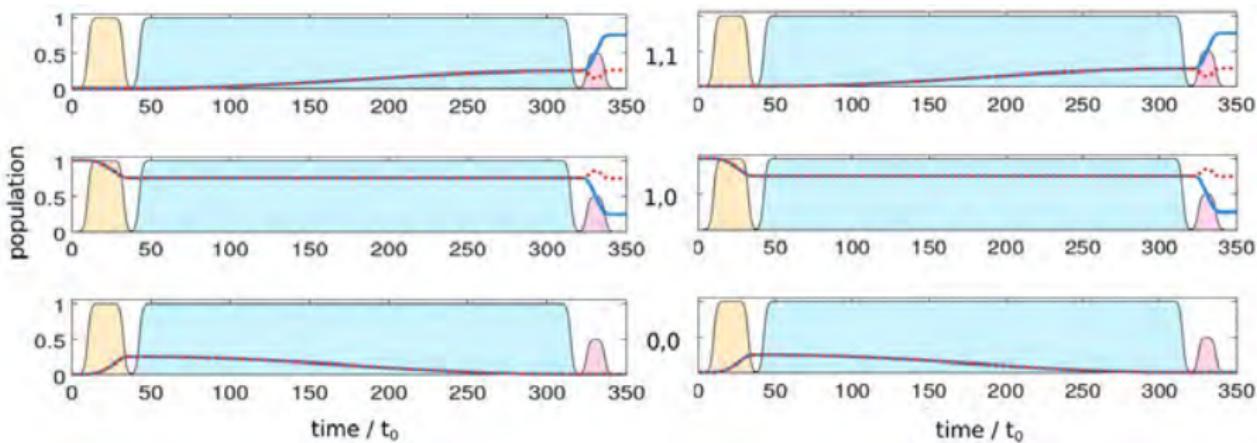
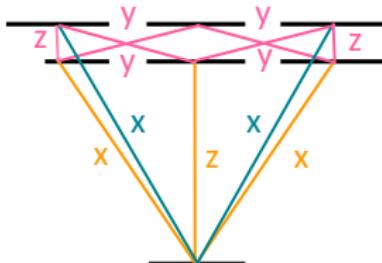


x- and y- polarization ($\Delta M = \pm 1$)



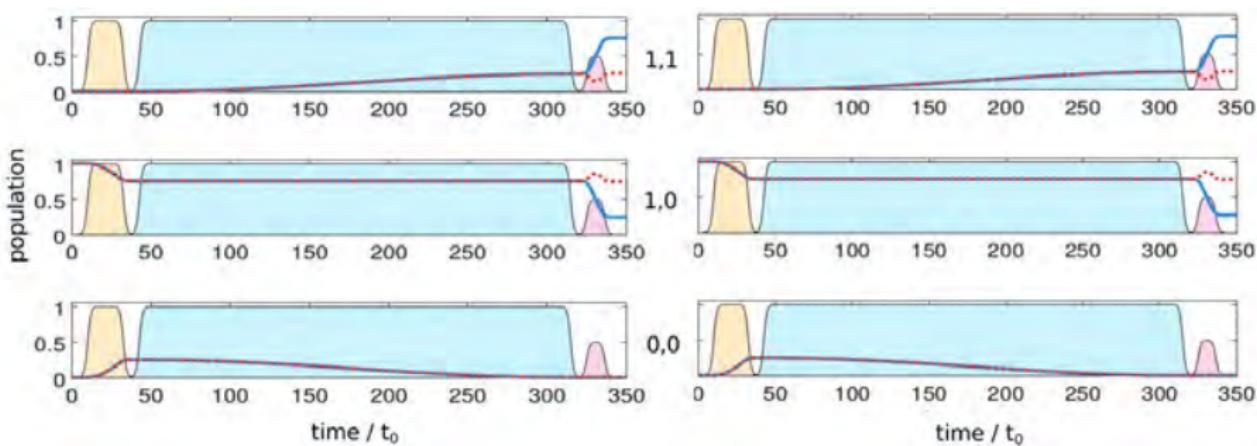
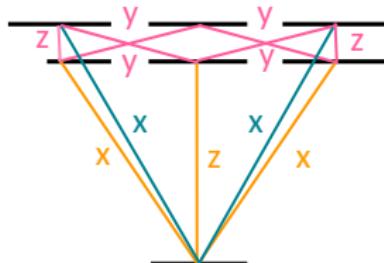
problem of M-degeneracy: how bad is it ?

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



problem of M-degeneracy: how bad is it ?

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



but a solution exists !

controllability

Molecular Hamiltonian

$$H_0 = \begin{pmatrix} E_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & E_N \end{pmatrix}$$

Interaction Hamiltonian

$$H_{int} = \sum_{i=1}^K u_i(t) H_i$$

control fields

Lie-algebra

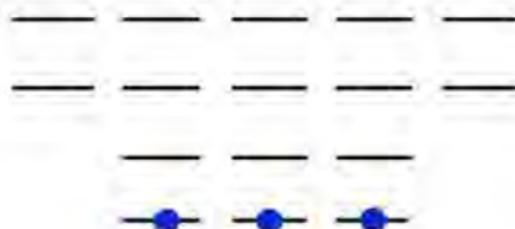
$$\left. \begin{array}{l} H_0, H_1, \dots, H_K \\ [H_0, H_i], [H_i, H_j] \\ [H_0, [H_i, H_j]], [H_k, [H_i, H_j]] \\ \vdots \end{array} \right\}$$

number of linear independent operators = dimension of Lie-algebra
N-state system is controllable if dimension of Lie-algebra is equal or larger than $N^2 - 1$

enantiomer-selective controllability

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

Two enantiomers of a chiral N-level system: $2N$ -level system



$$H_0^{chiral} = \begin{pmatrix} H_0 & 0 \\ 0 & H_0 \end{pmatrix} \quad H_{int}^{chiral} = \begin{pmatrix} H_{int}^{(R)} & 0 \\ 0 & H_{int}^{(S)} \end{pmatrix}$$

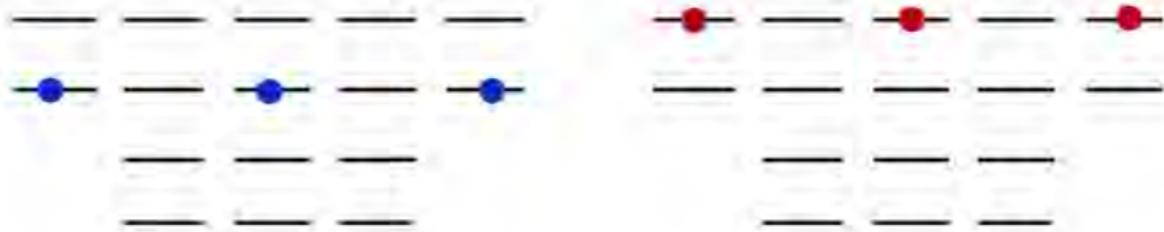
Without conversion between enantiomers:

The system is enantio-selective controllable if the dimension of the Lie-algebra is equal or larger than $2(N^2 - 1)$

enantiomer-selective controllability

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

Two enantiomers of a chiral N-level system: $2N$ -level system



$$H_0^{chiral} = \begin{pmatrix} H_0 & 0 \\ 0 & H_0 \end{pmatrix} \quad H_{int}^{chiral} = \begin{pmatrix} H_{int}^{(R)} & 0 \\ 0 & H_{int}^{(S)} \end{pmatrix}$$

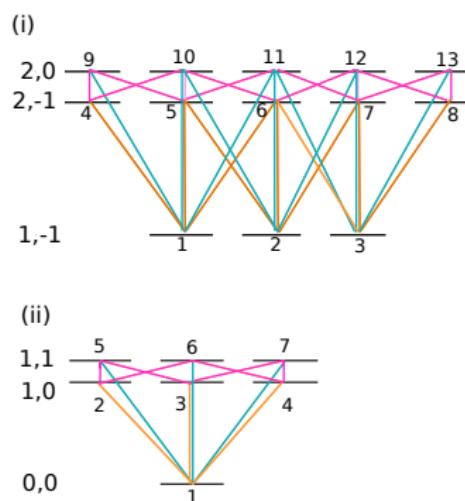
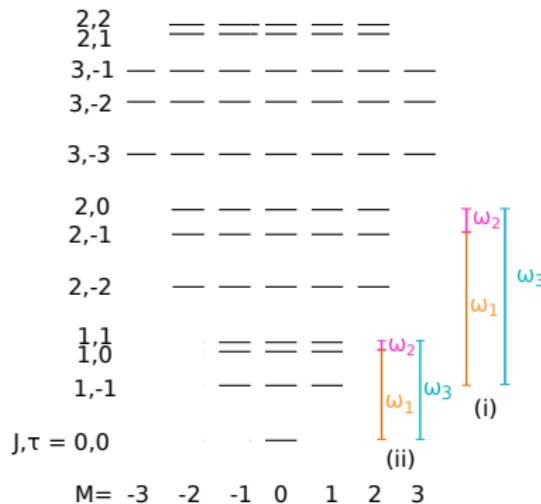
Without conversion between enantiomers:

The system is enantio-selective controllable if the dimension of the Lie-algebra is equal or larger than $2(N^2 - 1)$

enantiomer-selective controllability

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

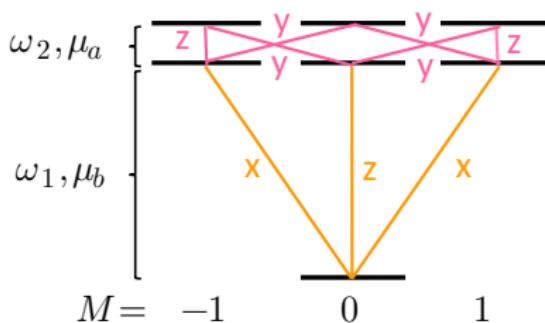
- can be proven for any rotational subspace with a finite number of J 's
- requires 3 orthogonal polarization directions & 3 dipole moment projections
- (exceptions have measure zero)



how many fields are needed?

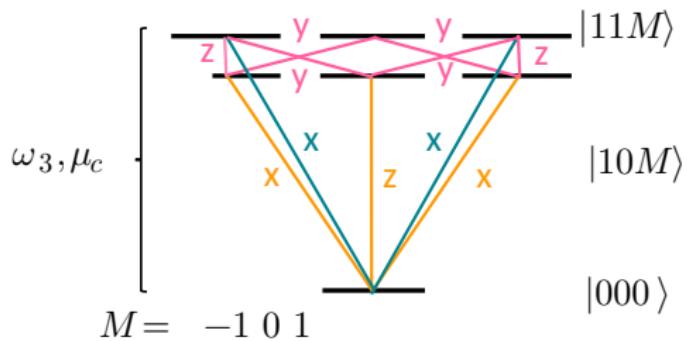
Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

single enantiomer controllability



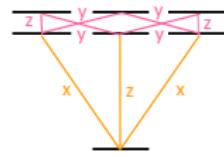
four

enantiomer-selective controllability

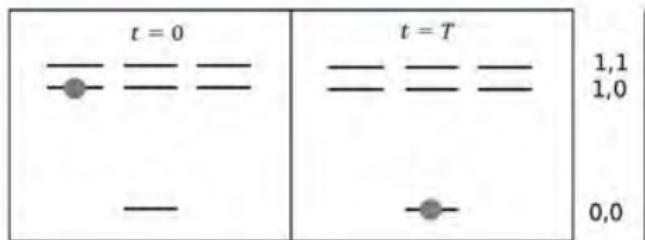
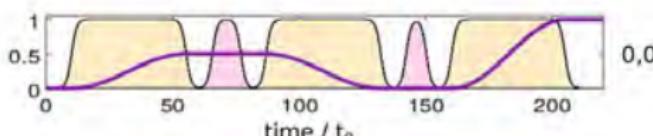
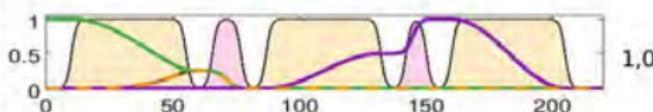
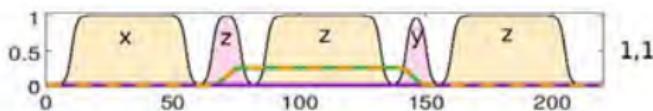


five

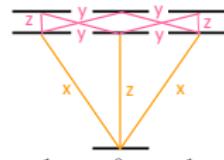
pulse design — step 1: separate $\pm M$



Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

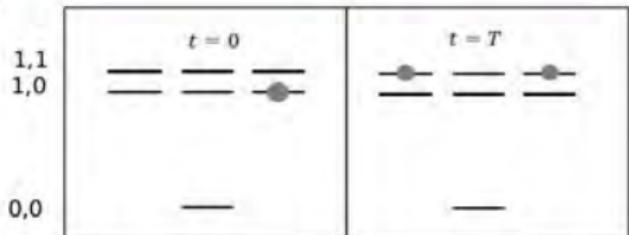
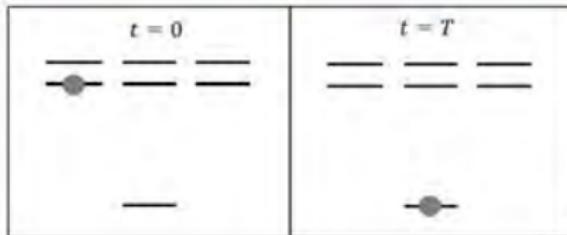
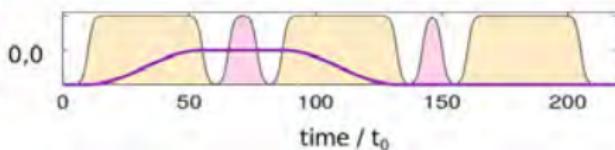
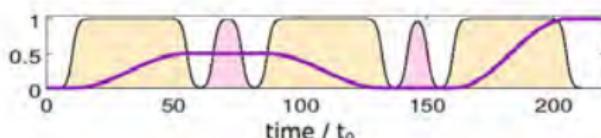
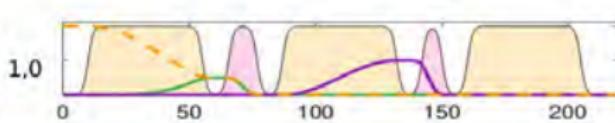
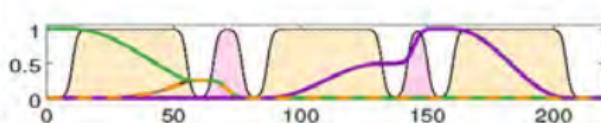
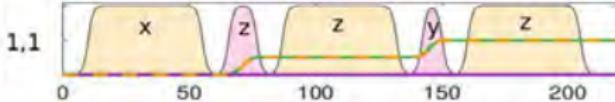
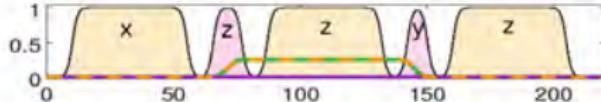


pulse design — step 1: separate $\pm M$

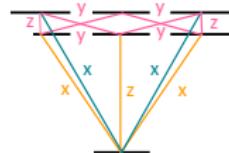


Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296

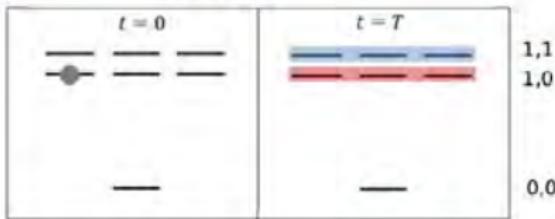
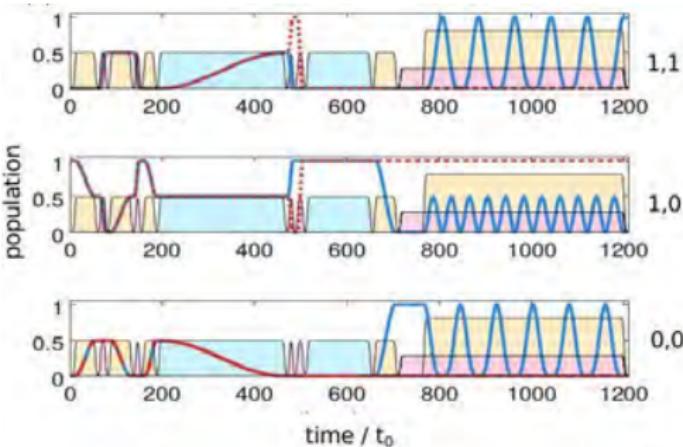
population



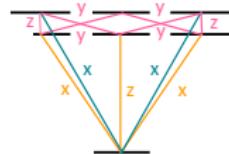
pulse design — step 2: separate R/S



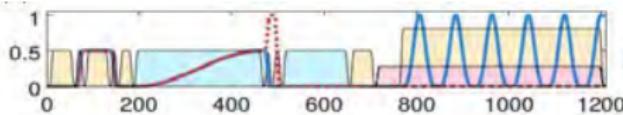
Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



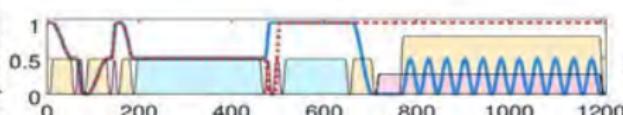
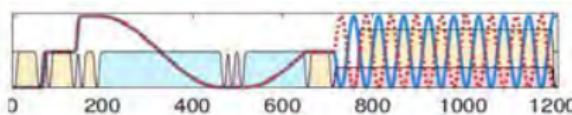
pulse design — step 2: separate R/S



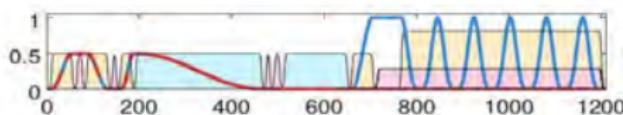
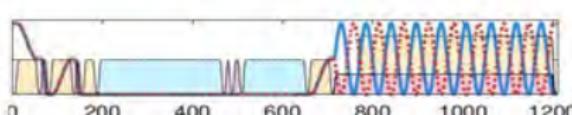
Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



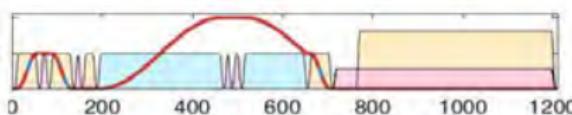
1.1



1.0

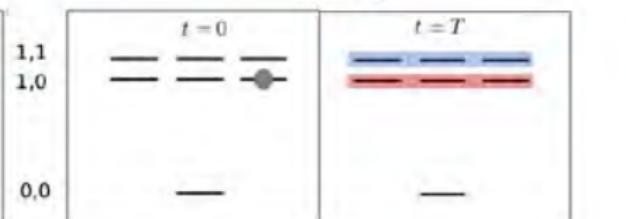
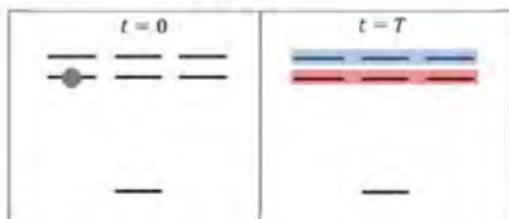


0,0



time / t₀

time / t₀



$t = 0$

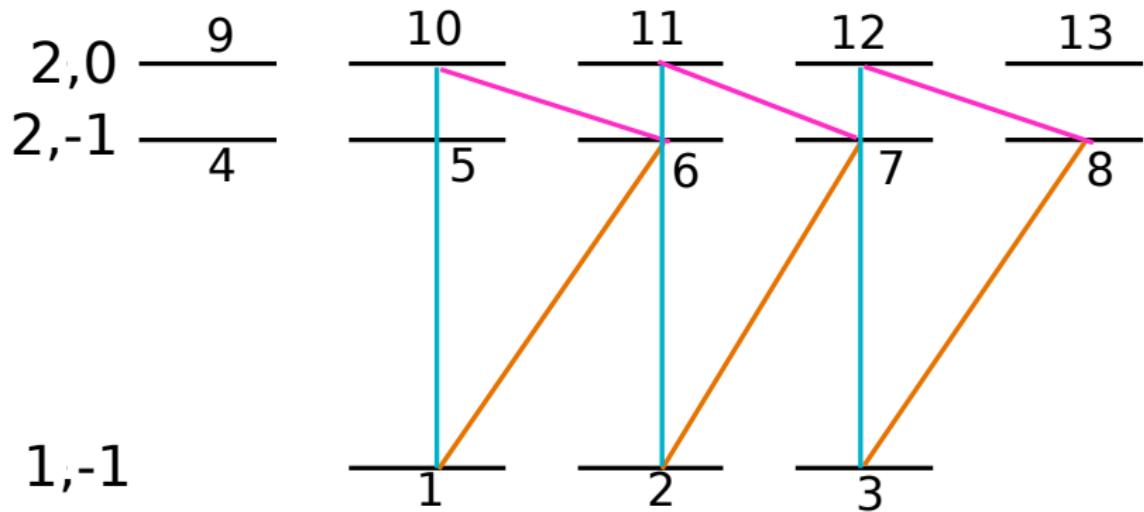
$t = T$

$t = 0$

$t = T$

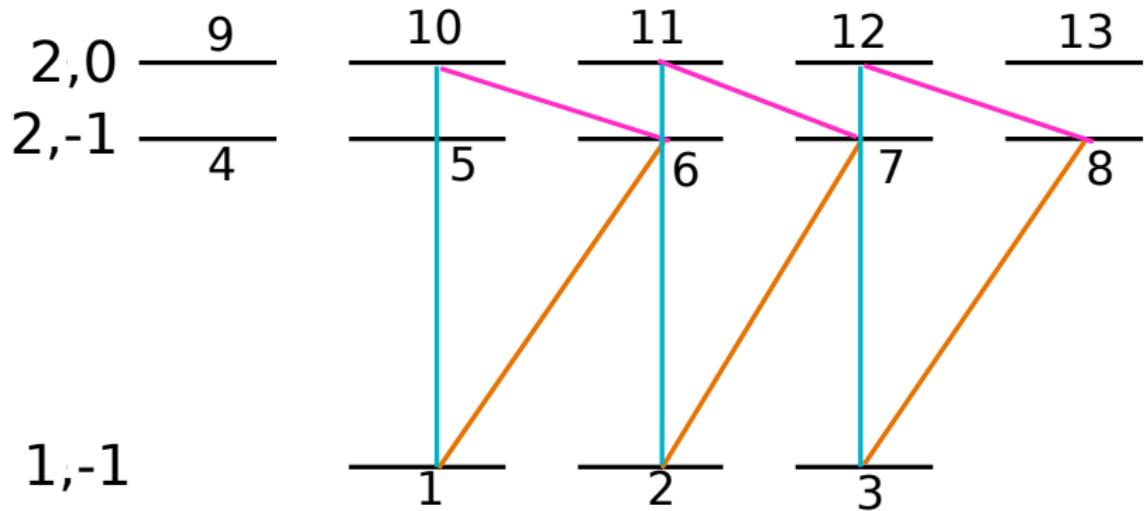
a much simpler solution

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



a much simpler solution

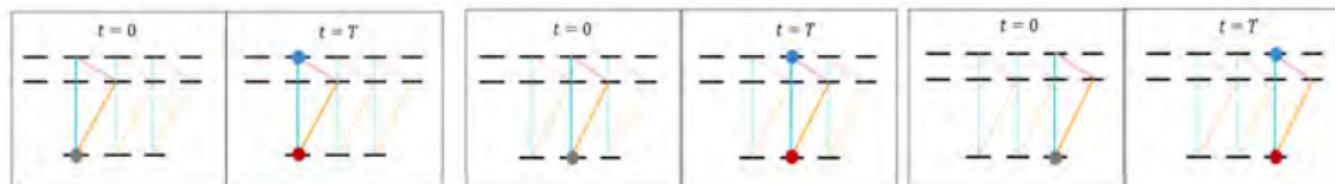
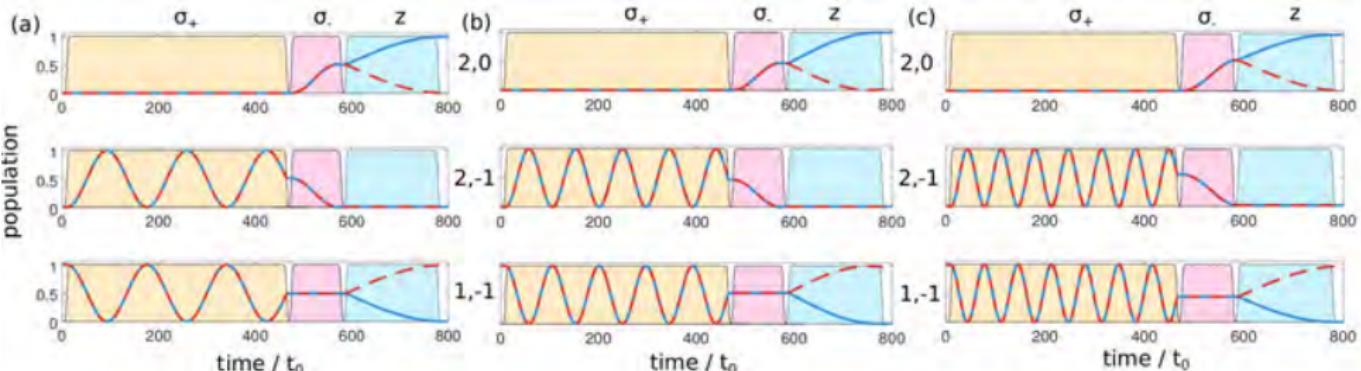
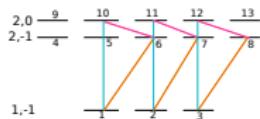
Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



feasible with current microwave technology

a much simpler solution

Leibscher, Pozzoli, Perez, Schnell, Sigalotti, Boscain, CPK, arXiv:2010.09296



feasible with current microwave technology

summary

quantum optimal control is a versatile tool

in qu info science

to bridge the gap between
basic concepts and complexity
of physical platforms

in molecular physics

to explore fundamental limits
of what can / cannot be
controlled

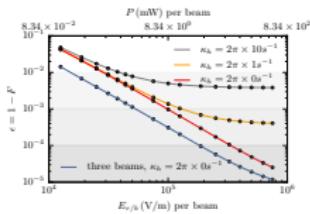
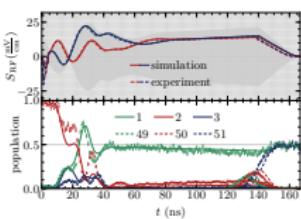
summary quantum optimal control is a versatile tool

in qu info science

to bridge the gap between
basic concepts and complexity
of physical platforms

in molecular physics

to explore fundamental limits
of what can / cannot be
controlled



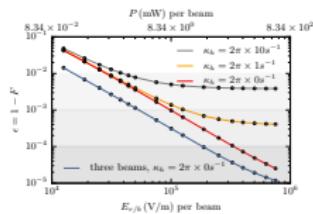
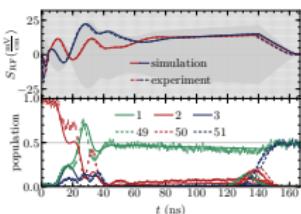
we can determine

- practically useful protocols
for various platforms
- fundamental performance
bounds

summary quantum optimal control is a versatile tool

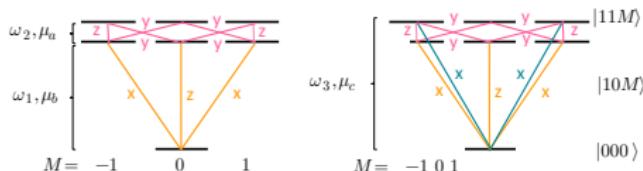
in qu info science

to bridge the gap between
basic concepts and complexity
of physical platforms



in molecular physics

to explore fundamental limits
of what can / cannot be
controlled



we can determine

- practically useful protocols for various platforms
- fundamental performance bounds

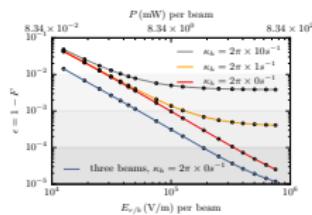
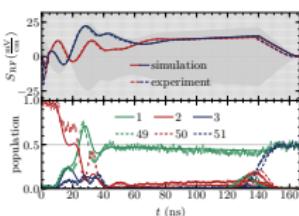
we can energetically separate

- population in degenerate states
- left-handed from right-handed molecules

summary quantum optimal control is a versatile tool

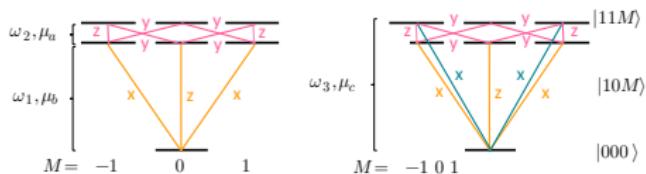
in qu info science

to bridge the gap between
basic concepts and complexity
of physical platforms



in molecular physics

to explore fundamental limits
of what can / cannot be
controlled



we can determine

- practically useful protocols for various platforms
- fundamental performance bounds

how to adapt these concepts when scaling up system size ?

we can energetically separate

- population in degenerate states
- left-handed from right-handed molecules

acknowledgements



Karl Horn

Sabrina Patsch

Monika Leibscher

collaborations
& funding:
A. Larrouy,
J.M. Raimond,
M. Brune,
S. Gleyzes
(CdF/ENS Paris)



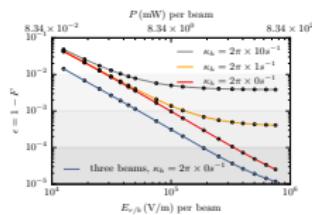
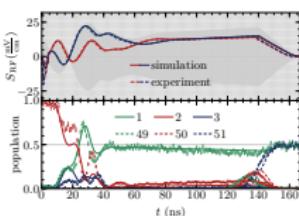
E. Pozzoli, M.
Sigalotti, U.
Boscain (INRIA)
C. Pérez, M.
Schnell (DESY)



summary quantum optimal control is a versatile tool

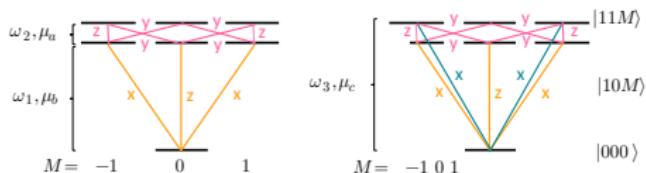
in qu info science

to bridge the gap between
basic concepts and complexity
of physical platforms



in molecular physics

to explore fundamental limits
of what can / cannot be
controlled



we can determine

- practically useful protocols for various platforms
- fundamental performance bounds

how to adapt these concepts when scaling up system size ?

we can energetically separate

- population in degenerate states
- left-handed from right-handed molecules