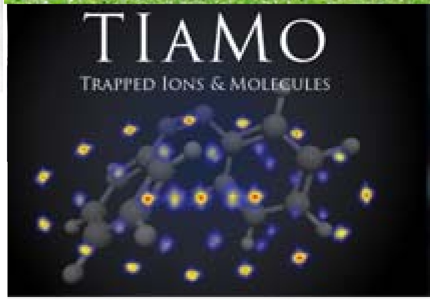
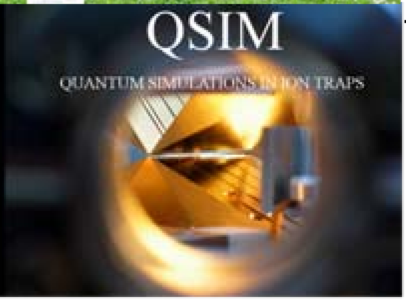
Thomas Huber [Christian Schneider]
Alex Lambrecht [Martin Enderlein]
Julian Schmidt [Michael Zugenmeier

+ Ulrich Warring [NIST]
+ Leon Karpa [MIT]





IMPRS-APS

TIAMO

Trapped Ions And MOlecules

"watch your single molecule"

+ topological defects [PICC]

col. Rezink, Landa, Retzker

→ Universität Freiburg

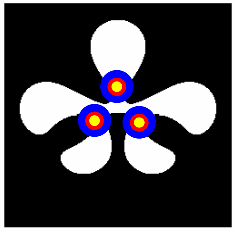
PICC

QSim

Quantum Simulations (with ions)

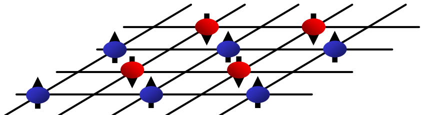
col. Porras, Bermudez

scaling QSim in rf-surface traps



col. NIST SNL Basel

optical trapping of ions (and atoms)



col. Lukin, Cote, Moszynski, Morigi

+ decoherence assisted spectroscopy **[NIST]**

2D Analogue Quantum Simulations
Exploiting Ions (and Atoms) in Optical and RF-Traps

➔ QSim: 2D arrays of rf-traps

➔trappology

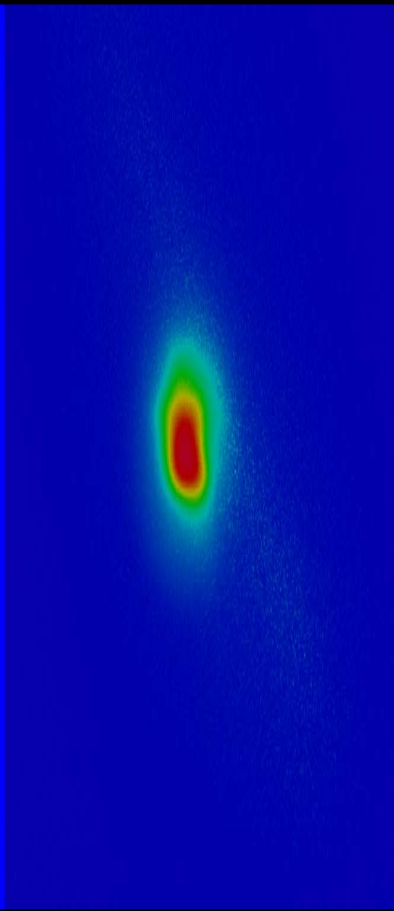
➔precursors (expl. decoherence)

+ [QSim - gauge fields]
+ [dissipation assisted entanglement]
+ decoherence assisted spectroscopy

➔ optically trapping of ions and atoms

➔ trapping of topological defects

+ defect assisted entanglement



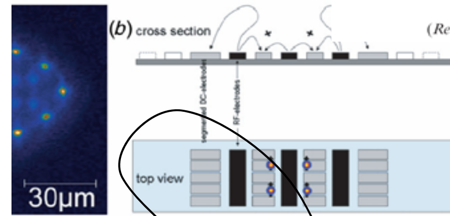
2D array - rf surface

Towards (scalable) quantum simulations in ion traps

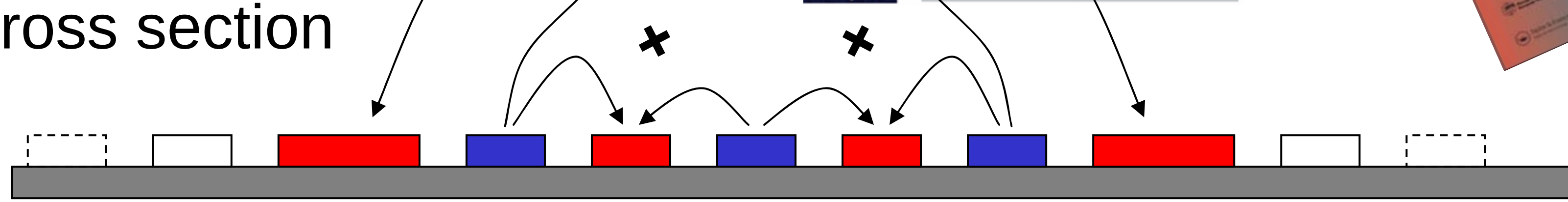
T. SCHAETZ*, A. FRIEDENAUER, H. SCHMITZ, L. PETERSEN and S. KAHRA
Max Planck Institut für Quantenoptik, Hans Kopfe... Strasse 1, 85748 Garching, German...

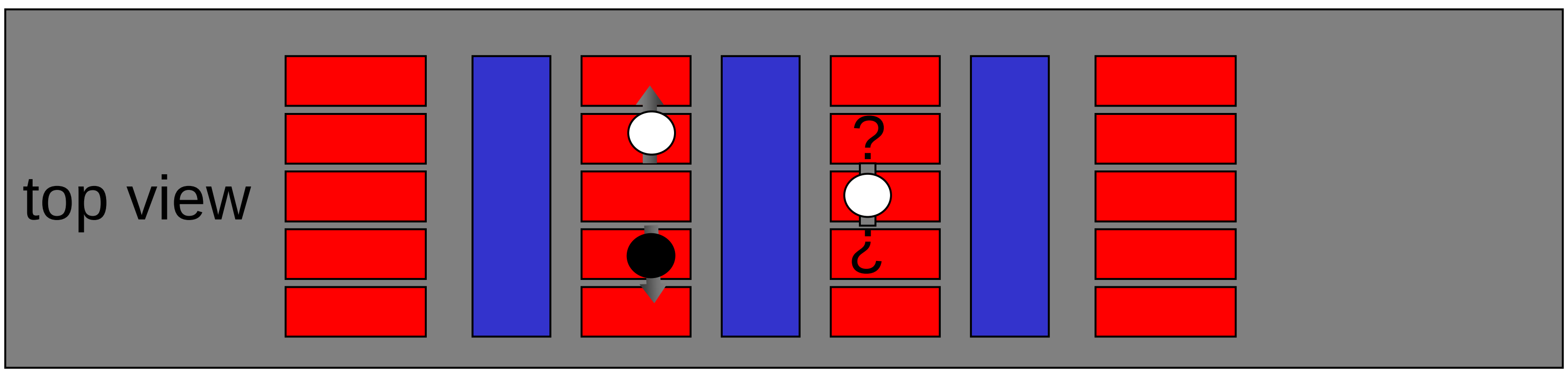
(Received 14 March 2007; ...

T. Schaetz et al.



cross section





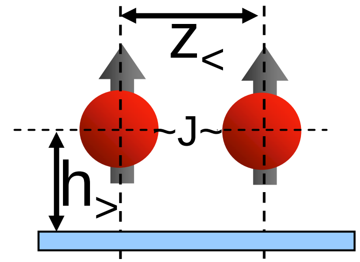
- ➔ extend into second dimension (arrays of ions) [see also Chiaverini, Hensinger, Blatt,..]
- ➔ **optimize architecture for quantum simulations** (no cryogenics, large $J_{spin/spin}$)
- ➔ (potentially without lasers)

2D - scaling

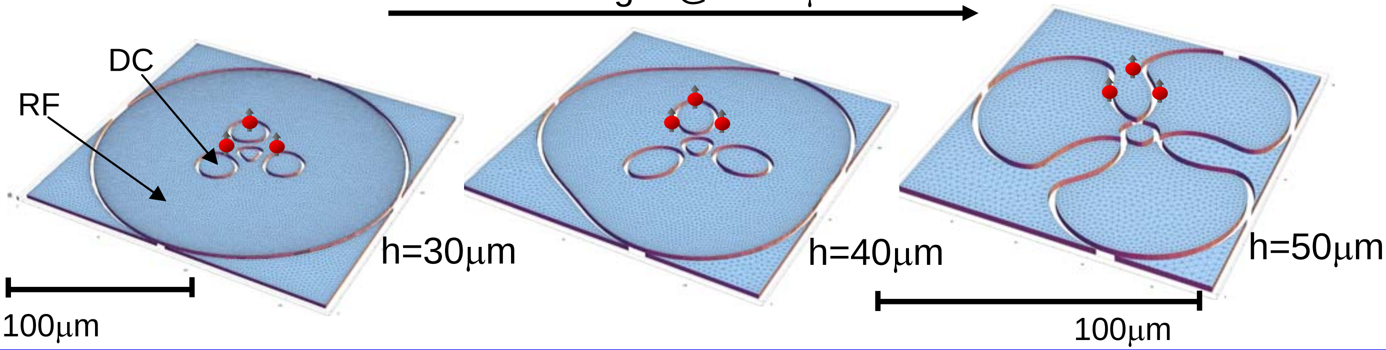
collaboration:
Roman Schmied

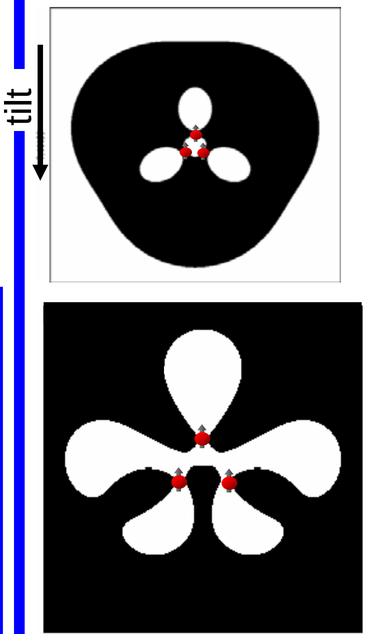
optimize (2D) trap architecture:

- minimal distance z~40μm ($J \sim z^{-3}$~kHz)
- maximal height h>50μm (heating~h^{-4})
- tilt of axis (access all dimensions)

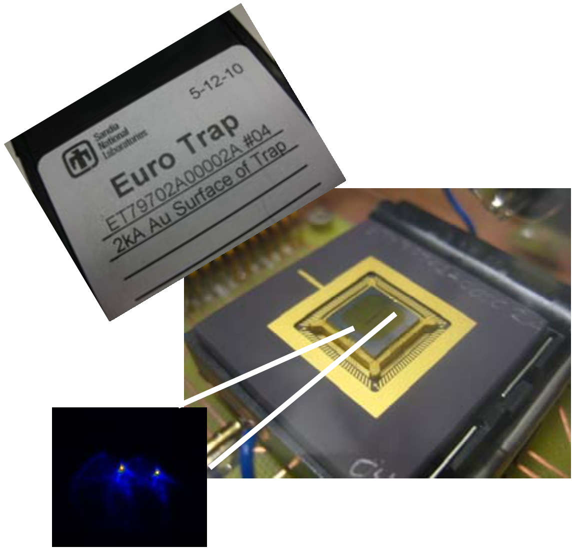


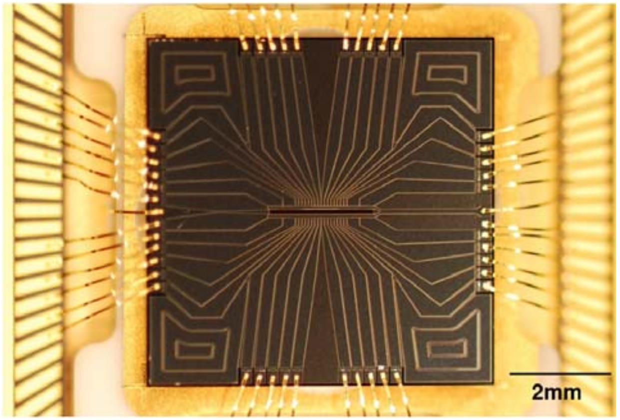
increasing h @ z=40μm





first step:
1D surface trap



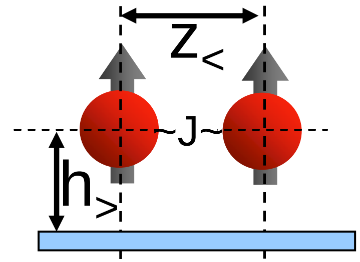


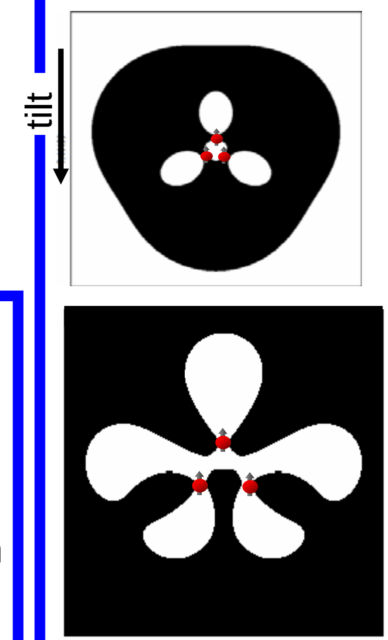
collaboration:
Sandia National Laboratories

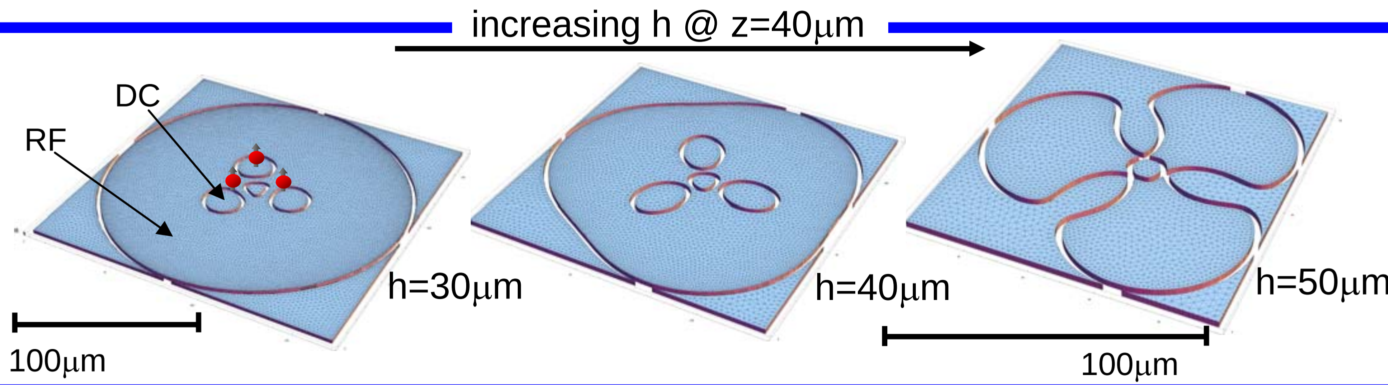
2D scaling

collaboration:
Roman Schmied

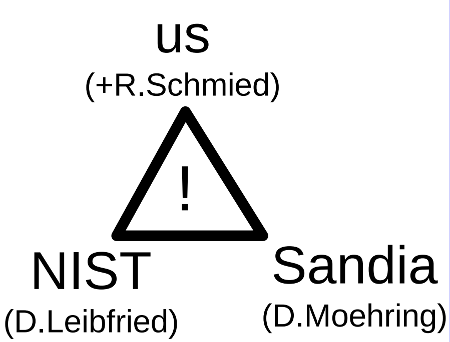
optimize (2D) trap architecture:

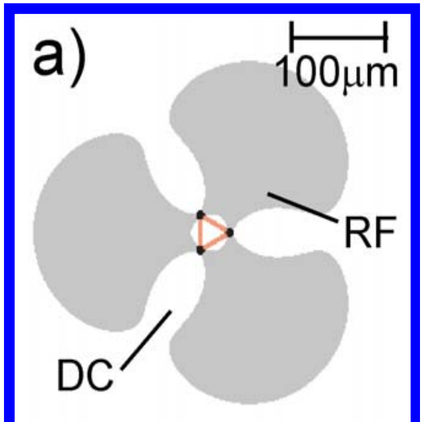






collaboration

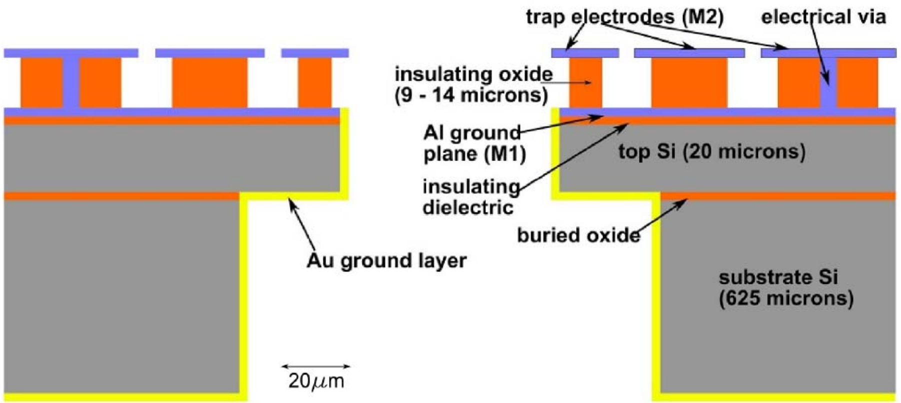


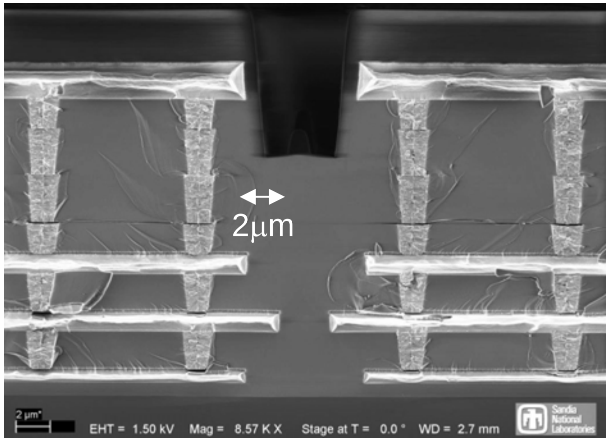


+ proof of principle studies:
spin frustration,
spin glass effects,
disorder,
quantum phase transitions
(Spin Boson, Bose Hubbard)

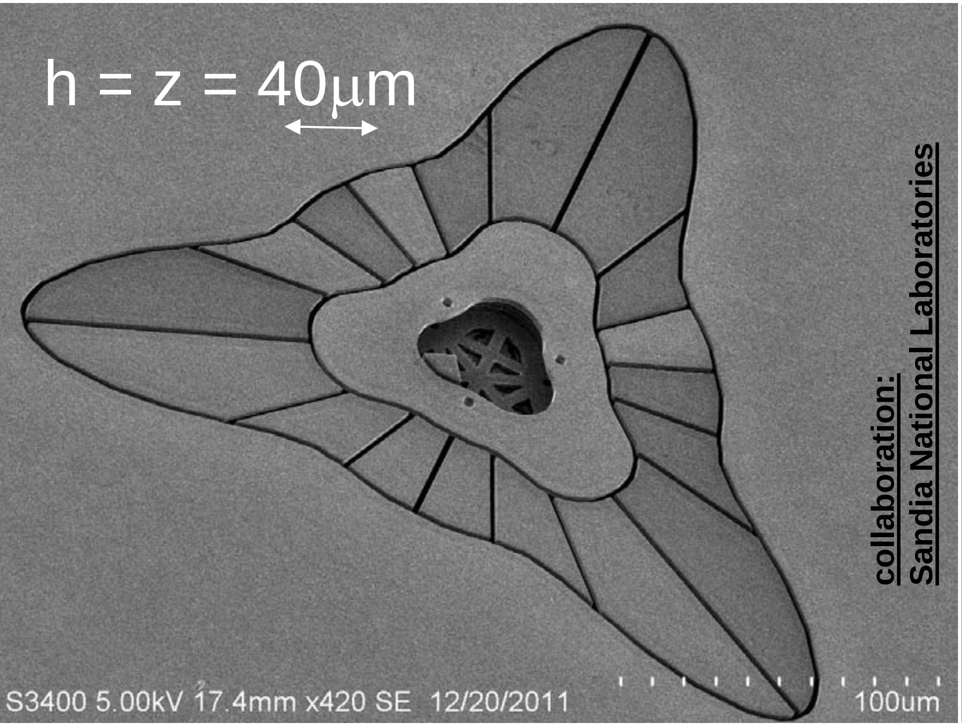
2D scaling – real life

collaboration:
Sandia National Laboratories

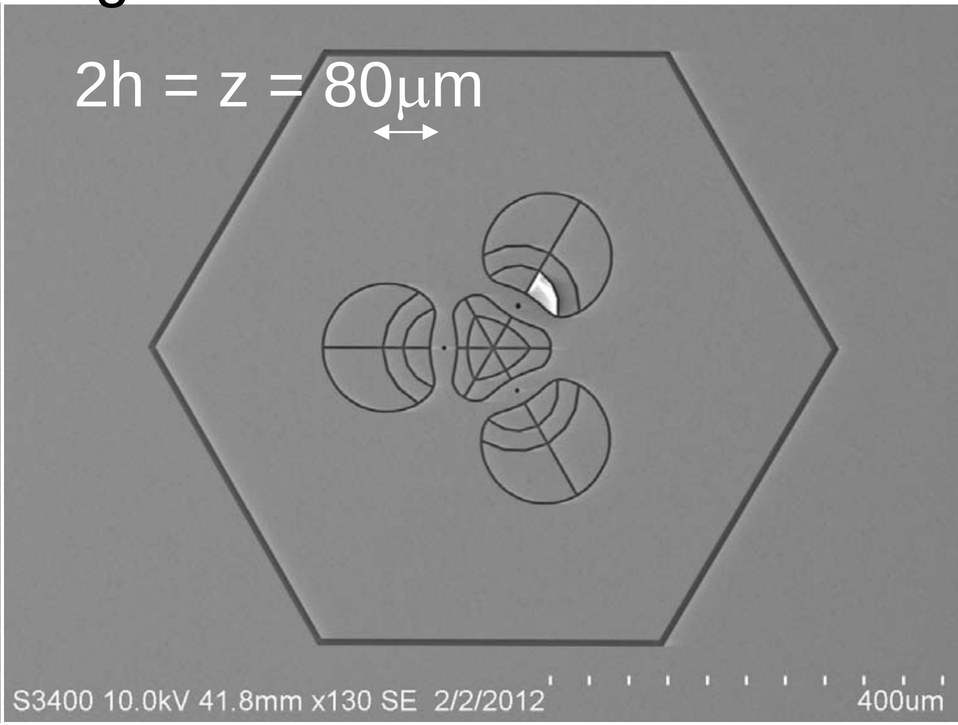




last challenges

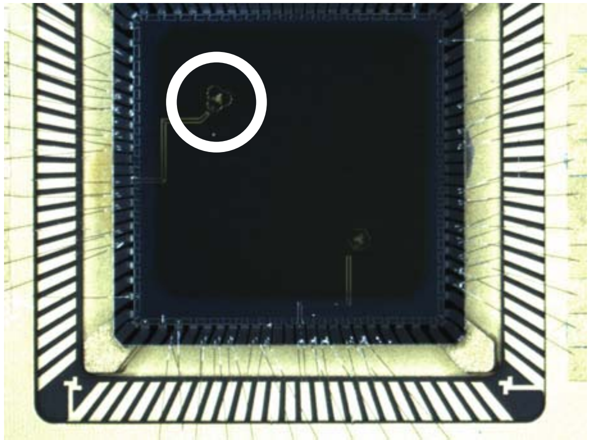


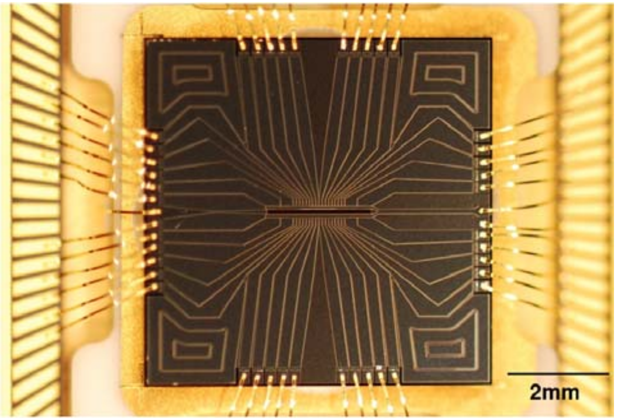
collaboration:
Sandia National Laboratories

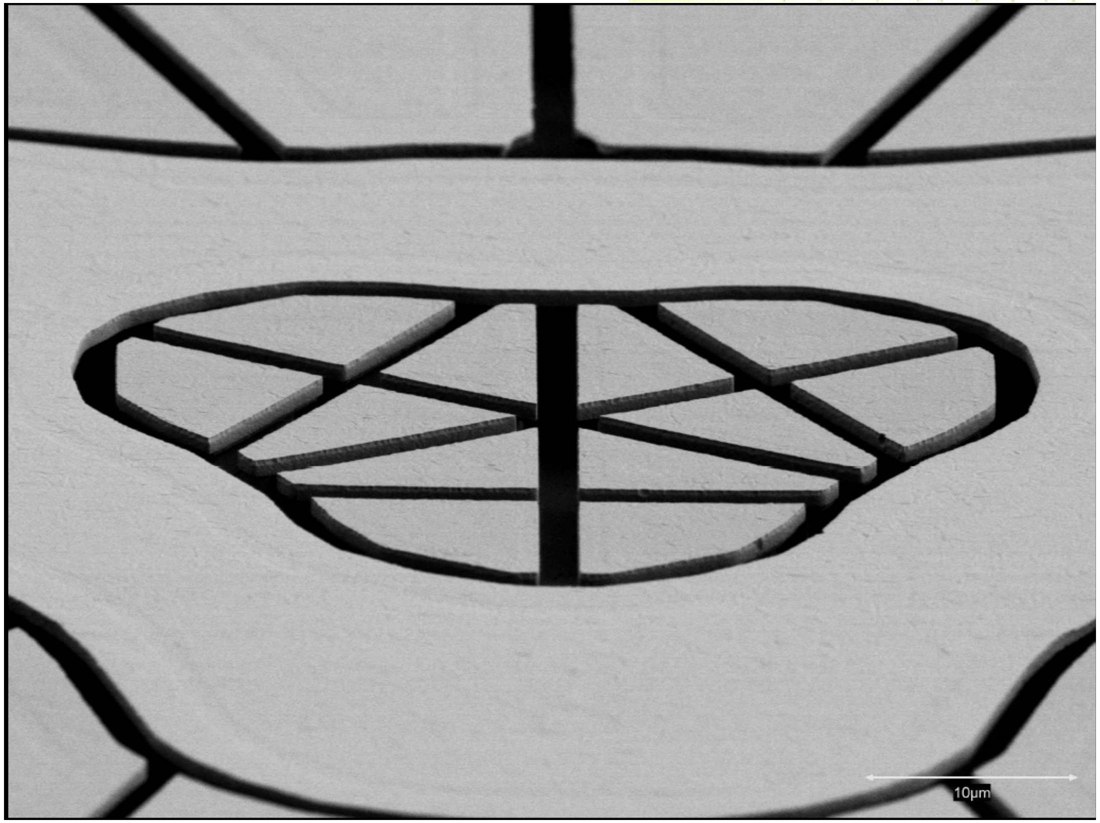


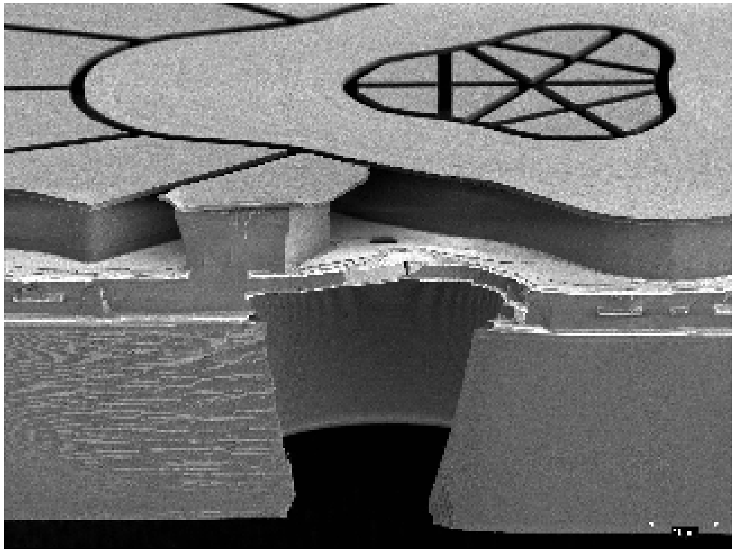
2D scaling – nice life

collaboration:
Sandia National Laboratories





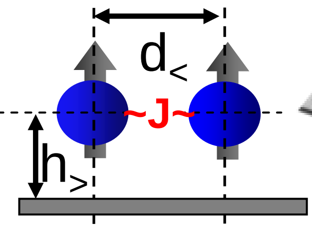


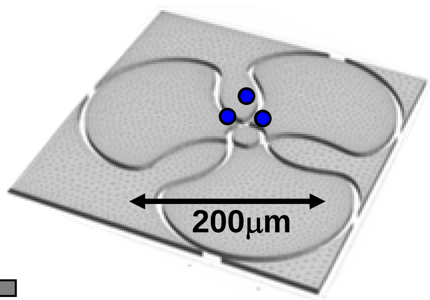


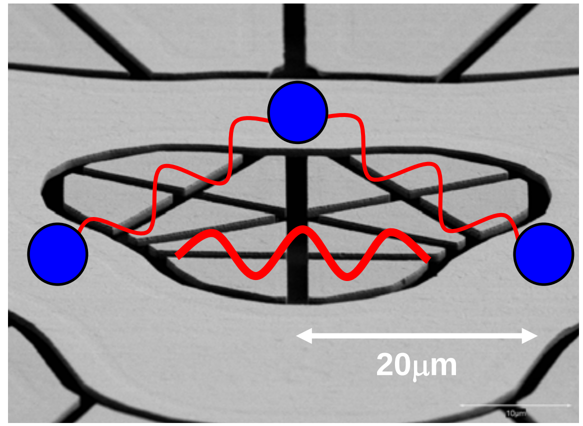
2D scaling – nice life

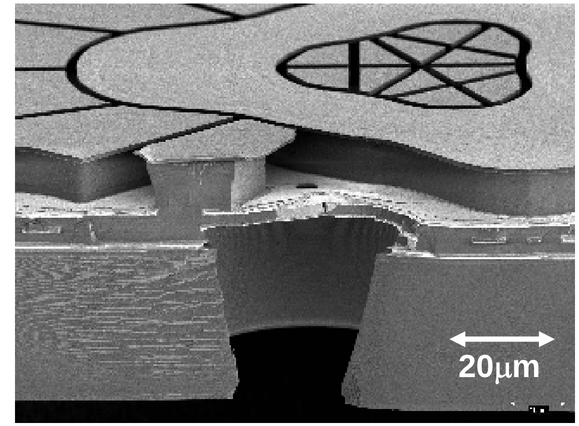
rf-surface electrode traps [ions]

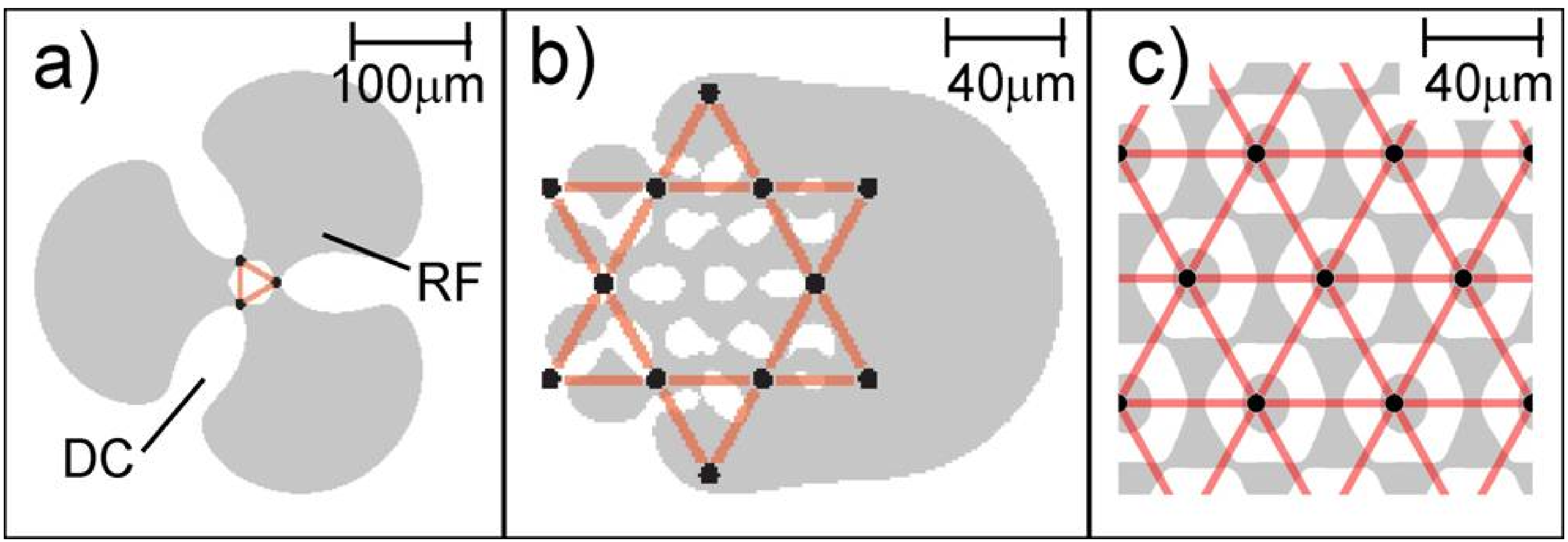
NIST, Basel, Sandia (3x)
Bermudez, Porras



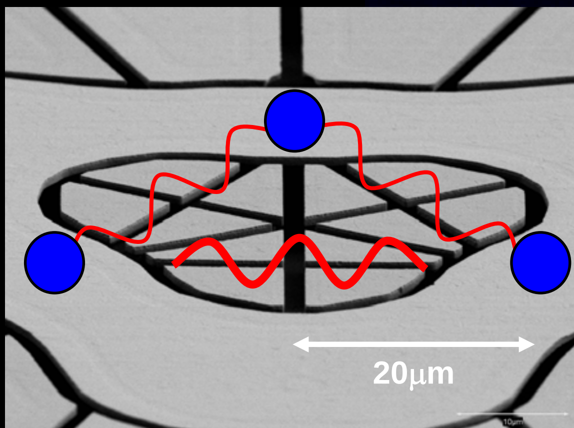


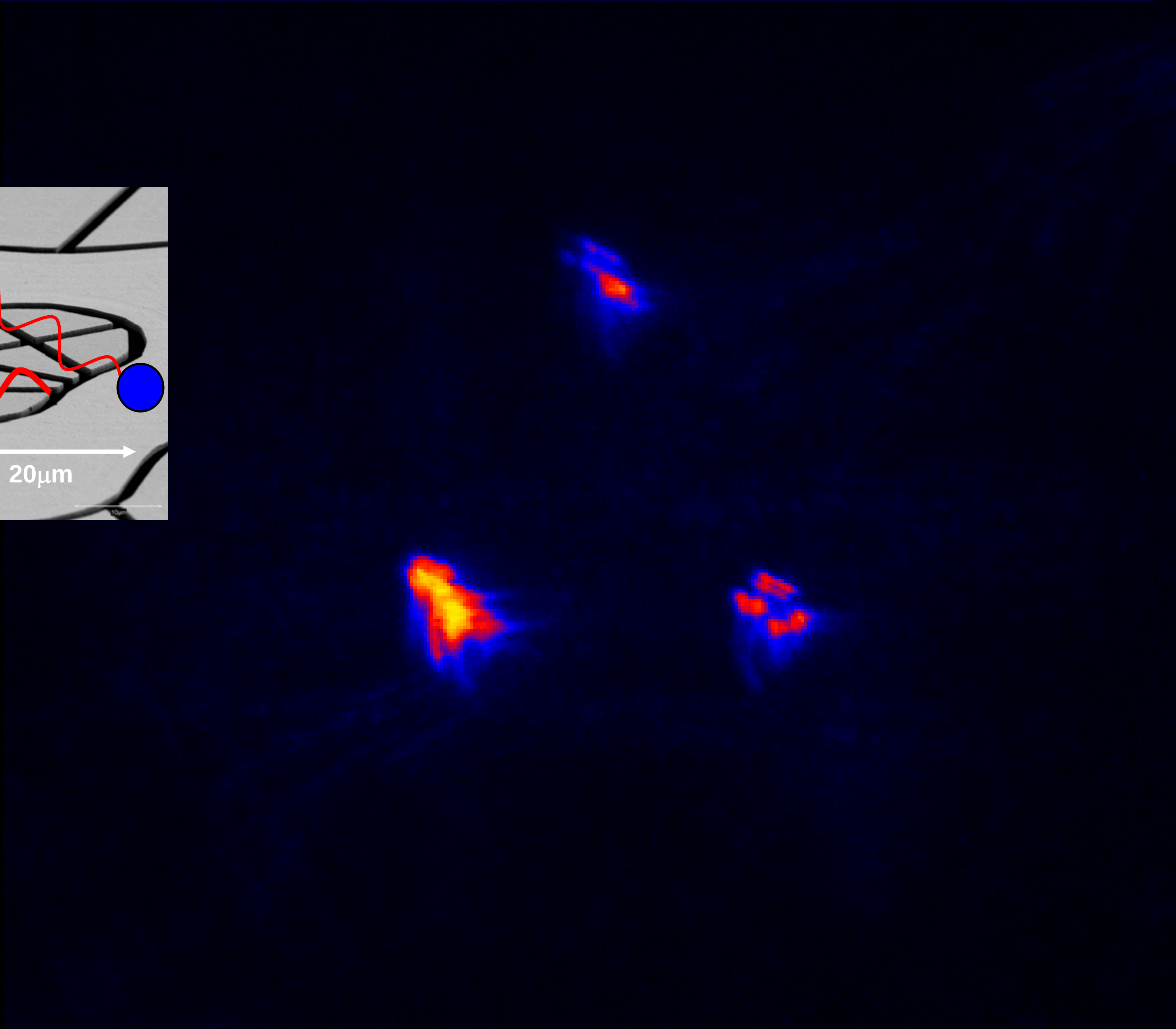






2D arrays – real nice life





2D Analogue Quantum Simulations
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➔trappology

➔precursors (expl. decoherence)

+ [QSim - gauge fields]
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+ decoherence assisted spectroscopy

➔ optically trapping of ions and atoms

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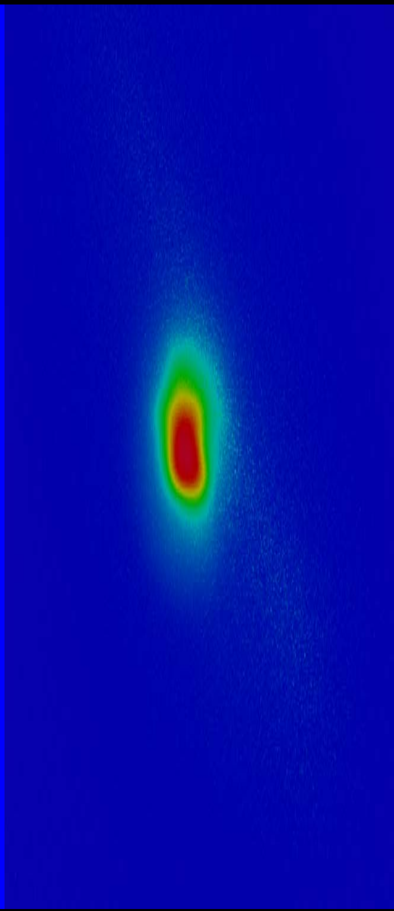
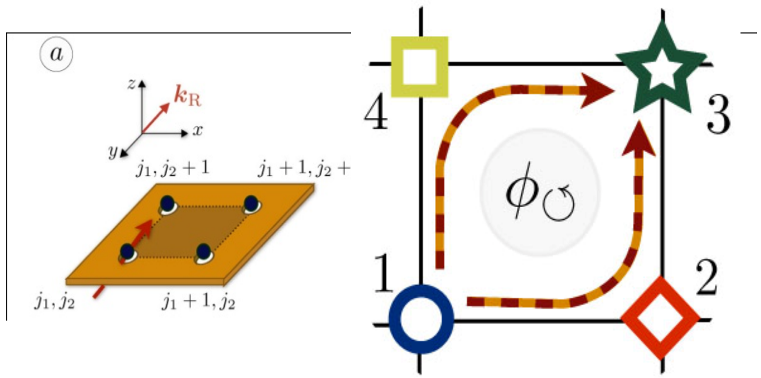


synthetic gauge fields in arrays of ion traps

Phonons simulate charged particles

[exploiting Coulomb directly (J>>) and 2D-array]



Alejandro Bermúdez
(University of Madrid)
Tobias Schätz
(University of Freiburg)
Diego Porras
(University of Sussex)

- A. Bermúdez, T. Schaetz, D. Porras, Physical Review Letters **107**, 150501 (2011)
- A. Bermúdez, T. Schaetz, D. Porras, New Journal of Physics **14**, 053049 (2012)
- Ch. Schneider, D. Porras, and T. Schaetz, Reports on Progress in Physics **75**, 024401 (2012)

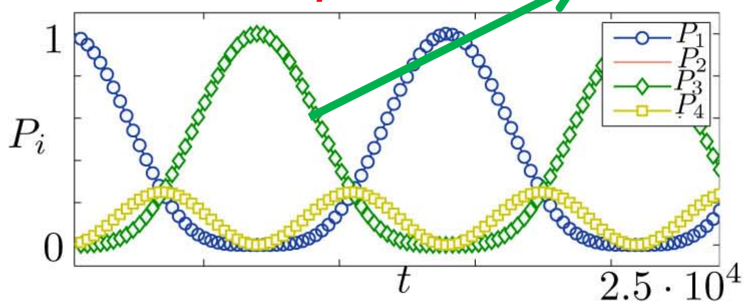
synthetic gauge fields on phonons

- Simplest example: 4 ions form a single plaquette

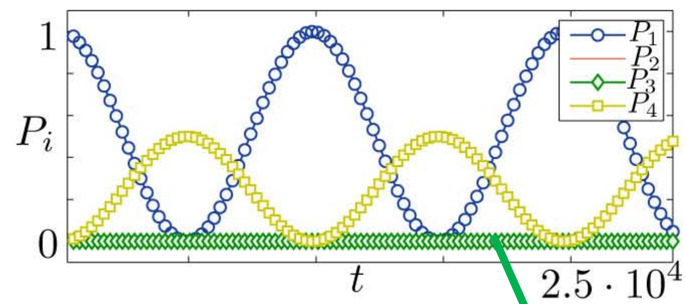
ϕ effective magnetic flux

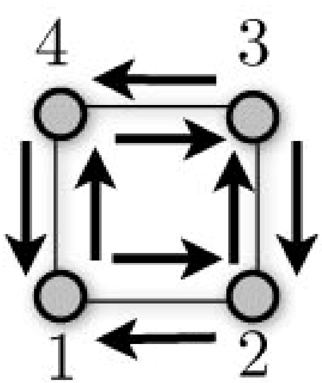
phonon tunnels to site 3

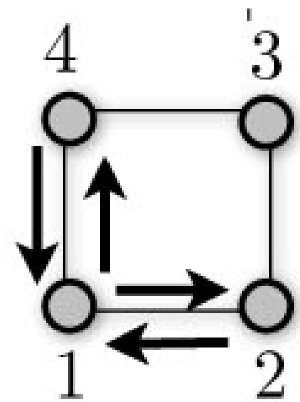
$\phi = 0$



$\phi = \pi$







Inhibition of phonon tunneling from "magnetic" destructive interference

adding:
electronic states (spins)
superposition states ~ disorder

2D scaling – real life

“fighting” decoherence [+ NIST- Ar^+]

PRL **110,** 110502 (2013) PHYSICAL REVIEW LETTERS week ending 15 MARCH 2013

Dissipation-Assisted Quantum Information Processing with Trapped Ions

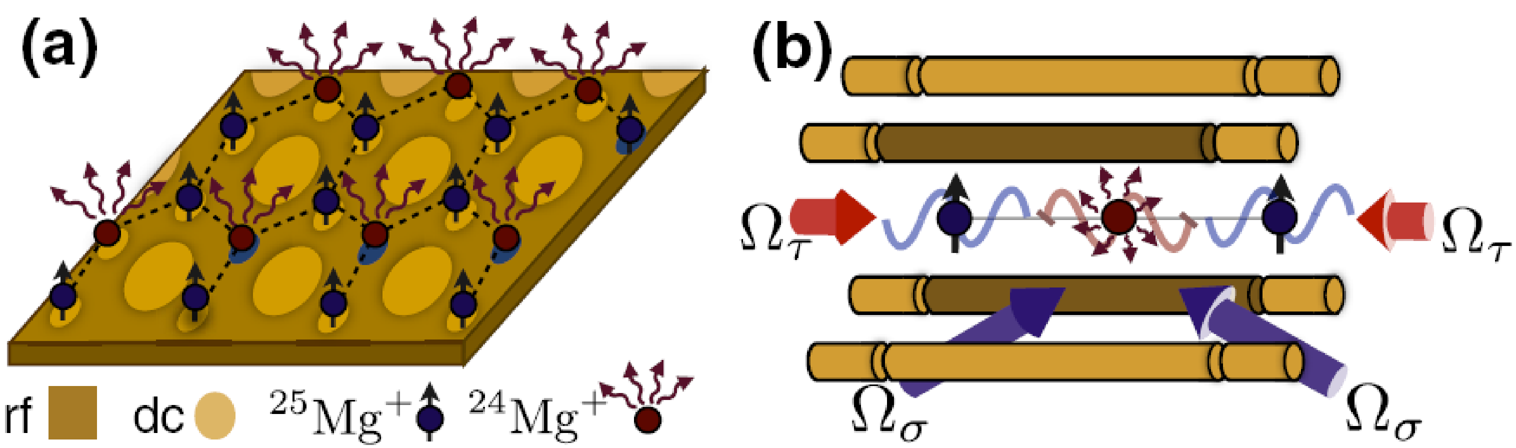
A. Bermudez,[1] T. Schaetz,[2] and M. B. Plenio[1]

[1]*Institut für Theoretische Physik, Albert-Einstein Alle 11, Universität Ulm, 89069 Ulm, Germany*

[2]*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany*

(Received 11 October 2012; revised manuscript received 21 December 2012; published 14 March 2013)

dissipation assisted ….



decoherence assisted spectroscopy

Govinda Clos, Martin Enderlein, Ulrich Warring

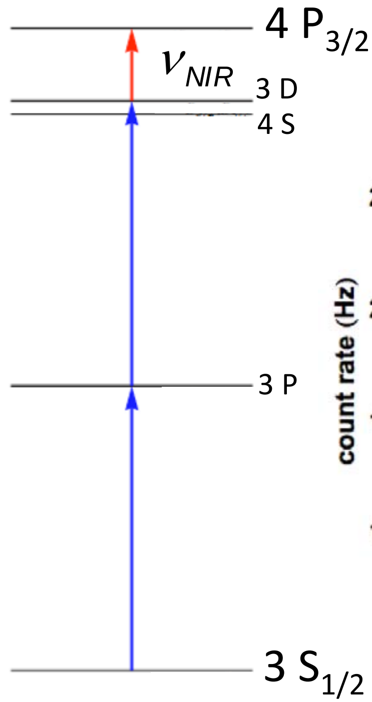
Spectroscopy based on decoherence:

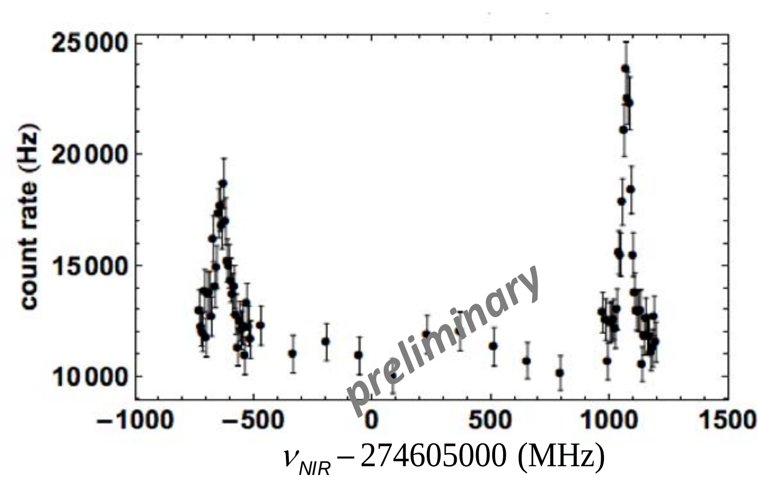
•Prepare spin-state superposition

•spin-decoherence gives the signal

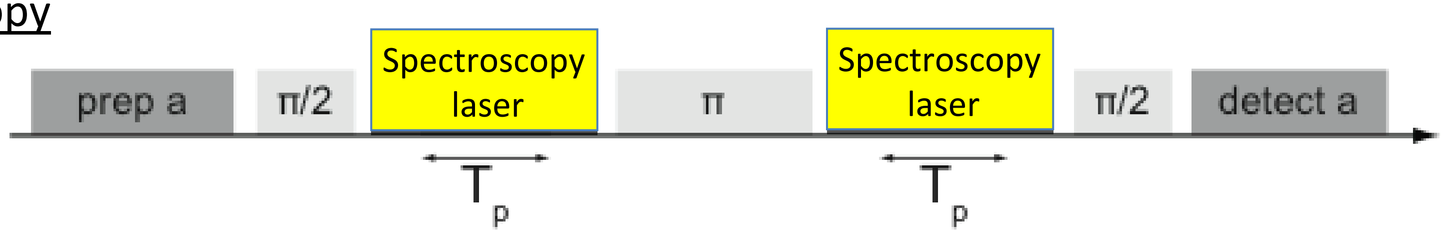
•Signal after scattering only a few spectroscopy photons

•Measure the astrophysical relevant line: 3 $S_{1/2}$ – 4 $P_{3/2}$



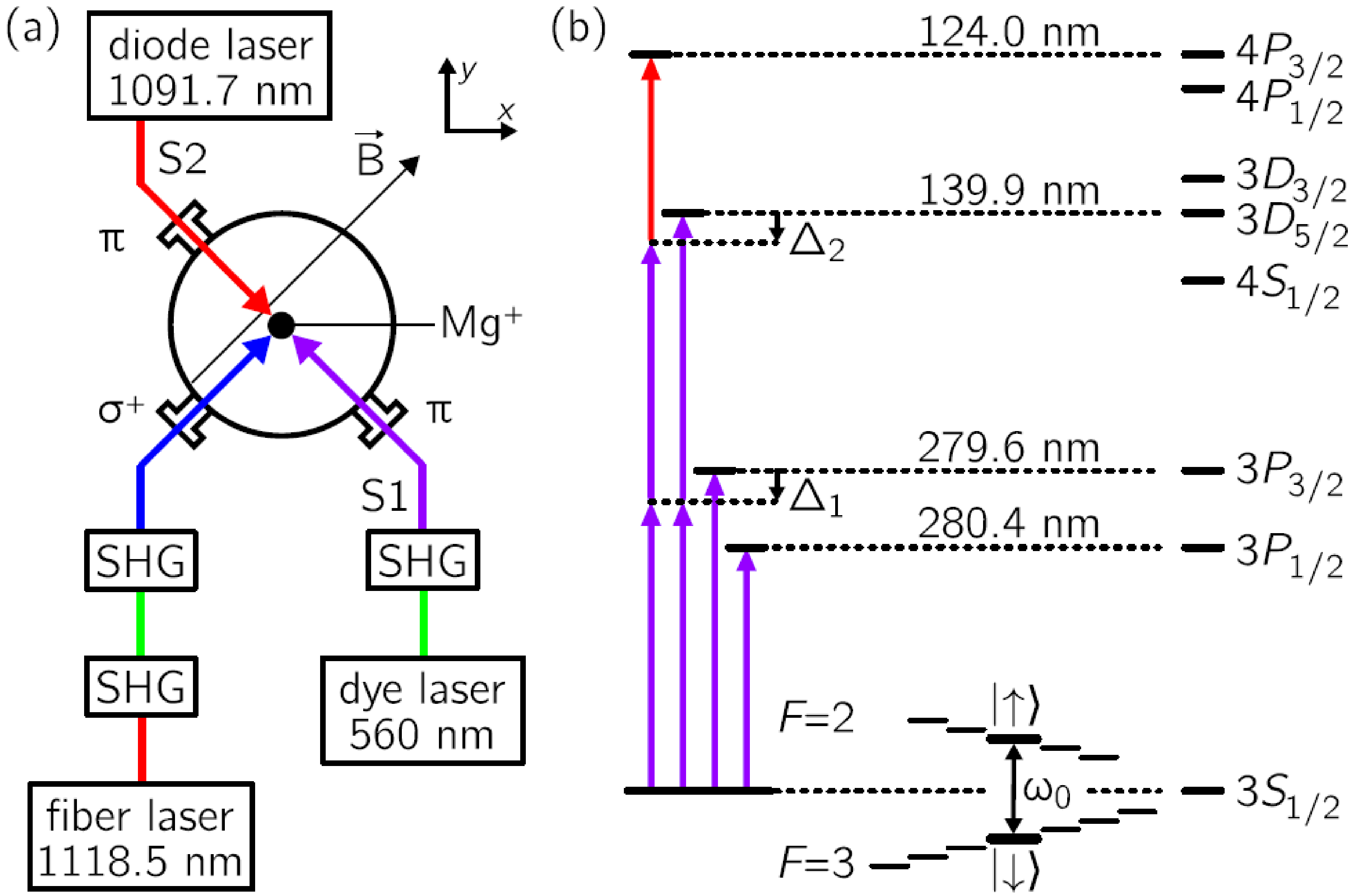


Spectroscopy sequence:

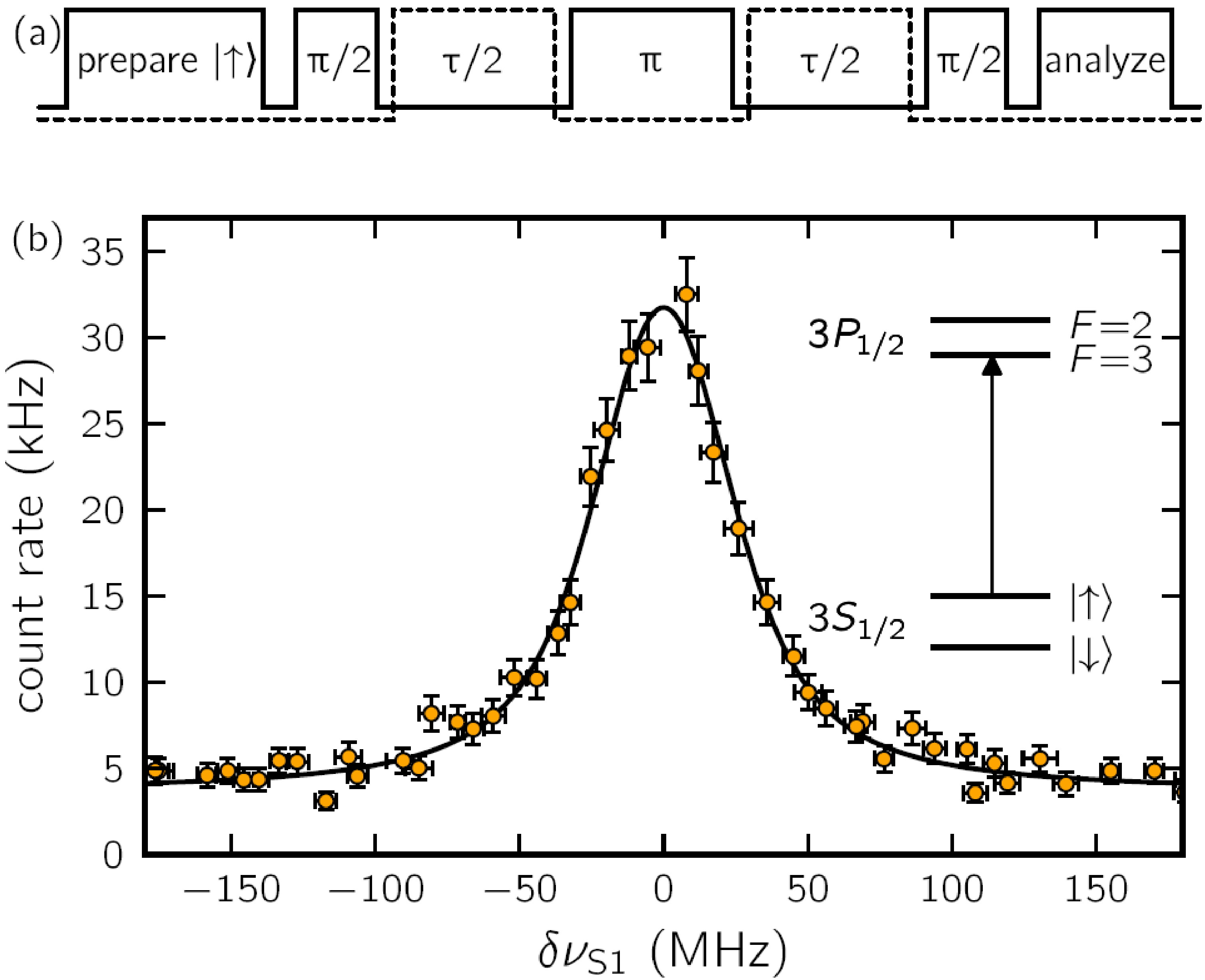


coll. D.Leibfried

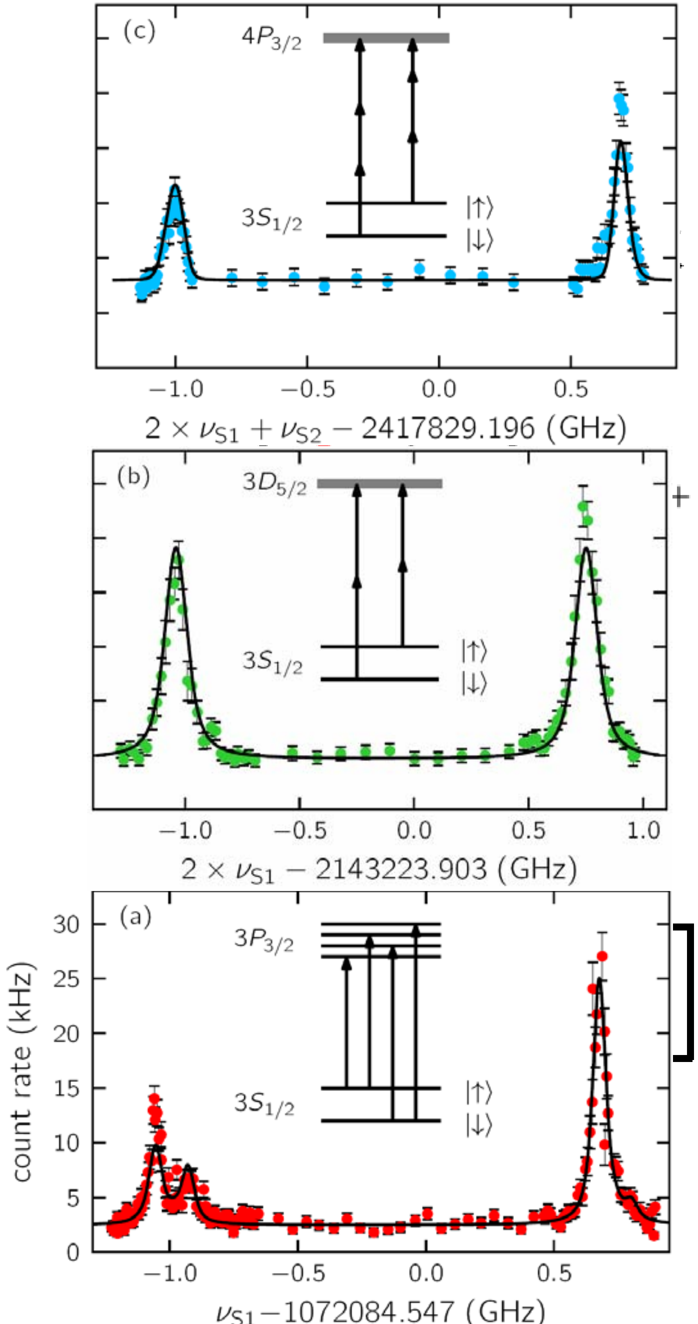
decoherence assisted spectroscopy

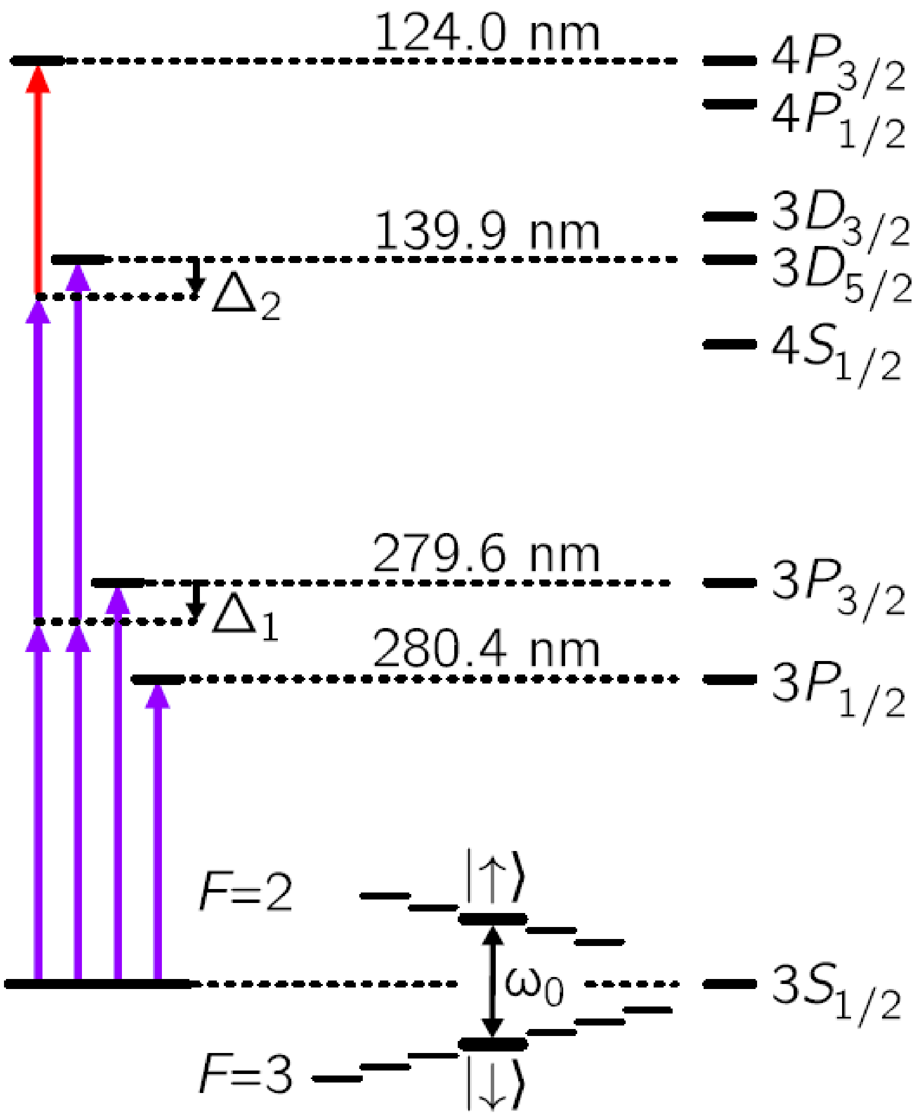


decoherence assisted spectroscopy

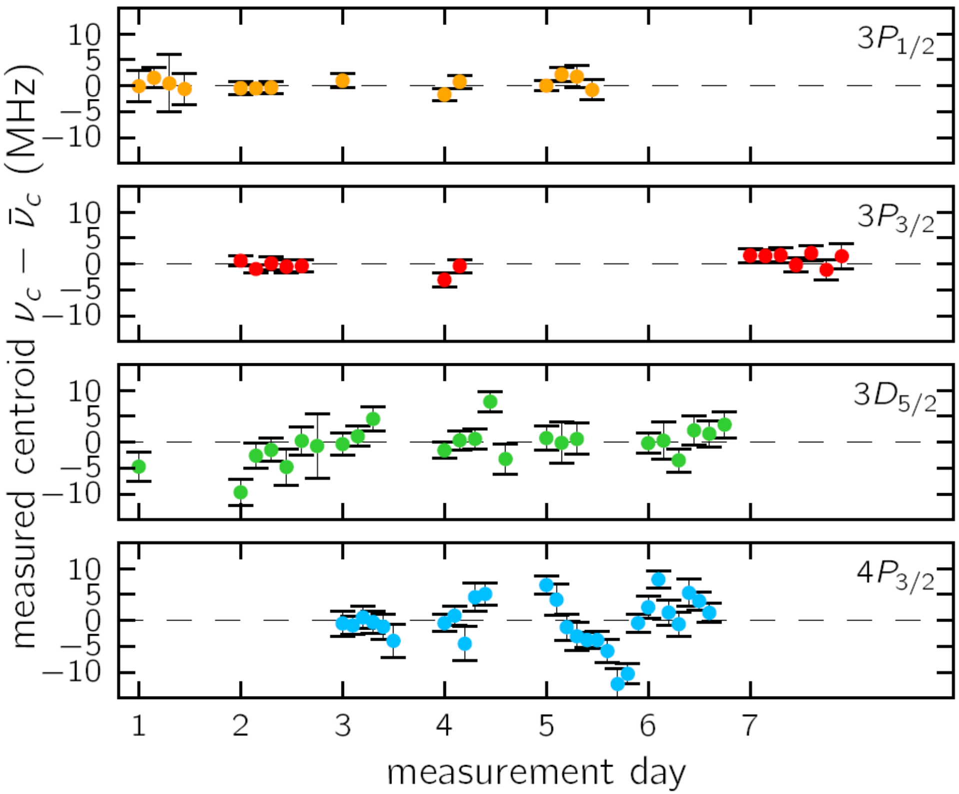


decoherence assisted spectroscopy





decoherence assisted spectroscopy



see also:
Innsbruck, PTB

Transition frequencies $\bar{\nu}_c$ in $^{25}Mg^+$ from $3S_{1/2}$ in THz

	$3P_{1/2}$	$3P_{3/2}$
This work	1 069.339 957 (5)	1 072.084 547 (5)
Batteiger et al. [9]	1 069.339 96 (2)	1 072.084 56 (2)
	$3D_{5/2}$	$4P_{3/2}$
This work	2 143.223 903 (7)	2 417.829 196 (12)
Martin et al. [22]	2 143.222 0 (15)	2 417.826 8 (15)
Goorvitch et al. [23]	2 143.227 7 (18)	2 417.805 (10)

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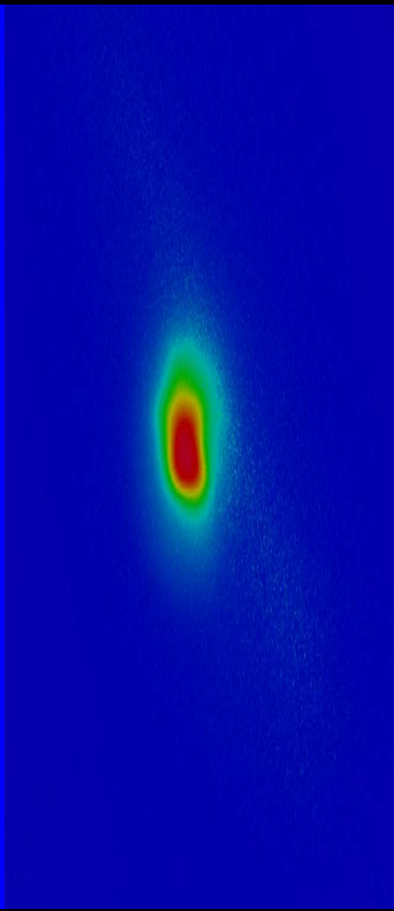
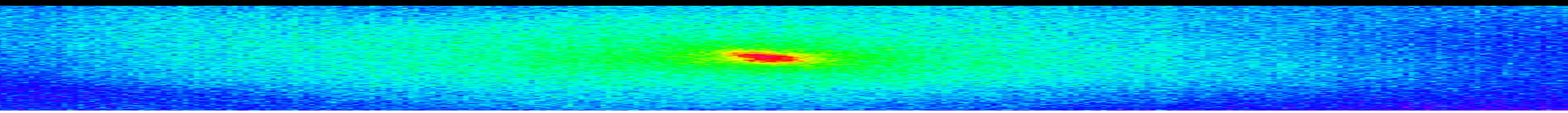
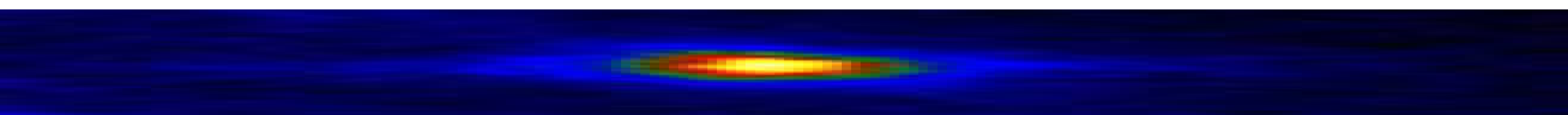


ion(s) and atoms trapped by light
towards chemistry in the Nano-Kelvin regime



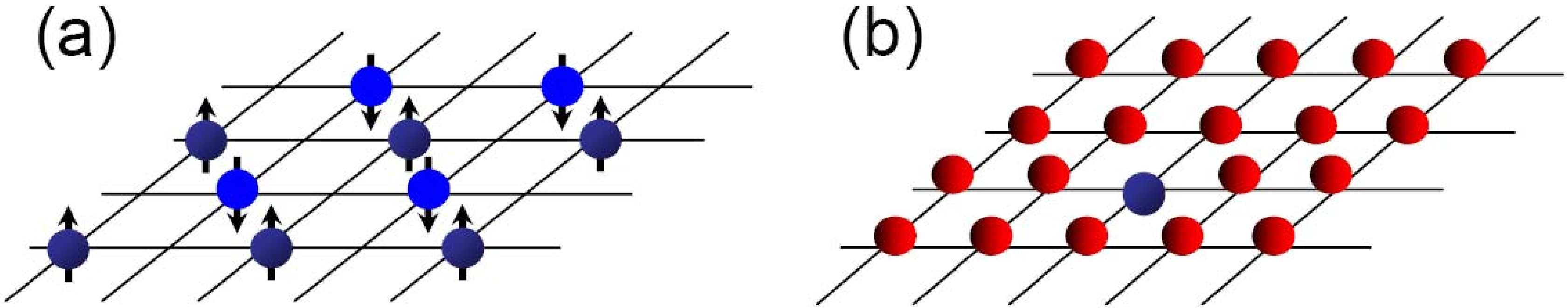
- standing up on Monday morning
- atomic system
- ionic system ("handicaps")
    - dipole trap
    - standing wave (conveyor belts: ion - atom)
- merging ionic-atomic systems (Rb and Ba^{+})
- standing up on Monday again



iontech _2_ 2013

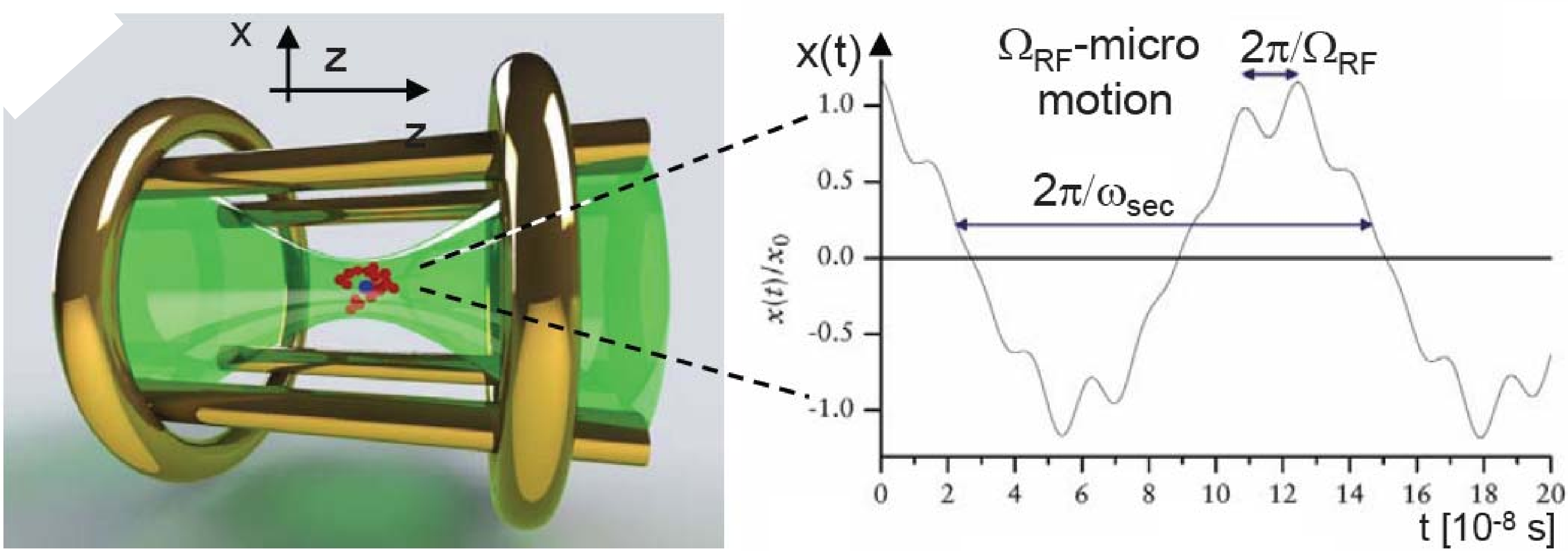
dreaming (part 1)

optical traps [ions or ions and atoms]

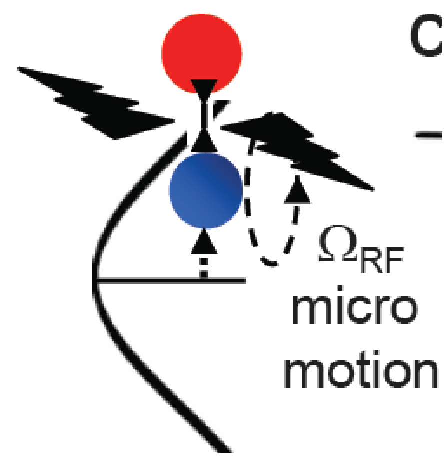


another motivation

towards Nano-cold chemistry



impressive proposals and results @ MIT, Ulm, Cambridge/Bonn, Mainz, UCLA, Weizmann, CQT-Singapore, Berkeley, …



optical trapping of atoms and ion(s)

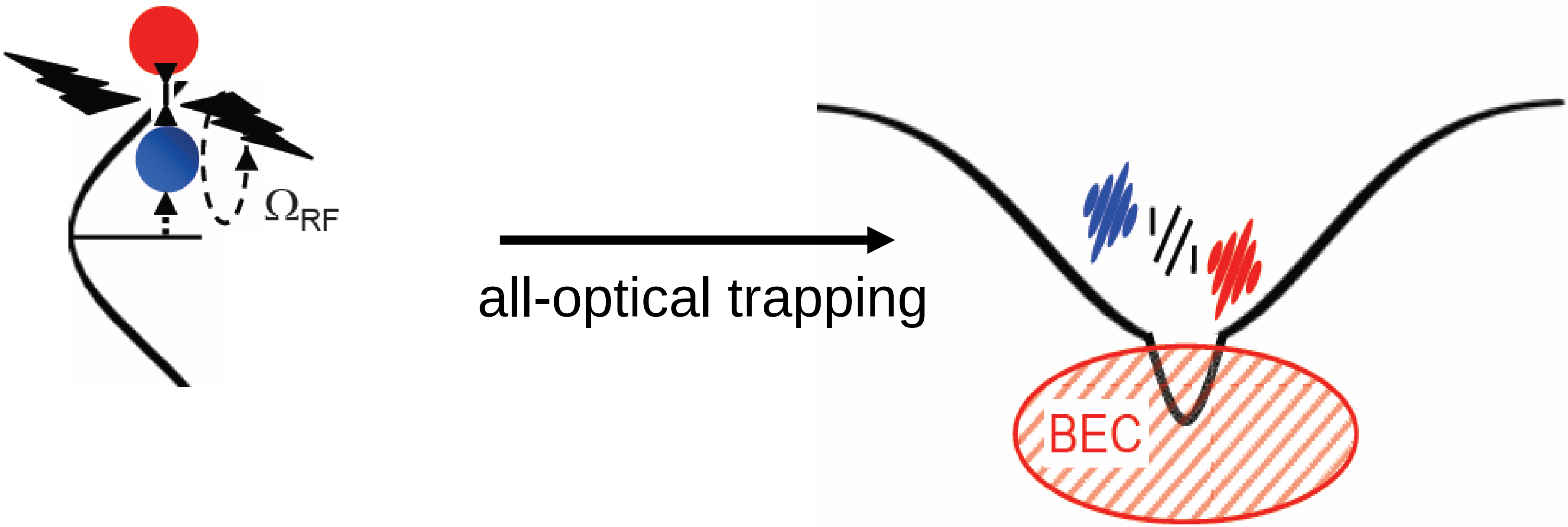
PRL **109**, 253201 (2012) PHYSICAL REVIEW LETTERS week ending 21 DECEMBER 2012

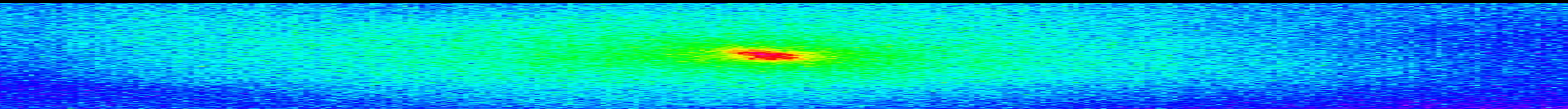
Micromotion-Induced Limit to Atom-Ion Sympathetic Cooling in Paul Traps

Marko Cetina,* Andrew T. Grier, and Vladan Vuletić

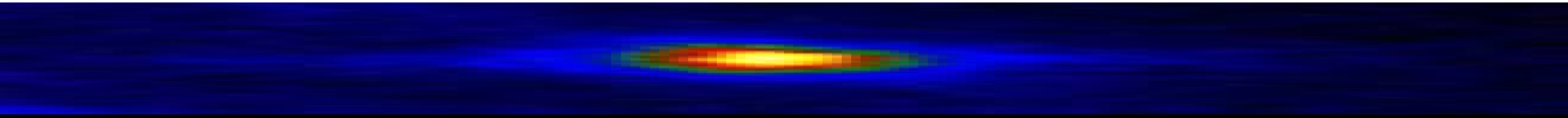
Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

(Received 12 May 2012; published 19 December 2012)

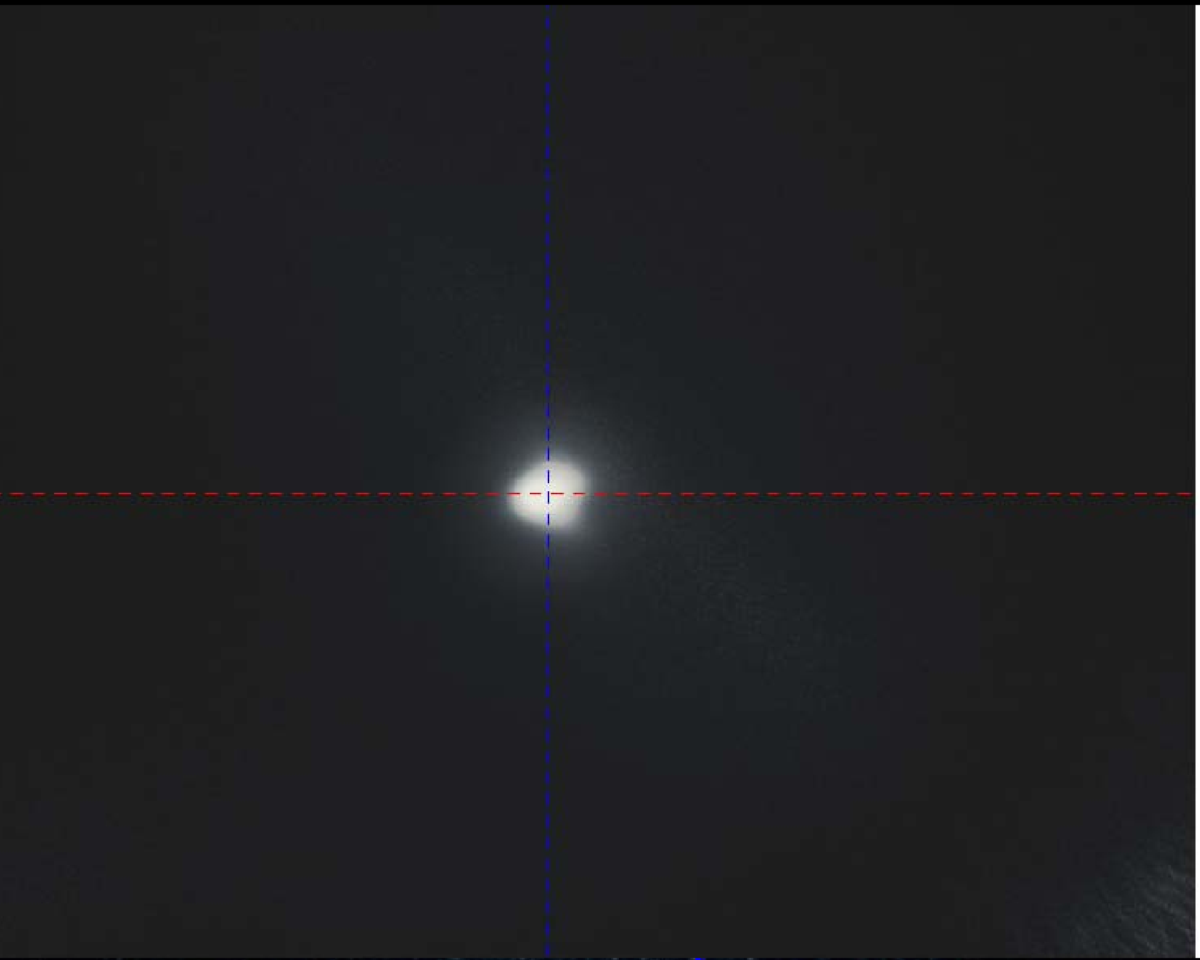


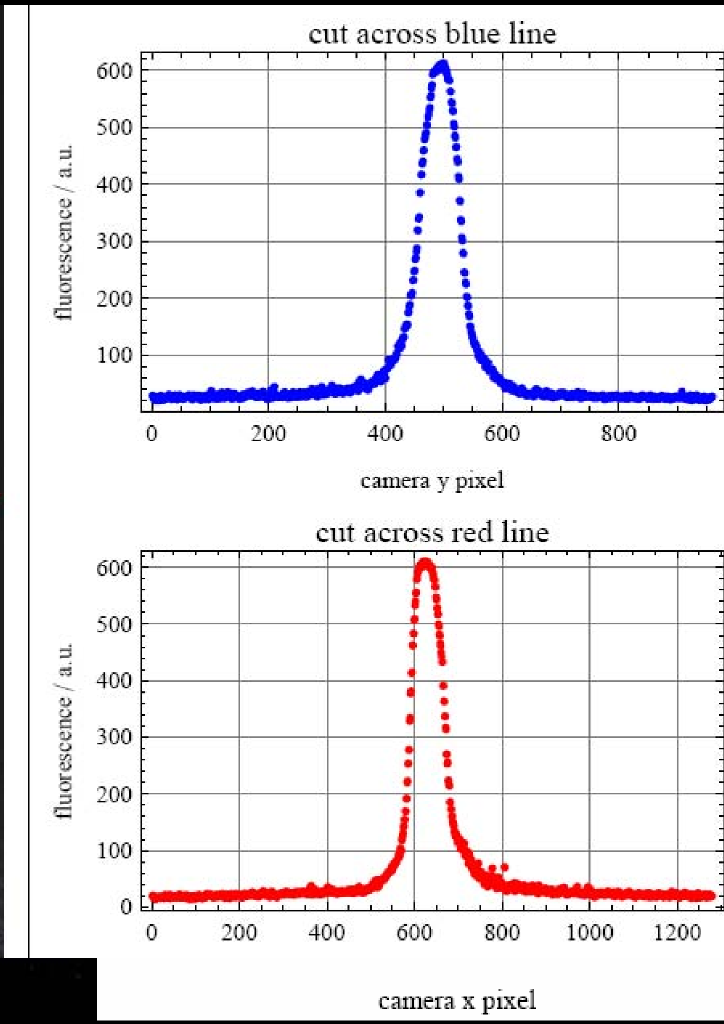


- motivation
- **atomic system**
- ionic system (“handicaps”)
    - dipole trap
    - standing wave (conveyor belts: ion - atom)
- merging ionic-atomic systems (Rb and Ba^+)
- outlook



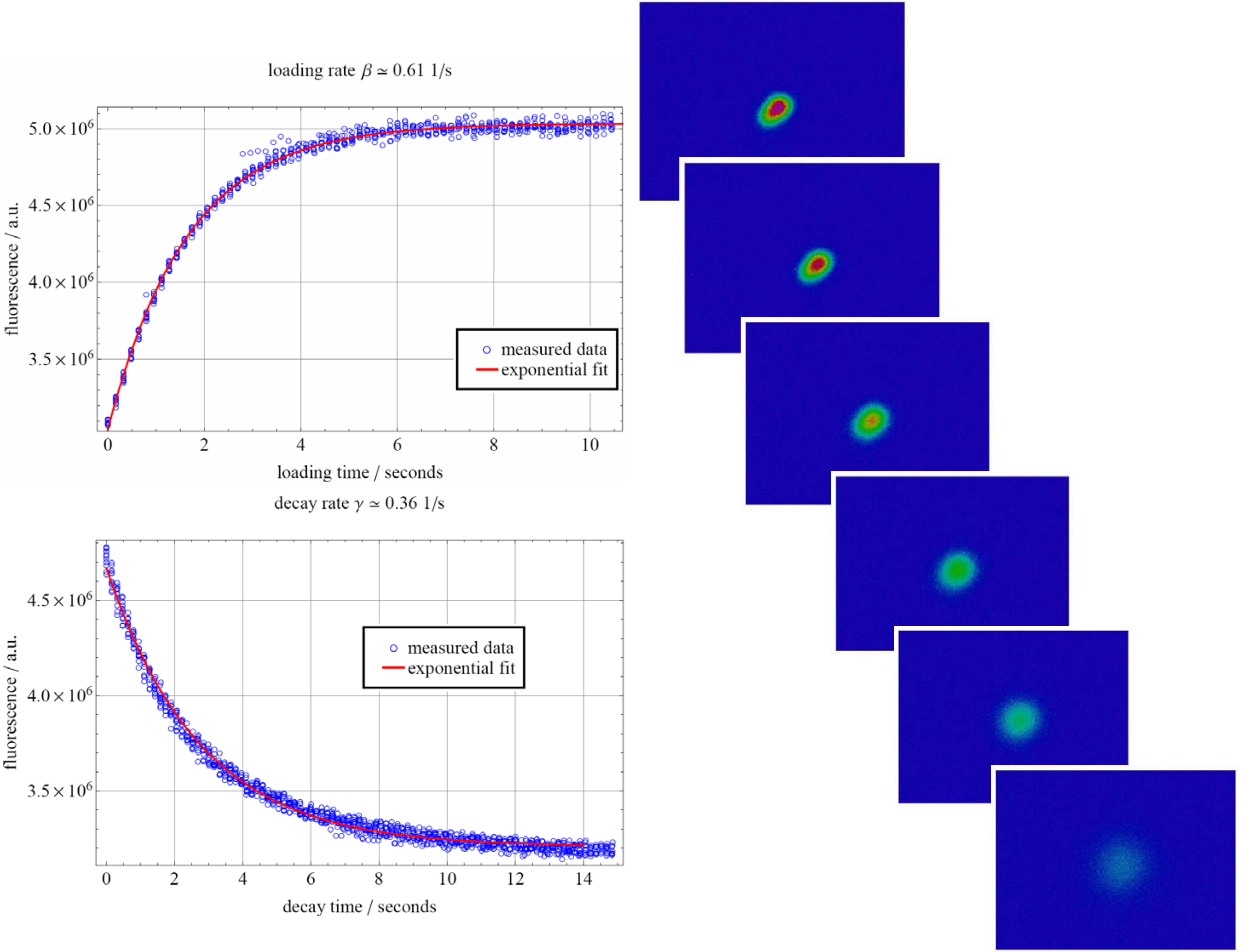
atomic part: Rb^{87} atoms in the $2D^{+}$ MOT @ Freiburg



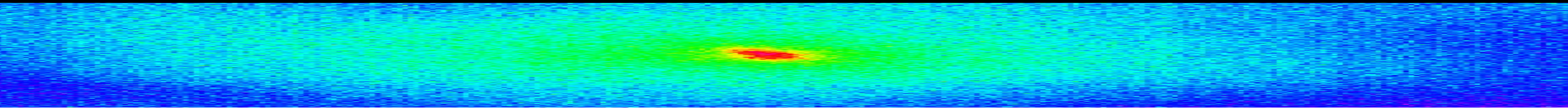


- loading the 3D MOT
- transferring atoms into dipole trap
- “BEC” it

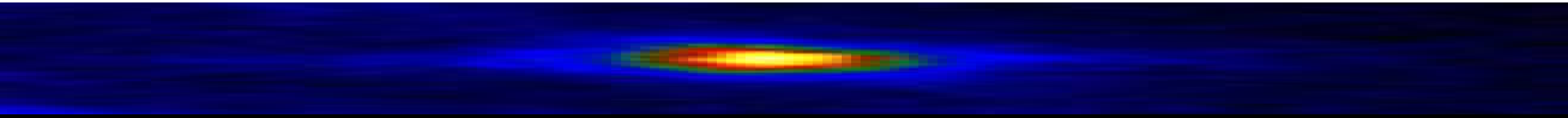
all optical BEC by Barrett at CQT [2011]



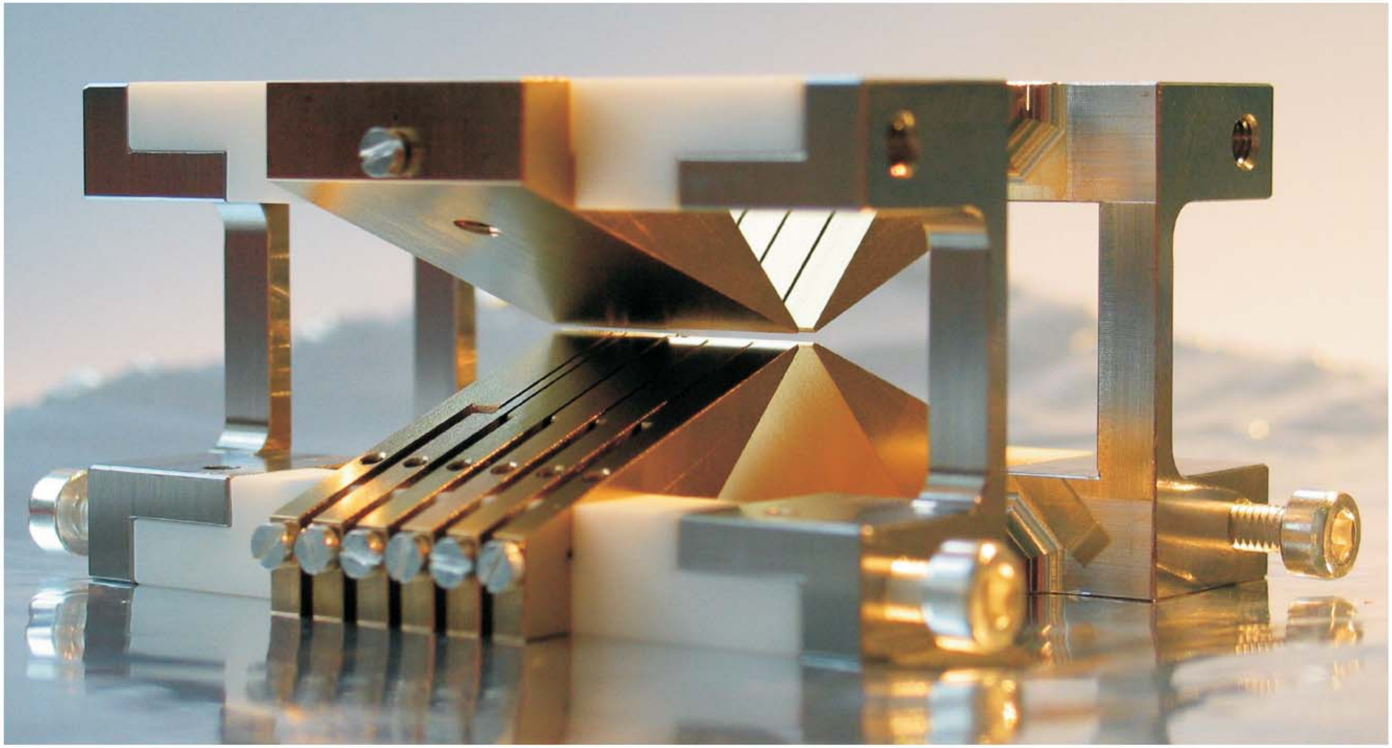
loading rate $\beta \simeq 0.61$ 1/s
fluorescence / a.u.
5.0×10^6
4.5×10^6
4.0×10^6
3.5×10^6
0
2
4
6
8
10
loading time / seconds
measured data
exponential fit
decay rate $\gamma \simeq 0.36$ 1/s
fluorescence / a.u.
4.5×10^6
4.0×10^6
3.5×10^6
0
2
4
6
8
10
12
14
decay time / seconds
measured data
exponential fit



- motivation
- atomic system
- **ionic system (“handicaps”)**
    - dipole trap
    - standing wave (conveyor belts: ion - atom)
- merging ionic-atomic systems (Rb and Ba^{+})
- outlook



ionic part: loading dipole- out of Paul-trap



U_{RF}~eV~10^4K

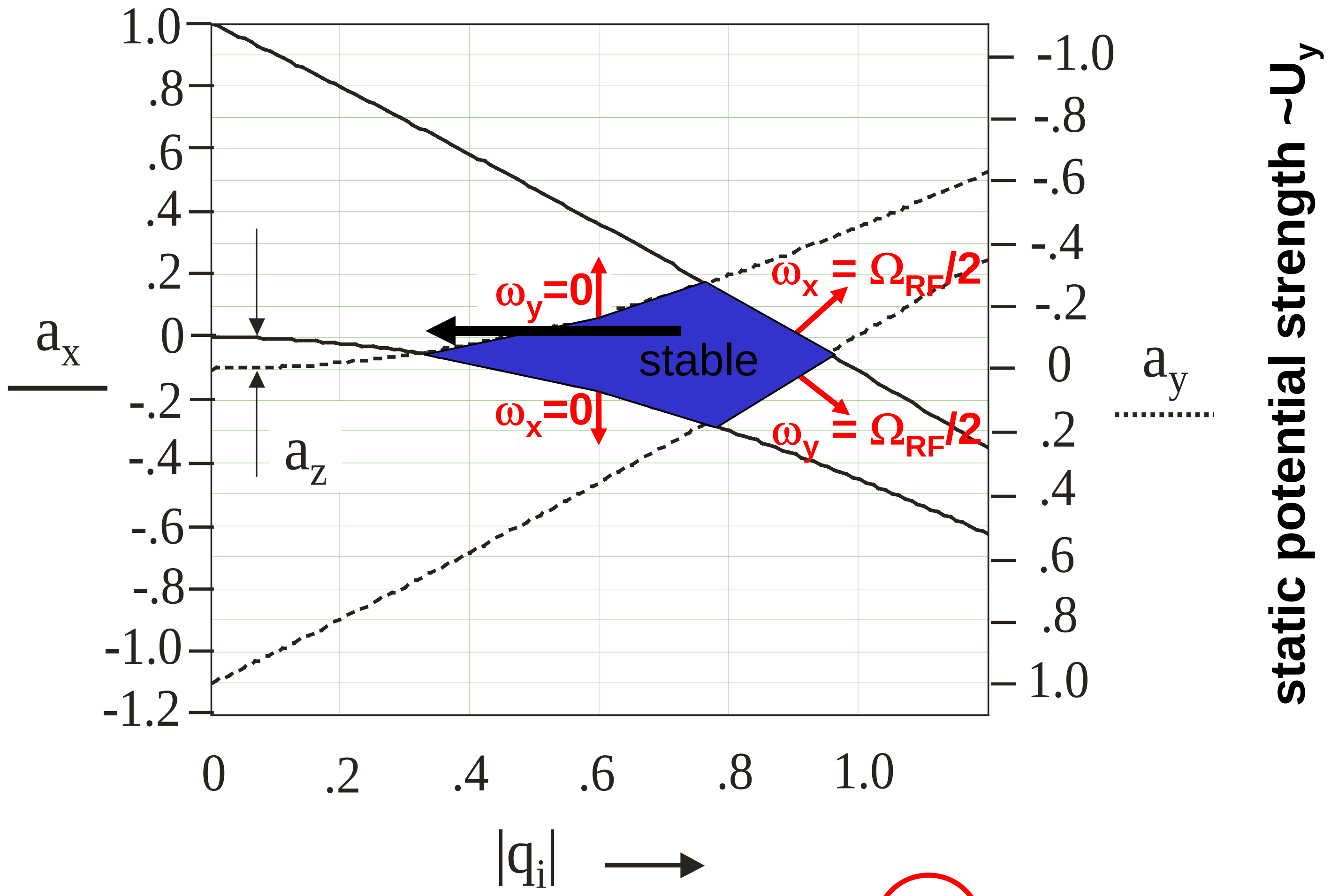
starting with $^+Mg^{24}$

U_D~10^{-3}K

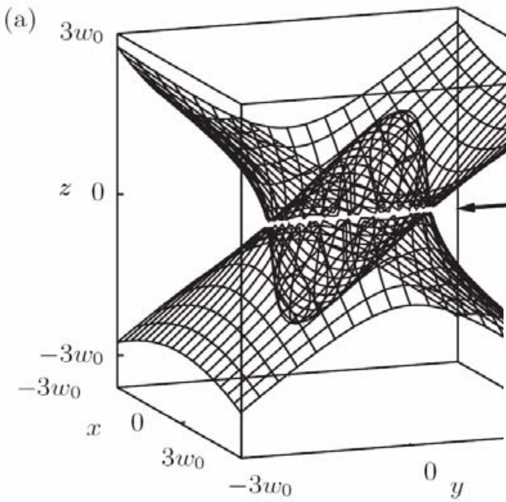
- considering charge in dipole trap [coll. G.Morigi NJP [2011]]
- sufficient compensation of stray fields ($F_{stray} < F_{dipole}$; ∇U not U)
- smooth reduction of RF- and DC- potentials (stability diagram)
- fast (but “adiabatic”) transfer (minimize heating)

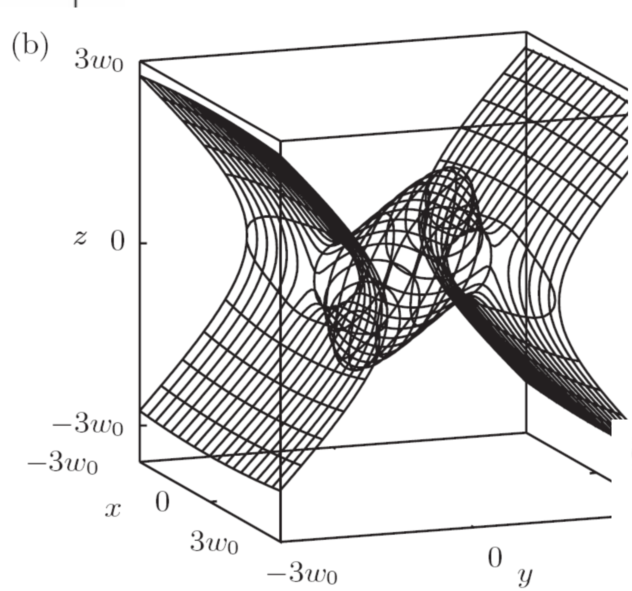
Quadrupole-RF and DC forces versus stability

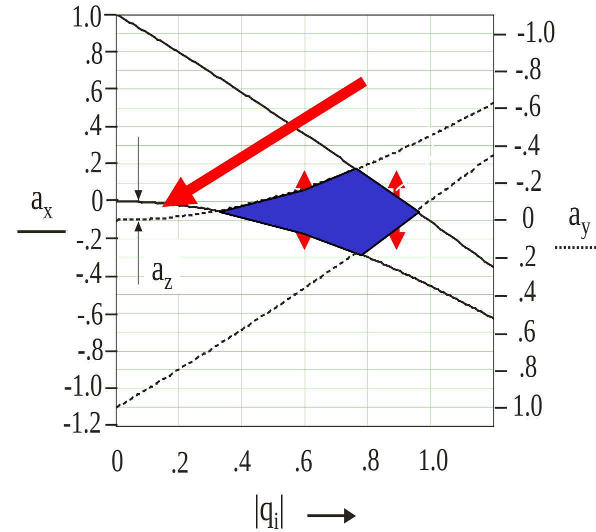
$^2_T R^2$

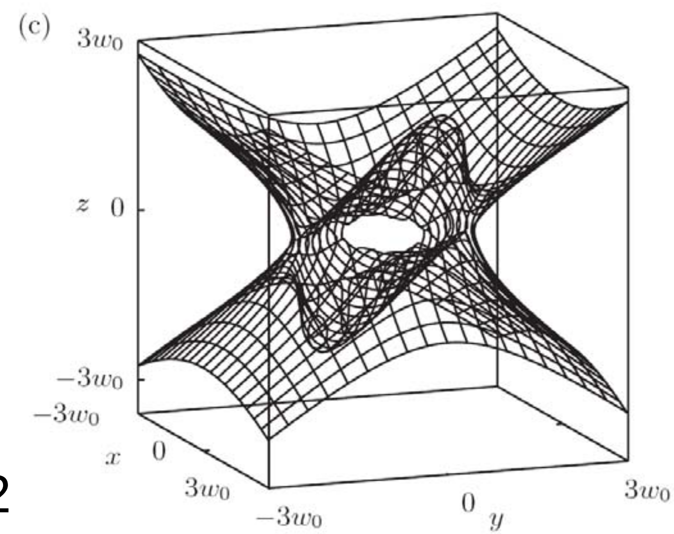


DC forces versus stability









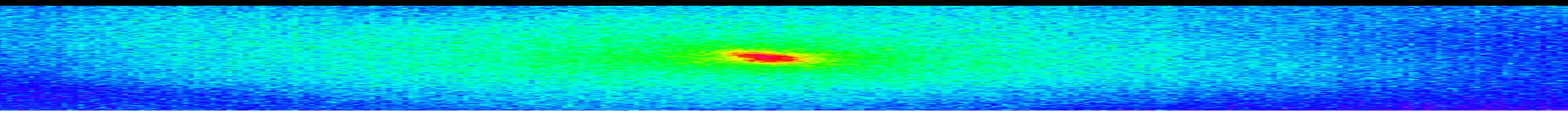
<u>Earnshaw – theorem:</u>

DC confinement in 1D

defocusing in other(s)

- DC<
- standing wave instead

PRA 2012



- motivation
- atomic system
- ionic system (“handicaps”)
    - **dipole trap**
    - standing wave (conveyor belts: ion - atom)
- merging ionic-atomic systems (Rb and Ba^+)
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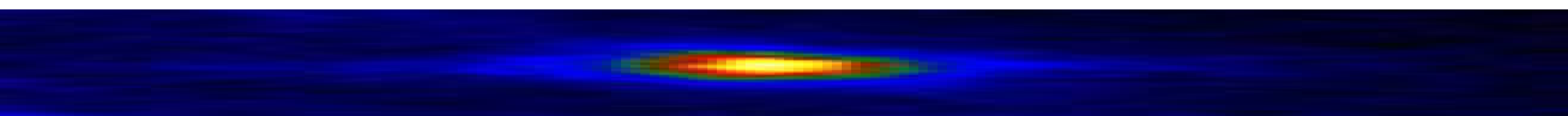
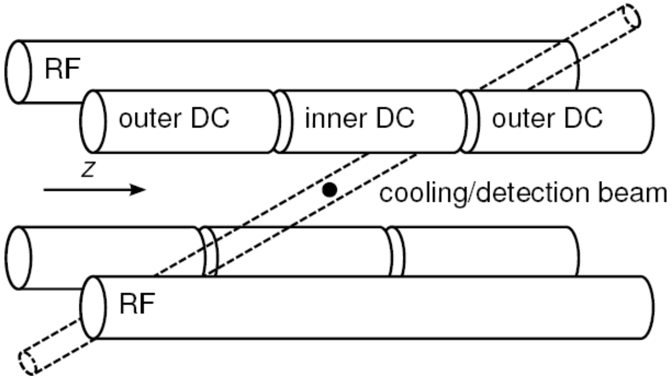


optical ion trapping –the protocol

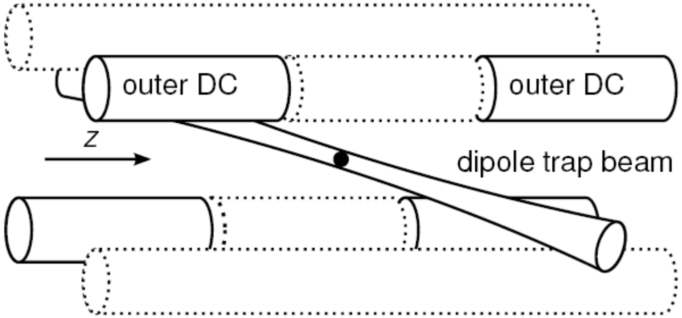
1

- loading into Paul-trap
- Doppler cooling (~1mK)
- stray field compensation



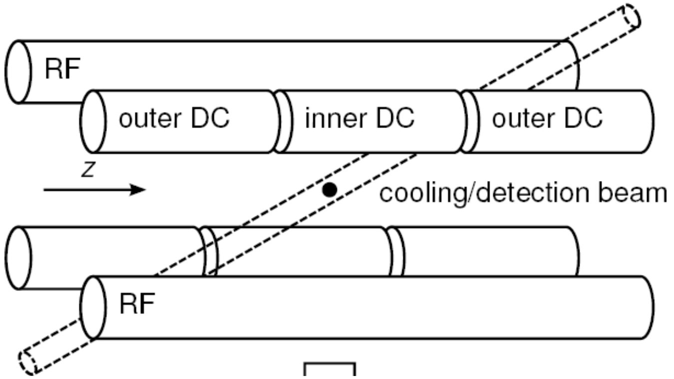
2

- switching on the dipole trap
- switching off the Paul-trap (not DC)
- storing the ion optically for t = x ms

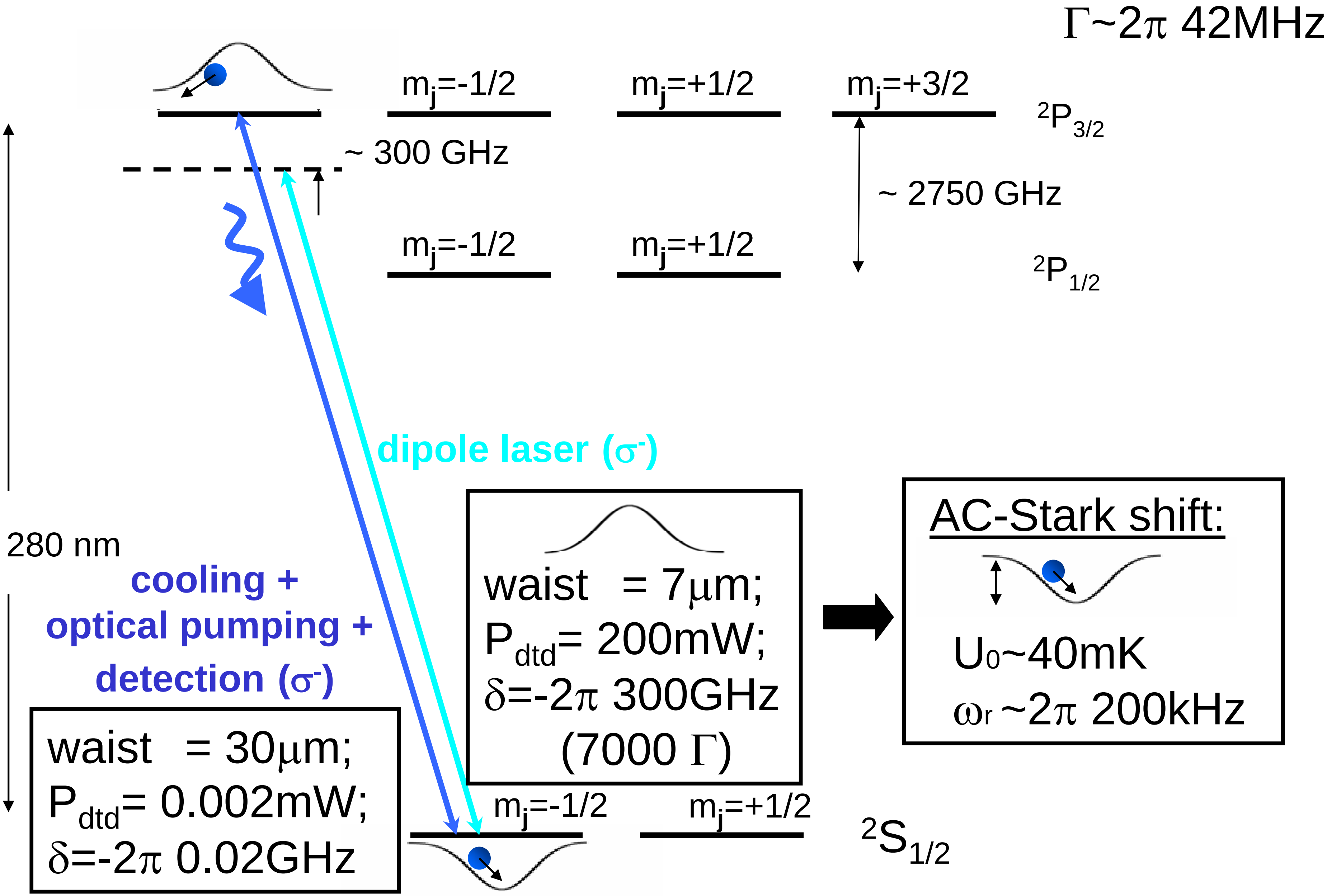


3

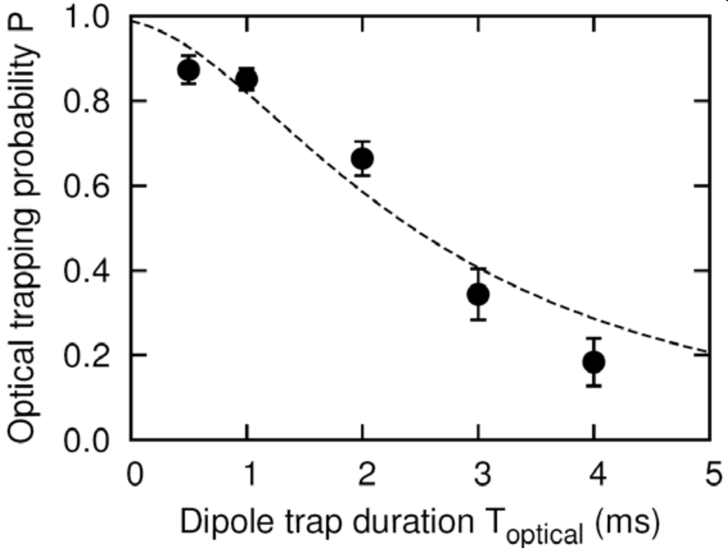
- switching Paul trap on
- switching optical trap off
- fluorescence detection

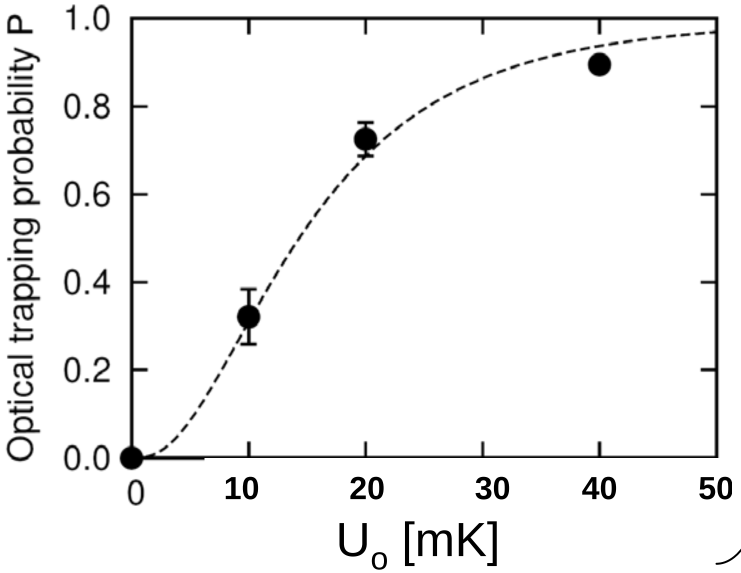


dipole trap - lasers on $^{24}Mg^{+}$ (I=0)- transitions



lifetime within optical dipole trap





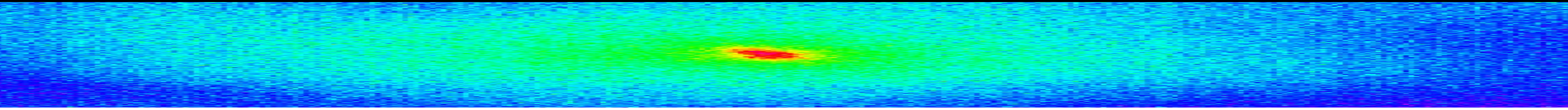
➔ lifetime limited by recoil heating "only"

➔ several 100s of oscillations in optical trap

➔ loading via rf-trap "without" heating

➔ dipole + DC trap works

Nat.Phot [2010]



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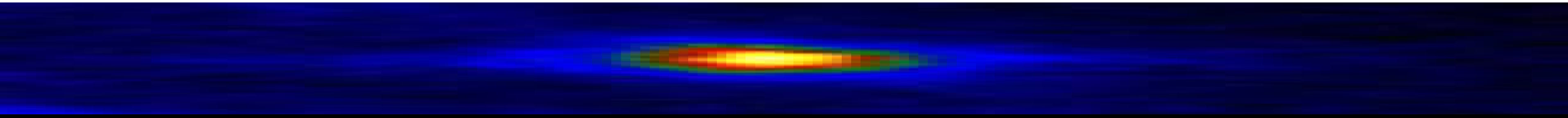
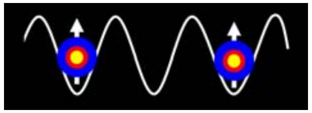
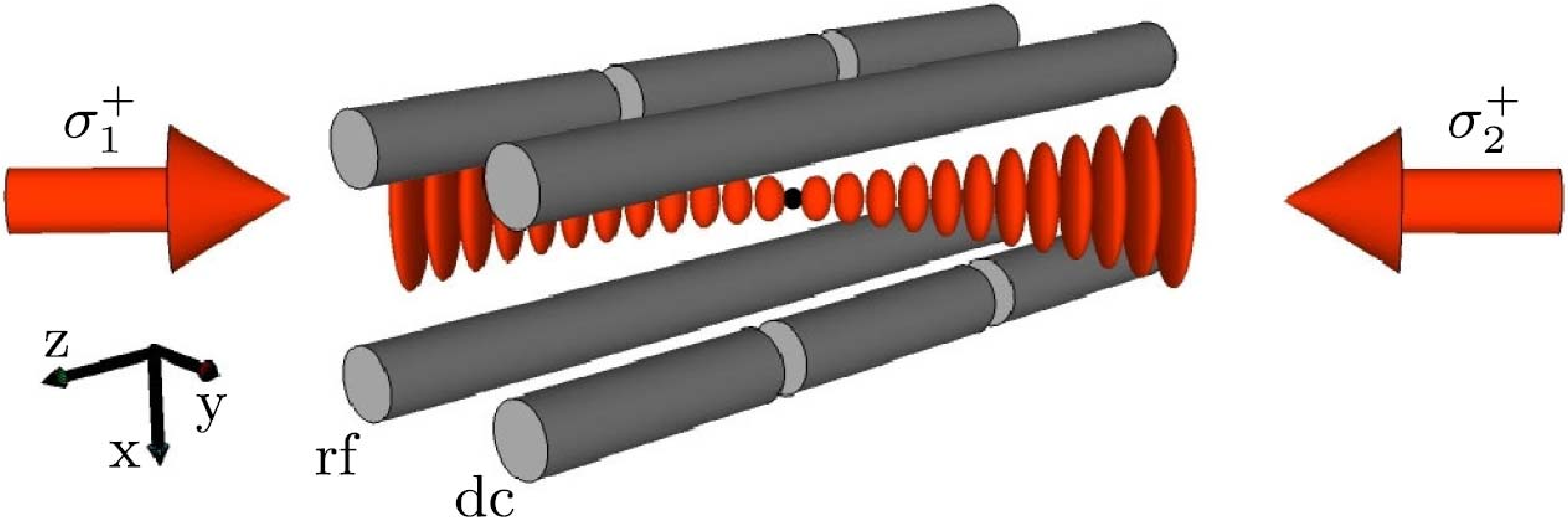


Mg^+ in 1D optical lattice (no RF and DC)





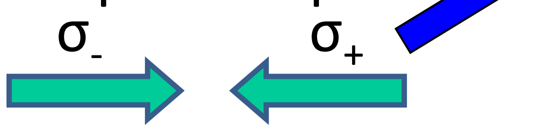
PRL [2012]

see also PRLs by:
Aarhus and MIT and others

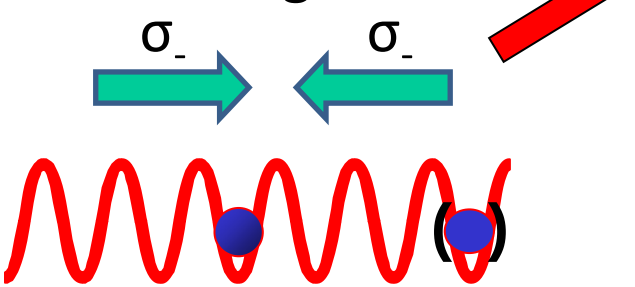
trapping ion in optical lattice

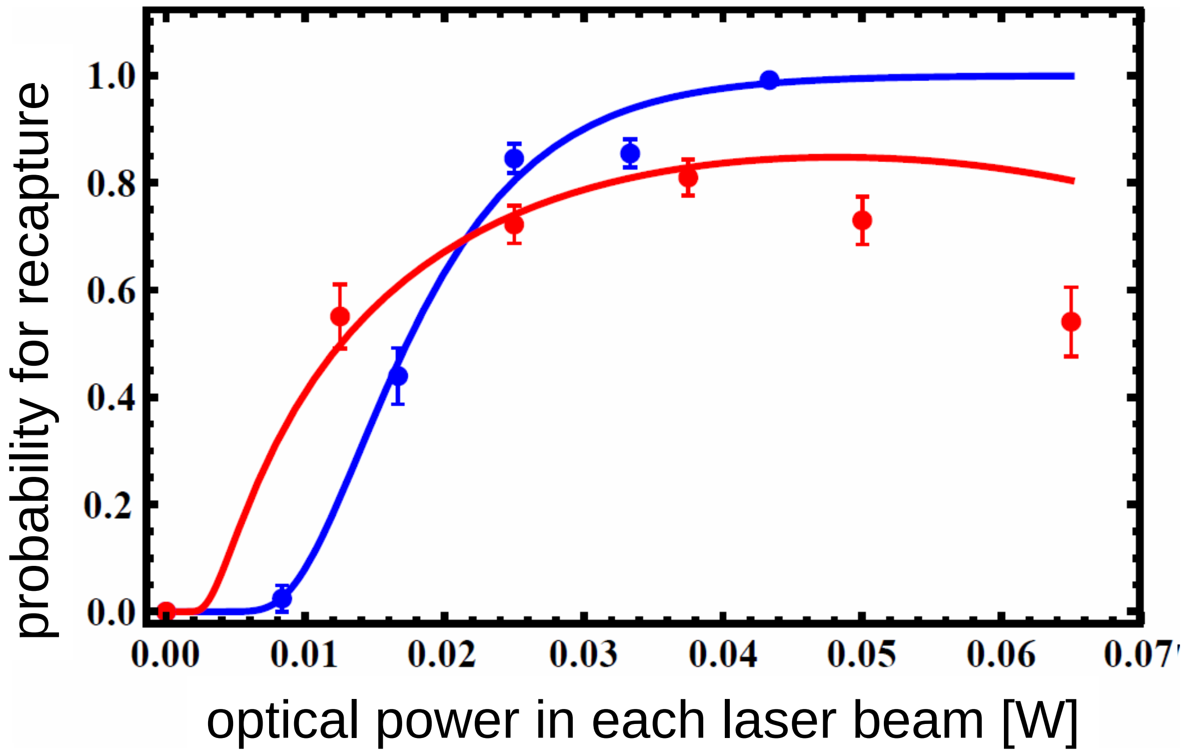
Dipole Trap vs. Standing wave

Dipole Trap:



Standing Wave:





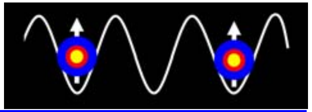
T_{trap} = 125 µs

waist ≈ 7 µm

Δ = - 2 π 300 Ghz ≈-7100 Γ

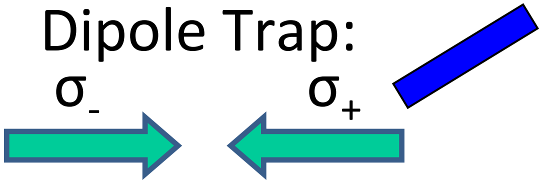
P_{trap} [0-70] mW

trapping ion in optical lattice

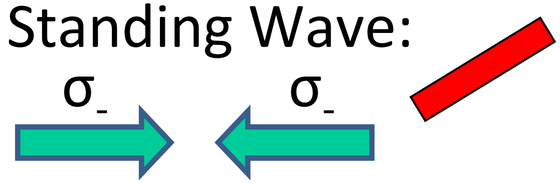


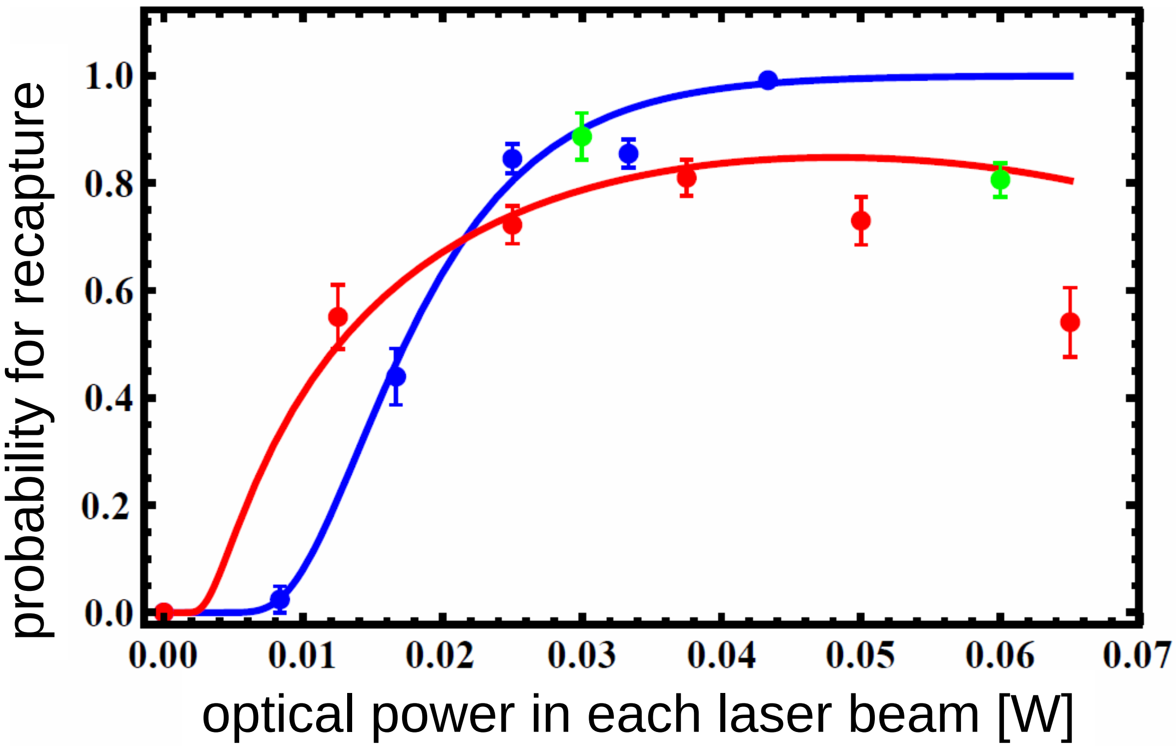
Dipole Trap vs. Standing wave

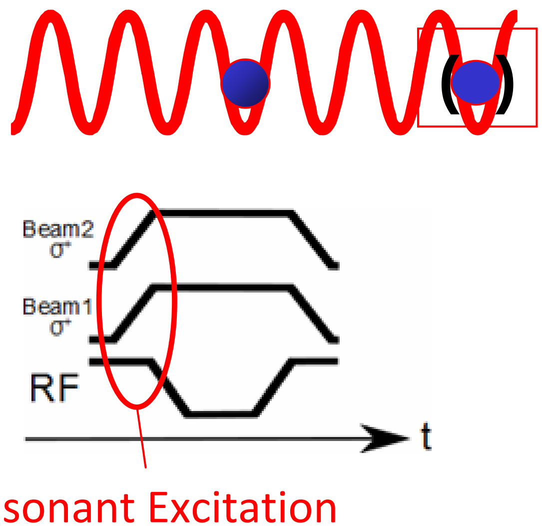
Dipole Trap:

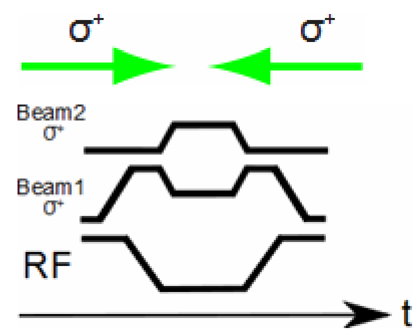


Standing Wave:









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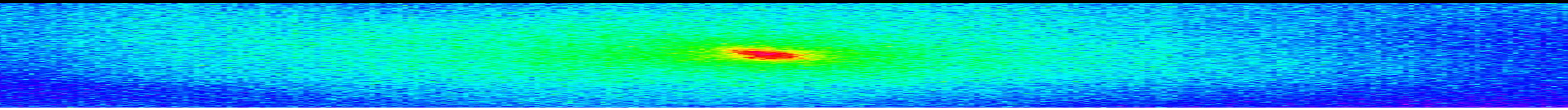

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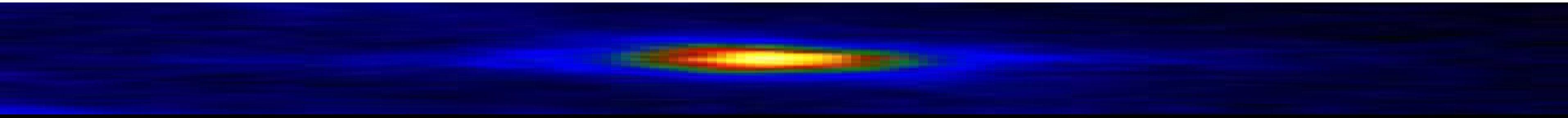
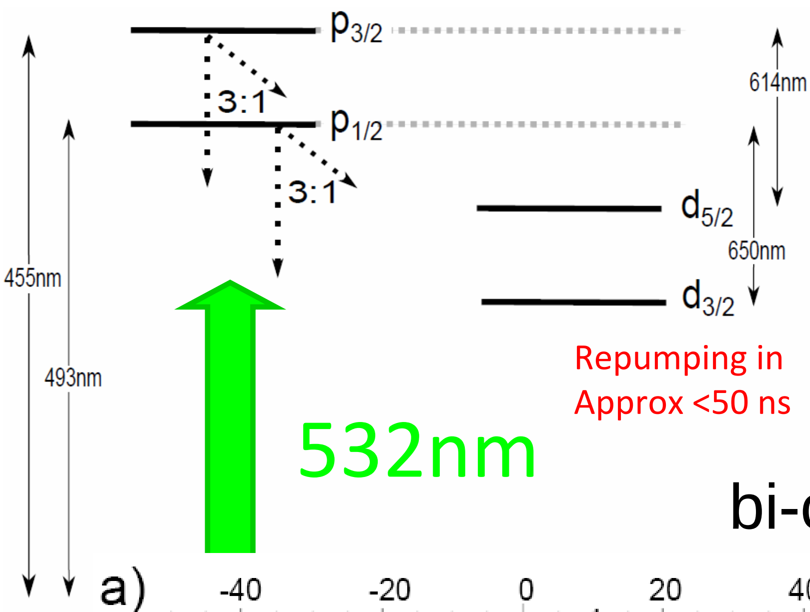
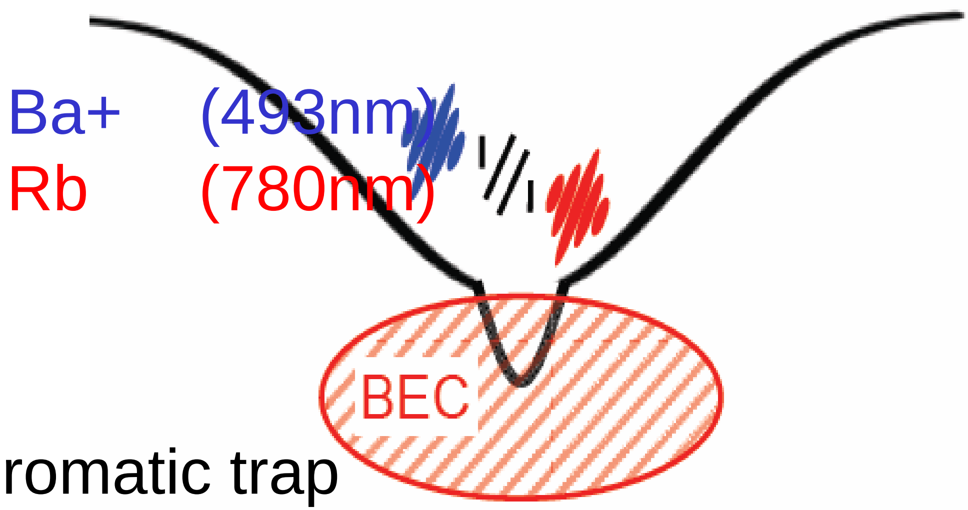


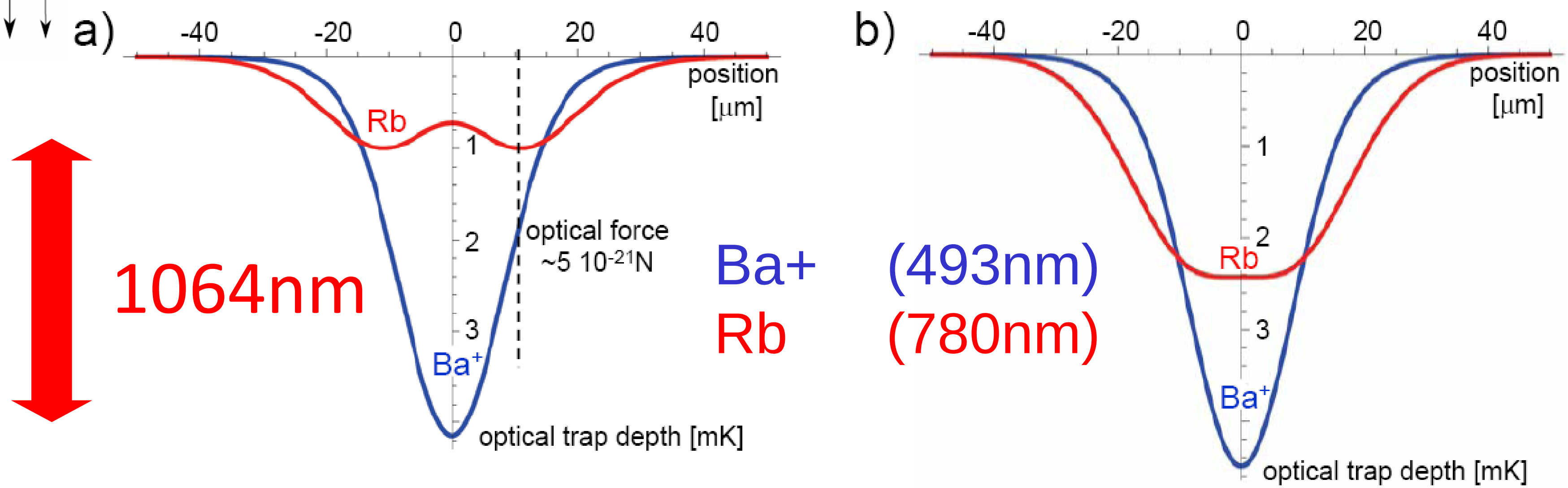
in progress (Ba^+ and Rb BEC)

$^{138}Ba^+$ efficient photoionization of Barium:

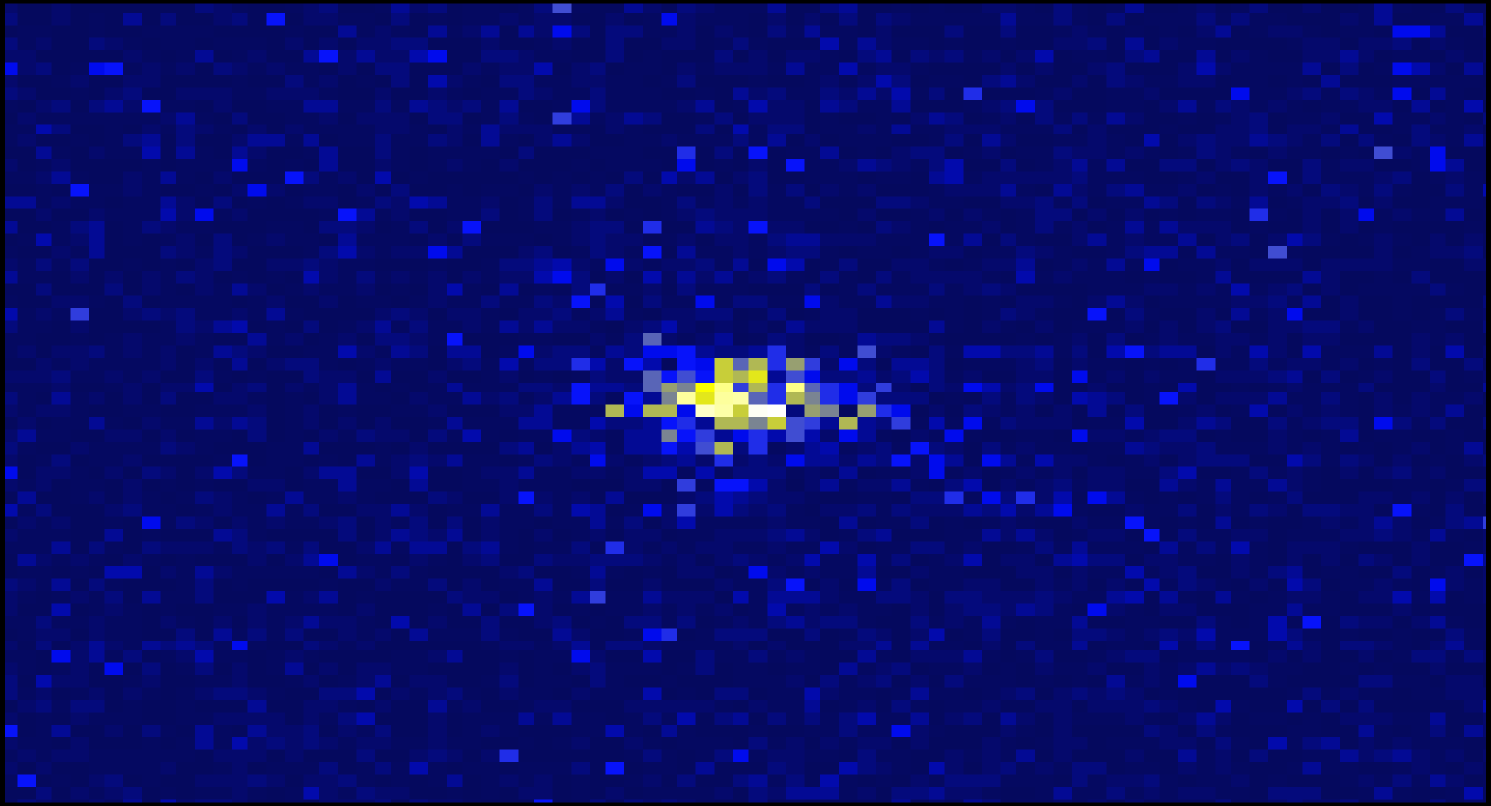


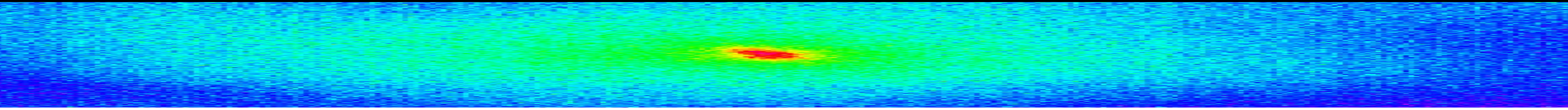


bi-chromatic trap



Ba^+ the Mc Lain





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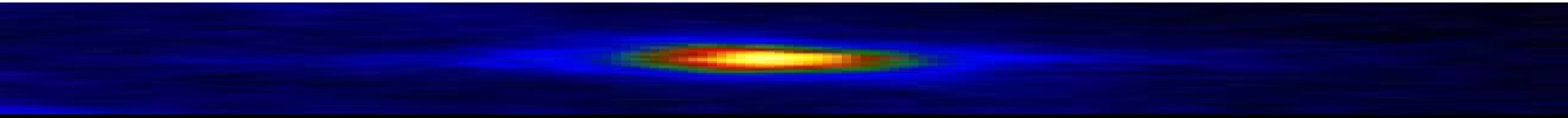
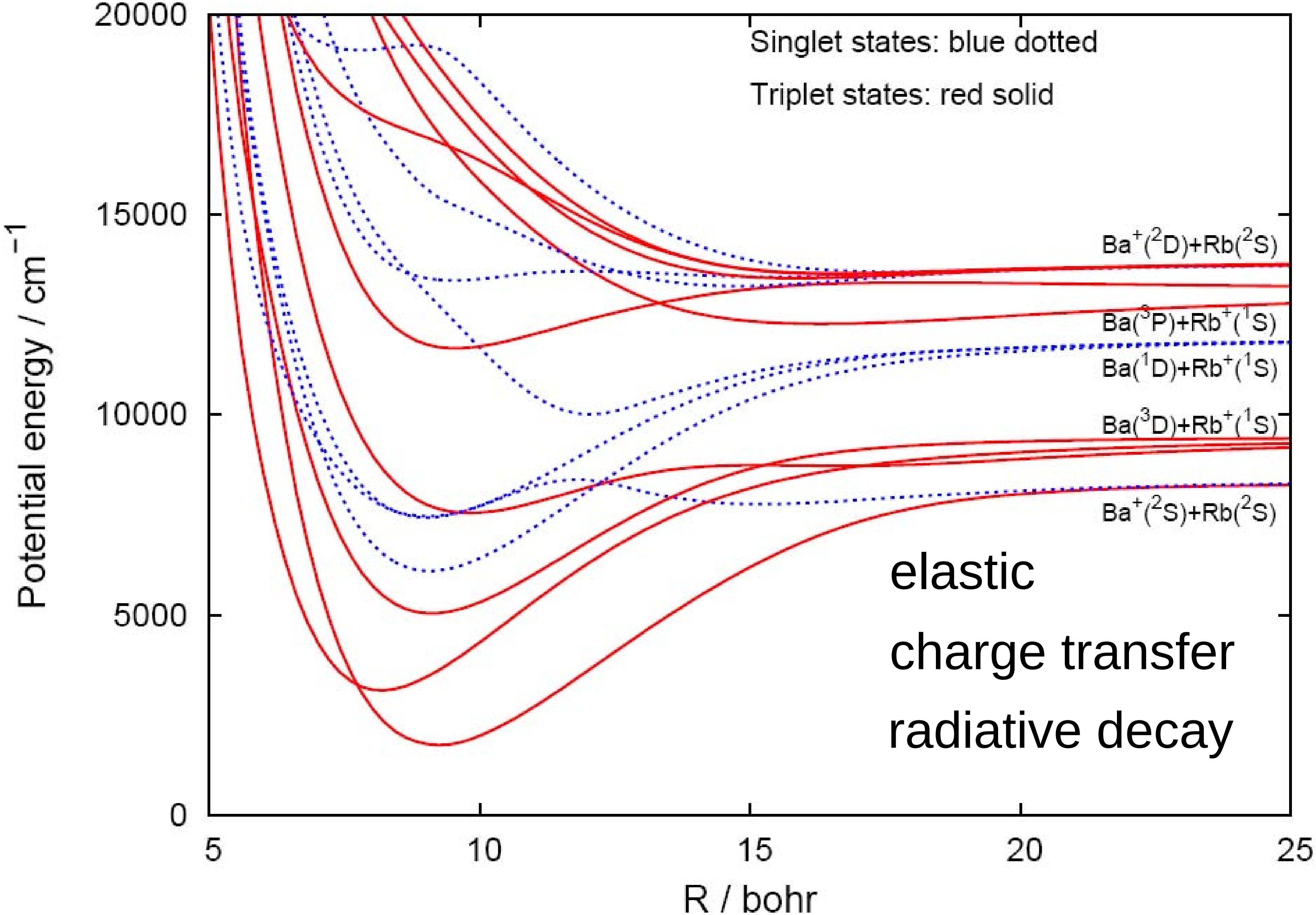
- **outlook**



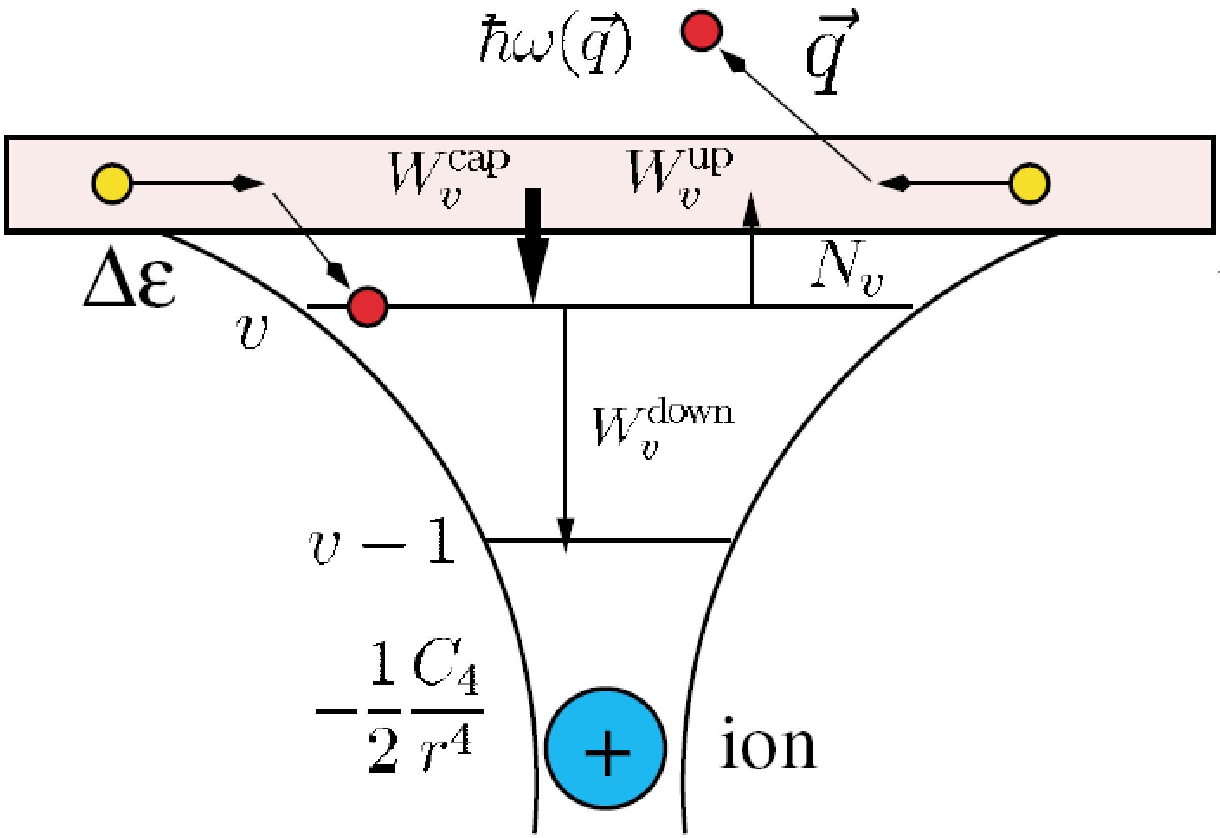
forming $BaRb^+$



see also ULM and Paris

coll. R.Moszynski (Warshaw) and C.Koch (Kassel)

forming Ba^+ + 600 Rb "molecule"



Rb-BEC

Rb atoms
bound to ion(s)

coll. R.Côté and M.Lukin [PRL 2002]

Add Ons

➔ QSim: 2D arrays of rf-traps

➔trappology

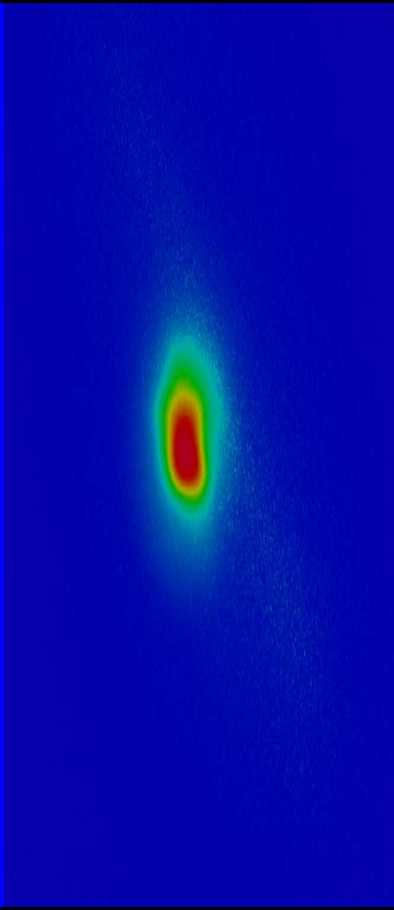
➔precursors (expl. decoherence)

+ [QSim - gauge fields]
+ [dissipation assisted entanglement]
+ decoherence assisted spectroscopy

➔ optically trapping of ions and atoms

➔ trapping of topological defects

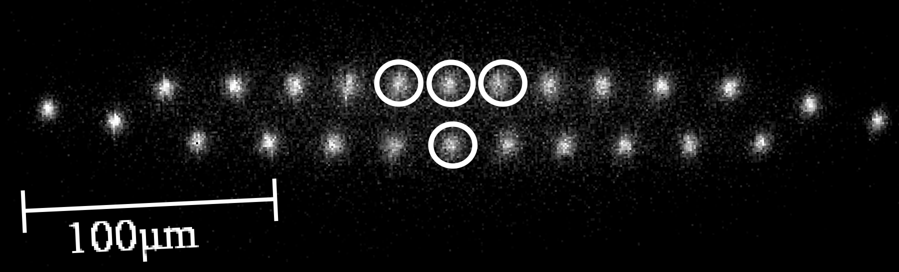
+ defect assisted entanglement

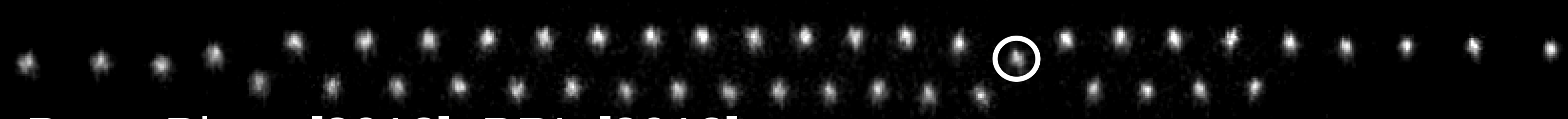


topological defects

Entanglement Generation Using Discrete Solitons in Wigner Crystals

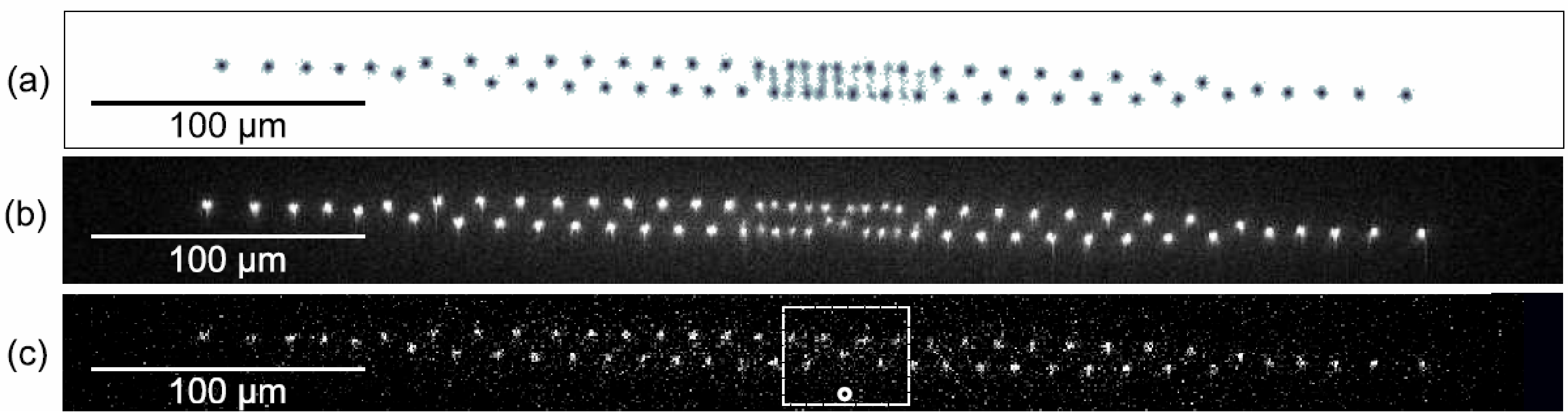
H. Landa[1], A. Retzker[2], T. Schaetz[3] and B. Reznik[1]
[1] *School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel-Aviv University, Tel-Aviv 69978, Israel*
[2] *Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Givat Ram, Israel*
[3] *Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany*





Rep. Prog. Phys. [2012], PRL [2013]
coll: B.Reznik, H.Landa, A.Retzker

see also Vancouver, Mainz, PTB



-56 ions (start at 6th lattice site, no cooling at T=0; t=1ms)

-57 ions (mass defect, t=200ms at t_tot=6s)

kink interaction

- commonly centered
- not (differently) blurred