Tools and progress in experiments on thermodynamics with ion traps

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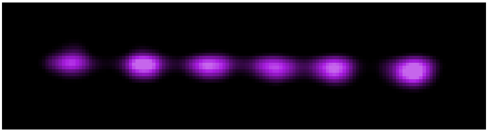
Trieste, 2019
College on Energy Transport and Energy Conversion in the Quantum Regime

tools and progress in experiments on thermodynamics with ion traps

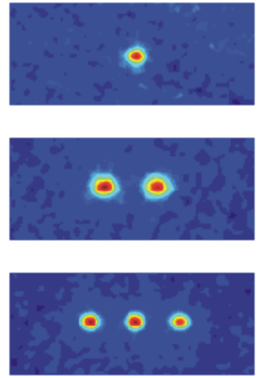
transport in oscillator chains	**motivation**
noise induced transport	**topic 1**
2D spectroscopy	**topic 2**
optical potentials	**experimental tools**
spin heat engine	**topic 3**
optical crysostat	**new device development**

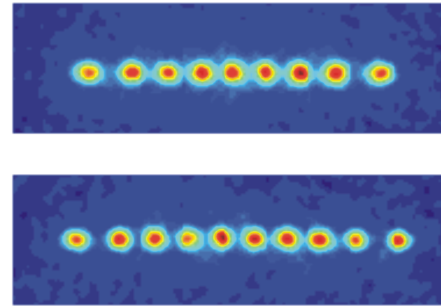
Cecilia Comick

FAMAF
Córdoba
Argentina



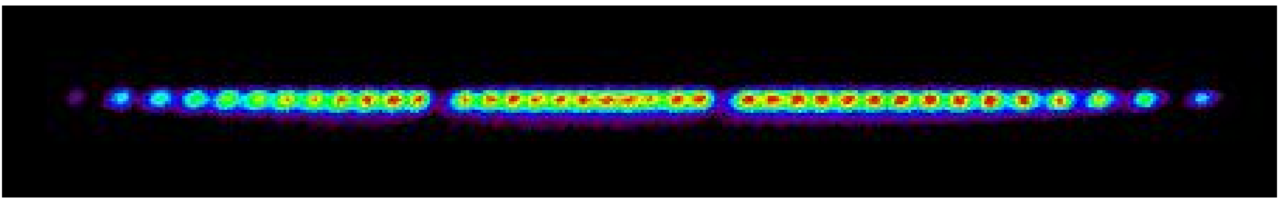
Oxford, England: $^{40}Ca^{+}$

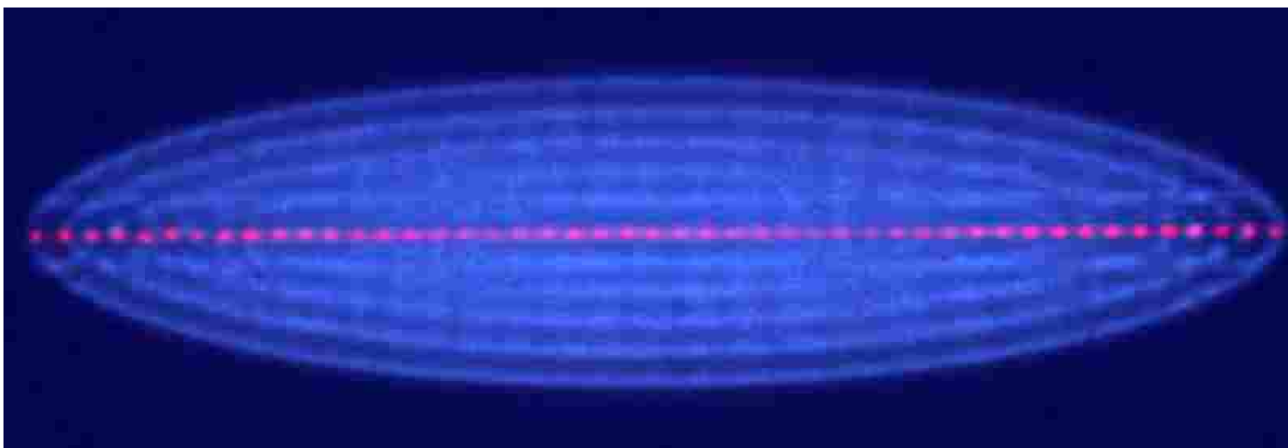




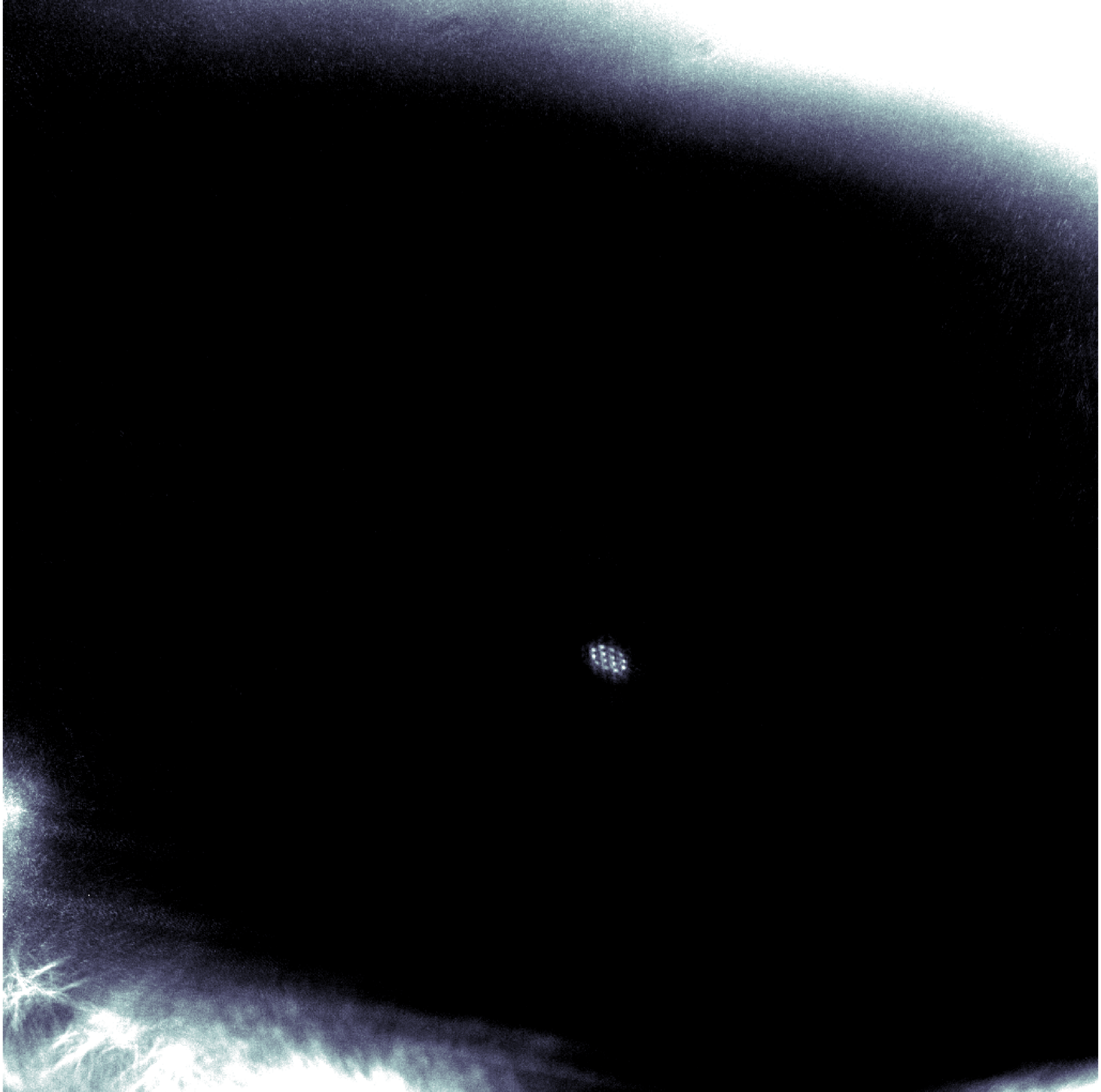
Innsbruck, Austria: $^{40}Ca^{+}$

Boulder, USA: Hg^{+}

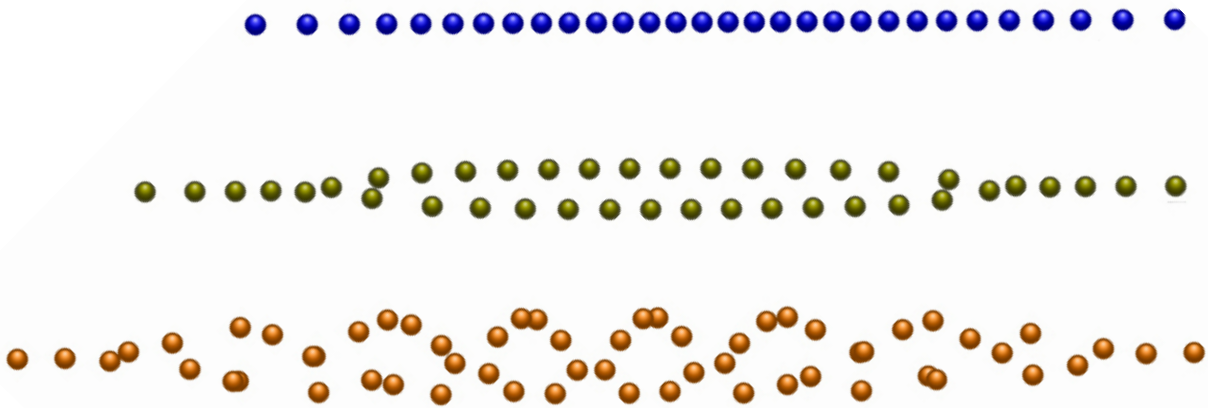


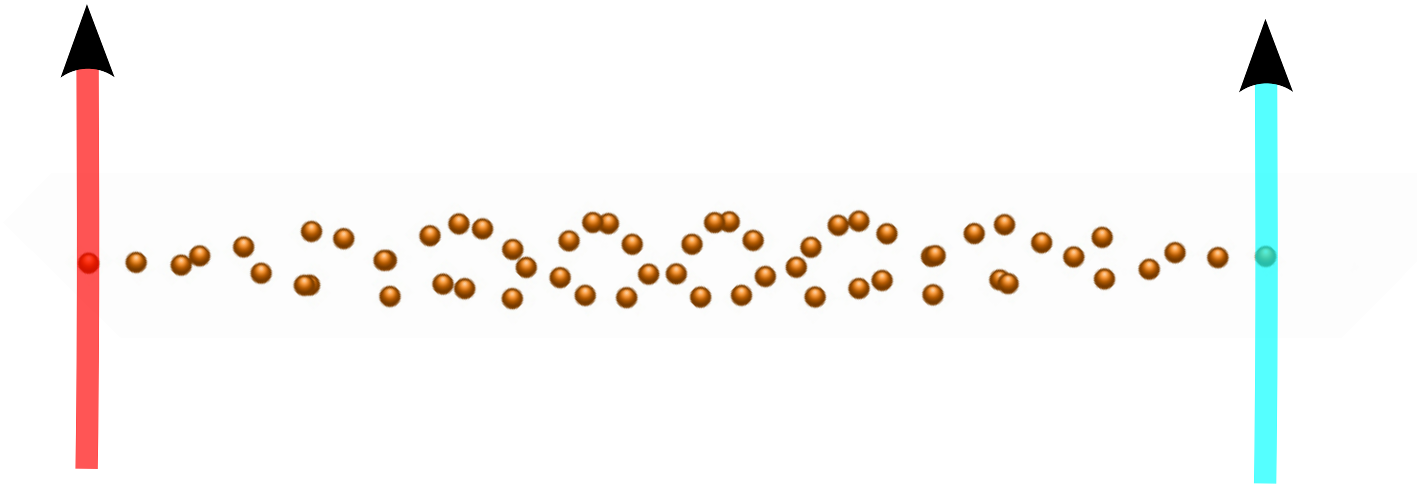


Aarhus, Denmark: $^{40}Ca^{+}$ (red) and $^{24}Mg^{+}$ (blue)

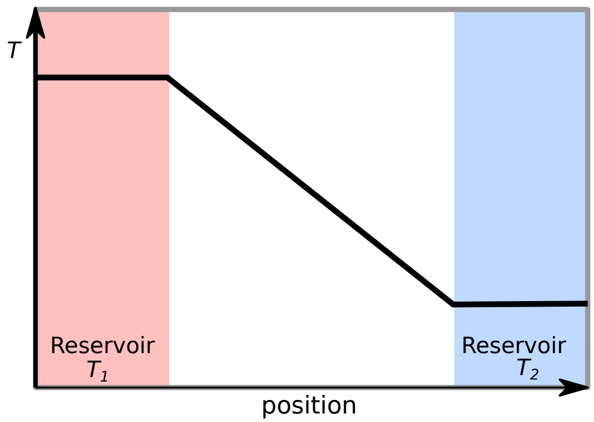


Buenos Aires,
Argentina

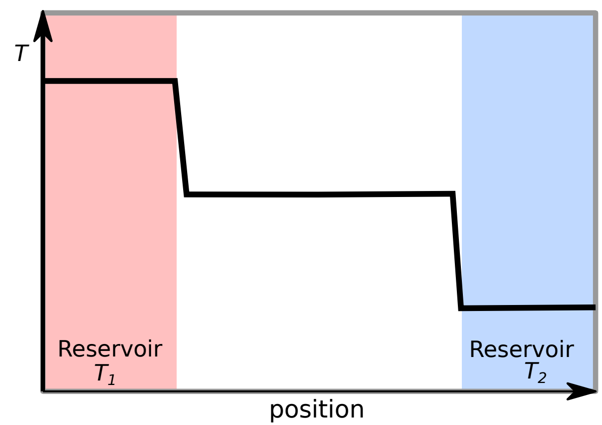




Fourier's heat conduction law

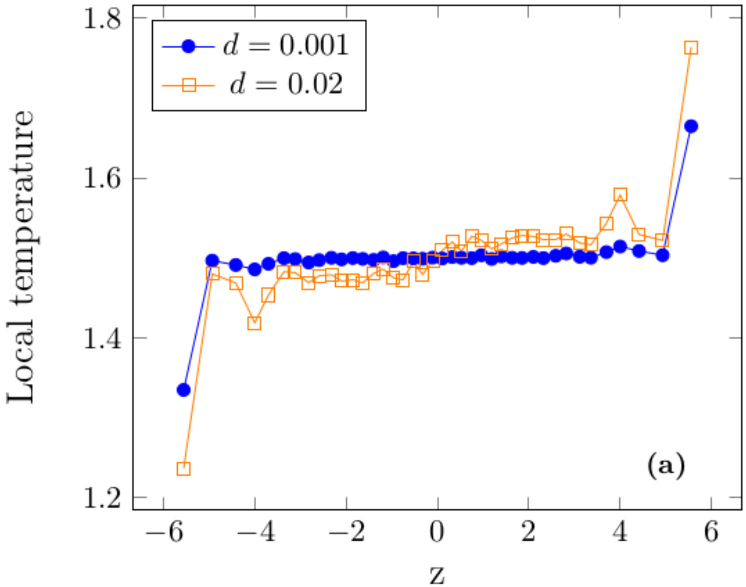


not valid for:
chain of quantum or calssical oscillators
low dimensional systems



Fourier's heat conduction law

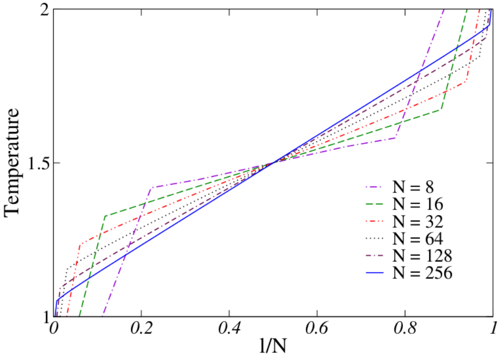
chains of quantum oscillators



EA Martinez, JP Paz **PRL110 (13), 130406**

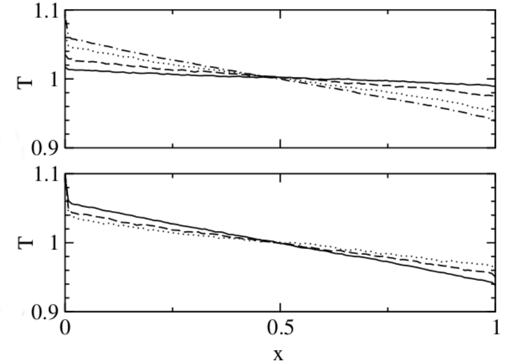
N Freitas, EA Martinez, JP Paz
Physica Scripta 91 (1), 013007 (2015)

low dimensional phonon systems



D. Roy, **PRE 77, 062102 (2008)**

classical harmonic oscilators



Lepri, S., Livi, R., & Politi, A.
Phys. Rep., 377(1), 1-80.(2003)

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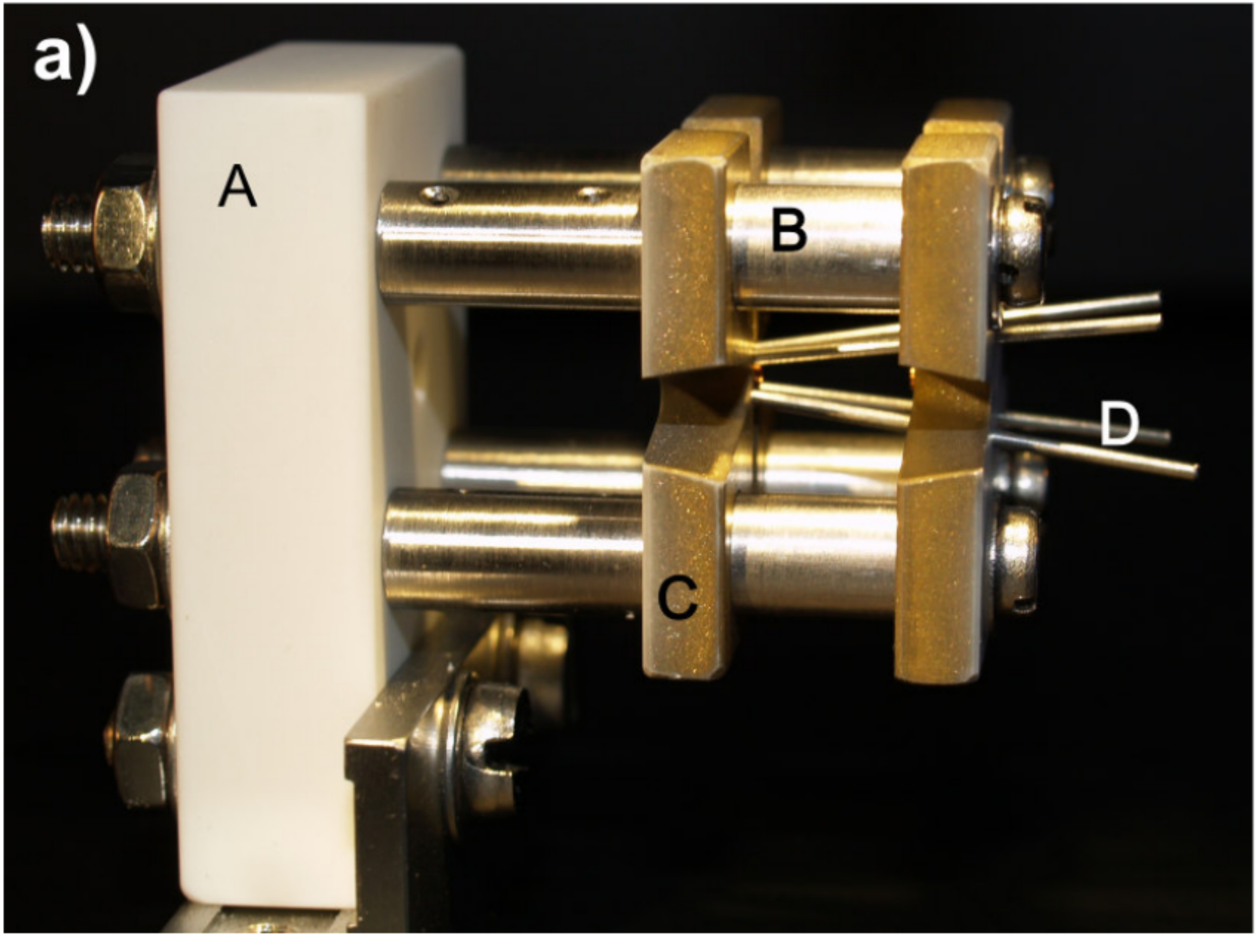
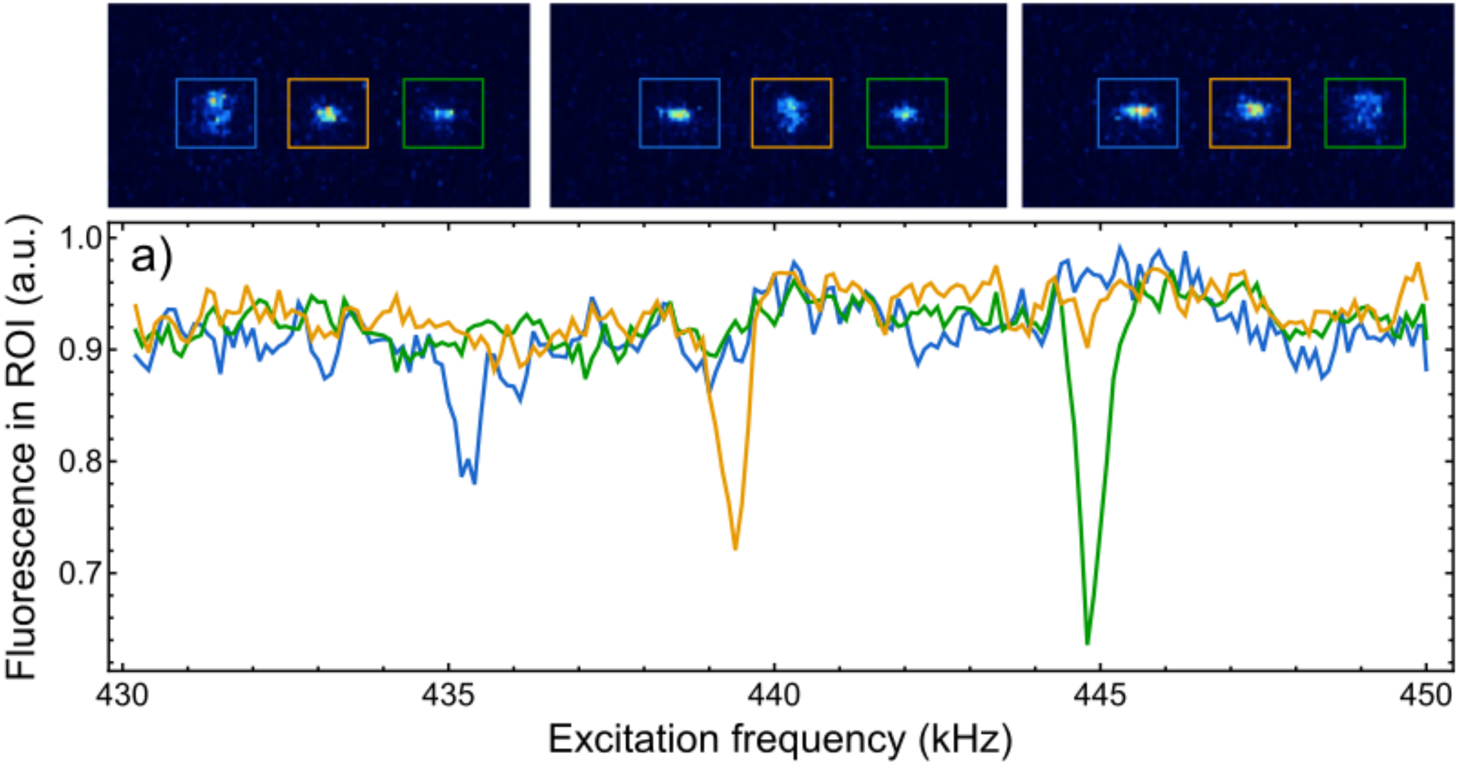

a)
A
B
C
D

funnel trap

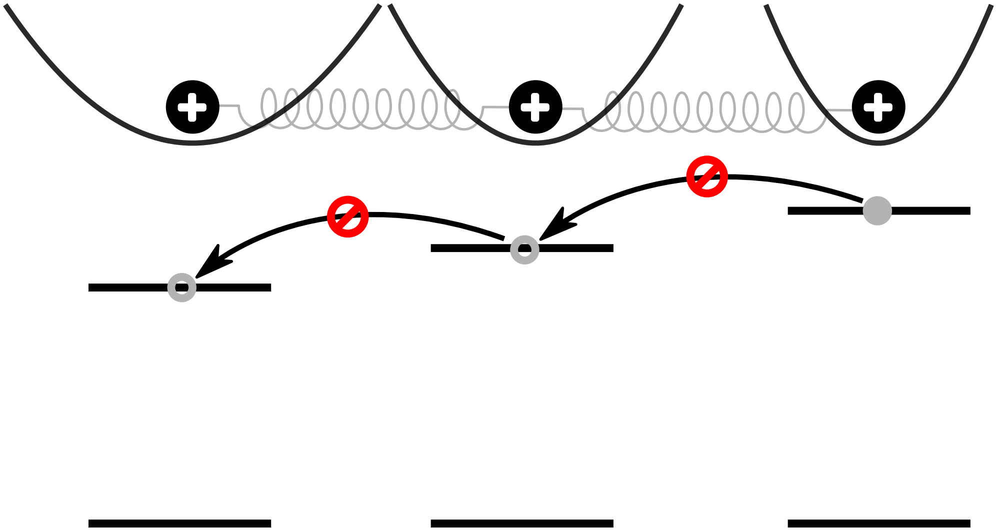
spectra ion by ion



Uni-Mainz, Schmidt-Kaler Group

noise-induced transport

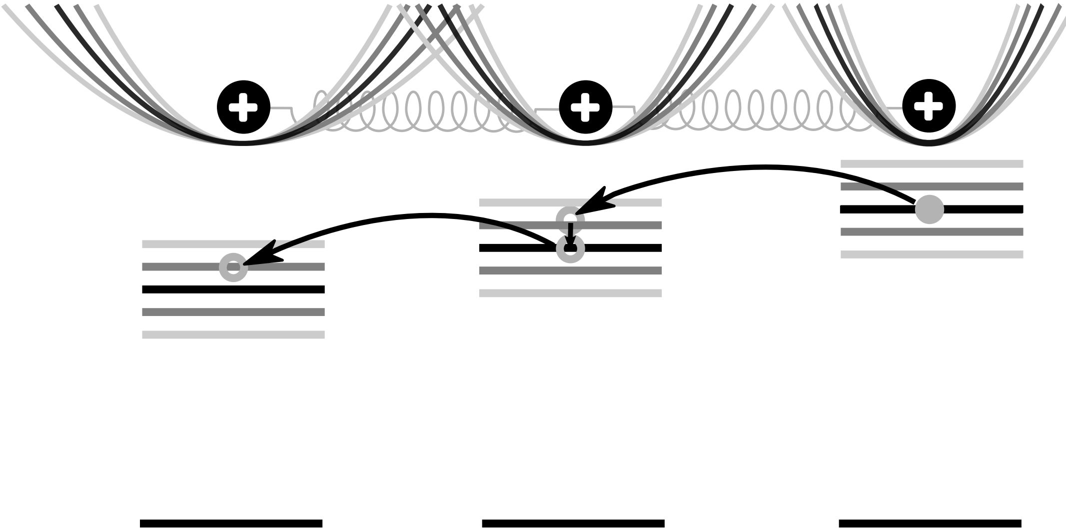
in the motion of trapped ions



Cecilia Cormick and CTS, **PRA 94, 053406 (2016)**

noise-induced transport

in the motion of trapped ions



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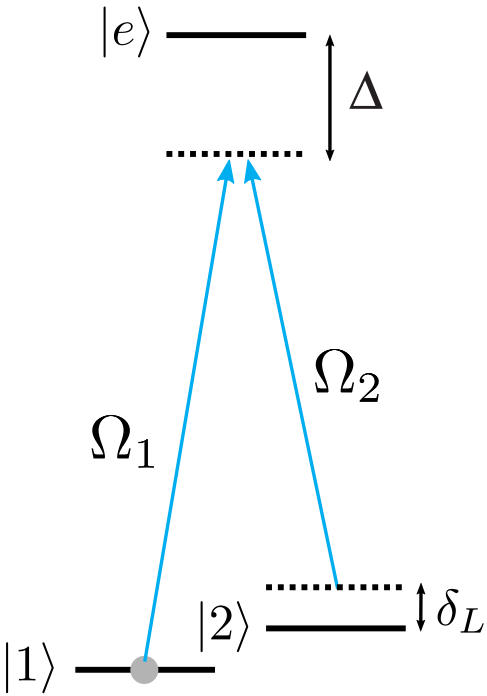
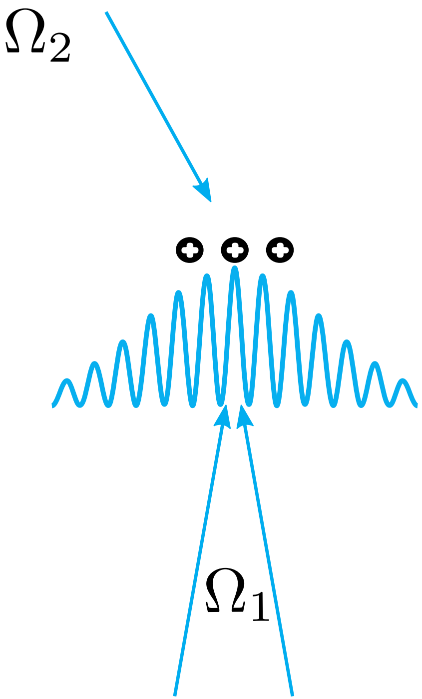
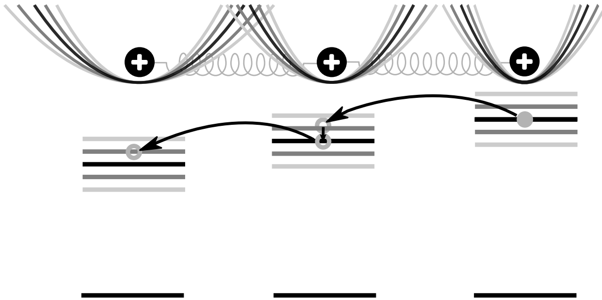


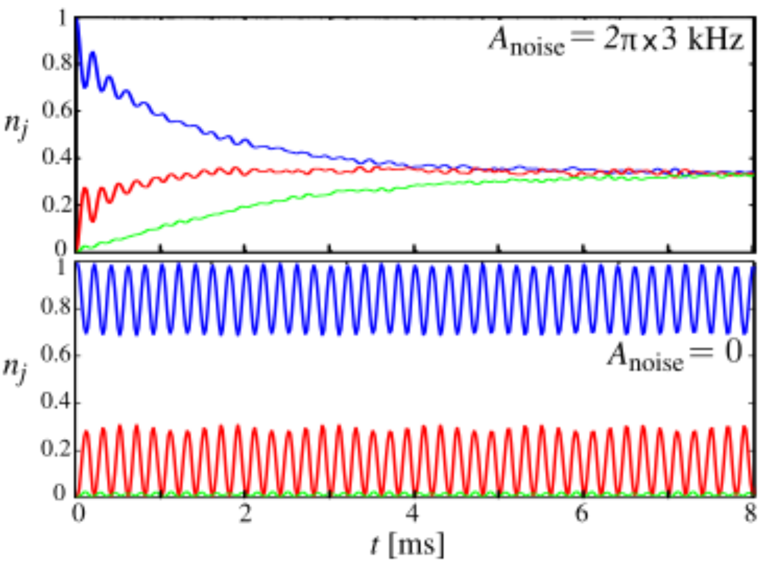


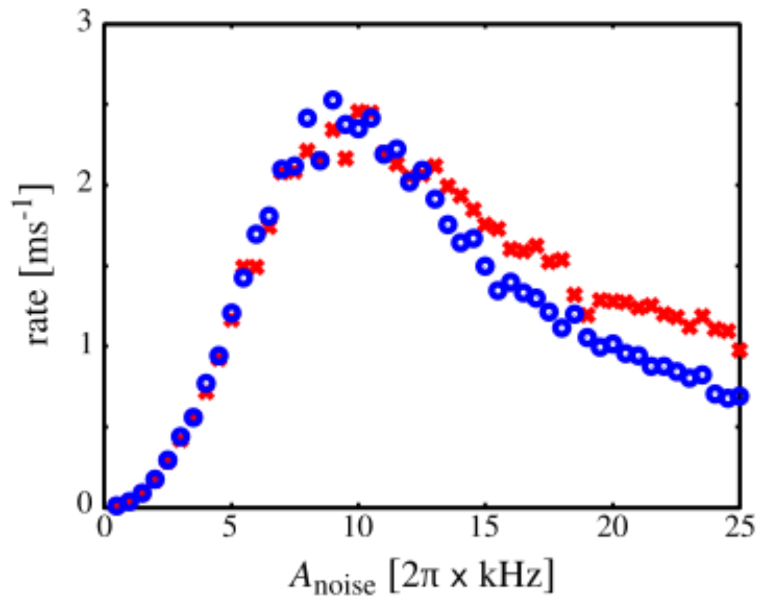
Cecilia Cormick and CTS, **PRA 94, 053406 (2016)**

noise-induced transport

in the motion of trapped ions



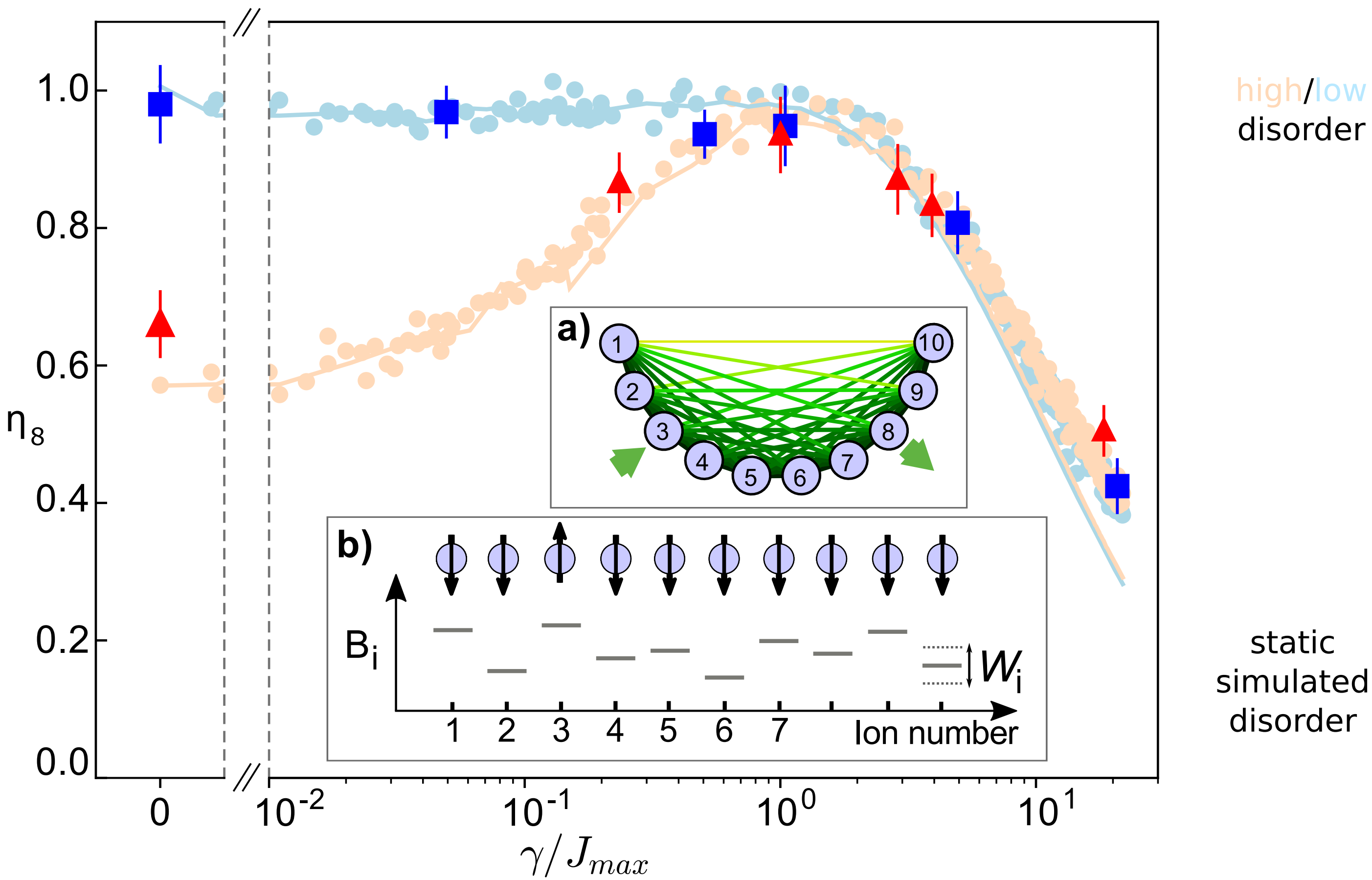




Cecilia Cormick and CTS, **PRA 94, 053406 (2016)**

environment-assisted quantum transportuced transport

in a 10-qubit network



C. Maier, (...) R. Blatt **. Lett. 122, 050501 (2019)**

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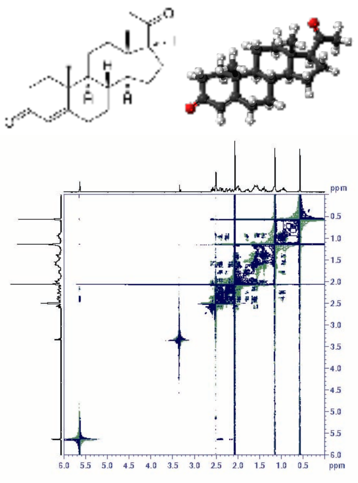
two-dimensional spectroscopy

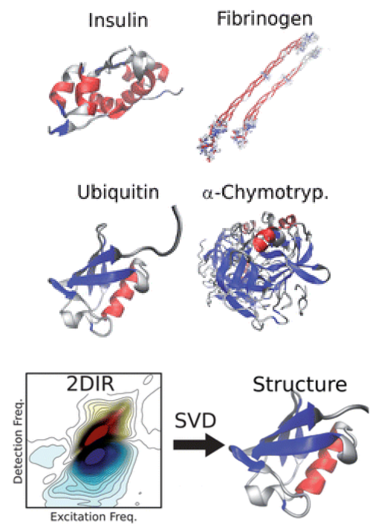
for the study of Ion Coulomb crystals

NMR: spin couplings



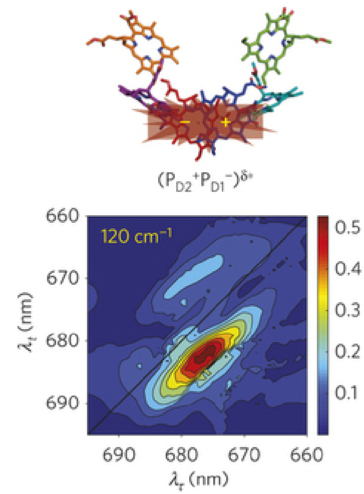
Progesterone molecule and COSY spectrum
Images: Wikipedia

Infrared: molecular vibrations



Protein structures
Images: [Baiz et al., Analyst 137, 1793 (2012)]

Optical: electronic dynamics

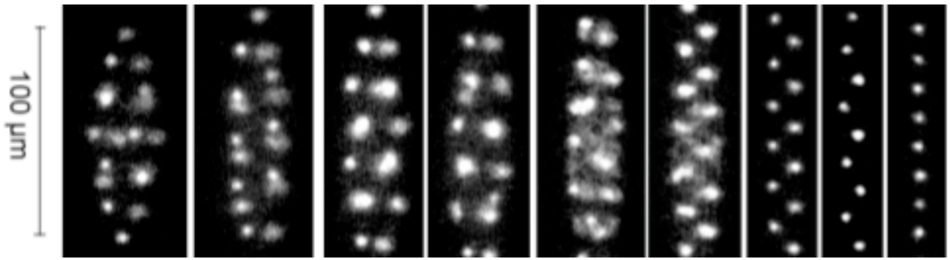


Photosystem II - Reaction center. Image: [Romero et al., Nature Phys. (2014)]

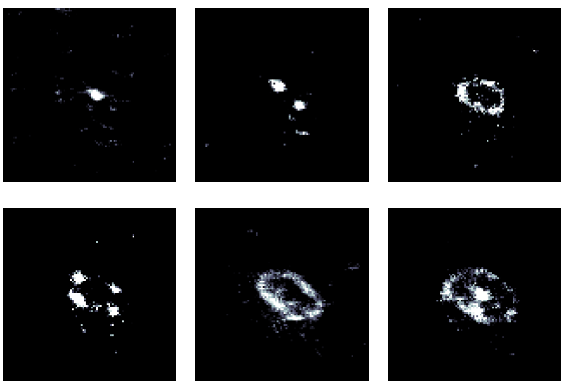
C. Maier, (...) R. Blatt and C. F. Roos Phys. Rev. Lett. 122, 050501 (2019)

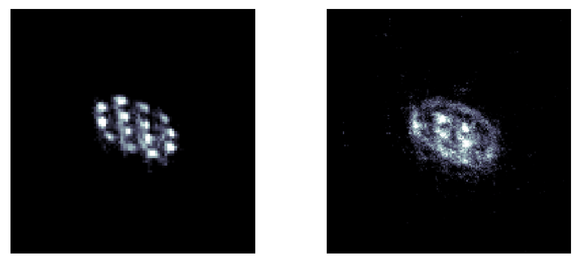
structural phase transitions

in Coulomb crystals



Bock et al., J. Phys. B 33, L375 (2000)

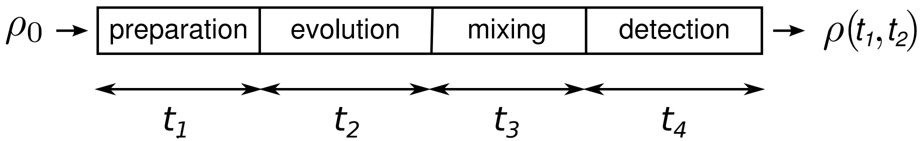




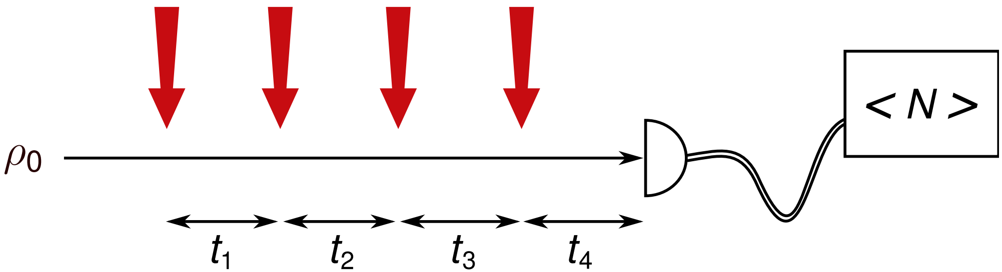
Laboratorio Iones y Átomos Fríos, Buenos Aires, Argentina

two-dimensional spectroscopy

for the study of Ion Coulomb crystals



Laser pulses: $D\,(\alpha_j\, e^{i\phi_j})$



Pulses: small phase-controlled displacements on a mode.

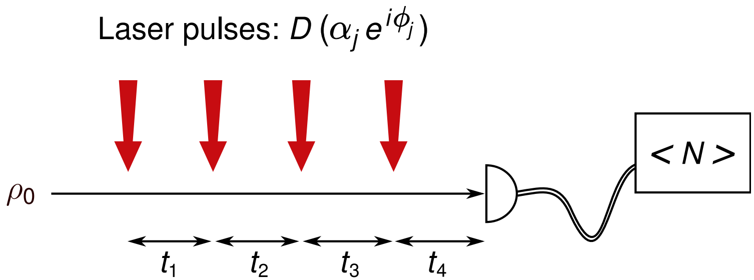
Sequence of four pulses.

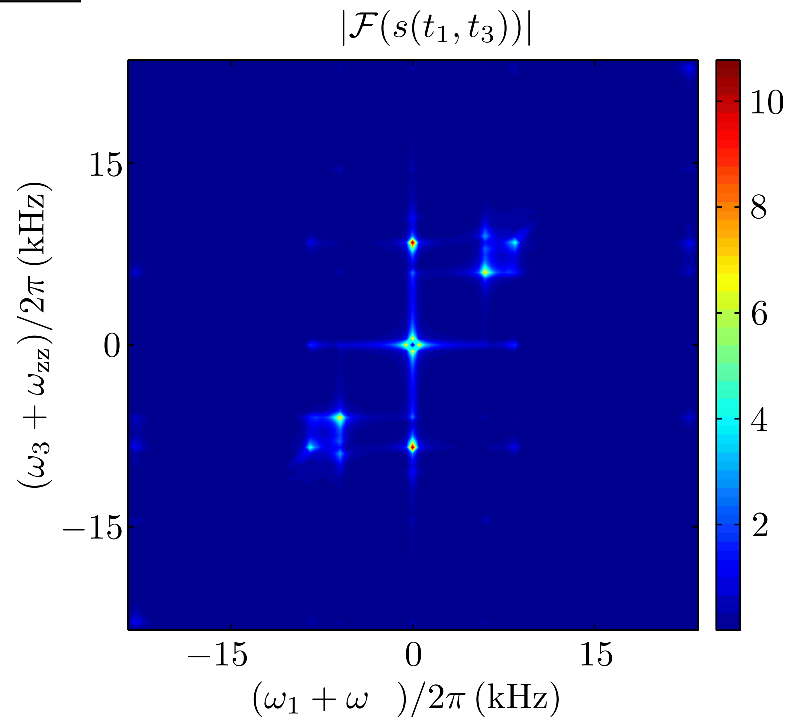
Final measurement of mode population.

Lemmer, Cormick, CTS, Schmidt-Kaler and Plenio, **PRL 114, 073001 (2015)**

two-dimensional spectroscopy

for the study of Ion Coulomb crystals





Lemmer, Cormick, CTS, Schmidt-Kaler and Plenio, **PRL 114, 073001 (2015)**

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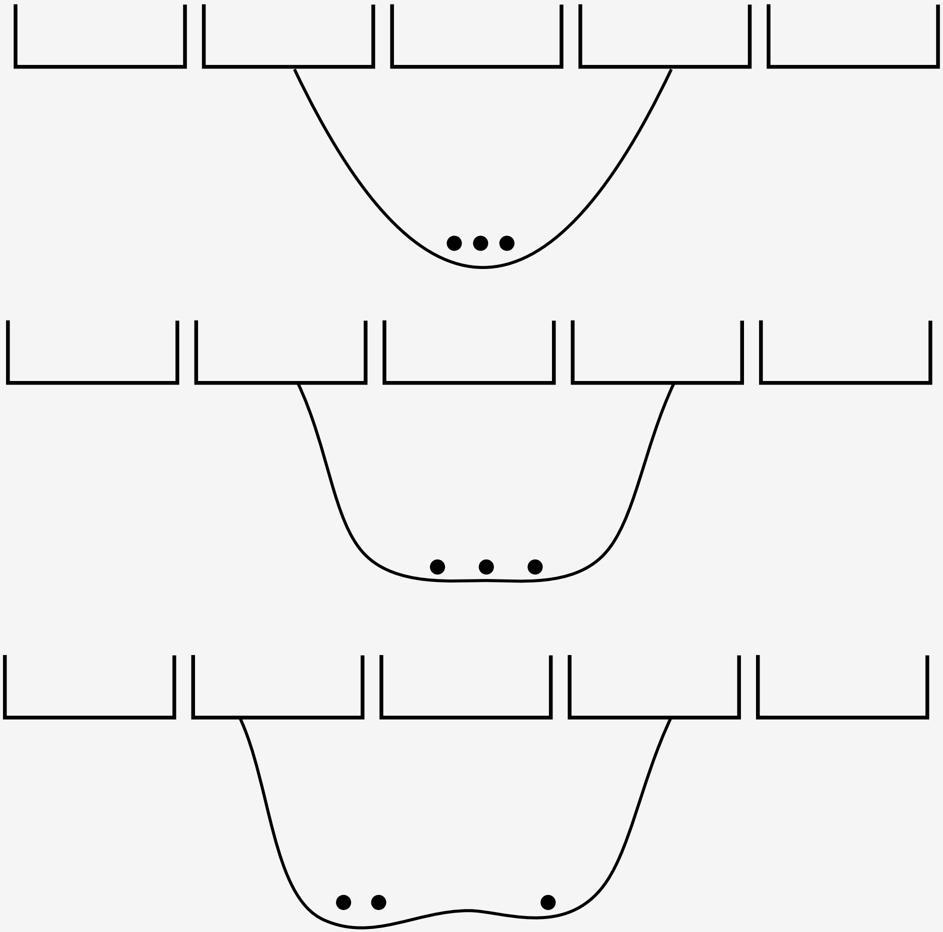
at the Schmidt-Kaler Group at Uni-Mainz

electric potential shaping



segmented traps

shaping of the external potential

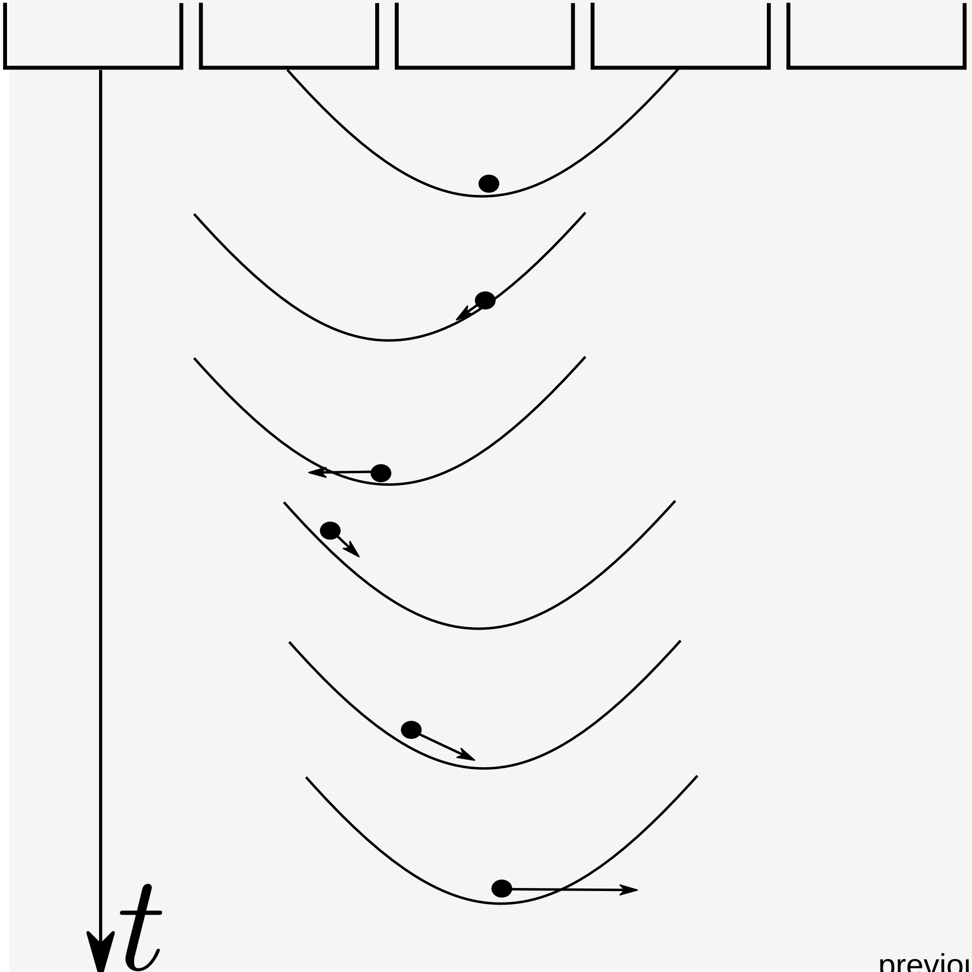
$$\Phi(x) = \beta x^4 + \alpha x^2 + \gamma x$$

characteristic scale $100\mu\mathrm{m}$

application **fast cold ion splitting**

Ruster et. al. PRA 90, 033410 (2014)

kicking the ion electrically by changing voltage on an electrode



electrical kick

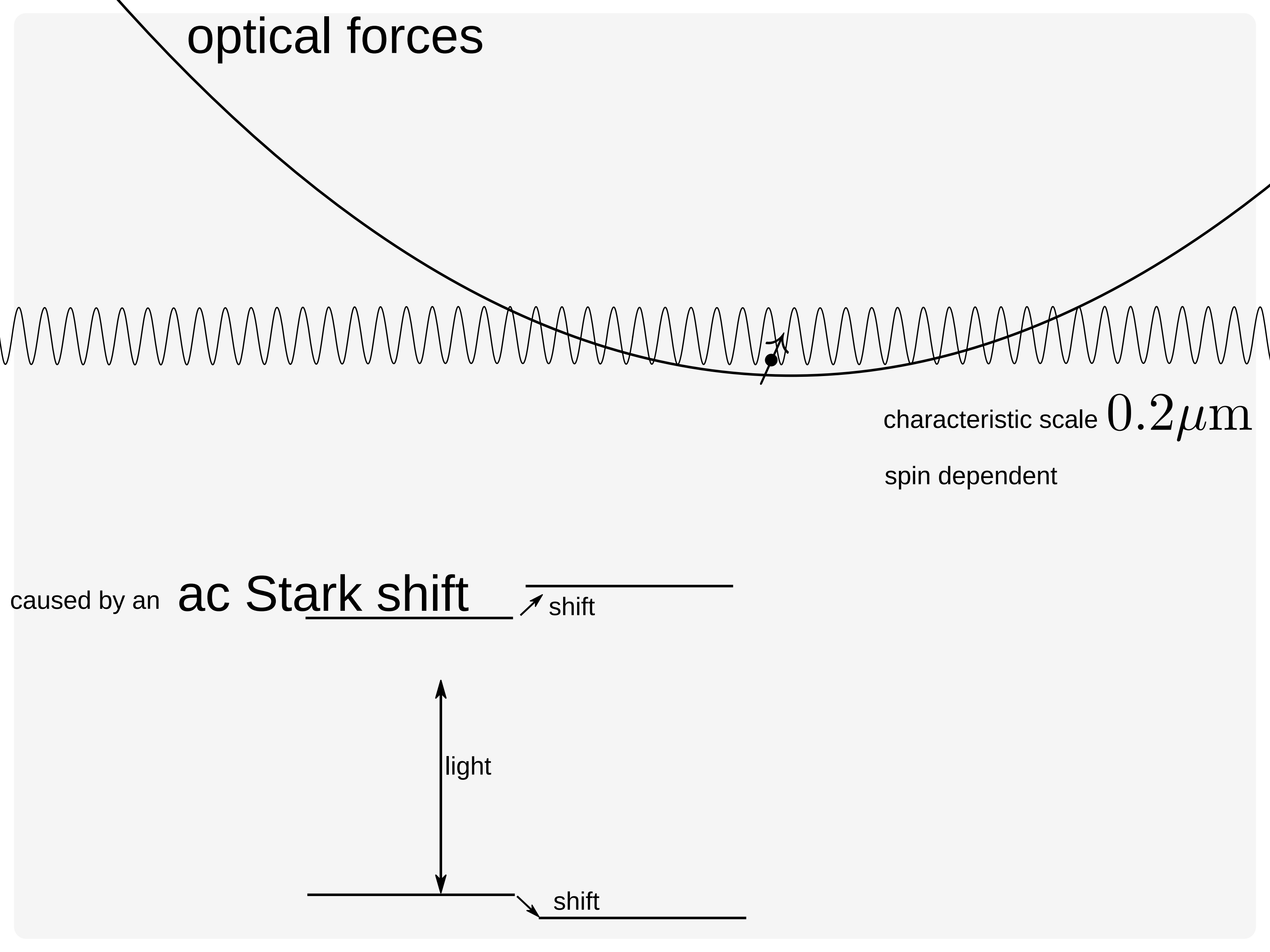
is not spin-dependent

is "locked" to real space coordinates

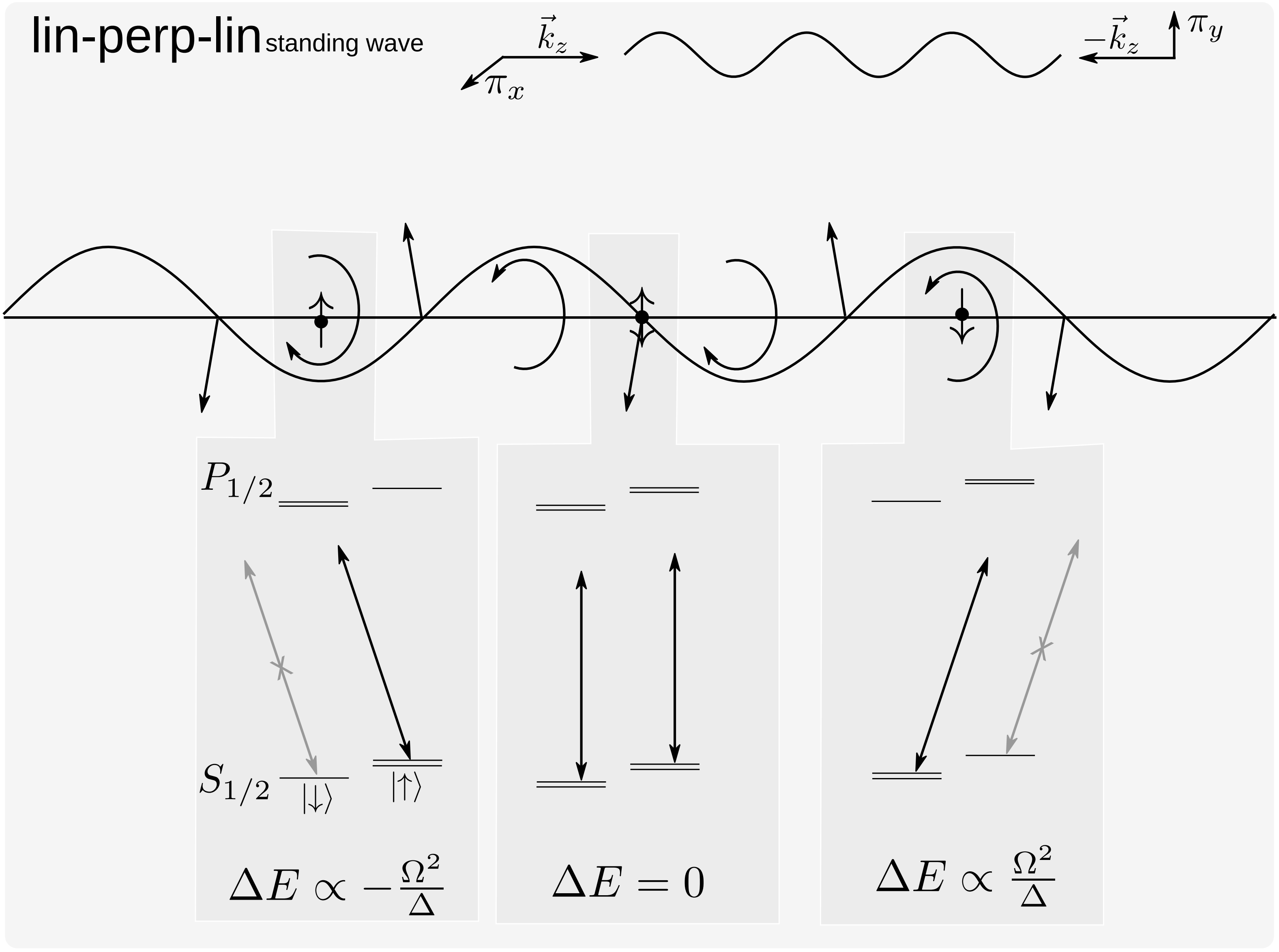
previously on **fast ion transport**

Walther et. al., PRL109, 080501 (2012)

Bowler et. al., PRL109, 080502 (2012)

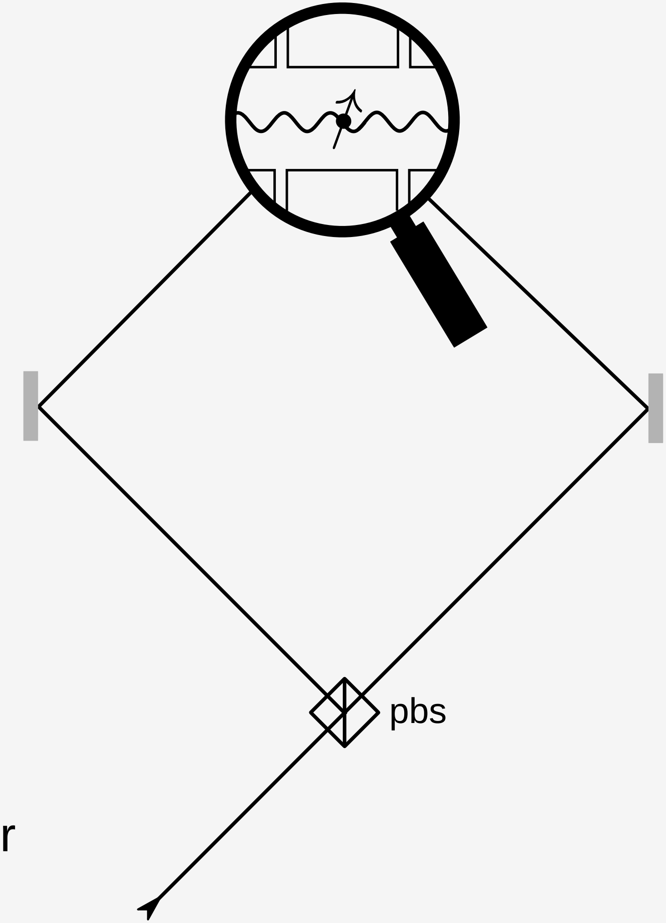


optical forces
characteristic scale $0.2\mu m$
spin dependent
caused by an ac Stark shift
shift
light
shift



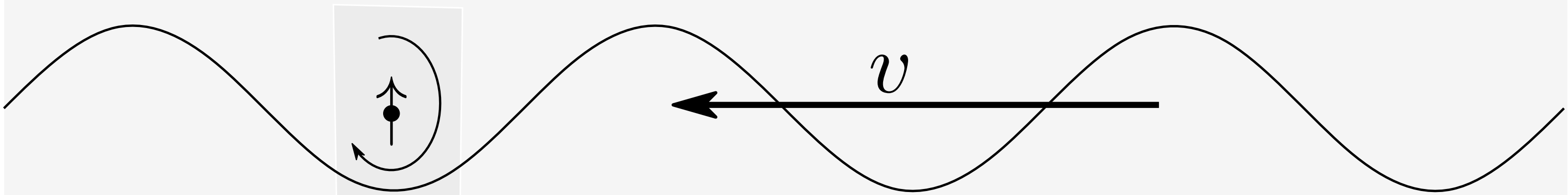
lin-perp-lin standing wave
$\vec{k}_z$
π_x
$-\vec{k}_z$
π_y
$P_{1/2}$
$S_{1/2}$
$|\downarrow\rangle$
$|\uparrow\rangle$
$\Delta E \propto -\frac{\Omega^2}{\Delta}$
$\Delta E = 0$
$\Delta E \propto \frac{\Omega^2}{\Delta}$

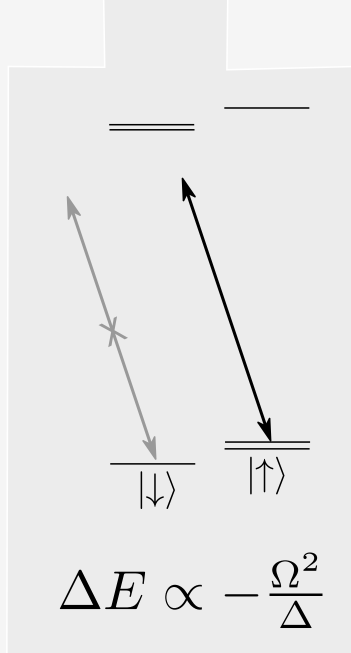
lin-perp-lin standing wave



Mach-Zehnder interferometer
with ion as last beam-splitter

resonant motion excitation





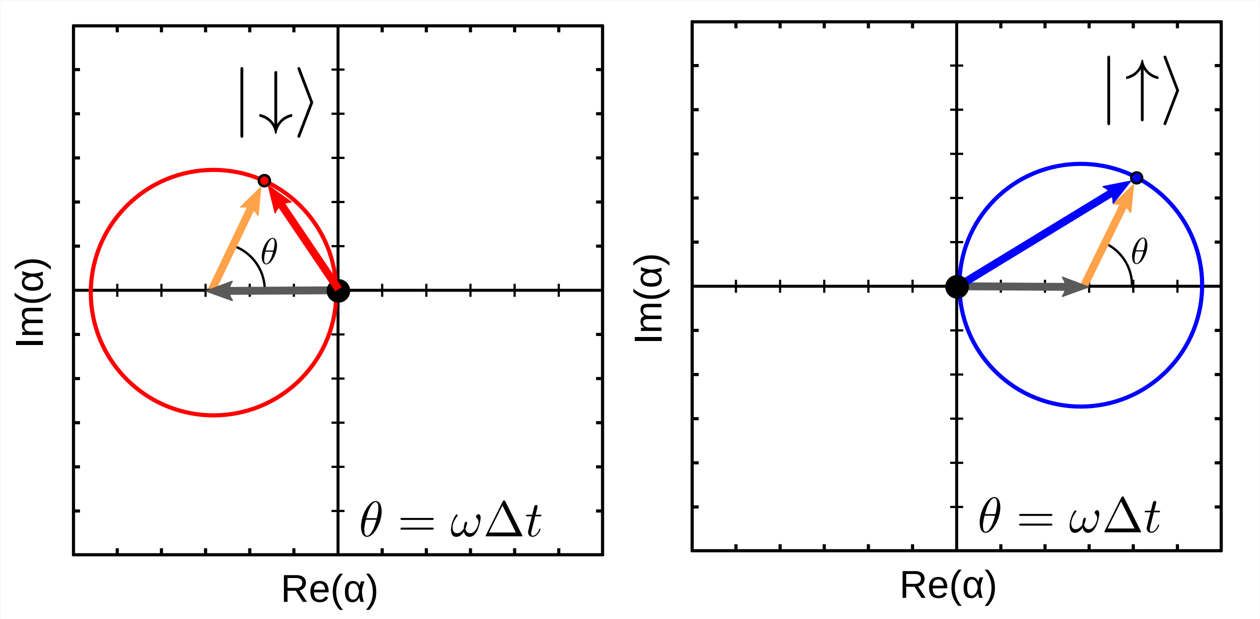
standing wave
extra potential energy landscape

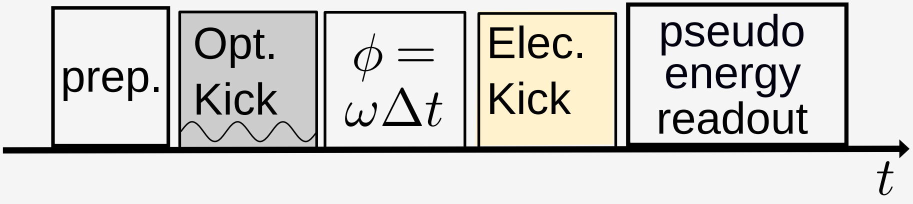
passing wave (aka standing-travelling wave)
periodic drive

resnonant excitation $v = \lambda f_{trap}$

phase stable optical forces

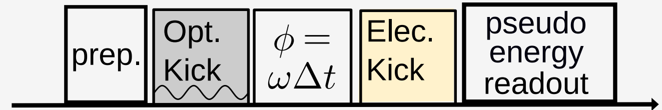
optical electrical kicks

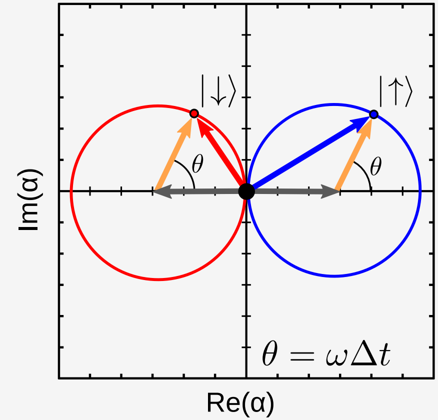


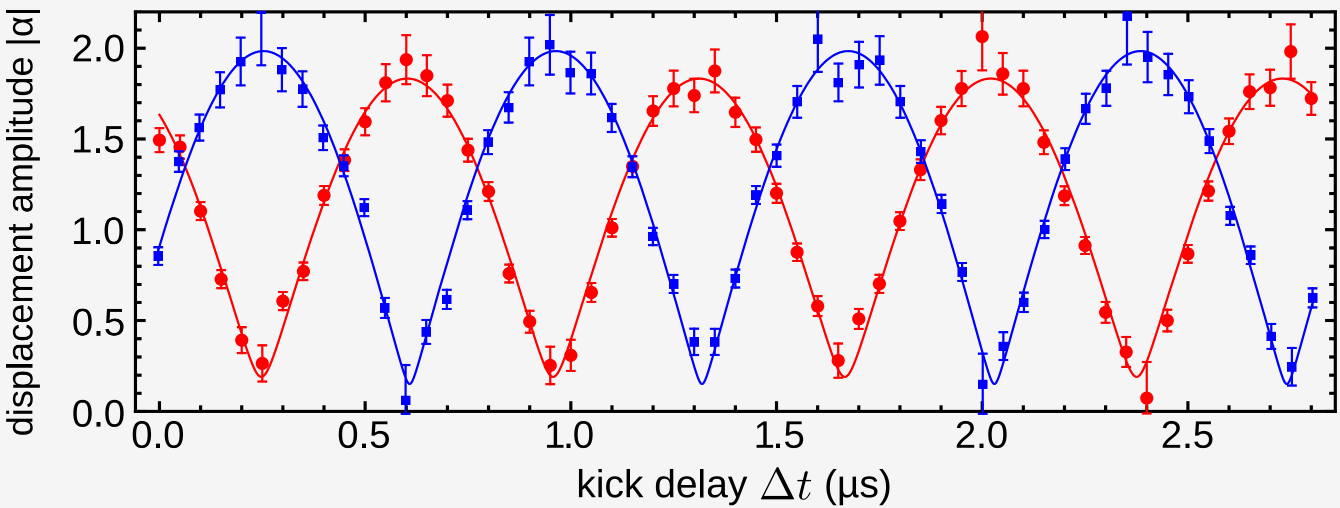


phase stable optical forces

optical electrical kicks

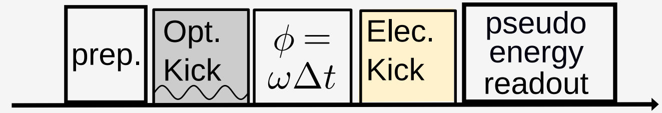


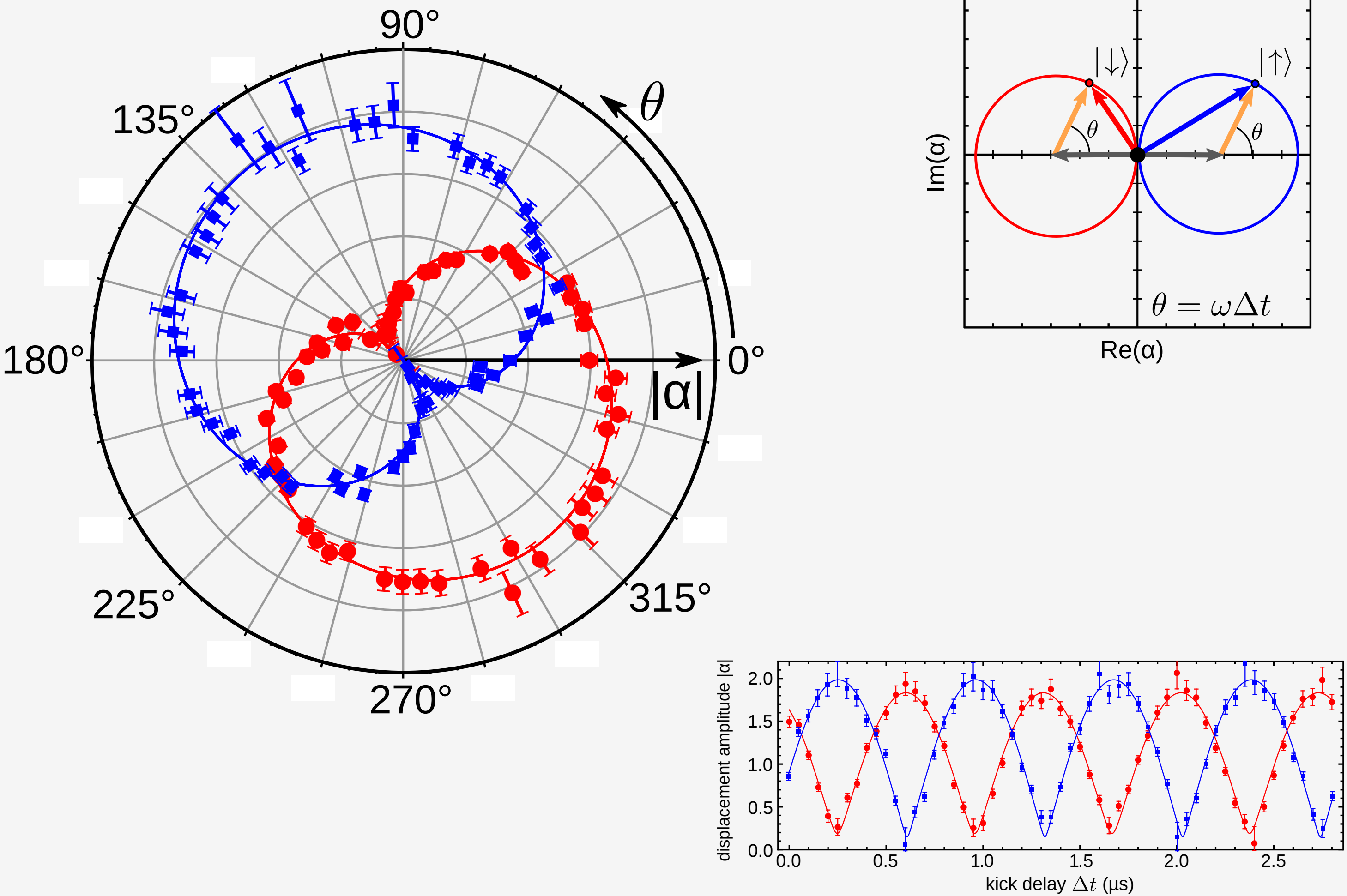




phase stable optical forces

optical electrical kicks





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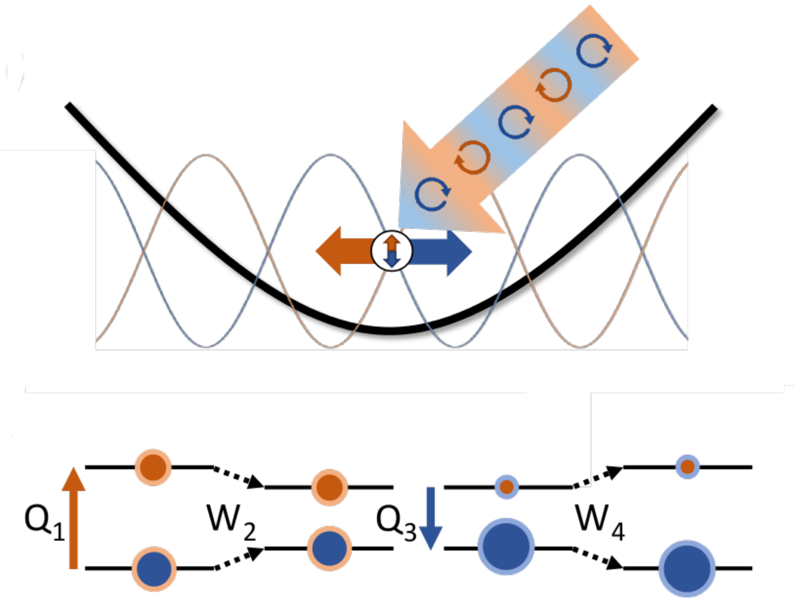
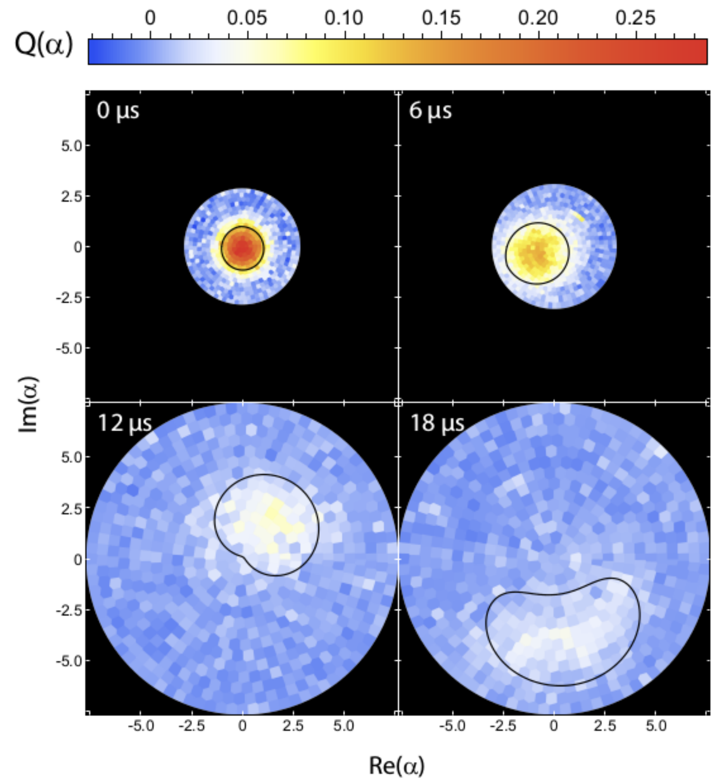
spin heat engine

coupled to a harmonic oscillator flywheel

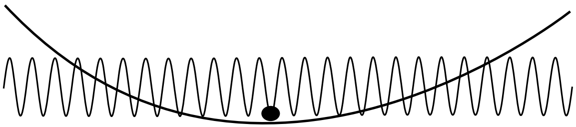


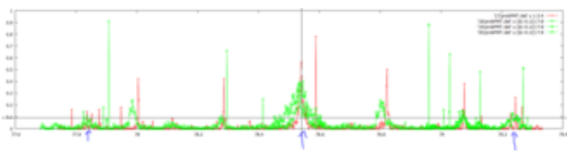


von Lindenfels, CTS, ... Schmidt-Kaler & Poshinger, **arXiv:1808.02390**

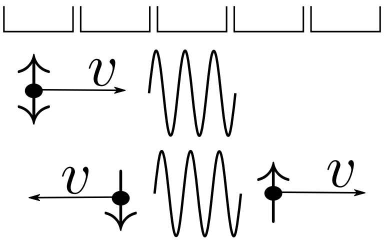
phase referenced optical forces
what's next

optical potential
analog quantum simulations
motional stark shift

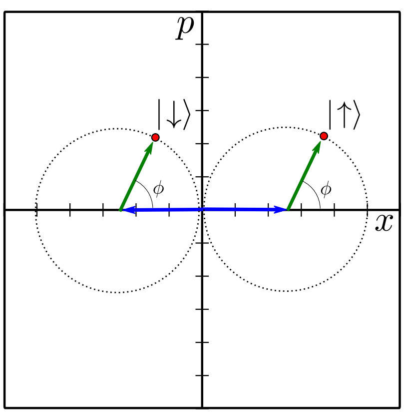




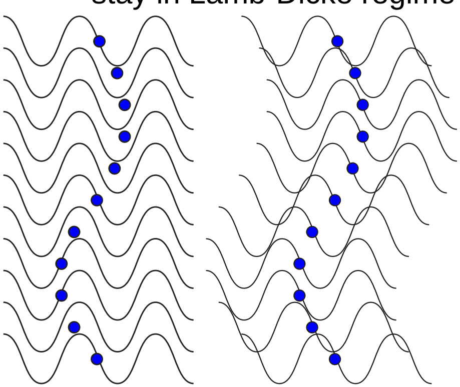
spin dependent filter
stern-gerlach like experiments with ions
discrete momentum expansion imaging



new tool in phase space
motional tomography
new motional states accesible



giant cats
follow the ion with your light field
stay in Lamb-Dicke regime



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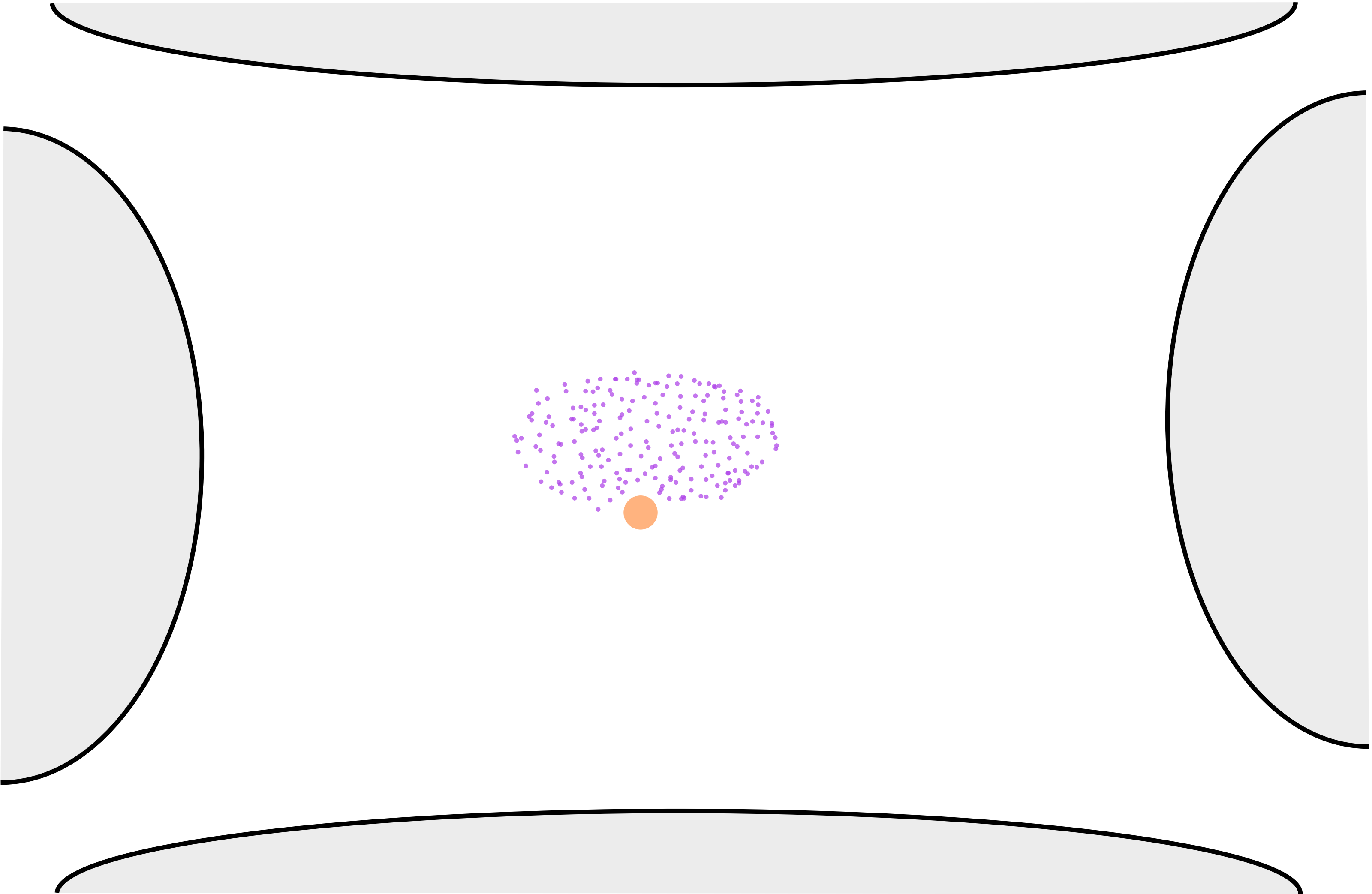
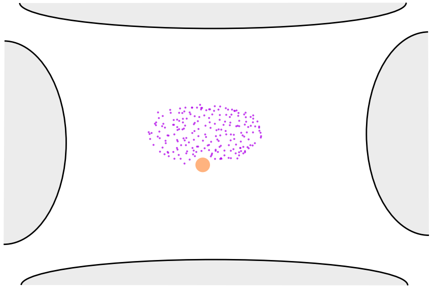
symapthetic laser cooling of nanoparticles

an optical cryostat



symapthetic laser cooling of nanoparticles

challenges and perspectives



simultaneous trapping of ions and nanoparticles

different q/m ration and stability

two frequency traps

laser cooling of ions
sympathetic cooling of nanoparticles

how well will the nanoparticle cool?

will it rotate?

what will happen with it internal DOFs?

laser cooling of internal DOFs of nanoparticles?

color enters, rare earth crystals, fluorophores

what can we do with and optical cryostat?

how about the themodynamics of this system?

can we construct themal machines with/in it?

at Universidad de Buenos Aires, Argentina