Trapped ions meet solid state physics

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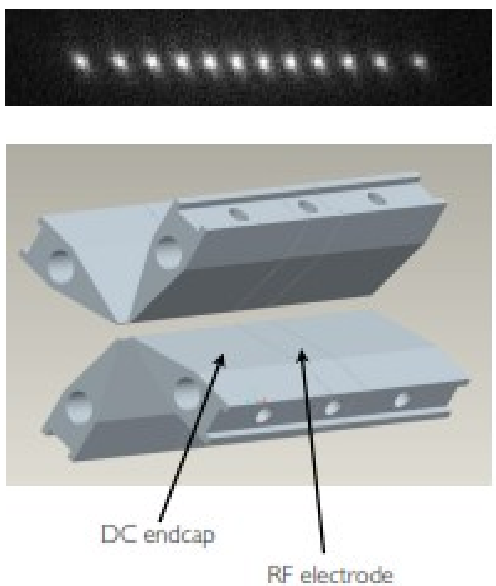
- Introduction
- Quantum emulation
- Shuttling charged particles in 3D
- Comments on anomalous heating
- Conclusions

Boulder, Feb 16th 2011

Trapped ions and condensted matter

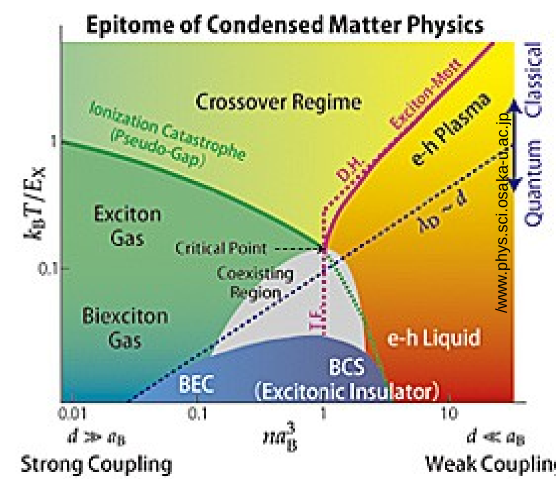
Trapped ions



Emulation

Better traps

Condensed matter



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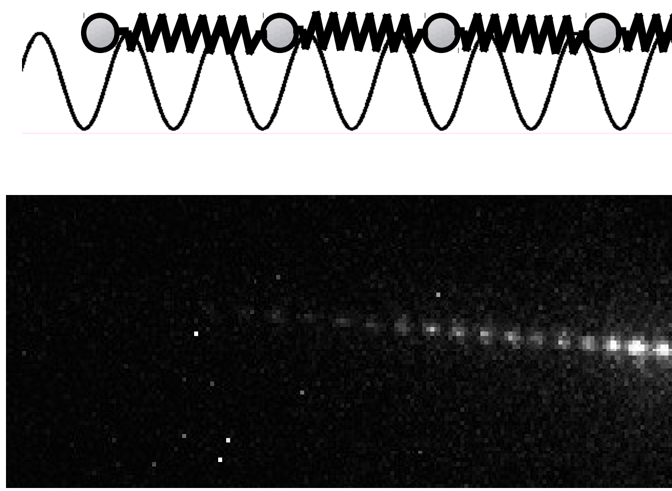
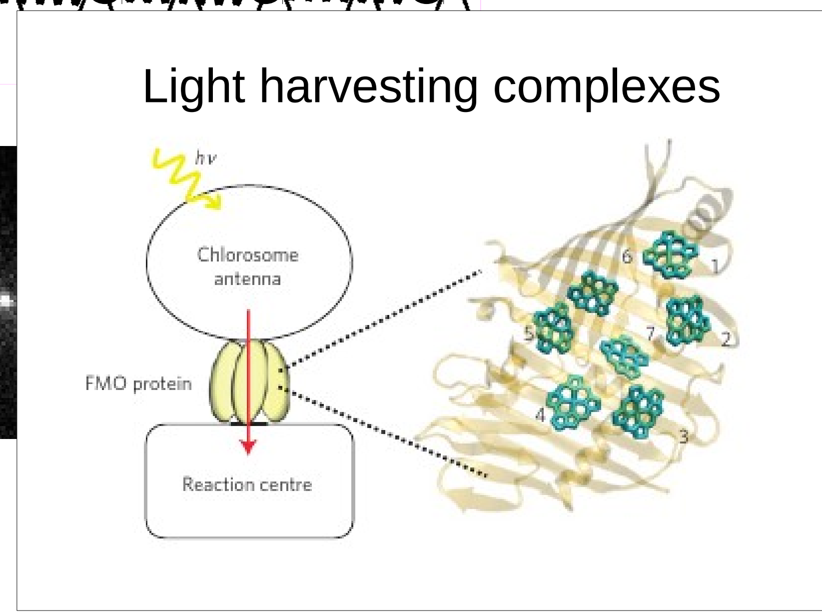
Quantum emulation

General idea: use the motion of ions in individual micro-traps to emulate interesting quantum physics





Questions:

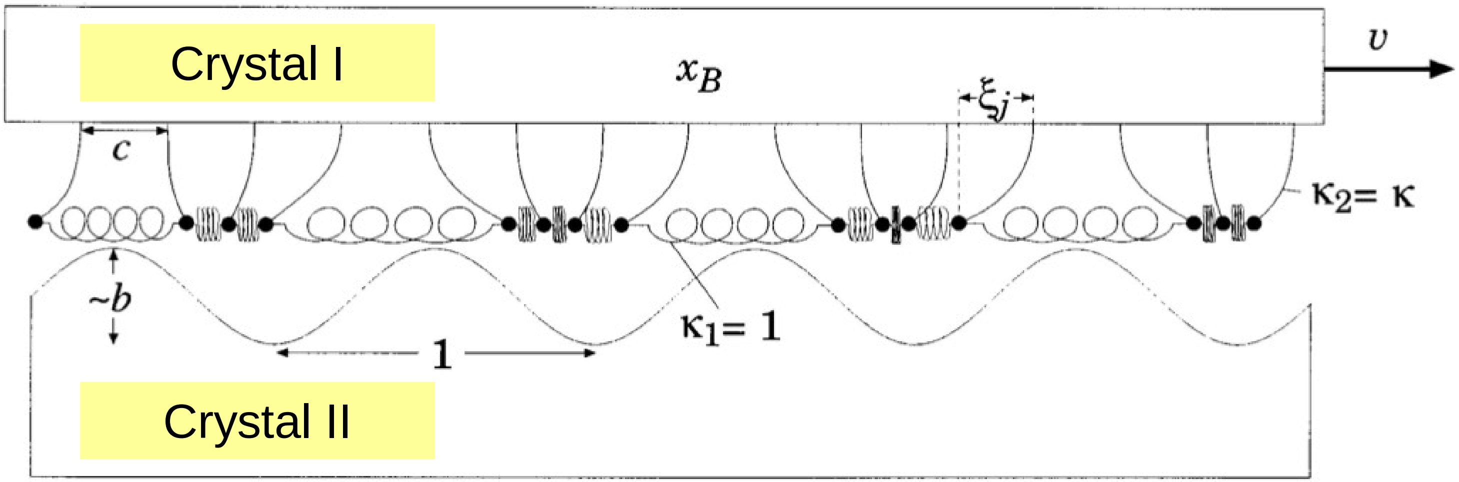
- how does energy flow?

- thermal equilibrium?

- can we trap an excitation by minimal reconfiguration?

Study emergent phenomena

Dry friction:

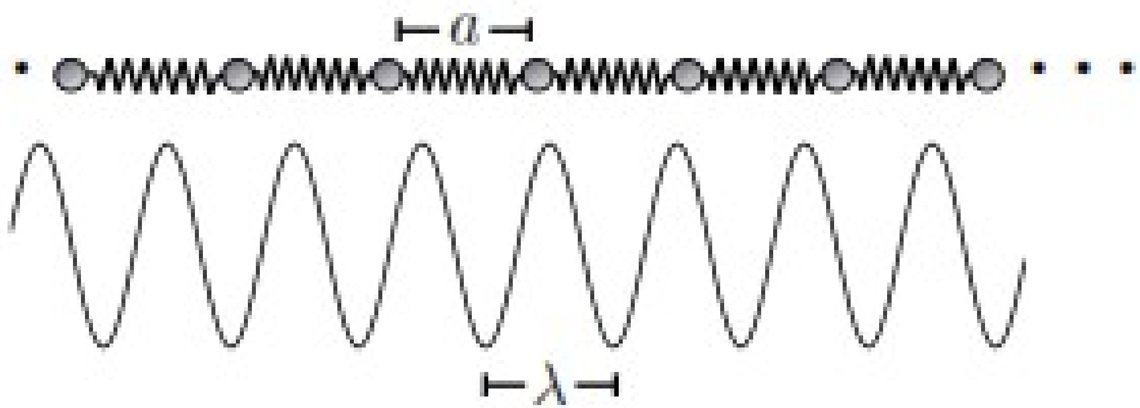


Quantum emulation of dry friction

A linear trap in an optical cavity: an ion string in a periodic potential

Crystal I

Crystal II



Optical trapping of ions: T. Schätz, Munich

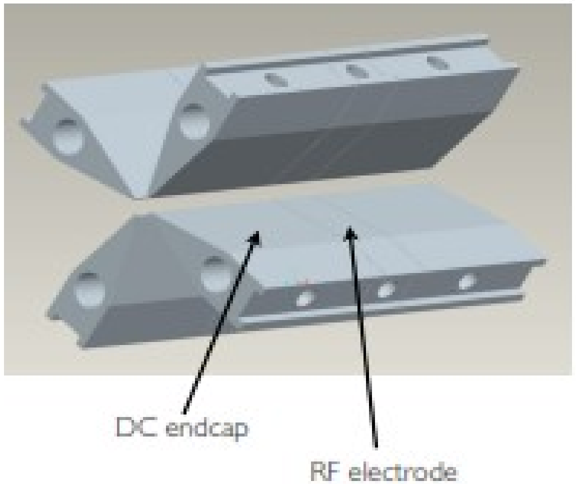
Frenkel-Kontorova model

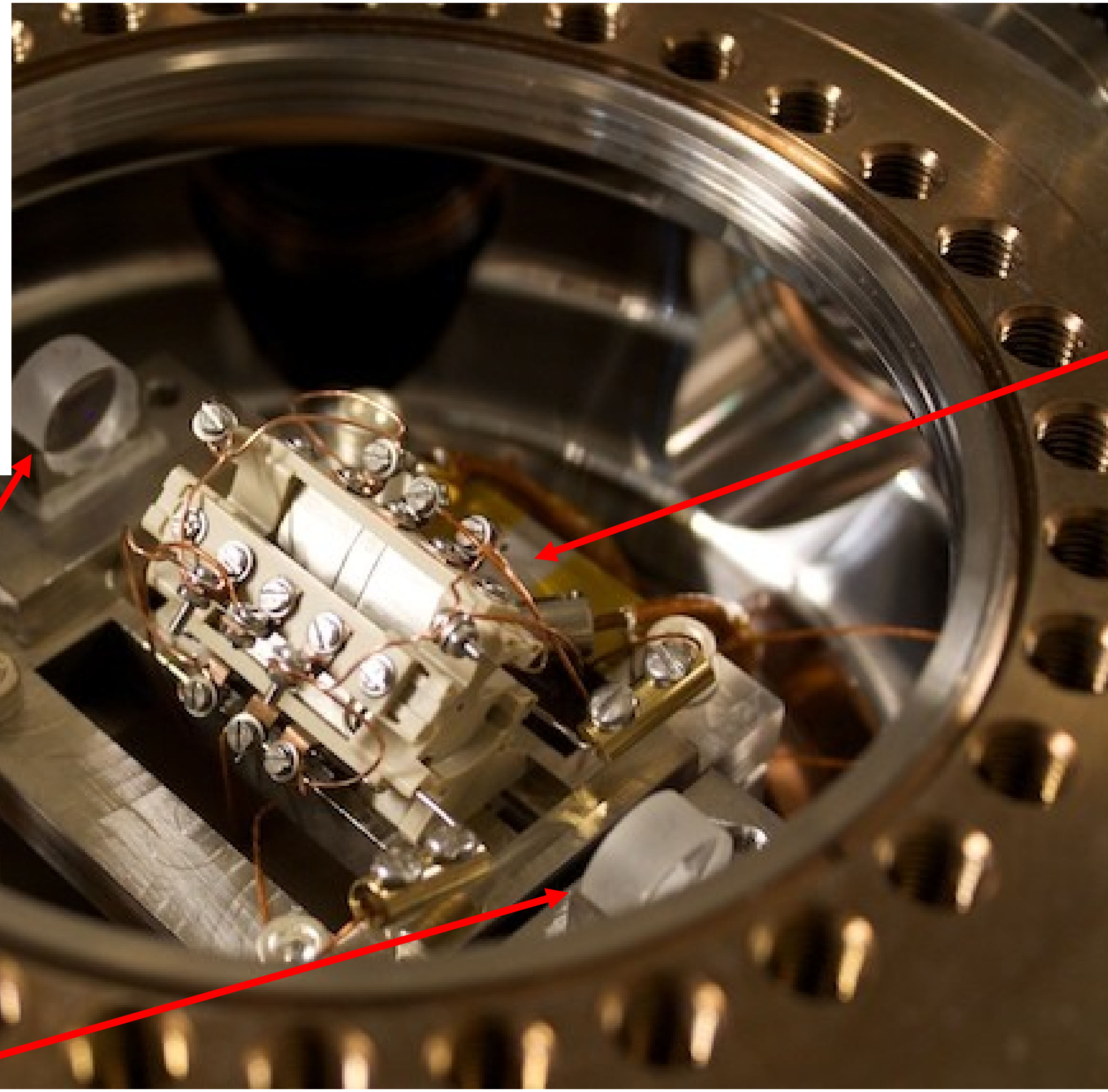
$$\mathcal{H} = \sum_{i=1}^{N} \left(\frac{P_i^2}{2} + \frac{\omega^2}{2} x_i^2 - K \cos x_i \right) + \sum_{i>j} \frac{1}{|x_i - x_j|}$$

Features:

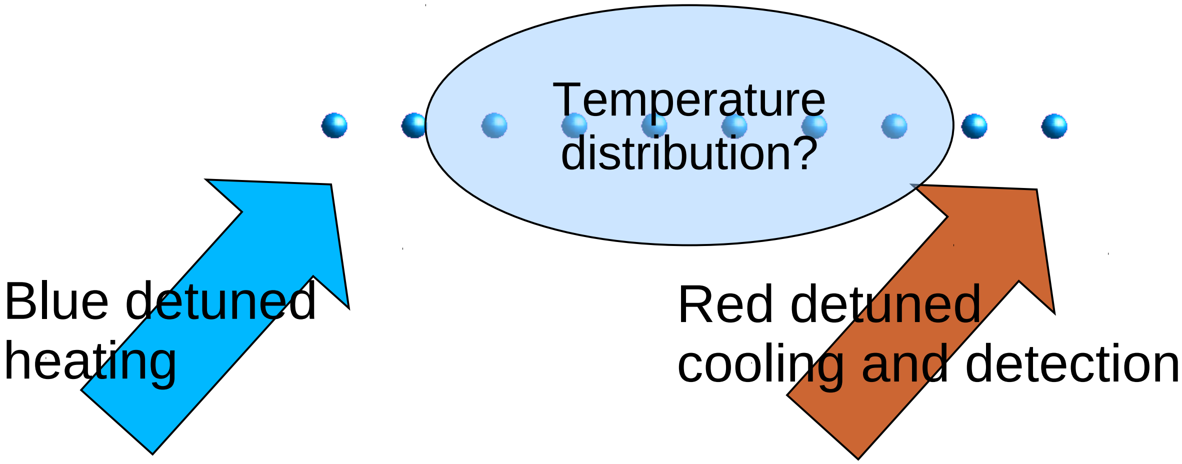
- quantum phase transition
- non-analytic breaking of KAM surfaces

Experimental set-up

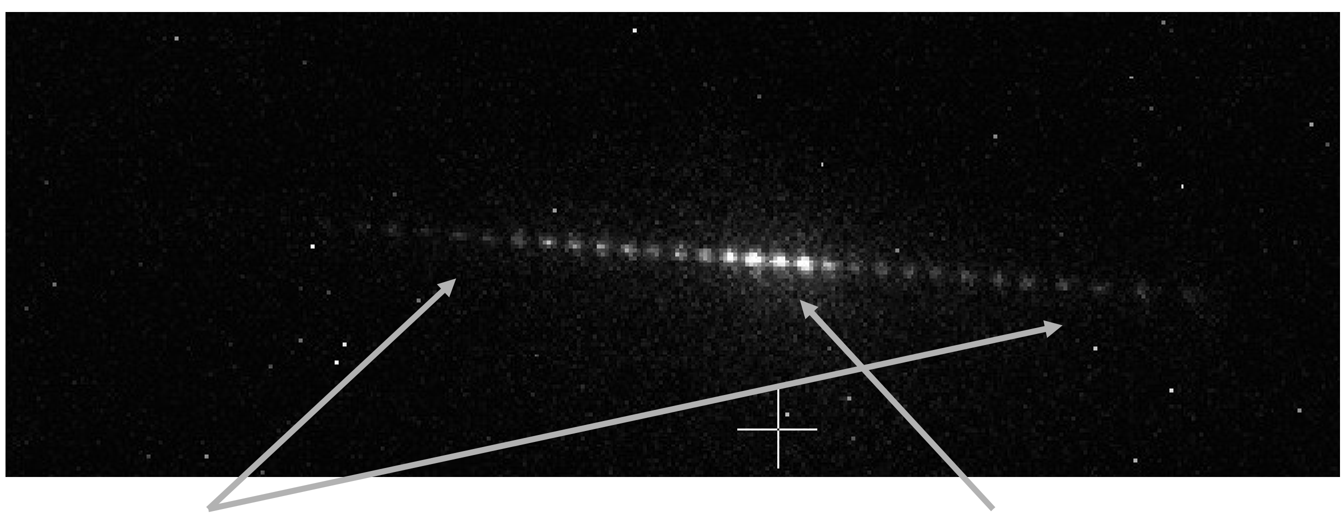




Heat flow in ion strings



Melting of crystal



Global cooling beam

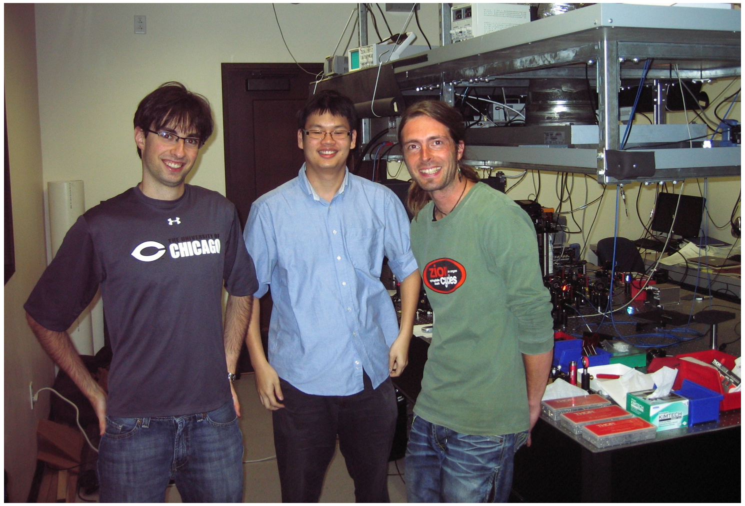
Focussed heating beam

Near term plans

Near term plans: basic thermodynamics with ion strings / crystals

- Heat flow
- Temperature distribution
- Heat capacitance
- Latent heat of crystal melting

Thaned (Hong) Pruttivarasin
Michael Ramm
Axel Kreuter



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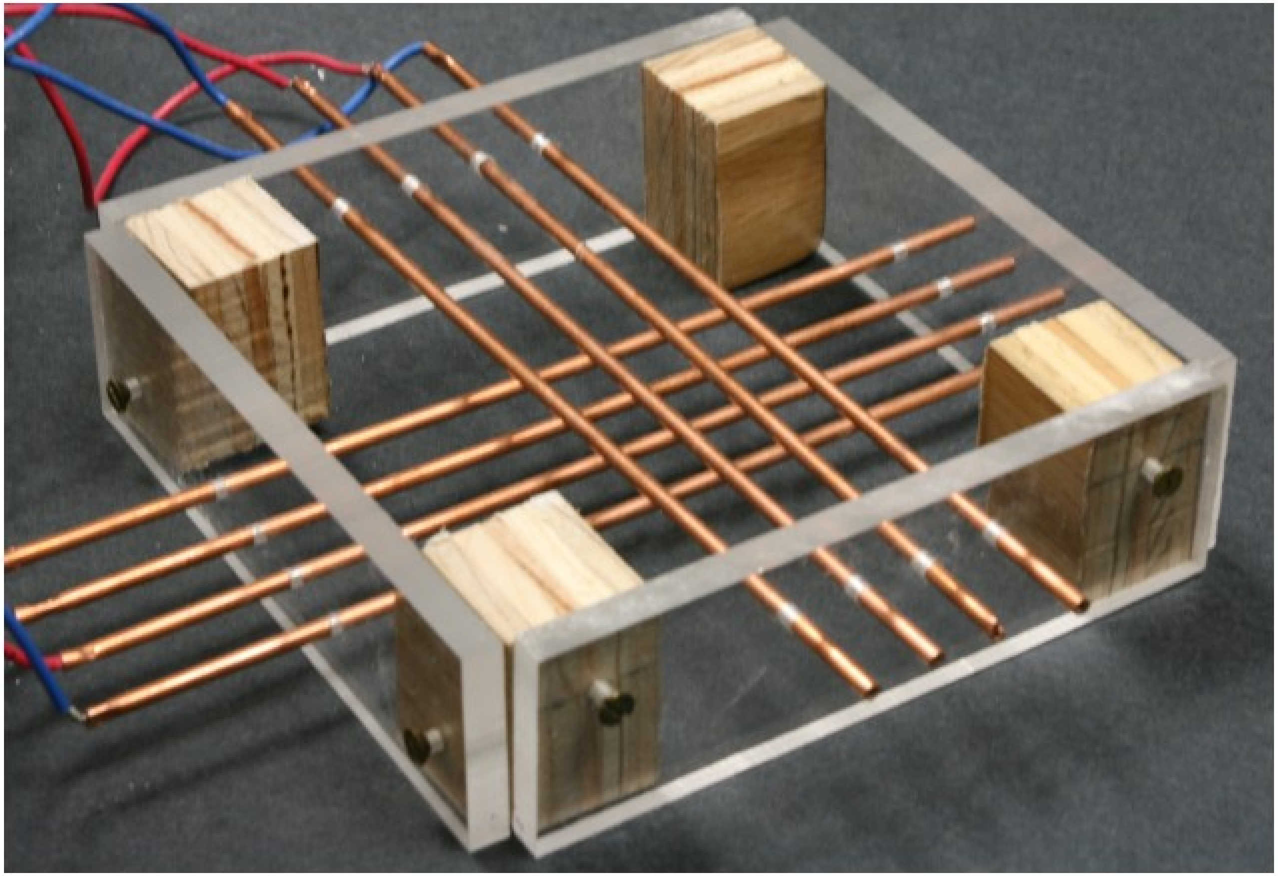
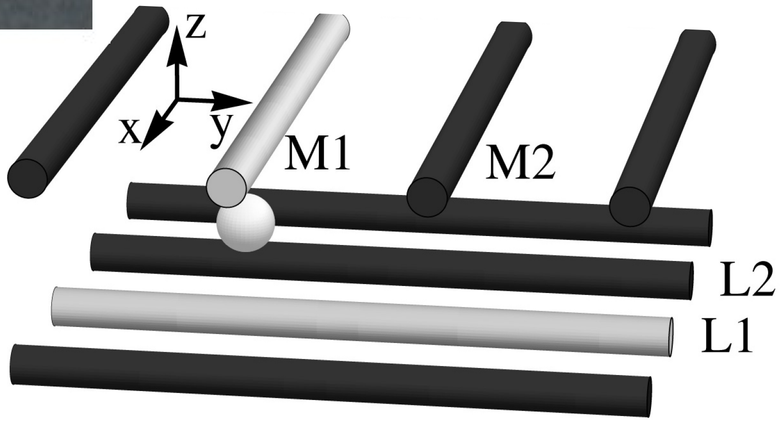
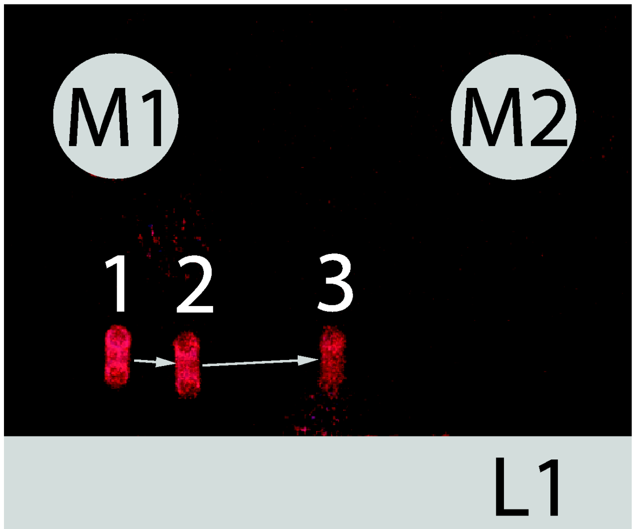
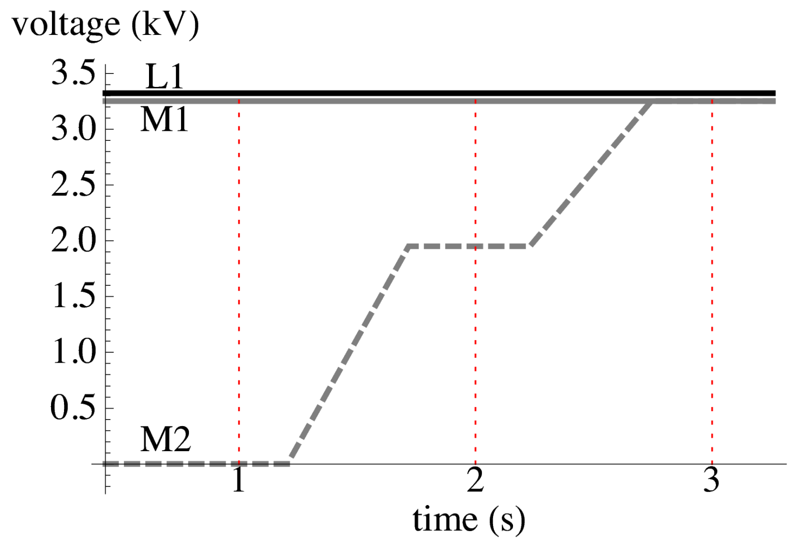
A lattice trap

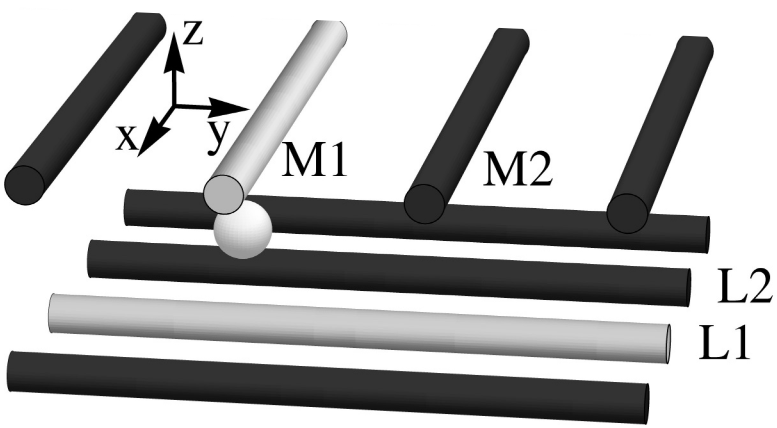




RF-transport







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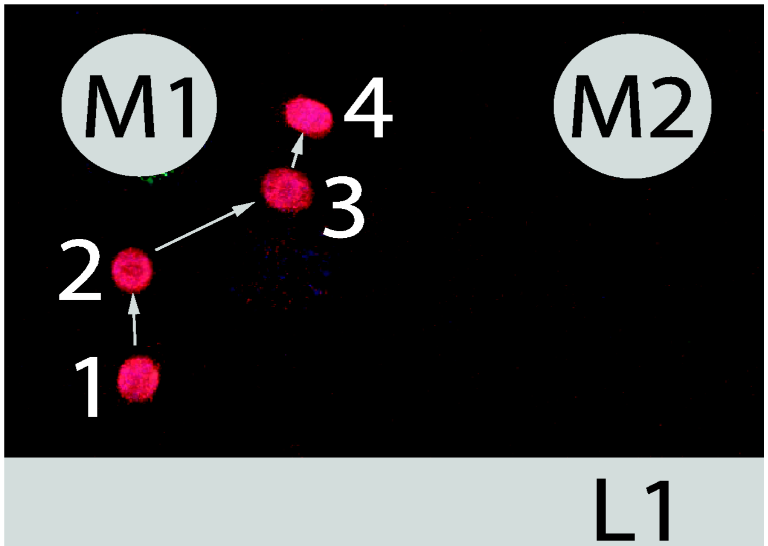
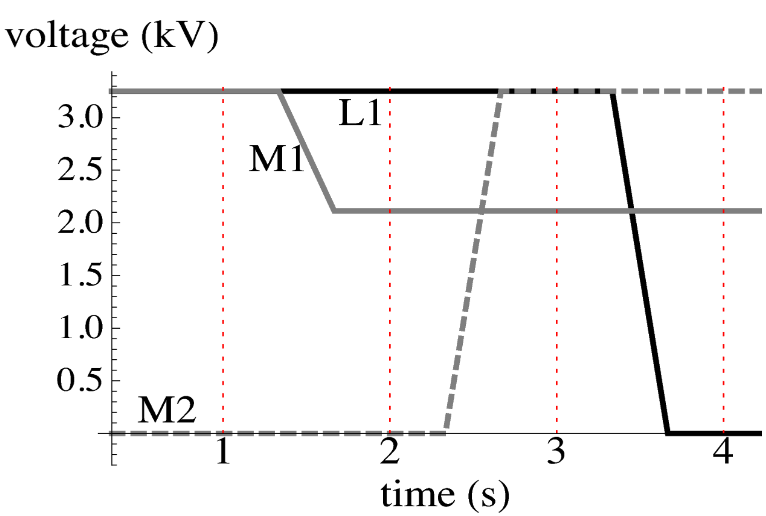
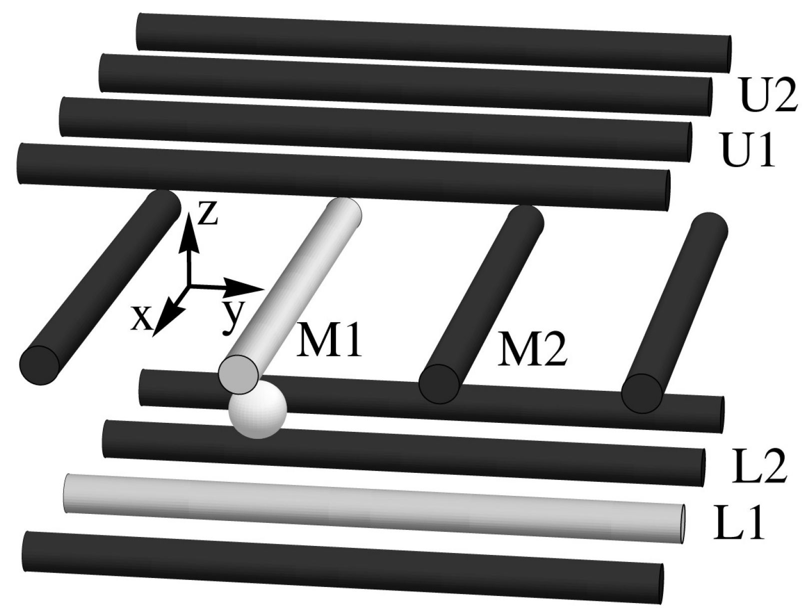
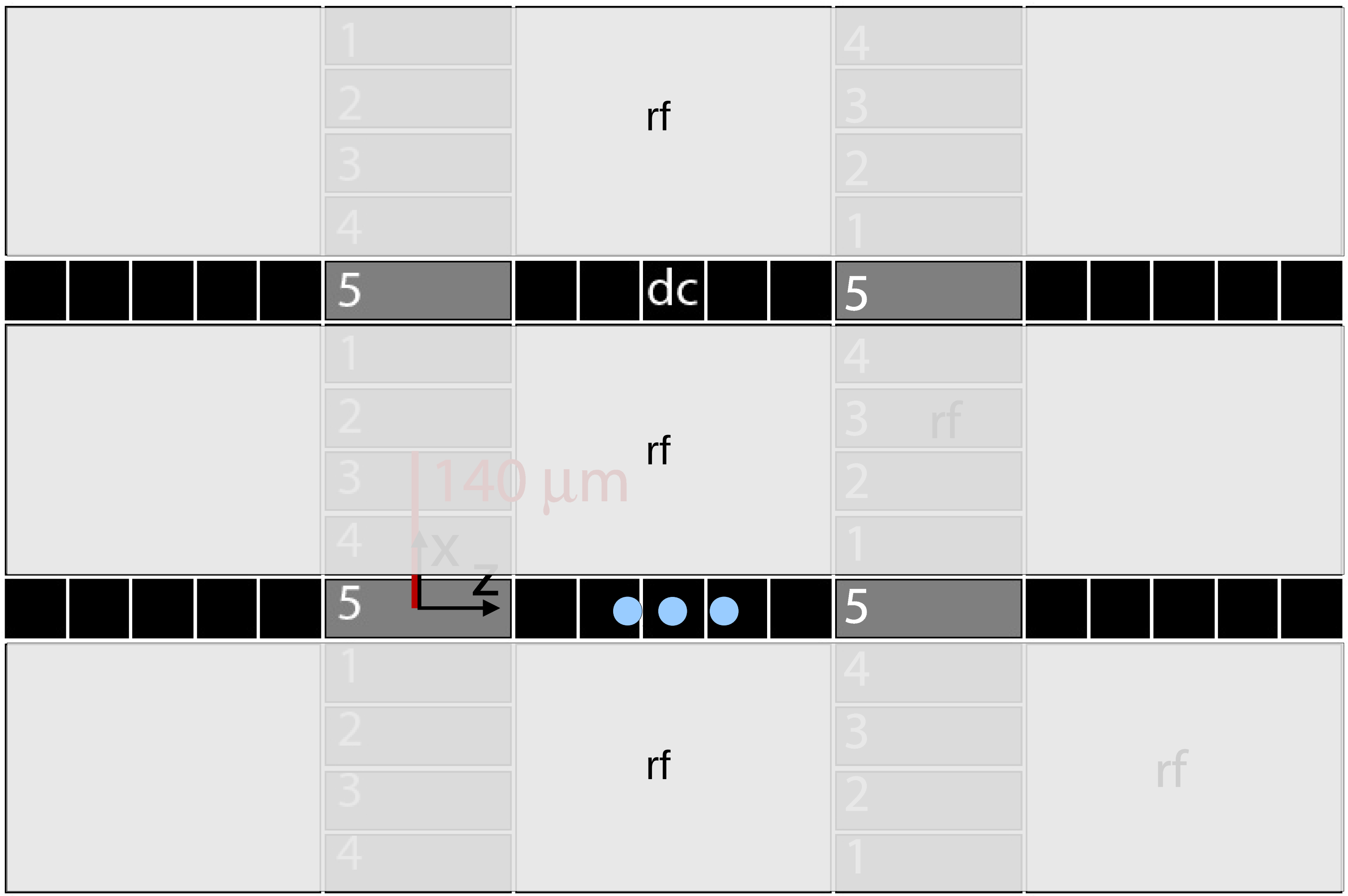






Karin et al., arXiv:1011.6116v2

Ion trap QIP proposal



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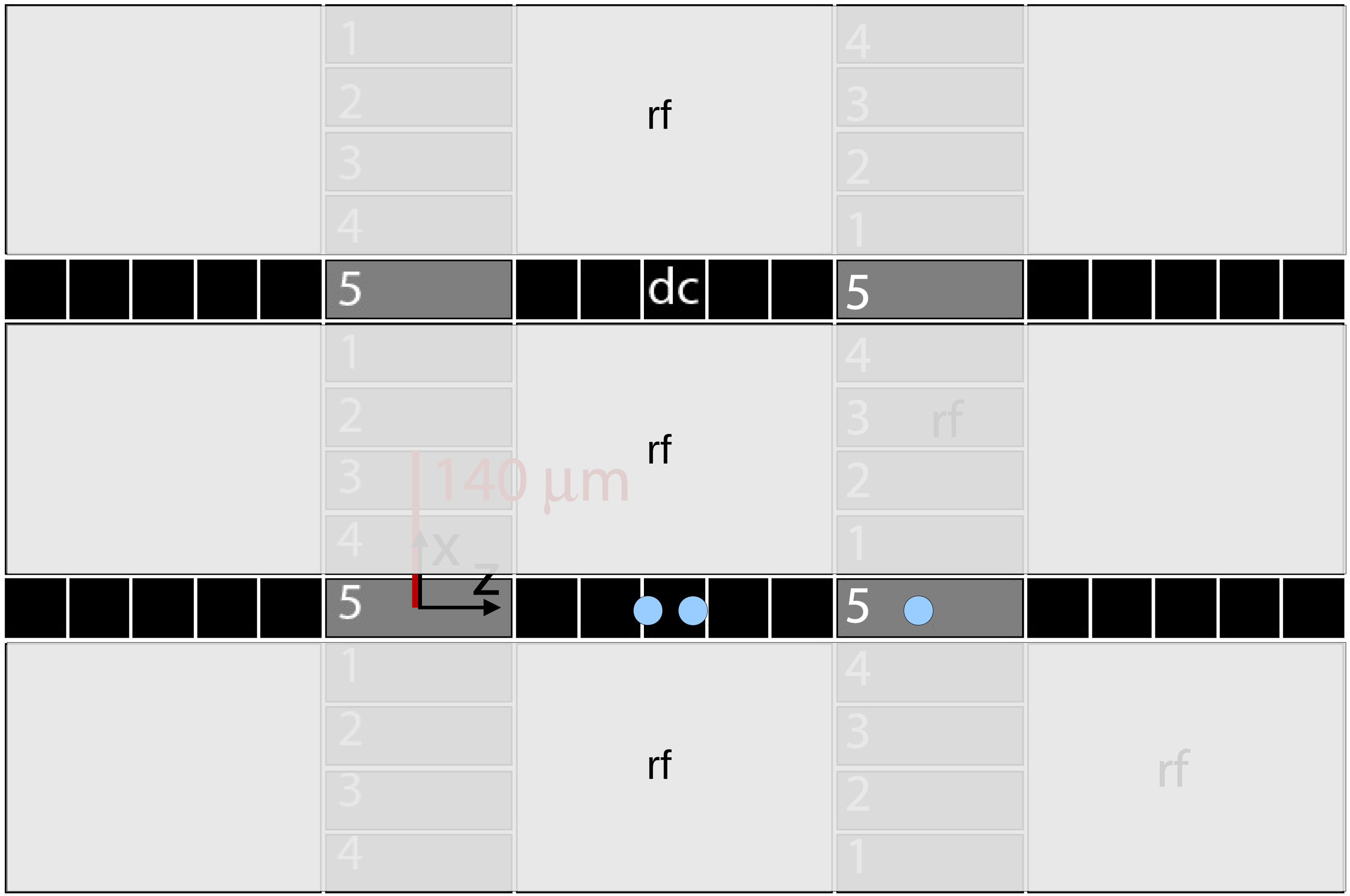

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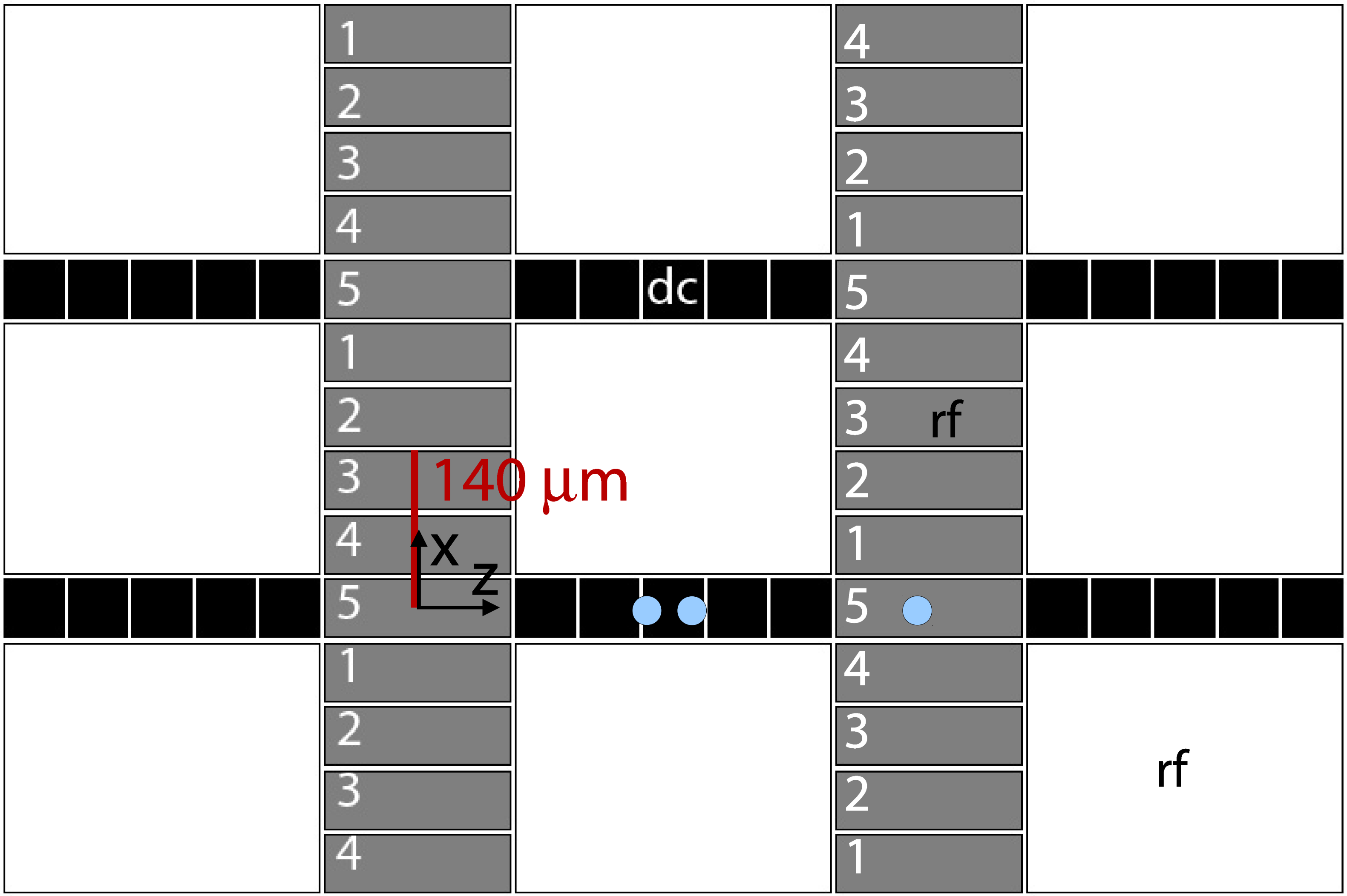
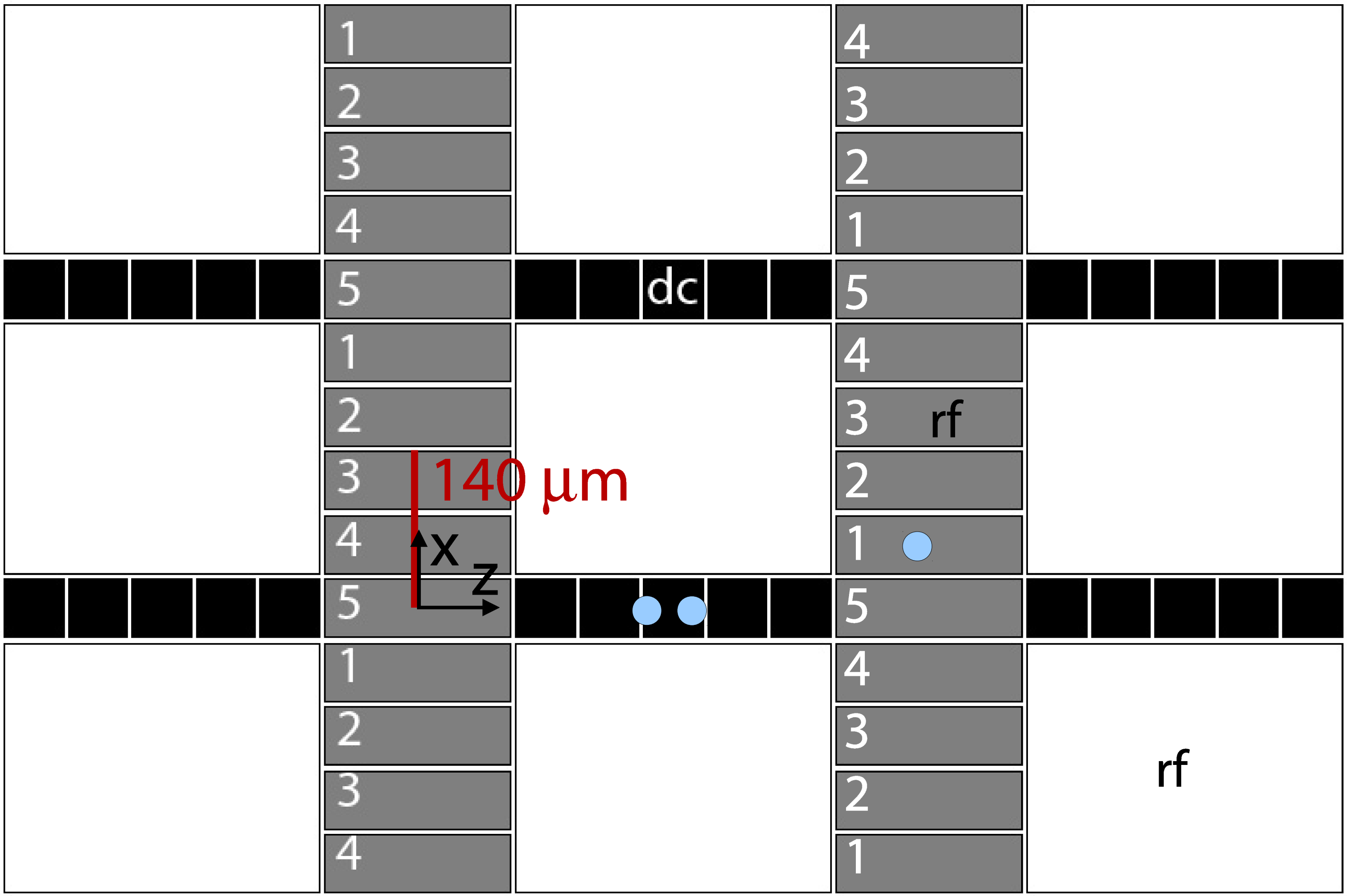


Ion trap QIP proposal

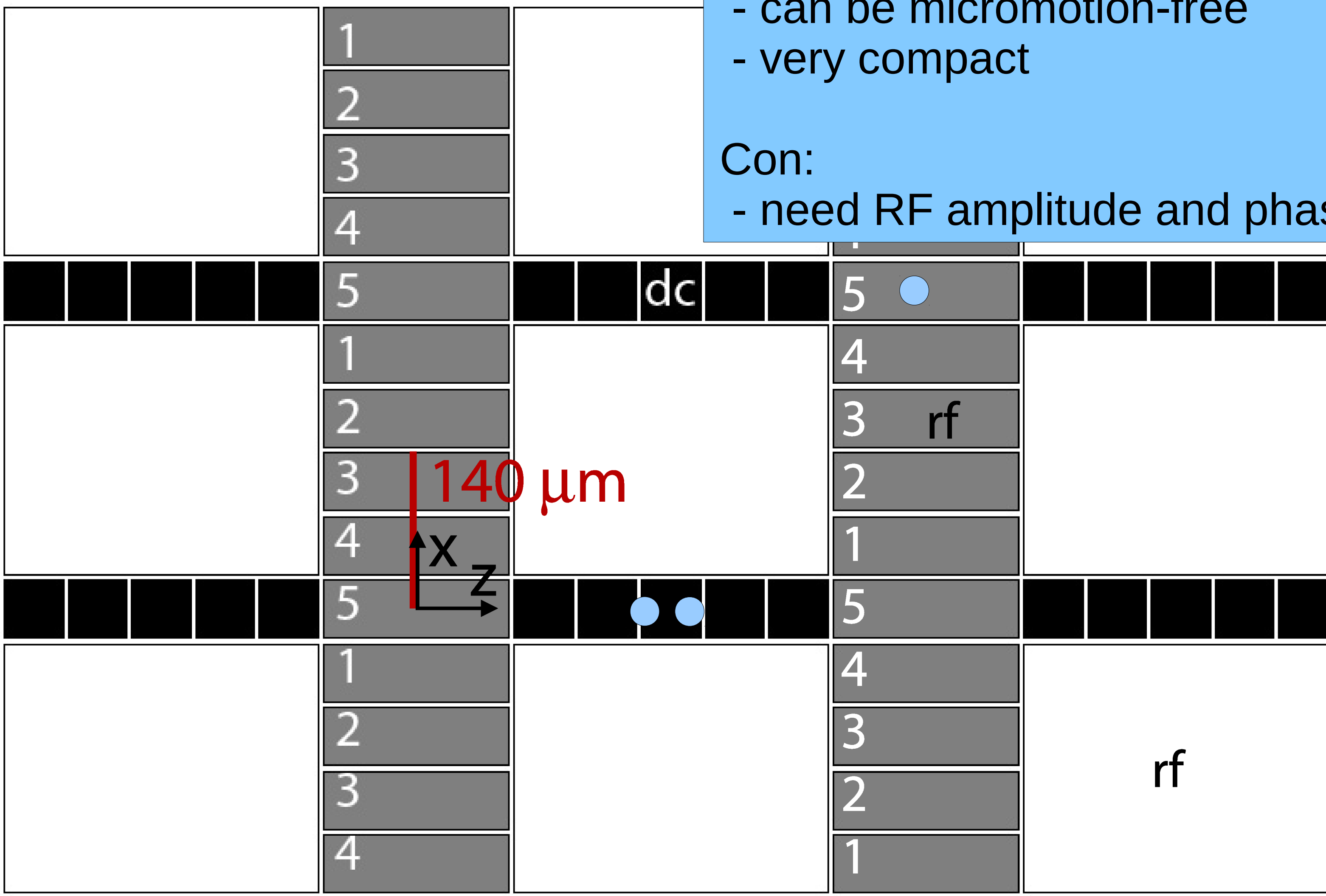


Karin et al., arXiv:1011.6116v2

Ion trap QIP proposal

Pro:
- can be micromotion-free
- very compact

Con:
- need RF amplitude and phase control



Karin et al., arXiv:1011.6116v2

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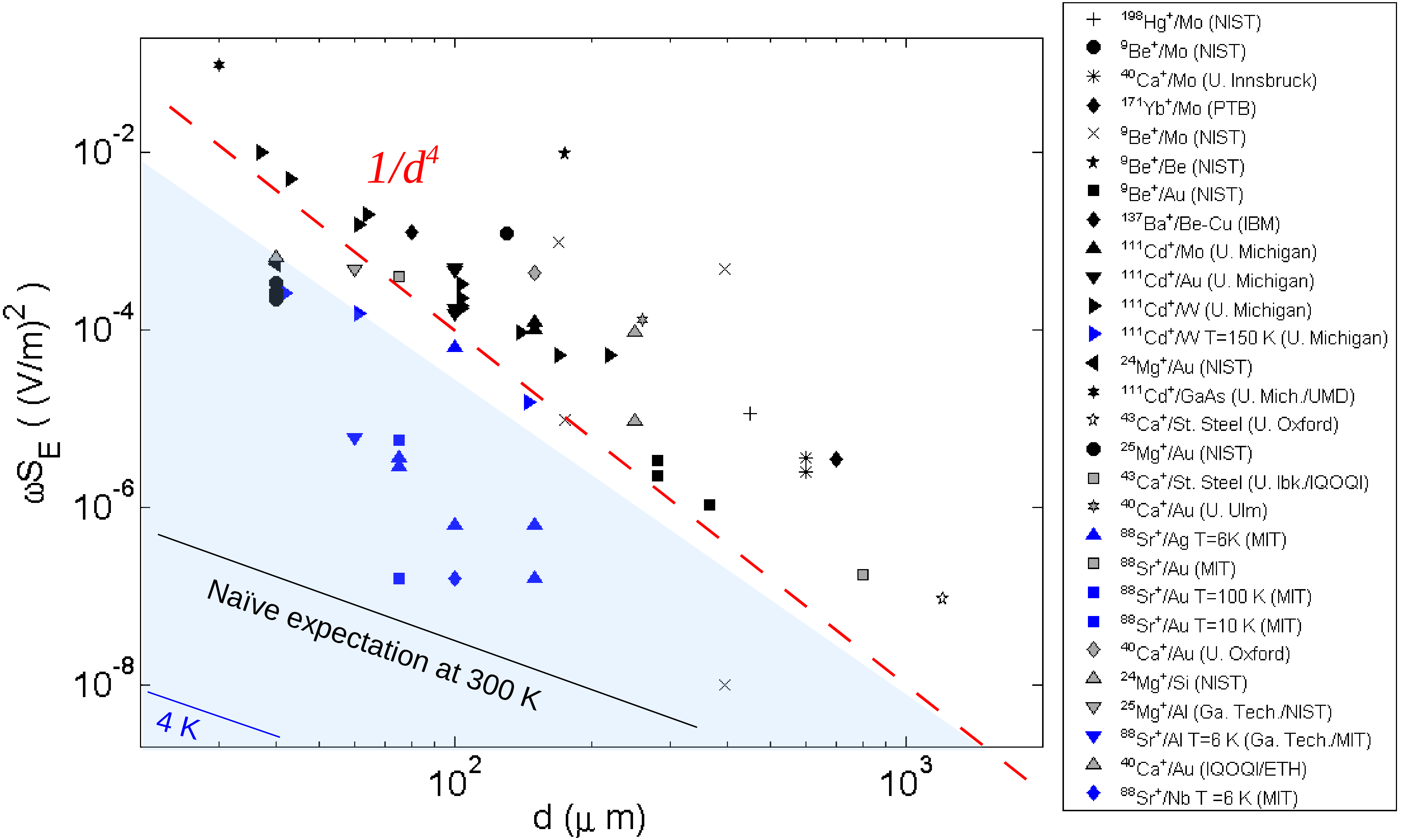
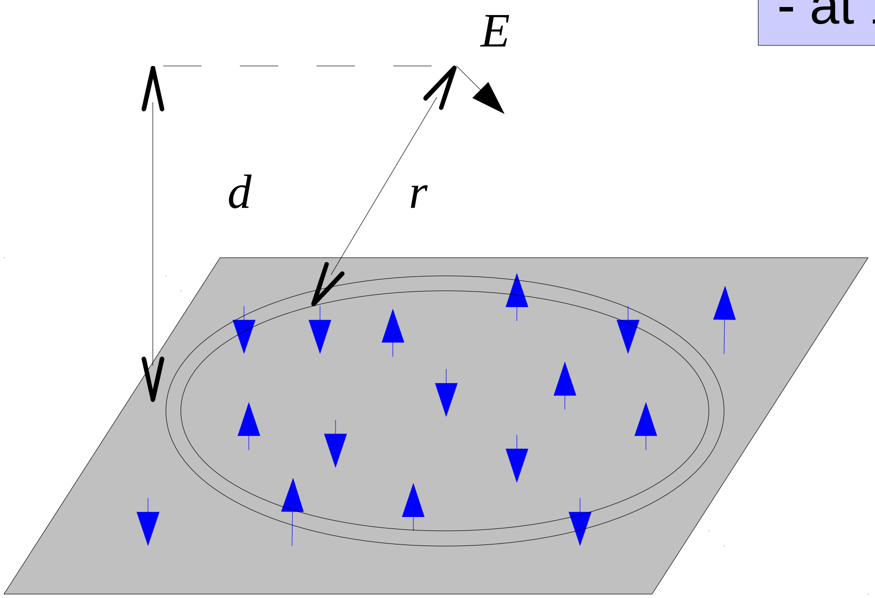
Anomalous heating



A suggestion for a heating mechanism

- no shielding from bulk metal
- one monolayer of adsorbates is sufficient!
- at 10^{-11} mbar: one monolayer / day



Sources on conducting surface produce dipole field

$$E_\mu(r) \sim \frac{\mu}{r^3}$$

Random dipole orientation

$$E_N(r) \sim \sqrt{N}\frac{\mu}{r^3}$$

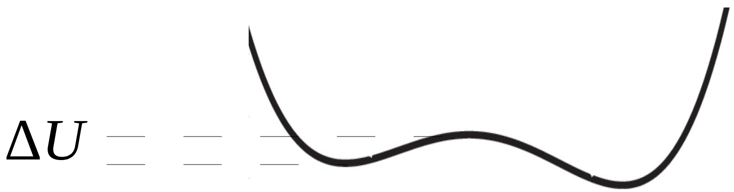
Noise spectral density over trap surface

$$S_\mathrm{E} \sim \int_\mathrm{surf} n_\mathrm{s}(r) \left(\frac{\mu}{r^3}\right)^2 S_\mu \, d\alpha \sim \frac{n_\mathrm{s}\mu^2}{d^4} S_\mu$$

Turchette *et al.*, Phys. Rev. A 61 63418 (2000)

Daniilidis *et al.*, New J. Phys. 13 013032 (2011)

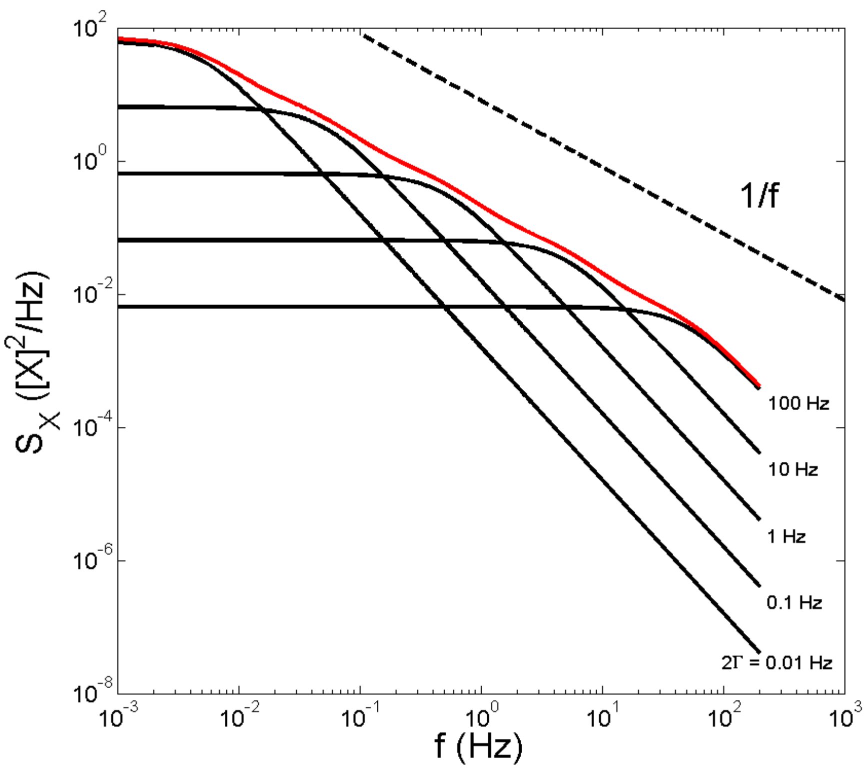
Hints from the spectrum



$$\Gamma = \omega_0 \exp(-\Delta U / k_B T)$$

Log-uniform distribution of relaxation rates

$$p(\Gamma) = \frac{\ln(\Gamma_{\max}/\Gamma_{\min})}{\Gamma}, \quad \Gamma_{\min} < \Gamma < \Gamma_{\max}$$



→ 1/f scaling

Nikos Daniliidis

Plasma surface cleaning

Repeated cleaning / annealing cycles

1. Ar^+ ion bombardment

   - Ion energy 150 eV - 2 keV

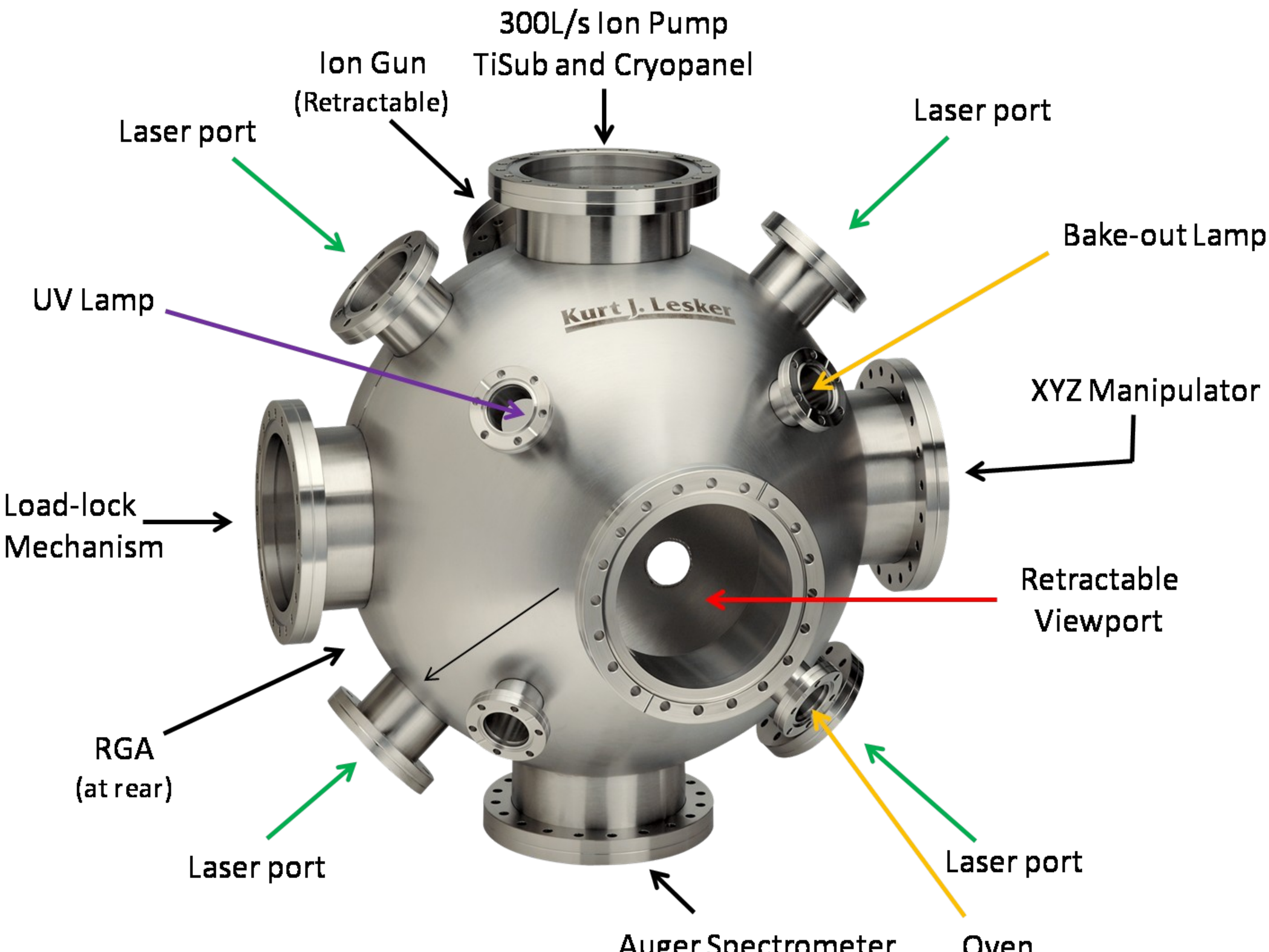
   - Beam diameter 5 mm – 20 mm

2. Anneal at 400°C – 800°C

3. Monitor surface contamination

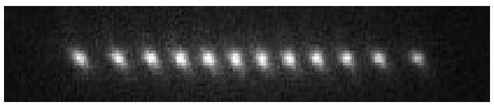
See also NIST, Dustin Hite

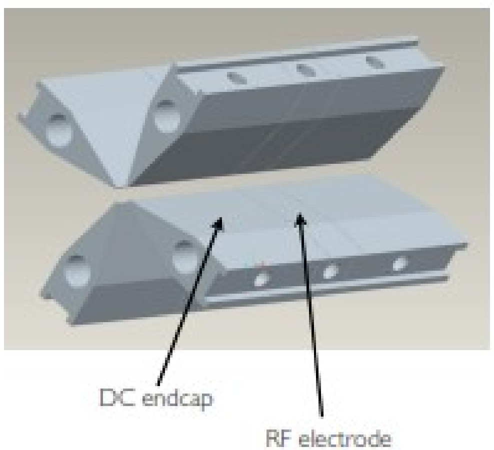
Trap testing and cleaning set-up



Conclusion

Trapped ions

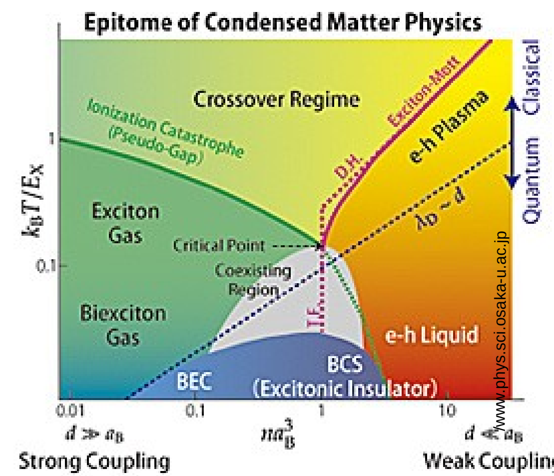




Emulation →

← Better traps

Condensed matter



- Study physics of ion crystals in microtraps
- Transport in 3D of charged particles
- Candidate mechanism for anomalous heating

People

Greg Bolloton	Sankara Narayanan
Nikos Daniliidis	Oliver Neitzke
Dylan Gorman	Thaned (Hong) Pruttivarasin
Axel Kreuter	Christopher Reilly
Gebhard Littich	Michael Ramm
Sönke Möller	Ishan Taludkar