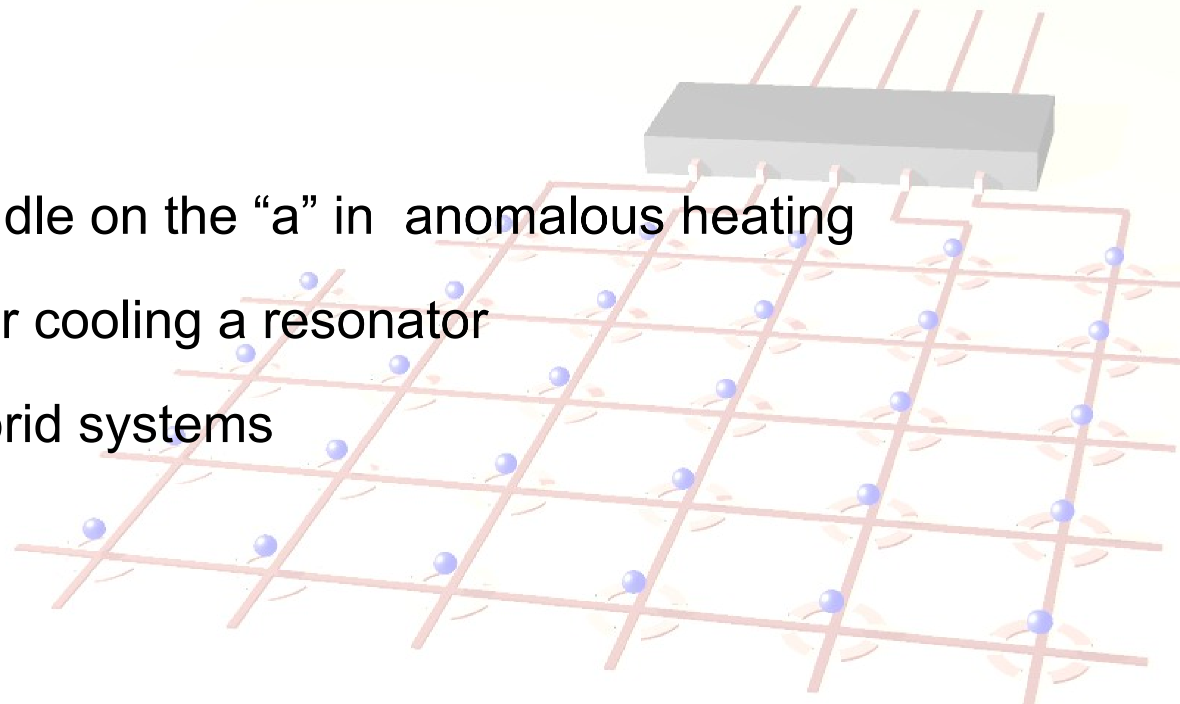
Ions interacting with trap electrodes

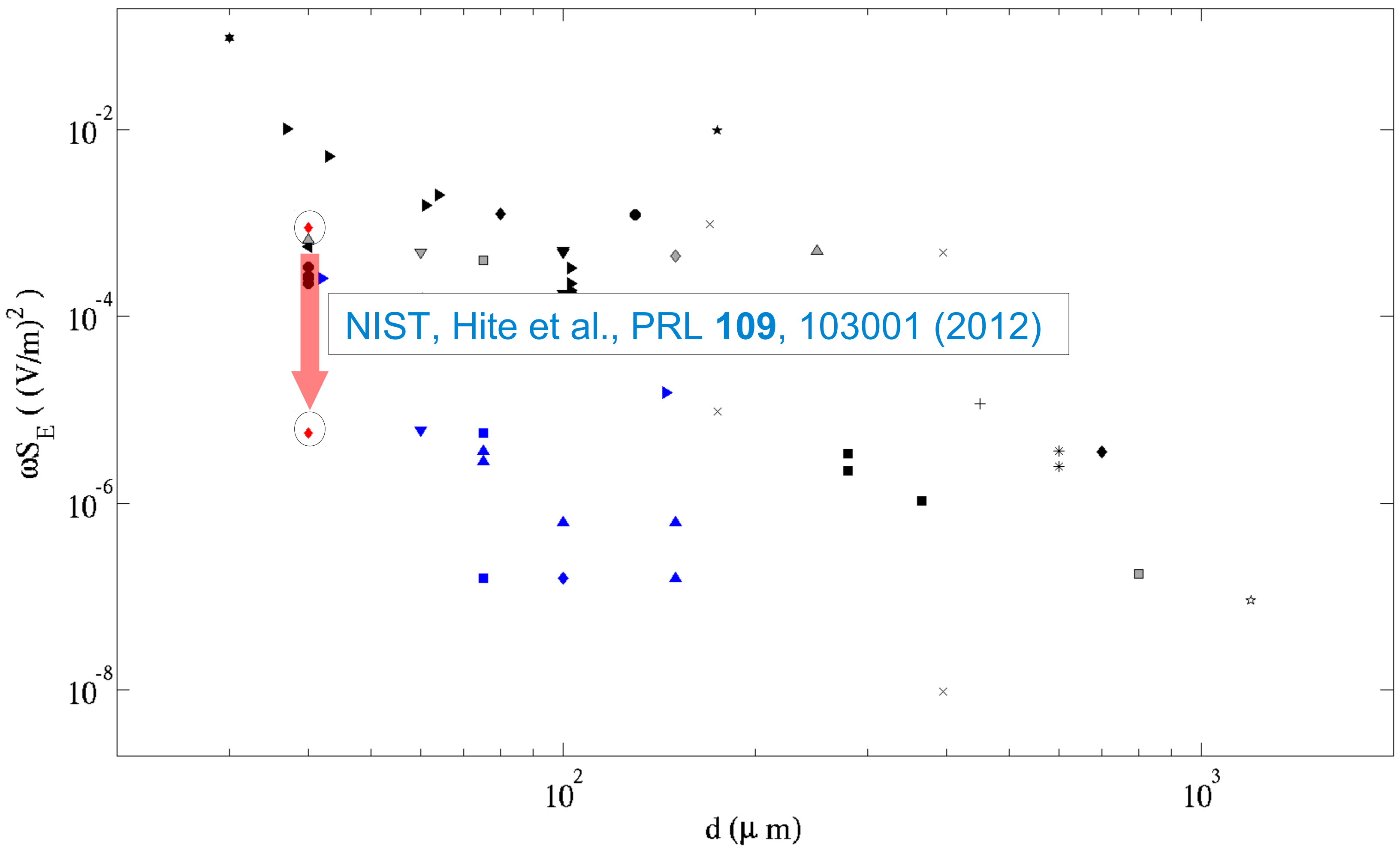
Hartmut Häffner

Department of Physics, University of California, Berkeley, USA

- Introduction
- Getting a handle on the “a” in anomalous heating
- Towards laser cooling a resonator
- Quantum hybrid systems
- Conclusions



Heating rates



Plasma surface cleaning

Repeated cleaning / annealing cycles

1. Ar^+ ion bombardment

   - Ion energy 150 eV - 2 keV

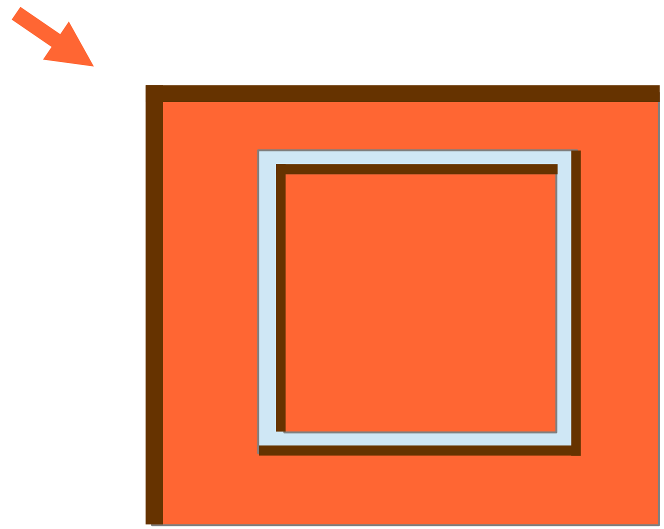
   - Beam diameter 5 mm – 20 mm

2. Anneal at 400°C – 1000°C

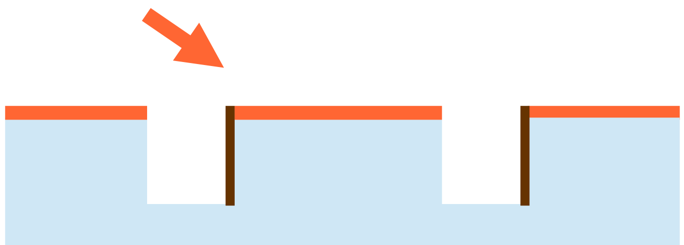
3. Monitor surface contamination

Fabrication of robust traps

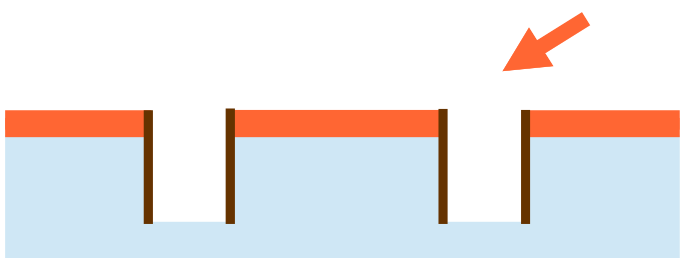
Fabrication of robust traps

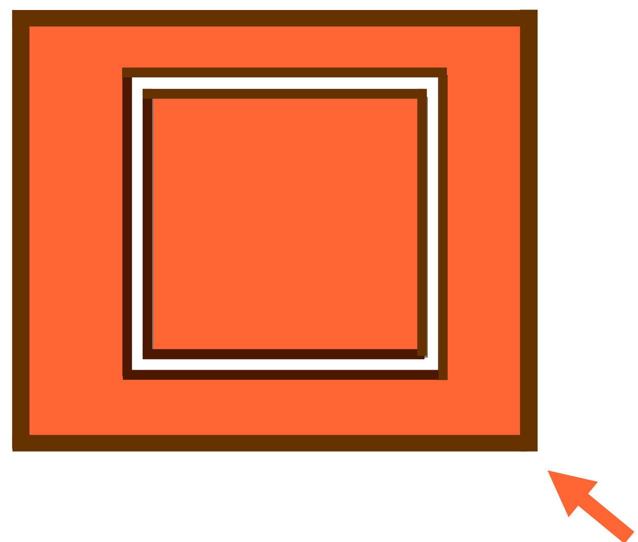


Step 1: evaporate diagonally



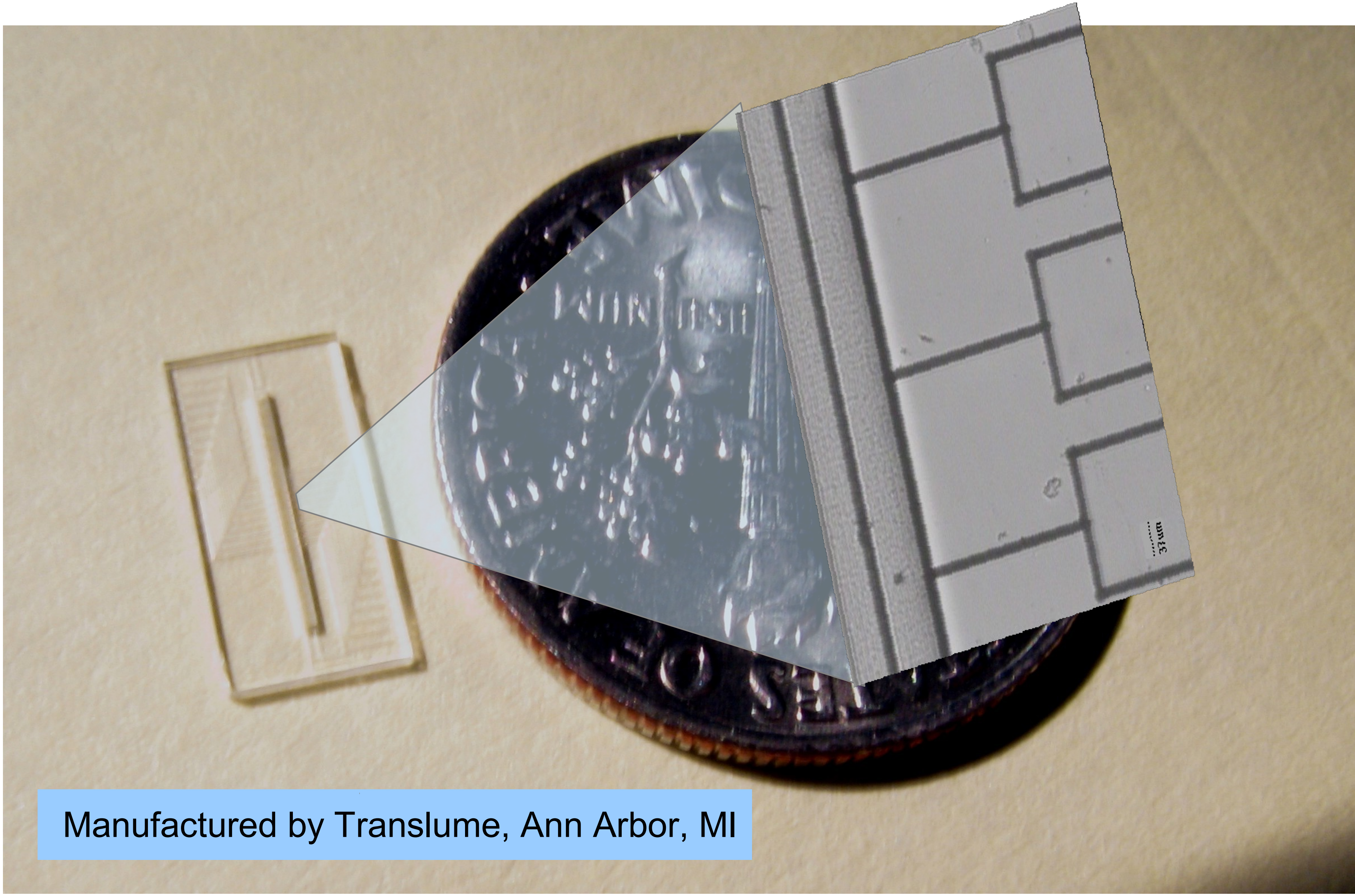
Step 2: evaporate from opposite side





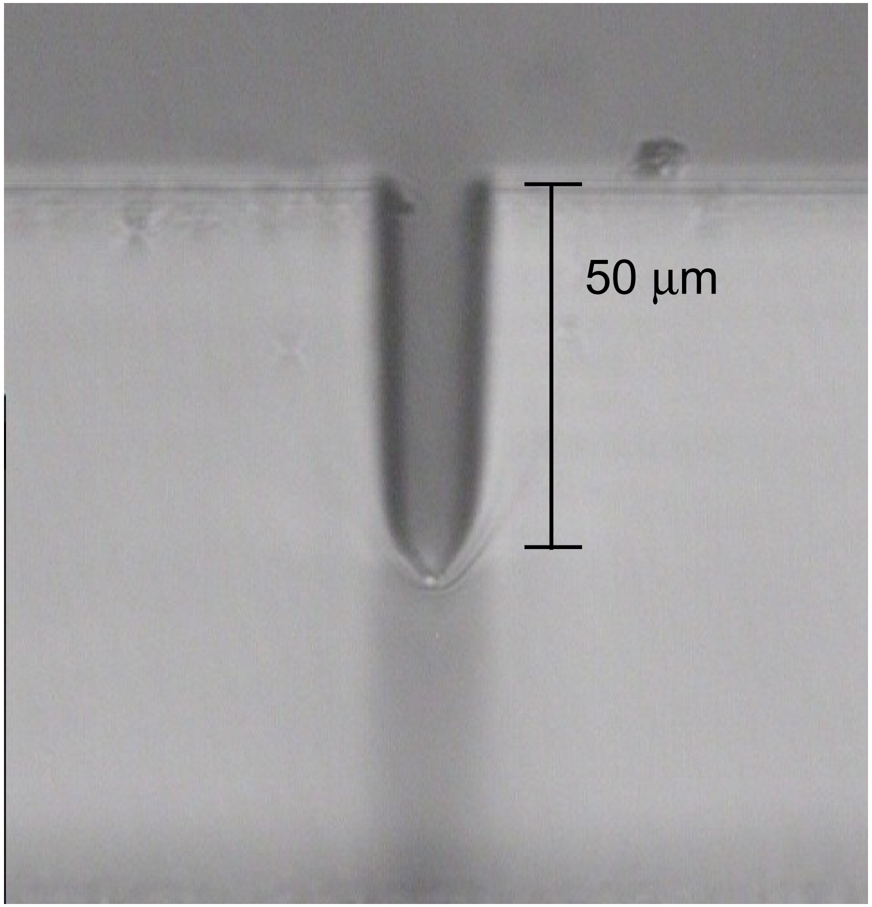
Advantages: robust, flexible materials choice, high quality films, large aspect ratio

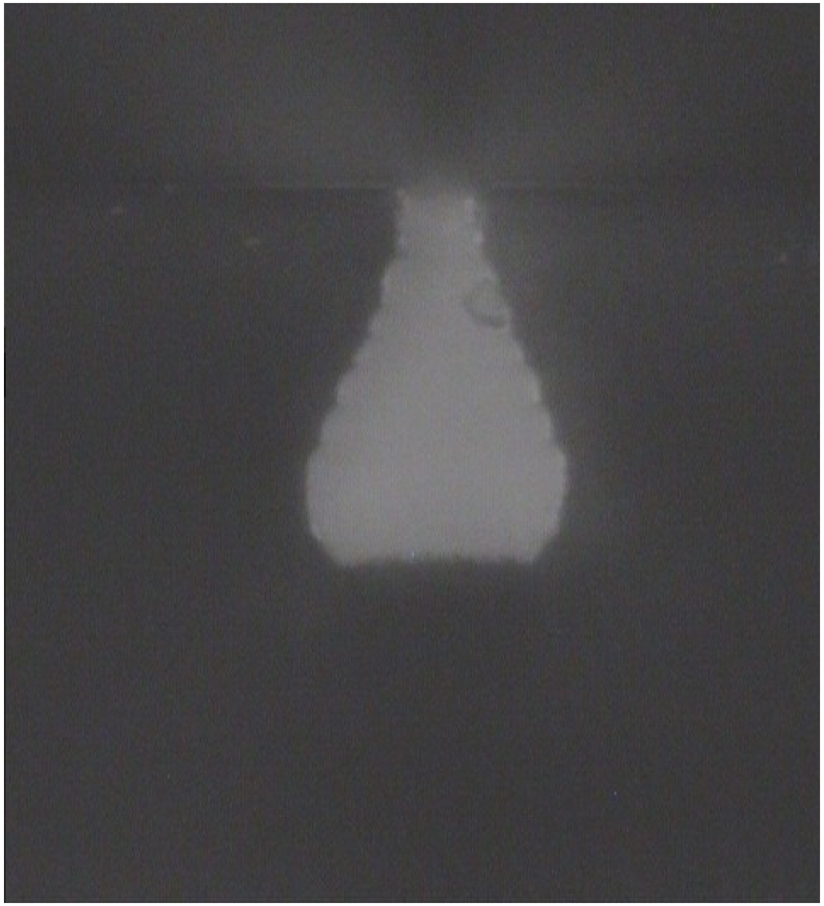
Planar trap substrate with slit

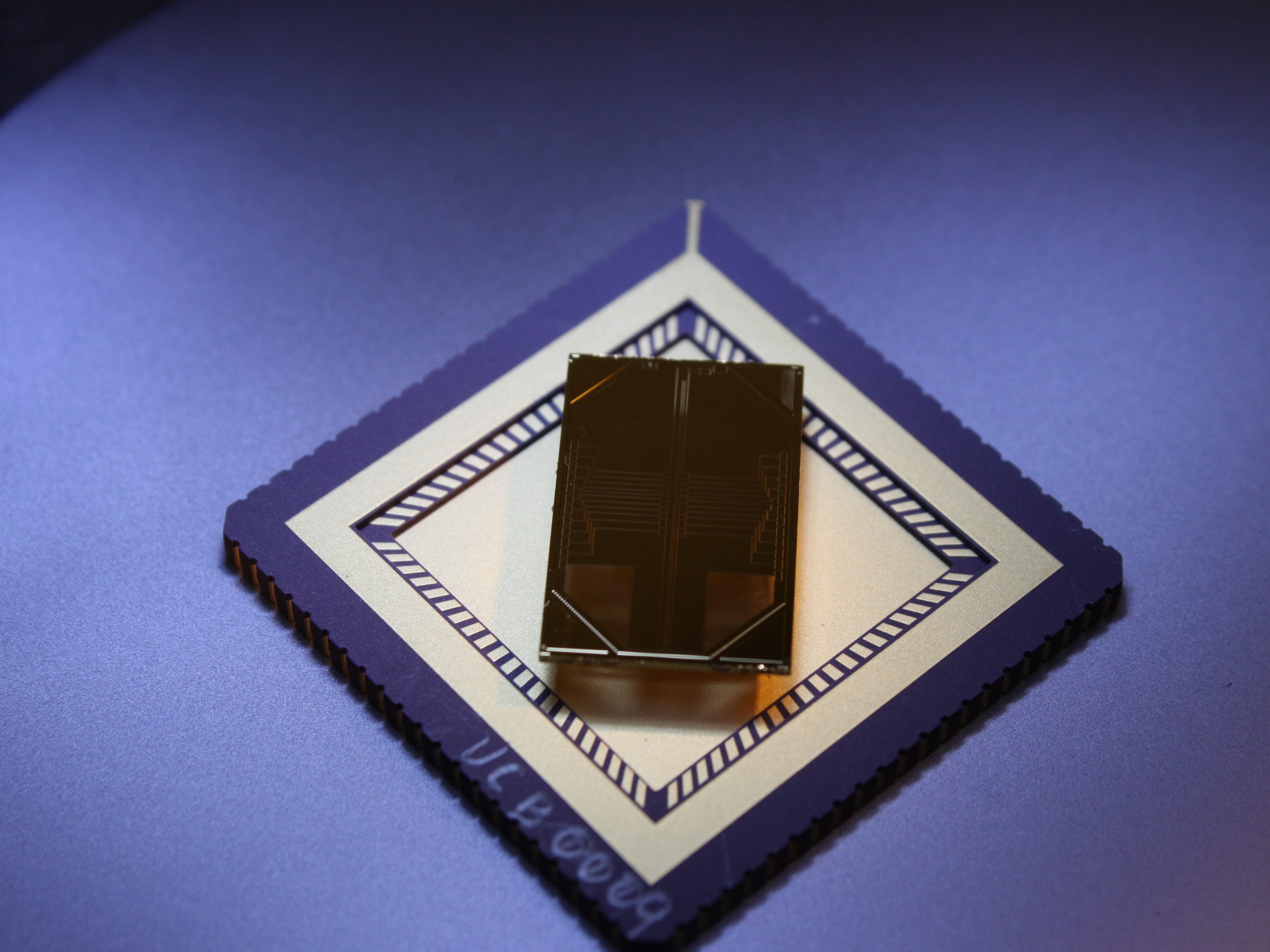


Manufactured by Translume, Ann Arbor, MI

Planar trap substrate with slit



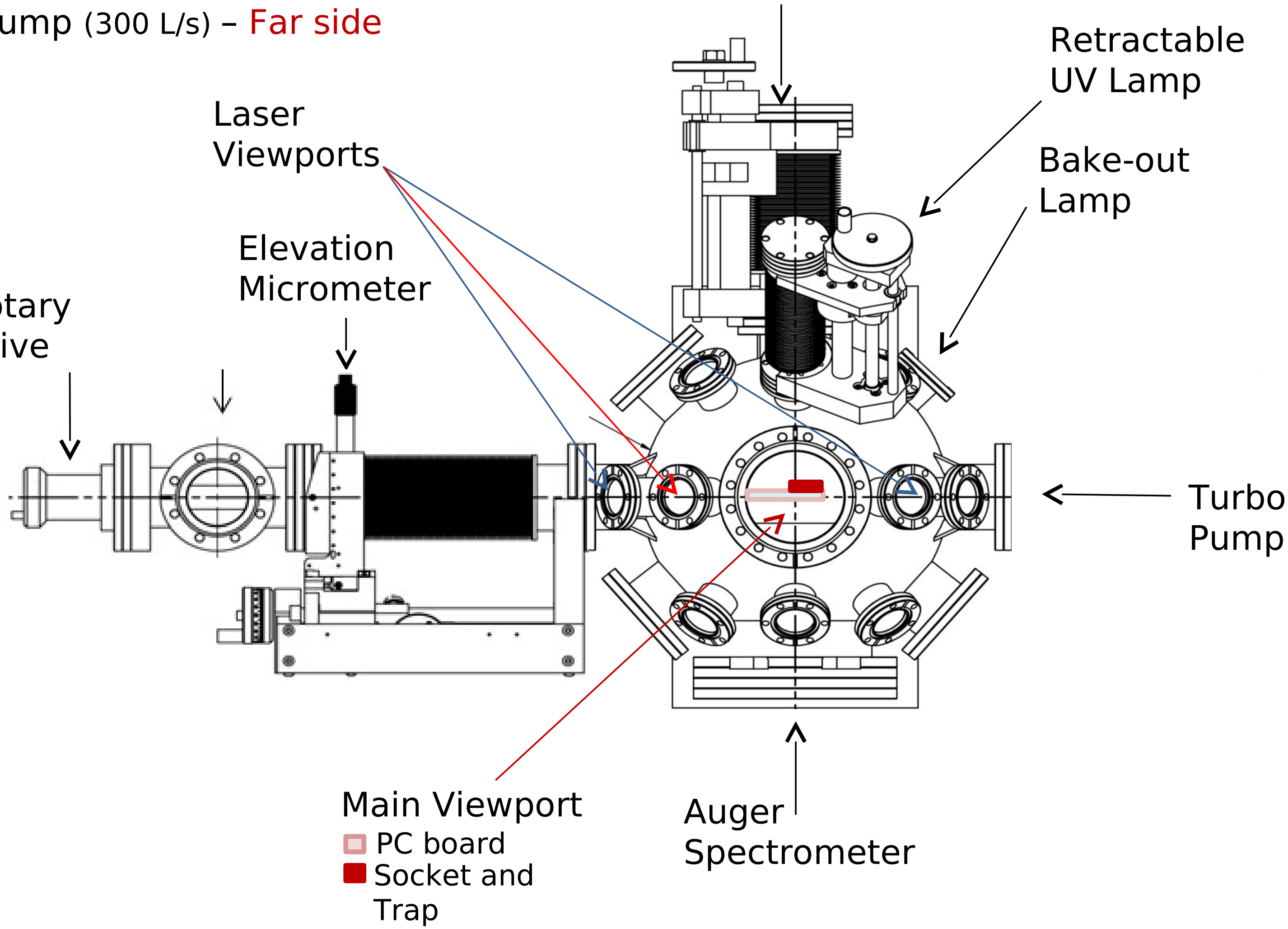




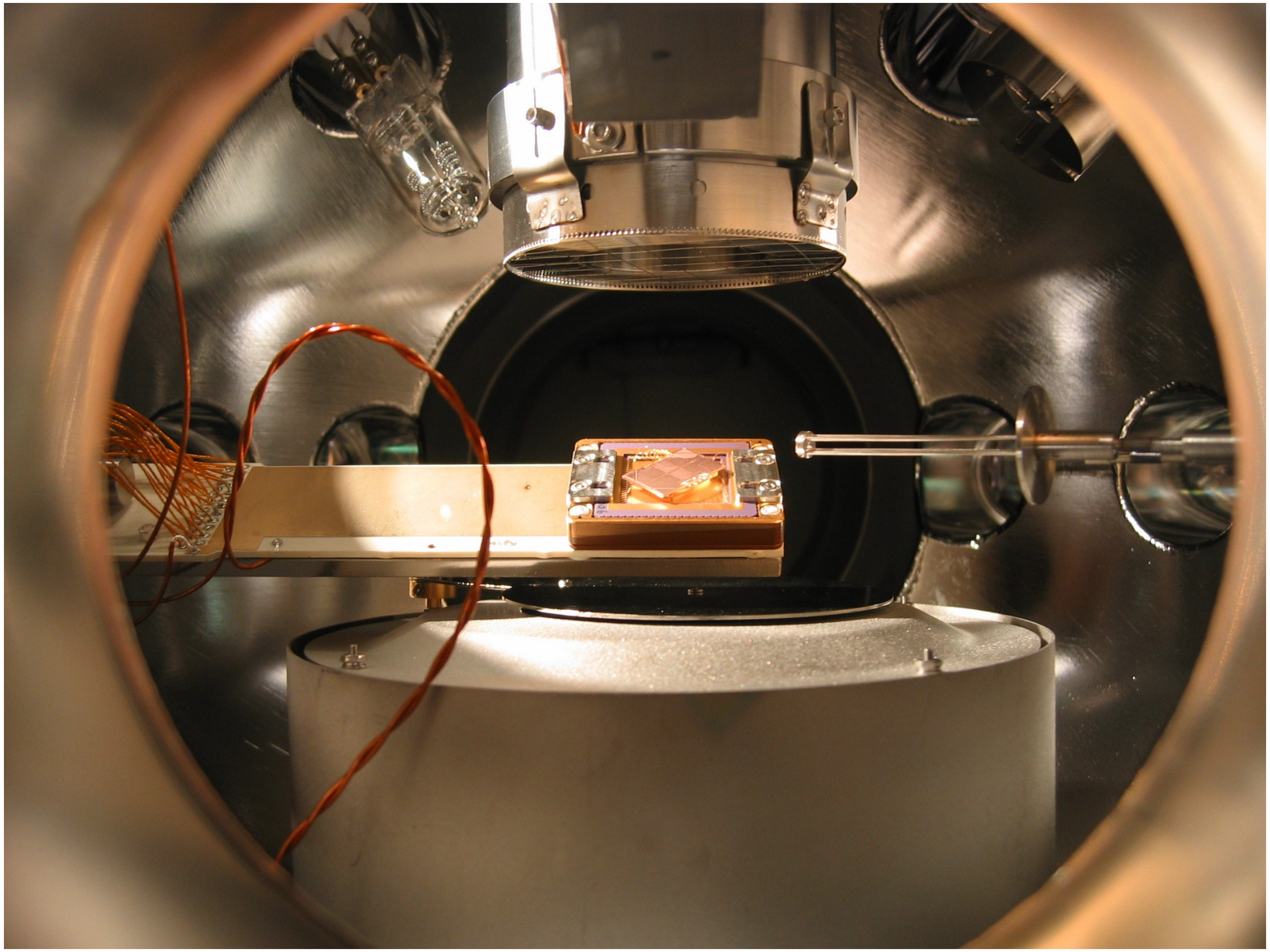
Surface science set-up

<u>Not Shown</u>

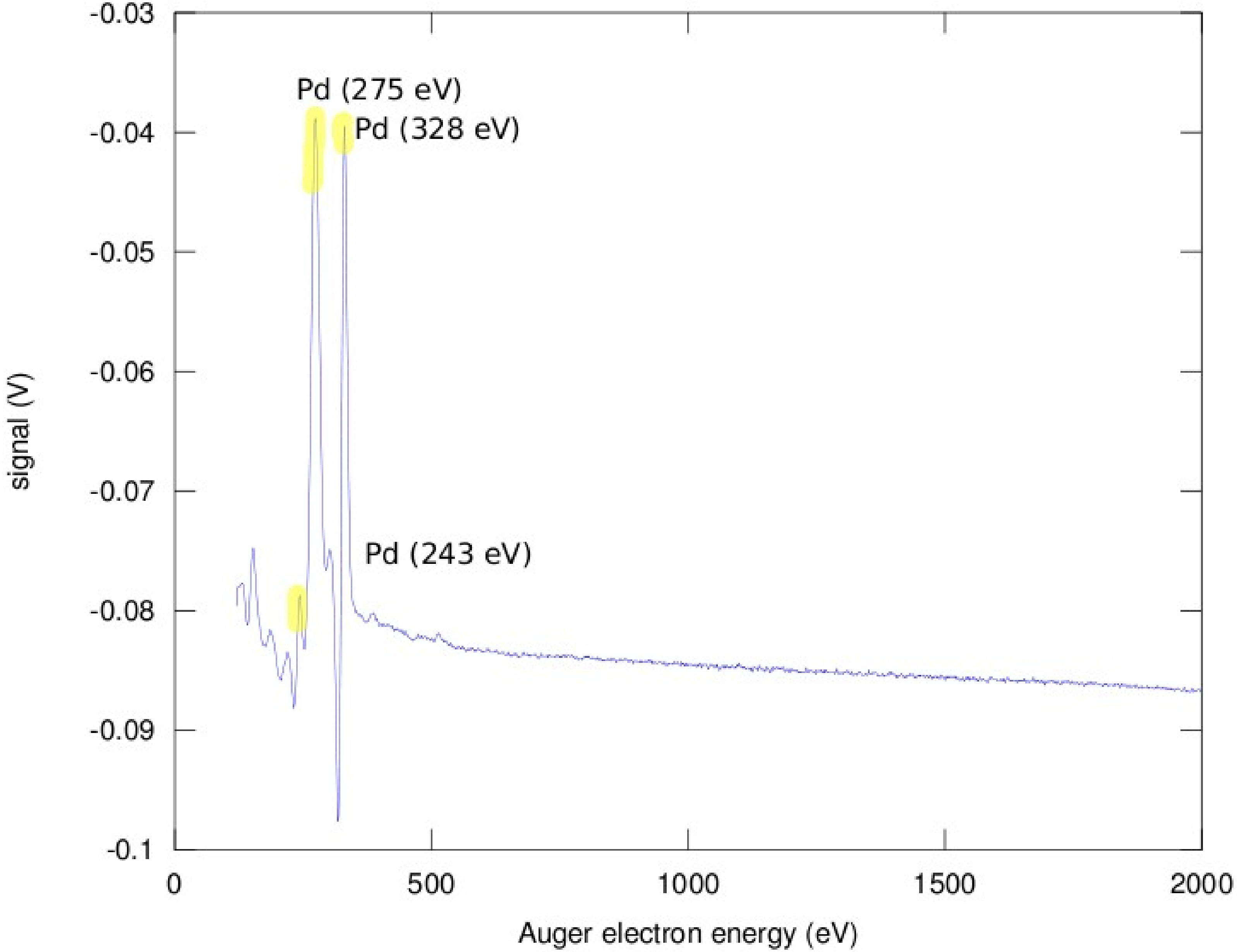
Retractable Ion Gun - Far side
Ion Pump (300 L/s) – Far side



Surface chamber set-up

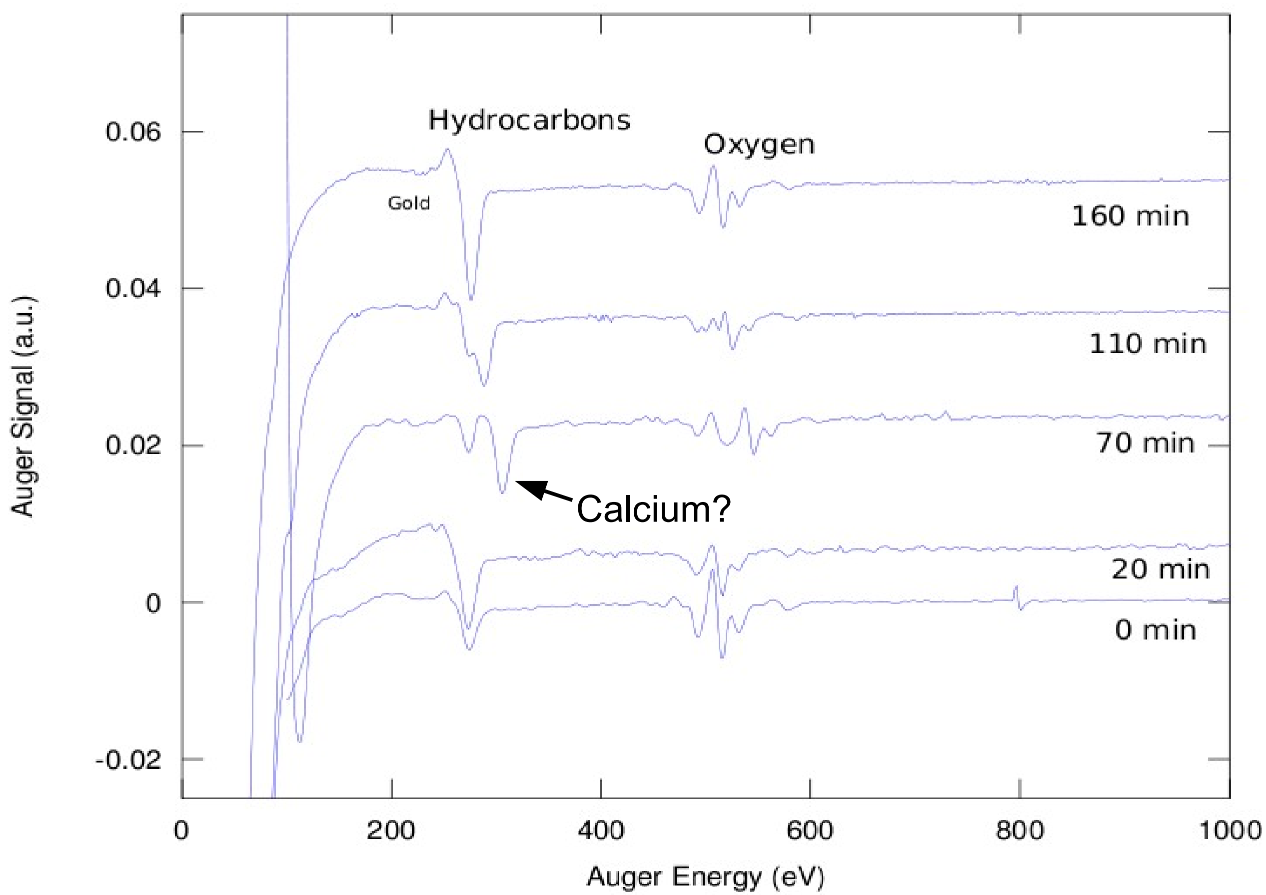


Auger spectroscopy

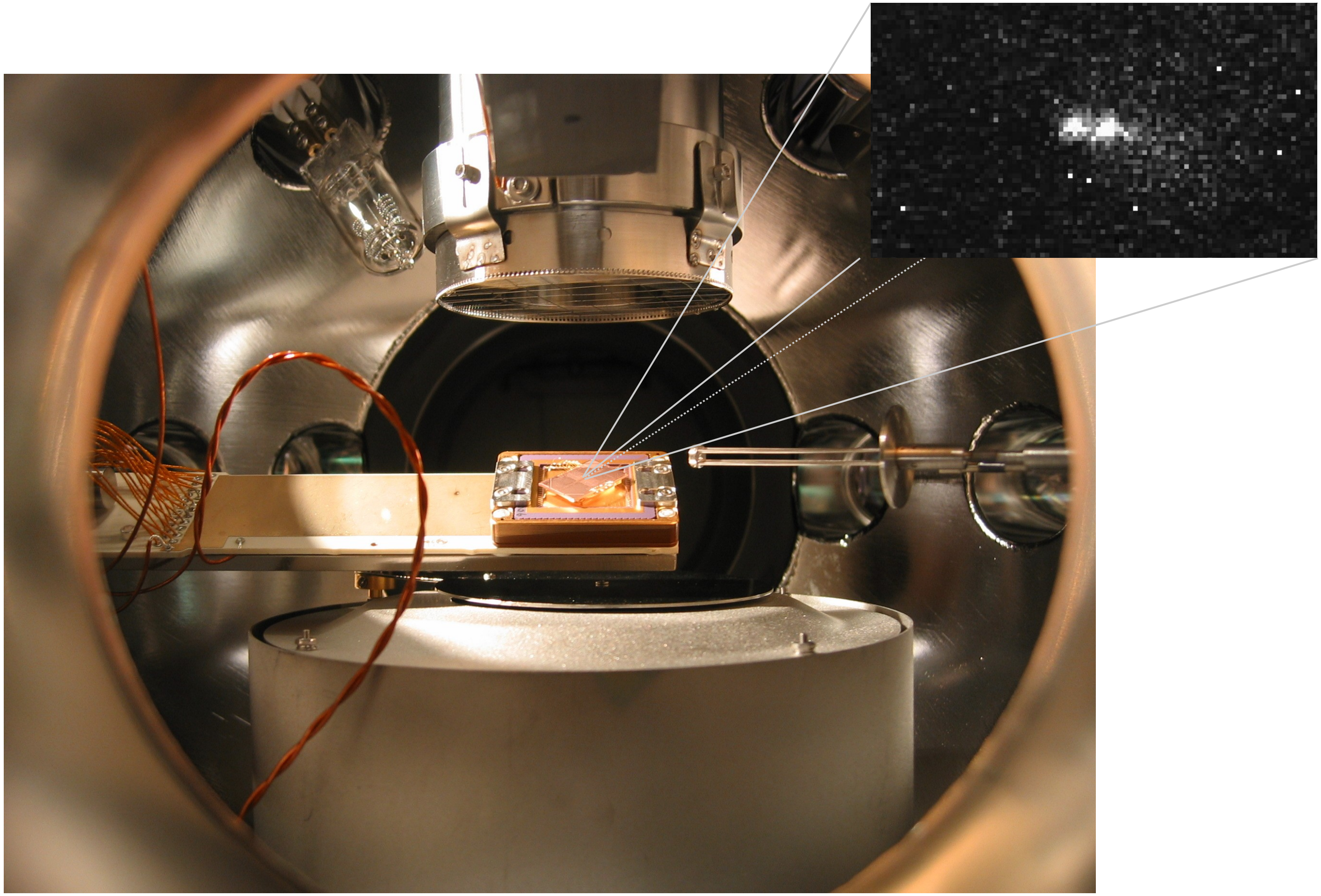


UV induced surface dynamics

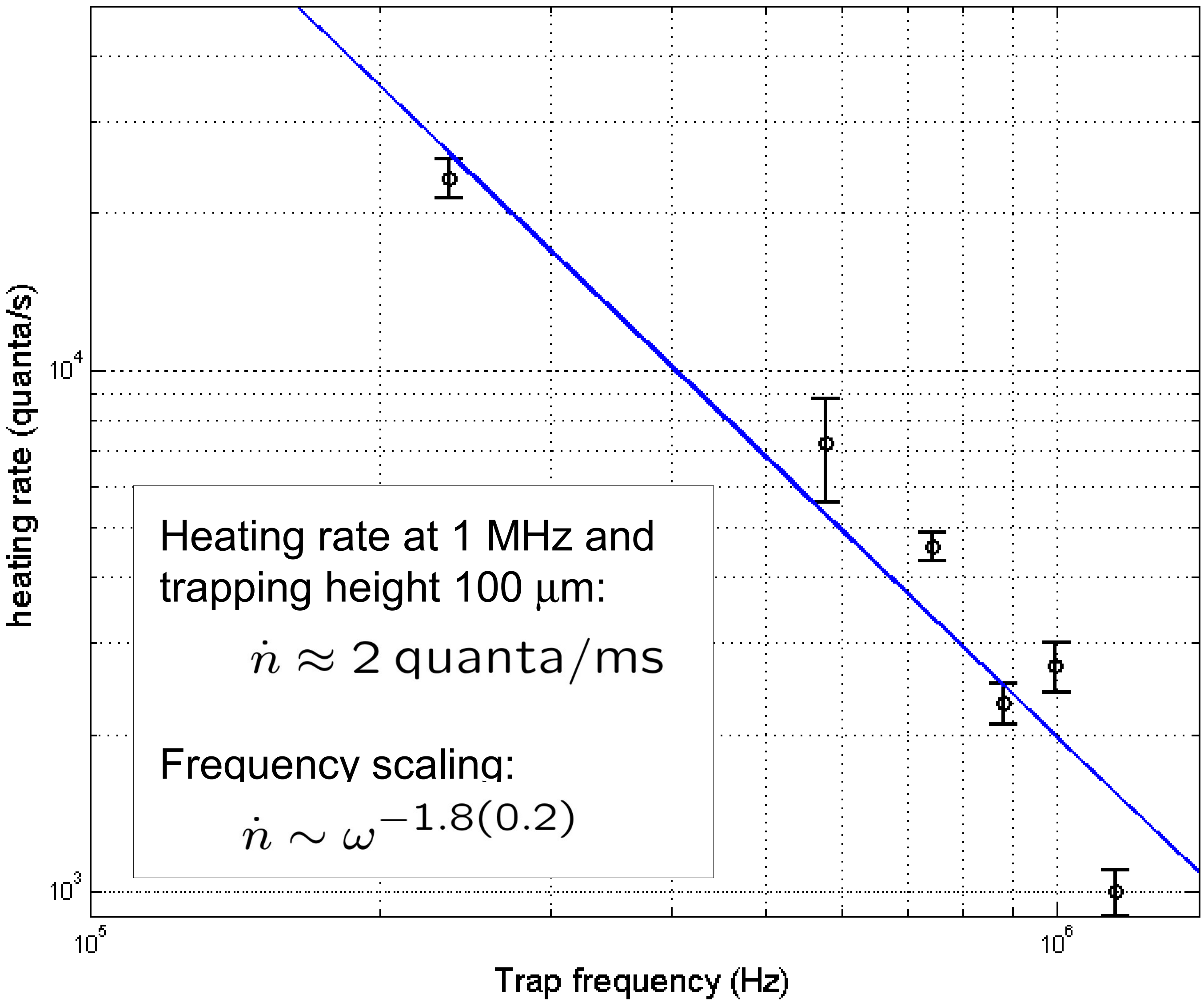
UV light dose (172 nm)



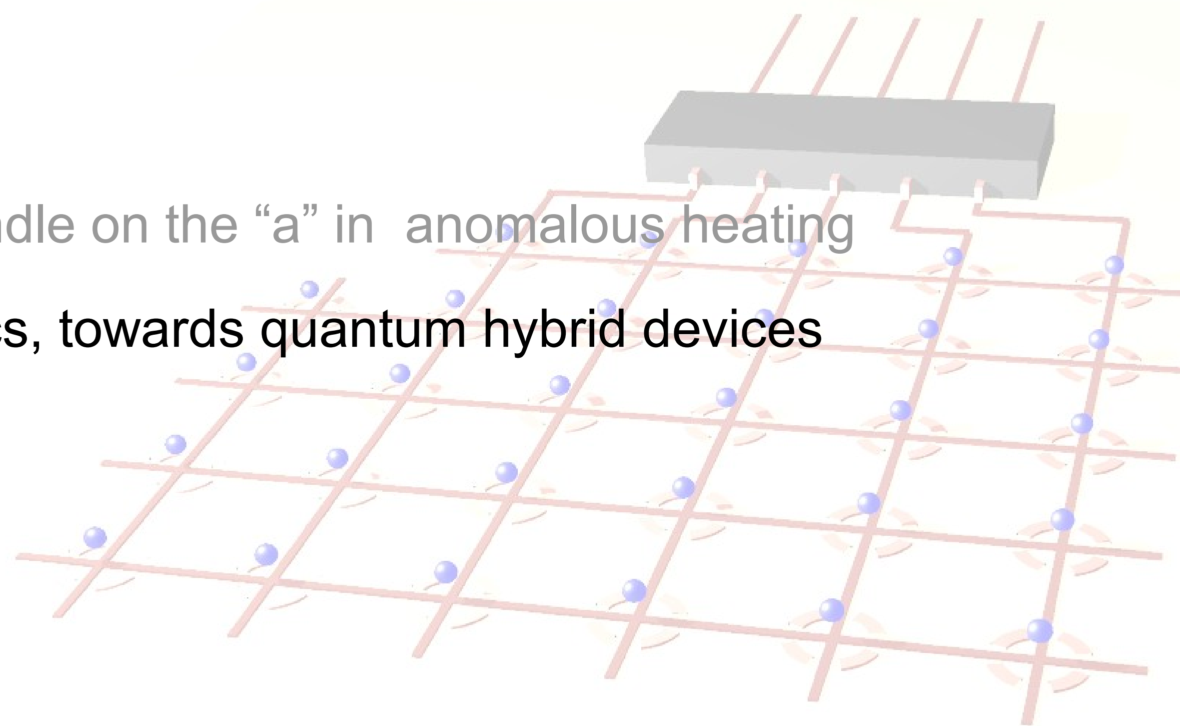
Ions in a surface science chamber



Heating rate scaling with frequency



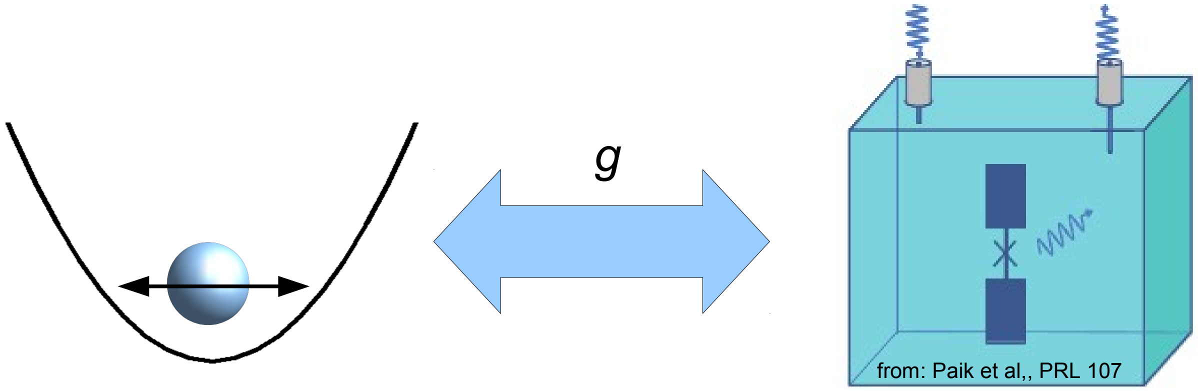
- Introduction
- Getting a handle on the “a” in anomalous heating
- Ion electronics, towards quantum hybrid devices
- Conclusions



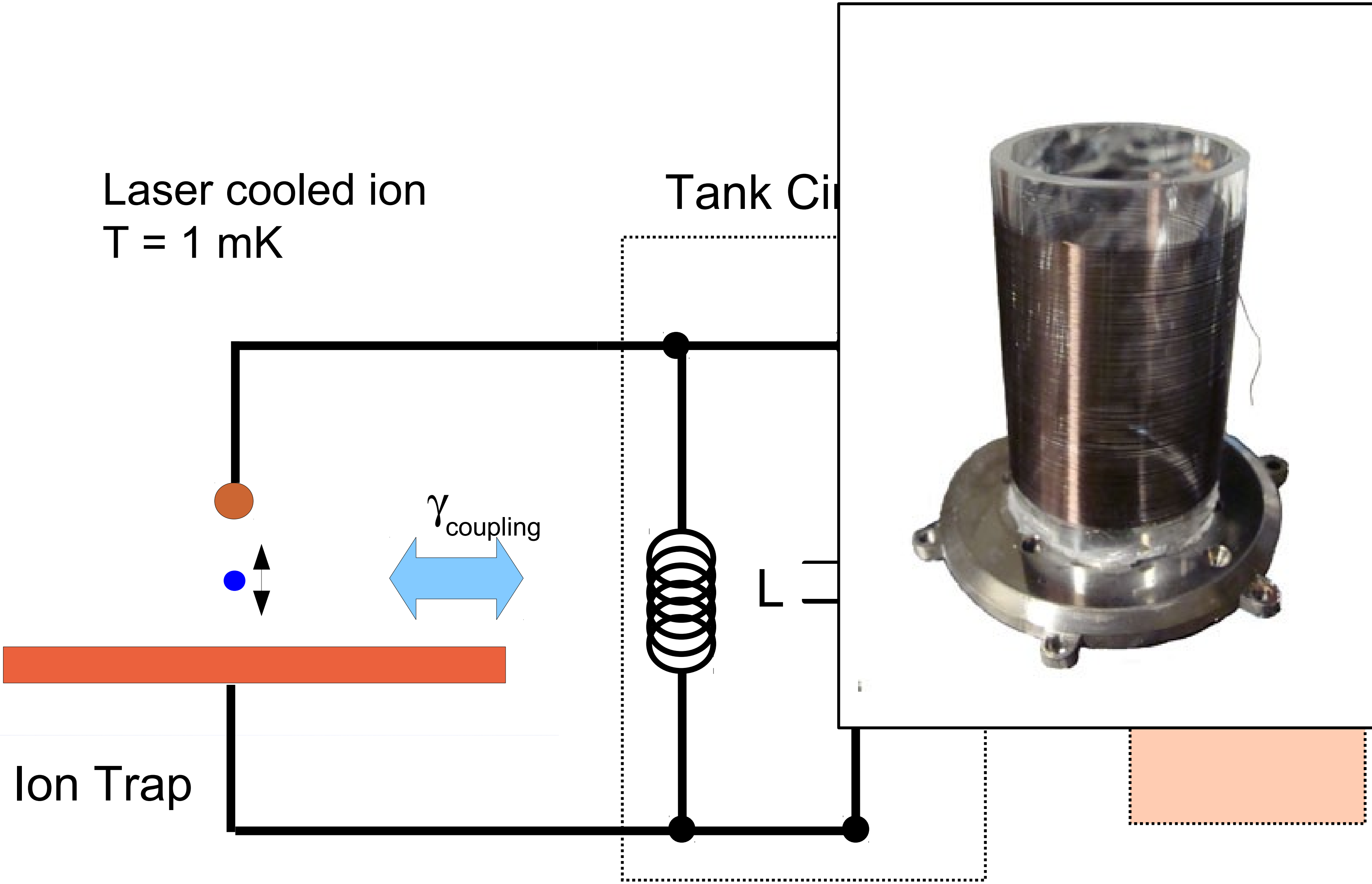
Long term goal

Merge trapped ions with superconducting devices for

- scalable quantum information processing.
- quantum sensing.

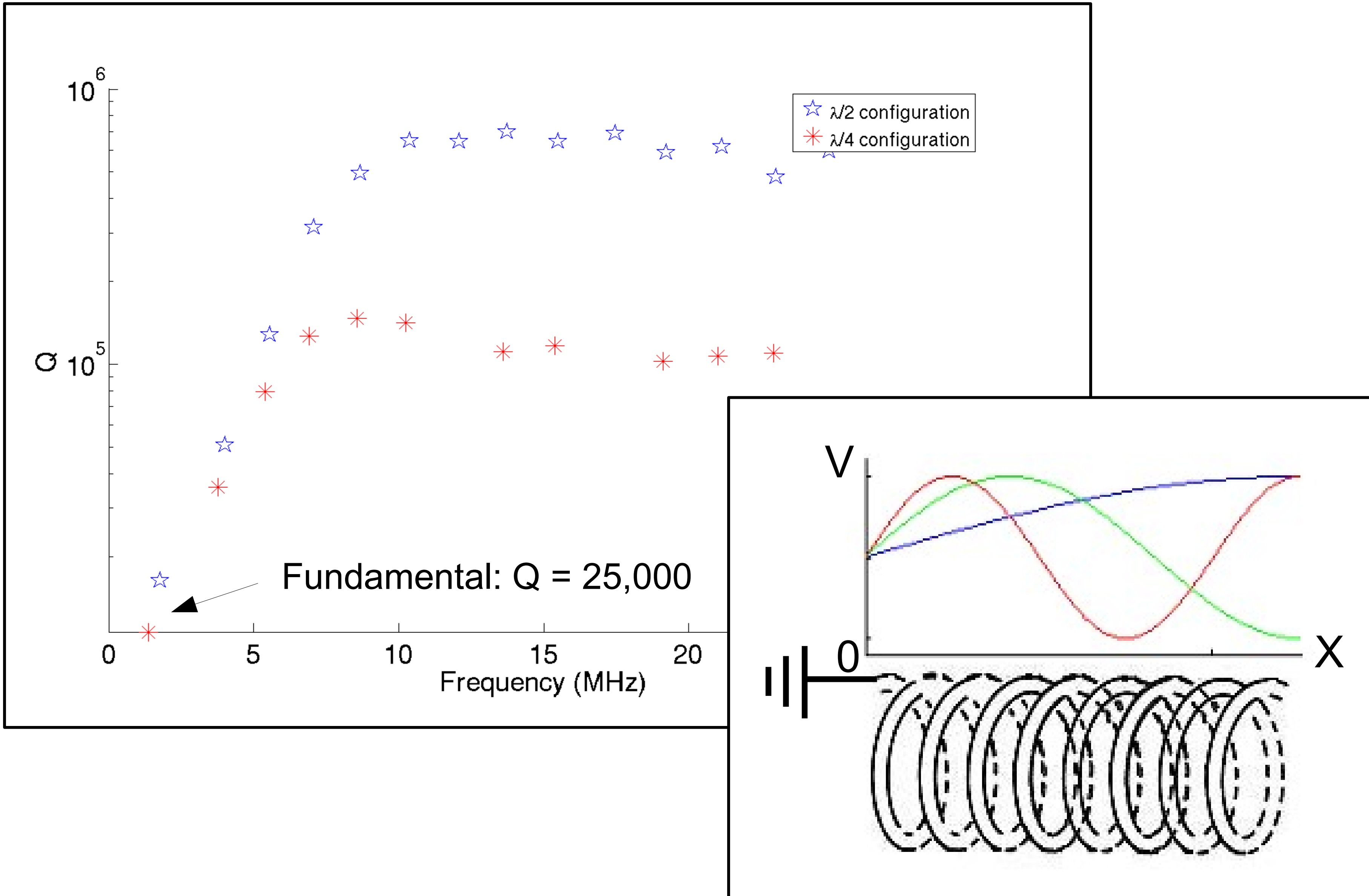


Laser cooling a tank circuit



Heinzen and Wineland, PRA **47**, 2977 (1990).

Quality factor of the resonator



Some estimates

Pick-up electrode distance: 100 μm

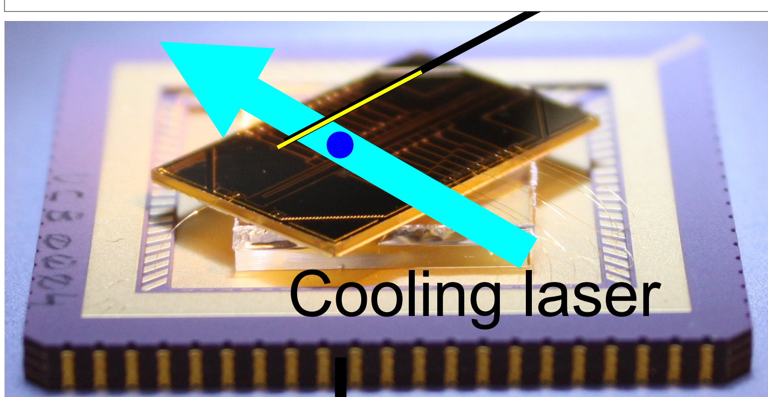
Resonator / ion frequency: 5 MHz

Ion-resonator coupling: 2π x 2 kHz

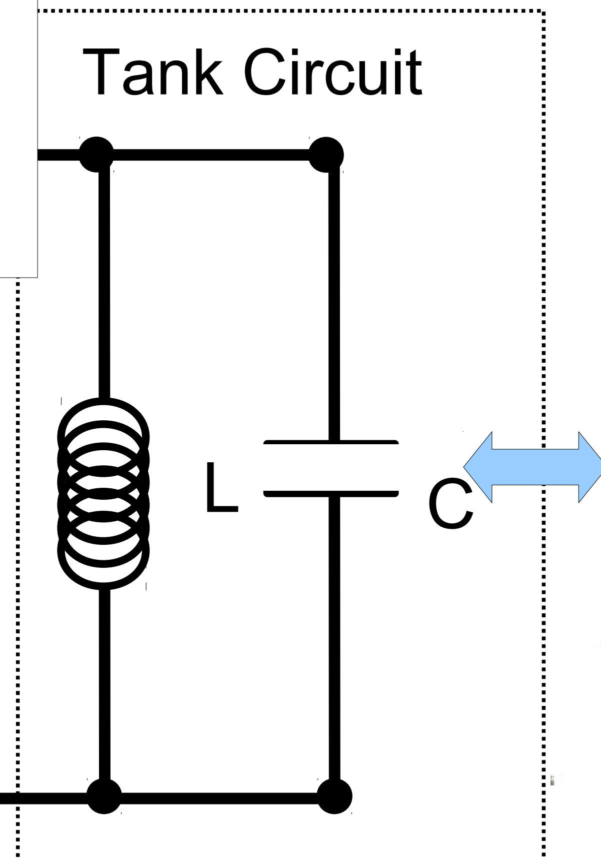
Resonator Q: 100,000

Resonator damping: 300 1/s

→ Expected cooling of resonant mode to 1/40 T_{env}

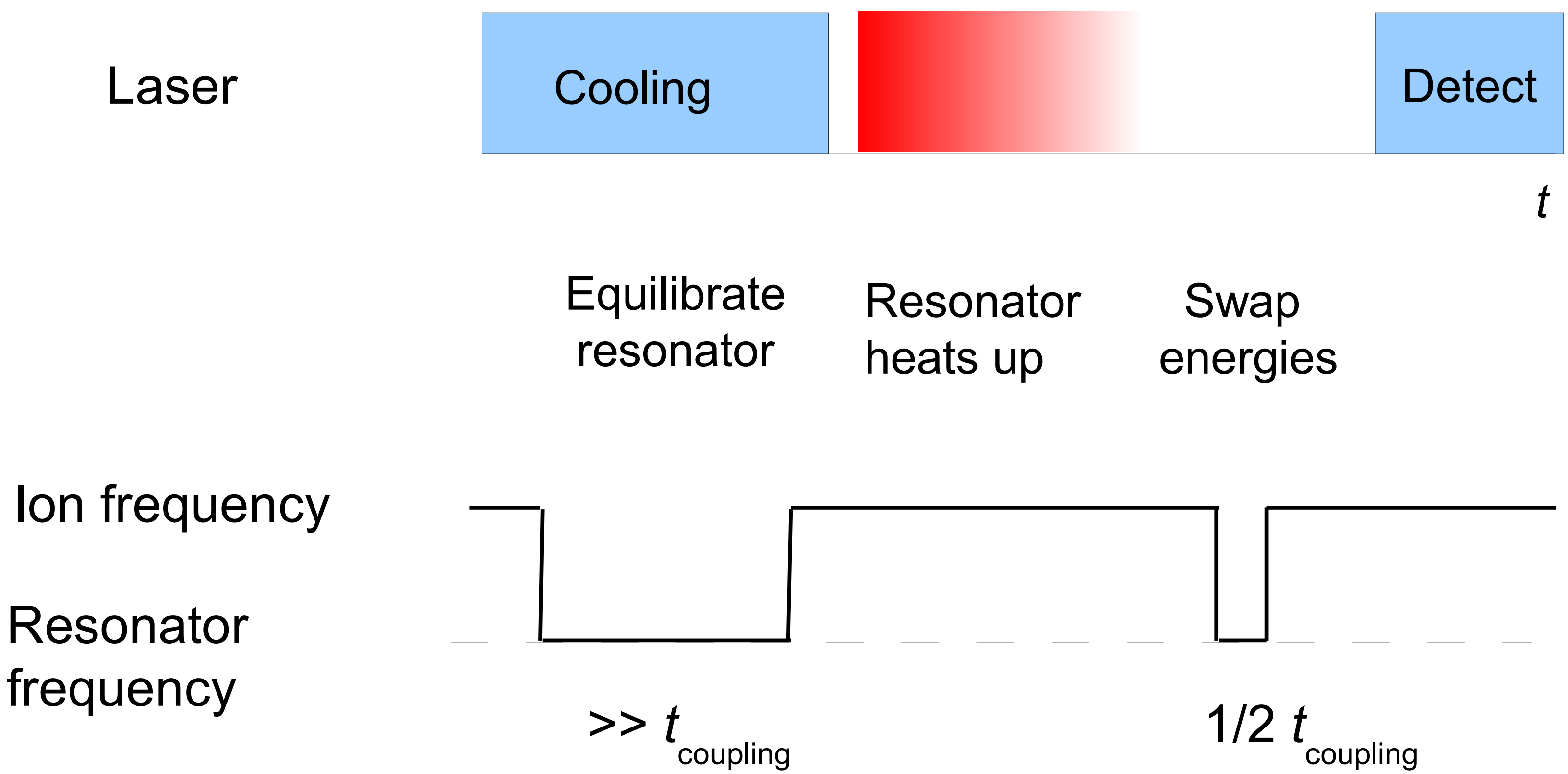


Ion Trap



Heat Bath
T=4K

Experimental procedure

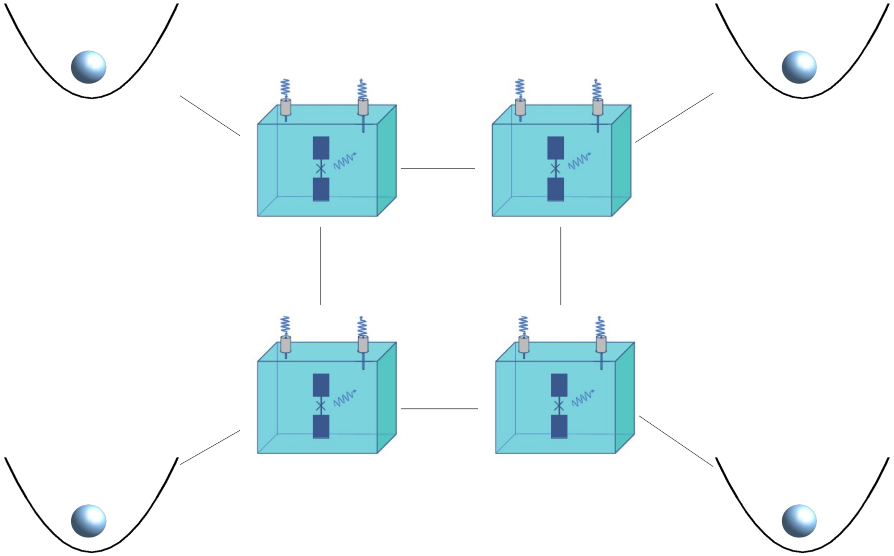


Some perspectives

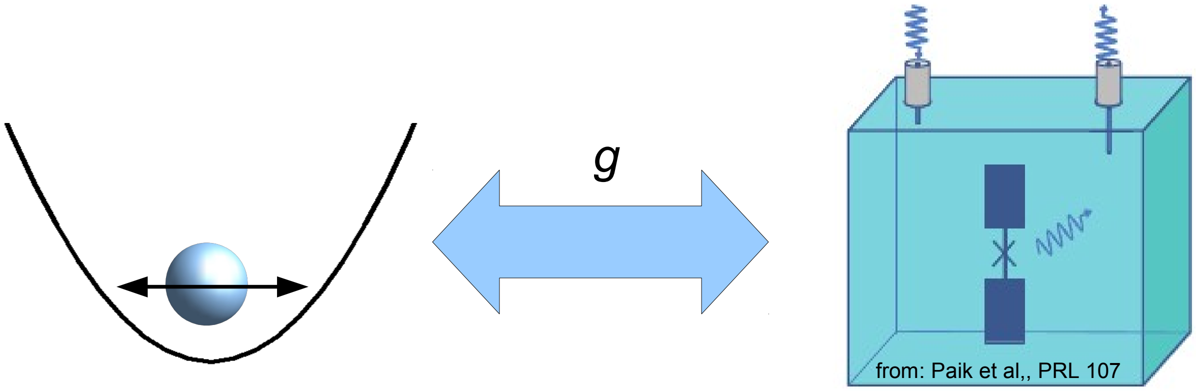
- Sense electromagnetic noise in electrical circuits

- Mediate cooling between traps

- Couple to Josephson junction circuits



Coherent coupling

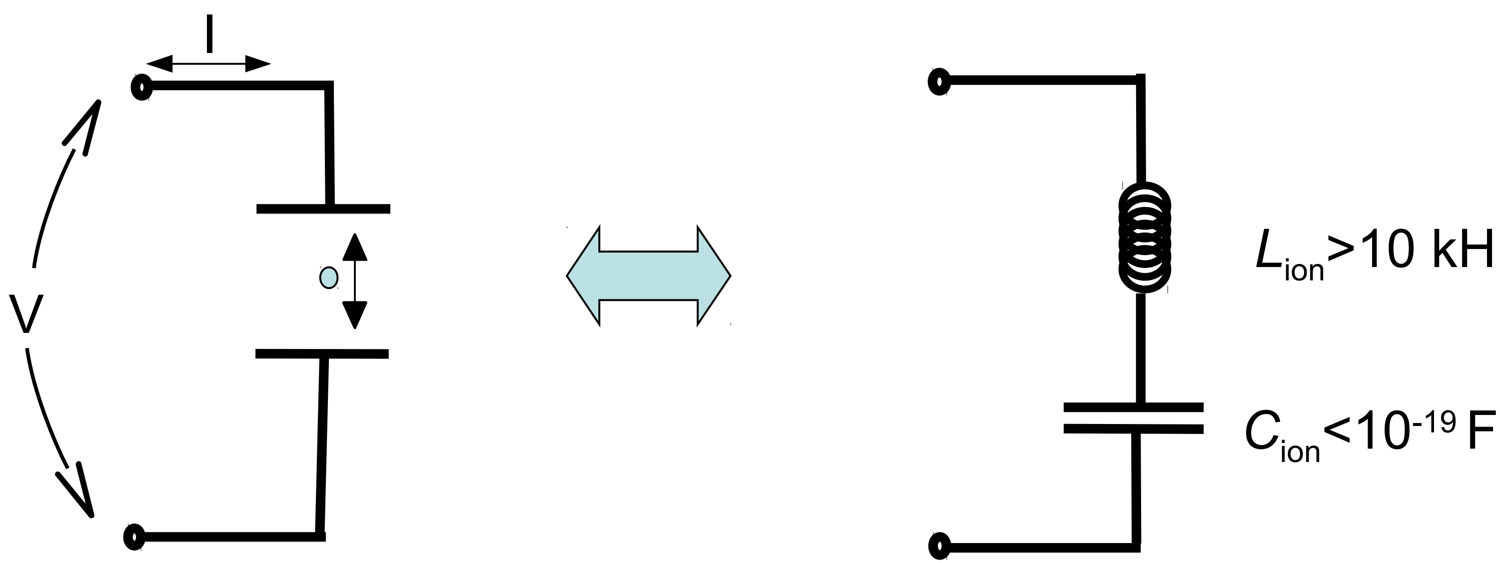


$g \gg \{\tau_{ion}, \tau_S\}$

This implies: the solid state qubit must couple much stronger to the ion than to the sum of all other degrees-of-freedom

Challenges: - Impedance mismatch
- Frequency mismatch

Ion impedance



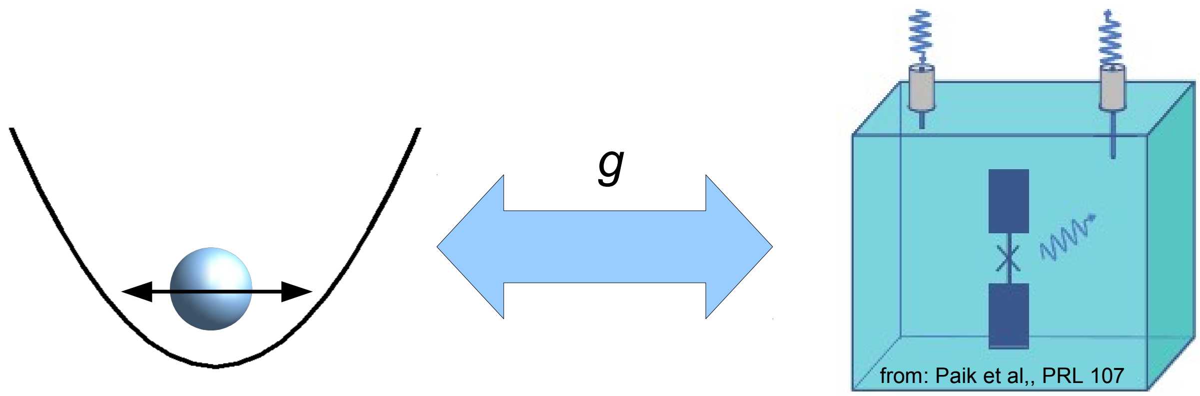
Induced current: $I = \frac{q}{D_{\text{eff}}} \dot{x} \approx 10^{-16}\ A$

Impedance matching problem

ion impedance 10^{12} Ohm and $g = \omega_{\text{r}} \sqrt{\frac{L}{L_{\text{ion}}}}$

DJ. Wineland and H.G. Dehmelt, J. Appl. Phys **46**, 919 (1975),
D.J. Heinzen and D.J. Wineland, PRA **47**, 2977 (1990)

Coherent coupling



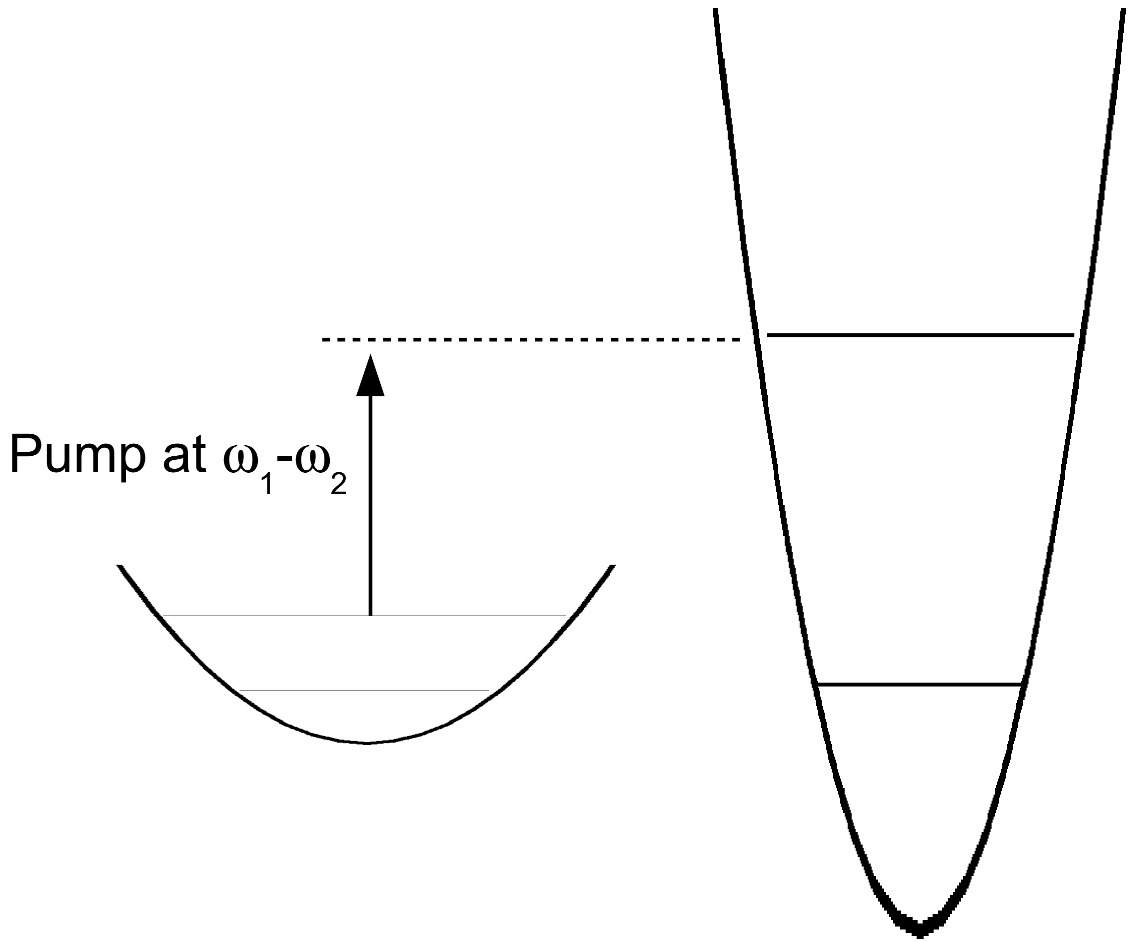
$g \gg \{\tau_{ion}, \tau_S\}$

This implies: the solid state qubit must couple much stronger to the ion than to the sum of all other degrees-of-freedom

Challenges: - Impedance mismatch
- Frequency mismatch

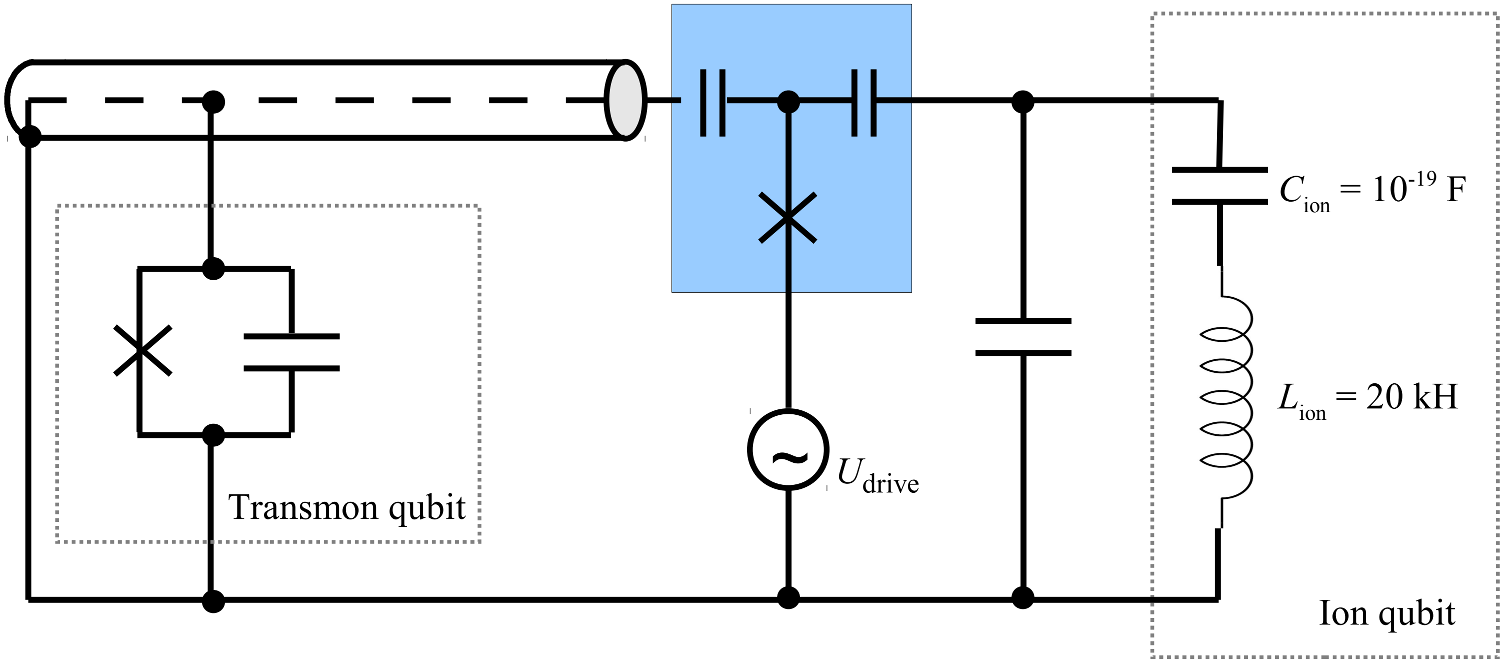
Quantum mixing

Parametric upconversion



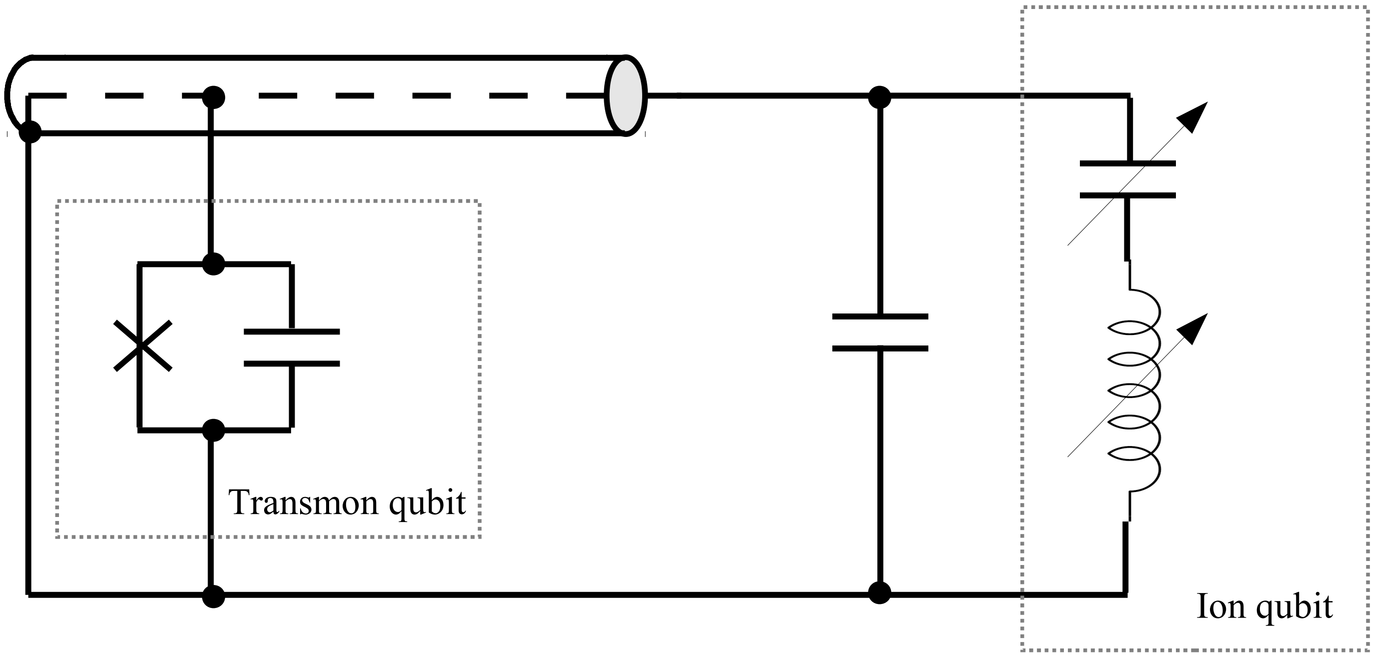
Quantum mixing

Problem: any well characterized non-linear solid state device has too much charge noise at 1 MHz.



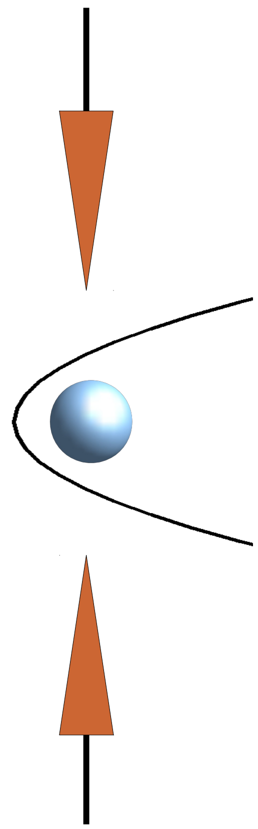
D.J. Heinzen and D.J. Wineland, PRA **47**, 2977 (1990)
Kielpinski *et al.*, PRL **108** 130504 (2012)

Parametric upconversion inside the trap



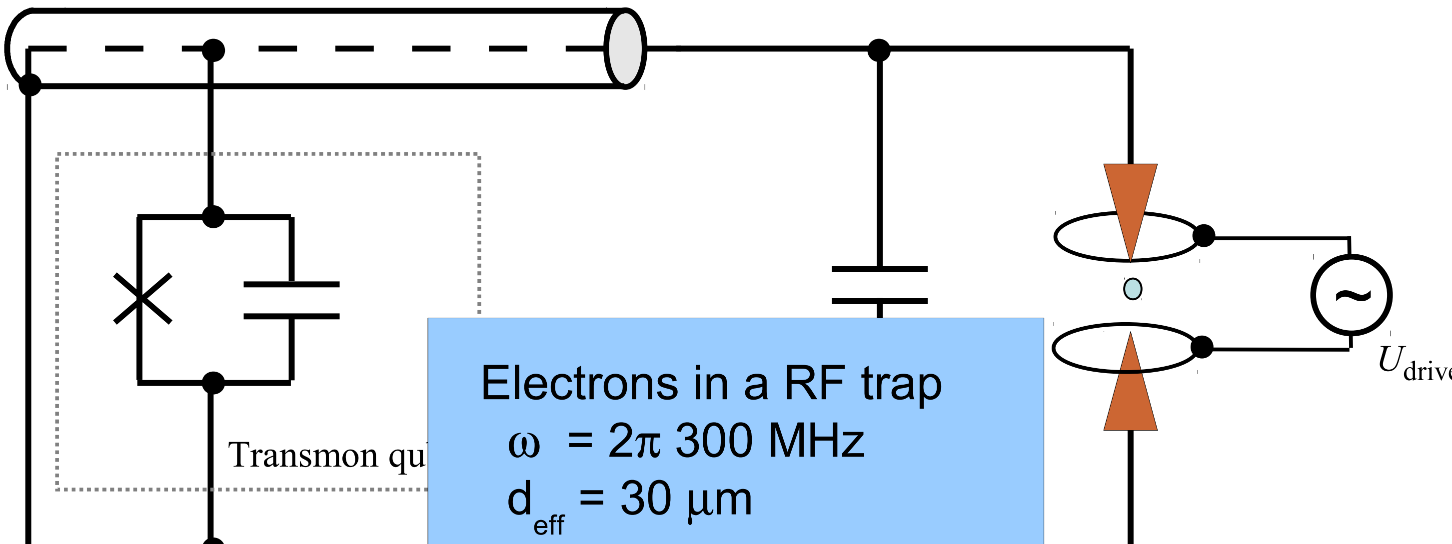
Daniilidis *et al*., in preparation

Parametric upconversion



Quantum mixing

Parametric upconversion inside the trap



Electrons in a RF trap

ω = 2π 300 MHz

d_{eff} = 30 μm

γ_{heat} ~ 1 quantum / ms

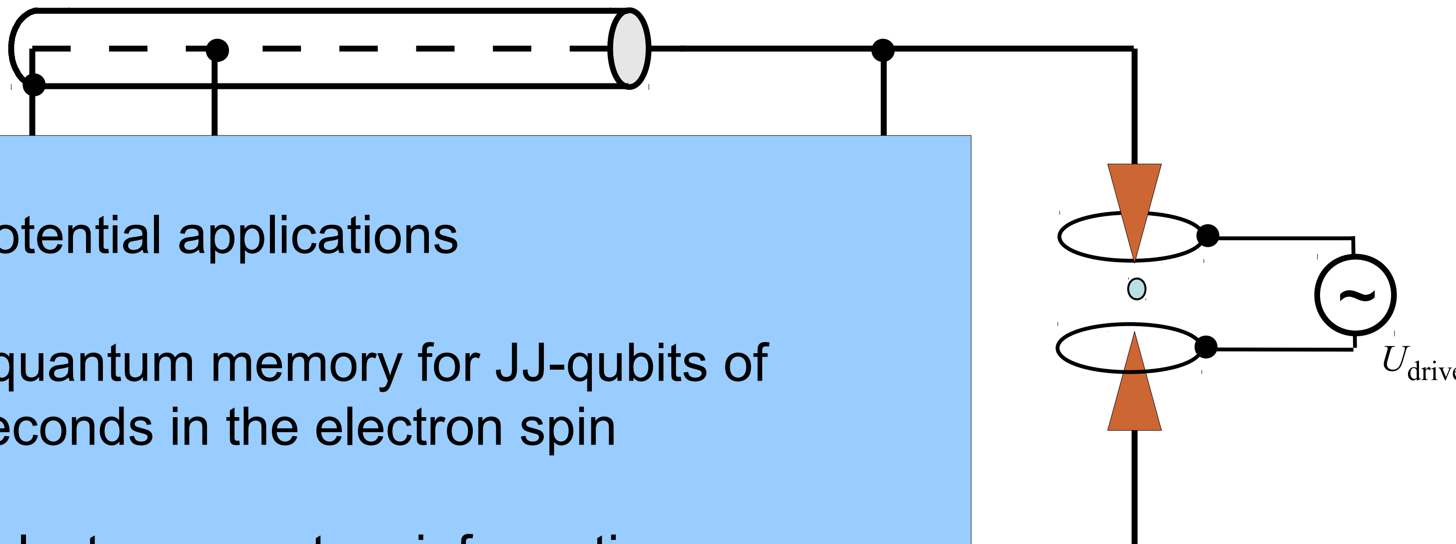
V_{drive} = 1 V @ 7 GHz

g = 2π x 350 kHz

Daniilidis *et al.*, in preparation

Quantum mixing

Parametric upconversion inside the trap



Potential applications

- quantum memory for JJ-qubits of seconds in the electron spin

- electron quantum information processing (see also QuELE)

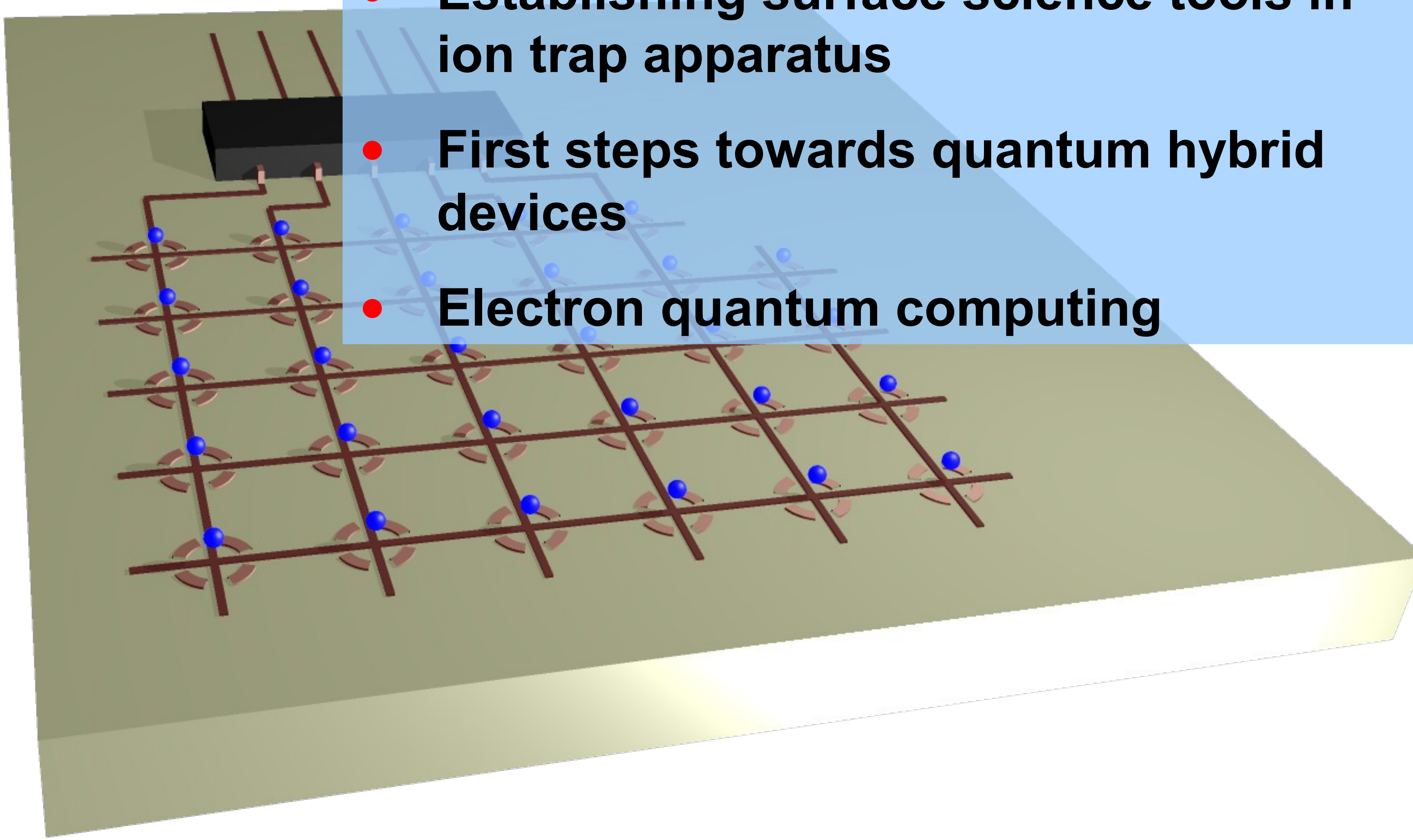
- cooling of charged particles for precision measurements

Daniilidis *et al.*, in preparation

Summary

Summary

- Establishing surface science tools in ion trap apparatus
- First steps towards quantum hybrid devices
- Electron quantum computing



People

- Greg Bolloton
- Nikos Daniliidis
- Dylan Gorman
- Sebastian Gerber
- Sönke Möller
- Sankara Narayanan
- Thaned (Hong) Pruttivarasin
- Michael Ramm
- Ishan Talukdar


ICOLS 2013
International Conference
on Laserspectroscopy
Berkeley
University of California
June 9-14, 2013