



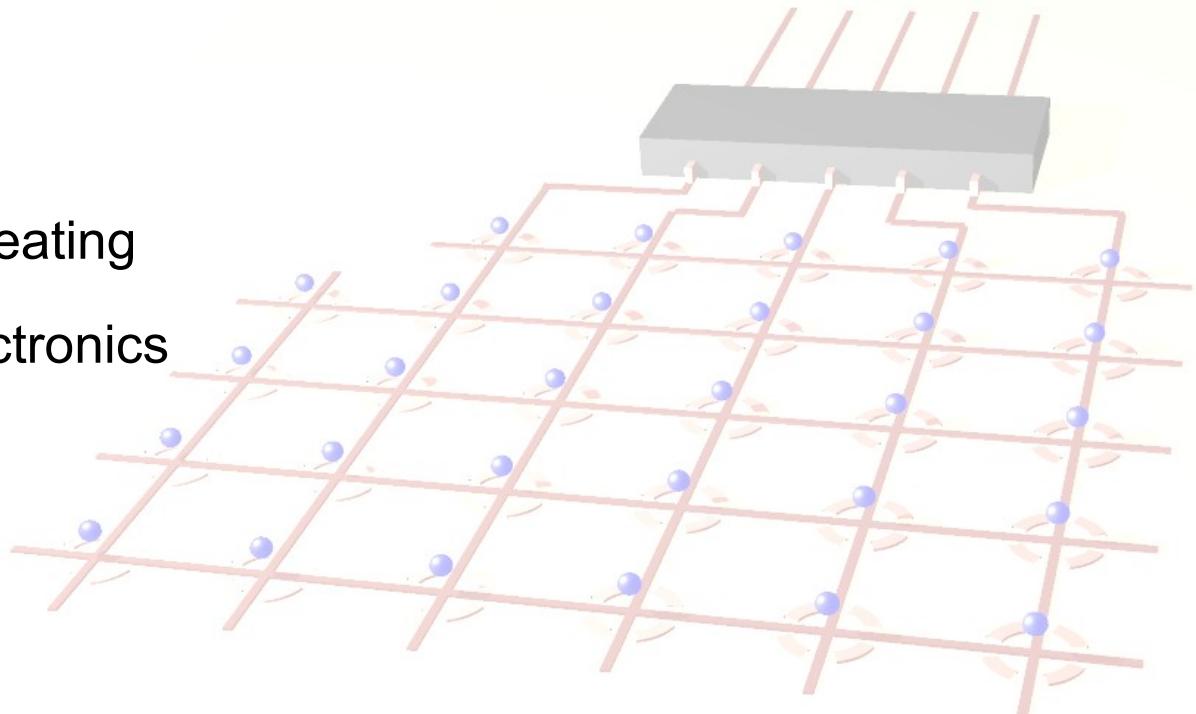
# Towards electronics with single charged trapped particles



Hartmut Häffner

*Department of Physics, University of California, Berkeley, USA*

- Introduction
- Anomalous heating
- Quantum electronics
- Conclusions



Rochester, Oct 19<sup>th</sup>



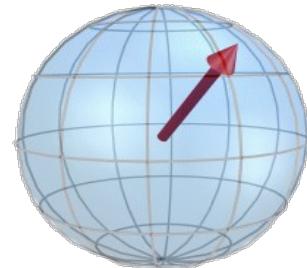
# Key challenges in quantum information



Carriers of quantum information need to be

- isolated perfectly from the environment

$$\alpha|0\rangle + \beta|1\rangle$$





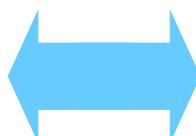
# Key challenges in quantum information



Carriers of quantum information need to be

- isolated perfectly from the environment
- interacting strongly among each other

$$\alpha|0\rangle + \beta|1\rangle$$



$$\alpha|0\rangle + \beta|1\rangle$$





# Key challenges in quantum information



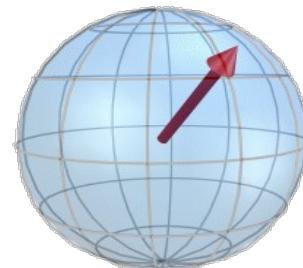
Carriers of quantum information need to be

- isolated perfectly from the environment
- interacting strongly among each other
- controlled by external parameters

$$\alpha|0\rangle + \beta|1\rangle$$

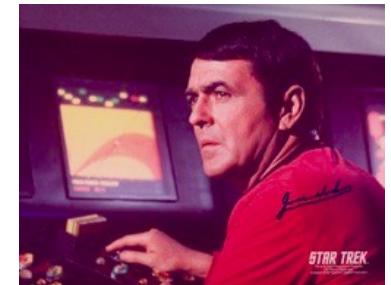


$$\alpha|0\rangle + \beta|1\rangle$$



Read out

Control





# Key challenges in quantum information



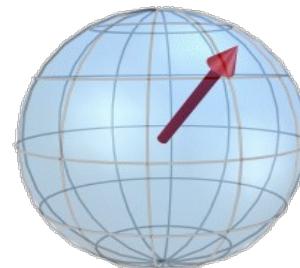
Carriers of quantum information need to be

- isolated perfectly from the environment
- interacting strongly among each other
- controlled by external parameters
- scalable

$$\alpha|0\rangle + \beta|1\rangle$$

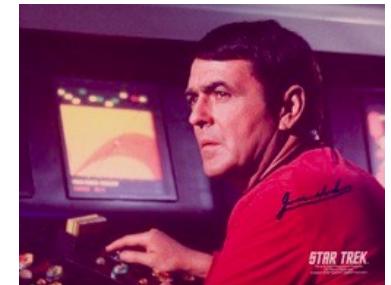


$$\alpha|0\rangle + \beta|1\rangle$$



Read out

Control

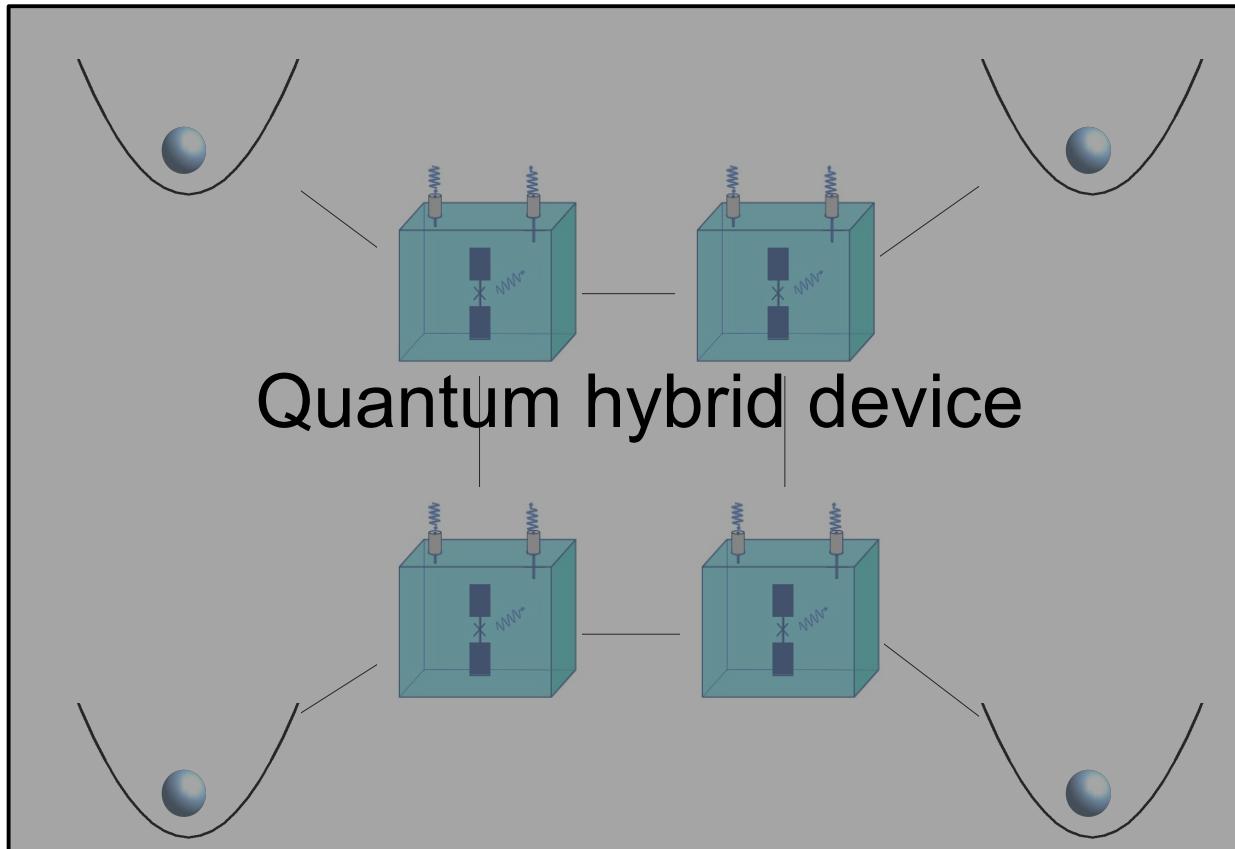




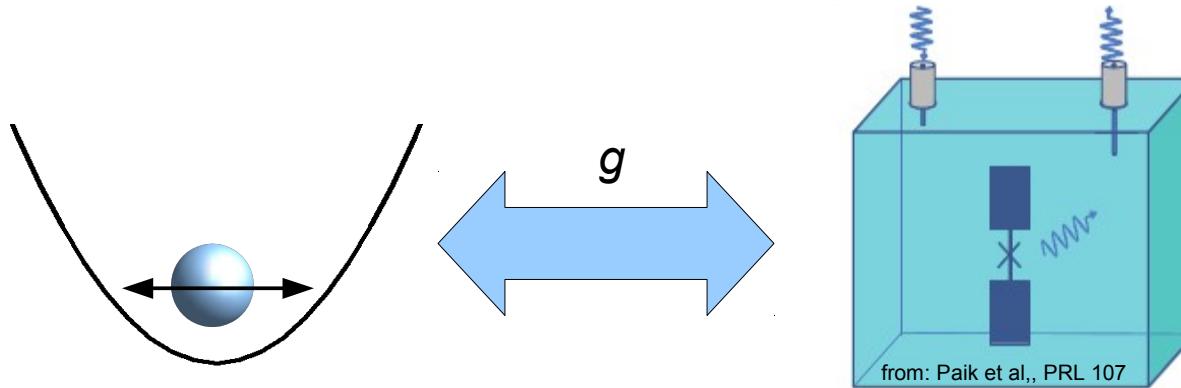
# Quantum hybrids



- quantum processor: solid state system
- quantum memory: atom



# Coherent coupling



$$g \gg \{\tau_{\text{ion}}, \tau_s\}$$

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



Need to bring the ion very close to the circuit



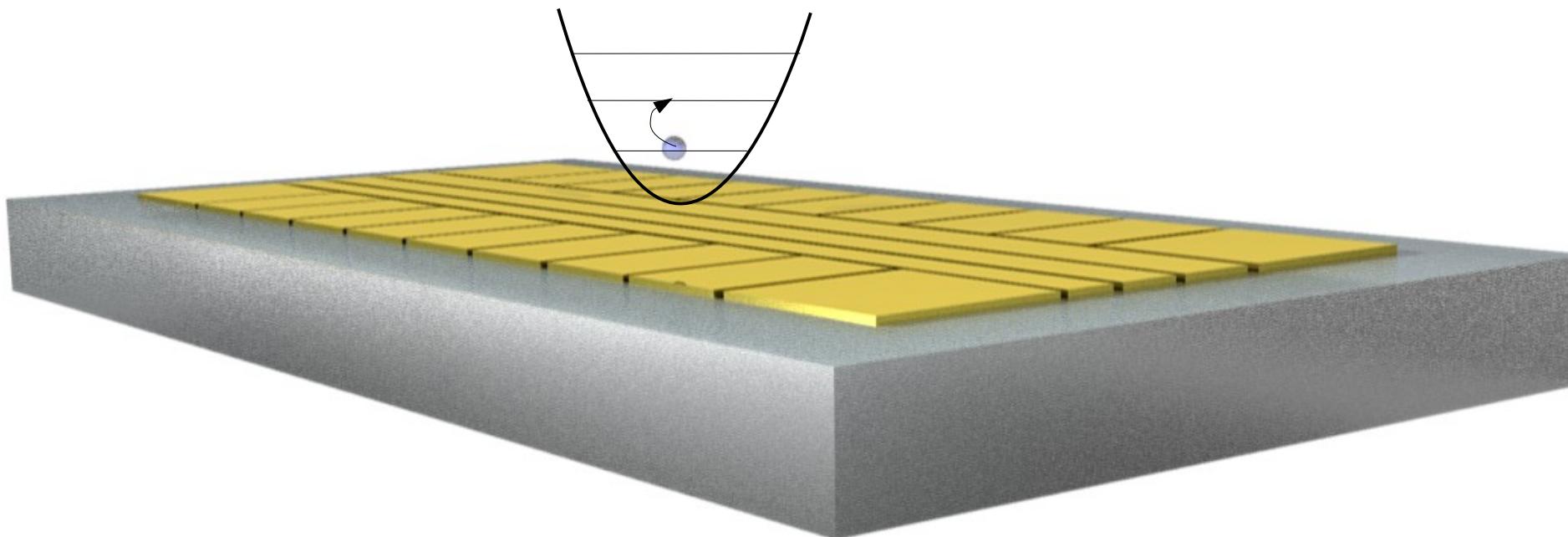
# Anomalous heating



Surface contamination?

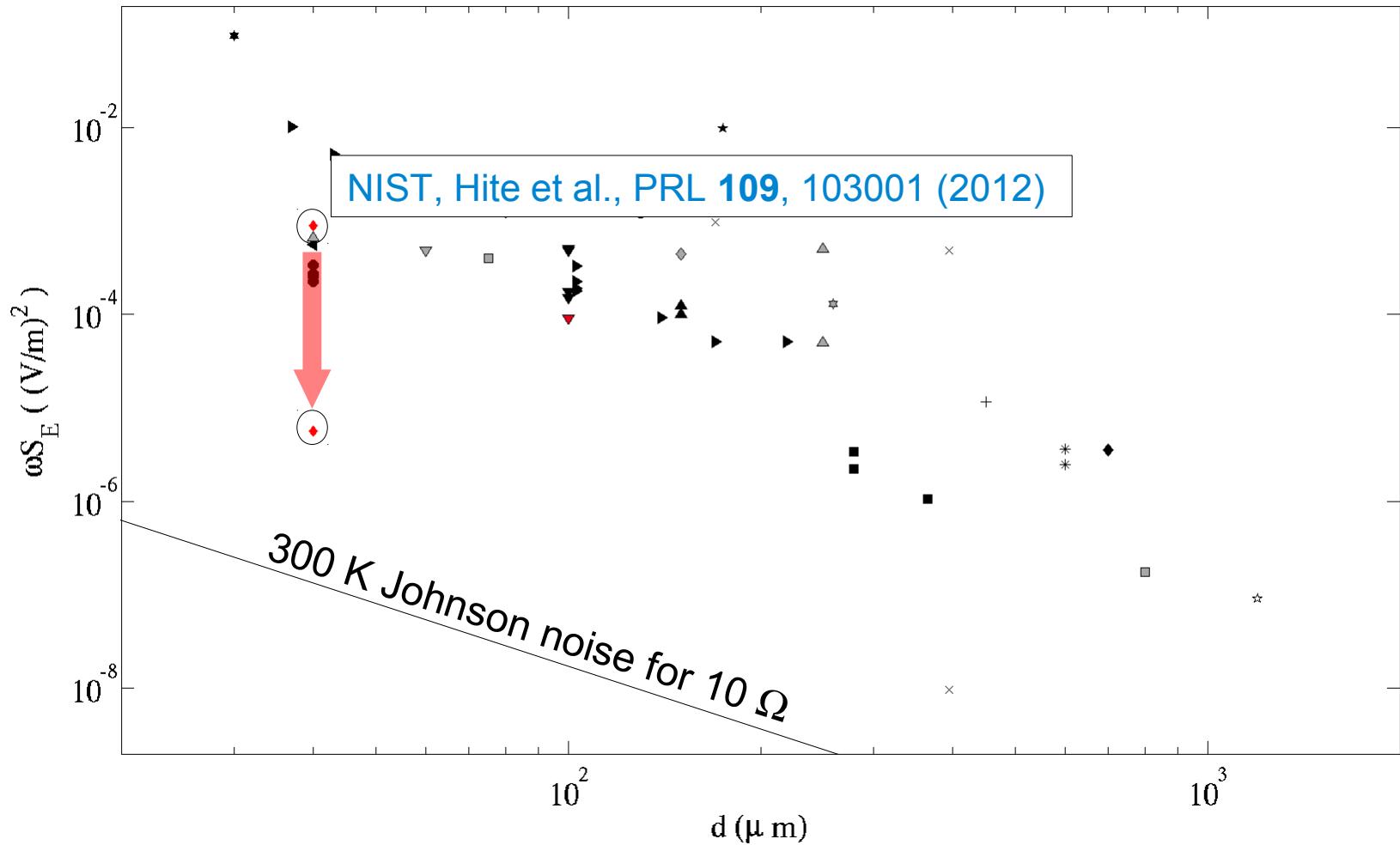
Daniilidis et al., New J. Phys. **13**, 013032 (2011).

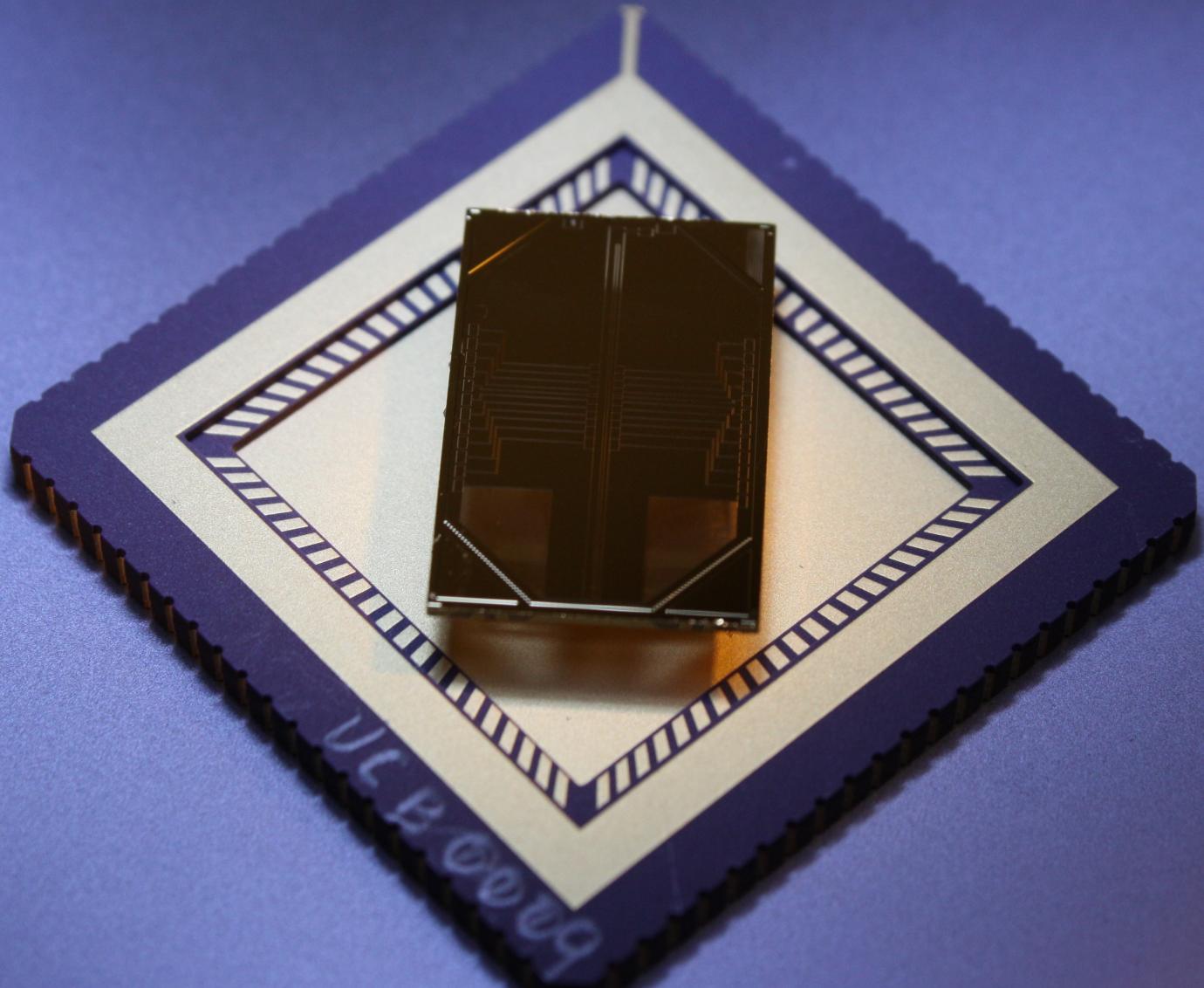
Safavi-Naini et al., Phys. Rev. A **84**, 023412 (2011).





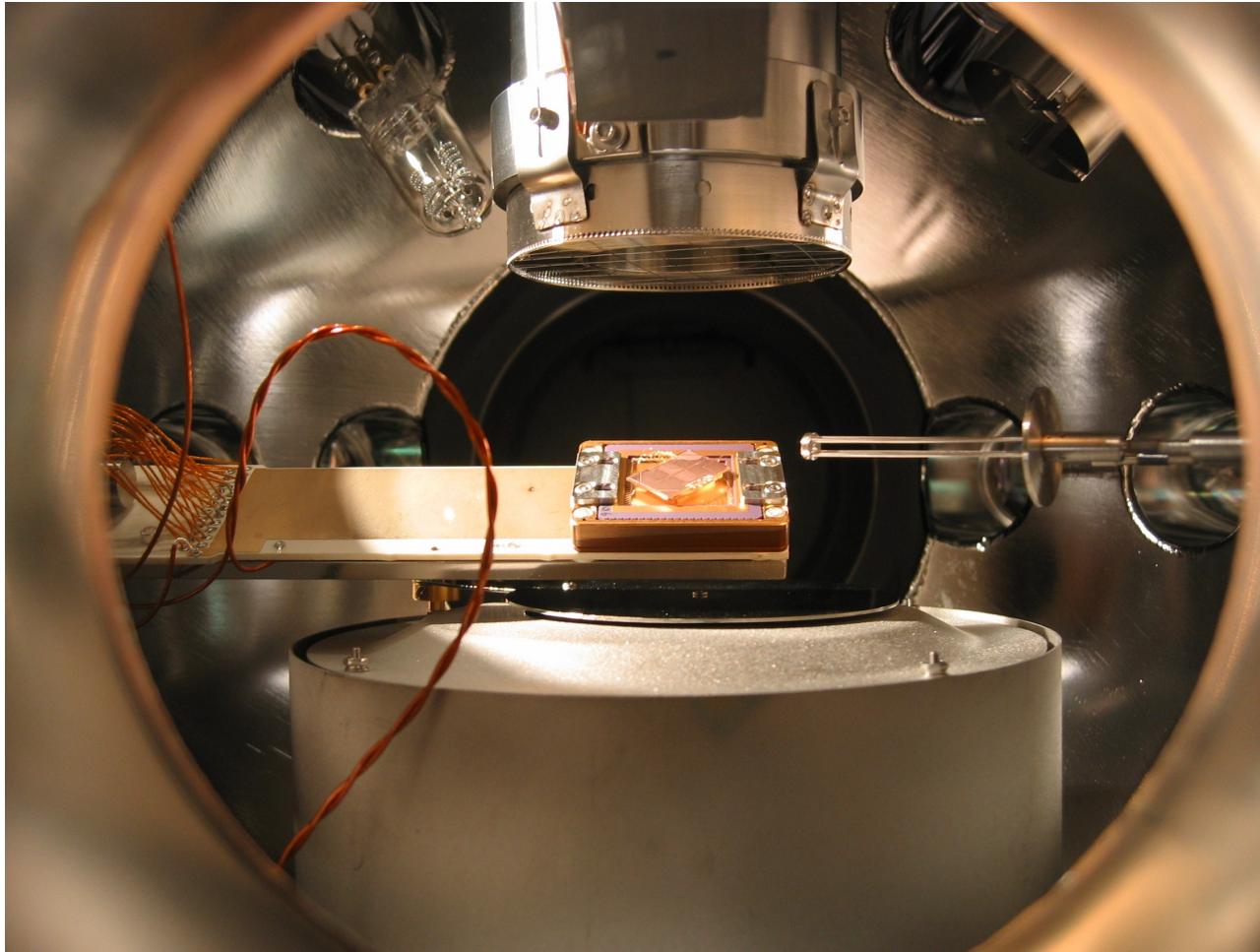
# Anomalous heating





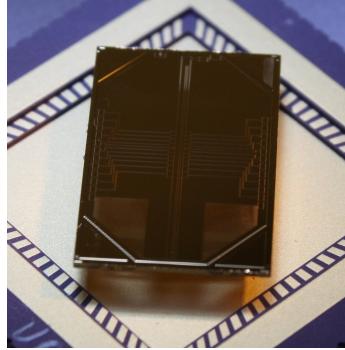


# Surface science chamber

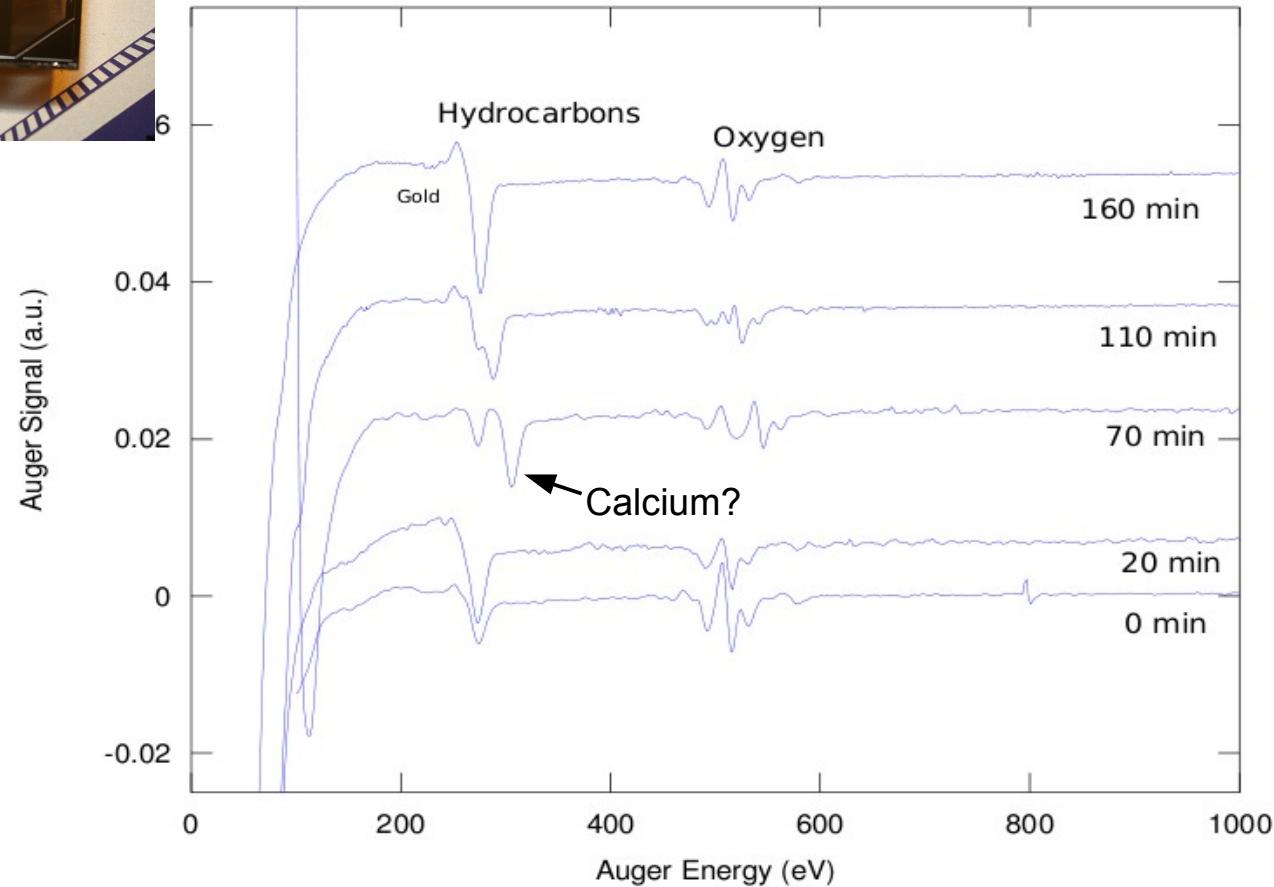




# UV induced surface dynamics

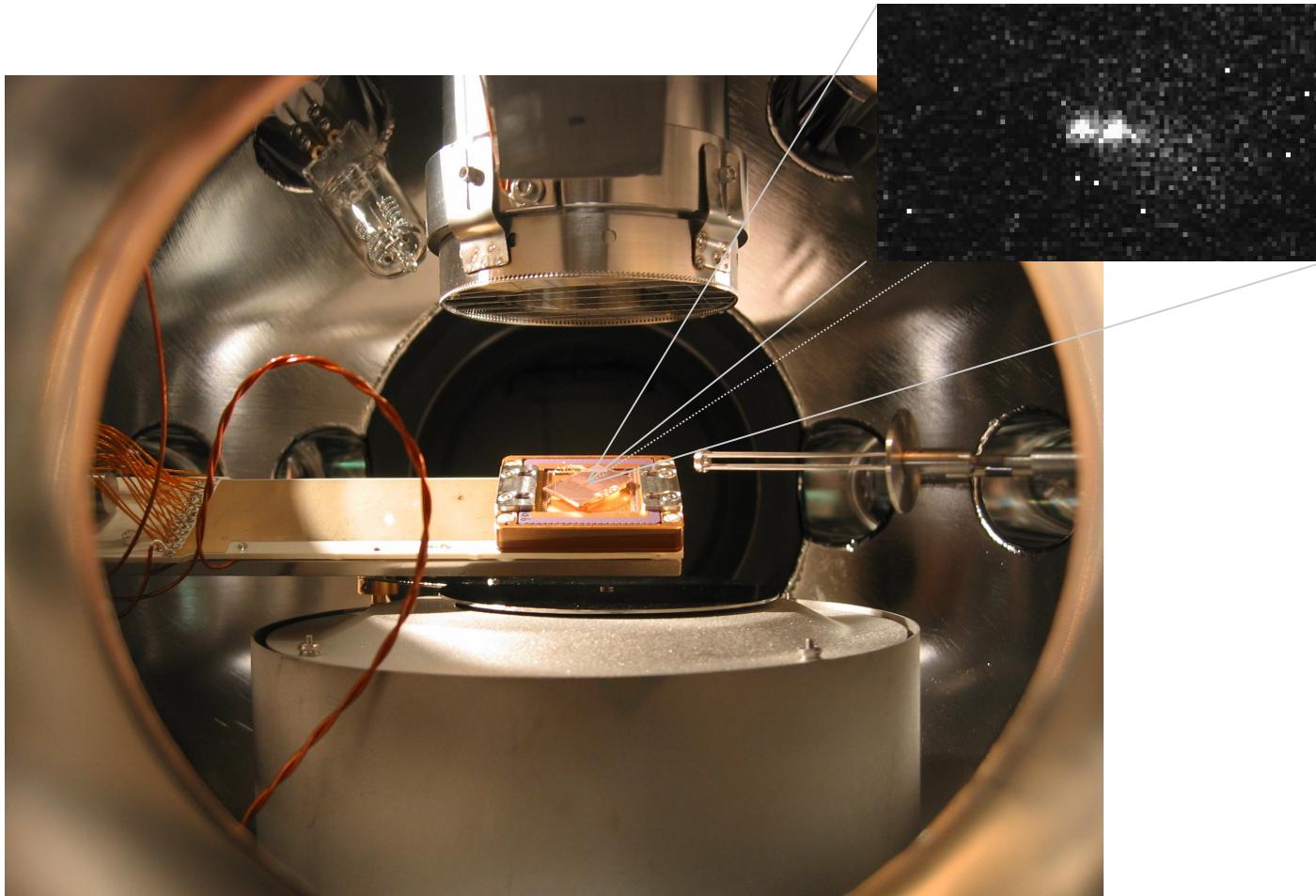


UV light dose (172 nm)



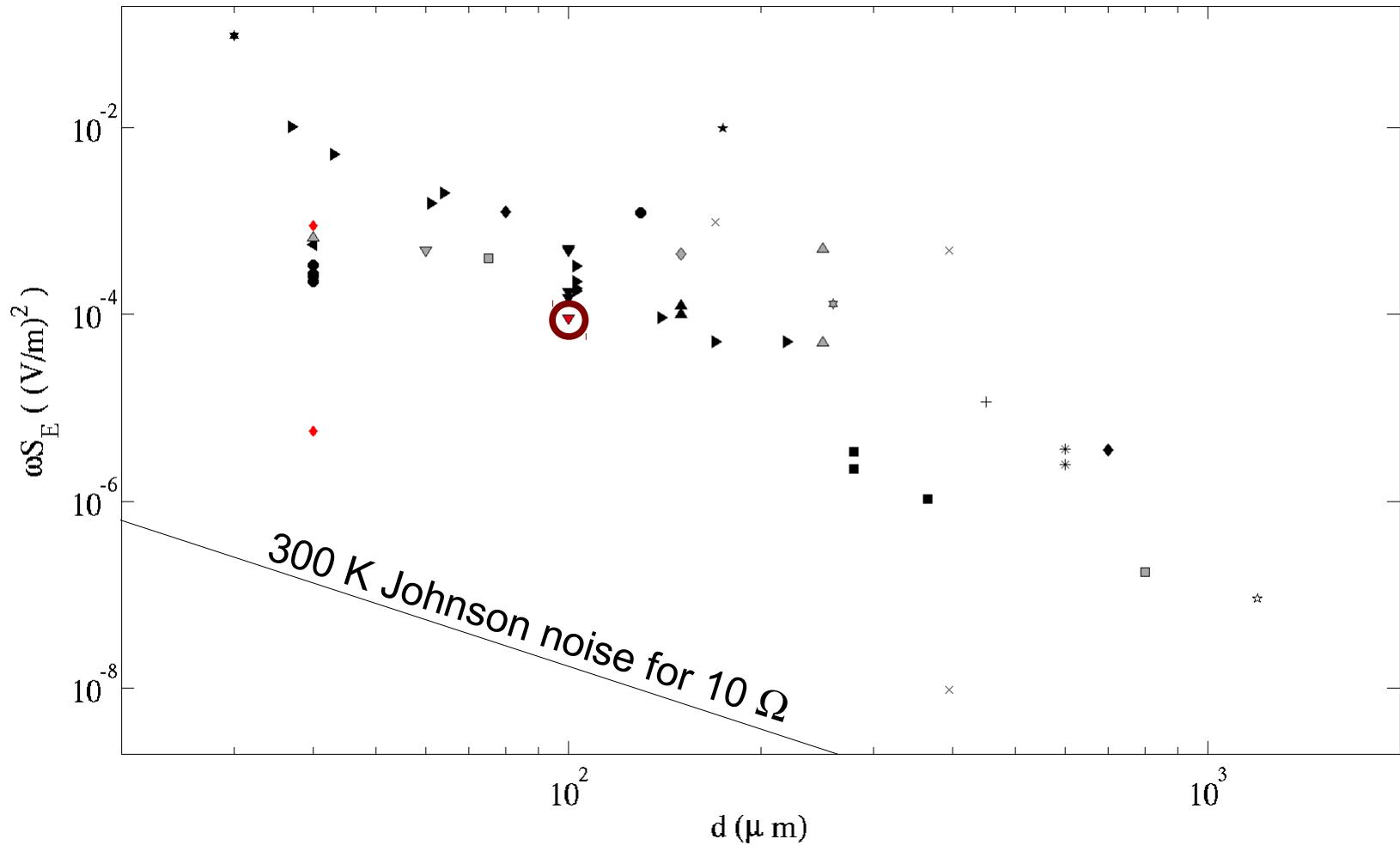


# Ions in a surface science chamber



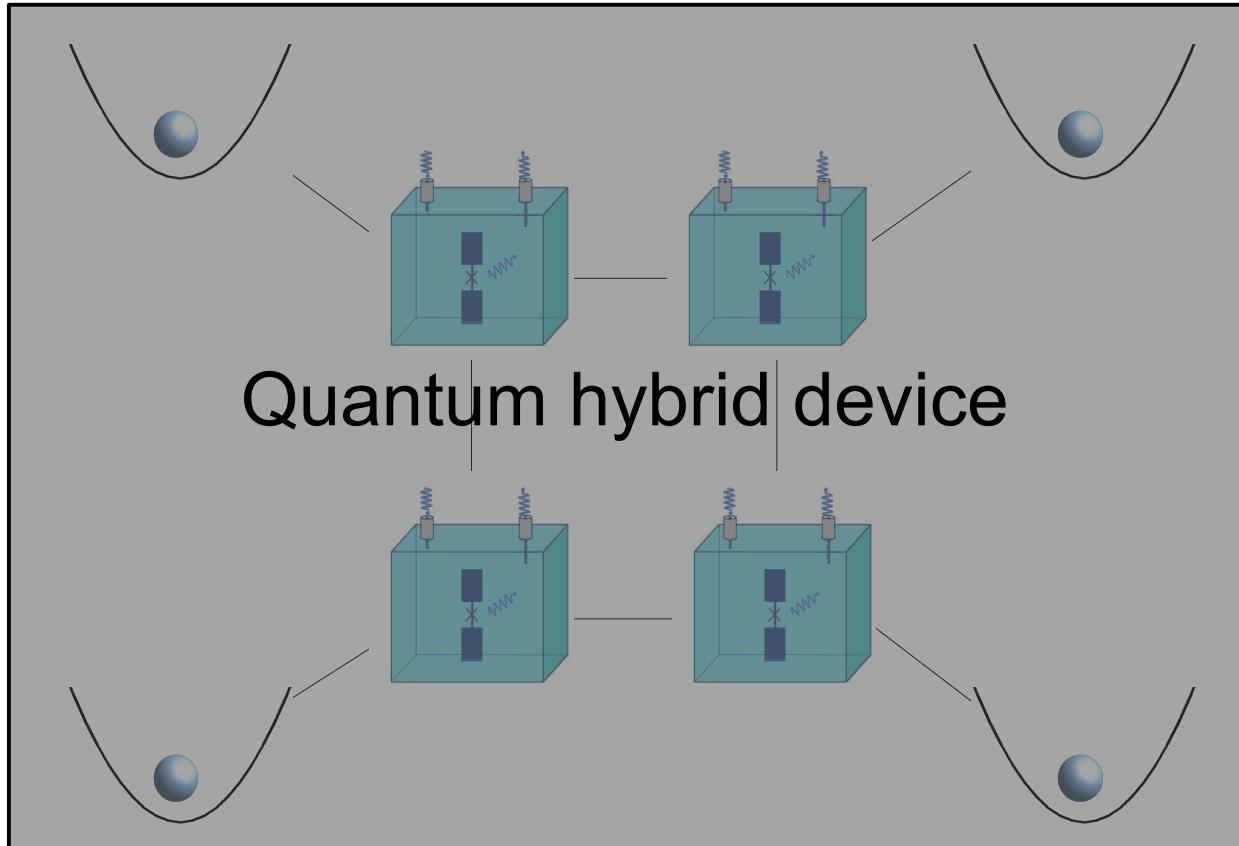


# Heating rates

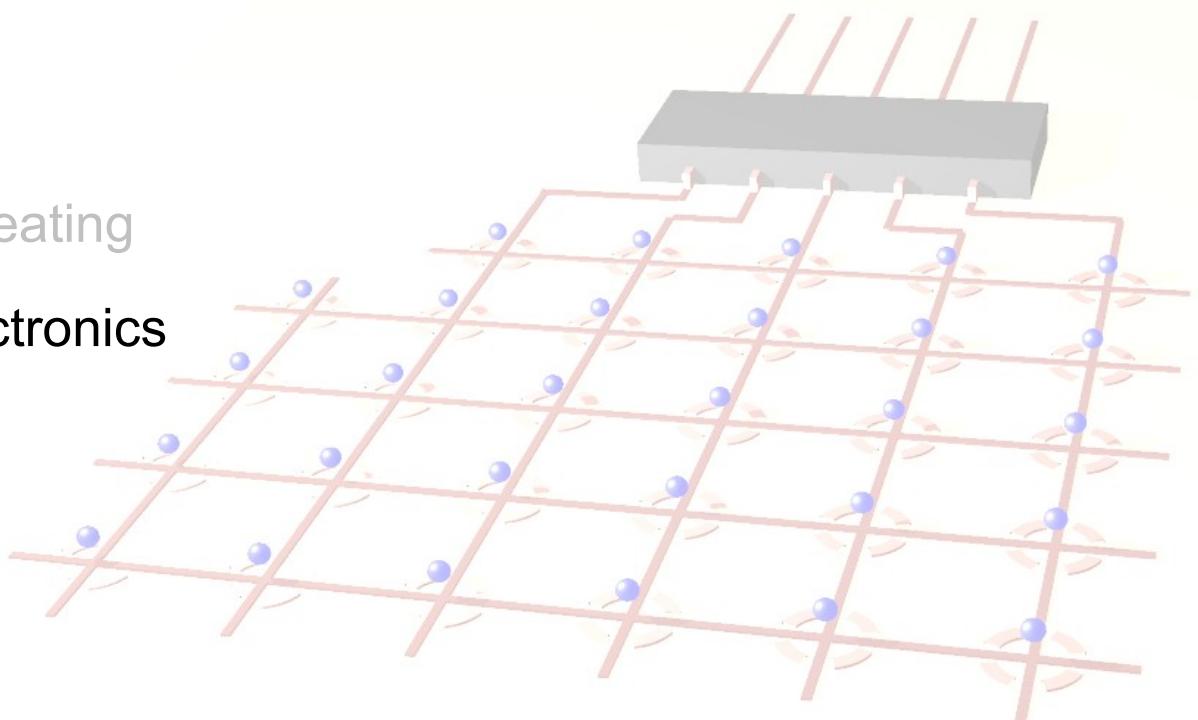




# Quantum hybrids

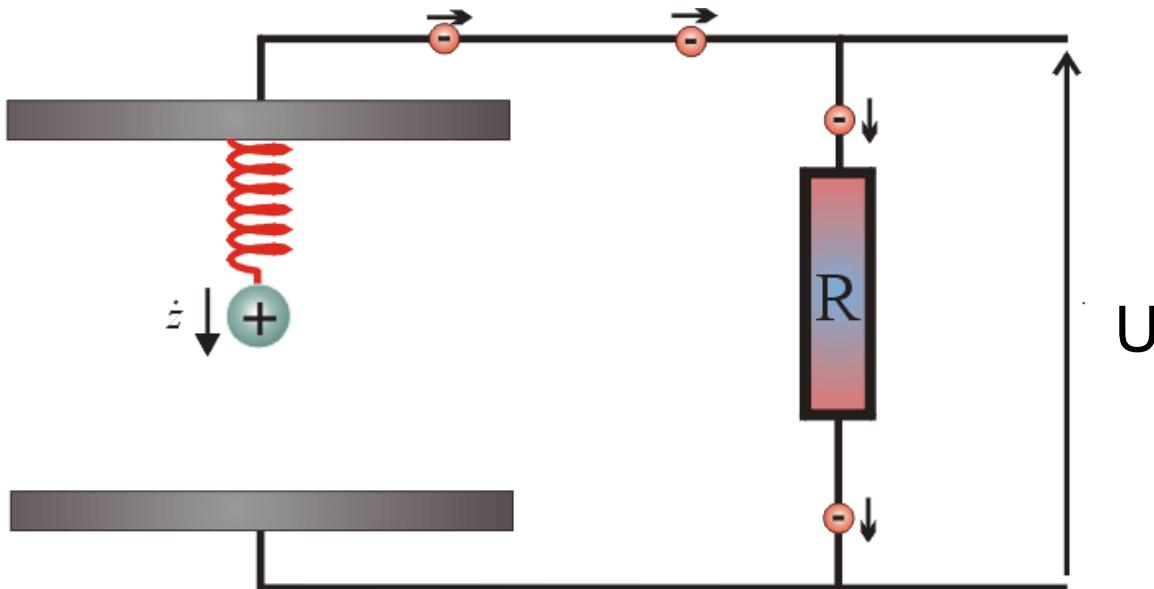


- Introduction
- Anomalous heating
- **Quantum electronics**
- Conclusions



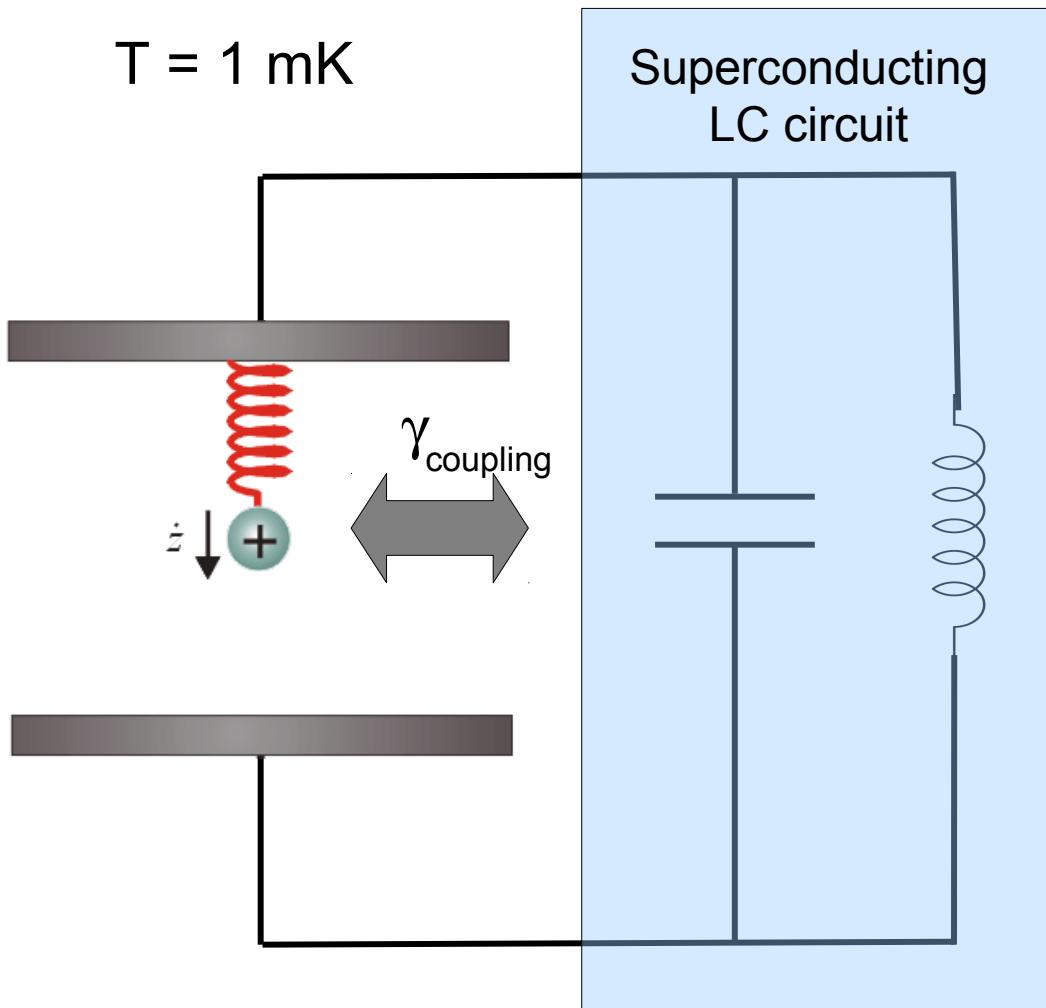


# Ion-electronics



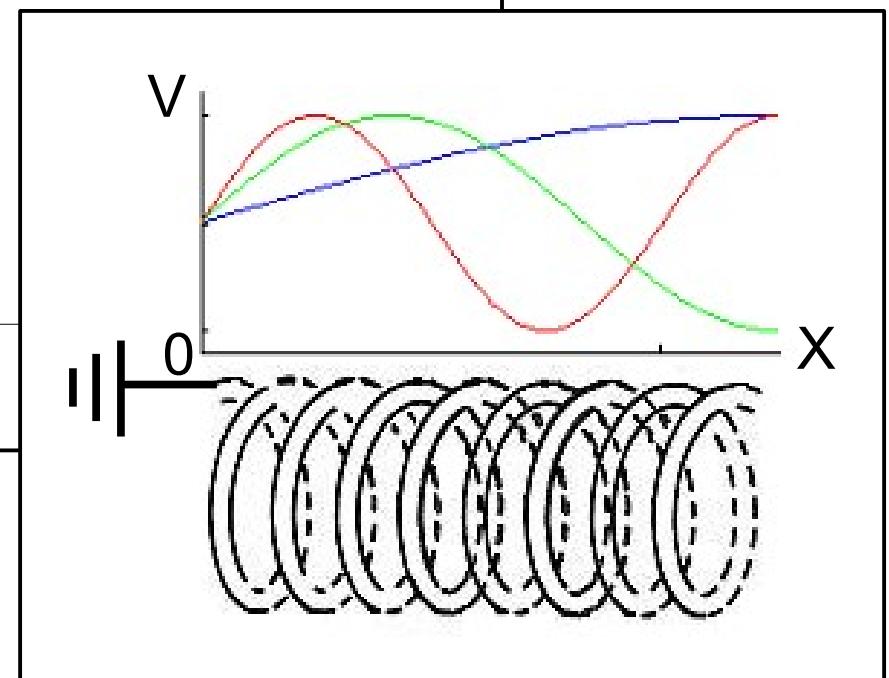
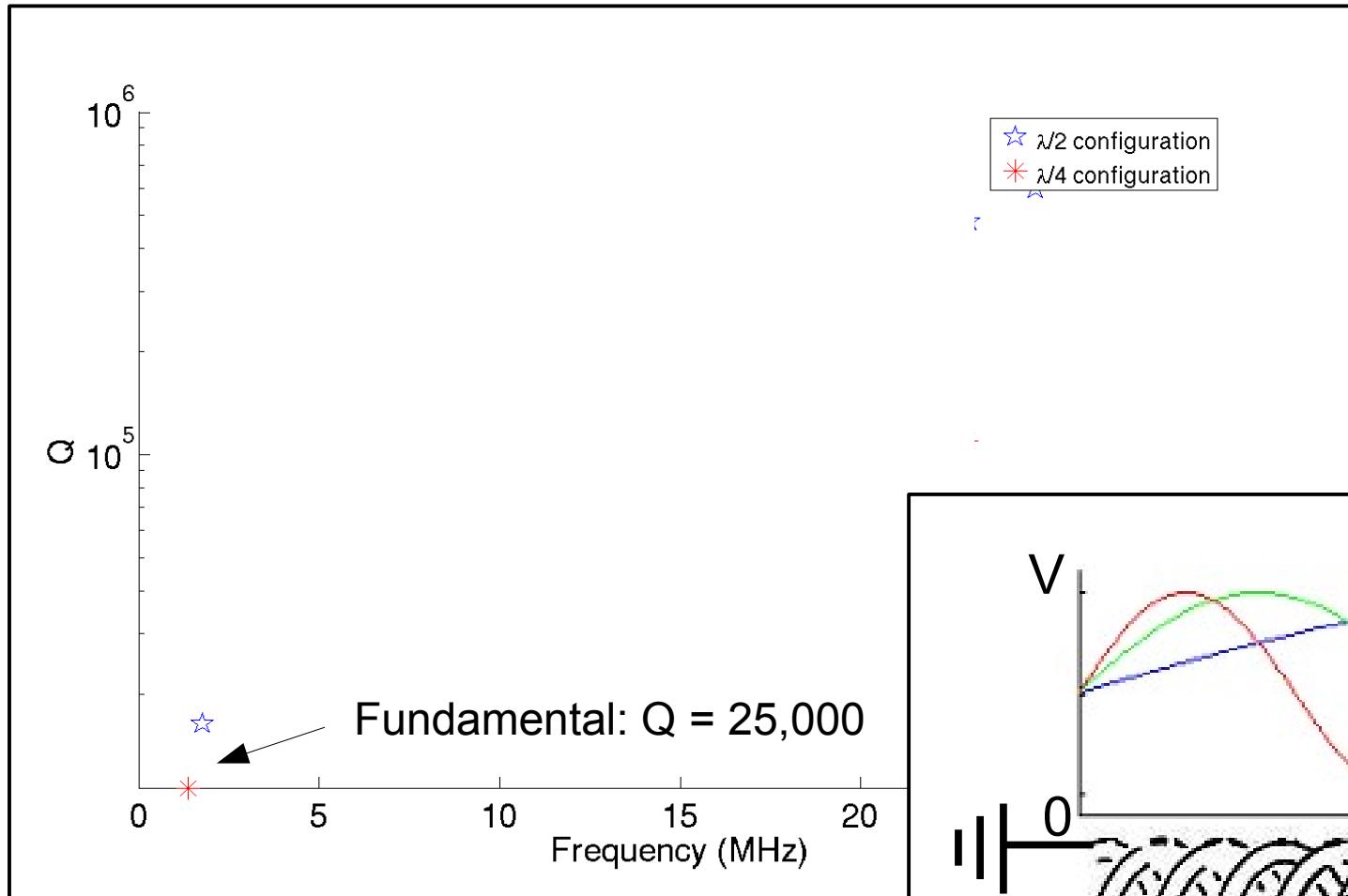


# Coupling an ion to a resonator mode



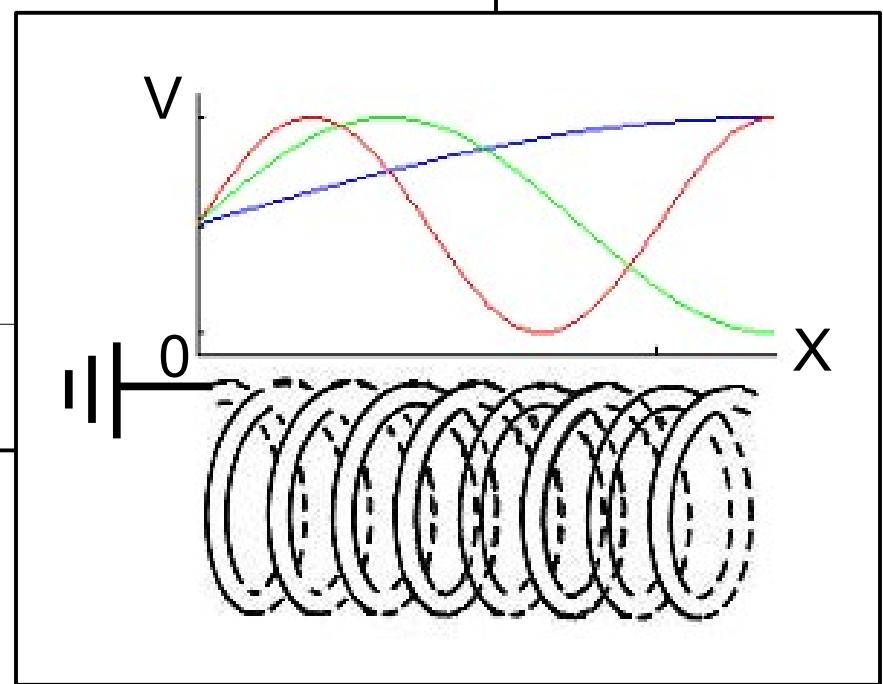
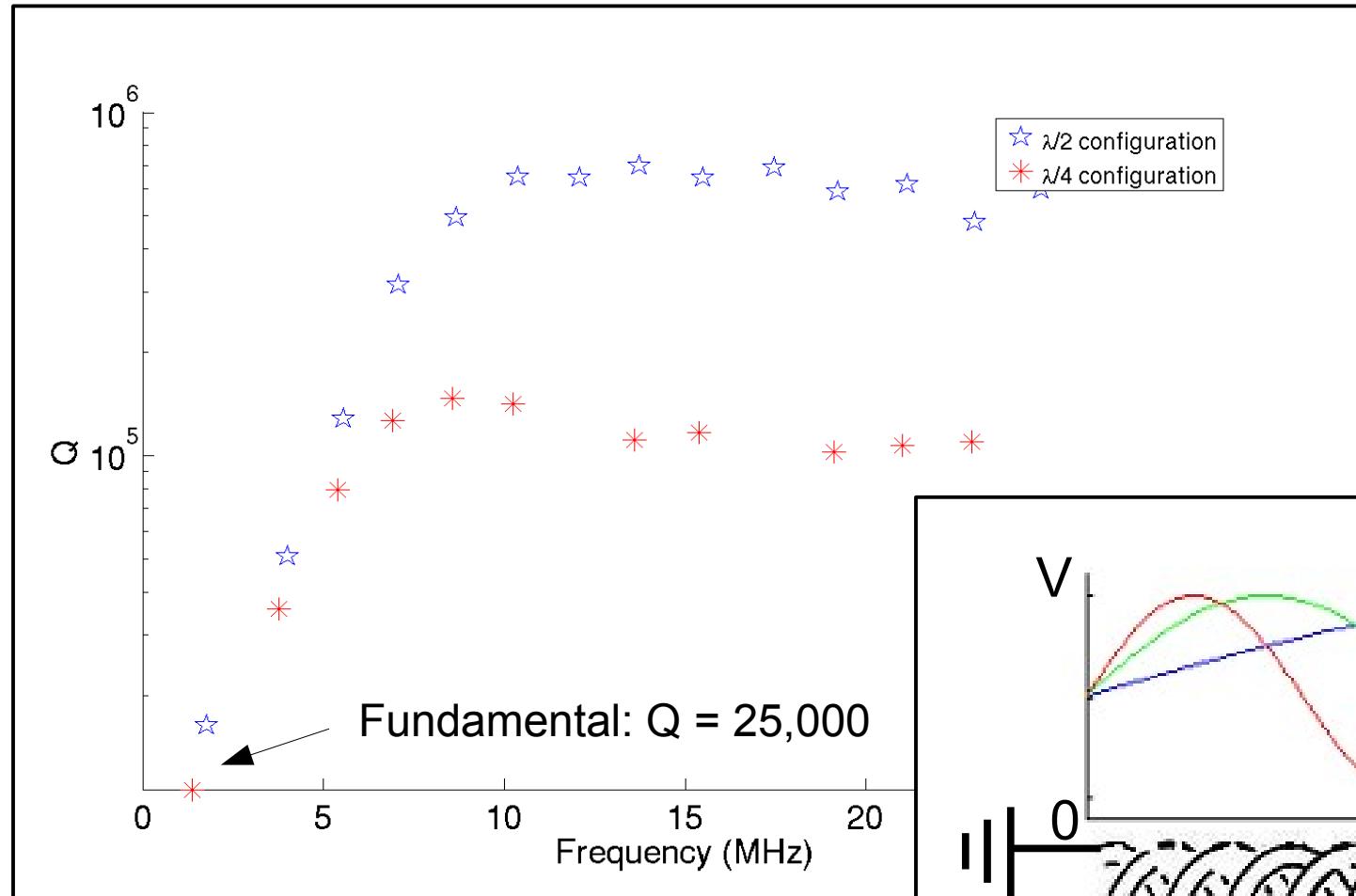


# Quality factor of the resonator





# Quality factor of the resonator





# Coupling an ion to a resonator mode



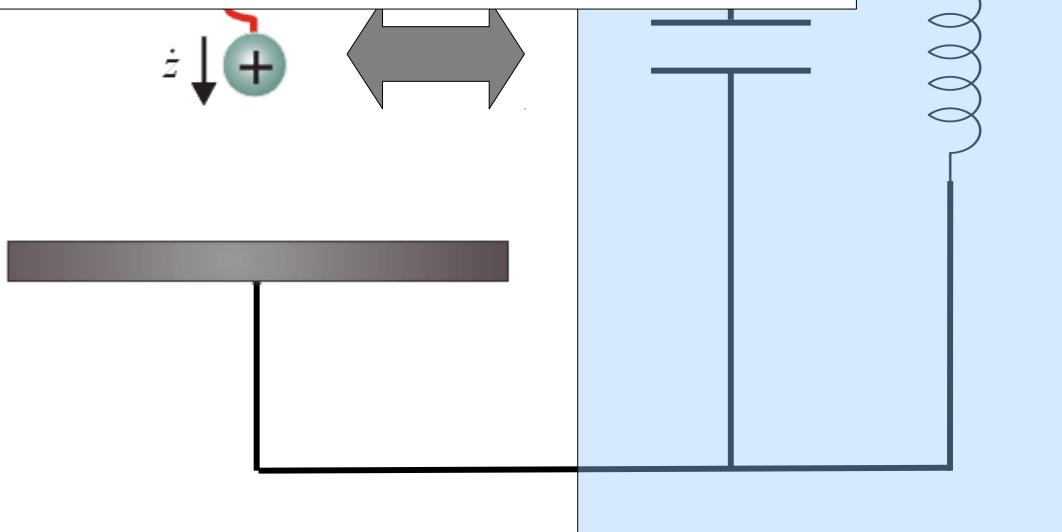
Pick-up electrode distance: 100  $\mu\text{m}$

Resonator / ion frequency: 5 MHz

Ion-resonator coupling:  $2\pi \times 2 \text{ kHz}$

Resonator Q: 100,000

Resonator damping: 300 1/s





# Coupling an ion to a resonator mode



Pick-up electrode distance:  $100 \mu\text{m}$

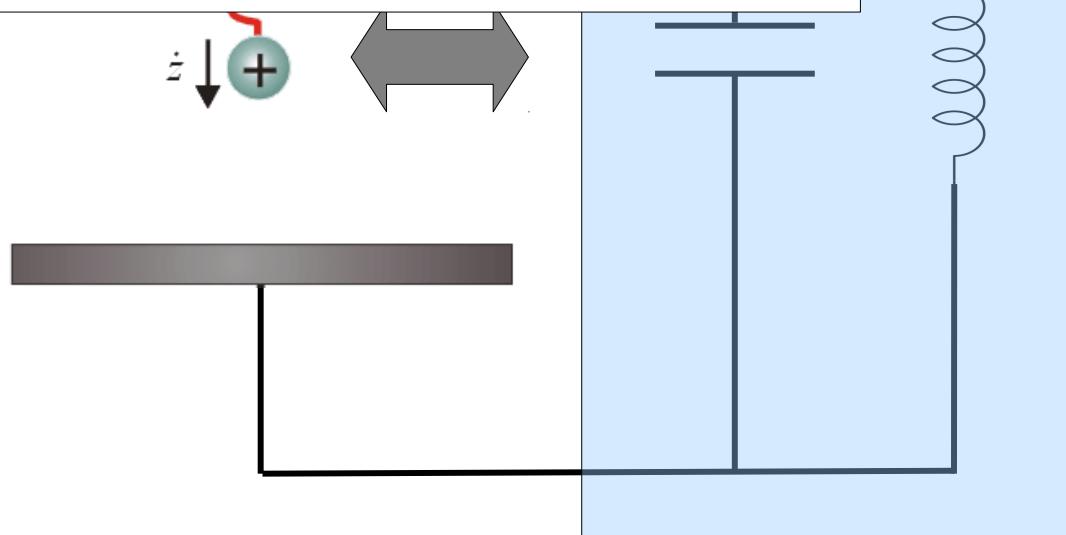
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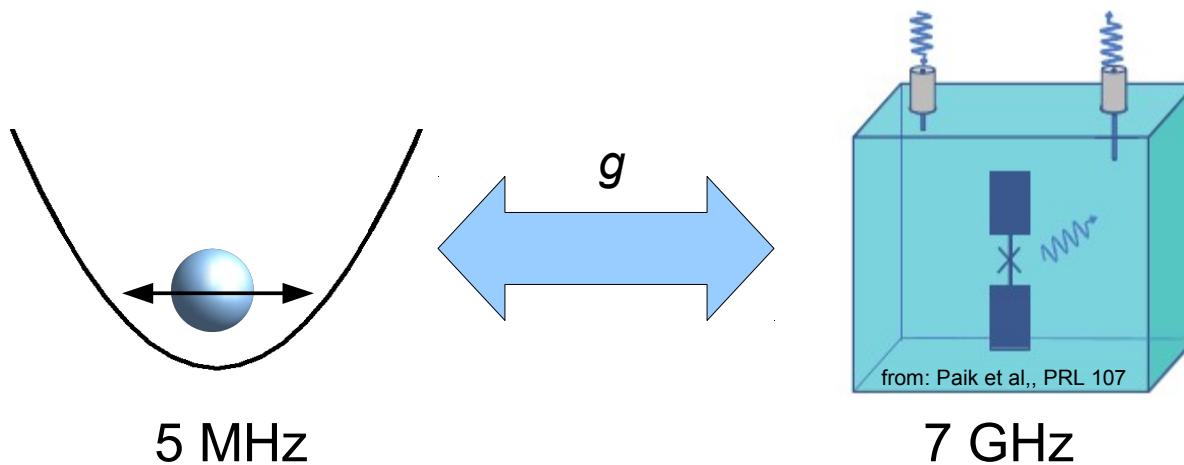
Resonator damping:  $300 \text{ 1/s}$

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





# Coherent coupling



Challenges:

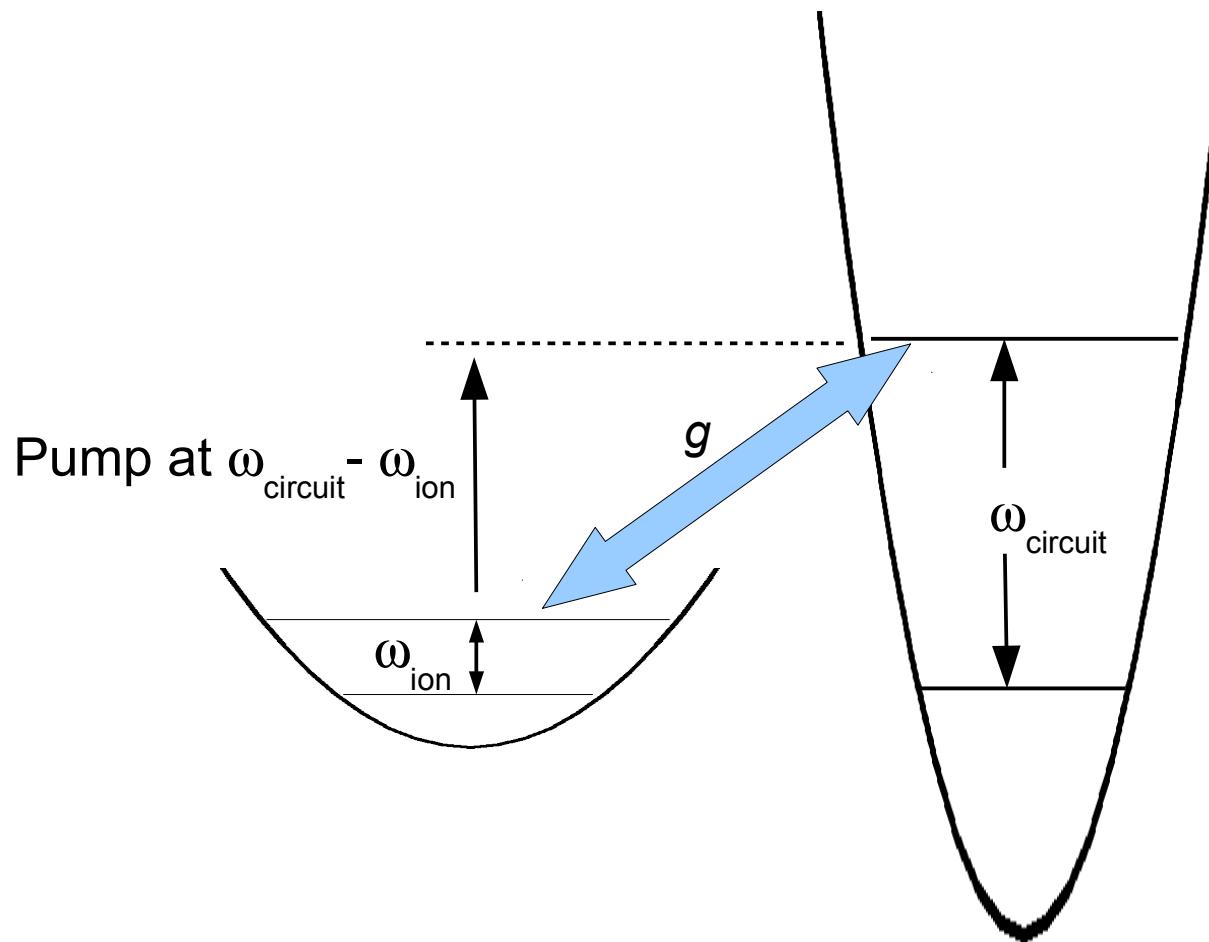
- Impedance mismatch
- Frequency mismatch



# Quantum mixing



## Parametric upconversion



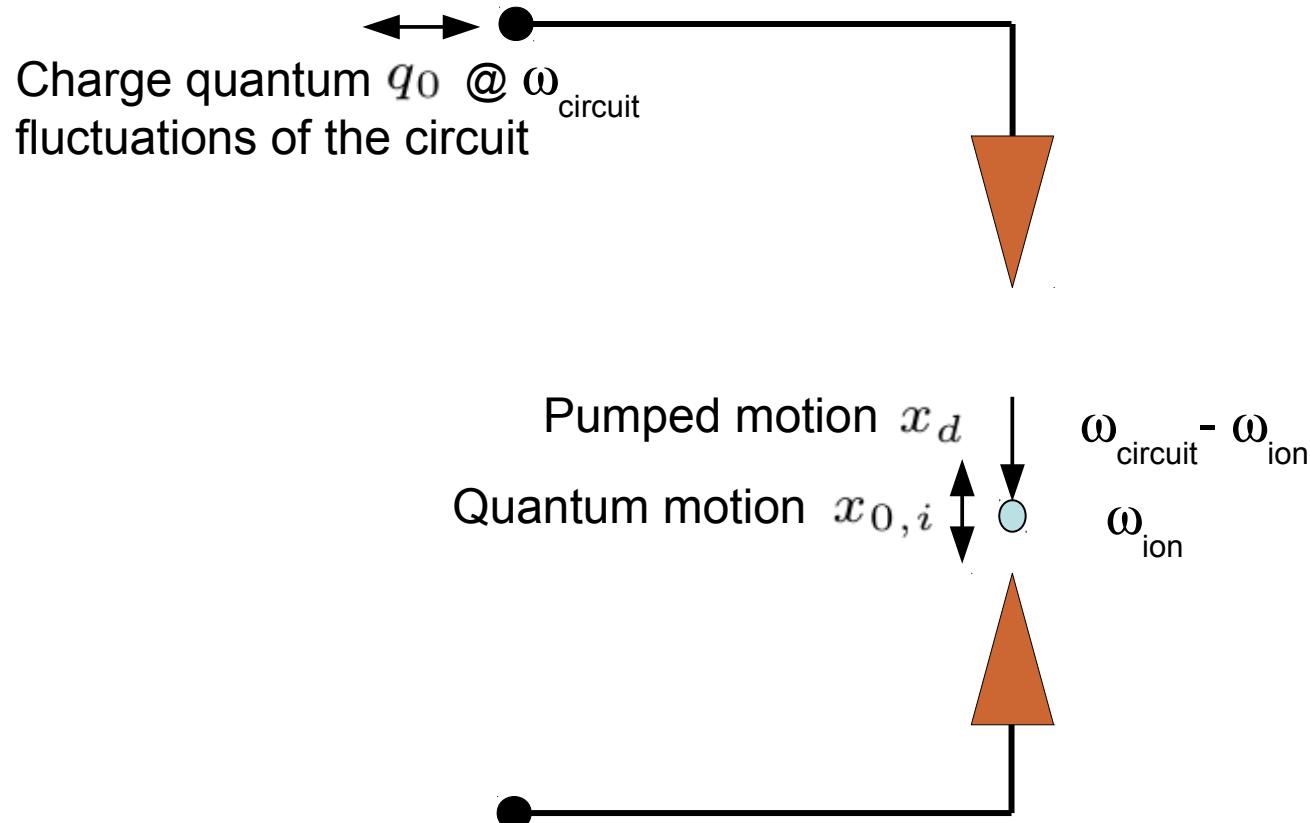


# Quantum mixing

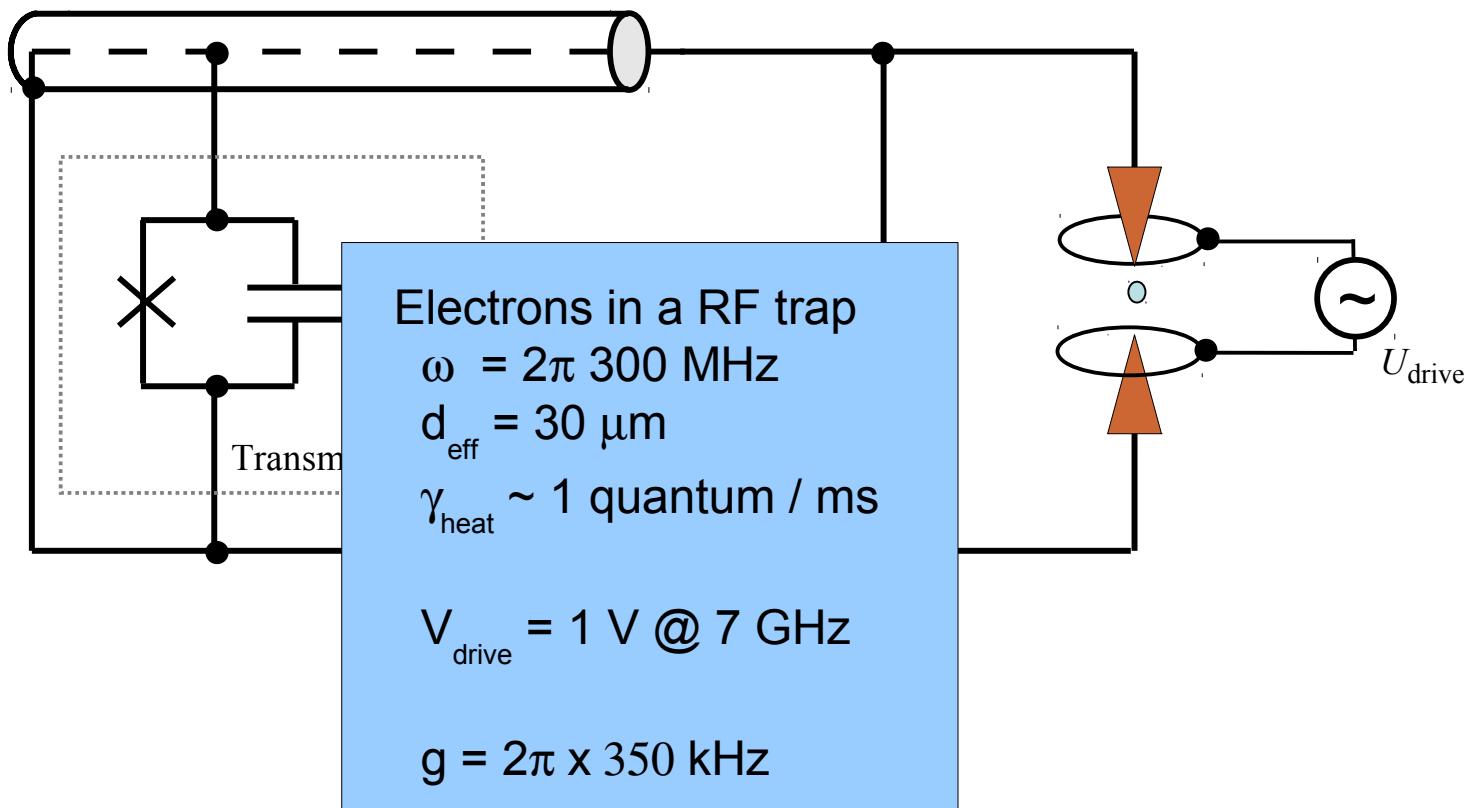


Parametric upconversion using a nonlinear induced current

→ side bands of the quantum motion on the pump field

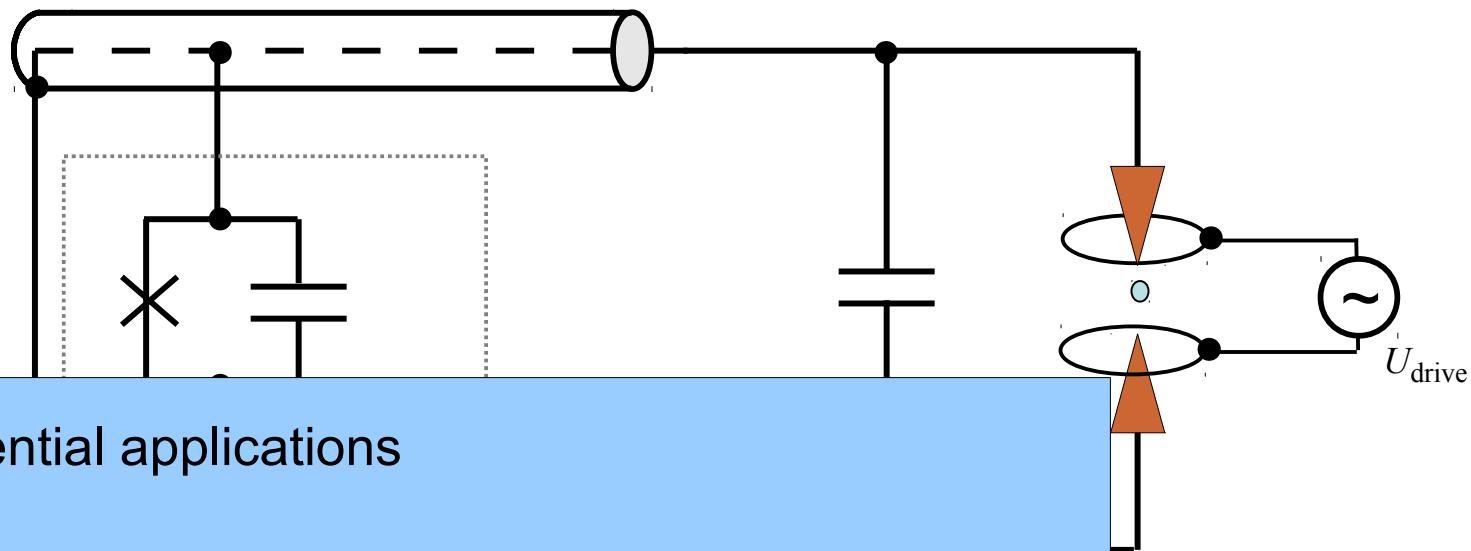


# Quantum mixing





# Quantum mixing



## Potential applications

- quantum memory for JJ-qubits of seconds in the electron spin
- electron quantum information processing
- cooling of charged particles for precision measurements

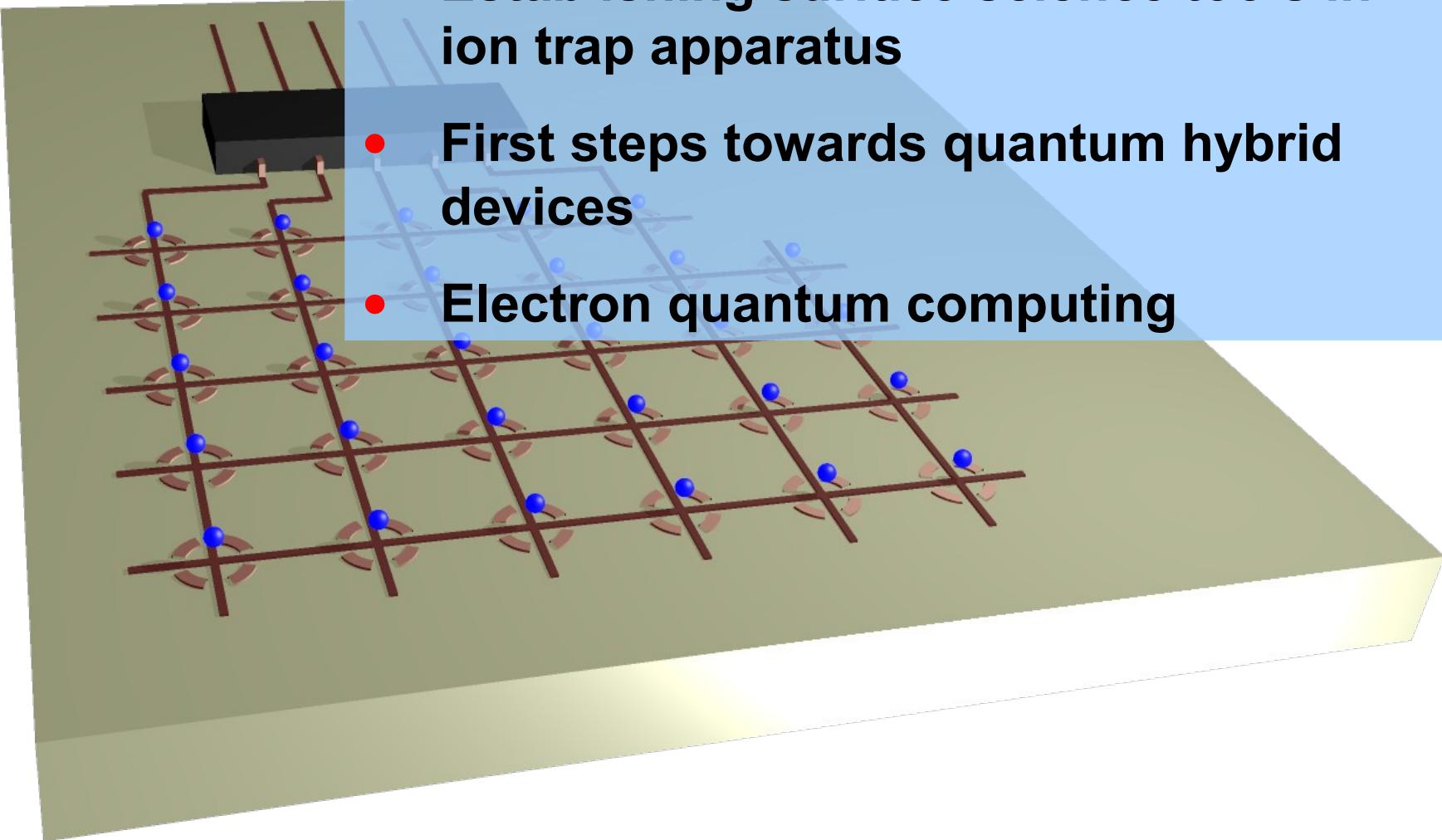


# Summary



## 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



June 9-14, 2013

