Trapped-ion quantum information in 2-dimensional Penning trap arrays

S. Jain, JA, M. Grau & J. Home, arXiv:1812.06755

IONPEN

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Trapped ions in RF traps

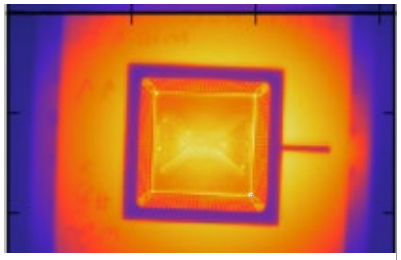
1. **Long-lived quantum coherence,**
2. **High fidelity laser control**
3. **Long-range Coulomb interaction**

Largest quantum computers (10 qubits) + simulators (50 qubits) (eg. Blatt, Monroe)

Work-horse: Radio-Frequency Paul trap $V_{\mathrm{static}}(\mathbf{r}) + \Phi_{\mathrm{RF}}(\mathbf{r})$

Challenges to scaling + flexibility:

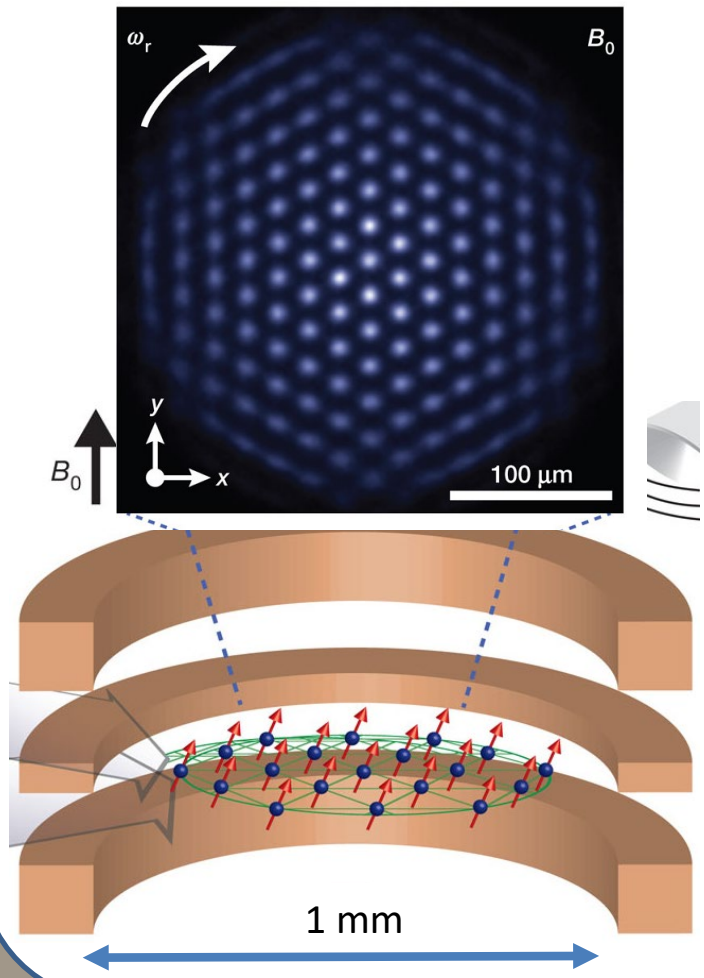
- **RF potential <u>inherently 1-D</u>**
- **Precise co-alignment of <u>*inhomogeneous*</u> RF + static potentials**
- **RF <u>power dissipation</u>**



Heatmap: Sandia NL

Macroscopic Penning traps

J. J. Bollinger, NIST



$$V_{\text{static}}(\mathbf{r}) + \{\mathbf{B}\}$$

Homogeneous magnetic field

REPORT

Quantum spin dynamics and entanglement generation with hundreds of trapped ions

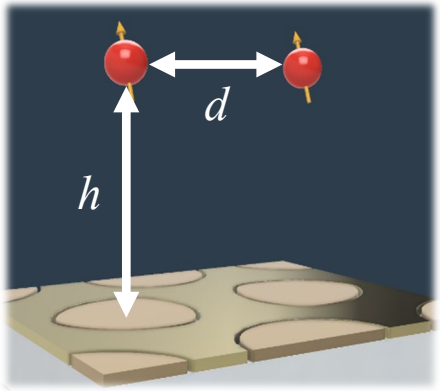
Science 352, 6291 (2016)

Global potential:

- **Fixed natural lattice**
- **Crystal rotation at 60 kHz**
- **Low frequency vibrations**
- **Inherently unscalable**

IONPEN quantum simulations

Micro-potentials $\sum_i V_i(\mathbf{r}_i) + \{\mathbf{B}\}$



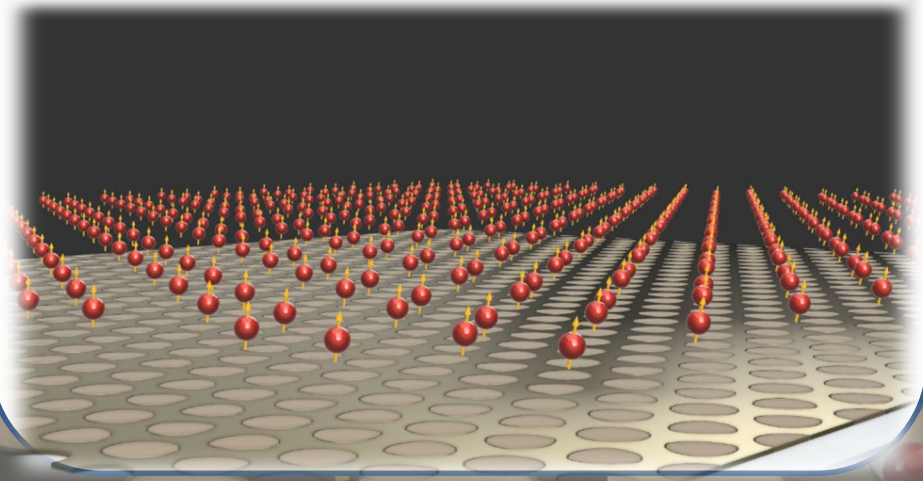
Coupled ion oscillations on infinite lattice

$$\Omega_{\text{exchange}}/(2\pi) >> \dot{\bar{n}}$$

$$\left(h = 30\ \mu\text{m}, d = 15\ \mu\text{m}, \text{Be}^+\right)$$

Electrode + B field geometry

- Kagome, tri-angular, hexagonal lattices
- (An)isotropy of motional coupling

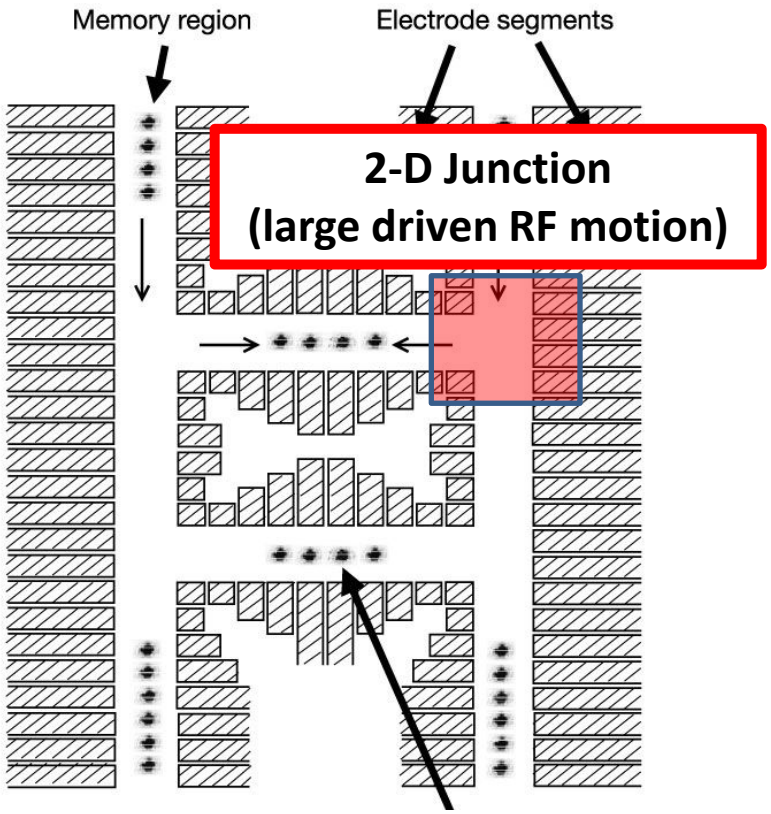


Scalable array of static potentials: 1 cm^2 chip can hold 444,000 ion traps!

IONPEN quantum computing

Scalable architecture

RF trap Quantum CCD (Wineland 1998)

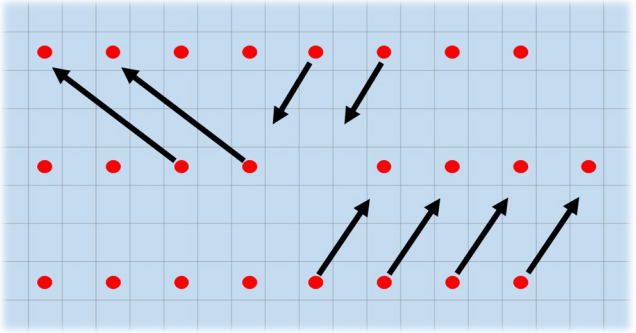


$$\sum_i V_i(\mathbf{r}_i, t) + \{\mathbf{B}\}$$

Homogeneous

***IONPEN* Quantum CCD**

2-D transport at any position



Parallel operations essential for error-correction

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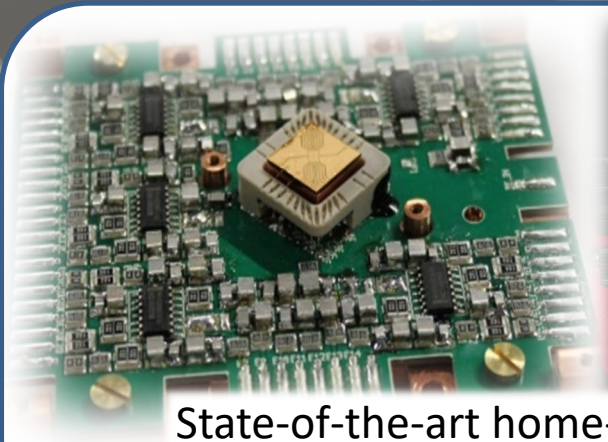
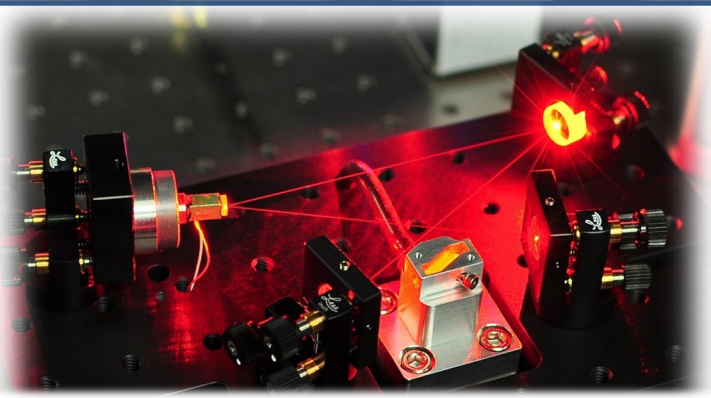
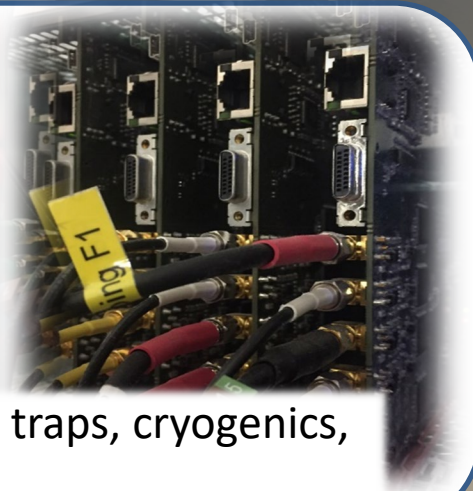
Access to great students, workshops, engineers







State-of-the-art home-built technologies: micro-fabricated traps, cryogenics, laser systems, computer control + electronics