Experimental Quantum Computing Progress

in a Pre-Quantum World

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Laboratory for Physical Sciences

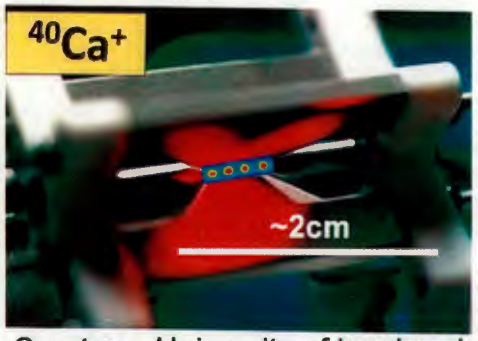
Status Update

Trapped-Ion Qubits

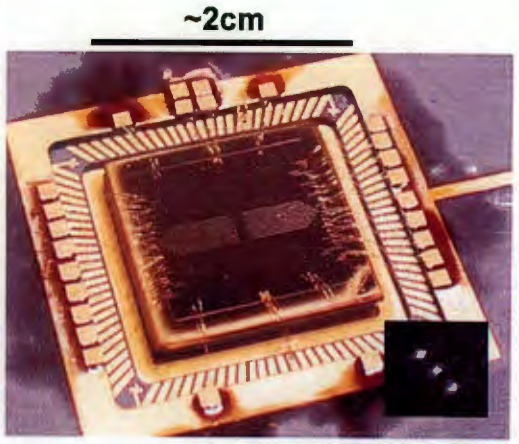
References:

Oxford 2014a:	Physical Review Letters **113** 220501
Oxford 2014b:	arXiv:1406.5473
Innsbruck 2014:	Science **345** p302

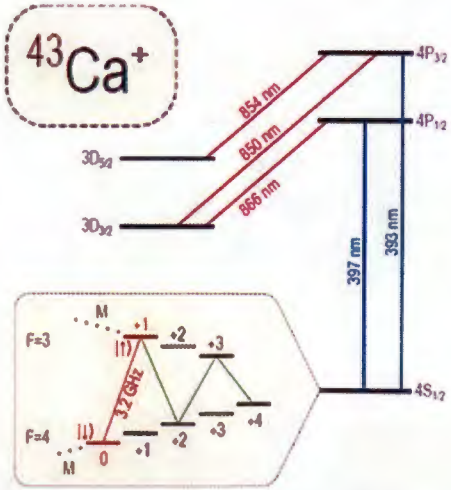
- **Single Qubit Gates**
  - Speed: 12 μs (Oxford 2014a)
  - Fidelity: 99.9999% (Oxford 2014a)
- **Number of Single Qubit Gates**
  - 2000 (Oxford 2014a)
- **Two Qubit Gates**
  - Speed: 100μs (Oxford 2014b)
  - Fidelity: 99.9% (Oxford 2014b)
- **Qubit Numbers**
  - Seven fully controlled (Innsbruck 2014)
  - Singles and pairs common (NIST, Univ. Maryland, Sandia, Duke,...)



Courtesy: University of Innsbruck
Bulk Ion Trap



Courtesy: Oxford University
Surface Trap



Courtesy: Oxford University
Atomic Energy Spacing

Selected for a Viewpoint in *Physics*
PRL 113, 220501 (2014) PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2014

High-Fidelity Preparation, Gates, Memory, and Readout of a Trapped-Ion Quantum Bit

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(Received 19 May 2014; revised manuscript received 2 September 2014; published 24 November 2014)

preparation/readout operation	error
stretch state $S_{1/2}^{4,+4}$ preparation	$< 1 \times 10^{-4}$
transfer to qubit (3 or 4 m.w. π-pulses)	1.8×10^{-4}
transfer from qubit (4 m.w. π-pulses)	1.8×10^{-4}
shelving transfer $S_{1/2}^{4,+4} \rightarrow D_{5/2}$	1.7×10^{-4}
time-resolved fluorescence detection	1.5×10^{-4}

single-qubit gate error source	mean EPG
microwave detuning (4.5 Hz)	0.7×10^{-6}
microwave pulse area (5×10^{-4})	0.3×10^{-6}
off-resonant effects	0.1×10^{-6}

Status Update

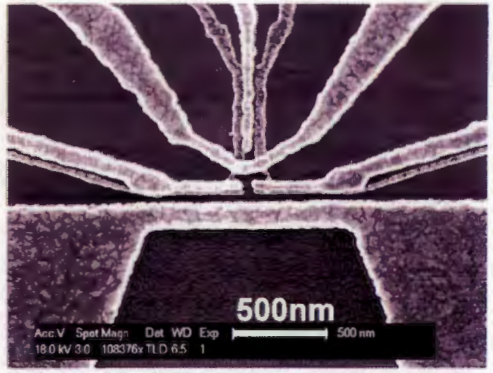
Silicon Qubits

References:

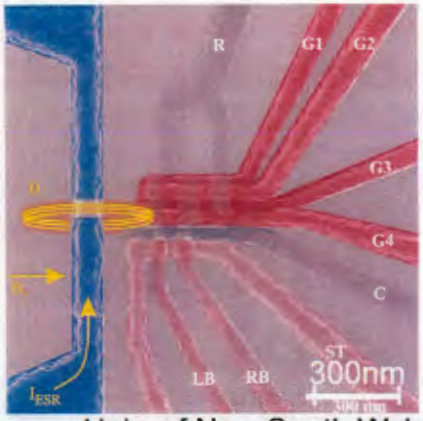
UNSWa: J. Phys: Cond. Matt. 27 154205

UNSWb: arXiv:1411.5760

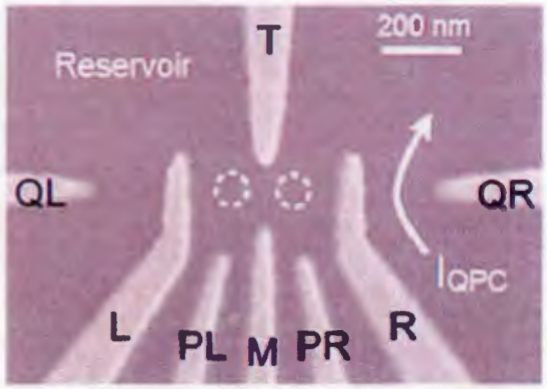
- Single Qubit Gates (UNSWa)
  - Speed: 30μs
  - Fidelity: 99.9%
- Number of Single Qubit Gates (UNSWa)
  - 400
- Two Qubit Gates(UNSWb)
  - Speed: 130ns
  - Fidelity: 99%
- Qubit Numbers(UNSWb)
  - Two max
  - Only a few labs have demonstrated silicon qubits



Courtesy: Univ. of New South Wales
Silicon Dopant -



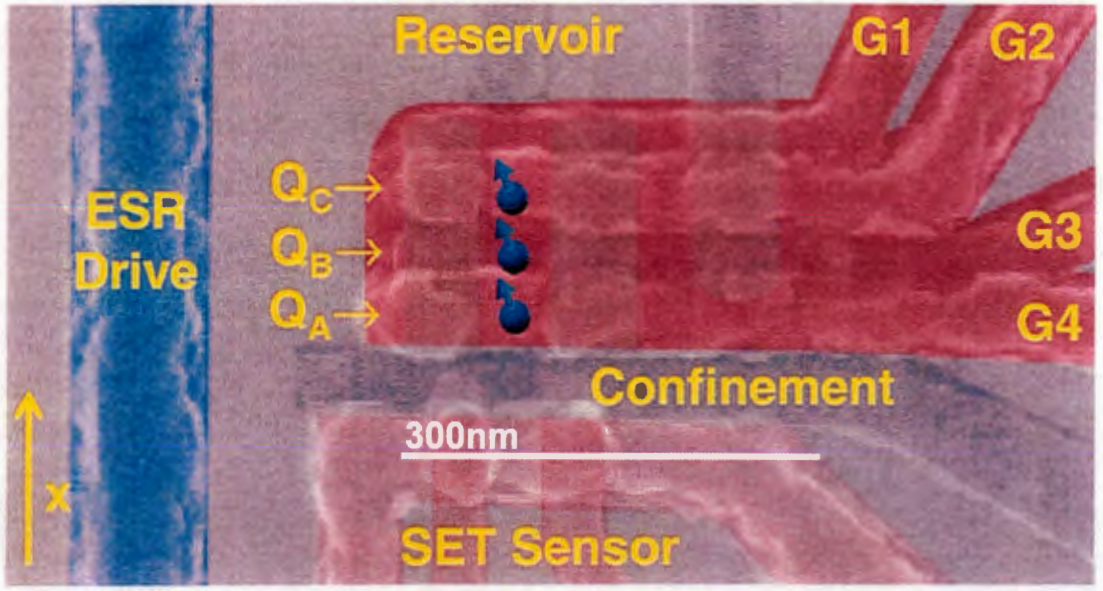
Courtesy: Univ. of New South Wales
Silicon MOS Quantum Double Dot

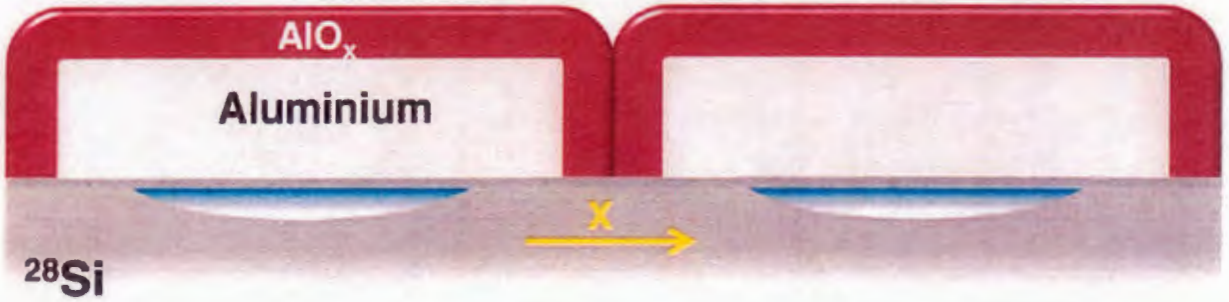


Courtesy: University of Wisconsin
Si/SiGe Quantum Double Dot

Silicon Qubits – U. New South Wales

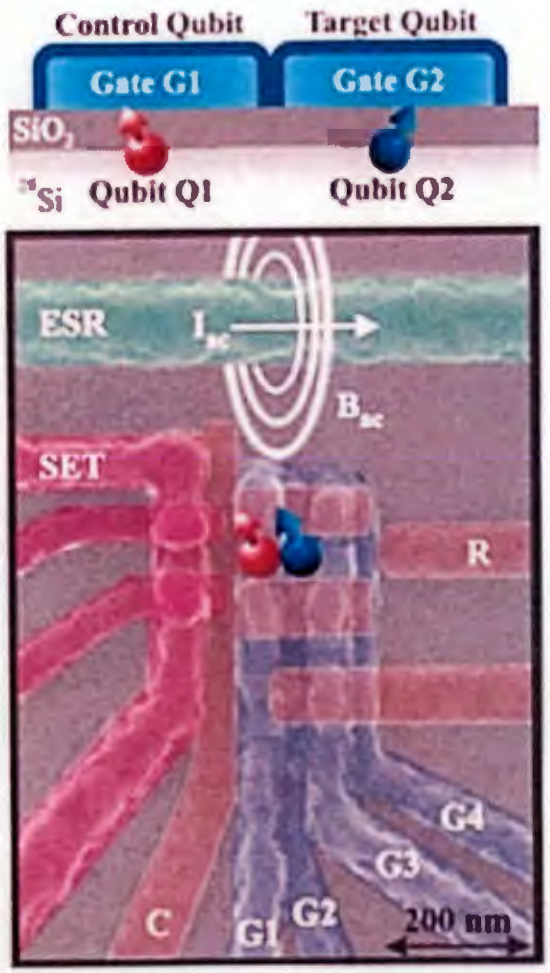
Device Geometry for Confining Single Electrons

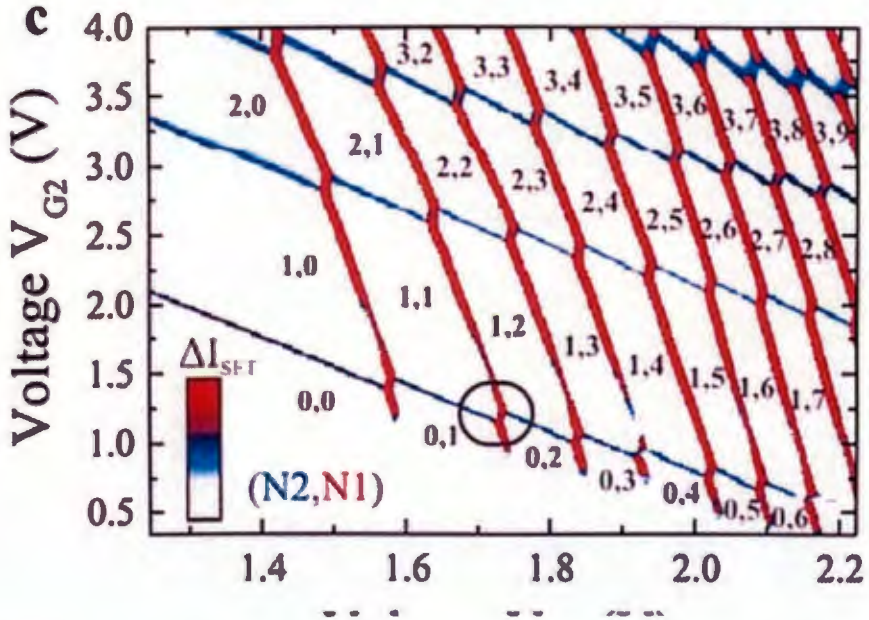


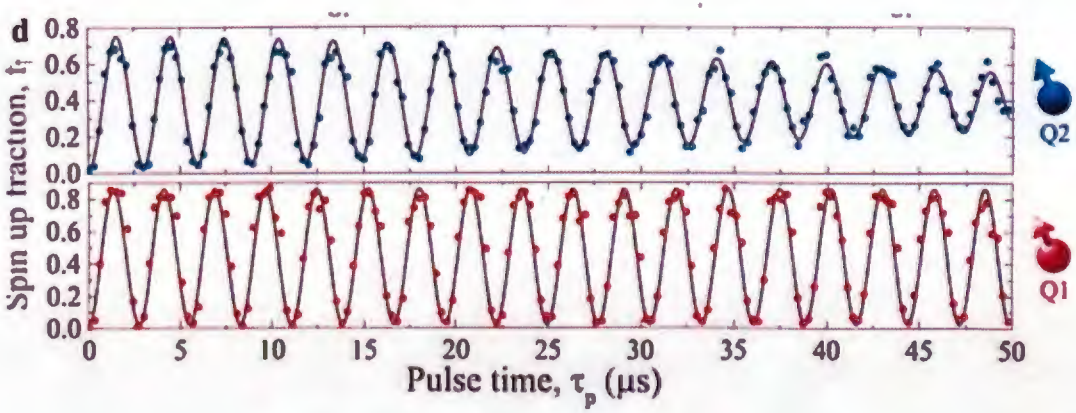


Silicon Qubits – U. New South Wales

Two-Qubit Characterization



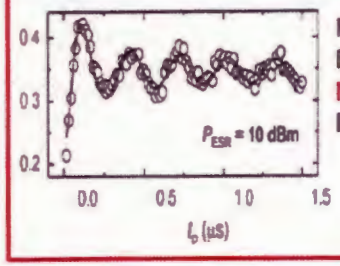




Silicon Qubits – U. New South Wales

Significant Impact of Enriched Silicon

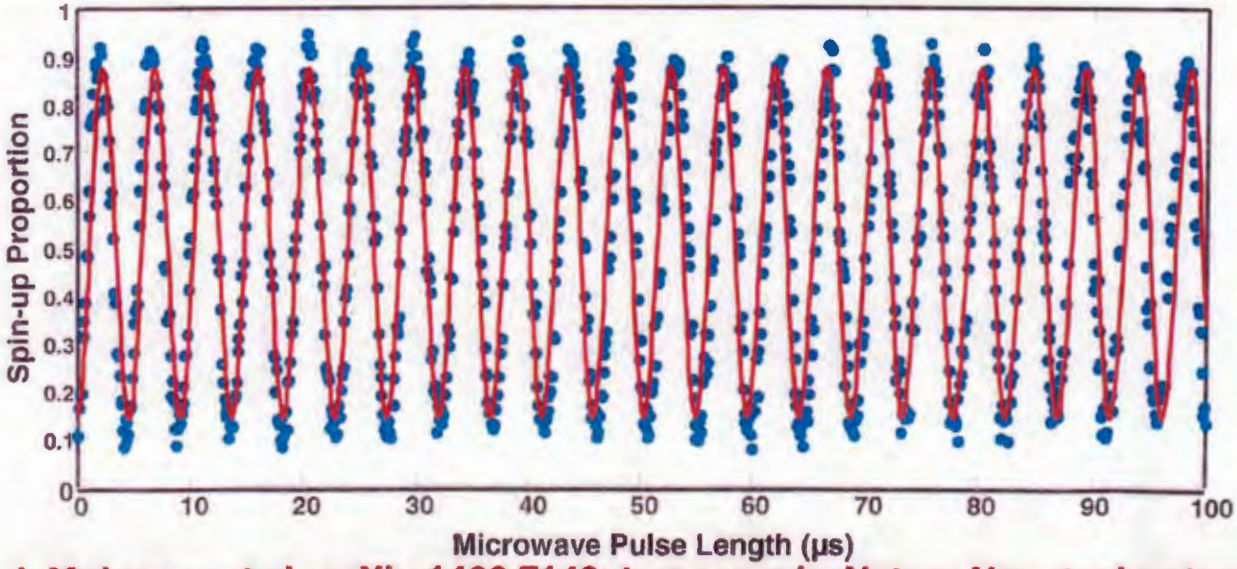
Implanted ^{31}P Electron Spin Qubit in ^{28}Si



P-atom Implanted
Electron Spin Qubit
Natural Silicon, 5% ^{29}Si
Pla et al, Nature (2012)
Rabi oscillations
$T_2^* = 55$ ns

P-atom Implanted
Electron Spin Qubit
^{28}Si Epilayer
Enriched to 99.9%

- Via Kohei Itoh,
Keio University, Japan



J. Muhonen et al., arXiv:1402.7140; to appear in *Nature Nanotechnology*

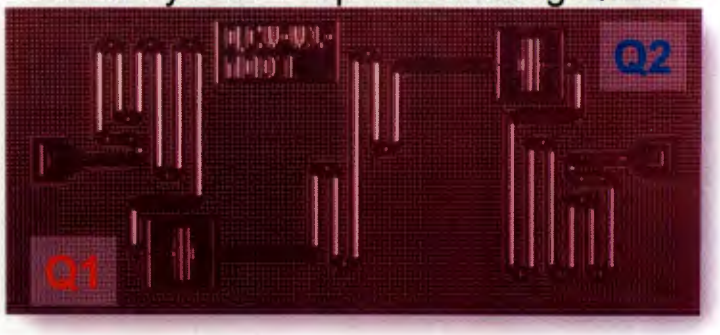
Status Update

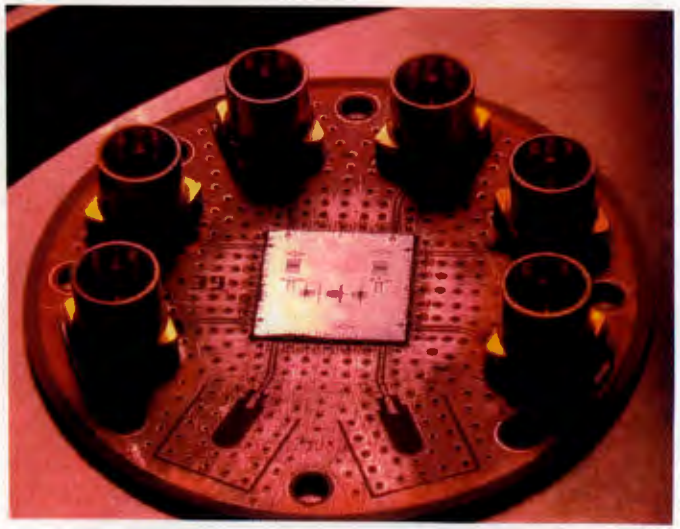
Superconducting Qubits

References:
UCSBa 2014: Nature 508 p500
UCSBb 2014: Nature 519 p66

- Single Qubit Gates (UCSBa 2014)
  - Speed: 20ns
  - Fidelity: 99.9%
- Number of Single Qubit Gates:
  - 350 (UCSBa 2014)
- Two Qubit Gates (UCSBb 2014)
  - Speed: 40ns
  - Fidelity: 99.4%
- Qubit Numbers (UCSBb 2014)
  - Nine fully controlled
  - Singles and pairs common

Courtesy IBM - Superconducting Qubits

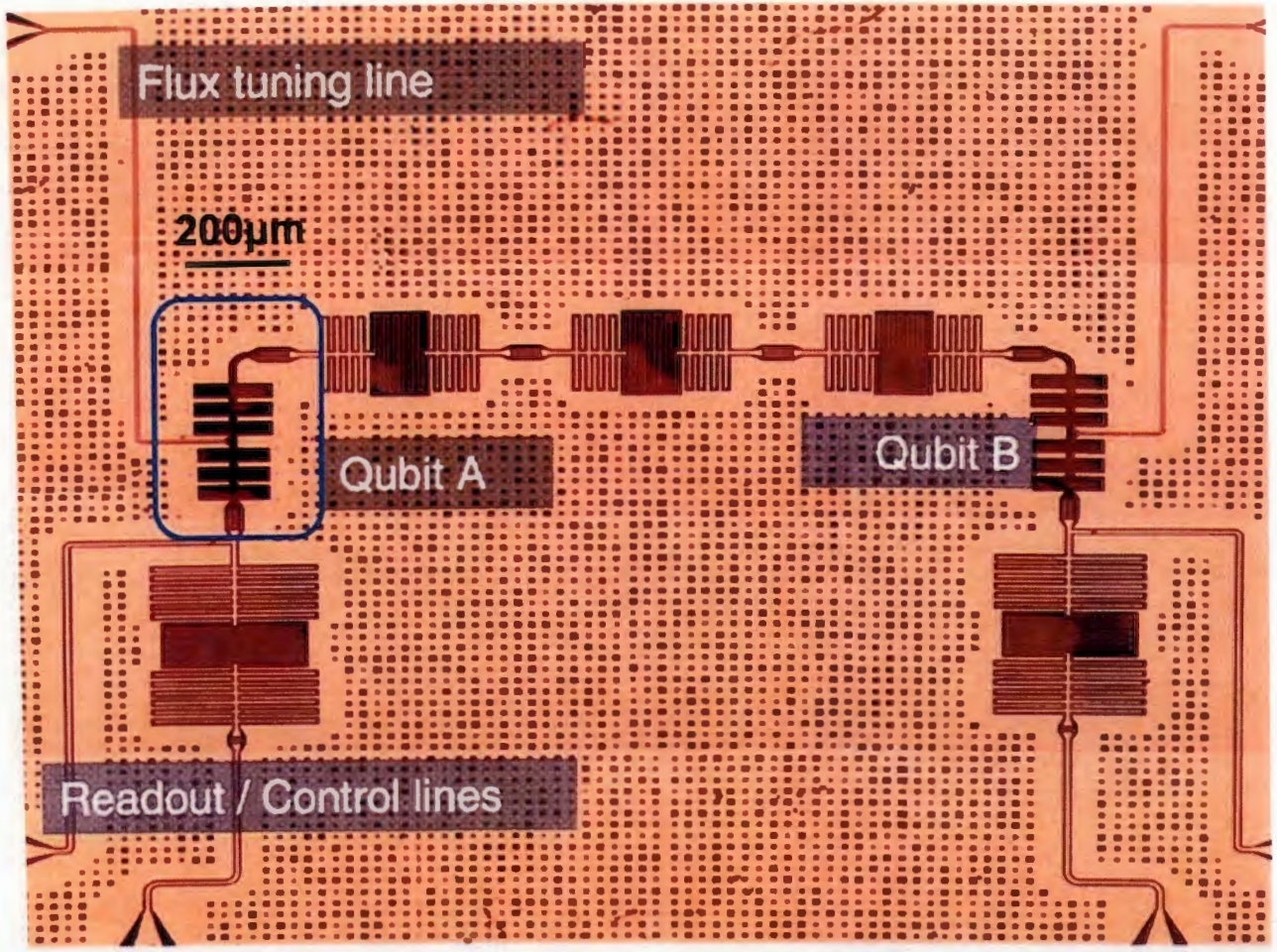




Courtesy University of Chicago
Superconducting Qubits

University of Chicago

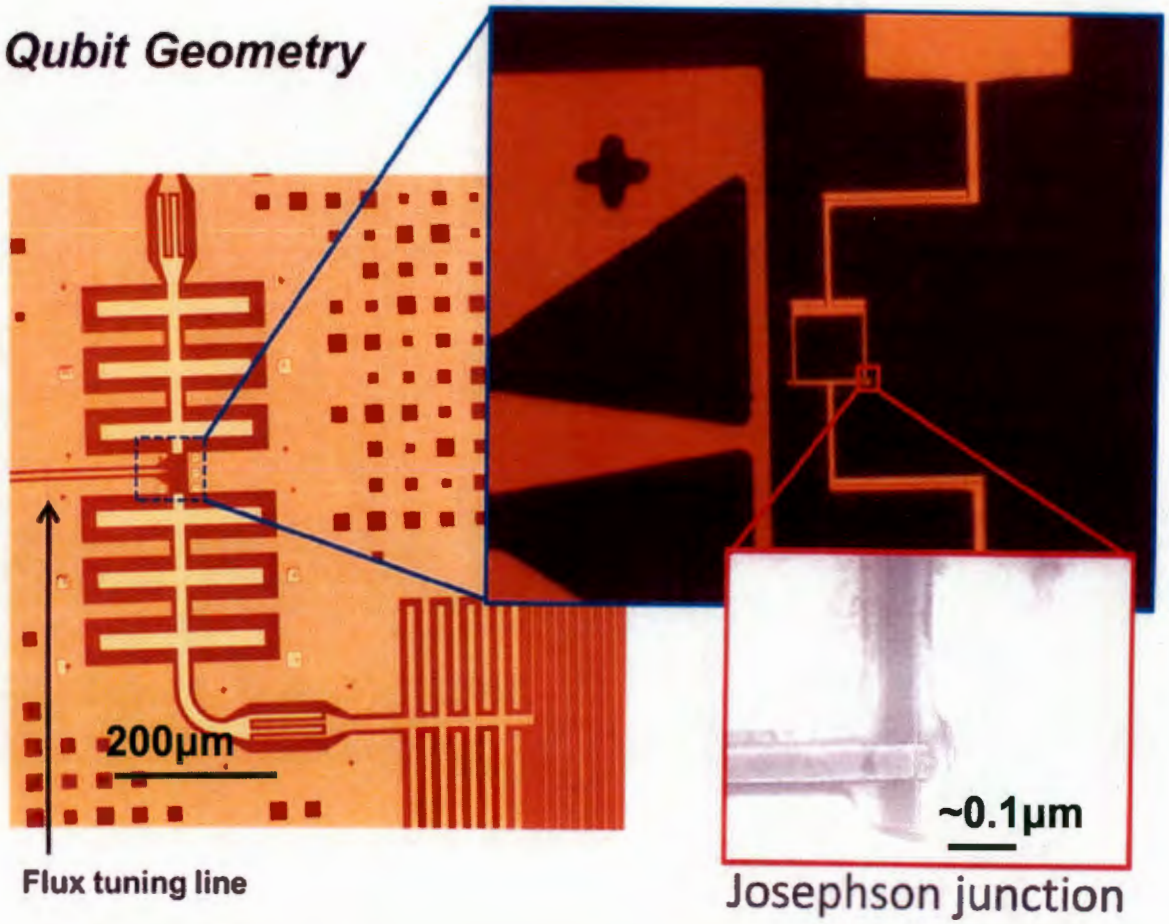
Superconducting Qubit Chip – Close Up



Courtesy of University of Chicago
David Schuster Group

University of Chicago

Superconducting Qubit Chip – Zoom In



Courtesy of University of Chicago
David Schuster Group

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Superconducting Qubit Chip

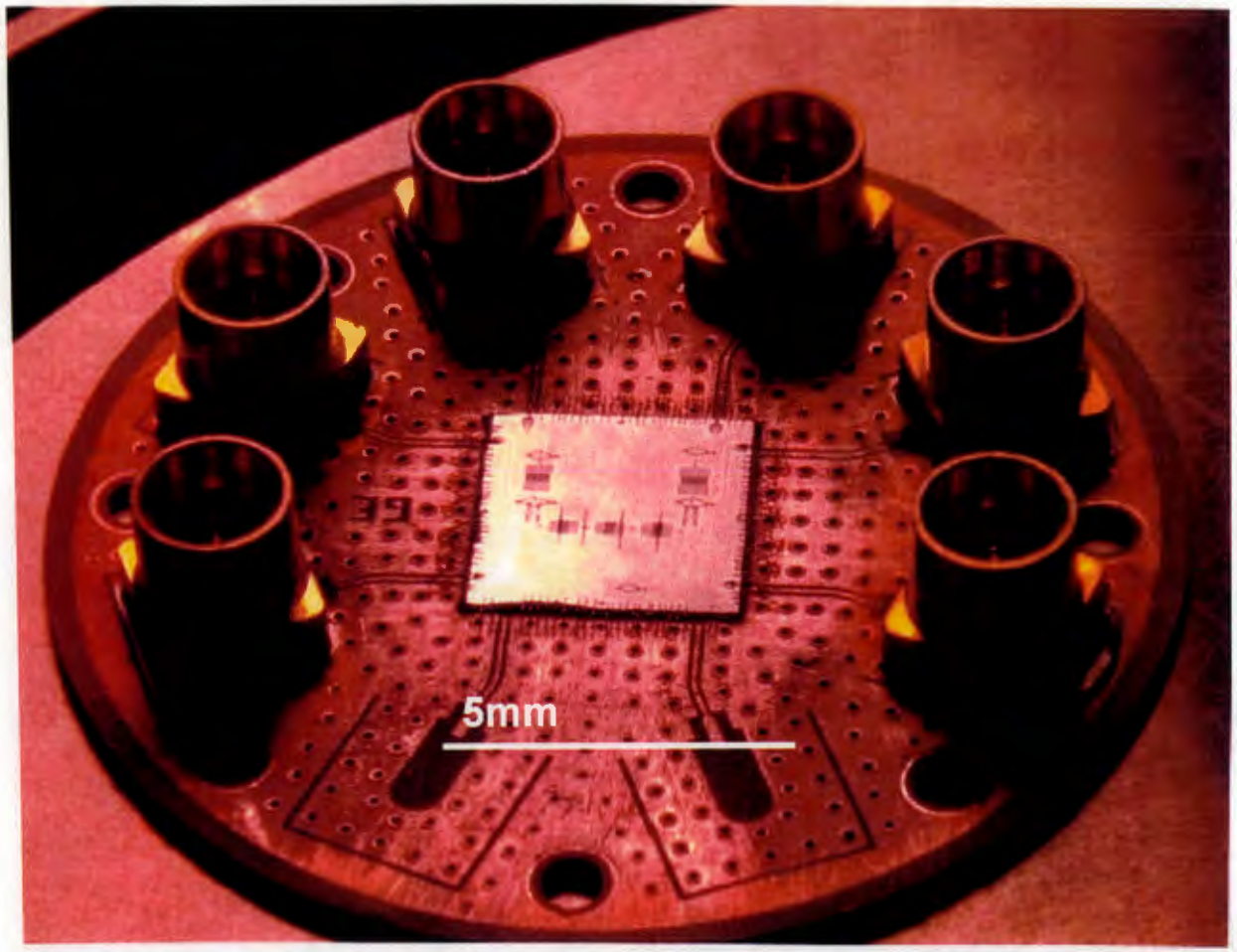

Photo Courtesy of University of Chicago
David Schuster Group

University of Chicago

Experimental Setup

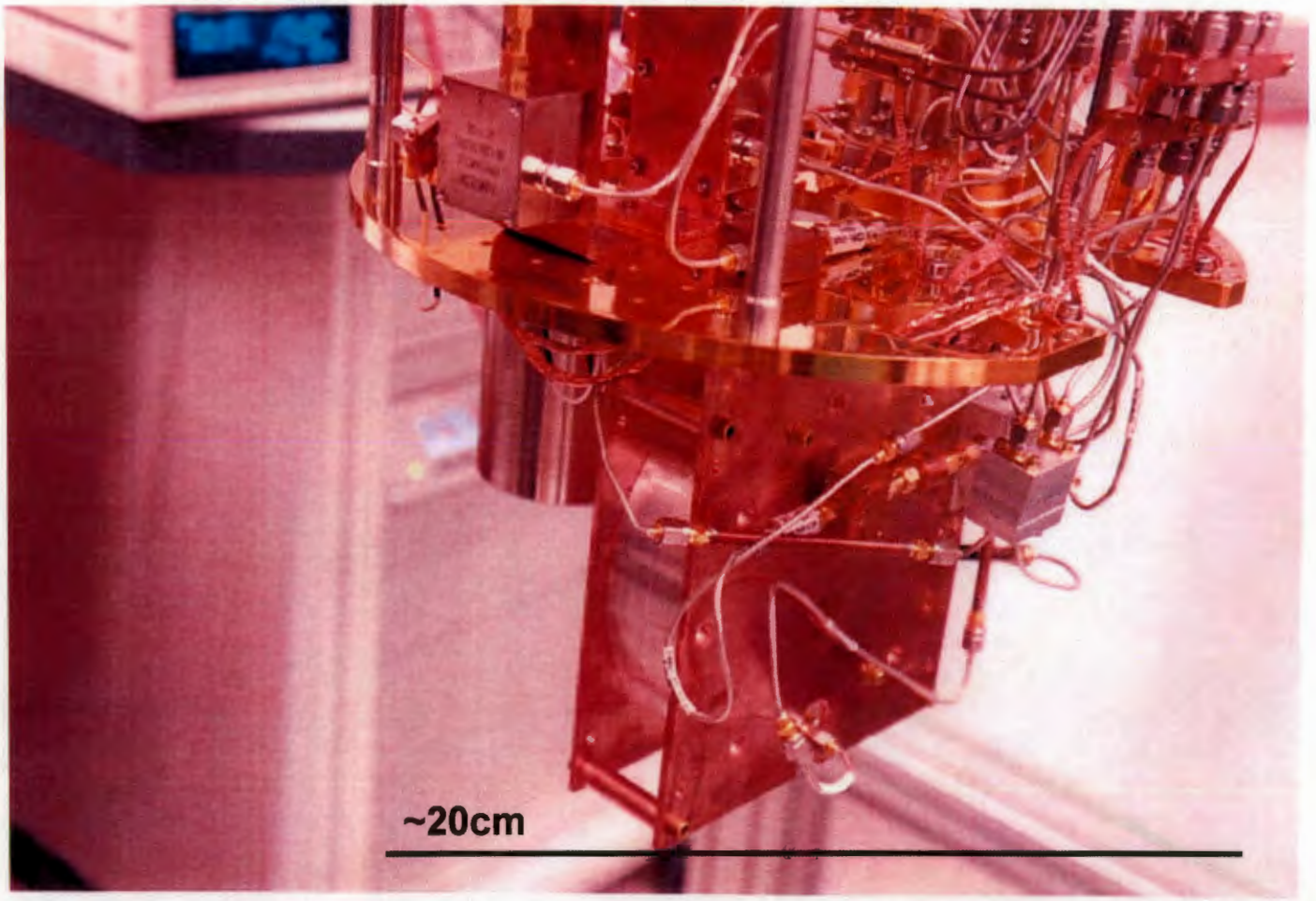

Photo Courtesy of University of Chicago
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