Ion trap quantum computing: future possibilities

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www.qubit.org

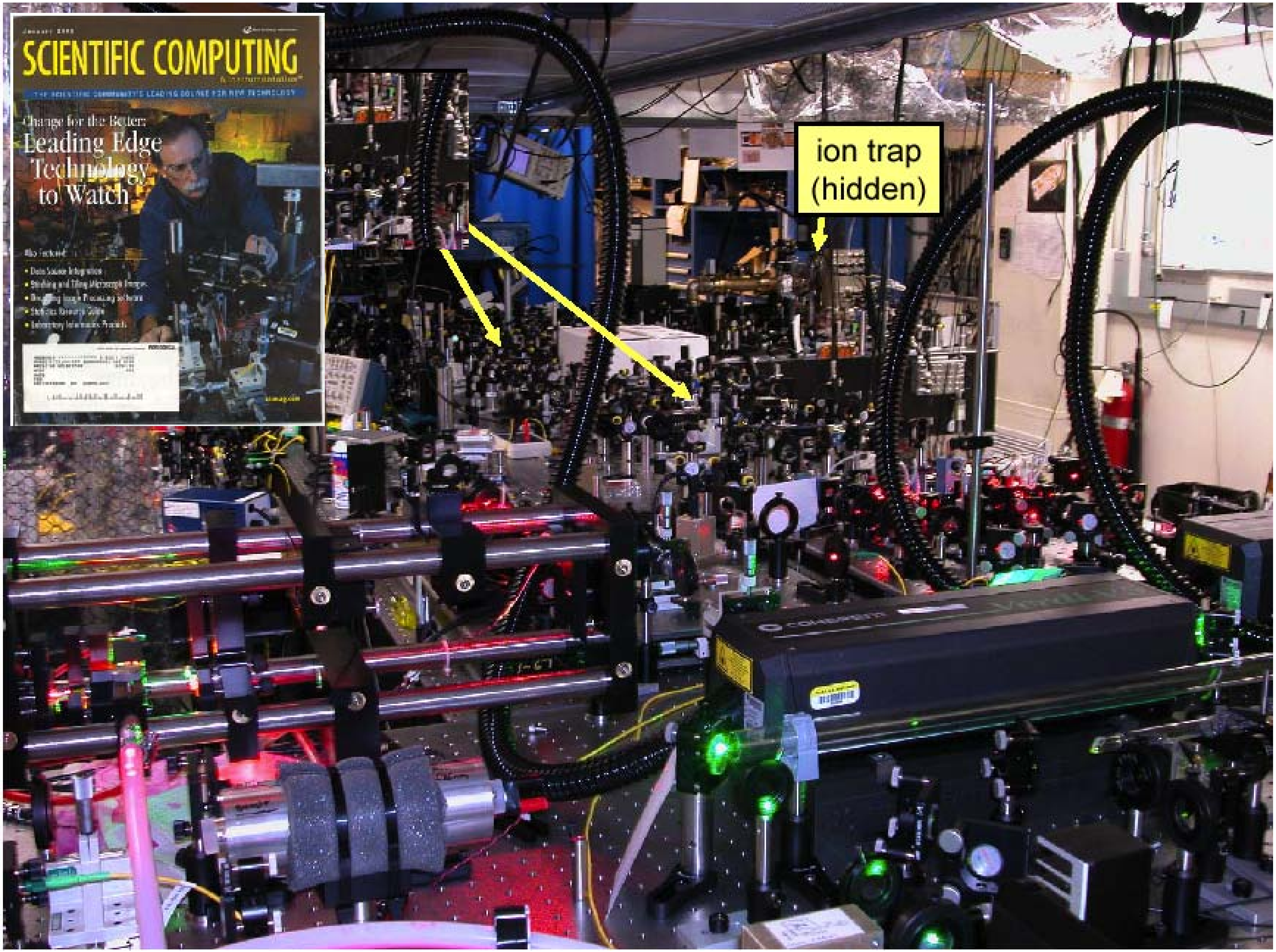
Ion trap strengths/weaknesses

Strengths

- Long coherence time, 1—10 s
- Reliable measurement (already 0.99; 0.999 not hard)
- Transport qubits around the computer (see later)
- Few unknowns
- Distance- and time-scale accessible to control by CMOS

Weaknesses

- slow (gate time tens of μs now, maybe 1 μs future)
- optical part (lasers etc.) far from large-scale integration


SCIENTIFIC COMPUTING
Change for the Better:
Leading Edge Technology to Watch
ion trap (hidden)

Requirements for QEC

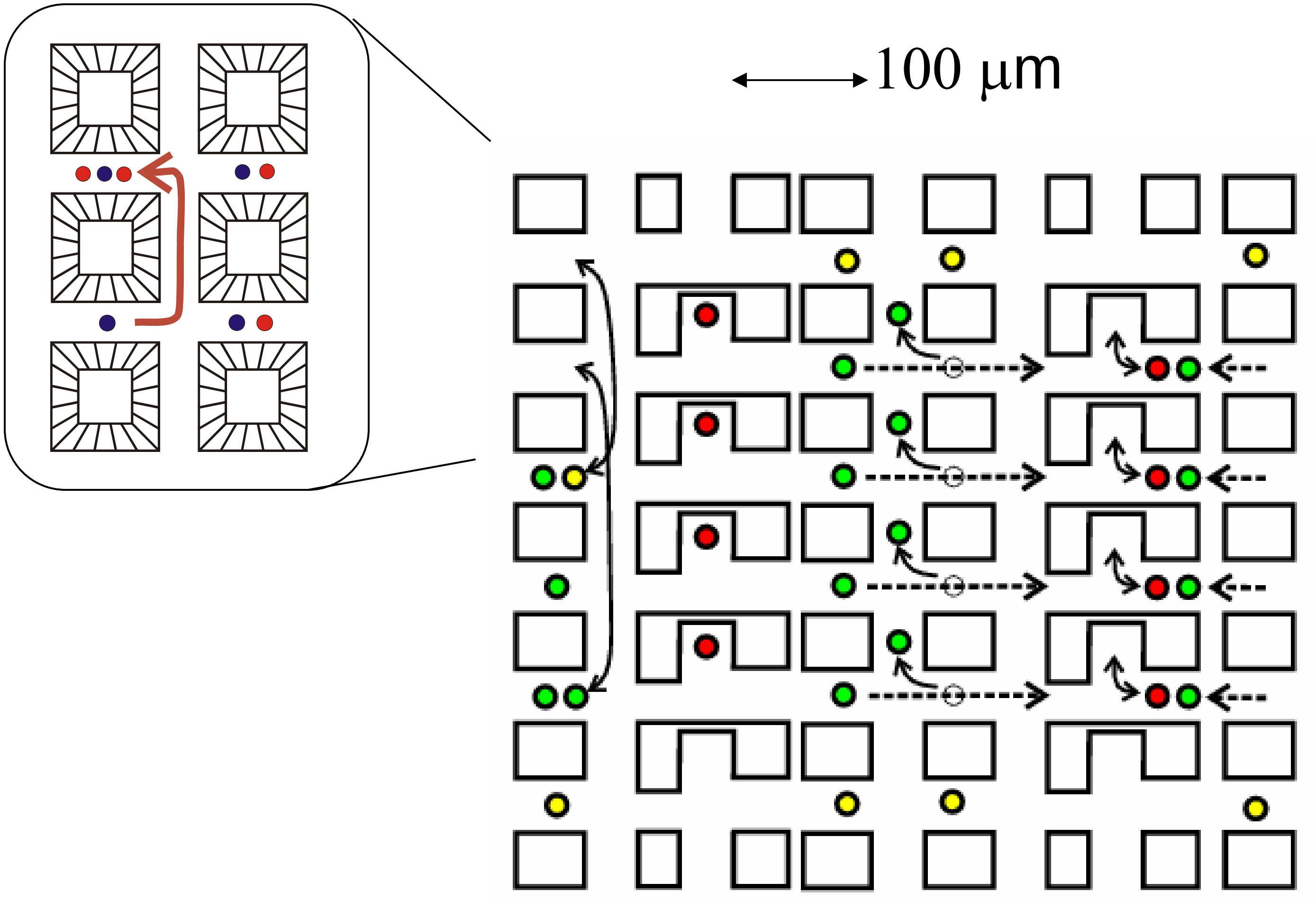
- Most needed operation = **move qubits around**

  2nd -most = 2-qubit gate such as c-phase or c-not

  3rd -most = measurement and single-bit rotation

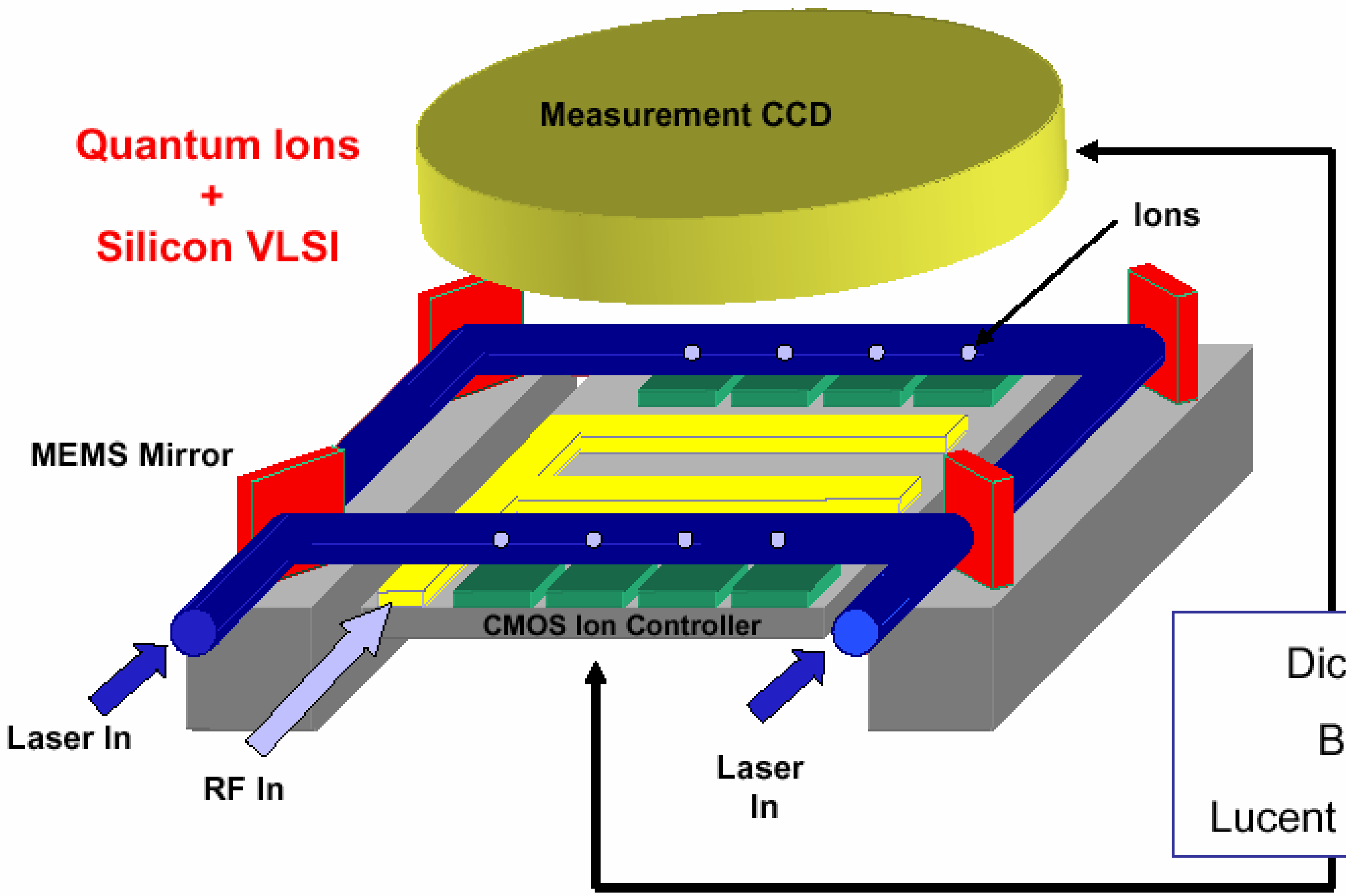
A. Steane, Phys. Rev. A **68**,042322 (2003); Quant.Inf.Comp. **2**,297 (2002).

Moving information around the machine



Kielpinski, Monroe, Wineland
Nature 417,709 (2002)

Scalable Ion Trap Quantum Computer Vision

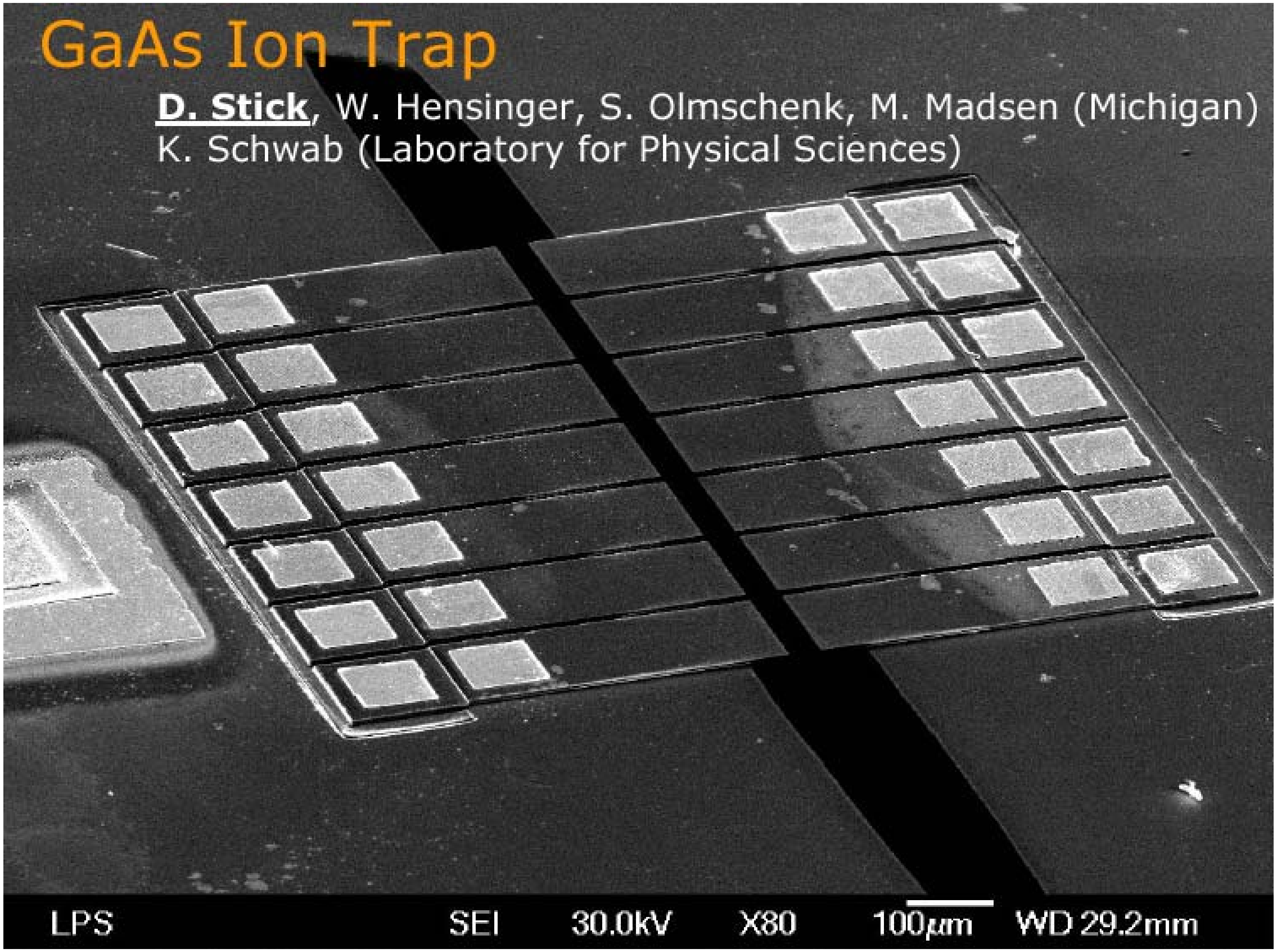


Dick Slusher

Bell Labs

Lucent Technologies

System Compatibility of Quantum & Classical: Spatial Pitch, Clock Speed
Operating Temperature, Power Dissipation


GaAs Ion Trap
D. Stick, W. Hensinger, S. Olmschenk, M. Madsen (Michigan)
K. Schwab (Laboratory for Physical Sciences)
LPS
SEI
30.0kV
X80
100µm
WD 29.2mm

Achievements to date with ion traps

• Single qubits with T2 ' 1 to 10s coherence time (→ 100s with spin echo)

• Typical 2-qubit gate time is 50 μs, so T2/gate time ' 10^5

• Gate fidelity 97% at best.

• Transport of ions over » 1 mm, and around corners, while preserving coherence.

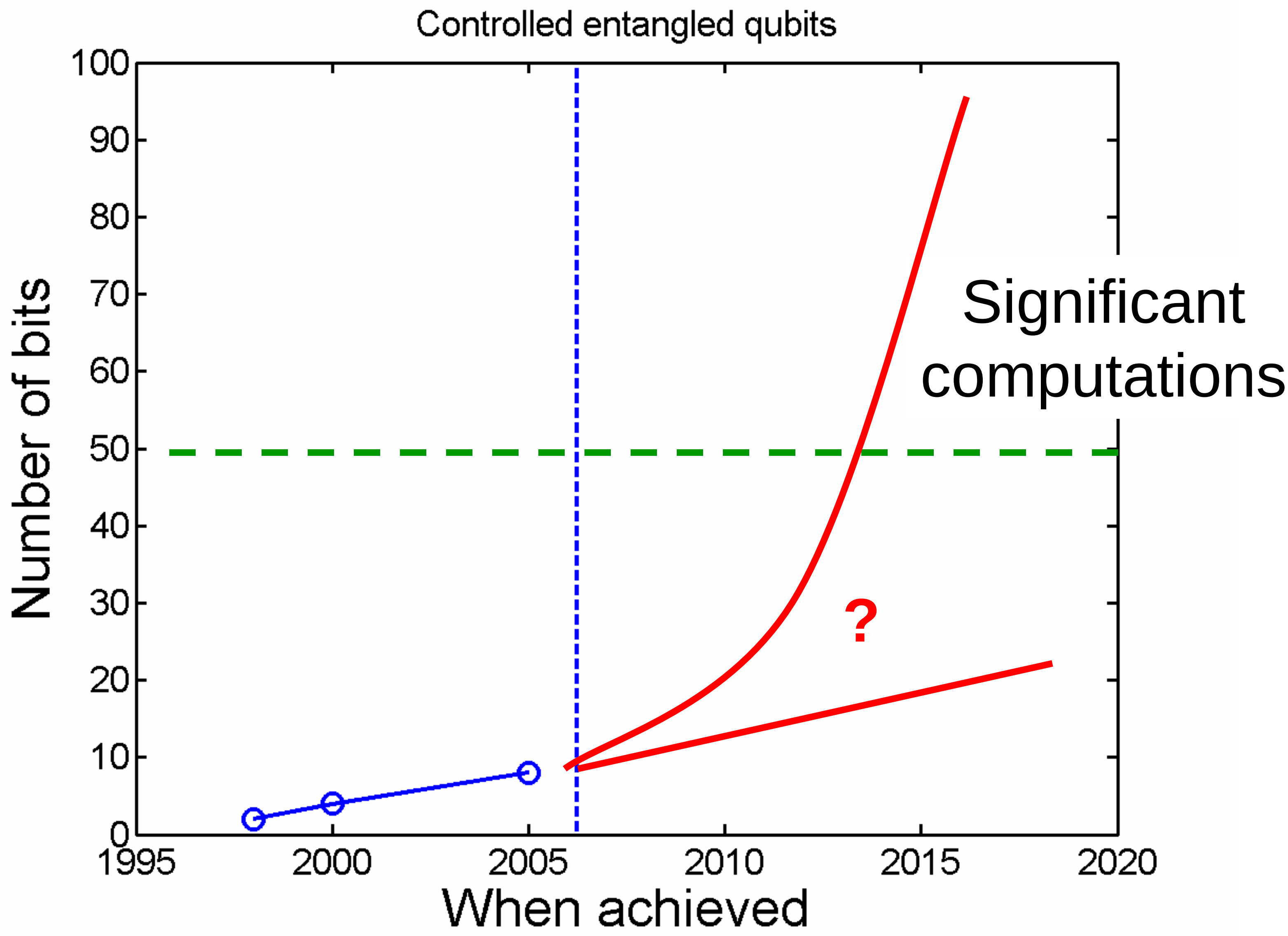
• Measurement (read-out) fidelity around 99%.

• Some trap systems fabricated at 10 micron scale by lithographic methods.

• The combination of the above can be assessed by the observation that it was (just) possible to demonstrate

6-bit “cat” state and 8-bit “W” state

with non-zero 6- or 8-bit entanglement. However, no other processing of these states. (Some “algorithms” were also demonstrated with 2 or 3 bits).



Controlled entangled qubits
100
90
80
70
60
50
40
30
20
10
0
Number of bits
1995
2000
2005
2010
2015
2020
When achieved
Significant computations
?

Forseable (?) computers

Current effort is focussed on fabricating “ion chip” structures.

I (AMS) looked into engineering issues for 2 computers:

(A) 64 bits, 1000 ops,

(B) 300 logical bits, 10^9 ops.

(A) uses little or no error correction. Looks quite feasible: “guesstimated” time to realise: 6 years.

(B) uses 30,000 physical bits and QEC.

“guesstimated” time to realise: 10 to 30 years.

I am moderately confident that ion traps could get to computer (B). This is still a factor 10 too few bits for useful factorization calculations, but could probably scale up.

Further away

The design of the “forseeable” computers (A) and (B) was based largely on things as they are done now in labs.

There are some ideas around for going smaller/faster with trapped ions: carbon nanotubes as electrodes, etc.

The speed limit (1 μs gate = 1 MHz rate) comes from optical manipulation of a “heavy” particle (1 ion). However to get precise control at rate R requires classical electronics at rate » 1000 R. All methods have a speed-limit from the classical control. Therefore apparently “faster” methods (quantum dots etc.) might not be so in practice.

Fault tolerance offers a trade-off:

(1) Fewer, highly-controlled qubits

vs.

(2) Many more, less well-controlled qubits

I (AMS) feel that ion traps offer a good prospect for type (1).
A rival system would probably be of type (2).
... and I feel there must be such a system, though no-one has thought of one (that convinces me).