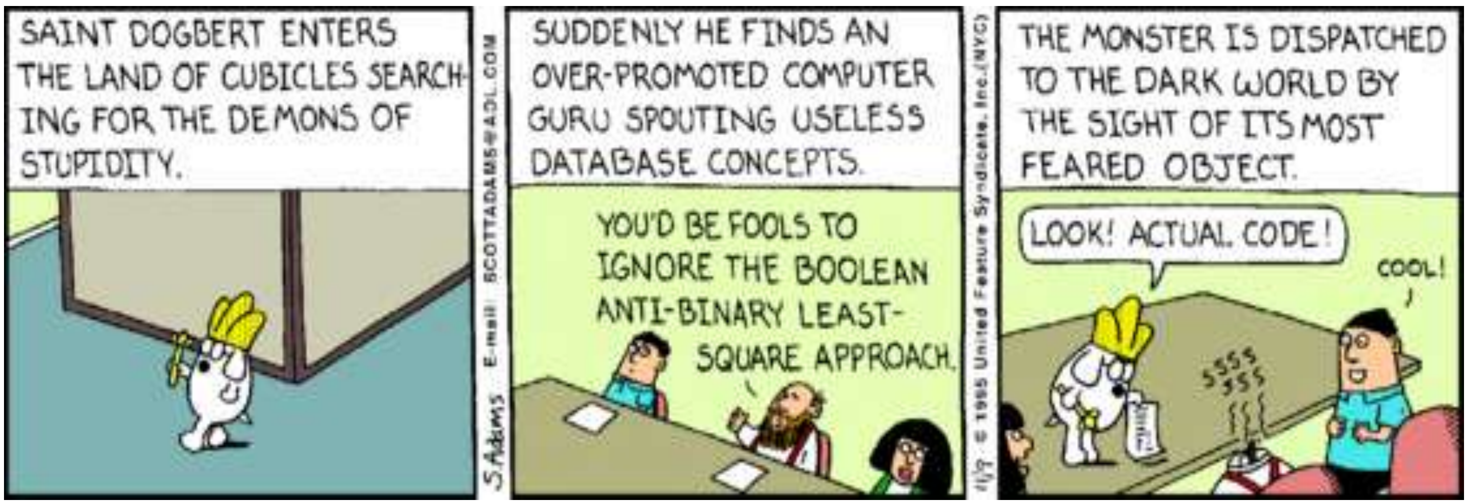
10:00 --- "Look! Actual Hardware!" – Jack Woehr
All the latest news from the frontiers of cryogenic quantum computing.

Jack's remote presentation will be delivered via Google+ Hangout from his carefully hidden mad scientist's lair in Colorado. A limited number of distributed participants can participate in the Q&A by communicating in advance!

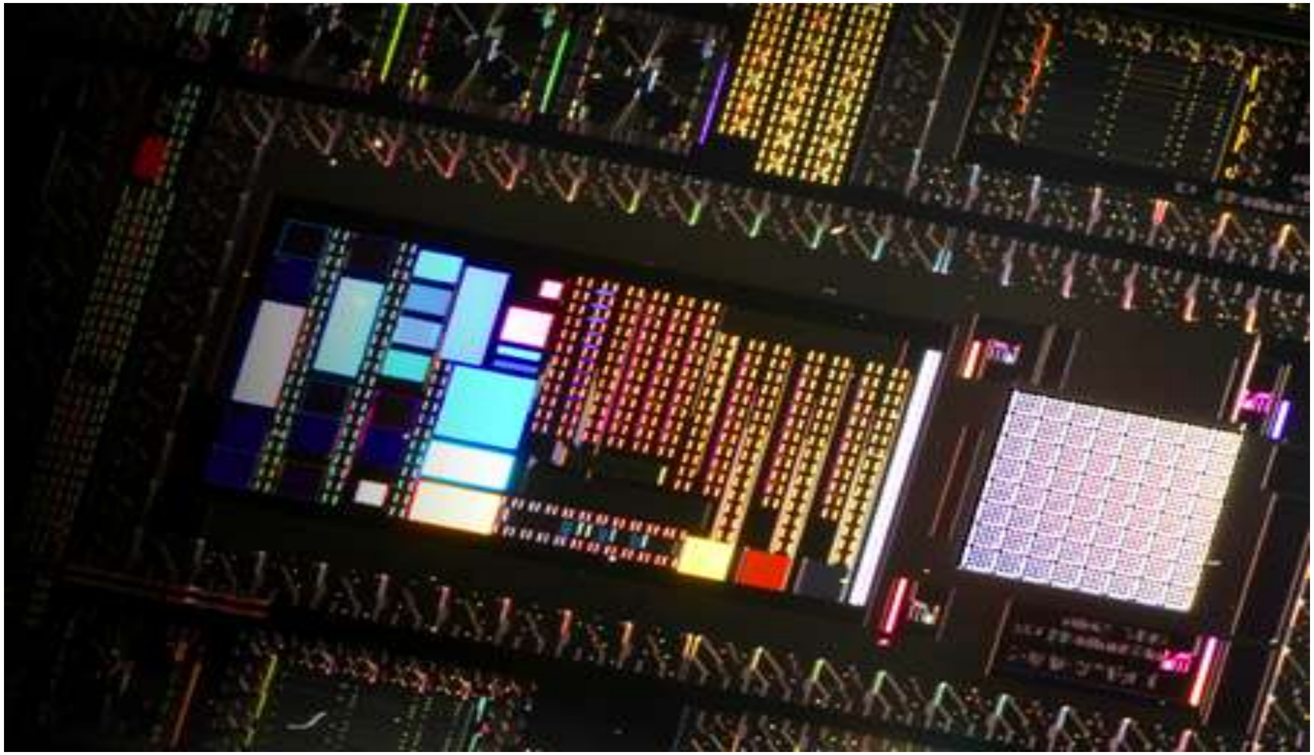
Somewhere in the Rocky Mountains ….

Look! Actual Hardware!



We now have actual working adiabatic quantum annealing computers at the low, low price of maybe $10 million.

D-Wave

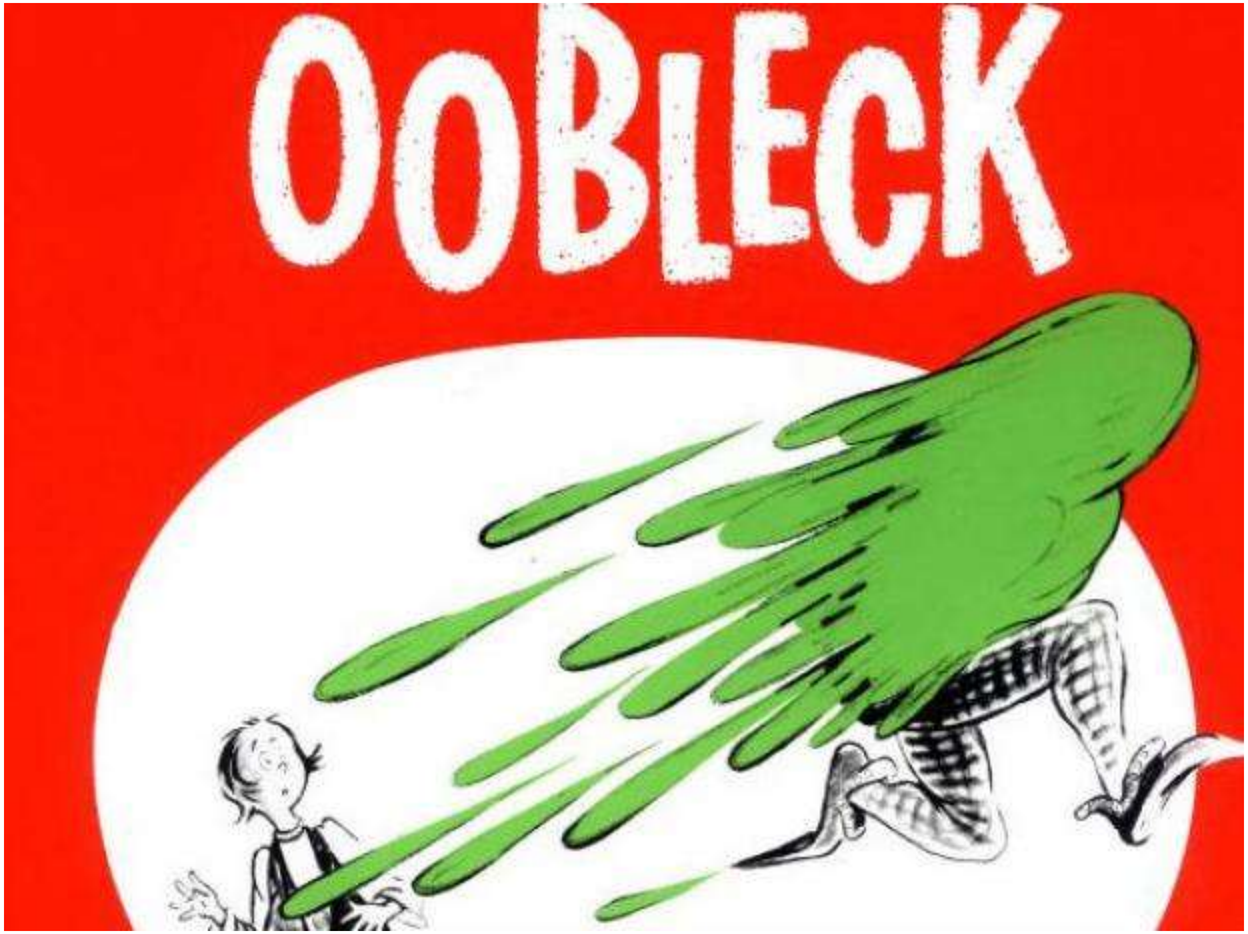


The chip is the size of a fingernail.

The box is the size of a walk-in refrigerator

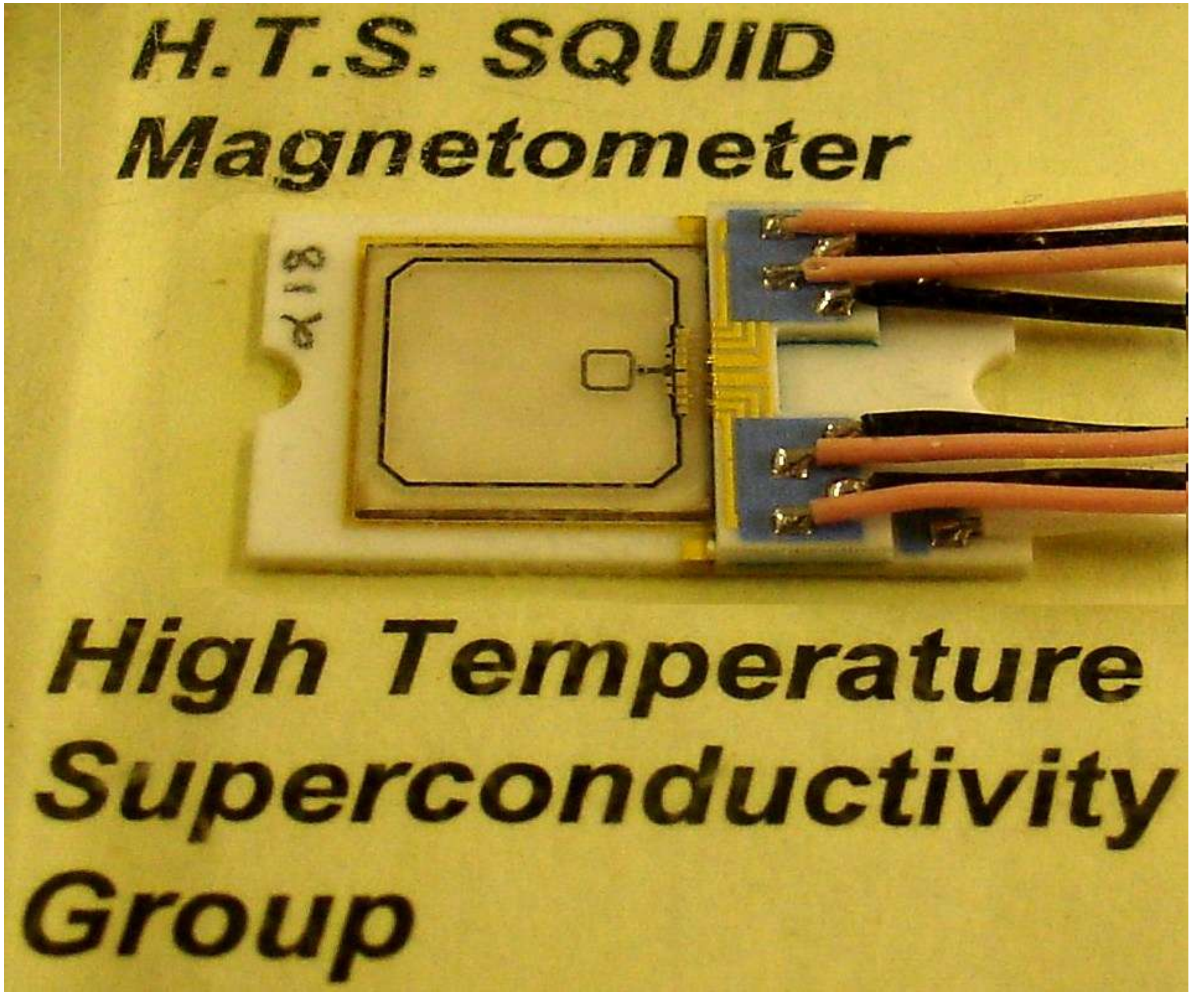
Because that is what it is.

There is one small question:



"What does it do?"

And how does a SQUID help?



“Programming this thing is ridiculously hard.” - Dr. Geordie Rose, CTO of D-Wave Systems

“I think it is not too strong to say they were initially ridiculed by the academic community,” says Jeremy O'Brien, a physicist at the University of Bristol, UK, who invented the computer that can factorize 21. “Still, D-Wave has chipped away at its credibility problem, concludes O'Brien, “and now they're taken ever more seriously”. - Nature Magazine

Customers:

- Lockheed Martin
- Google
- Others?

Evaluating results and controversies surrounding the results is especially difficult when all the links in contemporary articles seem to have been subsequently altered to refer to NIH studies on various diseases.

DWave certainly has a supercold computer that works by means of ***qubits*** built of Josephson junctions.

D-Wave Systems 128 qubit processor - "Inside the chip"

The relevant papers on the matter that seem to be easily available are PDFs found on D-Wave's own site:

D-Wave - Publications

of which the most technically oriented are in:
D-Wave – Technology Deep Dive

and there is also a video library.

“In mathematics and applications, quantum annealing (QA) [as opposed to quantum gating, e.g., Controlled gates for multi-level quantum computation] is a general method for finding the global minimum of a given objective function over a given set of candidate solutions (the search space), by a process analogous to quantum fluctuations. It is used mainly for problems where the search space is discrete (combinatorial optimization problems) with many local minima; such as finding the ground states of a glassy system.”

Controlled gates for multi-level quantum computation

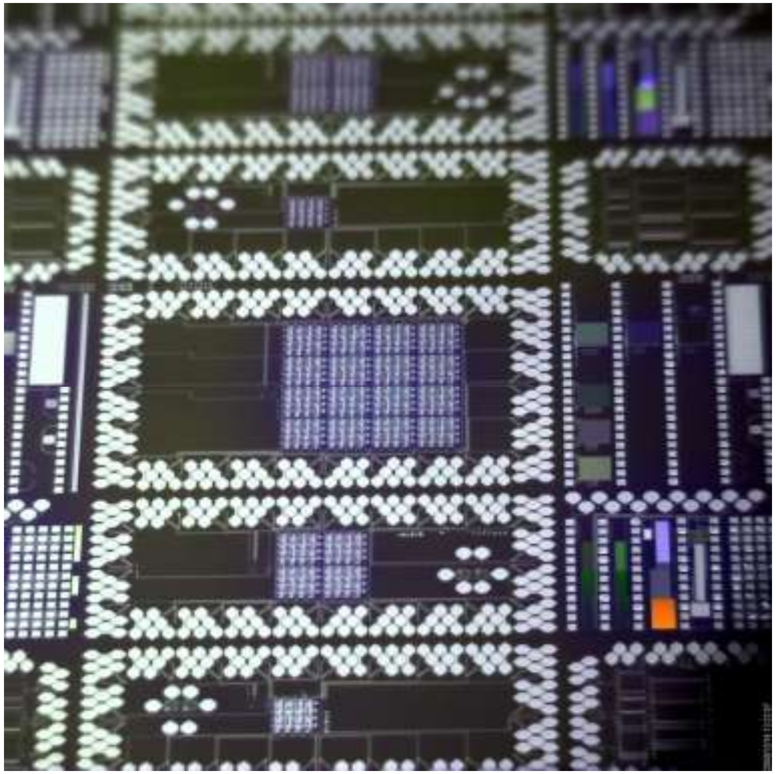
In quantum annealing, a "current state" (the current candidate solution) is randomly replaced by a randomly selected neighbor state if the latter has a lower "energy" (value of the objective function). The process is controlled by the "tunneling field strength", a parameter that determines the extent of the neighborhood of states explored by the method (Kadowaki and Nishimori, 1998). The tunneling field starts high, so that the neighborhood extends over the whole search space; and is slowly reduced through the computation (adiabatically; Farhi et al., 2001), until the neighborhood shrinks to those few states that differ minimally from the current states. By that time, the system finds a very deep (hopefully, the global one) minimum and settles there. At the end, we are left with the classical system at its global minimum. Indeed, the possibility of this quantum tunneling across the width of the barriers, instead of scaling their heights (as in classical or simulated annealing), was first pointed out by Ray et al. (1989) in the context of the search of replica symmetry restoration and the consequent advantage in the search of ground state(s) in quantum spin glasses. An experimental demonstration of the success of quantum annealing for random magnets was first reported by Brooke et al. (1999).

Quantum annealing from Wikipedia

128-Qubit Processor Physical Specifications

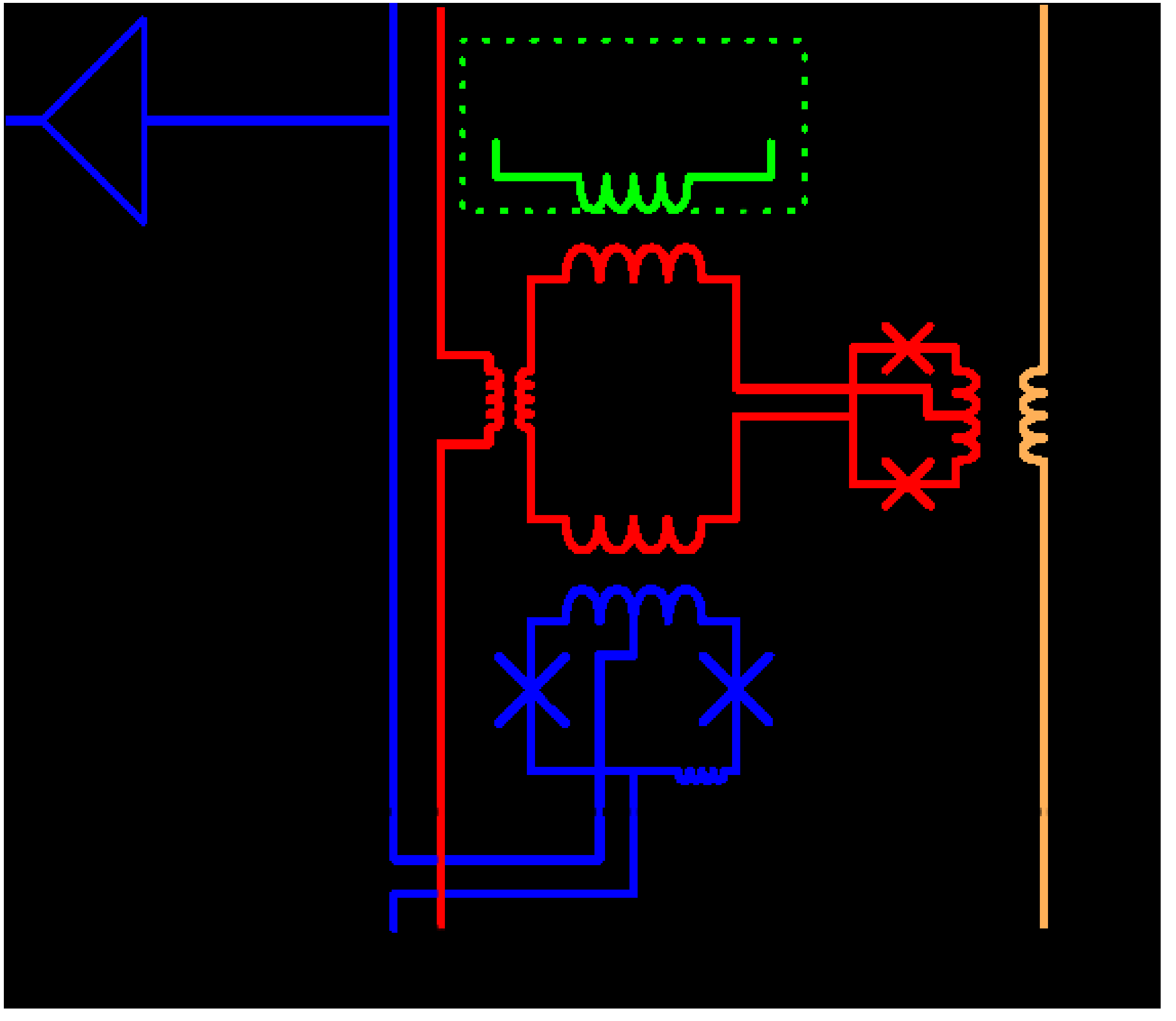
128-Qubit Processor
Die Size: 4.6mm x 7.2mm
Active Circuit Area: 2.8mm square
Josephson junctions: 23,360 JJ total
1,920 (0.6-0.7µm)
21,440 (1µm +)
Field
Total field includes:

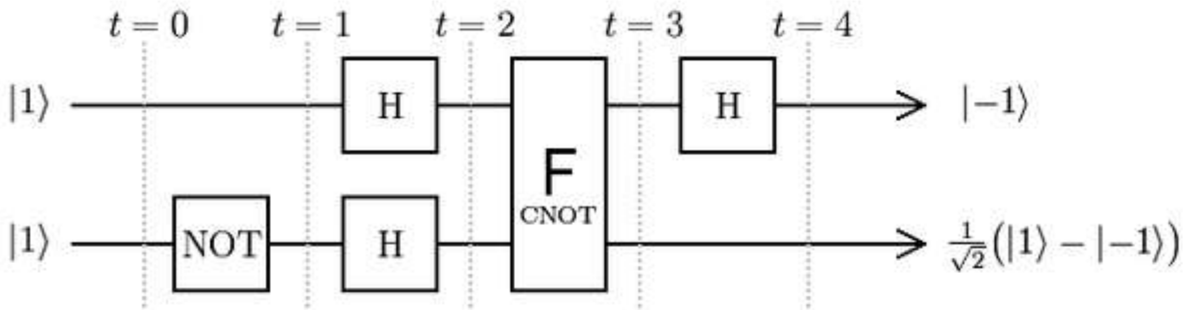
- 8-, 32-, and 128-qubit processors
- PCM and chip screening die for high throughput room and 4K temperature testing
- Flux noise characterization circuits
- Field is repeated 210 times on each 200mm wafer



Cryo

Squid at bottom





$$t = 0: \quad |\Psi(0)\rangle = |1\rangle|1\rangle = |1, 1\rangle$$

$$t = 1: \quad |\Psi(1)\rangle = |1\rangle|-1\rangle = |1, -1\rangle$$

$$\begin{aligned} t = 2: \quad |\Psi(2)\rangle &= \tfrac{1}{2}\big(|1\rangle + |-1\rangle\big)\big(|1\rangle - |-1\rangle\big) \\ &= \tfrac{1}{2}\big(|1,1\rangle + |-1,1\rangle - |1,-1\rangle - |-1,-1\rangle\big) \end{aligned}$$

$$\begin{aligned} t = 3: \quad |\Psi(3)\rangle &= \tfrac{1}{2}\big(|1, f(1)\rangle + |-1, f(-1)\rangle - |1, -f(1)\rangle - |-1, -f(-1)\rangle\big) \\ &= \tfrac{1}{2}\big(|1,1\rangle + |-1,-1\rangle - |1,-1\rangle - |-1,1\rangle\big) \\ &= \tfrac{1}{2}\big(|1\rangle - |-1\rangle\big)\big(|1\rangle - |-1\rangle\big) \end{aligned}$$

$$\begin{aligned} t = 4: \quad |\Psi(4)\rangle &= \tfrac{1}{2}\mathrm{H}\big(|1\rangle - |-1\rangle\big)\big(|1\rangle - |-1\rangle\big) \\ &= |-1\rangle \tfrac{1}{\sqrt{2}}\big(|1\rangle - |-1\rangle\big) \end{aligned}$$

The Hadamard gate

$$\mathrm{H}|1\rangle = \tfrac{1}{\sqrt{2}}\big(|1\rangle + |-1\rangle\big)$$
$$\mathrm{H}|-1\rangle = \tfrac{1}{\sqrt{2}}\big(|1\rangle - |-1\rangle\big)$$
$$\mathrm{HH}|1\rangle = |1\rangle$$
$$\mathrm{HH}|-1\rangle = |-1\rangle$$

Why Quantum Annealing Instead of Quantum Gates?

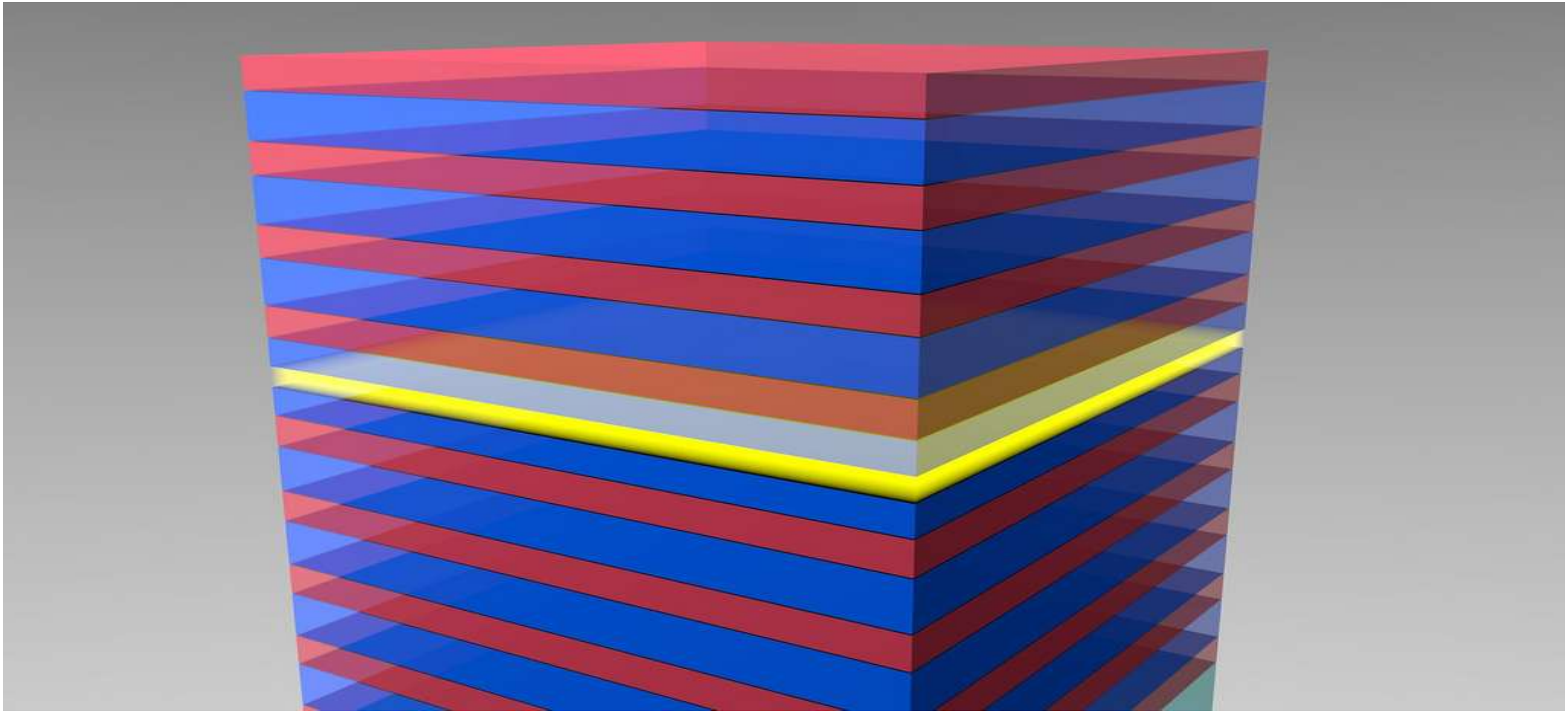
Quantum entanglement preserved beyond phase decoherence works for Quantum Annealing but not sufficient for Quantum Gates. This can be made to work today, and is being made to do so.

"Therefore, despite the fact that the evolution time is far beyond the qubits' dephasing time, the system still preserves its quantum mechanical behavior throughout the evolution. Once again, this is in contrast to what is expected in the gate-model QC. Qualitative demonstration of the non-vanishing ground state entanglement during the evolution is also important as it shows that the evolution cannot be described efficiently in only classical terms ...

"In the gate-model QC, there is no direct correspondence between the wavefunction and the instantaneous system Hamiltonian. The Hamiltonian is only applied at the time of gate operations and usually involves only a few qubits. The wavefunction, therefore, is strongly affected by the environment and is irreversibly altered after the decoherence time … This is not true for AQC, as the wavefunction is always very close to the instantaneous ground state of the system Hamiltonian and is consequently more stable against the decoherence. "

Role of Single Qubit Decoherence Time in Adiabatic Quantum Computation

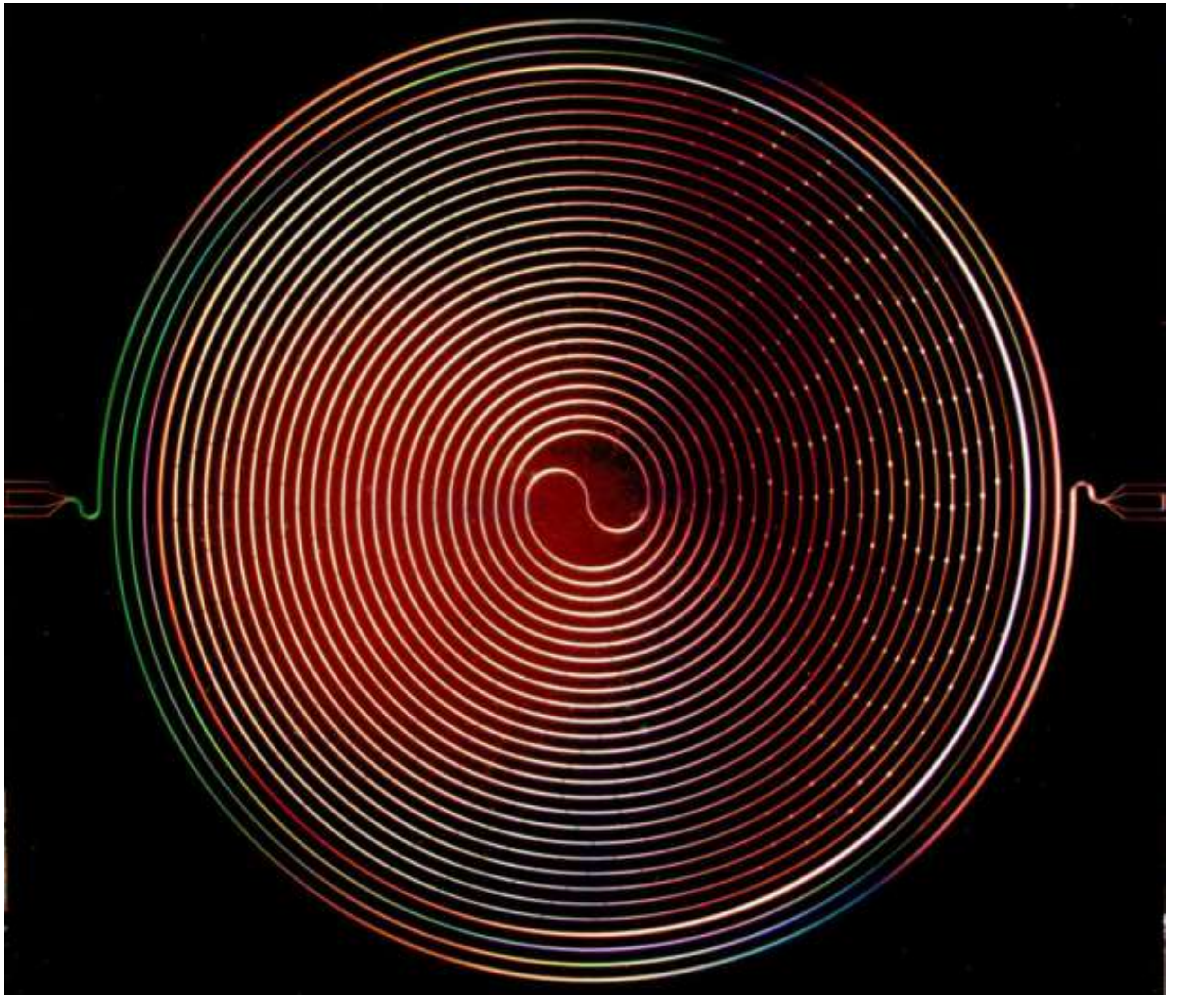
Device structure which is used to create the polariton Bose-Einstein Condensate. The luminescent polymer layer (yellow) is sandwiched between two mirrors which are formed by a stack of different oxide layers (red and blue).



This thin polymer film is approximately 35 nanometers thick, for comparison a sheet of paper is about 100,000 nanometers thick. The bosonic particles are created through interaction of the polymer material and light which bounces back and forth between the two mirrors.

[IBM Scientists Demonstrate Quantum Phenomenon for the First Time Using a Plastic Film]

And don't forget our old friend, the Quantum Amplifier



Nor should we forget these

Oxford Ultrafast quantum optics and optical metrology

Oxford Ion Trap Quantum Computing

Oxford NMR Quantum Computing