

QUANTUM MACHINES



THE TEAM

Bill



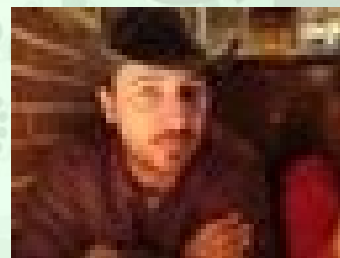
Stefano
(PDF)



Abhi
(visitor, Reykjavik)



Benjamin
(M. Sc.)



Gerson
(visitor, Sao Paulo)



Judy (B. Sc.)



Jacob (B. Sc.)

“TO START, PRESS
ANY KEY...”



“Where's the 'Any'
key??!!”

Warning:
This stuff can be
confusing...
but it's important!

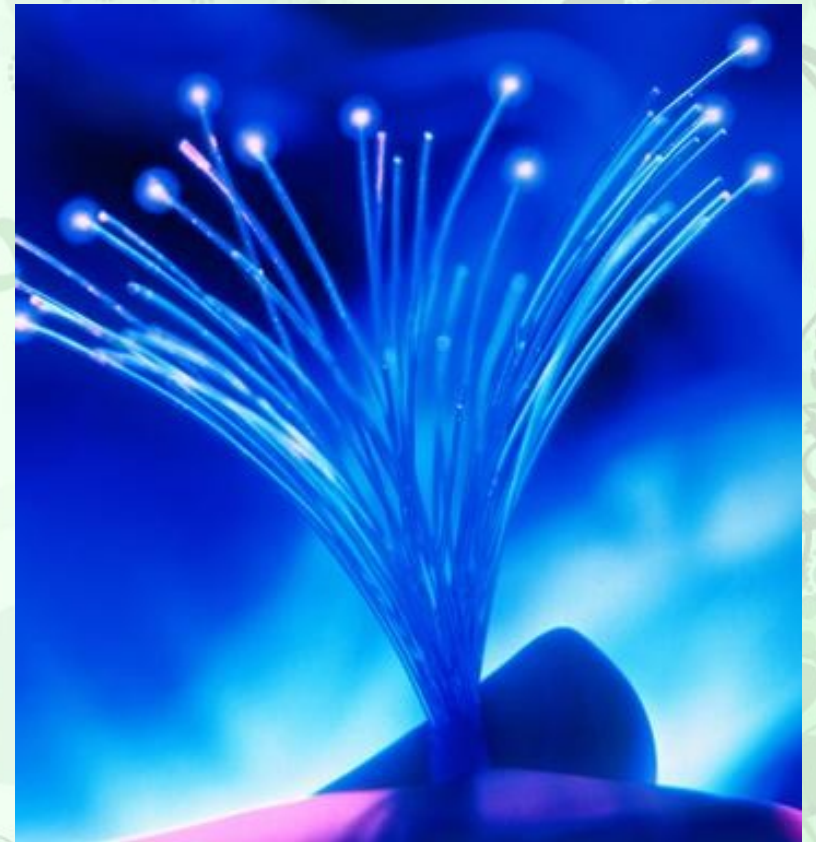
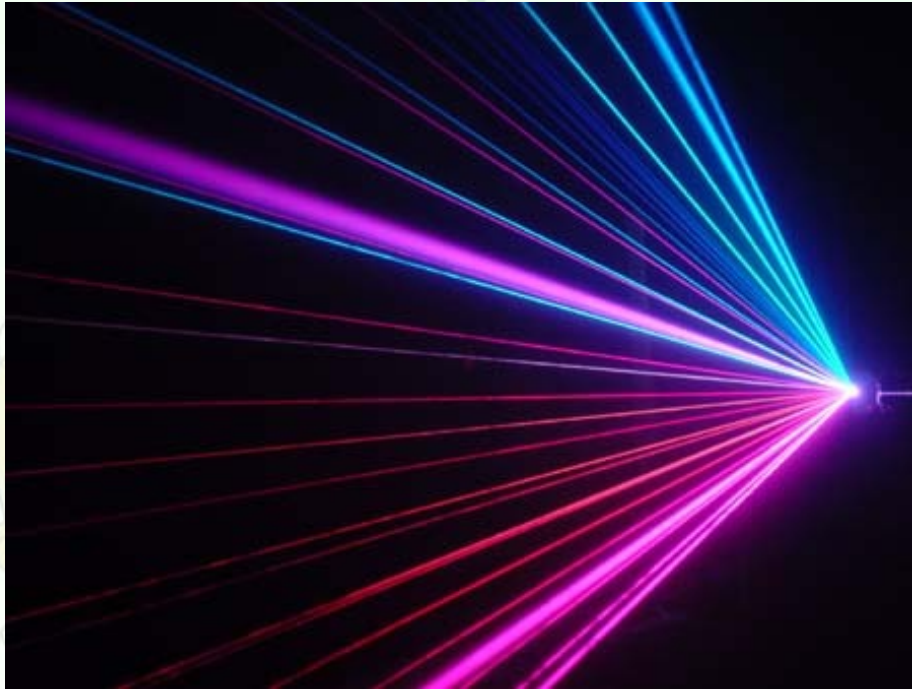




Quantum Mechanics is Everywhere you Look!



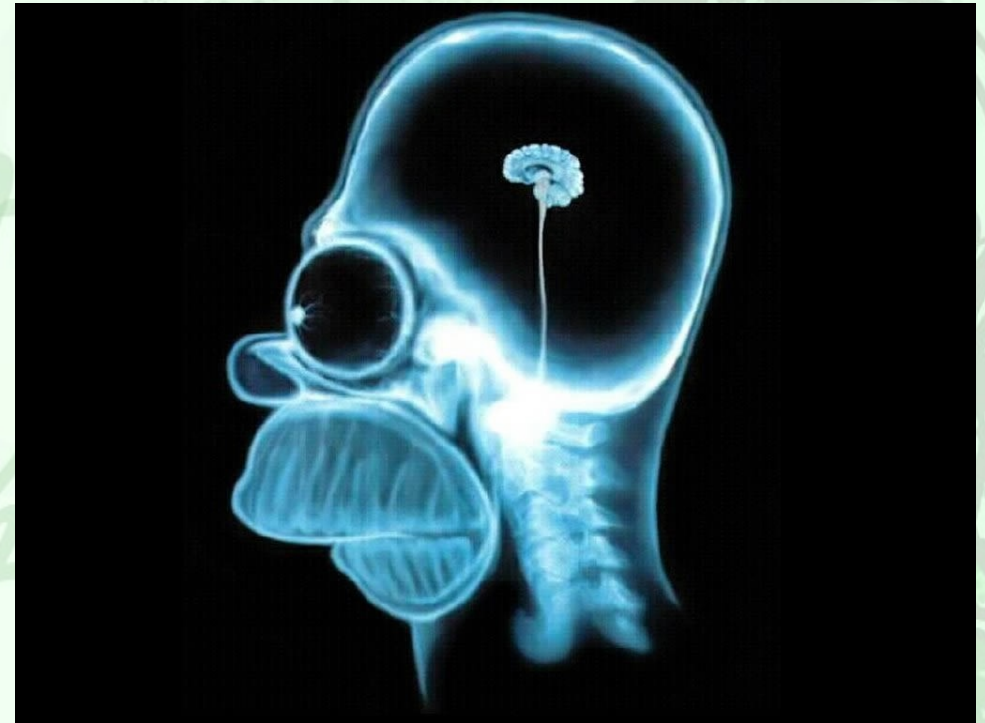
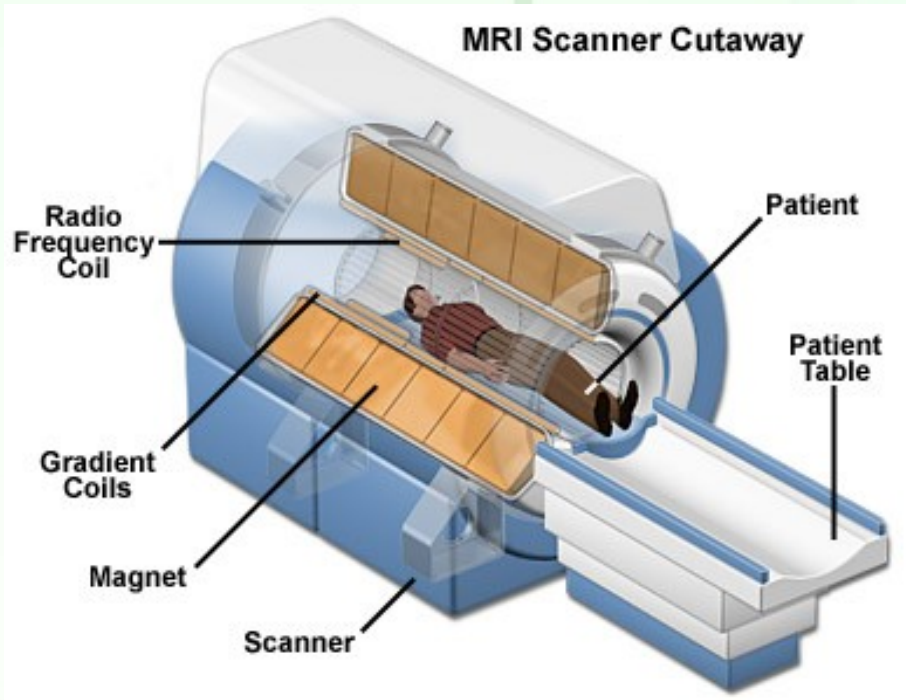
At the Heart of Many Technological Innovations



Networks, Communication



MRI Imaging



“Spukhafte Fernwirkung” = “Spooky action-at-a-distance”

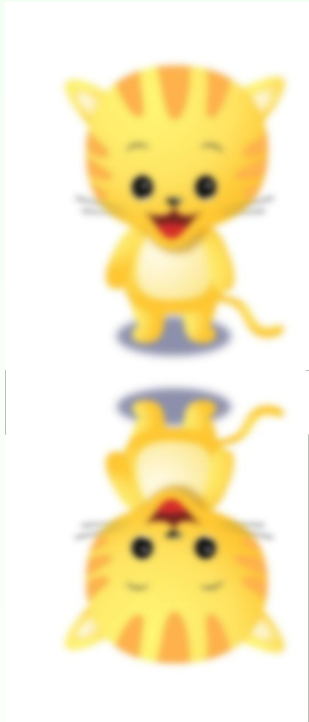
- A. Einstein



(1935): E. Schrödinger



Schrödinger's Cat

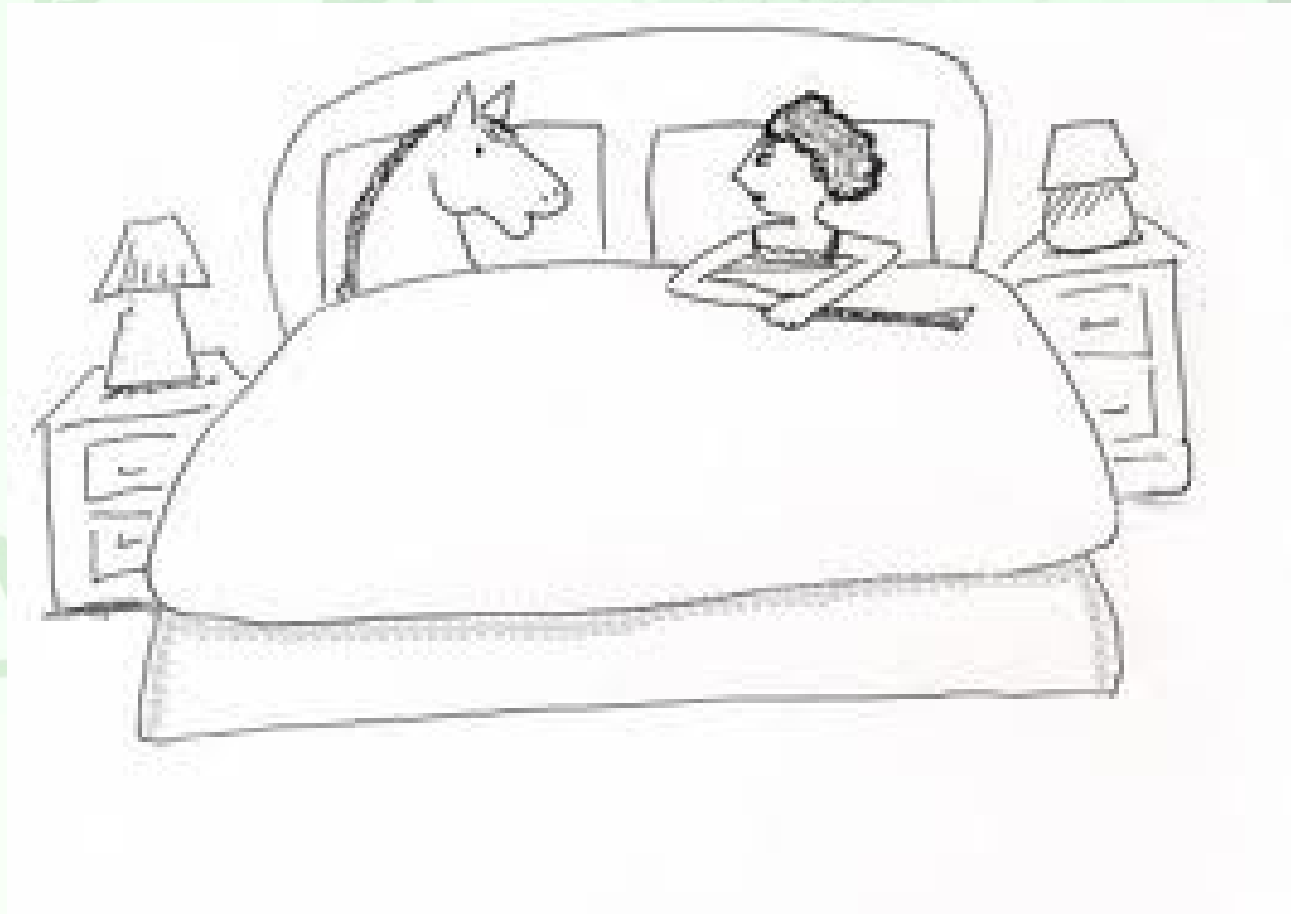


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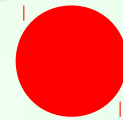
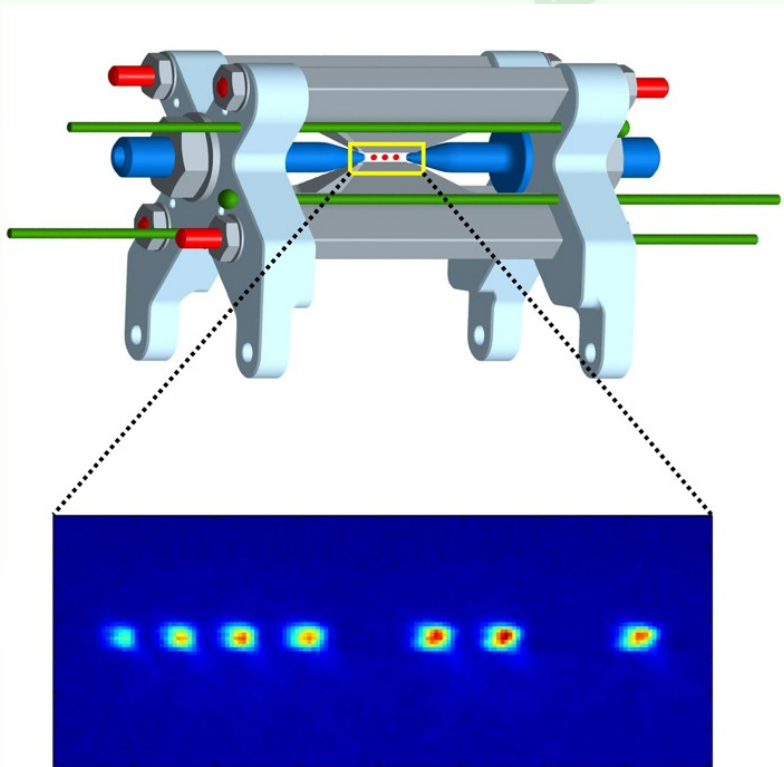


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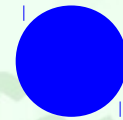




Building a cat one atom at a time...



Excited atom



Un-excited atom



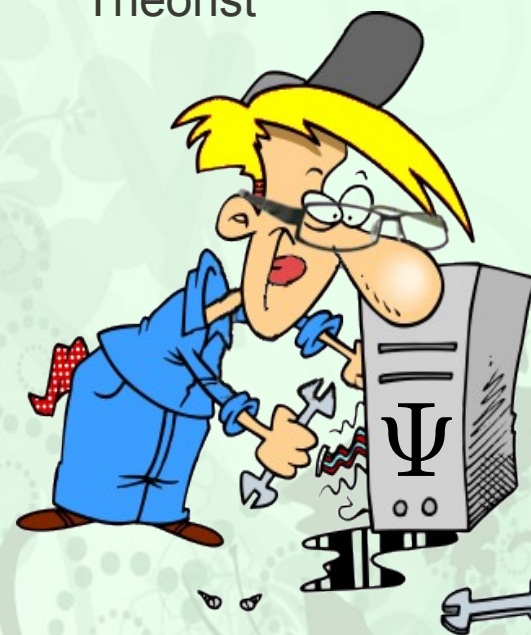
World record (2010): $N=14$ atoms

Real cat: $N > 10^{24} = 1\,000\,000\,000\,000\,000\,000\,000\,000$ atoms!!

Experimentalist



Theorist

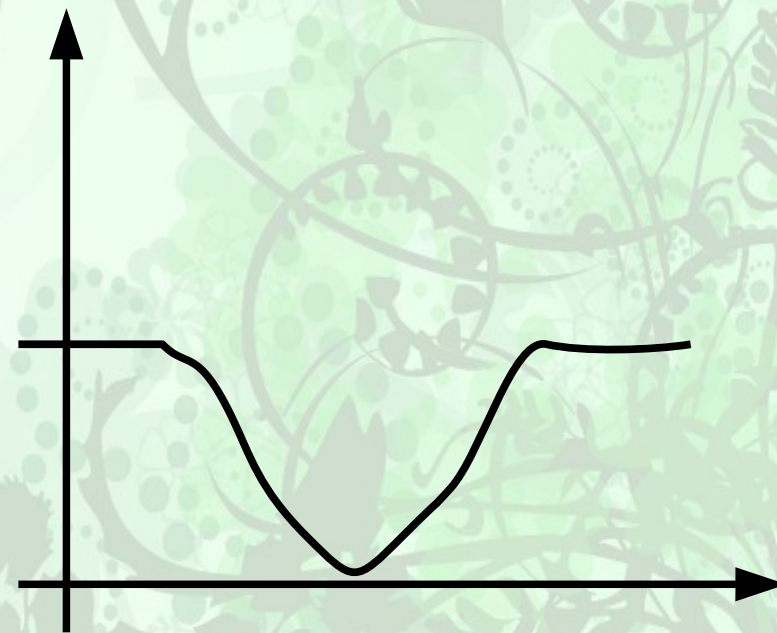
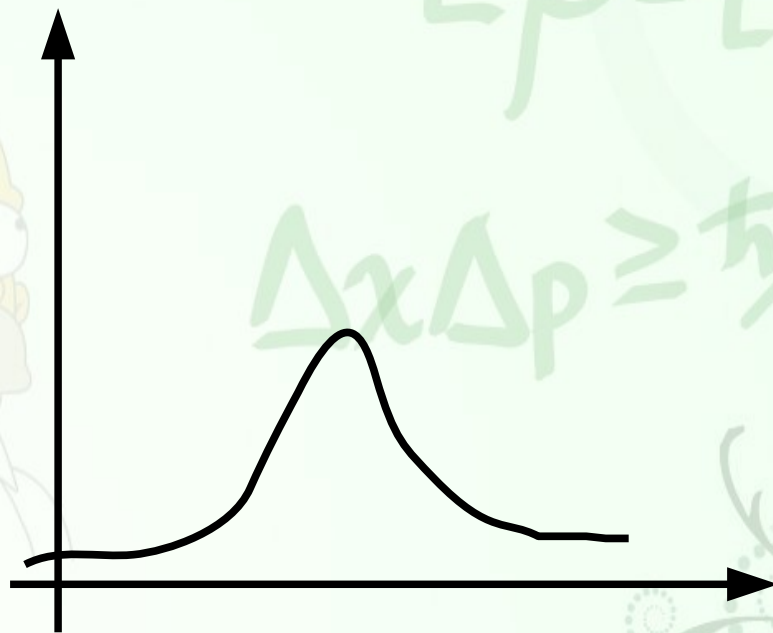


Ψ

$\dot{p} = -\dots$

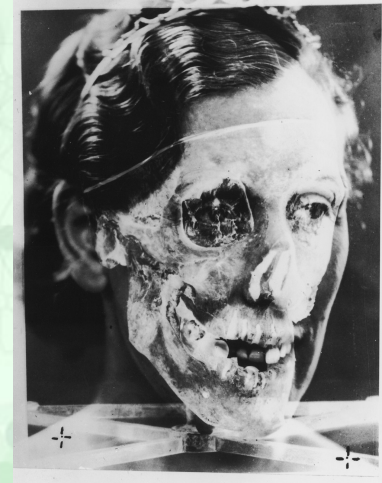
$Lp = [H, p]$

$\Delta x \Delta p \geq \hbar/2$?



The stuff that makes Quantum Mechanics weird

Superposition



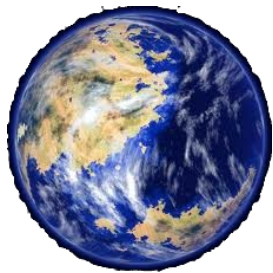
Entanglement



$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

What can quantum mechanics do for us?

$$i\hbar \frac{\partial}{\partial t} \Psi = \mathcal{H} \Psi$$



Computing reaches a roadblock

Moore's Law:

Rapid growth in computing power year after year...coming to an end.



The solution: A new approach

Quantum computing:

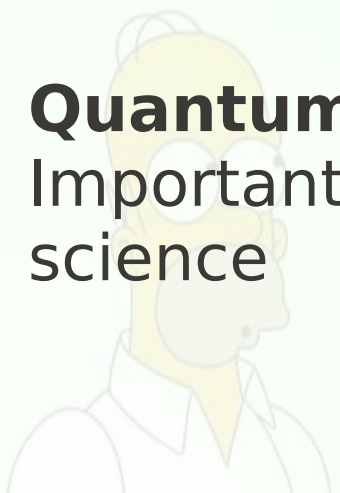
Factoring (e.g. $15=3 \times 5$),
database search, ...

Quantum communication:

Ultra-high security

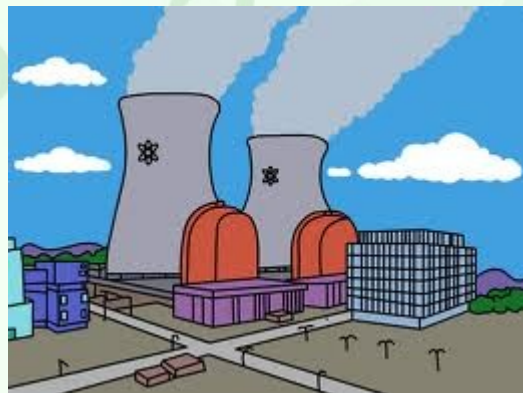
Quantum simulation:

Important for all branches of
science





Q.: What is the nuclear physicist's favourite meal?



A.: Fission chips



The power of quantum mechanics

“Classical” bit:

“0” or “1”

Quantum bit (qubit):

“0” + “1”

Many quantum bits can be in a **superposition** of many states at the same time → **Quantum parallelism**.



Quantum computer: Why would this work?

Quantum bit ("qubit"):

● = "0"

● = "1"

Quantum bits

Possible States

Classical bits

1

1, 0

$2^1=2$

2

11, 00, 10, 01

$2^2=4$

3

111, 000, 100, 010, ...

$2^3=8$

10

11...1, 11...0, ...

$2^{10}=1024$

20

11...1, 11...0, ...

$2^{20}=1 \text{ Mb}$

30

11...1, 11...0, ...

$2^{30}=1 \text{ Gb}$

40

11...1, 11...0, ...

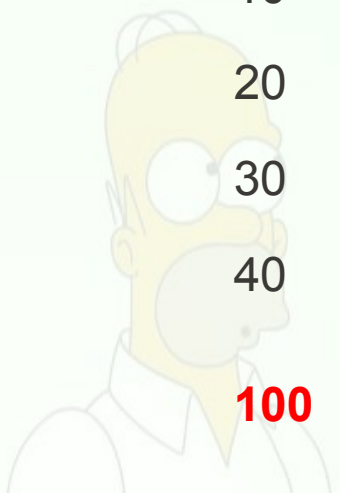
$2^{40}=1 \text{ Tb}$

100

11...1, 11...0, ...

2^{100}

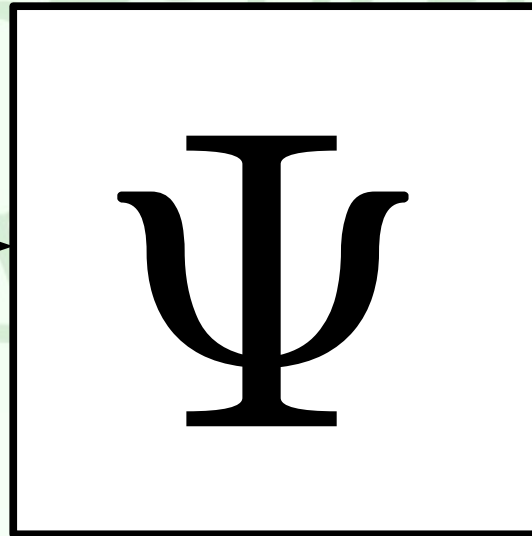
Larger than the internet!



How would a quantum computer work?

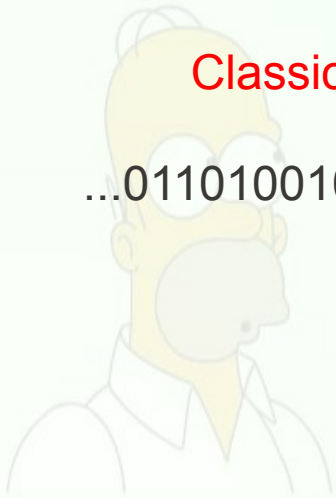


Classical input
...01101001001001001....



Classical output
...01101011001101....

Quantum processing



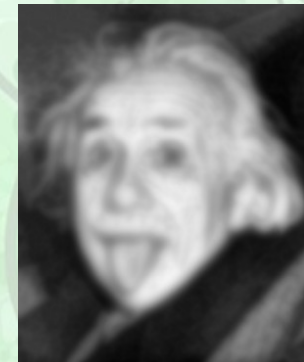
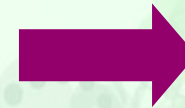
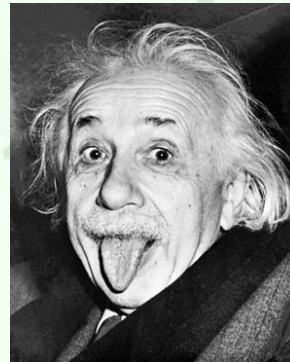
What keeps us from making a quantum computer?

Decoherence?

The 'classical' world:



The quantum world:



OR practical problems with storage, readout, ...

Heisenberg Uncertainty: You can't know everything all of the time



$$\Delta x \Delta p \geq \hbar/2$$

$$\Delta E \Delta t \geq \hbar/2$$

Quantum tunneling



If you know the **position**, you don't know the **momentum**.

If you know the **time**, you don't know the **energy** expended.



How far have we come?

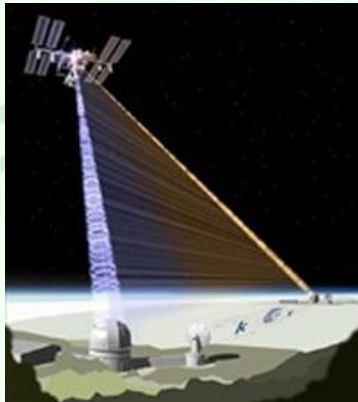
Quantum Computers:

Up to ~10 qubits



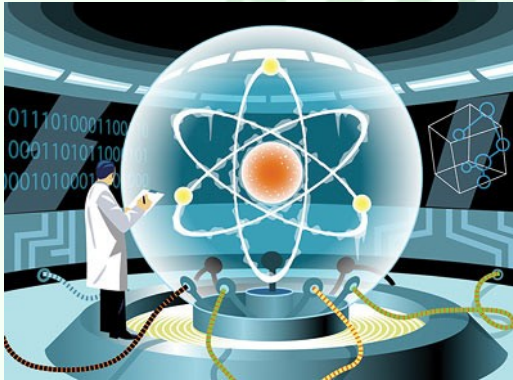
Quantum Communication:

Up to ~100 km

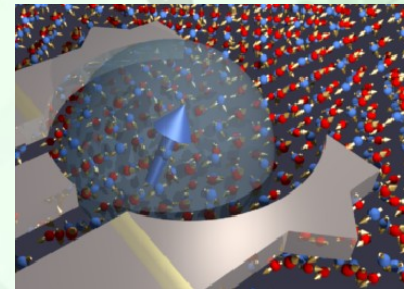


My own quantum playground: Quantum Hardware

Computing and information technology



Single "Spin"
(Quantum Coherence)



$$\Delta x \Delta p \geq \hbar/2$$



"0"

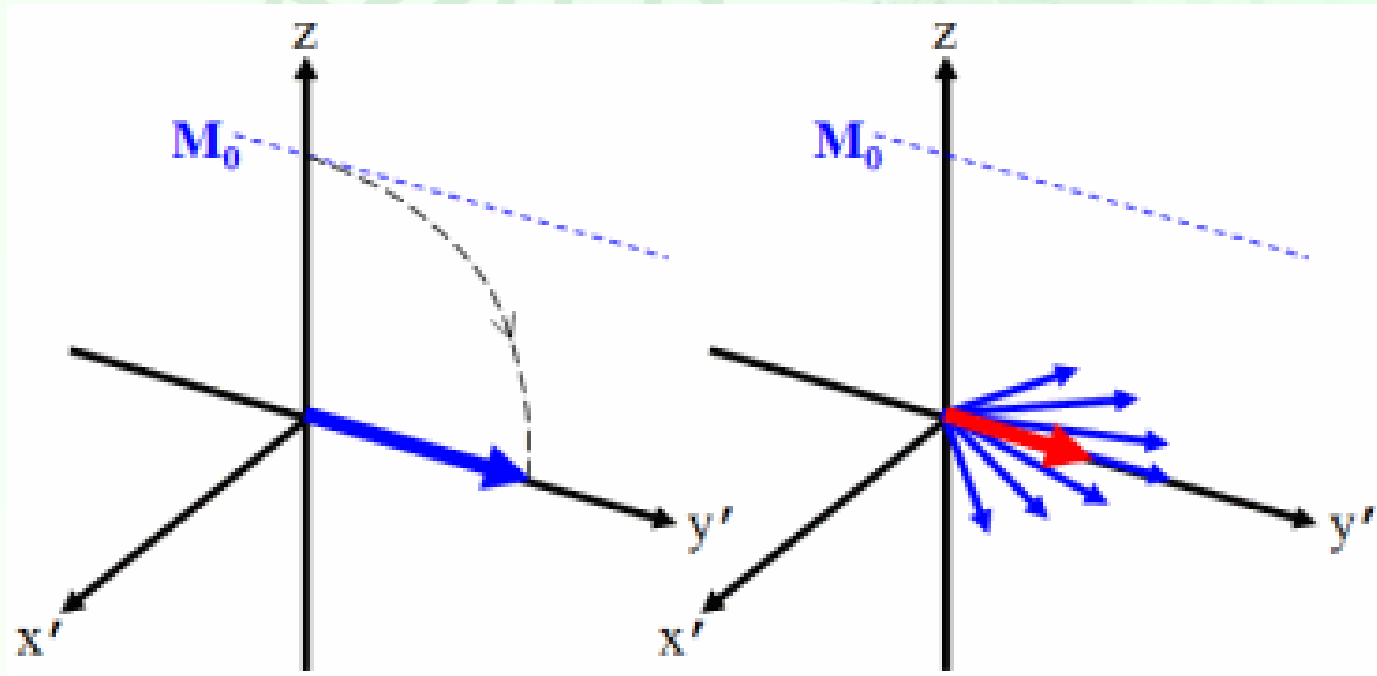


"1"



Decoherence!

$$\partial_t \Psi = -iH\Psi$$



“0+1”

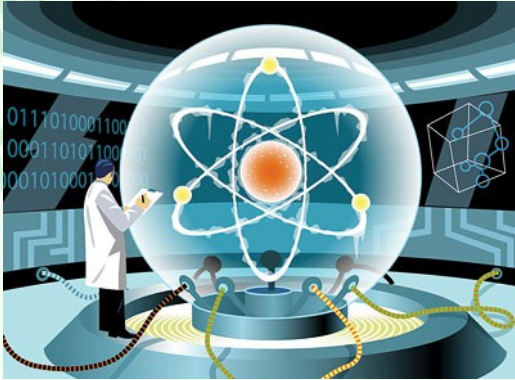


“0 or 1”?

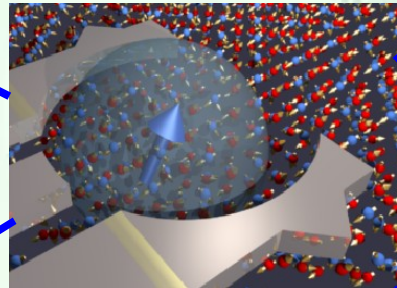


Where else is this important?

Computing and information technology



Single "Spin"
(Quantum Coherence)



The avian compass



Photosynthesis



Solar energy





FIN