Saturday Morning Physics

Dark Matter and Quantum Computing

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Prologue

We live in a time of remarkable scientific understanding and progress

Scientists are arrogant/crazy enough to think that it may be possible to solve major problems in Astronomy, Cosmology and Particle Physics with a single discovery that ties all three together: Dark Matter

It turns out that in our quest to discover dark matter, we might help improve quantum computing

Goals of this talk: *What is Dark Matter? What is Quantum Computing? How do we help both?*

Overview of the Talk

There is a lot here, so we'll go step-by-step:

- *What IS Dark matter and what is some of the evidence for it?*
- *What are scientists doing today to discover Dark Matter?*
- *What is Quantum Computing?*
- *What does it have to do with Dark Matter?*

Final Thoughts

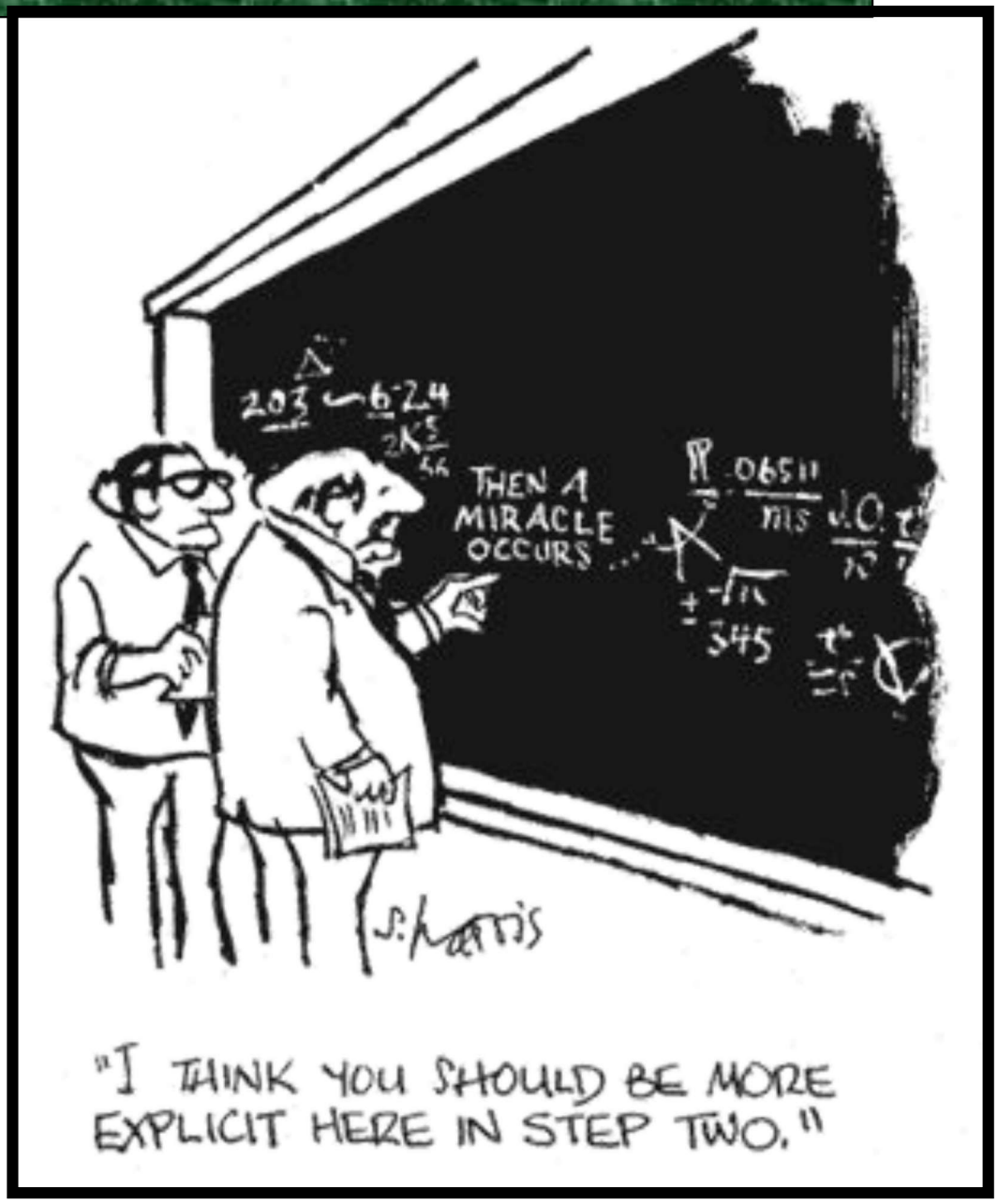
Quick Ideas

- **Dark Matter:** Basically an enormous about of "stuff" that fills the universe that we can't "see with our eyes"

- **Quantum Computing:** Basically, build computers using quantum information instead of just 1's and 0's (bits)

Dark Matter

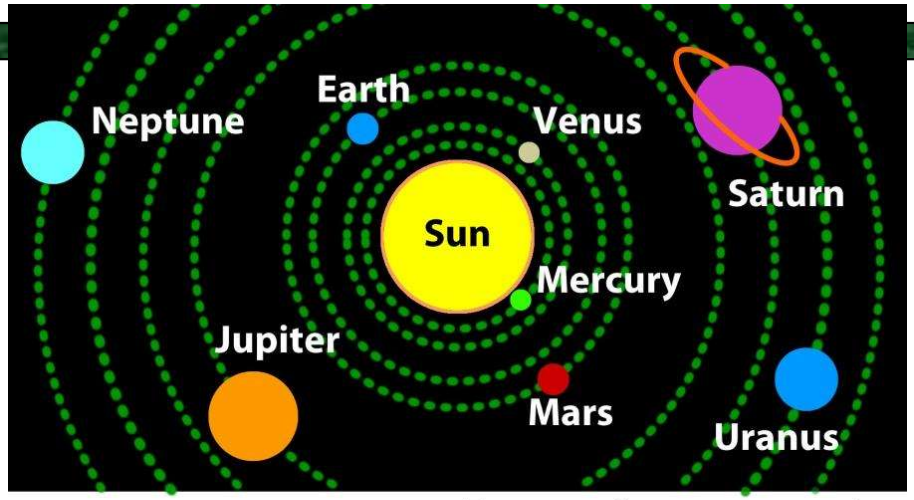
What is some of the evidence for Dark matter?



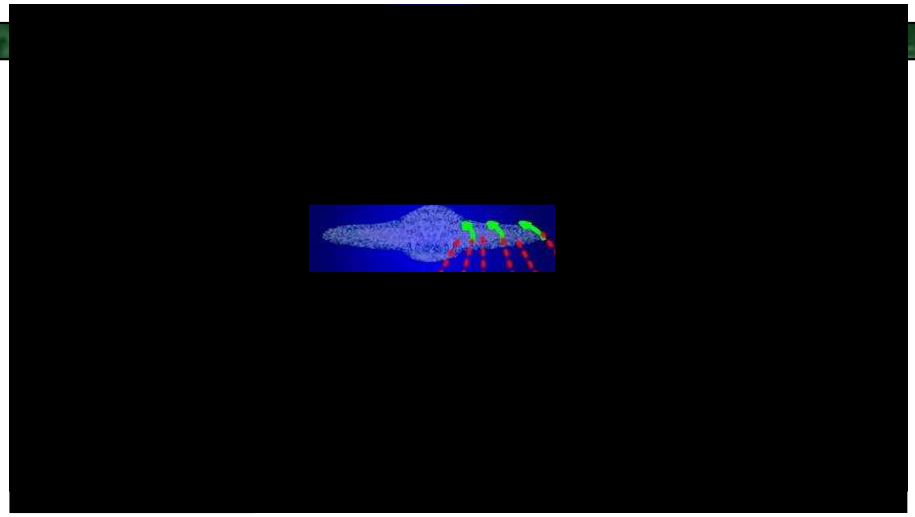
How Stars Move in Galaxies

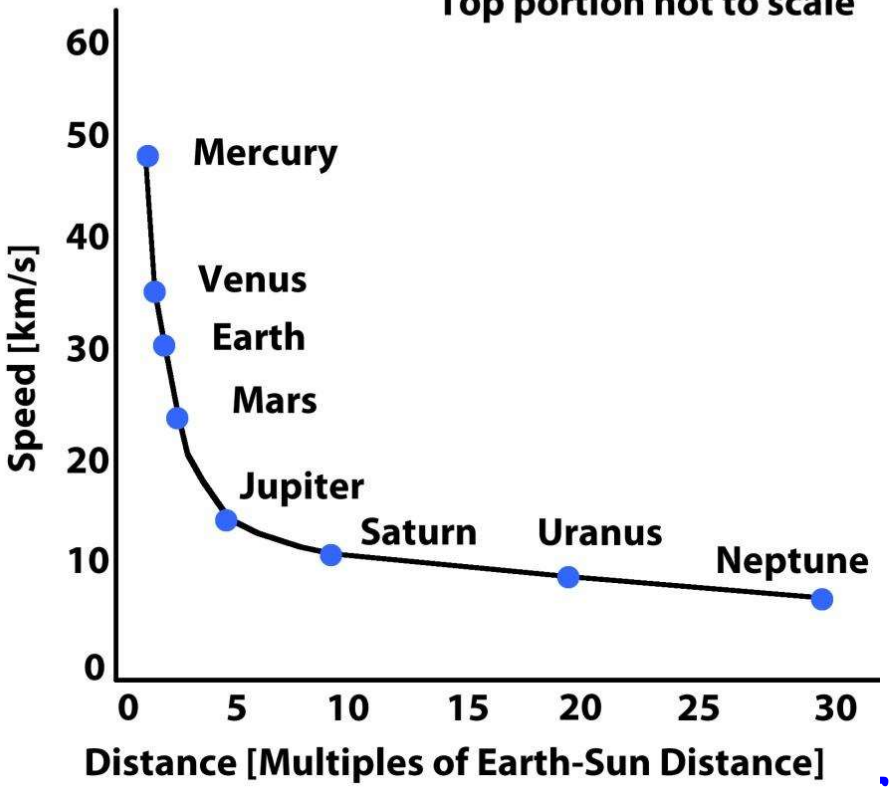
- Start by considering the case that there IS no Dark Matter in galaxies
- Can use laws of gravity to predict two things:
  - 1) The orbits of planets as they move around the solar system and
  - 2) Stars as they move around a galaxy
- Prediction: both have very massive centers so we expect the data to look consistent with that
- Data:
  - For the solar system, the data agree perfectly
  - For the stars in the outer part of galaxies, the prediction doesn't work at all

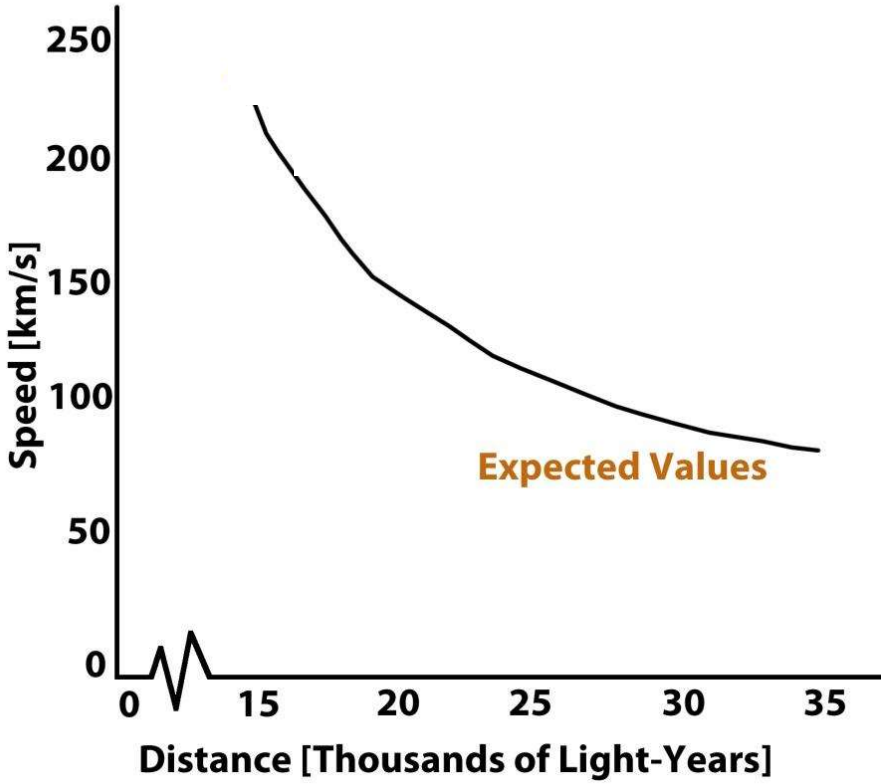
The Data



Top portion not to scale





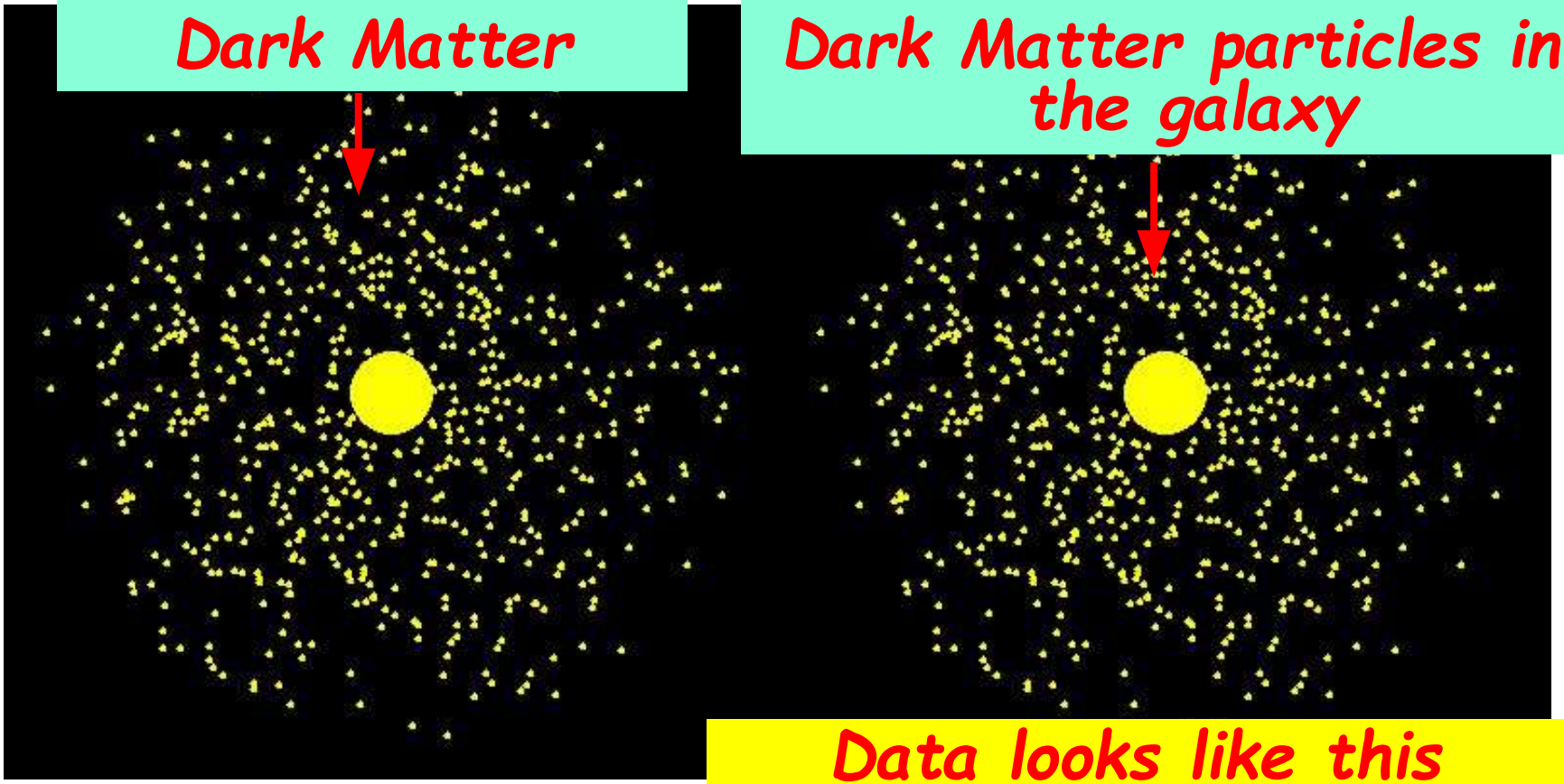


Does this work for Stars?

Watch how fast a star rotates around the center of the galaxy…

Simulation without Dark Matter

Simulation with lots of Dark Matter particles in the galaxy

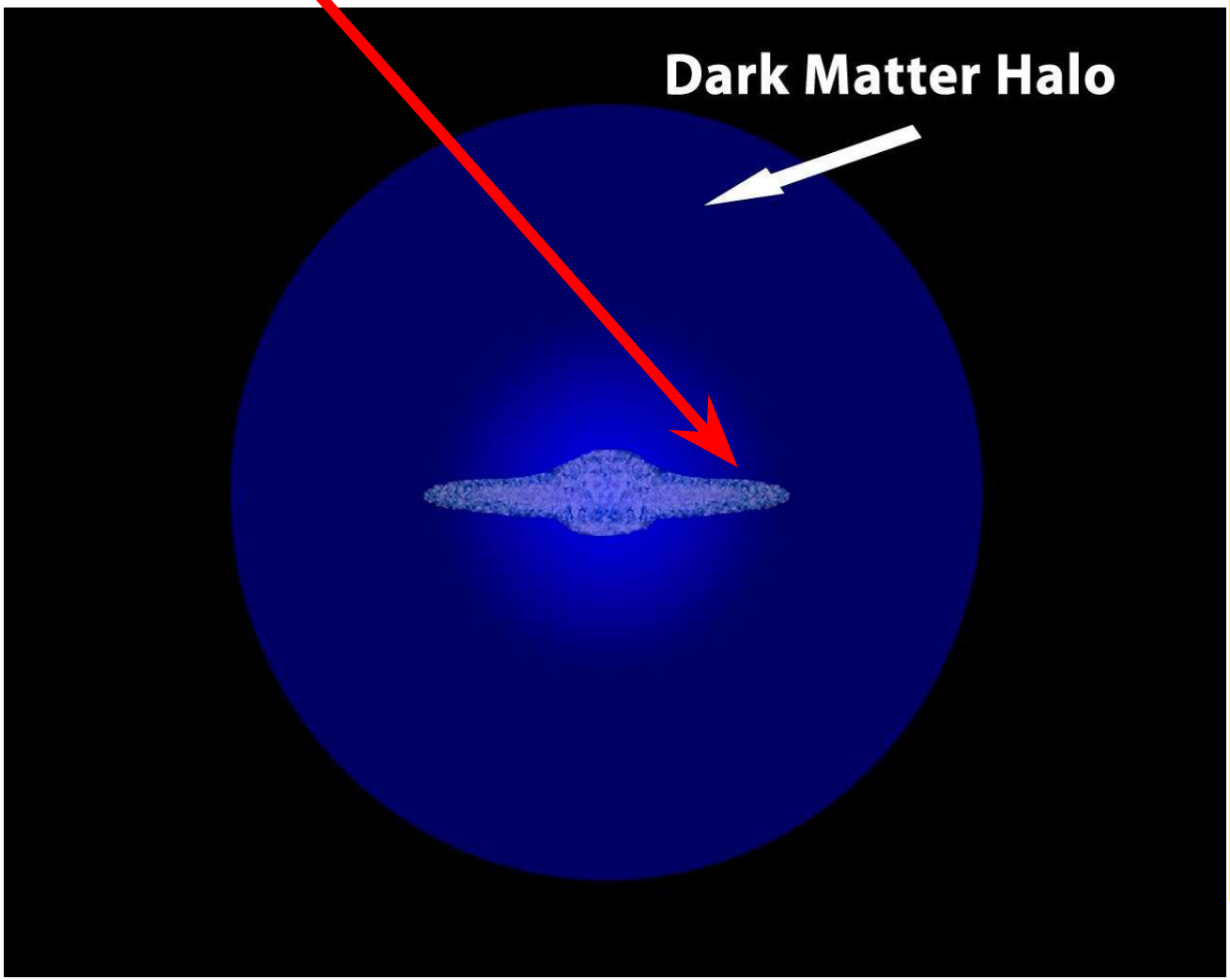


Data looks like this

https://drive.google.com/file/d/1yJ9YeD4Ino9wEwziPWQ4O5Jk4WYgDL18/view

Our Place in the Universe

You are here



The Dark Matter surrounds the galaxy like the water in a fishbowl surrounds a fish in the middle of the bowl

Not exactly the same… denser in the middle because of the pull of gravity

Data well explained by lots of "Dark Matter" we can't see

This is where it gets its name

In some sense, the name is a statement of almost all we know about it (it doesn't interact with light, and it has mass)

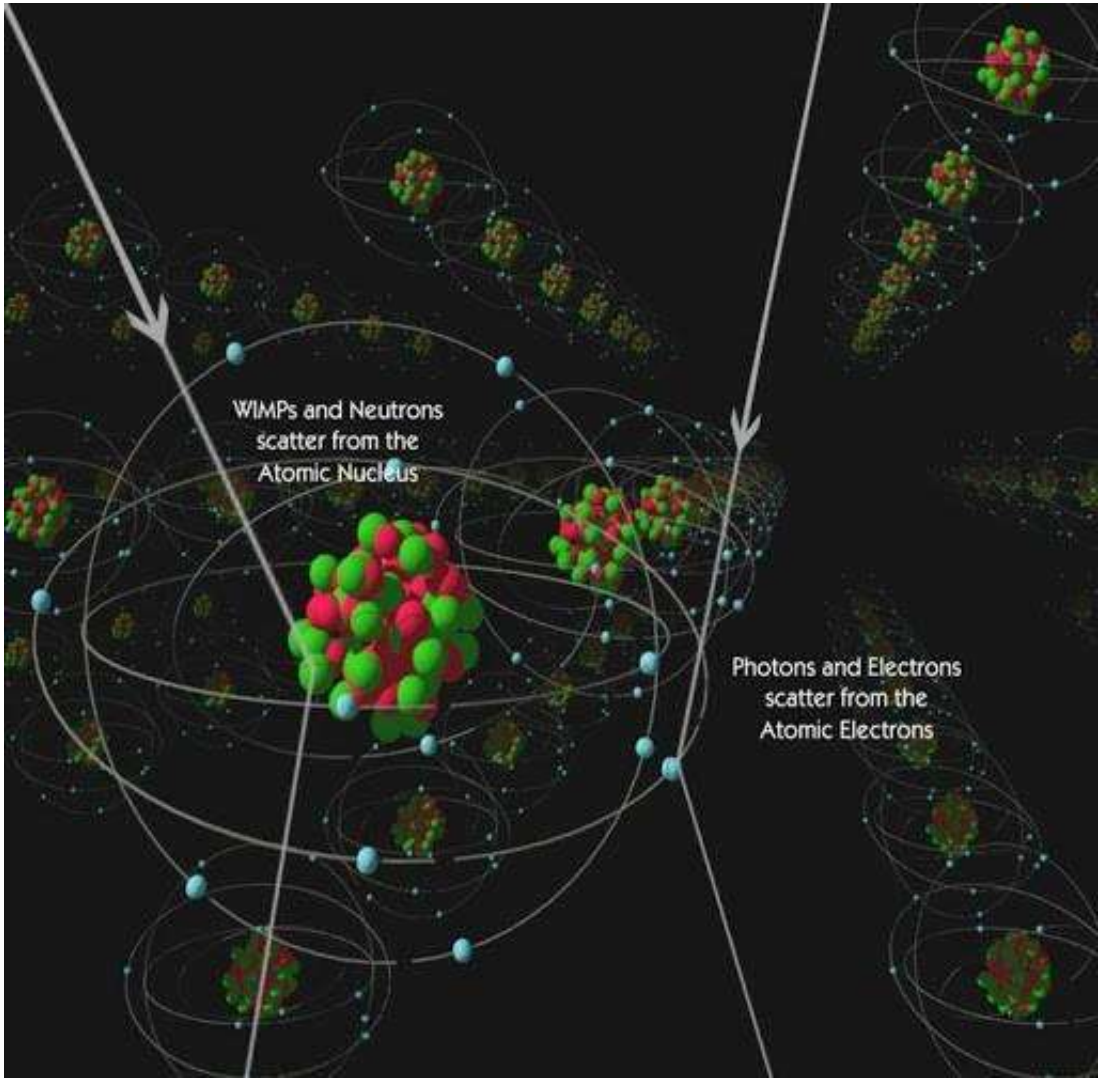
Lots of other evidence for dark matter like gravitational lensing, but that's for another day…

How would we Figure out what it is?

Since everything else in the universe is made of particles, let's guess that

Only a couple of ways to "detect" it here on Earth

- Hit a nucleus or hit an Electron
- Build a super sensitive detector!



Some Sources of Dark Matter are Cheap

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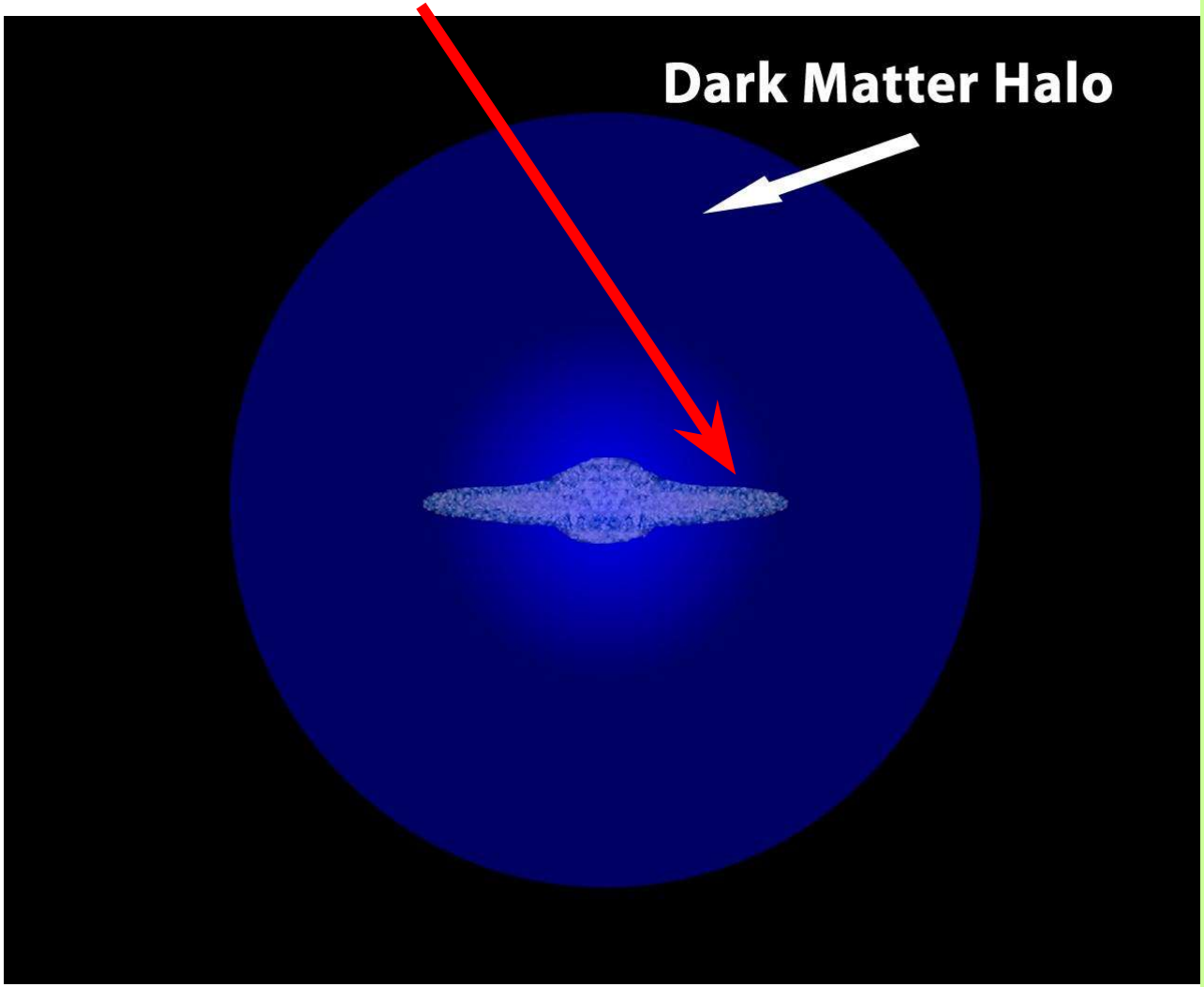
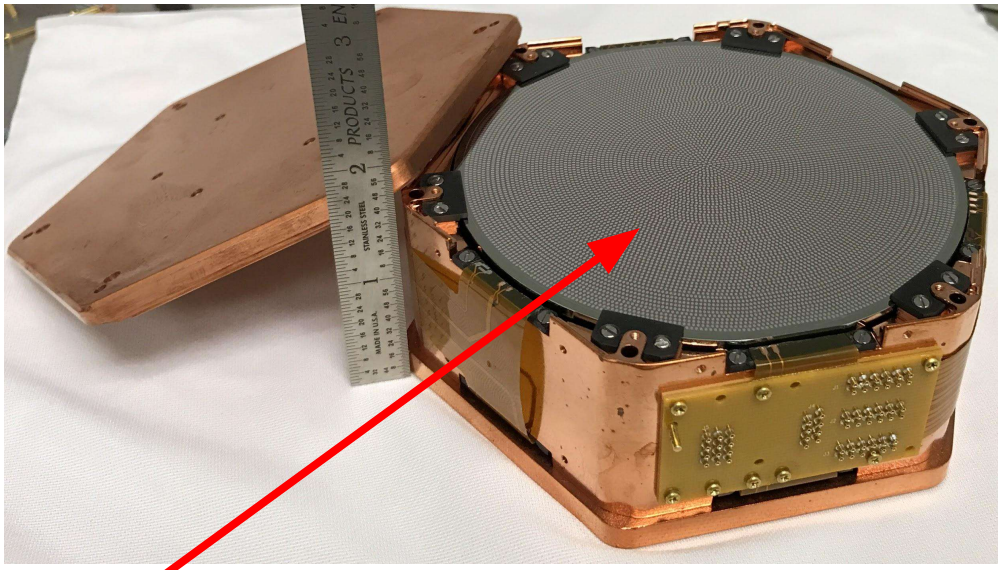


Our Sun is Moving through our Galaxy…

Lots of Dark Matter is hitting the Earth every second

Custom Detector

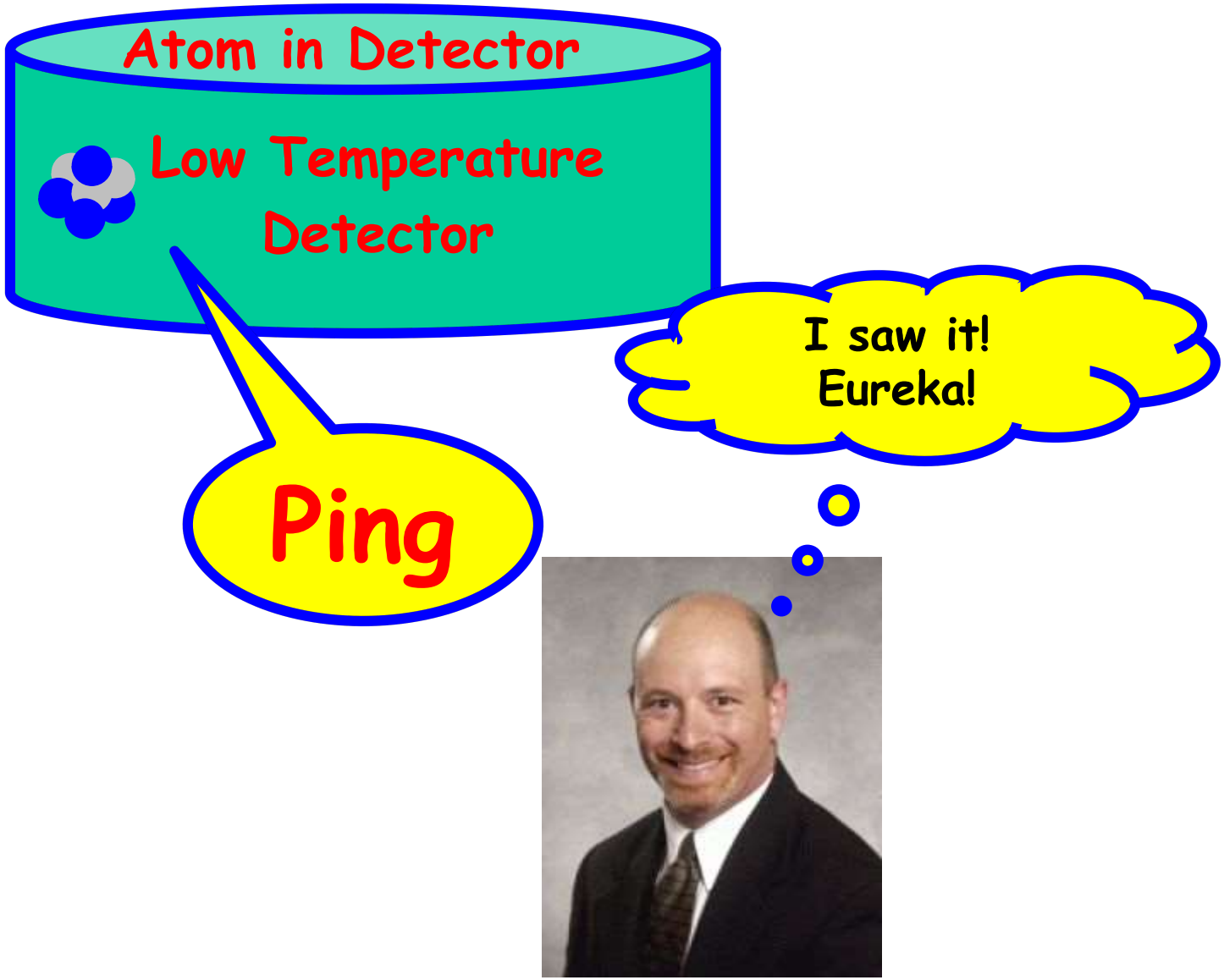
- Single Crystal of Silicon (like in computer chips)
  - About the size of a hockey puck
  - Ok… a quarter million dollar hockey puck
- Put Superconducting sensors on the top
- Make it super cold (microKelvin)
  - We have "cool" toys



Put it a mile underground (in Canada) to protect it

How does it work?

Dark Matter Particle



Switching Topics in a Funny Way

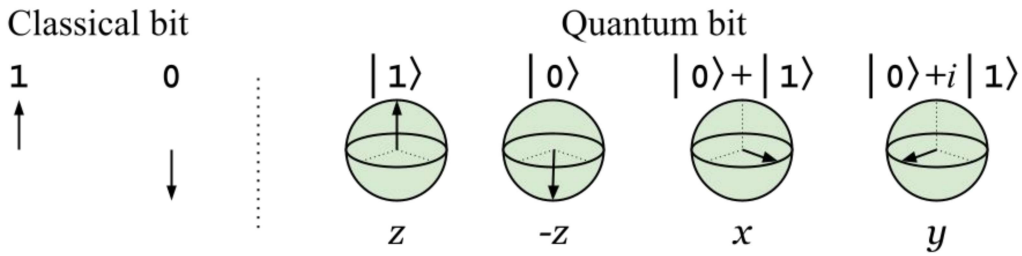
- One of the fun things in science is that scientists from VERY different fields talk to each other
- Particle Physicists have always been interested in computing
  - We gave you the Web and Grid Computing (what many call the Cloud)
- Next up: Quantum Computing

How do Computers Work, and what is Quantum Computing?

- Big picture: Normal computers are just a keepers of 1's and 0's and can do things to them (binary)
- Can make bigger numbers out of them: 1000 is the same as 8 (in Hex)
- Takes a LOT of bits to be useful, but we're pretty good at that…
- Would be good if we could take it to the next level … more information per bit!

"Classical Bits" vs. "Quantum Bits"

- Quantum mechanics can be a little hard to understand because of the Uncertainty Principle
- What this means is that if I look at things at the SMALLEST level, they don't have a well defined position, but have information that is "quantum"



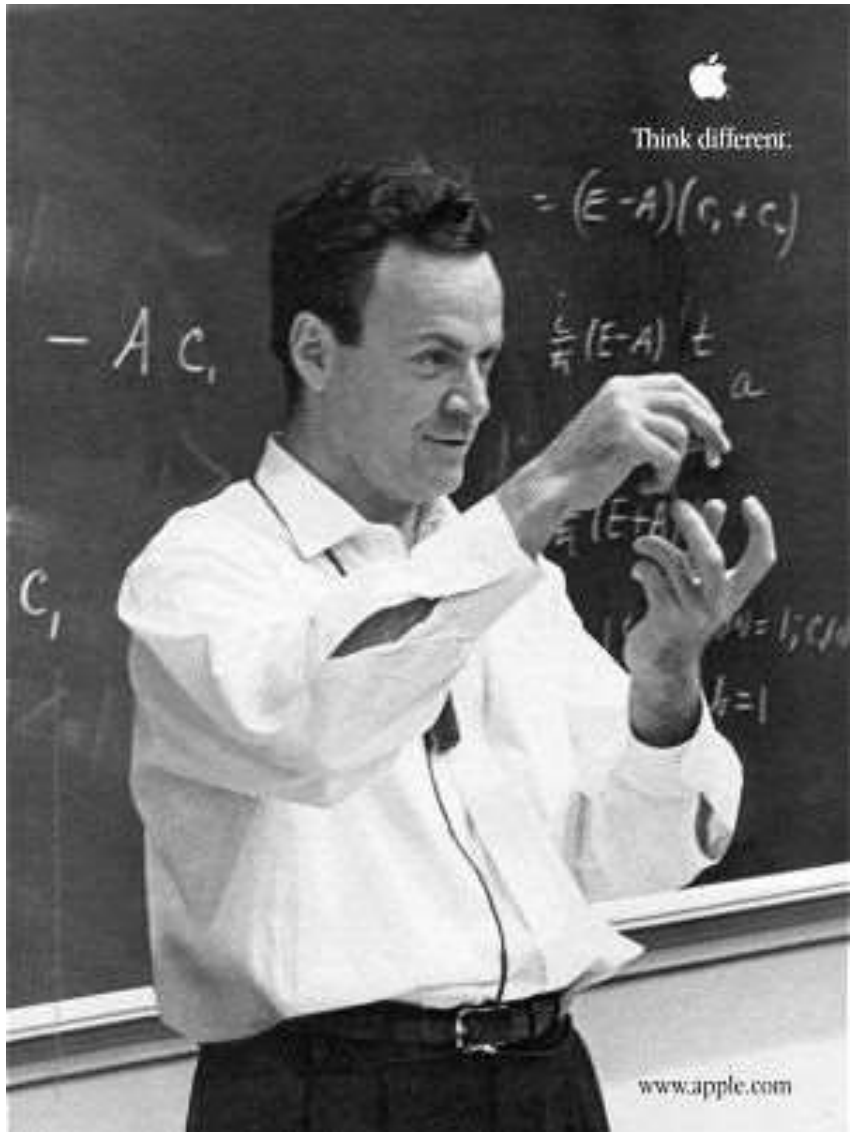
⇒ Can move from storing information in Simple ways to more complex ways

Why are Quantum Bits useful?

- Kinda complicated, but the bits can now also interact in "quantum ways"
- Can do calculations that require quantum mechanical calculations MUCH better
  - Example: How molecules work
- Can also do certain types of non-Quantum mechanical problems better
  - Example: Encryption security
- There are certain things that we believe can be solved "easily" with a quantum computer that it might take forever for a regular computer to calculate

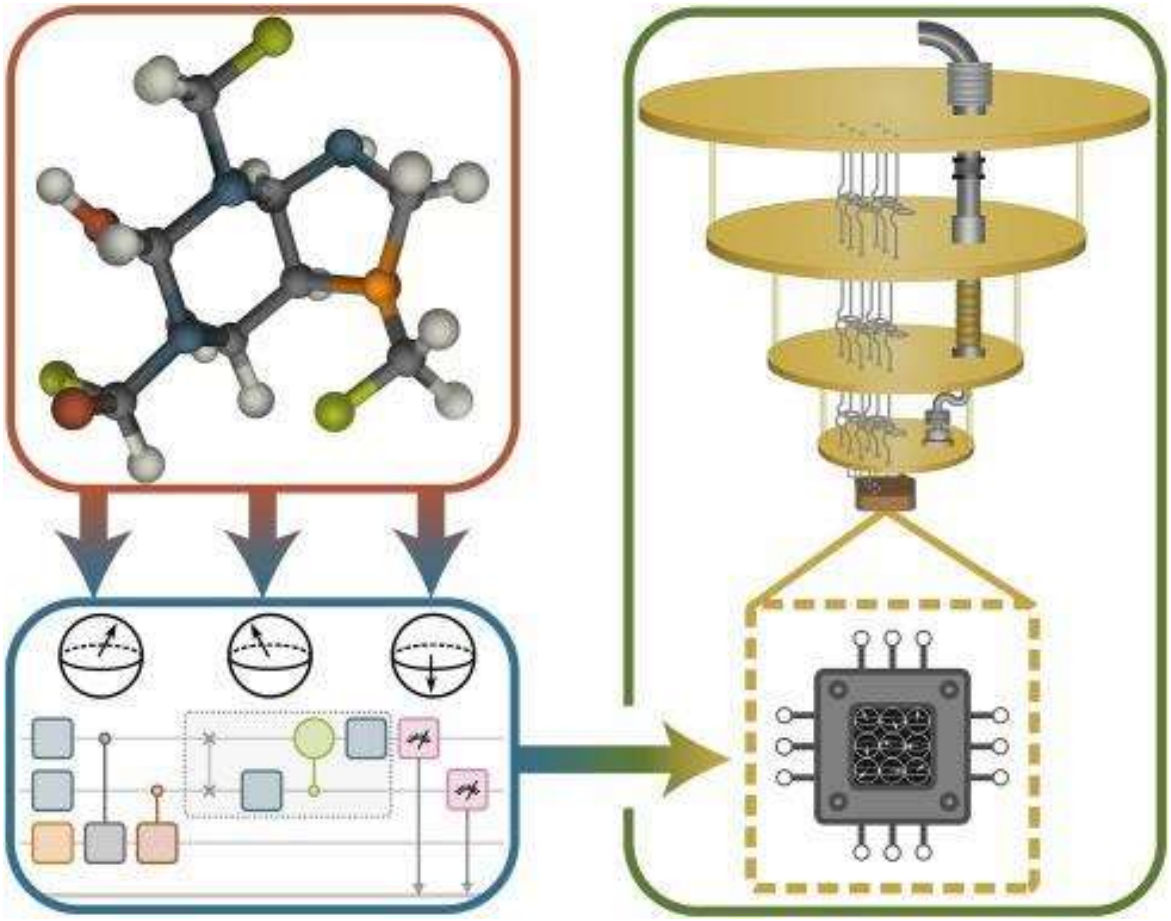
Taking it a step further

Richard Feynman Quote:
"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."



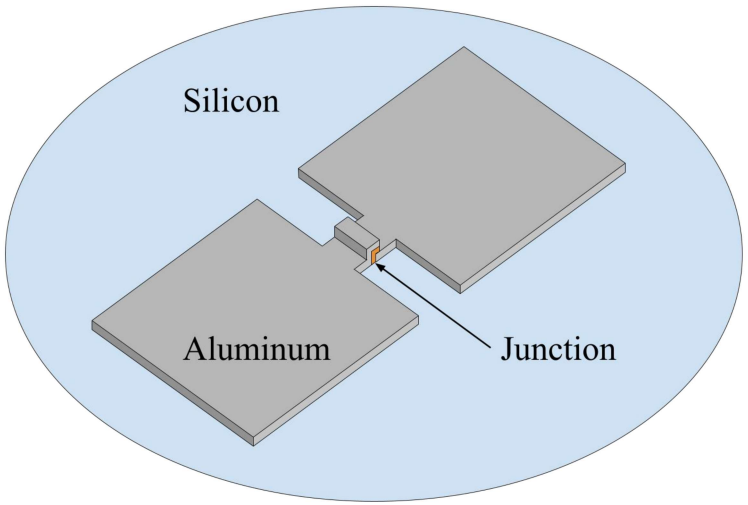
Ok… how do we DO quantum Computing?

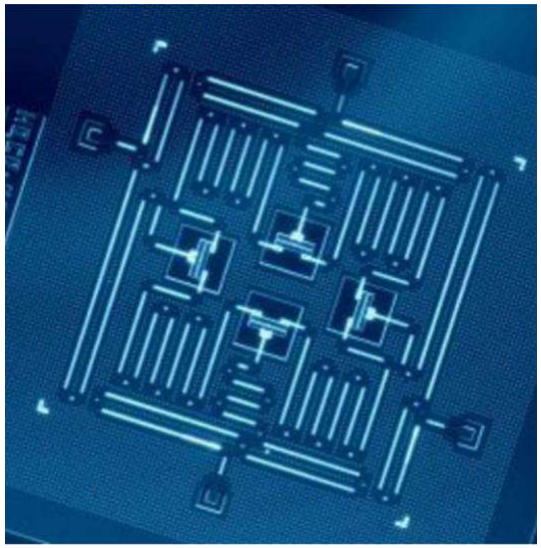
- Example problem: Simulating how a complicated molecule works
- Build a quantum computer, using quantum bits to do the calculation



Building Qubits

There are many ways to build qubits, but one of the most promising is to put superconducting aluminum on silicon, just like they do for regular computers





How well does it work?

- Unfortunately, qubits have a technical problem… it's really easy to mess up the information in a qubit
- This ISN'T true for regular computers

Example problem: A cosmic ray from outer space hits your computer and changes a 0 to a 1.

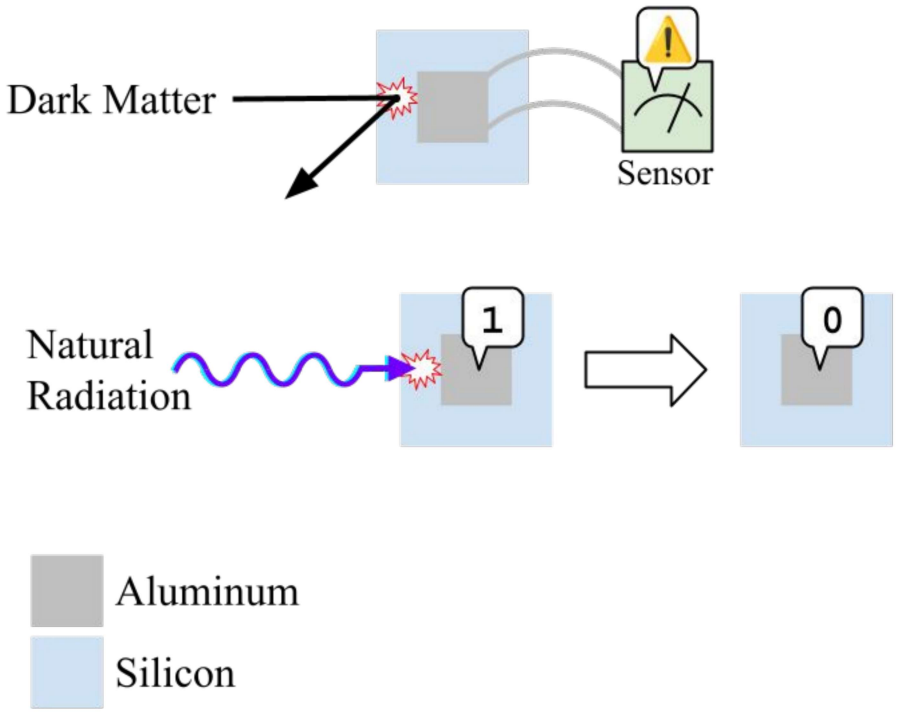
- Let's say you have $0000010.00 dollars in your account, but a cosmic ray changes that to $1,000.010.00

Normally this isn't a problem (although every now and then you need to reboot your computer because something got messed up and it's not clear why…)

It's even worse in quantum computers because it takes a small amount of energy to "flip a bit"…

Draw the problem….

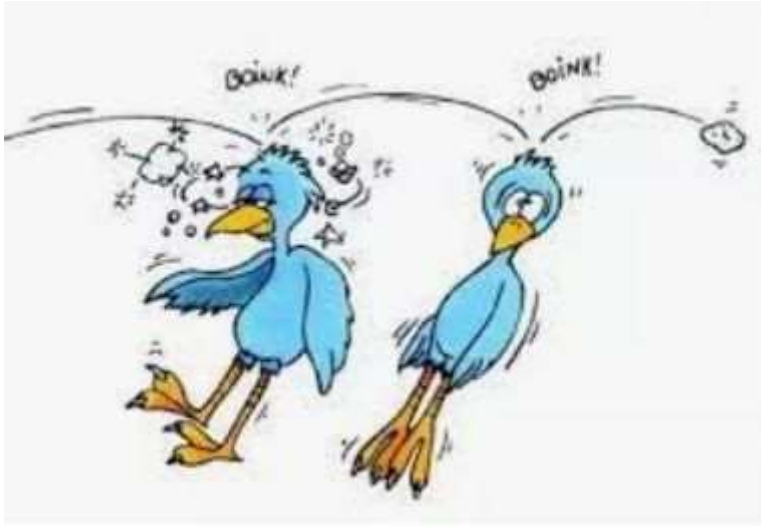
- Something comes in and hits the qubit, messing things up
- Gee… kinda looks like our dark matter detector



Cutting Edge Research

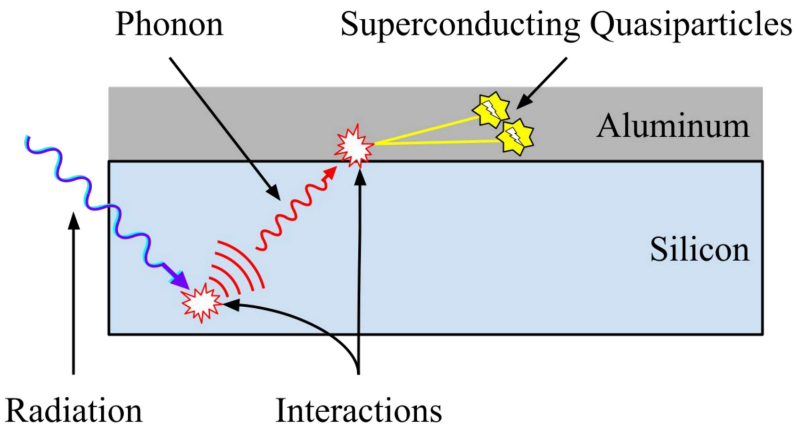
Idea… If we can REALLY understand how particles interact with the silicon and superconducting aluminum then we can:

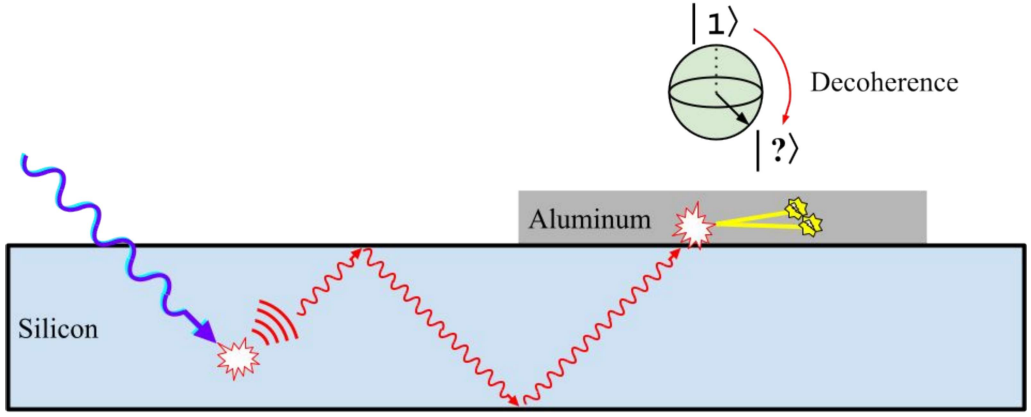
- Maximize the sensitivity of the aluminum to the interaction (dark matter)
- Minimize the sensitivity of the aluminum to the interaction (quantum computing)



Fancy Models

- Can think of it in a simple way… A dark matter particle hits the detector and makes it vibrate
- Energy moves through the crystal like a sound wave
  - Call that a phonon
- The phonon hits the superconductor and liberates quasiparticles
  - Good for Dark Matter detectors, bad for quantum computers

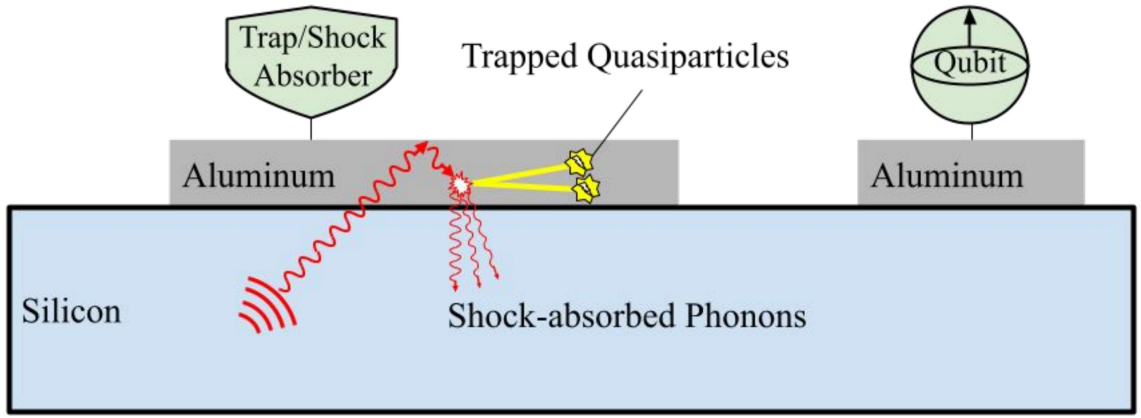




But…

If we can REALLY understand and predict how the phonons and quasiparticle behave, we can build quantum computers in ways that protect the qubits!!!

… Ok, we'll need some engineering help…



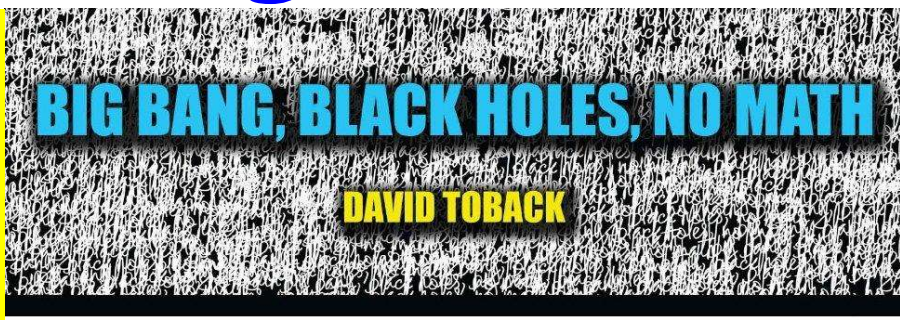
- Huge simulation project between Texas A&M, MIT, Fermilab, Pacific Northwest National Laboratory and others around the world
- Interface of particle physics, condensed matter and computer science might be able to help us discover dark matter….

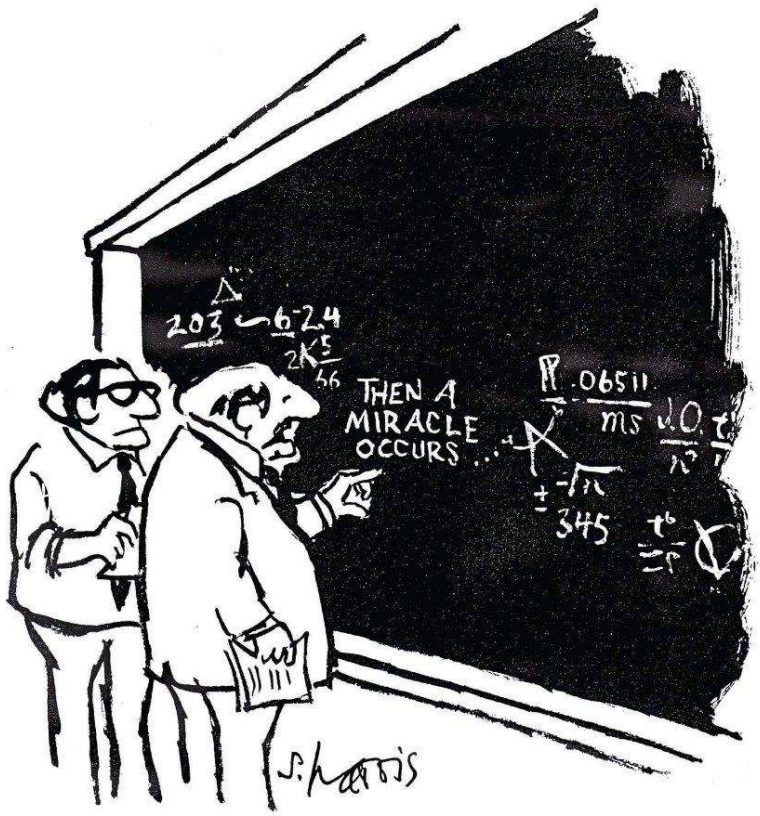
Final Thoughts

Interested in learning more?

- Physics department now offers a course entitled *"Big Bang & Black Holes"*

  (ASTR/PHYS 109)
  - Covers Stephen Hawking's *"Brief History of Time"*
  - Origin and Evolution of the Universe
  - How do stars form?
  - What is Dark Matter? Dark Energy? Anti-Matter?
  - What are Black Holes?
  - More on General Relativity, Quantum Mechanics and Particle Physics
  - There is an option to take is an Honors class





"I THINK YOU SHOULD BE MORE ...CIT HERE IN STEP TWO."

https://rebrand.ly/109_Homepage

Foreword by Eiichiro Komatsu

Conclusions

- It's an incredibly exciting time to be a scientist!
- Astronomy, Cosmology and Particle Physics are all coming together
- If our understanding is correct, a major discovery of Dark Matter may be just around the corner!
- If our methods are right, we might even bring quantum computing into your homes in the near future