Davidson Scholars

Dark Matter

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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

Overview of the Talk

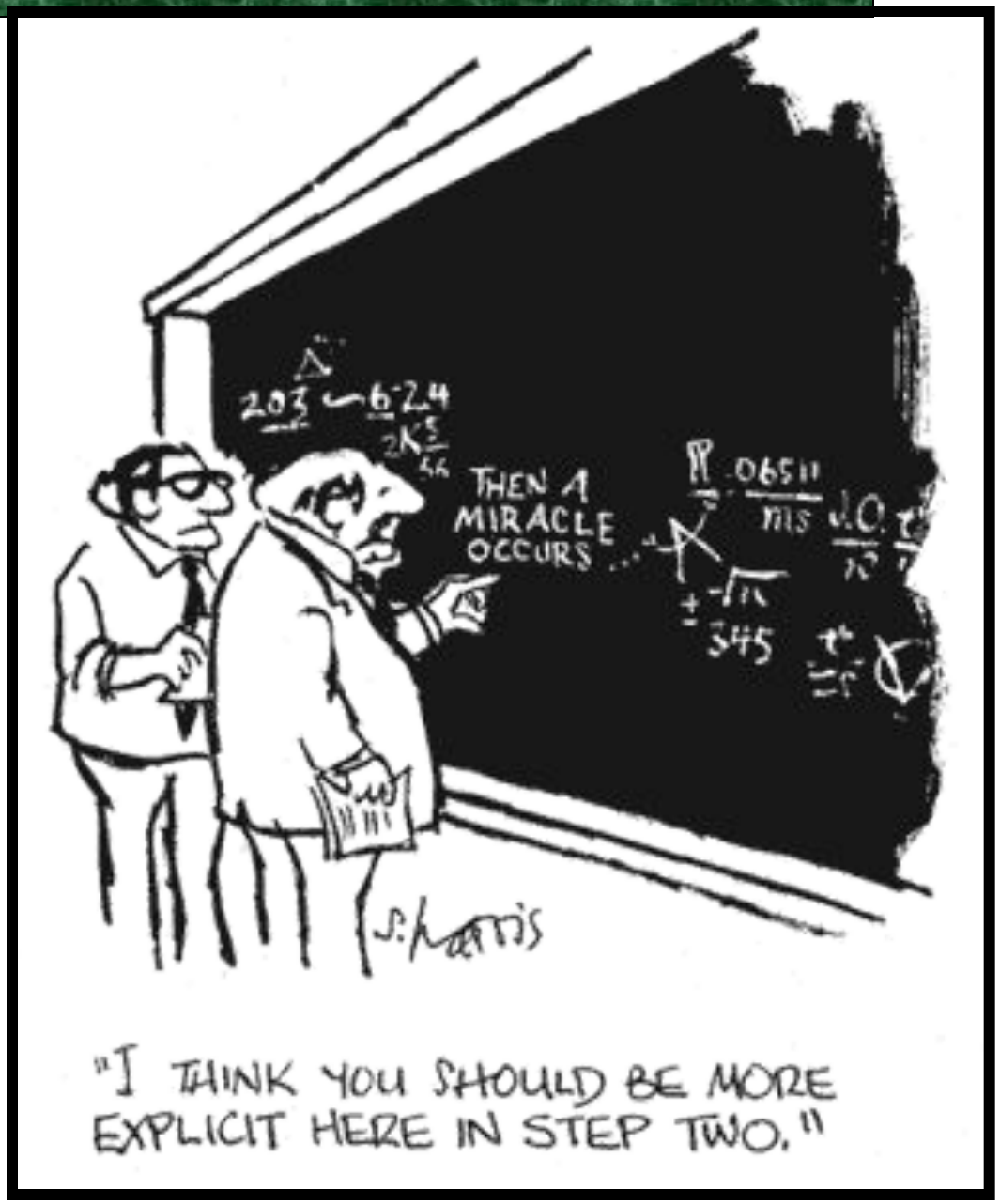
There is a lot here, so we'll go step-by-step:

- *What is the evidence that there is a large amount of mass that we can't see in the Universe?*
- *Why do we think it's a particle?*
- *What are scientists doing today to discover Dark Matter?*

Final Thoughts

Dark Matter

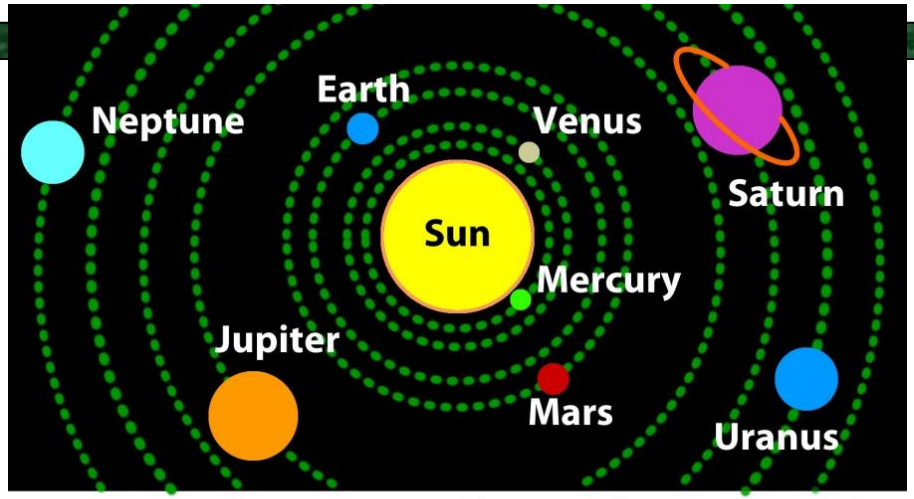
What is some of the evidence for Dark matter?



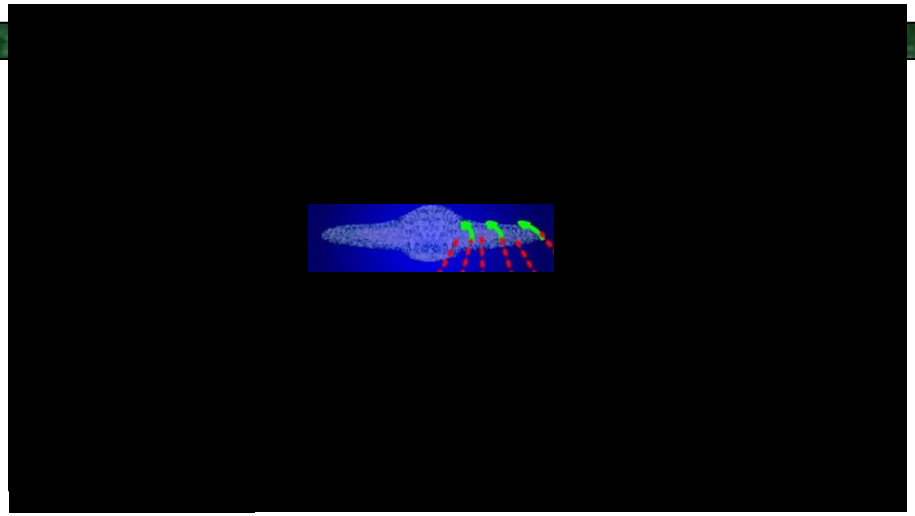
How Stars Move in Galaxies

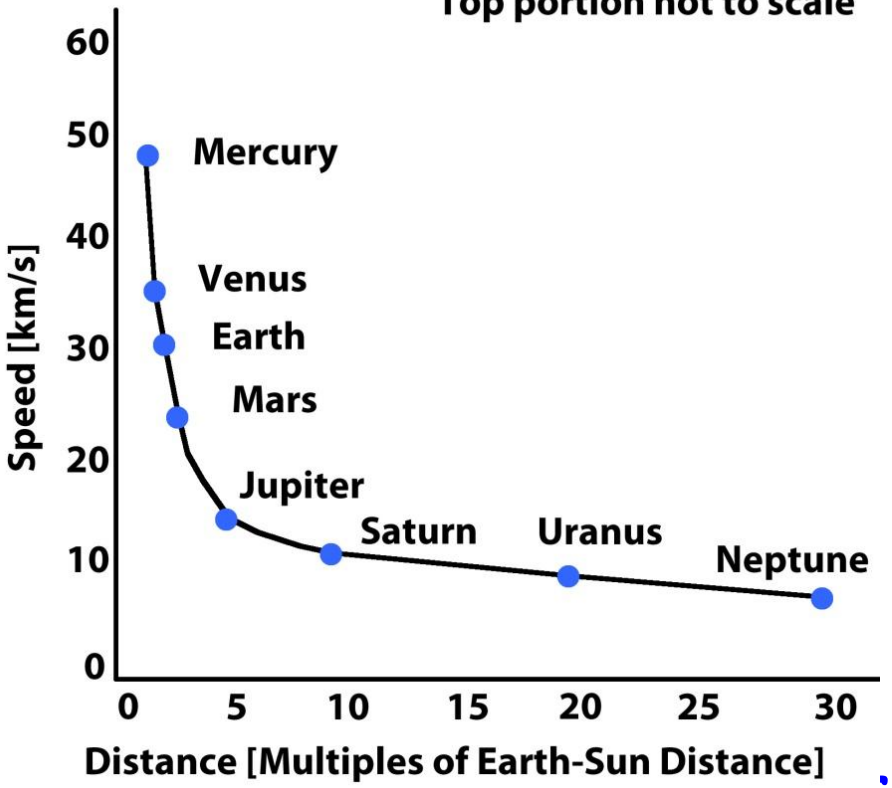
- Start by considering the case that there IS no Dark Matter in galaxies
- Can use laws of gravity to predict two things:
  - 1) The orbits of planets as they move around the solar system and
  - 2) Stars as they move around a galaxy
- Prediction: both have very massive centers so we expect the data 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

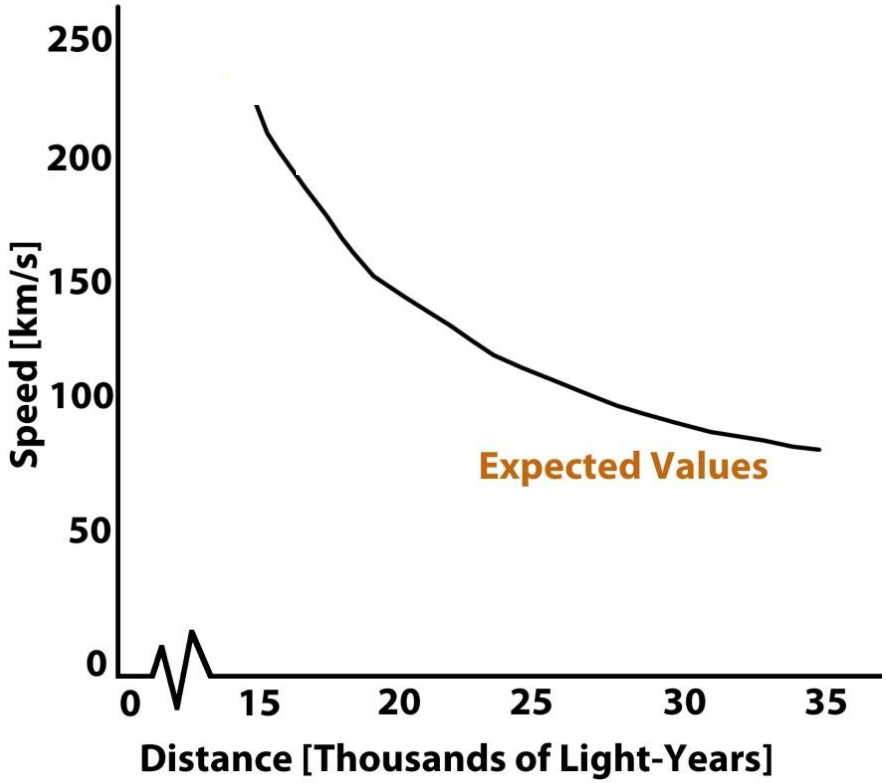
The Data



Top portion not to scale





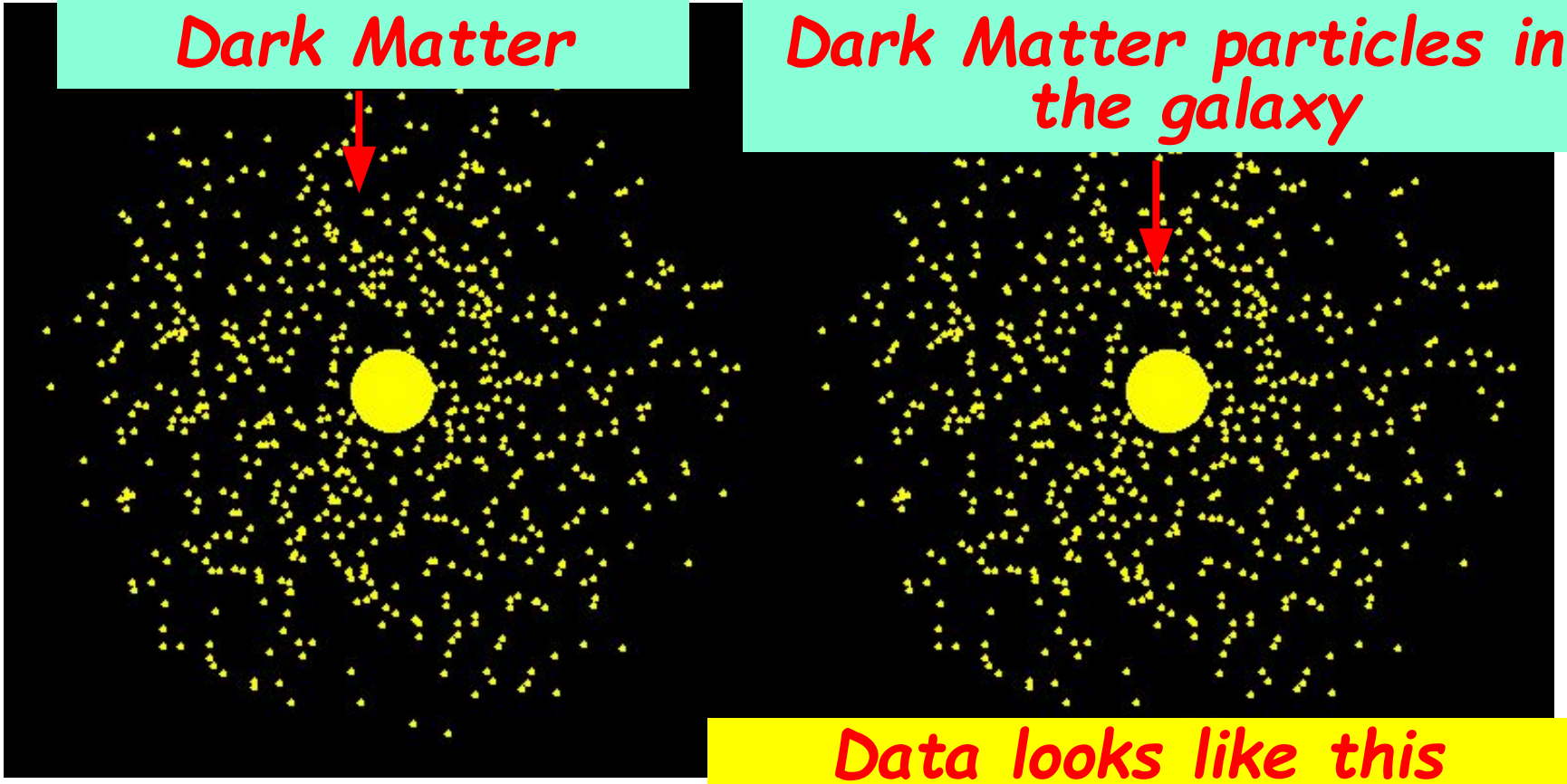


Does this work for Stars?

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

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)

Some fun evidence that Dark Matter is Made of Particles

Colliding Clusters of Galaxies

Look at Colliding Clusters of Galaxies

Atoms in the Galaxies interact and slow down as they pass through each other

Dark Matter doesn't interact much so it isn't slowed down much

Colliding Galaxy Clusters

The atom part and the Dark Matter part of Galaxies interact differently as they pass through each other

We get to look at them at a particular moment in time

Atoms and Dark Matter

Atoms and Dark Matter

https://drive.google.com/file/d/11We2s2g79b9zYi9nEIJ5_PyYT7skFEsd/view?usp=drive_link

Looking at the aftermath of a Colliding Galaxy Clusters

Light from a Galaxy

Atoms and Dark Matter

Atoms and Dark Matter

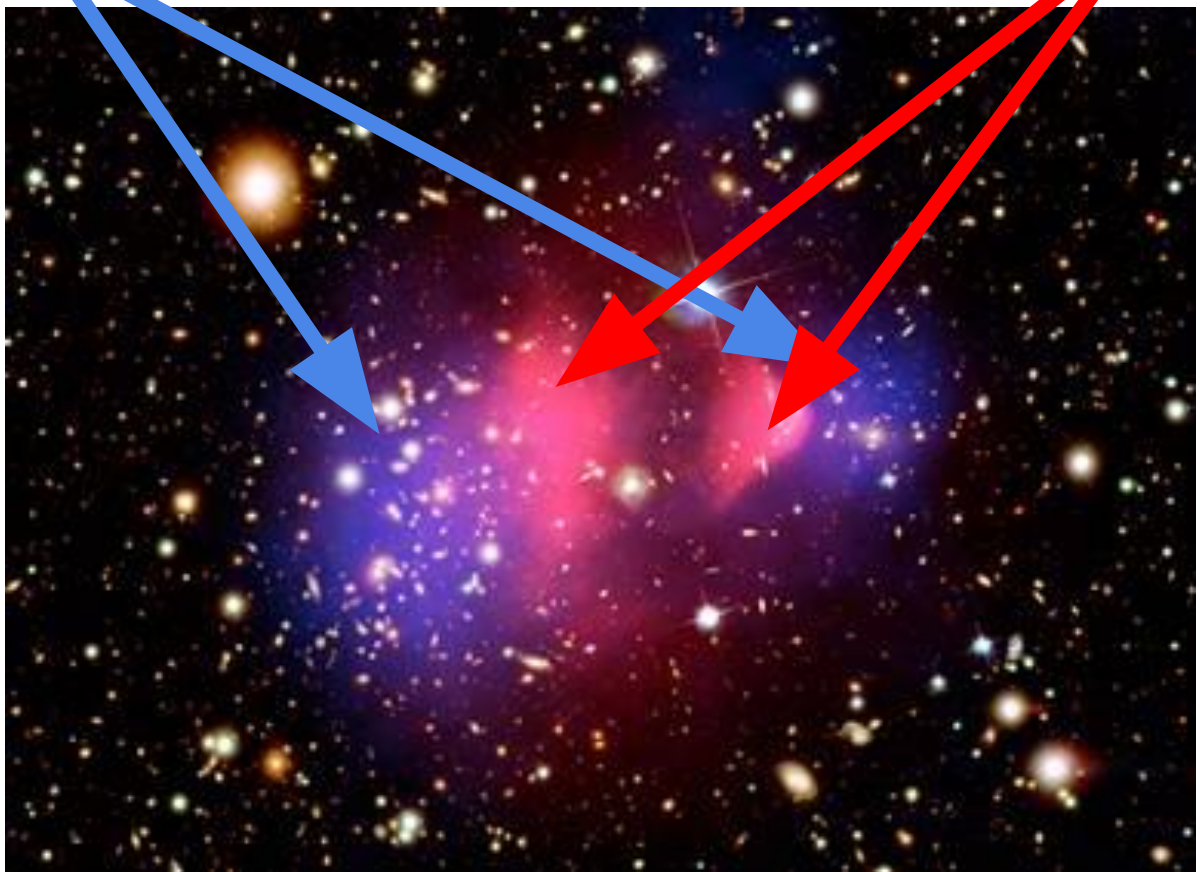
https://drive.google.com/file/d/1JFCxAo464z6Knx_C6EeUnlirIkM1c6a6/view?usp=drive_link

Evidence for This in Nature?

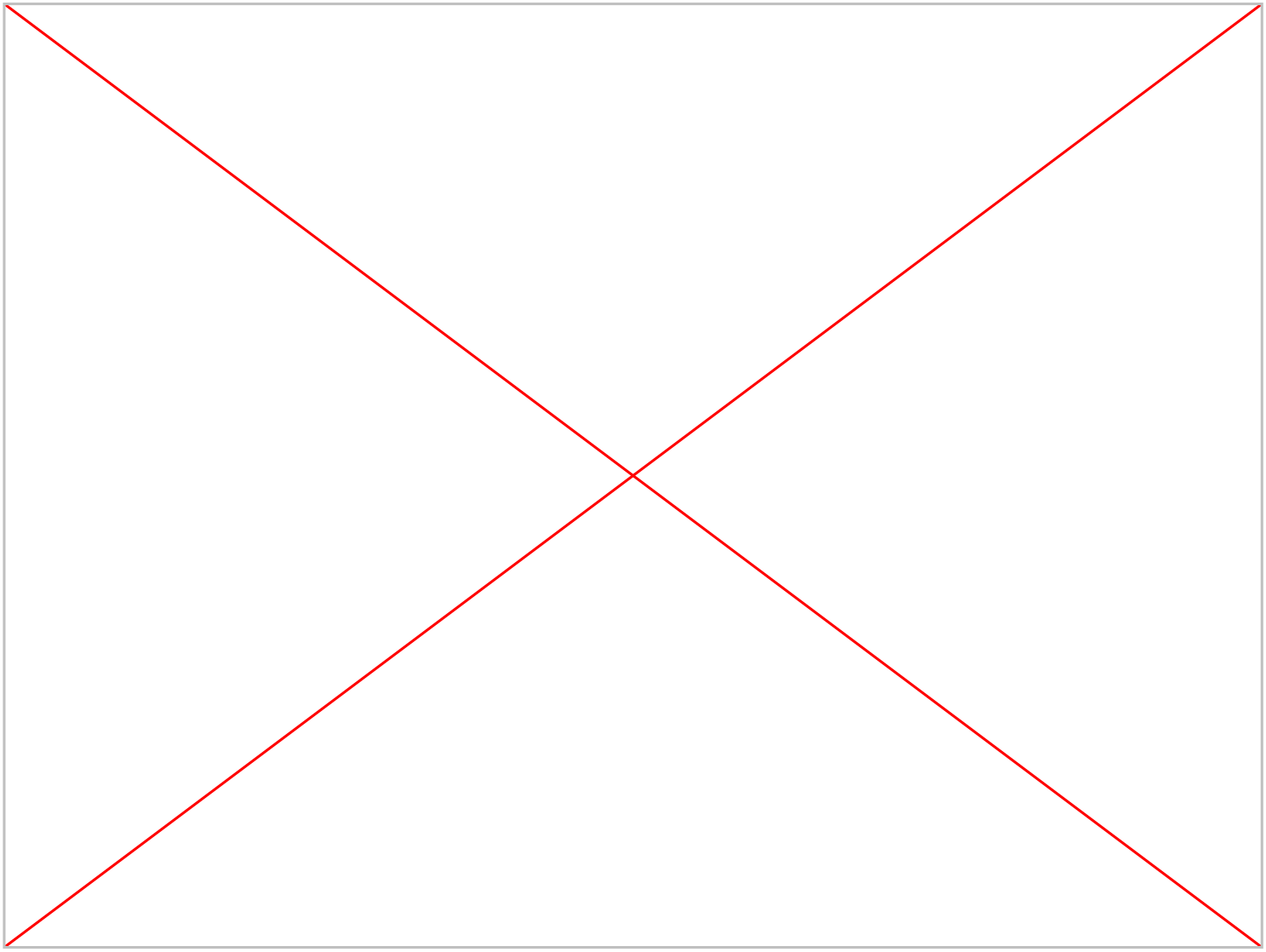
Colliding Clusters of Galaxies

Blue is the part from lensing only
"Fast → Dark Matter"

Red part from observing the light
"Slow → Atoms"



More sophisticated version



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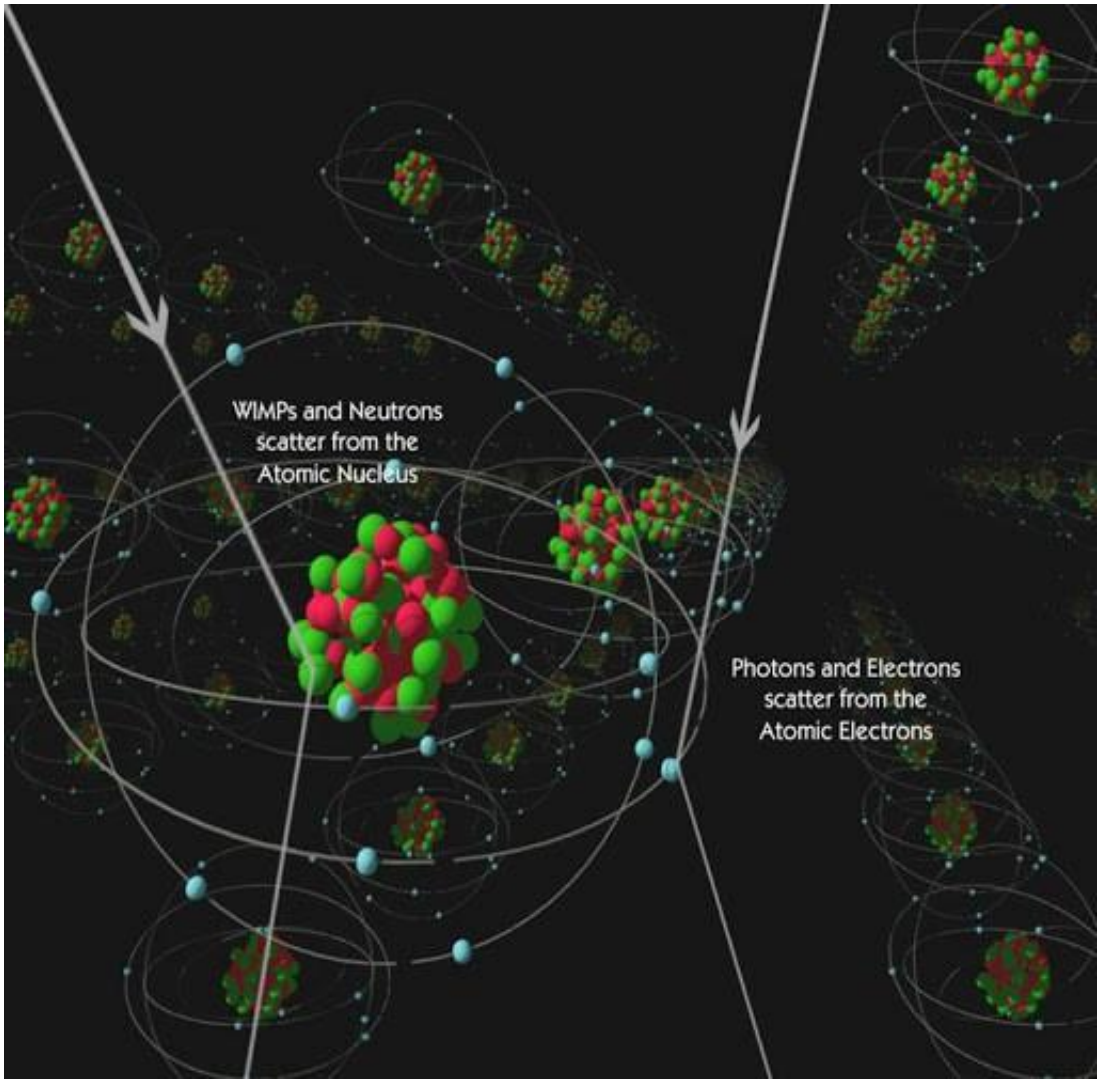
How would we Figure out what it is?

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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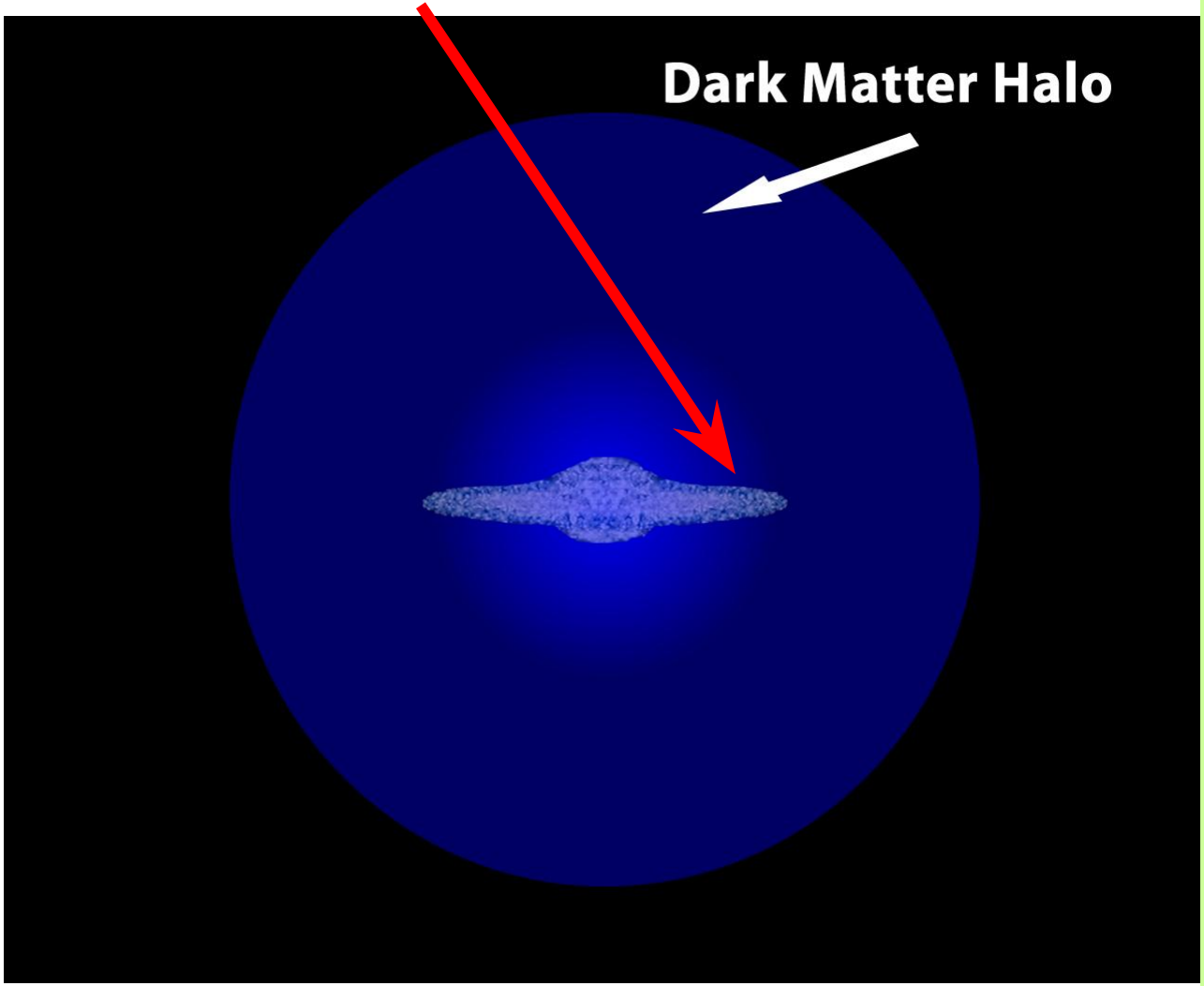


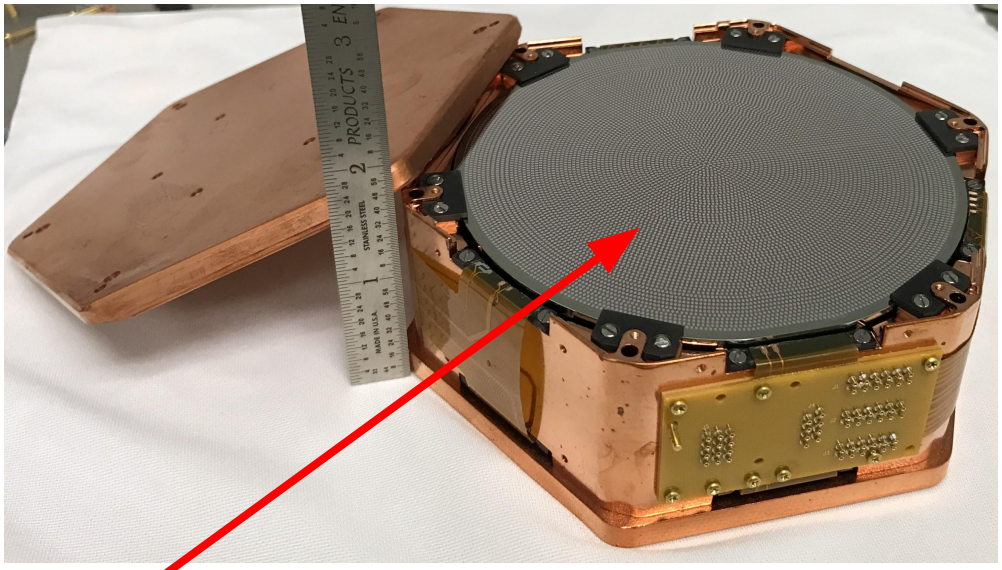
The Milky Way attracted lots of Dark Matter via Gravity

Our Sun is Moving through our Galaxy…

Lots of Dark Matter is hitting the Earth every second

Custom Detector

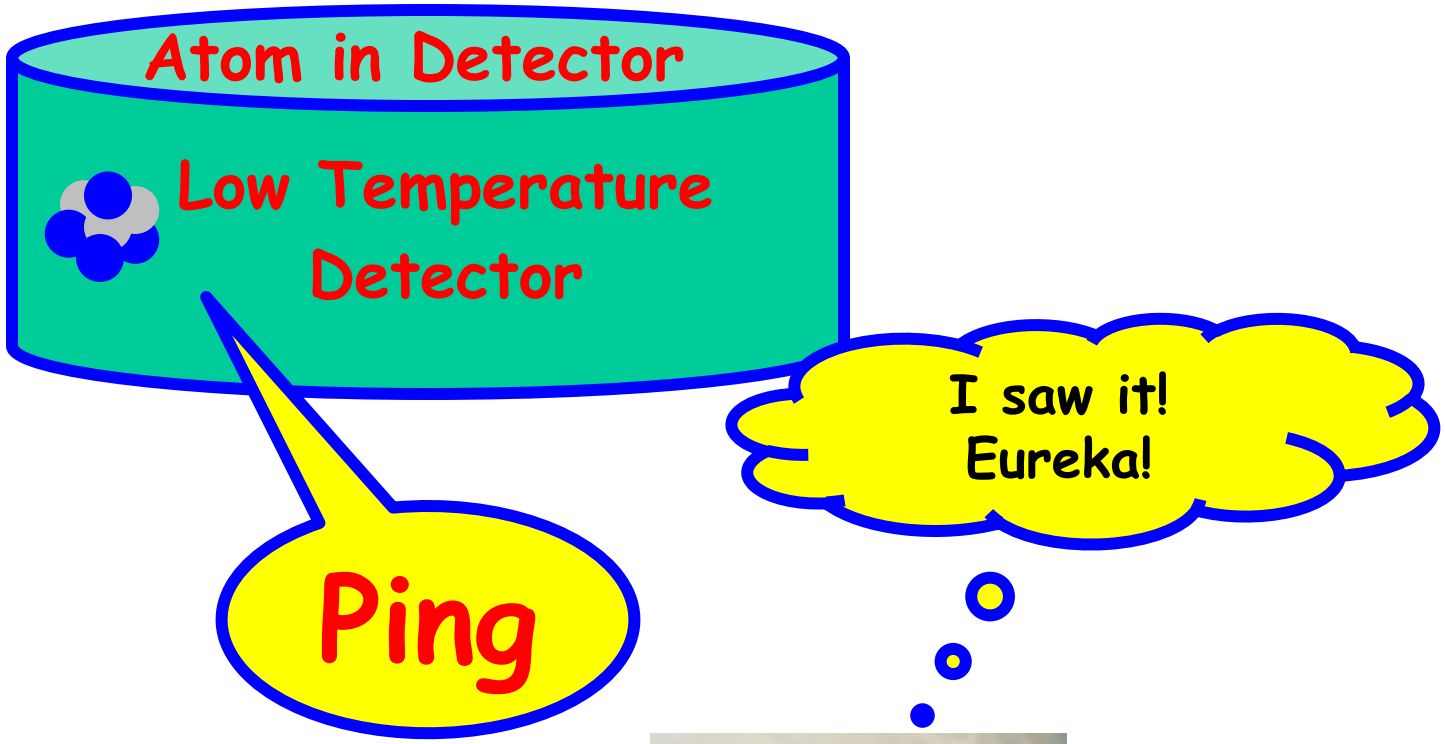
- Single Crystal of Silicon (like in computer chips)
  - About the size of a hockey puck
  - Ok… a quarter million dollar hockey puck
- Put Superconducting sensors on the top
- Make it super cold (microKelvin)
  - We have "cool" toys



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

How does it work?

Dark Matter Particle

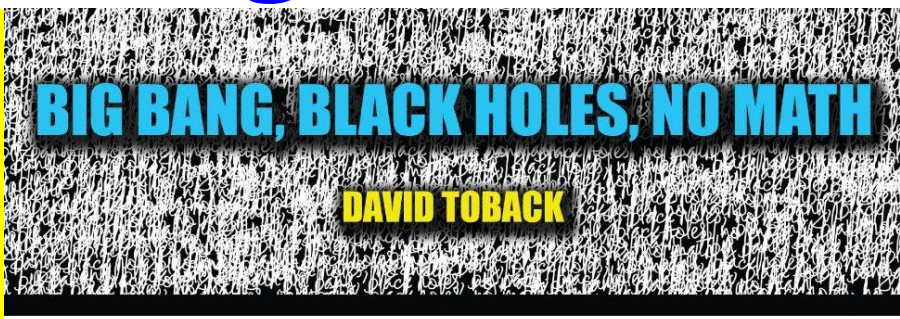


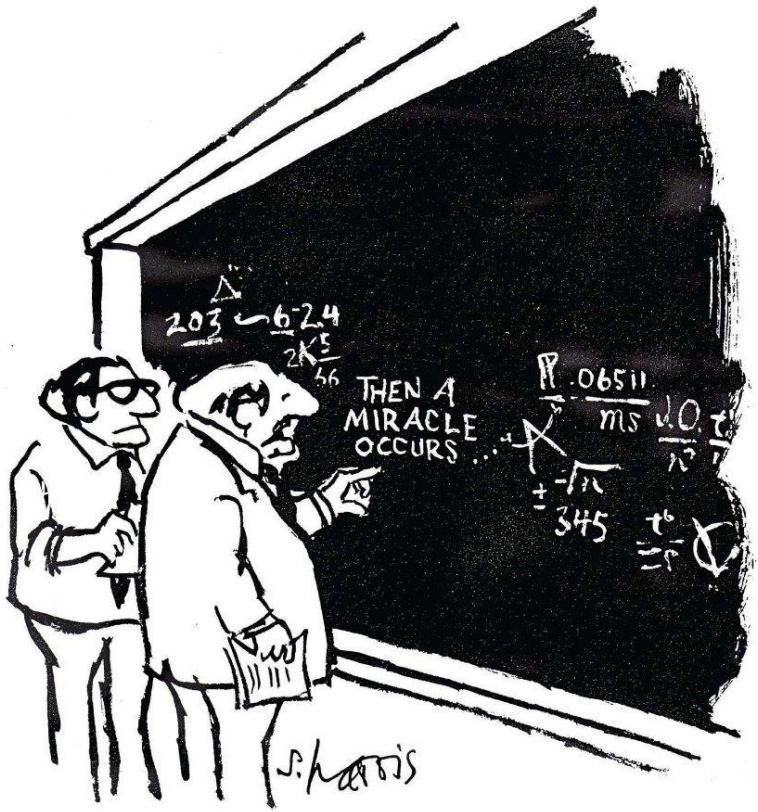
Final Thoughts

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 it as an Honors class





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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!


End of Lecture

A **quantum computer** is a computer that exploits quantum mechanical phenomena. On small scales, physical matter exhibits properties of both particles and waves, and quantum computing leverages this behavior using specialized hardware. Classical physics cannot explain the operation of these quantum devices, and a scalable quantum computer could perform some calculations exponentially faster[a] than any modern "classical" computer. Theoretically a large-scale quantum computer could break some widely used encryption schemes and aid physicists in performing physical simulations; however, the current state of the art is largely experimental and impractical, with several obstacles to useful applications.

The basic unit of information in quantum computing, the qubit (or "quantum bit"), serves the same function as the bit in classical computing. However, unlike a classical bit, which can be in one of two states (a binary), a qubit can exist in a superposition of its two "basis" states, a state that is in an abstract sense "between" the two basis states. When measuring a qubit, the result is a probabilistic output of a classical bit. If a quantum computer manipulates the qubit in a particular way, wave interference effects can amplify the desired measurement results. The design of quantum algorithms involves creating procedures that allow a quantum computer to perform calculations efficiently and quickly.

Quantum computers are not yet practical for real work. Physically engineering high-quality qubits has proven challenging. If a physical qubit is not sufficiently isolated from its environment, it suffers from quantum decoherence, introducing noise into calculations. National governments have invested heavily in experimental research that aims to develop scalable qubits with longer coherence times and lower error rates. Example implementations include superconductors (which isolate an electrical current by eliminating electrical resistance) and ion traps (which confine a single atomic particle using electromagnetic fields).

In principle, a classical computer can solve the same computational problems as a quantum computer, given enough time. Quantum advantage comes in the form of time complexity rather than computability, and quantum complexity theory shows that some quantum algorithms are exponentially more efficient than the best-known classical algorithms. A large-scale quantum computer could in theory solve computational problems unsolvable by a classical computer in any reasonable amount of time. This concept of extra ability has been called "quantum supremacy". While such claims have drawn significant attention to the discipline, near-term practical use cases remain limited.

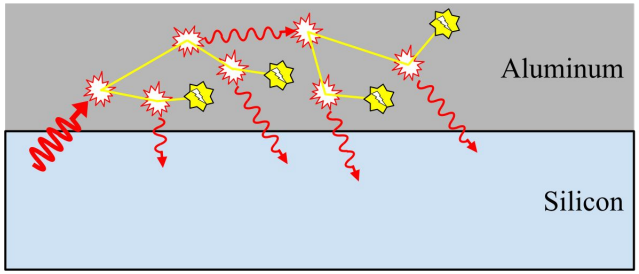
n a 1984 paper, Charles Bennett and Gilles Brassard applied quantum theory to cryptography protocols and demonstrated that quantum key distribution could enhance information security.[12][13]

In quantum computing, quantum supremacy or quantum advantage is the goal of demonstrating that a programmable quantum computer can solve a problem that no classical computer can solve in any feasible amount of time, irrespective of the usefulness of the problem.[1][2][3] The term was coined by John Preskill in 2011,[1][4] but the concept dates to Yuri Manin's 1980[5] and Richard Feynman's 1981[6] proposals of quantum computing.

Conceptually, quantum supremacy involves both the engineering task of building a powerful quantum computer and the computational-complexity-theoretic task of finding a problem that can be solved by that quantum computer and has a superpolynomial speedup over the best known or possible classical algorithm for that task.[7][8]

Will quantum computing ever take over? Not obvious. Very hard to MAKE them…. Very hard to keep them "stable", very hard to make them do computations .But SOME computations are much easier for quantum computers.

Richard Feynman showed that quantum mechanics could not be efficiently simulated on classical devices.[19] During a lecture, he delivered the famous 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."[19]



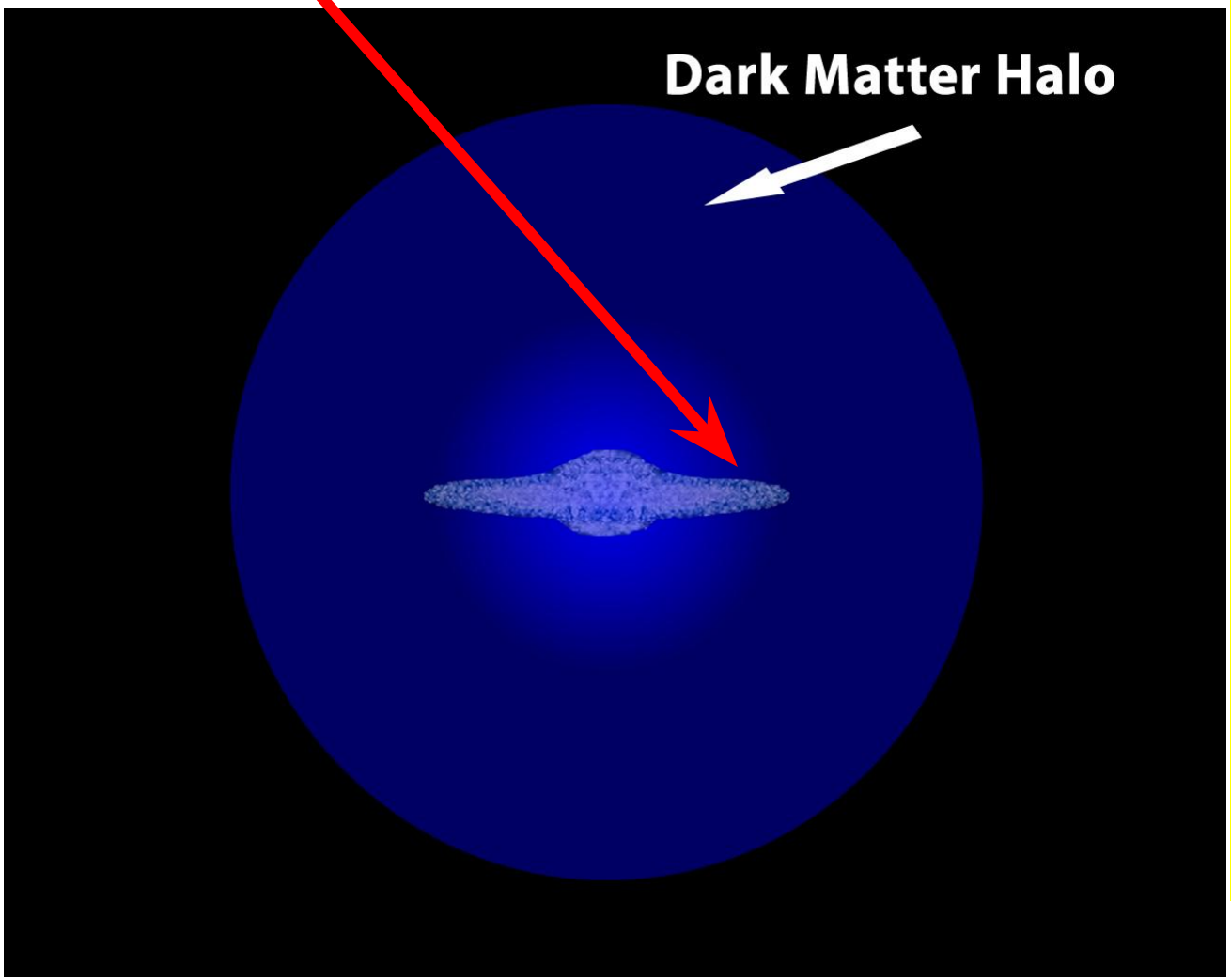
Quick Ideas

- **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)

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