One Cubic Kilometre of Antarctic Ice

(Catching Ghost Particles & a Nobel Prize)



Lecture series on frontier knowledge, imagination and initiatives
(based on the works of Nobel Laureates for the year 2026)
Tezpur University, 18/11/2026

Moon Moon Devi
Department of Physics

Nature's rulebook

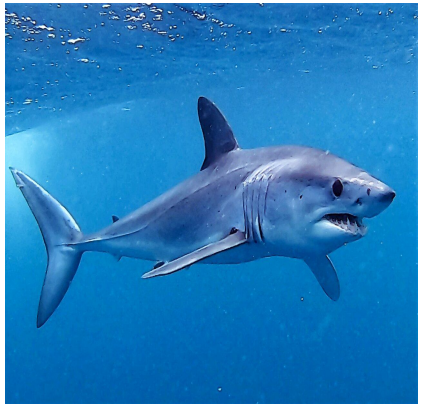
The basic building blocks of matter

What are we all made up of?

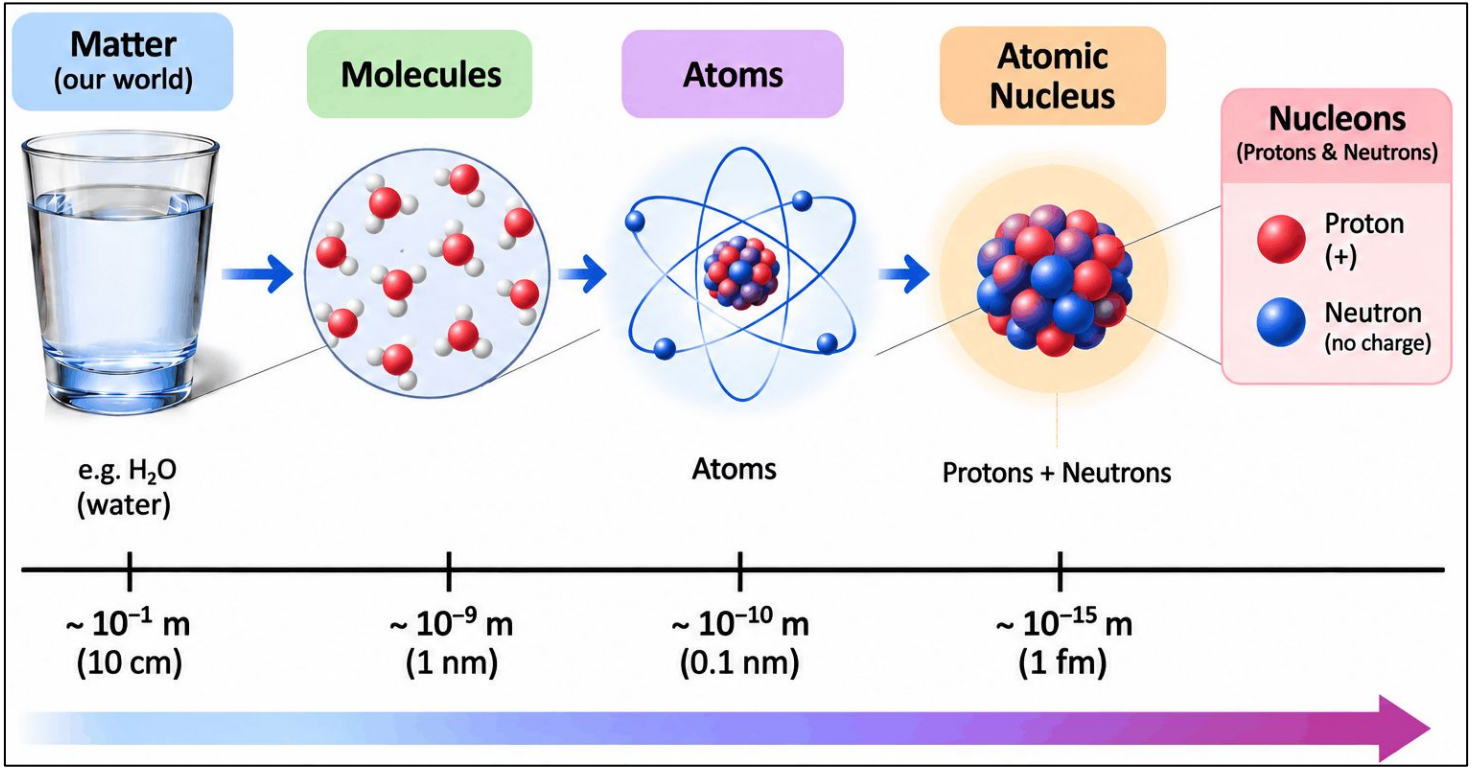




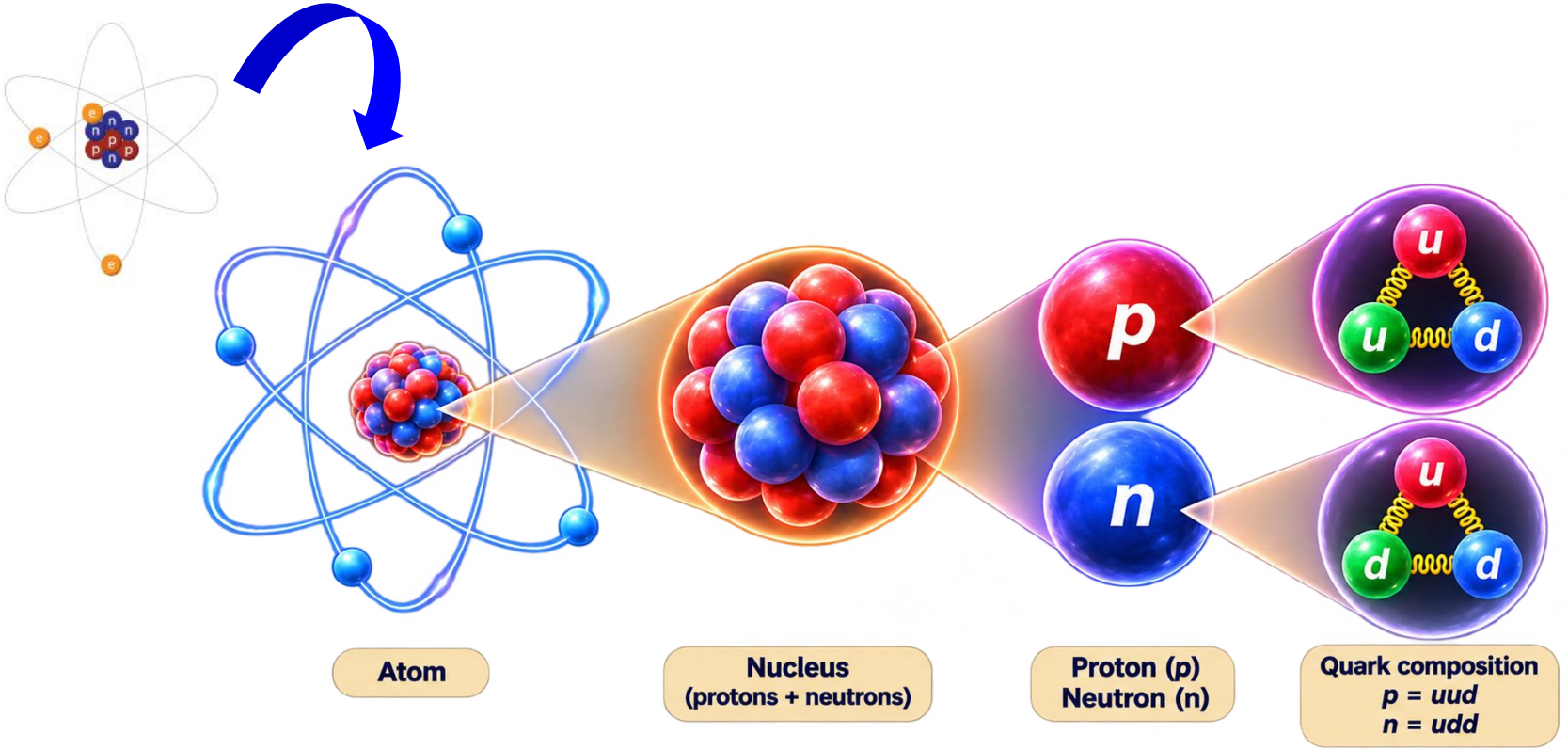




The basic building blocks of matter

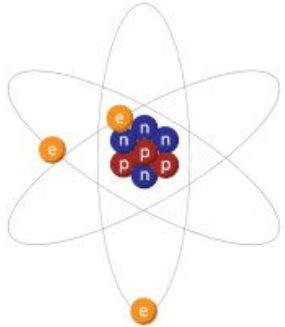


The basic building blocks of matter

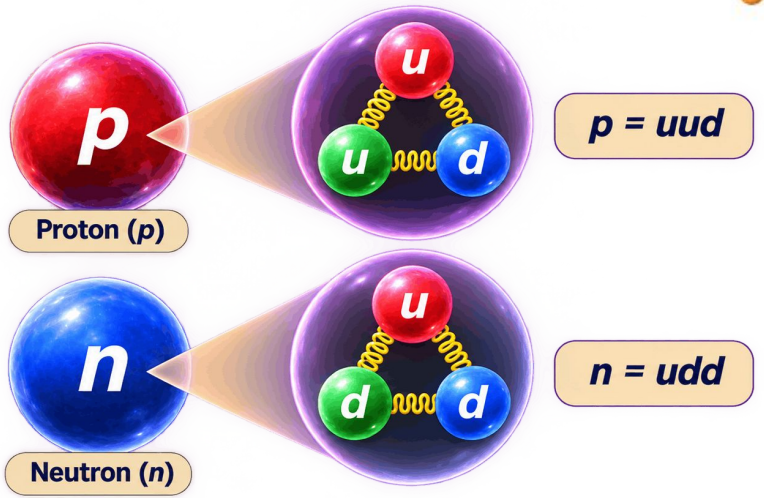


Elementary Particle

- Subatomic particle that is not made of smaller parts and has no known internal structure







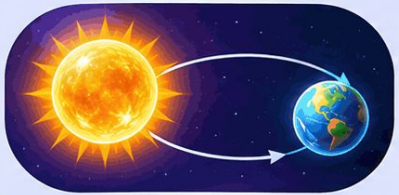
How do they constitute the universe?

The four fundamental forces of nature

They govern everything in the universe

Gravitational Force

Mediator: Graviton
(hypothetical)

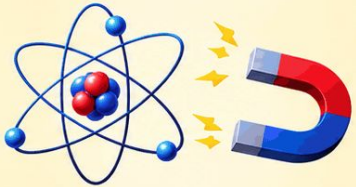


Acts between all matter and energy; attracts.

Example: Keeps planets in orbit.

Electromagnetic Force

Mediator: Photon (γ)



Acts between electric charges; can attract or repel.

Example: Electricity, magnetism, light.

Strong Force

Mediator: Gluon (g)

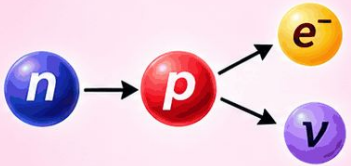


Holds quarks together to form protons and neutrons, and keeps the nucleus bound.

Example: Binds the nucleus of an atom.

Weak Force

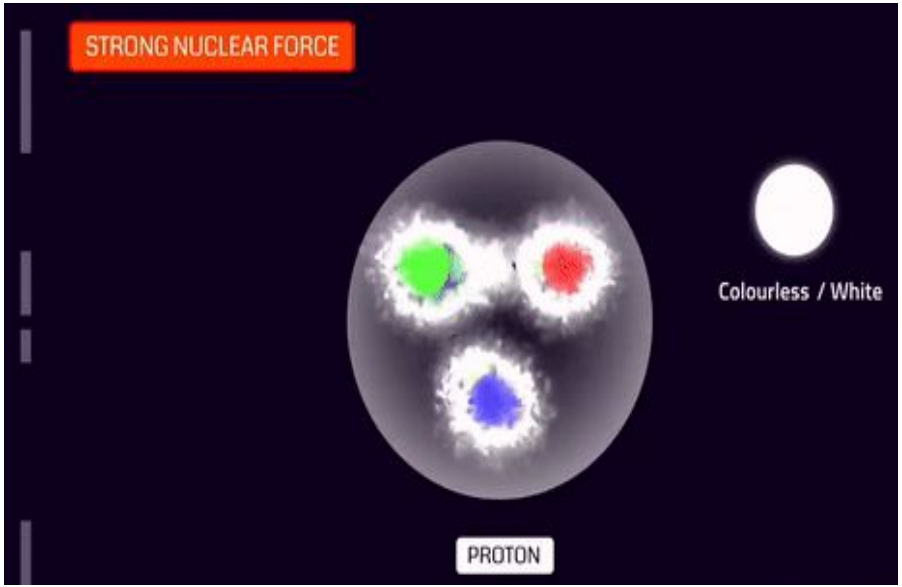
Mediators: W^+, W^-, Z^0



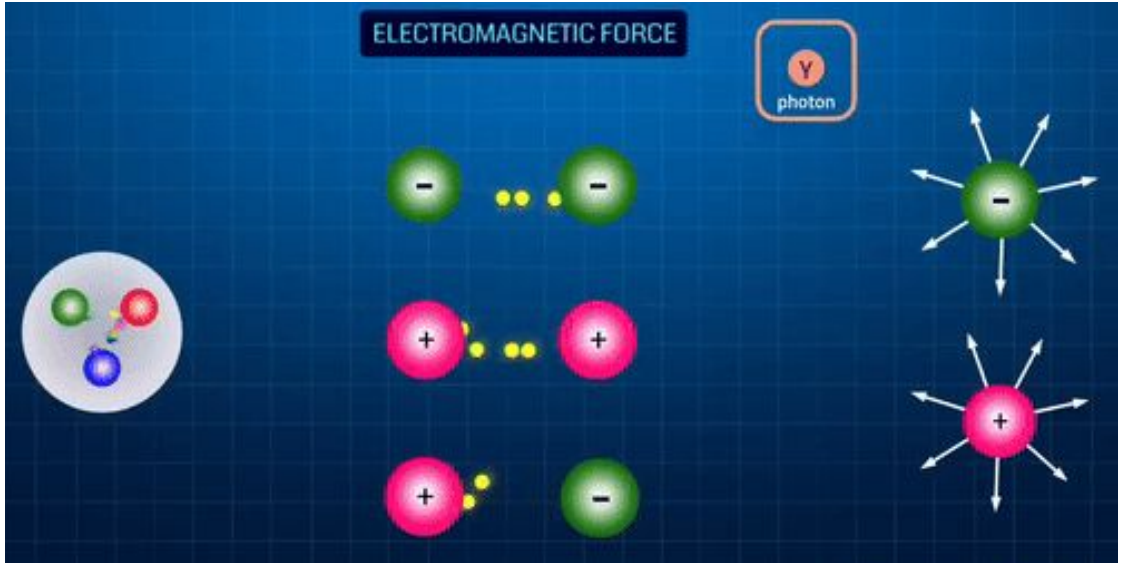
Responsible for certain changes of particles (e.g., turning a neutron into a proton).

Example: Radioactive decay and reactions in the Sun.

Strong nuclear force



Electromagnetic Force



Weak force



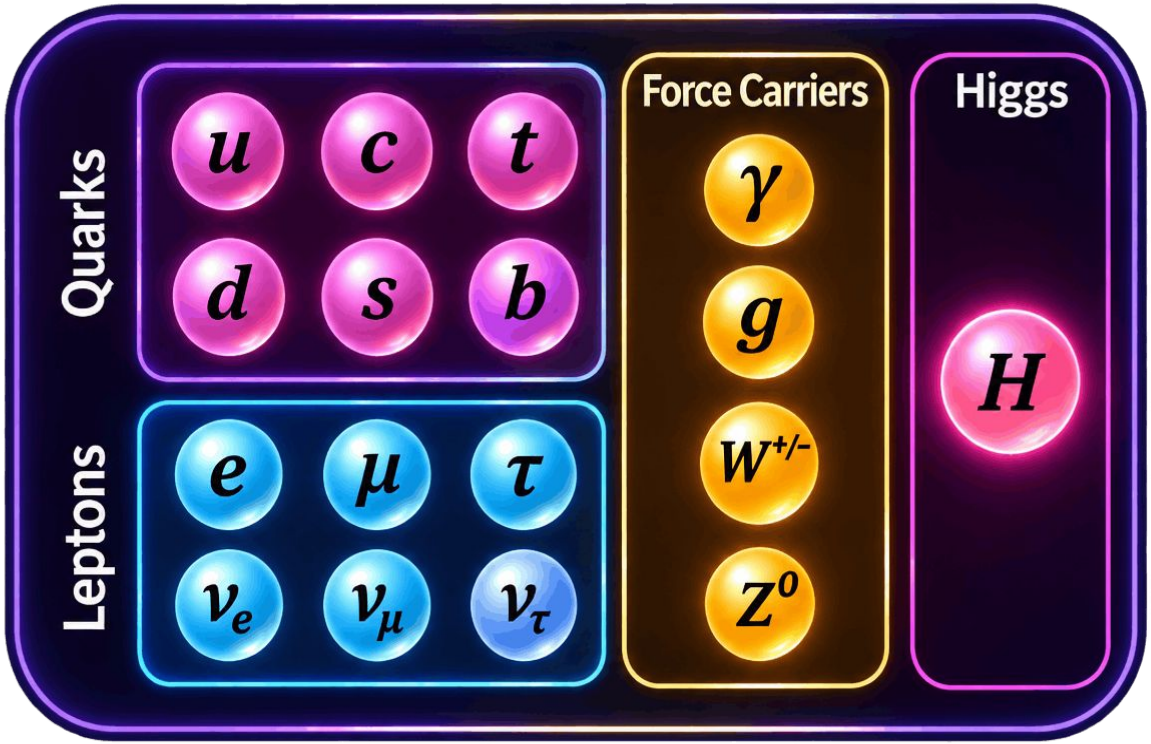
How do they constitute the universe?

- Strong force → Nucleus of an atom
- Electromagnetic force → Atom
- Weak force → Unstable atoms step towards stability
- Gravitational force → Binds matter

Nature's rulebook
Elementary particles, Forces, The governing Laws

Nature’s rulebook : The Standard Model of Particles

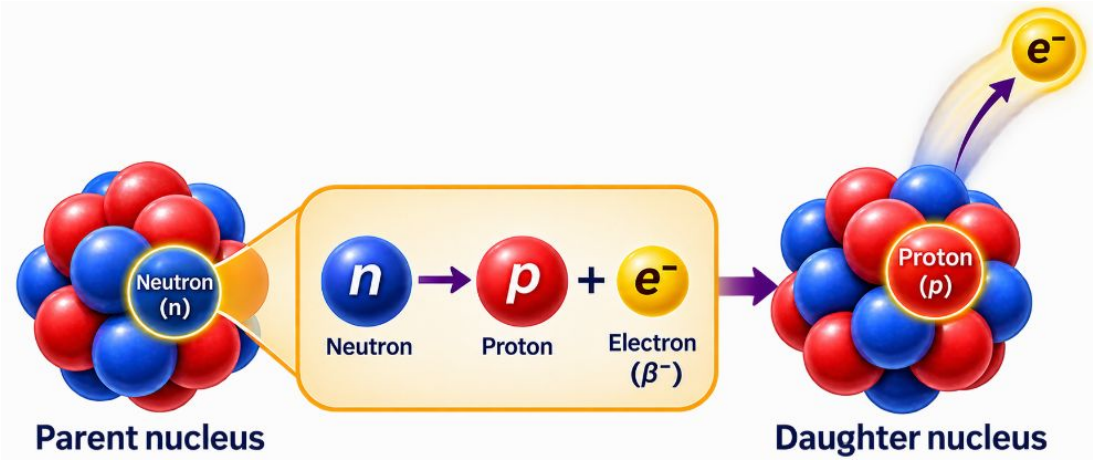
- Matter particles
- Force Carriers
- Mass generation
- Conservation laws & Symmetry
- The best theory we have: it explains a lot, but not everything



The neutrino story

A scary scenario

- **Radioactive decay** – *an unstable atomic nucleus naturally changes into a more stable one by releasing tiny particles and energy*
- **In certain decays, something was not added up!**



A neutron would turn into a proton and an electron.....

..... But the energy didn't balance!

A bold idea was needed to solve the puzzle

Pauli's brilliant idea

A daring hypothesis in 1930

There must be a tiny particle that we can't see. It has no electric charge, is very light and escapes detection.



- Pauli bravely proposed a particle that no one had ever seen!
- Must be hard to catch!
- Carries away the missing energy

I have done a terrible thing!

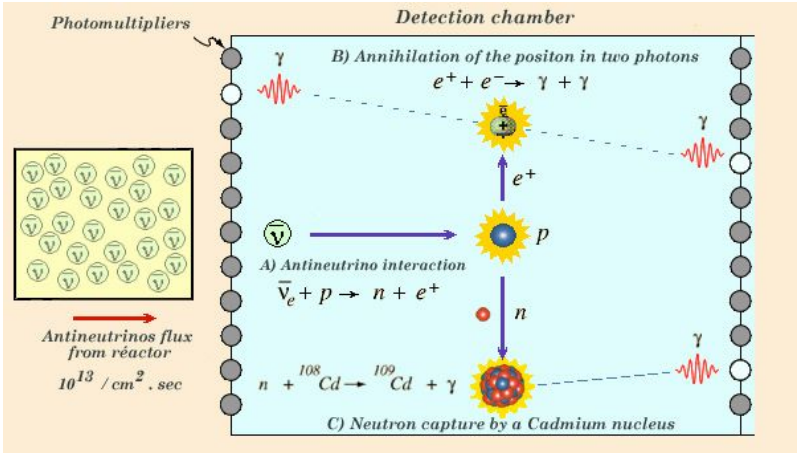
I have postulated a particle that cannot be detected.

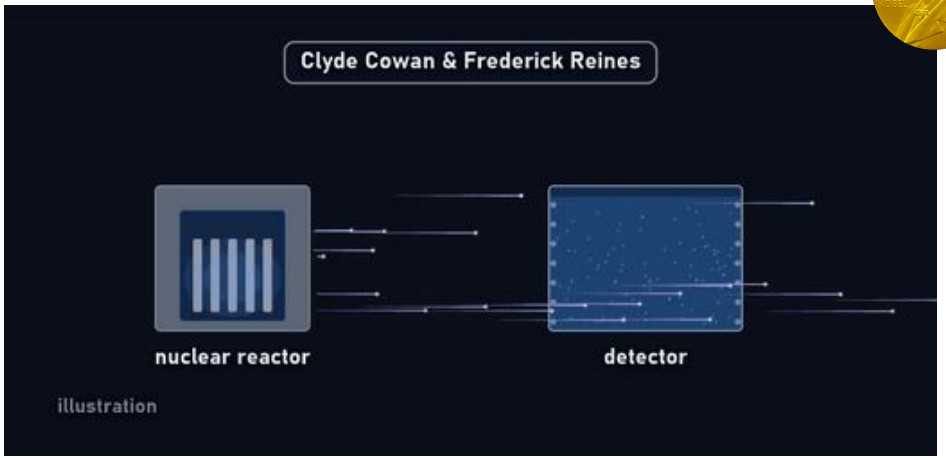
From Idea to Discovery

26 years of wait

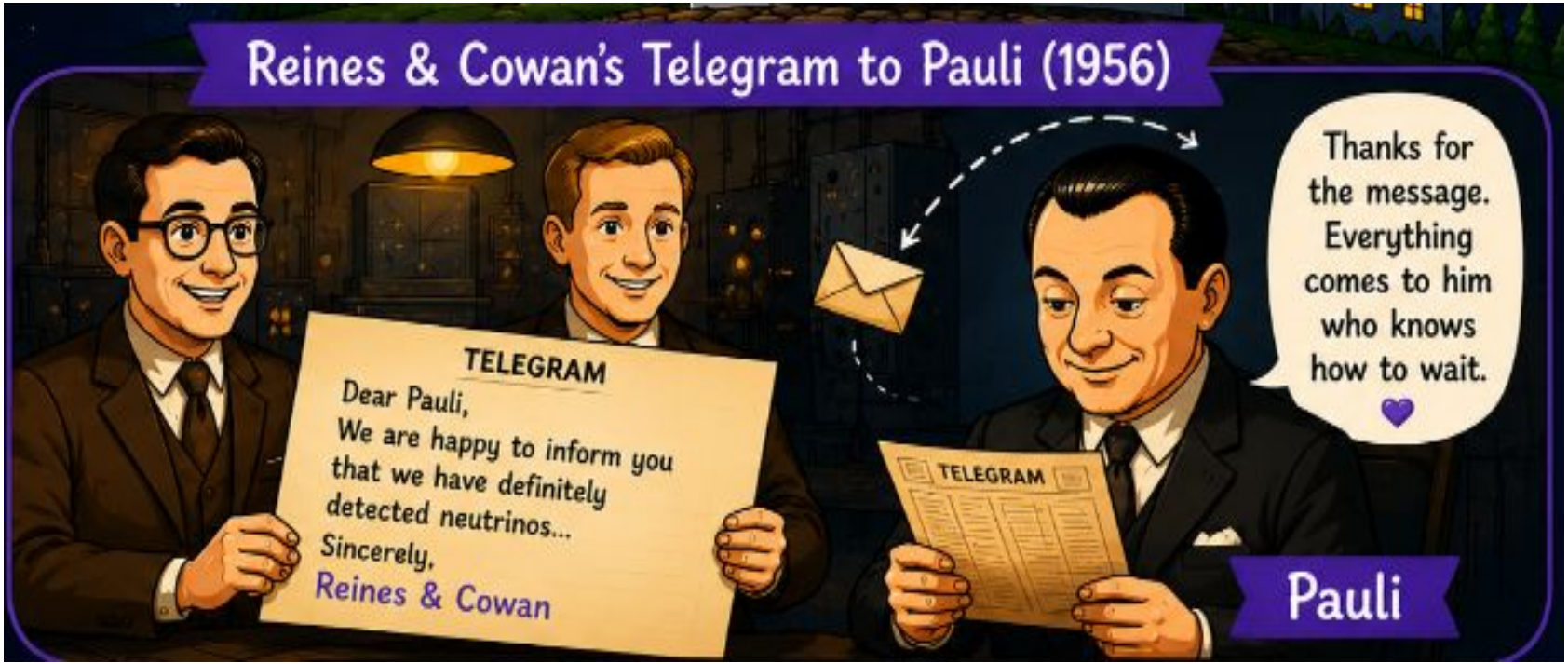


In 1956, Frederick Reines and Clyde Cowan made history by detecting neutrinos from a nuclear reactor. They observed tiny flashes of light produced by neutrino interactions, confirming their existence experimentally.



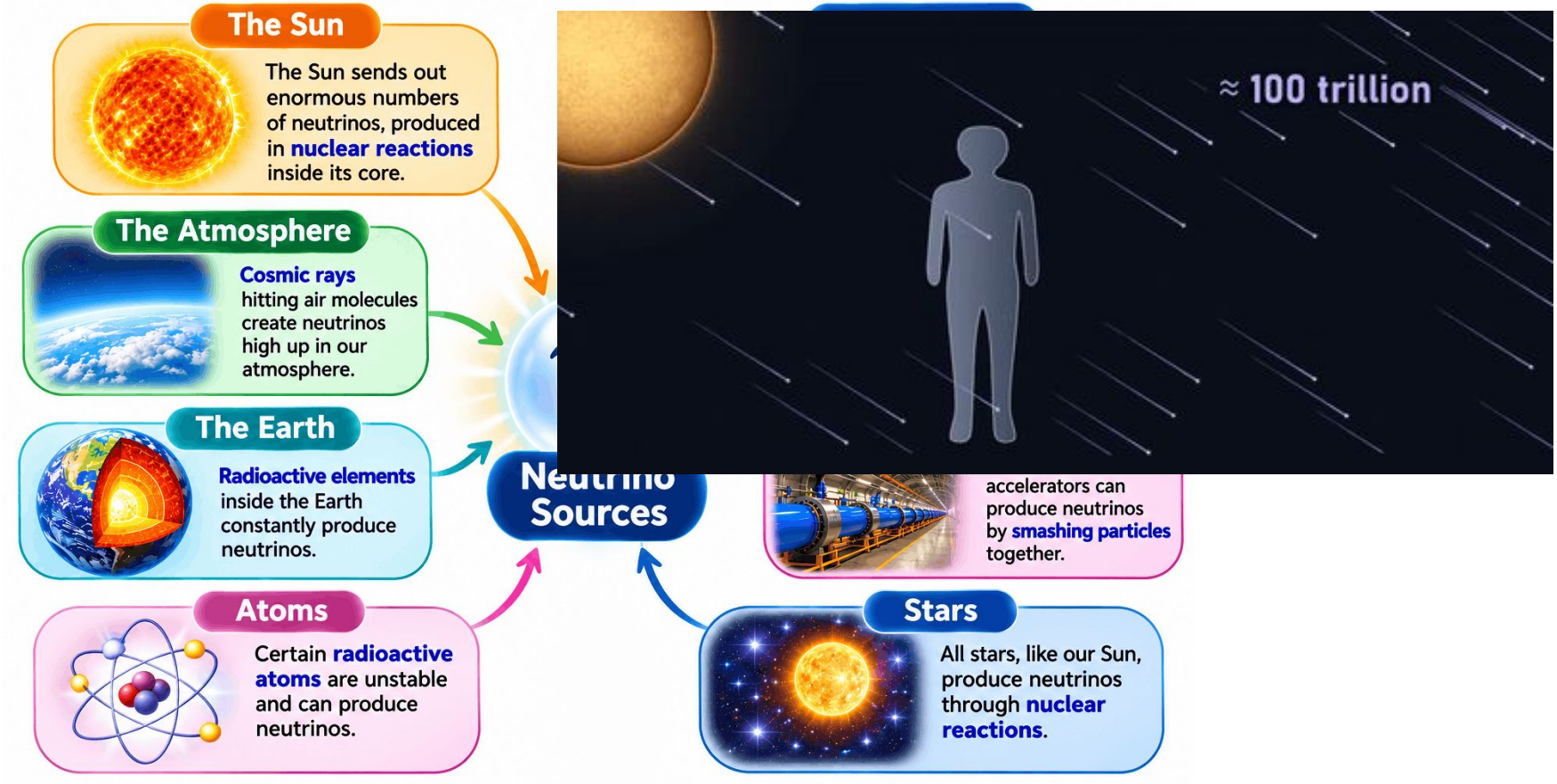


The wait is over!



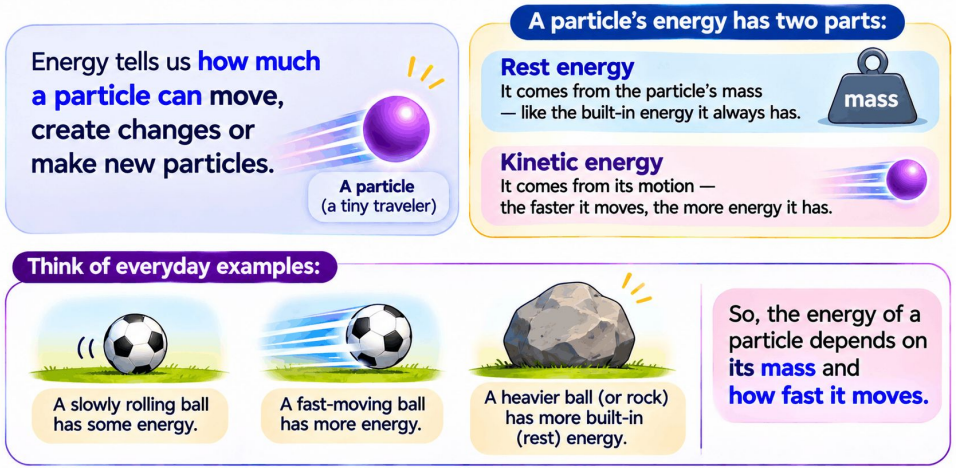
Enrico Fermi gave the name → Neutrino → "*the little neutral one*" in Italian

They are everywhere!



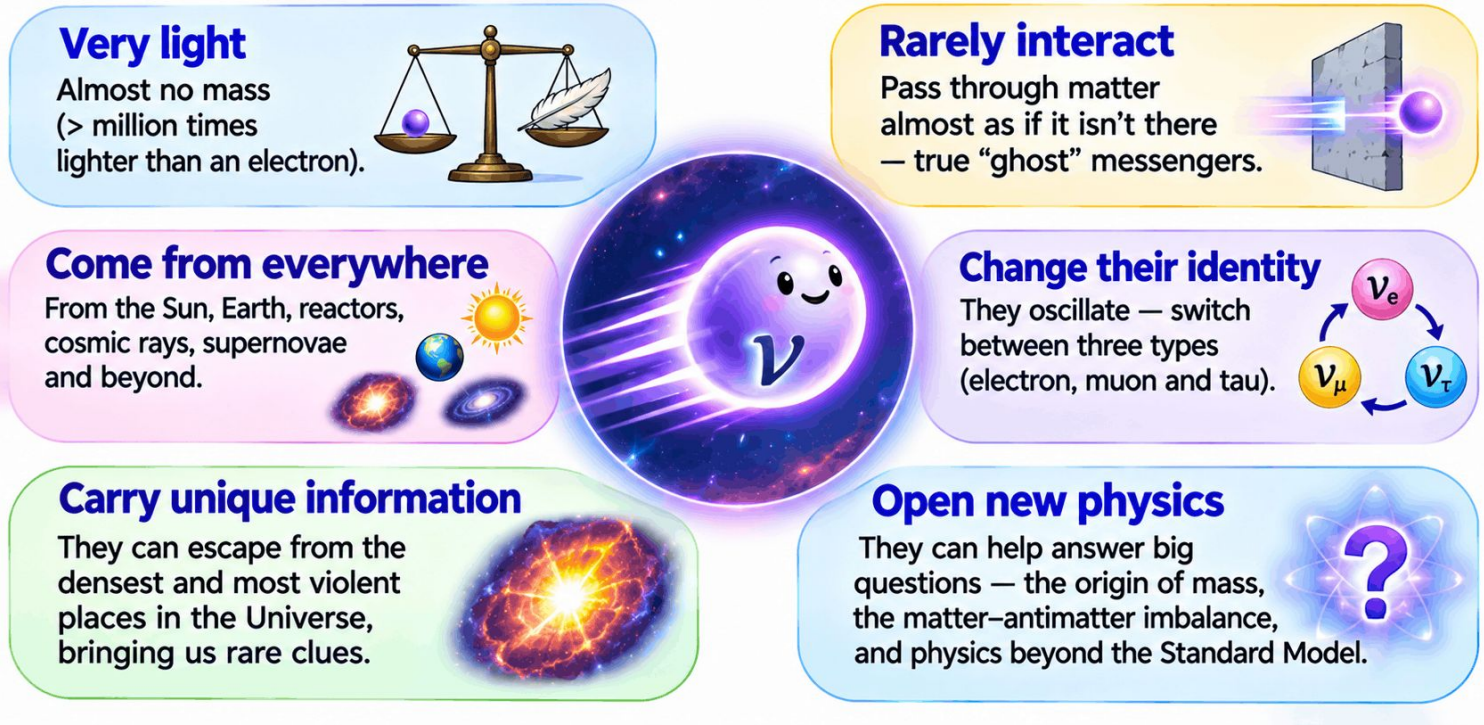
They are everywhere!

- Some neutrinos carry very little energy, while others carry enormous amounts
- Neutrinos from the Sun and those produced in violent cosmic events can have vastly different energies
- The more energetic a neutrino is, the more energy it can transfer when it interacts with matter



What makes neutrinos interesting?

“Ghost Particles”

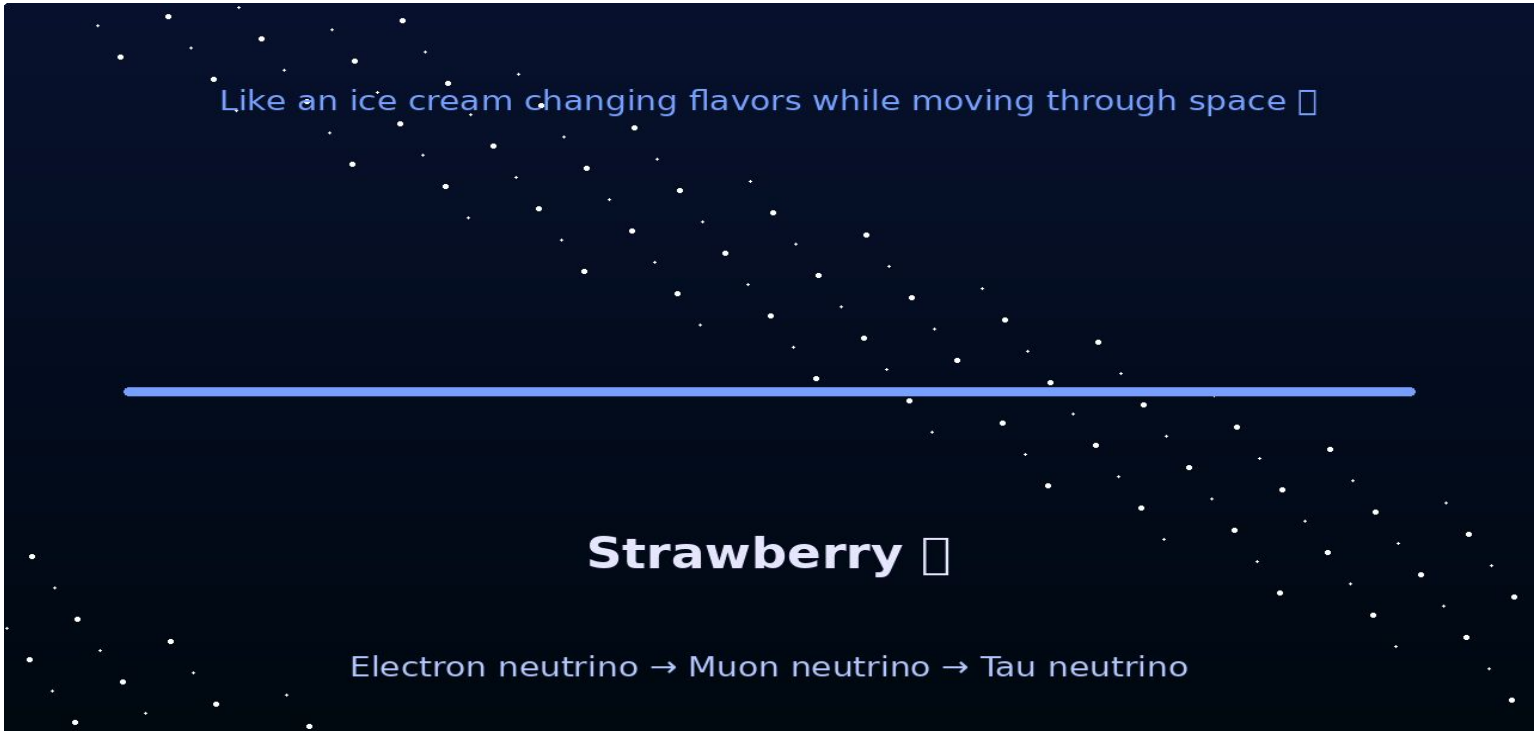


Many a time, the properties cannot fully be described by nature's rulebook

“Beyond the standard model”

Neutrino Oscillations

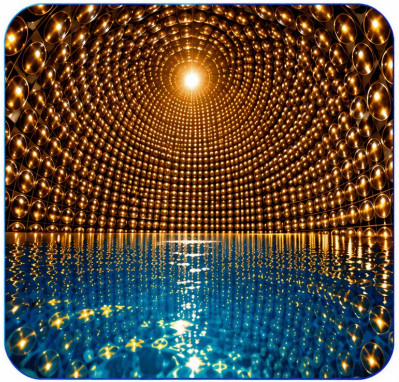
A shape shifting superpower!



Neutrino Detectors

- Trillions of neutrinos pass through us every second
- Only a very tiny number of them interact with anything
- Bigger detectors: more chances to catch these rare interactions!
- As the energy increases, the shyness increases too!

Super-Kamiokande

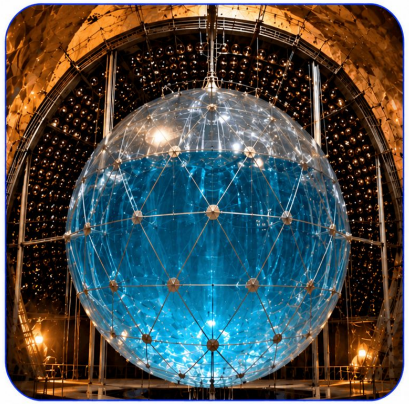


Location & Depth: Kamioka, Japan; about 1,000 m underground.

Detector: A 50,000-ton tank of ultra-pure water, lined with ≈ 11,000 light sensors (PMTs) to catch faint light from particle interactions.

Aim: To study neutrinos and their properties, such as neutrino oscillations.

Sudbury Neutrino Observatory (SNO)



Location & Depth: Sudbury, Canada; about 2,100 m underground.

Detector: A 1,000-ton tank of heavy water (D_2O), viewed by ≈ 9,600 light sensors (PMTs).

Aim: To study solar neutrinos and solve the "solar neutrino puzzle" by measuring all types of neutrino interactions.

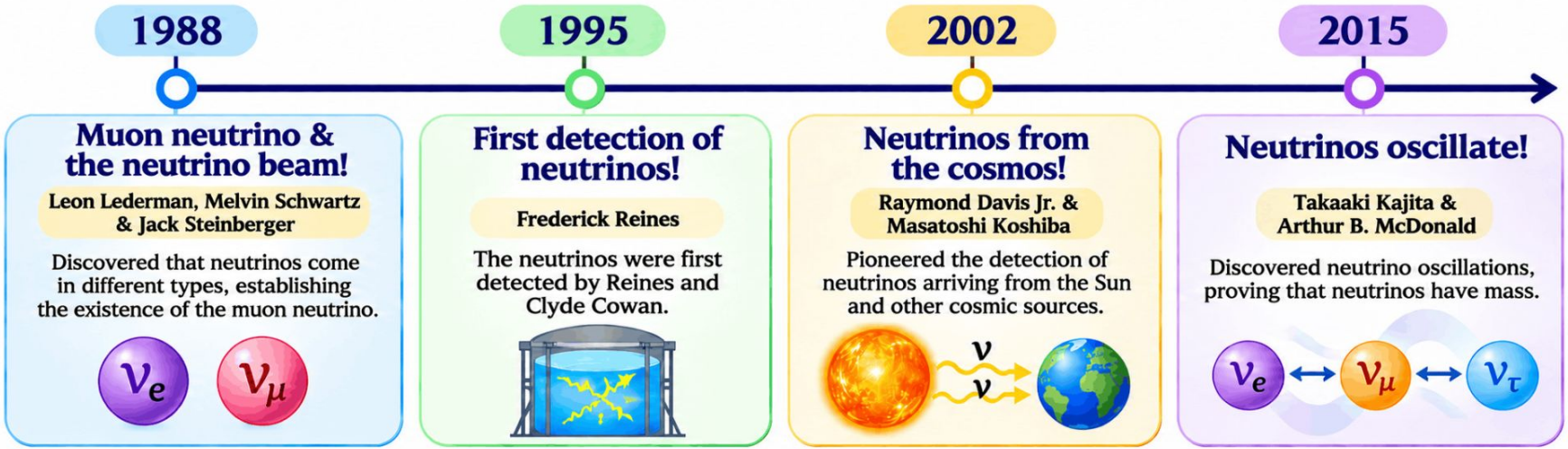
The Nobels



- Study of elementary particles → More than 20 awards (~14%)

A Nobel Prize every decade since the 1980s!

(From a barely believable idea to a cornerstone of modern physics)



- Neutrino properties → **a fundamental rethink** of how nature works!
- Pauli, Fermi, etc. were awarded for their other contributions, not directly related to neutrinos; **Clyde Cowan passes away in 1974** (Nobel is not awarded posthumously)

The Nobel Prize in Physics -2026

The Laureate

Francis Halzen

(Professor of Physics,
University of Wisconsin–Madison, USA &
IceCube principal investigator)



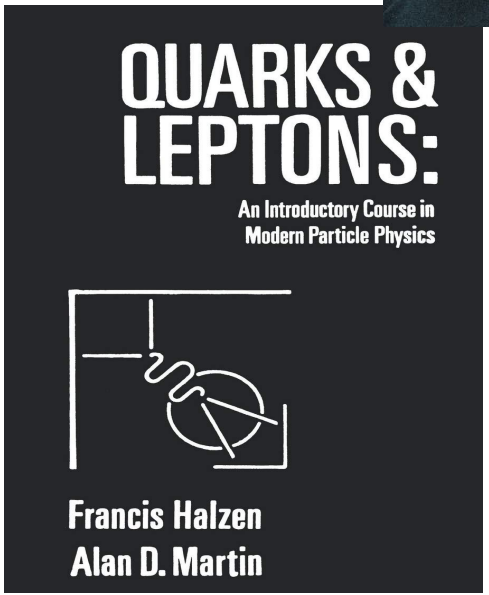
"For decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin"

A Belgian-American physicist who has worked in both theoretical and experimental particle physics

Quarks and Leptons: An excellent Introductory Course in Modern Particle Physics is a classic graduate and senior undergraduate textbook written by **Francis Halzen** and **Alan D. Martin**, first published by Wiley in 1984

- It has trained generations of physicists
- It remains widely celebrated



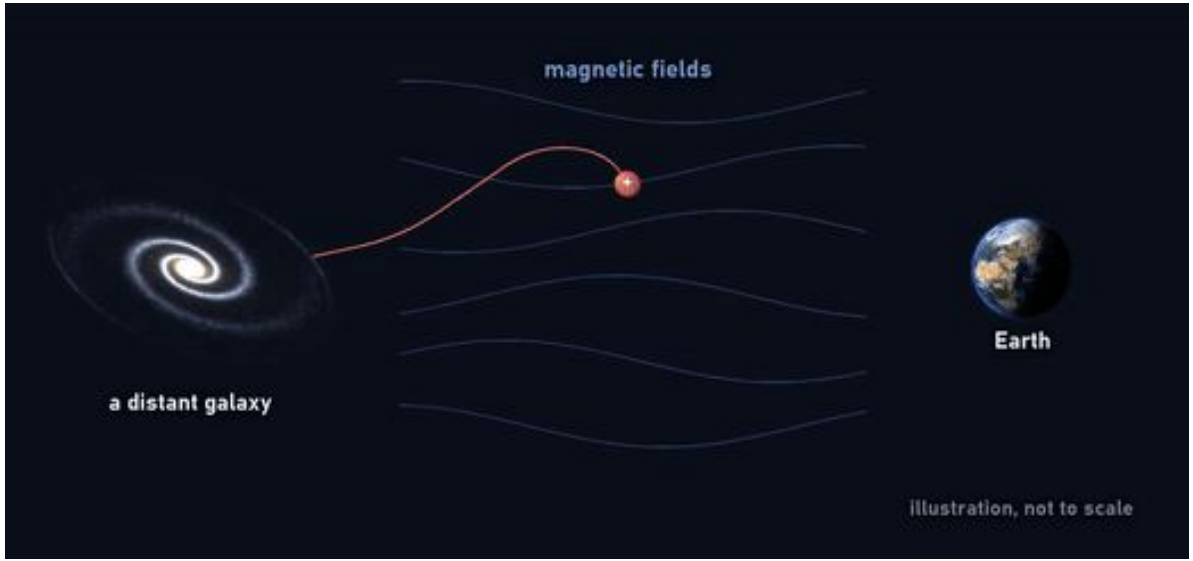


Messengers from a distant galaxy

- Charged particles like a proton →

  Gets deviated due to magnetic fields on the way

- **Source cannot be traced!**

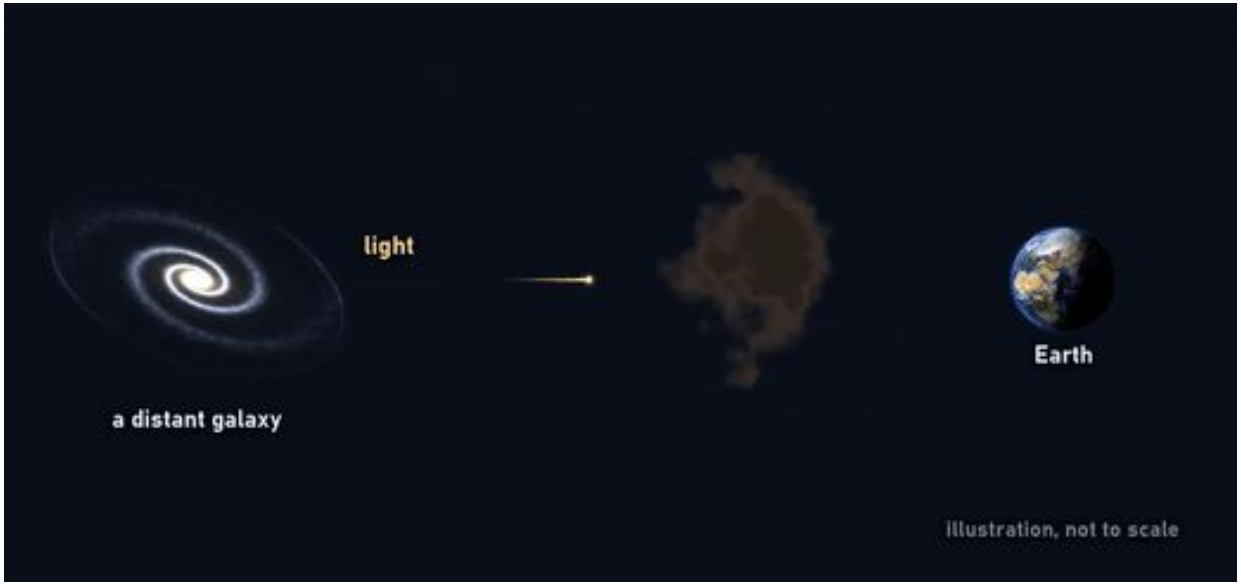


Messengers from a distant galaxy

- Light →

  Gets absorbed/blocked in the interstellar medium

- **Source cannot be fully imaged!**

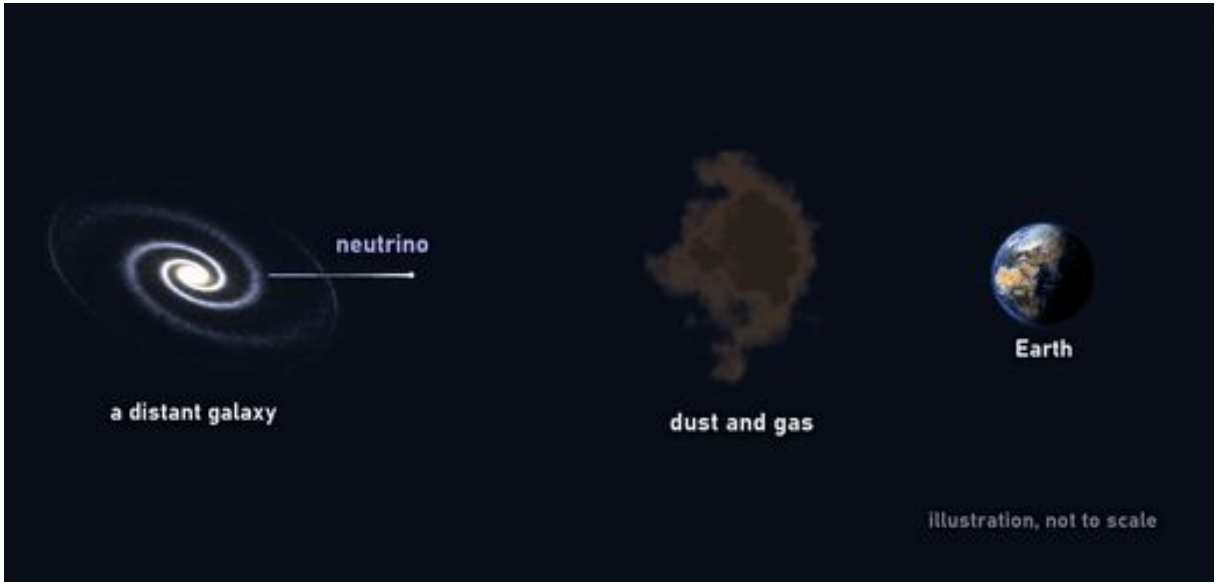


Messengers from a distant galaxy

- Neutrinos →

  Reaches straight, without any hindrance

- **The source can be pointed back!**

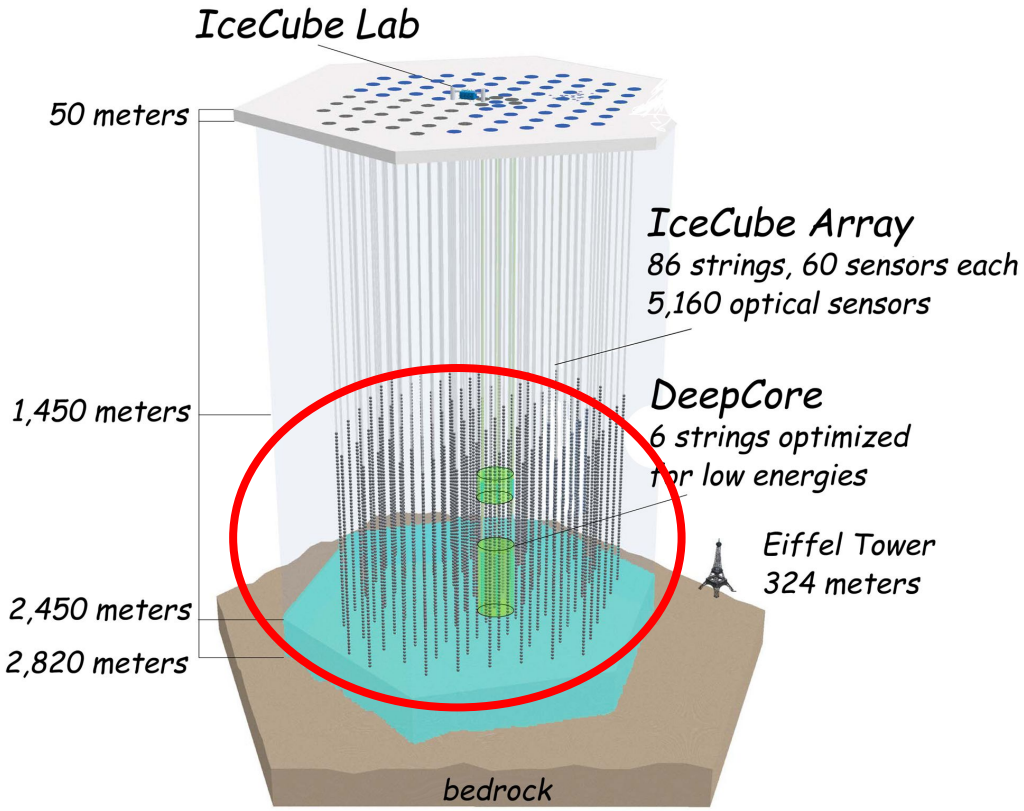


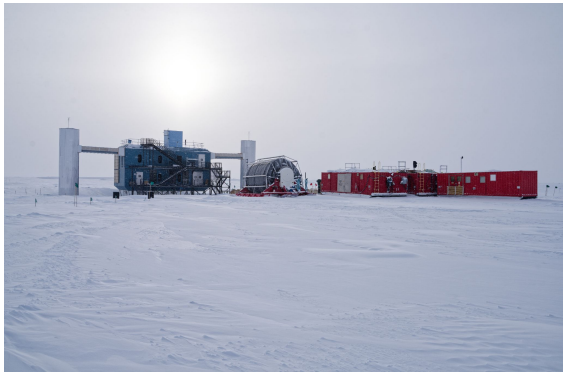
The Vision: Ice as a Neutrino Detector

- The deep, ultra-transparent ice at the South Pole → both a target and a detection medium for high-energy neutrinos
- **Volume:** A cubic kilometre
- **Clarity:** South Pole ice is among the clearest natural media on Earth
- **Logistics:** Existing Amundsen–Scott Station infrastructure made a polar project feasible



The IceCube Neutrino Observatory

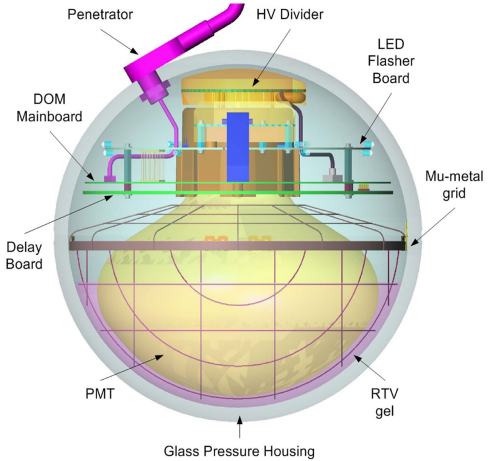




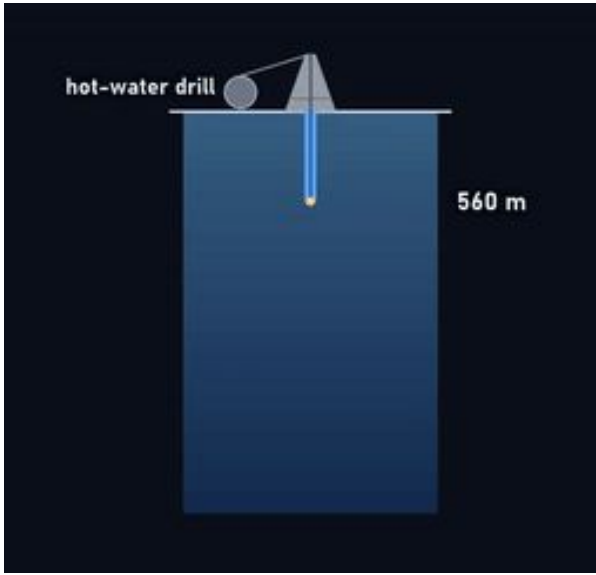


The Digital Optical Module (DOM)

The in-ice component of IceCube consists of 5,160 digital optical modules (DOMs), each with a light detector and associated electronics

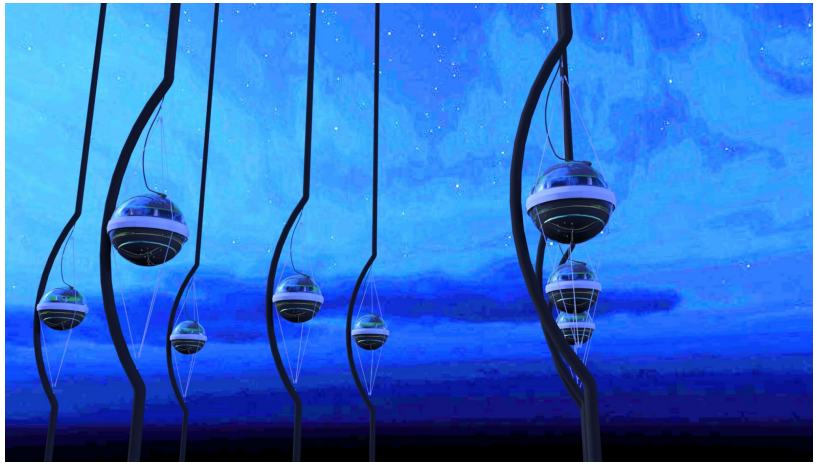


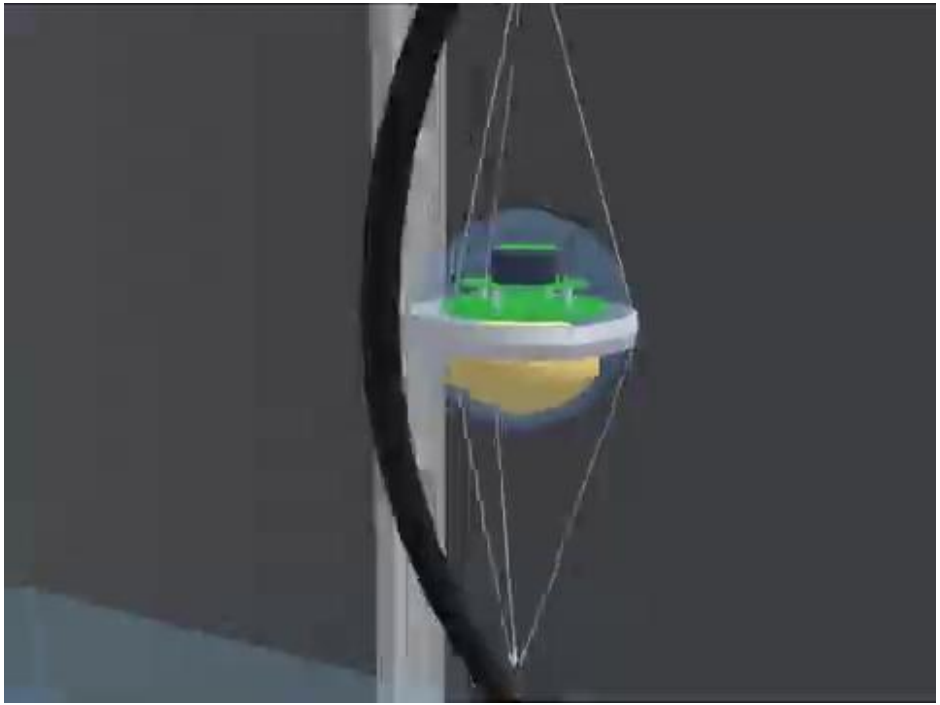




- Vertical “strings,” frozen into 86 boreholes and arrayed over a cubic kilometer from 1,450 meters to 2,450 meters depth.
- About 60 DOMs / grid

The Digital Optical Module (DOM)





The IceCube Neutrino Observatory



The journey (2004 - 2011)

Commissioning work progressed through **Antarctic summer: October-March**



All the equipment was transported to the south pole



Hot water drills to dig narrow 60 cm holes 2450 m deep



Lower the strings with 60 digital optical modules into 2.5 km deep ice

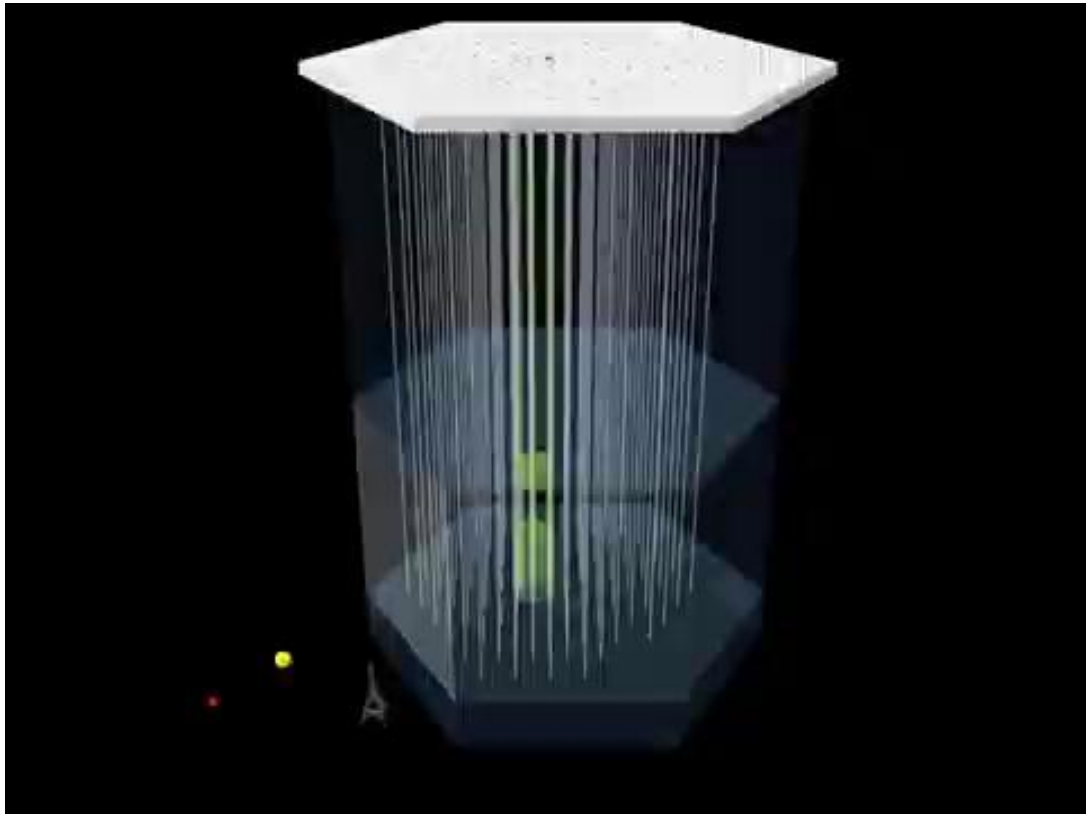
The journey (2004 - 2011)





Installation of 86 strings in 1 cubic kilometre antarctic ice completed in 2011

How IceCube Sees Neutrinos



- Neutrinos interacting with ice → electron, muon, tau

Cherenkov radiation
Particles traveling faster than light in ice → emits a cone of blue light

How IceCube Sees Neutrinos

Interaction

A high-energy neutrino interacts with an ice nucleus → producing a muon, electron, or tau (or a hadronic cascade)

Cherenkov light

A cone of blue Cherenkov radiation

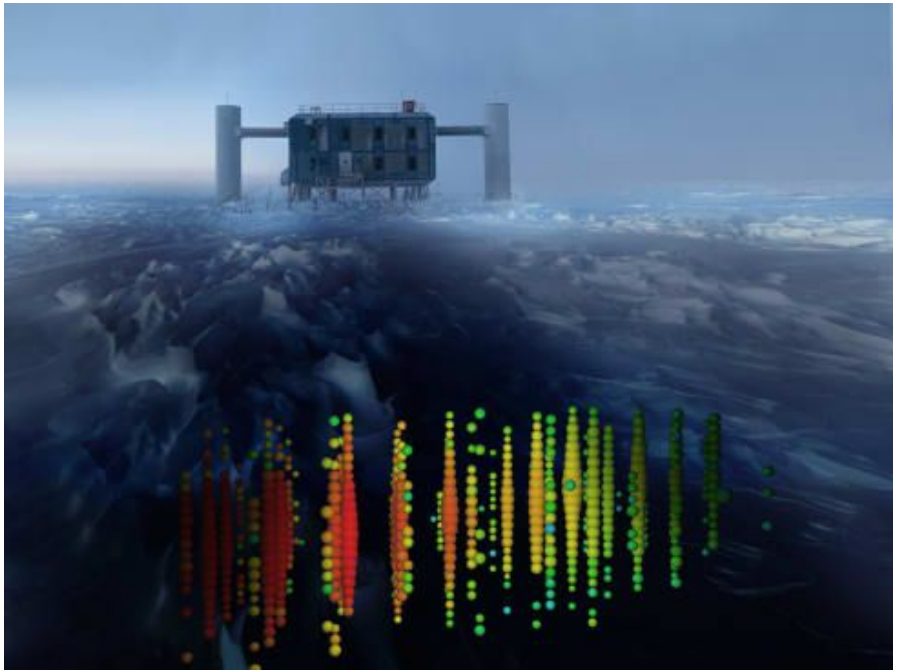
Detection

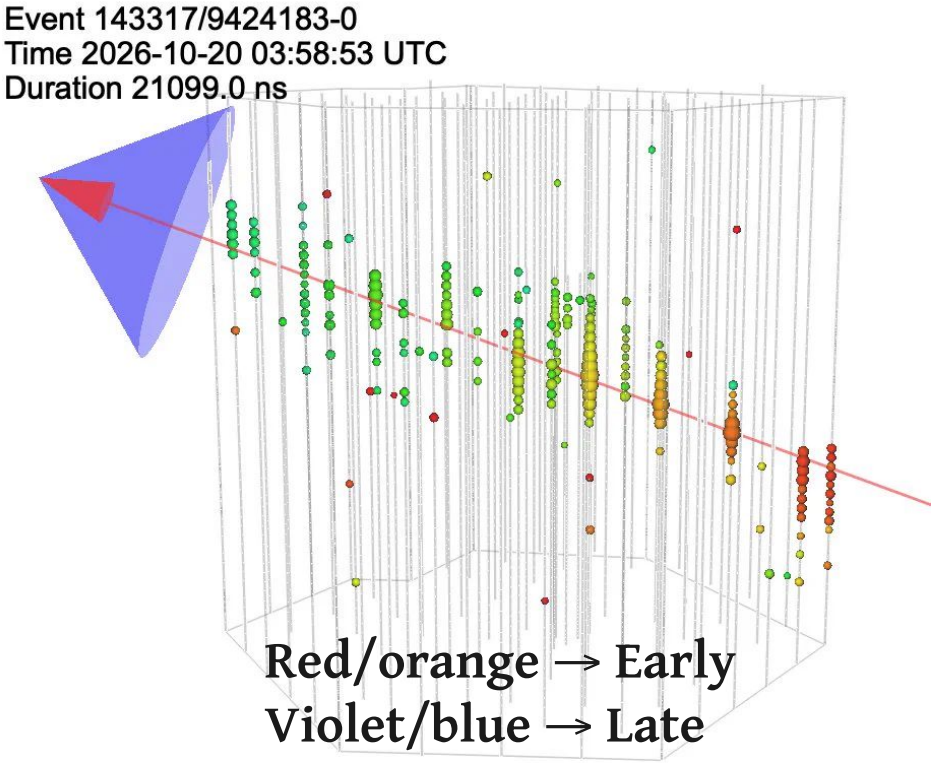
*DOMs record the **arrival times** and **intensities of the light pulses***

Reconstruction

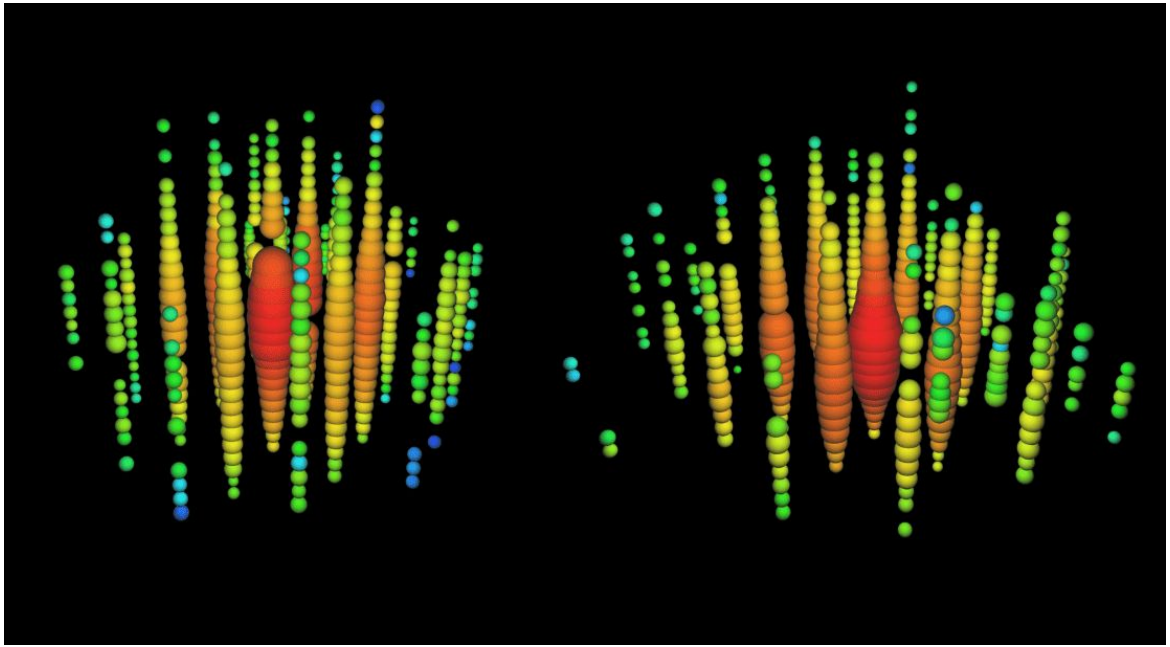
*Software reconstructs the **details** of the original neutrino*

How IceCube Sees Neutrinos



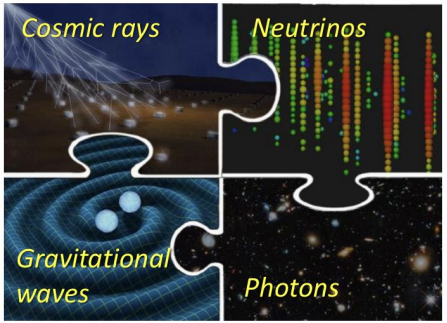


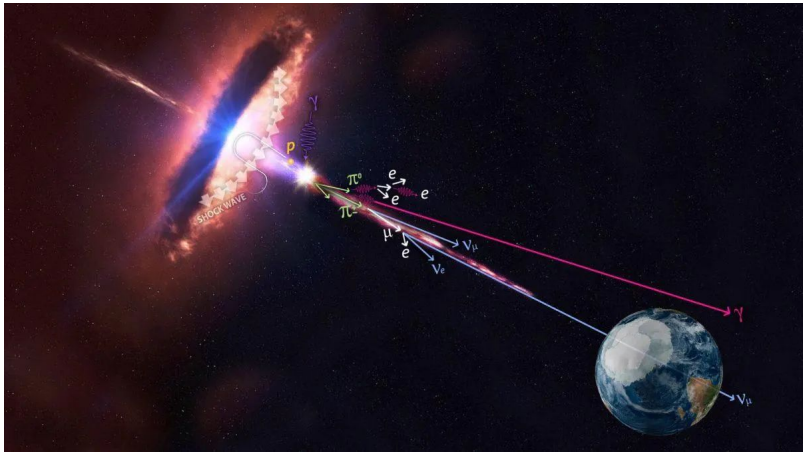
“Bert” & “Ernie”



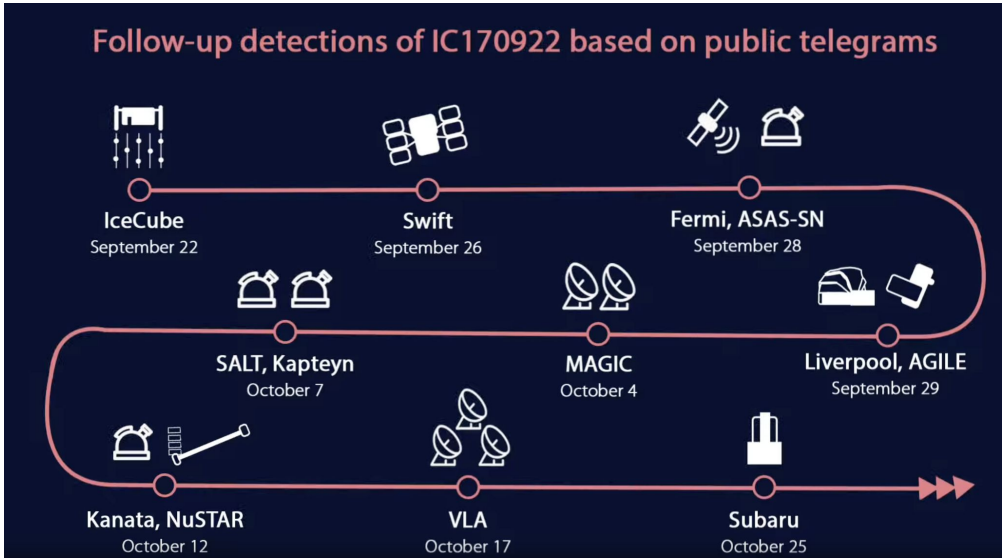
- *2013: IceCube published the evidence of two neutrino events: at very high energies*
- *26 more neutrinos with statistical significance*

2017: Multimessenger Observations

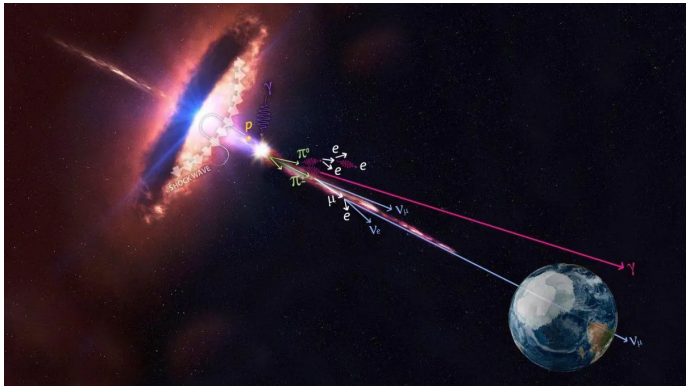




First evidence for a diffuse flux of high-energy neutrinos of extraterrestrial origin, from Blazar TXS 0506+056



2017: Multimessenger Observations





Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

[Science 361 (2018) no.6398, eaat1378]

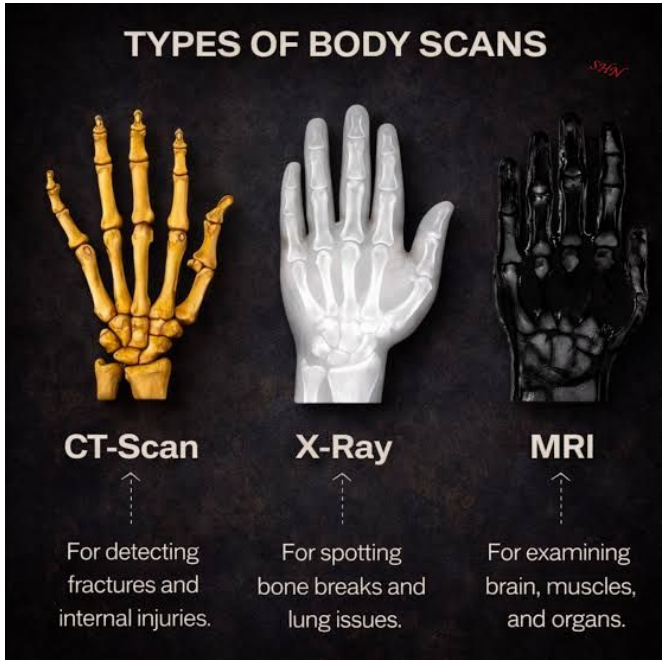
Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

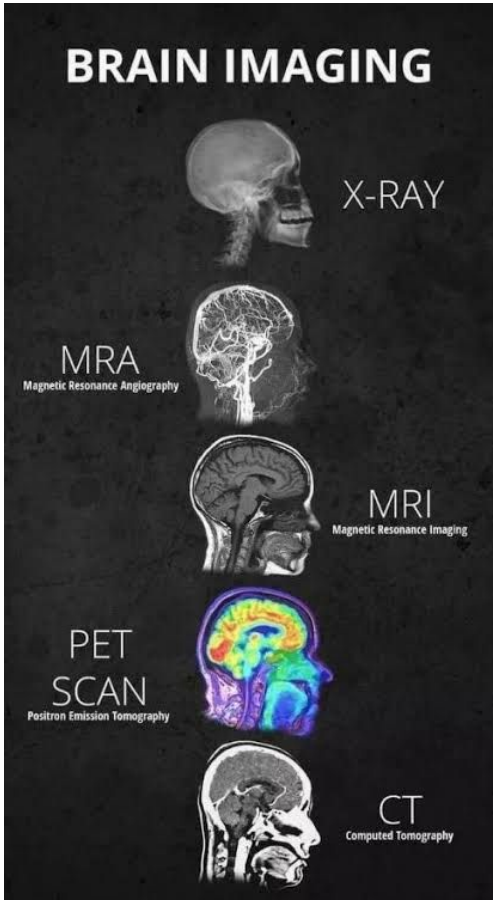
IceCube Collaboration*†

[Science 361 (2018) no.6398, 147-151]

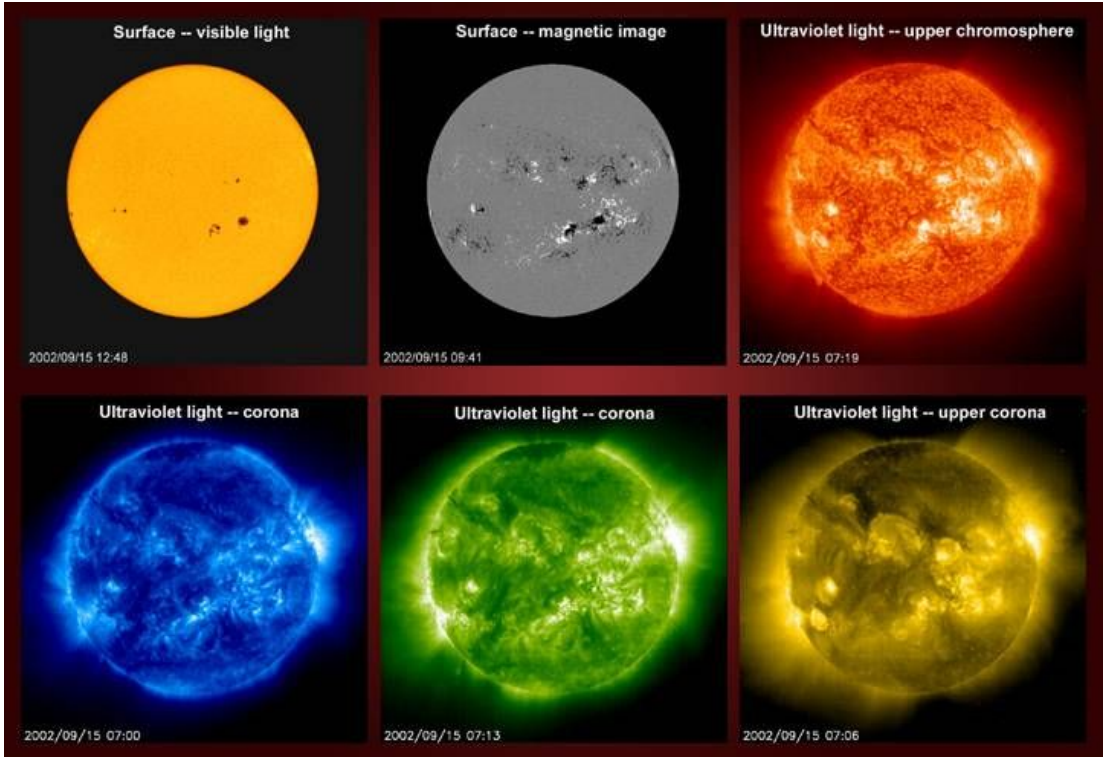
Opened a new observational window

Why multi-messenger?

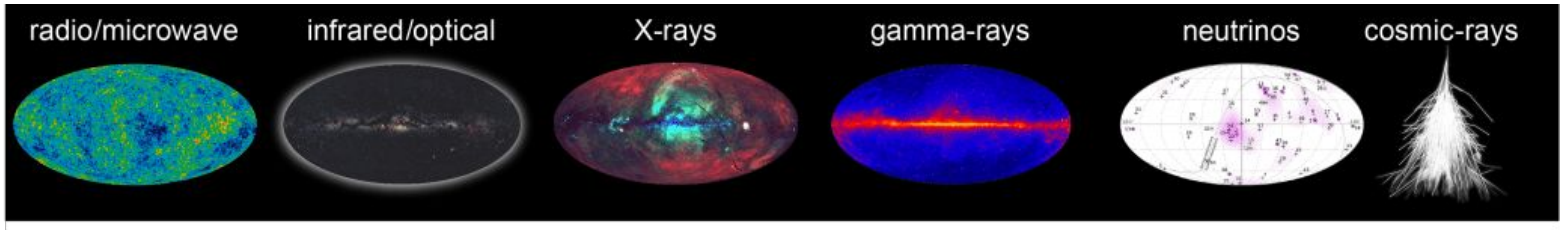




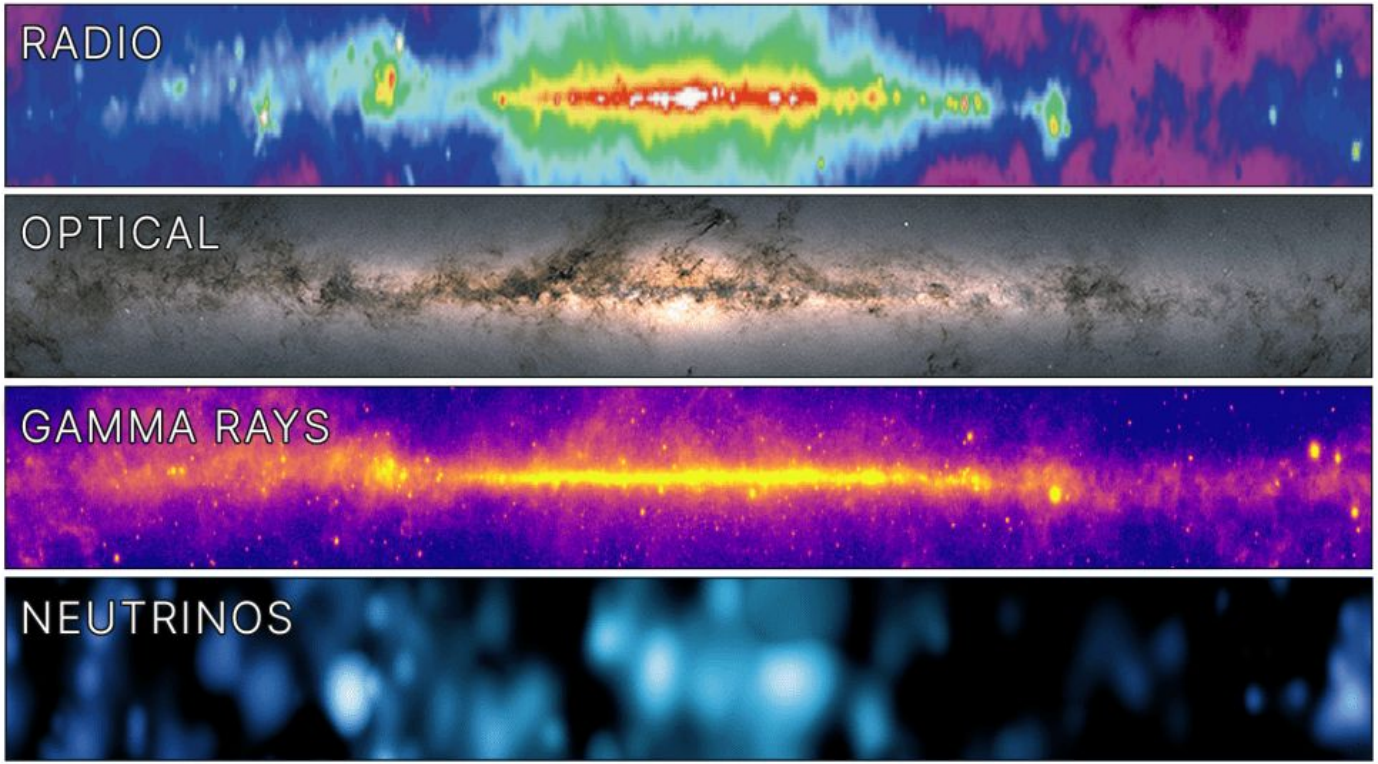
Why multi-messenger?



Why multi-messenger?



First map of Milky Way through IceCube neutrinos



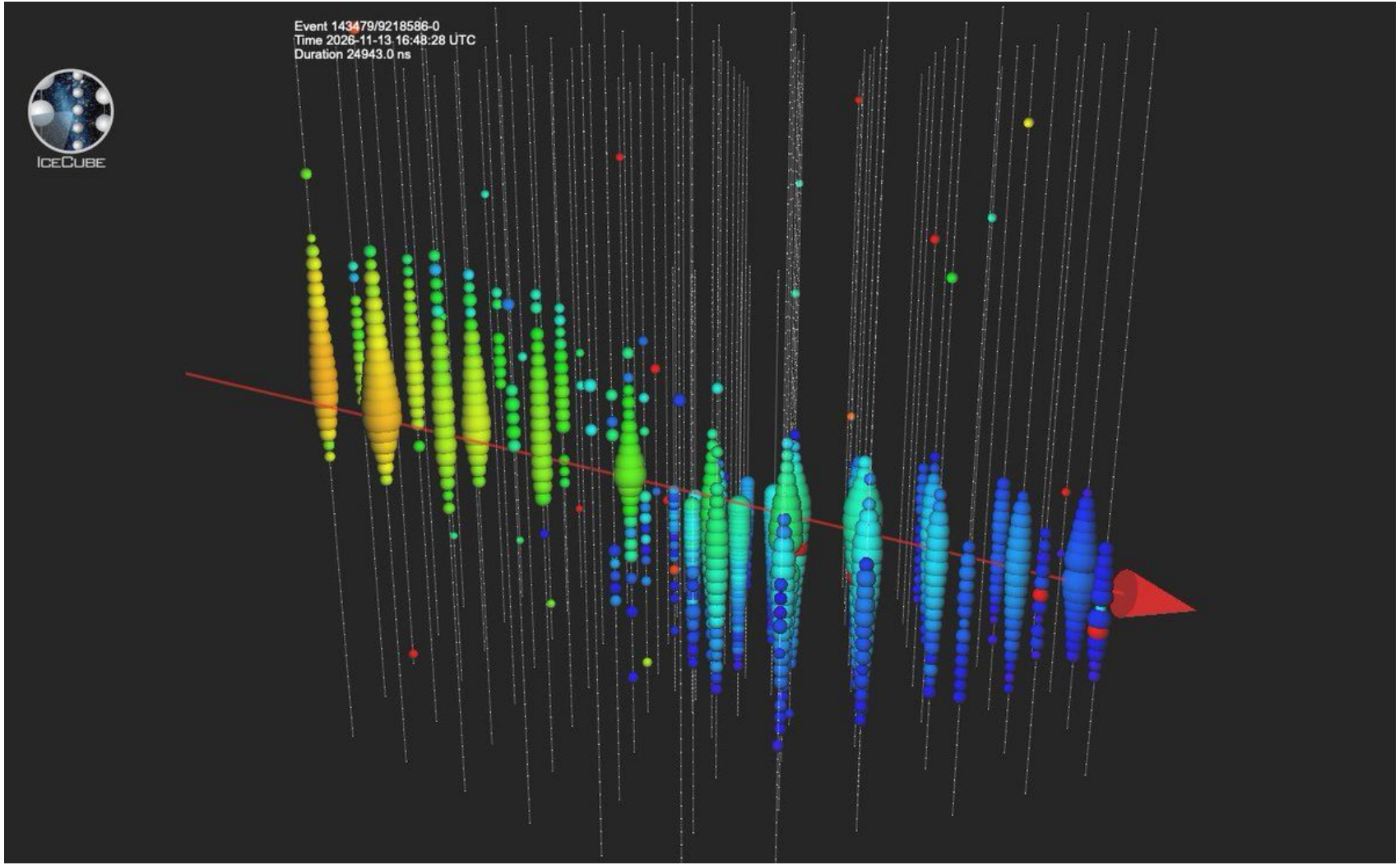
Evidence for high energy neutrino emission from NGC 1068 (2022)



Takeaways



- ★ Neutrinos are unique travellers through the univere
- ★ IceCube, under Francis Halzen's leadership, turned a visionary idea into a working kilometre-scale observatory
- ★ The 2026 Nobel Prize recognises the discovery of high-energy astrophysical neutrinos
- ★ Multimessenger astronomy → the standard paradigm now
- ★ The next decade will move from discovery to precision mapping of the neutrino sky


Event 143479/9218586-0
Time 2026-11-13 16:48:28 UTC
Duration 24943.0 ns
IceCube

"I have to emphasise how lucky I was because when we staffed this project everybody realised this was maybe a good idea, but very few thought it would work, including myself. So this was kind of an adventure where success was not guaranteed."

"Pursuing a career in physics is considered miserable from an objective standpoint. The only justification for entering this field is a deep personal enjoyment, obsession, and love for the work."

"Without understanding neutrinos, we'll never understand the universe."



Thank you for the kind attention!