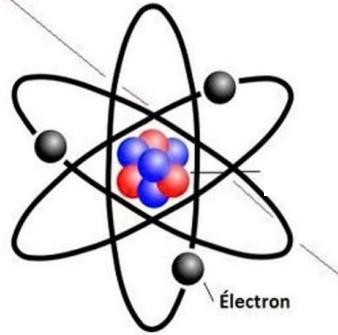


Les neutrinos

*J'ai fait une chose terrible.
J'ai proposé une particule
qui ne peut être détectée !*

Wolfgang Pauli

Robert Saint-Jean
Décembre 2017



La matière

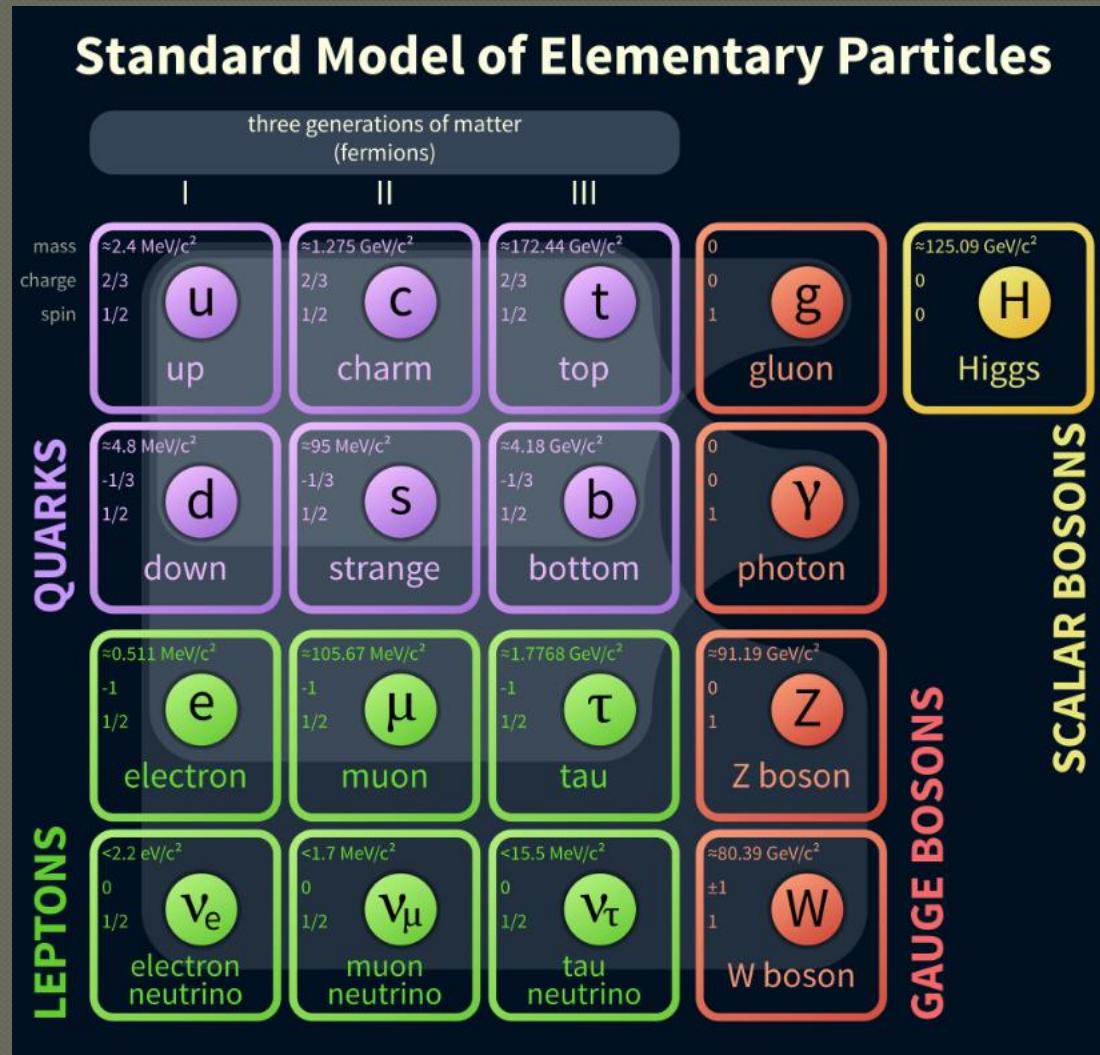
● La matière est formée d'atomes

- L'atome est la plus petite partie d'un corps simple pouvant se combiner chimiquement avec un autre

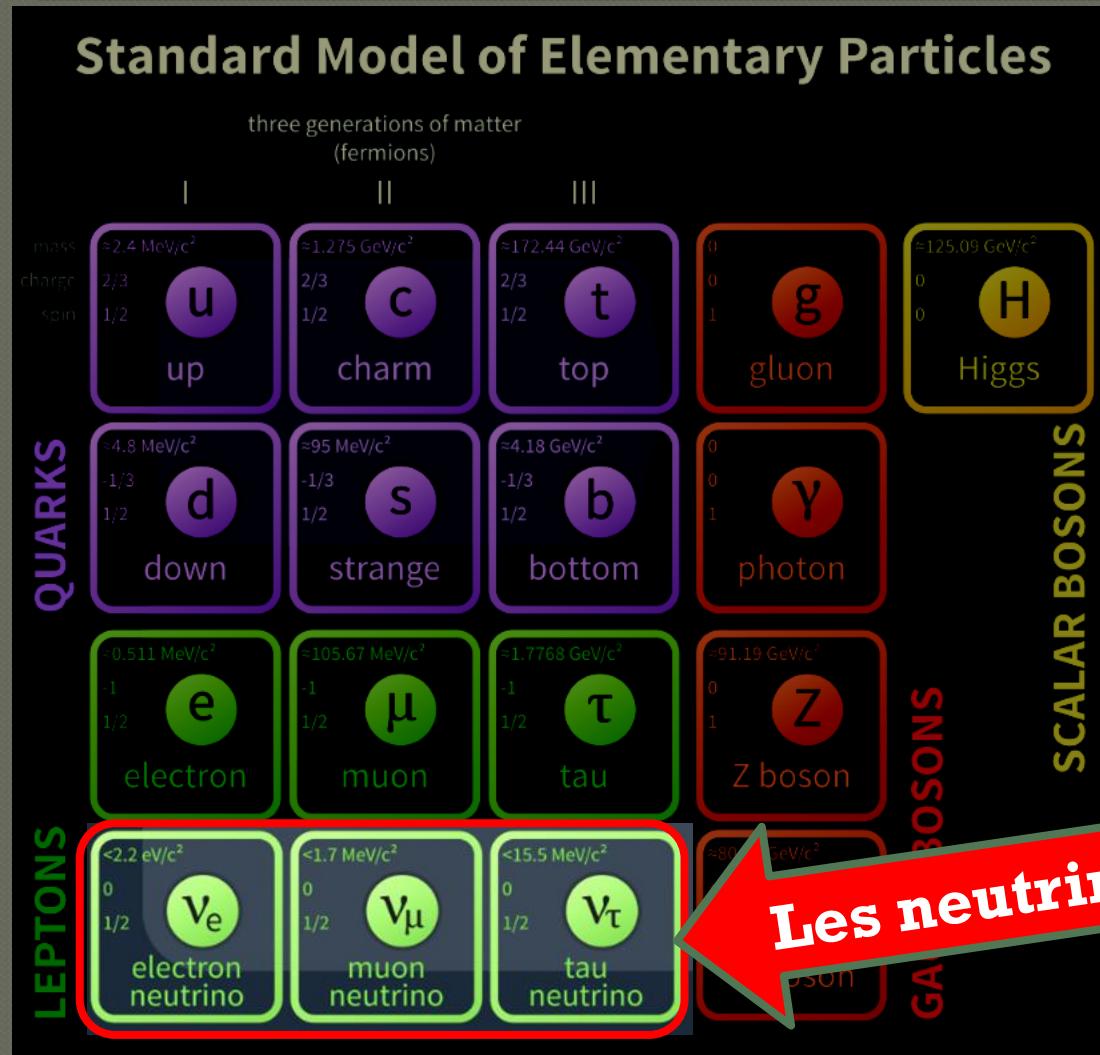
● Un atome est formé d'un noyau et d'un nuage d'électrons.

- Les électrons sont des particules élémentaires
- Le noyau est formé de protons et de neutrons qui sont des particules composites (formés d'un assemblage de particules élémentaires)

Le modèle standard



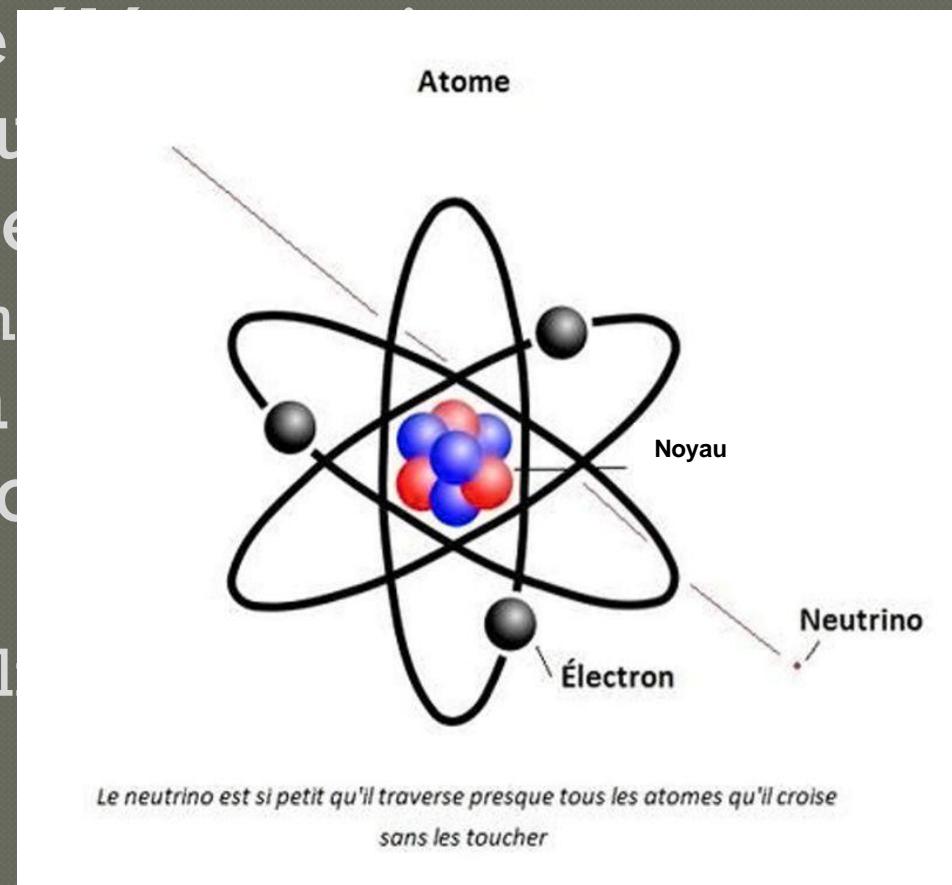
Le modèle standard



Qu'est-ce qu'un neutrino¹?

¹De l'italien « le petit neutre »

- C'est une particule
- Électriquement neu
- De masse « presque »
 - Moins de 10^{-6} de la masse d'un électron
- Voyage presqu'à la v
- A très peu d'interactions
 - Interaction faible
 - Force de gravité négl



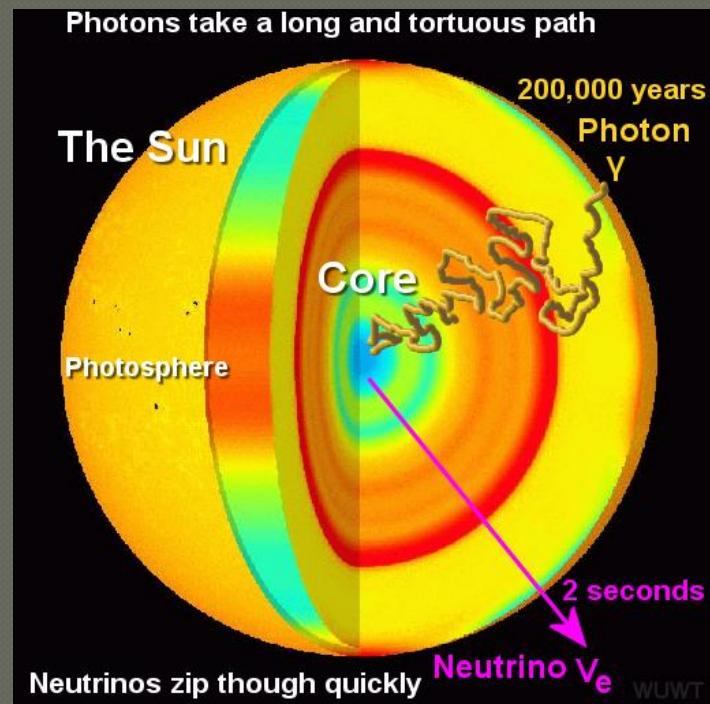
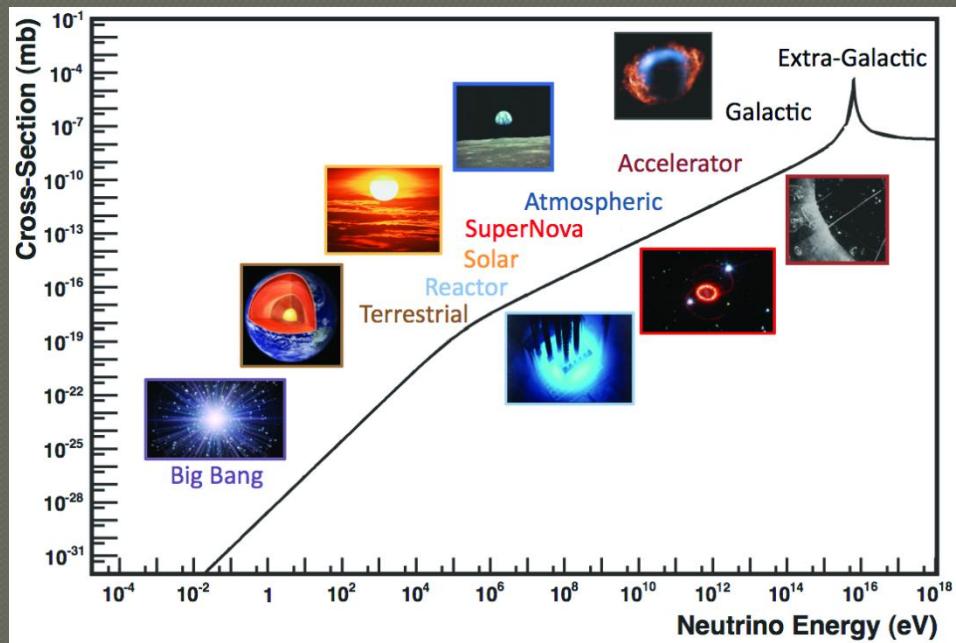
Ils sont partout !

- Un neutrino ayant une énergie de 1 MeV pourrait traverser environ 35 AL d'eau avant d'interagir avec une molécule.



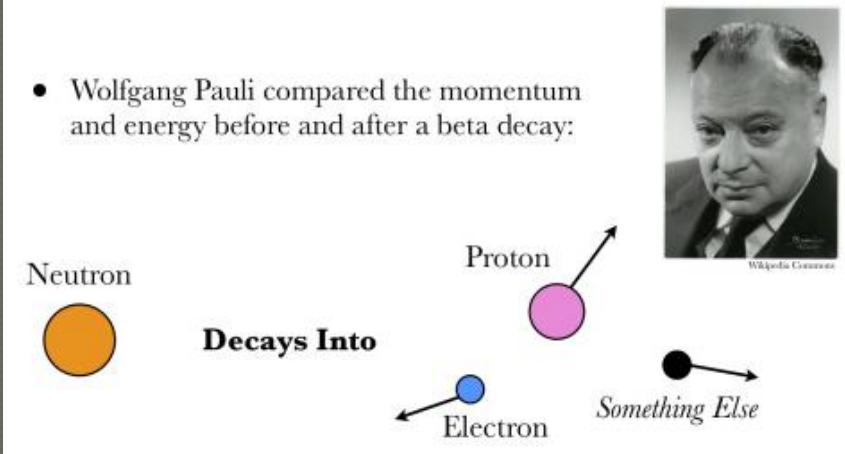
- En une seconde, cinq millions de neutrinos solaires de haute énergie passent dans chaque centimètre carré de votre corps !

Source des neutrinos



Découverte

- Wolfgang Pauli compared the momentum and energy before and after a beta decay:



Wolfgang Pauli, back in 1933, compared the momentum before and after a neutron decayed into a proton and electron – but he came up a little short.

He concluded that there must be some tiny, undetectable particle carrying away some of the final momentum from the system. That particle was called the neutrino.

Discovery of the Neutrino

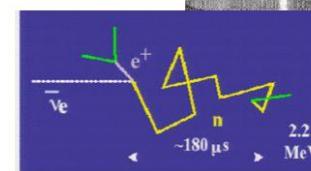
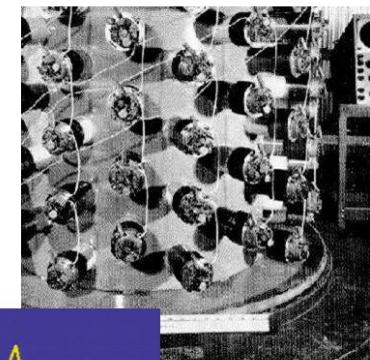
- Reines and Cowan (1955)

- Nobel Prize 1995
- 1 ton detector
- Neutrinos from a nuclear reactor $\bar{\nu} p \rightarrow e^+ n$



Reines and Cowan at
Savannah River

20 January 2010



K. McFarland, Neutrinos at Accelerators

12

Negative beta decay in the nuclear reactor, which is only one type of radioactive decay, produces an electron antineutrino, the electron antineutrinos interacted with protons in two tanks of water, creating neutrons and positrons:

Importance de la découverte

The Nobel Prize in Physics
1988



Leon M. Lederman
Prize share: 1/3

The Nobel Prize in Physics
1988
Lederman, Melvin L. Perl
beam method and the leptons through the neutrinos

Photos: Copyright © The Nobel Foundation

The Nobel Prize in Physics
1995



Martin L. Perl
Prize share: 1/2

The Nobel Prize in Physics
1995
experimental collaboration to Martin L. Perl
half to Frederick Reines

Photos: Copyright © The Nobel Foundation

The Nobel Prize in Physics
2002



Raymond Davis Jr.
Prize share: 1/4

The Nobel Prize in Physics
2002
Raymond Davis Jr.
contributions to cosmic neutrino astrophysics

pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources".

Photos: Copyright © The Nobel Foundation

The Nobel Prize in Physics
2015



Takaaki Kajita
Prize share: 1/2



Arthur B. McDonald
Prize share: 1/2

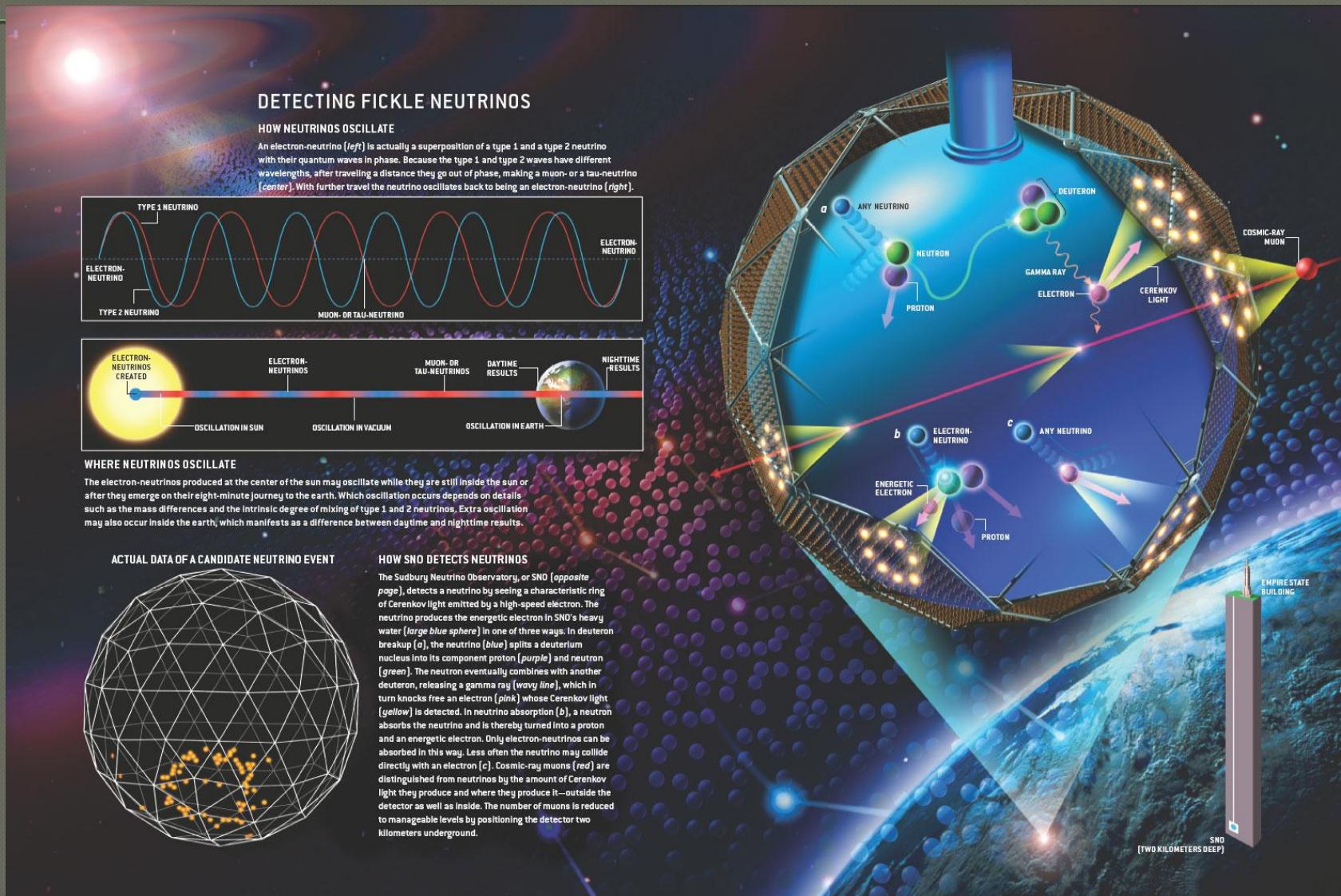
The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass"

L'énigme des neutrinos solaires



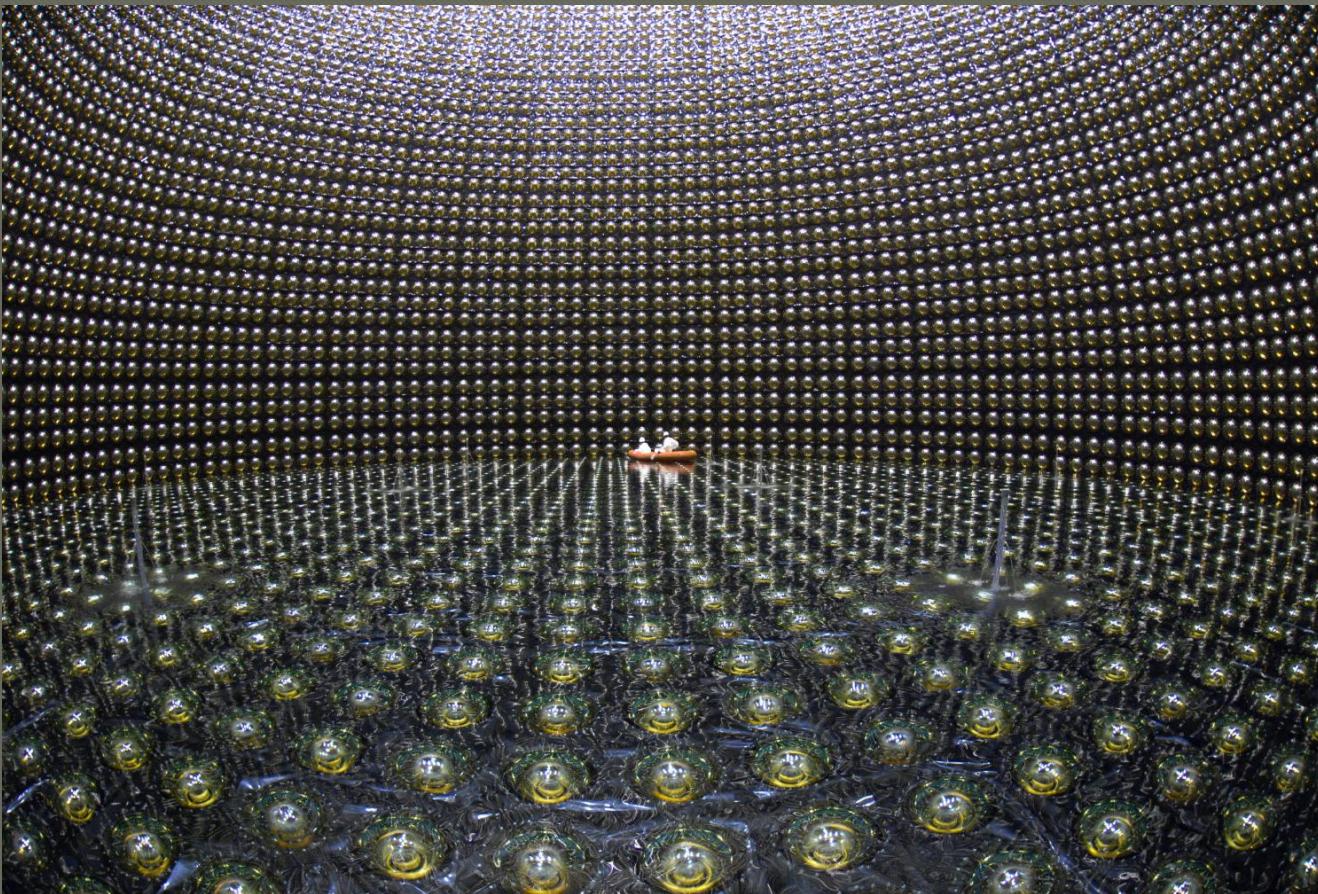
<https://www.youtube.com/watch?v=qpTylnnWAYg>

Différentes « saveurs »



Les principaux détecteurs

Le Super Kamiokande



- 50 000 t of water, 11 200 PMTs
- Inner and outer detector layers
- Implosion of 6600 tubes in 2001

Le SNO

Sudbury neutrino observatory (1999-2006)

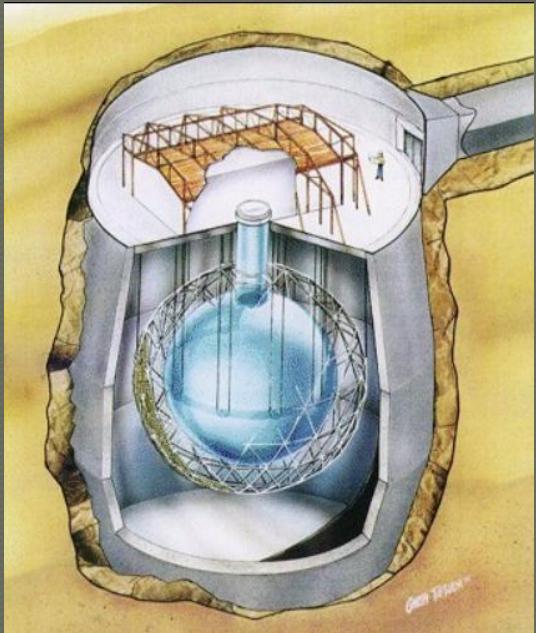
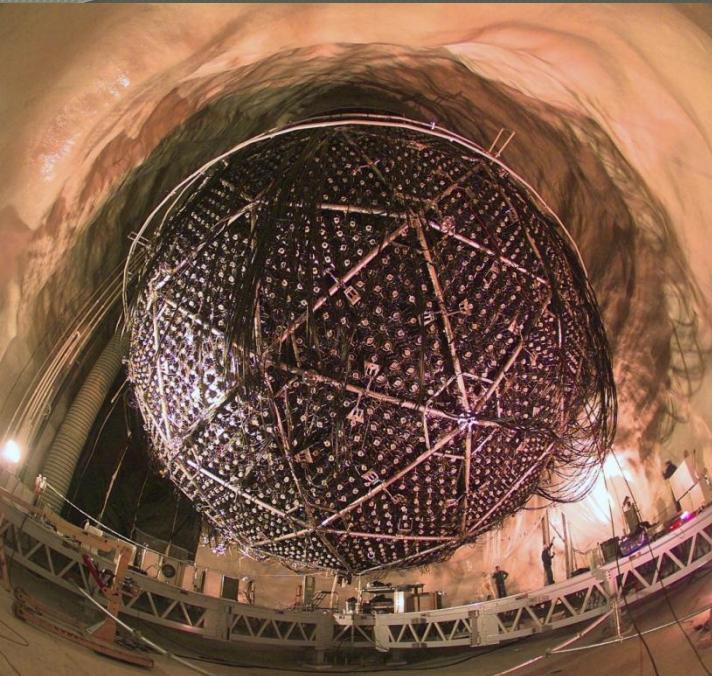
Uses heavy water (1000 t)

Cerenkov-detector with 9600 PMTs

SNO proved in 2001 that neutrinos come
in three flavours

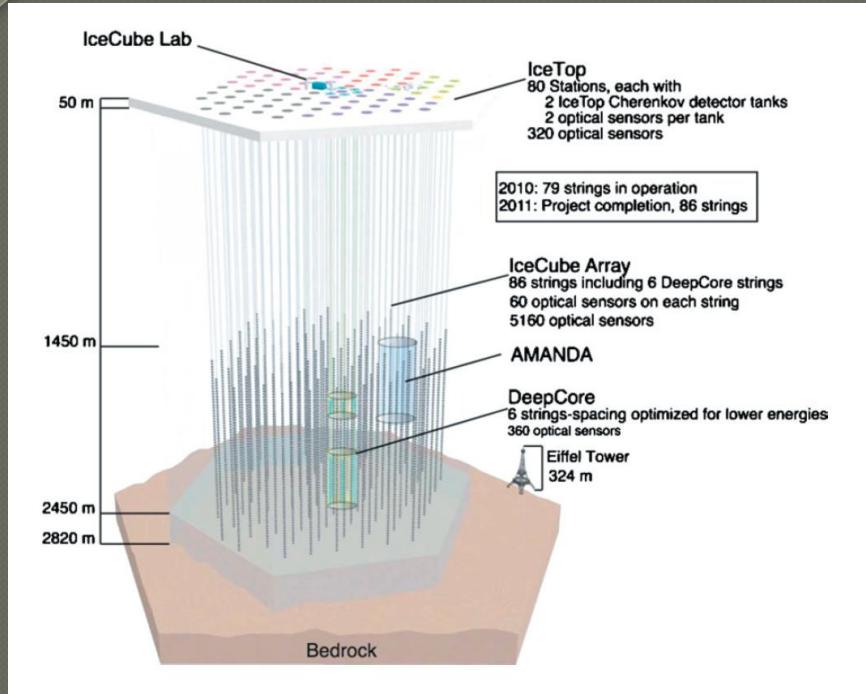
They can transmute into each other
while propagating through space
Non-zero mass

- SNO = Sudbury Neutrino Observatory.
- A neutrino collides with a molecule inside the reactor to produce two protons, an electron and light.
- The light gets detected by 10 000 detectors arranged in a sphere.
- In one day, there are only about 30 collisions in the sphere.



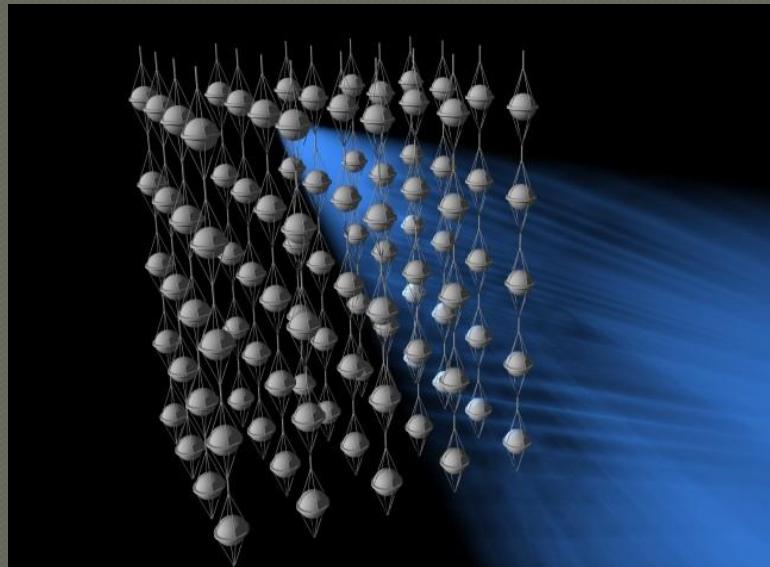
Courtesy SNO

IceCube



IceCube South Pole Neutrino Observatory

- Location: Amundsen-Scott South Pole Station, Antarctica
- Why there?
 - Interacting material (ice) already in place
 - Ice easy to drill into (unlike rock) – with specialized hot water drills
 - Detectors lowered into the holes
 - Better shielding from noise sources than anywhere else
- Completed in 2010



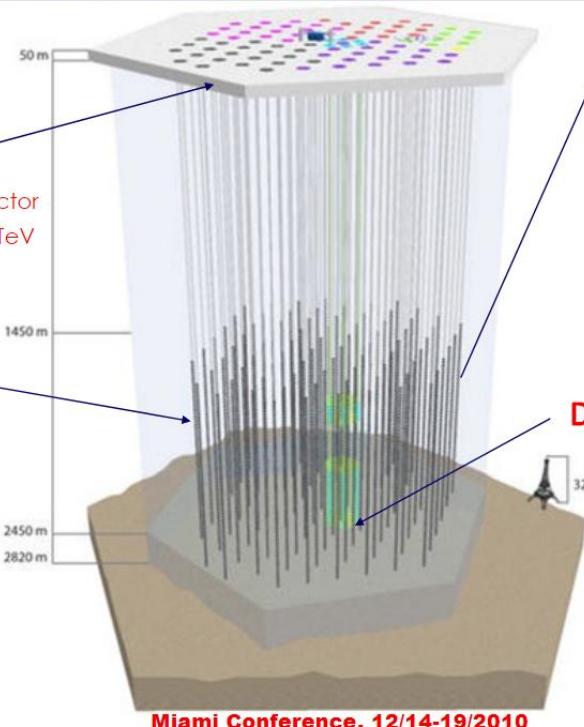
The IceCube Detector

IceTop

Air shower detector
threshold ~ 300 TeV

InIce

80-86 Strings,
60 Optical
Modules per
String



Miami Conference, 12/14-19/2010

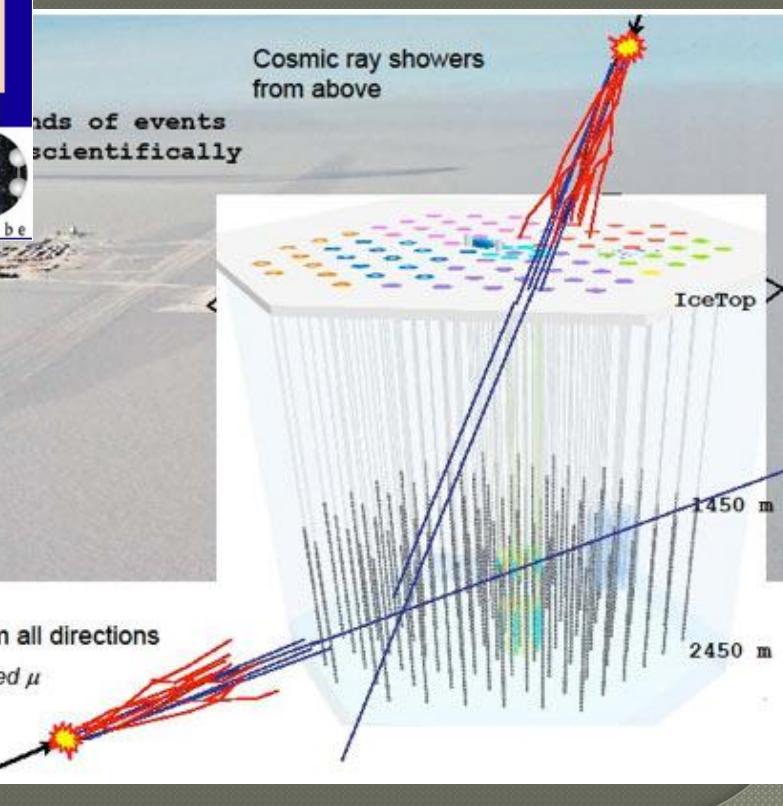
✓ Completion:
January 2011

✓ 2008: 40
Strings (This
Analysis)

✓ 2009: 59
Strings

Deep Core

✓ 2010: 79
Strings



Ice Cube



Neutrinos from all directions

Primarily ν_μ -induced μ^-
from below

Ice Cube

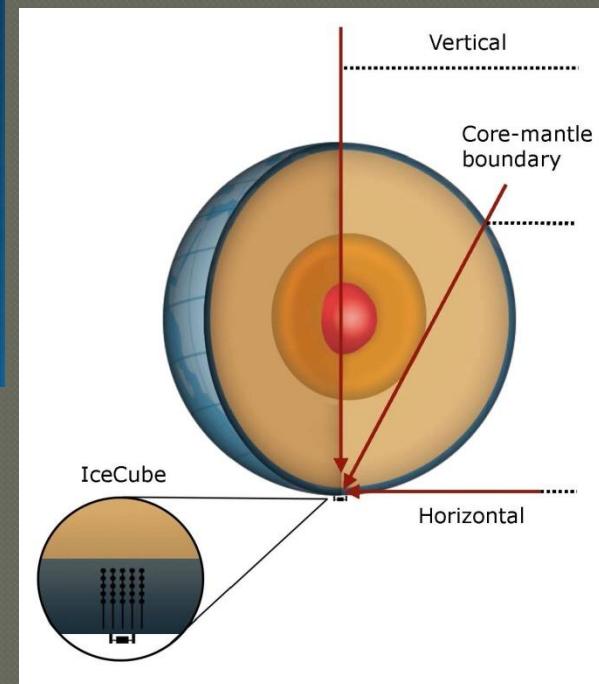
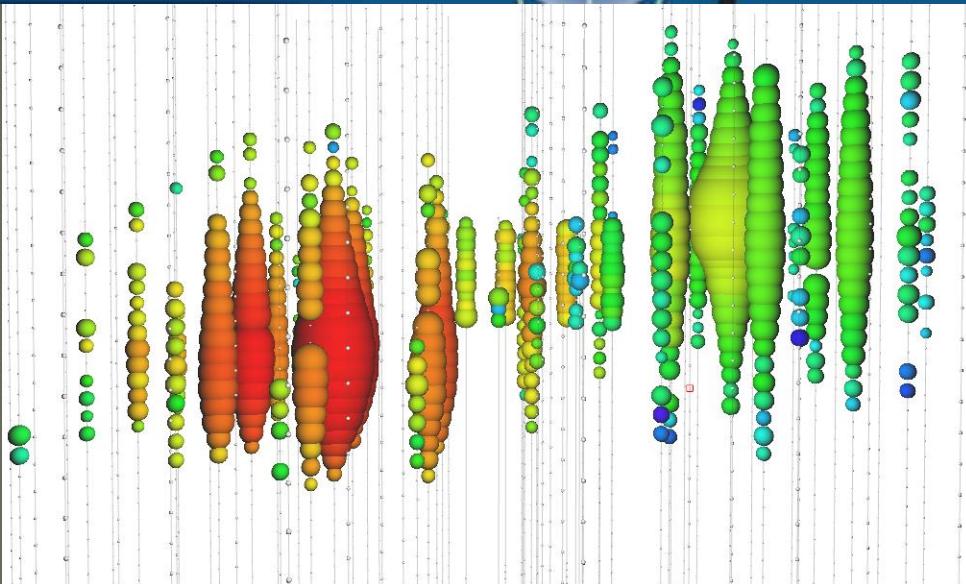
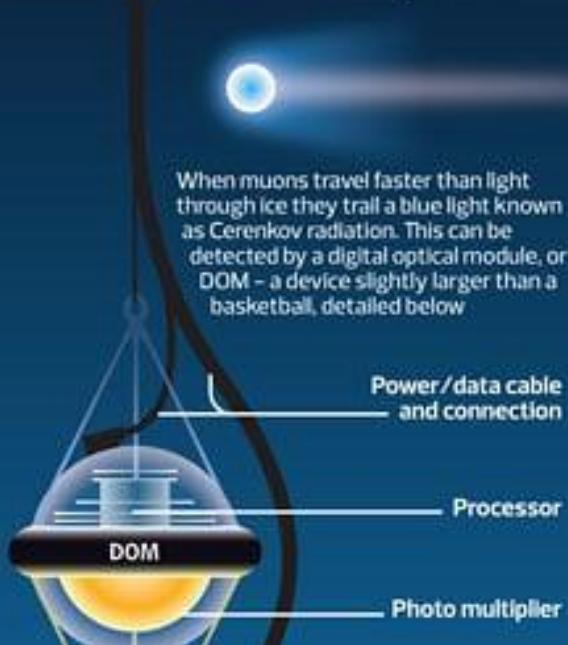
The neutrino

The IceCube array will trace the paths of neutrinos, subatomic particles formed in the decay of radioactive elements and other elementary particles.



Neutrinos have an infinitesimal mass and trillions of them pass through the planet every second. Carrying no electrical charge they are not affected by Earth's magnetic fields

The detection array



NOvA



The NOvA experiment is designed to search for oscillations of muon neutrinos to electron neutrinos by comparing the electron neutrino event rate measured at the Fermilab site with the electron neutrino event rate measured at a location just south of International Falls, MN 810 kilometers distant from Fermilab.

If oscillations occur, the far site will see the appearance of electrons in the muon neutrino beam produced at Fermilab.