Update and Neutrino Oscillations

Update:

- Reading about CEvNS, standard model, neutrinos, RAT, Root, Geant, Linux and programing overall

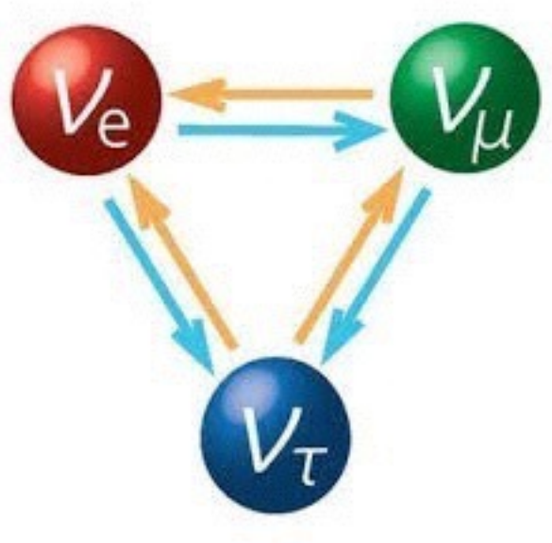
- Used Kim and Alex at MIT as my go-to for questions on material

- Compiled information in a write up paper for my reference

- In the process of installing RAT with IT at Madison and learning how to compile RAT at the same time

Neutrino Oscillations

"Metamorphosis in the quantum world"



- According to the Standard Model, there are three types of neutrinos-electron, muon and tau, and each has it's respective charged partner, the electron, muon and tau. Each neutrino is created with its distinct "flavor", but over distance a neutrino can oscillate between types.

- Importance: Based on math related to eigenvalues and vectors, neutrino oscillations imply that the neutrino is not massless, which requires modification of the Standard Model.

Origin of discovery

- Since the 1960s, scientists had theoretically calculated the number of neutrinos that were created in the nuclear reactions that make the sun shine, but when carrying out measurements on Earth, up to two thirds of the calculated neutrino amount was missing. This was because such predictions accounted only for the sun's electron-neutrinos, and not for neutrino oscillations.

- Later, neutrino oscillations resolved this discrepancy between measurements of the numbers of neutrinos flowing through the Earth and theoretical models of the solar interior.

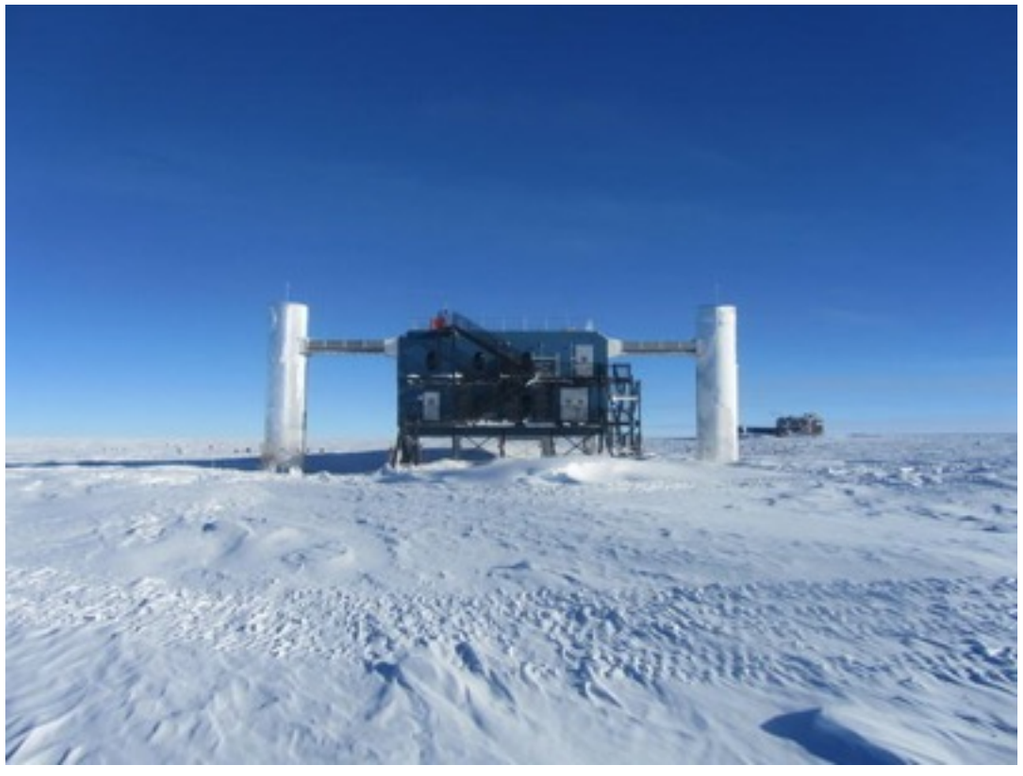
Nobel Prize of 2015

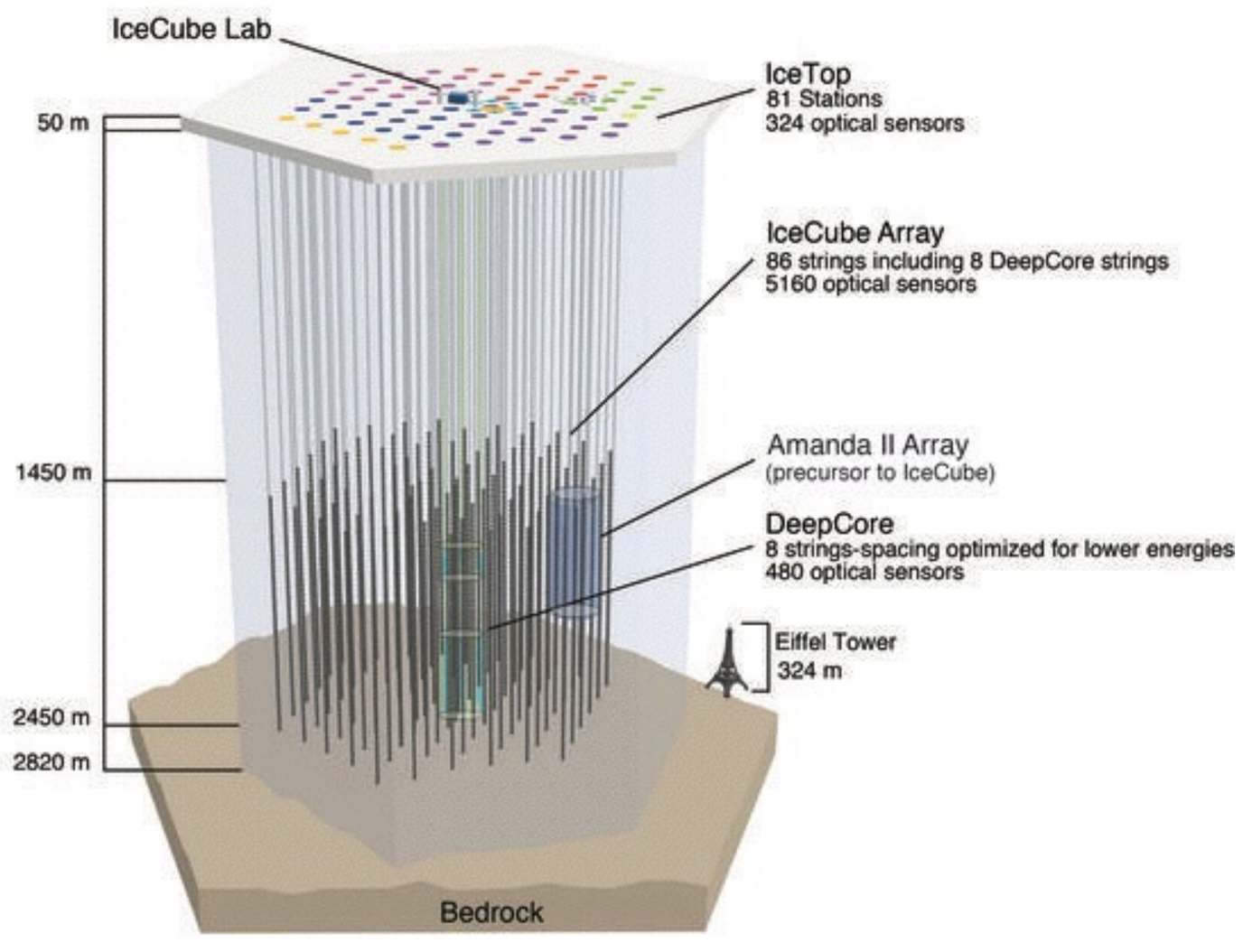
- Last year the Physics Nobel Prize was jointly awarded to Arthur McDonald and Takaaki Kajita for confirming the existence of neutrino oscillations.
- Extra information about their respective experiments attached at the end

- https://www.nobelprize.org/nobel_prizes/physics/laureates/2015/advanced-physicsprize2015.pdf

IceCube

- IceCube is the world's largest neutrino detector, encompassing a cubic kilometer of ice, located at the South Pole. It was built to search for very high energy neutrinos created in the most extreme cosmic environments.



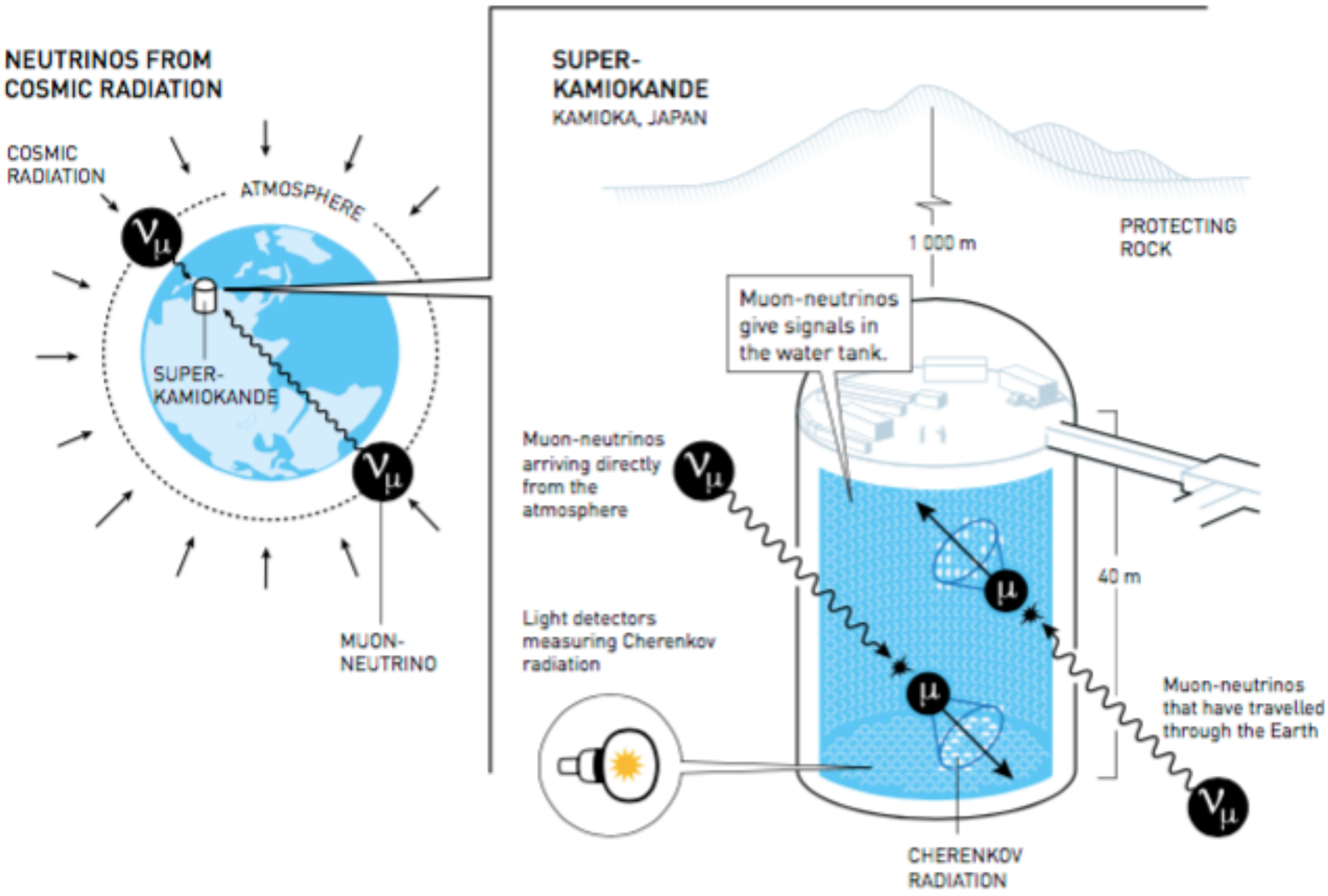


Oscillation Parameters

- IceCube has measured atmospheric oscillation parameters of neutrinos. Neutrino parameters are complicated trigonometric expressions that explains how strongly the flavors mix in terms of distance between production and detection and the energy of the neutrino.This set of information together with the energy of the neutrino and the distance it travels gives the oscillation probability.

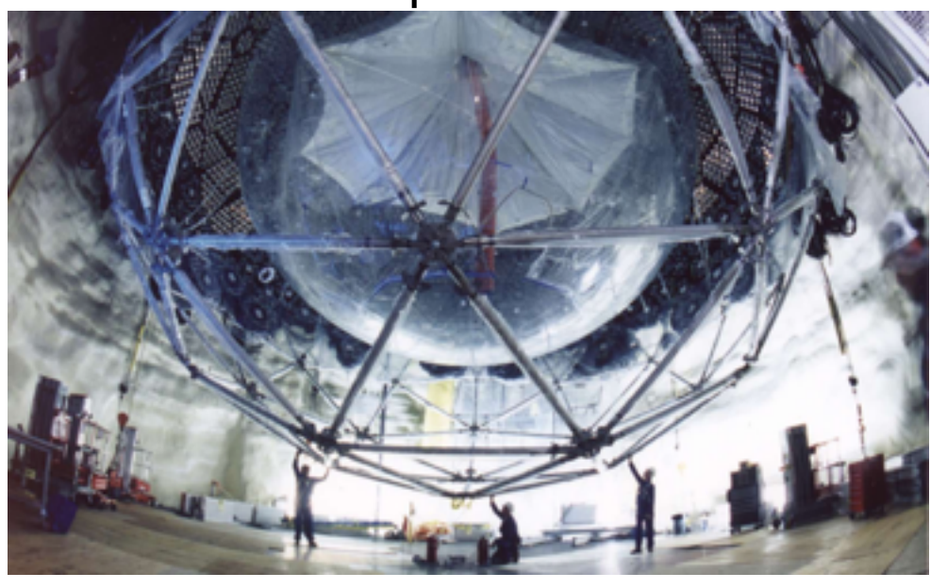
Extra on Nobel experiments

- Takaaki Kajita headed a team working at the Super-Kamiokande detector in Japan. The detector consists of a tank of 50,000 tons of water buried underground to shield it from cosmic rays. It detects electron and muon neutrinos coming from the Earth's atmosphere, where neutrinos are produced by collisions of cosmic rays with atmospheric atoms. Very rarely, these neutrinos will collide with atomic nuclei in the detector's water molecules and generate flashes of light. In 1998, the researchers reported that they detected fewer muon neutrinos coming up through the Earth than coming down from above. This asymmetry suggested that some atmospheric muon neutrinos coming through the Earth had oscillated to (undetectable) tau neutrinos in transit, while those coming from above, having a far shorter path,had not had time to do so.

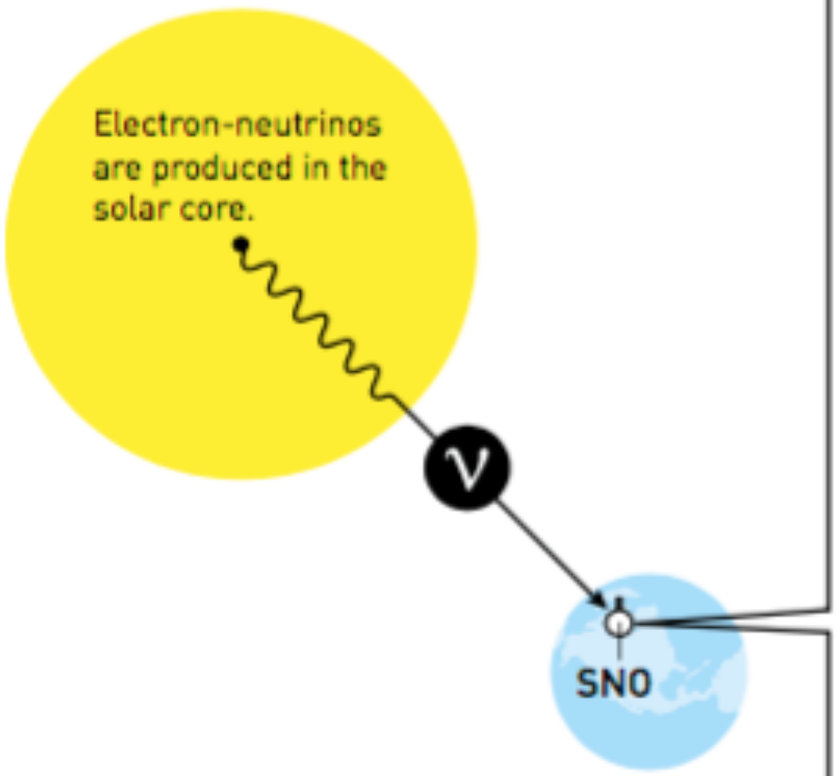

NEUTRINOS FROM COSMIC RADIATION
COSMIC RADIATION
ATMOSPHERE
ν_μ
SUPER-KAMIOKANDE
ν_μ
MUON-NEUTRINO
SUPER-KAMIOKANDE
KAMIOKA, JAPAN
1 000 m
PROTECTING ROCK
Muon-neutrinos give signals in the water tank.
Muon-neutrinos arriving directly from the atmosphere
ν_μ
Light detectors measuring Cherenkov radiation
μ
μ
40 m
Muon-neutrinos that have travelled through the Earth
ν_μ
CHERENKOV RADIATION

Extra on McDonald Experiment

- In 2001, the research group led by Arthur McDonald also confirmed neutrino oscillations. This experiment used the SNO detector containing 1000 tons of heavy water. There were two types of collisions between neutrinos and heavy hydrogen (deuterium) atoms, one involving only electron neutrinos, and the other involving all three flavors. Thus the relative amounts of different flavors were compared.



NEUTRINOS FROM THE SUN



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