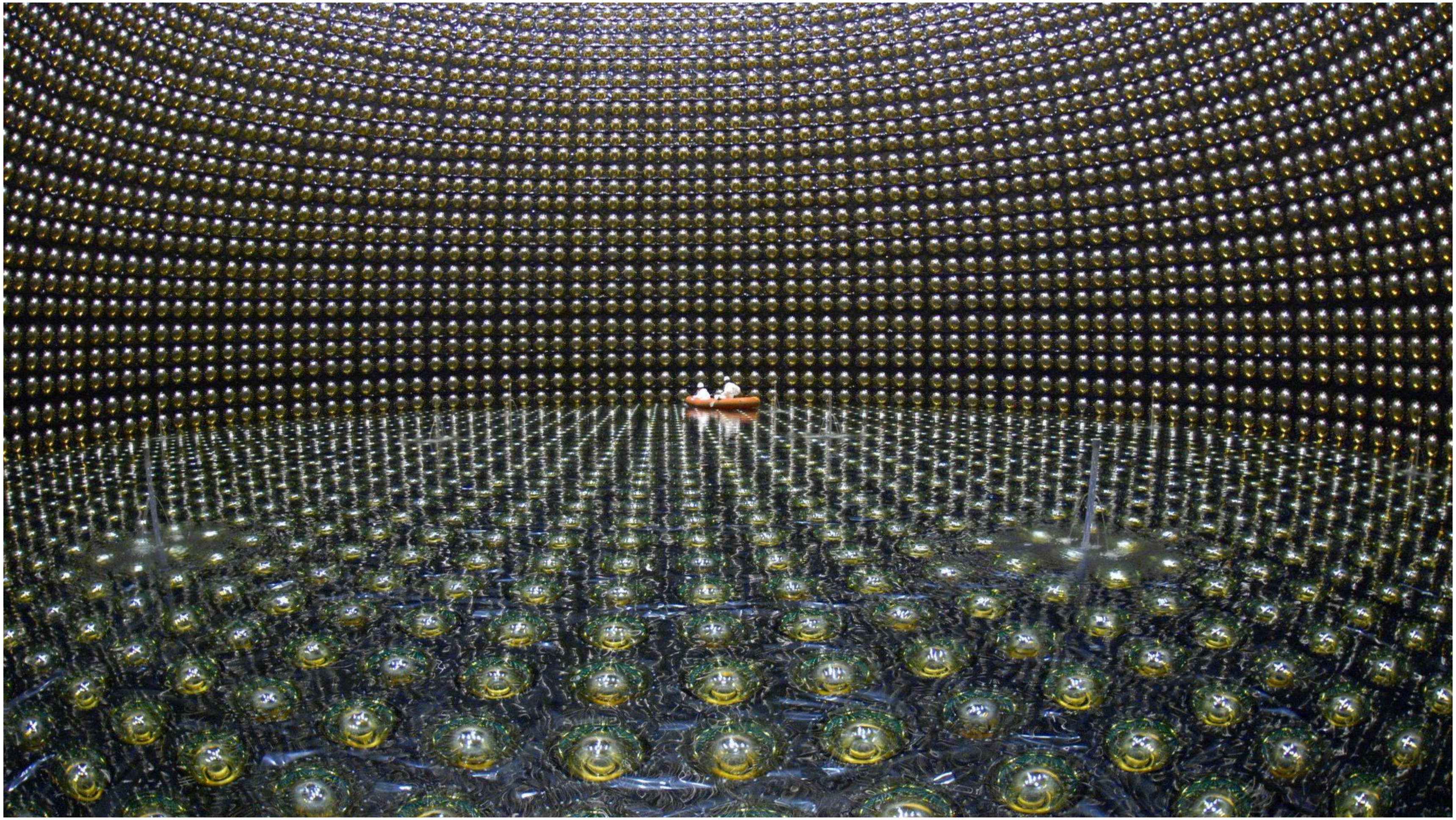
Neutrinos



Outline

- History
- Sources
- Properties
- Detectors

History

- Wolfgang Pauli first postulated in 1930
- Needed in order to conserve energy and momentum in beta decay
- Enrico Fermi gave it the name neutrino in 1933 and used it in his theory of beta decay
- He claimed that the newly discovered neutron could decay into a positive particle, a negative particle, and a neutral particle with incredibly small mass
- $n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$

First Detection

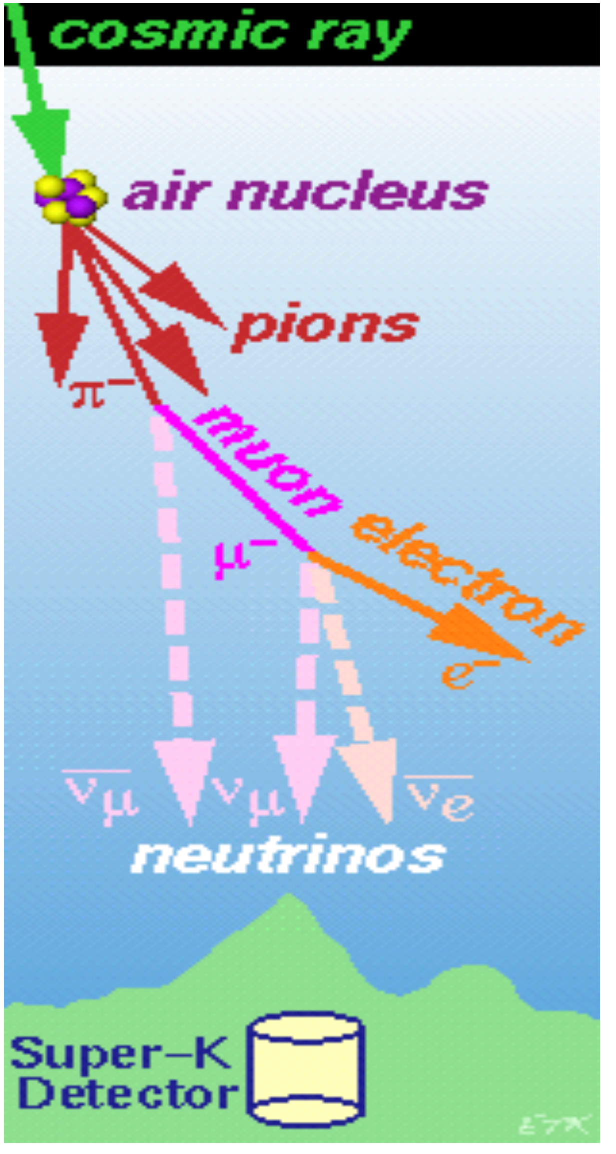
- First detected in 1956 by Clyde Cowan, Frederick Reines, F. B. Harrison, H. W. Kruse, and A. D. McGuire (1995 Nobel Prize)
- Antineutrinos from a nucelar reactor collide with protons in order to make neutron and positrons
- Positrons annihilate with electrons in order to form to gamma rays
- $\bar{\nu}_e + p^+ \rightarrow e^+ + n^0$

Sources of Neutrinos

- Nuclear reactions - Antineutrinos are produced by beta decay
- Roughly 5% of energy lost to neutrinos
- Nuclear bombs – Fission bombs produce antineutrinos while fusion bombs produce antineutrinos and neutrinos
- Bombs were first choice for detecting before reactors
- Decay of uranium and thorium (beta decay)

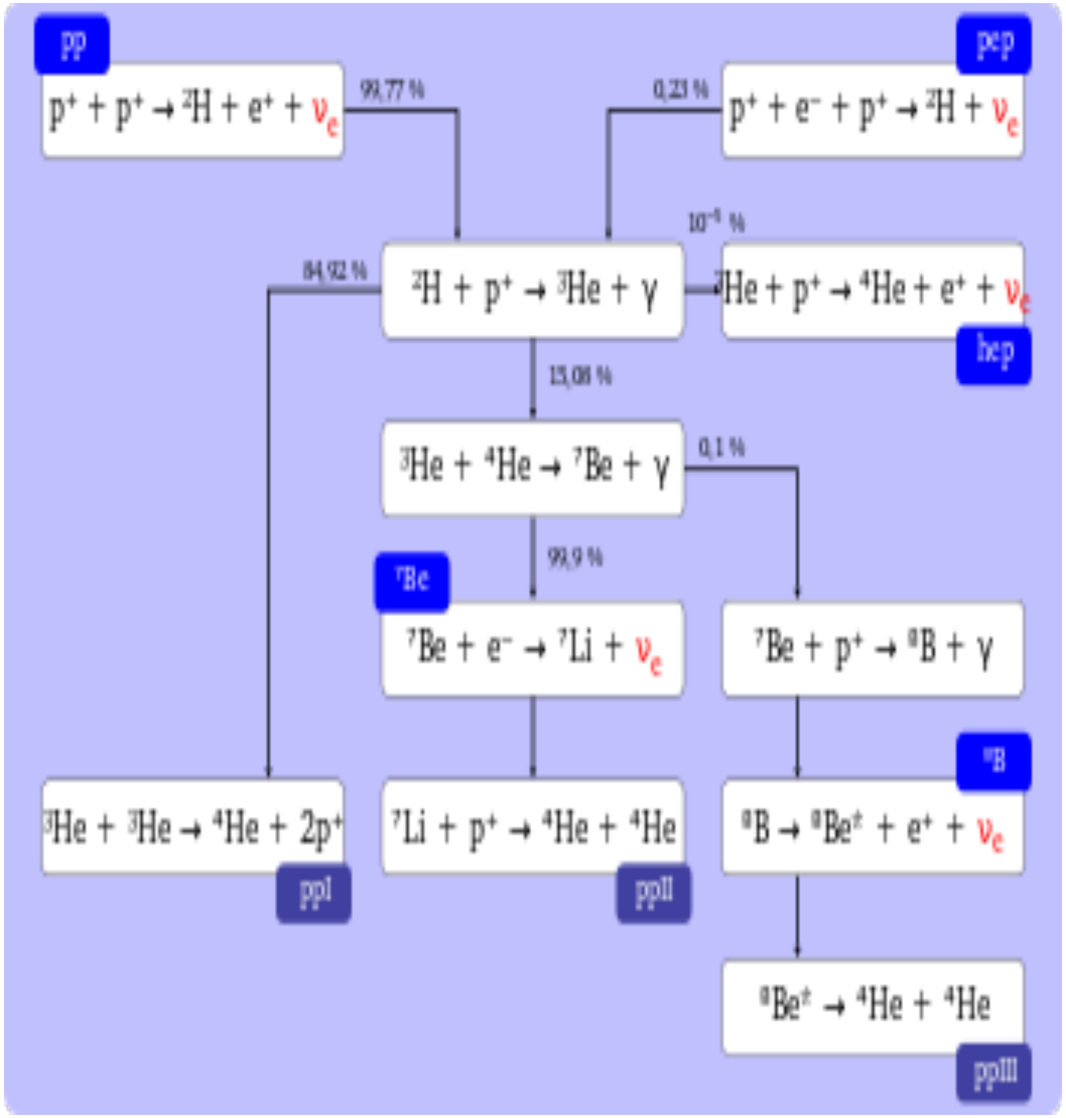
Sources of Neutrinos

- Particle Accelerators – Neutrino beams are created by smashing protons in order to produce kaons or pions, which then decay into a relativistic boosted beam of neutrinos
- Atmospheric - Cosmic rays slam into nuclei in the atmosphere which produces unstable particles that will decay into neutrinos



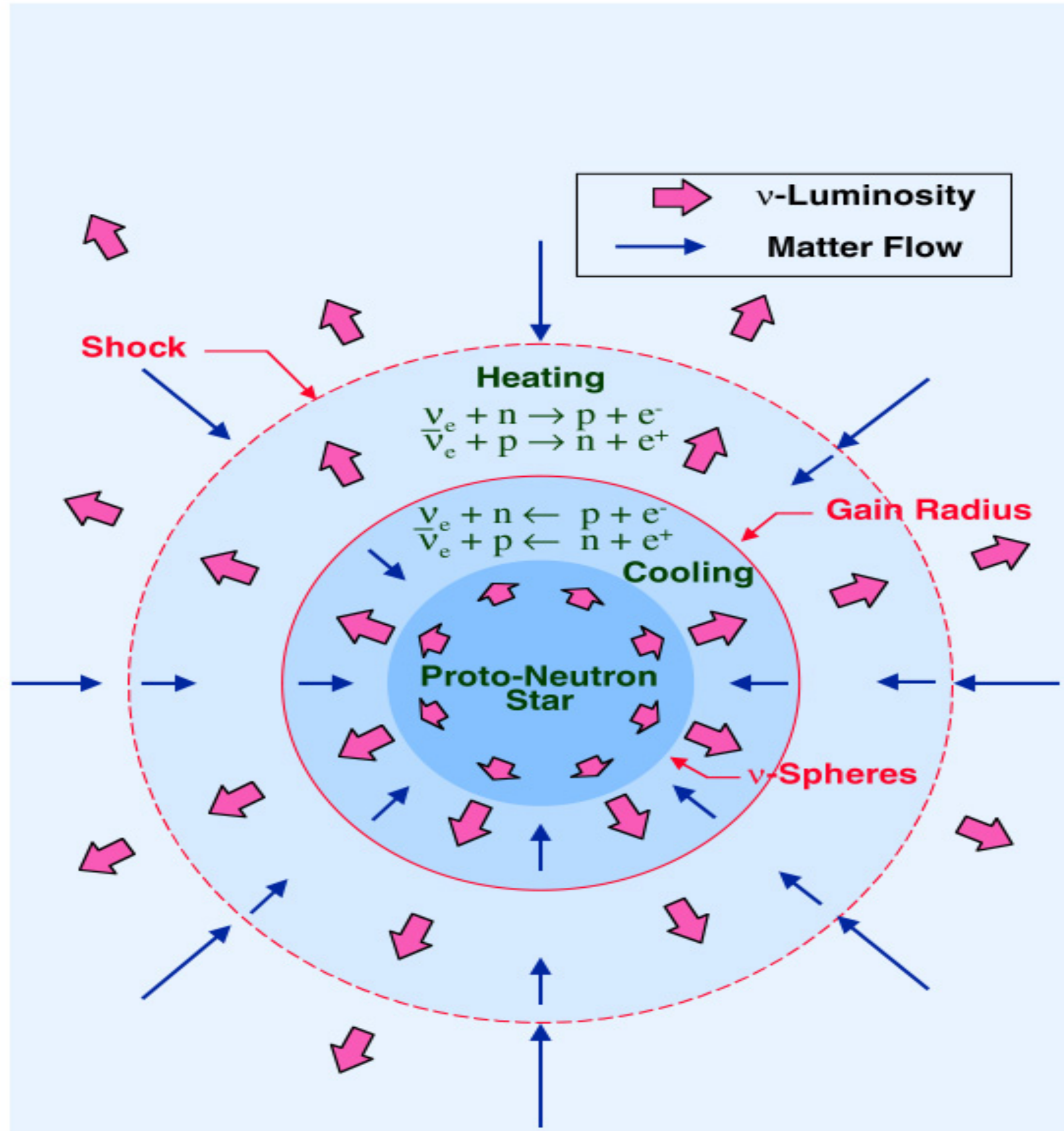
Sources of Neutrinos

- Solar – In the fusion process 4 protons fuse into one helium nucleus
- Two of the protons must decay into neutrons and each of these conversions produces a neutrino
- About 65 billion per square centimeter on Earth



Sources of Neutrinos

- Supernovae – When a giant star collapses, the densities become so large that the degeneracy pressure of the electrons can no longer prevent the electrons and protons from combining into



Properties

- Neutral particle - only interact through weak forces and gravity
- This allows neutrinos to pass straight through most objects in our universe
- This makes neutrinos an excellent particle for astronomical observations
- Supernova – neutrino burst comes before visible explosion due to its non-interacting properties

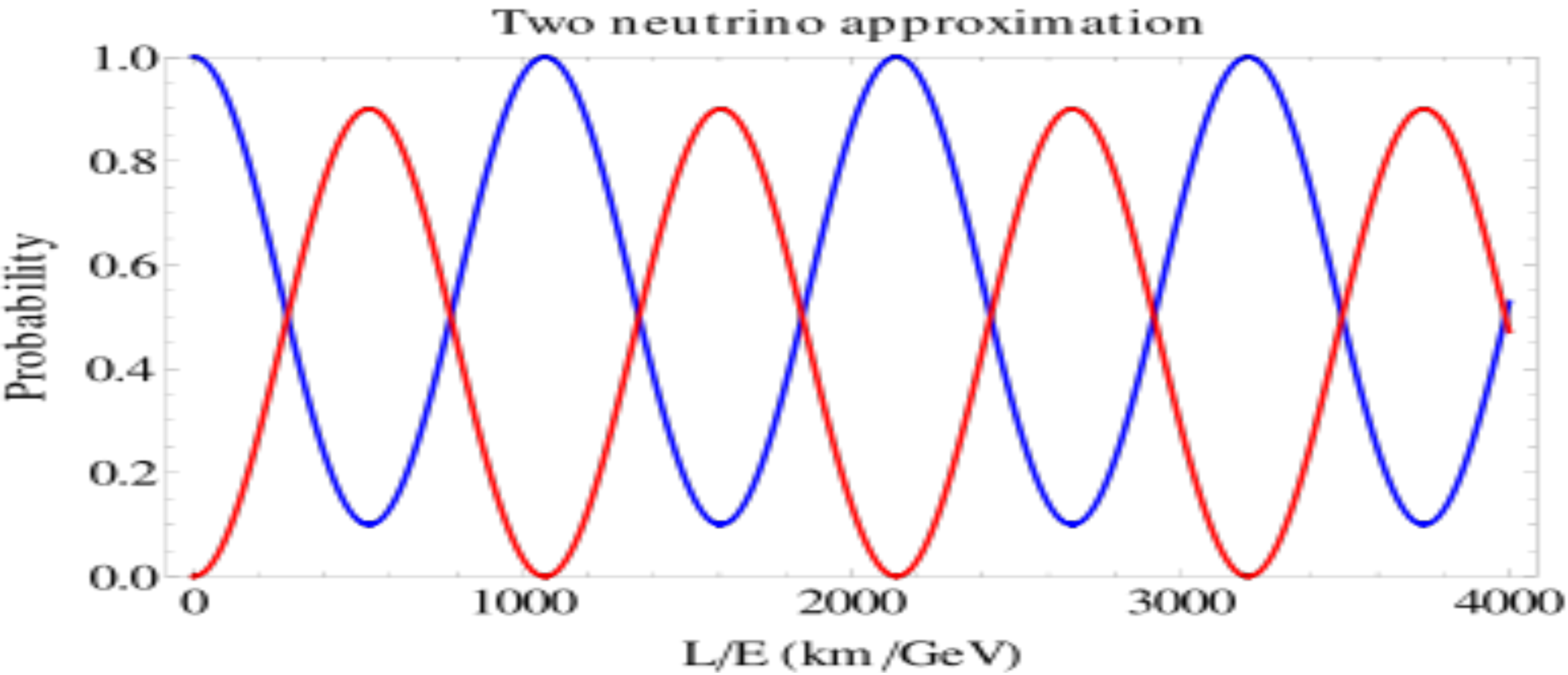
Properties

- Spin – the neutrino is a fermion with spin 1/2
- It obeys Pauli exclusion principle, as more neutrinos are added they must occupy higher momentum states
- Travels at about the speed of light
- Originally thought to be massless and travel at the speed of light

Properties

- Mass – The question of whether or not neutrinos have mass was settled when neutrino oscillations were discovered
- Oscillations – The neutrino has 3 flavors, electron, muon, and tau, all with different masses
- Neutrinos have a chance to switch between all three of these states when the propagate through space
- This is due to the interference of neutrinos with each other

Properties



Two neutrino approximation
Probability
L/E (km /GeV)
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000

Properties

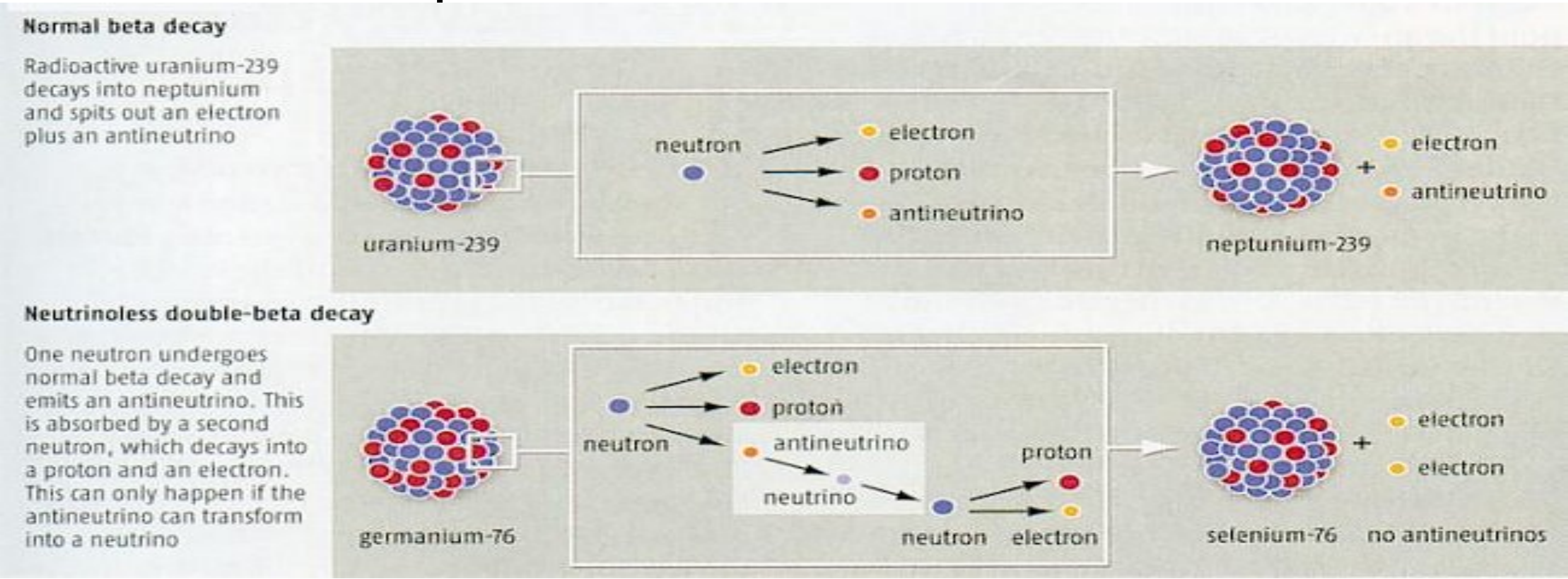
- Solar neutrino problem – Scientists struggled with the fact that they were detecting far less neutrinos than expected from the sun
- This problem was solved by neutrino oscillation, the neutrinos were being produced, but scientists hadn’t been looking in the right place.
- By giving the neutrinos mass oscillations could occur that would make up for the missing nuetrinos

Properties

- Mass -While oscillation proved that neutrinos have mass we still don’t know what that mass is
- Experiments are in progress to directly determine the mass
- KATRIN - measures spectrum of electrons emitted from beta decay and compares to energy limit
- GERDA – searches for neutrinoless double beta decay

Properties

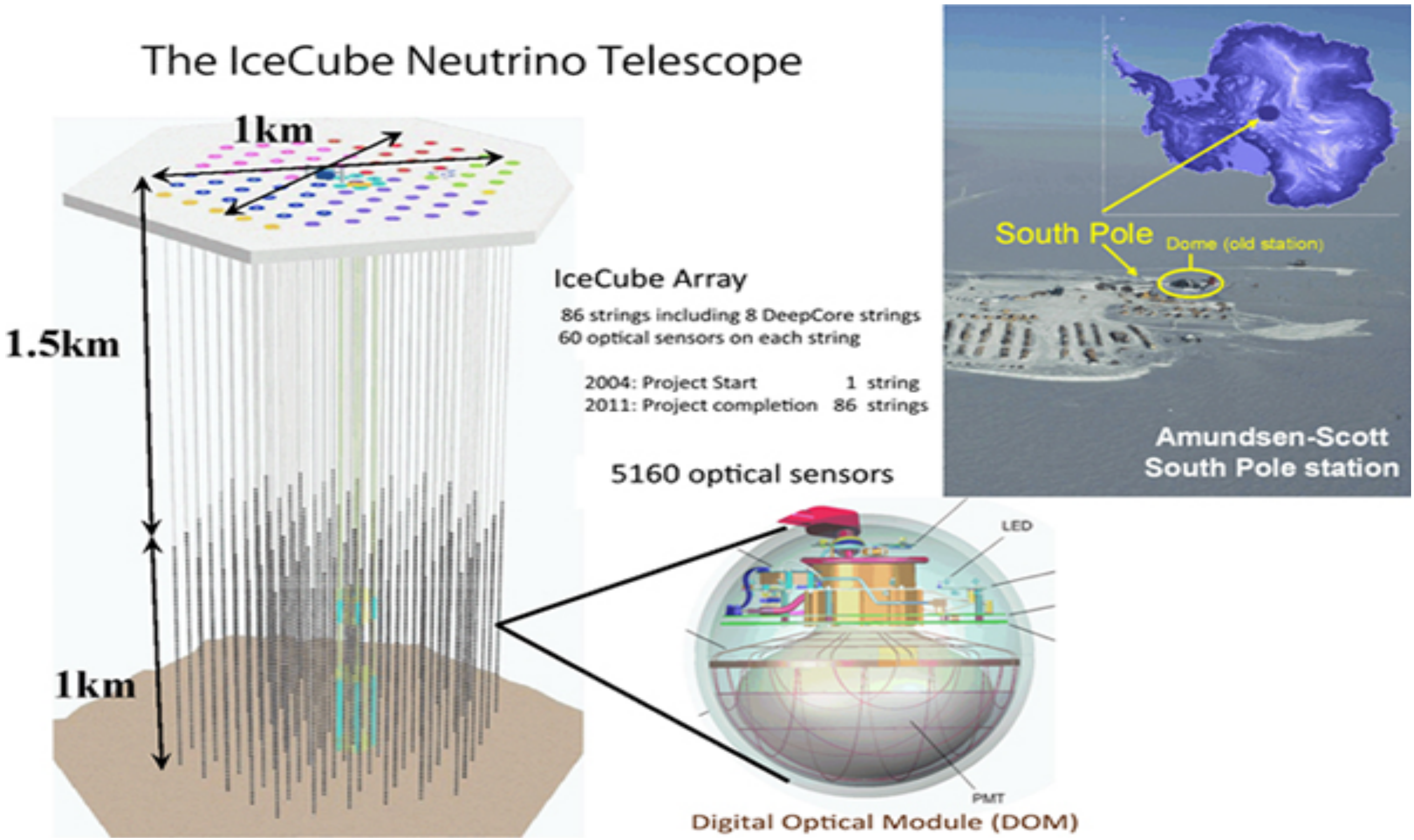
- Majorana particle - neutrinoless double beta decay is a process that can occur if the neutrino is its own anti-particle,
- This also implies that the neutrino has mass



Detectors Today

- IceCube - Located at the South Pole
- Cubic kilometer of ice turned into giant neutrino detector
- Designed to detect neutrinos from cataclysmic events such as super nova
- Uses Cherenkov radiation produced by electrons or muons moving faster than the speed of light in the medium to determine direction and energy of neutrino that created the electron/muon

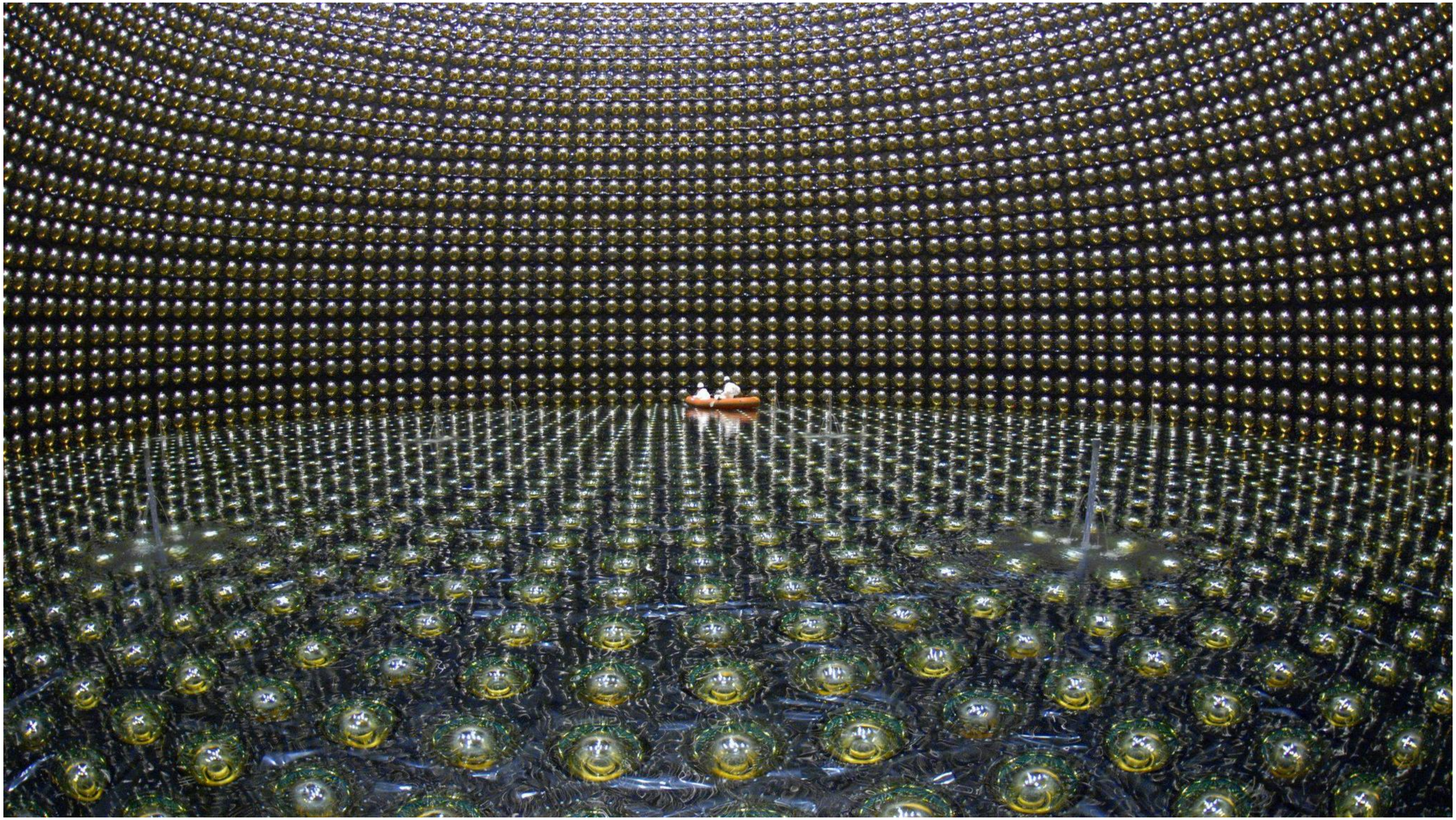
IceCube


The IceCube Neutrino Telescope
1km
1.5km
1km
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
2004: Project Start 1 string
2011: Project completion 86 strings
5160 optical sensors
South Pole
Dome (old station)
Amundsen-Scott
South Pole station
LED
PMT
Digital Optical Module (DOM)

Super-Kamiokande

- Located under Mount Kamioka in the city of Hida, Japan
- 1000 m underground, consists of 50,000 tons of ultra-pure water
- Originally designed to detect proton decay (lower limits 10^{33} years)
- First detector to be able to observe the direction of neutrinos and confirm that they are produced by the sun

Questions??



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Sources

- Francis Halzen and Thomas K. Gaisser, “IceCube” *Annual Review of Nuclear and Particle Science*, 64 (2014) 101-123
- Steen Hannestad “Neutrino masses and the number of neutrino species from WMAP and 2dFGRS”, *Journal of Cosmology and Astroparticle Physics* Volume 2003 May 2003
- R. L. McNutt Jr. “Correlated Variations in the Solar Neutrino Flux and the Solar Wind and the Relation to the Solar Neutrino Problem”, *Science* December 1995 Volume 270 pp. 1635 - 1639