Solar Neutrinos and UC Irvine

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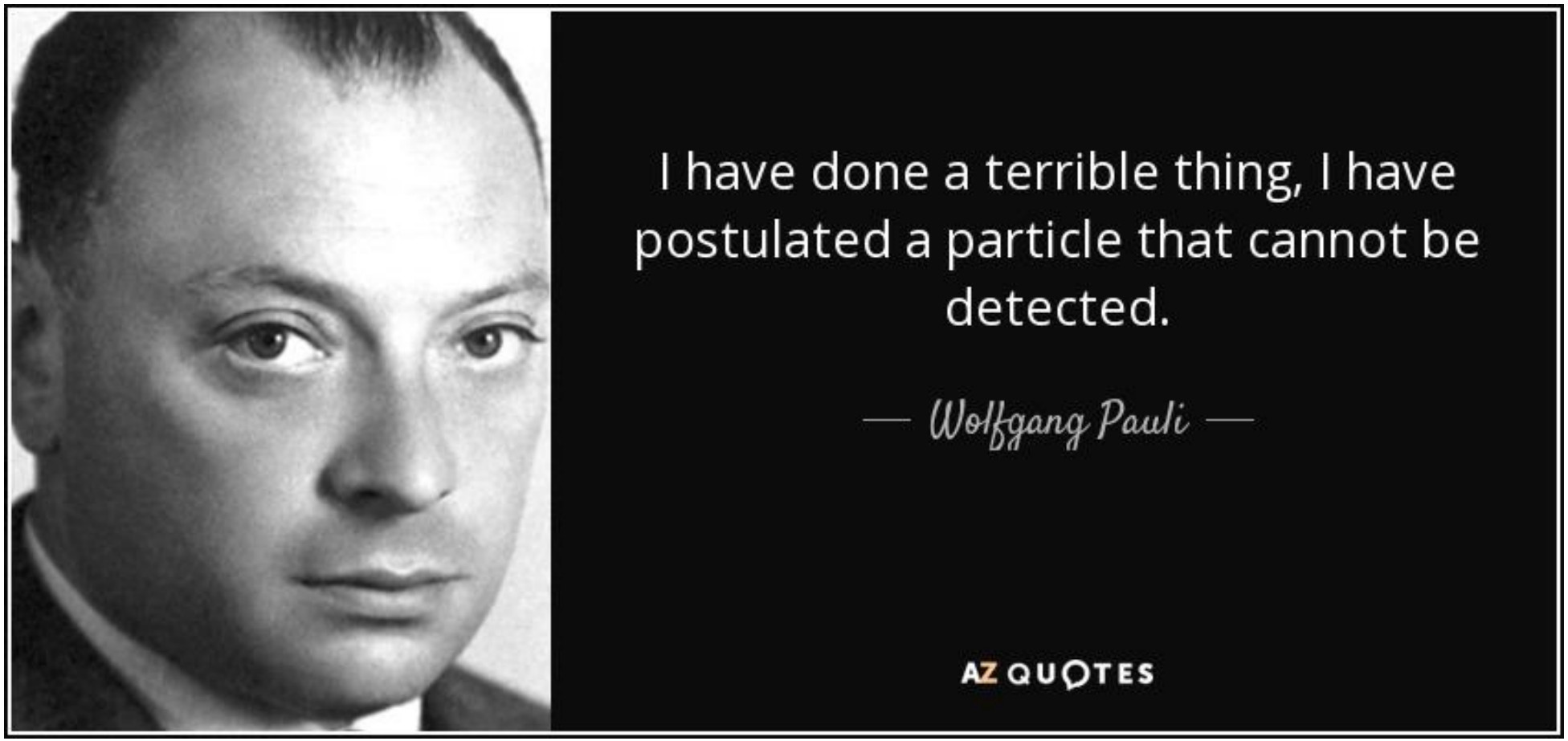
Physics and Astronomy

Beta Decay of Neutrons, and Postulate of the Neutrino

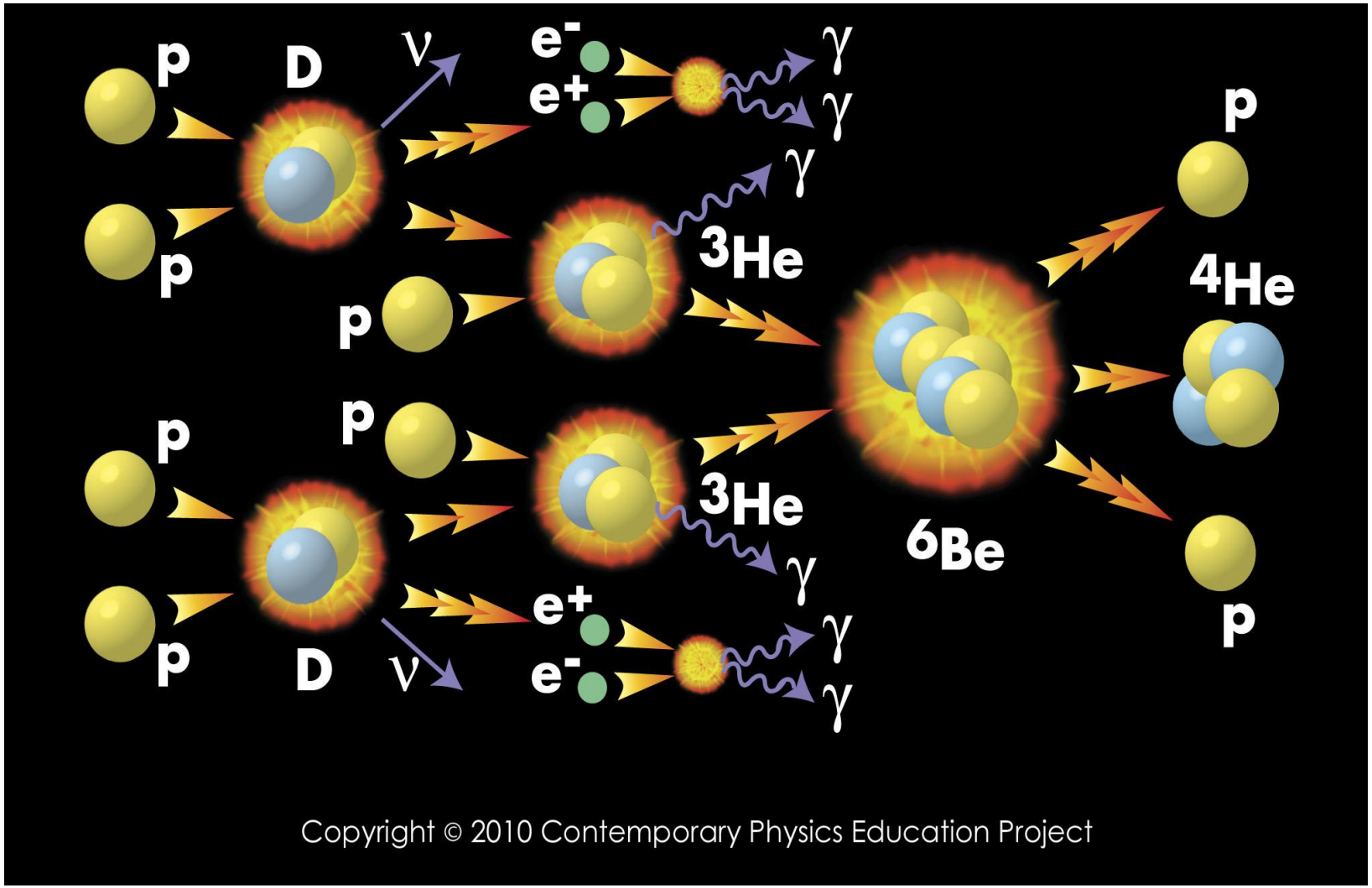
- Neutrons live about 15 minutes, and then decay to a proton plus a positron plus missing energy.
- Wolfgang Pauli in 1930 postulated that the energy was carried away by a light neutral particle of spin ½, which he named the neutrino.
- He won the Nobel Prize in 1945 for the Pauli Exclusion Principal, which states that no two electrons can occupy the same physical state.


I have done a terrible thing, I have postulated a particle that cannot be detected.
— Wolfgang Pauli —
AZ QUOTES

Beta Decay Turned Around to Make Solar Deuterons

- Beta Decay: $n \rightarrow p + e^{-} + \nu_e$ is a slow or weak interaction.
- Switch particle sides, making them their antiparticles:
- Proton to neutron conversion in a nucleus where neutron is better bound (inverse beta decay): $p \rightarrow n + e^{+} + \bar{\nu}_e$
- The start of solar fusion is then the merger of two protons, where one becomes converted to a neutron, and the proton and neutron combine to form a deuteron (pn): $p + p \rightarrow d + e^{+} + \bar{\nu}_e$
- Then a deuteron, which is larger than a proton and more strongly attracts another proton, can merge with another proton to form He^3 .

Solar Fusion: Protons to deuterons to He^3 to He^4
Two electron neutrinos produced

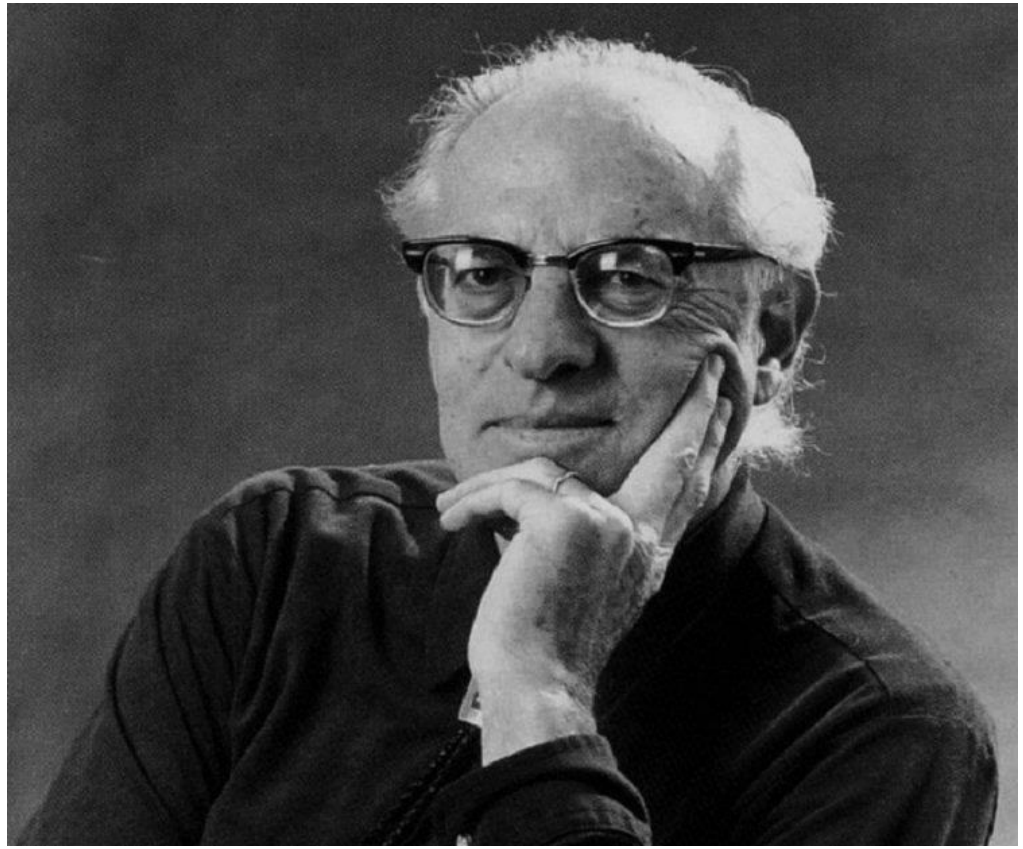


Cowan and Reines Detect Anti-neutrinos From Neutron Decays in Nuclear Reactors in 1956
Fred Reines and Marty Perl share 1995 Nobel Prize in Physics

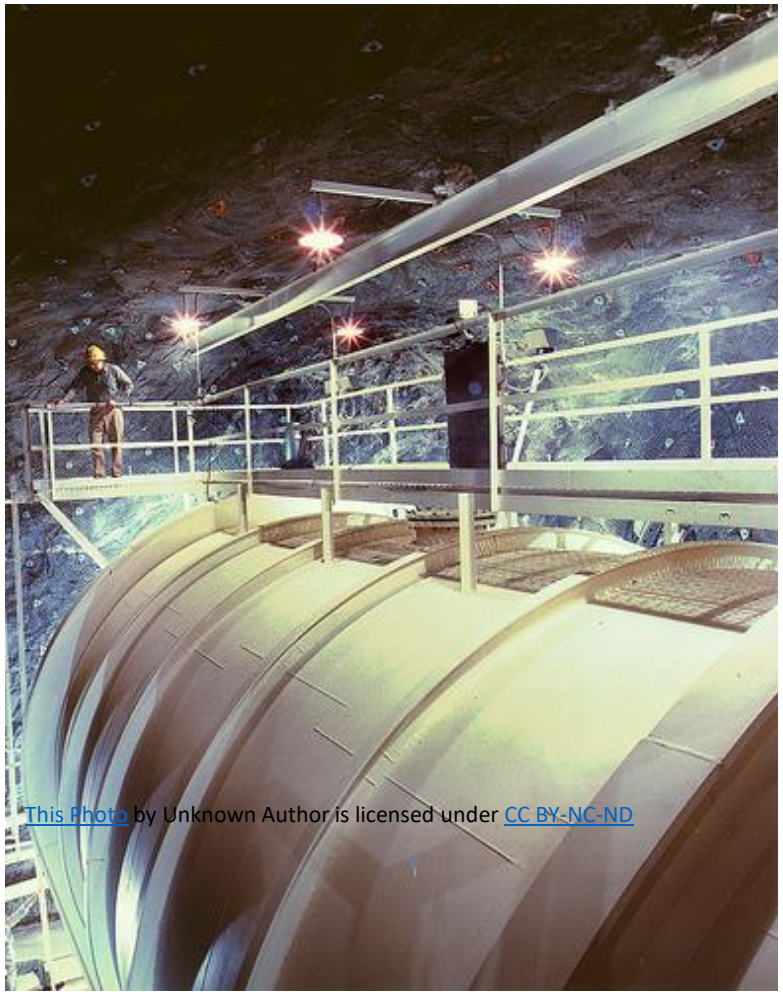
Reines and Cowan

Frederick Reines (left) and Clyde L. Cowan, Jr. with the control equipment used in their first tentative observations of the neutrino at Hanford, Washington, in 1953. Their definitive detection of the (anti) neutrino was performed at Savannah River, Georgia, three years later. (Courtesy General Electric Co.)

Fred Reines was Founding Dean of Physical Sciences at UC Irvine in 1965



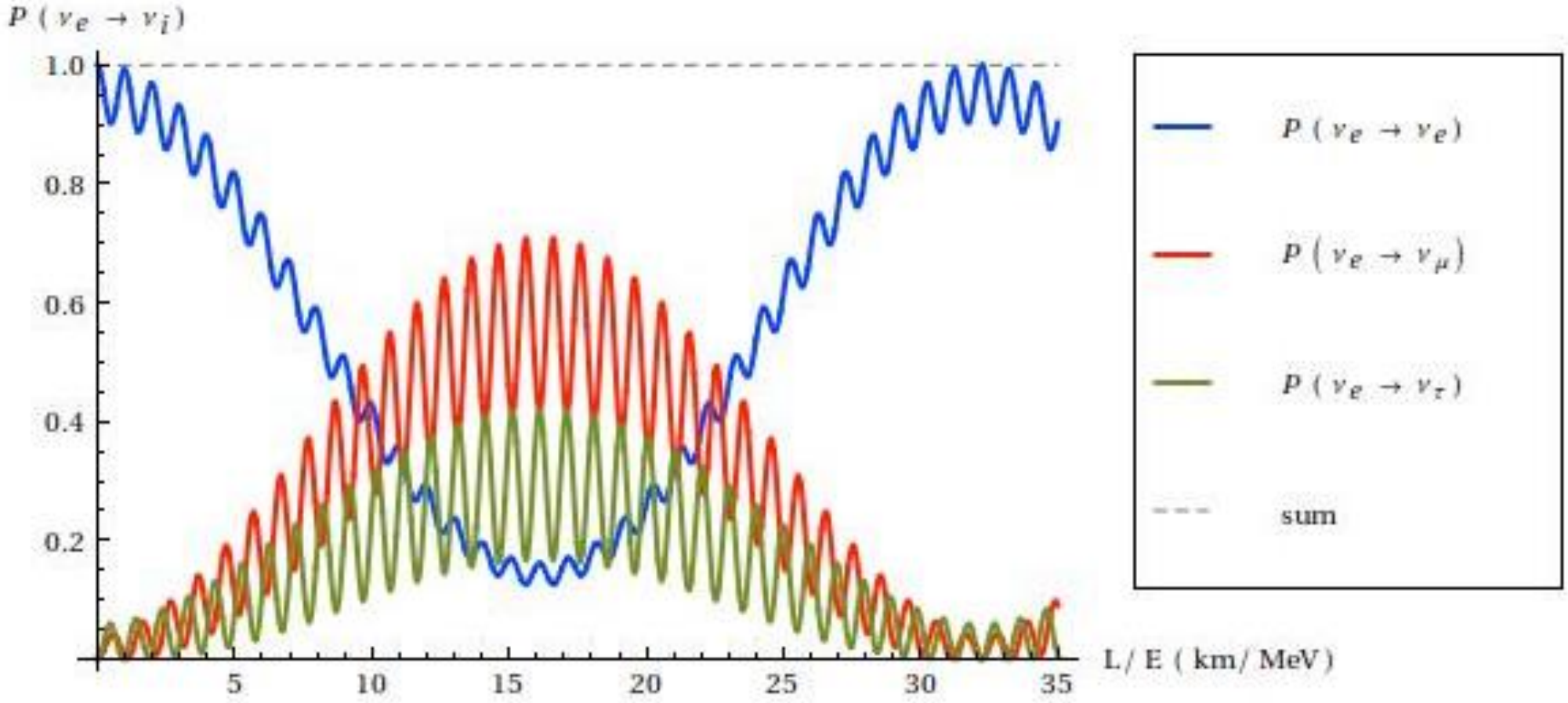
Ray Davis detects solar neutrinos with $\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$
John Bahcall did solar calculations. Only saw 1/3 of expected, due to neutrino oscillations.



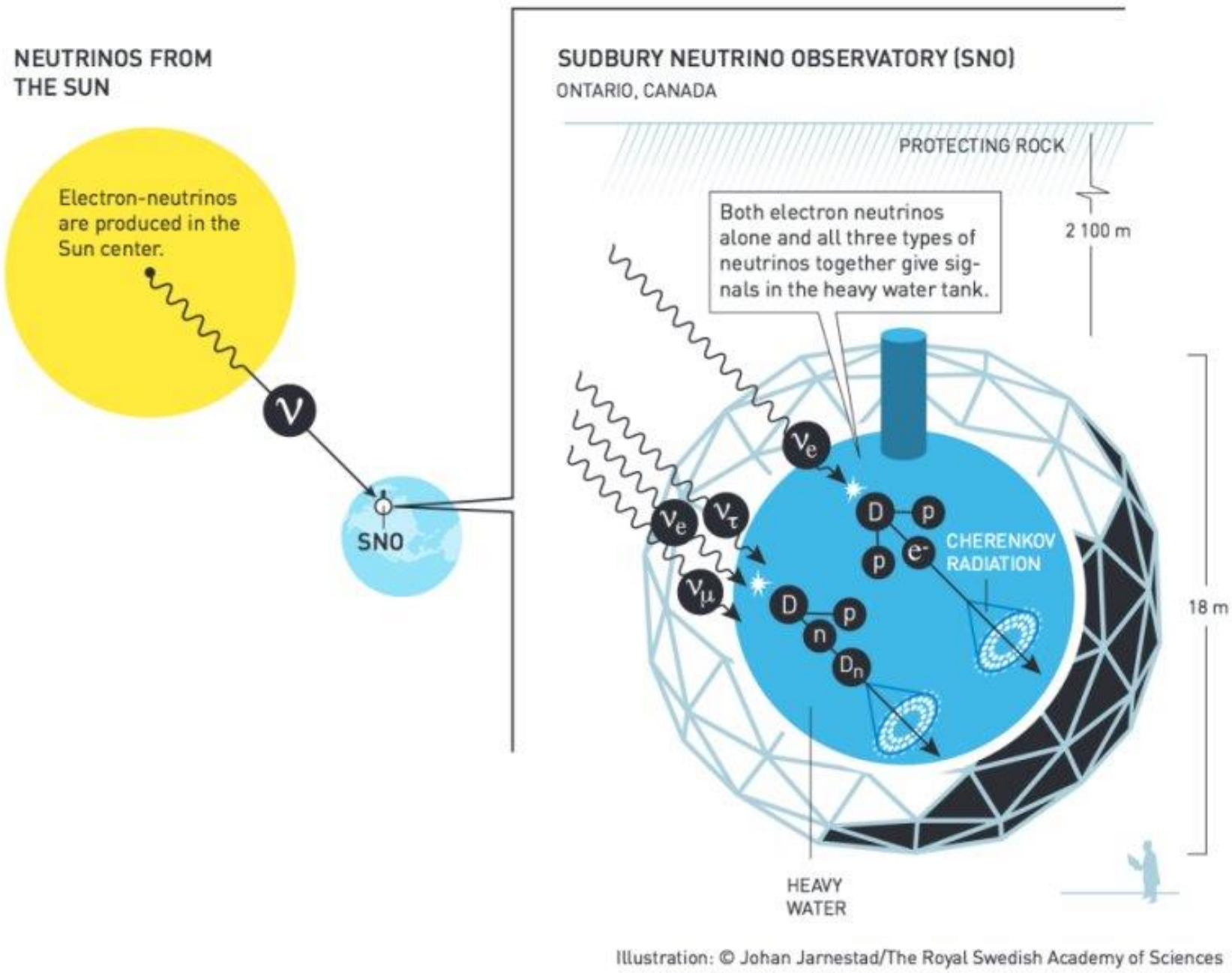
Two Other Leptons, Like the Electron, and Two Other Neutrinos

- Now have electron e, muon μ, and tau τ, all negatively charged.
- There are also their positively charged anti-particles with the same masses.
- Each one is co-produced with its own “flavor” of neutrino:
- ν_e, ν_μ, and ν_τ, or their appropriate anti-neutrinos.
- These neutrinos don’t have a definite mass, but are each mixtures of three fundamental neutrino states, each of which does have a definite mass:
- ν_1, ν_2, and, of course, ν_3. They propagate as waves as different frequencies.
- These are named in the order of their increasing, but unknown, masses.
- Their masses are less than the incredibly light 1 eV. (The electron mass is 0.5 MeV)

Oscillation of the solar ν_e (blue) to ν_μ (red), and ν_τ (green)

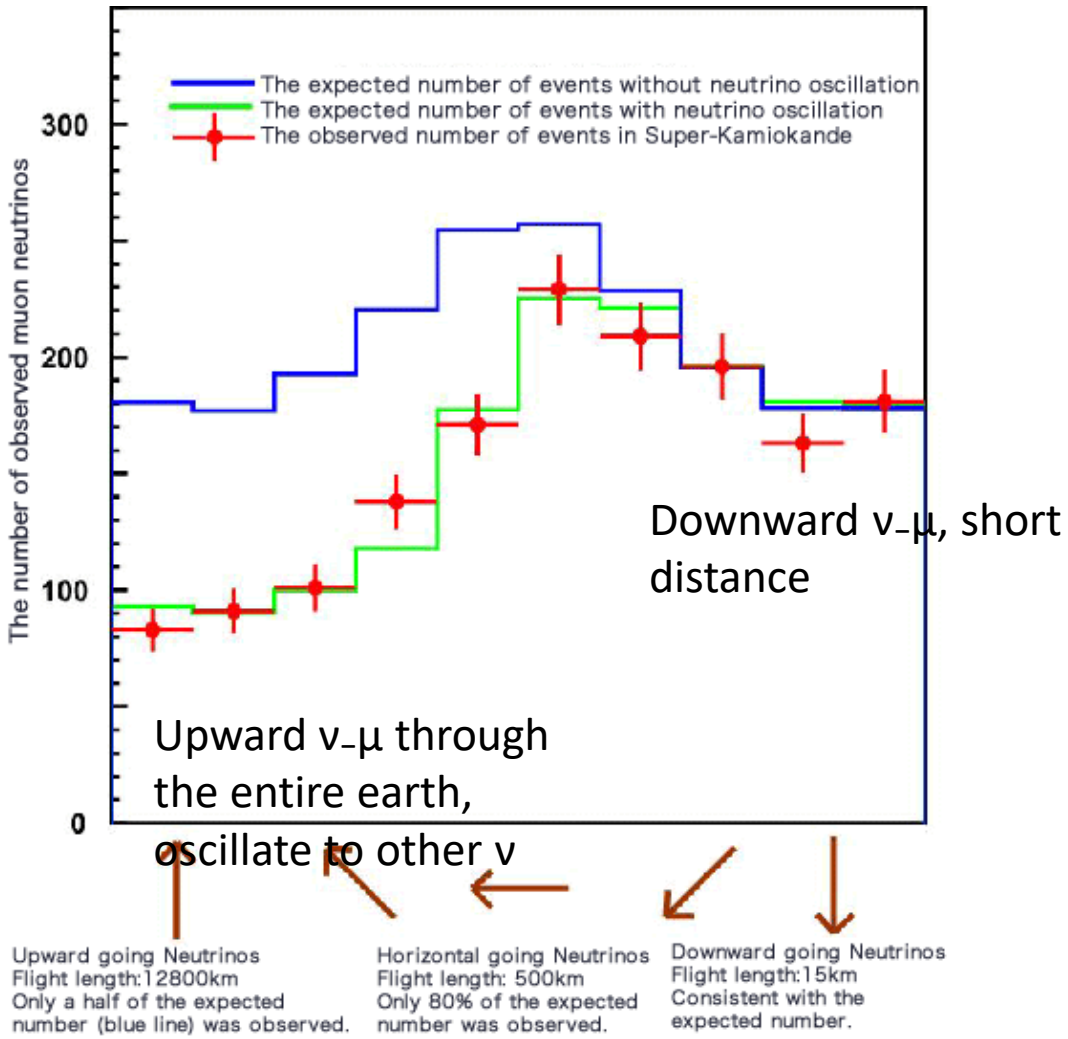


Sudbury Neutrino Observatory, SNO, counts ν_e, and then all ν's



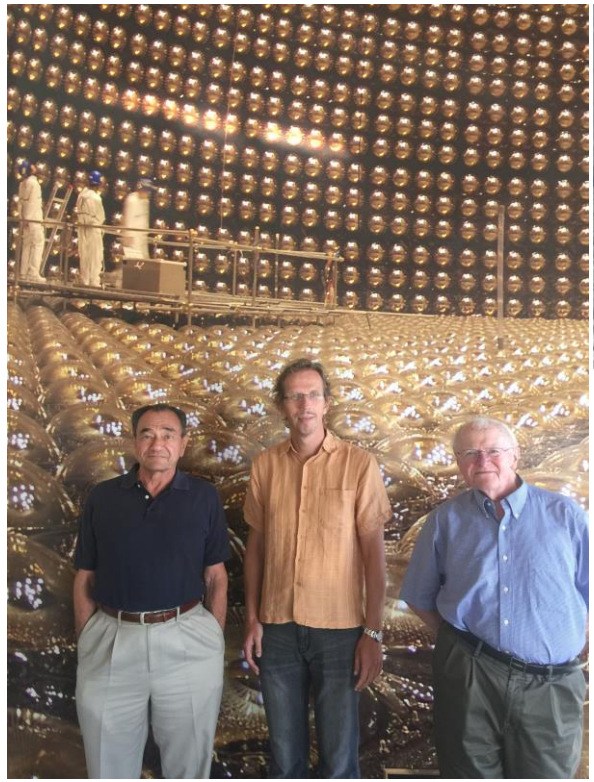
Super-Kamiokande, Oscillation of atmospheric muon neutrinos traveling through the earth

- Cosmic rays strike the atmosphere and produce positive pions
- They decay to muons and ν_μ's
- Traveling all the way through the earth, half of ν_μ's oscillate to other neutrinos

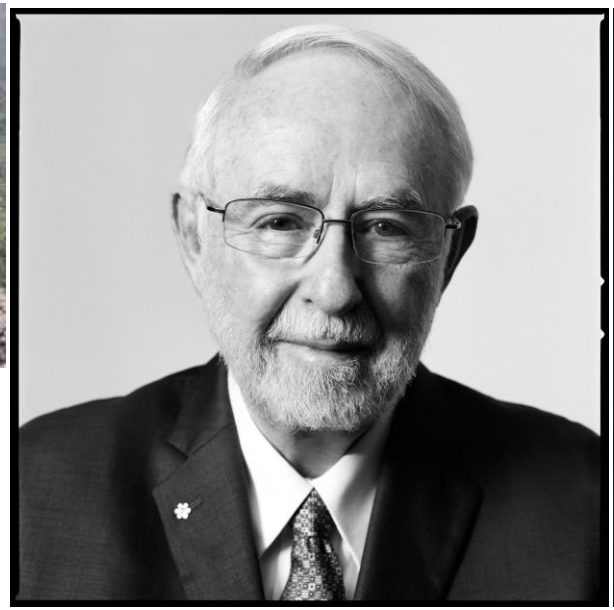


SNO lab Art McDonald and Super-K Takaaki Kajita Share 2015 Nobel Prize. Herb Chen, UCI, originator of SNO lab.

UCI Super-K Hank Sobel, Michael Smy, Bill Kropp. SNO lab originator, Herb Chen



SNO lab director Art McDonald



Super-K director Takaaki Kajita

2002 Nobel Prize in Physics

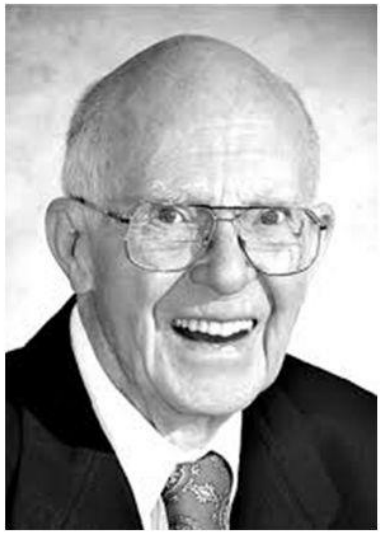
- Masatoshi Koshiba, Kamiokande
- Supernova 1987A

- Raymond Davis, Jr.
  Solar Neutrinos

Koshiba and Davis (2002)

- Nobel Prize for the detection of cosmic neutrinos

Koshiba



Davis

The 2016 Breakthrough Prize in Fundamental Physics was awarded to 5 neutrino oscillation experiments, including Super-K and SNO lab.

DUNE

- The future US high energy physics facilities are led by the neutrino oscillation experiment DUNE in 2026
- 40 kilotons of liquid Argon target
- $\nu_{-}\mu$ oscillating to ν_e
- And their anti-neutrino oscillation, to see what the differences between neutrinos and anti-neutrinos oscillations are.

DUNE: 800 Mile Oscillation Path