# INTRODUCTORY TALK AT THE 8$^{TH}$ INTERNATIONAL WORKSHOP ON "NEUTRINO TELESCOPES"


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Looking at the program, I am tempted to suggest that these workshops should be called "Neutrino Telescopes and Oscilloscopes."

It is a great pity that Bruno Pontecorvo did not live long enough to see the triumph of his conjecture that neutrinos might oscillate. I should like to use this occasion to pay a tribute to him. I first met him at a conference in Paris in 1937. He had been a member of Fermi's remarkable group in Rome and then of Joliot's group in Paris. I last saw him at Erice in 1980 where Nino Zichichi had arranged a conference to celebrate a half century since Pauli's suggestion of the neutrino. Pontecorvo had still his youthful enthusiasm. A while ago Professor S.M. Bilenky and colleagues have edited a notable collection of his papers. Pontecorvo was a physicist, who, when he could not use his hands, used his mind — a good example today for those physicists who are frustrated by the lack of accelerators!

The study of neutrino oscillations is a vast field of research, experimental and theoretical, which gives the impression that nearly everything has at some time been said, as well as its opposite. It is a field where there is no last word, only the latest word, and that word is usually "preliminary". Experiments and theory are pursued in many places, a popular one being Monte Carlo!

I came to the study of atmospheric neutrinos originally because of my interest in proton decay, starting in 1954, when we did the first experiment with Reines and Cowan who had built a large scintillation counter to study atmospheric neutrinos.

I shall confine myself to some general remarks on the present status of neutrino oscillations, since many experiments will be reported later in detail at this workshop.

Neutrinos have been studied from three natural and two man-made sources of neutrinos:

*1)* Solar Neutrinos,

*2)* Atmospheric Neutrinos and

*3)* Supernova Neutrinos.

The man-made sources of neutrinos are:

*1)* Reactors and

*2)* Accelerators.

To study neutrino oscillations the following requirements are desirable:

*1)* Knowledge of the energy-intensity distribution of the neutrino source,

*2)* Knowledge of the neutrino paths and the neutrino interactions when they traverse interposed matter,

*3)* Knowledge of the detector characteristics,

*4)* Knowledge of the background.

We also must aim at reproducibility and good statistics. Few experiments can be said to fulfill all these requirements satisfactorily.

Two experimental searches have yielded neutrino deficiencies, compared with expectations: solar $\nu_e$'s and atmospheric $\nu_\mu$'s.

These deficiencies have been explained by postulating $\nu$ oscillations, where neutrinos change flavor, and where for the new neutrino flavor there is too high a threshold to produce a charged lepton. The knowledge of the expected solar neutrino flux suffered at the beginning from a lack of reliable values for the important nuclear cross sections. Atmospheric neutrino intensities, however, could be calculated with reasonable accuracy and the variation of intensities could be measured for different path lengths through the Earth, thus giving convincing evidence of neutrino oscillations.

## 1. Neutrino masses

Oscillations prove neutrino masses are finite. There are two schools of thought: Some believe that the anomalous excess at the end of the $^3H\beta$ spectrum implies a $\nu_e$ mass of a few eV. Others ignore this observation as incompletely understood and believe that all $\nu$ masses are near zero. I discuss this further later.

Two kinds of theoretical approaches follow from these two different beliefs. Both kinds of theories go beyond the standard model in attempts to explain neutrino masses and their mixing.

*1)* The neutrino masses can be described by the so-called "see-saw" mechanism which puts them all near zero.

*2)* The neutrino masses start out degenerate at a few eV, leading to a fine-structure due to the influence of various interactions. Within the standard model some contribution to the fine-structure arises from differences in interactions of $\nu_e, \nu_\mu, \nu_\tau$ with the different charged leptons.

## 2. Problems for the next millenium

- The mass of $\nu_e$: $^3H$: $\beta$ end point anomaly. G.J. Stephenson, Jr. and T. Goldman (Phys. Lett. B 440 (1998) 89) tentatively explain the $^3H\beta$ end point anomaly as due to the presence of a small amount of a right-handed or scalar $\beta$-interaction, compatible with existing bounds on such interactions. This leads through interference with the left-handed $\beta$-interaction at the end point, where the neutrino has a kinetic energy comparable or less than its rest mass, to the anomalous increase in intensity, compatible with a neutrino mass of a few eV.

  $^{187}Re$: The end point of this first forbidden transition (Emax = 2.6 KeV, $T_{\frac{1}{2}} = 4 \times 10^{10}$ yr.) is being studied by a cryogenic method.

  If neutrinos from a supernova $< 10^4$ light years away should be discovered, an $\bar{m}_\nu$ down to $\sim$ 2eV may be measurable because of better statistics than were obtainable from SN1987A.

- Dirac or Majorana neutrinos? Finding neutrino-less $\beta\beta$ decay might be the only sure way to decide in favor of Majorana neutrinos. A negative experiment is not easily interpreted.

- Search for CP violation for neutrino mixing, e.g. by measuring the ratio $\nu_\mu \rightarrow \nu_e / \bar{\nu}_\mu \rightarrow \bar{\nu}_e$.

- Appearance experiments, e.g. $\nu_\mu \rightarrow \nu_\tau$.

## 3. Summary of Neutrino Properties (Some sure, some conjectured)

- There are only three light-weight neutrinos: $\nu_e, \nu_\mu, \nu_\tau$.

- All three are born left-handed in weak interactions, confirming universality.

- The neutrinos have finite masses: $m_1, m_2, m_3$, often assumed to be in the same hierarchical order as the $e, \mu, \tau$ masses.

- The neutrinos can mix with each other, characterized by a mixing angle $\theta$ and a $\Delta m^2$, leading to neutrino oscillations which cause flavor changes.

- $\Delta m^2$ is known for atmospheric neutrinos, but for solar neutrinos there is not yet a generally agreed solution. Together with a limit obtained for reactor neutrinos (the Chooz experiment) the $\Delta m^2$ for electron neutrinos can only be delimited at present:

  $10^{-10} eV^2 <\mid m_2^2 - m_1^2 \mid < 10^{-3} eV^2$,

  $\mid m_3^2 - m_2^2 \mid \approx 3.5 \times 10^{-3} eV^2$ and

  $m_1, m_2, m_3 < 3.5 eV$.

- If bi-maximally mixed, the neutrino changes are after phase-averaging:

| (For order of Earth radius and GeV energies) | (For order of Sun-Earth distance and MeV energies) |
|---|---|
| $\nu_e \to \nu_e$ | $\nu_e \to \frac{1}{2}\nu_e + \frac{1}{4}\nu_\mu + \frac{1}{4}\nu_\tau$ |
| $\nu_\mu \to \frac{1}{2}\nu_\mu + \frac{1}{2}\nu_\tau$ | $\nu_\mu \to \frac{1}{4}\nu_e + \frac{3}{8}\nu_\mu + \frac{3}{8}\nu_\tau$ |
| $\nu_\tau \to \frac{1}{2}\nu_\mu + \frac{1}{2}\nu_\tau$ | $\nu_\tau \to \frac{1}{4}\nu_e + \frac{3}{8}\nu_\mu + \frac{3}{8}\nu_\tau$ |

Thus, when emitted from a supernova, the three neutrino species will not be distinguishable by their arrival time.

This manuscript has been authored under Contract
No. DE-AC02-98CH10886 with the U.S. Department of Energy.