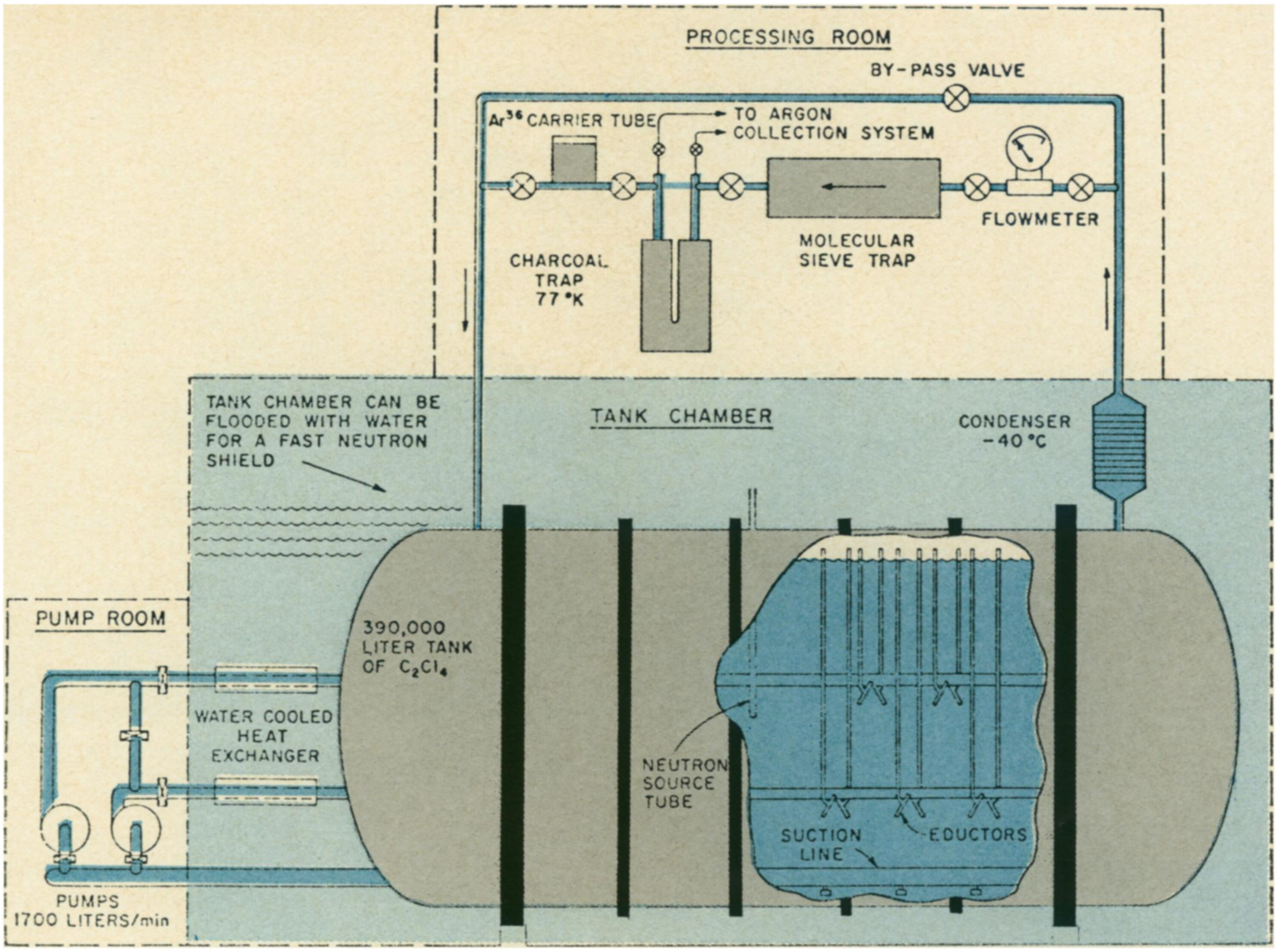


Brookhaven National Laboratory

Schematic arrangement of the cleaning fluid tank and other equipment for detecting solar neutrinos.

ASTRONOMY

Tracking the neutrino

Five years and one lone, negative result haven't dismayed astronomers in search of next to nothing

by Ann Ewing

Contemporary astronomy is ordinarily at least as much of an observational as a theoretical science. Sooner or later, on the basis of observation and analysis, what astronomers detect finds its way into theory or theory is modified to accept it.

Neutrino astronomy doesn't fit this pattern.

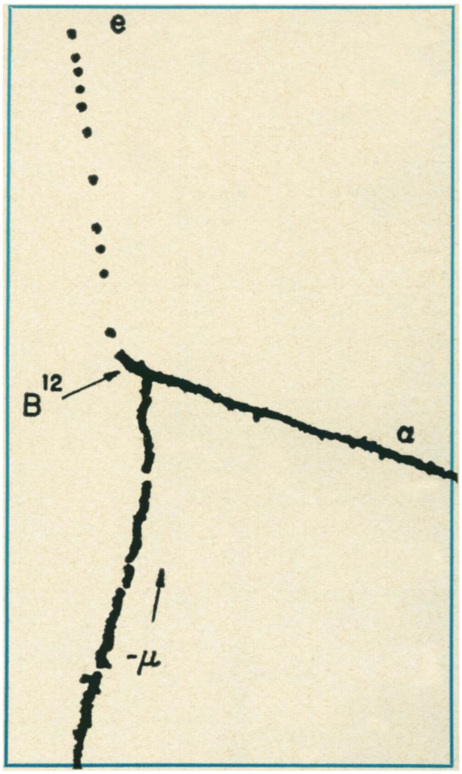
Its highly developed body of theory grew for 30 years without any possibility of verification. And despite the construction, finally, of a string of elaborate observatories, some buried in the earth from southern India to Utah to South Africa, the last five years as well have produced not a single, validated observation of an extraterrestrial neutrino.

It is a testament to the persistence of the neutrino astronomers and to the strength of their theoretical base that their intensive search for these ghost particles still goes on.

The neutrino is a particle with a vanishingly small mass and no charge. Having no charge, it does not interact with the fields around which most particle detection experiments are built; it can be detected only inferentially, by identification of the debris left following its rare interaction with matter.

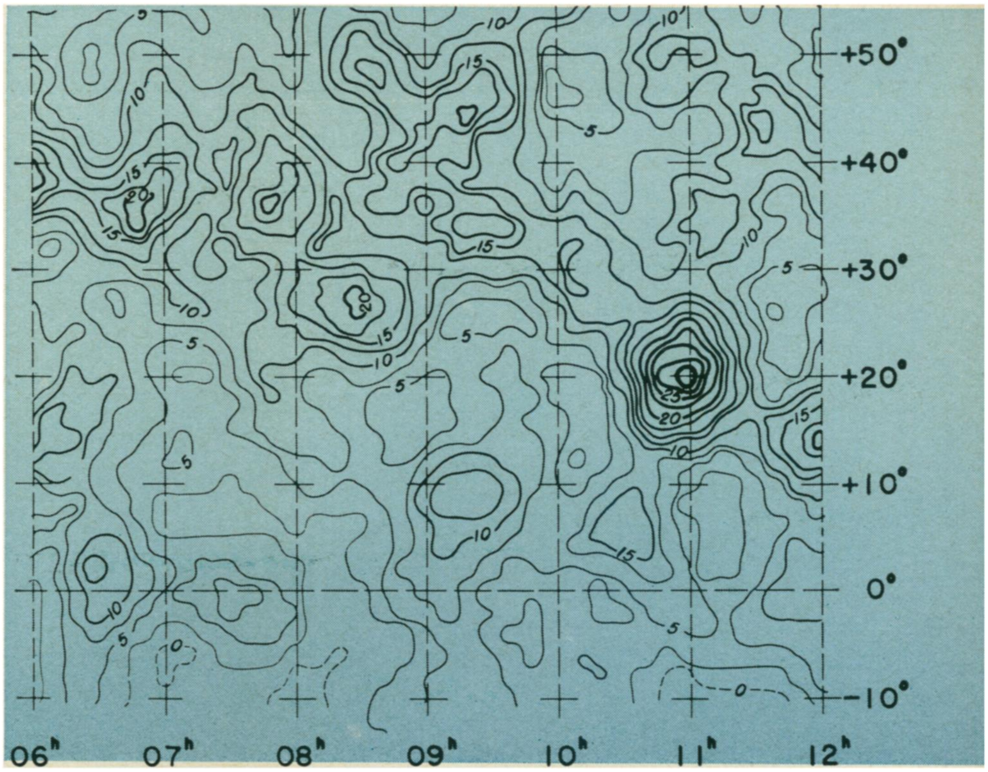
Even such indirect observations need elaborate and highly sensitive equipment, which didn't begin to go into place until about five years ago. But the goal is worth the effort: Once detected, extraterrestrial neutrinos will provide solid, first-hand information on the sources and conditions that spawned them.

Scientists are sure of this because of the sophistication of experiments on neutrino reactions in particle accelerators and other earth-bound apparatus.



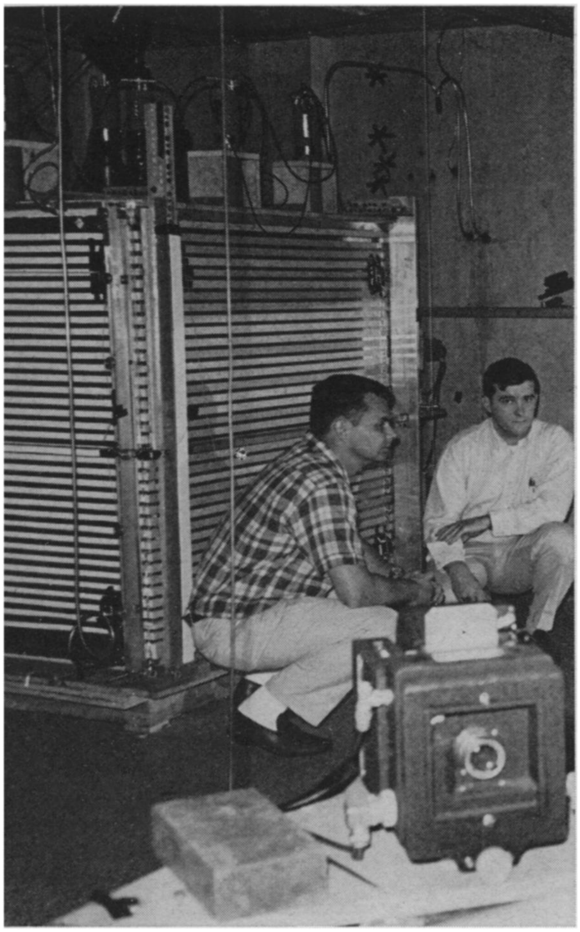
W. F. Fry

Accelerator detection of a neutrino.



Catholic University of America

Sources of neutral cosmic rays that may be related to neutrinos.



Catholic University of America

Equipment for a neutrino hunt.

These experiments have been refined rigorously over the years, and neutrino theory based on them is an integral part of modern physics.

The existence of neutrinos was first postulated by Wolfgang Pauli in the early 1930's, in order to explain a form of radioactive decay in which a beta particle—an electron—is emitted. Certain quantities that physicists insist should be the same after an interaction as before — momentum, energy and angular momentum — could only be conserved if another particle of zero charge and negligible mass were emitted.

The 1953 reactor neutrino detection experiments of Dr. Clyde L. Cowan, now at Catholic University in Washington, D. C., and Dr. Frederick Reines, now at the University of California at Irvine, demonstrated the validity of the conservation laws, even at the smallest dimensions known, about 10^{-45} square centimeters.

When a neutron decays, it gives a proton, electron and antineutrino. This reaction can be inverted by bombarding protons with antineutrinos, causing them to emit a positron and become neutrons. This was the reaction confirmed in 1956 by Drs. Reines and Cowan, using radioactive beta decays in the Savannah River nuclear reactor as an antineutrino source.

The existence of both neutrinos and antineutrinos had then been confirmed. However, experiments in 1962 at Brookhaven National Laboratory demonstrated that there were two species of neutrino—one, the electron neutrino, the other, the muon neutrino.

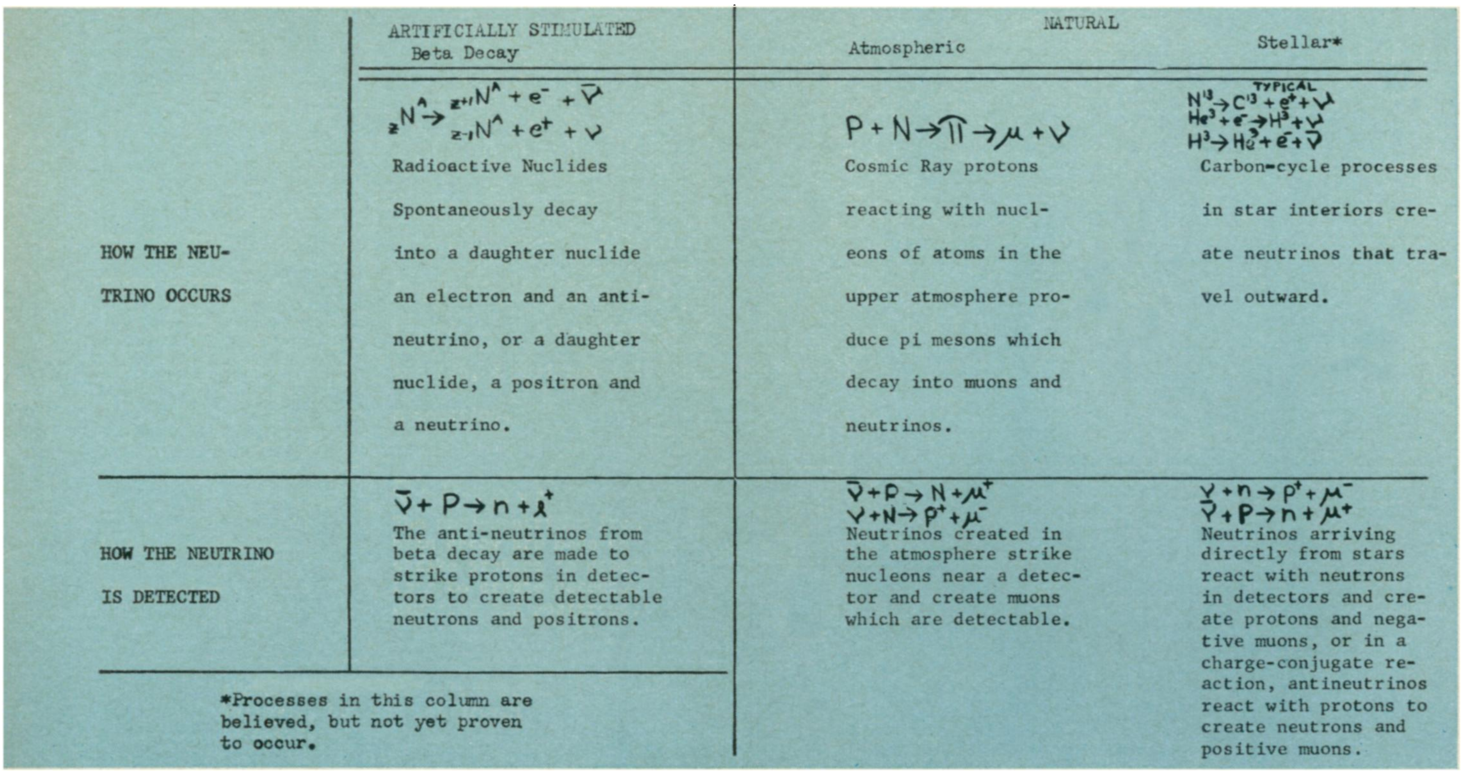
The Brookhaven experiment showed that the neutrino arising in meson decay is different from the neutrino formed in beta decay. Each species has its own antiparticle, so four neutrinos are now known.

For most purposes the characteristics of the four are sufficiently similar that the generic term neutrino is used unless there is reason to specify the different form.

The energy-producing processes in the sun and other stars yield nuclei that undergo beta decay to emit neutrinos. However, when very high temperatures are reached in stellar interiors, neutrino-antineutrino pairs can be emitted. Both types of neutrinos are of the electron variety.

High energy particles are also produced in nonthermal processes, such as occur in supernovas and galactic explosions. These react to form mesons, and the neutrinos emitted in the meson decay are the muon species.

Scientists do not agree concerning the conception date for neutrino astronomy. Some date it back to the 1930's when physicists realized for the first time that neutrinos could be produced in the sun. Others select the early 1950's when neutrinos were first detected by



	ARTIFICIALLY STIMULATED Beta Decay	NATURAL Atmospheric	Stellar*
HOW THE NEUTRINO OCCURS	${}_Z N^A \to {}_{Z+1}N^A + e^- + \bar{\nu}$ ${}_Z N^A \to {}_{Z-1}N^A + e^+ + \nu$ Radioactive Nuclides Spontaneously decay into a daughter nuclide an electron and an antineutrino, or a daughter nuclide, a positron and a neutrino.	$P + N \to \pi \to \mu + \nu$ Cosmic Ray protons reacting with nucleons of atoms in the upper atmosphere produce pi mesons which decay into muons and neutrinos.	TYPICAL $N^{13} \to C^{13} + e^+ + \nu$ $He^3 + e^- \to H^3 + \nu$ $H^3 \to He^3 + e^- + \bar{\nu}$ Carbon-cycle processes in star interiors create neutrinos that travel outward.
HOW THE NEUTRINO IS DETECTED	$\bar{\nu} + P \to n + \lambda^+$ The anti-neutrinos from beta decay are made to strike protons in detectors to create detectable neutrons and positrons.	$\bar{\nu} + P \to N + \mu^+$ $\nu + N \to P^+ + \mu^-$ Neutrinos created in the atmosphere strike nucleons near a detector and create muons which are detectable.	$\nu + n \to P^+ + \mu^-$ $\bar{\nu} + P \to n + \mu^+$ Neutrinos arriving directly from stars react with neutrons in detectors and create protons and negative muons, or in a charge-conjugate reaction, antineutrinos react with protons to create neutrons and positive muons.

*Processes in this column are believed, but not yet proven to occur.

Dr. Clyde L. Cowan

Chart showing possible sources and methods of detecting neutrinos, both on earth and extraterrestrial.

direct experiment in reactors. Still others date the beginning of neutrino astronomy to the advent of neutrino telescopes five or so years ago. Some believe it is just now entering the last phase of a long gestation period.

Whatever the beginning date, there is only one observational result so far, and it is negative.

That non-event was the failure to detect neutrinos in 100,000 gallons of cleaning fluid (tetrachloroethylene) buried deep in an old gold mine in South Dakota. The aim was to trap solar neutrinos and read the tracks of their reaction products in the fluid. The failure to do so has caused scientists to reevaluate their ideas about how the sun generates its power (SN: 5/4, p. 429).

Despite the problems in detecting them, neutrinos are numerous and ubiquitous. Those from the sun alone—the earth's major source by far — may amount to 60 billion a second for each centimeter of earth's cross-sectional area. There are also neutrinos from more distant stars, as well as from radioactive materials in earth's crust, nuclear reactors and accelerators.

Neutrino astronomy has one very great advantage over the usual methods of astrophysics or cosmic ray astronomy: The particles come directly from their source at the speed of light. The ones studied in their rare reactions with earthly matter are the particles themselves as they are upon formation. They thus furnish direct evidence of conditions at their source.

There are, however, disadvantages. Only a small fraction of the energy emitted by stars is in the form of neutrinos, and their extremely weak interaction with matter makes them extremely difficult to detect.

Efforts to pick them up from nonearthly sources, besides the cleaning fluid tank experiment still in progress, include:

- Detection by Dr. Cowan and his group at Catholic University of many mu mesons produced by an uncharged component of cosmic rays. They are now upgrading their equipment in an effort to determine if the uncharged particles causing the events they record may be related to neutrinos.
- A search for high energy neutrinos in a gold mine more than 10,000 feet deep in South Africa by a group including Dr. Reines and scientists from the University of Witwatersrand. Although they have found several events, the source is cosmic rays reacting in the atmosphere.
- Another group from Tata Institute in Bombay, England's Durham University and Japan's Osaka University with a somewhat similar experiment in a gold mine at Kolar in the state of Mysore in South India. Although possible neutrino events have been observed, their source is likewise probably atmospheric cosmic rays.
- Still another group using an old silver mine near the University of Utah. Although so far it, too, has no definite record of neutrino events, there is some evidence indicating that a new particle, possibly the intermediate boson or W particle, might be the source of the tracks recorded (SN: 5/4, p. 424).

In addition to solar neutrinos, theory holds there is a general flux of low energy neutrinos in the universe, resulting from a star's release of a small percentage of its energy in this form. As a star becomes hotter and hotter, the neutrino process becomes the major means for carrying the increasing energy away from the star.

In the very hottest stars, those reaching the end of their evolutionary track, most of the energy could be lost through neutrino emission in a very short time. The neutrino luminosity then becomes exceedingly high.

Although the neutrino flux from a supernova would be huge, the chance of detecting it is quite remote, unless such an explosion occurred within the Milky Way galaxy. Then the equipment being used to search for solar neutrinos is believed sufficiently sensitive to detect the supernova's neutrino flux.

The definite detection of non-terrestrial neutrinos, whether from the sun or from beyond the solar system, will yield a far deeper understanding of stellar interiors and, therefore, of how today's universe came to be.