Physics monitor

NEUTRINOS
Moriond spotlight

The regular 'Rencontres de Moriond' meetings in the French Alps, which celebrate their 25th anniversary this year, have a strong tradition of reflecting new trends in physics thinking and January's session on 'Tests of Fundamental Laws in Physics' was no exception. The spotlight this time fell on the neutrino sector, a branch of physics frequently in evolution, if not controversial. Currently the solar neutrino problem is still a preoccupation, while a wave of new heavy neutrino results also awaits clarification.

The Moriond neutrino sessions began with a review by D.Vignaud of the status of the 'solar neutrino problem' – the discrepancy between theoretical predictions (based on solar model calculations) and the experimentally observed fluxes of neutrinos from the Sun.

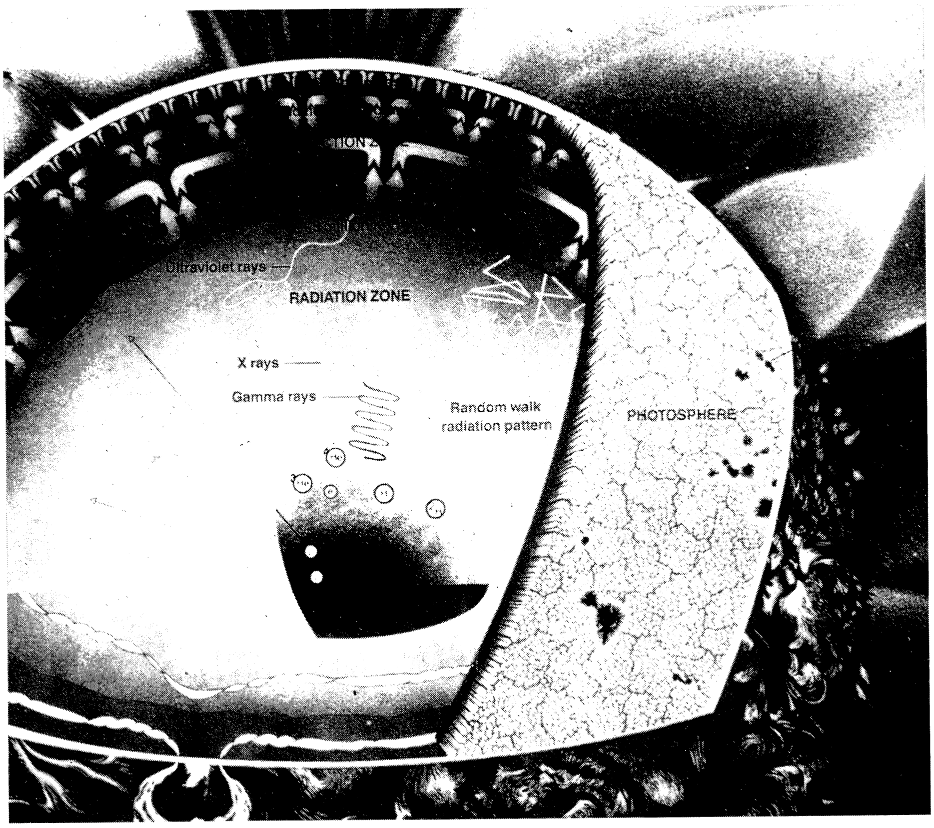
So far solar neutrinos have been detected in two experiments: the pioneer study led by Ray Davis, which began data-taking in 1970 and continues to run, and the Kamiokande II collaboration, operational in Japan since 1987.

The former uses the chlorine-37/argon-37 radiochemical method for detecting solar neutrinos, suggested in 1946 by Bruno Pontecorvo and somewhat later independently by Luis Alvarez. Neutrino capture in chlorine-37 has a threshold energy of 0.816 MeV. Davis' team uses a tank filled with 615 tons of perchloroethylene, and the observed average rate of argon-37 production over 20 years is approximately one atom every two days.

A remarkably efficient radiochemical method had to be developed to extract and detect the precious few unstable argon-37 atoms (half-life 35 days) produced by the solar neutrinos during exposures ranging typically from 35 to 60 days.

The temperature of the incandescent gas (mainly hydrogen) ball of the Sun ranges from 6000 degrees at the surface to 15 million degrees at its centre, where proton nuclei fuse together into deuterium, liberating a positron and a neutrino. Subsequently other reactions produce additional neutrinos, but most solar neutrinos emanate from the central fusion process.

Electromagnetic energy (photons) from nuclear reactions deep inside the Sun can take millions of years to migrate to the surface and escape. Neutrinos on the other hand give a unique glimpse deep into the Sun's interior, but the interpretation requires a representative sample of these elusive particles.



The Kamiokande II collaboration looks for Cherenkov radiation from neutrino interactions in a tank containing 3000 tons of water, of which only 680 tons are used for solar neutrino detection. The detector is presently capable of registering solar neutrinos above 7.5 MeV.

Both studies register neutrinos supposedly emitted in the decay of boron-8 with energies up to 14 MeV. According to current wisdom, boron-8 neutrinos are only a small fraction (one in ten thousand) of the total flux of solar neutrinos on the Earth's surface – approximately 6 x 10^{10} per sq cm per s.

The predicted value of the boron-8 neutrino flux is extremely sensitive to the temperature in the Sun's core where these neutrinos are thought to be produced.

Approximately 14 per cent of the argon-37 production rate seen by Davis' team is predicted to be due to monochromatic 0.86 MeV neutrinos produced with lithium-7 by electron capture in solar beryllium-7.

The solar-neutrino-induced event rates observed by Davis' team and Kamiokande II are typically several times smaller than predictions based on detailed solar model calculations. Estimates of the uncertainties in these calculations indicate that the discrepancy between the predicted and the observed event rates could actually be smaller.

It was suggested in 1982 by

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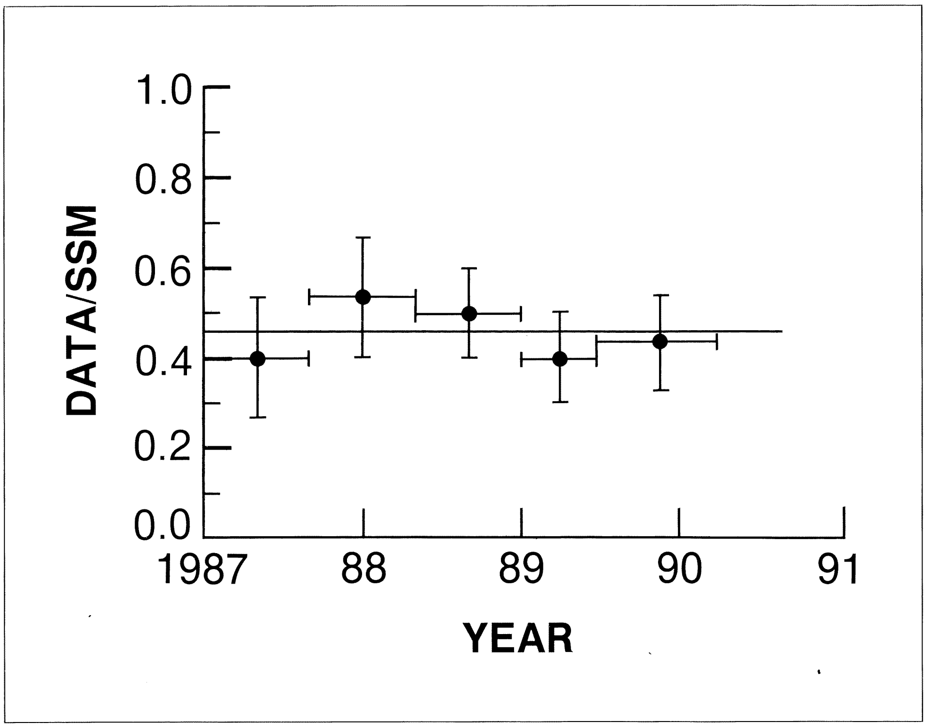
The solar neutrino flux (compared with the predictions of the Standard Solar Model – SSM) as seen by the Kamiokande II detector in Japan shows no appreciable time variation. Some hypotheses call for the solar neutrino signal to be linked with the sunspot cycle.



G.A. Bazilevskaya et al. that the solar neutrino flux detected by Davis' team varies in time, being (anti)correlated with the solar activity. A measure of the Sun's activity is the number of sunspots on its surface, in turn related to the strength of the toroidal component of the solar magnetic field. The latter is known to vary over a 11-year half-cycle, the last two maxima of the sunspot number having been in 1979-1980 and in 1989-1990.

D. Vignaud presented the results of four independent statistical analyses of data from Davis' team, all reporting evidence for (anti)correlation, although at very different levels of statistical significance.

The results of the Kamiokande II collaboration on possible variation of the solar neutrino flux from 1987-1990, presented by Y. Suzuki, show no time variations.

Solar neutrino studies have been boosted recently by the arrival of two new detectors – SAGE (Soviet-American Gallium Experiment in the Baksan Neutrino Observatory – June 1990, page 16) and Gallex (built by a collaboration of scientists from France, Germany, Israel, Italy and the US and installed in the Italian Gran Sasso Laboratory, January/February, page 10).

Rather than looking at a remote fringe of the solar neutrino spectrum, the major aim of these two experiments is to detect the major portion of the solar neutrinos – those accompanying proton fusion into deuterium, with a maximal energy of 0.42 MeV. This fusion is the first of a series of reactions eventually producing helium-4 and providing more than 98 per cent of the Sun's energy.

Measurements of this part of the solar neutrino flux would test basic ideas about the processes taking place in the initial stage of stellar evolution. Since these neutrinos come from a reaction which plays a fundamental role in the solar energy balance, their flux can be calculated more accurately than that of boron-8 neutrinos.

The theoretically predicted gallium-71/germanium-71 conversion rate in SAGE and Gallex due to solar neutrinos is approximately one atom per day, requiring the perfection of very efficient techniques to extract and detect the few germanium-71 atoms produced in the 30 ton detectors during typical exposures of 20-30 days.

Results from the first five physics runs of the SAGE collaboration, which took place between January and July last year, were presented at the Workshop by V. Gavrin. The observed rate of germanium-71 formation was found to be slightly above that expected due to background processes, with an upper limit of 74 SNU (each Solar Neutrino Unit – SNU – represents 10^{-36} solar neutrino captures per second per atom of target), smaller than the theoretically predicted rate of 132 SNU. (The contributions due to proton fusion, beryllium-7 and boron-8 neutrinos in the calculated rate are 71, 34 and 14 SNU, respectively.)

A crucial step in the interpretation of these results will be measurements of germanium-71 produced by neutrinos from a calibrated source.

A status report of the Gallex experiment was given by D. Vignaud. Here data-taking is not possible for the time being because of contamination of the detector by an unexpectedly large amount of radioactive germanium-68. This isotope was probably produced when the gallium-71 source material for the detector was stored for a certain time prior to installation underground without being protected from cosmic rays. This problem is being attacked.

The solar neutrino results of the Davis, Kamiokande II and SAGE experiments could have important implications for particle physics, signalling unconventional neutrino properties (like nonzero mass and mixing and/or a significant magnetic moment). The latter could imply partial conversion (due to vacuum or matter-enhanced oscillations and/or spin-flavour precession) of solar electron-type neutrinos into neutrinos of a different kind, undetectable by the current experiments, the transitions occurring during the solar neutrinos' journey from the central region of the Sun to the Earth's surface.

Hopefully new results from SAGE and Gallex over the next four years will help identify the cause of the solar neutrino problem, now more than fifteen years old.

With the Japanese Government's December approval for the improved 'Super-Kamiokande' detector (see page 9, reviewed at Moriond by Y. Suzuki), there are three more solar neutrino experiments in preparation (the other two being the Sudbury heavy water experiment in Canada – January/February 1990, page 23, and the Baksan chlorine-37 experiment, five times bigger than Davis').

All three are expected to accumulate much higher statistics than their predecessors. Although sensitive only to boron-8 and beryllium-7 neutrinos, they will be capable of measuring the total flux and spectrum of boron-8 neutrinos with high accuracy. The first results on this spectrum from Kamiokande II gave an initial glimpse of its shape.

Talks by R. Lannou, G. Zacek and R. Gaitskell on new methods of solar neutrino detection heralded the dawn of low energy threshold, high statistics, real-time detectors capable of measuring the spectrum of solar neutrinos from proton fusion.

Measurements of the overall solar neutrino spectrum and its different reaction components, which probably will not materialize before the end of the century, will reveal nuclear reactions deep inside the Sun, giving new information about solar physics.

The 17 keV neutrino (April, page 9) made a reappearance at Moriond, the first evidence (in the beta decay of tritium) having been presented by John Simpson in the January 1986 session. Subsequently, six spectrometer experiments looking for possible distortions of the beta-spectra of sulphur-35 and nickel-63 due to the emission of a 17 keV mass neutrino were performed between 1985 and 1989, all reporting negative results.

Meanwhile two additional experiments (with tritium and sulphur-35 implanted in semiconductor detectors) by Simpson and his student Andrew Hime confirmed the 17-keV sighting. Searches for a 17 keV neutrino continued by Hime and Nick Jelley at Oxford (with a sulphur-35 source), by Eric Norman's group at Berkeley (with a carbon-14 source), by a group at Zagreb (with germanium-71), all using semiconductor detectors and by a group at Caltech using a sulphur-35 source with a spectrometer.

Initial data from all these experiments were reported at the Workshop, the first three of seeing distortions in the beta spectra compatible with emission of a 17 keV neutrino, while the Caltech-based group gives a negative result.

With the electron coupled to a 17 keV neutrino as well as a massless (or lighter than 10 eV) neutrino, a new scenario is called for. In the neutrino mass and mixing hypothesis the electron-, muon- and tau-type neutrinos do not have definite masses, but rather are superpositions of at least three neutrino states of definite mass, at least some of which are nonzero.

The standard electroweak theory has only massless neutrinos, so that observation of a 17 keV neutrino could be the first evidence for the incompleteness of this theory.

Nonzero neutrino masses and mixing imply a remarkably rich spectrum of possible neutrino properties, a whole 'new world' of elementary particle physics. In particular, the electrically neutral massive neutrinos can be Dirac-type (having distinct antiparticles) or Majorana-type particles (coinciding with their own antiparticles), the type being determined by the symmetries of the underlying theory.

Dirac neutrinos can have intrinsic characteristics like magnetic and electric dipole moments which are zero for the Majorana neutrinos. Phenomenological considerations indicate that the 17 keV neutrino should be a Dirac particle if there are only three massive neutrinos and the neutrino oscillations are the cause for the solar neutrino problem. It can be a Majorana particle if, for instance, there are more than three neutrinos with definite mass. In this case at least one more 'heavy' Majorana neutrino should exist.

A 17 keV neutrino cannot be stable: cosmological arguments suggest that it should decay sufficiently fast into, e.g., three light neutrinos, or a light particle and neutrino. It should also show up in oscillation experiments with electron neutrino (and antineutrino) beams, leading to effects (for example the 'appearance' of tau neutrinos) of the order of one or two percent.

*** The June issue will include an article on the COBE results.**

Also reported at the Workshop were new results from cosmic ray studies; searches for dark matter, deviations from Newtonian gravitation, time-reversal violation in beta decay, the electric dipole moment of the neutron, and neutron-antineutron oscillations; strong field tests of gravitational theories and other subjects.

For the first time the session had an interdisciplinary character, with an invited lecture by Ed Fredkin on 'Digital Mechanics: the Universe as a Computer'. The improvised evening concert of classical music, given by attending physicists Michael and Myriam Treichel, Jim Faller, Elisabeth Ribs and Tibault Damour added to the pleasant informal atmosphere which is one of the elements of Moriond success.

By S.T. Petcov

ASTROPARTICLE PHYSICS
New synergy

Two major recent experimental results have further strengthened the links between particle physics and cosmology. These are the confirmation by experiments at CERN's LEP electron-positron collider that there are only three species of light neutrino, as predicted by Grand Unified Theories and needed for primordial nucleosynthesis, and the results from the US Cosmic Background Explorer (COBE) satellite that show beyond any doubt that the cosmic background radiation is primordial.*

With this in mind, a new international school was initiated recently by Houston's Advanced Research Center (HARC) and co-sponsored by the nearby Superconducting Supercollider Laboratory. It attracted many distinguished speakers in this rapidly evolving field, resulting in a wide-ranging and stimulating scientific programme.

CERN's John Ellis discussed the Standard Model of Particle Physics and beyond, and the implications of recent LEP data (April, page 1). Rocky Kolb of Fermilab gave an introduction to the Standard Big Bang, while School Director Dimitri Nanopoulos of Texas A&M and HARC presented a unified view of the two fields.

David Schramm of Chicago discussed the important issue of primordial nucleosynthesis, with the observational basis covered by Greg Shields of Texas (Austin). Robert Wagoner of Stanford examined probes of the Universe at all scales, from nuclei to supernovae. Andre Linde, now at Stanford, looked back to the very early stages of the Universe, including the inflation mechanism linking the initial Big Bang to present large-scale structure.

Mark Srednicki of Santa Barbara reviewed the need for Dark Matter, leaving his colleague David Caldwell to look at experimental searches for it. George Smoot of Berkeley discussed the beautiful COBE results confirming the nature of the cosmic background radiation, while Alan Dressler of Mt. Wilson and Las Campanas Observatories reviewed the intriguing large-scale structures, including the great attractor, the great wall and similar concentrations of matter, revealed by recent astronomical surveys. Nicola Vittorio of D'Aquila and Joe Silk of Berkeley tried to make sense of it all.

Neutrinos are never far from the physics headlines – currently solar neutrino observations are in a state of flux and there is a spate of reports on 17 keV neutrinos (see page 21). John Bahcall of Princeton was among the neutrino speakers at the Texas meeting.

Dimitri Nanopoulos – strengthening links between particle physics and cosmology

The status of Big Science was illustrated in talks on the US Superconducting Supercollider (SSC) from Fred Gilman, SSC's Associate Director of Physics Research; on NASA's role from Venon Jones; on the European Space Agency's work from Giacomo Cavallo; and on Hubble telescope from Peter Stockman of the Space Telescope Science Institute.

The meeting showed that while the 'Standard Models' of both particle physics and cosmology were doing fine, some refinements are necessary, especially for the Big Bang picture, at a loss to explain new large-scale structure. New simulations show that even cold dark matter, until now the best candidate for the missing material of the Universe, may not fit the bill. New observations over the next few years will help to clarify many of the major issues in both particle physics and cosmology. Hopefully a clearer picture will emerge before the second school in this series.

From Dimitri Nanopoulos