MEASUREMENT OF SOLAR NEUTRINOS IN KAMIOKANDE-II

Final Report
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Final Report on Grant DE-FGO2-89ER40496
Measurement of Solar Neutrinos in Kamiokande II

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Abstract

Work performed under this grant has resulted in the first direct observation of neutrinos produced by nuclear fusion reactions in the core of the sun. The quantitative results not only are the first direct confirmation that nuclear fusion is the source of solar power, but also place strong constraints on the properties of the neutrinos. During the course of the work, neutrinos from supernova SN1987a were observed. The observation of this signal confirms an important hypothesis of nuclear astrophysics, that gravitational collapse of the core of a massive star which has used up its nuclear fuel produces such a dense state of nuclear matter that neutrino emission is the principal mechanism for the escape of energy from the collapsed core.

Introduction

The work performed under this grant has continued under Department of Energy Grant DE-FGO2-88ER40479 at the end of the grant period. Although this latter grant is a continuing grant to support work to construct the Sudbury Neutrino Observatory, a second generation solar neutrino detector, the funding of the Kamiokande II work has continued through 1991.

Scientific Accomplishments

Detection of neutrinos emitted by the sun and a quantitative measurement of the flux of those neutrinos determines directly the rate at which the fundamental nuclear fusion reactions proceed in the core of the sun. Prior to work carried out under this grant, the only evidence that the sun emitted neutrinos came from the indirect radio-chemical measurements of the rate at which ^{37}Cl transformed to ^{37}Ar in an experiment begun in the 1960's. The result of that measurement was an inferred flux which was a factor of three below the best estimates deduced from a theoretical model of the sun. As the nuclear cross sections and other inputs to the model became well determined the discrepancy remained, but was unconfirmed by another experiment. Further research indicated that the discrepancy might not be in the model of the sun or the input to the model, but might rest in the assumptions made about the fundamental properties of the neutrinos.

When our group at the University of Pennsylvania was approached by the University of Tokyo group which constructed the Kamiokande Nucleon Decay Detector to participate in an upgrade of that detector (funded by the High Energy Physics Division of D.O.E.), we recognized that our contribution to the upgrade might make the detector sensitive to solar neutrinos, but that there would be extra operating expenses associated with our attempt to detect these neutrinos. This grant and its successor have enabled our group to pursue this line of research, and the outcome has been successful beyond our expectations.

The first direct detection of neutrinos emitted by the sun was reported in reference 16 in the attached bibliography. That result was the first confirmation that the deficit reported by the ^{37}Cl detector was real. Our participation in the operation of the detec-

tor continued into 1990, until the time that the statistical error on the measurement was approximately equal to the systematic error. The final data set and the interpretation of these results are reported in references 19, 20, and 21. These data, together with initial results from a radio-chemical ^{71}Ga experiment which has recently begun to collect solar neutrino data may indicate that the reduced neutrino flux from the sun is associated with the intrinsic mass and mixing of the neutrinos. If true, this would be the first indication of physics beyond the standard electroweak model of elementary particles. An archival paper describing the experimental technique and data analysis was also published (reference 26).

On February 23, 1987, the first supernova visible to the naked eye since the invention of the telescope was observed from the earth. The Kamiokande II detector observed a burst of twelve neutrinos over a period of approximately ten seconds, which had an energy and angular distribution, and detection time consistent with that expected when a massive star burns all its nuclear fuel and suffers a gravitational collapse of its core. The extremely dense state of nuclear matter created by the core collapse is opaque to all particles except neutrinos, which carry off 99% of the binding energy of the remnant neutron star. The Kamiokande II observation was confirmed by the IMB collaboration, and the two observations are now part of the history of twentieth century nuclear astrophysics. The discovery paper is reference 4 in the bibliography, and the archival paper is reference 11.

Other papers related to elementary particle physics, astrophysics, and cosmic ray physics are included in the bibliography for completeness.

Operations

Funds provided by this grant were used primarily for travel to the laboratory near Kamioka, Japan, and the laboratories of our Japanese collaborators. An additional major expense was the duplication of data tapes and shipment of them to the University of Pennsylvania so that our analysis of the important data sets would be performed completely independently of our collaborators.

Graduate students W.-P. Zhang and S.-B. Kim were supported by this grant. Both stayed at Penn as post-docs working for this grant for a short time following completion

of their dissertations. Upon leaving Penn, Dr. Zhang became an employee of the Los Alamos National Laboratory, and Dr. Kim became a post-doc at the University of Michigan.

Bibliography of Kamiokande II Collaboration Publications
as of November 1991

Abbreviations:

Phys. Rev. : Physical Review

Phys. Rev. Lett. : Physical Review Letters

Phys. Lett. : Physics Letters

Nucl. Inst. Meth. : Nuclear Instruments and Methods

Nucl. Phys. : Nuclear Physics

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