BPA NEWS

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U. S. Astronomy and Astrophysics: Managing an Integrated Program

Norman R. Augustine, Lockheed-Martin Corp. (ret.)

I recently chaired a distinguished committee that was charged to look into the way that research in astronomy and astrophysics is organized in the United States. The final report, *U.S. Astronomy and Astrophysics: Managing an Integrated Program*, was published in November by the National Academy Press. This article summarizes the results of our study.

In its fiscal year 2002 budget summary document[1] the Bush administration expressed concern—based in part on the findings and conclusions of two National Research Council studies[2]—about recent trends in the federal funding of astronomy and astrophysics research. The President's budget blueprint suggested that now is the time to address these concerns and directed the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) to establish a blue ribbon panel to (1) assess the organizational effectiveness of the federal research enterprise in astronomy and astrophysics, (2) consider the pros and cons of transferring NSF's astronomy responsibilities to NASA, and (3) suggest alternative options for addressing issues in the management and organization of astronomical and astrophysical research. NASA and NSF asked the National Research Council to carry out the rapid assessment requested by the President. The NRC established the Committee on Organization and Management of Research in Astronomy and Astrophysics for that purpose. COMRAA's report, focusing on the roles of NSF and NASA, provides the results of that assessment.

Overall, the federal organizations that support work in astronomy and astrophysics manage their programs effectively. These programs have enabled dramatic scientific progress,

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In this issue:

Solar Neutrino Deficit Vanishes

R. G. Hamish Robertson, University of Washington

Wolfgang Paul put forward the idea of neutrinos as a "desper ate remedy" in 1930 to account for the apparent non-conservation of energy when neutrons decay.

In the late 1930s, Hans Bethe described how nuclear burning of hydrogen in the Sun provides its power. The first reaction in the chain is $^{1}H + ^{1}H \rightarrow ^{2}D + e^{+} + \nu$. There are numerous other reactions, several of which produce neutrinos at various energies. High energy neutrinos are produced by the beta decay of ^{8}B produced when ^{7}Be captures hydrogen.

Willy Fowler and Al Cameron first speculated around 1960 that there might be enough of these neutrinos to be observed on the earth. Neutrinos react very weakly with matter, so detecting them was a formidable challenge.

In 1964, John Bahcall and Ray Davis proposed that a 100,000-gallon container of perchloroethylene would generate enough ^{37}Ar from solar neutrino capture by ^{37}Cl to be detected. The first detections occurred in 1968. It soon became evident that the measured neutrino flux fell far short of predictions by well-verified models of the fusion process in the sun. Thus began a search lasting more than 30 years for the solution to the puzzle: What happened to the rest of the neutrinos?

Neutrinos come in three different flavors associated with the electron, the muon, and the tauon. The reactions in the standard solar model lead to the production only of electron neutrinos. A speculation, put forward by Pontecorvo in 1969, as to what happens to the neutrinos from the sun is that the electron neutrinos are transformed in flight into other flavors not detected by the chlorine experiment.

The Sudbury Neutrino Observatory, using heavy water, is able to detect electron neutrinos and other flavors as well. The Bahcall-Davis experiment only detected electron neutrinos. In the hope of resolving the mystery of the missing neutrinos, a major experiment was mounted at SNO. The experiment ran from late 1999 to early 2001.

The SNO Facility

But before describing the results of the experiment, a few words about the SNO facility. It is a neutrino detector located 2 km under ground in the INCO Creighton Mine near Sudbury, Ontario. The detector is a 12-meter diameter acrylic plastic sphere containing 1000 tonnes of

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Highlights of the Fall Board on Physics and Astronomy Meeting

THE Board recently met at the Academies' Beckman Study Center on the U.C. Irvine campus on November 3-4. The agenda featured two science talks and a policy discussion. Much of the meeting was devoted to developing a five-year outlook for the Board. And there were progress reports from several chairs of committees operating under the BPA's auspices.

In the first science talk, Hamish Robertson presented recent results from the Sudbury Neuitrino Observatory, which reestablish consistency of measurements of the solar neutrino flux with solar models. In so doing, the SNO results reveal that about two-thirds of the most energetic electron neutrinos produced in the sun change on their way to the earth into other flavors. This neutrino oscillation implies that the neutrinos have mass, which has profound implications for the standard model of particle physics. Robertson contributed an article summarizing the SNO results, which begins on page 1 of this issue of *BPA News.*

Frederick Gilman addressed the future of high-energy physics, as foreseen in the report of the Subpanel on Long Range Planning of U.S. High-Energy Physics. The Subpanel was formed by the High-Energy Physics Advisory Panel, which advises the Department of Energy and the National Science Foundation on priorities and plans for the field.

Gilman made two points about the present circumstances. First, particle physics has had a strong international collaborative character for decades, but now the scope both intellectually and financially of future frontier facilities goes beyond a single country or region and demands a global scope for planning the course of the field. Secondly, we are at the beginning of a new era in which we are not only asking questions about the nature of matter, energy, space, and time that we wouldn't have dreamed of a few decades ago, but we can see how to build the facilities and experiments to begin to answer them.

The high-energy physics community has long had a planning process centered on the High Energy Physics Advisory Panel (HEPAP) and its subpanels. Recent reports include the 1994 HEPAP Subpanel (Drell) and the 1998 HEPAP Subpanel (Gilman). The 2000 HEPAP White Paper provided intermediate-term guidance and input to a long-range planning process that involved the community and a new subpanel with a broad charge, reporting to both the DOE and the NSF.

The Subpanel on Long-Range Planning for U.S. High Energy Physics presented a draft report to HEPAP on October 29. The draft report begins with a vision for the field. "Particle physics stands at the threshold of a new era of discovery. As experiments peer deeper and deeper into the heart of matter, they open strange new worlds and striking new vistas on the cosmos. They begin to address the most human of questions: Where did we come from? Where are we going? Particle physics is a grand adventure, a journey into the great unknown. It explores the frontiers of matter, energy, space and time, much like the early pioneers who explored a great new nation, 200 years ago.

"Why should we study a world so removed, so different from our own? The reasons are the same as for the exploration of space, the sea, or any other new frontier. In a sense, the journey is an end to itself. From Lewis and Clark to Shepard and Glenn, we have explored new territories because it is exciting and challenging, and a part of what defines our humanity.

"Today, we also recognize the role that science and technology have played in creating and defending the open and advanced society that we cherish. The U.S. Commission on National Security/21st Century has emphasized the extent to which national security rests on the strength of our scientific and technological base. Particle physics is very much a part of this overall fabric of science, drawing on discoveries in some areas and enabling progress in others. In particular, we advance the frontiers of science, push the outermost envelope of technology, and educate highly skilled members of our national workforce.

"From past explorations, we have learned much about the basic constituents of matter. During the past ten years, we discovered the top quark – the last quark, a quark as heavy as an atom of gold. We learned that neutrinos have mass, and that they change their identities over time. We confirmed electroweak unification to extraordinary accuracy, measured the matter-antimatter asymmetry in quark systems, and studied the interactions of quarks and gluons."

The report made several tentative recommendations, principal among which was its recommendation for the next major facility for the field: *"We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity, electron-positron linear collider, wherever it is built in the world. This facility is the next major step in the field and should be designed, built and operated as a fully international effort. We also recommend that the United States take a leadership position in forming the international collaboration needed to develop a final design, build and operate this machine. The U.S. participation should be undertaken as a partnership between DOE and NSF, with the full involvement of the entire particle physics community. We urge the immediate creation of a steering group to coordinate all U.S. efforts toward a linear collider."*

Robert Laughlin and Piers Coleman made presentations to the Board emphasizing the fundamental nature of our growing understanding of complex systems and the collective phenomena that emerge as the number of degrees of freedom is increased. Their overarching theme was the nonreductionist point of view: More is different! A research briefing was proposed that would develop this theme for a broad audience.

The Board then broke up into four working groups:

1. Astronomy and astrophysics,
2. AMO and plasma science,
3. Solid-state and materials science,
4. High-energy and nuclear physics.

Working Group 1 emhasized following up the recently-published survey, *Astronomy and Astrophysics in the New Millennium* and the COMRAA report (see article on p. 1). A key issue in both reports is the Telescope System Instrumentation Program (TSIP). NSF has assigned implementation of this program to the National Optical Astronomy Observatories. The Committee on Astronomy and Astrophysics, a standing committee under the joint sponsorship of the BPA and the Space Studies Board, will monitor developments closely. Another concern is promoting effective planning for astronomy at the NSF, as recommended in the COMRAA report.

Working Group 2 referred to the study now in progress on high-energy-density plasma physics led by Ron Davidson. Other topics in plasma physics to be pursued include burning plasma physics, low-temperature plasmas, planning for the plasma physics volume of the new survey, *Physics 2010*, and reintegrating plasma physics with the rest of the field of physics. In the area of atomic, molecular, and optical science, bose-einstein condensation, nanophotonics, and the issues raised in the COSE study were highlighted.

Working Group 3 pointed out that the traditional divisions of physics tend to miss the most exciting new areas. A different taxonomy for *Physics 2010* based on around 15 smaller volumes treating cross-cutting areas was suggested.

Working Group 4 suggested that a research briefing on the science being pursued in high-energy physics would be valuable. The briefing could explain the ideas that have been developed in lay language and review the results of major experiments.

The meeting concluded with reviews of the activites of the Plasma Science Committee and the Committee on AMO Science as well as the Committee on Astronomy and Astrophysics.

The next meeting of the Board will take place in Washington on April 26-27, 2002. ■

Committees of the Board on Physics and Astronomy

Committee on Astronomy and Astrophysics
John P. Huchra, Harvard-Smithsonian Center for Astrophysics, and Richard McCray, JILA/University of Colorado, *Co-chairs*

Committee on Atomic, Molecular, and Optical Sciences
Margaret Murnane, JILA/University of Colorado, *Chair*

Plasma Science Committee
Stephen C. Cowley, University of California at Los Angeles, *Chair*

Committee on Radio Frequencies
Paul Steffes, Georgia Institute of Technology, *Chair*

Solid State Sciences Committee
Sol Gruner, Cornell University, *Chair*

Astronomy and Astrophysics Survey Committee
Joseph H. Taylor, Jr., Princeton University, and Christopher F. McKee, University of California at Berkeley, *Co-chairs*

Physics Survey Overview Committee
Thomas Appelquist, Yale University, *Chair*

Committee on Physics of the Universe
Michael Turner, University of Chicago, *Chair*

Committee for an Updated Assessment of Atomic, Molecular, and Optical Sciences
C. Kumar Patel, University of California at Los Angeles, *Chair*

Committee on High-Energy-Density Plasma Physics
Ronald C. Davidson, Princeton University, *Chair*

Committee on Organization and Management of Research in Astronomy and Astrophysics
Norman R. Augustine, Lockheed Martin Corporation (retired), *Chair*

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More information on BPA committees may be found on the BPA Web page at <www.national-academies.org/bpa>.

COMRAA
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and they show excellent promise of continuing to do so. Nonetheless, the existing management structure for the U.S. astronomy and astrophysics research enterprise is not optimally positioned to address the concerns posed by the mounting changes and trends that will affect the future health of the field.

The existing management structure for astronomy and astrophysics research separates the ground- and space-based astronomy programs. NSF has responsibility for the former and NASA has responsibility for the latter. The ground-based optical/infrared observatories funded by private and state resources constitute an important third component of the system. In astronomical and astrophysical research, NASA's strength has been the support of work related to major space missions. NSF's strength in astronomy and astrophysics has been the support of a broad spectrum of basic research motivated by the initiative of individuals and small groups in the scientific community and by its role in assuring the continued availability of broadly educated scientists. The NSF also funds research in related fields such as physics, geophysics, computation, chemistry, and mathematics, providing a broad multidisciplinary context for astronomy and astrophysics research that can promote productive connections among these fields.

Three important changes have occurred in the field over the last two decades. First, ground- and space-based research activities have become increasingly interdependent as well as increasingly reliant on large facilities, major missions, and international collaborations. Second, NASA's relative role in astronomy and astrophysics research has grown markedly. (In 1980, most of the research grants in the fields of astronomy and astrophysics were provided by NSF. Today, most of the grants are provided by NASA.)[3] And third, large state-of-the-art optical/infrared telescopes built with non-federal funds now dominate this component of ground-based astronomy.

These changes necessitate systematic, comprehensive, and coordinated planning in order to sustain and maximize the flow of scientific benefits from the federal, state, and private investments that are being made in astronomy and astrophysics facilities and missions. The increasing financial and intellectual demands to be met by more than one nation in supporting large projects, particularly on the ground, require that the United States develop a unified planning and execution structure to effectively participate in such international ventures. To develop the needed integrated and comprehensive strategy for the field, the committee recommends the formation of an interagency planning board for astronomy and astrophysics.

The Committee on the Organization and Management of Research in Astronomy and Astrophysics was charged to consider, among other options, moving NSF's astronomy responsibilities to NASA.[4] Such a move would consolidate the bulk of the federal programs[5] in a single agency and, to some degree, integrate space- and ground-based astronomy. The committee concluded, however, that moving NSF's astronomy and astrophysics activities to NASA would have a net disruptive effect on scientific work. Because of its combined commitment to investigator-initiated research, interdisciplinary research, and educating the scientists of the future, NSF is the right institution to sponsor ground-based astronomy and astrophysics. And further, such a move would not necessarily address integration of the third component of the system (i.e., the ground-based optical/infrared private and state observatories). NSF's close working relationship with the college and university community makes it the natural focus for integration of this third component. The committee's recommendations address improving the present overall management structure, as well as strengthening NSF's ability to support ground-based astronomy and astrophysics and to work effectively in conjunction with the other two primary components of the system. The committee's detailed recommendations are contained in the box on the next page.

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[1] Executive Office of the President, *A Blueprint for New Beginnings: A Responsible Budget for America's Priorities*, U.S. Government Printing Office, Washington, D.C., 2001.

[2] The two National Research Council reports are *Federal Funding of Astronomical Research* (2000) and *Astronomy and Astrophysics in the New Millennium* (2001), National Academy Press, Washington, D.C.

[3] This trend was noted in *Federal Funding of Astronomical Research.*

[4] It would be unreasonable to consolidate under NSF, i.e., to place space missions under NSF, since NSF has no space experience, does not operate its own facilities, and does not have a large enough budget to carry out space missions.

[5] Additional important federal components include the Department of Energy, which conducts research in particle, high-energy, nuclear, and plasma physics and in computational science related to astronomy and astrophysics; the Smithsonian Institution, which plays a significant role in astronomy and astrophysics research through the Smithsonian Astrophysical Observatory; and the Department of Defense, which supports research in areas such as solar physics, astrometric astronomy, and observing technology that is carried out primarily through multiple programs in the Navy and Air Force research offices.

COMRAA Recommendations

1. The National Science Foundation's astronomy and astrophysics responsibilities should not be transferred to NASA.

2. In order to maximize the scientific returns, the federal government should develop a single integrated strategy for astronomy and astrophysics research that includes supporting facilities and missions on the ground and in space.

3. To help bring about an integration of ground- and space-based astronomy and astrophysics, the Office of Science and Technology Policy and the Office of Management and Budget should take the initiative to establish an interagency planning board for astronomy and astrophysics. Input to the planning board from the scientific and engineering community should be provided by a joint advisory committee of outside experts that is well connected to the advisory structures within each agency.

—The recommended interagency Astronomy and Astrophysics Planning Board, with a neutral and independent chair to be designated by the Office of Management and Budget in conjunction with the Office of Science and Technology Policy, should consist of representatives of NASA, NSF, the Department of Energy, and other appropriate federal agencies such as the Smithsonian Institution and the Department of Defense. The Planning Board should coordinate the relevant research activities of the member agencies and should prepare and annually update an integrated strategic plan for research in astronomy and astrophysics, addressing the priorities of the most current National Research Council decadal survey of the field in the context of tight discretionary budgets.

—The membership of the Planning Board's advisory committee should be drawn in part from the external advisory panels of the Planning Board's member agencies. The advisory committee should be chaired by an individual who is neither a member of the agency advisory panels nor an agency employee. The committee should participate in the development of the integrated strategic plan and in the periodic review of its implementation.

4. NASA and NSF should each put in place formal mechanisms for implementing recommendations of the interagency Astronomy and Astrophysics Planning Board and integrating those recommendations into their respective strategic plans for astronomy and astrophysics. Both agencies should make changes, as outlined below, in order to pursue effective roles in formulating and executing an integrated federal program for astronomy and astrophysics. These changes should be coordinated through the interagency Planning Board to clarify the responsibilities and strategies of the individual member agencies.

5. The NSF, with the active participation of the National Science Board, should:

a. Develop and implement its own strategic plan, taking into account the recommendations of the interagency Planning Board. Its strategic plan should be formulated in an open and transparent fashion and should have concrete objectives and time lines. NSF should manage its program in astronomy and astrophysics to that plan, ensuring the participation of scientifically relevant divisions and offices within NSF. To help generate this plan, NSF should reestablish a federally chartered advisory committee for its Astronomical Sciences Division to ensure parity with the NASA advisory structure. The chair of this Astronomical Sciences Division advisory committee should be a member of the Mathematical and Physical Sciences Directorate advisory committee. Furthermore, the Mathematical and Physical Sciences Directorate advisory committee should make regular written and oral reports of its key findings and recommendations to the National Science Board.

b. Address the outstanding issues that are affecting ground-based astronomy at present.

—Lead the development of an integrated strategy for assembling the resources needed to build and operate the challenging suite of ground-based initiatives recommended by the most current decadal survey.

—Work to create an integrated system for ground-based optical/infrared astronomy and astrophysics encompassing private, state, and federally funded observatories, as advocated by the decadal survey.

—Improve and systematize the process for initiating, constructing, managing, and using ground-based facilities, so that it includes:

- clear lines of authority for negotiations, particularly those involving international partners,
- an open bidding process for contracts,
- comprehensive budgeting that provides for all aspects and phases of projects, and
- provision of the resources required to exploit the scientific potential of the facilities, including associated instrumentation, theoretical work, data analysis, and travel.

c. Undertake a more concerted and well-funded effort to inform the press and the general public of scientific discoveries, and cooperate with NASA in developing a coordinated public information program for astronomy and astrophysics.

6. In parallel, NASA should:

a. Implement operational plans to provide continuity of support for the talent base in astronomy and astrophysics should critical space missions suffer failure or be terminated.

b. Continue and enlarge its program of research support for proposals from individual principal investigators that are not necessarily tied to the goals of specific missions.

c. Support critical ground-based facilities and scientifically enabling precursor and follow-up observations that are essential to the success of space missions. Decisions on such support should be considered in the context of the scientific goals articulated in the integrated research plan for astronomy and astrophysics.

d. Cooperate with NSF in developing a coordinated public information program for astronomy and astrophysics. ■

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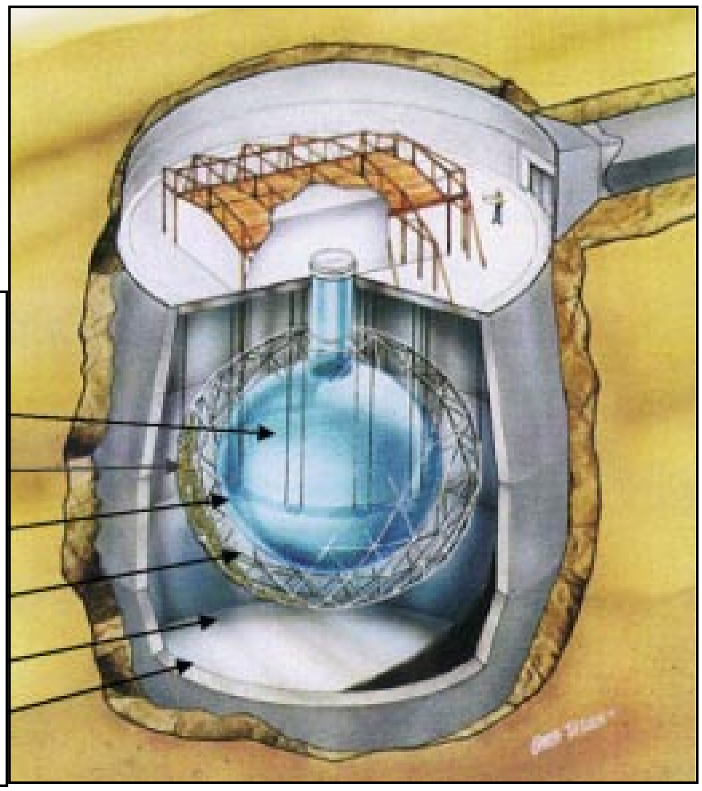
ultrapure heavy water. This sphere is surrounded by a 1700 tonnes of ultrapure ordinary water as an inner shield. Surrounding the sphere and the inner shield is a geodesic support structure on which 9456 photomultiplier tubes are hung. The photomultiplier tubes detects flashes of light given off by the scattering of neutrinos from the deuterium nuclei in the heavy water. The detection rate is about 10 per day, so long runs are required to gather sufficient data for a useful experiment. The laboratory has all the support systems and personnel necessary to operate the facility, including electronics and computers, control systems, and water purification plants for both heavy and ordinary water.

Sudbury Neutrino Observatory



Construction of the laboratory was completed in 1998 at a cost of $73M CDN. Several Canadian public- and private-sector contributors as well as the U.S. Department of Energy and the Particle Physics and Astronomy Research Council of the United Kingdom provided support. The heavy water is on loan from Atomic Energy of Canada Limited (a Canadian federal agency).

Neutrinos Redux

There are three different kinds of neutrinos. The electron neutrino, ν_e, is created, for example, when hydrogen fuses into deuterium as indicated above, with the release of a positron (hence the association with electrons). Another way to look at the association is to observe that an electron neutrino scattering from a neutron can generate a proton and an electron through the exchange of a W boson. In a similar way, there is a ν_μ neutrino associated with the muon and a ν_τ neutrino associated with the tauon. Observations constrain the masses of all the neutrinos to be fairly small, but not necessarily zero.

The Experiments

There is an easy way to estimate the electron neutrino flux from the sun based on energetics. The energy from hydrogen burning in the sun is given by

$4p + 2e^- \rightarrow {}^4He + 2\nu_e + 26.731$ MeV.

The measured power reaching the earth is 137 mW $cm^{-2} = 8.53 \times 10^{11}$ MeV $cm^{-2}s^{-1}$. So the neutrino flux is

$2 \times 8.53 \times 10^{11}/26.731 =$

$6.38 \times 10^{10}\ \nu_e\ cm^{-2}\ s^{-1}$.

Super-Kamiokande is a light-water cherenkov detector located in Kamioka, Japan. Such a detector only interecepts the high-energy part of the spectrum of the neutrinos generated in the various fusion reactions in the sun. In a recent measurement of the solar neutrino flux extending over 1117 days, concluding in April, 2000, Super-K only observed about half of the number of neutrinos that were expected. A number of other experiments, including the Chlorine experiment, SAGE, and GALLEX, show similar discrepancies.

What is the solution to this puzzle? Since all the experiments, which are quite different, show similar results, experimental error is unlikely to be the culprit. Is the physical model of what's going on in the sun in error? Possible, but even with all the fluxes in the standard solar model as free parameters, the observed data can't be reproduced. Another possibility was suggested by Pontecorvo in 1968. If lepton number is not conserved, then a ν_e could change into a ν_μ. Since the Cl-Ar detector was sensitive only to ν_e, it would appear that the flux was low.

SNO Experiment

The unique feature of SNO is its heavy water, a legacy from the Canadian atomic power industry. W. B. Lewis championed the idea of using reactors moderated by heavy water, which makes possible the generation of power using unenriched uranium. This policy resulted in the creation of a stockpile of heavy water, which SNO was able to borrow for its experiment.

The virtue of using heavy water is that reactions become possible that are sensitive to all neutrino types, not just electron neutrinos. The reactions are

$\nu_e + d \rightarrow p + p + e^-$ (charged current, CC)

$\nu_x + d \rightarrow p + n + \nu_x$ (neutral current, NC)

$\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering, ES).

The CC reaction only involves electron neutrinos. The NC reaction has an equal cross section for all active neutrino types. The ES reaction is mainly sensitive to electron neutrinos, but it has some sensitivity to the others.

THE BPA Web site at **www.national-academies.org/bpa** provides news on recently released reports and other developments as well as a link to this newsletter in PDF format. Reports may be ordered at **www.nap.edu**.

New reports:

- *Astronomy and Astrophysics in the New Millennium* (published version)
- *Physics in a New Era: An Overview* (published version)
- *An Assessment of the Department of Energy's Office of Fusion Energy Sciences Program* (published version)

Coming in 2001:

- Report of the Committee on Physics of the Universe: *Connecting Quarks and the Cosmos: 11 Scientific Questions for the Next Century*

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