

Quarks-to-Cosmos Report Calls for New Physics–Astronomy Collaborations

In the fall of 1999 while attending a meeting of the National Research Council's Board on Physics and Astronomy, NASA Director Daniel Goldin listened to what board members later described as a "stimulating session" on research at the intersection of physics and astronomy. At the end of the meeting, he asked board members if they could assess the science opportunities in this interdisciplinary area and develop a plan for turning the opportunities into reality. In March 2000, thanks to Goldin's request, several officials with NSF, the Department of Energy, and NASA formed the Committee on the Physics of the Universe to conduct the study.

The final result is *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, released by the NRC on 21 April 2002. The report was actually done in two phases, the first of which consisted of the 11 science questions referred to in the report's title, and was released in January 2001. Those questions, listed here, address what the report describes as "the universe at its two extremes—the very large and the very small":

- What is the dark matter?
- What is the nature of the dark energy?
- How did the universe begin?
- Did Einstein have the last word on gravity?
- What are the masses of the neutrinos, and how have they shaped the evolution of the universe?
- How do cosmic accelerators work and what are they accelerating?
- Are protons unstable?
- Are there new states of matter at exceedingly high density and temperature?
- Are there additional spacetime dimensions?
- How were the elements from iron to uranium made?
- Is a new theory of matter and light needed at the highest energies?

After identifying the questions that intertwine physics and astronomy, the report committee turned to developing a plan for finding the answers. The plan is contained in the seven recommendations for research and research coordination that make up the recently completed phase two of the report. Those recommendations are as follows:

- Measure the polarization of the cosmic microwave background with the goal of detecting the signature of inflation. The committee recommends that NASA, NSF, and DOE undertake R&D to bring the needed experiments to fruition.
- Determine the properties of the dark energy. The committee supports the Large-Aperture Synoptic Survey Telescope project, which has significant promise for shedding light on the dark energy. The committee further recommends that NASA and DOE work together to construct a wide-field telescope in space to determine the expansion history of the universe and fully probe the nature of the dark energy.
- Determine the neutrino masses, the constituents of the dark matter, and the lifetime of the proton. The committee recommends that DOE and NSF work together to plan for and fund a new generation of experiments to achieve these goals. "We further recommend that an underground laboratory . . . be built to house and operate the needed experi-

ments," the committee said.

► Use space to probe the basic laws of physics. The committee supports the Constellation-X and Laser Interferometer Space Antenna missions, which have high promise for studying black holes and for testing Einstein's theory in new regimes. The committee further recommends that the agencies proceed with an advanced technology program to develop instruments capable of detecting gravitational waves from the early universe.

► Determine the origin of the highest energy gamma rays, neutrinos, and cosmic rays. The committee supports the broad approach already in place and recommends that the US ensure the timely completion and operation of the southern Auger array.

► Discern the physical principles that govern extreme astrophysical environments through the laboratory study of high-energy-density physics.

► Establish an interagency initiative on the physics of the universe, with the participation of DOE, NASA, and NSF. This initiative should provide structures for joint planning and mechanisms for joint implementation of cross-agency projects.

University of Chicago astrophysicist Michael Turner, who chaired the study, said the recommendations were not given in order of importance, but that the first three would involve significant new projects. The third recommendation, which calls for an underground lab, is the most politically sensitive because of controversy in Congress over siting such a lab in South Dakota's defunct Homestake Mine (see PHYSICS TODAY, January 2001, page 23). The Homestake project is being used as a political prize in a heated and critical Republican Senate election challenge to Senator Tim Johnson (D-S. Dak.) by Representative John Thune (R-S. Dak.).

To avoid the political fray, the NRC study talked about Homestake only as one of several possible sites for an underground lab. "We just looked at the science," said committee member John Huchra of the Harvard-Smithsonian Center for Astrophysics. "Our job was to lay down the scientific requirements for underground experiments." The NRC has a separate study nearing completion that looks at the underground lab issue in detail.

The report does not discuss the cost of pursuing the recommendations, but Turner said his personal view is that much of the work could be done for about \$1 billion. He and others involved in writing the report said they were careful to make sure the recommendations do not conflict with the 2001 decadal survey *Astronomy and Astrophysics in the New Millennium*, by the Commission on Physical Sciences, Mathematics, and Applications. "There was worry at the beginning of the study that it might interfere with the decadal survey," Turner said. "We wanted to reinforce the survey, not interfere with it."

JIM DAWSON

approach." NSF is different in that it funds proposals from researchers based on merit and doesn't initiate its own research projects. There are examples in which the agencies coor-

dinate work on specific projects, but what Turner is hoping for is a deeper interagency relationship to carry out the recommendations in the new report. "I saw enthusiasm for working

closer together at NSF, DOE, and NASA," Turner said after his round of briefings. "I think that may happen. We want to get something done."

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