BPA News

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Committee on Organization and Management of Research in Astronomy and Astrophysics Formed

In reponse to requests from the National Science Foundation and the National Aeronautics and Space Administration, the National Research Council has appointed a committee to assess the organization and management of research in astronomy and astrophysics.

The request had its origins in language in the administration's Budget Blueprint for 2002, which called for the formation of a blue-ribbon panel to address the organizational effectiveness of federal support of the astronomical sciences. The pros and cons of transferring NSF's responsibilities in this area to NASA, as well as other options, are also to be considered.

The AASC and FFAR Reports

NSF and NASA provide more than 90 percent of federal funds for academic astronomy research and facilities. Historically, NASA has funded space-based astronomy and NSF has funded ground-based astronomy and proposals for research in astronomy and astrophysics. The status of astronomy in the United States was addressed in two NRC reports issued in 2000—*Federal Funding for Research in Astronomy* (the FFAR report) and *Astronomy and Astrophysics in the New Millennium* (the AASC report). Links to both reports may be found on the BPA website at http://www.nas.edu/bpa.

The FFAR report found that, over the last decade, the balance of support shifted toward NASA. NSF's share of support for grants fell, from 60 percent at the beginning of the 1980s to 30 percent at the end of the 1990s. The report found that this shift can produce imbalances. For example, funding for broad-based astrophysical theory has not kept pace. And it found that the number, size, and capability of ground-based observing facilities increased considerably, with a commensurate increase in NSF funds for utilizing the facilities, at the expense of funds available for research grants to astronomers.

The FFAR report also observed that much of the support of astronomy is now tied to a few flagship NASA space missions. It suggested including in the plan for each new space initiative a strategy for accomplishing its scientific mission. The report identified a number of elements that should be included in the science strategy for each mission. Among those elements are the provision of instrumen-

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In this issue:

The Next Generation Space Telescope

John C. Mather, NASA Goddard Space Flight Center, and Nino Panagia and Hervey S. Stockman, Space Telescope Science Institute

One of us (JCM) reported to the Board on Physics and Astronomy on the status of the NGST at the recent meeting of the Board on Physics and Astronomy meeting that took place on April 27-28, 2001, in Washington, D.C. This article summarizes the presentation, which addressed the recent adjustments in the baseline design of the NGST. It draws on an article published in the STScI March 2001 newsletter.

Introduction

The Next Generation Space Telescope (NGST) is a large-aperture optical and infrared telescope being designed to study the properties of the first stars and galaxies born after the Big Bang and to elucidate the mysterious process of star and planet formation in our own galaxy. The high spatial resolution and low background provided by a large-aperture, passively cooled telescope in an elliptical orbit around the Lagrange L_2 point (1.6 million km from Earth, overhead at midnight) are essential for these studies. Compared with current or planned observatories, NGST will have unique advantages in image quality, field of view, low background light, and environmental stability. In particular, observational sensitivity will be limited only by the zodiacal light background for near-infrared wavelengths less than 10 micrometers.

NGST will be a unique international facility with contributions from NASA, the European Space Agency, and the Canadian Space Agency. In the recent decadal survey of astronomy and astrophysics, sponsored by the National Academy of Science (http://books.nap.edu/catalog/9840.htm1), NGST was ranked as the highest-priority new initiative for the next 10 years. This ranking reflects both the exciting nature of NGST science and the recognition

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The Board on Physics and Astronomy is a continuing interdisciplinary body with expertise spanning the various subfields of physics, astronomy, and astrophysics. It serves as a focal point in the National Research Council for issues connected with these fields. The activities of the Board are supported by funds from the National Science Foundation, the Department of Energy, the Department of Defense, the National Aeronautics and Space Administration, the National Institute of Standards and Technology, and private and other sources, including the Keck Foundation.

The National Task Force on Undergraduate Physics: Some FAQs

Robert C. Hilborn, Amherst College

I gave a presentation to the Board on Physics and Astronomy at its last meeting on the National Task Force on Undergraduate Physics, which I chair. The essential facts about the Task Force are outlined in this article.

What Is the Purpose of the Task Force?

1. To provide an overview of undergraduate physics revitalization efforts and to coordinate the efforts of physics professional organizations, individual physicists and physics departments, and funding agencies.
2. To identify areas in which revitalization efforts are needed and to catalyze projects addressing those needs. Some of the projects will be national in scope; some local, some regional. Some will be centered in universities; some in professional societies. Some will require extensive external funding; some will leverage local resources. All these efforts will be strengthened if they can be coordinated and if those working on one activity can learn from the others.
3. To raise the visibility of undergraduate physics revitalization by having its members speak and write about the revitalization effort and maintain communications with the entire physics community.
4. To develop contacts with undergraduate revitalization efforts in the other scientific disciplines and to promote physics as a model for undergraduate revitalization efforts.

Who Is Sponsoring the Task Force?

The Task Force was established in the fall of 1999 by the American Association of Physics Teachers, the American Physical Society, and the American Institute of Physics. The Task Force members are appointed for 2-year terms by the three physics organizations. The ExxonMobil Foundation has provided a planning grant to assist the Task Force in its first year of activity.

Who Is on the Task Force?

J. D. Garcia, professor of physics, University of Arizona, former program officer at NSF

S. James Gates, John S. Toll Professor of Physics, University of Maryland

Robert C. Hilborn, *Chair*. Amanda and Lisa Cross Professor of Physics, Amherst College, former president of AAPT

Ruth H. Howes, *Deputy Chair*, George and Frances Ball Distinguished Professor of Physics and Astronomy, Ball State University, past president of AAPT

Karen Johnston, professor of physics, North Carolina State University, former president of AAPT, former program officer at NSF

Kenneth S. Krane, professor of physics, Oregon State, former program officer at NSF, PI of the New Physics Faculty Workshops program

Laurie McNeil, professor of physics, University of North Carolina at Chapel Hill

Jose P. Mestre, professor of physics, University of Massachusetts-Amherst

Thomas L. O'Kuma, professor of physics, Lee College, former president of AAPT

Douglas D. Osheroff, professor of physics, Stanford University

Carl Wieman, Distinguished Professor of Physics, JILA, University of Colorado

David T. Wilkinson, professor of physics, Princeton University

Ex Officio Members:

James H. Stith, Director of Physics Programs, American Institute of Physics

Jack Hehn, Manager, Education Division, American Institute of Physics

Judy Franz, Executive Officer, American Physical Society

Fred Stein, Director of Education and Outreach Programs, American Physical Society

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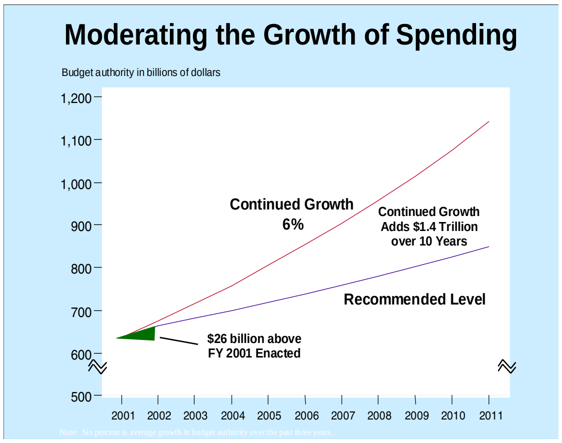
Highlights of the Washington Board on Physics and Astronomy Meeting

The BPA met on April 27-28 at the NRC's Georgetown facility. The board heard briefings from physics and astronomy program managers in the Department of Energy, the National Science Foundation, the National Aeronautics and Space Administration, the National Nuclear Security Administration, the Office of the Secretary of Defense, and the Office of Management and Budget.



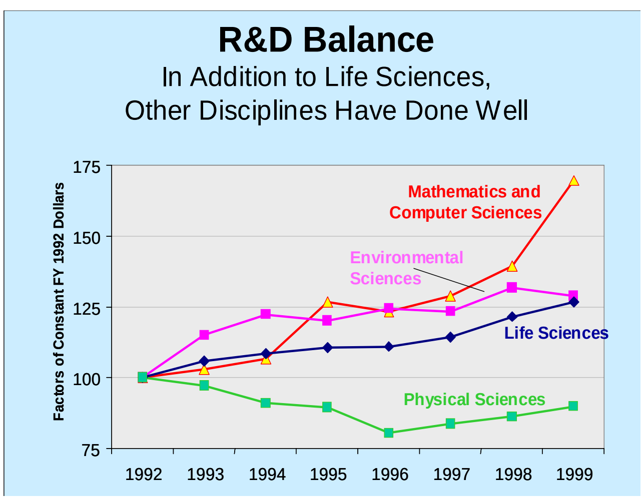
The budget outlook for science is generally very constrained. Michael Holland, representing the OMB, described the administration's plans to moderate federal government spending over the next decade. He pointed out that the private share of total R&D spending has grown dramatically. For basic research, the private share in 1970 was 30%, whereas in 1999, it had risen to 50%. The implication is that the growing role of the private sector in R&D will compensate for the moderation in the growth of public spending. Nonetheless, the administration's proposal for R&D spending outpaces all other increases in discretionary spending. Basic research will rise by 6.1%. But much of the increase will be in the life sciences. Budgets for the physical sciences have been relatively static over the last decade.

Highlights of the 2002 R&D budget include a 57% increase for NASA's origins program, which provides funding for astronomical research. The NSF's part in the nanoscale science, engineering, and technology initiative is proposed at $174 M, a 16% increase over 2001. The biomedical research budget (NIH) is projected to increase by 14%, to over $23 B.

Holland pointed out that earmarks to colleges and universities are increasing at an alarming rate, undermining the competitive, merit-based review process.

The remainder of the BPA meeting was devoted to science talks, a policy talk, and updates on various projects that are in progress under BPA auspices. The science talks were on the rescoping of the Next Generation Space Telescope (see article on page 1 of this issue) and copolymer templates (see article on page 8 of this issue). The policy talk focused on undergraduate physics (see article on page 2 of this issue). The full agenda of the meeting is posted on the BPA Web site at http://www.nas.edu/bpa.

The BPA also discussed the Committee on Organization and Management of Research in Astronomy and Astrophysics (see page 1 of this issue) and the launch of a new survey, *Physics 2010*. ■



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>.

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tation for ground-based telescopes, support for observations, and funds for the associated astrophysical theory.

The AASC report concluded, in addressing organization and management issues raised in the NSF authorization process in 1999, that "a robust and broadly based program is in place." But it went on to say, "Balance among various components of the program, however, remains a concern of the astronomical community. A large portion of the total support for astronomy is now tied to a few flagship missions of NASA."

To address the question of balance, the AASC recommended several steps to strengthen the ground-based program:

- National and independent observatories should be viewed as integrated systems of capabilities for the United States as a whole.
- Funds for grants should be included in the budgets of new ground-based facilities for their first 5 years of operation.
- The NSF should take more initiative in sharing the achievements of its scientists with the public, just as NASA does.
- The NSF should work with other agencies and with the astronomical community to build interagency programs that will aggressively pursue astronomical problems of broad national interest.

The AASC report also encouraged cooperation among NASA, NSF, and, for some projects, DOE. It recommended that these agencies work together with the research community to build new interagency programs and observed that the Office of Science and Technology Policy is the traditional broker for such cooperation.

In addressing the ways that NSF and NASA allocate funding, the AASC pointed out that, at NSF, provision of funds for research and analysis to capitalize on the observations made possible by new facilities is neglected. As a consequence, new facilities do not always reach their full potential and the NSF Astronomy Division grants program is under heavy pressure. The report recommends that NSF budget for operations, instrumentation, and research specifically tied to each new facility. It also recommends cross-disciplinary competitive reviews of major ground-based facilities.

The AASC report identifies the forefront problems in astronomy and astrophysics for the next decade and recommends a program of initiatives to address those problems. To realize this program, the report recommends a set of specific science goals and corresponding projects. The details are given in Table 2.1 of the AASC report. For example, the science goal of determining the large-scale properties of the universe is addressed by a combination of

- Next Generation Space Telescope (a successor to the Hubble Space Telescope),
- Giant Segmented Mirror Telescope (a major advance in ground-based telescopes) and
- Large-aperture Synoptic Survey Telescope (a ground-based survey telescope).

NASA plays a crucial role in realizing the first initiative, and NSF plays a central role in realizing the two ground-based facilities. These initiatives are extremely challenging. Success over the next decade will require an optimally functioning system of research in astronomy and astrophysics in the United States.

The Blue-Ribbon Panel

To address these problems, the NRC has formed the Committee on Organization and Management of Research in Astronomy and Astrophysics. To disseminate up-to-date information about the status of the work of COMRAA, a Web page has been established at http://www.nas.edu/bpa/projects/brp.

The membership of the committee is as follows:

Norman R. Augustine, Lockheed Martin Corporation (retired), Chair
Lewis M. Branscomb, Harvard University
D. Allan Bromley, Yale University
Claude R. Canizares, MIT
Sandra M. Faber, U.C. Santa Cruz
Robert D. Gehrz, University of Minnesota
Philip R. Goode, New Jersey Institute of Technology
Burton Richter, Stanford University
Anneila I. Sargent, Caltech
Frank H. Shu, U.C. Berkeley
Maxine F. Singer, Carnegie Institution of Washington
Robert E. Williams, Space Telescope Science Institute

The formal charge to the committee is as follows:

- Assess the organizational effectiveness of federal support for astronomical sciences.
- Discuss the advantages and disadvantages of transferring NSF's astronomy responsibilities to NASA.
- Consider other options for addressing the management and organizational issues identified by the committee and by recent NRC reports.

The first meeting of the committee, which was devoted primarily to organizing its work, was held by telephone on May 10, 2001. The second meeting was held on June 13-14. The agenda included an opportunity for public comment. The views of representatives from a number of agencies and institutions were represented, including:

- Office of Management and Budget
- National Science Foundation and National Aeronautics and Space Administration
- Professional societies
- Associated Universities Inc.
- Association of Universities for Research in Astronomy
- National Center for Atmospheric Research
- National Aeronomy and Ionospheric Center
- Laser-Interferometric Gravitational Observatory

There were also background presentations from the cochairs of the FFAR and AASC reports as well as from former agency managers responsible for astronomy programs at NASA and NSF.

The third meeting of the committee is scheduled to take place at the Stanford Linear Accelerator in Stanford, Cal., on July 12-13. The fourth meeting, at which conclusions and recommendations will be finalized, is scheduled for July 31-August 1 in Washington, D.C. The report will be released on September 1, 2001.

Up-to-date status information is available on the COMRAA website at http://www.nas.edu/bpa/projects/brp. ■

NGST
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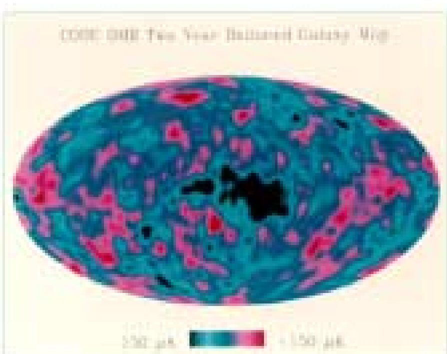
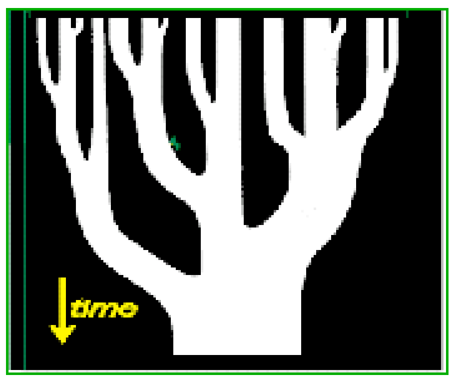
that NGST is technologically within reach.

The NGST project is in the preliminary design phase. Major studies of lightweight mirrors and detector technology developments are showing encouraging results, and new focal-plane assemblies for multi-object spectroscopy are being developed. Phase-A systems architecture studies are under way by industry consortia that include TRW, Ball Aerospace, Lockheed Martin, and B.F. Goodrich Corporation. Proposals for the instruments and the observatory will be solicited shortly.





Top Scientific Goal: The (Almost) First Light

The formation and early evolution of galaxies are almost completely unknown. The density fluctuations and the beginnings of mass motions of the primordial hydrogen and helium have been determined from measurements of the spatial fluctuations (anisotropy) of the cosmic microwave radiation. We therefore think we know the almost-initial conditions at a redshift of 1000, when the universe was filled almost uniformly with neutral gas and was only 300,000 years old and only 1/1000 as large as now. Extensive theoretical calculations and simulations predict that the first stars may have formed at a redshift of 10 to 30, and that these may have been extremely massive (10-300 solar masses). Such objects would have been extremely bright and would have burned all their fuel in a few million years, ending in a catastrophic supernova explosion. The debris from such explosions might have included high concentrations of heavy elements, which would explain why no stars have yet been found that do not contain some heavy elements. They would also have been capable of re-ionizing the remaining intergalactic medium. Hence, it may be possible to observe such objects even at high redshift. It might also happen that some such objects were immediately obscured by dust formed from these heavy elements. Theorists have also been working on how the galaxies were assembled. Were they made from small subunits, which collided and aggregated, as seems to be the case in recent times? This seems to be the favored scenario today. Or were large galaxies formed from large gas clouds very early? We are just now getting a glimpse of the cosmic web, the network of filaments of luminous galaxies, so the question is completely open.

NGST is intended to measure these hypothetical first objects, ranging from globular clusters to galaxy cores to various kinds of supernovae. Because of the high redshifts in question, NGST must measure infrared radiation and must be cooled to far below room temperature and the temperature of the Hubble Space Telescope. Because of the great distances and faintness of the hypothetical objects, NGST must also have the largest feasible aperture.

One interesting change of perspective has occurred since the NGST studies were started in October 1995. The Cosmic Background Explorer satellite found that the universe is filled with far-infrared background radiation, apparently the result of converting starlight and hot radiation from active galactic nuclei and quasars. About half the luminosity of the universe now appears at these long wavelengths. The sources of much of this radiation have been found with the SCUBA instrument on the JCMT 15-m ground-based telescope on Mauna Kea. However, these objects are apparently invisible at wavelengths less than 2 micrometers. Whether they are visible to NGST depends on the degree of dust obscuration. It seems unlikely that an object can be completely obscured by dust unless it is very compact, like an active galactic nucleus. Hence, NGST should see at least a portion of this population.

Another major event is that the ground-based astronomy community has developed realistic plans for a 25-m-aperture telescope with multi-conjugate adaptive optics. Such a telescope could come on line during NGST's operational lifetime and would be an extremely valuable complement at all wavelengths it can observe. Its greatest advantages are in spectroscopy at visible and near-IR wavelengths less than 2 micrometers, where its huge collecting area can overcome the hazards of observing through the atmosphere. NGST's competitive advantages shift toward longer wavelengths. The advantages for NGST of observations at wavelengths longer than 5 micrometers have been emphasized by the "HST and Beyond" committee report (Dressler, 1996), by the Ad hoc Science Working Group (ASWG), and, more recently, by

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NASA's Origins Subcommittee and the NRC Committee on Astronomy and Astrophysics.

Given these capabilities, NGST will also be turned toward many other scientific challenges, including the properties of the cosmic dark matter and dark energy, the formation of stars and planets, and the history of the formation of the elements, leading to the possibility for life elsewhere in the universe. It will be a general user facility, operated like the Hubble Space Telescope by the Space Telescope Science Institute in response to competitively selected observing proposals.

International Project Plan: Spacecraft and Instruments

NASA leads the NGST project, but major contributions are planned by ESA (the European Space Agency) and CSA (the Canadian Space Agency). ESA would contribute about $200 M (US, FY96) of effort, and CSA would contribute $50 M. In return, ESA would be guaranteed 15% of the observing time on HST and NGST and CSA would gain 5% of the time on NGST. ESA intends to provide a portion of the spacecraft bus, based on the Herschel/Planck bus design for two missions at L2, although the details are not yet known because the U.S. prime contractor has not been chosen. ESA and CSA would also provide staff members at the Space Telescope Science Institute in Baltimore.

NGST will also carry the three instruments given top priority by the Ad Hoc Science Working Group (ASWG). A visible/near-infrared (0.6 to 5 micrometers) camera with a field of view of 10 to 20 square arcminutes will be acquired through a NASA Announcement of Opportunity in 2001, with substantial Canadian participation. A near-infrared multi-object spectrograph will be provided by the European Space Agency, using NASA-provided detectors and a microelectromechanical (MEMS) device for object selection. A mid-infrared camera/spectrograph will be provided by a NASA-led NASA/ESA/CSA partnership, with NASA and ESA each offering about half of the effort. ESA would provide the cryostat for the mid-infrared instrument. In addition, a separate fine guidance sensor will share the focal plane of the telescope, and CSA is developing a plan to build it. In previous plans, the near-IR camera would have provided the fine guidance function. It should be stressed that concepts for NGST are still in development, and it will be up to the prime contractors to propose an observatory they can build within the cost and schedule constraints.

NGST Rescope: Meeting Cost and Schedule Constraints

In the light of results from costing exercises for other NASA missions, and in preparation for issuing a Request for Proposals for the NGST prime contract in mid-2001, the NGST project has undertaken a detailed reassessment of the design parameters. The principal goals are to get the most observatory capability per dollar and to launch in this decade. Moreover, it is essential for NGST to be compatible with more than one launch vehicle. We made every attempt to keep the priorities that were set by the science teams, although a smaller telescope clearly does not do as well as the telescope in the original plan. A major result of this exercise has been to relax the requirements on the diameter, areal density, and temperature of the primary mirror. A modest reduction in the aperture diameter can result in a stiffer mirror that still meets the launch weight constraints for more than one launch vehicle while retaining performance markedly superior to that of all other telescopes. Moreover, allowing the primary mirror to operate at a warmer temperature will permit active thermal control using heaters. The stiffer primary will provide better, more stable image quality at lower cost than other options. It will also enable much more complete verification of image quality and control in ground testing, reducing the need for a flight validation experiment.

Prior to this rescope activity, the NEXUS technology development flight had been planned, which would have verified a 2.5-m-aperture cold, deployable, adjustable mirror with wavefront control and a guide star system. However, the costs and schedule of this demonstration mission were found to be incompatible with flying NGST at anything like the desired schedule. Hence, design changes to NGST and its test program were such that its risk could be made small enough to make a flight demonstration unnecessary.

Interim Science Working Group Replaces ASWG

The NGST ASWG provided science guidance from September 1997 to September 2000. The ASWG was responsible for constructing the Design Reference Mission (http://www.ngst.stsci.edu/drm), which has been used heavily as a tool in design trade studies. The ASWG also made recommendations on the NGST instrument complement, taking into consideration the NASA, ESA, and CSA instrument concept studies, the NGST science goals, and the expected advances in ground-based facilities.

The ASWG recently underwent a metamorphosis into the Interim Science Working Group (ISWG). This group will function through the formulation phase (Phase A/B), until the instrument Announcement of Opportunity is released. An e-mail broadcast has already announced that this AO is imminent. ISWG members were selected in September 2000 from over 100 highly qualified applicants. The resulting committee includes observers, theorists, and instrument builders and reflects both the international nature of the project and the diverse scientific goals and capabilities of the observatory. The ISWG works in collaboration with the NGST Project, NASA headquarters, and the astronomical community to provide input during the formulation phase of NGST. The ISWG helps to provide astronomy community input on questions relating to the science mission of NGST and to disseminate information about NGST to the community.

The ISWG membership includes Heidi Hammel, Space Science Institute; George Helou, CalTech/SIRTF Science Center; Robert Kennicutt, University of Arizona; Robert Kirshner, Harvard University; Rolf-Peter Kudritzki, IfA University of Hawaii; Simon Lilly, Herzberg Institute of Astrophysics; Bruce Margon, Space Telescope Science Institute; Mark McCaughrean, Astrophysics Institute Potsdam: Marcia Rieke (Chair), University of Arizona; Massimo Stiavelli, Space Telescope Science Institute; Edwin Turner, Princeton University; Ewine van Dishoeck, Leiden University; and Michael Werner, Jet Propulsion Laboratory.

Technology Development: Mirrors, Detectors, and Wavefront Control

Key technology challenges for NGST include lightweight optics; cryogenic actuators for mirror control; deployable structures; sensitive infrared detector arrays; lightweight, programmable aperture masks for multi-object spectroscopy; and coolers for the thermal infrared detectors. All have seen significant progress over the last 2 years.

Mirrors

The NGST primary mirror must be lightweight (~20 kg/m^2) and deployable and must be capable of holding its figure at cryogenic temperatures. So far, eight designs involving five industry partners —including the University of Arizona, Composite Optics, Inc., Ball Aerospace, Raytheon Optical Systems, and Kodak—have been built as prototype ultralight mirrors. The University of Arizona built a 2-m "bed of nails" mirror, which uses a 2-mm facesheet of glass over a bed of more than 160 actuators to control the deformable surface. COI and IABG (Germany) developed a carbon-fiber-reinforced silicon carbide, semirigid mirror that uses sparse actuation to control radius of curvature and tip, tilt, and piston of the mirror. Ball Aerospace built a beryllium mirror, which recently underwent cryogenic testing at Marshall Space Flight Center to quantify the changes in figure due to temperature. The results are extremely encouraging for the concept of "cryofiguring," where interferograms taken at cryo temperatures are used to control the last stages of polishing.

Detectors

NGST requires detectors with large formats, a low dark current, and minimal readout noise. Candidates for the 0.6- to 5-micrometer region include indium antimonide (InSb) and mercury-cadmium telluride (HgCdTe) technologies, while arsenic-doped silicon (Si:As) holds the most promise for the longer wavelengths. The technical requirements that these detectors aim to meet are spelled out in the report of the NGST Detector Requirements Panel and summarized on the NGST Web pages (http://www.ngst.nasa.gov/cgi-bin/doc?Id=538 and http://www.ngst.nasa.gov/cgi-bin/doc?Id=641). For the near-IR (0.6 to 5 micrometers), both HgCdTe (U. Hawaii/Rockwell Science Center) and InSb (U. Rochester/Raytheon) are being supported as candidate options. Through these contracts, multichip focal-plane modules will be developed, chip manufacturing will be improved, readout sensitivity will be enhanced, and potential cost drivers and cost savings will be identified. Work also continues at Raytheon and Ames on the mid-IR candidate material, Si:As. Bare readouts of the new SB-226 detector have been evaluated down to 5 K, and optimum lot splits will be identified soon. Prototype 1K x 1K Si:As hybrid arrays (27 micrometer pixels) have been fabricated, with excellent operability. Detailed low-background characterization is continuing.

Wavefront Control Testbed

The Wavefront Sensing and Control Testbed (WCT) is a joint project between GSFC and JPL for NGST. Its purposes are to simulate the co-phasing process for NGST, deepen our understanding of all aspects of this process, develop and improve the algorithms for sensing and control of each step, and characterize the effects of various parameters on accuracy, sensitivity, repeatability, and reliability. WCT1 incorporates a pair of deformable mirrors for injection of controlled aberration and correction. WCT2 incorporates a small, three-segment rigid mirror assembly with tip/tilt and piston correction. The experiment suite for WCT1 is nearly complete, and the WCT2 assembly has recently been commissioned with the demonstration of the initial co-phasing.

Conclusions

The Next Generation Space Telescope has been restored to programmatic health by an aggressive analysis of the costs, benefits, and requirements. The requirement on telescope diameter has been relaxed from the original 8 m, and a diameter of 6 or 7 m seems feasible within the cost and schedule constraints. The smaller mirror can be much stiffer and more easily tested on the ground, significantly reducing programmatic risk. The mirror can be allowed to operate warmer, up to about 45 K, permitting active thermal control and avoiding the main cause of mirror figure instability. The international project agreements are sufficiently mature that major responsibilities can now be assigned. The Phase A studies are complete, and the cost estimates and technology are sufficiently mature to warrant proceeding to Phase B (detailed design) immediately after selection of the prime contractor.

Now, 5 years after the NGST studies were started under the guidance of Ed Weiler at NASA Headquarters, the mission has become NASA's flagship telescope for the next decade. Even with reduced aperture, it is still essential for progress in understanding the origins of galaxies and the formation of stars and planets. It will be a spectacular successor to the Hubble Space Telescope. ■

Block Copolymers: Easy Routes to Nanoscopic Structures

T.P. Russell and M.T. Tuominen, University of Massachusetts

Block copolymers are comprised of two chemically distinct polymers covalently linked at one end. The low entropy of mixing polymers translates generally into an immiscibility of one block with the other. While homopolymer mixtures macroscopically phase separate, the connectivity of one block with the second limits the size scale of phase separation to the size of the polymer chain. Block copolymers self-assemble into well-ordered arrays of nanoscopic spheres, cylinders, or lamellae where the nature of the morphology is dictated by the volume fraction of the two blocks. So, for example, a hexagonally close-packed array of cylinders of one component in a matrix of the second will be found if the volume fraction of the minor component is ~0.3. A particularly attractive feature of copolymers is that the size of the domains can be changed by varying the total molecular weight. Consequently, copolymers provide tremendous versatility in the size and type of morphology formed.

In thin films, the self-assembled morphologies of block copolymers are opening new avenues of research and applications in nanotechnology. However, it is imperative to control the orientation of these self-assembled morphologies in a simple, highly reproducible and inexpensive manner. The orientation of the copolymer morphology is dictated by the surface energies of the two blocks, the interfacial interactions between the blocks and the underlying substrate, the interactions between the blocks, and the commensurability between the period of the copolymer and the total film thickness. The chemical composition of the two blocks dictates the surface energies and the binary segmental interactions. By modifying the substrate surface, interfacial interactions can be varied. Film thickness provides control over additional contributions to the free energy due to incommensurability.

In general, one block of the copolymer will have a preferential interaction with the underlying substrate, which, in thin films, causes this block to segregate to the substrate. The connectivity and immiscibility of the blocks, coupled with the preferential interfacial interaction of either block with the substrate, causes an orientation of the copolymer morphology parallel to the substrate. Interfacial interactions can readily be altered by anchoring a polymer chain to the surface. Consider the case of a block copolymer of polystyrene (PS) and poly(methyl methacrylate) (PMMA), denoted P(S-b-MMA). If a PS chain is anchored to the surface, then the PS block will be attracted to the surface. If a PMMA chain is anchored to the surface, then the PMMA block will preferentially segregate to the substrate. In collaboration with C.J. Hawker at the IBM Almaden Research Center, random copolymers of PS and PMMA have been synthesized that can be anchored to the substrate. Here, styrene and methyl methacrylate monomers are randomly placed along the polymer chain and the concentration of each component can be adjusted in the synthesis. Therefore, the chemical composition of the chain anchored to the surface and, consequently, the interfacial interactions, can be controlled in a precise manner. For one composition of the random copolymer, the interaction of the blocks in the copolymer will be equal, and the strong enthalpic force causing a parallel alignment of the block copolymer morphology is removed. In the case of P(S-b-MMA), the surface energies of the two blocks are equal. Entropically, there is a preference for a polymer chain to orient parallel to the substrate. In addition, it is very difficult to control the film thickness to within a few nanometers. This initially causes an extension or compression of the copolymer chain. Both entropic contributions to the free energy cause the copolymer morphology to orient normal to the surface. Thus, by simply controlling the interfacial interactions, the orientation of the morphology in the thin films can be easily manipulated.

A dramatic demonstration of the control that can be achieved in thin films by balancing the interfacial interactions is shown in the atomic force microscopy (AFM) phase image in Figure 1A. This image shows a 30-nm spin-coated film of P(S-b-MMA) block copolymer having a 0.3 volume fraction of PMMA that has been heated to 160°C, i.e. above the glass transition temperatures of PS and PMMA. This image shows an array of 13-nm-diameter cylinders of PMMA in a PS matrix with an average separation distance of ~25 nm. The areal density of the PMMA cylinders exceeds 10^{10} cylinders/cm^2, and the cylinders span the entire film thickness, from the air surface to the substrate. As seen, micron-size grains of hexagonally close-packed cylinders cover the entire film. Exposing this film under an ultraviolet (UV) radiation cross-links the

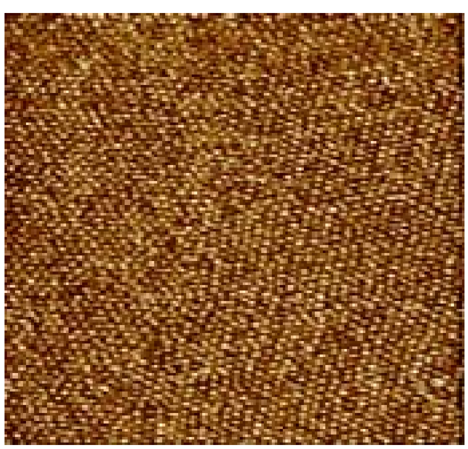
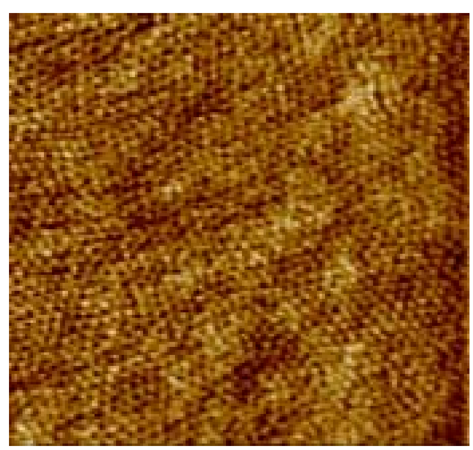


Fig. 1. (A) AFM image of P(S-b-MMA) copolymer film with cylinders oriented normal to the surface. Each cylinder is ~13 nm in diameter.



(B) Resultant nanoporous PS film.

PS matrix and degrades the PMMA cylinders, producing a cross-linked PS film containing an array of nanoscopic pores, as shown in Figure 1B. This porous film serves as a nanoscopic template that can be transferred to the underlying substrate or as a scaffold in which chemical reactions can be performed.

With C. Black and K. Guarini at the IBM TJ Watson Research Laboratory, we used SF_6 reactive ion etching (RIE) to transfer the copolymer template to an underlying silicon substrate. Initially, RIE removes the silicon oxide at the base of the nanopores while etching some of the cross-linked PS matrix. However, after removal of the oxide, the rates of RIE in Si and in the oxide are significantly different. This translates into an ability to etch deeply into the Si to produce holes with high aspect ratios. Such surfaces have potential use in dynamic random access memory devices. Alternatively, the cross-linked, nanoporous PS film on Si can be placed in silicon tetrachloride ($SiCl_4$) vapor in the presence of water. The $SiCl_4$ and water react with the silicon oxide at the base of the pores, generating an unstable silicon tetrahydroxide intermediate that releases HCl and forms silicon oxide. Consequently, glass posts can be grown within the nanoporous PS scaffold to a height that depends upon the thickness of the film and the time allowed for the reactions. Using oxygen etching or further exposure to UV, the PS matrix can be degraded and removed, leaving behind a surface that has a textured roughness replicating the copolymer morphology. More importantly, the total surface can be increased by orders of magnitude by changing the height of these nanoposts. Many trichlorosilanes with different functionalities can be reacted with this oxide surface. The increased surface area greatly enhances the lateral density of the functional groups attached to the surface compared with the density for a smooth surface. As a result, these surfaces provide a unique route for producing sensors with very high sensitivity.

The nanoporous, cross-linked PS matrix can also be removed from the underlying substrate, leaving a nanoporous film that can be used as a separations medium whose pore size can easily be controlled by changing the molecular weight of the copolymer. Furthermore, rather than a flood UV exposure, the copolymer can be cross-linked and degraded with an electron beam. Thus, by e-beam writing, the lateral placement of the nanoporous material can be precisely controlled. For device fabrication, such lateral control of the structures is mandatory. These are just a few of the many areas in nanotechnology where thin copolymer films have tremendous potential. Although the focus here has been on the cylindrical morphology, the arguments presented extend to the other morphologies into which block copolymers self-assemble.

Extension of these methods to thicker films, however, is not possible. The influence of interfacial interactions diminishes with increasing distance from the surface. For films thicker than a few periods, the alignment of the copolymer morphology becomes poorer. Thus, an external field is required to assure alignment of the morphology in a specific direction. In the bulk, mechanical shearing has proven to be the most effective route for aligning the copolymer domains. However, in thin films, this is not possible, since any particulate impurities preclude shearing. The dielectric constant difference between the domains of the copolymer allows one to use an electric field to achieve alignment. In thin films, small voltages applied across the film thickness translate into large applied fields. The anisotropic shape of lamellar or cylindrical domain will cause the domains to orient parallel to the lines of the applied electric field. Using an electric field, the cylindrical domains in films of P(S-b-MMA) as thick as 30 mm have oriented normal to the film surface. Small-angle x-ray and neutron scattering and electron microscopy have been used to demonstrate that PMMA cylinders extend from one surface to the other. With UV exposure, the PS matrix is cross-linked and the PMMA is degraded. As before, this produced a cross-linked nanoporous PS film that is on a conducting surface with pores that have aspect ratios in excess of 300. If this is used as one electrode in an electrochemical cell, then any material that can be electrochemically plated can be deposited in the nanopores of the PS scaffold.

Shown in Figure 2 is an electron micrograph of cobalt nanowires prepared in this manner. As can be seen, the wires are continuous and have a uniform diameter and length. The confinement of the cobalt to these nanoscopic domains causes an increase in the coercivity of the cobalt by orders of magnitude. Such arrays have attracted substantial attention as candidates for high-density magnetic storage media. If each wire could be separately addressed, the storage density of these arrays is such that 20 DVDs could be stored on a disk the size of a quarter! In addition, different materials can be deposited sequentially. Consequently, multilayers can easily be fabricated, which extends capabilities to a third dimension, expanding the potential for such scaffolding substantially.

These two simple routes demonstrate the ease by which the morphology of copolymers can be manipulated in thin films. Coupling control with routine chemistry can transform the morphology of copolymers into unique nanoscopic structures. These structures are opening numerous avenues of research and are enabling new technologies not achievable by other means. ■

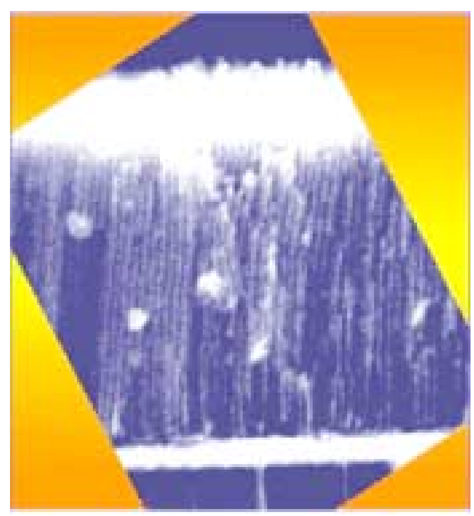


Fig. 2. Scanning electron micrograph of fractured surface of an array of cobalt nanowires approximately 13 nm in diameter in a polystyrene matrix. The length of the wires is approximately 1 micron.

Task Force (continued from page 2)

Bernard V. Khoury, Executive Officer, American Association of Physics Teachers
Warren Hein, Associate Executive Officer, American Association of Physics Teachers.

What Do We Mean by Revitalization?

The revitalization of undergraduate physics focuses on providing **constructive and creative responses** to the challenges posed by the changes in the environment in which physics operates. These changes are probably irreversible, and the physics community, if it is to thrive, must respond to those changes.

How Has the Environment for Physics Changed?

1. Physics itself is changing, with many new subfields that cross disciplinary boundaries (for example, materials physics, computational physics, biophysics, chemical physics, and photonics), most of which are completely absent from undergraduate physics programs.
2. The job market for physicists (and other scientifically trained workers) emphasizes the need for broader training within science and for enhanced skills in communication and the ability to work in teams.
3. Today's undergraduate student body is more diverse both ethnically and economically than that of 20 years ago. These students bring backgrounds and motivations substantially different from those of most current physics faculty when they were undergraduates.
4. Physics education research has established that there is a significant gap between what physics faculty believe they are teaching and what students actually learn. At the same time, physics education research has identified a number of teaching strategies that can help close that gap.
5. The profession as a whole faces a public perception that the most exciting scientific developments are likely to occur in fields other than physics.
6. Physics is increasingly disconnected from societal needs and federal priorities. The result is that potential students do not see the connection between physics and their daily lives and future careers.

Why Focus on Undergraduate Physics? Isn't K-12 in More Need of Attention?

At the undergraduate level, physics has contact with the students who will become tomorrow's leaders in science, education, and other fields. In many ways, undergraduate physics sets the tone for physics education in the K-12 grades. Tomorrow's K-12 teachers are today's college and university students. Furthermore, today about 70% of American high school students go on to some form of undergraduate education. Colleges and universities are no longer just for the elite. Science education in general and physics in particular must play an important role in educating a scientifically and technologically informed citizenry.

How Soon Should We Expect to See Results from the Task Force's Efforts?

Revitalizing undergraduate physics is a long-term program that moves the physics community toward continuing experimentation, evaluation, and improvement of undergraduate physics education. The initial stage of this effort will take 5 to 10 years.

What Is Needed for Undergraduate Physics Revitalization and How Do We Know What Works?

Over the past 3 years, AAPT, APS, and AIP have taken some first steps to address these issues. As a result of the Physics Department Chairs Conferences in May 1997 and April 2000 (both of which focused on undergraduate physics), the October 1998 conference "Building Undergraduate Physics Programs for the 21st Century," and extensive discussion with a wide spectrum of physicists, four key features of successful undergraduate physics revitalization can be identified:

1. There is **wide recognition and interest** in undergraduate revitalization from **all** kinds of physics departments and indeed from a wide spectrum of the entire physics community. But not from all. We still need lots of persuasion and discussion both within individual departments and in the physics community at large.
2. **The fundamental element for change is the department**. Real change in undergraduate physics programs demands the support of college and university administrators, but unless a significant number of the department's faculty, including the chair, buy into the effort, any changes are likely to evaporate quickly.
3. **An undergraduate physics program is more than just the curriculum.** An undergraduate physics program is not just pedagogy and courses. Physics departments also need to consider such activities as recruiting able students, mentoring physics students, providing courses appropriate for pre-service K-12 teachers, assisting with professional development for a diversity of physics careers, providing opportunities for undergraduates to participate in research, and making connections with the local industries and businesses that employ graduates.
4. **Effective change is local.** Physics departments have varying missions, sizes, geographical locations, and types of students. A one-size program will not fit all.

What Does the Task Force Plan to Do?

Task Force efforts are grouped into five categories:

1. Raise the consciousness of the physics community about the problems facing undergraduate physics and why solving those problems is crucial to the health of the physics profession.
2. Develop a catalog of case studies (with analysis) of departments that

have successfully improved their undergraduate physics programs.

3. Coordinate and publicize efforts by individuals, departments, and professional organizations to improve undergraduate physics.
4. Provide advice and ideas to professional organizations, funding agencies, and the physics community about revitalizing undergraduate physics.
5. Work with similar groups in other scientific and engineering disciplines to improve all aspects of undergraduate science, mathematics, engineering, and technology education.

What Specific Projects Will the Task Force Undertake?

1. Work with AAPT on plans for continuing and enhancing the New Physics Faculty Workshop program. Extend the program to workshops at APS division meetings. Perhaps develop ties with the Pew Preparing Future Faculty program, the PKAL Faculty 21 project, and Project NeXT.
2. Set up an activist editorial board for the undergraduate part of the Physics Sciences Resource Center (on the AAPT Web site) to provide a clearinghouse for information on undergraduate physics programs.
3. Use departmental site visits and other means to develop a catalog of case studies of departments that have undertaken successful undergraduate physics revitalization efforts. Document and analyze these case studies to provide information on what works and what is need to produce effective change in undergraduate physics programs.
4. Articulate departmental responsibilities for K-12 teacher preparation and find good case studies of where that effort has been successful. Build on the efforts of PhysTEC, the proposal submitted by APS, AIP, and AAPT to NSF for promoting physics departments to take more responsibility for K-12 teacher preparation. A small conference on the role of physics departments in pre-service K-12 teacher preparation will be held at the University of Nebraska-Lincoln in June 2000.
5. Develop a colloquium talk on undergraduate physics programs that can be given by Task Force members to physics departments around the country.
6. Plan for a proposal to establish a large-scale funding program to provide seed money for departments that have developed detailed plans for revitalizing their undergraduate physics programs. These departments can then serve as case studies and consultants for other departments.

What Other Activities Might the Task Force Consider?

1. Work with Project Kaleidoscope to run several regional conferences on undergraduate physics revitalization.
2. Explore the possibility of developing an accreditation program for undergraduate physics programs.
3. Consult with the Physics Education Research (PER) community on the design of assessment, identification of research needs, and mechanisms for dissemination of PER results that are important for undergraduate physics. Explore the possibility of having a Gordon Conference focused on PER.
4. Work with engineers, life scientists, etc. to coordinate undergraduate revitalization efforts across the disciplines.
5. Investigate connections with industry, business, etc. Focus on the breadth of physics both for the recruitment of potential physics majors and for marketing our majors to employers. Coordinate efforts with the APS Committee on Careers and Professional Development.
6. Work with AIP's Physics Programs to develop and disseminate materials promoting undergraduate physics as excellent preparation for diverse careers.
7. Work with the Council on Undergraduate Research to promote opportunities for undergraduate research participation in physics.
8. Set up a working group on evaluation and assessment instruments; perhaps have consultants who can do the evaluation and assessment for various revitalization projects.

How Can I Contact the Task Force?

Ideas, suggestions, comments, and questions can sent via e-mail to NTFUP@aapt.org or to the chair of the Task Force, rchilborn@amherst.edu. ■

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