

DIRECTOR'S OFFICE

NATIONAL OPTICAL ASTRONOMY OBSERVATORY

Design and Development of a Thirty-Meter Telescope

Jeremy Mould & Stephen Strom

AURA's New Initiatives Office (NIO) is proposing to carry out the design and development (D&D) phase of a project aimed at building and operating a Thirty-Meter Telescope (TMT). When complete, the TMT will be able to image and analyze galaxies at their birth, when the first stars formed in the Universe and started the processes that resulted in the world on which we live. A TMT will provide detailed views of stars and solar systems in the process of formation, and directly observe planets in orbits around other stars.

Our proposed program builds on the results of two thorough, independent feasibility studies: one undertaken by the University of California and Caltech, and the other by AURA's NIO. The proposed D&D phase will use the results of the two feasibility studies as the starting point to define the TMT system architecture. It will proceed to address key areas of technical, cost, and schedule risk to advance technologies crucial to enabling TMT and its instruments, and then to develop a Preliminary Design.

In accomplishing these D&D phase objectives, we propose to combine, in a public-private partnership, the talent and experience embodied in the institutions responsible for designing and building the four largest telescopes in the United States. We plan to do this by assembling an integrated, colocated project team to follow a design-to-life-cycle cost philosophy and management principles appropriate to a project of ultimate cost approaching \$700 million.

Completing the D&D phase will require \$70 million. The funds (\$35 million) requested by AURA from the National Science Foundation (NSF) represent the public half of the total needed to complete the D&D phase. We propose to invest these federal dollars in multiple programs to advance key technologies—detectors, durable coatings, adaptive optics (AO) components, large format gratings—that are essential to meeting D&D objectives. These technologies will also be of significant benefit to existing large telescopes and to other ongoing programs exploring next-generation telescope concepts. We plan to engage the community broadly in the technology development program via solicitations open to all community groups.

NSF investment now will ensure: (1) a strong community voice in shaping the design and operating modes of this flagship facility,

(2) public access to the TMT in proportion to invested funds, and (3) a facility that will be available to the US community early in the era of the James Webb Space Telescope (JWST). Additionally, since the TMT has the power to address questions that engage the imagination of the public as well as scientists, it offers a superb platform from which to stage and develop educational and public outreach activities.

The NIO's proposal takes a major step forward toward meeting the goal set by the Decadal Survey: to build a TMT that will be ready early in the JWST era, and to do so by combining federal and private resources. We see a historic opportunity to shape the direction of US astronomy in the 21st century by ensuring that the best minds in the community are engaged in developing the TMT design and making use of it a decade from now.

Technology Development: The Driving Force

Achieving the scientific goals of the TMT will require instruments of unprecedented power and sophistication, ranging from spectrographs that can observe thousands of galaxies or stars simultaneously to coronagraphs that enable characterization of extrasolar planets fainter than their parent stars by seven orders of magnitude or more. Exploring imaginative concepts matched to TMT science opportunities and advancing the most promising to conceptual designs are fundamental elements of the D&D phase.

It is essential that these activities proceed as an integral part of the design of the overall observatory system to enable telescope, AO, and instrument designs that result in optimal system performance. TMT instruments will be of a scale and complexity comparable to particle accelerator or spacecraft experiments, with estimated costs

between \$20 million and \$50 million each, compared to the \$5 million to \$10 million instruments now populating the focal planes of Keck and Gemini.

The figure on page 9 shows the moderate- to high-resolution (MTHR) optical spectrograph envisioned by the California Extremely Large Telescope (CELT) team for possible future deployment on the TMT. The perspective is looking down the optical axis of the 30-meter primary mirror with the MTHR spectrograph mounted on the side at the telescope's Nasmyth

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continued



Design and Development of a TMT continued

focus. To demonstrate the enormity of this instrument, the Gemini telescope is shown to scale; *the size of this one instrument is nearly the same as the entire Gemini telescope!* The MTHR camera mirrors, at a little under two meters in diameter, are larger than many telescope primaries used today, while the grating in this instrument would measure ~1.0x3.5 meters and actually consist of a mosaic of 40 of the largest individual gratings available today. Such a grating mosaic would dwarf any such system ever built.

Extremely Large Telescope (ELT)-class instruments thus represent a huge leap from instruments built to date. They will demand considerable investments in time and technology if they are to be realized. For Keck or Gemini, time from design concept to delivery on the telescope ranged from five to seven years. Given the even longer timescales anticipated for TMT instrumentation development—from the design phase through technology development to construction to commissioning—investment must begin quickly in order to have instruments in place at first light, a decade hence.

lower-cost components, while enabling the design of instrumentation for other ELT programs. As an example, the near-infrared detectors needed for an ELT imager must have per-pixel cost and system noise performance comparable to modern CCDs. Once developed, they can be mass-produced and used not only for the TMT, but also to populate very large focal planes for wide-field imagers on smaller telescopes with complementary science objectives.

Similarly, the proposed microelectromechanical systems (MEMS)-based deformable mirror technology development will have broad applications in other ELT and non-ELT astronomical instrumentation. Our proposed investment in MEMS as an integral part of the high-performance coronagraph will drive the unit cost below the estimated \$1,500-per-actuator cost of conventional deformable mirrors, enabling not only high-performance AO on the TMT, but also the extension of high-Strehl imaging into the visible for existing telescopes (as one example).

INSTRUMENT	SCIENCE APPLICATION
MCAO NIR Imager	Stellar populations
NIR Deployable IFU Spectrometer	Assembling galaxies
NIR Coronagraph	Detecting planets
Near/Mid-IR Imager and Spectrometer	Planet-forming environments
Wide-Field GLAO Optical Spectrometer	Assembling galaxies
High-Resolution Optical Spectrograph	Stellar abundances
Multi-object Optical Spectrometer	IGM structure and composition

TMT instrument applications

In selecting the technology development for the D&D phase of the TMT, NIO (1) mapped science goals to instrumentation requirements; (2) identified key component or technology developments needed to achieve instrument goals; (3) identified targeted studies or prototype developments needed to inform design choices for candidate first-light instruments; and (4) contacted a wide range of private sector vendors and university research groups to illuminate the development programs needed and the associated costs for advancing key technologies, components, or design studies.

Investments of this kind are not only critical to timely completion of capable first-light instruments for the TMT, but will also enhance instruments on current-generation telescopes by providing access to higher-performance,

Among the technology development areas NIO will pursue during the coming four years are: Optical Detectors, Near-Infrared Detectors, Mid-Infrared Detectors, AO WaveFront Sensor Detectors, Fiber Systems, Silicon Grisms, Mosaic Gratings, VPH Gratings, Integral Field Units, Large-Format Cryogenic Filters, SolGel AR Coatings, Optical Nulling, and MEMS. These technologies will find multiple uses in a suite of TMT instruments (see table). More details about this technology development program will appear in subsequent issues of the *Newsletter*.

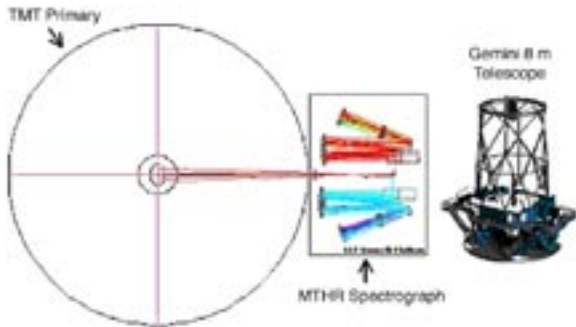
Site Testing: Another Critical Path Item

NIO is undertaking a comprehensive site evaluation program aimed at exploring a wide range of potential sites

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Design and Development of a TMT continued



An example of a possible ELT-class instrument. The MTHR spectrograph would provide a high-resolution optical spectroscopy capability from the Nasmyth platform, together with a massively multiplexed medium-resolution facility. For scale, the Gemini 8-meter telescope is shown next to the MTHR spectrograph.

for the TMT, from Hawaii to the southwest United States/Mexico to northern Chile, and from altitudes ranging from 2,000 to 5,500 meters. The data set from this program will not only provide the basis for selecting an optimal site for the TMT, but will also provide information critical to other groups currently evaluating potential sites for next-generation telescopes. This proposed program builds on extensive investments made over the past two years by AURA-NIO and the CELT partners in service of ensuring that site selection be made no later than fall 2007.

Over the past two years, CELT and the NIO have developed procedures, and where necessary, procured instrumentation, to allow evaluation of these sites. Final selection and weighting of the criteria for site selection and the final choice of candidate sites will be established formally at a Site Testing Methodology Review. The main site selection activities are

proceeding in the following order:

- Compilation and analysis of existing databases, both global and site-specific
- Remote sensing evaluations; derived statistics for prospective sites
- Wind flow and boundary-layer turbulence studies for prospective sites by means of computational fluid dynamics (CFD)
- Procuring, setup, and commissioning of site testing equipment at prospective sites; this includes meteorological stations, differential image motion monitors, and atmospheric turbulence profile monitors
- Recording meteorological and seeing data for extended periods at multiple sites
- Data reduction and evaluation leading to selection of a site for the TMT

Throughout this process, archival results and new conclusions will be stored in a form that allows objective evaluation and subsequent decision making, facilitating use for ELT projects other than the TMT.

The following sites are being evaluated, in a campaign that will continue for approximately three years:

- Mauna Kea (two locations)
- Three undeveloped sites in northern Chile, including a high-altitude site in the Chajnantor region
- San Pedro Martir
- Las Campanas

Uniform data (meteorological, seeing, and atmospheric turbulence) are being gathered and analyzed for all of these sites, so that a data set will be in place to guide an informed choice that takes into account astronomical, engineering, and cost data. These data will be ingested into the established site database and made available publicly to benefit all prospective ELT programs.

Frontier Science Enabled by a Giant Segmented Mirror Telescope

Jeremy Mould

“Frontier Science” is the title of the first report of the Giant Segmented Mirror Telescope (GSMT) Science Working Group (SWG). Chair Rolf Kudritzki and Vice-Chair Steve Strom issued the report on June 30 after the SWG’s first year of study of the Decadal Survey’s GSMT.

The evolution of the Universe from the dawn of known physics to the formation of atoms has been made plain by

the Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft mission. The GSMT will pick up the story from the formation of the first structural seeds manifest in the gas at the most distant observable reaches of the Universe. It will follow it through the appearance of the first stars and pregalactic forms, through 13 billion years of sometimes violent evolution of these galaxy building blocks, to the grand elliptical and spiral galaxies that populate the nearby

continued



Frontier Science continued

universe, like our Milky Way. The GSMT will reveal the process of the birth of planetary systems surrounding newborn stars, and their evolution to mature planets orbiting around neighboring suns.

In the words of 2002 physics Nobel Prize winner Riccardo Giacconi, 21st century astronomy is uniquely positioned to study “the evolution of the Universe in order to relate causally the physical conditions during the Big Bang to the development of RNA and DNA.” This is the opportunity that now presents itself to astronomy with a new ground-based telescope of unprecedented power: the GSMT.

The SWG finds that GSMT will, for the first time, permit direct observations of hundreds of extrasolar giant planets; the disks from which planetary systems take form; the building blocks of galaxies and the process of galaxy assembly; the earliest evolution of chemical elements heavier than helium; and, the emergence of large-scale structure as mapped by galaxies and intergalactic gas during the first billion years following the Big Bang. The SWG further reports that

- This telescope will have the light gathering power and angular resolution to open up discovery spaces that virtually assure the uncovering of unanticipated phenomena,
- From extensive analysis carried out by several groups, a 20-meter to 30-meter telescope can be built for a cost within the envelope estimated by the most recent National Academy of Sciences Decadal Survey (*Astronomy and Astrophysics in the New Millennium*), i.e., approximately \$700 million,
- While there are significant technical challenges to building telescopes of this size, there appear to be no show-stoppers,
- In order to reap the enormous potential synergy between the James Webb Space Telescope (JWST) and a 20-meter to 30-meter telescope, it is essential to initiate major design and technology development efforts immediately,
- Private consortia are open to public-private partnerships to design, build, and operate a next-generation telescope,
- Federal investment now in a major technology development program targeted at key areas can advance multiple design programs, and ensure a strong public voice at all stages in developing next-generation telescopes.

At the conclusion of this powerful report, the SWG urges the NSF to seize the moment and provide funding for advancing key technologies, noting that the US community appears poised to embrace a new paradigm: public-private partnerships to advance flagship research facilities.

The members of the GSMT SWG are Betsy Gillespie and Jill Bechtold, University of Arizona; Michael Bolte, University of California at Santa Cruz; Ray Carlberg, University of Toronto; Matthew Colless, Australian National University; Irene Cruz-Gonzalez, UNAM Instituto de Astronomia; Alan Dressler, Observatories of the Carnegie Institution of Washington; Terry Herter, Cornell University; Paul Ho, Center for Astrophysics and ASIAA; Rolf-Peter Kudritzki (Chair), Institute for Astronomy, University of Hawaii; Jonathan Lunine, University of Arizona Lunar and Planetary Lab; Claire Max, Lawrence Livermore National Laboratory and University of California at Santa Cruz; Christopher McKee, University of California at Berkeley; Francois Rigaut and Doug Simons, Gemini Observatory; Chuck Steidel, California Institute of Technology; and, Steve Strom (Vice-Chair), NOAO. Scientific support at NOAO was provided by Sam Barden, Robert Blum, Arjun Dey, Joan Najita, Knut Olsen, Stephen Ridgway, and Larry Stepp.

AURA Signs Letter of Intent with CELT Development Corporation

On June 11, AURA and the California Extremely Large Telescope (CELT) Development Corporation signed a Letter of Intent representing a first step toward a public-private partnership for the design and development of a Thirty-Meter Telescope. The CELT Board of Directors and the Association of Universities for Research in Astronomy (AURA) are working together to merge the CELT project with the US national effort in large telescope design and construction. The intent is to form the first public-private partnership for a giant telescope for the US astronomical community. Matching proposals for a joint four-year development program have been submitted to private and federal funding agencies.

AURA's New Initiatives Office (NIO)—a partnership of NOAO and Gemini—prepared the proposal for the NSF. NIO's approach emphasizes the technology development that is on the critical path for GSMT, as described in greater detail in the previous article of this *Newsletter*.

On its Web page (www.aura-astronomy.org/nv/nuresult.asp?nuid=67) AURA describes the status and prospects of their involvement, answers some questions, and provides a forum to receive your comments and input.

This is a milestone in implementation of the Decadal Survey, and builds on two feasibility studies, one by the CELT partners, and the other by NIO. The CELT study was initiated in the fall of 2000, and the GSMT program was formally started in January 2001. Although the two teams shared information through their public Web sites and occasional meetings, their studies were conducted independently. Each

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Frontier Science continued

study represents two years of effort at a cost of \$2 million. The CELT effort resulted in the production of a two-volume *Greenbook* (see celt.ucolick.org) in May 2002 describing their technical studies and telescope point design. The NIO effort resulted in the production of the Web-based *GSM T Book*, released in March 2002 and updated in November 2002 (see www.aura-nio.noao.edu).

Together, the CELT and AURA NIO point design efforts involved scientists, engineers, and program managers responsible for designing and building four of the world's largest telescopes and their instrument complements: the pair of 10-meter Keck telescopes and the 8-meter Gemini twins. The teams also include significant expertise in

astronomical adaptive optics, ranging from the practical experience with operating systems at Keck and Gemini to the modeling expertise at Gemini and the Center for Adaptive Optics (CfAO).

The goals of the next merged phase—the design and development (D&D) phase—are to advance a 30-meter telescope design to the Preliminary Design Review stage, and to develop key technologies that would be on the critical path if a prompt decision were made to proceed to construct a telescope of such capability. We look forward to reporting progress to the community as the fund-raising proceeds and the D&D phase goes forward.

Women in Astronomy II—Thoughts for NOAO and NSO

Richard Green, Pat Eliason, Patricia Knezek, & Nicole van der Bliek

Caltech hosted a meeting on June 27–28 to address the status of women in astronomy 10 years after the meeting that led to the Baltimore Charter. Speakers from a variety of disciplines examined employment statistics, as well as studies from behavioral psychology and sociology. Breakout groups facilitated further discussions leading to community-based action. A summary and posting of contributions can be found at the Web site for the Committee on the Status of Women, linked from the AAS home page.

This article contains our personal reflections on ways that we can interpret and apply the perspectives from the Women in Astronomy II meeting to the scientific and professional culture at NOAO and NSO. We recognize that any changes can have a broad impact in at least two ways. First, NOAO and NSO share resources, including space and personnel, both internally and with other affiliated institutions like Gemini, SOAR, and the WIYN Observatory. Second, NOAO and NSO maintain a high visibility within the international astronomical community. We acknowledge that

some issues discussed at the Pasadena meeting are broader than one institution's policy and practice; we highlight our awareness of them as well, even if we cannot offer immediate ways of addressing them.

Diversity

NOAO and NSO must reaffirm our endorsement of the value of a diverse scientific and technical workforce. Our mission specifically includes leadership for partnering in the development of major national projects, implementation of new technologies in major instruments and software programs, and provision of state-of-the-art observing facilities. *All* of these activities are team-oriented, a major sociological change in astronomical activities. That change emphasizes the value of multiple perspectives, the need for productive cooperation, the ability to build and maintain a cohesive team, and effective interaction with a broad segment of the astronomical community. Gender diversity within the staff is expected to contribute to enhancing those values. As an example, behavioral psychology studies indicate that female scientists are more likely to seek to build consensus and to create “win-win” situations.

The National Science Foundation (NSF) has recently emphasized its second criterion for evaluation: broader impact. Assuming that the distributions of innate ability are similar among gender- or ethnic-based crosscuts of our country's population, scientific research should be attracting the best and the brightest as a uniform fraction by gender and underrepresented minority. The way to accomplish that utopian goal in fact is to work toward a research community that “looks like” America.

In the meanwhile, NOAO will continue to pursue affirmative action and equal employment opportunity for scientific staff in the sense that it is understood by the federal compliance officers: aggressively recruit to assure that every “short list” is populated with the same fraction of qualified underrepresented applicants as the pool of those eligible to apply; assert standards of performance excellence in research and service (without subtle bias, as discussed below); and choose the clearly superior candidate. Only in less clear-cut cases may the longer-term question of staff balance appropriately enter into making the actual decision.

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Women in Astronomy continued

Further thoughts on attracting and maintaining a more diverse scientific workforce are presented below.

Snapshot of NOAO and NSO Scientific Staff

Van der Blik et al. presented a poster at the meeting that analyzed three snapshots of the entire scientific staff from statistics provided by Sandra Abbey and the Human Resources staff. The raw numbers of female scientists, irrespective of tenure-line status or source of funding, employed by and through NOAO and NSO are:

NOAO

1993	3 out of 52	(6%)
1998	6 out of 58	(10%)
2003	5 out of 49	(10%)

NSO

1993	0 out of 17	(0%)
1998	1 out of 19	(5%)
2003	5 out of 20	(20%)

On those three snapshot days (June 1 of the given year), there were at most three senior female scientists (Astronomer with tenure, Scientist or Senior Scientist), out of approximately 26 total in NOAO; currently there is one. In NSO, there were no senior female scientists out of an average of eight. The fraction of female postdocs is similarly limited:

NOAO

1993	1 out of 10	(10%)
1998	2 out of 12	(17%)
2003	0 out of 7	(0%)

NSO

1993	0 out of 3	(0%)
1998	0 out of 0	(N/A)
2003	0 out of 1	(0%)

The bottom line is that the fraction of female scientists at NOAO has been approximately constant at 10 percent over the last 10 years. American Institute of Physics (AIP) statistics presented at the meeting show that the fraction of female astronomy faculty is 14 percent averaged over 38 departments.

Two conclusions are apparent: a serious effort at the recruitment of female applicants, resulting in representation on nearly every short list, has not increased the fraction of female scientists in NOAO; the organization would need additional women on its scientific staff to be consistent with the national average. NSO does show a significant increase in the fraction of female scientists at the junior level in the most recent snapshot.

Climate

In the autumn of 2002, AURA asked all the female scientific staff at NOAO to fill out a questionnaire on gender issues. A small group of male staff ("matched" in number, location, job title and length of service) served as a control sample. Most responses were indistinguishable by gender: concerns were expressed about service overload, inadequate time for research, and potential inability to attract top candidates without improvement in those issues. Both groups felt they were treated fairly with respect to colleagues. The women were more concerned about the level of diversity of the NOAO scientific workforce and about the need for more infrastructure for family support.

An interpretation of the survey on attitudes combined with the employment statistics is that there are no red flags in terms of working environment, but we should continue to be attentive to developing and maintaining a climate that fosters the perception and reality of equal opportunity for success and advancement. The Women in Astronomy II meeting tangentially addressed the question of what constitutes a

favorable working environment for women. Presenters did paint a picture of favorable interactions, particularly in group settings: a respectful hearing of ideas, drawing out contributions from less assertive participants, and maintaining a noncombative style of discussion and resolution. The overall benefit of a favorable climate is making that aspect of the organization a positive when candidates consider job offers, and in subsequent retention of female scientific and technical staff.

Gender Bias

A number of speakers with behavioral and social science expertise illustrated graphically that all of us have built-in preconceptions related to gender, no matter how objective we think we are. Experiments with samples of undergraduates and faculty illustrated that men are perceived to be taller, more leaderlike, more effective presenters, and more skilled researchers. The responses to images, recordings, and documents had distributions favoring males, and they were indistinguishable by gender, i.e., both men and women favored men. Another study sent identical job applications to hiring committees under the name Joe or Jane Smith. The committees judged the application more favorably when the applicant was perceived to be male. The speakers left the strong impression that carefully executed experiments demonstrate conclusively that we are subject to strong gender bias in our judgments.

How should we conduct employment actions such as hiring and promotion in a way that explicitly recognizes these biases and approaches more closely true fairness in evaluating individual accomplishment? An important aspect of the behavioral psychology characterization can be taken explicitly into account: men tend to be more self-promoting and women more self-critical. In that case, going back to basics in evaluation makes sense. Committees must read the primary

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Women in Astronomy continued

scholarship and impose their own sense of its worth relative to hiring and promotion decisions. We can explicitly recognize that “impact” in terms of invited talks and wide dissemination of results through personal contacts is both personality dependent and gender-linked. In a service-oriented institution such as ours, we should also be cognizant of the qualifications we

qualifications for the service component, and continuing our practice of actively recruiting female candidates that we think have the necessary qualifications.

A Fundamental Issue

A recurrent theme of the meeting was the conflict between the apparent, although ill-defined, demand for all-out effort to achieve professional success versus the

while maintaining the same level of institutional accomplishment. Our budget history suggests that such a direction is unlikely.

Internal best effort is likely to be more focused on mentoring and setting clear expectations, especially for the more junior scientific staff. A standard of competitive excellence must be met, but in order to accommodate obligations to young families, it may not need to be exceeded, particularly if it is clearly defined. Mentoring can aid in focusing energy toward effective service and research productivity in a way that benefits both the scientist and the organization.

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want for our staff with respect to their likely service role, and weigh those qualifications accordingly. Without sacrificing quality, we can be conscious of the preconceptions we bring to the table and work to distinguish accomplishment from style.

By extension, we can also consider these differences in behavior in advertising for open positions. The cartoon sketch of gender-based reaction is that women would be less likely to apply for a position with a list of very specific qualifications if they felt they lacked key credentials, whereas men would be less reticent. Attracting the best female applicants in the pool for a given year may require listing a more general set of

desire to start and maintain a healthy family life or in general to achieve a balance between work and nonwork activities. It was noted that this conflict exists across the community, although family responsibilities tend to fall more heavily on females. The standard of competitiveness and achievement in today's research community mitigates against “having it all.” An institution like NOAO will be judged externally by its effectiveness in promoting community development priorities, by the competitiveness of the observing opportunities it offers, and by the research output and quality of its scientific staff. It would take a major infusion of resources on a national scale to enable lower expectations for individual productivity

Afterword

For NOAO and NSO, we can claim that the Women in Astronomy II meeting promoted two outcomes. It reinvigorated the discussion about the career paths of female scientists within our organization and the discipline as a whole. It also served to raise our consciousness about attitudes and approaches to hiring and evaluation. Our success may be measured by our ability to maintain “quality without compromise” (as the seal on one food product declares proudly), while feeling that we as staff members are judged fairly on the basis of ability and accomplishment.



Guest Column

Finding Our Place in the Cosmos

Astronomy doesn't produce technological spin-offs; in fact, we are massive consumers of technology. Astronomy doesn't contribute to the defense of the Nation; though, to borrow the late Robert R. Wilson's words to Congress about Fermilab, it is an activity that makes the Nation worth defending. Astronomy doesn't contribute to the economic output of the Nation; in fact, it is a relatively expensive activity.

So what's the point of astronomy? The two biggest questions that humankind can ask—"How did we get here?" and "Where are we going?"—are within its province. Our place in the Cosmos—and the light that astronomy can shed on it—sparks the imagination of everyone, from school child to politician, from biologist to high-energy physicist, from philosopher to film maker.

Over the past two decades we have learned much about our vast and complex Universe. The opportunities at hand for further progress are stunning, and I believe, unprecedented. We are poised to make major advances in our understanding of how the Universe began, of how the chemical elements, galaxies, stars, and planets formed, and even of our cosmic destiny.

We can trace the history of the Universe back to within a few microseconds of the Big Bang, a time when it was just a hot quark soup. We have a full accounting of the constituents of the Universe today—4 percent baryons (only 0.5 percent in stars!), 26 percent exotic dark matter (with 0.1 percent to 5 percent in neutrinos), and 70 percent mysterious dark energy. We also know that the Universe is spatially flat (uncurved) and that the expansion is speeding up, rather than slowing down. We are beginning to amass evidence that the Universe went through an earlier period of cosmic speed up, called inflation.

The questions ripe for answering include, "What is the dark matter?" "What is the nature of the mysterious dark energy?" and "Did the largest structures in the Universe begin as quantum fuzz, as predicted by inflation?" Even the question of how the Universe came to be is coming within the realm of science.

Because the early Universe takes us back to a time when particle energies were far greater than those available today at the most powerful accelerators, and because the most basic features of the Universe we observe today—its composition, spatial curvature, and the structures that exist—were shaped by its earliest evolution, astronomical observations provide a unique window to study the very nature of matter, energy, space, and time.

The Hubble Deep Field took us back to the time when galaxies like ours were forming, and Keck and other ground-based telescopes have begun to reconstruct the history of galaxy formation. The Sloan Digital Sky Survey has discovered the most distant quasars, and the Chandra X-ray Observatory has imaged their central black hole engines in X-rays. Rapidly improving infrared capabilities, on the ground and in space, are revealing the birth of the first galaxies, and the WMAP satellite found the footprint of the first generation of stars in their ionization of the intergalactic medium. The distribution of dark matter in galaxies, cluster, and on even larger scales is now routinely imaged by measuring how it distorts the images of distant galaxies, and the same technique will be used to study the effect of dark energy on the expansion rate of the Universe.

With the ambitious projects astronomers have in mind—from the James Webb Space Telescope to the Giant Segmented Mirror Telescope—it is likely that within the next decade we will begin studying in detail the formation of the first stars and galaxies.

It is hard to match the excitement of cosmology, but in the past ten years planetary science has come close (okay, maybe even matched or exceeded it). With extrasolar planets now outnumbering planets in our own solar system by 10 to 1, we can start addressing the big questions: "Where is our nearest neighbor?" and "How common are planetary systems that can support life?" The study of extrasolar planets thus far has brought more surprises than answers, along with many new questions. It has also created new opportunities for exciting interdisciplinary work with biologists. I think it is a safe bet to predict that one way or another, we will find evidence for life beyond our planet within the next 30 years.

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Finding Our Place in the Cosmos continued

These great opportunities for discovery are laid out in two recent National Academy studies: the McKee-Taylor Decadal Survey and the Quarks to Cosmos study that I chaired. The reports discussed the tools necessary to realize the science. These include a wide-field space telescope (SNAP), a giant (30 meters or larger) ground-based telescope (GSMT), a space-based gravity wave detector (LISA), a large-aperture, wide-field ground-based telescope for weak lensing studies (LSST), and new cosmic microwave background experiments optimized for studying polarization.

While identifying opportunities and prioritizing projects is a familiar decadal exercise in astronomy, both reports had something new and very important to say: *To realize the grand opportunities before us and to achieve our ambitious goals, we will need to change our culture and the way we operate, going beyond our traditional habits.*

More than ever before, ground- and space-based astronomy must be coordinated. Astronomical research is now supported significantly by three federal agencies—DOE, NASA, and NSF—and cross-agency cooperation and coordination is essential. Likewise, astronomy is supported by both public and private funds, and the two sectors must work as partners rather than as adversaries. Projects in astronomy are becoming larger, and international partnering, cooperation, and coordination will not only become more common, but will be more necessary.

The working style in astronomy must evolve. Targeted “astronomy experiments” (like the Sloan Digital Sky Survey and the MACHO project) will become more commonplace. The line between physics and astronomy has become thinner and fuzzier, and astronomers and physicists will need to work together. Astronomers will also have to use all the windows on the Universe available, including gravitational waves and particle accelerators. The virtual observatory of archived

observations and its data mining will rival fresh observations in their power to probe the Universe and answer deep questions. Some existing facilities will have to be closed to make room for new facilities. As our discoveries go beyond what can be shown in a beautiful optical image that speaks for itself, we will have to work harder to convey the meaning and excitement of these discoveries to the public.

Astronomy is changing, but its fundamental attraction has not. It still has a unique power to engage the public and inspire the next generation of scientists and engineers, and not just astronomers. More than any other science, astronomy is an ongoing adventure to understand our place in the cosmos, one in which both scientists and the public alike can share in the excitement.

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(Starting October 1, Michael Turner will serve for two years as the Assistant Director for Mathematical and Physical Sciences at the National Science Foundation)

Announcement of Opportunity Blanco Instrumentation

In the near future, NOAO plans to make an Announcement of Opportunity to solicit proposals for building a new instrument for the Blanco 4-meter Telescope. The contribution of the external institution or consortium would be rewarded with substantial guaranteed observing time (up to about 30 percent per year). We are anticipating that this new instrument would be ready for installation in the 2007–2008 time frame. The Announcement will be made on the NOAO (www.nao.edu) and CTIO (www.ctio.nao.edu) Web pages.