Association of Universities for Research in Astronomy

Comments on the draft NSF Strategic Plan and the Relationship of Astronomy to the American Competitiveness Initiative

July 17, 2006

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AURA welcomes the opportunity to comment on the draft version of NSF's Strategic Plan for FY 2006 – 2011. On your request for comments web page you ask what are the strengths and weaknesses of the draft plan and also ask for other comments. The draft plan states "*NSF has major roles in the American Competitiveness Initiative in the areas of research, infrastructure, and education*". In what follows we will show that many of the NSF supported astronomy related activities, in particular those carried out at the three NSF centers managed by AURA, are closely aligned with the objectives and goals of the ACI in each of the three legs of this ACI tripod – research, infrastructure, and education. This combined with the great popularity of astronomical sciences amongst people of all ages argues strongly that astronomy can and should play an important and visible role in the strategic planning process of the National Science Foundation, in furthering the goals of the plan that results from this process, and in supporting NSF's roles in the American Competitiveness Initiative in the three key areas noted.

INTRODUCTION

Astronomy is one of the most publicly accessible and visible of the physical sciences. Reports on the latest findings in astronomy and astrophysics appear on the front pages of major newspapers regularly and generate a high level of public excitement. NSF should maximize the advantage that accrues from this high level of visibility of astronomical sciences for promoting its broad agenda for science in the United States.

With the announcement of the American Competitiveness Initiative (ACI), President Bush's administration explicitly recognizes that past "Federal investment in research and development has proved critical to keeping America's economy strong by generating knowledge and tools upon which new technologies are developed." The centerpiece of the ACI is to double the investment in its key science agencies that support basic research in these two areas in the next ten years.

The Association of Universities for Research in Astronomy, Inc. (AURA) manages for the NSF the largest ground based optical-infrared observatories that are available for use by the entire US astronomical community on a competitive, peer reviewed basis. Through a cooperative agreement with NASA, AURA also manages the Space Telescope Science Institute (STScI) which is responsible for the science operations of the Hubble

Space Telescope as well as for planning the James Webb Space Telescope. This facilitates valuable synergism between ground and space based observatories.

Many of the functions that the astronomy enters managed by AURA for the NSF carry out in accordance with their strategic plans and goals are also strongly aligned with the objectives and goals of the ACI. In the sections below we will enumerate these particular goals and objectives and illustrate how the AURA centers support them. Here we give a brief summary

The ground-based observatories that AURA manages, the National Optical Astronomy Observatory (NOAO), the Gemini Observatory, and the National Solar Observatory (NSO), permit members of the astronomical community to carry out front line research projects on the full panoply of astronomical targets ranging from the Sun to the most distant galaxies. These projects range from ones that are directly relevant to everyday life on Earth, such as various aspects of solar studies, through ones that address the question of the possibility of life elsewhere in the Universe, and to those that address questions of "ultimate origins" – how did the Universe begin and how will it end. As we will describe below, astronomical research has had a number of valuable technology spin-offs with strongly positive implications for society. Therefore, with their merit-based peer reviewed research programs AURA's astronomy centers make important contributions to NSF's work on fulfilling its role in support of one of the three legs of the ACI tripod – research.

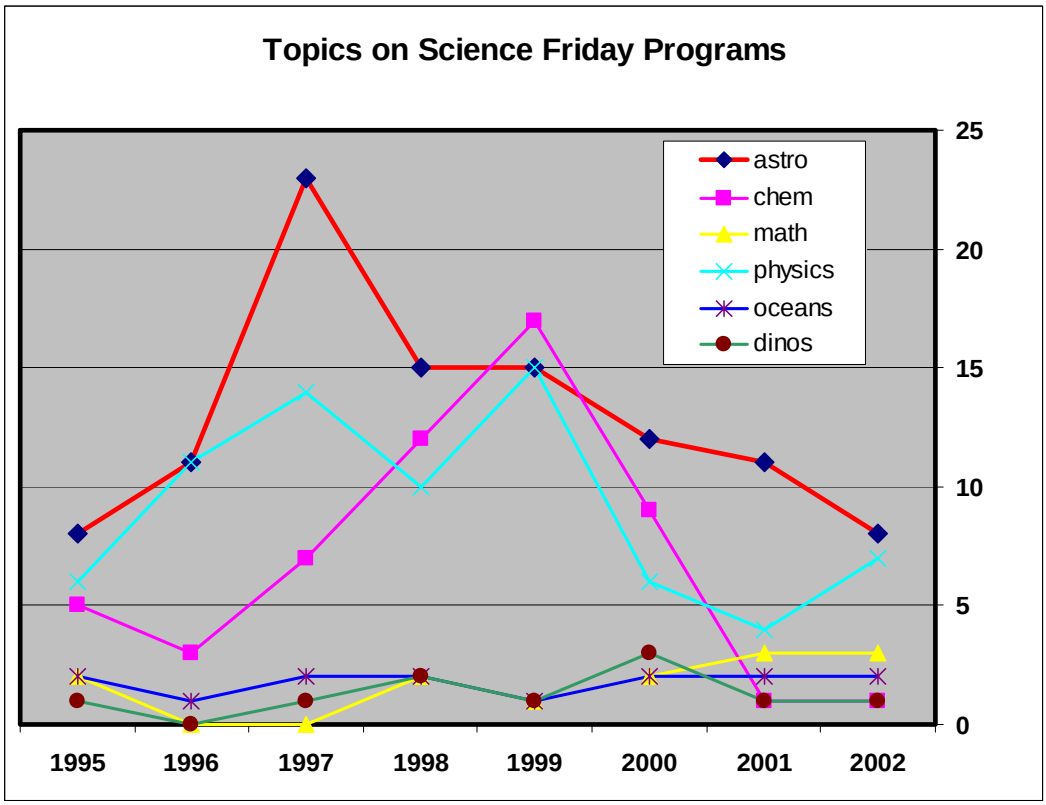
AURA and its centers have long been committed to education and public outreach both in their local communities and nationally. The involvement in education is at all levels. The centers carry out a wide range of active and successful programs aimed at teaching K-12 teachers about astronomy and how best to convey their new knowledge to students. All of the centers participate in programs, especially NSF's REU program, to give college and university undergraduates hands on experience in astronomical research. At the graduate level, nearly one-third of PhDs granted in astronomy each year in the US are based on data obtained on the telescopes of the AURA ground based observatories. Thus AURA and its astronomy centers strongly contribute to helping the NSF fulfill its role in supporting the second of the three legs of the ACI tripod – education.

In looking to future infrastructure for astronomical research from the ground, AURA and its centers have become heavily involved in the planning and development of three major new facilities: the Advanced Technology Solar Telescope (ATST), the Large Synoptic Survey Telescope, and a Giant Segmented Mirror Telescope. The first of these will be operated by the NSO. The other two represent unique opportunities for the NSF to establish public-private partnerships in the construction and operation of major research facilities. So with its work on these three highly innovative new research facilities all of which have been given high priority by the most recent NAS/NRC decadal survey of astronomy, AURA is helping NSF to fulfill its role in support of the third leg of the ACI tripod – infrastructure.

THE HIGH VISIBILITY OF ASTRONOMY AND ITS POPULARITY

Astronomy is one of the most publicly accessible and visible of the physical sciences. Reports on the latest findings in astronomy and astrophysics regularly appear on the front pages of major newspapers and generate a high level of public excitement. Astronomy is an easy and relatively inexpensive (compared to other sciences) way to signal to the world a country's commitment to science and technology. Astronomy is deeply rooted in almost every culture by virtue of its practical applications and its philosophical implications. It shows us a universe which is vast, varied and beautiful; it shows our place in time and space, and gives us a "cosmic perspective." It harnesses curiosity, imagination, and a sense of shared exploration and intellectual excitement. It shows "how small our bodies, how large our minds" (Henri Poincaré). It helps to advance physics and the other sciences by providing a cosmic laboratory with extreme environments. In its own right, it is one of the most rapidly moving sciences of our day. For all of these reasons, astronomy has the potential to increase public interest in science, and to attract young people to study science and engineering. It provides an enjoyable hobby for millions of people. (From the *Planetarian*, vol. 24, #3, September 1995).

In this section we examine some quantitative measures of astronomy's popularity amongst the general public.



Science Friday: "Science Friday" is a weekly program on National Public Radio which gets partial support from the NSF. Each program typically treats in some depth a few often diverse topics of current interest. We have tallied up how often one of the topics is

astronomy or astrophysics related. This tally is based on material on the show's web page and from Ira Flatow, the program's host. The graph above shows the results for the physical sciences. We singled out dinosaurs since the statement is often made that astronomy and dinosaurs are the two hottest topics. This graph shows that not only does astronomy win hands down over dinosaurs but it handily beats out all other physical sciences for the 8 year period shown. Only when we look at somewhat "softer" sciences do we find total numbers comparable to or slightly greater than astronomy's; two of these in particular are programs dealing with health and with environmental issues.

When we spoke to Ira Flatow, he said: "I think astronomy is very popular with the general public because it's part of our inquisitiveness to know if there is other life 'out there' besides our own… "We choose astronomy subjects [for Science Friday] according to news reports."

The New York Times: Next consider news reports in the New York Times over a 6 year period. In the accompanying table "astronomy" does not include space science, rocket launches, etc. On the Science Page itself astronomy easily beats out dinosaurs, human evolution, and nanotechnology. "Chemistry" includes many articles on health while "physics *minus* astronomy" is the repository for many articles on technology, fuels, etc. In looking at all articles about astronomy, we see that on average there is one every 3.5 days in the Times.

New York Times 1/1/2000 to 4/19/2006				Science News
Topic	All references	Front page only	Science Section	All references
Astronomy	626	19	161	608
Dinosaurs	909	23	98	102
Human evolution	120	9	55	55
Anthropology	1024	30	180	237
Fossils	473	23	128	224
Global Warming	2217	133	179	81
Geology	588	21	95	151
Chemistry	788	37	235	787
Physics - astronomy	2609	104	617	585
Nanotechnology	221	7	57	108

Science News: The audience for "Science News" is undoubtedly more selective than that for the New York Times and probably closer in demographics to listeners of Science Friday. The accompanying table shows, though, that only articles on chemistry (which again include a significant fraction of ones relevant to health) top astronomy for sheer numbers. Again, dinosaurs are way down with respect to astronomy.

Podcasting and Slacker Astronomy: Next, we look at the new phenomenon of "Podcasting" – programs prepared especially for downloading on one's computer and then played back on iPods. In February, 2004 the first podcast of feature astronomy was begun; it is called "Slacker Astronomy" was begun. The following information is drawn from a paper entitled: "Astronomy Podcasting: A Low Cost Tool for Effecting Attitude in Diverse Audiences" submitted to Astronomy Education Review by Gay, Price, and Searle. By 2006 January, 5 of the top 10 science podcasts in the iTunes Music Store were astronomy shows. Three of these were from NASA, the 4th was Slacker Astronomy. "On October 17, 2005 Slacker Astronomy was ranked 28th overall [out of 25,000+ podcasts] placing it in front of Business Week – Cover Stories (31) and News Hour with Jim Lehrer (32) in the ratings." There are about 14,000 listeners each week for the program and between its inception and January of 2006 episodes of Slacker Astronomer were downloaded 739,000 times.

Attendance at Planetarium shows: There are about 160 planetarium in the United States with dome diameters greater than 12 meters (40 feet). Attendance statistics are most accurate for domes of this size, according to Loch Ness Productions. Their estimate is that 13 million people a year attend the shows in these planetarium.

Other indicators of astronomy's popularity: The United States has more than 700 astronomy clubs, one-third of the world's total. There are also about 500 amateur astronomy observatories in the US. This level of interest supports three major popular level magazines devoted exclusively to astronomy – *Sky and Telescope, Astronomy,* and *Night Sky*. Articles about astronomy regularly appear in more general science oriented magazines such as *Discover* and *Scientific American.* New Jersey will be requiring astronomy as part of its state science standards. Both the Boy and Girl Scouts have astronomy merit badges.

Astronomy's Popularity amongst undergraduates: Our own informal survey of 8 big public universities found that 25% of undergraduate students will have taken an introductory astronomy course before graduation. Nearly all of these students are non-science majors. This is consistent with the nearly 10 year old AIP 1997 Astronomy Department Annual Survey of top 29 NRC ranked astronomy programs which showed that on average one in four of the 545,000 under graduates at these 29 universities will have taken one introductory astronomy course before graduating. It is important to note that astronomy, unlike all other physical science courses – including mathematics – is never a required course for some group of majors (astronomy majors are always a negligible fraction of the student body and they will not be taking the survey courses).

With one-quarter of a million students taking intro astronomy each year, (4-year colleges and universities in the above referenced survey plus programs at 2 year colleges)

astronomy makes a valuable contribution to the scientific literacy of the population of the US and its competitive ability. Therefore, it is important that those who teach these courses, in both 2- and 4-year colleges be well trained, not only in what they are teaching, but also in how to teach. Programs actively pursued at AURA managed observatories have these goals as their focus.

AMERICAN COMPETITIVENESS INITIATIVE: EDUCATION

Given astronomy's popularity and the fascination that even young children have with it, why isn't astronomy taught more at the K-12 level, In the same issue of the *Planetarian* quoted in the previous section another article gave six reasons why this might be the case and noted that the issue is not confined to the US alone but seems to be endemic to all countries. The reasons are:

1. Few teachers, especially at the elementary level, have any training in astronomy;
2. Teachers think that astronomy must be technical and mathematical, and requires elaborate teaching equipment;
3. Simple, inexpensive, "hands-on" activities are needed-preferably ones which get around the problem that "the stars come out at night, the students don't;
4. Inappropriate teaching techniques fail to overcome students' ingrained misconceptions about physical and astronomical phenomena;
5. Many students (especially girls) are turned off science at an early age;
6. Scientific illiteracy is widespread among students and the public.

The AURA managed observatories conduct a number of diverse Education and Public Outreach (E/PO) programs that include as their goals direct responses to these six "problems". Many of the larger colleges and universities in the US also have in place programs that attempt to respond to these problems.

The AURA centers play an important role in science education at all levels from secondary schools through undergraduate level to the training of future astronomers in graduate schools. Activities at the secondary school level are particular aimed at teachers with the goal of training a cadre of them in the methods of science education and helping them to acquire the skills and tools that they will need to be successful science educators. At the undergraduate level there are activities aimed at giving students hands on experience in astronomical research, as well as providing materials to help train students in a number of related scientific and technical areas. At the graduate level, about one-third of all Ph.Ds granted in astronomy each year in the United States are based on data obtained with telescopes at the AURA ground based centers.

NOAO is rapidly becoming a world leader in astronomy-related education and public outreach, thanks to a broad range of formal and informal programs targeting a wide audience that includes teachers, students, the general public, advanced amateur astronomers, museum visitors, and the media.

The Gemini Observatory is deeply involved in training and education on many levels. These range from the traditional training of the emerging generation of scientists through participation in postgraduate training in astronomy, to major contributions to the awareness of the future generation of citizens found in the K-12 levels.

The National Solar Observatory, although with a considerably smaller staff than either NOAO or Gemini, has conducted strong student programs since its inception in 1983. It has participated in both the REU and RET programs from their beginnings. A large fraction of active solar astronomers are alumni of the NSO summer programs. More than 30% of the participants in the program have been female, with this number growing to ~45% over the past several years.

The ACI And Secondary Educations

The ACI statement on secondary education: There should be "A system of education through the secondary level that equips each new generation of Americans with the educational foundation for future study and inquiry in technical subjects and that inspires and sustains their interest … Education is the gateway to opportunity and the foundation of a knowledge-based innovation driven economy… By improving the quality of math, science, and technological education in our K-12 schools, thus engaging every child in rigorous courses that teach important analytical, technical, and problem-solving skills, we will prepare our citizens to compete more effectively in the global marketplace."

The involvement of AURA's Centers in K-12 outreach and teacher training: All three of the NSF supported AURA centers have active and successful programs for the training of teachers at the K-12 level. The popularity of these programs amongst teachers and amongst those students who are subsequently taught by these teachers is a good example of the appeal of astronomy to all age groups. Increased NSF funding for these and similar programs such as regional summer workshops for K-12 teachers on how to do better and more astronomy and physical science education in their classrooms would clearly support ACI's goals.

- Journey Through the Universe

  NOAO/Gemini and Keck observatories in collaboration with the Hawai'i State Department of Education had a successful proposal to have the Big Island accepted into the Challenger Center's NASA-funded Journey Through the Universe program. This program (which began in early 2005) provides teacher training and significant K–12 classroom experiences for students, educators and the public of the Big Island. Hilo, HI, is one of only four communities awarded this honor in 2004. The District Superintendent of Hawai'i's State Department of Education, Dr. Valerie Takata, recently commented: *My principals are thrilled and* [the program has] *gotten rave reviews from their teachers and students. Kids want to be scientists!*

- NOAO and Project ASTRO (elementary and middle schools)

  NOAO is completing its tenth year as a flagship site of the Project ASTRO program (Astronomers and Educators as Partners for Learning) developed by the Astronomical Society of the Pacific. It is one of NOAO's primary tools for local outreach (Tucson) to elementary and middle school classrooms. This and NOAO's other local outreach work has reached more than 25,000 Tucson-area grade and middle school students with engaging, hands-on activities in astronomy and space science.

  As part of its involvement in Project ASTRO, NOAO established forty astronomer-educator classroom partnerships in FY 2005 via training of 40 teachers and 47 astronomer partners at NOAO workshops, bringing the totals for the past decade to more than 350 attendees trained and more than 240 astronomer-educator partnerships developed, with an estimated 70 percent active beyond their first year. These partnerships have directly impacted more than 28,000 students at over 100 schools in Southern Arizona with fun hands-on activities in astronomy and space science.

- NOAO's TLRBSE program (Teacher Leaders in Research Based Science Education (TLRBSE) program (high school level)

  NOAO's flagship TLRBSE program has pioneered the use of astronomical observing as a unique tool in teacher retention and renewal, and as a way to foster genuine teacher-student driven research. The original vision of this program has been expanded to include two-week summer workshops as well as later return visits by TLRBSE-trained high school teachers and their students. Teachers who participate in TLRBSE use several of the night-time telescopes on Kitt Peak as well as the McMath-Pierce Solar telescope to carry out peer-reviewed research projects. The program has trained more than 120 teachers between 2002 and mid 2006.

- Gemini's Star Teachers Program:

  On local and regional scales, Gemini's educational outreach program has made a significant impact in many areas. For example, the Observatory's StarTeachers program has organized exchange visits between K–12 teachers on Hawai'i's Big Island with their counterparts near Gemini South in La Serena, Chile. To date, twelve teachers (six from each country) have participated in a program of face-to-face classroom exchange visits utilizing extensive videoconferencing. This program has exposed several thousand students to the wonders of astronomy and its advanced technologies. Thus, astronomy has provided a unique link between two culturally diverse bi-hemispheric communities. The Gemini Observatory has also sponsored local teachers in attending major science meetings in their area, with Gemini staff acting as science interpreters.

  The Star Teachers program has been so effective that the Chilean Ministry of Education awarded the Observatory the Gabriella Mistral Medal for educational excellence in 2003. This was the first time this prestigious award has been awarded to

a non-Chilean organization. In mid-2005, six more teachers will participate in the second Star Teachers exchange.

- NSO's Efforts at the K-12 level

  NSO participates in the Southwestern Consortium of Observatories for Public Education (SCOPE) and in Project ASTRO. Approximately 30 K-12 teachers per year visit Sacramento Peak as part of co-sponsored workshops. NSO currently hosts four RET teachers each summer who work closely with staff and REU students on research projects and outreach. NSO also presents teacher workshops and exhibits on a range of topics at the National Association of Science Teachers annual convention. IT also works with the organizers of the American Indian Science and Engineering Society's conventions to provide exhibits and display material on the Sun.

  As part of the ATST project, NSO is developing two flexible K-12 curriculum projects that can be deployed as traveling museum or classroom exhibits or activities. One, *Magnetic Carpet Ride*, will provide education modules and public programs that emphasize the magnetic nature of the Sun and solar activities and that tie in with the rise of sunspot Cycle 24 (2007-08) and the International Heliophysical Year (2007). The second, *The Goldilocks Star*, will build on a new research initiative by NSO to characterize the activity cycles of stars that might host planets suitable for life in the context of our Sun's variability.

  The Global Oscillation Network Group, working with French partners, is developing an education CD using GONG data from the 2003 transit of Mercury and the 2004 transit of Venus. Entitled *Sizing Up Your Solar System* will provide classroom exercises to complement the solar system model described in the next sub-section.

<u>Programs in Spanish Language Astronomy Education</u>: There are sizable Hispanic communities around the AURA centers in Arizona and New Mexico. Also AURA's role as "observatory manager" in Chile is growing rapidly. In order to better connect with these communities, and convey to them the excitement of astronomy, NOAO has stepped up its activities in Spanish-language astronomy outreach. These activities range from the online Education Center (www.astronomyinspanish.org) to a series of bilingual educational videoconferences between Tucson and La Serena dubbed "ASTRO-Chile."

- Recently (2006 May), the Large Synoptic Survey Telescope Project chose to put its telescope on Cerro Pachon near the Gemini South Telescope. LSST will be the world's largest and most powerful telescope dedicated to surveying the sky. Working together with the LSST Project, NOAO will further expand its activities in Spanish-language astronomy program with special emphasis on the many exciting discovers and significant results that are expected to flow from the LSST when it begins operating in 2012. These new programs will be used extensively in the US as well as in Chile.

- Gemini outreach efforts in Chile, with support from CTIO, have facilitated the establishment of a volunteer astronomy program called Red LaSer (a Spanish

contraction for "Network La Serena"), a portable planetarium in the La Serena region and surrounding areas . This independent group of Chilean educators and university science students has carried the StarLab program far beyond that which Gemini and CTIO alone could do. Thousands of students, their teachers and many members of the general public have benefited from these programs

Other significant E/PO efforts by AURA Centers: The most common way in which the public at large interacts directly with the AURA centers is via visits to these centers - the telescopes themselves in the case of NOAO and NSO and to Gemini's operations center in Hilo. Thus all of the observatories actively support well equipped and well staffed visitor centers either at the telescope sites themselves or in close proximity to their headquarters. "Virtual" interaction with the observatories via their web sites is probably even more popular. In this section we describe some of these activities as well as other ways in which the observatories reach out to the public. The hands-on experience of observatory visits, often in conjunction with seeing real astronomers in action, presents an unrivalled opportunity to raise the scientific consciousness of the public. Activities such as these are very much aligned with ACI's goals.

- Kitt Peak attracts more than 60,000 public visitors per year, with the vast majority served by the staff, exhibits, tours and special programs of the Kitt Peak Visitor Center. Both KPNO and NSO are active in supporting the visitor center. The programs include the most in-depth night-sky observing experiences in the world. Also, the McMath-Pierce Solar Telescope is the only telescope on Kitt Peak that visitors can see in operation since it observes during the daytime and it has a visitors gallery.

- The NSO Visitor Center on Sacramento Peak houses solar, general astronomy and forest displays showing how the sun affects forestation. There are numerous hands on displays covering everything from the size scale of the solar system to properties of infrared and polarized light including a spectrograph fed by a live solar beam. A new hands-on solar optics bench display is in early planning. Approximately 20,000 visitors per year visit the Center and take both guided and self-guided tours of the telescope facilities.

- The Astronomy Education Review Website at NOAO (http://aer.noao.edu/) averages 150,000 hits and 6,600 visits from 5,500 separate sites per month.

- NSO is designing a solar system scale model that will stretch from Sunspot, NM, to Alamogordo, and that will provide highway markers at appropriate locations along NM6563 and lead the public to the Sunspot Astronomy and Visitor Center and a unique 18-foot-diameter walkthrough model of the Sun (see also K-12 below). NSO staff also actively participate in a number of astronomy and science themed events throughout Arizona and New Mexico.

- Following NOAO's success with the ASTRO program, it became a founding site of the new Family ASTRO program starting in 2002. This program trains people to be event leaders for informal science activities relevant for after-school and weekend

programs. Several hundred families have participated in NOAO-sponsored Family ASTRO events through mid-2005. NOAO has trained 55 Family ASTRO event leaders, including 31 teachers, 8 Girl Scout leaders and seven amateur or professional astronomers.

- Mauna Kea Astronomy Center

  Gemini is a key supporter of the University of Hawai'i Hilo in its development of the recently completed Mauna Kea Astronomy Education Center (MKAEC), a $25M NASA-funded planetarium and astronomy and Hawai'ian cultural museum across the street from the Gemini North Operations Center in Hilo. Gemini and the other AURA-South observatories in Chile have a similar relationship with the local Mamalluca astronomy center and planetarium at Vicuña, Chile near Cerro Pachón.

- An NOAO image gallery on the world wide web has had about 1.5 million page views per year since 2002, thus underscoring the purely visual appeal of astronomy to many people.

- Gemini Observatory has prepared a number reports for the general public. A noteworthy example on a local scale was the 48-page tabloid/newspaper insert on astronomy in Hawai'i, coordinated by Gemini public information staff and published in June 2003 in the Hawai'i Tribune-Herald. In February 2005, a similar tabloid was published in Spanish by the Chilean newspaper El Dia.

- Gemini images and video comprise an especially important resource for media distribution and use. An extensive collection of high-quality images have been produced and made available to the media over the past five years, resulting in broad use of many of these images in astronomy textbooks and by local, national and international media.

In addition to the programs at the AURA centers, a number of major Universities run successful science education programs at the K-12 level with which the astronomy departments are closely involved. For example, the University of Texas, Austin, has a program called "UTeach". It prepares majors within the College of Natural Sciences to teach K-12, including certification, teacher-training, and peer and advisor support for retention after graduation. UTeach is already making a noticeable contribution to the number of qualified physics teachers graduating from college in Texas each year. As the table below demonstrates, its popularity has more than tripled since it was started in 1997. Examination of the demographics of the students enrolled in the UTeach program for the Spring 2005 semester reveals that 57% are female and that 23% are Hispanic or African-American .

The ACI and Higher Educations

The ACI on higher education: "Sustained scientific advancement and innovation are key to maintaining our competitive edge, and are supported by a pattern of related investments in … institutions of higher education that provide American students access

Table 1. UTeach Enrollment History (Fall 1997 – Spring 2005)

	New Recruits	Enrollment*	Graduated*	Teaching
Fall 1997	28	28		
Spring 1998	20	47		
Fall 1998	36	68		
Spring 1999	39	90		
Fall 1999	65	133		
Spring 2000	53	154	2	1
Fall 2000	81	191	7	4
Spring 2001	59	188	26	21
Fall 2001	69	189	20	16
Spring 2002	63	191	26	22
Fall 2002	94	276	17	11
Spring 2003	99	368	23	22
Fall 2003	103	407	15	14
Spring 2004	80	410	51	43
Fall 2004	101	412	25	21
Spring 2005	80	403		
Total	1070	n/a	212	175 (83%)*

to world-class education and research opportunities in mathematics, science, engineering, and technology. It is important that our country maintain an adequate flow of well-trained STEM workers and for that reason President Bush supports a number of programs across the Federal government that seek to increase access to college and to recruit and retain students in STEM majors at the undergraduate and graduate levels."

The AURA Centers and Undergraduate Education and Training: All three of AURA's NSF funded centers have had significant, long term commitments to the education of both undergraduates and graduate students. For undergraduates, this usually consists of visits of a few months at one of the sites where they work with staff astronomers on research projects that usually result in published papers in refereed journals. For graduate students this can involve independent research on the telescopes to long term visits under the supervision of staff astronomers.

- The NOAO Research Experience for Undergraduates (REU) program

  Between 2000 and 2005 at KPNO in Tucson and between 1999 and 2004 at CTIO in La Serena there have been a total of 61 students – 36 females, 25 males representing a variety of colleges and universities in the United States. Both observatories subsidize REU students' attendance at a subsequent American Astronomical Society meeting, and nearly all REU graduates publish their research in poster papers at these meetings. An additional 12 Chilean undergraduates participated in the similar

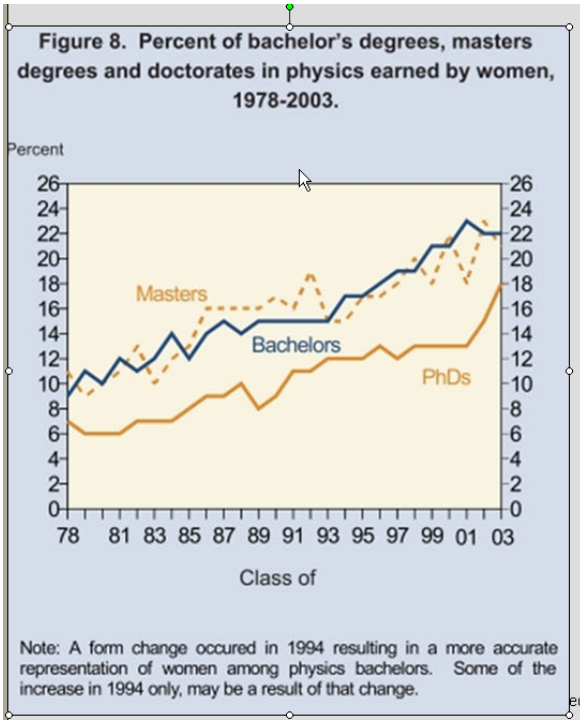
Práctica de Investigacíon en Astronomía (PIA) Program in parallel with the U.S. REU students, including two females.

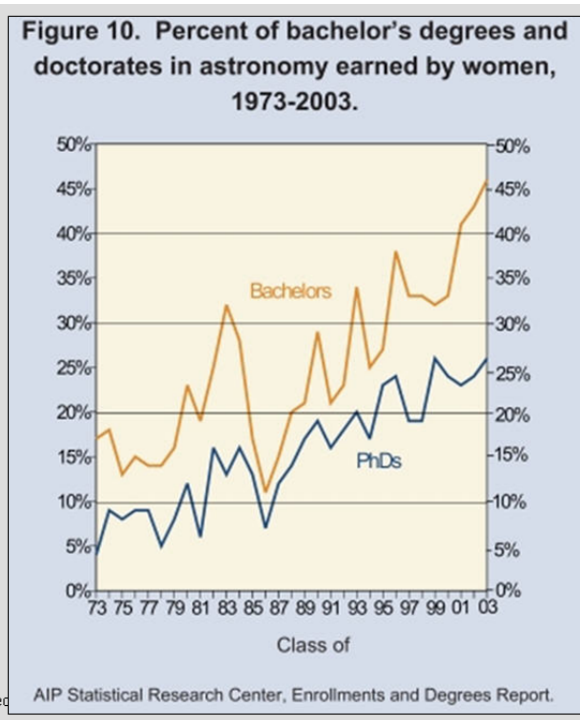
- The NSO REU Program

  NSO typically host between 5 and 10 REU students each summer. Several of these students from the most recent years have gone on or are currently enrolled in Ph.D. programs in solar astronomy including the development of instrumentation for solar observing.

- The Gemini Observatory at both its Hawai'i and La Serena sites offers internships for young people in many programs, ranging from science and engineering to outreach and administration.

Women in astronomy and Physics: As the figure below shows, for whatever the reasons, female students are being attracted to astronomy at the graduate and undergraduate levels at a rate that has gone up substantially more over the past 20 to 30 years than for physics. From 1978 to 2003 while the fraction of women earning bachelors degrees in physics has doubled, in astronomy it has tripled. The percentage of doctorates granted in astronomy to women has also increased relative to that in physics over the same period of time, though not as markedly as the percentage of bachelors degrees.





Training of graduate students in Astronomy: KPNO, CTIO, and the United States' National Gemini Science Center play a vital role in supporting U.S. graduate education in astronomy—not just in granting time to thesis programs, but also in subsidizing travel and lodgings for graduate students during observing visits. Every year there are approximately 150 Ph.D.s granted in astronomy and astrophysics in the United States,

40-50 of which rely on observing programs using NOAO telescopes at KPNO, CTIO, and the U.S. share of Gemini time. Thus, every year nearly one-third of the Ph.D.s in astronomy granted in the U.S. are based on usage of telescopes at the NSF supported AURA centers. In addition, NOAO staff often serve as thesis advisors to graduate students, particular from the universities that are in close proximity to the offices.

NSO annually hosts students working on advanced degrees. Typically, NSO staff members serve as adjunct faculty and act as local thesis advisors. Their work has included development of image reconstruction for AO systems, high-resolution observations of magnetic structures using adaptive optics, the development of an IR camera system, and the prediction of solar activity.

AMERICAN COMPETITIVENESS INITIATIVE: WORKFORCE TRAINING

The ACI statement: "Education, training, and retraining provide individuals with better career options, opportunities for promotion, and the ability to contribute to the U.S. innovation enterprise. According to the Bureau of Labor Statistics, 26 of the 30 fastest growing job categories require some type of post high school education or training." Therefore, the ACI includes a commitment to community colleges: "Community colleges make great training providers because they are affordable, accessible, and perhaps most important, adaptable. Community colleges are able to track changing local labor conditions and partner with local employers to provide training geared toward the jobs that are in demand."

The AURA centers have programs that support technical training of the workforce and a commitment to community colleges. These can serve as models for what can be done in other fields supported by NSF. We give some examples here.

- Gemini has led an effort by all of the observatories on Mauna Kea to encourage the establishment of a combination two-year and four-year electronics technology degree program within the University of Hawaii system. This "two-plus-two" program would include multiple community colleges offering a coordinated Associate of Science degree program, which would produce employable technicians, and at the same time offer these graduates the option of moving into the third year of a four-year Bachelor of Science technology program. While the immediate objective of such a program would be to provide a local source of trained technical staff for the observatories on the islands of Hawai'i and Maui, it will have a much broader reach for growing technology industries in the State. With input from the observatories, Hawai'i, Maui, and Kauai Community Colleges are developing the program with a projected start date of August 2006. The University of Hawai'i, West Oahu will offer the Bachelors component of the program.

- Another facet of the Gemini educational outreach program is the sparking of interest in children and young adults regarding careers in science and engineering. The science, engineering, and administrative groups at both telescopes also provide a variety of postgraduate internships with the aim of developing tomorrow's leaders in these key areas

- The NOAO educational outreach group is currently the lead organization for the design, development, and production of six major "kits" for informal optics engineering education via an NSF grant-funded program with the Society of Photo-optical Instrumentation Engineers (SPIE) and Optical Society of America (OSA) named "Hands-On Optics." This new initiative, which has great potential for expansion through such areas as adaptive optics and interferometry, will constitute a significant contribution to the emerging and underserved field of technology education in the U.S.

- NOAO has also added a major grant funded initiative to foster professional development in astronomy outreach for the staffs of small science museums and nature centers called *Astronomy From the Ground Up*. This is done in partnership with the Astronomical Society of the Pacific and the Association of Science-Technology Centers.

AMERICAN COMPETITIVENESS INITIATIVE: RESEARCH AND THE TOOLS OF RESEARCH

The ACI statement on the Tools of Research: "Sustained scientific advancement and innovation are key to maintaining our competitive edge, and are supported by a pattern of … Federal investment in the tools of science—facilities and instruments that enable discovery and development—particularly unique, expensive, or large-scale tools beyond the means of a single organization."

The ACI Statement on Research: "The ACI enhances basic research programs in priority agencies that employ best practices for identifying and funding the most promising research ideas. Careful planning, strong technical advisory mechanisms, and systematic merit-based peer review are acknowledged methods for optimizing research success."

AURA was founded in 1957 to create astronomical observing facilities that would be available for use by all qualified researchers and to serve the community through public outreach, education, and dissemination of information. AURA's mission is "*To promote excellence in astronomical research by providing access to state-of-the-art facilities."* To accomplish this AURA develops and operates national and international centers that enable peer reviewed merit-based research by members of the astronomical community. Many of the observing programs at AURA center facilities are themselves supported by merit based, peer reviewed grants to PIs from the AST division of the NSF.

Within the MPS division of the NSF, the ACI has placed emphasis on the "Eleven Science Questions for the New Century" from the NAS/NRC report *Physics of the Universe* of the National Science and Technology Council. NSF supported astronomy can play an important role in addressing six of these eleven questions. Indeed, four of these six questions can be addressed with telescopes at the AURA centers or that are part of TSIP: What is dark matter? What is the nature of dark energy? How were the elements from iron to uranium made? And, did Einstein have the last word on gravity?

In addition to the existing centers and infra-structure, AURA, in looking to the future of astronomy and as part of its commitment to advancing the goals of the NAS/NRC decadal survey *Astronomy and Astrophysics in the New Millennium,* is actively engaged in advancing three distinct major new facilities for astronomical research. These new facilities will be the premier research facilities on the ground for optical and infrared astronomy at least until well into the 21st century. One of these, the Advanced Technology Solar Telescope being designed under the auspices of the NSO, is currently in the "readiness phase" of NSF's MREFC process.

The two other new projects present unique opportunities for the NSF to engage private funding sources in public-private partnerships to significantly advance scientific research. The first project, the Large Synoptic Survey Telescope, will make a digital image of the entire sky visible from its site every few nights. It will conduct research ranging from a search for near-Earth asteroids and comets to a study of the distant structure of the Universe with the goal of understanding the nature of dark energy. The data rate from this telescope will be unprecedented. All of the data will be available to the entire US community in near real time. The second project in which AURA is a partner is the Thirty Meter Telescope Project. Its goal is to fulfill the Decadal Survey's top priority project for ground based astronomy – the building of a giant segmented mirror telescope. Its science goals range from the search for Earth-like planets and evidence for life elsewhere to studying the first stars and galaxies that formed after the big bang.

Aside from the immense scientific potential of these three projects, or perhaps because of them, all three have substantial associated E/PO efforts. As we have noted repeatedly in this document, NSF should take advantage of the opportunities offered by these new initiatives to advance both its scientific research and education agendas.

AMERICAN COMPETITIVENESS INITIATIVE: NEW TECHNOLOGIES

The ACI statement: "Sustained scientific advancement and innovation are key to maintaining our competitive edge, and are supported by a pattern of related investments and policies, including Federal investment in cutting-edge basic research whose quality is bolstered by merit review and that focuses on fundamental discoveries to produce valuable and marketable technologies, processes, and techniques… Research pays off for our economy. It leads to breakthroughs that inspire new products and have spawned entire industries"

Ground based astronomical research has made a number of important practical and beneficial contributions to life on Earth over a wide range of areas (see the NAS/NRC report Astronomy and Astrophysics in the New Millennium for a partial summary).

- *Adaptive Optics and Vision Science*: NSF's Center for Adaptive Optics (CfAO) spends ~25% of its budget on research relevant to Vision Science. Ophthalmic AO systems have been demonstrated in the laboratory for scientific research. The next horizon is to engineer compact, robust AO systems for use in clinics as well as scientific laboratories. The long-term goal is to commercialize a compact AO system for ophthalmic applications. Along the way, these new and existing AO

systems will be used to advance our understanding of human vision, and to explore medical applications of adaptive optics. A recent article on advances in retinal imaging with adaptive optics in Optics and Photonics News begins with this statement: "Since its first application to retinal imaging nearly a decade ago, adaptive optics has helped researchers make fundamental advances in the understanding of how the human visual system works." In addition to the work at the CfAO, the National Solar Observatory has pioneered wavefront sensing technology for AO that is required for observation of low-contrast objects. This technology is applicable for other low contrast situations such as satellite imaging of the ground as well as for studying human vision.

- *Mirrors, Antennae, and Telescopes*: Astronomy's need for high precision and large optics has resulted in major contributions to mirror and antenna technology with important applications in the public sphere including the development of lightweight materials and advances in mirror and antennae design and fabrication. An excellent example of this on the optical side is the pioneering work that has been done at the Steward Observatory Mirror Laboratory. The SOML startup was funded largely by an NSF grant to the Univ. of Arizona. One of its mirrors is being used at the Air Force's Star Fire Optical Range in NM. The SOML is also a test bed for AO R&D efforts and is complementary to the effort at CfAO.

- *Photon detectors*: If one wanted to single out the most important driver behind the major astronomical discoveries and advances made over the past three decades it would be the development of array detectors in the optical and infrared coupled with the vastly increased computing power that has allowed the gathering and interpretation of the data from these arrays. Astronomers have been the major force behind the development of ever better CCDs in terms of their sensitivity and their size. These have impacted our ability to image things as diverse as a baby's first steps to the interior of the human eye. Similarly, the push by astronomers on the development of large and sensitive infrared detectors has had significant societal benefits. The improvements needed by astronomers have been incorporated into IR detectors used for night vision, in the manufacturing of semiconductor devices, and in the medical field to image and help diagnosis a variety of human diseases and afflictions.

- *Computers:* "Astrophysics has been a major driver of supercomputer architecture and computational science or nearly 50 years… Computers are severely challenged by the gigabytes of data streaming in daily from modern astronomical sensors and large sky surveys and by the large computational speeds required for both simulations and database searches. These requirements are stimulating the development of large computers and innovative hardware components." As an example, the Large Synoptic Survey Telescope for which NSF has already given more than ten million dollars for development, will, when it is operational in 2012, produce one of the largest, if not the largest, publicly accessible data bases in the world.

- *Solar studies and controlled fusion energy sources*: The sun is an excellent laboratory for plasma physics in a highly magnetized plasma. Experimenters working on magnetic confinement are very interested in both trying to simulate and learn from solar processes. Understanding the mechanisms that trigger flares and coronal mass ejections will help plasma physicists understand how to construct stable field configurations in the lab (a necessary step toward controlled fusion).

SUMMARY

We have described at some length many of the activities of NSF supported astronomical research in the US, particularly those of the AURA astronomy centers, and emphasized how these activities align with and give strong support to the major role that NSF has to play in the ACI in the areas of research, infrastructure, and education. Astronomy has a wide appeal to the public at large with its exciting and fundamental research findings. The NSF supported astronomy centers under AURA's management as well as other facilities that receive major funding from the NSF such as the CfAO have many successful programs in place that take advantage of this wide appeal and strive to deepen the public's awareness and understanding of science. AURA is looking to the future of ground based astronomy and is actively involved in the planning for three major new facilities that will provide the necessary infrastructure to keep the US at the forefront of world astronomical research well into the 21st century. Astronomy should be the crown jewel in NSF's strategic plan for the next 5 years.