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Written Testimony Regarding the National Radio Astronomy Observatory

Dr. Ethan J. Schreier
President, Associated Universities, Incorporated
Adjunct Professor, The Johns Hopkins University

Chairman Brooks, Ranking Member Lipinski, and distinguished members of the committee, I thank you for this opportunity to testify. My name is Ethan Schreier, President of Associated Universities, Incorporated (AUI), a non-profit corporation that operates the National Radio Astronomy Observatory under a Cooperative Agreement with the National Science Foundation.

The National Radio Astronomy Observatory (NRAO) is a Federally Funded Research and Development Center (FFRDC) that enables forefront research into the universe at radio wavelengths. Radio astronomy is a relatively new branch of science, having started in 1932, but it has opened new vistas into the Universe, uncovering neutron stars, the birthplaces of stars and planets, super-massive black holes, gravitational waves and the remnant heat of the Big Bang, not possible via conventional optical astronomy. Radio astronomy has been responsible for several Nobel prizes.

AUI is the legal entity responsible for executing the responsibilities contained in its Cooperative Agreement with NSF. AUI established NRAO over 50 years ago, and NRAO has been the world's premier radio astronomy observatory ever since, building and operating the world's most advanced radio telescopes for use by the US astronomy community, as well as by astronomers from the rest of the world, under an *Open Skies* policy. Under the stewardship of AUI, NRAO has developed state-of-the-art technology in support of its facilities, and for the development of future facilities in the US community, maintaining US leadership in this important discipline. At the same time, it has promoted science, technology, engineering, and

mathematics (STEM) education through a variety of programs to inspire students and foster the next generation of scientists and engineers.

Certain physical phenomena are only observable by their radio signals. Just as visible light from space carries information about stars and things illuminated by them, radio waves are emitted by important celestial phenomena that are often invisible to our best optical telescopes. For example, stars form from collapsing cold clouds of molecules and dust, too cold and obscured to be observed by any other technique. The earliest stages of star formation, one of the most basic processes of astrophysics, are invisible even to the Hubble Space Telescope or the future James Webb Telescope and can only be studied using the techniques of radio astronomy. Radio astronomy also offers cost-effective methods to complement other techniques. For example, radio astronomers are using accurate timing of pulsars – fast-spinning, highly dense, collapsed (*neutron*) stars – to search for the gravitational waves predicted by Einstein's Theory of General Relativity. This technique, which uses NRAO's Green Bank Telescope among other facilities, is a complement to LIGO and other gravitational wave detectors.

NRAO currently operates four world-leading telescopes for use by the scientific community: the Jansky Very Large Array (JVLA) in New Mexico, the most productive, ground-based telescope in history; the Green Bank Telescope (GBT) in West Virginia, the world's largest, fully-steerable telescope; the Very Long Baseline Array (VLBA), the world's largest scientific instrument with 10 dishes spanning North America that enable the most precise angular measurements of any telescope; and the new international Atacama Large Millimeter/ submillimeter Array (ALMA), the largest ground-based astronomy project ever conceived and built, for which AUI is the North American lead (*Executive*), overseeing NRAO's construction and operations for the North American portion of ALMA. Each of these telescopes fills a unique and essential science role, and each is the best in the world in its category. NRAO's Headquarters, and the focus of its radio technology developments, is in Virginia.

Importantly, NRAO facilities provide transformational and unique scientific capabilities that enable the astronomy community to answer many fundamental questions about the universe including those highlighted by the recent National Academy's Decadal Survey, *New Worlds New Horizons*, studying galaxies as they form and grow since the earliest times of the Universe, directly imaging planets in formation around nearby stars, and directly detecting gravitational waves from the merging of massive black holes.

While these telescopes are geographically dispersed, now in South as well as North America, NRAO management effectively coordinates science operations, technical development, and administration to achieve synergies across the Observatory and to leverage each telescope to the maximal scientific benefit. Functions that are fundamentally site or telescope specific are delegated to site directors. AUI and its Board of Trustees maintain overall responsibility for

Observatory performance, including programmatic, administrative and budgetary oversight, with special attention to research community relations and to major construction projects.

The NRAO telescopes are national multi-user facilities operating under the "Open Skies" policy, with access governed solely by the scientific merit of proposals and not the national origin or affiliation of the applicants. Scientists may propose for observing time at regular, open proposal deadlines. The proposals are evaluated through a peer review process that is administered by NRAO, using independent reviewers and panel chairs who are members of the community. NRAO staff scientists receive no preference in the selection of projects or awarding of observing time. As ALMA is an international partnership, its proposals are evaluated by the international Joint ALMA Observatory, but the process is similar to the NRAO system. North American scientists receive 32.5% of total ALMA observing time, with the balance distributed to the European and East Asian partners and the Chilean hosts, in proportions determined by their respective contributions toward the project.

Historical Overview

Associated Universities, Inc. is a 501(c)(3) non-profit research management and educational organization, originally established after World War II by nine major US research universities. Its original purpose was to enable basic and applied research that had been started during the war to continue for the benefit of the country and the research community, initially by building and operating Brookhaven National Laboratory, a large civilian research facility, funded by the Atomic Energy Commission. The establishment of a national laboratory in the US to design, construct and operate large scientific machines that individual institutions could not afford to develop on their own, was a new development. Yet, the model created by AUI was so successful that it was then adapted and used by other disciplines across the sciences.

The National Radio Astronomy Observatory was created in 1956 when AUI responded to a need that arose in the US research community for a national radio astronomy facility. While radio astronomy had been invented in the United States in the 1930s, by the 1950s other countries were taking the lead. Recognizing the importance of this field to astronomical research and technological innovation, as well as the pioneering role the U.S. had played in its formation, AUI responded by submitting a proposal to NSF to build and operate NRAO. This proposal was accepted in November 1956. Within a few years, AUI had established NRAO and built two major radio telescopes, and the U.S. regained leadership in radio astronomy. AUI has managed NRAO ever since, overseeing its continued growth as the recognized premier radio astronomy observatory in the world.

Over its 56-year history, AUI and NRAO have developed nine major telescopes at four primary sites. Our long-term strategy is to upgrade facilities as possible; to plan, build and operate new facilities driven by developing scientific needs; and to retire facilities that have been made obsolete and superseded. NRAO's capacity for continuing renewal, providing forefront facilities relies on the excellence of its scientific and technical staff, working closely with the astronomy community.

AUI selected Green Bank, West Virginia as the initial site for NRAO. Its remote location, surrounded by the Appalachian Mountains, offers excellent protection from harmful radio interference. Significant early facilities built there include the 85-foot Tatel telescope (1958), the 300-foot transit telescope (1962), and the Green Bank Interferometer (1964). Today's vastly more capable 100-meter GBT, which was completed in 2002, has a precision surface larger than a football field with more than 2 acres of collecting area. Of the telescopes at Green Bank, only the GBT remains supported under the NSF Cooperative Agreement today, although the other facilities are used for various educational and independently-funded projects.

A 36-foot millimeter-wave telescope was completed in 1967 at Kitt Peak, near Tucson, Arizona. Upgraded to the 12-meter in 1984, this facility pioneered the entire field of millimeter-wave astronomy and was a direct precursor to ALMA. NRAO ceased operating this telescope in 2000 when ALMA construction was on the horizon; it continues to be used by the University of Arizona using state and private funds.

The iconic Very Large Array near Socorro, New Mexico was completed in 1980 and consists of 28 antennas, each 25-meters in diameter. Located on the high Plains of San Agustin, the antennas can be reconfigured along 40 miles of railway track to adjust the angular resolution of the telescope, analogously to the zoom lens of a camera. The VLA has recently been upgraded and re-dedicated just two weeks ago as the Jansky Very Large Array, with 10-1000 times the original capability. The original VLA, and the upgraded Jansky VLA project, were both carried out on-time and on-budget.

The Very Long Baseline Array, also controlled from Socorro, was completed in 1993. It consists of 10 antennas distributed across the continental U.S., in St. Croix, U.S. Virgin Islands, and on Mauna Kea, Hawaii. Because of the 5000-mile extent of the array, the VLBA has the highest angular resolution (image sharpness) of any telescope at any wavelength.

ALMA, the newest NRAO facility, shared with partner countries, is being built by an international collaboration among the United States, Canada, Europe, East Asia, and Chile. ALMA, a 66-telescope millimeter/ submillimeter array in the high Atacama Desert of northern Chile, is the largest ground-based astronomy project in the world and has the potential to revolutionize our understanding of the universe. AUI is the North American Executive for ALMA, and oversees NRAO in the construction and operations for the North American portion

of ALMA, acting on behalf of the NSF. ALMA began its first science operations in the fall of 2011, and all North American project deliverables will be completed in 2012. A formal inauguration is scheduled for Spring 2013. ALMA will provide for the first time detailed images of stars and planets as they are being formed, of young galaxies being assembled, of the structures around black holes at the centers of active galaxies, and it will open new windows into the cold Universe via a tremendous increase in sensitivity and resolution at millimeter and submillimeter wavelengths.

Other multi-user facilities managed or supported by AUI

In recent years, AUI has responded to research needs in several projects beyond NRAO. These projects represent important tools for astronomy and serve as examples of AUI's readiness to adapt to provide the most benefit to the scientific community.

AUI responded to a high priority need in the astronomy community to provide common access to data from major astronomy archives of both space and ground-based observatories. Several years ago, AUI joined with its sister organization, the Association of Universities for Research in Astronomy (AURA), which operates the National Optical Astronomy Observatory and the Hubble Space Telescope Science Institute, to manage the Virtual Astronomical Observatory (VAO). The VAO links together major astronomy archives to create an integrated, publically accessible tool for astronomical research. VAO is funded by NSF and NASA and is enabling innovative new methods to extract meaning from the massive quantities of data produced by astronomical instruments. This is an example of the type of Big Data Initiative recently announced by NSF and several other agencies. Astronomy is indeed a science where massive data sets are generated, are publicly accessible, and are more useful studied in combination than individually.

CCAT is a 25-meter single dish sub-millimeter telescope that will be built in Chile on top of a peak adjacent to ALMA. It will be a unique facility that allows large scale surveying of the sky to pinpoint targets for ALMA observations and ensure that US users get maximal benefit from its ALMA investment. CCAT is a university-based initiative, being built by a consortium of universities in the United States, Canada, and Germany, along with AUI. AUI is leveraging its experience building ALMA to navigate the issues of construction and operations in Chile. NSF is providing support for the detailed design and expects to contribute to the construction and operations, adding to the funds being supplied by the universities. The universities will benefit by engaging students and faculty in the design and development of instruments, with telescope time available for the broad US astronomical community.

Why Does NSF Fund NRAO and what is the National Return on this Investment?

The NSF is the only US agency dedicated solely to funding fundamental research across the spectrum of disciplines from physics to biology to engineering to social and behavioral sciences, and NSF is the dominant supporter of US ground-based astronomy. It is from the ground, not in space, that almost all state-of-the-art radio astronomy is conducted; this makes radio astronomy highly cost-effective when compared to equally important telescopes that must fly in space.

Astronomers need state-of-the-art tools that are often too big and expensive for single university groups to build, or if they could build them, would be too expensive and wasteful to replicate. NRAO, with funding from NSF, has consistently supplied such radio astronomy facilities to the astronomy community. A focused effort is also required to develop enabling technology, and NRAO maintains the US core competence in radio science technology. These two aspects – building and operating major multi-user instruments, and maintaining the technological underpinnings of the discipline, along with supporting the research community in using these capabilities – are the basic reasons to have a National Facility.

NRAO has a long history of enabling fundamental discoveries in radio astronomy. The entire field of molecular line astronomy, which probes star formation, began using NRAO telescopes. The carbon monoxide molecule, the most ubiquitous molecule of all, was discovered at NRAO, as was formaldehyde, the first of many organic molecules seen in space, providing clues to the origin of life. The powerful radio source at the center of our Galaxy, Sgr A*, now believed to be a massive black hole, was discovered at NRAO. The structure of the Milky Way was mapped and the distances to the spiral arms measured. Recently, astronomers have used pulsars to determine the fundamental nature of nuclear physics and confirm General Relativity in a manner that would never be possible in a man-made laboratory.

Aside from satisfying scientist's curiosity about profound questions in the physical realm, public support for fundamental research -- research not specifically aimed at solving immediate, practical problems -- has consistently resulted in very practical benefits to the nation and its people. Sometimes these benefits derive directly from understanding nature better. For example, studies of the Sun and its then-mysterious source of power aided our development of nuclear power. Sometimes the benefits come in the form of "spinoffs" from technology first developed to probe deeper into nature's secrets; examples include improved technology for cell phones first pioneered in radio astronomy by NRAO. The technology that NRAO has developed to detect chemicals at great distances also has practical applications on Earth.

Even in the realm of "pure" scientific research conducted with radio astronomy, there is often practical value. For example, NRAO's unique ability to map the rotation of Near-Earth Asteroids

can help us better understand, and thus prepare plans to counter the threat of, asteroids that could collide catastrophically with our planet.

NRAO also has a distinguished record of technology development that has not only made radio astronomy instruments highly sensitive and capable, but has also found application in other fields. NRAO has been a world leader in the development of cryogenic low noise amplifiers, superconducting detectors for millimeter wave radiometers, and digital correlators. NRAO built the low noise amplifiers for NASA's WMAP mission that measures cosmic background radiation. NRAO scientists and technologists have also pioneered software techniques later adopted for medical imaging, developed algorithms later used in cell-phone operations, and spawned an entire computer language (FORTH) still used in embedded processors.

To maximize the return on the taxpayers' investment, AUI and NRAO engage in an extensive program to bring the benefits of NRAO's research activities to the public, and to broaden the impact of its programs. This includes STEM education, student programs, teacher training, public news dissemination, and informal education. The Green Bank Science Center has a large visitor center with hands-on exhibits, displays, classrooms, and a guided tour of the site. The facility hosts approximately 50,000 visitors per year, including numerous school groups, and several formal programs such as the Governor's School for Math and Science. The JVLA Visitor Center hosts about 20,000 visitors per year. North American ALMA outreach is integrated with NRAO outreach, and has now extended to other countries. In addition, with AUI support, a student and teacher exchange program between the villages of San Pedro de Atacama, Chile and Magdelana, New Mexico was instituted.

NRAO has developed high impact STEM education programs to make use of the unique research opportunities afforded by radio astronomy. In the *Pulsar Search Collaboratory*, an NSF-funded program, high schools students are given raw pulsar survey data from the GBT and are trained to use straightforward software analysis tools to search for pulsars in the data. If a student discovers one, he or she becomes a co-author with professional astronomers on scientific journal papers. They are thus trained in the entire scientific research process, from experimental design to publication. Several high school students in the program have successfully detected pulsars. Surveys of the attitudes of the students before and after joining the program have shown that the female students, in particular, gained substantial confidence in their abilities in math and science as a consequence of their participation. The students participating in the program thus far have been located primarily in West Virginia and a few surrounding states. AUI and NRAO are currently exploring collaborations that would expand the program nationwide. In another program, backed by AUI and coordinated by the international astronomy professional organization IAU, and funded by Chilean industry, US astronomers and students will visit Chile to help train Chilean science teachers, promoting

international understanding, providing an important US ally with much-needed capacity, and providing US students a unique educational experience.

AUI and NRAO actively seek new opportunities to expand their outreach programs, not just at NRAO facilities but in collaboration with other programs AUI manages or helps to manage (*e.g.* VAO and CCAT). We are in active talks with NSF and several university partners to investigate potential new programs that use astronomy, its vast data archives, and its engineering-rich operations to enhance science and engineering education programs. Student interns from the New Mexico Institute of Mining and Technology already work at NRAO's Socorro operations, and AUI is currently in discussion with the administrations of West Virginia University and University of Virginia to broaden such programs. AUI is also in discussion with the University of Colorado, to determine how radio astronomy can participate in Colorado's national-impact STEM education programs.

What Steps are taken to ensure the Best Stewardship of NRAO?

AUI takes its role as steward of the facilities it operates very seriously; we feel responsible not only to the NSF, but to the research community and the taxpayers as a whole. NRAO not only builds and operates forefront facilities, but also engages and helps foster the university research community, and implements public outreach programs. NSF in turn takes its oversight role seriously, reviewing AUI and NRAO programmatic, management, and technical performance.

AUI seeks out the best management practices, and helps NRAO implement them. AUI and NRAO engage annually in many levels of internal and external review to ensure a process of continuous improvement. The AUI Board, which includes members of the university research community, senior engineers, administrators and managers, oversees and regularly reviews NRAO performance. The AUI Board has standing Audit and Operations and Administration Committees that monitor and advise AUI and NRAO management on fiscal and administrative matters. AUI also establishes ad hoc committees as necessary, notably including the ALMA Oversight Committee that has advised AUI and overseen its role in the construction of ALMA. It is noteworthy that ALMA, the largest facility ever funded by NSF, has already started early science on schedule and that the North American deliverables will be completed on the schedule and within the budget promised to the National Science Board over six years before.

AUI and NRAO take all steps necessary to ensure that business and financial practices follow best accounting practices and meet all existing NSF and AUI policies. AUI establishes policies and processes and monitors NRAO's adherence to these policies. AUI engages an external audit firm to perform annual A-133 external audits. AUI also conducts internal audits of AUI/NRAO, selecting for examination several major audit areas each year, on a rotating basis. The Board's

Audit Committee oversees all these processes and reports to the full Board. AUI and NRAO have a long record of excellent, unqualified audit reports. Approximately every four years, NSF performs a detailed Business Systems Review. The most recent BSR was completed just a few weeks ago, with no reported concerns. The Defense Contract Audit Agency (DCAA), working under contract with NSF, has also been conducting its own audit for the past two years, and has not reported any significant findings.

To review its science impact, policies, and programs affecting users, NRAO appoints a Users Committee made up of representative members of the community. NRAO evaluates the recommendations of this committee and reports on the status of implementing its recommendations. AUI also appoints a distinguished independent Visiting Committee made up of senior scientists and administrators to review overall NRAO program and organizational effectiveness. This Committee reports to AUI and its Board, and its report and the NRAO Director's response is forwarded to NSF. External ad hoc committees are established from time to time to review and/or advise on particular matters of concern, and to address matters of importance to the broad radio astronomy community.

What Roles do NRAO, AUI & NSF Play in the Scientific, Budget, and Management Components of the Facility?

AUI is responsible to NSF to execute the responsibilities contained in the Cooperative Agreement, but it delegates day-to-day operations to the NRAO Director and his or her staff.

Each year, NRAO drafts an annual Program Operating Plan written to the projected NSF budget allocation, together with a 5-year Long Range Plan written to NSF-supplied projections. These plans integrate community science priorities determined from major reviews such as the National Academies Astronomy and Astrophysics Decadal Survey, input from the NRAO Users Committee, and from NRAO's internal reviews and discussions. NRAO has an internal program prioritization process to ensure that within its budget, funds are spent for the highest priority activities with the greatest impact. Divisions develop internal plans for their activities, the proposed activities are evaluated and ranked by management according to impact. AUI reviews and approves the program plans and the associated budget before submission to NSF.

NSF convenes a formal review panel to evaluate the program plans, as well as the success of the previous year's program. After any necessary revisions based on comments and recommendations, NRAO manages to the revised Program Operating Plan during the fiscal year.

After Congress approves the NSF budget, and the NRAO allocation becomes final, NRAO submits quarterly estimates of cash draw-down requirements within the allocation amount

(Form 1030). In accordance with the cash management requirement of OMB A-110 to minimize time elapsed between the transfer and disbursement of funds, each week our fiscal office draws down the cash required to meet payroll and accounts payable needs for the next business week.

Formal and informal communications between NSF, AUI, and NRAO take place on a continuing basis to ensure good communication and to report progress toward goals. Formal Quarterly Status Updates are prepared by NRAO and submitted by AUI to NSF, with face-to-face presentations by senior NRAO management to NSF's program officers. These updates summarize progress against milestones, financial status, science, technical, and broader impact highlights, as well as any anomalies. AUI's North American ALMA Project Director at NRAO reports monthly to NSF. AUI meets approximately monthly with the NSF program officers to discuss any matters of concern, and NSF is also invited to share perspectives directly with the AUI Board of Trustees several times per year. The AUI Board routinely reviews NRAO progress toward meeting the plan at each Board meeting and AUI informs NSF of any significant events that could represent a departure from the Program Operating Plan.

Planning the Lifecycle of Facility Components

NRAO has built – and retired – multiple generations of facilities. NRAO's mission is to enable forefront research at radio wavelengths; this requires forefront facilities. Ground-based radio telescopes are typically constructed with a 20-30 year design lifetime, and may undergo one or more major upgrades or renovations that extend their productive lifetime. NRAO has never attempted to "hang on" to facilities that are past their prime, but rather has developed, built, or upgraded facilities so that they are state-of-the-art and the best in the world at what they do. All components of NRAO's current suite of telescopes: JVLA, GBT, VLBA, and ALMA, fit this description. Furthermore, the technology is freely shared with the university community and, in some cases, university groups actively collaborate in building NRAO instruments.

None of NRAO's first generation telescopes are still operational under the NSF Cooperative Agreement for NRAO, although some have found extended useful life with other organizations or external funding. For example, the Green Bank 140-foot telescope has been used under an Air Force contract with MIT / Lincoln Labs for radar studies, and other facilities at Green Bank have been used for dedicated educational purposes, solar monitoring, time keeping, and other non-research activities. The Kitt Peak 12-meter continues observations under the aegis of University of Arizona.

In all previous cases in which NRAO telescopes have been retired, a new and more capable facility has been on the horizon. NRAO has always conducted discussions with the NSF and the astronomical community about the proper time for closure and then proceeded.

Due to current tight budgets, NRAO may, for the first time in its history, be forced to close or drastically reduce operations of a telescope while it is still operating as a forefront facility with no near-term successor. Either or both the GBT or VLBA are presently vulnerable, and external funding is being actively sought.

Recompetition History

NSF's Cooperative Agreement with AUI for NRAO operations has had a typical term of five years. NSF has in the past conducted mid-term management reviews that have been asked to recommend whether the Cooperative Agreement should be competed. AUI has demonstrated an outstanding record of stewardship of NRAO over the years and has received high marks from all evaluations of its management, both recently and historically. Each time, AUI has been renewed without recompetition. However, given the National Science Board's (NSB) emerging policy of promoting recompetition for all facilities regardless of current management performance, AUI's Cooperative Agreement for both NRAO and ALMA operations will be recompeted next year. NSF recently convened a committee to recommend best practices for NSF's competitions.

The Cooperative Agreements for both NRAO and ALMA Operations expire in 2015. NSB issued a resolution that, "urges the use of a recompetition plan that ensures that the recompetition of the management and operation of ALMA is separated from the recompetition of the management and operation of NRAO." NRAO and AUI believe that separating ALMA and NRAO management would have a seriously negative impact on science in the U.S. The scientific, engineering, and administrative staffs supporting these instruments are highly integrated, which produces cost efficiencies and helps ensure that US researchers reap the scientific benefits of the US investment in ALMA. Splitting them apart would result in an enormous loss of efficiency and expertise that would cause the US research community and all Observatory components to suffer and increase the costs of operations to the US taxpayer. AUI and NRAO have urged NSF to keep NRAO and ALMA operations under a single Cooperative Agreement.

External Partnerships

Throughout their history, NRAO and AUI have engaged in collaborations with external partners, including both US and international institutions. These collaborations have increased scientific

productivity, aided university researchers, supported other US government agencies, expanded the funding base for NRAO, and resulted in the development of cutting-edge technology. Foreign collaborations in particular depend on stable long-standing relationships, good will and, and often legal agreements or MOUs.

The most notable example is the international partnership to build ALMA, which due to its sheer scale and expense would likely never have been built without a joint effort. The VLA upgrade also utilized a construction partnership among the U.S., Canada, and Mexico, which expanded the funding base for the project and procured a critical technical component.

University collaborations have included the development of instruments for the GBT. Several university groups have built receivers which not only supply needed capabilities for the GBT but also give students the much-needed opportunity for training in instrument building and software development. Foreign research groups (*e.*g. Max Plank Institute) have also contributed instruments to NRAO that become available to all users. This open exchange of scientific instrumentation has benefited the entire research enterprise.

NRAO has also on occasion provided critical mission support to NASA using the VLA, GBT, and the VLBA both for tracking spacecraft and for receiving telemetry from planetary flybys and landers. In addition, the U.S. Naval Observatory (USNO) has provided operational support for the VLBA in return for observations in support of their precision timekeeping mission. NSF's 2006 Senior Review recommended that in times of constrained budgets, NRAO should seek outside funding for the VLBA, which USNO provides.

Major Challenges Faced by NRAO

NRAO has been a pioneer of radio astronomy for 56 years, building world-leading telescopes and enabling forefront research throughout its history. The Observatory has blazed many trails technically, scientifically, and organizationally, and overcome many challenges.

The greatest technological and managerial challenge in recent years has been the construction of ALMA, due to its unprecedented technical complexity and size, its remote location in the desert of northern Chile, the need to manage a supply chain with contributions from around the world, and the need to coordinate with an international team of equal partners. Despite these difficulties, ALMA has been on time and on budget since a 2006 rebaselining.

NRAO has overcome other technical challenges, including the successful resolution of a GBT azimuth track problem. The track, which bears over 16 million pounds of moving weight – the GBT is the largest moving land-based structure – began to fail within the first year of operation. The contractor's design was faulty, and not only did NRAO, with added expertise from the AUI Board, convene engineering experts from around the world to develop a replacement design

that has worked superbly since, but AUI oversaw a hard-negotiated warranty settlement with the contractor that helped fund the corrective actions.

The current major challenge facing NRAO is maintaining its status as the world's forefront radio observatory under an extremely constrained budget, which may force the closure of one or more world-leading telescopes. In addition, US leadership and its core competence in radio astronomy are threatened by the potential split of domestic NRAO facilities from ALMA, the world's newest and transformational radio facility. AUI sees its role as ensuring that US researchers reap the benefits of the large US investment in ALMA, and the advantages of a unified national facility, and not put the US at a disadvantage in using this ALMA as compared with European astronomers interacting with ALMA via ESO.

The rest of the world is working hard to surpass the US in radio astronomy leadership. Europe, Asia, and Africa are actively engaged in planning for the next generation radio astronomy instrument, the *Square Kilometer Array*. The US must continue to invest in forefront radio astronomy research and facilities to continue unlocking the secrets of the universe and keep its leadership role in a key scientific discipline.

Key Points:

- Radio astronomy is an important tool for understanding the universe, and NRAO has consistently provided the research community the best radio astronomy capabilities.
- NRAO is the pre-eminent radio astronomy organization in the world, with major instruments in all relevant wavebands, and major facilities in Virginia, West Virginia, New Mexico and Chile.
- AUI created NRAO and continues to successfully and closely manage it via its active governance structure, regular technical, programmatic, and fiscal review and oversight, and close communication with both the research community and NSF.
- AUI has a long history of success, and in addition to managing NRAO, it is flexible in responding to research community needs, and representing radio interests in the broader astronomical community. It helps manage the Virtual Astronomical Observatory and is helping the university community build a new forefront observatory in Chile.
- AUI and NRAO actively work to leverage radio astronomy investments to promote STEM education through proven outreach and dissemination activities across the country.
- The current fiscal environment presents unique challenges; a major issue facing AUI is maintaining NRAO's status as the world's forefront radio observatory in an extremely constrained fiscal environment. One or more forefront facilities may face closure.
- AUI sees its role as ensuring that US researchers reap the benefits of the large US investment in ALMA. Recompetition of NRAO is approaching, and an issue of particular concern is the possible separation of ALMA from NRAO. US leadership and its core competence in radio astronomy are threatened by this potential split of domestic NRAO facilities from ALMA, the world's newest and transformational radio facility. We assert that the best use of taxpayer dollars is to continue the long association of NRAO and ALMA.
- Our long successful history indicates we know what we're doing. The experience gained in building and operating the world's leading radio facilities is guiding our way forward in these difficult times. We perceive that certain initiatives, like separating ALMA from NRAO, appear to greatly increase the complexity and risk of these successful programs, and we look forward to working with NSF and Congress to consider the options.