NATIONAL RADIO ASTRONOMY OBSERVATORY (NRAO) $98,110,000
-$100,000 / -0.1%

National Radio Astronomy Observatory Funding [1]
(Dollars in Millions)

FY 2021 Actual[2]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$98.21	-	$98.11	-$0.10	-0.1%

[1] Funding includes the base operations for NRAO and ALMA.

[2] Includes $10.08 million for ngVLA development.

Brief Description

NRAO is a Federally Funded Research and Development Center that conceives, designs, builds, operates, and maintains radio telescopes used to study all types of astronomical objects, from bodies in our own Solar System to galaxies in the distant Universe. Operating synergistically with optical, infrared and x-ray telescopes, NRAO's state-of-the-art, general-purpose facilities enable discovery over a broad range of key problems in modern astrophysics. NRAO operates the North American component of the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, the Karl G. Jansky Very Large Array (VLA) near Socorro, New Mexico, the Very Long Baseline Array (VLBA) throughout the Continental United States, Hawaii, and the U.S. Virgin Islands, and the Central Development Laboratory (CDL) in Charlottesville, Virginia.

Scientific Purpose

Since 1956, NRAO has provided world-class radio telescope facilities for use by the U.S. and international scientific community. NRAO also provides both formal and informal programs in education and public outreach for teachers, students, the general public, and the media. A brief overview of NRAO's facilities and the science they enable is given below.

Atacama Large Millimeter/submillimeter Array

ALMA is the world's preeminent facility for millimeter- and submillimeter-wave astronomy, providing one to two orders of magnitude improvement over previous facilities in all areas of millimeter- and submillimeter-wave observations, including sensitivity, angular resolution, and image fidelity. It consists of 66 precision 12-meter and 7-meter antennas located at 5,000 meters elevation in the Atacama Desert in Chile. ALMA is a general-purpose facility enabling transformational research into the physics of the cold Universe, regions that are optically dark but shine brightly in the millimeter/submillimeter portion of the electromagnetic spectrum. Within the broad range of science accessible with ALMA, the top-level objectives include imaging the redshifted dust continuum and molecular-line emission from evolving galaxies as early as a redshift of z~10 (only 500 million years after the Big Bang), determining the chemical composition and dynamics of star-forming gas in normal galaxies like the Milky Way but at z~3 (about 4 billion years after the Big Bang), and measuring the gas kinematics in young disks in nearby molecular clouds and detecting the tidal gaps induced by planet formation.

Karl G. Jansky Very Large Array

The VLA is the world's leading centimeter-wavelength radio telescope, consisting of 27 identical 25-meter antennas separated by up to 35 km on the Plains of San Agustin in New Mexico. Following a major upgrade completed in early 2013, the VLA provides one to three orders of magnitude improvement over all previous performance aspects except angular resolution. The VLA is one of the world's most sensitive and flexible instruments for centimeter-wavelength continuum and imaging spectroscopy over a very large range of wavelength (0.6 to 30 cm, plus narrow windows at 90 cm and 400 cm). Among a broad range of scientific capabilities, the VLA addresses four primary science themes: studying the formation and evolution of stars, galaxies, and active galactic nuclei; following the rapid evolution of energetic phenomena; imaging young stars and massive black holes in dust-enshrouded environments; and measuring the strength and topology of cosmic magnetic fields.

Very Long Baseline Array

The VLBA is the world's preeminent facility for high-precision astrometric studies and high-resolution imaging. The VLBA includes 10 identical 25-meter antennas that can work together as a continent-sized telescope with baselines up to 8000 km. The VLBA is unique in its ability to do extremely high-angular-resolution imaging and spectroscopy in the wavelength range of 3 mm to 30 cm and can carry out astrometry with precision that is about two times better than that achieved by the European Gaia spacecraft for stars. The VLBA enables a wide range of science returns including mapping the structure and dynamics of the Galaxy, searching for planets around low-mass stars, accurately measuring the masses of supermassive black holes, precisely determining the expansion rate of the Universe, determining Earth orientation parameters, and improving the International Celestial Reference Frame. The U.S. Naval Observatory (USNO) relies on VLBA data for mission-critical measurements of Earth orientation, data necessary for accurate functioning of GPS.

Central Development Laboratory

The CDL supports NRAO's existing facilities, and provides technology and expertise needed to build the next generation of radio astronomy instruments and facilities. The CDL is a world leader in designing, developing, and producing enabling technologies, including low noise amplifiers, millimeter and sub-millimeter detectors, optics, and electromagnetic components such as feeds and phased arrays, digital signal processing, and new receiver architectures. CDL produces these components not only for NRAO's telescopes, but also for the worldwide astronomical community. CDL develops techniques for producing higher quality, lighter weight, and more cost-effective components, and supporting rapid prototyping and more efficient R&D activities.

Status of the Facility

COVID-19 impacts in 2020 varied for the facilities under NRAO's responsibility. During the earliest stages of the pandemic, all staff worked from home. From approximately June 2020, staff for North American facilities worked onsite. The VLA and VLBA never ceased science operations but establishing procedures for safe operations delayed activities somewhat early in the pandemic. ALMA science observations were halted at the beginning of the pandemic in March 2020 but were resumed as of March 17, 2021.

Meeting Intellectual Community Needs

NRAO's observing facilities for radio astronomy are available to any qualified researcher, regardless of affiliation or nationality, based on merit-reviewed scientific proposals. NRAO facilities annually serve over 2500 users worldwide; moreover, continued high demand for ALMA has resulted in the most proposals ever received for an astronomical facility in response to a single proposal call. NRAO is among the top three astronomical facilities worldwide for the highest publication citation numbers.

NRAO facilities continue to enable a remarkable array of ground-breaking discoveries, from the detection of a massive flare from our nearest stellar neighbor, to imaging the magnetic field around the supermassive black hole and associated jet in galaxy M87, to the detection of unusually massive and surprisingly mature galaxies and black holes in the very early universe. Even in a pandemic year, the VLA, VLBA, and ALMA continued to produce significant scientific discoveries. For example, using data from VLA sky surveys twenty years apart, astronomers were able to detect jets of relativistic charged particles from near supermassive black holes that had been launched during that interval, providing insight into how these important and enigmatic phenomena are created. Closer to Earth, ALMA showed for the first time that volcanoes are responsible for the sulfur dioxide gas in the atmosphere of Jupiter's moon, Io. These observations allow the differentiation of different processes on the surface of Io, and how they affect its atmosphere. Astronomers using the VLBA made the first direct geometric measurement of the distance to a magnetar within the Milky Way galaxy. These observations will enhance our understanding of one of the most extreme and magnetic objects in the universe and help determine whether magnetars are responsible for the enigmatic "Fast Radio Bursts". The CDL has continued to excel in its mission to support the evolution of NRAO facilities by developing the technologies and expertise critical for the next generation of radio astronomy instrumentation.

In November 2021 the National Academies released the report from its Decadal Survey for Astronomy and Astrophysics, *Pathways to Discovery* (Astro2020)[1]. Many of the activities and initiatives being led by NRAO support recommendations in Astro2020. The report identifies time-domain astronomy (TDA) and multi-messenger astrophysics (MMA) as one of three scientific pillars ("New Messengers and New Physics") for the upcoming decade, and NRAO facilities provide access for radio observations of MMA events. NRAO is also continuing to lead development efforts for the next generation Very Large Array, a sensitive next-generation radio observatory also discussed in Astro2020.

Governance Structure and Partnerships

NSF Governance Structure

A program officer in the MPS Division of Astronomical Sciences (AST) carries out continuing oversight and assessment for NRAO and ALMA by making use of detailed annual program plans, long-range plans, quarterly technical and financial reports, and annual reports. The AST Division Director and NRAO Program Officer participate in the international ALMA Board and attend governance and advisory committee meetings for NRAO and its managing organization, Associated Universities Inc. (AUI). To address issues as they arise, AST has a dedicated Integrated Project Team that includes representatives from other NSF offices, such as the Office of the General Counsel, OISE, and the Division of Acquisition and Cooperative Support and the Large Facilities Office within BFA. The MPS

[1] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

Facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

NRAO is managed and operated through a cooperative agreement with AUI, a non-profit research management organization consisting of an Executive office overseen by a Board of Trustees, with input from several internal and external committees. AUI manages the observatory through its own community-based oversight and users committees. The NRAO director reports to the AUI president. Oversight of the international ALMA project is vested in the ALMA Board, which includes members from NSF, AUI, and the U.S. community. Coordination and management of the merged international efforts are the responsibility of the Joint ALMA Observatory, whose staff includes the ALMA director. An international review committee advises the ALMA Board.

Partnerships and Other Funding Sources

NRAO supplements NSF/AST support with funding provided by other NSF sources, other federal agencies, and non-federal sources. The development of new telescopes, instrumentation, and sensor techniques is conducted in partnership with relevant industries through competitive sub-awards to various large and small aerospace companies, radio antenna manufacturing firms, and specialized electronics and computer hardware and software companies. USNO provides approximately 50 percent of the funding for the VLBA.

ALMA is supported by an international partnership, comprising the United States and its partners Canada and Taiwan ("North America" or NA), the European Southern Observatory (ESO), and Japan and its partners Taiwan and South Korea (East Asia (EA)). NA and ESO are equal (37.5 percent) partners and EA contribute 25 percent. Canada contributes approximately 2.72 percent of operations (i.e., 7.25 percent of the 37.5 percent NA share). Taiwan contributed about 4 percent of NA construction but contributes operations funding through the EA partnership.

International agreements establish the terms under which the ALMA partnership operates and define the roles of the ALMA Board, the regional funding authorities, their Executives, and the Joint ALMA Observatory (JAO). A revised international agreement, fully incorporating Japan in ALMA operations, was signed in December 2015. The international ALMA Board acts as a supervisory and regulatory body responsible for exercising oversight and budgetary and policy control. Board membership includes one or more representatives from NSF. The regional funding authorities (the "Parties") have each designated an Executive to carry out and manage tasks and responsibilities on behalf of the Parties. AUI is NSF's Awardee for the O&M of NRAO and is the NA ALMA Executive. ESO serves as its own Executive. The EA ALMA Executive is the National Astronomical Observatory of Japan (NAOJ).

View of the Very Large Array. *Credit: NRAO/AUI/NSF.*

Funding

The program solicitation for NRAO O&M (including ALMA) identified a planning budget of approximately $863 million over a ten-year award period (FY 2017 – FY 2026), though the annual budget increased by about $3-$4 million following the reintegration of VLBA into NRAO in FY 2019.

Total Obligations for NRAO
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NRAO[2]	$49.53	-	$44.45	$42.81	$43.97	$45.19	$45.19	$45.19
Operations and Maintenance	*39.45*	-	*40.53*	*42.81*	*43.97*	*45.19*	*45.19*	*45.19*
Special Projects [3]	*10.08*	-	*3.92*	-	-	-	-	-
ALMA Operations	48.68	-	53.66	54.77	56.96	59.24	59.24	*59.24*
Operations and Maintenance	*48.68*	-	*50.63*	*54.77*	*56.96*	*59.24*	*59.24*	*59.24*
Special Projects [4]	-	-	*3.03*	-	-	-	-	-
Total	**$98.21**	**-**	**$98.11**	**$97.58**	**$100.93**	**$104.43**	**$104.43**	**$104.43**

[1] Outyear funding estimates are for planning purposes only and includes increases in cost due to local inflation. The current cooperative agreement ends in FY 2026.

[2] Operations funding for VLBA is included in NRAO total funding at $3.43 million per year.

[3] FY 2021 actual includes funding for the ngVLA program office. FY 2023 request includes special projects for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[4] Reflects additional funding for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

The FY 2023 Request funds NRAO and the U.S. share of ALMA O&M costs, including ongoing support for education and public outreach programs as well as development programs such as planning for a next-generation centimeter wavelength facility ngVLA. Additional funding was provided to NRAO in FY 2021 in support for the ngVLA program office. The FY 2023 request includes additional funding for research infrastructure costs and O&M related to repairs and maintenance projects. Funding for special projects also includes additional deferred maintenance projects, upgrades necessary for the continued effective operations of the facility, such as replacement of observatory dome mechanisms, removal of possible asbestos-containing materials and fortification of telescope tracks. The execution of projects will be prioritized based on the outcome of ongoing facility condition assessments.

Reviews

NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. Recommendations from these annual reviews with external panelists are routinely used to inform NRAO's operations planning and NSF's oversight of the facility. A comprehensive management review was conducted in December 2021 by an external panel of experts.

Renewal/Recompetition/Termination

Following a solicitation issued in FY 2014, the O&M of NRAO, including VLA, North American contributions to ALMA, and associated development laboratories, administration, and management functions, was competed and the NSB authorized a 10-year award to AUI for the period October 1, 2016 - September 30, 2026. MPS plans to develop an analysis, per NSF policy, in 2024 for consideration by the NSF Director to either compete the management of NRAO, review and fund a renewal proposal from the current management entity, or to divest components of the facility through stewardship transition or other means.