

NATIONAL RADIO ASTRONOMY OBSERVATORY (NRAO)

\$88,130,000
-\$6,910,000 / -7.3%

National Radio Astronomy Observatory Funding¹
(Dollars in Millions)

FY 2019 Actual ²	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual	
			Amount	Percent
\$95.04	-	\$88.13	-\$6.91	-7.3%

¹ This table aggregates the request NRAO and ALMA base operations.

² Includes \$8.09 million for continuity of operations into FY 2020.

NRAO conceives, designs, builds, operates, and maintains state-of-the-art radio telescopes used by scientists from around the world. Operating synergistically with optical, infrared, x-ray, gamma-ray, and gravitational wave telescopes, NRAO facilities enable discovery over a remarkably broad range of key problems in modern astrophysics that reach from within our solar system to the most distant galaxies in the universe. Using NRAO observing capabilities and data archives, scientists: carry out precision cosmological measurements; test fundamental physics; probe deep into the earliest, most intense, and optically obscured phases of planet, star, galaxy, and black hole formation; reveal the cool gas from which stars form; provide essential tools for studying magnetic fields and high-energy cosmic phenomena; and seek to detect the sources of gravitational waves.

As a Federally Funded Research and Development Center headquartered in Charlottesville, Virginia, NRAO operates the Karl G. Jansky Very Large Array (VLA) near Socorro, New Mexico; the Very Long Baseline Array (VLBA), with 10 sites throughout the continental United States, Hawaii, and the U.S. Virgin Islands; and is the North American implementing organization for the international Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. In support of these radio telescopes, NRAO also operates the Central Development Laboratory (CDL) in Charlottesville, which develops next-generation electronics and detectors for radio astronomy. These observing facilities for radio astronomy are available to any qualified researcher, regardless of affiliation or nationality, on the basis of scientific, merit-reviewed proposals. In addition to conducting NSF-funded astrophysical observations, the VLBA is used for fundamental support of the International Celestial Reference Frame, under an agreement with the United States Naval Observatory (USNO). NRAO facilities annually serve over 2,500 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 facilities have enabled a remarkable array of ground-breaking discoveries in the last year alone, ranging from imaging storms on Jupiter to radio detections of merging neutron stars, which are multi-messenger events. The most impressive scientific result, fundamentally enabled by the inclusion of ALMA as a cornerstone of the Event Horizon Telescope effort, was the direct imaging of a black hole event horizon. This result is already seen as one of the great scientific achievements of the century, and would not have been possible without utilization of ALMA and the close collaborative effort between the United States, international communities, and NRAO. The VLA and ALMA produced a stream of ground-breaking results in the fields of star and planet formation and astrochemistry over the last year. For example, the combination of high-resolution ALMA dust imaging and Very Large Telescope imaging of the ionized gas in the protoplanetary system, PDS 70, has shown evidence for accretion onto planets themselves, for the first time. 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.

Major Multi-User Research Facilities

In September 2017, Hurricane Maria damaged the VLBA facility on St. Croix, Virgin Islands. Funding for repairs was provided in the Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123). Of the total \$16.30 million provided for observatory repairs, \$2.0 million was identified for NRAO and obligated in FY 2018. These repairs are scheduled for completion in FY 2020.

Total Obligations for NRAO (Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES ²				
	Actual ¹	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance ³	\$49.83	-	\$39.45	\$40.53	\$40.96	\$39.10	\$40.19	\$41.31
<i>Telescope Operations</i>	14.24	-	11.28	11.60	11.72	11.18	11.50	11.82
<i>Development</i>	9.81	-	7.77	7.98	8.07	7.70	7.92	8.14
<i>Science Operations</i>	8.03	-	6.35	6.53	6.59	6.30	6.47	6.65
<i>Administrative Services</i>	13.60	-	10.77	11.06	11.18	10.67	10.97	11.28
<i>Directors Office</i>	3.15	-	2.49	2.55	2.58	2.46	2.53	2.60
<i>Education and Public Outreach</i>	1.00	-	0.79	0.81	0.82	0.78	0.80	0.83
ALMA Operations	45.21	-	48.68	50.63	52.66	57.77	56.96	59.24
Total	\$95.04	-	\$88.13	\$91.16	\$93.62	\$96.87	\$97.15	\$100.55

¹ Includes \$8.09 million for continuity of operations into FY 2020 (\$3.16 million for NRAO and \$4.93 million for ALMA) and \$4.0 million (under NRAO) for development of a next generation Very Large Array (ngVLA).

² Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2026.

³ Operations funding for VLBA is included in the NRAO total funding at \$3.82 million in FY 2019, \$3.43 million per year for FY 2020-FY 2022, and then \$2.74 million per year for FY 2023-FY 2026.

For information on continuity of operations funding, see the opening narrative of this chapter.

Partnerships and Other Funding Sources

NRAO supplements NSF Division of Astronomical Sciences (AST) support with funding provided by other NSF sources, other federal agencies, and non-federal sources. In FY 2019, NRAO received approximately \$100,000 from non-AST sources at NSF, \$1.20 million from other federal agencies, and \$1.50 million from U.S. universities, foreign scientific and technical institutes, and other non-federal and industrial 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 provided \$4.14 million in funding for the VLBA for FY 2019, \$4.19 million for FY 2020, and plans to provide \$4.30 million for FY 2021.

Telescope Operations (\$11.28 million)

This encompasses support for direct telescope and array operations of the VLA including maintenance, infrastructure upgrades, and telescope management.

Development (\$7.77 million)

The FY 2021 Request continues to support development programs including next generation electronics and detectors for radio astronomy, as well as planning and development of technologies for a next-generation centimeter wavelength facility (next generation Very Large Array, or ngVLA).

Science Operations (\$6.35 million)

This includes telescope time allocation, staff research, science training and education, and science community outreach.

Administrative Services (\$10.77 million)

This includes internal common costs used to allocate common and management expenses across the total pool of observatory activity, such as business services, utilities, and other facility costs at the operating locations, observatory management, and the library.

Director's Office (\$2.49 million)

This supports the director's office and managing organization costs.

Education and Public Outreach (\$790,000)

NRAO supports a comprehensive outreach program that makes radio astronomy information available to the public.¹ NRAO also supports a visitor and education center and conducts active educational and public outreach programs. The VLA visitor center attracts over 20,000 public visitors each year.

ALMA Operations (\$48.68 million)

Operations funding supports a share of observatory operations in Chile, a technical development program, and the North American ALMA Science Center (NAASC) in Socorro, New Mexico. The NAASC provides technical and scientific support for the broad astronomical community that uses ALMA. The NAASC also organizes summer schools, workshops, and courses in techniques of millimeter and submillimeter astronomy.

Management and Oversight

- **NSF Structure:** In consultation with community representatives, an AST program officer 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 participates in the international ALMA Board and attends Associated Universities Incorporated(AUI)/NRAO governance and advisory committee meetings. To address issues as they arise, AST has a dedicated Integrated Project Team which includes representatives from other NSF offices, such as the Office of General Counsel, OISE, and the Division of Acquisition and Cooperative Support and the Large Facilities Office in BFA. The MPS Facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.



ALMA is in science operations following the completion of construction in 2015. An international partnership between North America, Europe, and East Asia, ALMA provides orders-of-magnitude improvement in observing sensitivity and image quality over previous facilities. *Credit: ALMA (ESO/NRAO/NAOJ).*

- **External Structure:** Management is through a cooperative agreement with AUI, which 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 a member from NSF; 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.

¹ <https://public.nrao.edu/>

Major Multi-User Research Facilities

- Reviews: NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. A comprehensive mid-term review will be conducted in 2021.

Renewal/Recompetition/Termination

Following a solicitation issued in FY 2014 (NSF 14-568), management and operation of NRAO (including ALMA) was competed and NSB authorized a cooperative agreement with AUI for Oct. 2016 – Sept. 2026.