



NSF CONTRIBUTION BY THE NUMBERS

\$140,500

NSF grant to establish a radio astronomy facility in 1955

\$169 million

Cost for VLBA's initial 25 dish antennas in 2005

\$862 million

10-year cooperative agreement for National Radio Astronomy Observatory signed October 2016

\$28 million

Amount NSF invested in EHT over 19 years and 22 awards

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EVENT HORIZON TELESCOPE: NSF'S CONTRIBUTION

EHT didn't happen overnight. Decades in the making, the Event Horizon Telescope discovery involved telescopes and institutions on five continents and required expertise in areas ranging from detector development to high-performance computing and theoretical physics. The National Science Foundation played a pivotal role in the discovery by funding individual investigators, interdisciplinary scientific teams and radio astronomy research facilities.

Supporting Transformative Technologies. With NSF grants, scientists and engineers advanced the concept of long baseline arrays, as well as the devices and systems used to record and process the data. In the 1990s, researchers at MIT's Haystack Observatory pioneered the opening of the 3 mm wavelength window for very-long-baseline interferometry. Their work also led to a better understanding of overcoming signal recording issues. With NSF funding, other researchers improved VLBI recording, signal processing and hardware design. In addition to the advances in physics and astrophysics, this observation – and subsequent ones – enable technologies that will improve data analysis, storage and transmission, leading to improvements for broader societal uses of these technologies.

Funding Interdisciplinary Teams. NSF's Partnerships for International Research and Education program allows the agency to leverage U.S. dollars and improve scientific outcomes. A partnerships project on black hole astrophysics led by the University of Arizona (with partners in Germany, Mexico and Taiwan) contributed critical data on weather conditions at all EHT sites that triggered the 2017 EHT observations. The research team also developed the cloud computing infrastructure for the EHT's main postprocessing system. Other funded activities involved detector development and fast data transfer.

Investing in World-Class Facilities. Beginning with the Green Bank Observatory in 1955, NSF has supported multiple radio astronomy facilities including: the Very Large Array in New Mexico (initiated in 1972); the Very Long Baseline Array headquartered in New Mexico with 10 field sites throughout the U.S. and Virgin Islands (initiated in 1986); the Combined Array for Millimeter-wave Astronomy (initiated 2000); and the Atacama Large Millimeter/submillimeter Array [ALMA] (initial appropriation for construction in 2001).

NSF-funded telescopes and instrumentation involved in the EHT discovery include: ALMA, Submillimeter Telescope operated by the Arizona Radio Observatory, South Pole Telescope (NSF-funded research, instrumentation and support through the NSF U.S. Antarctic Program) and Large Millimeter Telescope (NSF-funded instrumentation).

Driving Big Ideas. The EHT discovery signals the entry of astronomy into the era of big and distributed data science. The massive amounts of data collected required a global processing and analysis effort. In one case, EHT data collected on disks at the South Pole Telescope in Antarctica traveled 15,000 km back to a supercomputer in the U.S. for processing.

As a data-driven discovery, the EHT project aligns with three of NSF's 10 Big Ideas. Future astrophysical discoveries will benefit from new hardware and software advances generated by *Harnessing the Data Revolution*, particularly development of a new data cyberinfrastructure for timely handling, processing, analysis and modeling of multi-messenger astrophysical data. By integrating new ways to probe the cosmos, *Windows on the Universe* is providing a more detailed view of the universe, and *Mid-Scale Research Infrastructure* offers a new funding mechanism that is responsive to ambitious projects like EHT requiring dynamic and flexible investment.