

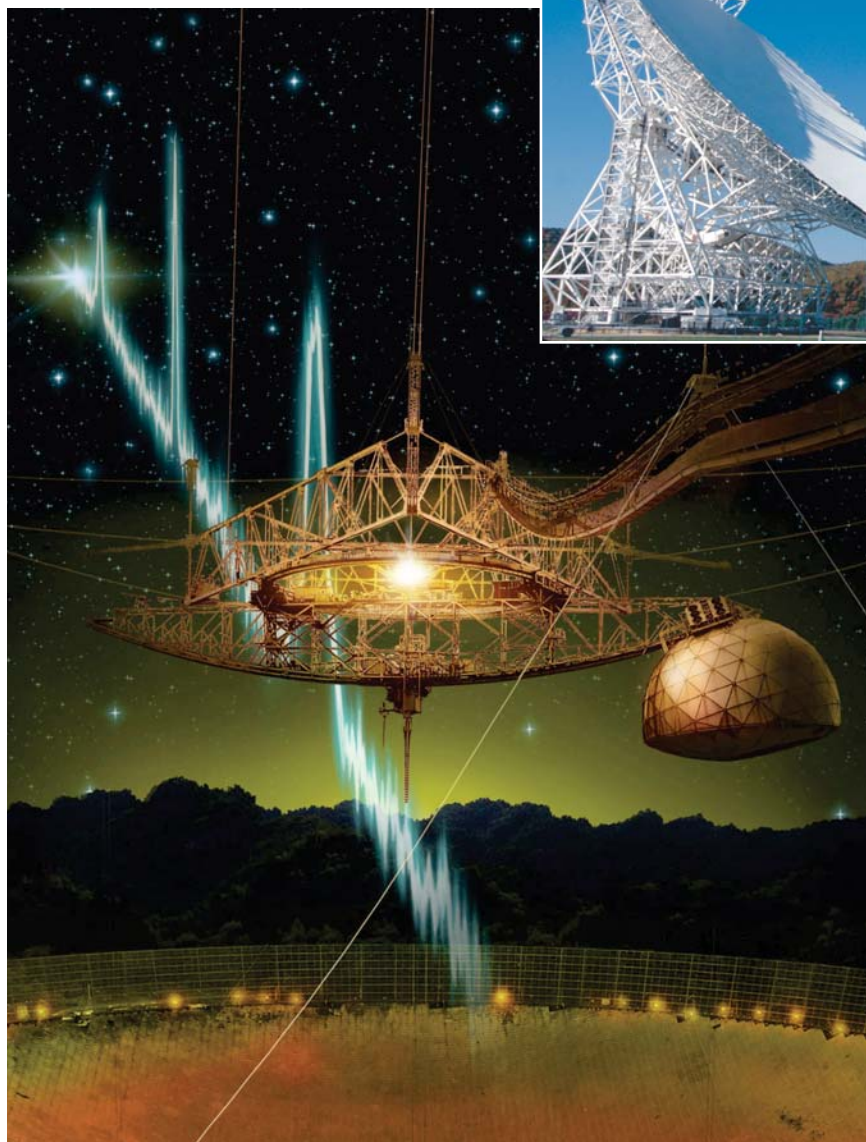
Fates of two big radio dishes hang in the balance

Although still productive, the facilities must find alternative funding to avoid being sacrificed for new cutting-edge telescopes.

Start up the Large Synoptic Survey Telescope (LSST). Invest in midscale telescopes and instrumentation. Join one of the extremely large telescopes. Increase funding for individual investigators. Those are some of the top recommendations for US ground-based astronomy from the 2010 decadal survey, *New Worlds, New Horizons*. They were made under assumptions of growing budgets. (See *PHYSICS TODAY*, October 2010, page 25.)

Soon after the survey, though, funding fell behind the optimistic projections, which had the budget of the NSF astronomical sciences division—the main US funder of ground-based astronomy—doubling by 2021. In its 2012 portfolio review, the division sketched out belt-tightening measures that included divesting from a handful of optical-IR, solar, and radio telescopes. Those telescopes, in order of priority to keep open, are the Nicholas U. Mayall Telescope, the Very Long Baseline Array (VLBA), the National Solar Observatory (NSO) Integrated Synoptic Program, the Robert C. Byrd Green Bank Telescope (GBT), WIYN, and the McMath-Pierce Solar Telescope. Also on the endangered list, but for future consideration, were Arecibo Observatory and the Southern Astrophysical Research Telescope (SOAR).

The cuts to existing facilities are intended to support the goals of keeping a “balance between current facilities and new endeavors, between large projects and small grants, and between risk and reward.” The review stresses that astronomy “is caught between budget realities and the transformative opportunities of new technologies.” Just how tightly caught is becoming increasingly clear. For several optical and radio telescopes, new partners and sources of funding are



TWO LARGE RADIO TELESCOPES are caught in the crosshairs of budget trimmers at NSF, as the foundation scrimps, saves, and shaves to stay at the frontiers of science. Arecibo Observatory (above) was used in an international collaboration that pinpointed the source of a fast radio burst in a host galaxy, and both it and the Green Bank Telescope (inset) in West Virginia are involved in the search for gravitational waves. Both need to find new funding streams to avoid closure. (Artist's conception courtesy of NAIC–Arecibo Observatory, an NSF facility.)

being found and new modes of operating are being implemented. But the future of others—notably two radio facilities, the GBT in West Virginia and Arecibo Observatory in Puerto Rico—remains uncertain. And if anything, the possibility of NSF joining one of the extremely large telescopes in the works—the Thirty Meter Telescope or the Giant

Magellan Telescope—has become more remote. (See *PHYSICS TODAY*, August 2015, page 24.)

The astronomical sciences budget has been nearly flat at around \$245 million throughout this decade. In recent years, about three-fifths has gone to operating facilities and two-fifths to research, education, and midscale innovations (projects

in the \$4 million to \$15 million range). But with new facilities coming on line, the budget is increasingly squeezed and the portion that goes to facilities could climb, says NSF's Jim Ulvestad, who was director of astronomical sciences until last month, when he became acting assistant director for mathematical and physical sciences. Even after the austerity measures, the numbers don't add up. (See the figure on page 28.)

The combined annual running costs of the main new facilities will be more than \$93 million. That's for the Atacama Large Millimeter/Submillimeter Array (ALMA), which started up in 2011 (see PHYSICS TODAY, December 2016, page 22); the Daniel K. Inouye Solar Telescope, for which first light is expected in 2018; and the LSST, which will follow in 2020. The divestitures outlined so far would save at most \$45 million a year.

"Just closing all existing facilities would not solve the problem of having money for the new ones," says the University of Arizona's Buell Jannuzi, chair of the Astronomy and Astrophysics Advisory Committee, which advises Congress and the Department of Energy, NASA, and NSF on how those agencies can coordinate US astronomy activities. The new facilities have been highly ranked by the astronomy community in past decadal reviews. But, notes Jannuzi, "most of the legacy facilities are still incredibly productive." Ulvestad calls having to fit the division's activities into a flat budget the "tyranny of arithmetic."

New partners, new purposes

Running ALMA costs NSF more than \$40 million a year. The astronomical sciences division has scrapped the money together by scrapping its university radio telescope program, ending its optical instrumentation program for university telescopes, cutting back on advanced technology instrumentation, reducing its grants program—which it was able to restore after a couple of years—and divesting from facilities to the tune of \$15 million.

Some of that divesting is taking place at the National Optical Astronomy Observatory (NOAO) in Kitt Peak, Arizona. The DOE is turning the 4 m Mayall telescope into a dedicated galaxy mapper to characterize dark energy (see PHYSICS TODAY, October 2016, page 28). NASA is taking over the NOAO's NSF-funded

40% share of the 3.5 m WIYN to determine the masses of exoplanets. And for now NOAO's 2.1 m telescope is being operated under a three-year agreement by a consortium of universities.

Starting last October, the VLBA has been getting half its funding (about \$4 million) from—and giving half its time to—the US Naval Observatory (USNO), which uses it to measure Earth's orientation parameters. Such measurements have "always been an important part of civilian timekeeping and naviga-

tion," says Tony Beasley, director of the National Radio Astronomy Observatory (NRAO), but previously the USNO got less time, contributed much less money to the VLBA, and got some data free.

Such arrangements mean less—or, as with the Mayall, no—time is available for open proposals by astronomers. "Some of the communities dependent on them for their science are getting squeezed," says Beasley. "Losing 50% of observing time on the VLBA will have a huge impact on the science community. But it

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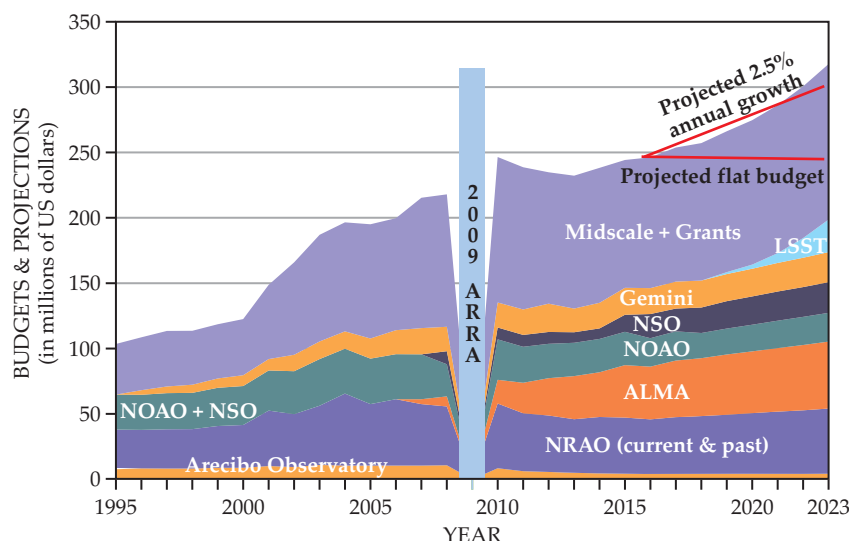
would be terrible if the facilities had to be closed.” And, he adds, “since someone wants to put money in, the science new partners fund is generally exciting.”

Radio troubles

The fingering of the GBT for divestment in the portfolio review surprised many radio astronomers. Not only is it, at 100 m diameter, the world’s largest steerable dish, but it is relatively new. The GBT was completed in 2001, and after commissioning and implementation of new instruments, it reached prime operating condition in 2012, says Green Bank Observatory director Karen O’Neil. It is in the National Radio Quiet Zone and sees 85% of the sky, she says. “There is no other telescope that can do what the GBT does.” For example, she says, “if you want to see how gas is distributed in a galaxy, you need an array for high-resolution detail, but you need a photon bucket to see how gas is distributed and to find the low-surface brightness features.”

The NSF astronomical sciences division is prepared to fund up to half of the tapped facilities’ operating costs, but if the facilities can’t come up with the difference, NSF will have a tough time staying involved. The total for the GBT is \$12 million a year. So far West Virginia University, the Breakthrough Initiative, and NANOGrav—a project that keeps tabs on pulsars to search for gravity waves and, ironically, gets its funding through NSF’s physics division—are together putting in about half the needed \$6 million a year. The Breakthrough Initiative is a good partner, says O’Neil. The initiative’s project involves listening for signs of extraterrestrial life. “They are willing to make their data public, and they are flexible so the astronomy community can get in urgent observations.”

Arecibo is used for radio astronomy and radar studies of Earth’s atmosphere, meteors, asteroids, and planets (see the article by Daniel Altschuler and Chris Salter, *PHYSICS TODAY*, November 2013, page 43). It is 52 years old and, at 305 m in diameter, still the world’s largest dish. (When China’s recently completed Five-Hundred-Meter Aperture Spherical Radio Telescope, or FAST, starts doing science, its strengths will be different, since it will operate at lower frequencies and without planetary or atmospheric radar instruments.) The NSF divisions of



SINCE THE SPIKE IN 2009 from the American Recovery and Reinvestment Act (ARRA), the budget for NSF’s division of astronomical sciences has been nearly flat. To cover the growing operating costs of new facilities as they ramp up and hold funding constant for individual grants and midscale projects requires 2.5% annual growth, as shown by the sloped red line—and even in that optimistic scenario many wished-for division activities would remain undone. The projections do not account for inflation. LSST, Large Synoptic Survey Telescope; NOAO, National Optical Astronomy Observatory; NSO, National Solar Observatory (includes Daniel K. Inouye Solar Telescope); ALMA, Atacama Large Millimeter/Submillimeter Array; NRAO, National Radio Astronomy Observatory (includes some non-NRAO radio astronomy facilities). (Figure adapted from one provided by NSF’s Jim Ulvestad.)

astronomical sciences and of atmospheric and geospace sciences each pay about \$4 million a year, as does NASA, which uses Arecibo for its congressionally mandated activities in tracking near-Earth objects. Another \$1 million comes from the facility’s visitor center and education activities.

The 2012 portfolio review considered two budget scenarios, and reality is closer to the more pessimistic one, says Ulvestad. The revision to the divestment stance on Arecibo came in late 2013, in an open letter NSF wrote to the astronomy community; the facility would need to find other funding. To make matters worse, in April 2016 a separate portfolio review recommended that NSF atmospheric and geospace sciences reduce its annual Arecibo contribution to \$1.1 million by 2020.

To keep Arecibo open, officials are considering everything from running zip lines for tourism to collaborating with the Breakthrough Initiative, says the observatory’s deputy director Joan Schmelz. NANOGrav, already a big user, would like to help save the telescope and have more time on it, says project chair Xavier Siemens of the University of Wisconsin–Milwaukee. The project team has “approached private donors [for

grants] to buy time” on both Arecibo and the GBT, he says. So far, though, neither facility has come up with an alternative formula for survival.

Fates and frontiers

For radio pulsars, a single dish is perfect, says Ulvestad. But most of the science in the decadal survey requires imaging at arcsecond resolution or better. “You can’t do that with a single radio dish. Interferometers are king. Fundamentally, they have the capability to do more of the recommended science.”

So how can operations for the new facilities be paid for? The simple answer is more money. Building and operating facilities are funded separately at NSF. “When they agree to build something new, the estimate for operations is not rigidly budgeted into future costs,” says NRAO’s Beasley. “It’s hard to have life-cycle budgeting.” Not only that, he says, but new facilities cost 10 times as much to build and operate as the earlier generation. “No reasonable growth of the budget can absorb that.”

One of NSF’s most important roles, Ulvestad says, is driving innovation to stay at the cutting edge of science. “If we build big facilities and don’t give grants

to people to do science with them, that doesn't advance the frontier. Staying at the frontier as science evolves costs money. If the budget stays flat, we'll have to make more really tough choices."

NSF is conducting environmental impact studies at Arecibo, Green Bank, and NSO's Sacramento Peak in New Mexico. The possible recommendations are to continue running the facilities with no change, continue running with less NSF funding but with money from new collaborations, partially shut the facilities but keep open educational aspects,

mothball, or permanently shut down the observatories.

The studies look at social and economic factors in addition to financial and environmental ones. The Green Bank Observatory is the second-largest private employer in its county, notes O'Neil. And shuttering Arecibo would quash morale and be a big loss for education in already financially devastated Puerto Rico (see PHYSICS TODAY, January 2016, page 28). NSF says it will decide this summer about Arecibo and by early next year about Sacramento Peak and the GBT. **Toni Feder**

Citizen observers chart Arctic change

Researchers are increasingly partnering with local residents to obtain climate and environmental data. But the endeavor calls for interpersonal savvy.

For the past decade, Joe Leavitt, an Inupiat subsistence hunter in the coastal Alaskan town of Utqiagvik (formerly Barrow), 500 km north of the Arctic Circle, has filled notebook after notebook with his observations of the sea: the buildup of *qinu*, or slush ice, before the fall freeze-up; the thrusting up of ice ridges by colliding floes; the fracturing and healing of the winter pack ice. Once a month he mails his notes to a team of geophysicists at the University of Alaska Fairbanks, who collect them, along with the dispatches of a dozen or so other observers scattered along the Alaskan coast, as part of a project known as the Seasonal Ice Zone Observing Network. The hope is that the observations, paired with the team's traditional fieldwork, can shed new light on Arctic sea-ice trends—trends that still aren't fully explained by climate models.

The NSF-funded project is one example of what's come to be known as community-based monitoring. The practice has proliferated in the Arctic, where local residents can often obtain information that would be impractical, if not impossible, to acquire by more conventional means. The Atlas of Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic lists the Seasonal Ice Zone Observing Network as one of four dozen such projects under way throughout the region.

According to Henry Huntington, sci-

ence director of Arctic ocean projects at the Pew Charitable Trusts, the rise of community-based environmental monitoring has coincided with a sea change in scientists' attitudes toward the endeavor: "Twenty years ago it was, 'Hmm, that's an interesting little curiosity.' Now, even in the hard-science and glaciology worlds, they're beginning to see it as a serious line of inquiry."

Yet the pursuit isn't without its growing pains. Piecemeal funding has hampered efforts to establish sustained, large-scale projects, and some scientists still struggle to cultivate relationships in the Arctic's typically small, predominantly indigenous communities. But recent gestures by the US government—including a joint commitment with more than 20 other governments to expand scientific partnerships with the Arctic's indigenous communities—signal that the region's growing league of citizen observers may play a rising role in research.

Climate collaborators

Although the vast majority of global greenhouse gas emissions are released outside of the Arctic, communities inside the Arctic are bearing an outsized share of the consequences. In its 2016 Arctic Report Card, the National Oceanic and Atmospheric Administration noted that the region is warming at twice the rate of lower latitudes and is already 2 °C warmer than its 1981–2010 average. Last



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