

still include capabilities at the scientific forefront. Far from business as usual, Astro2020 does not forward a ranked list of missions; rather, it imagines the Great Observatories Mission and Technology Maturation Program to study multiple mission concepts in the same decade. Individual mission cost targets would be appropriate for the scientific scope. While the survey prioritizes the first mission to enter the maturation program, it emphasizes that multiple missions should be studied this decade, so that if the one at the top of the list runs into problems, delays, or large cost overruns, backup options are ready.

First in the list of missions to be matured is an observatory that spans the wavelength range covered by the *Hubble Space Telescope* (which is 2.4 m in diameter and covers UV to near-IR) and has the collecting area of the *JWST* (6.5 m in diameter but mainly IR). The large IR/optical/UV (IR/O/UV) mission would have the ability to image a target planet while blocking out the light of its parent star, even when the star is 10 billion times brighter than the planet. It is an ambitious mission, on the scale of the *JWST*, yet the survey sets a target that it should not cost significantly more than the *JWST*.

The choice is motivated by the mission's ability to diagnose the atmospheres of planets outside the Milky Way to search for signatures of life—which, if detected, would change the way humans view their place in the universe. Like *Hubble*, the IR/O/UV mission would revolutionize our understanding of galaxies and stars and of the interstellar, circumgalactic, and intergalactic gases that give birth to them and would link them in a complex cosmic ecosystem. The IR/O/UV mission is technically challenging, and like the *JWST* and *Hubble* before it, it demands a major investment; NASA is the only agency worldwide capable of leading it.

Also compelling—and essential to advancing modern astrophysics—are a next-generation x-ray telescope and a mission sensitive in the far-IR. The former, with resolution matching that of NASA's *Chandra X-Ray Observatory* but with a vastly greater collecting area, would map hot, diffuse structures that are believed to feed the growth of galaxies and would peer back to find black holes forming in the early universe. The latter would unveil the dense regions of gas and dust enshrouding sites of star for-

mation and the active central regions of many galaxies, and it would reveal the complex chemical processes that give rise to stars, planets, and ultimately life. With disciplined study and technology development, both missions can realize transformative capabilities on a size scale only one-third that of the large IR/O/UV mission. With strategic investment in the coming decade, both could also be ready to launch in quick succession.

Our "crystal ball" description of future missions and observatories beyond the *JWST* has focused on the largest space missions, but Astro2020 also recommends that NASA continue with a balanced portfolio of mission sizes from the large missions or Great Observatories described here down to probe, explorer, and smaller missions. Our committee was only tasked with planning future US-based activities, but in reality many of the projects will involve international partnerships, and implementation of the NASA road map will need to take into consideration missions led by the European Space Agency and other countries.

Astro2020 envisions a bright future, with eyes on the universe spanning the electromagnetic spectrum.

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LETTERS

STEM volunteers

In response to Toni Feder's item "The US is in dire need of STEM teachers" (March 2022, page 25), I would like to make note of the work being done by the American Association for the Advancement of Science's STEM Volunteer Program (stemvolunteers.org), which I coordinate. We recruit STEM (science, technology, engineering, and mathematics) professionals to assist K–12 teachers in their classrooms.

The program began in 2004 and currently has 110 volunteers in four school

districts in the Washington, DC, metropolitan area. Our retired volunteers commit to a few hours one day a week in the classroom for the school year. Those still working commit to a few hours every two to three weeks. Many volunteers exceed those commitments.

Volunteers help students learn subject matter through projects rather than by rote. They also present on technical subjects in the curriculum and organize "Ask a Scientist" sessions, in which they answer questions from groups of students.

One teacher wrote an email to a volunteer thanking him for the gift of his time and stating that it was an "absolute pleasure" to work with him. "You make science come alive for our children and I am very grateful," she wrote. "I will do all I can to encourage more schools to use the program and get visiting scientists."

Prospective volunteers are contacted through a variety of mechanisms—such as through societies' local sections, newsletters, the DC MIT Club, and retirement associations. The American Physical Society has supported the program from the beginning, including annually sending recruiting notices to its members in the DC metropolitan area.

I am convinced that a national program can be designed to produce a significant increase in the number of volunteers from the large number of STEM graduates. As of 2019, there were 12.3 million college graduates whose highest degree was in a science or engineering field, according to NSF's National Survey of College Graduates. A consortium of STEM societies is the best approach for implementing a program in support of K–12 STEM education.

Increasing the number of volunteers will not solve the teachers shortage, but volunteers can be a significant help, in particular with assisting teachers who have a limited background in STEM. And they can serve as substitute teachers, as several of our volunteers have done.

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Mind and matter

Andrew Zangwill's March 2022 article (page 28) presents an insightful portrait of Philip Anderson in dynamic,