

## Commentary

# Astronomy from space after the *JWST*

Last year the *James Webb Space Telescope* (*JWST*) trained its sights on the distant universe and began returning stunning images in IR light that captured the imagination of the public around the world. The *JWST* has only just begun its exploration of the universe, yet astronomers are already looking to the future.

Every 10 years, panels of experts convened by the National Academies create a survey in astronomy and astrophysics to assess scientific frontiers and plan the capabilities that will keep advancing humankind's understanding of the cosmos. The *JWST*, originally called the *Next Generation Space Telescope*, was recommended as the top-priority large strategic mission in the 2000 decadal survey, and given its technical ambition and scale, it took more than two decades to be realized. But it was also conceived as costing less than 10% of the eventual price tag, in part because of wishful thinking by NASA and the scientific community and in part because the project began full-scale development before it was ready.

The 2010 decadal survey gave the highest priority for a large space mission to the *Nancy Grace Roman Space Telescope*, then known as the *Wide-Field Infrared Survey Telescope*, an observatory that will image large swaths of the sky in IR light to make three-dimensional cosmic maps of many millions of galaxies, elucidate the nature of the mysterious dark matter and dark energy, search for and image exoplanets, and explore many other topics in IR astrophysics. *Roman* is scheduled for launch in 2027, some 17 years after it was recommended as a priority. That delay was a result of funding issues directly related to the cost overruns on the *JWST*. Like the *JWST*, *Roman* was chosen to address the big, outstanding scientific questions identified at the time. But the delays bring with them costs in both taxpayer dollars and scientific opportunities.

The most recent astronomy and astrophysics survey, *Astro2020* (for which the two of us served as committee cochairs), considered how to accomplish its charge



**STEPHAN'S QUINTET**, as captured by the *James Webb Space Telescope*. The image, a mosaic constructed from almost 1000 separate IR images, reveals previously unseen details of the group of galaxies. (Courtesy of NASA, ESA, CSA, and STScI.)

to chart a course for the future of space astrophysics. In previous surveys, the committees have provided a rank-ordered list of concepts for large space missions, and in the decade that followed, NASA began development of the top project on the list as its next priority. *Astro2020*, however, took a different course.

The lessons of the past 20 years indicate that with business as usual, the next large mission beyond the *JWST* and *Roman* would be two or more decades away from its realization, and the next one after that more than four decades away. In the 1990s and early 2000s, NASA was able to launch a suite of Great Observatories—

with four strategic missions, launched within a period of 13 years—that significantly advanced observational capabilities across a broad swath of the electromagnetic spectrum. The scientific impact of that panchromatic suite was enormous, as the universe could be simultaneously probed in many different and complementary ways, and it achieved leverage and insights well beyond what was imagined for any of the individual telescopes.

*Astro2020* therefore includes a strategy to realize a new generation of Great Observatories: They have intervals between launches greatly reduced from the roughly two decades that is the recent norm yet

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,