Next-generation space telescopes could use deformable mirrors to image Earth-sized worlds

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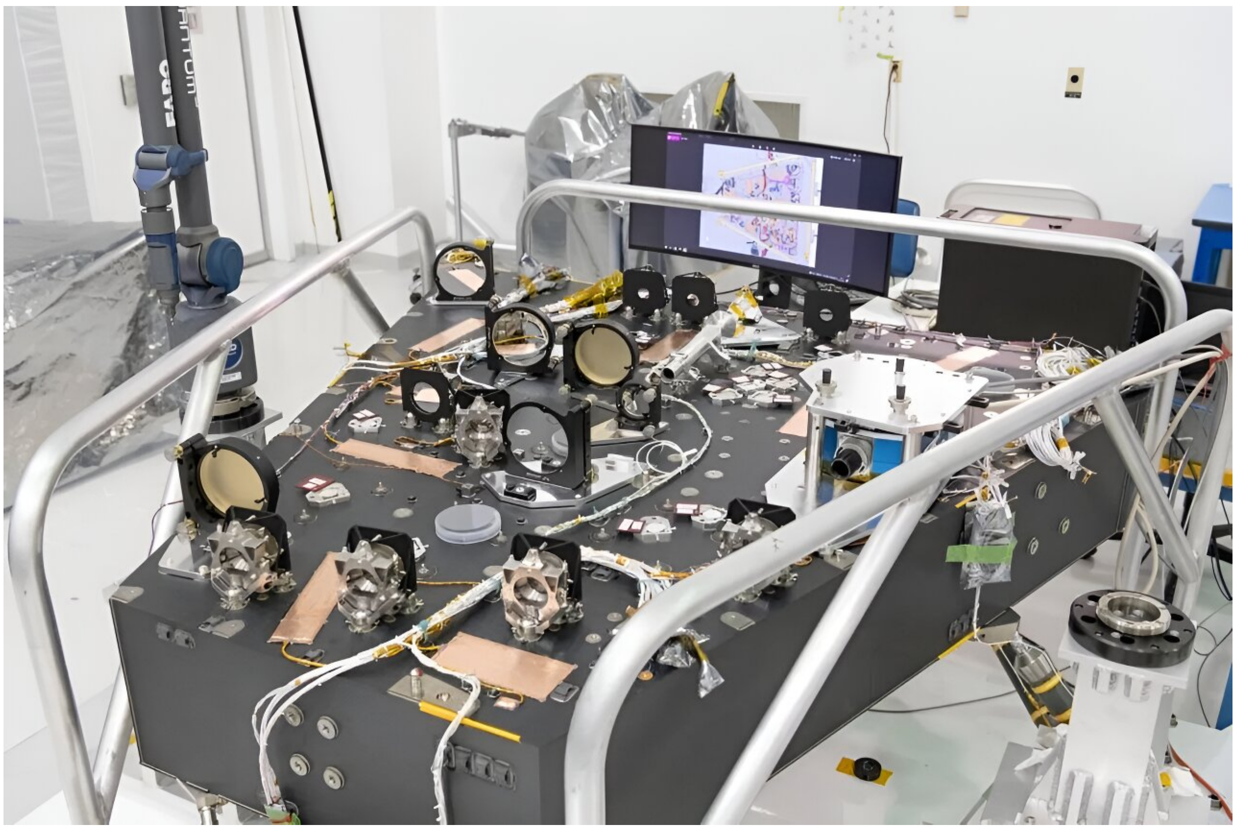

The Roman Space Telescope Coronagraph during assembly of the static optics at NASA's Jet Propulsion Laboratory. Credit: Dr. Eduardo Bendek

Observing distant objects is no easy task, thanks to our planet's thick and fluffy atmosphere. As light passes through the upper reaches of our atmosphere, it is refracted and distorted, making it much harder to discern objects at cosmological distances (billions of light years away) and small objects in adjacent star systems like exoplanets.

For astronomers, there are only two ways to overcome this problem: send telescopes to space or equip telescopes with mirrors that can adjust to compensate for atmospheric distortion.

Since 1970, NASA and the ESA have launched more than 90 space telescopes into orbit, and 29 of these are still active, so it's safe to say we've got that covered.

But in the coming years, a growing number of ground-based telescopes will incorporate adaptive optics (AOs) that will allow them to perform cutting-edge astronomy. This includes the study of exoplanets, which next-generation telescopes will be able to observe directly using coronographs and self-adjusting mirrors. This will allow astronomers to obtain spectra directly from their atmospheres and characterize them to see if they are habitable.

NASA is pursuing the development of adaptive optics through its Deformable Mirror Technology project, which is carried out at the Jet Propulsion Laboratory at Caltech and sponsored by NASA's Astrophysics Division Strategic Astrophysics Technology (SAT) and the NASA Small Business Innovation Research (SBIR) programs.

The research is being led by Dr. Eduardo Bendek from JPL and Dr. Tyler Groff from NASA's Goddard Spaceflight Center (GSFC)—the co-chairs of the DM Technology Roadmap working group—Boston Micromachines (BMC) founder and CEO Paul Bierden, and Adaptive Optics Associates (AOX) Program Manager Kevin King.

Directly imaging exoplanets

The field of exoplanet studies has exploded in recent years, with 5,539 confirmed candidates in 4,129 systems and over 10,000 more awaiting confirmation. Finding habitable planets among these many candidates is crucial to addressing one of the greatest mysteries of all time: are we alone in the universe?

Thanks to advances in instrumentation, advanced analytics, and data-sharing, the field has been transitioning from discovery to characterization. However, to date, most exoplanets have been discovered using indirect methods.

To do this effectively, scientists need to be able to observe exoplanets directly. This is known as the direct imaging method, where astronomers study light reflected directly from an exoplanet atmosphere and/or surface. This light is then analyzed with spectrometers to determine its chemical composition, allowing astronomers to constrain habitability.

Unfortunately, it is very difficult to resolve smaller, rocky planets that orbit closer to their parent stars—which is where Earth-like planets are expected to be found—due to the overpowering glare from their stars.

This is likely to change with cutting-edge telescopes like James Webb, as well as next-generation arrays like the Extremely Large Telescope (ELT), the Giant Magellan Telescope (GMT), and the Thirty Meter Telescope (TMT). These ground-based arrays will combine 30-meter primary mirrors, advanced spectrometers, and coronographs (instruments that block out starlight). Deformable mirrors are an essential component of a coronagraph, as they can correct for the tiniest of imperfections in the telescope and remove any remaining starlight contamination.

This is essential since a misalignment between mirrors or a change in the mirror's shape—i.e., which leads to instability in the telescope's optics—can result in glare that obscures the detection of smaller rocky exoplanets. Moreover, detecting an Earth-like planet demands an extremely precise optical quality of 10s of picometers (pm)—about the size of a hydrogen atom. This requires very precise control of a telescope's mirrors in real-time that can correct for any source of interference.

Deformable mirrors

Deformable mirrors (DM) rely on precisely controlled pistol-like actuators to change the shape of a reflective mirror. For ground-based telescopes, DMs allow them to adjust the optical path of incoming light to correct for external perturbations (like atmospheric turbulence) or optical misalignments or defects in the telescope.

For space telescopes, DMs do not need to correct for Earth's atmosphere but for very small optical perturbations that occur as the space telescope and its instruments heat up and cool down in orbit.

Ground-based deformable mirrors have been tested and offer state-of-the-art performance, but further developments are needed for space-based DMs that future missions will use.

Two main DM actuator technologies are currently being developed for space missions: electrostrictive technology and electrostatically-forced Micro-Electro Mechanical-Systems (MEMS). For the former, actuators are mechanically connected to the DMs and contract to modify the mirror's surface when voltages are applied. The latter consists of mirror surfaces being deformed by an electrostatic force between an electrode and the mirror.

Several NASA-sponsored contractor teams are advancing the DM technology, including MEMS DMs manufactured by Boston Micromachines Corporation (BMC) and Electrostrictive DMs manufactured by AOA Xinetics (AOX). Both the BMC mirrors have been tested in vacuum conditions and undergone launch vibration testing, while the AOX mirrors have also been vacuum tested and qualified for spaceflight.

While ground-based DMs have validated the technology—like the BMC's coronagraph instrument at the Gemini Observatory—steps must be taken to develop DMs for future space telescopes.

Future observatories

NASA plans to demonstrate the effectiveness of DMs with a chronograph technology demonstrator that will launch aboard the Nancy Grace Roman Space Telescope (RST) in May 2027.

The lessons learned from this demonstration will help lead to an even more sophisticated system for the Habitable Worlds Observatory (HabEx). This proposed NASA mission will directly image planetary systems around sun-like stars (scheduled to launch by 2035). The HWO will require DMs with up to ~10,000 actuators, each of which will rely on high-voltage connections—which will be a major challenge to design.

The HWO would also involve unprecedented wavefront control requirements down to single-digit picometers and a stability of about 10 pm/hour. These requirements will drive not only the development of DM technology but also the electronics that control them since the resolution and stability are largely dependent on the quality of the command signals sent by the controller. Ensuring this requires the implementation of filters to remove any electronic noise.

This work will be overseen by NASA's Astrophysics Division, which is preparing a Technology Roadmap to further advance the DM performance to enable the HWO.

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