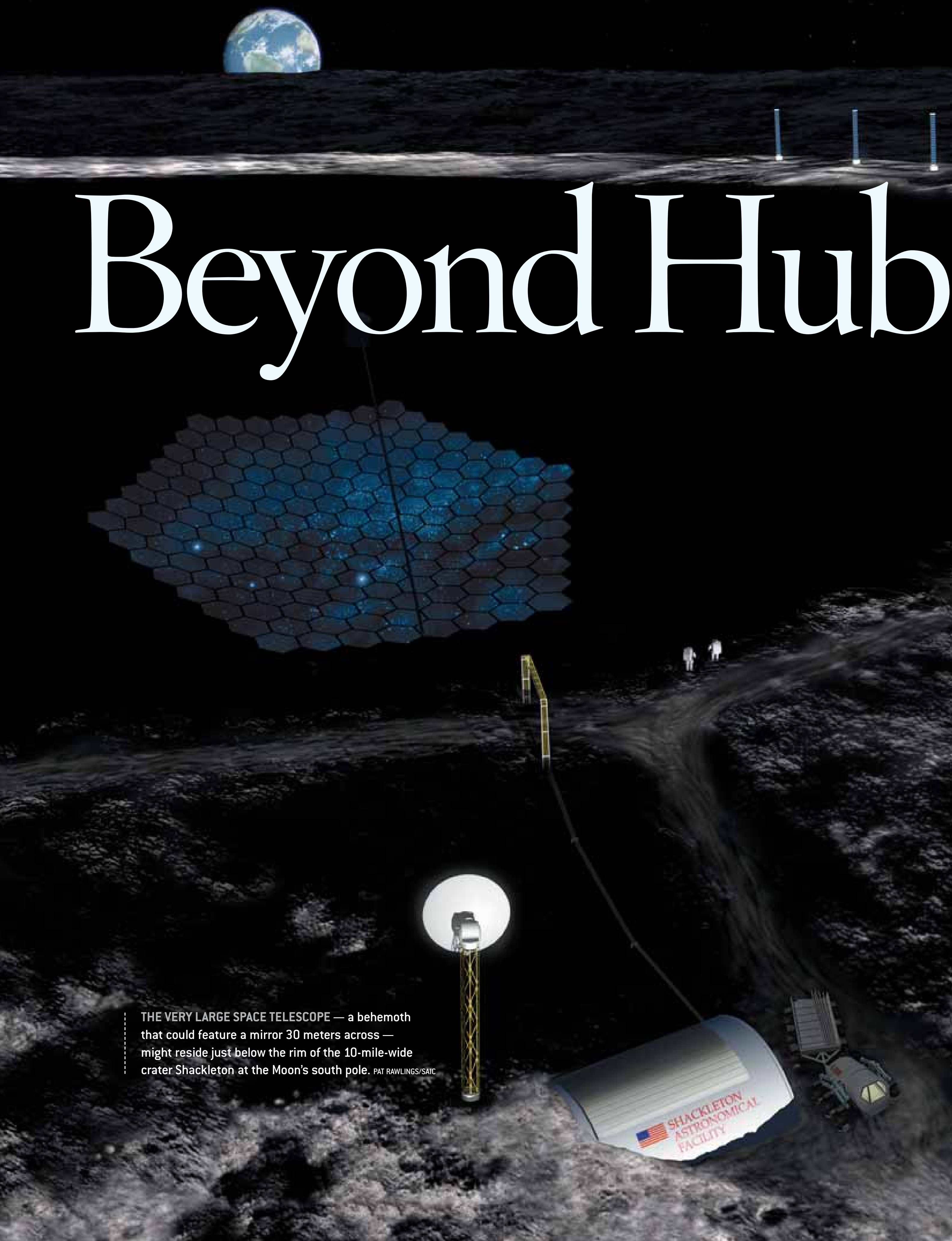
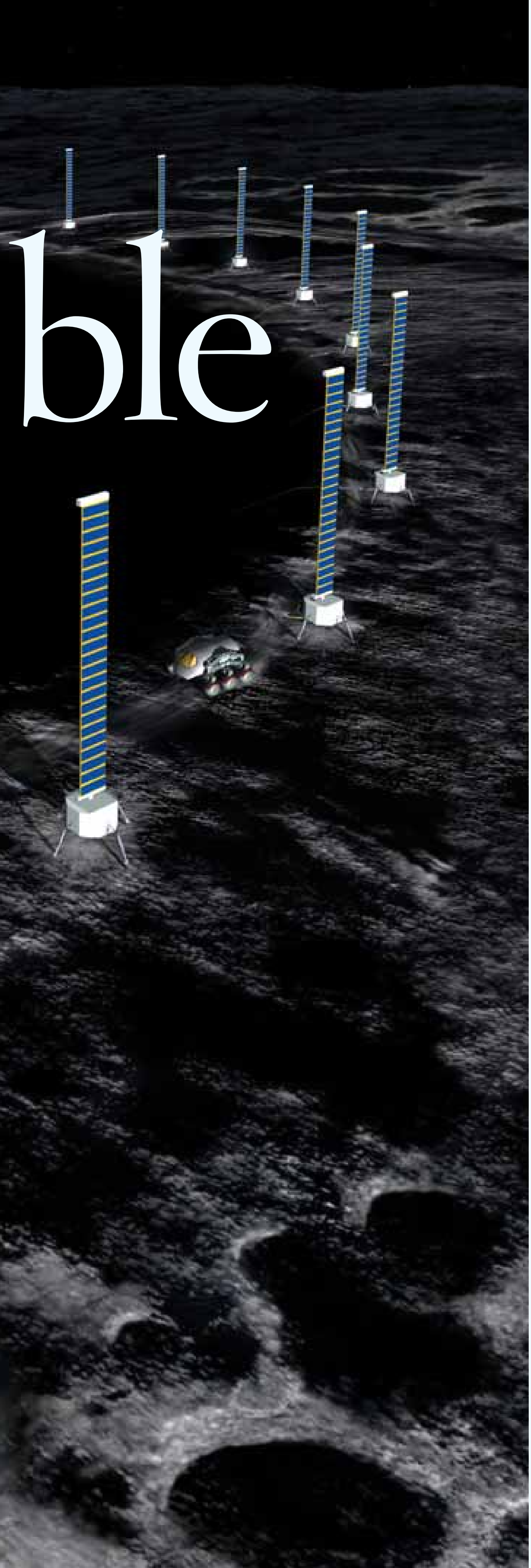
# Beyond Hub




**THE VERY LARGE SPACE TELESCOPE** — a behemoth that could feature a mirror 30 meters across — might reside just below the rim of the 10-mile-wide crater Shackleton at the Moon's south pole. PAT RAWLINGS/SAIC




The Hubble Space Telescope's true heir has astronomers abuzz. This space-based observatory will show details 10 times sharper than Hubble does. /// BY RAY VILLARD

ROUGHLY A DECADE FROM NOW, A BRILLIANT METEOR will flash across the sky above the South Pacific Ocean. Breaking apart into several glowing streamers, it will look like an exploding aerial firework before fading away. A casual observer might think this is nothing more than an unusually bright fireball. But to the astronomy community, this will be akin to the mythical Icarus falling from the heavens. It will mark the fiery death of the legendary Hubble Space Telescope.

One million miles above this streaking $1.5 billion meteor, NASA's 6.5-meter James Webb Space Telescope (JWST) will pick up the gauntlet of high-powered space astronomy. It will peer even farther into the universe than Hubble, revealing the very first stars to emerge from the "Dark Ages" that followed not long after the Big Bang. But the Webb telescope *should* be considered the successor to the recently commissioned Spitzer Space Telescope, the infrared telescope that forms the final pillar of NASA's Great Observatories Program. The true successor to Hubble could be called the *Great-er Observatory*. The telescope has various names at present: Next Hubble Space Telescope, Next-Next Generation Space Telescope, or Very Large Space Telescope (VLST).

NASA has not yet funded, much less scheduled, the VLST. Instead, the agency is focused on returning humans to the Moon and eventually landing them on Mars. But the mission is the buzz among optical astronomers. They face the prospect that after Hubble breaks down — perhaps as early as 2008 without one more human or robotic servicing mission — there likely will be a decade-or-longer hiatus in precision space-based optical and ultraviolet astronomy.

The types of unique and exquisite research we've become accustomed to will grind down: stunning views of remote galaxies, characterizing dark matter and dark energy, analyzing the atmospheres of extrasolar planets, and studying dynamic phenomena such as the expanding debris around Supernova 1987A and the eruptive star Eta Carinae. What's more, when astronomers discover anything interesting in space that requires razor-sharp visibility — like the recent detection of a Kuiper Belt Object named Sedna — scientists and the public alike will lament: "If only we had Hubble . . ."

To rival Hubble's tremendous boost to optical astronomy, some astronomers say the VLST should provide a sharpness and sensitivity 10 times better than Hubble does. "The VLST will be to HST, what HST is to ground-based telescopes," says Holland Ford of Johns Hopkins University, the designer of Hubble's unmatched Advanced Camera for Surveys (ACS).

The goal of a tenfold improvement would require a mirror 25 meters in diameter, 2.5 times the size of the twin Keck Telescopes on Mauna Kea — currently the largest telescopes on Earth. As NASA develops the infrastructure for supporting an extended human presence in space, it should be increasingly feasible to build such a space behemoth. With a fundamental need for this capability, the construction of a giant optical space telescope is more a question of *when* rather than *if*.

At 30 meters in diameter, the VLST's mirror would deliver images 12 times sharper than Hubble's and see objects 300 times fainter than the ACS, astronomy's premier camera today. In near-infrared light, the VLST would see stars and galaxies 25 times fainter than even the JWST will. The telescope's resolution at optical wavelengths would be 0.004 arcsecond, equivalent to seeing a soccer ball 7,500 miles (12,000 km) away.

The VLST could see tremendous detail in galaxies pretty much anywhere in the universe. That's because the angular sizes of galaxies do not change much beyond a redshift of one — a distance of approximately 7 billion light-years, or halfway across the universe — due to relativistic effects in our expanding universe. "Any details you can see at a redshift of one, you can go anywhere in the universe with comparable sharpness," says Doug Richstone of the University of Michigan. However, because the surface brightnesses of galaxies continue to dim with increasing distance, astronomers need ever-larger apertures to collect the faint light.

The VLST could monitor Cepheid variable stars to make distance measurements out to 800 million light-years. It could see stars like our Sun as far away as the Virgo cluster of galaxies. It could detect 1-billion-solar-mass black holes anywhere in the universe. Closer to home, the VLST could track the proper motion of all the visible stars in our galaxy.

In image sharpness and sky visibility, the VLST easily would outperform 30- to 100-meter ground-based telescopes planned for the next decade. The VLST would beat out the best of what adaptive optics could offer even a decade from now to un-blur stellar images. Like all space telescopes, the VLST would never have to contend with the practical limits imposed by Earth's turbulent atmosphere. It would enjoy pristine optical stability all the time, looking anywhere in space. The VLST would work especially well in the near-infrared part of the spectrum (0.7 to 2 micrometers), where the night sky glows brightly when viewed from the ground but not at all when seen from space.

For NASA to fund and build the VLST, the telescope's science goals must align, at least for the foreseeable future, with the

**THE HUBBLE SPACE TELESCOPE** has enjoyed a long, successful life because it was designed to be serviced by shuttle astronauts. NASA

agency's new prime mandate for deep-space astronomy: find and characterize Earth-like planets around nearby stars. The VLST is a logical follow-on to NASA's first generation of planet-hunting observatories. In 2008, the Kepler mission will look for planets transiting across a sample of 100,000 stars. In 2009, the Space Interferometry Mission will look for tiny wobbles induced by Earth-mass planets in the motions of 250 nearby stars. A decade later, the Terrestrial Planet Finder (TPF) will look for exoplanets tens of light-years from Earth.

A 30-meter VLST fitted with a coronagraph to block a star's light would extend the search five times farther than the TPF's capability. For every single Earth-like planet TPF detects, VLST could find 100. These kinds of numbers will be necessary to begin assembling a statistically meaningful sample of Earth-like planets in our galaxy.

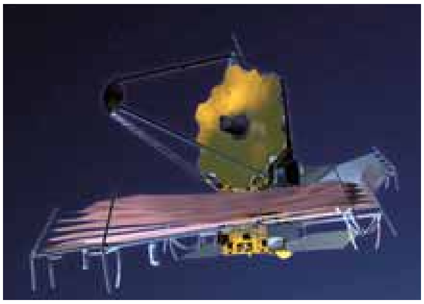
The VLST not only would image exoplanets but also would study their atmospheres spectroscopically at visible wavelengths. Oxygen, for example, can be measured only at visible wave-

## /// HUBBLE'S INFRARED SUCCESSOR

Astronomers have long dreamed about a successor to Hubble, a space-based telescope that would take observational astronomy to a new level. And they will get that — in a manner of speaking — with the James Webb Space Telescope (JWST). However, the JWST will be optimized for viewing in the infrared, not in the optical, part of the electromagnetic spectrum.

Scientists chose this wavelength region because of the expansion of the universe. To observe the epoch when galaxies formed, a few hundred million years after the Big Bang, astronomers have to look at objects receding from Earth at a good fraction of the speed of light. That speed shifts the radiation these objects emit to significantly longer wavelengths, making observations in the infrared crucial. In addition to observing these young galaxies, astronomers using the JWST will seek to understand the birth and formation of stars, determine how planetary systems form, and probe the nature of dark matter.

The JWST will sport a 6.5-meter primary mirror consisting of 18 segments. Currently scheduled for launch in 2011, it will be placed in orbit at the L2 Lagrangian point of the Sun-Earth system, some 1 million miles from Earth. During its expected 5 to 10 years of operation, the $800 million observatory should revolutionize our knowledge of the universe and pave the way for the Very Large Space Telescope.
— *Richard Talcott*



**THE JAMES WEBB SPACE TELESCOPE** should be launched in 2011. Although some people think of it as Hubble's successor, the JWST is optimized for infrared rather than optical observations. NORTHROP GRUMMAN SPACE TECHNOLOGY

**THE VLST'S ULTRA-SHARP VISION** would render galaxies halfway across the universe with the same clarity as Hubble sees in nearby ones. This would allow astronomers to view galactic structure as well as study individual star clusters and giant regions of starbirth. The three images shown here simulate what a galaxy located 7 billion light-years away would look like when viewed through three different telescopes: an 8-meter ground-based telescope with excellent, 0.4" seeing conditions (left); the Hubble Space Telescope with its 0.1" resolution (middle); and the VLST with a resolution of 0.004". NASA/STScI

lengths, and even an exoplanet's atmospheric pressure can be deduced from the amount of reddening in the star's light as it passes through the planet's atmosphere. These measurements could be done out to a distance of 50 to 150 light-years from Earth, depending on the telescope's mirror size.

## Spacecraft design

A 10-meter VLST might be built on the technology developed for the JWST. No current rocket booster can carry a payload as wide as a 10-meter mirror — the largest can accommodate something only half that size. If that doesn't change, the VLST would have to be unfolded in space like the JWST will be. NASA even might develop wide-body, heavy-lift boosters like the Apollo-era Saturn V that launched manned lunar missions. However, such rockets probably would be far too expensive for the VLST's budget.

Like the JWST, the VLST's primary mirror would be tiled with many hexagonal mirror segments. Unlike the JWST, the mirror would need to be shielded to block the glare of visible light from the Sun, Earth, and Moon. A free-flying telescope also would need optics designed to sense incoming light and automatically deform the mirror to maintain perfect, diffraction-limited performance.

The first suite of instruments could include an ultra-wide-field imager for taking galaxy surveys. It would seek distant supernovae to continue the quest to nail down the behavior of dark energy. Other instruments would include spectrographs and an optical coronagraph for hunting planets. All these instruments would be packaged into a single, integrated science module. The spacecraft bus would house the data storing and transmitting electronics, the pointing control system, reaction wheels, rocket thrusters, and gyroscopes.

A free-flying VLST likely would be deployed at the L2 Lagrangian point of the Earth-Sun system, where the JWST will be headed. The L2 point — one of a few gravitationally stable balancing points between the Sun and Earth — lies about 1 million miles from Earth, on an extension of the line that joins the Sun and Earth. A space telescope placed out there could not be serviced by astronauts. Hubble survived beyond the nominal 10-year lifespan for space observatories because astronauts tended it. But NASA has no plans to send astronaut repairmen out to the L2 point, a treacherous two-week journey with today's rockets. This means a VLST at L2 must be designed conservatively and with a lot of redundancy because it is inherently risk intolerant.

One logical way to make the telescope more risk tolerant than the JWST would be to service it robotically. Replacement parts could fly out to L2 autonomously. This concept envisions modules designed so that replacement units of electronics, computers, and attitude control systems could plug into the main spacecraft bus. Such a module would dock with the spacecraft bus and enhance or take over the tasks of aging or faulty components. The same concept also could be applied to the VLST's science instrument module, which might be built so it could be swapped out every few years with a replacement module.

## The high frontier

A VLST larger than 10 meters in diameter would not be built without human construction and servicing capability. "The fiscal and technical risk becomes very large beyond a certain aperture," says Robert Williams of the Space Telescope Science Institute in Baltimore. "Larger telescopes will go beyond what could be accomplished without on-orbit assembly, testing, and servicing." A once-promising stepping stone was the idea of constructing the VLST at the International Space Station. However, the $60 billion station will be retired by 2016.

As a logical next step, NASA might construct a habitat, dubbed the "Lunar Gateway Portal," stationed at the L1 Lagrangian point of the Earth-Moon system. (This point lies on a line connecting the Moon and Earth where the gravity of the two bodies cancels.) Just a 2.5-day journey from Earth, it would be the first big "truckers' stop" in circumlunar space. The Lunar Gateway Portal (NASA no longer uses the word "station") could be an inflatable habitat with docking bays, fuel reserves, workshops, and launch preparation facilities for sending manned and unmanned missions to the Moon and beyond. From the Portal, vehicles could reach any point on the Moon's surface within hours.

Presumably, mission crews would reach the Lunar Gateway Portal aboard NASA's touted Crew Exploration Vehicle, planned as the do-it-all, human-rated spacecraft to replace the space shuttle. Astronauts would live at the translunar construction shack for perhaps several weeks, staging any number of human and robotic missions. The Lunar Gateway Portal might be a platform where the VLST could be assembled and fully tested. A solar-electric-powered orbital transfer vehicle then would carry the telescope on the several-week journey to the Sun-Earth L2. The telescope would be towed back to the Portal for repairs and upgrades.

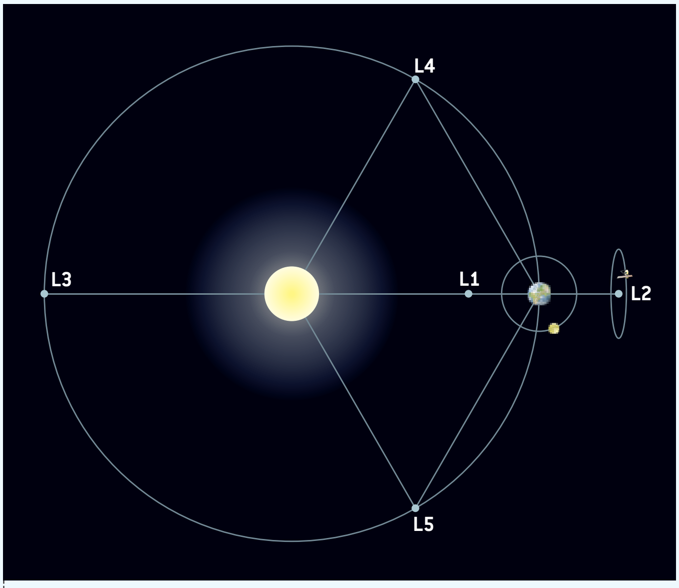
The Lunar Gateway Portal's primary purpose would be to launch cargo and manned lunar landers in support of NASA's return to the Moon. The first human lunar outpost likely would be at the Moon's south pole, which is more easily accessible because it would require less rocket fuel to reach from the Lunar Gateway Portal than from a direct Earth-launch, as now is being discussed for the Crew Exploration Vehicle.

The base would lie near the rim of the 10-mile-wide crater Shackleton (named after the early 20th-century Antarctic explorer Ernest Shackleton), which sits near the Moon's south pole. NASA's new charter is to establish a manned base on the Moon simply as an interim step toward a human mission to Mars. Nevertheless, Shackleton Ridge Base might offer a modest supporting infrastructure that could facilitate a project as ambitious as constructing a 30-meter VLST.

Untouched by sunlight for 4.5 billion years, the 1-mile-deep Shackleton crater should contain some of the most pristine material in the solar system. The Moon's orbit inclines to its equator only slightly, so some regions at the poles remain in permanent shadow. Water ice, oxygen, hydrogen, and maybe even nitrogen — all transported here by comets billions of years ago — could be harvested as resources for supplying the base with air and water.

To make transportation economically viable, a lunar ferry would refuel at Shackleton Ridge Base with hydrogen and oxygen harvested from the frozen water reserves. The ferry would shuttle between the Moon and Lunar Gateway Portal. The lunar base camp would not necessarily be permanently occupied, but would serve as quarters for various expedition crews. One or more expeditions could erect and test a prefabricated 30-meter telescope. The undertaking could be justified as a construction project to practice for building structures on Mars.

A 30-meter telescope could be built just over Shackleton's rim, 150 feet down into the crater. The VLST would not be placed in the perpetual shadow deeper in the crater because, given the crater's 45° slope, it would be treacherous to reach. Instead, the telescope would be encased in a foldable cocoon to block sunlight.




**FIVE LAGRANGIAN POINTS** mark stable positions in the gravitational spheres of two orbiting objects. The L2 point of the Sun-Earth system will be home to the James Webb Space Telescope, and possibly the Very Large Space Telescope. *ASTRONOMY:* RICK JOHNSON

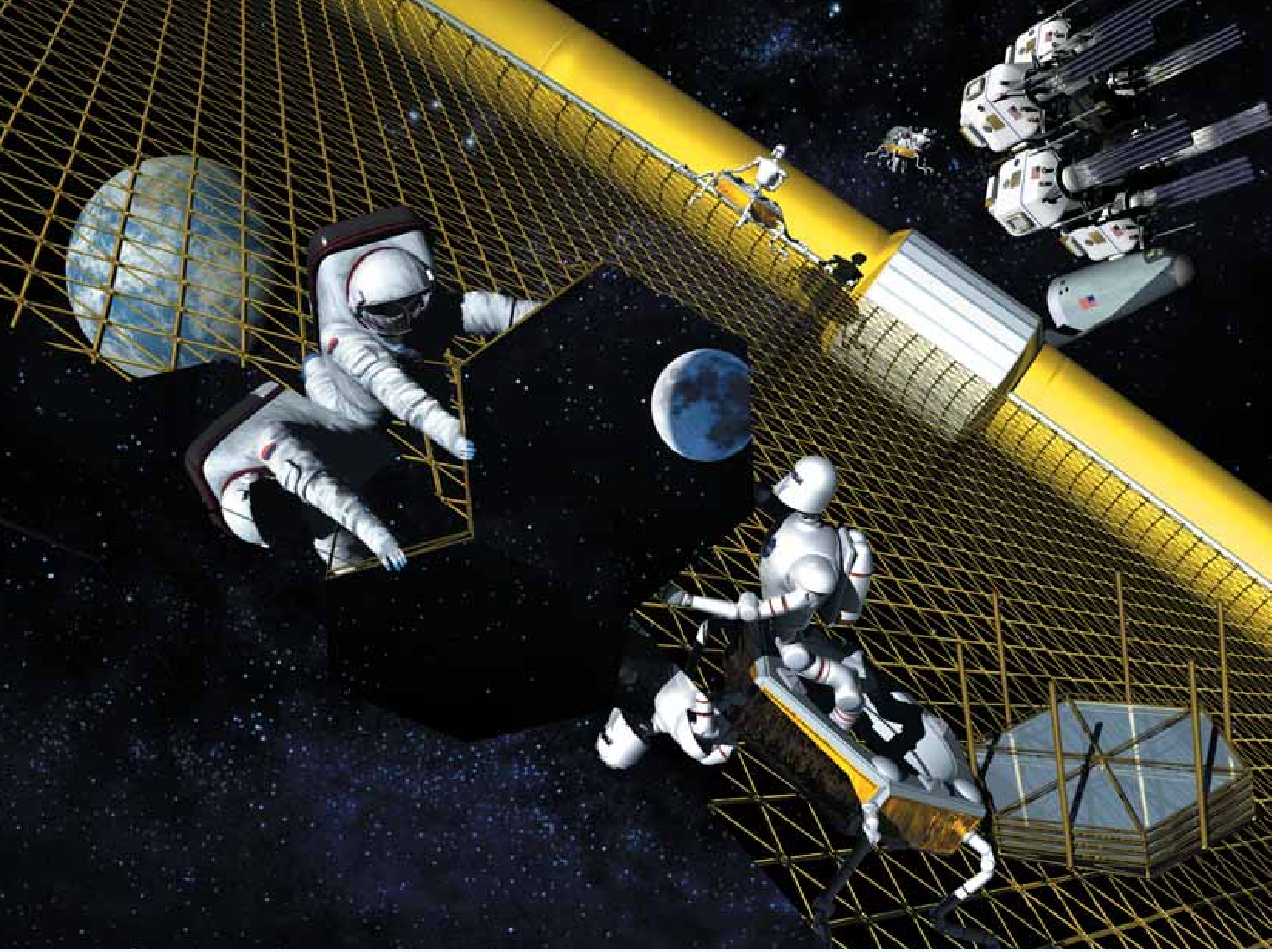
A lunar VLST would not be hobbled by the three common ailments of space-based telescopes: failed gyroscopes, empty tanks of maneuvering fuel, and dead batteries. However, the Moon presents its own environmental challenges. Dust on the lunar surface is gritty and could damage machinery. The suits worn by the Apollo astronauts had mechanisms that were clogged with dust after just 3 days on the Moon. On a more encouraging note: The lunar ranging retroreflector mirrors left on the Moon more than 30 years ago continue to operate without any apparent signs of dust coating them.

The pointing and control system for a lunar VLST would be much simpler than for a space-based observatory. The Moon rotates very slowly, and pointing and stabilization would be no different than for telescopes on Earth. Issues of pointing and jitter that bedevil floating space observatories will go away. In the Moon's ⅙ gravity, the telescope could be built on a six-leg hexapod mount that would point by changing leg length.

The Moon base's infrastructure also would include continuous power generation from solar panels on the crater's rim. They would bathe in sunlight for all but a few hours out of the year. Power could be beamed down as microwaves from the ridge to the VLST site. Moon-orbiting relay satellites would serve as switchboards in the sky to send commands and data between the VLST and Earth. The elegance with this approach is that the complex, automated planning and scheduling of observations

> The VLST's resolution at optical wavelengths would be an astonishing 0.004 arcsecond, equivalent to seeing a soccer ball 7,500 miles away.


**Ray Villard** *is the public information officer at the Space Telescope Science Institute in Baltimore. His most recent article for* Astronomy *was "Did NASA fake the Moon landing?" in the July 2004 issue.*



**THE VLST MIGHT BE ASSEMBLED** at the Lunar Gateway Portal and then deployed in a stable orbit a million miles from Earth. NASA ARTWORK BY PAT RAWLINGS/SAIC

demanded by Hubble and the JWST wouldn't be needed. In principle, a lunar VLST could be operated in real-time like Palomar, Keck, or any ground-based facility. The only difference is that the "mountaintop" is 250,000 miles high.

A telescope at the Moon's south pole would see only half of the celestial sphere — as opposed to a space-based VLST that could access the whole sky. Nevertheless, the southern sky is ripe for all kinds of astronomy. It is home to the galactic center and the stellar incubators within our satellite galaxies, the Magellanic Clouds. A lunar telescope could re-examine the Hubble Ultra Deep Field in the southern constellation Fornax. And it could examine some of the closest Sun-like stars that might harbor planets: Alpha Centauri, Epsilon Eridani, Tau Ceti, and 18 Scorpii.

A 30-meter telescope would entail such a capital investment that, with regular maintenance and upgrades, it should be capable of doing cutting-edge science for decades. Hubble enjoyed robust support from NASA because it was married to the manned space shuttle program. But as in any marriage, such a partnership boils down to "for better or for worse." When the space shuttle's days became numbered, so did Hubble's.

Equally sobering is the fact that there always will be a risk that a future administration or Congress may abandon support for a human presence on the Moon because of the danger, expense, or a fundamental shift in the nation's priorities. The proper blend of human, robotic, and teleoperated capabilities is an emerging paradigm for NASA. Humans might erect a lunar VLST, but robots would service it periodically long after humans have departed the Moon for Mars. If NASA support for the VLST should stop, the telescope could be designed to be mothballed — quite literally for decades — until some future generation, or even another nation, decided to return and operate it.

Whatever the final design, the VLST will inspire a new generation of skywatchers and dreamers, just as the Hubble Space Telescope did. Like Hubble, it will bolster public interest and curiosity in the universe as no other type of telescope can. Whether perched in the weightlessness of space or standing in a 4.5-billion-year-old lunar crater, this spidery monster of glass will be a lasting monument to our passionate curiosity. Luckily, our deep vision will not falter for too long between the exciting universe unveiled by Hubble and the unimaginably more exciting universe awaiting the VLST.

To learn more about the James Webb Space Telescope and its capabilities, visit www.astronomy.com/toc