September 2014

AEROSPACE AMERICA

Out there somewhere could be A PLANET LIKE OURS

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A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Beaming home a photo of a planet like ours will require money, some luck and a giant telescope rich with technical advances. Erik Schechter looks at NASA's 30-year technology roadmap toward the discovery that could change everything.

by Erik Schechter

Sara Seager, a professor of planetary science and physics at MIT, has developed an equation positing that in the next decade at least one life-bearing planet will be found orbiting one of our galaxy's M-class dwarf stars – fainter versions of our sun and attractive targets because of their relative proximity to Earth. It's a bold prediction, but Seager is buoyed by the Kepler mission, which detected 4,200 new planet candidates by searching for the telltale dips in the intensity of light when a planet crosses in front of its host star. A thousand of those transits have been confirmed as planets, including a few Earth-sized ones. Extrapolating from the small patch of sky examined

FINDING EARTH 2.0

An artist's rendering of exoplanet Kepler 186f.

NASA Ames/SETI Institute/JPL-Caltech

by Kepler, scientists believe that small planets, as opposed to lifeless gas giants, should be common. "They're basically everywhere," says Seager.

The ultimate feat would be to return a picture of a planet resembling Earth, and so NASA and university technologists have devised a 30-year technology roadmap spelling out how this might be achieved. Weighty funding decisions will be required by NASA and Congress; optics will need to be tested on the ground and maybe in space; technical lessons will have to be drawn from a succession of planned and proposed astrophysics telescopes; the small list of Earthlike candidates will have to be expanded. At stake is what one astronomer calls a second Copernican revolution: "There will be a fundamental change in how the human race views itself on the day that we look out there and say there is a planet out there that we believe has other life on it," says Doug Hudgins, the program scientist for the Exoplanet Exploration Program at NASA headquarters.

A big challenge for planet hunters is that light is diffracted the moment it touches a telescope, which is why a host star obscures the view of any Earth 2.0 that might be nestled near it in the Goldilocks, or habitable, zone. In the coming years, scientists and technologists will need to settle on a technique for suppressing that starlight so the dimmer light reflected by the planet becomes visible.

Planet hunters will also be watching to see how things go with the James Webb Space Telescope when it is launched in 2018 on an Ariane 5 rocket. Its main mission will be to study the early universe in the infrared, but it will also look at infrared and visible light that has passed through exoplanet atmospheres. On top of that, Webb must undergo a complex metamorphosis in space. Success could boost confidence about deployment of an even larger space telescope whose astrophysics mission would include giving humanity the equivalent of the famous Valentine's Day 1990 "pale blue dot" photo of Earth, taken by the Voyager 1 probe. Planet hunters don't want to stop there. They want to deliver a photo showing continents and oceans — a lower resolution version of the iconic Earth-rise scene taken by the Apollo 8 crew in orbit around the moon on Christmas Eve 1968. That would require something even more advanced: A formation of space telescopes designed for interferometry, in which the interference patterns of light waves are used to stitch together images almost as if they came from a giant unitary aperture. Scientists have a name for that telescope, the ExoEarth Mapper, but not much more. Building it "might be a little bit out there on the edge of the 30 years," NASA's Gary Blackwood told an audience at the AIAA Space Forum in San Diego in August. Blackwood is manager of the Exoplanet Exploration Program at the Jet Propulsion Laboratory.


Northrop Grumman

Exposing exoplanets:
A starshade, like the one here being prepared for testing in Nevada by Northrop Grumman and NASA JPL staff, would block light from a host star.

Looking at the neighbors

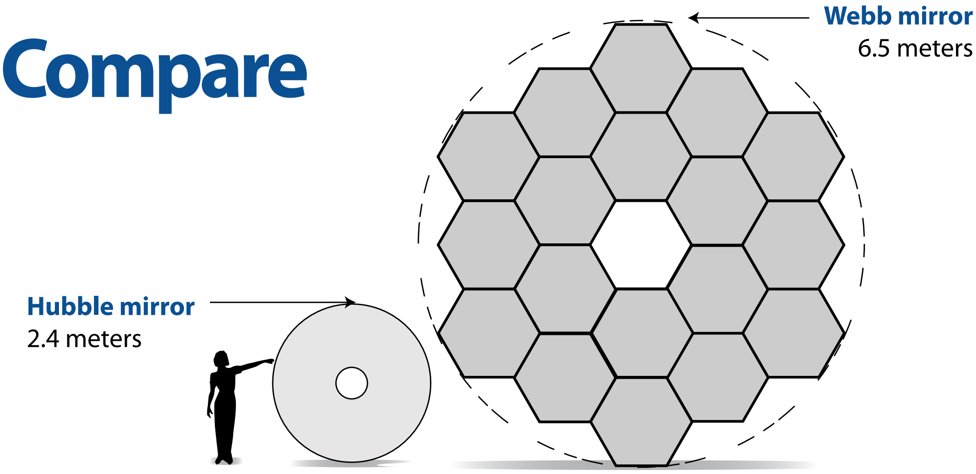
The work of expanding today's handful of planetary candidates will fall to designers of the Transiting Exoplanet Survey Satellite, scheduled for launch in 2017. TESS was proposed by the Massachusetts Institute of Technology and chosen by NASA in 2013 for construction and launch under the agency's Astrophysics Explorer Program. The spacecraft, in development by Orbital Sciences Corp., will look for dips in the intensity of light emitted by stars, which sounds a lot like what Kepler did before its collections were halted in May 2013 by a reaction-wheel failure that left it unable to maintain its observing position. "People ask, 'Why do we need TESS?'" says astrophysicist Natalie Batalha, the Kepler mission scientist. "And the answer is simple: TESS is going to look all around the sky, at every single patch of sky."

The TESS goal of gradually surveying the entire sky over the course of two years led to a very different design. Kepler collected light with a 1.4-meter-diameter mirror. That was fine for staring in one direction at a patch of sky measuring 100 square degrees – less than a quarter of 1 percent – of the total view. TESS must examine the whole sky by assembling patches measuring 2,300 square degrees, or 5.5 percent of the sky. Designers opted to equip TESS with four 16.8-megapixel cameras developed by MIT Lincoln Lab. Each will be a tenth of the size of the Kepler telescope and will be capable of detecting infrared and red-orange visible wavelengths.

There was a tradeoff for this wide field of view: Kepler peered 1,200-3,000 light-years into space in the direction of the constellations Cygnus and Lyra. The best TESS will do is scan stars 4.3-150 light-years away. Its targets will be the M-class dwarfs, whose habitable planets would have to be close in, with a shorter orbit than Earth's. Batalha compares the situation to camping at night. "If you've got weak campfires, and in order to be at that just-right temperature, you have to cozy up next to them," she says. Of particular interest would be planets whose orbits suggest they would be the right temperature and atmospheric pressure to allow for surface water in liquid form.

TESS will travel in a lunar resonant orbit, a lopsided circuit that sends the spacecraft out past the moon and close to Earth every two weeks. This orbit will keep its sensors protected from heat and radiation and, on the return trip, position the spacecraft close to ground stations so it can download data via its 100-Mbps Ka-Band antenna. Flying with its back to the sun, TESS will scan the whole northern hemisphere of the sky in a gradual, "step-and-stare" approach the first year. Then it will do the same with the southern hemisphere the second year. In addition, TESS will always have one camera fixed on a location

Compare



	HUBBLE PRIMARY MIRROR	WEBB TELESCOPE PRIMARY MIRROR
Material:	Glass coated with aluminum	Beryllium metal coated with gold
Mass:	828 kilograms*	362 kilograms (18 segments of 20.1 kg)*
Thickness:	46 centimeters	5 centimeters
Resolution:	0.05 arc-seconds (14 millionths of a degree)** *Could distinguish two fireflies a meter apart at a distance of 4,800 kilometers.*	0.1 arc-seconds (28 millionths of a degree)** *Could see details the size of a penny at a distance of 40 kilometers.*
Spectrum:	Primarily ultraviolet and visible	Optimized for infrared
Manufacturer:	Perkin-Elmer Corp., Danbury, Conn. (Now part of UTC Aerospace Systems)	Ball Aerospace, Boulder, Colo., and Tinsley Laboratories, Richmond, Calif. (Now part of L-3 Integrated Optical Systems)
You should know:	Hubble's primary mirror was ground to the wrong specification, requiring a spacewalk in 1993 to install a set of optics to correct its focus.	Webb must operate at minus 370 degrees Fahrenheit to maximize its infrared sensitivity. Beryllium holds its shape well across a range of temperatures, sheds heat easily and is strong. Coating it with gold maximizes infrared reflectivity. Seven motorized actuators on each segment will fine tune alignment and curvature.

** Figure includes mirror material only – does not include support equipment.*
*** Resolutions are based on observed wavelengths and can be misleading. Webb is designed to look back in time by sensing longer-wave, infrared radiation, something Hubble does not do.*

Source: NASA

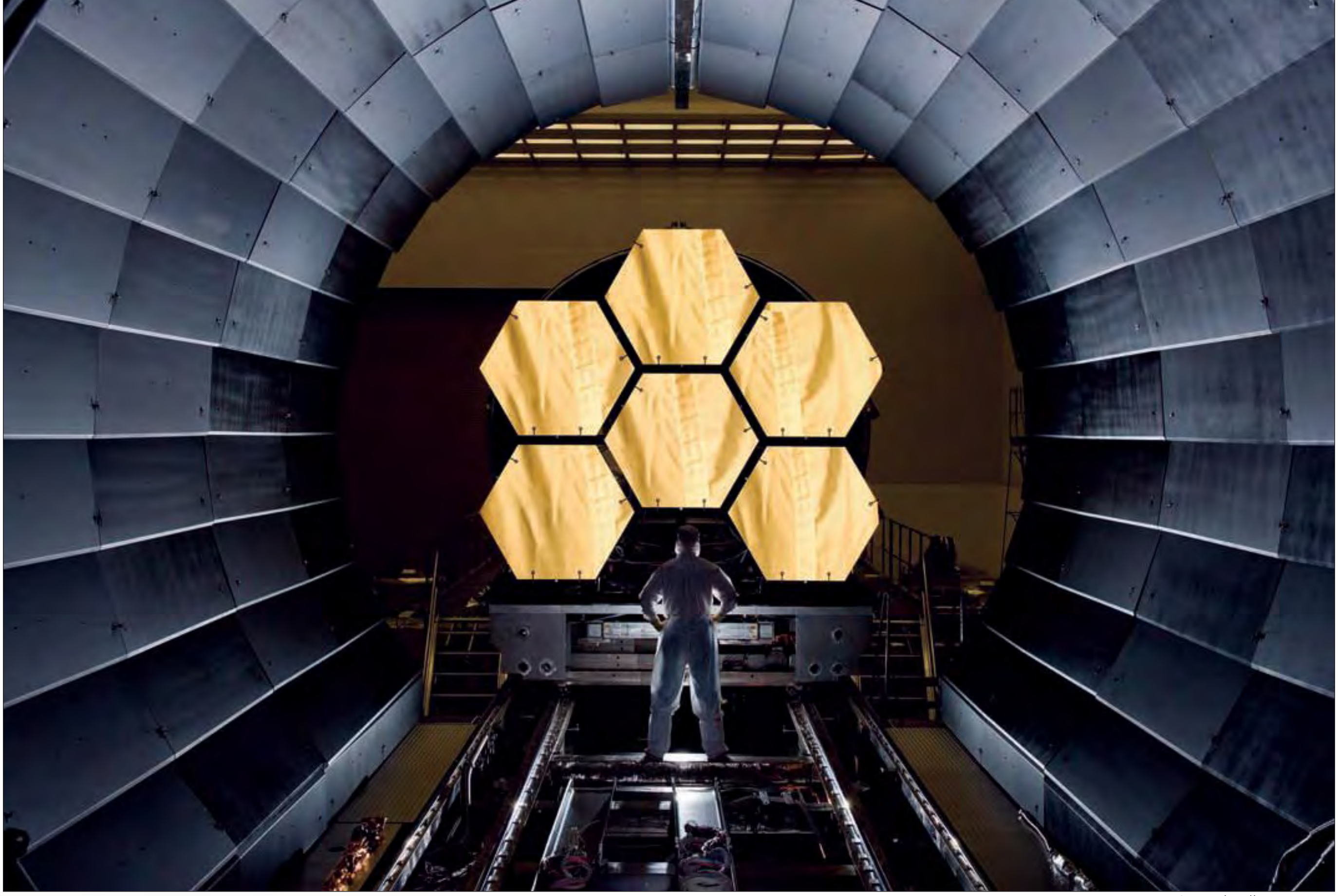
in the sky known to astronomers as the ecliptic pole of the Zodiac plane. "It is a special place in the sky, because that's also the location that the Webb telescope can look at any time of the year," says George Ricker, the principal investigator for TESS at MIT's Kavli Institute for Astrophysics. "If you want to find a target for Webb, that's the sweet spot in the sky."

Based on Kepler, researchers expect TESS to find at least 3,000 exoplanet candidates, including some 40 Earth-sized and 330 "Super Earth" planets. Of course, finding a right-sized planet in a habitable zone is one thing. Being sure you've found a rocky planet, like Earth, is another. For that, scientists need to know the density of the exoplanet. Scientists using TESS will be able to calculate the diameter and volume of a transiting planet, but to get density, one also needs the mass. So researchers will need a ground-based telescope with a spectrograph to study the planet's host star and look for a telltale wobble. "That's induced by the planet revolving around its host star," Ricker says. Density can be calculated from that wobble. "If you get a number that's roughly five grams or six grams per square centimeter, you've got a rocky planet like the Earth," he explains.

How Webb can help

Planet hunters are excited about Webb, for two reasons:

Webb's 18 mirror segments will be arranged in three petals and stowed inside the launch shroud, along with solar arrays, antennas, and a tennis-court sized, multilayered sunshield made of a flexible Dupont Kapton polyimide film. All this must unfold and unfurl in a complex series of maneuvers within two weeks of the launch. Something like that technique is likely to be required for a telescope capable of delivering the first rough image of an Earthlike planet. Scientists have a preliminary name for this envisioned telescope, LUVOIR, short for Large UV/Optical IR sur-



NASA and Ball Aerospace

An engineer in front of mirror segments bound for the James Webb Space Telescope. Successful deployment in 2018 could build confidence for projects like the proposed Large Ultraviolet Optical Infrared Surveyor.

veyor. They plan to draft a white paper in hopes of winning a coveted nod in 2020 from the National Research Council's Decadal Survey scientific panel, a blessing that could clear the way for technology investments and construction. For LUVOIR, "We're almost certainly looking at some kind of segmented, deployable or assembled aperture," said Blackwood, the exoplanet manager at JPL.

Webb also will collect starlight that has passed through the atmospheres of some of the planetary candidates identified by TESS. Molecules in those atmospheres will take signature "bites" out of particular wavelengths, and scientists will show how this transmission spectroscopy can be used to search for specific chemical signatures. The same transmission phenomenon can be seen here on Earth with rainbows. "If you look really closely at the rainbow, you'll see some colors missing. Not, like, big colors, but you'll see small chunks of some of the colors actually missing," says Seager. "And that's because of molecules in our own Earth's atmosphere that are actually absorbing the sunlight."

Webb's main planetary targets will be Neptune-sized gas giants, but Webb also will examine Earth-sized planets. Whatever Webb learns about exoplanets will be interesting, but MIT's Seager and other scientists hope that the spacecraft finds biosignatures. This would indicate that the TESS planet not only inhabits a Goldilocks zone, but is home to life or is at least capable of supporting it. Besides water vapor, biosignature chemicals would include carbon dioxide to help create a greenhouse effect; methane, a building block of organic life; and ozone to block harmful ultraviolet radiation from the host star. Free oxygen might indicate the presence of alien vegetation, because it vanishes from an atmosphere unless plant life is replenishing it. Webb might also pick up thermal emissions from an exoplanet by tracking its mid-infrared radiation over the course of an orbit. But don't expect to see signs of vast alien cities or nuclear reactors. Webb might "see what I would call very gross thermal features on the planet by monitoring all the way through a transit," giving researchers a "very crude idea of what sort of atmospheric dynamics" are at play," explains astronomer Mark Clampin, the Webb observatory project scientist. Detecting a civilization visually from deep space would be hard, based on the look the Galileo probe gave Earth in 1990 after approaching within 960 kilometers on a flyby toward Jupiter. Carl Sagan and other scientists examined the Galileo images and saw no "unambiguous sign of technological geometrization," according to their 1993 Nature magazine paper, "A search for life on Earth from the Galileo spacecraft."

Distant imaging

Trying to make out a planet orbiting a sun is like trying to spot a firefly next to a lighthouse. Earth is 10 billion times dimmer than the sun, and scientists expect they will have to cope with similar contrast ratios to spot Earthlike planets. Researchers are looking for ways to block out the light of the planet's host star while preserving the light reflected off the planet, says NASA's Hudgins.

Right now, scientists and technologists are looking at two competing concepts:

- A **coronagraph** in which starlight would be filtered out by an arrangement of optics and light stops inside the telescope. Coronagraphs were originally developed to expose the sun's corona, but they have potential for planet hunting too.
- A petal-shaped **starshade** meters across that would be positioned 50,000 kilometers in front of a telescope to control diffraction and block light from a specific star. The result would be a very dark shadow, like a solar eclipse, because "the shape of the petals, when seen from far away, creates a softer edge that causes less bending of light waves," Hudgins says.

The coronagraph approach would be demonstrated in space starting in 2024, provided NASA chooses to build a new flagship astronomy spacecraft with an unwieldy name: the Wide-Field Infrared Survey Telescope-Astrophysics Focused Telescope Assets, or WFIRST-AFTA. The initial proposal for this telescope called for a 1.5-meter mirror, which meant there would have been no room for a coronagraph. All that changed in 2012 when NASA announced that the spy satellite developers at the National Reconnaissance Office had donated two spare telescopes for scientific research. If WFIRST-AFTA is built, it would be centered on a 2.4-meter diameter mirror – the same size as the Hubble's primary mirror – culled from one of the NRO telescopes. There's now plenty of room behind the primary mirror to install a coronagraph, and scientists almost can't believe their good fortune: "It's 2.4 meters. It exists. I've seen it. I've almost touched it," NASA's Wes Traub, the chief scientist for the Exoplanet Exploration Program at JPL, told an audience at AIAA's Space Forum. WFIRST-AFTA would demonstrate the coronagraph technique on large planets, but "it's probably not going to see Earths, unless we're incredibly lucky," Traub cautioned. "You don't have the angular resolution. You can't get as close to the star as the habitable zone, and you're not going to collect enough light from a planet that's the size of the Earth."

As for the starshade, tests have been conducted in a lab at Princeton University and by Northrop Grumman in the Nevada desert. The potential advantage of starshades is that they block starlight before it can be diffracted by a telescope's optics. But testing a starshade on the ground is difficult, because in space it would work in tandem with a telescope positioned thousands of kilometers away, something that can't be easily simulated on Earth. A team of scientists is defining a possible starshade space mission, nicknamed Exo-S with the S standing for starshade. Another mission is under study, tentatively called Exo-C, for coronagraph. These are backup concepts in case NASA or Congress decides not to pursue a large flagship astrophysics mission like WFIRST-AFTA.

Of course, the desire to image an Earth 2.0 begs the question: How might human beings reach a far-off planet? The closest star to Earth is Alpha Centauri, and that's 4.3 light-years, or 26.5 trillion miles, away. To put that into perspective, it would take explorers on a conventional spacecraft 165,000 years to reach that solar system. Undaunted, Ricker of MIT suggests that humanity's best bet for reaching Earth 2.0 could be to launch an unmanned probe with some advanced, still-to-be invented propulsion technology. As a thought experiment, he imagines a probe that can travel one-tenth the speed of light to a planet 10 light years away. "It would take the probe a century to get there, and then it would start transmitting [images] back, so in 110 years, you would know" what the planet and its native flora and fauna looked like, he says.

Voyager left our solar system in 2012 and has lasted for nearly 37 years. This future spacecraft would have to do even better, and the people who launch it would definitely not be the same people receiving its transmissions from the vicinity of an alien world.

"It's no different from the way it was when the cathedrals were being built in the Middle Ages," Ricker says. "It took several generations. Perhaps this is our version of a cathedral."