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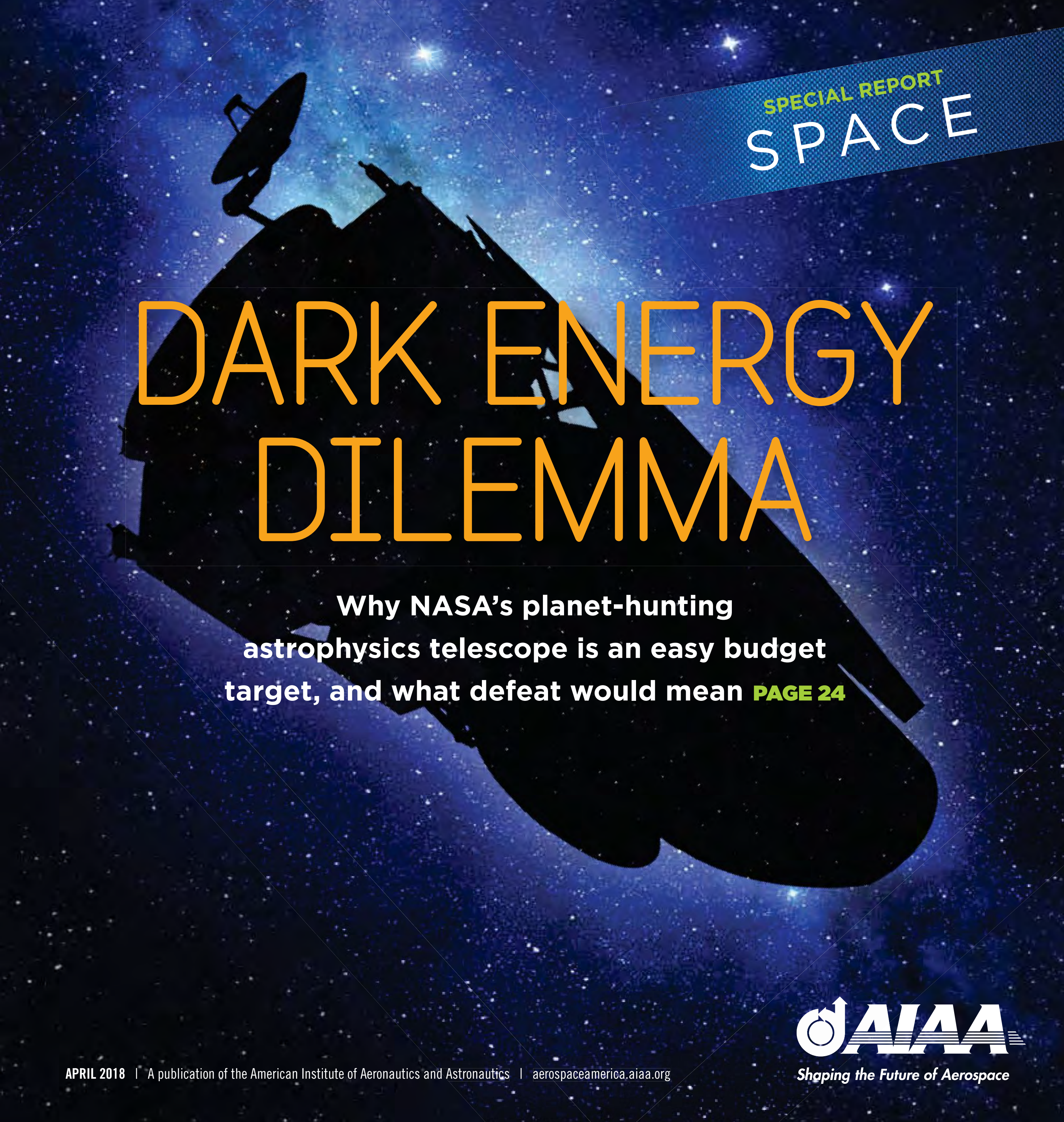

SPECIAL REPORT
SPACE

DARK ENERGY DILEMMA

Why NASA's planet-hunting astrophysics telescope is an easy budget target, and what defeat would mean PAGE 24

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The case for WFIRST

Overlayed on a rendering of deep space, the white box shows Hubble Space Telescope's field of view compared to that of WFIRST, shown by the blue lines.

The Trump budget would cancel development of the Wide Field Infrared Survey Telescope, a spacecraft that would help measure the amount of dark energy in the universe while giving scientists a better sense of its properties and possibly delivering images of exoplanets, albeit giant gaseous ones at best. Is the proposed cancellation punishment for past sins on other projects? Will it be another close call for a project that's been on the brink before? Amanda Miller spoke to the scientists who could be asked to make the case for WFIRST as Congress weighs its future.

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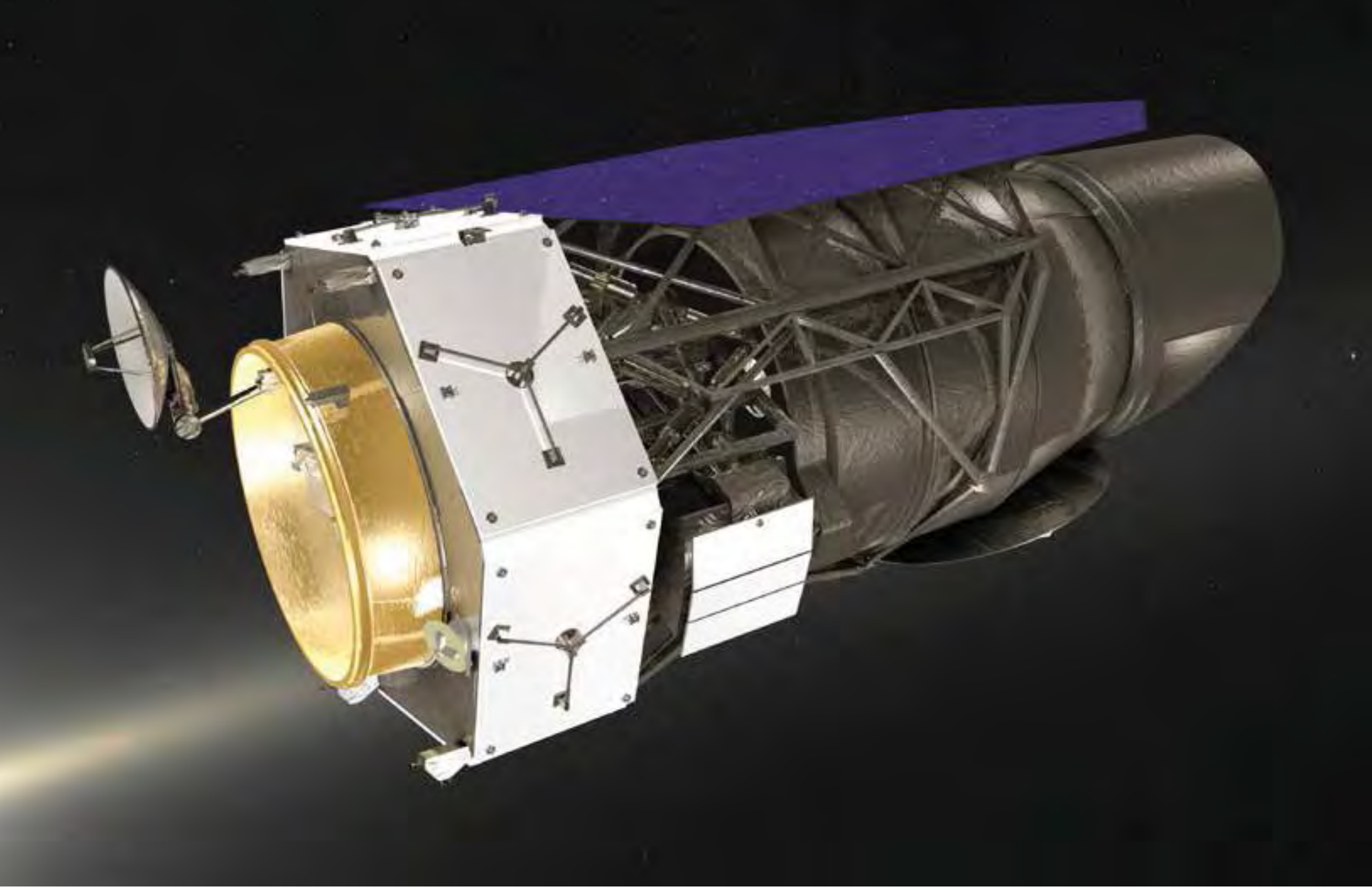


NASA

▲ **An artist's rendering** of the Wide Field Infrared Survey Telescope.

If you love astronomy, you probably have some questions right now. Are the most thrilling aspects of space science about to get delayed by a decade or more? Why shut down the American astronomy community's top spacecraft priority, which would target the biggest astrophysical mystery known to humans?

At this point, you figure it's all about the money. NASA wants to get astronauts back to the moon.

But maybe it's not so simple.

If you're one of those working on NASA's Wide Field Infrared Survey Telescope, you're starting to sense additional reasons why the White House wants to end development of the spacecraft, even though the $3.2 billion program is pretty much on budget and WFIRST shows all the scientific promise it did when you went to work on it going on a decade ago.

"I think in some ways this may be OMB" — as in the White House Office of Management and Budget — "and others trying to punish the astronomy community for [past] overruns," says astrophysicist David Spergel of Princeton University, co-lead investigator for WFIRST, scheduled to launch in the mid-2020s. He's referring to President Donald Trump's budget request, now over to Congress, with a proposal to zero out funding for WFIRST in fiscal 2019.

"I think that some people have been saying that the cost has gotten out of control, and I think we're actually doing a pretty good job," says Spergel, one of the scientists who was anticipating pitching the project's virtues to congressional funding committees.

Scientifically speaking, NASA's three forthcoming space telescopes are meant to piece together a few different puzzles. Cutting out WFIRST would leave gaps in calculating the numbers and types of planets in the galaxy and decloaking the preponderance and properties of "dark energy," a theorized phenomenon or force that seems to be making the universe fly apart faster and faster. Also halted would be an optical demonstration of a technique that could, on a more powerful telescope in the future, give humanity its first image of an Earth-like planet.

International partners contributing hardware, technology and research are nervous that their investments could come to naught. Spergel has been giving "civics lessons" to explain that "just because the president's budget says it's canceled doesn't mean it's canceled." The president's budget is a request to Congress that never "gets accepted as is, and they shouldn't drop out and panic yet."

As the science team and NASA got ready to brief their oversight committees in Washington, I spoke to the astrophysicists who may be called on to explain WFIRST.

Biggest mystery in the universe

The Hubble Space Telescope's observations of distant-past supernovae led to a startling announcement in 1998. Astrophysicists said a substance, or phenomenon, or repulsive force of some kind must be causing the universe to expand at an accelerating rate, and that this dark energy must make up most of the universe. In fact, with today's observations, they estimate that dark energy makes up 68 percent. Scientists think that another 27 percent of the universe consists of "dark matter," a term coined decades before the Hubble discovery to explain why galaxies rotate as though they are heavier than suggested by their emitted light. The remaining 5 percent is the normal matter that we can see or detect.

Adding to the dark energy mystery is Einstein's theory of general relativity, which says gravity ought to be slowing the expansion. "Is this cosmic acceleration due to a strange, previously unknown 'dark energy' that is defeating the pull of gravity on the vast scale of the universe, or is it possible that we have discovered that Einstein's formulation of the law of gravity is not quite right?" That's the question posed in the 2010 decadal survey of astronomy and astrophysics priorities conducted by the National Research Council, an arm of the U.S. National Academies of Sciences, Engineering and Medicine. The survey listed WFIRST as the country's recommended "highest priority" space mission for astronomy and astrophysics.

WFIRST's cosmology experiments are meant to target this question about Einstein's theory. Scientists will measure the brightness of supernovae and the distortions in how galaxies appear caused by intervening dark matter. "These are all techniques used to try to understand how much dark energy there is in the universe and what its properties are," says Paul Hertz, director of NASA's Astrophysics Division in the Science Mission Directorate. "Because dark energy is so weak, it has such small effects, you have to study large numbers of galaxies and clusters of galaxies in order to accumulate enough statistics to do something measurable. So that's why WFIRST is so sensitive and has, compared to Hubble, such a large field of view."

In fact, WFIRST's field of view is 100 times larger than Hubble's.

Eight years ago, when WFIRST emerged as the highest priority, plans called for a 1.5-meter-wide mirror, but the science case grew less compelling as the European Space Agency continued developing its Euclid spacecraft to investigate the "dark universe" of dark energy and dark matter with a 1.2-meter mirror. Everything changed in 2011, when the National Reconnaissance Office gave NASA a 2.4-meter-wide mirror among telescope hardware that no longer fit within the scope of that agency's missions. Better resolution — and the prospect of adding another instrument — put WFIRST back on the table.

"It really enabled us to be a much more capable mission," Spergel says. "It also made it a very powerful successor to Hubble." The mirror is being retrofitted to collect light in the near-infrared from a million galaxies at a time.

WFIRST's Wide Field Instrument is a 300-megapixel digital camera that records the measurements meant for both the dark energy research and a new statistical survey of exoplanets.

Belief that dark energy makes up so much of the universe is enough, astronomers say, to justify their desire to know more about it.

WFIRST's supernova survey would carry on what Hubble's started, but on a much larger scale, along with more measurements to factor into the expansion history.

Hertz of NASA headquarters explains that WFIRST will stare at a bunch of points in the sky that are loaded with galaxies. WFIRST "will keep coming back to them, regularly looking to see if one of the stars in those galaxies goes supernova," he says. Once a supernova is found, WFIRST will measure how bright it appears. "Because we know how bright supernovae actually are, how bright that supernova looks tells us how far away that galaxy is. And so we can then independently measure the redshift of that galaxy" — the term for how celestial objects shift to the infrared spectrum as they move farther away — "so that we know how fast it's moving away from us."

This gives scientists the distance and the redshift of the supernova. "If we do that for a lot of galaxies, we can map out how fast the universe is expanding. And since the further away we look, the further back in time we're looking, we can convert that map of the expansion of the universe into a description of the expansion history of the universe," Hertz explains. "And so by comparing what the actual expansion of the history of the universe is to what it would be if there was only gravity and there was no dark energy, we can measure the impact of dark energy on the expansion history of the universe."

It's just one of the gaps that the James Webb Space Telescope, now due for launch in spring 2019, with its much narrower field of view, won't be able to fill.

Another is a very big chunk of time.

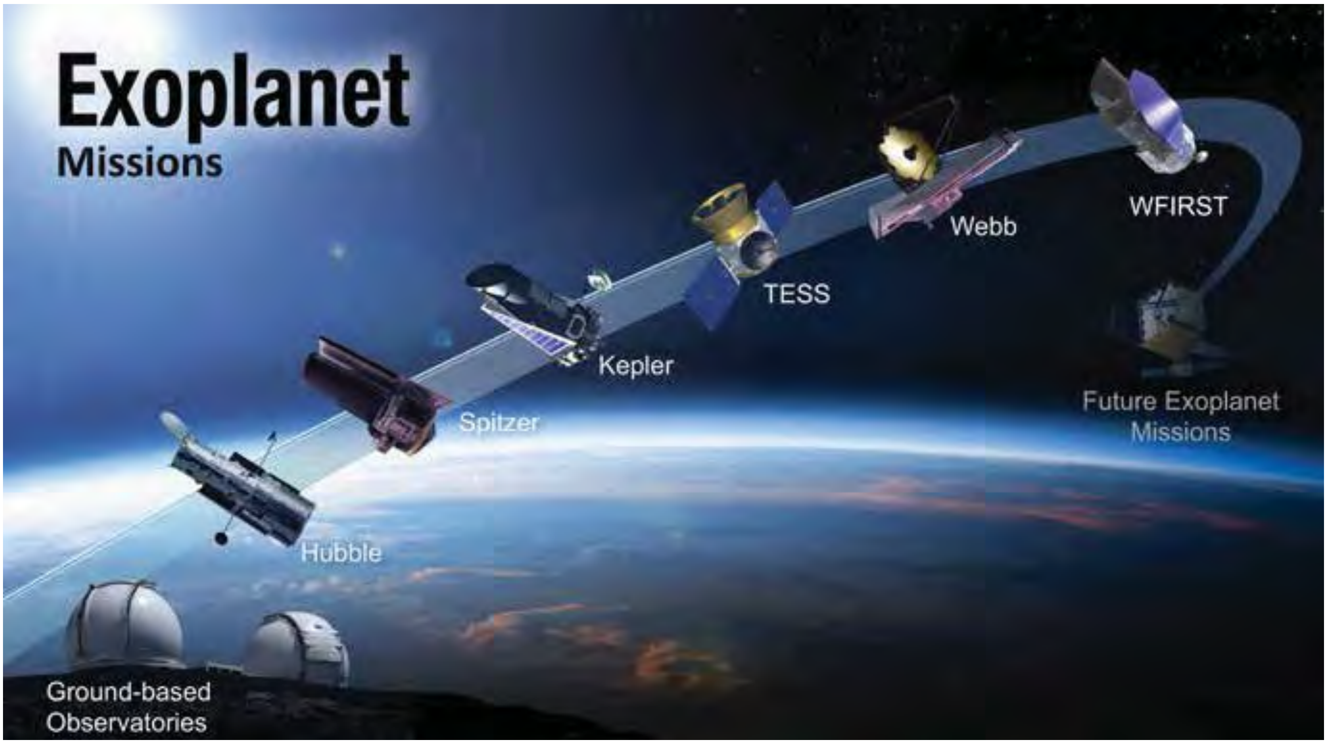
Webb's mission prioritizes the mid-infrared — "wavelengths that are way redder than our eyes can see," Hertz says. "So that's the early universe. Webb is designed to see the first stars and galaxies after the Big Bang."

WFIRST, on the other hand, "operates in the near-infrared, which is just a little bit redder than our eyes can see," providing a look midway back in time.

"If we don't do WFIRST — if the U.S. chooses not to build and launch WFIRST — then we will not make the progress that we need to make to understand

WFIRST VS. EUCLID

Like WFIRST, the European Space Agency's Euclid space telescope will investigate dark energy when it is launched 2021. ESA says Euclid will observe billions of galaxies to investigate the origin of the universe's accelerating expansion and "reveal the signatures of dark energy." The WFIRST and Euclid missions looked similar enough that in 2012 a committee of U.S. scientists considered whether the missions might be redundant while weighing whether the U.S. should have a role in Euclid. WFIRST "had the more robust and powerful approach" and would tackle "more ambitious" measurements, including a supernova survey and observations intriguing to planet hunters, reported the Board on Physics and Astronomy of the National Academies of Sciences, Engineering and Medicine. David Spergel of Princeton University, today's WFIRST co-principal investigator, was chair of the study committee. The U.S. is supplying Euclid's near-infrared detectors.



▲ Astronomers are looking at NASA's next three telescopes to help solve mysteries relating to dark energy and where there are planets that might be like Earth.
NASA

dark energy," Hertz says. "There is 15 times more dark energy than there is normal matter in the universe, and we don't understand it, and the National Academy of Sciences has said it was the highest priority science problem that needs to be solved."

Back at Princeton, WFIRST's Spergel says he hopes Congress will follow the decadal recommendation, as it has historically done, versus going along with the White House's plan to redirect WFIRST funds.

"I know in conversations with congressional staffers and conversations with some of the members of Congress, they have said to me they value the decadals," Spergel says. "I hope they continue to support [WFIRST]."

Trump's nominee for NASA administrator, Rep. Jim Bridenstine, R-Okla., was firm on following the decadal recommendations, when asked during his Nov. 1 confirmation hearing. They help policymakers "make good decisions," he said, and added:

"We need to follow the decadals."

All the planets in the galaxy

Why does NASA even need a new exoplanet survey of the galaxy, when the Kepler Space Telescope has already defined the population of planets potentially suitable for human habitation and TESS, the small Transiting Exoplanet Survey Satellite planned for launch this month, is expected to find 20,000 new exoplanet candidates?

"The reason why you want a mission like WFIRST and a mission like TESS is, TESS is most sensitive to exoplanets that are close to the star because they're the ones that are most likely to pass in front of the star and block out a little bit of that star's light," says Hertz, NASA's astrophysics director, describing the technique of transit photometry used by TESS and made famous by Kepler. Such planets are more likely to be in the "habitable zone" at temperatures that allow for liquid water.

Even within its much smaller field of view, Kepler gathered enough data to satisfy scientists that they understand how many close-in planets populate the galaxy. Now TESS will monitor vast swaths of sky to single out possible exoplanets close enough to Earth for follow-up by ground telescopes and the James Webb Space Telescope scheduled to launch in 2019, to try to find out things such as atmospheric composition.

"WFIRST, because it's using a completely different method, will be sensitive to different kinds of planets. So in particular, WFIRST is more sensitive to planets that are far away from their star," Hertz explains — "out in the areas where in our solar system Jupiter and Saturn and Uranus and Neptune reside.

"We don't actually know how common planets are outside of the habitable zone because Kepler was not sensitive to those planets."

The big pictures brought in by WFIRST would enable an observational technique called microlensing — a way of finding planets that's like the reverse of transit photometry.

In WFIRST's microlensing, the gravity of a planet in a totally other solar system from a background star crosses in front of that star and bends and amplifies the star's light. Researchers find the planets statistically, the planets' effects recorded as smaller increases in brightness than those created by their own host stars.

"So you will see the distant star will get brighter, and then start to get faint, and then get a little bit brighter again, and then continue getting faint, and that would indicate that there is a planet around the 'lensing' star — the intermediate star — and so that's how WFIRST will discover exoplanets," Hertz says.

The method is better for finding bigger planets orbiting farther out, as their effects are less likely to get mixed up with those of their stars.

"It will complete the statistical census of exoplanets in our galaxy," Hertz says. "We're not counting every planet, but we're counting enough that we can extrapolate as to the whole population."

First look at an Earth-like world

The gift of the big mirror came with the feasibility of adding another planet-focused instrument that wasn't part of the original plan but which Hertz regards as addressing "one of the most exciting science questions of the day" — namely, how to find life on other planets.

Getting a direct visual image is widely thought to be the surest way of knowing whether a planet is truly Earth-like, says Jeremy Kasdin, principal investigator of the WFIRST coronagraph instrument. Coronagraphs are optics that block out a star's light, revealing planets otherwise shrouded in the glare.

For the first time, a coronagraph in space would have controls to compensate for telescope pointing drift and jitter. Webb's won't, making it a lot less accurate.

NASA reclassified the WFIRST coronagraph as a technology demonstration instrument after an independent review, concluded in 2017, suggested doing so. This lowered classification reduced the required testing load and helped get WFIRST back on budget.

WFIRST's coronagraph is appropriate for photographing giant planets, but capturing a smaller rocky world, like Earth, would require a more powerful telescope. A goal of WFIRST is to demonstrate the technology for a future telescope like that. With a more sensitive telescope and a tried-and-true coronagraph, Kasdin thinks the first photos of Earth-size exoplanets will be possible.

The money part

Spergel at Princeton was surprised by the 2019 budget proposal, but not totally shocked, partly because it's a vulnerable time in the development — the end of Phase A, the concept definition stage in which requirements are set. Some work has been done on long-lead-time components, such as the infrared detector arrays.

> **"If we don't do WFIRST — if the U.S. chooses not to build and launch WFIRST — then we will not make the progress that we need to make to understand dark energy."**
>
> **—Paul Hertz, director of NASA's Astrophysics Division in the Science Mission Directorate**

The original WFIRST, with the smaller mirror, was going to cost $1.6 billion, according to the 2010 projection. A cap was set at $3.2 billion with the addition of the bigger mirror and added capabilities. The independent review concluded last year found that it was on track to cost closer to $3.9 billion, so the coronagraph was reclassified, bringing the estimate back down to $3.2 billion.

In the meantime, the congressional Government Accountability Office has said Webb is likely to exceed its $8 billion cap.

NASA Acting Administrator Robert Lightfoot, before announcing his plan to retire at the end of this month, sent a different message from what members of the astrophysics community are saying.

"I think when you look at the priorities that we have today, that we're still meeting the majority of our science priorities going forward," Lightfoot told a congressional committee in March in defending the cut. "We're going to launch TESS, for instance, this upcoming year. We've got James Webb going out. So the astrophysics area's in pretty good shape from that standpoint."

Later, when pressed on WFIRST, he acknowledged that "the gap in astrophysics data that we would get from WFIRST — I mean, to the astrophysics community, that's a challenge, from a scientific perspective. The positive side of that, though, is that those funds can perhaps get the data in a different way." He said WFIRST is "definitely what the decadal survey has asked for, but we think there's other ways to get that same data."

WFIRST was budgeted for $350 million in 2019. As of early March, Spergel hoped Congress would approve the Senate's budgeted $150 million for fiscal 2018 and thought a thumbs-up vote by Congress could be a good sign. The program had been operating at the 2017 spending level of $105 million.

WFIRST could easily image 1 billion galaxies in its lifetime.

"It would be a great loss to science and a great loss to U.S. leadership in science" if WFIRST were cut, says Hertz, NASA's head of astrophysics. ★