National Aeronautics and Space Administration

HUBBLE FOCUS

Strange New Worlds

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CONTENTS

About the *Hubble Space Telescope*

Since its launch in 1990, NASA's *Hubble Space Telescope* has made more than one million observations, amassed a huge archive of scientific findings, and had a profound effect on all areas of astronomy. *Hubble* has addressed fundamental cosmic questions and explored far beyond the most ambitious plans of its builders. It has captured views farther out in space and further back in time than any other observatory to date. *Hubble* has discovered that galaxies evolve from smaller structures, found that supermassive black holes are common at the centers of galaxies, verified that the universe's expansion is accelerating, probed the birthplaces of stars inside colorful nebulas, analyzed the atmospheres of extrasolar planets, and supported interplanetary missions. The rate of discovery with *Hubble* is simply unparalleled for any telescope in the history of astronomy.

Hubble observes the universe from Earth orbit, just outside our planet's atmosphere.
Credit: NASA

As NASA's first Great Observatory and the first major optical telescope in space, *Hubble* ushered in a new era of precision astronomy. The heart of the telescope is its 94.5-inch-diameter primary mirror. It is so smooth that if it were scaled up to the width of the United States, there would be no bumps taller than six inches.

Operating above Earth, free from the blurring and filtering effects of our planet's atmosphere, *Hubble* can resolve astronomical objects ten to twenty times better than typically possible with large ground-based telescopes. It also can observe those objects across a range of the electromagnetic spectrum, from ultraviolet light through visible and to near-infrared wavelengths.

Hubble can detect objects as faint as 31st magnitude, which is about 10 billion times fainter than the human eye can see. The telescope can see faint objects near bright objects—an important requirement for studying the regions around stars and close to the glowing nuclei of active galaxies. Astronomers have used *Hubble*'s sharp vision to probe the limits of the visible universe, uncovering never-before-seen objects that existed not long after the birth of the universe in the Big Bang.

Hubble's view is optically stable, meaning the quality of its observing conditions never changes from day to day or even orbit to orbit. *Hubble* can revisit celestial targets with the same acuity and image quality over and over again. This is crucial for precision observations in which astronomers try to detect small changes in the light, motion, or other behavior of a celestial object.

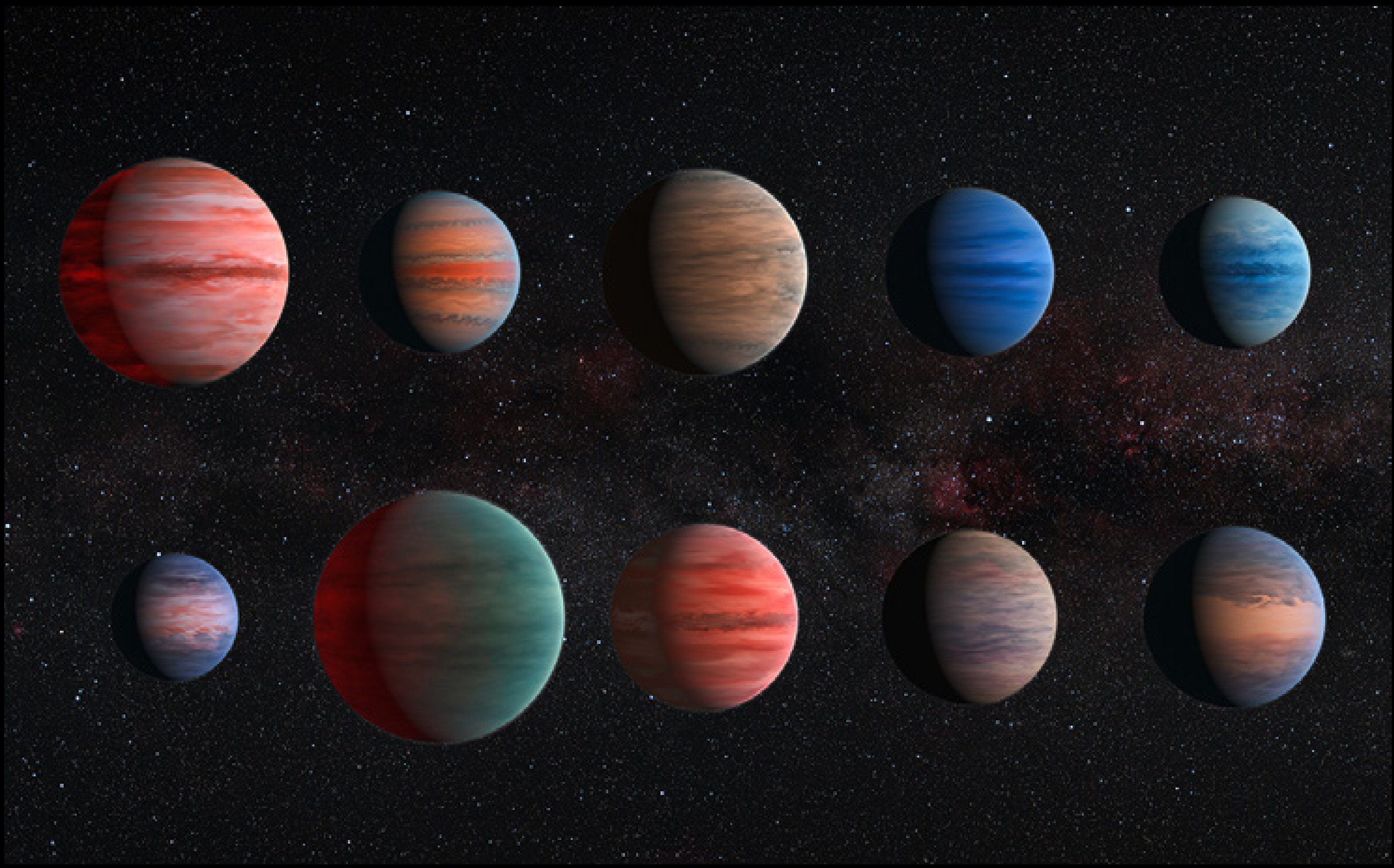
Hubble is more technologically advanced now than it was when launched, thanks to the maintenance and upgrades provided by five space shuttle servicing missions between 1993 and 2009. *Hubble* is expected to continue operating for years to come.

Astronaut John Grunsfeld performs work on the *Hubble Space Telescope* during the first of five spacewalks conducted on the last servicing mission in 2009.
Credit: NASA

INTRODUCTION

This e-book is part of a series called *Hubble Focus*. Each book presents some of *Hubble*'s more recent and important observations within a particular topic. The subjects span from our nearby solar system out to the limit of *Hubble*'s view.

This book, *Hubble Focus: Strange New Worlds*, highlights some of *Hubble*'s recent discoveries about planets outside our solar system. *Hubble*'s contributions are often in partnership with other space telescopes, as well as those on the ground, and build on decades of discoveries that came before *Hubble*'s launch. Its findings are helping us understand how our universe and our own planetary system have come to be the way they are today.



Ten "hot Jupiters" are on parade in this artist's impression. One of several exoplanet categories, hot Jupiters are unlike any of the worlds in our solar system. They are enormous, like Jupiter, but orbit extremely close to their host stars. Studying hot Jupiters with *Hubble* helps astronomers learn more about how planetary systems form and evolve.

Illustration credit: NASA and ESA

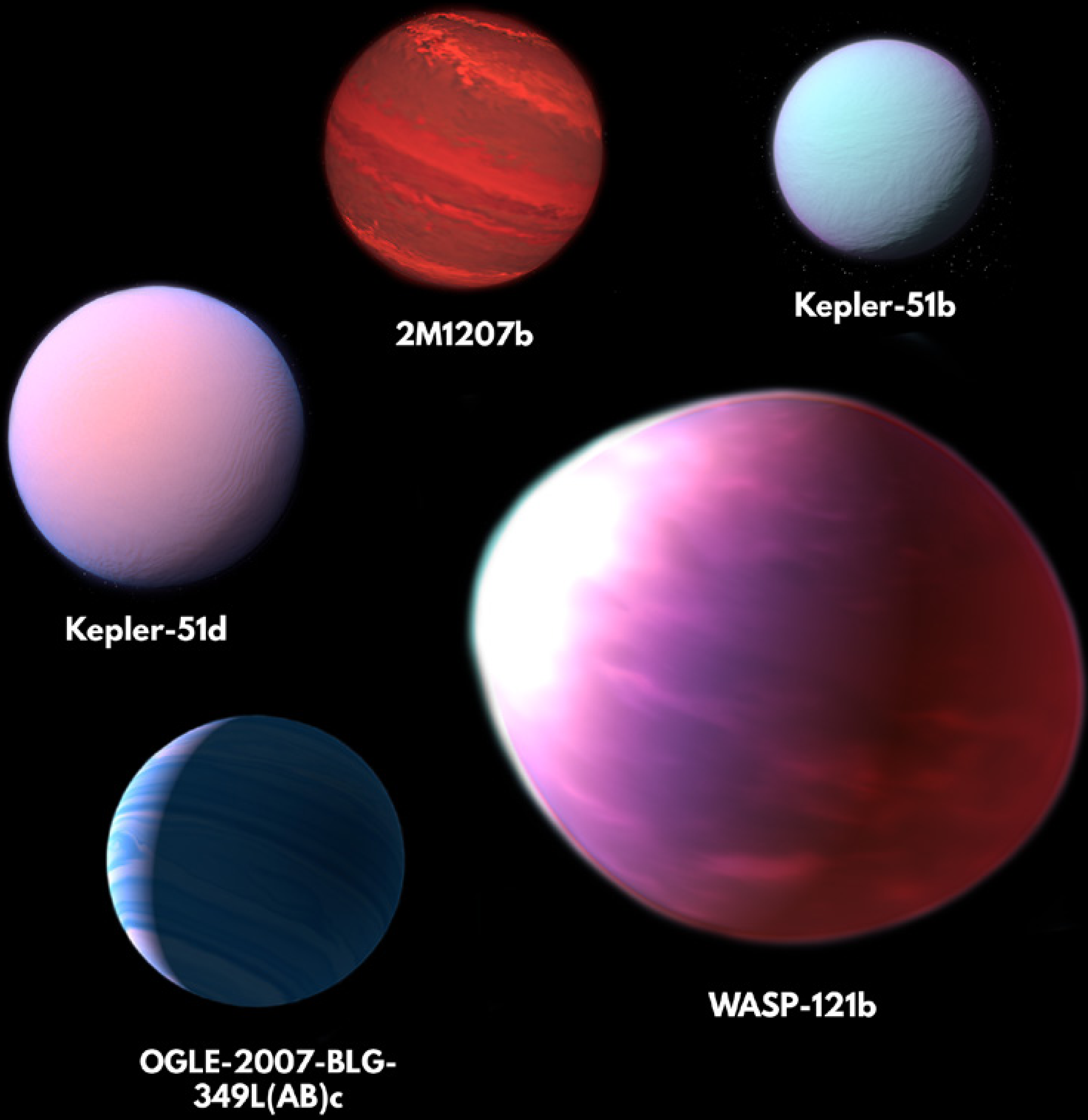
CHAPTER 1: The Search for Other Earths

For thousands of years, people believed that Earth was fixed at the center of the universe and that every other celestial object revolved around our planet. But over time, it became clear that Earth did not occupy such a special position. In 1610, Italian astronomer Galileo Galilei saw moons orbiting Jupiter in a series of monumental discoveries that strengthened an idea that had been around since at least the third century BC—heliocentricity. This theory proposed that Earth and the other bodies in our solar system orbited the Sun. As the previous framework for understanding the universe crumbled, people began to see that perhaps Earth was not as unique as they thought. Some even wondered if there might be planets circling other stars.

Fast forward to today, and exoplanets—worlds beyond our solar system—are discovered in droves. Astronomers have found more than 5,000 planets orbiting other stars. The *Hubble Space Telescope* offers insight into what these worlds are like. Most of the first exoplanets astronomers unveiled were wild and exotic compared to the worlds in our solar system. However, the prospect of finding habitable, Earth-like planets that could host living things is also exciting. *Hubble* has studied exoplanets' atmospheres and found several that contain water vapor—an essential ingredient for life as we know it. Some of these worlds even orbit within their star's habitable zone, which is the range of orbital distances where temperatures are mild enough that liquid water could pool on planetary surfaces. *Hubble* may have even extended Galileo's discoveries of moons around Jupiter by potentially finding a moon orbiting a planet located 8,000 light-years from Earth. The observatory will continue to help us learn more about exoplanets for years to come, offering clues about our own solar system's formation and evolution along the way.

The planet visualized in this illustration, TRAPPIST-1f, is roughly the same size as Earth and orbits within its star's habitable zone. Astronomers are interested in studying such worlds as part of the search for other Earths—other planets that could host life.

Illustration credit: NASA/JPL-Caltech



Exoplanet names may seem complicated, but they have a logic behind them that is important to scientists cataloging thousands of planets. The first part of the name is usually the telescope or survey that found the planet. For example, "WASP" stands for Wide Angle Search for Planets, "OGLE" is short for Optical Gravitational Lensing Experiment, and "Kepler" refers to the *Kepler Space Telescope.* "2M1207" is simply the name of 2M1307b's host object, a brown dwarf. The lowercase letter "b" stands for the planet, in the order in which the planet was found. The first planet found is named b, with ensuing planets named c, d, e, f, and so on. The star or other object that the exoplanet orbits is usually the undeclared "A" of the system, which can be useful if the system contains multiple stars, which themselves may be designated B, C. (Star designations are capital letters; planets' are lowercase.) If several exoplanets around the same star are found at once, the planet closest to its star is named b with more distant planets named c, d, e, and so on.

Illustration credit: NASA

Probing the Atmospheres of Rocky, Habitable-Zone Planets

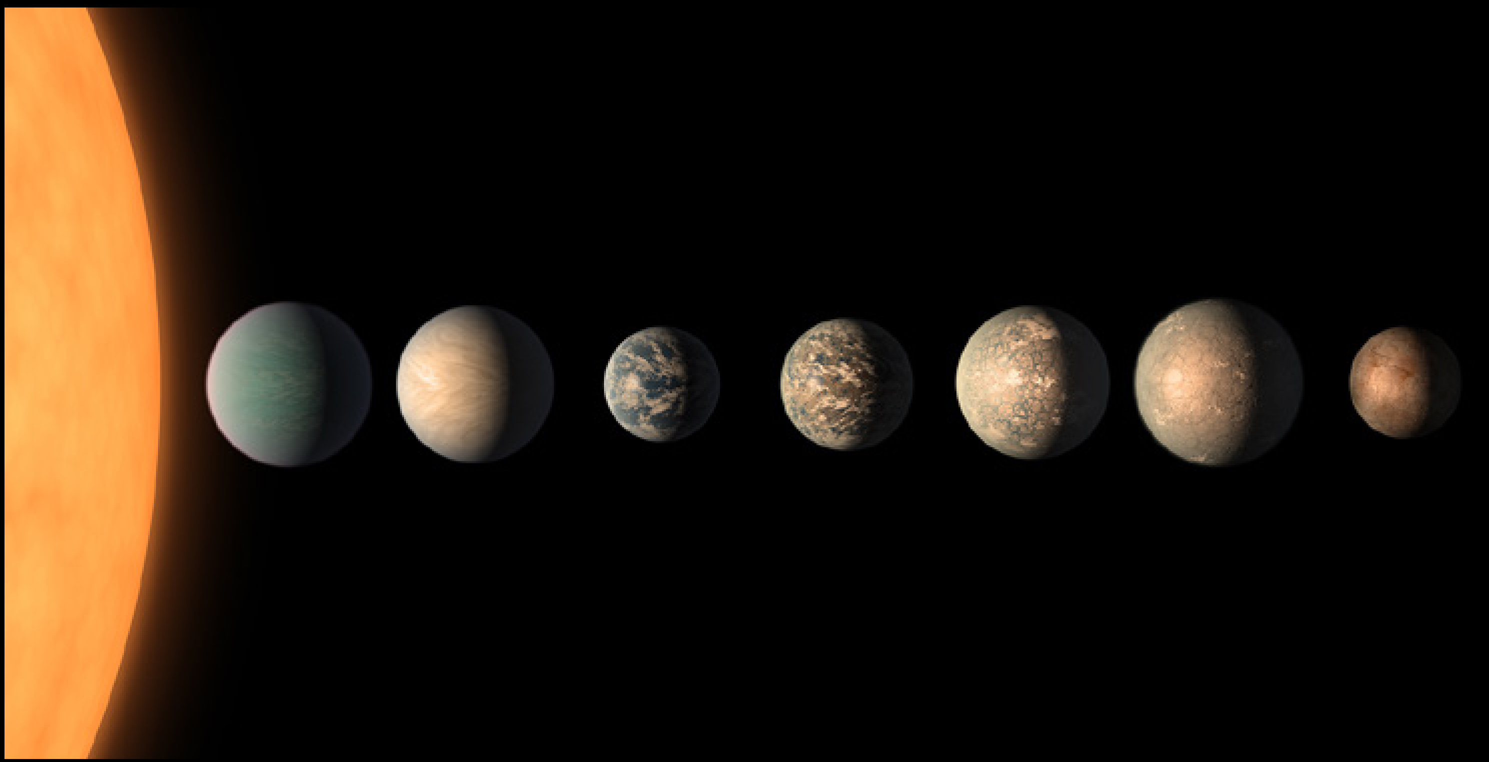
About 40 light-years away, seven Earth-size planets whirl around a diminutive star in tiny orbits. Any of the planets in this system, called TRAPPIST-1, could have liquid water depending on what their atmospheres are like. But the chances are highest for four that are located in the star's habitable zone, where conditions are neither too hot nor too cold for liquid water to pool on planetary surfaces. The TRAPPIST-1 worlds were discovered by The Transiting Planets and Planetesimals Small Telescope (TRAPPIST) in Chile and the *Spitzer Space Telescope*, with assistance from several ground-based telescopes. *Hubble* performed follow-up observations to probe several of the system's planets and help assess their habitability.

"This discovery could be a significant piece in the puzzle of finding habitable environments, places that are conducive to life."

Associate Administrator, Thomas Zurbuchen, NASA Science Mission Directorate

First, *Hubble* observed the two innermost planets and found that they lack puffy, hydrogen-dominated atmospheres that are common for gaseous worlds like Neptune. Hydrogen is a greenhouse gas that can smother planets orbiting close to their host stars, making them hot and inhospitable to life. Astronomers think the two nearest TRAPPIST-1 planets are likely rocky with atmospheres more similar to Earth's, making it much more likely that the worlds could be habitable. The observatory then turned its sights on the four habitable-zone planets and discovered that at least three of them also lack hydrogen-rich atmospheres. Instead, their atmospheres may contain heavier gases like those found in Earth's atmosphere, such as carbon dioxide, methane, and oxygen.

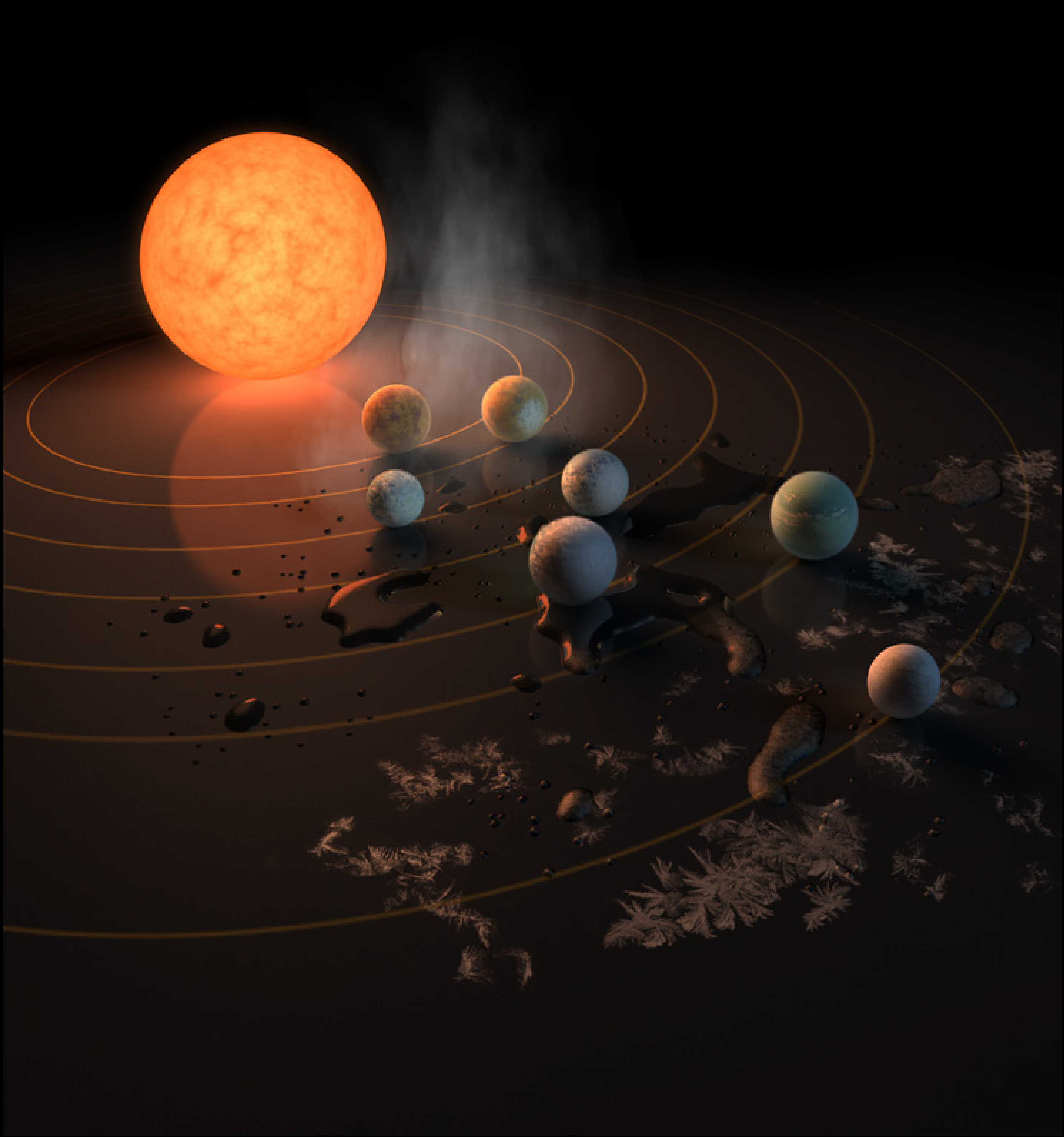
NASA's *James Webb Space Telescope* will observe the TRAPPIST-1 planets with even greater sensitivity, offering the opportunity to detect the chemical fingerprints of water, methane, oxygen, ozone, and other atmospheric components. *Webb* will also analyze the planets' temperatures and surface pressures, offering vital information for assessing habitability.



This artist's concept shows what the TRAPPIST-1 planets may look like, based on available data about their diameters and masses. All seven of these worlds are about the same size as Earth, while the host star is barely larger than Jupiter (though more than 90 times as massive). *Hubble* studied several of the planets' atmospheres and found that they could be conducive to life as we know it, though follow-up observations are needed to confirm this finding.

Illustration credit: NASA/JPL-Caltech

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-07.html



The TRAPPIST-1 planets, pictured in this illustration, all circle their host star much closer than Mercury orbits the Sun. In our solar system, such small orbits would render the worlds far too hot to be good candidates for life as we know it. However, since the host star is a red dwarf, which is much smaller and cooler than the Sun, its habitable zone is much closer in. Too close to the star, planets are too hot for liquid water, as indicated by steam in the graphic. Too far, and surface water exists only as ice, indicated by frost. *Hubble* observations showed that several of the planets, including three that orbit within the habitable zone, may be rocky and have atmospheres similar to Earth's.

Illustration credit: NASA and JPL/Caltech; Science: NASA, ESA, J. de Wit (MIT), H. Wakeford (University of Exeter/STScI), and N. Lewis (STScI)

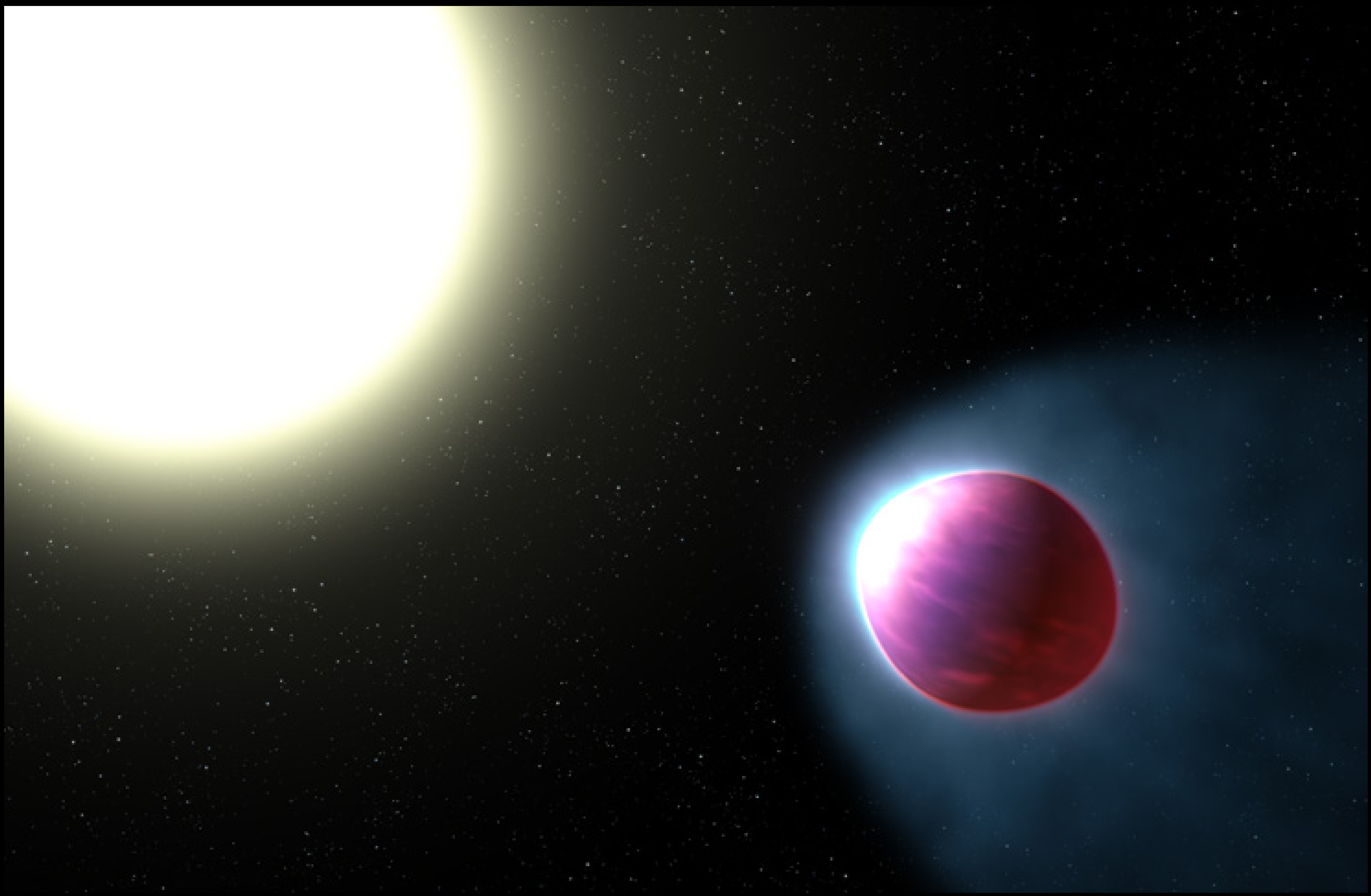
Spotting a World with a Glowing Water Atmosphere

Earth's atmosphere has five major tiers, including a stratosphere—home to Earth's ozone layer, which protects us from the Sun's harmful ultraviolet radiation. Because of that UV radiation, the temperature increases with higher altitudes (unlike most atmospheric layers). Warm stratospheres are a common component of the atmospheres in our solar system, though chemicals other than ozone, such as methane, are usually to blame. However, scientists had never very confidently detected a stratosphere on an exoplanet until they trained *Hubble* on WASP-121b—a hot Jupiter located about 900 light-years from Earth.

> "We can now compare processes in exoplanet atmospheres with the same processes that happen under different sets of conditions in our own solar system."
>
> Mark Marley, NASA Ames Research Center

While previous research revealed possible signs of stratospheres on some other exoplanets, this new study presents the best evidence yet because scientists observed the signature of hot water molecules for the first time. Atmospheric water vapor behaves in predictable ways in response to certain wavelengths of light, depending on the temperature of the water. If water molecules are cooler, they absorb certain wavelengths of light passing through them. But if they're warmer, they glow at the same wavelengths instead, which is what researchers saw on WASP-121b.

The team's observations support theoretical models which suggest that stratospheres may define a distinct class of ultra-hot planets. Additional Hubble observations have explored WASP-121b's stratosphere further, revealing iron and magnesium as the likely culprits behind the temperature increase in WASP-121b's atmosphere.



The slightly egg-shaped exoplanet WASP-121b is seen near its host star in this artist's impression. It orbits so close to its star that the top of its atmosphere is heated to a blazing 4,600 degrees Fahrenheit. By studying this planet's atmosphere using *Hubble*, scientists detected the strongest evidence yet for a stratosphere—an atmospheric layer in which temperature increases with higher altitudes—on a planet outside our solar system.

Illustration credit: NASA, ESA, and G. Bacon (STScI); Science: NASA, ESA, and T. Evans (University of Exeter)

Learn more: https://hubblesite.org/contents/news-releases/2017/news-2017-31.html

Discovering an Alien Atmosphere that is Brimming with Water

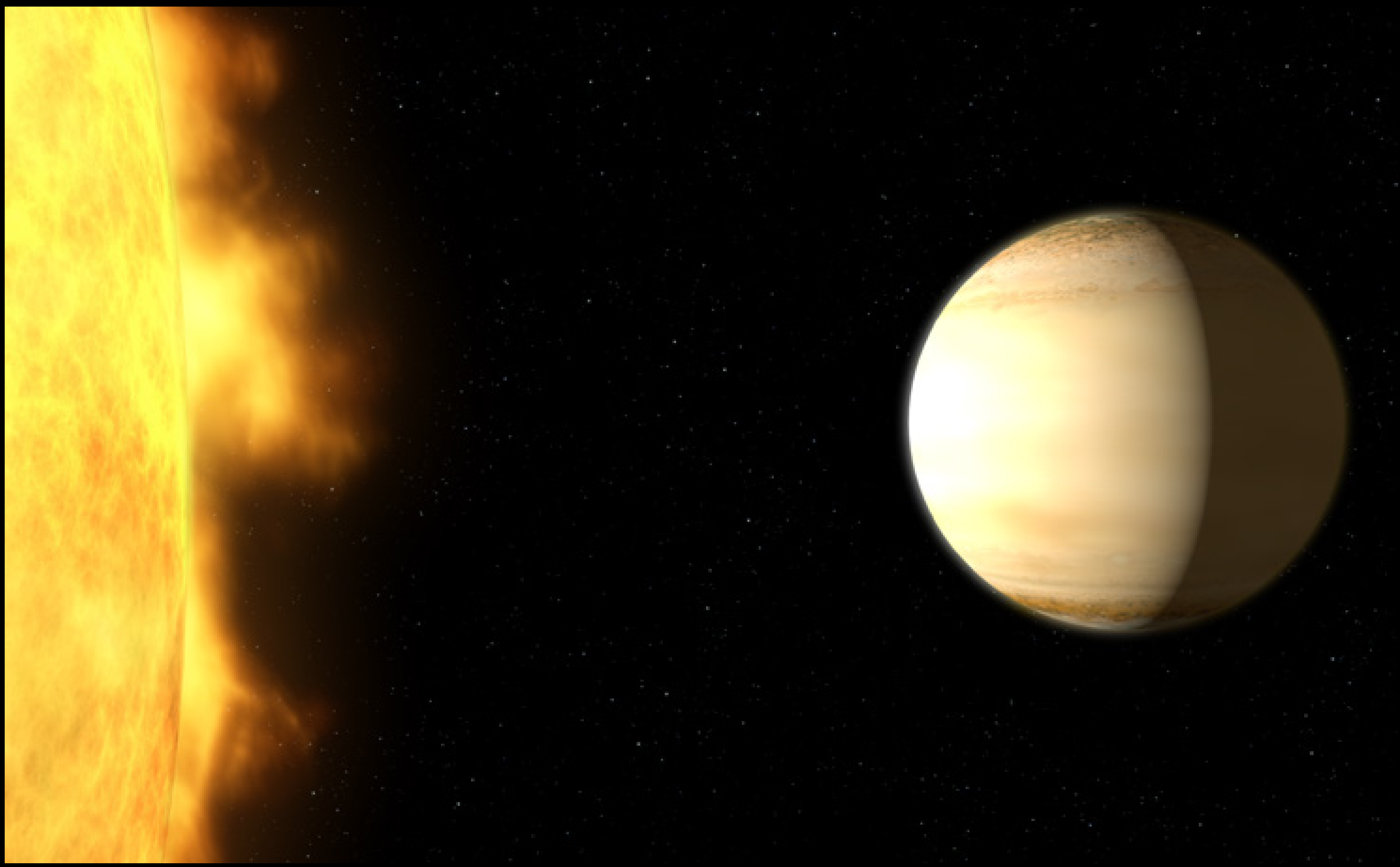
Hubble teamed up with the *Spitzer Space Telescope* to study a hot, Saturn-mass planet called WASP-39b, which is located about 700 light-years from Earth. Astronomers dissected starlight filtering through the planet's atmosphere and found clear evidence of a large amount of water vapor—much more than they anticipated, totaling three times as much water as Saturn. This was a surprising discovery because the planet orbits so close to its host star, completing one orbit in just four days. If the planet formed in its current, warmer location, its water would have evaporated into space.

"WASP-39b shows us that planet formation is more complicated than we thought it was."

Hannah Wakeford, Space Telescope Science Institute and the University of Exeter

WASP-39b is an excellent case study for planetary formation and evolution. While Saturn likely formed near its present location, far from the Sun, astronomers think giant planets that orbit very close to their host stars likely formed farther away and then migrated inward over time. WASP-39b observations strongly support this theory. The planet probably accumulated its water much farther from its star, where cooler conditions allow icy material to exist and bombard the young planet. Then WASP-39b likely made its epic journey inward, migrating to its current star-hugging location.

The *James Webb Space Telescope* could take an even more comprehensive look at WASP-39b's atmospheric components, which are relatively easy to study because the planet's atmosphere is not blocked by high-altitude clouds. *Webb* may reveal information about this world's atmospheric carbon, which absorbs light at longer wavelengths than *Hubble* can see. By understanding the amount of carbon and oxygen in the atmosphere, scientists can learn even more about where and how this planet formed.



The hot, bloated planet WASP-39b hugs its star in this illustration. *Hubble* and *Spitzer* revealed that though WASP-39b is more than 20 times closer to its star than Earth is to the Sun, it contains a large amount of water in its atmosphere. This finding strongly supports the theory that giant gas planets in tiny orbits likely formed farther from their host stars and then migrated inward over time.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-09.html

Detecting Water Vapor on a Habitable-Zone Exoplanet for the First Time

Astronomers have spent decades searching for other habitable worlds. Habitability for life as we know it is dependent on a non-poisonous atmosphere, a rocky surface, and a temperature range that allows water to pool on the surface. *Hubble* detected water vapor in the atmosphere of a habitable-zone planet for the first time. However, it fails to meet the other two habitability criteria.

> "This represents the biggest step yet taken towards our ultimate goal of finding life on other planets."
>
> Björn Benneke, University of Montréal

A team of researchers used data from *Hubble*'s archive to analyze the host star's light filtered through K2-18b's atmosphere. They discovered signatures of water vapor as well as hydrogen and helium, the latter two of which are not hospitable for life as we know it. With about eight times as much mass as Earth, K2-18b is probably a giant ball of gas and liquid like Neptune, with no rocky surface. Its host star is also a very active red dwarf, which blasts high-energy radiation out into the planetary system.

But despite its hostile environment, K2-18b offered the first opportunity for astronomers to detect and study water on a habitable-zone planet that likely features a temperate climate. Future observations could estimate how much water the planet's atmosphere contains, detect other molecules, and determine what percentage of the planet is cloud-covered. K2-18b is especially interesting because it is one of hundreds of known super-Earths—planets with masses between those of Earth and Neptune. The *Transiting Exoplanet Survey Satellite* (*TESS*) will likely discover hundreds more super-Earths in the coming years, and the next generation of space telescopes will be able to take a more detailed look at their atmospheres. As astronomers learn more about these fascinating worlds, we will come closer to finding out whether Earth is unique.

Astronomers using *Hubble* data made the first-ever detection of water vapor in the atmosphere of a planet that orbits within its star's habitable zone. The system, shown in this illustration, is about 110 light-years away. It is home to a super-Earth called K2-18b, which is the only exoplanet known to have both water and temperatures that could support life. While astronomers are not sure whether K2-18b is truly habitable, studying it brings us closer to understanding whether other planets like Earth exist.

Credit: ESA/Hubble, M. Kornmesser

Learn more: https://hubblesite.org/contents/news-releases/2019/news-2019-50.html

Hubble data revealed water vapor in a habitable-zone exoplanet's atmosphere for the first time. The planet, known as K2-18b, is a super-Earth, which may be the most common type of planet in our Milky Way galaxy. It also orbits the most common kind of star in our galaxy, called a red dwarf—a star that is much smaller, cooler, and more active than the Sun, which could affect the planet's atmosphere and environment. Detecting water on a habitable zone exoplanet is a major step toward identifying other habitable worlds.

Credit: NASA's Goddard Space Flight Center

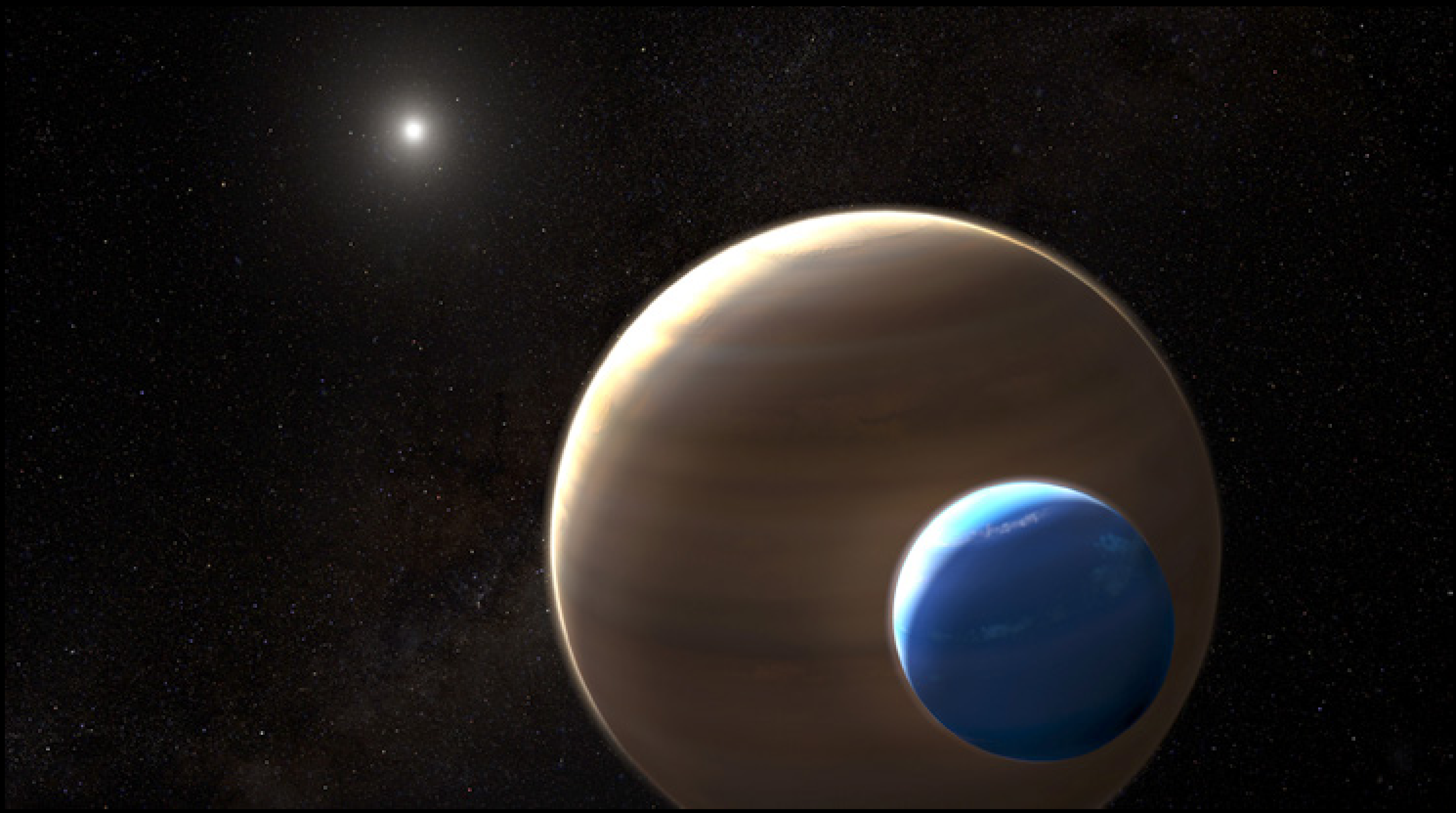
Exposing the First Evidence of a Possible Exomoon

While astronomers have discovered more than 5,000 exoplanets so far, they have yet to confirm the existence of an exomoon—a moon orbiting a world beyond our solar system. However, using *Hubble* and the *Kepler Space Telescope*, researchers found evidence that a Neptune-sized moon may be circling the Jupiter-sized planet Kepler-1625b, located 8,000 light-years from Earth. While both the planet and possible exomoon orbit within their star's habitable zone, they are both likely gaseous and therefore unsuitable for life as we know it.

> "If confirmed, this finding could completely shake up our understanding of how moons are formed and what they can be made of."
>
> Thomas Zurbuchen, NASA Headquarters

If our solar system is a typical example, moons may drastically outnumber the planets in our galaxy. But since they tend to be much smaller than planets, they are more difficult to detect. Researchers first inferred the presence of a large moon orbiting Kepler-1625b by monitoring the light from its host star using *Kepler*. The planet transited, or crossed in front of, its host star, which temporarily dimmed the star's light. But the dimming contained wobbles which could indicate that the planet is not alone—a giant moon, around four times larger than Earth, may whirl around it.

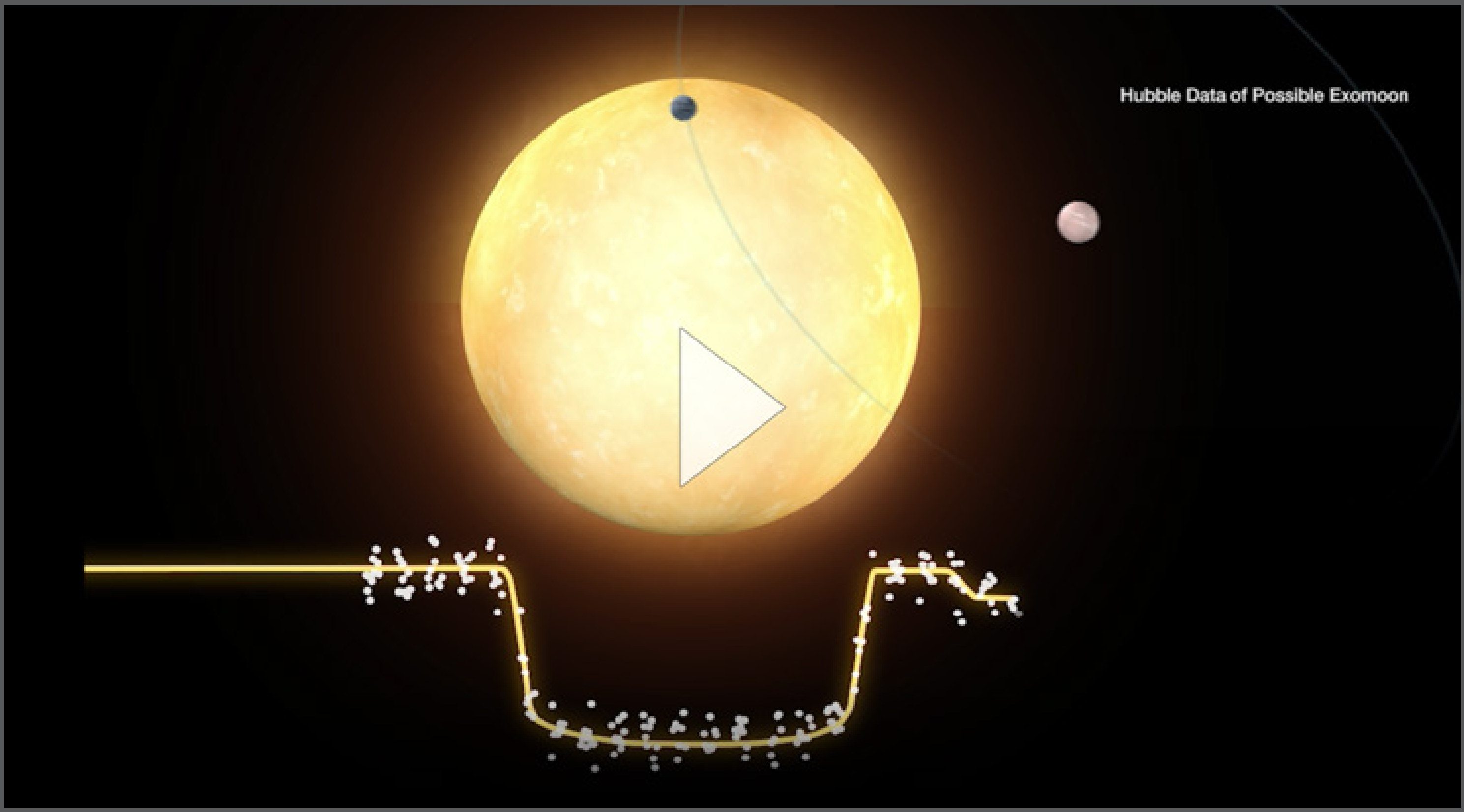
Hubble observed the planet as a follow-up to the *Kepler* observations, also using the transit method. Researchers gathered a more detailed look at the dips of light, which included a secondary dimming that could be caused by a moon. Since the scheduled *Hubble* observations ended before the team could measure a complete transit of the candidate moon and confirm its existence, follow-up observations are necessary to validate the exomoon. The *James Webb Space Telescope* could find and study candidate exomoons in greater detail, possibly revealing very small ones.



A large, gaseous moon lurks in the shadow of its parent planet in this illustration of the Kepler 1625 system. While the moon is enormous—roughly the same size as Neptune, or four times as large as Earth—astronomers estimate that it is only 1.5 percent as massive as the planet it orbits, which is several times more massive than Jupiter. This mass-ratio is similar to the one between Earth and our Moon, but finding such a large moon may cause experts to revisit theories about how moons form around planets.

Illustration credit: NASA, ESA, and L. Hustak (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-45.html



This video visualizes *Hubble* data that indicates a moon may be orbiting the distant planet Kepler-1625b. Follow-up observations are necessary to confirm whether an exomoon is the definitive cause of the anomalies researchers saw in the host star's light as the planet crossed in front of the star.

Credit: NASA's Goddard Space Flight Center and J. Koynock

CHAPTER 2: Weird Worlds

When astronomers began hunting for planets orbiting other stars, they expected to find systems similar to ours. Instead, they discovered swarms of strange and exotic worlds that required a reevaluation of planetary formation and evolution theories, which were developed to explain how our own solar system came to be. *Hubble*'s exoplanet studies continue to help broaden our view of planetary systems by revealing even more oddballs, often by investigating the chemistry of their atmospheres via spectroscopy.

Hubble's spectroscopic observations have unveiled withering worlds that dwindle as they lose their atmospheres to space, sometimes releasing a stream of heavy metals. These leaky planets could help explain why astronomers find relatively few hot, Neptune-sized worlds—while many likely form, they may have a tendency to shrink. The mission has also revealed a world that gobbles up nearly all of the starlight that reaches the planet, rather than reflecting it back into space. This strange planet would look as black as fresh asphalt if we could see it directly. Another world *Hubble* studied is in such an extreme orbit that it's on the verge of being ripped apart, as the host star's gravitational pull stretches a once spherical world into a football shape. Scientists using *Hubble* have even found evidence that a planet orbiting a distant star may have lost its atmosphere but gained a second one through volcanic activity.

Extreme worlds are often the easiest to discover because they have the strongest, most detectable effect on their host star. But these planets are certainly not the easiest to understand. *Hubble*, in tandem with other observatories, will continue to reveal new information about the worlds that grace our galaxy, helping unveil a more complete picture of planetary formation and evolution.

A "sub-Neptune" world withers under the fiery radiation its young, hot host star is emitting in this illustration. *Hubble* results have shown that such active stars can bake away their planets' atmospheres, leaving airless, rocky cores behind instead. But *Hubble* has also revealed that some of these wilted planets could generate all-new atmospheres.

Credit: ESA

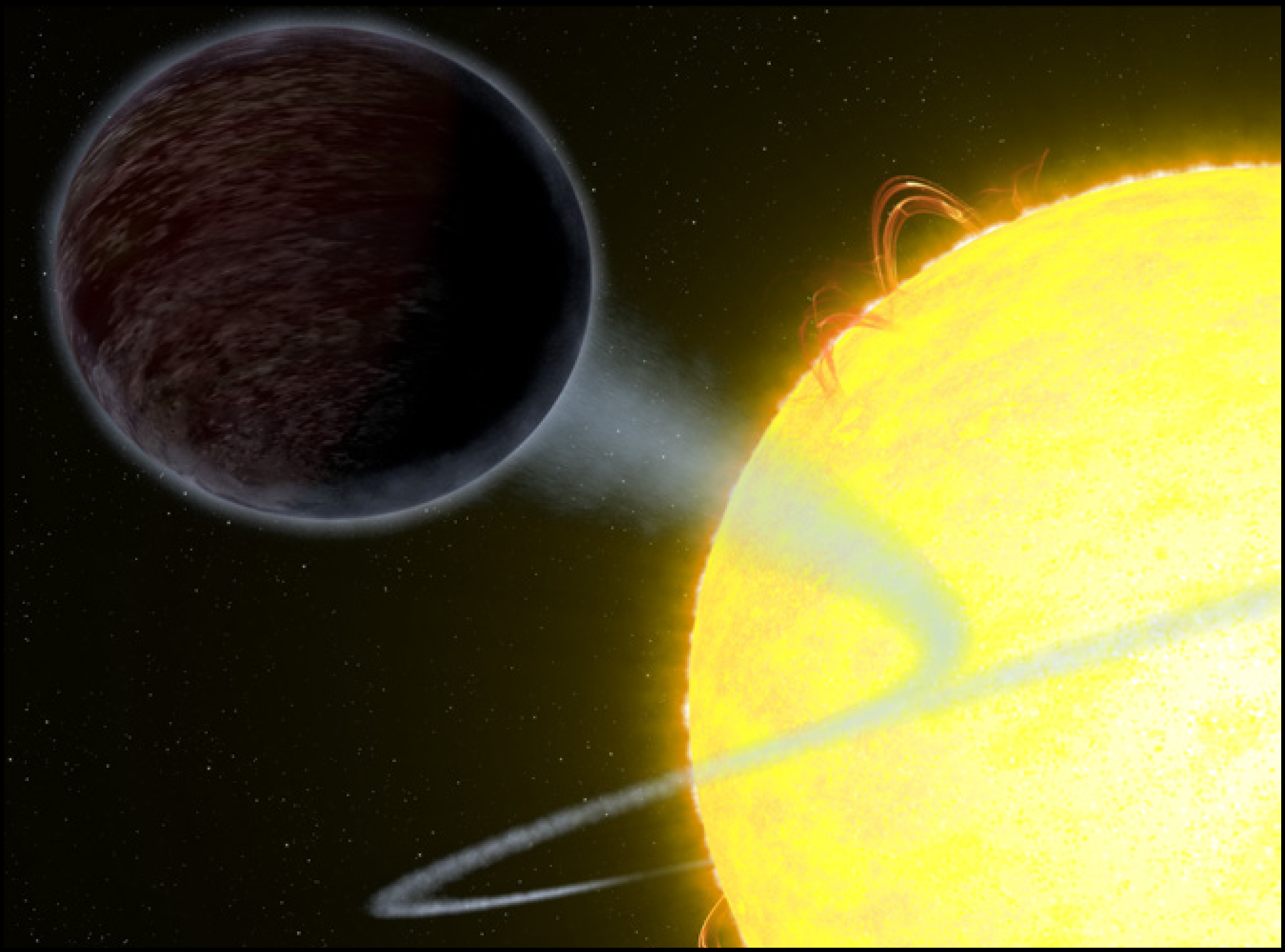
Capturing a Blistering Pitch-Black Planet

About 1,400 light-years from Earth, an inky alien world dubbed WASP-12b circles a Sun-like star. Far from resembling any of the planets in our solar system, WASP-12b—a member of a class of planets called hot Jupiters—is gargantuan and hellishly hot. It hangs so close to its star that it spins only once per orbit—a phenomenon called tidal locking. The same side always faces its star, just like we always see the same side of the Moon, which is tidally locked to Earth. This heats the atmosphere on WASP-12b's day side to a roiling 4,600 degrees Fahrenheit, so hot that water vapor molecules break apart. Yet the planet's night side is more than 2,000 degrees cooler, which is mild enough for clouds to form.

"This research further demonstrates the vast diversity among the strange population of hot Jupiters."

Taylor Bell, McGill University and the Institute for Research on Exoplanets

Astronomers using *Hubble* found that although most hot Jupiters reflect about 40 percent of the starlight falling on them, WASP-12b reflects less than 10 percent. The planet traps so much light that it would look as black as fresh asphalt if we could see it directly, hinting that reflective aluminum oxide clouds are not present on the planet's day side. The researchers made this discovery by using *Hubble* to view the components of light (or spectra) given off by the system. By observing how much the system dimmed as the planet passed behind the star, they could determine how much starlight the planet reflects. Their observations did not detect any dimming, which means the daytime side of the planet is absorbing nearly all of the starlight falling onto it. This result draws a stark contrast to the only other hot Jupiter observed this way, hinting at the wide variety among these extreme worlds.



This illustration shows one of the darkest known exoplanets, called WASP-12b, orbiting extremely close to a star like our Sun. *Hubble* observations revealed that it gobbles up nearly all of the starlight that reaches the planet, rather than reflecting it back into space. This light-eating prowess is due to the planet's unique capability to trap at least 94% of visible starlight falling into its atmosphere. A swirl of material from the planet's super-heated atmosphere is seen spilling onto its star in this illustration.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

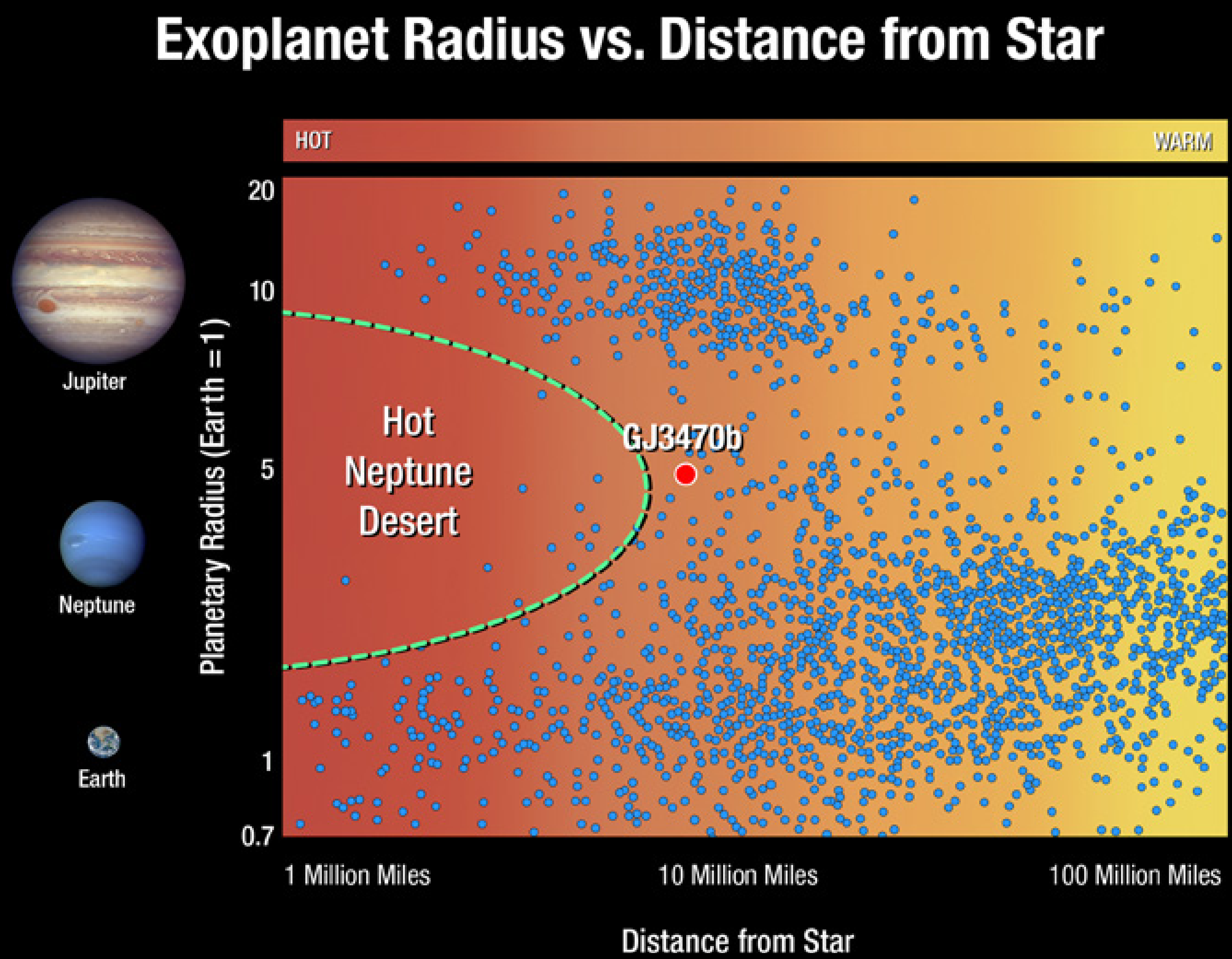
Learn more: https://hubblesite.org/contents/news-releases/2017/news-2017-38.html

Finding a Shrinking Planet

The exoplanet hunt has revealed a shortage of Neptune-sized worlds located precariously close to their host stars. These planets, dubbed “hot Neptunes,” may not have strong enough gravity to hold on to their atmospheres in the face of the powerful stellar radiation that comes from having such small orbits. Astronomers discovered strong evidence in support of this theory when *Hubble* observations revealed that the planet GJ 3740b is rapidly losing mass as its atmosphere evaporates.

> “This is one of the most extreme examples of a planet undergoing a major mass-loss over its lifetime.”
>
> Vincent Bourrier, University of Geneva

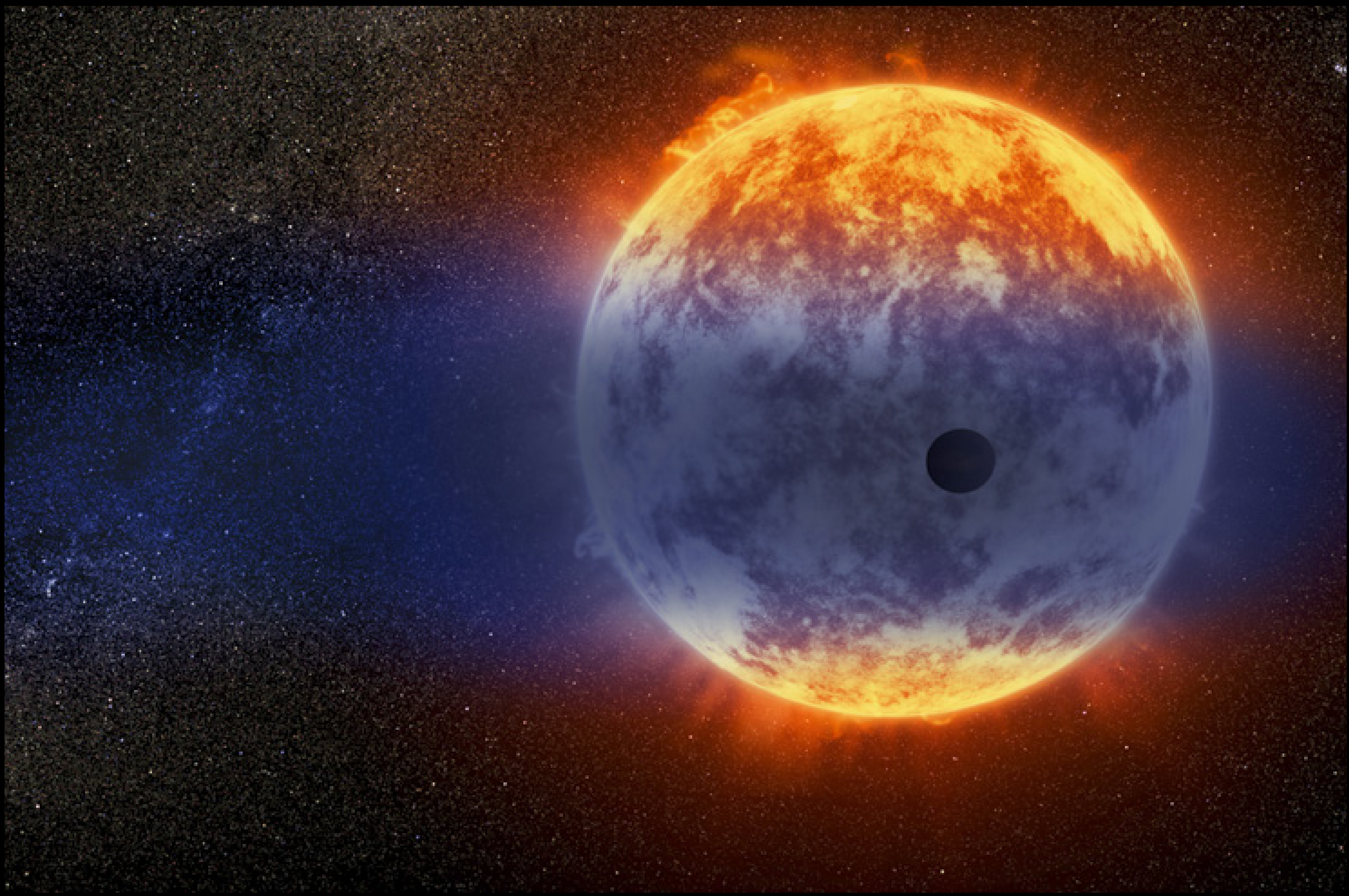
Prior to this discovery, only one similar planet (GJ 436b) was observed leaking its atmosphere into space. Both planets are known as “warm” Neptunes because they orbit farther from their host stars and therefore are cooler than hot Neptunes. The more recently studied planet is losing its atmosphere about 100 times faster than the first. Astronomers estimate that GJ 3740b has already lost more than a third of its original mass and may ultimately shrink down to the most common type of known exoplanet, a mini-Neptune. The team detected the ultraviolet-light signature of hydrogen in a huge cocoon surrounding the planet as it passed in front of its star. The cocoon is evidence of the planet’s atmosphere bleeding off into space. If this phenomenon is widespread among exoplanets, it could explain the hot Neptune void—while many likely form, they may have a tendency to shrink. Studying such worlds further will help us learn more about how planets form and evolve.



Astronomers expected to find many “hot Neptunes” orbiting very close to their stars, but so far the search has turned up relatively few. This plot, which looks like someone has taken a bite out of it, reveals the so-called hot Neptune desert. *Hubble* observations of the planet GJ 3740b support the theory that these worlds may shrink over time as their atmospheres evaporate into space.

Credit: NASA, ESA, and A. Feild (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-52.html



Astronomers used *Hubble* to detect a giant cloud of hydrogen streaming off the warm, Neptune-sized planet GJ 3740b, located just 97 light-years from Earth. The cloud, shown in blue in this artist's illustration, is evidence that the planet is shrinking as its atmosphere escapes into space. The findings lend credence to a theory that explains why so few Neptune-sized worlds are found orbiting extremely close to their host stars—while many probably form, they may dwindle over time as their atmospheres leak away.

Credit: NASA, ESA, and D. Player (STScI)

Uncovering a Football-Shaped 'Heavy Metal' Exoplanet

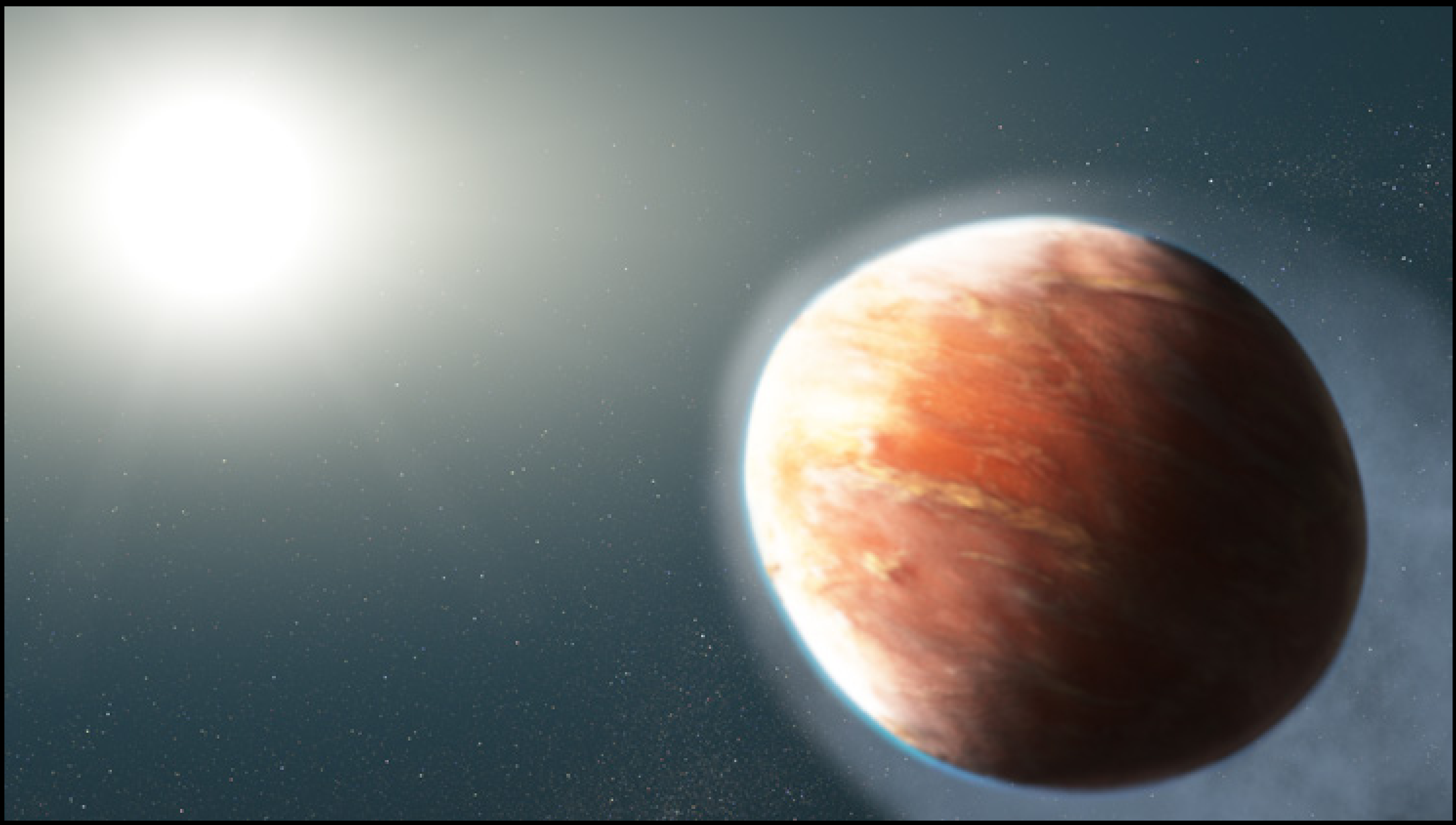
Astronomers used *Hubble* to observe WASP-121b and for the first time detected the heavy metal gases iron and magnesium streaming away from an exoplanet. Iron and magnesium are known as heavy metals in astronomy because they are heavier than lightweight hydrogen and helium. These chemicals are thought to cause the increasing temperature in a layer of the planet's atmosphere, which astronomers previously detected using *Hubble*.

"This planet is being actively stripped of its atmosphere."

David Sing, the Johns Hopkins University

Scientists previously detected strong evidence of a stratosphere on WASP-121b, leading them to study it further. The planet orbits so close to its star that the top of its atmosphere is heated to a sweltering 4,600 degrees Fahrenheit. *Hubble* observations reveal that the lower atmosphere is also hot enough for iron and magnesium to be gaseous, allowing them to stream to the upper atmosphere where they escape into space on the coattails of hydrogen and helium. The heavy metals can escape because while the planet is big, it is not dense, making its gravity relatively weak.

Researchers used *Hubble*'s unique sensitivity to ultraviolet light to search for the signatures of magnesium and iron imprinted on starlight filtering through WASP-121b's atmosphere as the planet passed in front of its host star. WASP-121b will be an excellent target for the *James Webb Space Telescope*, which is optimized for the longer, infrared wavelengths that water and carbon dioxide are visible at. The combination of *Hubble* and *Webb* observations would give astronomers a more complete inventory of the chemical elements that make up the planet's atmosphere. Further observations could also add to the developing story of how planets lose their primordial atmospheres.



This artistic illustration reveals how WASP-121b's atmosphere is scorched and blown away by a torrent of ultraviolet light from its star. *Hubble* observations revealed that the star is super-heating the planet's atmosphere, baking off heavy metals like iron and magnesium. WASP-121b orbits the star so closely that it is on the verge of being ripped apart. The powerful gravity of its nearby star has stretched the planet out, making it appear more oblong (like a football) than round.

Credit: NASA, ESA, and J. Olmsted (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2019/news-2019-19

Unraveling Mysteries Surrounding 'Cotton Candy' Planets

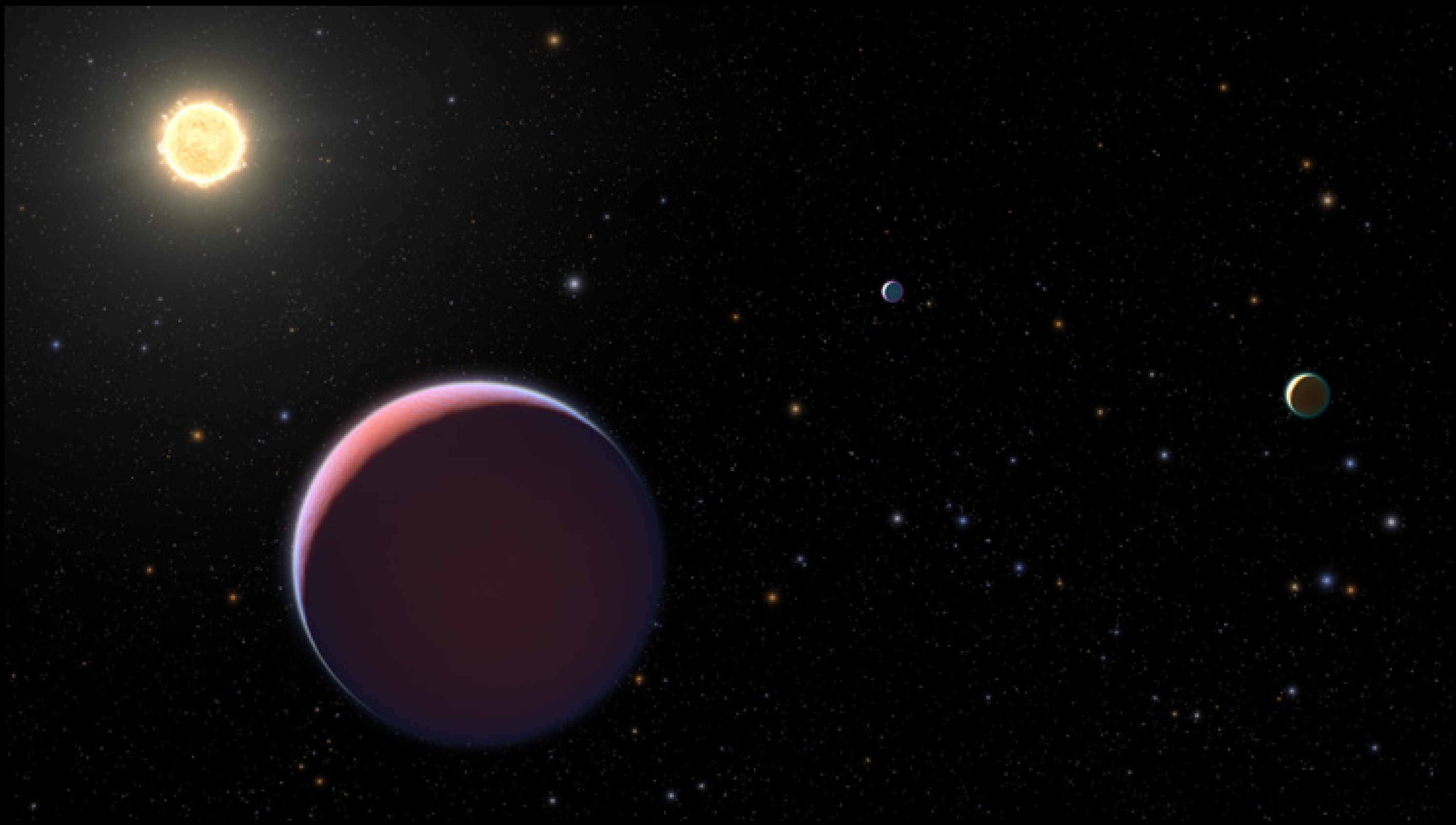
The planets in our solar system are vastly different from each other—just compare the small, rocky planet Mercury to the bloated, gas giant Jupiter. But an even wider variety of worlds circle other stars. Thanks to *Hubble*, we now know that our galaxy is even home to "cotton candy" planets.

"This system offers a unique laboratory for testing theories of early planet evolution."

Zach Berta-Thompson, University of Colorado Boulder

Rather than being made of spun sugar, *Hubble* observations confirmed that three super-puffy planets in the Kepler 51 system have extremely low densities. Astronomers discovered the planets in 2012 using the *Kepler Space Telescope* and measured their densities two years later. Combining *Kepler*'s data with the most recent *Hubble* results refined the mass and size estimates for these worlds. The team found the planets' masses by monitoring their orbital motion, and then combined that with the planets' sizes to determine how dense they are. Though they appear to be as big and bulky as Jupiter, they are actually one hundred times less massive.

The researchers used *Hubble* to investigate the chemistry of two of these strange planets' atmospheres, searching for signs of water. As each planet passes in front of the host star, starlight shines through the atmosphere allowing astronomers to detect its chemical makeup. To their surprise, the search came up empty. Obscuring clouds of particles high in the planets' atmospheres are the likely culprits for the missing chemical signature. Unlike Earth's water-clouds, the clouds on these planets may be composed of salt crystals or photochemical hazes, like those found on Saturn's largest moon, Titan. The *James Webb Space Telescope* may be able to peer through the cloud layers, potentially providing insight into what these low-density, cotton-candy-like planets are actually made of.



This illustration shows three swollen planets in the Kepler 51 system, located about 2,600 light-years from Earth, orbiting their Sun-like star. These strange, puffy worlds have been dubbed "cotton candy planets" because they are Jupiter-sized but with much lower densities, based on *Hubble* observations.

Credit: NASA, ESA, and L. Hustak, J. Olmsted, D. Player, and F. Summers (STScI)

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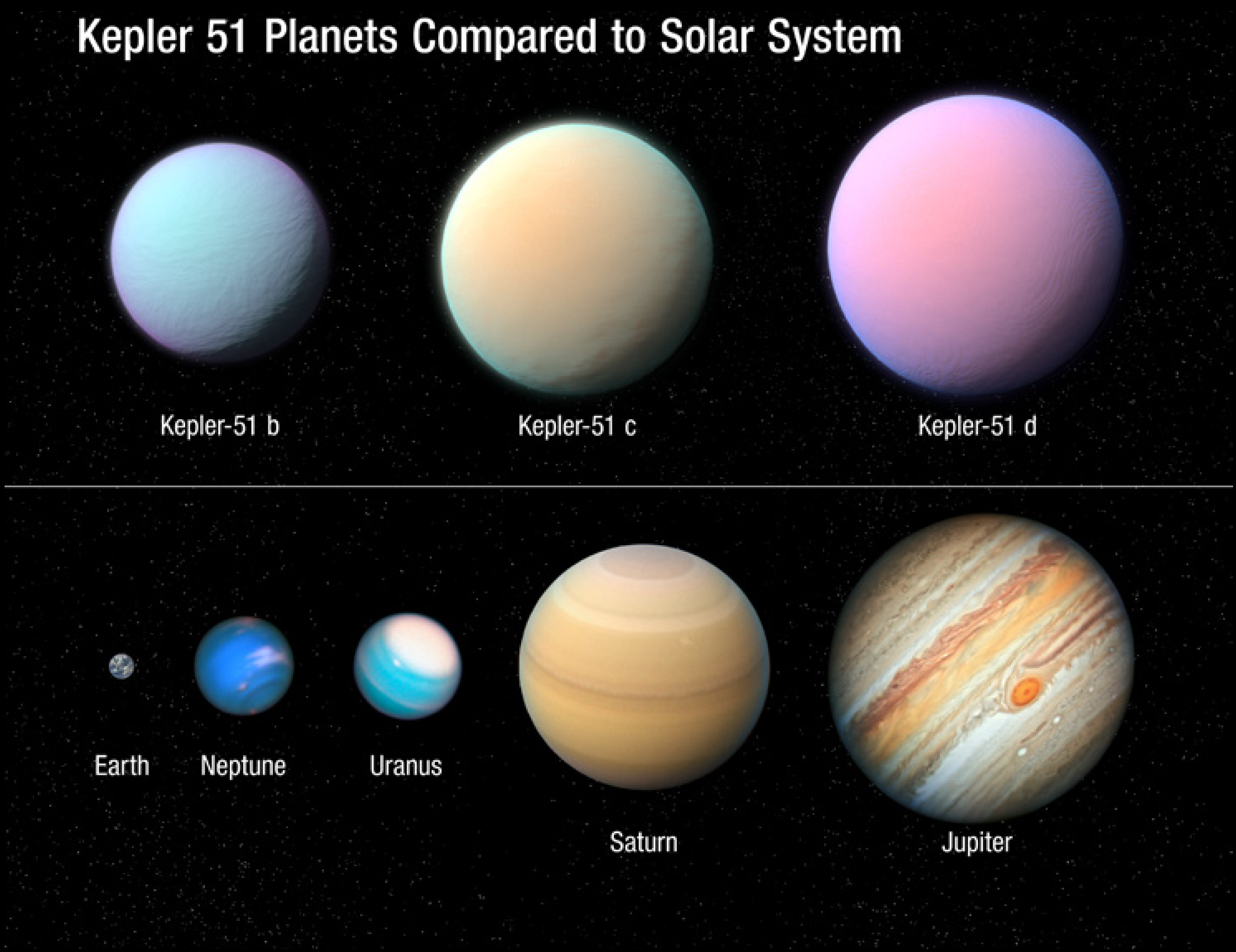


Artist illustrations of the three bloated planets in the Kepler 51 system are compared to photos of worlds in our solar system to show their relative sizes. While the Kepler 51 planets are around Jupiter's size, they are one hundred times less massive. Astronomers using *Hubble* confirmed their puffy nature, which may indicate that they formed farther from their star and then migrated inward. Now much closer to their host star, their low-density atmospheres will likely evaporate into space over the next few billion years.

Credit: NASA, ESA, and L. Hustak, and J. Olmsted (STScI)

Tracking an Exiled Exoplanet's Far-Flung Orbit

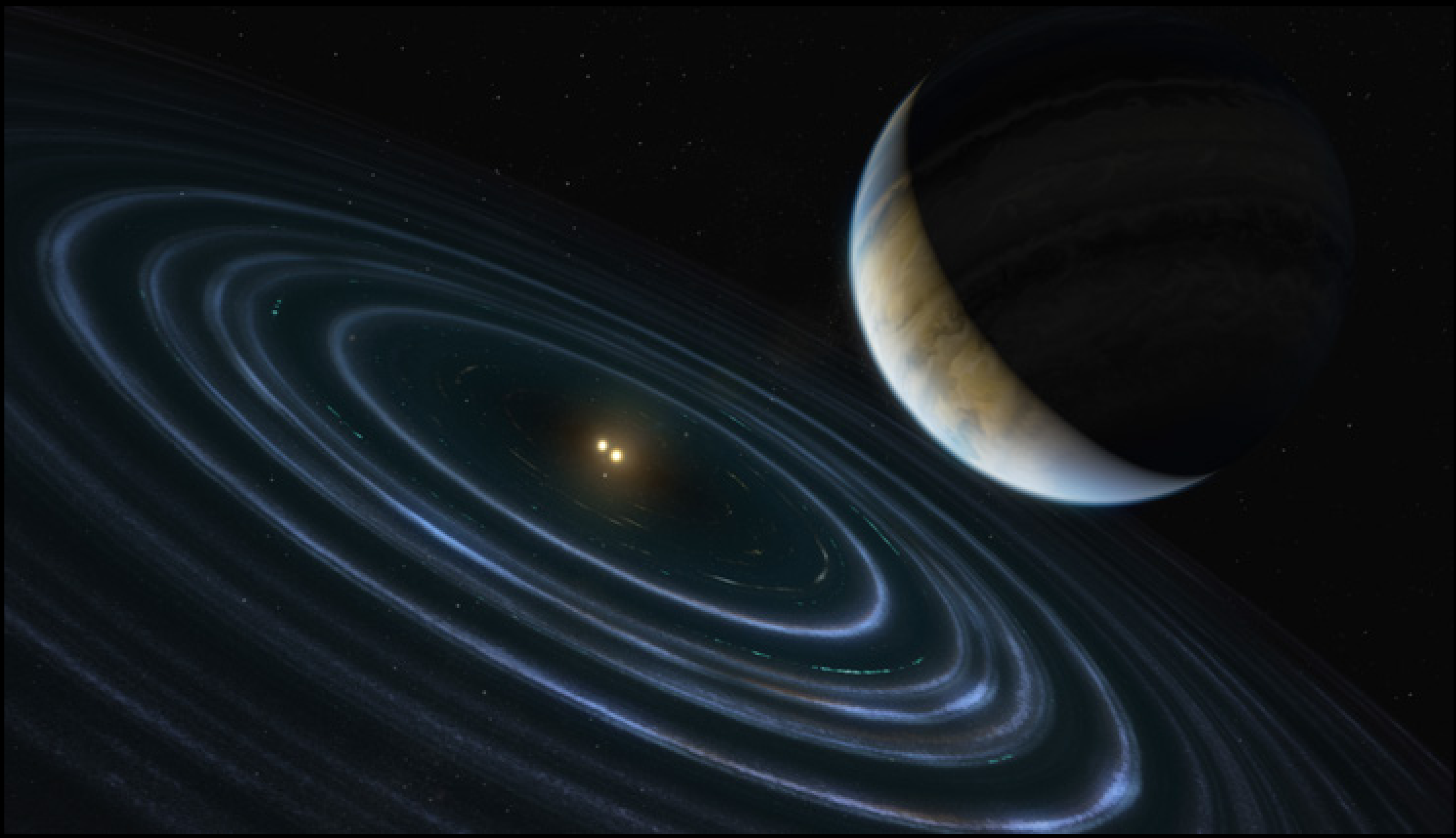
Nearly all of the currently known exoplanets orbit closer to their host stars than Earth orbits the Sun. But *Hubble* has revealed that a giant world called HD 106906 b circles its two host stars in a gigantic 15,000-year-long orbit. Its path is very elongated and tilted with respect to the disk of debris encircling the host stars, hinting that the world's current location may be a result of a game of planetary pinball that transported it from a much closer original position.

"It's as if we have a time machine for our own planetary system."

Paul Kalas, University of California

Astronomers discovered HD 106906 b using the Magellan Telescopes in Chile, but learning about its orbit required something only *Hubble* could do: track the vagabond's motion with extreme precision across more than a decade. A team of researchers mined *Hubble*'s archive for this data, marking the first time astronomers were able to measure the motion of a massive planet that is orbiting very far away from its host stars and visible debris disk. The prevailing theory to explain the planet's strange orbit is that it formed much closer to its host stars, but the drag from the system's gas disk caused the planet's orbit to decay, forcing it to migrate inward. Then the host stars' gravity nearly slingshot the planet out of the system, but a passing star stabilized the planet in a new, enormous orbit. Astronomers have identified candidate passing stars using the European Space Agency's Gaia satellite.

The strange planetary system offers insight into what may have happened in our own solar system billions of years ago. Circumstantial evidence suggests that a planet with five times Earth's mass, dubbed Planet Nine, may be lurking in the outskirts of our solar system beyond Pluto's orbit. Though the search for Planet Nine continues, HD 106906 b is evidence that such oddball orbits are possible.



About 336 light-years away, a planet called HD 106906 b—shown in this illustration—circles a pair of host stars in an unlikely orbit. *Hubble* revealed that the world orbits its stars at a distance of about 68 billion miles, more than 700 times farther than Earth is from the Sun. This observation could offer clues about a hypothesized distant member of our solar system, dubbed Planet Nine. The HD 106906 system is only 15 million years old, suggesting that our Planet Nine—if it does exist—could have formed very early on in the evolution of our 4.6-billion-year-old solar system.

Credit: NASA, ESA, M. Kornmesser (ESA/Hubble)

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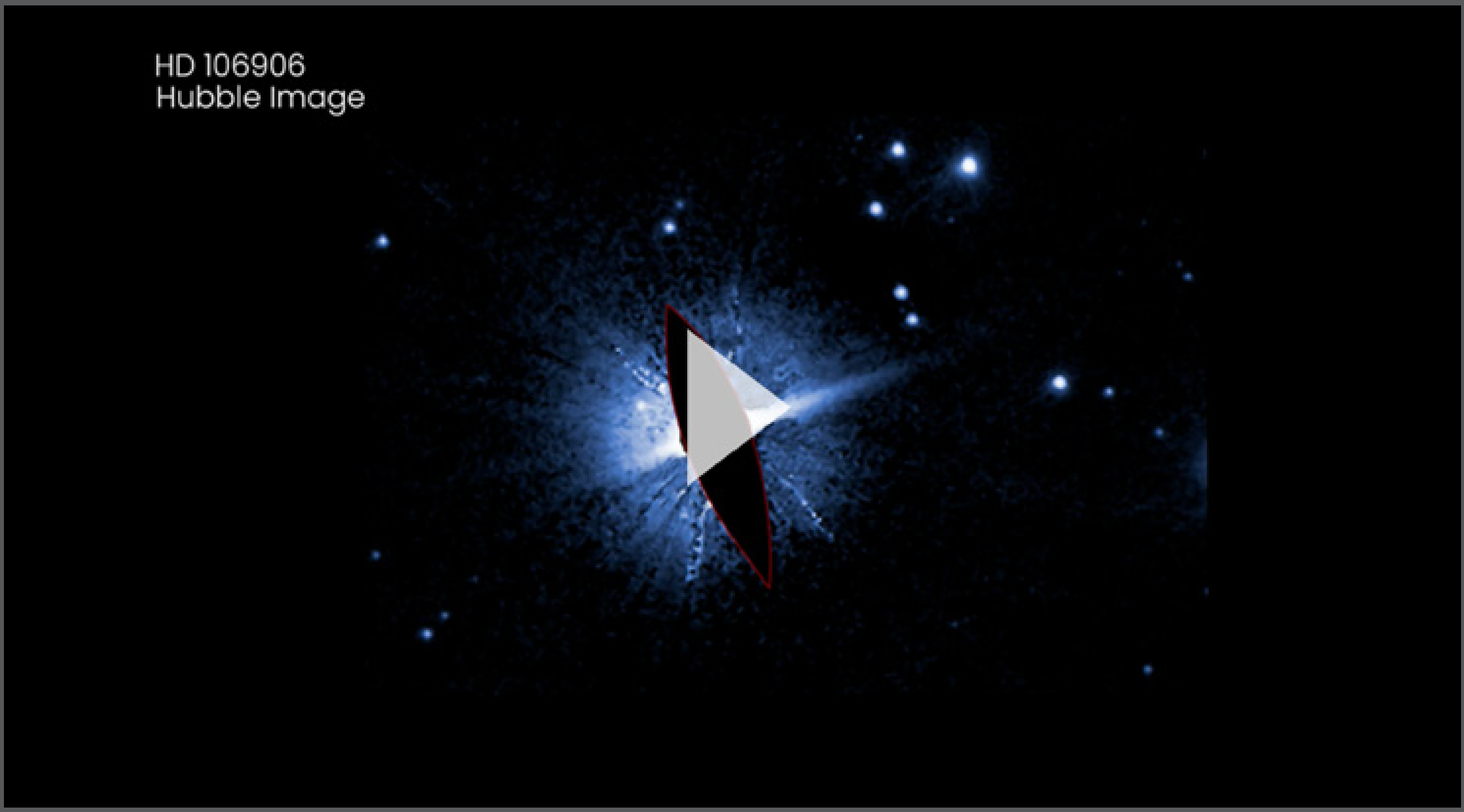


This video simulates a possible orbit for the vagabond planet HD 106906 b, showing its skewed, elongated path. *Hubble* masked light from the system's central twin stars to reveal the surrounding debris disk, which is akin to our own Kuiper Belt, and the orbiting planet. HD 106906 b's enormous orbit is evidence that other planets may occupy similarly large orbits, including the hypothesized Planet Nine in our own solar system.

Credit: NASA, ESA, P. Kalas (University of California, Berkeley and SETI Institute), and J. DePasquale (STScI)

Revealing a Volcanic World that May Be on its Second Atmosphere

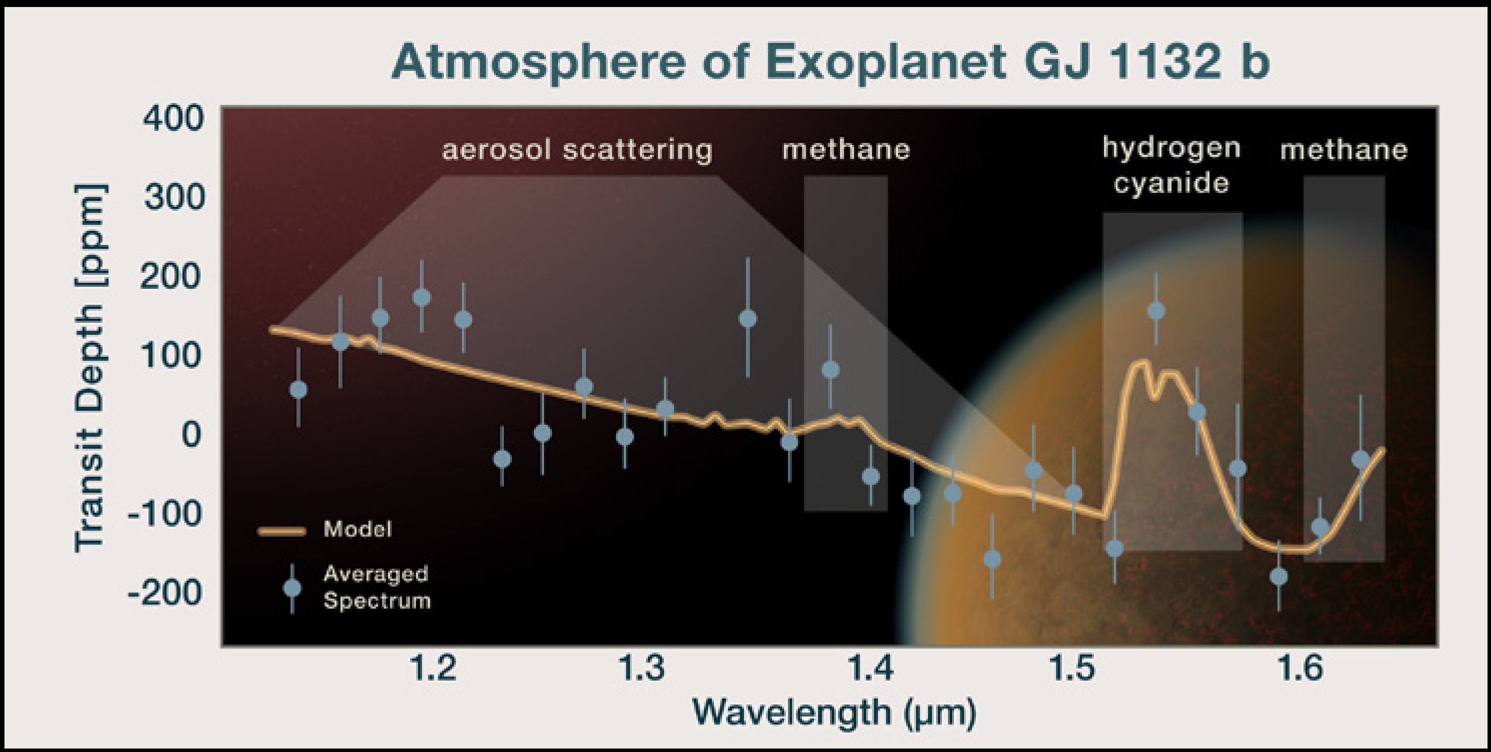
Hubble's vast data archive contains untold treasures waiting to be mined. One such treasure was uncovered by astronomers who were exploring small planets that have lost their atmospheres. The rocky world GJ 1132 b, located just 41 light-years from Earth, stood out because its spectrum showed that it does have an atmosphere—a toxic haze of hydrogen, methane, and hydrogen cyanide.

"We believe the atmosphere that we see now was regenerated."

Raissa Estrela, NASA's Jet Propulsion Lab

Its composition hints that it is not GJ 1132 b's original atmosphere, which was likely blasted away by radiation from the planet's host star. Researchers think the planet's new atmosphere is continuously replenished as molten lava oozes up through volcanic fissures. Gas seeps through the cracks and into the sky in a process called outgassing, and eventually escapes to space. Astronomers had never found a secondary atmosphere on an exoplanet before. This discovery could indicate that similar worlds may have detectable atmospheres as well.

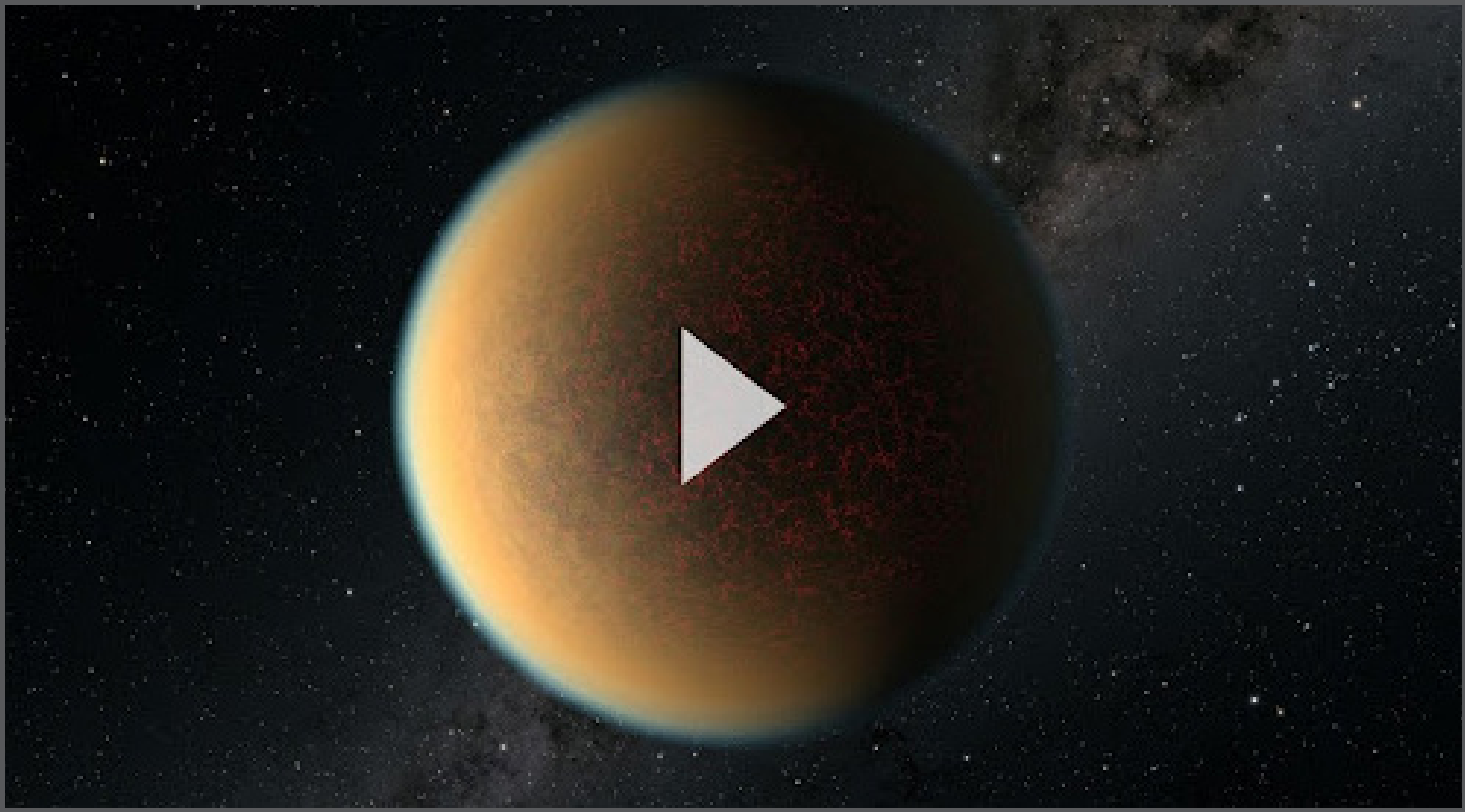
The key to GJ 1132 b's atmosphere is volcanic activity, which scientists think occurs on this planet because it orbits so close to its star that it experiences extreme tidal heating. This phenomenon is similar to Earth's ocean tides, which rise and fall each day because of the Moon's gravitational pull on Earth. Since GJ 1132 b and its star are far more massive than the Moon and Earth, the effect is much more exaggerated. All of the stretching and pulling the planet experiences as it orbits the star creates enormous amounts of friction, which heats the planet's interior and makes volcanism and outgassing possible. Jupiter's volcanically active moon Io experiences the same phenomenon due to the giant planet's gravity. Future observations by the *James Webb Space Telescope* may allow scientists to see down to the planet's surface. The mission's infrared vision could spot volcanic areas since they will be hotter than their surroundings.



This plot shows the model atmospheric spectrum (orange line) scientists made using data points from GJ 1132 b's observed spectrum (blue dots with error bars). The planet wasn't expected to have a detectable atmosphere, but its spectrum suggests that it consists primarily of hydrogen with notes of methane, hydrogen cyanide, and aerosols. Scientists think this analysis marks the first discovery of an exoplanet's secondary atmosphere, which was replenished after the planet lost its original atmosphere.

Credit: NASA, ESA, Pam Jeffries (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2021/news-2021-013



Scientists using *Hubble* have found evidence that a planet orbiting a distant star may have lost its atmosphere but gained a second one through volcanic activity. The planet, GJ 1132 b, is hypothesized to have begun as a gaseous world with a thick hydrogen blanket of atmosphere. Starting out at several times the diameter of Earth, this so-called “sub-Neptune” is believed to have quickly lost its primordial hydrogen and helium atmosphere due to the intense radiation of the hot, young star it orbits. In a short period of time, such a planet would be stripped down to a bare core about the size of Earth. That’s when things got interesting.

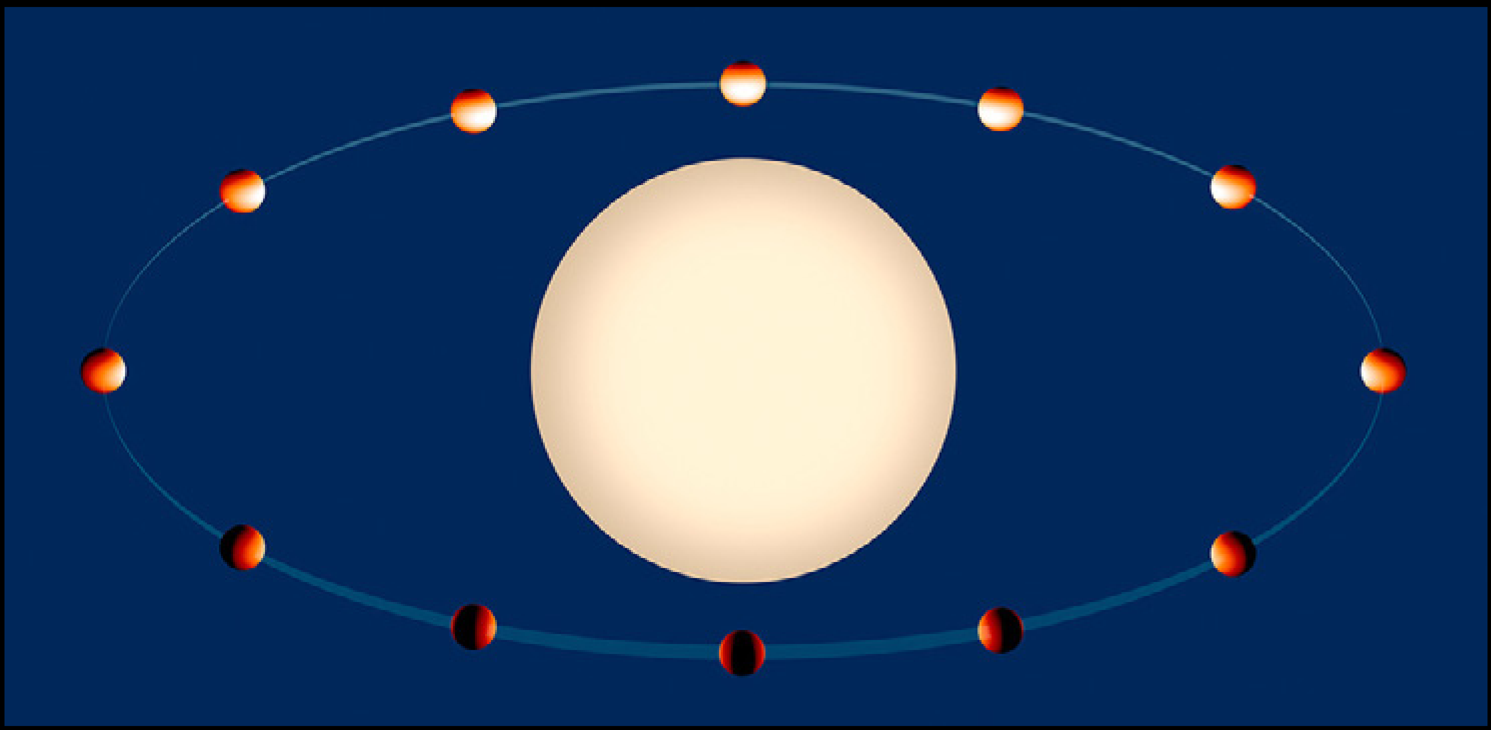
Credit: NASA Goddard Space Flight Center

CHAPTER 3: Alien Weather

Earth exhibits a wide range of weather, from rolling thunderstorms to sunny skies to blizzards. Thanks to *Hubble*, astronomers have also monitored the weather on our neighboring worlds, revealing sulfuric acid rain on Venus, cloudy skies on Uranus, storms on Neptune, and more. But *Hubble*'s exoplanet observations have unveiled even more exotic weather.

Astronomers used *Hubble* and the Magellan II Telescope to study WASP-79b, a hot Jupiter with a blazing atmosphere that is so hot that its scattered clouds might rain molten iron. The researchers also found that the planet does not experience the same blue light scattering effect that we see on Earth. Instead, they saw the opposite effect, which likely means the planet's skies appear yellowish instead of blue. In another study, *Hubble* revealed stark differences between two "cousin" hot Jupiters. While the planets are similar in several respects, researchers were surprised to learn that one is very cloudy while the other has clear skies. Perhaps most startling of all, *Hubble* has also revealed a world that snows sunscreen on the planet's permanent nighttime side. The discovery marked the first time astronomers detected this precipitation process, called a cold trap, on an exoplanet.

Hubble's exoplanet observations complement those of other telescopes, which sometimes follow up on its findings to provide additional data. Further studies will yield clues about how different planets form and what drives their weather activity.



Rain, snow, sunny skies—exoplanets can experience weather just like Earth does, sometimes with their own strange twists. Some planets, like WASP-43b, shown above, feature extreme temperatures and winds because they orbit so close to their host stars. Others are home to toxic rain and snow due in part to their bizarre atmospheres. *Hubble* continues to help us study alien weather to learn more about the worlds that populate our galaxy.

Credit: NASA, ESA, and Z. Levay (STScI)

Using a Super-Jupiter's Cloudy Skies to Measure its Rotation Rate

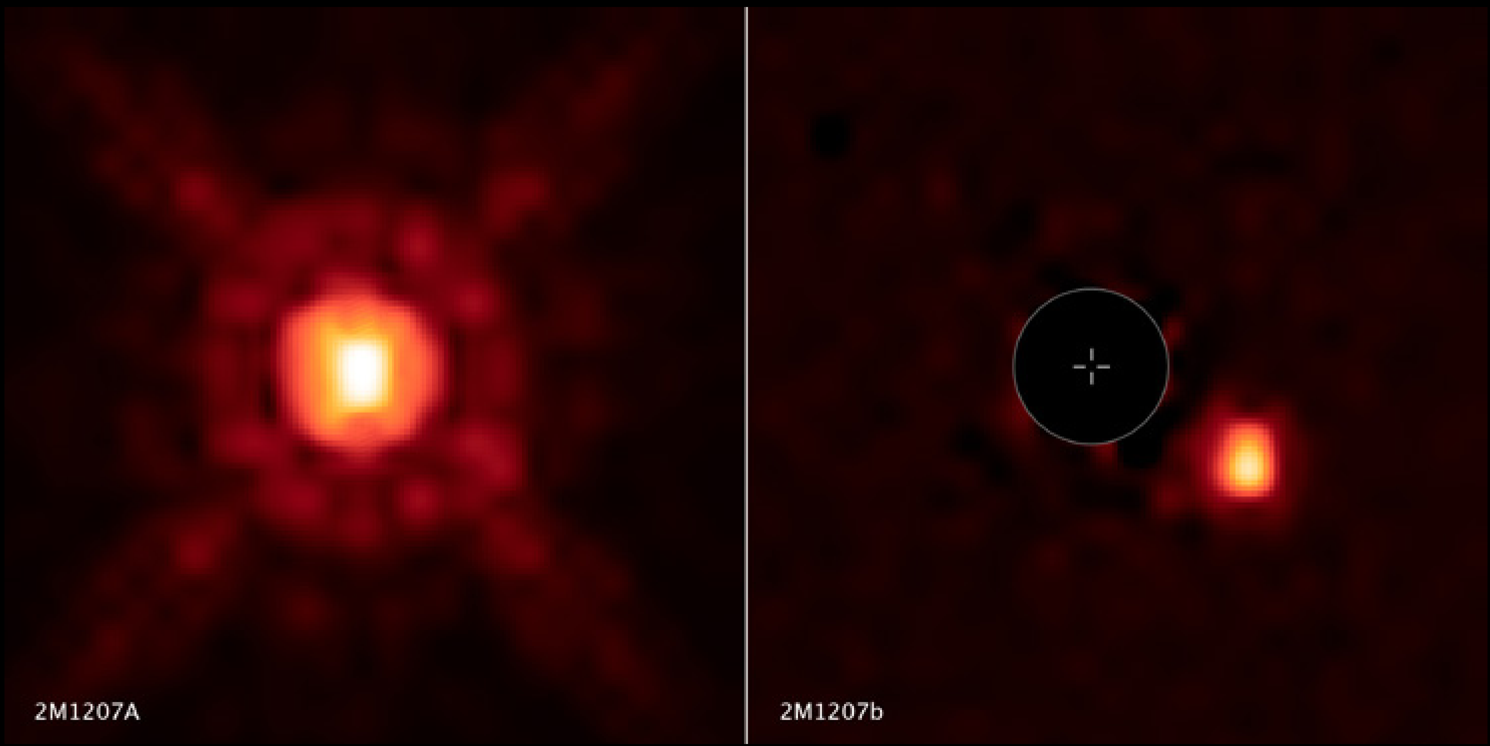
Measuring the length of a day on our neighboring world Mars was relatively simple. Using a telescope, Dutch astronomer Christiaan Huygens spotted a dark splotch on the red planet's surface and tracked how much time it took for the feature to return to the same position. Around 350 years later, a team of scientists used a similar method but a far more powerful instrument—the *Hubble Space Telescope*—to make the first direct measurement of an exoplanet's rotation rate, thanks to its cloudy skies.

"This result gives us a unique technique to explore the atmospheres of exoplanets and measure their rotation rates."

Daniel Apai, University of Arizona

Astronomers previously used *Hubble* to observe the planet, dubbed 2M1207b, and discovered that it rains glass high in the atmosphere and molten iron at lower altitudes. The bizarre world is located about 170 light-years from Earth and orbits a brown dwarf—a so-called failed star, which is not massive enough to power itself by nuclear fusion the way stars do. Since the brown dwarf is so dim and far from the planet, astronomers more recently used *Hubble* to observe 2M1207b directly. The planet is so young that it is still hot as it contracts under gravity, making it glow in infrared light. Using *Hubble*'s infrared vision, astronomers saw that the planet rhythmically flickers as it spins on its axis like a top. The subtle changes in the planet's brightness are likely due to a variegated cloud cover of comparatively bright and dark patches.

Based on their observations, astronomers estimate the gaseous world completes one rotation approximately every 10 hours, which happens to be nearly the same as Jupiter's rotation rate. The *James Webb Space Telescope* will help astronomers better determine 2M1207b's atmospheric composition and derive detailed maps from brightness changes with the new technique demonstrated by *Hubble*'s observations.



This image shows the brown dwarf 2M1207A (left) and an orbiting planet, 2M1207b (right). Planets are usually difficult to see directly because their host stars tend to be so bright that orbiting planets are lost in the glare. But 2M1207b glows brightly in infrared light since it is so young and hot while 2M1207A is quite dim since it doesn't shine like stars do. Astronomers using *Hubble* blocked the brown dwarf's light to see 2M1207b directly and measured fluctuations in the planet's brightness. This suggests the planet has patchy clouds that appear to flicker as the planet spins.

Credit: NASA, ESA, and Y. Zhou (University of Arizona)

Learn more: https://hubblesite.org/contents/news-releases/2016/news-2016-05.html

This artist's illustration features the super-Jupiter planet 2M1207b in the foreground and its parent brown dwarf in the background. The planet orbits at a distance of about five billion miles—nearly twice as far as Neptune is from the Sun. Because the planet is only 10 million years old, it is so hot it may rain molten glass and iron in its atmosphere. *Hubble* has measured fluctuations in the planet's brightness that suggests the planet has patchy clouds as it completes one rotation every 10 hours.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

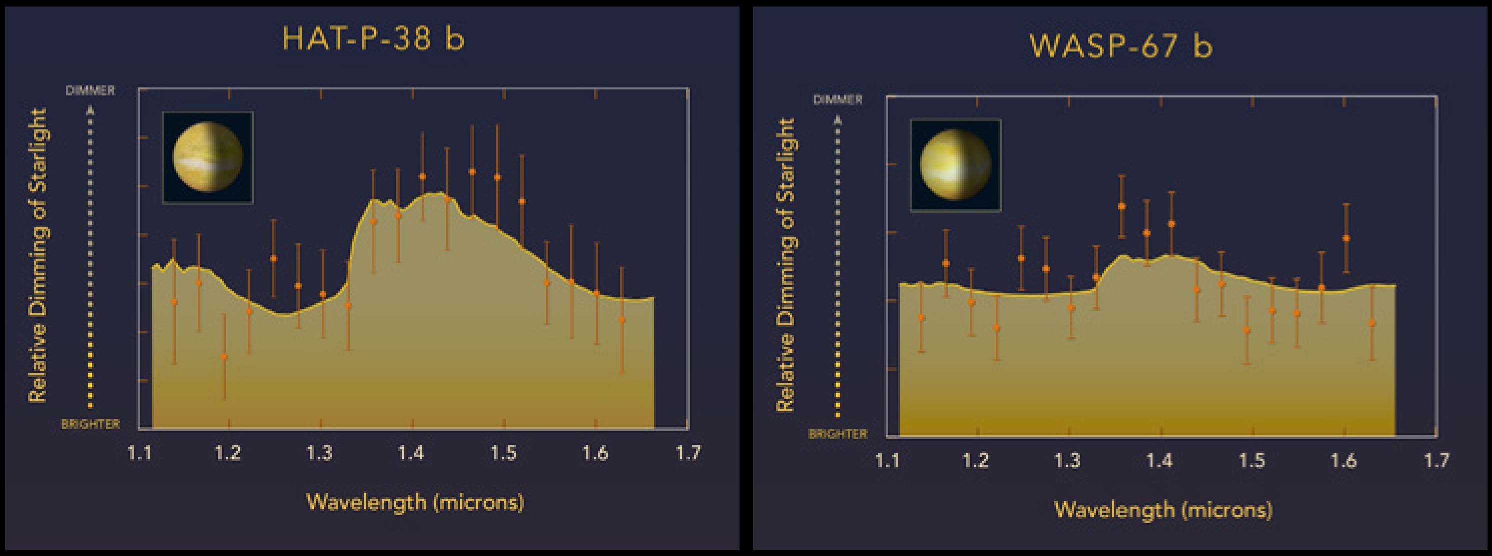
Forecasting Opposite Weather on 'Cousin' Hot Jupiters

Most of the first few hundred exoplanets astronomers discovered were hot Jupiters—wild worlds that are vastly different from those in our solar system. Recent *Hubble* results show that there is great diversity among hot Jupiters; while some have sunny skies, others are covered in thick blankets of clouds.

"We don't see what we're expecting with these planets, and we need to understand why."

Giovanni Bruno, Space Telescope Science Institute

Researchers used *Hubble* to study two remarkably similar planets: WASP-67 b and HAT-P-38 b. While they are nearly the same temperature and size, and orbit very similar host stars at the same distance, their atmospheres could hardly be more different. The researchers used *Hubble* to search for spectral signs of water by analyzing how starlight filtered through the planets' atmospheres. Since WASP-67 b's spectrum lacks water signatures, the team concluded that the planet is bland-looking with a high cloud deck. But they did find spectral fingerprints of water in HAT-P-38 b's atmosphere, indicating that the planet must have relatively clear skies, which allowed them to see deep into the atmosphere. Since these "cousin" planets have such different atmospheres, scientists think something in their past must have influenced the way they evolved. Further research using *Hubble* and the *James Webb Space Telescope* could offer valuable clues.



This diagram compares *Hubble* observations of two strikingly similar exoplanets: HAT-P-38 b and WASP-67 b. For each of these worlds, astronomers measured how light from the host star filters through the planet's atmosphere. WASP-67 b's spectrum is relatively flat, lacking an absorption feature that indicates that water is present. This suggests that the atmosphere is masked by high-altitude clouds. HAT-P-38 b's spectrum, however, bumps upward in the middle, which means the atmosphere contains water. Scientists interpret this peak as evidence that the upper atmosphere is free of clouds or hazes.

Credit: Artwork: NASA, ESA, and Z. Levy (STScI); Science: NASA, ESA, and G. Bruno (STScI)

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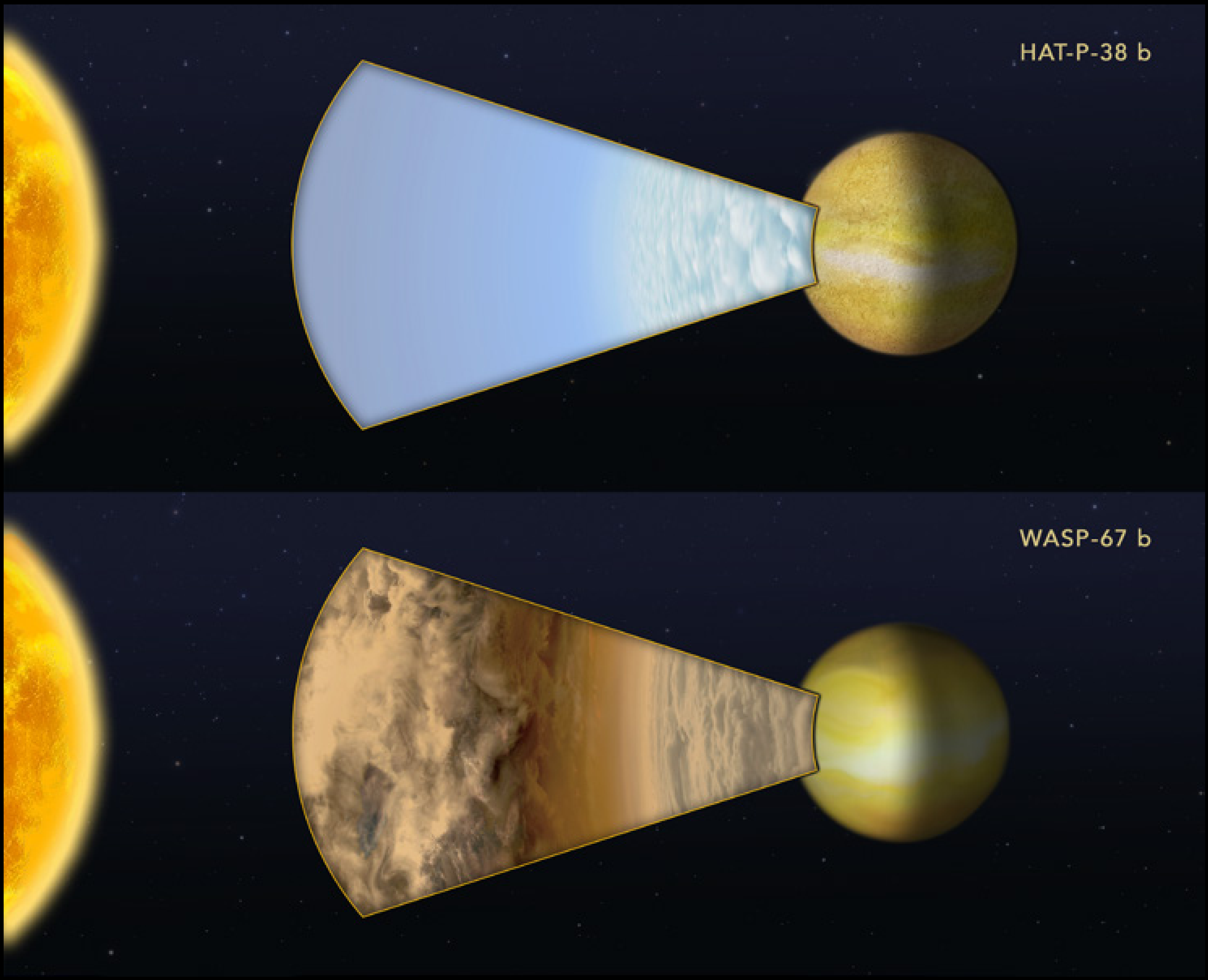


This illustration compares the atmospheres of two hot Jupiters. While they are too far away for *Hubble* to see their atmospheres directly, scientists can infer what they look like by studying the planets' spectra. Since HAT-P-38 b's spectrum shows the presence of water, it likely has relatively clear skies. However, WASP-67 b's spectrum lacks the spectral signature of water, indicating that most of its atmosphere is masked by high-altitude clouds. Future observations could help explain why these planets have such different atmospheres.

Illustration credit: NASA, ESA, and Z. Levy (STScI)

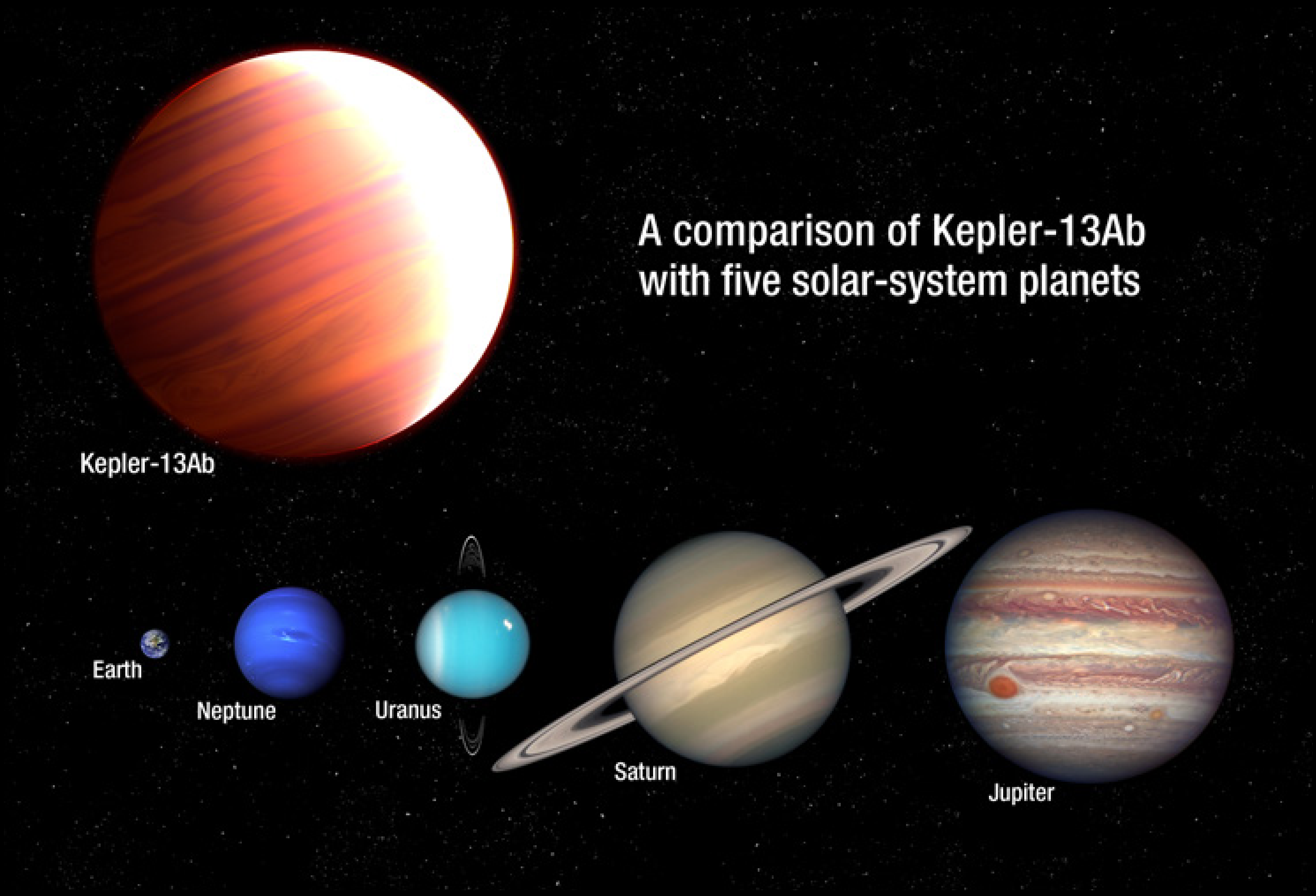
Discovering a World that Snows Sunscreen

Precipitation is extremely common on our planet. But it isn't unique to Earth; some other worlds have their own exotic variations. For example, astronomers using *Hubble* discovered that it snows titanium dioxide—a common ingredient in sunscreen—on the hot Jupiter called Kepler-13Ab—but only on one side of the planet.

> "These studies are testbeds for how we're going to do atmospheric studies on terrestrial, Earth-like planets."
>
> Thomas Beatty, Pennsylvania State University

Kepler-13Ab is tidally locked to its star, which means the same side of the planet always faces the star while the other is trapped in an endless night. Astronomers used *Hubble* to study the planet's atmosphere in near-infrared light as the world passed behind its star, an event called a secondary eclipse. Observing the secondary eclipse allowed astronomers to gather the temperature of atmospheric components on the planet's day side. The researchers found the giant planet's atmosphere is cooler at higher altitudes—the opposite of what they expected.

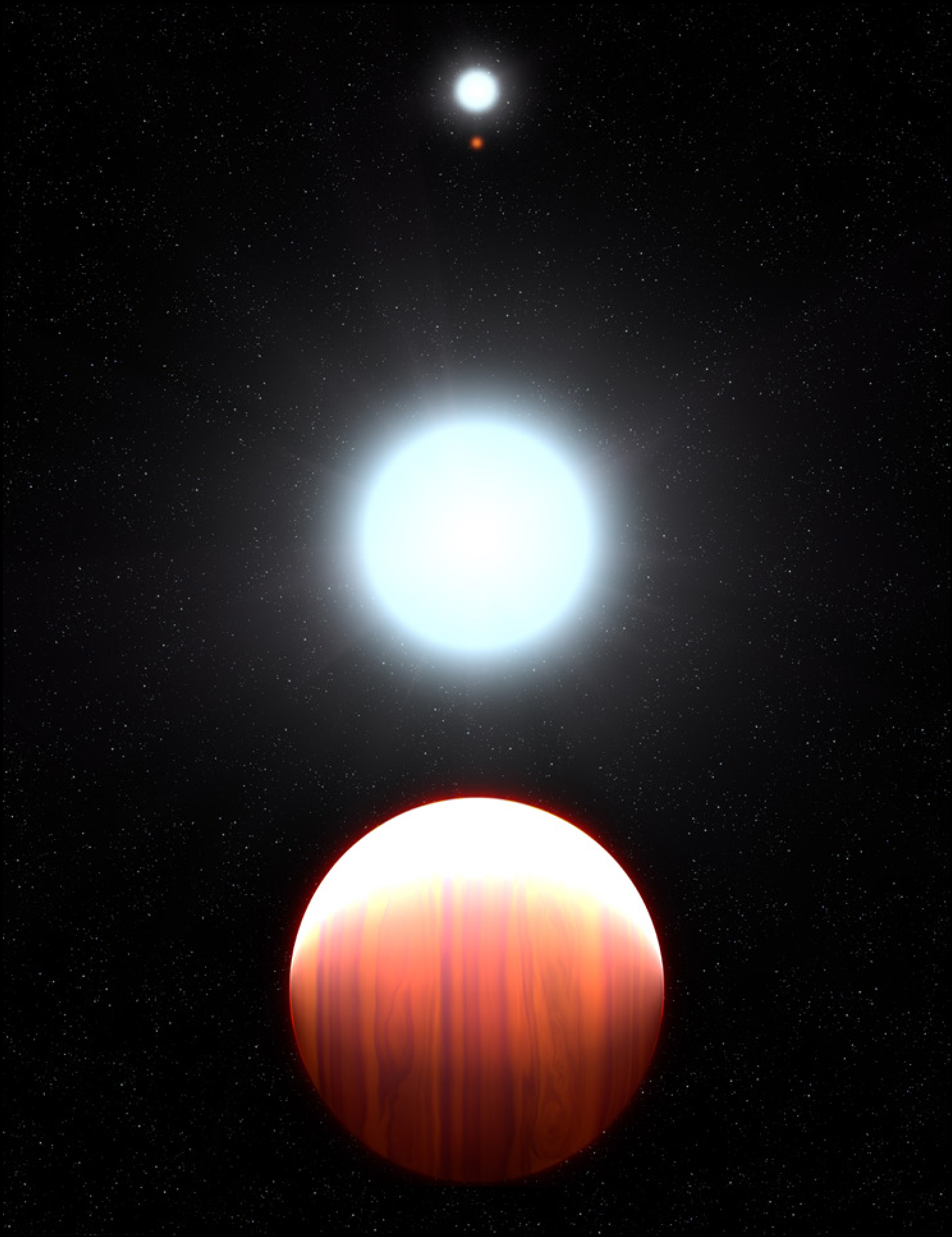
Hot Jupiters typically have a gaseous form of titanium oxide that absorbs light and heats the upper atmosphere. Astronomers think high winds on Kepler-13Ab carry titanium oxide around to the permanently dark side of the planet, where it condenses to form clouds and falls as flurries of titanium *di*oxide. The planet's gravity is so strong that the titanium dioxide can't be recycled back into the upper atmosphere on the planet's day side. Instead, it remains trapped on the night side, leading astronomers to call this precipitation process a "cold trap." These *Hubble* observations marked the first time astronomers detected a cold trap on an exoplanet.



Kepler-13Ab looms large among some of the planets in our solar system in this illustration. Known as a hot Jupiter due to its size and proximity to its star, Kepler-13Ab is one of the hottest known planets with a dayside temperature of nearly 5,000 degrees Fahrenheit. Astronomers used *Hubble* to study the planet's atmosphere and found that it snows sunscreen (titanium dioxide).

Illustration credit: NASA, ESA, and A. Feild (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2017/news-2017-36.html



This illustration shows the scorching hot planet Kepler-13Ab that orbits extremely close to its host star, Kepler-13A, which is part of a multiple star system. The star's companions, Kepler-13B and the small orange dwarf Kepler-13C, are in the background. Astronomers used *Hubble* to study Kepler-13Ab's atmosphere and for the first time they detected a strange precipitation process called a cold trap on an exoplanet. This cold trap produces some wild, sunscreen-snowfall weather on the permanently dark side of the planet.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

Unveiling a Planet with Yellow Skies

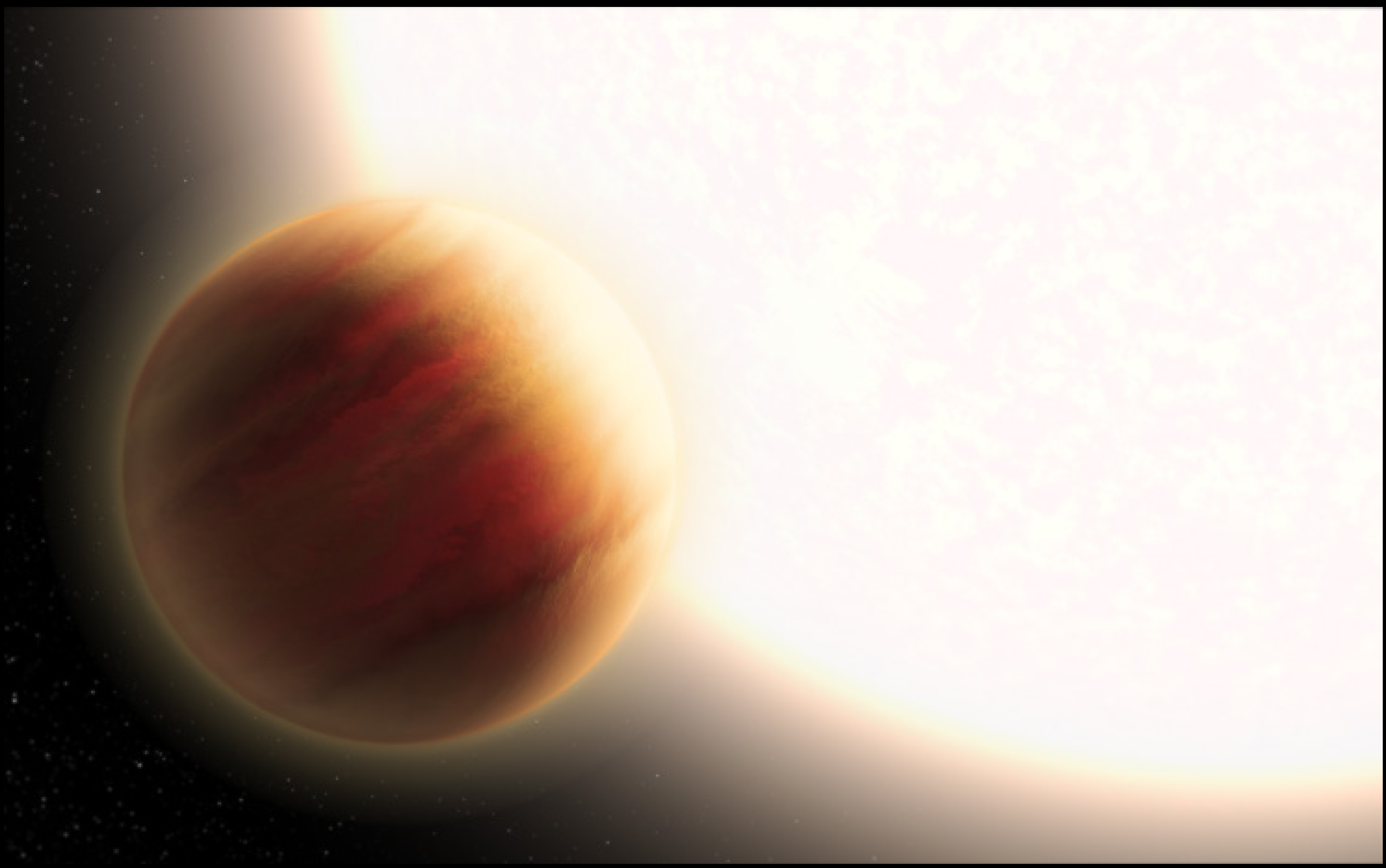
Harnessing the power of multiple telescopes often enables astronomers to learn more than they could otherwise. *Hubble* teamed up with the Magellan Consortium's Magellan II Telescope in Chile to study WASP-79b, a hot Jupiter located about 780 light-years away. The planet's atmosphere is about 3,000 degrees Fahrenheit, which is so hot that its scattered manganese sulfide or silicate clouds might rain molten iron. While that may seem startling, the real surprise for astronomers was that the planet's sky isn't blue.

"This is a strong indication of an unknown atmospheric process that we're just not accounting for in our physical models."

Kristin Showalter Sotzen, the Johns Hopkins University Applied Physics Laboratory

Earth owes its azure skies to Rayleigh scattering, a phenomenon where very fine dust particles in the upper atmosphere disperse shorter, bluer wavelengths of light. Astronomers combined *Hubble* and Magellan observations to find that WASP-79b does not experience Rayleigh scattering. Instead, they saw the opposite effect—shorter wavelengths of light appear to be more transparent. Researchers are not sure what atmospheric processes may be causing it, but the result is that the planet's skies likely appear yellowish instead of blue. These findings support independent observations by the *Transiting Exoplanet Survey Satellite* (*TESS*).

The water vapor *Hubble* spotted in WASP-79b's atmosphere designated it as a prime target for the *James Webb Space Telescope*. *Webb*'s observations will provide a detailed view of the planet's chemical makeup, which could yield clues about how its atmosphere has evolved and perhaps reveal the secret behind its amber skies.



The steamy world in this illustration, WASP-79b, orbits its host star in just 3.5 days. But its orbit brings the planet around the star's poles instead of the equator, defying planetary formation theories. Astronomers used *Hubble* and the Magellan II Telescope to study the strange world and found even more surprises—its sky is likely yellowish instead of blue.

Illustration credit: NASA, ESA, and L. Hustak (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2020/news-2020-18

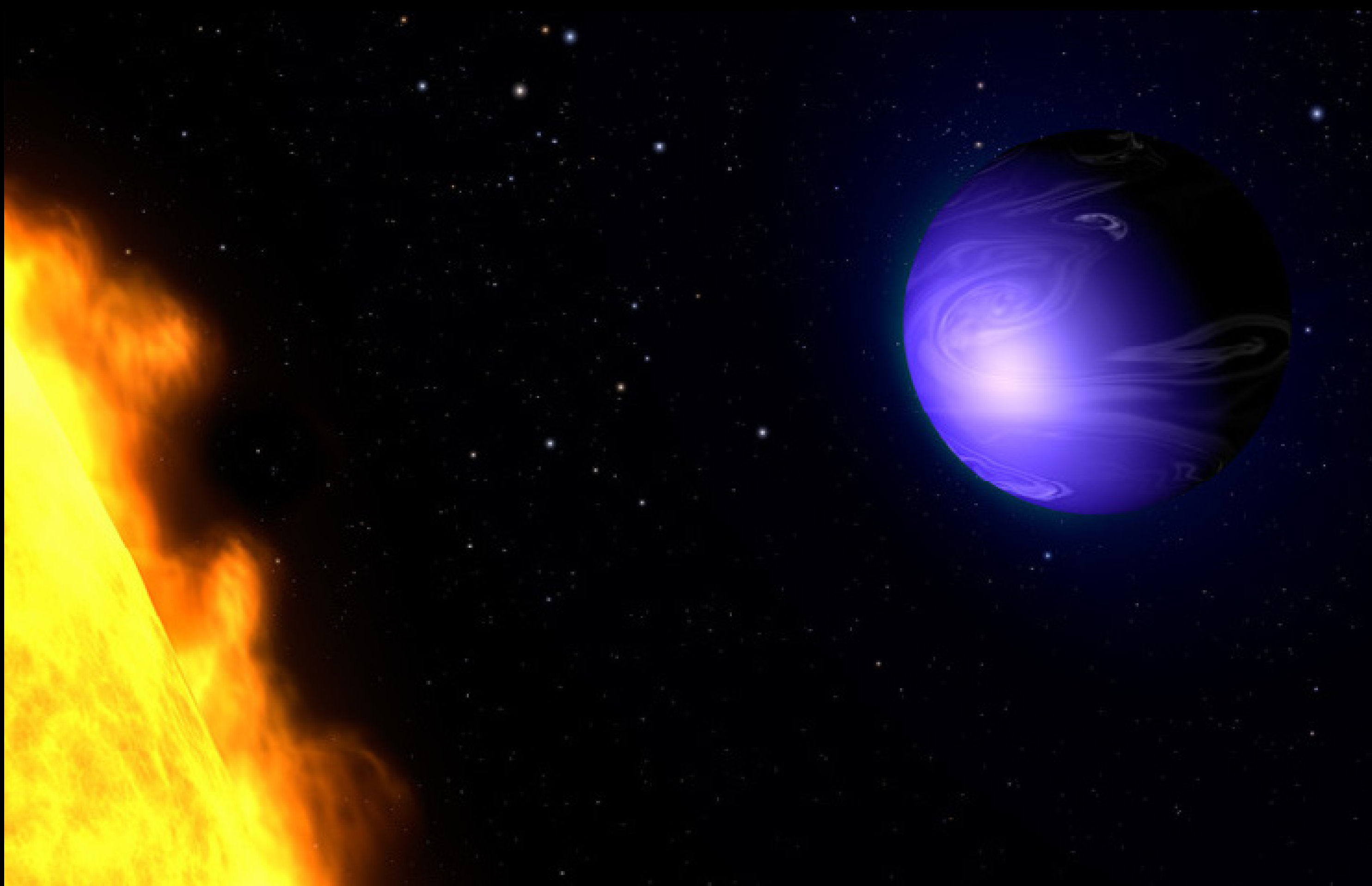
CHAPTER 4: Planet-Star Relationships

To learn as much as we can about planets throughout our galaxy, astronomers must consider the relationship between these worlds and their host stars. If our own host star, the Sun, were just a little hotter or colder, or if it were much older or younger, Earth might not be habitable. *Hubble* has helped astronomers explore what other planetary systems are like, offering clues to how they may evolve and informing our search for habitable worlds.

Using *Hubble*, astronomers brought a little piece of science-fiction to life by confirming that a world like Luke Skywalker's home planet Tatooine—a world with two suns—actually exists. The planet was discovered using a ground-based telescope, but astronomers needed *Hubble*'s crisp resolution to distinguish both of the small, faint host stars.

Hubble has also studied different types of stars to explore which are most conducive to life. Astronomers used the telescope to study small, red stars and found that they are extremely violent when they are young. Another study revealed that rocky worlds orbiting red dwarfs may be bone dry and lifeless. Water and organic compounds, essential for life as we know it, may get blown away before they can reach the surface of young planets.

While Sun-like stars may be the most obvious targets to search for habitable planets, *Hubble* revealed that orange dwarfs—smaller and cooler than our yellow-white Sun, but larger and hotter than red dwarfs—could offer better chances. These stars are not too hot, too cool, or too violent to host life-friendly planets over vast stretches of cosmic time. *Hubble*'s future observations will continue to help us focus our search for habitable worlds, bringing us ever closer to the possibility of finding life on other planets.



Stars and planets often have intricate relationships. The system shown here features a planet, called HD 189733b, that is tidally locked to its star—one side always faces the star, while the other is always dark. *Hubble* has revealed that stars can have even more extreme effects on orbiting worlds, sometimes blasting planetary atmospheres away and rendering entire worlds uninhabitable.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

Pinpointing a Planet with Two Suns

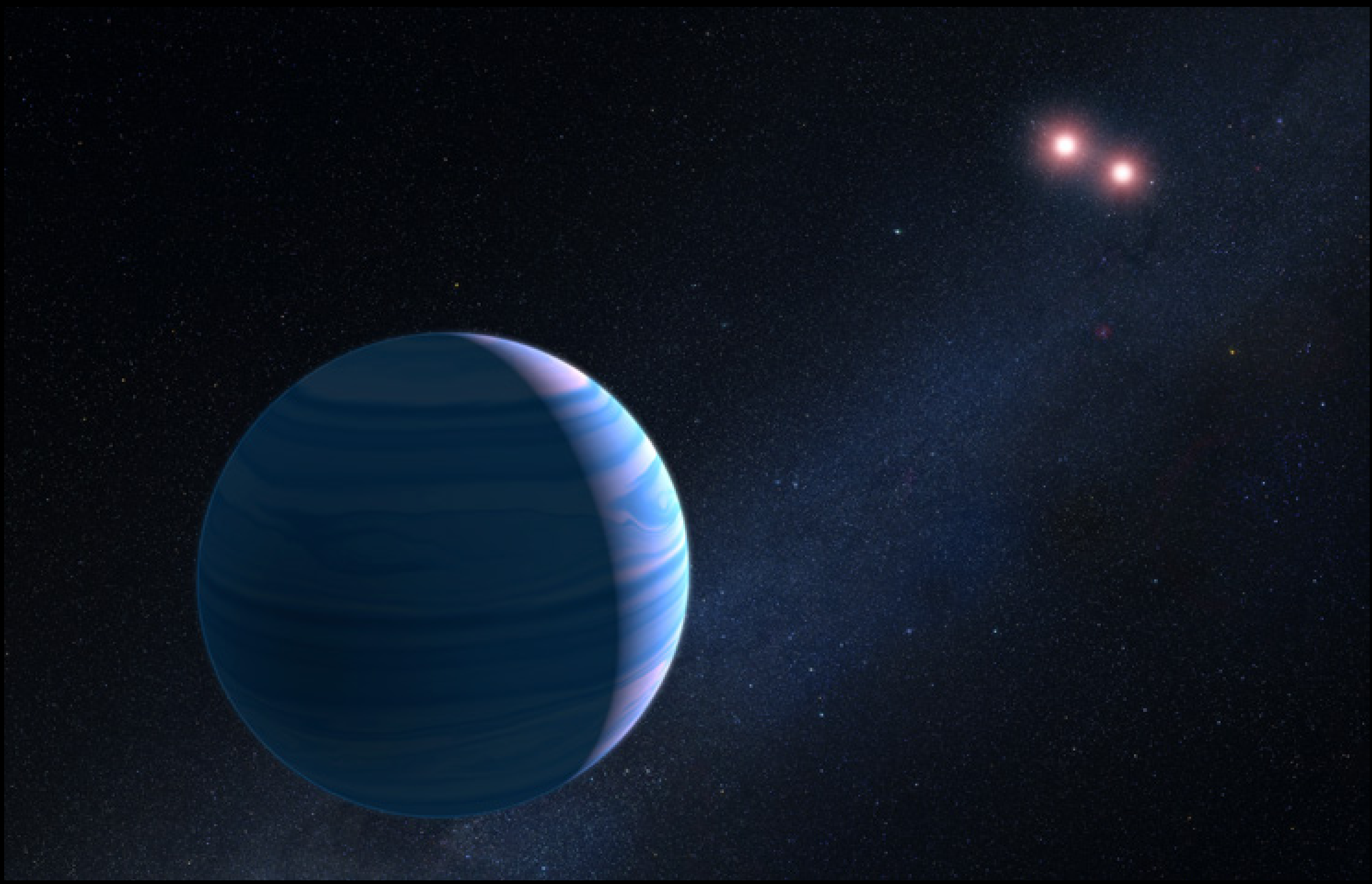
Astronomers using *Hubble* confirmed that a world like Luke Skywalker's home planet Tatooine is located 8,000 light-years from Earth. The planet, known as OGLE-2007-BLG-349L(AB)c, orbits a pair of small, faint stars. Scientists have known such worlds, called circumbinary planets, exist since the first one was discovered in 2011. However, this was the first to be confirmed using a quirk of gravity called microlensing.

"We needed *Hubble*'s crisp resolution to tease out the identities of the members of this planetary system."

David Bennett, NASA Goddard Space Flight Center

When two stars closely align from our vantage point, the gravity of the nearer star can bend, or "lens," the light from the farther star. Astronomers see this effect as a temporary increase in the distant star's brightness. Planets orbiting the nearer star can also create a detectable effect, changing the pattern of the lensed light. The planet OGLE-2007-BLG-349L(AB)c was originally detected by a collaboration of five different observing teams using the microlensing method, but it was unclear whether the system contained one planet orbiting two stars or a pair of planets orbiting a single star. The data revealed that the mass of the star or stars in the system totaled 70% of the Sun's mass.

Ultra-sharp *Hubble* images settled the mystery, confirming that the Saturn-mass planet is circling two stars in a tight orbit around each other. The diminutive stars are only 40% and 30% of the Sun's mass, respectively. Scientists came to this conclusion because a single star that is 70% of the Sun's mass would be much brighter than two smaller stars, even if they add up to the same combined mass. The system, collectively called OGLE-2007-BLG-349, aligned nearly perfectly with a background star, which allowed astronomers to determine such detailed properties.



This artist's illustration shows the planetary system known as OGLE-2007-BLG-349. The identities of the members of this system were unclear from ground-based observations. *Hubble*'s high-resolution follow-up observations revealed that the system contains a gaseous, Saturn-mass planet orbiting two red dwarf stars.

Illustration credit: NASA, ESA, and G. Bacon (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2016/news-2016-32.html

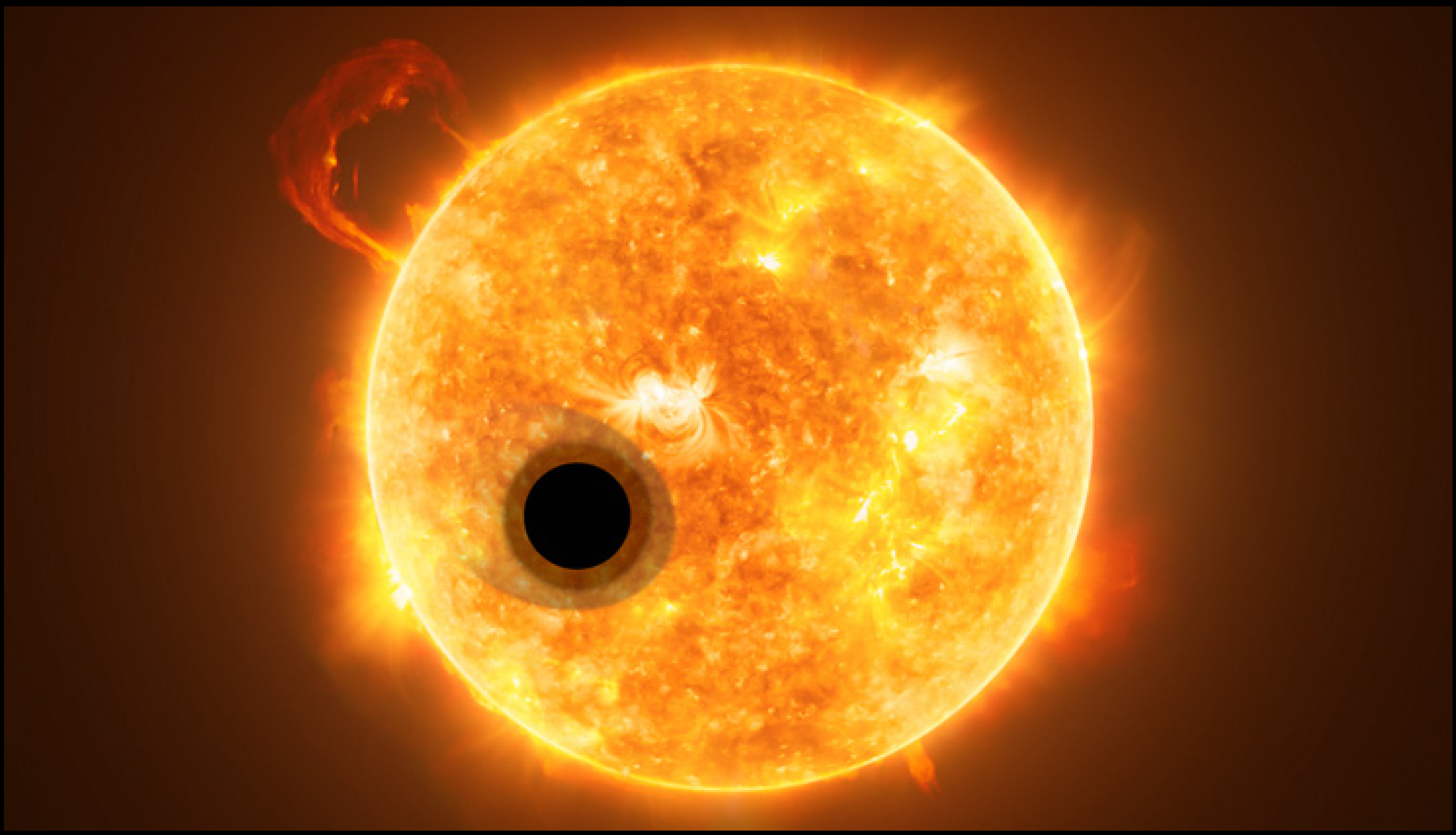
Seeing a Star Sweep Helium from a Planet's Bloated Atmosphere

About 200 light-years from Earth, a windy world called WASP-107b orbits a turbulent star. Scientists using *Hubble* observed the system and found that the star is blasting helium out of the planet's upper atmosphere. This discovery marked the first time astronomers detected helium in an exoplanet's atmosphere.

> "This new technique may help us detect atmospheres around Earth-sized exoplanets, which is very difficult with current technology."
>
> Jessica Spake, University of Exeter

Scientists originally thought helium would be one of the most readily-detectable gases on giant exoplanets, especially because it is the second-most common element in the universe after hydrogen. However, decades of searching exoplanets for the element came up empty. It took *Hubble*'s infrared vision to spectroscopically tease out the element's presence in WASP-107b's atmosphere. When the planet passed in front of its star, *Hubble* detected helium's fingerprints in the starlight filtered through WASP-107b's atmosphere. Based on how much helium they found, astronomers think the planet's atmosphere must stretch tens of thousands of miles into space. The host star's strong radiation and stellar winds are blasting the world's atmospheric gases away at a significant rate, totaling between .1-4% of the atmosphere's total mass every billion years. As a result, the planet leaves a trail of material in its wake as it makes its six-day orbit around its star.

Astronomers had never discovered an exoplanet's extended atmosphere using infrared spectroscopy before, relying instead on ultraviolet and optical wavelengths of light. Using infrared vision extends such studies to a wider range of planets, including ones that orbit farther from their host stars. Future telescopes, such as the *James Webb Space Telescope*, will use this new method to analyze exoplanet atmospheres in far greater detail than ever before.



The planet WASP-107b crosses in front of the face of its tempestuous host star in this artist's illustration. The same size as Jupiter but only 12% of Jupiter's mass, WASP-107b is one of the lowest density planets astronomers have discovered. Using infrared spectroscopy, scientists using *Hubble* found helium the host star is blasting out of the planet's atmosphere.

Credit: ESA/Hubble, NASA, and M. Kornmesser

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-26.html

Revealing that Small, Red Stars May Hinder Habitability

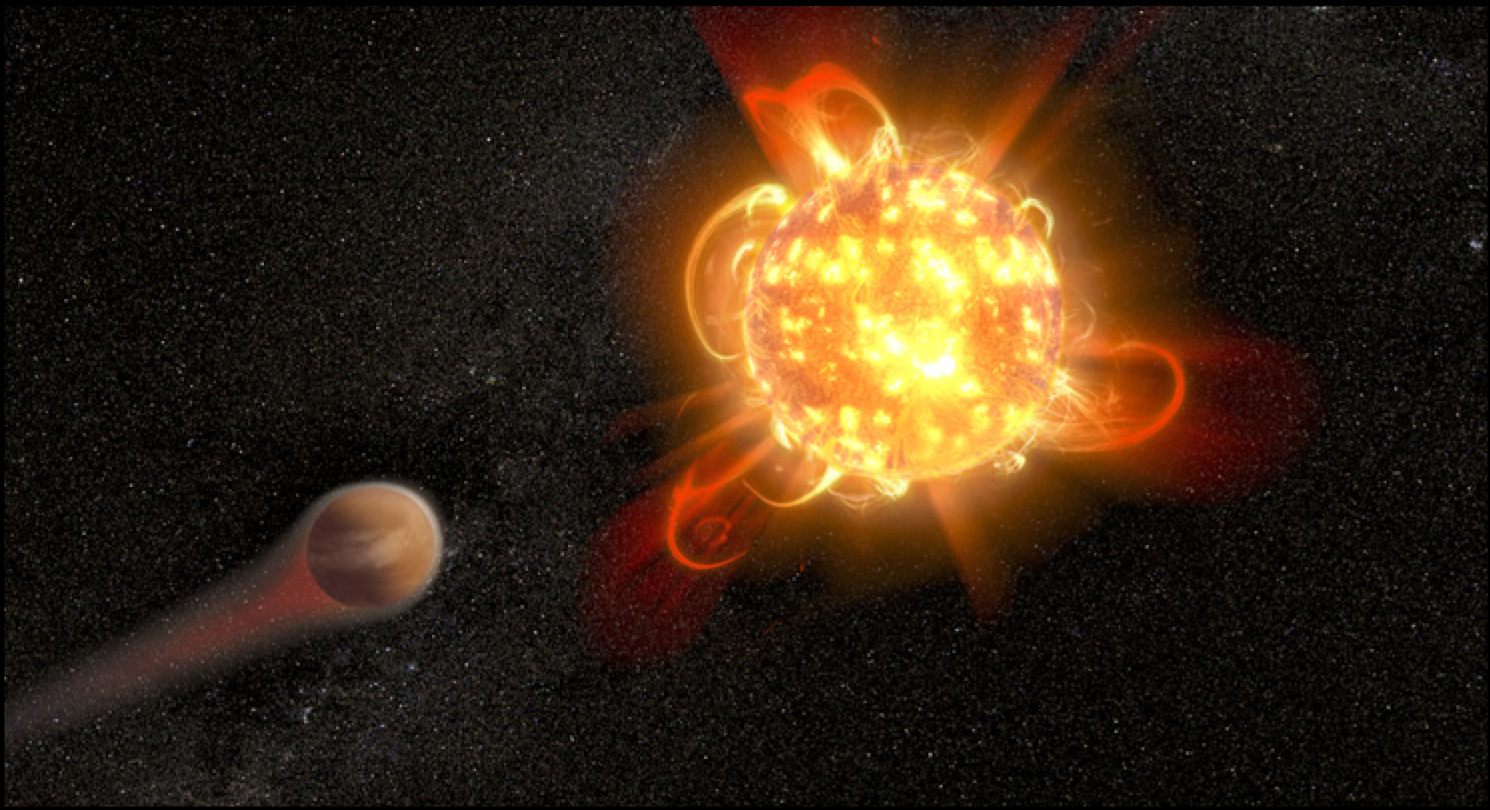
Host stars strongly influence the habitability of orbiting planets. Two *Hubble* studies indicate that M dwarfs—small, red stars—are often poor hosts, bathing their planets in harmful radiation and blasting away ingredients that are necessary for life as we know it. These results have implications for the search for life throughout the galaxy.

"These low-mass stars are critically important in understanding planetary atmospheres."

Evgenya Shkolnik, Arizona State University

M dwarfs are very common and live extremely long lives, however a *Hubble* program found that these stars produce violent superflares when they are young. The program, called Habitable Zones and M dwarf Activity across Time (HAZMAT), surveyed M dwarfs at three different ages: young, intermediate, and old. The HAZMAT team found that ultraviolet flares from the youngest red dwarfs they surveyed, which are around 40 million years old, are 100 to 1,000 times more energetic than when the stars are older. Such intense flares of high-energy radiation may blast the atmospheres away from fledgling planets—especially terrestrial worlds, whose atmospheres change dramatically in the first 100 million years.

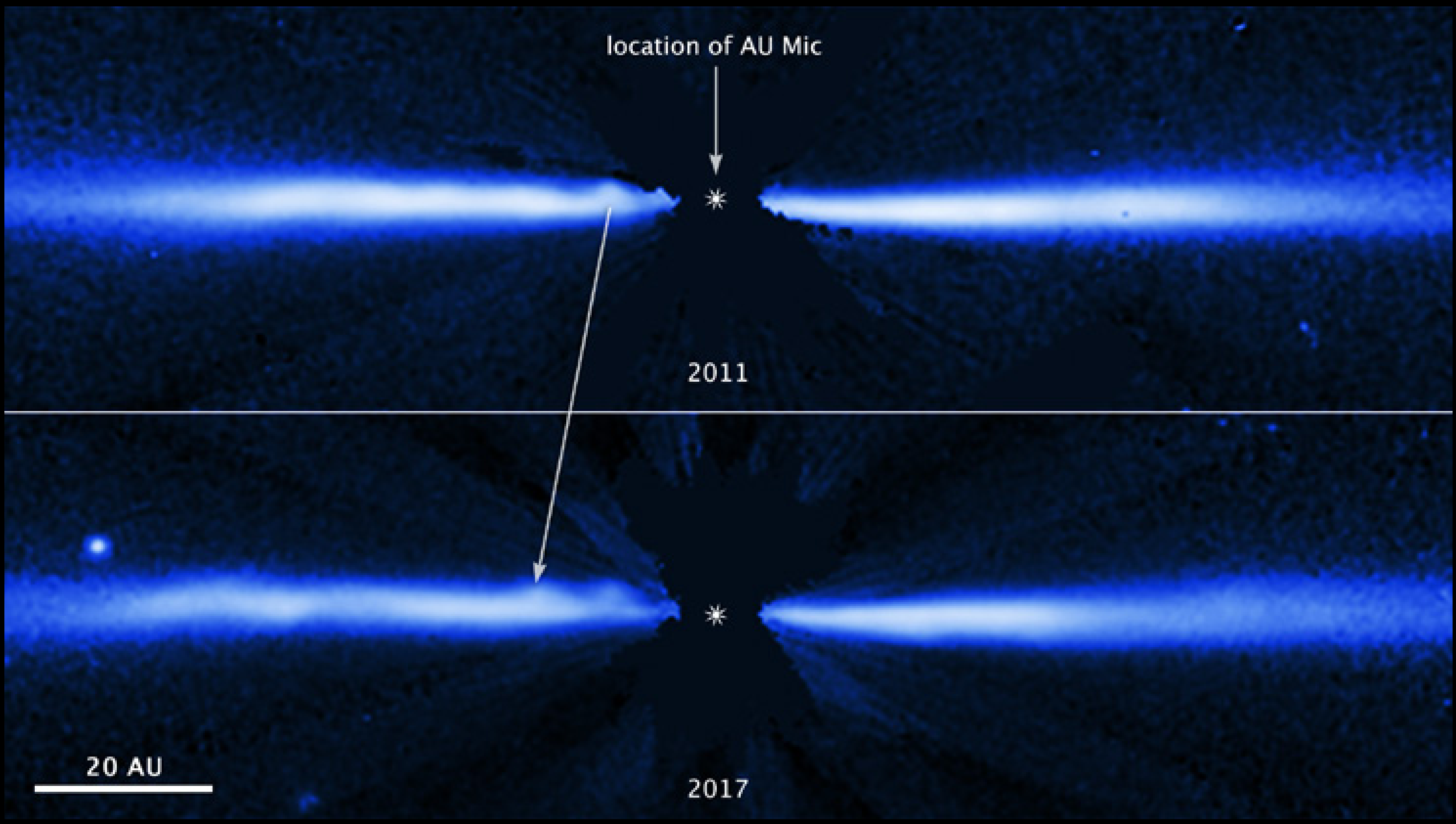
Another study revealed more bad news for rocky worlds circling M dwarf stars. While some orbit within their star's habitable zone, where the temperature could allow liquid water to pool on the planets, they may be bone dry and lifeless instead. *Hubble* and the European Southern Observatory's Very Large Telescope in Chile discovered a rapidly eroding disk of gas and dust around the nearby M dwarf star AU Microscopii (AU Mic). Fast-moving blobs of material are excavating the disk, acting like a snowplow by pushing small particles—possibly containing materials like water—out of the system. Astronomers are not sure how the blobs originated, though one theory proposes that the turbulent star's powerful mass ejections expelled them. This suggests that many rocky planets around M dwarf stars may not harbor water or organic material.



A fiery M dwarf star is blasting a fledgling planet's atmosphere away in this illustration. Powerful flares from young M dwarf stars may render orbiting planets uninhabitable, based on *Hubble* observations. As part of the same study, astronomers also detected one of the most intense stellar flares ever observed in ultraviolet light.

Illustration credit: NASA, ESA, and D. Player (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2018/news-2018-46.html
https://hubblesite.org/contents/news-releases/2019/news-2019-02.html



These two *Hubble* images, taken six years apart, show a debris disk around the young M dwarf star Au Mic. *Hubble*'s coronagraph blocked out the glare from the star to view fainter features in the disk. An arrow traces the movement of a blob of material, which is zipping along at nearly 15,000 miles per hour. Astronomers were able to study this system in such detail partly because it's so close to Earth—only 32 light-years away, while other M dwarf systems with starlight-scattering debris disks are typically about six times farther away.

Credit: NASA, ESA, J. Wisniewski (University of Oklahoma), C. Grady (Eureka Scientific), and G. Schneider (Steward Observatory)

Exploring 'Goldilocks' Stars

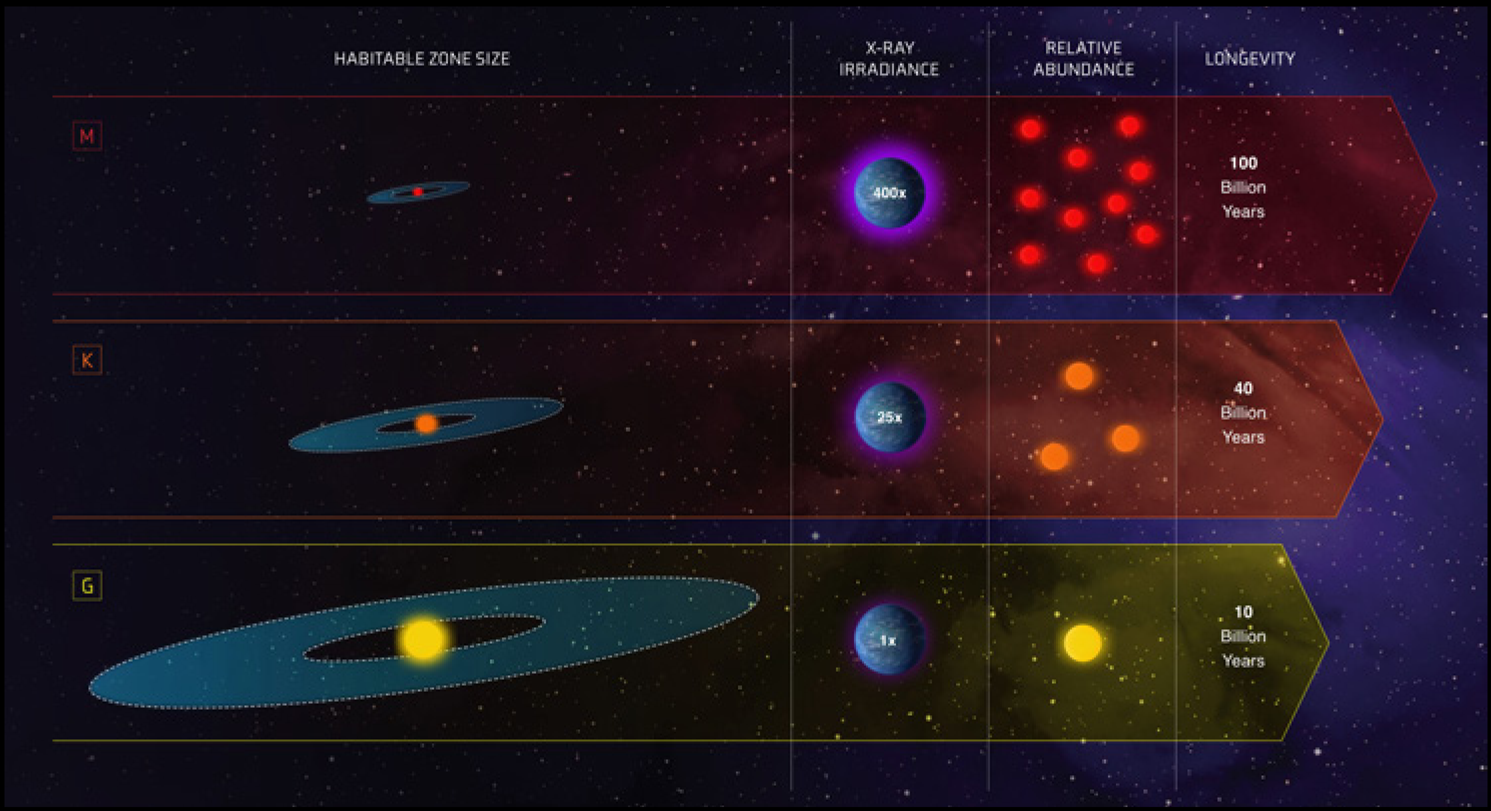
While M dwarf stars may be poor hosts for planets, surveys by *Hubble* and other telescopes have revealed that our galaxy is home to "Goldilocks stars." Small, orange stars called K dwarfs are not too hot, too cold, or too violent to host habitable planets over vast stretches of time.

"The Kepler-442 system is a Goldilocks planet hosted by a Goldilocks star!"

Edward Guinan, Villanova University

As part of the "GoldiloKs" Project, scientists used *Hubble*, the *Chandra X-ray Observatory*, and the European Space Agency's XMM-Newton satellite to probe relationships between a star's age, rotation rate, X-ray and ultraviolet emissions, and flare activity. *Hubble* performed sensitive ultraviolet observations to study radiation from about 20 K dwarf stars, while other telescopes focused on larger G stars, which are like our Sun. Conventional wisdom suggests that Sun-like stars would be prime candidates to host life-bearing planets, however researchers found that K dwarfs may be more hospitable.

K dwarfs are a happy medium because they're about three times as common as G stars and live much longer lives. They are not as common or long-lived as M dwarfs, however they are much milder; while M dwarfs commonly produce potentially planet-sterilizing flares, K dwarfs lack the intensely active magnetic fields that generate such outbursts. As a result, orbiting planets would only receive about 0.01 times as much deadly X-ray radiation as worlds orbiting M dwarfs. K dwarfs also have mid-sized habitable zones, compared to M dwarfs (which have small habitable zones close in) and G stars (which have wider habitable zones farther out). Scientists also took a closer look at some of the K stars that host planets. They found that the star Kepler-422 is home to a rocky planet that is about twice as massive as Earth. Future observations could study this potentially habitable world's atmosphere to search for possible signs of life.



This infographic compares the characteristics of the smallest three classes of stars in our galaxy: Sun-like G stars, cooler and less massive K dwarfs, and even cooler and smaller M dwarfs. M dwarfs are most common and live the longest lives, however they have small habitable zones and blast orbiting planets with X-ray radiation. G stars are much milder and have wide habitable zones, however they have much shorter lives and are less common. K dwarfs are in between, both in size and characteristics, making them the best candidates for potentially hosting habitable worlds for long periods of time.

Credit: NASA, ESA, and Z. Levy (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2020/news-2020-06

CHAPTER 5: Disk Dwellers

New stars emerge into the Milky Way from swirling clouds of gas and dust that are peppered throughout our galaxy. Vestiges of those clouds remain, surrounding each star in a disk that grows ever more diffuse as debris clumps together to form objects like planets. *Hubble*'s exoplanet studies have largely focused on the worlds themselves, but occasionally surprises pop up in the disks these planets are embedded in.

For example, astronomers trained *Hubble* on a nearby star and saw an enormous shadow sweeping across its surrounding disk. An unseen planet orbiting close to its star may be warping the inner part of the disk, blocking the star's light and casting the looming shadow *Hubble* revealed. A separate observation revealed an imposter exoplanet's disappearing act, hinting that a full-grown planet never existed in the first place. Instead, *Hubble* may have captured the aftermath of a colossal collision between two icy bodies.

Hubble has helped study comets that a planet is hurling into its star, and probed a rare mid-size planet's atmosphere. The latter observation could help astronomers understand why so few planets between the sizes of Earth and Neptune exist—the disks they orbit in may dissipate before the worlds can bulk up further. Using *Hubble*, astronomers have even studied a growing planet that is gobbling up material from the disk surrounding its host star.

By revealing new information about the dusty disks planets live in, *Hubble* helps astronomers learn how planetary systems form and evolve and offers additional insight into how our own solar system came to be.

This artist's illustration shows two 125-mile-wide bodies colliding in orbit around the star Fomalhaut, located just 25 light-years from Earth. Astronomers using *Hubble* likely saw the aftermath of this collision, though it was first identified as a planet. Subsequent observations showed the object expanding and fading until it disappeared, supporting researchers' recent conclusion that it was never a planet at all. The dust cloud from the collision has now ballooned to more than 200 million miles across, making it so diffuse that *Hubble* can no longer detect it. Smashups like this are estimated to happen around Fomalhaut once every 200,000 years. *Hubble* was looking at the right place at the right time to capture this rare event.

Credit: ESA, NASA, and M. Kornmesser

Observing 'Shadow Play' Caused by Suspected Planet

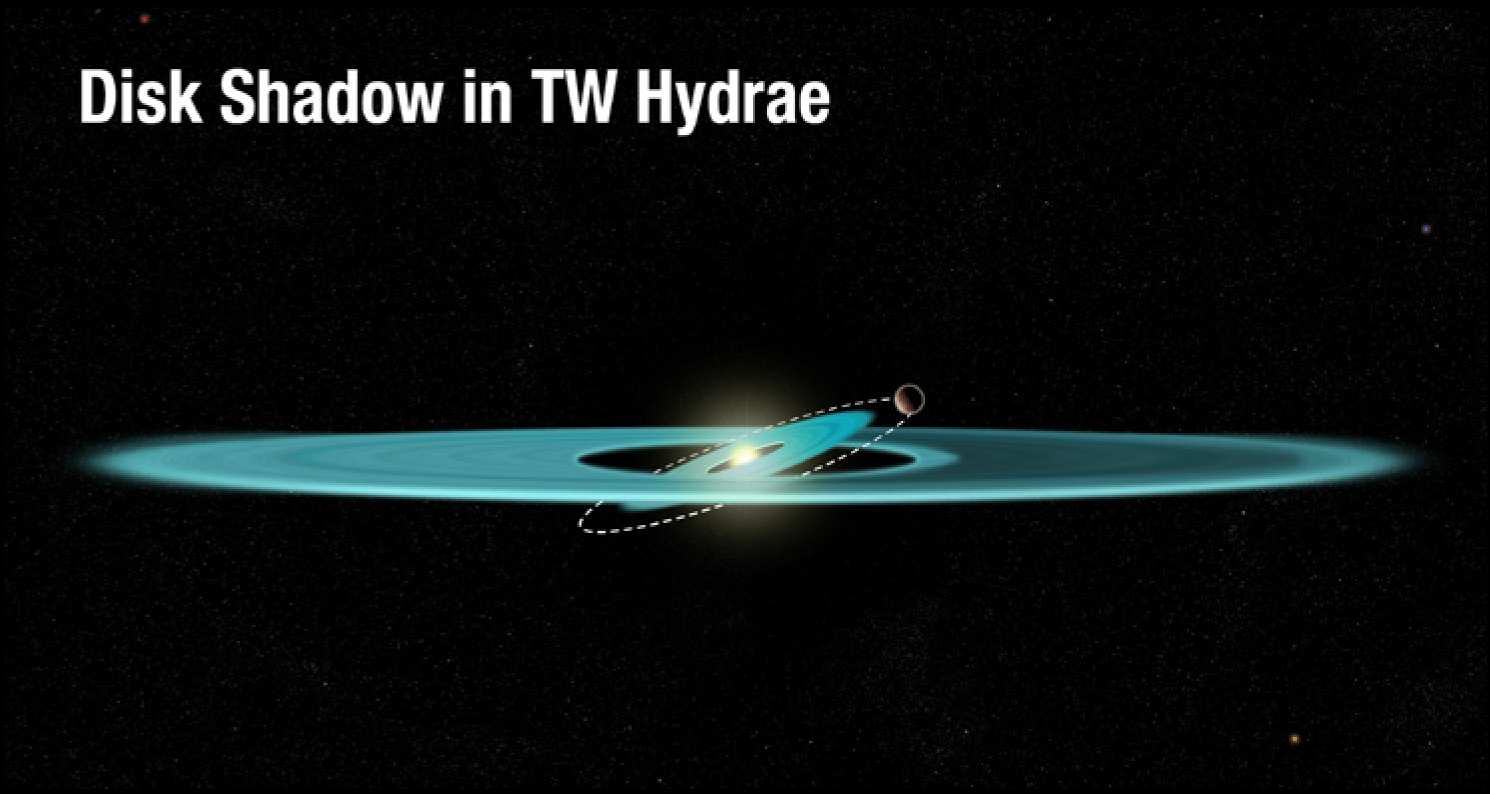
Nearly all the information we receive from space comes in the form of light. But shadows can be telling, too. Astronomers using *Hubble* noticed a mysterious dark splotch covering an enormous portion of a disk of dust and gas encircling a young, nearby star. Since *Hubble* had observed the star, called TW Hydrae, multiple times over the previous 18 years, the team was able to assemble a time-lapse movie that revealed a strange phenomenon—a gigantic shadow whirling around the disk like the hands moving around a clock.

"This shadow phenomenon may be fairly common in young stellar systems."

John Debes, Space Telescope Science Institute

TW Hydrae's 41-billion-mile-wide disk is tilted face-on to Earth, providing *Hubble* with a bird's-eye view of the system. When astronomers combed through *Hubble*'s image archive to investigate the strange shadow, they found that it sweeps around the disk in a regular motion, completing a lap every 16 years. Scientists say the feature moves much too quickly to be physically part of the disk. Instead, the shadow may be the result of an unseen planet that orbits too close to the star—around 100 million miles away, nearly as close as Earth orbits the Sun—for *Hubble* or any other present-day telescope to see it directly.

Astronomers think the possible planet may be pulling on nearby material and warping the inner part of the disk. The misaligned portion of the disk blocks the star's light, casting a large shadow on the outer disk. Submillimeter observations by the Atacama Large Millimeter Array (ALMA) in Chile support this explanation, and even reveal a gap in the disk. An unseen planet could create such a gap as it clears debris out of its path. The new *Hubble* study offered a unique way to probe what is happening very close to the star.

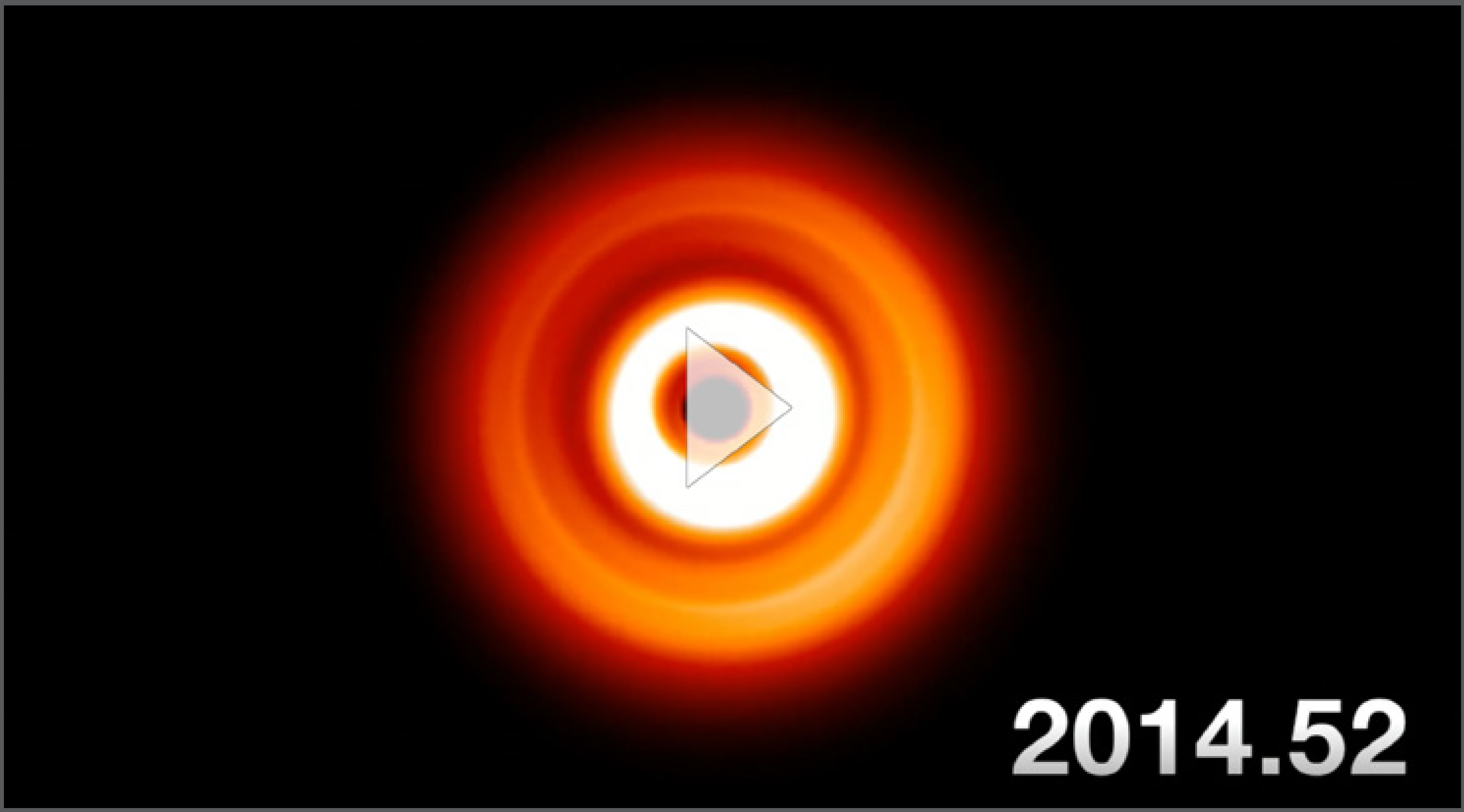


About 190 light-years from Earth, an unseen world may be doing some heavy lifting. The theorized planet circles a star called TW Hydrae, which is only eight million years old. Astronomers think the planet is gravitationally pulling on material near the star and warping the inner part of the disk of gas and dust that surrounds it. A twisted, misaligned inner disk would explain the shadow *Hubble* spotted on the outer disk.

Credit: NASA, ESA, and A. Feild (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2017/news-2017-03.html

Watching an Eerie Shadow Haunt a Young Star



This simulation shows a shadow moving around the disk of gas and dust that encircles the young star TW Hydrae. The video is based on *Hubble* data taken between 1998 and 2016, and it also projects the shadow's future motion around the disk. Astronomers think a planet is pulling on material near the star and warping the inner part of the disk, though the planet is too close to the star for *Hubble* to detect it directly. The misaligned inner disk is casting its shadow across the surface of the outer disk. The planet must be roughly Jupiter's size to have enough gravity to pull material up out of the plane of the main disk. The planet's gravitational pull causes the inner disk to wobble around the star, giving the shadow its 16-year rotational period.

Credit: NASA, ESA, and J. Debes (STScI)

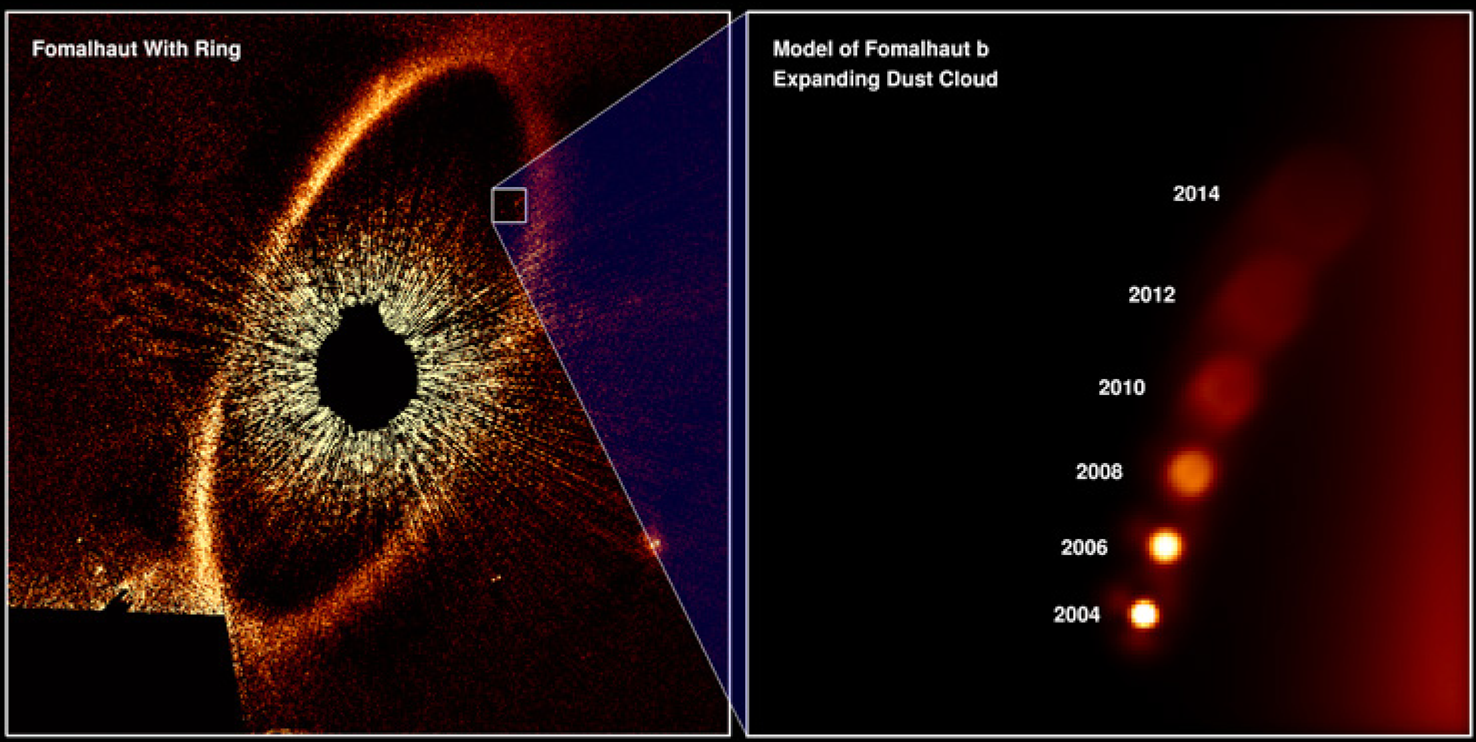
Exposing an Otherworldly Case of Mistaken Identity

In 2008, astronomers announced that *Hubble* captured its first image of a planet orbiting another star, called Fomalhaut, about 25 light-years from Earth. However, a team of researchers from the University of Arizona suggests that the object was actually a billowing cloud of dust, which would explain why it seems to have disappeared.

> "This is a blueprint of how planets destroy each other."
>
> George Rieke, University of Arizona Steward Observatory

The "planet," called Fomalhaut b, was puzzling in several ways. Its orbit was strange, and it was unusually bright in visible light yet lacked detectable infrared heat signatures. Then as astronomers performed follow-up observations during subsequent years, the object appeared to fade until it vanished entirely. The University of Arizona team mined *Hubble*'s data archive to trace the object's disappearing act, concluding that it was never a full-grown planet in the first place.

Instead, the researchers think two icy bodies in the disk surrounding Fomalhaut collided and shattered, spilling dust into space in an expanding cloud. Such collisions have happened in our own solar system billions of years ago, leaving behind rocky debris that we can still see today as asteroid families. No one has ever seen one of these cataclysmic events around another star because they are so rare, occurring about once every 200,000 years in Fomalhaut's case. But *Hubble*'s original observations of the Fomalhaut system may have witnessed the aftermath, which appeared as a small dot next to a giant ring of icy debris encircling the star. Follow-up observations using the *James Webb Space Telescope* will study more details of Fomalhaut's debris ring and will look for evidence of other, bona fide planets in the system.

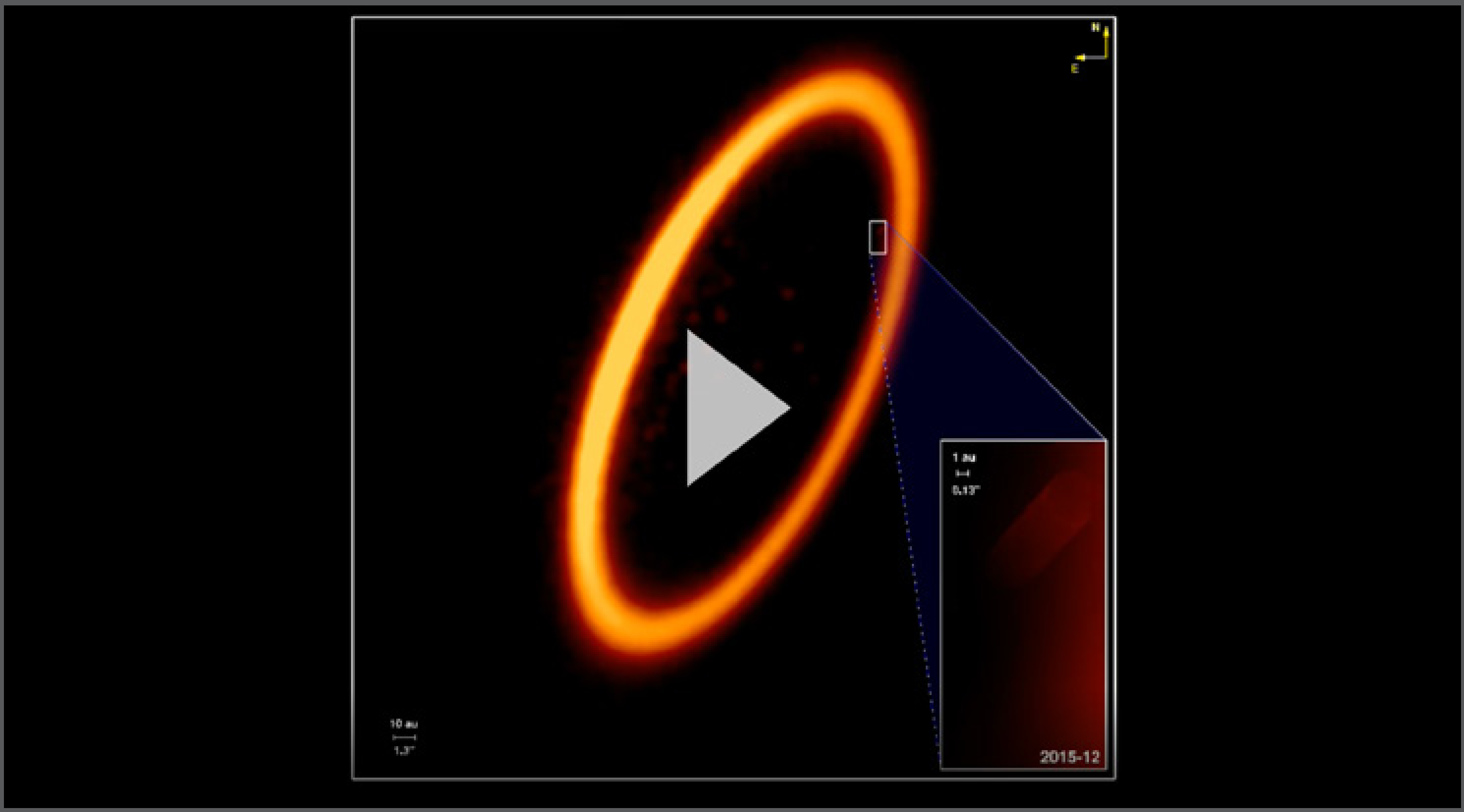


This diagram shows the findings of several years of *Hubble* observations. It illustrates what astronomers consider evidence of the aftermath of a titanic collision in another star system. The *Hubble* image on the left is a vast ring of icy debris encircling the star Fomalhaut. A black disk blocks the star's glare, so the dust ring is visible. The diagram on the right zooms in to trace *Hubble*'s observations of an object orbiting the star. While astronomers originally thought the object was a planet, subsequent observations show it expanding and fading until *Hubble* could no longer detect it. A team of researchers thinks it is actually a dust cloud left behind from a collision between two icy bodies. By now, the cloud is likely larger than Earth's orbit around the Sun.

Credit: NASA, ESA, and A. Gáspár and G. Rieke (University of Arizona)

Learn more: https://hubblesite.org/contents/news-releases/2020/news-2020-09

Tracing the Aftermath of a Cosmic Collision



Astronomers using *Hubble* thought they had captured an exoplanet, but subsequent results hint that it was actually a cloud of debris instead. The simulated image in the background of this video shows the star system without the central star's light, making the surrounding features easier to see. The supposed planet was found orbiting near a large dust ring. The animated inset zooms in on the object and simulates how it expanded and faded, based on several years of *Hubble* observations. Researchers consider this evidence of the aftermath of a titanic collision between two icy bodies.

Credit: NASA, ESA, and A. Gáspár and G. Rieke (University of Arizona)

Gathering Evidence of a Planet Flinging Comets Into a Young Star

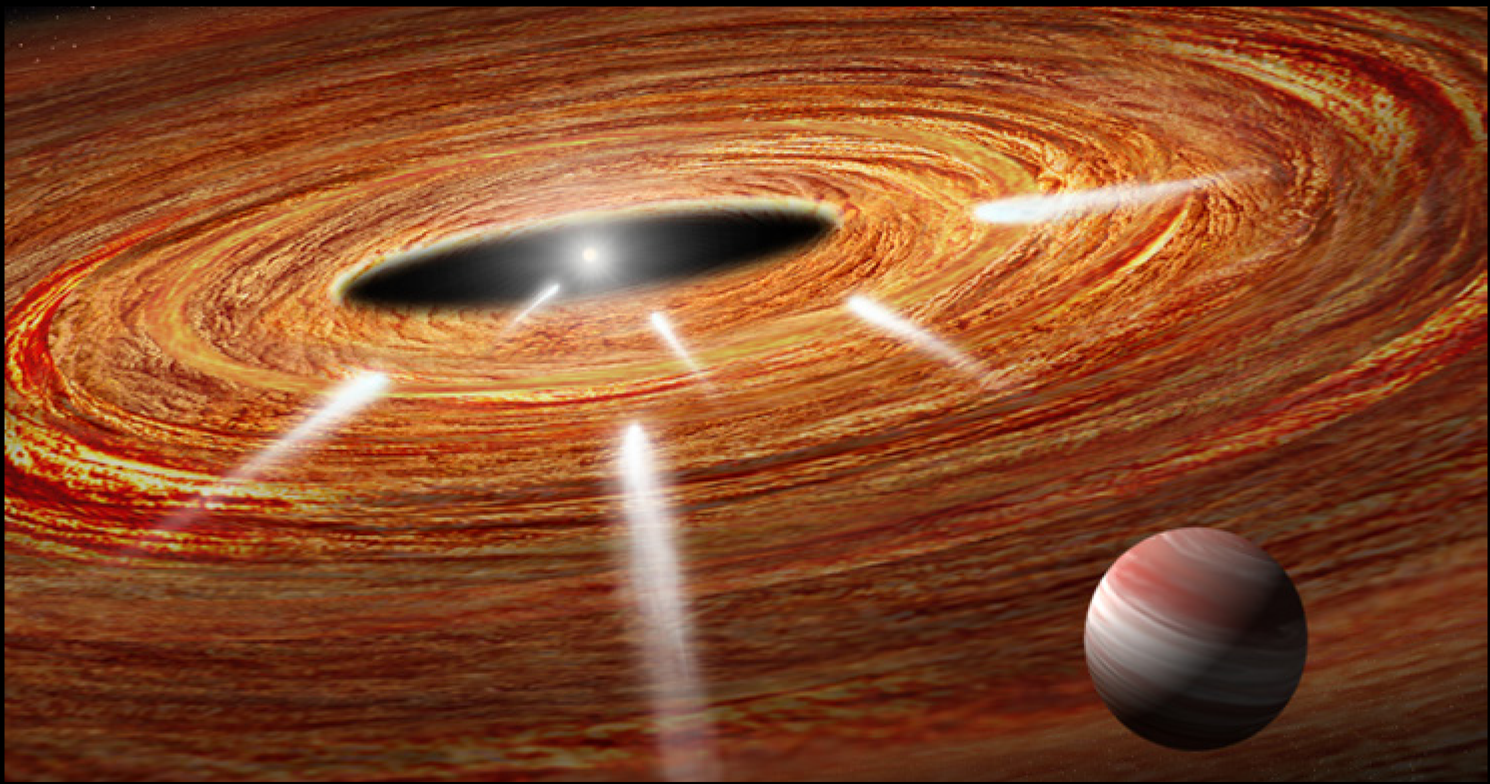
As *Hubble*'s images of the comet Shoemaker-Levy 9 impact on Jupiter help illustrate, Jupiter sometimes serves as Earth's protector by blocking or deflecting objects that could collide with our planet. But the reverse can be true, too; when our solar system was younger, the giant planet also hurled asteroids and comets in Earth's direction, toward the Sun. Astronomers using *Hubble* recently found clues that something similar is happening around the young star HD 172555—a Jupiter-sized planet seems to be flinging comets toward its star.

"These star-grazing comets may make life possible, because they carry water and other life-forming elements to terrestrial planets."

Carol Grady, Eureka Scientific Inc. and NASA Goddard Space Flight Center

Scientists didn't see either the planet or comets directly, but pieced this explanation together from various lines of evidence. First, a team of French astronomers mined archival data gathered by the European Southern Observatory and found the chemical fingerprints of calcium imprinted in HD 172555's light—evidence of comet-like objects plunging into the star. Then another group of astronomers followed up by using *Hubble* to conduct a spectrographic analysis in ultraviolet light. *Hubble* detected fast-moving silicon and carbon gas in the starlight. The most likely explanation for the speedy gas is that material from the comets vaporized after streaking across the star's disk.

Astronomers consider this circumstantial evidence for gravitational stirring by an unseen Jupiter-size planet, where comets deflected by the massive object's gravity are catapulted into the star. This is the same mechanism that may have transported water to Earth and the other inner planets of our solar system. HD 172555 is the third extrasolar system where astronomers have detected doomed, wayward comets, and all three systems are young. Studying them offers insight into what probably happened in the early days of our own solar system.



This illustration shows an enormous disk of dusty material surrounding the young star HD 172555. Astronomers using *Hubble* found evidence that comets are falling in toward the star when they detected gas that is likely the vaporized remnants of the icy comet cores. The gas was moving at about 360,000 miles per hour across the face of the star. The gravitational influence of a suspected Jupiter-size planet in the foreground may have catapulted the comets into the star.

Credit: NASA, ESA, and A. Feild and G. Bacon (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2017/news-2017-02.html

Puzzling Out the Atmosphere of a Mid-Size World

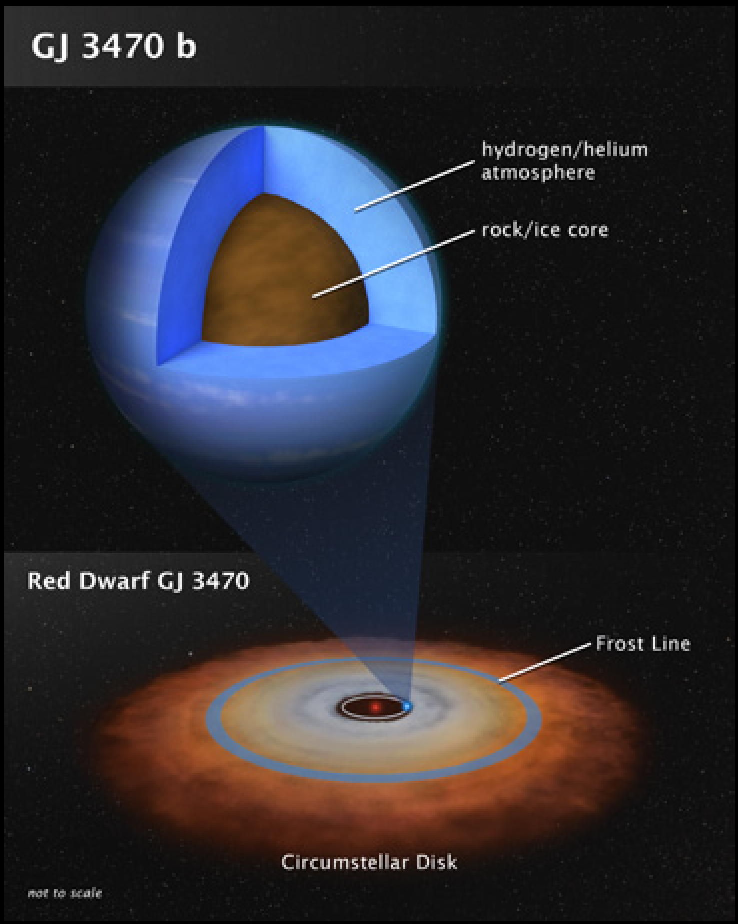
Kepler Space Telescope surveys suggest that the most common type of planet found in the Milky Way's disk doesn't resemble any of the worlds in our own solar system, but is instead something like an Earth-Neptune hybrid. *Hubble* teamed up with the *Spitzer Space Telescope* to study the detailed spectroscopic fingerprint of the atmosphere of one such world, dubbed GJ 3470 b, for the first time to learn more about the nature and origin of these prevalent planets.

"We don't have anything like this in the solar system, and that's what makes it striking."

Björn Benneke, University of Montreal

GJ 3470 b weighs in at nearly 13 times Earth's mass and orbits its host red dwarf star in just three days. Astronomers enlisted the combined multi-wavelength capabilities of *Hubble* and *Spitzer* to determine the composition of the wild world's atmosphere. They discovered that the planet has clear skies with only thin hazes, which allowed them to probe deep into the atmosphere. They expected to see an atmosphere enriched with plenty of heavier elements like oxygen and carbon, possibly incorporated in water vapor molecules and methane gas. However, they found mainly hydrogen and helium in the atmosphere, similar to the Sun's makeup.

Astronomers think star-hugging planets typically formed farther from their host star and then migrated inward over time. However, in GJ 3470 b's case, the planet may have formed in place as a large rocky core that then accumulated hydrogen from a primordial disk of gas around its star when the star was very young. The disk may have dissipated before the planet could bulk up further. The *James Webb Space Telescope* will be able to probe even deeper into GJ 3470 b's atmosphere thanks to its unprecedented sensitivity to infrared light, possibly unveiling even more about this perplexing planet.



Hubble and *Spitzer* revealed tantalizing clues about the chemical nature of a mid-size planet, GJ 3740 b, which is between the masses of Earth and Neptune. The planet has a large rocky core buried under a crushing atmosphere of hydrogen and helium. Astronomers think it was able to accrete hydrogen from the disk that surrounded the young star, but the disk may have dissipated before the planet accumulated enough material to become a hot Jupiter.

Credit: NASA, ESA, and L. Hustak (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2019/news-2019-38.html

Measuring a Giant Planet's Growth

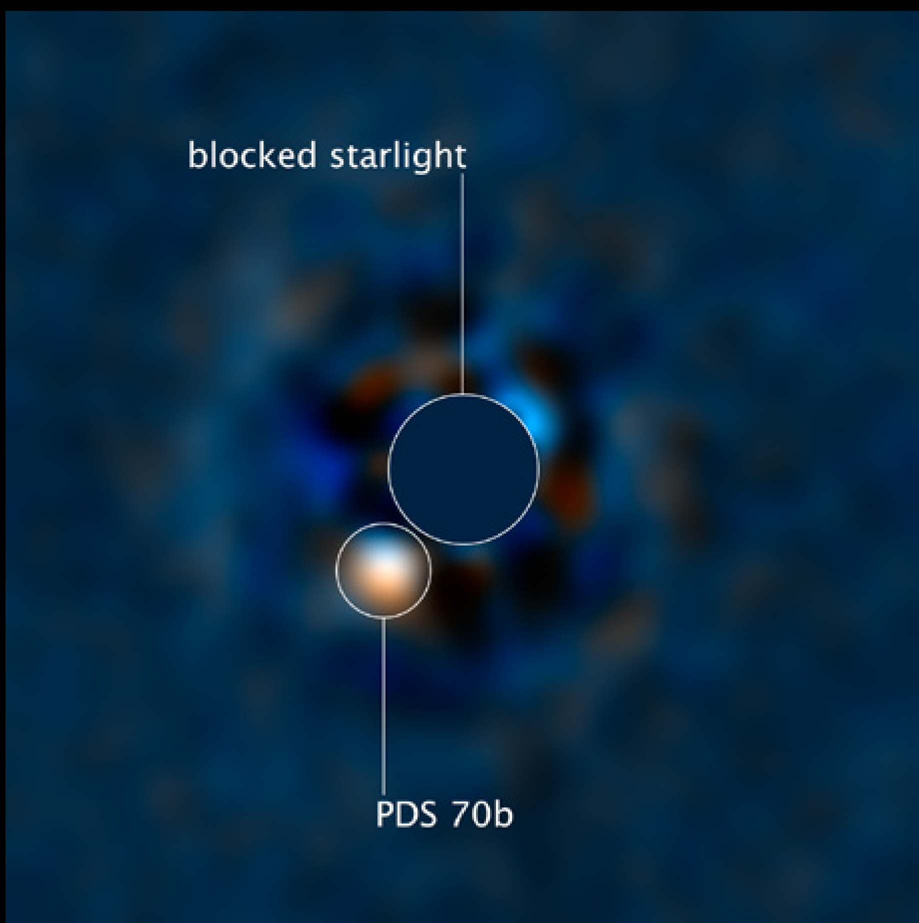
Hubble has primarily found fully-formed planets, but a new study shows that the observatory can also identify worlds that are still growing. Researchers homed in on a young system called PDS 70, located 370 light-years from Earth. The central star is surrounded by a primordial disk of gas and dust that provides fuel to feed the growth of orbiting planets. The team directly imaged the giant world PDS 70b in ultraviolet light—something that had never been done before—and spotted radiation from extremely hot gas falling onto the planet. The observation provided a way to estimate how quickly the planet is growing. No other telescope is currently capable of making such high-sensitivity measurements in ultraviolet light.

"This is the youngest bona fide planet *Hubble* has ever directly imaged."

Yifan Zhou, University of Texas at Austin

PDS 70b has been amassing material for about five million years and has already bulked up to five times Jupiter's mass. However, it may be nearing the end of its formation process. Researchers found that the planet is building up mass so slowly now that if the rate remains steady for another million years, its bulk will only increase by about 1/100th of Jupiter's mass.

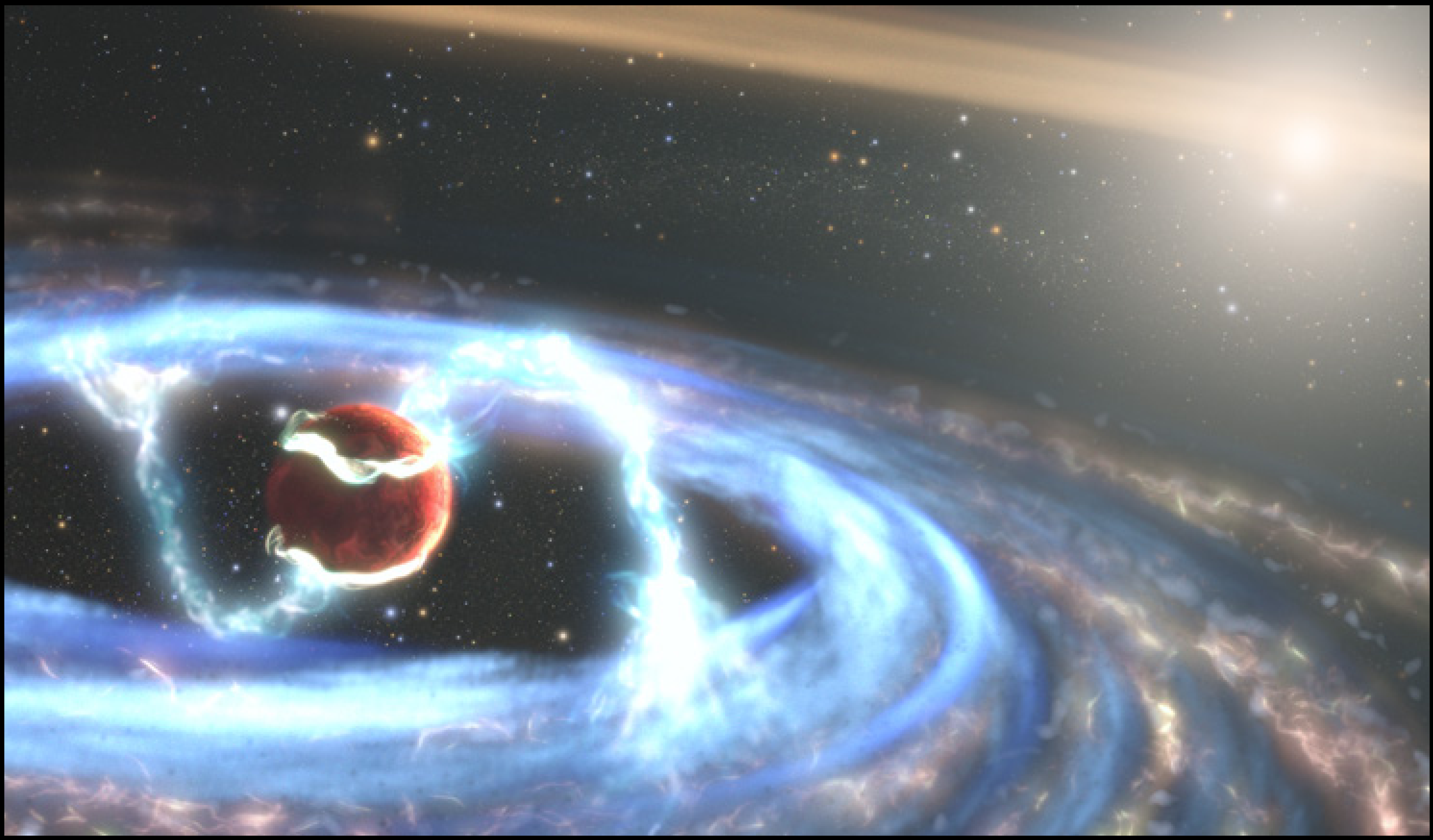
The study relied on a novel observing strategy and post-processing technique designed to overcome the glare from the host star, which is 3,000 times brighter than the planet in ultraviolet light. The team's results offer a new way to study how giant planets grow out of circumstellar disks around other stars. Future observations could reveal how much of the gas and dust in such disks fall onto their planets, and whether the process occurs at a steady rate. While ground-based telescopes and the *James Webb Space Telescope* will be able to help measure PDS 70b's growth rate in visible and infrared light, *Hubble*'s unique ultraviolet observations remain critical for studying planet formation because the process is mostly visible in ultraviolet.



This *Hubble* image shows the giant world dubbed PDS 70b, marking the first time an exoplanet was directly imaged in ultraviolet light. Astronomers used a coronagraph on *Hubble*'s camera to block out the glare from the planet's host star. The observation revealed radiation from super-heated gas falling onto the world, offering a way to estimate how quickly the planet is growing.

Credit: NASA, ESA, McDonald Observatory–University of Texas, Yifan Zhou (UT), Joseph DePasquale (STScI)

Learn more: https://hubblesite.org/contents/news-releases/2021/news-2021-021



This illustration of the exoplanet PDS 70b shows how the giant planet is growing. Material that forms the disk around the world's host star is being siphoned by the planet, creating a smaller disk within the larger circumstellar disk. By employing *Hubble*'s ultraviolet light sensitivity, researchers took a unique look at radiation from extremely hot gas falling onto the planet, allowing them to directly measure the planet's growth rate for the first time.

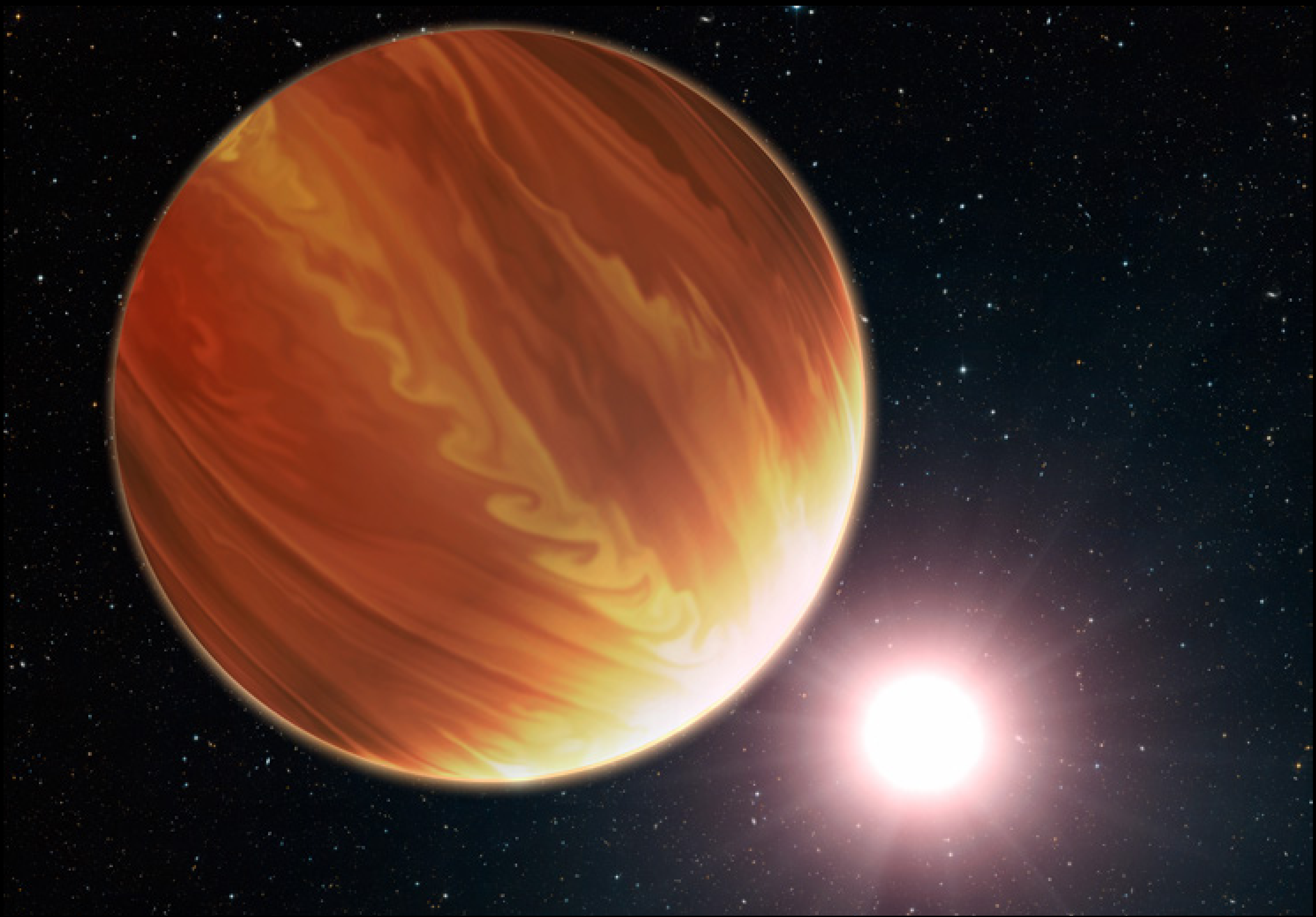
Illustration credit: NASA, ESA, STScI, Joseph Olmsted (STScI)

SUMMARY

The *Hubble Space Telescope* launched in 1990, two years before the first exoplanets were announced. Though the observatory was not designed with exoplanet science in mind, it has revealed exceedingly valuable information about hundreds of other worlds. Thanks to its location in space, *Hubble* does not have to look through Earth's turbulent atmosphere, which distorts images and largely blocks infrared and ultraviolet light. And *Hubble*'s unique ultraviolet-light capabilities help astronomers study planetary atmospheres and environments in greater depth.

Using *Hubble*, astronomers probed an exoplanet's atmosphere for the first time more than 20 years ago. Now, such *Hubble* observations have extended to Earth-size worlds and have even identified atmospheres that contain sodium, oxygen, carbon, hydrogen, carbon dioxide, methane, and water vapor. While most of the planets *Hubble* has studied to date are too hot to host life as we know it, the telescope's observations demonstrate that the basic organic components for life can be detected and measured on planets orbiting other stars, setting the stage for more detailed studies with future observatories.

Over just the last several years, *Hubble* has confirmed that a planet orbits two suns, and made a detailed global map of another world showing the temperature at different layers in its atmosphere and the amount and distribution of its water vapor. The observatory has revealed a cosmic case of mistaken identity and uncovered an immense cloud of hydrogen bleeding off a nearby world. Perhaps most exciting of all, *Hubble* has identified water vapor on planets that orbit in their star's habitable zone. Other current and future missions, including the *James Webb Space Telescope*, will follow up and build on some of *Hubble*'s most compelling findings, offering complementary information and even more detailed views. The mission's ongoing observations will continue to enhance our understanding of the cosmos and reveal new planetary wonders, propelling us forward in our search for life on other planets.



A hot Jupiter is nearly aligned with its host star in this artist's illustration. Such planets are ideal candidates for *Hubble* to study because astronomers can gather precise measurements of the chemical composition of planetary atmospheres as starlight filters through them.

Credit: NASA, ESA, and G. Bacon (STScI)

MORE INFORMATION

For more information about the *Hubble Space Telescope* mission and its discoveries, visit NASA's *Hubble* website at nasa.gov/hubble. For additional details and resources, visit HubbleSite.org.

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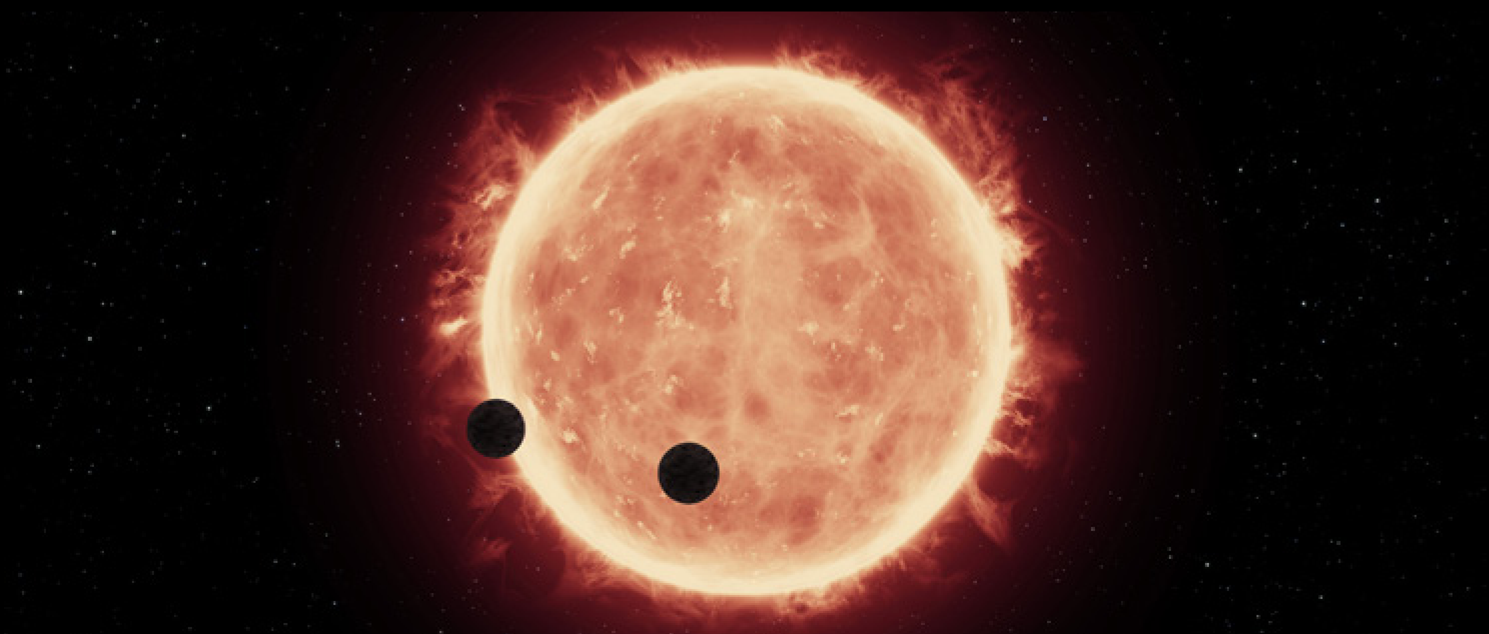

Two planets are transiting, or passing in front of, their host star in this illustration. *Hubble* studies exoplanet atmospheres spectroscopically during transits, helping astronomers understand what the atmospheres are made of. This offers clues to the planets' formation and evolution and hints at whether they are likely to be habitable.

Credit: NASA, ESA, and G. Bacon (STScI)

CREDITS

The *Hubble Space Telescope* is a cooperative project between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The Hubble Space Telescope Operations Project at the NASA Goddard Space Flight Center (GSFC) manages the mission. The Space Telescope Science Institute (STScI), operated by the Association of Universities for Research in Astronomy (AURA), conducts *Hubble*'s science operations and Lockheed Martin conducts *Hubble*'s mission operations, both under contracts with NASA.

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The production team for this book included Ashley Balzer (writer), Katrina Fajardo, Ed Henderson, and Mike Marosy (designers), Ken Carpenter and Jennifer Wiseman (science advisors), Vanessa Thomas, Kevin Hartnett, James Jeletic, and Andrea Gianopoulos (editors) at GSFC.

This illustration gives an impression of how common planetary systems are. Astronomers have discovered that there are even more planets than stars in our Milky Way galaxy. The planets, their orbits, and their host stars are all vastly magnified to make them visible in this image. Studying these worlds using *Hubble* helps us understand more about the universe and our place within it.

Credit: NASA, ESA, and M. Kornmesser (ESO)