

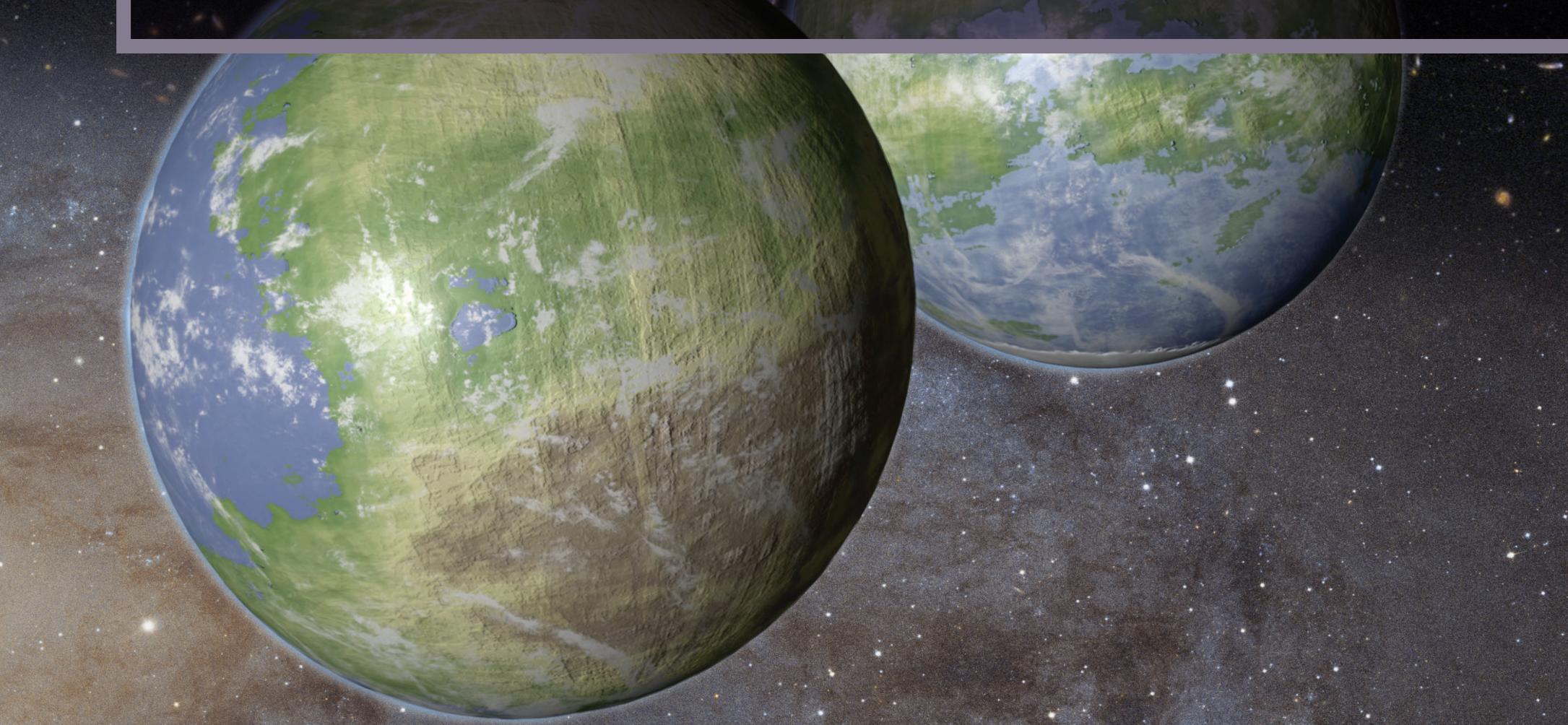


Twenty years ago, astronomers discovered the first exoplanet around 51 Pegasi b, a Sun-like star. In the last 20 years, astronomers have discovered thousands of new exotic worlds, begun to characterize atmospheres of faraway planets, and started developing cutting-edge technology to launch us on our search for alien life. This is the story of the pioneers in planet-hunting and how those who have followed are seeking to answer one of humanity's most ancient questions: Is there life elsewhere in the universe?

Scan the QR code to watch the video again!

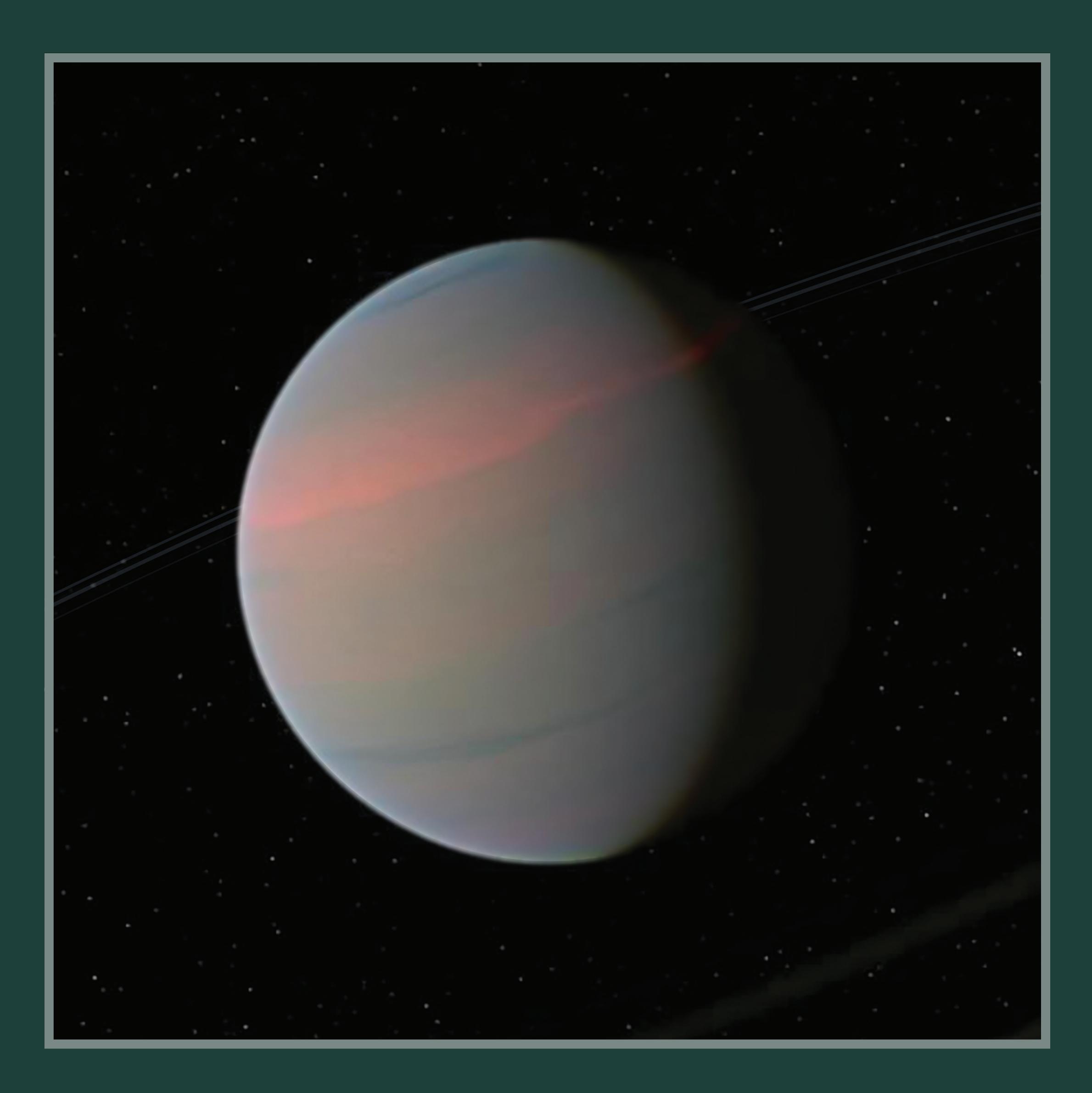


http://planetquest.jpl.nasa.gov/video/80



NA SA

Gamma Cephei Ab



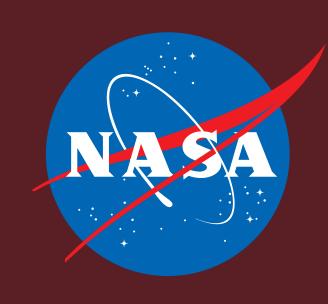
The discovery of Gamma
Cephei A b was proposed in
1987 and then withdrawn in
1992. But in 2003, new measurements confirmed that it really was
a planet—a giant exoplanet about
twice the size of Jupiter that takes
903 days to orbit a star 45 lightyears away.

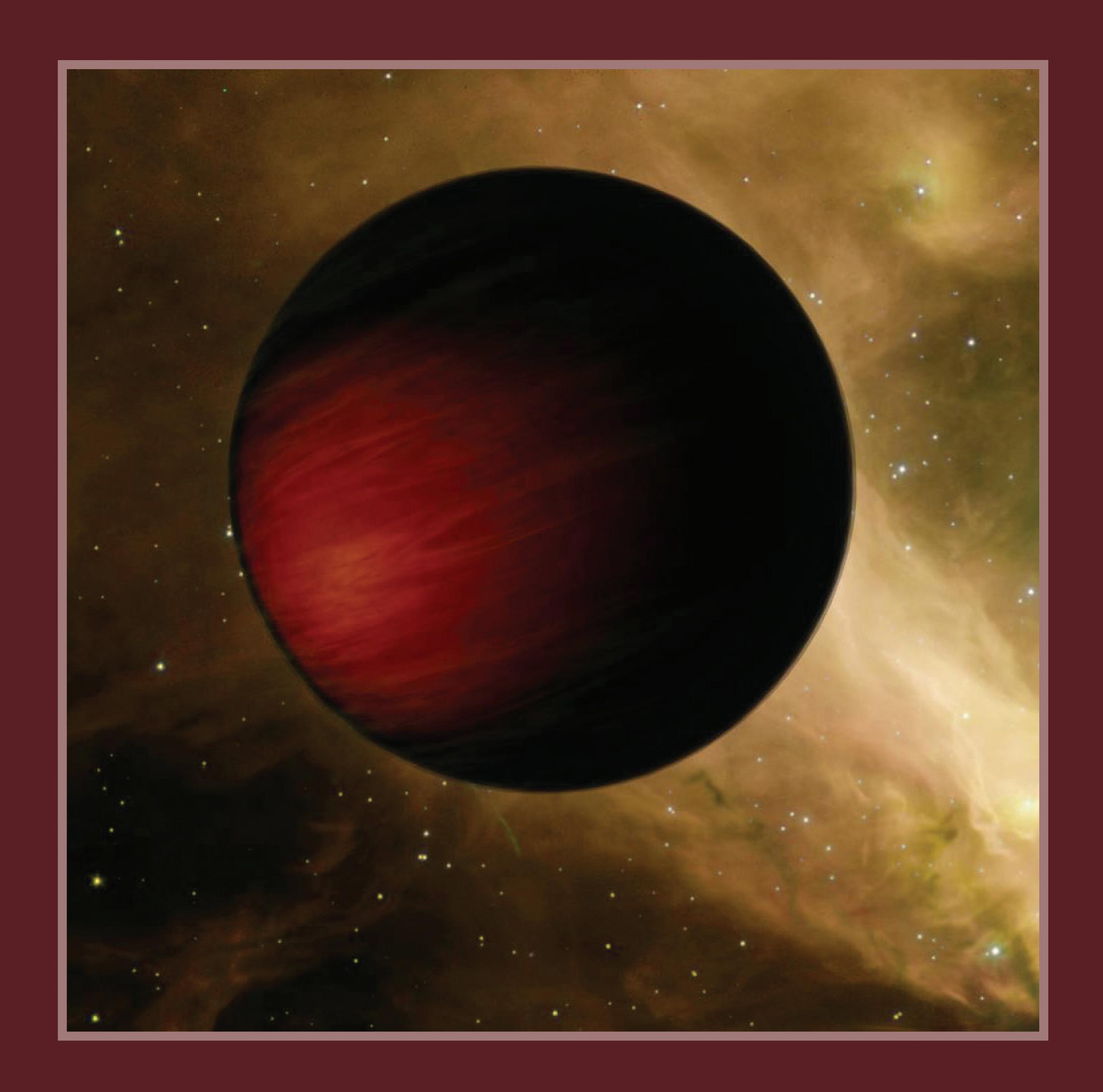
Pioneers: Gordon Walker, Bruce Campbell

Twenty years ago, our cosmic neighborhood looked very different. Key observational breakthroughs have changed the way we see our universe.

HD 114762 b

National Aeronautics and Space Administration



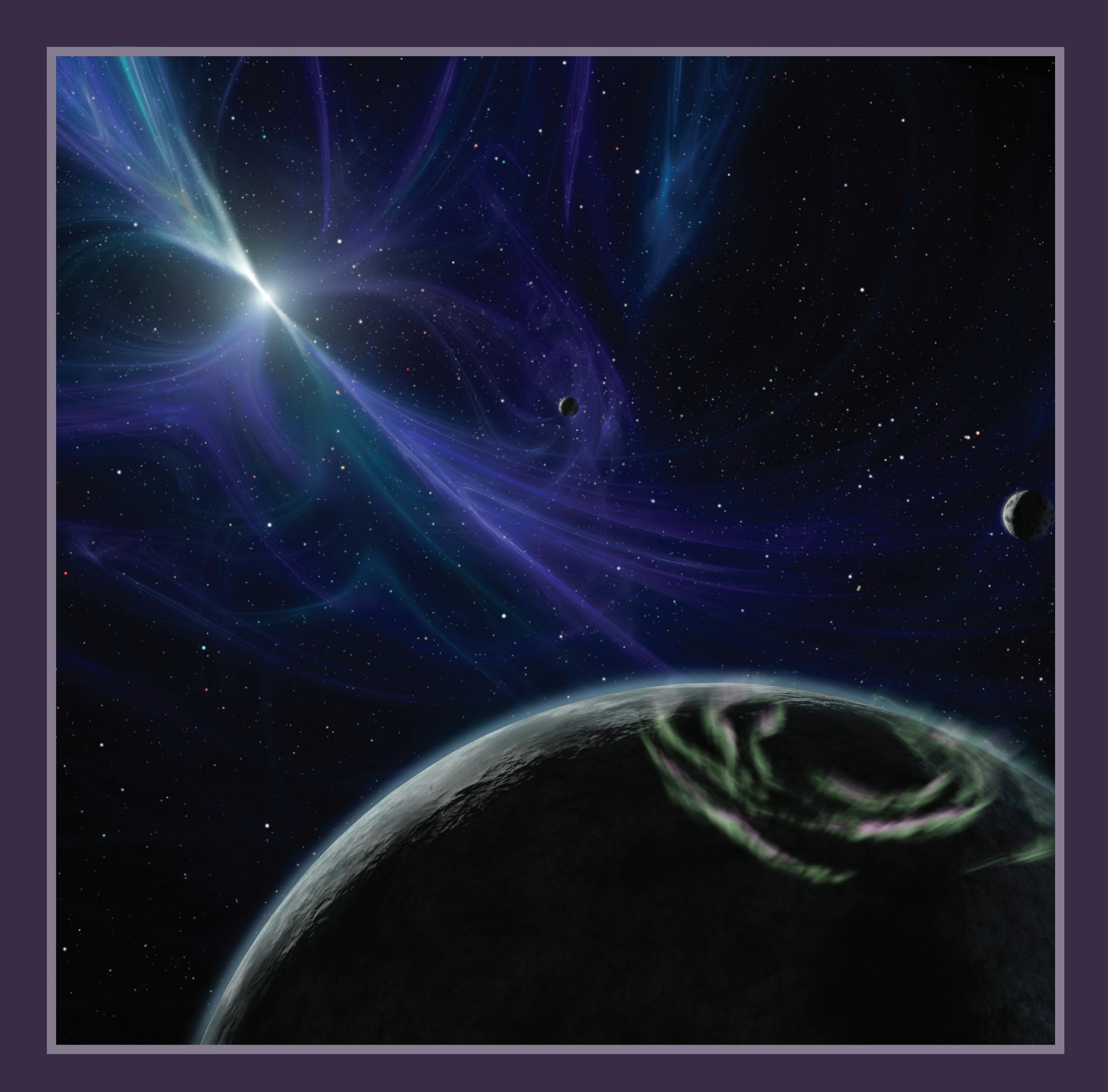


Discovered in 1989, HD 114762 b was so unusual that it was thought to be a failed star, a brown dwarf. However, in later years the planet was accepted as a massive giant exoplanet—at least 11 times Jupiter's mass, with an 83-day orbit around a star 132 light-years away.

Pioneer: David Latham

NASA.

PSR B1257+12b, c, d

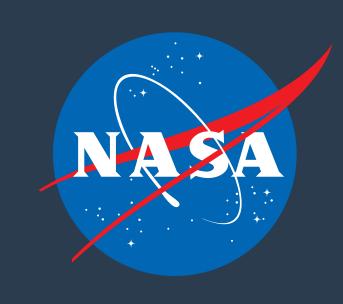


The discovery of two planets around a pulsar was announced in 1992—the very first planetary bodies to be clearly identified outside our solar system. These planets, as well as a third confirmed 2 years later, prompted plenty of debate because they orbited a rapidly spinning neutron star, rather than a star like our Sun. Although this environment is unlikely to be conducive to life, the very existence of planets around a pulsar predicted the amazing diversity of planetary systems observed today.

Pioneers: Alex Wolszczan, Dale Frail

51 Pegasi b





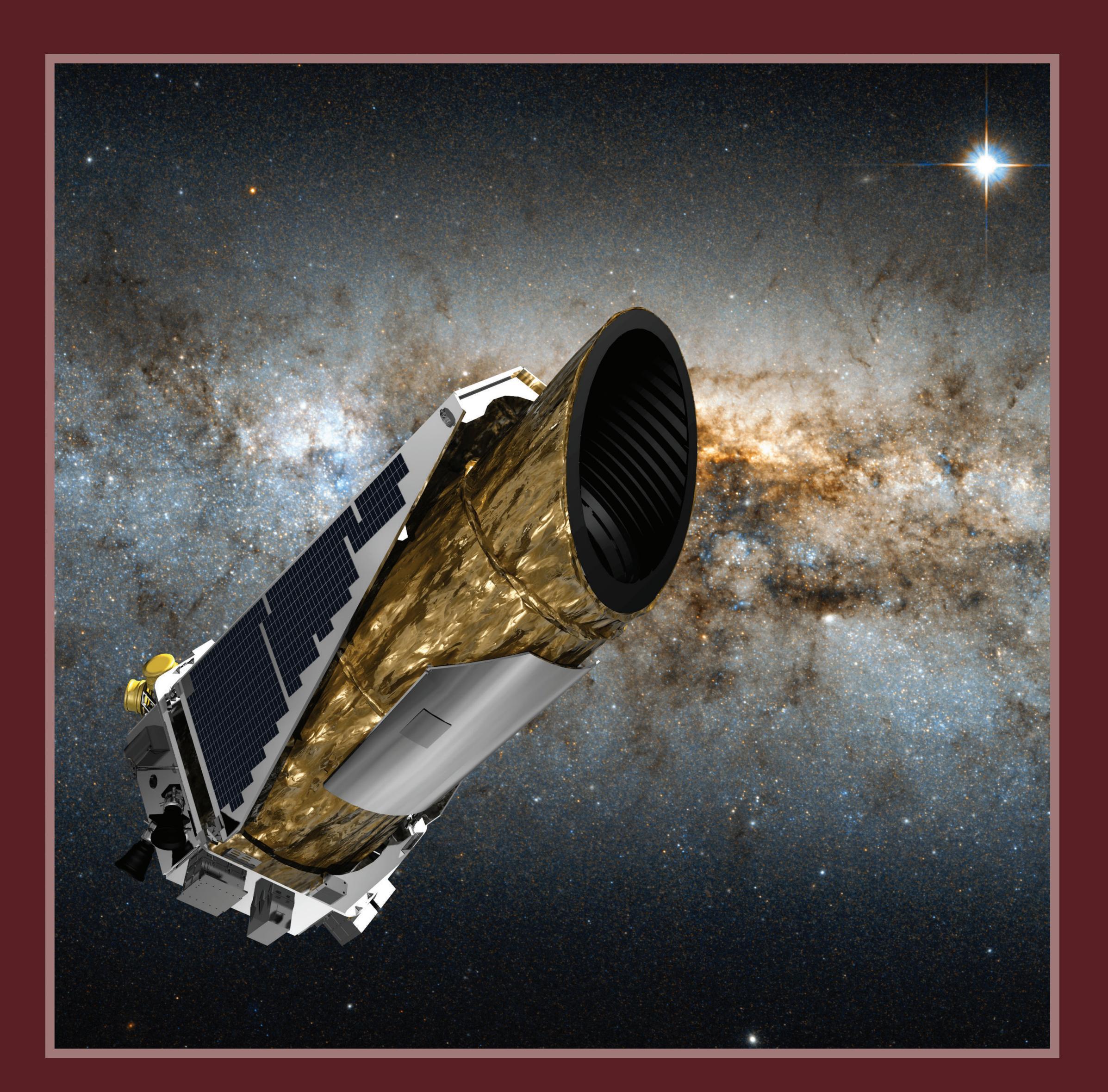
The first widely accepted planet to be found orbiting a main sequence star, 51 Pegasi b, was announced in 1995. This exoplanet is like nothing in our solar system because the planet is massive—at least half the mass of Jupiter—yet it races around its star in an extremely close 4.2-day orbit.

Pioneers: Michel Mayor, Didier Queloz, Paul Butler, Geoff Marcy

Kepler Mission

National Aeronautics and Space Administration

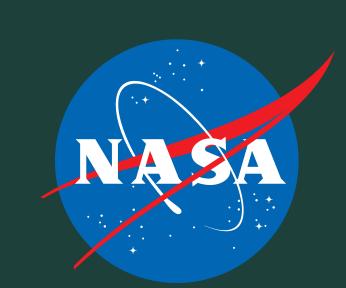




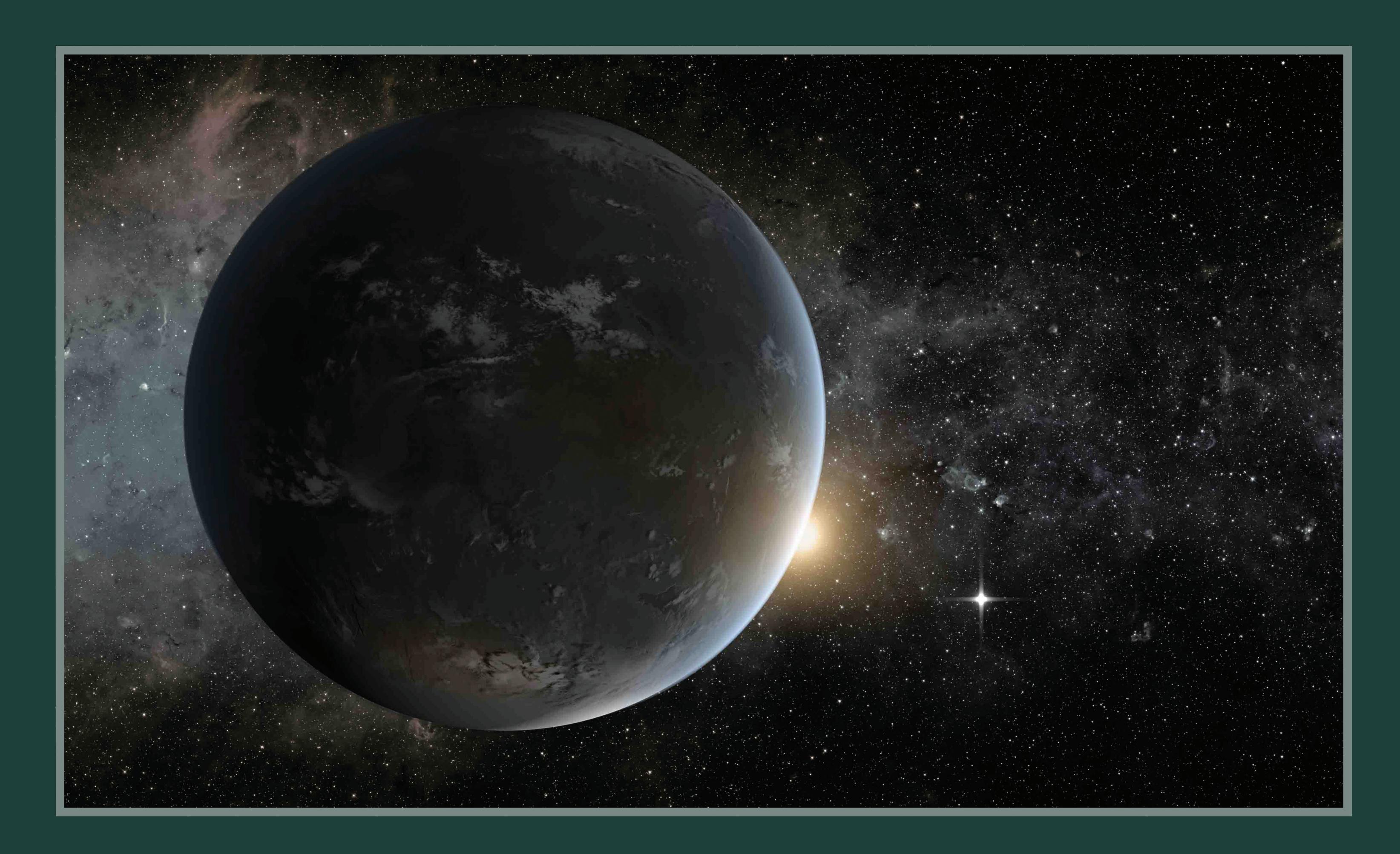
Launched in 2009, Kepler has detected approximately 5,000 exoplanet candidates, with more than a fifth of those confirmed. The primary mission ended in 2013. Since then, the spacecraft has embarked on its second mission, K2, and has made numerous exoplanet discoveries so far.

Pioneer: Bill Borucki





Searching for Another Earth



NASA's Kepler mission has helped astronomers find thousands of planets orbiting other stars in the galaxy and has helped reveal that there may be billions more.

In our search for the familiar—another planet like Earth—we have also made many unusual and unexpected discoveries, from scorching-hot planets that orbit their stars in just a few days, to worlds that have multiple suns in the sky.



Exoplanets Identified by Kepler

National Aeronautics and Space Administration



This image shows just some of the Kepler planetary candidate host stars with their exoplanet companions in silhouette. The sizes of the stars and exoplanets are properly scaled. The colors of the stars represent how the eye would see the star outside of the Earth's atmosphere. Our Sun is shown below the top row on the right by itself with the Earth and Jupiter in transit.

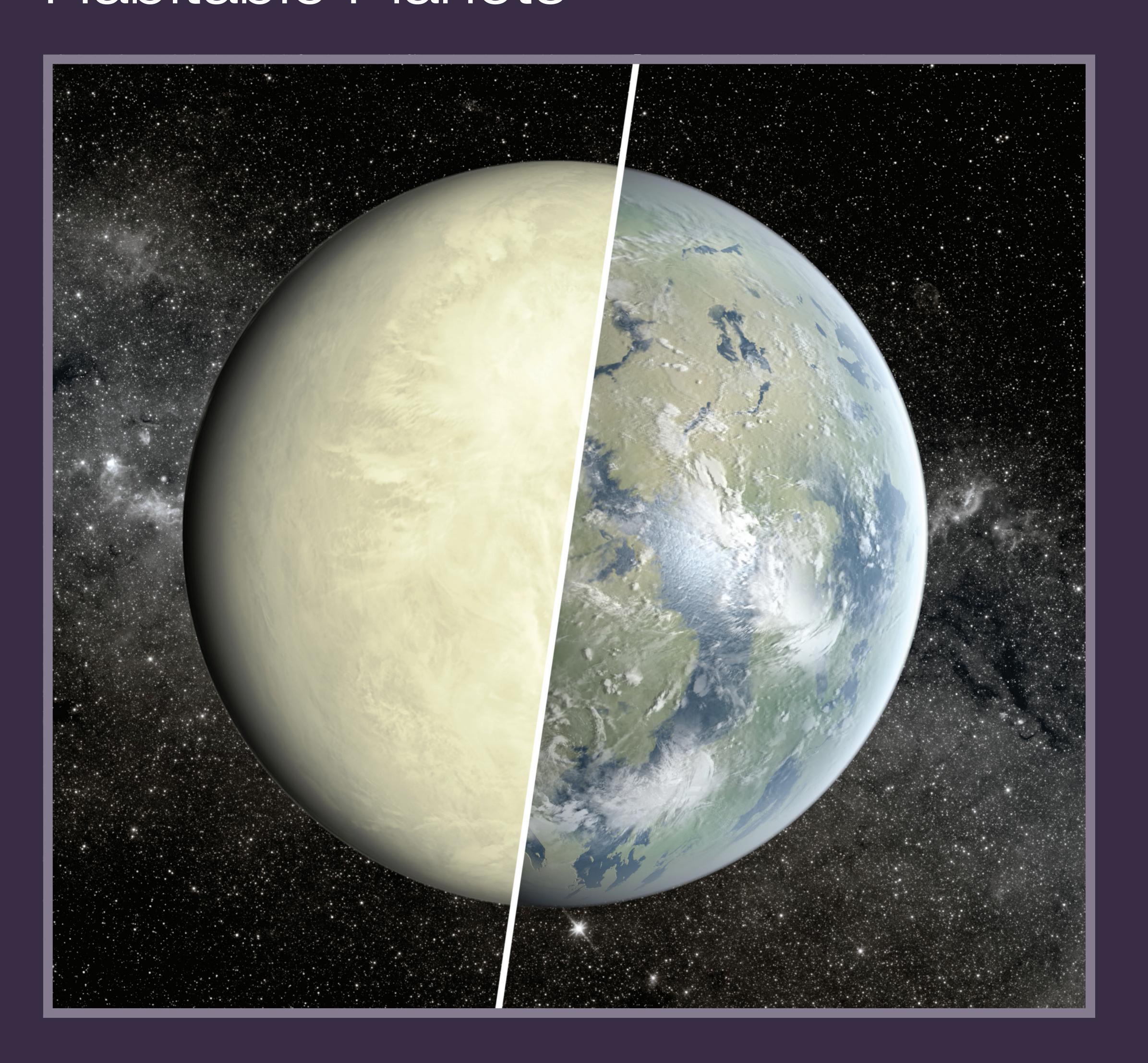
Illustration: Jason Rowe



Kepler Closing in on Potentially Habitable Planets

National Aeronautics and Space Administration





Potentially habitable planets discovered by Kepler share the following properties:

- a size small enough to harbor a rocky surface, yet large enough to hold on to a gaseous atmosphere (0.5-1.5 Earth radii)
- an orbital distance from a host star that provides surface temperatures conducive to liquid water

An Earth "twin," if discovered by Kepler, would have:

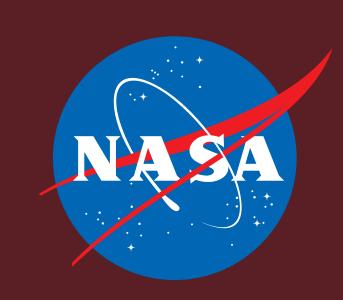
- Earth's size
- a Sun-like host star
- a 1-year orbit

All such exoplanets would become primary targets for future NASA missions in order to:

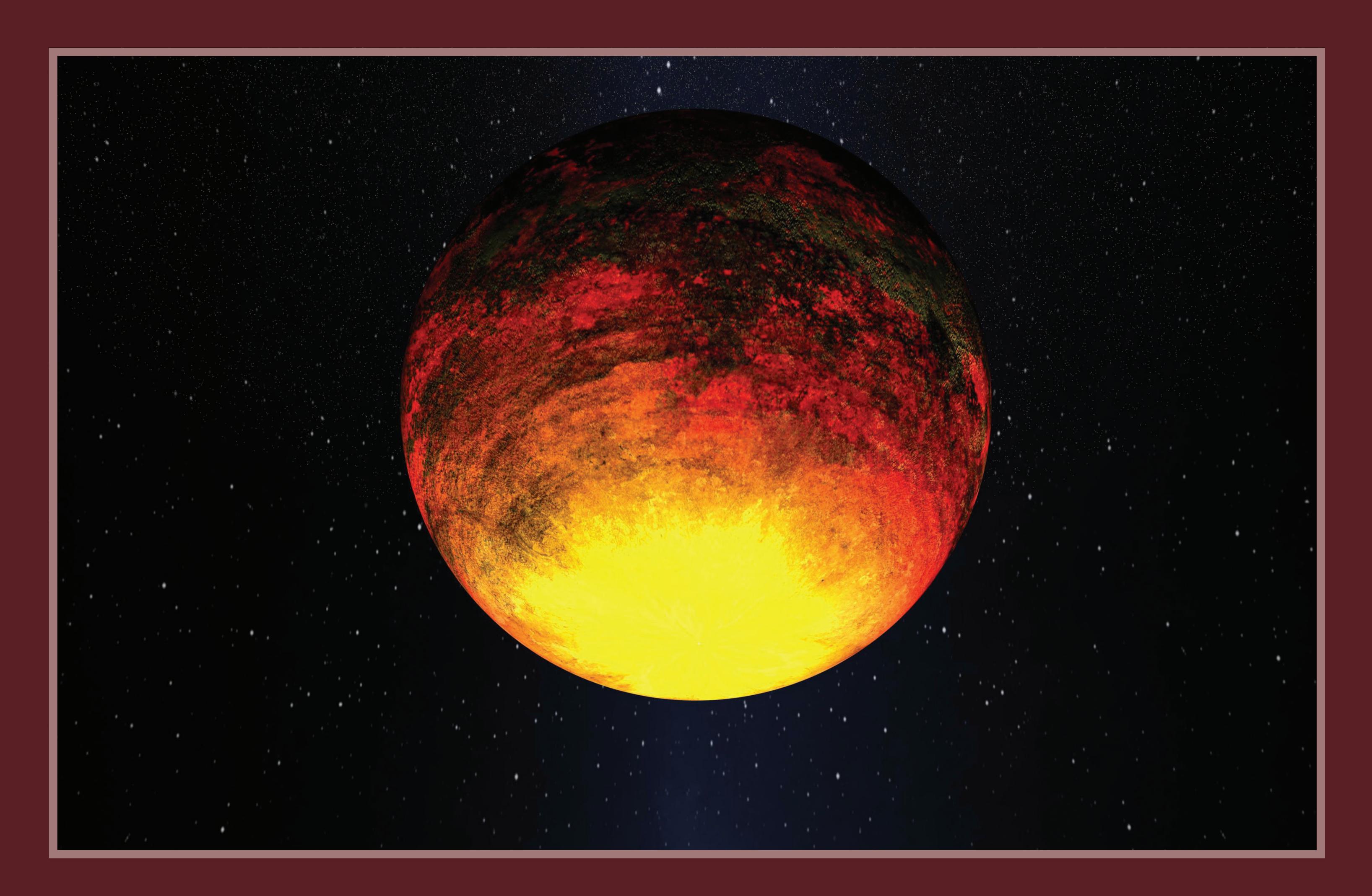
- detect potential atmospheres
- determine their chemical constituents
- search for chemical signatures of biology

Credit: NASA/JPL-Caltech/Ames

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Kepler-10b

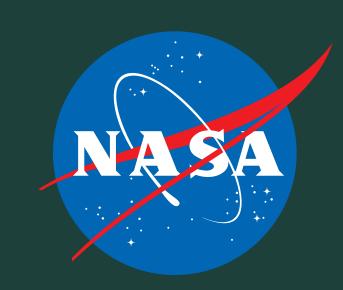


The first Earth-sized exoplanet discovered—but not in the habitable zone.

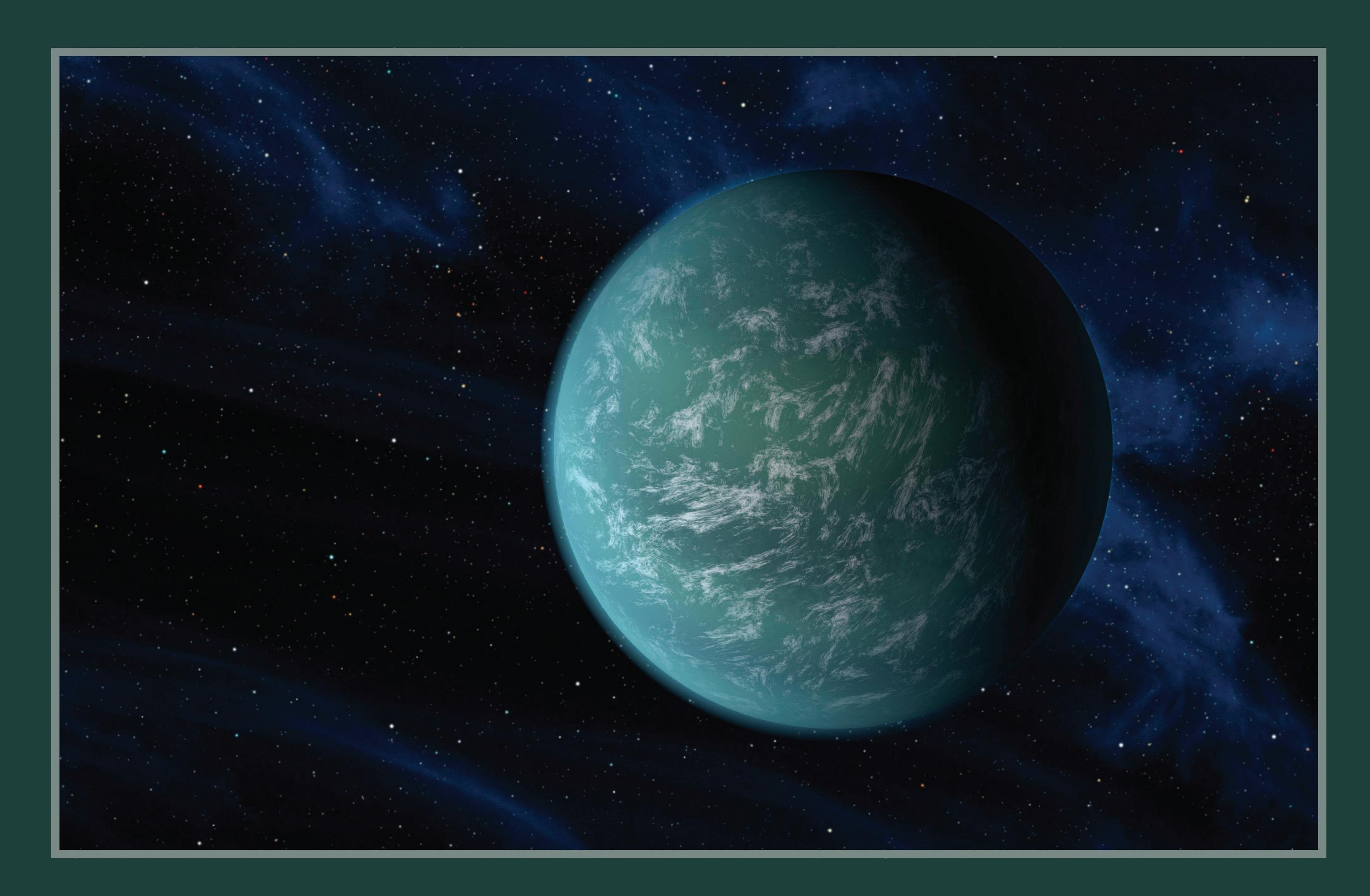
Credit: NASA



National Aeronautics and Space Administration



Kepler-22b



The first exoplanet discovered in the habitable zone—but a bit too large to have a rocky surface.

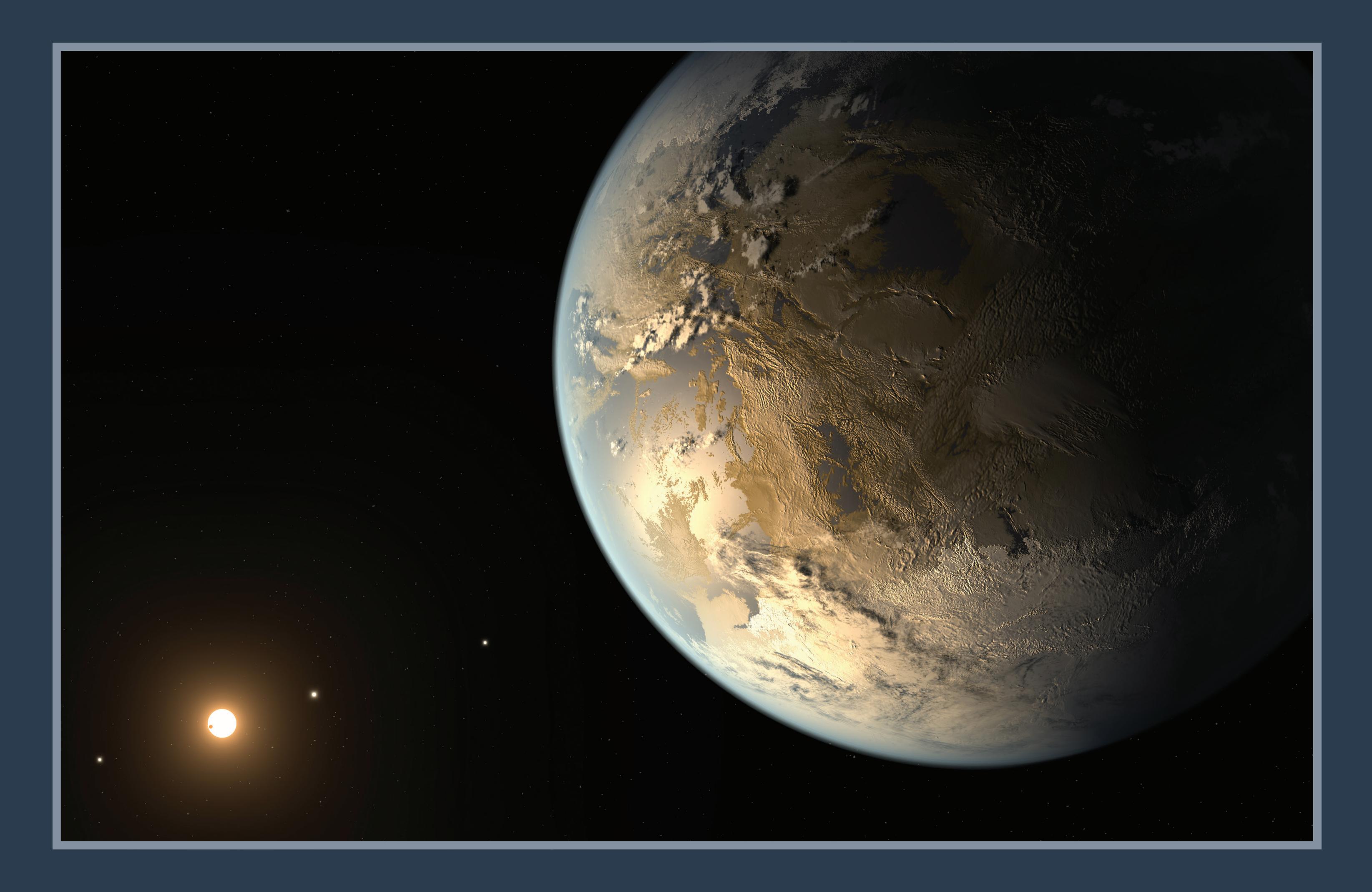
Credit: NASA/Ames/JPL-Caltech



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Kepler-186f



The first Earth-sized exoplanet discovered in the habitable zone—but around an M-dwarf star, which is smaller and cooler than our star.

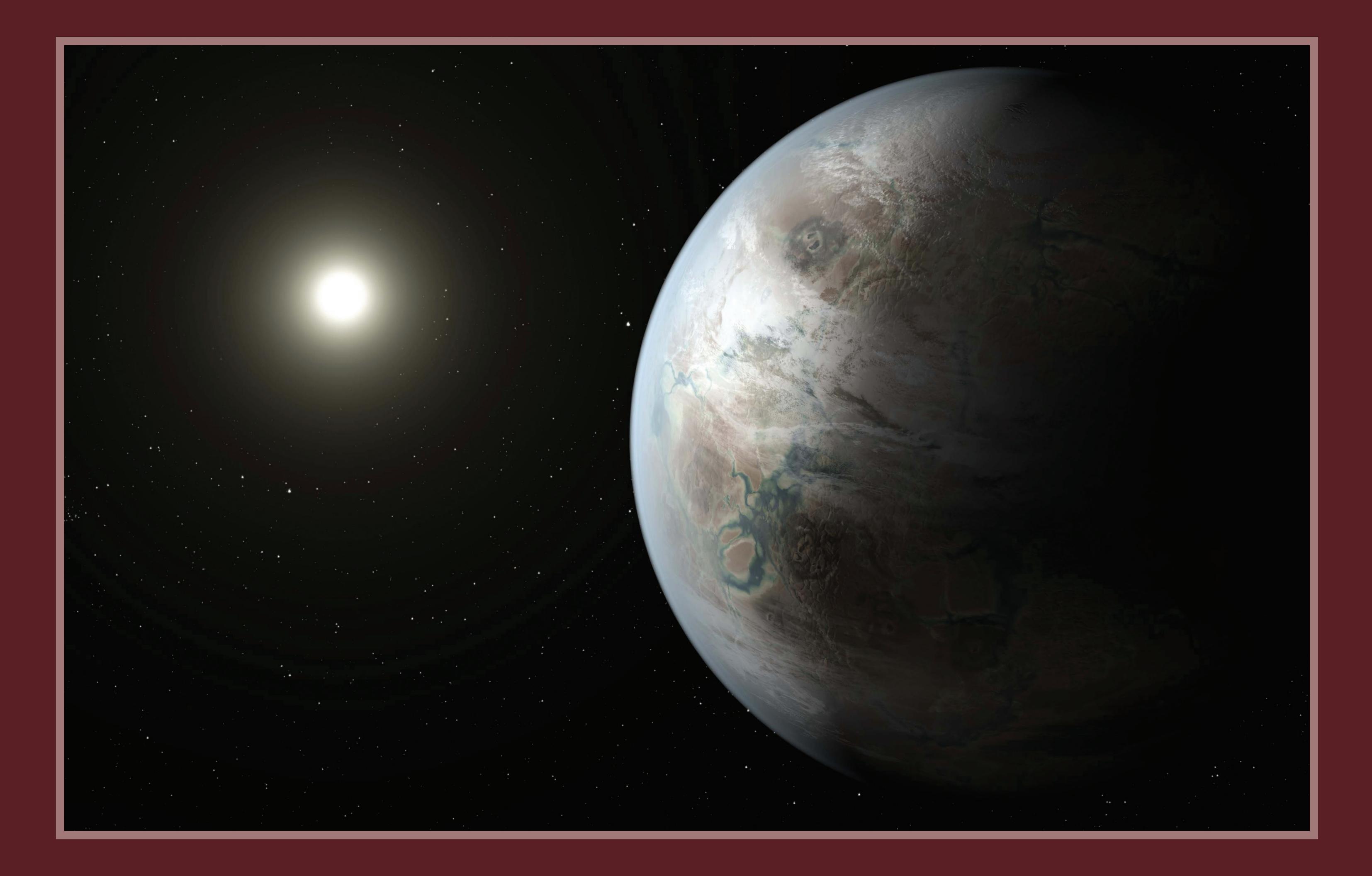
Credit: NASA Ames/SETI Institute/JPL-Caltech



National Aeronautics and Space Administration



Kepler-452b



The first super-Earth-sized exoplanet in the habitable zone around a Sun-like star.

Credit: NASA Ames/JPL-Caltech/T. Pyle

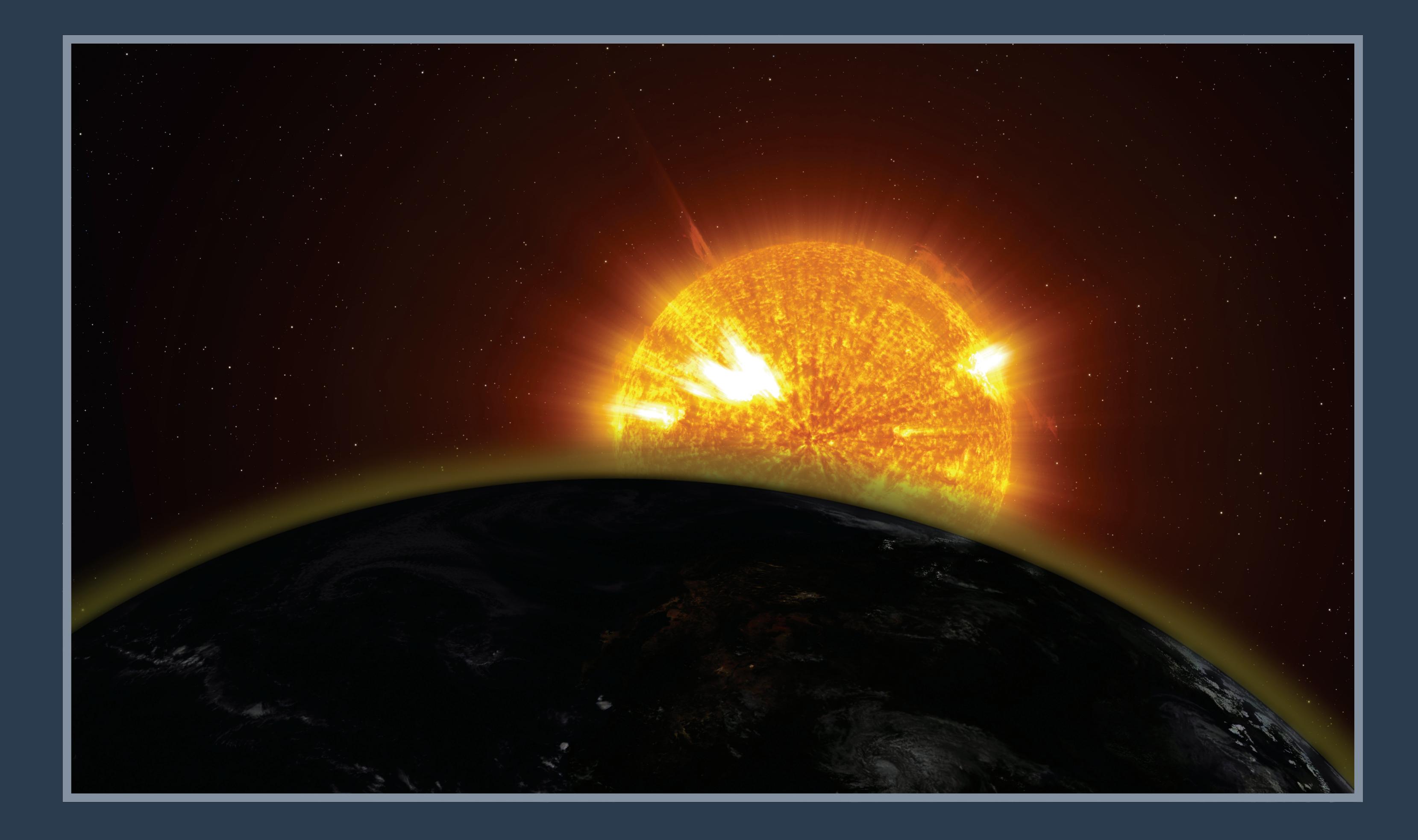


NASA's Great Observatories at the forefront of exoplanet science

EXAMETS Analyzing Alien Atmospheres

National Aeronautics and Space Administration





In 2000, NASA's Hubble Space Telescope first detected an atmosphere around an exoplanet. Since then, Hubble has examined the atmospheres of multiple alien worlds, finding a wealth of chemicals, including organic molecules and water.

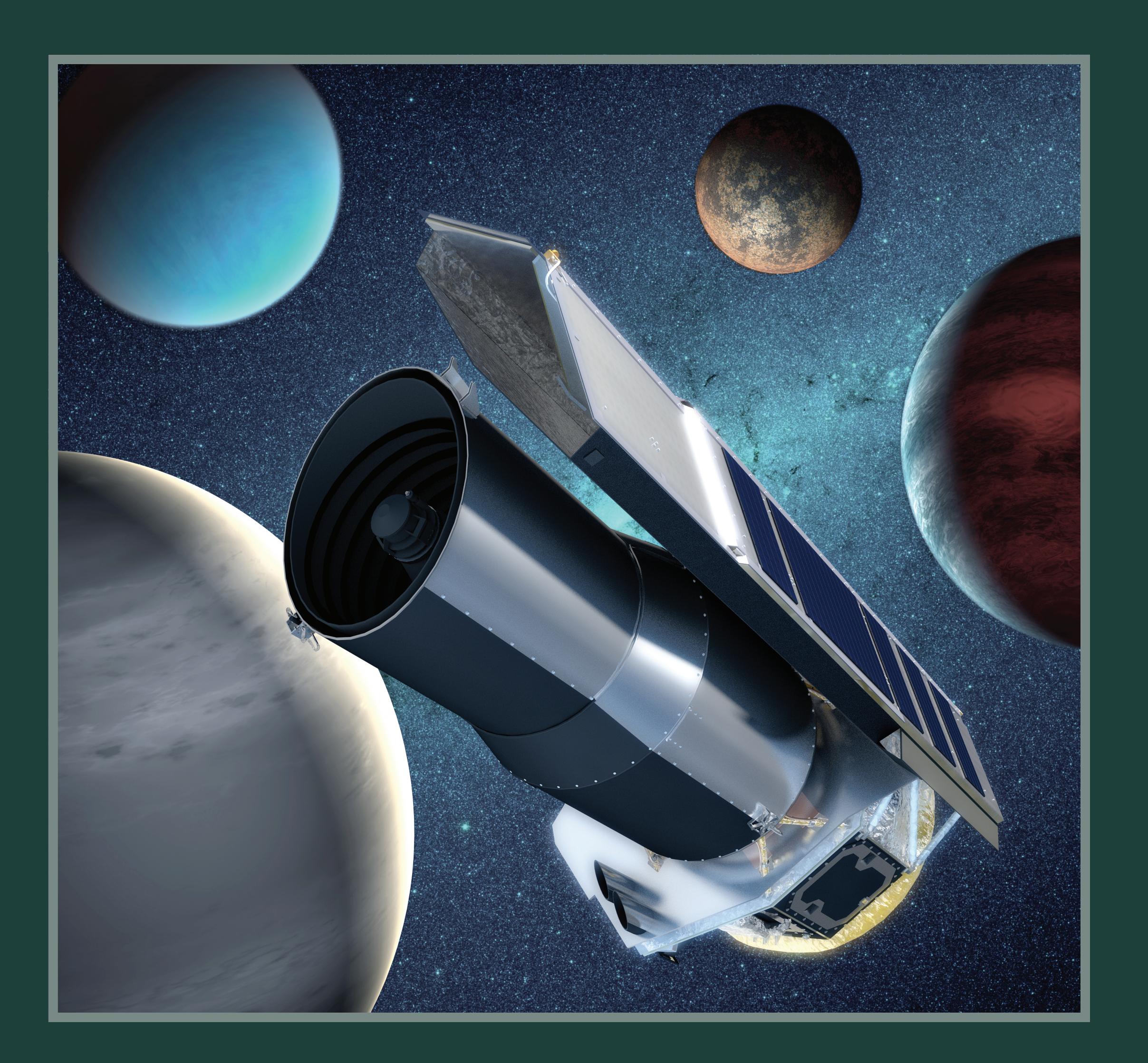
Astronomers study habitability by observing changes in the light of the host star as it passes through the planet's atmosphere, as shown here.

Credit: NASA Goddard Space Flight Center



NASA.

How's the Weather?



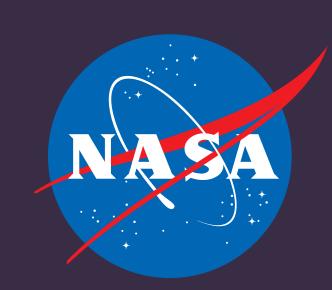
The Spitzer Space Telescope is measuring the warmest worlds and finding the coldest ones. With its sensitive IR camera in orbit around the Sun, Spitzer uniquely furthers our understanding of planets around other stars.

Spitzer is able to detect the thermal emission from exoplanets, is the only mission directly measuring their dayside temperatures, and, in conjunction with HST, is determining the composition of their atmospheres. Spitzer also finds cooler planets in two ways: (1) by detecting distant, large Jupiter-like planets through their infrared light and (2) by observing the bending of the light of background stars by planets as small as Mars.

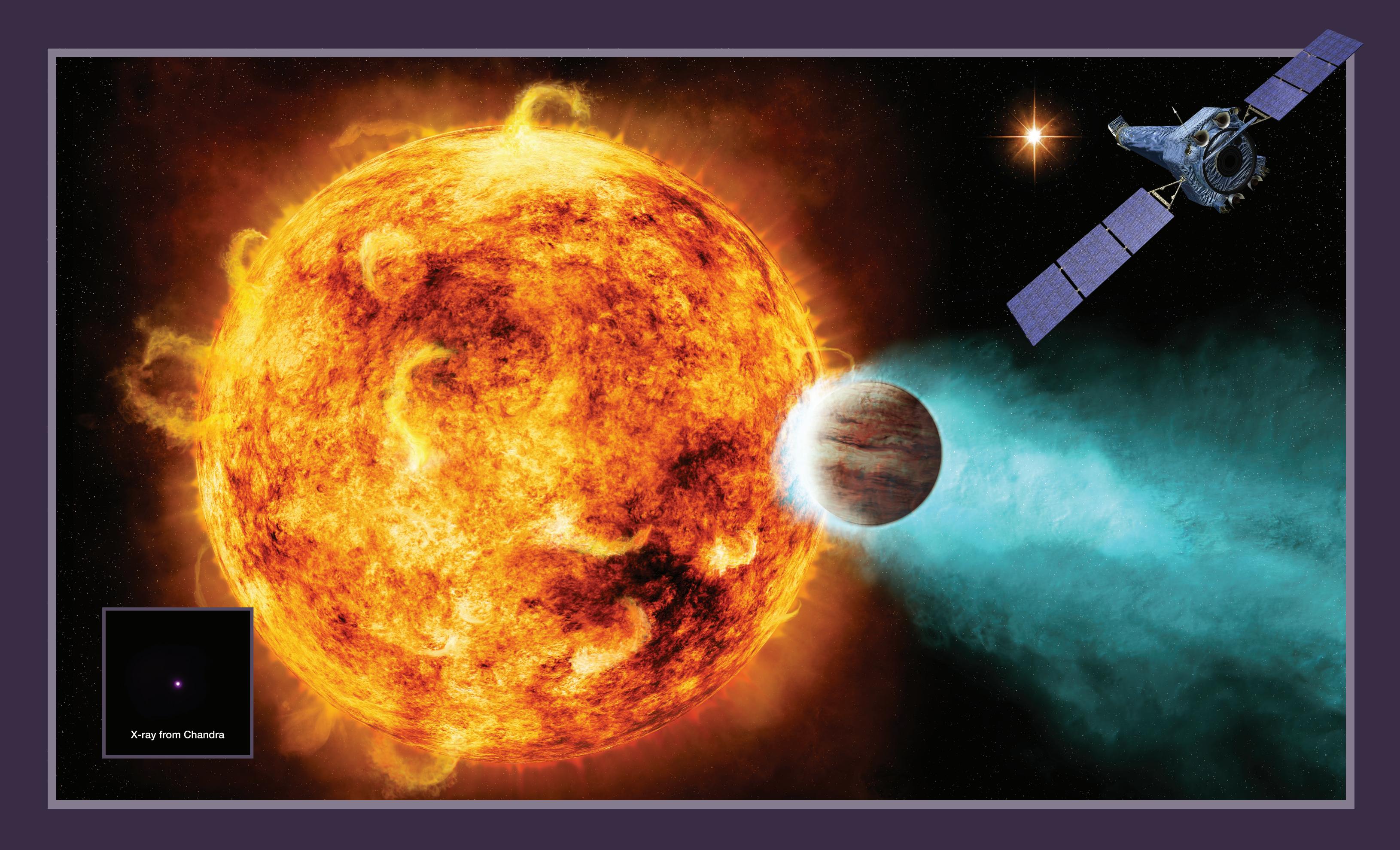
Spitzer's discoveries are fundamental for follow-up by future NASA missions JWST and WFIRST.



National Aeronautics and Space Administration



Exoplanets and Chandra



X-ray observations from NASA's Chandra X-ray Observatory can detect exoplanets passing in front of their parent stars and help contribute to the growing knowledge of these exotic worlds.

For example, CoRoT-2 is an exoplanet that is in extremely close orbit with its host star, as seen in this artist's illustration. Researchers discovered that the star is blasting the planet with a very high level of X-rays. This intense radiation may be eroding the planet at a rate of 5 million tons of material per second.

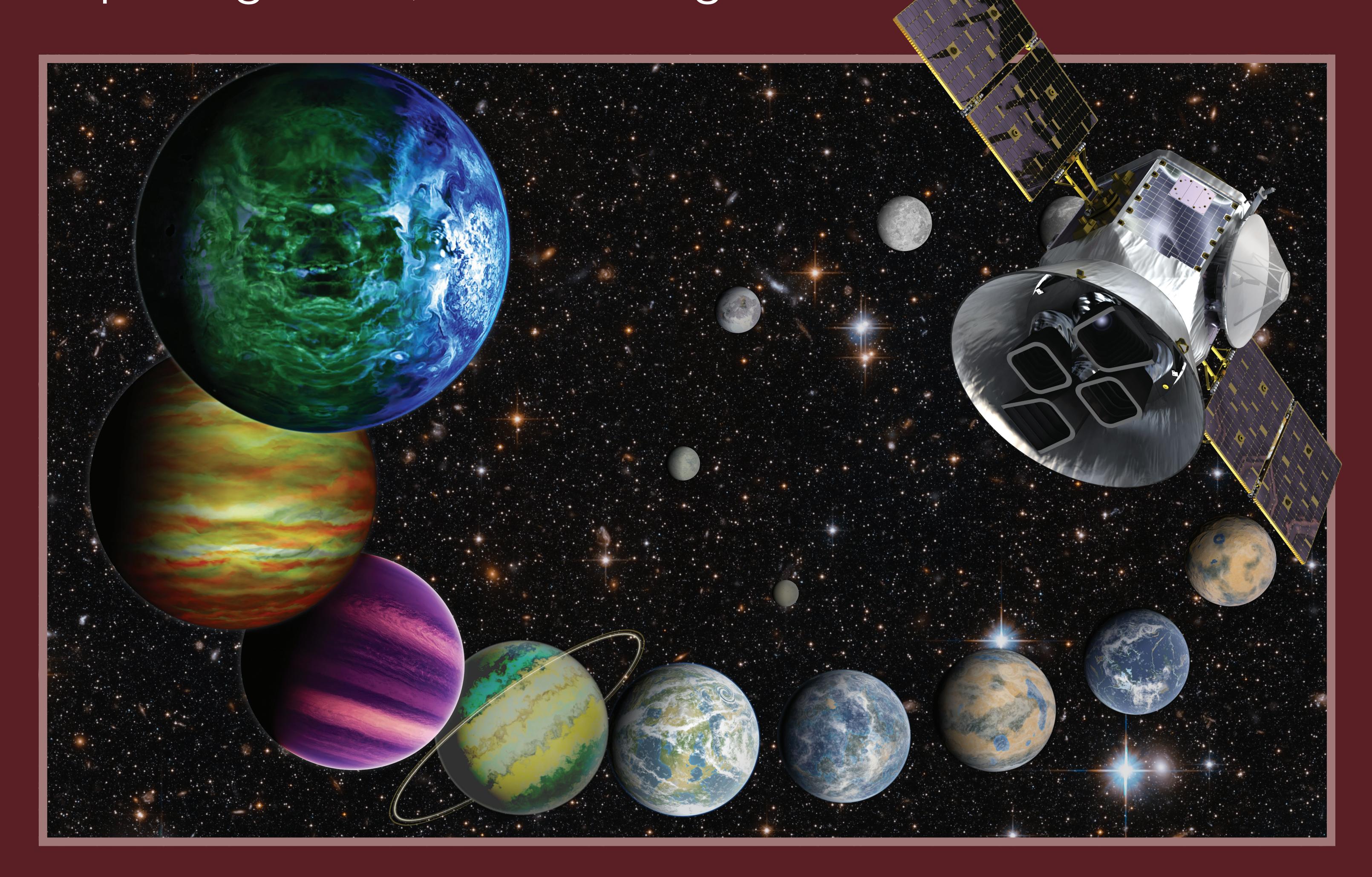
Illustration: NASA/CXC/M.Weiss; X-ray: NASA/CXC/Univ of Hamburg/S.Schröter et al.



Looking to the future



Exploring Stars, Discovering Worlds



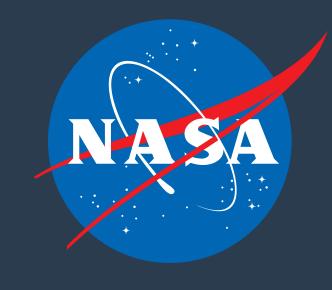
The Transiting Exoplanet Survey Satellite (TESS) will find planets in our galactic neighborhood to study into the future. By discovering and collecting information about these planets, their orbit, and compositions, TESS will give other missions favorable targets to investigate important questions such as whether a planet can support life.

This first-ever spaceborne all-sky transit survey will identify planets, ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances.



James Webb Space Telescope

National Aeronautics and Space Administration

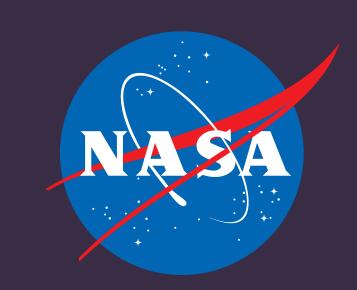


Secondary Eclipse Orbital Phase Variations See cyclical variations in brightness of planet Wavelength (micrometers) through the planet's atmosphere

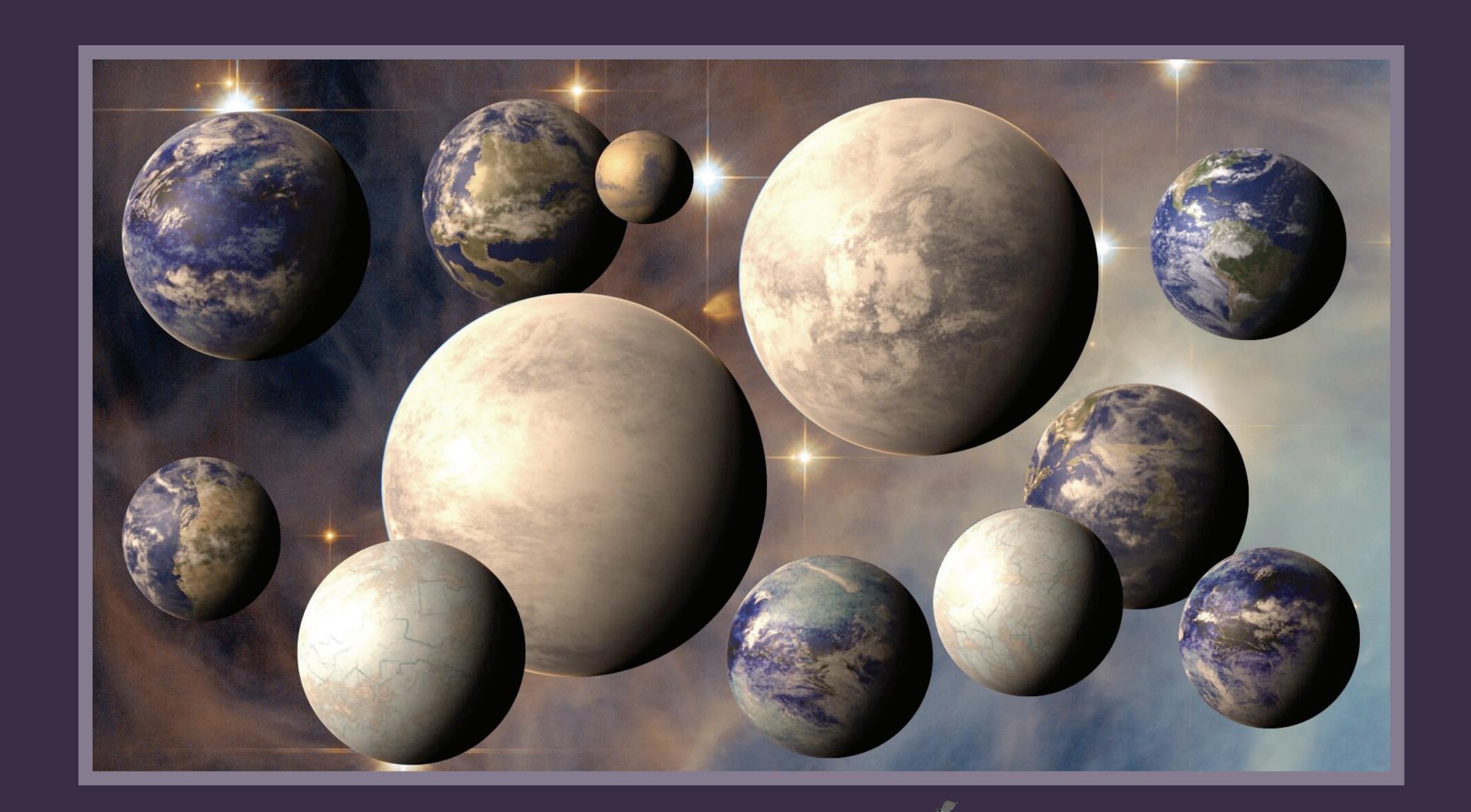
The James Webb Space
Telescope will be used to observe
transiting exoplanets along all
phases of their orbits. Transit
spectra will reveal details
about exoplanet atmospheric
compositions. Secondary eclipse
observations will be used to
measure the reflected and
intrinsic thermal radiation from
the exoplanets. Data from other
points along the planetary orbit
will yield information about its
albedo (reflectivity) and horizontal
temperature structure.

Credit: Northrop Grumman





Exploring Exoplanetary Systems



Kepler's Field of View

Main Belt Asteroids (2.3-3.3AU)

Mars (1.5AU) Jupiter (5.2AU) Saturn (9.5AU) Uranus (19.6AU)

Farth (1.0AU)

Venus (0.7AU)

Mercury (0.4AU)

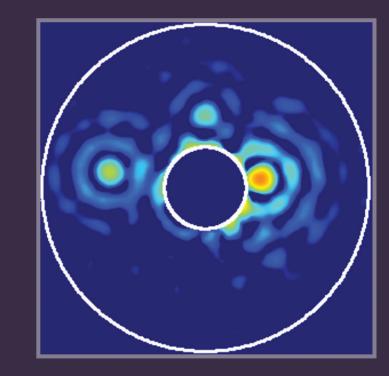
Sun

WFIRST's Field of View

+

Figure B

Advanced coronagraph technology will enable WFIRST to directly image exoplanets and study them.



NASA is studying the Wide-Field Infrared Survey Telescope (WFIRST), a new strategic mission that could launch in the middle of the next decade. To advance exoplanet research, WFIRST features two major exoplanet surveys.

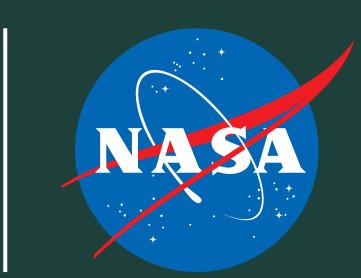
WFIRST will complete the census of exoplanets, including rocky planets in the habitable zone—those most likely to be like Earth. WFIRST is sensitive enough to measure planets smaller than Mars and will find planets around other stars at distances similar to what is found in our own solar system (Figure A).

WFIRST will directly image exoplanets around nearby stars by using a coronagraph (Figure B) to block the light of those stars. Super-Earths are the most numerous planets currently known. Do they all have atmospheres? Do their atmospheres show signs of water, a key part of life as we know it? Do they show signs of methane, potentially indicative of life? WFIRST's coronagraph will pave the way for a future mission designed to study other worlds like our own in the quest to find life elsewhere in the universe.

Credit: PHL @ UPR Arecibo (phl.upr.edu), ESA/Hubble, NASA

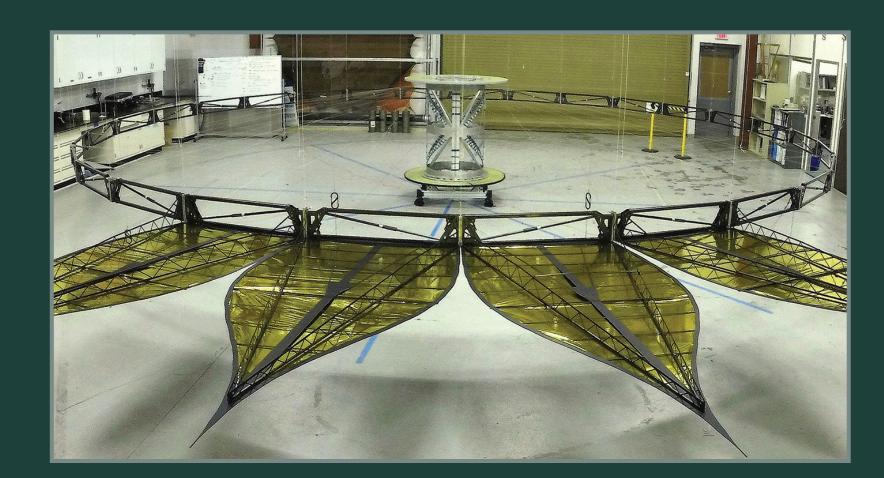


Toward Life on Other Worlds

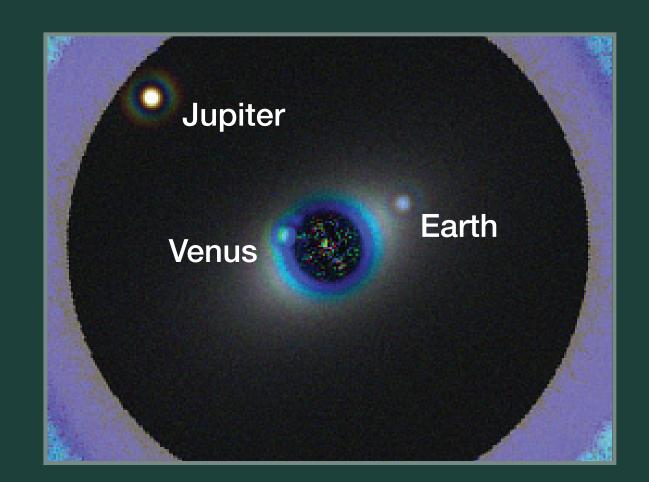


NASA is developing ambitious future missions intended to find signs of life on worlds around other stars. Those clues would be present in the planet's atmosphere: water vapor indicating an ocean, oxygen from green plants, and methane from bacteria. NASA also studies more exotic life found in extreme environments on our own planet to understand what surprises we might discover on other worlds.

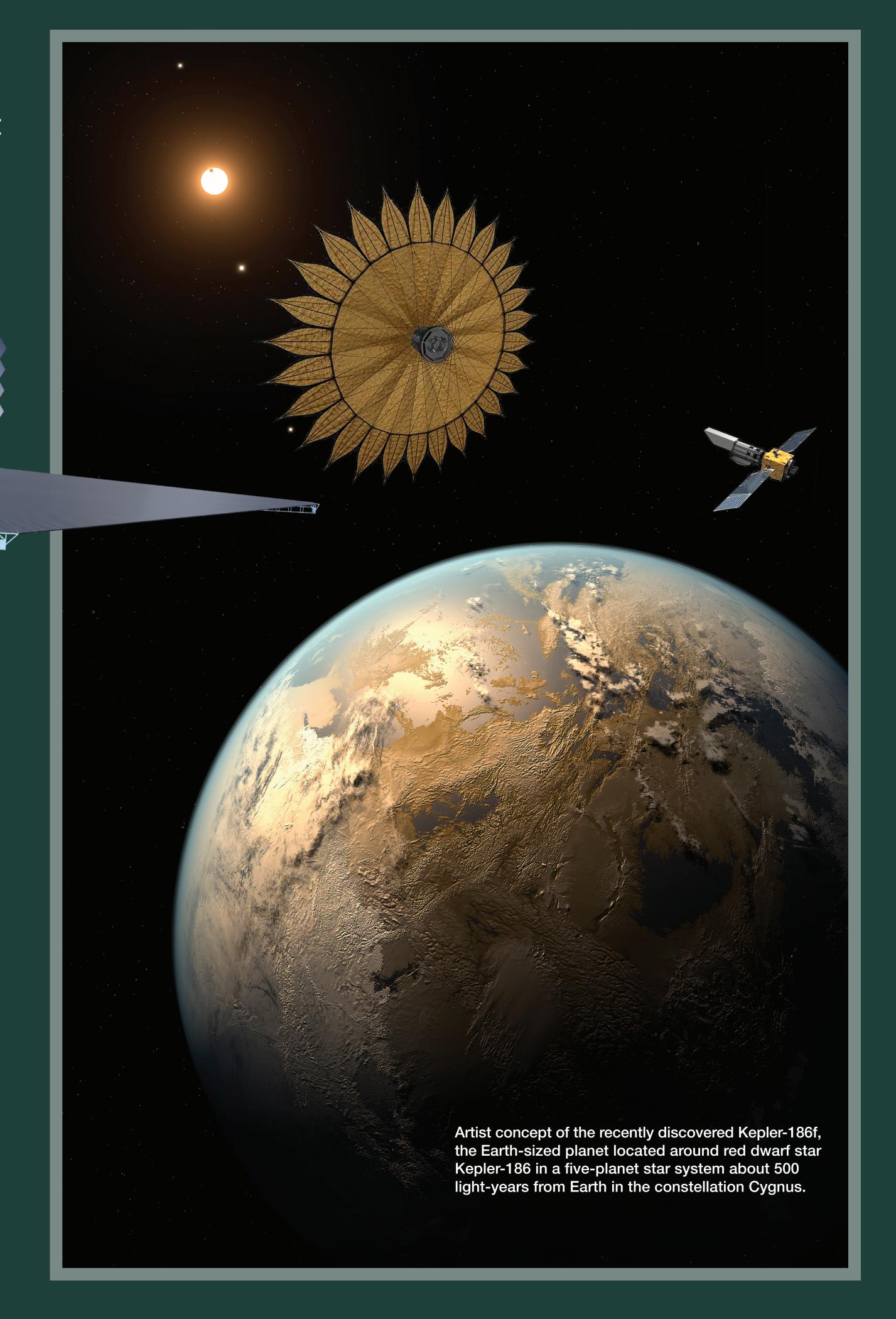
To achieve this challenging goal, we need to massively suppress the bright light from the stars to see faint orbiting planets. Two technologies being developed to achieve this are starshades and coronagraphs, which are displayed here.



Starshades are independent spacecraft tens of meters in diameter, flying tens of thousands of kilometers out in front of their host telescope. The petals on the shade suppress the "leakage" of starlight around the shade into the telescope in much the same way a hand blocks the Sun (concept mission far right).



Coronagraphs are placed inside the telescope and use a small mask to cover the star. Additional advanced optics, such as deformable mirrors, further control the leakage of light around the mask. Shown here is a simulation of our inner solar system viewed with a coronagraph mounted on the large space telescope (concept shown above).



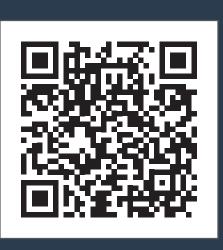


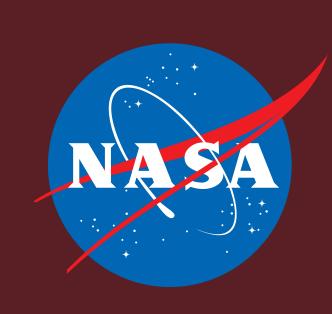


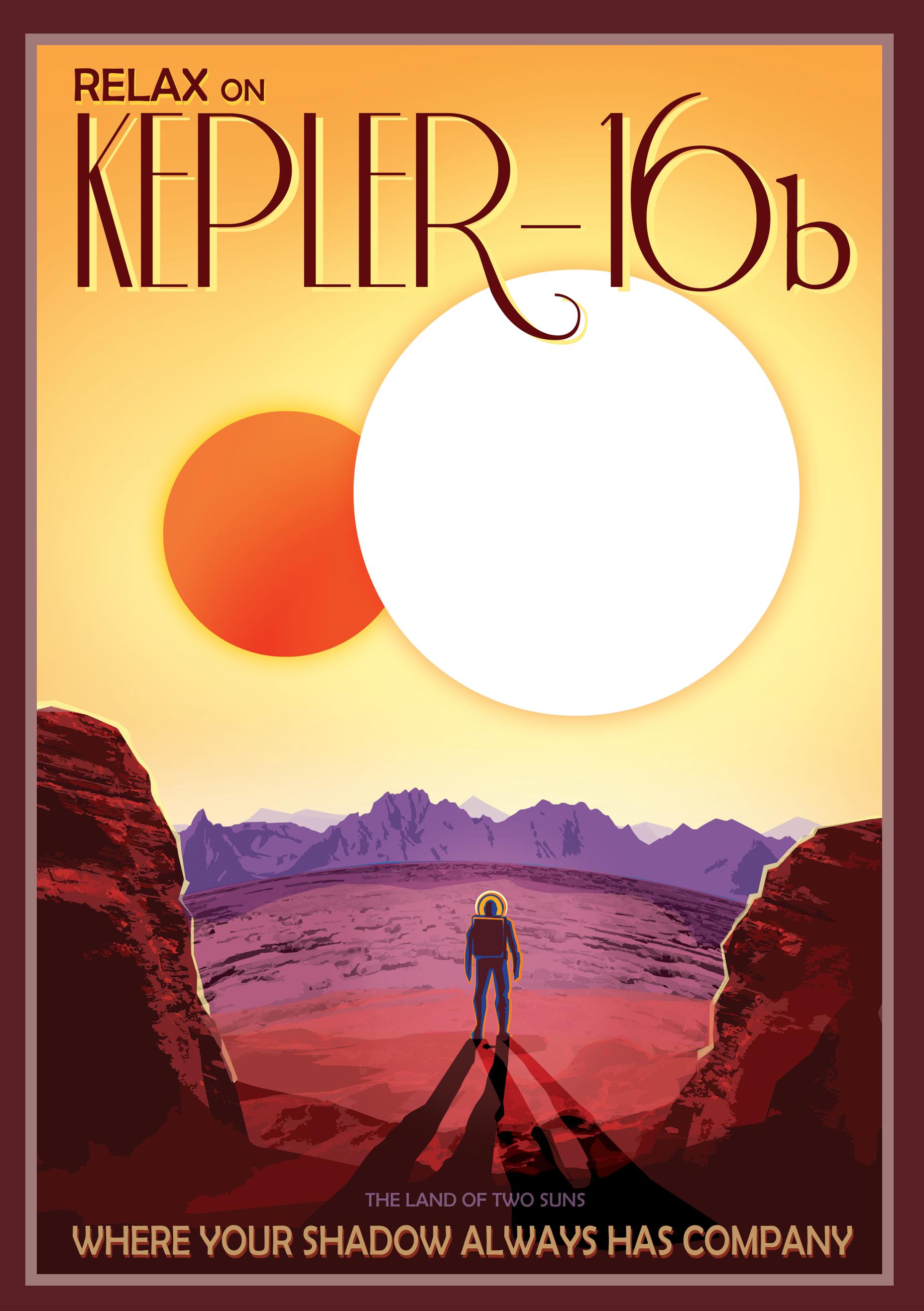


51 Pegasi b

While there is much debate over which exoplanet discovery is considered the "first," one stands out from the rest. In 1995, scientists discovered 51 Pegasi b, forever changing the way we see the universe and our place in it. The exoplanet is about half the mass of Jupiter, with a seemingly impossible, star-hugging orbit of only 4.2 Earth days. Not only was it the first planet confirmed to orbit a Sun-like star, but it also ushered in a whole new class of planets called "hot Jupiters": hot, massive planets orbiting closer to their stars than Mercury orbits our Sun. Today, powerful observatories like NASA's Kepler space telescope will continue the hunt of distant planets.







KEPLER-16b

Like Luke Skywalker's planet Tatooine in *Star Wars*, Kepler-16b orbits a pair of stars. Depicted here as a terrestrial planet, Kepler-16b might also be a gas giant like Saturn. Prospects for life on this unusual world aren't good, as it has a temperature similar to that of dry ice. The discovery indicates that the movie's iconic double-sunset is anything but science fiction.







PS0 J318.5-22

Discovered in October 2013 using direct imaging, PSO J318.5-22 belongs to a special class of planets called rogue, or free-floating, planets. Wandering alone in the galaxy, they do not orbit a parent star. Not much is known about how these planets come to exist, but scientists theorize that they may be either failed stars or planets ejected from very young systems after an encounter with another planet. These rogue planets glow faintly from the heat of their formation. Once they cool down, they will be dancing in the dark.



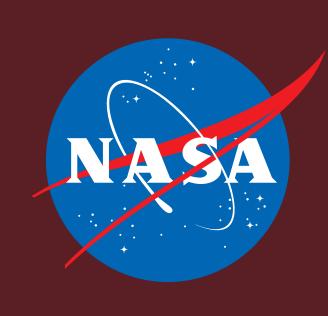




HD 40307g

Twice as big in volume as the Earth, HD 40307g straddles the line between "super-Earth" and "mini-Neptune," and scientists aren't sure if it has a rocky surface or one that's buried beneath thick layers of gas and ice. One thing is certain, though: at eight times the Earth's mass, its gravitational pull is much, much stronger.







KEPLER-186f

Kepler-186f is the first Earth-sized planet discovered in the potentially "habitable zone" around another star where liquid water could exist on the planet's surface. Its star is much cooler and redder than our Sun. If plant life does exist on a planet like Kepler-186f, its photosynthesis could have been influenced by the star's red-wavelength photons, making for a color palette that's very different from the greens on Earth. This discovery was made by Kepler, NASA's planethunting telescope.

