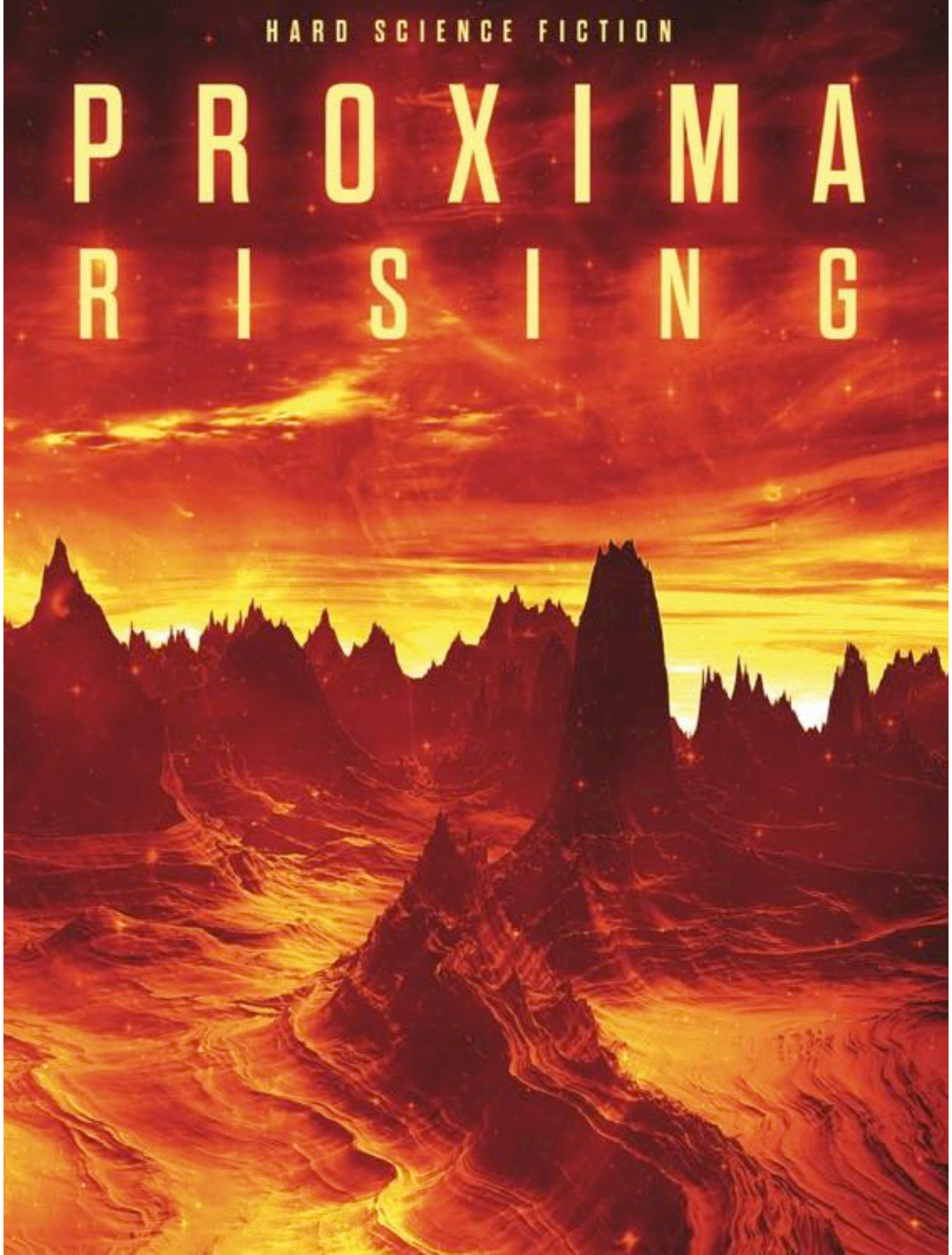
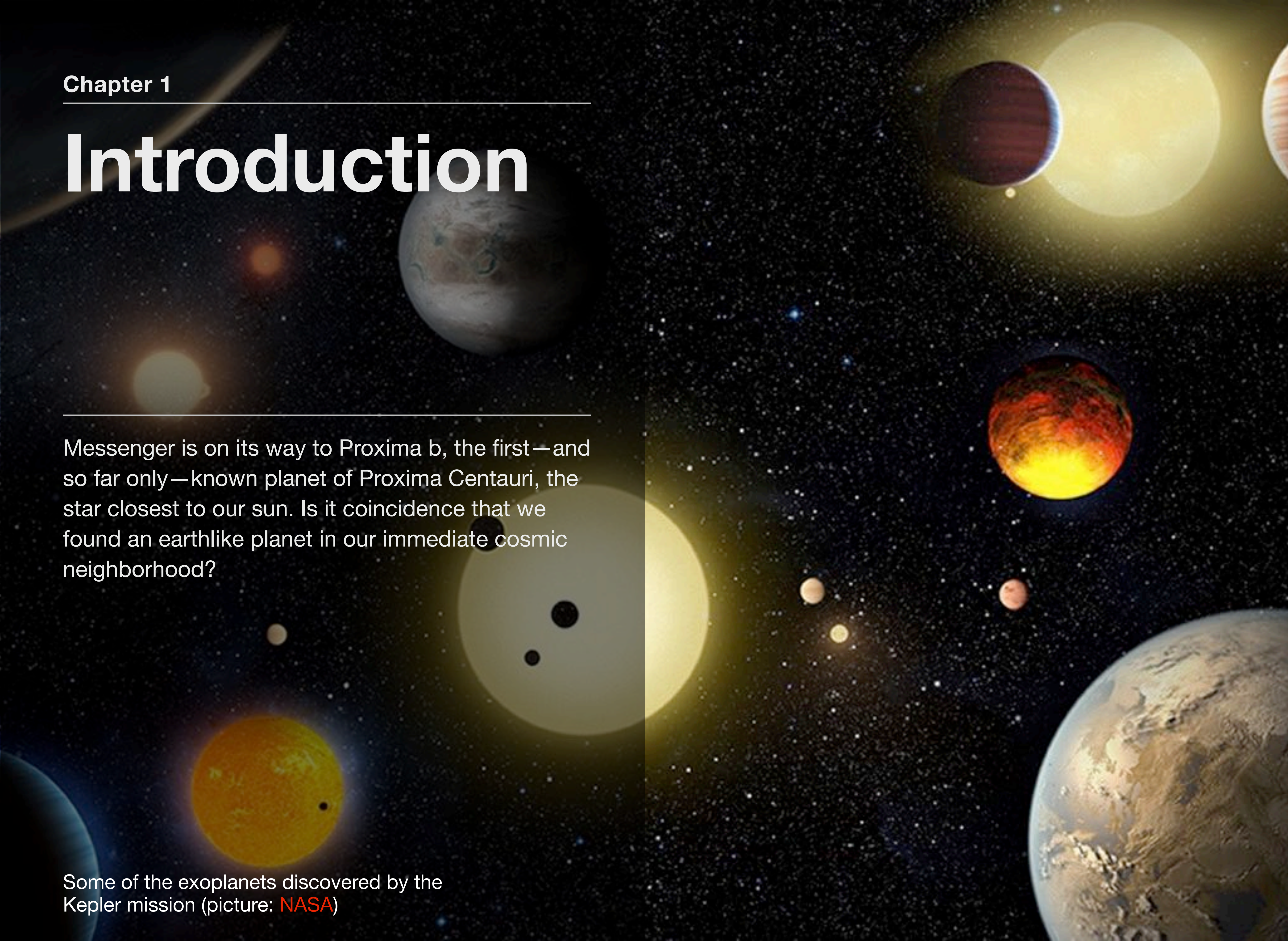

HARD SCIENCE FICTION
PROXIMA
RISING

Chapter 1

Introduction

Messenger is on its way to Proxima b, the first—and so far only—known planet of Proxima Centauri, the star closest to our sun. Is it coincidence that we found an earthlike planet in our immediate cosmic neighborhood?



Some of the exoplanets discovered by the Kepler mission (picture: NASA)

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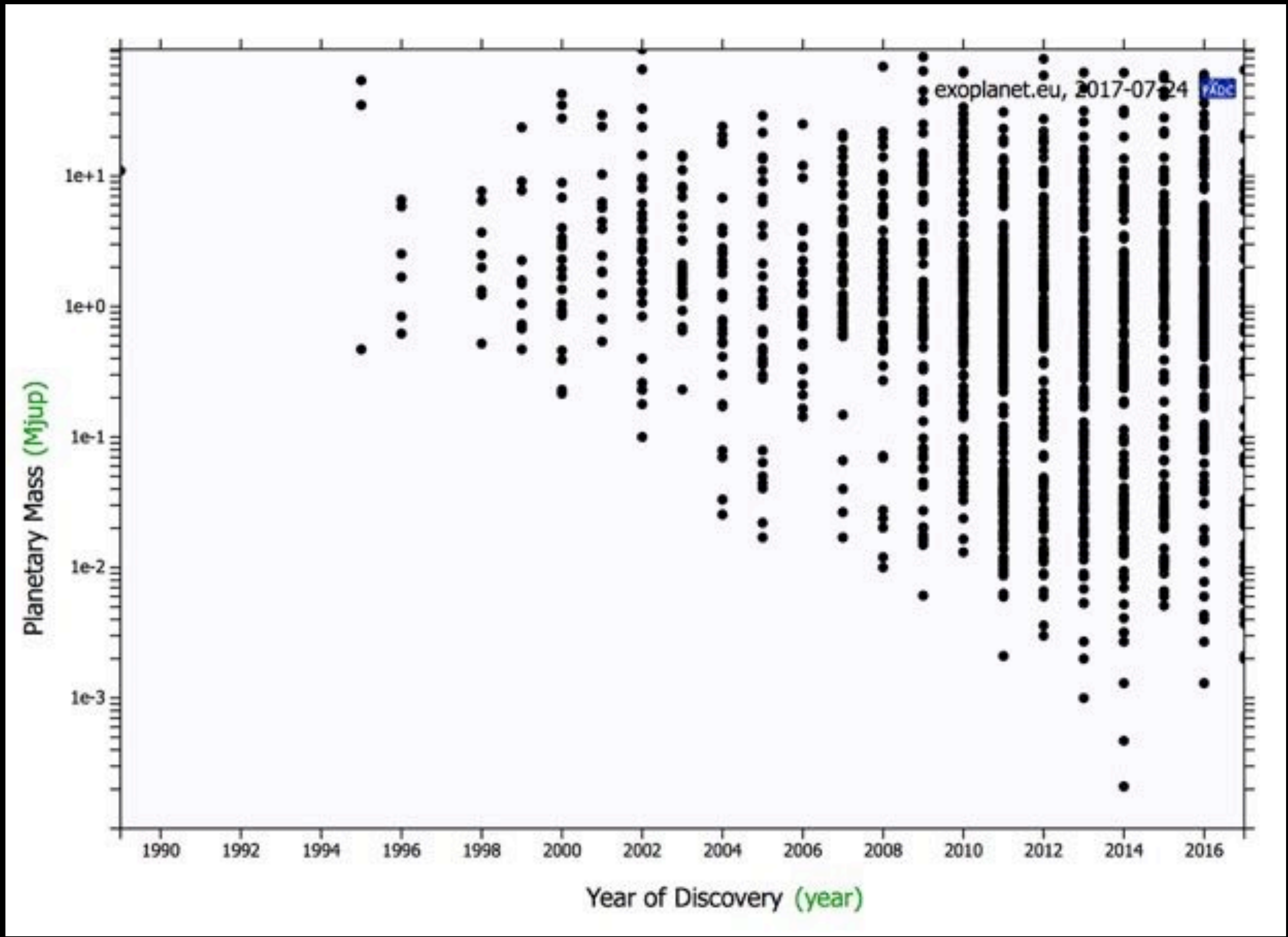
Introduction

No, not at all. It would be strange if we had looked for one in vain. Today astronomers know that most stars develop a planetary system during their lifetime. It is estimated that the number of planets exceeds that of stars. On average, each star possesses between one and two planets. The Milky Way, with its 200 billion stars, might accordingly contain about 300 billion planets.

However, great variability exists. There are gas giants that closely orbit their mother star and are almost as hot. Far on the outskirts there are ice planets, like Neptune in our solar system. Then there are planets comparable to Earth, and there are also a large number of cosmic loners racing through the solitude of space without a star. What these systems specifically look like—and if life could develop there—depends on the local circumstances.



Exoplanet discoveries per year, sorted by mass. Detection methods obviously have become increasingly better

We are now going to examine possible characteristics and variations. I am going to use the terms ‘planet’ and ‘exoplanet’ as

Chapter 1

Introduction

synonyms—actually any planet not orbiting our sun is an exoplanet. This, however, is a very ‘human-centric’ perspective, since any extraterrestrial would clearly classify Mars, Venus, and Earth as exoplanets.

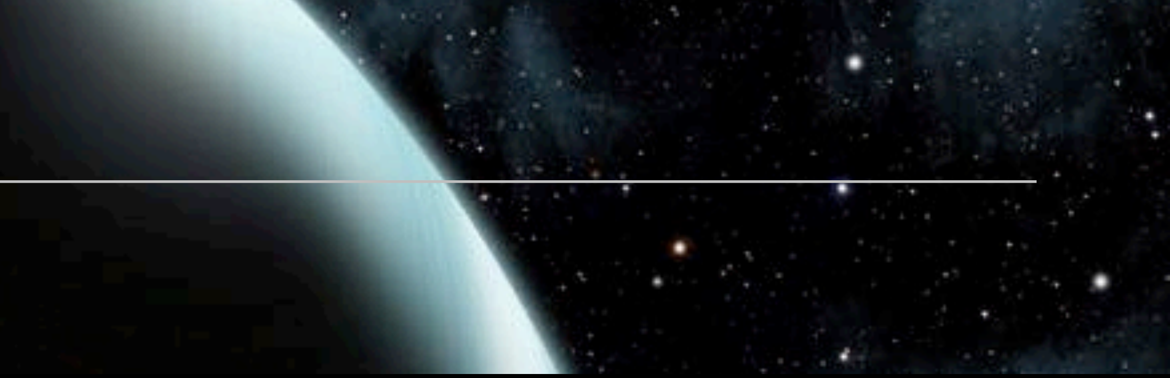
The milkyway without the stars, just the planets are shown (picture: ESO/M. Kornmesser)

Chapter 2

Naming and Types

Before a planet comes into being, a young star—or two or three, which is the norm—grows within a cosmic disk of gas and dust. The cloud condenses more and more strongly at its center, until it becomes so hot and dense that the fusion of hydrogen nuclei—i.e. protons—begins.

Exoplanet Kepler-421 b (artist‘s view) is a bit larger than Uranus



Chapter 2

Naming and Types

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Yet, this does not use up the entire material of the cloud. Normally, considerably less than ten percent of the total mass remains, which is still located within the rotating disk of gas and dust. The heat of the young star allows only elements with a high atomic number to condense in the inner area—iron, nickel, silicon, and so on. These then form the rocky planets. Further out, where it is colder, the lighter hydrogen and helium atoms can condense. Accordingly, the planets developing in this region contain more of the plentiful gases.

This explains the basic division of planets into rocky planets and gas planets. Later, there still might be some changes. Gas planets can wander inward and push smaller rocky planets into the sun, or even completely out of the system. Sometimes the mass available in a certain orbit is insufficient for a complete planet. Then an asteroid belt forms, like the one between Mars and Jupiter. At the outer fringes of the system, the cloud is too thin for larger objects to develop. Here dwarf planets or comets come into being. In our solar system, the Kuiper belt and the Oort cloud represent these celestial garbage dumps.

However, the planets also change during their lifetime. A gas planet, for instance, might lose its gas under the influence of its star—then only its core remains as a rocky planet.

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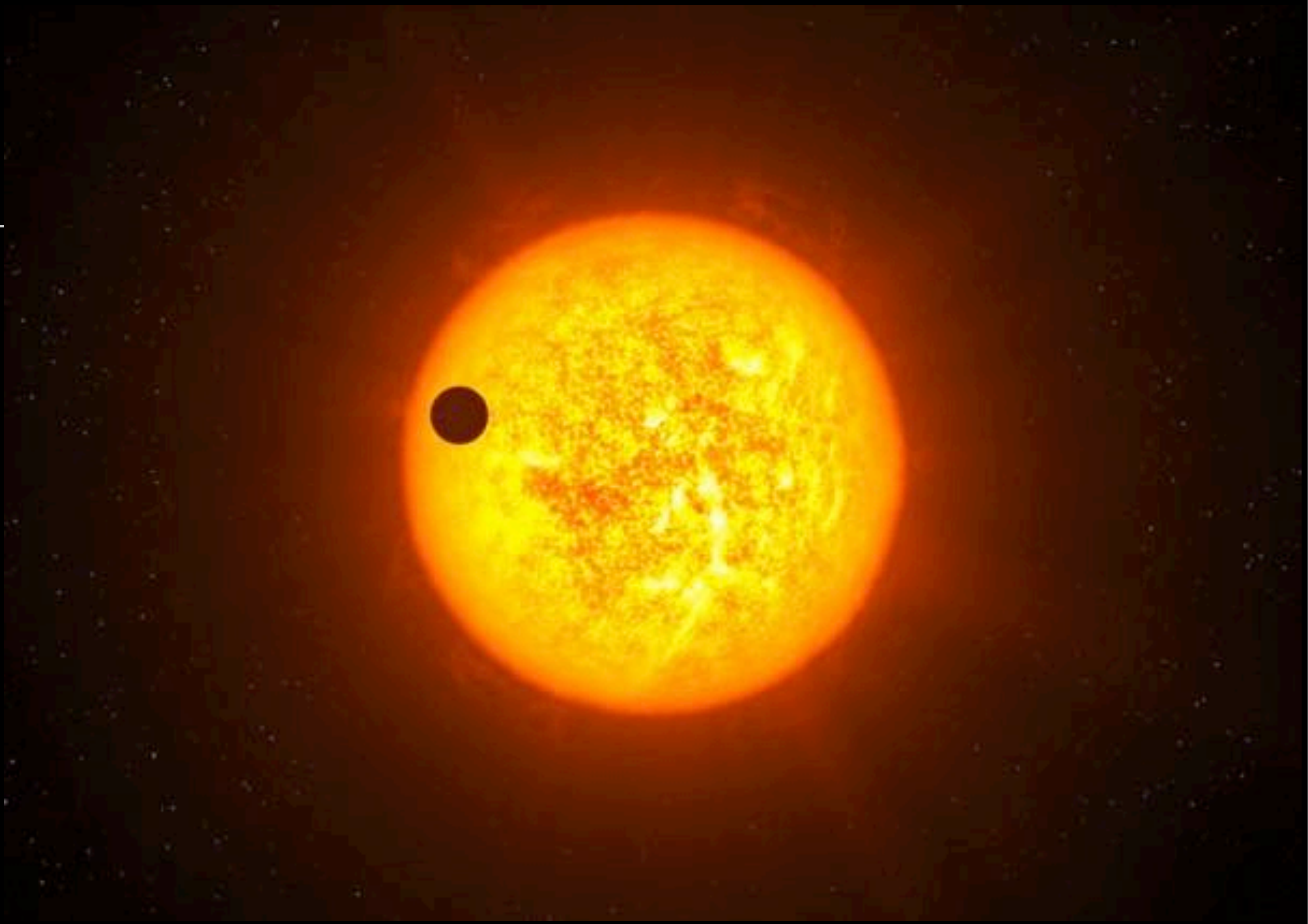
Naming and Types

It might be a bit Earth-centric again, but exoplanets are often classified after their counterparts in our solar system.

GAS GIANTS (JUPITERS)

Gas giants consist mostly of light gases like hydrogen and helium, and they do not have solid surfaces. Instead, the gas becomes more dense with increasing depth, and at some point it reaches a solid state. Hydrogen can even become metallic. These factors make it difficult to precisely measure the size of gas giants. Therefore, the point where the atmospheric pressure equals that on the surface of Earth is defined as a gas planet's surface, while everything above it is considered atmosphere.



Corot-9b orbits a star at a distance of 1500 ly in the constellation of the Snake. It has 20 times the mass of Erath (picture: ESA)

Gas giants cannot exceed 13 times the mass of Jupiter, which is about 1.2 percent of the mass of the sun. If a planet gets heavier, the pressure in its interior becomes so high that deuterium fusion processes set in... and it becomes a brown dwarf. Brown dwarfs assume a position between planets and stars because no hydrogen-helium fusion happens inside them. This type of fusion is a defining feature of true stars, but it only occurs at about 70 times the mass of Jupiter.

HOT GAS GIANTS (HOT JUPITERS)

Hot gas giants are gas giants with one special characteristic: They move around their mother star in a very tight orbit, with an orbital period shorter than ten days. They can form in either of two ways: when a gas giant wanders too far inside the system; or when a rocky planet sucks up so much gas it becomes a gas giant. Due to their proximity to a star they are extraordinarily hot, some exhibiting temperatures of several thousand degrees. The chance of life existing on them is minimal. Due to their large mass and their short orbital periods they were among the first exoplanets to be discovered. Some of them have been expanded by the heat of their star, reaching gigantic proportions. Then they are called ‘Hot Saturns’—Saturn also has a relatively low density.

ICE PLANETS (NEPTUNES)

Ice planets have a structure similar to gas giants, but instead of primarily consisting of light hydrogen and helium atoms, they are composed of compounds with nitrogen, oxygen, carbon, or sulfur. The ‘ice’ in their names does not refer to water ice, although water

189733b is a hot Jupiter. It orbits a yellow dwarf that is 63 ly away from us. (picture: Hubblesite, artist‘s impression)

Chapter 2

Naming and Types

is usually present in liquid form in the interior of these planets. However, other compounds such as methane, ammonia, or sulfur dioxide can exist here in frozen form. Sometimes, though, the ice planets have a hydrogen layer that can amount to almost a fifth of their mass.

HOT ICE PLANETS (HOT NEPTUNES)

If an ice planet ventures too close to its star, it is no longer an ice planet, since the heat of the star also warms up its interior. Then it is designated a 'Hot Neptune.'

MOA-2007-BLG-192Lb is a planet orbiting a brown dwarf. It is similar to Neptune and has at least three Earth masses. (picture: NASA, artist's impression)

EARTH-LIKE PLANETS

Compared to gas giants, rocky planets like Earth are much harder to discover due to their small size. On the other hand, they are very common. According

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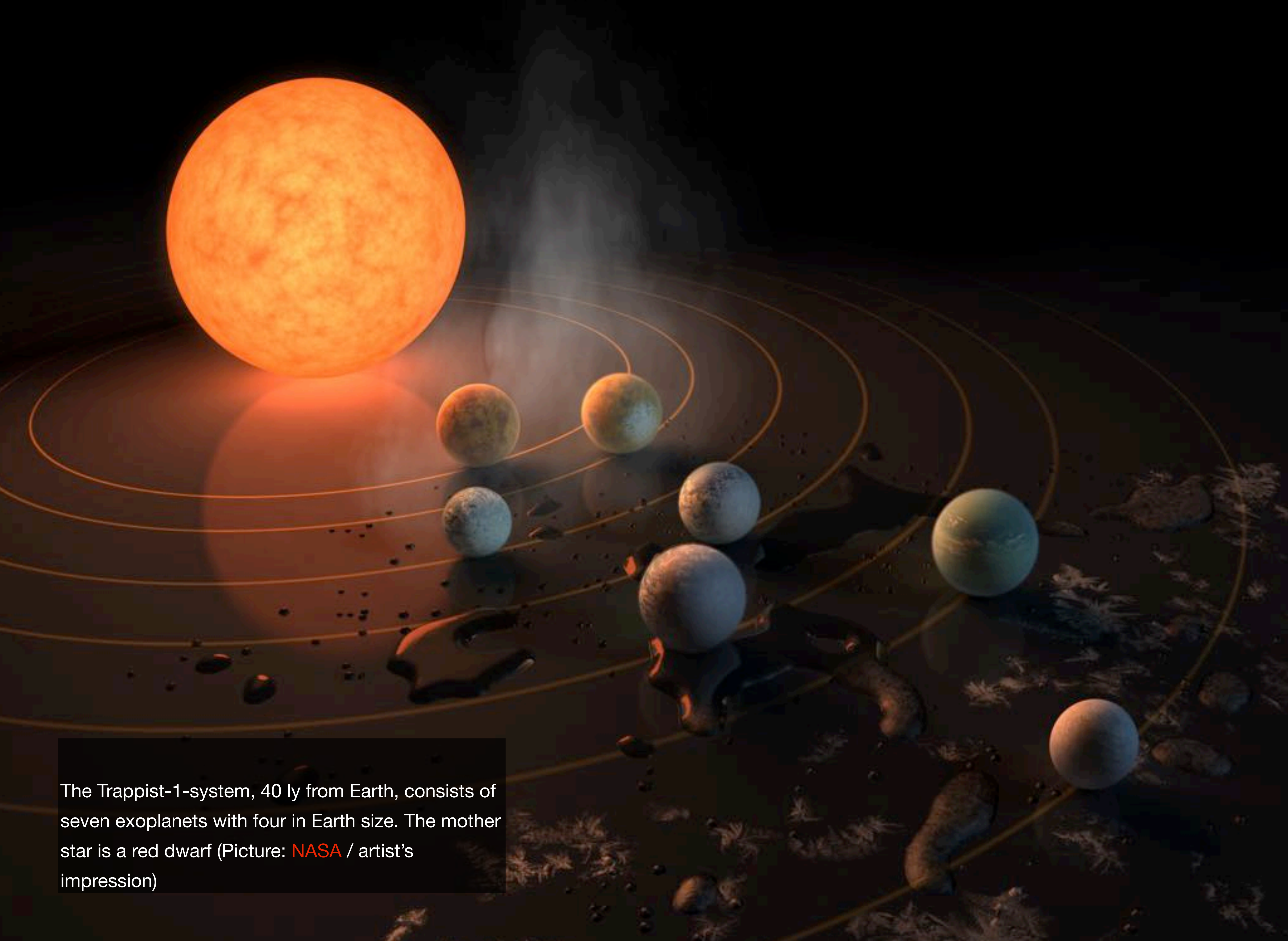
Naming and Types

to some estimates, one in five sun-like stars might have an Earth-like companion in its habitable zone. That means there could be 11 billion potentially-habitable planets in the Milky Way alone. In addition, there are planets orbiting smaller stars such as red dwarfs, for which no good statistics yet exist.

Earth-like planets might not look like exact replicas of Earth. The only common defining feature is that they have a solid surface with rock underneath it. The interior is often structured in layers, with a hot, sometimes liquid core of iron and other heavy elements. Above that might be a mantle of silicates and a crust, which is also made of silicates and other light components. This is sometimes followed by a layer of air, i.e. atmosphere. Some planets have water on the surface—a hydrosphere.

Kepler-186f, with 1,1 times the mass of Earth, orbits its mother star (a red dwarf 500 ly from Earth) together with four more planets (Picture: NASA, artist‘s impression).



The Trappist-1-system, 40 ly from Earth, consists of seven exoplanets with four in Earth size. The mother star is a red dwarf (Picture: NASA / artist's impression)

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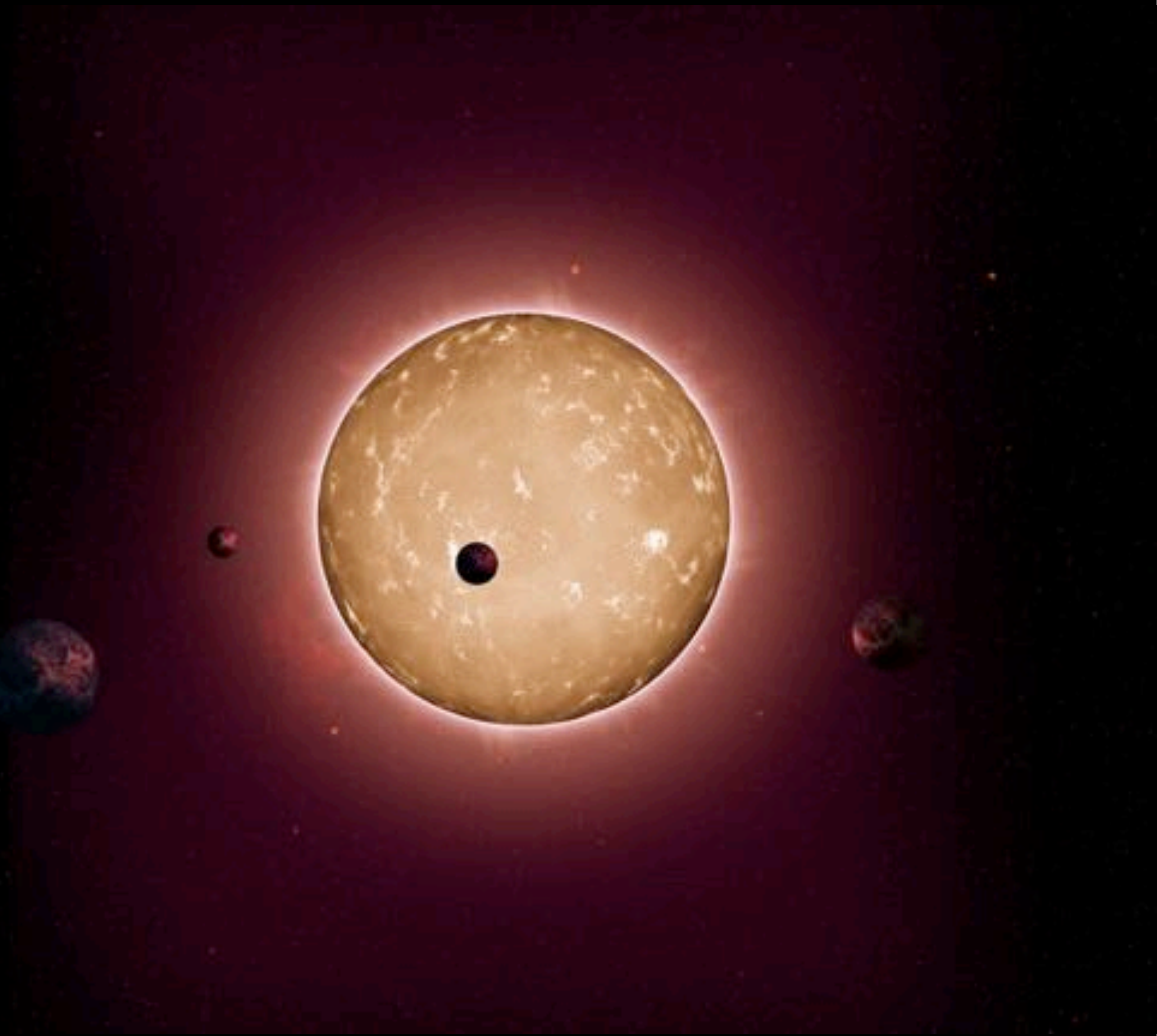
Naming and Types

HOT EARTH-LIKE PLANETS (VENUS-LIKE)

These rocky planets have a very high temperature—several hundred degrees, like Venus in our solar system—either because of proximity to their sun, or because they have dense enough atmosphere to create a greenhouse effect.

SUPER-EARTHS

So far, most of the rocky planets discovered belong to the group of Super-Earths, meaning their masses are greater than that of Earth. There are various definitions, ranging from between 1 and 14 times to between 5 and 10 times Earth's mass. However, the measurements are often subject to errors. Determining the diameter is insufficient to distinguish between a planet with a small rocky core plus a large gas cover, and a genuine rocky planet.

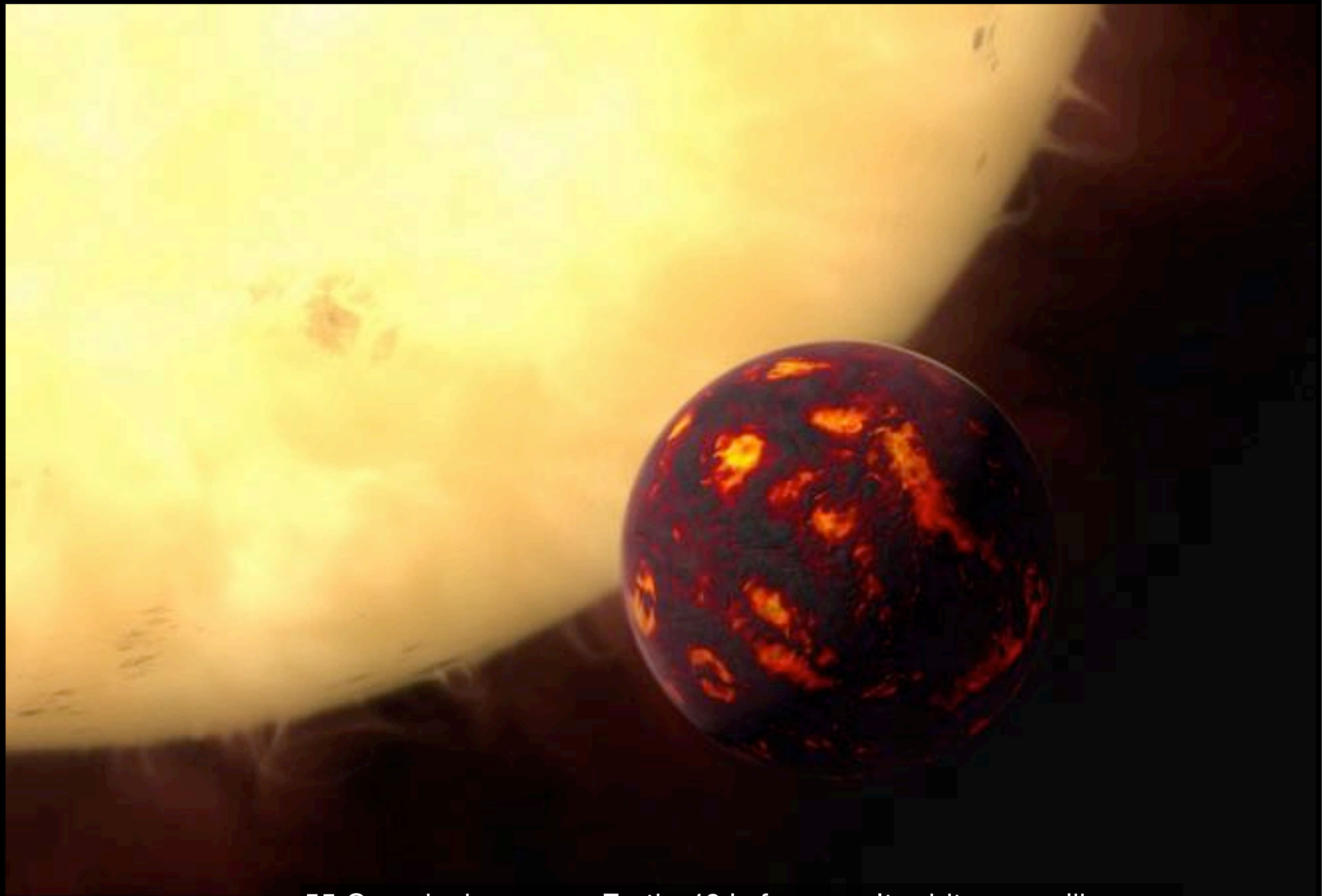


The star Kepler-444 is orbited by four planets; one is about the size of Venus. (Picture: NASA / artist's impression)

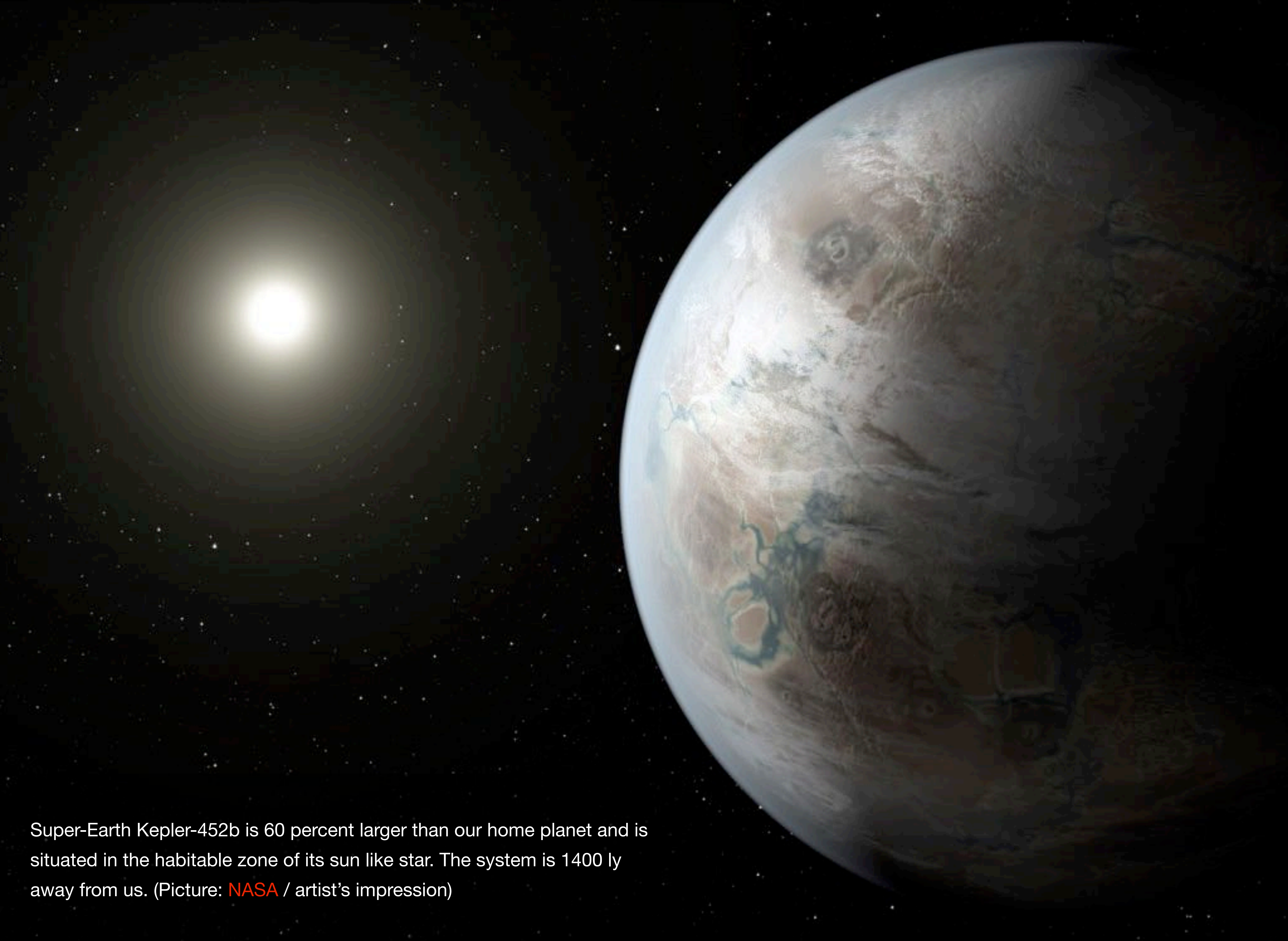
If the original dust disk is large enough, huge rocky planets can form, so-called Mega-Earths. This would, in particular, be the case for planets in orbit around giant stars of the spectral classes B and O, that have up to 150 times the mass of the sun. Such giant Earths could weigh up to 4,000 times as much as our Earth.

However, this is certainly not the only classification system, and scientists consider it rather impractical. A different method does not look at the outside of a planet, but instead focuses solely on its composition. This distinguishes between:

- Metallo-silicate planets, similar to Mercury and Earth
- Silicate planets like Europa and Io; and Earth's moon
- Hydro-silicate planets, comparable to Ganymede, Callisto, Titan, and Pluto
- Ice planets like Enceladus, with very low silicate content
- Gas giants with methane clouds below 80 degrees Kelvin



55 Cancri e is a super Earth, 40 ly from us. It orbits a sun like central start one every 18 hours. The temperature on its surface are around 2000 degrees Celsius. (Picture: ESO / M. Kornmesser, artist's impression)



Super-Earth Kepler-452b is 60 percent larger than our home planet and is situated in the habitable zone of its sun like star. The system is 1400 ly away from us. (Picture: NASA / artist’s impression)

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Naming and Types

- Gas giants with ammonia clouds below 150 Kelvin
- Gas giants with water vapor clouds, 150 to 350 Kelvin
- Gas giants with an albedo around 12%, 350-900 Kelvin, ‘Hot Jupiters’
- Gas giants with alkali absorption, 900-1500 Kelvin
- Gas giants with silicon dioxide clouds above 1500 Kelvin

NAMING OF EXOPLANETS

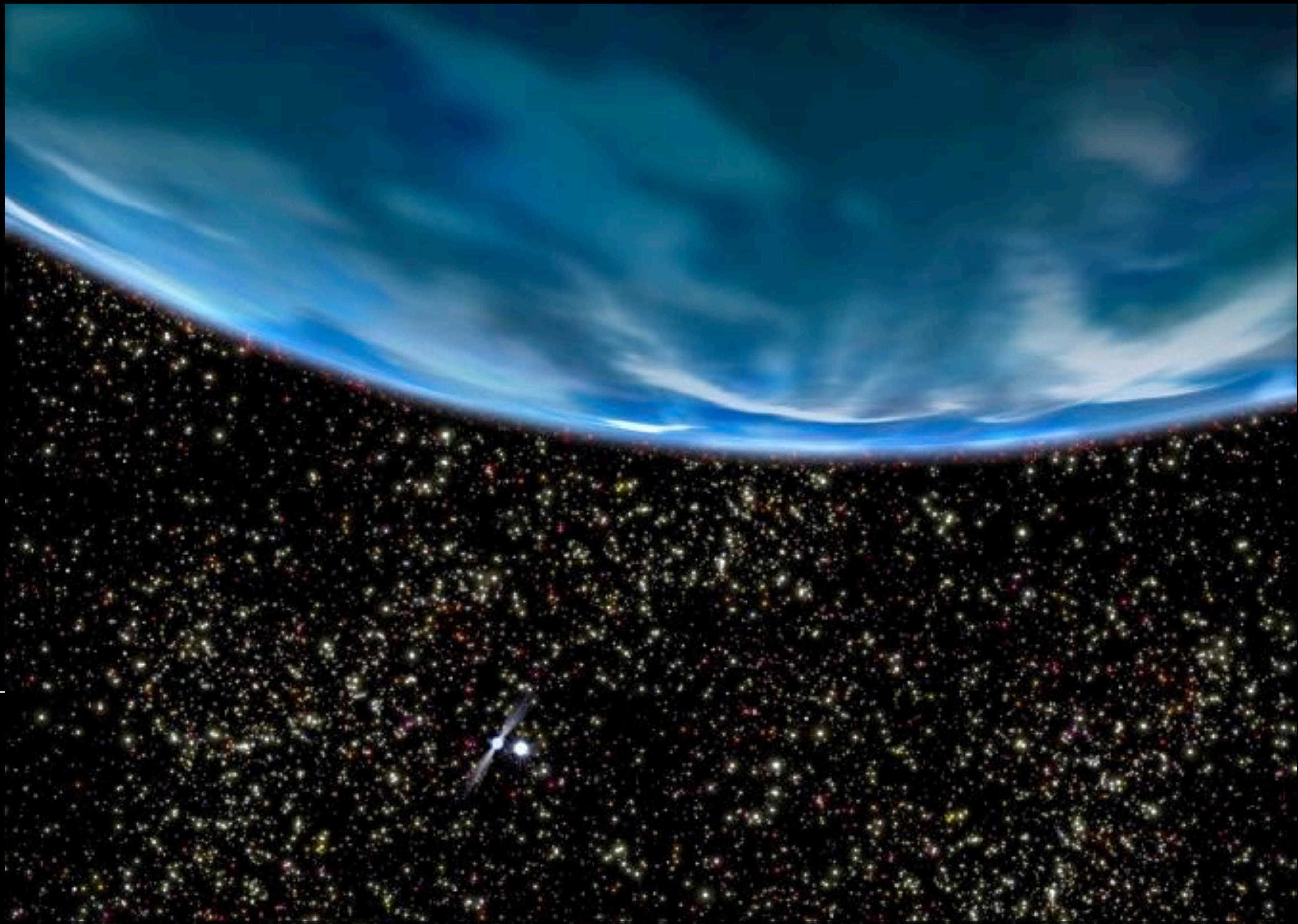
Once planets are discovered, they usually receive the name of the star they orbit, but with an additional letter. The naming system starts with b, as a is reserved for the star itself. If several planets are discovered in a system, the innermost one receives the b, and then the other ones become c, d, etc. going outward. Planets orbiting a binary star system receive a letter after the two letters designating the two stars. For instance, HD202206 AB b follows its course around the

Kepler-35 b could be habitable even though it orbits a binary star system. The planet has eight Earth masses. (Picture: NASA / artist’s impression) binary system consisting of HD202206 A (sun-like) and HD202206 B (brown dwarf).

In 2014, the International Astronomical Union gave ‘real’ names to a number of exoplanets: Ægir, Amateru, Arion, Arkas, Brahe, Dagon, Dimidium, Draugr, Dulcinea, Fortitudo, Galileo, Harriot, Hypatia, Janssen, Lipperhey, Majriti, Meztli, Orbitar, Phobetor, Poltergeist, Quijote, Rocinante, Saffar, Samh, Smertrios, Sancho, Spe, Tadmor, Taphao Kaew, Taphao Thong, and Thestias.

MULTI STAR PLANETS

Planets can also develop in systems with multiple stars. In these systems, however, it is more difficult for them to reach permanently-stable orbits. Conditions are most favorable if both stars are very far away from each other—or very close. In the former case we



PSR B1620-26 was the first planet discovered in a binary system. It orbits a white dwarf and a pulsar and has 2,5 Jupiter masses (Picture: NASA / artist’s impression)

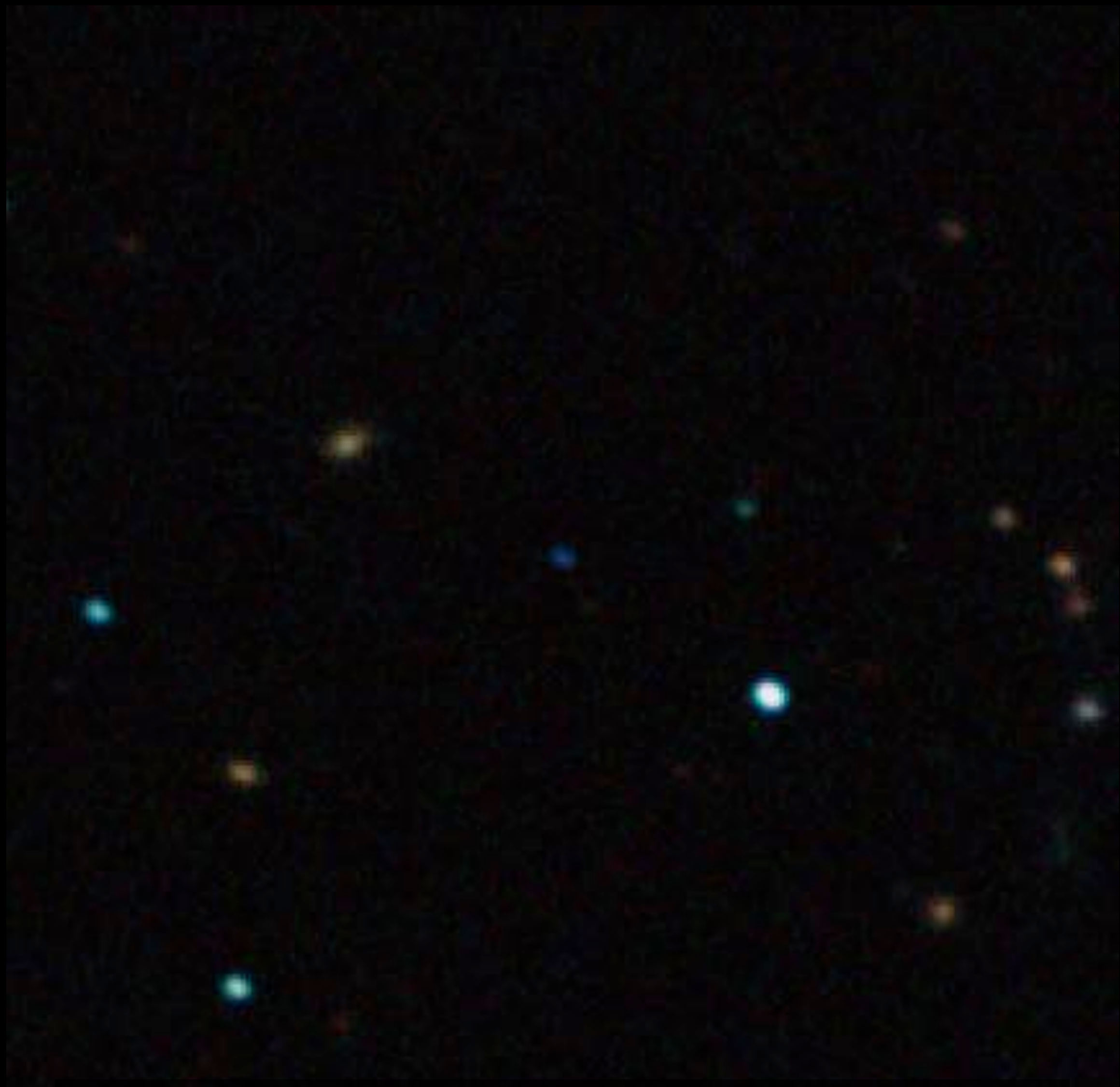
A strong solar wind strips planet HD 209458b of its atmosphere (Picture: ESO / artist's impression) basically have separate planetary systems.

For instance, Proxima b orbits its mother star Proxima Centauri, while that star moves around a common center of gravity with the binary pair, Alpha Centauri A and Alpha Centauri B. In the case of stars being close together, planets usually move around both and are called circumbinary planets. Such combinations seem to be relatively common. The Kepler telescope investigated 1,000 binary star systems and has found seven with planets.

LONE PLANETS

There is another class of planets which is so exotic that scientists have not even agreed on a name for it. These are objects that travel all alone through interstellar space, far away from the light and warmth of a star. Up to now, we only know of a handful of these lonely wanderers, but there are probably many more of them. Astronomers' estimates diverge considerably: For each of the approximately 200 billion stars in the Milky Way, there might be a handful or up to 100,000 loner planets.

The term most often used for them is Planetary Mass Object, sometimes shortened to Planemo, or simply PMO. Before we can determine their origins—and therefore their number—more precisely, we first have to find and examine one, and this is an



The lone planet CFBDSIR J214947.2-040308.9 visible in infrared (the blue dot in the middle). It is about 100 ly away and has around four to seven Jupiter masses. (Picture: ESO / J. Delorme) enormous challenge. All the search methods for exoplanets, to be discussed in the next section, fail here. An Earth-like PMO far out in space is a frozen stone ball almost impossible to detect unless it happens to move in front of a star that, from our perspective, lies behind it. This bends the star's light, which astronomers can record as a gravitation lens effect.

There are a few of these planets, though, that radiate in certain wavelengths, one reason being that they stored enough of the heat generated during their development process. An exciting example, cataloged as PSO J318.5-22, was discovered by a team in 2013.

Where do these lonely wanderers come from? Some, especially the smaller, Earth-like ones, are probably cosmic runaways that originally formed like normal planets in a protoplanetary disk. But then some accident hurled them out of their system—for example, the influence of a heavy neighbor or another star that approached the system. Many others have been solitary all their lives. They developed from interstellar nebulas in the same manner as stars or brown dwarfs. Astronomers believe there is a lower mass limit for objects to form this way. They estimate it to be between two and three Jupiter masses

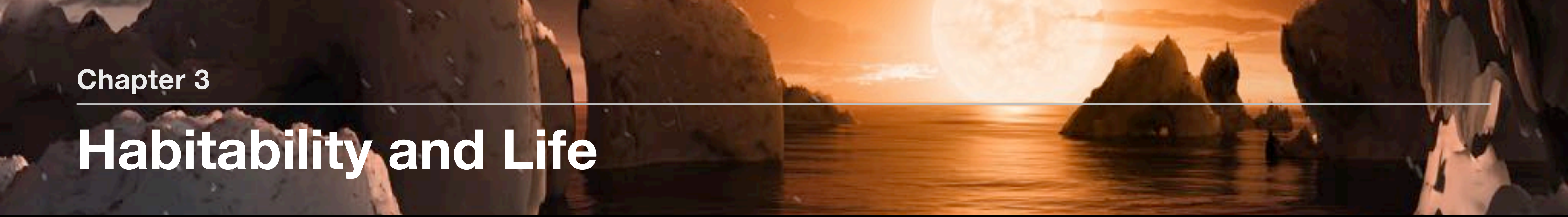
PSO J318.5-22 has approximately six Jupiter masses and is located 80 ly away from Earth. (Picture: MPIA / V. Ch. Quetz, artist's impression)

Chapter 3

Habitability and Life

It is very difficult to determine from afar whether a planet could, in principle, harbor life. The problems lie in the fact that we only know one system of life so far: life on Earth.

Trappist-1f is an Earth size planet in the habitable zone of it‘s star so it could harbor water on the surface (Picture: NASA / artist’s impression)



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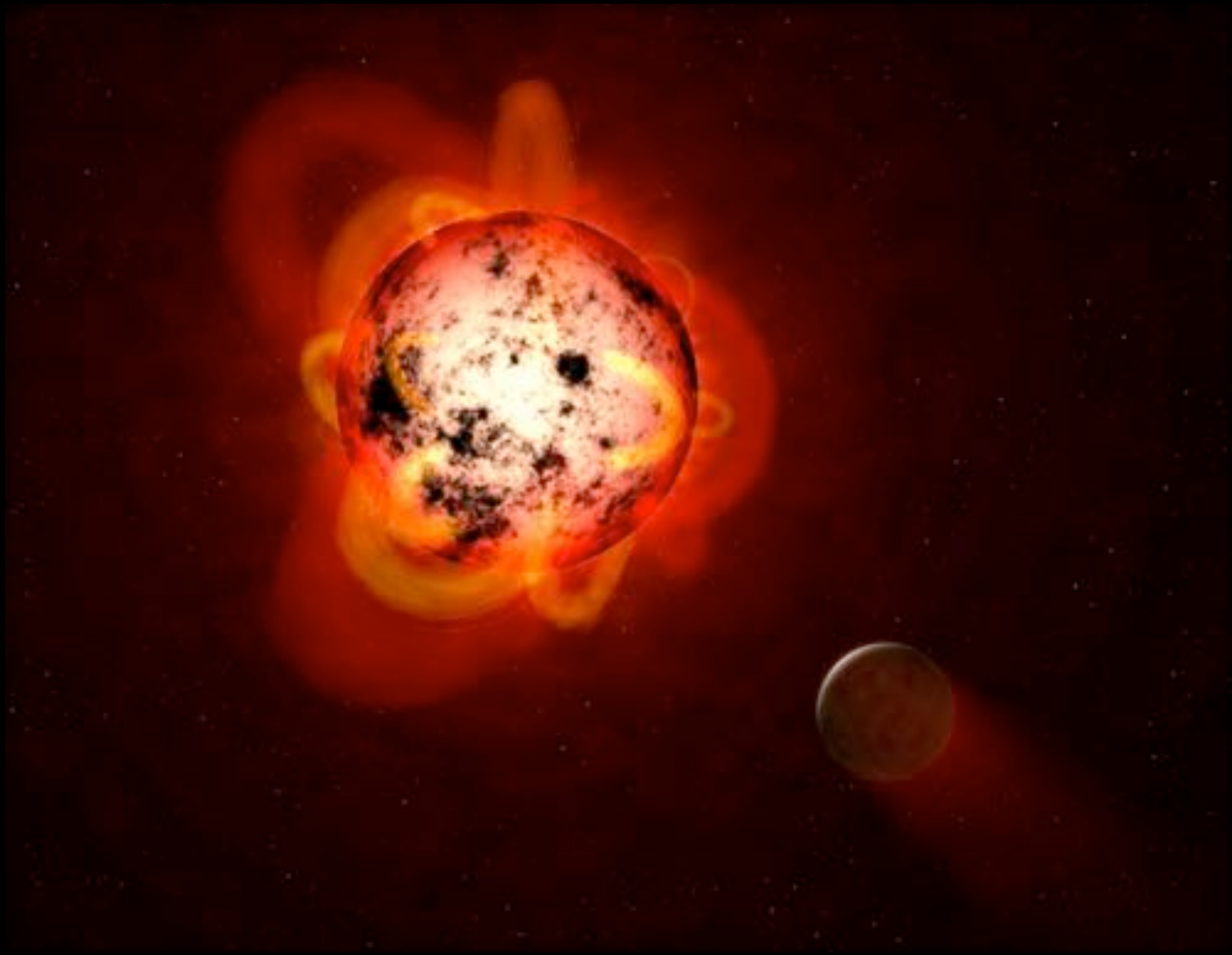
that we only know one system of life so far: life on Earth. It is generally based on surface water in its liquid state. There might be many other types of life that would be based on completely different preconditions.

But the researchers had to agree on something. Therefore, they define the habitable zone around a star as that area in which water could exist on the surface of a planet orbiting it. This does not mean that water actually exists. And what if some lifeforms do not acquire their energy from sunlight but instead from heat? Then they could also use water below the surface, which is closer to the core of the planet.

How far the habitable zone reaches depends on how much energy a star emits. And this can change due to the aging process. If the sun keeps increasing its output, which is a typical phenomenon of aging, Earth will at some point no longer be in the habitable zone, as it will get too hot. And if the sun becomes a red giant at the end of its lifecycle, then conditions near Jupiter and Saturn will turn more advantageous. Then Saturn's moon Titan might become the most fertile place in the solar system.

But apart from the size and the distance of the habitable zone, the nature of the main star has a great influence on the possibility of life. Very bright giant stars often do not last long enough for life to develop on their planets. Red dwarfs, on the other hand, emit strong X-ray and UV radiation. This could be an obstacle for the development of life, because in these cases the habitable zone would be very close to the star. It is very important for the development of life that the star should provide a constant energy output over a long period of time. Sudden eruptions or fluctuations can have disastrous consequences. The 11-year solar cycle has a significant effect on the climate of Earth, even though the energy output only changes by 0.1 percent. Therefore stars with stronger cycles are presumed problematic for the development of life.

Several other characteristics of the planet also must be considered. A dense atmosphere can retain solar energy better than a thin one, due to the greenhouse effect. Mars, for instance, would be noticeably colder than Earth, even if it had the same orbit around the sun. A strong magnetic field prevents the solar wind from ripping away the atmosphere over time. It also protects against radiation eruptions of the star, which is particularly helpful in the case of red dwarfs like Proxima Centauri. The issue of whether a planet always faces its star with the same side or whether it has a strongly elliptical orbit can also influence the chances for life on its surface.

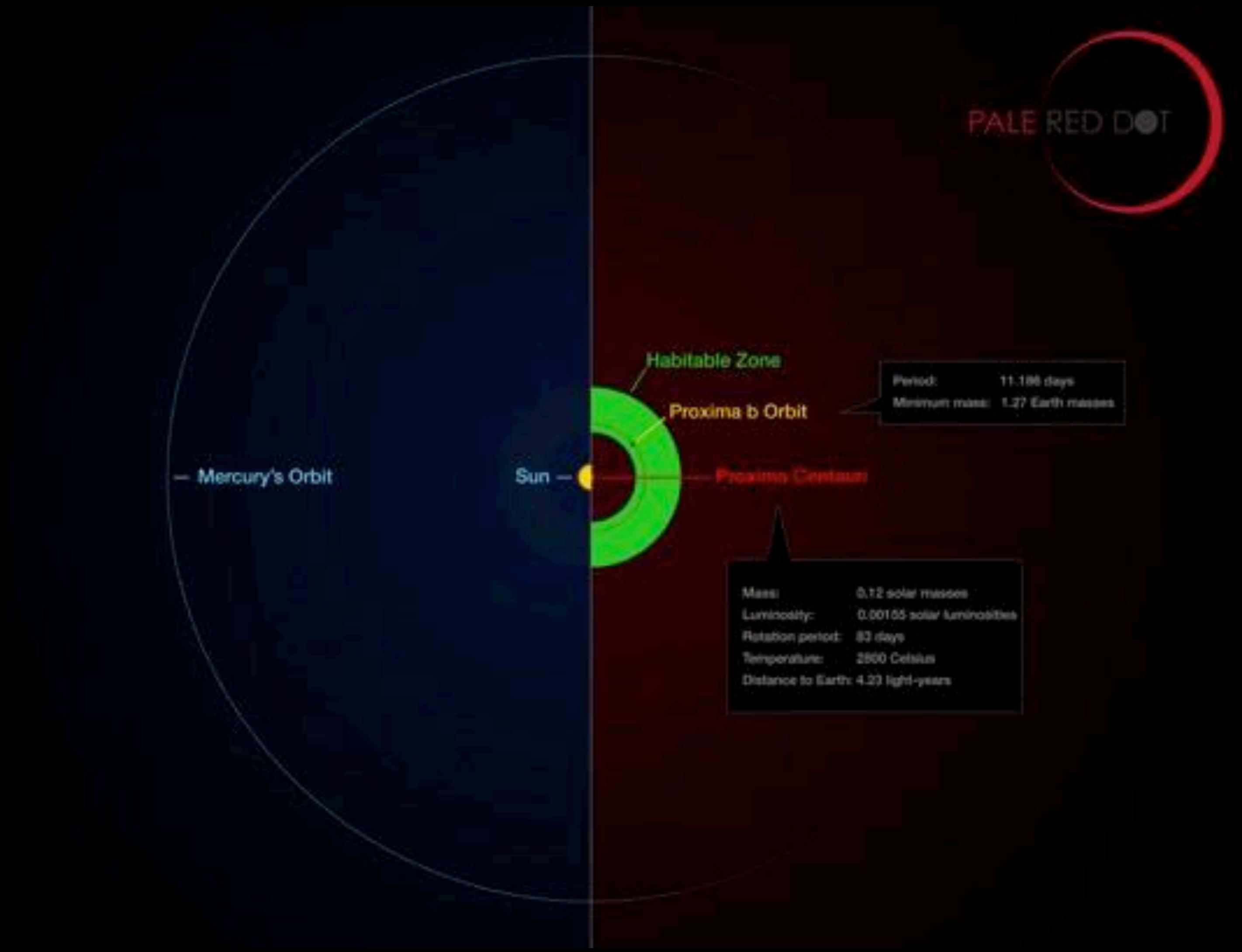


Flares könnten die Bewohnbarkeit eines erdähnlichen Planeten einschränken (Picture: NASA)

Chapter 3

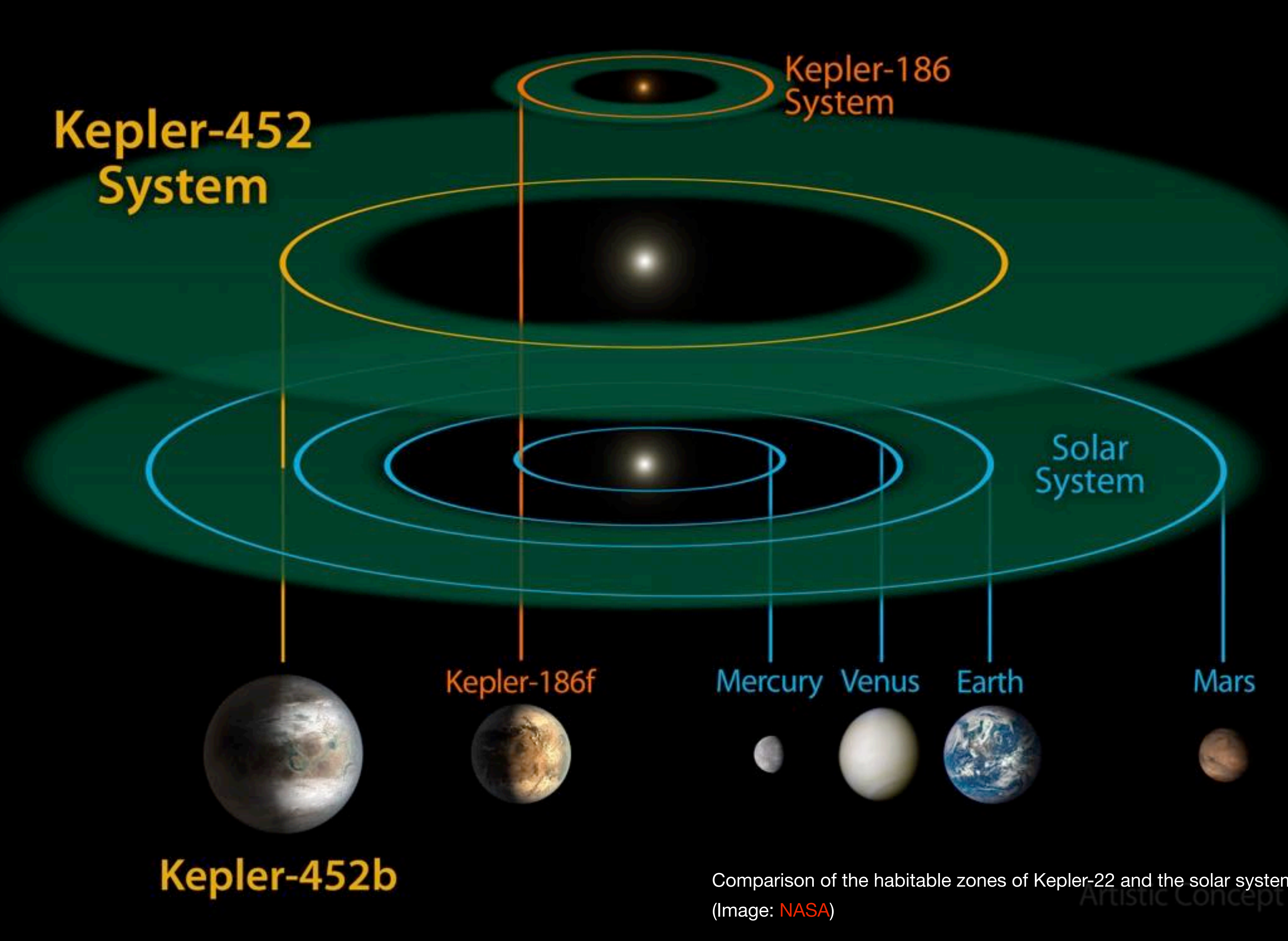
Habitability and Life

Life as we know it is very particular, and the planet must not be too small. Smaller planets do not have enough gravity to retain a dense atmosphere. Their interior also cools off soon after they develop, leaving neither plate tectonics nor a magnetic field, both of which presuppose a liquid core. Therefore it is probably no accident that Earth is the densest of all rocky bodies in the solar system. Studies estimate that the lower limit for habitability is 0.9 Earth masses—looks like we humans were lucky—as the Earth is only slightly above that. However, with a growing planetary size, the risk of the atmosphere becoming too dense also increases. Then the greenhouse effect would make the surface too hot, so that a Super-Earth would have to orbit its star at a greater distance than Earth does around the sun.



The habitable Zone of Proxima Centauri compared to the solar system (Picture: ESO / M. Kornmesser)

And the planet had better move around its star in an almost circular orbit, because otherwise it would sometimes get too hot, and then too cold. The Earth is exemplary in this aspect, as the eccentricity of its orbit—a measure of being close

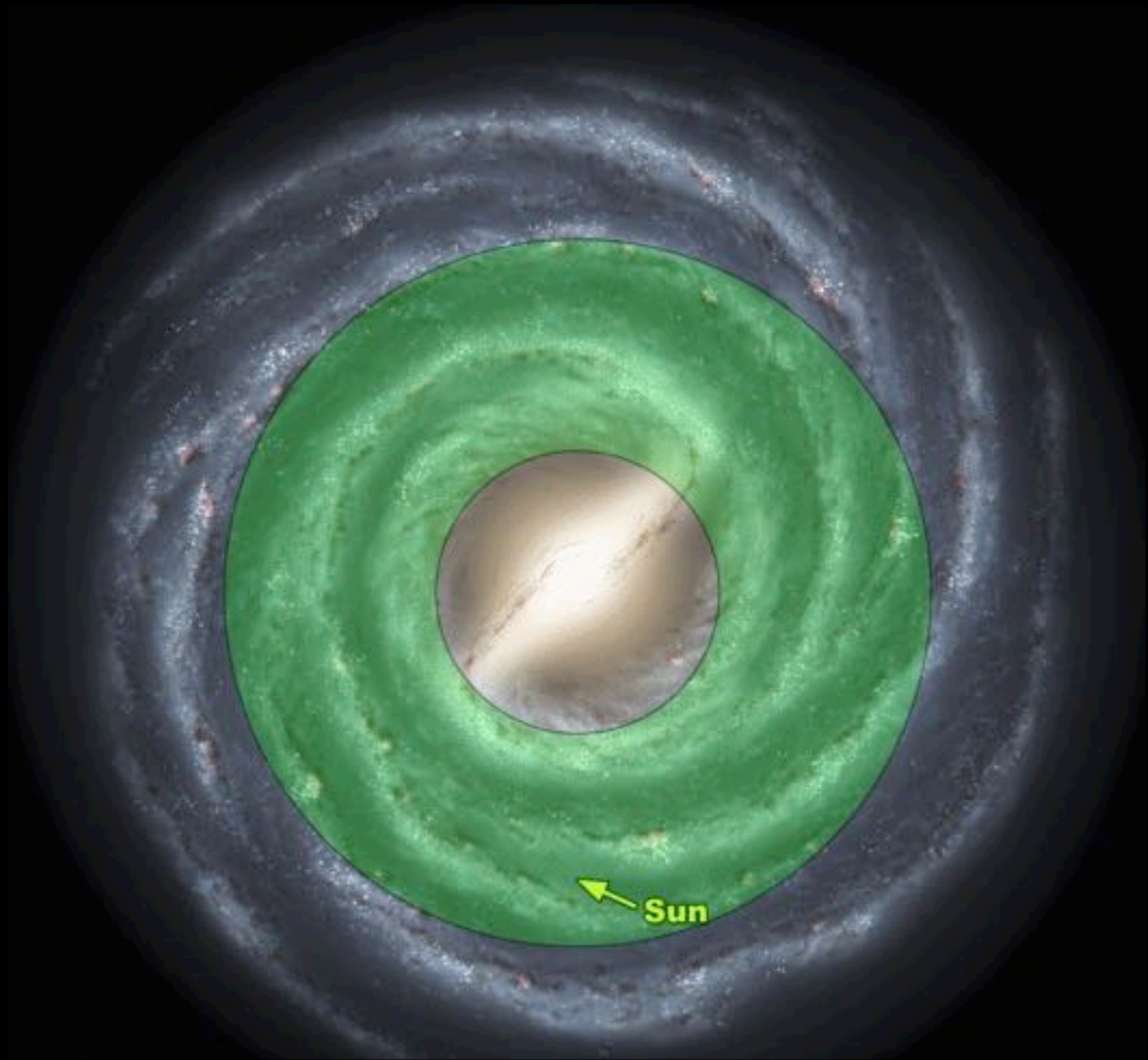


Comparison of the habitable zones of Kepler-22 and the solar system
(Image: NASA)

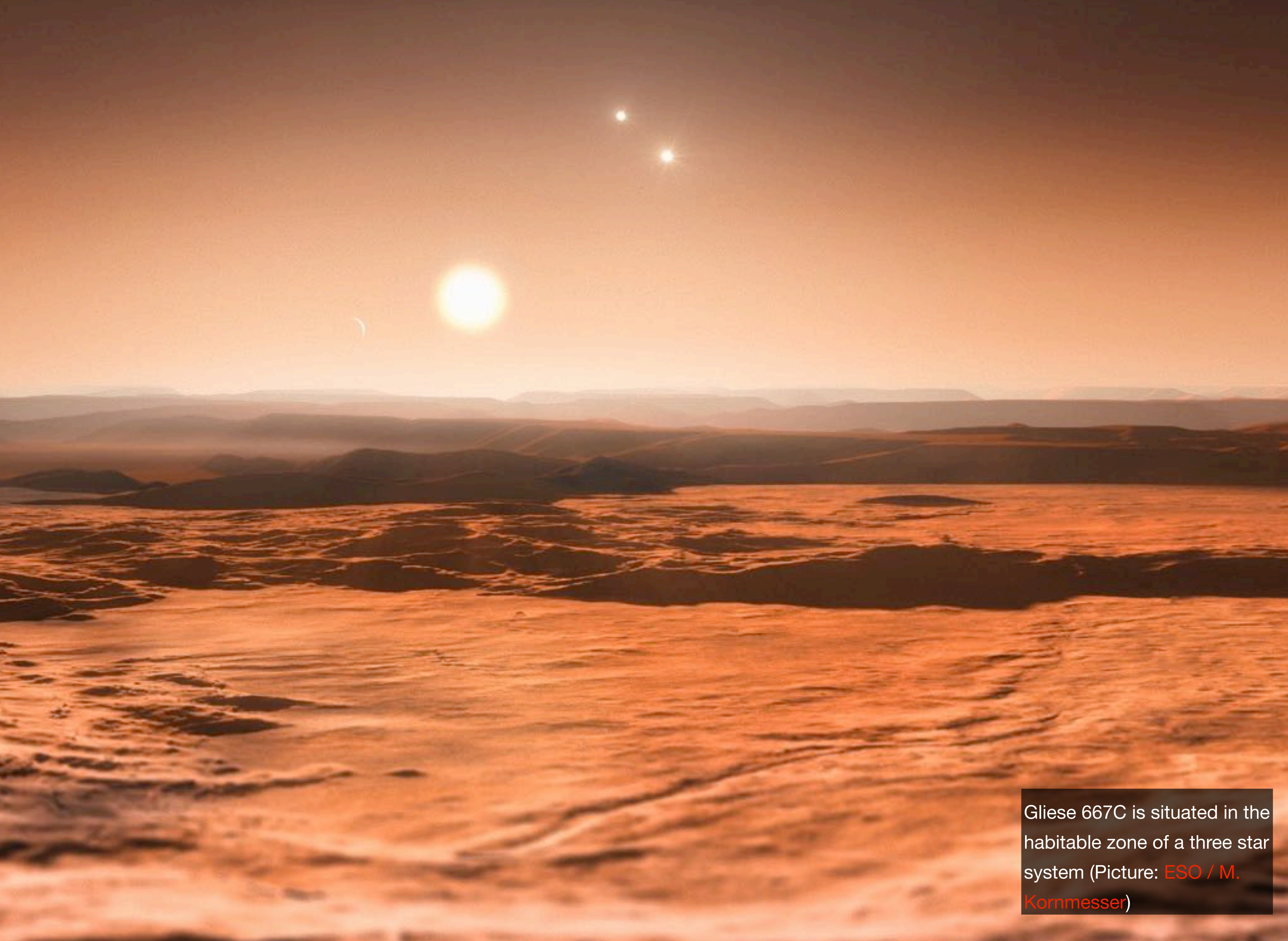
to a circle—lies below 0.02. The exoplanets discovered so far, and whose eccentricities are known, have values above 0.25. Their oceans would alternately freeze and boil with the changing seasons.

Two final aspects: If a planet does not meet the criteria, either because it is too large or made of gas, it is possible that its moons, which usually are made of ice or rock, could still carry life.

And finally, life itself plays a role in its spread. The fact that there is so much oxygen in Earth's atmosphere—which animals can breathe—is based on the good preparation by plant-based life that produces oxygen as a side product. So if we find a planet that seems to be suitable but does not have enough oxygen, we would just have to sow plants—and then wait a few million years. Patience is always helpful in space.



The habitable zone of the milkyway. In the center, the stars are packed to tight while outside there are not enough resources



Gliese 667C is situated in the habitable zone of a three star system (Picture: ESO / M. Kornmesser)

Chapter 4

How to Find Exoplanets

Compared to stars, exoplanets are small, light, and extremely dim. It is therefore not surprising that the first ones detected were not near normal stars, but around a rotating neutron star, the Pulsar PSR 1257+12—also called Lich—2,300 light years from Earth.

To make exoplanets discoverable with the transit method, they must transit their stars in our plain of view (Image: NASA)

Chapter 4

How to Find Exoplanets

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Pulsars send radio signals with extreme regularity due to their rotation, but in the case of Lich, astronomers noticed tiny delays. These could only be caused by several companions. At first they suspected the existence of two planets, but now we know there are three planets, Draugr, Poltergeist, and Phobetor, as well as the ‘exo-comet’ PSR 1257+12 e. Pulsars are the remnants of a supernova explosion. These three companions must either have survived the supernova, or they developed later and were captured by the pulsar. Up to now, only one other planet has been found this way.

What other methods are there which astronomers successfully used to discover planets?

TRANSIT METHOD

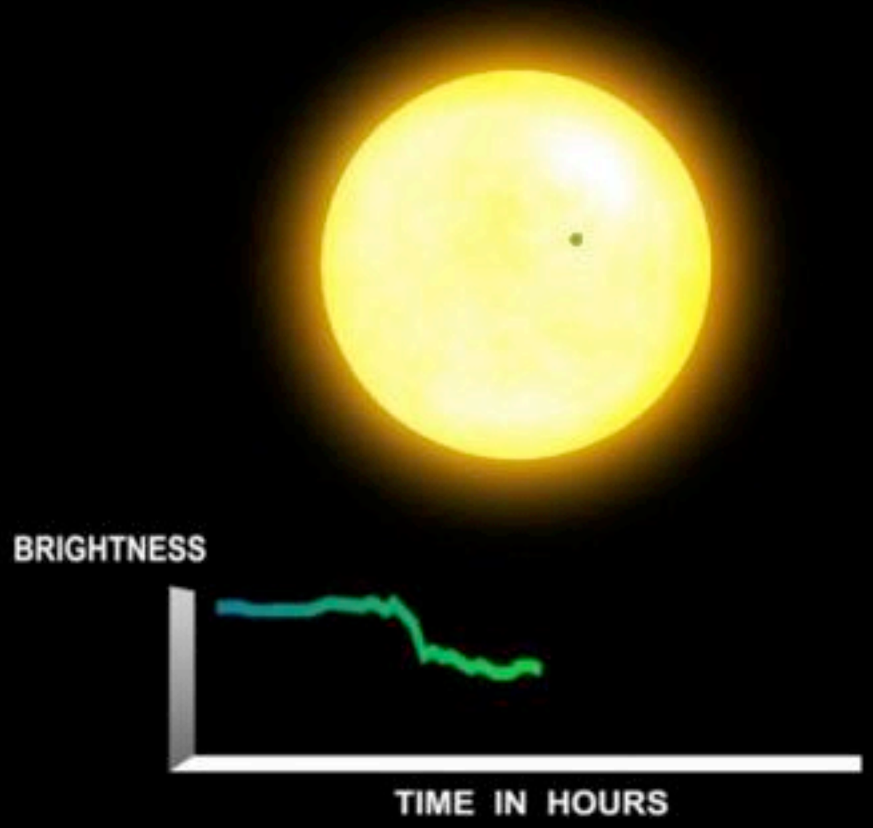
The transit method presupposes that the course of the planet moves directly across the axis between the Earth and a star. This reduces the brightness of the star in specific intervals, which can be measured by telescopes. Space telescopes like Kepler are especially suited for this.

Using the transit method allowed scientists to detect about 80 percent of the currently 4,062 exoplanets in 3,038 systems as of May 2019.

The procedure is successful, but it suffers from a major disadvantage: The mass—and therefore the type—of the planet cannot be determined, only its size and orbit. Furthermore, only about one percent of all existing planets can be detected this way, as the others may be moving in different courses around their stars.

RADIAL VELOCITY METHOD

When considering the rotation of the Earth around the sun, one often imagines the sun as if it were stationary, twirling the Earth around it on a string, so to speak. This image is incorrect. In reality, both the Earth and sun —planet and star—move around a common center of gravity. So the star also turns in circles, though small ones, when it is influenced by the planet. We cannot see this circular motion from the Earth, but we can see this star move back and forth, away from us and toward us. The speed with which this happens is called the 'radial velocity,' and via the Doppler Effect, this slightly shifts the star's spectral lines. We can measure this shift with special instruments and then

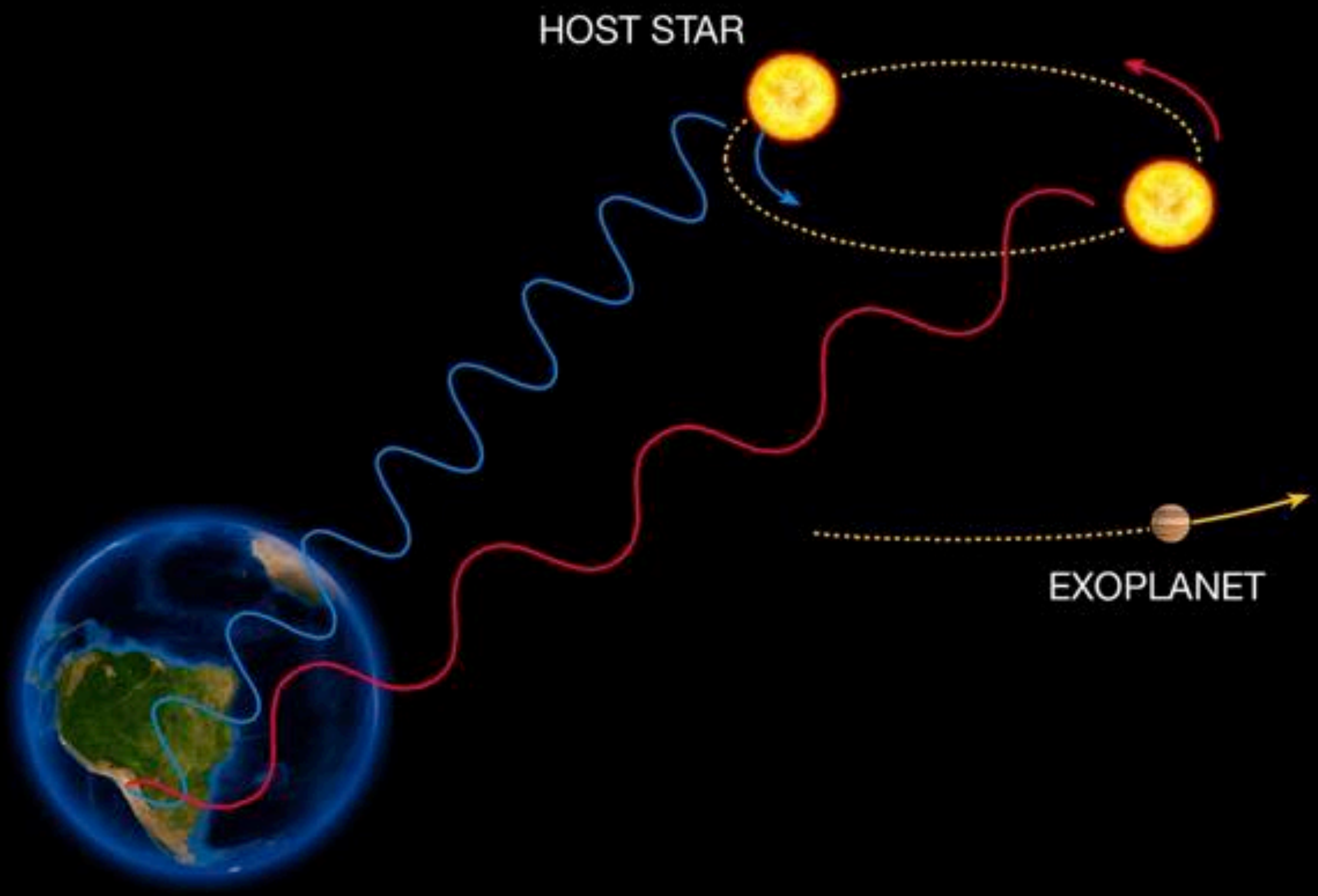


If a planet transits a star, the brightness of the star decreases (Picture: NASA)

How to Find Exoplanets

calculate how heavy the planet—or planets—pulling on this star must be.

If just this technique is used, though, it yields only a lower limit for the planetary mass. In order to calculate the exact mass, and thus the density, the planet would also have to be detected by the transit method. About one in five of all planets has been found using this method.



How the radial velocity method works (Picture: ESO)

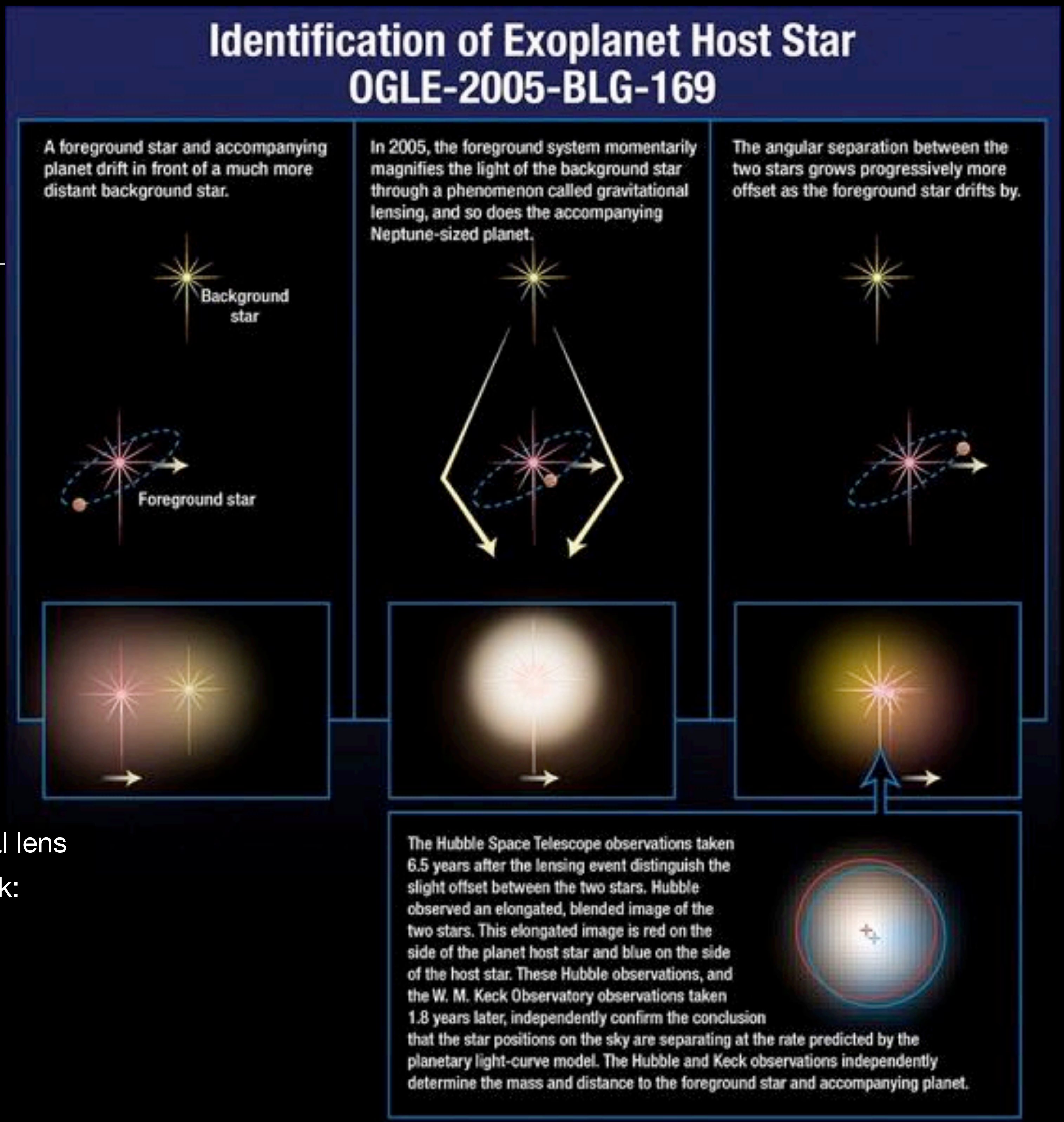
GRAVITATIONAL LENS METHOD

If the light of a background star passes by another star on its way to Earth, it can be bent and magnified, just like going through a lens. However, if the star in the foreground has planets, this effect will change periodically. With the help of this method, 19 planets have already been identified, often at large distances of several thousand light years. Unfortunately, such gravitation lenses are hard to find. In addition, these observations cannot be repeated, as the stars move on in the meantime. One advantage of this method, though, is that it also works for planets with a wide orbit or low mass. Scientists hope to get an overview this way, to determine how common Earth-like planets really are.

DIRECT OBSERVATION

Ten years ago, nobody would have considered observing an exoplanet through a telescope. Now significantly improved technology has increased the number of planets discovered this way to more than 20. Once the E-ELT at the ESO or NASA's James Webb Telescope become operational in a few years, we should gain exciting new data about many planets in our neighborhood. A direct view of your target offers many more details than an indirect proof.

Today this method works well for young planets. They retain enough heat from the period when they came into being that they still radiate energy. The coldest exoplanet detected this way is 59 Virginis b, which is no more than 500 million years old and has an average temperature of 240 degrees.

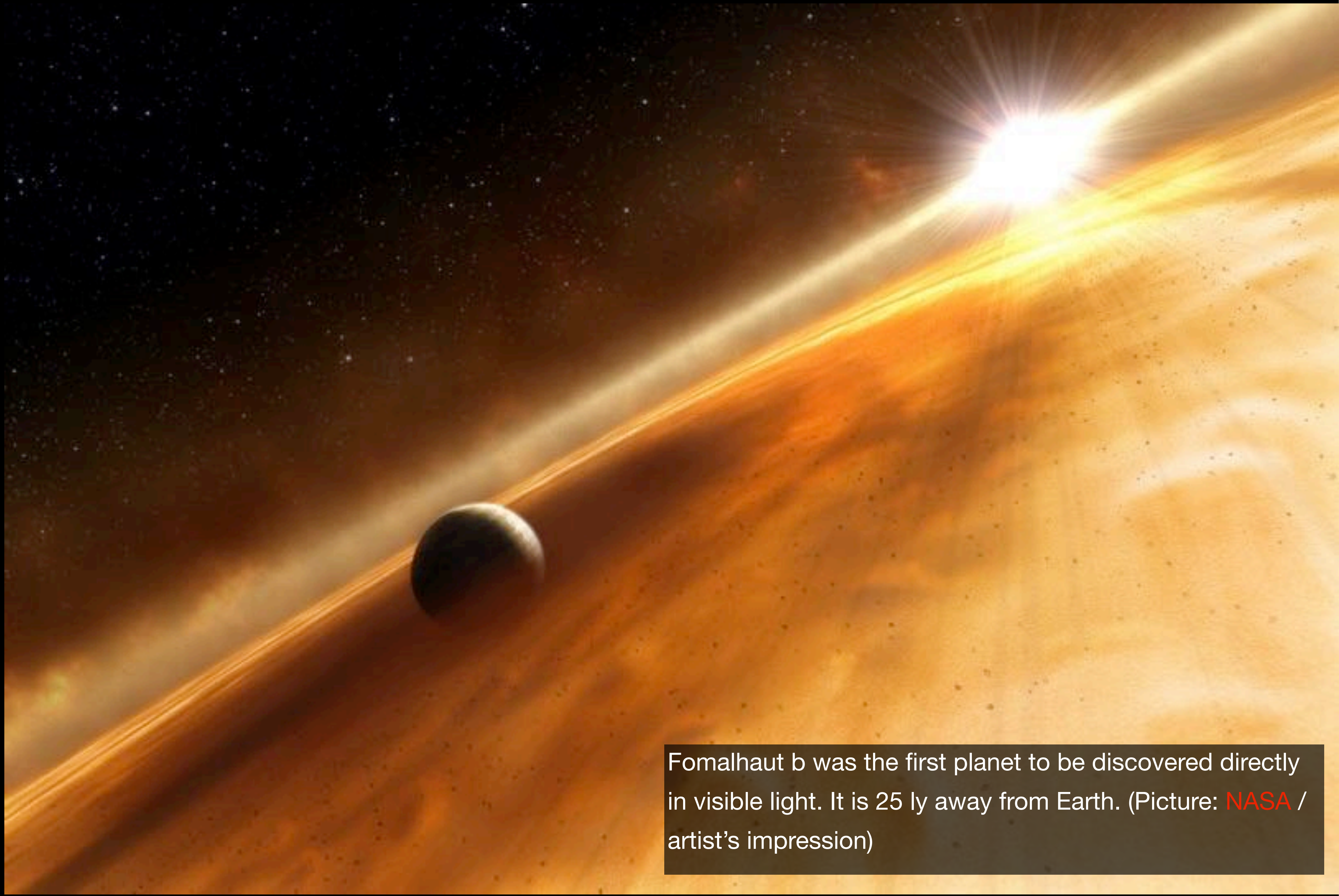


How the gravitational lens method works (Grafik: NASA)

Chapter 4

How to Find Exoplanets

The smallest planet that has been directly observed is Fomalhaut b, with approximately two Jupiter masses.

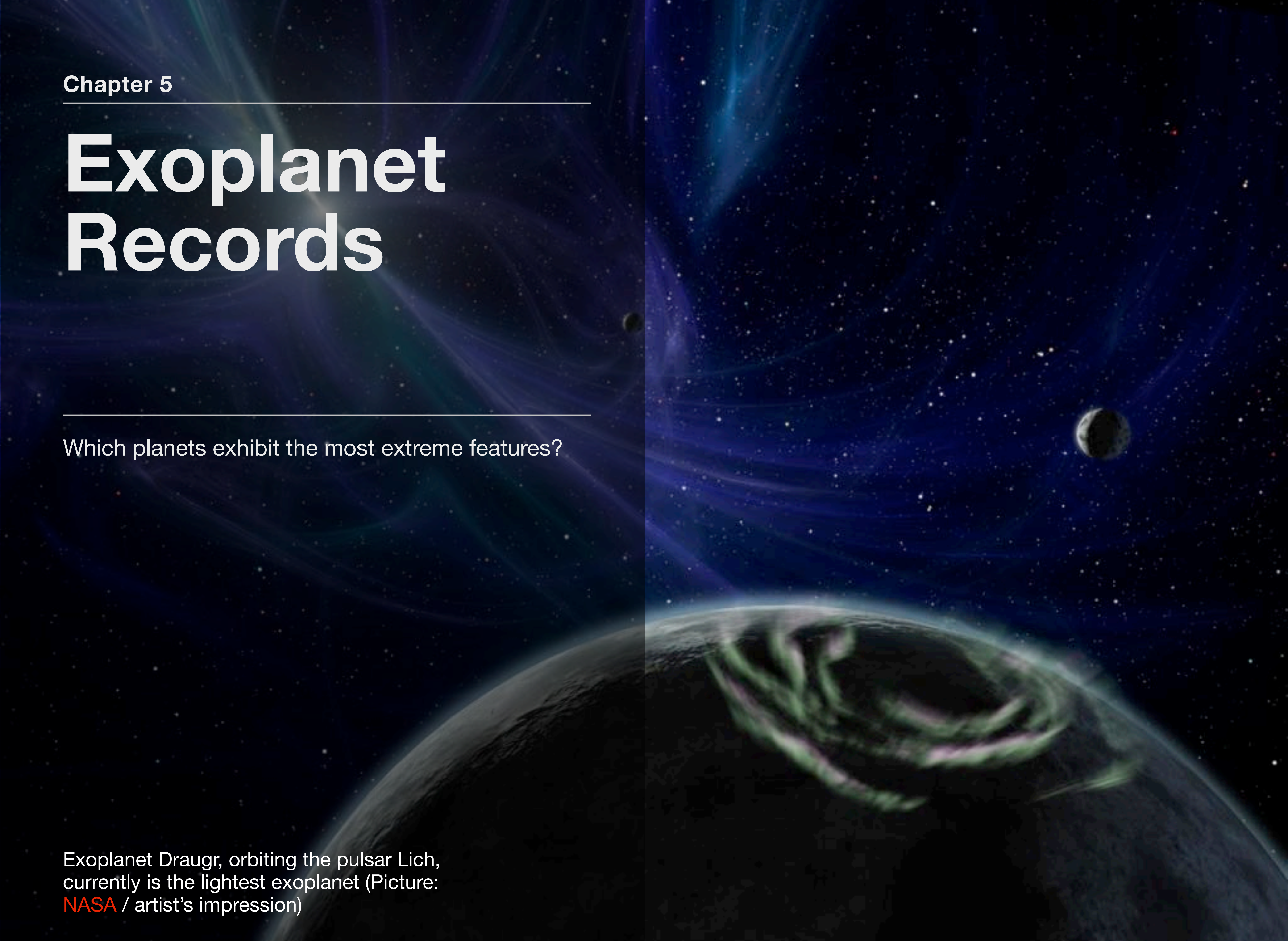


Fomalhaut b was the first planet to be discovered directly in visible light. It is 25 ly away from Earth. (Picture: NASA / artist’s impression)

Chapter 5

Exoplanet Records

Which planets exhibit the most extreme features?



Exoplanet Draugr, orbiting the pulsar Lich, currently is the lightest exoplanet (Picture: NASA / artist’s impression)

Chapter 5

Exoplanet Records

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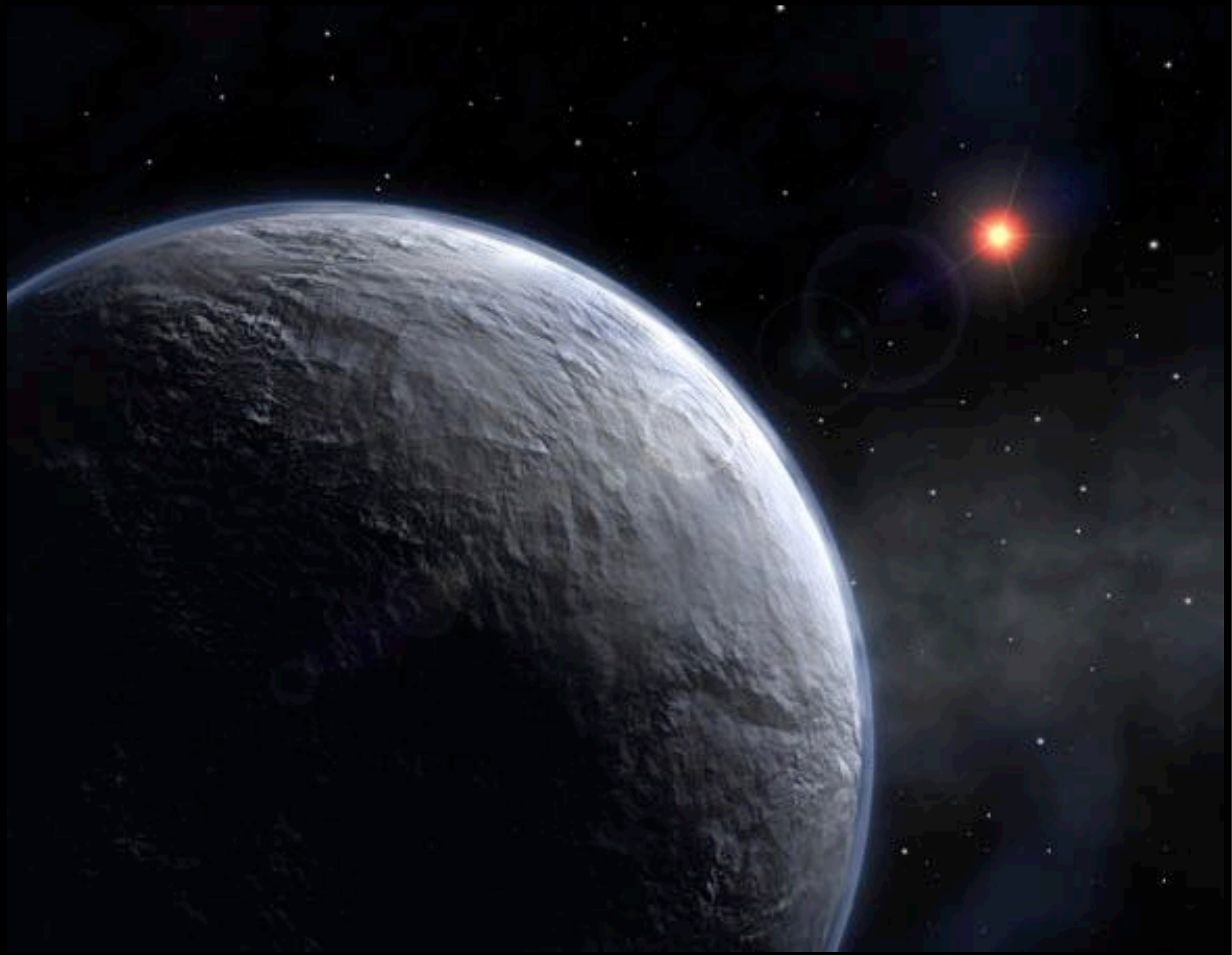
- Farthest away: SWEEPS J175853.92-291120.6 b—27,700 lightyears
- Closest: Proxima b—4.22 lightyears
- Heaviest: DENIS-P J082303.1-491201 b—28.5 Jupiter masses
- Lightest: Draugr—0.02 Earth masses
- Biggest: HD 100546b—6.9 Jupiter radii
- Smallest: Kepler-37 b—0.3 Earth radii
- Densest: PSR J1719-1438 b—at least 23 g/cm3
- Hottest: Kepler-70 b—several thousand degrees
- Coldest: OGLE-2005-BLG-390L b—50 Kelvin or -223 degrees Celsius
- Youngest: V830 Tau b—2 million years
- Oldest: PSR B1620-26 b—13 billion years
- Longest year: 2MASS J2126-8140—about 1 million Earth years
- Shortest year: PSR J1719-1438 b—2.2 hours

Chapter 5

Exoplanet Records

- Farthest away from its sun: HD 106906 b—about 650 astronomical units
- Closest to its sun: PSR J1719-1438 b—0.004 astronomical units
- Closest to other planets: Kepler-70 b approaches Kepler-70 c to within 0.0016 AU
- Heaviest mother star: HD 13189 b—mother star with 4.5 sun masses
- Lightest mother star: TRAPPIST-1b, c, and d—mother star with 0.08 sun masses
- Most extensive planetary system: HD 10180—9 planets, 7 of them confirmed
- Most mother stars: Kepler-64—orbits in a system with 4 stars



OGLE-2005-BLG-390Lb is five times as heavy as Earth and the coldest planet so far (Picture: ESO)

Chapter 6

Eleven Exemplary Exoplanets

Exoplanets appear in the most diverse forms—almost as if they sprang from the imagination of a science fiction writer.

Could that be the surface of planet Proxima Centauri b?
(Picture: ESO / M. Kornmesser, artist's impression)

Chapter 6

Eleven Exemplary Exoplanets

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PROXIMA CENTAURI B

Proxima b is the exoplanet closest to our sun and therefore the obvious destination for the expedition depicted in this novel. If you ever go there, you will find most things just as described. I imagined the life forms on my own, based on scientific knowledge, of course. The planet is 30 to 50 percent heavier than Earth. Due to the planet's tight orbit, its star surely must have forced it to always direct the same side toward the sun, as the moon does to Earth. One orbit around its mother star takes 11.2 days. However, one would not notice this on the planet, as there are no seasons, and it is always day if you're on the 'front' side. Proxima b is located within the habitable zone, so water could exist on its surface in liquid form. Compared to Earth, 30 times more UV radiation and 250 times more X-rays reach the surface. Whoever wants to live there has to adapt to high radiation levels. A magnetic field, which has not yet been proven to exist, could mitigate their effects considerably. This also applies to the radiation eruptions of the mother star.

WASP-17 B

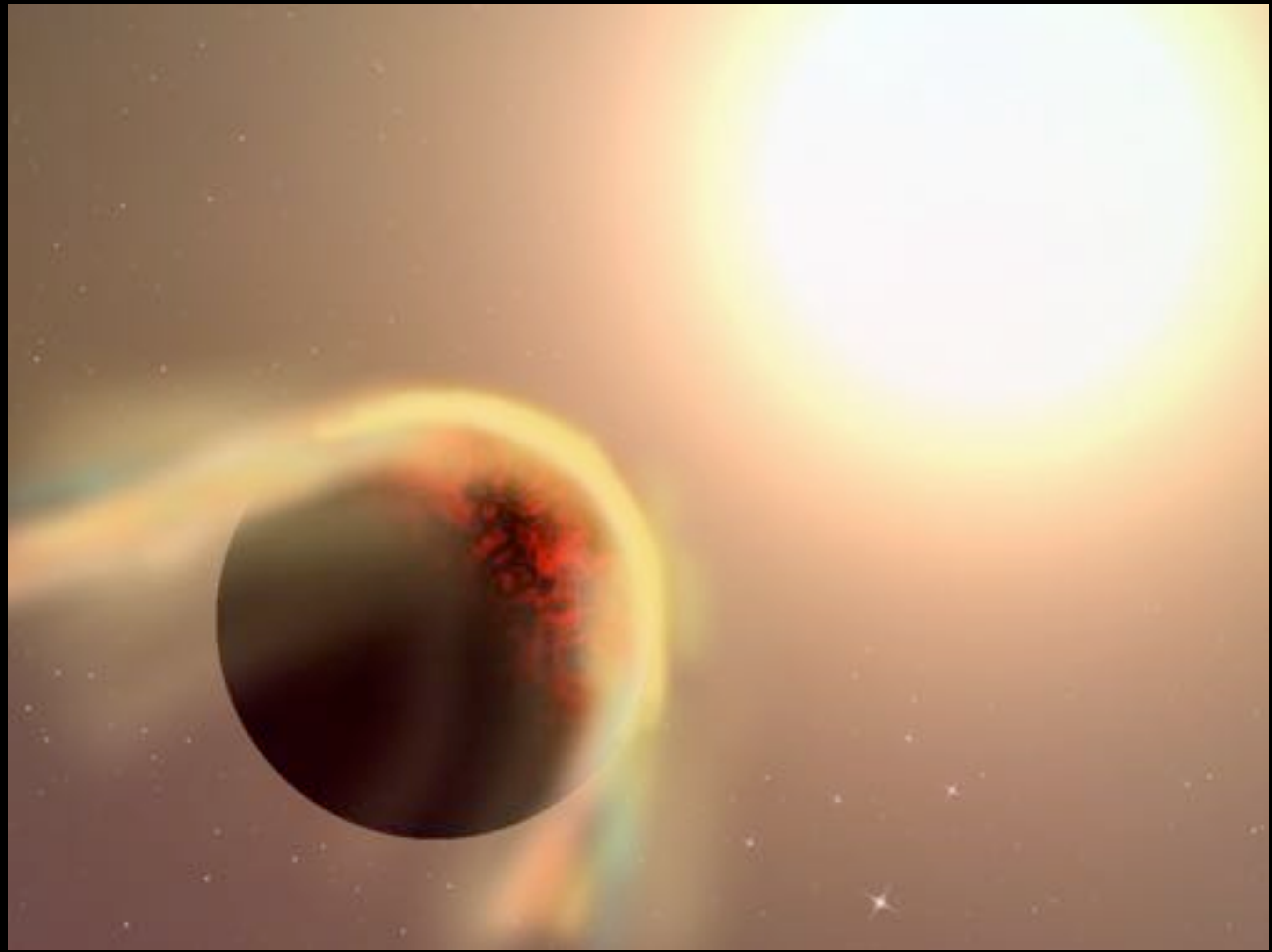
Almost all known planets rotate the right way—meaning that their orbits follow the rotation of their central star. This is only logical, because planets form from the swirling disk of matter around a rotating protostar. It is different in the case of WASP-17b. This world has an orbital inclination of 149 degrees, which means it completes a retrograde orbit around its star every 3.74 Earth days. In addition it is very bloated and therefore has an extremely low density.

The reason for this strange orbit is unknown: Some researchers suspect that a near-collision, or the gradual gravitational effect of another planet might be responsible for it. WASP-17b was the first of the retrograde-orbiting planets to have been discovered. The mass of the planet is 0.5 of Jupiter's and its radius 1.5 to 2 times the radius of Jupiter.

KEPLER-70 B

Kepler-70b is really fast—the planet moves around its central star, a red giant, in only 5.76 Earth hours or 0.24 Earth days. This is the shortest orbital period of all planets known today, and the velocity lies slightly below five percent of the speed of light. It is believed that this planet used to be a Hot Jupiter, but that now only a remnant of the former gas giant is left, with less than half the mass of Earth. Due to the tight orbit of Kepler-70b, 65 times closer to its sun than Mercury is to ours, it has such extreme temperatures that it is one of the hottest exoplanets.

Its central star probably expanded into a red giant approximately 18 million years ago and in doing so swept away the planet's

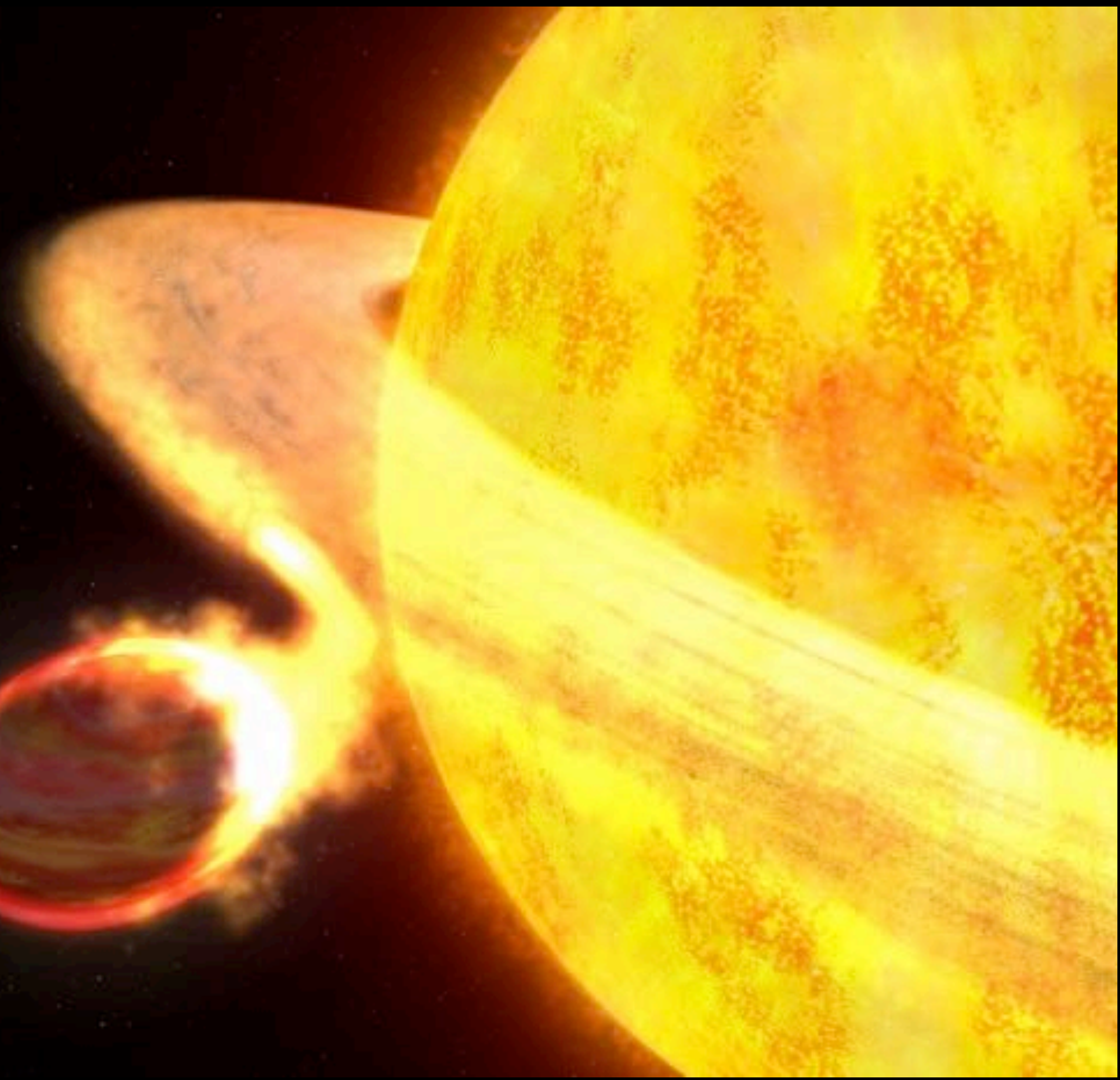


Kepler-70 b could be the core of a former Hot Jupiter (Picture: NASA, artist's impression) atmosphere. This is what might happen to Earth a few billion years from now. The planet might have been engulfed by the atmosphere of its star at one time, but its rocky core survived, nevertheless.

WASP-12 B

When WASP-12b was discovered in 2008, it ran counter to all expectations. Since then, it has been considered one of the hottest planets. It is more than 50 percent larger than Jupiter. But this Hot Jupiter is particularly interesting because it is being eaten alive. It orbits its sun so closely—one revolution takes 1.1 Earth days—that it probably loses 6 trillion kilos of mass every second, while its atmosphere is being blown away. It is assumed that the planet will die within 10 million years.

In addition, the planet might exhibit a high concentration of carbon in the form of carbon monoxide and methane. This means it could have a solid core containing a lot of diamond. Perhaps millions of years from now only a gigantic diamond will be left of WASP-12b. In addition, this planet was long considered the fastest-moving known planet. It moves at an impressive speed of 830,000 km/h.



WASP-12 b probably only has a remaining life span of ten million years (Picture: NASA / artist’s impression)

Chapter 6

Eleven Exemplary Exoplanets

GLIESE 436 B

Gliese 436 b acts like a comet, because it drags a long tail behind itself. In its orbit, it seems to lose between 100 and 1,000 tons of hydrogen per second. It is assumed that during its existence Gliese 436 b has lost up to ten percent of its atmosphere. But its huge tail, which is approximately 50 times larger than the central star, obscures the sun during its orbit of less than three days.

There had been suggestions that planets with comet-like tails might exist, but Gliese 436 b was the first one actually discovered. Due to its size and proximity to its central star, it is called a Hot Neptune. Its gaseous tail might continue to exist for a longer period, because the sun that the planet orbits is a relatively cool red dwarf.

Gliese 436 b wears a tail like a comet (Picture: NASA, ESA, STScI, and G. Bacon)

Chapter 6

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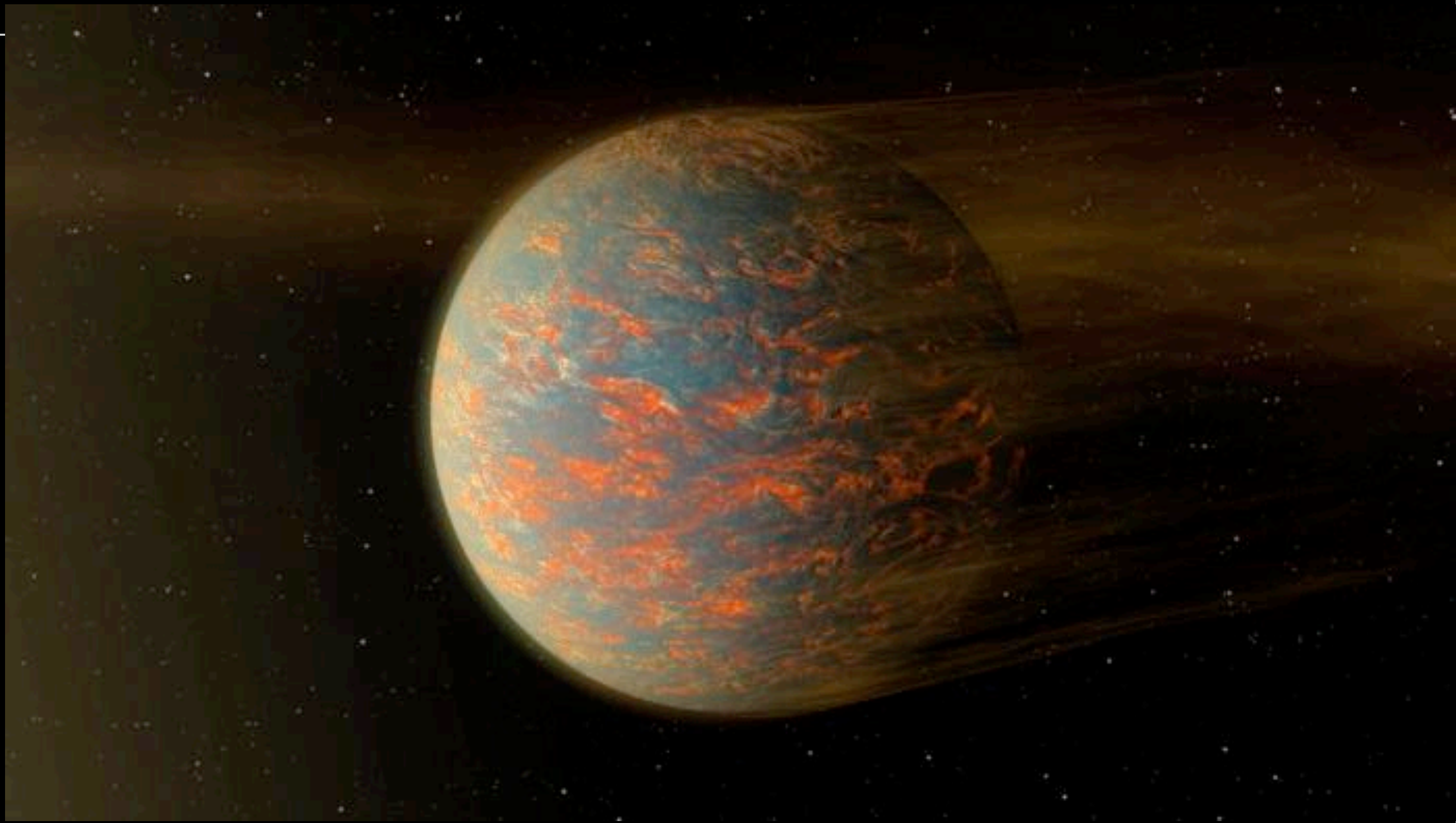
JANSSEN



On this world, one of the few with a real name, diamonds aren’t just a ‘girl’s best friend.’ Janssen, alias 55 Cancri e, is a Super-Earth and one of the five planets orbiting its star, the A component of the binary system Copernicus. We used to believe that a lot of water exists on 55 Cancri e. However, today researchers assume that the planet consists mainly of carbon in the form of graphite, diamond, and other minerals. An entire third of the planetary mass, about three times the mass of Earth, could be a single huge diamond.

Due to these findings, it is assumed that far-away rocky planets don’t have to be similar to Earth. They could be completely different, and Janssen was the first rocky planet to be detected that had a totally different composition than ours. On the day side, the planet reaches temperatures up to

Planet Janssen could be a glowing hot terrestrial planet (Picture: NASA)

2,400 degrees, while the night side is refreshingly cool with a maximum of 1,100 degrees.

HAT-P-1 B

When astronomers discovered HAT-P-1b in 2006, they were amazed to find that it is almost twice the size of Jupiter, while weighing only half as much. Accordingly, its density is only a quarter of the density of water and it is lighter than cork. In a giant bathtub, it would float three times higher than Saturn. So far, nobody knows why this is the case. Perhaps additional heat reaches the interior of the planet, but there is also no explanation for that. One possibility is that the planet might be ‘lying on its side’ and rotating vertically to its orbit, like Uranus in our system. However, as this position is very rare, and other ‘bloated’ planets have already been discovered, this theory definitely does not apply to all of them. The planet’s star, by the way, is part of a binary system.

HAT-P-1 b has an unusually low density (Picture: David A. Aguilar (CfA), artist’s impression)

GLIESE 1214 B

Gliese 1214 b is a Super-Earth. Its mass reaches almost 7 times that of Earth, and its radius is estimated to be more than two and a half Earth radii. It orbits its star at a distance of only 2 million kilometers. The most interesting aspect is that observations indicate its atmosphere consists mostly of water vapor.

The density of the planet might be around 2 grams per cubic centimeter. For comparison, that of Earth is 5.5 grams, and water weighs 1 gram per cubic centimeter. Scientists concluded that there must be lots of water there from the time the planet was farther away from its sun, in the habitable zone. The current close orbit and the high temperatures evaporate the water into a hot haze enveloping the planet. The planet is still considered one of the exoplanets most likely to have an ocean, but with a surface temperature of 120 to 280 degrees it would be so hot you'd better not jump into the water.

HD189733 B

The next time you stand in the rain, you might want to think of the inhabitants of HD 189733 b, even though it is rather unlikely they exist. On this planet there is not only a scorching temperature of 850 degrees, but perhaps also a rain of glass falling sideways, driven through the atmosphere by winds reaching up to 8,700 km/h. The cobalt blue color of the planet is not caused by oceans but by silicate particles

Gliese 1214 b has a thick, water rich atmosphere (Picture: NASA, ESA, and D. Aguilar (Harvard-Smithsonian Center for Astrophysics), artist's impression) in the clouds of its atmosphere. When these silicates condense in the extreme heat, they are turned into small drops of glass, which not only create the blue light, but are also carried around the planet by hurricanes. The planet is 30 times closer to its sun than Earth is to ours, and it has a captured rotation, meaning it always faces its star with the same side. The enormous temperature difference further reinforces the storms.

HD80606 B

All the planets in our solar system have relatively circular orbits, so that their closest and most distant points from the sun are not so different. The orbit of HD 80606 b, on the other hand, is strongly elliptical. During an orbit lasting 111 Earth days, the distance of HD 80606 b from its sun varies between 0.03 AU and 0.88 AU, where one astronomical unit equals the distance from the Earth to the sun. When it approaches the point closest to the sun, the temperature rises from 500 to 1,200 degrees within just six hours. Accordingly, the seasons on HD 80606 b are not determined by the angle of inclination but by its orbit. If you stayed high up in the atmosphere of the planet for one orbit, you would observe its star getting 30 times as large as the apparent size of our sun in our sky, while increasing its brightness by a

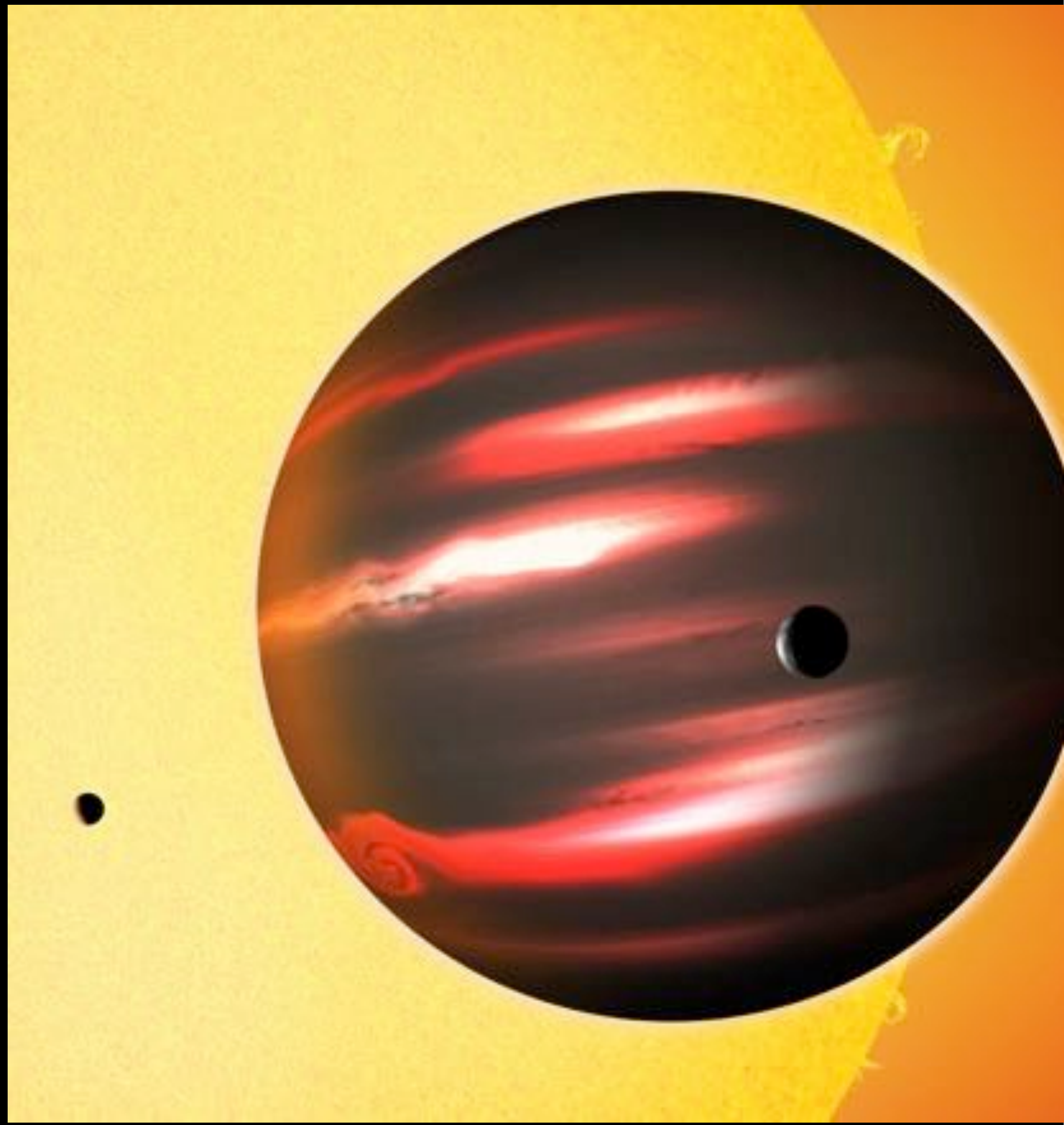
The blue color of HD189733 b is not created by water but by silicate particles in the atmosphere (Picture: ESO)

Eleven Exemplary Exoplanets

factor of 1,000. The extreme temperature changes must create storms just as extreme, with winds blowing at 18,000 km/h.

TRES-2 B

Could there be a world that is darker than the color black? Of course! The best example is TrES-2 b, one of the darkest exoplanets discovered so far. It only reflects one percent of the incoming sunlight, but it glows in a dull red like a heating coil, because an extreme heat of more than 1,000 degrees exists there. TrES-2 is about 750 light years away from us, in the direction of the constellation Draco, and it orbits its star at a distance of only 5 million kilometers. Unlike Jupiter, this planet apparently has no reflective clouds that can repel sunlight—in Jupiter's case, more than a third of it. Instead, it contains many light-absorbing chemicals that capture 99 percent of the radiation.



TrES-2 b is darker than coal – but why? (Picture: David A. Aguilar (CfA), TrES, Kepler, NASA)