Wonderful world: a blue planet orbits a red dwarf star in this artistic rendering. Is it a second Earth, a water world, or a planet without a solid surface like Neptune, where methane reflects the blue portion of sunlight? All these options are plausible.

IMAGE: PICTURE ALLIANCE / COVER IMAGES | A. SMITH, N. MADHUSUDHAN (UNIVERSITY OF CAMBRIDGE) / COVER

RARE EARTH

TEXT: AENEAS ROOCH

Is there a planet like ours in the vastness of space – not too big, not too small, not too hot, not too cold, made of rock and with an atmosphere that supports life? Laura Kreidberg and her team at the Max Planck Institute for Astronomy are searching for a second Earth with the James Webb Space Telescope. The most surprising thing is what they are not finding.

An Earth-like exoplanet – a term that fires the imagination and conjures up images from science fiction films. In astrophysics, it is a sober category, a pigeonhole for all planets beyond the Sun that are roughly the same size and weight as Earth, consist of rock, and orbit their star at a distance that allows liquid water to exist on their surface. This requires a cover made of gases – the atmosphere – that warms it through the greenhouse effect and exerts sufficient pressure on the surface to prevent the oceans from boiling off. Laura Kreidberg, director at the Max Planck Institute for Astronomy in Heidelberg, is searching for this kind of atmosphere in our Milky Way.

But how many are there out there? A glance at our immediate cosmic neighborhood reveals three rocky worlds – Venus, Earth, and Mars – which are roughly the same size on a cosmic scale but have very different atmospheres: while Earth has a thin atmosphere consisting mainly of nitrogen and oxygen, Venus has a suffocating greenhouse climate under a thick shell of carbon dioxide that is a hundred times heavier and thus exerts much higher pressure than Earth's atmosphere. Mars, with its wafer-thin gas layer, offers a rather sandy space environment. There are no traces of life on either Venus or Mars. But even on Earth, viewed from the International Space Station during the day, there is little evidence of life – only at night does a network of glowing cities and streets light up. And it was only when the ESA probe *Juice* pointed its measuring instruments at the Earth's atmosphere during its flyby in the fall of 2024 and found traces of life in the Earth's atmosphere that the first metrological proof of life on a planet from outer space was successful. However, this finding would not have been possible from light years away.

Detecting planets outside the solar system that pass through the darkness, hundreds of thousands to millions of times as far away from us as the Sun , is a complicated undertaking. After all, they are much smaller and shine much more dimly than their stars, for example, when they reflect their light in our direction or emit thermal radiation in infrared light themselves. Although it is speculative, even in our solar system, right in our cosmic backyard, there could be a planet hiding that has not yet been discovered by telescopes. If there are habitable worlds out there, they can only be seen as microscopic and faint dots, hidden in the glare of the star and the noise of the data. It is like trying to detect a small stone in the light of a floodlight on the moon.

It was not until the 1990s that the first planets outside our solar system were discovered. Astronomers now know of almost 6,000 exoplanets. Only around 80 of these, mainly massive gas giants that emit thermal radiation visible in infrared light, have been photographed directly. The rest were discovered indirectly and with great sophistication by planet hunters in the depths of the Milky Way, over 70 percent using the transit method: when a planet passes in front of its star as seen from our perspective, it blocks a tiny part of the starlight. In the telescope, the overall brightness of the star therefore appears to decrease by a few hundredths of a percent, and this faint flickering allows conclusions to be drawn about the size and orbital period of the planet. Of course, the larger the planet, the better this method works.

However, this indirect measurement reveals nothing about whether Earth-size planets have an atmosphere, because their atmospheres are far too thin to play a role in blocking starlight – on Earth, for example, the gas layer contributes less than one percent to the total diameter. Laura Kreidberg and her colleagues therefore use a trick. When the light from the star behind shines through the gas envelope of the orbiting planet, it encounters gas molecules and reacts with them: whether water vapor, methane, or carbon dioxide, each molecule leaves characteristic traces in the starlight – in the spectrum of all colors and wavelengths – and astronomers use these fingerprints to draw conclusions about the composition of the atmosphere.

SUMMARY

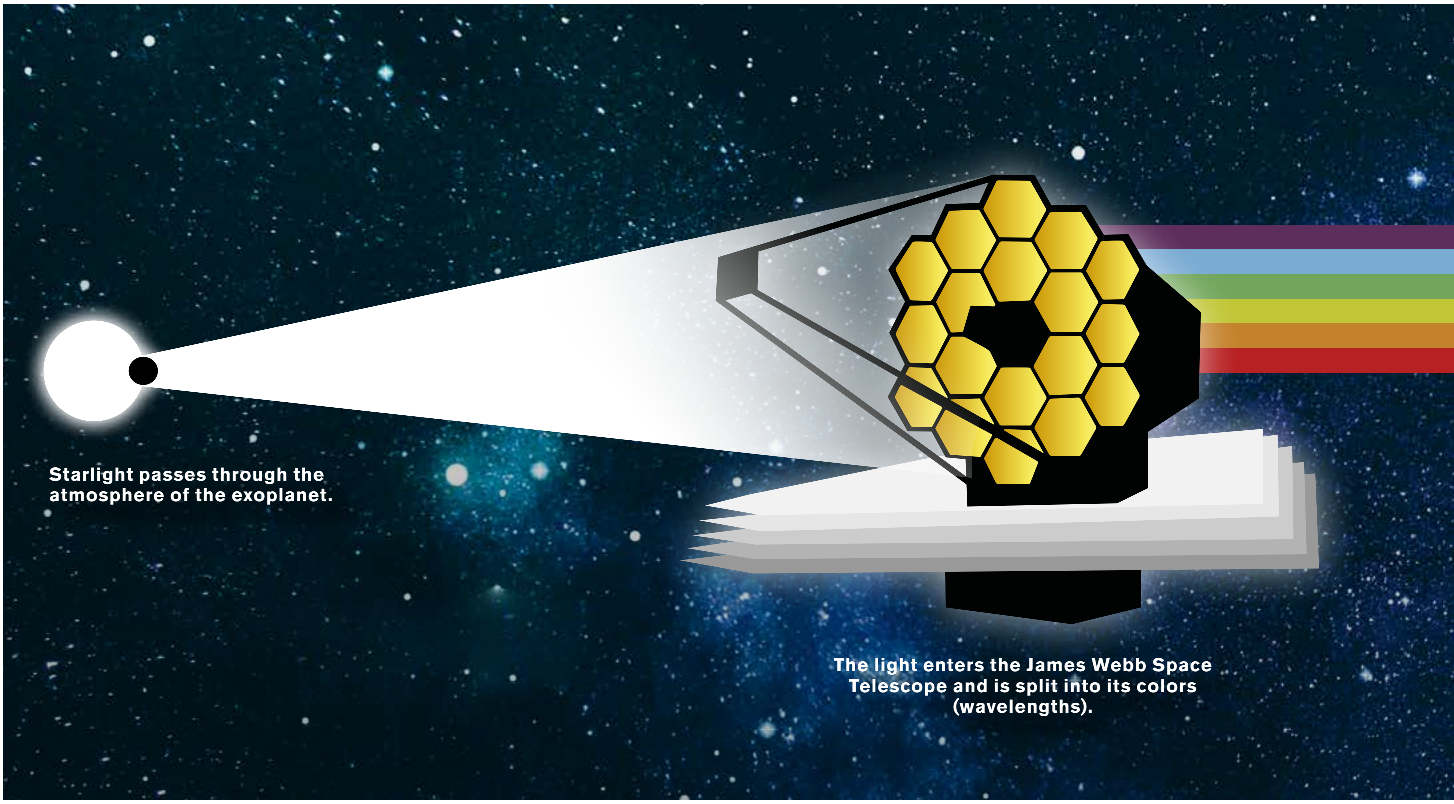
Laura Kreidberg and her team are using the James Webb Space Telescope to search for a second Earth – more precisely, for atmospheres around distant rocky planets.

The thinner the atmosphere, the harder it is to detect. What is certain, however, is that none of the planets studied have a thick atmosphere – one resembling that of Venus.

The researchers are focusing on rocky planets orbiting red dwarf stars. This is the most common class of star in the Milky Way, but also one of the most temperamental. Thinner atmospheres like Earth's may survive only around less active stars such as the Sun.

It is still unclear whether Earth-like atmospheres around Earth-sized planets are rare or simply difficult to measure. Future observations will reveal how special Earth truly is.

GRAPHIC: GCO BASED



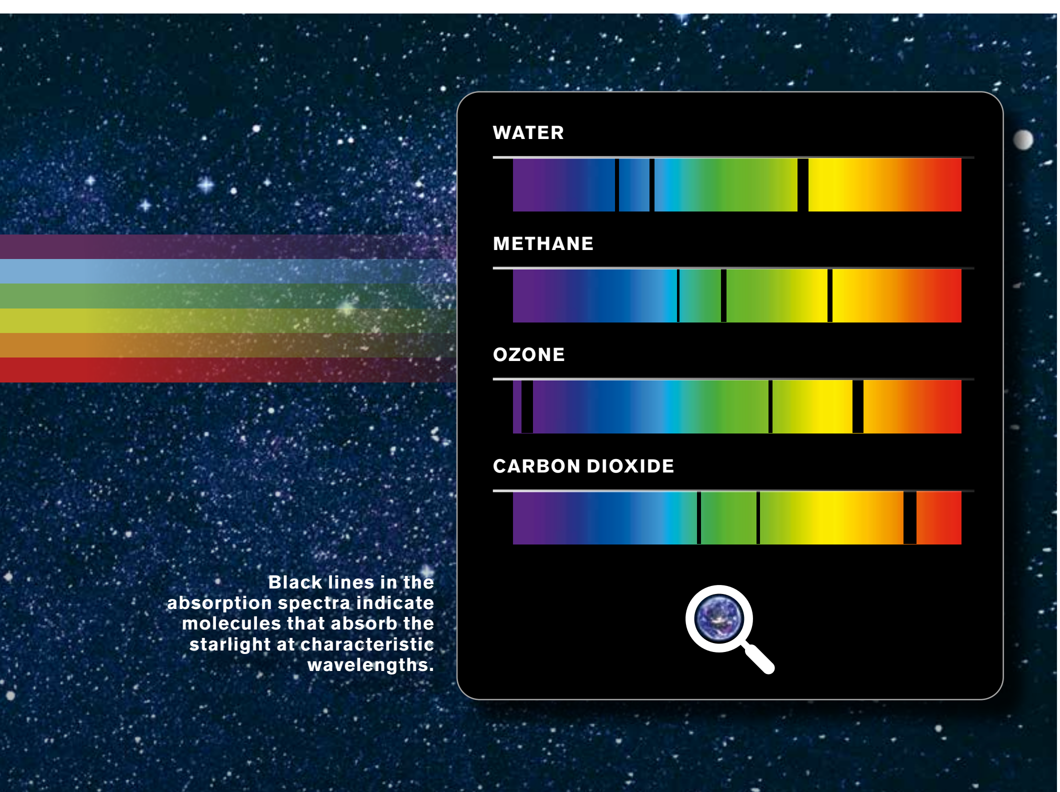
Laura Kreidberg and her team use the James Webb Space Telescope to break down the starlight that has been altered on its journey through the planetary atmosphere – a process known as transmission spectroscopy. “James Webb is the most advanced scientific instrument ever sent into space,” Kreidberg enthuses. “It took almost three decades to develop, and I’m lucky to have been born at just the right time to be able to work with it.” And even though the measured signal is weak, they do find fingerprints of chemical elements in worlds many light years away. “We’re pushing the measuring instruments to their limits,” she explains.

Before researchers venture to study rocky planets, it is worth taking a look at a class of planets known as Sub-Neptunes. Their size and density lie somewhere between those of Earth and Neptune. Their enormous atmospheres make them quite valuable for spectroscopy. The more extended the atmosphere through which the starlight passes, the stronger the signal left by the molecules in the atmosphere in the starlight.

One example is K2-18 b, which orbits a red dwarf star. In addition to a lot of hydrogen, astronomers have also detected methane and carbon dioxide in the spectra of the James Webb Telescope. If the atmosphere of K2-18 b were only as thin as Earth’s, it would have been even more difficult to detect the fragile traces of gases in the noise of the data – even if they existed. Then, in 2025, it prompted an outcry, which even made it onto the news: possible signs of life discovered! A research team claimed to have found signs of molecules in the atmosphere of K2-18 b that are only produced by plankton here on Earth. Laura Kreidberg urges caution: “These claims are not legitimate – at all!” Together with many colleagues, she has been trying to bring this hype back down to Earth. The data is actually far too noisy, these complex molecules cannot be statistically proven. And they may not even be stable: the deeper you dive into an atmosphere, the greater pressure and temperature get. On the deep-lying surface of K2-18 b, it could be as hot as 2000 to 3000 degrees Celsius. That’s a bad sign for DNA and life. “This planet is definitely not habitable,” Kreidberg writes in a commentary in Scientific American. One could get the impression that scientists are divided on the issue, but the opposite is true. Shortly after the news threatened to spread like wildfire, the research community vehemently refuted it. Even though many would have liked to find signs of life, science has its methods, and they apply to everyone.

Ambiguous Results

But even if the work was carried out methodically and correctly, there may still be room for speculation. Before



With a clear view: researchers point the James Webb Space Telescope at an exoplanet that is just passing in front of its home star. As the light flows through the planet’s atmosphere, the molecules it contains leave characteristic traces in the starlight, which the telescope’s camera records. Spectroscopy makes it possible to split the light into its wavelengths and to make the discrete signatures of the distant atmosphere visible, provided the signal is strong enough. The rainbow colors serve only for illustration, as the infrared light is invisible.

astronomers can draw conclusions from the measurement data, they must compare it with models that mathematically describe how starlight changes as it passes through the atmosphere given a mixture of ingredients. Depending on which model the scientists use, the same data set can lead to different conclusions, especially with such weak signals. That is why several teams in Heidelberg are working independently on the same data, each using a different model approach. "It is generally considered good practice to perform at least two independent analyses of the data to ensure that conclusions are reliable," says Kreidberg.

The challenge of discovering and studying an atmosphere at such immense distances is enormous. Atmospheres are highly dynamic systems. On Earth, for example, oceans, clouds, plants, volcanoes, and living organisms influence each other; there are chemical reactions, stratification, mixing, and currents. Reconstructing such a complex system from hundreds to thousands of light-years away is difficult. Especially since the planet may not even be passing in front of its star but hiding behind it while James Webb is pointed at it. "That's what keeps me awake at night," Kreidberg admits, "the worry that we're looking at the wrong time." What's more, if there is a second Earth out there orbiting its home star at the same distance as our Earth orbits the Sun, then its orbit is most likely not inclined in such a way that, when seen from our perspective, it passes exactly in front of the star – such a constellation only occurs in 5 out of 1000 cases.

Venuses Are Rare

Before investing time and effort in using James Webb to search for atmospheres, whose molecules either emit measurable light themselves or affect the light of the star behind, it is worth doing a preliminary check: Is there any hope of an atmosphere at all? To clarify this in advance, Laura Kreidberg and her team measure the surface temperature of rocky planets. The temperature can be measured from the contrast in brightness between the planet and the star. Here, the researchers are focusing on planets orbiting red dwarf stars.

Such systems are easy to find as red dwarfs are most common, accounting for three quarters of all stars in the Milky Way. In addition, these stars are smaller and not as bright as the Sun, making it easier to measure rocky planets. And they are comparatively lightweight, with rocky planets orbiting them at a shorter distance than Earth orbits the Sun. The tidal forces at work cause such planets to often show the same side to the red dwarf – like the Moon to Earth – and this is exactly what helps Laura Kreidberg and her team in their search for an atmosphere. This means that the planets have a hot, constantly illuminated day side and a freezing cold, eternal night side. Depending on where these planets are located in their orbit, different amounts of the day side are visible, similar to the way we see different phases of the moon over time. The scientists use the temperature differences between these two sides as a diagnostic tool: if a gas envelope exists, it should distribute the heat on the planet's surface, and the temperature difference between the day and night sides would be small – as is the case with Venus. If, on the other hand, the day side is extremely hot and the night side is freezing cold, this indicates a bare surface without an atmosphere. And that is the decisive advantage of this method, because transmission spectra are much more ambiguous – the absence of a signal could mean there is no atmosphere, it's masked by clouds, or the atmosphere is too compressed to be detectable.

Have Laura Kreidberg and her team in Heidelberg been able to finally discover the first traces of a life-friendly

Icon on a wire: Laura Kreidberg stands next to a 1:10 scale model of the Hubble Space Telescope. Before the James Webb Space Telescope began operations, this was the most powerful eye in space.

atmosphere on a distant rocky world – the first indications that we are not alone in the universe – using that method? "Unfortunately, we have to be bearers of bad news," says Laura Kreidberg, "none of the rocky planets around red dwarfs we have studied since 2024 appear to have atmospheres – thick atmospheres to be precise." Thick atmospheres like that of Venus exert high pressure onto their surface and are relatively easy to detect with James Webb using the temperature method. But what does that mean for Earth? How unique is it? Laura Kreidberg is cautious in her assessment: "It's too early to say that Earth is special. But Venus is." This sounds disappointing at first. However, Kreidberg and her colleagues have only analyzed about ten planets in detail so far. It is a very small sample amid the billions of planetary systems that must exist in the Milky Way, and therefore no proof that there isn't a second Earth. "Based on what we've seen so far, I think the most likely scenario is that thick atmospheres are simply rare," the astronomer interprets. The rocky worlds she has focused on with the James Webb Space Telescope so far appear hot and exposed to space without protection.

Earth: The Result of a String of Coincidences

This is surprising. Carbon dioxide escapes from the interior of rocky planets and, unlike more volatile gases, remains stable in the atmosphere, even under the extreme X-ray and ultraviolet radiation that is common to red dwarfs, which erodes other molecules over millions of years . Earth was also surrounded by a heavy envelope of greenhouse gases before photosynthesis broke down most of the CO_2 a few billion years ago. So, the crucial questions are: Are there no Earth-like atmospheres around Earth-sized planets because they can't be easily detected or because they never existed? Or because they have been blown away by stellar radiation? Laura Kreidberg is optimistic about the future: "In ten years, we will have measured the atmospheres of another 50 rocky planets, which will give us a clearer picture of what is typical for the universe and what is not."

Maybe the handful of planets that have been studied so far simply form an unfavorable sample. Maybe one has to focus on calmer stars like the Sun to form stable shells around rocky planets. But such stars are less common in the Milky Way, accounting for about 20 percent. But maybe a Sun-like star just isn't enough. The Earth's atmosphere could also be the result of further cosmic coincidences: the Earth is neither too large nor too small, neither too hot nor too cold, and it has a magnetic field that adequately protects the gas envelope from strong solar storms, which the Sun also regularly emits; Earth has a moon that ensures a stable axial tilt and tides, oceans that act as CO_2 reservoirs, a tectonically active crust that allows gases to circulate, and a Jupiter in its neighborhood that captures asteroids or deflects them from their course into the inner solar system. "Science is still a long way from understanding what caused the Earth's atmosphere to form and exist," says Kreidberg. "Looking at other planets and how atmospheres form there or not, how they disappear or stay there, can also help to clarify this."

Every clue that scientists uncover from the depths of space brings us closer to answering one of the most fundamental questions humans can ask: Are we alone? "In a world facing many challenges, from climate change to war, this research highlights just how special the Earth really is – how much it should be cherished and protected," says Laura Kreidberg. ←

We are real: the ESA probe *Juice* was en route to Jupiter's moons when, on August 20, 2024, it briefly aimed its instruments at Earth for testing. Spectrographs on board confirmed: Earth is inhabited!

PHOTO: ESA/JUICE/

GLOSSARY

SPECTROSCOPY
is a method in which an instrument splits the light of, for example, a star into its wavelengths (or colors) – similar to a rainbow. In transmission spectroscopy, light passes through, for instance, a gas, where it interacts with molecules or atoms of the gas at specific wavelengths, exciting or being absorbed by them. As a result, lines appear in the recorded spectrum at precisely those wavelengths, allowing conclusions to be drawn about the composition of the gas.