Two years ago, a new department opened at the Max Planck Institute for Astronomy in Heidelberg in which researchers study the atmospheres of extrasolar planets. Its young director, Laura Kreidberg, has made a name for herself with some of the first observations of these worlds and is one of the lucky ones who will get to observe with the new James Webb Space Telescope.

TEXT: THOMAS BÜHRKE

To be appointed the new director at a renowned Max Planck Institute is a great honor. But in the middle of a Covid lockdown, such a turn of events can be an unexpected challenge. That's what happened to Laura Kreidberg when she wanted to move to Heidelberg in June 2020. "The most difficult thing of all was the preparation," says the young American, "but fortunately we received a lot of help from the institute during this time."

The head of the travel office viewed apartments for them, and the managing director wrote a formal document in which he justified Kreidberg's travel on one of the few transatlantic flights that were currently in service. "It was exhausting, but we made it!" By "we," the scientist also means her husband, who soon found a job at a startup in Germany thanks to his specialty in data science. The job happened to be in Berlin, but this was not a problem as working from home had become standard due to the Covid pandemic. At the time of her appointment, Laura Kreidberg was just thirty years old, making her one of the youngest directors in the history of the Max Planck Society. Her research field of Atmospheric Physics of Exoplanets seamlessly connects to the Planet and Star Formation department, where a focus on the discovery and investigation of extrasolar planets has been established for a long time. Since the spectacular discovery of the first planet orbiting a distant star in 1995, hardly any other field in astronomical research has developed as rapidly as this one. To date, around 5000 exoplanets are known.

The diversity of these bodies, some of which are very exotic, surprised the experts: there are gas planets with temperatures above 1000 degrees, some of which are so close to their central sun that they are literally evaporating; others are made of rock and may be similar to Earth. What these distant worlds are like, what temperature exist on them, or whether they have an atmosphere that can perhaps allow the emergence of life – these are the questions that fascinate Laura Kreidberg, and led her to study astronomy in the first place. Unlike many of her colleagues, it was not the fascination of staring at the night sky through a telescope that got her

⟶

VISIT TO

LAURA KREIDBERG

PHOTO: ANNA ZIEGLER FOR MPG

Difficult shadow play: when a small celestial body passes in front of the sun that it orbits, it covers a tiny part of its surface. The existence of such an exoplanet can be inferred from the resulting decrease in stellar brightness. Laura Kreidberg, director at the Max Planck Institute for Astronomy, studies the geological properties and atmospheres of these objects.

started. “In fact, to this day, I’ve hardly ever looked through a telescope,” she confesses, and she is not very familiar with the constellations either. “When someone asks me to show them where this or that planet that I’ve been studying is in the sky, I can only shrug my shoulders.”

The researcher grew up in the mid-sized city of Reno in the U.S. state of Nevada, which is best known for its casinos. However, its proximity to the Sierra Nevada and Lake Tahoe makes it great for hiking – a passion that Kreidberg still indulges in today. In high school, she became interested in physics because the subject “didn’t require as much memorization as, say, biology.” Every now and again, she participated in Science Bowls, a competition for young scientists.

Then she learned that someone had studied the atmosphere of an exoplanet for the first time. This was her personal light-bulb moment. “Studying the composition of the atmosphere and the climate on a distant planet places the highest demands on observational techniques and I was fascinated by this,” she recalls. “It was clear to me that this was something I could work on for the rest of my career.”

For her doctoral research, Kreidberg pounced on the topic, using the Hubble Space Telescope to observe a planet orbiting a star 48 light-years away called Gliese 1214. This type of planet is referred to as a super-Earth, which has no analog in our solar system. Gliese 1214 b is seven times heavier and almost three times larger than Earth, but smaller than Neptune. Astronomers had already tried to analyze

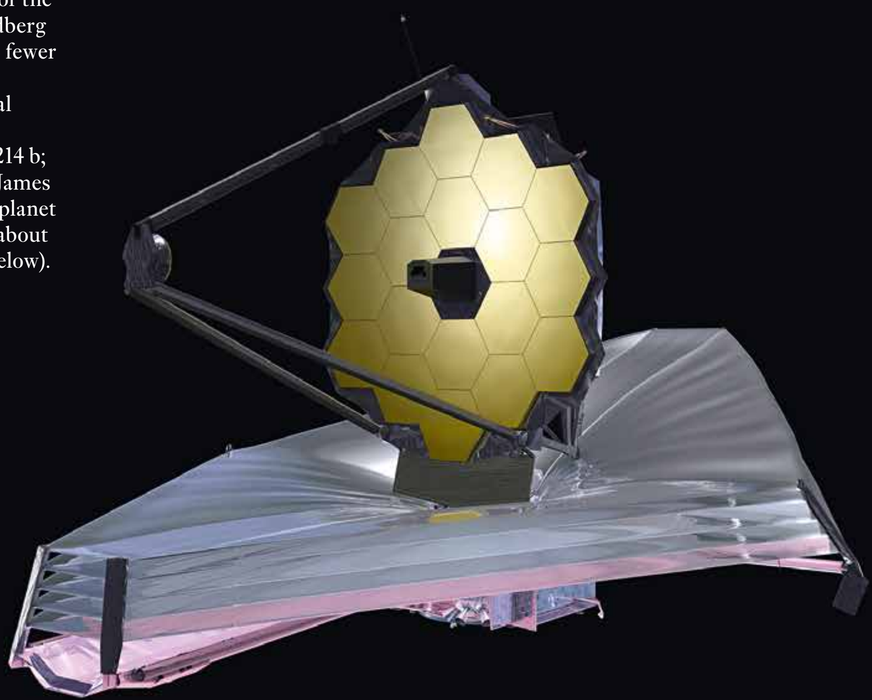
“We’ve even seen planets orbiting two stars, like Tatooine in *Star Wars.*”

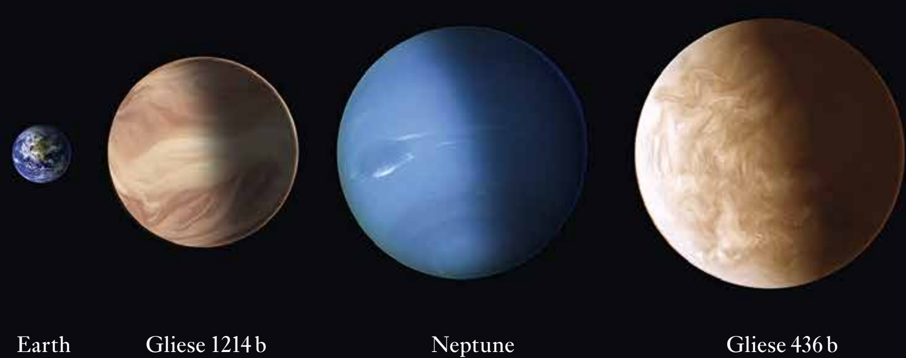
There were no scientists in her family, but as a child, she was inspired to ask really big questions by reading her father’s popular science books on astronomy. “I remember asking my mom where the edge of the universe was,” she says. She was also immensely fascinated by the books of Stephen Hawking and Brian Greene, as they opened up a view of a universe that was as mysterious as it was immeasurable. No sooner had she gotten bored and frustrated by her physics classes – which focused on old, long-solved problems – when another coincidence steered her toward astronomy. She became aware of the work of Nate Silver – a journalist who used statistical methods to analyze the results of baseball games and later applied the technique to presidential elections. “I found that you can also use these methods to address many questions in astronomy,” says Kreidberg. “I applied them in my undergraduate research, which was about black hole masses.”

the atmosphere of Gliese 1214 b – without getting any clear results. One assumption was that the atmosphere consists mainly of water vapor, which would mean that the planet could also be covered largely or entirely by water – an ocean planet, in other words. However, the new observational data from Kreidberg and colleagues largely ruled out this scenario. The conclusion was that the atmosphere must be covered by dense clouds.

This was followed by observations of other exoplanets, which revealed their diversity time and again. In our solar system, there are the inner, terrestrial rocky planets and then, beyond the asteroid belt, the gas giants. Most other solar systems do not look like this. There are many planets that orbit so close to their central stars that their atmospheres evaporate or the rocks melt into lava. In the case of extremely hot gaseous planets, it was possible to detect clouds composed mainly of metals such as iron, magnesium, chromium, and vanadium. →

Alien worlds: using the James Webb Space Telescope, researchers will study the atmospheres of distant rocky planets for the first time. Laura Kreidberg was successful with no fewer than two observing proposals. Her doctoral thesis focused on the 'super-Earth' Gliese 1214 b; another target for the James Webb could be the exoplanet Gliese 436 b, which is about the size of Neptune (below).





GRAPHICS: NASA, DEEP SPACE NETWORK (TOP); NASA, ESA, AND A. FEILD AND G. BACON (BOTTOM).

PHOTO: ANNA ZIEGLER FOR MPG

Dedicated teamwork: Laura Kreidberg places a lot of emphasis on communication in her department. Here she is holding a discussion with her doctoral student Evert Nasedkin.

"We've even seen planets orbiting two stars, like Tatooine in *Star Wars*," Kreidberg says. The zoo of exoplanets boasts a host of exotic specimens.

Laura Kreidberg made a name for herself with her doctoral thesis and other publications; she has also won several prizes. No wonder, then, that she soon had several attractive job offers to choose from – for example, at the renowned Harvard University. Ultimately, there were several reasons for her decision to become a director at the Max Planck Institute for Astronomy in Heidelberg. Here, she has the opportunity to build up her own research group over the long term with fixed funding. Seven of a total of fifteen approved positions have been filled, and she has already acquired additional positions through grants. This is advantageous, as it allows experts from all over the world and different disciplines to work under one roof: observers as well as theorists who can calculate complex atmospheric models. "Research on exoplanets is interdisciplinary," says Kreidberg.

Another important reason was easier access to large European observatories, especially the Very Large Telescope housed in the European Southern Observatory ESO in Chile. It is also set to be joined by what will then be the largest telescope on Earth, ESO's Extremely Large Telescope, by the end of this decade. This will have a concave mirror with a diameter of 39 meters, setting completely new standards in observational astronomy. The Max Planck Institute in Heidelberg is involved in the construction of an instrument that will record both images and spectra in the infrared range. "With support for instrumentation projects from the Max Planck Society, I have the opportunity to make observations with state-of-the-art facilities over a very long period of time," says Kreidberg.

But before this happens, the astronomer will observe with the new superstar on the scene: the James Webb Space Telescope. After years of delays and increasing costs, the ten-billion-dollar instrument finally entered space in December 2021 and reached its destination four weeks later – 1.5 million kilometers from Earth. There, in the deepest darkness, it is expected to surpass the capabilities of the Hubble telescope many times over. "It will be 10,000 times better," Kreidberg enthuses. The mirror, the wavelength coverage, and the spectral resolving power are each ten times better. "By observing in infrared light, we can access much cooler and, therefore, potentially habitable planets than before, and we can also more easily detect a wide range of molecules in the atmospheres of exoplanets."

However, the James Webb is an all-around instrument that is just as well suited for studying distant galaxies, black holes, or faint comets. Accordingly, there is high demand for observation time from researchers. For the 6000 hours available for the first observation cycle, a total of 1172 applications were received from scientists in 44 countries. Of the 266 proposals ultimately selected, one-third came from member states of the European Space Agency (ESA), which is involved with the new super telescope.

Laura Kreidberg emerged from this competition rather successfully: the international committee approved no fewer than two of her proposals. "I had actually written four proposals, which was a really busy time," she says. All details in the proposals had to be worked out to the nth degree. "For a month, I sat at home with my laptop filling out applications while my husband fed me ice cream." The work, and the ice cream bill, paid off. So far, atmospheres could only be detected on hot planets the size of Jupiter, which is why these celestial bodies are also called hot Jupiters. The James Webb Space Telescope is now expected to make the breakthrough and provide access to the atmospheres of smaller rocky planets. The problem in all cases is that the star is thousands of times brighter than the nearby planet and outshines it.

This is also the case with an exoplanet called Trappist-1 c, which Kreidberg chose for her observations with the space observatory. Forty light-years away, this rocky planet is only slightly larger than Earth but orbits its star at such a close distance that its temperature is similar to that of Venus. "This body is the coolest terrestrial planet we can detect heat from with JWST," the astronomer says. "We want to find out if it has an atmosphere."

The first step will be to do this in an indirect way because the star and planet themselves cannot be observed separately with James Webb. The brightness of the star and planet are measured together in the infrared range where the planet emits thermal radiation. As the planet passes behind the star, the heat emanating from its surface or atmosphere is blocked.

⟶

The brightness of the planet can be determined from the change in the total brightness, and from this, its temperature can be derived. This process is strongly dependent on whether an atmosphere is present or not. Without an atmosphere, all the starlight hits one hemisphere and heats it very intensely. But if the planet is surrounded by a thick atmosphere, the gas envelope transports heat from the hot day side to the cooler night side balancing it out. The day side is not as hot with an atmosphere as it is without. Hence such a measurement provides an indirect indication of an atmosphere.

search for volcanic basalts, solidified magma surfaces, and granite – all indicators of crustal reprocessing and tectonics. "We also want to look for traces of sulfur dioxide as a result of volcanic outgassing."

One of the overarching goals of exoplanet atmosphere research is to detect biosignatures on Earth-like planets. Most commonly cited in this regard is the simultaneous presence of oxygen and methane. Normally, these gases react quickly with each other to form carbon dioxide and water. "So if we see the

"We want to look for traces of sulfur dioxide as a result of volcanic outgassing."

Should this observation indicate the existence of an atmosphere, Kreidberg will request a complementary measurement for the next round with the James Webb; this time with a spectrograph. As the planet passes in front of the star, some of the light passes through the planet's atmosphere whose molecules leave their fingerprints in a spectrum. "This allows us to determine, for example, whether the atmosphere contains water, methane, or carbon dioxide," she says.

As recording a spectrum is time-consuming, it makes sense to do this only when the previous brightness measurement has confirmed that an atmosphere exists in the first place. While planning her JWST observations, the astronomer discovered a fun fact about the telescope. The color filter she will use to observe TRAPPIST-1c is part of a filter wheel whose mechanics were developed and built by the Max Planck Institute. "Yet another reason to come here," says Kreidberg with a grin.

The second rocky planet she will observe, LHS 3844 b, is also slightly larger than Earth but has a temperature of +770 degrees and probably has no atmosphere. In this case, the aim is to understand the geological conditions of a terrestrial planet for the first time. Kreidberg plans to use the James Webb to

two gases at the same time, this means they are constantly being produced and replenished by something, and that something on Earth is life," the Max Planck director says. However, even the James Webb will probably fail in this task. Oxygen, in particular, leaves only a very weak spectroscopic signature. In addition, clouds in the atmosphere could make such observations difficult.

The question of what other biomarkers might exist is currently highly topical. We know, for example, that Earth's atmosphere contained hardly any oxygen until about 600 million years ago, but life did exist, albeit primitive life. This means that the atmosphere at that time had different biomarkers than the atmosphere today. Perhaps it will be possible to detect these on other planets in the years to come.

In any case, the scientist is convinced that life exists somewhere out there. Again, as with exoplanets, there could be much greater diversity than we imagine. "To search for signs of life in the atmospheres of distant planets, we need even better telescopes – and patience," says the astronomer, summing up. At NASA and ESA, the search for biomarkers is a top priority. Plans are already underway for next-generation space telescopes that could launch in the 2040s. "So, before I retire!" says Kreidberg, laughing.