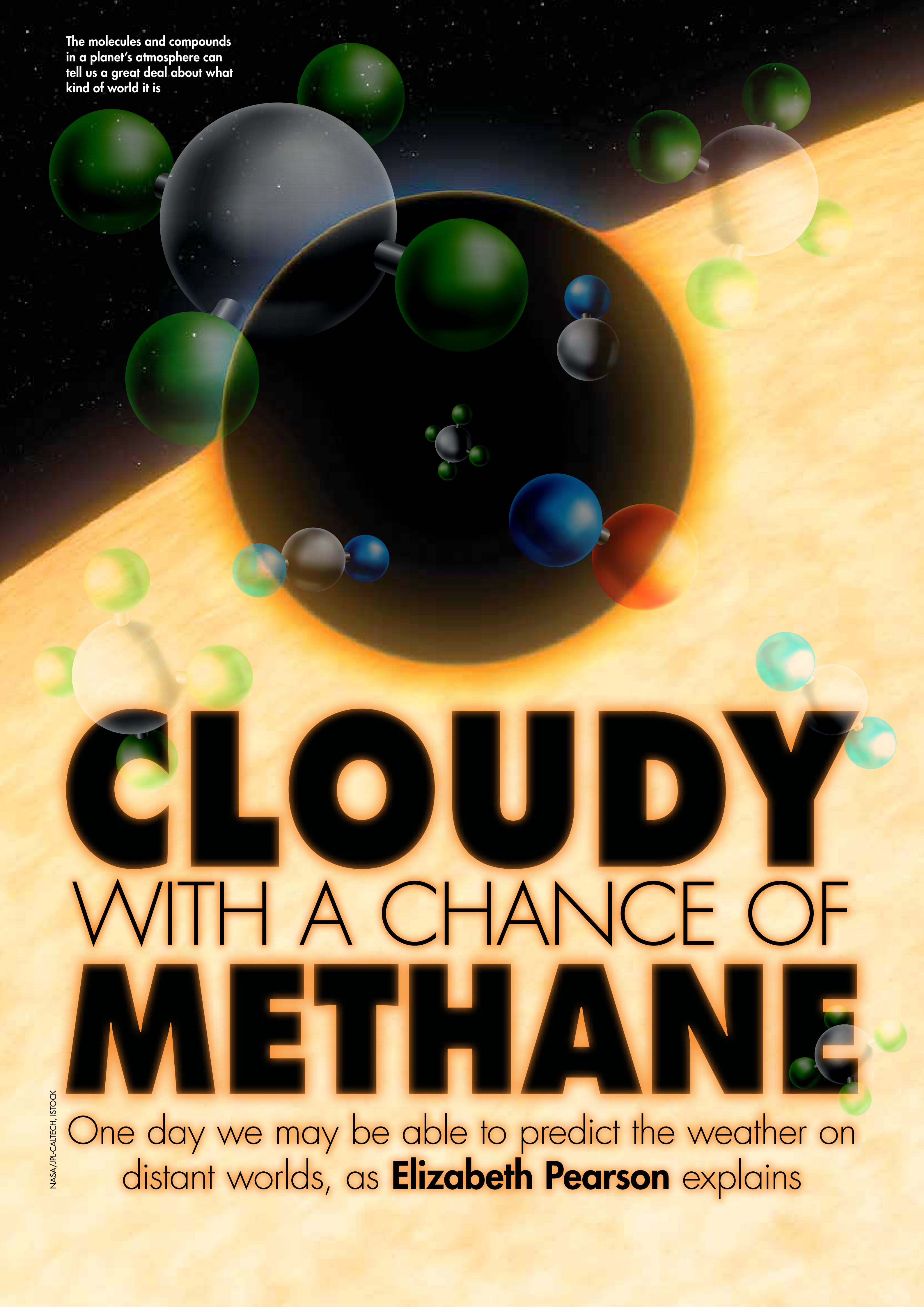


The molecules and compounds in a planet's atmosphere can tell us a great deal about what kind of world it is

CLOUDY WITH A CHANCE OF METHANE

One day we may be able to predict the weather on distant worlds, as **Elizabeth Pearson** explains

NASA/JPL-CALTECH, ISTOCK

▲ Hot Jupiters bear close similarity to their Jovian namesake – save for the fact they orbit so close to their parent stars

Our Galaxy is littered with worlds, from gas giants that skim past their stars to super-Earths only a few times more massive than our planet. In recent years, the field of exoplanet research has boomed, detecting thousands of new planet candidates. But finding them isn't enough anymore. Now we need to know what these worlds might be like.

Getting up close and personal as we have done with our companions in the Solar System isn't an option. These exoplanets are so far away that we can't even begin to consider sending probes to take pictures and create maps. Yet it is still possible to get to know them better, not by looking at the planet itself, but at the star it orbits. By examining the light from its host star, we can learn a great deal about the composition of an exoplanet's atmosphere.

"Some of the starlight is filtered through the planet's atmosphere and when it hits the molecules in the atmosphere it makes them swing and rotate," says Lisa Kaltenegger from the Carl Sagan Institute at Cornell University. Each element and molecule has a specific energy of light that causes it to move and it absorbs only this specific energy of light when it's struck. "That light is missing when the light gets to the telescope – it's used up. And this is how you can tell exactly what chemicals are in the atmosphere of a planet."

This technique is called spectroscopy, and by using it to look at the light from the host star it is possible to find 'spectral features', specific energies that are missing from the stellar light. The unique pattern of features spells out what elements are found inside the atmosphere. But the observations are extremely difficult to make and there are limits to what can be determined.

"A lot of the science is driven by the observations we can currently make. The Hubble Space Telescope's Wide Field Camera 3 can detect strong features due to water and methane, but can only make good measurements for hot Jupiters," says Nikku Madhusudhan, an astrophysicist from the University of Cambridge.

Giant roasters

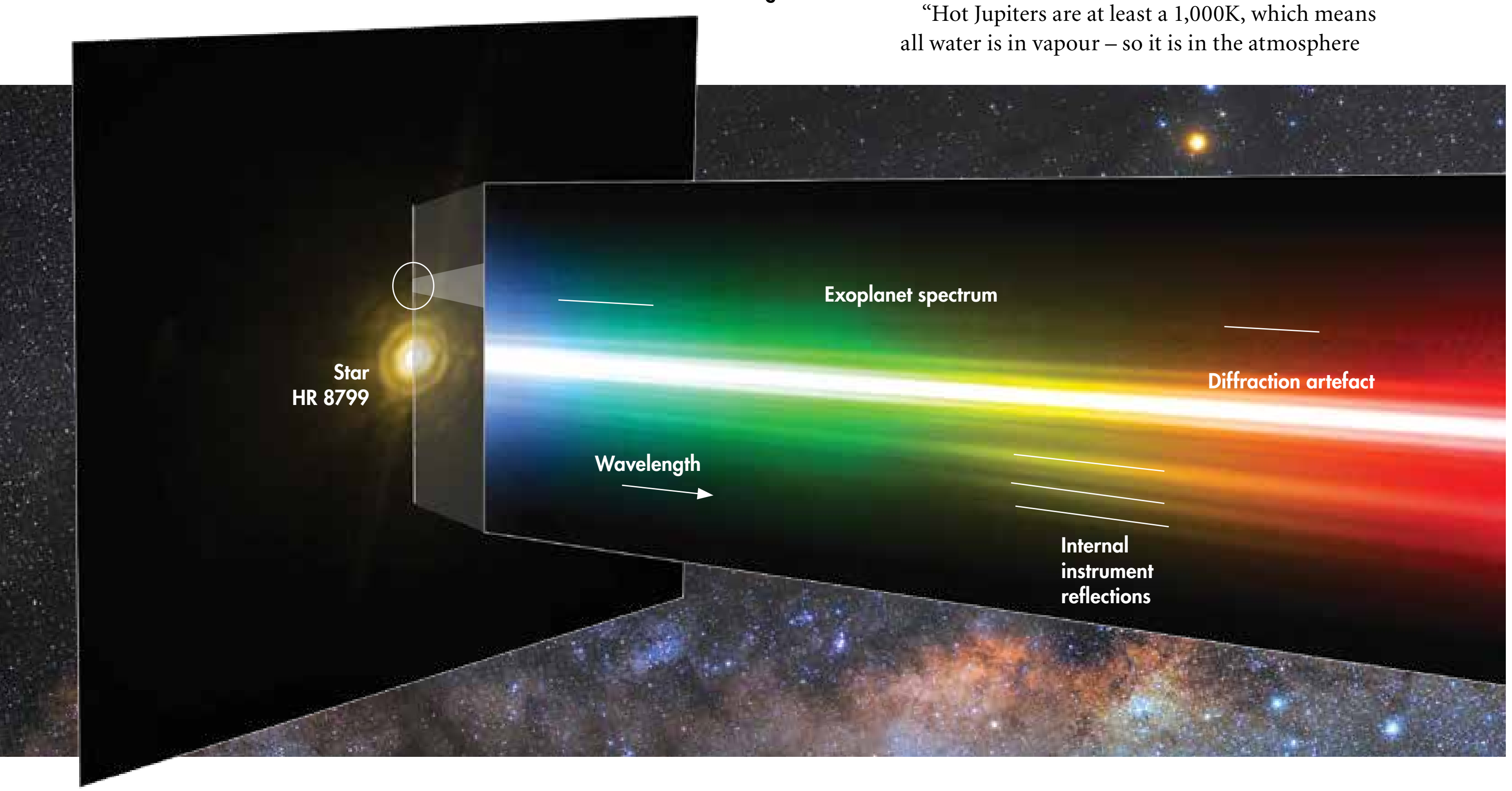
Hot Jupiters are gas giants that are incredibly close into their stars, earning them the nickname 'roaster planets'. Their tight orbits cause their atmospheres to become superheated and expand.

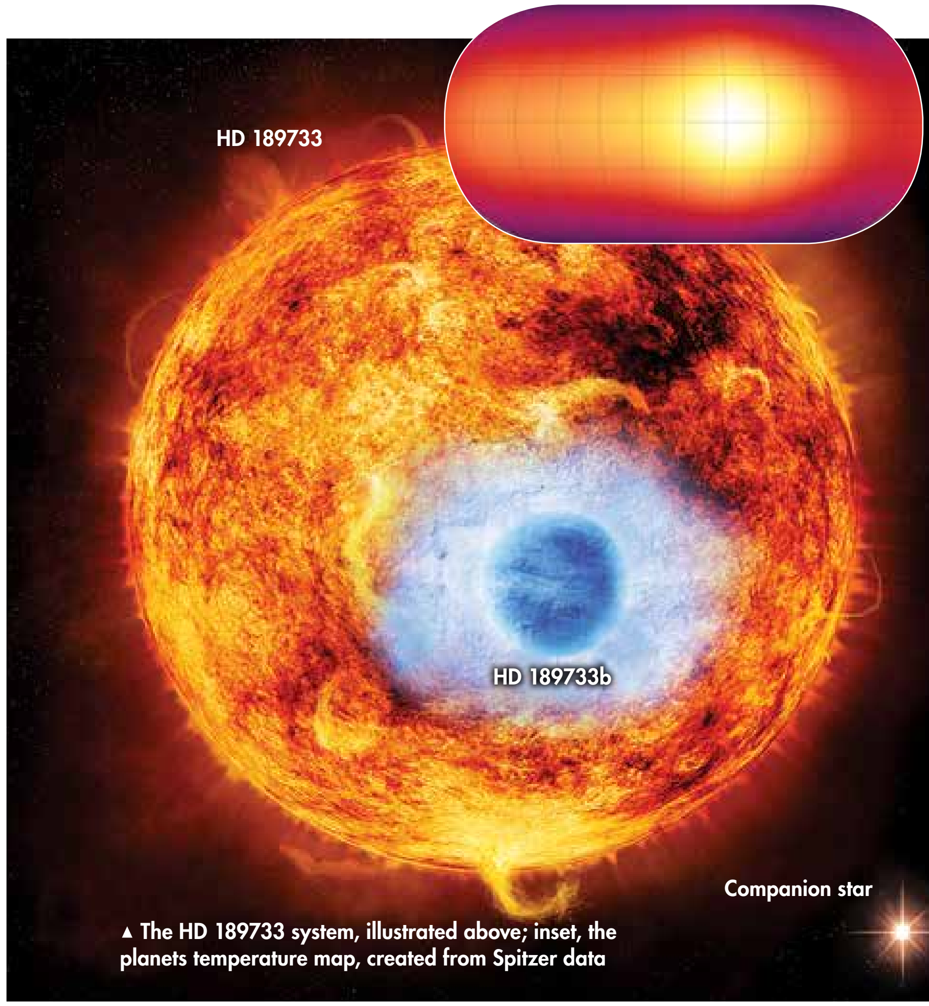
"Hot Jupiters are at least a 1,000K, which means all water is in vapour – so it is in the atmosphere and you can see it in spectra," says Madhusudhan. "We don't know the water abundance of Jupiter within our own Solar System. For the first time there is a quantity that we can measure better in an exoplanet than we can in our own Solar System."

Luckily water is key for planet formation, and so understanding it is critical to understanding how these worlds came to be. It is also vital for finding habitable worlds, a task which exoplanet searches have always been inextricably linked with.

But here comes the problem. Currently, we can't look for water, or any other atmospheric molecule, on an Earth-like planet. On a hot Jupiter the change in brightness betraying the presence of water is 0.01 per cent, which is difficult enough. For an Earth-like planet the change is 10 times smaller, far beyond the capabilities of current equipment. But this may not remain the case for long.

▼ Picking the planet out of the starlight is tricky; the spectra detected often hold misleading artefacts





▲ The HD 189733 system, illustrated above; inset, the planets temperature map, created from Spitzer data

THE WORLD WITH 8,700km/h winds

The exoplanet HD 189733b, located 63 lightyears away in Vulpecula, is not what could be classed as a hospitable world. This hot Jupiter loops around its star 30 times closer than the Earth does to the Sun, completing an orbit every 2.2 days.

Like many of its close-orbiting fellows, HD 189733b is tidally locked. While one side reaches enormous temperatures, the other freezes. Over the course of the planet's orbit the Spitzer Space Telescope managed to track changes in the planet's infrared emission, creating a thermal map of the planet showing this split personality.

The huge dichotomy of temperature, combined with a thick atmosphere, creates such a stark air pressure difference between the two sides that it results in winds that blow as fast as 8,700km/h.

"One hemisphere will have winds blowing in one direction towards you, whereas the other hemisphere will have winds blowing away," says Laura Kreidberg of the University of Chicago. You can compare the spectral features of the two and measure the Doppler shift and use that to constrain how fast the wind is blowing.

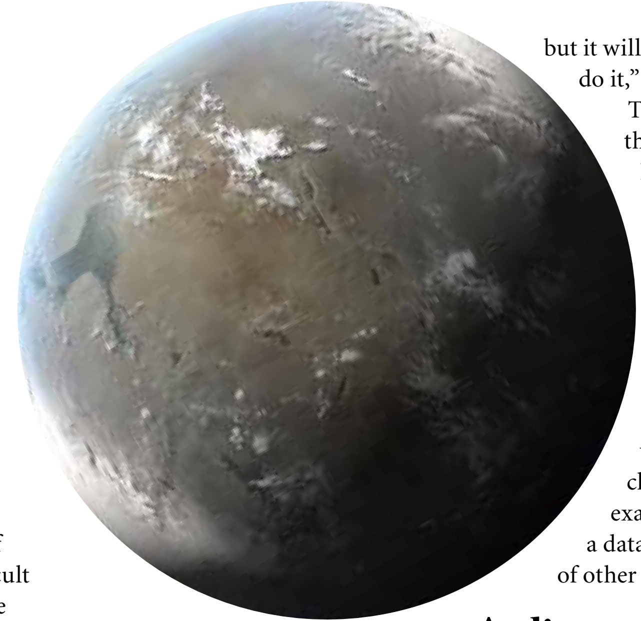
At 8,700km/h, the winds gust at more than four times the speed of fastest measured in our Solar System, which are found on Neptune. There, bands of storms whip and whirl at a comparatively tame 2,100km/h.

"We are creating a database of these spectral fingerprints of other worlds, other Earths"

"When the James Webb Space Telescope (JWST) goes up it will catch enough light to look at the atmospheres of planets like Earth. It's going to take a lot of time but it will be technologically possible to do it," says Kaltenegger.

To make sure they are ready for the results when they come, Kaltenegger has already begun predicting what it is that the JWST would see if it looked at a world like our own.

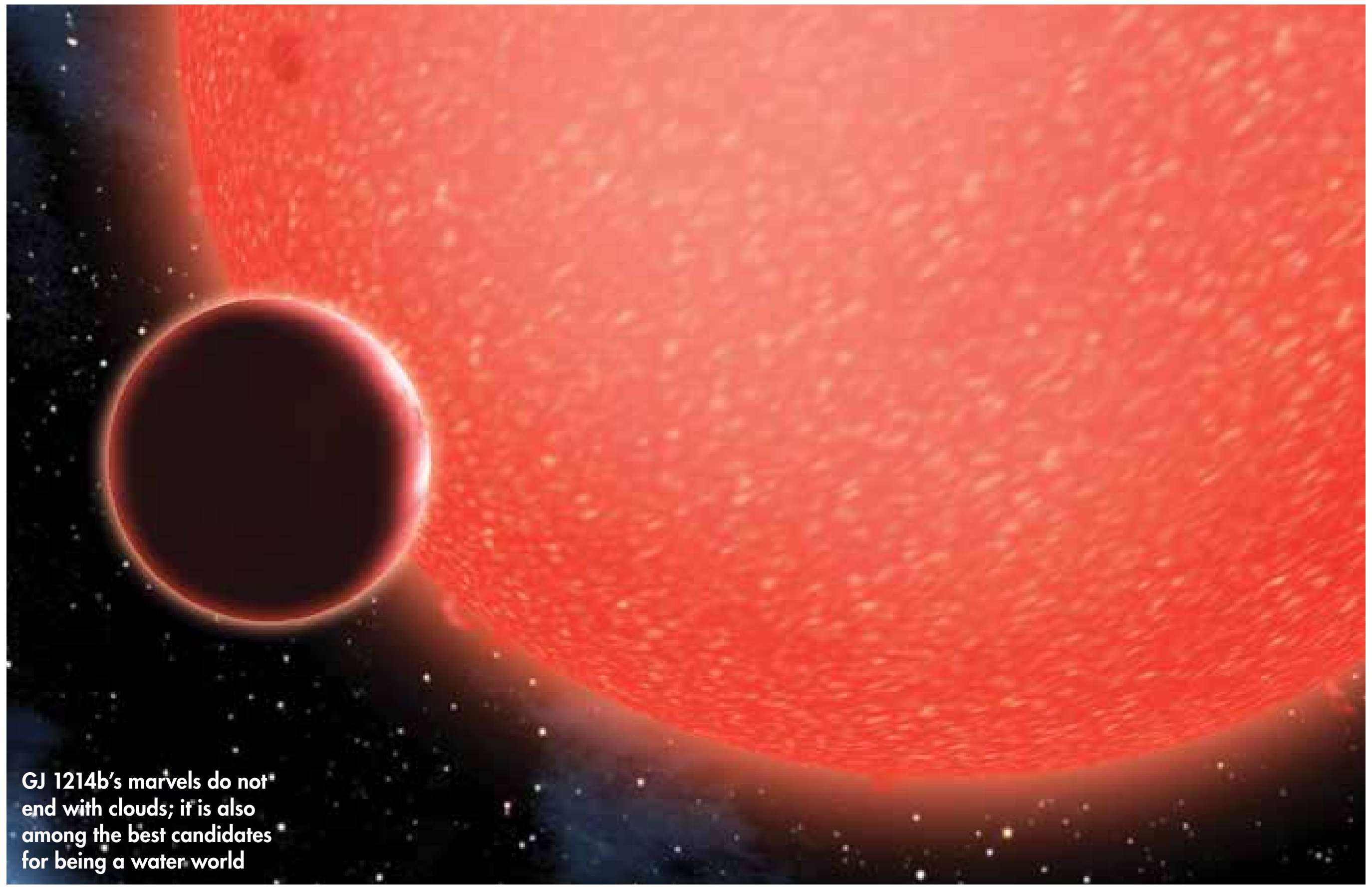
"We know what Earth looks like now, but what if it was younger? Earth and its atmosphere looked significantly different when it was young. If you see another Earth-like world, chances are it's not going to be at exactly the same age. We are creating a database of these spectral fingerprints of other worlds, other Earths."



▲ Discovering a true Earth analogue is the grail for exoplanetary researchers

A glimpse of things to come?

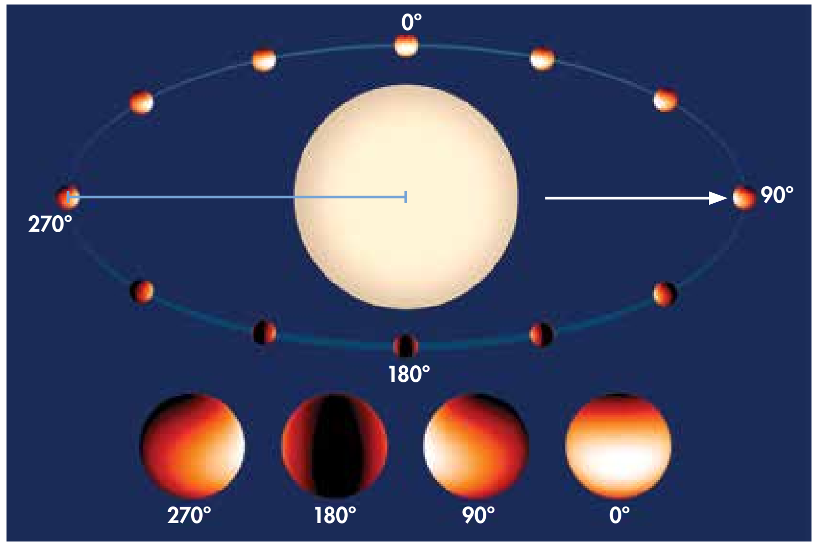
This database will help scientists select the most interesting targets as they hunt for Earth-like ▸



GJ 1214b's marvels do not end with clouds; it is also among the best candidates for being a water world

▸ worlds. But it's not just young Earths that we might find. Perhaps there are Earth-like planets much further down their evolutionary track out there.

"What if all the Earths that you see that are older have a lot of sulphur in their atmosphere?," says Kaltenegger. "That doesn't mean it is going to happen to our planet, but it means it would be very intelligent of us to use technology that can cycle sulphur out of the air. It's a potential glimpse into our future."



▲ Wasp-43b's year only lasts 19 hours, allowing researchers to map changes in temperature

Beyond detection

Already, though, we are beginning to take one step beyond detecting the simple composition of what makes up an exo-world's atmosphere to look into its climate and weather. The closest to Earth of those studied is GJ 1214b, a super-Earth 42 lightyears away in the constellation of Ophiuchus, orbiting the star Gliese 1214.

"On that planet we discovered clouds," says Laura Kreidberg of the University of Chicago. The discovery came not by looking for what was there, but by looking for what was not.

"We did not see any spectral features from things like water, ammonia, carbon dioxide or methane, and what we were able to work out from that was that there must be something in the atmosphere that is blocking the transmission of light," says Kreidberg.

"It's hoped that one day we'll be able to record the weather on another planet"

It's even hoped that one day we'll be able to record the weather on another planet, watching how the climate changes throughout its year. Already this is being done on hot Jupiters, though their 'years' only last a few Earth days or even hours. If the years were more like that of Earth's then this would mean taking an already difficult measurement and spreading it out over a much longer period.

"It's hard to trust yourself that you really understand your instrument well enough to make that measurement, to distinguish between the instrument varying and the actual planet," says Kreidberg. "So I tend to be sceptical of those measurements."

It's likely that we'll be getting to know these distant worlds on a much more individual basis, but just like the Earth is not alone in our Solar System, these planets don't exist in isolation.

"I'm very intrigued by some of the Kepler multi-planet systems," says Kreidberg. "Having a bunch of planets in one system, some of which are rocky, is very reminiscent of our own Solar System. It's very exciting."

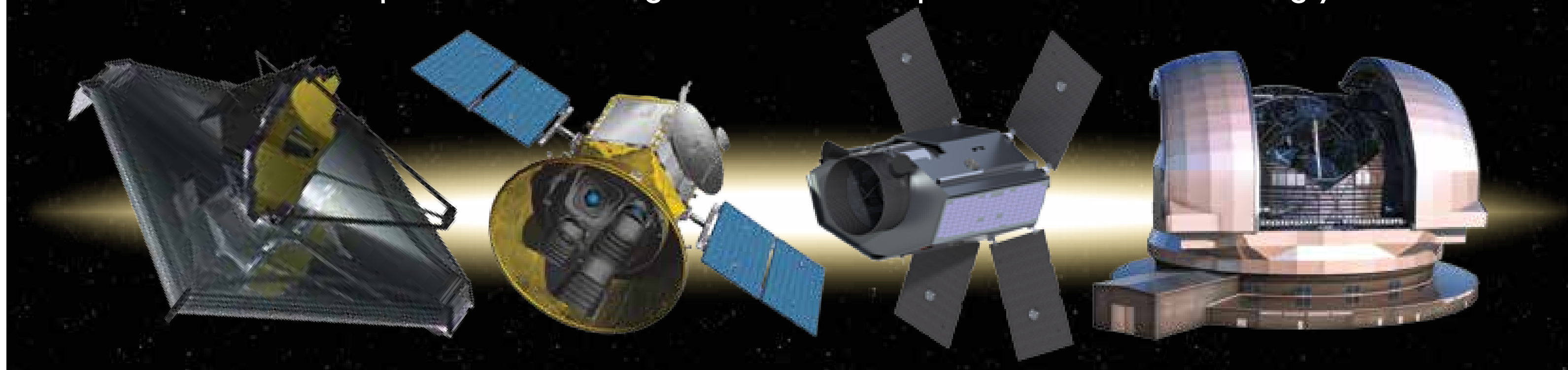
As we have found in our own planetary exploration, our neighbours, from Mercury to Pluto, are all vastly different. Is the same true for every other planetary neighbourhood?

Looking at planets within the context of their own planetary systems is important not only for understanding how the worlds work with their neighbours but also how they fit into the wider picture, and that is what is at the heart of exoplanet research.

"I think it's very important to put our own world in context of the Universe that we live in," says Kreidberg. "There's great value in the self reflection that comes from looking at worlds orbiting other stars." Ⓢ

THE NEXT EXOPLANET HUNTERS

These are the scopes that will change the face of exoplanet research in coming years



JWST
Launch: October 2018
The JWST will use its 18m mirror to create enormously detailed infrared images. This huge light-gathering power will allow atmospheric spectroscopy for planets similar to Earth. Not only will it will be possible to image smaller planets, but it will also allow us to detect a wider range of compounds and molecules.

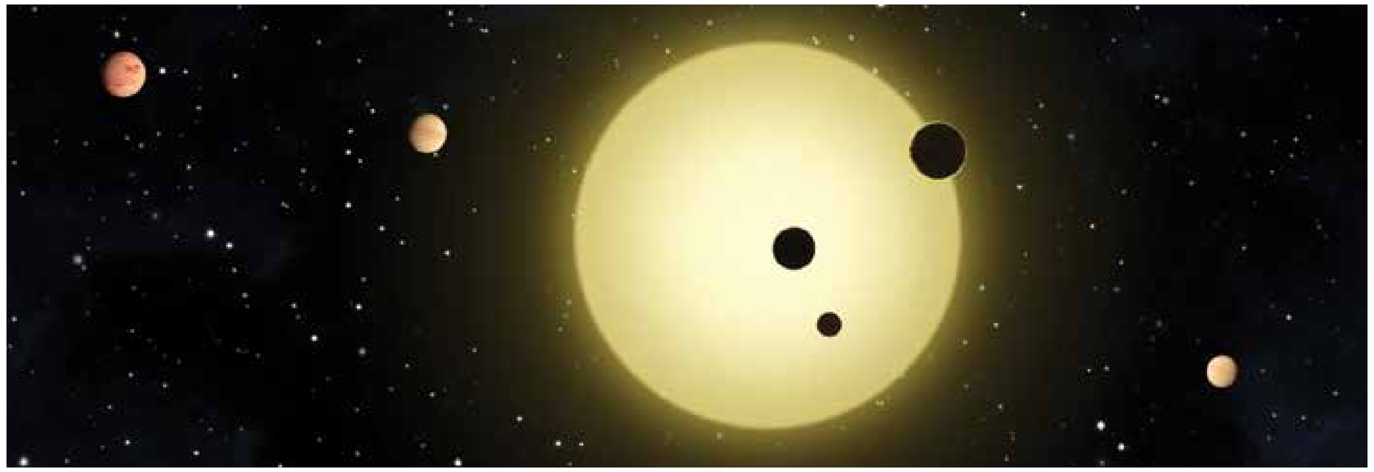
TESS
Launch: August 2017
TESS, or the Transiting Exoplanet Survey Satellite, will look for exoplanets around 200,000 of the brightest stars, searching for tell-tale temporary drops in brightness. Though it will not be able to characterise atmospheres itself, it will be able to find super-Earths around bright stars – worlds destined for follow-up study.

TWINKLE
Launch: 2018
Being designed and built in the UK, the Twinkle satellite is a low-cost mission that will analyse starlight in the visible and near-infrared wavelengths for organic molecules and the precursors to amino acids. It will also attempt to track changes over time and create weather maps of the exoplanets.

E-ELT
First light: 2024
Though based on Earth, the European Extremely Large Telescope's 39m mirror will be more than up to the task of detecting metals, water, oxygen and other molecules in exoplanet atmospheres. It will also be useful in investigating protoplanetary discs around young stars, from which planets may be born.

ABOUT THE WRITER

Dr Elizabeth Pearson is *BBC Sky at Night Magazine*'s news editor. She gained her PhD in extragalactic astronomy at Cardiff University.



▼ Kepler 11 is multi-world system' quite unlike ours, with six planets all larger than Earth but no bigger than Neptune

NASA ESA AND D. AGUILAR (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS), NASA/ESA AND Z. LEVAY (STSCI), NORTHROP GRUMMAN, MIT, TWINKLE/SSTL, ESO/L. CALÇADA, NASA/TIM PYLE