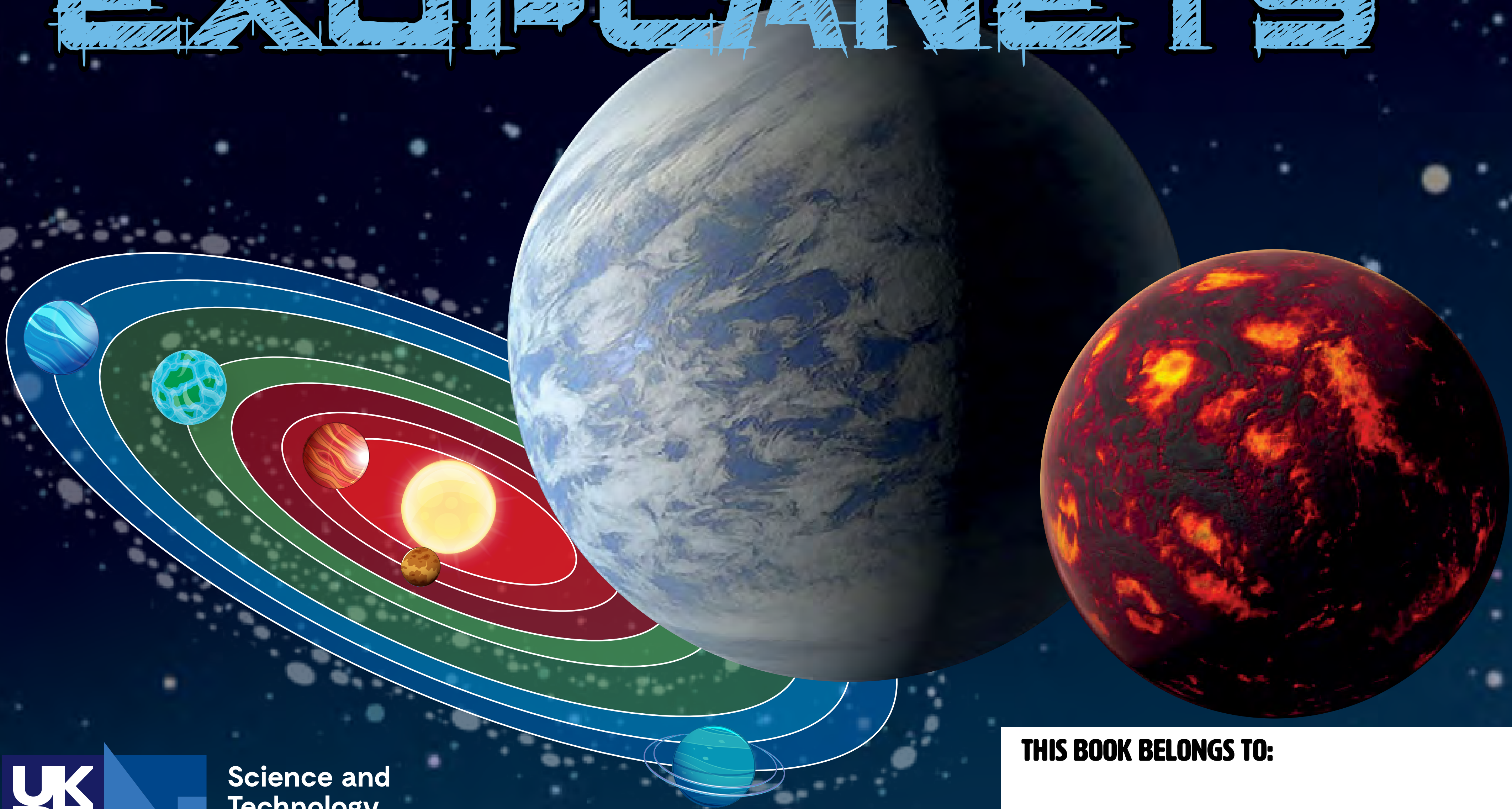
THE LITTLE BOOK OF EXOPLANETS



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THIS BOOK BELONGS TO:

What is an exoplanet and how do we find them?

Are there exoplanets made of diamond, or where it rains glass?

How can an exoplanet be shaped like an egg?

Could there be alien life on exoplanets?

You'll find all this out (and lots more) in...

THE LITTLE BOOK OF EXOPLANETS

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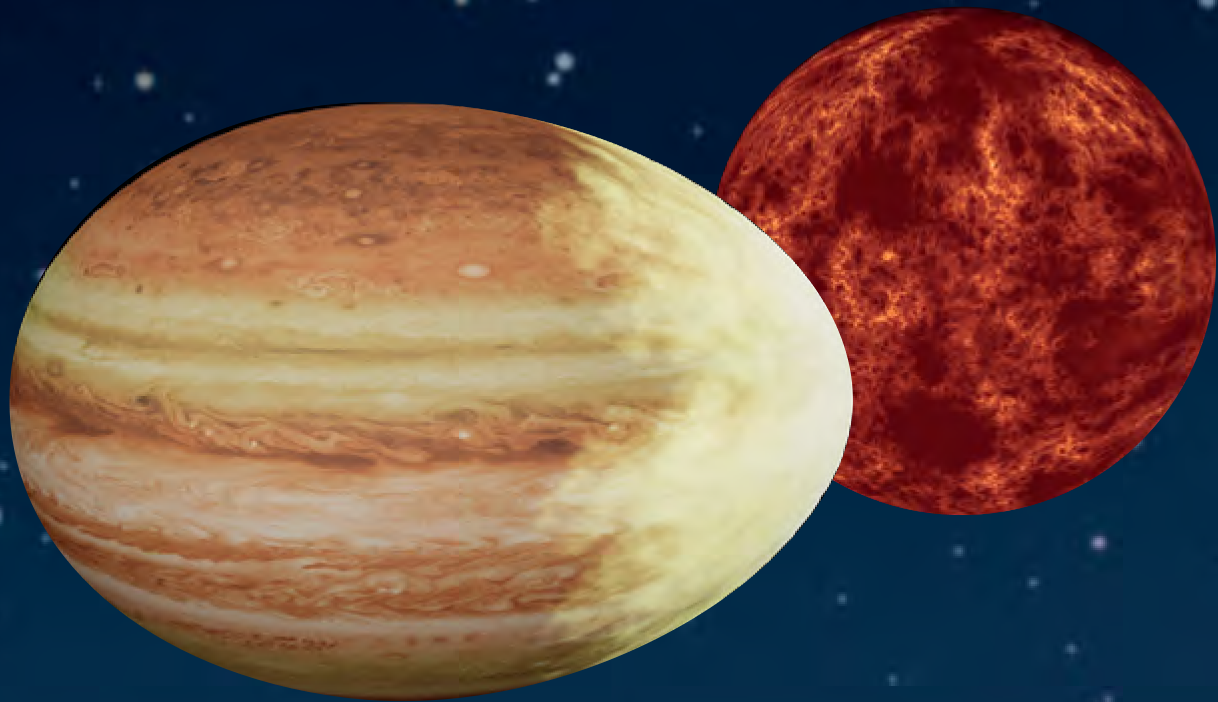

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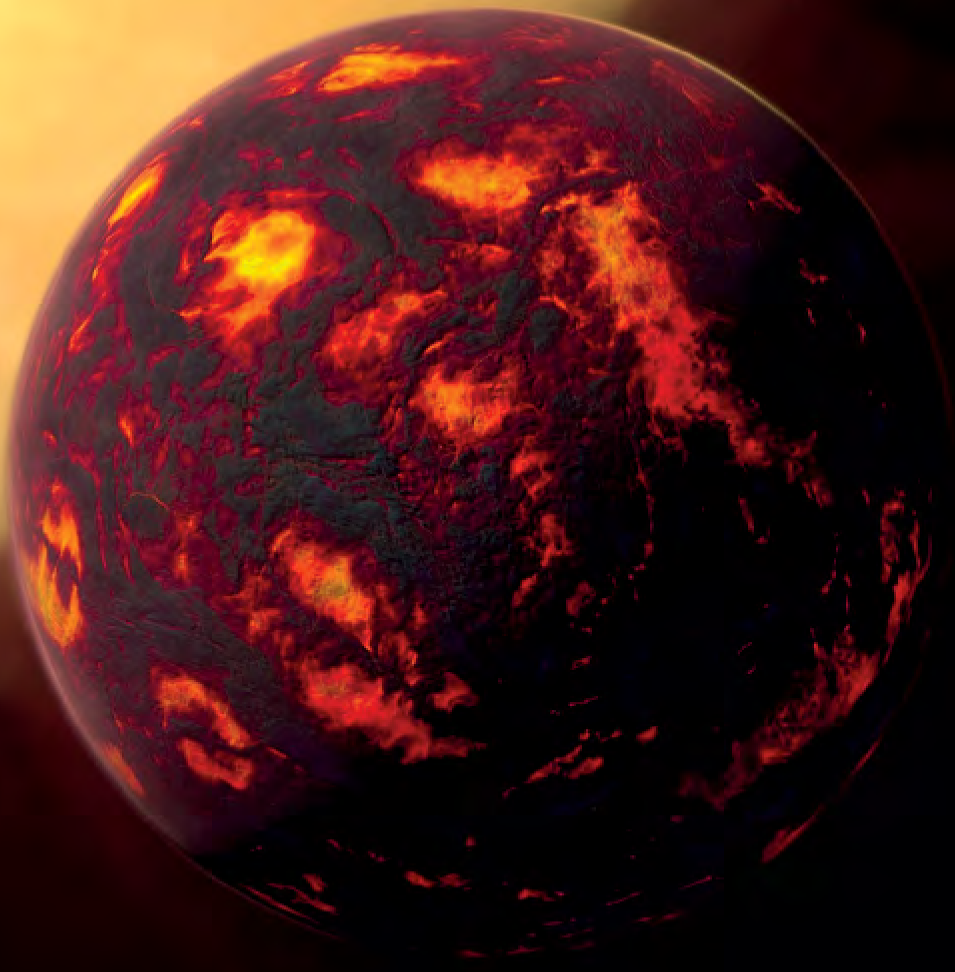
1 WHAT IS AN EXOPLANET?

Our Solar System is full of fascinating planets – from tiny Mercury to giant Jupiter, each world is unique. Scientists have spent decades getting to know the eight planets that orbit our local star, the Sun. You can find out all about these in our 'Little Book of the Planets' resource!

But, did you know that, beyond our Solar System there are trillions of other stars and each of those stars might have their own solar systems of orbiting planets? These planets are called 'extrasolar planets', or 'exoplanets' for short. Scientists have already discovered thousands of these alien worlds but there could be trillions more yet to find.



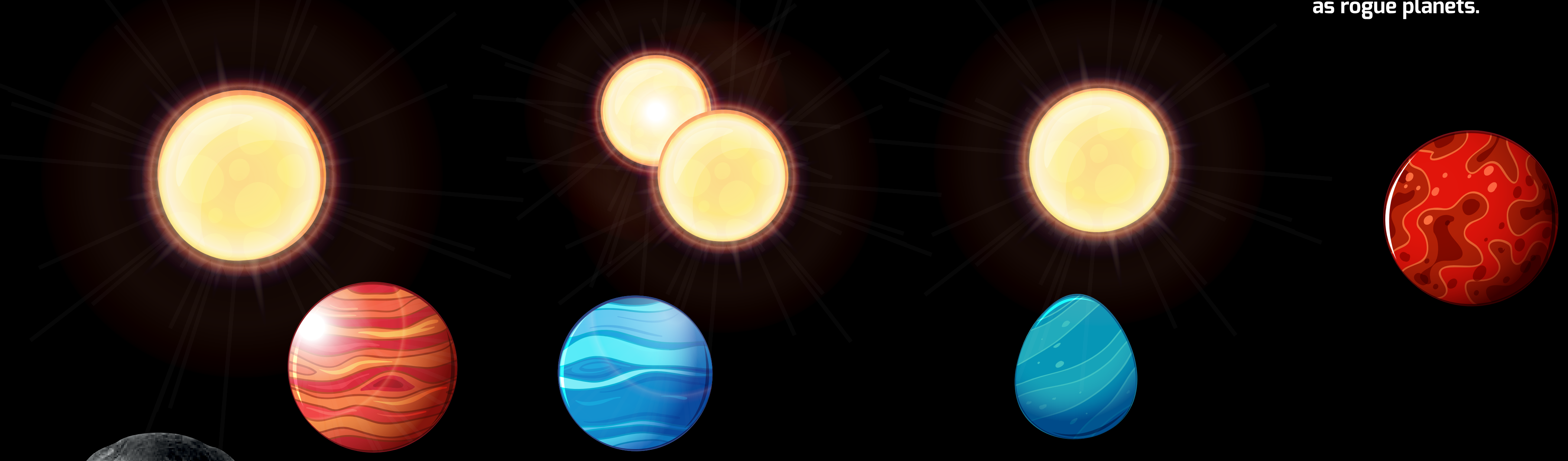
Exoplanets can be very weird! This is an artist's impression of an exoplanet called **55 Cancri e**. Scientists believe much of the planet could me made up diamonds!

1.1 WHAT IS AN EXOPLANET?

If you thought that the planets in our Solar System are full of variety, you'll be amazed by the variety of exoplanets. After all, we have only eight planets but there are thousands of exoplanets out there!

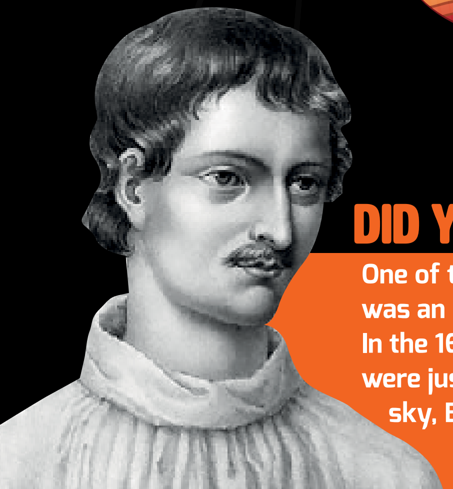
Like our nearby planets, most exoplanets orbit there own star but these stars can be very different to our own.

And some exoplanets don't orbit a star at all and live in the dark. These are known as rogue planets.



Some exoplanets orbit more than one star.

Some exoplanets are even shaped like eggs!



DID YOU KNOW?

One of the first people to imagine the existence of exoplanets was an Italian called Giodiano Bruno.
In the 16th century, when the church told people that the stars were just specks of light that God used to decorate the night sky, Bruno imagined that they were in fact distant stars.

He also imagined that orbiting those stars there might be "an infinity of worlds of the same kind of our own".
Unfortunately, the church thought Bruno's ideas where heracy and he was burned at the stake (although not just because of his ideas about exoplanets).

1.2 TYPES OF EXOPLANET

Scientists have so far discovered more than 5,000 exoplanets and, although we probably never know exactly how many there, we do know that they come in all sorts of shapes and sizes. We'll look at some of the exoplanet discoveries in more detail in section 3, but here are some of the main types of exoplanet.

GAS GIANT

A gas giant is a large planet mostly composed of helium and hydrogen. Like Jupiter and Saturn in our Solar System, these planets don't have hard surfaces and instead have a swirling soup of thick gases above a solid core.

NEPTUNIAN

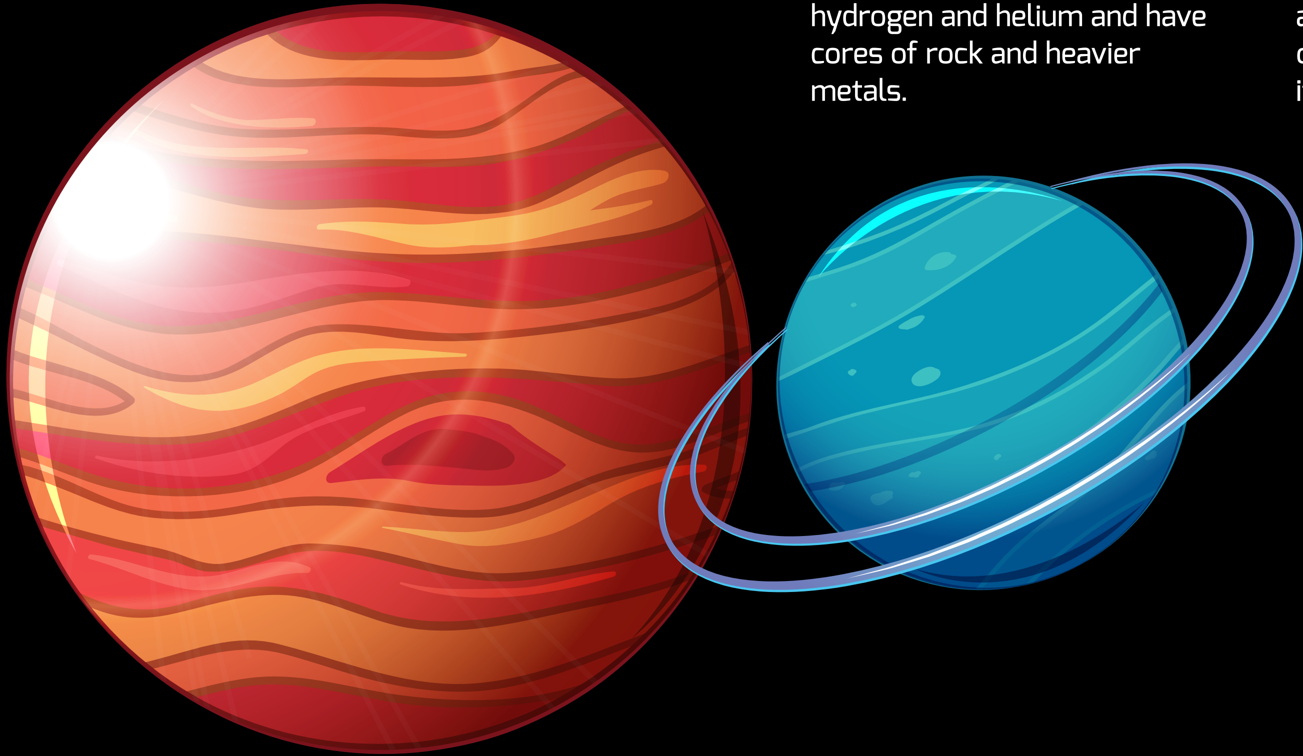
Neptunian exoplanets are similar in size to Neptune or Uranus in our Solar System. Neptunian planets often have atmospheres made up of hydrogen and helium and have cores of rock and heavier metals.

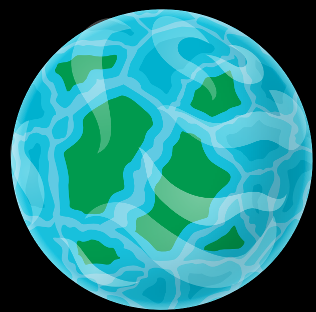
SUPER-EARTH

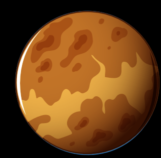
Super-Earths are not like anything we can find in our Solar System. They are can be made of gas, or rock or a bit of both and are between twice the size of Earth and up to 10 times its mass.

TERRESTRIAL

Terrestrial exoplanets are made up rocks and metals and are a lot like the terrestrial planets you can find in our Solar System – Mercury, Venus, Earth, and Mars. For exoplanets, anything up to twice the size of Earth is considered a terrestrial planet.







2 HOW TO FIND EXOPLANETS

Scientists think that almost every star in our galaxy has at least one exoplanet in orbit around it. That means there could be trillions of exoplanets out there, so you'd think that would make them easy to find! Unfortunately, its not that easy:

THEY ARE A LONG WAY AWAY

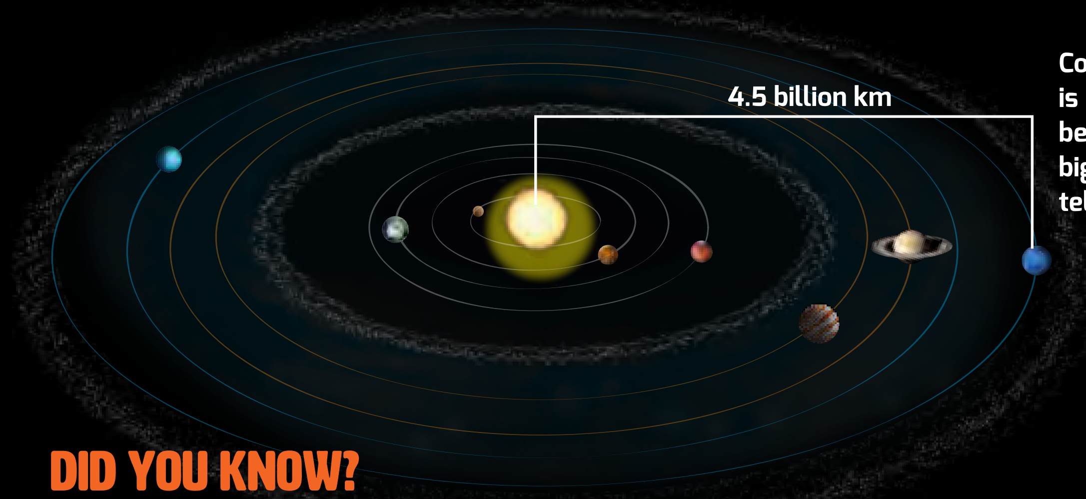
Even the closest exoplanet yet discovered, Proxima Centauri b, is about 4.2 light-years away from Earth. A light-year is the distance light can travel in one year. Since light travels at about 300,000 km per second, a light-year is about 9.5 trillion km. The Earth is only 8.3 light-minutes from the Sun… so a light-year is a really, really, really long way!

THEY ARE REALLY SMALL

We all know that Jupiter is very big planet but, seen with the naked eye at night, it appears to be a tiny little dot because it is so far away from Earth. Imagine trying to find a planet smaller than Jupiter that is thousands of times further away!

THEY ARE NOT VERY BRIGHT

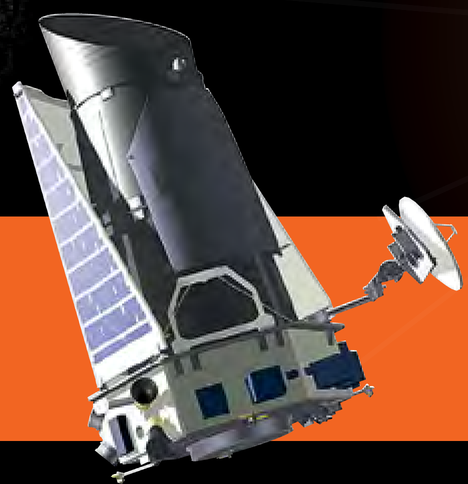
Not only are exoplanets a long way away and really quite small, they usually orbit stars that are millions of times brighter than the planet. Trying to find a planet close to a bright star is a bit like trying to see a speck of dust on a car headlight on full brightness.

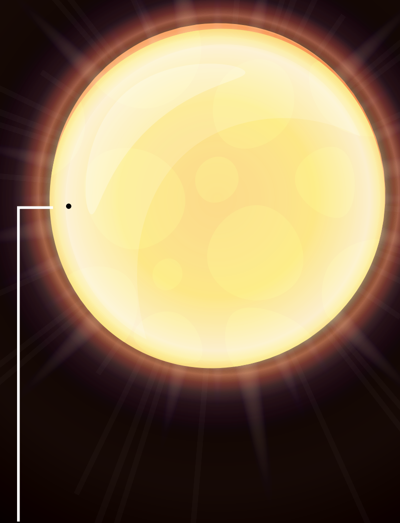


Compared to exoplanets, Neptune is not very far away. Yet, despite being quite close and really quite big, only the most powerful telescopes can see it.

DID YOU KNOW?

There are dozens of telescopes dedicated to hunting down exoplanet candidates. There are lots of ground-based telescopes but the most successful by far are the space-based telescopes and the most successful of those (so far) has been Nasa's Kepler Space Telescope. Kepler has found more than 2,600 confirmed exoplanets since it was launched in 2009.





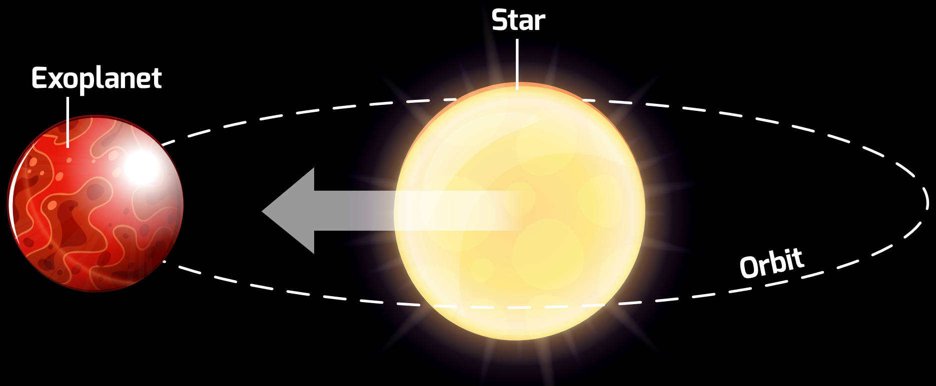
Imagine trying to see this speck of a planet from trillions of kilometres away!

2.1 FIND THAT EXOPLANET: WOBBLING SUN

METHOD 1: RADIAL VELOCITY

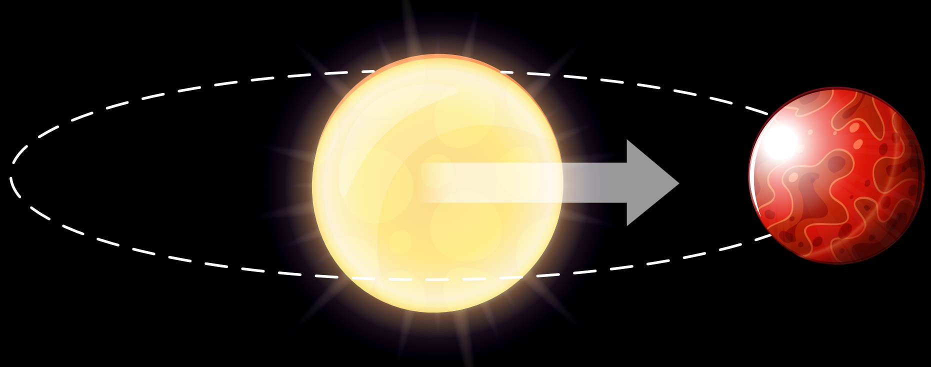
For all the reasons listed on the previous page, exoplanets are very hard to see directly. Most exoplanets are detected using indirect methods, such as 'radial velocity'.

When a large planet orbits its star, the planet's gravity tugs ever so slightly on the star and makes it wobble from side to side. If astronomers see a distant star wobbling it might mena there is exoplanet orbiting it.



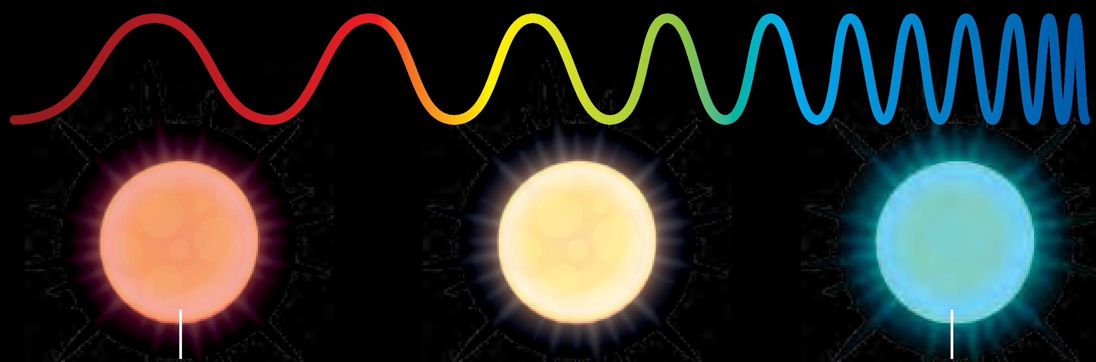
1 The exoplanet's gravity tugs on the star and pulls it ever so slightly closer towards it.

2 As it orbits the star, the exoplanet continues to pull on the star – making the star wobble from side to side.



3 Light from the star travels towards Earth as waves that can be squeezed or stretched as the star wobbles. Seen from Earth, the appearance of the light changes as the star wobbles.

Longer wavelength light is red **Shorter wavelength light is blue**



If the star is pulled slightly away from us, the wavelength of light is stretched and the star appears redder.

If the star is pulled closer to us, the wavelength of light is squashed and the star appears to be more blue.

This change in wavelength due to motion is called 'Doppler shift'.

The very first exoplanet ever detected to orbit a star like our Sun. 51 Pegasi b, was found using the radial velocity method in 1995.

2.2 FIND THAT EXOPLANET: A LITTLE BIT DIM

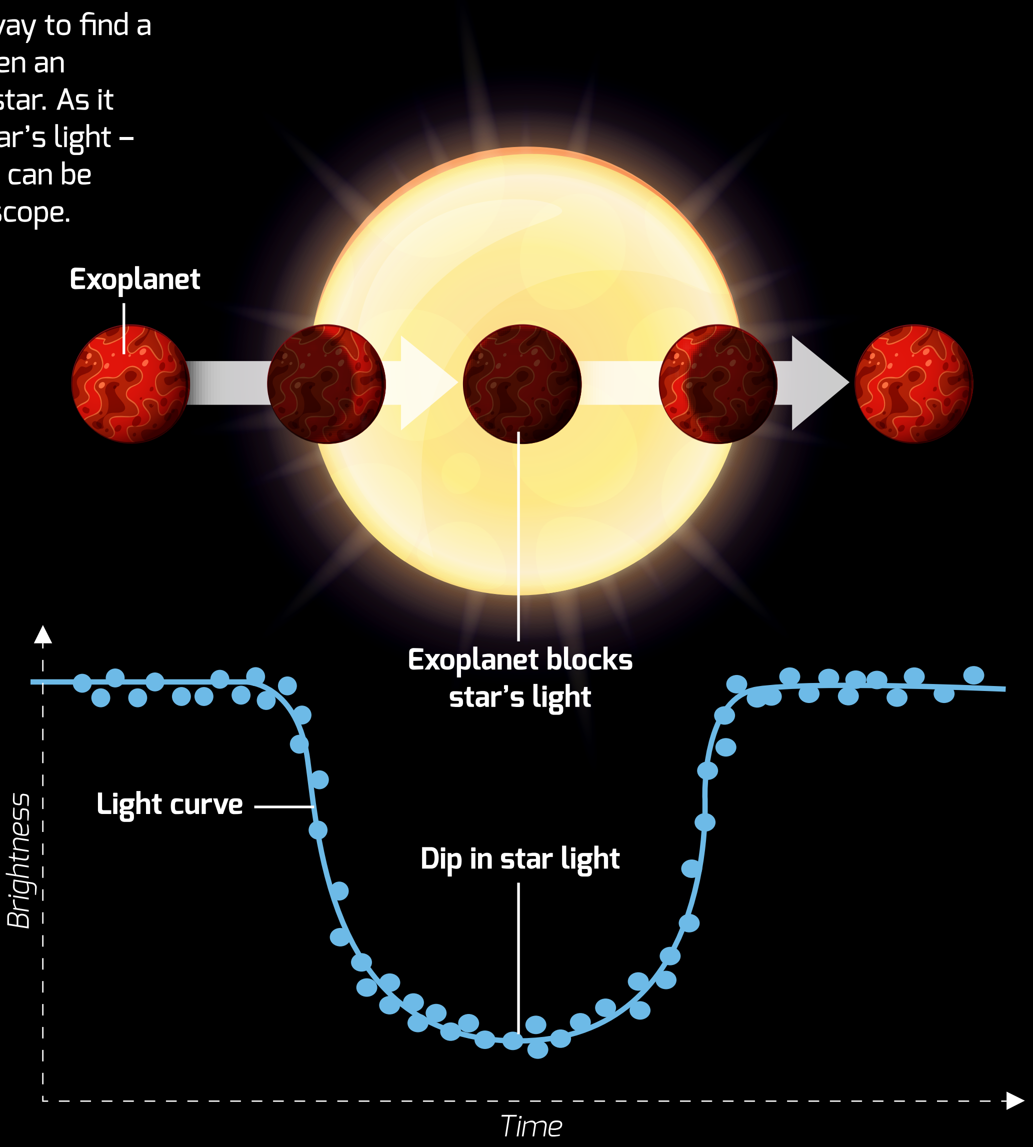
METHOD 2: TRANSIT

The transit method is an excellent way to find a new exoplanet. A transit occurs when an orbiting planet passes in front of a star. As it passes, it blocks a little bit of the star's light – dimming the star just enough that it can be measured by a really sensitive telescope.

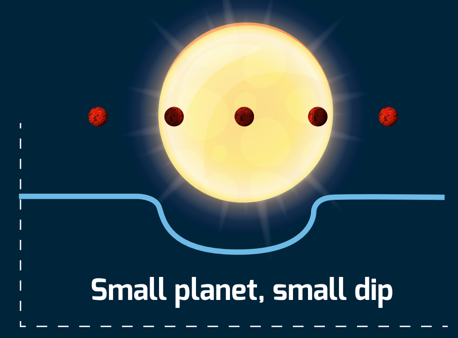
1 As an exoplanet passes across the front of a star it blocks some of the star's light – making appear to dim slightly.

2 Astronomers make a graph called a light curve that shows any changes in the level of light observed over time.

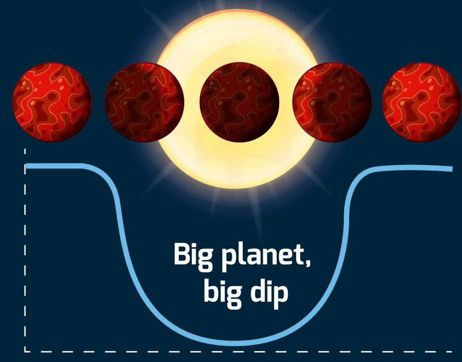
A repeating dip in the star's brightness might be a sign that there in an exoplanet in a regular orbit around the star



The transit method can tell us a lot about an exoplanet.



It can tell us how big the planet is (a bigger planet blocks more light).



By measuring how often the star's light dims, it can tell us about the exoplanet's distance from the star (closer planets have faster orbits than more distant planets).

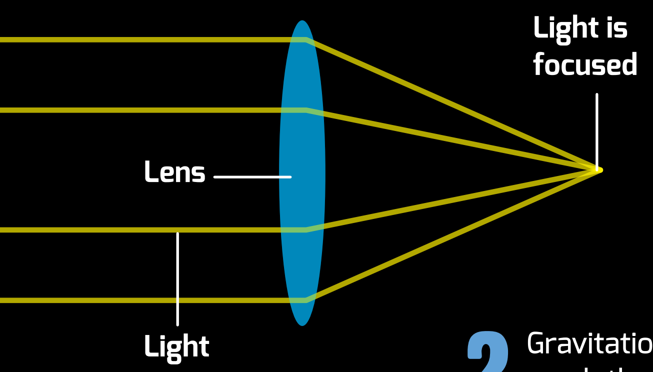
2.3 FIND THAT EXOPLANET: PLANET AS A LENS

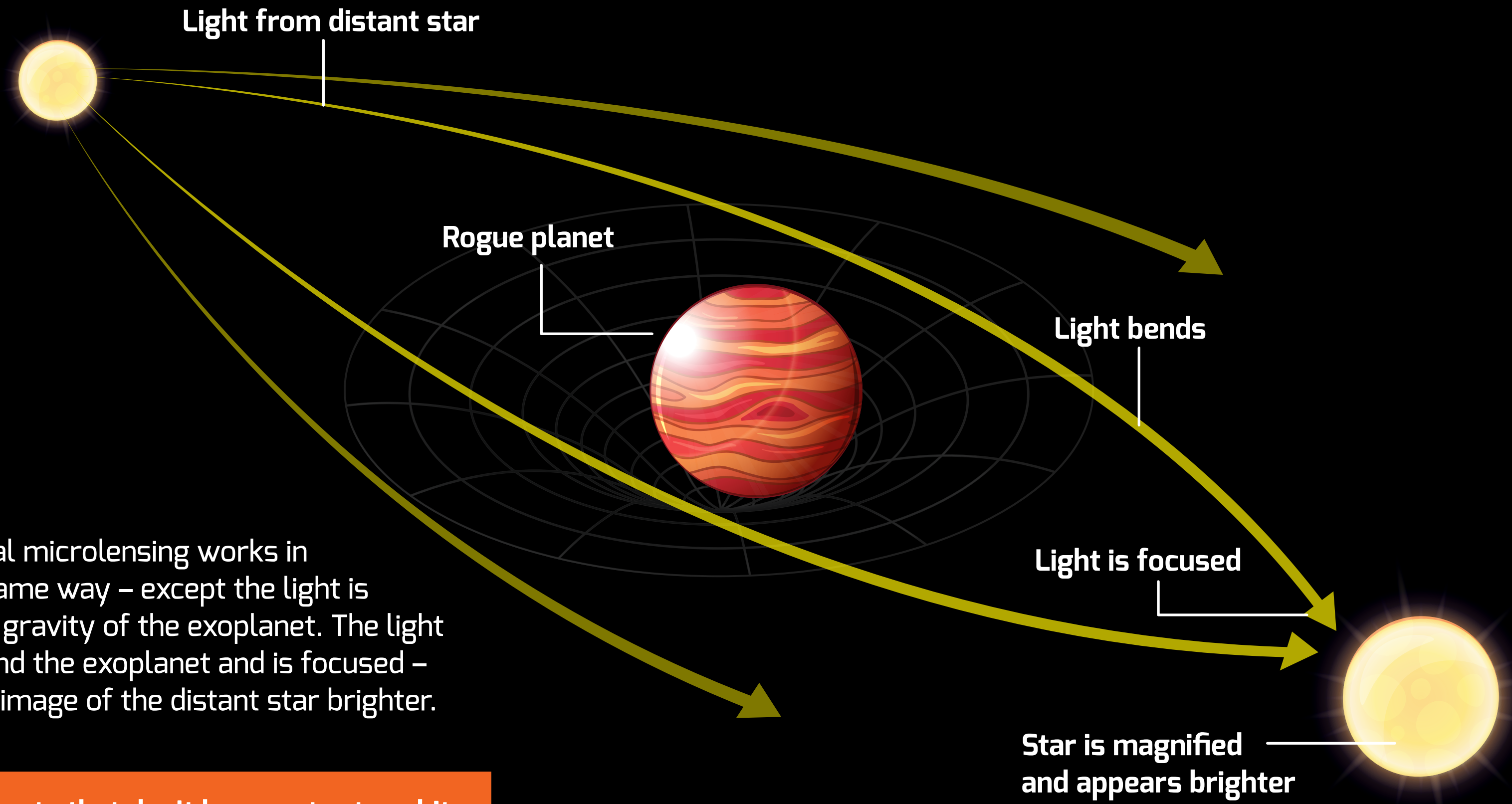
METHOD 3: GRAVITATIONAL MICROLENSING

Gravitational lensing takes advantage of the effect that gravity has on light. An object with lots of gravity, such as a planet, can actually bend the path of light that passes by it. Sometimes it bends the light so much that it is focused like a lens.

Unlike the transit method, which looks for a star getting dimmer, gravitational microlensing looks for a star getting brighter. Astronomers looking at a star's light curve will look for an increase in brightness.

1 This is this sort of lens you might find in a telescope or magnifying glass. When light passes though the lens, it's path is bent and focused.





2 Gravitational microlensing works in much the same way – except the light is bent by the gravity of the exoplanet. The light bends around the exoplanet and is focused – making the image of the distant star brighter.

This method is very good at finding rogue planets that don't have a star to orbit. But it only works if a rogue exoplanet were to pass directly in front of a distant star (from our point of view on Earth), so it requires a lot of luck to find one!

2.4 FIND THAT EXOPLANET: JUST LOOK FOR IT

METHOD 4: DIRECT IMAGING

As we've seen, exoplanets are a very long way away and, compared to the star they orbit, very small and dim. This makes just looking for a exoplanet very hard indeed. New technology, such as super-sensitive cameras, is making it possible to actually see an exoplanet directly.

1 This is a distant star with an exoplanet orbiting it. Unfortunately, we can't see the planet because the star is too bright.

2 But if we block the light from the star the glare is reduced and we can see the tiny, dim exoplanet!

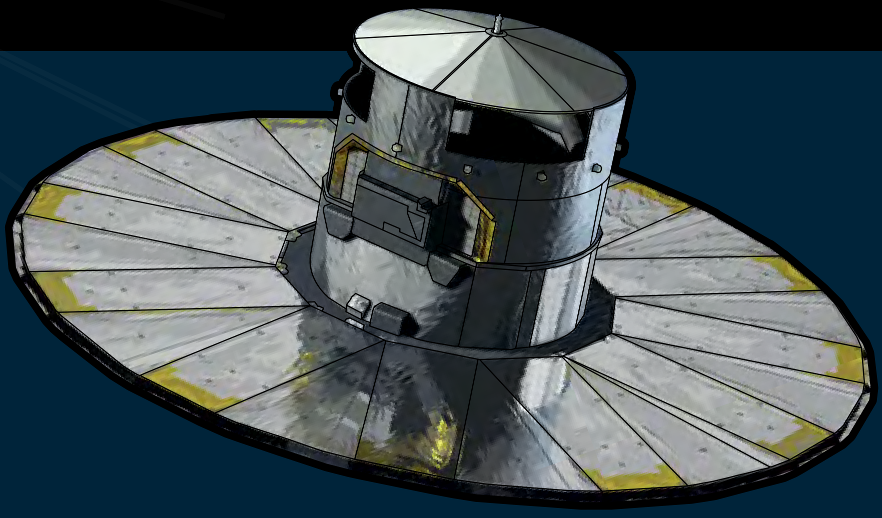
Astronomers have two ways to block a star's light. Coronography uses a device inside a telescope to cover the star. Another way is to build a telescope with a starshade that block the star's light (like holding your hand up to cover the Sun).

METHOD 5: ASTROMETRY

Like radial velocity, this method looks for a wobbling star. But, instead of looking for changes in the light from the star, it directly measures the movements of the star.

Astrometry relies on being able to study an individual star for long periods. If a star has a planet orbiting it, the telescope will see the tiny wobble.

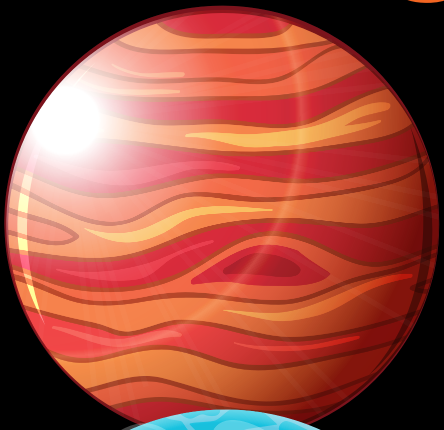
The European Space Agency's (ESA) Gaia satellite is able to identify the position and movement of up 8,000 stars. To do this it is equipped with a one billion pixel camera – the largest camera sensor ever flown into space.



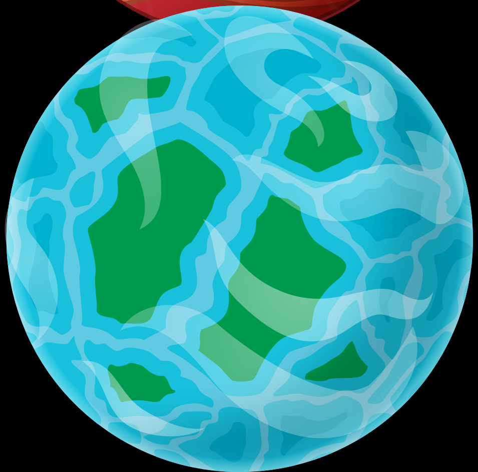
3 EXOPLANET DISCOVERIES

We've briefly met some of the different types of exoplanet: gas giants, Neptunian, super-Earth, and terrestrial, but how many of each type have been discovered?

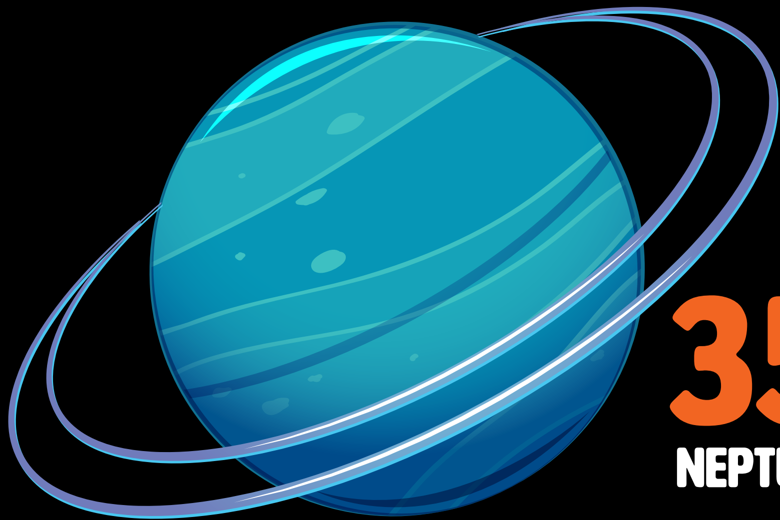
OF THE MORE THAN 5,000 EXOPLANETS FOUND...



30% GAS GIANTS



31% SUPER-EARTHS



35% NEPTUNIAN

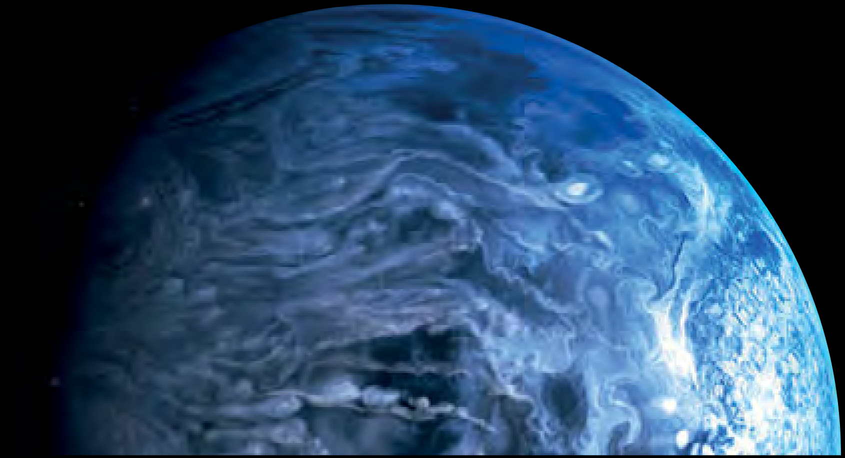
4% TERRESTRIAL

With so many exoplanets discovered so far (and more being discovered all the time), we don't have room to show you them all here – we'd have to call this the 'Very, Very, Very Big Book of Exoplanets'. As exoplanets can be very weird indeed, we'll have a look at ten of the weirdest exoplanets discovered so far!

NIGHTMARE OF GLASS RAINS!

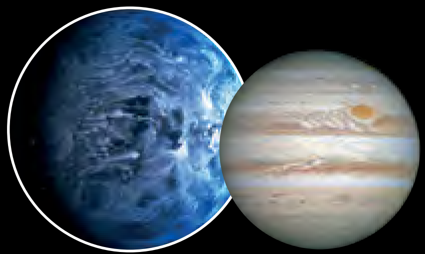
HD 189733 B

Type: Gas Giant (Hot Jupiter)
Discovery method: Transit



This gas giant might look invitingly cool and blue, but HD 189733 b is a nightmare world. This exoplanet is a type of gas giant known as a Hot Jupiter. It's weather is a deadly combination of thousand degree C heat and 8,000 kph winds.

You wouldn't want to get caught in the rain on this planet because, instead of water droplets, this planet rains shards of glass, which are driven sideways by the planet's insane winds! Ow!!

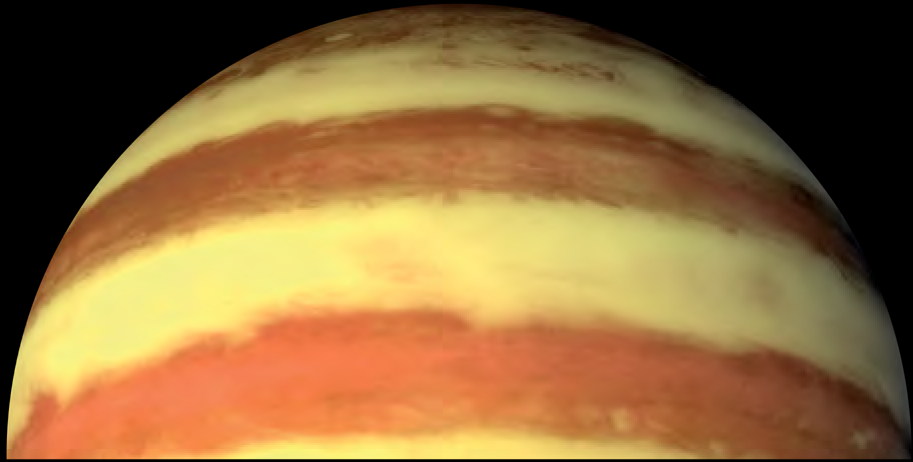


HD 189733 b size compared to Jupiter

A NAKED ROCKY GIANT

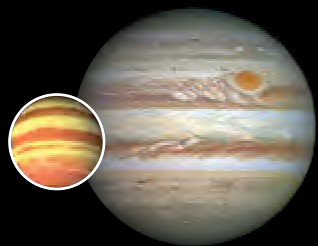
TOI 849 B

Type: Gas Giant
Discovery method: Transit



This is a gas giant that lost its gas. This exoplanet orbits its star so closely that all of its atmosphere has been blasted away by solar radiation and its surface has been baked by 1,530 degree C temperatures!

TOI 849 b is about the same size as Neptune and is the largest rocky world yet discovered. It started life as gas giant but after it lost all of its gassy atmosphere all that's left is its giant rocky core!



TOI 849 b size compared to Jupiter

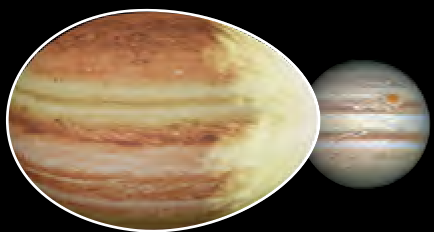
EGG-SHAPED AND DOOMED!

WASP-12 B

Type: Gas Giant (Hot Jupiter)
Discovery method: Transit

If you thought TPI 849 b had it bad, spare a thought for poor Wasp-12 b! This giant exoplanet orbits so close to its star that the star's gravity stretches the planet into the shape of an egg and sucks up its atmosphere.

To make matters worse the planet is subjected to temperatures of more than 2,000 degrees C. In about 10 million years the planet will have been complete devoured by its star. Gulp!



HD 189733 b size compared to Jupiter

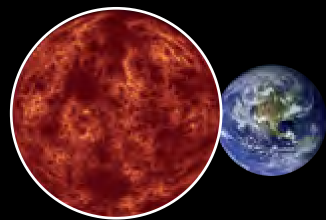
A REAL GEM OF A PLANET

55 CANCRI E

Type: Super Earth
Discovery method: Radial velocity

This exoplanet is a real diamond in the rough. It was the first super-Earth discovered to be orbiting a Sun-like star. Unfortunately, that's where its similarity to Earth ends because it orbits its star so closely that its surface is hot enough to melt iron.

Some scientists think that 55 Cancri e is so rich in carbon that, as a result of the temperatures and pressures near the core, as much as one third of the planet could be made up of diamond!

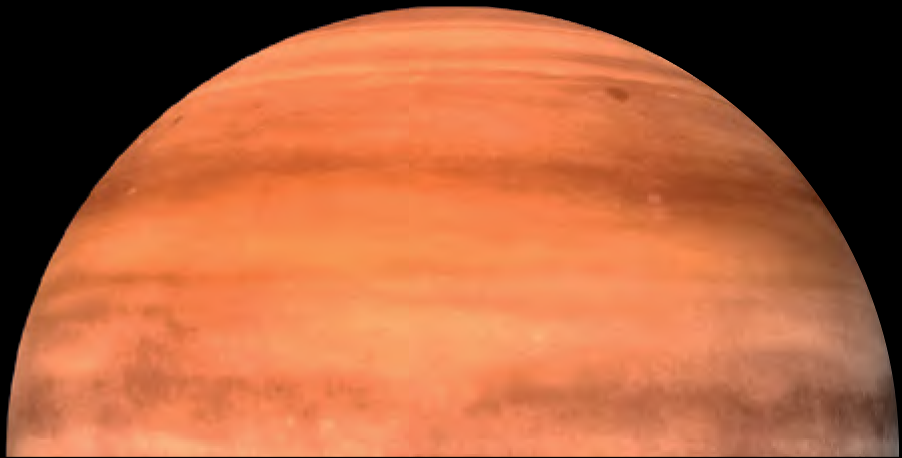


55 Cancri e size compared to Earth

TOO HOT TO HANDLE!

KELT-9 B

Type: Gas Giant (Hot Jupiter)
Discovery method: Transit



This exoplanet is so hot its not just a Hot Jupiter, it's an Ultra-Hot Jupiter! KELT-9 b is so scorching that it is even hotter than many stars. It orbits so close to its star that its surface is a roasting 4,300 degrees C.

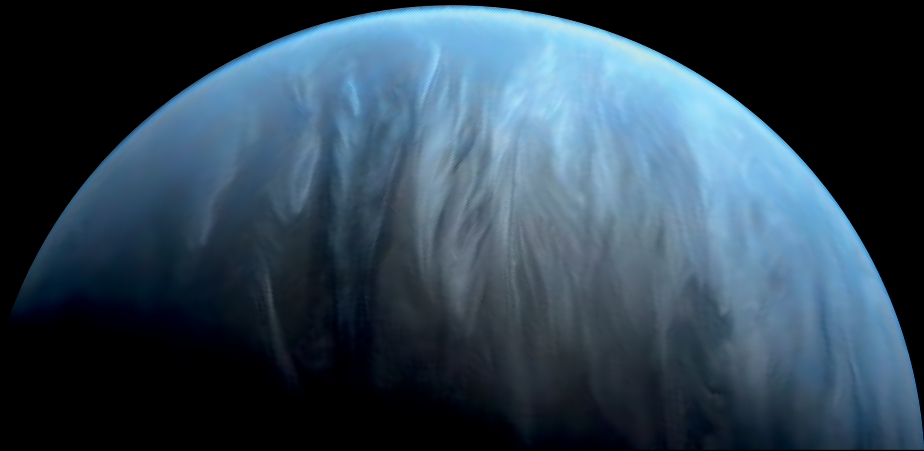
It's so hot that the heat tears apart hydrogen atoms in its atmosphere. It's only when they flow around to planet's night side that cool enough to recombine, only to be torn apart again the next day.

KELT-9 b size compared to Jupiter

DON'T SWIM HERE!

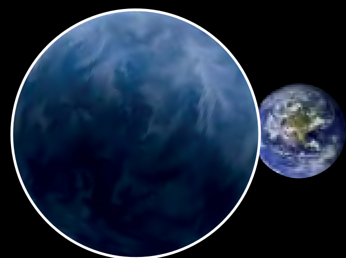
K2-18 B

Type: Super-Earth
Discovery method: Transit



This planet is only about twice the size of the Earth, sits right in the habitable zone of its star, and might even have a liquid water ocean. Sounds like a great place to find life, right? Unfortunately not!

K2-18 b is actually more like a mini-Neptune than a Super-Earth. Although it is rocky planet like Earth, its atmosphere is more like a sort of hot Neptune. Oh, and those water oceans are super-hot and super-dense so, if you dived in for a swim, you'd be vapourised!



K2-18 b size compared to Jupiter

A PLANET JUST LIKE EARTH (NEARLY)

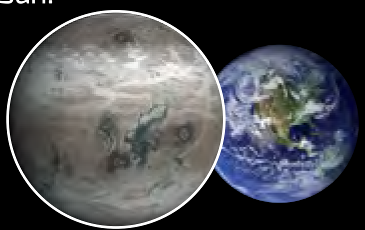
KEPLER-452 B

Type: Super-Earth
Discovery method: Transit

This world was the first near-Earth-size planet discovered to orbit a star the size of the Sun. Kepler-452b is 60 percent larger than Earth and its parent star (Kepler-452) is 10 percent larger than the sun. Kepler-452 is very similar to our Sun, and the exoplanet orbits in the star's habitable zone (meaning it could possibly support life).

At 1.6 times the size of Earth, it is likely that Kepler-452b is a rocky planet just like the Earth. The exoplanet even a has a year that is about the same length as the Earth's – taking just 20 days longer to complete an orbit.

It is thought that the planet received about 75 per cent of the light that Earth does from the Sun.

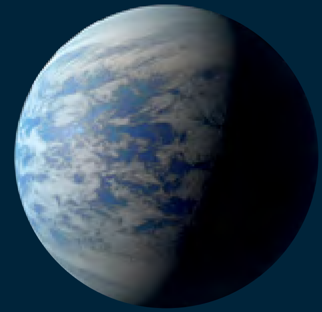


Kepler-452 b size compared to Earth

We'll explore what the habitable zone is in the next section!

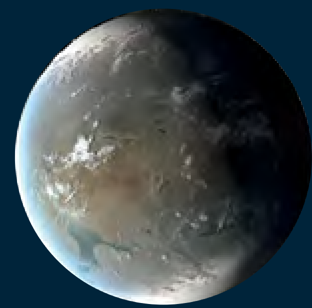
OTHER EARTH-LIKE WORLDS

KEPLER-69 C



Kepler-69c, is 70 percent bigger than Earth, and is the smallest exoplanet found to orbit in the habitable zone of a sun-like star.

KEPLER-62 F



This planet is about 40 percent bigger than Earth and orbits in the habitable zone of a red dwarf star that is much cooler than our Sun.

KEPLER-1649 C

Kepler-1649 c, is thought to be a almost exactly the same size as Earth and orbits in its star's habitable zone.

4 COULD WE FIND ALIEN LIFE?

For as long as humans have imagined worlds beyond the Earth we have also imagined that there must also be alien life living on those worlds. Finding evidence of alien life is one of science's greatest ambitions. But how do you go about finding life on a planet so far away that you can't even see the planet directly?

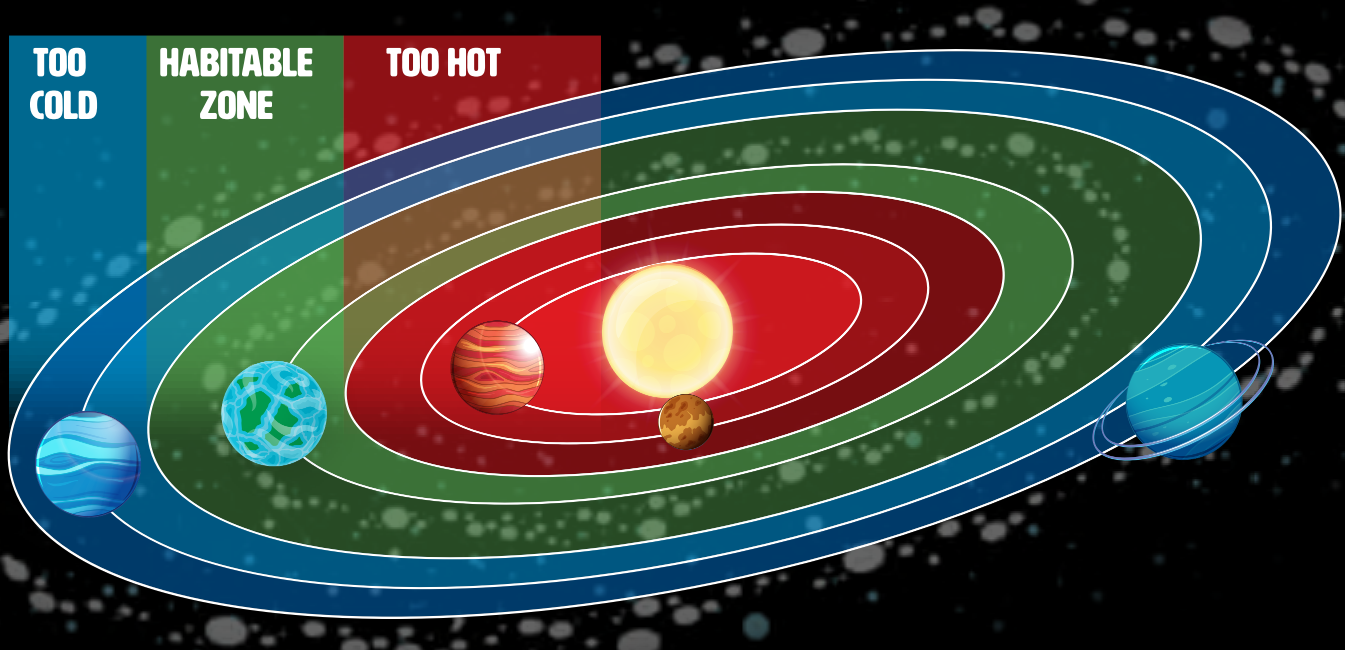
In the previous section we mentioned something called the 'habitable zone', but what is it exactly, and how does it affect the search for life?

4.1 FINDING LIFE ON EXOPLANETS

THE HABITABLE ZONE

One of the first things astronomers look for when trying to figure out if a planet might be suitable for life is how far away it is from its star. Too close and its likely to be too hot for life to survive.

Too far away and its going to be far too cold. The habitable zone is the zone where liquid water could exist on the surface of a planet – its not too hot, not too cold, but just right... which is why this area also known as the Goldilocks zone'.



Where the habitable zone is depends on the sort of star the planets orbit. A small red dwarf star is much cooler than our Sun, so the habitable zone will be much closer. If the star is huge and hot, the habitable zone will be much further away!

Scientists believe there could be

300 MILLION PLANETS

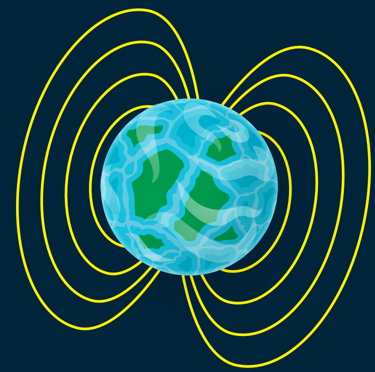
in their star's habitable zone in our galaxy alone.

WHAT SHOULD WE LOOK FOR?

An exoplanet being in a star's habitable zone is just the start when it comes to being a good place for life to evolve and survive.

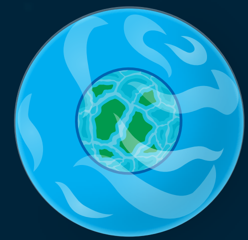
MAGNETIC FIELD

A magnetic field protects the planet from harmful radiation from its star, which can damage or kill life on the surface.



PLANET SIZE

The size of a planet affects how much atmosphere it can hold. (and life need a nice breathable atmosphere).



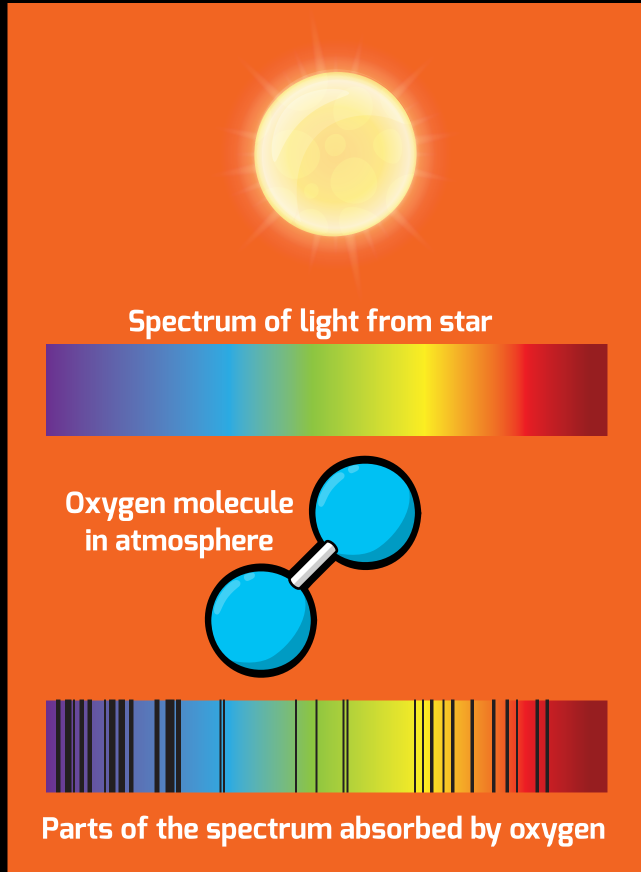
A planet that's too big could have so much atmosphere that light can't reach the surface. The pressure could also be too much for life.

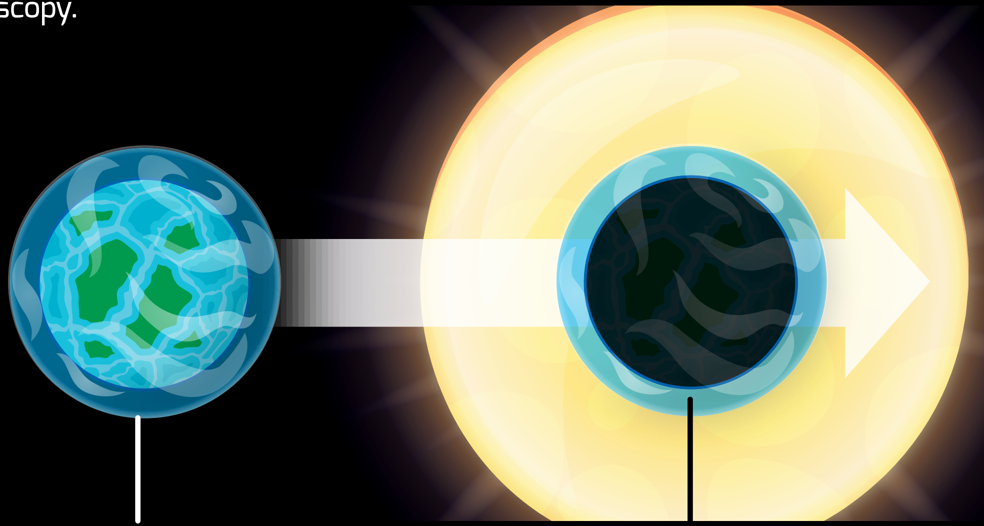
A planet that's too small can't stop the stellar winds from blowing its atmosphere into space.

LOOKING AT AN EXOPLANET'S ATMOSPHERE

One of the best ways to know if a planet can support life is to look at what its atmosphere is made of. Even though exoplanets are so far away, scientists have come up with clever ways to learn about a planet's atmosphere. One of those is called spectroscopy.

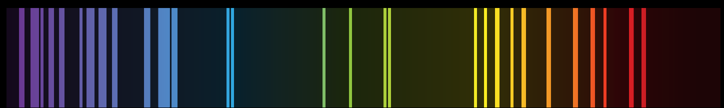
Light is made up of a spectrum of different colours (like you see in a rainbow). Every chemical element absorbs or reflects different parts of that rainbow. By looking at what part of the rainbow is absorbed or reflected scientists can create a sort of chemical barcode that identifies the elements.





Light reflects from atmosphere

EMISSION SPECTRUM



Light passes through atmosphere

ABSORBTION SPECTRUM

Scientists can look at the light reflected from a planet and by seeing what parts of the rainbow are reflected back, they can identify the chemical elements.

When a planet passes in front of a star, light passes through the atmosphere. As it passes though, chemicals in the atmosphere absorb certain parts of the spectrum. Scientists can figure out what is in the atmosphere by looking for what is missing from the rainbow.

CHECK OUT OUR ACCOMPANYING RESOURCE

The Science and Technology Facilities Council operates world-class, large-scale research facilities; supports scientists and engineers world-wide; funds researchers in universities and provides strategic scientific advice to government.

The Council's Public Engagement Team offers a wide range of support for teachers, scientists and communicators to facilitate greater engagement with STFC science which includes astronomy, space science, particle physics and nuclear physics:

FOR SCHOOLS

- **Free Publications and resource guides** suitable for teaching ages 10-18.
- **Funding** schemes for projects and school visits.
- **A Moon rock and meteorite loan scheme.**
- **Visits** to STFC's UK laboratories in Cheshire, Oxfordshire and Edinburgh plus CERN in Geneva.

www.stfc.ukri.org

Science and Technology Facilities Council

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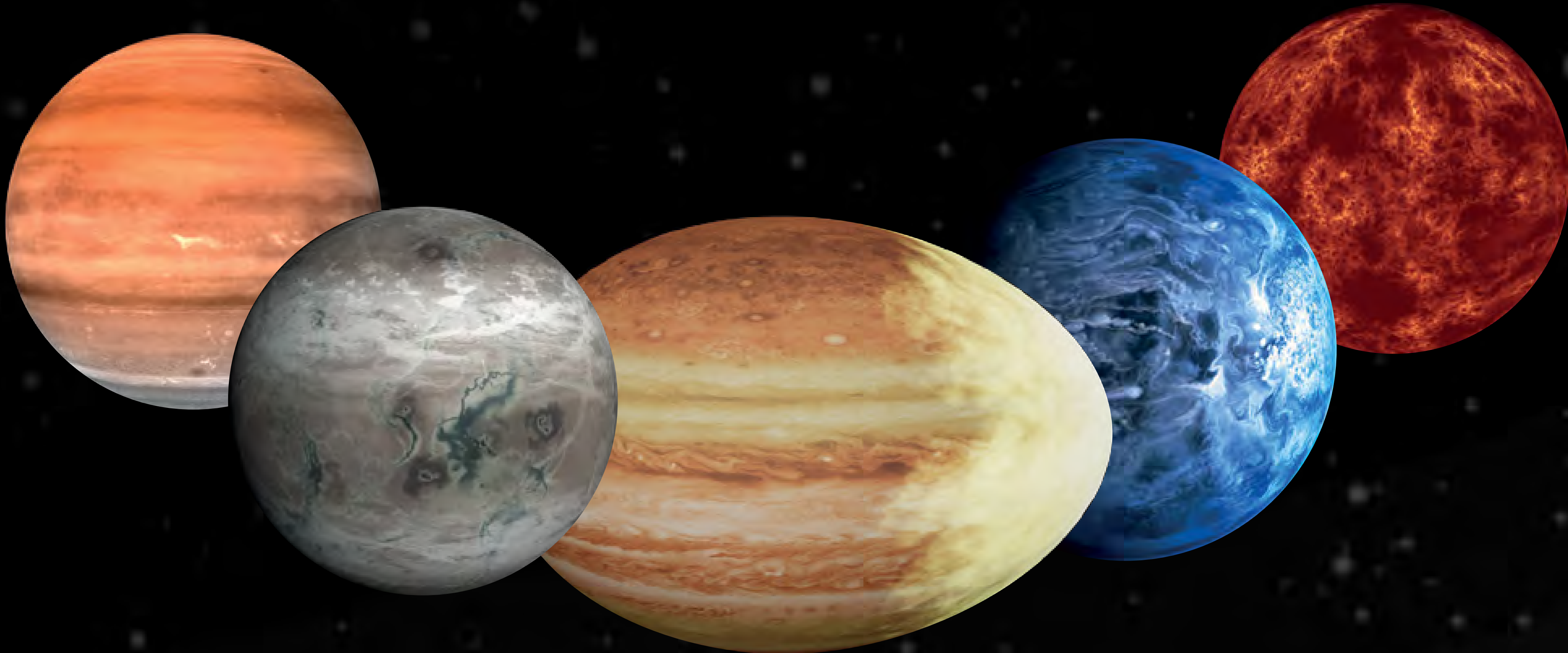
THE LITTLE BOOK OF EXOPLANETS



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