
*"I'm afraid it's true. Earth is a cosmic franchise."*

# Extrasolar Planets

## Is Anybody out There?

What are we made of? Where do we come from? And where will our journey go? A lot of scientists try with high motivation to answer these questions. While particle physicists try to find out our composition and the way our building blocks interact, astrophysicists want to know if we are alone in the universe or if life exists on other planets as well or is at least possible. Maybe, in the far future we will be able to colonize other planets. Who knows for how long Earth will stay as comfortable as it currently is?


We check our neighboring planets with care, measure their properties and look for signs of life. We search for water, which is already a good indicator, and check the temperatures on the surfaces of our neighboring planets. We found some ice on Mars, for example. The water which was found at the polar caps of Mars is frozen, and that's because of the temperature of Mars. Being further away from the sun makes it colder than Earth: the mean temperature is -67 °F. What about our neighbor on the other side, Venus? Not too cold, but with 867 °F also not very comfortable for life. So it seems that there is not too much life going on on our neighbors in the solar system. Some expect life in the oceans under the ice on Titan, the largest moon of Saturn. But next to that candidate, that is not much promising.

### Searching a Second Earth

But why should we restrict ourselves to our own solar system? The estimation of the total number of stars in our universe is about $10^{22}$. You can write down the number with all the 22 zeros to see how large it is. Of all these stars, several billion can be seen from Earth. How many depends on your telescope. So why not check these stars for planets? There must be planets orbiting those stars as well! Planets outside our own solar system are called extrasolar planets or exoplanets.

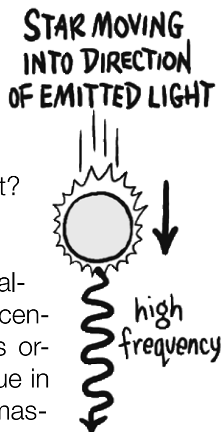
The best way to observe a planet is to take a look at it and see it with our eyes. This is called direct observation. Unfortunately, this turns out to be very difficult. Unlike their star, planets do not emit light directly. The only way they make themselves visible is via the reflection of starlight. While some planets, such as Mars, can be seen with the bare eye, others are very difficult to find, even with telescopes. The planet which is the furthest away from Earth, Neptune, was first observed in a passive way. Distortions of Uranus' orbit, the planet which was the furthest known planet at that time, could only be explained with a yet unknown nearby planet: Neptune. Today we can see him, but only with telescopes. So Neptune, which is "only" about 30 AU (1 AU is an astronomical unit, corresponding to the average distance between the sun and Earth, so about 90 million miles) away from Earth, is already so hard to see. You can imagine that it's also not too easy to see a planet of a neighboring star system. The closest one we know, Alpha Centauri (which is actually a system of two close-by stars), is already 276,110 AU away. Even though that planet would only have to reflect the


B. Bahr, B. Lemmer, R. Piccolo, *Quirky Quarks*, DOI 10.1007/978-3-662-49509-4_17

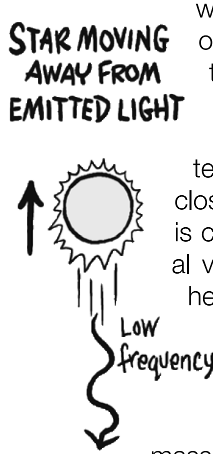
light of its own star to us, it is still very difficult. So you have to make use of other techniques. We will explain the most popular ones.

## Make It Shake

The problem with the extrasolar planets is not only their faint passive light. It is also the relatively bright light of their stars which superimposes onto the planet's own light. In case that the star is a brown dwarf (↗[1]), whose light is not very bright, a direct observation with a good telescope is still possible. But what to do in the case of bright stars? Let us take a closer look at their light. Is there maybe a way that the planet influences its star's light? There is.




In our heliocentric models we always assume a star is in the center of the system, and planets orbit around it. But this is only true in case the star is by far more massive than its surrounding planets. If there is a very heavy planet In that system, it will constantly pull on the star, so it will not stand still. It also gets attracted by the planet and in the end, both of them surround a common center of mass. For a distant observer this looks as if the star would shake a little, periodic movements both to the left and the right as well as to the front and the back. Now think of observing the moon (which is safe to observe by eye, in contrast to the sun). What could you see more easily, left/right or the front/back movements of the moon? Right, you would see the left/right movement. The two-dimensional projection that we see makes it hard to see the front/back movements. Now, the situation for a star, shaking because of the movement of a surrounding planet, is different. Here, the resolution of our telescopes is not sufficient to see left/right movements. But instead, these telescopes can use a trick to see both front/back and left/right movements, or more general: changes in its radial velocity. The Doppler shift (↗[2]) leads small variations of the emitted light's frequency while its emitter (the star) moves towards us and away from us. So if we carefully check the frequency of the light, emitted by a star, and there are periodic fluctuations of its frequency, then we know that it is slowly shaking. And this then tells us that there must be another close-by planet. This method, which is called "Doppler method" or "radial velocity method", works best for heavy planets, very close to their stars. An example for a discovery with this method is the observation of the gas giant TrES-4, which has 1.7 times the mass of Jupiter (heavy!) and revolves around its star in only 3.5 days (fast!).

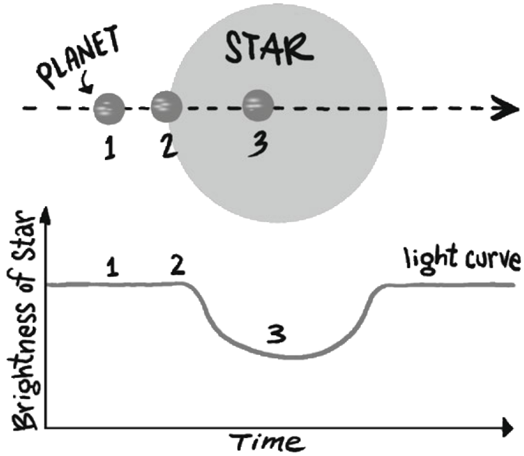



## Mini Eclipses

Another method used for the indirect observation of planets is the "transit method". In the case where an extrasolar planet orbits its star and passes it in such a way that it is between us, observing the star, and the star itself, we get something like a mini eclipse. As we are quite far away from the planet/star system and the star is usually much larger than the planet, the part of the star, which is covered by

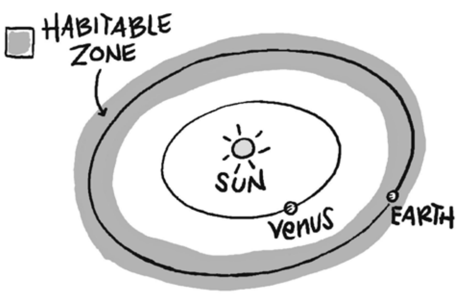
↗[1]: *"Spectral Classification" on page 73*
↗[2]: *"The Doppler Shift" on page 15*

the planet, is typically very small. But still, this leads to a small reduction of the intensity of the star's light that reaches our telescopes. If you check how large the reduction is and how long it takes, you can get some information about the planet's velocity and its size. As the variations of the starlight intensity is very small, you need modern telescopes with high intensity resolutions. The Kepler telescope, which started operation in 2009, is able to perform such measurements. You can see the transit method in our illustration.




## Planets in the Comfort Zone?

About 2000 exoplanets have already been discovered. But you do not simply want to count them – instead, you want to find out what their properties





are. Are there maybe some where humans would feel comfortable? This would be a so-called "terrestrial planet", one that has a solid surface and is not just a ball of gas. It's also important to note the planet's distance to its star. As we mentioned earlier, it can be too hot if it is too close or too cold if it's too far. The zone which is "just right" is called "habitable zone". It is the place where water can exist in its liquid form. In our solar system, only Earth lies within this zone. There are also definitions of the habitable zone which are less strict ("not the best place to live, but some kind of life might still be possible") and cover also the orbit of Mars. Some planets might also have orbits that pass the habitable zone only partially. For an ideal study of an exoplanet's atmosphere and chemical composition, one would have to analyze the planet's emitted light with high precision, in particular its wavelengths. The presence or absence of certain wavelengths is a hint for the emission and absorption of light by certain atoms. As the technology for the search of exoplanets evolves rapidly, we can expect a lot of interesting discoveries in the future!