A trio of Earths 40 light years away?

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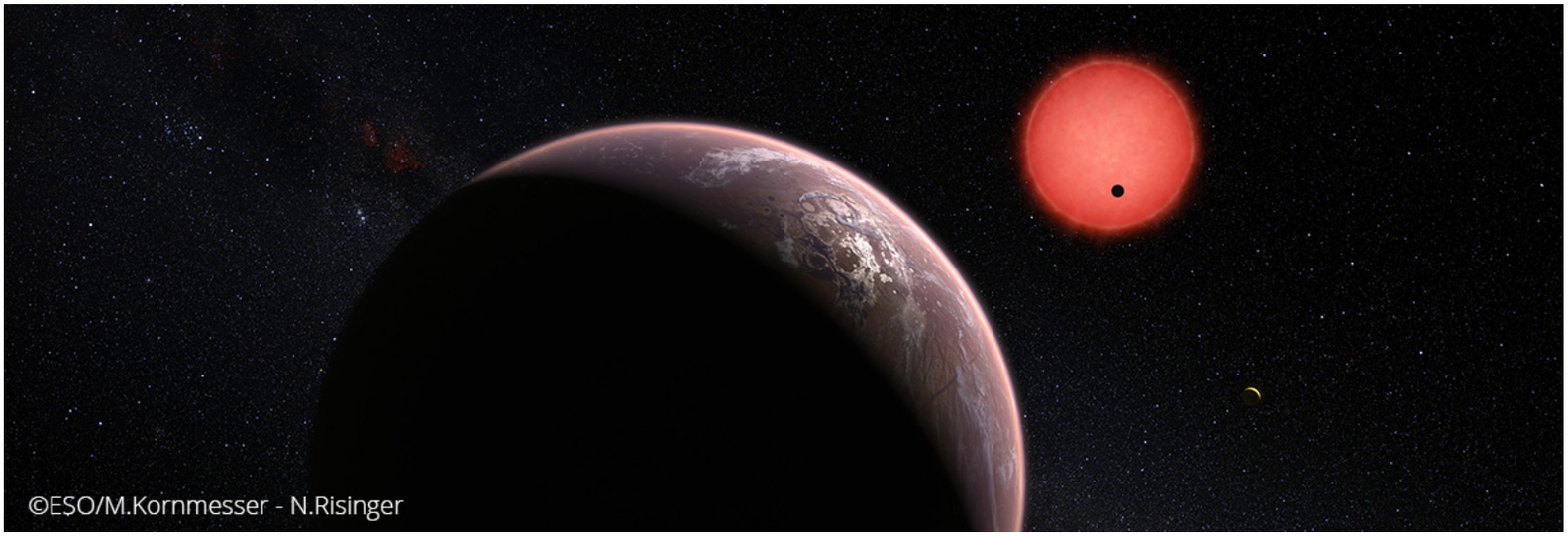
Astrophysicists from the University of Liege using the TRAPPIST telescope have discovered a planetary system formed of three Earth-sized planets around an « ultracool red dwarf star » slightly bigger than Jupiter in size. While these planets are close to their host star, they are not exposed to very high temperatures and could harbor areas on their surfaces that are suitable for life. The new planetary system is only 40 light years away from Earth. This proximity should allow the future generation of large telescopes to study the atmosphere of these planets with precision. As of today, these planets are the most promising candidates for having liquid water or even life outside the solar system. Even though the news has just been published in the journal ***Nature***, it is probably a safe bet that teams of astrophysicists over the world will be tripping over each other to study this planetary system. In the meantime, the team that made the surprising discovery only has eyes for "its" small nearby star...

The news is incredible. **Michaël Gillon** and **Emmanuël Jehin**, both of whom are FNRS research associates at the **Origins in Cosmology and Astrophysics Laboratory** of the University of Liege make no effort to hide their joy and amazement at the discovery. They lead the TRAPPIST project which has just discovered a new system which is composed of three Earth-sized planets (1). Better still, these planets could very likely be habitable and are currently the most likely candidates for the detection of life outside our solar system that we know of.



This discovery is great news for the astronomers from Liege because it augurs well for their new SPECULOOS project which will be officially launched in 2017. Financed for the most part by Europe, this unique experiment led by Michaël Gillon, will pursue an already promising intuition despite the fact that it goes against current beliefs, that ultracool **red dwarf** stars, which are a lot smaller, colder and frequent than sun-like stars, could harbor rich, complex and numerous planetary systems. SPECULOOS consists of four robotic telescopes with a diameter of 1 meter that will observe around 500 of these small cold stars located in the neighborhood of the sun, that is to say, less than 100 **light years** away. In the preliminary phase of this mission, the team of astronomers has been observing fifty target stars since 2011 using the University of Liege's TRAPPIST

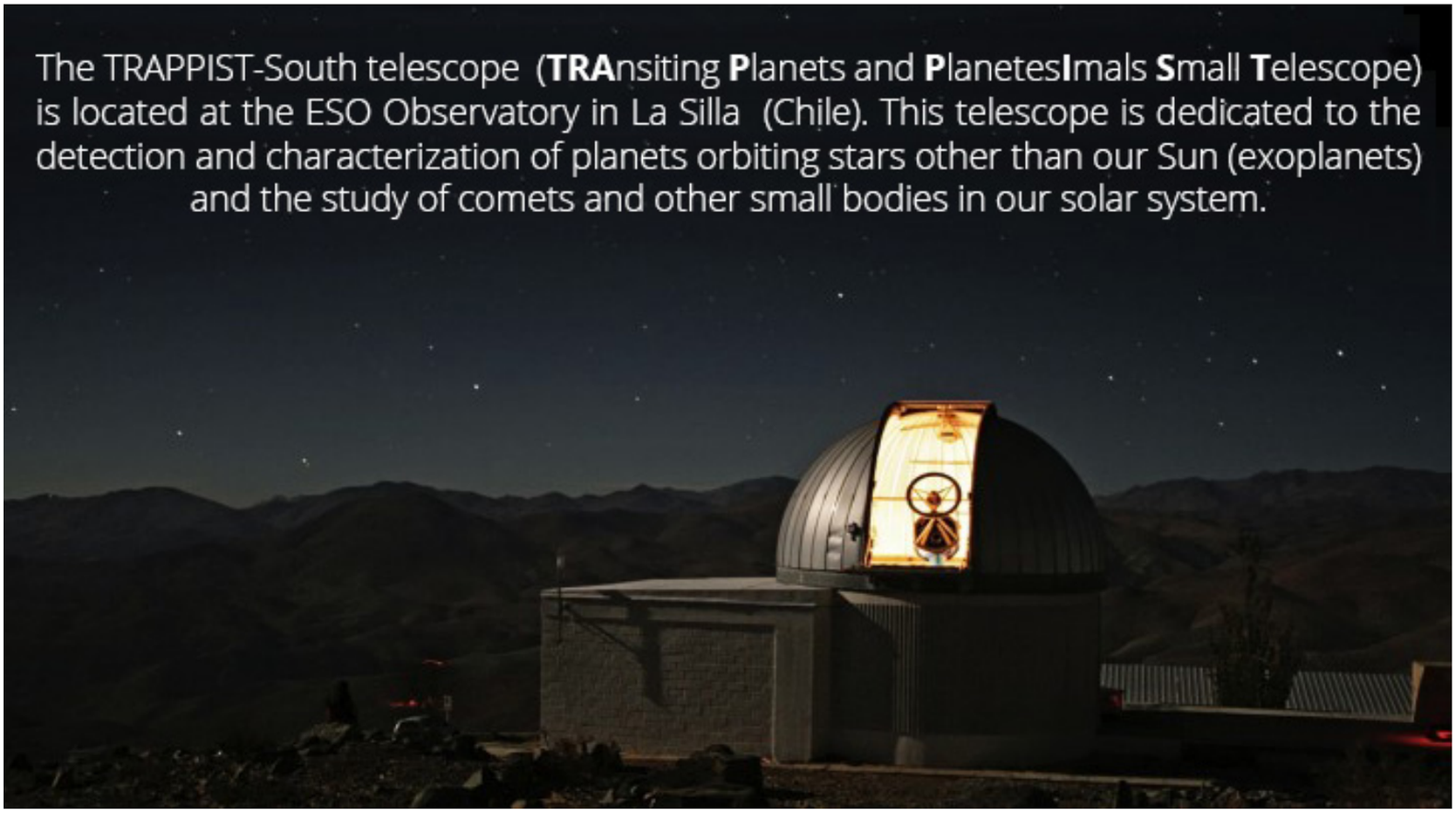
telescope which is based in Chile (see article **Astrophysicists from Liege in seventh heaven**). This preparation should provide a statistical basis to determine whether this idea has any chance of success. After 5 years, which is a very rapid result given the small number of stars studied, three planets in orbit around their sun have just been detected at a distance of only 40 light years from Earth in the constellation Aquarius. Their name of the host star is 2MASS J23062928-0502285. Following the discovery, it is now also officially named TRAPPIST-1.

Planetary systems that are still unknown

It may seem astonishing that the planetary systems of ultracool red dwarf stars had not been studied earlier, especially given the fact that these stars are very frequent in the Galaxy, much more so than sun-like stars. In fact, most of the new stars that form in the universe are small in size, much smaller than the sun. Moreover, the lifespan of stars increases the smaller they are. Stars produce their own energy by nuclear fusion in their core. Smaller stars are subjected to weaker internal temperatures and pressures, and for this reason, they consume their fuel a lot less quickly. By way of comparison, the sun will last 10 billion years while an ultracool red dwarf can live more than 10 times longer. What is also very interesting is the fact that these stars are less luminous and their habitable zone is therefore much closer to their surface. A planet could complete an orbit in just a few days while offering mild temperatures. A greater orbital frequency drastically increases the chance of detecting a planet because it will have a lot more transits. And transits by planets orbiting around these small stars will be easier to detect given that a greater fraction of the stellar disc will be obscured when the planet passes between it and the Earth.

But this also presents a difficulty. These stars only emit a small amount of light, most of the time they can only be detected in the **infrared** by the most powerful instruments. Those that are closest to the Earth have just begun to be studied and TRAPPIST-1 has itself only recently been discovered. At distances of around one hundred light years they remain unobservable while more massive stars like the sun emit a signal that is visible over distances of several thousand light years. *"Therefore, there are a lot fewer known ultracool red dwarf stars than large stars due to the fact that we can only detect the closest ones. Up to now, research campaigns have concentrated on finding as many exoplanets as possible while probing large sections of the heavens without categorizing the type of stars. This made it possible to study thousands of stars at the same time therefore increasing the chances of detection, but included almost no ultracool red dwarf stars"*, explains Emmanuël Jehin. Finally, up to the present time, the scientific community has depicted these stars as being too active, with an emission of light that is too variable to allow for the detection of planetary transits, the presence of which was very doubtful anyway, according to the results of several models. In a nutshell, these planets were considered to be of little interest for planetary research due to the fact that they were so different from the sun.

The researchers from Liege think the opposite and they believe that almost all of these stars hide a planetary system as this first discovery seems to confirm. Concentrating on ultracool red dwarf stars would seem to be a promising prospect. *"In addition",* adds Michaël Gillon, "*the large telescopes of the future such as the **JWST**, NASA's next space telescope, will have a degree of precision that will enable them to study the atmosphere of Earth-like planets and even find traces of life, but only around the nearest and smallest stars. For bigger stars that are further away, we will have to wait for more powerful instruments".*



An exceptional start to a project

For the SPECULOOS project, the challenge will therefore be to observe all the ultracool red dwarfs near the Earth. *"In total, we have detected around a thousand stars that are sufficiently nearby to enable us to conduct subsequent studies of the atmosphere of Earth-like planets transiting them",* says Michaël Gillon. *"They are distributed just about everywhere in the sky and we have almost no chance of finding two of them in the same field. While* ***NASA's Kepler space telescope*** *can probe thousands of stars at the same time, we have to study them one by one by observing each of them in turn for around ten nights on average. It is a very slow process which obliges us to use several telescopes in order to finish the project within a reasonable time frame"*. Another practical difficulty is the fact that, in order to detect a transit, a planet must pass exactly in front of its star as seen from the Earth, which is a statistically rare occurrence. *"Given this fact, interjects Emmanuël Jehin, "relatively large telescopes are very sought after in order to be able to focus on one star in particular for a period of several nights. Unless of course it is a star around which we have already discovered planets which are worth studying. Having our own telescopes was therefore vital for the project. We can devote the necessary time to this research. It is a challenge and a risk we are willing to take".*
Before fully launching the SPECULOOS project, it was necessary to ensure the viability of such a wild intuition and launch a prototypical version. *"The project is ambitious",* acknowledges Michaël Gillon who is the head and creator of the project, *"and given the reputation of these stars, we needed to be sure that we have a chance of detecting Earth-like planets. We knew that TRAPPIST was too small to meet the demands of such a large sample. However, it could easily observe the brightest ones and the ones that are nearest to each other.*

We therefore selected fifty target stars which was enough to be able to draw statistical conclusions before going any further".

In the end, fortune favored the brave and the TRAPPIST telescope found its Holy Grail even before observation of all fifty candidates was finished. A first exceptional discovery which demonstrated the potential of the project. At the beginning of 2017, four bigger and more powerful telescopes which will be operational from the famous European observatory of Cerro Paranal, in the Acatama desert in Chile. One of the best astronomy sites in the world says a jubilant Emmanuël Jehin. A twin telescope of TRAPPIST financed by the University of Liege will also very soon be installed in Morocco giving access to the brightest ultracool red dwarf stars in the Northern Hemisphere. *"In the coming years, we are going to probe 20 times more ultracool stars than those observed to date. We can expect to find a lot more planetary systems, unless we were incredibly lucky with this one, which is hard to believe. This discovery is the result of a first five years of work, and that seems to indicate that small planets are very frequent around this type of star!"* Say the two delighted researchers.

Planets similar in size to Earth

TRAPPIST-1 is a star that is barely bigger than Jupiter (1.2 times its radius). Its light emission was only detected for the first time in 2000, during the course of a systematic observation programme of the heavens in the infrared. Its mass is 80 times greater than that of the gas giant but it remains 12 times dimmer than the Sun. Its surface temperature of only 2550 **Kelvin**, is barely half the temperature of our star.
Around the TRAPPIST-1 star, three planets comparable in size to ours have been discovered. Two of them have a radius equivalent to 110% that of the Earth, the third 100%. What remains unknown is their mass. *"It is a big challenge but we will succeed"*, say the astrophysicists. *"There are two possible methods. For the technique known as "**radial velocity**" which is the most common and involves observing the small movement of the star around the center of mass of the system due to the attraction of the planets that orbit it. But TRAPPIST-1 is so weakly luminous in the visible spectrum that a high-precision IR spectrograph would be required. A first instrument of this type is available in Spain, but it has not yet proved its worth. Our best chance lies rather in the presence of several planets in this system. These planets disturb one another in fact. Therefore, the gravitational interactions between them will influence their orbital periods according to their respective masses. By observing dozens of transits and the small variations in the moments when they are produced, we will be able to deduce the mass of each of these planets. We will then have a much better idea of their composition: rocky planets like the Earth, quite rich in metals like Mercury, or even rich in ice like the moons of Jupiter".*

Similarities with the Jovian system

The size of the star and the distances separating the planets remain two of the biggest differences with our solar system. *"The first planet orbits at 0.011 **astronomical units** (AU) from its star, the second at 0.15 and the third at probably between 0.02 and 0.06", explains Michaël Gillon. In less academic terms, this would correspond to orbital periods of a day and a half, two and a half days, and a third orbit of between 4 and 20 days. "We have only been able to observe two transits of the furthest planet which is not sufficient to determine its period".* The fact remains that this system is very different to ours. By way of comparison, Mercury, the planet closest to the Sun needs 88 days to complete an orbit while Earth, the only viable planet in our system, takes 365.25.
By way of contrast, there is a quite astonishing resemblance with the Jovian system. The satellites of the giant planet are certainly closer to each other, but they orbit with very similar periods. "This similarity is not surprising", comments Michaël Gillon. "When they are born, these small stars are surrounded by protoplanetary

discs that are much more compact than those of sun-like stars. The planets therefore form closer to their star. According to theoretical predictions, it is what we expected. What is most surprising is the fact that there are so many Earth-sized planets, even though we know that protoplanetary discs do not necessarily have a mass that is in proportion to their star. Everything depends on the conditions under which they were formed, the composition of the initial gas cloud and dust, the speed of rotation of the system, etc. Above all, we know that objects can form further away before migrating towards their star. If I had to bet, I would say that these objects formed beyond the ice line of this star, which is only at 0.06 astronomical units. Emmanuël Jehin continues, "At that distance, temperatures do not exceed 100°C. It is cold enough so that the volatile elements remain solid in the form of ice. They can then mix with rocks to form planets. There is therefore more material and we can more easily imagine how Earth-sized objects are formed, even within such small discs. Planets then only need to migrate closer to their star to create a system like TRAPPIST-1".

Liquid water?

Let's imagine now that these planets cross this ice line but that they do not get too close to the star. The ice is not exposed to temperatures that are so high they would sublimate it or cause an outgassing that would dry up the planets as a result. *"At a good distance",* summarize the two researchers, *"this ice can melt and form oceans. The two first planets are at the limit of the* ***habitable zone****. They are too close to the star. But models have shown that they could harbor habitable regions in the western* ***limb*** *between their day and night sides".* The heat is not distributed in a homogenous way on these planets. The proximity of their star traps them in a state known as synchronous rotation. Like the Moon with the Earth, they always show the same hemispheres, the day side, which is a lot drier than the night side. The prevailing winds, which are too hot to keep water in the liquid state, have a tendency to blow towards the east, preserving a milder region and also brighter than in the west. The third planet seems even more promising and could be totally inhabitable.

A veritable Eldorado

The discovery is as encouraging as it is new. But it is the nature of the system that will be one of the most sought after objects by astrophysicists in the months and years to come. "As the contrast between the size of the star and its planets is particularly favorable and the system is very close, we will be able to study the atmospheric composition of each planet with unparalleled precision", explains Emmanuël Jehin *"We hope to discover biomarkers like water molecules, carbon dioxide, ozone etc. If these traces are in proportions similar to those of the Earth, it would be even more incredible. We could also imagine that these planets, given their proximity to their star, are subject to significant volcanic activity. That would also be an observable dynamic which could also favor the presence of life".*

This discovery clearly comes at the right time. In just a few months, new, more powerful telescopes will be able to satisfy the curiosity of the astronomers. *"We are already preparing observation of the system with the famous JWST, for example, which will be launched into space in 2018 and which should enable us to study these planets in a much more precise way"*, explains Michaël Gillon. *"In the meantime, we have already obtained some observation time on the Spitzer space telescope to constrain the orbital period of the third planet and confirm its position in the habitable zone. We will also be able to use it to observe the star for a period of around ten days and to try to detect other possible planets. We are also preparing a study programme of the variation in the moments of the transits in order to get their masses by means of many telescopes on the ground, but also a programme on the* ***Hubble space telescope*** *(HST) to try to detect the atmospheres of these planets. In the near infrared, we could already discern certain molecular constituents including water"*. And that's not all. Many things can be learned about the **magnetosphere** of these planets, or on the characterization of the host star itself; its composition, its activity, its variations in brightness due to its magnetic field or the heterogeneity of its surface, its photosphere, which made it possible to establish its rotation period as 1.4 days compared to 26 days for the Sun. There are many research ideas, and all the study demands so far have been collected and accepted with a lot of enthusiasm. It should not be long until astronomers the world over rush to study TRAPPIST-1. There is incredible excitement which pleases the two researchers and which promises to rapidly accelerate the level of knowledge about this system and others yet to be discovered. "As we found this system by looking at only 50 stars, there is a great chance that they are more numerous and easily detectable. TRAPPIST-1 has ensured that little-studied stars are taking center stage, with their specific behavior and their particular protoplanetary discs etc. A completely new area of research has just been created", the researchers conclude.

(1) M. Gillon, E. Jehin, et al. *Temperate Earth-sized planets transiting a nearby ultracool dwarf star*, Nature, May 2016