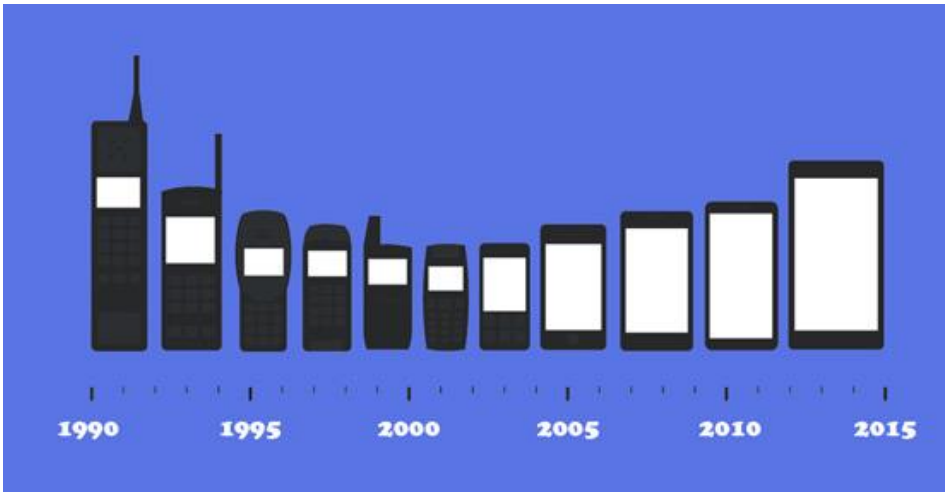
**Introduction**

Trying to predict what other, potential life form could look like is quite similar to fortune-telling. This life probably exists in completely different environments etc. It is also quite hard to say how any potential, highly developed, space civilisations look like, especially if they are on a different level of technological advancement than we are. To be honest, we cannot really say what our civilisation will be like in a few dozen years, not to mention hypothetical civilisations thousands of years ahead of us.

Examples of wrong predictions of the future: John von Neumann, a mathematician and one of the co-creators of modern day computers, in the mid-20th century formulated the following hypothesis. He stated that in the future the computers would have been so big and expensive that only the wealthiest countries in the world could afford to own them, and those computers would be capable of precisely forecasting the weather in a long enough period of time. His predictions concerning the computers have all been based on an assumption that the computers would be still using vacuum tubes in the future. The bigger and more complex a computer would be, the more tubes and other electronic parts would be necessary to build it. However, the invention of transistor in the middle of the 20th century has led to the elimination of large vacuum tubes from electronic devices. This, in conjunction with the invention of transistor-based integrated circuits, allowed the miniaturization of computers. However, even modern computers, incomparably more advanced and faster than those based on vacuum tubes, are not capable of accurately forecasting weather in a period longer than just a few days.

In short periods of time, we can extrapolate certain phenomena but the technological advancement is not a simple extrapolation of what we know, it depends on certain qualitative breakthroughs (e.g. the invention of a transistor) in new fields. A good example to illustrate this can be the development of cellular phones presented below:




*Cell phones size and shape evolution. Source: https://easytechnow.com/learn-technology/the-evolution-of-mobile-phones/*

Let's assume we are in the year 2000 and we are trying to predict the cell phone development. The graph shows us that they have been getting increasingly smaller. This could lead us to think that in the future cell phones will be still getting smaller, but e.g. their batteries could last not a week but a month without charging. However, touchscreens have been invented and this development followed a completely different path, and the batteries need charging every 1-2 days.

Instead of predicting what our civilization would look like in the future, or how other alien civilizations could look like, a Russian astronomer, Nikolai Kardashev, suggested classifying a civilization's

development not by its technology, but by the energy that a given civilization could use. Kardashev has listed the three civilization types.

*Type I civilization.* It controls the energy resources of its planet. It can affect and change the weather, prevent earthquakes, etc. This civilization has already explored the entirety of its planetary system.

*Type II civilization.* It controls the energy of its star. It does not mean they passively use the energy, they actively utilize the star. This civilization colonizes its local planetary system.

*Type III civilization.* It controls all of its galaxy and extracts energy from the stars within the galaxy.

*Sources*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2. *Michio Kaku – "Hyperspace: A Scientific Odyssey Through Parallel Universes, Time Warps, and the 10th Dimension", Chapter 13 "Beyond the future"*


**Biosignatures**

Biosignatures are certain chemical substances, the existence of which (e.g. in a planet's atmosphere) can indicate that there is life on the planet. Biosignatures can be geological fossils, a specific combination of isotopes of certain elements, like c, H, N, which could not exist in a given environment without any life forms. Other biosignatures are certain substances, that are usually created through biological processes. Another example of a biosignature can be the Keeling Curve showing yearly[1] changes of carbon dioxide in a planet's atmosphere, connected to the change in plant activity.

Examples of biosignatures present in the atmosphere:

$O_2$ – quickly degrades in the atmosphere, and if an atmosphere contains significant amounts of oxygen, it can mean (although it doesn't have to, its sources can also be non-biological) that photosynthesis occurs on a given planet. Oxygen can also be created in a non-biological way through photodissociation of vapour by the UV radiation.

$O_3$ – it is formed by the UV rays affecting $O_2$. It is easier to detect with stereoscopic methods in an atmosphere than $O_2$.

$Ch_4$ – the main source of methane are living organisms (or decomposition of organic substances). Seasonal changes of methane in the atmosphere can indicate the existence of life (see also the point concerning methane on Mars).

Chloromethane ($CH_3Cl$) – certain plants and fungi; ocean (the effect that sunlight has on plankton and chlorine); it is also formed as the result of combusting plants.

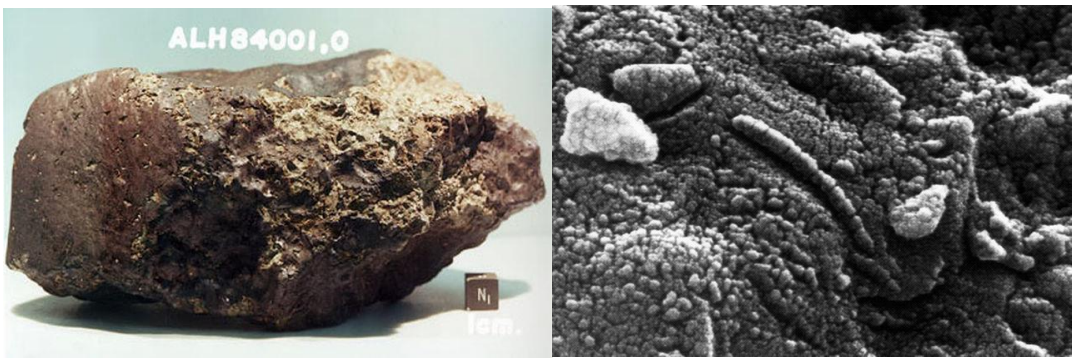
$H_2O$ – best as a fluid as a necessary component of living organisms.

$N_2O$ – it's exuded during the decomposition of vegetal matter.

Of course, we can imagine life based on elements completely different from carbon and hydrogen. It means that we can miss information about this kind of life by looking only for the biosignatures listed above.

[1] A year is the time a body (e.g. a planet) needs to orbit its star once.

An example of a biosignature being a geological fossil is Allan Hills 84001 (ALH 84001) meteorite. It was discovered in 1994 on the Allan Hills ice field in Antarctica. At the moment of its discovery, it weighed 1,93 kg. A picture of this meteorite is presented below. It is assumed that ALH 84001 had come from Mars and that it had been detached from the planet about 3,9 – 4,0 billion years ago as a result of other meteorite hitting Mars and thus throwing it into space. Supposedly it fell on Earth 13 000 years ago. As a result of conducted research, we have found microscopic structures, that looked just like fossilised bacteria. However, currently, most scientists believe that those structures were created through non-biological processes.




*The left picture shows ALH 84001 meteorite. The one on the right is a microscopic view of its fragment, showing structures that look like fossilised bacteria. Source: NASA.*

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*http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Signatures_of_life*

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*4. Krzywa Keelinga dla różnych odcinków czasu w przypadku atmosfery ziemskiej*

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*5. Informacje na temat meteorytów z Marsa.*

*http://www.ptmet.org.pl/old/psm/mars.htm*

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**Extremophiles**

Those are living organisms tolerating or needing for life and reproduction extreme environmental conditions. In most cases those are unicellular organisms (of the Archaea domain), however, they are also present among other groups. There are a few types of extremophiles:

- Thermophiles living in the temperature of 60-80℃, and hyperthermophiles in even above 80℃. An example of thermophiles are Archaea Strain 121 bacteria living in the hot geysers of the Yellowstone National Park.
- Acidophiles living in the environments with pH lower than 3. Example: Sulfolubus living in Lechunguilla Cave, New Mexico.
- Radioresistant: organisms resistant to strong ionizing radiation. Example: Deinococcus radiodurans living at the site of nuclear waste storage in the USA.
- Xerophiles: living in the environments with restricted access to water, e.g. in the deserts.
- Piezophiles: living under extremely high pressure (>40 MPa), e.g. in the ocean depths.

And many others. Some organisms, e.g. moss piglets, can be a part of a few groups. An interesting example of extremophiles are also Hesiocaeca methanicola (methane ice bugs) living under the ocean's bottom surface in an environment containing water ice rich in methane. Their source of nourishment are methanotrophic bacteria (those capable of metabolizing methane). Another example of extremely resistant organisms are moss piglets. In the state of suspended animation (when their life functions are limited due to unfavourable environmental conditions, they can survive extreme temperatures (from close to absolute zero to over 100℃). They also show high resistance to lack of water, high pressure or high concentration of salt.

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**The search for life in the Solar System**

*Before reading this part you should read parts "Biosignatures" and "Extremophiles". Parts titled "Water on Mars" and "Methane on Mars", located towards the end of this document, are great additions to this part of the description.*

While looking for ideal spots in the Solar System, it seems natural to look for places where the surface temperature ranges from -70 to 80 ℃, whether an object has an atmosphere (and how dense it is), and whether there are biosignatures in the atmosphere's composition ($O_2$, $O_3$, $CH_4$, $H_2O$ (is it liquid?)). Additionally, we should note whether there is (or at least we suppose so) a water container (or multiple

containers) underneath the surface. Of course, not all data is always available, especially when it comes to planet's moons.

This subject should be discussed after the introduction of biosignatures and extremophiles. We can suggest the students pick bodies within the Solar System (based on biosignatures) that potentially could host life. They should focus on Mars, Jupiter's moons (Europe, Ganymede, Callisto) and Saturn's moons (Titan, Enceladus). Students should take into consideration the object's surface temperature (it should range from -70 to 80℃ ), whether it has an atmosphere (and how dense it is), and whether the atmosphere contains any biosignatures ($O_2$, $O_3$, $CH_4$, $H_2O$ (is it liquid?)). In addition to that, they ought to check (if such data is available for the analysed planet or moon) whether there is (or we suppose there is) an ocean with liquid water underneath the surface. Of course, not all data is always available, especially when it comes to planet's moons. This subject should be discussed after the introduction of biosignatures.

Examples:

*Take note. Students might receive slightly different values of a body's surface temperature, atmosphere composition or other parameters, based on the sources they will use.*

*Mercury*. The temperature reaches from -173 up to 427℃ and there is practically no sign of an atmosphere (trace amounts of hydrogen and helium). In conclusion, this planet is not well suited for life (students should find this information on websites: https://spacefacts.com/mercury/ or https://pds.jpl.nasa.gov/planets/special/mercury.htm).

*Venus*. Its atmosphere does contain water (0,1%), but the average surface temperature is over 700 K, which means that the planet is not suitable for life development. Information from various sources, e.g.: https://pds.jpl.nasa.gov/planets/special/venus.htm. However, there are speculations of potential life in the upper layers of Venus's atmosphere, where the conditions aren't nearly as harsh (https://solarsystem.nasa.gov/planets/venus/indepth).

*Mars*. During the day the temperature changes from -89 to -31 ℃, the atmosphere consists mostly of carbon dioxide, although it contains tiny amounts of water, oxygen and methane. Those substances are biosignatures, which leads us to a conclusion that there are conditions good enough for the existence of living organisms (most likely not on the surface (pressure, effects of radiation caused by lack of planet's magnetic field), but underneath it). Information gathered from various websites.

*Jupiter*. Although its atmosphere contains small amounts of a biosignature (methane, https://nssdc.gsfc.nasa.gov/planetary/factsheet/jupiterfact.html), the other conditions (temperature, pressure) are not suitable for the existence of life (https://pds.jpl.nasa.gov/planets/special/jupiter.htm or https://solarsystem.nasa.gov/planets/jupiter/indepth). For similar reasons we can safely assume that there are no such conditions under Jupiter's surface either.

*Saturn*. Similarly to Jupiter, its atmosphere contains methane (as an example of biosignatures), however, other conditions (temperature, pressure) do not indicate the presence of life. https://nssdc.gsfc.nasa.gov/planetary/factsheet/saturnfact.html

*Uranus*. *Neptune*. Just like Jupiter and Saturn (above).

*Earth's Moon*. Practically lacks atmosphere. The surface temperature ranges from -233 to 123 ℃ (depending on whether a given part of the Moon is currently shined upon by the Sun). These

conditions make us believe that there are no life forms to be expected on the Moon (https://space-facts.com/the-moon/).

*Jupiter's moon Europe*. Its atmosphere consists of mostly oxygen (however, it is extremely thin and the surface temperature is about 100 K). Which means that there are no conditions to sustain life on the surface, but there might be liquid water underneath it (according to http://nineplanets.org/europa.html), so potentially some living organisms might be hiding in this body of water (https://www.astrobio.net/newsexclusive/jovian-moons/).

*Jupiter's moon Io*. The average temperature on the surface is -155 ℃. Volcanism (the temperature around volcanos reaches up to 1500 ℃) and the heating of the moon's interior caused by Jupiter's gravity have been discovered there. No organic substances have been discovered on this moon. It can be considered to a certain (tiny) degree a potential host to living organisms (under the surface and near volcanos). https://nssdc.gsfc.nasa.gov/planetary/factsheet/galileanfact_table.html

https://www.astrobio.net/news-exclusive/the-chance-for-life-on-io/

*Jupiter's moon Ganymede*. The atmosphere contains mostly oxygen and is very thin, and the surface temperature is -163 ℃. It is a sign that most likely there is no life on its surface. However, there might be an ocean (or oceans) filled with liquid water under its surface, where life could have developed. https://space-facts.com/ganymede/ and https://www.urania.edu.pl/ksiezyce/ganimedes.html

*Jupiter's moon Callisto*. The conditions on the surface could not support life's existence (temperature at the level of about -155 ℃ and pressure, the atmosphere consists of mostly $CO_2$ and probably of also molecular oxygen), but it could contain a subsurface body of liquid water (https://www.urania.edu.pl/ksiezyce/kallisto.html

https://www.astrobio.net/news-exclusive/jovian-moons/

https://nssdc.gsfc.nasa.gov/planetary/factsheet/galileanfact_table.html).

*Saturn's moon Titan*. The life could exist in a probable subsurface ocean (made of water), the conditions on the surface are too extreme (too low temperature at the level of -179 ℃) in spite of the presence of $CH_4$ biosignature, thick atmosphere and bodies of liquids (mainly hydrocarbons like methane, ethane, and propane in different proportions depending on the body they are in) existing on the surface (https://solarsystem.nasa.gov/planets/saturn/indept https://www.urania.edu.pl/ksiezyce/tytan.html https://space-facts.com/titan/).

*Saturn's moon Enceladus*. Its atmosphere consists of 91% vapour, 4% nitrogen, 3,2% carbon dioxide, and 1,7% methane (those are 2 biosignatures), but it is sparse. On top of that, the temperature is too low to sustain life (-198℃ on average, and minimum of -240℃). It is assumed that it contains a subsurface body of water, where life could potentially exist (https://www.urania.edu.pl/ksiezyce/enceladus.html

http://nineplanets.org/enceladus.html

https://solarsystem.nasa.gov/planets/enceladus/indepth).

*Saturn's moon Iapetus*. Surface temperature ranges from -143 to -183℃. Its density of 1,08 g/cm$^3$ indicates that it mostly consists of water ice. There were no bodies of liquid water found on its surface. The conditions on its surface are too extreme for life to develop (https://www.urania.edu.pl/ksiezyce/japet.html https://space-facts.com/iapetus/).

Conclusions.

Probably the only objects of the Solar System capable of sustaining life are Earth (100% certainty) and Mars (however, not on the surface, but underneath it), and in case of other bodies we have to look for water containers potentially located under their surfaces, since the conditions on the surface are too extreme for life to exist.

*Literature*


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https://pds.jpl.nasa.gov/planets/special/planets.htm

*2. Inna strona (wraz z podstronami) zawierające bardziej szczegółowe informacje o planetach, Księżycu i Plutonie.*
https://nssdc.gsfc.nasa.gov/planetary/factsheet/

*3. Informacje o księżycach planet*
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**Fermi paradox**

It is estimated that the number of stars in our galaxy is somewhere within the range of 100-400 billion. To this day a few thousand planets orbiting stars other than Sun have been discovered and it is assumed that the majority of stars in our galaxy has got planets orbiting them. It is also assumed that there are many planets, around those stars, that are similar to Earth and are placed within the habitable zone. The habitable zone is the place around a star where liquid water, and other conditions necessary for the development of life as we know, it is possible. To be more precise, the temperature there should be at the level of -70 to 80 ℃. The habitable zone of our Solar System is about 1 au away

from the Sun. Let's try and approximate the amount of extra-terrestrial civilizations in our galaxy. Let's assume it contains 200 billion stars. 10% of those stars are similar to Sun. On top of that let's make only each 10th orbited by planets. Lat's assume that 1 in 10 of those planets are Earth-like. Moreover, let's make just 10% of those planets have conditions (atmosphere composition, temperature, etc.) suitable for life to exist. Every 10th of these planets is actually inhabited. Just 1 in 10 of those planets has developed intelligent life. It means that 200 000 000 000*0,1*0,1*0,1*0,1*0,1*0,1=200 000 stars are orbited by planets on which we can expect to find intelligent life[2]. Enrico Fermi has pointed out that if there is such a vast number of technologically advanced civilizations in the galaxy, then why can't we see traces of their presence, like signals emitted by them, their probes, spaceships or representants of alien civilizations. This is the so called Fermi paradox. If the traces of alien civilizations were not yet discovered, then this could mean that:

- The assumptions concerning extra-terrestrial civilizations are wrong and life is far more scarce (the footnote below).
- Alien civilizations indeed send signals into space, but our civilization is too primitive to detect them. In other words, we are looking for the wrong things (e.g. we look for traces of emission of electromagnetic waves as we know them, whereas other civilizations might a medium to communicate that we don't know or a one we know but we cannot receive nor interpret it).

Attempts to solve the Fermi paradox:

1. **Annihilation of a civilization:**
   - *Annihilation due to global conflicts*. A space civilization's development might go in a way that it could have at its disposal a weapon capable of completely destroying their world (nuclear, thermonuclear, biological, chemical weapons) before it could have reached the level of social development allowing them to solve all conflicts peacefully. Planets that are particularly in risk of such conflicts are those running low on certain supplies (food, water, precious minerals, etc.) where hostile countries (or other organized social structures) start to fight for supplies by waging wars with the use of mass destruction weapons leading their world to a global fall or even a complete annihilation of their civilization.
   - *Global ecological degradation*. A civilization's development can be halted, or it can be completely destroyed, before it could create a technology enabling them to receive signals from other space civilizations or to send such signals, by overly polluting the environment in which said civilization lives. It could be an effect of water pollution, making the soil infertile, greenhouse gasses emission, or destruction of the layer of the atmosphere protecting the surface from radiation (e.g. the ozone layer in the Earth's atmosphere).
   - *Ice age*. It has never been precisely stated what is the cause of ice ages on Earth. It could be minimal changes of Earth's orbit parameters (eccentricity, inclination) and changes of the equator's inclination to the ecliptic causing climate changes. Ice ages played a major part in the changes of the number of living species on Earth. In case of insufficiently developed space civilizations, the appearance of an ice age might result in its destruction in the early stages of its existence.
   - *Planetoid or comet collisions*. In the scale of a thousand or million years type I civilizations have to take into consideration the probability of colliding with a planetoid or a comet flying by. Depending on their sizes, they can cause local and global destruction. One of the

[2] While discussing this point with the students we should also reflect on those assumptions and modify them, assuming that e.g. life can develop in conditions different than those present on Earth, around another type of stars, etc. These approximations are a simplified form of the Drake's equation.

ways of protecting against these events is changing their path. However, to do that, such an object needs to be discovered in advance. Civilizations in the early stages of technological development (like the one on Earth) may not have the ability to actively protect themselves against objects on collision course with their planet.

- *Nearby supernova explosions*. A supernova is an explosion ending the life of certain stars. As a result of this explosion, huge amounts of energy are emitted – way larger than billions of stars at the same time. During such an explosion, X radiation is emitted in such amounts that it can cause major disruptions in nearby planetary systems. This radiation, while entering the atmosphere, causes electrons to "pop out" of atoms leading to the creation of huge electric fields. Those fields can disrupt electric devices and communications. In extreme cases a supernova explosion can cause total annihilation of life on a planet.

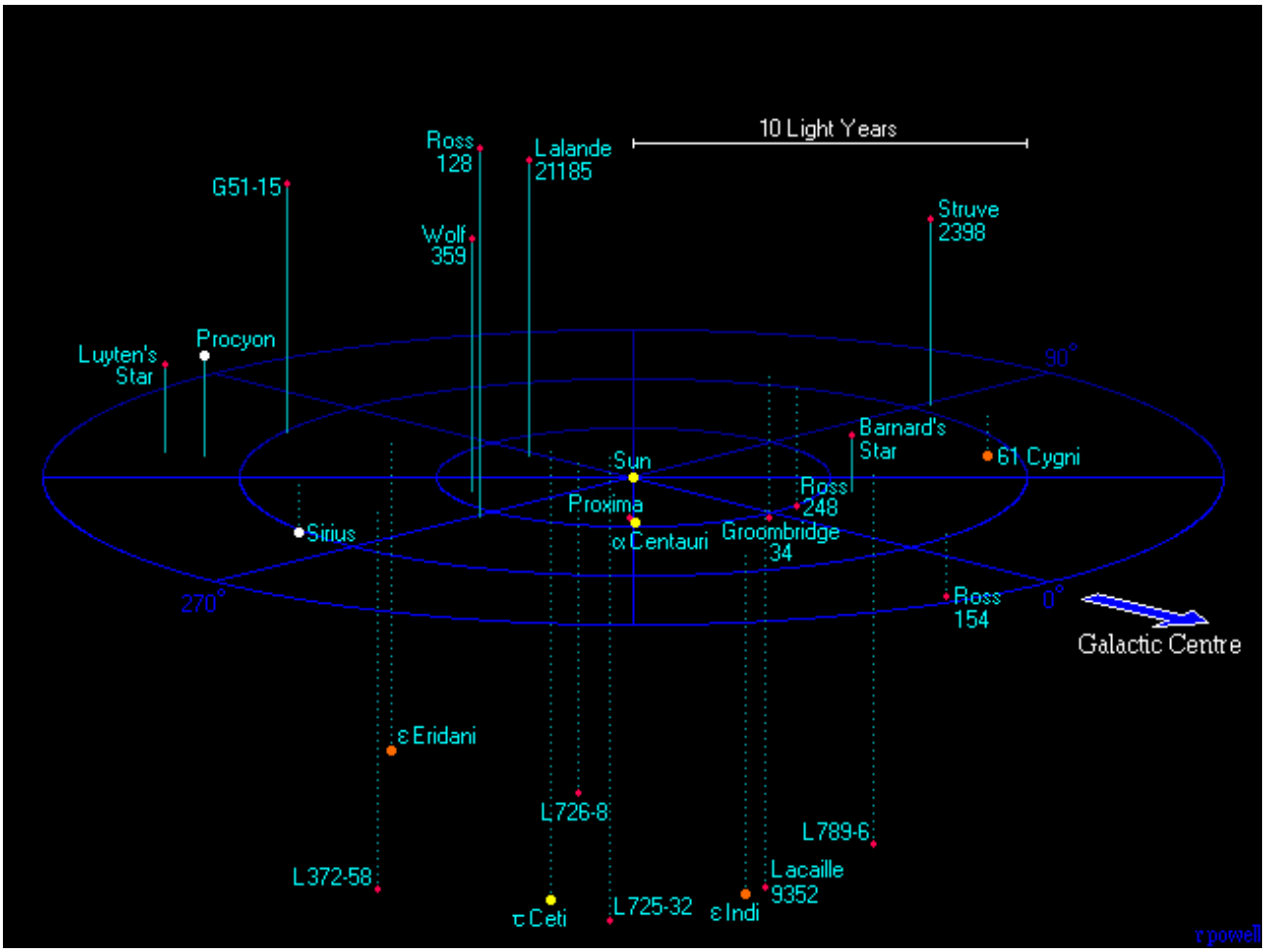
The reasons listed above show that space civilizations can appear quite commonly, but the duration of their existence on a cosmic scale is short. This implies that the probability of two technologically developed civilizations capable of communicating with each other, existing at the same time, is really small. It's worth noting that life on Earth has been existing for a few billion years already, the humans appeared a few hundred thousand years ago, but we can intentionally send and receive electromagnetic waves (in the non-visible spectrum) for just 150 years.

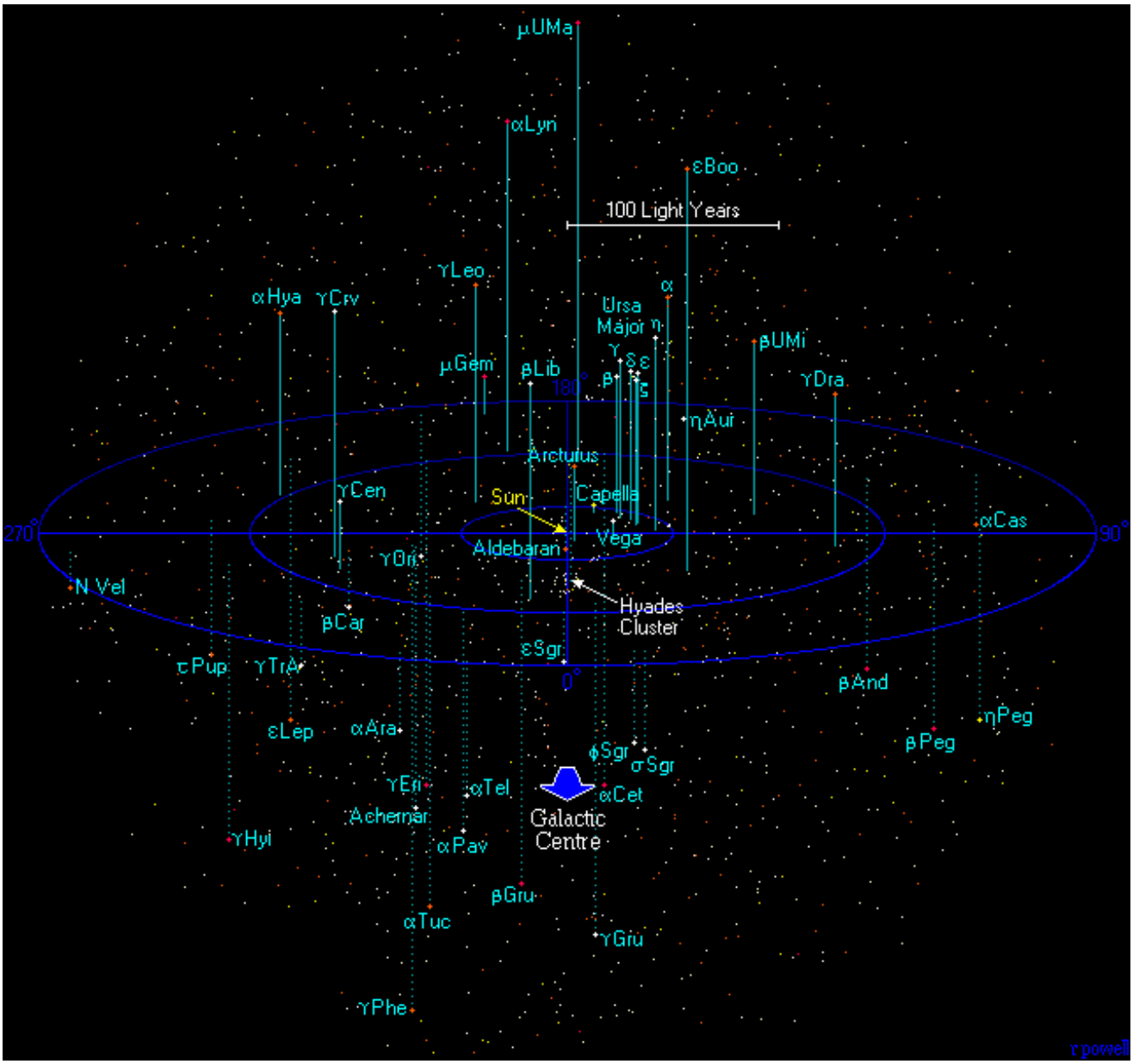
## 2. The problem of distance between stars

A light year is the distance travelled by the light in one year. The speed of light is equal to about 300 000 km/s. This means that in a year, light will travel the distance of $9{,}4*10^{12}$ km.

There are about a dozen stars at the distance of 10 light years. The 2 pictures below (source: http://www.atlasoftheuniverse.com/12lys.html) show the closest proximity of the Solar System (at the sizes of 10ly and a few hundred light years). A star the closest to us (right after Sun) is Alpha Centauri at 4,22ly away from Earth. It is worth noting here that a ray of light need a bit over 8 minutes to reach Earth from the Sun.

Our galaxy has a diameter of 100 000ly and thickness of 1000ly. Space ships sent from Earth are moving at the speed of around a dozen km/s. For example, the velocity of Voyager 1 is 13 km/s, and it is estimated that it will approach a star Gliese 445, at around 17,5ly away from Earth, in 40 000 years. Assuming that some civilizations can travel at the speed of 10% of the speed of light, because of huge distances in space, it would take them dozens of years to get from one star to another. Such a journey involves a lot of problems. One of which is the amount of fuel that would suffice for dozens of years. Another one is the space radiation threatening the ship and its crew. Distances between 2 inhabited planetary systems can be way larger and instead of dozens they could equal to hundreds or thousands of light years. So before a signal sent from Earth reaches another planetary system, that hosts intelligent life, the civilization we try to contact may cease to exist. Similarly, if said civilization somehow received the signal from Earth and decided to answer, the life on Earth could be completely annihilated by that time and we wouldn't be able to get the message.


10 Light Years
Ross 128
Lalande 21185
G51-15
Wolf 359
Struve 2398
Luyten's Star
Procyon
90°
Barnard's Star
61 Cygni
Sun
Ross 248
Proxima
α Centauri
Groombridge 34
Sirius
270°
Ross 154
0°
Galactic Centre
ε Eridani
L726-8
L789-6
L372-58
Lacaille 9352
τ Ceti
L725-32
ε Indi
r powell




*The Solar System's closest vicinity (sized 10 light years – top, and 100 light years – bottom; source: [http://www.atlasoftheuniverse.com](http://www.atlasoftheuniverse.com)).*

### 3. The ZOO hypothesis

This hypothesis states that aliens avoid contacting Earth's inhabitants and affecting the life on Earth etc. just like ZOO keepers observe its inhabitants (this is not a complete analogy of course). Reasons for such behaviour might vary. Perhaps their civilization is so advanced that we would be unable to communicate (just like people cannot communicate with ants, etc.), so they are waiting until people reach a sufficient level of development. This hypothesis however, has a weakness. If there are many alien civilizations, there is a probability that some of them would like to contact us in a different manner than the one presented by the hypothesis.

## 4. The planetarium hypothesis

This hypothesis is one of the modifications of the ZOO hypothesis. It claims that we all live in a virtual reality. This reality had been designed for the humanity by an alien civilization (probably a type III civilization on the Kardashev's scale) in such a way that there are no life forms other than the Earth ones in it. This creates an illusion that we are the only life existing in space. An example of a simulation like this was presented in the movie "Matrix" from the year 1999. The more knowledge of space (which is virtual according to this hypothesis) we gain, the more things require being simulated resulting in more and more energy being spent on such a simulation.

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*https://www.youtube.com/watch?v=sNhhvQGsMEc*

*https://www.youtube.com/watch?v=1fQkVqno-uI*

*Are You Alone? (In The Universe)*

*https://www.youtube.com/watch?v=PKMQzkIiB0Y*

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*http://www.urania.edu.pl/wiadomosci/czy-zrozumiemy-wiadomosci-hipotetycznychobcych-cywilizacji-3208.html*

*6. Dlaczego nas nie odwiedzają?*

*http://www.urania.edu.pl/urania/u4_1976-a2.html*

*7. Twelve ways the world could end*

*https://www.ft.com/content/260e3168-b177-11e4-831b-00144feab7de?siteedition=intl#axzz3S5K9MYXc*

*8. Lista najbliższych gwiazd*

*http://www.solstation.com/stars.htm#sthash.NJSXAw7K.zt5RoBsk.dpbs*

*Poniższa lista zawiera również informacje o planetach krążących wokół gwiazd*

*https://www.space.com/18964-the-nearest-stars-to-earth-infographic.html*

*9. Wizualizacje najbliższego otoczenia Słońca*

*http://stars.chromeexperiments.com/*

http://www.atlasoftheuniverse.com/12lys.html

*10. Nick Bostrom: Czy żyjemy w symulacji komputerowej?*

http://filozofuj.eu/nick-bostrom-czy-zyjemy-w-symulacji-komputerowej/

**Exoplanets**

Exoplanets are planets within a planetary system and orbiting a star (or multiple stars) other than Sun. Exoplanets can be potential places where life could have formed. The probability of life appearing on an exoplanet depends on various factors. Main of them are:

- Whether the planet is in the habitable zone. A habitable zone is a place in space around a star, where liquid water, and conditions allowing sustaining life as we know it, can exist. More precisely, the temperature there should range from -70 to 80℃. In our Solar System the habitable zone is located about 1au away from the Sun. We can assume it's the zone between Venus and Mars.
- The exoplanet's structure. The only life we know exists on Earth, which is a rocky (terrestrial) planet containing a lot of liquid water on its surface. This makes it safe for us to assume that an exoplanet capable of hosting life is one that has a radius r that complies with the following restrictions: $0{,}5r_e<r\leq 1{,}5r_e$ where $r_e$ is the Earth's radius, and/or its mass m complies with: $0{,}1m_e<m\leq 5m_e$ where $m_e$ is the Earth's mass.
- Whether an exoplanet has an atmosphere and what is its composition. Gasses like methane, vapour or carbon dioxide, if they exist in a planet's atmosphere, affect, through the greenhouse effect, the temperatures on the planet.
- Whether an exoplanet has a magnetosphere. A magnetosphere protects exoplanets against the harmful radiation emitted by its star or stars.
- The structure of the star orbited by an exoplanet.

Data base of exoplanets can be found on the http://exoplanets.org/table website. There is also a lot of information about their stars. We are not always presented with its mass, but most often with e.g. its radius. It could be used to approximate the location of the habitable zone in a given planetary system. We can assume that in the Solar System it is between the orbits of Venus and Mars (0,72-1,52au)[3].

Let's define the borders of a habitable zone as locations around a star, where the stream of energy is equal to the stream of energy emitted by the Sun at the distance of 0,72au and 1,52au correspondingly. Assuming, that both the Sun and a given star, for which we try to calculate the borders of the habitable zone, emit the energy of perfectly black bodies we are left with:

$$r_{min} = r_0 \frac{R_*}{R_\odot}\left(\frac{T_{eff}^*}{T_{eff}^\odot}\right)^2$$

$$r_{max} = r_1 \frac{R_*}{R_\odot}\left(\frac{T_{eff}^*}{T_{eff}^\odot}\right)^2$$

[3] That's one of the definitions. Others claim that it is at the distance of 0,5-3,0au.

Where $r_0$=0,72au and $r_1$=1,52au are correspondingly the average distances from Venus and Mars to Sun, $R_*$ and $R_\odot$ - diameters of a given star and the Sun, $T_{eff}^*$ and $T_{eff}^\odot$ - effective temperatures of a given star and the Sun. The formulae above show that both the minimal and the maximal extremes of a habitable zone increase as the star's radius and effective temperature increase as well.

The PHE_eng.xlsx file contains the calculated, following the formulae presented above, borders of habitable zones of certain stars. The teacher can tell students to find planets located in habitable zones while giving them a few stars from the file mentioned above with a few additional ones (list of exoplanets: http://exoplanets.org/table). We can also suggest that students, as part of an exercise, determine which planets of a star, e.g. Kepler-296 (5 exoplanets), are in the habitable zone.

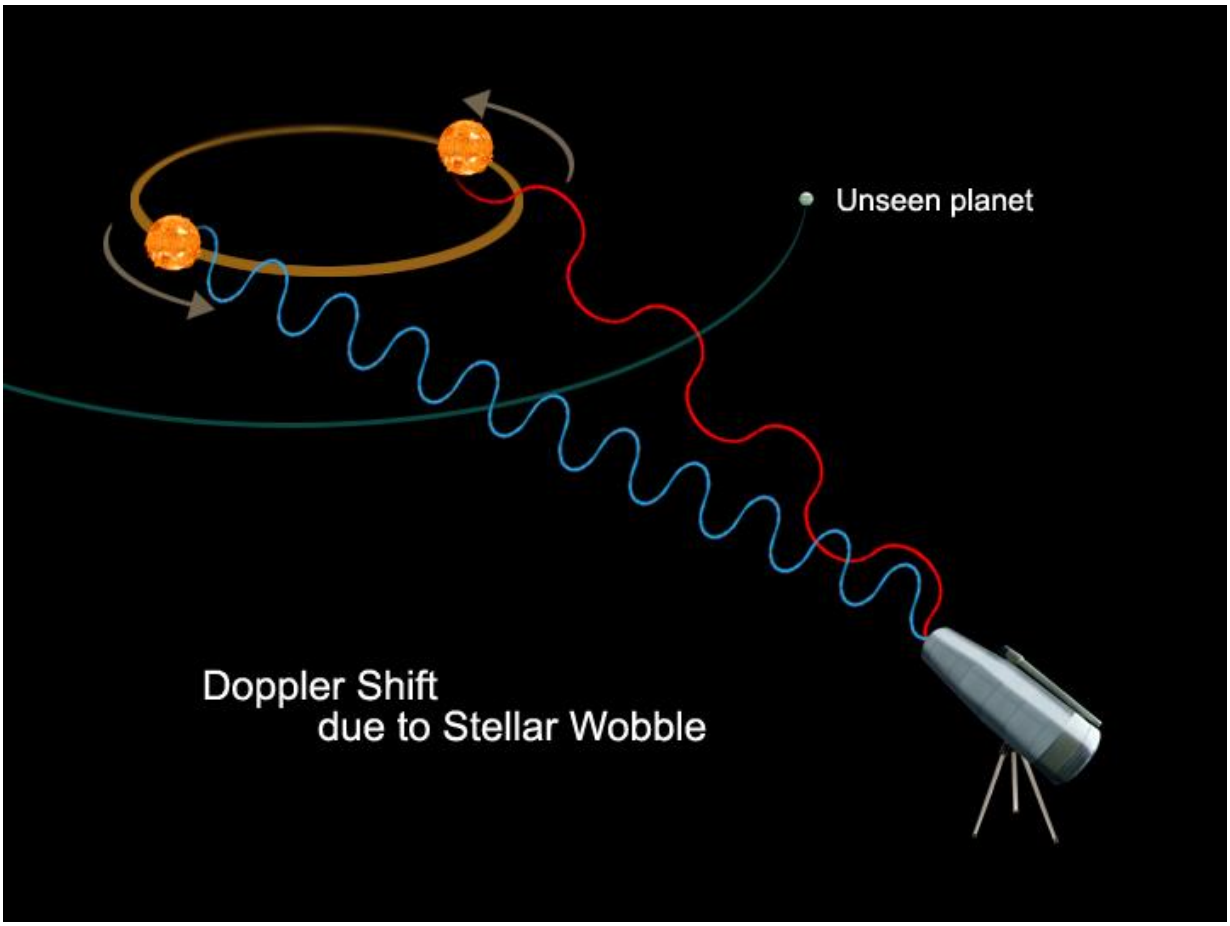
The list of exoplanets in potential habitable zones can be found here: http://phl.upr.edu/projects/habitable-exoplanets-catalog. This is an information for the teacher. Students should look for exoplanets themselves instead of just using a finished sheet.

Because of vast distances between potential stars orbited by exoplanets, and because of the fact that an exoplanet reflects just a tiny fraction of light in comparison with its star, direct methods of observing exoplanets are extremely difficult. This led to the creation of methods allowing us to detect exoplanets not by directly observing them, but by detecting different effects appearing in a planetary system that contains exoplanets. Those effects are looked for by watching the star. Those methods are ideologically simple, however, they require extremely precise measurements due to the fact that exoplanets usually have a tiny effect on their stars. The main methods are:

- *Radial velocity method*

The Doppler Effect is based on a phenomenon of the change of wavelength (e.g. a sound wave in the air or electromagnetic wave) emitted by a moving source and observed by the observer. When an exoplanet orbits a star, in reality, those objects are moving around a common mass centre. The motion of the star causes us on Earth to see seasonal changes of spectral lines in the star's spectre, all because of the Doppler effect. About 30% of all exoplanets were discovered using this method.

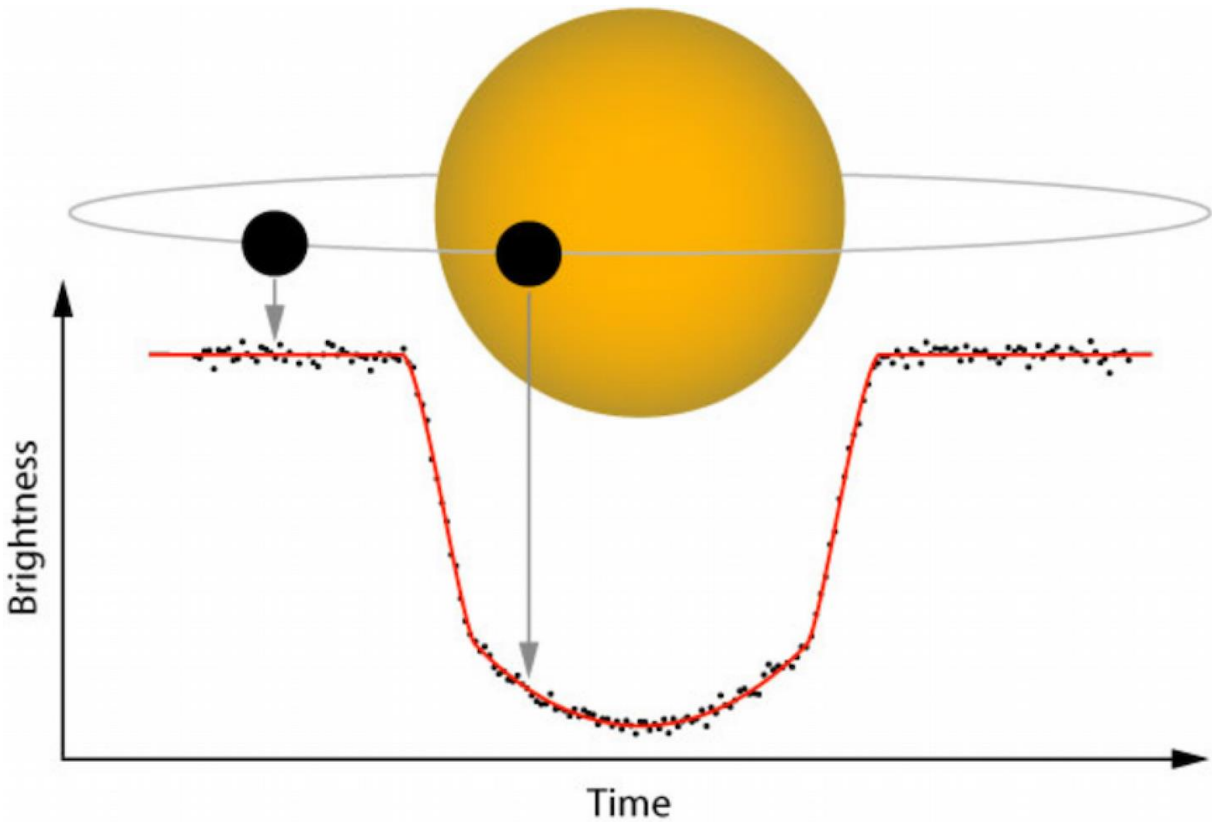
*When a star moves away from the observer, the length of wave observed by the observer decreases (red line), and when a star moves closer, the observer observes the increase of this wavelength (blue line). Source: NASA.*




- *Transit method*

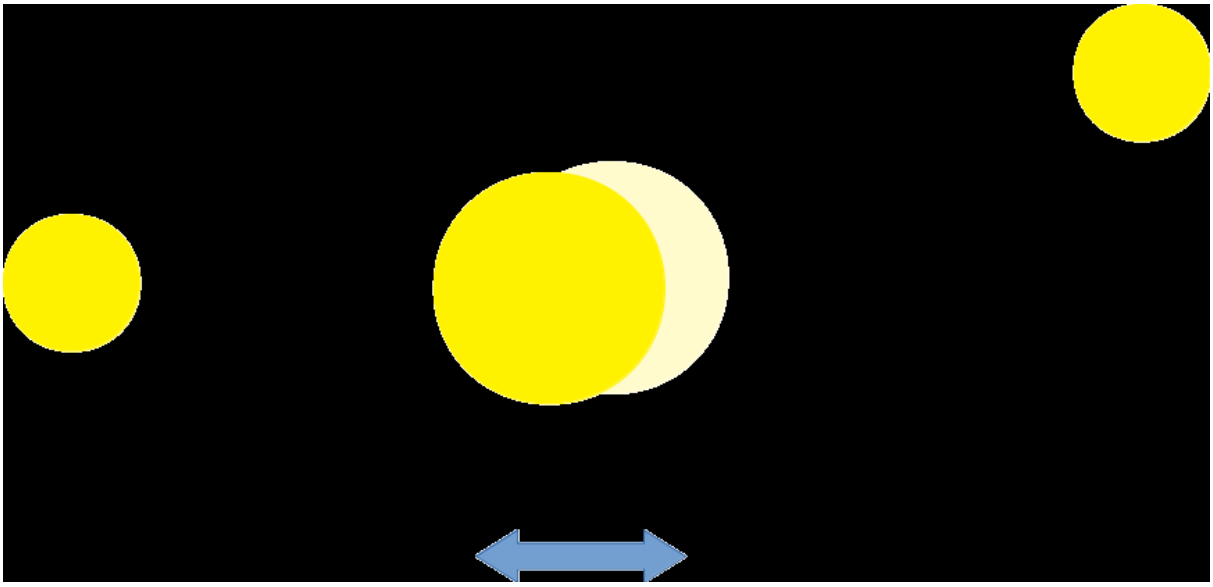
When a planet crosses the face of its star, it causes a temporary and slight weakening of the star's brightness. By analysing this weakening we can assume that it had been caused by an exoplanet moving in front of the star. However, this method has a few flaws. First of all, there are many reasons causing a temporary decrease of the brightness. Which means that detecting an exoplanet with this method requires additional confirming with another method. Second of all, a transit can be observed only for those exoplanets, whose orbits cross the line of observation of the star. For exoplanets moving close to their stars, this happens in 10% of the cases. For those that are further, it is even rarer. The transit method, however, has a few advantages over other methods. It allows us to determine the exoplanet's diameter based on the brightness change curve and permits researching the chemical composition of a planet's atmosphere because when light passes through the atmosphere, its spectre changes and based on those changes we can deduce the contains of an exoplanet's atmosphere. The majority of exoplanets have been discovered that way.

*Planet's transit across a star's face and the observed change in star's brightness caused by the transit. Source: NASA.*




- *Astrometry method*

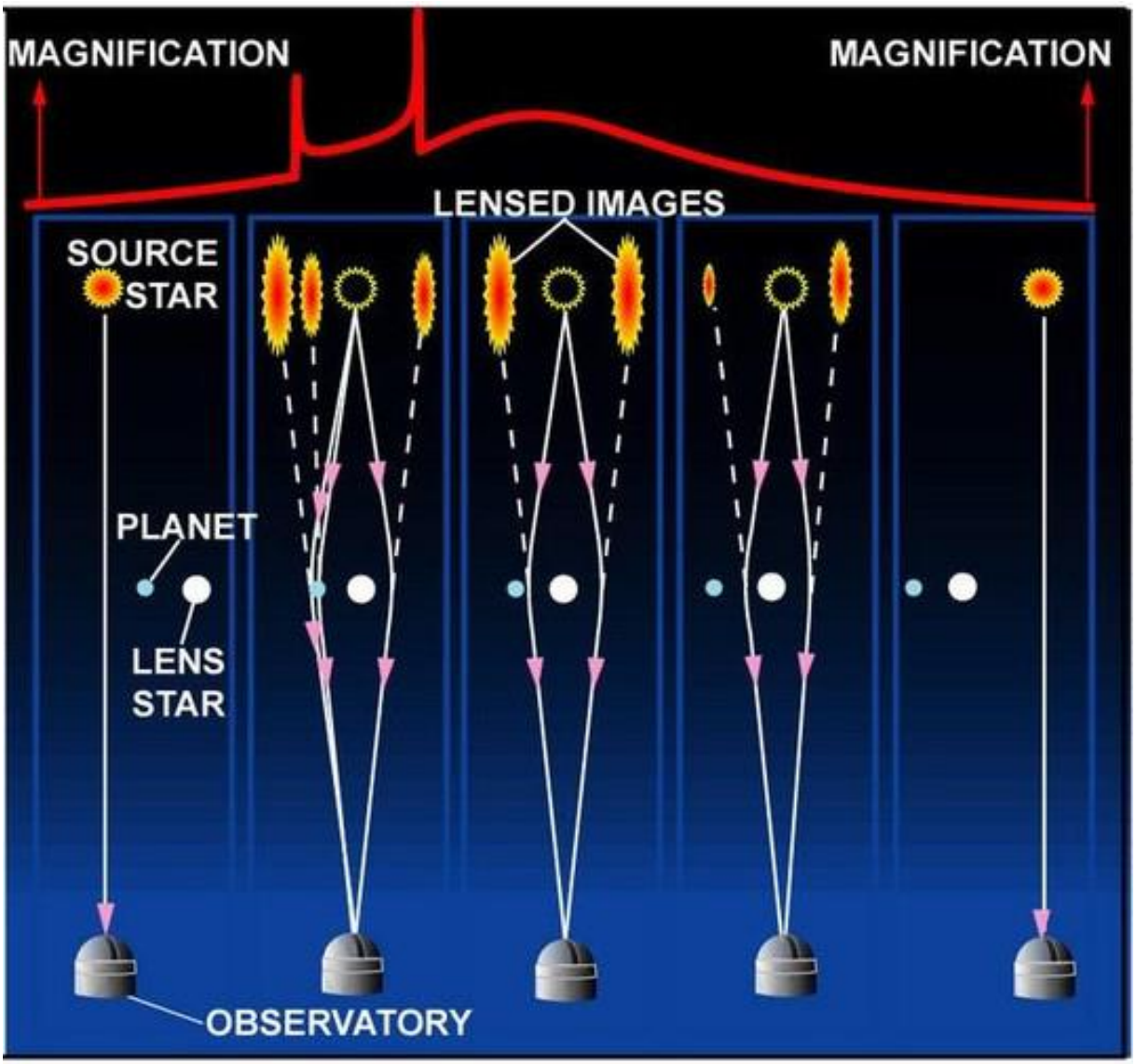
It uses very precise measurements of a star's position in order to see if it changes. If a star has got planet (or planets) orbiting it, its position will change. However, those changes are so tiny that none of the telescopes stationed on Earth can detect them. The effectiveness of this method was proved in 2002 by the Hubble Space Telescope, thanks to which we have discovered the movement of the Gliese 876 star caused by the existence of planets orbiting it.



*The movement of a star in relation to other stars can indicate that it has got a planet (or planets) orbiting it. Source: private gallery.*

- *Gravity microlensing method*

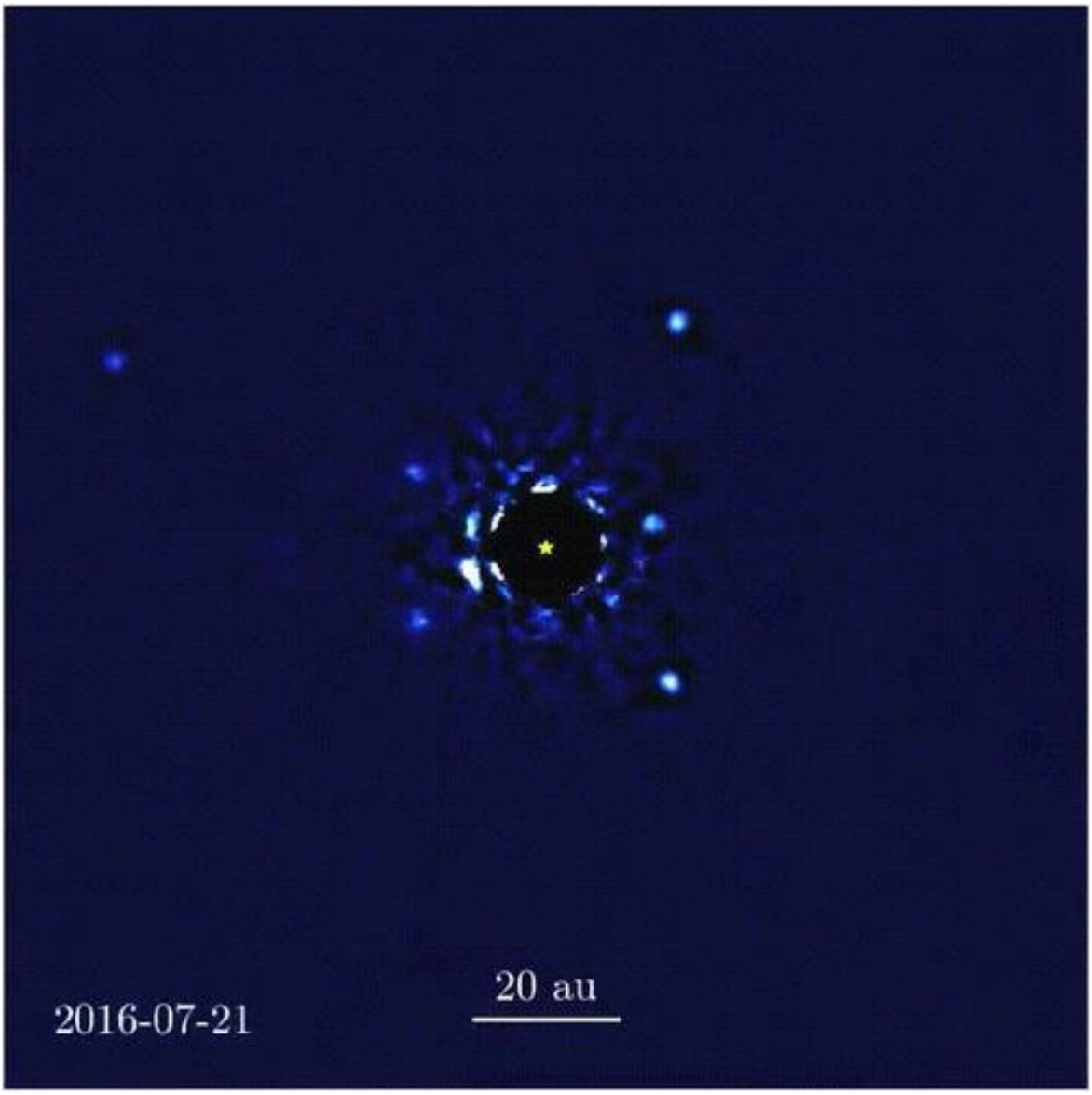
It uses the bending of rays of light by a star (called the lensing one) in case when a star being the source of light and the lensing star align almost perfectly. This situation results in the increase of the source's brightness. If the lensing star is orbited by a planet, then it causes an even greater increase in a star's brightness. This method allows us to detect Earth-sized planets. So far we have managed to discover a few exoplanets using this method.




*An illustration explaining the principle used by the gravity microlensing method. Source: [http://www.planetary.org/explore/space-topics/exoplanets/microlensing.html](http://www.planetary.org/explore/space-topics/exoplanets/microlensing.html)*

- *Direct detection and imaging method*

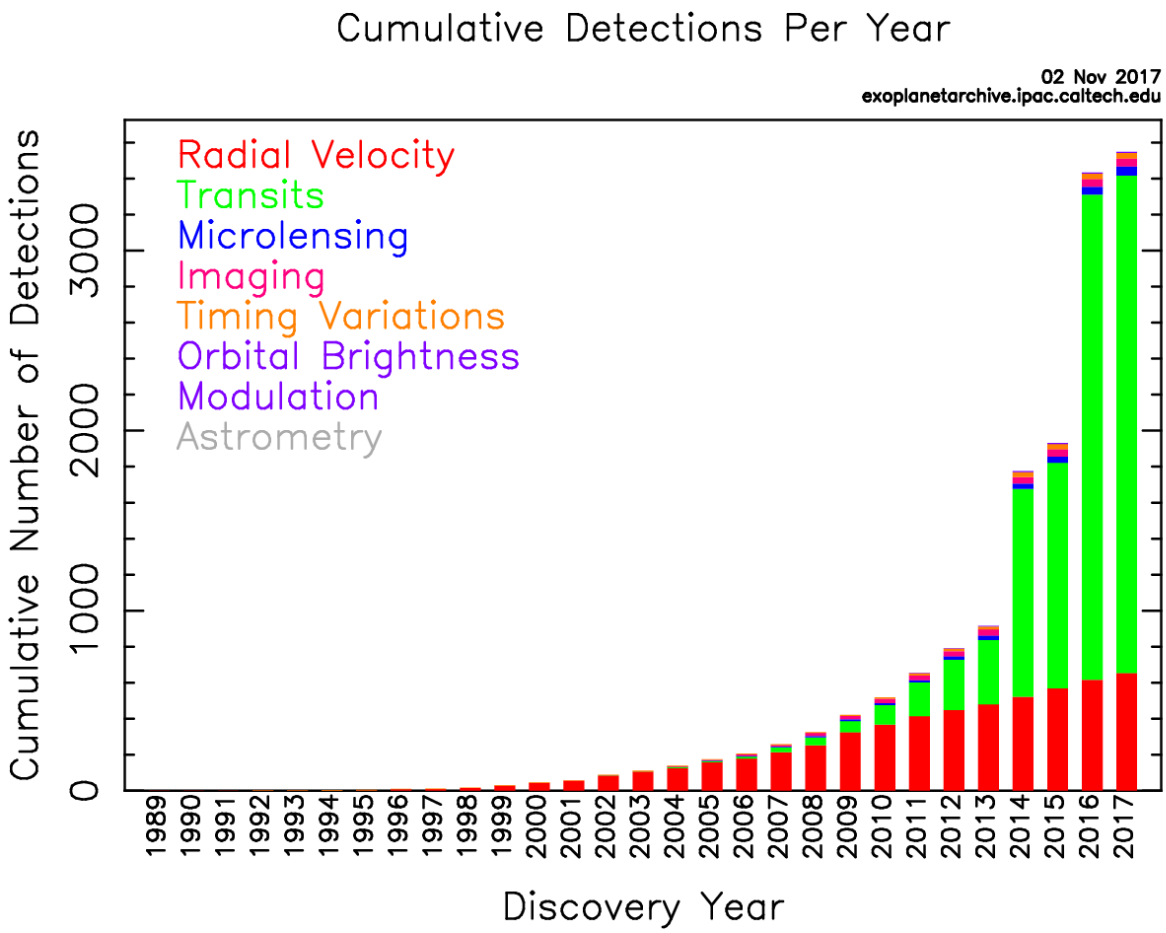
It is focused on directly taking photographs of exoplanets. It is possible when a planet moves around a star in a significant distance. It should also be a massive and hot object and the star should be relatively close to Earth. A few exoplanets have been discovered via this method.




*HR 87799 star with its planets. Source: Keck's observatory.*

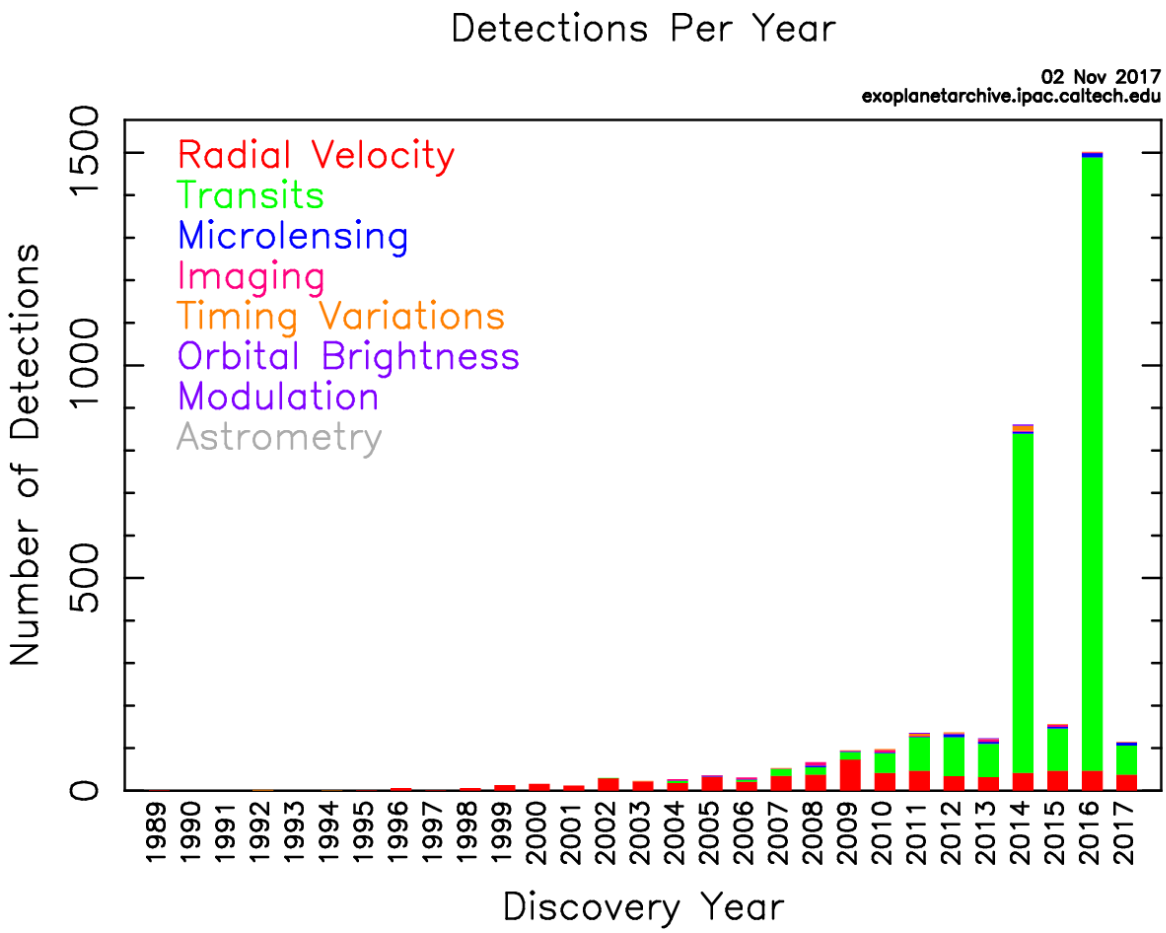
Currently, we know over 3500 exoplanets. A cumulated graph with segregation by the discovery method is presented below.

Source: https://exoplanetarchive.ipac.caltech.edu/exoplanetplots/




The picture below presents the amount of discovered exoplanets as a function of the year of their discovery (segregated by the detection method).

Source: https://exoplanetarchive.ipac.caltech.edu/exoplanetplots/




*Literature:*

*1. Katalog egzoplanet http://exoplanets.org/table*

*2. Planety w ekosferze http://phl.upr.edu/projects/habitable-exoplanets-catalog*

*3. Lammer et al., 2009. What makes a planet habitable? Astron Astrophys Rev (2009) 17:181–249*

*4. Animacje wyjaśniające działanie róznych metod poszukiwania planet pozasłonecznych:*

*5 ways to find a planet https://exoplanets.nasa.gov/interactable/11/*

*5. How to find an extrasolar planet*

*http://www.esa.int/Our_Activities/Space_Science/How_to_find_an_extrasolar_planet*

*6. How to search for exoplanets*

*http://www.planetary.org/explore/space-topics/exoplanets/how-to-search-forexoplanets. Html*

*7. Strony pozwalające na wizualizacje różnych statystyk dotyczących egzoplanet*

*http://www.exoplanet.eu/*

*https://exoplanetarchive.ipac.caltech.edu/exoplanetplots/*

*8. Animacja pokazująca jak działa metoda tranzytów*

https://www.youtube.com/watch?time_continue=2&v=xNeRqbw18Jk

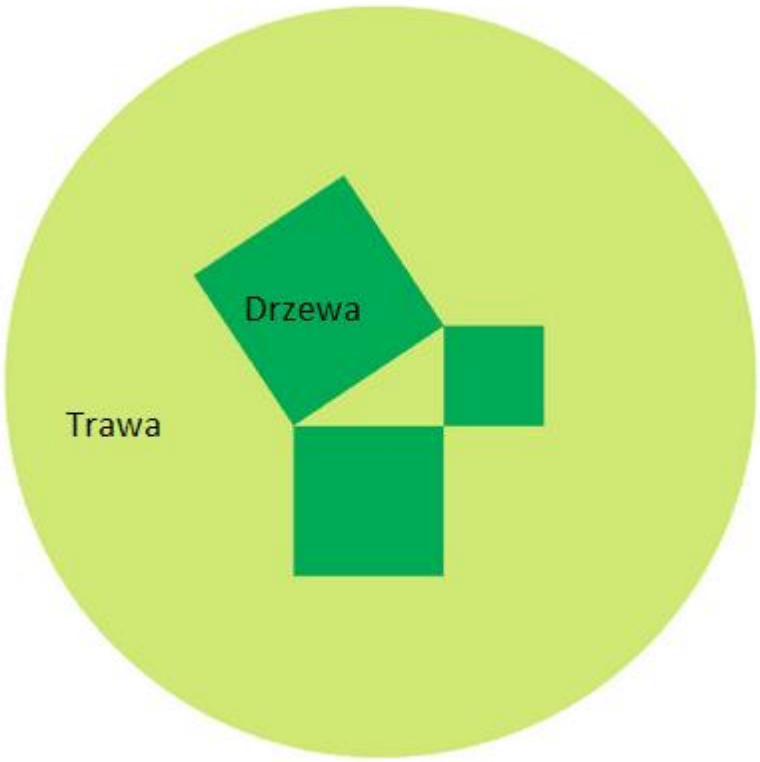
*9. Urodzaj światów - egzoplanety*

https://mlodytechnik.pl/technika/28843-urodzaj-swiatow-egzoplanety

**"This is Earth speaking" – sending information about Earth into space**

*The part titled "Search for life in the Universe", located at the end of this document, supplements this part. This part can support the parts concerning exoplanets and the search for life in the Solar System.*

*First attempts.* In order to communicate with the inhabitants of Moon and Mars, Gauss suggested creating a large triangle with squares attached, symbolizing the Pythagoras' theorem, all made of plants and located in Siberia. The Moon (or Mars) inhabitants would then find out that Earth is inhabited by intelligent creatures that know mathematics.




Trawa -> Grass

Drzewa -> Trees

Gauss also suggested, as a way of communicating with the Moon, to send them solar reflections.

Charles Cross turned to the French government to fund the construction of massive mirrors to respond to the previous signals allegedly sent from Mars.

*Present times:*

*The Arecibo message.* It is a radio message meant for potential alien civilizations, emitted into space on November 16th, 1974 using the Earth's largest radio-telescope in Arecibo.

It was sent towards the M13 globular cluster in the Hercules constellation (Hercules Cluster, NGC 6205) located at the distance of 25 000 light years from the Solar System. The message's length was 1679

bits. It was emitted at the frequency of 2380 MHz (wavelength of 12,6 cm). It was broadcasted for 3 minutes. In about 25 000 years it will reach this cluster consisting of a few hundred thousand stars. If there is an intelligent civilization on a planet orbiting one of those stars, and if it deciphers the information correctly, it should receive something like this:

The message contained information, encrypted in the binary code, about the DNA structure, the looks of a human, the amount of people on Earth, the location of Earth in the Solar System and about the Arecibo radio-telescope itself. It is not easy to figure out what the picture above presents. We have to assume that potential recipients will not only be able to receive and decipher the message, but also come up with an idea what it could mean. It doesn't have to be easy, especially if such civilization is completely different from ours, uses different technology, etc. The deciphering of this message doesn't have to be easy. The 1679 bits making up the Arecibo message were sent consecutively:

0000001010101000000000000101000001010000000100100010001000100010110010101

0101010101010010010000000000000000000000000000000000000000011000000000000000

0000110100000000000000000000110100000000000000000000101010000000000000000000

1111100000000000000000000000000000000011000011100011000011000100000000000

0011001000011010001100011000011010111110111110111110111110000000000000000

0000000000010000000000000000010000000000000000000000000000000100000000000000

0000111111000000000000001111100000000000000000000000000110000110000111000110

0010000000100000000010000011010000110001110011010111110111110111110111110

0000000000000000000000000100000011000000000100000000000011000000000000000

1000001100000000000111111000001100000011111000000000001100000000000000010000

0000100000000100000100000011000000010000000110000110000001000000000001100

0100001100000000000000001100110000000000000110001000001100000000001100001 10

0000010000000100000001000000000100000100000000110000000001000100000000110000

0000100010000000001000000010000010000000100000001000000010000000000000110

0000000011000000001100000000001000111010110000000000010000000100000000000

0001000001111100000000000001000010111010010110110000001001110010011111110

1110000111000001101110000000000101000001110110010000001010000011111100100

0000101000001100000010000011011000000000000000000000000000000000000111000

0010000000000000011101010001010101010100111000000000101010100000000000000

0001010000000000000011111000000000000000001111111110000000000001110000000

1110000000001100000000000011000000011010000000000101100000110011000000110

0110000100010100000101000100000100010010001001000100000000100010100010000

0000000010000100001000000000000100000000010000000000000000100101000000000

0111100111110100111100 0.

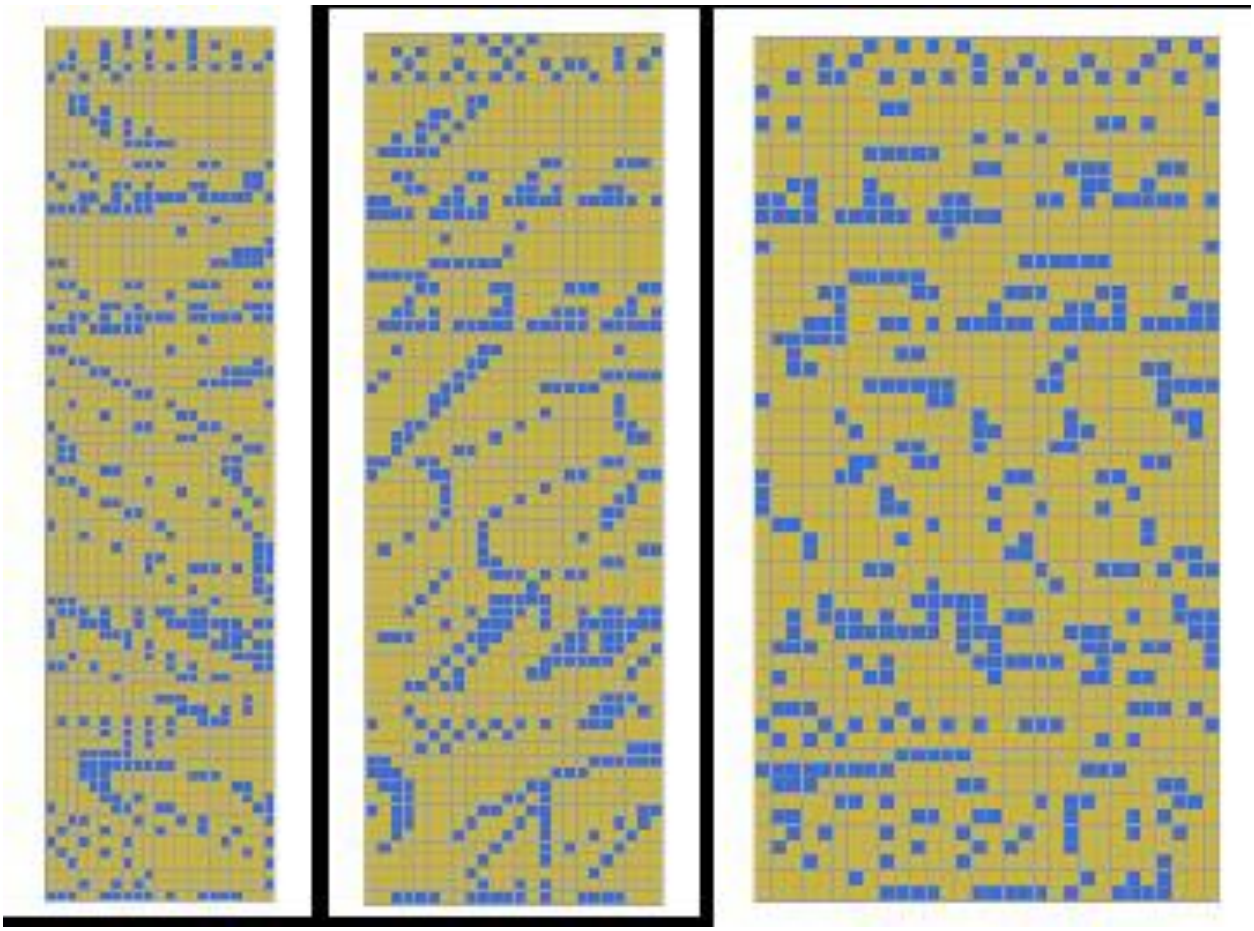
Where for symbols 0 and 1 there are corresponding signals sent at different frequencies. The correctly deciphered Arecibo message (23 columns and 73 rows) looks like this:

000000101010100000000000
00101000001010000000100
10001000100010010110010
10101010101010100100100
00000000000000000000000
00000000000110000000000
00000000001101000000000
00000000001101000000000
00000000010101000000000
00000000011111000000000
00000000000000000000000
11000011110001100001000
10000000000000110010000
11010001100011000011010
11111011111011111011111
00000000000000000000000
00010000000000000000010
00000000000000000000000
00001000000000000000001
11111000000000000011111
00000000000000000000000
11000011000011110001100 0
10000000100000000010000
11010000110001110011010
11111011111011111011111
00000000000000000000000

000100000011000000000010
000000000011000000000000
000010000011000000000001
111110000011000000011111
000000000011000000000000
001000000001000000000100
000100000011000000001000
000011000011000000010000
000000110001000011000000
000000000011001100000000
000000110001000011000000
000011000011000000010000
000100000010000000001000
001000000011000000000100
010000000011000000000100
010000000001000000001000
001000000010000000010000
000100000000000011000000
000011000000000110000000
001000111010110000000000
001000000010000000000000
001000001111100000000000
001000010111010010110110
000000100111001001111111
101110000111000001101111
000000000101000001110111
001000000101000001111111
001000000101000001110000
001000001101100000000000
000000000000000000000000
001110000001000000000000
001110101000101010101001
001110000000001010101000
000000000000001010000000
000000001111100000000000
000000111111111100000000
000011100000000111000000
000110000000000011000000
001101000000000101100000
011001100000000110011000
010001010000010100001000
010001001000100010001000
000001000101000010000000
000001000010000010000000

00000**1**0000000000**1**0000000
0000000**1**00**1**0**1**0000000000
0**1111**00**11111**0**1**00**1111**000

If an alien civilization would have set those bits not in 23 columns but in 22, 24 or 30, it would come up with the following patterns[4]:

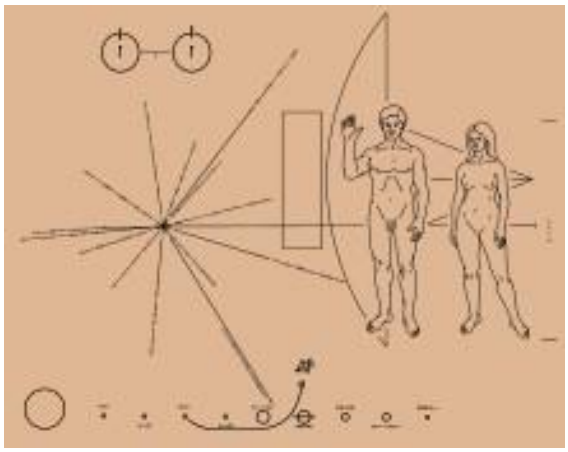


Of course said civilization could wonder what those images present but they wouldn't get truthful information about humanity and the Solar System. How are they then supposed to know that the message should be formed into 23 columns and 73 rows? The hint lays in the choice of the message length – 1679 bits. This is a complex number and at the same time a product of 2 prime numbers: 23 and 73. This suggest that the bit sequence should form a rectangular picture (an array). Of course the aliens could form it as a picture the size of 73 columns and 23 rows. But by choosing the sequence length as a product of 2 prime numbers there are only 2 options. If the sequence had the length of e.g. 1000 bits, the amount of ways to factorize it into 2 numbers (representing the number of columns and rows) would be higher, e.g. 1000=10*100=20*50=25*40 etc.

Here we can suggest students to code and decipher something for themselves. Of course, their sequence should be shorter.

[4] Those pictures were created using the Mathematica software with the use of code available on the website http://demonstrations.wolfram.com/DecodingTheAreciboMessage/

*The Pioneer plaques* are two metal plaques placed on space probes Pioneer 10 and Pioneer 11 (source: http://www.wikiwand.com/pl/P%C5%82ytka_Pioneera).



*Voyager Golden Records* are golden plated discs placed on two probes launched by NASA in 1977 as part of the Voyager programme. They contain music and information concerning the life on Earth (including greetings in 56 languages).

ADDITIONAL MATERIALS

**Water on Mars**

*Completing and expanding on "the search for life in the Solar System" part.*

Water is a crucial element for the development of life, however, just the presence of liquid water cannot guarantee that life will form. According to our current state of knowledge about Mars, in the past there were oceans, lakes and rivers on the surface of Mars. Moreover, it had a much denser atmosphere. Currently, due to low surface temperature and low pressure, there are no conditions for the existence of liquid water, however, recent studies show that it can appear temporarily and form the surface of Mars. However, this is water containing melted chlorine compounds, which decrease its freezing temperature[5]. Most of the water on the Red Planet is held as ice caps on the poles, hydrated minerals, or, also far from the poles, underneath the surface (cryosphere). The cryosphere is most likely located from a few hundred meters to a few kilometres below Mars' surface. Deeper, due to higher temperatures, we can expect a hydrosphere – a zone below Mars' surface, in which, due to a higher temperature, might be liquid water.

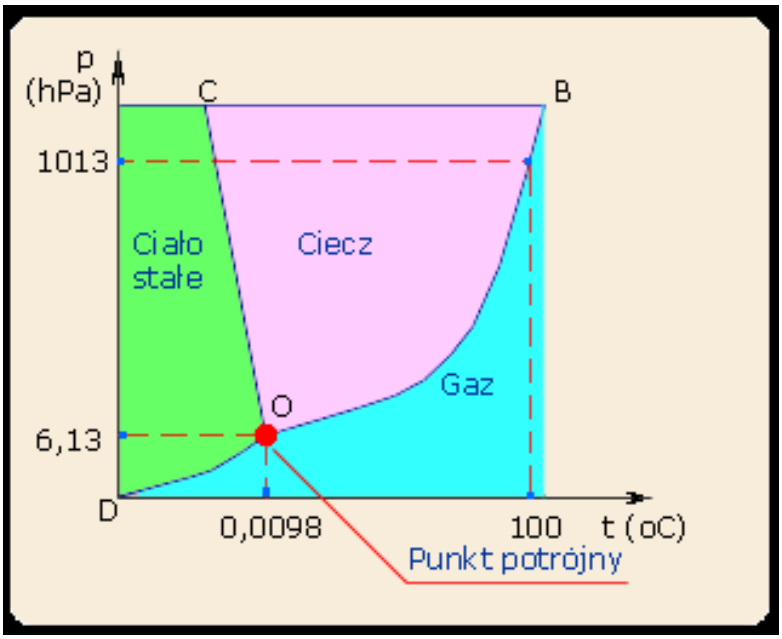
While discussing this point it is worth thinking why there is no liquid water on Mars. Let the graph of equilibrium be the key to solving this case (source: http://chemia.wpt.kpswjg.pl/semestr1/temat16/temat16.html).

*Literature:*

[5] Mars Reconnaissance Orbiter (MRO) probe has collected evidence that there is liquid water on Mars, but those are salt springs with decreased freezing temperatures (even -70℃). Numeric simulations also indicate the possibility of liquid water existing in some regions of Mars (*http://www.urania.edu.pl/wiadomosci/wedlugmodeli-numerycznych-na-marsie-moze-istniec-woda-stanie-cieklym-1838.html*).

*1. Dane dotyczące temperatury i ciśnienia na Marsie*

*https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html*




*https://hypertextbook.com/facts/2000/LaurenMikulski.shtml*

*ciało stałe -> solid*

*ciecz -> liquid*

*gaz -> gas*

*punkt potrójny -> triple point*

**Methane on Mars**

*Completing and expanding on "the search for life in the Solar System" part.*

In the years 2003 and 2004 a few research groups, using observations from Earth and Mars Express probes, declared discovering methane in Mars' atmosphere. Since then, many questions, concerning unsolved phenomena connected to $CH_4$ in the planet's atmosphere, have arisen:

- Quick (seasonal) change of the amount of $CH_4$ opposing the long (a few hundred years) photochemical time of life of this molecule in atmosphere,
- The nature of sources of $CH_4$ causing fast changes of the amount of this molecule in the atmosphere,
- The nature of sources of destruction of $CH_4$ molecules reducing its amount to a very low level in a very short time.

The problems shown above might indicate that the methane on Mars comes from certain sources and is also destroyed in such. A possible mechanism of its destruction might be highly reactive surface of Mars. What is more, the sources of its creation might have a geological, geochemical or biological nature. On Earth, there are certain methanic bacteria capable of reducing $CO_2$ to $CH_4$. At this point, it might be worth asking students to find information about sources of methane on Earth.

*Literature:*

*1. http://exploration.esa.int/mars/46038-methane-on-mars/*

*2. S. Atreya. The Mystery of Methane on Mars and Titan. Scientific American 296, 42 - 51*

*(2007)*

*http://www.atmos.umd.edu/~rjs/class/spr2013/supplemental_readings/sci_am_ch4_may_2007.pdf*

*3. Bartosz Gawęda, Paweł Wajer, Zbigniew Wilczyński, Natalia Zalewska. Metan na*

*Marsie – nadzieje na znalezienie życia? Fizyka w Szkole 1 (28.02.2017).*

*4. Źródła metanu ziemskiego*

*http://naukaoklimacie.pl/aktualnosci/nieoczywisty-metan-205*

**The search for life in the Universe**

One of the methods (another one being looking for biosignatures) of searching for life in space is radio monitoring in order to detect possible signals sent willingly or unwillingly by alien civilizations. This monitoring was first originated by Frank Drake in the 1960s as part of the project called Ozma (to commemorate a princess from a children's book "Ozma of Oz"). For the purposes of radio monitoring Drake used a radio-telescope with a diameter of 26 meters, which was pointed towards the Tau Ceti star located 12 light years away from Earth. The star is similar to Sun and Drake assumed it might have a planetary system similar to ours. The radio-telescope was supposed to look for electromagnetic signals at the wavelength of 21 cm (1420 MHz) which are responsible for the emission of hydrogen gas. Drake believed that such a wavelength is the most suitable for space communication. A few hours of monitoring the Tau Ceti star yielded no results.

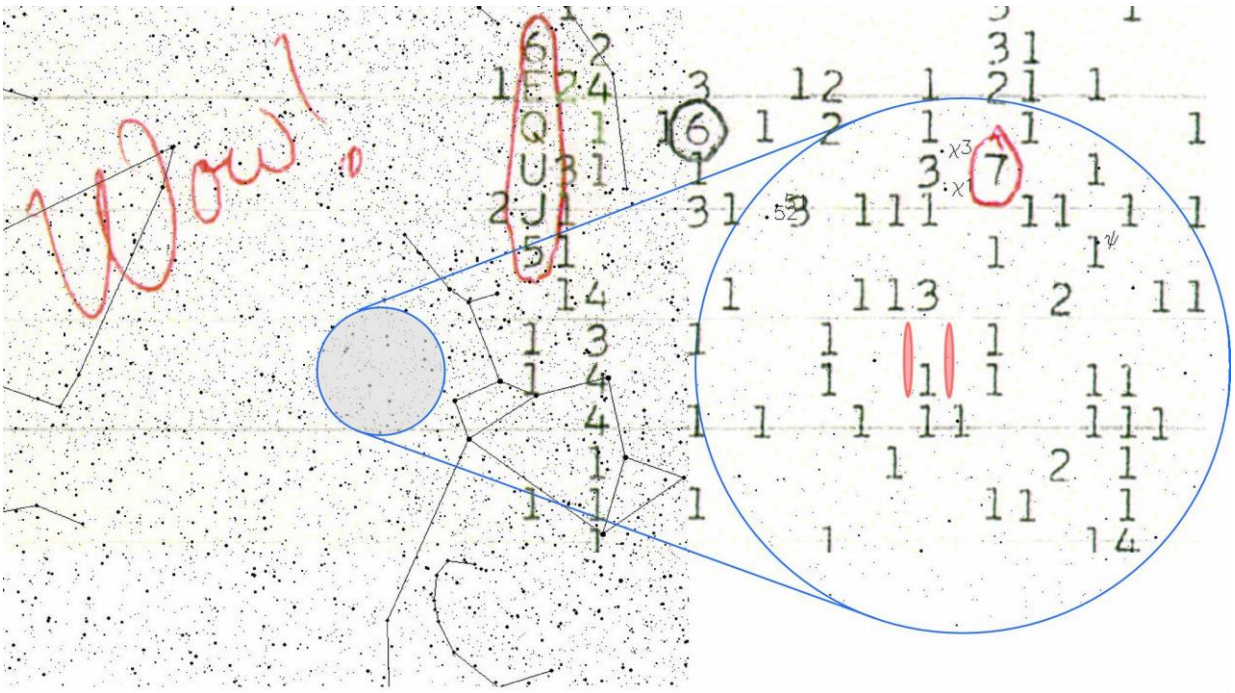
The second target picked by Drake was Epsilon Eridani star, located 10,5 light years away from Sun. This time a strong pulsating signal was detected, which might have seemed to be broadcasted by an alien civilization. However, it turned out that they have unknowingly detected a secret military experiment.

The Ozma project began a long lasting and systematic monitoring of space in order to detect signals from alien civilizations as part of the SETI (Search for Extraterrestrial Intelligence) programme. Data from around a dozen huge radio-telescopes was gathered and then processed as part of this programme. Any computer owner could have become engaged in the data processing. All you would have to do was to install a specific computer program to analyse the data gathered by radio-telescopes. In spite of decades of research, to this date no signal, indicating it had been sent by alien life forms, has been received. However, in the year 1977 we received a signal giving us hope for communicating with aliens. In 2017 it turned out that the source of the signal had been a cloud of hydrogen accompanying the 266/P Christensen comet, which was still undiscovered in 1977.

We can ask ourselves why we haven't received any signals from other civilizations despite trying for so many years. One of the reasons might be the fact that they either do not exist or do not exist close enough to the Solar System for their signals to reach us. Maybe extra-terrestrial civilizations do exist, but they try to communicate in a way that the humanity simply doesn't know.

*The WOW signal represented as "6EQUJ5" sequence. Source: Big Ear Radio Observatory and North American AstroPhysical Observatory (NAAPO).*

*Literature:*


1. [http://orion.pta.edu.pl/projekt-ozma-poczatki-seti](http://orion.pta.edu.pl/projekt-ozma-poczatki-seti)

2. [https://www.polityka.pl/tygodnikpolityka/nauka/1504198,1,co-astronomowie-mowia-oseti.read](https://www.polityka.pl/tygodnikpolityka/nauka/1504198,1,co-astronomowie-mowia-oseti.read)