Elements of Astrobiology

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Abstract

This workshop is essentially divided into two parts. The necessary chemical elements for life, a simple study of the periodic table corresponding to the objectives of this work and some concepts of astrobiology are introduced.

Goals

- Understand where from or how the different elements of the periodic table arise
- Understand the main characteristics of extra-solar planetary systems.
- Understand the habitability conditions necessary for the development of life
- Study the minimum guidelines of life outside the Earth.

Formation of planetary systems

When a star forms from a gas and dust cloud the remains of the cloud around the star go on to form the planets. In the same way that we can know the composition of the star by studying its spectrum, spectroscopy is used to determine the atmosphere of the exoplanets.

Each chemical element and each molecule have a specific and unique spectrum. In some systems a planet will pass in front of its star. The light of the star will pass through the atmosphere of the planet and absorption will occur. By observing the light spectra of the stars of exoplanetary systems the chemical composition of the atmospheres of the planets can be discovered (figures 1 and 2).

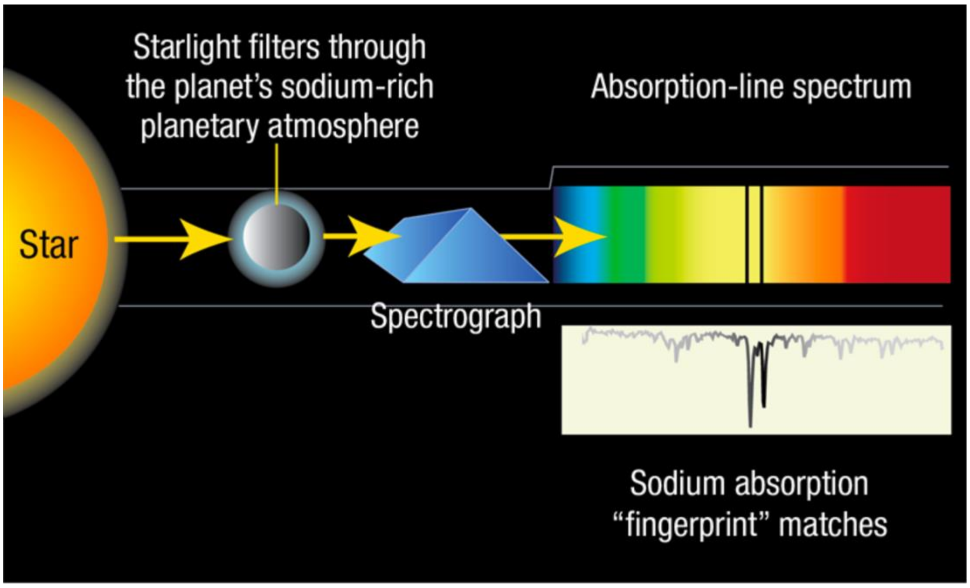

Fig. 1: Spectroscopy applied to the study of the atmosphere of the planet HD 209458b, with the detection of sodium in its atmosphere. Source Wikipedia / A. Feild (STSci)

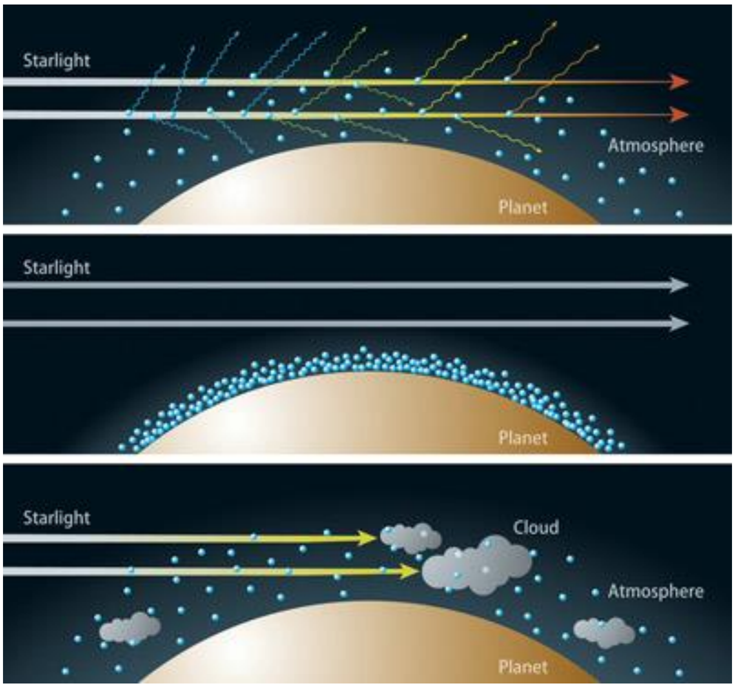

Fig 2: How do we know if there is water or even organic molecules in the atmosphere of a planet? Each chemical element, each molecule, has a specific and unique spectrum. Comparing the light spectra of the stars of exoplanetary systems we can discovered the chemical composition of one exoplanet atmosphere, if the light passes eventually through the respective atmosphere

But let's look at an example of planetary system formation using a method of participants involvement in an active model.

Activity 1: Formation of a Planetary System from gas and dust

The theme of this activity is to explain the formation of the Solar System or any planetary system according to Immanuel Kant's Nebular Hypothesis (1755).

The action consists of dividing the class into two groups that are easy to identify by the naked eye, for example: the girls' group and the boys' group. (Other criteria can be taken, but this is usually the simplest.) Each group has a role, the girls can represent the gas and the boys the dust (or vice versa). If there is a substantial difference in the number of participants from one group and the other, it is recommended that the group representing the gas to be the one that contains the greatest number of participants, since in a planetary system during formation the mass of the gas is 100 times the mass of dust.

As participants listen to the story, they react dynamically to what they hear, for example:

Story Text:	**Participants performance:**
There was once a cloud of a lot of gas and a little less dust.	All are mixed in a cloud. There are more participants representing gas. In the cloud, all participants hold hands randomly, forming as a network.
Then the gas began to gather in the centre of the cloud and around there is the dust.	They begin to separate. Participants representing the gas gather (accumulate) in the centre and those representing the dust hold hands in a ring around the centre.
There was a lot of movement, gas particles attracted gas and dust particles attracted dust.	They begin to rotate, move, hit (crash), vibrate, jump. Some shoot out as a result of so much movement and others "rescue", catch, hug those particles by identifying (gas with gas and dust with dust)
In the centre a dense opaque core has formed, surrounded by a disk of dust and gas.	Those in the centre (gas) accumulate and around them the participants representing the dust form an approximate circle taking each other's hands. Clarification: not all gas is in the centre, there is remote gas outside the circle.
This nucleus is the part that would finally give rise to the Sun or the host star of an extrasolar system.	The Sun or the host star begins to shine so that its rays must be shot towards all directions. Clarification: The moment the Sun or the host star begins to shine the "loose" gas begins to move away.
Some small planets are formed by the union of larger and larger dust grains, then rocks and so on.	The participants representing the dust that forms the terrestrial planets begin to group together. Clarification: not all dust stays with the terrestrial planets, there must be some dust in the farthest regions.
The giant planets formed away from the heat of the Sun or the host star where the gas could gather without hindrance.	The rest of participants begin to come together to form the giant planets:: a lot of gas and some dust. Clarification: The decrease in temperature due to the greater distance from the Sun or the host star is the cause of the main differences between the internal rocky planets and the external gas giants.

Table 1: The story to explain the formation of a planetary system.

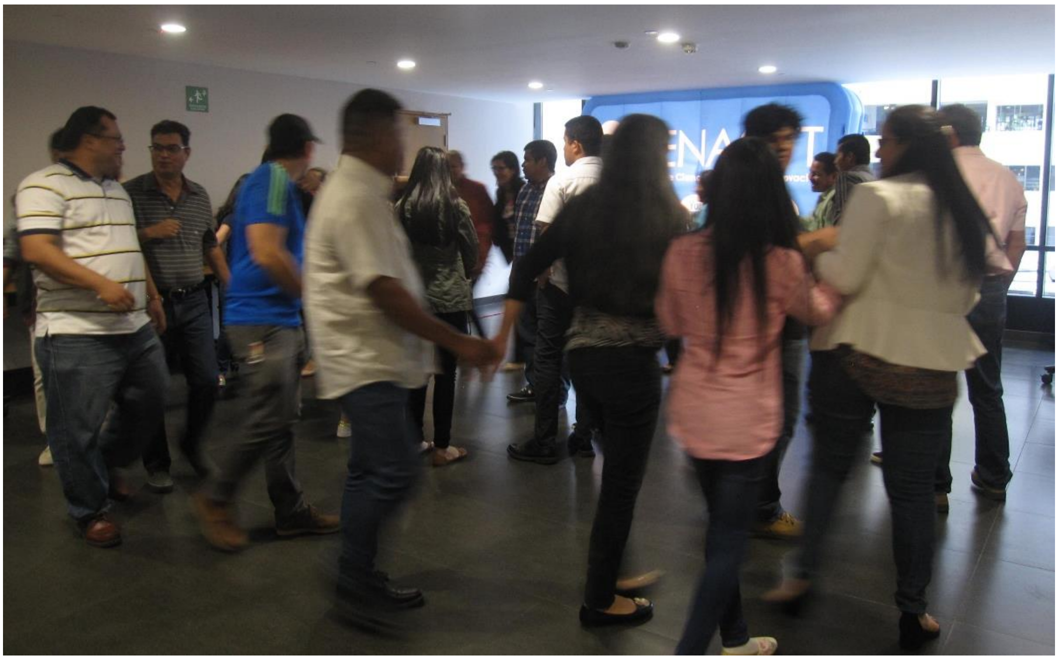

Fig. 3: All are mixed in a cloud. There are more participants representing the gas. In the cloud, all participants hold hands randomly, like in a network or forming a network.

Fig. 4: The participants begin to separate. Who represented the gas gather in the centre and those who represent the dust hold hands around the outhers.

Fig. 5: Participants representing the dust that forms the terrestrial planets begin to group.

Fig. 6: The rest of participants begin to gather to form the giant planets: a lot of gas and some dust.

Chemical aspects of stellar evolution

This periodic table allows us to realise that the elements we are made of have been created in the evolution of the stars.

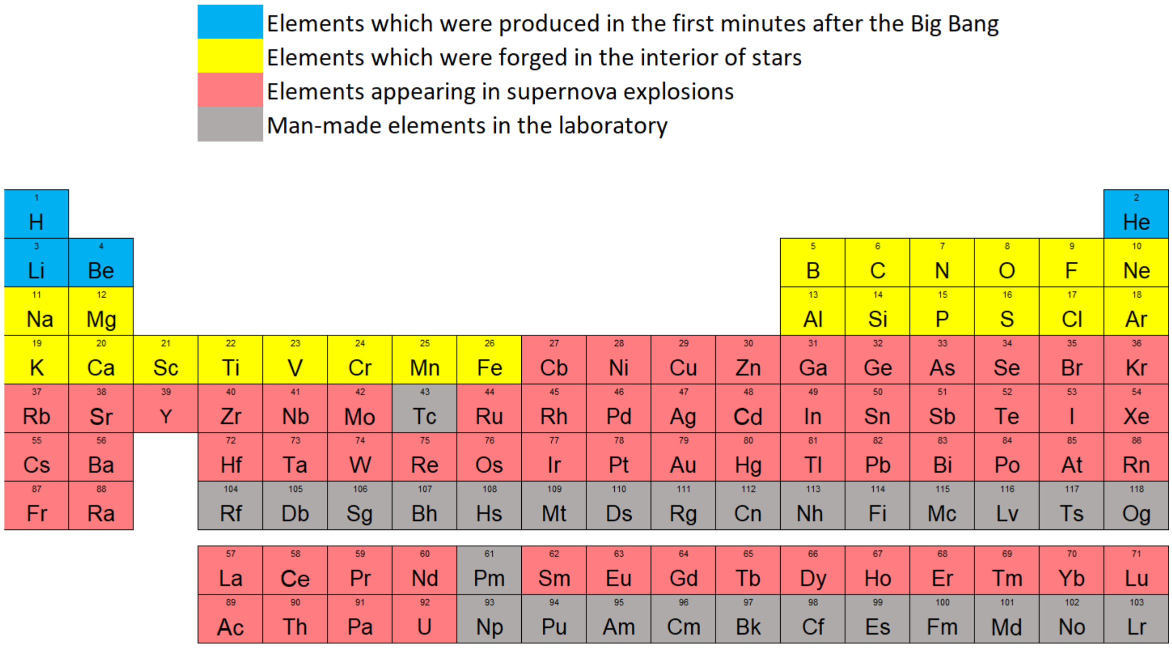

Fig. 7: The periodic table from the point of view of stellar evolution

In the Periodic Table (figure 7) the different elements are classified as follows:

1) Elements created in the first minutes after the Big Bang. Initially the Universe was essentially composed of the simplest atom: the hydrogen atom. A short time later this gave rise to slightly more elaborate elements such as Helium, Lithium and Beryllium.
2) The elements that are formed in the cores of the stars by nucleosynthesis are already somewhat heavier such as Boron, Carbon, Nitrogen, Oxygen, Fluorine, Neon, Sodium, Magnesium, Aluminium, Silicon, Phosphorus, Sulfur, Chlorine, Argon, Potassium, Calcium, Scandium, Titanium, Vanadium, Chromium, Manganese and Iron.
3) The heaviest elements formed in large supernova explosions make up the rest of the table. Some of them are unstable but can be produced in laboratories.
4) Synthetic elements produced by man in a laboratory and not found in nature.

Activity 2: Classification of the Elements of the periodic table

Below is a list of objects that will have to be classified according to the three levels in three baskets:

1. Elements produced in the first minutes after the Big Bang (Blue basket)

2. Elements formed within the stars (Yellow basket)
3. Elements that appear in supernova explosions (Red basket)

It is necessary to place in one of the three baskets (blue, yellow and pink) each object of the following list, according to its constitution:

Ring: Gold Au	Drill bit coated with: Titanium Ti	Gas inside a child's balloon: Helium He	Pan cleaner: Nickel Ni
Mobile / button battery: Lithium Li	Car spark plugs: Platinum Pt	Electric copper wire: Copper Cu	Iodine Solution: Iodine, I
H_2O water bottle: Hydrogen H	Old Cooking Pan: Aluminium Al	Black pencil lead: Graphite C	Sulfur in agriculture: Sulfur, S
Can of Fizzy Drink: Aluminium Al	Wristwatch: Titanium Ti	Medal: Silver Ag	Old water pipes: Lead Pb
Pencil Sharpener: Zinc Zn	Rusty old nail: Iron Fe	Thermometer: Gallium Ga	Matchbox: Phosphorus P

Table 2: Objects to classify.

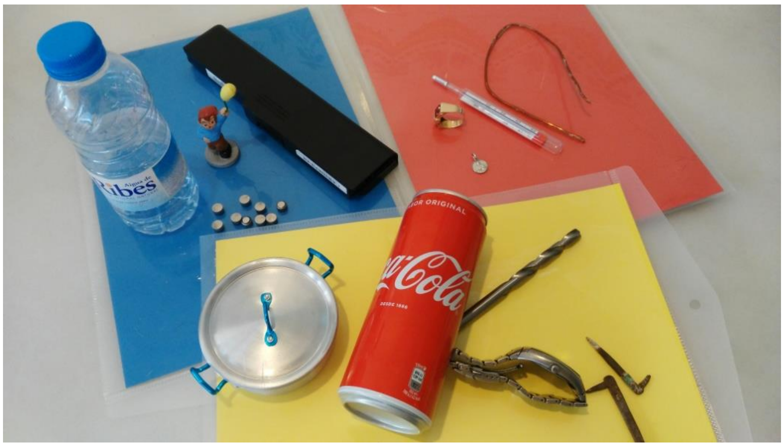

Fig. 8: Correct classification. In the blue zone: cell phone or button battery: Lithium, Water bottle H_2O: Hydrogen, Gas inside a child's balloon: Helium. In the yellow zone: Can of fizzy can of sparking drink: Aluminium Al, Water bottle H_2O: Oxygen O. Drill bit coated with: Titanium Ti, Old cooking pan: Aluminium Al, Titanium wristwatch Ti, Rusty old nail: Iron Fe, Black pencil lead: Graphite C, Sulphur in agriculture: Sulphur, S, Matchbox: Phosphorus, P. In the red zone: Electric copper wire: Copper Cu, Spark plugs: Platinum Pt, Ring: Gold Au, Medal: Silver Ag, Thermometer: Gallium Ga, Pencil Sharpener: Zinc Zn, Pan cleaner: Nickel Ni, Iodine Solution: Iodine, I, Old water pipes, Lead, Pb.

Activity 3: Children of the stars

The chemical elements that are considered essential for life have the following characteristics:

- An insufficiency of the element causes functional deficiencies (reversible when it is again in the appropriate concentrations).
- When the organism lacks this element it does not grow or complete its life cycle.
- The element directly influences the organism and is involved in its metabolic processes.

- The effect of this element cannot be replaced by any other element.

Below is the list of bio-elements present in humans ordered according to their abundance.

- Abundant elements: oxygen, carbon, hydrogen, nitrogen, calcium, phosphorus, potassium, sulphur, sodium, chlorine, iron and magnesium.
- Trace elements: fluorine, zinc, copper, silicon, vanadium, manganese, iodine, nickel, molybdenum, chromium and cobalt.

Not all living things have the same proportions of essential elements. Figure 9 highlights the essential elements as well as some that could be recognized as such: lithium, cadmium, arsenic and tin.

Comparing the periodic table of figure 7 with that of figure 9, you can see that all major elements (except hydrogen) have been produced within the stars. Without the heavier elements created by stellar evolution, we could not exist. For regarding those elements that appear only as traces, there are some that have formed within star and others in a supernovae explosions. However the majority arise from the reactions of nucleus synthesis in the cores of the stars: We

Abundant elements	Trace elements	Essential elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Fig. 9: Periodic table of elements essential for life

are children of the stars! We are made of stardust!!

Although it is not the main objective of this workshop it would be a good exercise to make a periodic table assigning an everyday object to each element and/or an experiment involving that element. This should lead to a better understanding of the periodic table by the students.

The Sun is not a first generation of star

First-generation stars are essentially hydrogen and helium from the Big Bang (and some helium that they have generated themselves). The stars that comprise heavier elements formed from an initial cloud that contained the remains of supernova explosions. The supernova explosions created the heavier elements by fusion. For example, the solar spectrum has a distinct set of spectral line of sodium which suggests that due to its small mass and state of evolution, it cannot be a first-generation star. The sodium cannot have been generated by the Sun. In addition, in the planets of the Solar System, a multitude of elements that arise after the explosion of a supernova are detected. It is a reasonable theory that the Sun formed from an initial cloud of the remains of at least two supernova explosions. Consequently, the Sun can be thought of as a third-generation star.

Let's look at a couple of examples of spectra shown below: the spectrum of a first-generation star where only the lines of the primitive elements can be seen (figure 10). The Solar Spectrum with the sodium lines already mentioned are clearly visible (figure 12).

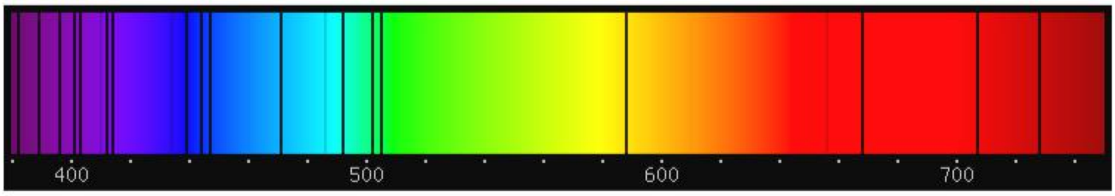

Fig. 10: First generation stars spectrum (artist impression). These stars are predominantly tens or hundreds of times more massive than the Sun. They lived fast, died young and have not survived to this day. There would only be spectral lines of hydrogen, helium and a little lithium.

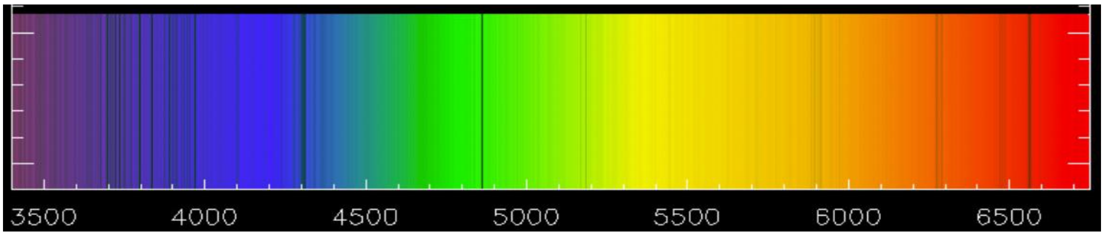

Fig. 11: Spectrum of SMSS J031300.36-670839.3, a second-generation star that only shows lines of hydrogen and carbon.

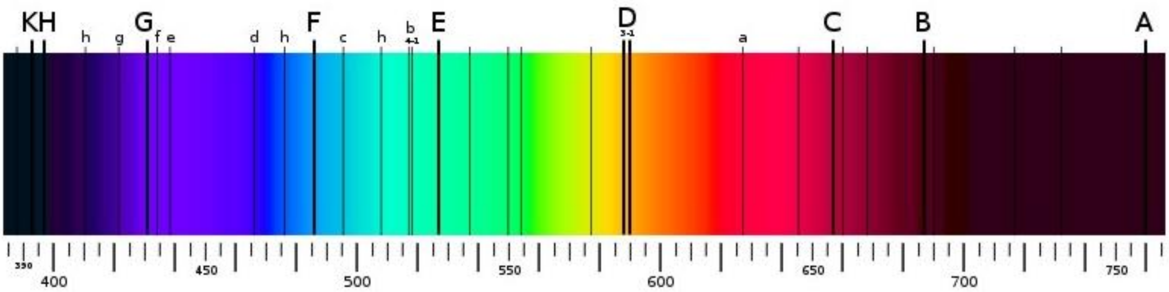

Fig. 12: Spectrum of the Sun. With many spectral lines of various elements and among them sodium (marked with bold letters).

Habitability Zone

When we talk about life, it is usually assumed that these are carbon-based life forms and thus a central criterion for habitability is defined, which is the presence of liquid water. The region around a star in which the flow of radiation on the surface of any rocky planet (or satellite) would allow the presence of water in a liquid state is called stellar habitability zone. It usually occurs on bodies (or on surface of bodies with a mass) of mass between 0.5 and 10 M_t and with an atmospheric pressure greater than 6.1 mbar, corresponding to the triple point of water at a temperature of 273.16 K (when water coexists in the form of ice, liquid and steam).

The habitability zone depends on the mass of the star. If the mass of a star increases, its temperature and brightness increase and consequently the habitability zone is increasingly distant.

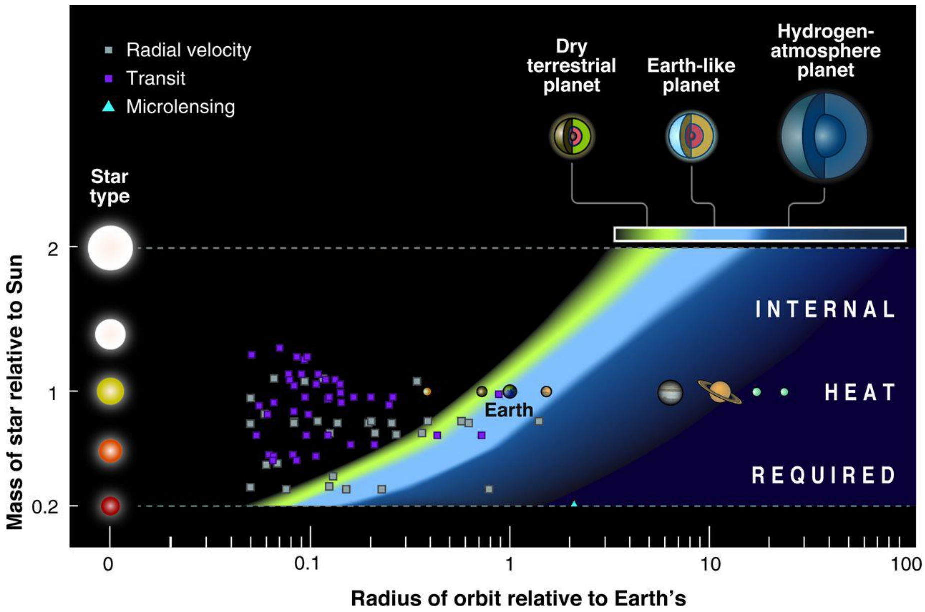

Fig 13: Habitability zone determined by the host star.

That a planet is in the habitability zone does not imply that there must be life. For example, in our solar system the habitability zone includes the planets Earth and Mars, but of the two, the only one in which life is known is on Earth. The habitability zone for the solar system is between 0.84 AU and 1.67 AU. Venus is at 0.7 AU with an uncontrolled greenhouse effect and instead Mars is at 1.5 AU without the existence of surface water, but there could well be underground frozen water.

In addition to the existence of liquid surface water there are other conditions for the habitability of a planet. Let's see in detail the most important:

- **An orbital distance** from the planet that places it in the habitable zone is a necessary but not sufficient condition for a planet to be hospitable to life. Example: Venus and Mars.

- One factor that decisively influences habitability is **the mass of the planet. This must be large enough** so that its gravity is able to retain the atmosphere. That is the main reason why Mars is not habitable at present, as it lost most of its atmosphere and all surface water, which it had in its first billion years.

In any case, it may happen that although the planets are not in the habitability zone, the factors necessary for the existence of some kind of life may exist, either on the planets themselves or on some of their moons. It could be the case for some moons of Jupiter or Saturn.

Preliminary Astrobiology: The process of the formation of the Earth's atmosphere

The knowledge of photosynthesis is essential to understand the relationships of living beings and the atmosphere, and to understand the balance of life on Earth, given the profound impact it has on the Earth's atmosphere and climate.

Photosynthesis is a physicochemical process by which plants, algae and certain photosynthetic bacteria use the energy of sunlight to synthesize organic compounds. It is a fundamental process for life on Earth and has a profound impact on the Earth's atmosphere and climate: every year organisms with photosynthetic capacity convert more than 10% of atmospheric carbon dioxide into carbohydrates. This means that the increase in the concentration of atmospheric carbon dioxide generated by human activity has a great impact on photosynthesis. From the evolutionary point of view, the emergence of oxygenic photosynthesis (the one that produces oxygen) was a real revolution for life on Earth: it changed the Earth's atmosphere by enriching it, a fact that enabled the emergence of organisms that use oxygen to live.

Oxygenic photosynthesis	Anoxygenic photosynthesis
$H_2O \rightarrow 2\,H^+ + 2\,e^- + 1/2\,O_2$	$H_2S \rightarrow 2\,H^+ + 2\,e^- + S$

Fig. 14: Oxygenic and anoxygenic photosynthesis.

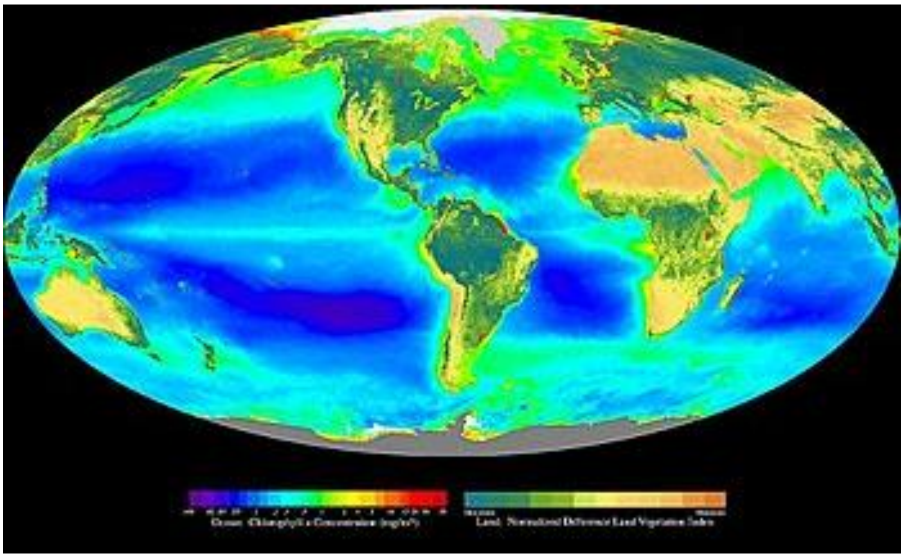

Fig. 15: Image shows the distribution of photosynthesis in the terrestrial globe carried out by both the oceanic phytoplankton and by terrestrial vegetation.

Things were not always as we know today; the evolution of the Earth, the evolution of the primitive atmosphere, the evolution of the primitive metabolisms, constitute a framework of events that leads to phototrophic bacteria that use light as a source of energy but release sulphur (called anoxygenic photosynthesis as it does not releases oxygen). Later oxygenic photosynthesis appears on Earth. It releases oxygen to the atmosphere, increasing its concentration and enabling the great explosion of life that we know now. It can be said that the primitive atmosphere of our planet barely contained traces of oxygen. But there was life before. And there is the agreement that the air we breathe today, with 21% oxygen, is a product of the biological activity of the Earth and it is very different from the atmosphere of the primitive Earth.

The process of organic matter formation. Why are plants green?

Life on our planet is maintained fundamentally thanks to the photosynthesis that algae and some bacteria carry out in the aquatic environment and that plants carry out in the dry environment (on the surface of the Earth) All of them have the capacity to synthesize organic matter (essential for the constitution of living beings) starting from light and inorganic matter. In fact, every year the photosynthetic organisms fix about 100 billion tons of carbon in the form of organic matter.

The initial steps of converting light energy into chemical energy depend on molecules called photosynthetic pigments. The term ‘pigment’ is used to describe a molecule that has the ability to capture energy from photons (exciting the electrons from their energy levels in the atoms; a molecule that is “excited by light”). All biological pigments selectively absorb certain wavelengths of light while reflecting others.

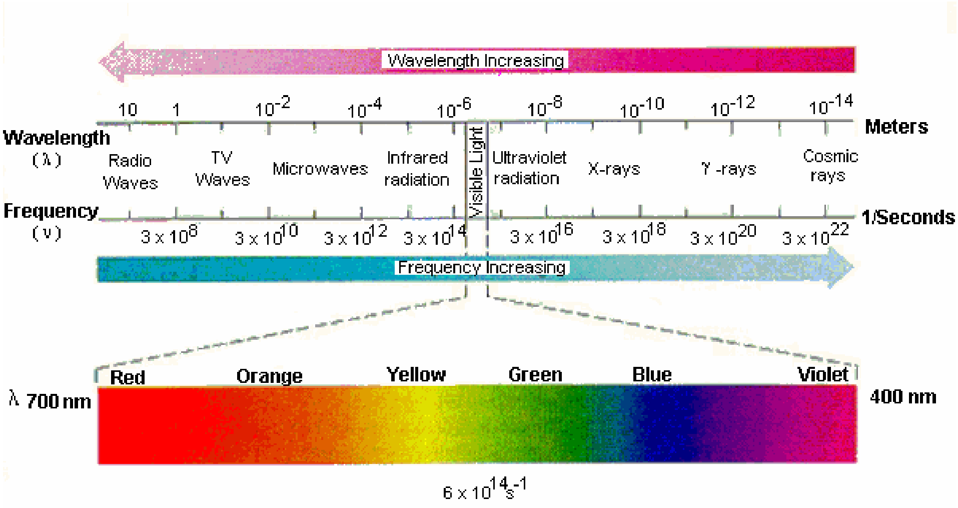

Fig. 16: The spectrum of visible light.

Sunlight is composed of different colours; each has a different wavelength that ranges between 400 and 700 nm. Chlorophyll absorbs the energy of red and blue light but does not absorb the energy of green light. The green colour is reflected by the leaf and our eyes see it green.

Activity 4: Production of oxygen from CO_2 using photosynthesis or chlorophyll function

In this experimental proposal we will use leaves of a plant to produce oxygen thanks to the sodium bicarbonate, carbon and the light of a lamp. We will use two transparent glass jars and on them we will place blue and red filters.

Green vegetable leaves should be fresh, consistent and fully green, so spinach or leaf beet is advised. With the help of a punch or paper punch, we will cut disks of uniform sheets (calculate to have 10 disks per bottle, avoiding areas with central ribs).

We will prepare a 25% solution of sodium bicarbonate, that is, 25 g of bicarbonate per 1 litre of water, with the aim of impregnating the disks cut from the leaves with it. We hope to increase the amount of carbon available in the form of sodium bicarbonate thus making more visible and speeding up the phenomenon we wish to observe. We put 20 ml of the sodium bicarbonate solution in each glass jar.

We remove the plunger from a 10 ml disposable syringe and place the disks in its body, then gently place the plunger and suck 10 ml of the bicarbonate solution until the disks are suspended in the solution.

We must replace the air in the disks with the bicarbonate solution. To achieve this, seal the end of the syringe with a finger and suck tightly, trying to make the vacuum and then release. In the internal spaces of the plant tissue, air will be replaced by bicarbonate solution: in this way, the disks will not float in the bicarbonate solution, and the solution will be an available carbon source and close to the photosynthetic structures of the leaf.

We place the leaf disks so treated in each glass jar (which their turn contain 25% bicarbonate solution). Cover one of the jars with an aluminium foil and cover the other jar with the coloured cellophane paper. A lamp should be installed on each bottle (with the paper covering it), so that the light beam affects the sample to be studied: both lamps at the same distance (it is necessary to have individual light sources for each bottle, of the same power, not less than 70 W: they can be fluorescent sources, but the use of LEDs is recommended; avoid incandescent ones, such as halogen lamps, since they lose a lot of energy as heat).

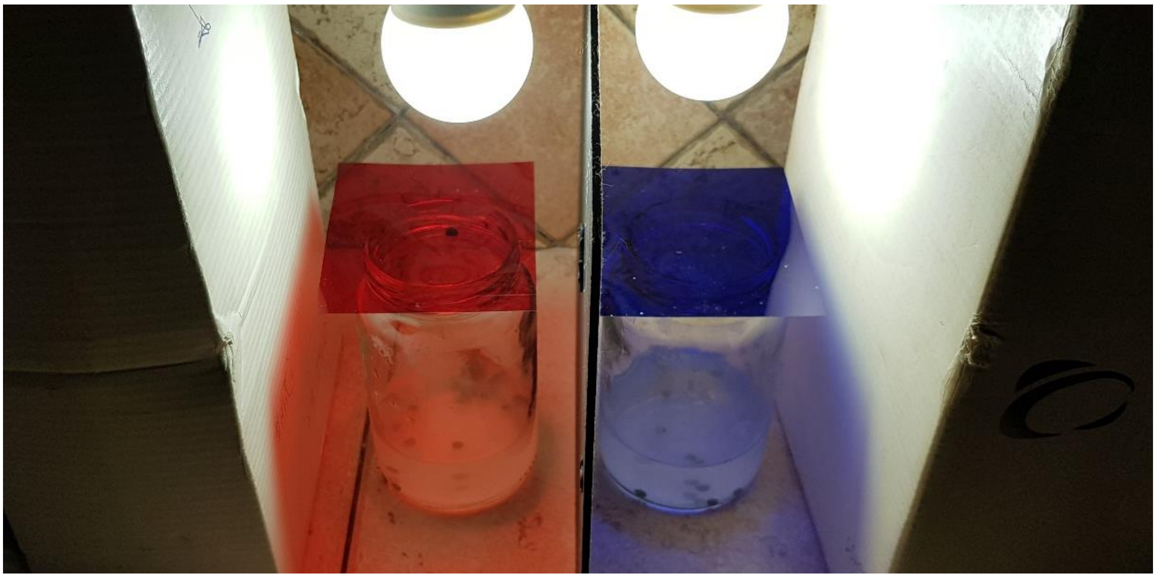

Fig. 17 and 18: The solution and the lamps with red filter and with blue filter.

When we turn on the light, we begin to measure the time with a stopwatch. We record the time it takes for the disks to begin to rise in the solution.

The process is not immediate, it can take about 5 minutes for the disks to start ascending (it depends on the intensity of the lights and the distance at which the lamp is placed). The disks begin to rise as they release oxygen in the form of bubbles, which help in ascension. It will be noted that the movement in each bottle occurs at different times, depending on the colour of the light: it is faster for blue light. In this way we demonstrate that the higher energy component of electromagnetic radiation is the most efficient in the process. The photosynthetic rate is directly related to the time it takes for the disks to start rising, a phenomenon linked to the production of oxygen. The photosynthetic rate is higher for blue than for red. Therefore, with this experiment we are demonstrating how plants and other photosynthetic organisms are responsible for the existence of oxygen in our atmosphere. The replacement of air with the bicarbonate solution accelerates the process and allows us to visualize it in less time.

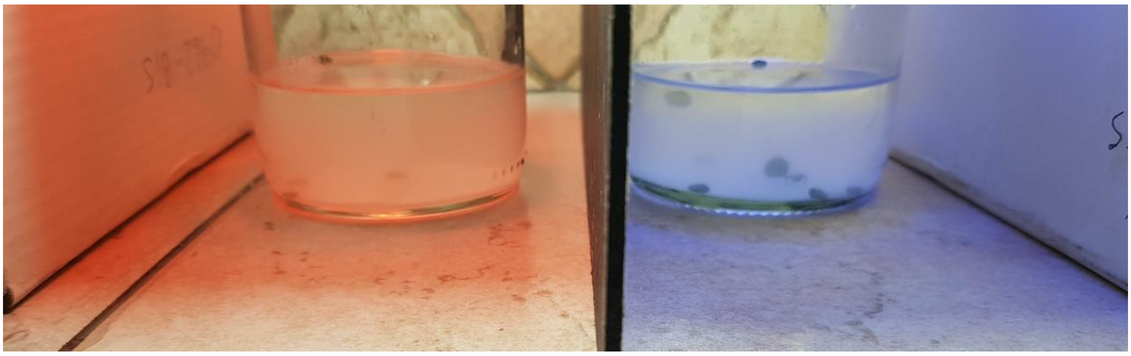

Fig. 19 and 20: The solutions with the lamps of different colour showing the disks rise differently in each case.

In addition, over time, the interaction of the UV radiation of the Sun with the oxygen molecules generated ozone (O_3). This process protects us from the most energetic UV radiation, but that lets UVA and UVB pass, which helpfully creates vitamin D in human's skin.

Alternative variables to explore: bicarbonate concentration in the solution used, temperature, light sources of different colours and intensities (keeping the rest of the conditions constant and controlling darkness in all cases), leaves pre-exposed to light or dark, etc.

Activity 5: Check the possibility of life in extreme conditions

Fermentation to produce alcohol is an anaerobic process performed by yeasts (fungi). Together with bacteria, the fermentation process is the basis for obtaining energy in microorganisms. Yeasts transform sugar (glucose) into ethyl alcohol or ethanol and carbon dioxide. Fermentation is a process of low energy efficiency, while breathing is much more profitable and more recent from the evolutionary point of view.

Thus, as sugar is transformed into ethyl alcohol and carbon dioxide, we will base our experiment on the presence of this gas. If we observe the presence of it we will know that there has been fermentation and therefore the possibility of life has been tested.

Microbiology experiences require time to reach reliable conclusions, in our case, the presence or absence of carbon dioxide will allow us to know if, given a change in environmental conditions, we can deduce that life is possible. In all cases of our experiment we start from a crop in which water is present. To have enough time to observe the evolution of the experiment, it is prepared at the beginning of the workshop and the situation of the 7 different procedures can be observed after one hour.

For this we will use 1 tablespoon of yeast (use yeast to make bread that can be purchased in a supermarket), it is a live microorganism easy to get, 1 glass of warm water (just over half a glass between 22º and 27º C) and 1 tablespoon of sugar that the microorganisms can consume.

We will use the same procedure in the control experiment and the other experiments developed in extreme conditions.

Procedure for the control experiment

Sugar is dissolved in hot water in a glass cup. Then the yeast is added and mixed in with the help of a spoon. Then the mixture obtained is placed in a plastic bag with a zipper (it is not possible to enter air inside). All the air is extracted from the interior (spreading it on the table and pressing with the extended hands) before sealing it. It is important to take care not to leave any air inside the bag. After 5 minutes we observe how carbon dioxide has begun to accumulate in the bag. After 20 minutes, bubbles appear inside the bag due to the release of this gas, one of the final products of the fermentation that occurs inside the bag. The presence of this gas shows that the microorganisms are alive.

Fig. 21: The control experiment with carbon dioxide bubbles that show the existence of life

Procedure on an "alkaline planet" (eg NEPTUNE or Titan both have ammonia present): Repeat the experience using any "base" material available (sodium bicarbonate, ammonia ...) in the water and wait to see if bubbles appear, that is, if microorganisms can live or not. Ph scales Alkaline: Sodium bicarbonate: Ph 8.4 and Household ammonia: Ph 11.

Procedure in a "saline planet" (eg MARS or Ganymede is believed to have water with a high salt concentration). Repeat the experience by dissolving different amounts of sodium chloride (common salt) in the tap water.

Fig. 22 and 23: The alkaline solution and the saline solution both with bubbles

Procedure on an "acid planet" (eg VENUS that has rain of sulfuric acid): Repeat the experience dissolving vinegar, lemon… or any other acid available in the water. Ph scales Acid: Vinegar: Ph 2.9 and Lemon: Ph 2.3.

Procedure on an "icy planet" (eg Europe or Trappist-1 h)
Place the bag in a container full of ice and observe if there is activity, that is, if the bag swells. If a refrigerator or freezer is available it can also be used. If bubbles do not appear there is no life.

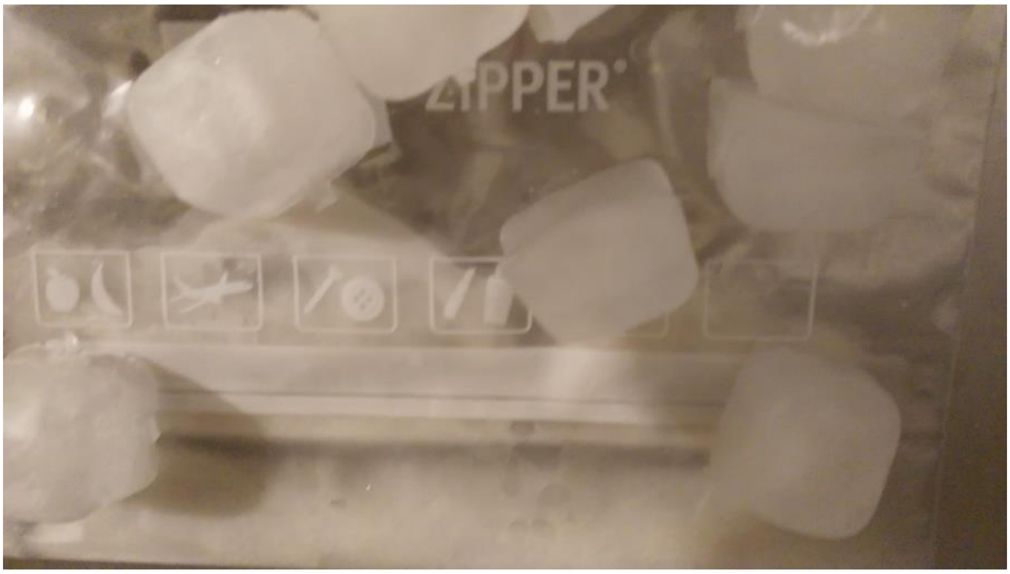

Fig. 24: The frozen solution without bubbles

Procedure on a "planet with UV" (eg MARS): Perform the same experiment but keeping the bag tight with yeast and sugar under the action of UV light produced by a special lamp for it. If the UV lamp used is high energy (UV-C) or (UV-B), no bubbles will appear, which means that no life is possible. But the commercialized lamps, called "black light", are low energy ultra violet (UV-A), that is, they are not dangerous for life and are often used in gardening for the good results they give in facilitating the growth of the plants. Using this type of lamps, it is observed that a greater number of bubbles are formed. If bubbles appear there is life.

Procedure on a "warm planet" (eg VENUS due to the greenhouse effect)

Perform the same experiment with very hot water. In the case of Venus we must use boiling water. (If a thermometer is available, it can be repeated at different temperatures and an activity table can be obtained at these temperatures.) If bubbles appear there is life.

Planets and exoplanets with extreme conditions and similar to those used in this activity

VENUS. It has a dense atmosphere, composed mostly of carbon dioxide and a small amount of nitrogen. The pressure at the surface level is 90 times higher than the atmospheric pressure on the Earth's surface. The huge amount of carbon dioxide in the atmosphere causes a strong greenhouse effect that **raises the planet's surface temperature to about 464 °C in the less elevated regions near the equator.** This makes Venus hotter than Mercury, despite being more than twice the distance from the Sun where it only receives 25% of its solar radiation. The clouds are mainly composed of droplets of sulfur dioxide and sulfuric acid and cover the planet completely, hiding the surface details to external visual observation.

MARS. Under the icy surface of that desert world there **could be saltwater. That water could be home to life forms capable of tolerating these extreme conditions.** In the past it was a very different place. We know it could have looked a lot like Earth. It had oceans, volcanoes and an atmosphere as dense as ours, rich in carbon dioxide, but that would not have been an impediment to microbial life. **The only thing missing from the red planet and caused it to end so differently from our planet, was a magnetic field.** The lower gravity and the lack of a magnetic field meant that the solar wind was able to slowly remove its atmosphere. In addition, Mars is a planet that receives on its surface solar ultraviolet (UV) radiation with a strong biologically very harmful component (UV-C and UV-B), which notably influences the deterioration of the surface in order to find some sign of life.

NEPTUNE. Neptune's internal structure resembles that of Uranus: a rocky core covered by an icy crust, hidden under a thick atmosphere. The inner two-thirds of Neptune is composed of a mixture of molten rock, water, liquid ammonia and methane. The outer third is a mixture of hot gas composed of hydrogen, helium, water and methane. Its atmosphere comprises approximately 7% of its mass. At great depths, the atmosphere reaches pressures of approximately 100 000 times greater than that of the Earth's atmosphere. **The concentrations of methane, ammonia and water increase from the outer regions to the inner regions of the atmosphere.**

Ganymede the satellite of Jupiter, is composed of silicates and ice, with an ice crust that floats above a muddy mantle that might contain **a layer of liquid water with a high concentration of salt.** The first overflights of Ganymede of the Galileo spacecraft discovered that the satellite has its own magnetosphere. It is probably generated in a similar way to the Earth's magnetosphere: that is, it results from the movement of conductive material inside.

Titan the satellite of Saturn. **It is believed that there is also an underground ocean of water with ammonia dissolved in it** to a depth of 100 kilometres below the surface, and perhaps another of hydrocarbons. The atmosphere is composed of 94% nitrogen and is the only nitrogen-rich atmosphere in the Solar System apart from our own planet. Significant traces of various hydrocarbons make up the rest. Ice is very similar to that which exists at the Earth's poles, drifting ice.

Europe the satellite of Jupiter. Europe has an **icy surface and a subsurface ocean of liquid water**. The atmosphere it has is thin and of low density but is composed of oxygen. Ice is very similar to what exists at the Earth's poles, drifting ice. Europe has a nickel-iron core surrounded by a hot rocky mantle, over it there is an ocean of liquid water with a depth, under discussion by geologists, of around 100 km and with an icy surface of 10 km.

Activity 6: Finding a second Earth

Earth is the only known planet which supports life. So if we are searching for a planet with extra-terrestrial life, it is a good option to look for planets providing similar conditions. But which parameters are important?

The following table lists some exoplanets with properties. Rule out the exoplanets not suitable for life and maybe find a second Earth. You can find some criteria after the table.

Exoplanet Name	**Mass** in masses of Earth	**Radius** in Earth radii	**Distance to star** in AU	**Star Mass** in masses of the Sun	**Star Spectral Type/surface temperature**
Beta Pic b	~~4100~~	~~18.5~~	~~11.8~~	~~1.73~~	A6V
HD 209458 b	~~219.00~~	~~15.10~~	~~0.05~~	1.10	G0V
HR8799 b	~~2226~~	~~14.20~~	~~68.0~~	1.56	A5V
Kepler-452 b	**unknown**	**1.59**	**1.05**	**1.04**	**G2V**
Kepler-78 b	1.69	1.20	~~0.01~~	0.81	G
Luyten b	**2.19**	**unknown**	**0.09**	**0.29**	**M3.5V**
Tau Cet c	3.11	unknown	~~0.20~~	0.78	G8.5V
TOI 163 b	387	~~16.34~~	~~0.06~~	1.43	F
Trappist-1 b	0.86	1.09	~~0.01~~	0.08	M8
TW Hya d (yet unconfirmed)	~~4~~	unknown	~~24~~	0.7	K8V
HD 10613 b	~~12.60~~	~~2.39~~	~~0.09~~	1.07	F5V
Kepler-138c	**1.97**	**1.20**	**0.09**	**0.57**	**M1V**
Kepler-62f	2.80	1.41	~~0.72~~	0.69	K2V
Proxima Centauri b	1.30	1.10	~~0.05~~	0.12	M5V
HD 10613 b	~~12.60~~	~~2.39~~	~~0.09~~	1.07	F5V
KIC 5522786 b	unknown	1.21	~~1.98~~	~~1.79~~	A

Table 3: Candidates for a second Earth.

Radius and mass

In our Solar System there are terrestrial planets (Mercury, Venus, Earth, Mars) and giant planets (Jupiter, Saturn, Uranus, Neptune). Earth-like terrestrial planets are composed of silicate rocks and metals and have a higher density than the giant planets. Good indicators for a fitting density are the radius and the mass of the planet.

We are using the definition of the Kepler Mission team: Earth-size and super-Earth-size planets have a radius less than 2 Earth radii. 10 Earth masses are considered an upper limit for super-Earth-size planets.

Habitable Zone

The habitable zone is the range of orbits around a star within which a planetary surface can support liquid water.

The main sequence stars we are focusing on have a direct correlation between brightness and surface temperature of the star. The hotter the surface temperature, the brighter is the star and the further away is the habitable zone. Spectral types indicate the surface temperature (see table below).

Spectral type	**Temperature** K	**Habitable zone** AU
O6V	41 000	450-900
B5V	15 400	20-40
A5V	8 200	2.6-5.2
F5V	6 400	1.3-2.5
G5V	5 800	0.7-1.4
K5V	4 400	0.3-0.5
M5V	3 200	0.07-0.15

Table 4: Habitable zone depending on spectral type.

The spectral types are classified with a letter (O, B, A, F, G, K, M) and subdivided by a numeral from 0 to 9 (0 is the hottest in a given spectral type). The V indicates a main sequence star.

Hint: If the spectral type of a star is slightly different or the subtype is unknown, use the given values for the habitable zone as approximation.

Mass of the Host Star

To study the habitability in a planetary system around main sequence stars, we must consider the evolution of the host star.

About 1 billion years after the formation of the Earth, the first life forms occurred. Maybe there was life even before, but this is uncertain. So, the host star must be stable for at least $\sim 10^9$ years for life to evolve.

The energy that a star can produce from hydrogen fusion is proportional to its mass. And you get the main sequence time by dividing this energy by the luminosity of the star. If you use this proportionality and use the Sun as reference, you get the first part of formula, from these considerations, we can estimate the main sequence lifetime of a star:

$$t_*/t_s = (M_*/M_s)/(L_*/L_s)$$

For normal dwarf stars or the main sequence of the H-R diagram, the luminosity is approximately proportional to the mass raised to the power of approximately 3.5. $L \propto M^{3.5}$

$$t_*/t_s = (M_*/M_s)/(M_*^{3.5}/M_s^{3.5}) = (M_*/M_s)^{-2.5}$$

$$t_*/t_s = (M_s/M_*)^{2.5}$$

which gives the lifetime of a star as a fraction of the Sun's expected lifetime (10^{10} yr).
A simplified version of this formula is:

$$t_* \sim 10^{10} \text{ x } (M_s/M)^{2.5} \text{ years}$$

Let's calculate an upper limit for the mass of the star if the time interval of the main sequence is at least 3 billion years.

$$M^* = (10^{-10} \text{ x } t)^{-0.4} \text{ Ms}$$

$$M^* = (10^{-10} \text{ x } 3\,000\,000\,000)^{-0.4} \text{ Ms}$$

$$M^* = 1.6 \text{ Ms}$$

We see that for stars with masses > 2M, the main sequence lifetime drops below 1 Galactic year (time to go around the galactic centre 250 million years), thus, even if habitable planets exist around them, life would probably not have enough time to evolve.

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