# Elements of Astrobiology

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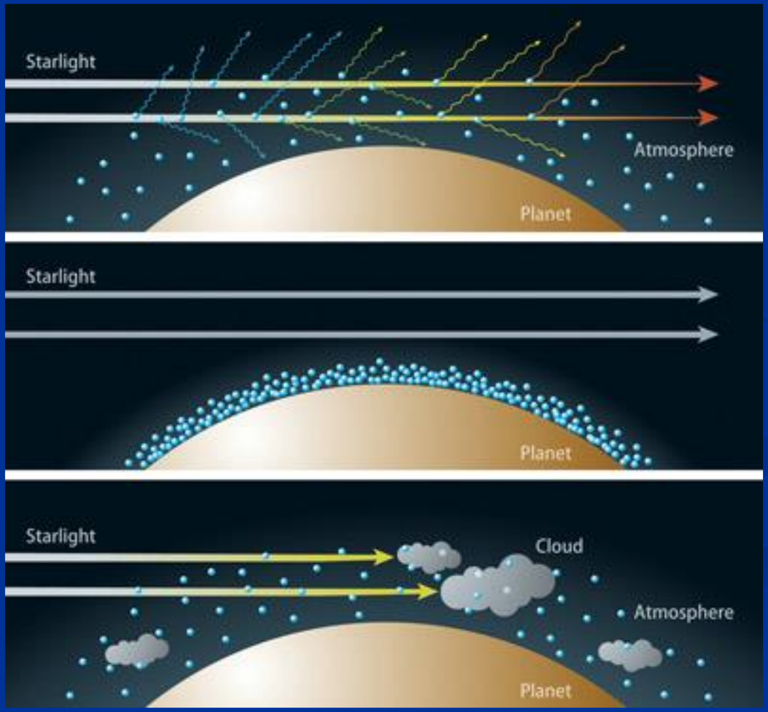
# Objectives

- Understand where the different elements of the periodic table arise.
- Understand the habitability conditions necessary for the development of life.
- Manage the minimum guidelines of life outside the earth.

# Formation of planetary systems

During the formation of a star its planetary system is also constituted with the remains of material close to the star.

Spectroscopy is used to know the composition of the star and is also used to know the atmosphere of the exoplanets.



# Activity 1: Formation of the planetary system from gas and dust

The group is divided into two: girls (gas) and boys (dust) e.g. (If there is a substantial difference in the number of participants from one group and another, it is recommended that the group representing the gas be the largest, since, in a planetary system in formation, the mass of the gas is 100 times the mass of the dust).

As the participants listen to the story, they make a dynamic actions of what they hear, for example:

# Activity 1: Formation of the planetary system from gas and dust

| Text of the story: | 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 begins to gather in the center of the cloud and around it, the dust.** | They begin to separate. Participants representing gas accumulate in the center and those representing dust hold hands around the centre. |

# Activity 1: Formation of the planetary system from gas and dust

| Text of the story: | Participants performance: |
|---|---|
| **There was a lot of movement, gas particles attracted gas and dust particles attracted dust.** | They begin to rotate, move, crash, vibrate, jump. Some shoot out as a result of so much movement and others "rescue", catch, hug those particles by identification (gas with gas and dust with dust). |
| **In the center, a dense opaque core formed surrounded by a disk of dust and gas.** | Those in the center (gas) accumulate and around them participants who represent dust in a kind of circle are taken by the hand. Clarification: not all gas is in the center, there is remote gas outside the circle. |

# Activity 1: Formation of the planetary system from gas and dust

| Text of the story: | Participants performance: |
|---|---|
| **This nucleus is the one that would finally give rise to the Sun or the parent star of an extrasolar system.** | The Sun or the parent star begins to shine so that its rays must shoot outwards in all directions.<br>Clarification: The moment the sun or the parent star begins to shine the "loose" gas begins to move away. |
| **Some small planets were formed by the union of increasingly larger and larger dust grains, then rocks and so on until terrestrial planets are made.** | The participants representing the dust that forms the terrestrial planets begin to group together.<br>Clarification: not all dust stays on terrestrial planets, there must be some dust in the furthest regions. |

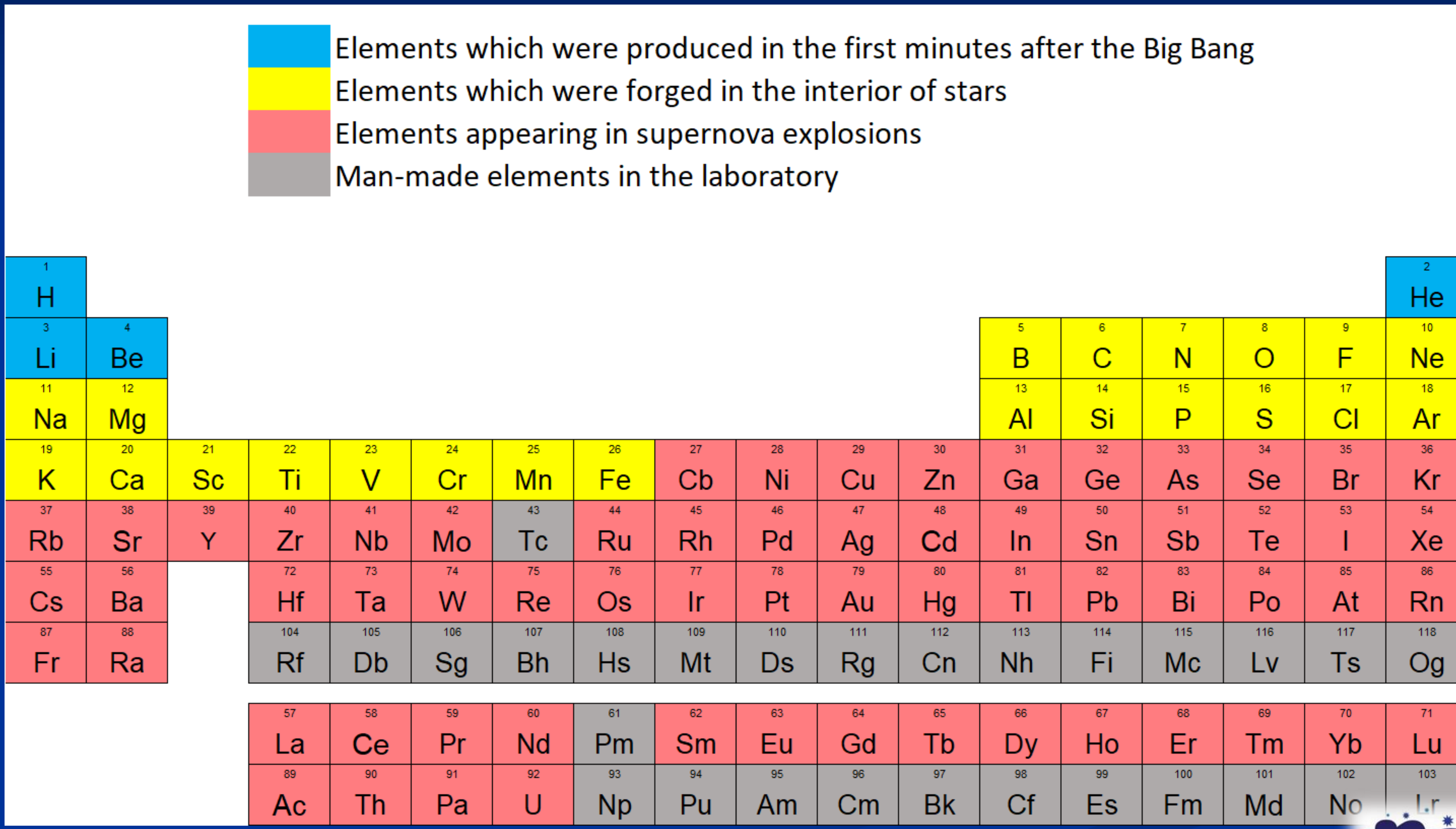
# Activity 1: Formation of the planetary system from gas and dust

| Text of the story: | Participants performance: |
|---|---|
| **The giant planets formed away from the heat of the Sun or the central star where the gas could gather without hinderance.** | The rest, the giant planets, begin to come together: a lot of gas and some dust. Clarification: The decrease in temperature due to the greater distance from the Sun or the mother star was the cause of the main differences between the inner rocky planets and the outer giants. |

# Activity 2: Emission spectrum

Spectroscopy allows us to know some information about the chemical composition of exoplanets and their atmospheres. We can visualize the spectrum of a light bulb with a DVD (we see the lines of the gases it contains inside)

# Chemical aspects of stellar evolution



# Activity 3: Periodic Table Classification

Place in each basket (blue, yellow and red) each object

| | | | |
|---|---|---|---|
| Ring: Gold Au | Drill bit coated with: Titanium Ti | Gas inside a child's balloon: Helium He | Pan scourers: Nickel Ni |
| Mobile/button battery: Lithium Li | Car spark plugs: Platinum Pt | Electric copper wire: Copper Cu | Iodine solution: Iodine I |
| Water bottle $H_2O$: Hydrogen H | Old Cooking Pan: Aluminum Al | Black Pencil Lead: Graphite C | Sulfur for agriculture: Sulfur S |
| Can of soft drink: Aluminum Al | Wrist watch TitaniumTi | Medal: Silver Ag | Pipe: Lead Pb |
| Zinc pencil sharpener: Zinc Zn | Rusty Old Nail: Iron Fe | Thermometer: Gallium Ga | Matchbox: Phosphorus P |

Elements generated in the first minutes after the Big Bang (blue)

Elements forged inside the stars (yellow)

Elements that appear in supernova explosions (red)

# Activity 3: Periodic Table Classification

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Elements Big Bang (blue)

Elements inside the stars (yellow)

Elements in supernova (red)

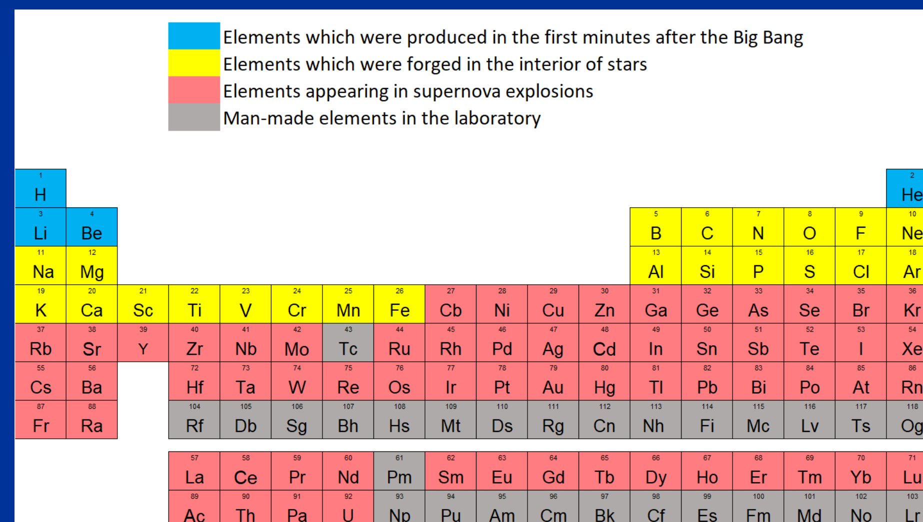
# Activity 4: Children of the stars

## Composition of the human body:

Abundant elements: oxygen, carbon, hydrogen, nitrogen, calcium, phosphorus, potassium, sulfur, iron sodium, chlorine, and magnesium.

Trace elements: fluorine, zinc, copper, silicon, vanadium, manganese, iodine, nickel, molybdenum, chromium and cobalt

Essential elements: lithium, cadmium, arsenic and tin.

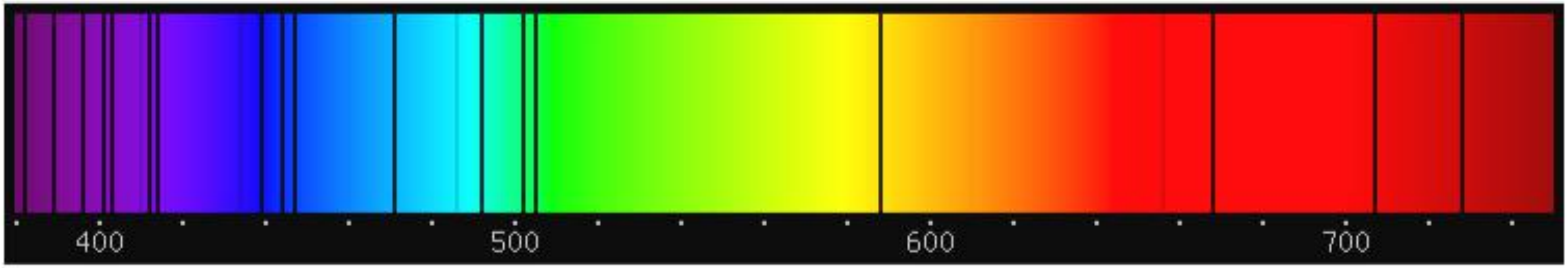



All abundant elements (except H) have been produced within the stars.

**We are children of the stars !!!!**

# The Sun is not a star of first generation

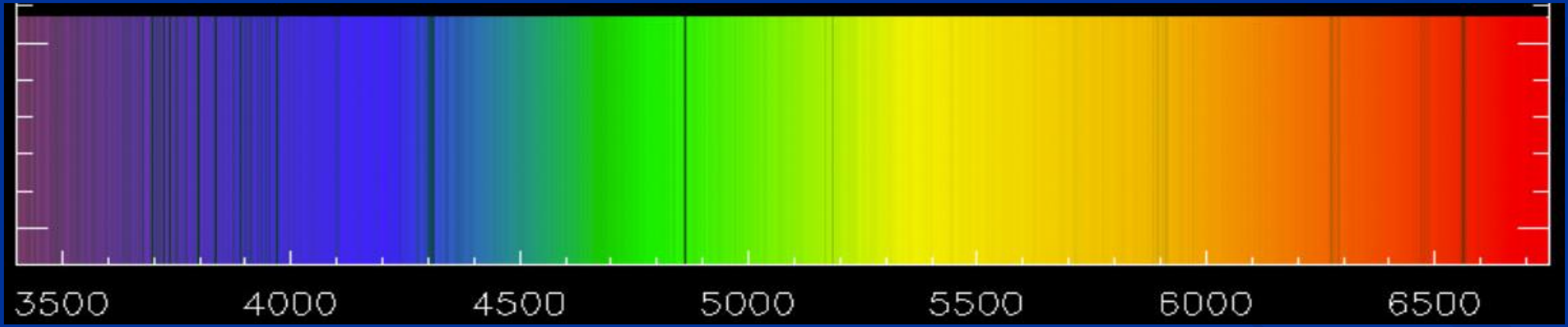
The first generation stars lived fast, died young and have not survived to this day. Only with Hydrogen, Helium and perhaps Lithium lines are visible.




First Generation star spectrum (Artist's impression).

# The Sun is not a stars of first generation

The stars with more elaborate elements means that their initial cloud started from the remains of a supernova explosion.

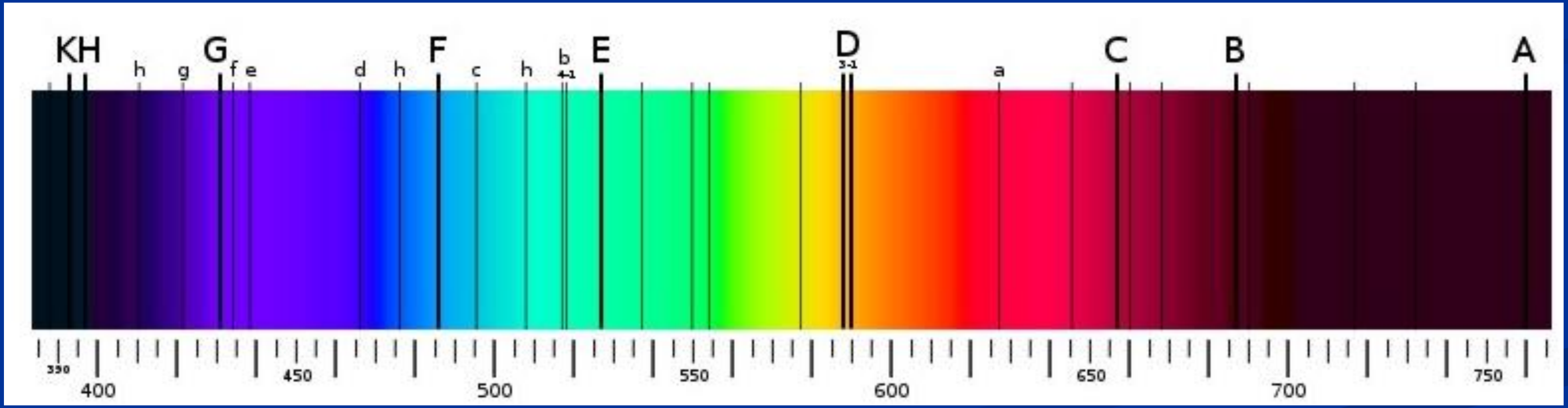



Second Generation star spectrum.

SMSS J031300.36-670839.3 with Hydrogen and Carbon lines

# The Sun is not a first generation star

In the solar system many elements that arise after a supernova explosion are detected. Therefore the Sun was possibly formed from an initial cloud that corresponded to the remains of at least two supernova explosions, that is, it is a third-generation star.

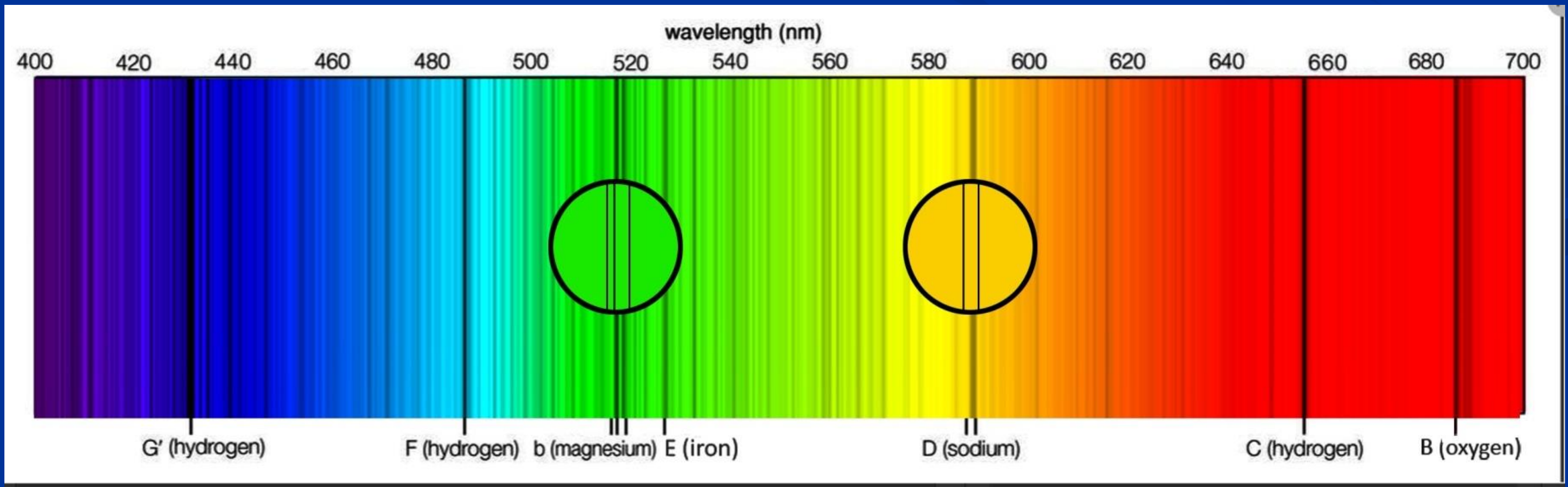



Spectrum of the Sun. With various spectral lines

# Activity 5: Fraunhofer lines of the Sun

The Sun's spectrum is continuous, with dark lines called Fraunhofer lines, which correspond to the chemical elements contained in its atmosphere.

They can be seen with the naked eye in the reflection of sunlight on a DVD. Many Fe lines are observed, the Mg triplet (in green), the Na doublet (in yellow)

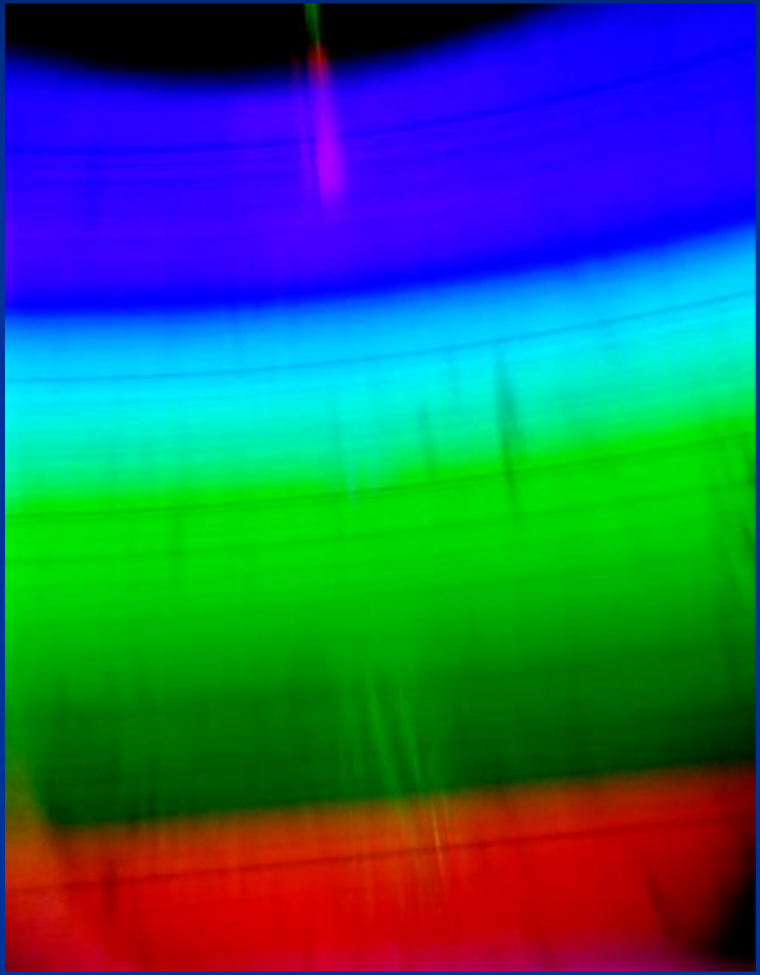


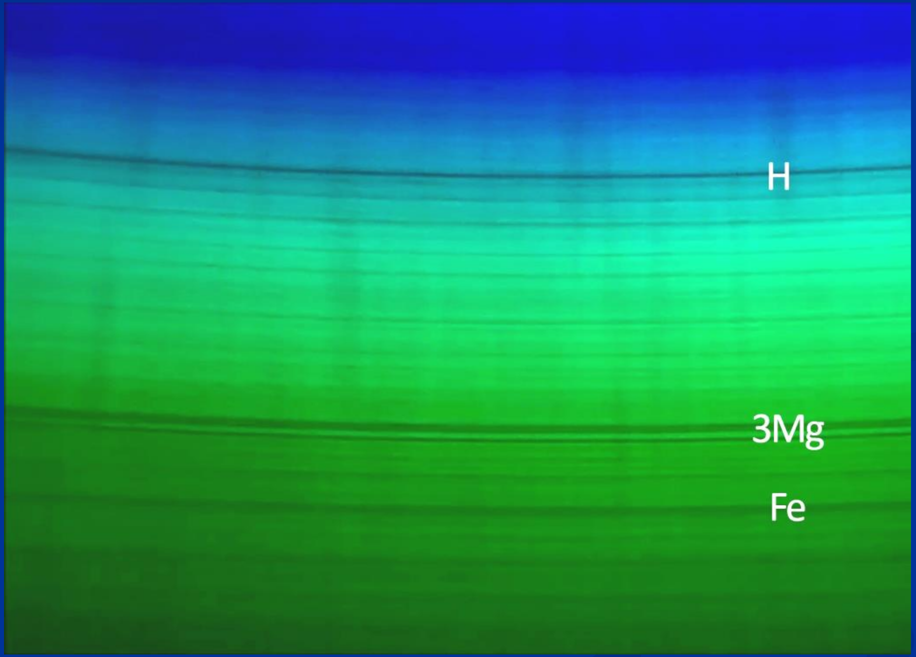
# Activity 5: Fraunhofer lines of the Sun

To see the Fraunhofer lines, you have to face the Sun, with the DVD horizontal, bring your face about 5 cm from the DVD, placing your eye just above the central hole of the DVD.

In that position, you look at the colors of the reflection of the Sun near the edge of the DVD next to your body.

# Activity 5: Fraunhofer lines of the Sun





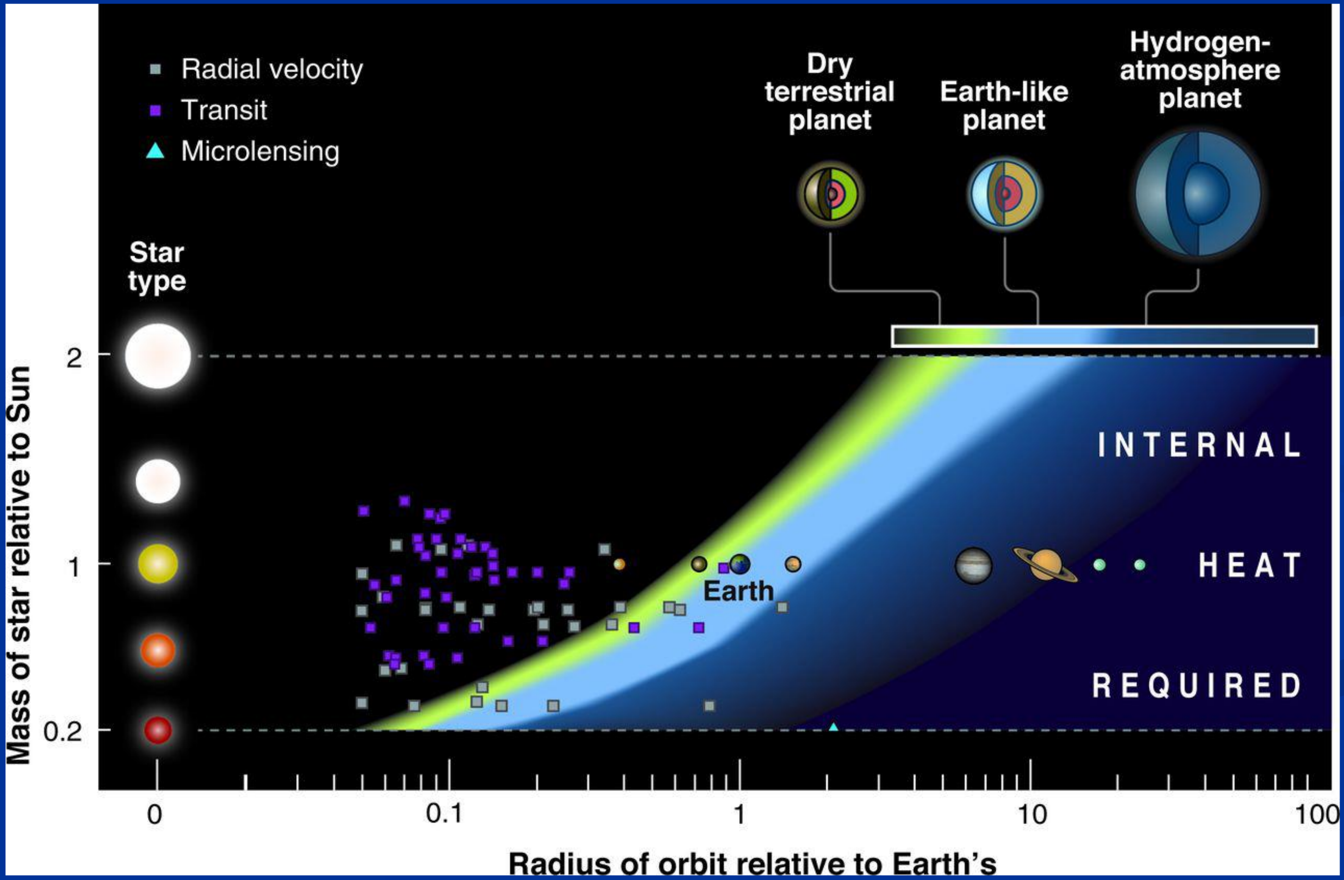
# Zone of Habitability

Zone of habitability is the region around a star in which the flow of radiation onto the surface of a rocky planet would allow the presence of liquid water (carbon-based life is assumed the presence of liquid water).

It usually occurs in bodies of mass between **0.5 and 10 Me** and 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).

# Zone of Habitability

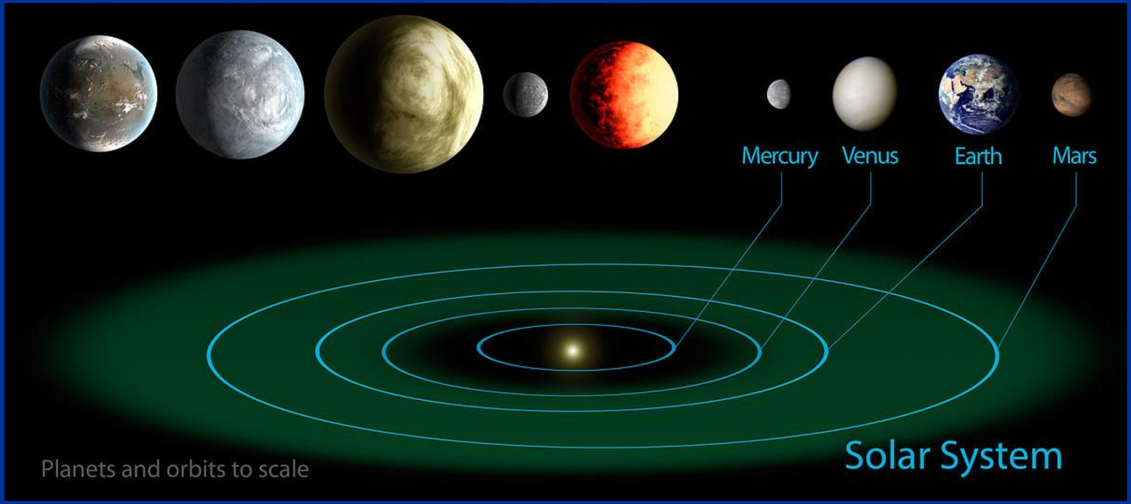
The zone of habitability **depends on the mass of the star**. If the mass is greater then its temperature and brightness increase and consequently the zone of habitability is increasingly distant.



# Other conditions for Habitability

The **orbital distance** of the planet that places it in the zone of habitable is a necessary condition, but not enough for a planet to embrace life.

Example: Venus and Mars.



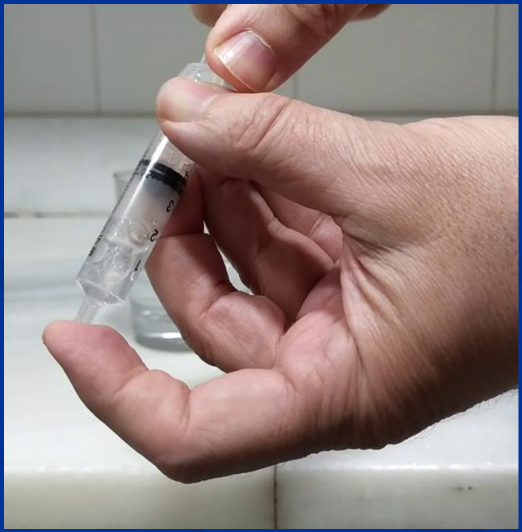

The **mass of the planet must be large enough** so that its gravity is able to retain the atmosphere.

It is the main reason why Mars is not habitable at present, since it lost most of its atmosphere and all surface water, which it had in its first billion years.

# Activity 6: Liquid water on Mars?

On Mars the atmospheric pressure is weak (0.7% of the Earth's one). Despite this low pressure, the water form clouds at the planet's poles. But why does Mars have no liquid water on its surface?

We put inside the syringe hot water close to boiling



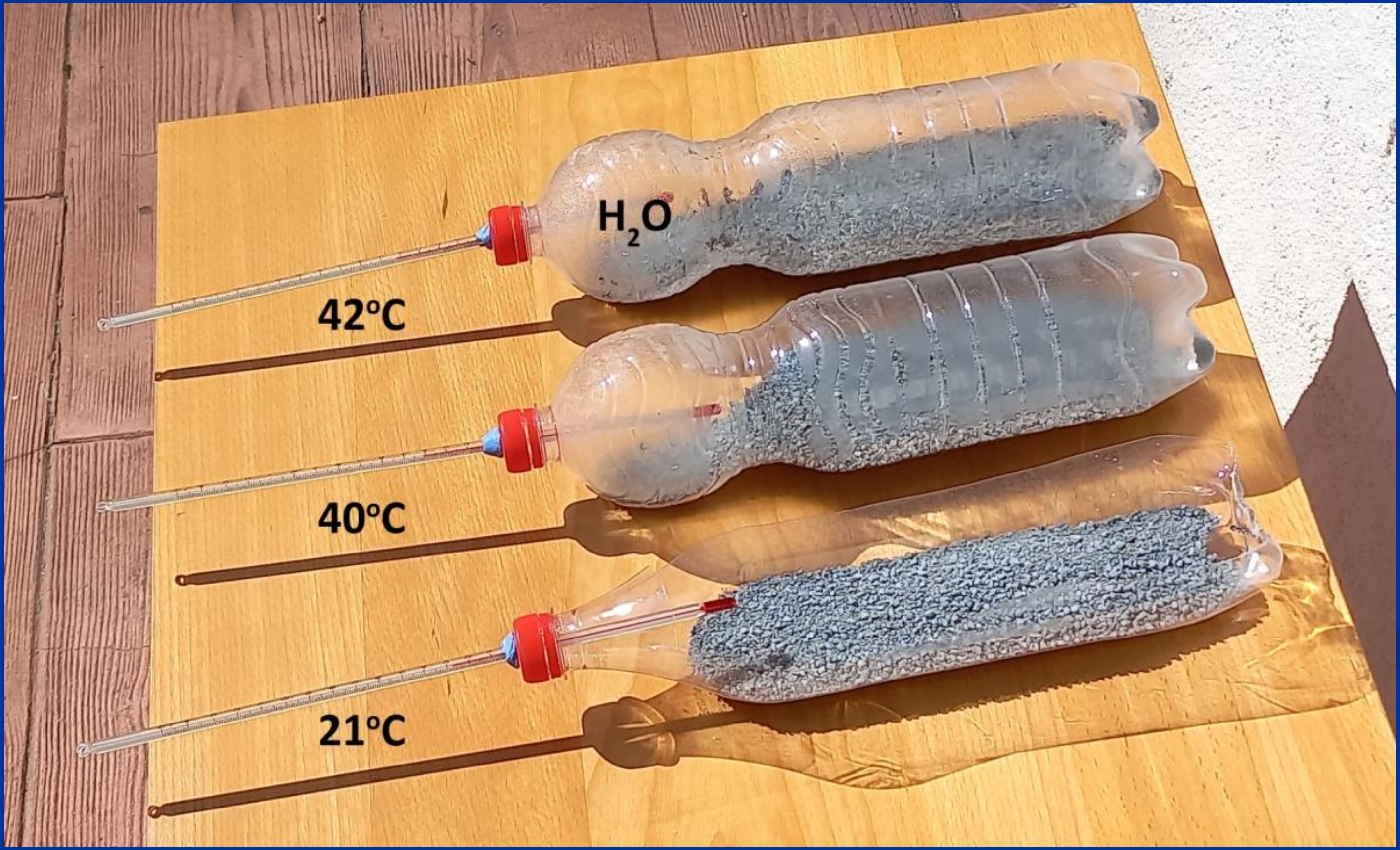
**If we pull the plunger the inside pressure lowers and the water begins to boil, becomes steam and gradually disappears. To simulate the Martian pressure we should have a very long syringe and to pull the plunger up to 9 m.**

# Activity 7: Greenhouse effect

We put dark earth inside 2 empty plastic bottles, and in a third cut lengthwise in half. We inserted a thermometer into the stopper of each bottle. The cut bottle simulates the planet without clouds, the first whole bottle simulates the planet with clouds, and in the last one, we put a few drops of water inside it, to simulate an atmosphere with water vapor.

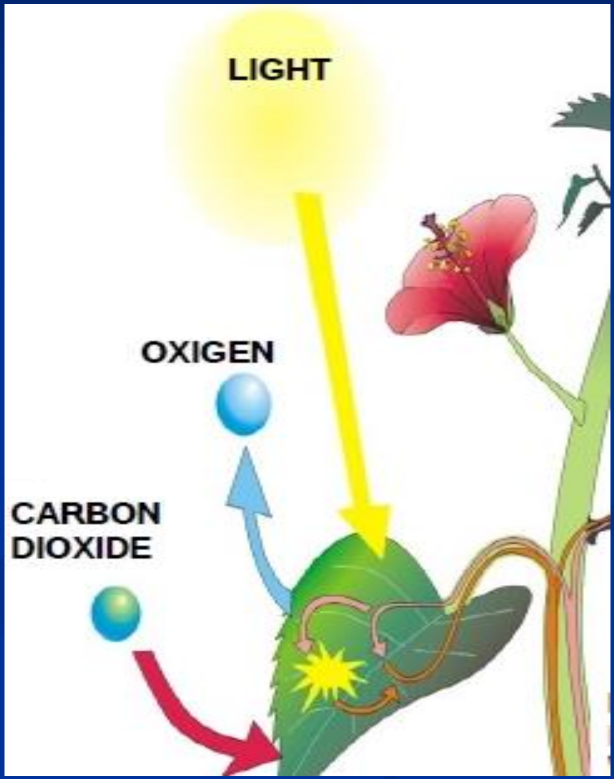
# Activity 7: Greenhouse effect

We put the bottles in the sun and measure the temperature inside every 5 minutes. We write down the measurements to determine how the greenhouse effect influences.



# Photosynthesis: Oxygen production

Photosynthesis is the process by which plants and some bacteria use sunlight **to produce glucose, carbohydrates and Oxygen** from Carbon Dioxide and water.

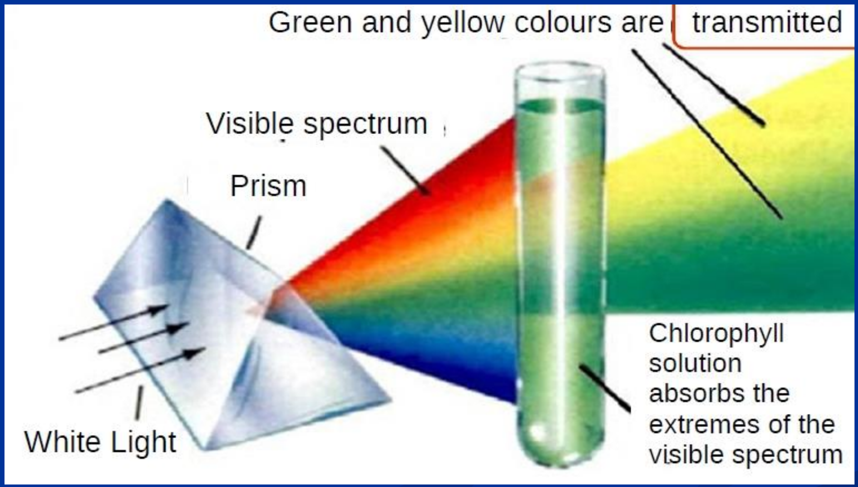



**Molecules called photosynthetic pigments convert light energy into chemical energy.**

# Photosynthesis: why the leaves are green?

**The light that is absorbed can be used by the plant in different chemical reactions, while the reflected wavelengths of the light determine the color of the pigment that will appear to the eye.**

One of the groups of photosynthetic pigments are chlorophylls that typically have two types of absorption in the visible spectrum, one in the blue region (400-500 nm), and another in the red zone (600-700 nm).




**However they reflect the middle part of the spectrum, which corresponds to the green color (500-600 nm).**

# Photosynthesis: Oxygen production

**The pigments are illuminated and transfer their electrons that are excited by the light.** Water is a donor of electrons that jump from one molecule to another and **the end result is the production of oxygen when the water molecules break down.** This is the luminous phase of photosynthesis.

In the dark phase carbohydrates or sugars are produced. Light is not necessary for that part.

# Activity 8: Oxygen production by photosynthesis


Use two transparent glass jars and place blue and red cellophane paper at the end of the jar.

# Activity 8: Oxygen production by photosynthesis

With the help of a punch, cut discs of uniform sheets (spinach or chard avoiding veins). Put 10 discs in each jar.

# Activity 8: Oxygen production by photosynthesis


Prepare a solution of sodium bicarbonate of 2 g / 1 litre of water. Place 20 ml of it in each bottle.

Soak the leaf discs with the bicarbonate solution. Place the discs in a 10 ml disposable syringe and draw in the bicarbonate solution until the discs are suspended.

# Activity 8: Oxygen production by photosynthesis

Remove as much as possible the air that has entered, leaving only discs suspended in bicarbonate.
Seal the end of the syringe with a finger and suck tightly, trying to make the vacuum, so in the internal spaces of the plant tissue air is replaced by bicarbonate solution that will be an available carbon source, close to the photosynthetic structures of the leaf.

# Activity 8: Oxygen production by photosynthesis

Place the leaf discs in each jar. Cover each of the jars with red and blue cellophane paper.

Place an individual light bulb (not less than 70W) over each jar (with the paper covering it). Both lights at the same distance.

Better LED because others emit energy as heat.

# Activity 8: Oxygen production by photosynthesis

When turning on the light, start recording the time for the discs to float.

It is an indirect measure of the rate of photosynthesis.

# Activity 8: Oxygen production by photosynthesis

Wait about 5 minutes and the discs begin to rise (depending on the powers of the lights and their distance).

# Activity 8: Oxygen production by photosynthesis

The discs begin to float as they release oxygen in the form of bubbles, which help in floating.

Times are different, depending on the color of light: it is faster for blue light (it is the high energy component of electromagnetic radiation, it is the most efficient in the process)

# Activity 9: Life in extreme conditions

Yeasts (fungi) transform sugar (glucose) into ethyl alcohol or ethanol and carbon dioxide.

Fermentation is a low energy efficiency process, while breathing is much more cost-effective and more recent from an evolutionary point of view.

# Activity 9: Life in extreme conditions

**If the presence of carbon dioxide is observed we will know that there has been fermentation and therefore the possibility of life has been tested.**

In all cases of our experiment we start from a crop in which water is present.

# Activity 9: Life in extreme conditions

We will use:

1 tablespoon of yeast (to make bread). It is a live microorganism easy to get,

1 glass of warm water (just over half a glass between 22º and 27º C),

1 tablespoon of sugar that microorganisms can consume.

The same procedure in the control experiment and the other experiments developed under extreme conditions.

# Activity 9: Life in extreme conditions

**Control experiment:**
In a glass, dissolve the yeast and the sugar in warm water. The mixture obtained is quickly placed in an airtight plastic bag, removing all the air inside and closing it.

It is important not to leave any air inside the bag.

# Activity 9: Life in extreme conditions

**Control experiment**

After 15-20 minutes you see the carbon dioxide bubbles in the swollen bag

The presence of carbon dioxide bubbles shows that microorganisms are alive.

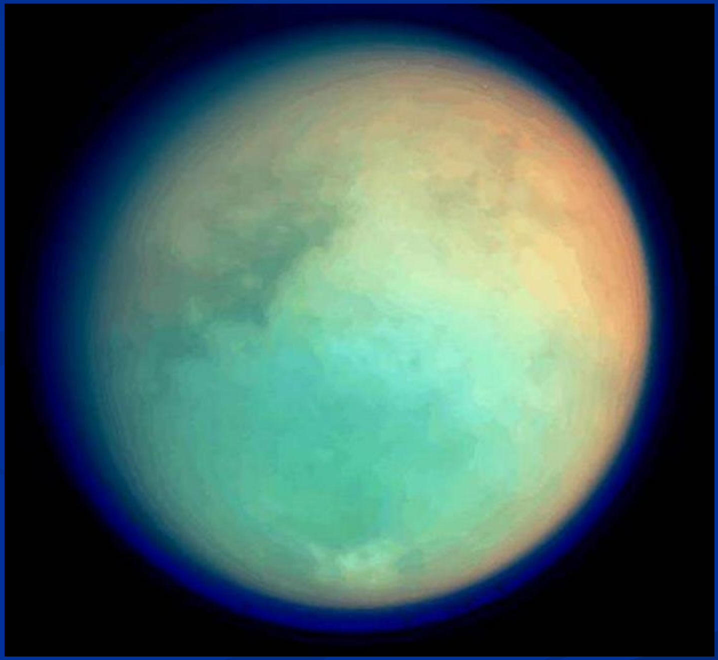
# Activity 9: Life in extreme conditions

**Procedure on an "alkaline planet" (e.g. Neptune or Titan or GJ1132b with ammonia):** Repeat the experiment with sodium bicarbonate or ammonia

Ph alkaline scales:

Sodium Bicarbonate or Baking soda: Ph 8.4

Homemade Ammonia: Ph 11

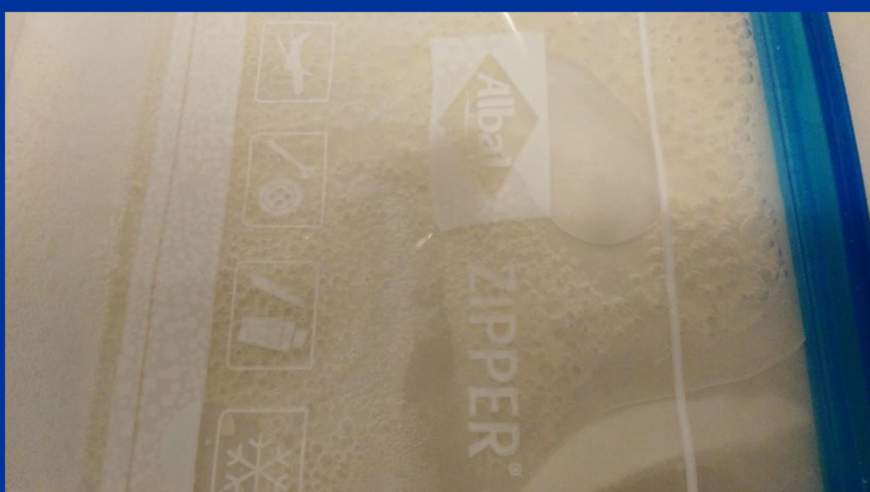
Titan, Credit NASA

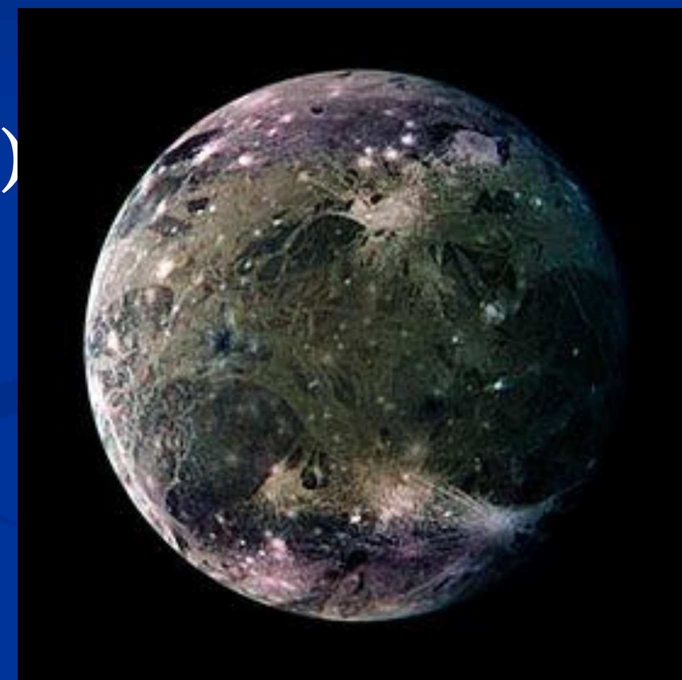
If there are bubbles there is life

# Activity 9: Life in extreme conditions

**Procedure on a "saline planet"**
**eg Mars or Ganymede or WAPS 96b)**

Repeat the experiment dissolving sodium chloride (common salt) in the water.



Ganimede, Credit NASA

If there are bubbles there is life

# Activity 9: Life in extreme conditions

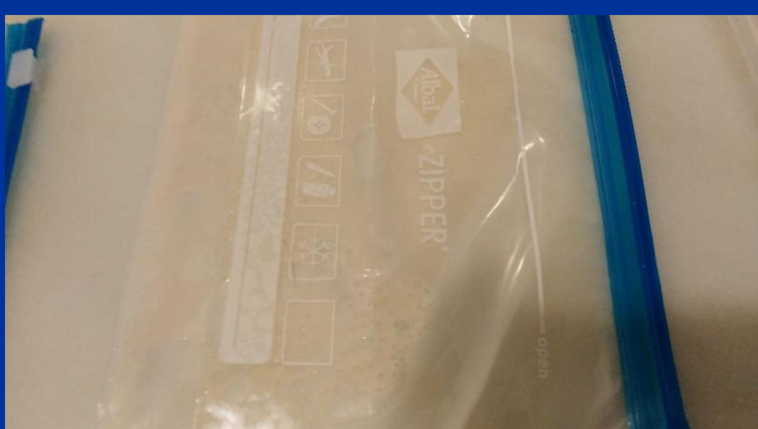
**Procedure on an "acid planet" (eg Venus that has sulfuric rainfall or Io or WAPS 39b):**

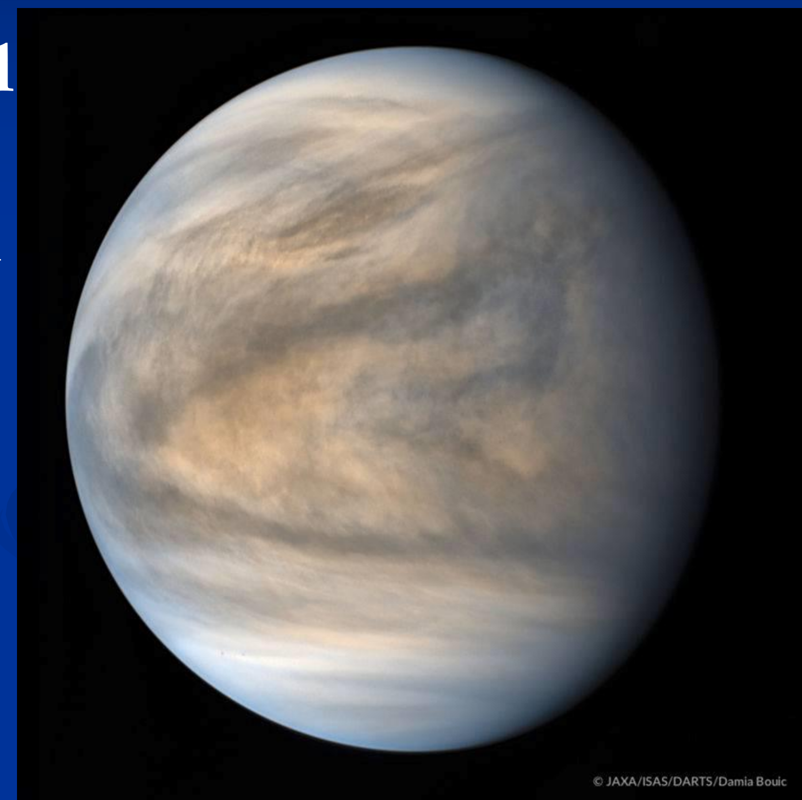
Repeat dissolving vinegar or lemon juice in the cultivation water.

Ph Acid scales:

Vinegar: Ph 2.9

Lemon juice: Ph 2.3



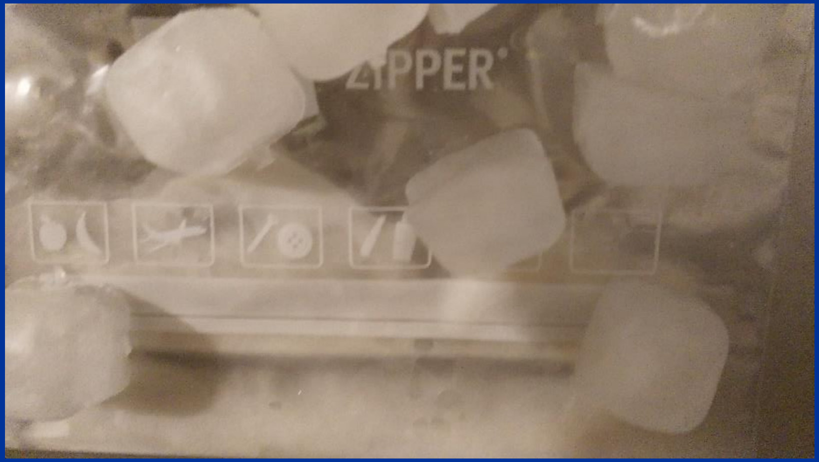

Venus, Credit NASA

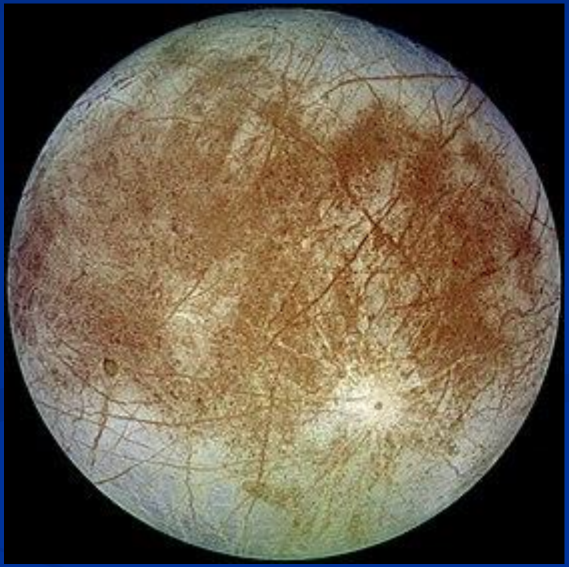
If there are bubbles there is life

# Activity 9: Life in extreme conditions

**Procedure on an "icy planet" (eg Europa or Gliese 667 C d or Barnard b)**

Place the bag in a container full of ice or use a freezer



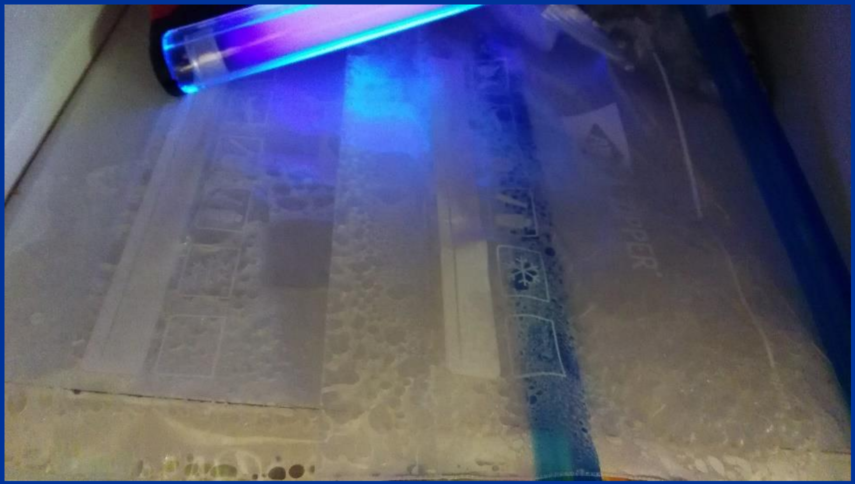
Europe (Credit NASA)

If there are no bubbles there is no life

# Activity 9: Life in extreme conditions

**Procedure on a "planet with UV" (eg Mars or Trappist-1 e, f y g)**

**Perform experiment but with the bag under UV light**



Mars, (Credit iStock)

If there are no bubbles there is no life

# Activity 10: Looking for a second Earth

Earth is the only known planet with life. Let's look for an exoplanet with similar conditions. But what parameters are important?

- ❑ Radius and Mass of exoplanet
- ❑ Habitable zone
- ❑ Mass of the Host Star

# Radius and Mass (exoplanet)

The radius and mass of the planet must be considered to assess an adequate density.

**Using the Kepler Mission criteria:**

- Earth-sized planets must have a radius of less than 2 Earth radii. R<2Re
- 10 Earth masses are considered an upper limit for super-terrestrial planets M<10Me

# Habitability Zone

The main sequence stars have a direct correlation between brightness and temperature. The hotter the surface temperature is, the brighter the star is and the further away is the habitable zone.

| Spectral Type | Temperature K | Habitability 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 |

# Host Star Mass

The evolution and life of a star depends on its mass. The energy that a star can obtain from hydrogen fusion is proportional to its mass. And **the main sequence time is obtained by dividing it by the luminosity of the star.** Using the Sun as a reference, the life of a star in the main sequence is $t_*/t_s = (M_*/M_s)/(L_*/L_s)$

For the main sequence, the luminosity is proportional to the mass according to $L \alpha M^{3.5}$

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

# Host Star Mass

Then $t*/ts = (Ms/M*)^{2.5}$

As the life of the Sun **$ts=10^{10}$** years, the lifespan of a star is:

$$t* \sim 10^{10} \cdot (Ms/M*)^{2.5} \text{ years}$$

Let's calculate the upper limit for the mass of the star so that the residence time in the main sequence is at least 3 x $10^9$ years to give time for life to evolve.

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

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

$$\mathbf{M* =< 1.6\ Ms}$$

# Looking for a second Earth

| 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 |

# Looking for a second Earth

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| HD 209458 b | ~~219.00~~ | ~~15.10~~ | ~~0.05~~ | 1.10 | G0V |
| HR8799 b | ~~2226~~ | ~~14.20~~ | ~~68.0~~ | 1.56 | A5V |
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| **Luyten b** | **2.19** | **unknown** | **0.09** | **0.29** | **M3.5V** |
| Tau Cet c | 3.11 | unknown | ~~0.20~~ | 0.78 | G8.5V |
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| 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 |

# Conclusions

- Know the concept of habitability zone.
- Introduce the concepts of astrobiology.
- Show how it is possible to generate oxygen and obtain carbon dioxide.
- How to locate a second Earth.

# Thank you very much for your attention!