

Elements of Astrobiology

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Objectives

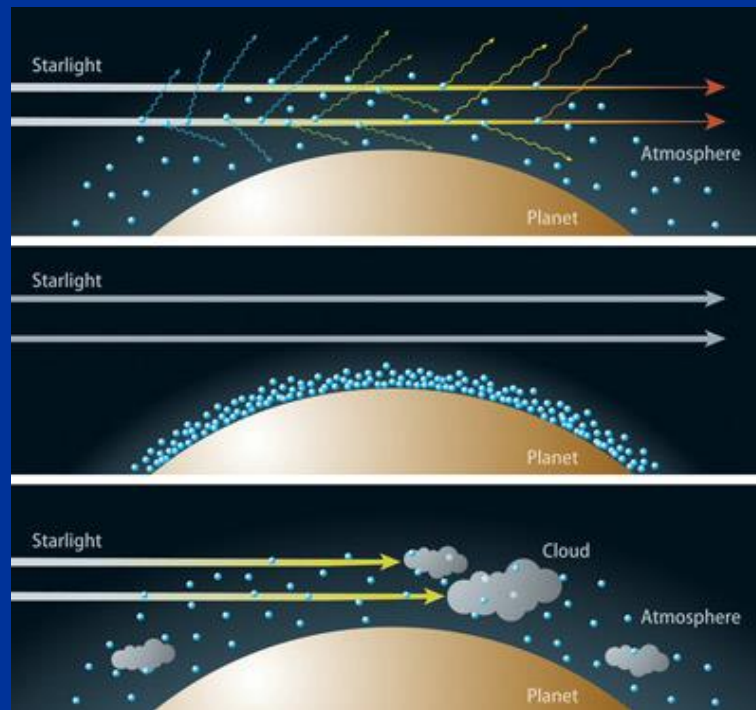
- Understand where the different elements of the periodic table arise.
- Understand the habitability conditions necessary for the development of life.
- Manage the minimum guidelines of life outside the earth.



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 began 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:

There was a lot of movement, gas particles attracted gas and dust particles attracted dust.

In the center a dense opaque core formed surrounded by a disk of dust and gas.

Participants performance:

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).

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:

This nucleus is the one that would finally give rise to the Sun or the parent star of an extrasolar system.

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.

Participants performance:

The Sun or the parent star begins to shine so that its rays must shoot outwards in all directions.

Clarification: The moment the sun or the parent star begins to shine the “loose” gas begins to move away.

The participants representing the dust that forms the terrestrial planets begin to group together.

Clarification: not all dust stays on terrestrial planets, there must be some dust in the farthest regions.



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

Text of the story:

The giant planets formed away from the heat of the Sun or the central star where the gas could gather without hinderance.

Participants performance:

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.

Chemical aspects of stellar evolution

	Elements which were produced in the first minutes after the Big Bang
	Elements which were forged in the interior of stars
	Elements appearing in supernova explosions
	Man-made elements in the laboratory

1 H																	2 He	
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba			72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra			104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		



Activity 2: 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 ₂ O: 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 Titanium Ti	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: 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.**

Legend:

- Elements which were produced in the first minutes after the Big Bang
- Elements which were forged in the interior of stars
- Elements appearing in supernova explosions
- Man-made elements in the laboratory

1																	2															
H																	He															
3	4											5	6	7	8	9	10															
Li	Be											B	C	N	O	F	Ne															
11	12											13	14	15	16	17	18															
Na	Mg											Al	Si	P	S	Cl	Ar															
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36															
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Cb	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr															
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54															
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe															
55	56											57	58	59	60	61	62	63	64	65	66											
Cs	Ba											Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn						
87	88											104	105	106	107	108	109	110	111	112	113	114	115	116	117	118						
Fr	Ra											Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og						
																		57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
																		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
																		89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
																		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

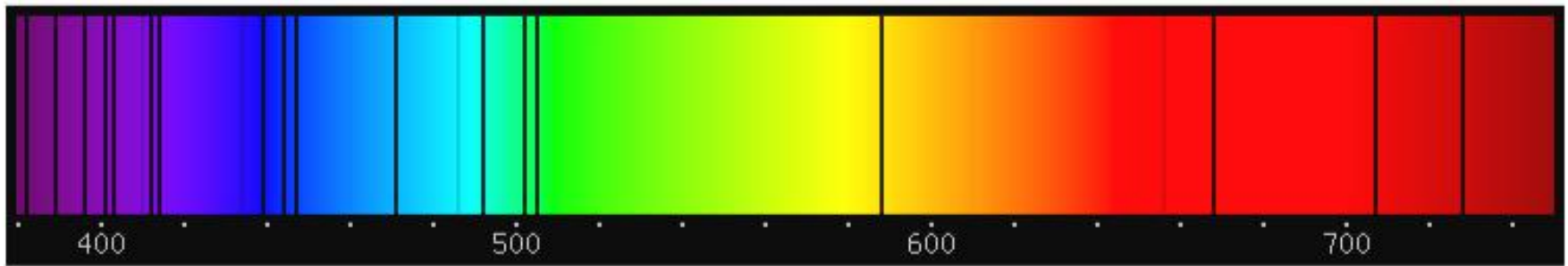
All abundant elements (except H) have been produced within the stars.

We are children of the stars !!!!



The Sun is not a star of first generation

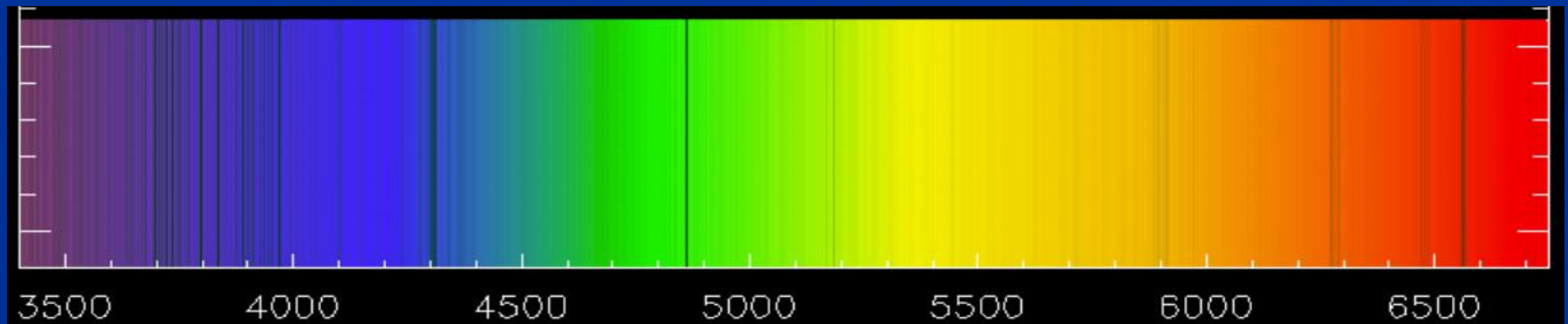
The first generation stars lived fast, died young and have not survived to this day. Only with Hydrogen, Helium and perhaps Lithium lines are visible.



First Generation 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.



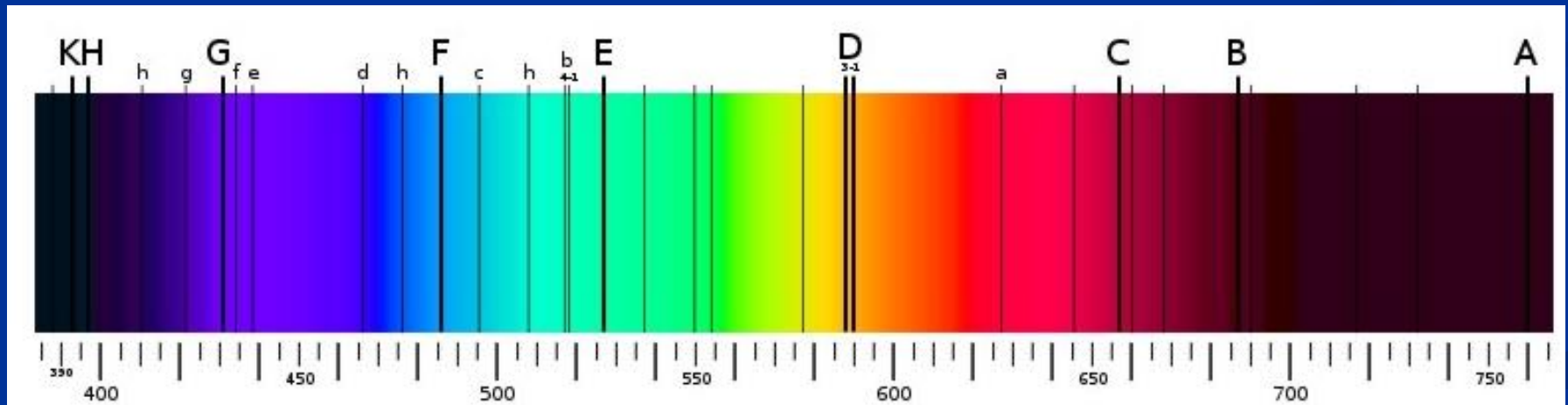
Second Generation Spectrum.

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

Zone of Habitability

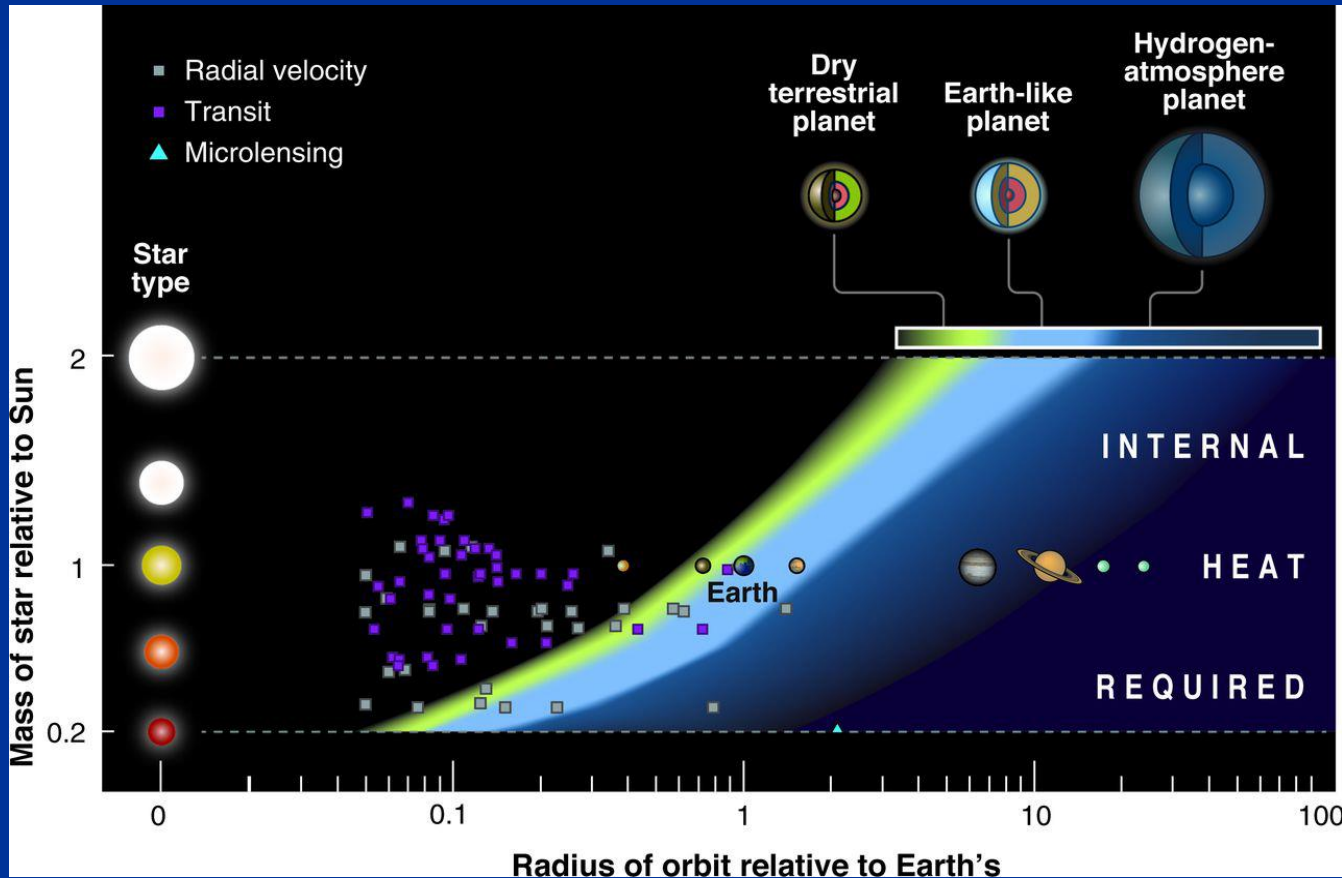
Zone of habitability is the region around a star in which the flow of radiation onto the surface of a rocky planet would allow the presence of liquid water (carbon-based life is assumed the presence of liquid water).

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

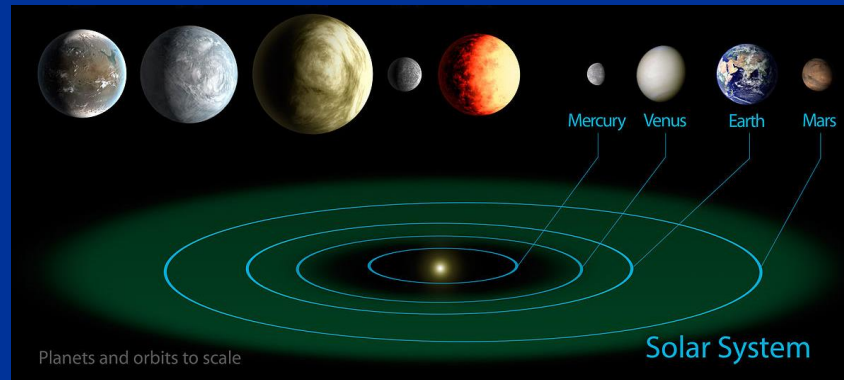
The zone of habitability **depends on the mass of the star**. If the mass is greater then its temperature and brightness increase and consequently the zone of habitability is increasingly distant.



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.



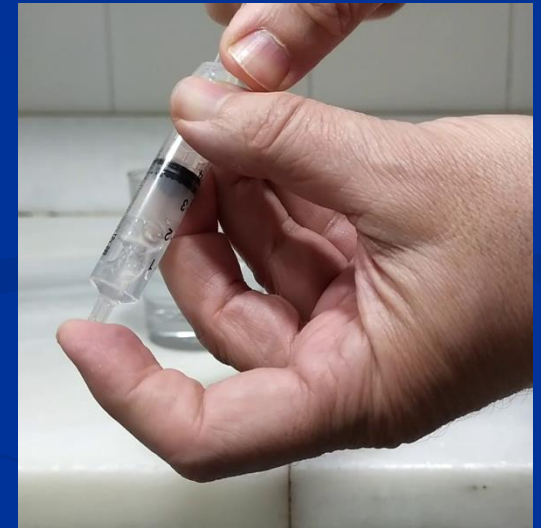
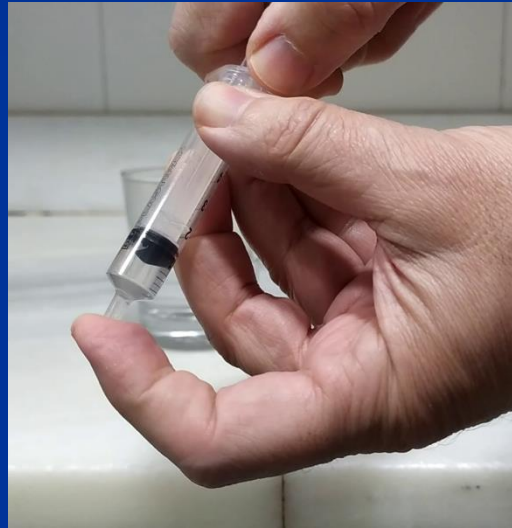
The **mass of the planet must be large enough** so that its gravity is able to retain the atmosphere.

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 4: 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 Mars has no liquid water on its surface?

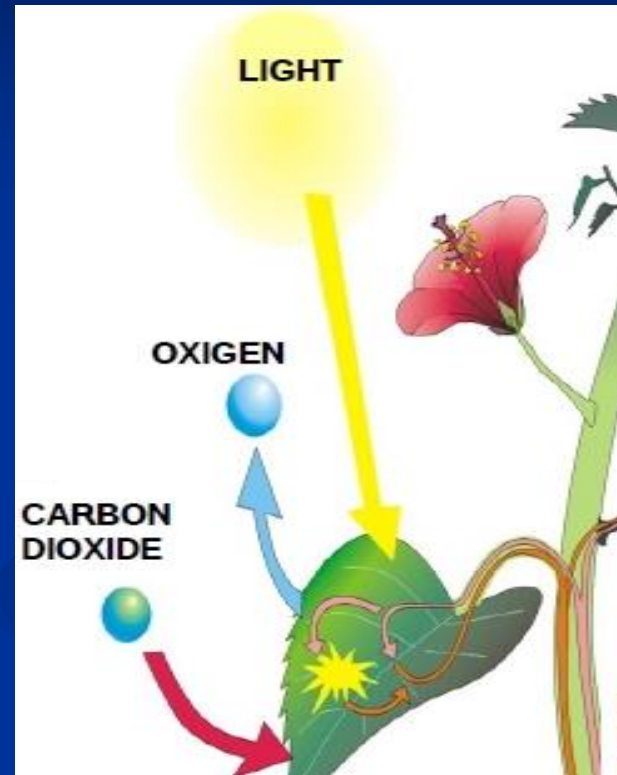
We put inside the syringe hot water close to boiling



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.

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.



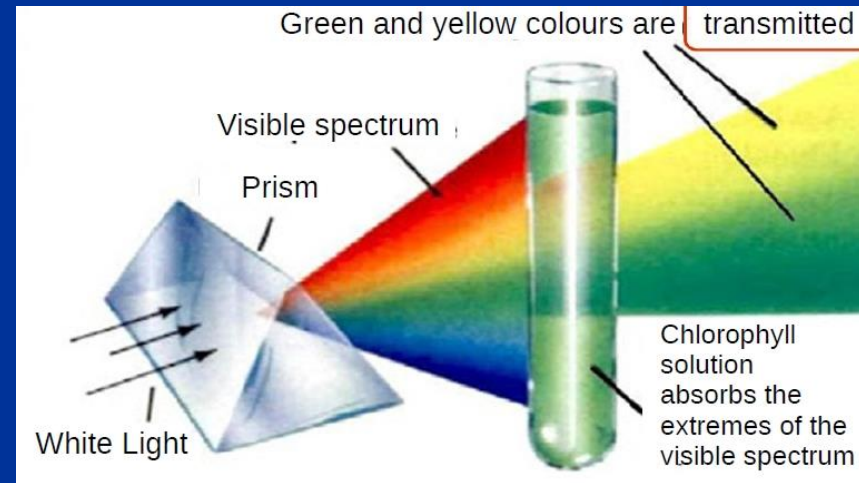
Molecules called **photosynthetic pigments** convert light energy into chemical energy.

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 5: Oxygen production by photosynthesis



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

Activity 5: 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 5: Oxygen production by photosynthesis



Prepare a solution of sodium bicarbonate of 25 g / 1 litre of water. Place 20 ml of it in each bottle.

Impregnate 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 5: 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 5: 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 5: Oxygen production by photosynthesis

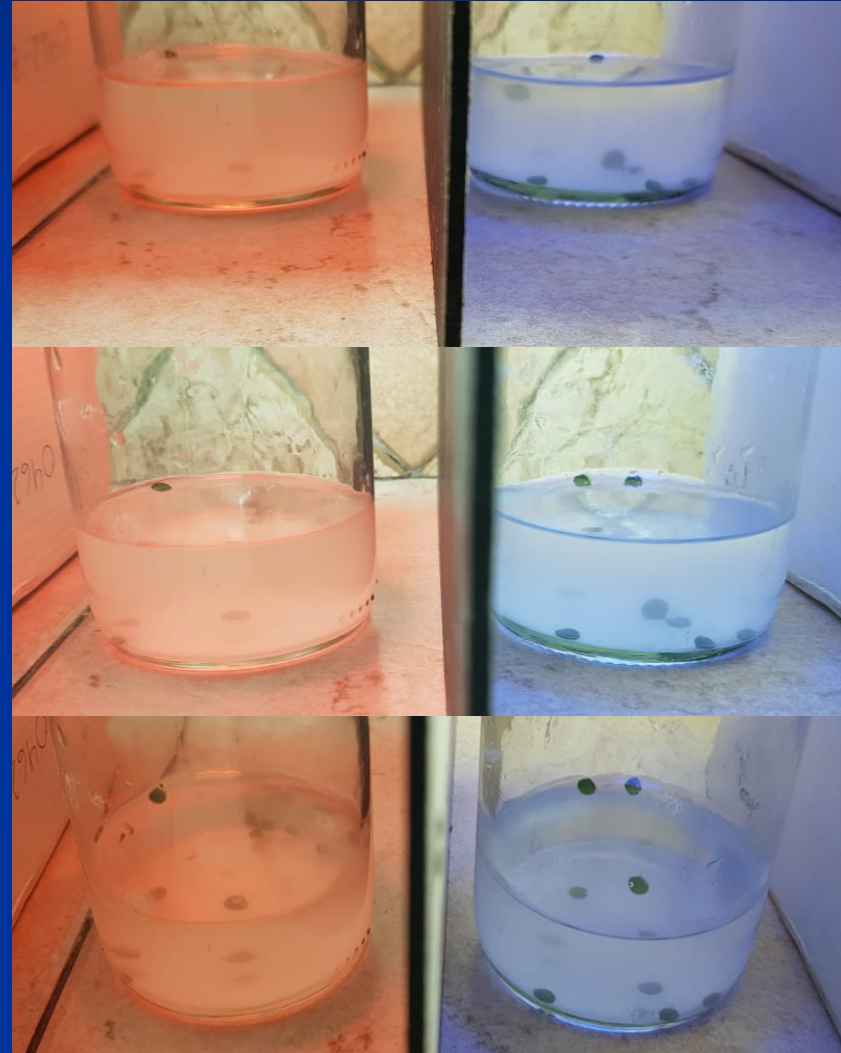
When turning on the light and start recording the time for the discs to float.

It is an indirect measure of the rate of photosynthesis.



Activity 5: 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 5: 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 6: 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 6: 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 6: 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 22° and 27° 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 6: 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.

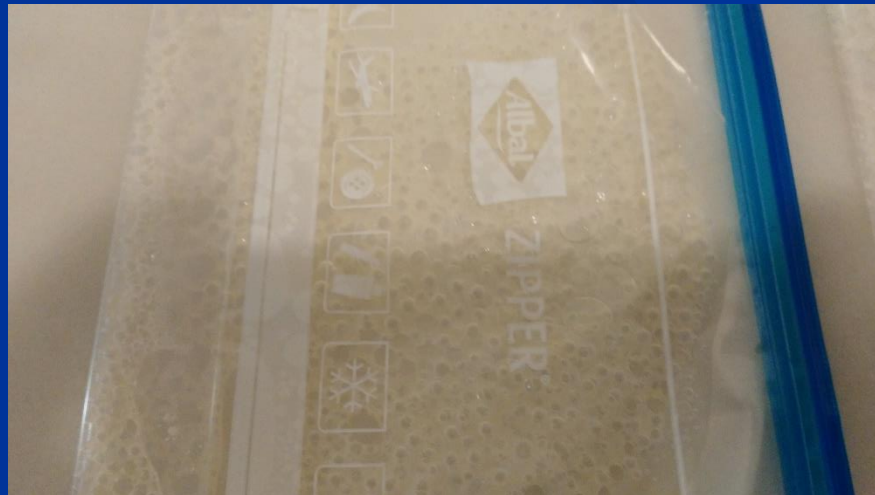


Activity 6: Life in extreme conditions

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.



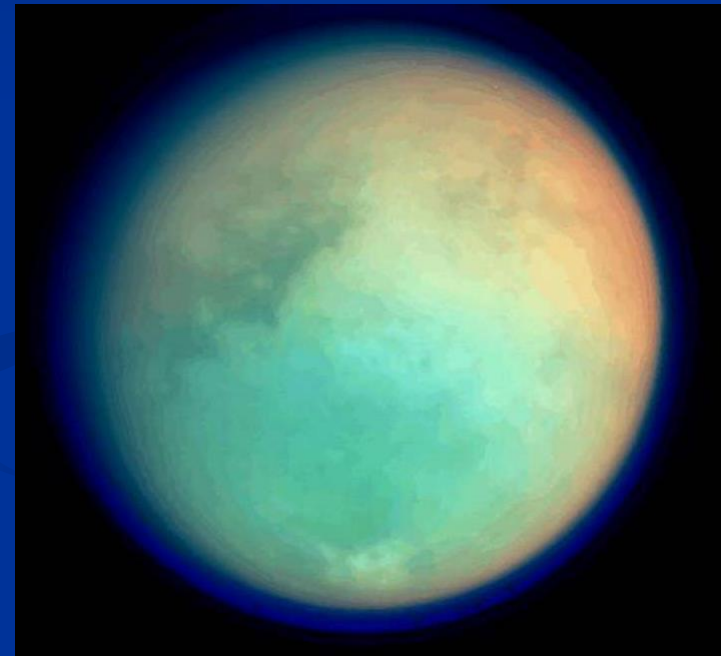
Activity 6: Life in extreme conditions

Procedure on an “alkaline planet” (e.g. Neptune or Titan both 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 6: Life in extreme conditions

Procedure on a “saline planet”
eg Mars or Ganymede).

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



Ganymede, Credit NASA

If there are bubbles there is life



Activity 6: Life in extreme conditions

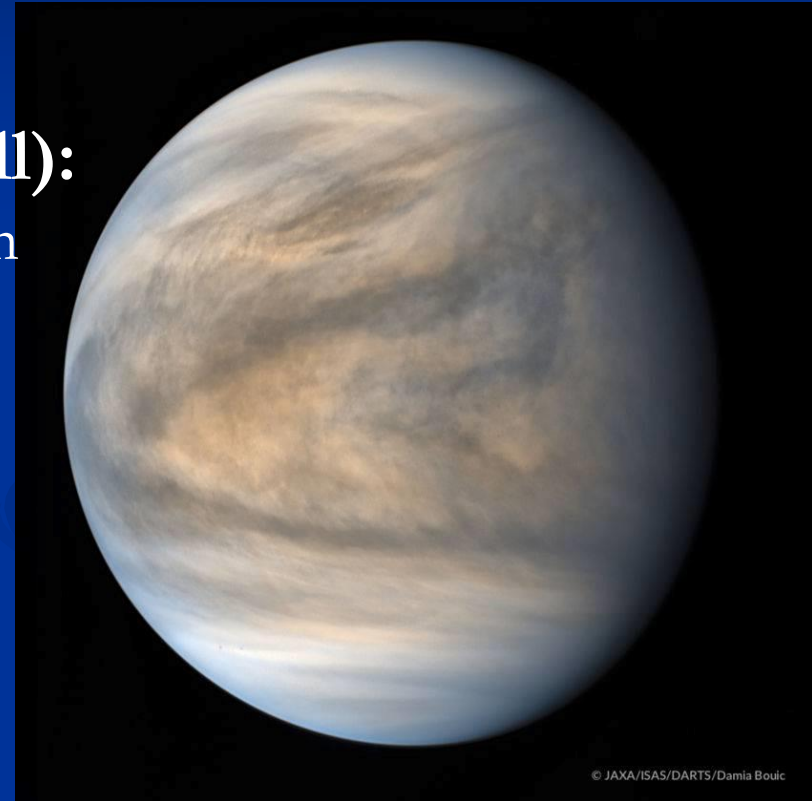
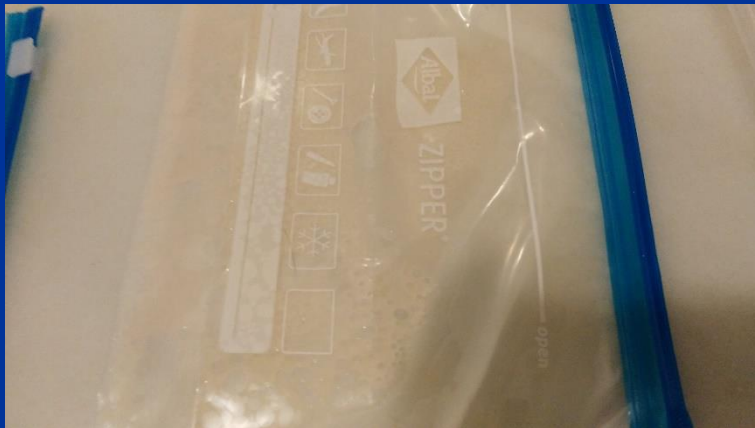
Procedure on an “acid planet”
(eg Venus that has sulfuric rainfall):

Repeat dissolving vinegar or lemon juice in
the cultivation water.

Ph Acid scales:

Vinegar: Ph 2.9

Lemon juice: Ph 2.3



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Venus, Credit NASA

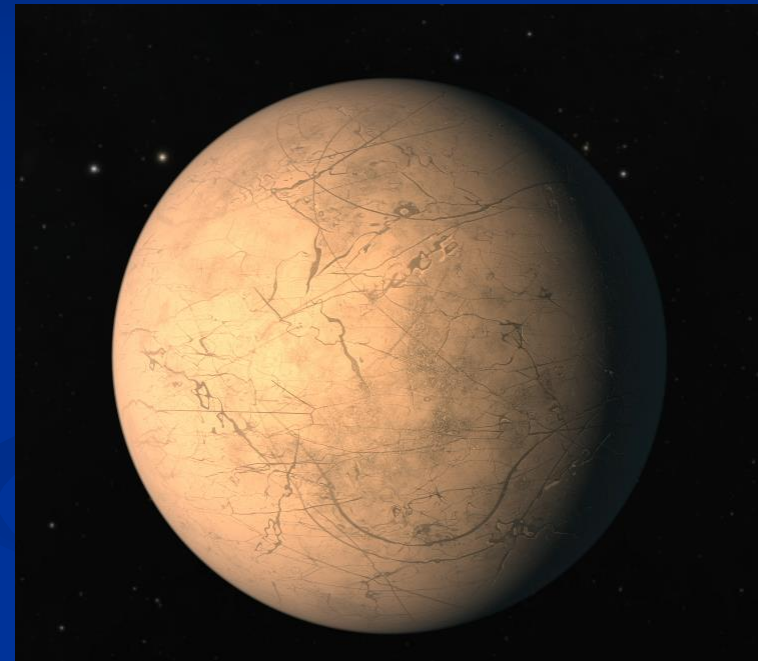
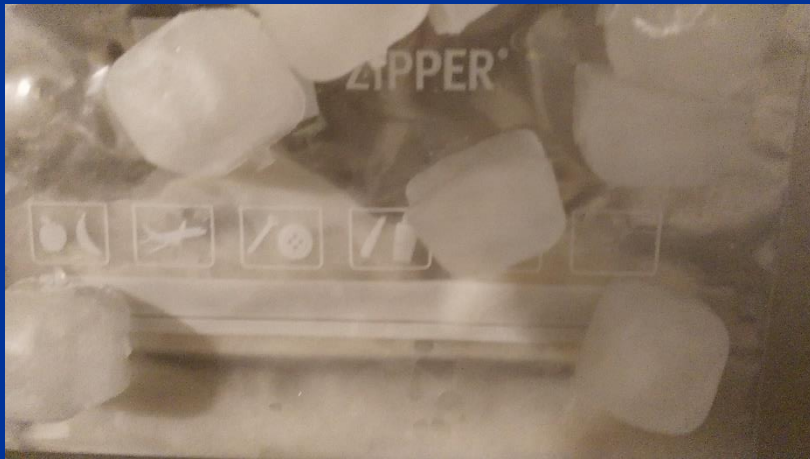
If there are bubbles there is life



Activity 6: Life in extreme conditions

Procedure on an “icy planet” (eg Europa or Trappist-1 h)

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



Trappist 1h Artist's impression

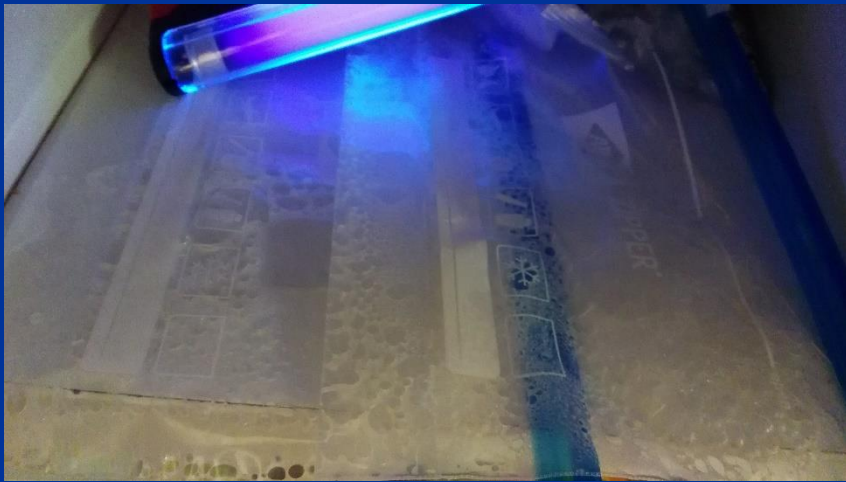
If there are no bubbles there is no life



Activity 6: Life in extreme conditions

Procedure on a “planet with UV”
(eg Mars)

Perform experiment but with the bag under UV light



Marte, Credit iStock

If there are no bubbles there is no life



Activity 7: DNA extraction

Astrobiologists study on the ground (Minas de Río Tinto, Antarctica, Atacama Desert, etc.) how life evolves or adapts to understand how it originated.

The DNA extraction process is the first step in many of the protocols that are used to discover organisms adapted to extreme environments and to find out their adaptation mechanisms.



Activity 7: DNA extraction

The sequence DNA allow detecting the existence of life (current or past), and this is used to search for life in space.

The DNA molecule is very long and packed with proteins (like a ball of wool) inside cells.

Solution to break the cell: 1/2 glass of water

1 teaspoon of Salt, Sodium Chloride, to remove the proteins and thus release the DNA

3 teaspoons of Sodium Bicarbonate, to keep the pH of the solution basic and constant and that the DNA remains undegraded

Add dishwashing liquid until the solution has the same color, to break the membrane of the greasy cells

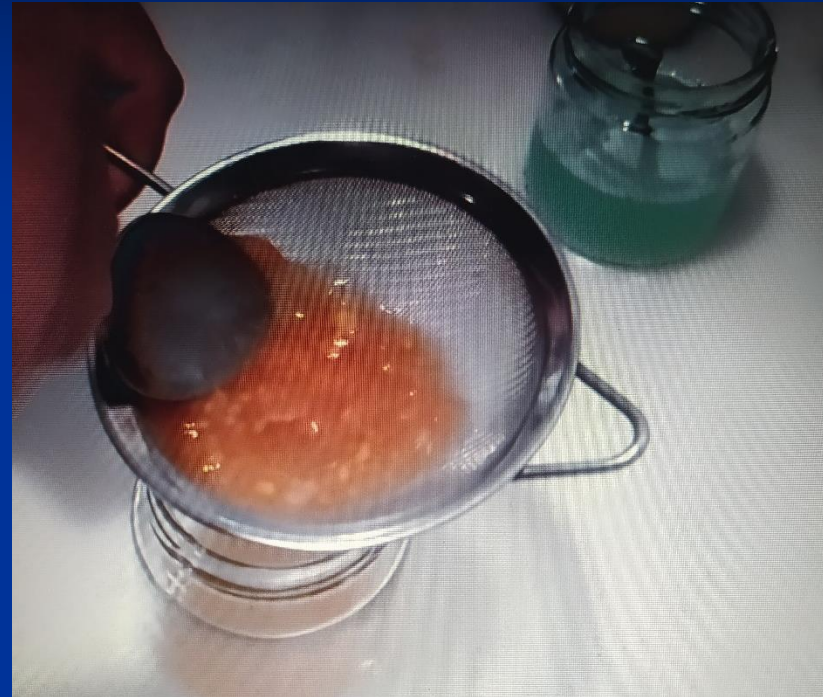
mix without foaming to get a good view of the DNA.



Activity 7: DNA extraction

Prepare the cell juice "of tomato"

2 tablespoons tomato pulp, mash it with a fork until becomes pureed
We add the innovative solution (the volume of the solution is double compared to that of the tomato puree).



We mix carefully to break the cells, being careful not to foam.
Then we strain to remove the large pieces

The content inside the cells is in the juice



Activity 7: DNA extraction

Make DNA visible

When there are many strands of DNA we see it as a white cloud (salt gives it a whitish color, DNA is not visible to the naked eye). We slowly add alcohol, dripping it on the wall of the glass of juice, because we want the layer of alcohol to remain above the juice without mix them.

In 3 or 4 minutes a white cloud of DNA forms which agglomerates and becomes visible (climbing to the top). Alcohol is added because the DNA is not soluble in alcohol and thus a cloud of DNA is formed.



Activity 8: 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. $R < 2R_e$
- ❑ 10 Earth masses are considered an upper limit for super-terrestrial planets $M < 10M_e$

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

$$t^*/t_s = (M^*/M_s)/(L^*/L_s)$$

Host Star Mass

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

$$t^*/t_s = (M^*/M_s) / (M^{*3.5}/M_s^{3.5}) = (M^*/M_s)^{-2.5}$$

$$t^*/t_s = (M_s/M^*)^{2.5}$$

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

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

Host Star Mass

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

$$M^* = (10^{-10} \times t)^{-0.4} M_{\text{S}}$$

$$M^* = (10^{-10} \times 3\,000\,000\,000)^{-0.4} M_{\text{S}}$$

$$M^* \leq 1.6 M_{\text{S}}$$

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

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	48.5	41.8	4.73	A6V
HD 209458 b	219.00	45.10	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	46.34	0.06	1.43	F
Trappist-1 b	0.86	1.09	0.01	0.08	M8
TW Hya d <small>(yet unconfirmed)</small>	4	unknown	24	0.7	K8V
HD 10613 b	42.60	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	42.60	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!

