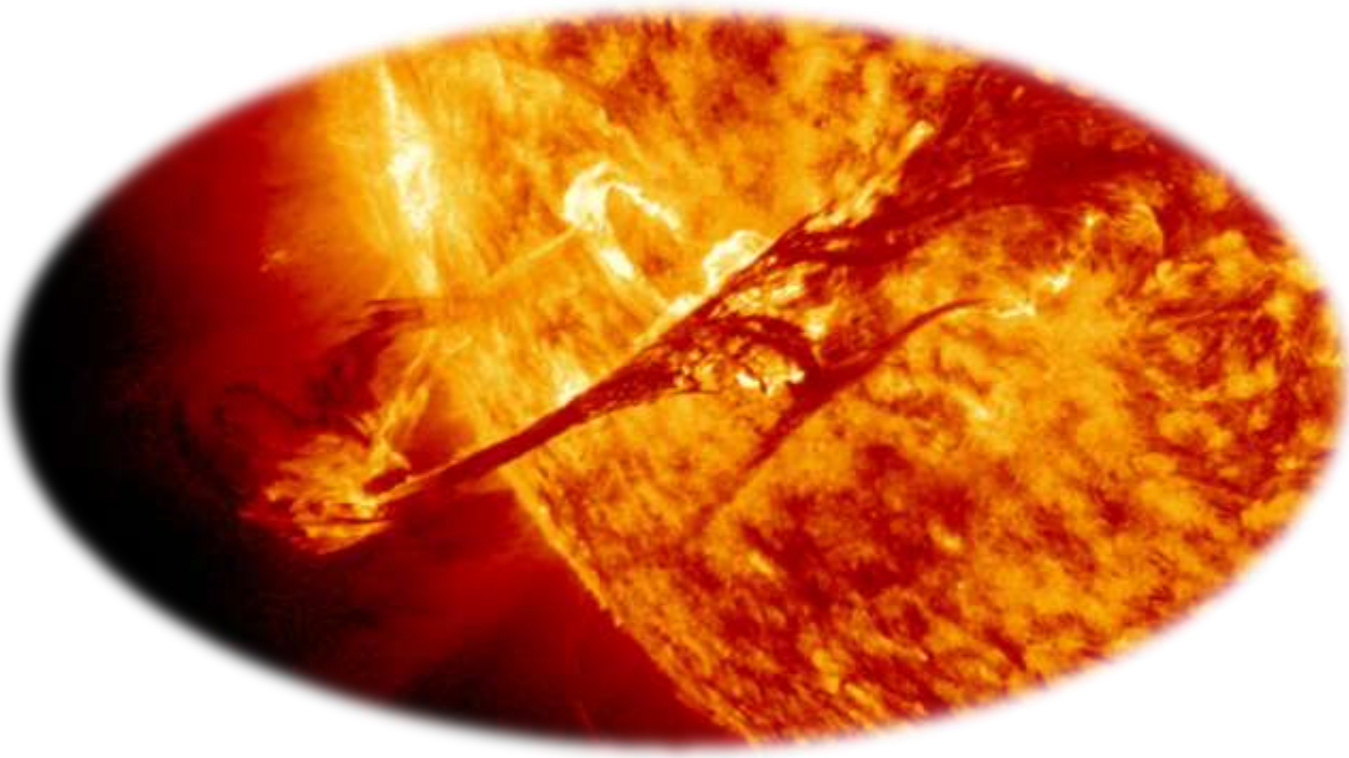
CESAR Scientific Challenge

Solar storm heading towards Earth

Study the magnetic activity of the Sun with SOHO

Student Guide



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Your Scientific Challenge

S.O.S! Solar Storm heading towards Earth

Message from the European Space Agency's missions monitoring the Sun:

"S.O.S! STOP. S.O.S! STOP. SOHO has detected a solar storm towards Earth. STOP. Take cover! STOP."

Solar Orbiter has confirmed that the storm is coming to Earth. How long do we have to take cover? **Help us!**

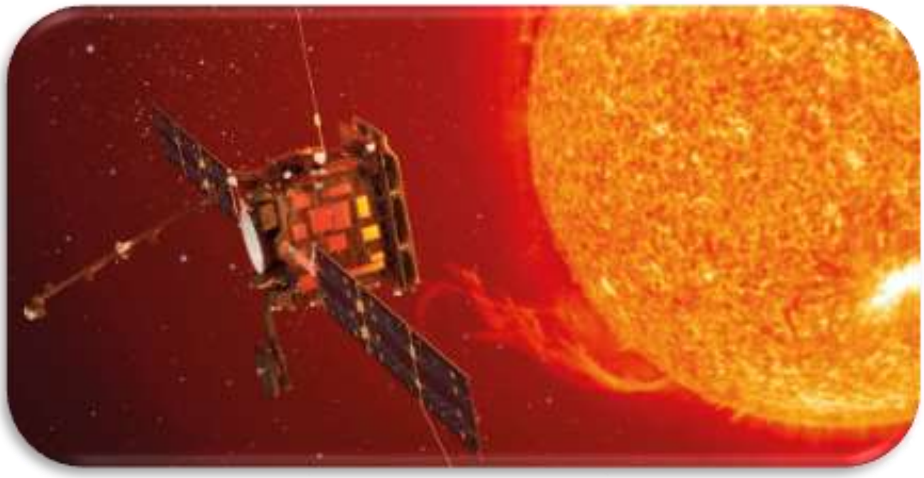

Figure 1: Solar Orbiter satélite (Créditos: www.agenciasinc.es)

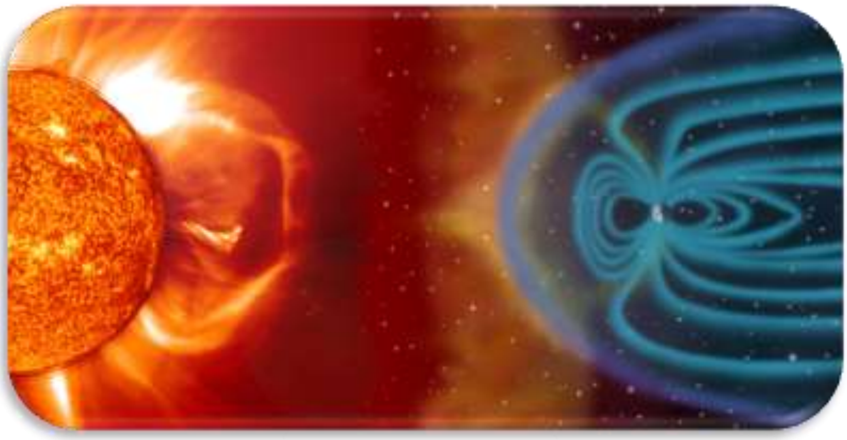

Figure 2. Coronal mass ejection (CME). (Créditos: https://www.quo.es/explosion-solar/)

In this scientific challenge you will discover what kind of material the Sun is sending into space and the impact it has on the Earth. Also, by observing the images from the SOHO satellite we will obtain information about the solar ejections, so we can know when they will arrive to Earth. **Can we count on you?**

Phase 0

To put us in context we recommend looking at these **videos**:

- This is ESA (5 min)
- ESAC: ESA's A window on the Universe (3 min)
- Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura (15 min)
- Other videos about Space.

You will work in Teams of (4-6) people, each of you having an specific key role, unique and needed for the Team. Fill in Table 0 with the Identification for the Challenge, Number of the Team and Name of the Team members.

Challenge ID			**Team Number (1-6):**	
Members				
Professions	**Mathematics Software Engineer**	**Astrophysicists**	**Engineers**	**Biologists/ physicist**
Roles	She/he leads the correct execution of the calculations	She/he controls the solar telescope	He/She is in charge of finding agreements and leading the team.	He/She addresses the need for further research.
References **(female)**	Katherine Johnson 	Vera Rubin 	Samantha Cristoforetti 	Marie Curie 
(male)	Steve Wozniak 	Matt Taylor 	Pedro Duque 	Albert Einstein 

Table 0: *Write down the Identification of your Challenge (an unique number), the Number of your Team (1-6) and the name of the team members, one of them with a clear role (and assigned tasks), all needed.*

Note: The documentation makes use of the International System of Units.

Phase 1

Activity 1 Refresh concepts

You can refresh concepts needed for the Scientific Challenge by clicking on the links in Table 1. These correspond to the contents of the school curriculum.

Motion Velocity and acceleration	Science of motion	Time units convertion
Magnets	The state of the matter	How does the nuclear energy work?

Table 1: Concepts that need to be refreshed before facing this scientific challenge.

Rectilinear uniform motion and Motion under constant acceleration:

- The rectilinear uniform motion, as its name indicates, is that which is performed in one dimension (straight line) and does not suffer changes in its speed. Its equation is :
  - $v = \frac{s}{t}$ $\qquad t = \frac{s}{v}$ (Equation 1)

Where v is the velocity, s the space and t time.

- The uniformly accelerated rectilinear movement is that which is carried out in one dimension (straight line) but its speed varies with time. Its equation is :

$$s = v_0 t + \frac{1}{2} a\, t^2 \quad \text{(Equation 2)}$$

Where v is the velocity, s the space, t time, a acceleration and v_0 is the initial velocity, which is the same that v if there is Rectilinear uniform motion and different if there Motion under constant acceleration.

1. To better understand the concepts explained before, access the following simulation. It represents with examples the equations 1 and 2 of position, velocity and acceleration.

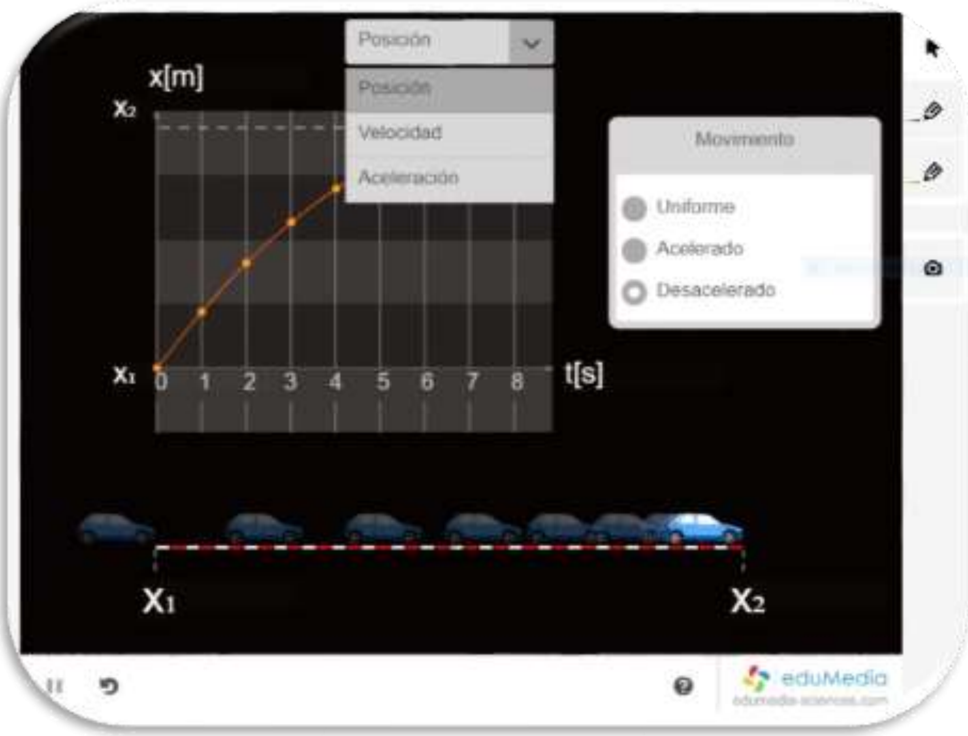

Figure 3: *Simulator rectilinear motion (Credits: EduMedia)*

Activity 2: Compare the speed and time it takes several vehicles to travel the Earth-Sun distance.

1. Complete Table 2 with the speed or time values.

Vehicle	*Velocity*	*Time*
Light	$3 \cdot 10^8\ m/s$	
Spacecraft		$6\ meses$
Aircraft	$1000\ km/h$	
Car		$142\ años$
Bike	$25\ km/h$	

Table 2: *Speed and time values of each vehicle with respect to the sun*

2. From Table 2, estimate how long do you think it would take for a coronal mass ejection to reach Earth.

3. Do you think that all Coronal mass ejection CMS will take the same amount of time to arrive to the Earth? Give your reasons behind your answer

Activity 3: The Sun

The Sun is our closest star. It is a big ball of hot ionized gas or "plasma". It generates energy through nuclear reactions inside it, compensating the gravitational collapse. Figure 4 shows some of the Sun's properties.

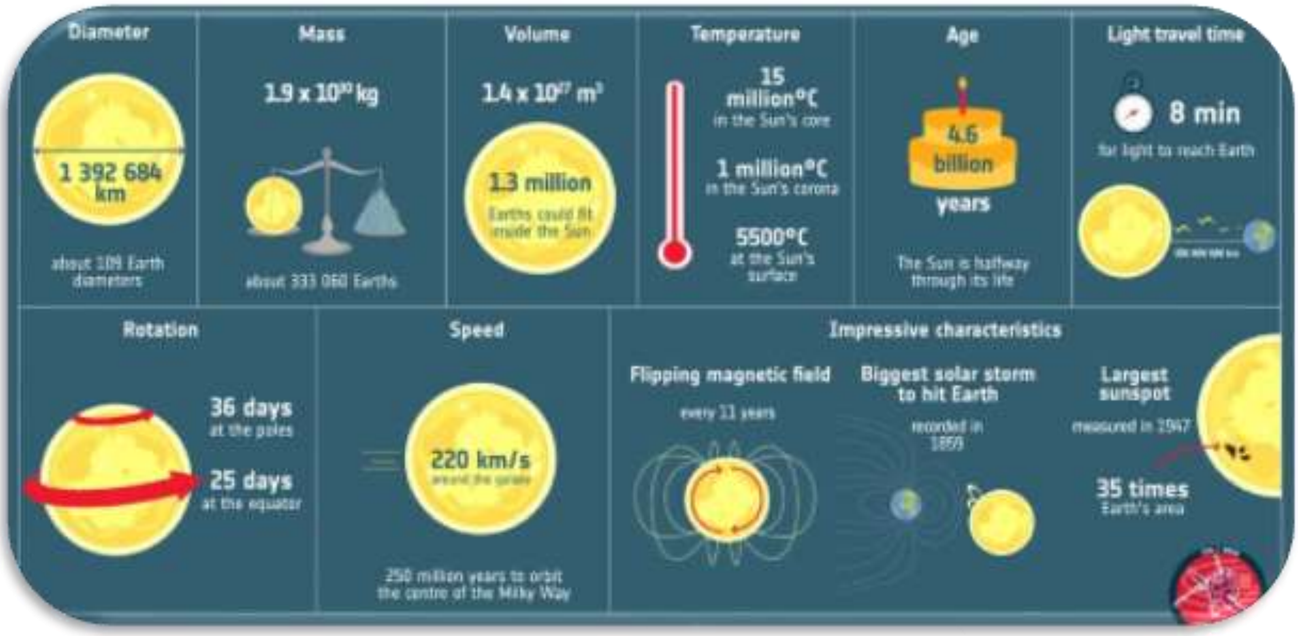

Figure 4: *Meet the Sun (Credits: ESA)*

Figure 5 shows how old do we think the Sun is, about 4 600 million years, and that we expect that in another 5 000 million years it will become a red giant.

***Figure 5**: Life Cycle of the Sun (Credits: Wikipedia)*

1. Watch this ESA video about The Sun and tell us what have you learnt.

For more information about the evolution of the Sun and other stars we recommend you to access to CESAR booklet about the Sun and the CESAR booklet about stellar evolution

Activity 3.1: The structure of the Sun

1. Draw what you think the structure of the Sun looks like.

2. Check what have learnt until now with this game (Figure 6).

Basic instructions:

- Press "play" or the upper right button "Again" if it is not the first time you play
- At the top you will be shown the name of a zone of the Sun, your mission will be to click on the number you think corresponds to that zone.
- The results appear in the upper left corner
    - If your answer is correct, the number will turn green.
    - If you fail, the number will turn red.

Pay attention to the clock. You could repeat this game as many times as needed until you get a high score. **Congrats! You can make it!**

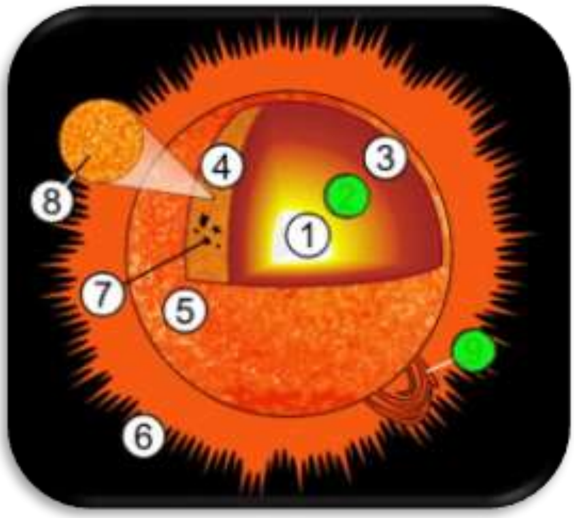

Figure 6: *Simulation layers dollars. (Credits: https*://www.purposegames.com)

1. Write here the name of the Sun layers that you remember, in order, from the inside to the outside part:

1. What layer(s) of the Sun do we see from the Earth?

WARNING-Never look directly at the sun, it can cause serious damage to your eyes.

Activity 3.2: The Chemistry of the Sun

The nuclear reactions that take place in the Sun generate the energy that makes life possible on our Planet. During the most stable phase of the stars, chemical reactions take place in their nucleus that transform 4 atoms of hydrogen into one of helium, as shown in Figure 7.

The nuclear reactions that take place in the Sun generate the energy that makes life possible on our Planet. During the most stable phase of the stars, chemical reactions take place in their nucleus that transform four atoms of hydrogen into one of helium, as shown in Figure 7.

Curiosity 1: Specifically 92 sextillions (92 000 000 000 000 000 000 000 000 000 000 000 000) of nuclear reactions occur every second in the Sun

Curiosity 2: Every second 4 260 000 tons of matter are converted into energy, which is capable of providing a (standard) home with electricity for 9 500 billion years.

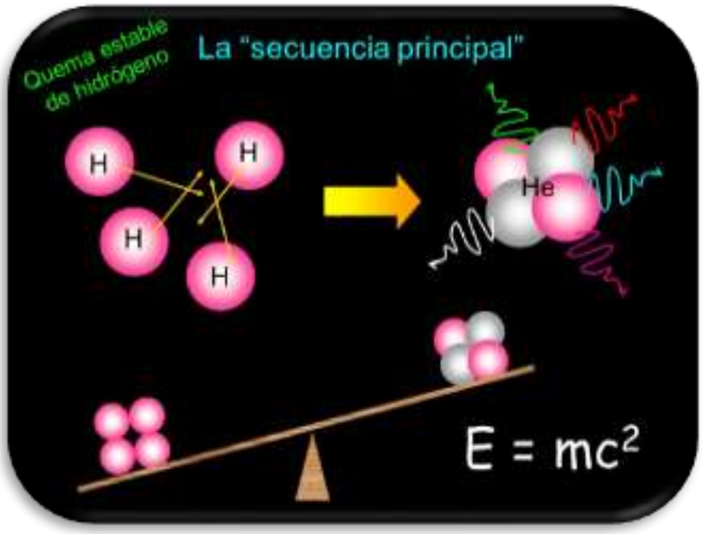

Figure 7: *Nuclear reaction of stars in their most stable phase (Credits: Talk by Dr. Benjamín Montesinos Comino at CESAR Teacher workshops).*

As shown in Figure 8, the Sun is composed mainly of hydrogen (H ~91%) and helium (He ~8.8%), plus other chemical elements in a much smaller percentage.

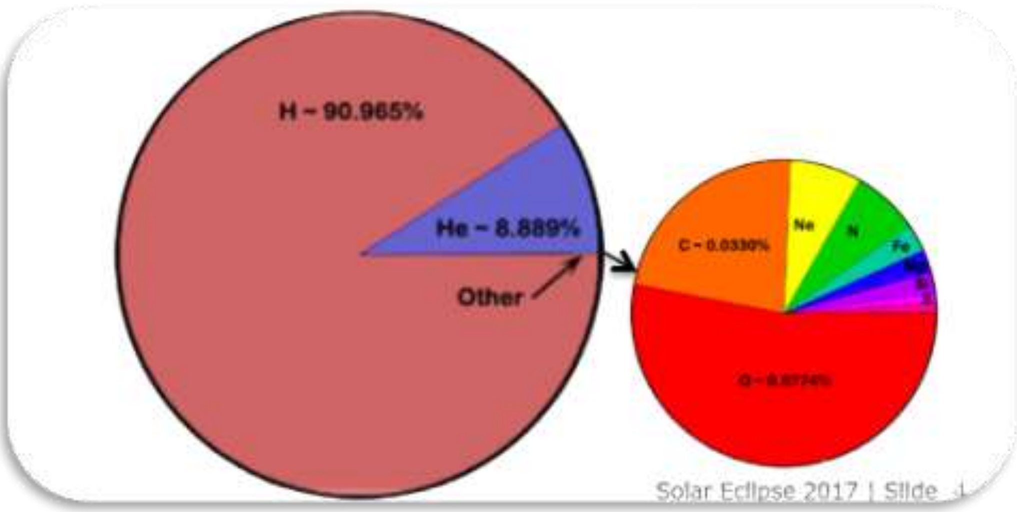

***Figure 8: Elements of the Sun (Credits: Presentation of Dr. Anik De Groof, in course of professors** CESAR).*

1. Fill in Table 4 with the most abundant elements on the Sun:
    a. The percentage of these elements can be obtained from Figure 8
    b. The identification of the chemical elements can be obtained from the Dynamic Periodic Table (Figure 9).

Figura 9: *Tabla Periódica Dinámica (Créditos: PTable).*

Proportion of that element (%)	Nomenclature	Chemical element	Group in the Periodic Table	Atomic number
90.96	H	Hydrogen	No metal	1
8.89	He			
0.07	O			
0.03	C			
< 0.1	Ne			
< 0.1	N			
< 0.1	Fe			
< 0.1	Mg			
< 0.1	Si			
< 0.1	S			

Table 4: Chemical composition of the Sun.

Proportion of that element (%)	Nomenclature	Chemical element	Group in the Periodic Table	Atomic number
47	O	Oxigen	No metal	8
28	Si			
8.1	Al			
5.0	Fe			
3.6	Ca			
2.8	Na			
2.6	K			
2.1	Mg			
0.8	Otros			

Table 5: Chemical composition of the Earth

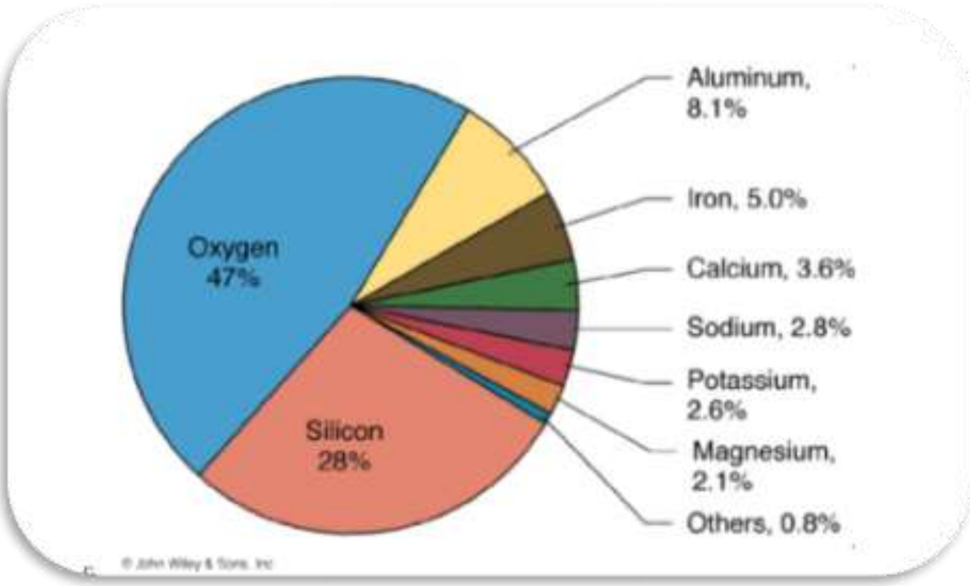

***Figure 10: Elements of the Earth (Credits: Presentation by Dr. Anik De Groof, in course of professors** CESAR).*

2. Compare the composition of the Sun and the Earth .

Figure 11 shows the positions in the electromagnetic spectrum occupied by the transitions of the different elements found in the Sun .

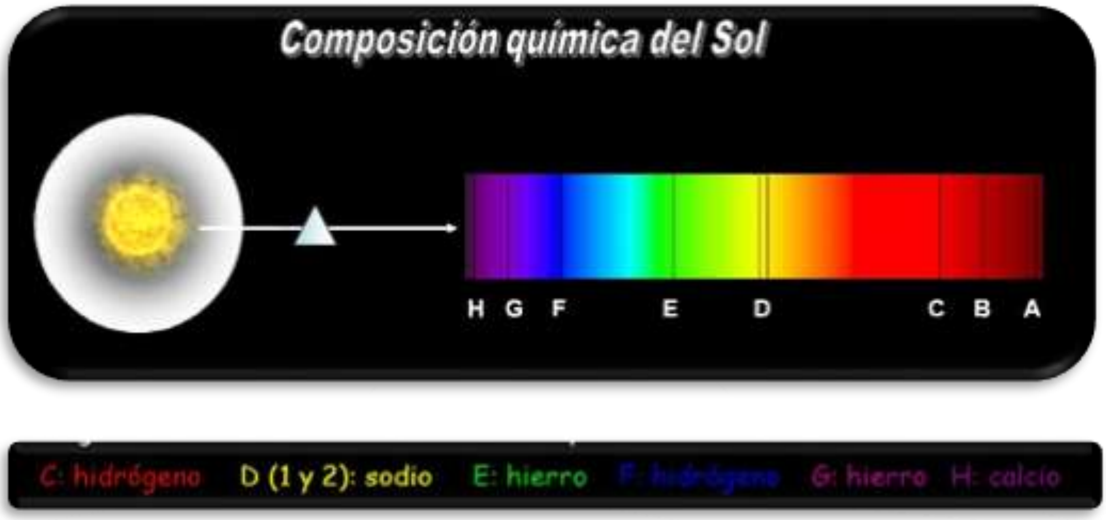

Figure 11: *Chemical Composition of the Sun (Credits :* https://slideplayer.es*)*

You may perform the activity [CESAR " What are the stars made of?](#) using the application https://spectralworkbench.org/

Activity 4: The Magnetic Activity of the Sun

As we commented in [Activity 3](#), the Sun is a large ball of gas at very high temperatures that is in a [plasma](#) state, as seen in Figure 12.

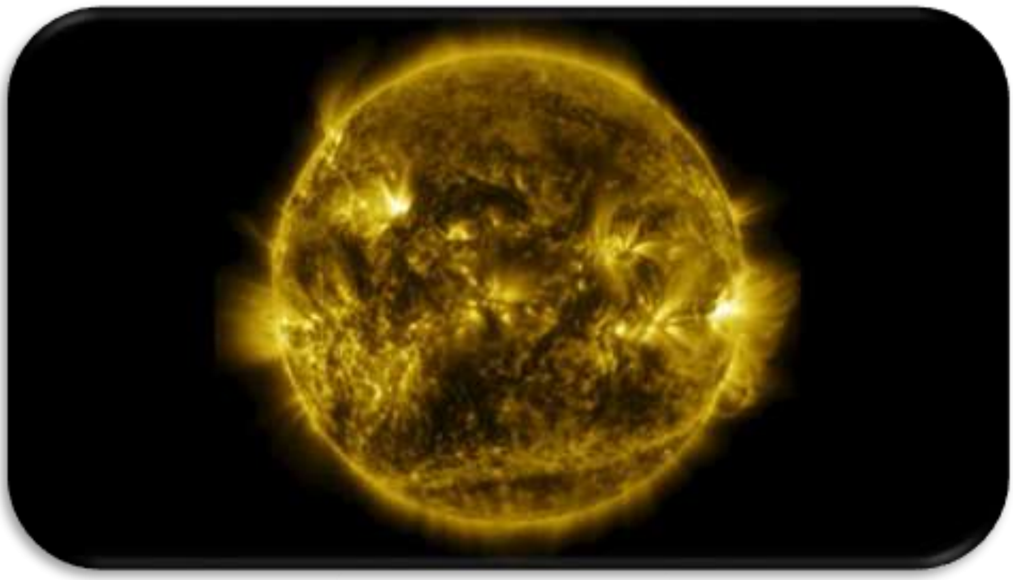

Figure 12: *Image of the Sun (Credits: Presentation by Dr. Benjamín Montesinos Comino for the CESAR teacher workshops)*

Due to the Sun is in plasma state, as the Sun spins equatorial and polar areas rotate at different velocities, twisting the magnetic field lines and causing variations in the Sun magnetic field, as shown in Figure 13.

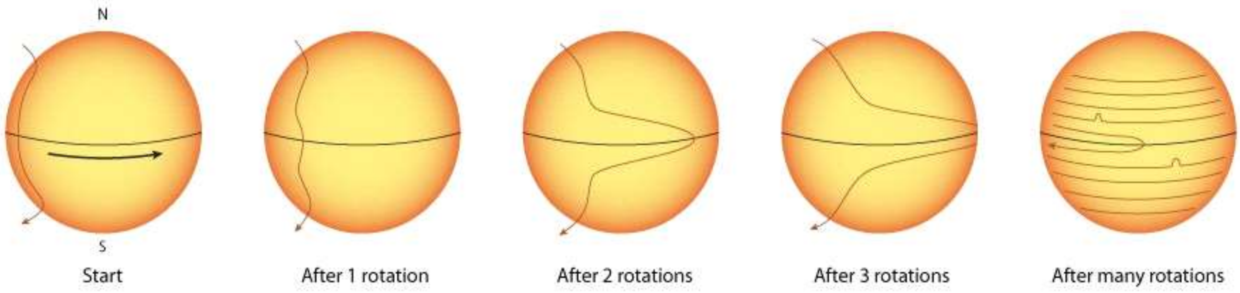

Figure 13: Explanation of how the differential rotation of the Sun is generated over several days (Credits: NASA / IBEX)

Our star is very active, from a magnetic point of view, because its magnetic field is quite intense and variable, that changes every year. The orientation of its magnetic poles changes after every maximum of activity (which occurs once per cycle or every 11 years, approximately), as shown in the data recorded in Figure 14.

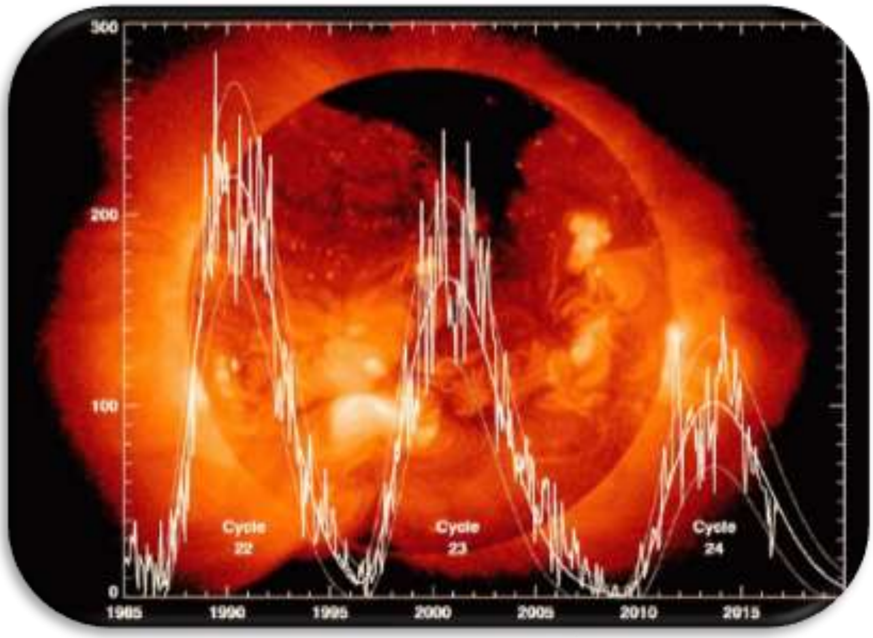

Figure 14: *Cycles of activity of the Sun (Credits https://ciencia.)*

The solar magnetic activity produces numerous effects, which altogether are known as solar activity. Figure 15 shows some of them **solar flares**, **erupting prominences**, **sunspots** and **coronal mass ejections)**.

For more information about the different effects caused by the magnetic field, we invite you to visit [CESAR's booklet on the Sun.]

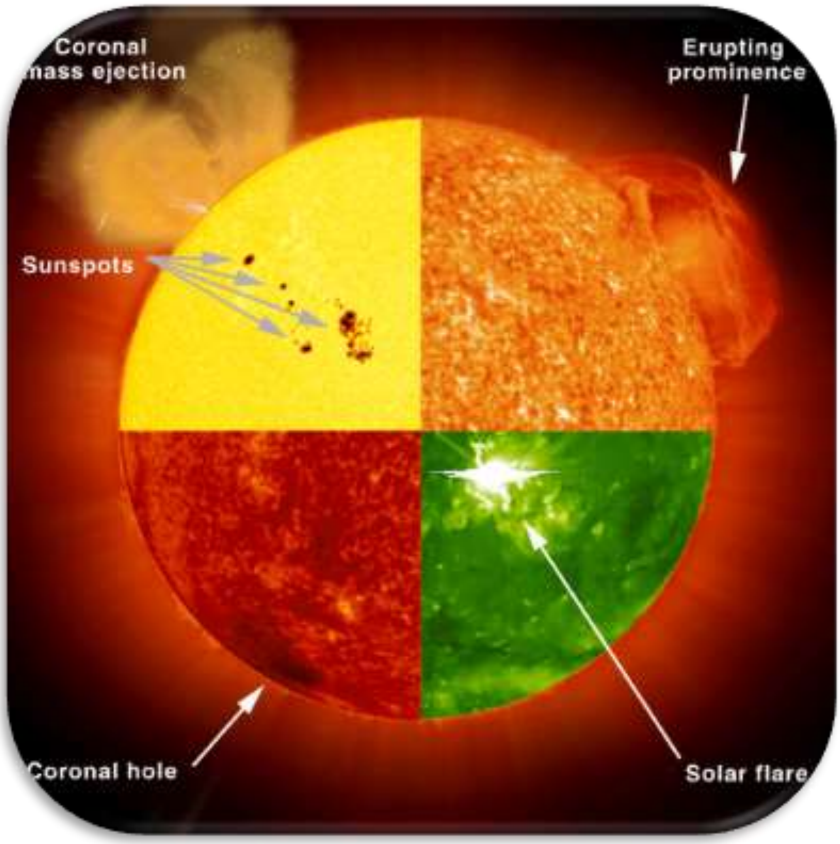

***Figure 15**: Connection between the different effects of solar activity (Credits: geomag)*

Activity 4.1: Coronal Mass Ejections (CME):

Coronal mass ejections, also called CME, are clouds of solar material (plasma) emitted from the Sun. They tents to appear when bundles of magnetic field lines, containing solar plasma, get intertwined and reconnect which causes the material to escape with high velocity. They are often a consequence of solar prominence eruption. When this happens, the material of the prominence will be ejected by the Sun, reaching velocities of about 1 000 km/s while the magnetic lines recombine. These are known as coronal mass ejections. Sometimes they occur at the same time as the **flares**, but while the former only emit light, the latter emit matter towards the Solar System, and can reach the Earth

1. ¿ In which layers of the Sun do you think coronal mass ejections are found?

Activity 4.2: The influence of the Sun on the Earth

The Sun allows the existence of life (Figure 16, zone of habitability [1]) as we know it on Earth, and the variations in its activity impact on Earth at many levels.

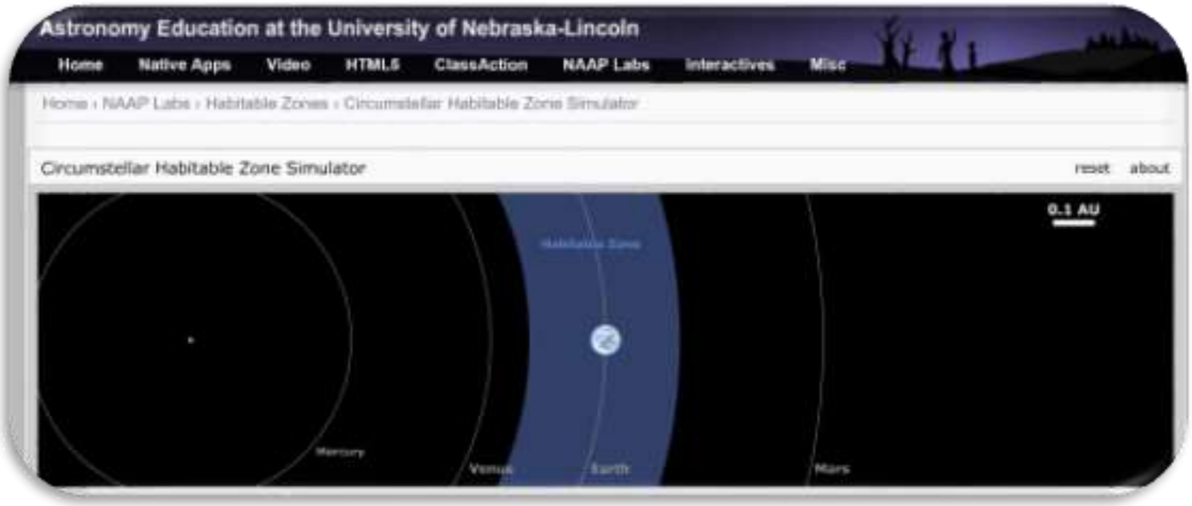

Figure 16: *Habitability zone around the Sun where the Earth is located. (Credits: Astronomy Education at the University of Nebraska-Lincoln)*

Most of the planets in the Solar System are surrounded by large magnetic envelopes. They are known as magnetospheres and are produced by activity inside the planet. These magnetospheres form the largest structures in the Solar System, being between 10 and 100 times larger than the planet itself.

The solar wind interacts with those "magnetic bubbles" deforming them. They can therefore be induced by this interaction with the solar wind and its ionosphere (Venus and comets) or by a magnetic dynamo process (as it occurs on Mercury, the Earth or the giant planets).

The Earth's magnetic field is very stable and does not change much over time, unlike the solar magnetic field. However, some of the ultraviolet radiation manages to pass through the atmosphere and so we must protect ourselves

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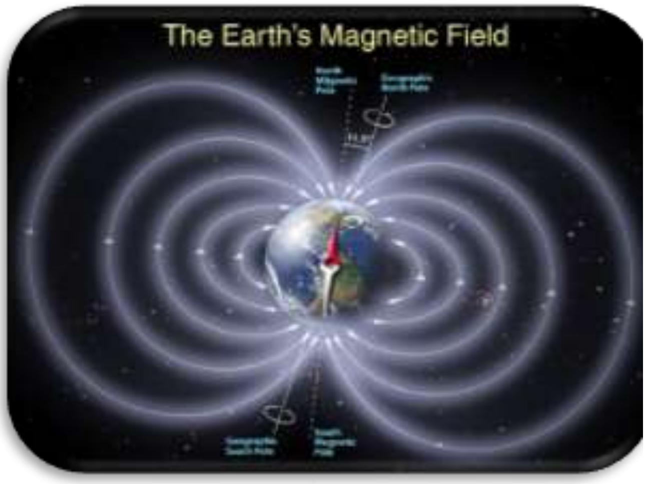
[1] Habitable zone: https://en.wikipedia.org/wiki/Circumstellar_habitable_zone. For more details about the circumstellar habitable zones, please visit this GoLabz activity.



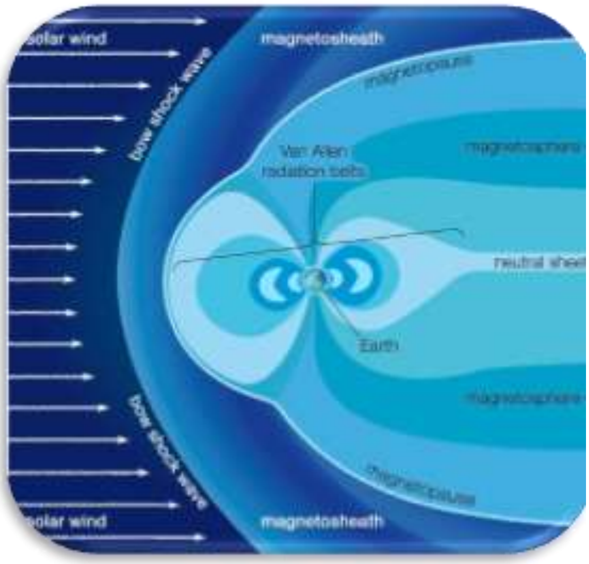


Figure 17: Earth's magnetic field and the influence of the solar wind on it (Credits NASA, ESA)

The Earth's magnetic field is very stable and does not change much over time, unlike the solar magnetic field. However, some of the ultraviolet radiation manages to pass through the atmosphere and so we must protect ourselves.

1. Watch this TED-ED video to see the effect of the sun on people and the need to use sunscreen. Write down here your findings

2. Draw how do you think it might affect the Sun's magnetic activity on Earth

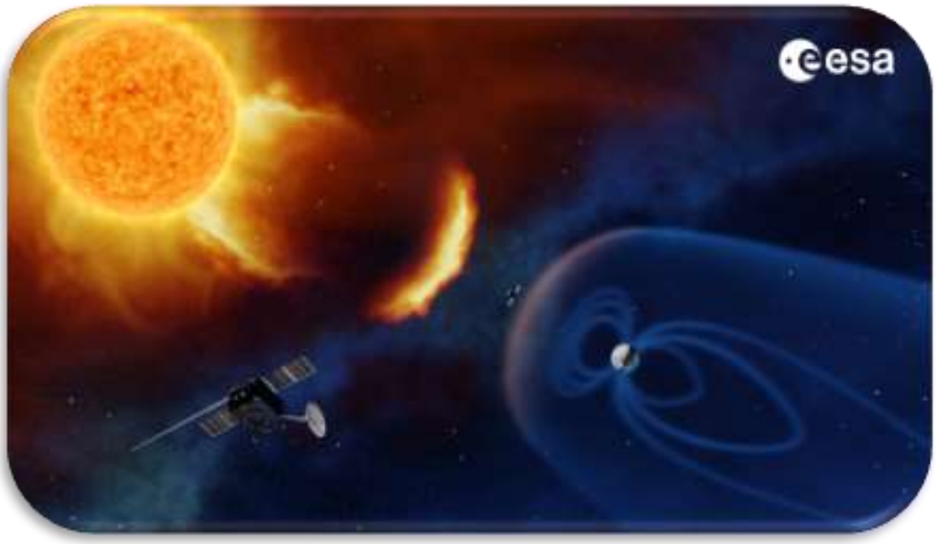


Figure 18: *Earth's magnetic field and its effect on the Sun and satellites (Credits : ESA)*

1. Do you think there is any relationship between the Sun and the Northern Lights?

Figure 19: *Auroras Boreales Training (Credits :* www.meteorologiaenred.com)

4. Watch the following video explains the appearance of the Northern Lights as a cause of the Sun's influence on the Earth's magnetic field. What other influence can solar activity have on the Earth?

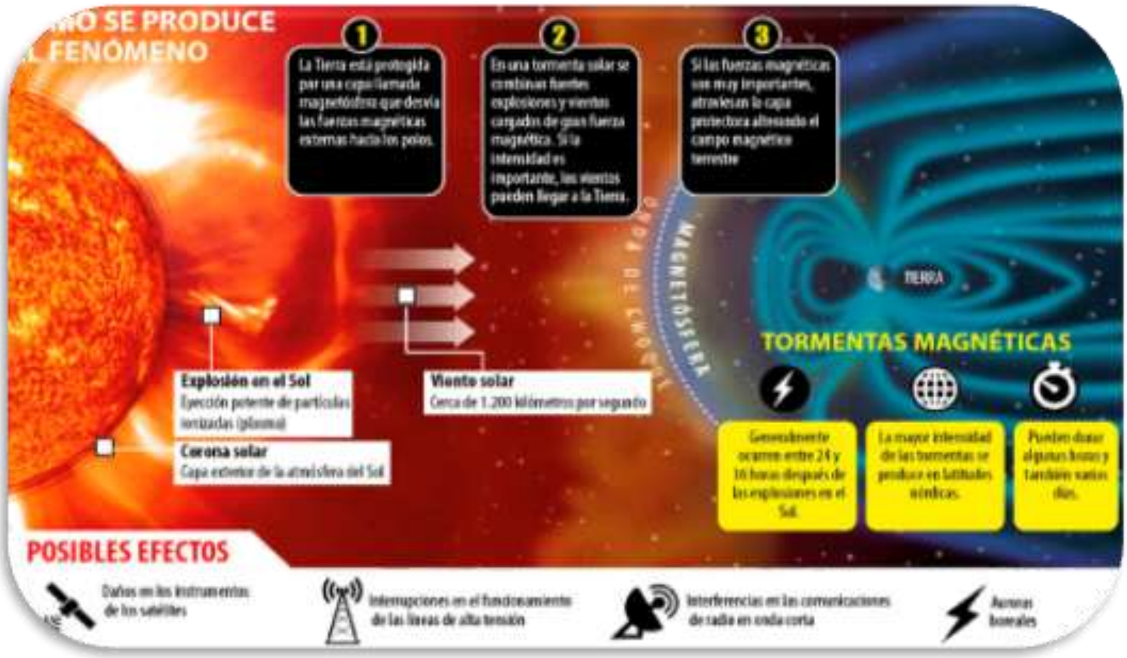


Figura S.: *La influencia del Sol sobre el campo magnético de la Tierra. (Créditos: www.capasdelatierra.org))*

Activity 5: The Space Exploration of the Sun by the European Space Agency (ESA).

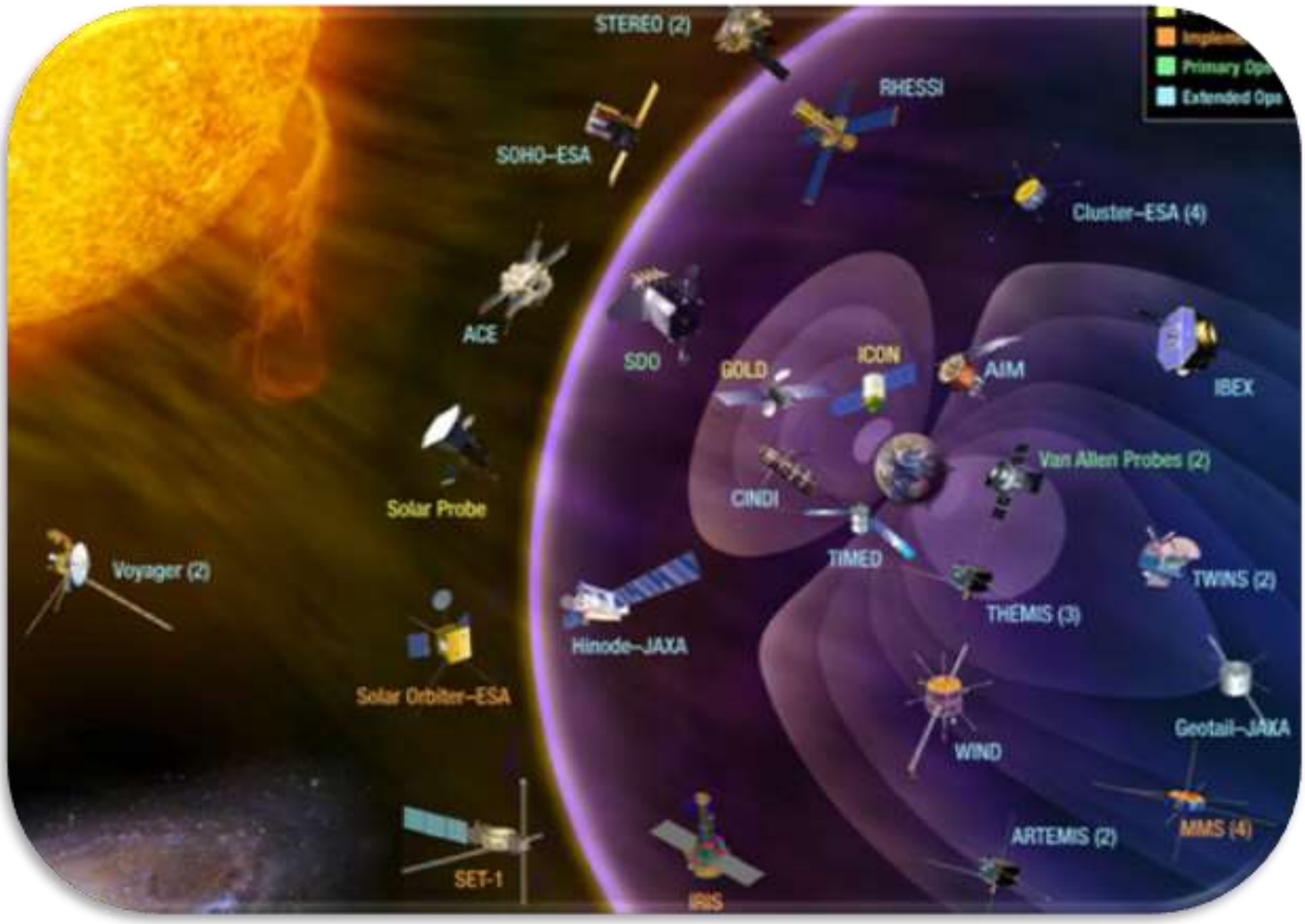


Figure 20: *European Space Agency mission fleet. (Credits: www.fidefundacion.es)*

For more than two decades, the European Space Agency, together with the US Space Agency, has been studying the Sun, as its variations can significantly affect the Earth. Figure 20 shows all of them and Figure 21 those with a high European contribution (PROBA-2 , SOHO y Solar Orbiter). The field of physics that studies the Sun is called **Heliophysics.**

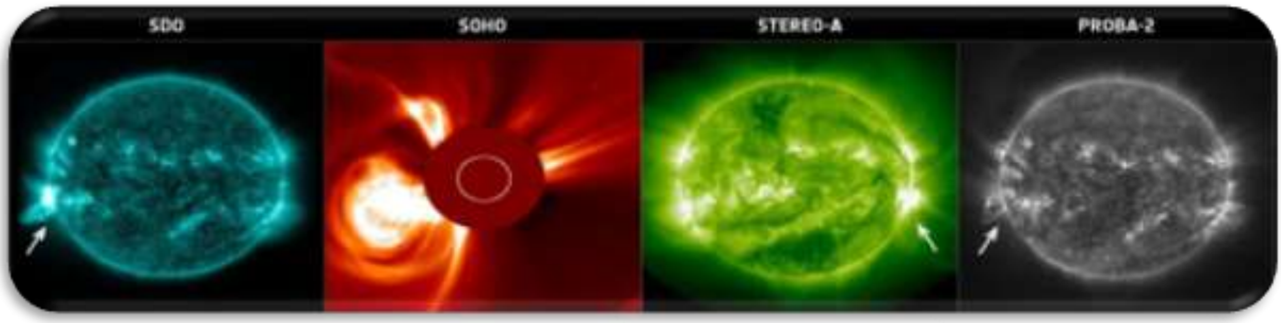


Figure 21: *The Sun observed in different filters (Credits: kiri2ll.livejournal.com)*

Actividad 5.1. Solar Orbiter. SOLO

Figure 22: *ESA/SOLO simulations (Credits: ESA)*

ESA's Solar Orbiter mission is an ESA-led mission with strong participation of NASA, launched in February 2020, with the main objective of closely studying the Sun, its poles and the solar wind around it. In particular it will analyze the behavior of its magnetic fields to predict the behavior of the star on which our lives depend.

Figure 23: *SOLO launch, ESA. (Créditos: ESA–S. Corvaja)*

Discover the [travel blog and educational activities](#) created by the SOLO mission scientist, Dr. Anik De Groof and her husband, to chronicle her journey to see the mission launch, in February 2020. Here is [a video of the launch of the SOLO mission.](#)

The following links are extra resources to know the missions in charge of the study of the Sun:

- [ESA missions to the Sun](#)
- 3D Simulators of the [European Space Agency mission spacecraft's fleet](#)
- [The mission ESA SWARM](#) studies the variations of the Earth's magnetic fields.

Activity 5.2: Solar telescope CESAR (HELIOS)

The HELIOS telescope, as shown in Figure 24, is a solar telescope belonging to the CESAR Team and installed at ESAC since 2012. Its main objective is to observe the Sun's disk every day (in the visible and H-alpha range) as shown in the calendar created with the images of the Sun taken in 2017 in Figure 25.

***Figure 24: Solar** Observatory HELIOS (Credits: CESAR)*

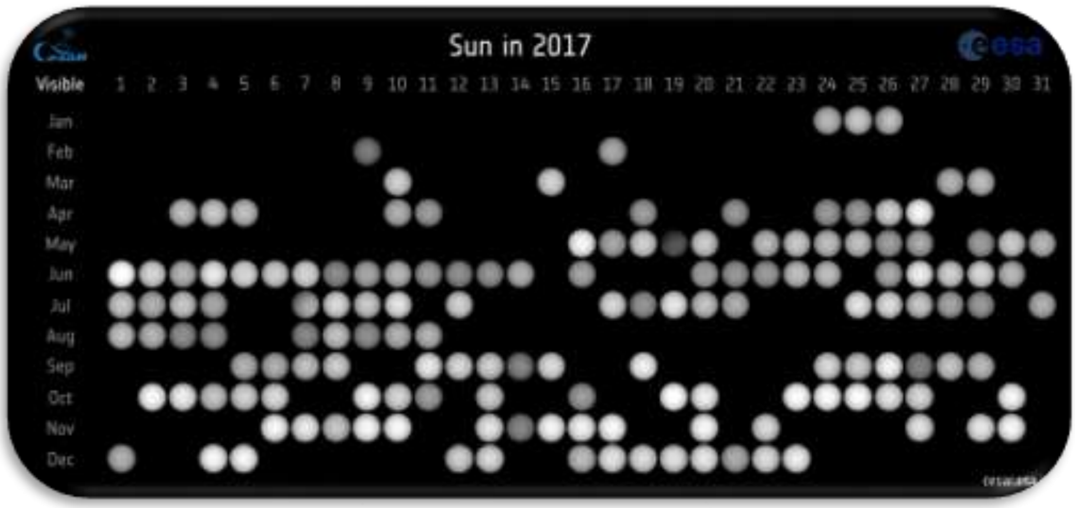


***Figure 25:** 2017 calendar with images of the disc of the Sun collected by HELIOS (Credits: CESAR)*

From this scientific data, the CESAR Team creates educational material such the one of this Scientific Challenge. For more information about this ground-based telescope access the ESAC SOLAR OBSERVATORY, in the following link.

Curiosity: If you want to see the last image taken by this telescope Access to "The Sun live"”

Activity 6: Evaluate what you have learnt so far

Check what you have learnt so far with this questionnaire

Phase 2

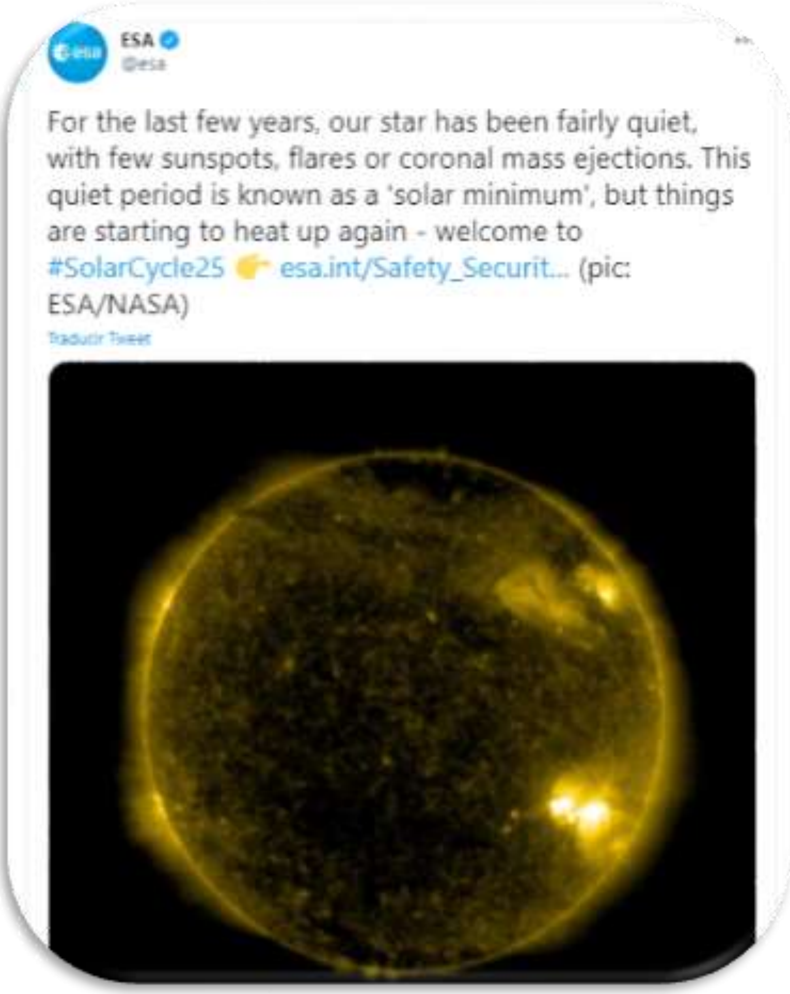


Figure 26: *Image of the Sun taken by ESA mission (Credits: https://twitter.com/esa/status/1322117428806123520)*

Phase 3

This phase is structured according to the **scientific method**. First you will make an **hypothesis**[2] about a non-familiar topic (the one from your Challenge), then you will perform an **experiment** (procedure) with real data about it and finally you will arrive to your own **conclusions** (and will check your hypothesis).

Are you prepared to work like a scientist? Let's start!

Activity 8: How long would it take for a solar storm to reach the Earth?

From real data of the ESA/NASA SOHO scientific mission, you can study the evolution of a coronal mass ejection (CME) and calculate the time that it takes for it to reach the Earth, since detected by the spacecraft.

In this Activity we consider a **scene in which the ejection evolves following a uniform rectilinear movement** and we propose two types of Experiments:

- **Experiment 1:** Using an on-line version (Activity 8.1)
- **Experiment 2:** Using printed images (Activity 8.2)

Hypothesis:

Review your answers from Activity 2

1. How long do you think that it would take to a CME to reach the Earth (Tip: bear in mind that the Earth-Sun distance is about 150 000 000 km)

2. Do you think that all the solar eruptions will take the same time to arrive to the Earth?

[2] A **hypothesis** (plural **hypotheses**) is a proposed explanation for a phenomenon.
https://en.wikipedia.org/wiki/Hypothesis

Experiment 1:

Activity 8.1: On-line version

General view:

- **Data**: Images taken by the LASCO instrument on board the SOHO satellite. In them we see a disk blocking the light of the Sun, called coronagraph. We can only see the external parts of the Sun where the coronal mass ejections happen. The white circle represents the surface of the Sun or photosphere.
- **Tools:**
  - Web tool designed by the CESAR Team
  - Calculator
- **Video tutorial:** https://youtu.be/OSakxrwiL5I

Preparation:

- Watch the video tutorial and repeat the exercise for CME captured by SOHO on 13-05-2013.
- **Access the CESAR web tool "Coronal Mass Ejection Study"**
- **Recommendations:**
  - You can take measurements as many times as desired (click on the centre of the Sun or the cross, and at the edge of the sun disk/ejection) until you are happy with your selection.
  - The CESAR webtool provides the output data with spaces for kilometers. However, **the input data required by the tool should be free of spaces, otherwise it will not be able to make calculations.**

Procedure

- **Step 1/4**: **Choose a set of images in the webtool** (for example, Option 3). Each of these sets corresponds to four consecutive images of an CME ejection.

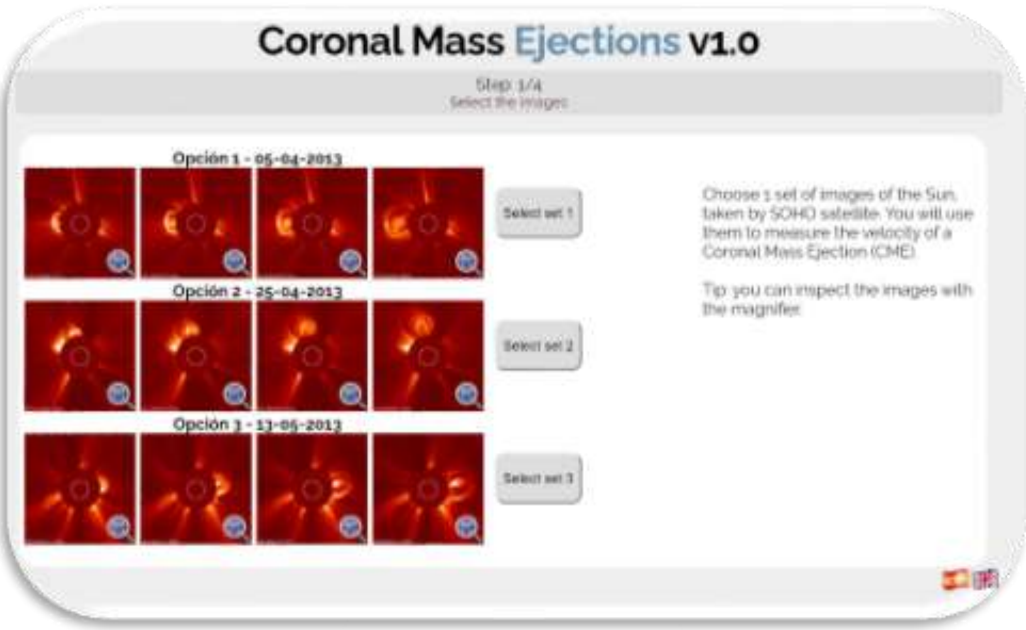


Figure 28: *Step 1 of 4 of the web tool (Credits: CESAR)*

- **Step 2/4 (I): Calculate the radius of the Sun** to know the scale of the image.
    - Click with the mouse on the center of the Sun (black cross) and then on any part of the white circle (Note: The white circle indicates the actual size of the Sun).

      This will allow the tool to internally do pixel to kilometre conversion.

- **Step 2/4 (II):** For each image **measure the length of the coronal mass ejection.**
    - Click on the center of the Sun and on the edge of the ejection
    - Repeat this action for the other three images.

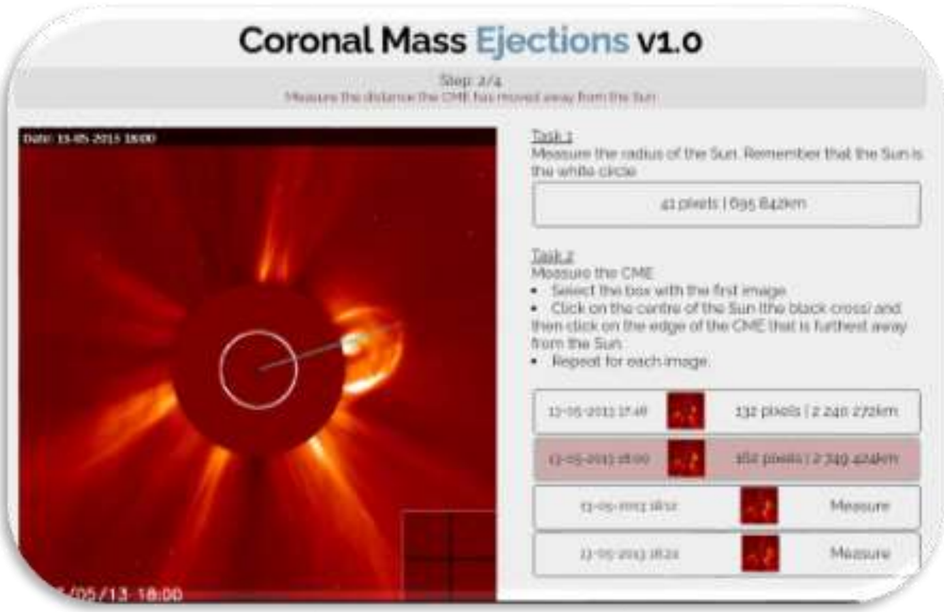


__Figure 29:__ Step 2 of 4 of the web tool (Credits: CESAR)

- **Step 3/ 4: Calculate the velocity of ejection between images.**

    - Fill in in the numerator **the length of the CME** in the image (N) and in the image (N-1)**, in kilometres, to see how the CME evolves.**

    - Fill in the denominator with the **time difference** between the image (N) and image (N-1) ,**in seconds**. (Note: The time the images were taken is given as DD-MM-YYYY hh:mm, with DD being the day, from the month MM of the year YYYY to the hour hh and minutes mm).

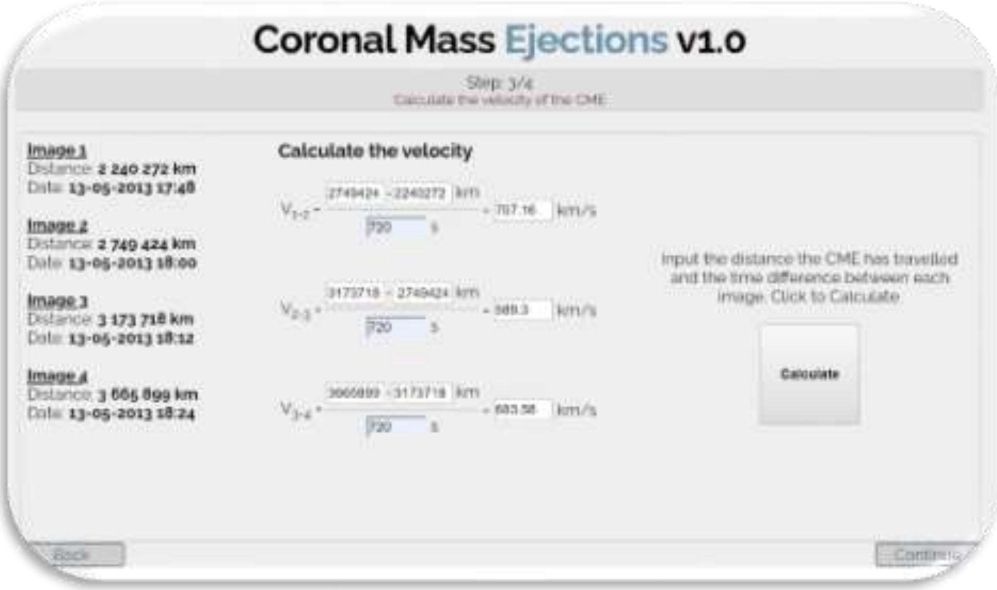


Figure 30: *Step 3 of 4 of the web tool (Credits: CESAR)*

- **Step 4/4 (I): Calculate the average velocity for the CME.**
  - Use the values of the three velocities (calculated between pairs of images) in Step 3 to obtain the average velocity.

- **Step 4/4 (II): Calculate the time it would take the ejection to travel the Sun-Earth distance**.
  - Enter the average velocity that you have calculated into the tool.
  - Enter the Sun-Earth distance, which is 150 000 000 km

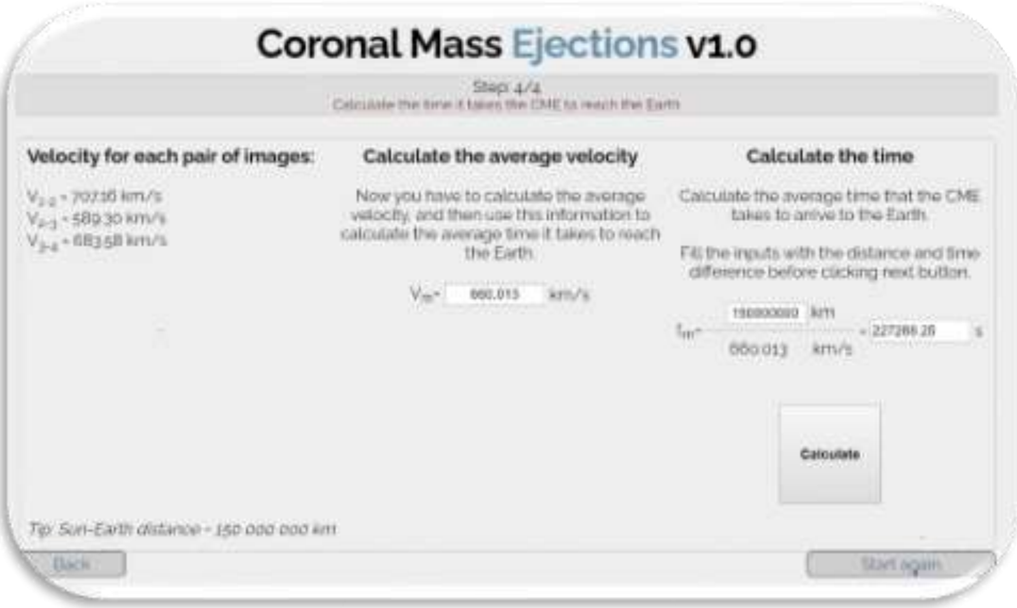


Figure 31: *Step 4 of 4 of the web tool (Credits: CESAR)*

Experiment 2:

Activity 8.2: Version using printed images

General view:

- **Data**: Images taken by the LASCO instrument on board the SOHO satellite. In them we see a disc blocking the light of the Sun called a choronograph. We can only see the external parts of the Sun where coronal mass ejections occur. The white circle represents the surface of the Sun or photosphere.
- **Tools:**
    - Ruler
    - Calculator

Preparation:

- Download and print the images in this link.
- **Recommendations:** Pay attention to the main direction of the ejection evolution for the measurements.
- **Possible solutions:** we have filled the tables with one possible solution. This may be or not the one calculated by the students.

Procedure:

- **Step 1/4:** Inspect SOHO images.

- **Step 2/4 (I): Calculate the radius of the Sun** to know the scale of the image.
    - Measure with the ruler from the center of the Sun (yellow cross) to any part of the white circle (Note: The white circle indicates the actual size of the Sun).

- **Step 2/4 (II):** For each image **measure the length of the CME and the time.**
    - Measure with the ruler the distance from the center of the Sun to the end of the ejection.
    - **Fill in Table 4 with:**
        - **the date** the image$_N$ was taken (Note: This can be found in the format DD/MM/YYYY hh:mm, where DD is the day, from the month MM of the year YYYY to the hour hh and minutes mm).
        - **The length of the coronal mass ejection**
    - Repeat this action for the other three images.

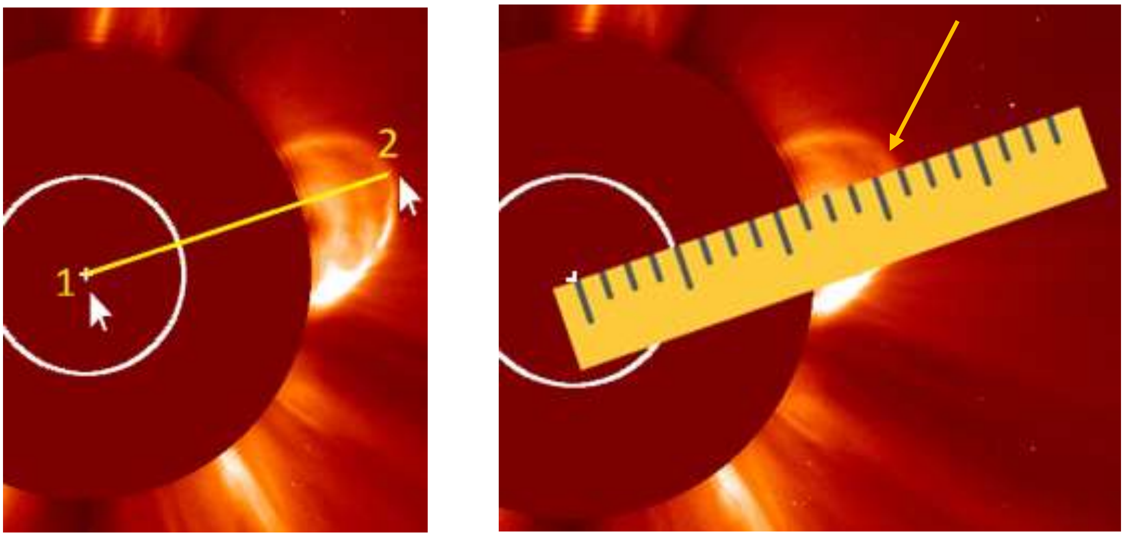


Figure 32: *How to make measurements for the on-line (left) and the PDF (right) versions (Credits: CESAR)*

Imagen	Date (DD/MM/YYYY hh:mm)	CME length (in millimeters)
1		
2		
3		
4		

Table 4: *Flare length of an image set*

- **Step 3/4: Calculates the velocity of the CME between images.**
  - Fill in **Table 5** with:
    - **The time difference** between the image (N) and image (N-1), **in seconds** (Note: The time when the images were taken is given as DD/MM/YYYY hh:mm, with *DD* being the day, from month *MM* of year *YYYY* to hour *hh* and minutes *mm*).
    - **The length difference (**ejection progression) of the CME between the image(N) and image(N-1), **in kilometres**.

pair of images	Time difference between images (s)	Distance that the CME has travelled between both images (km)	Speed (km/s)
(1,2)			
(2,3)			
(3,4)			

Table 5: *CME evolution for a set of images*

- **Step 4/4 (I): Calculate the average velocity of the ejection.**
  - Use the values of the three velocities (calculated between pairs of images) in Table 5 to obtain the average velocity.

- **Step 4/4 (II):** Calculate the time it would take for the ejection to travel the Sun-Earth distance.
  - Considering that the ejection evolves following a uniform rectilinear movement, calculate the time it would take for this ejection to reach the Earth using Equation 1 of Activity 1:

$$v = \frac{s}{t} \Rightarrow t = \frac{s}{v}$$

    - v is the average velocity you calculated in the previous step.
    - s is the distance Sun-Earth, which is 150 000 000 km.

Conclusions

1. Based on your observations, What is the average velocity for a CME?

2. How long do you think it would take a solar flare to reach the Sun from Earth, knowing that the Earth-Sun distance is about 150,000,000 km?

3. Do you think that all the CME will take the same time to arrive to Earth?

Activity 9: Coronal ejection evolves following a uniformly accelerated movement:

Hypothesis

Will the CME evolve at a constant velocity? If this were not the case, do you think they experience some kind of acceleration?

Experiment

In this activity we take into account the difference in the velocity of the CME between pairs of images, because indeed, the CME evolves following an accelerated movement. Once more, for simplicity, we consider that this is a uniformly accelerated rectilinear movement.

1. We start this Activity recovering the values of the velocities calculated in Activity 8:
   - **Extension of Activity 8.1:** From the data calculated in Step 3 of 4.
   - **Extension of Activity 8.2:** From the data calculated in Step 3 /4 (Table 4)

2. Make a graph representing:
   - On the Y-axis: **the difference between the lengths ($s_n - s_{(n-1)}$)** , in kilometers, obtained between the n and (n-1) images
   - On the X-axis: **the time difference ($t_n - t_{(n-1)}$)**, in sec between image ejections *n* y (*n*-1).

Conclusions

1. What kind of movement does the ejection follow? What do you think it is due to?

2. Calculate the arrival time of the ejection to Earth using Equation 3. Note: If the teacher wishes he can ask the students to develop the Equation 3.

$$v = v_0 + a\,t$$

$$s = s_0 + v_0 t + \frac{1}{2} a\,t^2 \quad \Rightarrow$$

$$t = \frac{(v - v_0)}{a}$$

$$\Delta s = v_0 t + \frac{1}{2} a\, t^2 \quad \Rightarrow$$

$$\Delta s = v_0 \frac{(v - v_0)}{a} \; + \frac{1}{2} a \left[\frac{v - v_0}{a}\right]^2$$

$$2\, a\, \Delta\, s = (v^2 - {v_0}^2)$$

$$v = \sqrt{v_0^2 + 2\, a\, \Delta\, s} \quad \Rightarrow$$

$$t = \frac{(v - v_0)}{a} \; = \frac{(\sqrt{v_0^2 + 2\, a\, \Delta\, s} - v_0)}{a} \quad \text{(Equation 3)}$$

- $\Delta\, s$: the maximum distance from the center of the Sun to the end of the ejection (measured in the last image), $\boldsymbol{v_0}$: the velocity of the first pair of images (v_{1-2}) ,$\boldsymbol{a}$: the acceleration obtained previously.

Note: The real movement of the ejection does not have this constant acceleration, but rather it decreases due to the friction with the interplanetary medium, especially with the solar wind that is in its path. In the Figure 32 we can see the density of this material, and also the velocity distribution as the ejections move away from the Sun.

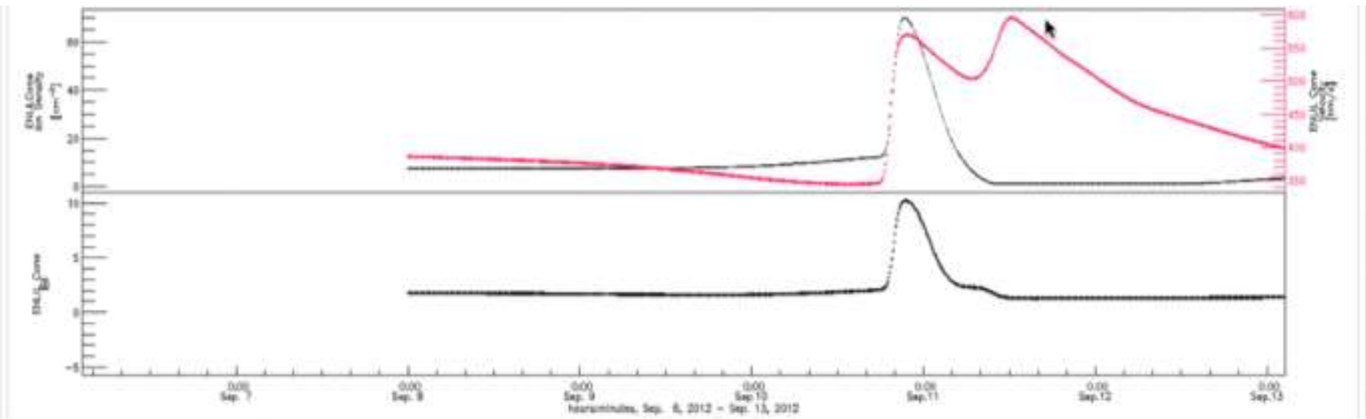


***Figure 32: Speed-Distance to Sun Chart (Credits**: SpaceWeather)*

Phase 4

Congratulations!
You have completed your Scientific Challenge!
Tell us your story!

Recall you Adventure and do these last Activities

Activity 10: Evaluation

- **Teams:** Fill in this questionnaire so that you can check what you have learned in the Challenge.
- **With your teacher:** Give us your feedback

Activity 11: Present your results

Create a final product (A0 poster) showing what have they learnt in the different Phases of their Scientific Challenge and present it to their classmates/school.

This poster is your ticket to participate in the *worldwide contest for the CESAR Adventures*.

Links

PHASE 0:

VIDEOS:

This is ESA: https://www.youtube.com/watch?v=9wdbNU7Pu8U&feature=youtu.be

ESAC: La ventana de ESA al Universo:
http://www.esa.int/ESA_Multimedia/Videos/2015/01/ESAC_ESA_s_Window_on_the_Universe

Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura:
http://cesar.esa.int/index.php?Section=Multimedia&Id=63

APP:

Simulación de cinemática: https://www.edumedia-sciences.com/es/media/112-cinematica

WEBS:

Katherine Johnson: https://kids.britannica.com/kids/article/Katherine-Johnson/628677
Vera Rubin: https://www.nytimes.com/2016/12/27/science/vera-rubin-astronomist-who-made-the-case-for-dark-matter-dies-at-88.html
Samantha Cristoforetti: https://www.nytimes.com/2016/12/27/science/vera-rubin-astronomist-who-made-the-case-for-dark-matter-dies-at-88.html
Marie Curie: https://es.wikipedia.org/wiki/Marie_Curie
Steve Wozniak: https://es.wikipedia.org/wiki/Steve_Wozniak
Matt Taylor: https://www.famousbirthdays.com/people/matt-taylor-scientist.html
Albert Einstein: https://es.wikipedia.org/wiki/Albert_Einstein

PHASE 1:

VIDEOS:

https://www.youtube.com/watch?v=AQnkWw_lQ8g

https://www.youtube.com/watch?v=_qgVKmOsqV8&t=36s

http://www.esa.int/ESA_Multimedia/Videos/2013/07/Science_ESA_Episode_8_The_Sun_our_local_star/(lang)/es

Solar Orbiter (varios):
https://www.esa.int/ESA_Multimedia/Missions/Solar_Orbiter/(result_type)/videos
https://www.esa.int/ESA_Multimedia/Videos/2020/02/Solar_Orbiter_launch_highlights
https://www.esa.int/ESA_Multimedia/Missions/Solar_Orbiter/(result_type)/videos
https://www.esa.int/Applications/Observing_the_Earth/Swarm/Highlights/Earth_s_magnetic_field
https://dlmultimedia.esa.int/download/public/videos/2013/07/020/1307_020_AR_ES.mp4
https://www.youtube.com/watch?v=VBO9MDt8Gvs

APP:

https://www.purposegames.com/game/layers-of-the-sun-game
https://www.ptable.com/?lang=es
http://cesar.esa.int/index.php?Section=SSE_Composicion_de_las_estrellas_portada
: https://spectralworkbench.org/

http://scifleet.esa.int/#/.
http://scifleet.esa.int/#/model/sun
SOHO: http://scifleet.esa.int/#/model/soho
SOLO: http://scifleet.esa.int/#/model/solar_orbiter

WEBS:

http://cesar.esa.int/upload/201809/la_estructura_del_sol_booklet.pdf
http://cesar.esa.int/upload/201905/jupiter_moons_booklet_pdf.pdf
http://cesar.esa.int/upload/201809/mod_evolucion_estelar_booklet.pdf
http://cesar.esa.int/upload/201809/el_sol_magnetico_booklet_es.pdf
https://www.esa.int/Space_in_Member_States/Spain/Explorando_el_Sol
https://www.esa.int/Space_in_Member_States/Spain/El_Sol_en_2018
http://cesar.esa.int/index.php?Section=News&Id=183

http://cesar.esa.int/index.php?Section=Live_Sun
http://cesar.esa.int/index.php?Section=Observatories_ESAC_Sun
Ehttps://www.esa.int/kids/es/Aprende/Nuestro_Universo/El_Sol/Eclipses_solares
http://www.esa.int/Our_Activities/Space_Engineering_Technology/Proba_Missions/About_Proba-2

SOHO: http://www.esa.int/Our_Activities/Space_Science/SOHO_overview2
Solar Orbiter: http://sci.esa.int/solar-orbiter/

APP

http://cesar.esa.int/tools/15.coronal_mass_ejections/index.php?ChangeLang=es

PHASE 2:

PHASE 3:

VIDEOS:

LASCO
https://www.esa.int/ESA_Multimedia/Keywords/System/SOHO_LASCO_coronograph/(result_type)/videos
Video tutorial https://drive.google.com/file/d/1Zn410gfmi9IYnehhDtWypS0LV4CxkC1t/view

APP

http://cesar.esa.int/tools/15.coronal_mass_ejections/index.php?ChangeLang=es

WEBS:

https://es.wikipedia.org/wiki/Coron%C3%B3grafo

PHASE 4:

VIDEOS:

APP

http://cesar.esa.int/form.php?Id=11&k=9gPSn9hqRN&ChangeLang=es

WEBS:

http://cesar.esa.int/upload/202001/bases_concurso_sse_final.pdf

Credits:

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