CESAR Scientific Challenge

Solar storm heading towards Earth

Study the magnetic activity of the Sun with SOHO

Teacher Guide

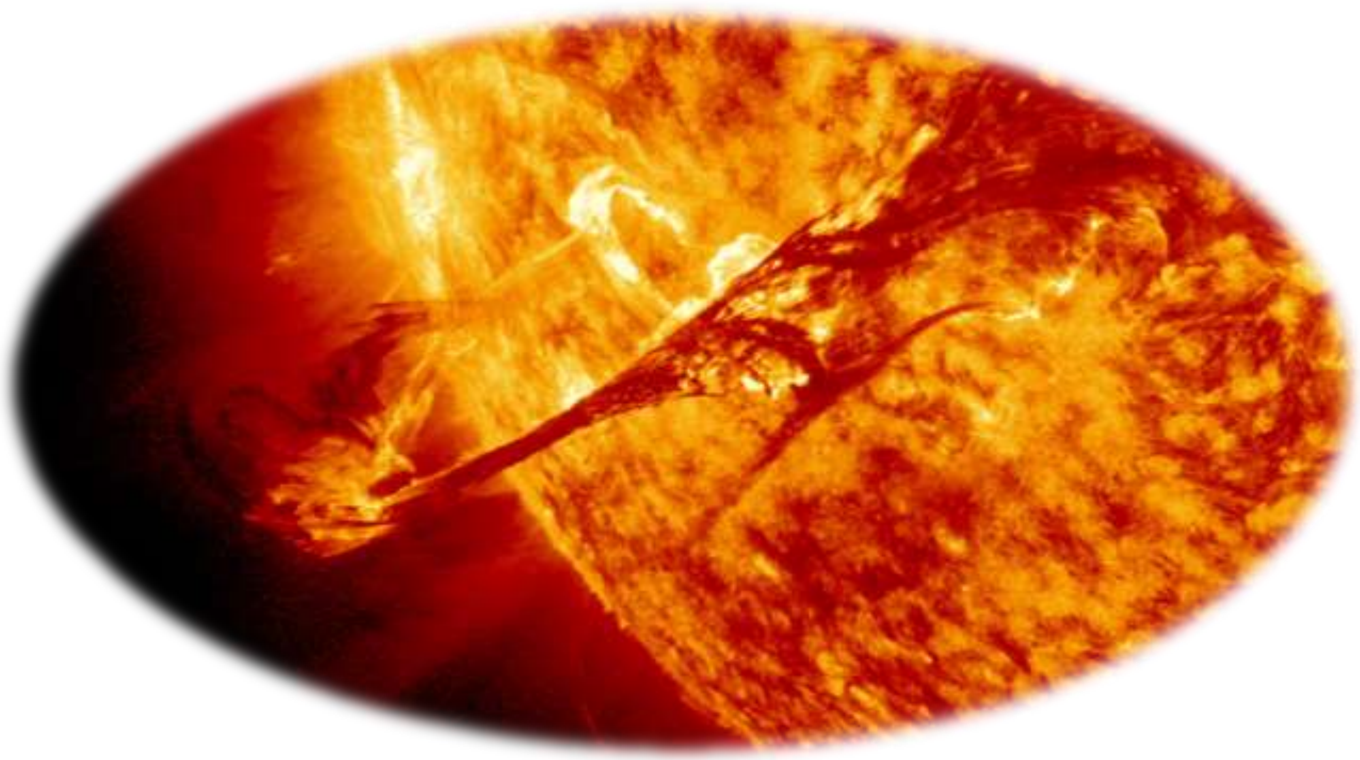

Table of Contents

Didactics

Learning objectives

Figure I: *The considered top 10 skills in the 2020. (Credits: Refthinking).*

The CESAR Team generates activities for students to develop the considered top 10 skills in the 2020, where problem solving requires critical thinking and creativity. Our proposal is to execute these activities in teams. Students will find the environment where to develop their communication skills, managing different opinions and approaches, and making use of their emotional intelligence.

The CESAR scientific challenges aim to follow the thinking skills order established by the Bloom's taxonomy diagram, from a low order thinking skills (**remembering, understanding)** to a high order thinking skills (**evaluating, creating**), passing through mid-order thinking skills (**applying** methods and concepts for **analysing** events).

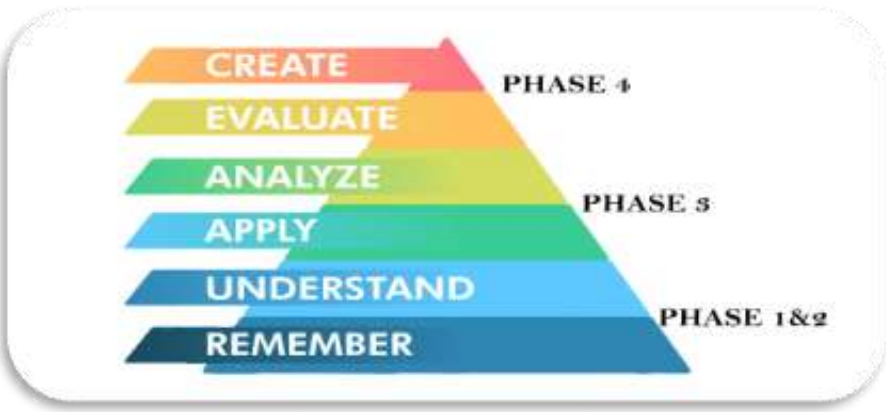

Figure II: *Bloom's Taxonomy diagram. (Credits:* https://medium.com/@ryan.ubc.edtech/*)*

Teaching Techniques:

In order to achieve the previously mentioned Learning Objectives, the CESAR Team recommends the use of some techniques like, ***flipped-classroom, solution of daily life problems (using the scientific method) and collaborative work.***

In this activity students will make use of the *flipped classroom* for Phases 0 and 1 to get ready for the problems solution of their Challenge during Phase 3. Phase 2 is optional and consist on a video call with us. In Phase 4, each team will evaluate their Experience and share it with the Scientific Community (their class/center and us, the CESAR Team). All phases are recommended to be executed as collaborative work (using **forum and blogs)**. Here we detail the process:

- **Your Scientific Challenge:** We introduce the Challenge to students and ask for their support
- **Phase 0: Putting things into context**
  - The role of the **European Space Agency** and their center in Spain (European Space and Astronomy Centre, ESAC) as well as the CESAR Team. (in videos)
  - **Role models** for students to build the **Teams for their Challenge**. We recommend that Teams are formed by 4-6 people, each one of them with well-defined tasks. When possible, try to balance them in gender and diversity of capabilities.
- **Phase 1 and Phase 2:** ***remembering and understanding*** using different sources:
  - **Phase 1**: scholar cv material & new concepts (videos, documents, games)
  - **Phase 2 (optional)**: learn from an expert
    - For the teachers: talks provided by experts on the topic in previous CESAR teacher workshops.
    - For the classroom: A video call with the CESAR Team to solve doubts that may have appeared. At this stage, students have already become "experts" on the topic of the Challenge .
- **Phase 3:** ***applying*** the already known concepts following a methodology (procedures) for ***analysing*** *data* and *solving daily life problems* (their Scientific Challenge).
- **Phase 4:**
  - ***evaluating*** their learning process during the Challenge (self and co-evaluation)
  - ***creating*** a final product to show to the Community (class/school/us) their learning process. With this you could participate in the CESAR Scientific Challenge contest.

As Figure III shows, the CESAR Scientific Challenges should execute all mentioned Phases. Phase 0 and 1, are the roots for all the Scientific Experiences, always to be done in the classroom/home. Phase 2 (video call executed from the classroom to us) is optional.

Depending on the type of Phase 3, there are various CESAR Experience Types:

- **Type I: Space Science Experience(s) @ESAC**: At ESAC, (as always in the past), completely run by the CESAR Team. Total duration 1.5 hours, with 45 minutes for the Activity and another 45 minutes the tour around the ESA spacecraft models.

1. **Type II : On-line Space Science Experience(s)**: In the classroom/home, (Type I but completely guided by the teacher). Total duration 1h (MIXED when combined with Type I/III)
2. **Type III: On-line Research Project**: In the classroom/home, completely guided by the teacher. Total duration several days. (Type II but executing more or all the Activities of the Guide).

Phase 4 is always executed in the classroom/home to evaluate the learning process per Team as a whole.

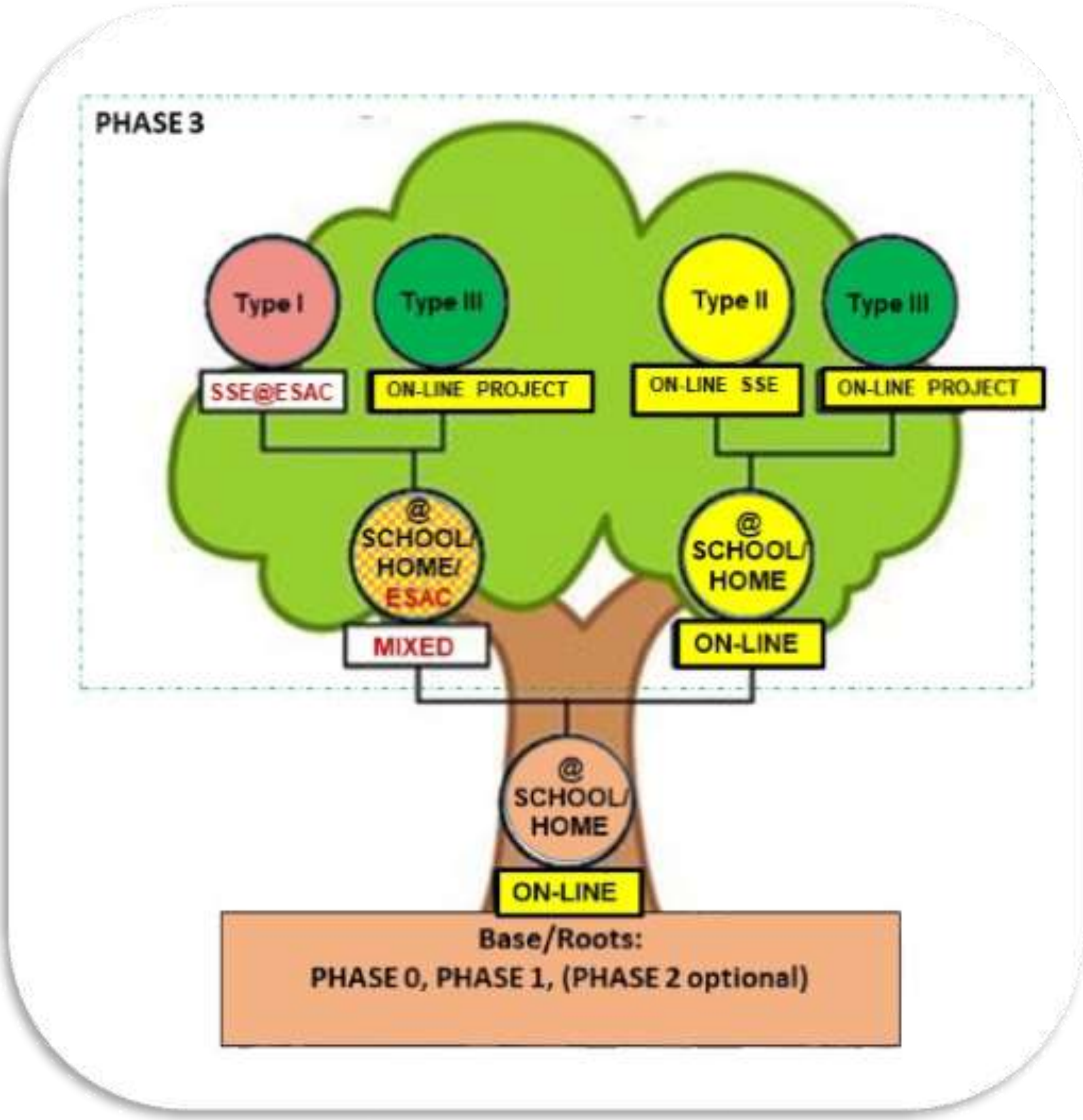

Figure III: Decision tree of the CESAR Experiences according to Phase 3 (Tipo I @ESAC, Tipo II y III, on-line) .In yellow are indicated those paths that can be run completely on-line.(Credits:teacherspayteachers.com)

Teachers are the best ones in assessing the Type of Experience (Challenge) for their classroom and school year conditions. **For each Type of Experience we propose different Adventures. The teacher decides if each Team in the class execute an Adventure and once finish they put them in common or whether all the Teams execute the same Adventure(s) at the time (see Tables I, II and III).** Teachers can also decide whether they want to execute some Activities on-line, and when it became feasible, to ask for the already well known an SSE @ESAC (Type I), for the same Challenge but different Adventure or another Challenge (see Figure III).

The CESAR Team recommends you to follow the phases in order (for an optimum learning process) and do not start one before closing the previous one. The Table Summary of Activities will mention when the execution of a previous Activity is required.

The CESAR Team can be contacted once per Scientific Challenge in phase 2 (with the class) and in phase 3 (only for the teacher). For that, dedicated slots of 30 minutes are scheduled.

- For the Scientific Challenge, the Fast Facts section provides the information regarding the school curriculum and the contents of each of the Activities (by Phase) can be found in the Table "Summary of Activities". The flavors of Adventures, per each Type of Scientific Experience are in Tables I, III and III.

- **Table I: Space Science Experience @ESAC (SSE @ESAC):**

PHASES	0	1	2	3 (@ESAC)	3 (@school)	4	Minimum duration
ACTIVITIES (Adventure 1)	3 videos	1,2,3,4,5	7	8.1		9 and 10	3,40h
ACTIVITIES (Adventure 2)	3 videos	1,2,3,4,5	7	8.2		9 and 10	3,40h
ACTIVITIES (Adventure 3)	3 videos	1,2,3,4,5	(7)	8.2	8.1	9 and 10	3,55h
ACTIVITIES (Adventure 4)	3 videos	1,2,3,4,5	(7)	8.1	8.2	9 and 10	3,55h

- **Table II: On-line Space Science Experience (On-line SSE):**

PHASES	0	1	2	3 (@school)	4	Minimum duration
ACTIVITIES (Adventure 1)	3 videos	1,2,3,4,5	(7)	8.1	9 and 10	3,40h
ACTIVITIES (Adventure 2)	3 videos	1,2,3,4,5	(7)	8.2	9 and 10	3,40h

- **Table III: On-line Research Project:** All Activities

PHASE	0	1	2	3 (@school)	4	Minimum duration
ACTIVITIES	videos	1,2,3,4,5 and 6	(7)	8	9 and 10	4,45h

REALLY IMPORTANT

- ✓ As a teacher, **register as part of the CESAR Community here** (If you approach us for the first time, it may take some time – a non-automatic process -, but you will not regret ;o))
- ✓ **Once you have been confirmed as part of the CESAR Community** ask for the CESAR Scientific Experiences to live with your class **and you will be guided in the process:**
  - Click here to request an on-line experience – Type II & III
  - Click here to request a combined experience - Type I (Only for schools in the Comunidad de Madrid and close cities)
- ✓ **Guides are very long (many possible tools) to build your Experience but also very flexible**

It is your time! Choose your Adventure!

Fast Facts

Recommended target age range: (14-16) years old

Recommended academic courses: (3-4) ESO

Type: Student activity, **Complexity:** Medium

Teacher preparation time: (2+) hours, depending on the Type of Experience and contents selected.

Lesson time required: (4 hours – several days), depending on the Type of Experience and contents selected by the teacher.

Location: Indoors

Includes use of: Computers, internet

Curriculum relevance

Physics and Chemistry

- The need of strategies in the scientific activity, the use of ICT and communication skills. Research project.
- Uniform and uniformly accelerated line movement.
- The periodic system of the elements. The chemical reaction.
- Errors in measurement

Mathematics

- Planning of the problems solution process. Generation and presentation of scientific forms. Mathematical studies of daily life concepts.
- Interpretation of phenomena by statements, data in tables/plots or by analytical expressions.

Scientific culture

- The scientific method. The use of ITC.
- Research and exploration of the Universe. The solar system. The evolution of the stars and the origin of the elements.
- Working in teams. Debates.

You will need...

- CESAR web tool http://cesar.esa.int/tools/15.coronal_mass_ejections/index.php?
- Printed SOHO images/document

Abstract

In this activity, students will learn about the Sun, the solar magnetism and their events. In particular, they will learn about coronal mass ejections (CME).

Using three sets of real scientific images, taken by the ESA/SOHO missions, students will analyze the velocity of the CME. Assuming that a CME evolves following a uniform line movement, students will determine how long will it take them to reach the Earth. This case could be extended, assuming that CMEs follow uniformly accelerated rectilinear motion(s), as it is the case. By plotting the positions versus the time, students will identify the CME acceleration(s).

Students should know...

- The concepts of velocity and acceleration.
- The equation of uniform line motion and uniformly accelerated line motion.
- Time units conversion.

Students will learn...

- The basics of solar activity.
- How to make scientific measurements.
- How to obtain information from astronomical images.

Students will improve ...

- Their understanding of scientific thinking.
- Their strategies of working scientifically.
- Their teamwork and communication skills.
- Their evaluation skills.
- Their ability to apply theoretical knowledge to real-life situations.
- Their skills in the use of ICT.

Summary of Activities

Phases	Activity	Material	Results	Requirements	Time
Phase 0	Putting things into context	VIDEOS: • This is ESA • ESAC: ESA's A window on the Universe • Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura • Other inspirational videos about Space • Inspirational video about education	Students will get familiar with • ESA • ESAC • The CESAR Team	None	30 min -1 hour
Phase 1	1. Refresh concepts	VIDEOS a) Motion b) Velocity and acceleration c) Science of Motion d) The state of the matter e) Magnets f) How does the nuclear energy work?	Students will refresh some concepts • Types of motions • Velocity and acceleration • Science of motion • States of the matter. • Magnets • How does nuclear energy work?	None	30 min -1 hour
Phase 1	2. Compare the velocity and time, for various vehicles, to travel the Earth-Sun distance	Blog or Forum	Students will improve: • Their teamwork and communication skills. • Their knowledge of the Sun and its magnetic activity.	It is requires to have executed Activity 1.	30 min

Phases	Activity	Material	Results	Requirements	Time
Phase 1	3. The Sun 3.1. The structure of the Sun 3.2. The Chemistry of the Sun	Time permitting VIDEO: a) The Sun our local star (ESA video) PDFs: b) The Sun c) The structure of the Sun d) The solar system e) The evolution of the stars	Students will improve: • Their knowledge of the Sun as a star and its evolutionary state. • Their knowledge about the layers of the Sun (Game) • Their knowledge about the chemistry of the Sun (Periodic Table)	None	30 min – 1 hour
Phase 1	4. The magnetic activity of the Sun 4.1. CME 4.2. The influence of the Sun on the Earth	Time permitting VIDEO: a) The Sun our local star (ESA video) PDFs: b) Introduction to the Sun c) The structure of the Sun d) The solar system e) The evolution of the stars f) The magnetic sun	Students will improve their knowledge about: • The origin of the solar magnetism. • The influence of solar magnetism on the Earth.	It is necessary to have done Activity 3.	30 min – 1 hour

Phases	Activity	Material	Results	Requirements	Time
Phase 1	5. The Exploration of the Sun by the European Space Agency 5.1. SOLO 5.2. HELIOS	Time permitting VIDEOS: • Solar Orbiter • ESA missions to the Sun. • The electromagnetic spectrum and its study by ESA missions • COSMOGRAPHIA: (30 min demo video, en inglés) 3D models: • Fleet of ships of the European Space Agency. • The Sun • SOHO • SOLO WEB: • Exploring the Sun • The Sun in 2018 • Studying the Sun with the HELIOS telescope	Students will learn: • What is like to work at the European Space Agency. • ESA space exploration. • To recognize the different processes that happen in the Sun. • How scientifics get information.	It is necessary to have done Activities 3 and 4	30 min – 2 hours
Phase 1	6. Evaluate what you have learnt so far		Students will evaluate in a fun way what they have learnt so far	Have done Activities 1 to 5	10 min
Phase 2	7. Ask for a videocall with the CESAR Team if needed	http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=21&ChangeLang=en	**Teachers** will have first-hand information from ESA experts talks given in CESAR teacher courses **The class** could have a video call with an astronomer from the CESAR Team	It is convenient to have carried out Activities 1 to 6	30-40 min

Phases	Activity	Material	Results	Requirements	Time
Phase 3	8. Calculate the time it would take, for a coronal mass ejection (CME), to reach the Earth, if it followed an MRU. *8.1.* On-line version *8.2.* Printed images version	video web tool	Students will learn: • What astronomical images look like. • How to identify patterns in real images (ejection). • How to analyze patterns variations in real data (evolution of ejections). • How to calculate the average velocity of an ejection. • How to calculate the time it takes for an ejection (CME) to reach Earth. Students will improve: • Their abilities to use TIC. • Their knowledge about MRU. • Their scientific and critical thinking.	It is recommended that you have executed the Activities 1, 3, 4, 5 y 6	30 min- 1 hour
Phase 3	9. Calculate the acceleration of a coronal mass ejection (CME), if it follows a MRUA.		Students will learn: • How scientists extrapolate information. • To Identify differences in the velocity calculated for different pair of images • The different interactions the ejection encounters and their impact on movement Students will improve: • Their understanding of the scientific method and critical thinking. • Their strategies for working as scientists. • Their evaluation skills. • Their ability to apply theoretical knowledge to real life situations. • Their ability to represent results in graphs.	You need to have completed Activity 8 (use these values for velocities and times)	20 min

Phases	Activity	Material	Results	Requirements	Time
Phase 4	10. Evaluate yourself		Students will check whether they have had a meaningful learning process. • Students improve their team work and communication skills.	It is necessary to have performed at least Activities 1,3,4,5,6,8 and 9.	15 min – 1 hour
Phase 4	11. Present your results	Free student format (ppt, youtube, Word)	Students will improve: • Their ability to work in teams and communication skills.. • Their knowledge of the Sun, its solar activity and its impact on the Earth's climate.	It is necessary to have performed at least Activities 1,3,4,5,6,8, 9 and 10.	30 min – 2h

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!**

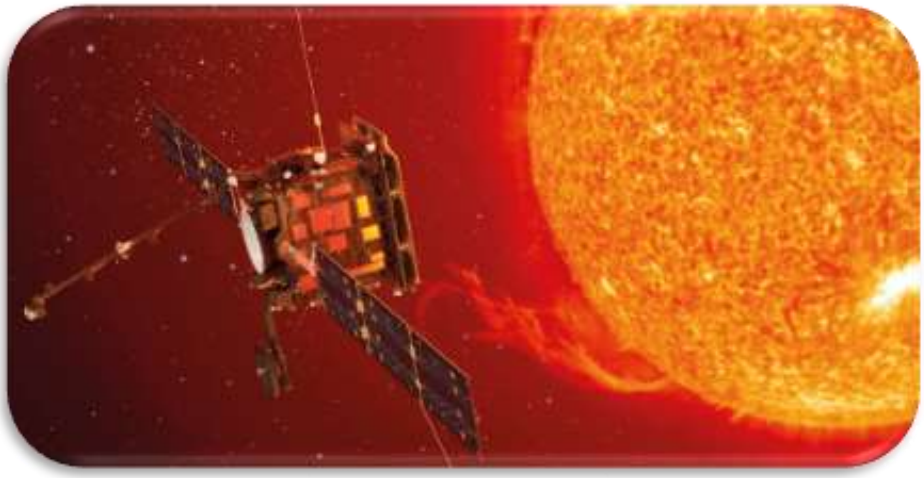

Figure 1: Solar Orbiter satellite (Créditos: www.agenciasinc.es)

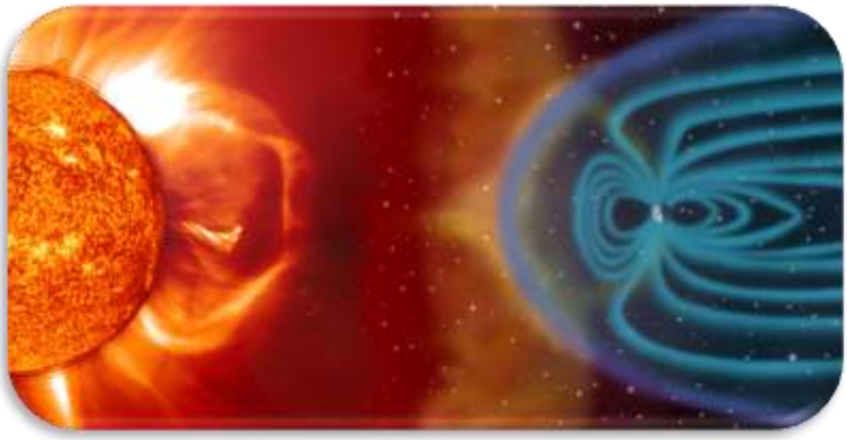

Figure 2. Coronal mass ejection (CME). (Créditos: https://www.quo.es/explosion-solar/)

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	Leads the correct execution of the calculations	She/he guides the solar telescope	She/he is in charge of finding agreements and leading the team.	She/he 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.

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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 velocity. Its equation is :

$$v = \frac{s}{t} \qquad t = \frac{s}{v} \qquad \text{(Equation 1)}$$

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 velocity varies with time. Its equation is :

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

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.

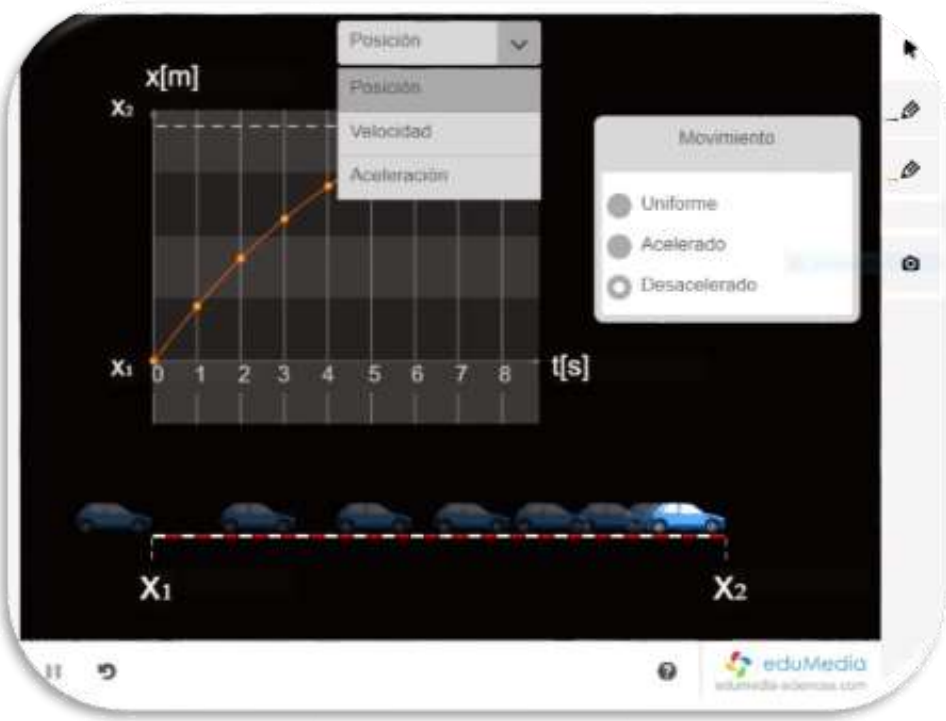


Figure 3: *Simulator rectilinear motion (Credits: EduMedia)*

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

The main objective of this activity is for students to realize how far away the Sun is from our planet (**Sun-Earth distance** = 150 000 000 km)

1. Complete Table 2 with the velocity or time values. The given values are in purple.

Vehicle	*Velocity*	Time
Light	$3 \cdot 10^8\ m/s$	$8\ minutos\ 30\ segundos$
Spacecraft	$30\ 000\ km/h$	$6\ meses$
Aircraft	$1000\ km/h$	17 años
Car	$120\ km/h$	142 años
Bike	$25\ km/h$	683 años

Table 2: *Velocity 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.

An ejection takes 2 to 5 days to arrive from the Sun to the 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

They do not all take the same time; it depends on their mass, on the energy released in their explosion and on whether more than one ejection has taken place at the same time

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.

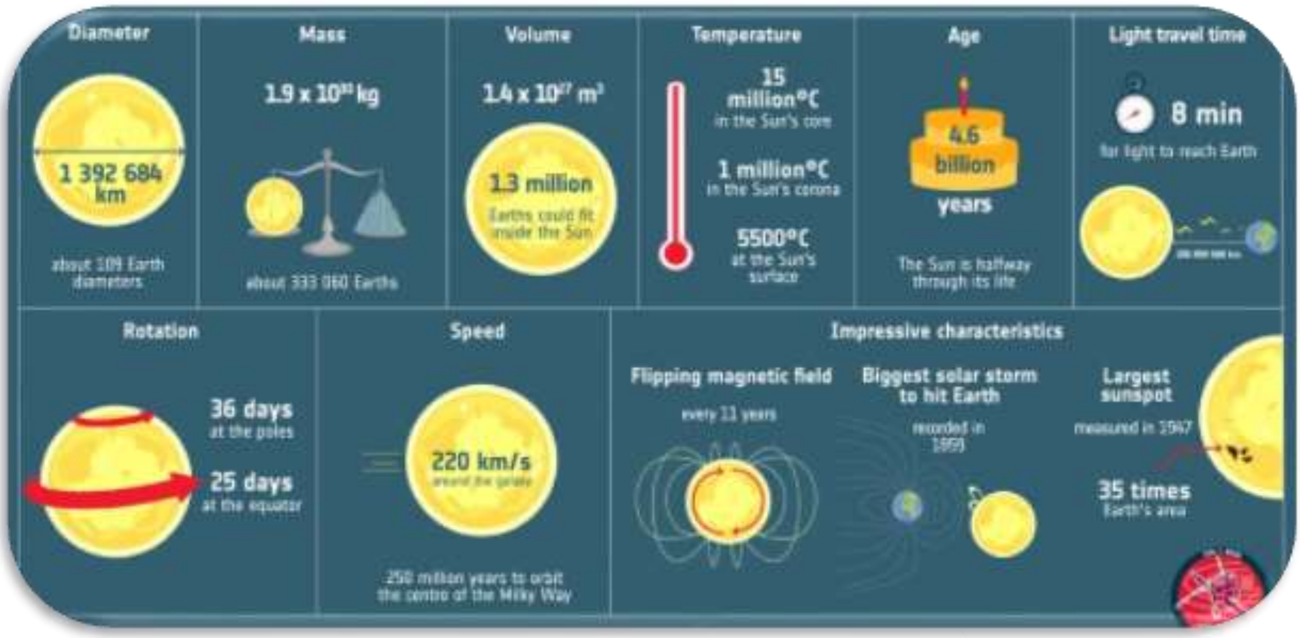


Figure 4: *[Meet the Sun](#) (Credits: ESA)*

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.

***Figura S.1:** The layers of the Sun (Credits: Talk by Benjamín Montesinos Comino for CESAR teachers' course, June 2018)*

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!**

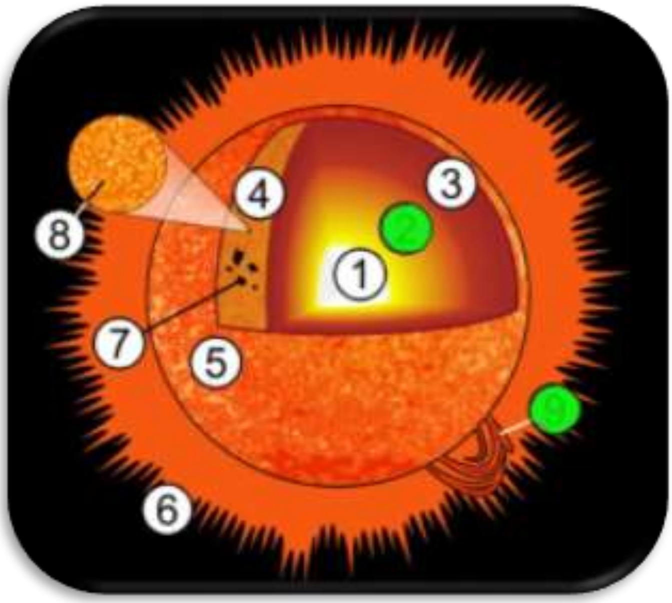


Figure 6: *Simulation layers dollars. (Credits: https*://www.purposegames.com)

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

2. 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 .

When we look at the Sun from the Earth (with solar telescopes) we see what we call the photosphere or solar disk. Look at the table to understand the properties of the different outer layers of the Sun

Tipo radiación	Temperatura	Grosor de la capa	Densidad
Fotosfera	8000 – 4500 K	500 km	$\sim 10^{-4}$ kg/ m^3
Cromosfera	4500 - 20000 K	1600 km	$\sim 10^{-8}$ kg/ m^3
Zona de transición	20000 – 10^5 K	100 km	$\sim 10^{-10}$ kg/ m^3
Corona	10^6 - 3×10^6 K	$>10^7$ km	$\sim 10^{-13}$ kg/ m^3

The outermost layers (corona) can only be seen from the Earth with special glasses during solar eclipses .

Figure S.2:*Solar Eclipse (Credits: ESA Kids)*

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 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.

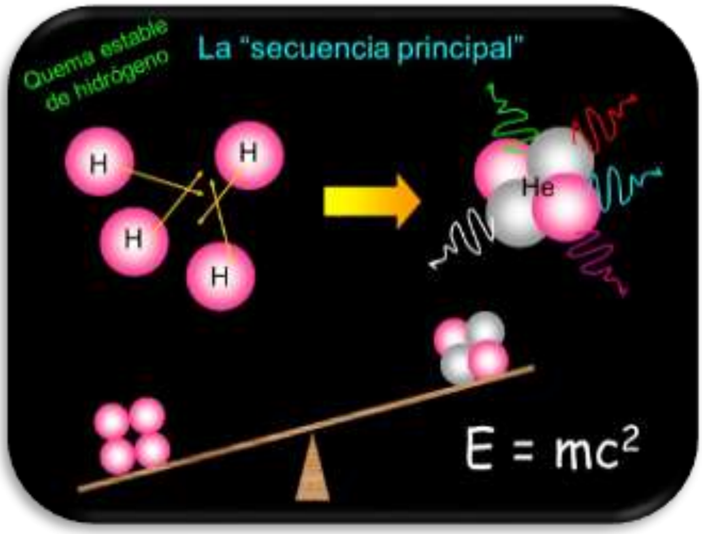


__Figure 7:__ Nuclear reaction of stars in their most stable phase (Credits: Talk by Dr. Benjamín Montesinos Comino at CESAR Teacher workshops).

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.

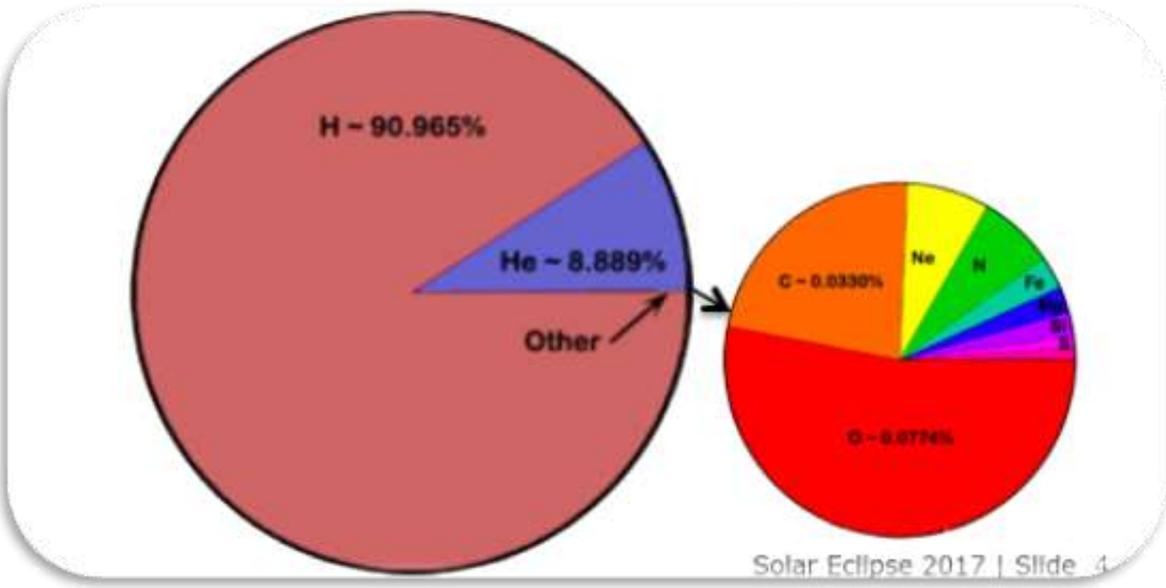


__Figure 8:__ Elements of the Sun (Credits: Presentation of Dr. Anik De Groof, at CESAR teacher workshop)

1. Fill in Table 4 with the most abundant elements on the Sun:
   1.1. The percentage of these elements can be obtained from Figure 8
   1.2. 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	Helio	Gases	2
0.07	O	Oxigen	No metal	8
0.03	C	Carbono	No metal	6
< 0.1	Ne	Neon	Gas	10
< 0.1	N	Nitrogen	No metal	7
< 0.1	Fe	Iron	Metal	26
< 0.1	Mg	Magnesium	Metal	12
< 0.1	Si	Silicon	Metal	14
< 0.1	S	Sulfur	No metal	16

Table 4: Chemical composition of the Sun.

2. Repeat previous activity for the case of the Earth and fill in Table 5.

Proportion of that element (%)	Nomenclature	Chemical element	Group in the Periodic Table	Atomic number
47	O	Oxigen	No metal	8
28	Si	Silicon	Metaloides	14
8.1	Al	Aluminion	Metal	13
5.0	Fe	Iron	Metal	26
3.6	Ca	Calcium	Metal	20
2.8	Na	Sodic	Metal	11
2.6	K	Potassium	Metal	19
2.1	Mg	Magnesium	Metal	12
0.8	Otros			

Table 5: Chemical composition of the Earth

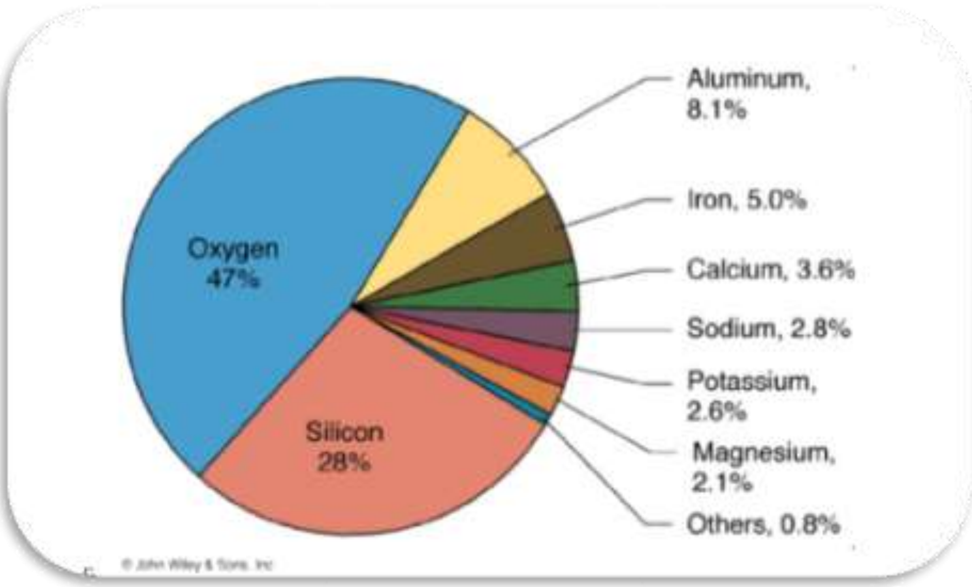


***Figure 10: Elements of the Earth (Credits: Presentation by Dr. Anik De Groof, in course of professors** CESAR).*

3. 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.

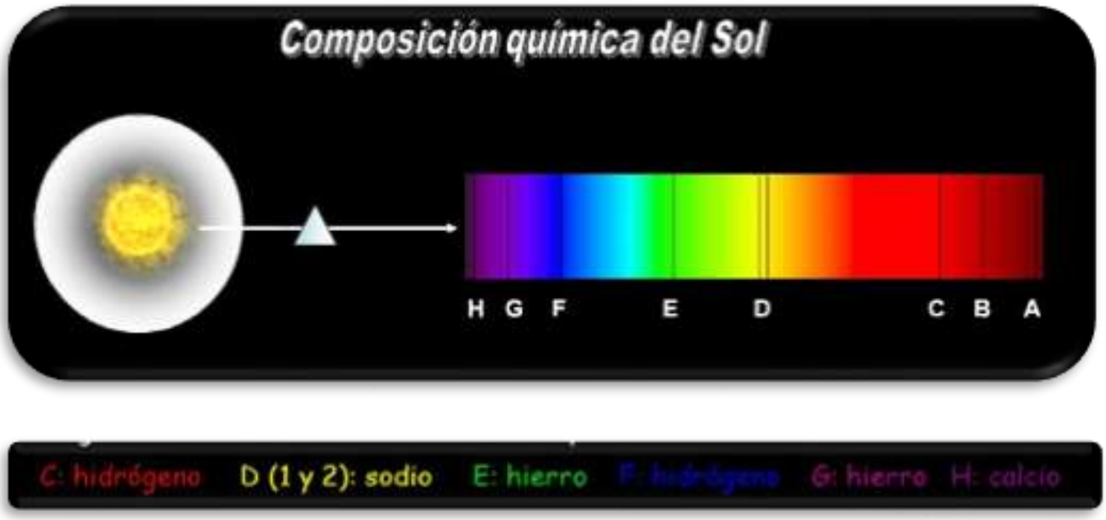


Figure 11: *Chemical Composition of the Sun (Credits :* https://slideplayer.es*)*

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.

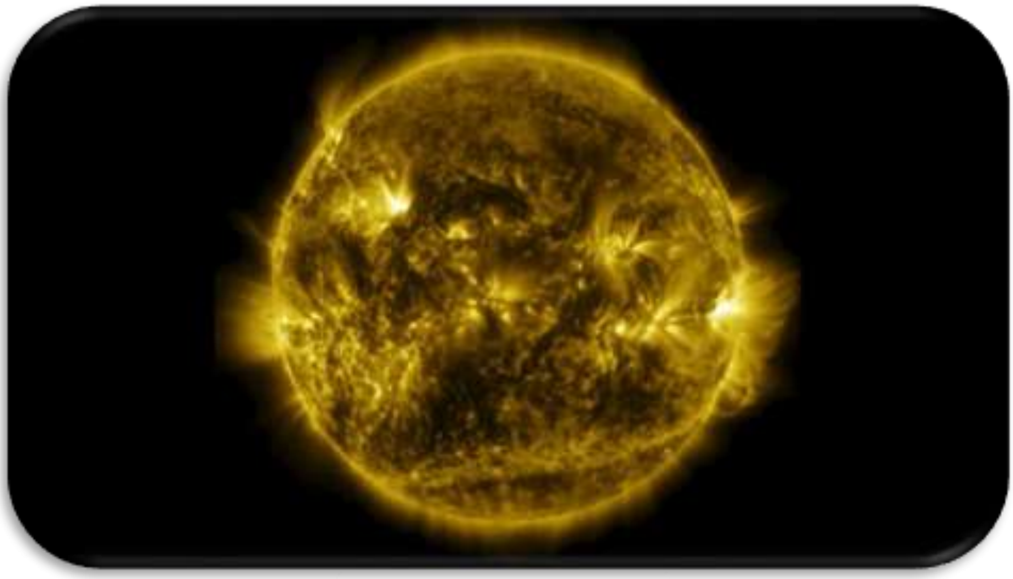


Figure 12: *Image of the Sun (Credits: Presentation by Dr. Benjamín Montesinos Comino for the CESAR teacher workshops)*

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.

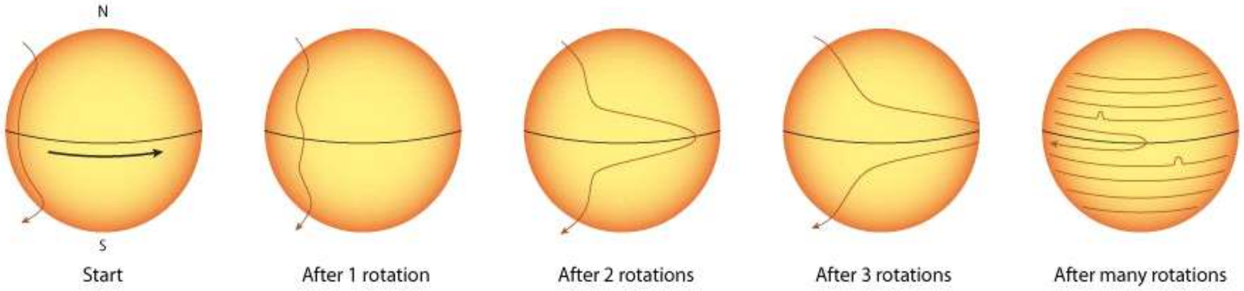


Figure 13: Explanation of how the differential rotation of the Sun is generated over several days (Credits: NASA / IBEX)

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.

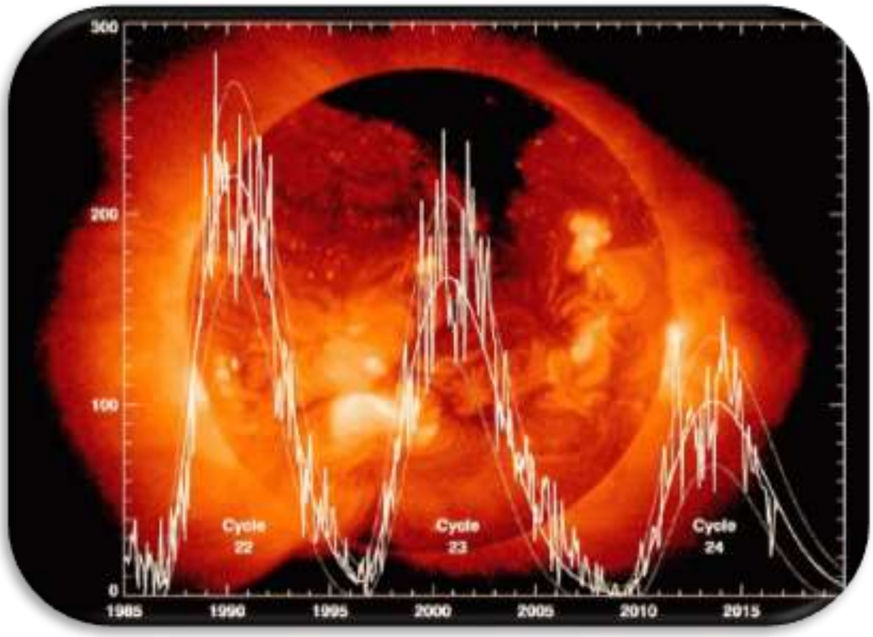


Figure 14: *Cycles of activity of the Sun (Credits https://ciencia.)*

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.]()

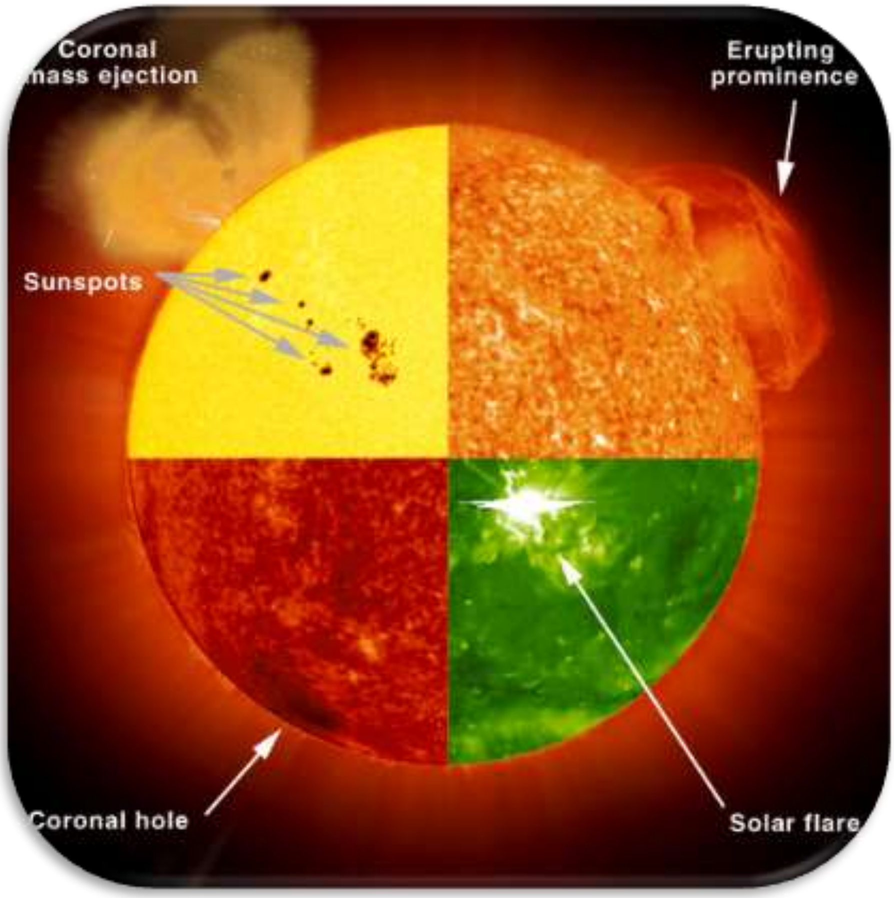


***Figure 15**: Connection between the different effects of solar activity (Credits: geomag)*

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?

Coronal mass ejections, as their name suggests, come from the corona, which is the outermost layer of the Sun.

Activity 4.2: The influence of the Sun on the Earth

The Sun allows the existence of life (Figure 17, zone of habitability [1]) as we know it on Earth, and the variations in its activity impact on Earth at many levels.

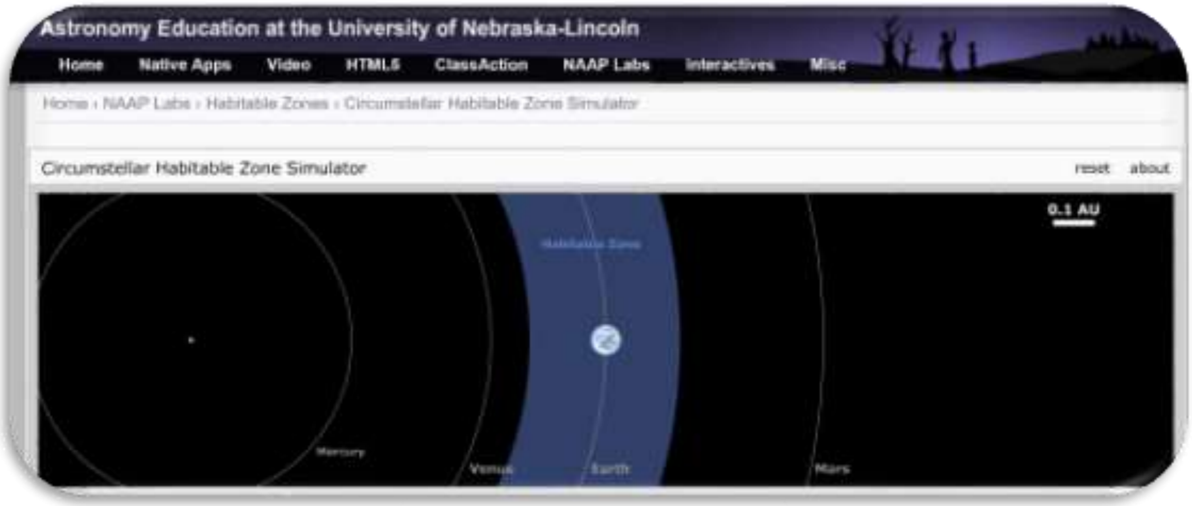


__Figure 16:__ Habitability zone around the Sun where the Earth is located. (Credits: Astronomy Education at the University of Nebraska-Lincoln)

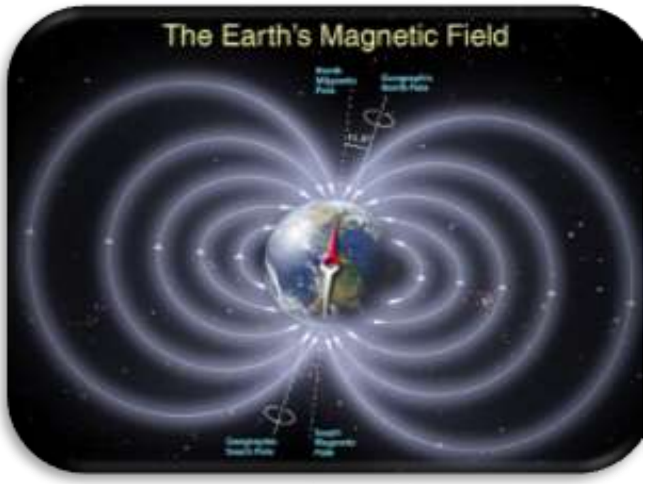
Most of the planets in the Solar System are surrounded by large magnetic envelopes. They are known as magnetospheres and are produced by activity inside the planet. These magnetospheres form the largest structures in the Solar System, being between 10 and 100 times larger than the planet itself.

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

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

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



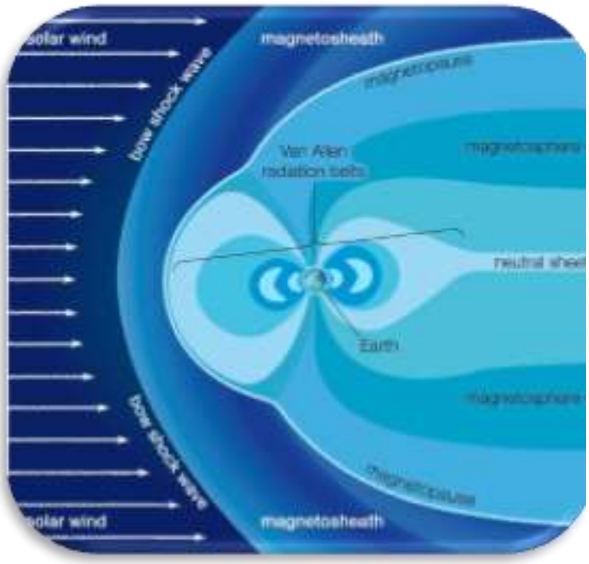


Figure 17: Earth's magnetic field and the influence of the solar wind on it (Credits NASA, ESA)

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

Figure S.3: Example of how not all ejections impact the Earth (Credits: CESAR)

.

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

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

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

The Earth is protected by a magnetic field where the charged particles emitted by the Sun get captures and this can produce very impressive visual effects, such as the Northern Lights.

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?

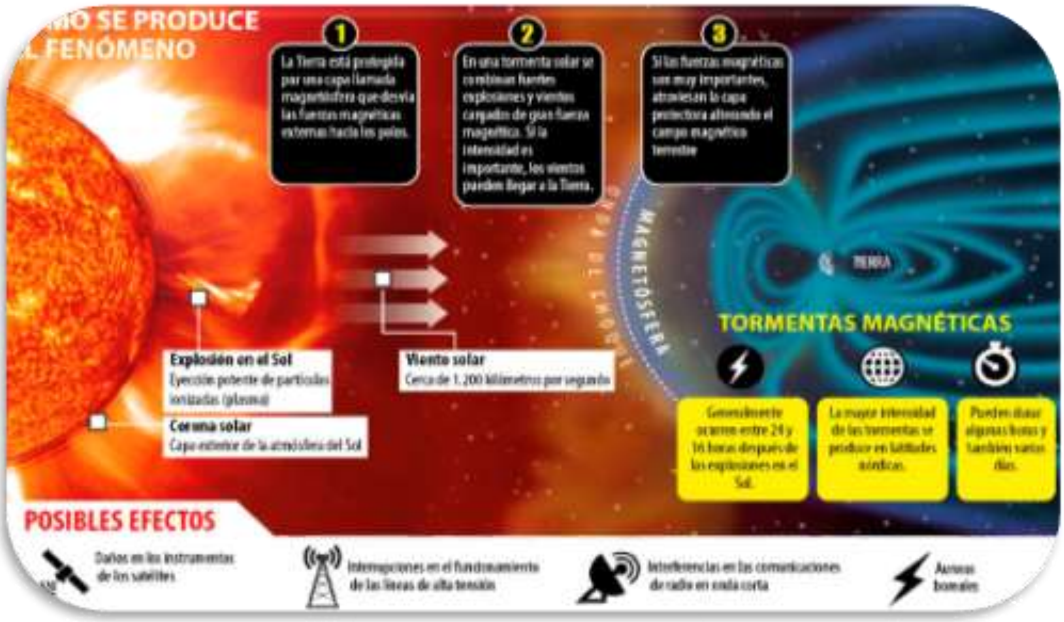


Figure S.4: The influence of the Sun on the Earth's magnetic field (Credits: www.capasdelatierra.org))

The Sun also has a magnetic field, but this changes constantly (Solar Activity), this can cause large explosions in the outer layers of the Sun, which are known as Coronal Mass Ejections It is important for scientists to monitor solar activity, because if the ejection is powerful enough, when it reaches Earth, it can damage telecommunication satellites and even surface electrical installations.

Connection between climate and sunspots detection has not been confirmed jet. Only when the Sun was not active for many (years/cycles) in a row, some effects in climate were identified.

Figure S.5: The Little Ice Age

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

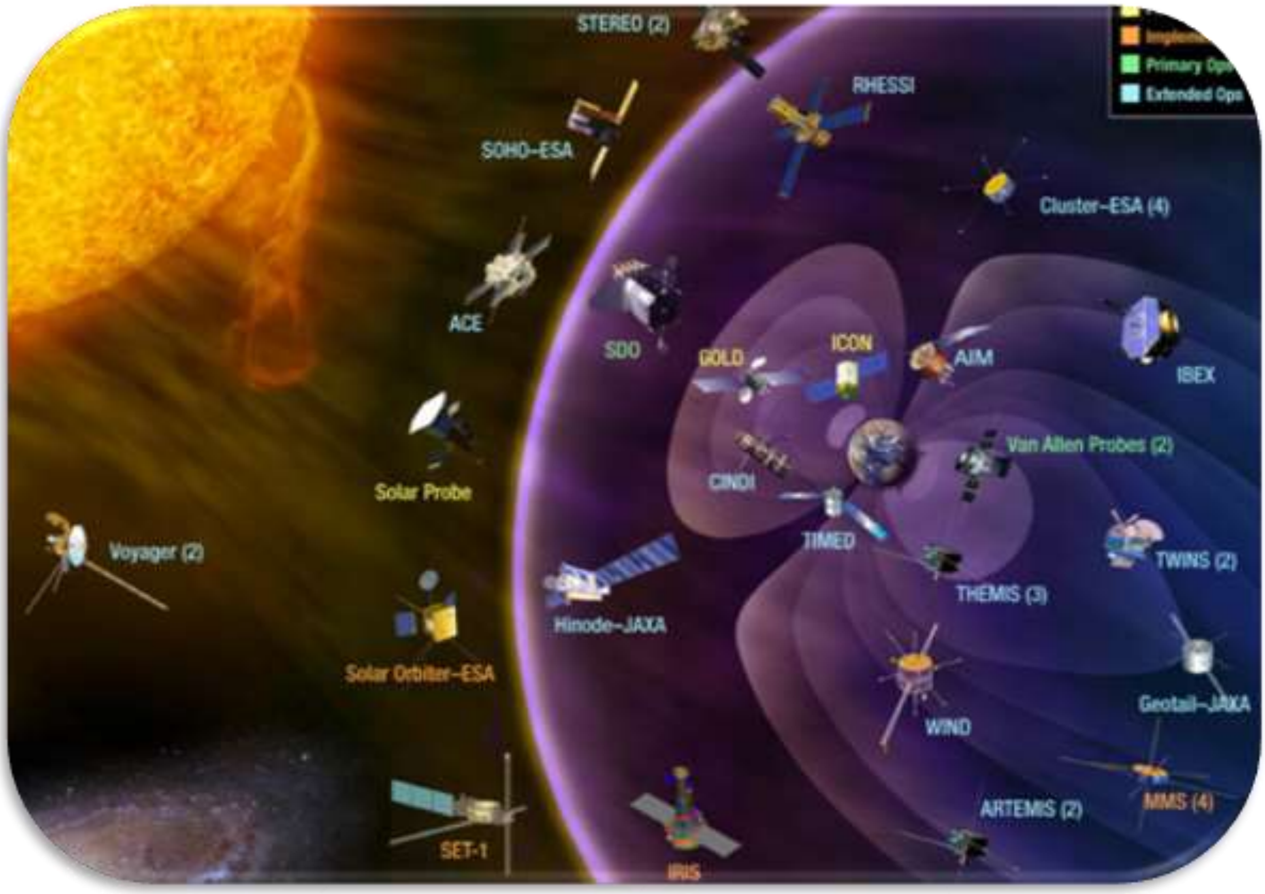


***Figure 20:** European Space Agency mission fleet. (Credits: www.fidefundacion.es)*

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.**

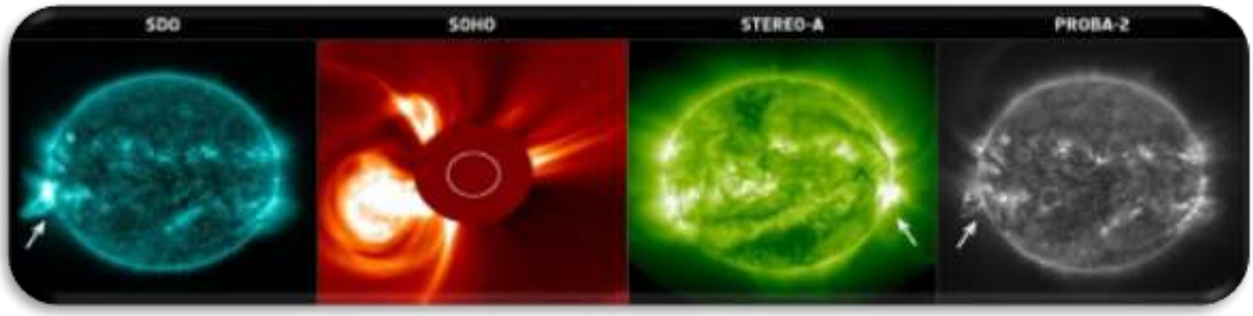


***Figure 21:** The Sun observed in different filters (credits: kiri2ll.livejournal.com)*

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 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: The CESAR solar telescope (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)*

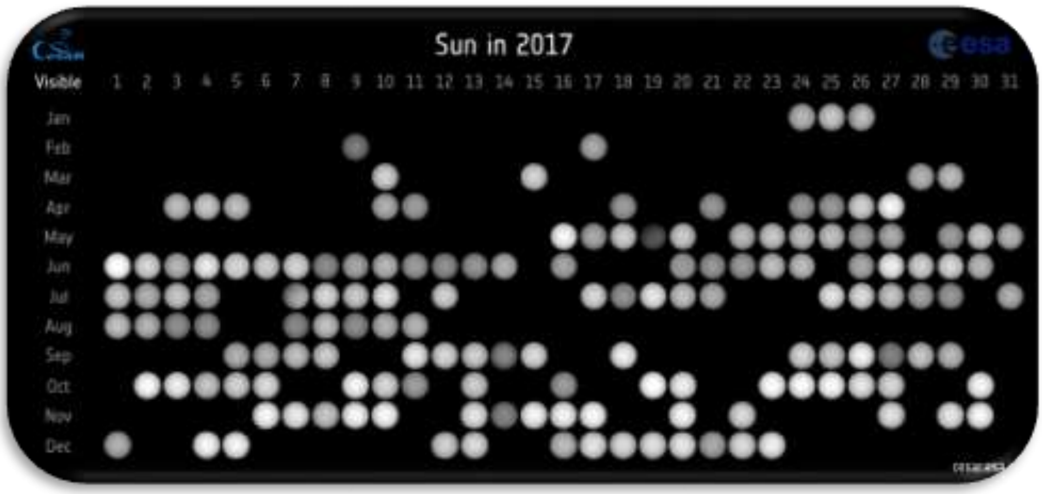


Figure 25: *2017 calendar with images of the disc of the Sun collected by HELIOS (Credits: CESAR)*

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

How to proceed in this Phase depends on the results obtained in the latest Activity of Phase 1 (questionnaire).

- **<u>Case 1:</u>** Your students replied quite well to the quizz
  - ➔ **Go to PHASE 3**

- **<u>Case 2:</u>** Your students did not reply very well to the quizz or they have many questions related to the topic of the Scientific Challenge
  - ➔ **Review PHASE 1** (see below) and use this complementary material

<table>
<tr><td colspan="2">http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=21&ChangeLang=en</td></tr>
<tr><td>Expert talks given at CESAR Teacher workshops (pdf and/or videos)
ESA dedicated videos
CESAR Monographics (booklets)
Simulators/websites</td><td></td></tr>
</table>

➔ **Go to PHASE 3**

- **<u>Case 3:</u>** You can not make it alone and you need interaction with the CESAR Team

Activity 7: Ask for a video-call with the CESAR team if needed.

Figure 27: *Image of the CESAR Team in a video call with teachers (Credits: ESA)*

Note: Per scientific challenge you have the opportunity to ask for 30 min video call
- with your class (in PHASE 2) to clarify concepts
- teachers only (in PHASE 3) in case you are stuck with software/answers

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.

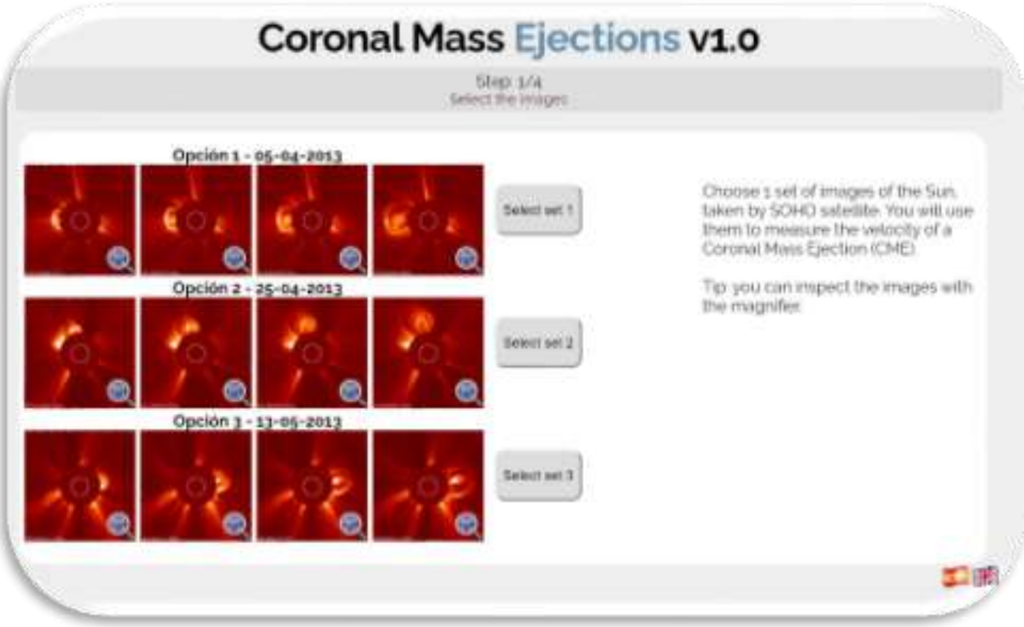


Figure 28: *Step 1 of 4 of the web tool (Credits: CESAR)*

- **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 kilometer conversion.
    The result is around 39 pixels representing 695 842 km.

- **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.

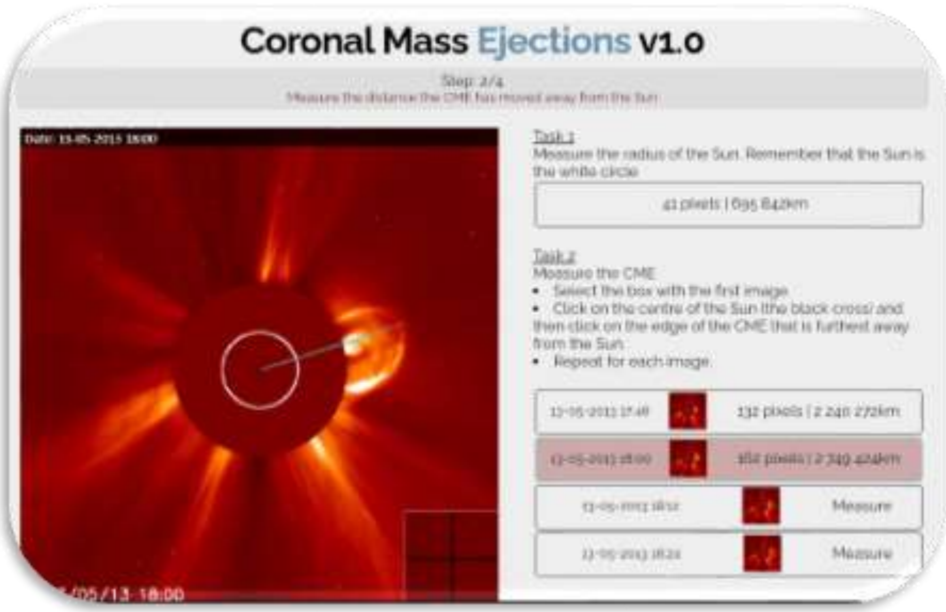


Figure 29: *Step 2 of 4 of the web tool (Credits: CESAR)*

- **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).

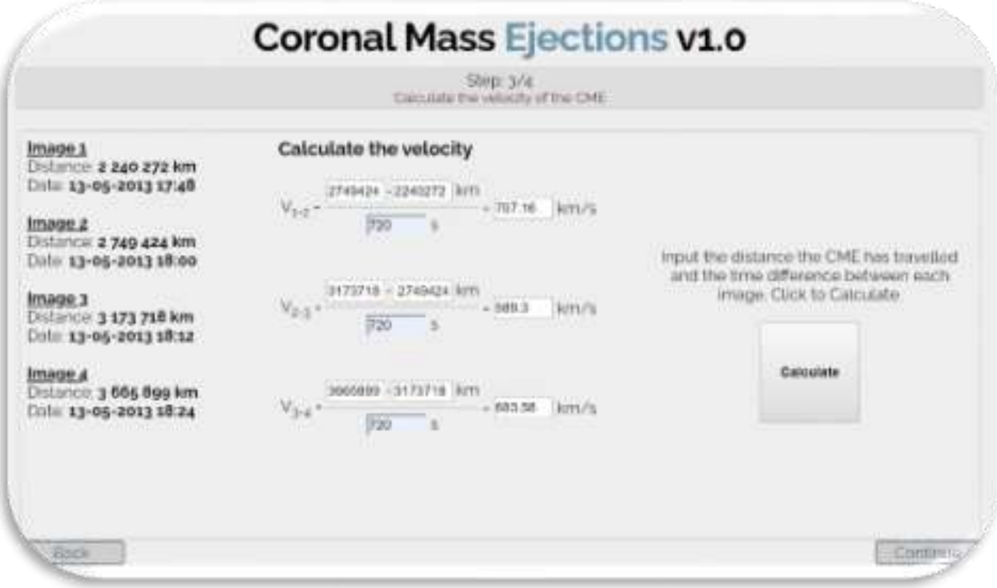


__Figure 30:__ Step 3 of 4 of the web tool (Credits: CESAR)

- **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

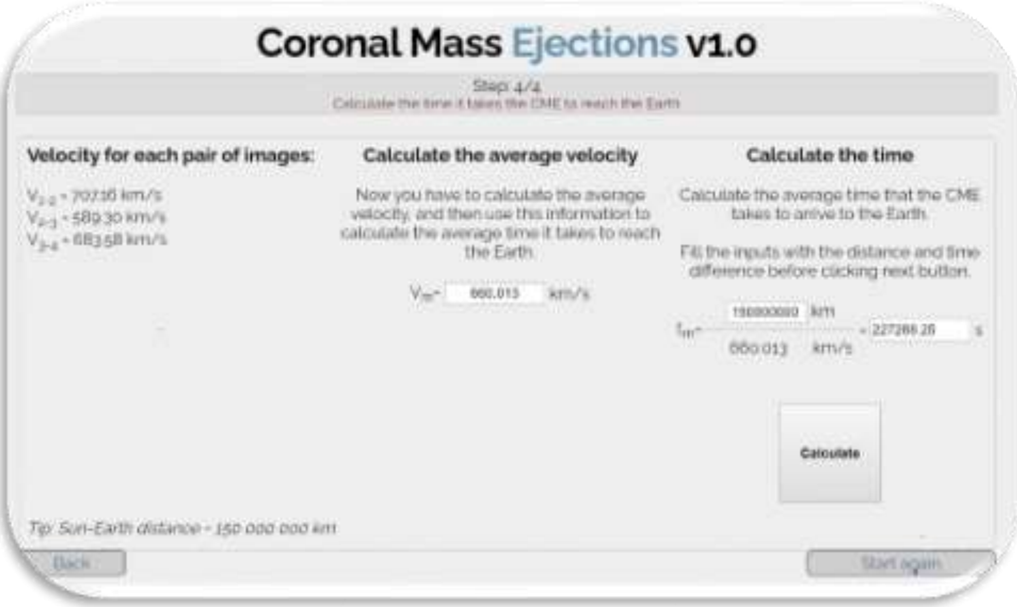


__Figure 31:__ Step 4 of 4 of the web tool (Credits: CESAR)

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).

    The result is that 4 millimeters (millimeters) represent 695,842 km, so the scale factor is of the order of 1:174,000,000,000 (because one millimeter in the image represents 174,000 km or 174,000,000,000 millimeters)).

- **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.

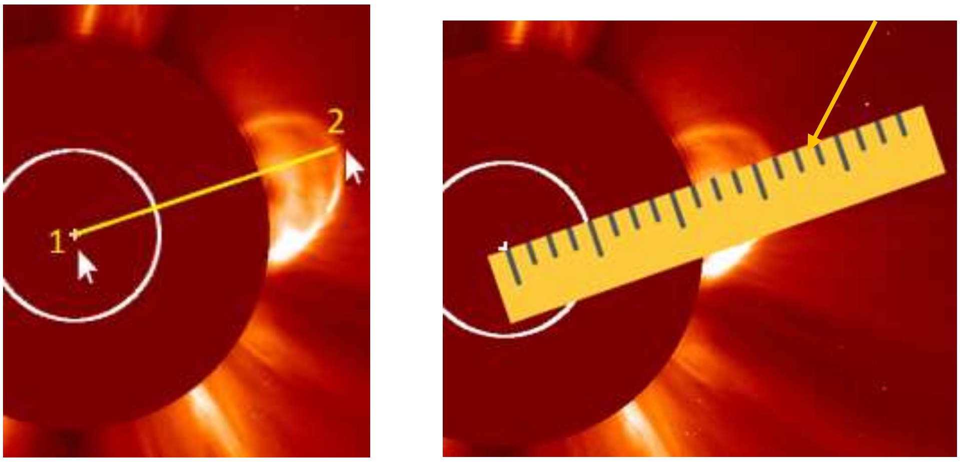


__Figure 32:__ How to make measurements for the on-line (left) and the PDF (right) versions (Credits: CESAR)

Imagen	Date (DD/MM/YYYY hh:mm)	CME length (in millimeters)
1	25/04/2013 09:24	17 mm = 2 958 000 km
2	25/04/2013 09:36	20 mm = 3 480 000 km
3	25/04/2013 10:00	23 mm = 4 176 000 km
4	25/04/2013 10:24	26 mm = 4 524 000 km

__Table 4:__ CME length for a set of images

- **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 kilometers**.

Pair of images	Time difference between images (s)	Distance that the CME has travelled between both images (km)	Velocity (km/s)
(1,2)	12 x 60 = 720	522 000	725.00
(2,3)	24 x 60 = 1440	696 000	497.142
(3,4)	24 x 60 = 1440	348 000	241.666

__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.

    From the data taken in this example, the average velocity would be 497,936 km/s. (Note: This example is intended to exercise the calculation of the average of a value and the MRU equation. However, in this example we clearly see a deceleration (MRUA) in the ejection 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?

Accepted values in the range ($v_{min} = 350\ km/s$, $v_{max} = 875\ km/s$).

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?

The values accepted are between 2-5 days

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

Compare your results with your classmates. For the set of images selected they may have obtain a similar results of (2-5) days.

But …

- Not all CMEs will arrive at Earth because they may be heading in another direction.
- Some CMEs never really escape the Sun's gravitational pull. Some ejections are 'unsuccessful' in the sense that the ejected material falls back to the Sun.
- Some CMEs can also be deflected on their way to Earth because they interfere with other CMEs or with a denser solar window stream.

Activity 9: CME evolves following a uniformly accelerated rectilinear 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).

Students should obtain something similar to a parabola, since the position depends on t^2 (see Figure 31). They should also be able to recognize that this plot corresponds to the distribution of an accelerated movement.

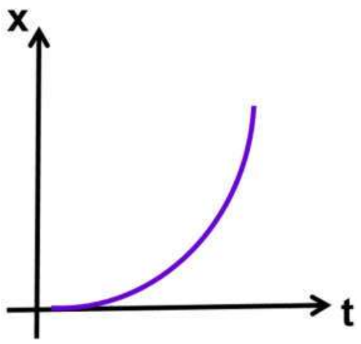


Figure 31: *Chart that students should obtain when representing the position against time*

Conclusions

Students should have noticed that the ejection velocities between the different images are not the same for all three pairs of images. (Note: This is not only due to measurement errors, but also because the ejection does not follow a constant velocity motion

Possible results are presented in Figure 31.

Note 1: for t=0, the ejection distance (between image 1 and 2) is not zero.

Note 2: The results will vary according to the set of images chosen 1 and the error in the measurements.

The acceleration values could be around $(0.1 - 0.4)\ km/s^2$.

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

Once students have obtained the acceleration, they will be able to make a more precise calculation of the time it takes for the coronal mass ejection to reach the Earth following a Rectilinear Motion Uniformly Accelerated

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.

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

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

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

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

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

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

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

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

- Δs: 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 time it takes for CME to do the Sun-Earth path obtained by students in Activity 7.2 will be very different from that obtained in Activity 7.1, and can be up to 10 times less. Assuming that the movement of the ejection has a constant acceleration, for example, of 0.25 km/s^2 , every 4 seconds it moves 1 km/s faster, so the velocity it would acquire when arriving to Earth would be enormous.

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.

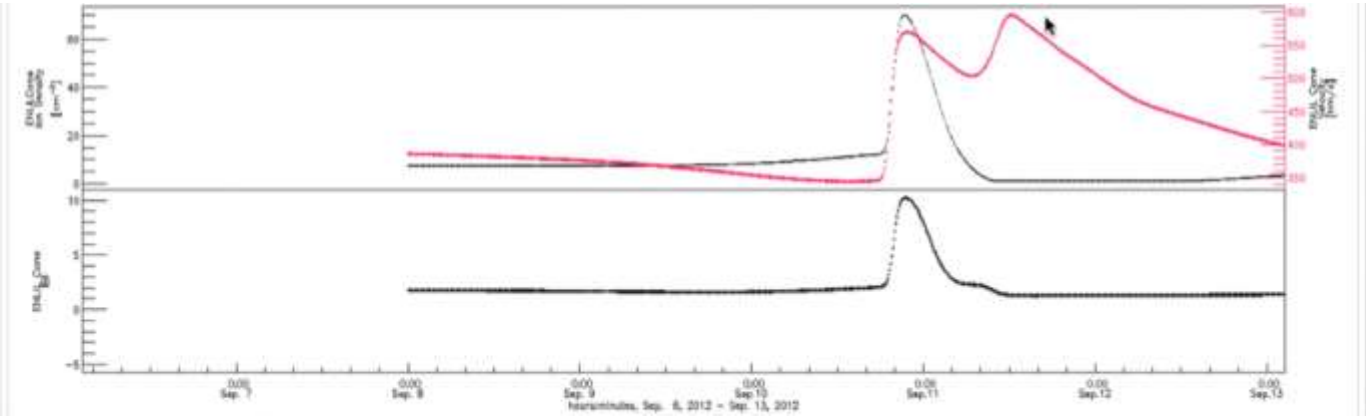


***Figure 32: Velocity-Distance to Sun Chart (Credits**: SpaceWeather)*

Phase 4

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

In Teams and with some support from the teachers, Recall the Experience about your Adventure and do these last Activities

Activity 10: Self-assess and co-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

IMPORTANT NOTES

- Teachers will make sure that each Team performs the evaluations (quizzes)

Activity 11: Tell us about your Adventure

Students will have to create a final product (an A0 poster in pdf format, using power point, for example) showing what they have learned in the different phases of the Scientific Challenge.

This poster is the ticket to participate in the CESAR international adventure competition.

IMPORTANT NOTES:

- It would be very interesting if you could present it to your schoolmates on a certain date, simulating a congress of scientists.
- Any document involving photos of your students can be published on the CESAR website or social networks. Therefore, please only attach those images for which you have explicit permission for publication, intellectual property and image. The CESAR Team is not responsible for their intellectual property and image.

Congratulations teacher!
Thanks to your dedication your class will receive a CESAR Team Super Diploma

Links

PHASE 0:

VIDEOS:

- This is ESA: https://www.youtube.com/watch?v=9wdbNU7Pu8U&feature=youtu.be
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- Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura: http://cesar.esa.int/index.php?Section=Multimedia&Id=63

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- : https://spectralworkbench.org/
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- SOHO: http://scifleet.esa.int/#/model/soho
- SOLO: http://scifleet.esa.int/#/model/solar_orbiter
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PHASE 2:

PHASE 3:

VIDEOS:

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