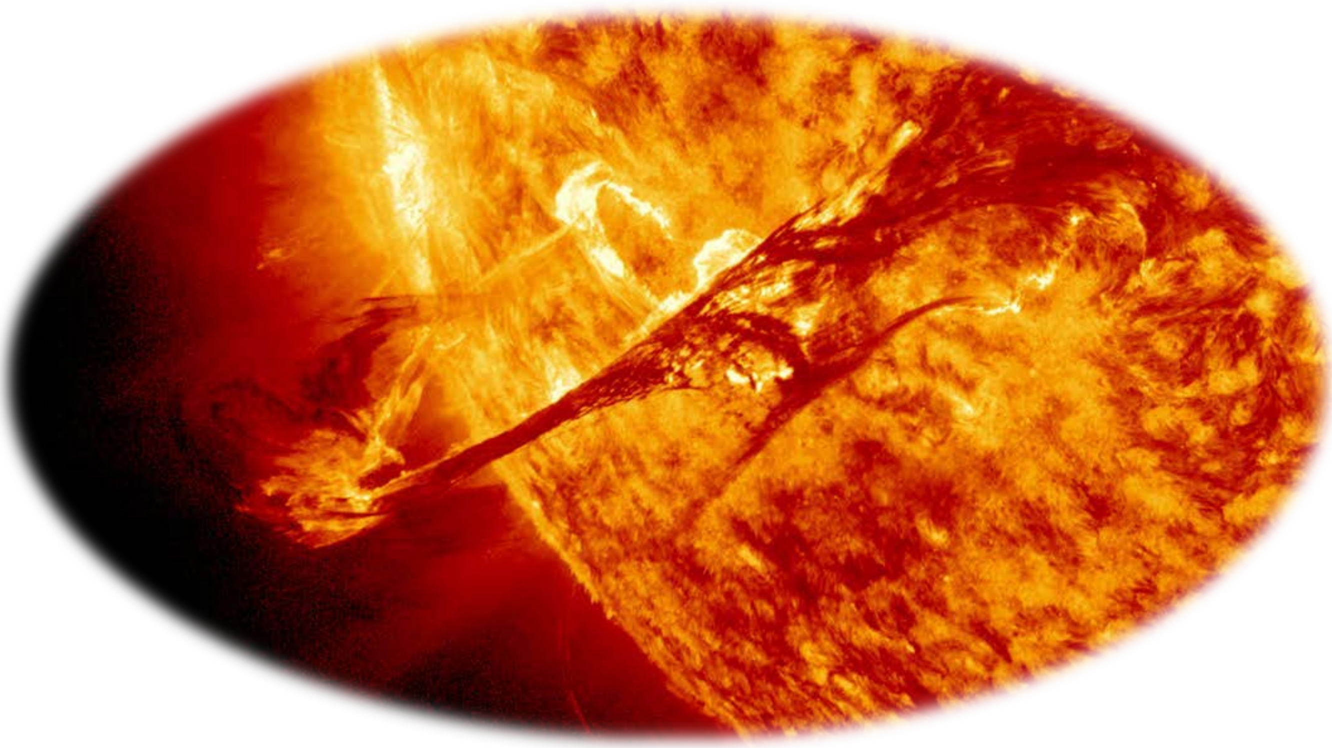
CESAR Science Case

Solar Eruptions

What are they and how do they affect us?

Teacher Guide



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Fast Facts

FAST FACTS

Age range: 14-18

Type: Student activity

Complexity: Medium

Teacher preparation time: 20 minutes

Lesson time required: 1 hour

Location: Indoors

Includes use of: Computers, internet, CESAR Solar Eruptions web tool

Outline

This set of activities provide an introduction to solar activity, in particular the evolution of a Coronal Mass Ejection (CME) and its evolution. Students will use real images of the Sun from observations made by space missions to apply their knowledge of kinematics to an astrophysical scenario.

The activities can be carried out either by using a specially developed online web tool or by using a printed version of the images. Student Guides for both options are available.

Curriculum relevance

General

- Working scientifically.
- Use of ICT.

Physics

- Estimating velocities and accelerations.
- Draw and interpret quantitatively graphs of distance, velocity, time
- Equations for uniformly accelerated motion in one dimension.

Space/Astronomy

- The Sun (structure).

Students should already know…

1. Basic concepts of the Sun and its structure.
2. The relationship between velocity, distance and time.

You will also need…

- Solar Eruptions web tool [URL]

Students will learn…

1. How to apply the relationship between velocity, distance and time to real situations.
2. How to apply the equations for uniformly accelerated motion to real situations.

To know more…

- CESAR Booklets:
  - "The Sun"

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

Title	Activity	Outcomes	Requirements	Time
1.Hypothesizing	Students apply the velocity, distance, time relationship to build awareness of the Earth-Sun distance, and make a hypothesis for how long it a CME would take to travel to Earth.	Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Application of the relationship between velocity, distance and time.	None.	15 min
2.Velocity and time	Students use real images of the Sun and to measure the development of a CME in order to calculate how long it would take to reach Earth.	Students learn: • What information can be seen and extracted from an astronomical image. Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Their ability to apply theoretical knowledge to real-life situations. • Their skills in the use of ICT.	• Completion of Activity 1.	30 min
3. Extension activity: Acceleration	As an extension, students can use their results from Activity 2 to calculate the time the CME would take to travel to Earth more accurately by considering its acceleration.	Students learn: • What information can be seen and extracted from an astronomical image. Students improve: • Their understanding of scientific thinking. • Their strategies of working scientifically. • Their teamwork and communication skills. • Their ability to apply theoretical knowledge to real-life situations.	• Completion of Activity 1. • Completion of Activity 2. . • Knowledge of equations for uniformly accelerated motion.	15 min

Introduction

Our planet is surrounded by an invisible magnetic field, that protects the Earth from harmful radiation from space, most of which comes from the Sun (see Figure 2). The magnetic field of the Earth is very stable and does not change much over time. The Sun also has a magnetic field but unlike that of the Earth, its magnetic field is erratic. It is composed of many magnetic poles whose position and strength are changing constantly.

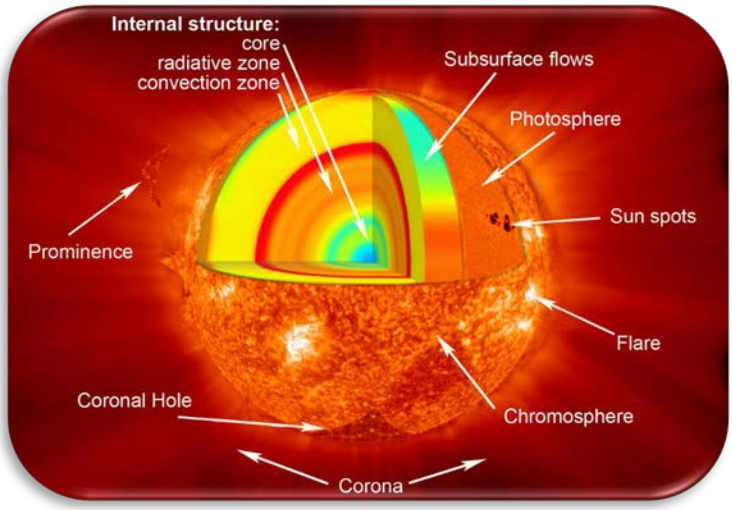

Figure 1: A slice of the Sun (Credit: NASA)

The activity of the Sun's magnetic field can cause huge explosions in its outer layers. These explosions are called Coronal Mass Ejections or CMEs for short.

The influence of the Sun on Earth is what scientists call 'space weather'. The magnetic field of the Earth is the main link between Earth and space, and the charged particles emitted by the Sun can create beautiful light shows, such as the Aurora Borealis or more dangerous phenomenon.

That is why tracking all this information is very important, because if a CME is strong enough the geomagnetic storm can damage satellites and electronic equipment here on Earth. If a CME is known to be approaching scientists can shut down satellites for several hours. However, there is also another important effect of the solar activity. Some research has shown that, in some cases, periods of high solar activity (high number of sunspots) are associated with warm periods on Earth and low solar activity (low number of sunspots) to cold periods on Earth. Therefore, solar activity seems to be linked to Earth's climate.

Figure 2: Illustration of the Earth's magnetic field (Credit: ESA)

Nevertheless, just as we cannot avoid larges hurricanes or devastating earthquakes, studying the activity of the Sun allows us to know where and when they will occur providing time to take preventive actions to eliminate or mitigate damage and loss. In recent times have been and still are many space missions that are focused on studying the Sun and obtaining valuable data to further understanding of our nearest star. These missions include the ESA–NASA Solar and Heliospheric Observatory, SOHO, and the ESA Proba-2 satellite, and the ESA-NASA Ulysses deep-space mission, that completed in 2009.

Much of these data is openly available for everyone to explore, including students in the classroom. These activities make use of these real data, in the form of images and give students an opportunity to apply their theoretical knowledge to the real-life situation of the solar activity

Activity 1: Hypothesizing

In this activity, students consider the vast distance between the Earth and the Sun by applying the velocity-distance-time relationship in order to calculate the velocity or time of various modes of transport. With this knowledge, students are then asked to make a hypothesis as to how long a CME might take to travel from the Sun to the Earth. The main purpose of the activity is for students to realise how far the Sun is from Earth.

Answers to questions in Student Guide

1. The following table shows how long it would take light and different types of vehicles to travel from the Earth to the Sun. Use the following relationship between velocity, distance and time to complete the table.

$$v = \frac{d}{t} \qquad t = \frac{d}{v}$$

Where v is velocity, d is distance, and t is time.

Hint: Sun-Earth distance = 150 000 km

Vehicle	Velocity	Time
Light	$3 \cdot 10^8\ m/s$	$\underline{8\ minutes\ 30\ seconds}$
Fastest Space craft	$\underline{30\ 000\ km/h}$	$6\ months$
Plane	$1000\ km/h$	$\underline{17\ years}$
Car	$\underline{120\ km/h}$	$142\ years$
Bike	$25\ km/h$	$\underline{683\ years}$

2. Make a hypothesis as to how long do you think it would take a Coronal Mass Ejection (or CME for short) to travel to the Earth from the Sun. In addition, do you think that every CME travels with the same velocity? Explain your answer.

A CME takes around 2-5 days to travel from the Sun to the Earth.

Not every CME takes the same amount of time to travel to the Earth, it depends on the mass and energy released, and if more than one ejection is emitted by the Sun at once.

3. Do you think that Earth can be hit by every CME the Sun emits? You could use a sketch to aid your explanation.

CMEs can be emitted from the Sun in any direction (see Figure 3). Therefore, only a small portion of them are emitted in the direction of the Earth.

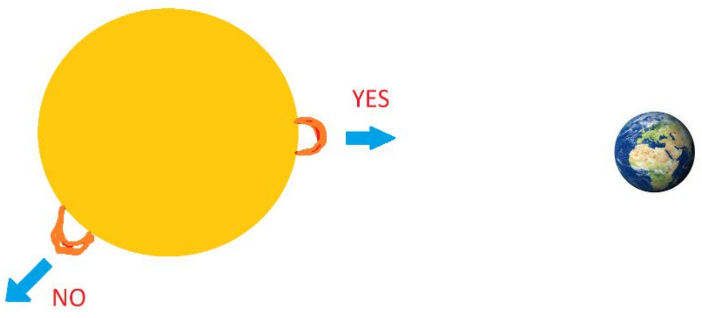

Figure 3: Example of a sketch showing that not all ejections hit Earth

Activity 2: Velocity and time

In this activity, students will use images of the Sun taken by the ESA-NASA SOHO satellite to calculate the velocity of a CME. Students will then calculate how long it would take to reach the Earth.

This activity can be completed either by using an online tool developed for this activity or by using a set of printed images, that can be found in the Appendix.

Several sets of four images are available for students to use to make their measurements. After they have selected a set of images students should follow the instructions given in their Student Guide to complete the activity. Separate Student Guides are available for the online version and the printed version.

1. In both versions, their first task is to measure the radius of the Sun.

    - **Online version:** students must click on the centre of the Sun (the centre of the cross) and then on any point of the white circle, which indicates the size of the Sun in the images.

    - **Printed version:** students must measure from the centre of the Sun (the centre of the cross) to any point of the white circle, which indicates the size of the Sun.

2. The next measurements are from the centre of the Sun up to the edge of the CME. **Figure 4** shows an example of this measurement. This must be repeated four times, one measurement per image.

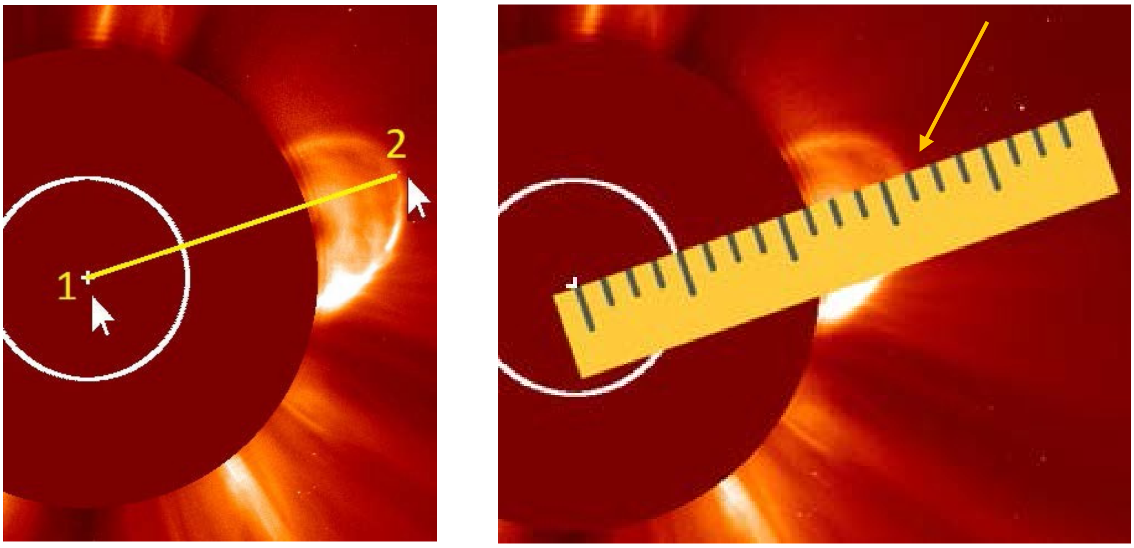

***Figure 4**: How to make the measurements for both versions of the activity, online version (left), printed version (right)*

Answers to questions in the Student Guide

- Velocity

Accepted values are in the range

$$v_{min} = 348 \text{ km/s}$$

$$v_{max} = 870 \text{ km/s}$$

- Time

CMEs usually spend 2-5 days travelling. Every value in this range is acceptable.

Students will measure the expansion of different CMEs that will have different velocities and therefore take different amounts of time to travel to the Earth. Ask students to compare their results with the results of their classmates. In addition, students could repeat the activity with a different set of images.

Extension activity: Acceleration

In this extension activity students plot the results they obtained in Activity 2 to find the acceleration of the CME. Once the acceleration is known students calculate a more accurate time for the CME to travel to the Earth using the equation of uniform acceleration.

Students may have noticed that they obtain different values for the velocity of the CME for each of their four images. This is not due to errors in measurement, it is because the CME is not following a linear uniform motion - It has an acceleration. Therefore, its movement requires a more precise study.

Answers to questions in the Student Guide

1. Use the values of the velocities you calculated in Activity 2 to find the CME's acceleration.

   Values should be between 0.1 km/s and 0.4 km/s.

2. Plot the CME's movement in a graph representing distance travelled versus time. What kind of motion does the CME have? Why do you think that is?

   Students should obtain something similar to a parabola because the position depends on t^2 (see Figure 5). Students should be able to recognise the graph of uniformly accelerated linear motion.

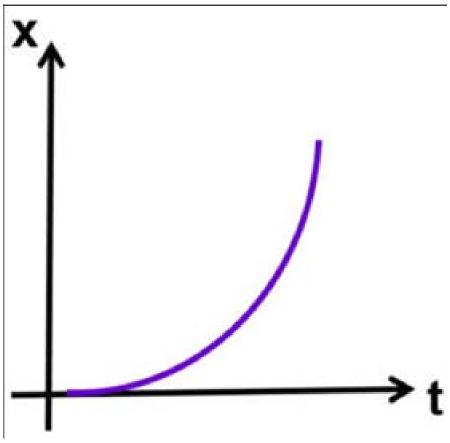

Figure 5: Example shape of graph students should obtain when plotting measurements.

3. Once you have the acceleration, use the equation of motion for uniform acceleration to make a more accurate calculation of the time the CME would take to travel to Earth. Solve the following equation for t .

Students should solve the equation given in their guides for t, where only a positive term is valid, as follows:

$$s = v_0 t + \frac{1}{2} at^2 \quad \rightarrow \quad t = \frac{\pm\sqrt{v_0^2 + 2as} - v_0}{2a} \quad = \quad \frac{\sqrt{v_1^2 + 2ad_{S-E}} - v_1}{2a}$$

The time calculated by students will be very different from the one obtained in Activity 2, it will in fact be around ten times lower. Assuming that the CME is following a uniform accelerated motion a value of 0.25 km/s^2, for example, means that every 4 seconds its velocity increases by 1 km/s, so the final velocity reached will be enormous and the time needed smaller. The real movement of a CME is not acceleration uniform, its velocity decreases due to friction, produced by the solar wind.

Continuation…

The acceleration of the real movement of the CME is no constant. Its acceleration is decreasing due to the friction produced by the interplanetary medium, especially with the solar wind. On Figure 6 we can see the density of the material and the velocities distribution as the CME moves away from the Sun.

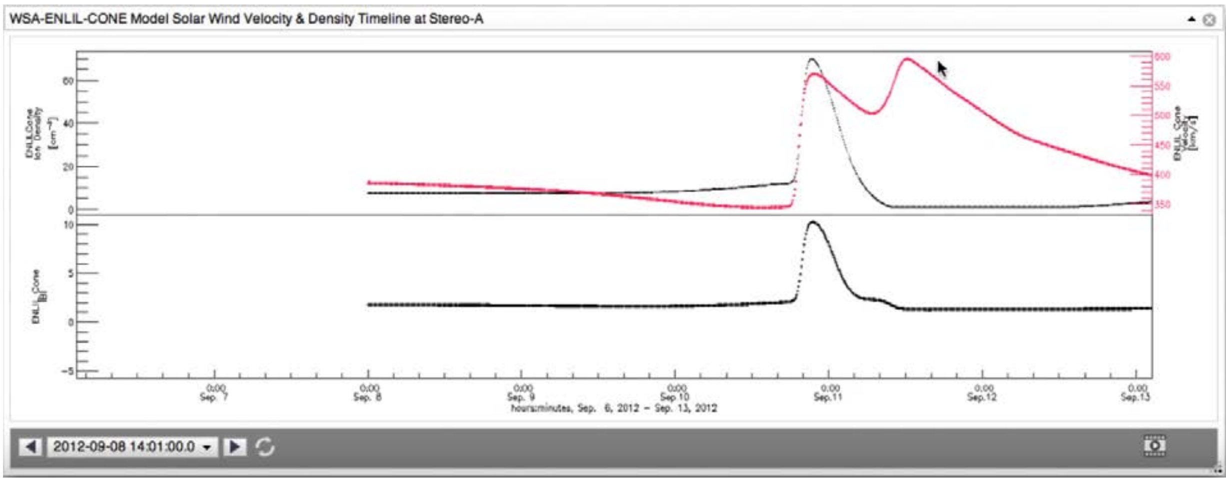

Figura 1: Velocity-Distance to the Sun Graph (Crédits: CUASpaceWeather)

Links

Stars

- CESAR Booklet: *Stellar evolution*
- Stellar processes and evolution: http://sci.esa.int/education/36828-stellar-processes-and-evolution/

The electromagnetic spectrum and ESA missions

- CESAR Booklet: *The electromagnetic spectrum* http://cesar.esa.int/upload/201711/electromagnetic_spectrum_booklet_wboxes.pdf
- Science@ESA: *The full spectrum* (video) http://sci.esa.int/education/44685-science-esa-episode-1-the-full-spectrum/
- Science@ESA: *Exploring the infrared universe* (video) http://sci.esa.int/education/44698-science-esa-episode-3-exploring-the-infrared-universe/
- Blackbody radiation: http://sci.esa.int/education/48986-blackbody-radiation/