CESAR Science Case

Solar Eruptions

What are they and how do they affect us?

Student Guide

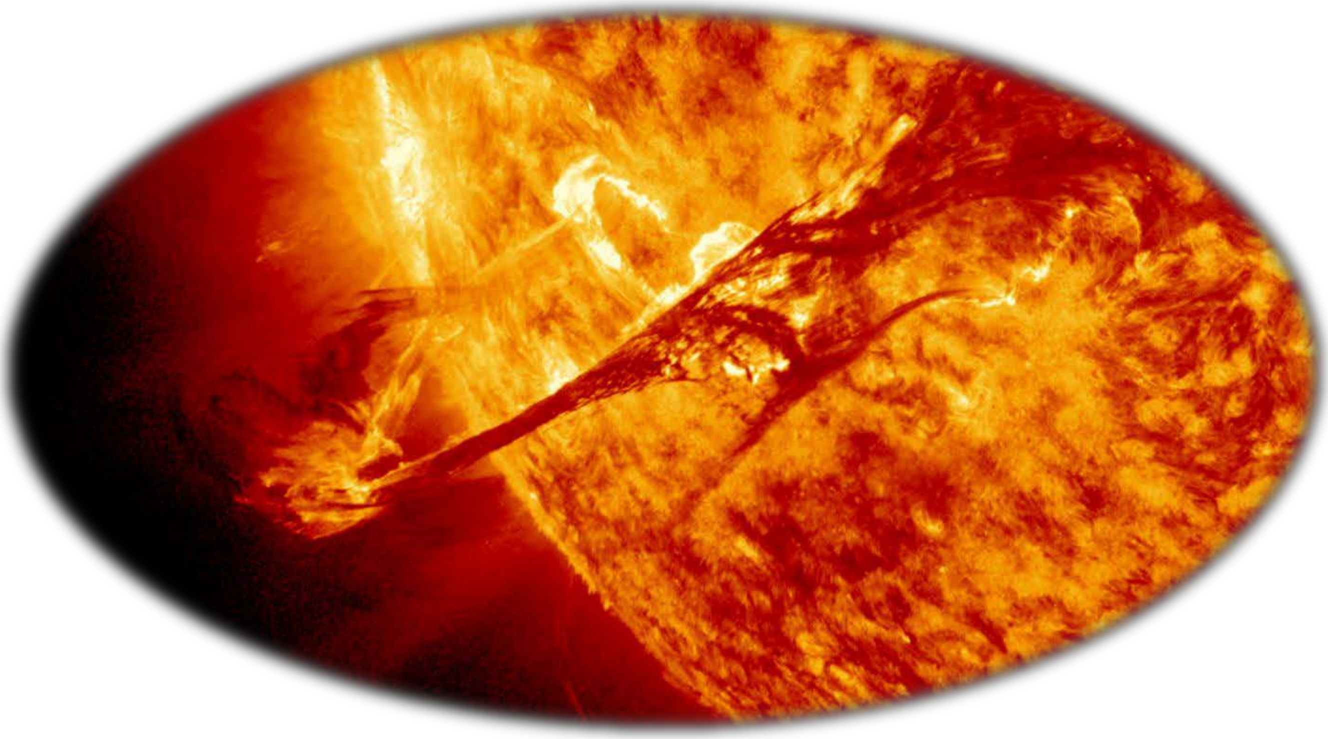


Table of Contents

Background

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.

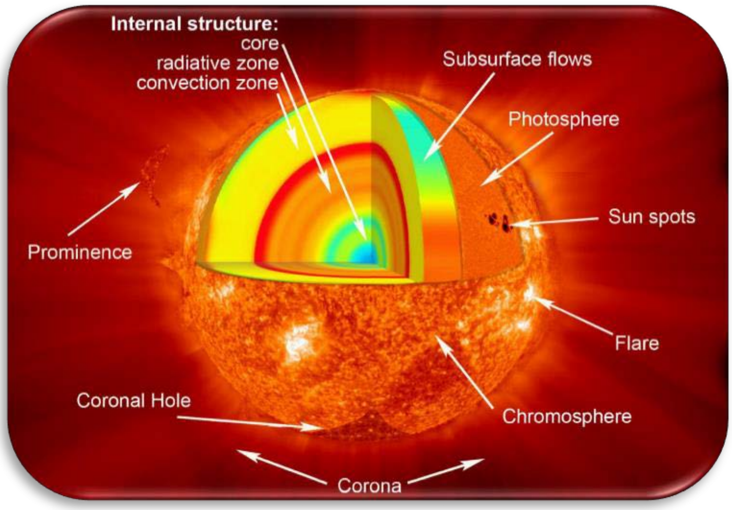


Figure 1: *A slice of the Sun (Credit: NASA)*

This 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 the 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 to protect them. However, there is also another important effect of 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 the 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 lesson damage and loss. In recent times there 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.

Investigating CMEs

Activity 1: Hypothesizing

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

Object	Velocity	Time
Light	3x 10^8 m/s	
Fastest spacecraft		6 months
Plane	1000 km/h	
Car		142 years
Bike	25 km/h	

Use the following box for your calculations

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.

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

Activity 2: Velocity and time

In this activity, you will calculate the velocity and time of a Coronal Mass Ejection (CME). To do this you will use real images of a CME emitted by the Sun and observed by the ESA-NASA SOHO satellite. You will use a set of four images of a CME that shows how it develops over time.

Did you know?

Many satellites and ground-based telescopes are constantly observing Sun. A whole branch of study, known as Heliophysics, gets daily data from space observatories like the ESA **PR**oject for **O**n **B**oard **A**utonomy mission (PROBA-2) and the Joint ESA-NASA **So**lar and **H**eliospheric **O**bservatory (SOHO).

ESA is currently working on Solar Orbiter, scheduled for launch in 2020. This new solar mission will orbit the Sun and take close-up images of its surface. In addition, it will take new and unique data to aid understanding of how our nearest star works.

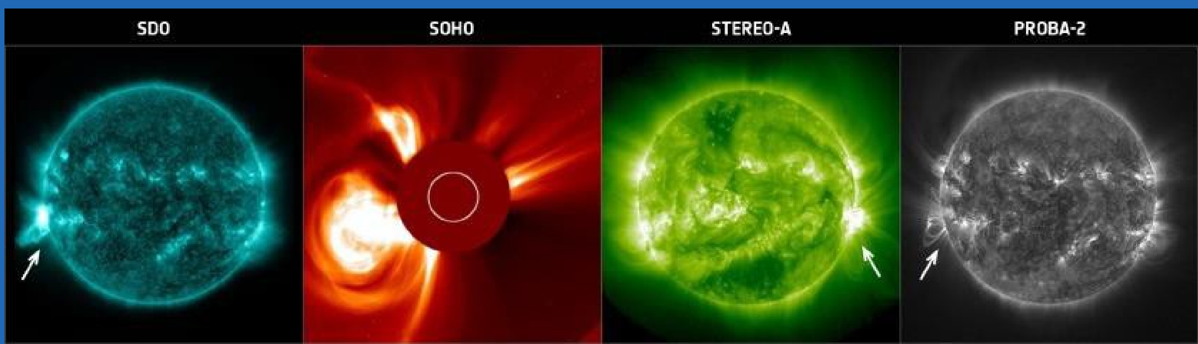


Figure 3: Sun observed with different filters (Credit: kiri2ll.livejournal.com)

- ## Step 1: Select images

First, go to the online web tool [link here].

You will see that there are several sets of images. Each set contains four images of a Coronal Mass Ejection that show how it develops over time.

There is a white circle on every image this indicates the size of the Sun. The images were taken by the LASCO instrument on board the SOHO satellite. LASCO is a coronagraph that blocks out the direct light from the Sun so that its atmosphere, the corona, can be observed. A coronagraph is a bit like a hat or a cap that we would wear on a sunny day to shield our eyes from bright sunlight.

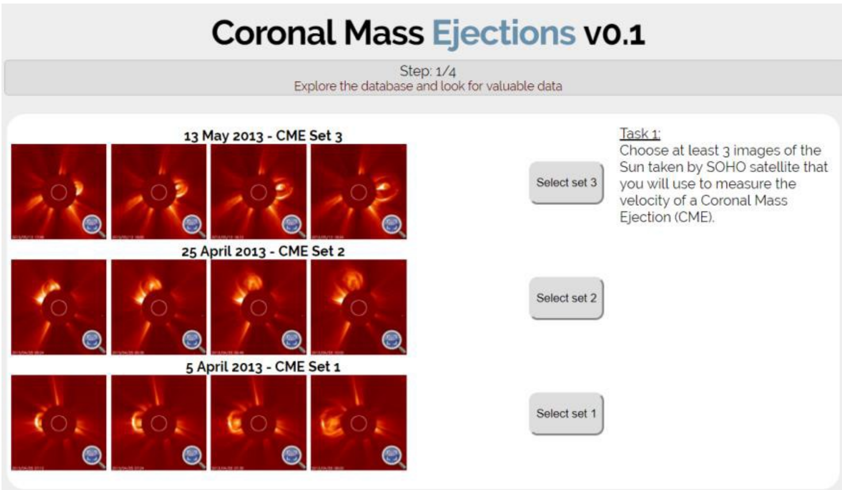


Figure 5: *Online Tool, Step 1*

- Step 2: Make measurements

You need to measure the radius of the Sun with the online tool. We already know its size in kilometres, once measured with the tool you will also know the radius in pixels.

Did you know?

A pixel is the smallest element in an image. It give us a lot of information about the object we are photographing. If one square is 40 pixels wide, it is smaller than another square 80 pixels wide. We know immediately that the second one is twice the size of the first one. So if we know the size, for example in metres of the first one (let us say 2 metres), we know that the second one is 4 metres.

Following the same reasoning, we can work out the distance a CME moves away from the Sun if we have one reference. This reference is the size of the Sun. Its radius is 695 842 km. Solving for the term in bold in the equation below we will know the size of the ejection's path in km.

$$\frac{\underline{Radius\ of\ the\ Sun\ (km)}}{Radius\ of\ the\ Sun\ (pixels)} = \frac{\underline{Path\ of\ the\ ejection\ (km)}}{Path\ of\ the\ ejection\ (pixels)}$$

In the following steps, you will measure the path of the CME. Move to the second box. Click first on the black cross and then on the furthest point of the CME. You will again see the distance in pixels and in kilometres, as well as the date and time the images were taken.

You need to repeat this measurement for every image. The web tool records the values, so once you have measured all the distances, click on **Continue** to move to the next step**.**

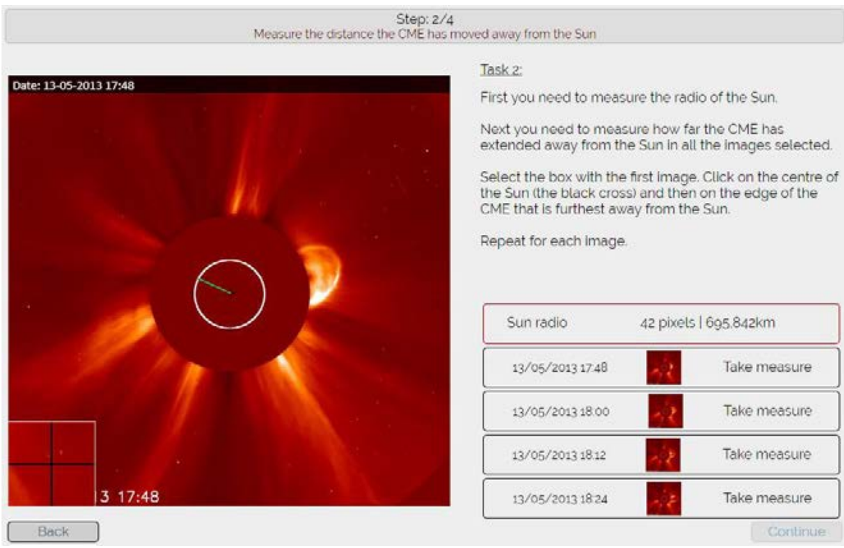


***Figure 6**: Online Tool, Step 2*

- Step 3: Calculate velocity

On the left-hand side of the web tool, the following information is displayed for each image: your measurement of the distance between the edge of the CME and the centre of the Sun, and the date and time each image was taken.

To estimate the velocity of the CME complete the empty boxes in the web tool.

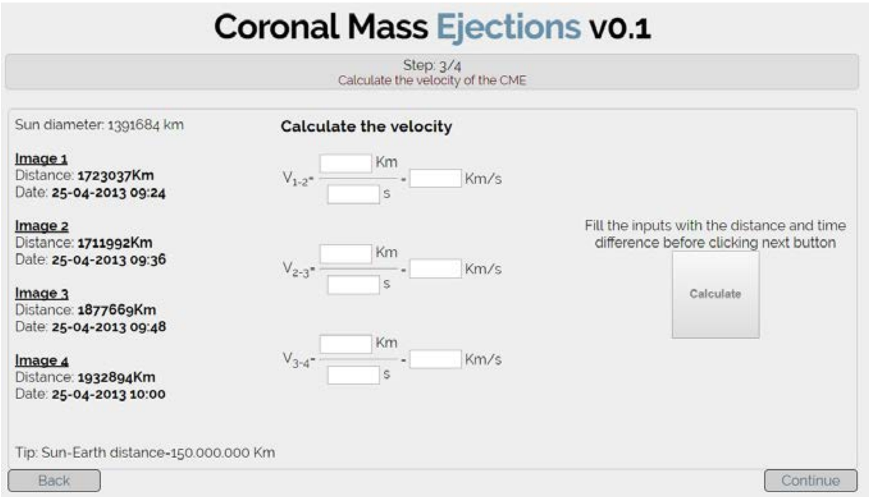


Figure 7: *Online tool, Step 3*

You need to enter the values for the distance the CME has travelled (in kilometres), and the time it has taken to travel this distance (in seconds).

The distance travelled is the difference between the final and the initial measurement from one image to the next, and the time is the time between the final and the initial image. Use the equation below, in which v is velocity, d_1 is the distance measured in the first image, d_2 is the distance measured in the second image, and so on….. t is the time interval (in seconds).

Tip: *Just take hours and minutes into account, the day is the same!*

Click on **Calculate** to get the results.

Write down your results here.

v_{1-2}	=	km/s
v_{2-3}	=	km/s
v_{3-4}	=	km/s

Then click on **Continue**.

- Step 4: Calculate travel time

It is time to estimate the CME travel time!

You will notice that the speed is not the same for every pair of images; however, they all belong to the same CME. Calculate the mean velocity and write it down here:

v_m	=	km/s

Insert the mean velocity into the v_m box of the web tool.

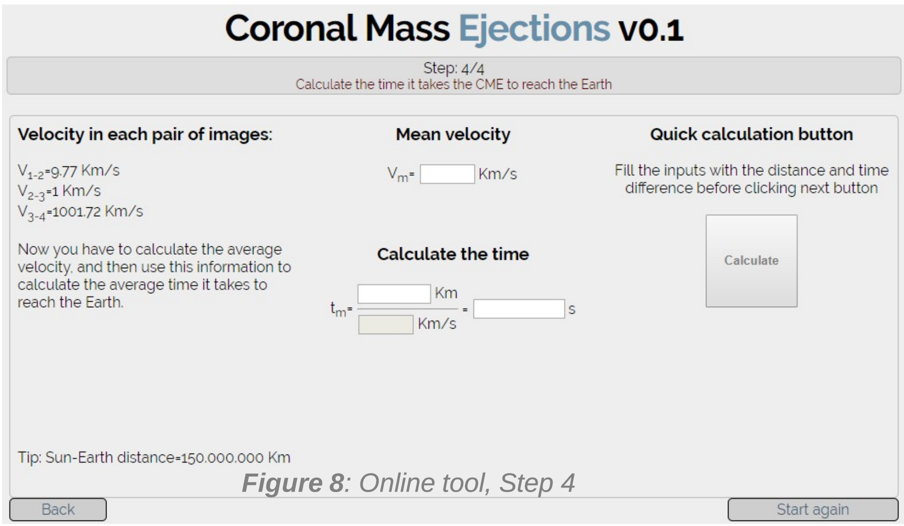


***Figure 8**: Online tool, Step 4*

Using the equation below, calculate the estimated time.

$$t = \frac{d_{S-E}}{v_m}$$

Help: *Sun-Earth distance = 150 000 000 km*

Using the mean velocity v_m and the Sun-Earth distance (d_{S-E} in the equation), you can estimate the travel time of the CME. Insert all data into the web tool and click on **Calculate**. The time will be given in seconds; you must convert this into the most intuitive units, such as **hours**, **days** or **minutes**.

$t_m =$	s

$t_m =$	days	hours	minutes

When you have finished, you can compare your result with your classmates, or you can also choose another set and compare it with your first measurements. Is the velocity the same for every CME?

Write down your conclusions here.

Extension activity: Acceleration

A more precise study would require us to look at the movement of the CME as uniformly accelerated linear motion.

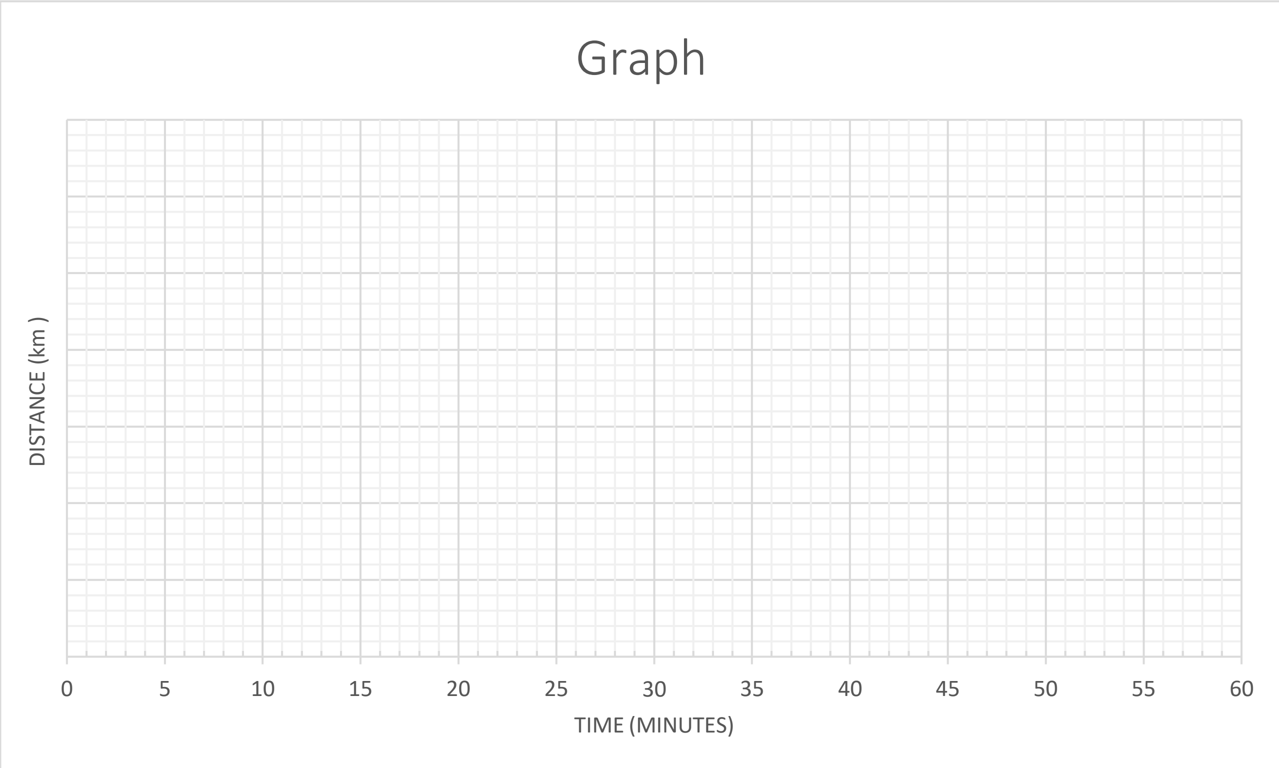
You may have noticed that the velocity of the CME is not always the same, which means there is an acceleration. This can be obtained by measuring the velocity over different time intervals. If you use the first velocity v_1 and the last velocity v_3 calculated in Activity 2 you will get a close approximation of the acceleration.

$$a = \frac{v}{t} = \frac{(v_3 - v_1)}{(t_3 - t_1)}$$

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

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?

Measurement n	t	s	v
1			
2			
3			
4			



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 .

$$s = v_0 t + \frac{1}{2} a t^2$$

To know more…

…about galaxies

- CESAR Booklet: *Galaxies*
  http://cesar.esa.int/upload/201801/galaxies_booklet.pdf
- The *Galaxy Zoo* project: https://www.galaxyzoo.org

…about 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/

…about CMEs

- Top 50 Solar Flares (archive):
  https://www.spaceweatherlive.com/en/solar-activity/top-50-solar-flares