NAROM | ANDØYA SPACE CENTER

Co-funded by the Erasmus+ Programme of the European Union

UNDERSTANDING A NORTHERN LIGHT EVENT

Task Box: The Sun-Earth Connexion

Summary

- This exercise provides an understanding of the relationship between the solar activity and the formation of northern lights.

Content

Overview	
Purpose	This exercise will provide a general overview about the Northern Lights, how they are related to the solar activity, how they are produced, and how we can predict them.
Duration	Four hours (2 inside, 2 outside)
Location	Classroom / Outside (ASC)
Equipment	Computer with internet connexion.
Safety issues	None
Background	Basic knowledge about Northern Lights
Literature	Included
Software	Mobile Phone Apps.

Learning objectives

Gain increasing knowledge about:

- using the scientific methodology
- the relationship between the solar activity and the formation of Northern Lights.
- the use of online resources, in particular SDO
- the term "radiation" at basic level and the relation to the Sun.
- the relationship between solar wind and the variation of the Earth's electromagnetic field.

21st Century skills:

- Work in international groups using English as communication language
- Problem solving skills
- Critical thinking
- Collaboration
- Communication
- Information and media literacy

Introduction

In this exercise, an analysis of a Northern Light event that happened on February 2014 will be done. To carry it out, we will make a historical tour that will allow us to discover why the Northern Lights are produced. Later, we can generalize to other past events and we will learn to know how the northern lights are currently predicted.

Northern Lights in the history. Myths and legend

Throughout history, the Northern Lights have aroused the curiosity of humanity. Obviously, those cultures settled at higher latitudes were the ones that most developed myths about these strange lights that are usually seen in the dark skies in the polar regions.

Even so, there are records by other cultures established in middle latitudes. It is believed that some drawings found in caves in the South of France, around 30,000 years ago, in the Cro-Magnon era, refer to the northern lights. Eastern Asian cultures, like the Chinese, also picked up these strange lights with myths and allusive legends. Greek and Roman civilizations have also echoed them, and it is even believed that some Old Testament passages describe auroral phenomena. The Northern Lights continue to inspire artists of all kinds. Listen as example the song of the Irish group The Script – Flares (see link in the bibliography at the end of the document).

It was in the 18th century when important attempts to give a scientific explanation to this phenomenon started, despite of some previous ones based on erroneous premises.

Activity 1:

Investigate the mythology about the northern lights in your culture. If you are coming from a southern latitude and cannot find any, please choose a northern culture like Vikings in Scandinavia, inhabitants of Greenland, sami people...

Northern Lights event: 27/2/2014

Let's try to do an exercise that allows us to make a scientific description of this natural phenomenon. For that purpose, we will study what happened the night of the 27th of February 2014.

Activity 2:

Read the following articles. Both talk about spectacular northern lights in latitudes where it is unusual to see them, as they are usually circumscribed at higher latitudes

https://www.theguardian.com/travel/2014/feb/28/northern-lights-southern-uk-aurora-borealis-essex-jersey

https://globalnews.ca/news/1178645/8-stunning-images-as-aurora-borealis-light-up-uk-sky/

Discuss in groups and write hypotheses about how do you think the auroras are formed, what produces them and how we can predict them.

After you have written your expectations and hypothesis, check the following link: *https://www.youtube.com/watch?v=8S_LPFOa-zs*

Discuss what new things you have learned and what is different from your expectations.

Support links

https://www.swpc.noaa.gov/phenomena/aurora
https://www.swpc.noaa.gov/phenomena/earths-magnetosphere
https://www.swpc.noaa.gov/phenomena/solar-wind
https://www.swpc.noaa.gov/products/planetary-k-index

Northern Lights and geomagnetic field

The English scientist, Sir Edmund Halley, saw the most beautiful Northern Light of the 18th century in 1716. Halley explained the aurora as follows: "The auroral rays are due to the particles, which are affected by the magnetic field; the rays are parallel to the Earth's magnetic field, and the shape of the vault is due to perspective phenomena." This is the first scientific finding that was accepted at that time and is still true. Halley, of course, is not known for the Northern Lights but for Halley's comet, whose movement he could predict.

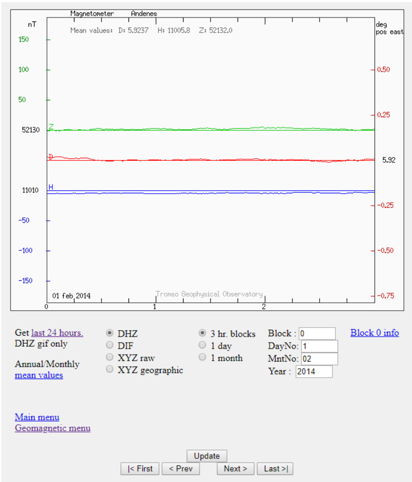
A multitude of theories were presented to explain the northern lights. A common proposal was to include a burning gas as a key part of the theory. Some of the theories of this kind had already been introduced by the ancient Greeks, more than 2,000 years before. In 1741, the Swedish scientific, Celsius, observed a connection between the northern lights and magnetic activity. In fact, he stole the result and the resulting honor from his student Hjorter. However, we should consider this result as the second correct scientific finding in the Northern Lights, which has been accepted since it was proposed. Let's explore this way.

Activity 3:

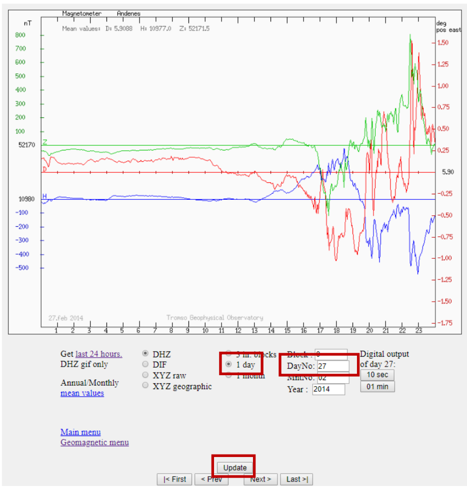
Let's study how the Earth's magnetic field varied in the range of days from February 25th to 28th, 2014.

Click the link: *http://flux.phys.uit.no/ArcMag/*

You will see a list with different stations. Choose Andenes. In the new window you will see options to choose different years and months per each year. Select February 2014. You should obtain the following graph.



Now select the day the whole day 27. See indications below:



Discuss in groups and write your findings. What conclusions can you draw? Is the appearance of Northern Lights related to the variation of the magnetic field? Who has produced this variation?

Northern Lights and Sun activity

In 1859 the English amateur astronomer Richard Carrington also connected a very strong aurora to an event he observed on the Sun 17 hours earlier. However, no physical explanation was presented. This is called Carrington Event.

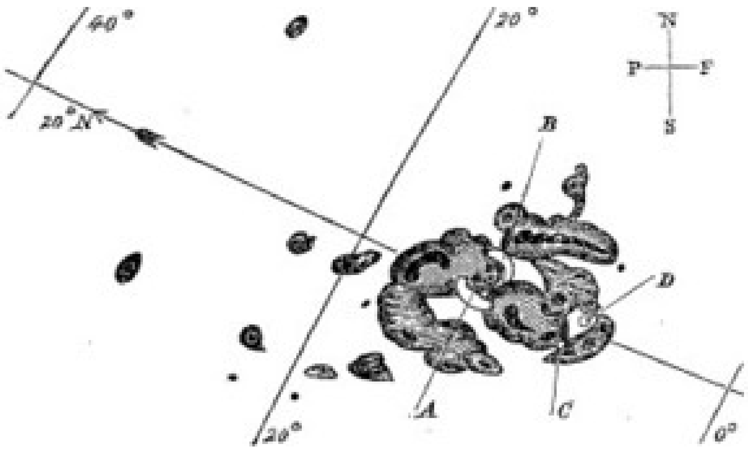


Figure 1: Richard Carrington's drawing in 1859 of the solar flares he identified while observing sunspots.

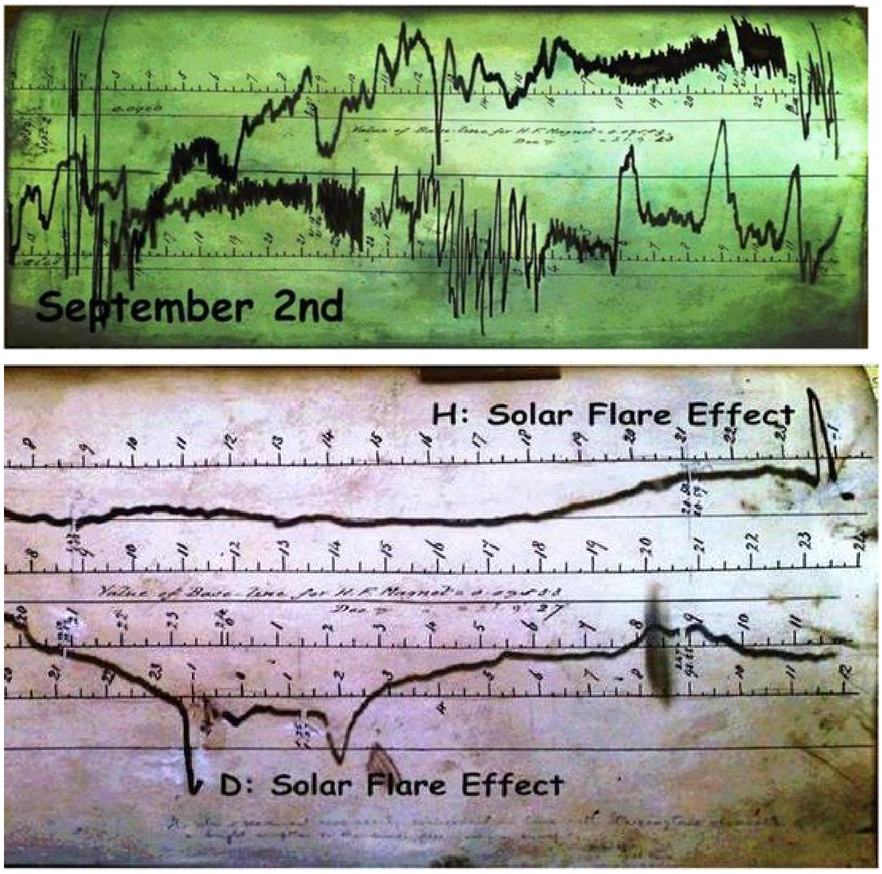
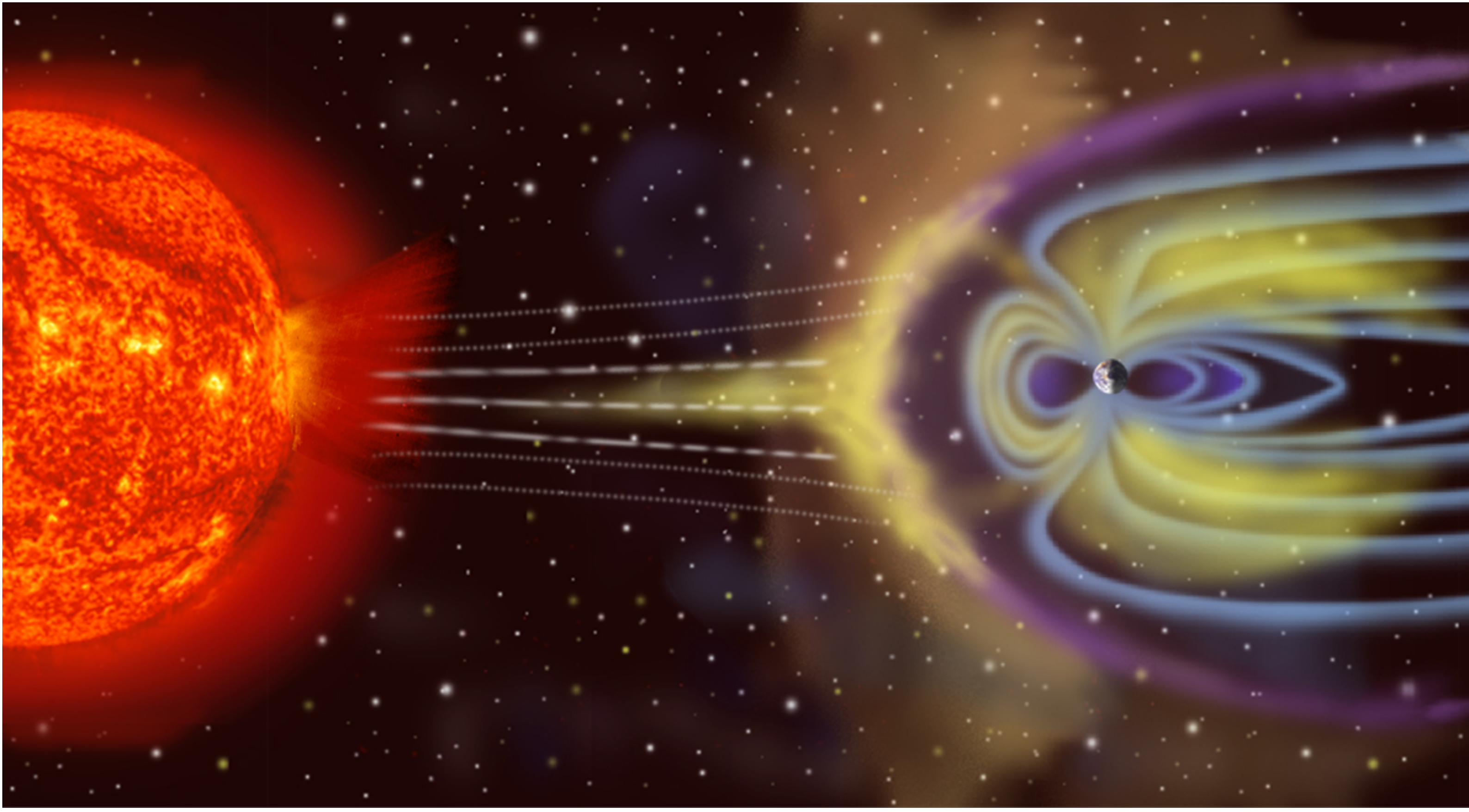


Figure 2: Magnetograms recorded at the Greenwich Observatory in London during the Carrington Event of 1859. The bottom line (D) represents the direction of the compass; The upper line (H) represents the horizontal force.



Due to energetic process that happens in the external layers of the Sun mainly related to its magnetic activity, its outer layers(corona) are very hot and cannot be held in place by the Sun's immense gravity, thus the Sun is constantly losing its atmosphere as it flows away into space. The solar wind is a constant output of highly charged particles from the Sun. These particles are electrified and magnetic. Important points to take into account are the following:

- There is a constant flow of charged particles and magnetic field going away from Sun.
- The Magnetic field doesn't "flow" towards Earth; it expands outward from the Sun
- The solar wind takes 1 to 3 days to travel to the Earth.

Solar Wind - Magnetic Field

The solar wind is a stream of charged particles (also called plasma) released from the upper atmosphere of the Sun, the corona. This plasma consists mainly of electrons, protons and alpha particles with thermal energies between 1.5 and 10 keV. Embedded within the solar-wind plasma is the interplanetary magnetic field. The solar wind varies in density, temperature and speed over time and over latitude and solar longitude. Its particles can escape the gravity of the Sun due to its high energy resulting from the high temperature of the corona, which in turn is a result of the coronal magnetic field.

Just like in the Earth, the Sun has a magnetic field, but much more complex. Important points to consider:

- The solar wind is magnetic.
- Magnetic fields are vectors - they have strength and direction.
- Where the lines converge, the strength is higher.
- Unlike solids, liquids, or gases, plasmas are stuck to magnetic fields (and vice versa).
- As plasma flows away from the Sun, the magnetic field is dragged with it.
- This magnetic field fills the space between the planets, so it is called the interplanetary magnetic field (IMF).

The speed of the solar wind is the reflection of solar activity and, therefore, at a higher value, more will interact with the Earth's magnetic field and may form more spectacular northern lights.

From the solar wind to Northern Lights:

- The solar wind Interacts with Earth's magnetic field forming a magnetosphere.
- If we could see the magnetosphere (but we can't – magnetic fields are invisible), it would look kind of like a comet with a long tail pointing away from the Sun.
- The solar wind is not steady, just like Earth winds – sometimes weak, sometimes strong.
- Interaction with the magnetosphere can produce aurora or northern lights (nice).
- Interaction with the magnetosphere can also damage satellites usually protected by the magnetosphere (not so nice).

The Solar Dynamics Observatory (SDO)

The Solar Dynamics Observatory (SDO) is a NASA satellite that was built to observe the Sun. It reached its current orbit at Lagrange Point L1 in 2010 and was scheduled to investigate the sun for five years or longer. SDO help to improve knowledge of the aspects of the Sun's activity that directly affect life and society here on Earth, namely the sun's radiation. SDO observes at many different wavelengths simultaneously that allow to have a better perspective of the solar activity (see below).

The main task of SDO is to study the Sun magnetic field, how it is generated and structured, and how it affects the release of solar energy in the form of particles and electromagnetic waves.

Observations at different wavelengths

Light with different wavelengths are produced in different ways and in different places in the sun. Therefore, observing the Sun in a specific wavelength gives us information on where the light is "produced" / emitted from the sun. The visible surface of the sun (photosphere) is the region we can observe with our eye. To observe other regions, we need the special "eyes" installed at the SDO, because these other regions are observed in other wavelengths we cannot reach with our eyes or from the surface of the Earth. These are the different wavelengths SDO (measured in Angstrom) can register, and the regions associated:

- 1700: Displays the photosphere and chromosphere.
- 1600: Displays the upper photosphere and the so-called "transition region" between the chromosphere and the corona.
- 304: Displays chromosphere and transition region.
- 171: Shows the atmosphere and the quiet corona. Also shows the so-called "Coronal Loops".
- 193: Showing warmer parts of the corona and "solar flares"
- 211: Displays warmer and magnetically active parts of the corona.
- 335: Same as 211.
- 94: Showing solar flares.
- 131: Displays the hottest materials in a solar flare.

Coronal Mass Ejections (CMEs) and Flares

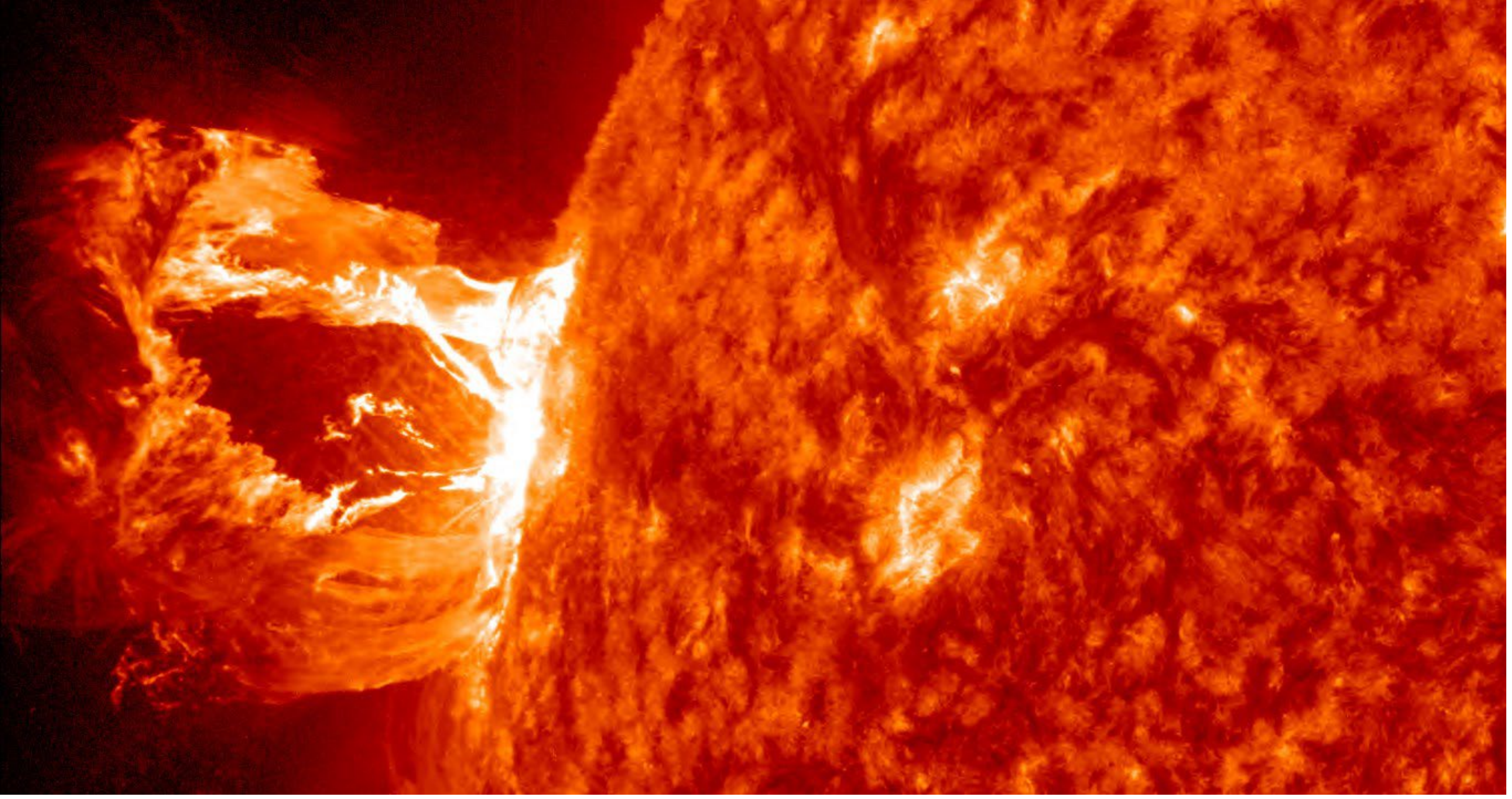
In addition to the solar wind, there are other important events that happen associated to the solar activity. Now we can observe them better thanks to satellites as SDO. These are Coronal Mass Ejections and Flares.

The solar wind is not steady. There are times when the Sun unleashes huge amounts of mass and energy (ions, electrons, and magnetic fields) out into space. These large solar storms come from the Sun's outermost atmosphere, known as the Corona.

CMEs and flares are both explosions that occur in the sun. Sometimes they occur together. Flares are giant burst of X-rays and energy, which travel at the speed of light in all directions. Therefore, they take 8 minutes to reach the Earth. CMEs are giant clouds of particles hurled out into space. CMEs take one to three days to reach the Earth. SDO see flares as flashes of light on the sun and CMEs as eruptions spreading out into space.

The following video from SDO observations at various wavelengths shows well these phenomena: *https://www.youtube.com/watch?v=ouCX5_rVZak*

Therefore, let's look at the Sun in the days before February 27, 2014. We will use images taken by the solar observatory SDO.



Activity 4:

Let's analyse the solar activity on 24th February 2014 using SDO images, to study what happened in the Sun just before the data analysed in the activity 3 for the geomagnetic field. Click the following links:

https://spaceweather.com/archive.php?view=1&day=25&month=02&year=2014

https://sdo.gsfc.nasa.gov/assets/img/dailymov/index.php?b=2014%2F02%2F24

For the second link, watch the videos with label finishing in 1600, 304, 171, 193, 211, 335, 94 y 131. Download the mp4 files.

Discuss in groups. Answer the following questions:

- Which wavelengths have you found more useful to provide information? Explain
- Have you noticed anything unusual? Describe the anomalies observed. What are they?
- Write a small description summarising your observations and conclusions.
- Compare this data from 24th February 2014 with todays data. You can obtain the latest in the next link: *https://sdo.gsfc.nasa.gov/data/* . Describe similarities and differences.
- Review your findings in the activities 2 and 3 to set them together with your conclusions using the SDO data for making a chronology of the event.

Northern Lights prediction

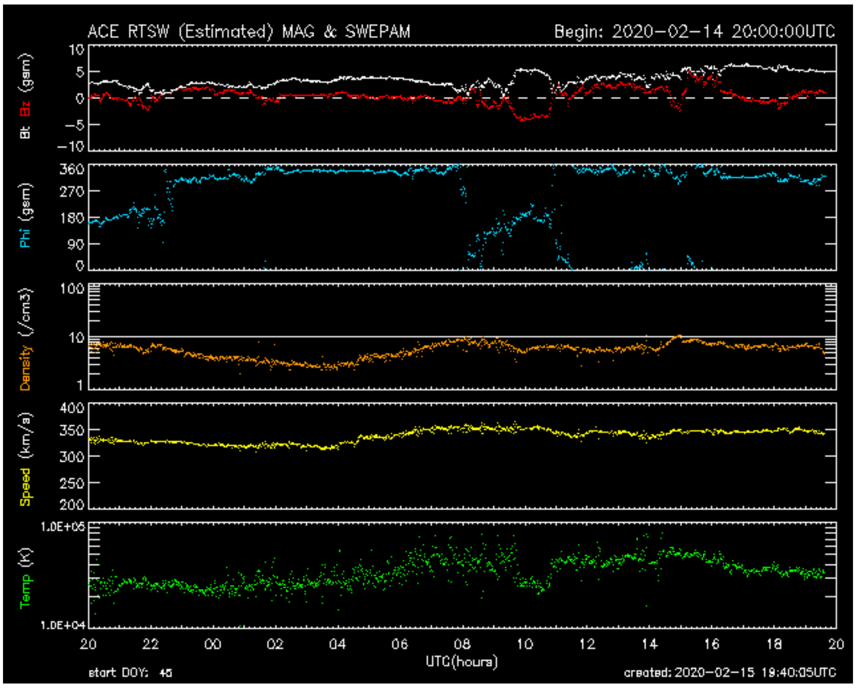
In order to make prediction of the Northern Lights, we need to measure the solar wind and IMF on the way from the Sun to the Earth. This ca be achieved with scientific instruments on satellites. To measure the solar wind plasma, we have instruments that count the ions and electrons. The IMF can be measured with a sophisticated compass that measures the strength and direction of the IMF. NASA's spacecraft ACE, Wind and STEREO are designed to measure solar wind ions, electrons, and the IMF.

The NASA Advanced Composition Explorer (ACE) satellite enables to give advance warning of geomagnetic storms. Geomagnetic storms are a natural hazard, like hurricanes and tsunamis. Geomagnetic storms can impact the electric power grid, aircraft operations, GPS, manned spaceflights, and satellite operations, to name some of the most damaging. Severe geomagnetic storms can result in power blackouts over a wide area. The National Oceanic and Atmospheric Administration (NOAA) through the Space Weather Prediction Center (SWPC) forecasts these possible warnings for the public's benefit. The location of ACE at the L1 Lagrangian point between the Earth and the Sun, about 1,500,000 km from the Earth (240 Earth radius), enables to give up to one-hour advance warning of the arrival of damaging space weather events at Earth.

The parameters we will use to create a Northern Lights warning are:

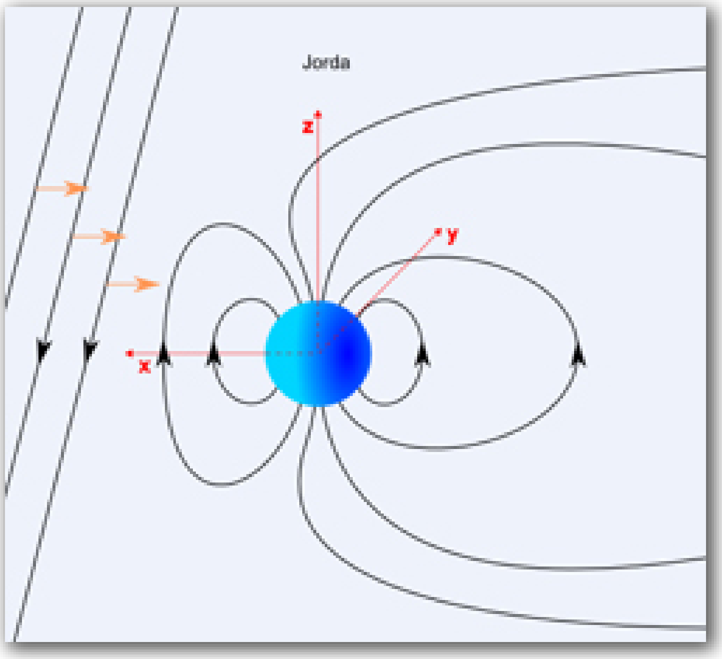
- The total solar wind magnetic field (B) and in z direction (Bz).
- Density
- Speed
- Temperature (Temp)

Here (*http://www.swpc.noaa.gov/products/ace-real-time-solar-wind*) you will find recent measurements from ACE. From the options to the right, choose "Magnetic Field & Solar Wind Electron Proton Alpha Monitor (SWEPAM)" (default).



ACE measures the magnetic field in three different directions and states this in a coordinate system called GSM - Geocentric Solar Magnetospheric. This coordinate system has the origin (zero point) in the center of the earth. The x-axis points directly towards the sun, the z-axis points north and lies along the magnetic axis of the earth and the y axis points to the side of the earth.

In order to get the most energy transferred from the solar wind to the magnetosphere, which is an area that is within the Earth's magnetic field, **it is important that the magnetic field is as much as possible in the negative z-direction**. That is, it points south (as shown in the image below). We then say that Bz (the z-component of the solar magnetic field) is negative. When Bz is positive the solar wind is not transferred to the geomagnetic field. However, when it is negative, the magnetic field coming with the solar plasma and the geomagnetic field are coupled and the charged particles from the solar wind enter the earth's magnetic field. There they follow the magnetic field lines towards the magnetic poles and produce northern lights as they encounter the atmosphere.



The picture above shows the earth and the sun with the GSM coordinate system drawn in red. The x-axis points towards the sun, and the z-axis points north. The black lines represent a cross-sectional view of the Earth's magnetic field and the magnetic field in the solar wind. We see that the Earth's magnetic field is compressed by the solar wind during the day (the side facing the sun) while it is stretched out at night. The magnetic field in the solar wind is facing south here, that is, Bz is negative. Will it be Northern Lights?

In the ACE plot, the Bz component of the solar magnetic field is seen as a red line in the first graph. When it is positive there is little chance to see Northern Lights. When it is negative, there is a possibility that there will be Northern Lights somewhere. The intensity of the Northern Lights is determined by some of the other parameters being measured. The white line in the first graph shows the total solar magnetic field.

The last three graphs show density, speed and temperature. All these affects how much energy there is in the solar wind, and thus how much can enter the Earth's magnetic field. High density, high temperature and high speed are good for getting a lot of Northern Lights, but things can happen even if not all parameters are very high. Take into account that, if any of these increase, it may be a sign that the Northern Lights are coming. Especially important is to look for sudden changes. It could mean something is happening. The density should also be above 1 particle per cm3.

Occasionally, the Northern Lights can come without any major changes in the solar wind. This is especially true in the north where there is almost always a kind of northern light, although it can often be dim.

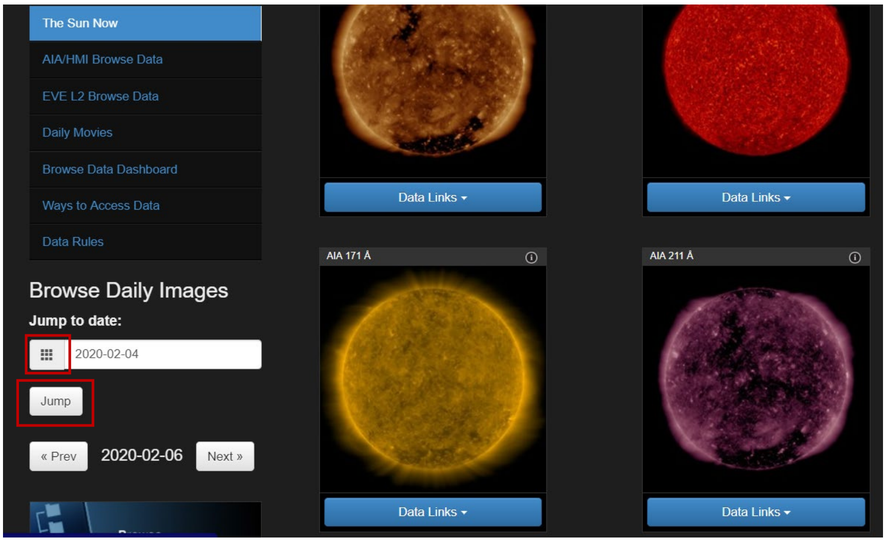
Activity 5:

Let's see the prediction about possible auroras visible in our location today by using the following links:

- ACE Real time solar wind: *https://www.swpc.noaa.gov/products/real-time-solar-wind*
- Aurora 30-minute forecast: *https://www.swpc.noaa.gov/products/aurora-30-minute-forecast*

Discuss in groups and answer the following questions:

- What are the most important ACE graphs (first link) you need to use to predict about the aurora status for tonight? Explain.
- Based on ACE data, do we expect aurora tonight? Explain
- What the 30 minutes forecast shows?
- Check if the magnetometers notice any currents in the ionosphere (*http://flux.phys.uit.no/stackplot*). Select "Norwegian line". Look at the different magnetic field components and try to find out where the Northern Lights are.
- Look for sunspots on the sun (*https://sdo.gsfc.nasa.gov/assets/img/latest/latest_1024_HMIIF.jpg*). What is the relationship between sunspots amount and the possibility to see Northern Lights?
- Is this what is expected from the solar activity we can infer from SDO images. Note: use the link *https://sdo.gsfc.nasa.gov/data/* and select the correspondent date (2-3 days ago) in the "jump to date" field (see below).



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- *https://en.wikipedia.org/wiki/Aurora#Historical_theories,_superstition_and_mythology*
- *http://cse.ssl.berkeley.edu/stereo_solarwind/index.html*
- *https://sdo.gsfc.nasa.gov/*
- *The Script - Flares (Official Audio) https://www.youtube.com/watch?v=r7jaXI6oXpQ*

(...) In the darkness all alone
And no one cares, there's no one there
But did you see the flares in the sky?
Were you blinded by the light?
Did you feel the smoke in your eyes?
Did you? (Did you?) Did you? (Did you?)
Did you see the sparks, feel the hope
That you are not alone?
Cause someone's out there
Sending out flares (...)