TNU/SAGI international summer school of Research and Exploration in Astronomy 2024

Sun and its effects on the Earth

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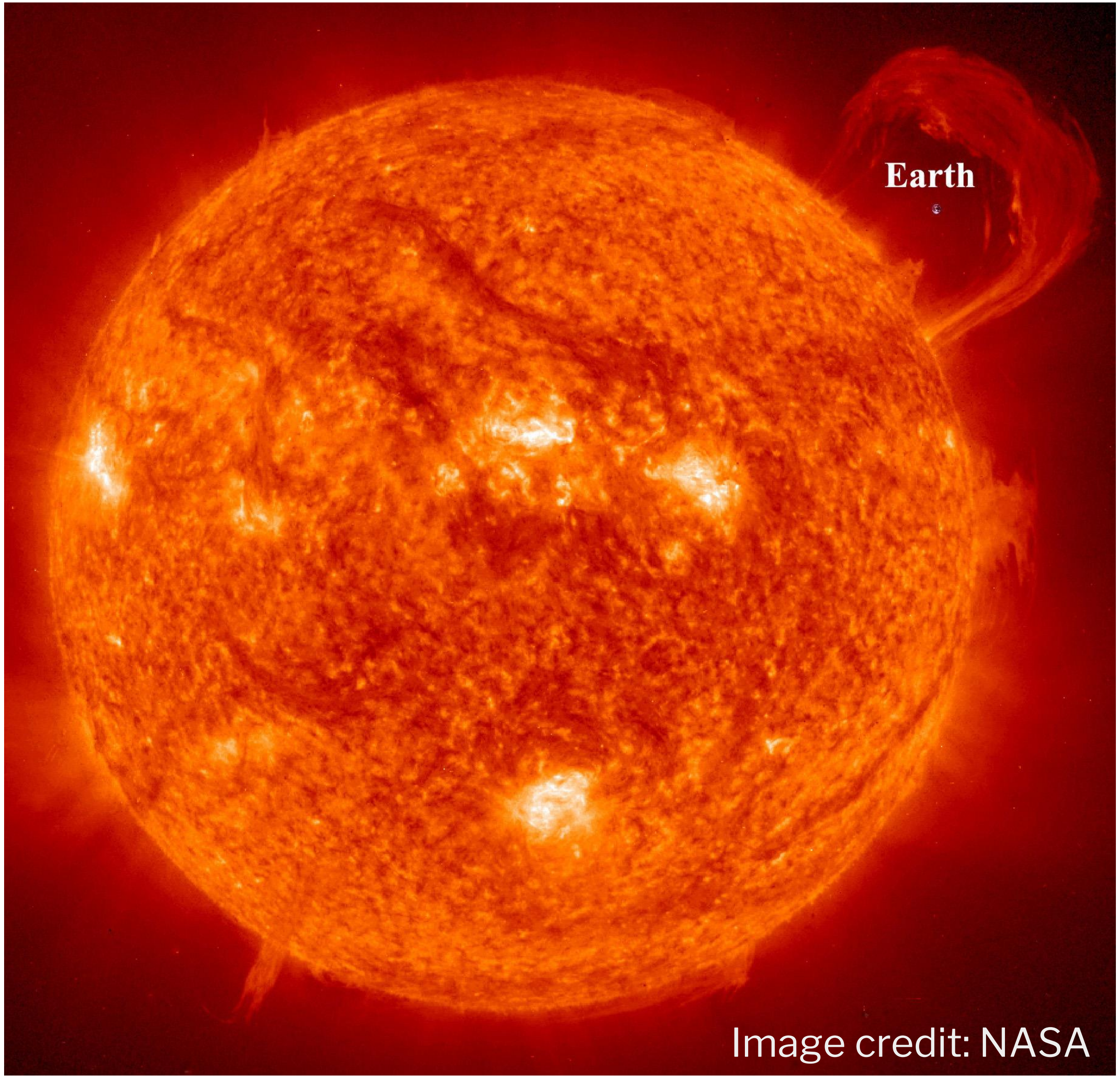
Đắk Lắk, 2024

- The Sun, like other stars, is a huge spherical object made of hydrogen and helium. Its diameter reaches 1.400.000 km, or 109 times the Earth's diameter



Consider the following facts about the Sun:

1. **Sunspots** are cooler than the surrounding photosphere. WHY?
2. **Granules** have typical lifetimes of about 10 minutes
3. Solar **prominences** are arcs of ionized gas.
4. **Solar flares** emit bursts of X rays and affect on the ionosphere
5. **Coronal Mass Ejections** (CMEs) cause aurorae, disrupt power grids, interfere comunications

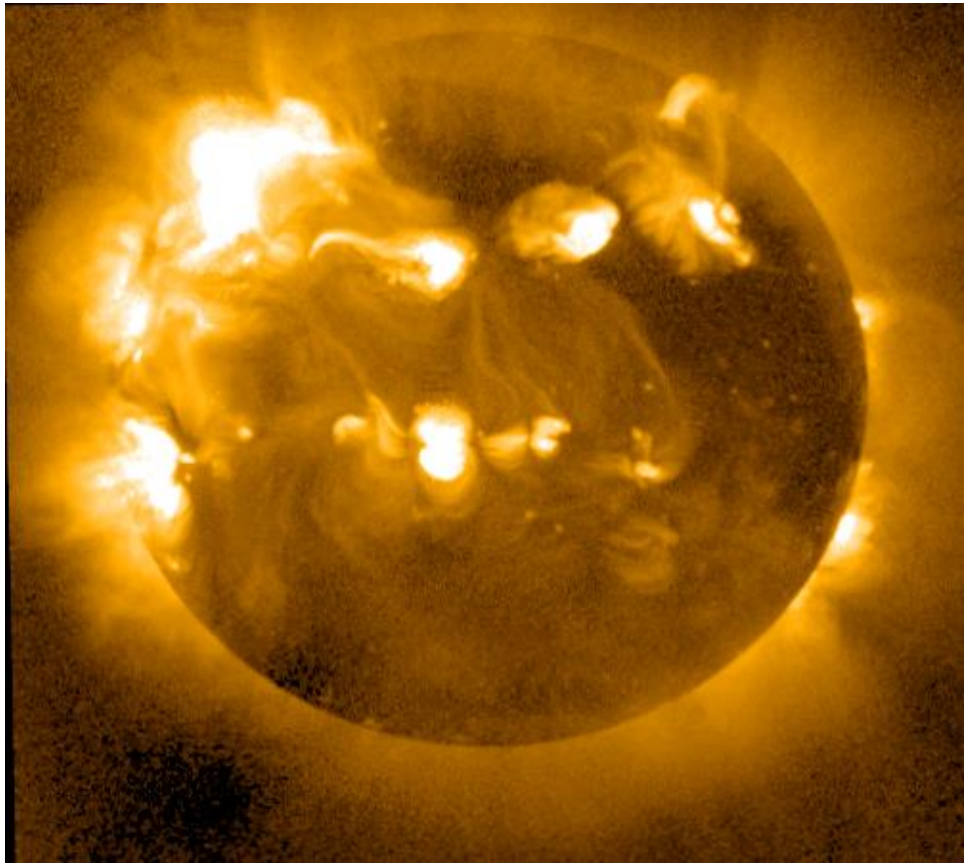
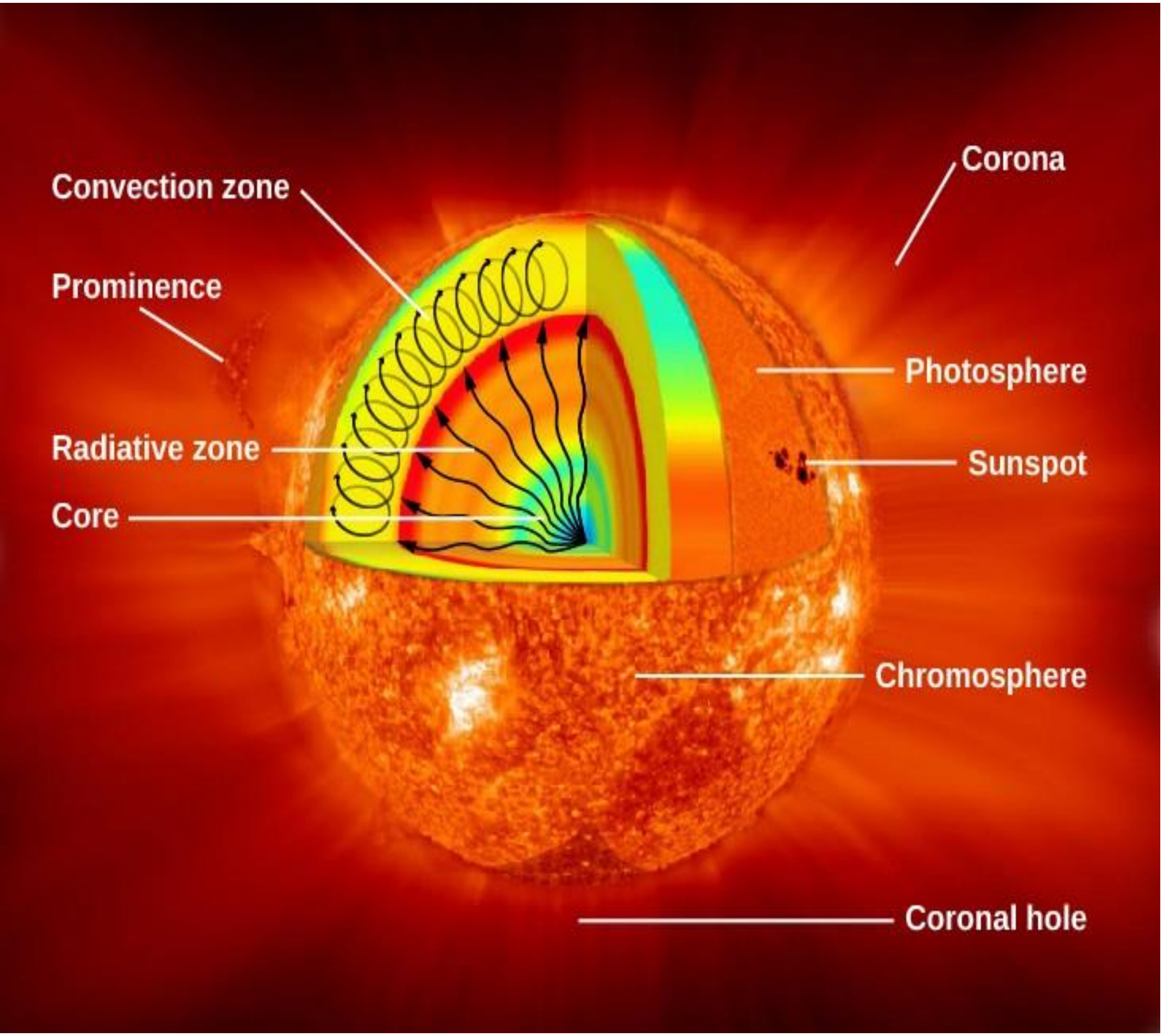


Image taken by Yohkoh sattlite

Structure of the Sun



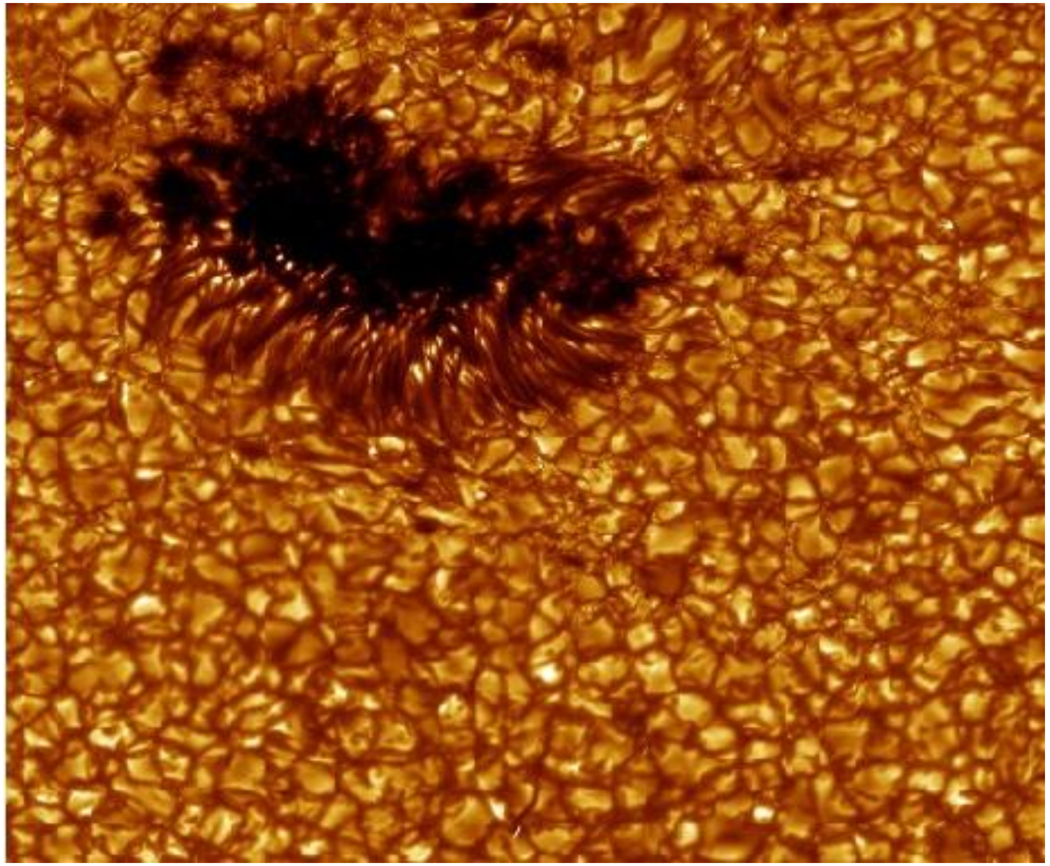
The Sun is divided into two parts: the interior and the atmosphere.

The Photosphere

The thickness of the photosphere layer is ~ 500 km. The temperature at the bottom of the photosphere is 6600 K and temperature at the top of the photosphere is 4400 K.

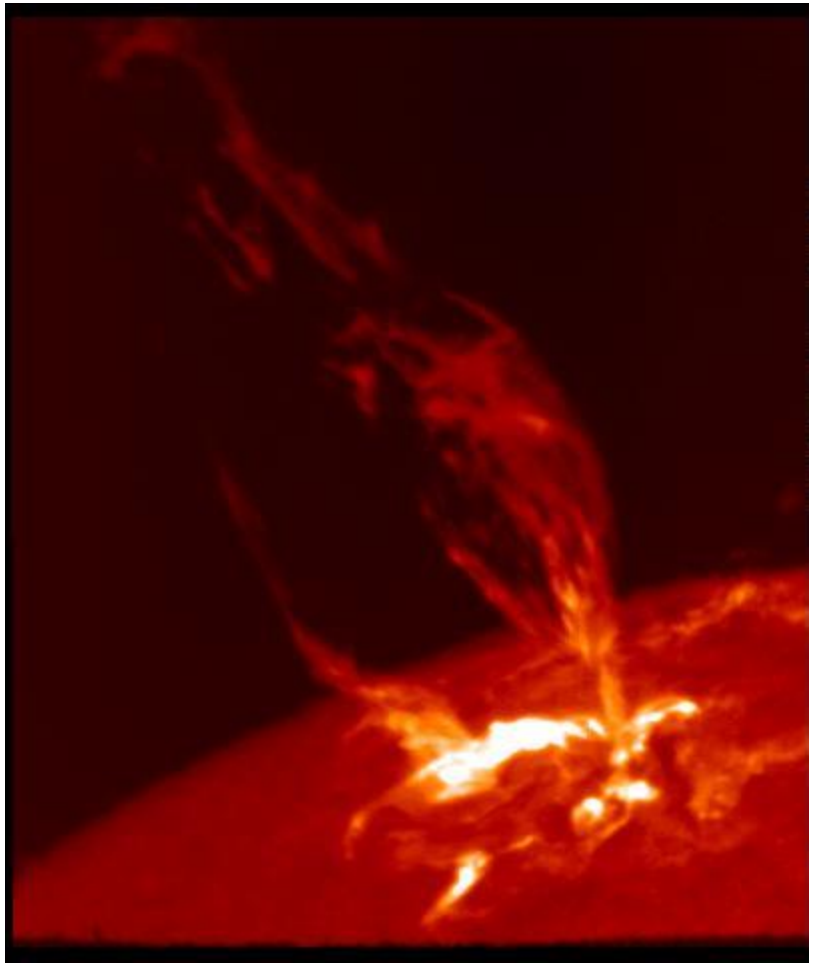
On the photosphere, there are remarkable features such as sunspots, granules and solar flares.

The lifetime of an individual granule is only 5 to 10 minutes



The image shows an irregular-shaped sunspot and granules on the Sun’s surface, seen with the Swedish Solar Telescope on August 22, 2003. (credit: ISP/SST/Oddbjorn Engvold, Jun Elin Wiik, Luc Rouppe van der Voort)

The Chromosphere



H-alpha image courtesy of NOAA Space Environment Center

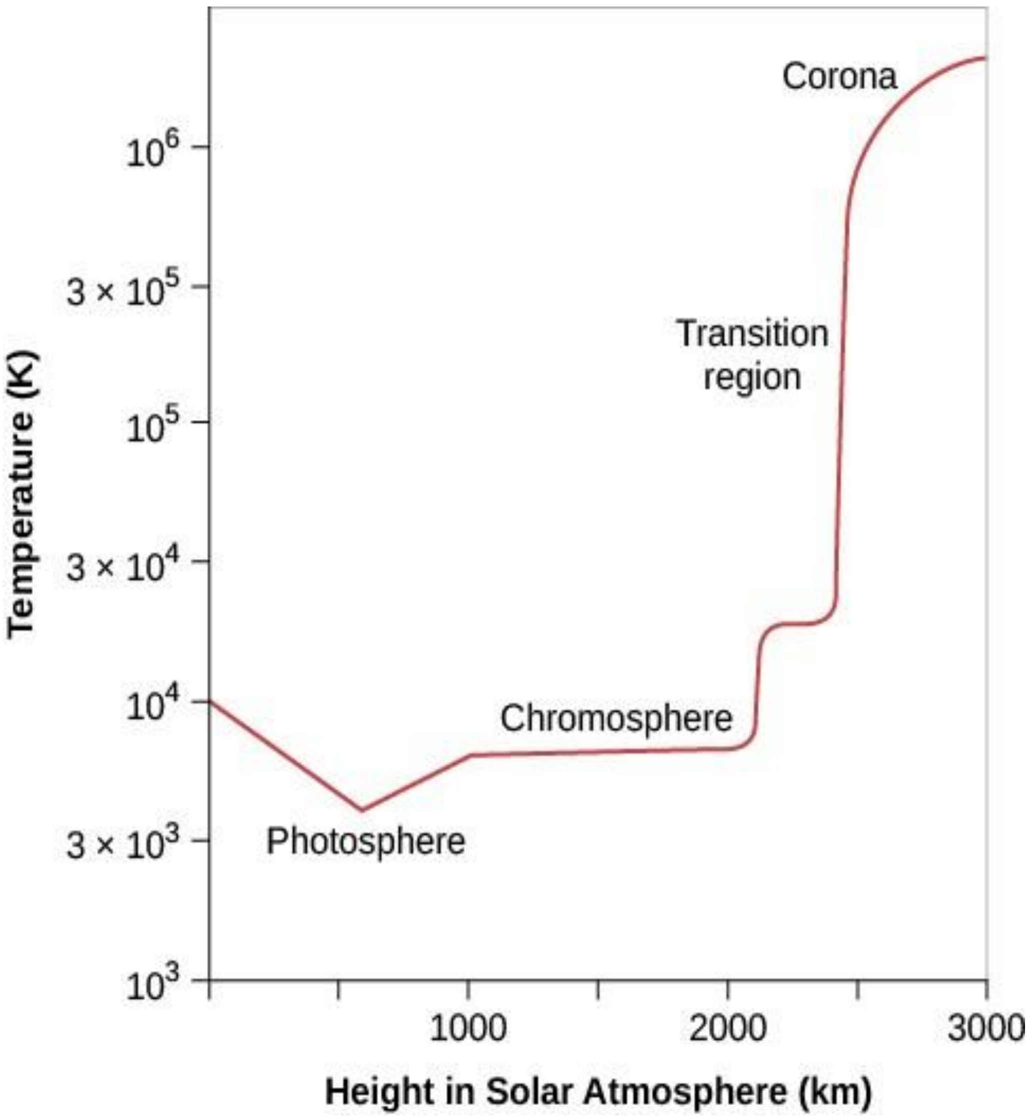
The chromosphere is the next layer of the photosphere with a thickness of about 2000 km to 3000 km.

Temperature is about 10000K

Prominences can be seen above the limb of the Sun using telescope with H-α filter.

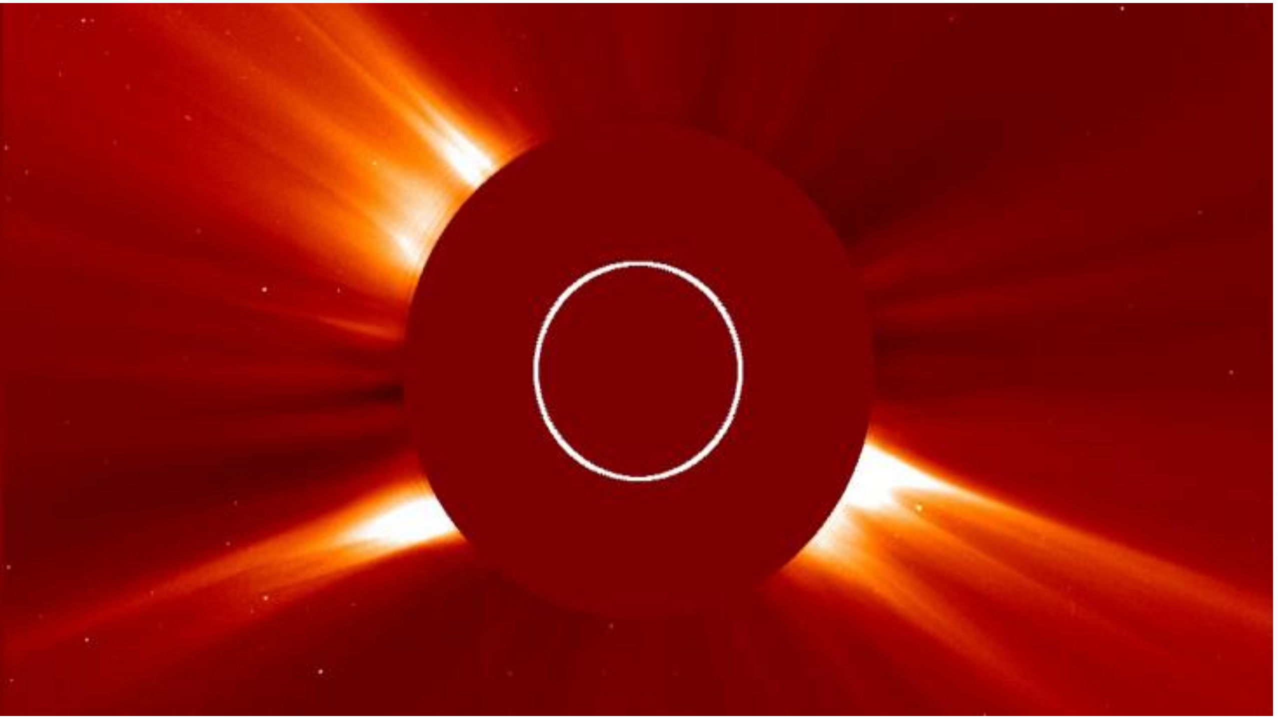
The explosions often occur with increased brightness, ultraviolet and X-ray radiation, called solar flares

The Transition Region



- Thickness is a few kilometers
- Temperature increases sharply from 10000 K to millions K in the corona

The corona



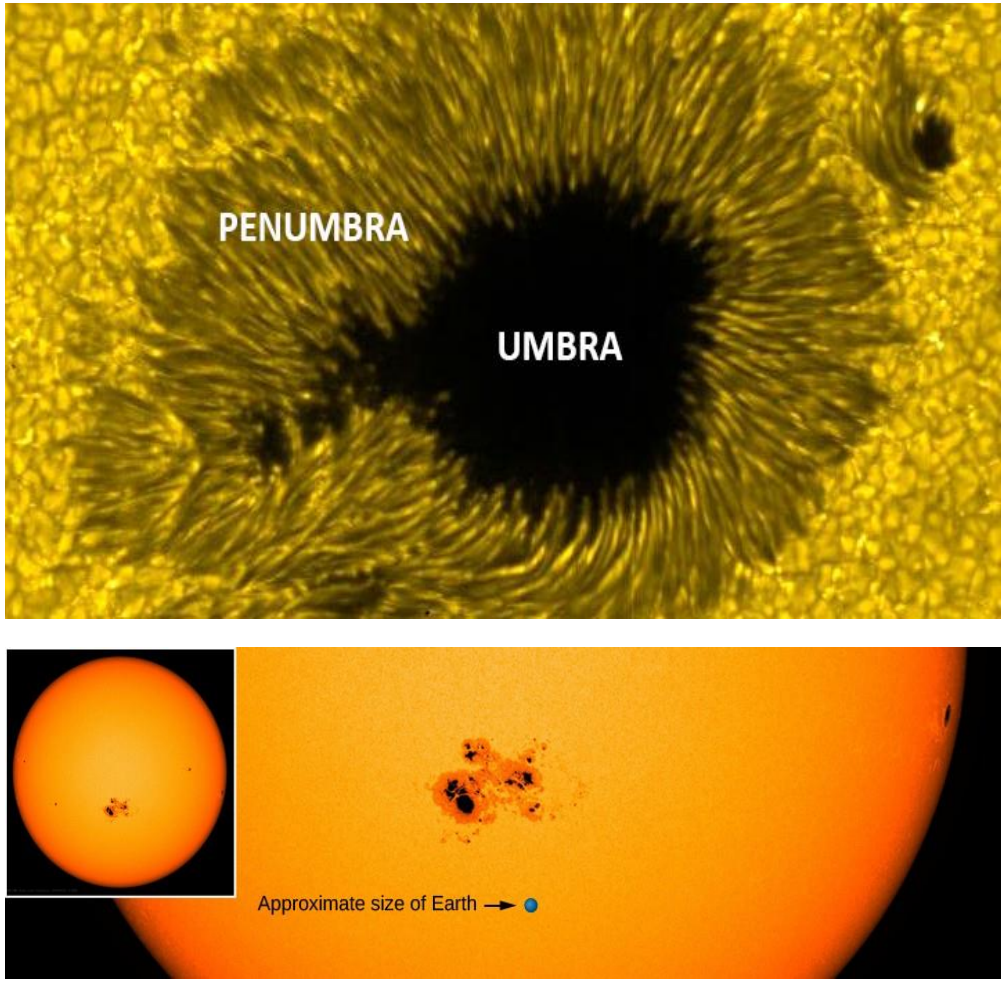
- The corona has a length of 50.000 to 100.000 km, and temperature of 40.000 K- 1.000.000 K
- When elipses occur, we can see the corona

The corona are taken by EUV and continuum wavelength from the Solar and Heliospheric Observatory (SOHO)

The Sun’s activity

- Solar activity is the transformation of its electromagnetic field
- The Sun’s activity: **Sunspots, Prominences, Solar flares, CMEs**

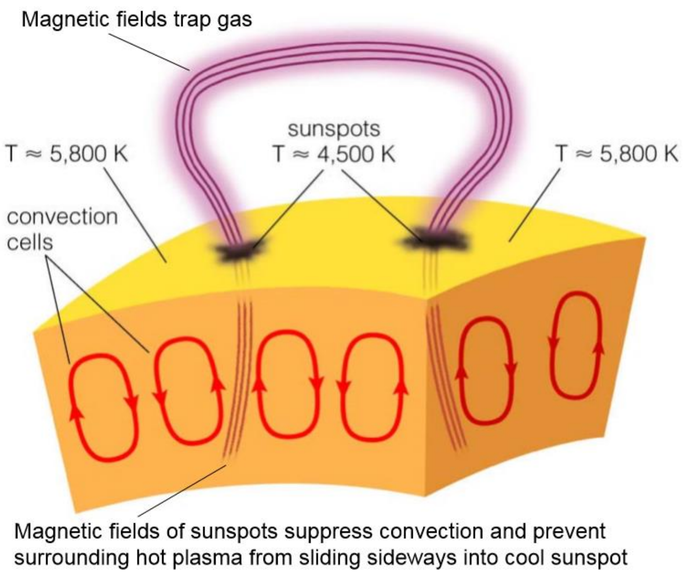
Sunspots

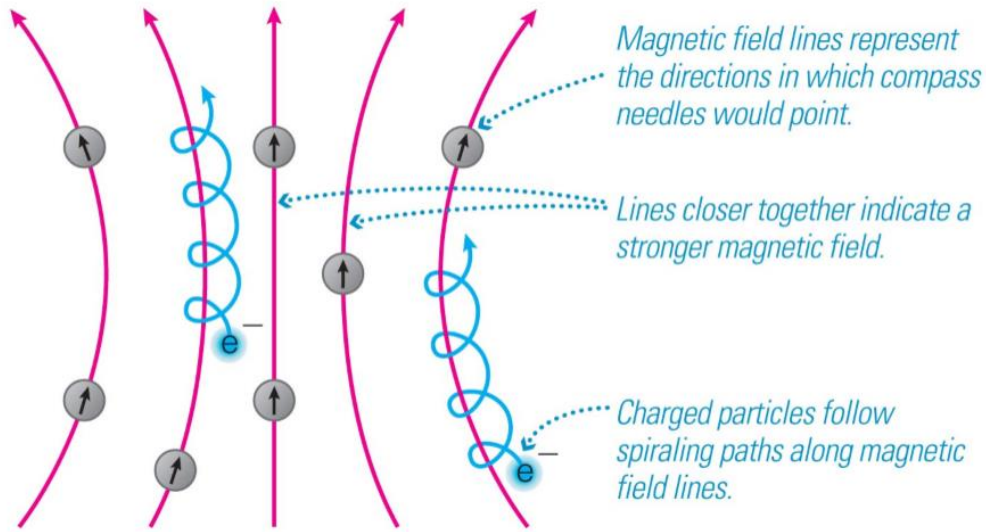


The photosphere plus sunspots (credit: by NASA/SDO)

- The spots have a darker center are called the umbra and a lighter edge called the penumbra.
- The temperature at the sunspot is lower than the temperature around it
- Regions with strong magnetic fields.
- The sunspots are usually about 10.000 km in diameter

Sunspots



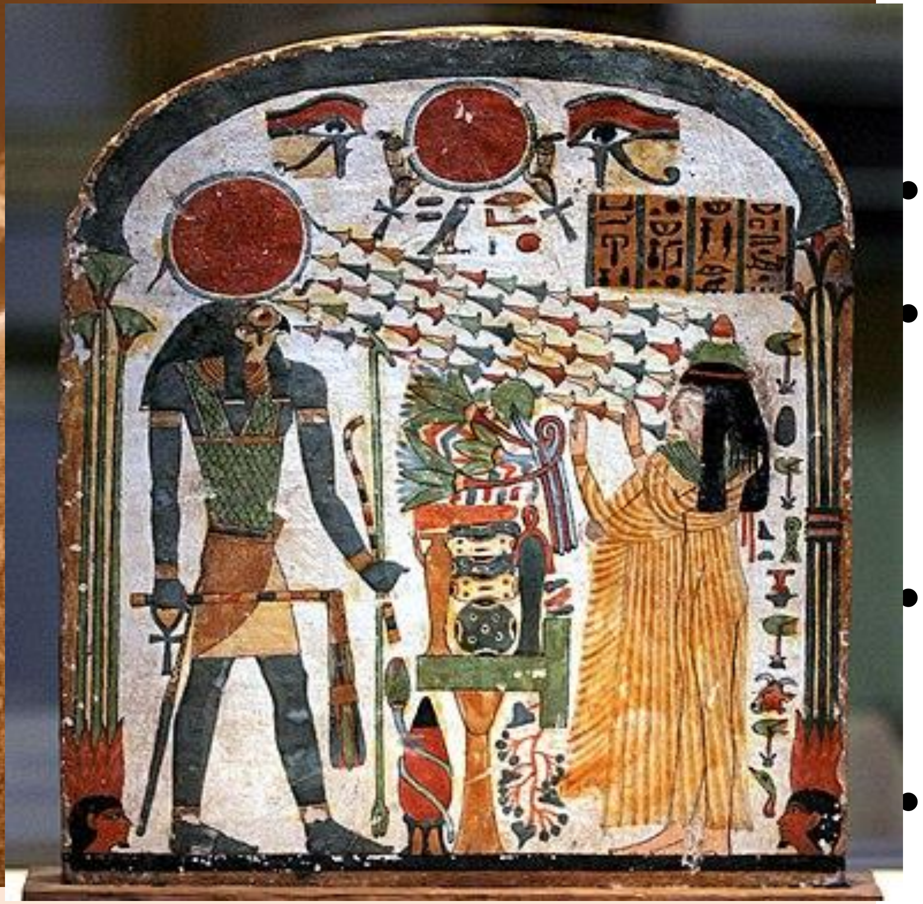


• Charged particles spiral along magnetic field lines.

- The field lines at sunspots are closer together where the field is stronger.
- The solar plasma including ions and electrons cannot easily move perpendicular to the field lines.
- Strong magnetic fields prevent the inflow of hot plasma to replace plasma that has been sitting on the surface, radiating to space, and cooling down

Prominences

Coronado 40mm of QNO with H-alpha narrow (0,1nm) band filter



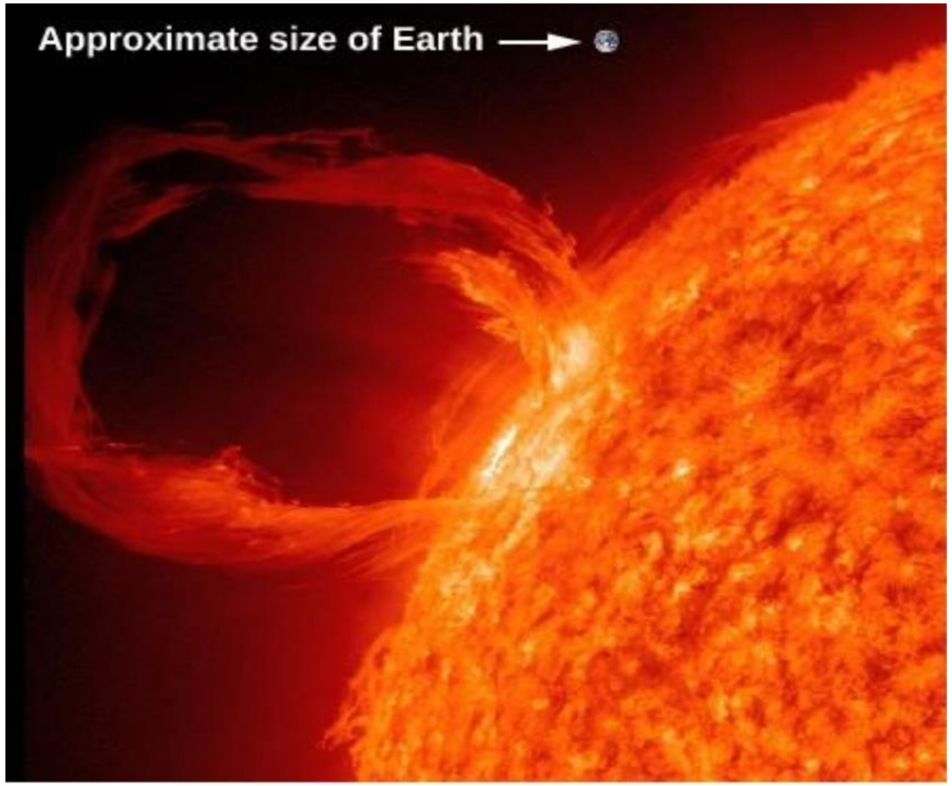
The Egyptian God Ra

- Prominences are graceful loops of hot plasma
- originate near sunspots
- Heights of some loops are more than 1 million kilometers above the photosphere
- Prominences can be seen when elipses occur
- When we view against the photosphere, prominences appear as dark snake like objects, called *filament*

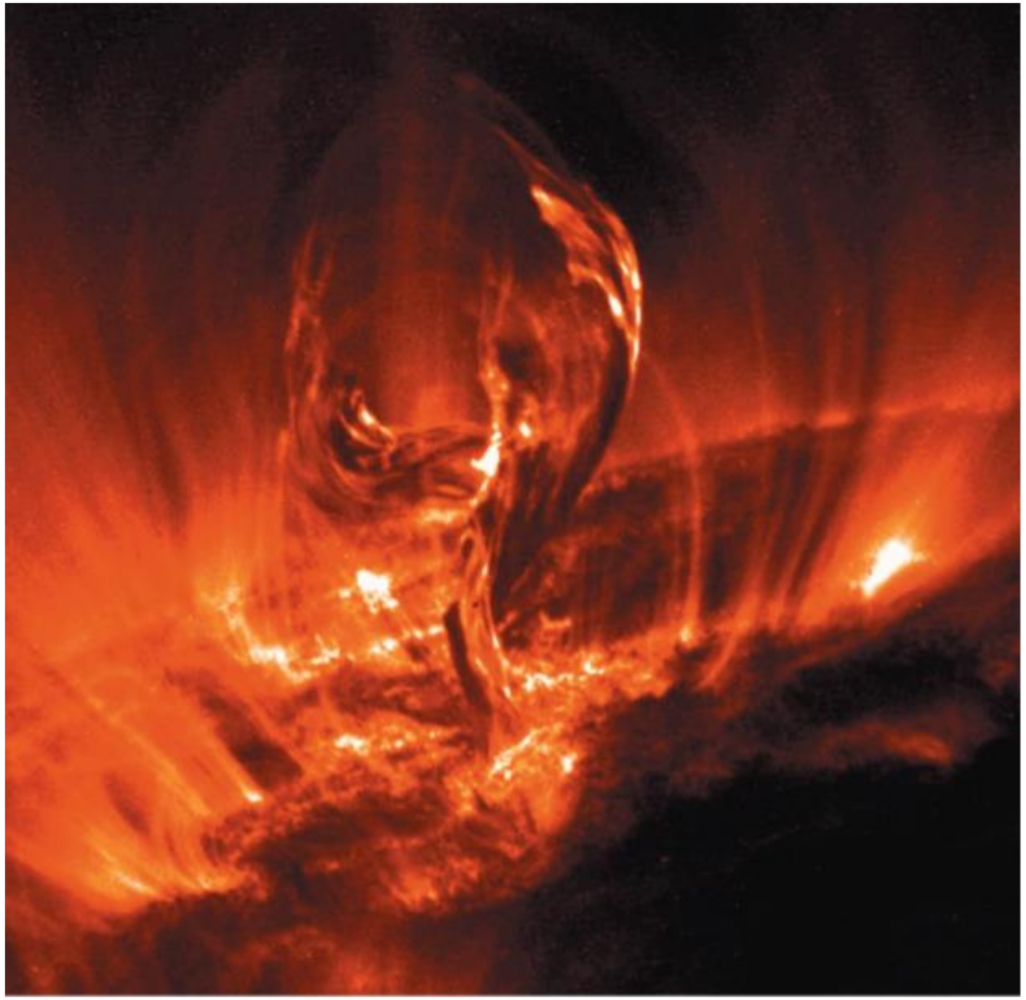
Prominences

Some prominences are graceful loops of plasma (ionized gas) that can remain nearly stable for many hours or even days.

The relatively rare eruptive prominences appear to send matter upward into the corona at high speeds and the most active surge prominences may move as fast as 1300 kilometers per second.

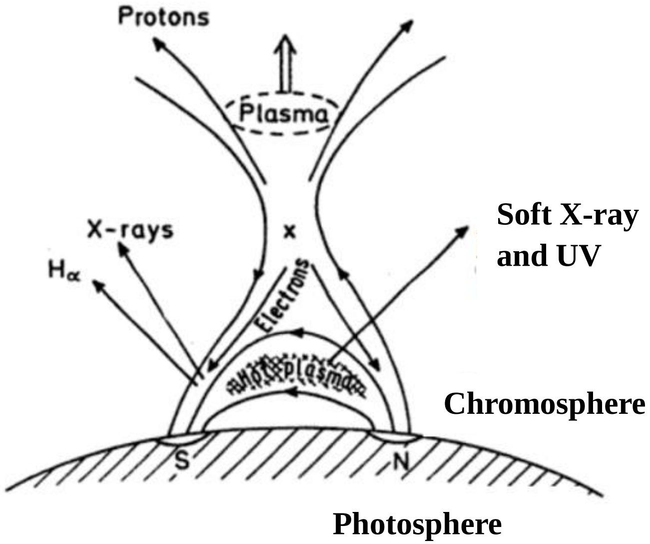


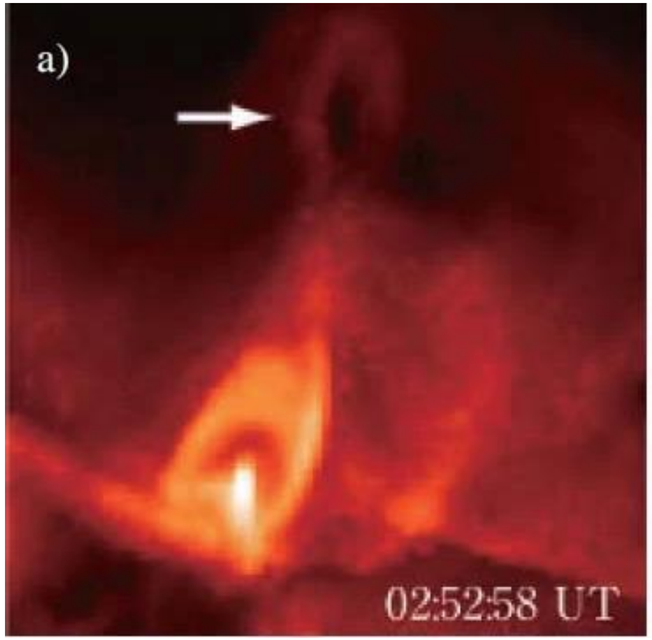
Solar flares



- Solar flares are defined as a sudden, rapid, and intense change in the luminosity of the chromosphere or corona.
- Solar flares occur when the magnetic energy in the Sun's atmosphere suddenly increases.
- Radiation is emitted from radio waves to gamma rays

Solar flares





Soft X-ray image of a long-durational-event flare observed by *Yohkoh*.

- The transformation of magnetic energy begins at the neutral point above the two sunspot groups.
- The magnetic field lines break and reconnect
- Some protons move faster and cause the solar proton event at the Earth's poles causing the absorption of radio waves and affecting communication…
- Electrons move to chromosphere and are blocked at the chromosphere and hard X-rays are produced by the bremsstrahlung radiation.
- On the chromosphere, the hydrogen atom is ionized by collision with an electron and radiates out the Hα spectral line (656.3 nm).

Solar flares

Classification	Intensity I (W/m^2)
B	$I \leq 10^{-6}$
C	$10^{-6} \leq I \leq 10^{-5}$
M	$10^{-5} \leq I \leq .10^{-4}$
X	$10^{-4} \leq I$

Relationship between the number of solar flares and the sunspot number presented by the following formula:

$N = \alpha(R - 10)$

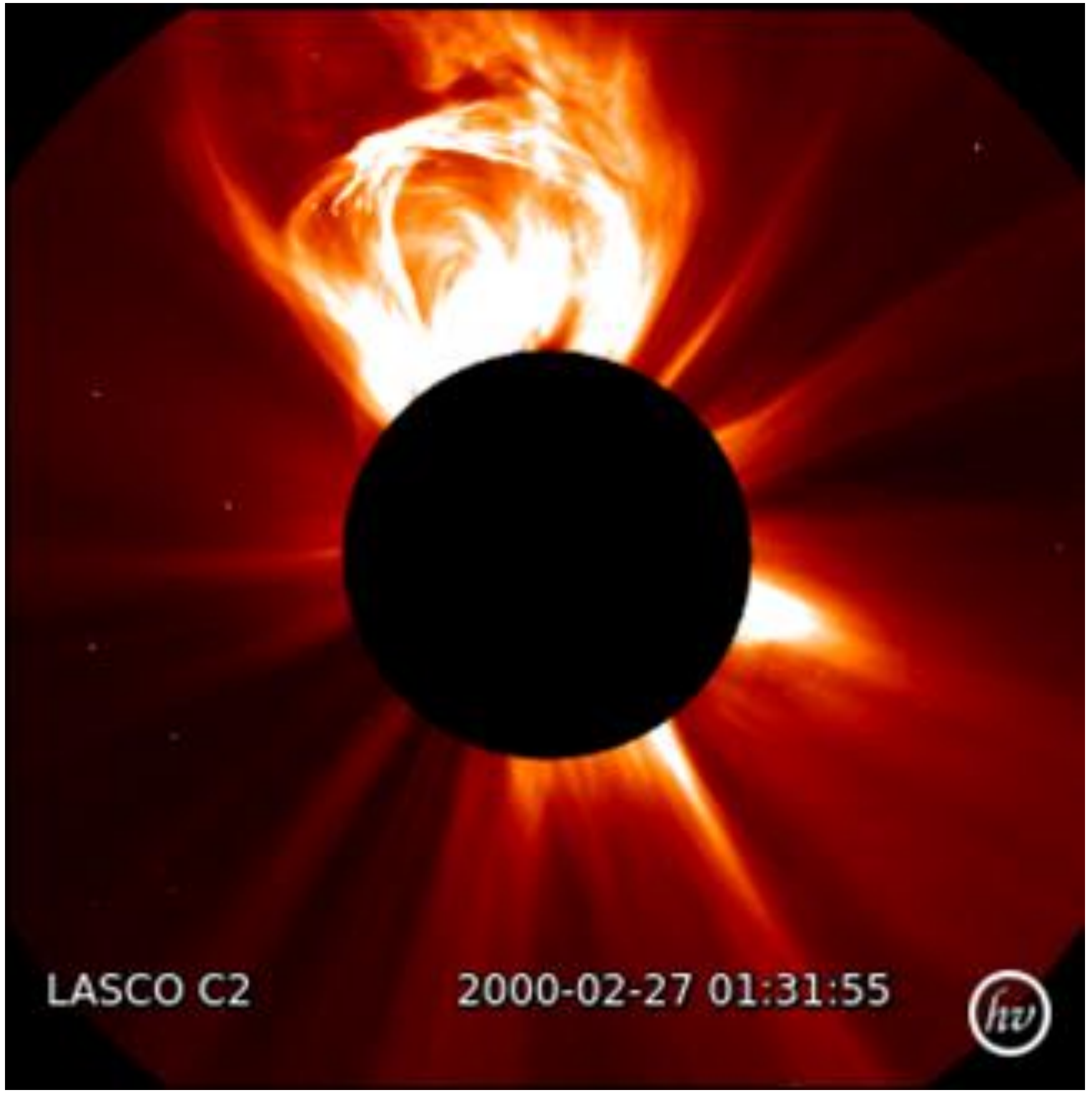
Where,

N: number of solar flares.

R: number of sunspots.

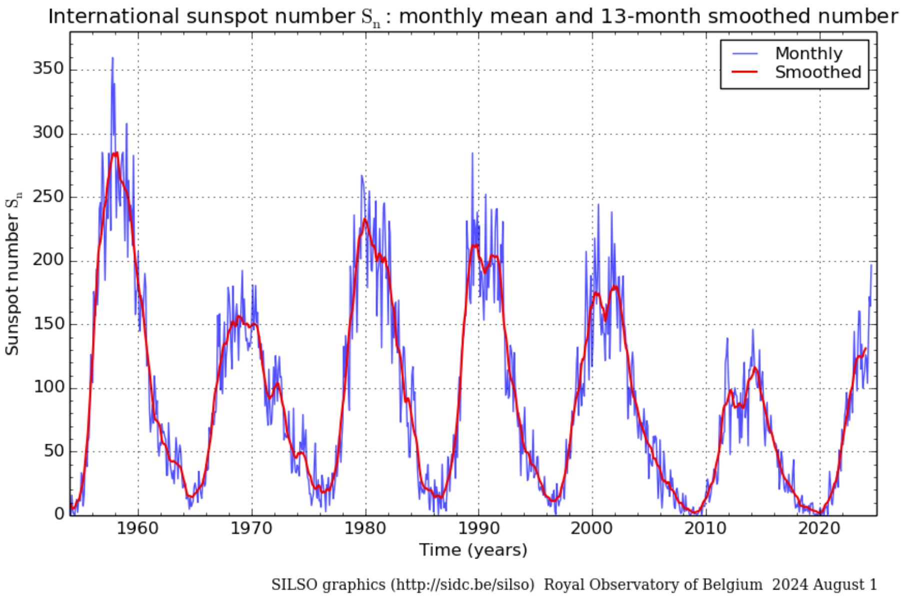
α: 1.5 - 2

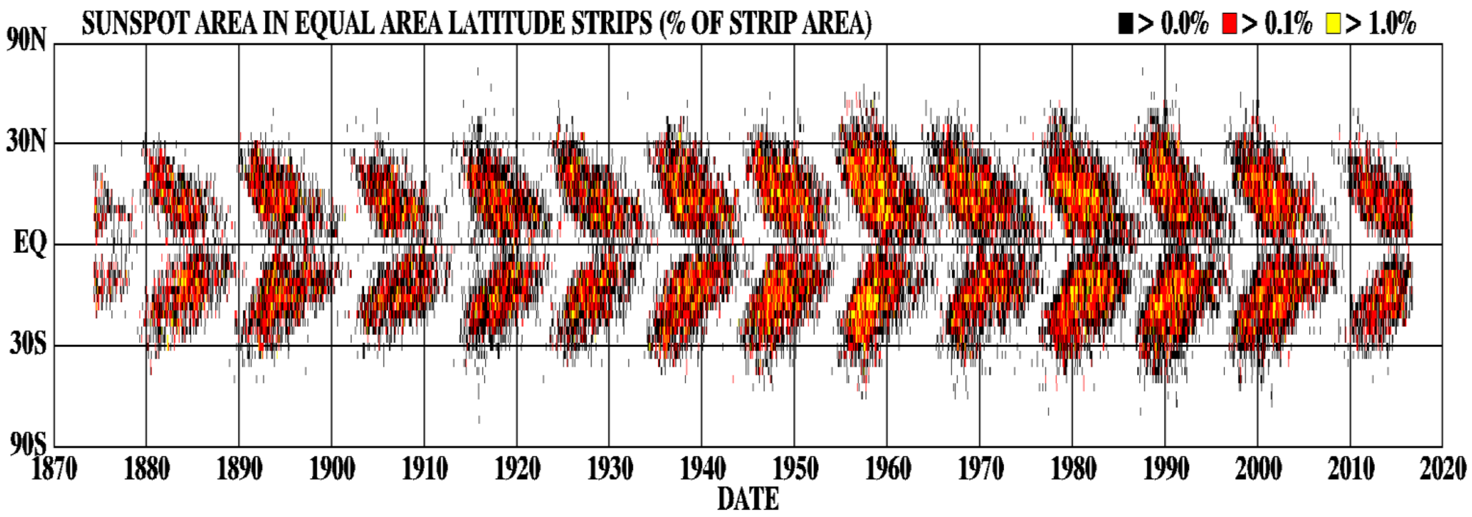
Coronal mass ejections



- It may occur that the twisted magnetic field holding up a prominence becomes unstable and rises up very suddenly and quickly.
- If that occurs, the material of the prominence could be released out of the Sun, reaching a speed of 1000 km/s.
- They sometimes happen at the same time as flares, but where the flare releases light, a coronal mass ejection releases material.

Solar Cycle





- The number of sunspots varies in a cycle with an average period of 11 years
- At the start of a sunspot cycle the number of sunspots is at a minimum and most of them are at around 35° from the equator. At solar maximum when the sunspot number peaks about 5.5 years later, most of the sunspots are within just 5° of the equator.
- It is currently in cycle 25 which began in December 2019

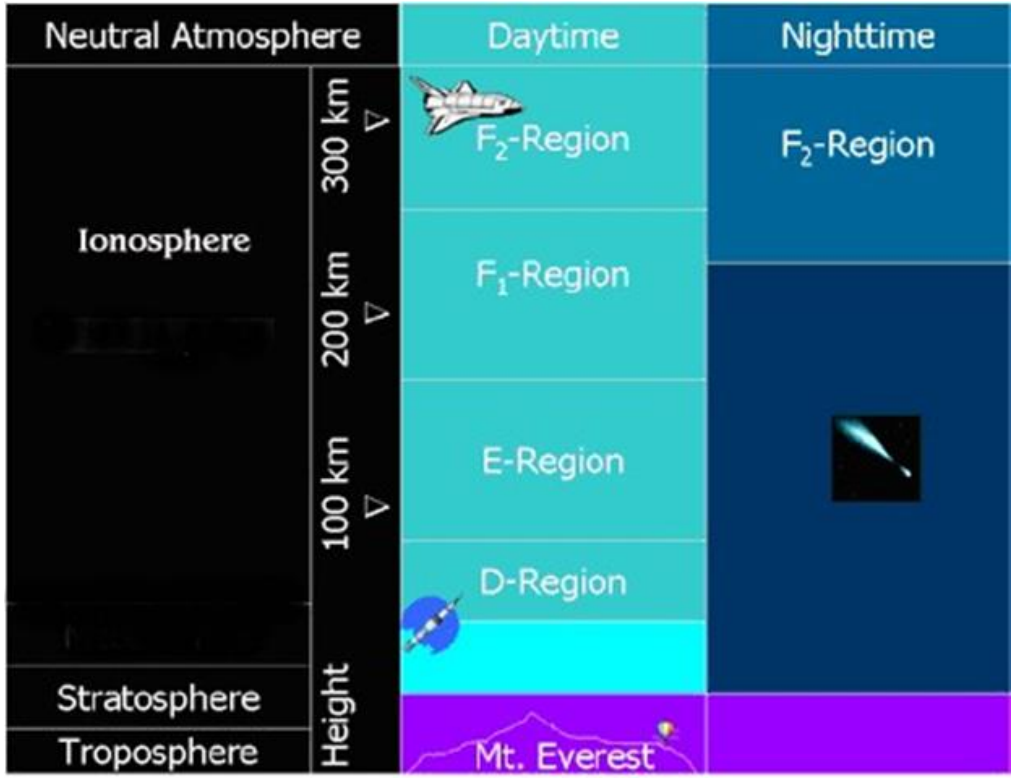
Exercise 1

Go to the website: https://www.helioviewer.org/index
Making solar flares at 00:00 UT 27/2/2000 (using Yohkoh)
Making solar flares today (using SDO: Solar Dynamics Observatory)

Solar flares cause the disturbances of the Earth’s ionosphere

The Earth's ionosphere

- The Earth's ionosphere is the top part of the atmosphere with an altitude of 60 km to 1500 km. Energy in the solar radiation ionizes gas molecules such as N_2, O_2, and O into positive ions and free electrons.
- The free electrons generated during this process can greatly affect the transmission of radio signals. The ionosphere is divided into different layers including D, E and F



(Deborah Scherrer, 2007)

Solar flares effects on the ionsphere

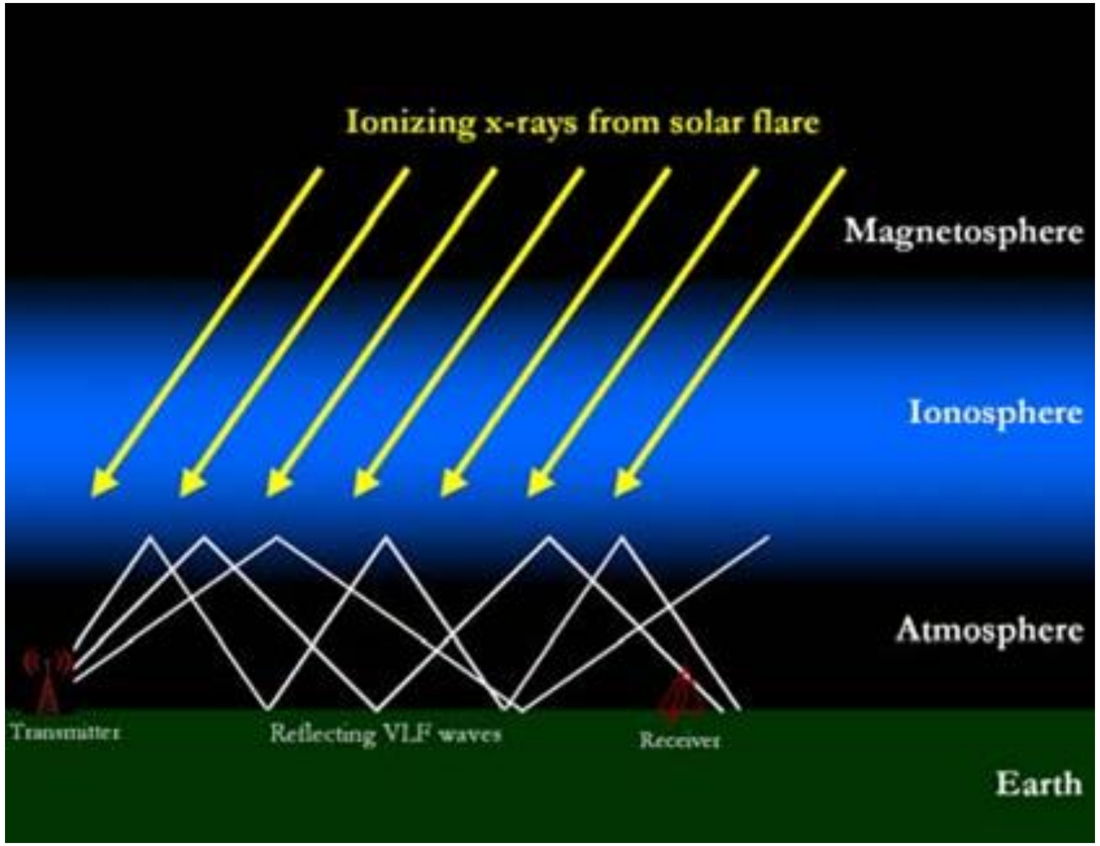
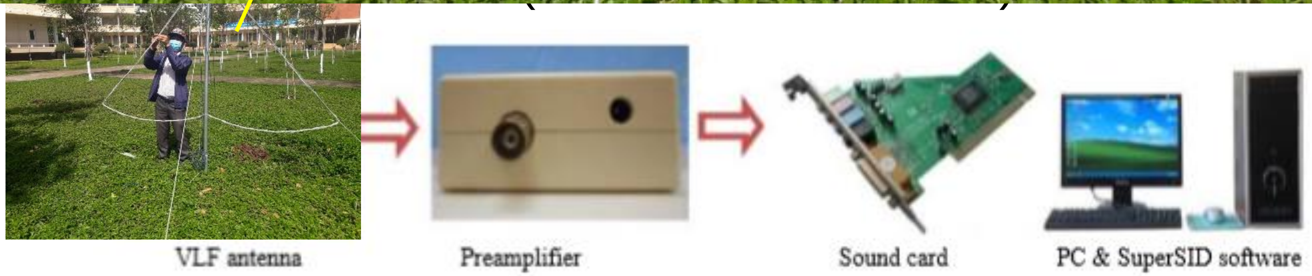


Image courtesy of Morris Cohen, Stanford University

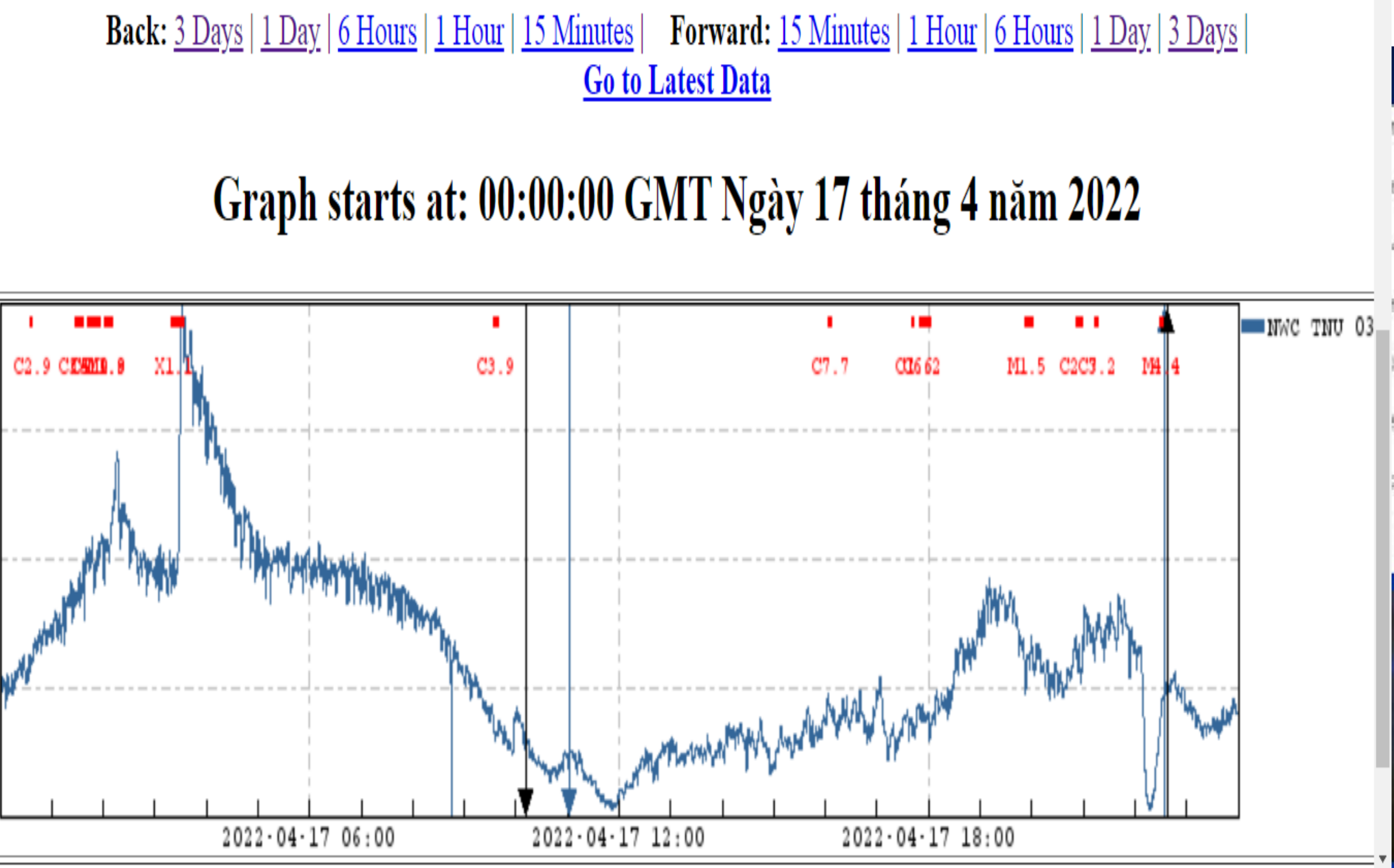
- When the solar flares occur, the strong ionizing radiation causes the electron density of the D layer to dramatically increase with 1-2 orders of magnitude
- Very Low Frequency (VLF) signals (3 kHz – 30 kHz) propagate in the Earth - Ionosphere waveguide

VLF array

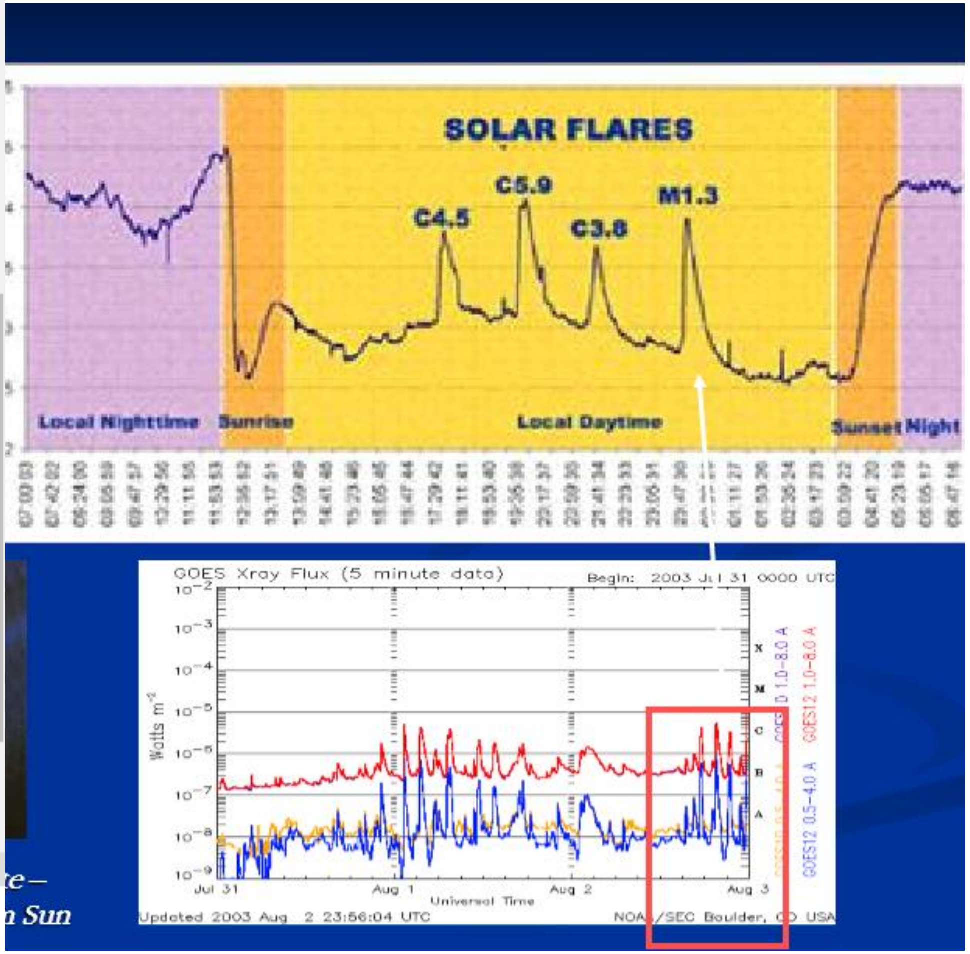
- VLF array: SuperSID receivers are installed around the world
- They can observe the effects of sunrise and sunset phenomena and solar flares on the Earth’s ionosphere via monitoring the VLF signals propagating from many transmitters to a receiver site
- Education



Solar flares effects on the ionsphere



- Enhancements of electron density cause the sudden changes of VLF amplitude



(Scherrer, 2007)

VLF array

English Español

About SID DATA Linking to this Page

- ○ Superimposed
- ◉ Vertical

- ☐ Don't Display Monitor Sunrise and Sunsets (Colored Arrows)
- ☐ Don't Display Station Sunrise and Sunsets (Black Arrows)

- ☐ Don't Display Solar Flares (From GOES)

(C1.0) Visible Minimum Flare Strength

- ☐ Show estimated data quality (lower is better)

Download Data Files

Update Graph

View Data by Date
Experimental Event Search
Map of Monitors

View Data by Monitor
Clear Monitor Selection
Selected Monitors:

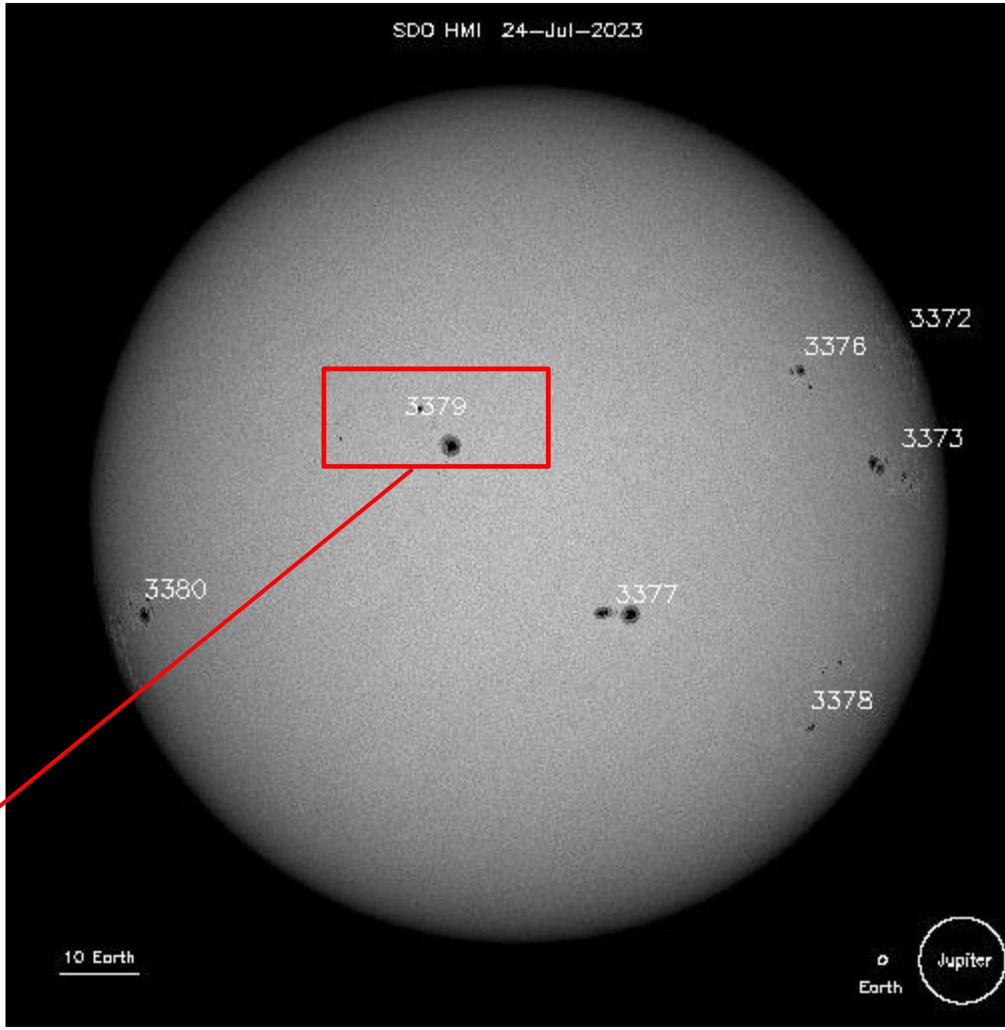
Graph Length:
- ○ 1 Hour
- ○ 6 Hours
- ◉ 1 Day
- ○ 3 Days

Graph Size:
- ◉ Small
- ○ Medium
- ○ Large

VLF array

Flares can be trach back to the solar active region that produced them

#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
5580	0003	0014	0020	HOL	3	FLA	N21W37	SF		3376
5540 +	0004	0021	0036	G16	5	XRA	1-8A	C8.4	1.1E-02	3379
5540 +	0008	////	0948	LEA	C	RSP	132-180	CTM/1		3379
5540 +	0010	0016	A0023	HOL	3	FLA	N16E24	2N	ERU	3379
5550	0110	0110	0114	LEA	3	FLA	N22W38	SF		3376
5560	0117	0121	0126	LEA	3	FLA	N22W38	SF		3376



https://services.swpc.noaa.gov/text/solar-geophysical-event-reports.txt

https://soho.nascom.nasa.gov/data/synoptic/sunspots_earth/

CMEs cause magnetic storm and auroral

Magnetic storm

If the CME has a high enough velocity, it will lead the solar wind to form shock waves that will affect the Earth's magnetic field, affect the magnetosphere and create fluctuations in the Earth's magnetic field, called a magnetic storm.

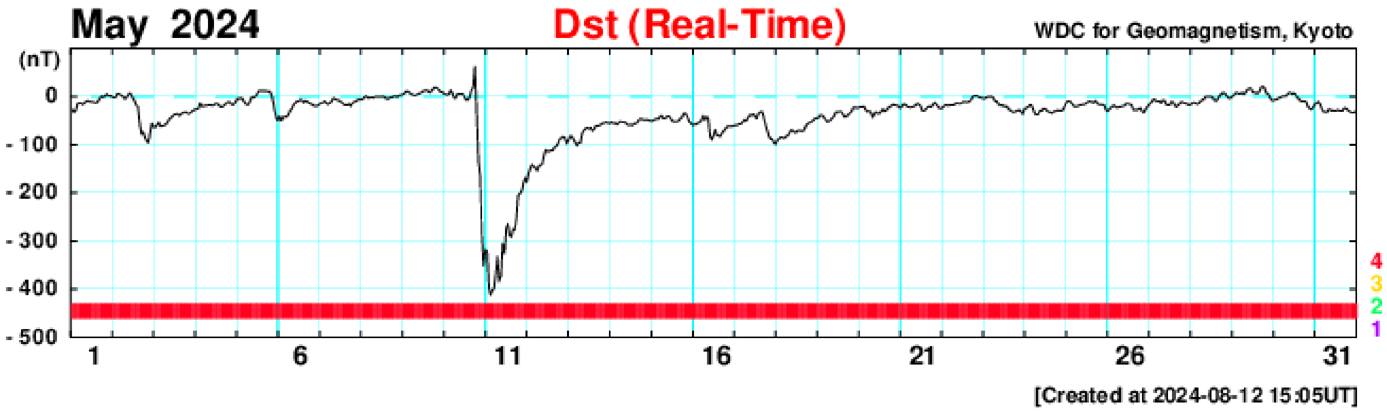
The streams of charged particles ejected from the Sun generate a magnetic field, with a magnitude of about 6.1 T - 9T.

This magnetic field presses on the Earth's magnetic field causing the magnetic field where the pressure is increased.

Magnetic storm

As the Earth's magnetic field increases, the magnetic flux will vary and produce an induced current that counteracts the increase in the Earth's magnetic field (according to Lenz's law).

This induced current can reach a magnitude of millions of Amperes moving around the Earth and causing a very large magnetic field to act on the Earth's magnetic field. This phenomenon continues to make the Earth's magnetic field continuously vary.



https://wdc.kugi.kyoto-u.ac.jp/dstdir/

Auroral

The aurora is the result of the interaction between the solar wind and Earth's magnetic field.

Auroras occur because charged particles in the solar wind travel toward the planets. When these particles encounter the planet's magnetic field, they are deflected due to the Lorentz force. This force causes the particles to move along spiral paths following the planet's magnetic field lines. At the poles, these field lines converge and direct the charged particles into the planet's atmosphere.

Aurora over Icelandic lake, Copyright: C. Gauna, Date: 09 April 2015

Coronal mass ejections

Auroral

As the particles enter the atmosphere, they collide with molecules and atoms in the air, exciting them and causing them to emit light. Since the planet's atmosphere contains various gases, each type of gas emits light at different wavelengths when excited, resulting in a spectrum of colors and creating the vibrant displays seen in the auroras at the poles.

The colors of the aurora depend on the type of atoms and molecules being excited. Atomic oxygen produces red light, molecular oxygen produces green light, molecular nitrogen produces blue light, and atomic nitrogen produces purple light. As a result, auroras often display dominant colors of red, green, blue, and purple, blending together to create vibrant, colorful displays

Summary

- Solar activity includes sunspots, solar prominences, solar flares, and coronal mass ejections (CMEs).
- Flares and CMEs affect on the Earth's ionosphere and magnetosphere.

Thank you for your attention!

Analyzing the CME events

Goal: Understanding CME events and calculating their velocities towards Earth.

Python: https://www.python.org/downloads/

Data sources:

- https://cdaw.gsfc.nasa.gov/CME_list/
- https://www.helioviewer.org/index
- **Step 1:** Download images of CME taken by SOHO satellite from webpage https://cdaw.gsfc.nasa.gov/CME_list/.

Go to https://www.helioviewer.org/index for checking the solar flares which relate to CME event using website. You should choose Yohkoh satellite.

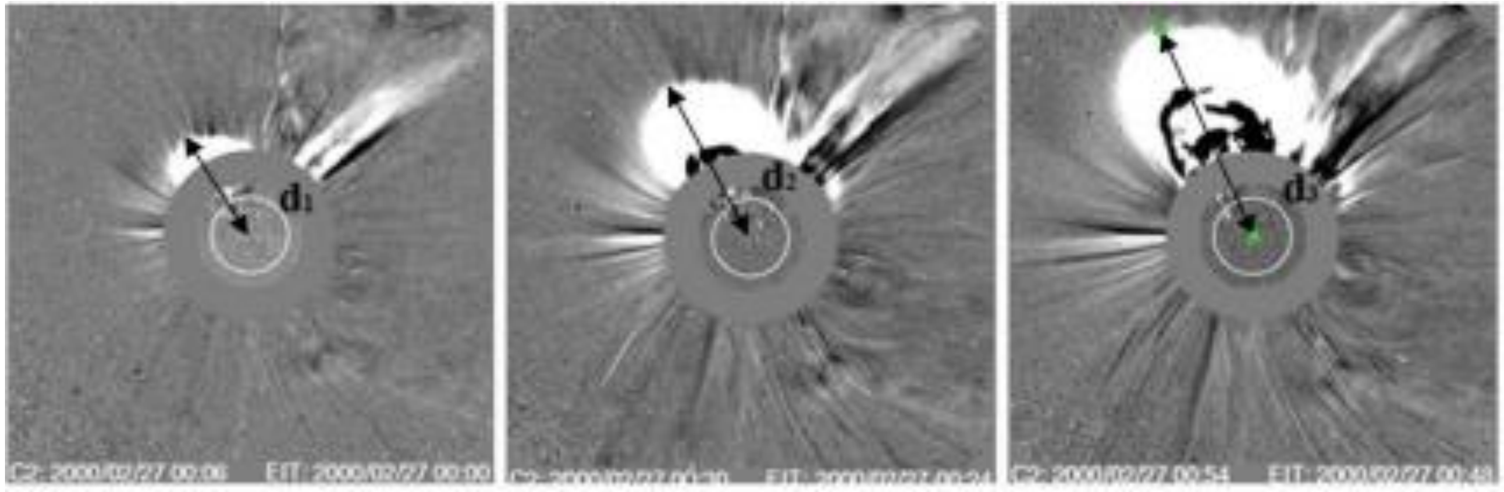
- **Step 2:** Display CME images using anaconda or another suitable software. Anaconda requires '.png' images and determine coordinates in pixels.

- Step 3: Open the first image and determine coordinates (x0, y0) of the center of the Sun (The size of the Sun's disk is limited to the white circle).

Calculate the radius of the Sun using the formula: $r = \mathrm{sqrt}\,[(x_i - x_0)^2 + (y_i - y_0)^2]$

Compare the radius of the Sun in pixels and that in kilometers to know how many kilometers are in one pixel.

For example, the center of the Sun has coordinates (255.5 px; 243.8 px) and the Sun’s radius is 39.37 px and 695700 km, respectively. Thus we can see that one pixel in the image corresponds to 17670.73 km in real space.



Step 4: For each subsequent image, pay attention to the time stamp, and get the pixel coordinates of the CME edges (points at the beginning of the arrows). Calculate the distance of CMEs for each image.

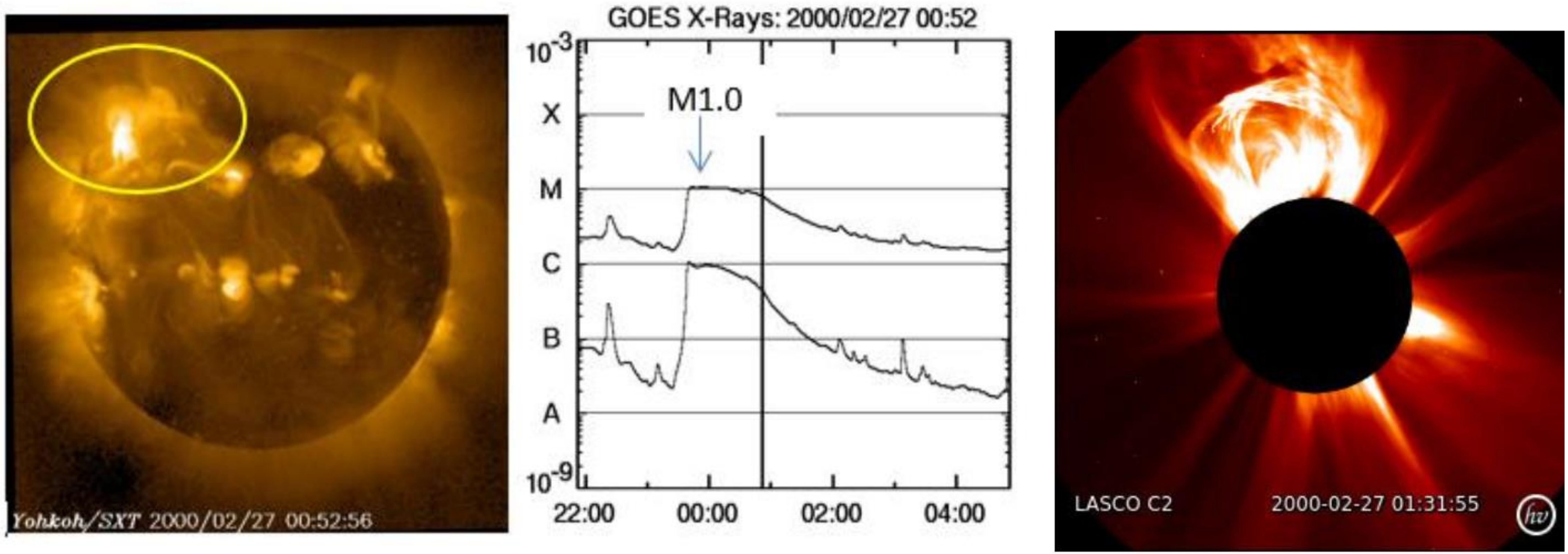
Step 5: Create a data file with time in seconds, x and y coordinates, and distance of CMEs respectively.

Step 6: Use the Excel application to plot the graph of the CME distance changes over time and then fit the graph of the form y = ax + b to get the average speed of the CMEs.

For showing solar images, open Anaconda and type python manucript as belows,

```
In [1]: import numpy as np
In [2]: import matplotlib.image as mgimg
In [3]: import matplotlib.pyplot as plt
In [4]: img=mgimg.imread("D:/????????????????/*.png")
In [5]: plt.imshow(img)
In [6]: plt.show()
```

Example: Analysis of the CME event on 27/2/2000 at 00:30 UT

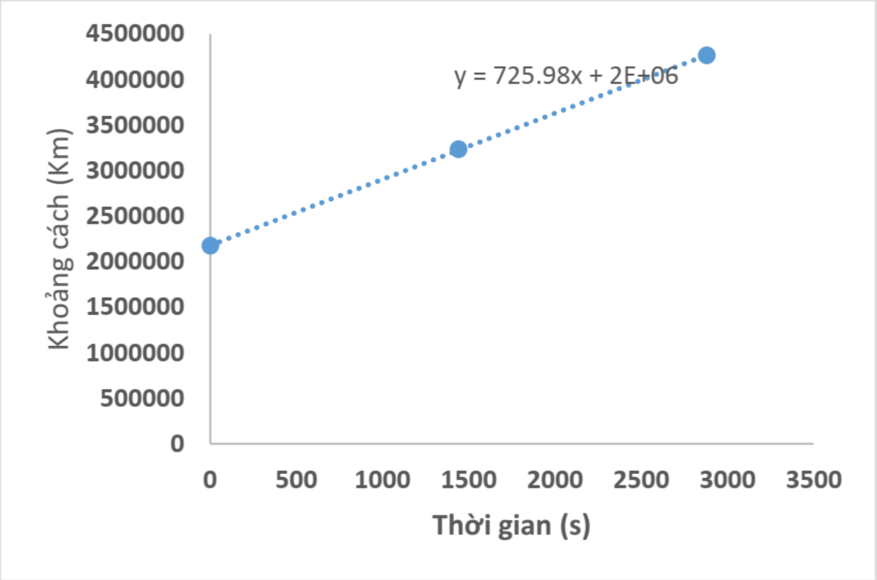


a) b) c)

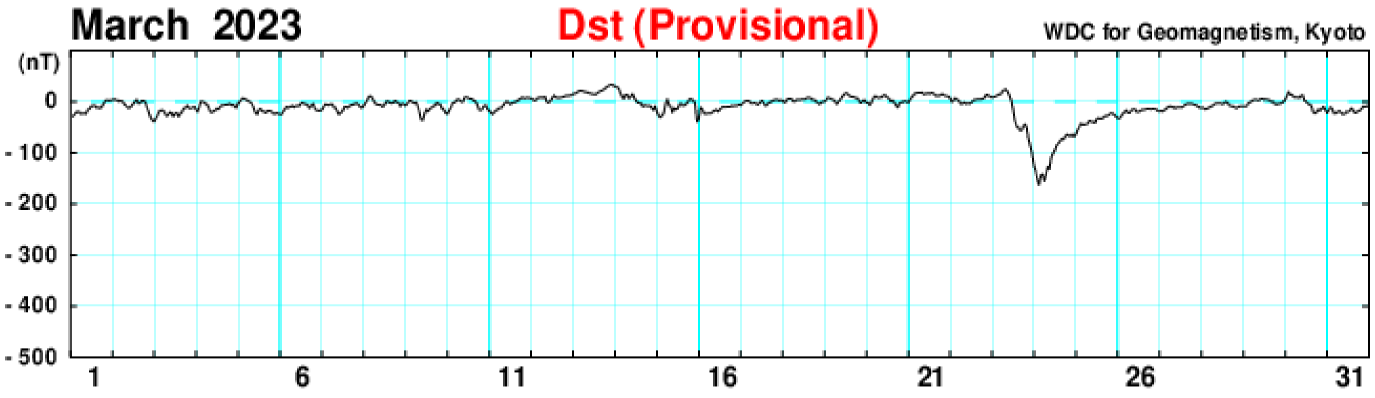
Figure 2.3. Solar flare and CME event on February 27th, 2000

Results

X coodinate (px)	Y coodinate (px)	Distance from CME to center of the Earth (px)	Time (s)	Distance from CME to center of the Earth (km)
234,63	210,44	39,37		695700 (Radius)
185,94	142,28	123,08	0	2175002,59
166,47	83,85	183,07	1440	3235134,20
144,21	29,60	241,40	2880	4265835,73



- **Exercises 2:** *Determine the velocity of CMEs at 02:00 of March 20th 2023*



- Joseph Shaw photographed the luminous ribbon over Bozeman, Montana, 23-24 March