Space Climate

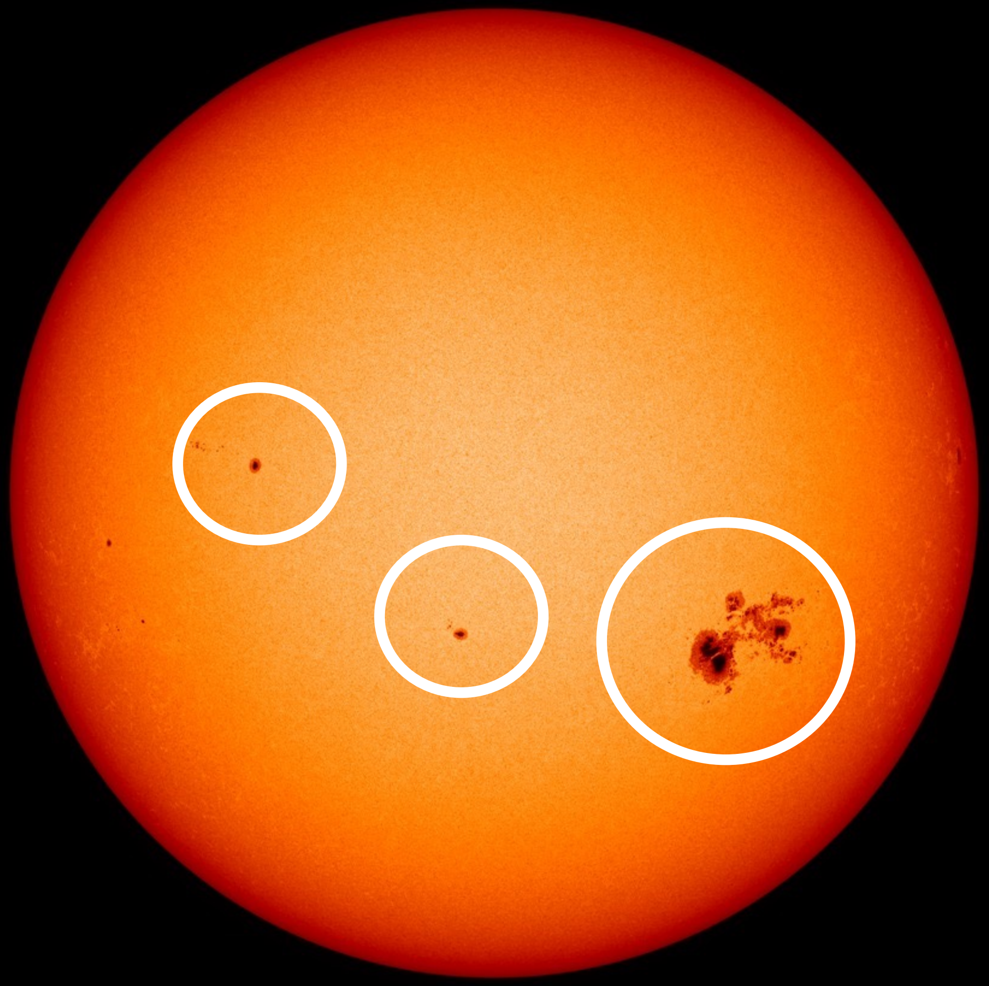
Aurora Forecast

Shabnam Nikbakhsh

What to do:

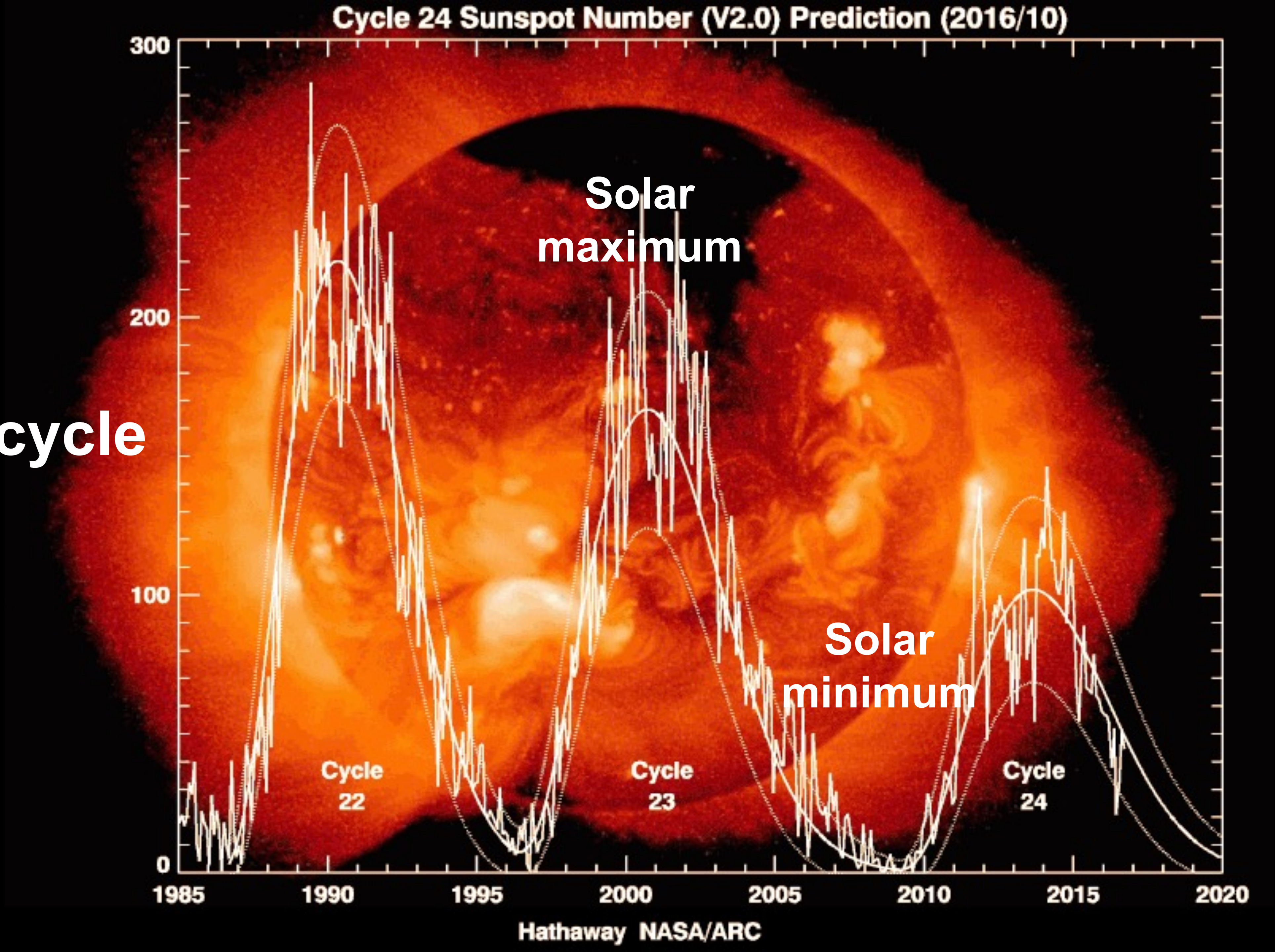
- Check the current state of the sun
  - Active regions
  - Solar max/min
  - CME/flare or coronal holes
- Check solar wind data
  - Fast/slow solar wind
  - Shock wave
- Check geomagnetic data
  - Dst,Kp, AE

Video credit: ISS/NASA



Sunspot groups
Credit: SDO/NASA

Solar cycle



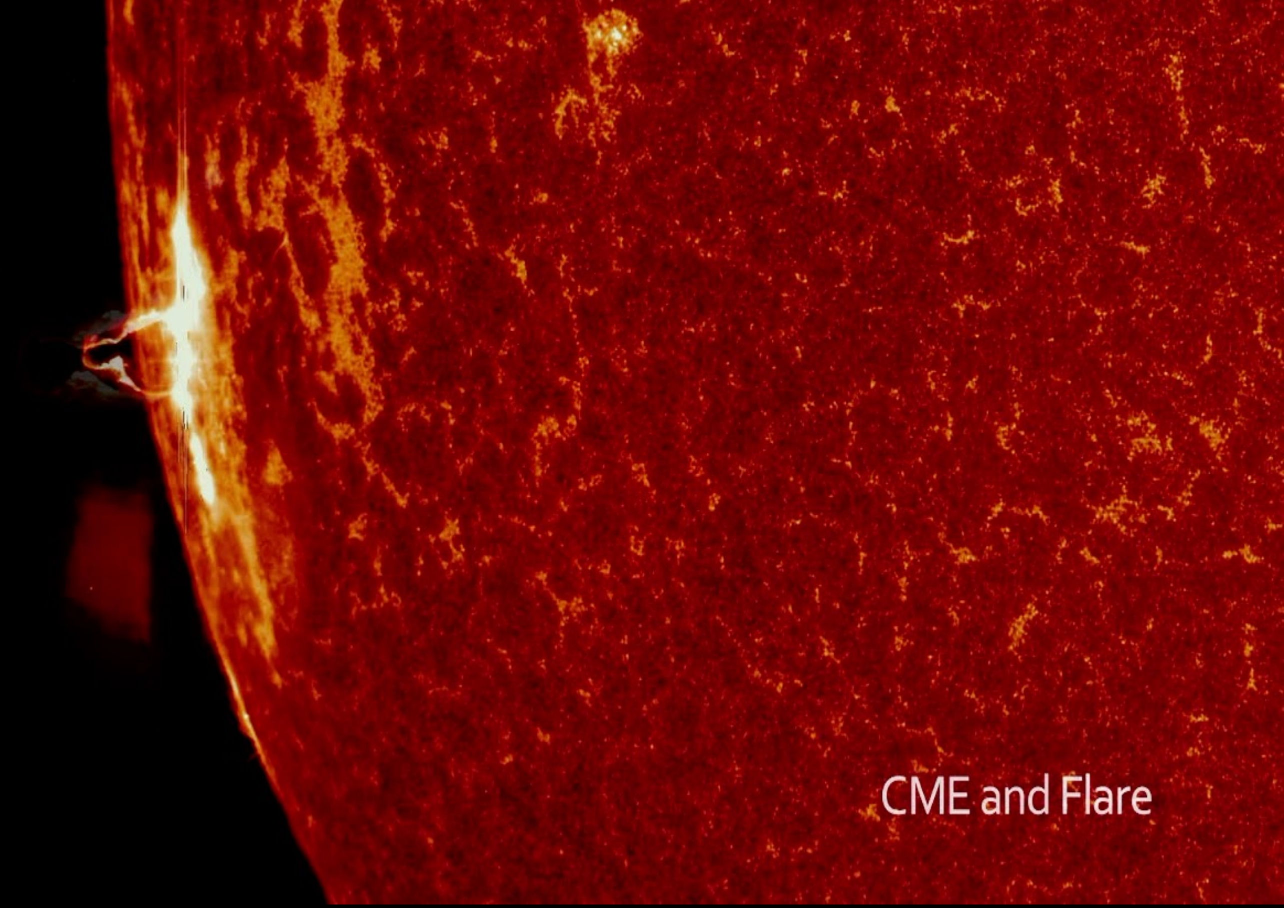
Cycle 24 Sunspot Number (V2.0) Prediction (2016/10)
300
200
100
0
1985
1990
1995
2000
2005
2010
2015
2020
Cycle 22
Cycle 23
Cycle 24
Solar maximum
Solar minimum
Hathaway NASA/ARC

CME and flare

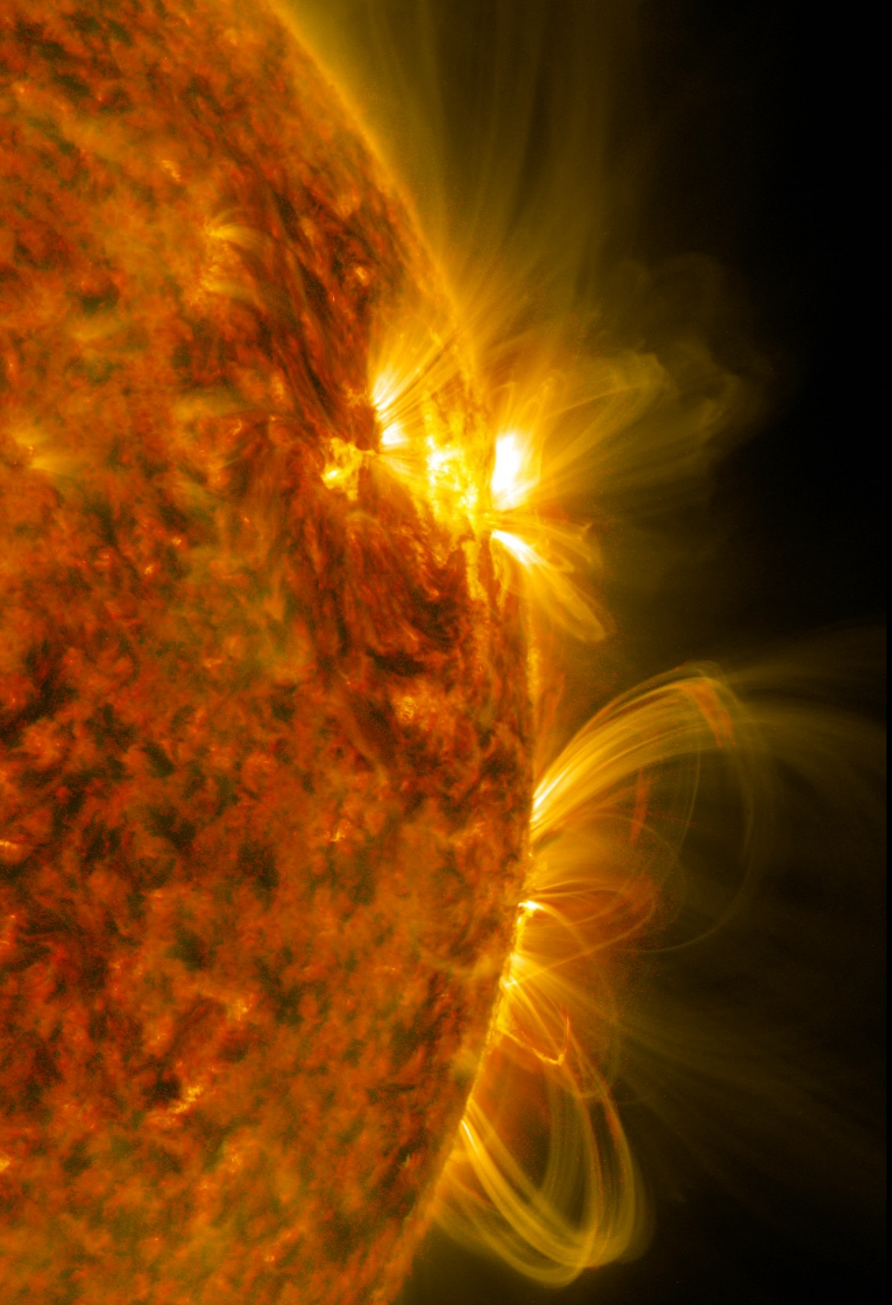
- Coronal mass ejections (CMEs) and solar flare are <u>explosive phenomena</u> that occur on the Sun

- Often occur <u>together</u> but they are not the same

- Often <u>emerge</u> from solar active regions



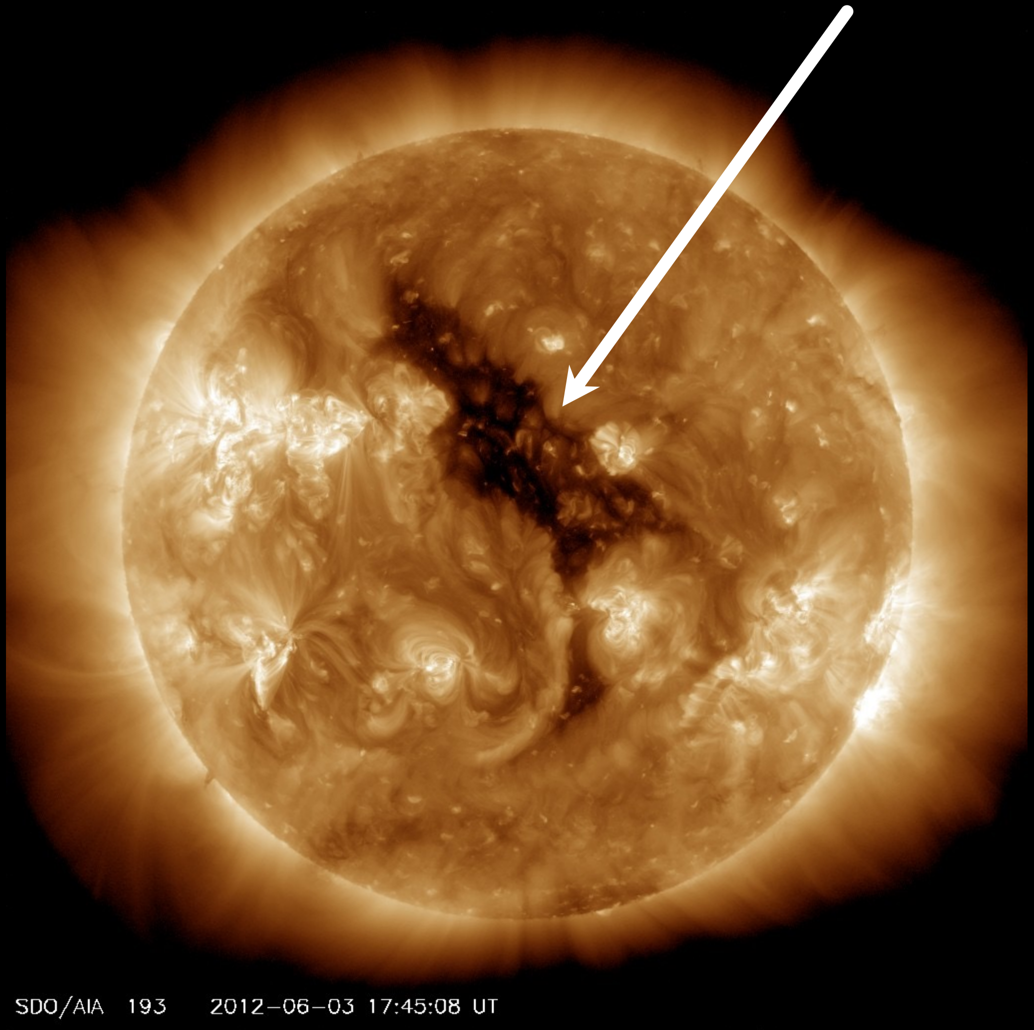
Video credit: SDO/NASA



Sept. 10, 2017, X8.2-class solar flare observed by SDO. The video shows a blend of light from the 171- and 304-angstrom wavelengths. Image credit: SDO/NASA

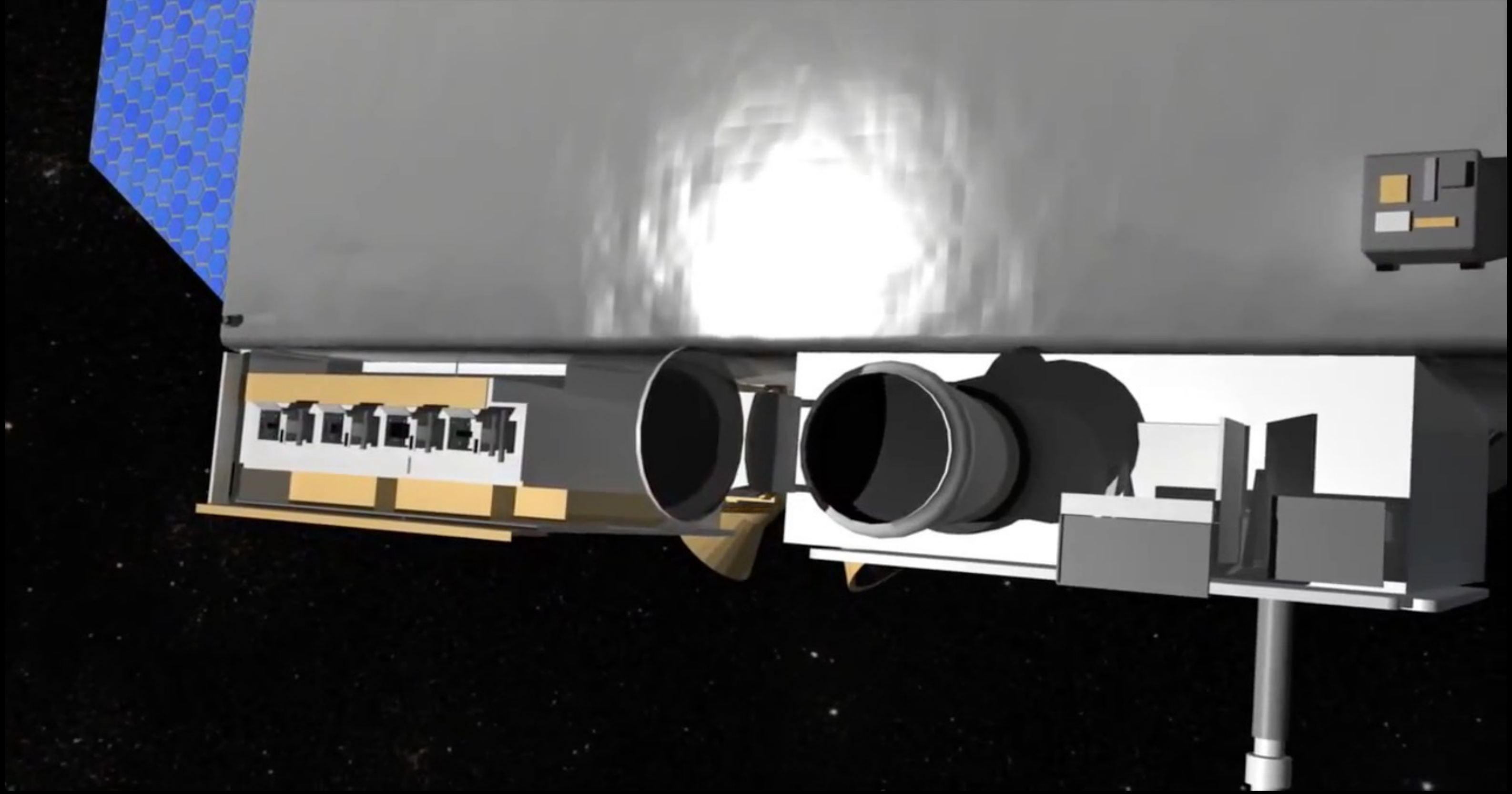
Solar Flare classification

- Flares produce electromagnetic radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays
- Solar flares are classified according to their X-ray brightness, in the wavelength range 1 to 8 Angstroms
- Flares classes have names: A, B, C, M, and X, with A being the smallest and X being the largest
- Each category has nine subdivisions ranging from, e.g., C1 to C9, M1 to M9, and X1 to X9. These are logarithmic scales, much like the seismic Richter scale. So, an M flare is 10 times as strong as a C flare



Coronal Holes

- Appear in the Corona
- Observed in the EUV and soft X-ray images
- Cooler and less dense than surrounding plasma
- Associated with open and unipolar magnetic field lines which allows the solar wind to escape more easily to the space
- Produces the fast solar winds, referred to as high-speed streams
- Develop at any time, but more common and persistent during solar minimum



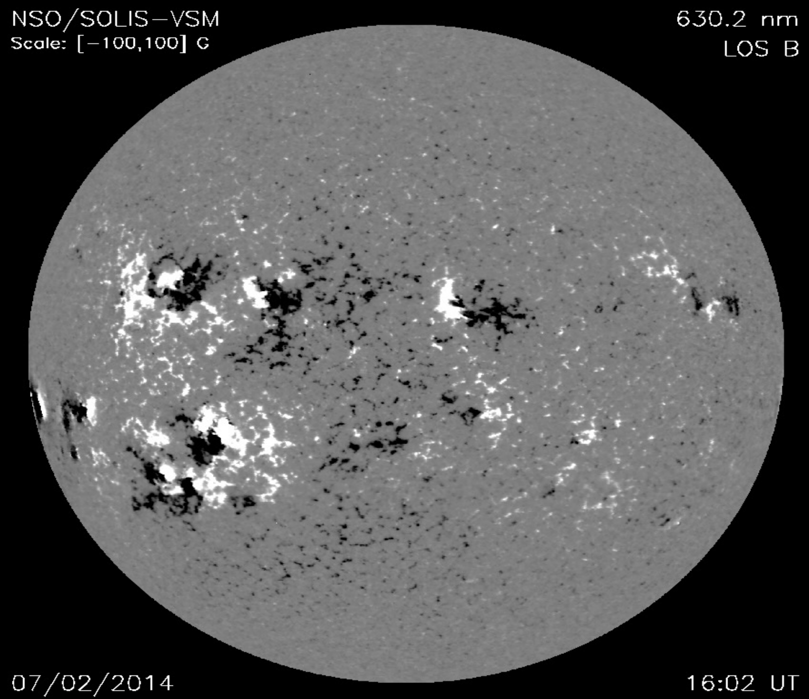
Near-Earth Space Observation

Solar Dynamic Observatory (SDO) Satellite

- Launched in : February 2010 Orbit: ~35,000 km
- HMI: Studies oscillation and magnetic field at photosphere
- AIA: Studies the sun in multiple wavelength (white light, Seven EUV & two UV)
- EVE: Studies solar EUV irradiance

Zeeman effect

- In the presence of a magnetic field, the energy levels of atoms are split into more than one level
- This causes spectral lines to also be split into more than one line, with the amount of splitting proportional to the strength of the magnetic field
- This effect is called the Zeeman Effect
- A magnetograph is used to measure sunspot's magnetic fields strength and direction



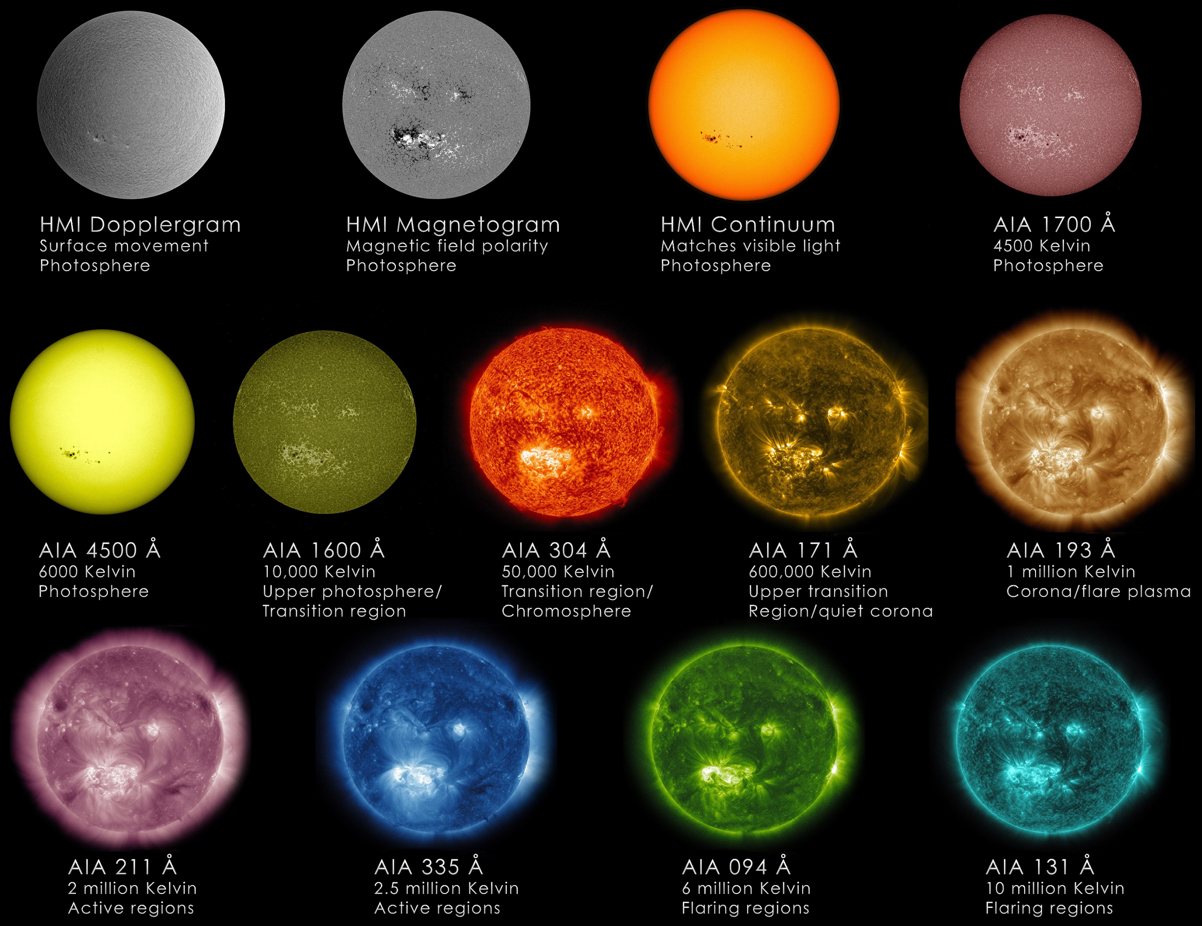
Magnetogram

07.02.2014

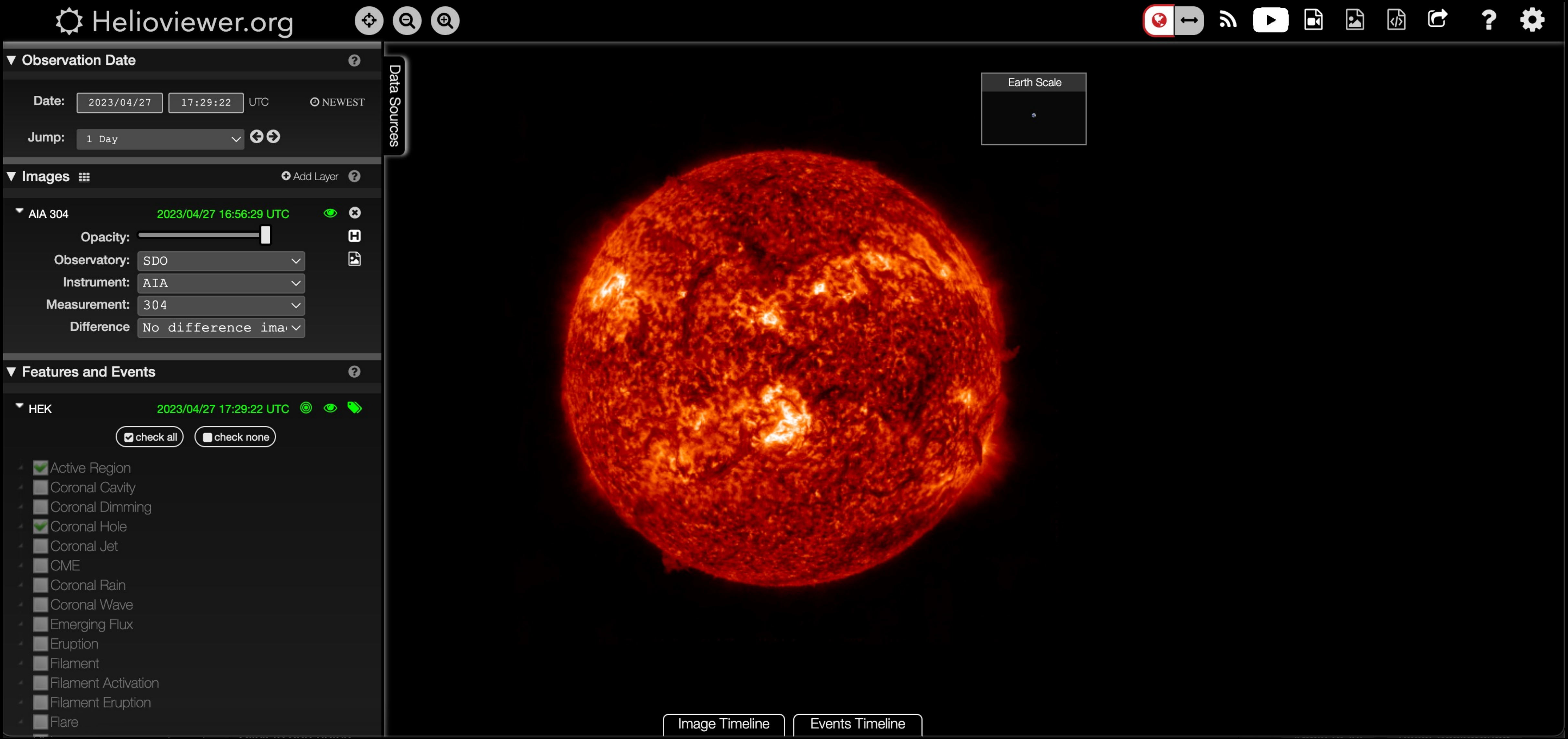
Iron spectral line at 8468 Å

Solar observations

- Solar Cycle, sunspot, flare, CME, coronal holes
- Declining phase or minimum
- https://helioviewer.org/
- https://solarmonitor.org/index.php



Helio viewer website



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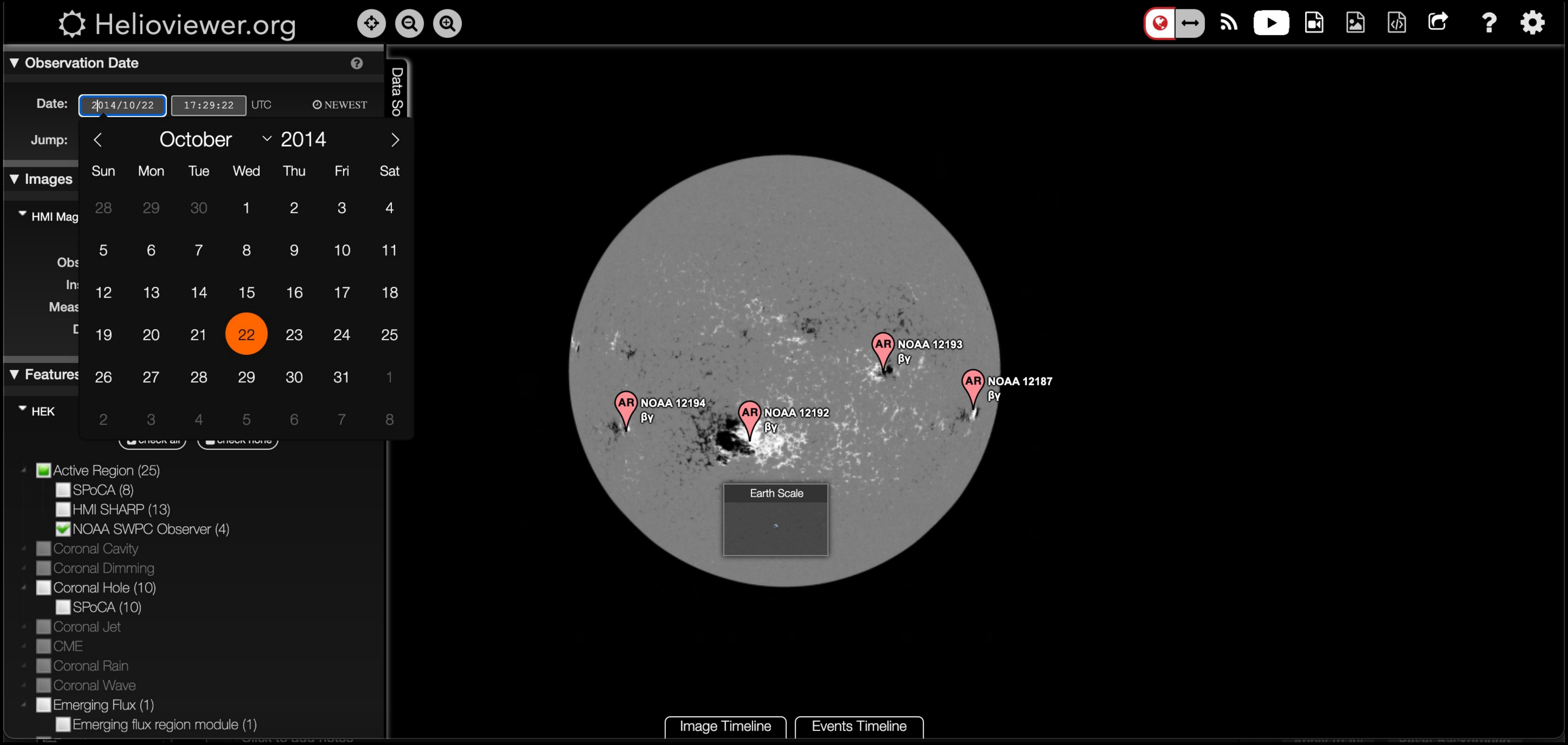
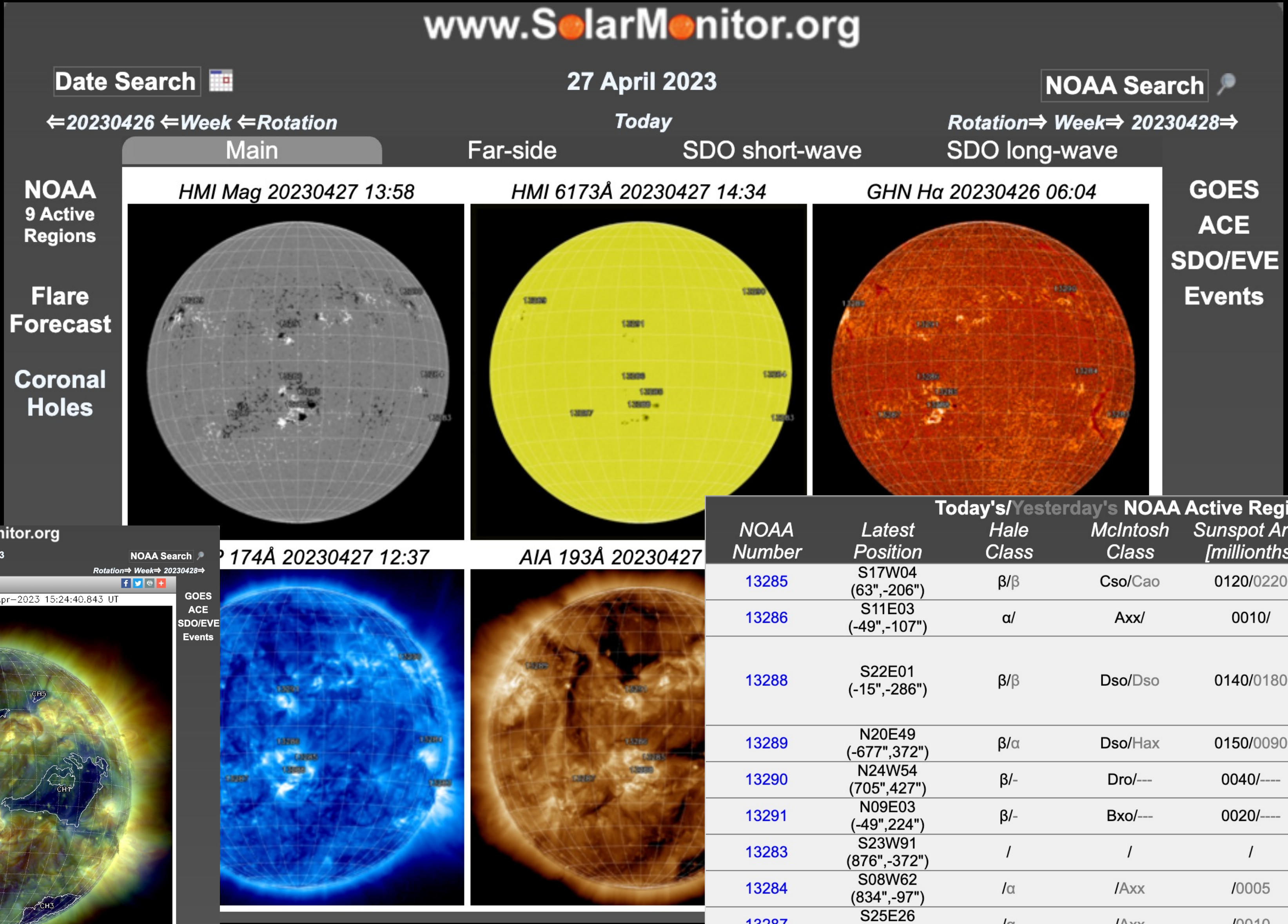
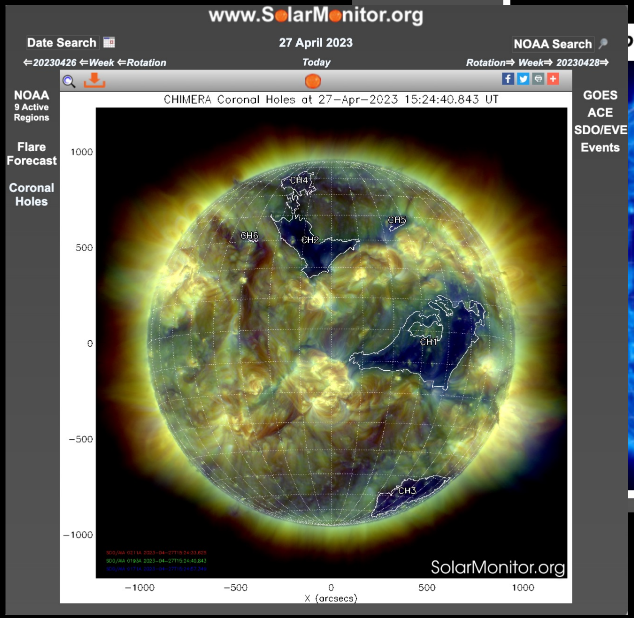






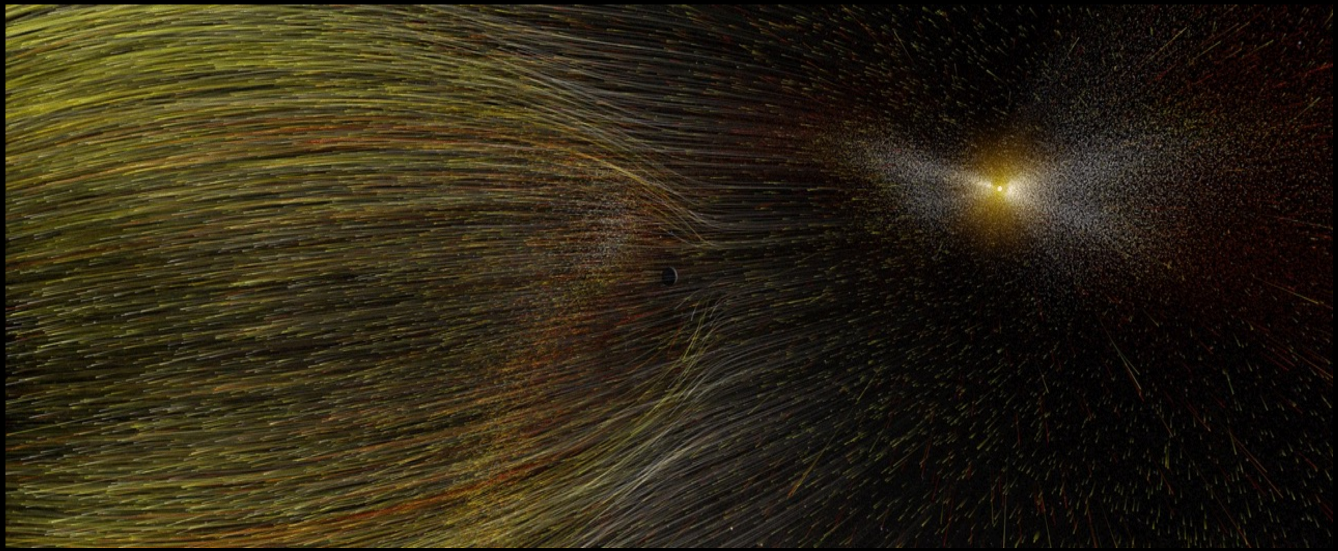
Today's/Yesterday's NOAA Active Regions

NOAA Number	Latest Position	Hale Class	McIntosh Class	Sunspot Area [millionths]	Number of Spots	Recent Flares
13285	S17W04 (63",-206")	β/β	Cso/Cao	0120/0220	04/05	- / C2.7(23:57)
13286	S11E03 (-49",-107")	α/	Axx/	0010/	02/	-
13288	S22E01 (-15",-286")	β/β	Dso/Dso	0140/0180	05/04	M1.8(11:04) C1.4(10:30) C1.2(09:37) C1.0(09:14) C1.2(08:42) / -
13289	N20E49 (-677",372")	β/α	Dso/Hax	0150/0090	03/02	-
13290	N24W54 (705",427")	β/-	Dro/---	0040/----	03/--	-
13291	N09E03 (-49",224")	β/-	Bxo/---	0020/----	04/--	-
13283	S23W91 (876",-372")	/	/	/	/	-
13284	S08W62 (834",-97")	/α	/Axx	/0005	/01	-
13287	S25E26 (-380",-341")	/α	/Axx	/0010	/01	-

Class (HH:MM) -Today
Class (HH:MM) -Yesterday

https://www.solarmonitor.org/index.php

Solar wind



Credit:NASA/Goddard

- Continuous stream of charge particles, mostly electrons and protons
- Average speed 400 (km/s)
- Fast solar wind (~750 km/s
- Slow solar wind (~350 km/s)

Observations at L1:

- Lagrange points: Zones in space where the gravitational and centrifugal force of two bodies balance out
- Lagrange points can be used by spacecraft to reduce fuel consumption needed to remain in position
- L1 ~1.5 million km
- Spacecraft in L1: SOHO DSCOVR, ACE, Wind

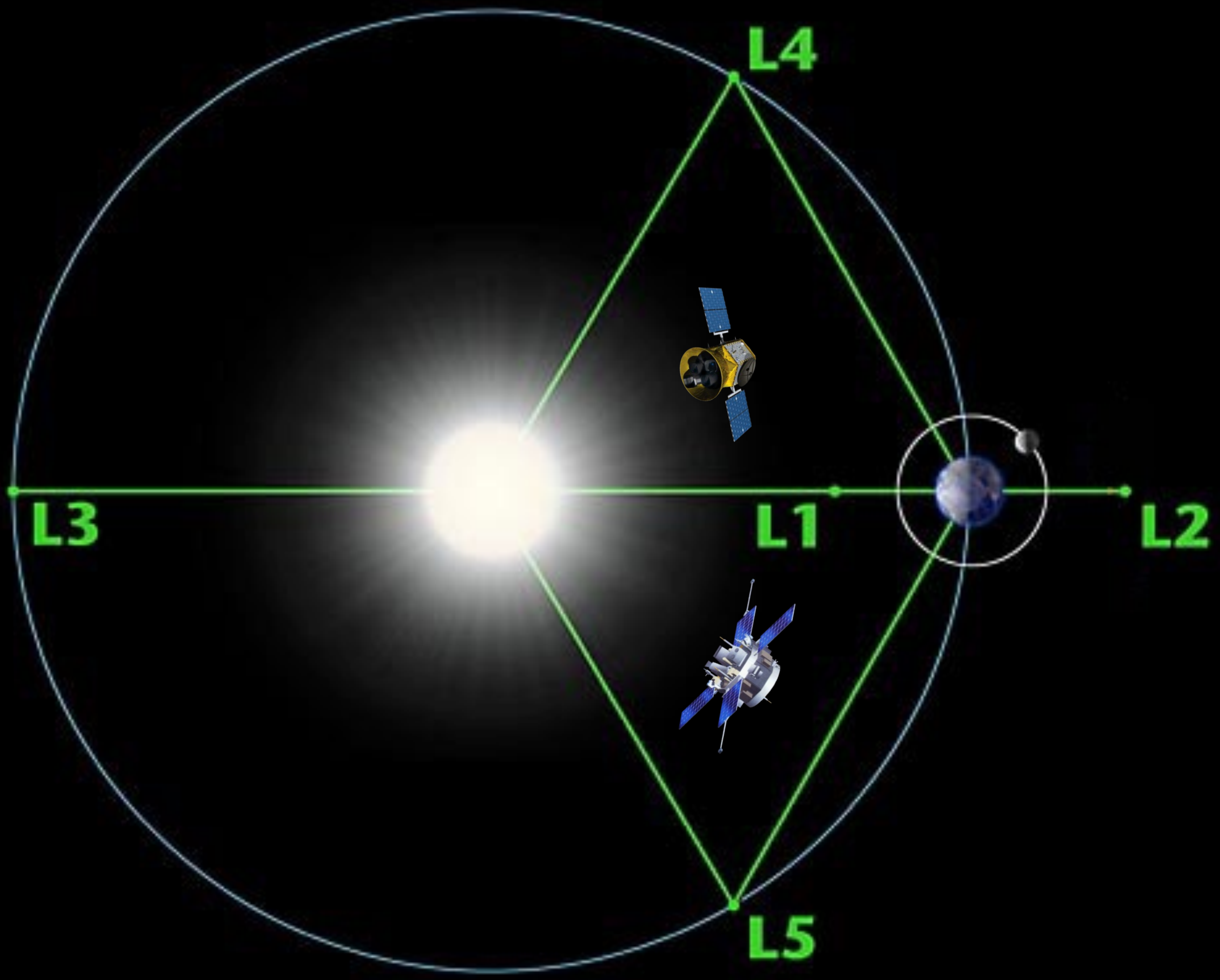


Image credit: NASA/WMAP Science Team

Solar Wind data

- Deep Space Climate Observatory (DSCOVR) Satellite

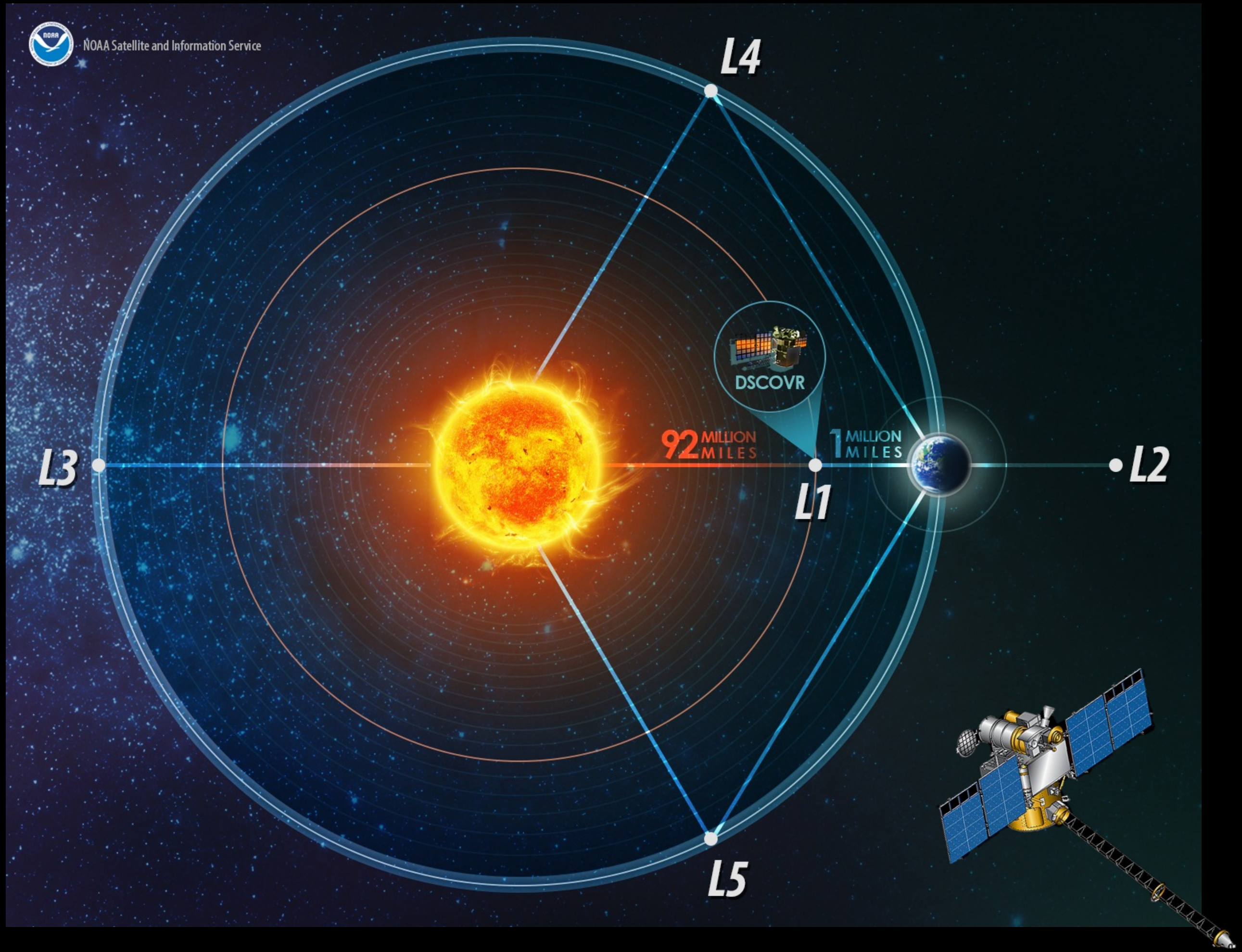
- Built in 2001, Launched February 2015

- PlasMag Instrument:

    - Part 1: a vector magnetometer

    - Part 2: a Faraday cup, measures the three-dimensional distribution function of proton and alpha components

    - Part 3: a “top-hat” analyzer, gives 3-D electron velocity distribution functions

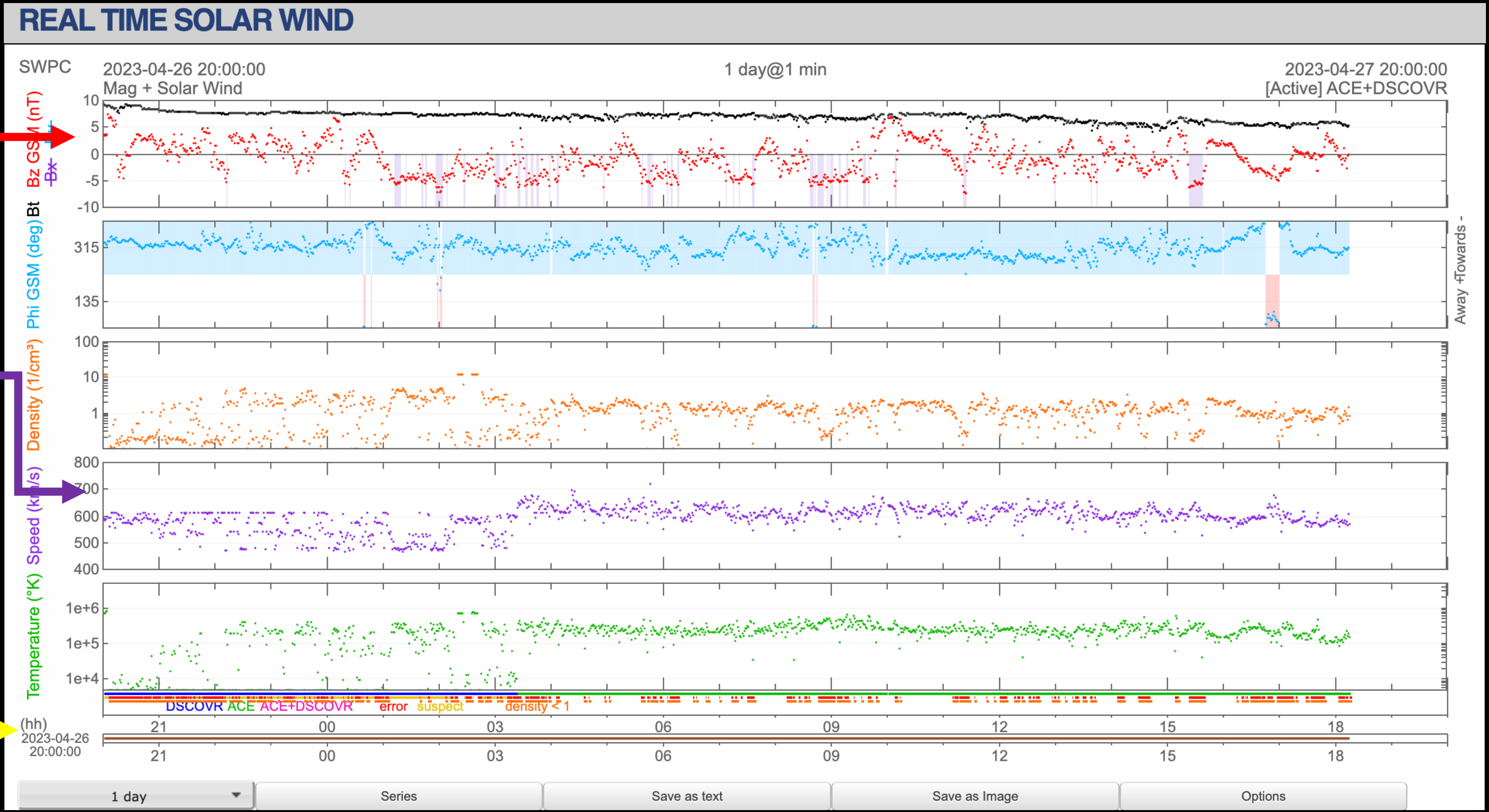


What to look

Z component of the solar wind magnetic field

Solar wind Speed

Note Coordinated Universal Time (UTC)

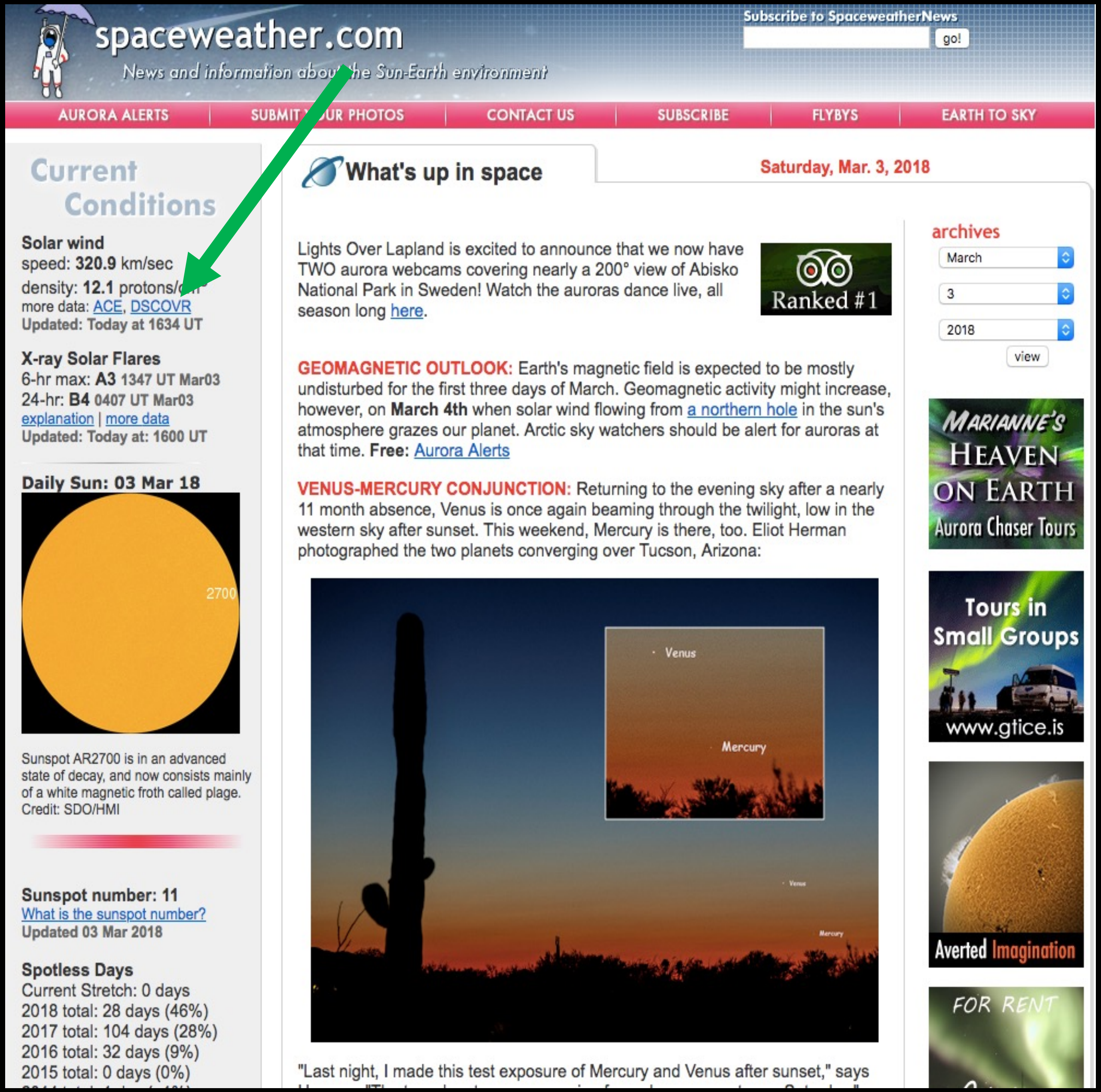


https://www.swpc.noaa.gov/products/real-time-solar-wind

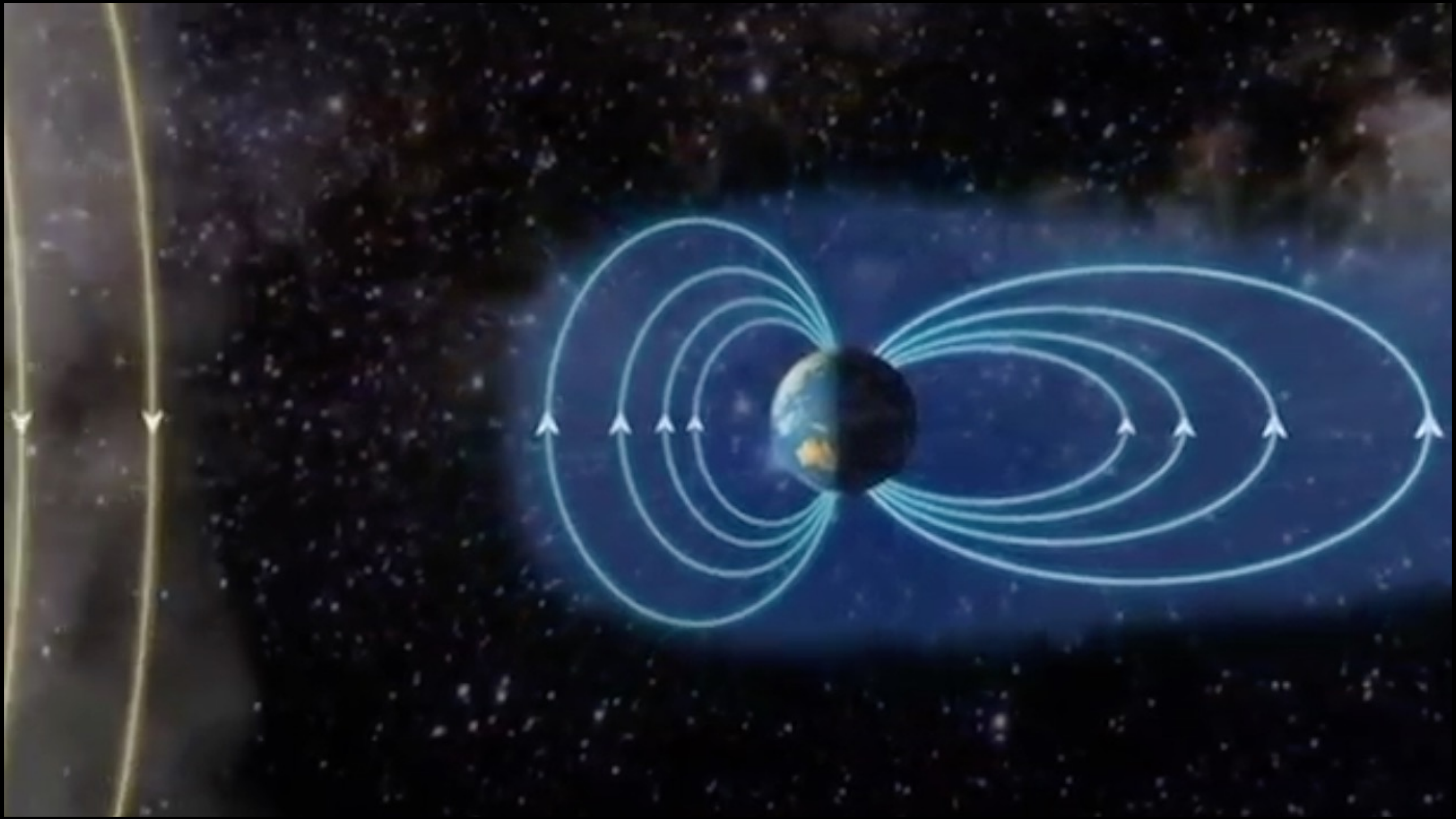
You can also find DSCOVR data at this website:

- Space Weather website

http://spaceweather.com/



How Auroras Are Formed



Magnetosphere

- When you look at the Earth from space, it looks like it is floating in a black void
- The Earth's core is surrounded by an ocean of liquid metal. The flow of this material creates electric currents, which in turn <u>creates</u> the magnetic field
- The Earth is <u>surrounded</u> by a complex system formed by the <u>interaction of the solar wind with the Earth's magnetic field</u>
- The solar wind compresses the <u>sunward side</u> of the magnetosphere to a distance of ~ 10 $R_{\oplus}$ and its nightside to possibly 1000 $R_{\oplus}$
- The magnetosphere is highly dynamic

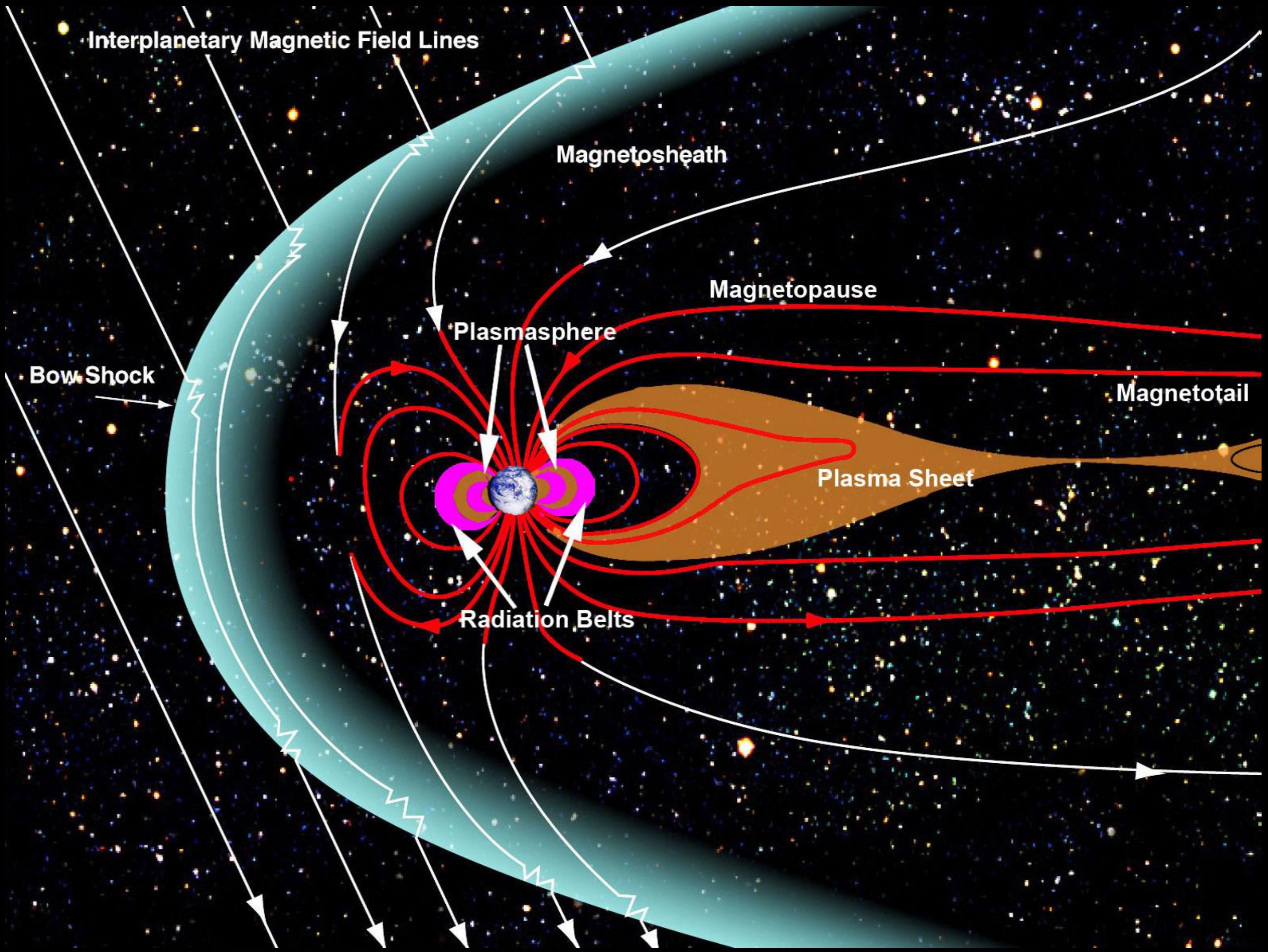


Image credit: NASA

Magnetopause

- Magnetopause is the boundary between the magnetosphere and solar wind
- Total pressure = thermal + dynamic + magnetic

$$P = n\,k_B\,T_i \;+\; n\,m_i\,V^2 \;+\; \frac{B^2}{2\mu_0}$$

$k_B \sim 10^{-23}$

Parameters	Solar Wind	Magnetosphere
$k_B T$ [keV]	0.01	5
n [cm^{-3}]	5	0.1
V [km/s]	400	50
B [nT]	5	55
P_{TH} [nPa]	**0.01**	**0.08**
P_{DYN} [nPa]	**1.3**	**0.0004**
P_B [nPa]	**0.01**	**1.2**

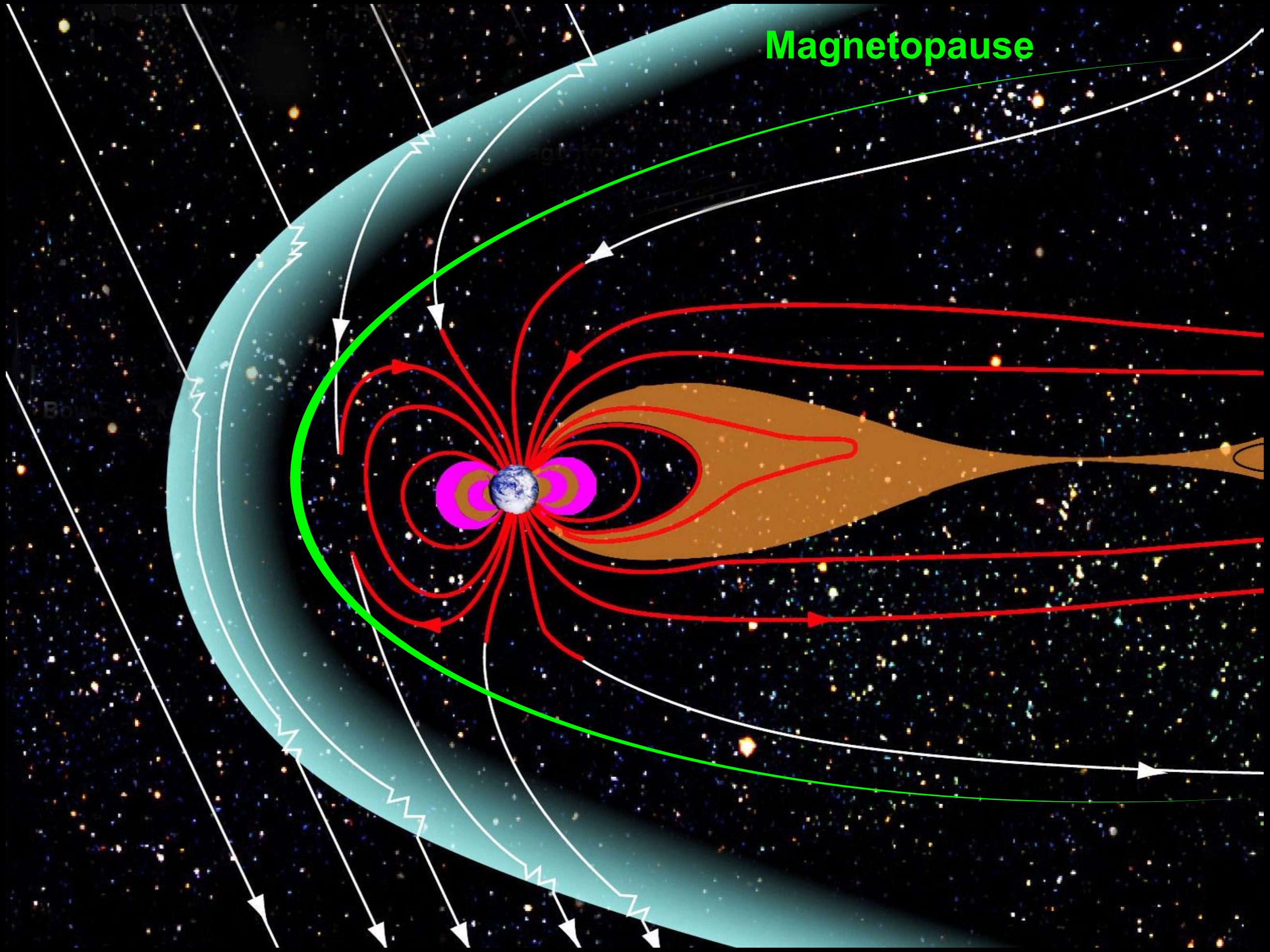


Image credit: NASA/Goddard

Estimate the magnetopause location

- Remember we are dealing with solar wind which is carrying magnetic field and charged particles

- So the total the pressure will be:

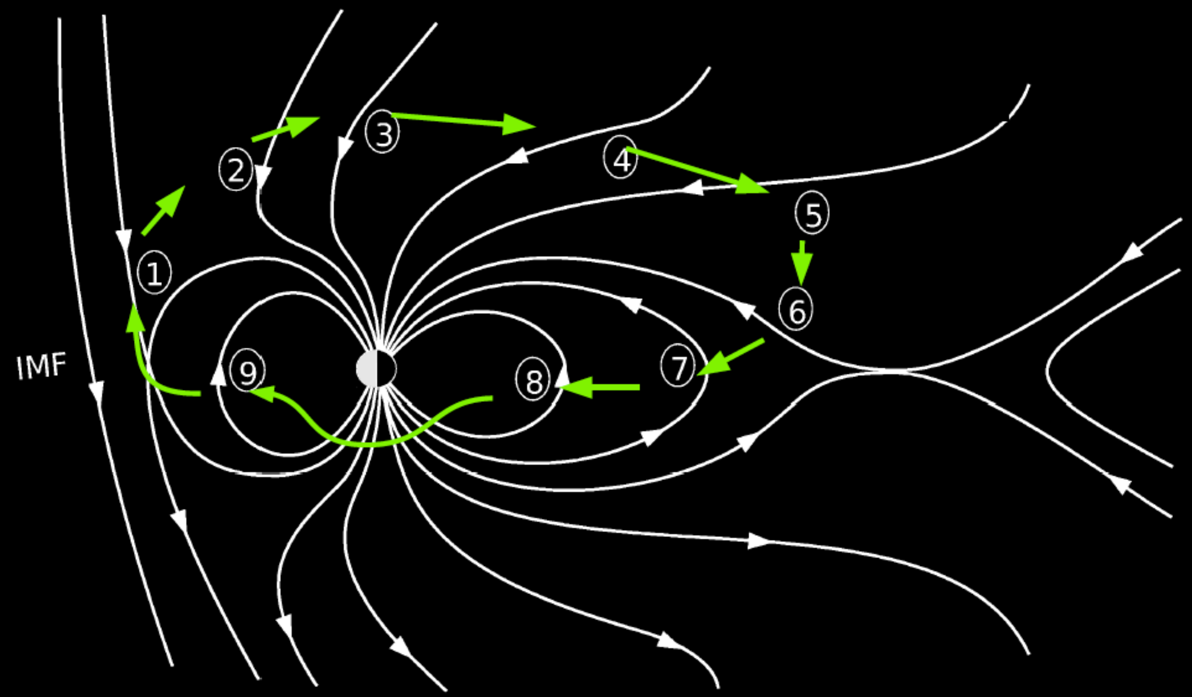
$$P = \underbrace{n\, k_B T_i}_{\text{Thermal pressure}} + \underbrace{n\, m_i V^2}_{\text{Dynamic pressure}} + \underbrace{\frac{B^2}{2\mu_0}}_{\text{Magnetic pressure}}$$

- Now read again the definition of the magnetopause

- Note: Inside the magnetopause, $B_{inside} \sim 2B_{dipole\ value}$

Consider the Dungey Cycle

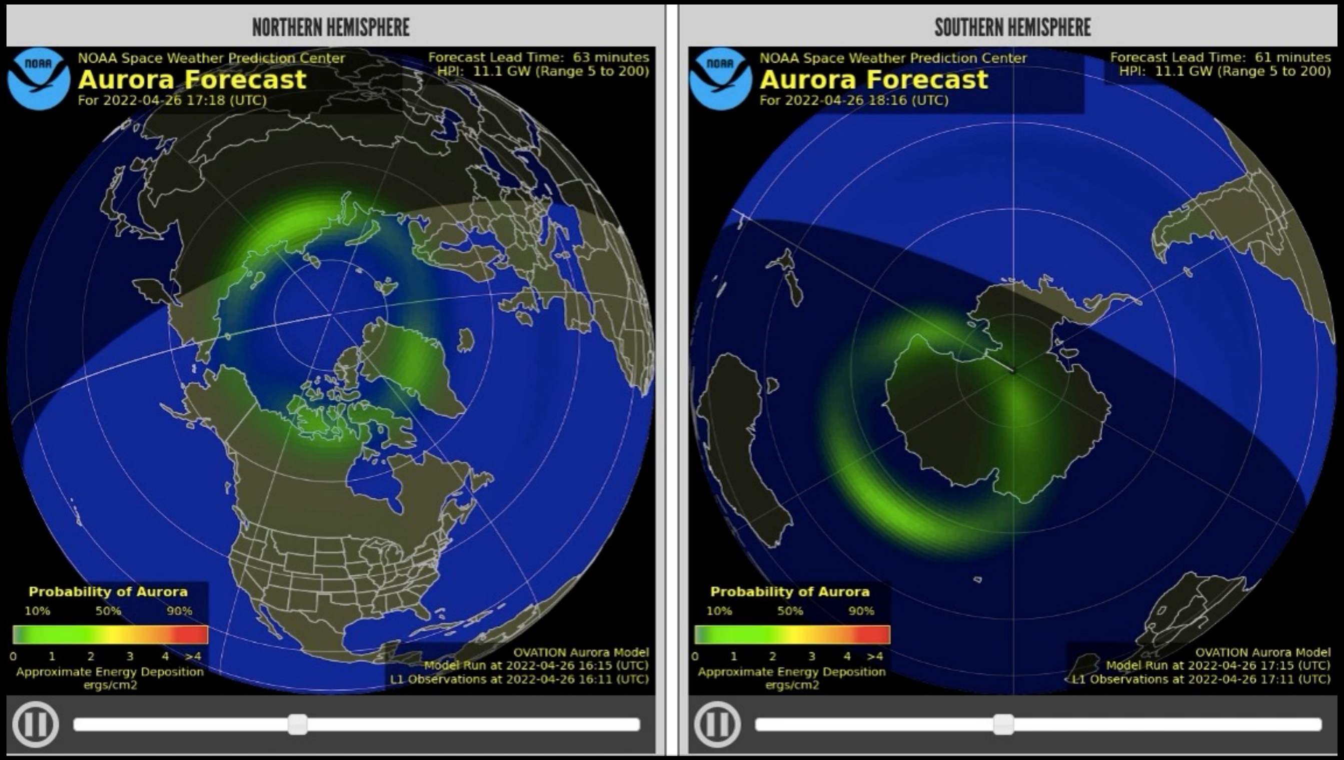
- If IMF has a southward component
- Magnetic reconnection opens the dayside magnetopause
- IMF connects to the Earth magnetic field
- Solar wind flow around the magnetosphere drives a global convective motion



The Dungey cycle. After Dungey, 1961

OVATION Aurora Forecast

- 30-minute forecast, based on the current solar wind condition at L1
- Remember: The model uses a fixed 30 minutes delay time between L1 and Earth
- You can make better prediction based on the real-time solar wind speed
- https://www.swpc.noaa.gov/products/aurora-30-minute-forecast



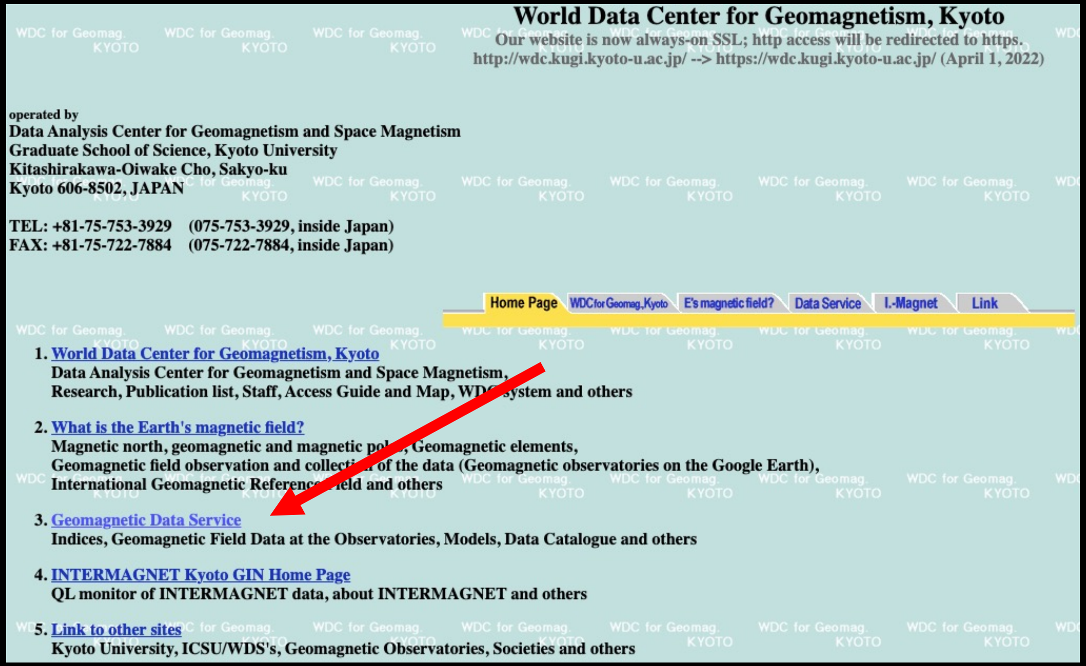
Database for the Geomagnetic indices

Check these indices

- Dst index
- AL/AU or AE index
- Kp index

World Data Center for Geomagnetism

- https://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html



Ring current

- The Ring current is located at ~ 3 to 8 $R_{\oplus}$, circulates clockwise (when viewed from the north)

- The current produces a B-field in opposition of $B_{\oplus}$

- Dst index measures the intensity of the ring current

- Dramatic enhancement during geomagnetic storm

$R_{\oplus}$= 6,371 (km)

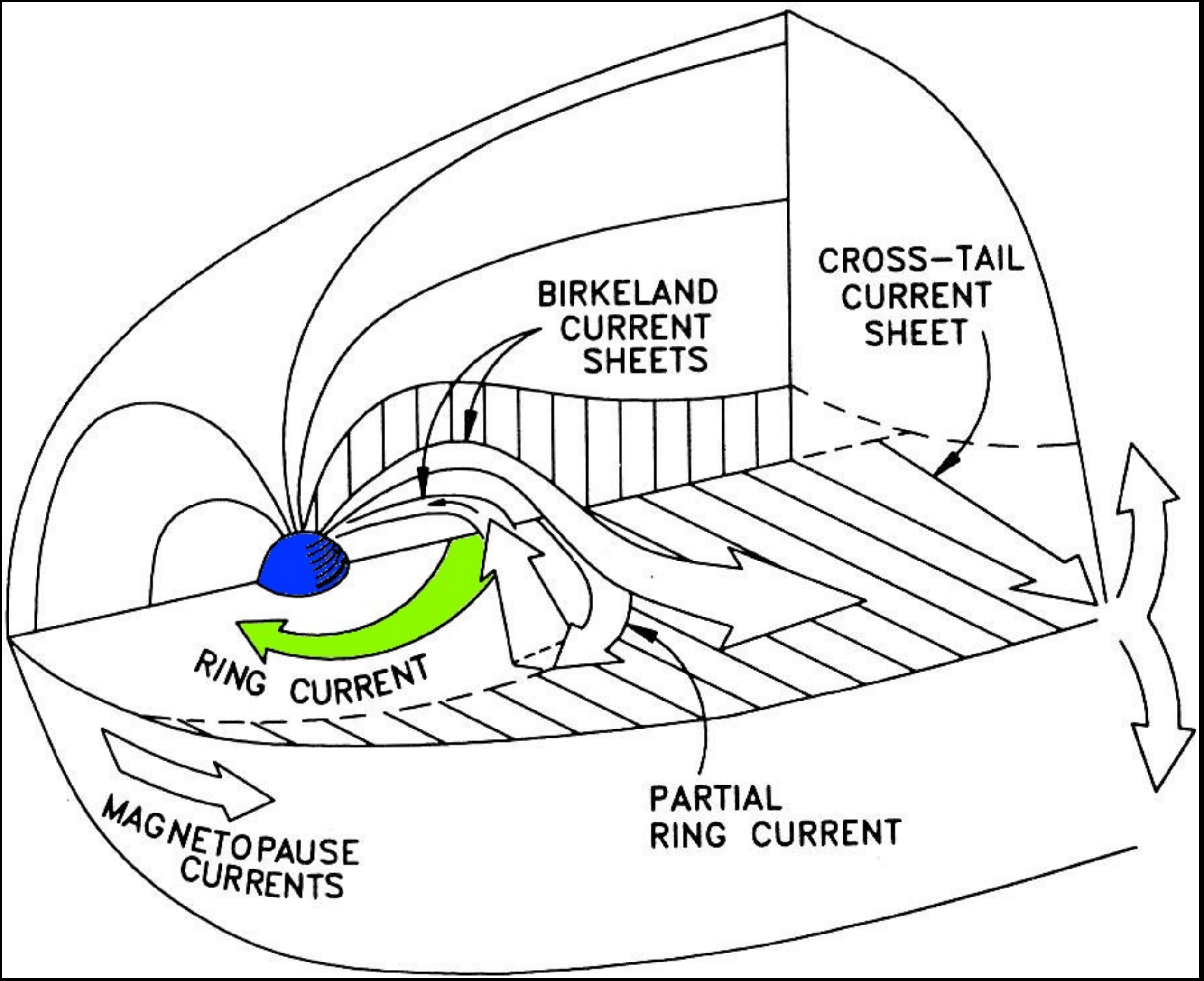


Illustration credit: David P. Stern

WDC for Geomagnetism, Kyoto
Hourly Equatorial Dst Values (FINAL)
MARCH 2015

unit=nT

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24 UT
1	-34	-44	-30	-31	-28	-42	-55	-53	-56	-51	-50	-47	-46	-41	-36	-32	-29	-26	-22	-21	-22	-21	-27	-26
2	-21	-20	-30	-35	-30	-42	-43	-53	-64	-62	-54	-50	-53	-53	-49	-49	-41	-40	-36	-29	-27	-27	-25	-23
3	-24	-22	-28	-26	-25	-26	-27	-26	-22	-26	-28	-27	-25	-27	-27	-27	-25	-25	-28	-21	-21	-23	-27	-31
4	-27	-18	-16	-17	-15	-13	-11	-8	-4	-5	-6	-7	-11	-15	-16	-19	-20	-20	-17	-14	-15	-11	-14	-18
5	-15	-11	-9	-9	-7	-5	-4	-3	-3	-6	-8	-7	-12	-19	-13	-14	-15	-12	-10	-10	-8	-7	-3	-3
6	-3	0	2	6	3	-5	-14	-30	-30	-20	-17	-14	-16	-16	-14	-12	-11	-8	-8	-9	-14	-17	-9	-6
7	-8	-11	-12	-17	-20	-27	-27	-25	-19	-20	-24	-22	-19	-12	-11	-12	-10	-14	-14	-16	-20	-24	-24	-20
8	-17	-13	-13	-14	-15	-12	-7	-7	-9	-8	-12	-18	-21	-18	-21	-19	-17	-20	-21	-18	-15	-14	-13	-15
9	-18	-23	-21	-22	-19	-16	-17	-18	-17	-16	-14	-11	-9	-9	-10	-9	-10	-10	-5	-4	-4	-4	-4	-3
10	-1	-4	-4	-6	-6	-4	-2	-1	1	-3	-7	-3	-5	-6	-6	-7	-7	-6	-6	-8	-6	-4	-4	-5
11	-6	-6	-6	-6	-5	5	6	8	0	2	1	2	-6	-11	-14	-14	-12	-12	-15	-20	-19	-16	-15	-14
12	-15	-12	-8	-10	-11	-7	-12	-22	-24	-23	-19	-19	-15	-17	-18	-13	-9	-9	-9	-8	-8	-11	-13	-15
13	-13	-12	-9	-3	-2	1	1	0	-1	-2	-2	0	-3	-16	-20	-11	-7	-10	-15	-15	-11	-10	-7	-10
14	-12	-11	-12	-13	-14	-15	-12	-9	-8	-7	-5	-4	-4	-4	1	3	4	2	3	2	-1	-3	-5	-11
15	-11	-11	-11	-12	-11	-11	-9	-9	-7	-6	-7	-5	-5	-3	1	4	-1	0	2	1	-2	-7	-7	-2
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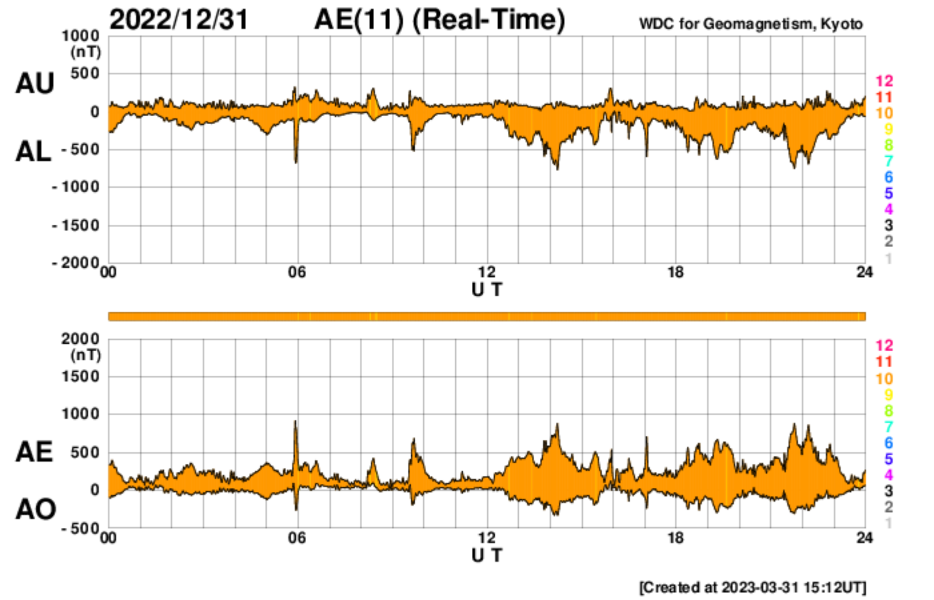
18	-200	-189	-172	-155	-148	-136	-133	-124	-123	-117	-111	-99	-97	-91	-88	-91	-86	-82	-88	-94	-95	-94	-94	-93
19	-99	-94	-86	-81	-86	-84	-81	-73	-71	-76	-75	-76	-77	-83	-84	-80	-73	-72	-71	-70	-71	-69	-65	-70
20	-75	-81	-74	-69	-65	-64	-71	-68	-63	-61	-62	-65	-58	-57	-55	-56	-62	-66	-64	-60	-59	-56	-56	-65

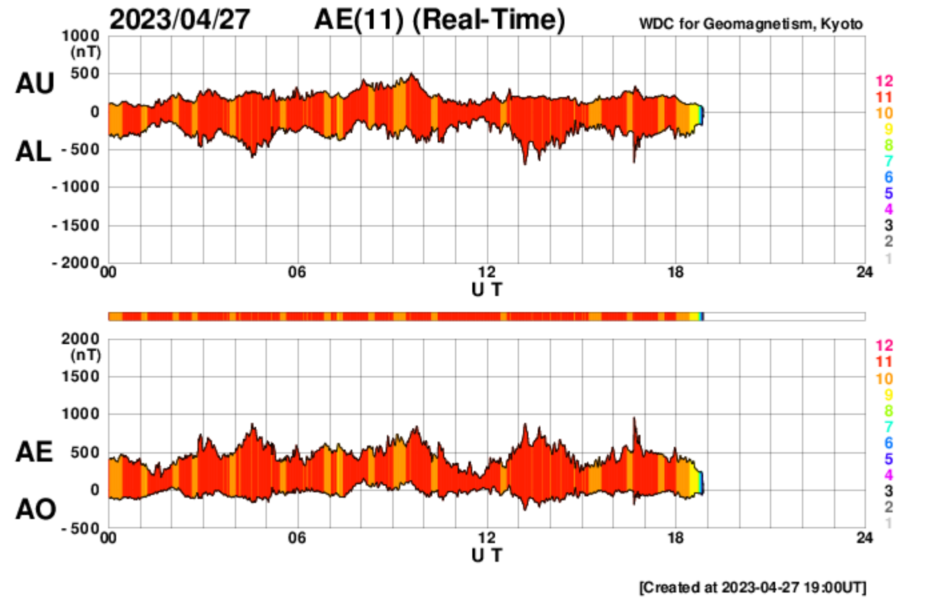
Auroral Electrojets

- An electrojet is an electric current which travel around the Erath's ionosphere
- Near the Northern and Southern Polar circles
- Enhancement during substorm

Representation of the East (EEJ) and West (WEJ) auroral electrojet
Image credit: Piccinelli et al. 2014

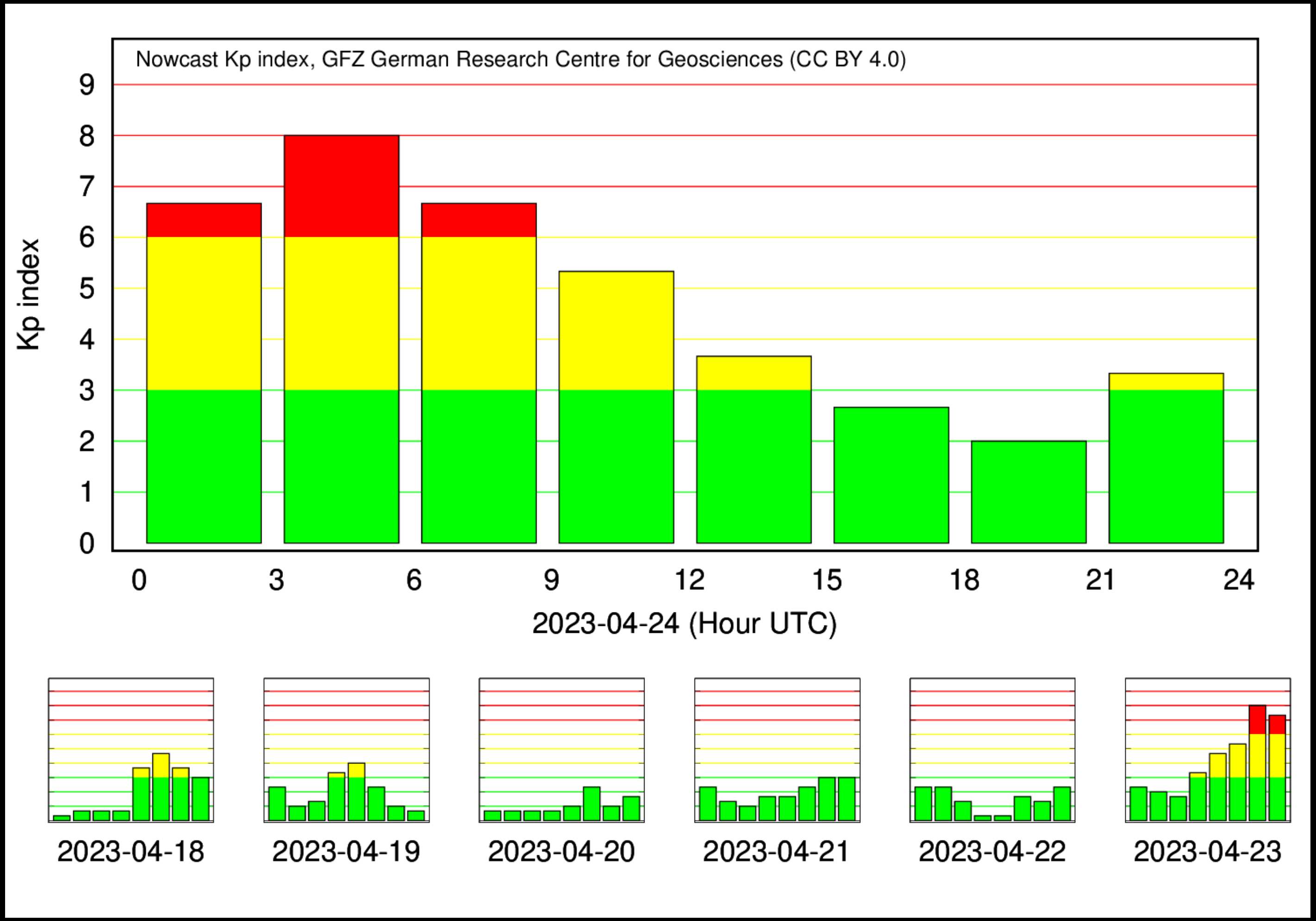
Auroral Electrojet (AE) index





Kp index

- The K_P is used to characterize the magnitude of geomagnetic storms,
- Quantifies disturbances in the horizontal component of earth's magnetic field
- https://kp.gfz-potsdam.de/en/figures/kp-daily-plots



K_p index
Credit: GFZ Helmholtz Centre Potsdam

All sky camera

- Used in meteorology, astronomy and visual observation of auroras
- Capture a photograph of the entire sky
- All-sky cameras that are used for imaging auroras have special optical elements such as <u>fish-eye lenses or spherical mirrors</u> to acquire an image of the <u>whole sky in one shot</u>

All sky camera data

Tromso, Norway
Oct. 27, 2010
Photo Credit: Terence Murtagh & Nicholas Holdsworth
Cades Observatory, Kingston, TAS, Australia

- Sodankylä Geophysical Observatory
http://www.sgo.fi/Data/RealTime/allsky.php

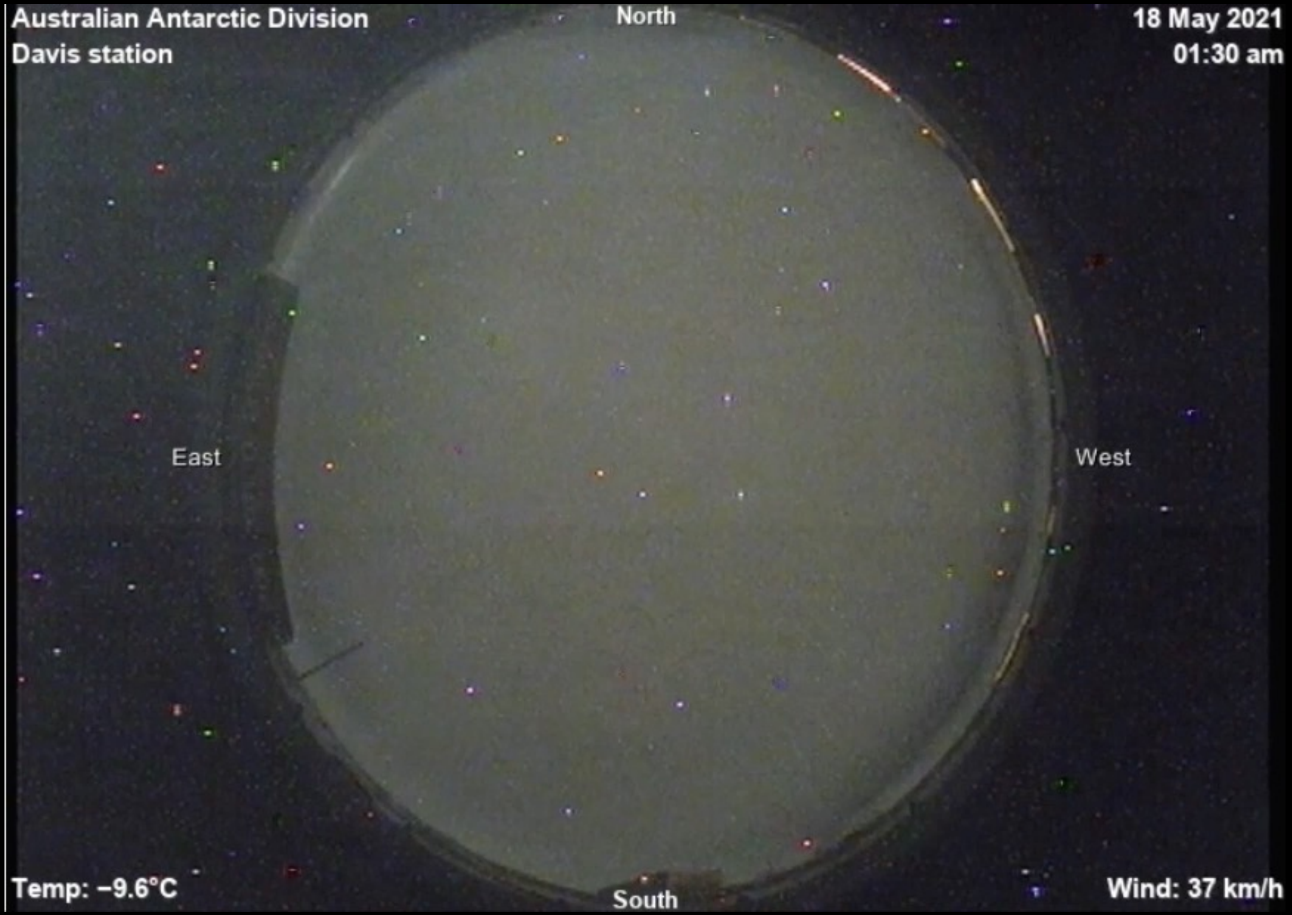
- Skibotn Observatory, Norway:
https://fox.phys.uit.no/ASC/ASC01.html

- Kiruna station, Sweden:
https://www2.irf.se/Observatory/?link=All-sky_sp_camera

- Syowa (or Showa) station, South Pole:
http://polaris.nipr.ac.jp/~acaurora/aurora/Syowa/ Not working!

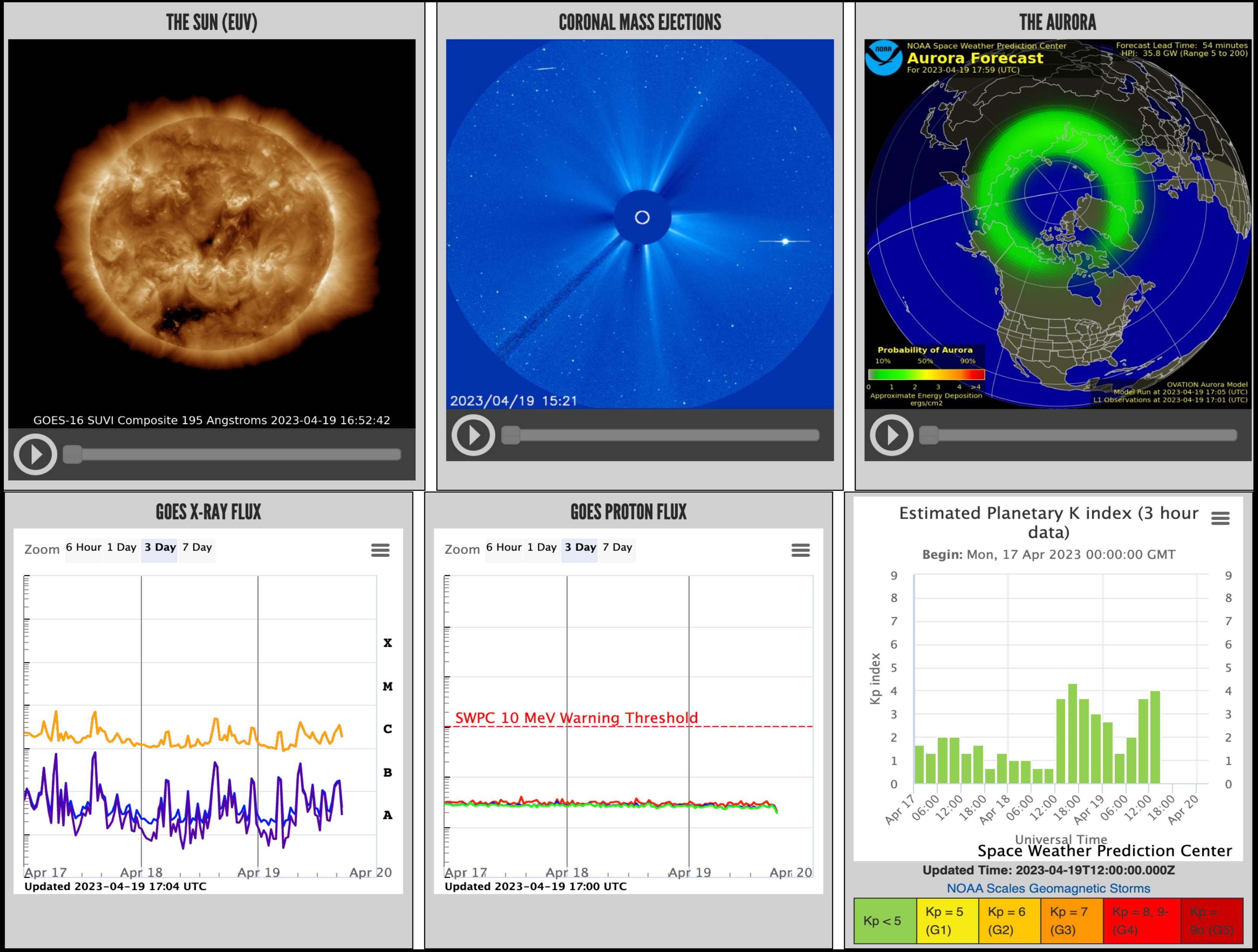
Davis Station Sky-cam

- Davis station is one of the permanent research center in Antarctica
- Operated by Australian Antarctic Division
- Coordinates: 68° 34′ 36″ S, 77° 58′ 3″ E
- Sky-cam produces images of the full sky and provides a view for the study of Antarctic clouds with similar sensitivity to the naked eye
- https://www.antarctica.gov.au/antarctic-operations/webcams/davis/



Sky-cam at the Davis station
Video credit: Australian Antarctic Division

NOAA Space Weather Prediction Center



https://www.swpc.noaa.gov/

Summary of what you need to report

i. Theory

- **Calculate the location of the magnetopause**
  - Explain the theory and all approximations you need to make

- **Estimate solar wind travel time from L1 to the magnetopause based on your observation**
  - You need to check solar wind data (for example DSCOVR satellite) and pick an average speed

- **Explain which geomagnetic data are more suitable for your forecast and why**

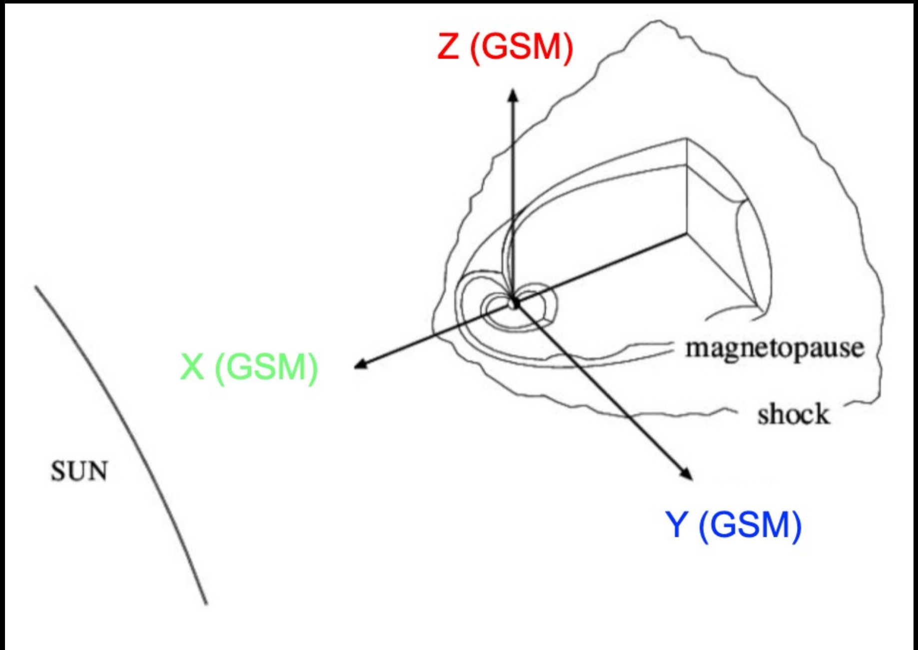
- **Explain the Dungey Cycle**
  - Find a scientific article that estimate the duration of the Dungey cycle and use that estimation for your forecast. Please mention your reference as well.

ii. Observation

- **Pick a date for your forecast**
- **Find these Solar observations and discuss your findings:**
  - Ground-based and space-based data:
    - Magnetogram data
    - SDO short and long-wave
    - Active regions
    - Coronal holes
    - Solar wind data
    - Flaring activity

- **Show plots of these geomagnetic indices and discuss your findings:**
  - Dst, Kp, and AE
- **Image from all Sky camera data:**
  - North/South Hemisphere

- Phi is the angle of the interplanetary magnetic field that is being carried out by the solar wind
- It is measured in the GSM (geocentric solar magnetospheric) coordinate system
- In this system the X-axis points from the Earth to the Sun and the Z-axis is pointing along the direction of the Earth's north magnetic pole. This puts the Y-axis roughly pointing to the left as one looks at the Sun from the Earth
- Phi is the angle made by the field in the XY plane. This means that Phi would be 0° if it were pointing at the Sun and 180° if it were pointing from the Sun to the Earth. Sudden and rapid changes in the Phi angle in conjunction with increased solar wind speeds and B_z fluctuations is common during a CME impact



Credit: Eija Tanskanen