

Space Climate Aurora Forecast

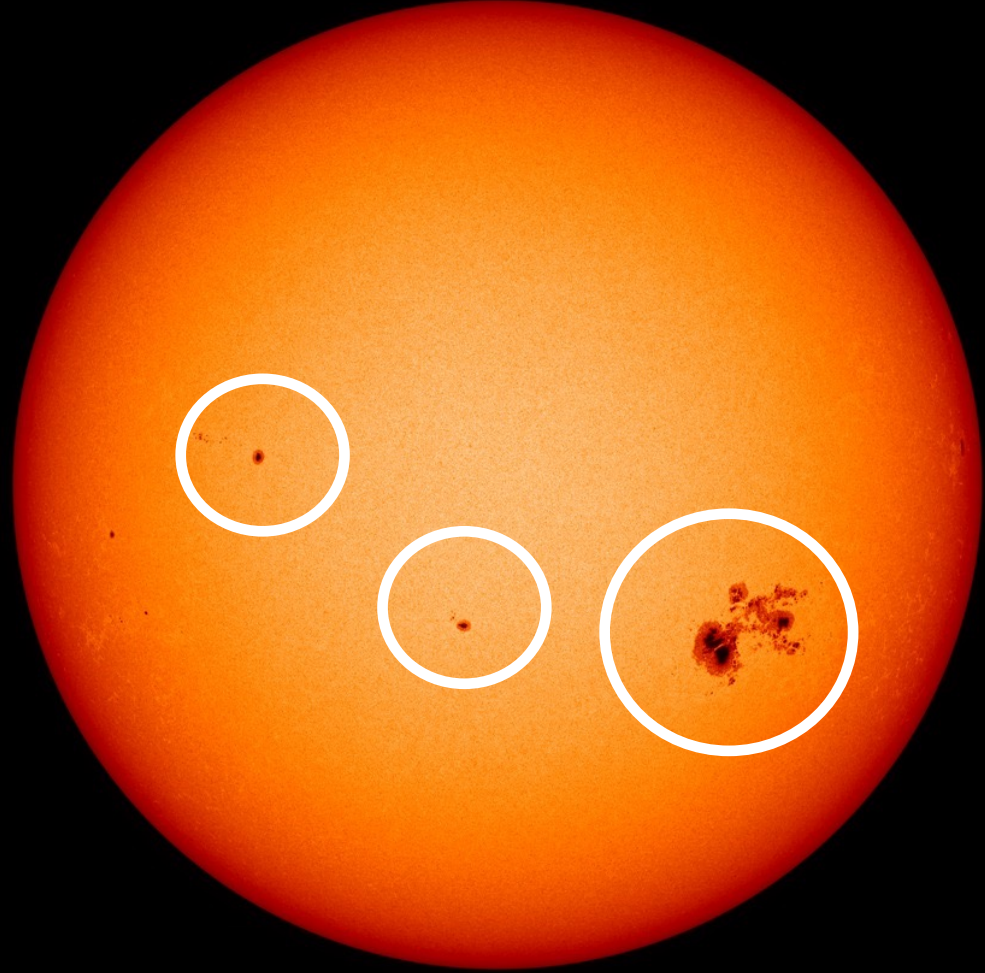
Shabnam Nikbakhsh

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



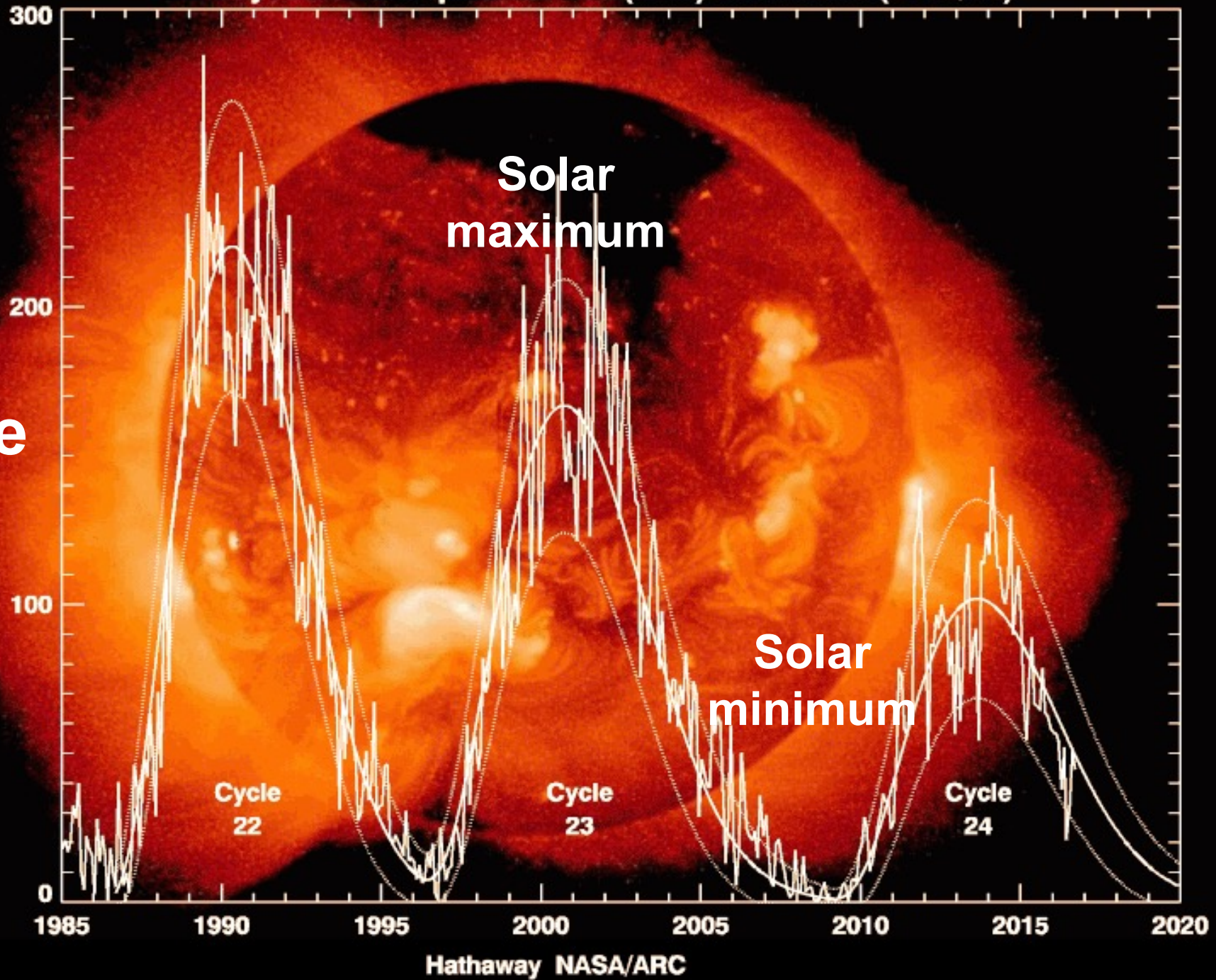
Video credit: ISS/NASA



Sunspot groups
Credit: SDO/NASA

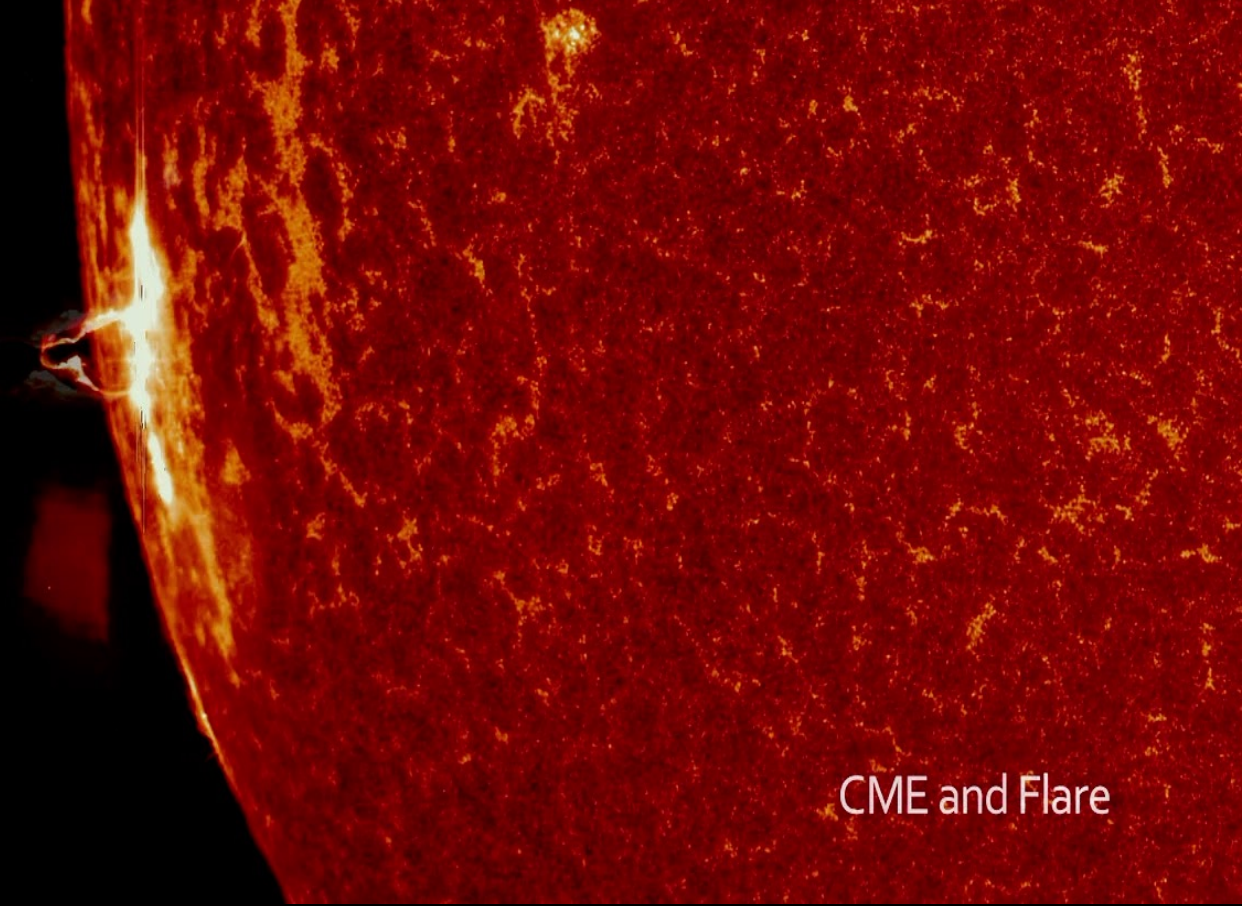
Cycle 24 Sunspot Number (V2.0) Prediction (2016/10)

Solar cycle



CME and flare

- Coronal mass ejections (CMEs) and solar flare are explosive phenomena that occur on the Sun
- Often occur together but they are not the same
- Often emerge from solar active regions

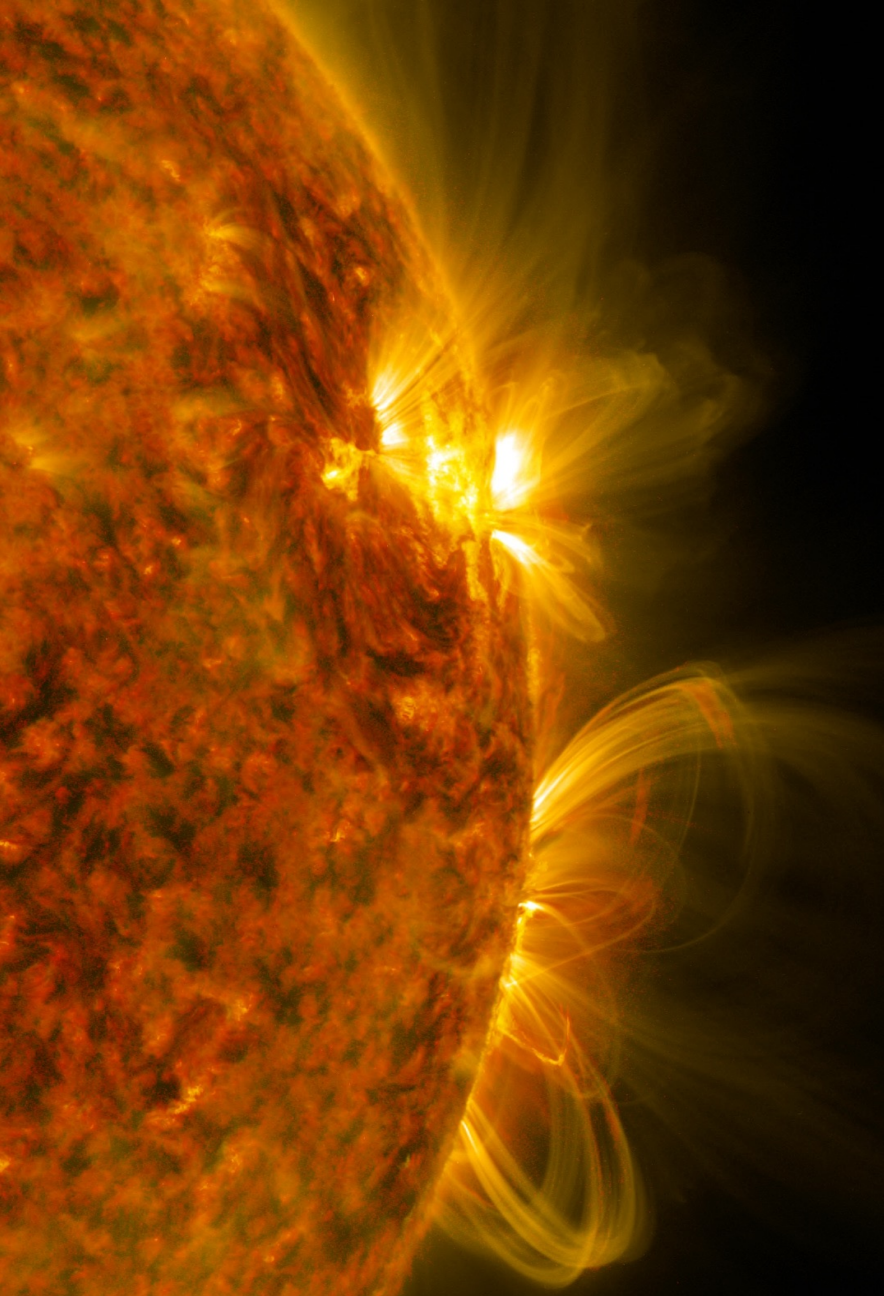


CME and Flare

Video credit: SDO/NASA

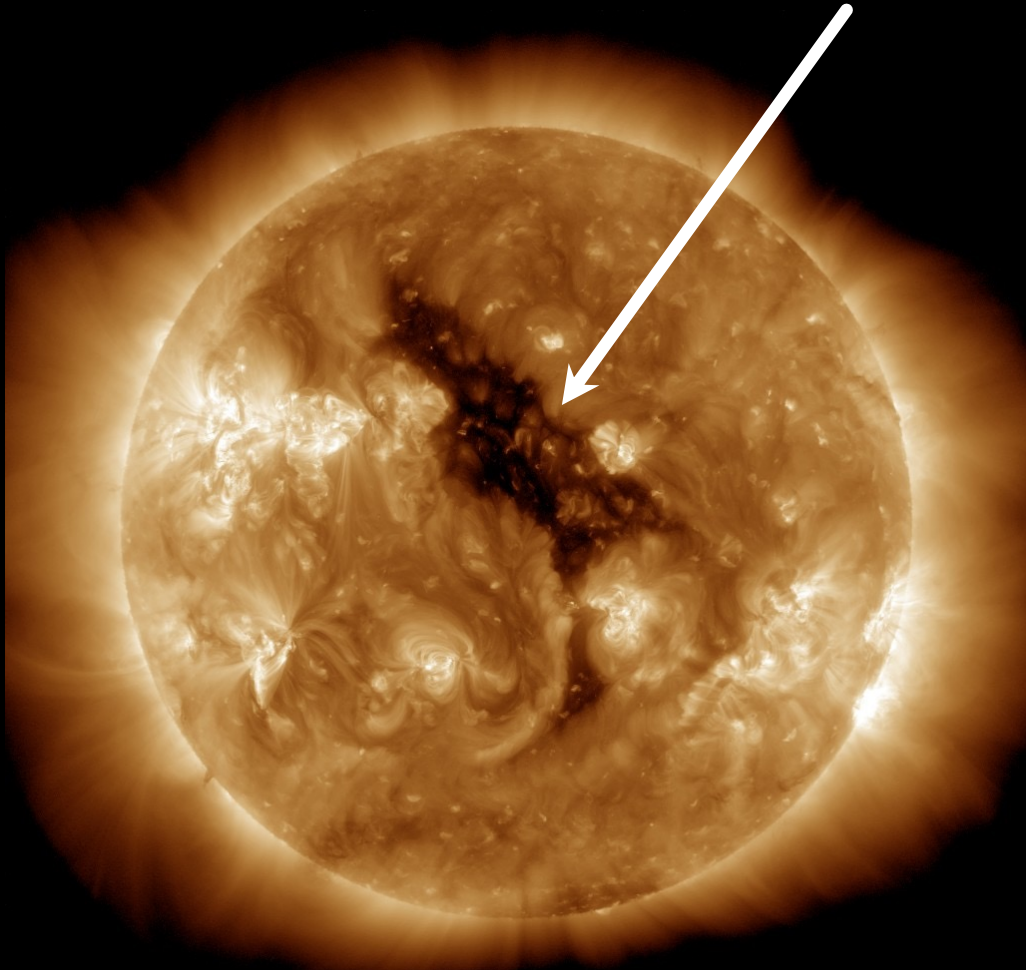
Solar Flare classification

- 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

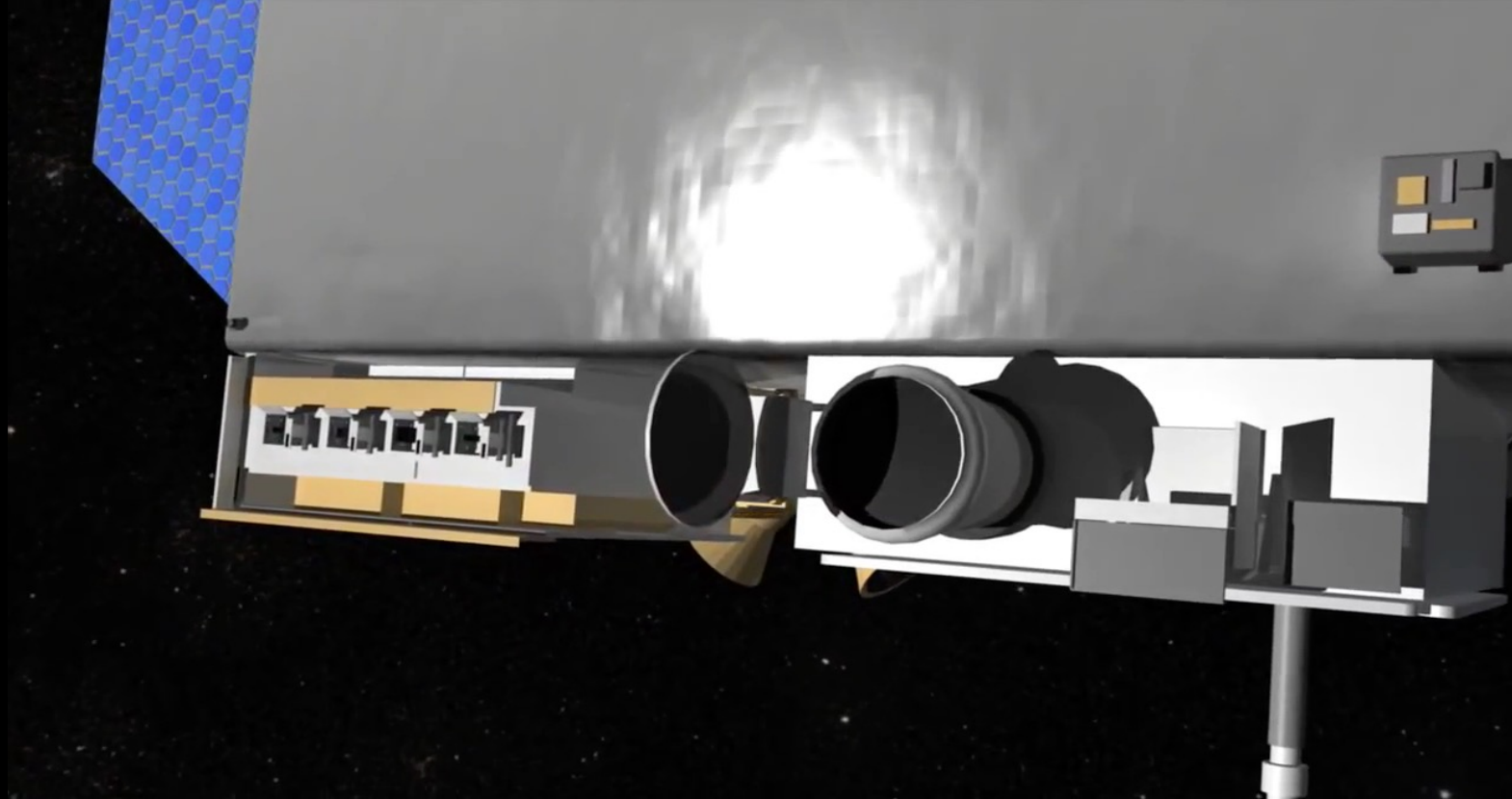


Sept. 10, 2017, X8.2-class solar flare observed by SDO. The video shows a blend of light from the 171- and 304-angstrom wavelengths.
Image credit: SDO/NASA

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

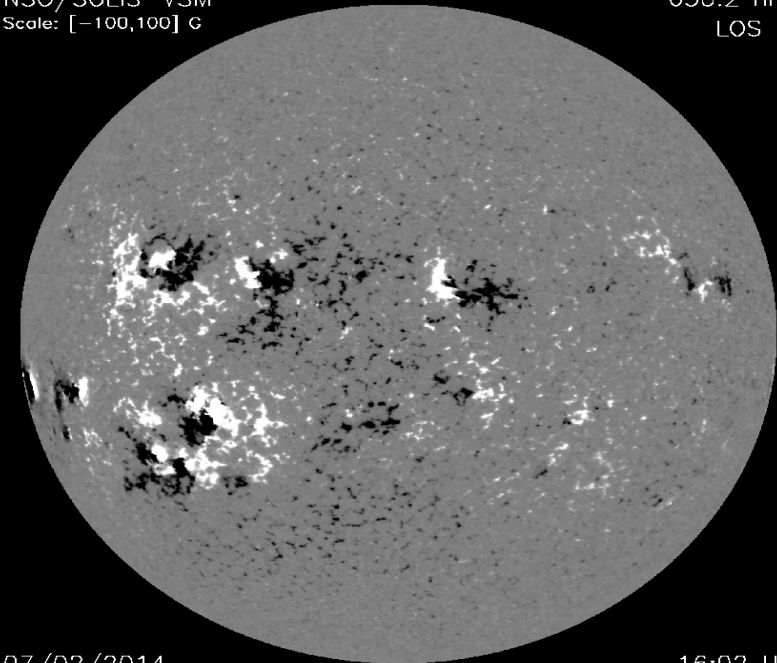
- Launched in : February 2010 Orbit: ~35,000 km
- HMI: Studies oscillation and magnetic field at photosphere
- AIA: Studies the sun in multiple wavelength (white light, Seven EUV & two UV)
 - EVE: Studies solar EUV irradiance

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

NSO/SOLIS-VSM
Scale: [-100,100] G

630.2 nm
LOS B



07/02/2014

16:02 UT

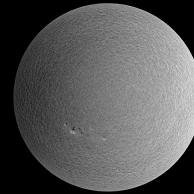
Magnetogram

07.02.2014

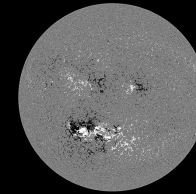
Iron spectral line at 8468 Å

Solar observations

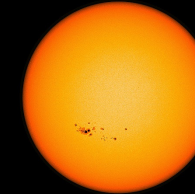
- Solar Cycle, sunspot, flare, CME, coronal holes
- Declining phase or minimum
- <https://heliviewer.org/>
- <https://solarmonitor.org/index.php>



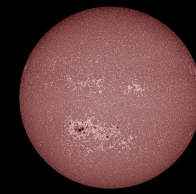
HMI Dopplergram
Surface movement
Photosphere



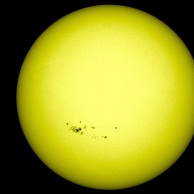
HMI Magnetogram
Magnetic field polarity
Photosphere



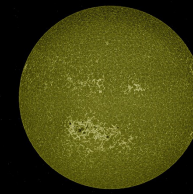
HMI Continuum
Matches visible light
Photosphere



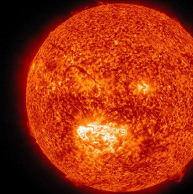
AIA 1700 Å
4500 Kelvin
Photosphere



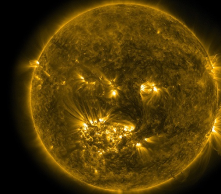
AIA 4500 Å
6000 Kelvin
Photosphere



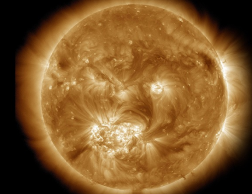
AIA 1600 Å
10,000 Kelvin
Upper photosphere/
Transition region



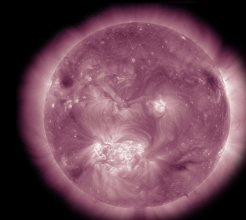
AIA 304 Å
50,000 Kelvin
Transition region/
Chromosphere



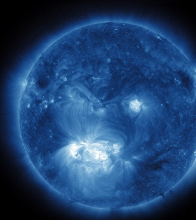
AIA 171 Å
600,000 Kelvin
Upper transition
Region/quiet corona



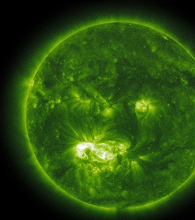
AIA 193 Å
1 million Kelvin
Corona/flare plasma



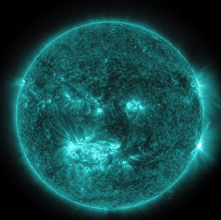
AIA 211 Å
2 million Kelvin
Active regions



AIA 335 Å
2.5 million Kelvin
Active regions



AIA 094 Å
6 million Kelvin
Flaring regions



AIA 131 Å
10 million Kelvin
Flaring regions

Helio viewer website

Helioviewer.org

2023/04/27 17:29:22 UTC ○ NEWEST

Jump: 1 Day

▼ Images + Add Layer ?

▼ AIA 304 2023/04/27 16:56:29 UTC

Opacity:

Observatory: SDO

Instrument: AIA

Measurement: 304

Difference: No difference ima

▼ Features and Events ?

▼ HEK 2023/04/27 17:29:22 UTC

check all check none

- Active Region
- Coronal Cavity
- Coronal Dimming
- Coronal Hole
- Coronal Jet
- CME
- Coronal Rain
- Coronal Wave
- Emerging Flux
- Eruption
- Filament
- Filament Activation
- Filament Eruption
- Flare

Data Sources

Earth Scale

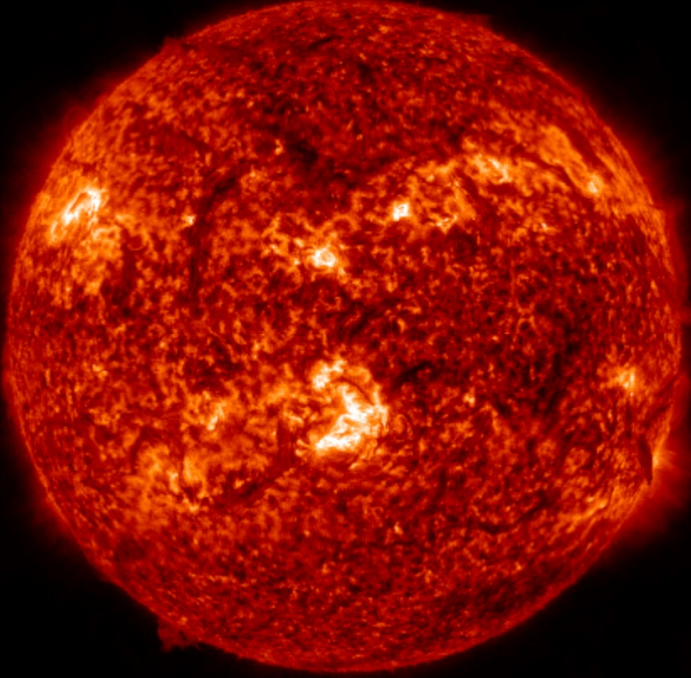


Image Timeline Events Timeline

Helio viewer website

Helioviewer.org

Observation Date: 2014/10/22 17:29:22 UTC NEWEST

Jump: October 2014

Images	Sun	Mon	Tue	Wed	Thu	Fri	Sat
HMI Mag	28	29	30	1	2	3	4
Obs	5	6	7	8	9	10	11
In	12	13	14	15	16	17	18
Meas	19	20	21	22	23	24	25
Features	26	27	28	29	30	31	1
HEK	2	3	4	5	6	7	8

- Active Region (25)
 - SPoCA (8)
 - HMI SHARP (13)
 - NOAA SWPC Observer (4)
- Coronal Cavity
- Coronal Dimming
- Coronal Hole (10)
 - SPoCA (10)
- Coronal Jet
- CME
- Coronal Rain
- Coronal Wave
- Emerging Flux (1)
 - Emerging flux region module (1)

AR NOAA 12194 $\beta\gamma$

AR NOAA 12192 $\beta\gamma$

AR NOAA 12193 $\beta\gamma$

AR NOAA 12187 $\beta\gamma$

Earth Scale

Image Timeline Events Timeline

Date Search

27 April 2023

NOAA Search

←20230426 ←Week ←Rotation

Today

Rotation⇒ Week⇒ 20230428⇒

Main

Far-side

SDO short-wave

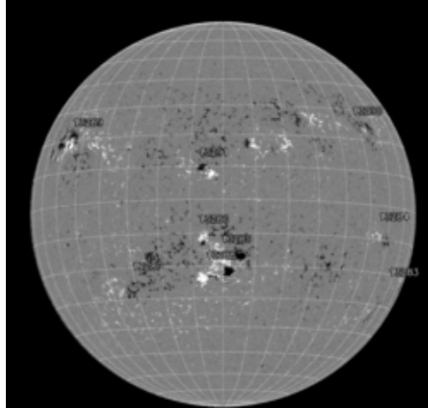
SDO long-wave

NOAA
9 Active
Regions

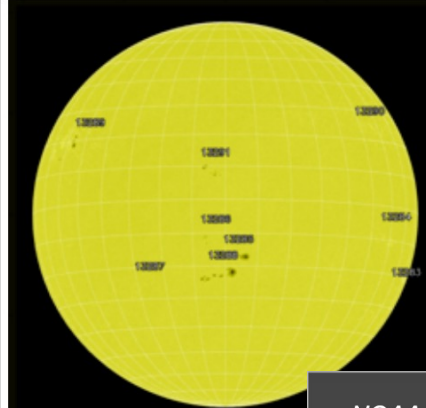
Flare
Forecast

Coronal
Holes

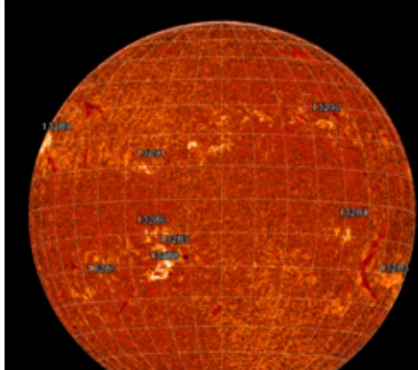
HMI Mag 20230427 13:58



HMI 6173Å 20230427 14:34



GHN Hα 20230426 06:04



GOES
ACE
SDO/EVE
Events

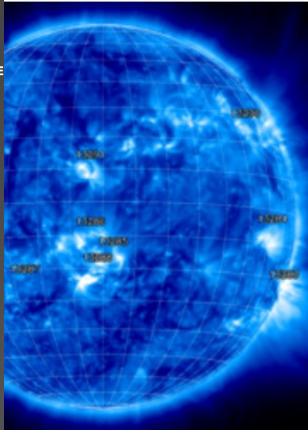
Today's/Yesterday's NOAA Active Regions

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	-

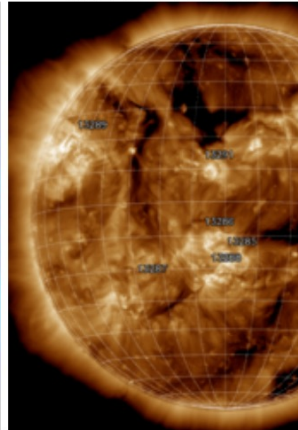
Class (HH:MM) -Today

Class (HH:MM) -Yesterday

CHIMERA 174Å 20230427 12:37



AIA 193Å 20230427



www.SolarMonitor.org

Date Search 27 April 2023 NOAA Search

←20230426 ←Week ←Rotation Today Rotation⇒ Week⇒ 20230428⇒

NOAA 9 Active Regions

Flare Forecast

Coronal Holes

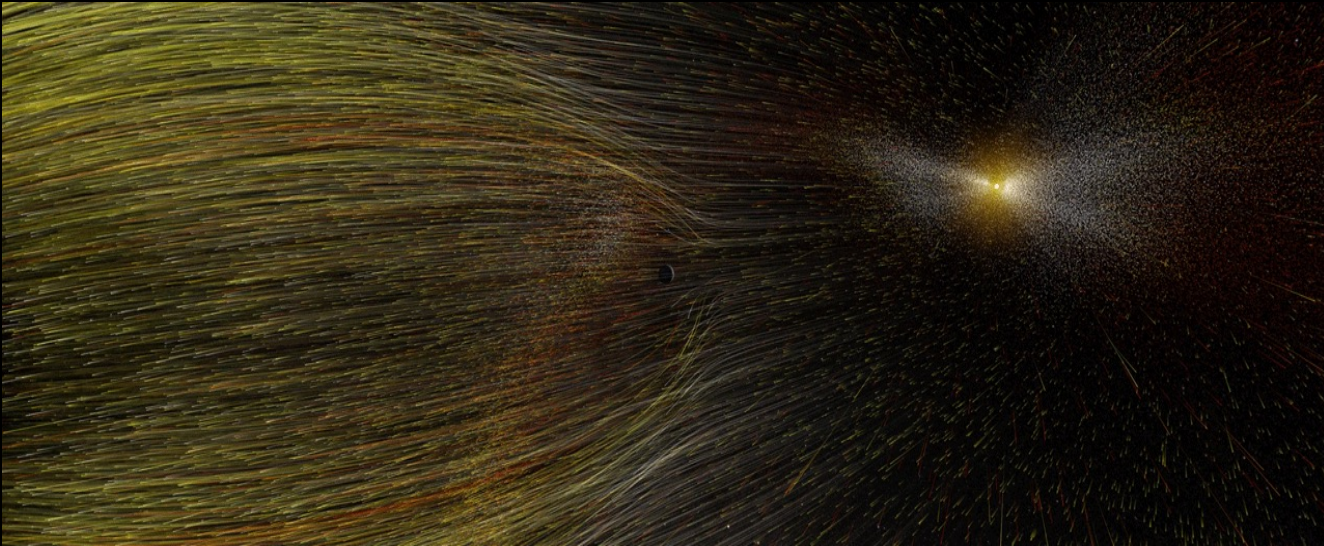
CHIMERA Coronal Holes at 27-Apr-2023 15:24:40.843 UT

GOES ACE SDO/EVE Events

SolarMonitor.org

X (arcsecs)

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

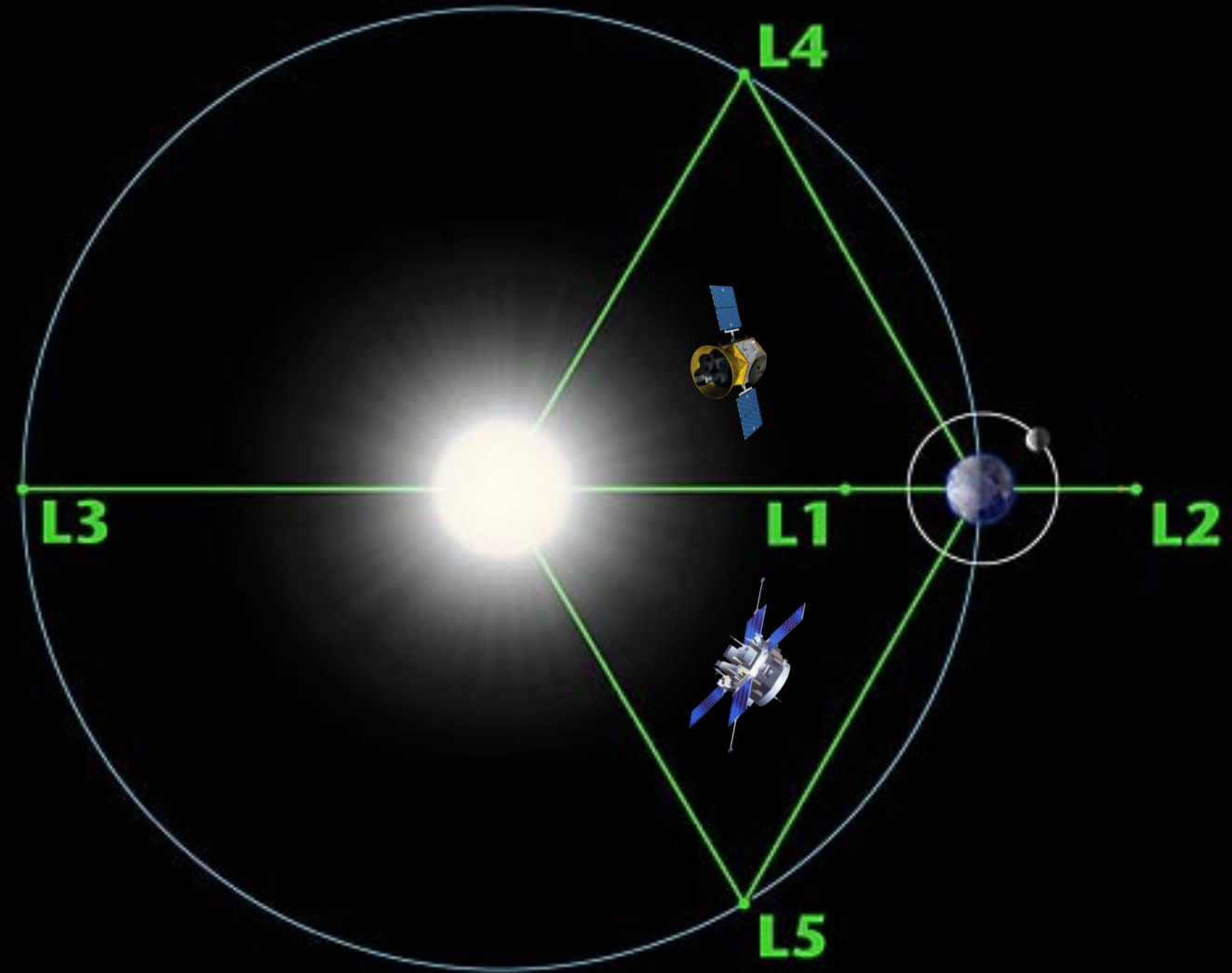
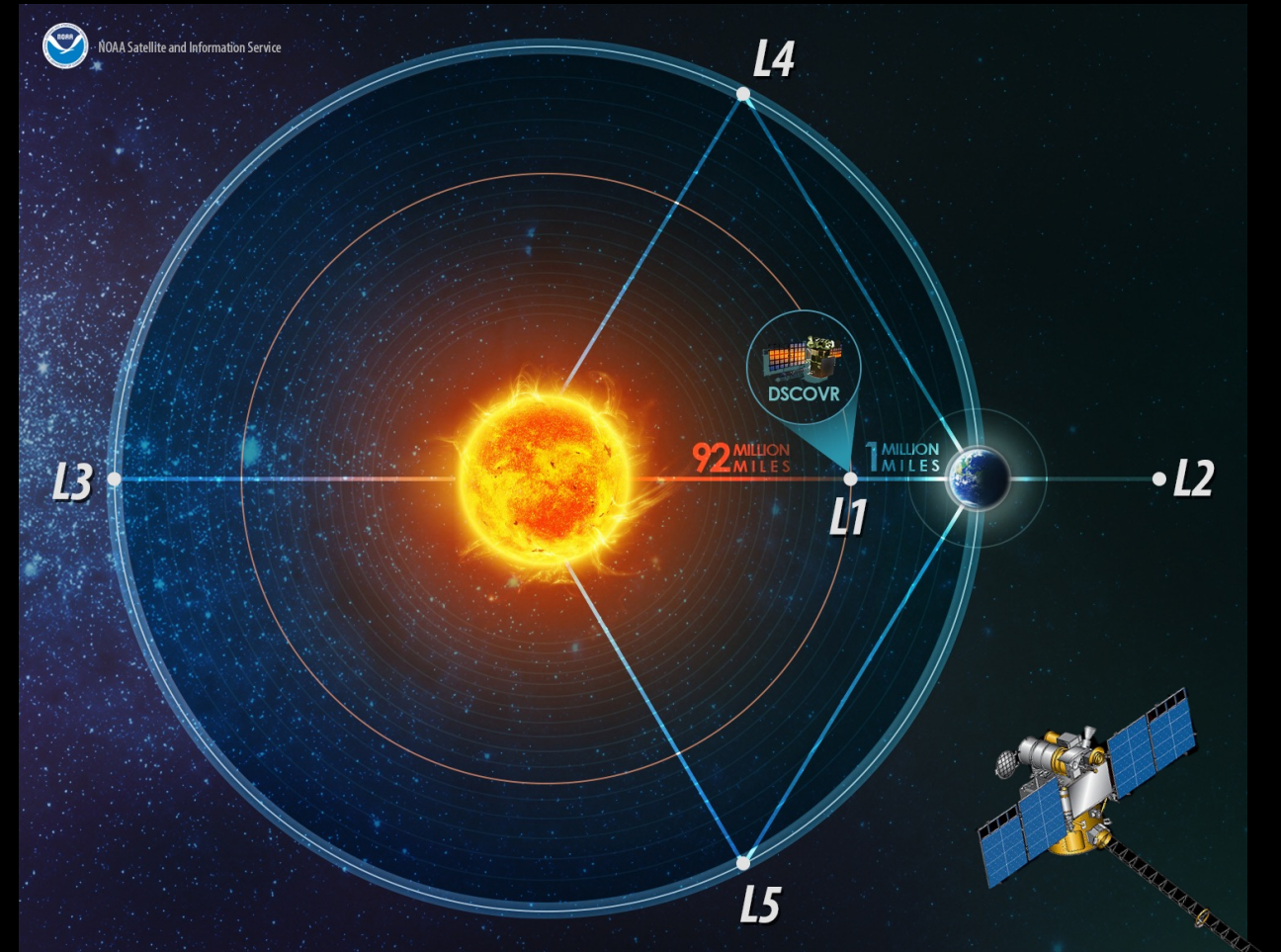


Image credit: NASA/WMAP Science Team

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

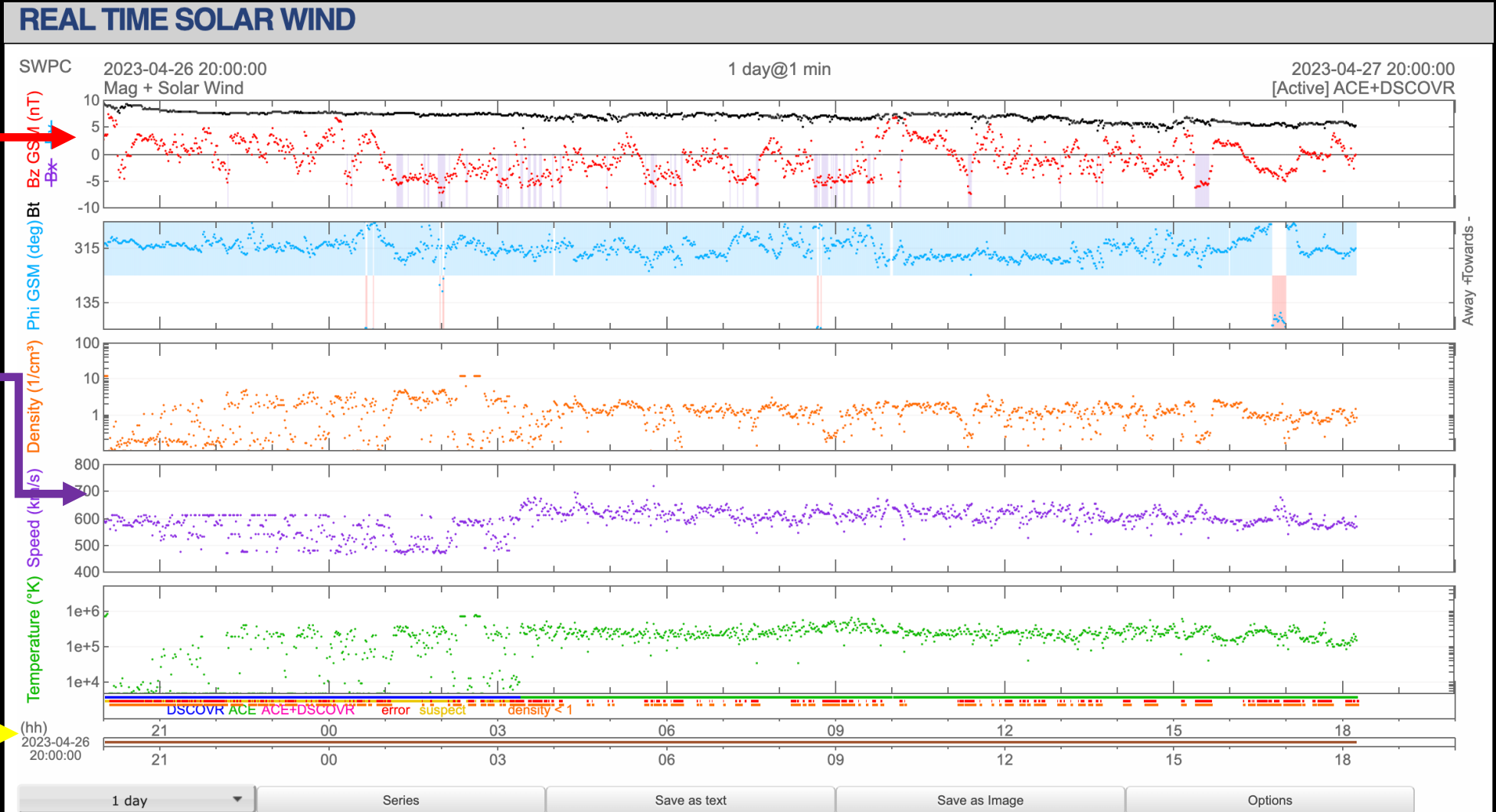


What to look

Z
component
of the
solar wind
magnetic
field

Solar wind
Speed

Note
Coordinated
Universal
Time (UTC)



You can also find DSCOVR data at this website:

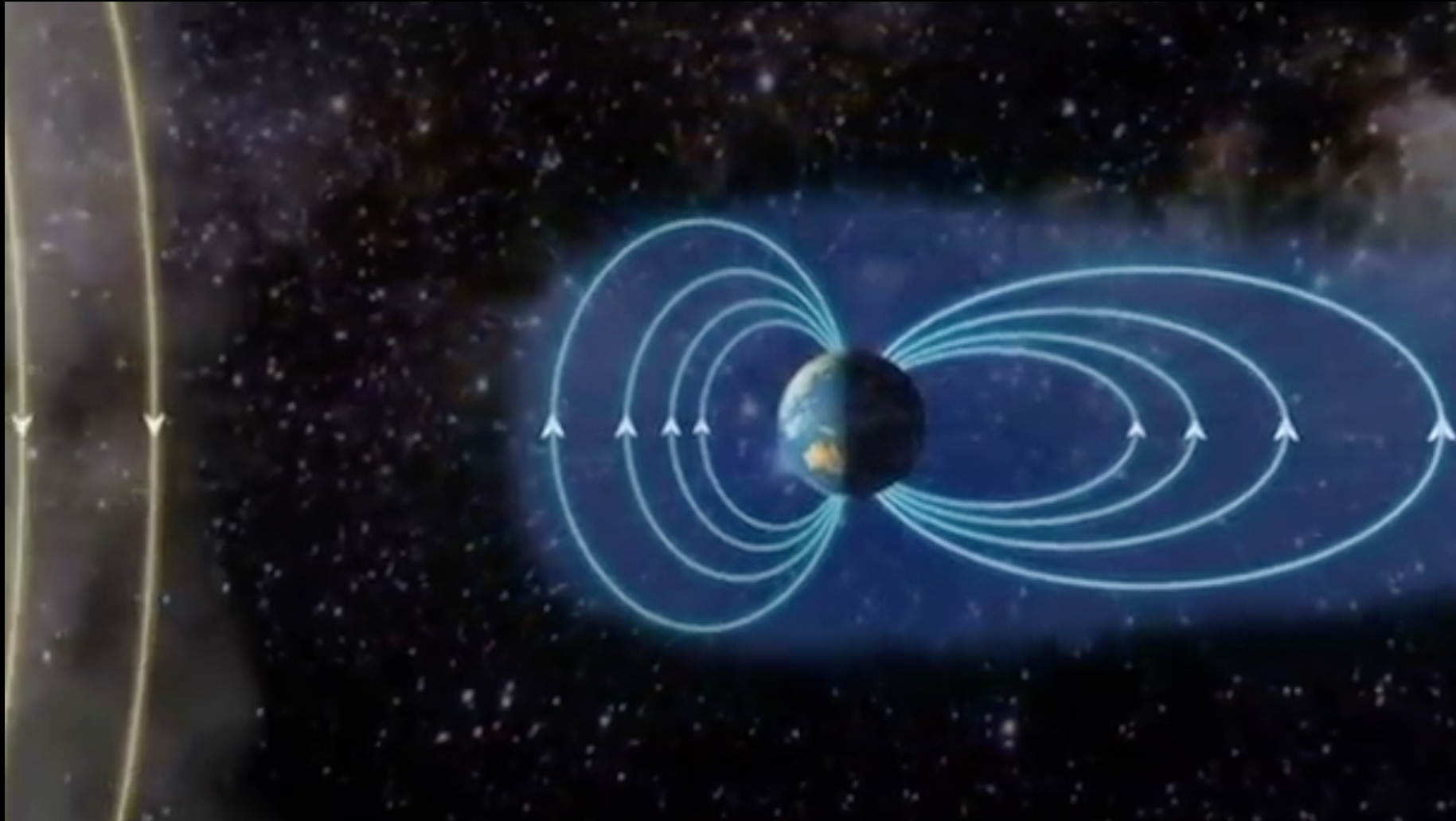
- Space Weather website
<http://spaceweather.com/>

The screenshot shows the homepage of spaceweather.com. At the top, there is a navigation bar with links for 'AURORA ALERTS', 'SUBMIT YOUR PHOTOS', 'CONTACT US', 'SUBSCRIBE', 'FLYBYS', and 'EARTH TO SKY'. A search bar for 'Subscribe to SpaceweatherNews' is also present. The main content area is divided into several sections:

- Current Conditions:** This section provides real-time solar data. A green arrow points to the 'Solar wind' data, which includes a speed of 320.9 km/sec and a density of 12.1 protons/cm³. It also lists X-ray Solar Flare activity for the 6-hour and 24-hour periods.
- Daily Sun: 03 Mar 18:** This section features a large orange circle representing the sun, with a sunspot labeled '2700'. Below it, text describes sunspot AR2700 and its state of decay.
- Sunspot number: 11:** This section provides the current sunspot number and a link to learn more about sunspot numbers.
- Spotless Days:** This section shows statistics on the number of days without sunspots for the current year and previous years.
- What's up in space:** This section contains news articles. One article, 'Lights Over Lapland', mentions two aurora webcams. Another article, 'GEOMAGNETIC OUTLOOK', discusses Earth's magnetic field. A third article, 'VENUS-MERCURY CONJUNCTION', describes the planets' positions in the sky. Below the text is a photograph of a sunset with Venus and Mercury visible in the sky, and a silhouette of a saguaro cactus in the foreground.

On the right side of the page, there are several promotional banners and a sidebar with 'archives' for the month of March 2018.

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 creates the magnetic field
- The Earth is surrounded by a complex system formed by the interaction of the solar wind with the Earth's magnetic field
- The solar wind compresses the sunward side of the magnetosphere to a distance of $\sim 10 R_{\oplus}$ and its nightside to possibly $1000 R_{\oplus}$
- The magnetosphere is highly dynamic

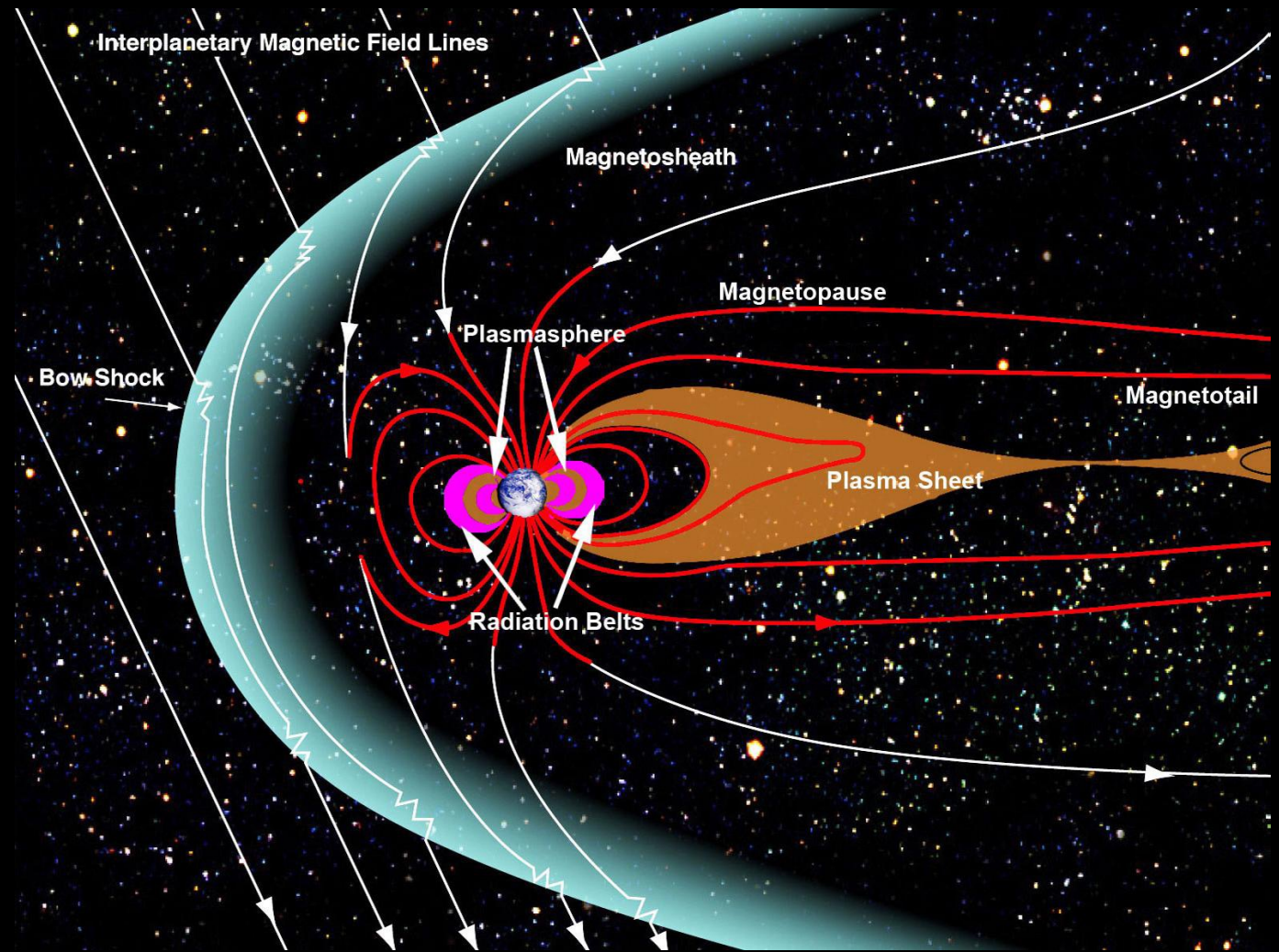


Image credit: NASA

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

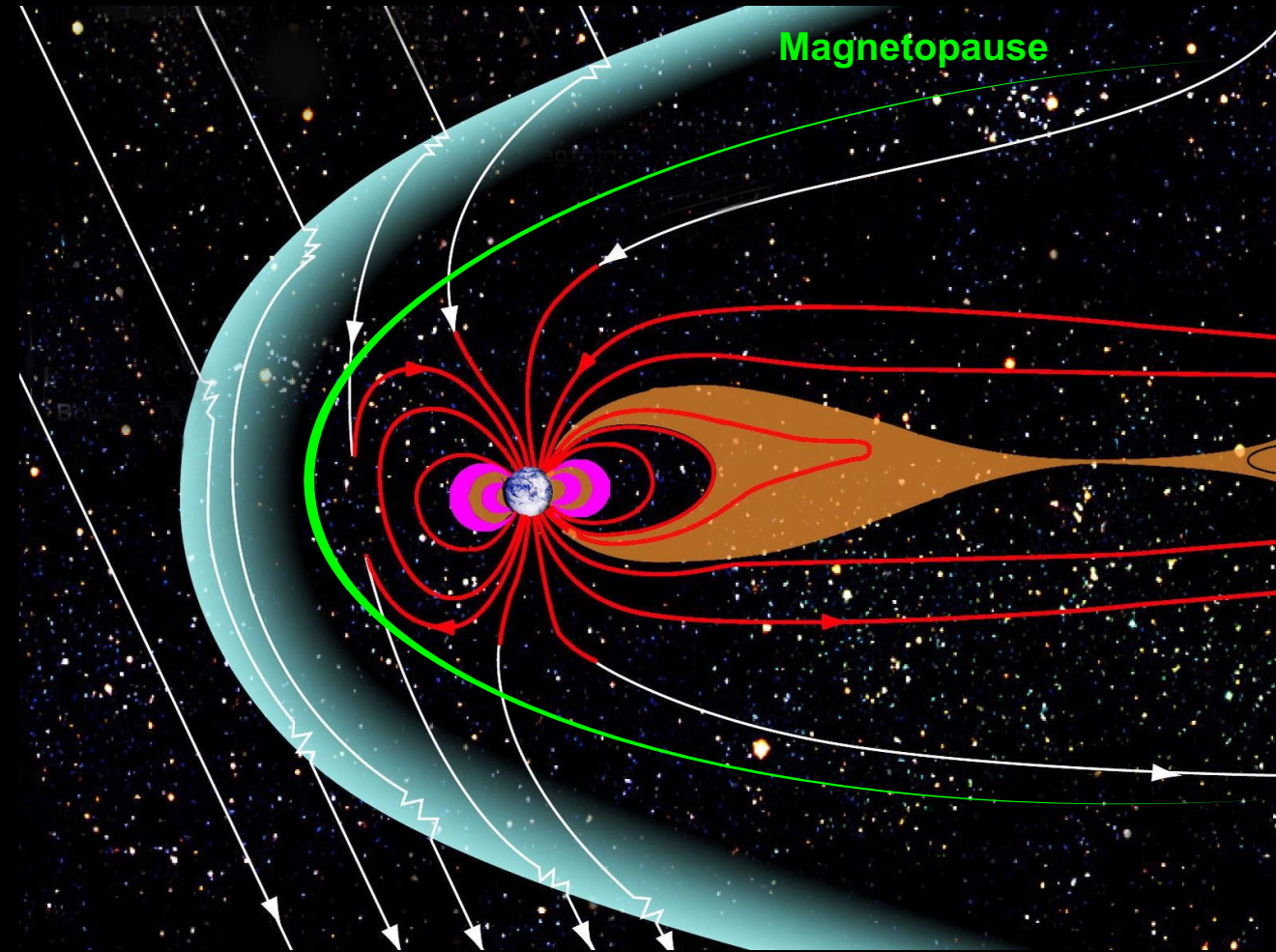


Image credit: NASA/Goddard

Estimate the magnetopause location

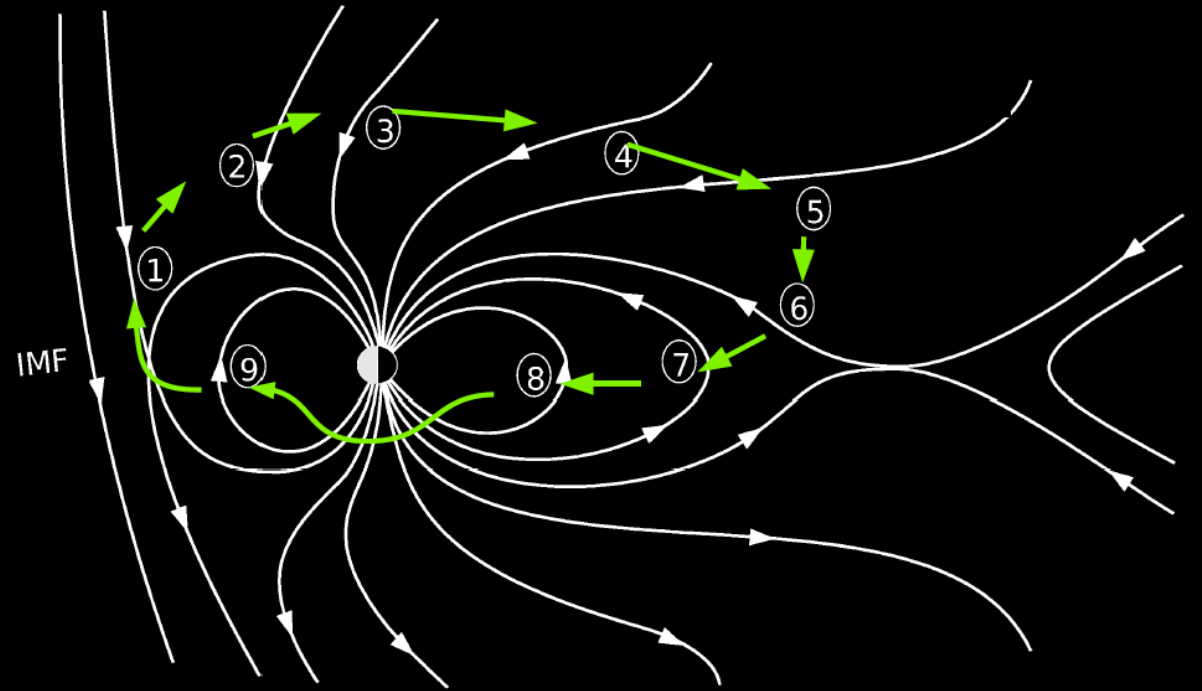
- Remember we are dealing with solar wind which is carrying magnetic field and charged particles
- So the total the pressure will be:

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

- Now read again the definition of the magnetopause
- Note: Inside the magnetopause, $B_{\text{inside}} \sim 2B_{\text{dipole value}}$

Consider the Dungey Cycle

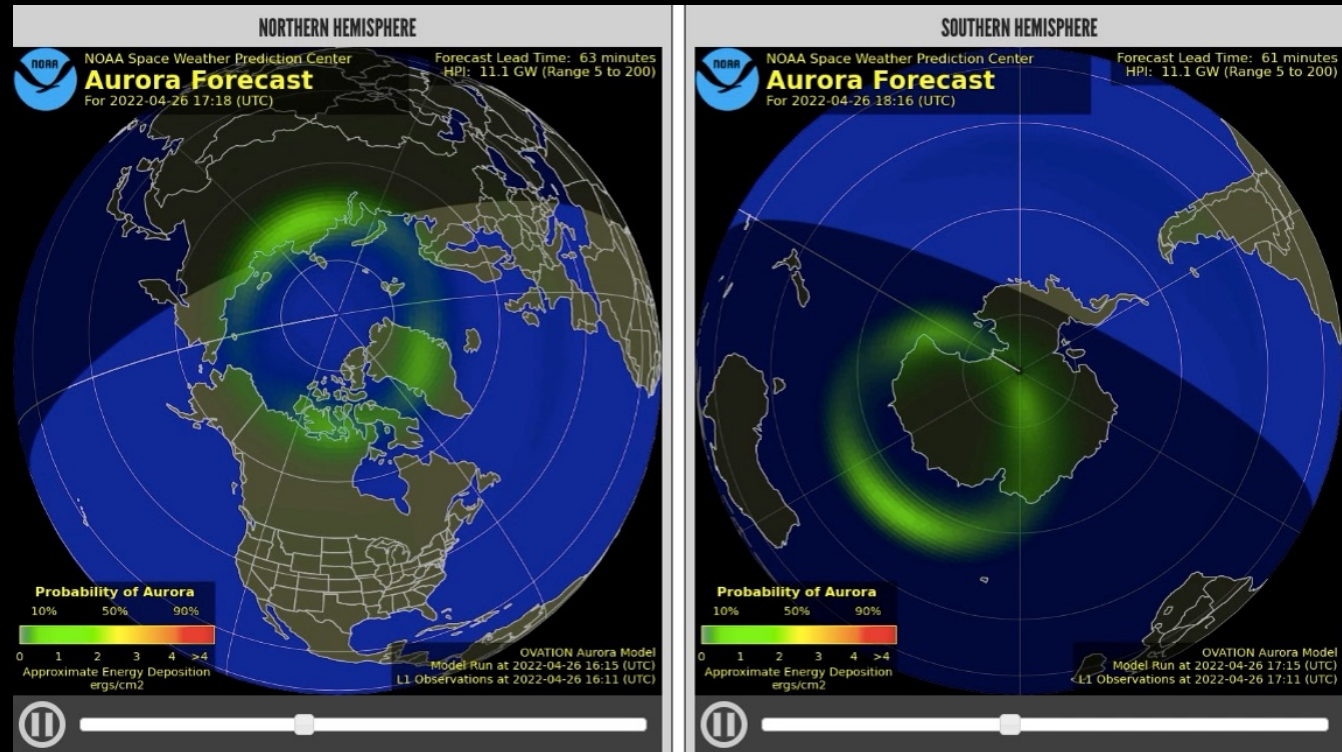
- If IMF has a southward component
- Magnetic reconnection opens the dayside magnetopause
- IMF connects to the Earth magnetic field
- Solar wind flow around the magnetosphere drives a global convective motion



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>

World Data Center for Geomagnetism, Kyoto
Our website is now always-on SSL; http access will be redirected to https.
<http://wdc.kugi.kyoto-u.ac.jp/> --> <https://wdc.kugi.kyoto-u.ac.jp/> (April 1, 2022)

operated by
Data Analysis Center for Geomagnetism and Space Magnetism
Graduate School of Science, Kyoto University
Kitashirakawa-Oiwake Cho, Sakyo-ku
Kyoto 606-8502, JAPAN

TEL: +81-75-753-3929 (075-753-3929, inside Japan)
FAX: +81-75-722-7884 (075-722-7884, inside Japan)

Home Page | WDC for Geomag, Kyoto | E's magnetic field? | Data Service | I-Magnet | Link

- 1. World Data Center for Geomagnetism, Kyoto**
Data Analysis Center for Geomagnetism and Space Magnetism,
Research, Publication list, Staff, Access Guide and Map, WDC system and others
- 2. What is the Earth's magnetic field?**
Magnetic north, geomagnetic and magnetic pole, Geomagnetic elements,
Geomagnetic field observation and collection of the data (Geomagnetic observatories on the Google Earth),
International Geomagnetic Reference field and others
- 3. Geomagnetic Data Service**
Indices, Geomagnetic Field Data at the Observatories, Models, Data Catalogue and others
- 4. INTERMAGNET Kyoto GIN Home Page**
QL monitor of INTERMAGNET data, about INTERMAGNET and others
- 5. Link to other sites**
Kyoto University, ICSU/WDS's, Geomagnetic Observatories, Societies and others

Ring current

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

- 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

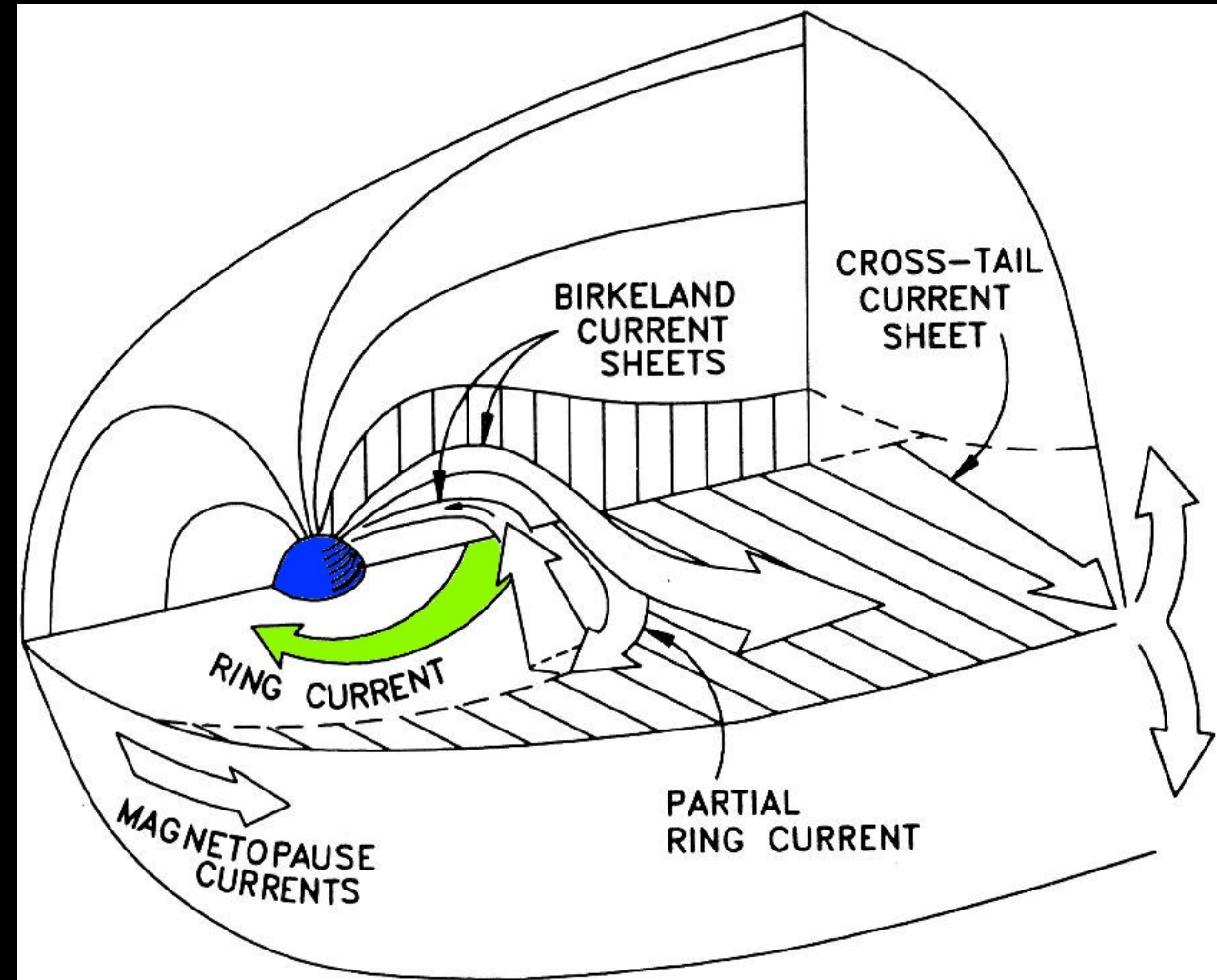


Illustration credit: David P. Stern

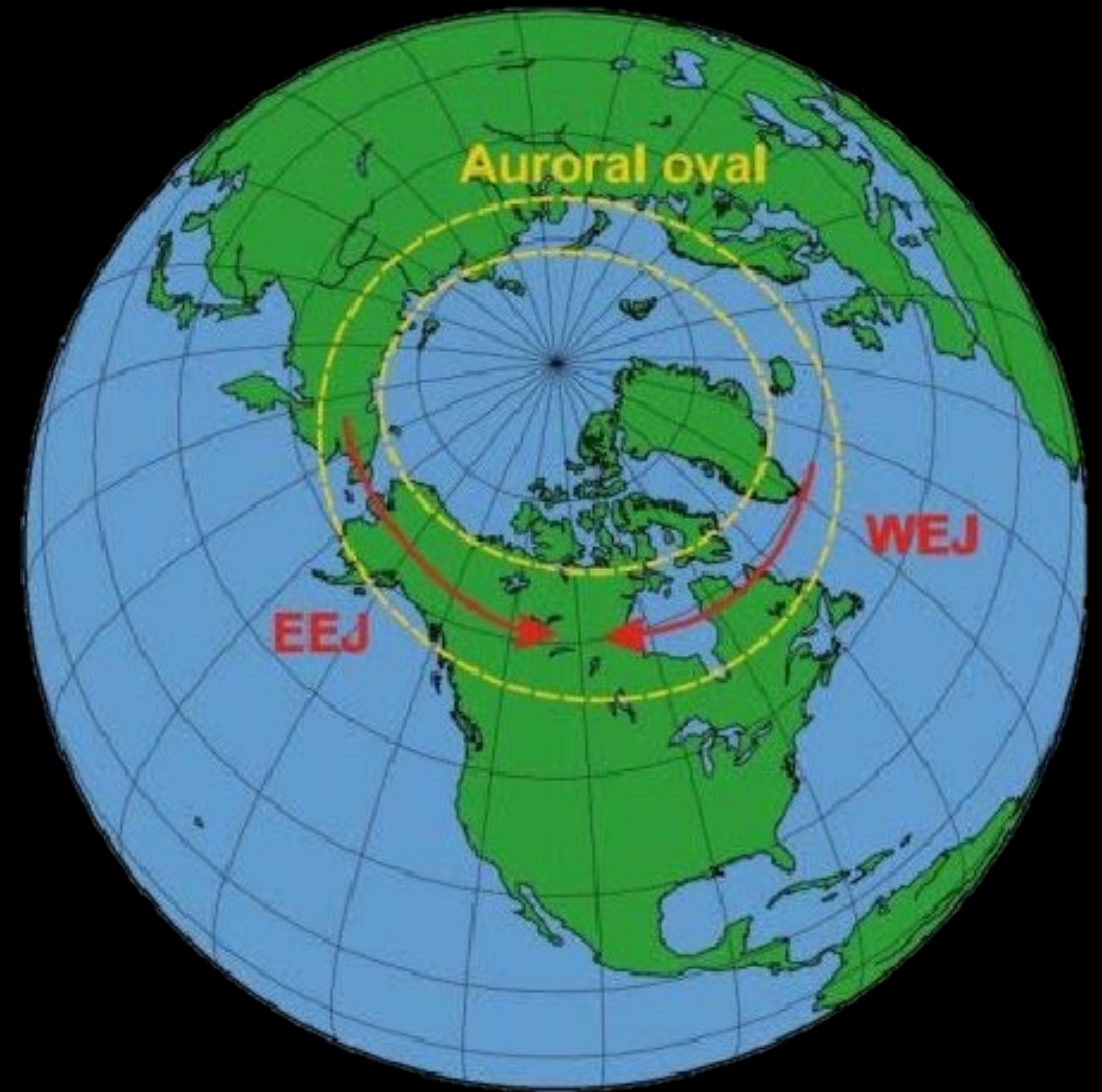


WDC for Geomagnetism, Kyoto
Hourly Equatorial Dst Values (FINAL)
MARCH 2015

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
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
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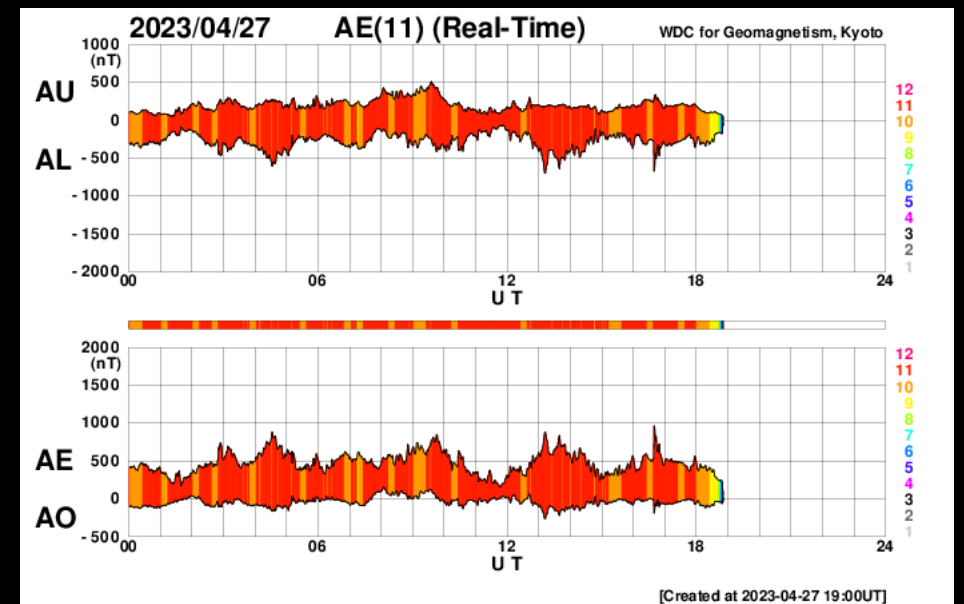
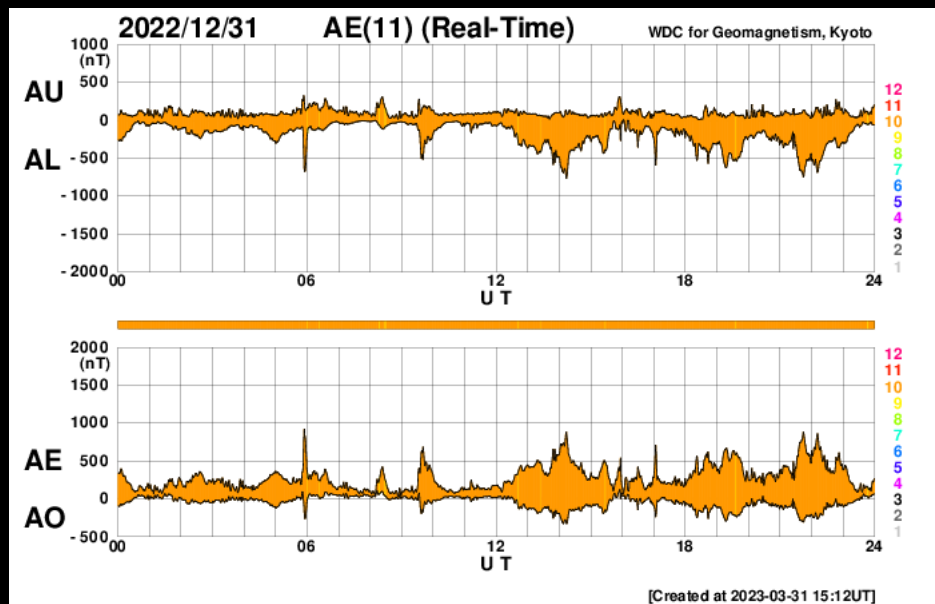
Auroral Electrojets

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



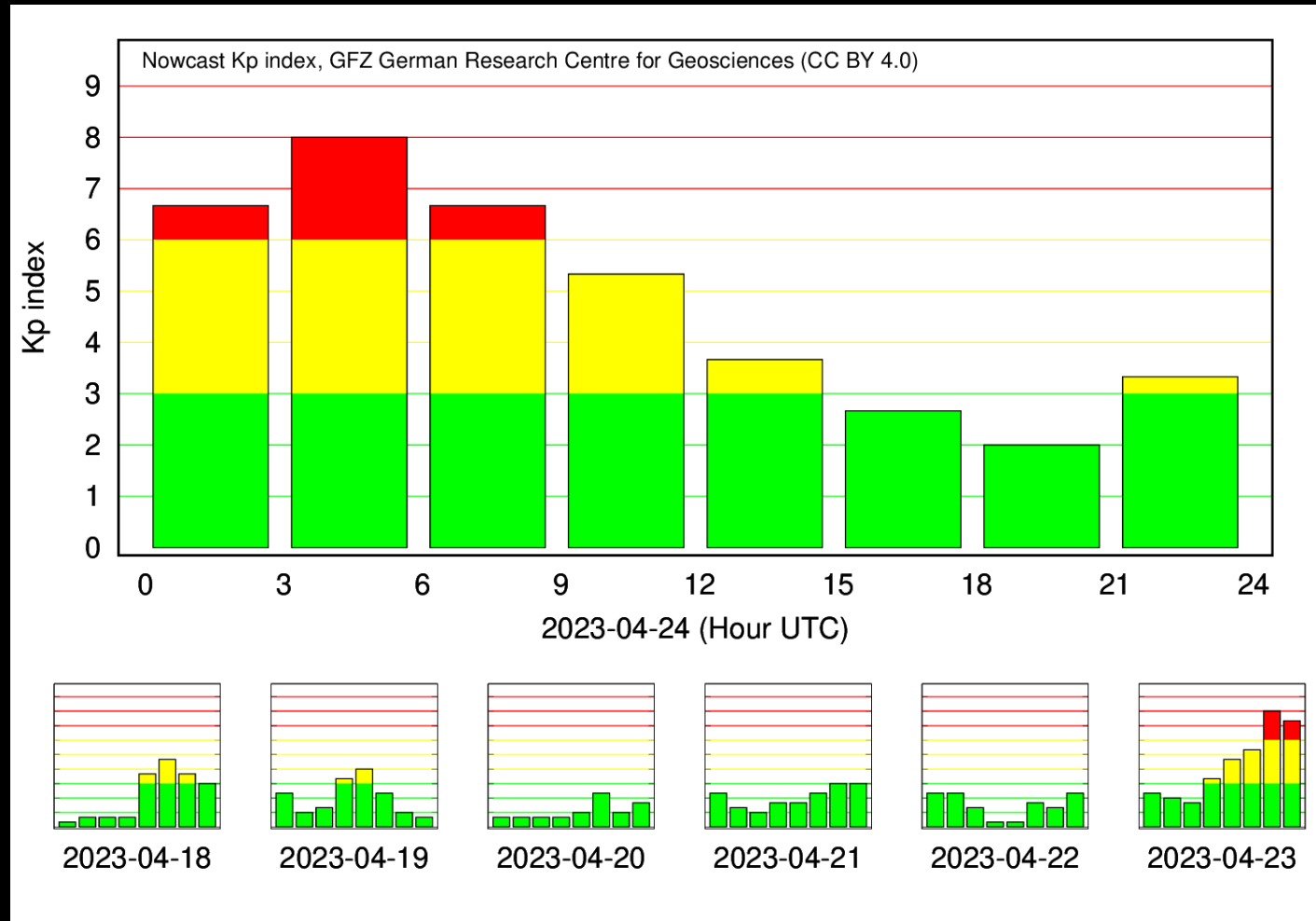
Representation of the East (EEJ) and West (WEJ) auroral electrojet
Image credit: Piccinelli et al. 2014

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>




All sky camera

Longyearbyen all-sky camera

National Institute of Polar Research

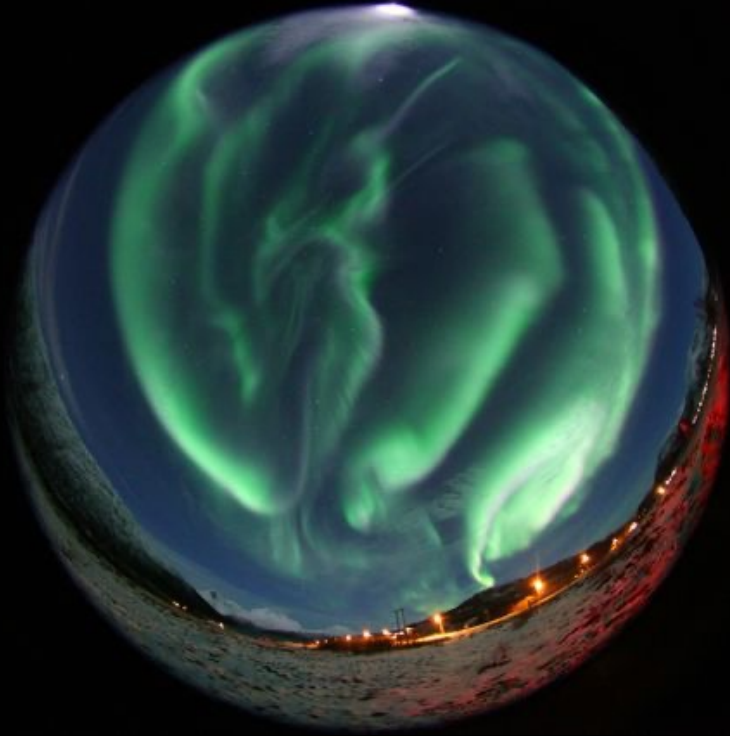


ScreenCast-O-Matic.com

2013/03/02
18:50'10" 

- 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 fish-eye lenses or spherical mirrors to acquire an image of the whole sky in one shot

All sky camera data



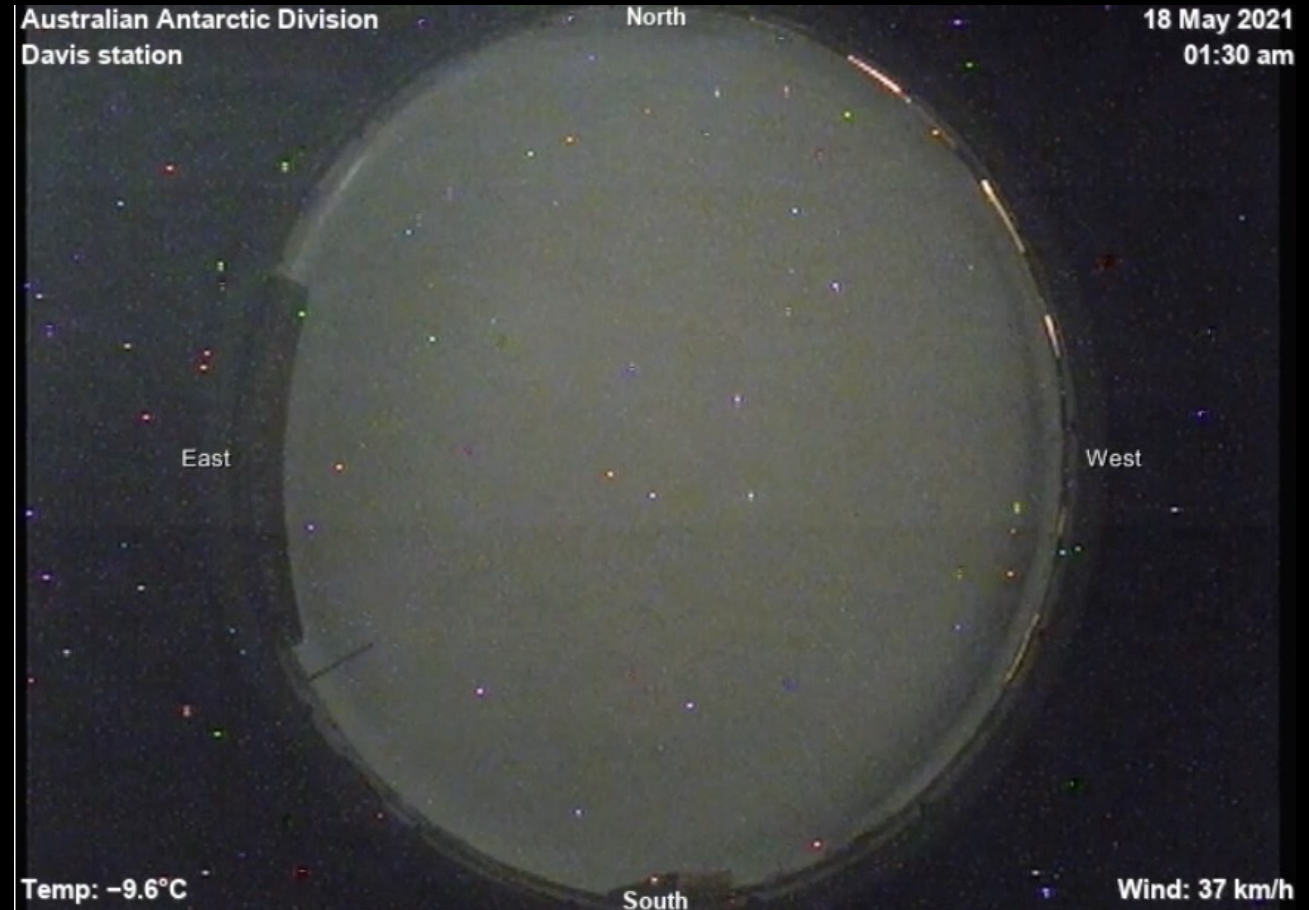
Tromsø, Norway
Oct. 27, 2010

Photo Credit: Terence Murtagh & Nicholas
Cades Observatory, Kingston, TAS, Australia
Holdsworth

- 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/~acauro/auro/a/Syowa/> **Not working!**

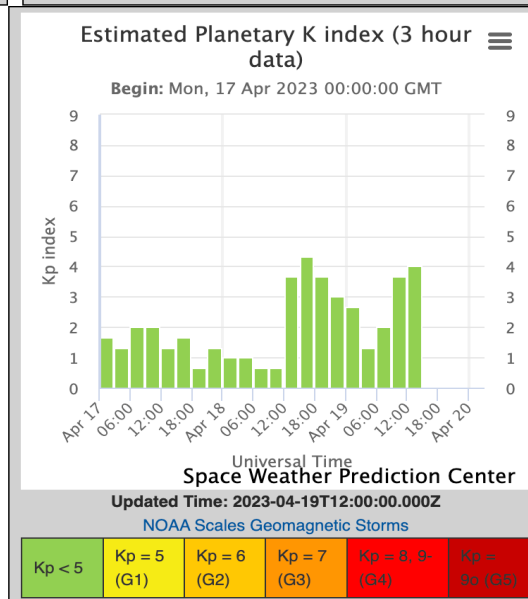
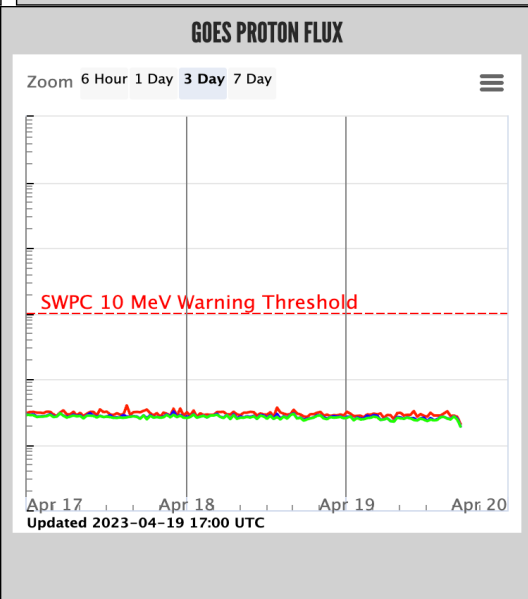
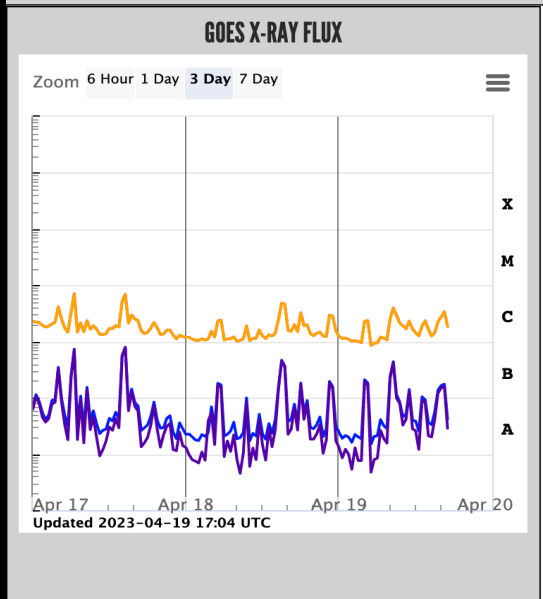
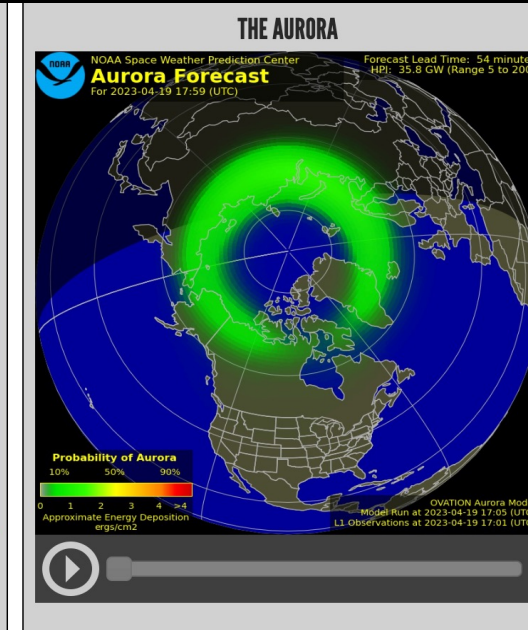
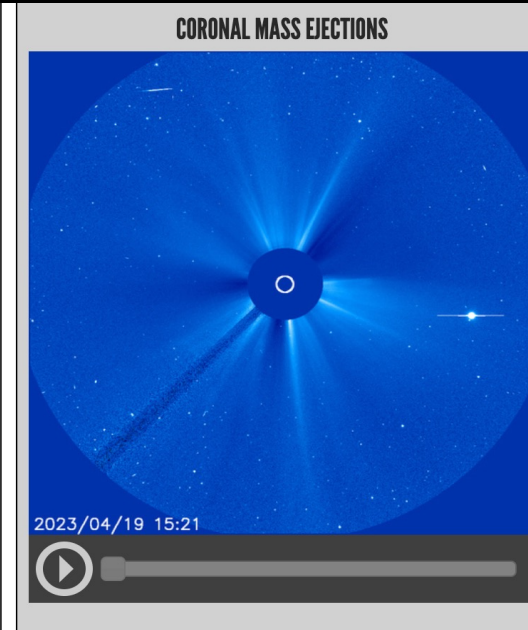
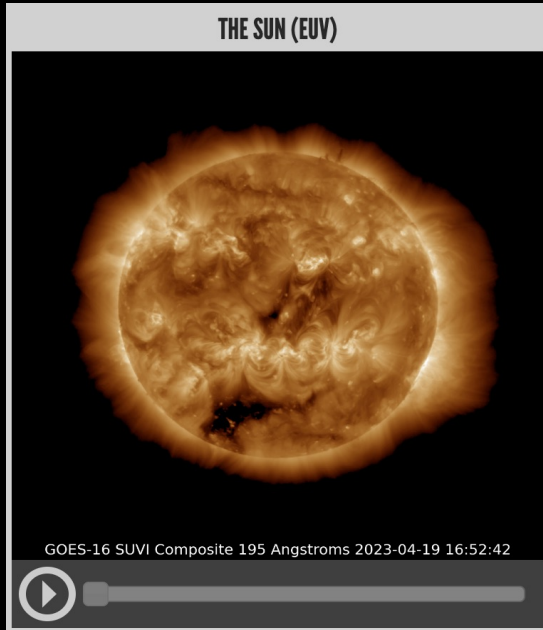
Davis Station Sky-cam

- Davis station is one of the permanent research center in Antarctica
- Operated by Australian Antarctic Division
- Coordinates: $68^{\circ} 34' 36''$ S, $77^{\circ} 58' 3''$ 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



Summary of what you need to report

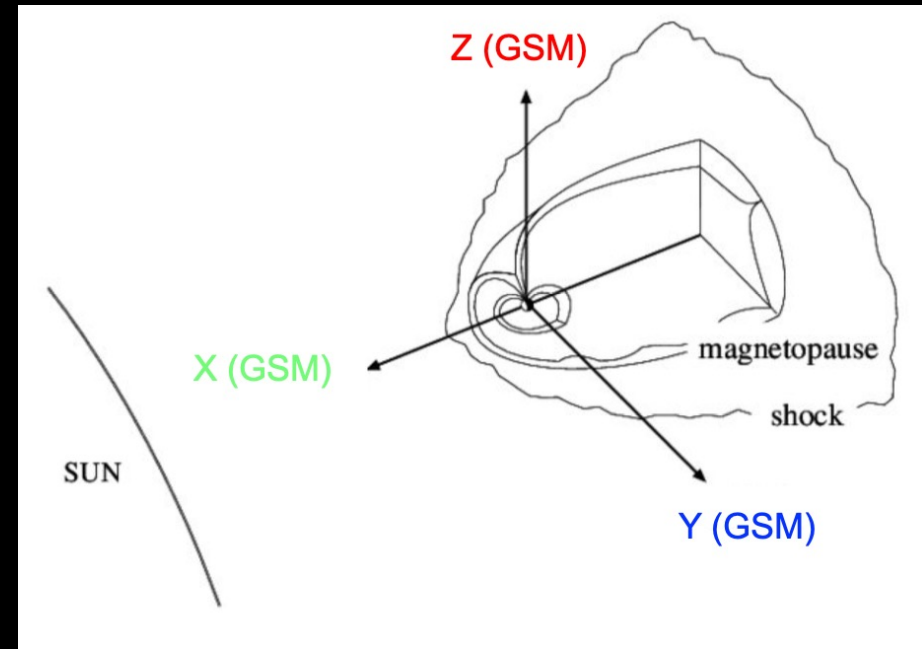
i. Theory

- **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