Space Climate

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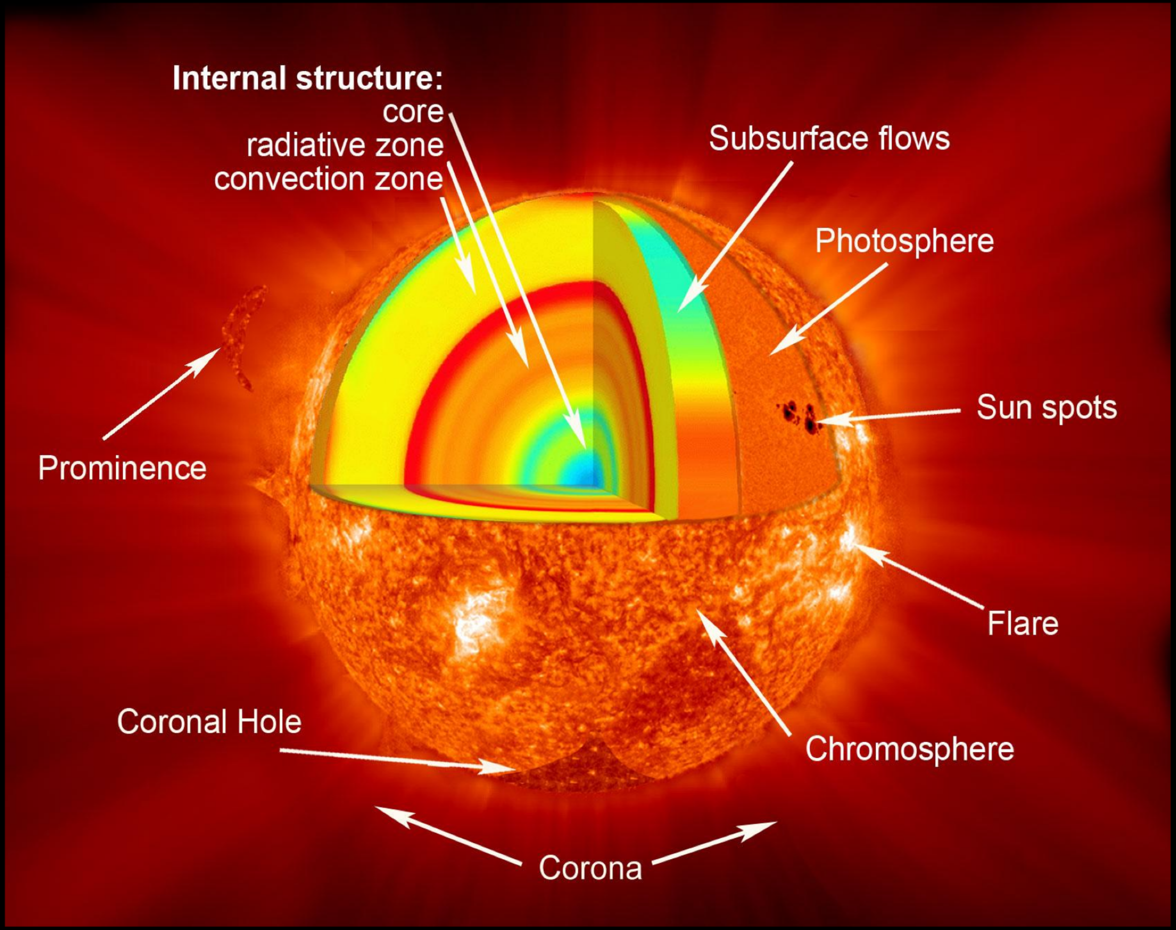
The Sun



$R_{\odot}$ = 695,700 (km)

Core:
- Nuclear fusion process H → He
- Temp: ~15 Million Kelvin, radius: ~0.2 to 0.25 $R_{\odot}$

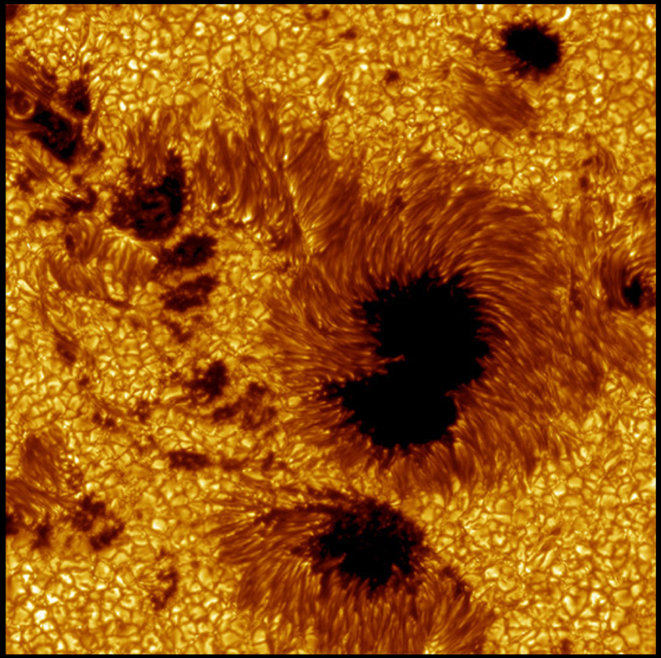
Radiation Zone:
- Energy moves outward as electromagnetic radiation
- Temp: ~8 MK, radius: ~300,000 km

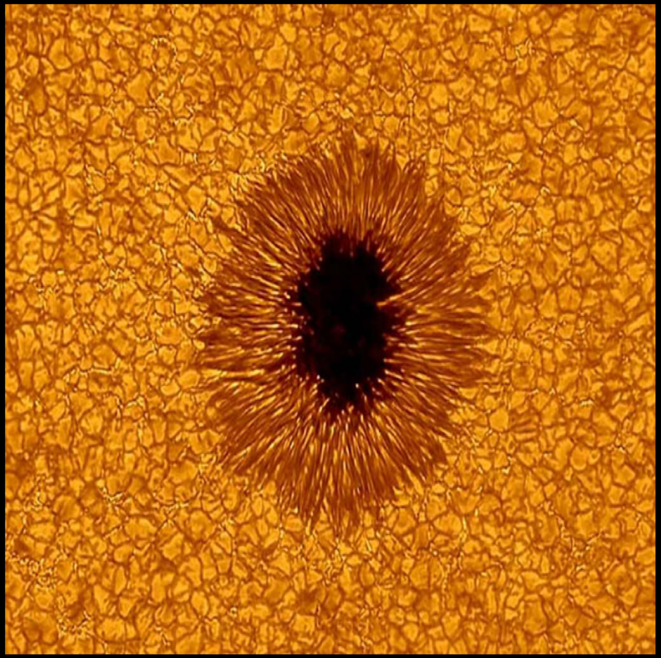
Convection Zone:
- Consist of plasma, generates magnetic field
- ~200,000 km, 30% of the radius

Photosphere:
- Visible surface, Radius: ~500 km thick, T: 5800 K
- Features can be seen in this layer: Active regions, sunspots, bright faculae, granules

Chromosphere:
- ~10,000 km thick
- Features can be seen in this layer: filaments or prominences, spicules

Corona:
- Extremely hot (over 1,000,000 kelvin) but tenuous plasma $<10^9$ cm^{-3}



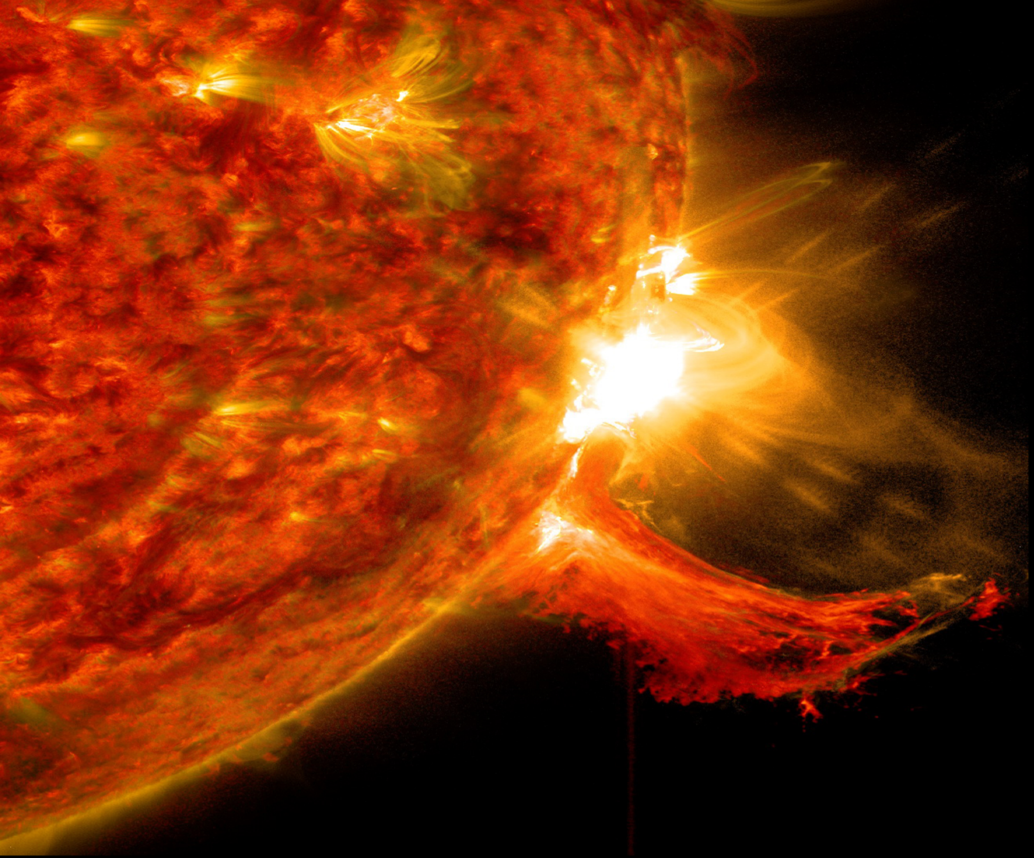


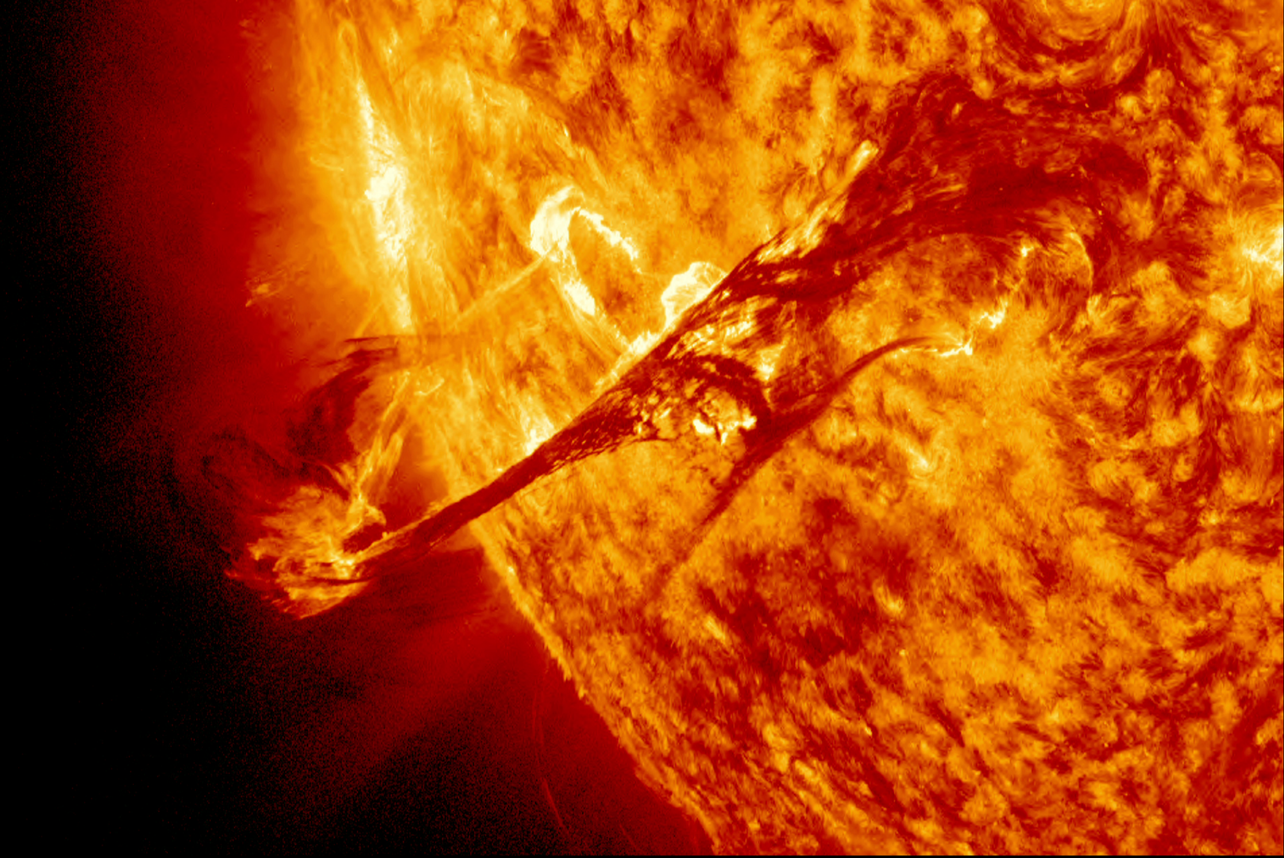
Solar Active Regions (ARs)

- Might produce sunspots
- B ~1000 or more times stronger than the average magnetic field of the Sun
- Most of flares & CMEs are originated from these regions

Sunspots:

- Cooler than the surrounding
- Magnetic field strength 0.1 to 0.3 Tesla
- Temp: ~ 4000 K
- Size: 16 km to 160,000 km





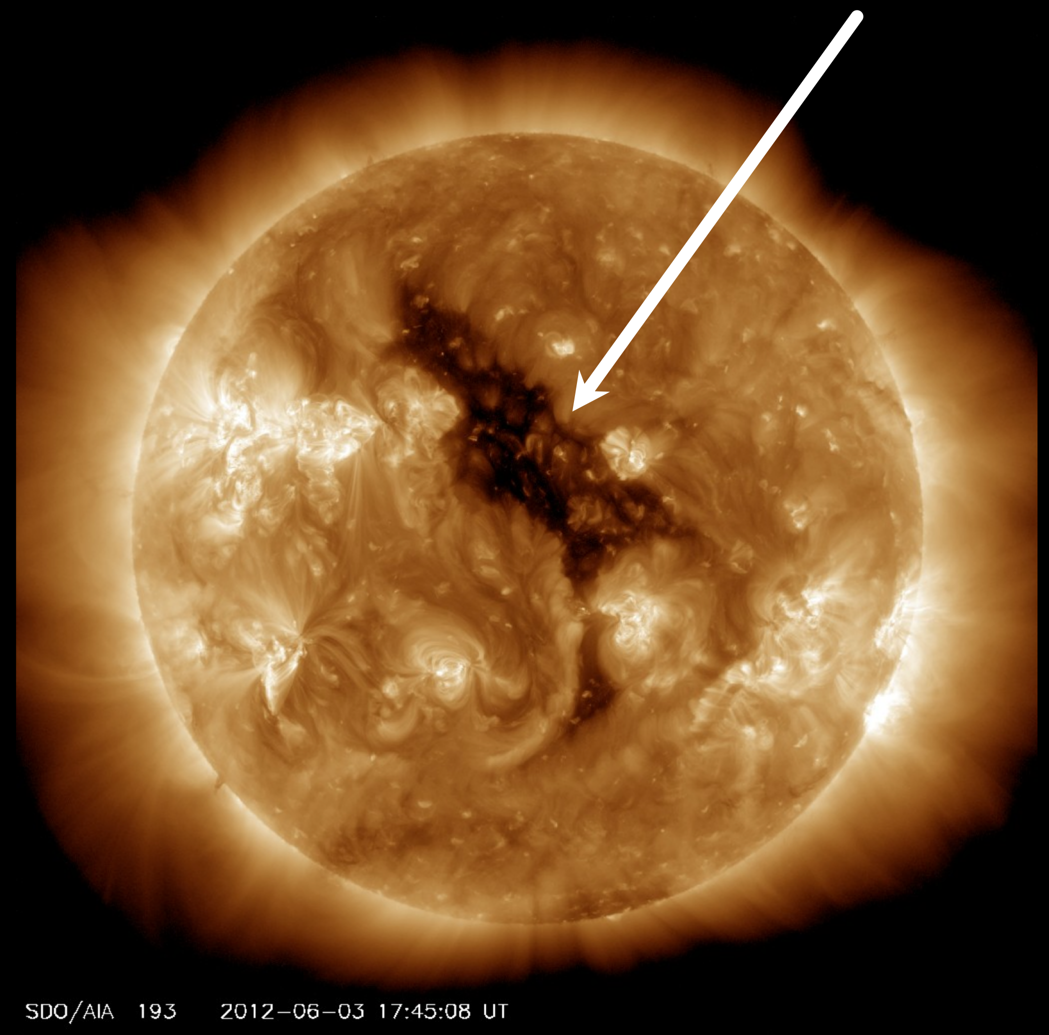
Solar flare:

- Sudden explosion of energy
- Release lot of radiation into space
- Sometimes accompanied by a CME

Coronal Mass Ejection (CME):

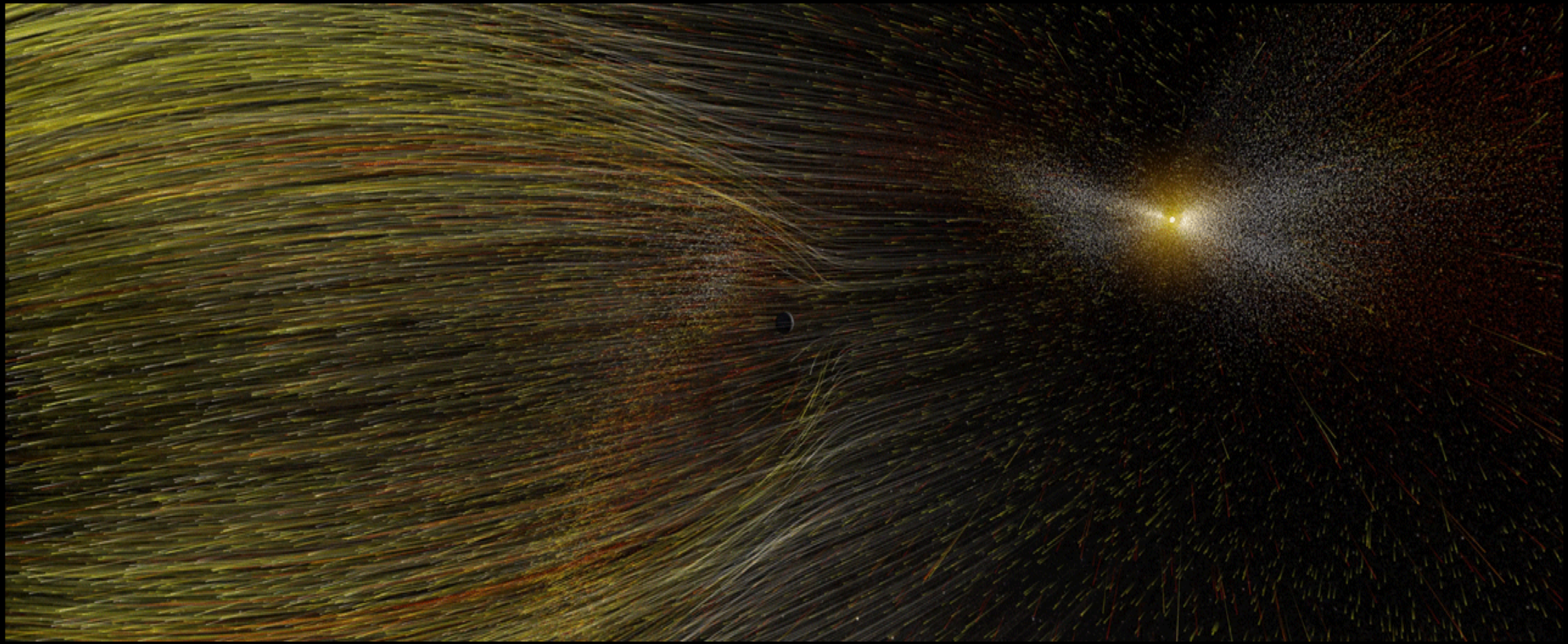
- Sudden outflow of plasma
- Often associated with flares
- Might reach to the Earth 1-2 days

Coronal Holes



- Appear in the Corona
- Observed in the <u>EUV</u> and <u>soft X-ray</u> images
- Cooler and less dense than surrounding plasma
- Associated with <u>open and unipolar magnetic field lines</u> 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 <u>any time</u>, but more common and persistent during <u>solar minimum</u>

Solar Wind

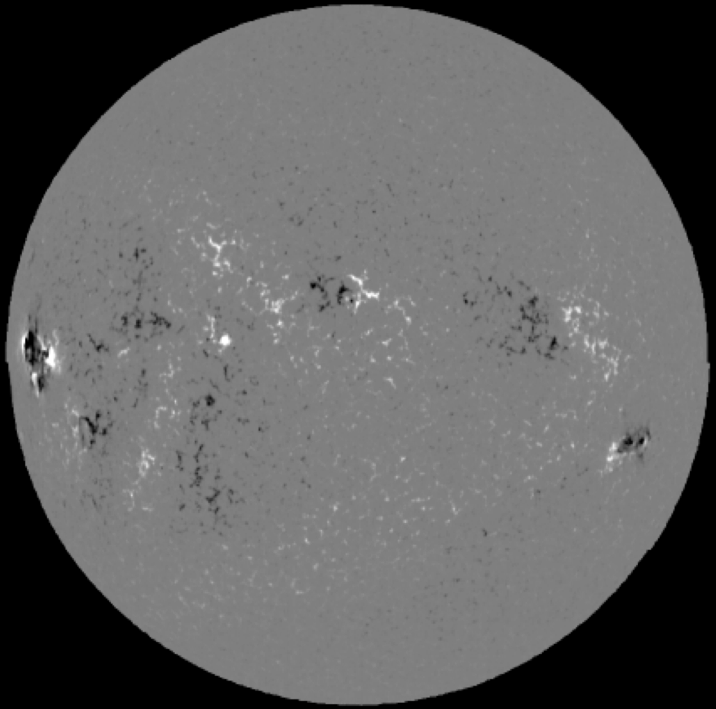


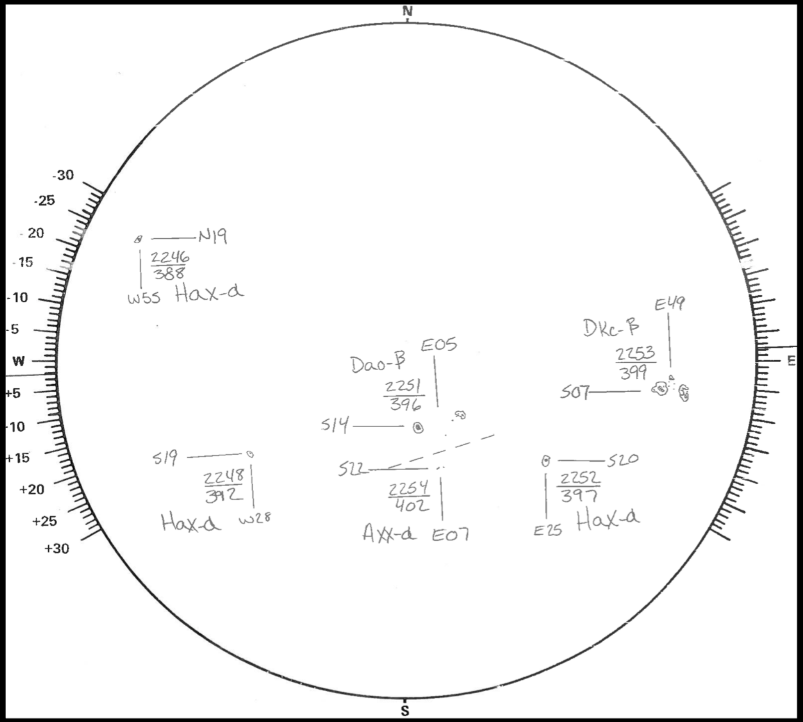
- Continuous stream of charge particles
- Average speed <u>400 (km/s)</u>
- Fast solar wind (~750 km/s): spews from coronal holes
- Slow solar wind (~350 km/s): origin is unknown

Solar Observation

150-Foot Solar Tower at Mount Wilson Observatory

Solar Observing Optical Network (SOON) Observatories





Magnetogram

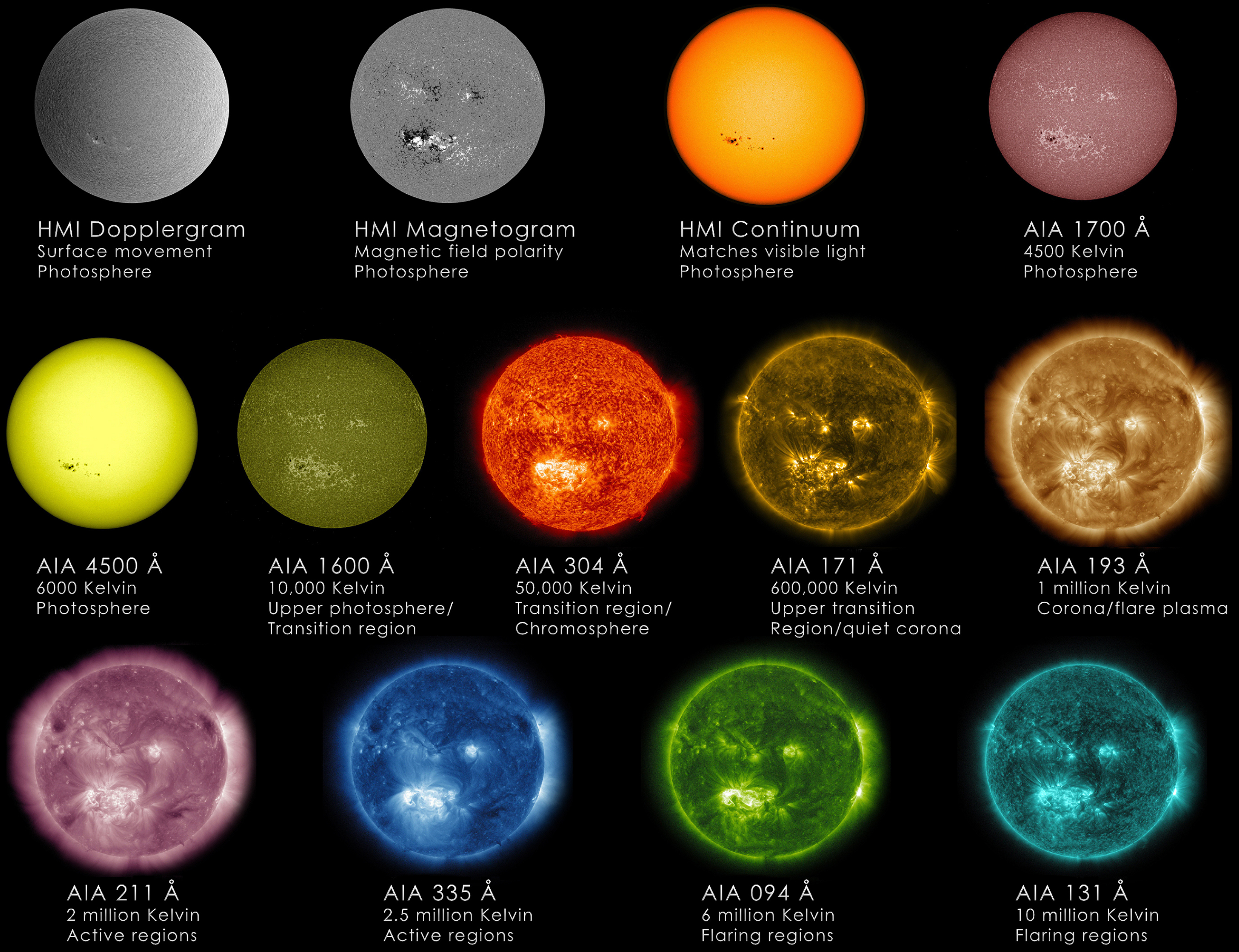
27.06.1998

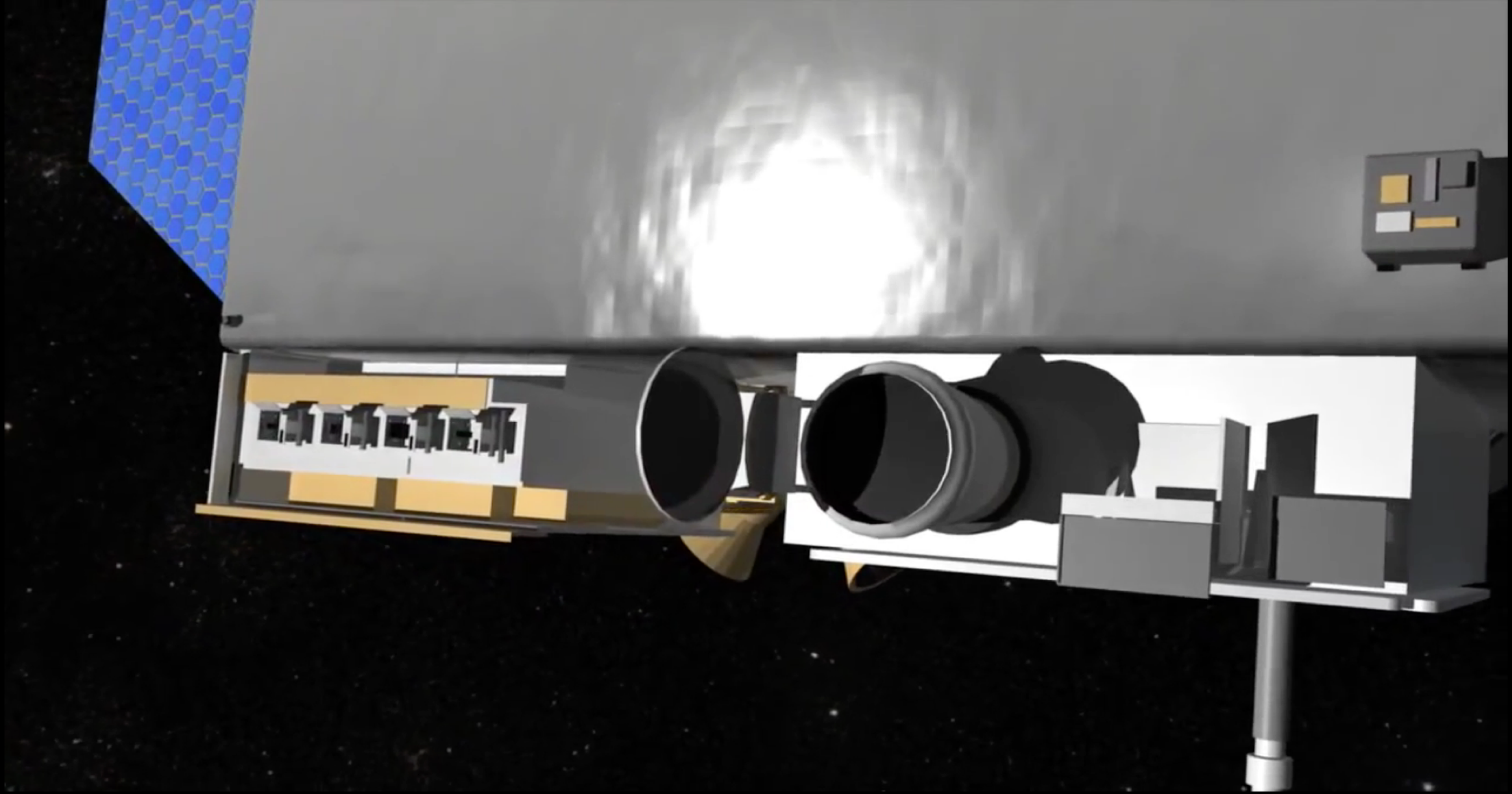
Observes: Iron at 8468 Å

Sunspot Drawing

01.01.2015

Observes: Hα at 6563 Å


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



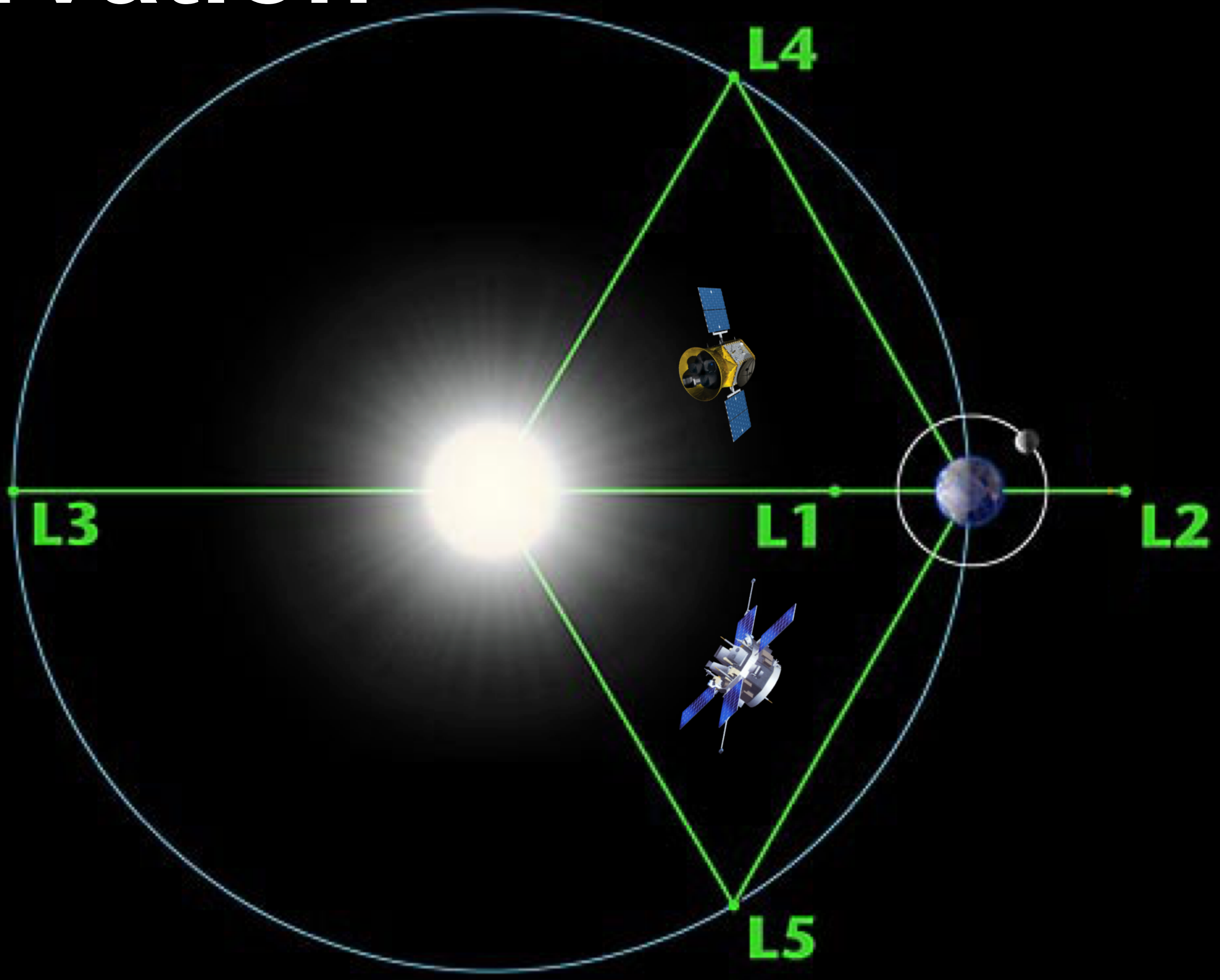
Near-Earth Space Observation

Solar Dynamic Observatory (SDO) Satellite

- Launched in : February 11, 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

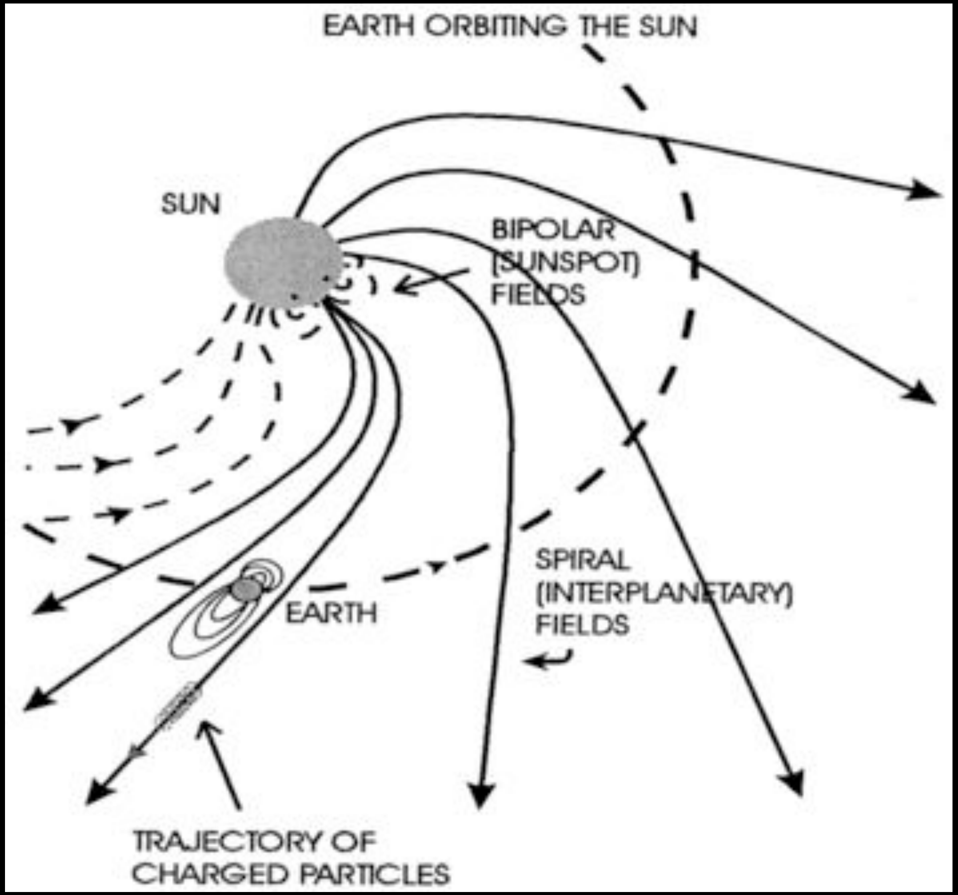
Space based Observation

- Lagrangian points: Zones in space where the gravitational and centrifugal force of two bodies balance out
- L1 ~1.5 million km
- Spacecraft in L1: SOHO DSCOVR, ACE, Wind



Sun-Earth

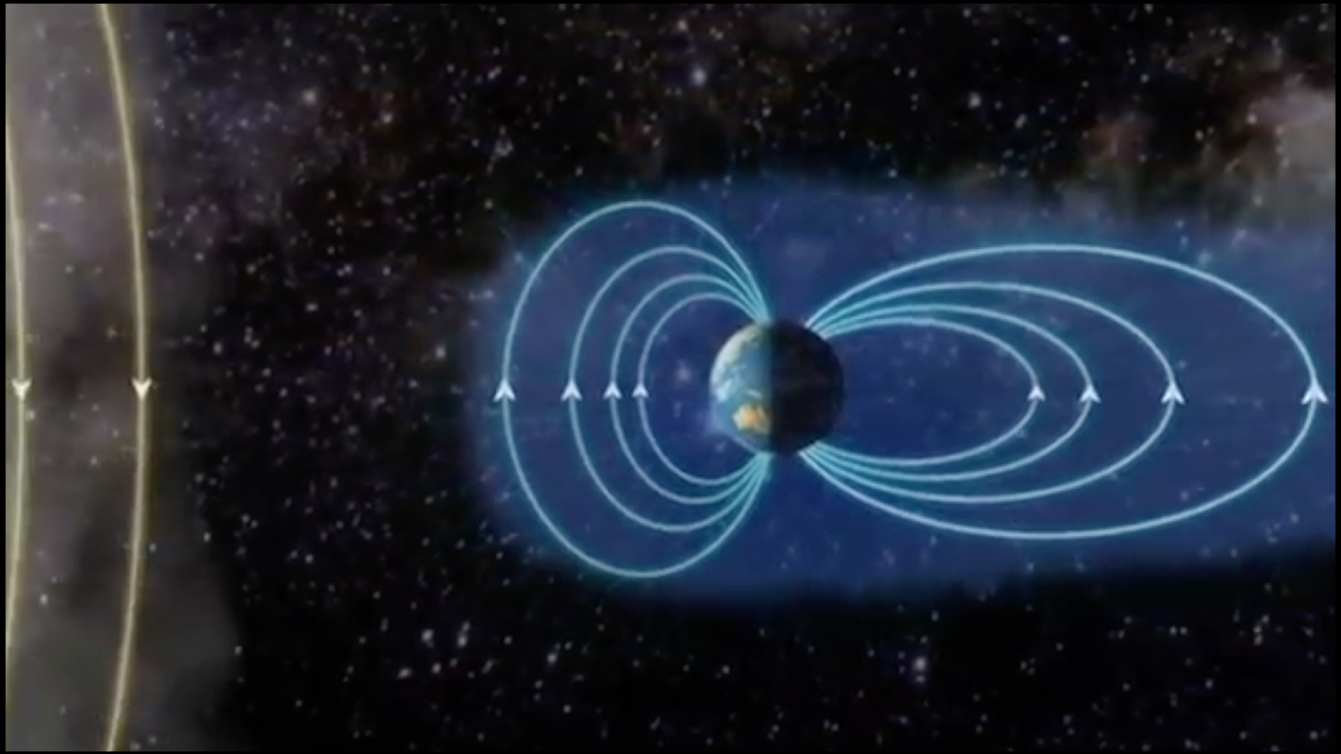
Interplanetary Magnetic Field (IMF)



- Solar magnetic field, carried by the solar wind into interplanetary space
- Note that the sun rotates
- Causes the solar wind twist into an Archimedean spiral

Magnetic Reconnection

- Breaking and reconnecting of oppositely directed magnetic field lines
- Happens in highly conductive plasma
- Magnetic energy converts to kinetic and thermal energy
- Accelerates particles
- Solar flares, CMEs and accretion disks around black holes

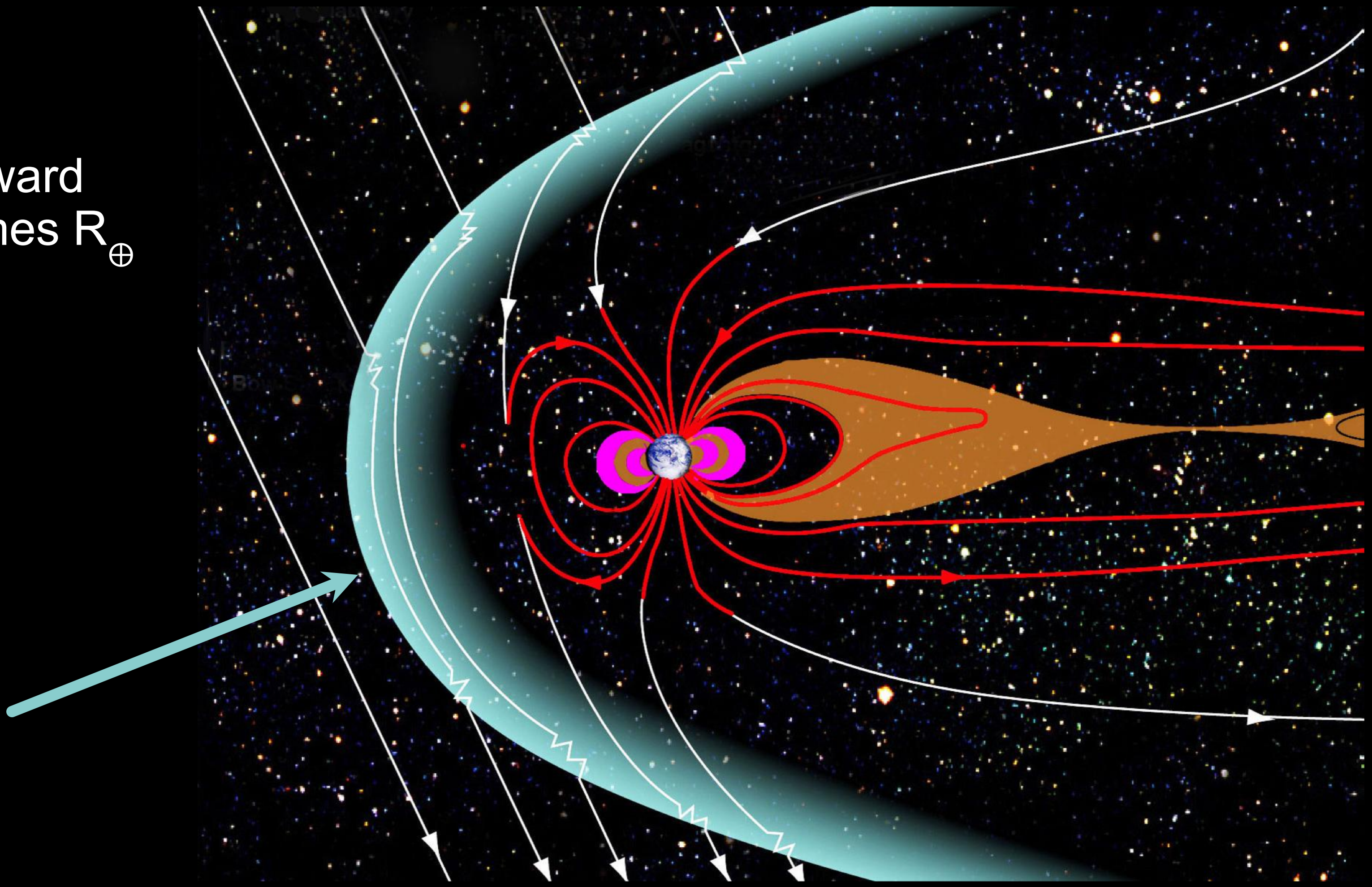


Magnetosphere

- A cavity formed by Earth's magnetic field
- Highly dynamic
- The solar wind compresses its sunward side to a distance of only 6 to 10 times $R_\oplus$ and its nightside to possibly 100 $R_\oplus$

Bow shock

- A shock wave on the sunward of the magnetosphere
- Formed by interaction between supersonic solar wind with the Earth's magnetic field



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

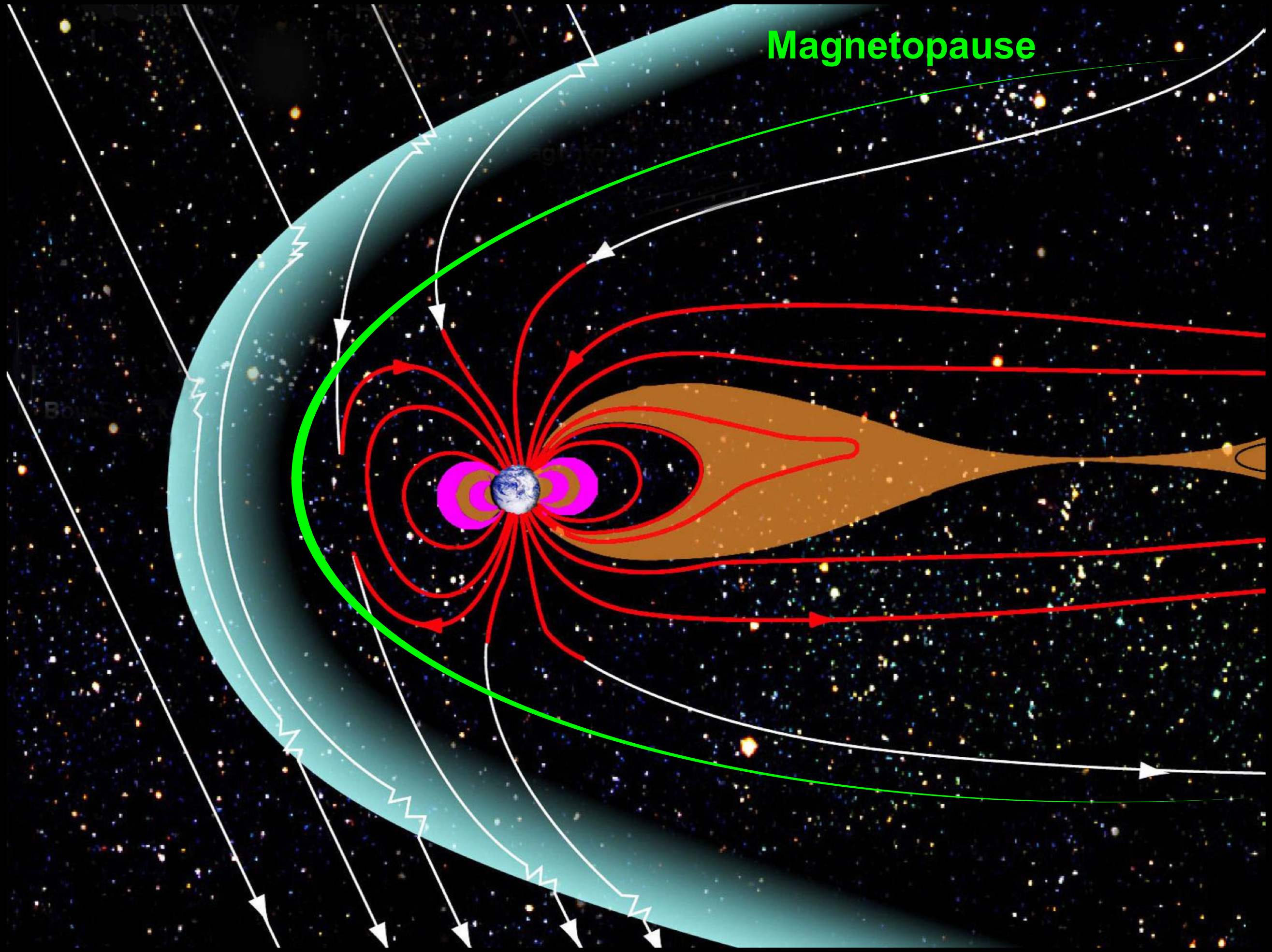
Magnetopause

- 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**

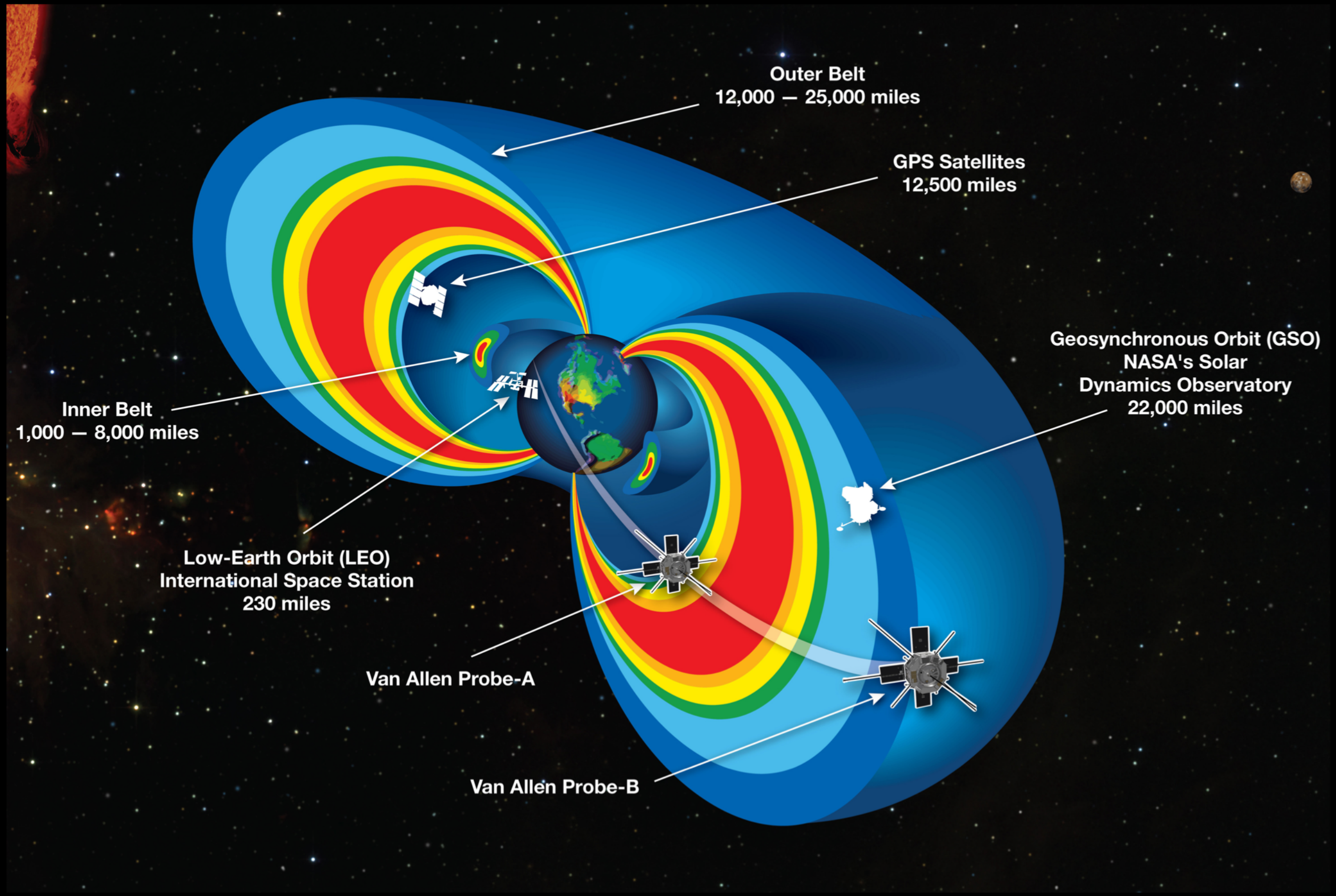


Radiation belts

- Donut-shaped regions encircling Earth
- At 1.2 to 6 $R_{\oplus}$
- High-energy particles, mostly electrons and ions, are trapped by Earth's magnetic field

- **Inner belt:** part of plasmasphere and corotates with the Earth
- proton energy range: 100 keV -100 MeV

- **Outer belt:** Extends on to the magnetopause on the sunward and to about 6 $R_{\oplus}$
- Proton energy range: 0.1 to 10 MeV



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

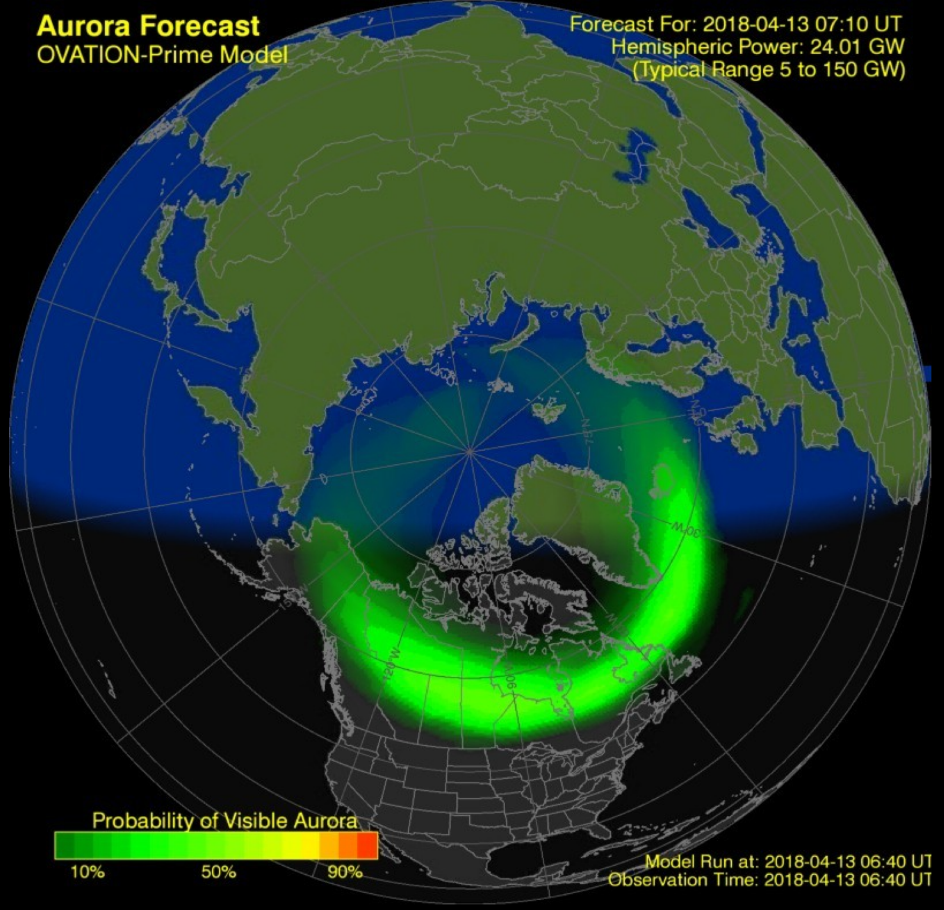
Geomagnetic Storm

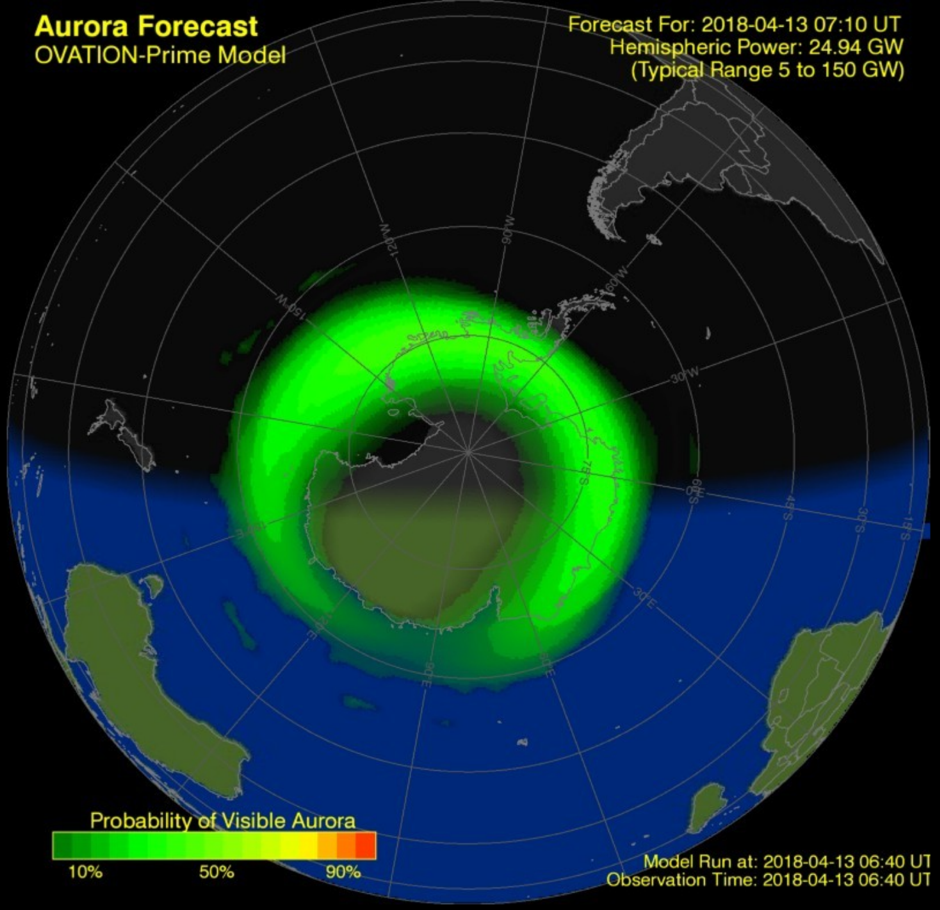
- A temporary disturbance of magnetosphere
- Last for several days
- Dst index

Substorm

- A localized & brief disturbance of magnetosphere
- Last for few hours
- AE index

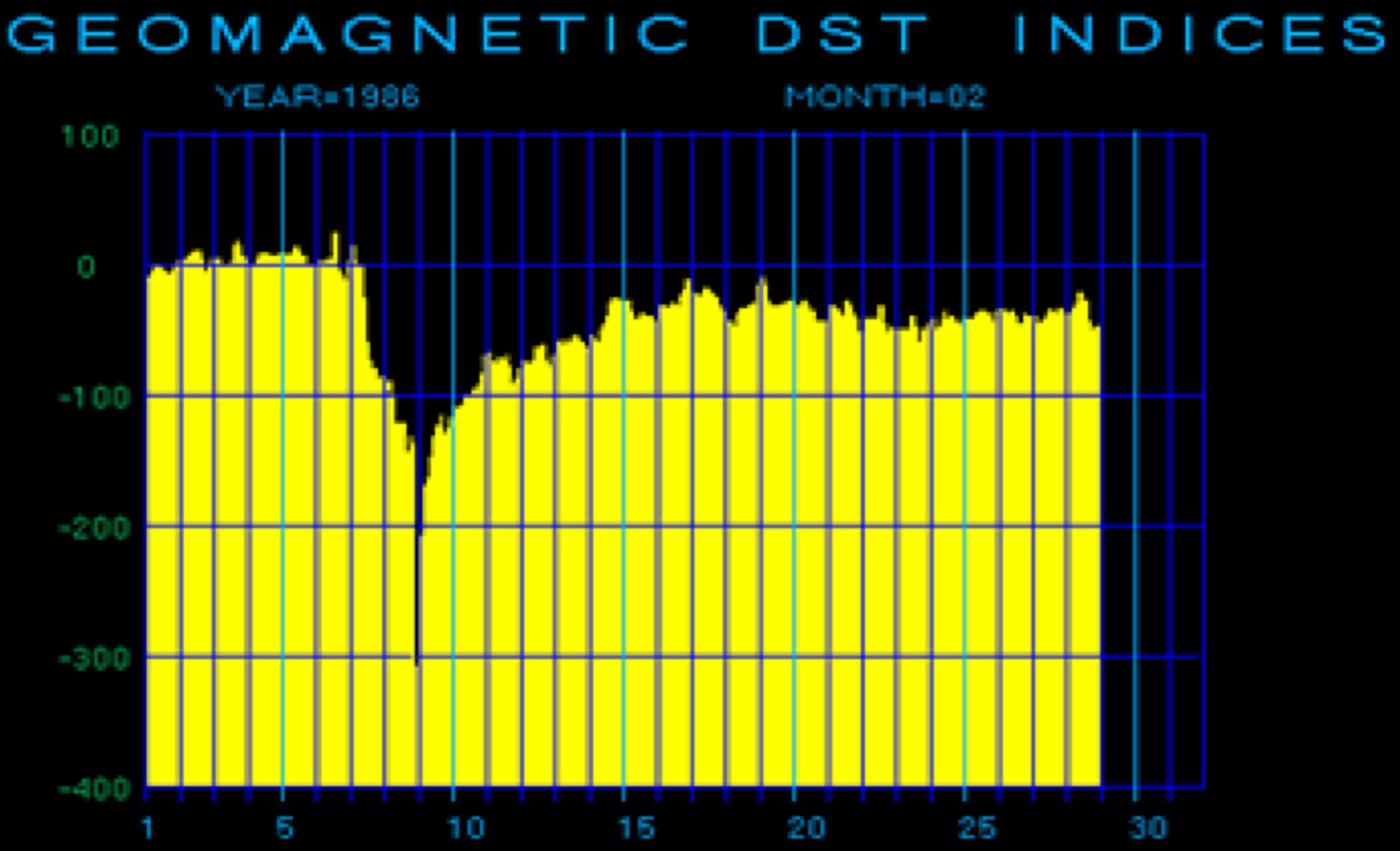
Geomagnetic Data





Auroral oval:

- Region where the auroras typically occur
- Elliptical region around each geomagnetic pole, from ~56° at midnight ~75° at noon
- Becomes wider during geomagnetic storm

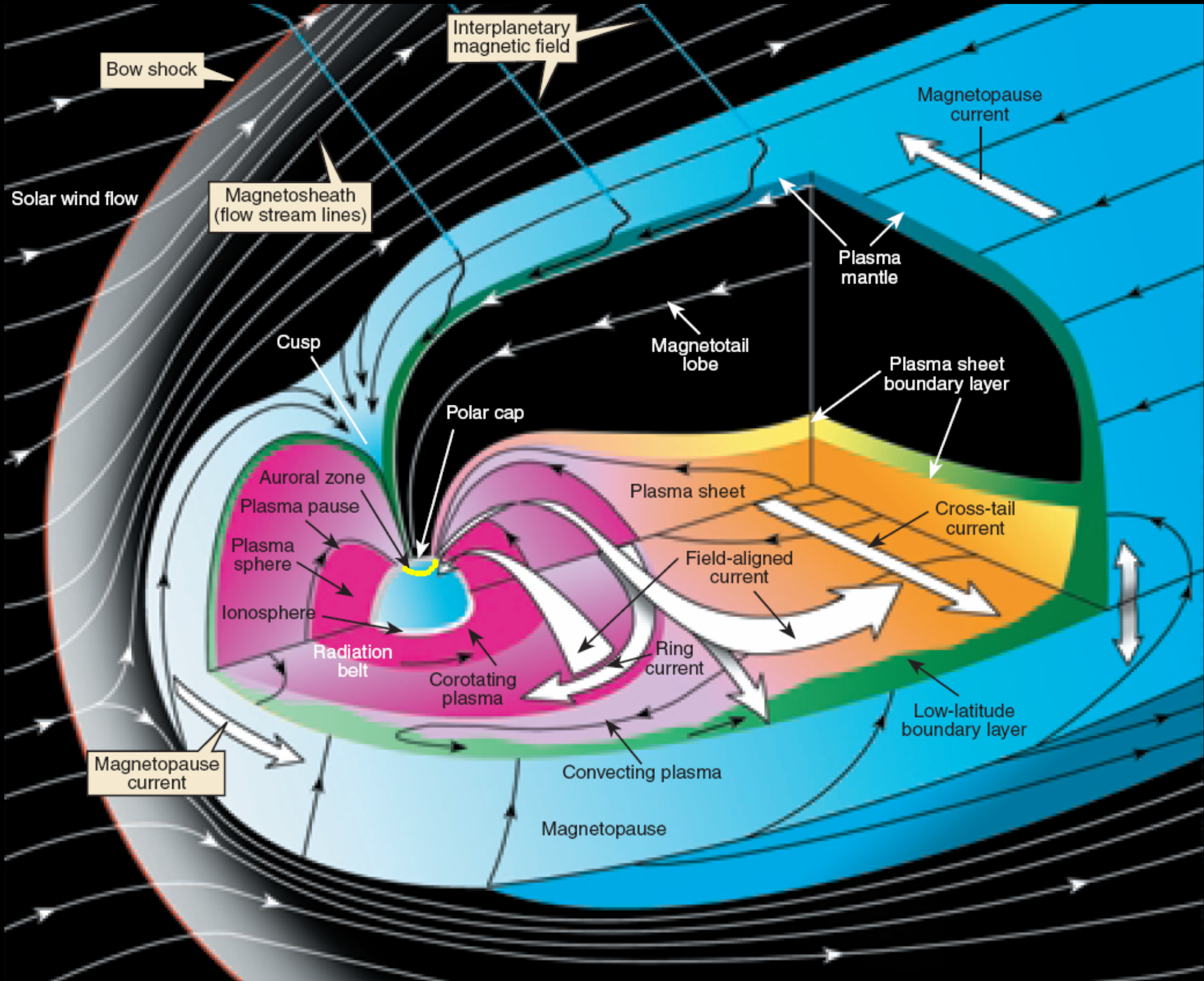


GEOMAGNETIC DST INDICES
YEAR=1986
MONTH=02
100
0
-100
-200
-300
-400
1
5
10
15
20
25
30

Disturbance storm time (Dst) index

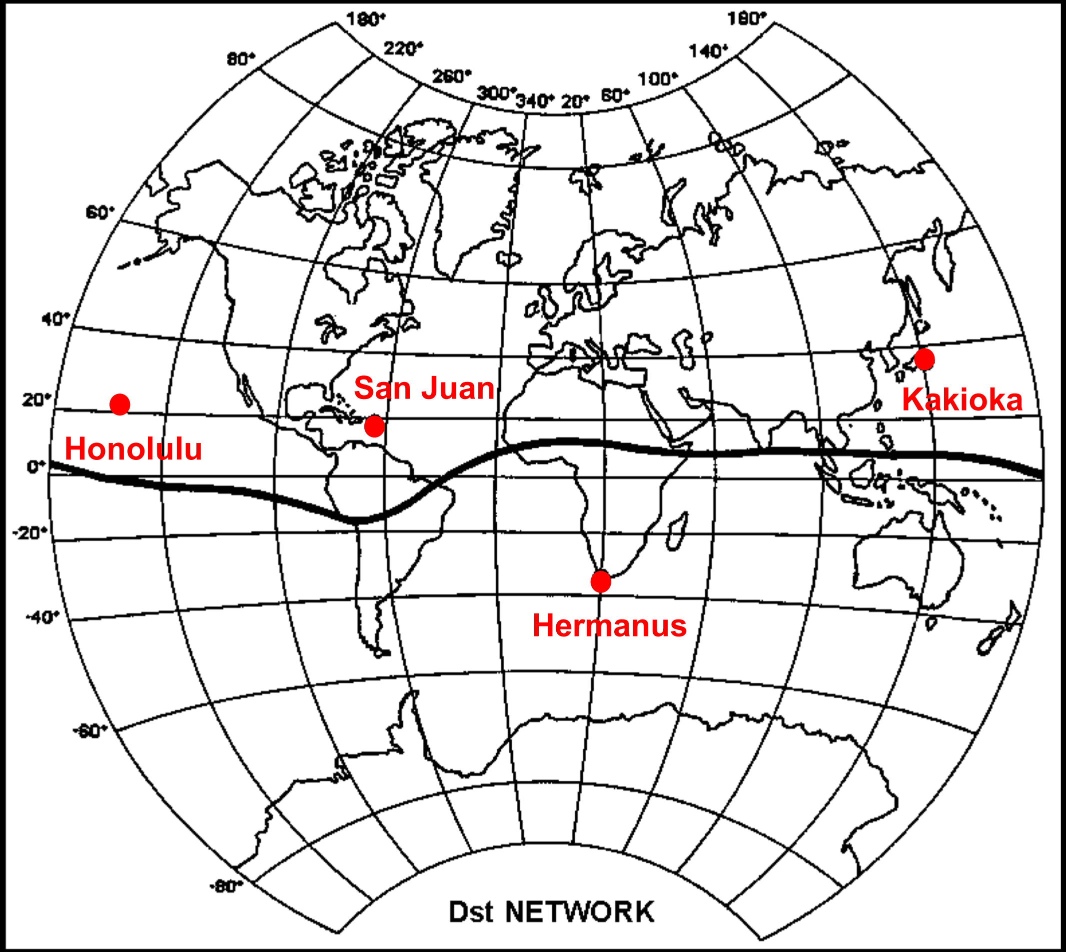
$R_{\oplus}$= 6,371 (km)

- 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 measures the intensity of the ring current
- Deviation of H (north-south) component of the magnetic field



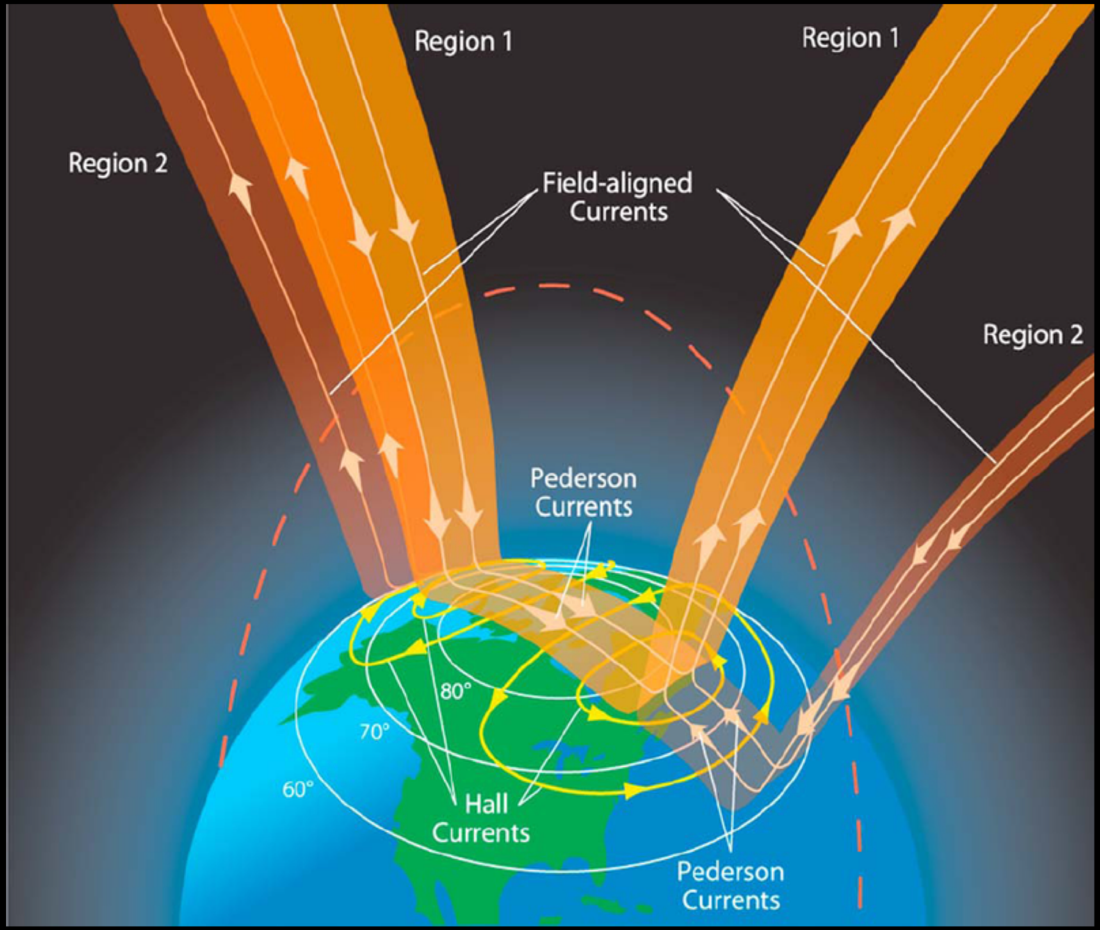
Disturbance storm time (Dst) index

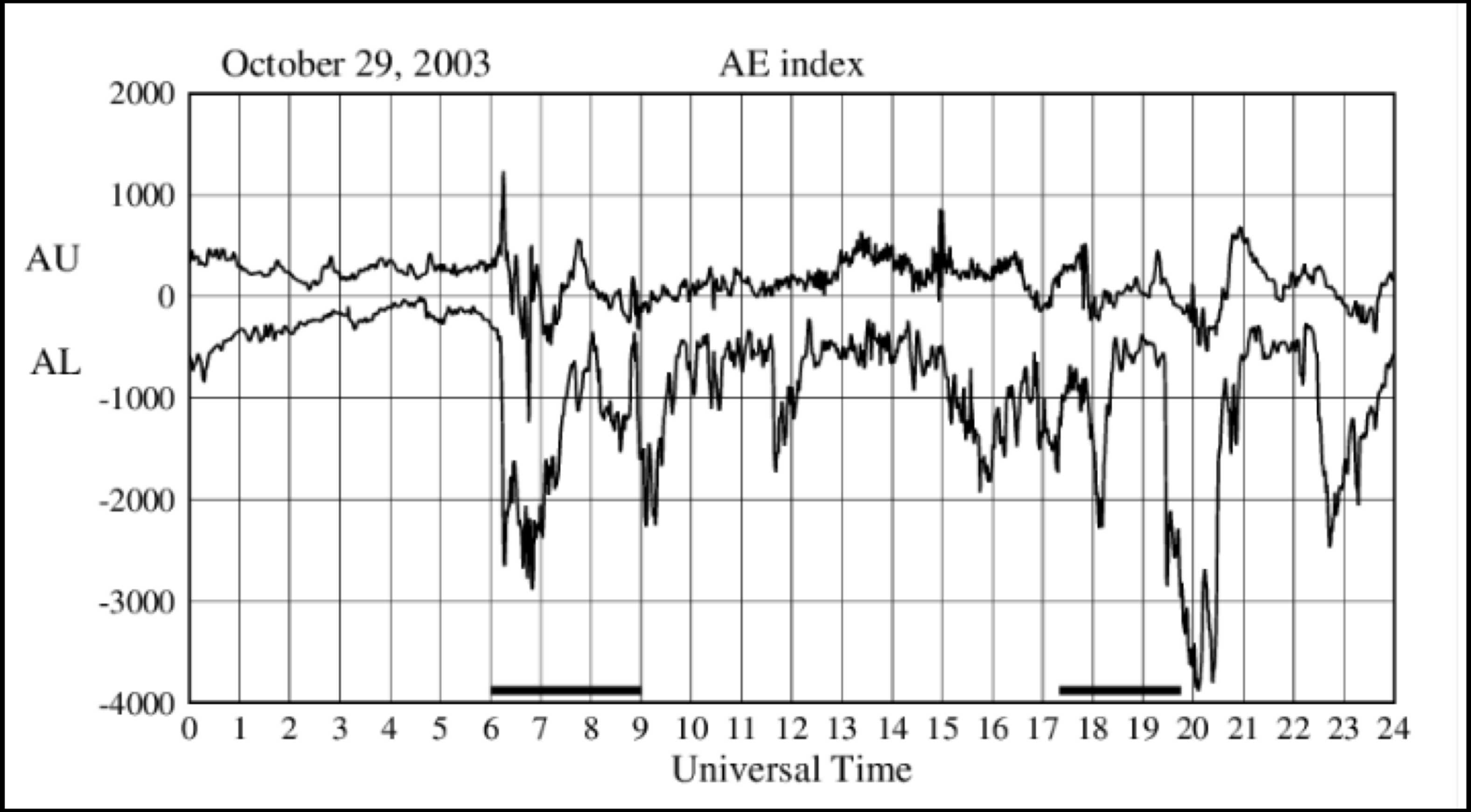
- Four stations near the geomagnetic equator
- Magnetic equator: There is no vertical (Z) component to the magnetic field
- The magnetic equator is not fixed, but slowly changes



Auroral Electrojet (AE) index

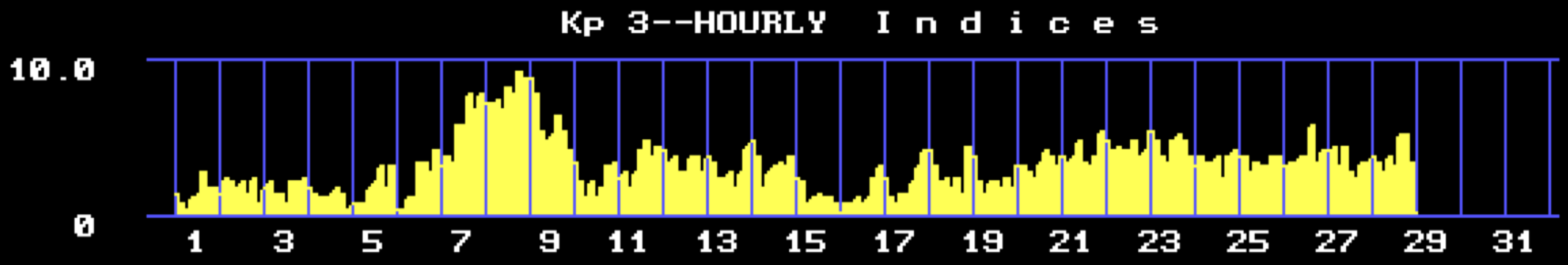
- Measure of auroral zone magnetic activity
- Produced by enhanced ionospheric currents flowing below and within the auroral oval
- Derived from variations in the horizontal component observed at selected (10-13) observatories





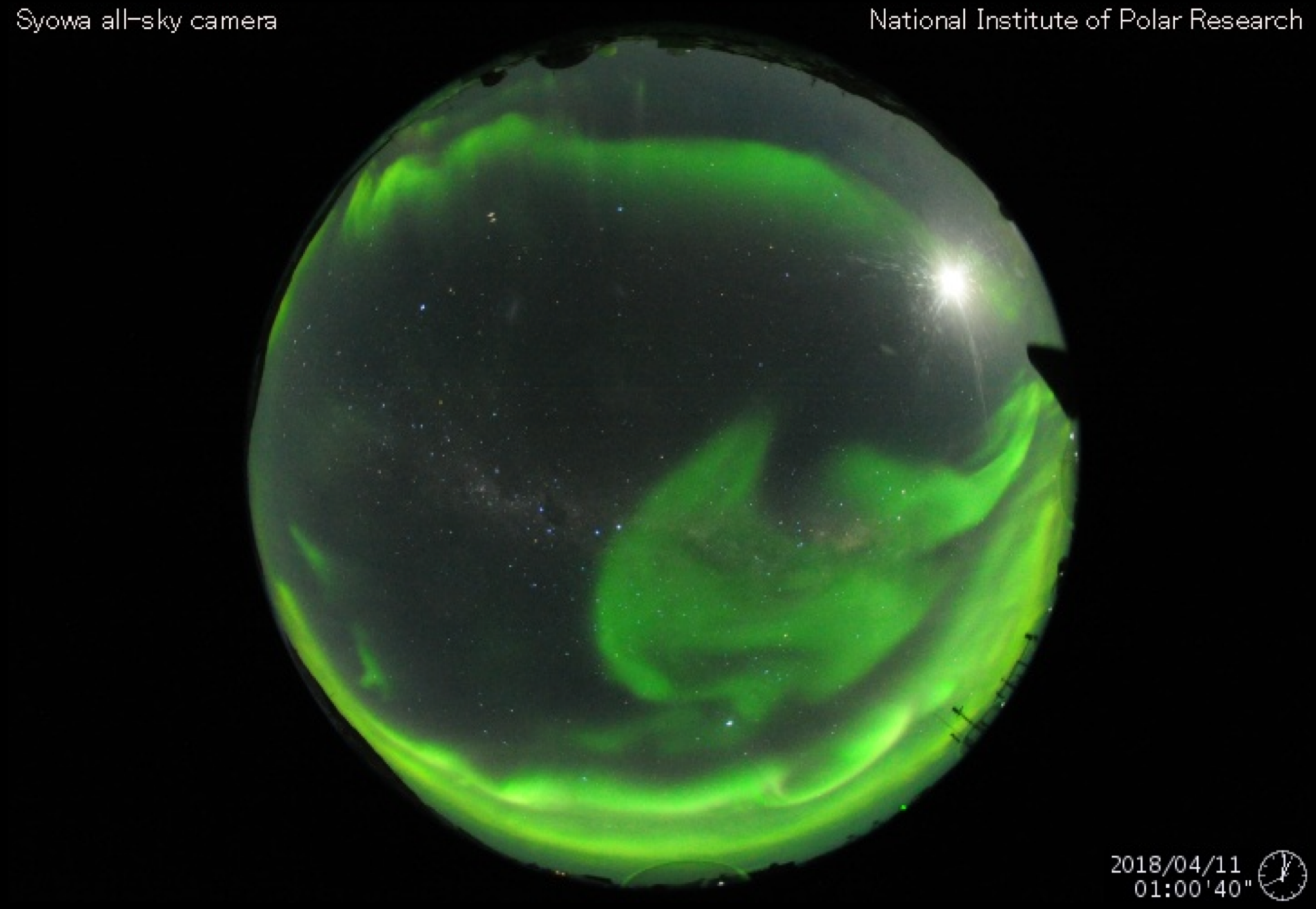
- AU and AL indices are respectively the largest and the smallest values in the horizontal component
- The difference, AU minus AL, defines the AE index

Geomagnetic Kp index



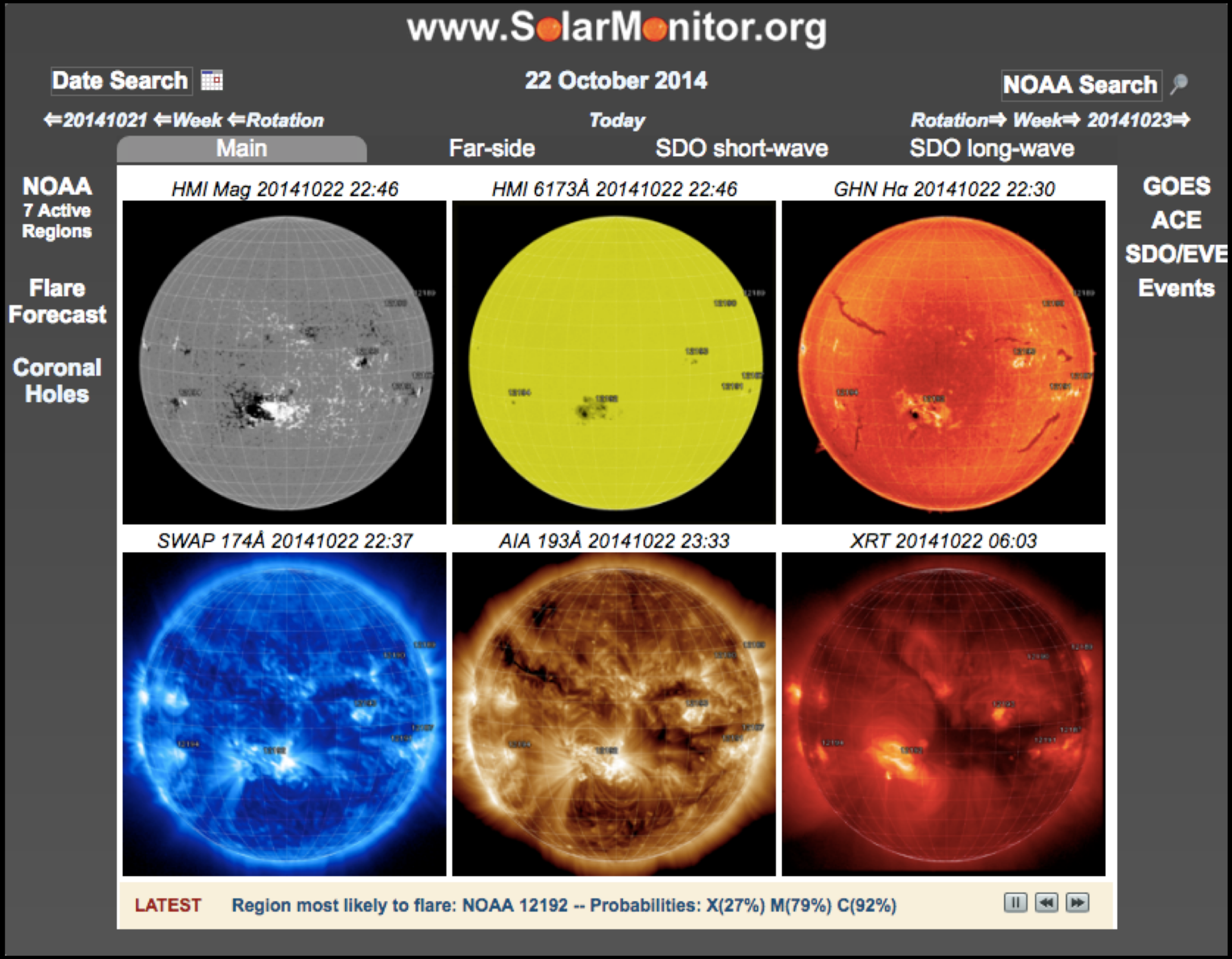
- 3-hourly range index
- 13 geomagnetic observatories (ranging from 44° to 60° northern or southern geomagnetic latitude)
- Scaled from 0 to 9, expressed in thirds of a unit, e.g. 5- is $4\frac{2}{3}$, 5 is 5, 5+ is $\frac{1}{3}$

All sky camera

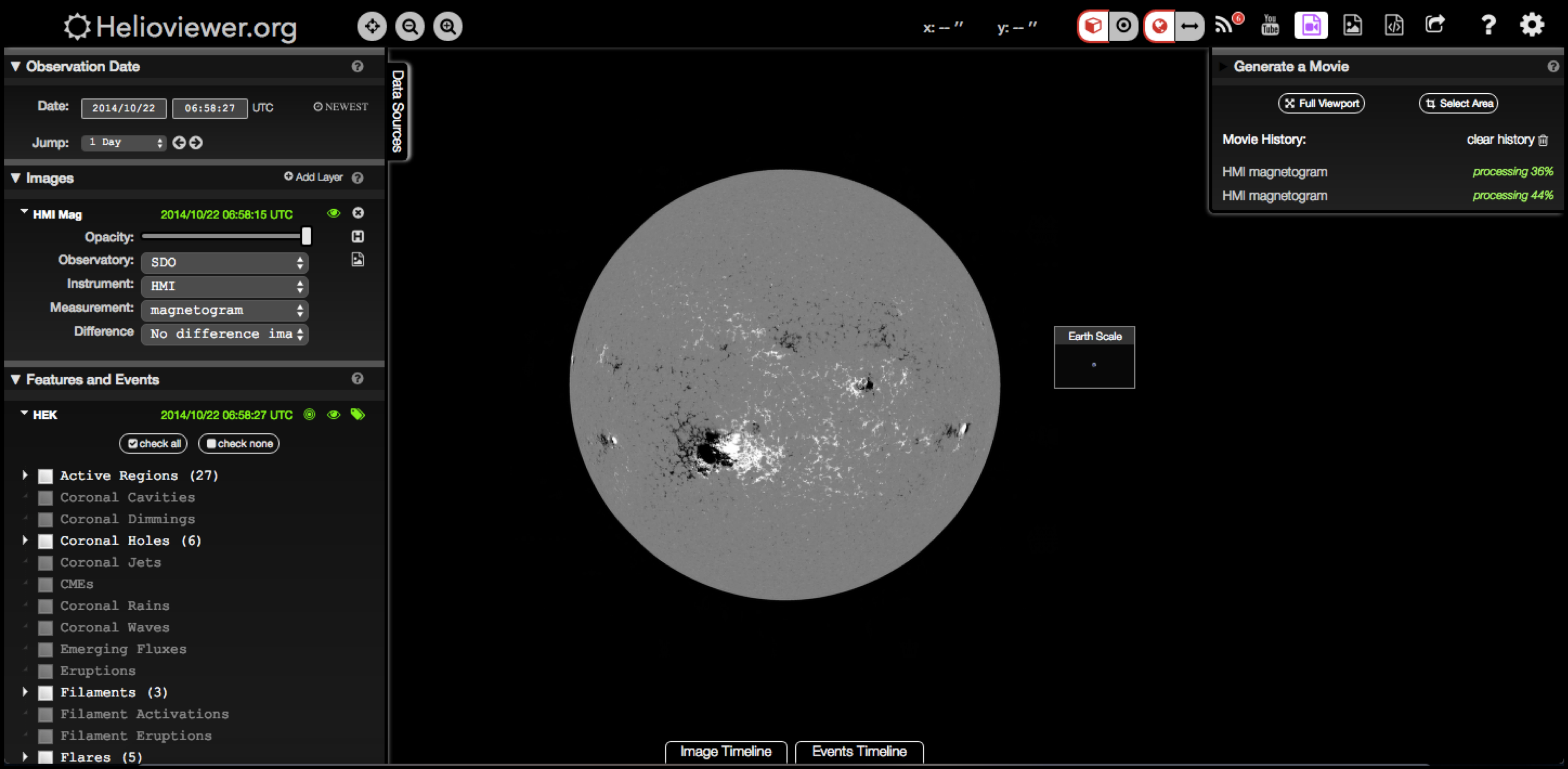


- Used in meteorology, astronomy and visual observation of auroras
- Capture a photograph of the entire sky
- Typically equipped with a fisheye lens

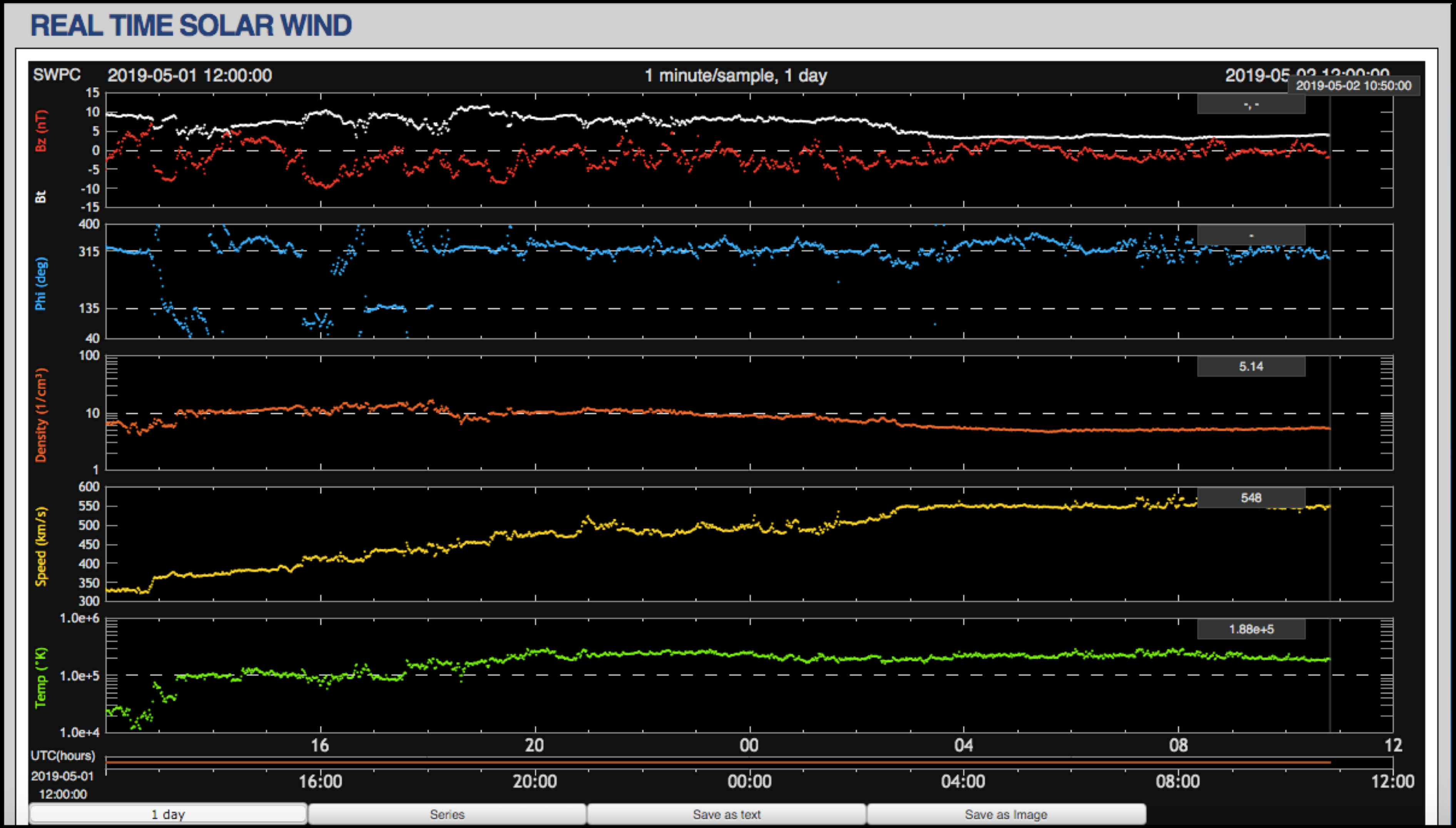
Where To Find Data For Space Weather Prediction



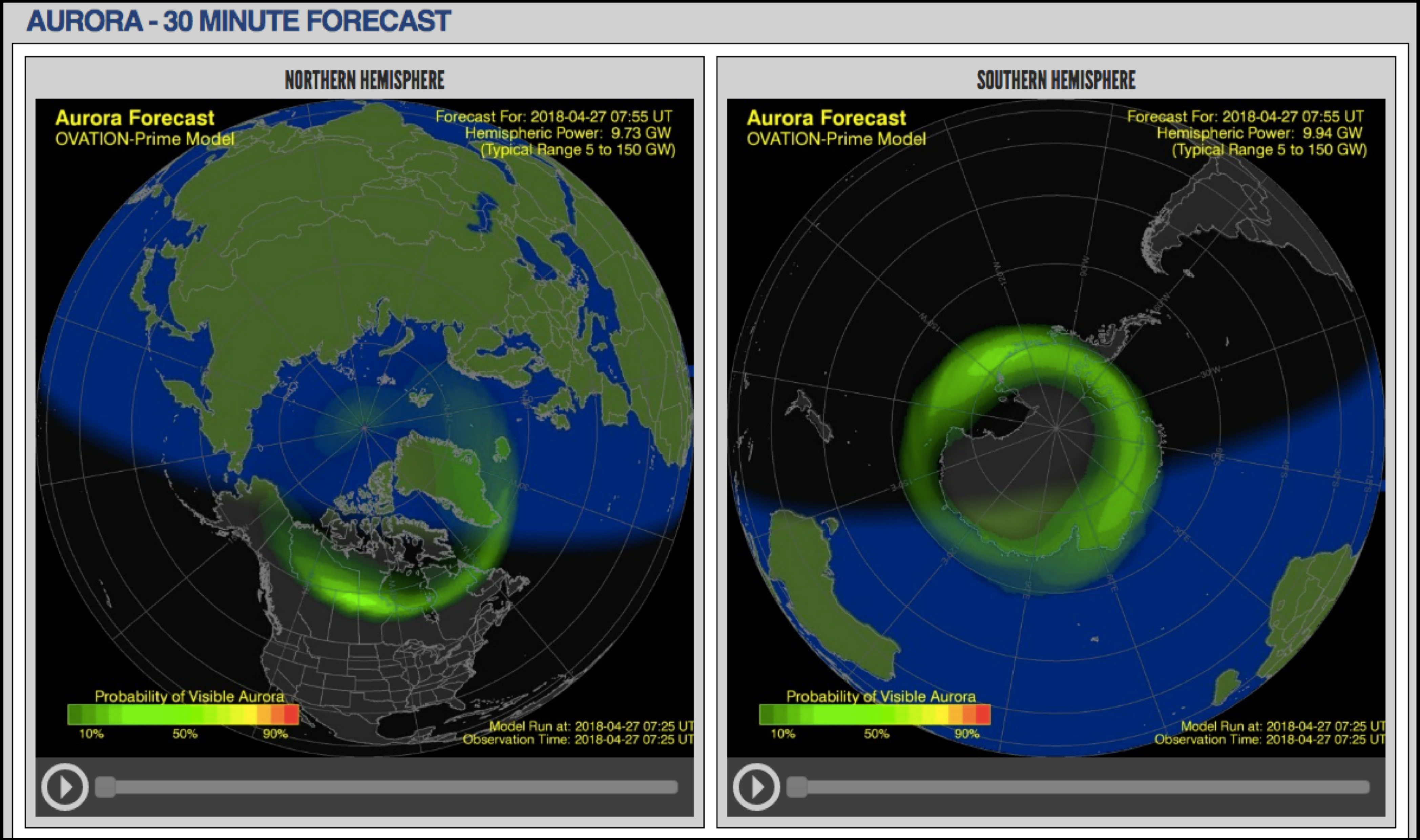
https://solarmonitor.org/index.php



https://helioviewer.org/



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



https://www.swpc.noaa.gov/products/aurora-30-minute-forecast

What's New

Japanese

World Data Center for Geomagnetism, Kyoto

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 poles, Geomagnetic elements,
   Geomagnetic field observation and collection of the data (Geomagnetic observatories on the Google Earth),
   International Geomagnetic Reference Field and others

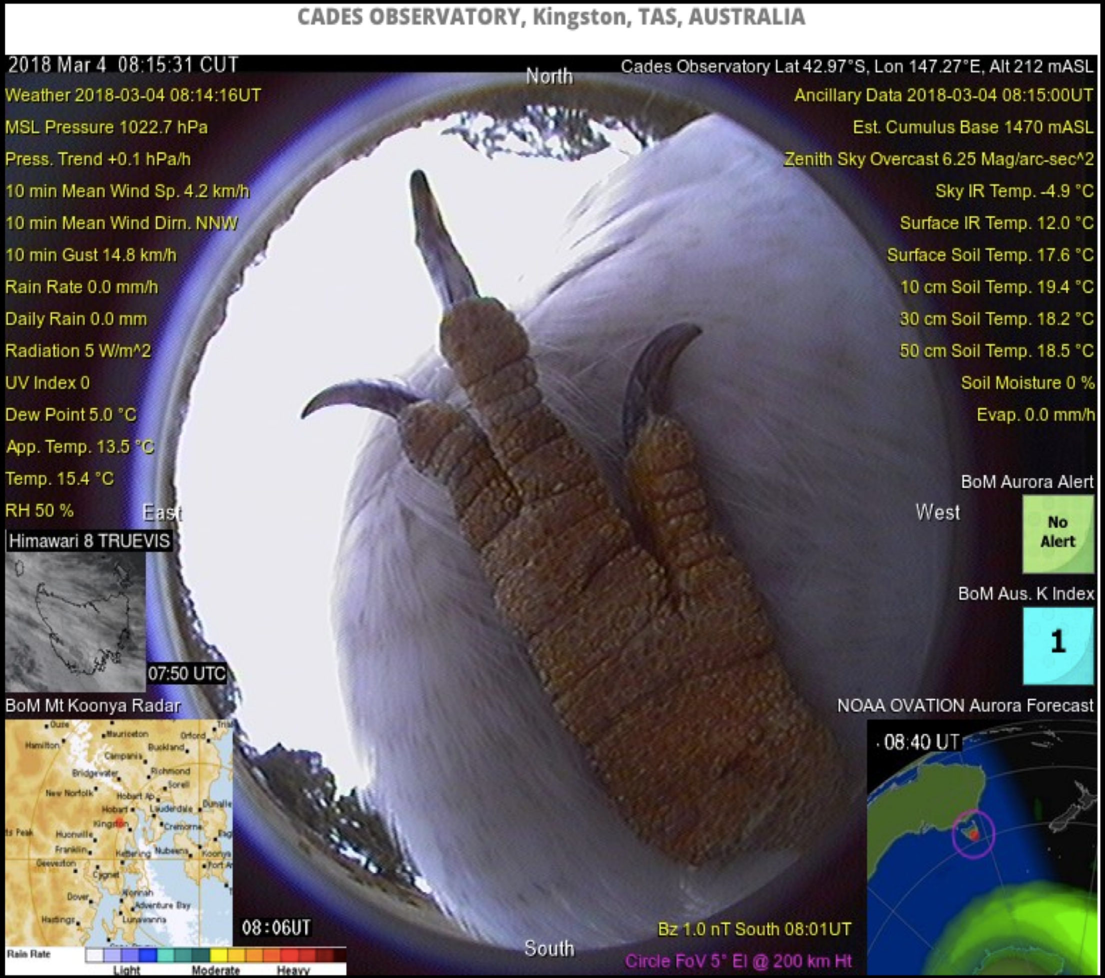
3. Geomagnetic Data Service
   Indices, Geomagnetic Field Data at the Observatories, Models, Data Catalogue and others

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

http://wdc.kugi.kyoto-u.ac.jp/

All sky camera



Cades Observatory, Kingston, TAS, Australia

- Sodankylä Geophysical Observatory http://www.sgo.fi/Data/RealTime/allsky.php
- Tromso station, Norway: http://polaris.nipr.ac.jp/~acaurora/aurora/Tromso/
- Kiruna station, Sweden: http://www2.irf.se/allsky/data.html
- Syowa (or Showa) station, South Pole: http://polaris.nipr.ac.jp/~acaurora/aurora/Syowa/

Extreme Geomagnetic Storms

Space Weather Impacts

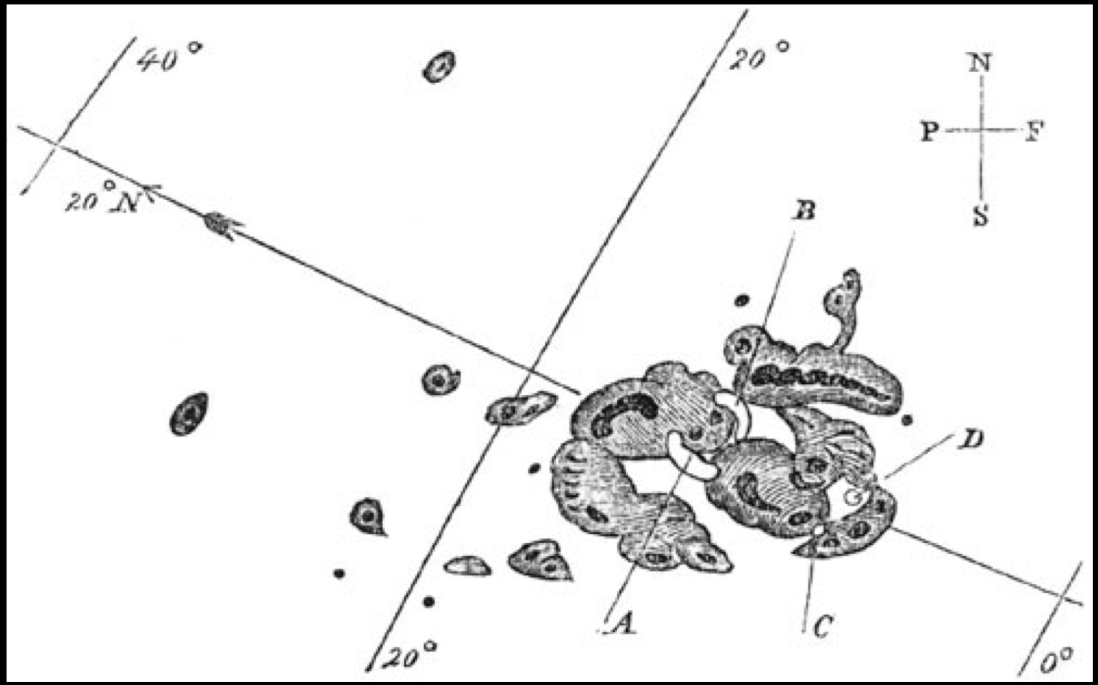
- GPS systems
  - The charged plasma of the ionosphere bends the path of the GPS radio signal

- Satellite communications
  - Radio signals propagating to and from a satellite in orbit are affected by ionosphere condition

- Satellite Drag
  - Especially for satellite in low Earth orbit (LEO)
  - air resistance drags them closer to the Earth
  - International Space Station & Hubble telescopes operate in LEO

1. Carrington Event

- September 1859, cycle 10
- Major CME arrived in ~18 hours
- Caused Global telegraph lines to spark
- Northern lights were observed as far south as Cuba, Hawaii and Tahiti
- Estimated total economic impact on modern technology : $2 trillion (National Academy of Science)



Sunspot of September 1, 1859 as sketched by Richard Carrington

2. Quebec Blackout

- March 13, 1989
- Caused a 12-hour blackout in Quebec
- Kept the Montreal metro shut and closed the Doral Airport
- Caused a malfunction of the Space shuttle Discovery
- Auroras could be seen as far south as Florida and Cuba

3. Halloween Geomagnetic Storm

- November 20, 2003
- Cycle 23, 2-3 years after solar maximum
- 17 major flares
- Solar & Heliospheric Observatory (SOHO) satellite failed temporary
- Auroras could be seen in Texas & Florida

Check following data:

Solar data:

- Magnetogram data
- sunspot data
- List of flares

If you are interested about CMEs: https://cdaw.gsfc.nasa.gov/CME_list/

Geomagnetic data

- Dst index
- Kp index

All Sky Camera data:

- Tromso station, Norway
- Kiruna station, Sweden