The Sun-Earth Connection: The Science and Processes Behind the Northern Lights

Vincent Ledvina

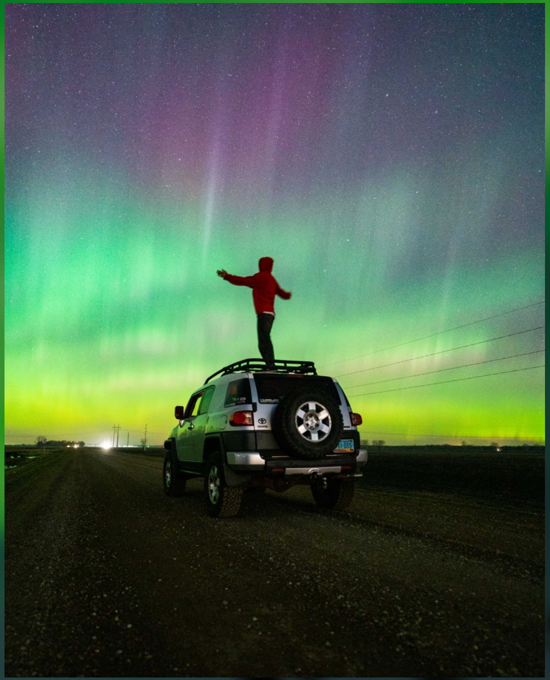
5th Annual Aurora Summit

Outline

- Introduction and Background
- The Sun
- Space Weather
- The Magnetosphere
- The Ionosphere
- Aurora Chasing Resources
- Conclusion

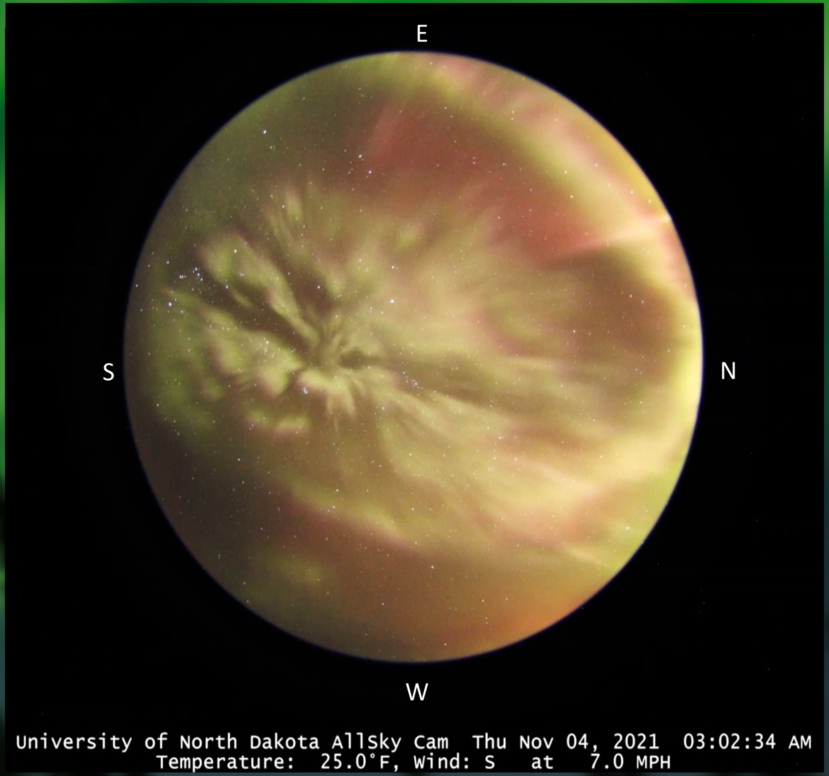
Who am I?

- Aurora chaser, photographer, citizen scientist, and student!
- Other fun things this year:
  - Spent three weeks in Churchill chasing auroras
  - Helped launch a sounding rocket into the aurora
  - Published my first paper!
  - Moved to Fairbanks, Alaska
  - Starting to produce more aurora short films (can share if we have time)



NoDDAC

- Helped found the project in 2020
- Partnership with UND, Aurorasaurus, and the Live Aurora Network
- Nice resource for aurora chasers in the upper Midwest and southern MB
- Secured NASA EPSCoR in June 2020 to start science
- Live streaming every night on NoDDAC YouTube channel



Other Interests

- Space weather
  - Adopting risk-resiliency framework involving open data, interdisciplinary science, and citizen science
  - Working with CME models now
- Citizen science
  - STEVE
  - Central hub/data repository for citizen science image uploads (optimized for timelapse/large datasets)

Agile Collaboration: Citizen Science as a Transdisciplinary Approach to Heliophysics

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Synopsis

Citizen science connects scientists with the public to enable discovery, engaging broad audiences across the world. There are many attributes that make citizen science an asset to the field of heliophysics, including agile collaboration. Agility is the effect to which a person, group of people, technology, or project can work efficiently, pivot, and adapt to adversity. Citizen scientists are agile—they are adaptable, efficient, and responsive. Citizen science projects and their underlying technology platforms are also agile in the software development sense—by utilizing beta testing and short timeframes to pivot in response to community needs. As they capture scientifically valuable data, citizen scientists can also bring expertise from other fields to scientific teams. The impact of citizen science projects and communities means citizen scientists are a bridge between scientists and the public, facilitating the exchange of information. These attributes of citizen scientists form the framework of agile collaboration. In this paper, we contextualize agile collaboration primarily for aurora chasers, a group of citizen scientists actively engaged in projects and independent data gathering. Nevertheless, these insights scale across other domains and projects. To advance the field of heliophysics over the next decade, we recommend the Committee take four actions: (1) Increase the prevalence of citizen science, (2) evolve policies and principles that consider citizen scientists as skilled transdisciplinary colleagues, (3) provide funding for relationship building and reciprocity efforts, and (4) leverage citizen science to facilitate collaborative efforts between related fields. Citizen science is an emerging yet proven way of enhancing the current research landscape. To tackle the next generation's biggest research problems, agile collaboration with citizen scientists will become necessary.

White Paper submitted to the Heliophysics 2024–2033 Decadal Survey 1

How Open Data and Interdisciplinary Collaboration Improve Our Understanding of Space Weather: A Risk & Resiliency Perspective

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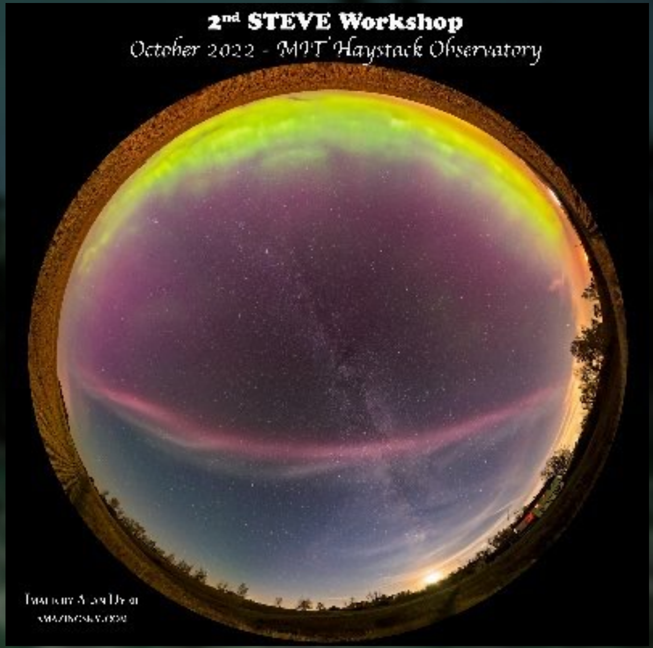
Synopsis

Space weather refers to conditions around a star, like our Sun, and its interplanetary space that may affect space assets, ground-based assets, and human life. Space weather can manifest as many different phenomena, often simultaneously. It can create complex and sometimes dangerous conditions. The study of space weather is inherently trans-disciplinary, including subfields of solar, magnetospheric, ionospheric, and atmospheric research communities, but benefiting from collaborations with policymakers, industry, astrophysics, software engineering, and much more. Effective communication is required between scientists, the end-user community, and government organizations to ensure that we are prepared for any adverse space weather effects. With the rapid growth of the field in recent years, the upcoming Solar Cycle 25 maximum, and the evolution of research-ready technologies, we feel that space weather deserves a reexamination in terms of a risk–resiliency framework. By utilizing open data science, cross-disciplinary collaborations, information systems, and citizen science, we can forge stronger partnerships between science and industry and improve our readiness as a society to mitigate space weather impacts. These ideas fit into a broader space weather "risk–resiliency framework" that can be used to further assess areas of improvement in the field.

White Paper submitted to the Heliophysics 2024–2033 Decadal Survey 1

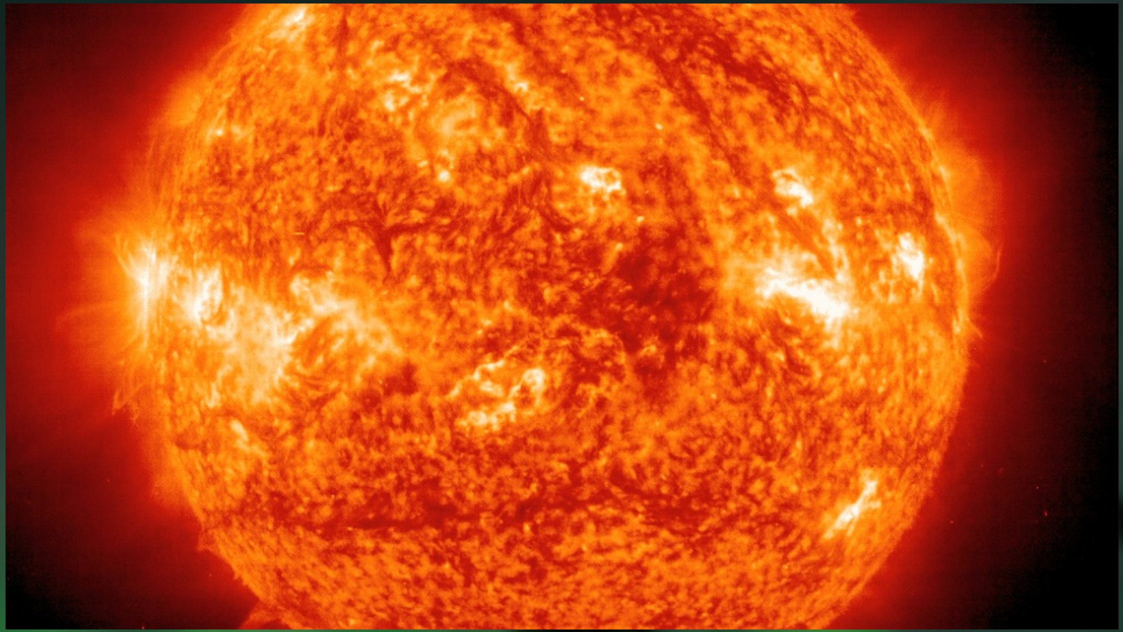
AURORASAURUS
Reporting Auroras From the Ground Up



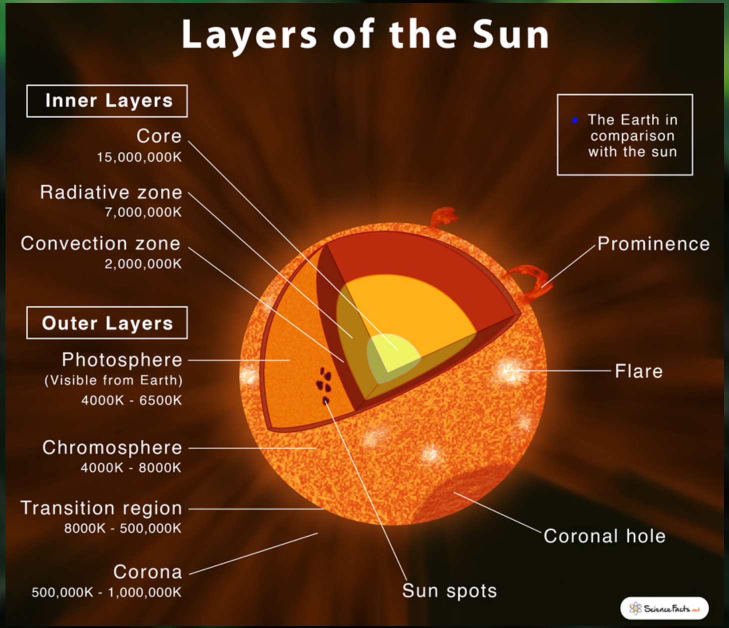
The Sun – An Overview

The aurora starts with the Sun!

- Ordinary star
- Made of plasma
- Has layers, like an onion!
  - Photosphere – the layer we see
  - Convection zone – source of Sun’s dynamo
  - Chromosphere/Transition Region – magnetic fields very strong, hotter temps, where we see lots of flares and image the Sun in EUV
  - Corona – the Sun’s outer atmosphere, what you see during an eclipse, also see this in EUV images



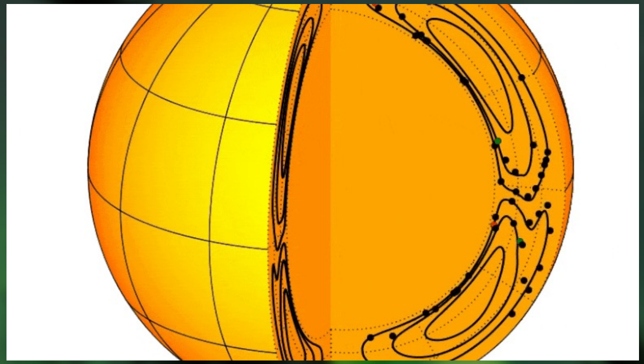
Credit: NASA/SDO



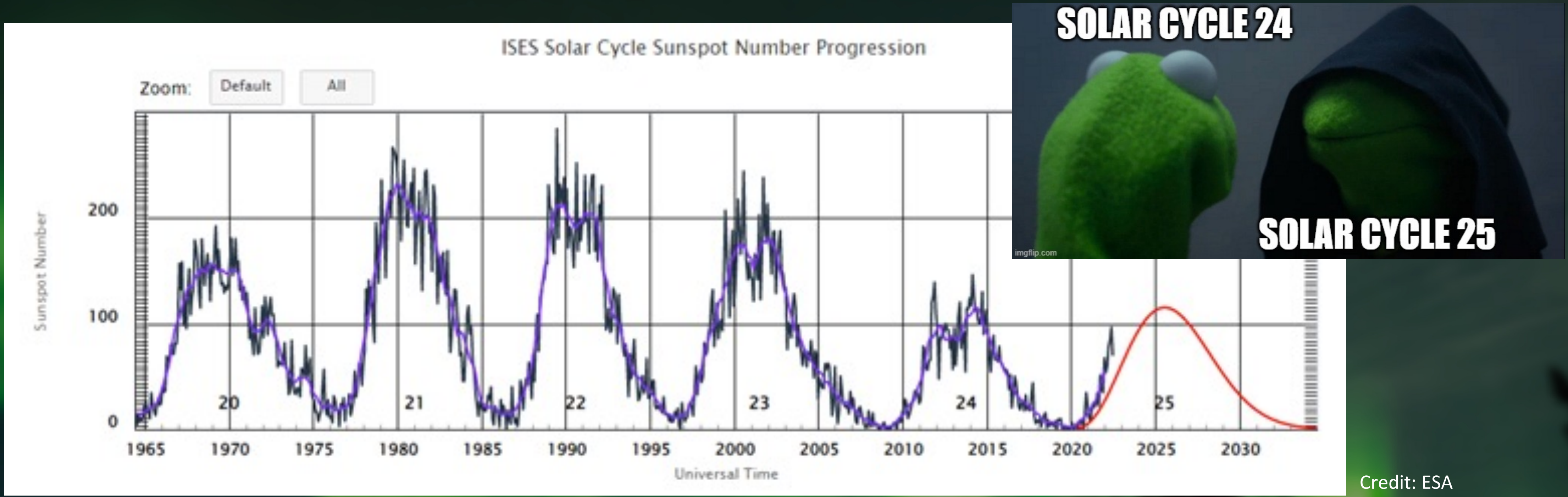
Solar Cycles

The solar cycle forms the backbone of space weather

- 11-year activity cycle
- Attributed to convection patterns and differential rotation
- Differences between solar min. and max.
  - Solar min: low # of sunspots, sun has dipolar field
  - Solar max: high # of sunspots, sun has multipolar field
- Coronal holes tend to be more prevalent on the descending phase
- Weaker cycles mean less frequent but more extreme space weather



Credit: ASU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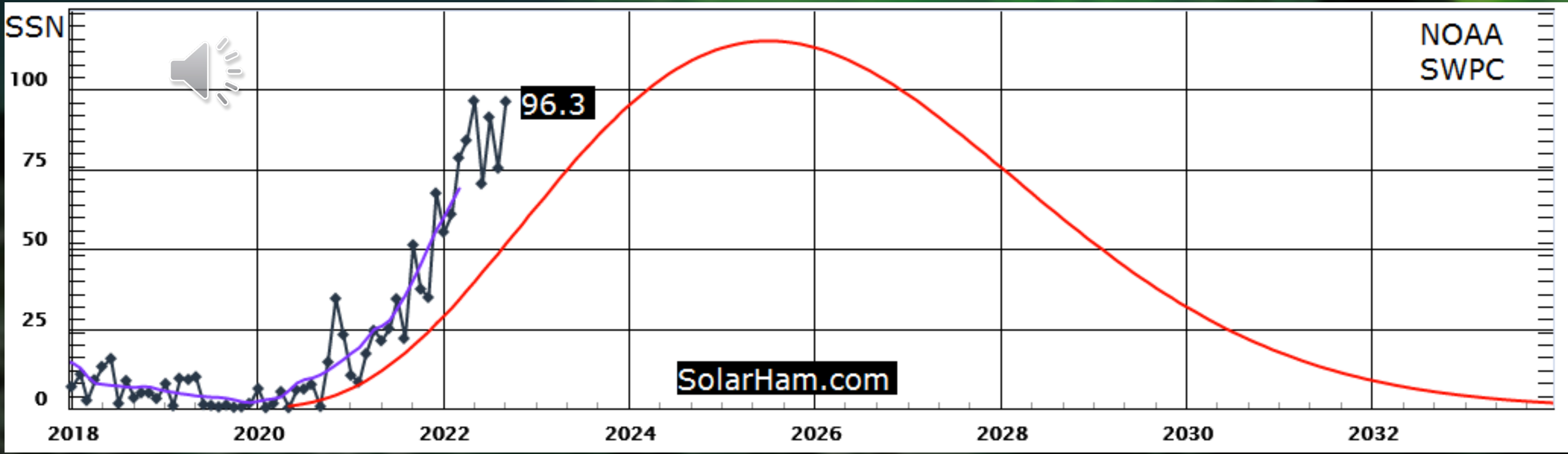
SOLAR CYCLE 25
imgflip.com

Credit: ESA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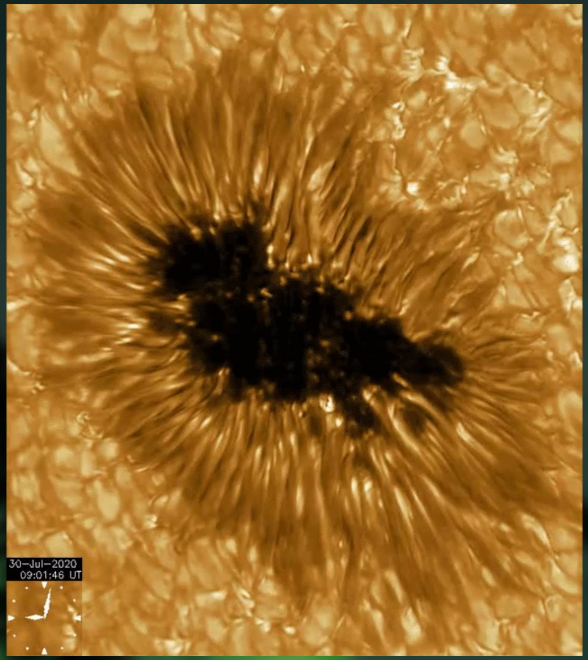
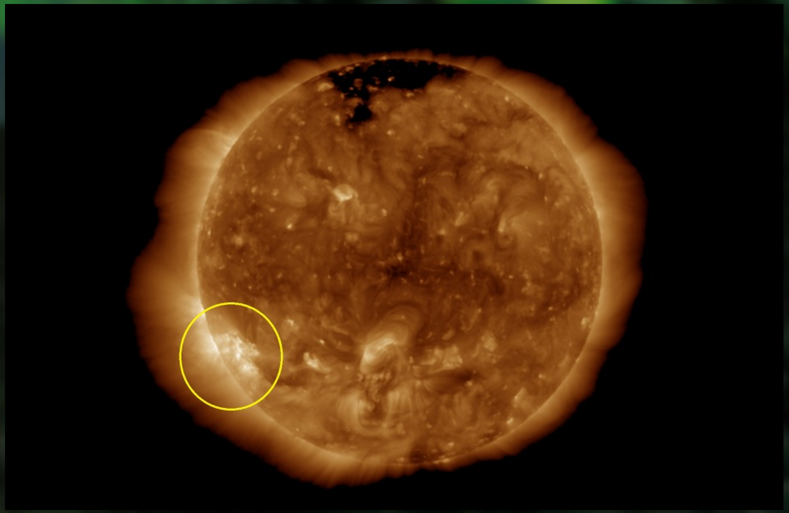
Sunspots

Sunspots are sources of space weather

- Magnetically-instable regions
- Appear dark in white light: cooler in temp.
- Appear bright in EUV; lots of magnetic activity
- Sunspots are sources of solar flares and coronal mass ejections (CMEs)
- Number of sunspots varies with the solar cycle



Credit: Teide Observatory

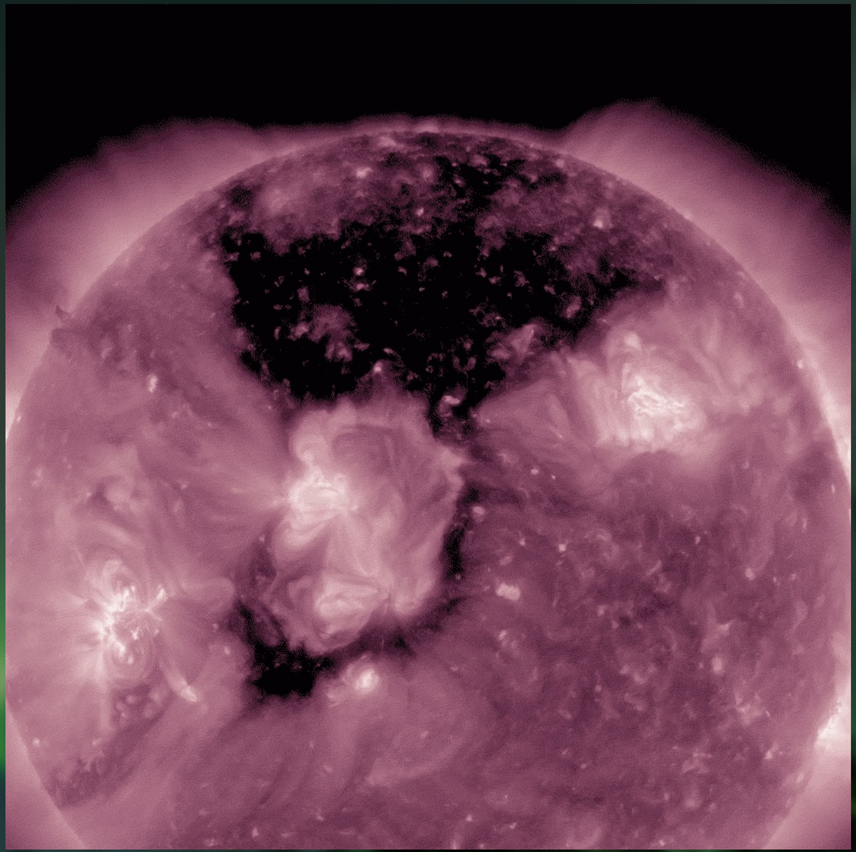


Credit: NASA/SDO

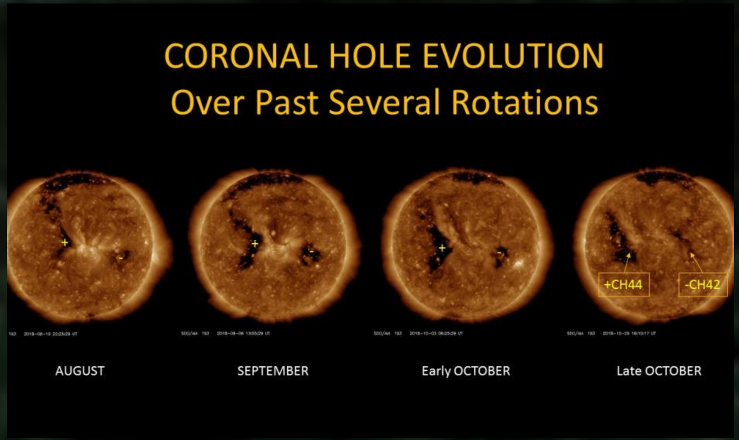
Coronal Holes

Coronal Holes are sources of space weather

- Open magnetic field lines
- Solar wind is free to escape
  - Creates stream interaction regions and coronal hole high speed streams
  - Ambient solar wind ~350 km/s; CHHSS ~500-700 km/s
- There is NOT an actual hole in the Sun ☺



Credit: NASA/SDO



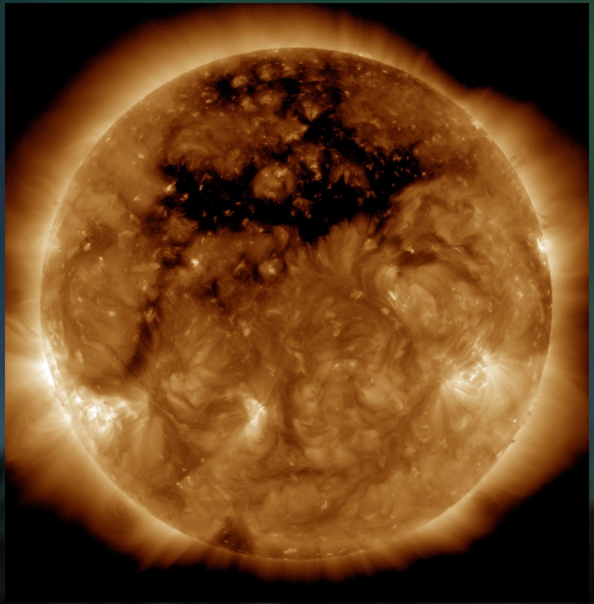
Prominence/Filament

- Loops of hot plasma high above the solar surface
- Can last from days to months
- May become unstable and erupt, leading to a coronal mass ejection
- A prominence is just a filament viewed from the side

Credit: NASA/SDO

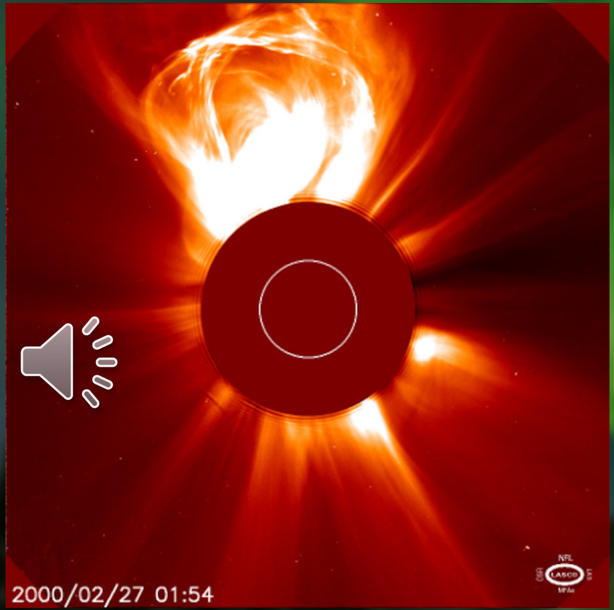
Space Weather – An Overview

Space weather refers to conditions around a star, like our Sun, and its interplanetary space that may affect space- and ground-based assets as well as human life.



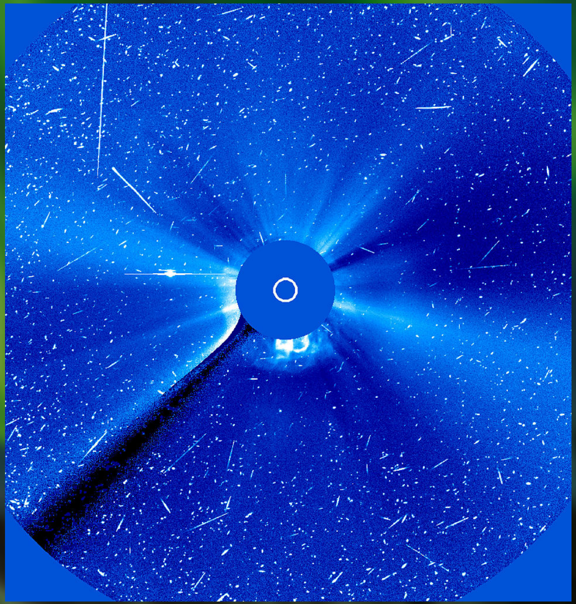
High Speed Streams

Credit: NASA/SDO



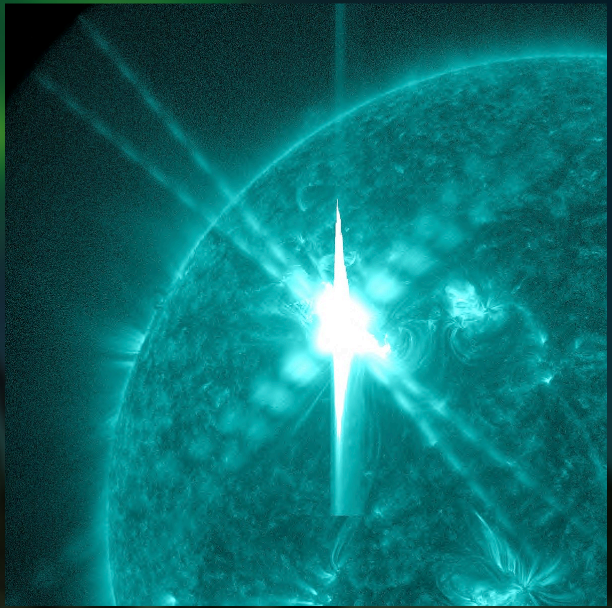
CME

Credit: NASA/SOHO



Radiation Storm

Credit: NASA/SOHO

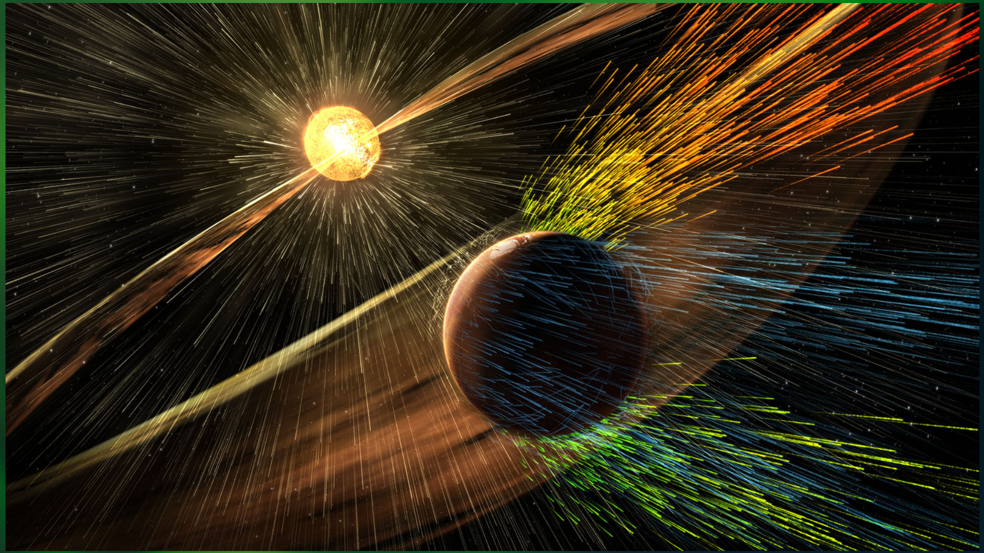


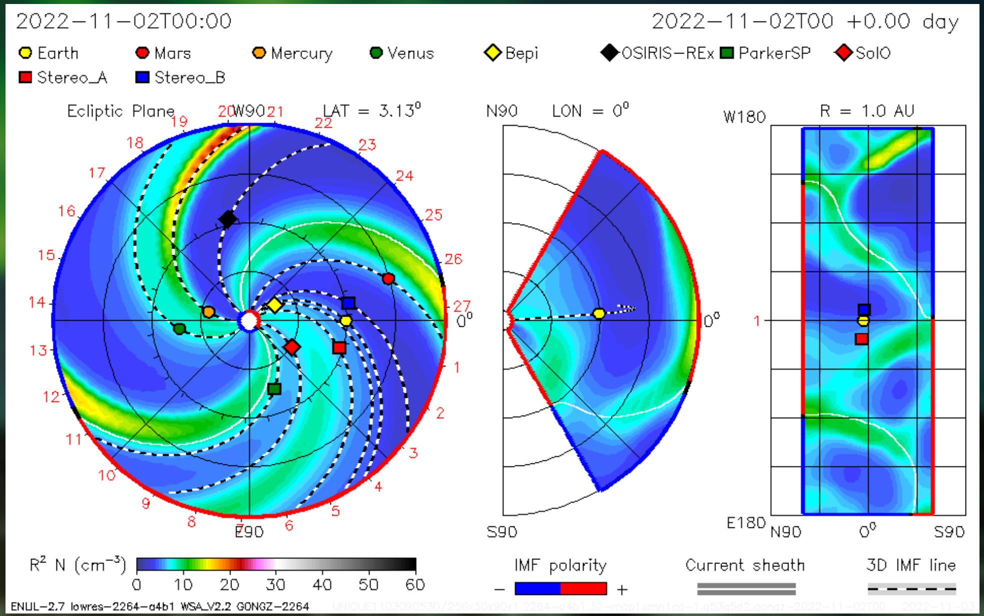
Solar Flare

Credit: NASA/SDO

The Solar Wind

- Constant stream of charged particles coming from the Sun
  - Mainly protons and electrons
- Charged particles (plasma) carries with it a magnetic field called the interplanetary magnetic field (IMF)
- Solar wind can become "enhanced" and is dynamic due to space weather
- Frequently measured properties include B-field strength (total and component), speed, density, and temperature

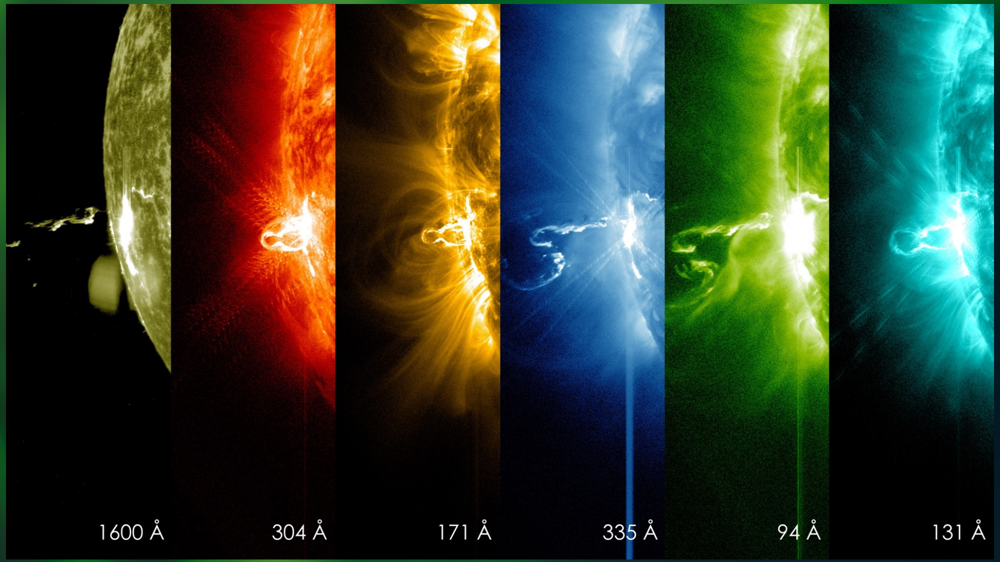




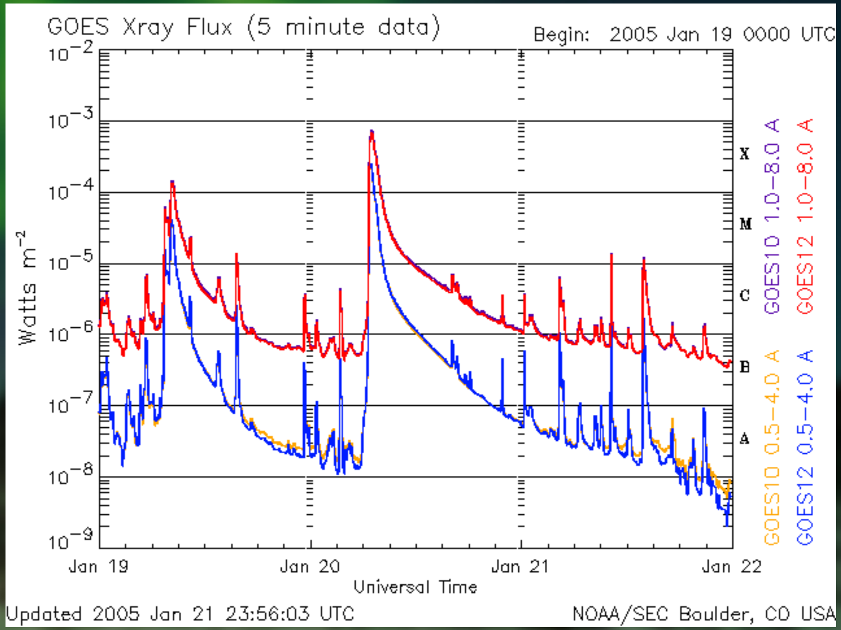
Credit: NASA

Solar Flares

- Sudden bursts of electromagnetic radiation, usually from sunspots
- Impulsive vs. long-duration events (LDE)
  - LDE almost always implies a CME is associated
- Can cause radio blackouts, trigger CMEs and radiation storms
- Do not directly cause aurora
- Measured on a scale from A (weakest) to X (strongest)



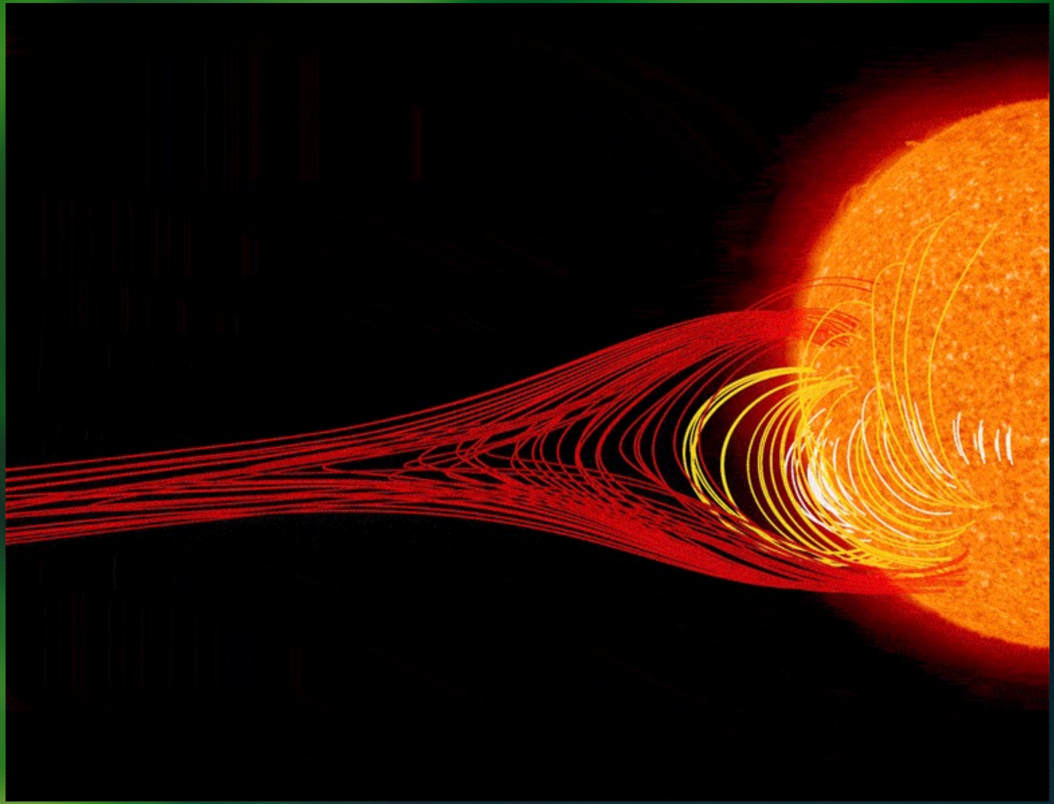
Credit: NASA/SDO

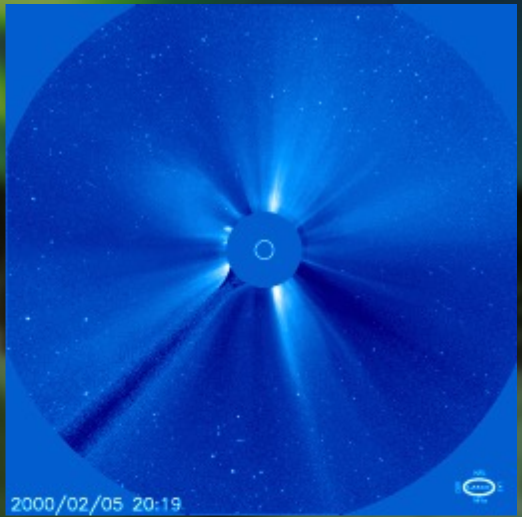


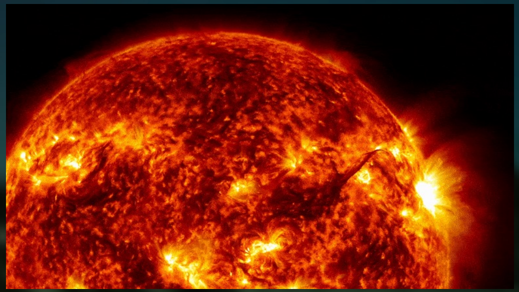
Credit: NOAA/GOES

Coronal Mass Ejections

- Large eruptions of charged particles into interplanetary space, occasionally directed toward Earth
- Contains their own magnetic fields in the form of magnetic flux ropes "slinkies."
- Frequently coincident with solar flares but can also happen spontaneously
- Coronagraphs can be used to detect CMEs
- Can cause geomagnetic storms increasing aurora potential







Credit: NASA/SO, NASA/SOHO

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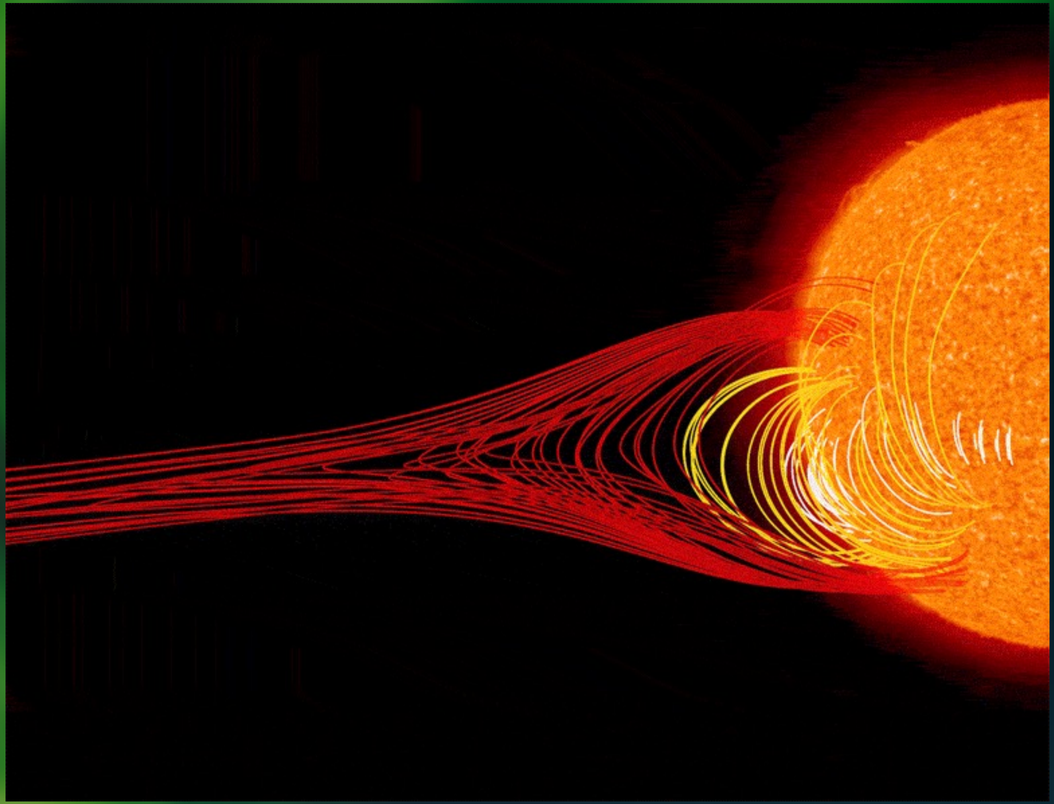
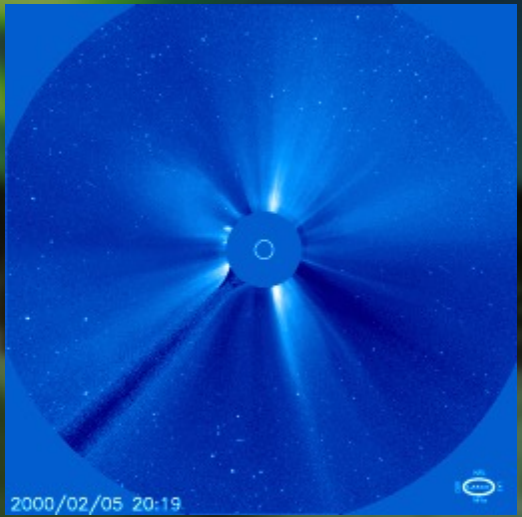
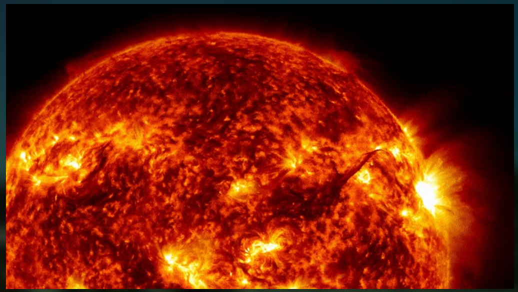


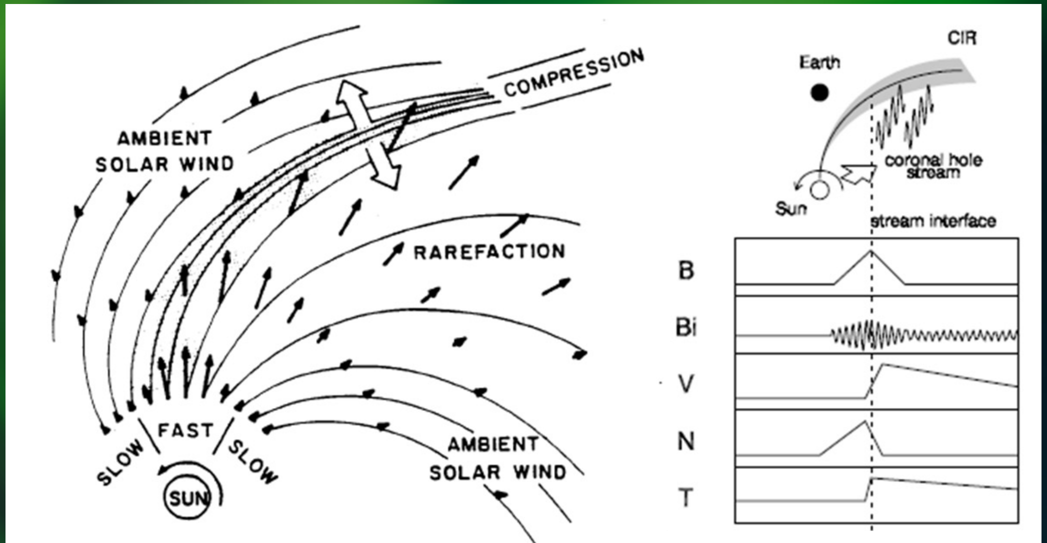




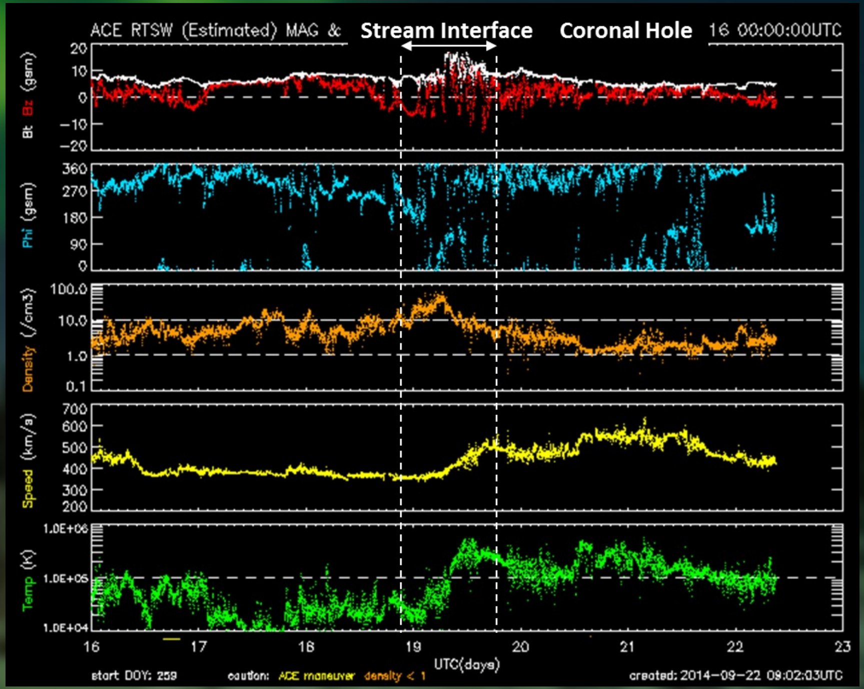
Credit: NASA/SO, NASA/SOHO

High Speed Streams

- Come from coronal holes
- Propagate with the solar wind
- Act as a snowplow and creates a stream-interaction region (SIR) ahead of the fast wind.
  - SIR is also called a CIR in many cases
- Can cause geomagnetic storms
- Predictable and since CH's often time last 2+ solar rotations, 27-day KP forecast includes geomagnetic storms from CHHSS



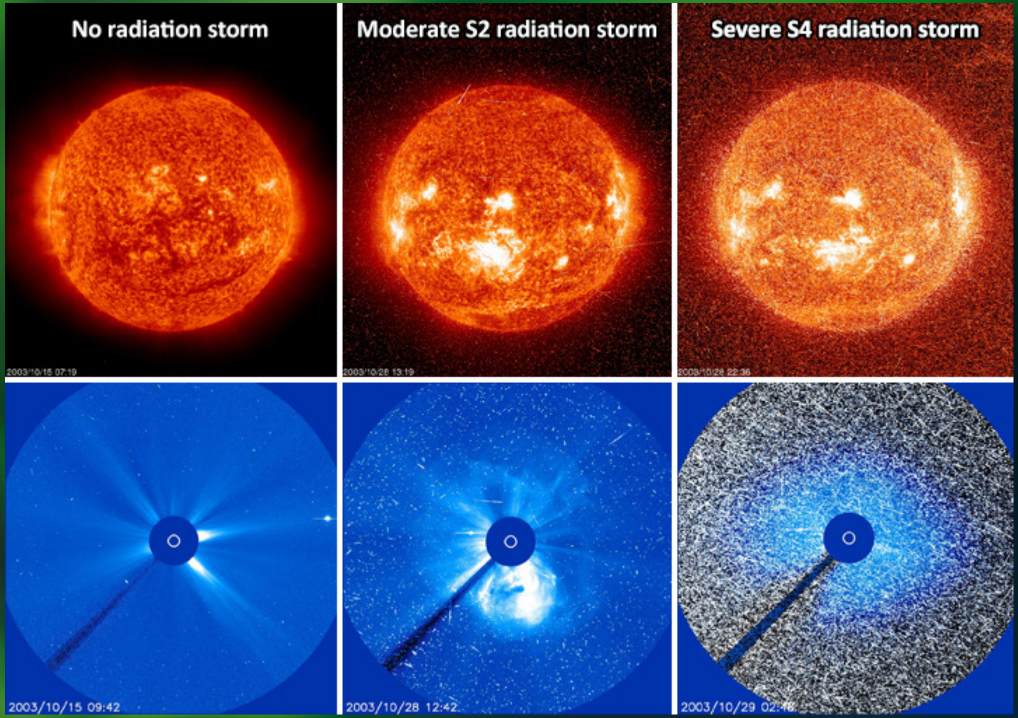
Pizzo, 1978



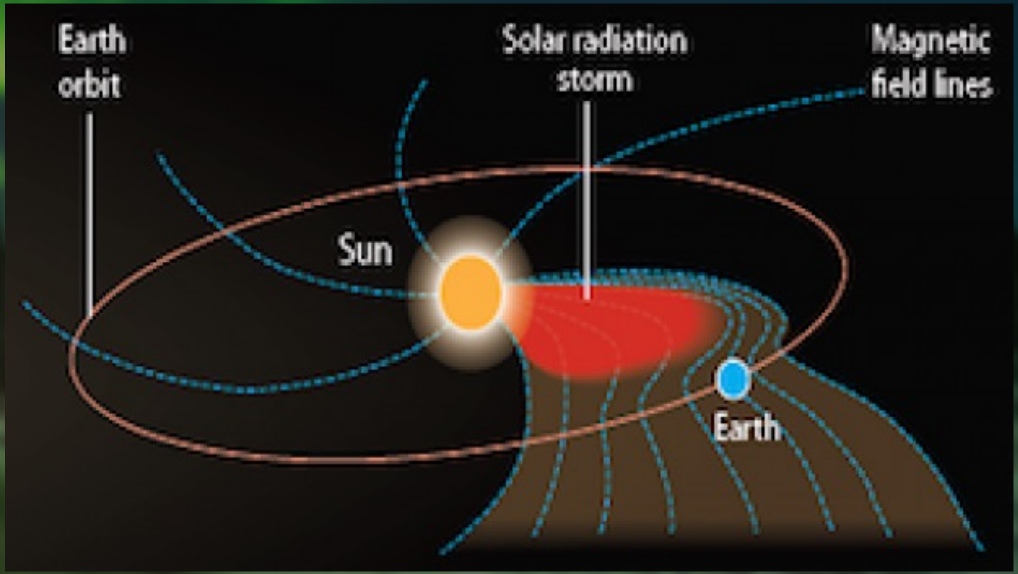
Credit: Solar-Terrestrial Centre of Excellence

Radiation Storms

- Relativistic electrons and protons released during a solar flare
  - CMEs can also sweep up the particles
- Potentially harmful effects for electronics and humans at high latitudes and altitudes
- No major effects that relate to aurora

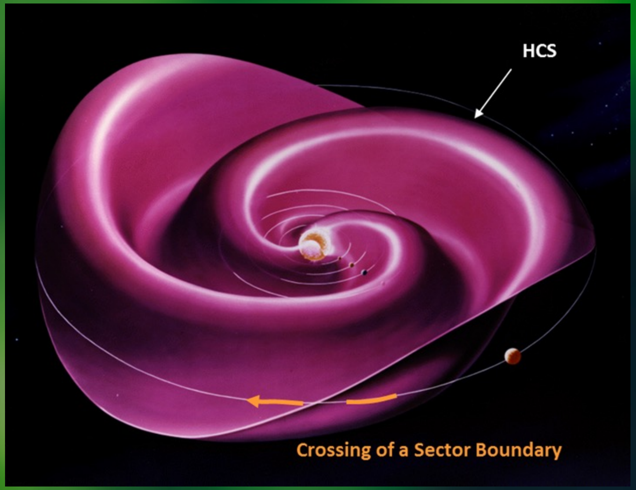


Credit: NASA, NOAA

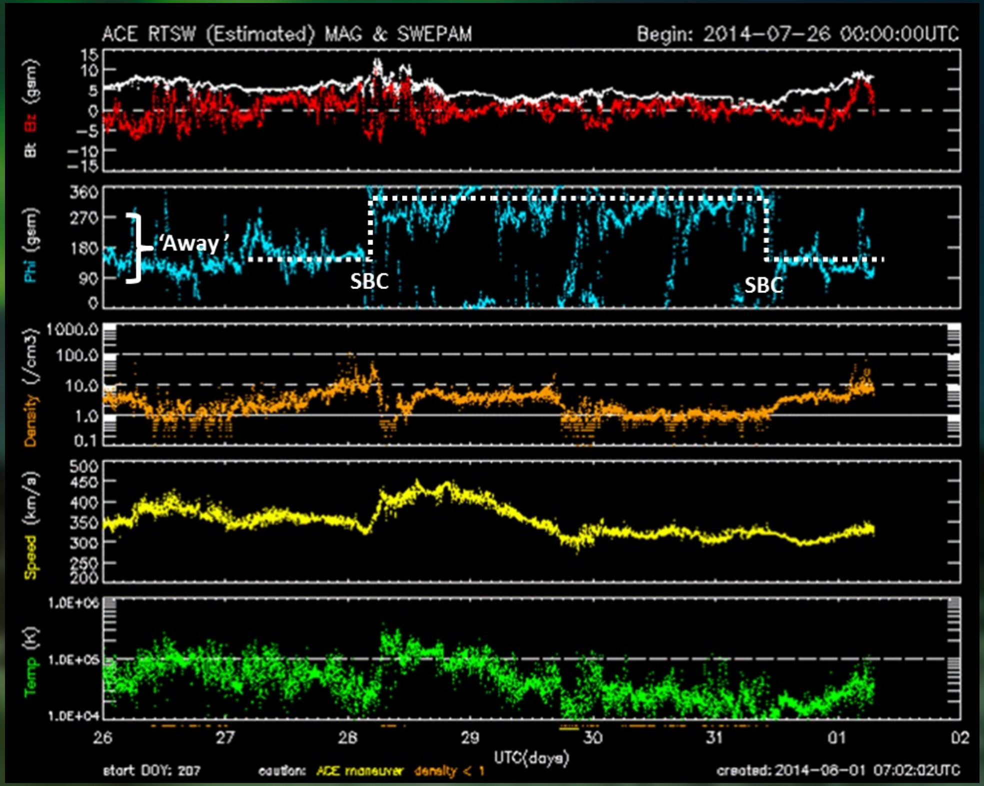


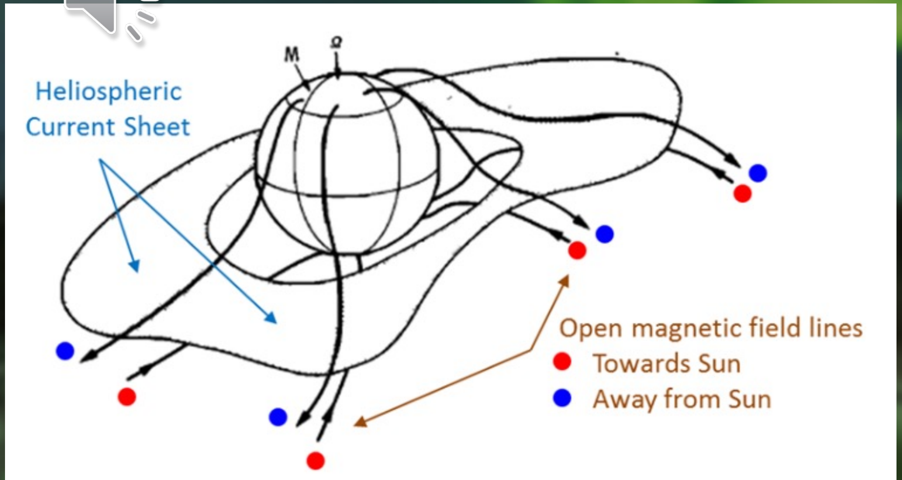
Other Phenomena

- Sector Boundary Crossing (SBC)
  - Occurs when we cross the heliospheric current sheet and field switches polarity
  - Sometimes accompanies changes in speed, density, field strength
  - Not a major factor for auroras



Credit: Solar-Terrestrial Centre of Excellence



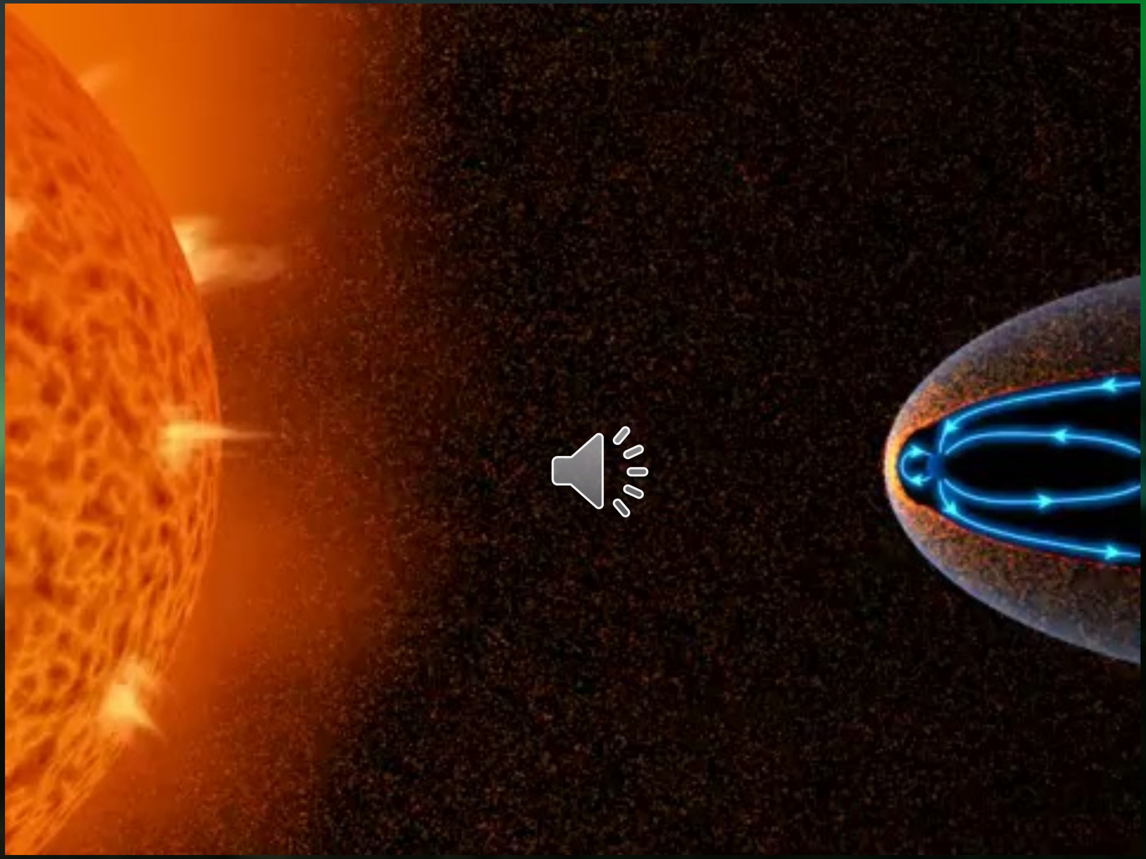


Adapted from Smith et al., 1978

The Magnetosphere – An Overview

Solar wind particles are streamed along Earth's magnetic field lines creating auroral ovals centered around the geomagnetic poles.

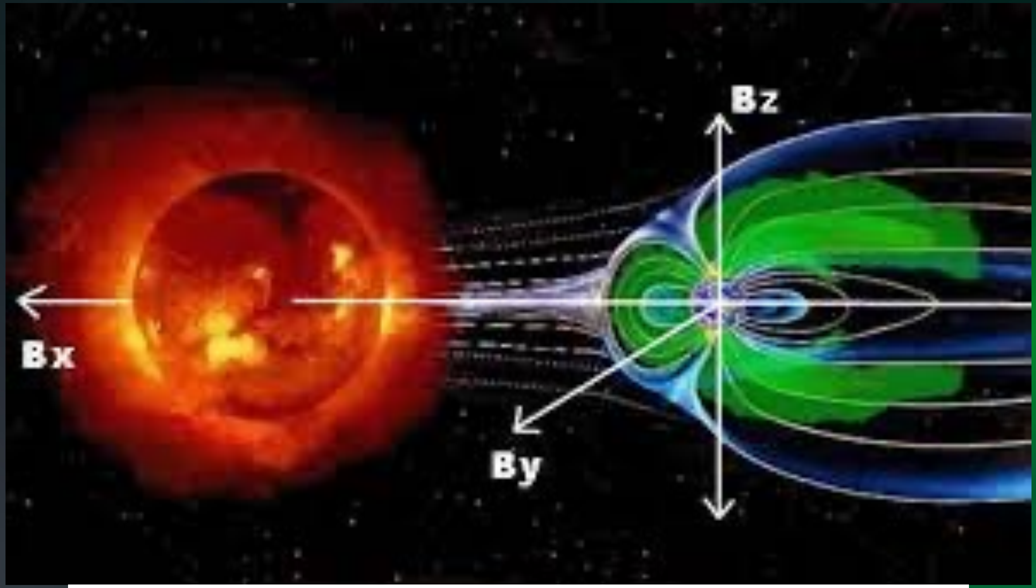
- Earth's magnetic field lines on the dayside get peeled back by solar wind and convected to the night side
- Magnetic reconnection occurs in the magnetotail, funneling particlces into the inner magnetosphere like a "slingshot"

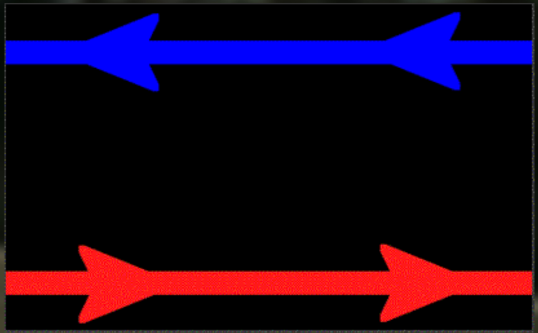


Credit: Aurorasaurus

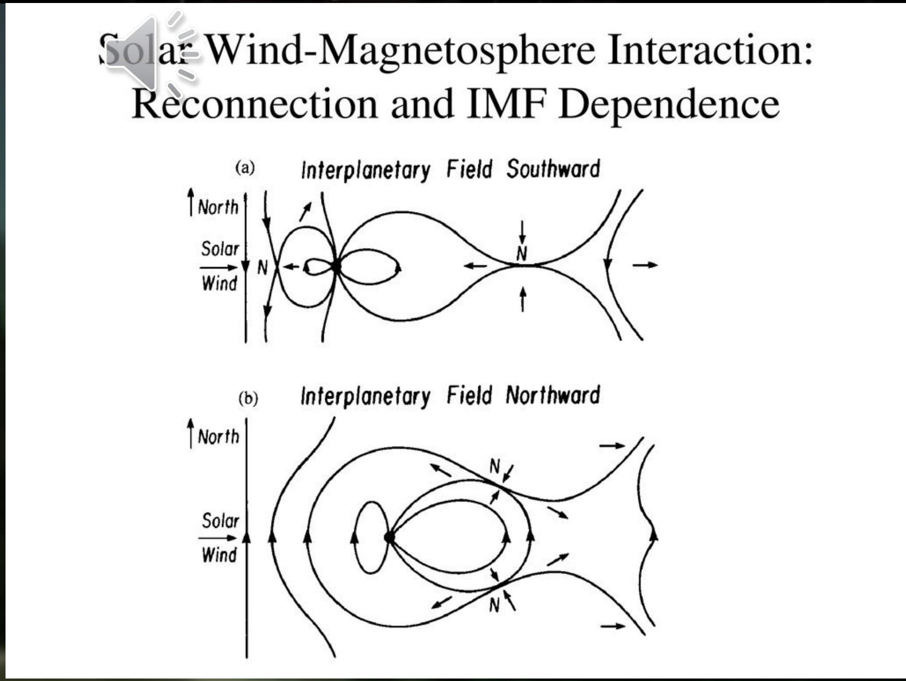
Why "Bz south" matters

- The amount of energy transferred into the magnetosphere is dependent on the orientation of the IMF
- Earth's magnetic field flows south to north (Bz=north) so if solar wind is Bz=south, magnetic fields can interact leading to maximum magnetic reconnection





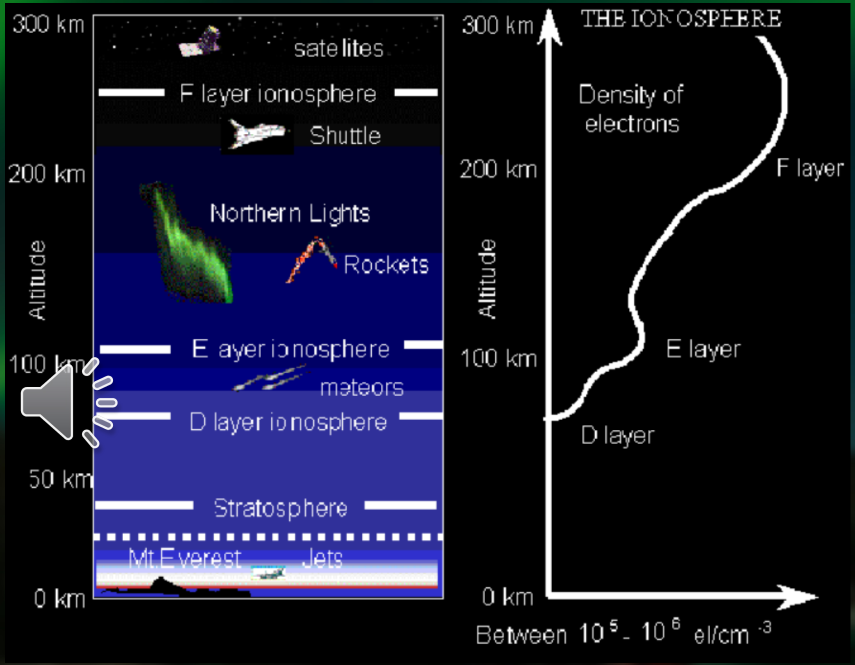
Credit: ESA



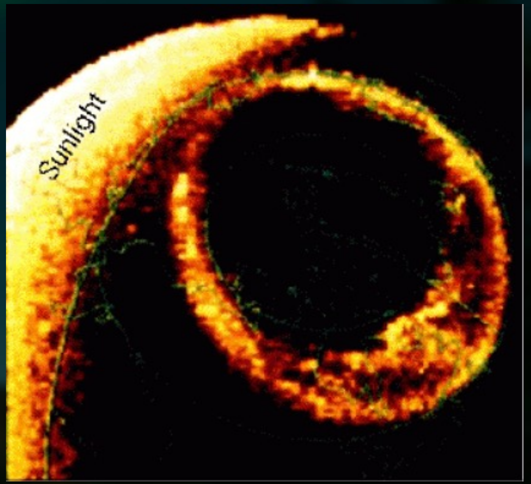
Credit: NASA CCMC

The Ionosphere – An Overview

- Series of layers in the Earth's upper atmosphere with high concentration of charged particles
- Protons and electrons from the magnetosphere precipitate into the ionosphere
- Auroral ovals are formed in a region usually a few degrees wide around 65-75º MLAT.



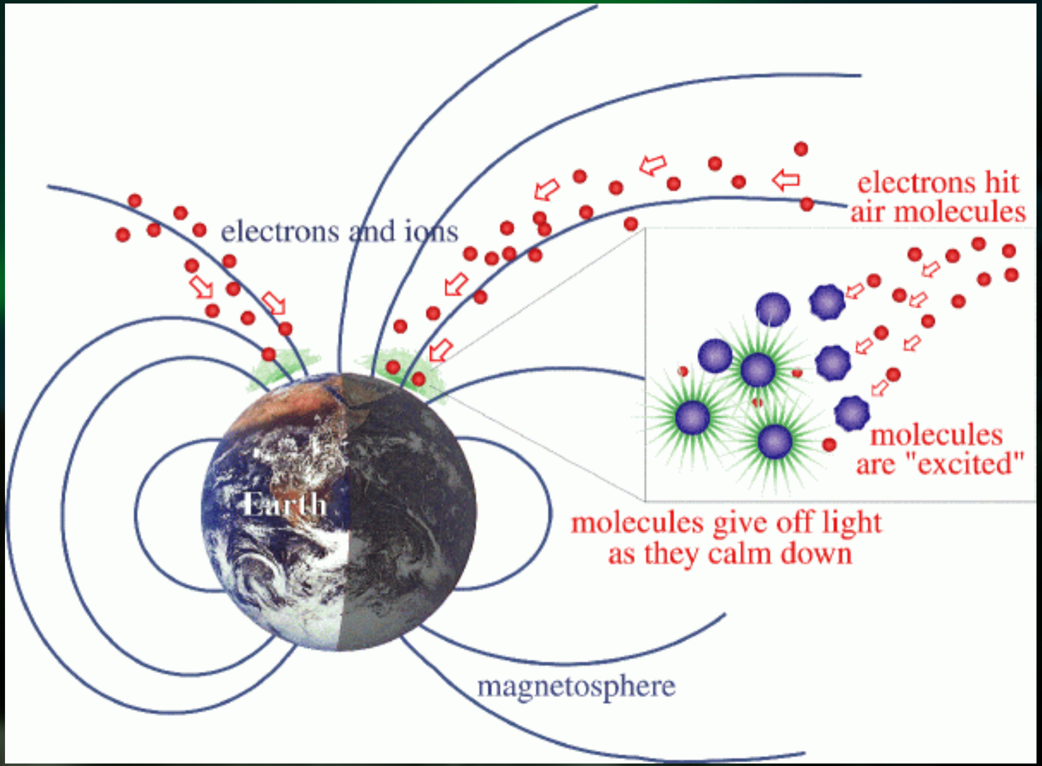
Adapted from Bamford (2000)



Actual picture of an auroral oval from 1996
Credit: NASA

How the Aurora is Created

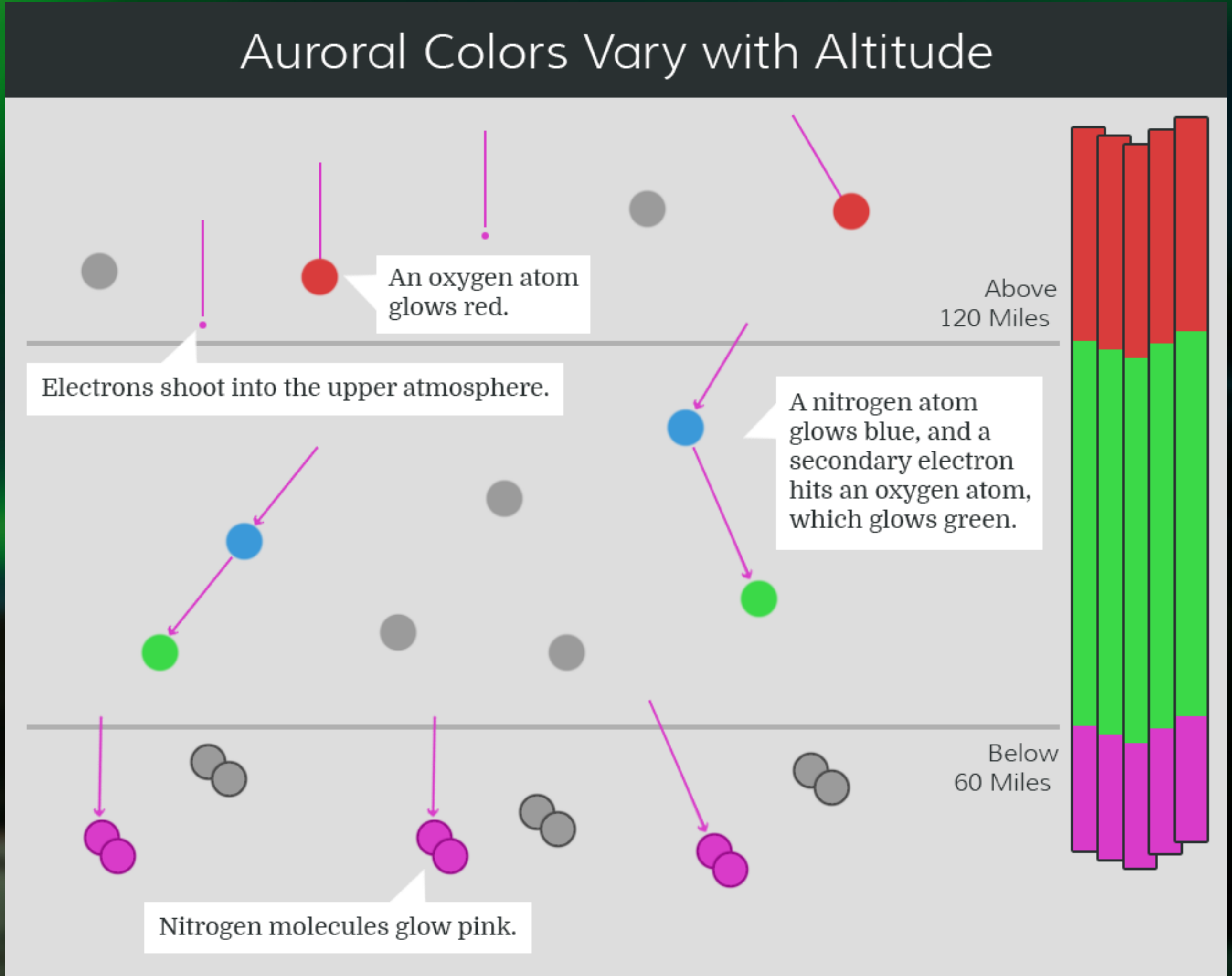
- Auroras are formed by chemical interactions
- Magnetospheric particles interact with ionospheric particles, collisions take place
- Atmospheric particles become excited but when they return to ground state, emit photons in specific wavelengths according to the particle being excited



Credit: EarthSky

Colors and Altitudes

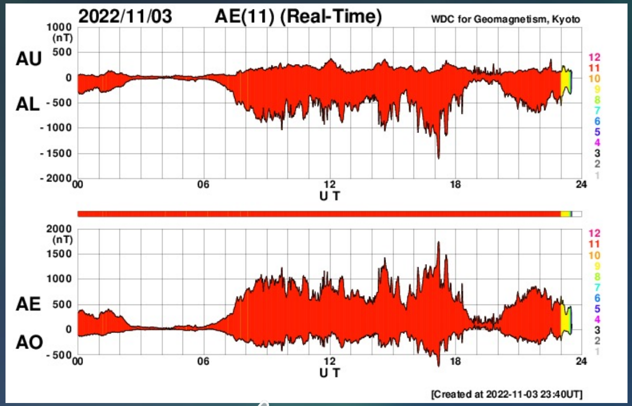
- The color of the aurora depends on the type of atmospheric gas being excited
- Different altitudes contain different gases, therefore the colors are also altitude dependent



Credit: Aurorasaurus

Aurora Chasing Resources/Advice

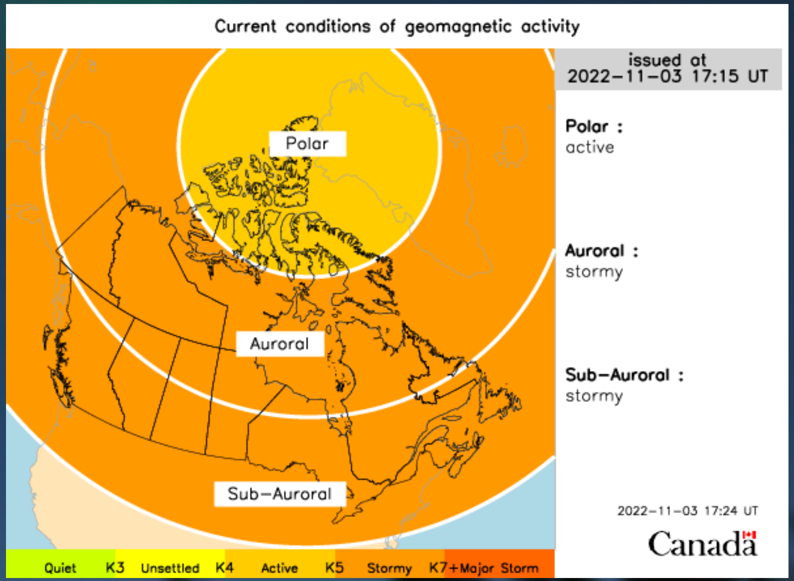
- Stop using KP!
  - Use AE instead!
  - Look for values >500 nT
- The OVATION PRIME model is just that… a *model*
  - It can't forecast substorms, STEVEs, etc.
  - Doesn't consider things like the flywheel effect
- Solar flares ≠ CMEs



Credit: World Data Center for Geomagnetism

Aurora Chasing Resources/Advice

- Solarham.net is a great site with tons of data readily available
- Spaceweatherlive is great for notifications of KP thresholds reached, flares, radio bursts, etc.
- Aurorasaurus for citizen scientist reports + data is helping science!
- Spaceweather.gc.ca gives local K-indices
  - KP is K "Planetary"; you can get local k-indices, too!
- NOAA products
  - ENLIL, OVATION Prime, Real-Time Solar Wind



Credit: spaceweather.gc.ca

Wrapping it up “from Sun to Mud”

- The Sun and its space weather largely control the aurora and its strength
- The solar wind constantly buffets our planet with plasma
- CMEs and Coronal Holes (HSS+SIR) are the two main space weather sources of aurora
- IMF direction determines how much energy is transferred into Earth’s magnetic system (think Bz)
- Particles from the magnetosphere precipitate into Earth’s polar regions, creating auroral ovals
- Auroras are formed by chemical reactions in the ionosphere

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Questions and Discussion