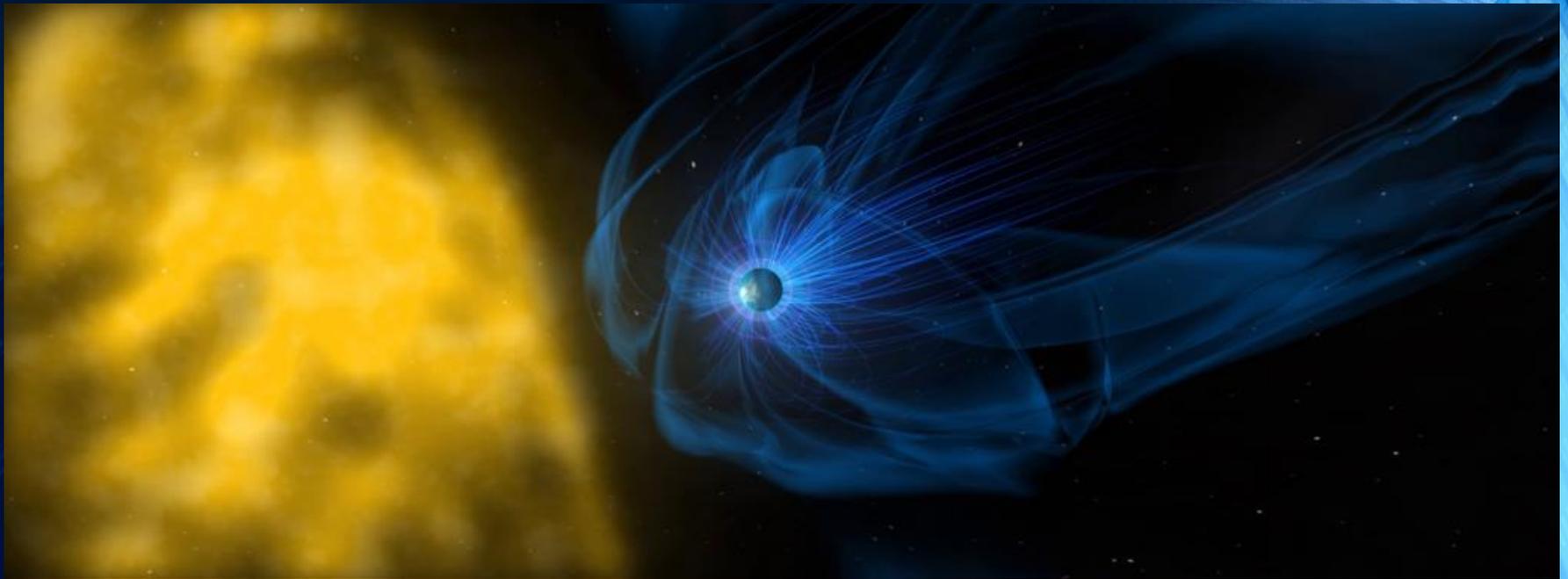


Space Weather

AN INTRODUCTION

Stanislav Sazykin (Rice University)

(with material from SWREDI 2017 bootcamp (A. Pulkkinen, NASA GSFC), MIT Haystack Observatory (A. Coster), and NASA GSFC Visualization Studio)



What is Space Weather?

- Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses.

Heliophysics

helio-, pref., on the Sun and environs, from the Greek helios.

physics, n., the science of matter and energy and their interactions.

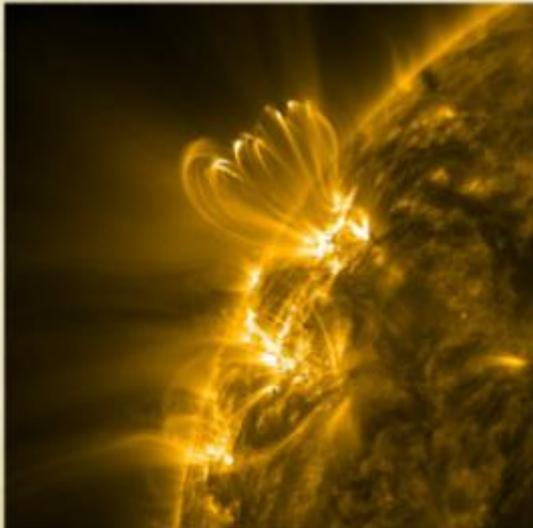
Heliophysics is the

- *comprehensive new term for the science of the Sun - Solar System Connection.*
- *exploration, discovery, and understanding of our space environment.*
- *system science that unites all of the linked phenomena in the region of the cosmos influenced by a star like our Sun.*

Heliophysics concentrates on the Sun and its effects on Earth, the other planets of the solar system, and the changing conditions in space. Heliophysics studies the magnetosphere, ionosphere, thermosphere, mesosphere, and upper atmosphere of the Earth and other planets. Heliophysics combines the science of the Sun, corona, heliosphere and geospace. Heliophysics encompasses cosmic rays and particle acceleration, space weather and radiation, dust and magnetic reconnection, solar activity and stellar cycles, aeronomy and space plasmas, magnetic fields and global change, and the interactions of the solar system with our galaxy.

Physics of Space Weather

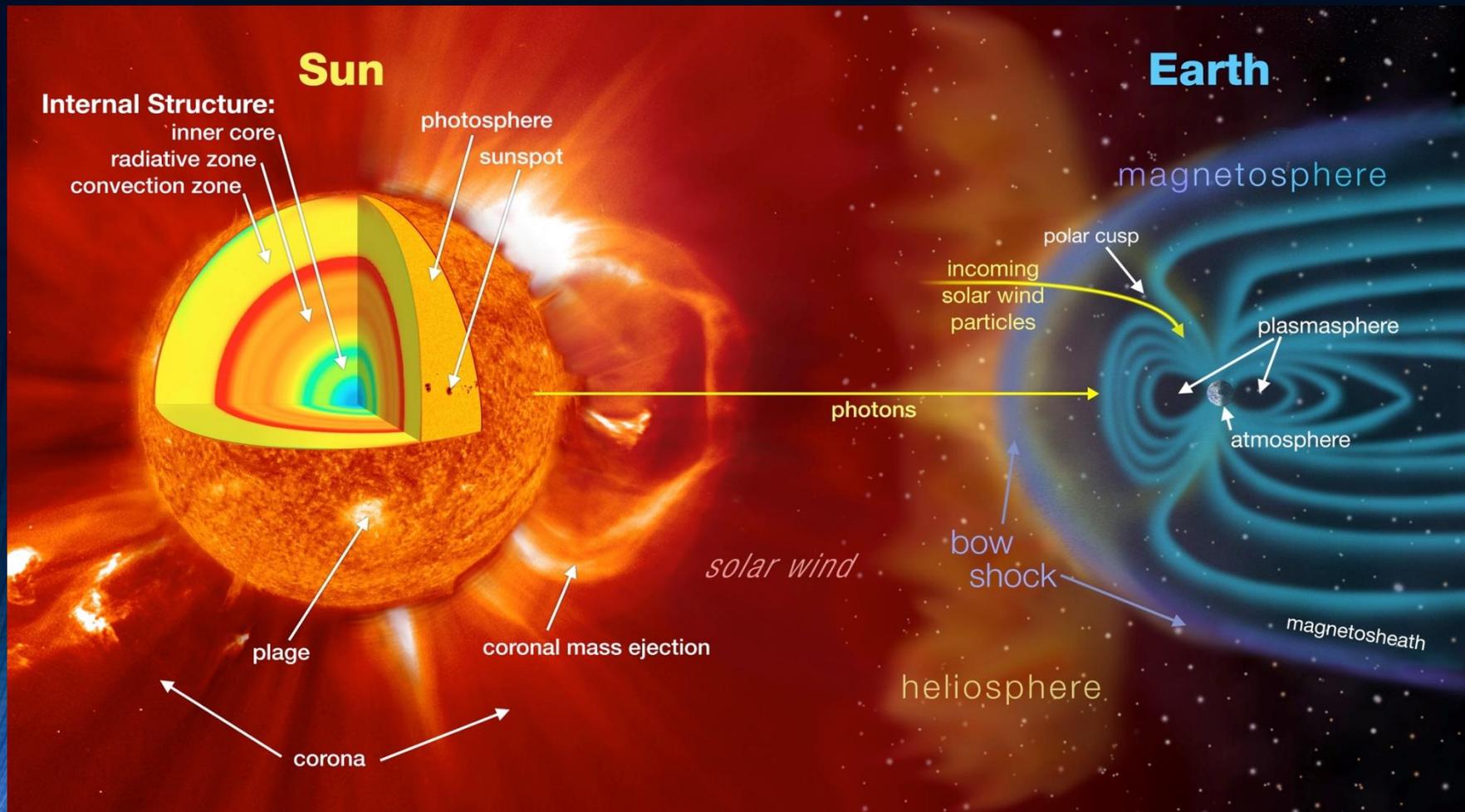
- The physics of space weather is plasma physics.
- “Plasma is quasi-neutral ionized gas containing enough free charges to make collective electromagnetic effects important for its physical behavior”

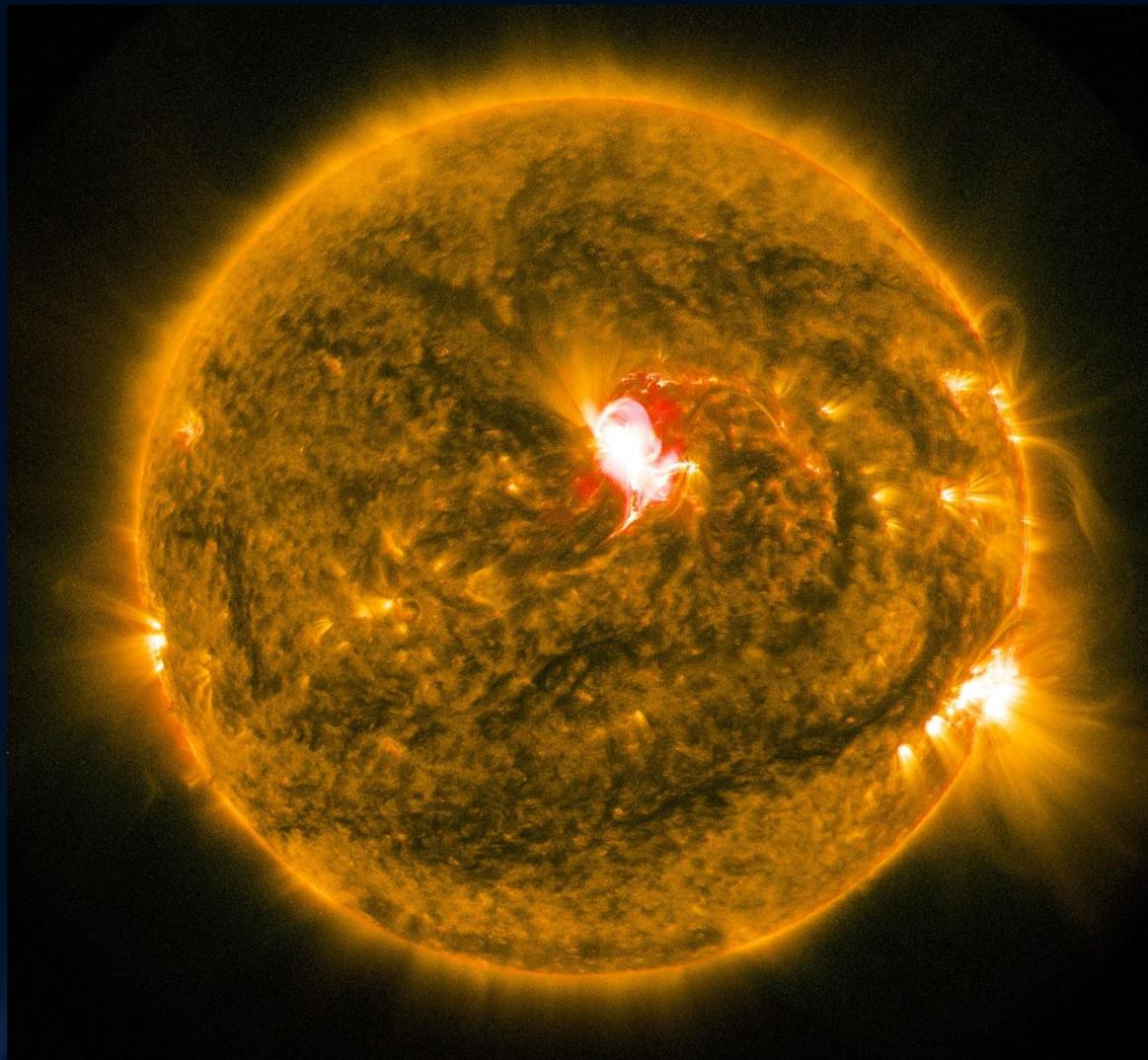


EUV image of solar corona
(credit: NASA SDO)

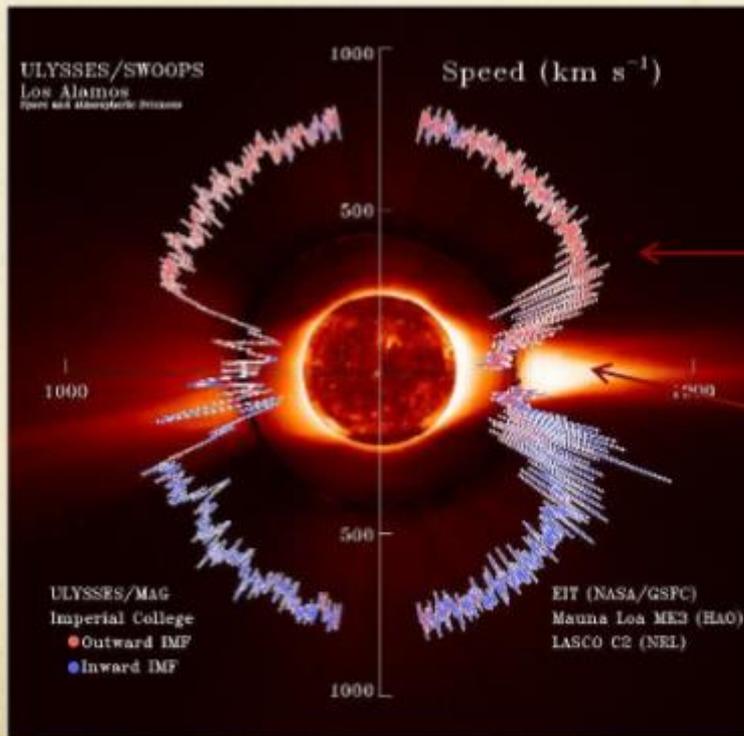


Image of auroras at visible wavelengths
(credit: spaceweather.com)





Solar atmospheric mass, momentum and energy are being carried away by *solar wind*.



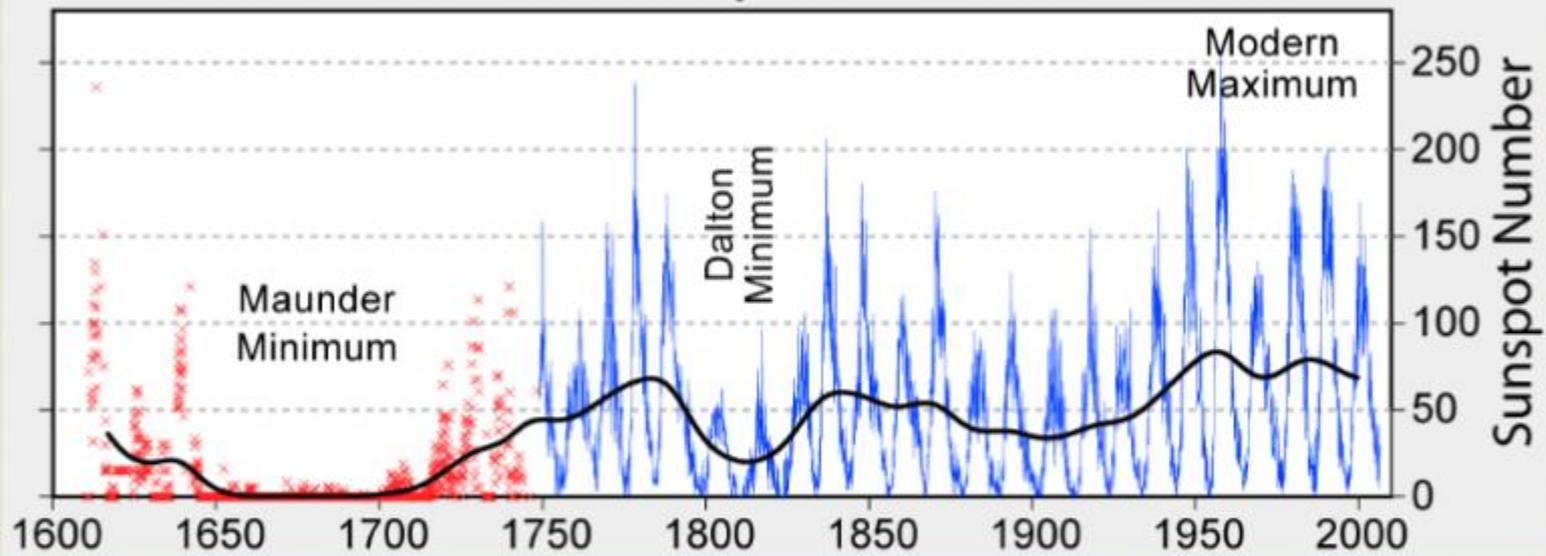
NASA/ESA Ulysses spacecraft data from 1.3-5.3 AU (credit: NASA/ESA)

Fast wind from coronal hole(s)

Denser low speed wind from lower latitudes

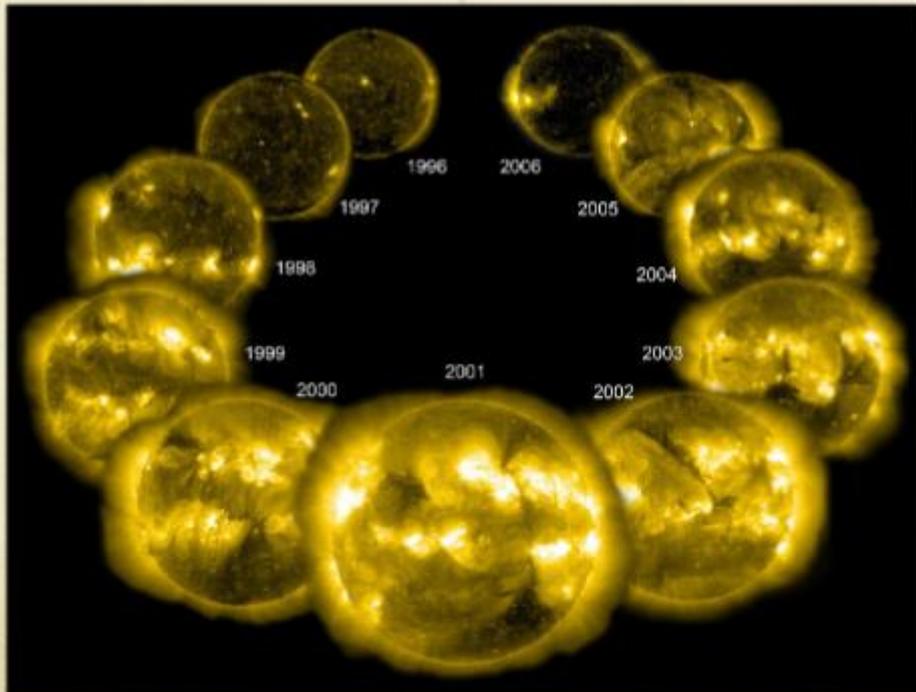
Credit: Wikipedia/Solar_cycle

400 Years of Sunspot Observations



Increasing sunspot number indicates more complex global solar magnetic field structure → eruptions more likely

As the global solar magnetic field structure gets more complicated also plasma configurations in the solar corona gain *complexity*.



SOHO EIT 284 Angstrom
images (2 million degree
plasma)

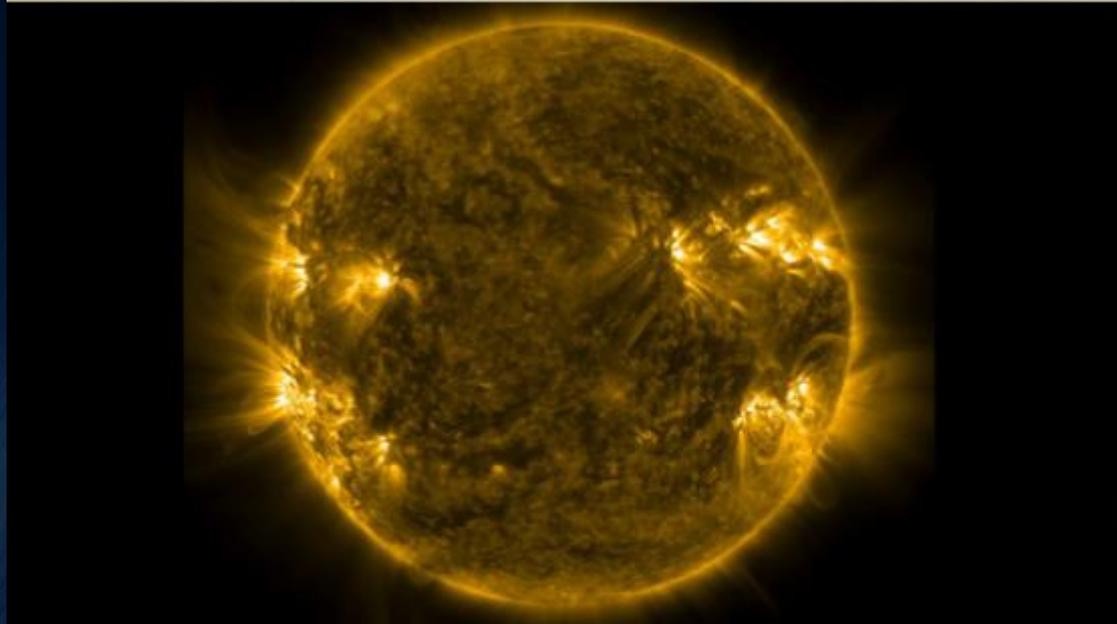
Credit: NASA/ESA

The build up of complexity in the corona is associated with build up of *free energy* in plasma configurations.

A variety of *plasma instabilities* such as flux tube instabilities are important for relaxation of plasma configurations in the solar corona.

However, we believe that *magnetic reconnection* plays the key role in converting the (magnetic) free energy into thermal and kinetic energy (plus electromagnetic radiation) of the transients.

Solar flares lasting, depending on the signature of interest, 1-60 min are the largest eruptions in the solar system. Energy of the order of 10^{25} J can be released by flares (annual world energy consumption $\approx 10^{20}$ J).



SDO AIA 171
Angstrom (1 million
degree plasma)

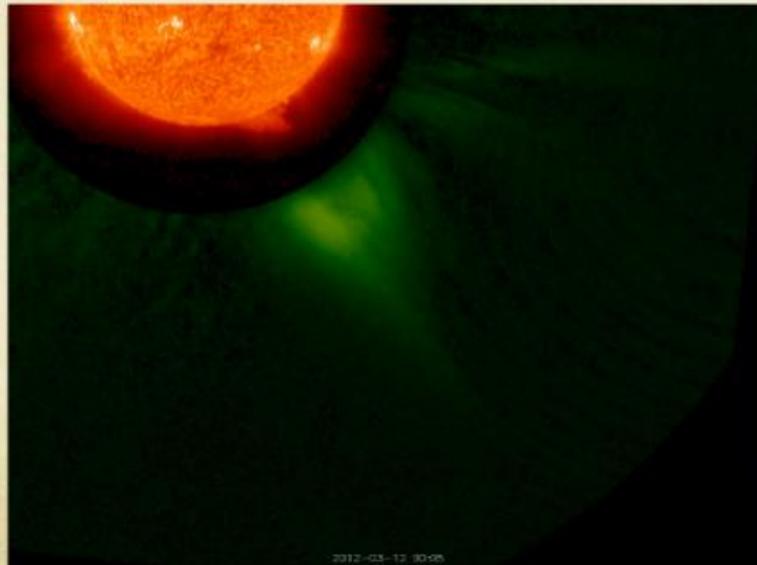
Credit: NASA GSFC
SVS

Generally speaking in solar flares free magnetic energy converted into heat, non-thermal particle acceleration and electromagnetic radiation.

Solar flares generate, for example, X-ray, Extreme Ultraviolet (EUV) and radio emissions, and solar energetic particles (SEPs).

All of the above have significant space weather consequences.

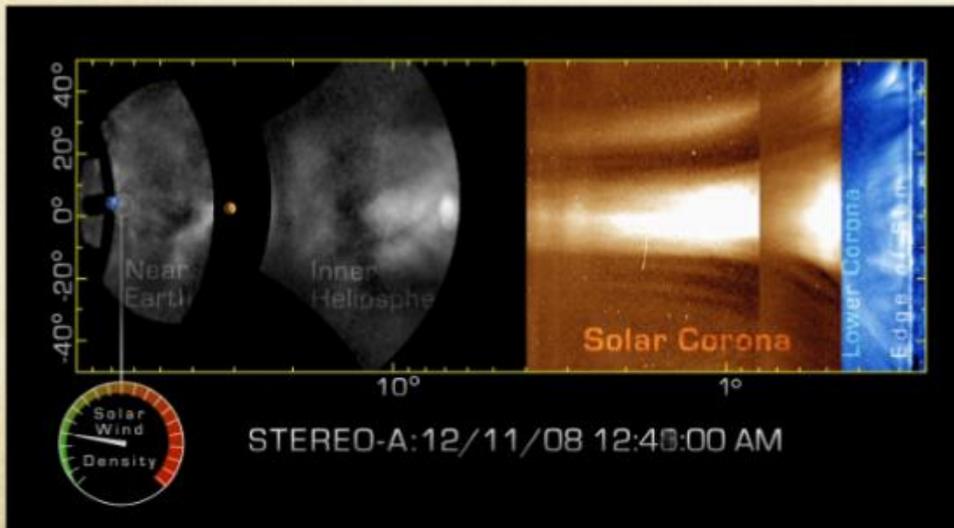
Many large flares are associated with *coronal mass ejections* (CMEs) releasing billions of tons of solar corona material at speeds of 200-3000 km/s. Total kinetic energy of CMEs can be of the order of 10^{25} J.



STEREO B 304 Angstrom
EUV and white light
coronagraph March 12, 2012

Credit: NASA

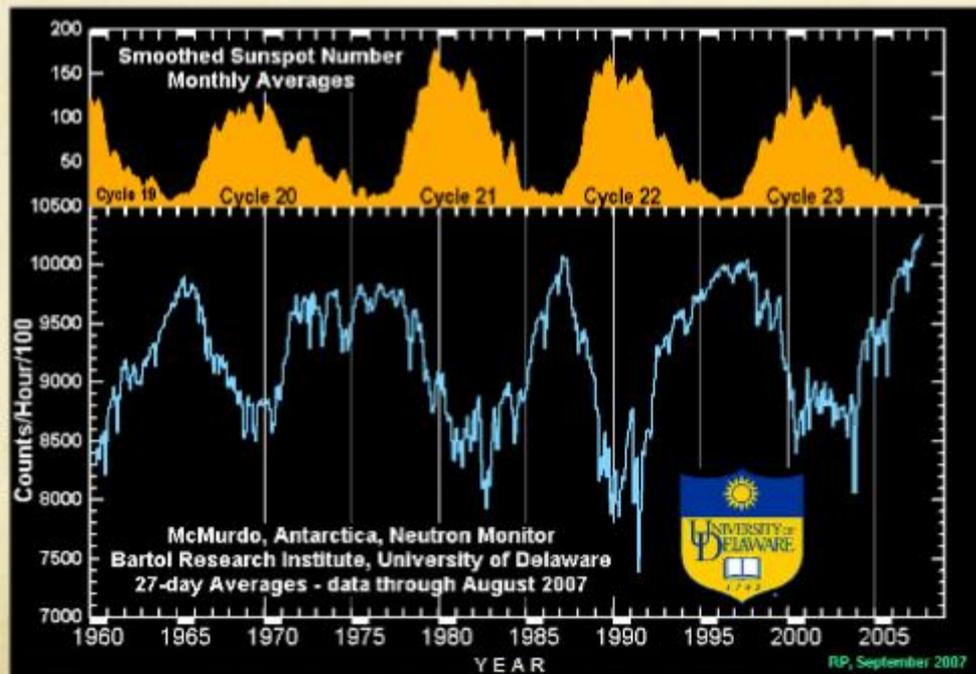
- CME eruptions drive shock waves that also accelerate charged particles. These particles generate the second (and often more significant) SEP component.
- CME propagation to the Earth takes typically 1-3 days.



STEREO A white light coronagraphs and heliospheric imagers
December 2008

Credit: NASA GSEC

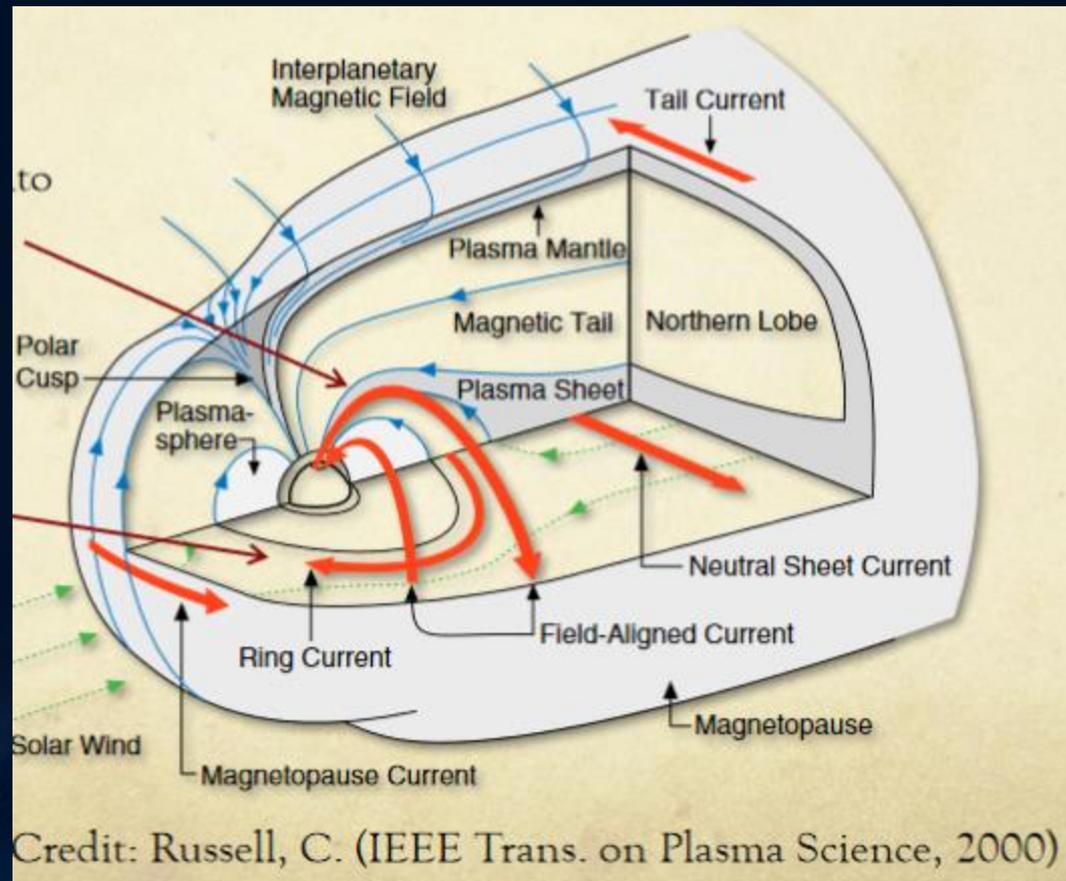
Also low flux but very energetic *galactic cosmic rays* (GCRs) coming from galactic sources contribute to charged particle radiation in the solar system.



Anti-correlation between solar activity and GCRs

Credit: University of Delaware

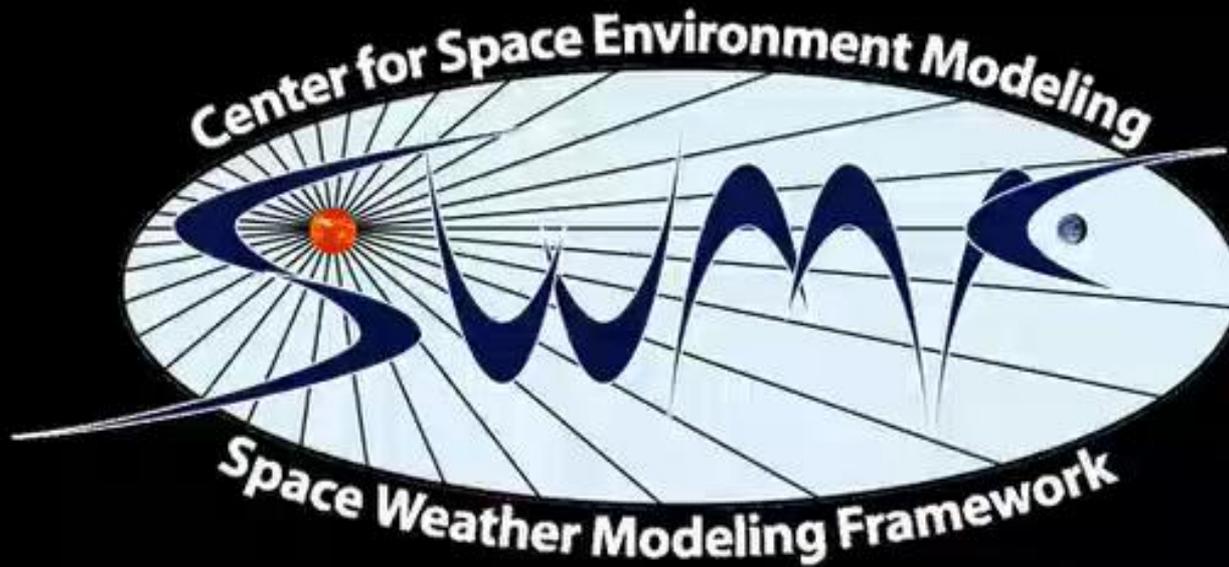
- Charged particles flowing from the Sun interact with the Earth's plasma environment called magnetosphere. Magnetic reconnection "opens up" magnetosphere to allow entry of mass, momentum and energy.



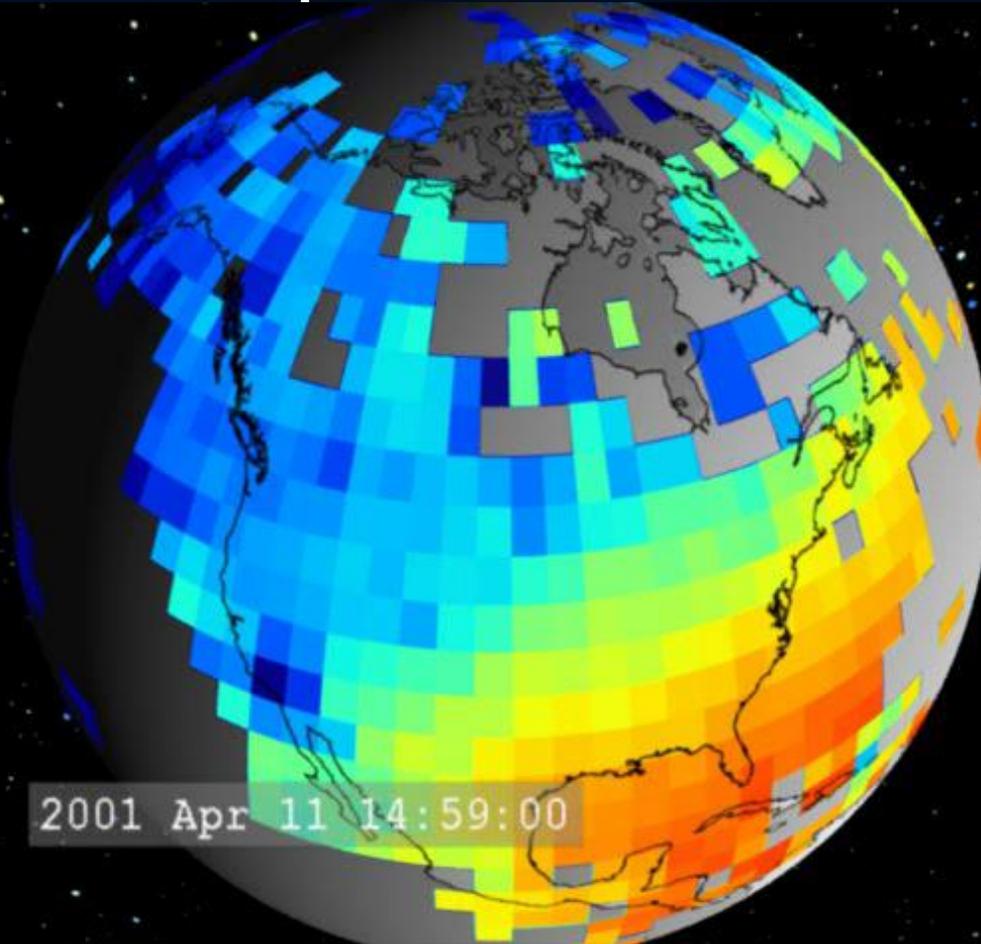
Solar Eruptions and Magnetic Storms



NASA/GSFC Scientific Visualization Studio.

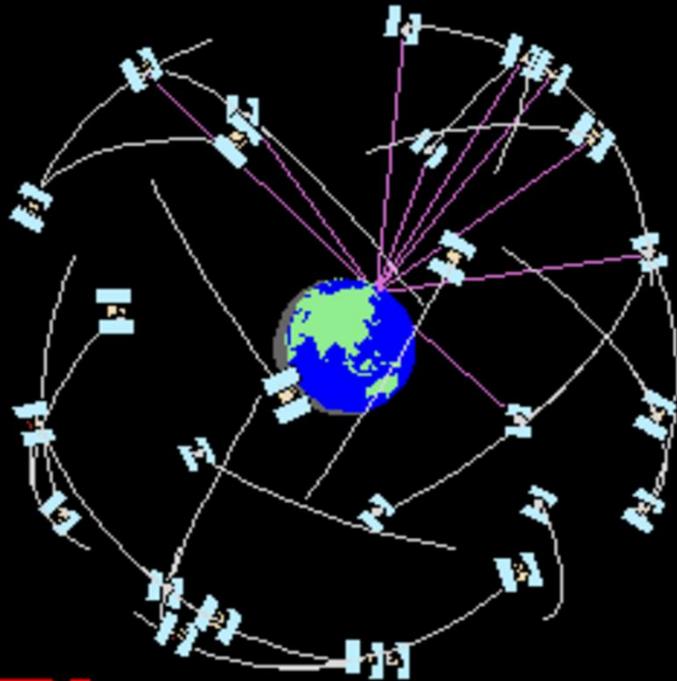


Magnetic Storms: Ionospheric Storms



WAAS

GPS Background



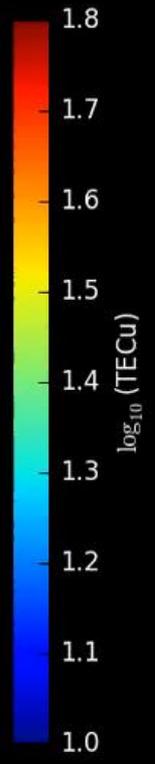
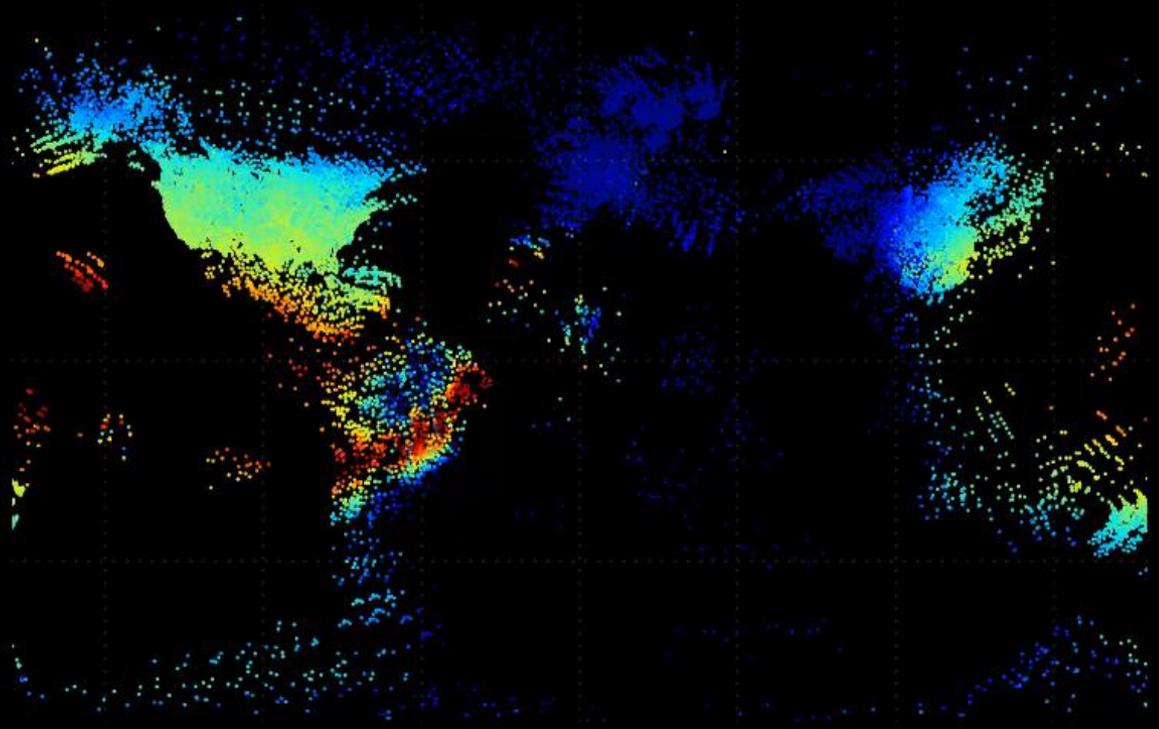
JPL

L. Romans

- at most 32 satellites
- 6 orbital planes
- 4~6 satellites per plane
- 55° inclination angle
- near circular orbit
- ~ 20000 km altitude
- ~12 hours round trip
(11 hour 58 min 2.05 sec)

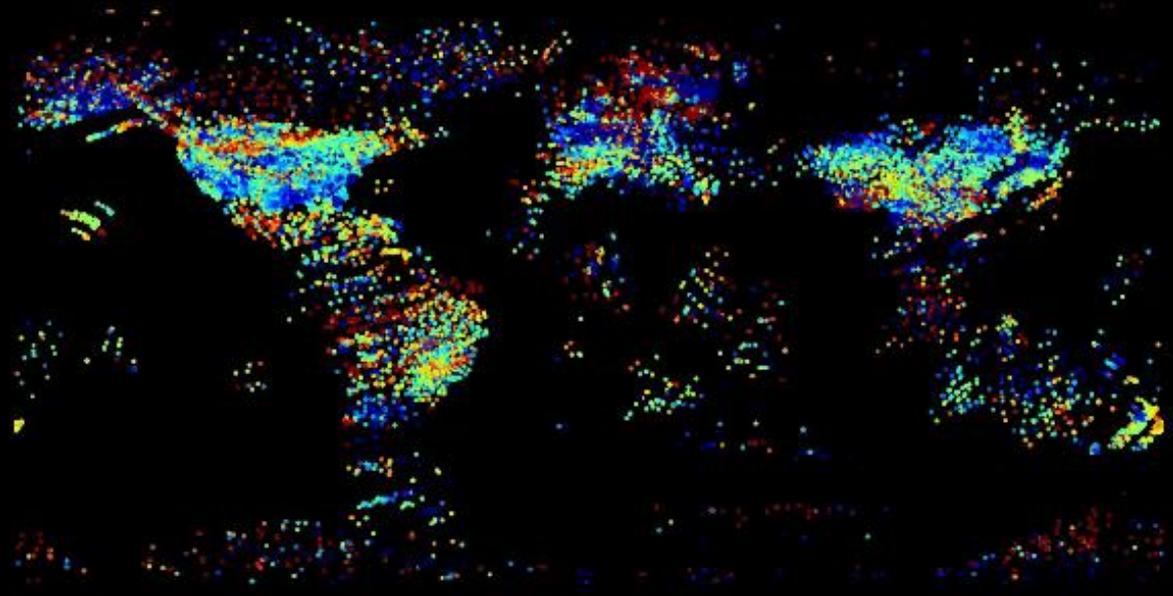
VTEC
2015-03-17 00:00:00 UTC

Latitude (deg)



Longitude (deg)

$\Delta VTEC$
2015-03-17 14:00:00



- Geomagnetic field fluctuations drive geomagnetically induced currents (GIC) that can be a hazard to long conductor systems on the ground.

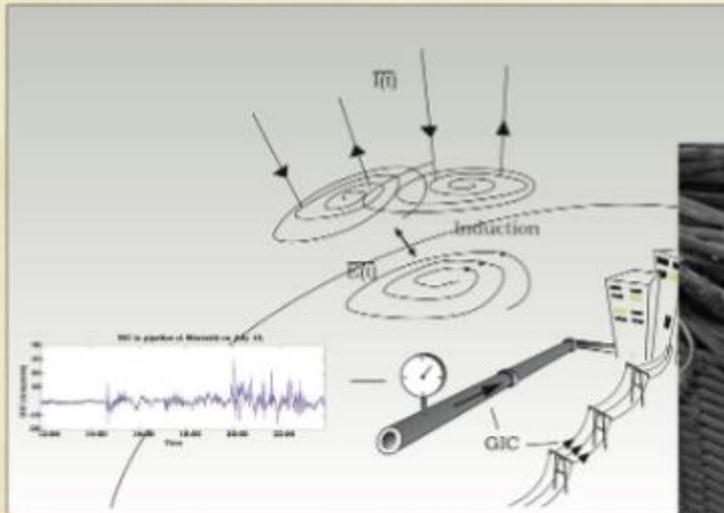


Illustration of mechanism for generating GIC

Transformer damage in South Africa



Credit: Gaunt and Coetzee (2007)

SPACE WEATHER IMPACTS

AURORA
(NORTHERN LIGHTS)



GPS



SATELLITES



COMMUNICATIONS



HUMAN SPACE
EXPLORATION



AVIATION



ELECTRIC POWER



WEATHER.GOV/SPACE

Resources

- NOAA Space Weather Prediction Center (<http://spaceweather.gov>)
 - Education and Outreach
- Spaceweather.com (<http://spaceweather.com>)
- Heliophysics @ UCAR (<https://cpaess.ucar.edu/heliophysics/home>)
- NASA Goddard CCMC (<http://ccmc.gsfc.nasa.gov>)
- NASA GSFC Visualization Studio (<https://svs.gsfc.nasa.gov>)
- Books

NOAA SWPC

NOAA SPACE WEATHER PREDICTION CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

HOME ABOUT SPACE WEATHER PRODUCTS AND DATA DASHBOARDS MEDIA AND RESOURCES SUBSCRIBE ANNUAL MEETING FEEDBACK

Tuesday, June 27, 2017 05:24:19 UTC

SPACE WEATHER CONDITIONS on NOAA Scales

24-Hour Observed Maximums: R (none), S (none), G (none)

Latest Observed: R (none), S (none), G (none)

Predicted 2017-06-27 UTC: R1-R2 (1%), S1 or greater (1%), R3-R5 (1%), G (none)

Solar Wind Speed: 511 km/sec Solar Wind Magnetic Fields: Bt 4 nT, Bz 0 nT Noon 10.7cm Radio Flux: 74 sfu

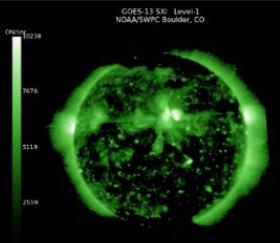


- SWPC Plans Return to On-Site Operations 28 June 2017**
published: Friday, June 23, 2017 15:40 UTC
SWPC anticipates a return to on-site processing starting at about 1000 MT (1200 ET) on 28 June 2017. Brief, intermittent outages a
- Regional Geomagnetic Model Products now Fully Operational**
published: Tuesday, May 02, 2017 15:03 UTC
SWPC is pleased to announce that we have transitioned the entire set of Geospace model derived products from experimental to fully operational in o
- Conference announcement: 2017 Space Weather Enterprise Forum**
published: Monday, May 01, 2017 21:41 UTC
We are pleased to announce the National Space Weather Partnership will host the 2017 the Space Weather Enterprise Forum on June 27, 2017 at the Nat
- New Space Weather Toolkit released**
published: Tuesday, April 11, 2017 17:18 UTC
Want to learn more about Space Weather?

SERVING ESSENTIAL SPACE WEATHER COMMUNITIES

- Aviation
- Radio Communications
- Electric Power Satellites
- Emergency Management
- Space Weather Enthusiasts
- Global Positioning System (GPS)

THE SUN'S X-RAYS

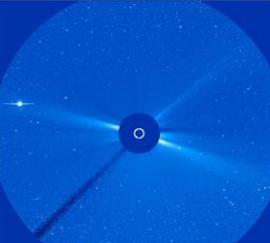


GOES-13 SX, Level-1
NOAA/SWPC Boulder, CO

2017-06-27 05:16:00 UTC PTHMA 0.4 s

GOES X-RAY FLUX

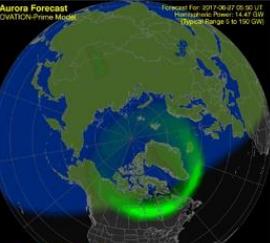
CORONAL MASS EJECTIONS



2017/06/27 04:42

GOES PROTON FLUX

THE AURORA



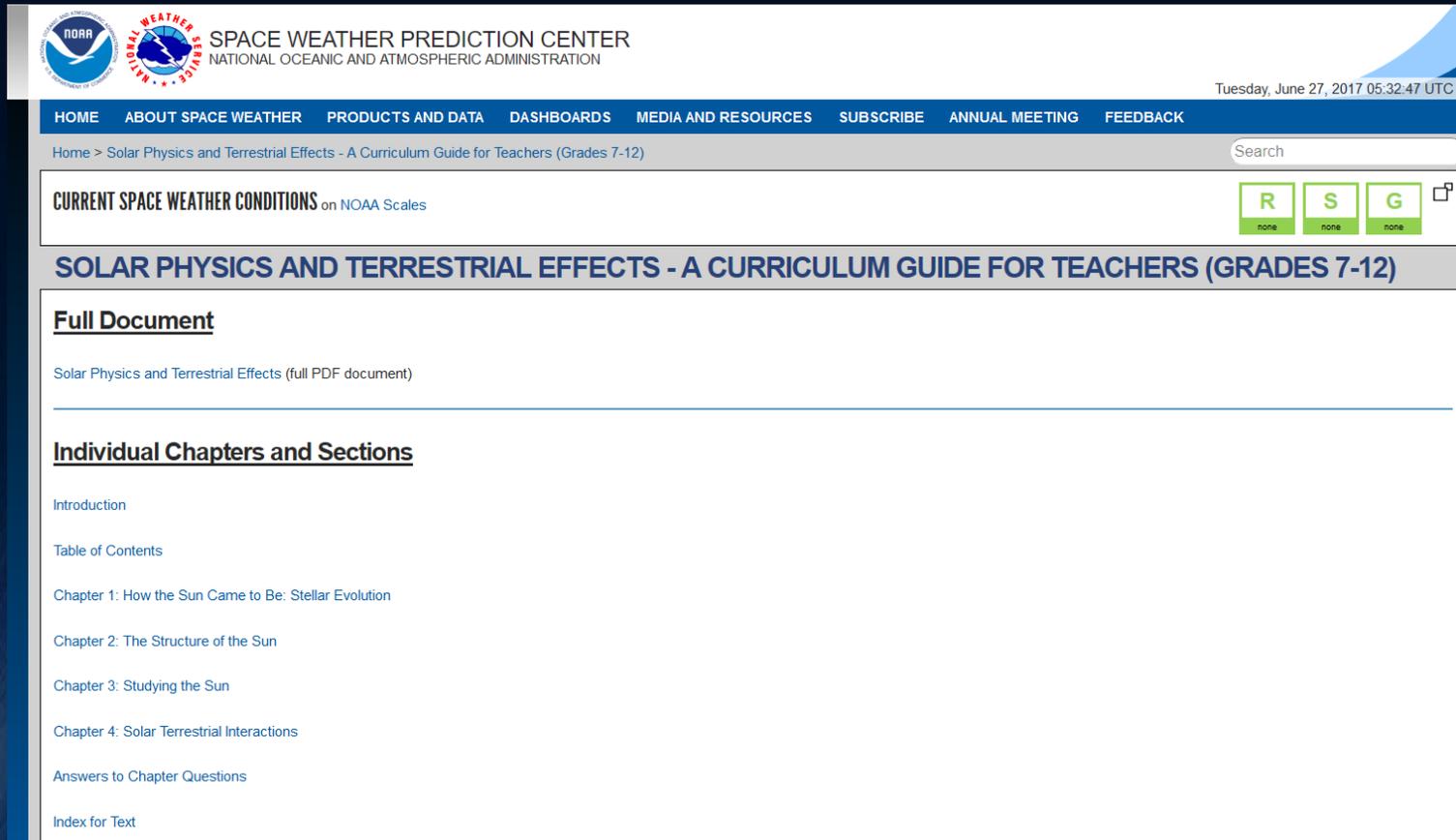
Aurora Forecast
OvATION-Prime Model

2017-06-27 09:00 UTC
Forecast Range: 1000 km
Repeat Range: 5 to 150 km

ESTIMATED PLANETARY K-INDEX

- <http://spaceweather.gov>

NOAA SWPC Education and Outreach



The screenshot displays the NOAA Space Weather Prediction Center (SWPC) website. At the top left, there are logos for NOAA and the National Weather Service. The main header reads "SPACE WEATHER PREDICTION CENTER NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION". The date and time "Tuesday, June 27, 2017 05:32:47 UTC" are shown in the top right. A navigation menu includes links for HOME, ABOUT SPACE WEATHER, PRODUCTS AND DATA, DASHBOARDS, MEDIA AND RESOURCES, SUBSCRIBE, ANNUAL MEETING, and FEEDBACK. Below the menu, a breadcrumb trail shows "Home > Solar Physics and Terrestrial Effects - A Curriculum Guide for Teachers (Grades 7-12)". A search bar is present on the right. The main content area features a "CURRENT SPACE WEATHER CONDITIONS on NOAA Scales" section with three green boxes labeled "R", "S", and "G", each with "none" underneath. Below this is the title "SOLAR PHYSICS AND TERRESTRIAL EFFECTS - A CURRICULUM GUIDE FOR TEACHERS (GRADES 7-12)". Underneath, there is a "Full Document" section with a link to "Solar Physics and Terrestrial Effects (full PDF document)". A "Individual Chapters and Sections" section lists the following items: Introduction, Table of Contents, Chapter 1: How the Sun Came to Be: Stellar Evolution, Chapter 2: The Structure of the Sun, Chapter 3: Studying the Sun, Chapter 4: Solar Terrestrial Interactions, Answers to Chapter Questions, and Index for Text.

- <http://www.swpc.noaa.gov/content/solar-physics-and-terrestrial-effects-curriculum-guide-teachers-grades-7-12>

Spaceweather.com

spaceweather.com
News and information about the Sun-Earth environment

Subscribe to SpaceweatherNews
 go!

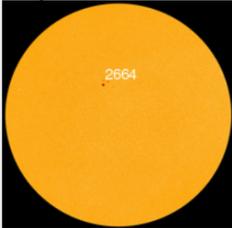
AURORA ALERTS | SUBMIT YOUR PHOTOS | CONTACT US | SUBSCRIBE | FLYBYS | EARTH TO SKY

Current Conditions

Solar wind
speed: 515.7 km/sec
density: 3.9 protons/cm³
more data: [ACE](#), [DSCOVR](#)
Updated: Today at 0339 UT

X-ray Solar Flares
6-hr max: **A7** 1904 UT Jun26
24-hr: **B1** 0729 UT Jun26
[explanation](#) | [more data](#)
Updated: Today at: 2359 UT

Daily Sun: 26 Jun 17



Sunspot AR2664 poses no threat for strong solar flares. Credit: SDO/HMI

What's up in space

Tuesday, Jun. 27, 2017

Lights Over lapland is excited to announce that [Autumn Aurora Adventures](#) are available for immediate booking! Reserve your adventure of a lifetime in Abisko National Park, Sweden today!

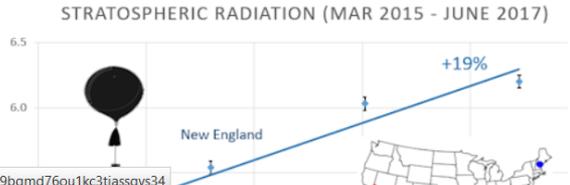


SLIGHT CHANCE OF STORMS TODAY: NOAA forecasters say there is a 25% chance of **G1-class** geomagnetic storms on **June 26th** as Earth passes through a minor stream of solar wind. High-latitude sky watchers should be alert for auroras, especially in the southern hemisphere where winter darkness favors visibility. **Free:** [Aurora Alerts](#)

NEW ATMOSPHERIC RADIATION RESULTS: For the past two+ years, Spaceweather.com and the students of Earth to Sky Calculus have been monitoring cosmic rays in the atmosphere above California using high-altitude [space weather balloons](#). After more than 100 flights, they find that dose rates have increased over the Golden State by 13% since March 2015.

Now we know the same thing is happening over New England--only more so.

STRATOSPHERIC RADIATION (MAR 2015 - JUNE 2017)



Location	Change in Radiation
Golden State (California)	+13%
New England	+19%

Archives: June, 27, 2017

Aurora at its Best
Cleary Summit Alaska

Captain Boom FIREWORKS

- <http://spaceweather.com>

Home About Us What We Do Career Opportunities Events Partnerships CAMP Website For Staff

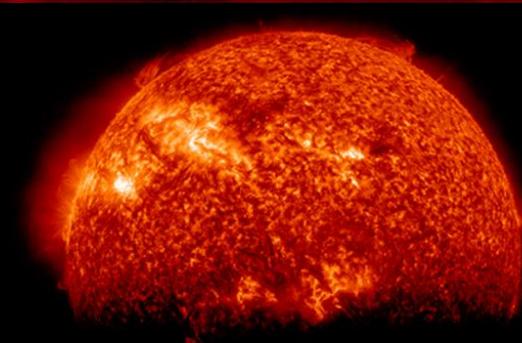
HELIOPHYSICS

Supported by the Visiting Scientist Programs

Deepening our understanding of the Sun-Earth Connection

Search

Home About the Science Resources Summer School Jack Eddy Fellowships LWS Institute NASA Ames



What is Heliophysics

Heliophysics is all of the science common to the field of the Sun-Earth connections. This fast-developing field of research covers many traditional sub-disciplines of space physics, astrophysics, and climate studies. The NASA Living with a Star program, with its focus on the basic science underlying all aspects of space weather, acts as a catalyst to bring the many research disciplines together to deepen our understanding of the system of systems formed by the Sun-Earth connection.

Two programs have emerged from this effort:

- Heliophysics Summer School
- Jack Eddy Postdoctoral Fellowship Program

Fellowships, Workshops, & Resources

Announcements

Jack Eddy Postdoctoral Fellowships

Heliophysics Summer School

[See New Fellows](#)

- <https://cpaess.ucar.edu/heliophysics/home>

Books:

- Carlowicz, M.J., R.E. Lopez, Storms from the sun: the emerging science of space weather, Joseph Henry Press, 2002.
- Clark, S., The Sun Kings: The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began, Princeton University Press, 2007.
- Knipp, D., Understanding Space Weather and the Physics Behind It, McGraw -Hill, 744 p., 2011.
- Moldwin, M., An introduction to space weather, Cambridge UP, 146p., 2008.