

Meteorología del Espacio (Space Weather)

Tercera Reunión sobre Proyectos del Programa MET del GREPECAS para la Región SAM

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17 de Junio de 2019

Space Weather

The background of the slide is a composite image. On the left side, there is a large, detailed view of the Sun, showing its fiery surface and a prominent solar flare or coronal mass ejection. On the right side, there is a depiction of Earth's magnetosphere, shown as a blue, glowing, multi-lobed structure surrounding the planet. The background is a dark space filled with numerous small, white stars.

The World Meteorological Organization (WMO) defines space weather as, “The physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments.”

Space Weather

From an operations perspective, space weather events occur when the Sun causes disruptions to aviation communications, navigation and surveillance systems, and elevates radiation dose levels at flight altitudes. Space weather events may occur on short time scales, with the effects occurring from almost instantaneous to a few days hence.

News | Published: 06 November 2003

Satellite loss throws Japan's space programme into disarray

David Cyranoski

Nature 426, 3 (2003) | Download Citation ↓

Tokyo

Japan's space agency is facing tough questions this week after the unexplained loss of Midori-II, one of the most ambitious scientific



EOS Earth & Space Science News

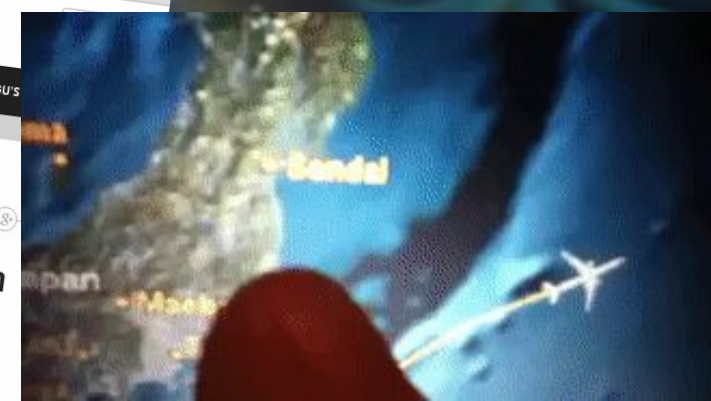
NEWS FROM AGU JOURNALS TOPICS & DISCIPLINES OPINIONS BLOGS AGU'S

NATURAL HAZARDS Research Spotlight

Solar Flares Increase Radiation Risk on Commercial Aircraft

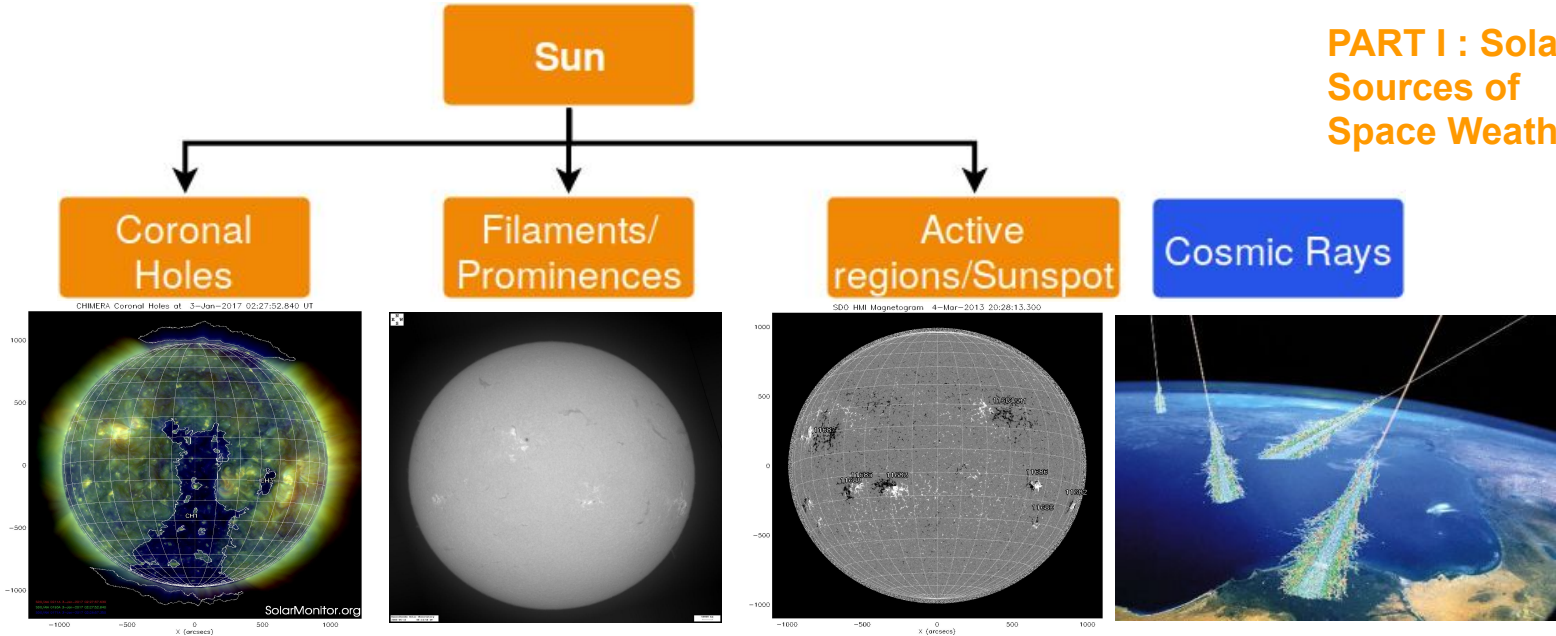
A new study quantifies how space weather may affect polar transcontinental flight.

SOURCE: Space Weather

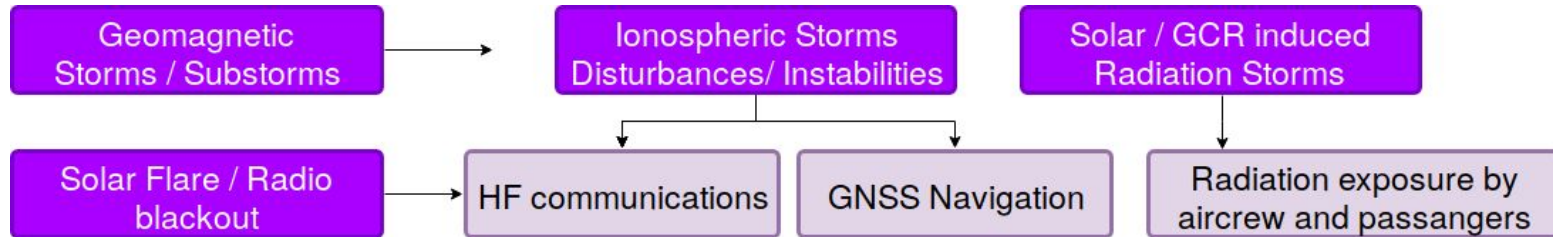


Outline - Space Weather

PART I : Solar Sources of Space Weather



PART II: Space Weather Impacts

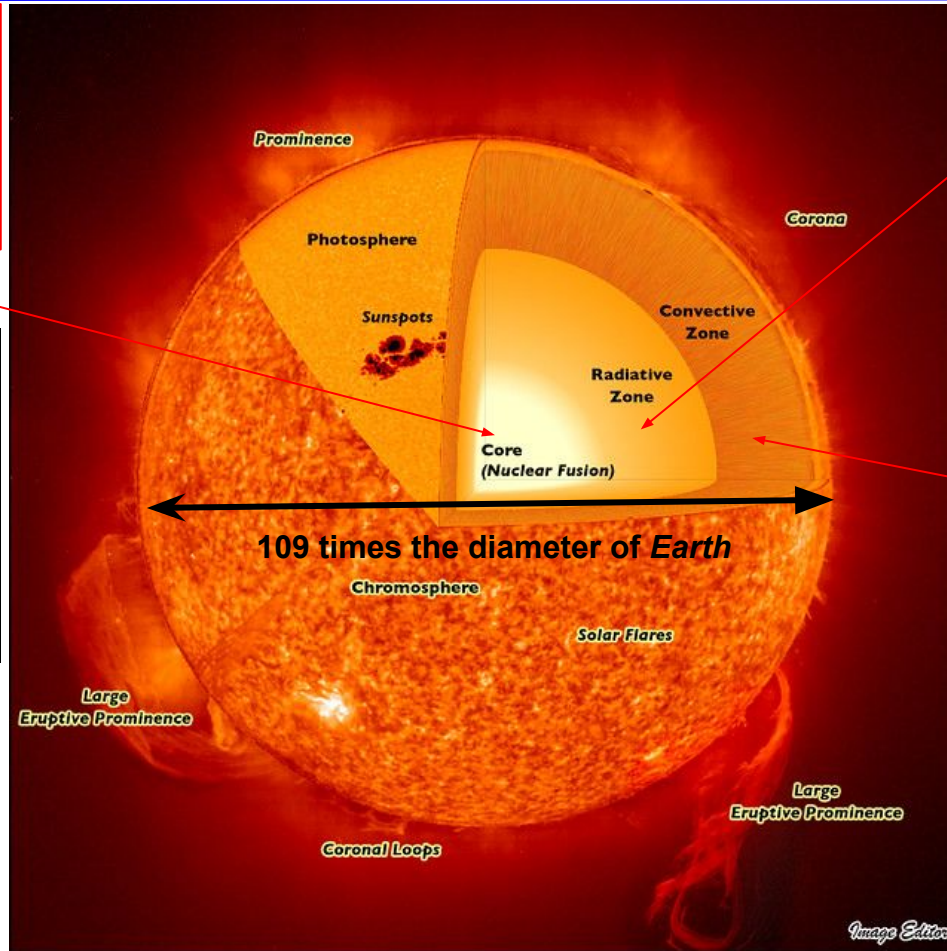
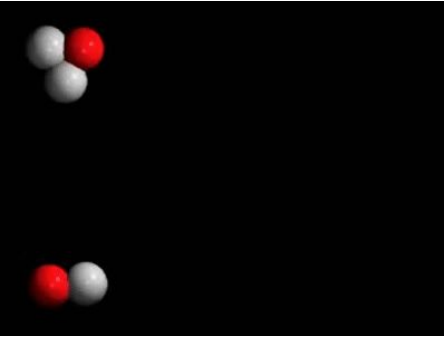


The Sun



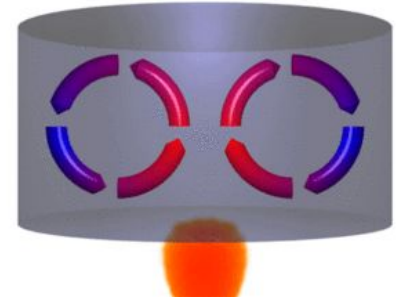
The Sun

Energy is generated by thermonuclear reactions creating extreme temperatures deep within the Sun's core

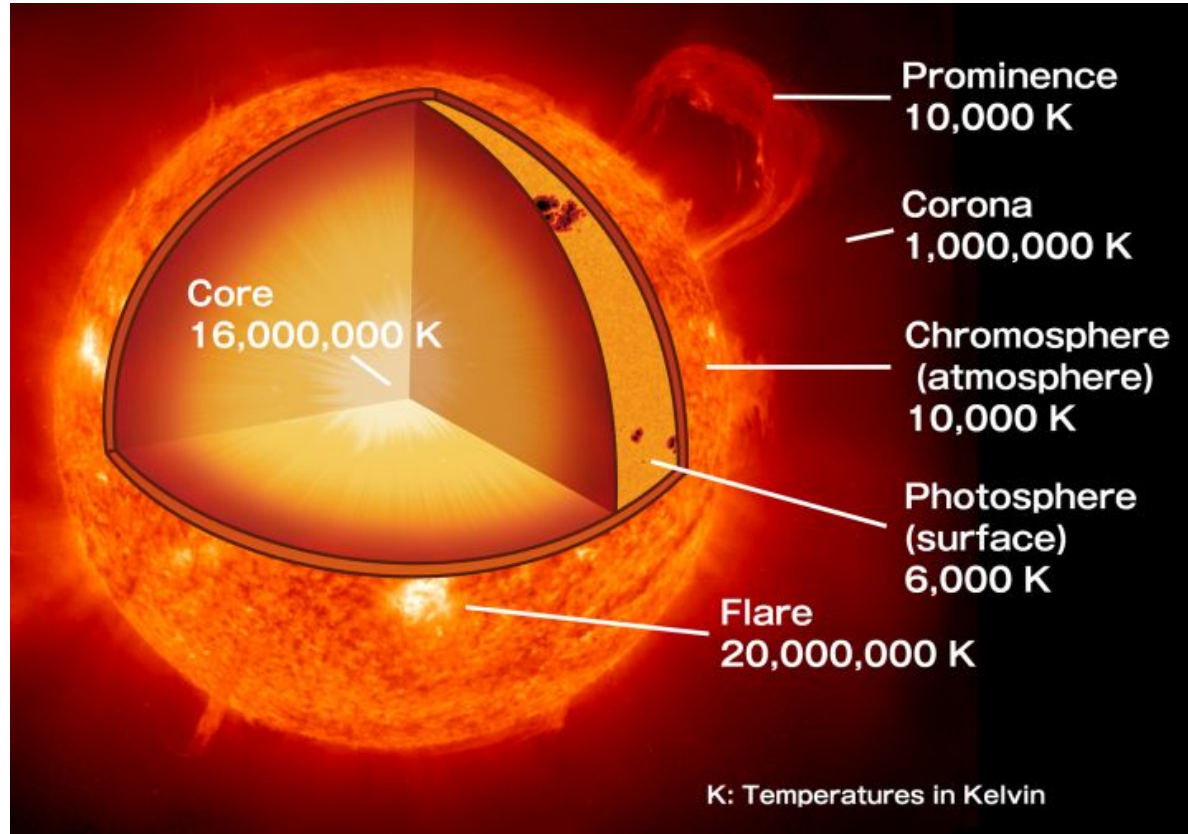


Energy moves slowly outward taking more than 170 000 years to radiate through the layer of the sun known as the radiative zone

Energy continues to move toward the surface through convection currents of heated and cooled gas in the convection zone



The atmosphere of the Sun

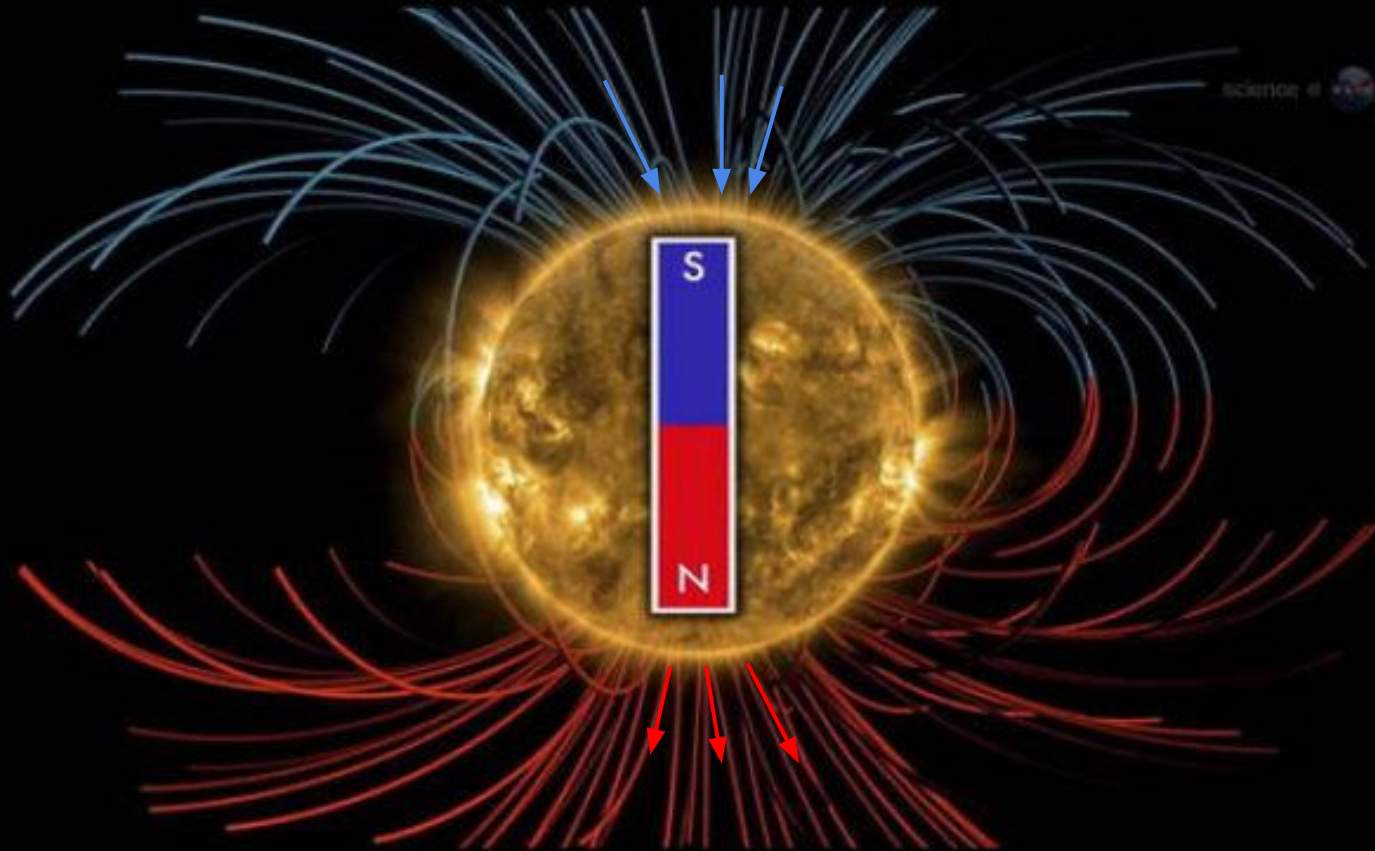


Parker solar probe (August 2018)

Trace the flow of energy that heats the **corona** and accelerates the **solar wind**.



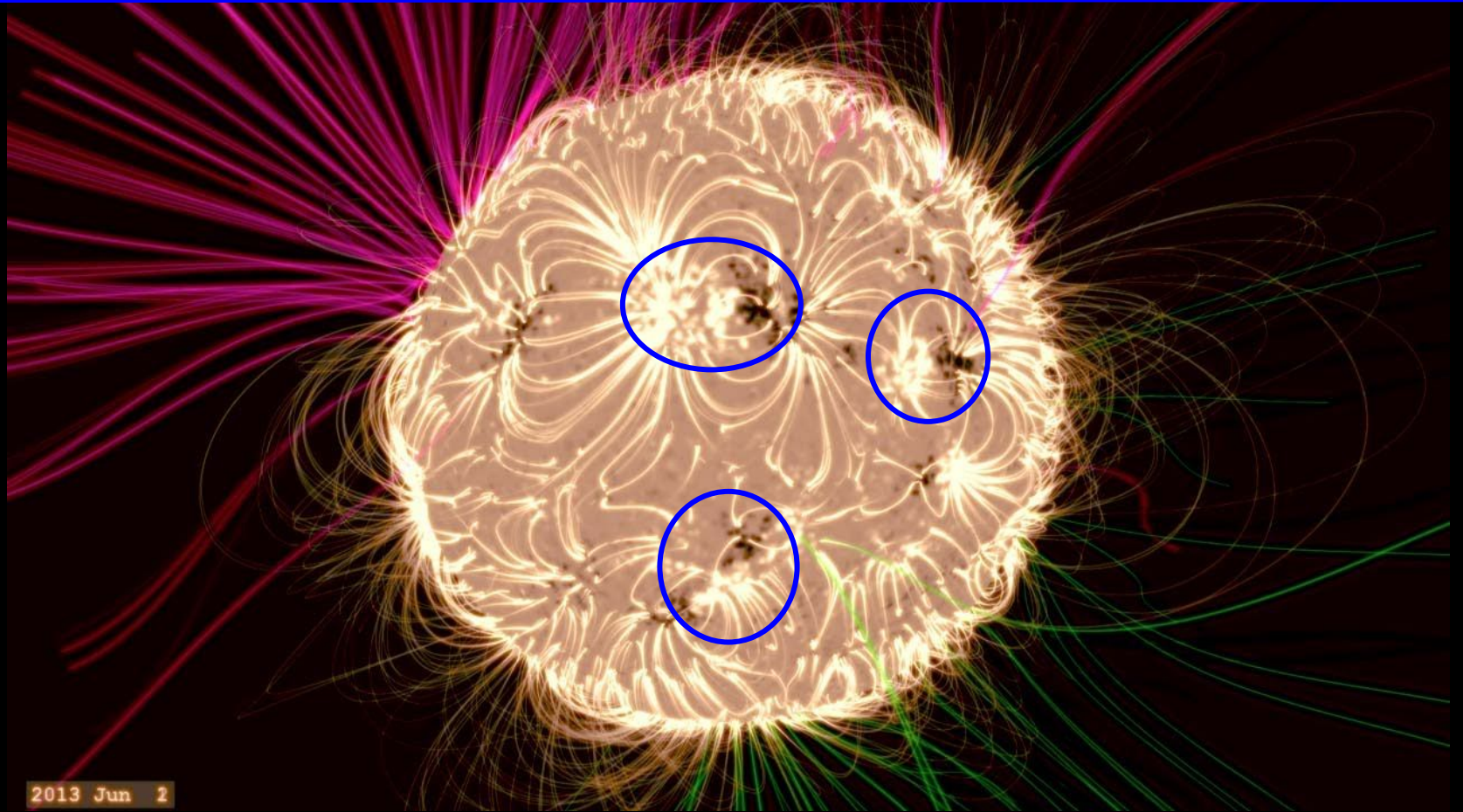
The magnetic field of the Sun



The magnetic field of the Sun

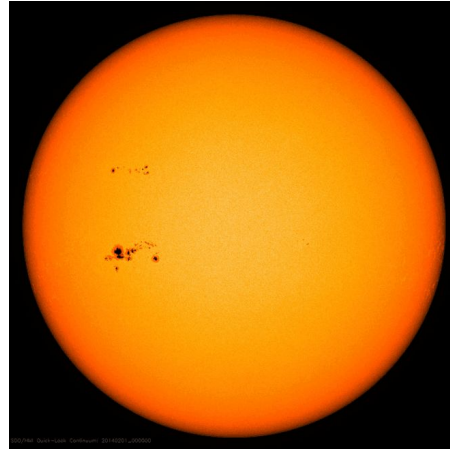
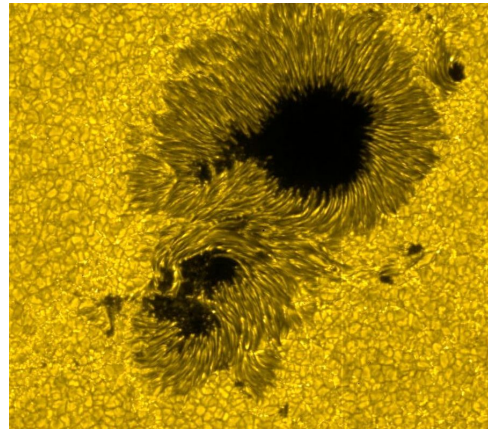
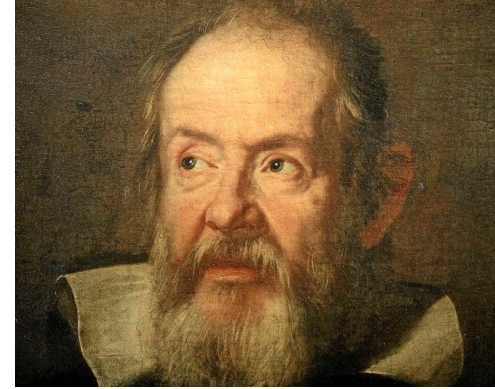
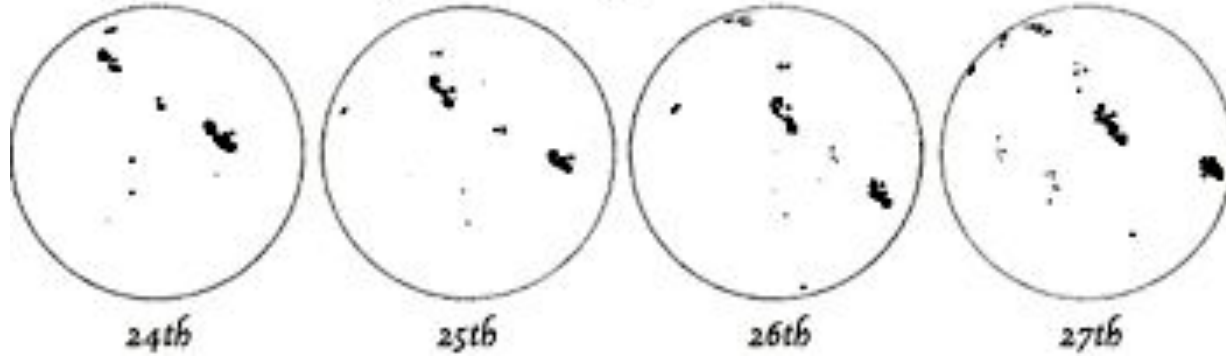


The magnetic field of the Sun



Sunspots

Sunspots drawn by Galileo, June 1612



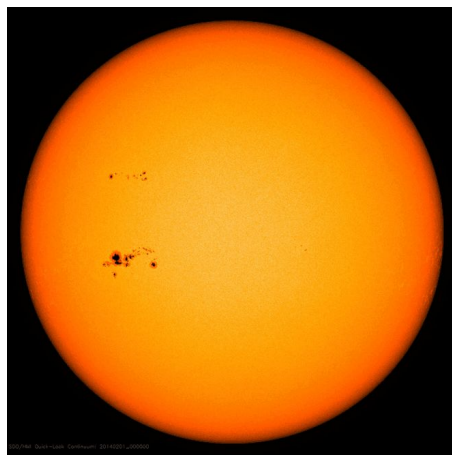
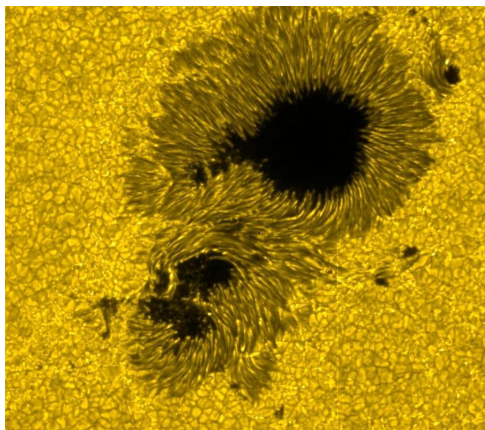
The gas rotates more rapidly at the equator than at the poles.

A spot at the equator goes around in about 24 days, while the polar regions take six days longer

Geomagnetic
Storms / Substorms

Solar Flare / Radio
blackout

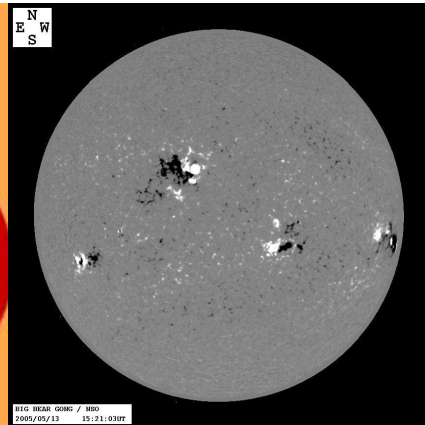
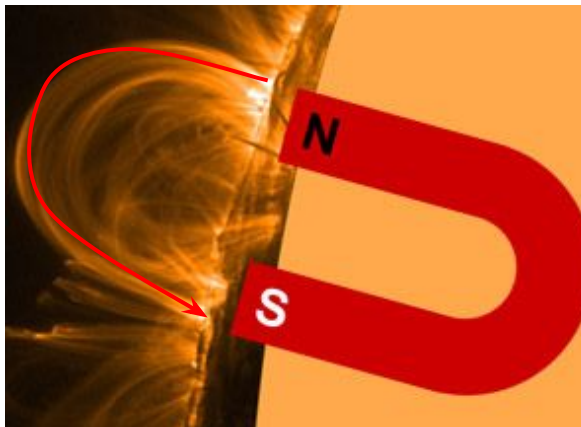
Sunspot and Active regions observation



"**Sunspot** appear as dark regions in the solar disk" They are regions of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection

Active Region: Bright spots and illuminated arcs (in ultraviolet and X-ray images of the Sun) of solar material hovering in the Sun's atmosphere highlight what's known as active regions on the Sun

Dark sunspots are visual indicators of active regions.



EUV: 171 A

Geomagnetic
Storms / Substorms

Solar Flare / Radio
blackout

Sunspot cycle



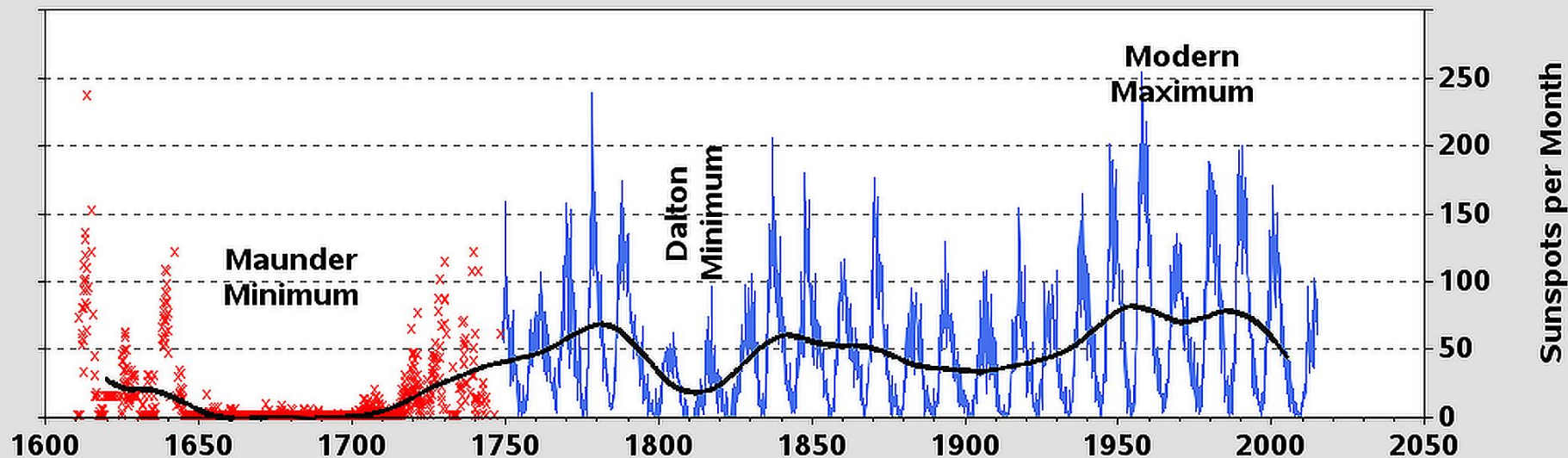
Solar cycle: ~11 years

No all the cycles are the same:

- Time duration
- Max. Sunspot number

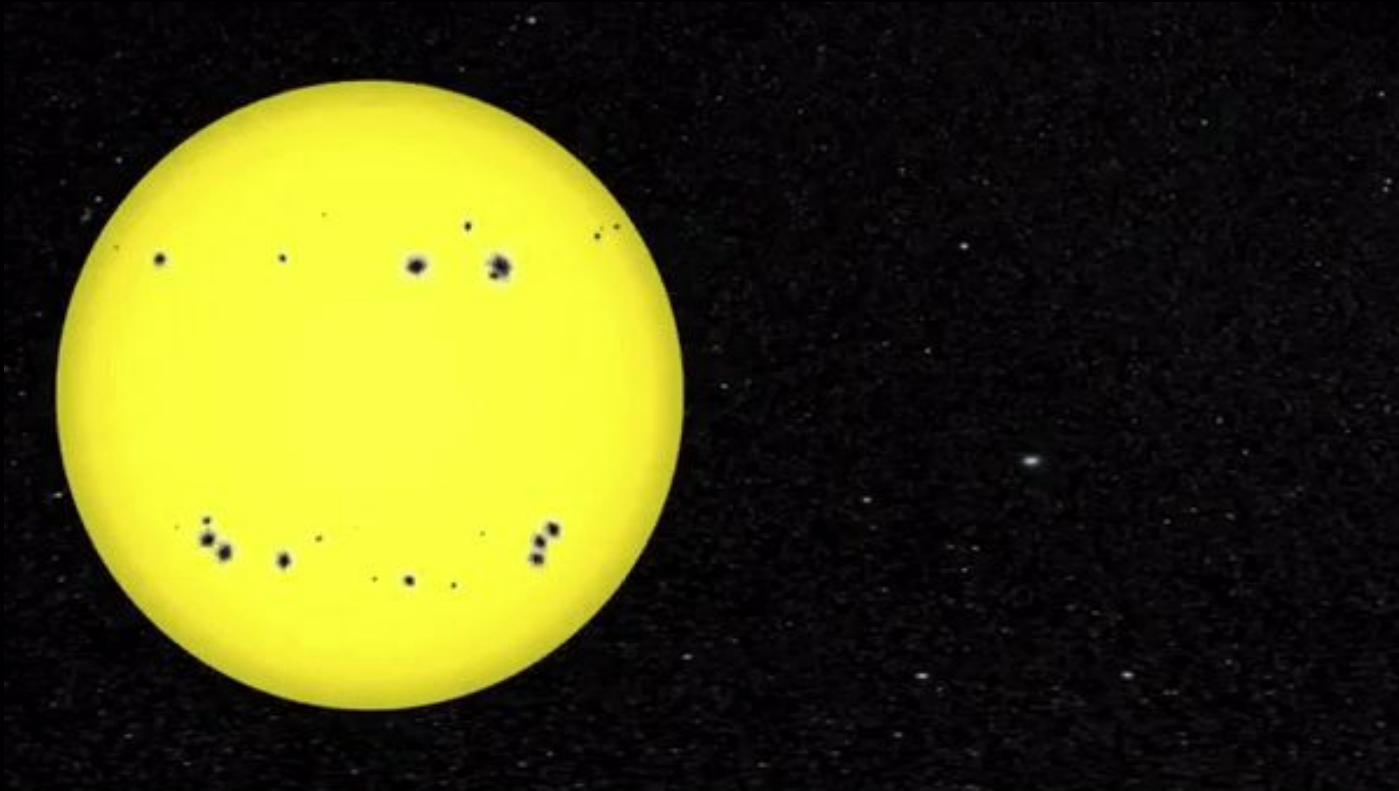
Sunspot cycle

400 Years of Sunspot Observations



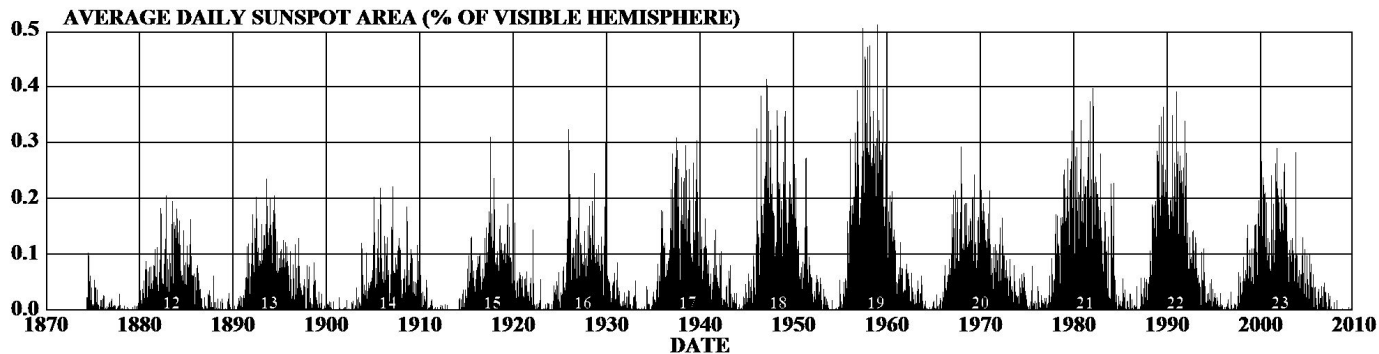
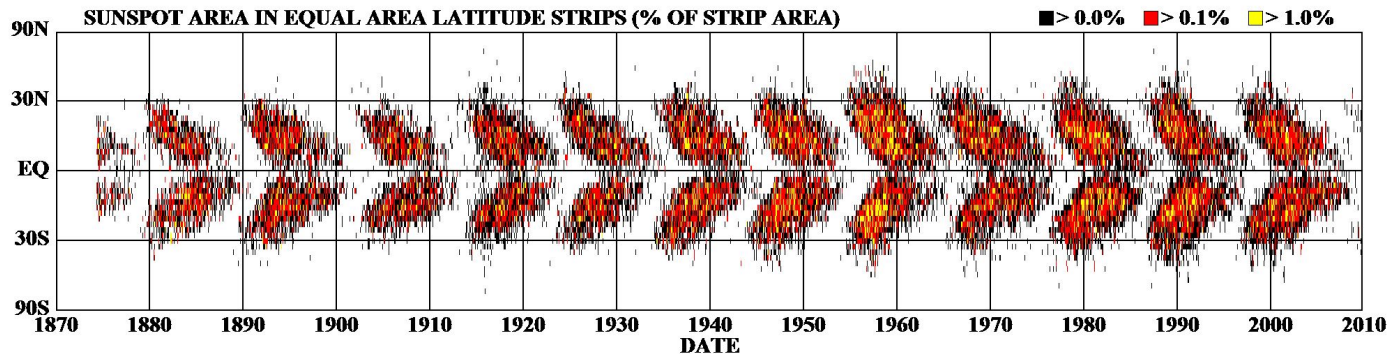
Data through: JAN2015

Sunspot cycle

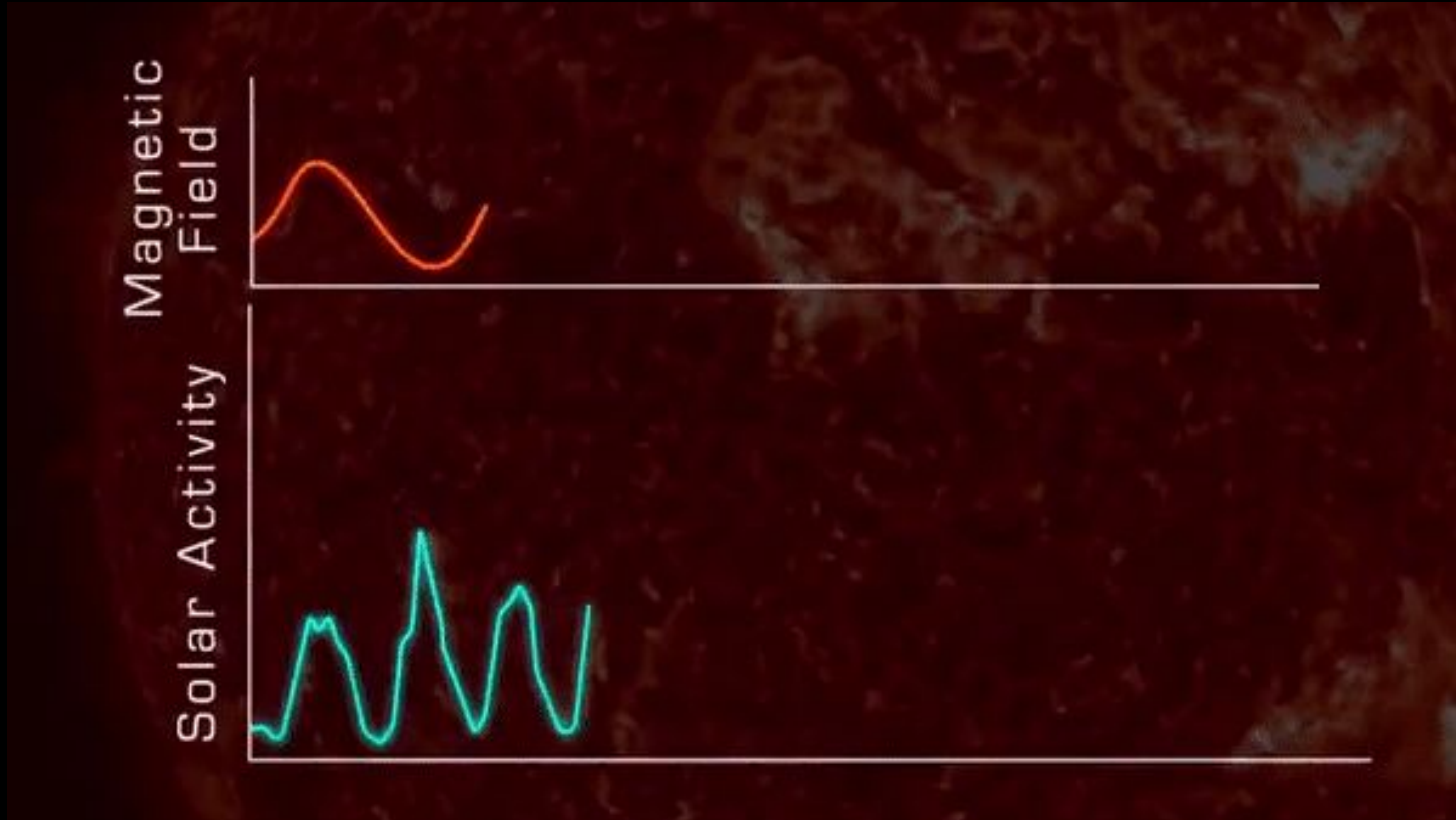


Sunspot cycle

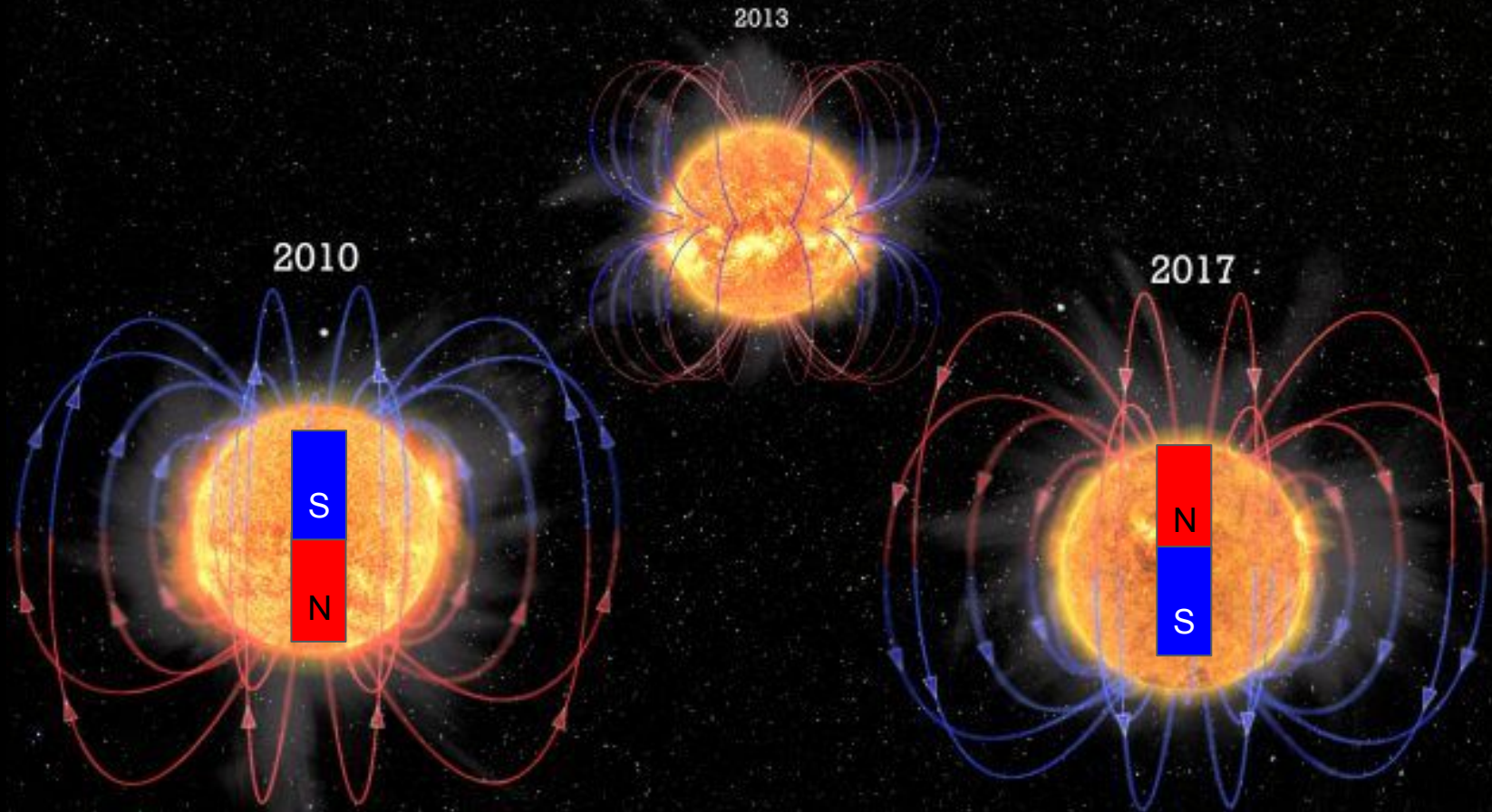
DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



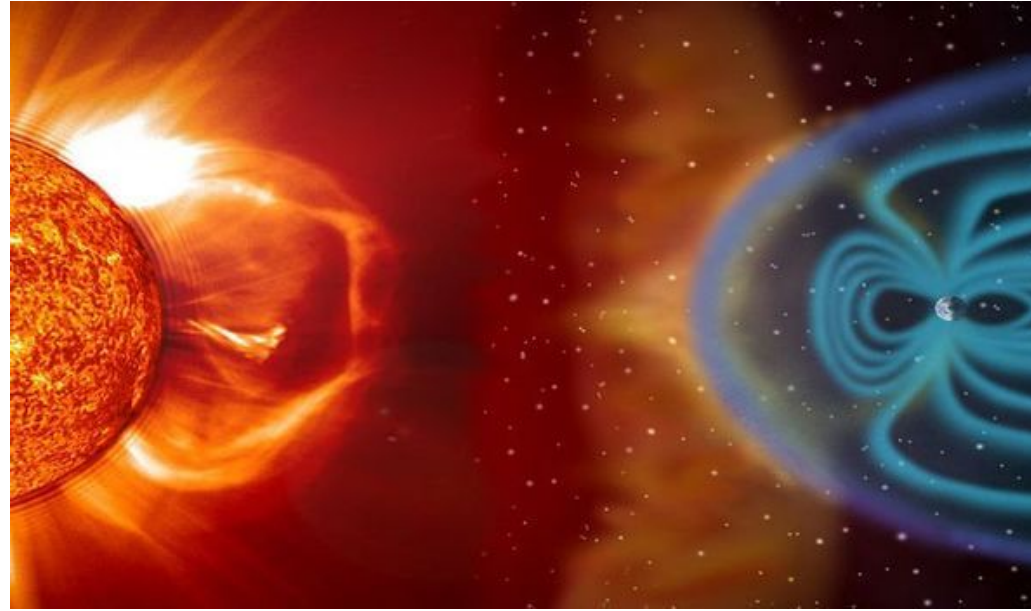
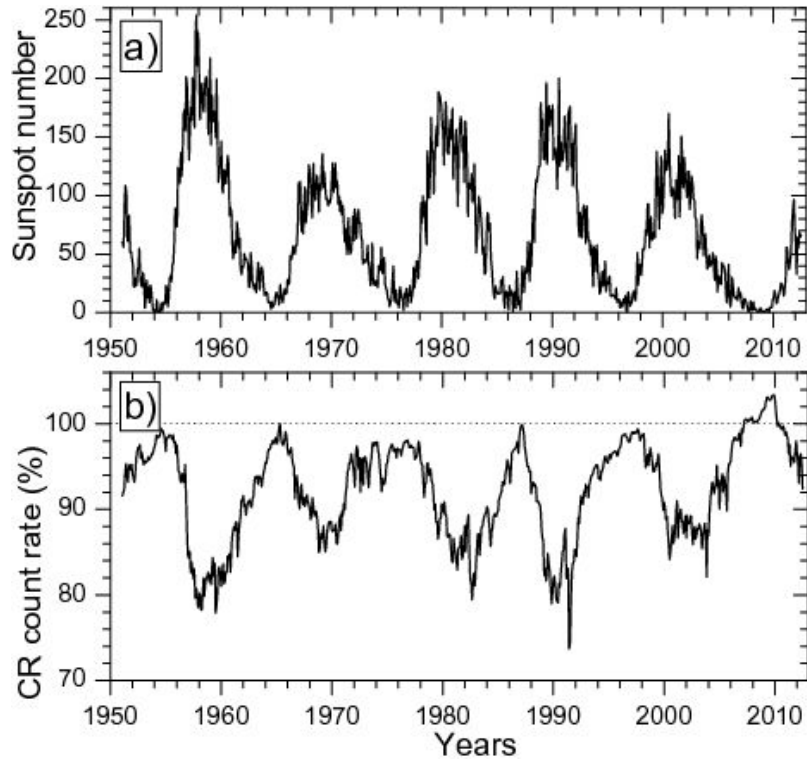
Sunspot Cycle vs Solar cycle



Sunspot Cycle vs Solar cycle



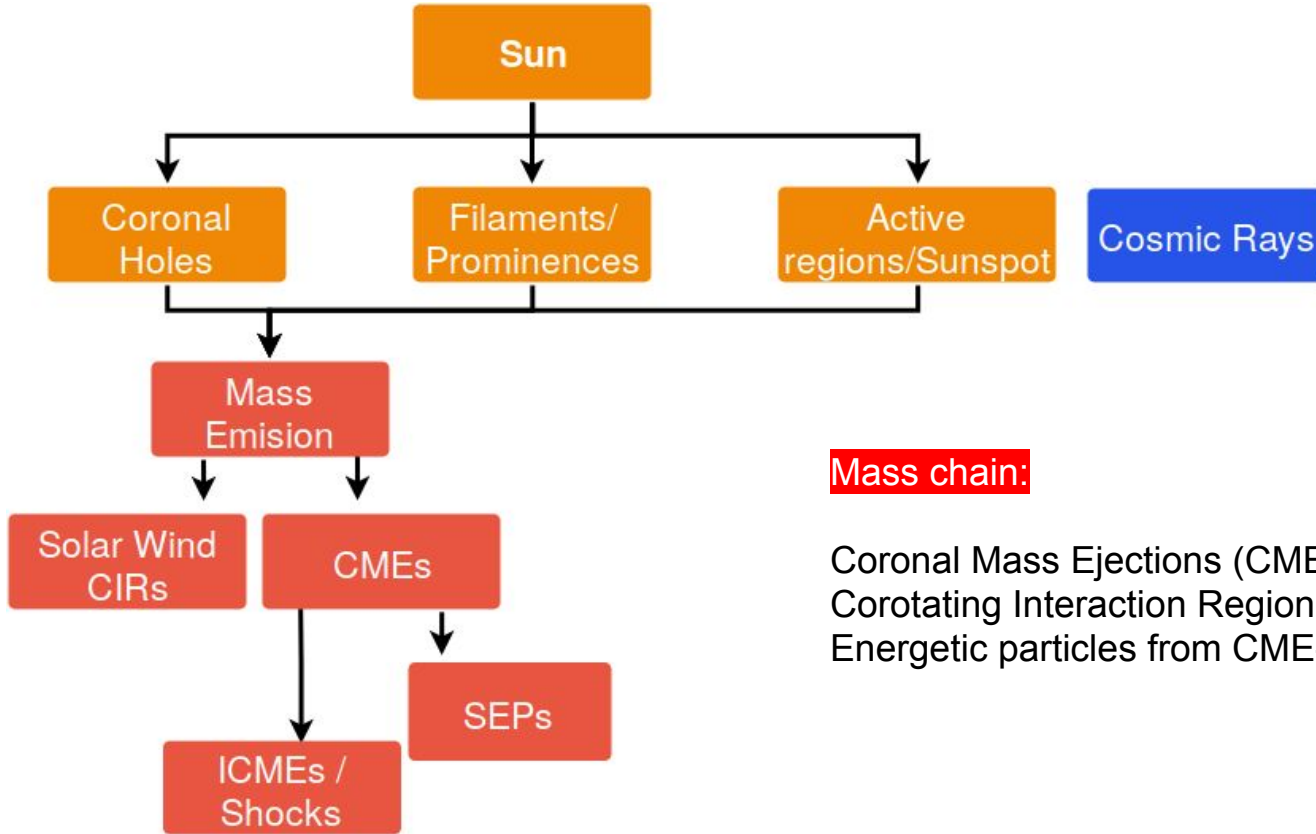
Solar activity and Cosmic Rays



Solar / GCR induced
Radiation Storms

Less cosmic rays when the solar activity is high

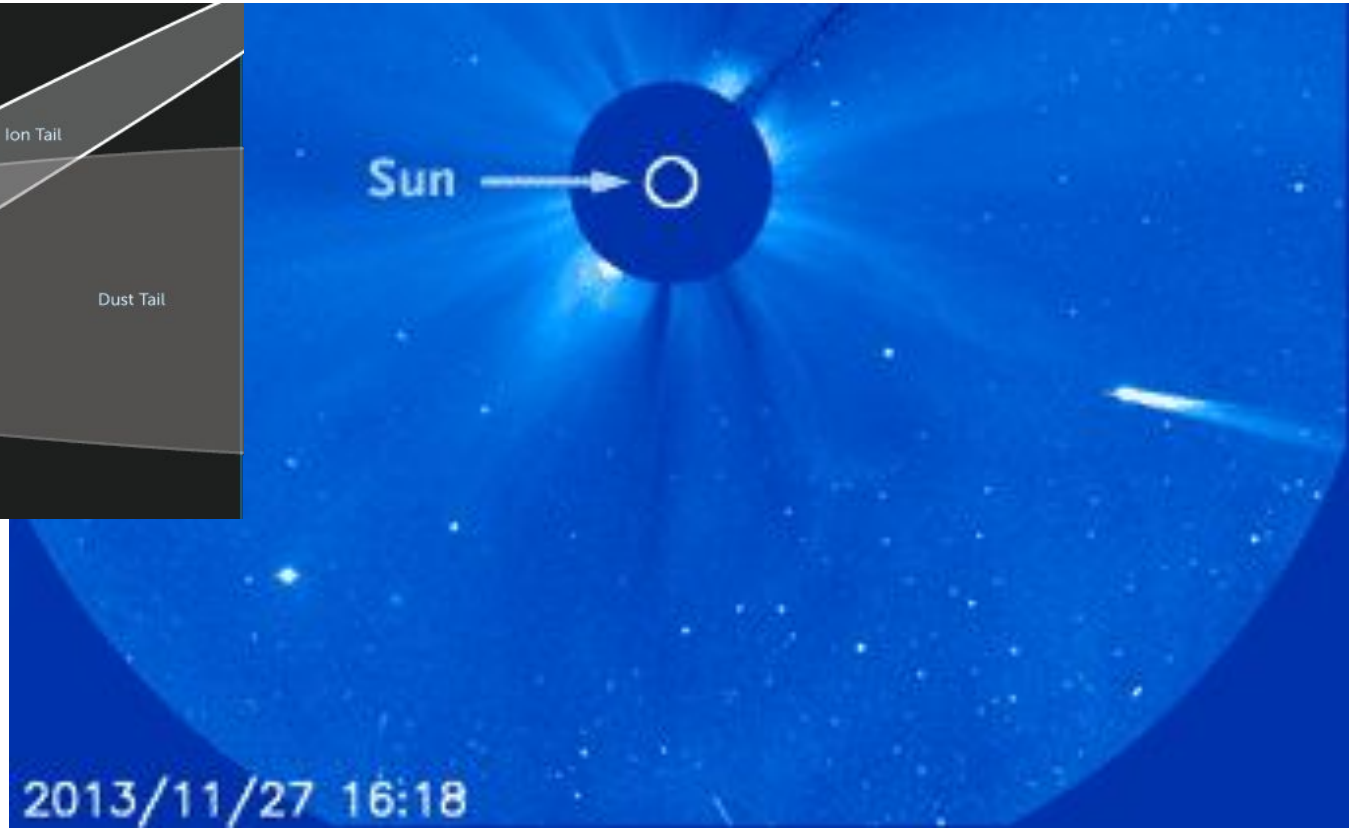
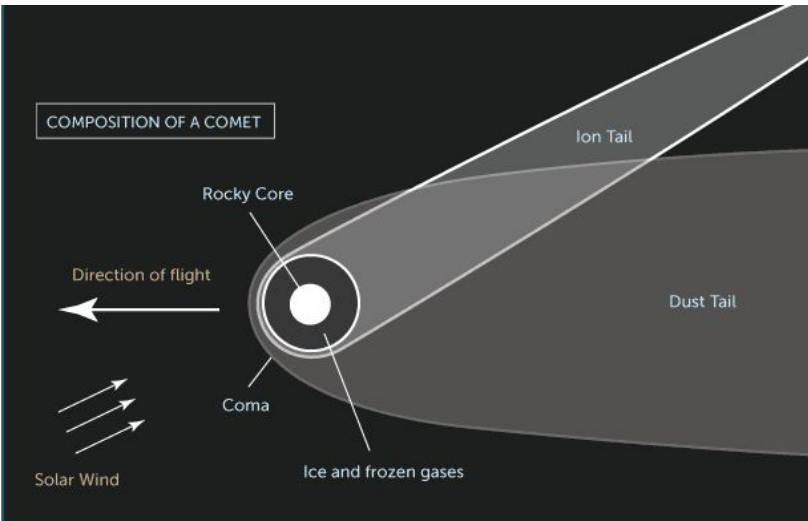
Solar sources of Space Weather



Mass chain:

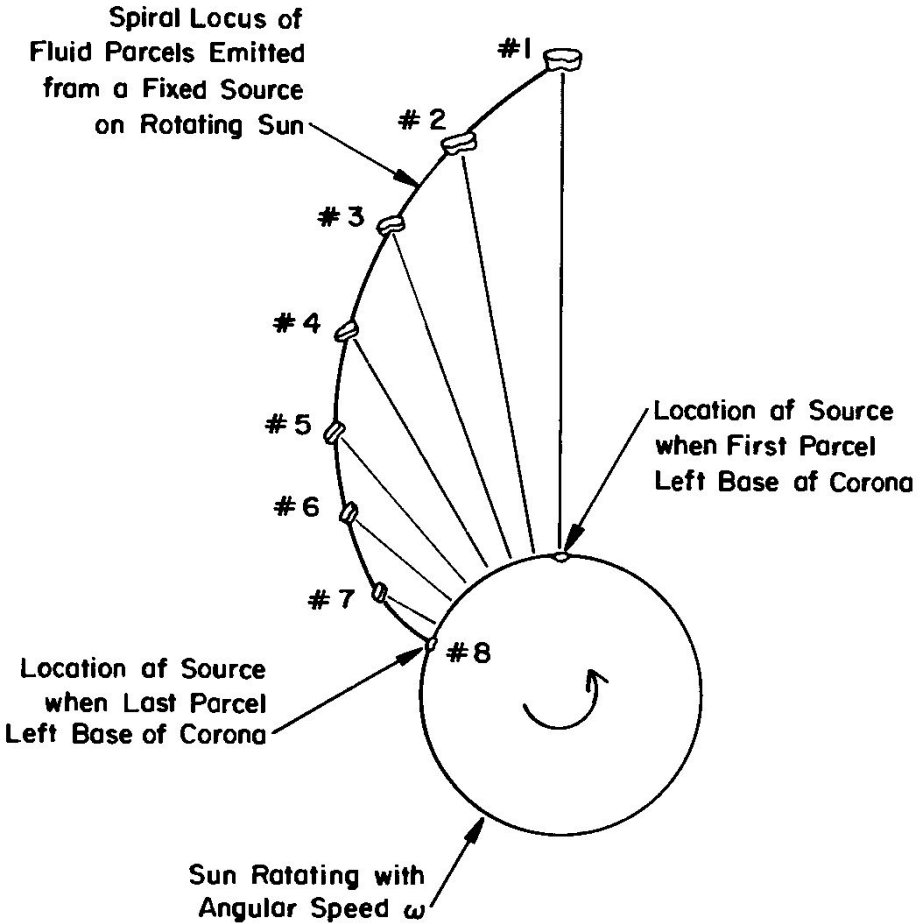
Coronal Mass Ejections (CMEs) (18 h to ~days)
Corotating Interaction Regions (CIRs) (~days)
Energetic particles from CME-driven shocks (1 h)

First evidence of the presence of the Solar Wind



Particles can escape the Sun's gravity because of their high energy resulting from the high temperature of the corona

Solar wind



Observed parameters at 1AU

TABLE 4.1. Observed Properties of the Solar Wind near the Orbit of the Earth (1 AU)

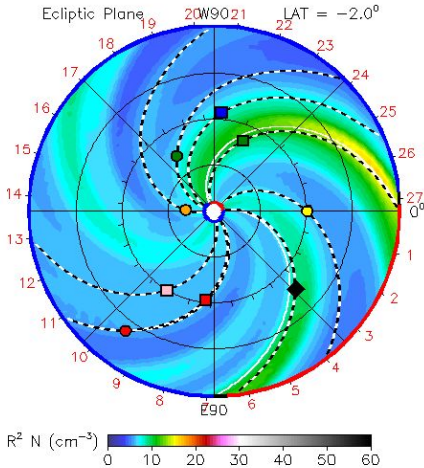
Proton density	6.6 cm^{-3}
Electron density	7.1 cm^{-3}
He ²⁺ density	0.25 cm^{-3}
Flow speed (nearly radial)	$450 \text{ km} \cdot \text{s}^{-1}$
Proton temperature	$1.2 \times 10^5 \text{ K}$
Electron temperature	$1.4 \times 10^5 \text{ K}$
Magnetic field (induction)	$7 \times 10^{-9} \text{ tesla (T)}$

Parker spiral form:

- Solar rotation
- Radial flow
- Frozen in condition

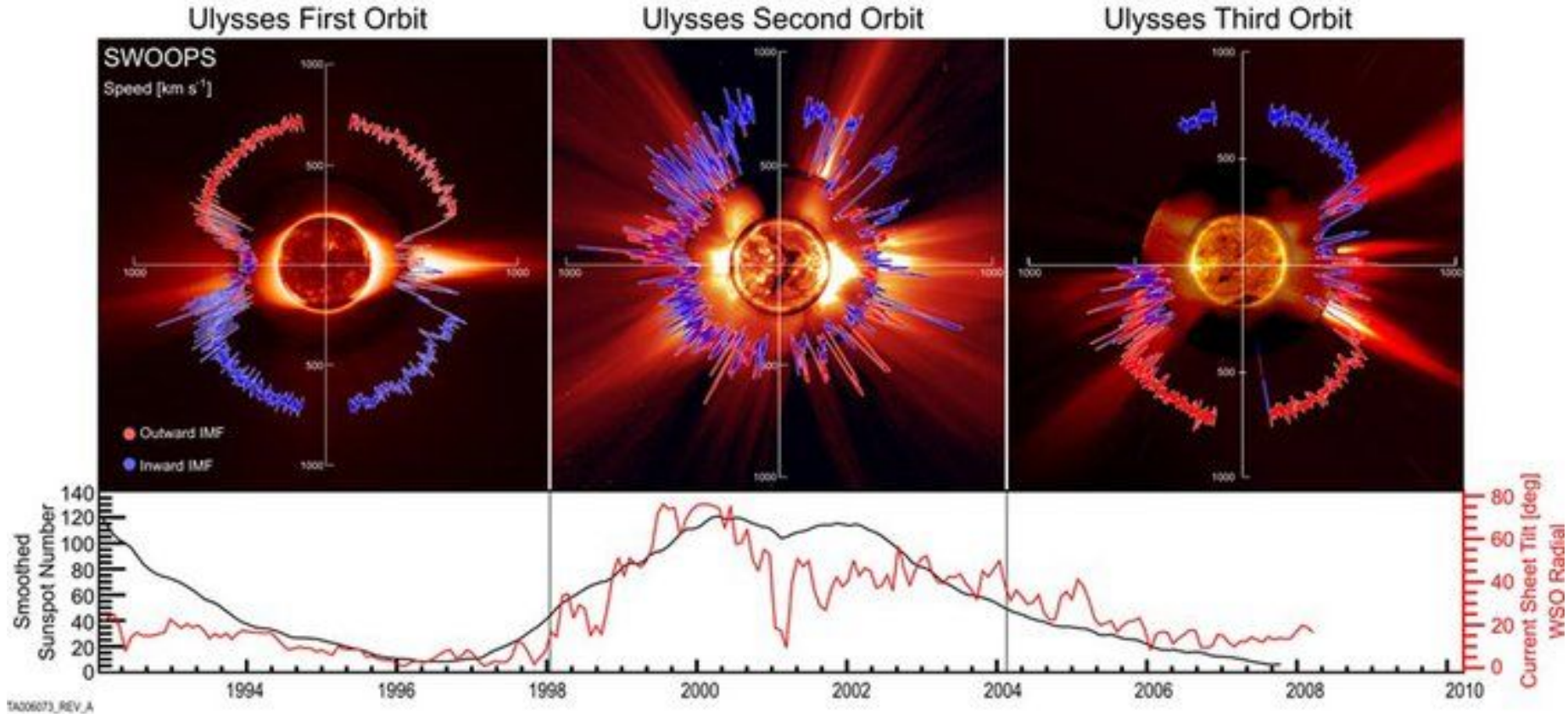
2019-05-20T00:00

● Earth
 ● Mars
 ● Mercury
 ● Venus
 ■ Stereo_B



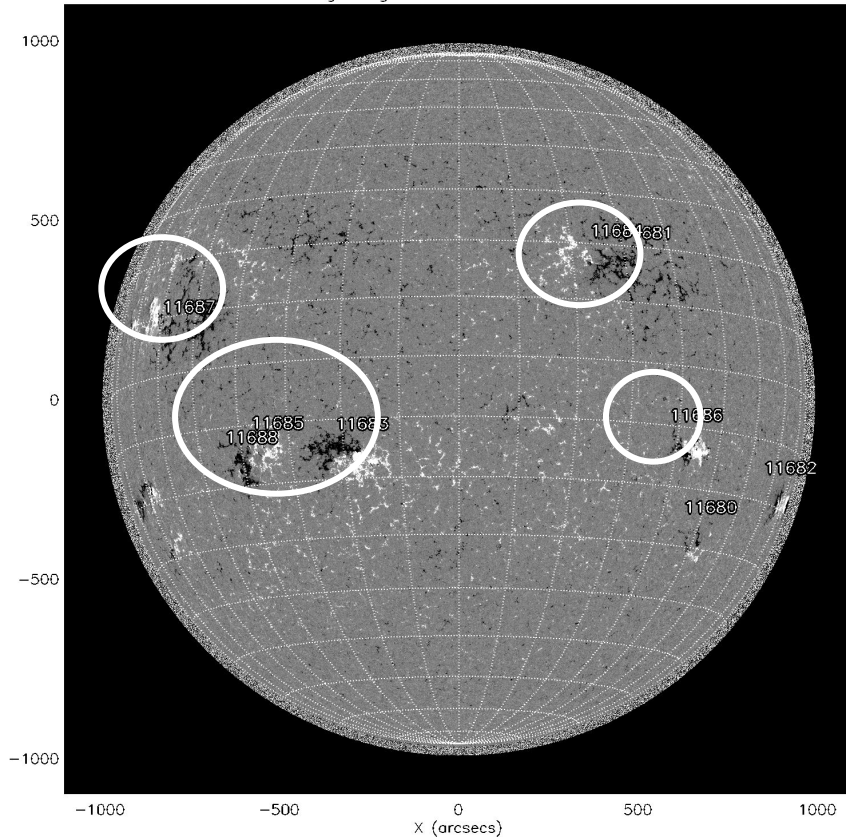
ENUL-2.7 lowres-2217-04b1 WSA-V2.2 GONG-2217

Solar wind during the Solar Cycle

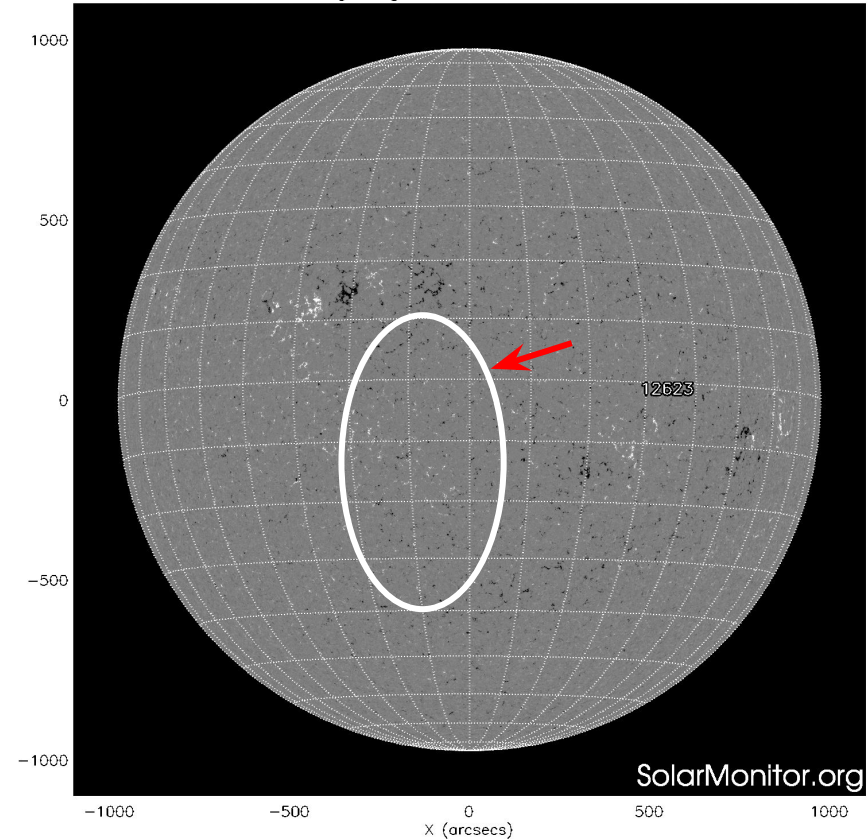


Two different Magnetic Topologies: ARs from closed field regions; fast wind from coronal holes

SDO HMI Magnetogram 4-Mar-2013 20:28:13.300

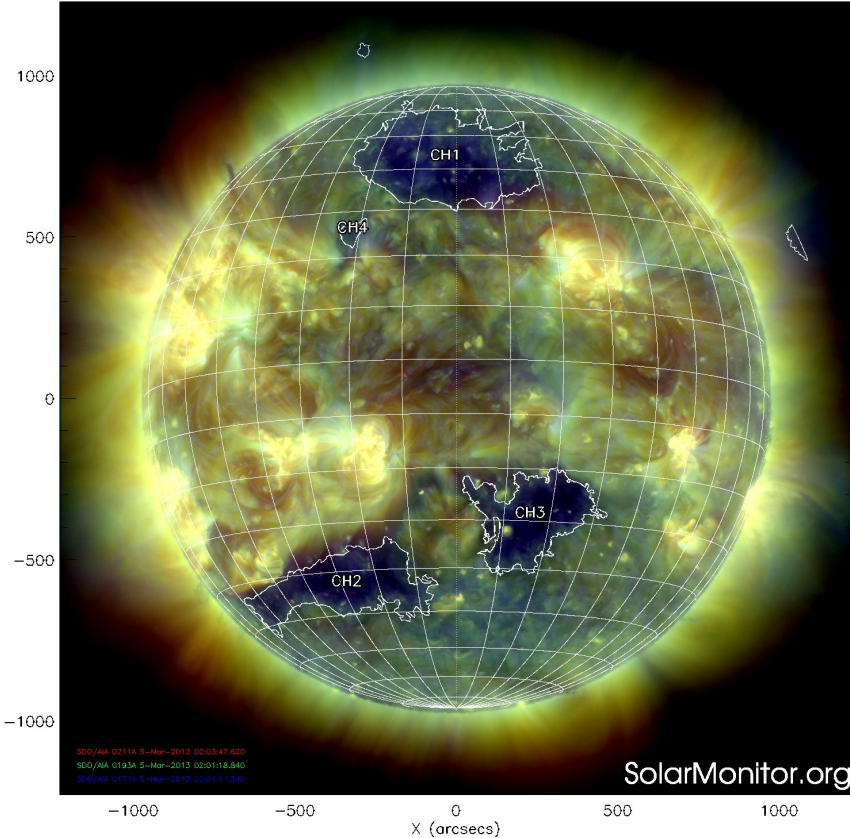


SDO HMI Magnetogram 3-Jan-2017 19:34:29.600



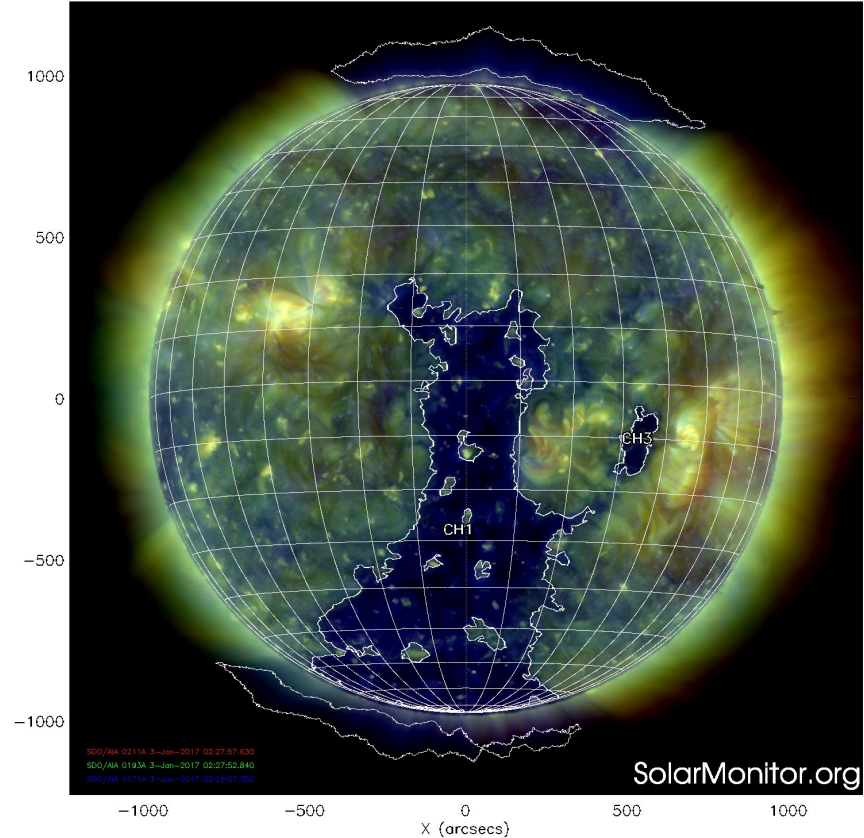
Coronal Holes during the Solar Cycle

CHIMERA Coronal Holes at 5-Mar-2013 02:01:18.840 UT



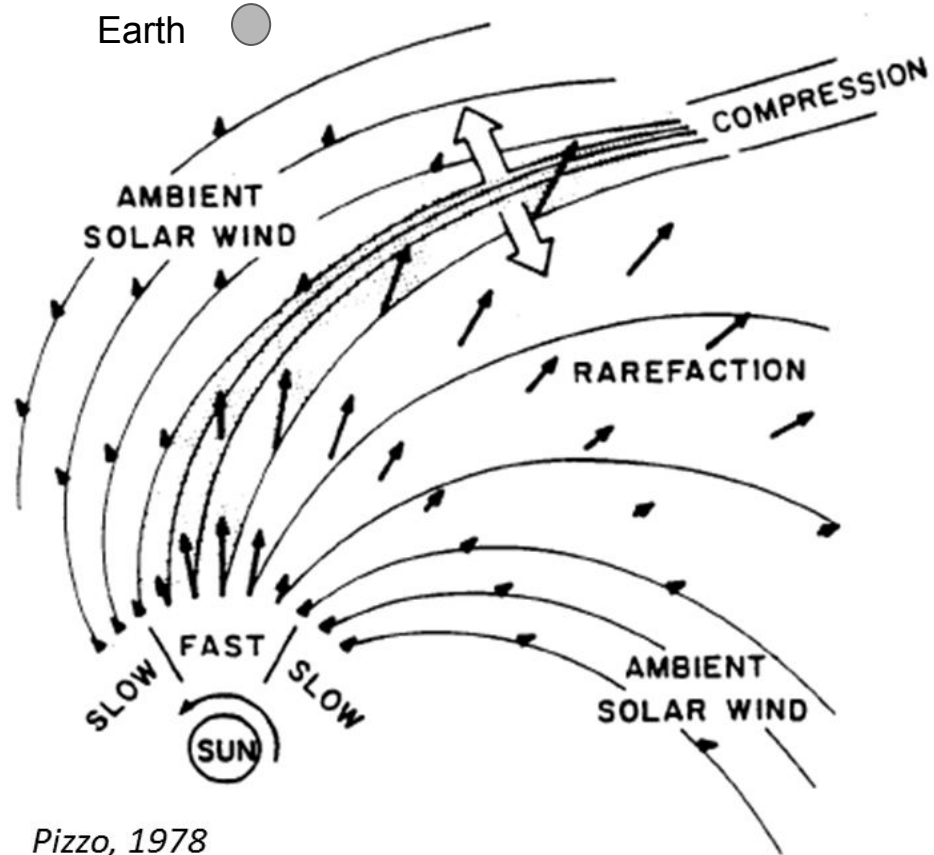
Solar Maximum

CHIMERA Coronal Holes at 3-Jan-2017 02:27:52.840 UT

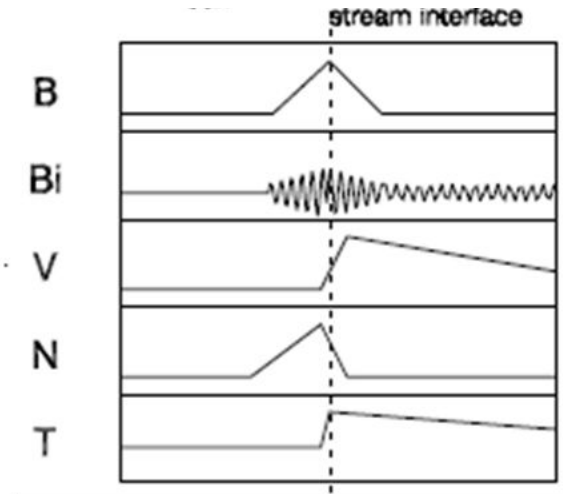


Solar Minimum

Co-Rotating Interaction Region (CIRs)



Pizzo, 1978



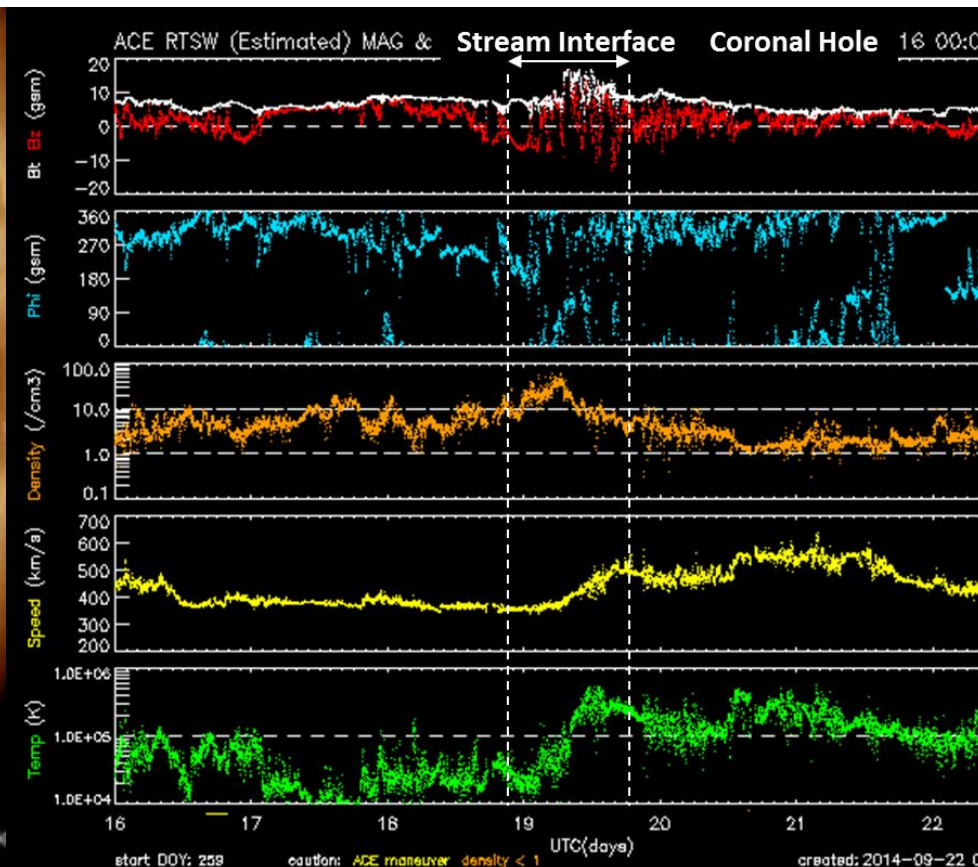
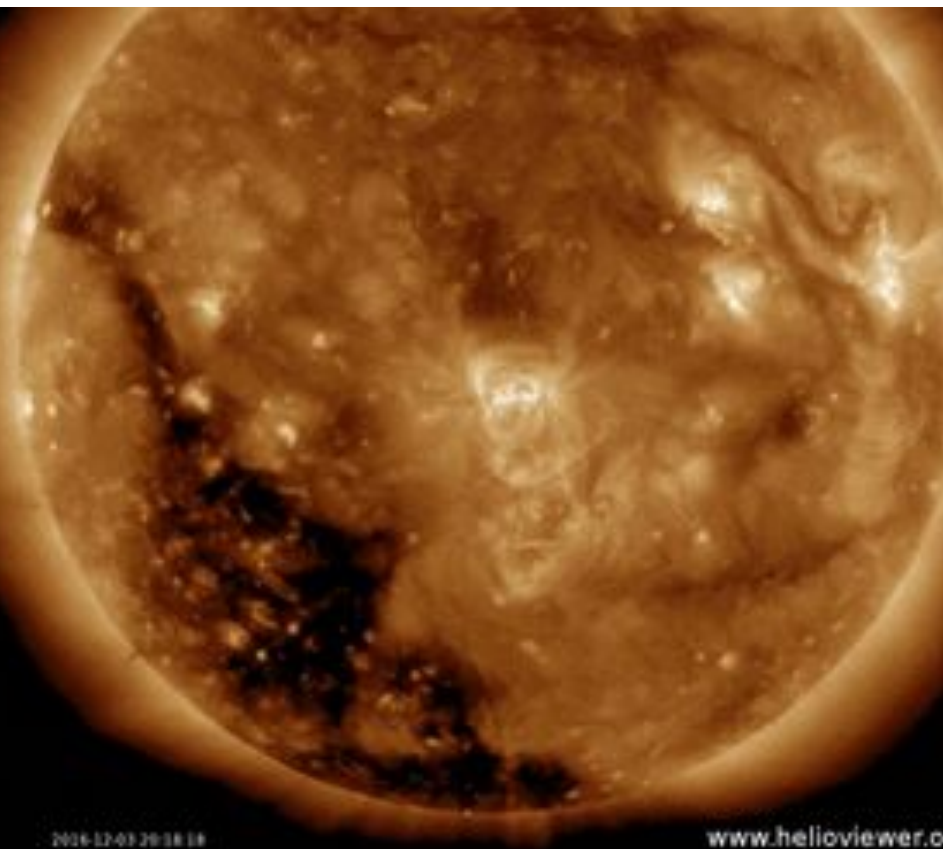
Kataoka et al., 2006

Geomagnetic
Storms / Substorms

Coronal hole impact on Earth

Geomagnetic
Storms / Substorms

Time to arrive the Earth: ~days



Solar Wind

- Slow wind from streamers ~300 km/s fast wind from coronal holes up to 800 km/s
- Slow and fast winds often collide producing corotating interaction regions
- While fast wind emanates from coronal holes, the speeds from all coronal holes are not the same.

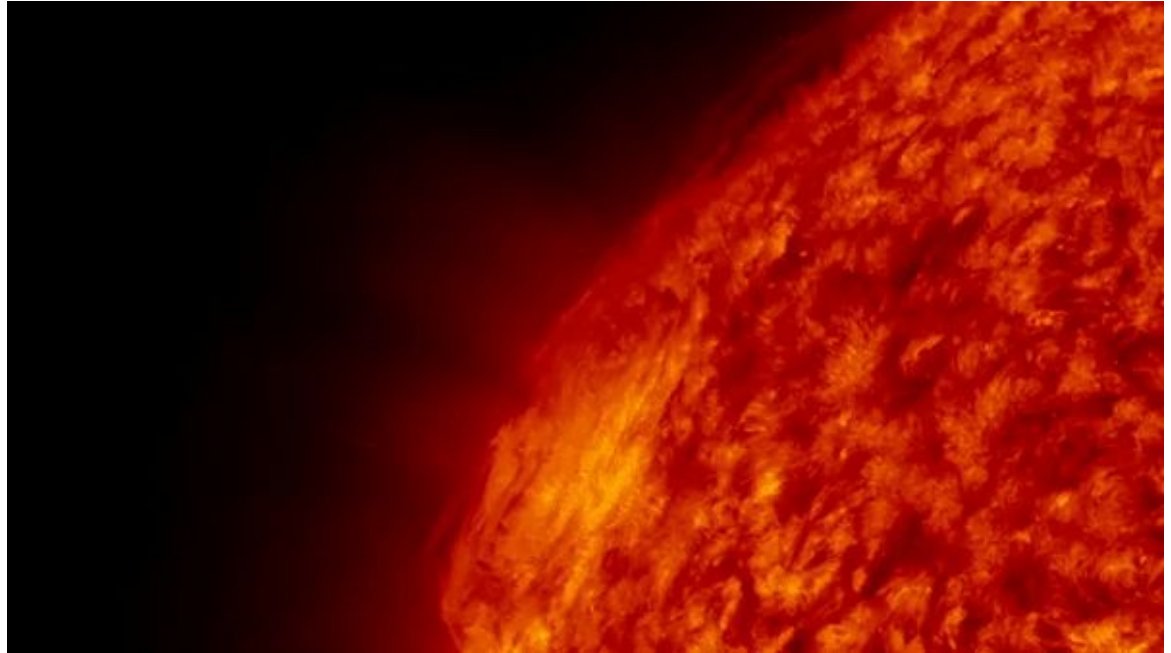


What is a CME?

- CMEs have energy up to 10^{26} joules
- Annual US power consumption: 1.4×10^{19} joules
- CME Energy is about 7 million times the energy consumed by the entire US in one year!

- Earth's mass: 6×10^{24} kg
- CME Mass: 10^{12} kg

Time to arrival: 18hs to ~days

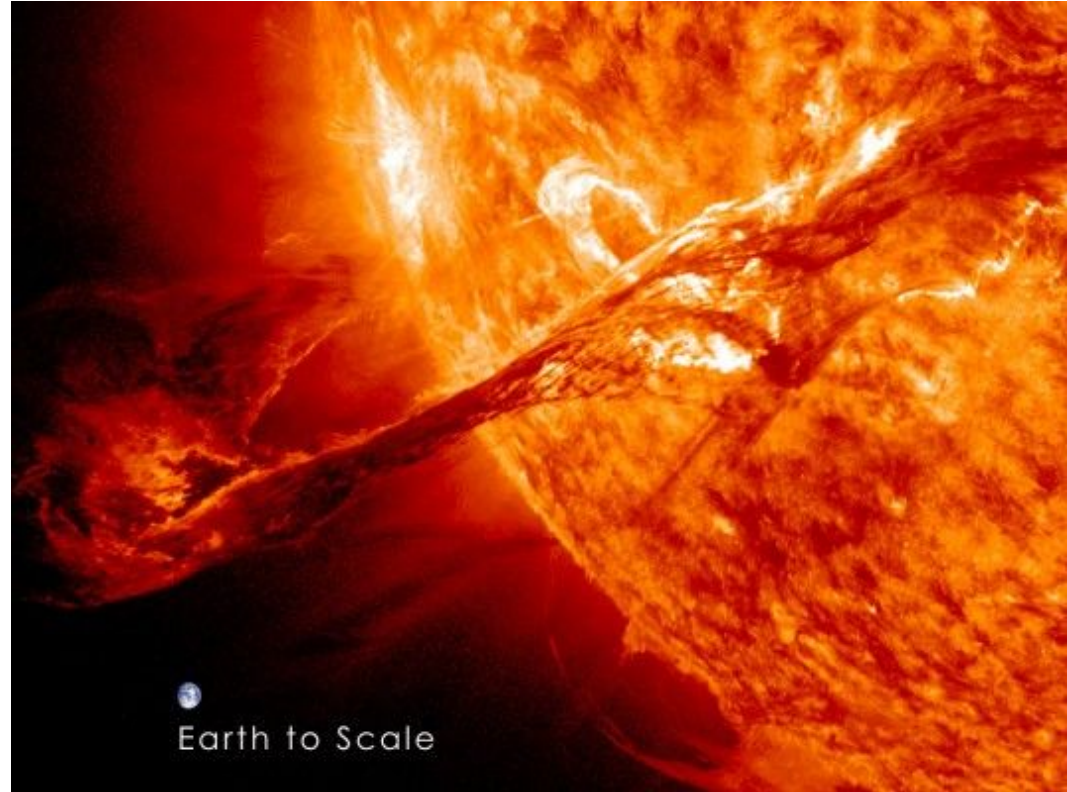


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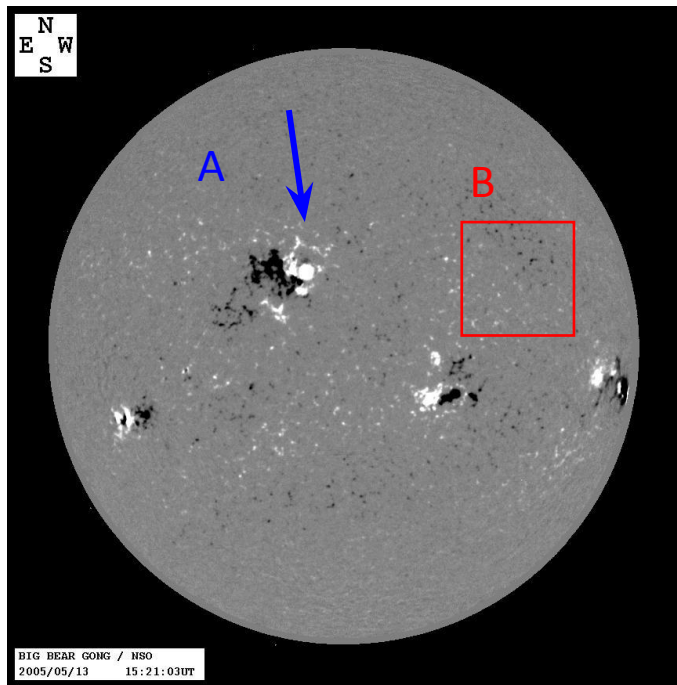


Geomagnetic
Storms / Substorms

→
Ionospheric Storms
Disturbances/ Instabilities

CME Source Regions

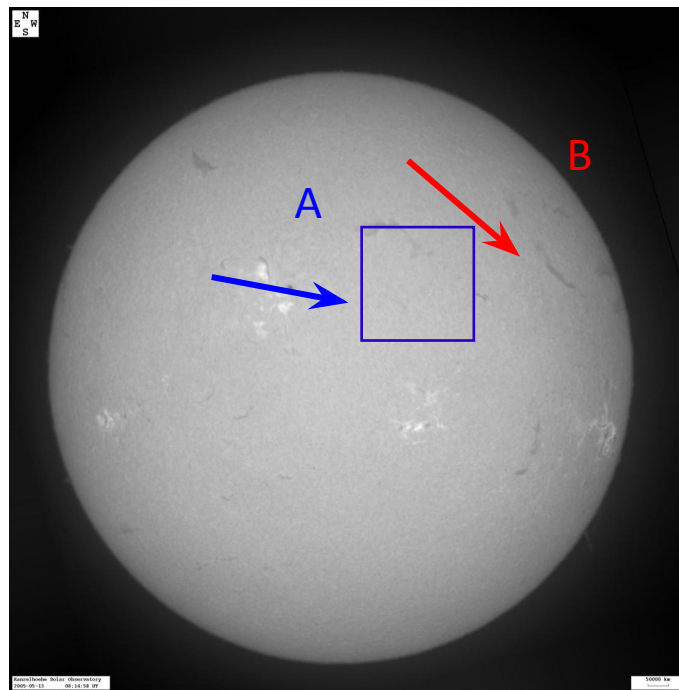
Photospheric Magnetogram



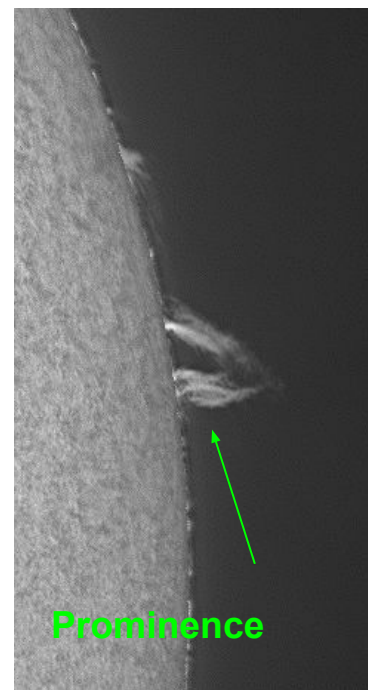
A: active region

B: Filament region (also bipolar, but no sunspots)

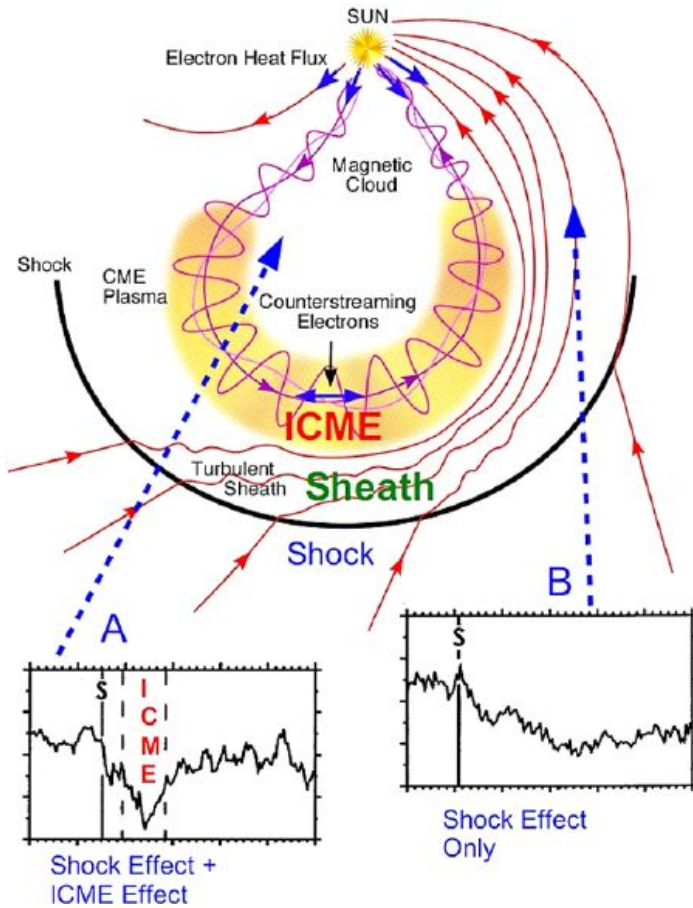
Chromosphere (H-alpha)



Both regions have filaments along the polarity inversion line



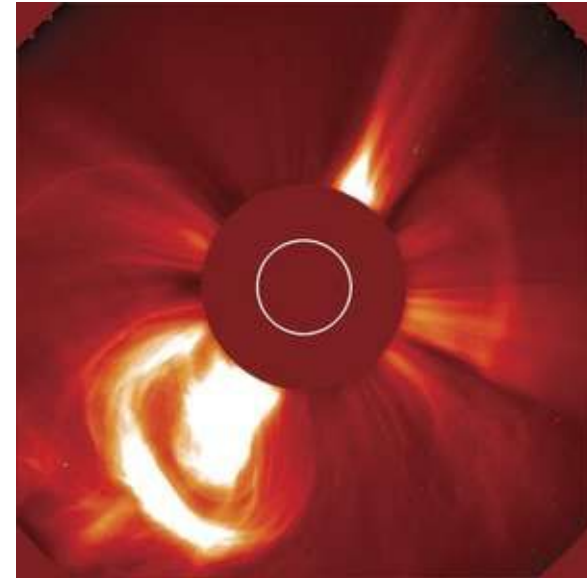
CME morphology



Densities from 10^8 to 10^{12} cm^{-3}

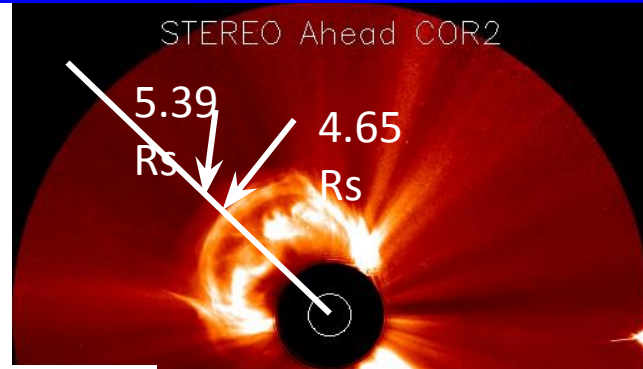
Speeds range from <100 km/s to >3000 km/s

A subgroup of CME are the **Magnetic clouds**, characterized by a flux rope (smooth rotation of the magnetic field vector) and low proton temperature

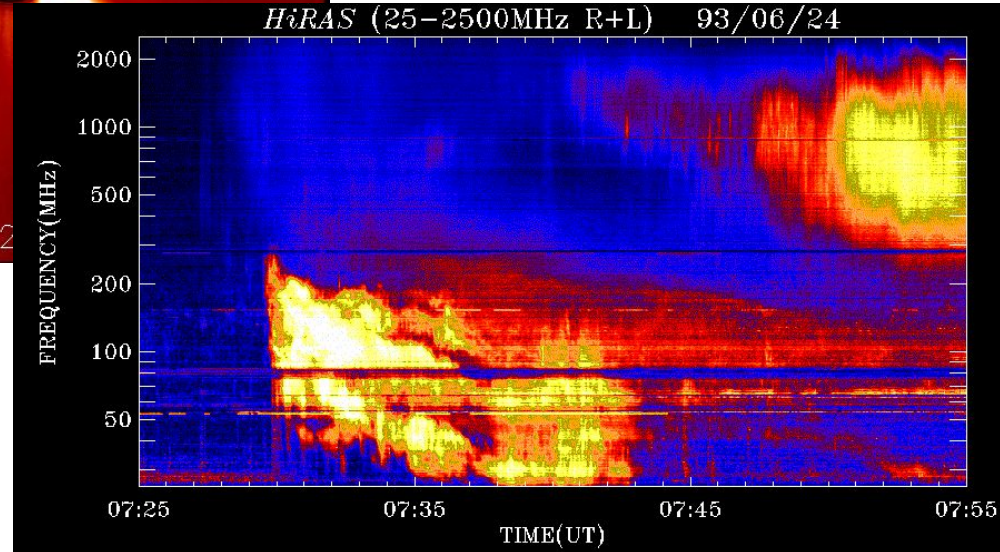
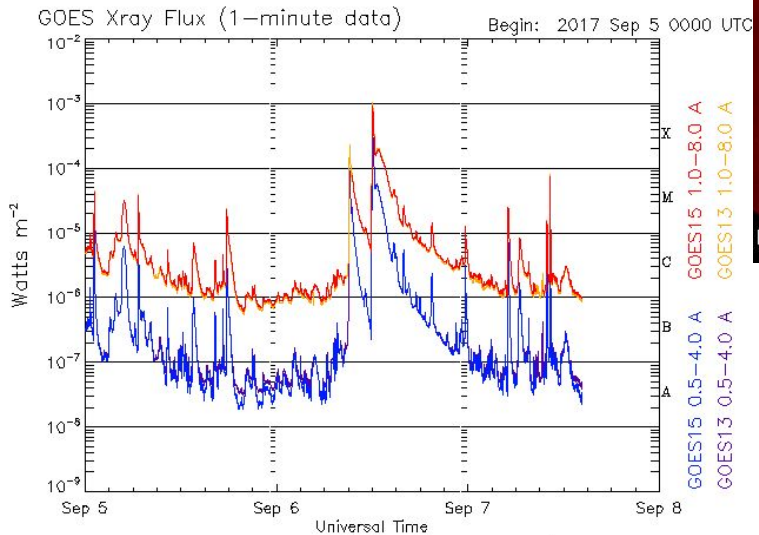


CME associated phenomena: Flares, SEPs, Shocks, Radio Bursts

Solar Flare

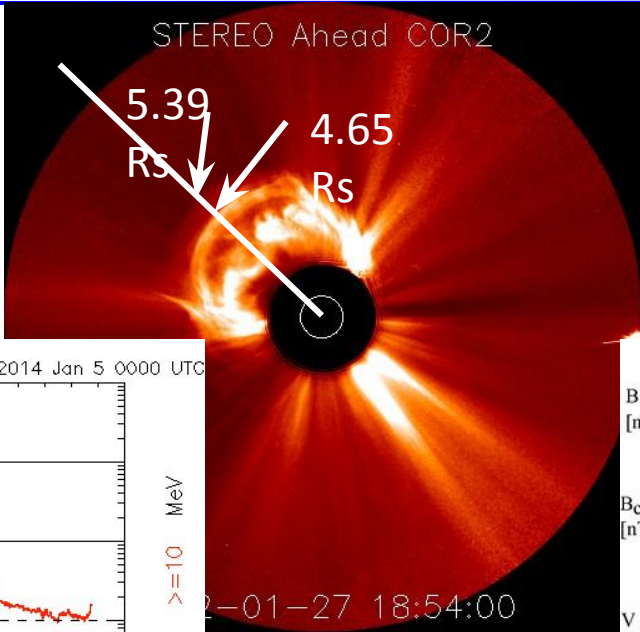


Radio Blackout

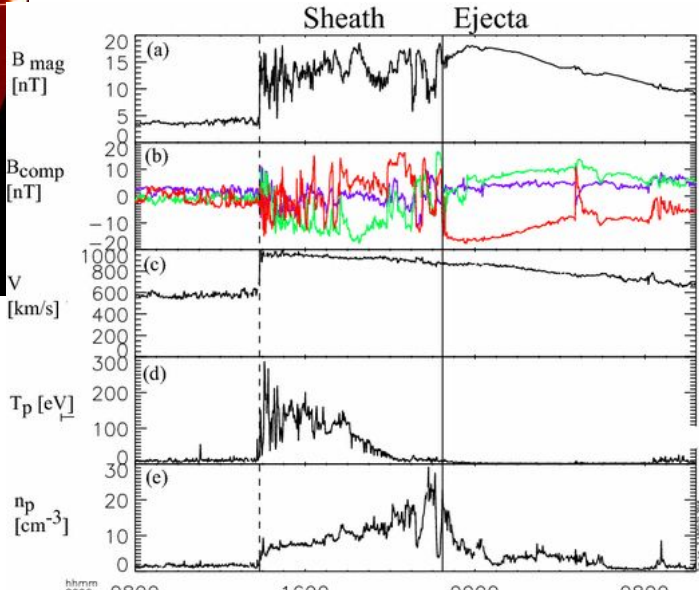
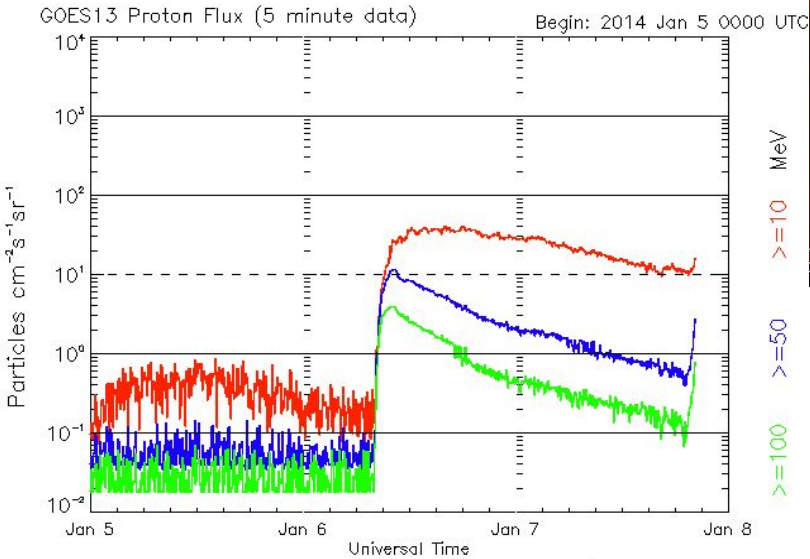


CME associated phenomena: Flares, SEPs, Shocks, Radio Bursts

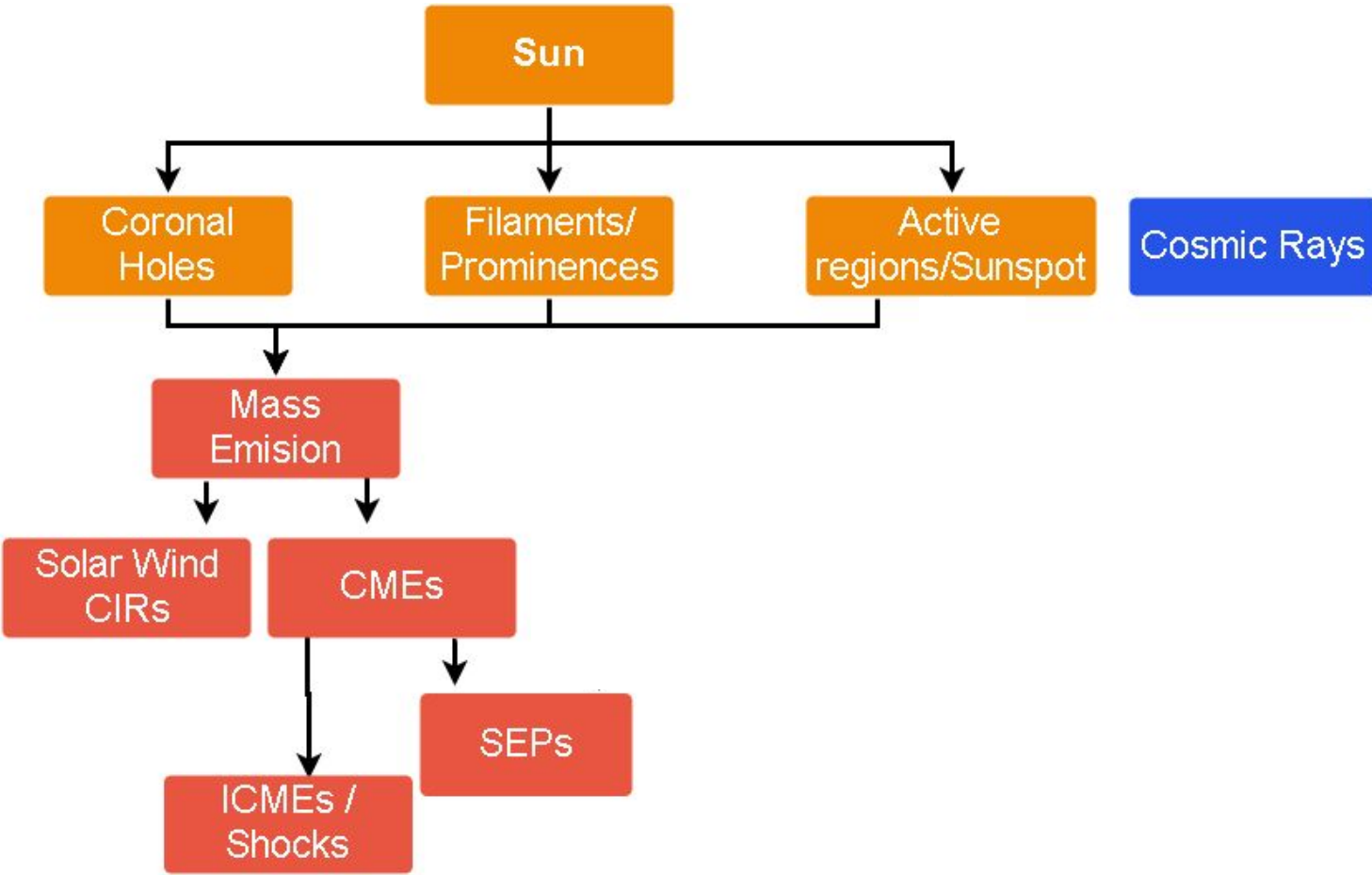
Solar / GCR induced
Radiation Storms



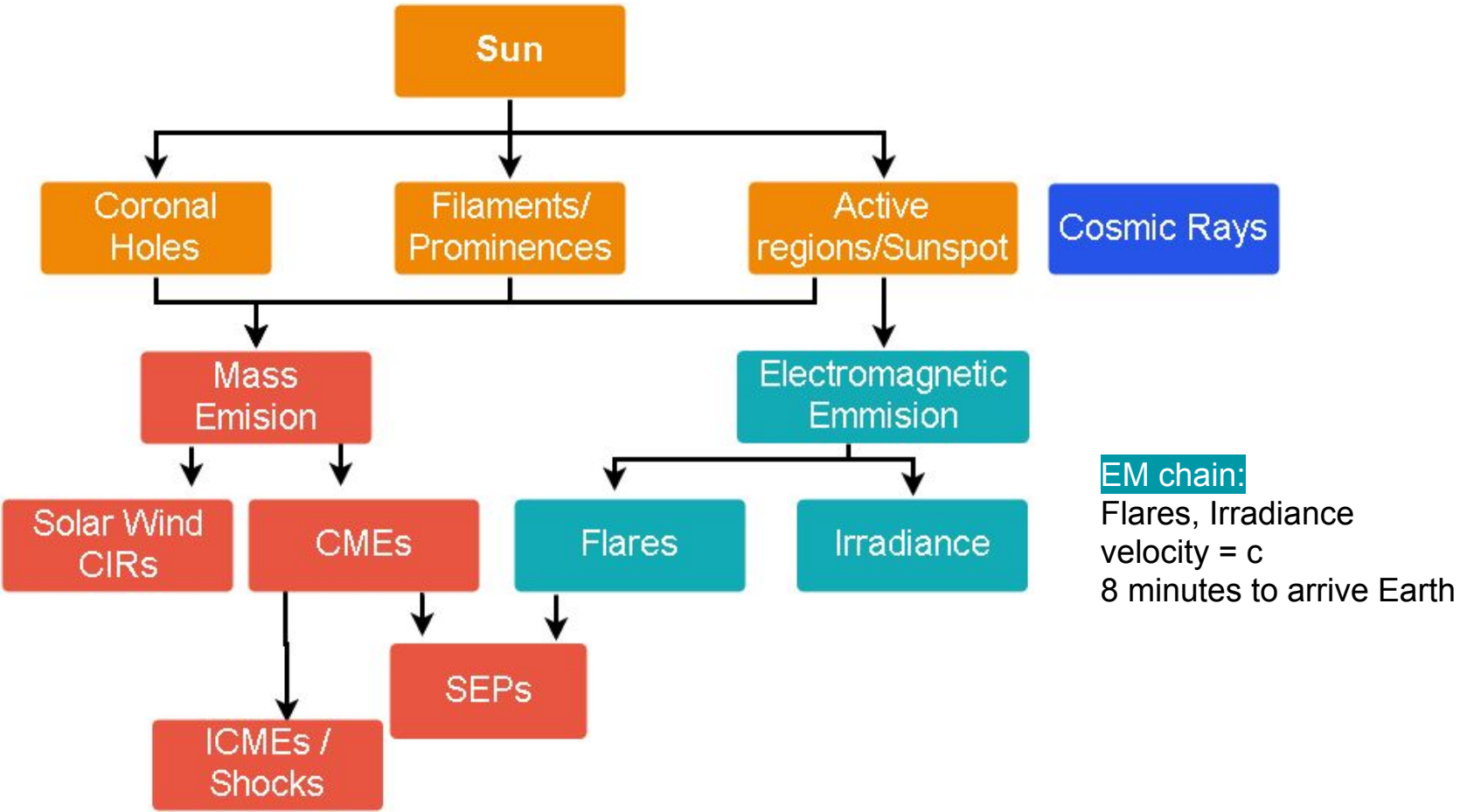
Geomagnetic
Storms / Substorms



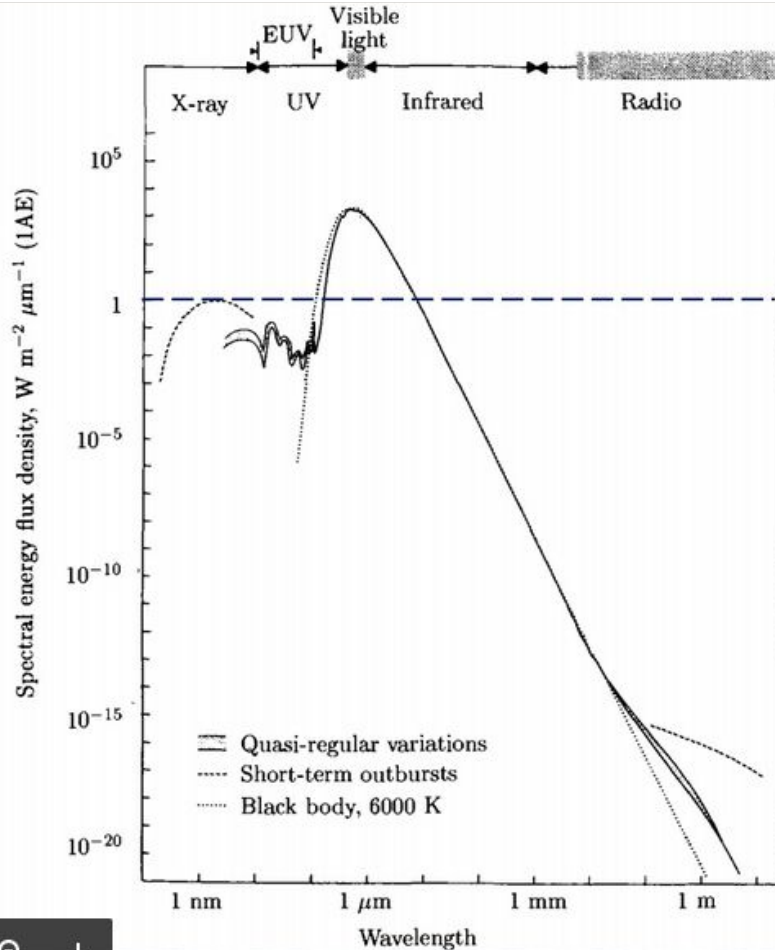
Solar sources of Space Weather



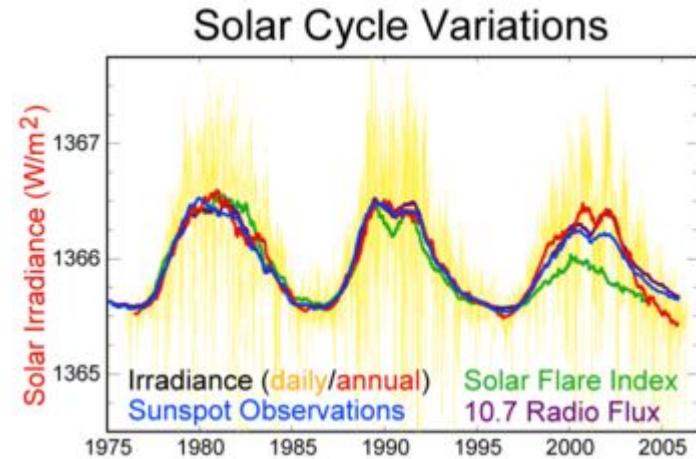
Solar sources of Space Weather



Variation in the solar electromagnetic spectrum

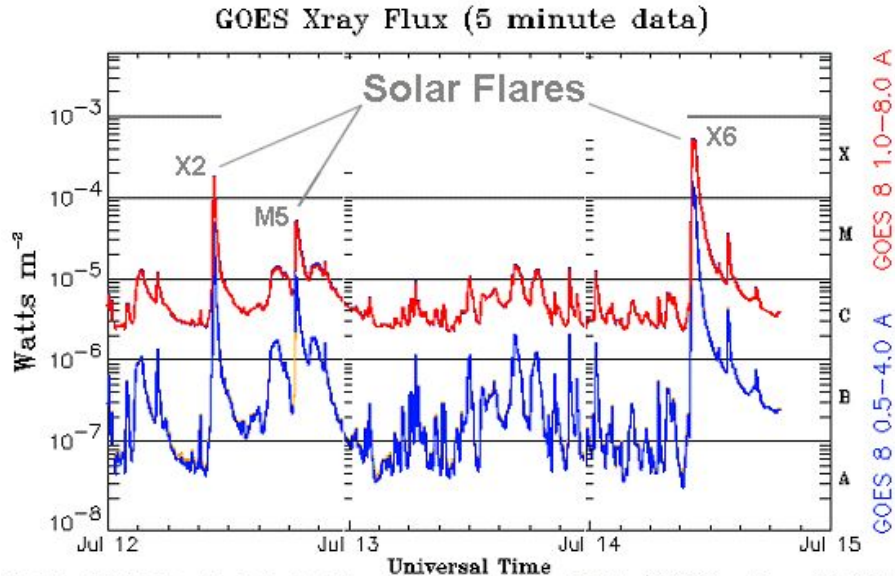


- More energy in Visible and IR
- More variability in X-rays and Radio band



What is a solar flare?

- Magnetic energy released suddenly
- Efficient plasma heating and particle acceleration
- Radiation emitted from radio to gamma rays
- Operational definition: sudden brighten in X-rays
- Time to arrive at Earth: a little more than 8 minutes



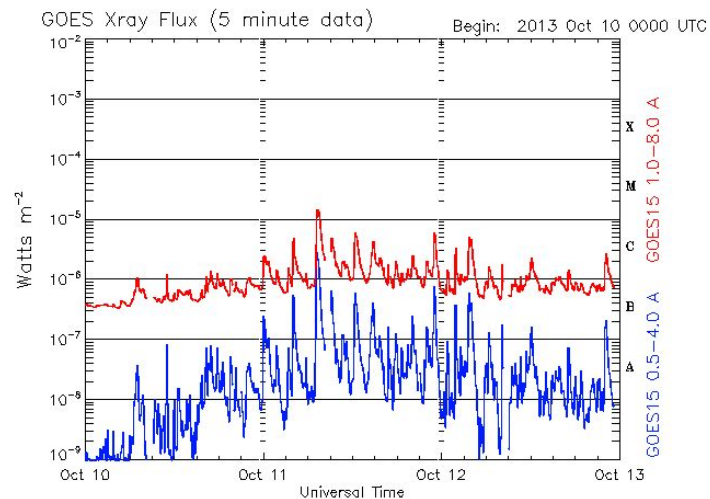
Updated 2000 Jul 14 19:04:03

NOAA/SEC Boulder, CO USA

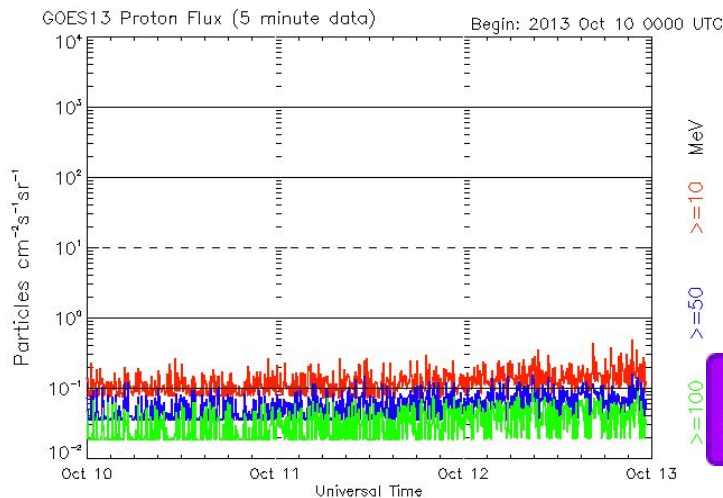
Ionospheric Storms
Disturbances/ Instabilities

Oct. 11, 2013

Active regions/Sunspot



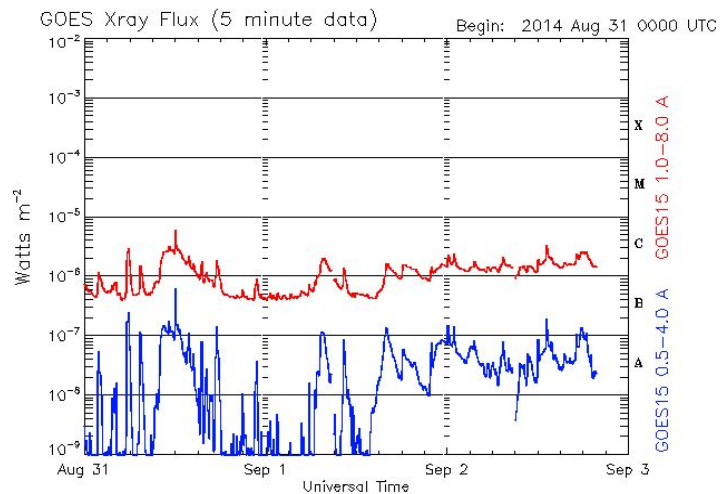
No Solar Energetic Particle recorded



Ionospheric Storms Disturbances/ Instabilities

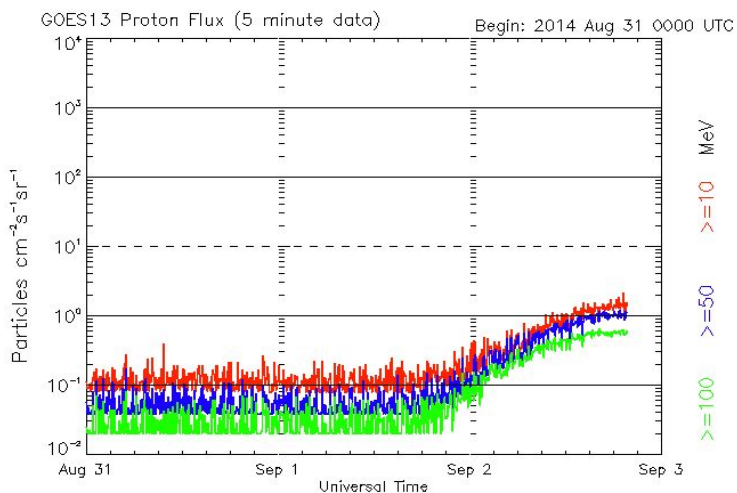
Sept. 1, 2014

Active regions/Sunspot



Updated 2014 Sep 2 20:00:12 UTC

NOAA/SWPC Boulder, CO USA



Updated 2014 Sep 2 19:56:02 UTC

NOAA/SWPC Boulder, CO USA

Solar energetic
Particle observed

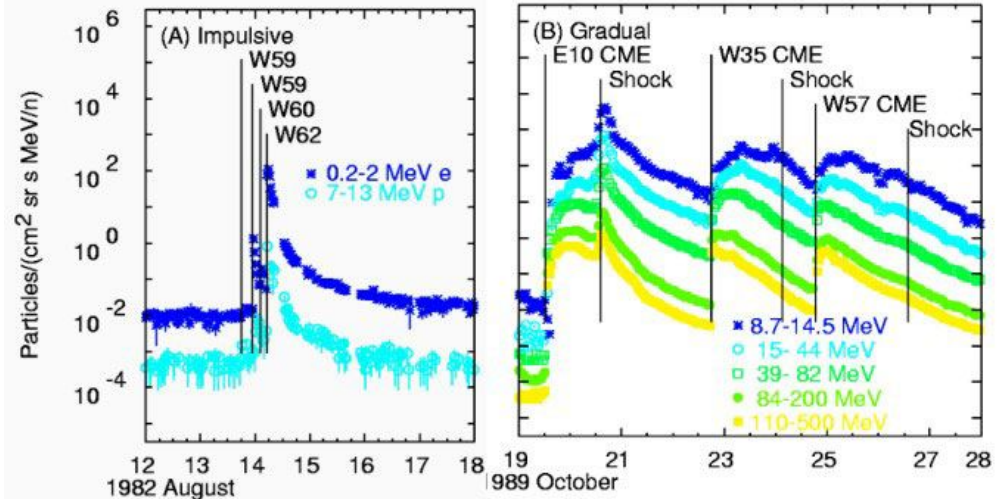
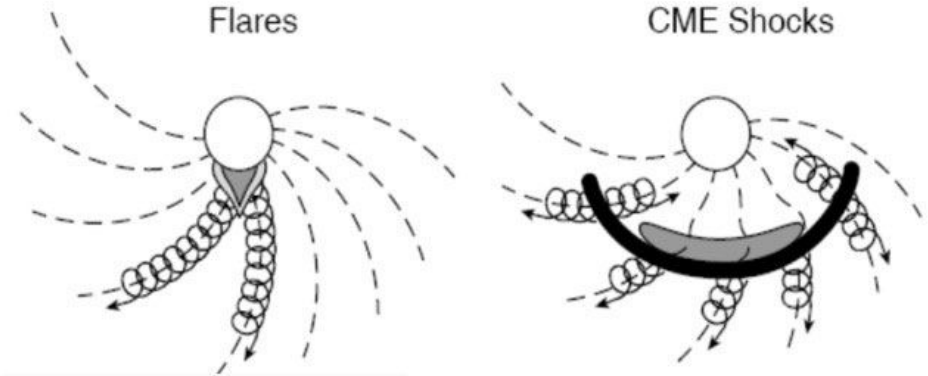
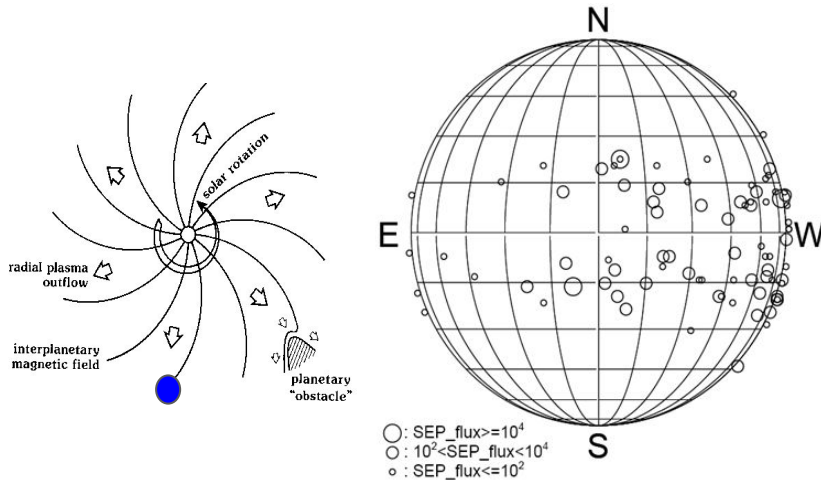
Ionospheric Storms
Disturbances/ Instabilities

Solar / GCR induced
Radiation Storms

Solar Energetic Particles source

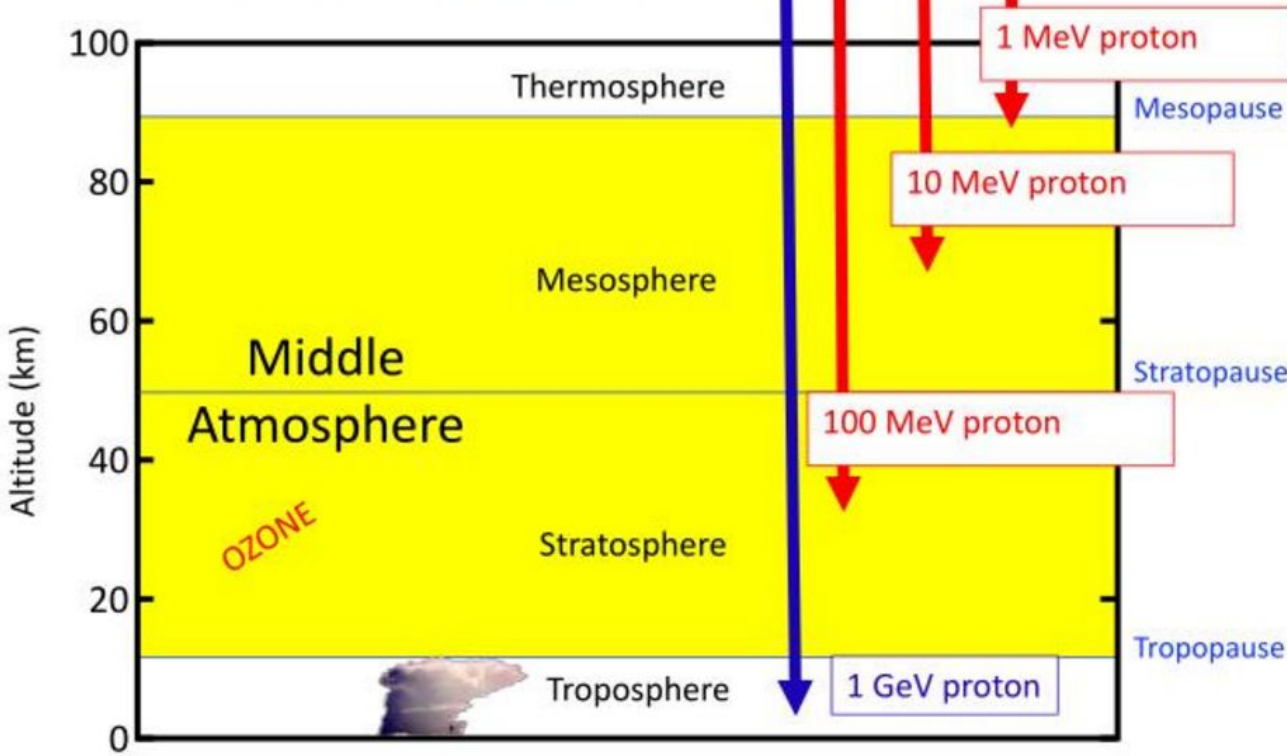
Particles and B need to reach Earth

- Solar Flares need to drive shocks
- CME need to drive shocks
- Source region needs to be magnetically connected to Earth



Solar energetic particle - Solar radiation storm

GOES provides Proton flux for >1 MeV to >100 MeV

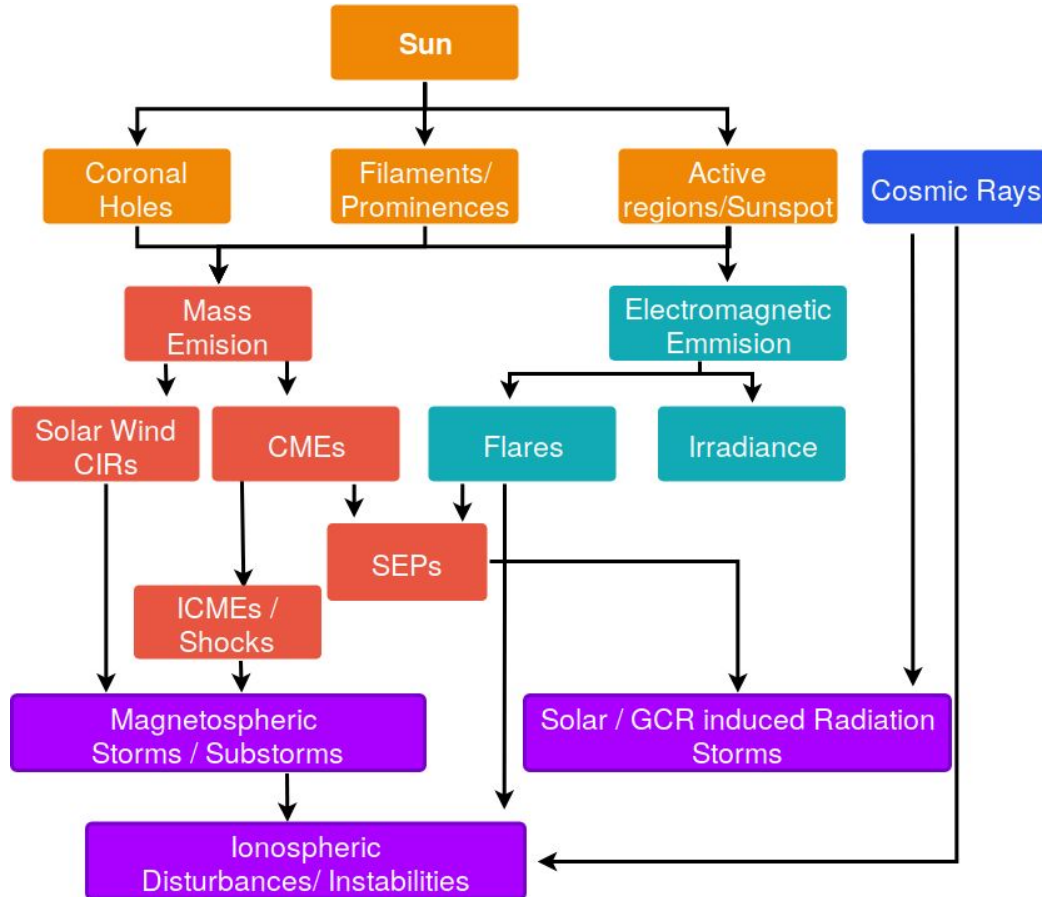


100 MeV protons penetrate to the stratosphere and can destroy ozone.

GeV particles can affect airplane crew/passengers in polar routes

Solar / GCR induced Radiation Storms

Solar sources of Space Weather



Mass chain:

Coronal Mass Ejections (CMEs)
Corotating Interaction Regions (CIRs)
Energetic particles from CME-driven shocks

EM chain:

Flares, Irradiance

Galactic cosmic rays (GCRs)

Preguntas

