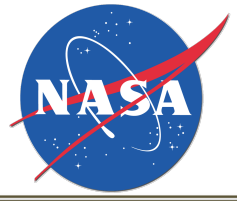

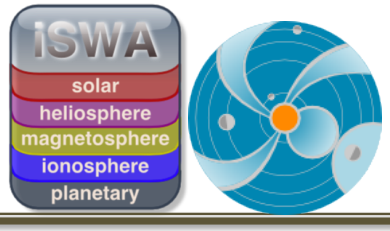

Introduction to Space Weather

Yihua Zheng

Internal Use Only

June 8, 2012

NASA/GSFC Space Weather Center

A sibling organization of CCMC

CCMC: Community Coordinated Modeling Center

Website

http://swc.gsfc.nasa.gov

NASA Goddard Space Weather Center

Forecasts • Alerts • Research • Education

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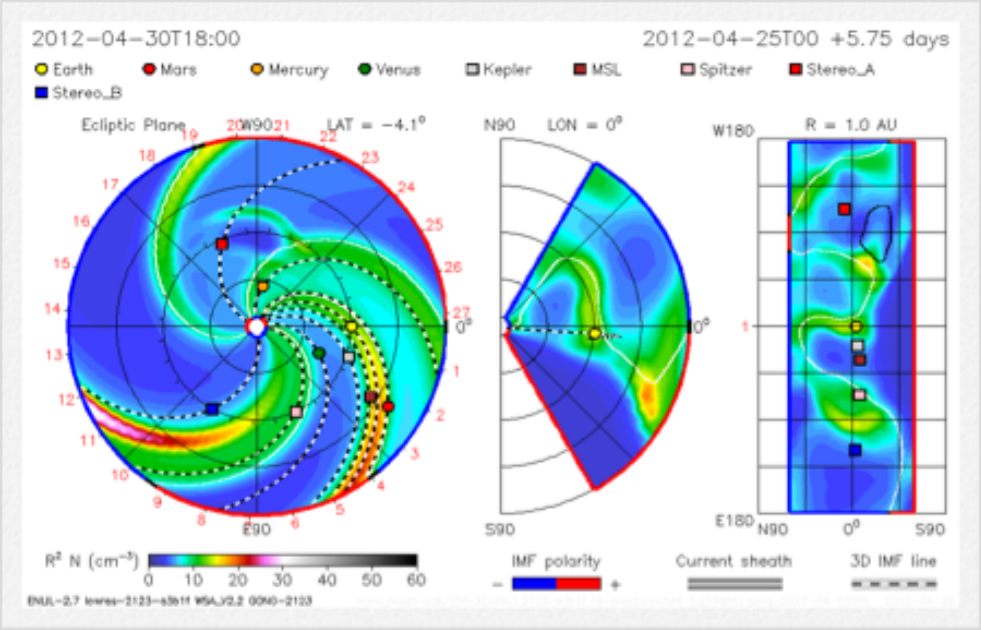


Latest Space Weather Storm

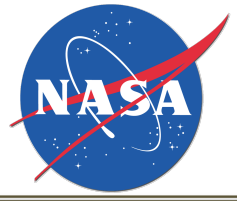
Forecasted CME Track

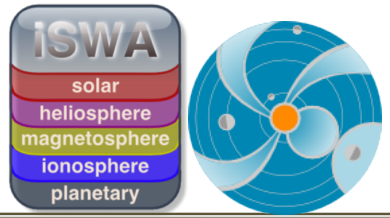
WSA-ENLIL Cone Model

The Space Weather Center at NASA GSFC routinley executes complex space weather model simulations to determine the path and impact of space weather storms through the heliosphere.

More

Address Space Weather needs of NASA's robotic missions.
Bring Space Weather knowledge to the public.

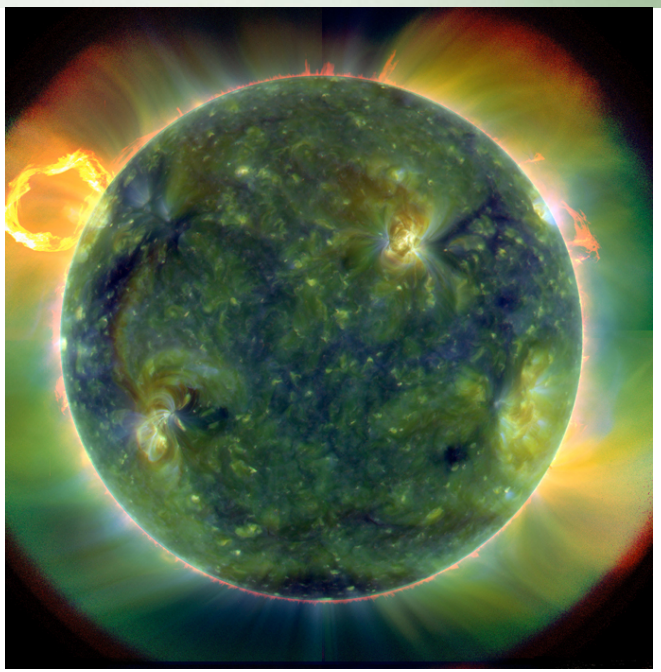




SWx Services provided by NASA/ SWC

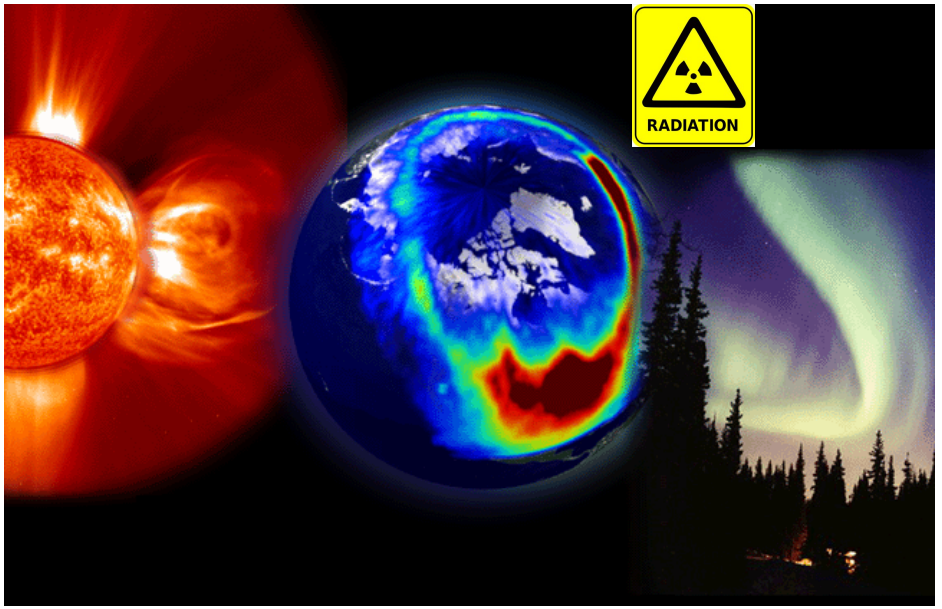
NASA SWC: Types of SWx Services

1. Providing assistance in spacecraft anomaly resolution by assessing whether space weather has any role in causing the observed anomaly/ anomalies.
2. Sending out weekly space weather reports/ summaries to NASA mission operators, NASA officials and involved personnel.

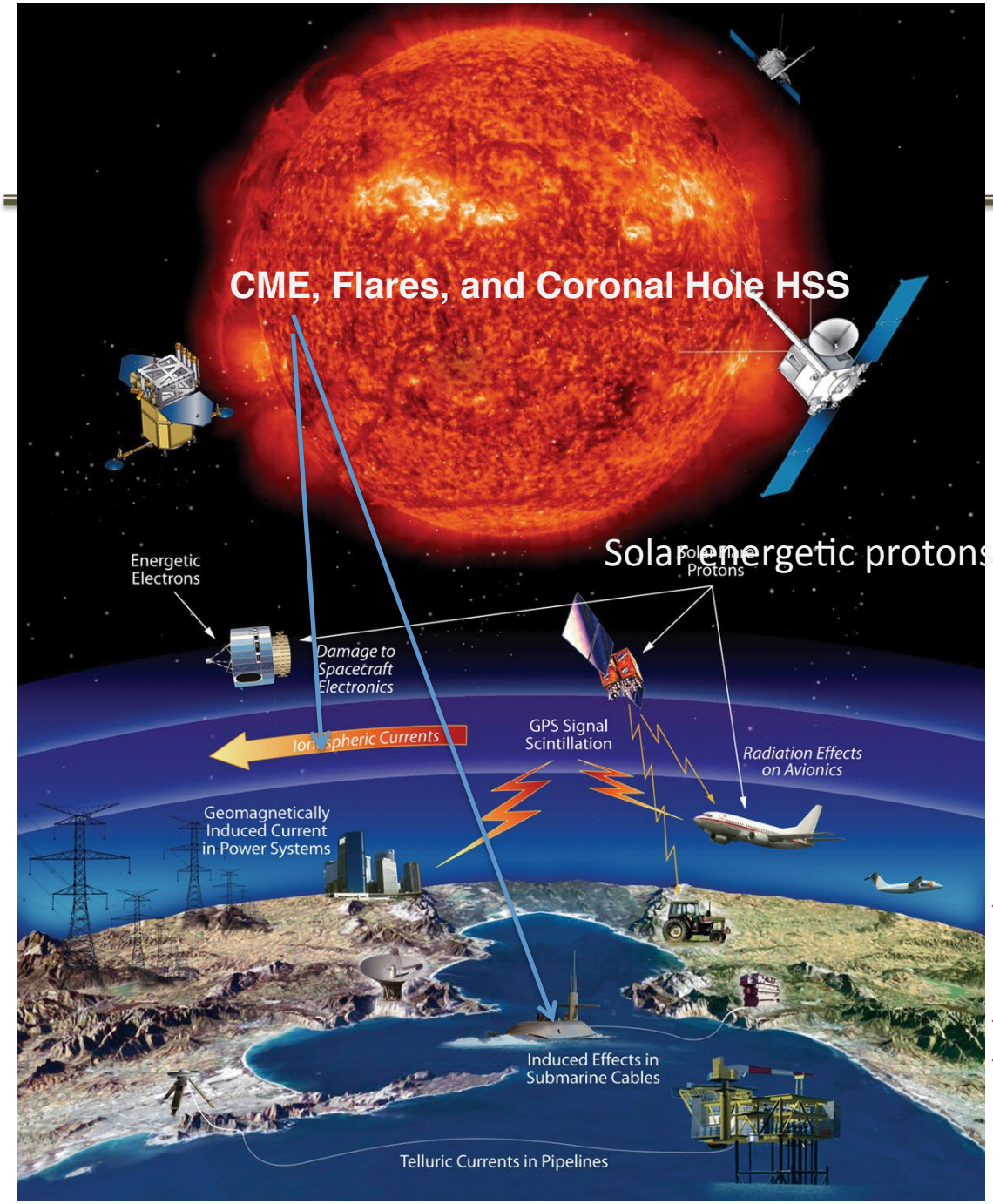


Types of SWx Services
- continued

3. Sending out timely space weather alerts/ forecasts regarding adverse conditions throughout the solar system, such as significant CME events, elevated radiation levels, etc.



4. Providing general space weather support for NASA customers.



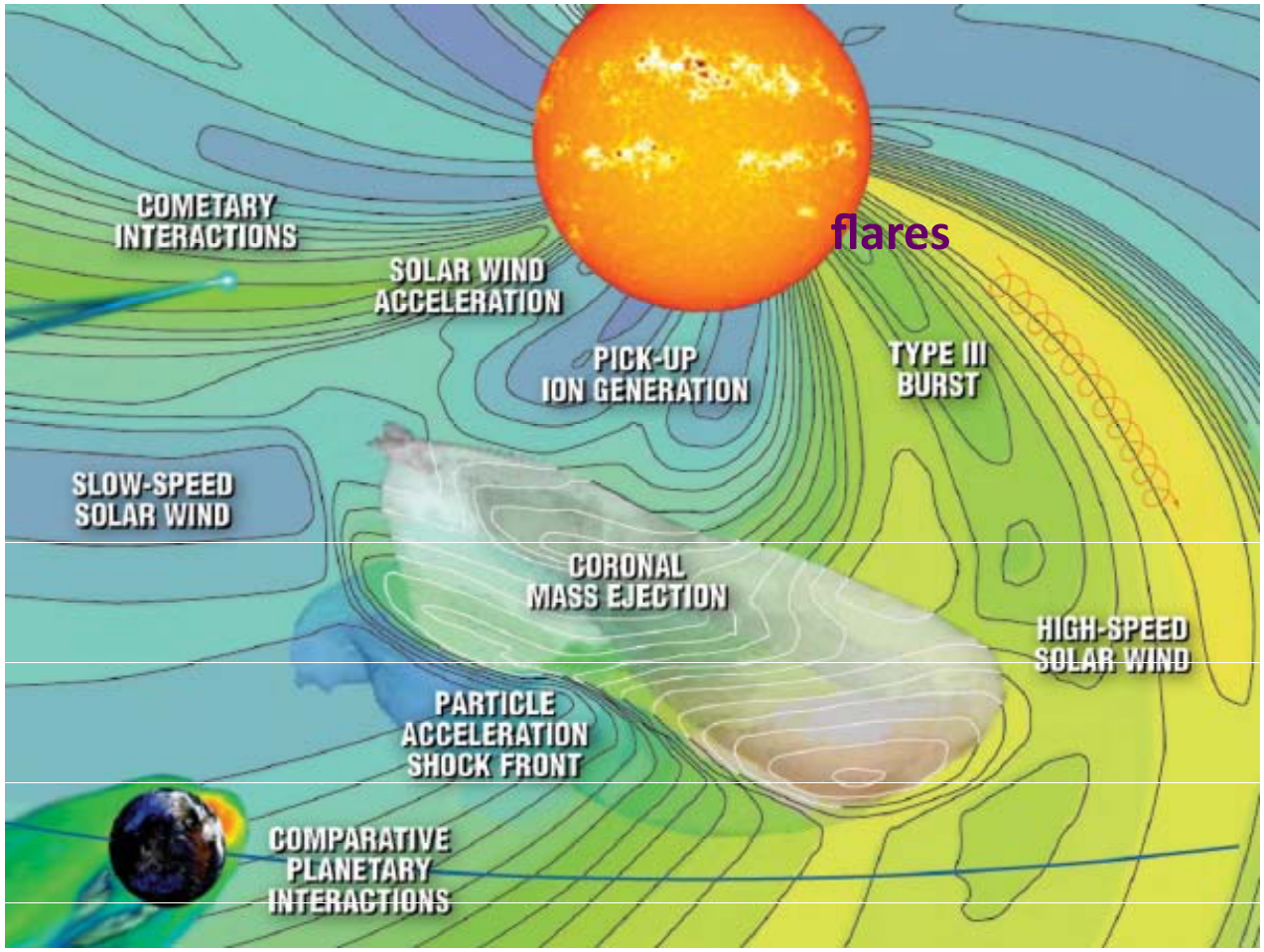
The Sun
maker of space weather

CME, Flares, and Coronal Hole HSS

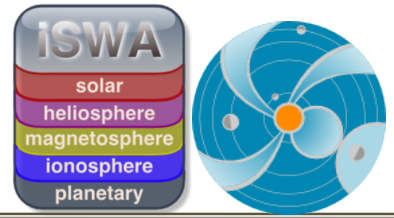
Three very important solar wind disturbances/structures for space weather

- ✓**Radiation storm**
  - **proton radiation (SEP) <flare/CME>**
  - **electron radiation <CIR HSS/CME>**
- ✓**Radio blackout storm <flare>**
- ✓**Geomagnetic storm**
  - **CME storm (can be severe)**
  - **CIR storm (moderate)**

Flares/CMEs/HSS



Outline



- Brief introduction of the Sun
- Flare and its space weather impacts
- CME and its space weather impacts

- Summary

Plasma

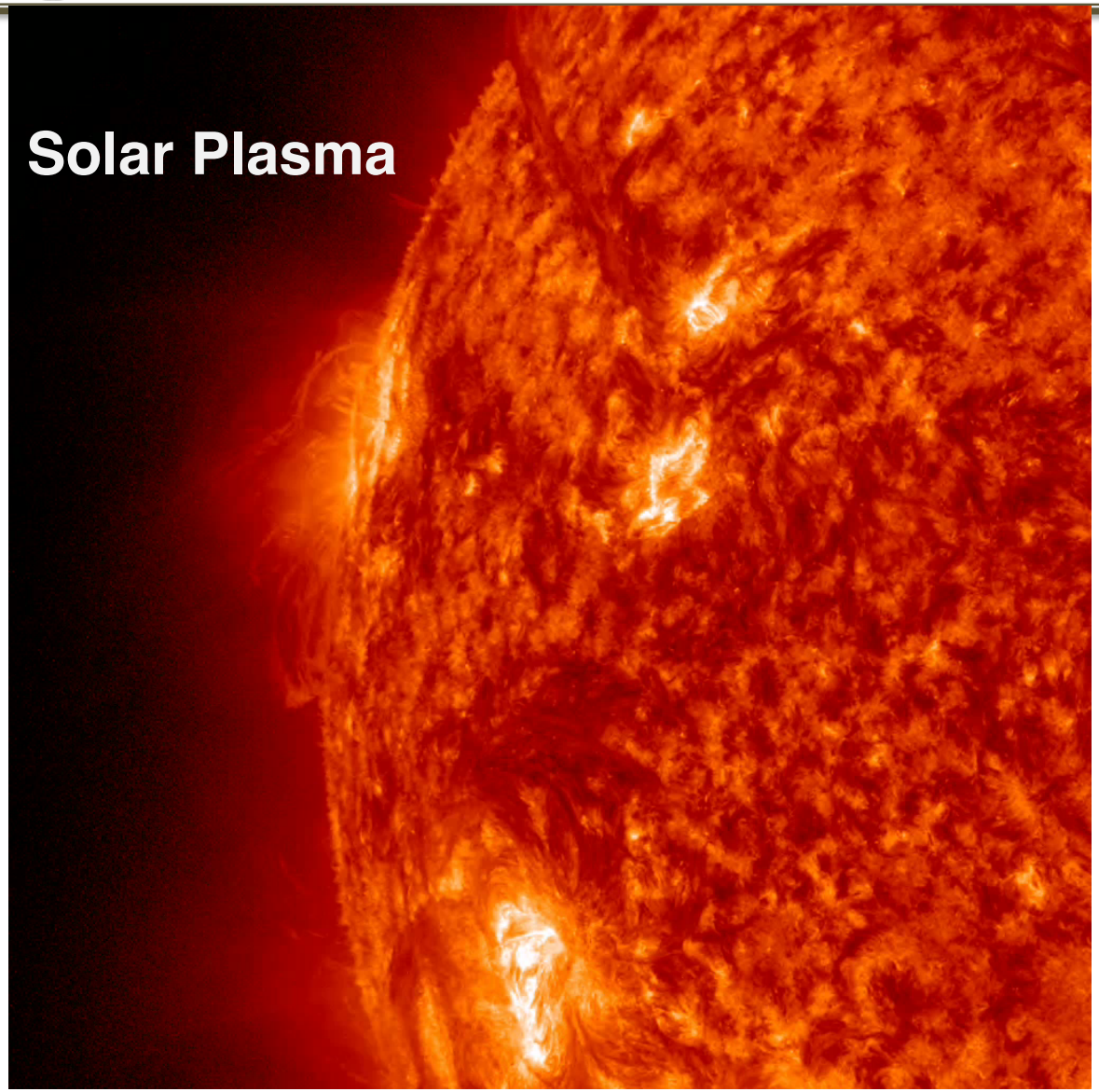
electrified gas with atoms dissociated into positive ions and negative electrons

- 99% of the matter in universe is in the plasma state (gas, liquid, solid)
  - May not be very accurate, but certainly a reasonable ones
  - Stellar interiors and atmospheres, gaseous nebulae, interstellar material are plasmas, Earth's ionosphere and above

We live in the 1% of the universe in which plasmas do not occur naturally

A plasma is a quasineutral gas of charged and neutral particles which exhibits collective behavior

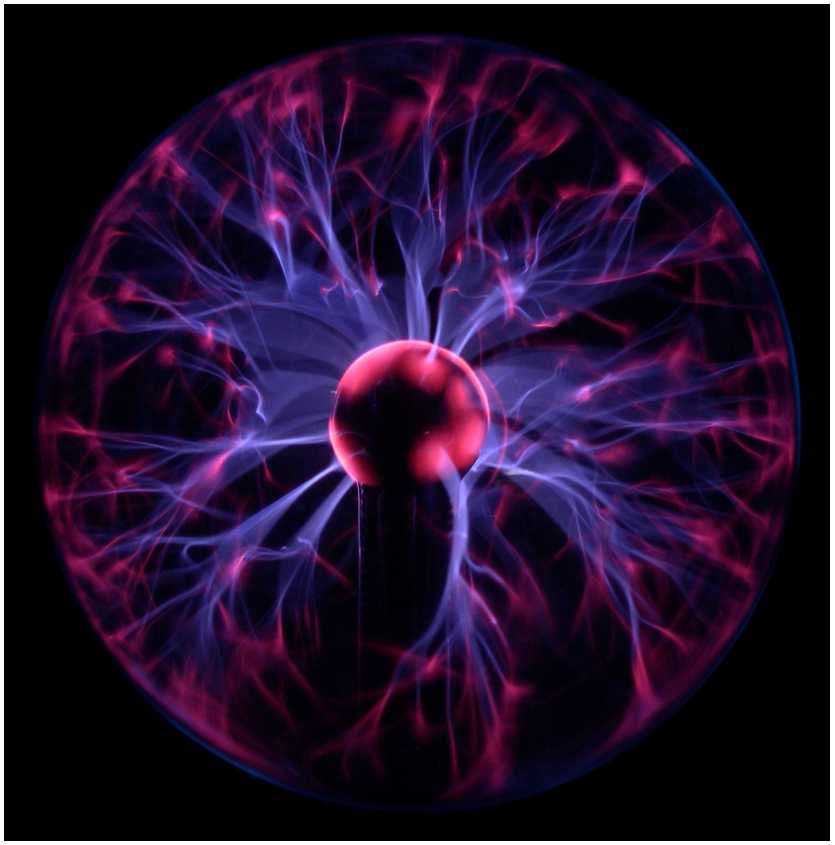
Prominence Eruption



April 16, 2012
Associated with the M1.7 class flare

Plasma in everyday life

- A **plasma display** panel (PDP) is a type of flat panel display common to large TV displays 30 inches (76 cm) or larger. They are called "plasma" displays because the technology utilizes small cells containing electrically charged ionized gases, or what are in essence chambers more commonly known as fluorescent lamps.



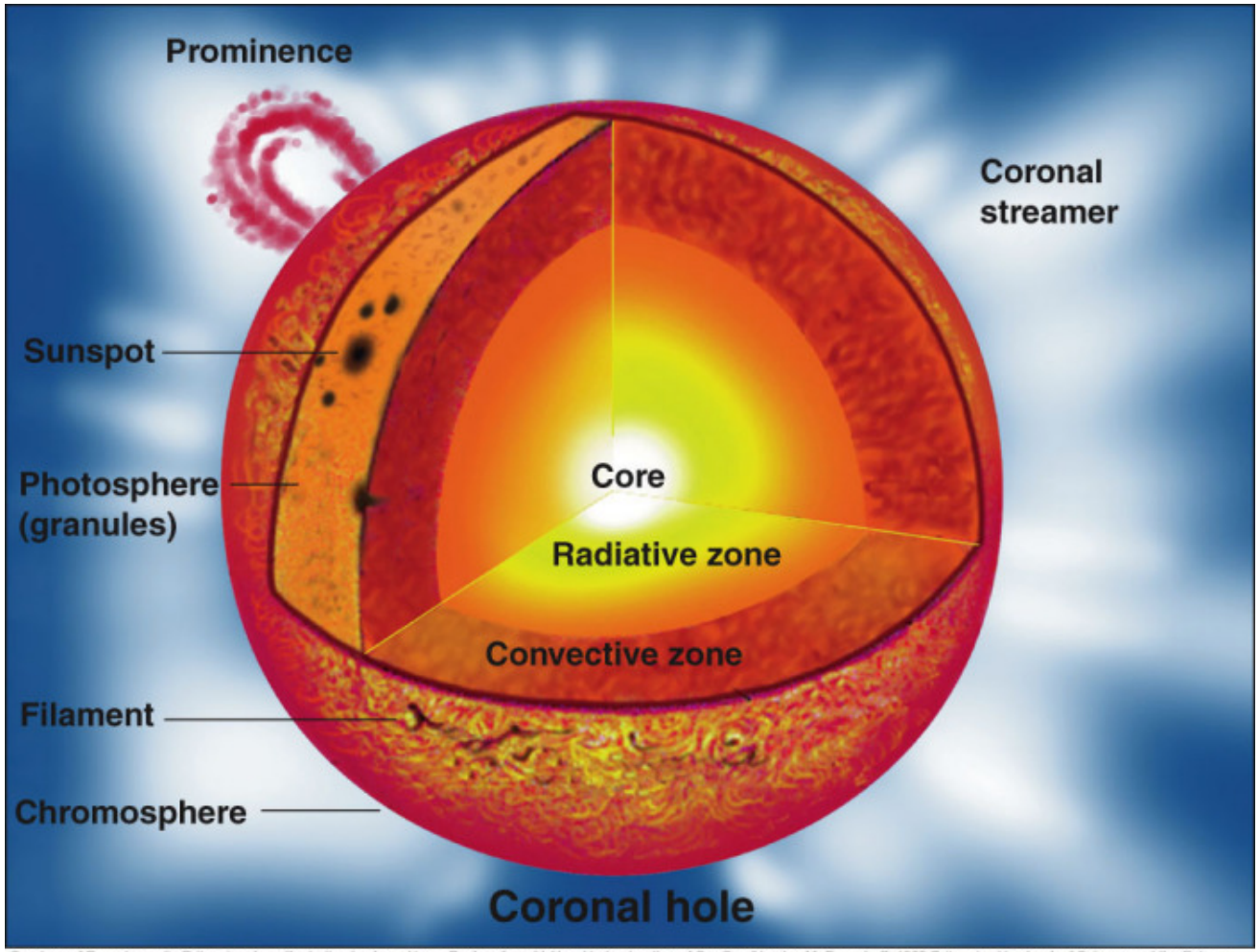
Plasma lamp

Plasma TV, a lightning bolt, fluorescent tube, aurora, neon sign

Manmade: plasma TV, lamp, fluorescent tube, neon sign

Structures of the Sun

- peculiar in its structure



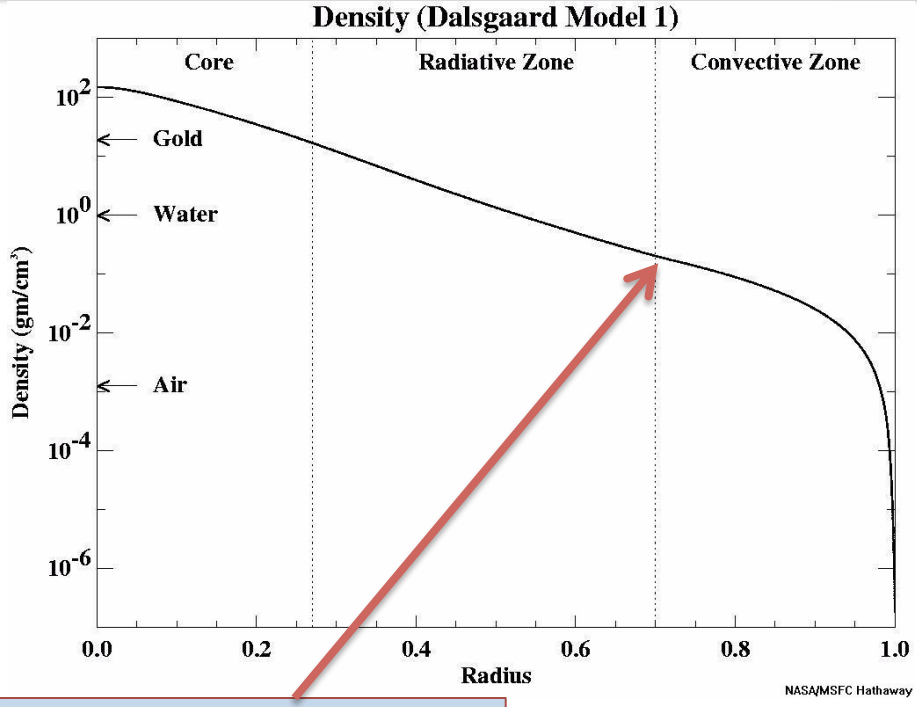
Courtesy of Encyclopaedia Britannica, Inc.; illustration by Anne Hoyer Becker; from "A New Understanding of Our Sun," by Jay M. Pasachoff, 1989 Britannica Yearbook of Science and the Future

Core (up to ~0.25 Rs): high temperature and pressure – 15 Million Kelvin
160 g/cm^3 – 10 times of gold/lead
Gaseous state: plasma

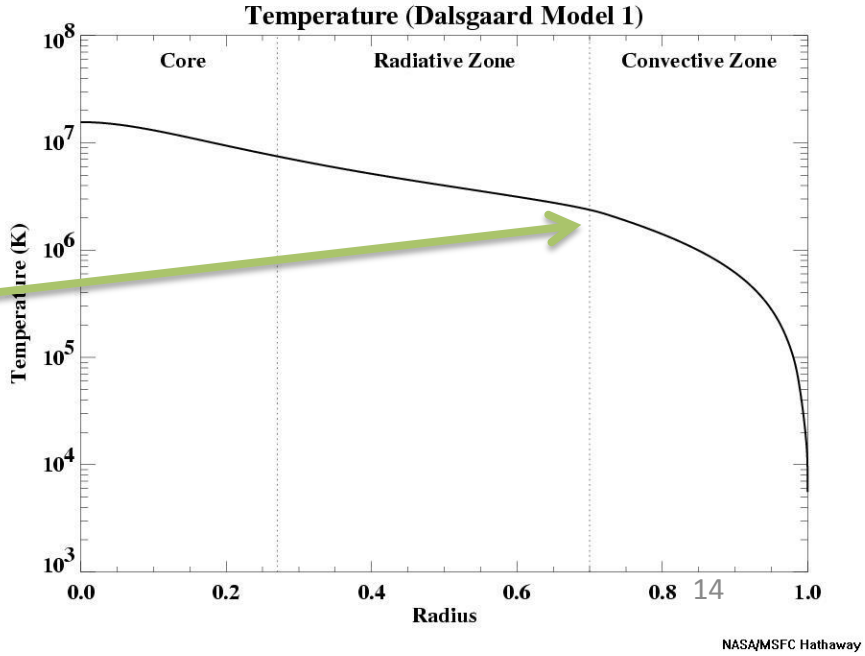
Radiative Zone (0.25 – 0.7 Rs): transparent enough that photons can travel moderate distances before being absorbed or scattered. Temp: 7 million – 2 million K. Density: 20 g/cm^3 - 0.2 g/cm^3 – from density of Gold to less than water)

Convective zone: (0.7 – 1.0 Rs): the temperature is lower, and radiation is less significant. Energy is transported outward mostly by *convection.*

The interior of the Sun

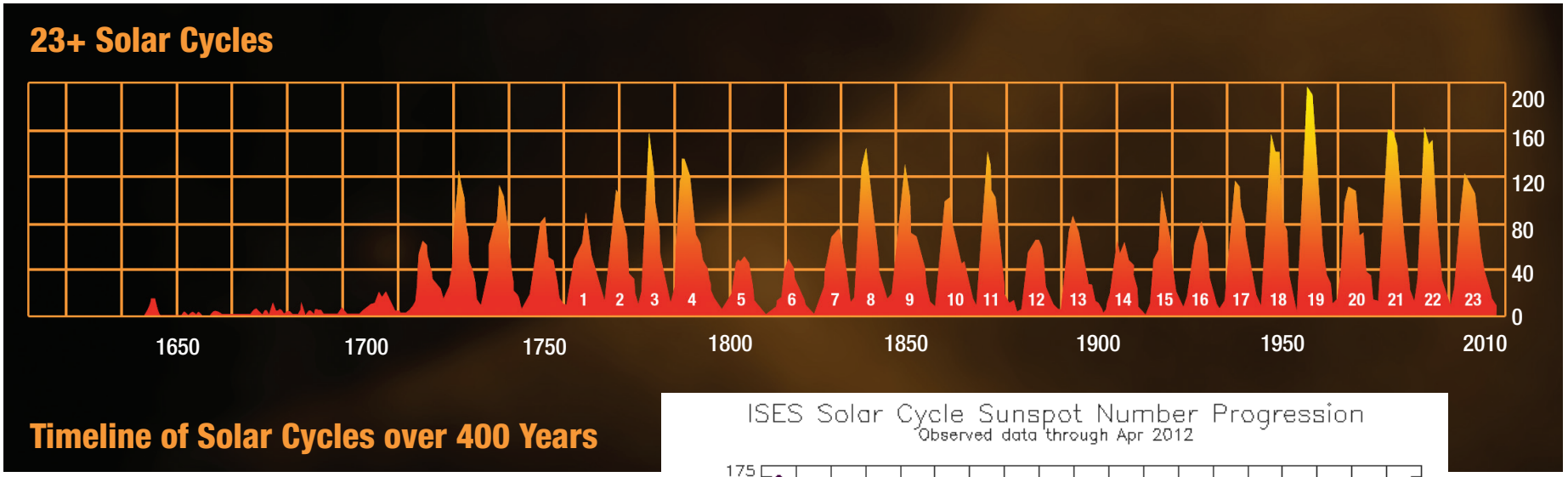


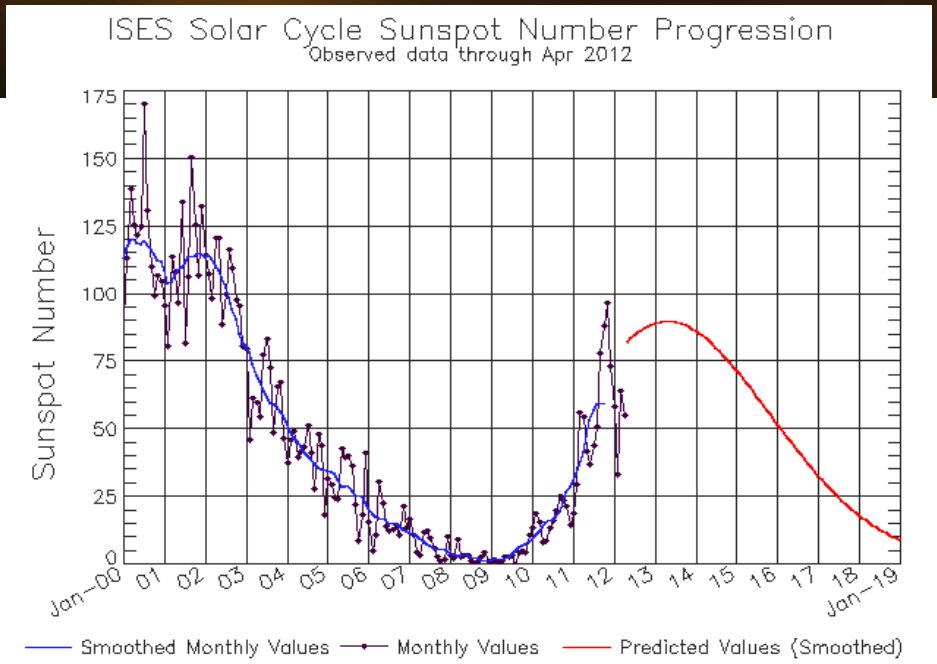
Tachocline: the interface layer between the radiative zone and the convective zone.
Believed to be the seat of Solar Dynamo.
drives the solar cycle of magnetic activity

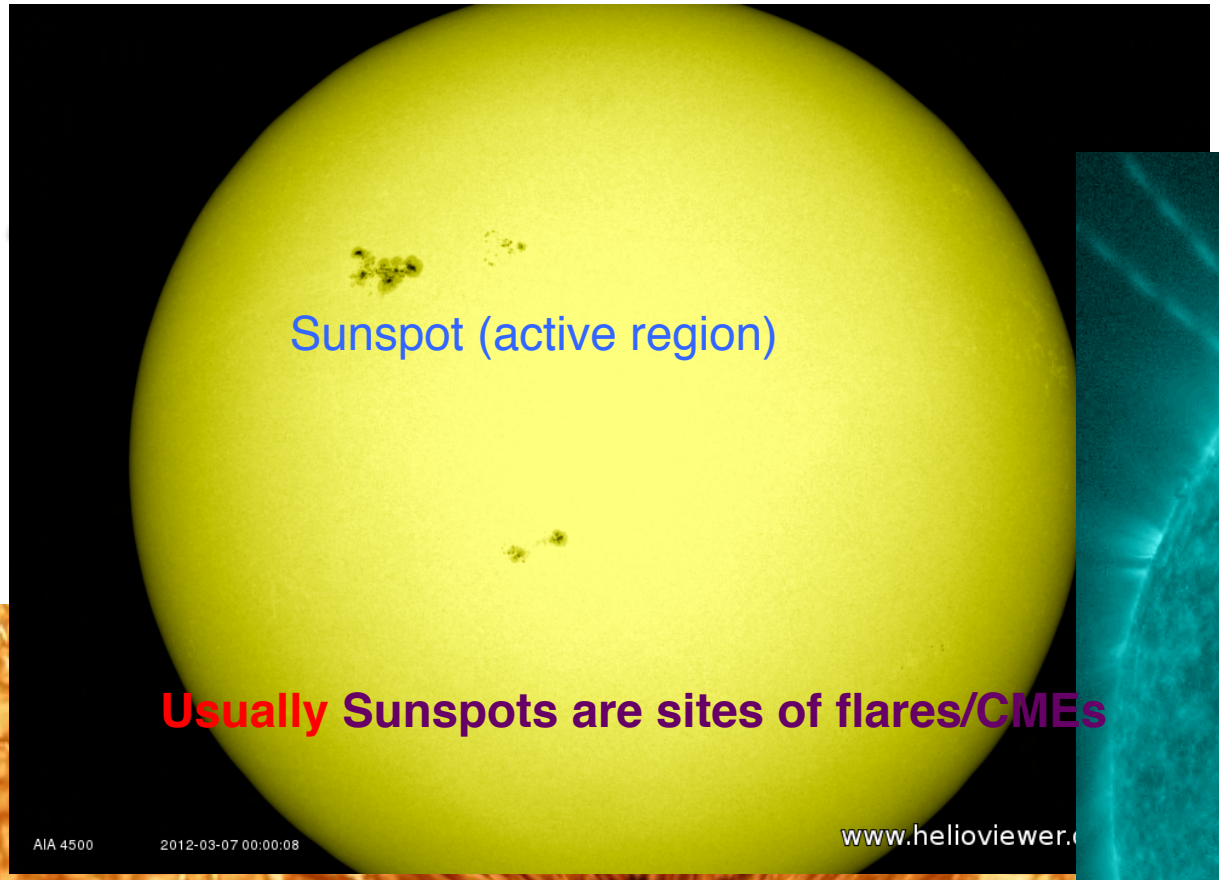


Solar Cycle

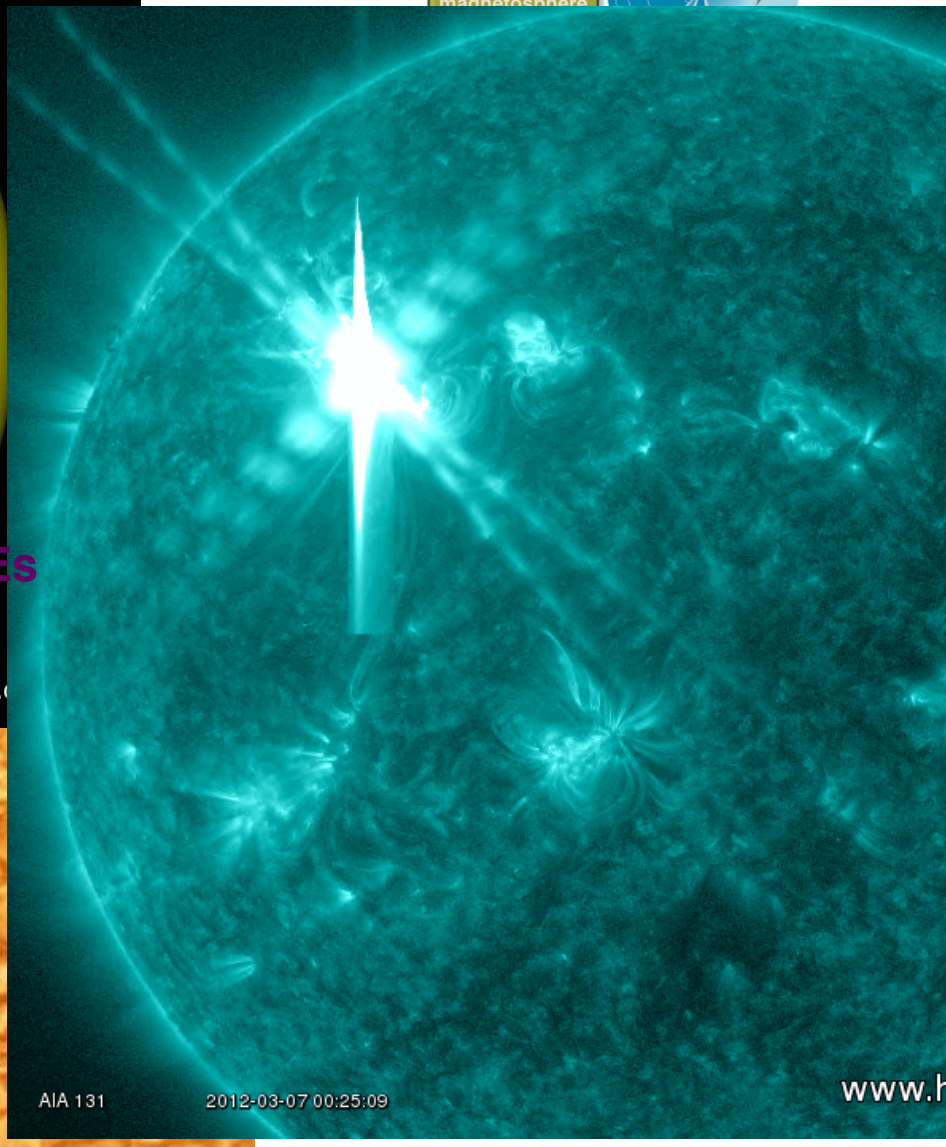
high and low sunspot activity that repeats about every 11 years

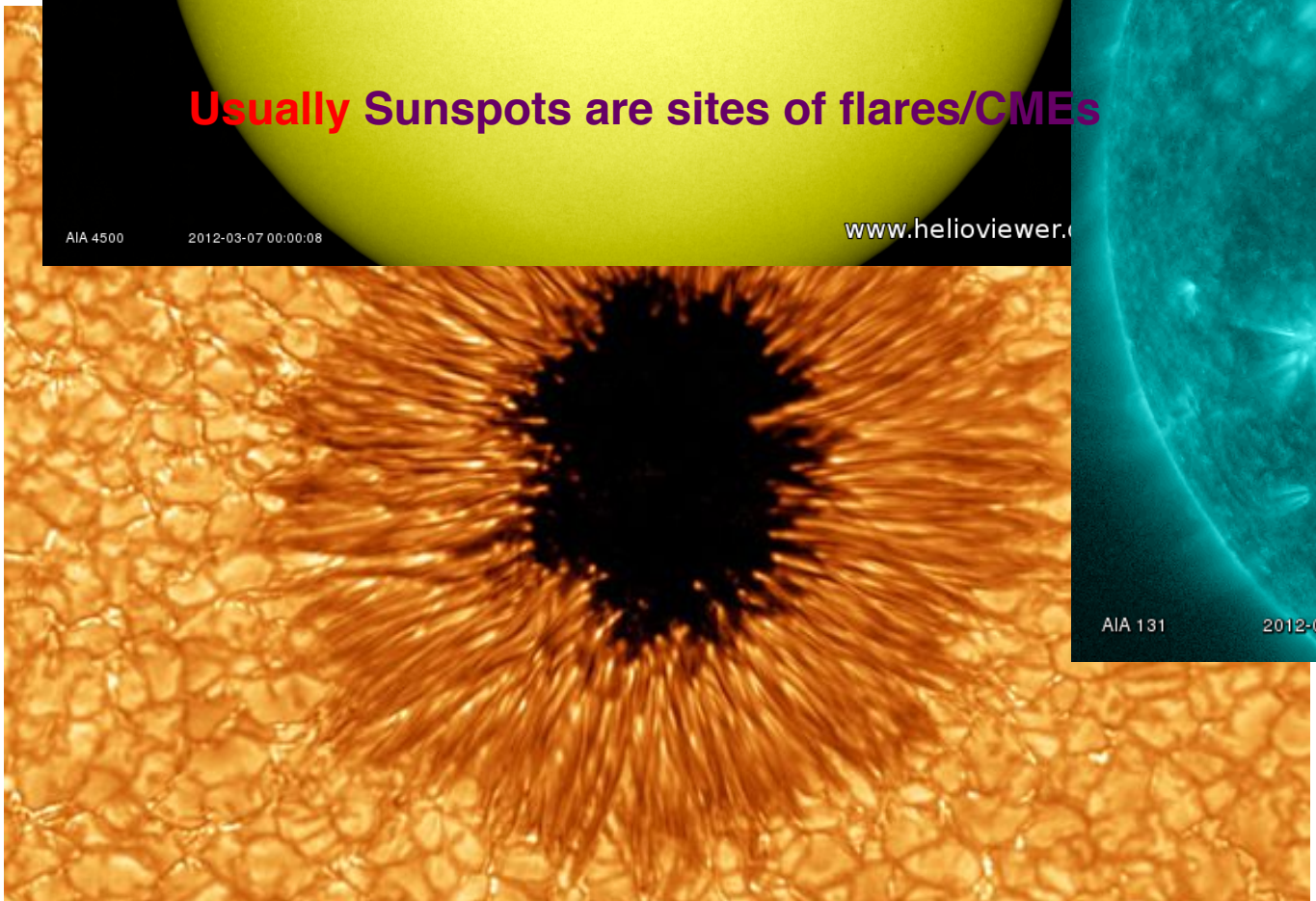






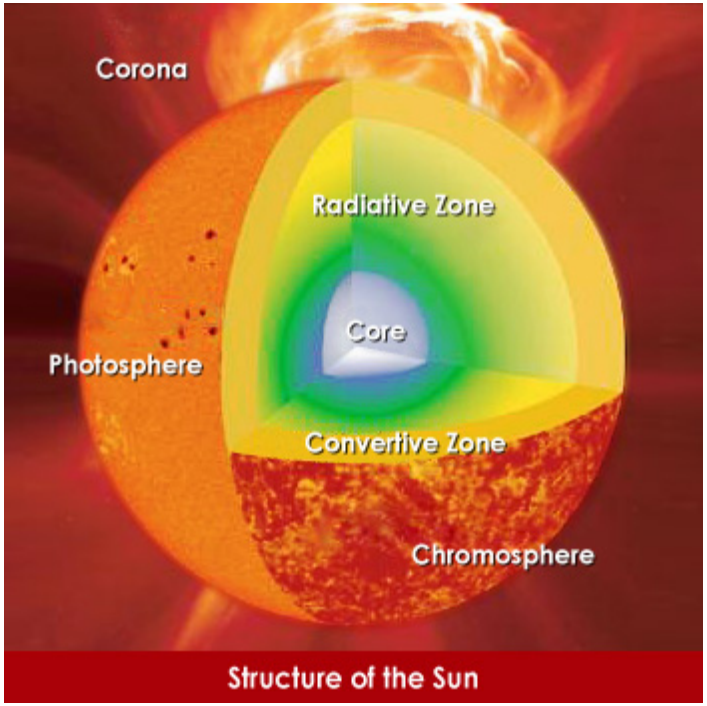
Usually Sunspots are sites of flares/CMEs

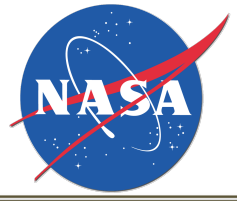




Solar Atmosphere

- Photosphere 5780 K
  - Sunspot (typical) 4200 K
- Chromosphere 20,000K
- The transition region
  20000K – 1-2 millionK
- Corona: 2 million K





SDO/AIA wavebands

What different wave length images 'see' about the Sun?

Channel name	Primary Ion(s)	Region of atmosphere	Char. T (log)
White light	continuum	photosphere	3.7
1700 A	continuum	Temperature minimum, photosphere	3.7
1600 A	C IV +cont.	Transition region, upper photosphere	5.0
304 A	He II	Chromosphere, transition region	4.7
171 A	Fe IX	Chromosphere, transition region	5.8
193 A	Fe XII, XXIV	corona and hot flare plasma	6.1, 7.3
211Å	Fe XIV	Active region corona	6.3
335 A	Fe XVI	Active-region corona	6.4
94 A	Fe XVIII	flaring regions	6.8
131 A	Fe VIII, XX, XXIII	Flaring regions	5.6, 7.0, 7.2

How we probe different layers of the Sun?

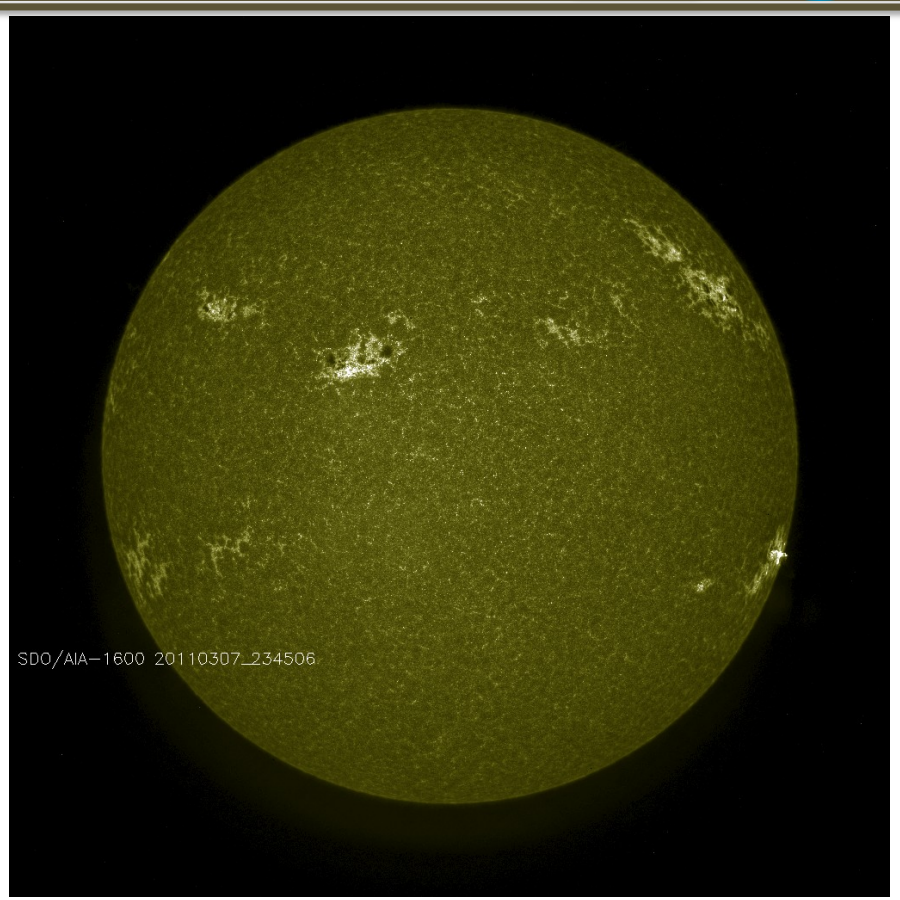
photosphere

- The photosphere is the visible surface of the Sun that we are most familiar with. a layer about 100 km thick (very, very, thin compared to the 700,000 km radius of the Sun)
- the Sun's equatorial regions rotate faster (taking about 27 days) than the polar regions (which rotate once in more than 30 days). differential rotation

0 degree :26.8 d
30 degree: 28.2d
60 degree: 30.8d
75 degree: 31.8d

SDO/AIA wavelength for photosphere

4500 A



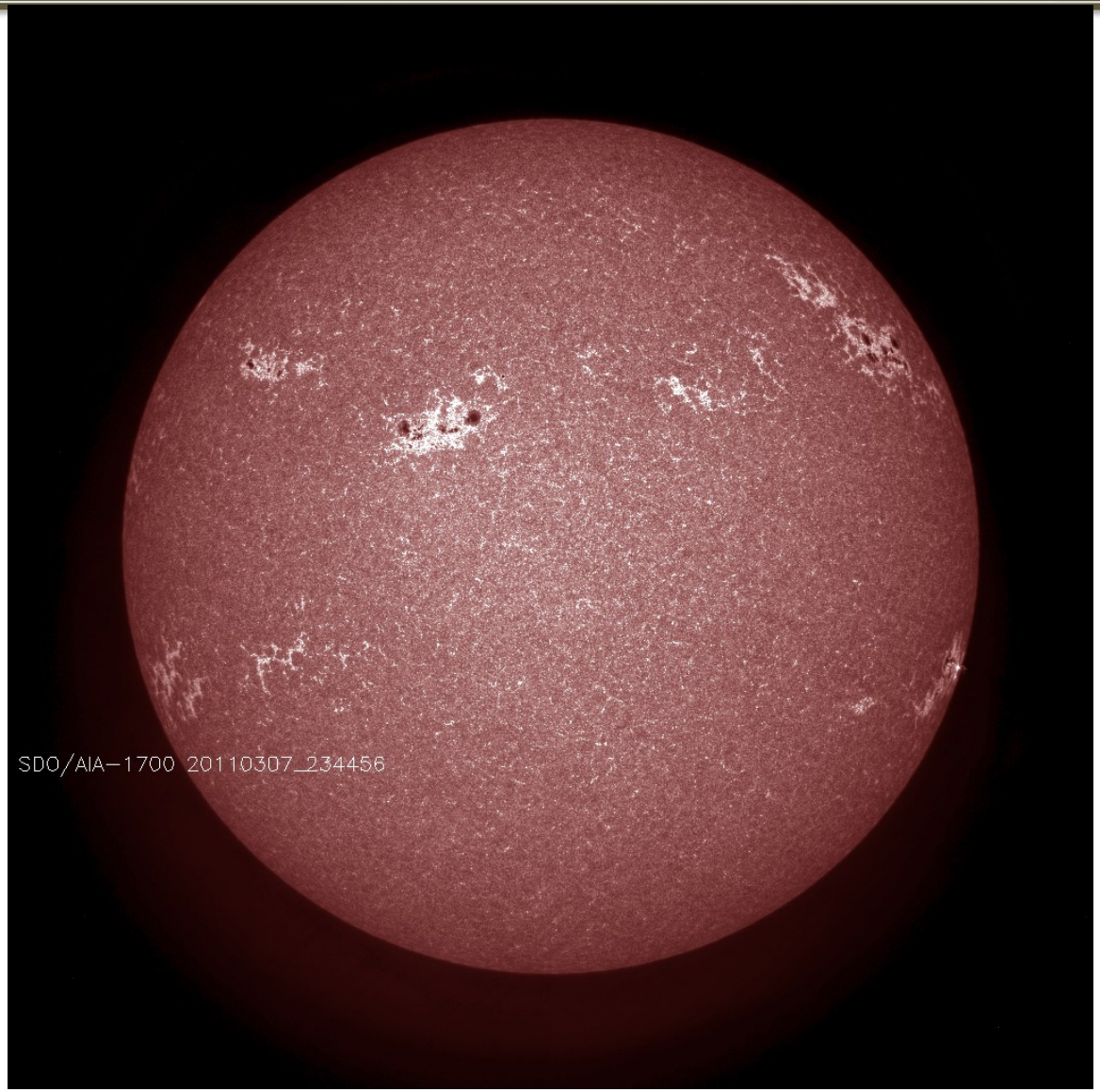
1600 A

Transition region

They are imaging/seeing photosphere

Imaging photosphere

1700 A



Chromosphere

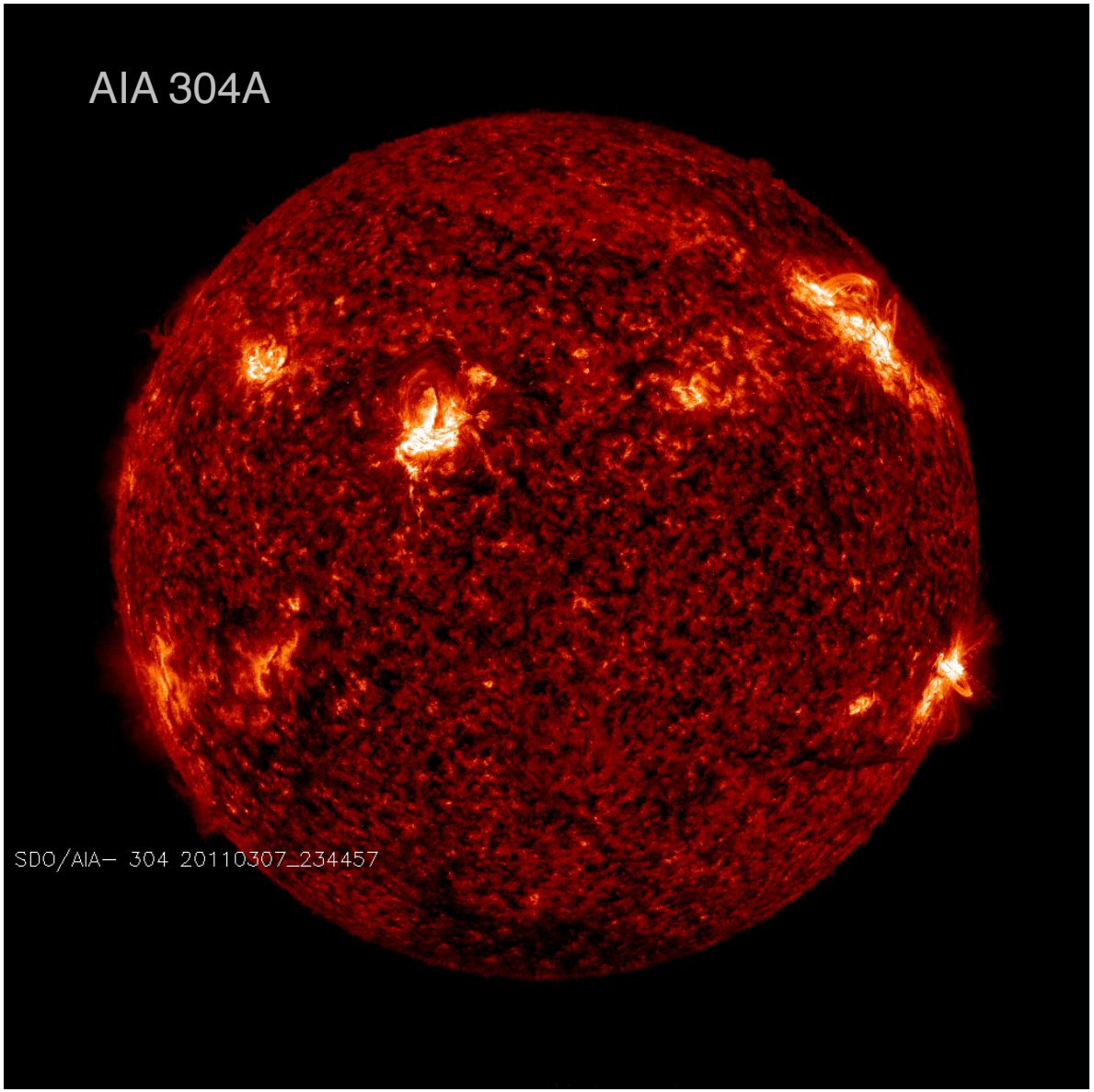
The chromosphere is an irregular layer above the photosphere where the temperature rises from 6000° K to about 20,000° K. At these higher temperatures hydrogen emits light that gives off a reddish color (H-alpha emission). This colorful emission can be seen in prominences that project above the limb of the sun during total solar eclipses. color-sphere.

The chromosphere is the site of activity as well. Changes in solar flares, prominence and filament eruptions, and the flow of material in post-flare loops can all be observed over the course of just a few minutes.

SDO/AIA wavelengths for Chromosphere

Also 171A

Imaging chromosphere, transition region



Corona

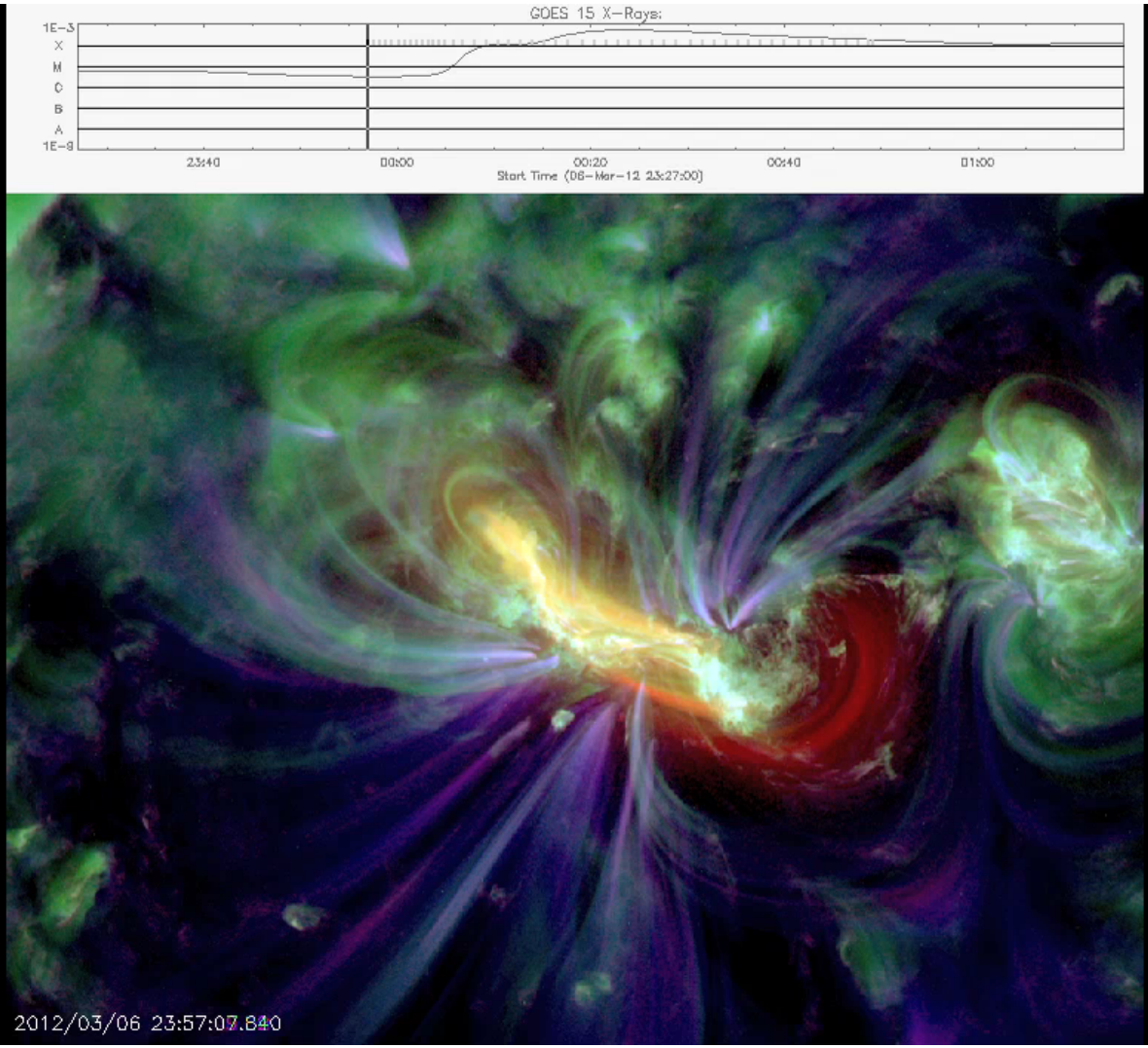
The Corona is the Sun's outer atmosphere. It is visible during total eclipses of the Sun as a pearly white crown surrounding the Sun.

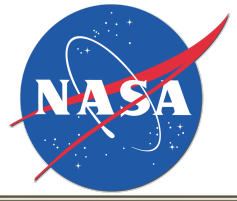
The heating of corona is an ongoing research area

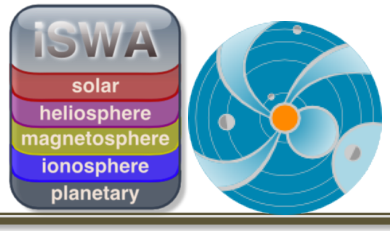
SDO/AIA wavelengths for corona/flaring region

193 A
211 A
335 A
94 A
131 A

131A
193A
171A
blend

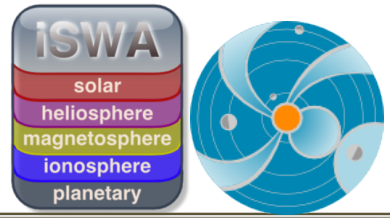



NASA


iSWA
solar
heliosphere
magnetosphere
ionosphere
planetary

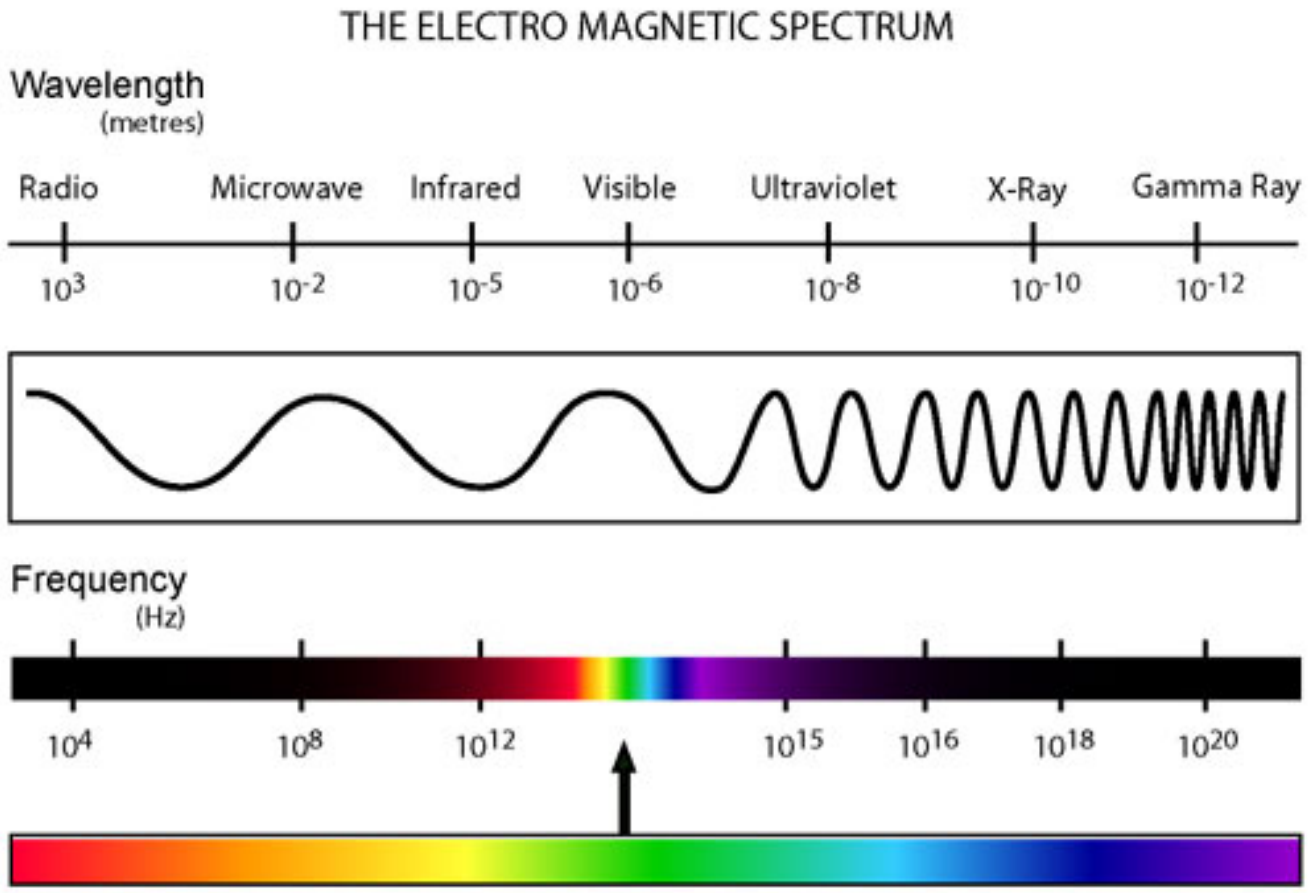
Solar Flare

Flare: SWx impacts



- Cause radio blackout through changing the structures/composition of the ionosphere (sudden ionospheric disturbances) – x ray and EUV emissions, lasting minutes to hours and dayside
- Affect radio comm., GPS, directly by its radio noises at different wavelengths
- Contribute to SEP – proton radiation, lasting a couple of days

A powerful solar flare radiates across the whole electromagnetic spectrum

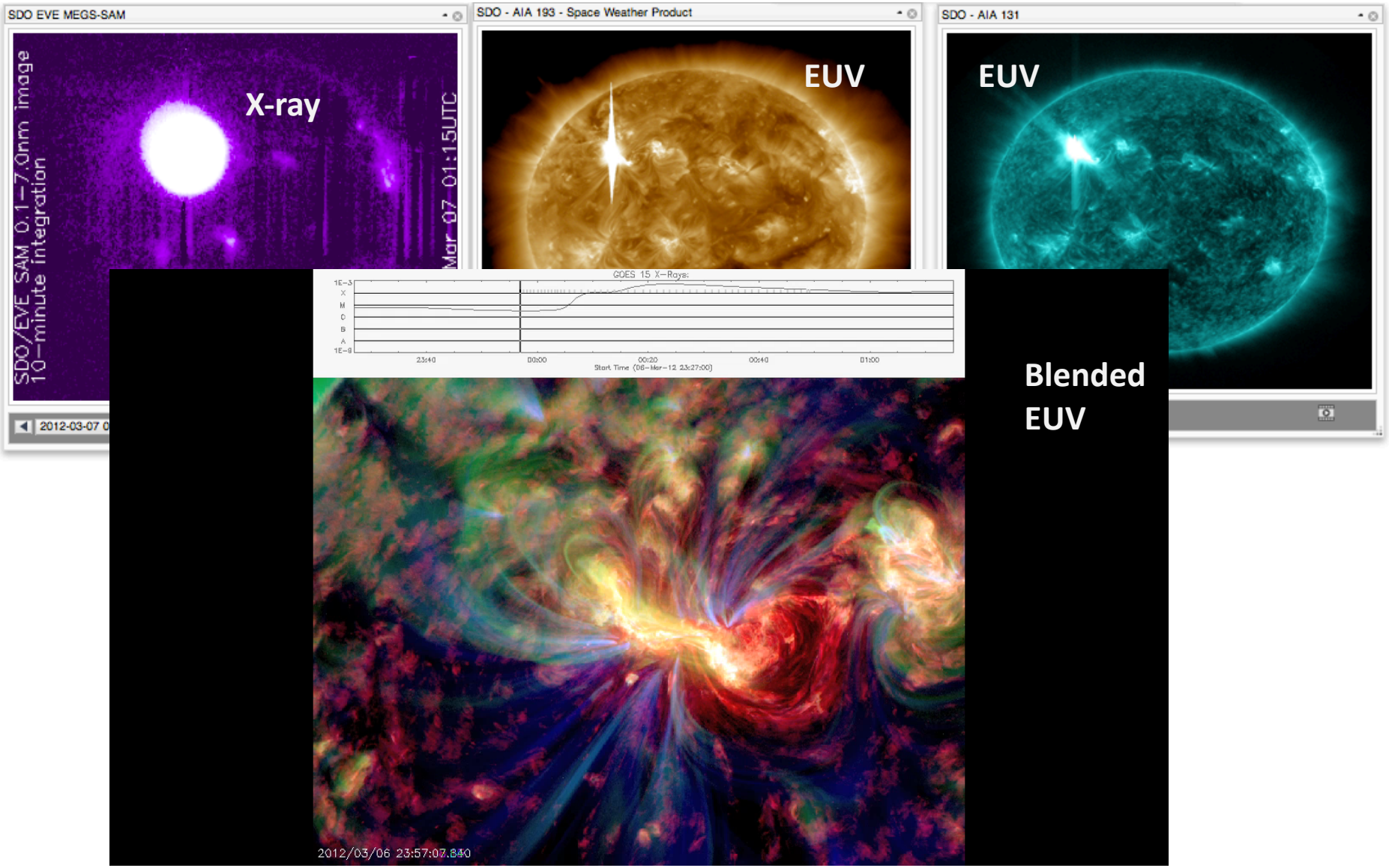


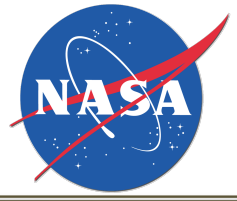
Solar Flare

- In the chromosphere flare detectability becomes far easier, and spectroscopic observations in (e.g.) H*α defined flare physics for many decades.*
- UV and X-ray astronomy: coronal observations possible. At these extreme wavelengths the photosphere becomes dark (for the short wavelengths) or elevated in altitude (for radio waves), and flare effects become dominant.

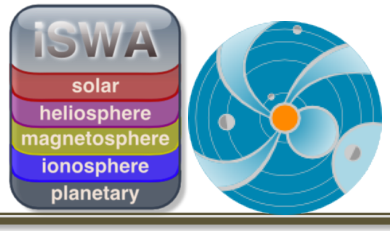
2012 March 7 X5.4/X1.3 flares

Most pronounced in x-ray and EUV





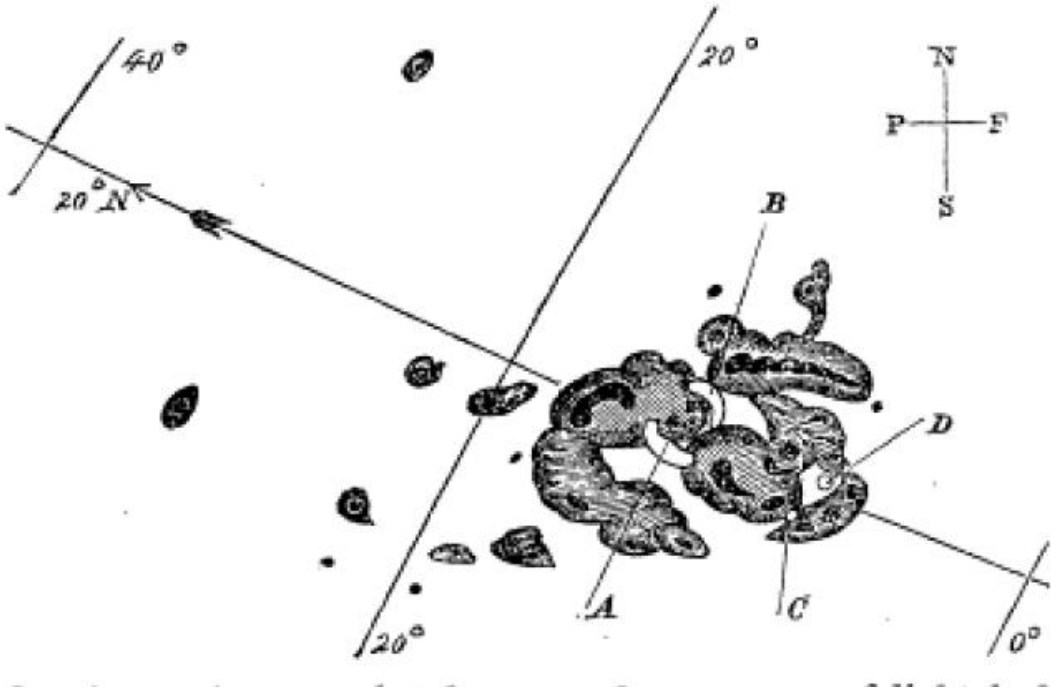
Flare characteristics



- Flares tend to occur in isolation, localized in space and time but with strong correlations; typically one active region will produce dozens of flares, especially during periods of flux emergence (often near the beginning of the lifetime of a given region, but not always). The most powerful events usually occur in active regions.

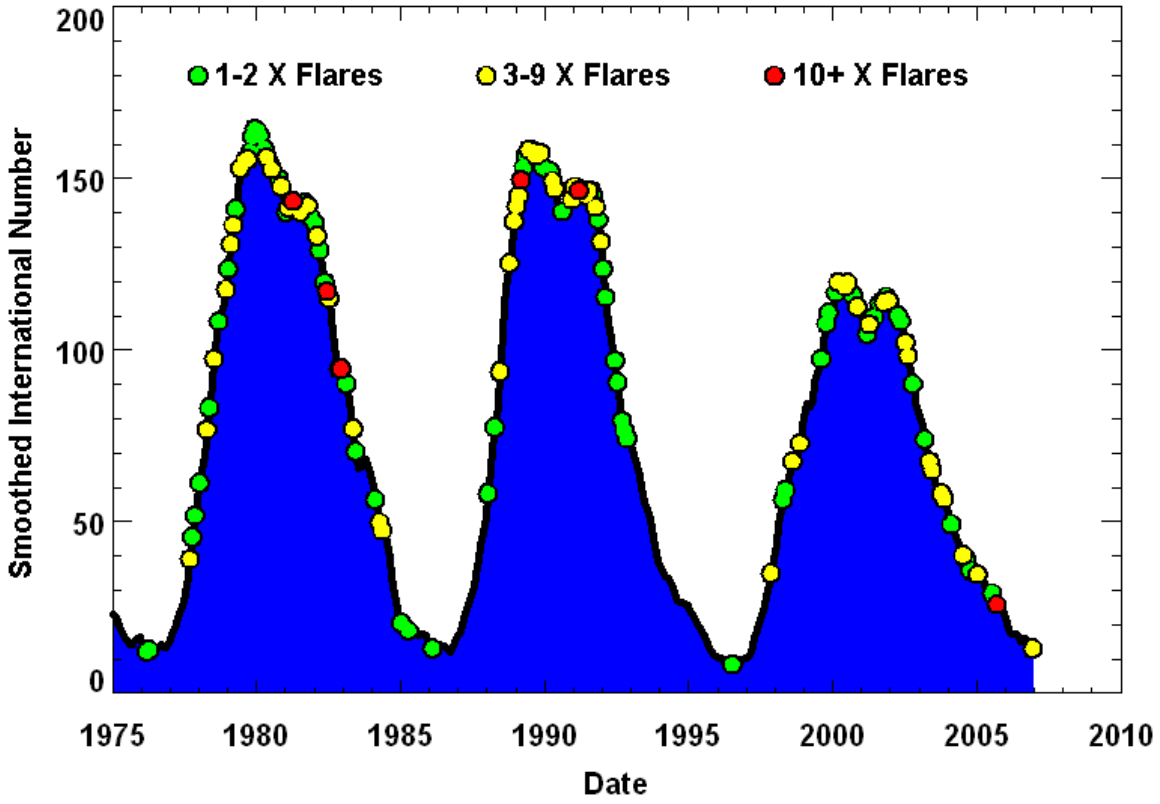
Solar Flares Discovered

In 1859 Richard Carrington reported observing a large sunspot group on the afternoon of September 1st when "…*two patches of intensely bright and white light broke out*…" R. Hodgson observed and reported on the same event which he described as having "…*the appearance of a very brilliant star of light, much brighter than the sun's surface*…"



Flares over the Solar Cycle

Solar flares have been monitored by x-ray detectors on GOES satellites since 1976. They are classified by how bright they are in x-rays with X-Class flares being the brightest. The number of X-Class flares per month increases with the number of sunspots but **big flares can occur anytime sunspots are present.**



Solar Flare Consequences

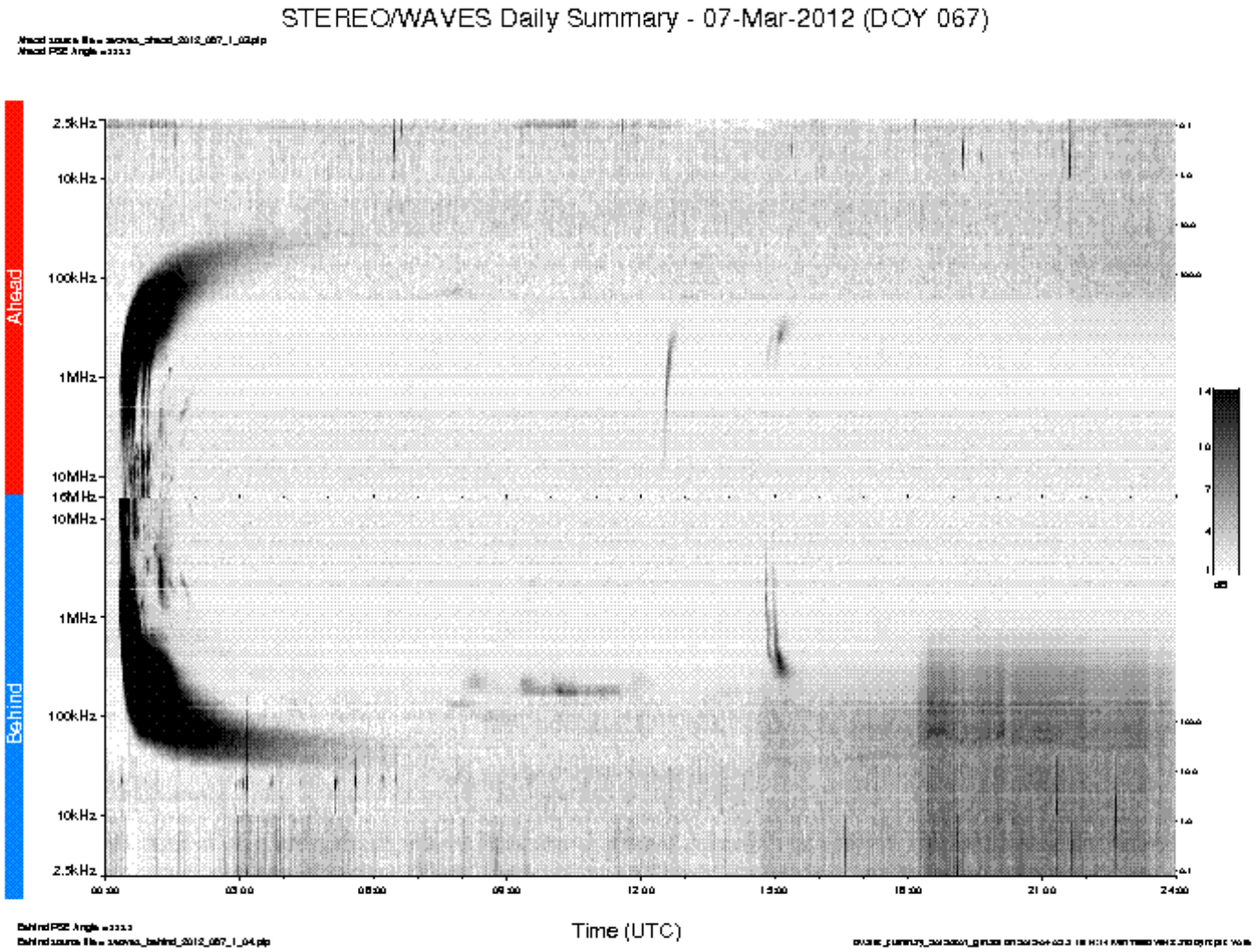
1: ionospheric dynamics

X-ray and EUV

- The extreme Halloween solar flares are shown to have extreme ionospheric effects. Enhancements in **ionospheric total electron content of 30% nominal values** were noted for the 28 October 2003 event. These changes occurred on timescales of 5 min. The enhanced ionospheric TEC lasts for hours after the flares.
- The **260–340 A °** portion of the flare spectra through photoionization creates electron-ion pairs at **altitudes >160 km**, where the recombination rates are long. **The x-ray portion** of the flare spectra, on the other hand, creates ionization at **95–110 km altitude**, where the recombination timescales are only approximately tens of seconds.
- There is a wide variation in **flare spectra** from event to event. It was shown that although the 4 November flare (X28) was almost double the intensity of the 28 October flare (X17) in 1–8 A ° x-rays. The 28 October flare was more than double the 4 November flare peak intensity in the 260–340 A ° EUV wavelength band.

Tsurutani, B. T., et al. (2006), Extreme solar EUV flares and ICMEs and resultant extreme ionospheric effects: Comparison of the Halloween 2003 and the Bastille Day events , *Radio Sci.* , 41 , RS5S07, doi: 10.1029/2005RS003331.

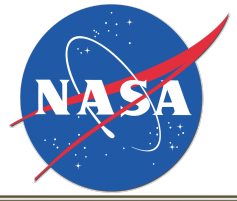
Type II Radio Emission

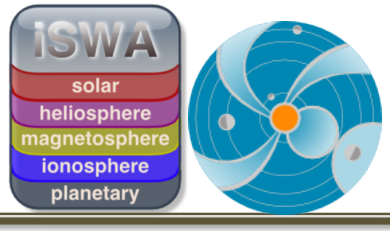


Solar Flare: radio noise

SUMMARY: 10cm Radio Burst
Begin Time: 2012 Mar 07 0007 UTC
Maximum Time: 2012 Mar 07 0117 UTC
End Time: 2012 Mar 07 0210 UTC
Duration: 123 minutes
Peak Flux: 7200 sfu
Latest Penticton Noon Flux: 138 sfu

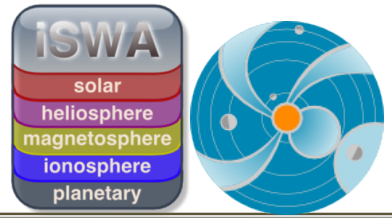
This noise is generally short-lived but can cause interference for sensitive receivers including radar, GPS, and satellite communications.





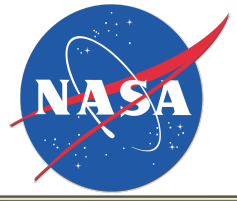
Coronal Mass Ejection (CME)

SWx impacts of CME

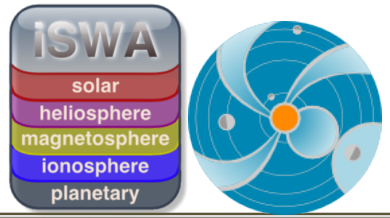


- Contribute to SEP (particle radiation): 20-30 minutes from the occurrence of the CME/flare
- Result in a geomagnetic storm: takes 1-2 days arriving at Earth
- Result in electron radiation enhancement in the near-Earth space (multiple CMEs): takes 1-3 days

Affecting spacecraft electronics – surfacing charging/internal charging, single event upsets
Radio communication, navigation
Power grid, pipelines, and so on

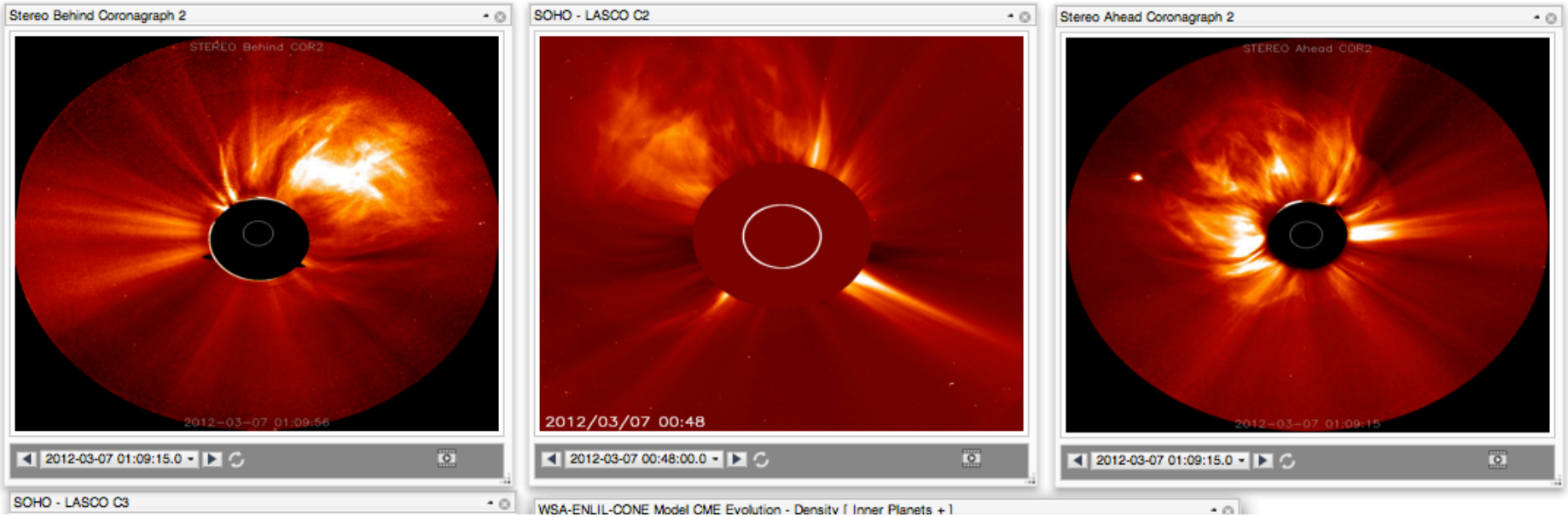


CME



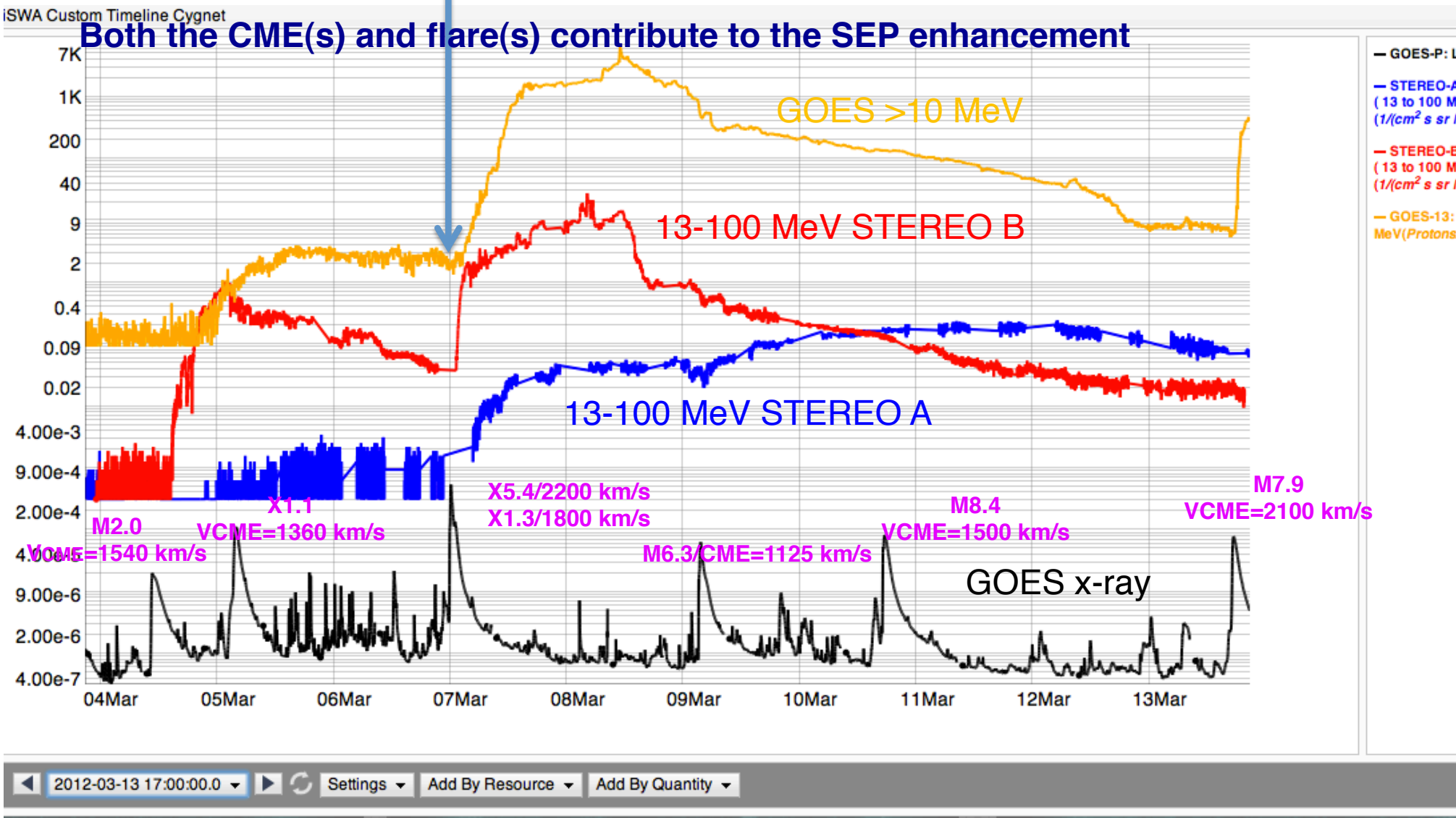
- Massive burst of solar materials into the interplanetary space: 10^15 g
- Kinetic energy 10^32 erg
- Yashiro et al. (2006) find that virtually all X-class flares have accompanying CMEs

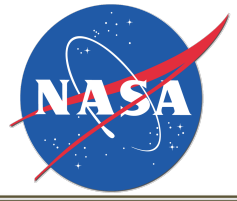
CME viewed by coronagraph imagers

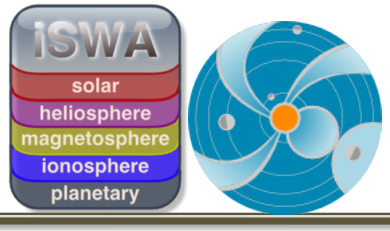


Eclipses allow corona to be better viewed
Does not happen often
Modern coronagraph imager is inspired by that
Occulting disk blocks the bright sun so we can observe corona features better

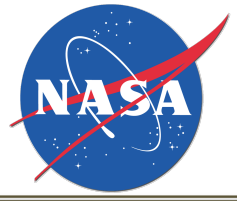
SEP: proton radiation



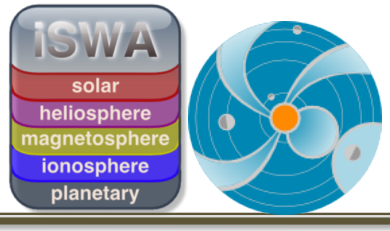




Solar Flare/CME any relationship?



CME/flare



- the well-known property of CME initiation: namely that it may significantly precede the flare impulsive phase
- The most energetic CMEs occur in close association with powerful flares. Nevertheless large-scale CMEs do occur in the absence of major flares, even though these tend to be slower and less energetic.

CME/flare

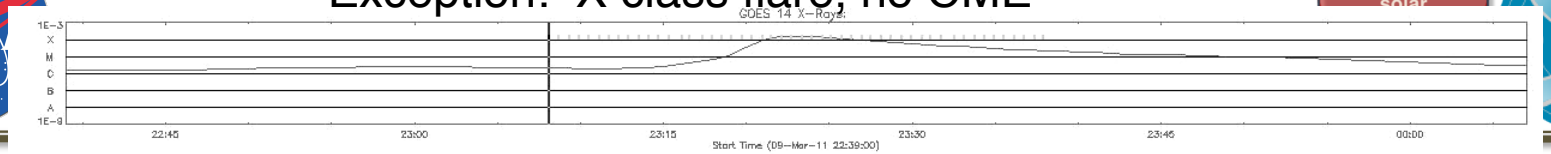
- When strong flare/CME occurs, it gives off emission across the whole EM spectrum, at the same time energetic particles.

CME consequences: magnetic storms in space

Demo: the March 7, 2012 event
2 flare/CMEs
Consequences: SEPs across broad heliospheric longitudes

major impacts (called geomagnetic storms for Earth) in terms of field disturbances (and also in particles) due to the propagation of the CME.

Exception: X class flare, no CME



X1.5 class flare detected by GOES 14 at 2011-03-09T23:23Z

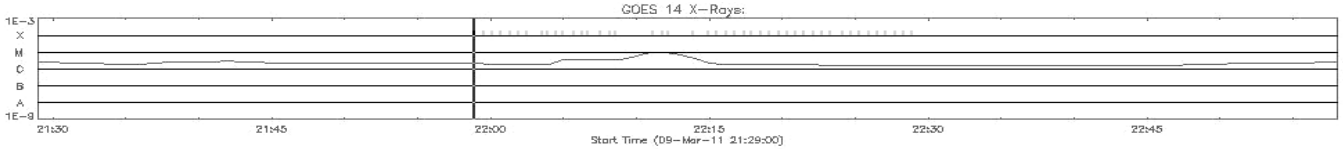
Yet no CME

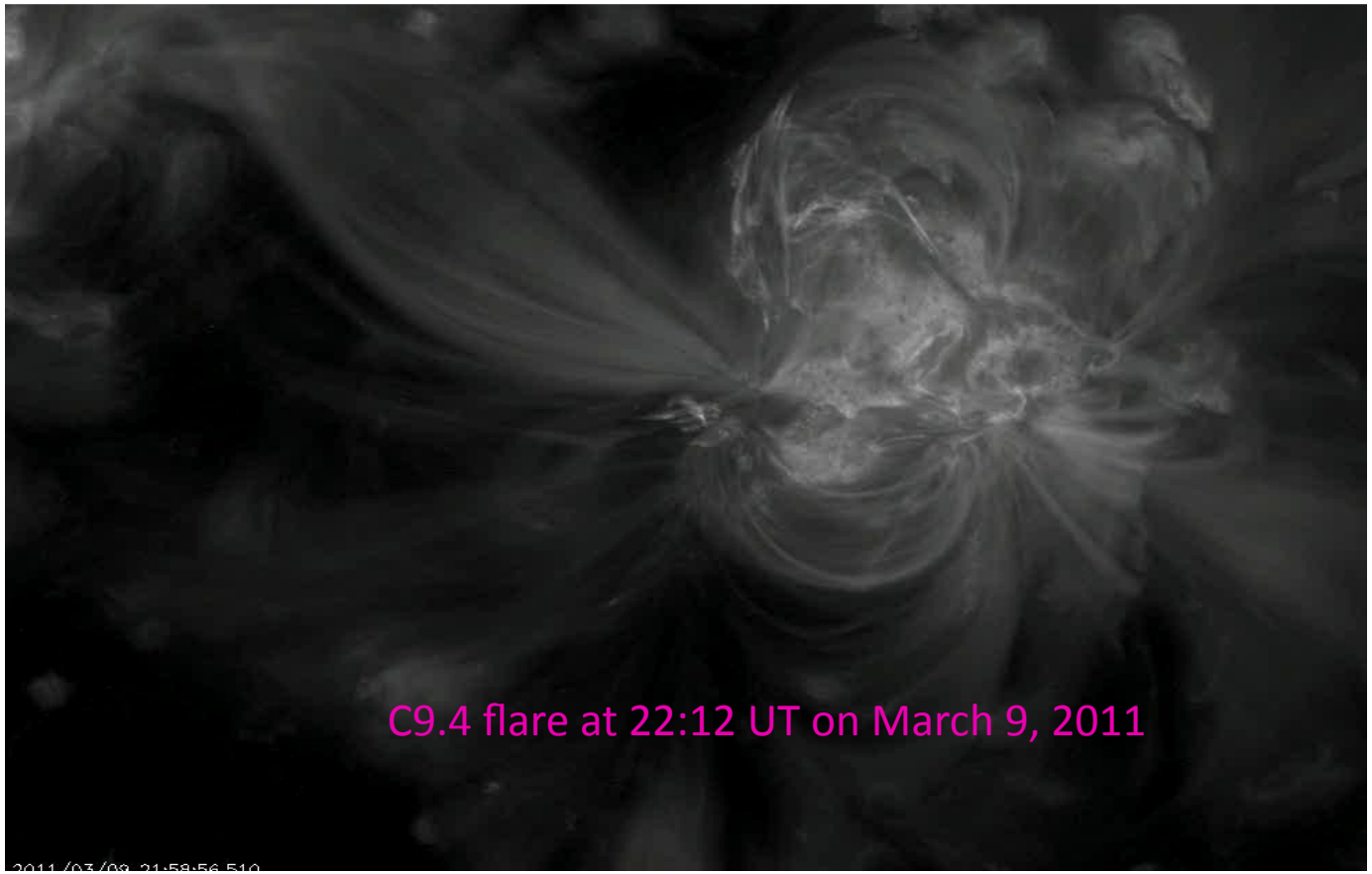
Check it out using iswa too

Flare and CME relationship
Not always 1 to 1 correspondence

2011/03/09 23:08:07.840

On the contrary, the C class (rather weak) flare generated some disturbances





Stealth CME

It is hard to find the solar disturbance/transient that is associated with this CME.

Realtime Cone Model run has been launched! Below is the control file used:

start=2011-03-03
nclouds=1
tstart=-288
tstop=792
ttfrom=480
ttto=792
ttstep=6
procs=8
dates=2011-03-03
times=14:30
latcld=-23
loncld=17
radcld=30
vcld=400

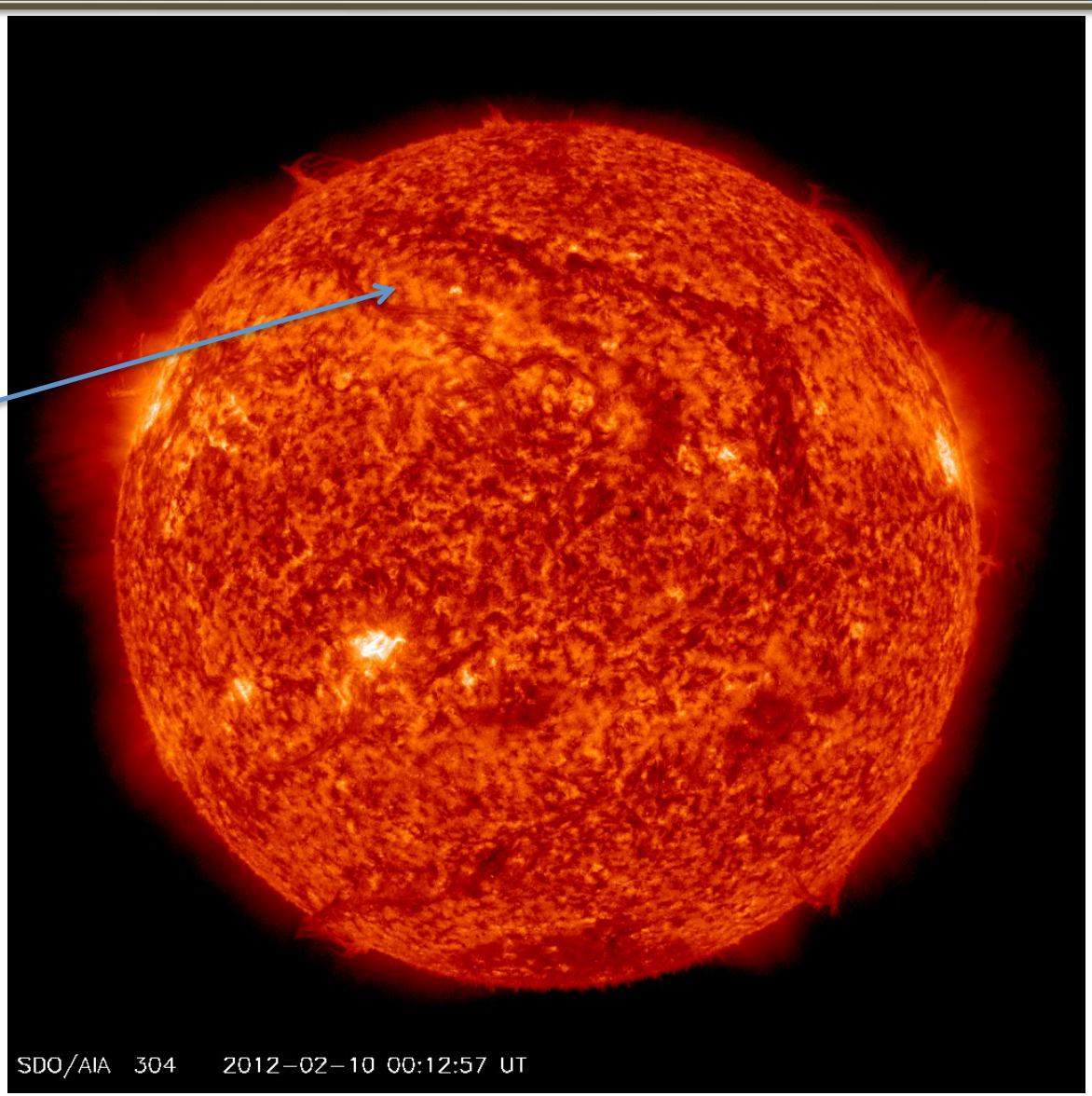
Refers to the CMEs that do not have obvious solar disturbances

Another example: 2012-04-29T10:24Z

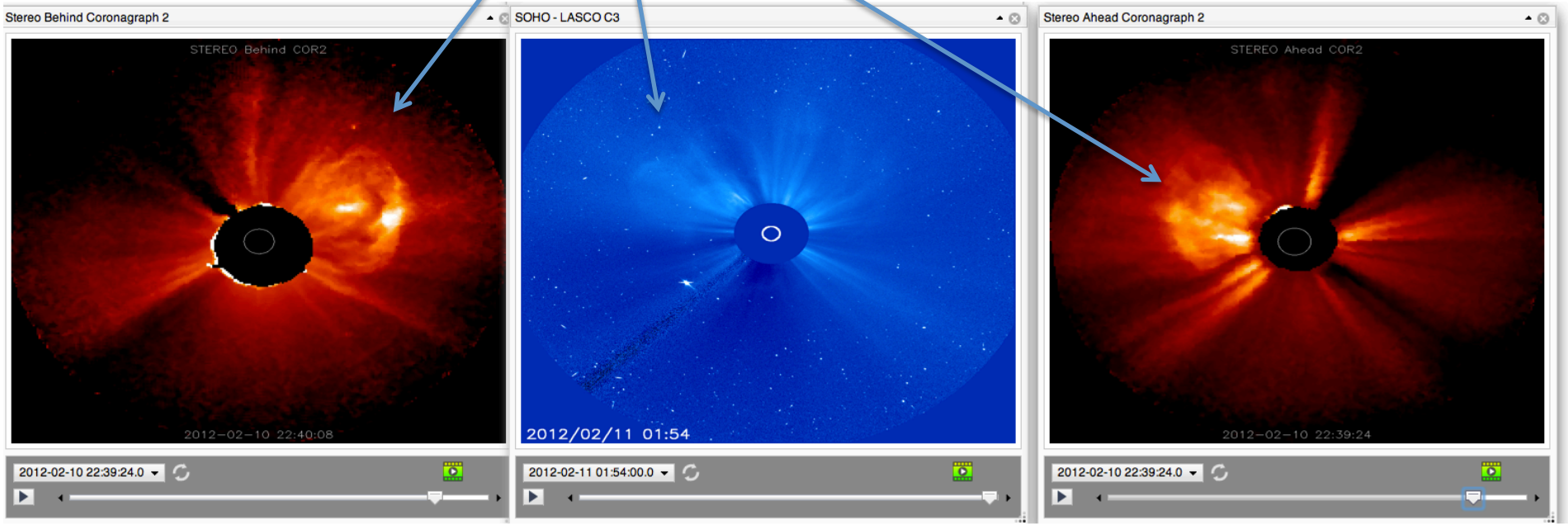
CME from Filament eruption

A movie

Northeast (upper left) quadrant starting around 19:00 UT on Feb 10, 2012



The associated CME

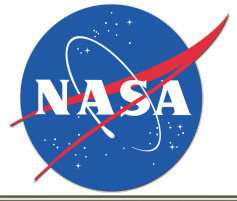


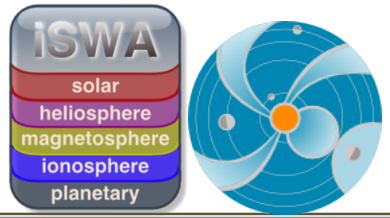
STEREO B

SOHO

STEREO A

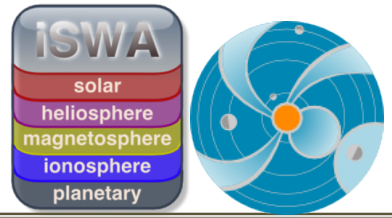
Heart-shaped


NASA


iSWA
solar
heliosphere
magnetosphere
ionosphere
planetary

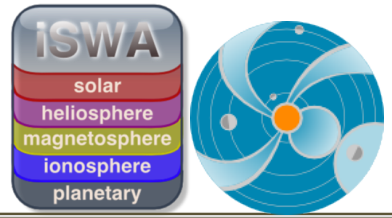
Summary

Flare: SWx impacts



- Cause radio blackout through changing the structures/composition of the ionosphere (sudden ionospheric disturbances) – x ray and EUV emissions, lasting minutes to hours and dayside
- Affect radio comm., GPS, directly by its radio noises at different wavelengths
- Contribute to SEP – proton radiation, lasting a couple of days

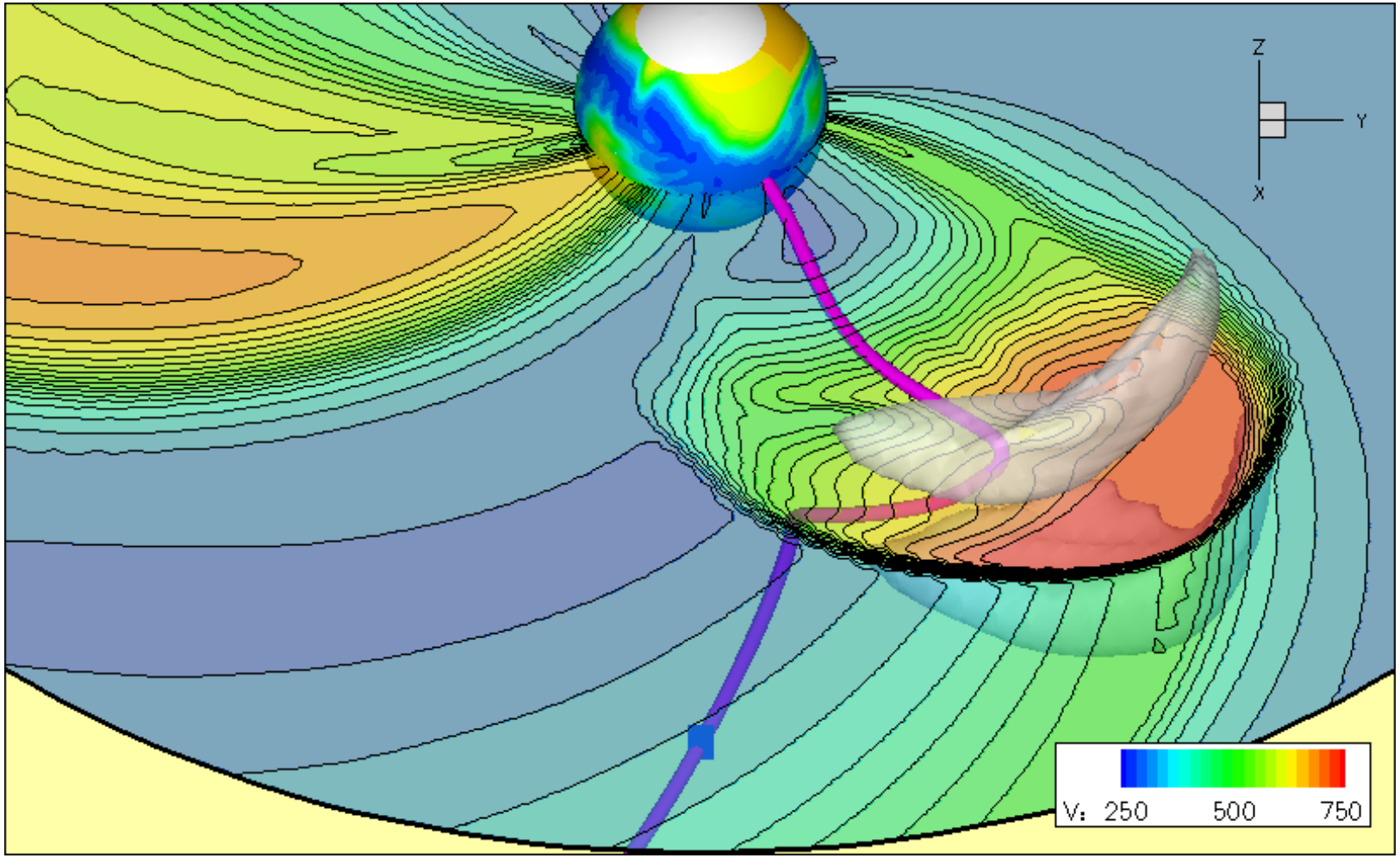
SWx impacts of CME



- Contribute to SEP (proton radiation): 20-30 minutes from the occurrence of the CME/flare
- Result in a geomagnetic storm: takes 1-2 days arriving at Earth
- Result in electron radiation enhancement in the near-Earth space (multiple CMEs): takes 1-3 days

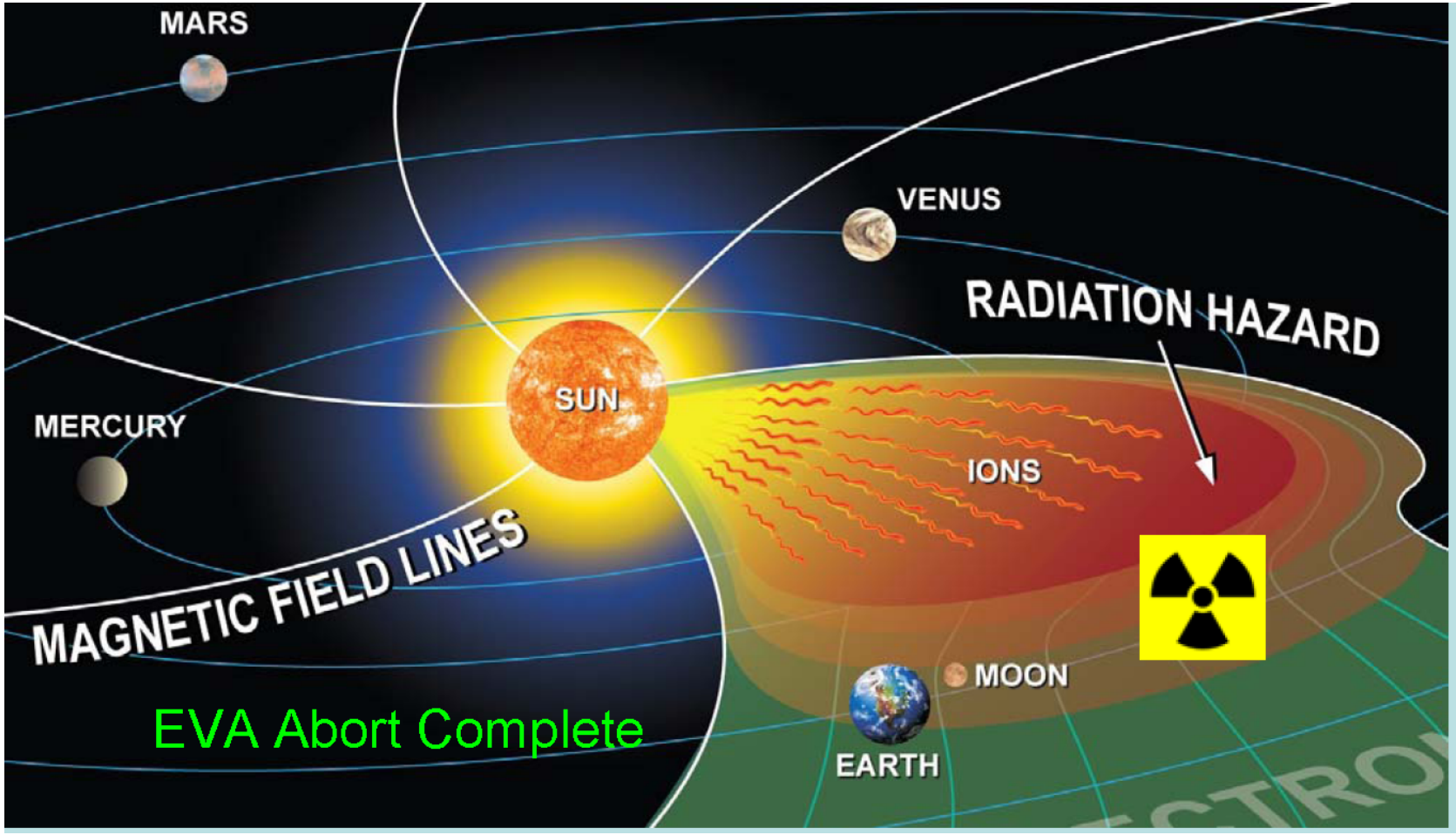
Affecting spacecraft electronics – surfacing charging/internal charging, single event upsets
Radio communication, navigation
Power grid, pipelines, and so on

CME path



Could get deflected, bended, but more or less in the radial direction

SEP: guided by the interplanetary magnetic field



Homework

Go through careful analysis of these events yourself using iswa in the order of its appearance:

- ✓ March 7, 2012 event
  - ✓ Identify the two CME/flare pairs on the same day (now)
  - ✓ derive CME parameters, finding out when the CMEs arrived at ACE (Earth) and at STEREO A, watch out SEP behaviors (later)

- ✓ March 3, 2011 and April 29, 2012 (starting around locate the 'stealth' CME (now)
- ✓ derive its parameters, do you think you can find some solar activity/disturbance leading to it (after June 9)

- ✓ March 9, 2011 locate the X class flare (peaked at 23:23 UT) and is there a significant CME associated with it? (now) What about the C9.4 class flare peaked at 22:12 UT on the same day?
- ✓ Locate the CME starting around 2012-02-10 19:00 UT (from a filament eruption). Derive its parameters after June 9.

- ✓ Find all the CMEs occurred on Oct 22, 2011. Identify their associated active region and flare if there is any (now).
  - ✓ Derive their parameters after June 9

You can do the homework using this iSWA layout
http://bit.ly/CME_flare_template