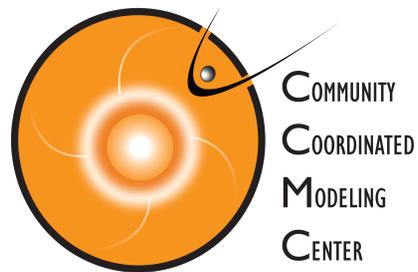




# Flares and CMEs



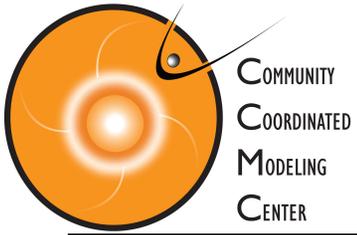
*A. Taktakishvili*



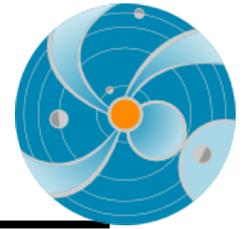
**CCMC, SWRC**

**NASA Goddard Space Flight Center**

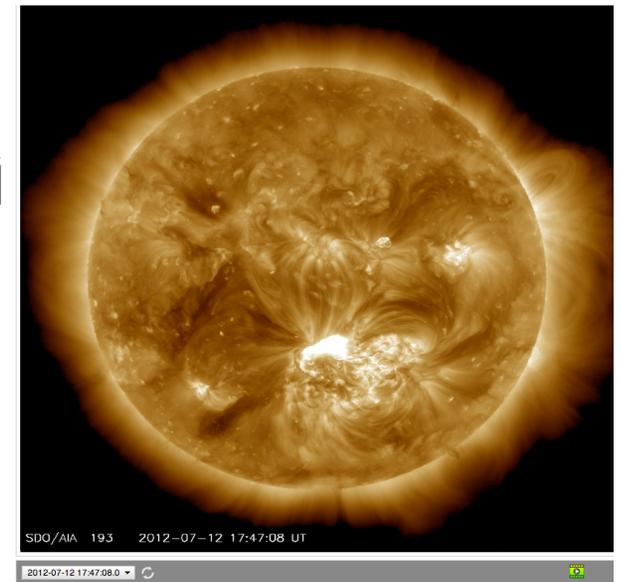
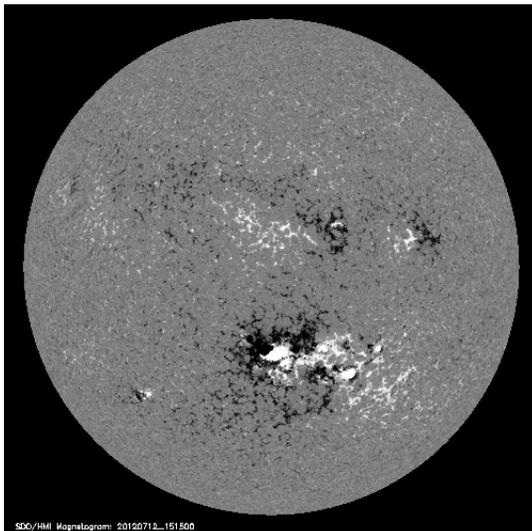
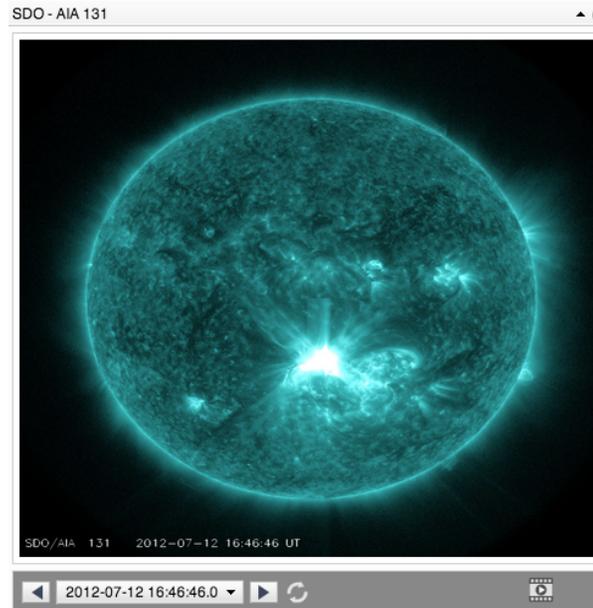
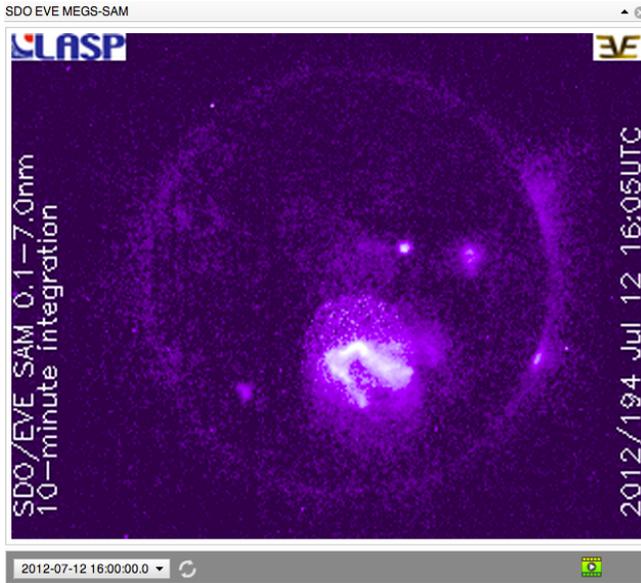
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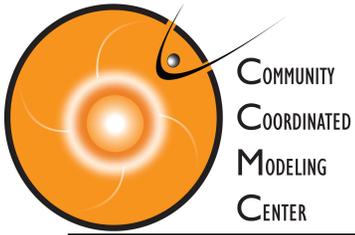


# Solar Flare



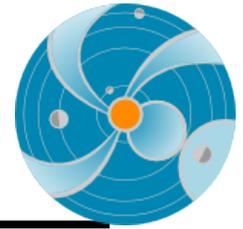
2012 July 12 X1.4 class flare



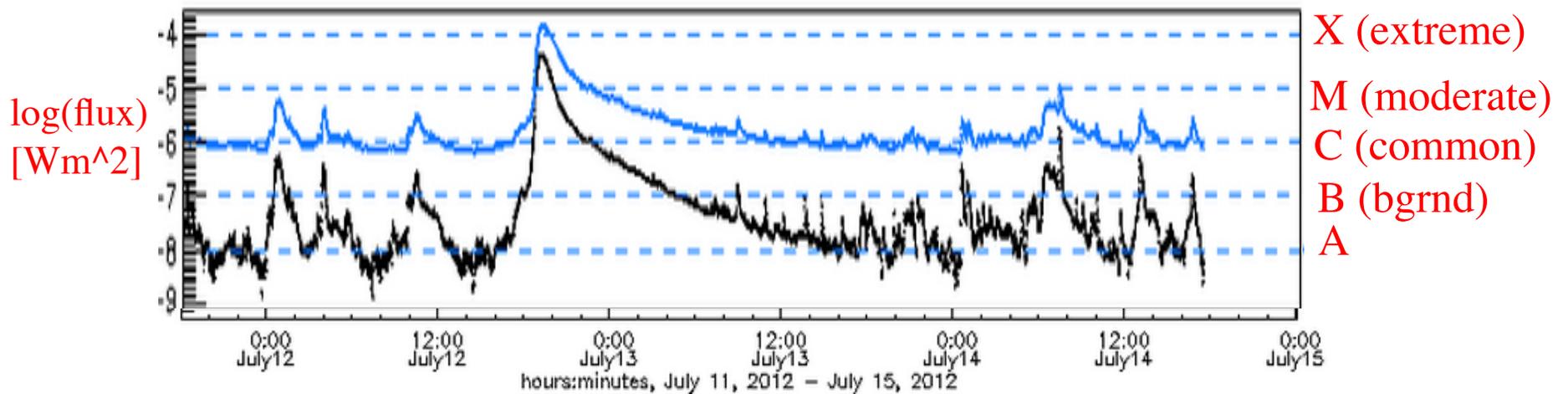
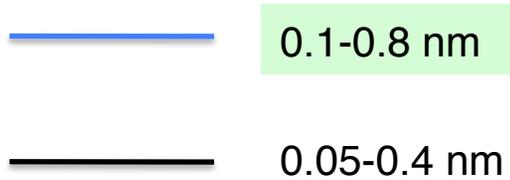


COMMUNITY  
COORDINATED  
MODELING  
CENTER

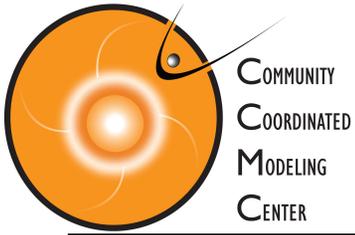
# Solar Flare Class



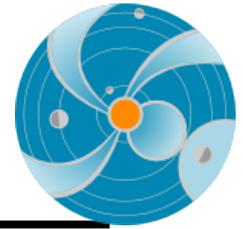
2012 July 12 X1.4 class flare



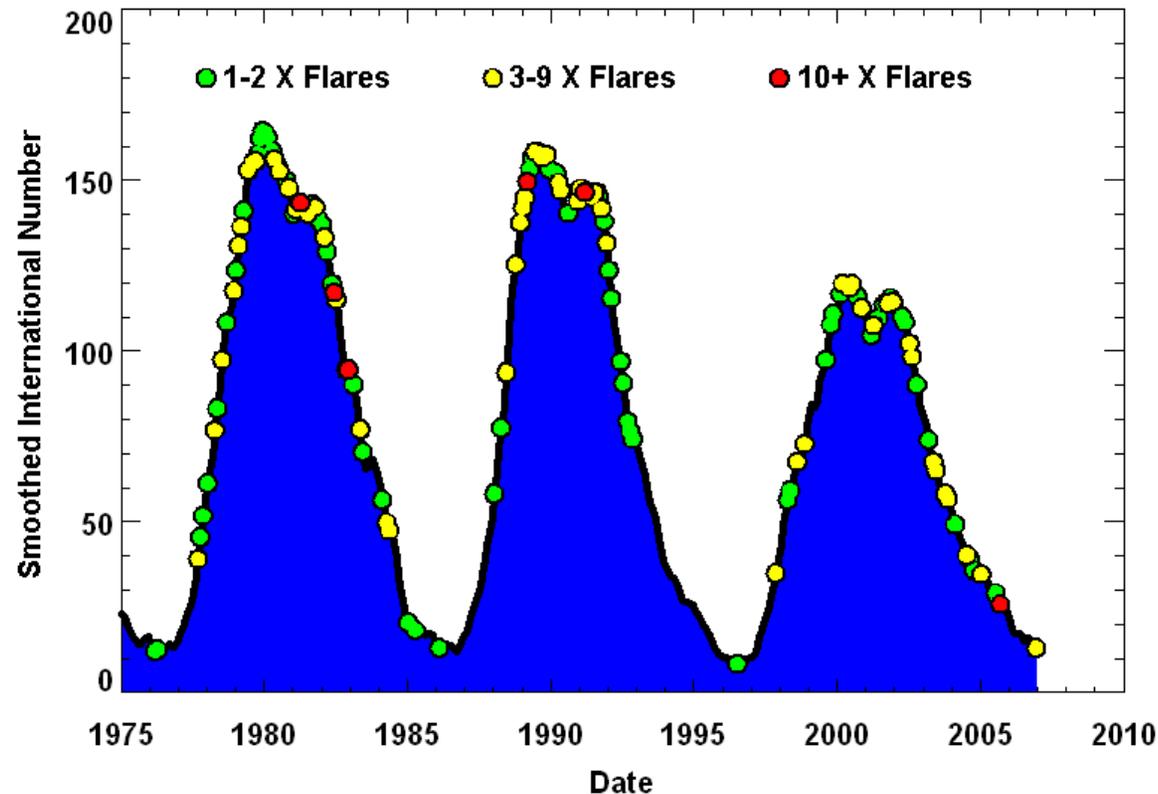
$$\text{X1.4 class: flux}(0.1\text{-}0.8\text{nm})[\text{Wm}^2]=1.4*10^{(-4)}$$

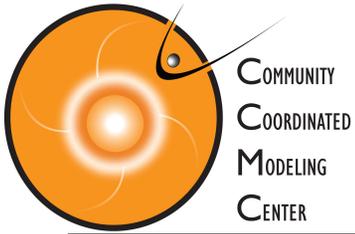


# Flares over the Solar cycle

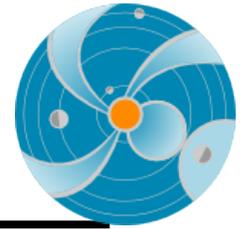


Solar flares have been monitored by x-ray detectors on GOES satellites since 1976. The number of X-Class flares per month increases with the number of sunspots but **big flares can occur anytime sunspots are present.**

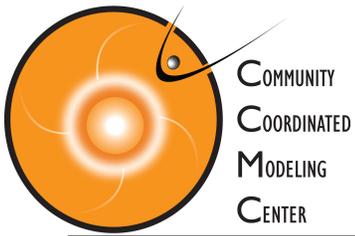




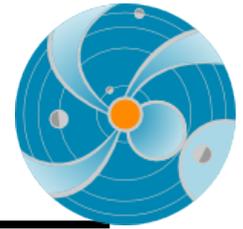
## Flare: SWx impacts



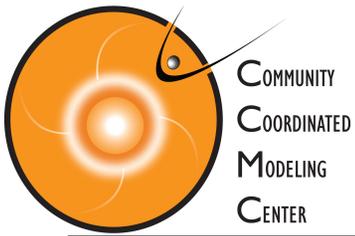
- Cause radio blackout through changing the structures/composition of the ionosphere (sudden ionospheric disturbances) – x ray and EUV emissions, **lasting minutes to hours**
- Affect radio communications, GPS, directly by its radio noises at different wavelengths
- Contribute to SEP – proton radiation,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



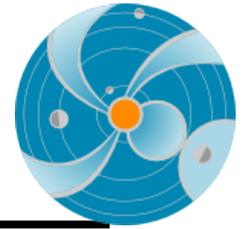
# Flare Characteristics



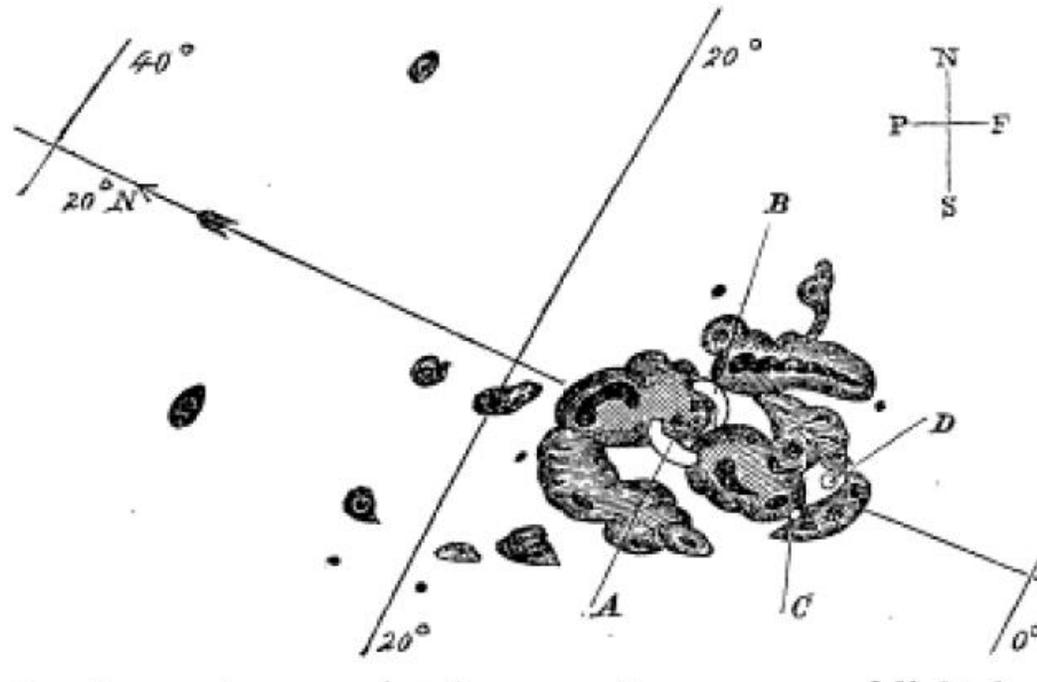
- Flares tend to occur in isolation, localized in space and time but with strong correlations; typically one active region will produce dozens of flares, especially during periods of flux emergence (often near the beginning of the lifetime of a given region, but not always). **The most powerful events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

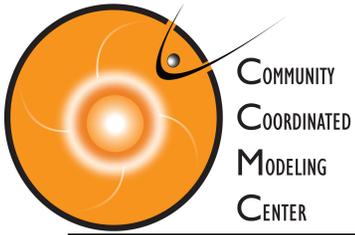


# Solar Flare Discovered



In 1859 Richard Carrington reported observing a large sunspot group on the afternoon of September 1<sup>st</sup> when “...*two patches of intensely bright and white light broke out...*”

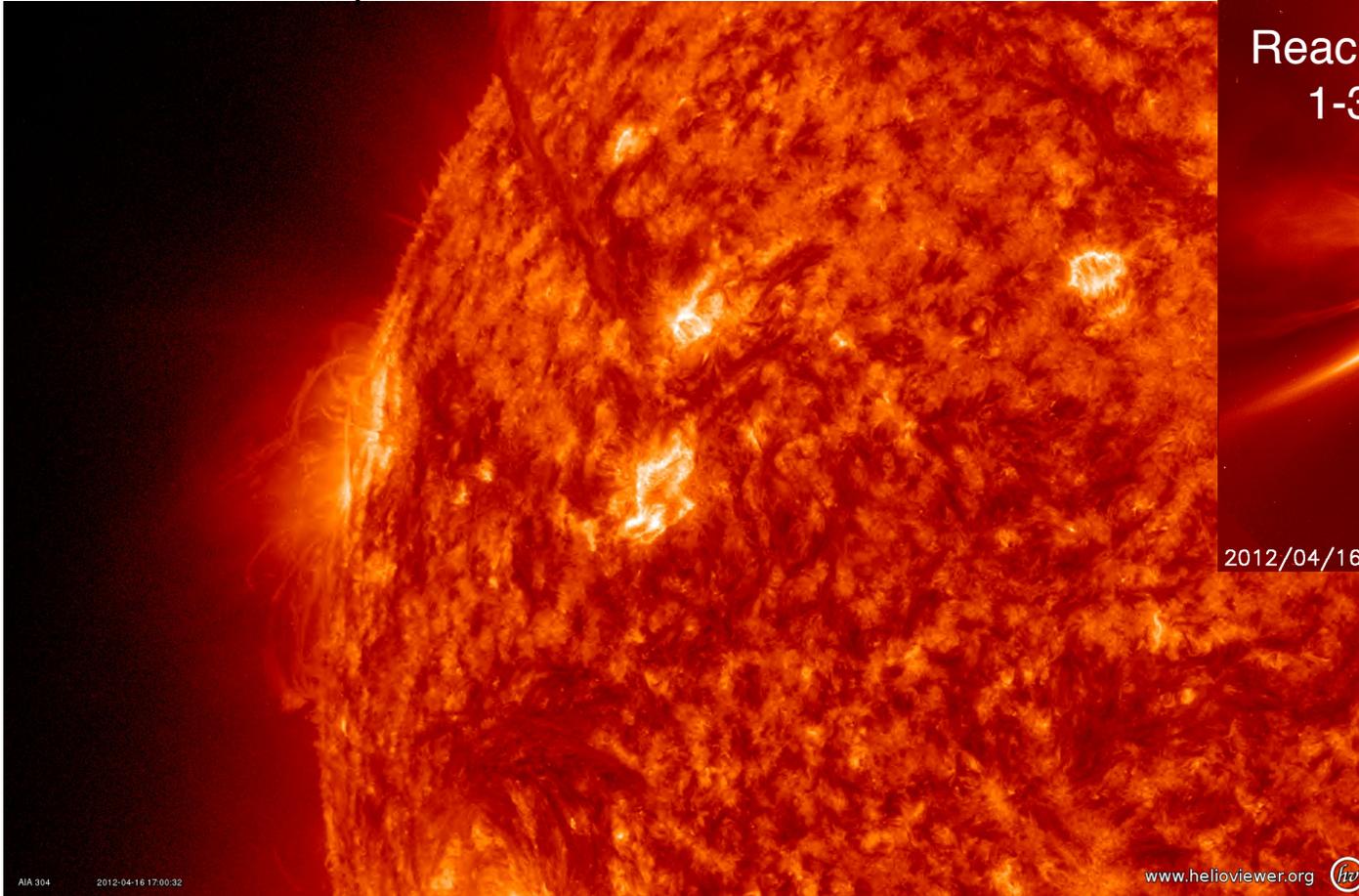




# Coronal Mass Ejection



## Prominence Eruption

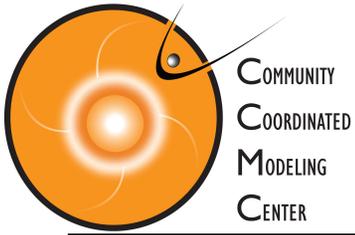


Coronal Mass Ejection:  
Reaches the Earth in  
1-3 days

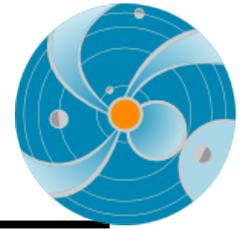
2012/04/16 18:24

AIA 304 2012-04-16 17:00:32

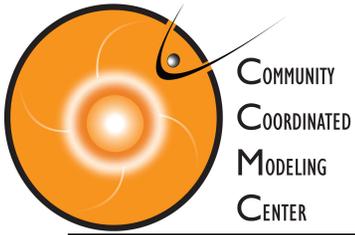
[www.helioviewer.org](http://www.helioviewer.org) 



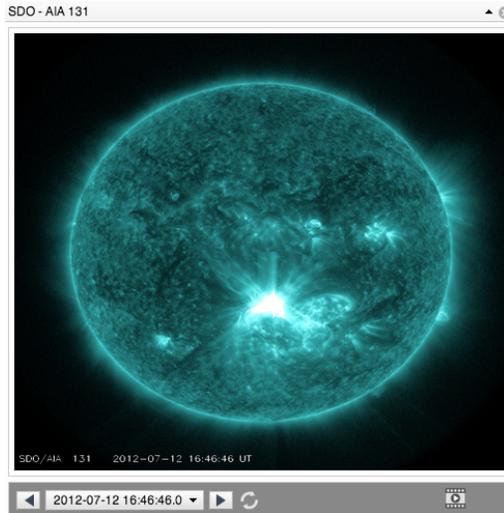
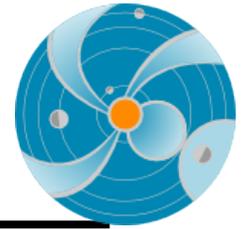
## CME/flare



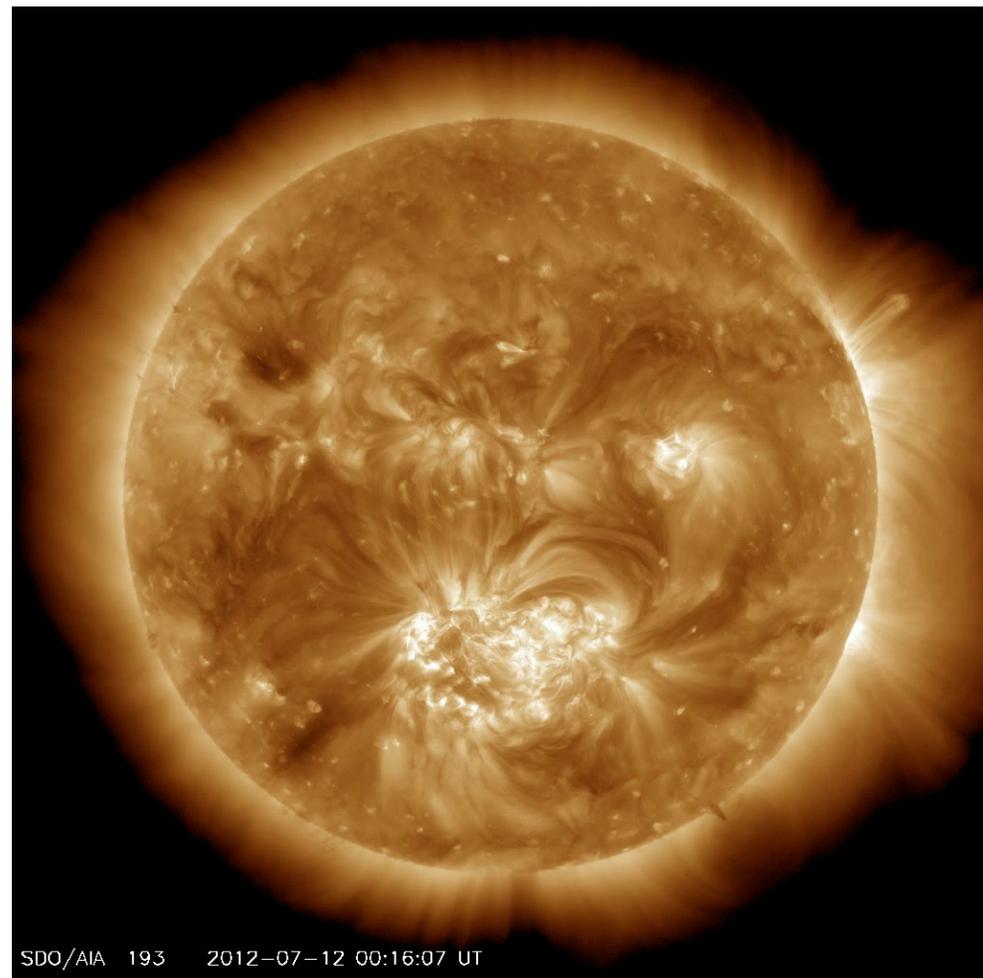
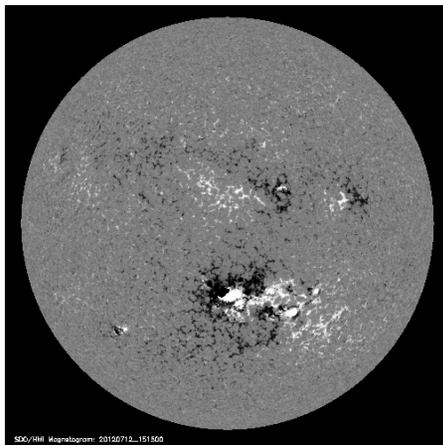
- **The most energetic CMEs occur in close association with powerful flares.** Nevertheless large-scale CMEs do occur in the absence of major flares even though these tend to be slower and less energetic.
- When strong flare/CME occurs, it gives off emission across the whole electromagnetic spectrum, at the same time energetic particles

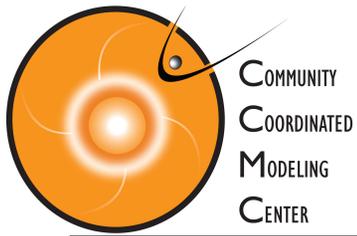


# Most of the CMEs Originate From the Active Regions

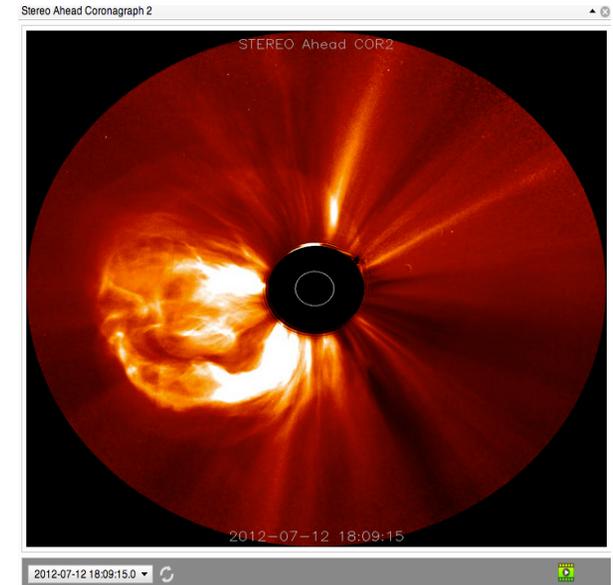
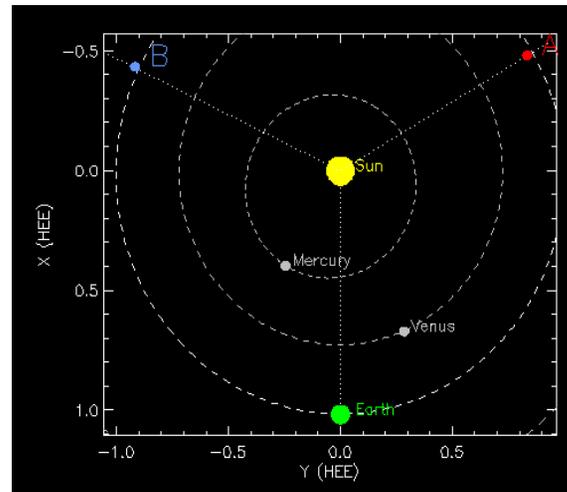
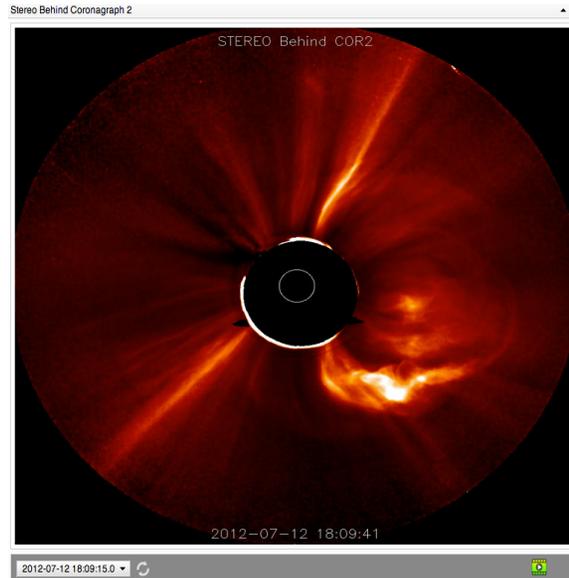
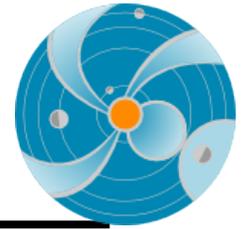


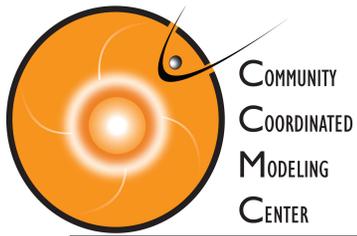
2012 July 12 X1.4 class flare and a following CME



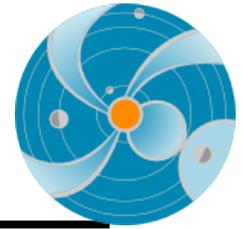


# July 12, 2012 CME Viewed by Coronagraph Imagers

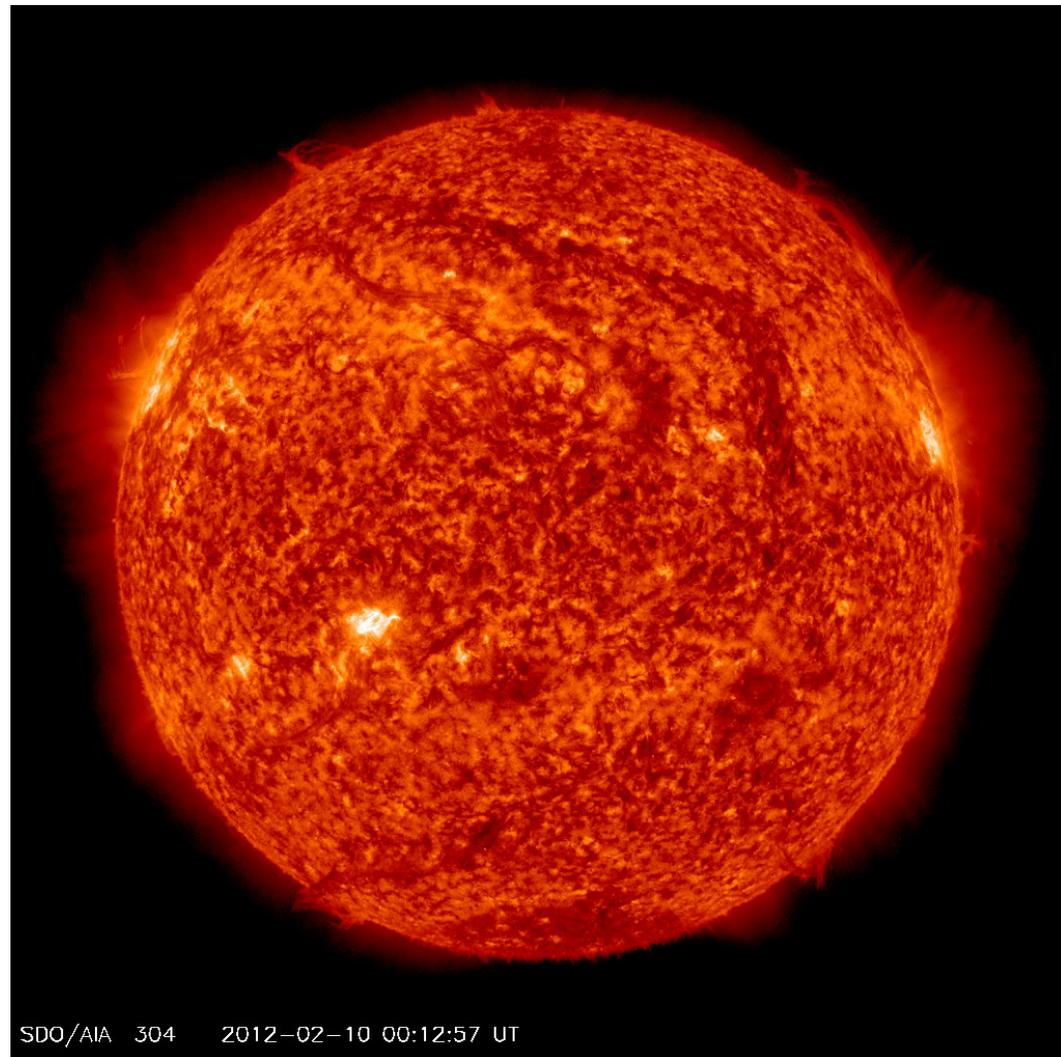


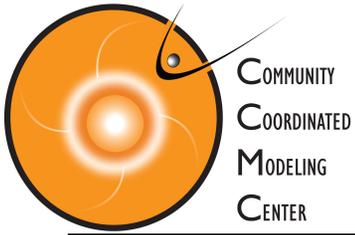


# CME from a Filament Eruption

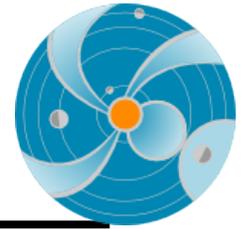


Northeast (upper left) quadrant starting around 19:00 UT on Feb 10, 2012





# CME Properties



- Mass:  $\sim 10^{14}$ kg
- Speed: few hundred - 3000km/s

..Or

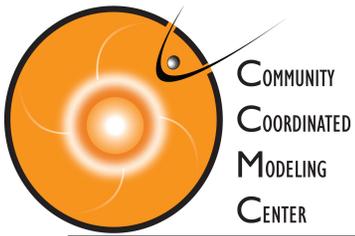
- Mass:  $\sim 1$  million Nimitz-class aircraft carriers
- Speed: 1.5 -10 million km/hour



Earth?



- Arrives to Earth in 1-2 days

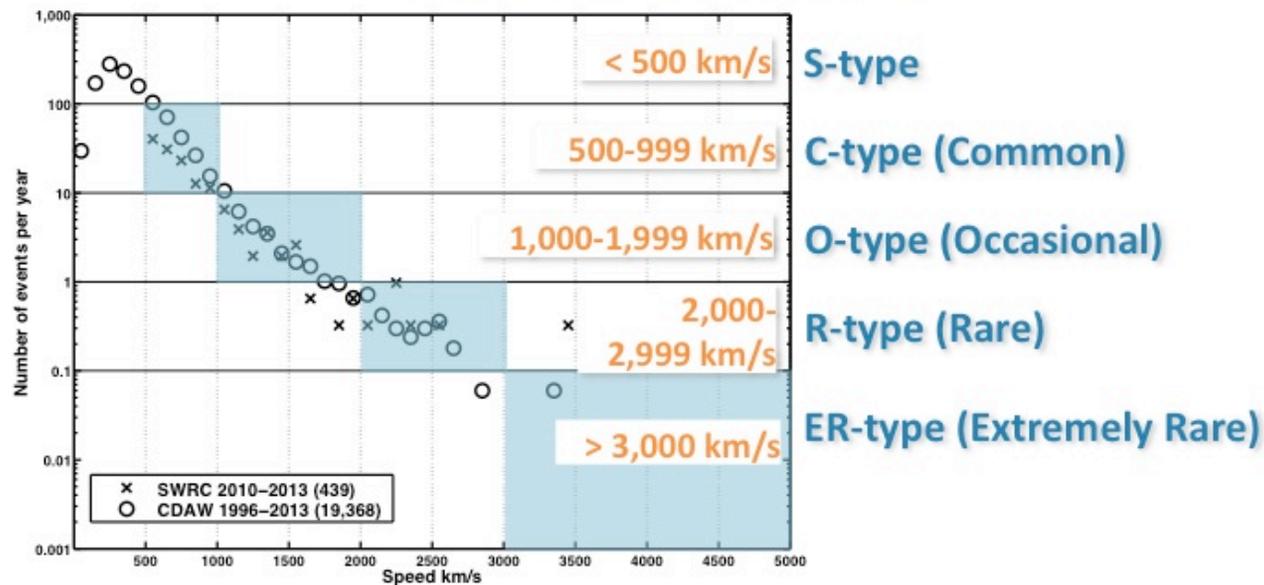


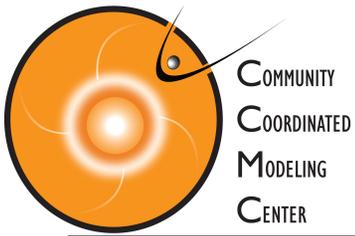
# CME SCORE



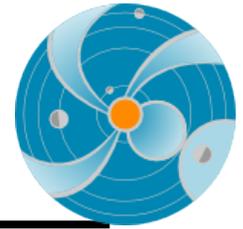
- A simple new category system for CMEs based on frequency of detection and speed
- Complements Flare Classes
- Applicable in space weather operations and research

## Space Weather Research Center CME SCORE Scale



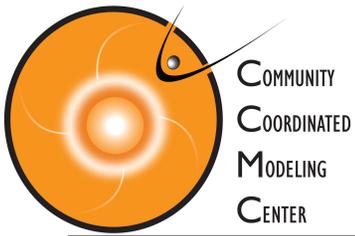


## SWx impacts of CME



- 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: takes 1-3 days

Affecting spacecraft electronics – surfacing charging/ internal charging, radio communication, navigation power grid, pipelines, and so on

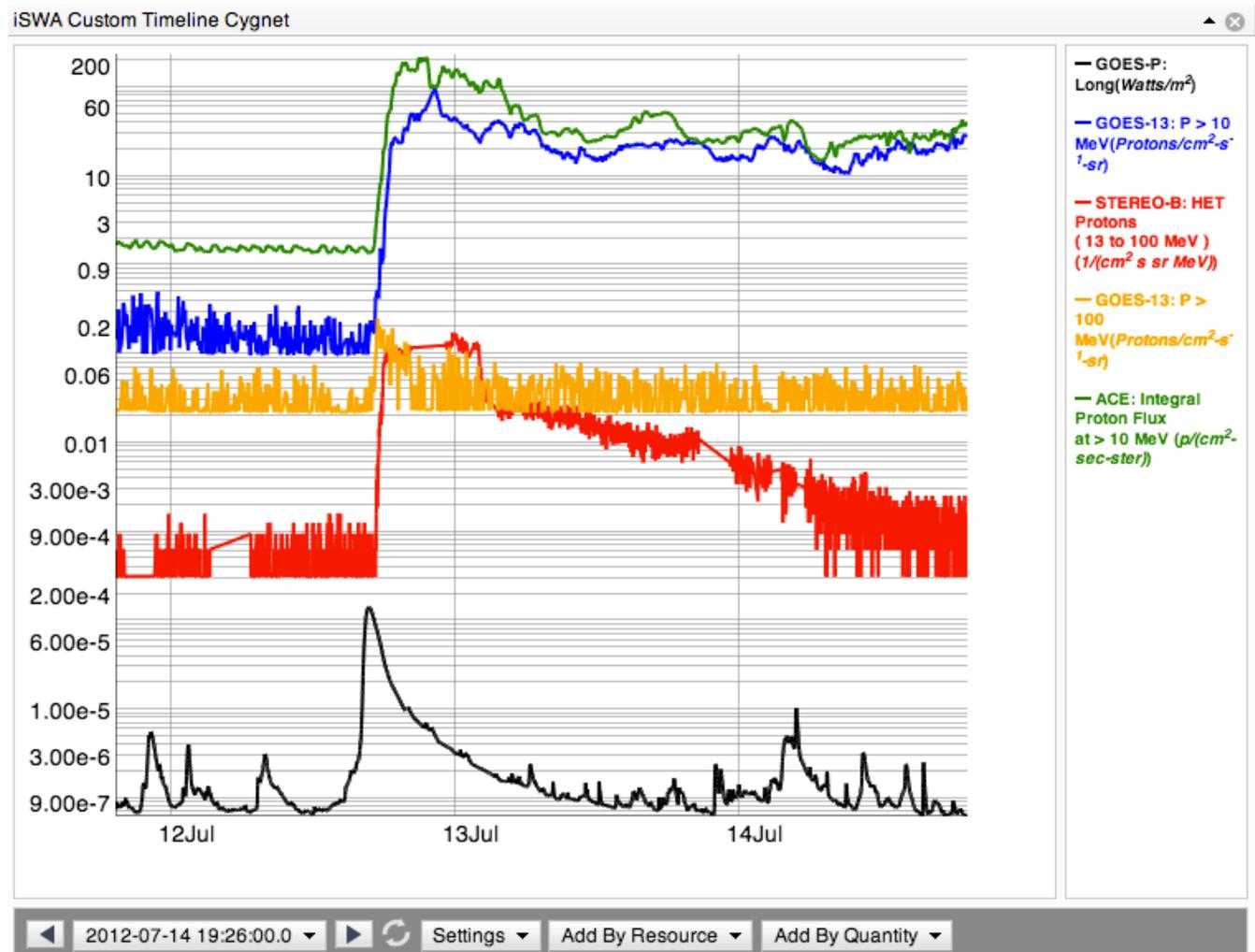


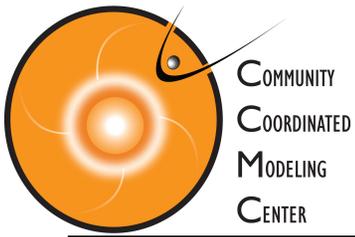
# SEP: proton radiation



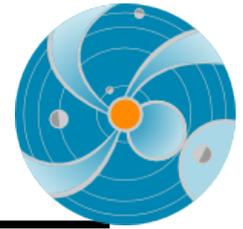
Both the CME (s) and flare (s) contribute to the SEP enhancement

SEP event related to July 12, 2012 flare and CME

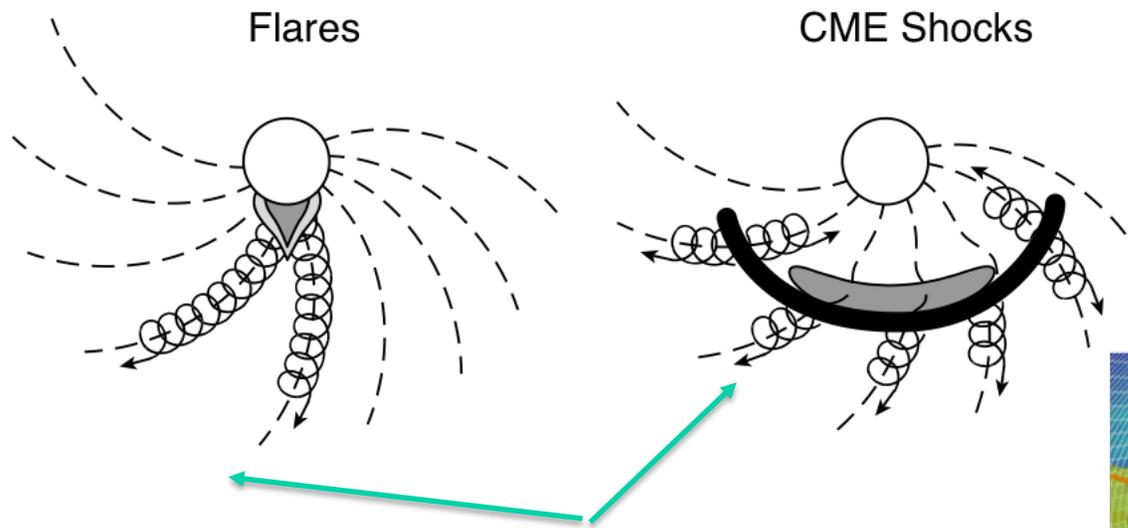




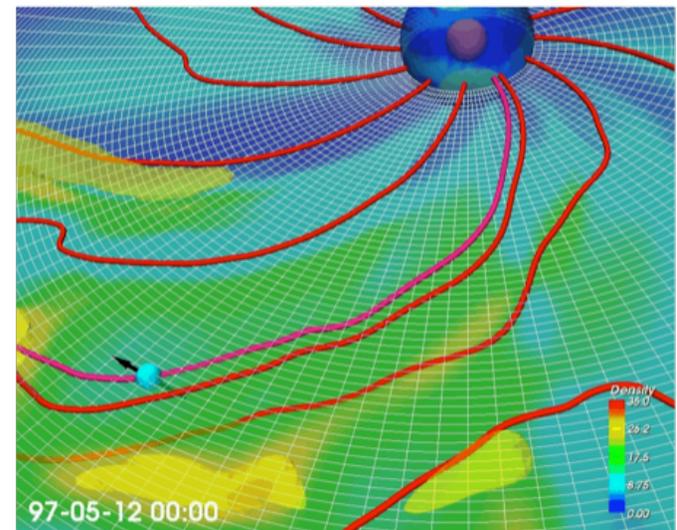
# Flares, CMEs and SEPs and the Magnetic connectivity

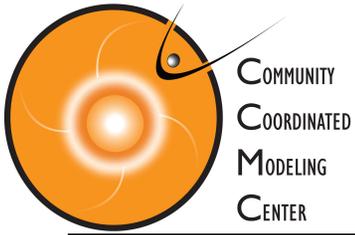


When flare and CME occurs accelerated charged particles start to move along the interplanetary magnetic field lines.

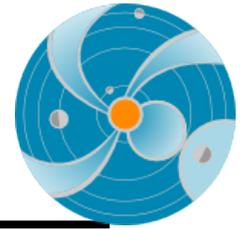


Magnetic connectivity

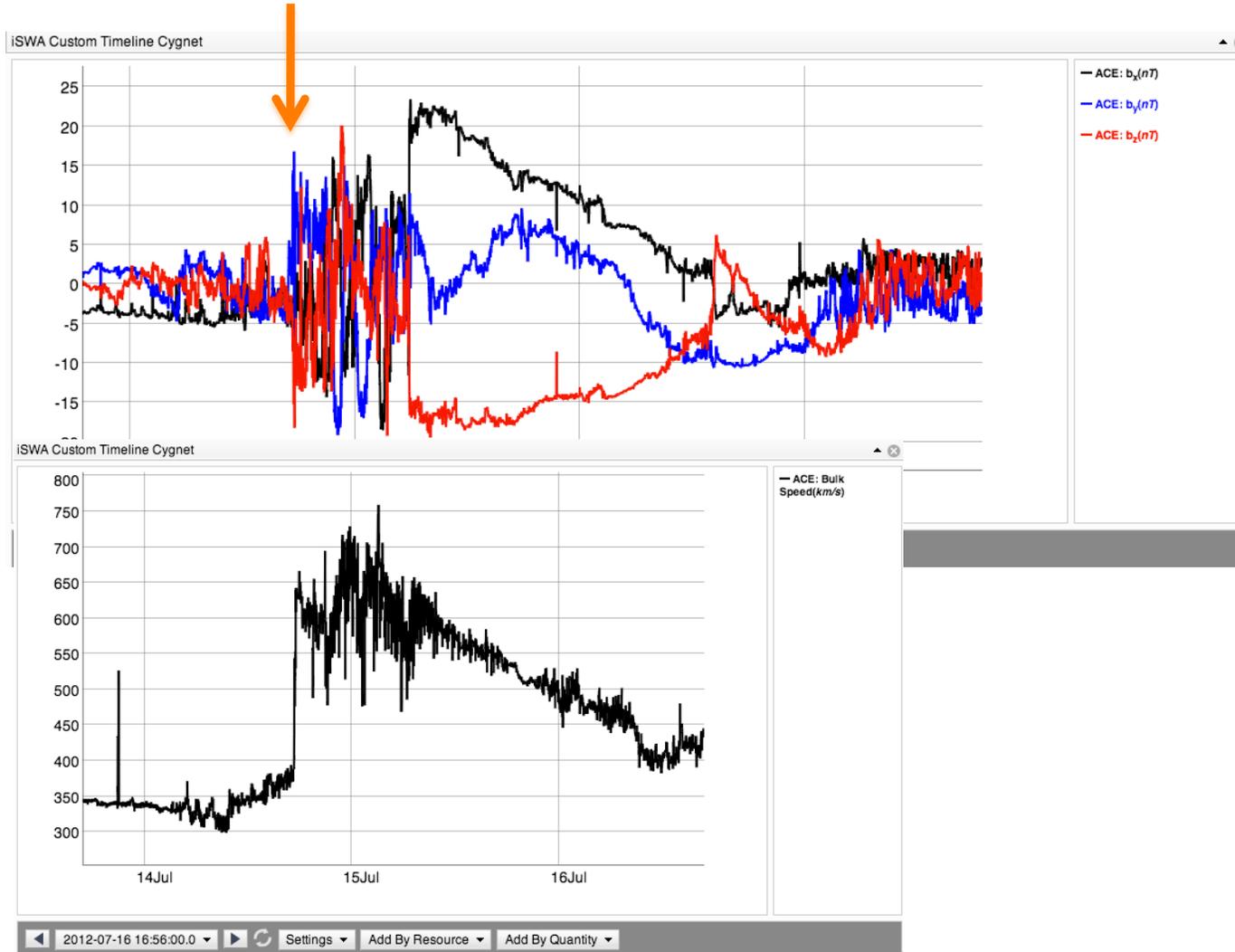


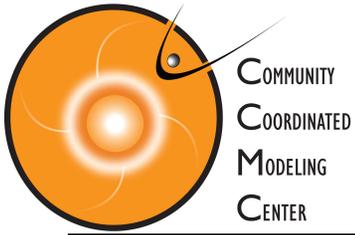


# Geomagnetic Storm Caused by the CME Arrival

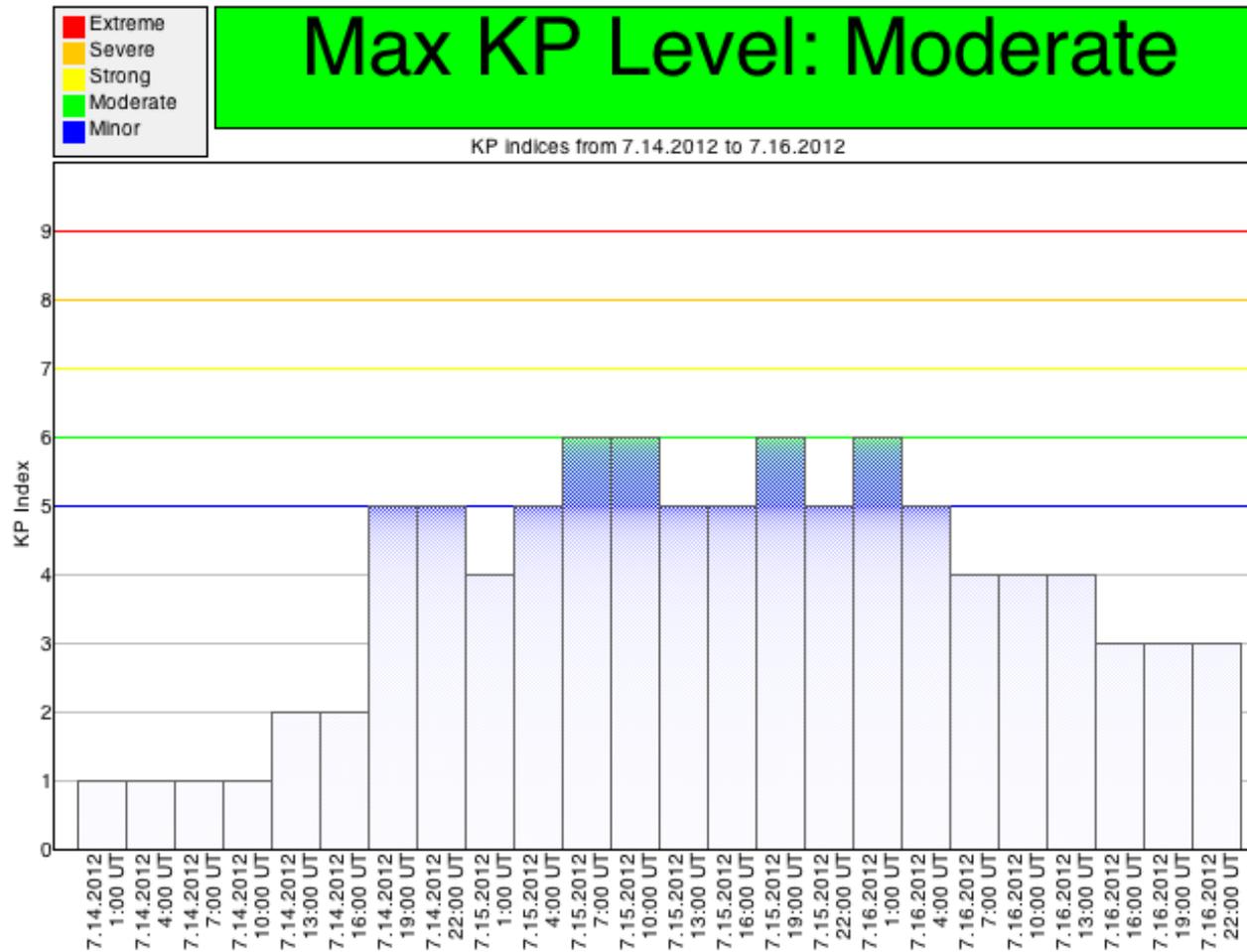
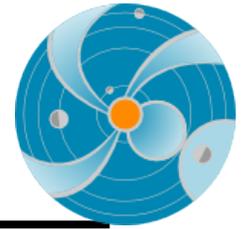


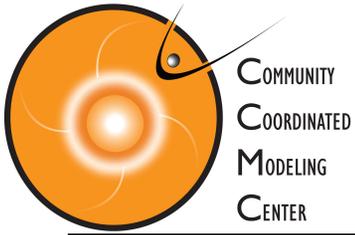
## CME Arrival at ACE



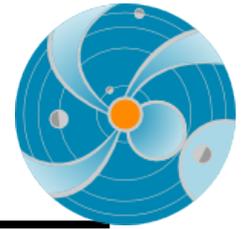


# Geomagnetic Storm Caused by the CME Arrival





# Physical Mechanism Behind the Flares and CMEs



It is believed that solar magnetic field, releases energy, accelerating solar plasma and causing flares and CMEs. Magnetic reconnection.



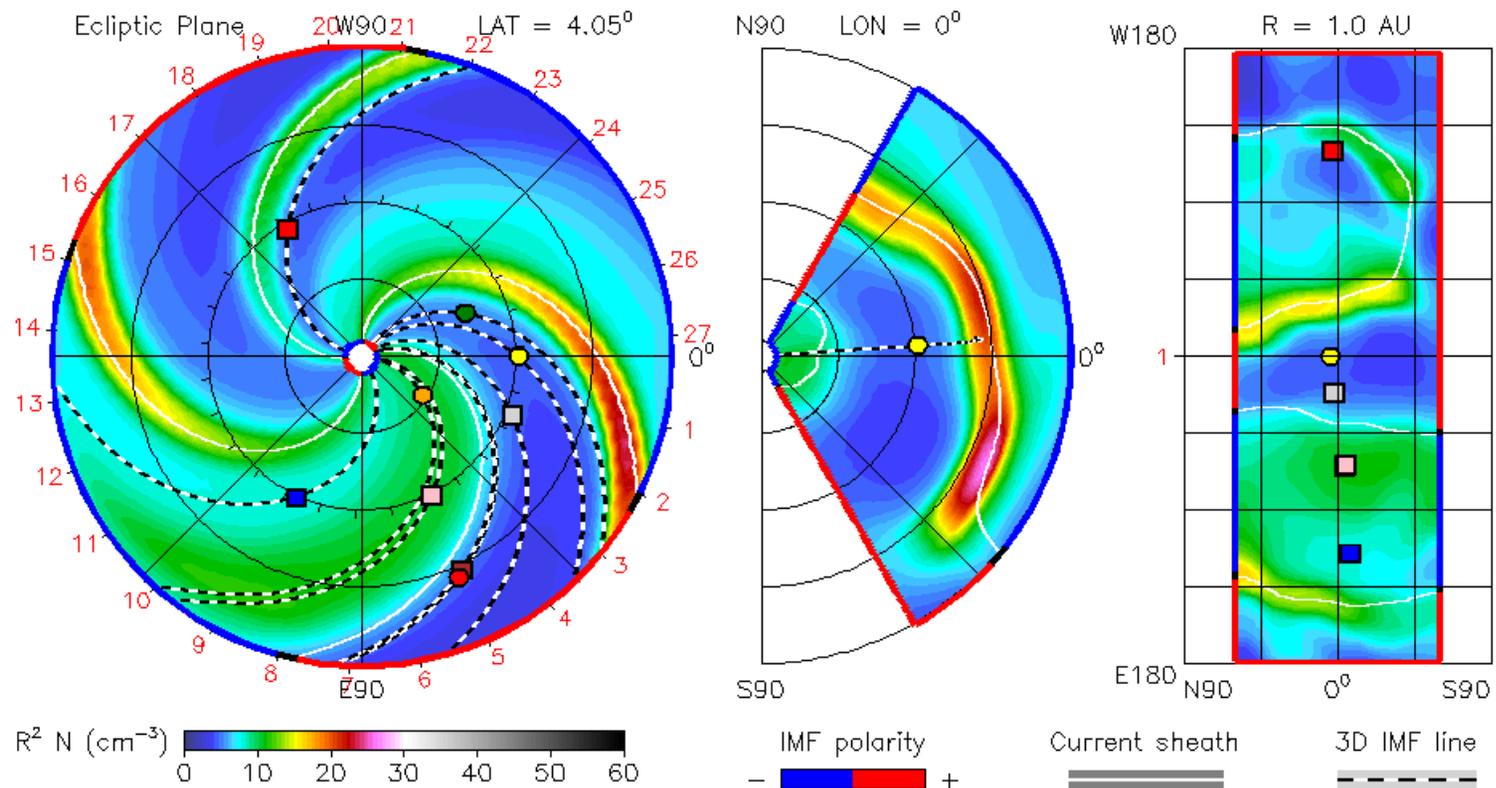
# CME Modeling

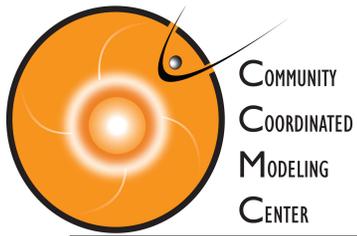


2012-07-12T00:00

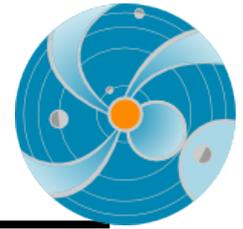
2012-07-12T00 +0.00 day

● Earth    ● Mars    ● Mercury    ● Venus     Kepler     MSL     Spitzer     Stereo\_A  
 Stereo\_B





# Homework



- In SDO AIA 193 image find the location of the flare that started around 2013-03-15T06:00
- What was the class of the flare?
- Was the flare accompanied by a CME?
- If yes, was the CME Earth directed?
- What was the start time of the CME in different coronagraph images?
- Was there an SEP event observed related to the flare and CME?
- Did the CME arrive to the Earth (ACE)?
- If yes, when did it arrive?
- What was the Kp geomagnetic storm index due to the CME arrival?
- Was this CME modeled?
- When was the predicted arrival of the CME?