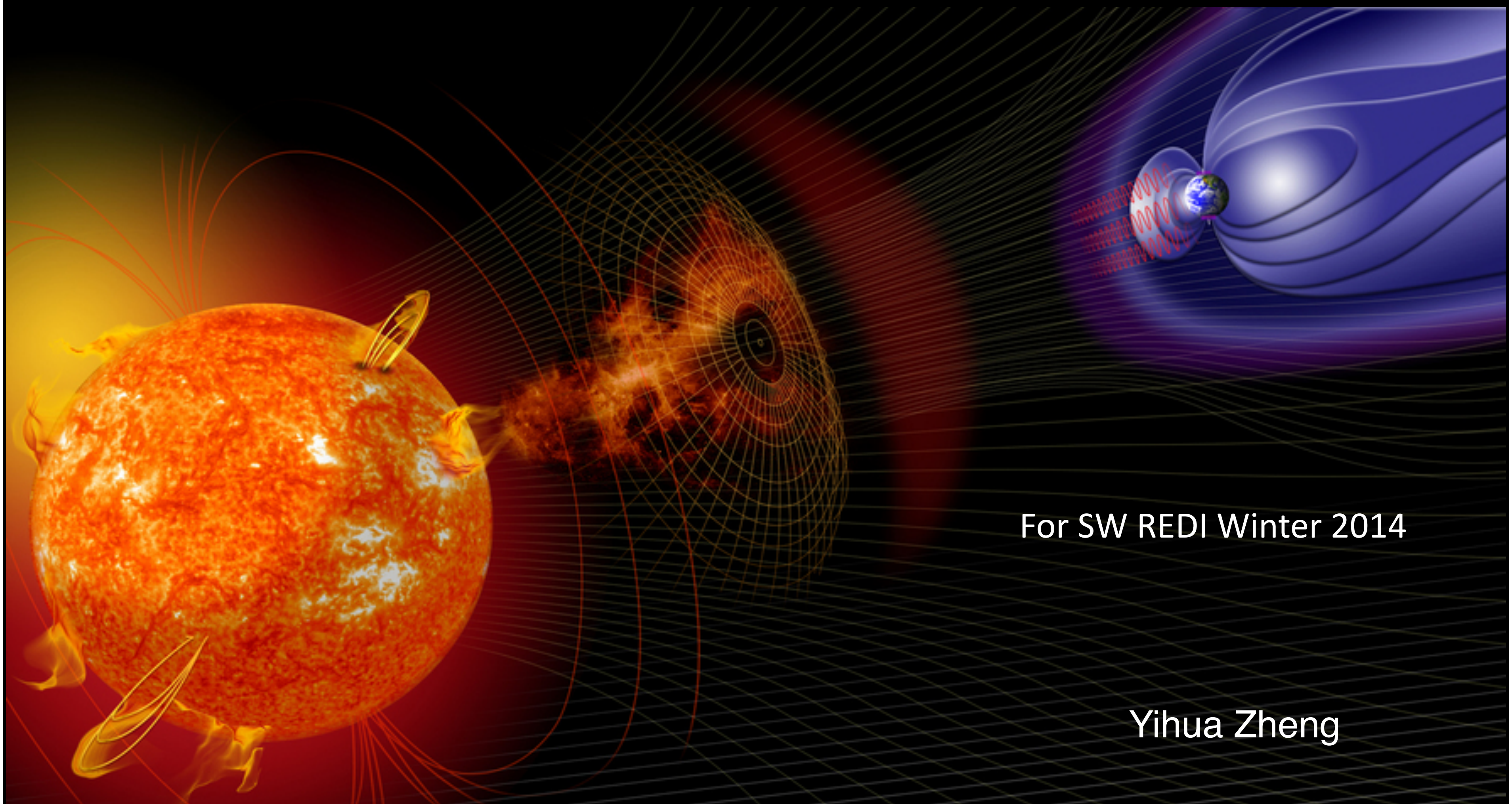
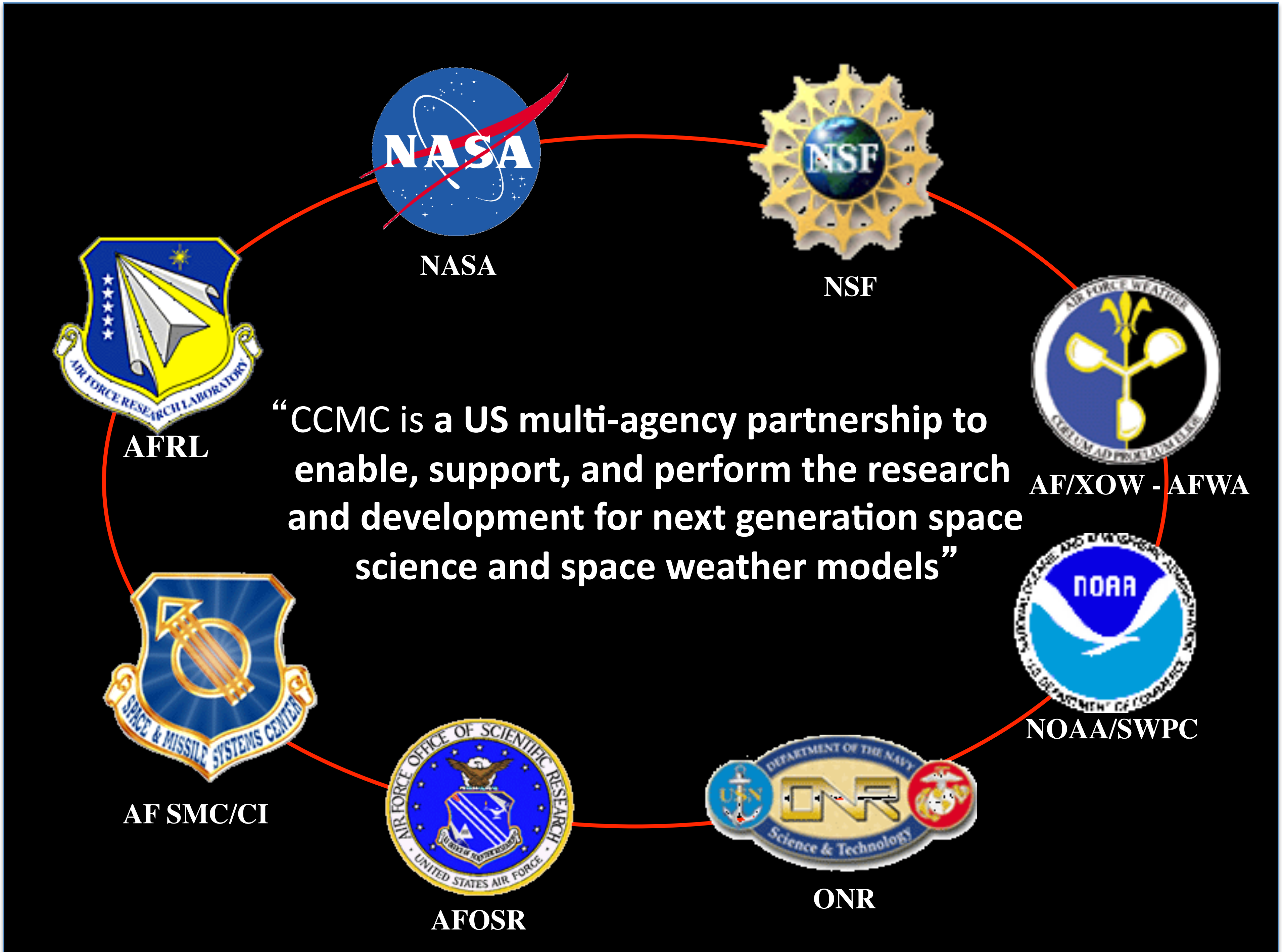
Recap of Day 1

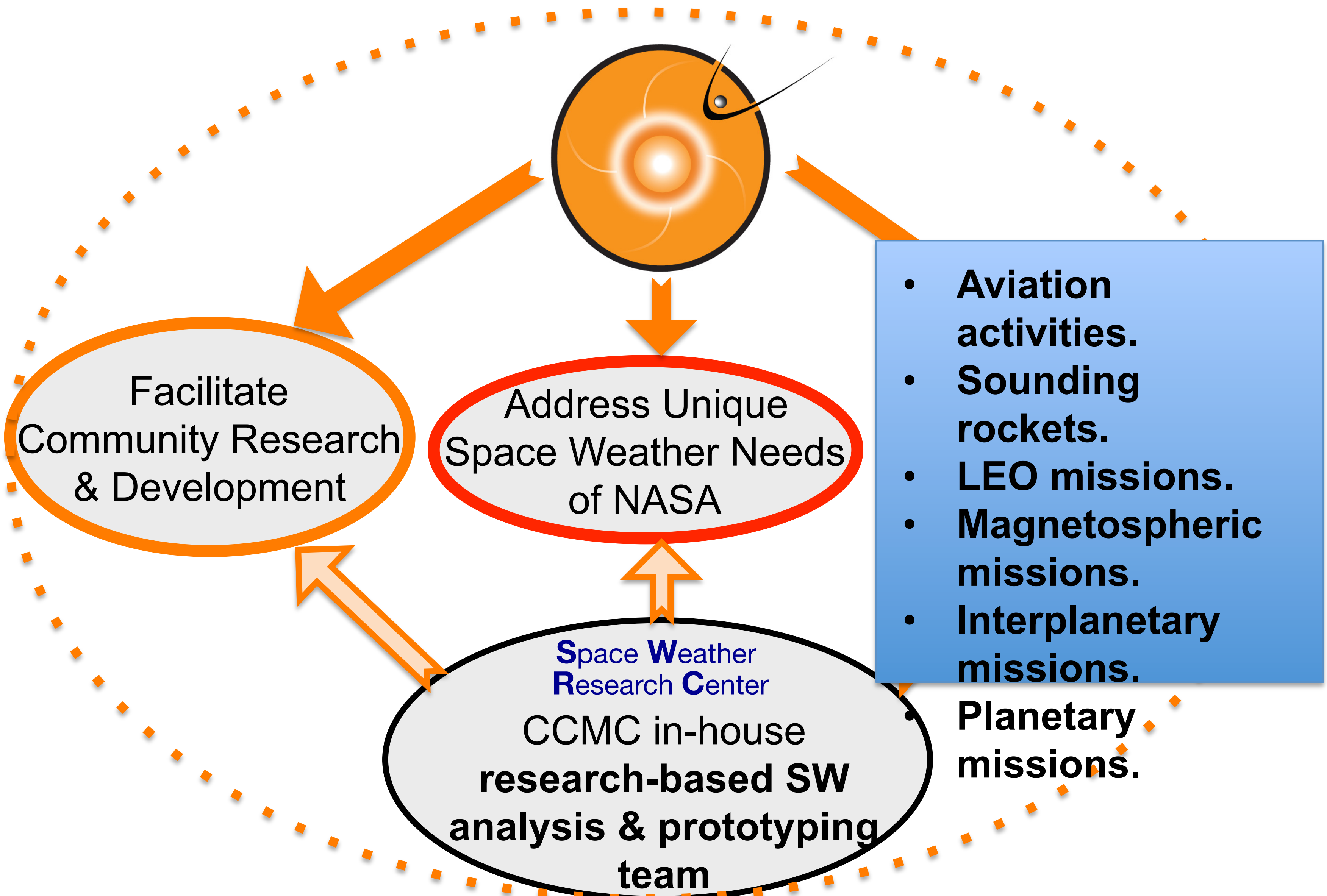


For SW REDI Winter 2014

Yihua Zheng


NASA
NSF
AF/XOW - AFWA
NOAA/SWPC
ONR
AFOSR
AF SMC/CI
AFRL
"CCMC is a US multi-agency partnership to enable, support, and perform the research and development for next generation space science and space weather models"

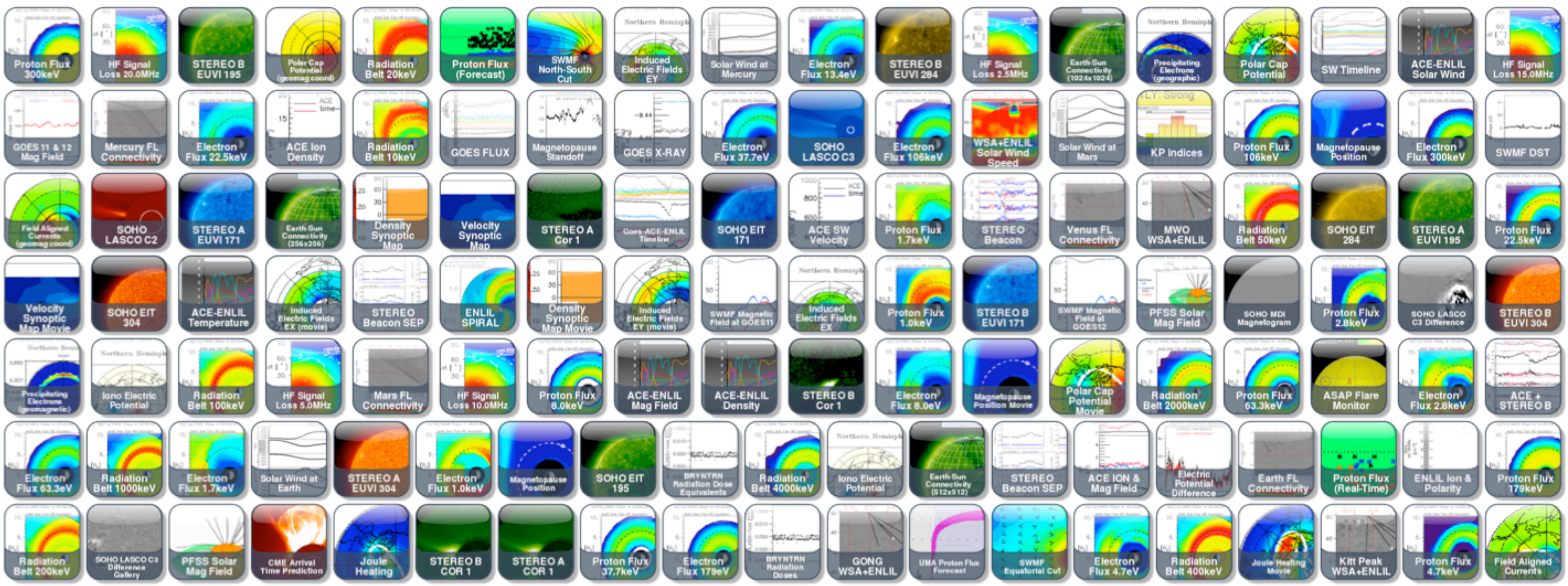
CCMC/SWRC



Facilitate Community Research & Development
Address Unique Space Weather Needs of NASA
Space Weather Research Center
CCMC in-house research-based SW analysis & prototyping team
• Aviation activities.
• Sounding rockets.
• LEO missions.
• Magnetospheric missions.
• Interplanetary missions.
• Planetary missions.

Innovative Dissemination

ISWA has ~300 products including modeling results and comprehensive sets of observational data.



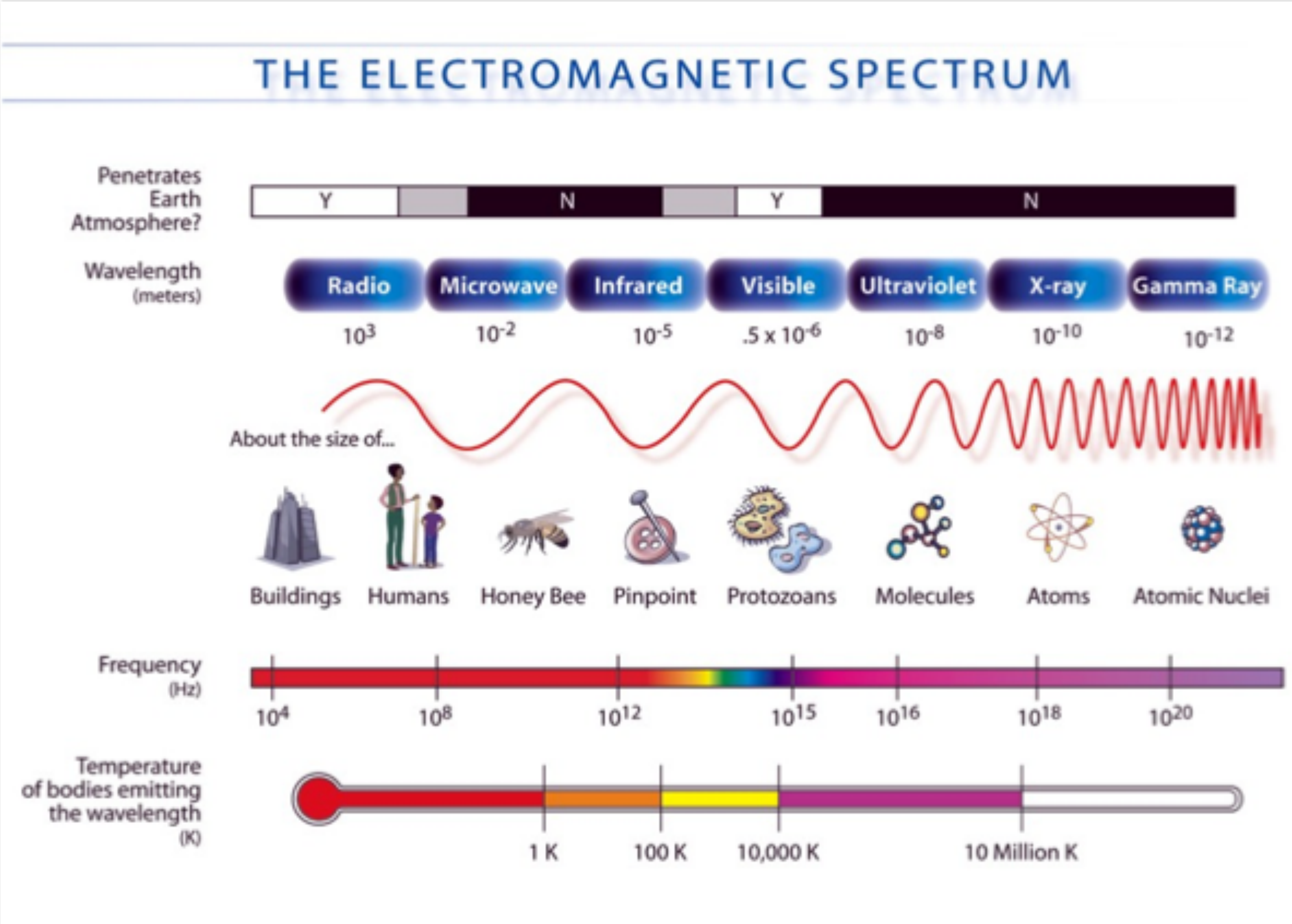
Web-based. User configurable. Available world-wide.
One-stop shop for state-of-the-art information!
http://iswa.gsfc.nasa.gov

Main Drivers of Space weather: Flares/CMEs/high speed solar wind streams

Solar Flares

radiation across the electromagnetic spectrum

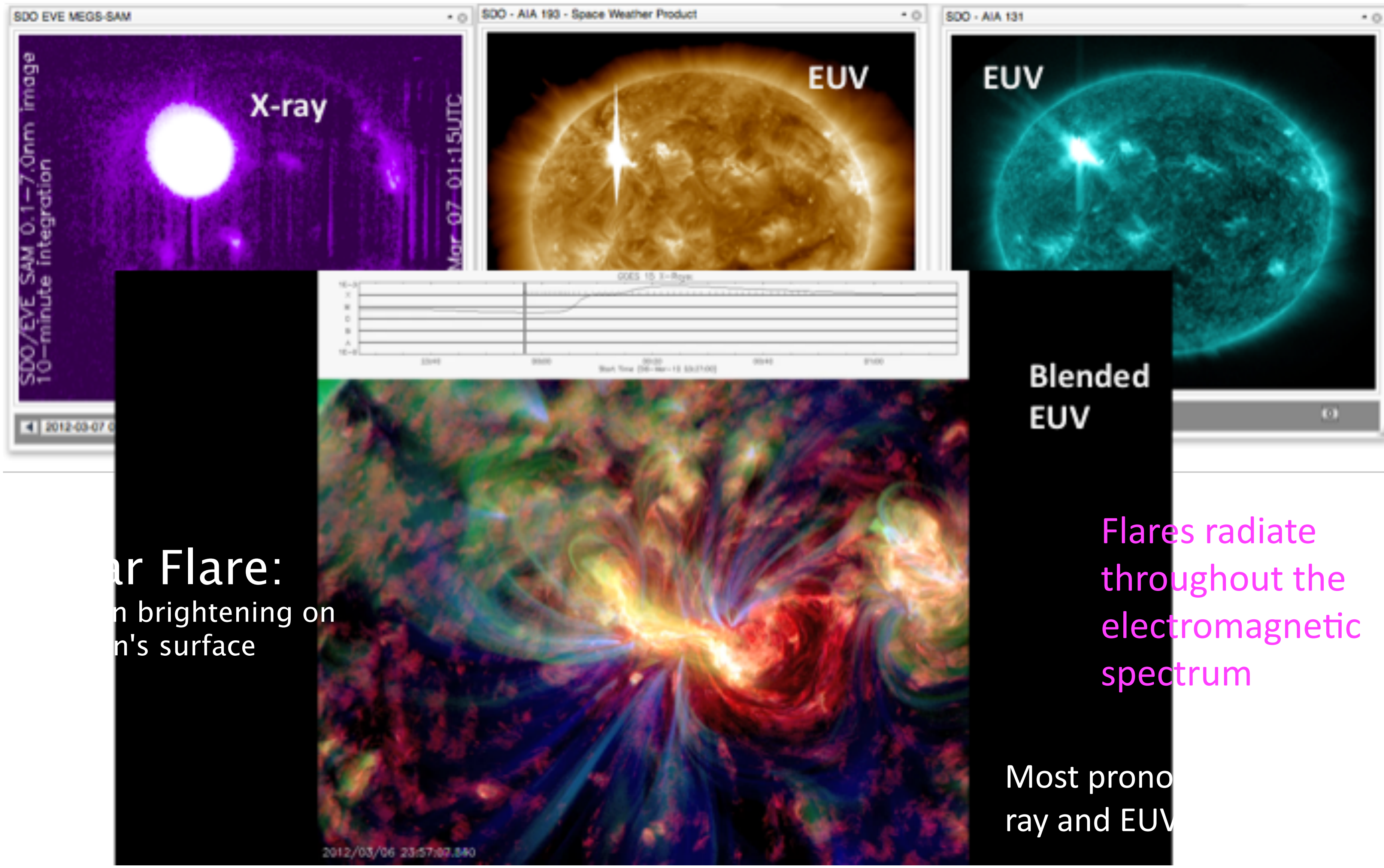
most pronounced in EUV and soft X-ray



THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

2012 March 7 X5.4/X1.3 flares

Most pronounced in x-ray and EUV



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

Coronal Mass Ejections (CMEs)

CME

- Massive burst of solar materials and magnetic field/flux 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

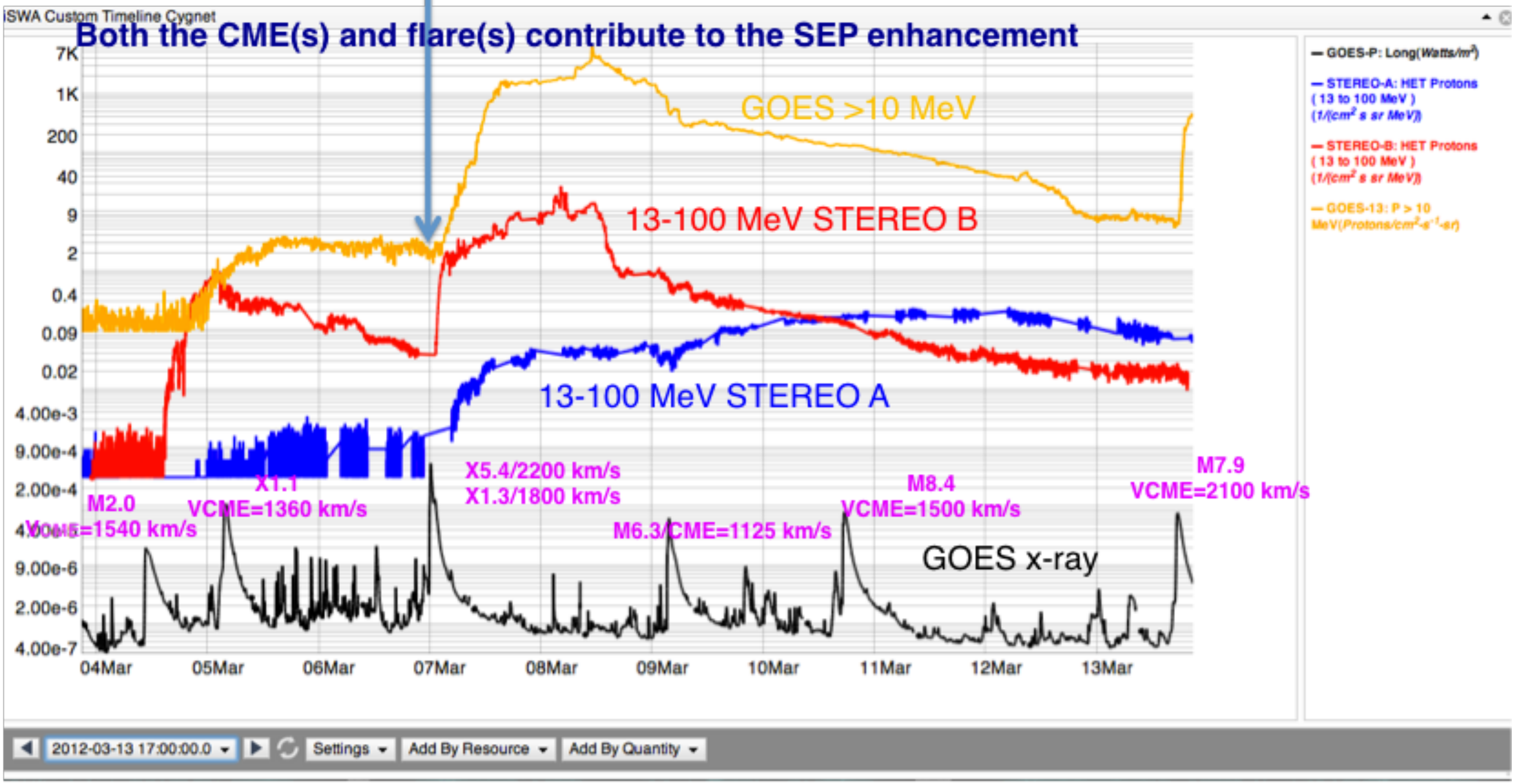
CME viewed by coronagraph imagers

- 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

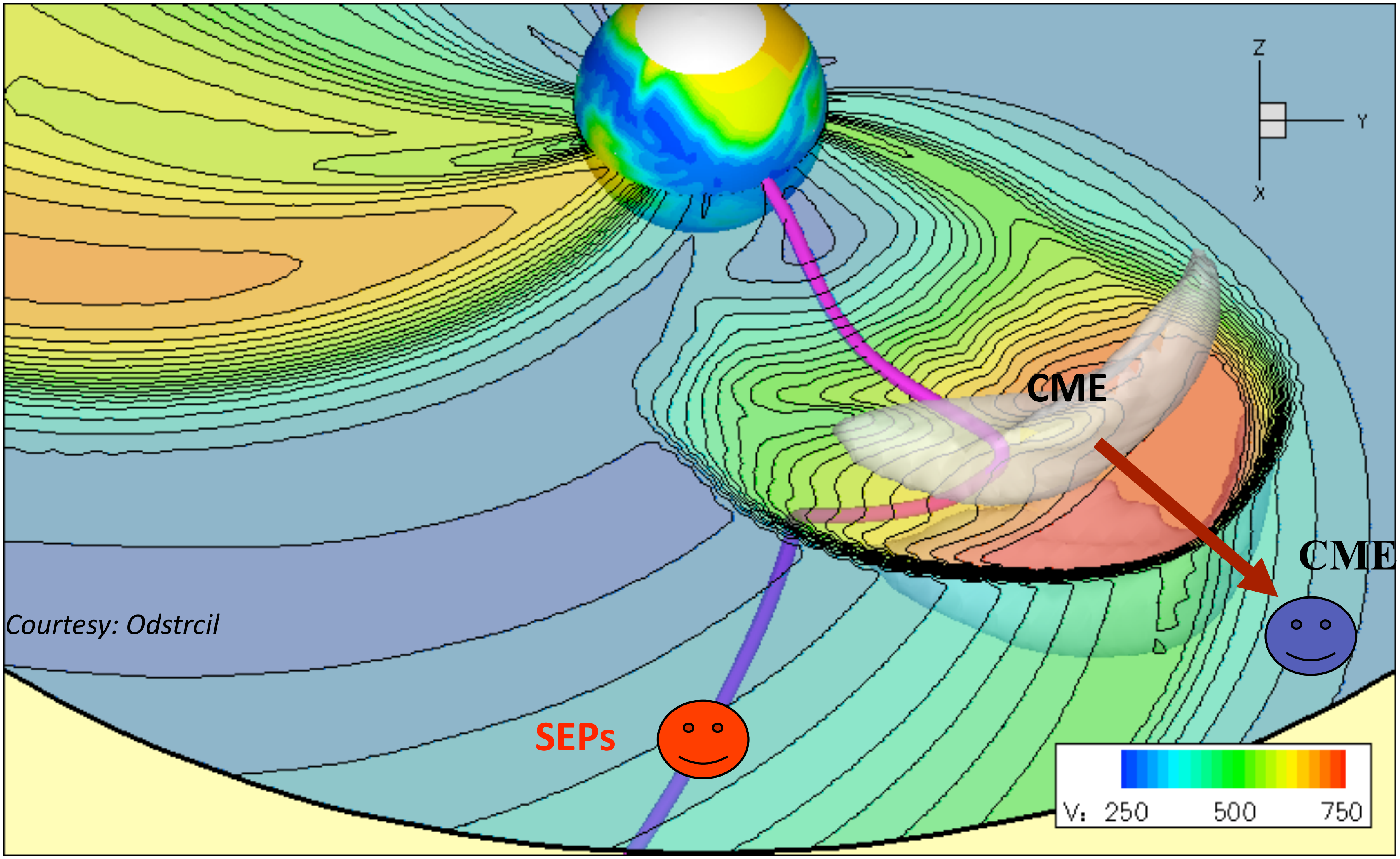
SWx Impacts of a CME

- Contribute to SEP (proton/ion 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 (via SEPs)
- Radio communication, navigation
- Power grid, pipelines, and so on

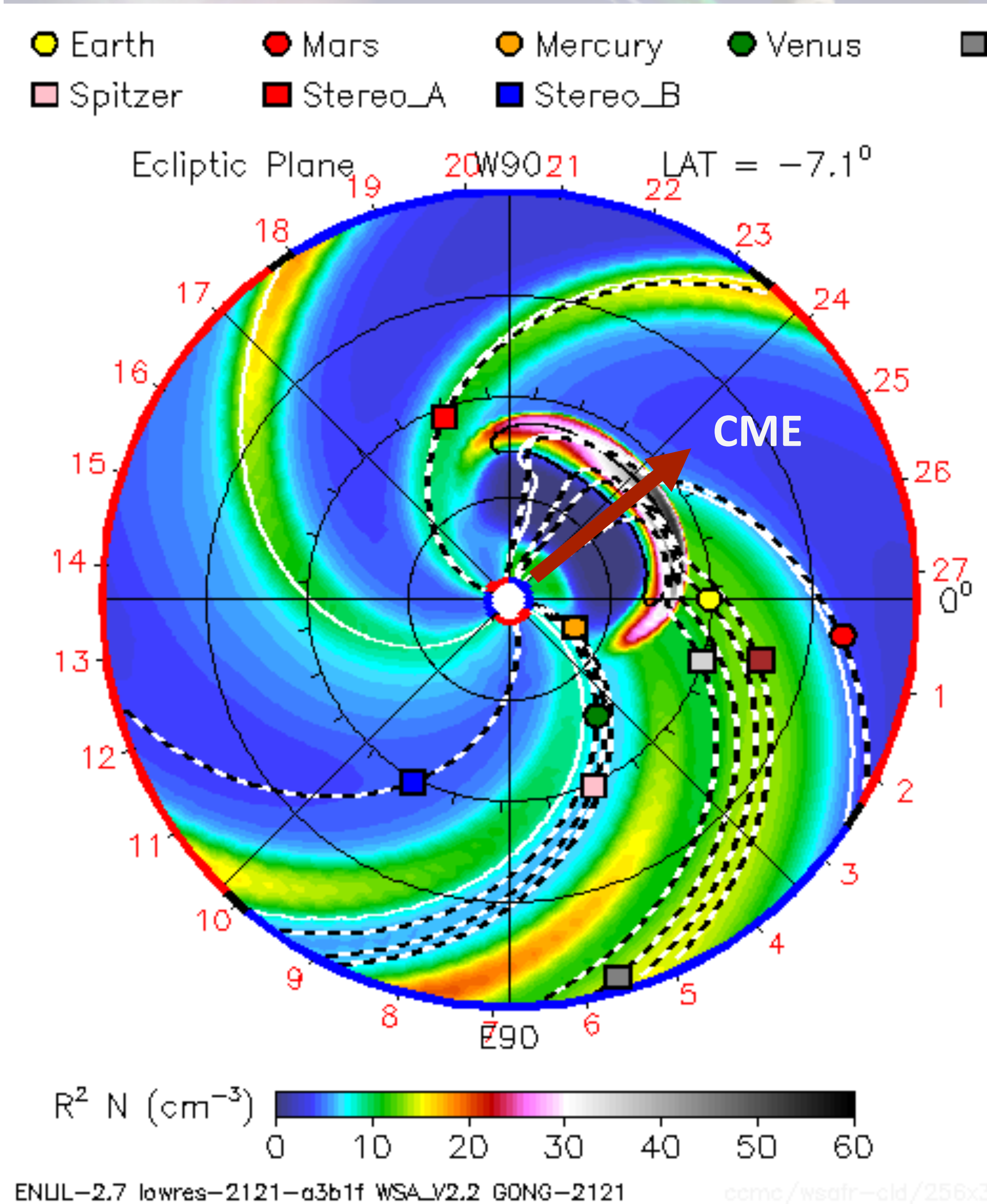
SEP radiation



CME and SEP path are different



CME: could get deflected, bended, but more or less in the radial direction



Important distinction

Ion Radiation storm vs
Geomagnetic storm

CME impact and SEP (Solar Energetic Particle) impact are different

CME impact @ Earth: Geomagnetic Storm

Radiation storm @ Earth from SEPs

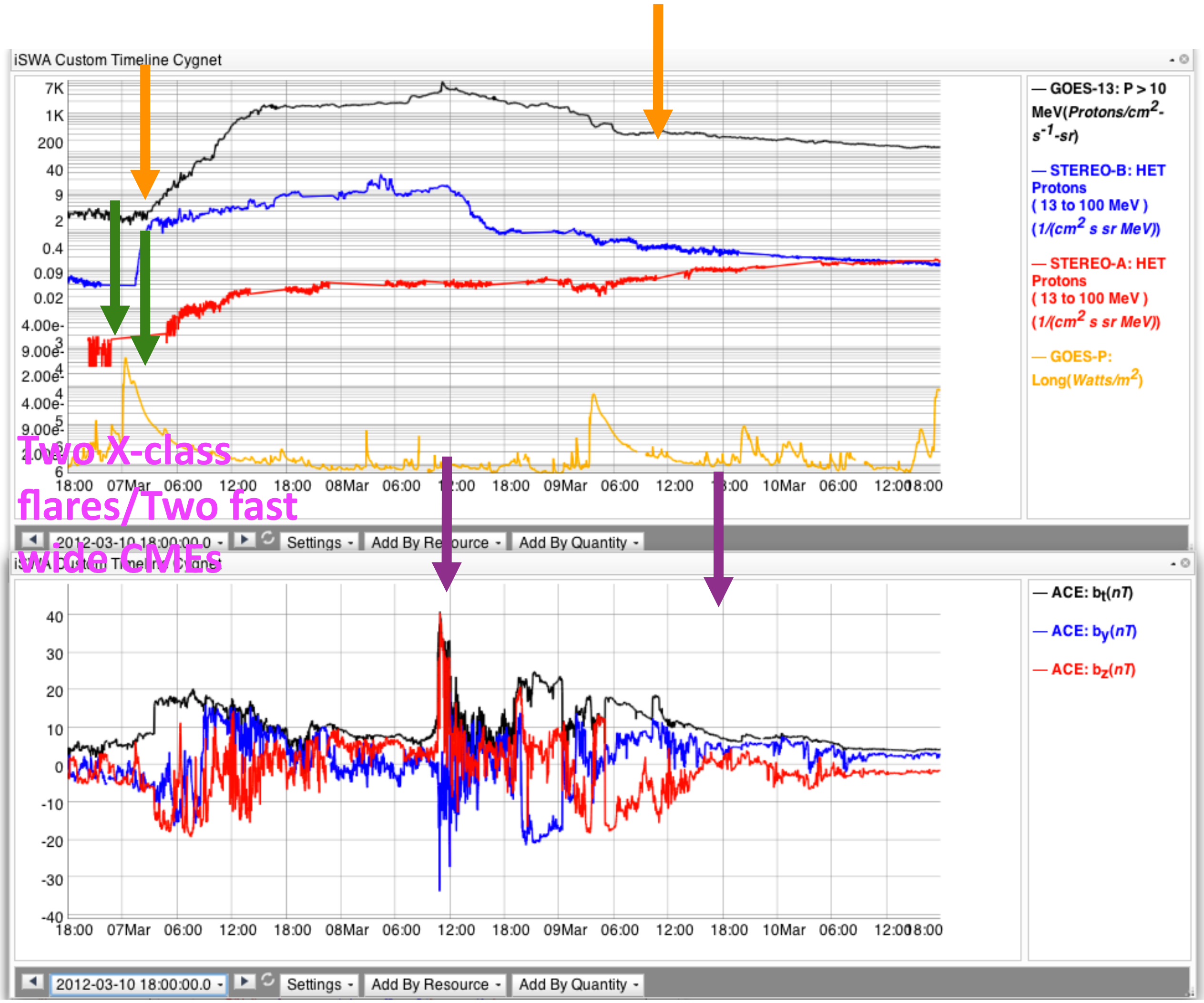
CME speed: 300 – 3500 km/s
SEPs: fraction of c
Light speed c: 3 x10^5 km/s

SEPs: ion radiation storms

Potentially affect everywhere in the solar system

Space Weather Effects and Timeline

(Flare and CME)



Flare effects at Earth:
~ 8 minutes (radio blackout storms)
Duration: minutes to hours

SEP radiation effects reaching Earth: 20 minutes – 1hour after the event onset
Duration: a few days

CME effects arrives @ Earth: 1-2 days (35 hours here)
Geomagnetic storms: a couple of days

SWx Consequences of CIR HSS

CIR HSS: usually long-duration (3-4 days)

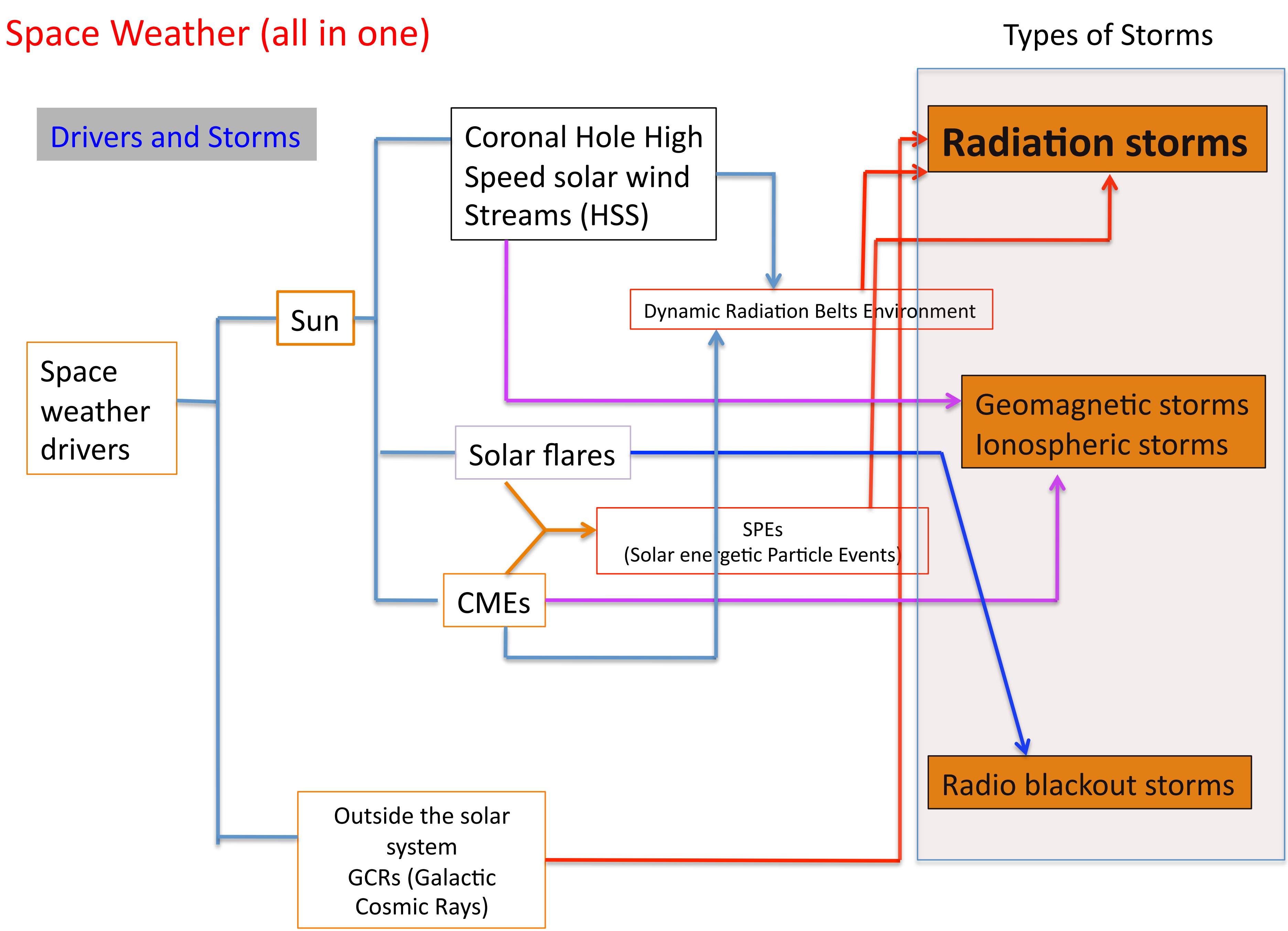
- Radiation belt electron flux enhancement
- Surface charging
- Geomagnetic disturbances (moderate at most)
- heating of upper atmosphere: satellite drag

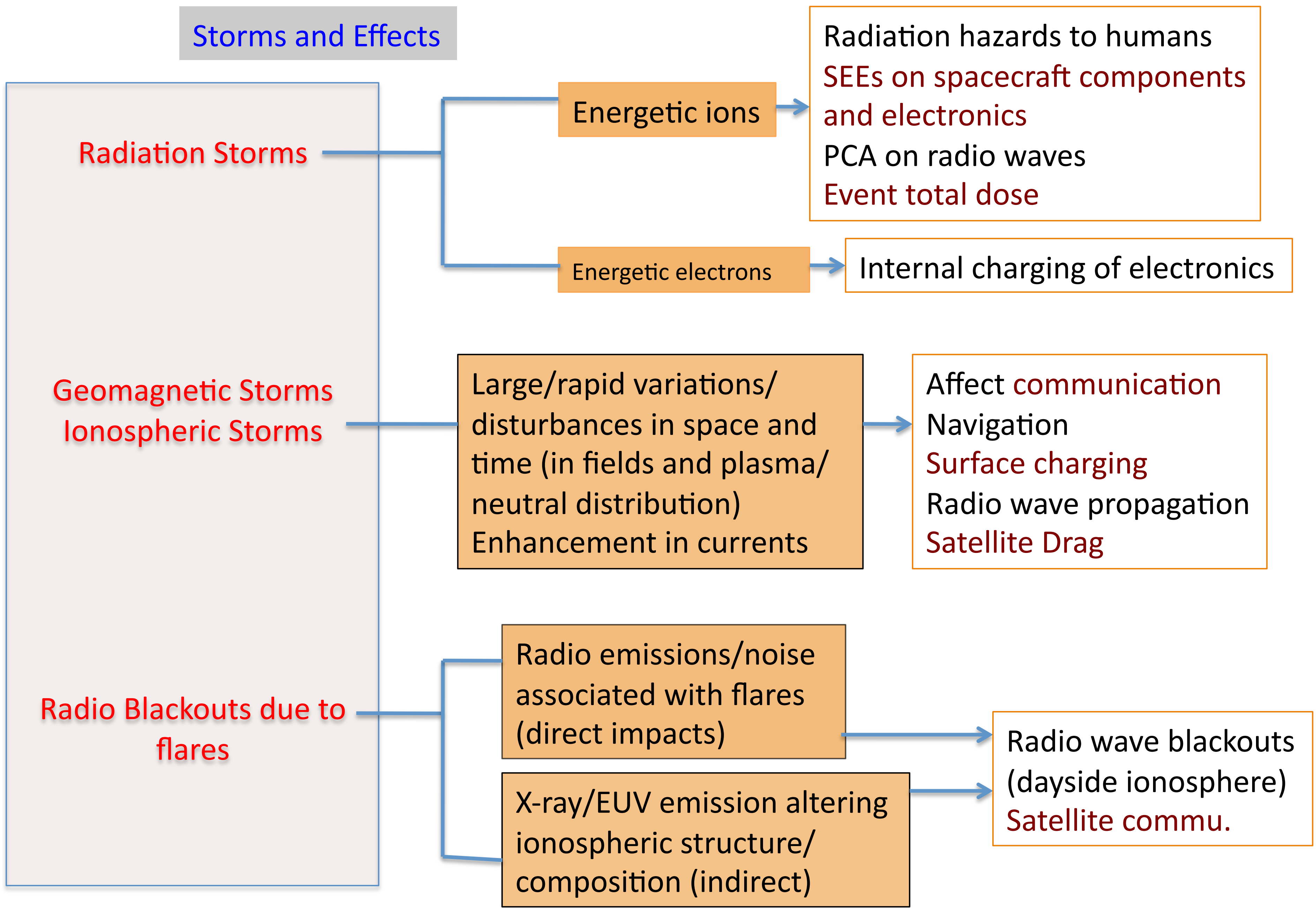
Energetic electron radiation: (the >0.8 MeV electron flux exceeding 10^5 pfu alert threshold): takes 2-3 days from the CIR interface

Although geomagnetic activity (due to CIR HSS) during the declining and minimum phases of the solar cycle appears to be relatively benign (especially in comparison to the dramatic and very intense magnetic storms caused by interplanetary coronal mass ejections (ICMEs) that predominate during solar maximum), this is misleading. Research has shown that the time-averaged, accumulated energy input into the magnetosphere and ionosphere due to high speed streams can be greater during these solar phases than due to ICMEs during solar maximum!

Tsurutani et al., 2006

Space Weather in a nutshell


Space Weather (all in one)
Types of Storms
Drivers and Storms
Coronal Hole High Speed solar wind Streams (HSS)
Radiation storms
Dynamic Radiation Belts Environment
Sun
Space weather drivers
Geomagnetic storms
Ionospheric storms
Solar flares
SPEs
(Solar energetic Particle Events)
CMEs
Radio blackout storms
Outside the solar system
GCRs (Galactic Cosmic Rays)


Storms and Effects
Radiation Storms
Energetic ions
Radiation hazards to humans
SEEs on spacecraft components and electronics
PCA on radio waves
Event total dose
Energetic electrons
Internal charging of electronics
Geomagnetic Storms
Ionospheric Storms
Large/rapid variations/ disturbances in space and time (in fields and plasma/ neutral distribution)
Enhancement in currents
Affect communication
Navigation
Surface charging
Radio wave propagation
Satellite Drag
Radio Blackouts due to flares
Radio emissions/noise associated with flares (direct impacts)
X-ray/EUV emission altering ionospheric structure/ composition (indirect)
Radio wave blackouts (dayside ionosphere)
Satellite commu.

SWx Impacts on Satellites Electronics/ Components

hazards presented by the radiation and plasma environment in space

- Single Event Effects (affect all SC)
  - caused by protons and heavy ions with energies of 10s of MeV/amu
- Internal Charging (those in radiation belt)
  - caused by electrons with energies above about 100 keV that penetrate inside a vehicle
- Surface Charging (all in Earth's environment)
  - caused by electrons with energies of 10s of keV that interact with spacecraft surfaces
- Event Total Dose (all SC)
  - caused primarily by solar protons and possibly also by transient belts of trapped particles, typically protons with energies near 10 MeV

Effects on Satellite Orbit

- Satellite drag (LEO)
- Orientation effects (spacecraft that use Earth's magnetic field for orientation)

Effects on Satellite Communication

- During strong solar flares (strong radio noise)
  - Directly cause interference via solar radio noise
  - Through modification of the ionosphere
- Scintillation effects during geomagnetic storms

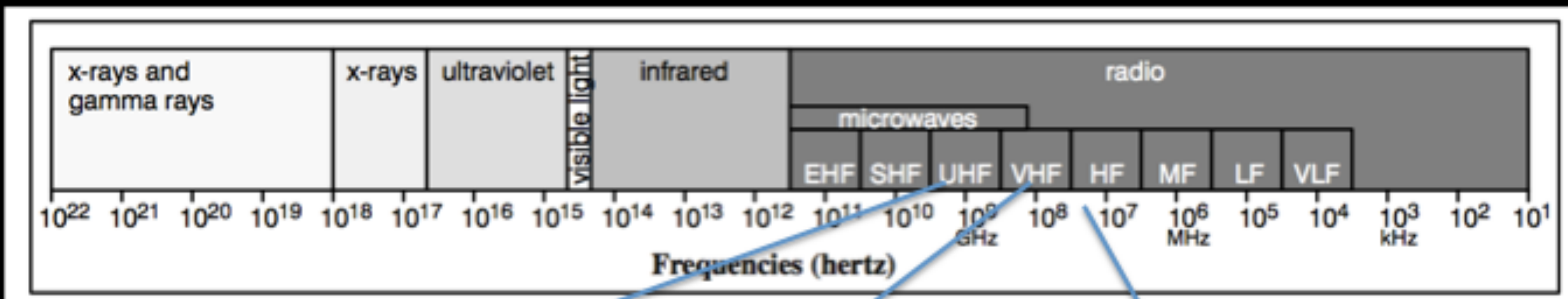
Environment Hazards for different orbits

Space hazard	Spacecraft charging		Single-event effects			Total radiation dose		Surface degradation		Plasma interference with communications	
Specific cause	Surface	Internal	Cosmic rays	Trapped radiation	Solar particle	Trapped radiation	Solar particle	Ion sputtering	O^+ erosion	Scintillation	Wave refraction
LEO <60°	Not applicable	Not applicable	Relevant	Important	Not applicable	Important	Relevant	Relevant	Important	Important	Important
LEO >60°	Relevant	Not applicable	Important	Important	Important	Important	Relevant	Relevant	Important	Important	Important
MEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GPS	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
GTO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
GEO	Important	Important	Important	Not applicable	Important	Important	Important	Relevant	Not applicable	Important	Important
HEO	Important	Important	Important	Important	Important	Important	Important	Relevant	Not applicable	Important	Important
Interplanetary	Not applicable	Not applicable	Important	Not applicable	Important	Not applicable	Important	Relevant	Not applicable	Relevant	Relevant

Important (red) | Relevant (yellow) | Not applicable (grey)

Joe Mazur

Types of space weather events affecting nav and commu



UHF – GPS

- Energetic protons/ particles – via SEEs - affecting GPS satellites components
- Geomagnetic storms/ ionospheric storm - cause scintillations

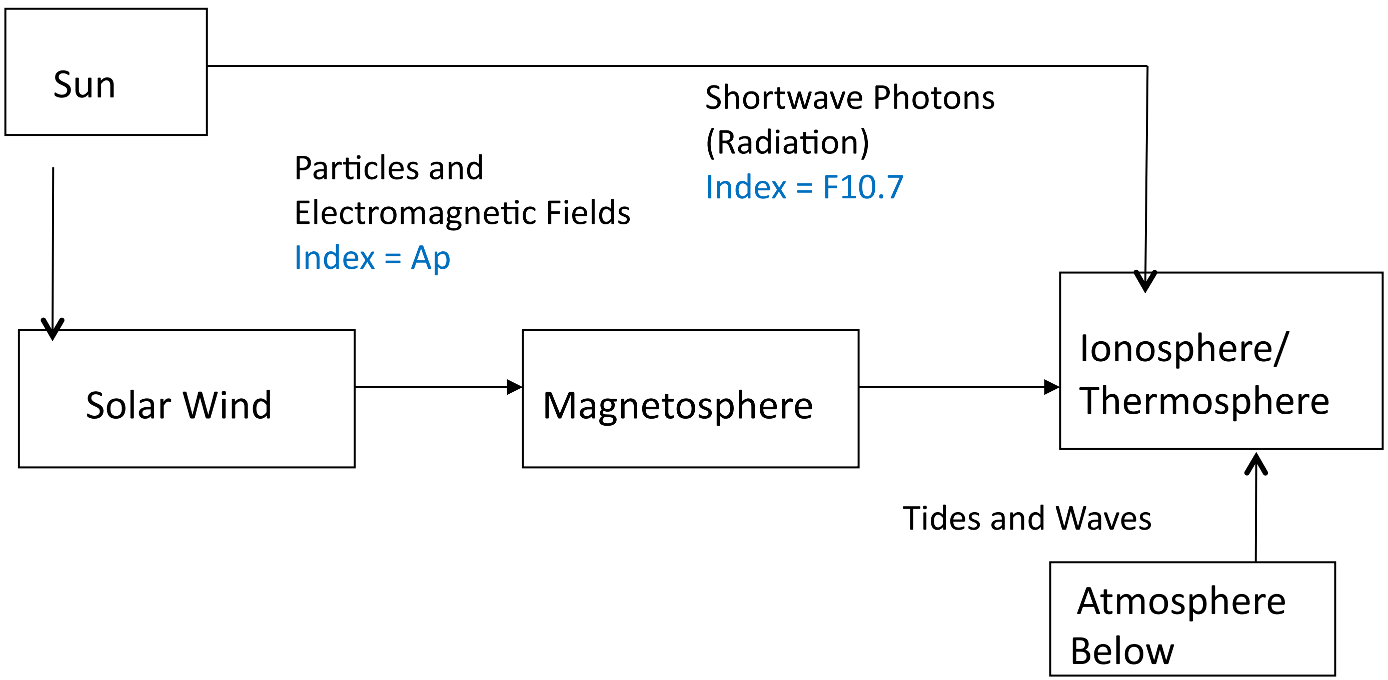
VHF:

- Energetic protons - PCA
- Geomagnetic storms
- Solar radio emission associated with flare/CME

HF:

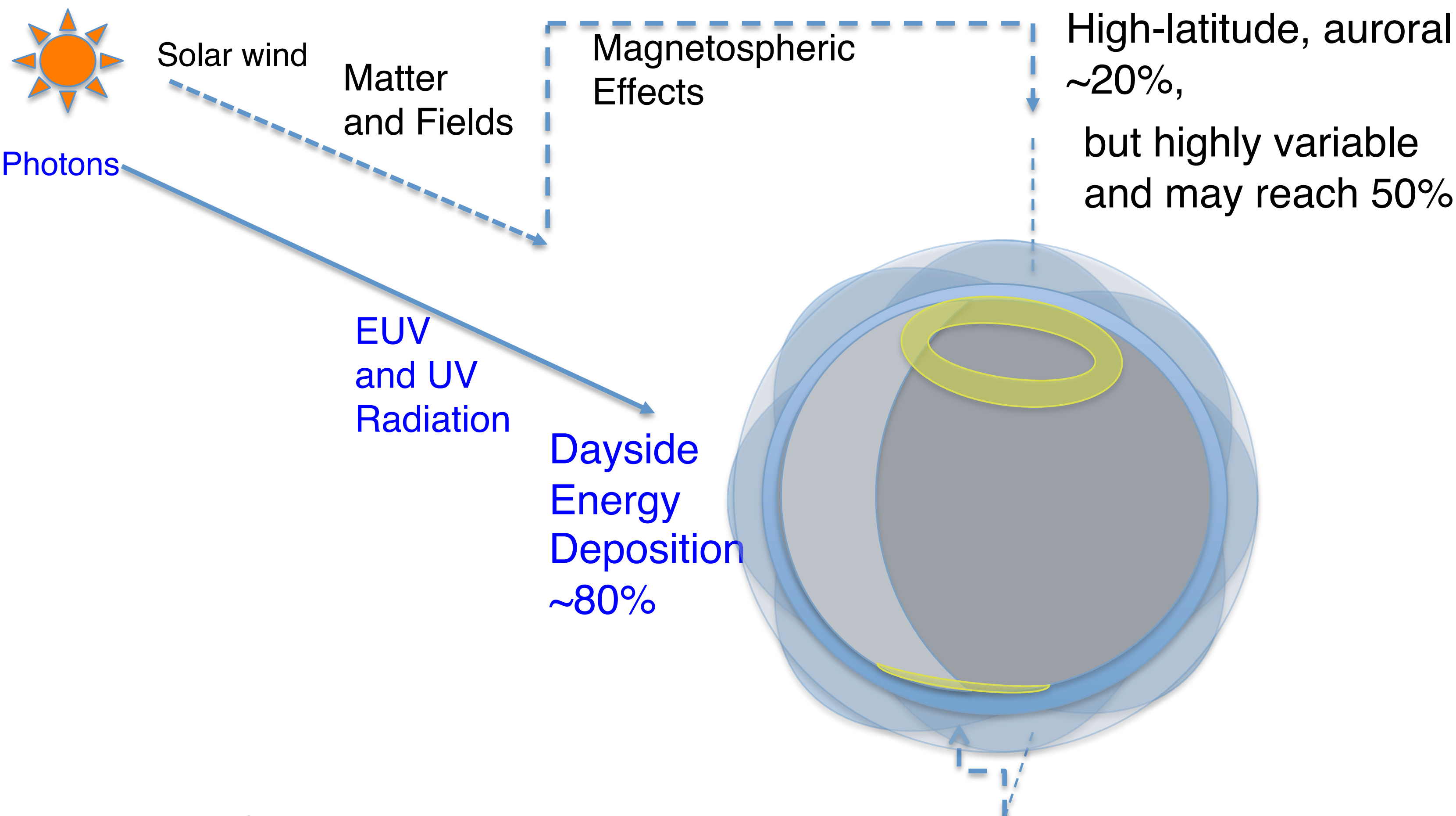
- Solar flares/x-ray
- Energetic protons - PCA
- Geomagnetic activities

Energy Flow to the Thermosphere



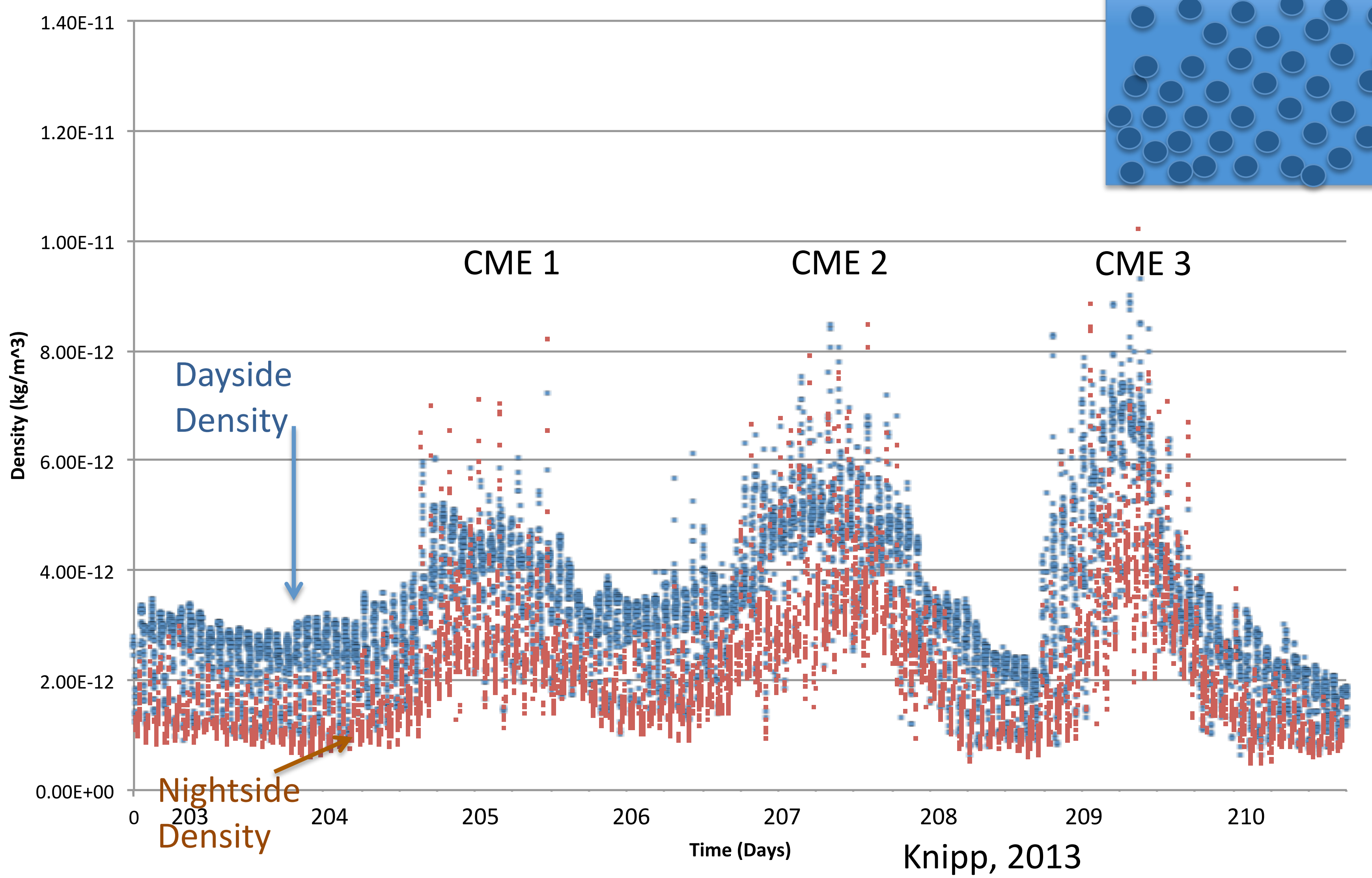
Knipp 2011 Understanding Space Weather and the Physics Behind It

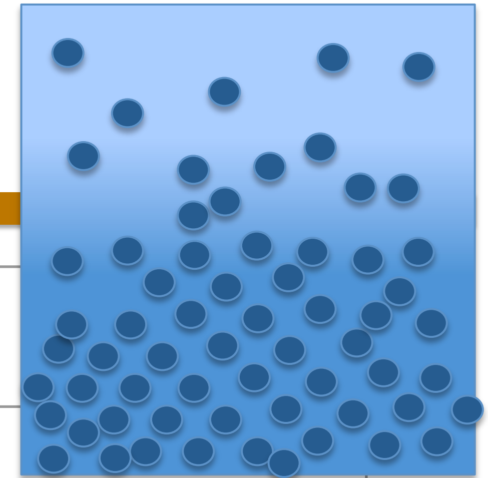
Solar /Solar Wind Energy Deposition



After Prolss, 2011

CHAMP Density Extrapolated to 400 km (ng/m^3)





Energy deposition causes atmospheric expansion; Heated molecules and atoms, fighting for more room, migrate upward

Summary

Significant Challenges are posed by satellite drag

- Track and identify active payloads and debris
- Collision avoidance and re-entry prediction
- Attitude Dynamics
- Constellation control
- "Drag Make-Up" maneuvers to keep satellite in control box
- Delayed acquisition of SATCOM links for commanding /data transmission
- Mission design and lifetime

Flare impact on neutral density (sat. drag)

Thermospheric Density: An Overview of Temporal and Spatial

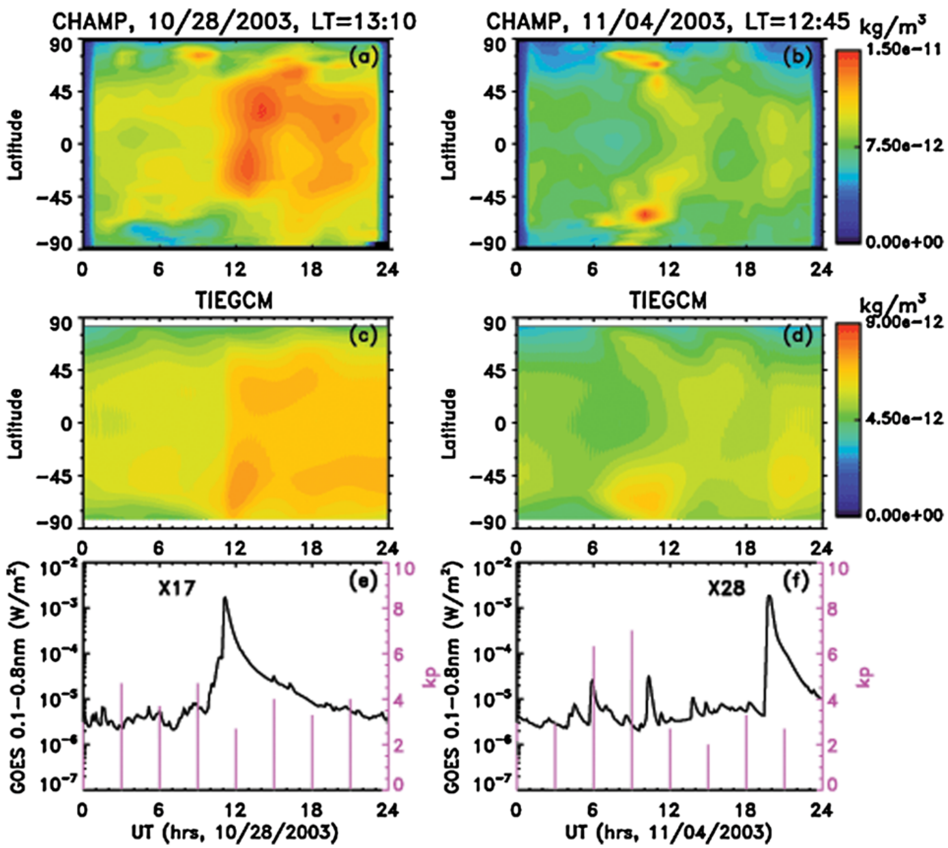


Fig. 1 Neutral density responses to an X17 flare occurred on October 28, 2003 and an X28 flare occurred on November 4, 2003. (**a**) Neutral density observed by CHAMP on October 28, 2003. The solar local time of CHAMP orbit was ~13:10. (**b**) Neutral density observed by CHAMP on November, 2003. The solar local time of CHAMP orbit was ~12:45. (**c**) Neutral density simulated by TIE-GCM for October 28, 2003, sampled along the CHAMP orbit. FISM flare spectra were used as solar input for the TIE-GCM. (**d**) Neutral density simulated by TIE-GCM for November, 2003, sampled along the CHAMP orbit. FISM flare spectra were used as solar input for the TIE-GCM; (**c**) GOES 0.1–0.8 nm solar irradiance and geomagnetic Kp index for October 28, 2003. (**d**) GOES 0.1–0.8 nm solar irradiance and geomagnetic Kp index for November 4, 2003

Solar flares can cause abrupt changes in dayside neutral density – as shown in the left panel with the X17 flare.

Neutral density response to a flare depends on the spectral characteristics of the emission enhancement – which is location dependent. Flare emission in the EUV range (~25 nm – 120 nm) is optically thick so a limb flare's influence on the neutral density is weaker – which explains why the X28 flare didn't make much enhancement in neutral density as it originated near the solar limb region.

Qian and Solomon (2011), Space Sci Rev
DOI 10.1007/s11214-011-9810-z