Introduction of Space Weather

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For SW REDI Winter 2014
• Space is NOT empty!

• There is weather in space - space weather

• Space is full of plasma - 4th state of matter (gas, liquid, solid)

  • plasma: important role in our plasma universe

  • plasma: important for space weather
99% of the matter in universe is in the plasma state

- 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

Aurora: plasma interaction with molecules/atoms in the atmosphere
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.

**Manmade:** plasma TV, lamp, fluorescent tube, neon sign
Space Weather

- NSWP: Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of spaceborne and ground-based technological systems, as well as endanger life or health.

- ESA: “Space weather refers to the environmental conditions in Earth’s magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health”.

- ESA: Space weather deals with phenomena involving ambient plasma, magnetic fields, radiation, particle flows in space and how these phenomena may influence man made systems. In addition to the Sun, non-solar sources such as galactic cosmic rays can be considered as space weather since they alter space environment conditions near the Earth.
Main Causes of Space Weather

» Solar Activity and the Solar Wind (Flare, CME, SEP, coronal hole high speed streams)
  - driver

» Galactic Cosmic Rays - driver

» Meteoroids and Space Debris - driver

The sun is the main driver of space weather
Main Causes of Space Weather

- Solar Activity and the Solar Wind - *driver*
- Solar energetic particles and their entry into the magnetosphere - *driver/internal response*
- Galactic Cosmic Rays - *driver*
- Meteoroids and Space Debris - *driver*
- The Earth's Magnetosphere: Geomagnetic Storms (and Substorms) - *driver & internal response*
- Radiation Belts - *driver & internal response*
Different regions of Space Weather
Orientation/Scales

1 AU = 150 million km = 93 million miles
1 Rs = 695,500 km = 110 RE
1 RE = 6371 km
MESSENGER: 0.3 AU
1 Sun can fill a little more than 1 million Earth
ACE/SOHO at L1: 1/100 of the Sun–Earth distance
A movie on space weather

- http://missionscience.nasa.gov/sun/sunVideo_01spaceweather.html
• A movie on space weather
Space Weather Vocabulary
Why do we care?

Solar flares
These explosions on the sun's surface occur without warning and can launch huge amounts of X-rays, other radiation and particles into the ionosphere, the outer edge of Earth's atmosphere.

Coronal mass ejections
Those slow-moving "space hurricanes" occur when the sun ejects part of its outer atmosphere.

Solar winds
Streams of gas particles and magnetic clouds pour from the sun's surface in all directions.

92.5 million miles

Magnetic field lines

Diverted particles

Earth's magnetic field
Earth's atmosphere is least protective around the polar regions, so those areas are most easily disrupted by solar weather.

Vulnerable to space weather

Satellites and GPS devices
Radiation storms can befuddle satellites, delaying or garbling radio waves and mucking up sensitive electronic controls.

Oil pipelines
Aboveground pipelines can conduct stray currents and become corroded. Alaska's lines are vulnerable because they're so near the North Pole.

Aircraft communications
Transmissions that depend on low-frequency radio waves become unreliable, especially near the North Pole.

Water supply
Because water processing and distribution depend so heavily on electricity, a major loss of power would affect water delivery within days.

International space station
No humans are closer — therefore more vulnerable — to space radiation than residents of the space station.

Power grid
Power lines can conduct currents that develop in the ionosphere. The grid is so interconnected that a few blown transformers can cripple a large area.
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/ion radiation (SEP) <flare/CME>
- electron radiation <CIR HSS/CME>
- Radio blackout storm <flare>
- Geomagnetic storm
- CME storm (can be severe)
- CIR storm (moderate)
SWx impacts on spacecraft components

Major Space Environment Hazards

- False stars in star tracker CCDs
- Surface degradation from radiation
- Electronics degrade due to total radiation dose
- Solar array arc discharge
- Electromagnetic pulse from vehicle discharge (on surface, behind thin shielding, or deep inside)
- Spacecraft components become radioactive
- Single event effects in microelectronics
- Solar array power decrease due to radiation damage

Before

During exposure to multi-MeV protons

After

Induced Voltage

Time

THE AEROSPACE CORPORATION
SWx impacts on satellite tracking
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

<table>
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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)
- $1 \text{ K}$
- $100 \text{ K}$
- $10,000 \text{ K}$
- $10 \text{ Million K}$
2012 March 7 X5.4/X1.3 Flares

Solar Flare: sudden brightening on the sun's surface

Flares radiate throughout the electromagnetic spectrum

Most pronounced in x-ray and EUV
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
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
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
Both the CME(s) and flare(s) contribute to the SEP enhancement

SEP: proton radiation

GOES >10 MeV

13-100 MeV STEREO B

13-100 MeV STEREO A

GOES x-ray
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
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 – 1 hour after the event onset
Duration: a few days

CME effects arrives @ Earth: 1-2 days (35 hours here)
Geomagnetic storms: a couple of days
Extras
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
CME and SEP path are different

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

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: $3 \times 10^5$ km/s
SEPs: ion radiation storms
Potentially affect everywhere in the solar system

Courtesy: SVS@ NASA/GSFC
Geomagnetic storms due to CIRs are at most moderate.
1. SID (Sudden Ionospheric disturbance due to x-ray in solar flares 
dayside
2. Solar energetic particle precipitation - particularly protons 
   High-latitude
3. Geomagnetic storm disturbances 
   Ubiquitous/global

Communication/Navigation 
Problem
Solar radio bursts during December 2006 were sufficiently intense to be measurable with GPS receivers. The strongest event occurred on 6 December 2006 and affected the operation of many GPS receivers. This event exceeded 1,000,000 solar flux unit and was about 10 times larger than any previously reported event. The strength of the event was especially surprising since the solar radio bursts occurred near solar minimum. The strongest periods of solar radio burst activity lasted a few minutes to a few tens of minutes and, in some cases, exhibited large intensity differences between L1 (1575.42 MHz) and L2 (1227.60 MHz). Civilian dual frequency GPS receivers were the most severely affected, and these events suggest that continuous, precise positioning services should account for solar radio bursts in their operational plans. This investigation raises the possibility of even more intense solar radio bursts during the next solar maximum that will significantly impact the operation of GPS receivers.

Cerruti et al., 2008, Space Weather
Ionosphere Irregularities

- plasma bubbles: typical east–west dimensions of several hundred kilometers contain irregularities with scale-lengths ranging from tens of kilometers to tens of centimeters (Woodman and Tsunoda). Basu et al. (1978) showed that between sunset and midnight, 3-m scale irregularities that cause radar backscatter at 50 MHz, co-exist with sub-kilometer scale irregularities that cause VHF and L-band scintillations. After midnight, however, the radar backscatter and L-band scintillations decay but VHF scintillations caused by km-scale irregularities persist for several hours.