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Space Weather Impacts on Aerospace and Modern Society

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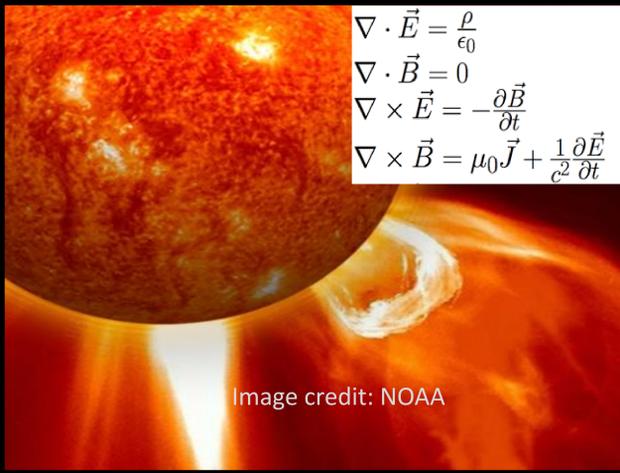


Image credit: NOAA

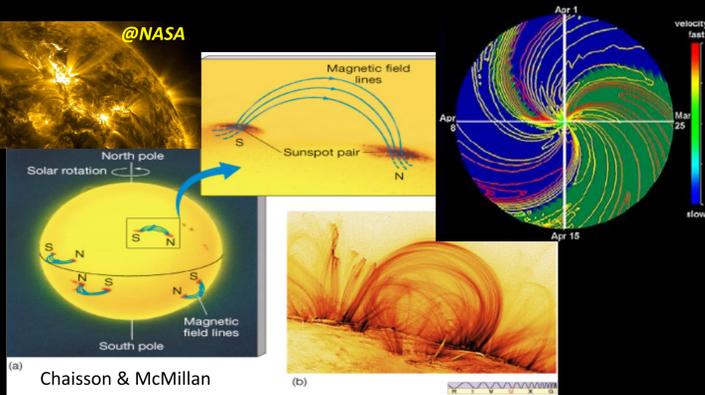
Space Weather = Series of physical processes starting in the sun, resulting in violent energy release into the heliosphere in forms of radiation, energetic particles and high speed streams and subsequently affecting the current systems and infrastructure in geospace: magnetosphere, ionosphere and upper atmosphere, as well as in ground. Space weather can generate geomagnetic storms which can lead to Induced currents and high energy particles that can harm satellites, aeroplanes, power grids, pipelines, GPS receivers, communication systems, time stamping of financial transactions etc.

On 29th of October 2015, National Space Weather Strategy and Action Plan was released.

On 13th of October 2016, President's Executive Order -- Coordinating Efforts to Prepare the Nation for Space Weather Events.

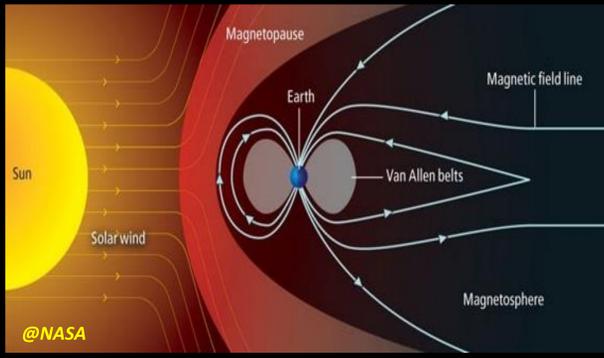
Magnetic Field of the Sun

- Sun spots are localized regions of strong magnetic flux.
- They appear in pairs of opposite polarity.
- Origin of Sun's magnetic field is not fully understood.



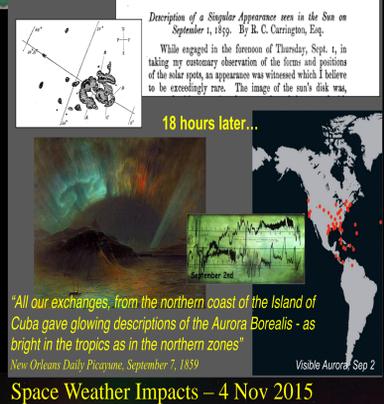
Magnetic Field of the Earth

- Earth's magnetic field is similar to field of a bar-magnet, dominated by dipolar field.
- Solar Wind interaction with the Earth's field generates, an elongated structure, the magnetosphere.



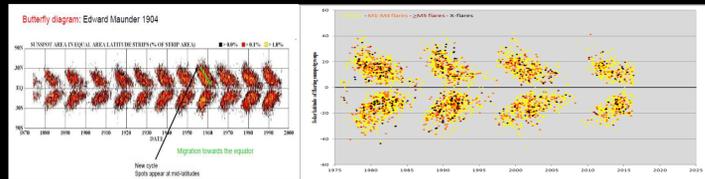
Extreme Space Weather

- 1859 'Carrington' event produced visible aurora even in Cuba!!
- In 1989 geomagnetic storm Knocked out power across large sections of Quebec.
- In 2012 a "Carrington-class" Solar Superstorm (Solar flare, CME, Solar EMP) was observed; its trajectory missed Earth in orbit.
- In 2015 Geomagnetic storm Stops airtraffic in Sweden.
- In 2013, Lloyd's of London and AER estimated the current cost of a Carrington event to the U.S. alone at ~ **\$1-2.6 trillion**



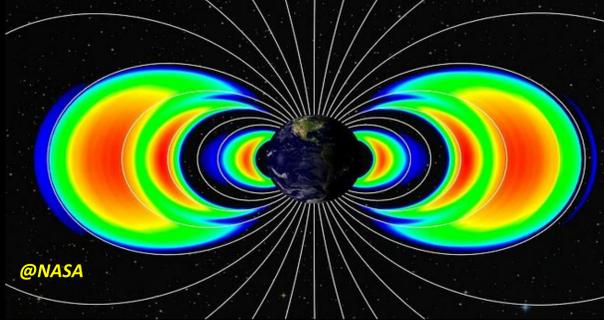
Solar Activity and Solar Cycle

- Maximum activity correlates with # of sunspots.
- Time between two maximums is ~ 11 years.



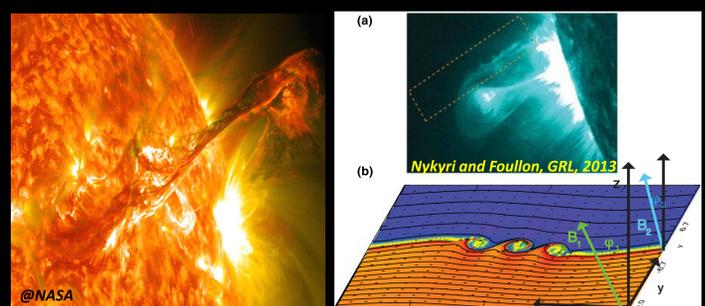
Earth's Radiation Belts

- The outer belt consists mainly of high energy (0.1-10 MeV) electrons, the inner belt mainly of protons above 100 MeV

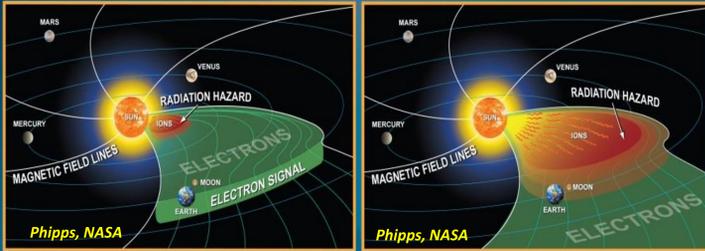


Solar Structures Driving the Space Weather

- Prominences, Flares, Coronal Mass Ejection (CME or Ejecta), Solar Energetic Particles (SEPs), high speed streams, Stream Interaction Regions (SIRs), ICMEs and ICME sheaths.

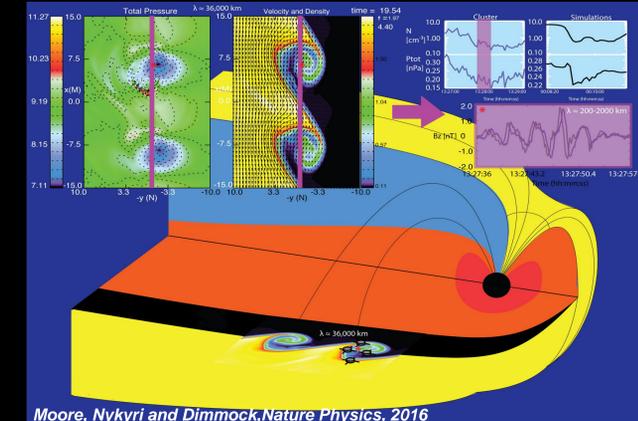


- Ions from solar activity arrive about 10 minutes later than electrons

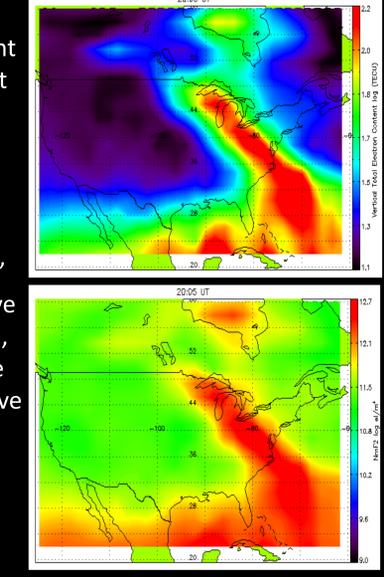


Space Hurricanes aka Kelvin-Helmholtz waves

- Large (18,000-55,000 km in wave length) waves that can provide seed population for radiation belt electrons.
- Can also directly heat plasma via magnetosonic waves.
- Kelvin-Helmholtz Waves can generate ULF range Pc5 waves that can accelerate radiation belt electrons.

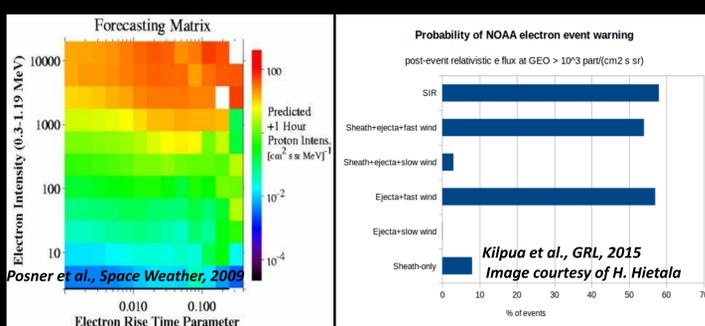


Intense plume of enhanced ionospheric total electron content (TEC) over the continental USA at the maximum phase of the November 20, 2003 magnetic storm (20:05 UT), F-region electron density (NmF2). The plume feature is called "Storm Enhanced Density" (SED). When it occurs, it can have significant impacts on navigation, communication and surveillance systems. When present, SEDs have caused **complete outage of the FAA's WAAS** that is designed to facilitate aircraft landings with a higher cadence due to improved navigation capabilities.



Space Weather Prediction

- When electrons arrive, 10 minute warning for arrival of SEPs
- The electron flux variations at radiation belts are determined by the combined effect of the structured solar wind driver and prestorm electron flux levels.
- Post event analysis indicates that SIRs, Ejecta+Fast Wind, Sheath+Ejecta+Fast Wind most effective in creating NOAA electron event warning. **BUT 10 min is not ENOUGH!!!!!!!**



Space Weather Can Be Harmful

- Strong and rapid variations in magnetic field can induce electric fields and produce currents
- The induced currents can take down power grids etc.
- High energy particles and radiation the biggest obstacle for manned missions to Mars.
- GPS technology unreliable due to enhanced TEC.



Next Gen. Space Weather Prediction Mission

- More Warning time needed! Need to develop next gen. space weather models using multi-point, multi-scale measurements in L1.
- Cube sats. will be build in ERAU research park. Carrier Spacecraft using industrial partnerships.
- Using these measurements, new space weather models can be created to be able to predict the solar wind structure and magnetic field orientation at the Earth's Bow Shock nose.

