Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

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Automation Framework for XGEO Space Environment Resiliency

Initial Space Weather Information Set for Autonomous Spacecraft

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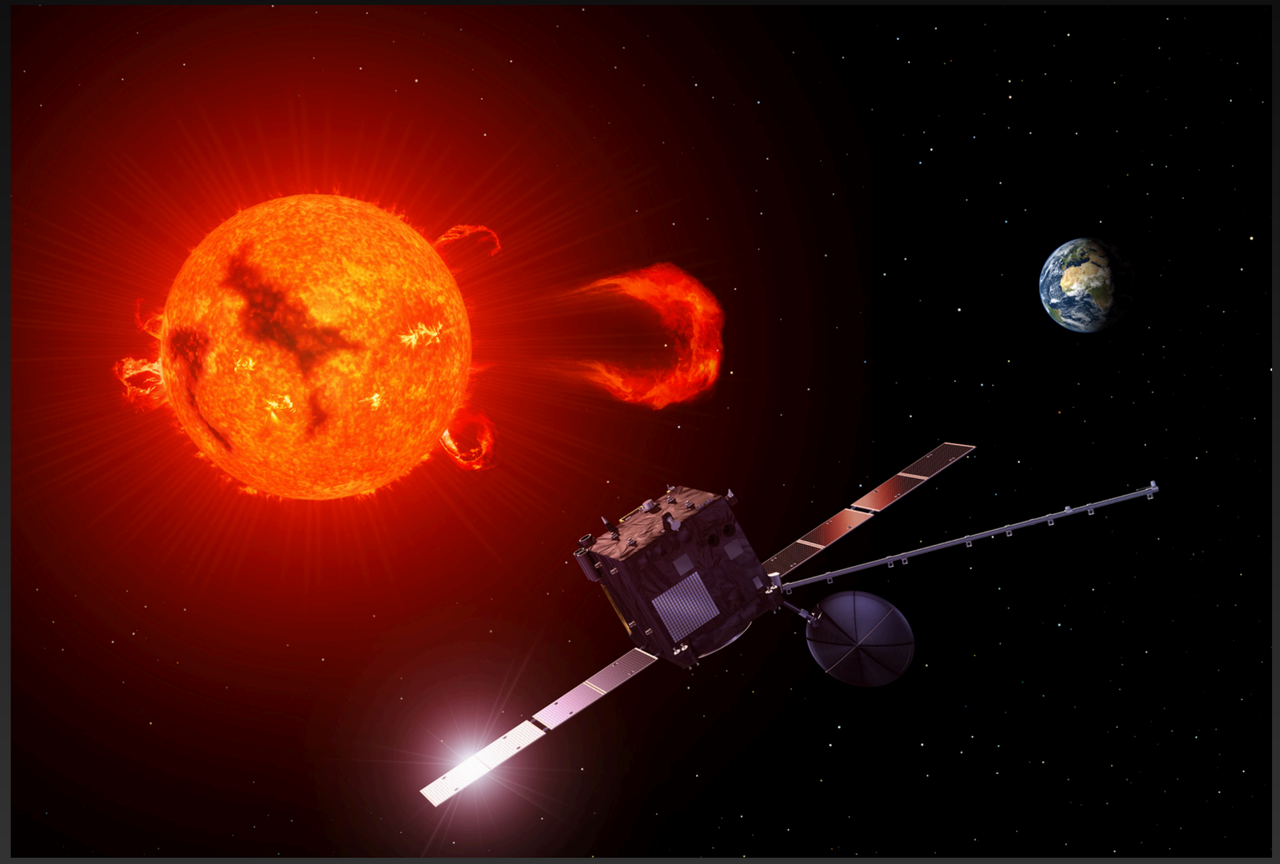


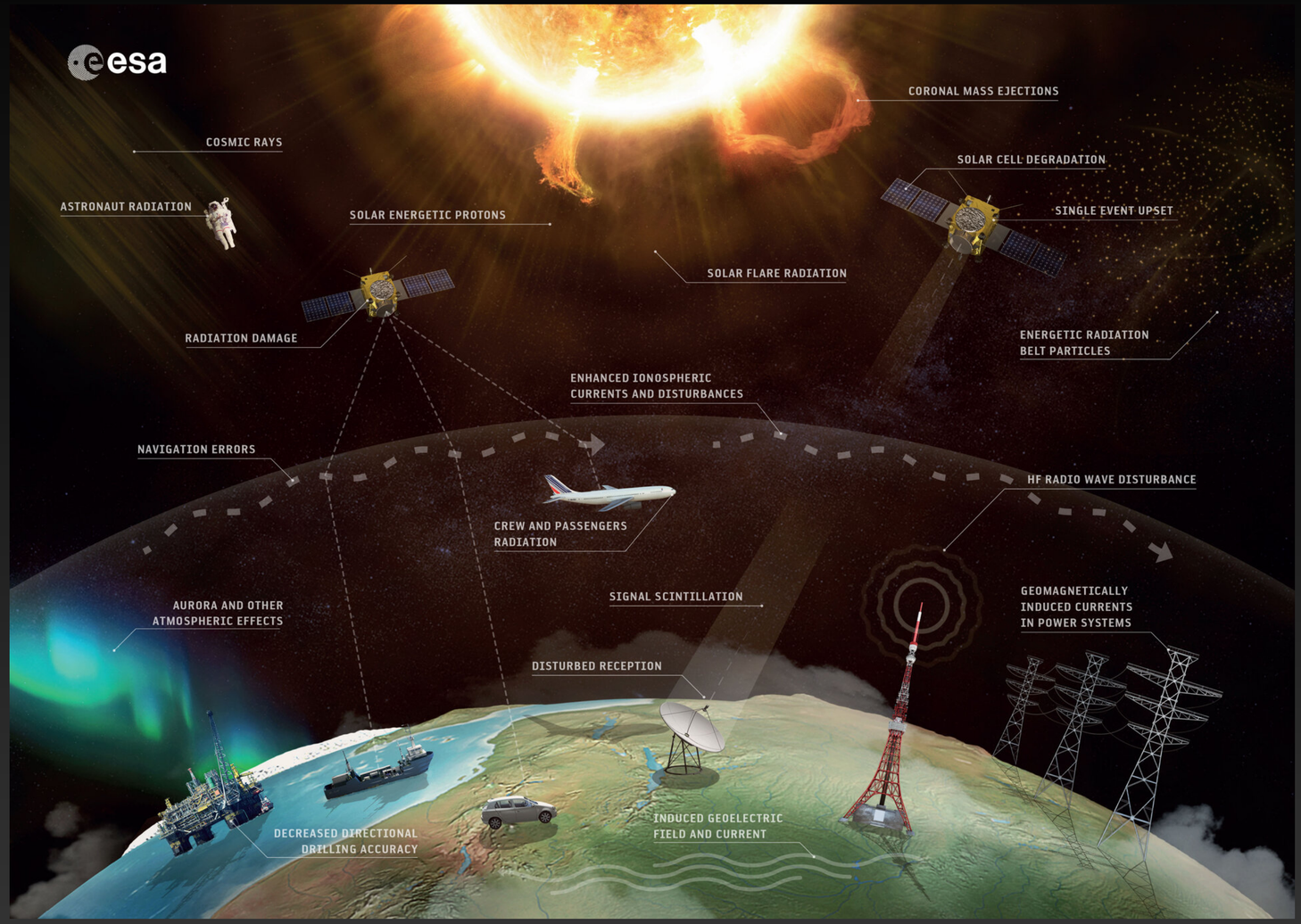
In collaboration with

Prof. Christopher Petersen
Department of Mechanical and Aerospace Engineering, UF

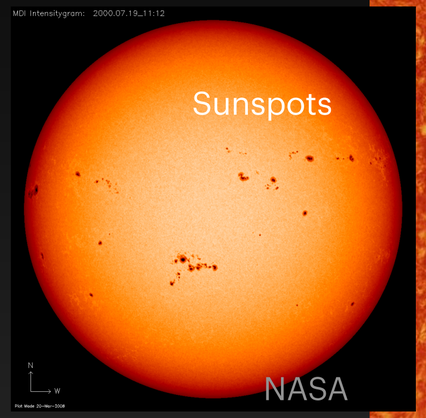
AFOSR Center of Excellence for Assured Autonomy in Contested Environments

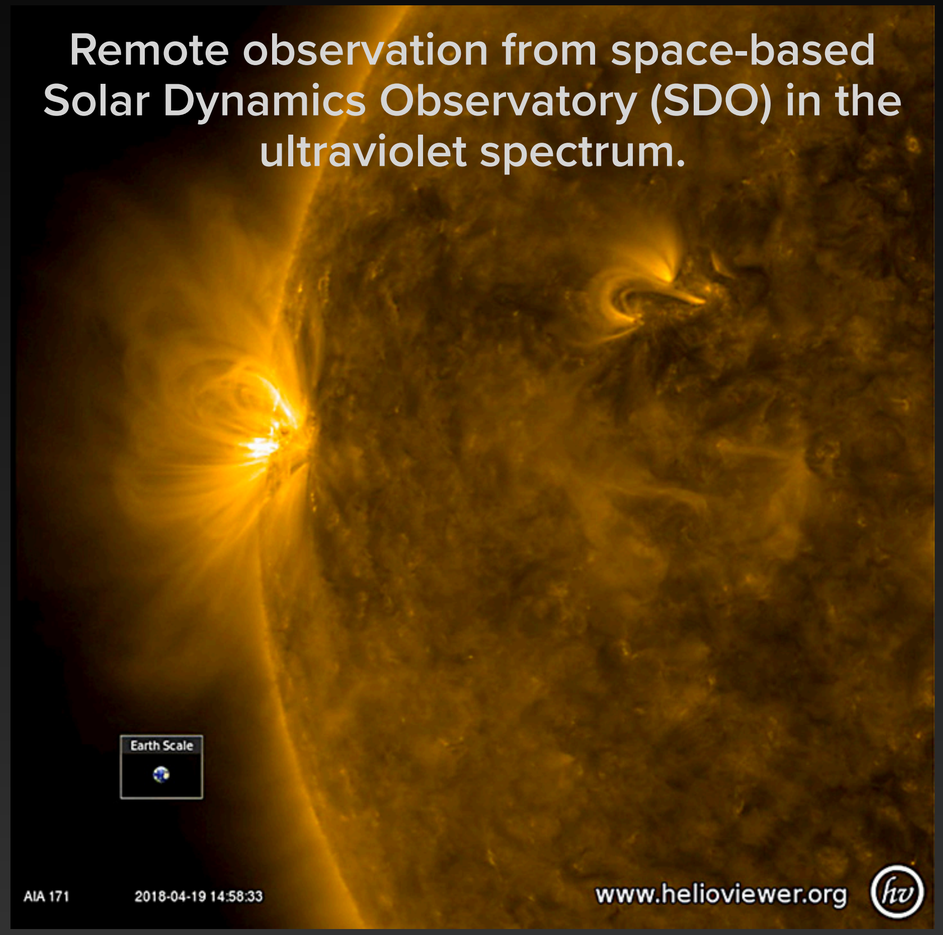
Effects of Space Weather at Earth

- Aurora Borealis & Aurora Australis
- Damage to Spacecraft Hardware and Electronics
- Geomagnetic Storms
  - Dramatic Changes to Currents, Electric Fields and Earth's Magnetic Fields in Earth's Space Environment
  - Increases Ionization in Earth's Ionosphere
  - Increases Density, Especially in LEO
    - Increases Satellite Drag
  - Influx of High Energy Protons and Electrons
  - Influx of Radiation Belt Particles
  - Influx of heavy ions (C, O, Fe, etc.)
- Damage to the Power Infrastructure on the Ground
- Satellite, Radio & HF Communications Interference
  - Greatly impact error in GNSS signals and timing
- Increased Harmful Ionizing Radiation in Polar Regions
  - Affects Polar Aeronautical Flights
  - Harms Astronauts in LEO onboard the ISS



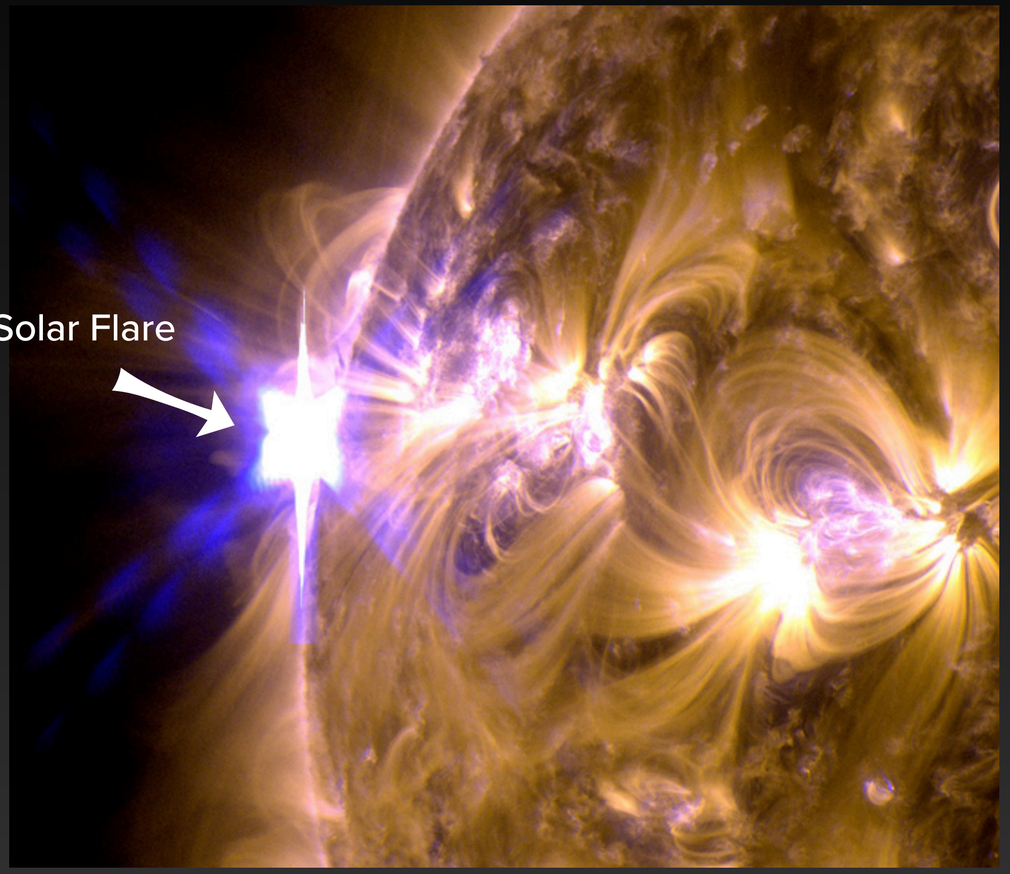
Space Weather drivers such as solar flares, solar energetic particles (SEPs) and coronal mass ejections (CMEs) originate in active regions on the solar surface.

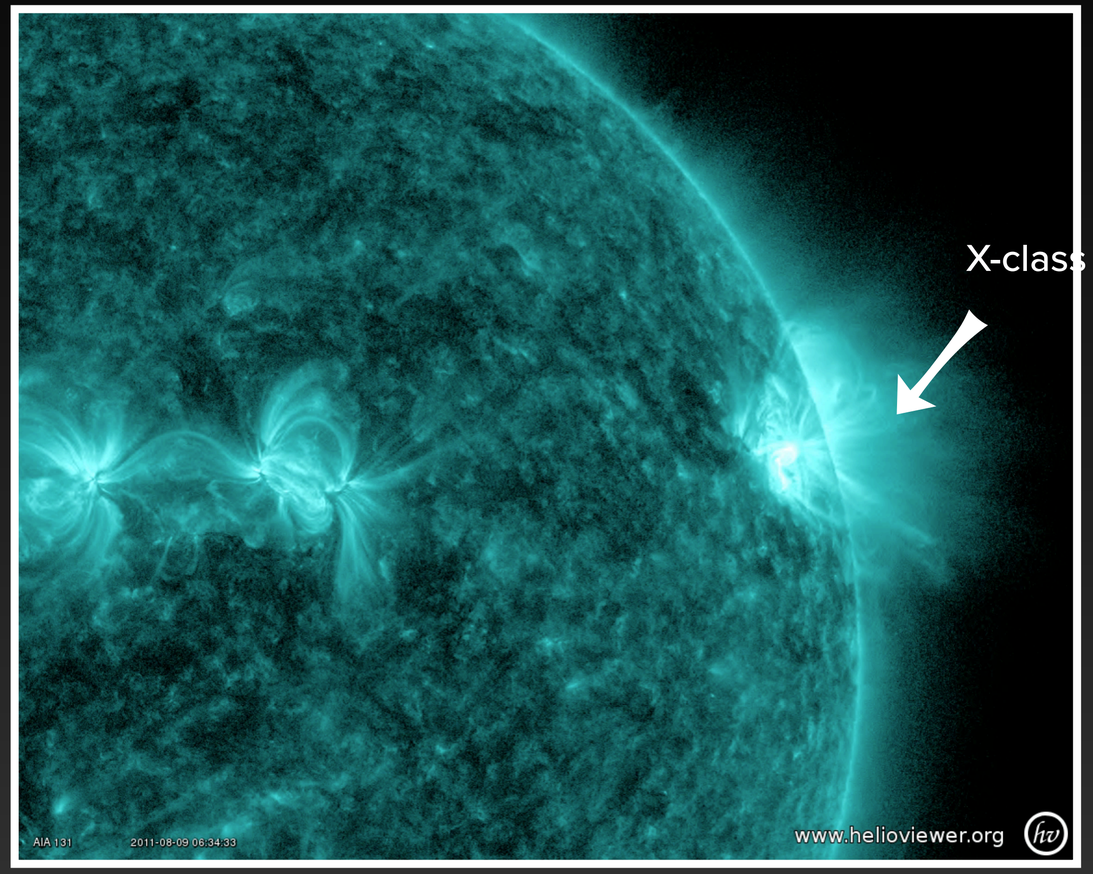




[Andrew McCarthy, @Cosmic_Background]

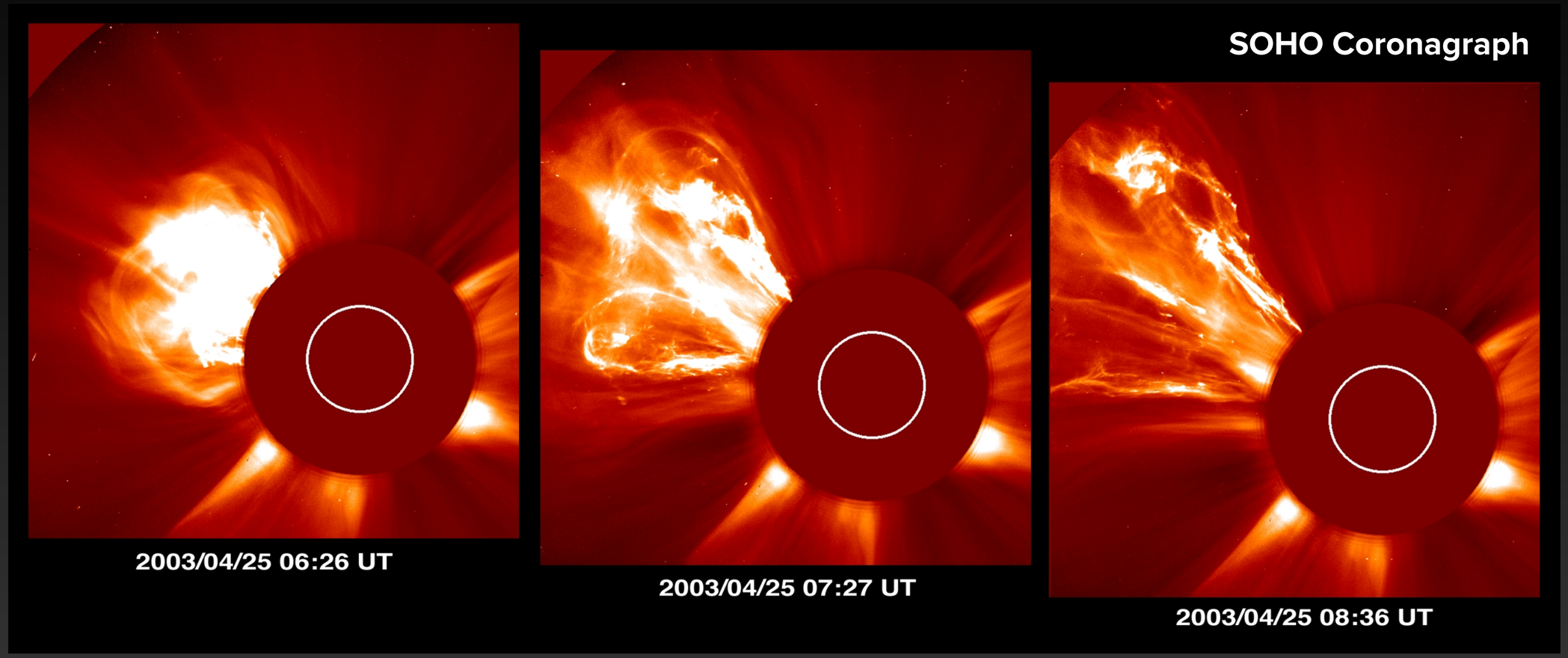
Solar Flares are bursts of visible light and x-rays.



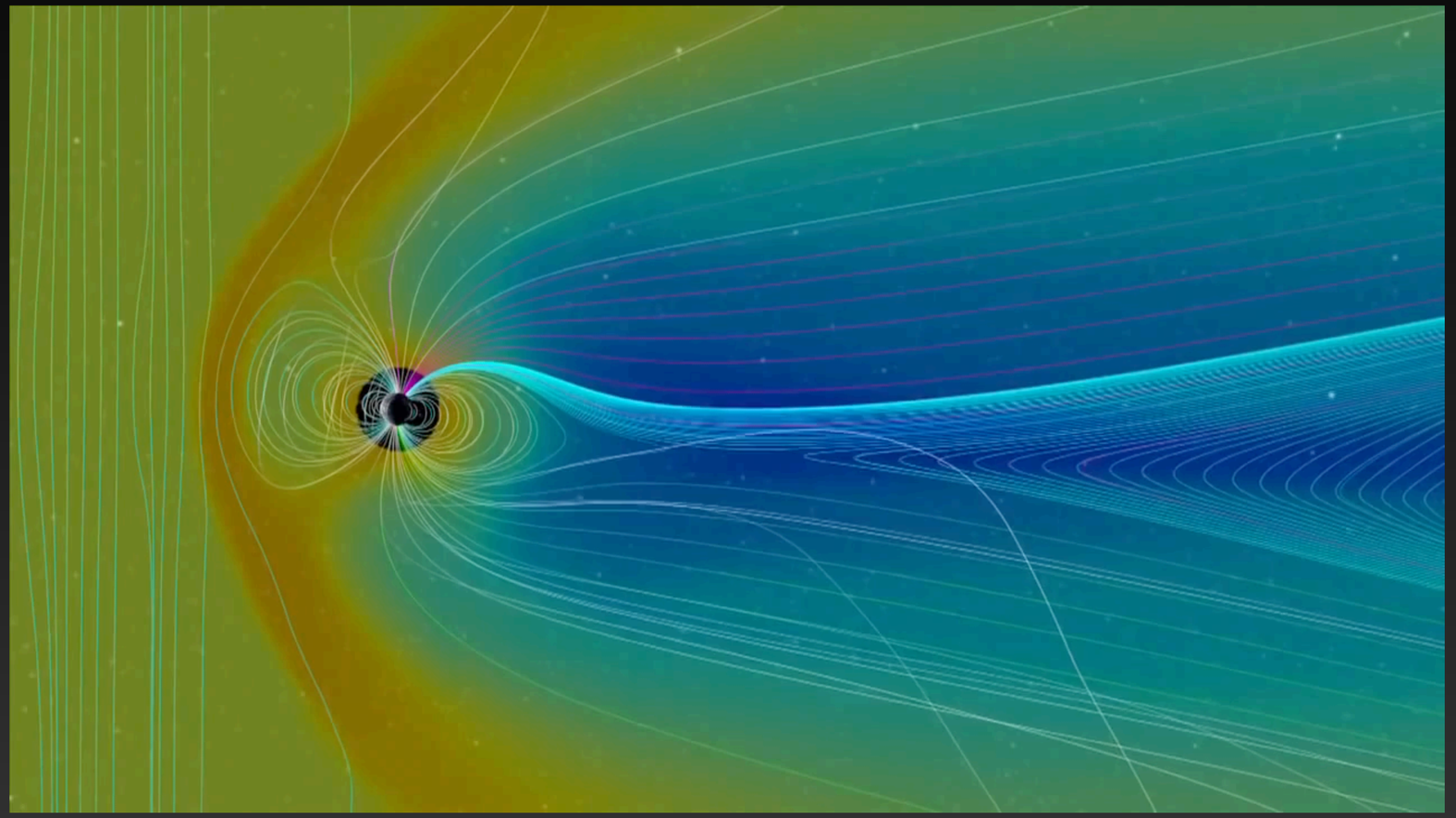


[Remote observations taken by AIA on NASA's SDO Spacecraft]

Eruption of a Coronal Mass Ejection



When ICMEs reach Earth they can interact with Earth's magnetosphere and induce geomagnetic storms.



[Space Weather Modeling Framework Simulation Results]

The Halloween Storms

Between October 19th, 2003 and November 7th, 2003, extreme space weather events from three solar active regions caused damage to more than half those in orbit at the time. [1]

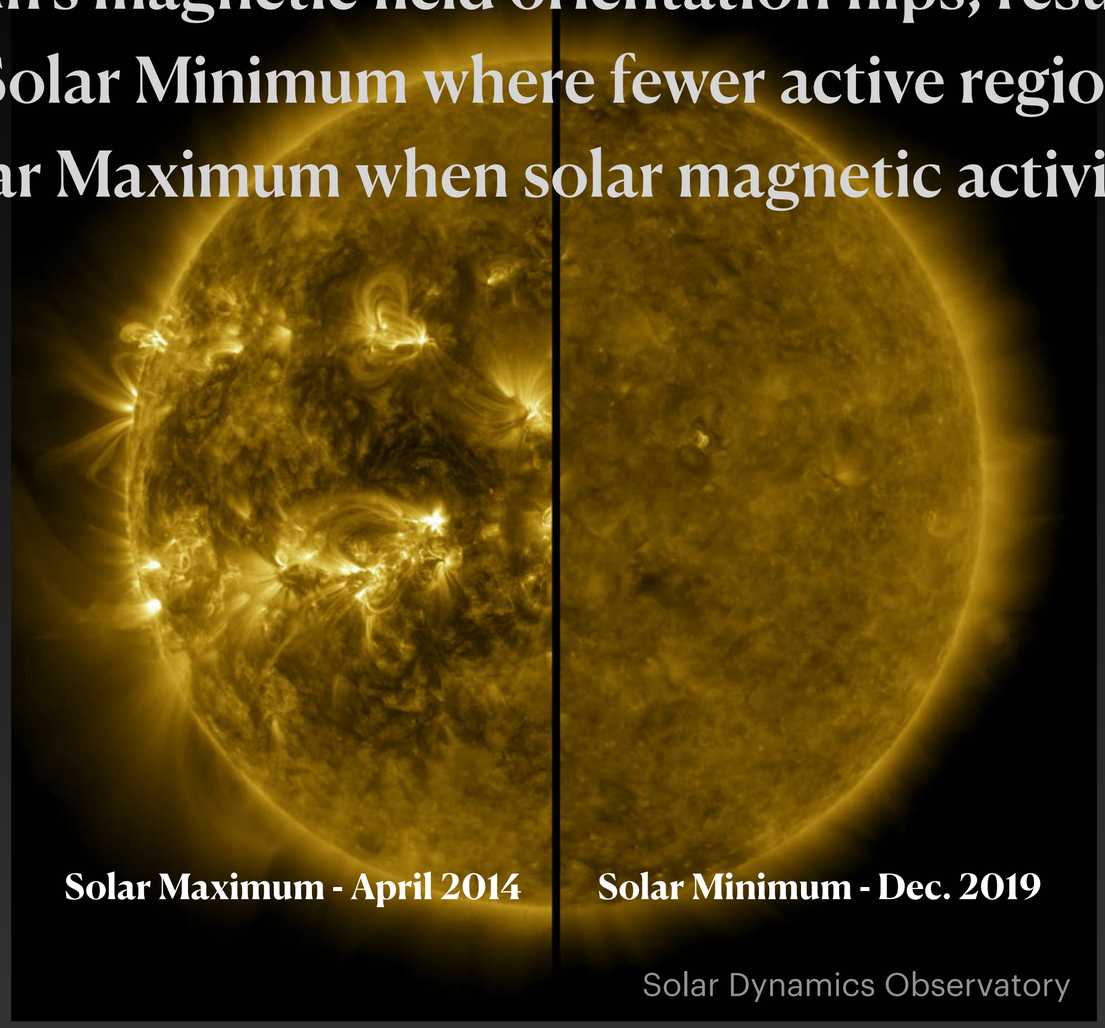
- The events peaked on 28-29Oct2003.
- A CME traveling at 2125 km/s (almost 5 million mph), took only 19 hours to impact Earth causing a level G5 geomagnetic storm. [2]
- Included the strongest solar flare ever recorded, an X45-class flare, on 04Nov2003. Prior records were X20-class on 01April2001 and 16Aug1989. [3]
  - It overloaded the sensor maxing out at X28. Determined actual severity by measuring its impact on the ionosphere.
  - This particular flare was thankfully not aimed directly at Earth.

Aurora Observation in Houston, Texas on October 29th, 2003

[Photo Credit: Christie Ponder]

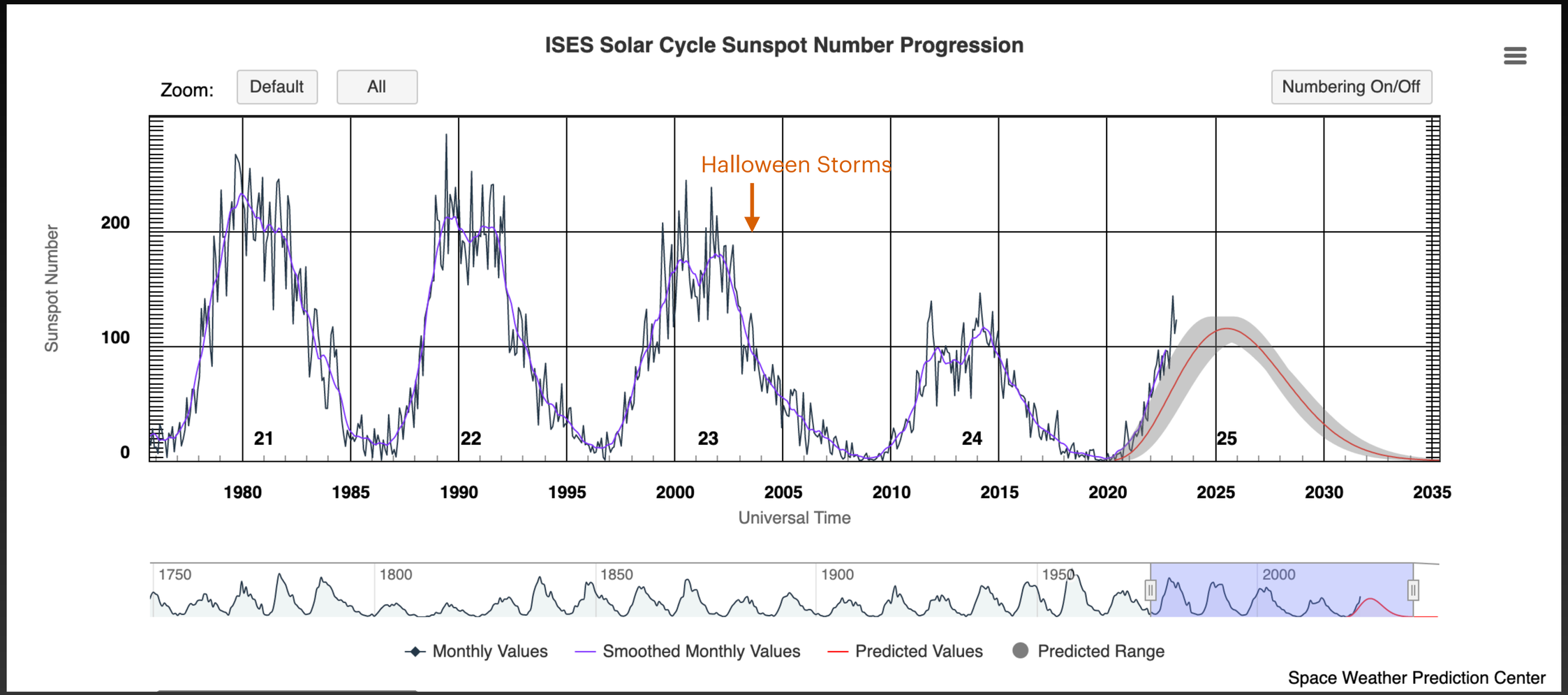
Solar Maximum vs Solar Minimum

Every 11 years, the Sun's magnetic field orientation flips, resulting in a Solar Cycle which varies from Solar Minimum where fewer active regions exist on the Sun, through Solar Maximum when solar magnetic activity is highest.



https://www.nasa.gov/press-release/solar-cycle-25-is-here-nasa-noaa-scientists-explain-what-that-means

Even as the number of spacecraft in orbit about Earth has exponentially increased, the most recent Solar Cycles have lulled many into a false sense of security.



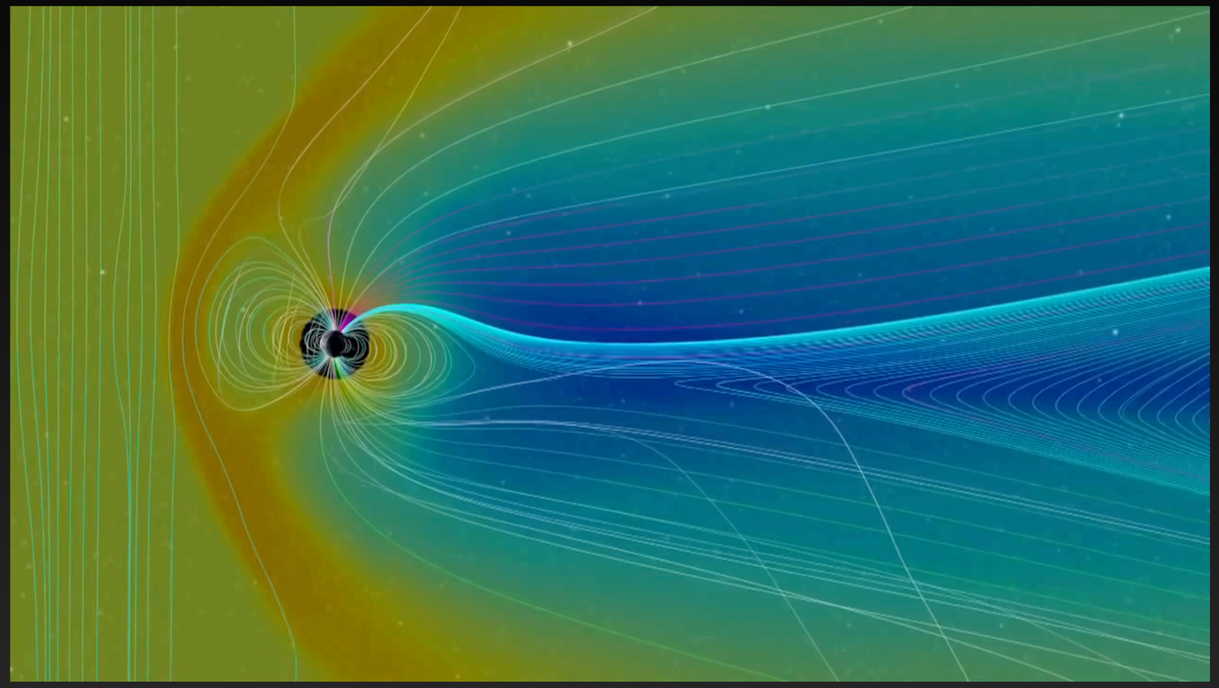
[https://www.swpc.noaa.gov/products/solar-cycle-progression]

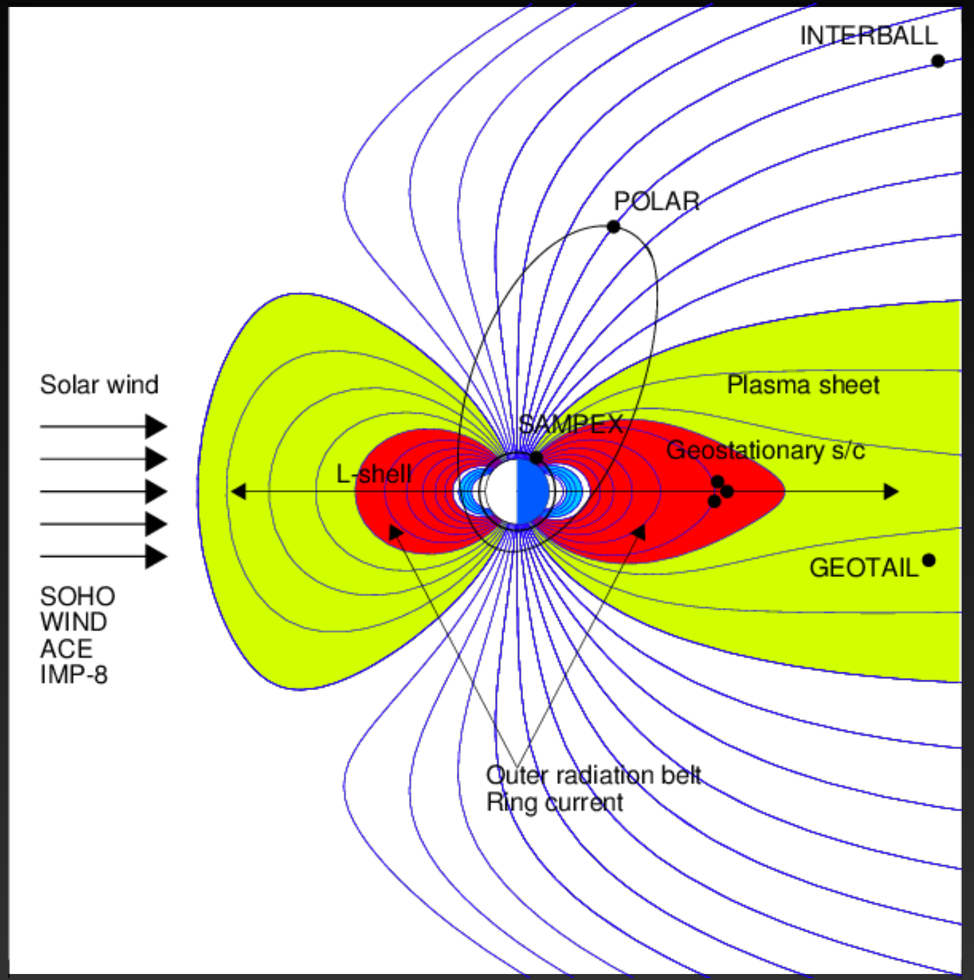
How Vulnerable Are We?

As of January 2022, the U.N. Office for Outer Space Affairs (UNOOSA) numbered the currently orbiting satellites as 8,261 of which only 4,852 are active. [4,5]

- As the space domain becomes increasingly congested, and a more severe solar cycle might wait for us in the future, are we prepared?
  - Twenty years after the last severe solar cycle and the Halloween Storms:
    - How many of our controls engineers and spaceflight industries are aware of possible responses to space weather forecasts or how to identify space weather caused spacecraft failures?
    - Greater and greater percentages of spacecraft in orbit are small sats and highly susceptible to space weather.
- As we increase missions that extend into regimes beyond LEO & GEO, i.e. XGEO & cislunar, what other considerations beyond the realm of the Earth orbital regime do we need to be considering?
  - Communication, timing and control differences
  - Different radiation environment - Outside Earth's magnetosphere
  - Targeted space weather forecasts - Currently for either Earth, Mars or specific NASA missions

XGEO - Outside the Earth's Magnetosphere





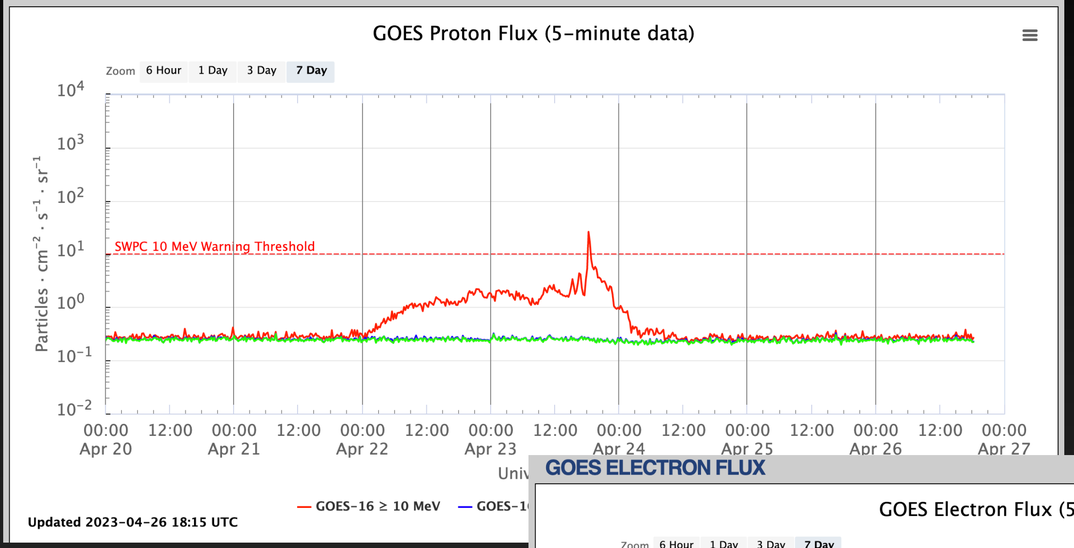
Where your spacecraft is located, changes the environment in consideration and the corresponding space weather concerns.

[Space Weather Modeling Framework Simulation Results]

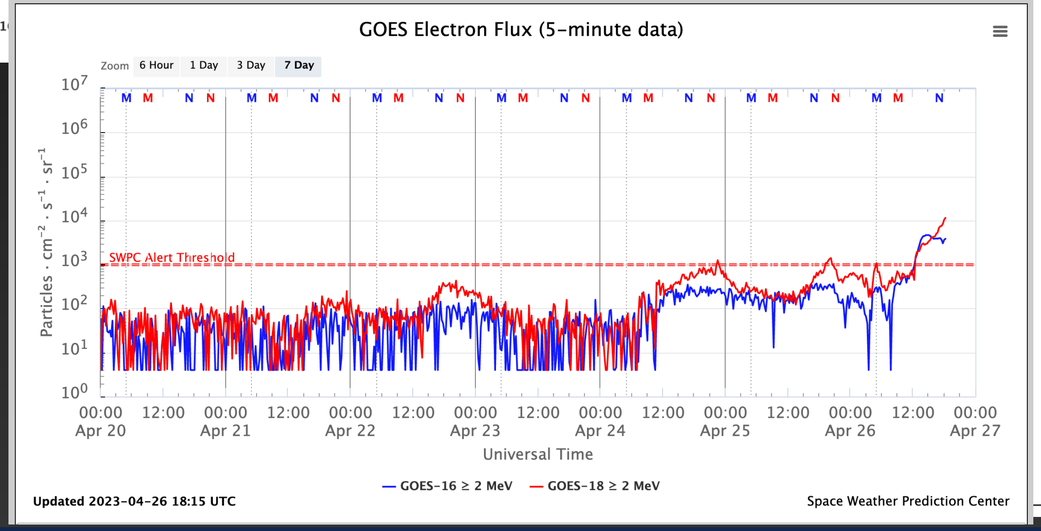
[Tuija Pulkkinen, University of Michigan]

Forecasting the Impacts of Space Weather

GOES PROTON FLUX



GOES ELECTRON FLUX



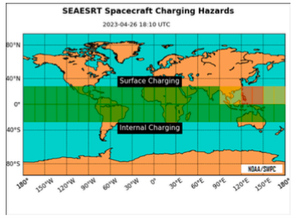
CURRENT SPACE WEATHER CONDITIONS on NOAA Scales

R none S none G none

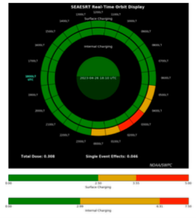
Solar Wind Speed: **547** km/sec Solar Wind Magnetic Fields: Bt **9** nT, Bz **-5** nT Noon 10.7cm Radio Flux: **131** sfu

SATELLITES COMMUNITY DASHBOARD

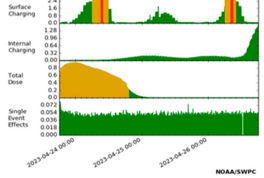
SEAESRT SPACECRAFT CHARGING HAZARDS



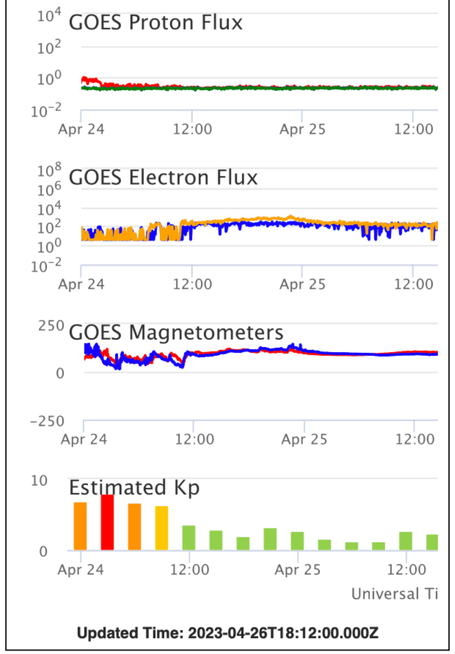
SEAESRT SPACE ENVIRONMENT



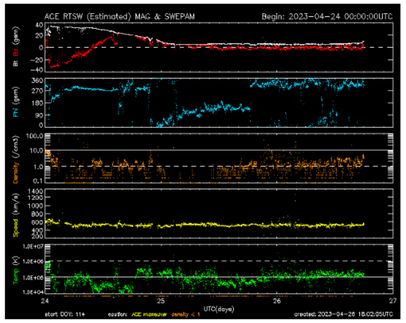
SEAESRT HAZARD QUOTIENTS



GOES ENERGETIC PARTICLES



SOLAR WIND

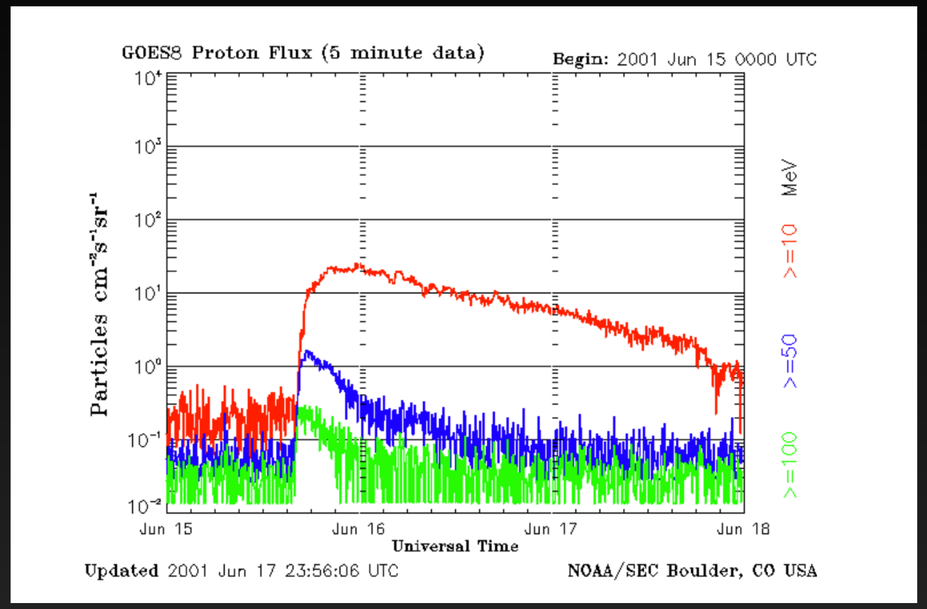


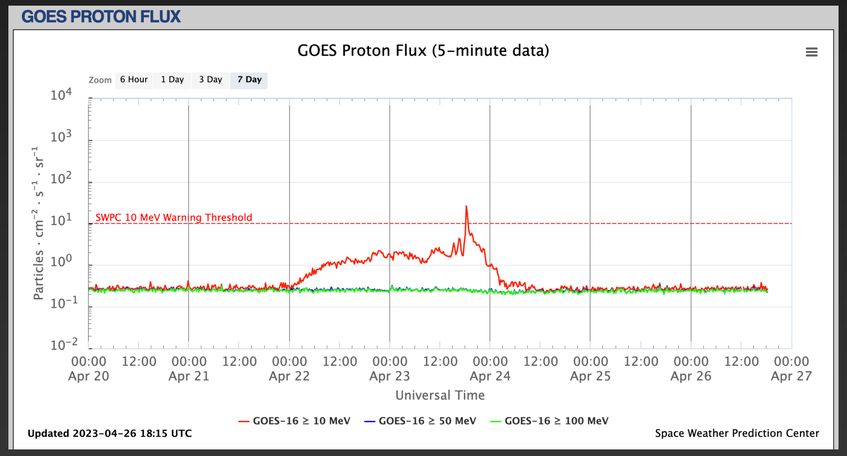
[https://www.swpc.noaa.gov/]

How do you actively mitigate the impacts on a spacecraft?

1. Identify the potential event or impact.
   - Focus on those events you are most concerned about.
     - Based on location, spacecraft features, mission, current task, etc.
     - What are you most vulnerable to?
       - XGEO - Solar Energetic Particles, Coronal Mass Ejections, Galactic Cosmic Rays,
   - Focus on those specific events you can respond to.
     - Solar flares have very little warning time. Galactic cosmic rays cannot be individually predicted.
     - Solar Energetic Particle rise times indicate overall event features which can be forecasted once the event begins.
2. What do you need to know in order to determine your best response?
   - Length of the event.
   - Strength of the event.
   - Confidence of event identification.
   - Overall predicted impact.
3. What is your best response?
   - Safe modes particular to the anticipated impact.

Active Impact Mitigation: Onboard SEP Detection





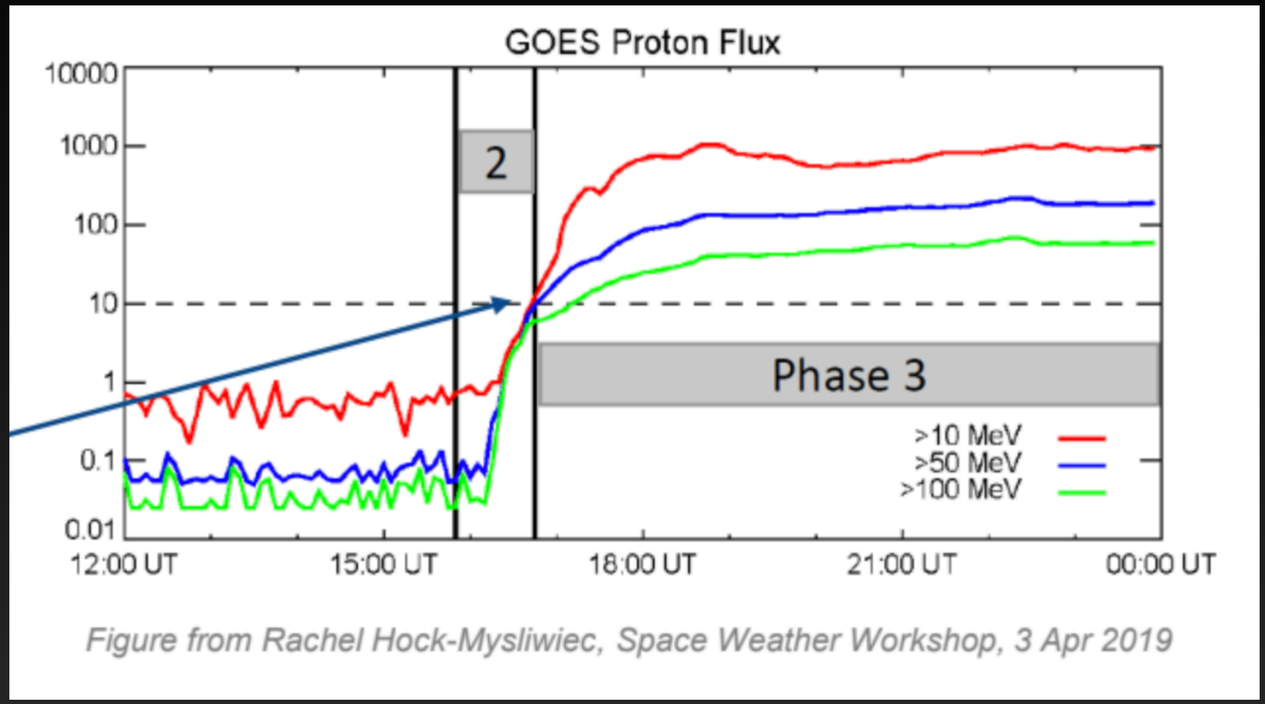


Figure from Rachel Hock-Mysliwiec, Space Weather Workshop, 3 Apr 2019

ADEPT = SEP Real-Time Forecast Tool Developed by Stephen White and others at AFRL RVBXD

Initial Space Weather Information Set for Autonomous Spacecraft

Thank You!

Any Questions?

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