

What is “Space Weather”?



Dr. Thomas Berger

University of Colorado at Boulder

Space Weather Technology, Research, and Education Center

SmallSat Conference Side Meeting

August 4th, 2020



Grand Challenge

UNIVERSITY OF COLORADO BOULDER

SPACE WEATHER CENTER



Definition of “Space Weather”

For the purposes of this conference, Space Weather is **defined as** the variation in

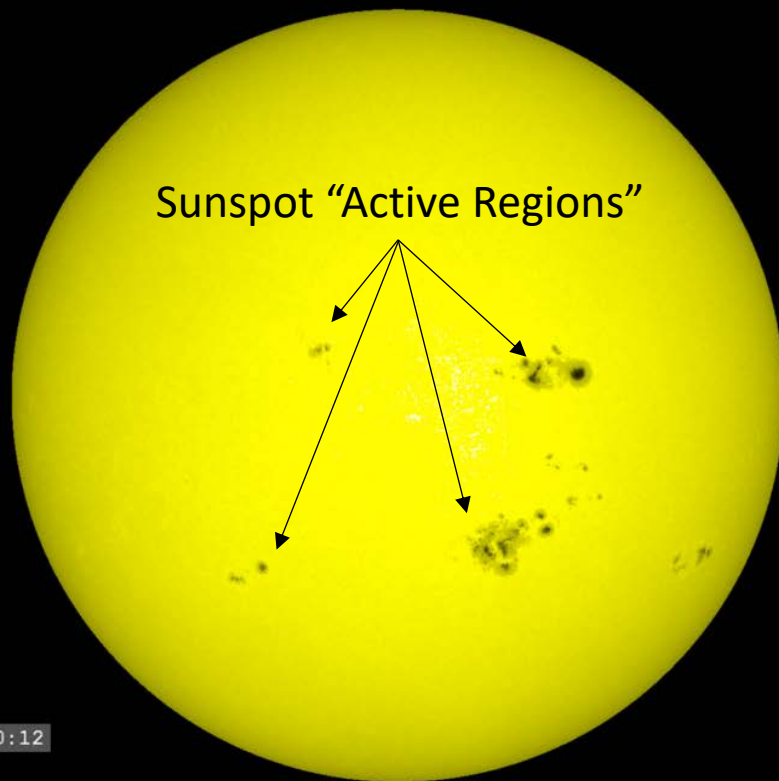
- Photon radiation
- Charged particle radiation
- Magnetic fields
- Plasma density
- and Upper atmospheric composition

in near-Earth space, i.e., in all orbits from LEO to GEO and cislunar.

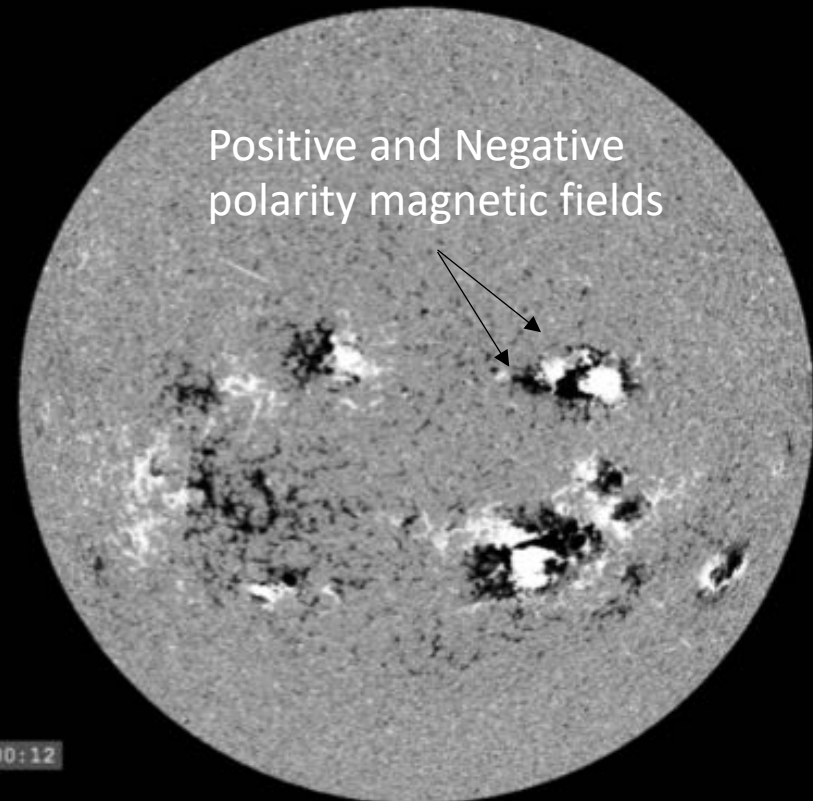
Space Weather is **caused by**

- Interaction of the Earth’s magnetic field and atmosphere with outputs from the **Sun**
- Propagation of disturbances from the **lower atmosphere**

The Sun is a Magnetic Star



"White Light" Image

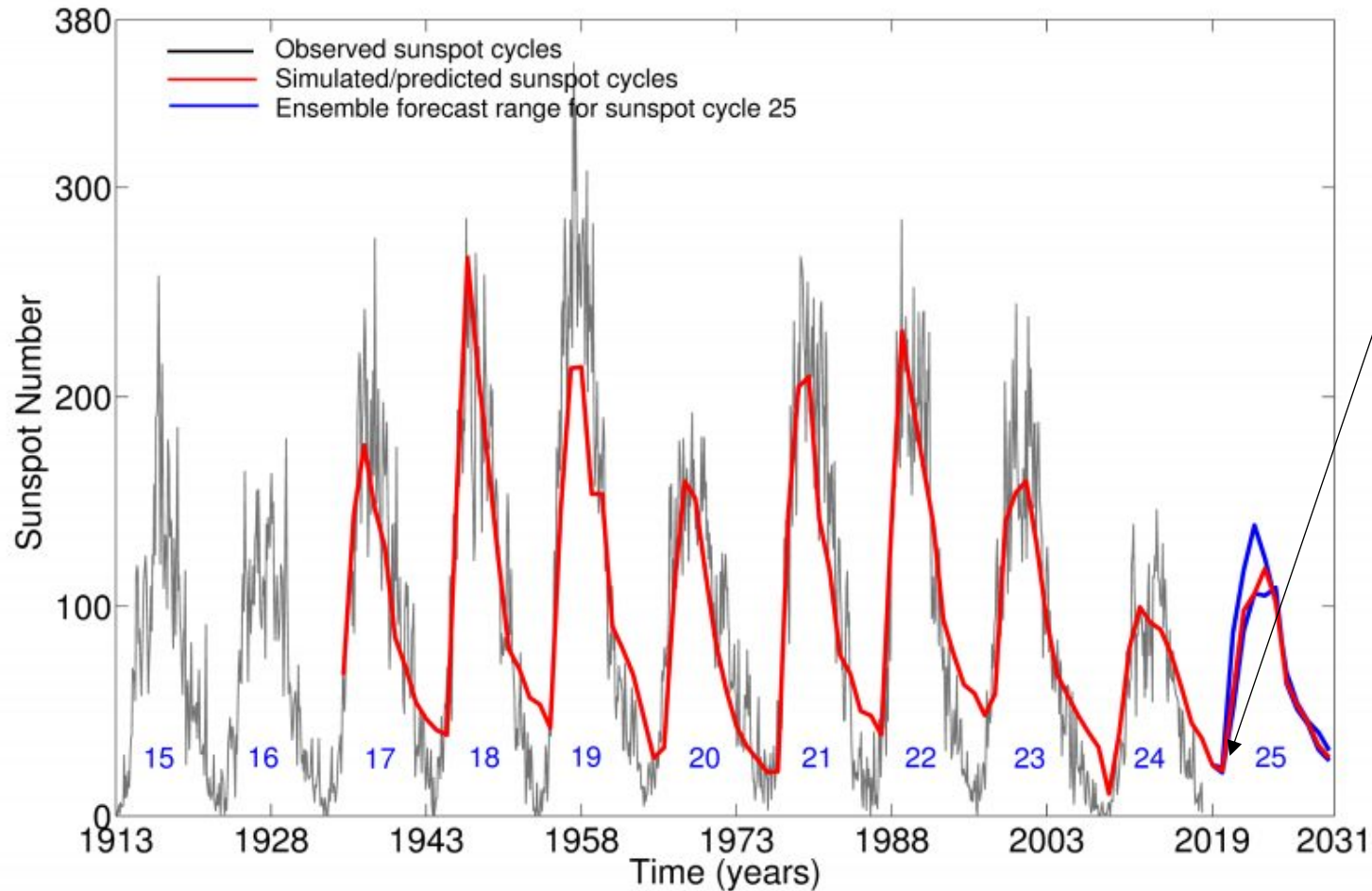


"Magnetogram"

- Magnetic "reconnection" occurs where strong opposite polarity fields are adjacent.
- Reconnection causes magnetic eruption activity.

The “Solar Magnetic Cycle”

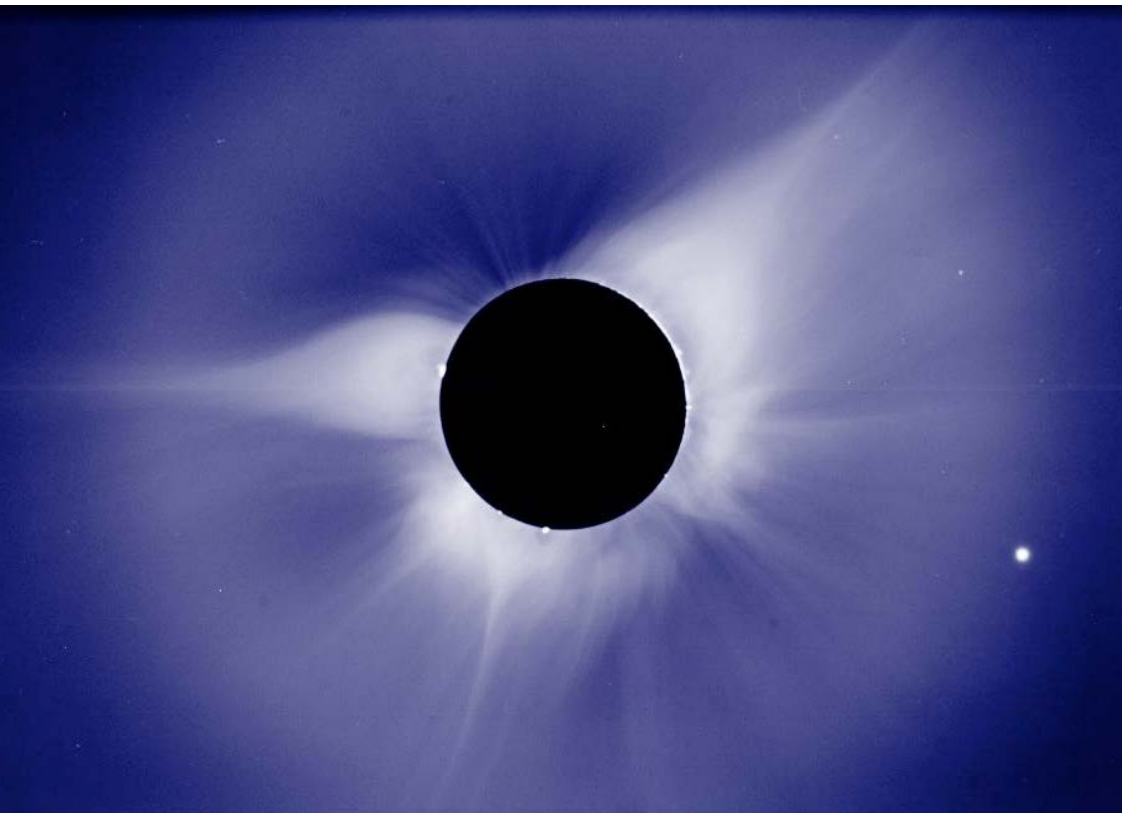
Every 11 ± 1 years, the number of sunspots on the Sun peaks



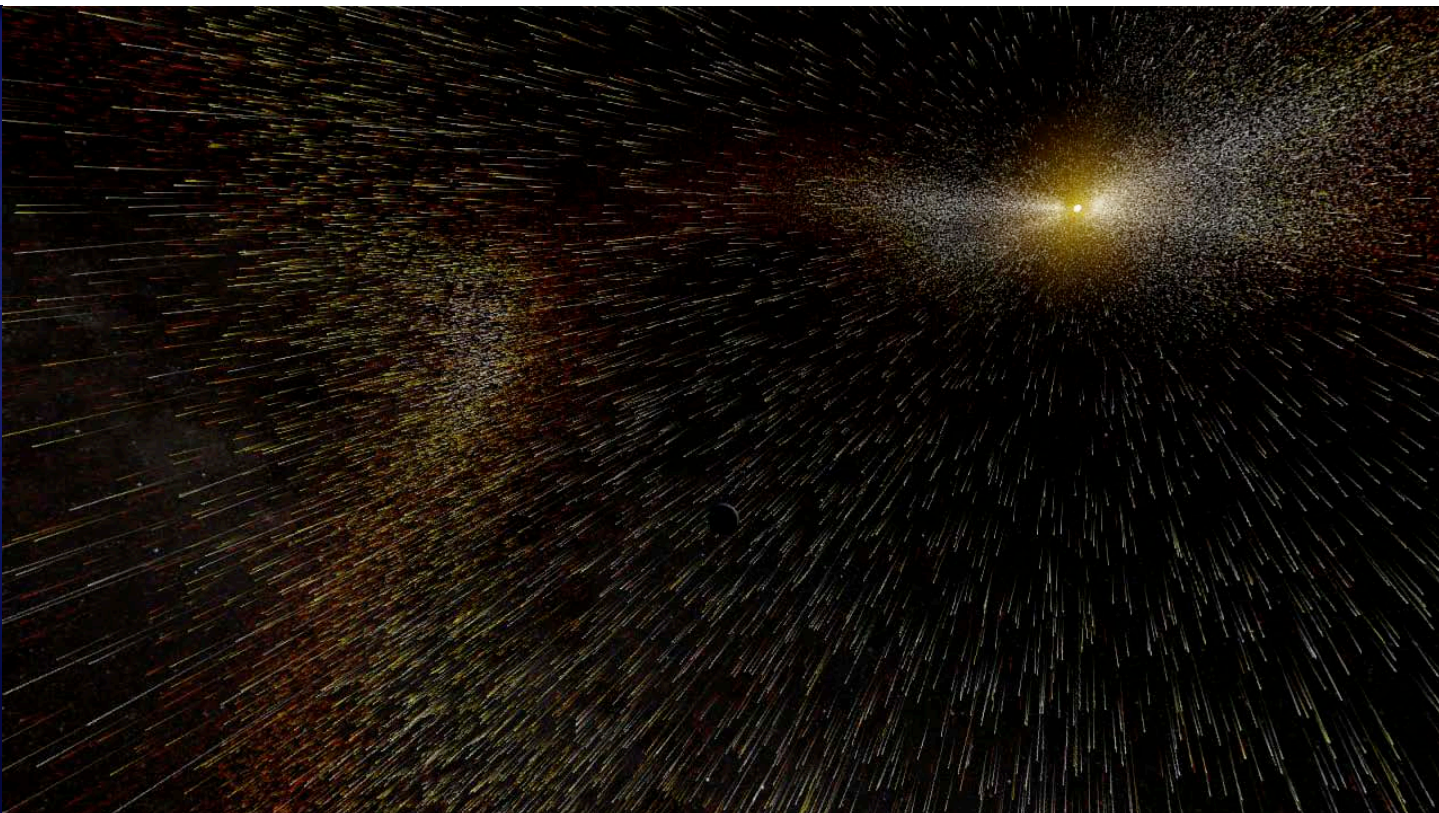
We are here:
very little sunspot activity
Occasional solar wind disturbances
1st sunspots of Cycle 25 have arrived in the last few months

Bhowmik, P., Nandy, D. Prediction of the strength and timing of sunspot cycle 25 reveal decadal-scale space environmental conditions. *Nat Commun* 9, 5209 (2018). <https://doi.org/10.1038/s41467-018-07690-0>

The Solar Magnetic Field heats the Corona to 10^6 K and drives the Solar Wind

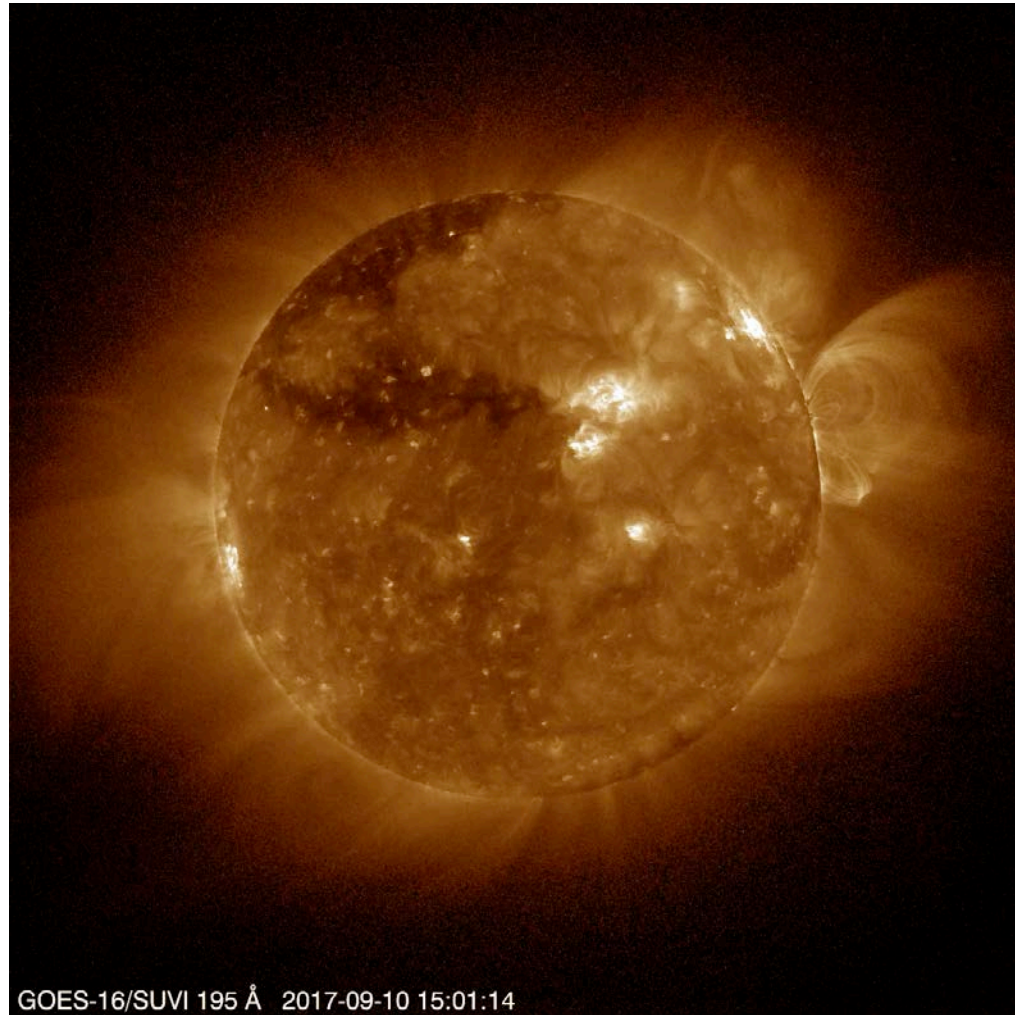


Solar corona visible during
Solar Eclipse

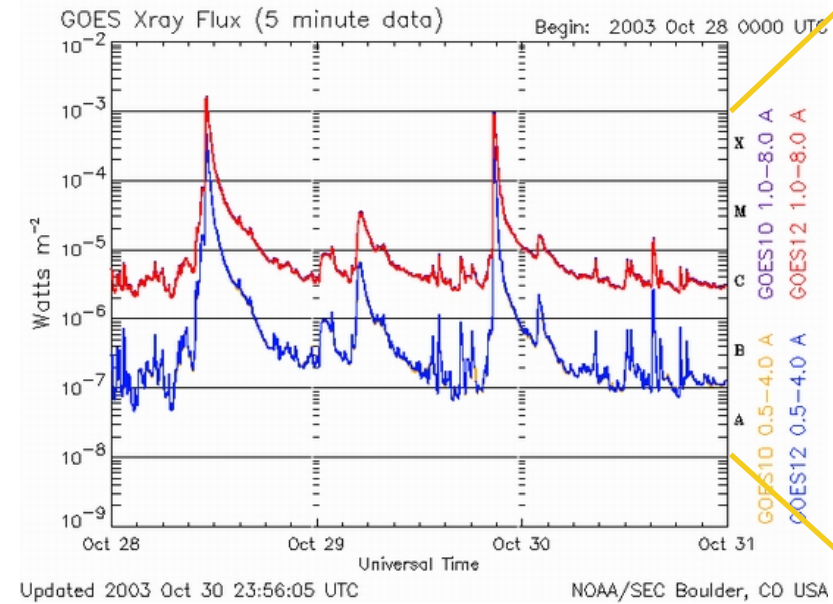


Supersonic "solar wind" of protons, electrons, ions
and *magnetic field*

Solar Magnetic Eruptions → X-ray Flares



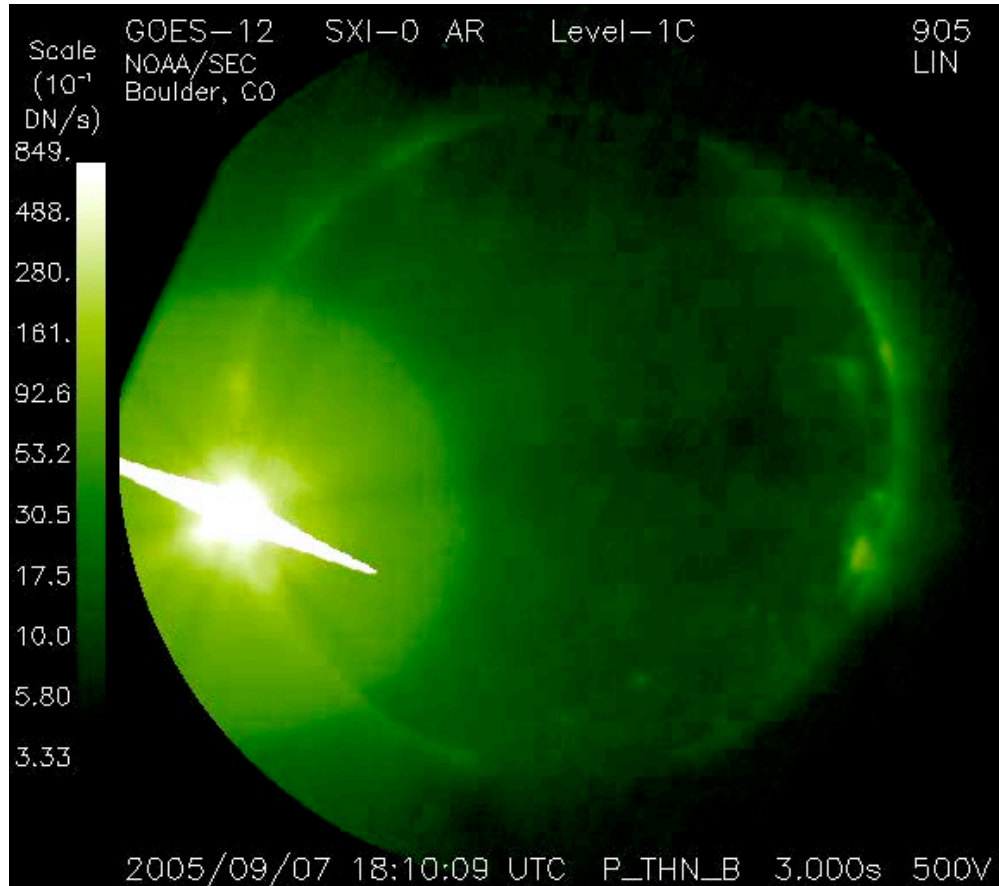
NOAA
Solar Ultraviolet Imager (SUVI)
extreme ultraviolet light (19 nm)



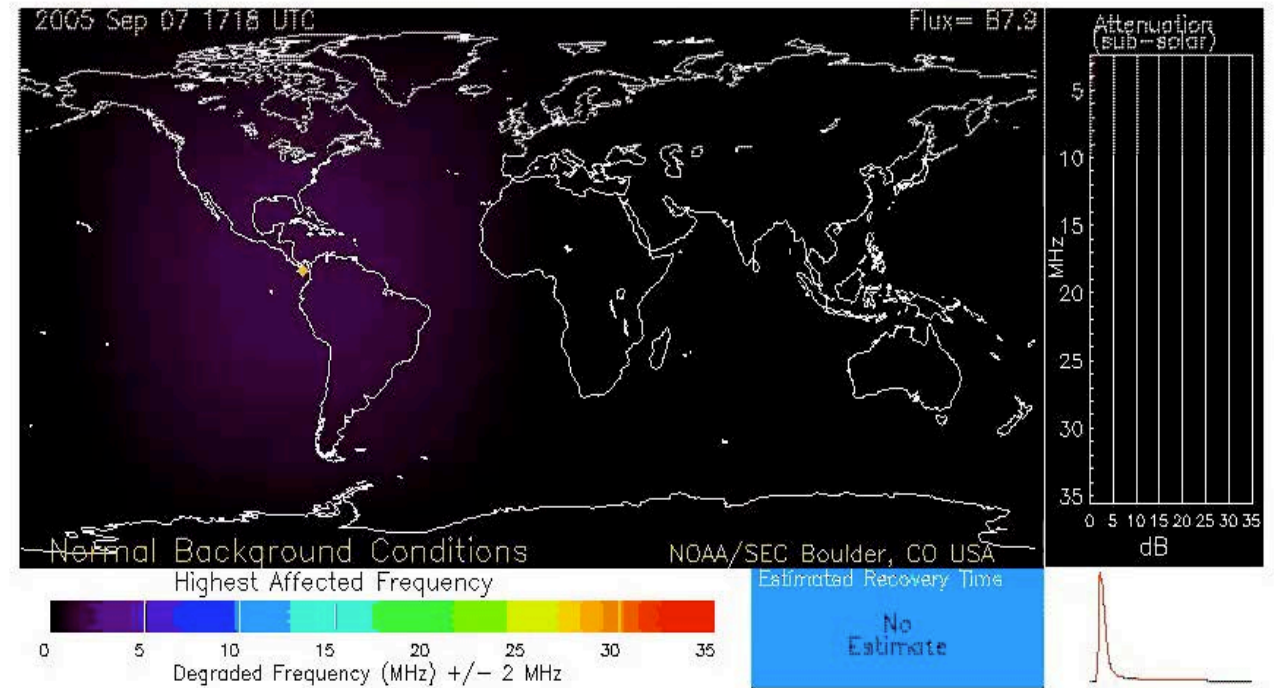
X
M
C
B
A

NOAA Space Weather Prediction Center
X-ray Flare Class

Flare X-rays cause OTH radio and radar blackouts



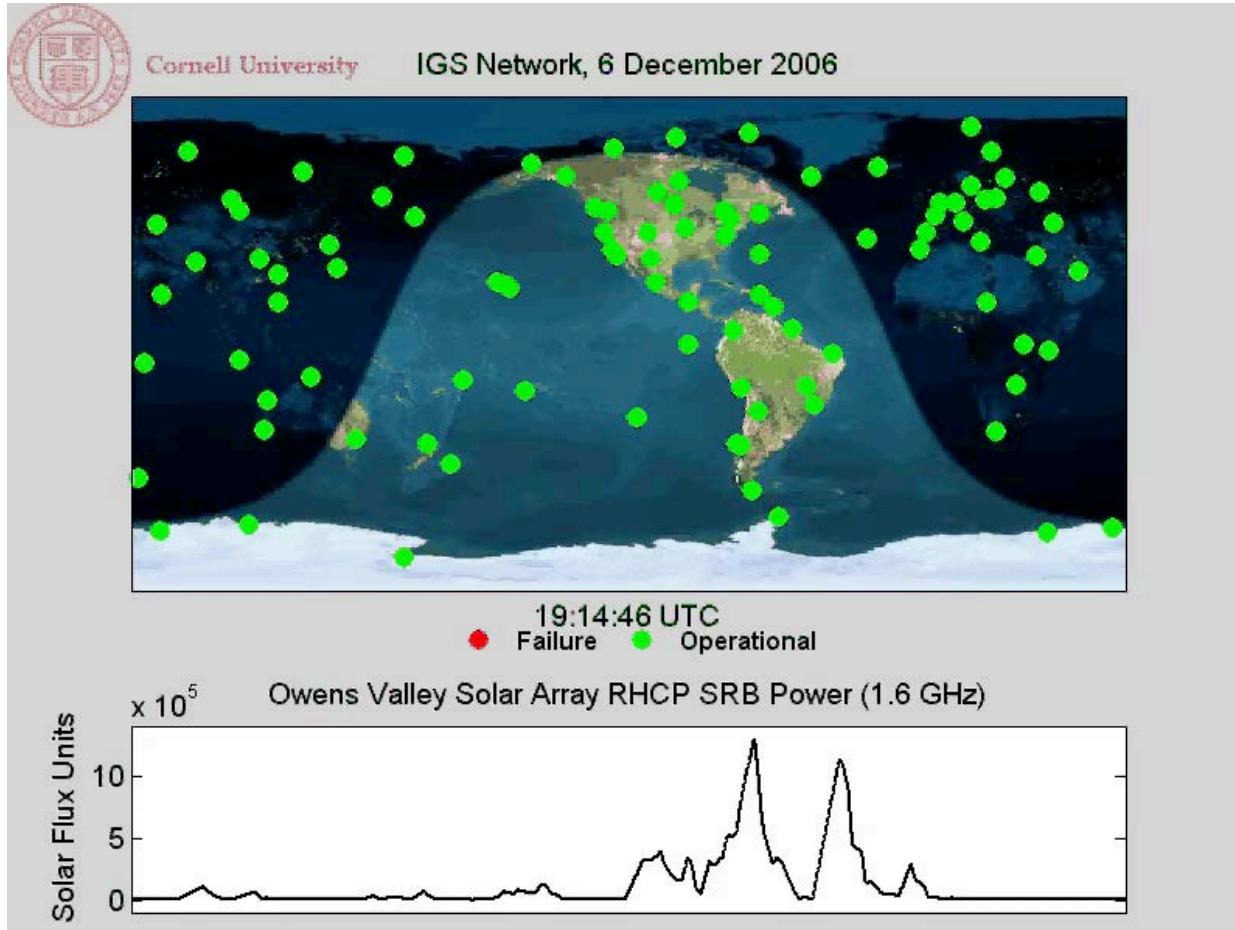
NOAA Geostationary Operational Environment Satellite (GOES)
X-rays



HF Radio Attenuation

- X-rays cause excess ionization of Earth's "ionosphere" Leading to radio wave absorption rather than reflection.

Flare “radio bursts” can cause GPS and radar blackouts

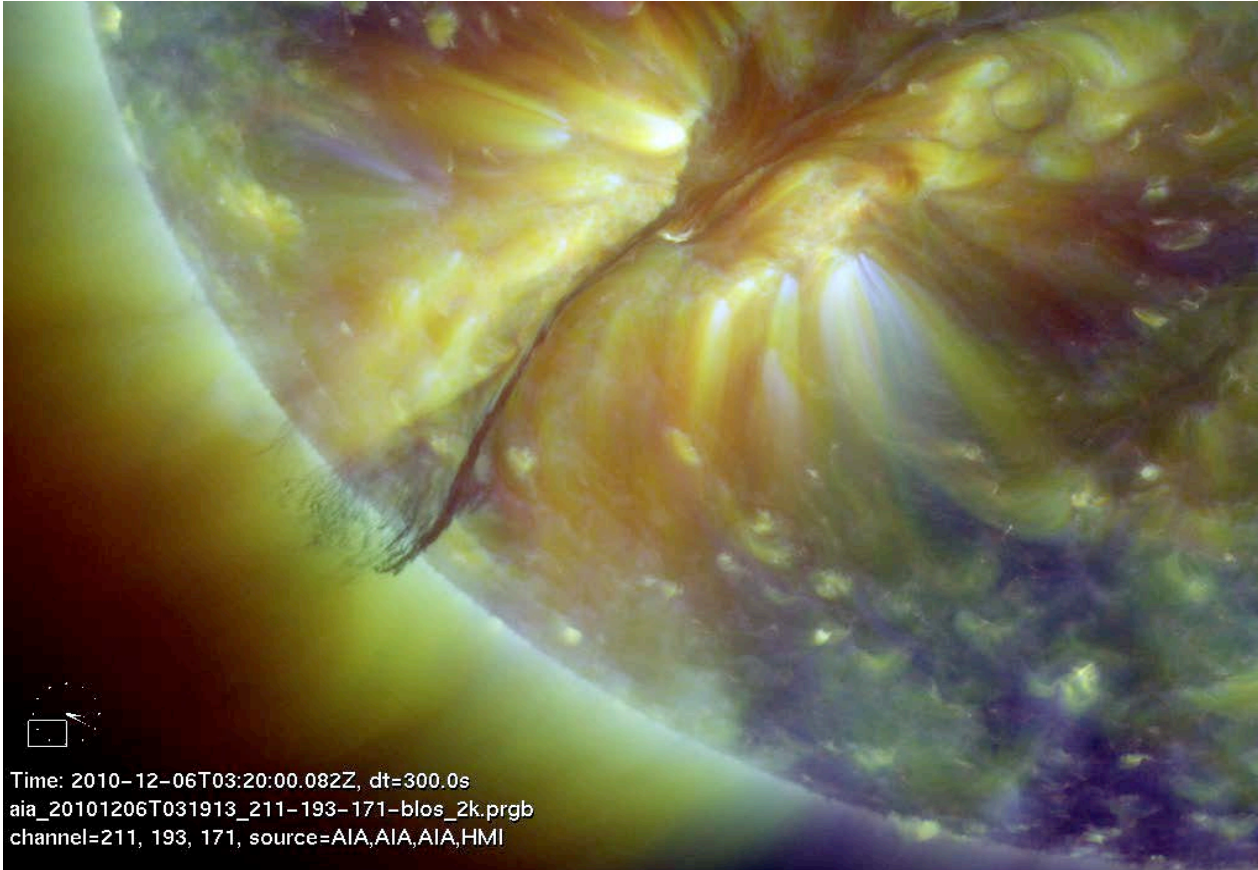


Travellers wait in the terminal building at Stockholm's Arlanda on August 17, 2013

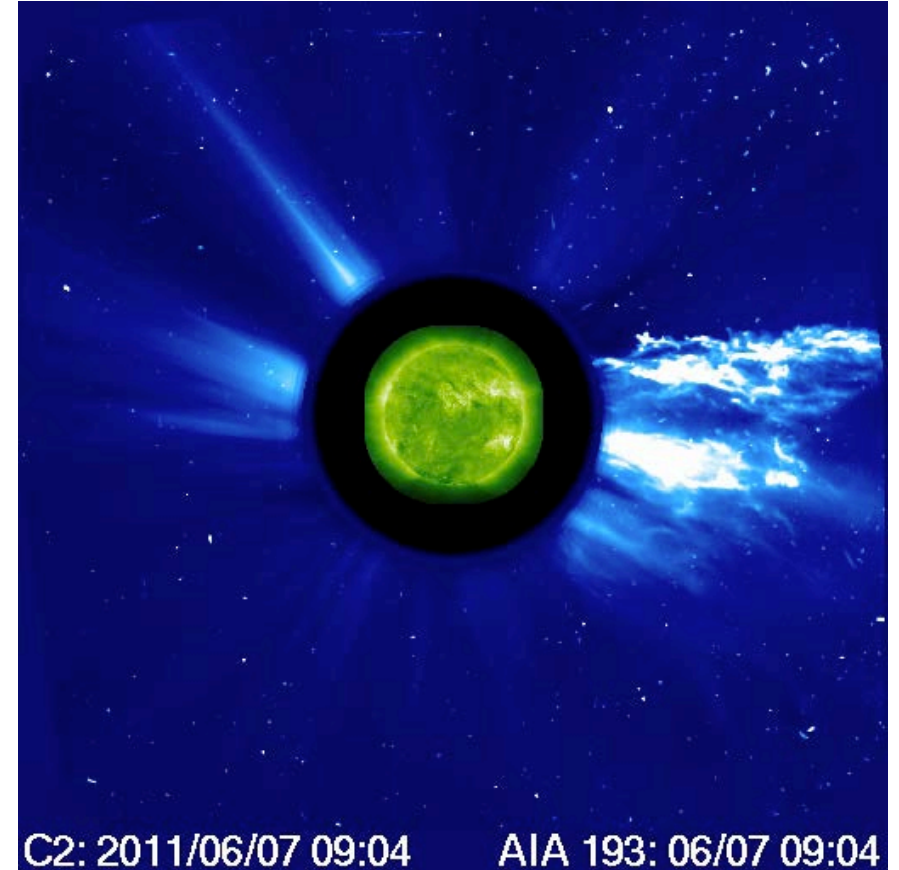
“Solar Storm knocks out flight control systems in Sweden”

- Receivers pointing at Sun swamped by solar “noise”

Solar Magnetic Eruptions → Coronal Mass Ejections (CMEs)



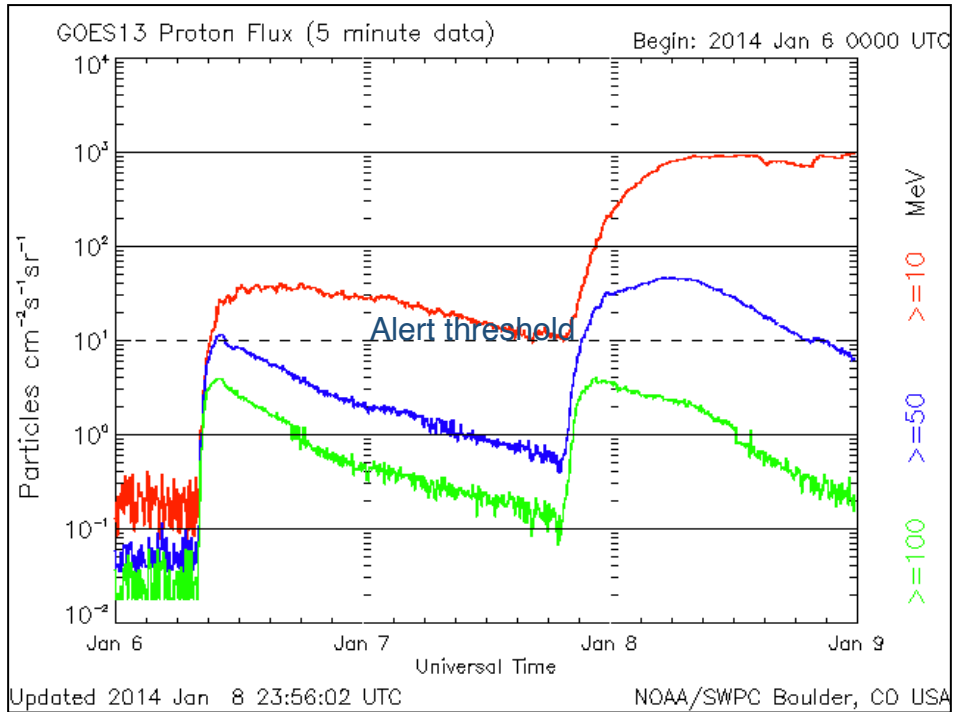
NASA
Solar Dynamics Observatory (SDO)



ESA/NASA
Solar and Heliospheric Observatory (SOHO)

- CMEs can go any direction in the solar system
- Space weather forecasting challenge: determine whether a CME will impact Earth

CMEs cause radiation storms and Geomagnetic storms



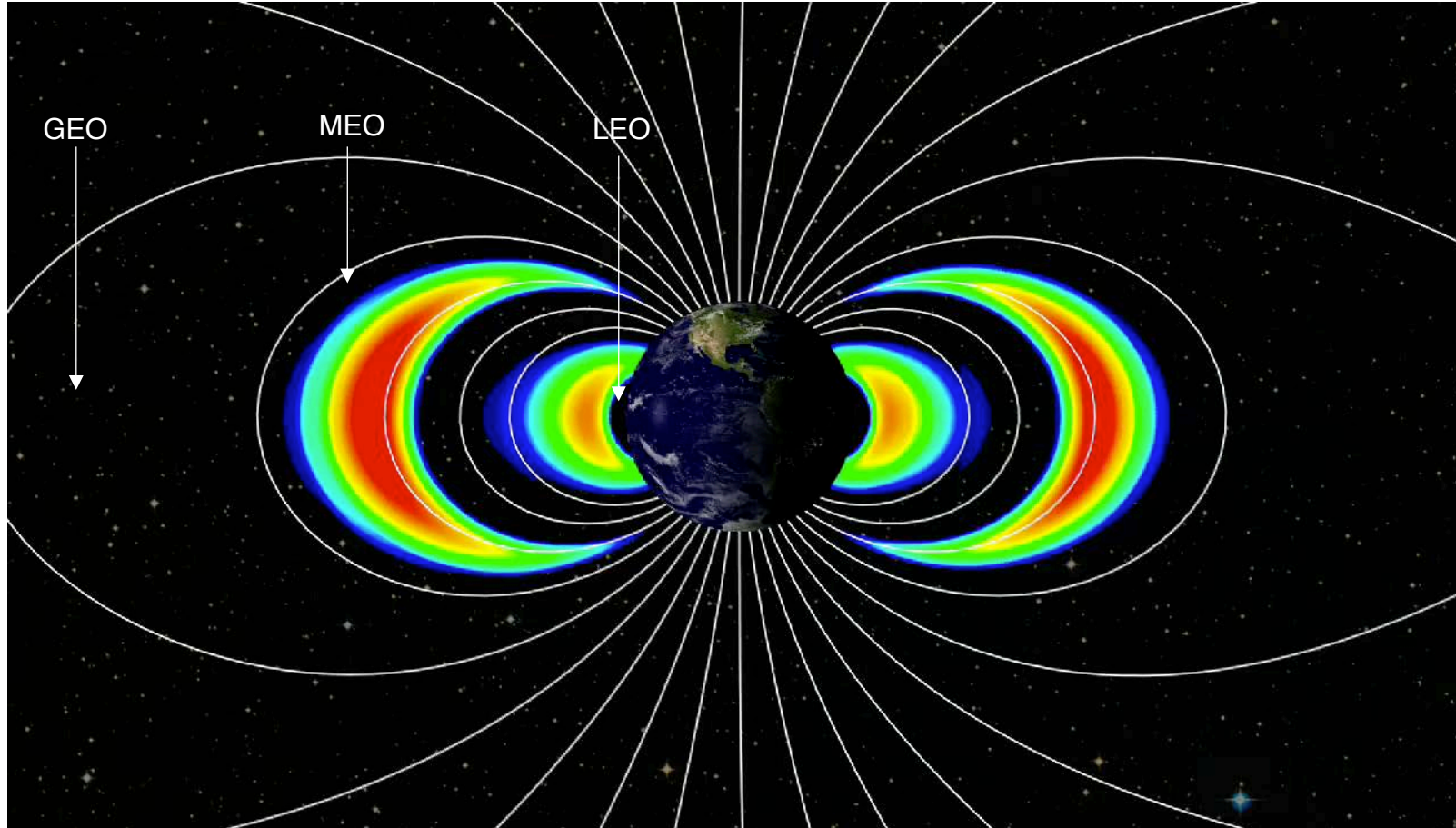
NOAA GOES
Relativistic Proton Flux



The Aurora: the only visible effect of space weather.
The farther south the aurora is visible, the bigger the geomagnetic storm.

- Radiation storms threaten astronauts in orbit or on the Moon and can damage or permanently disable satellites in *any* orbit.
- CME impact drives geomagnetic storms which in turn drive electric currents in the **ionosphere**.
- Ionospheric currents heat the upper atmosphere (**thermosphere**) causing **atmospheric expansion**.
- Disturbed geomagnetic field causes **Geomagnetically Induced Currents (GICs)** in the Earth's crust.

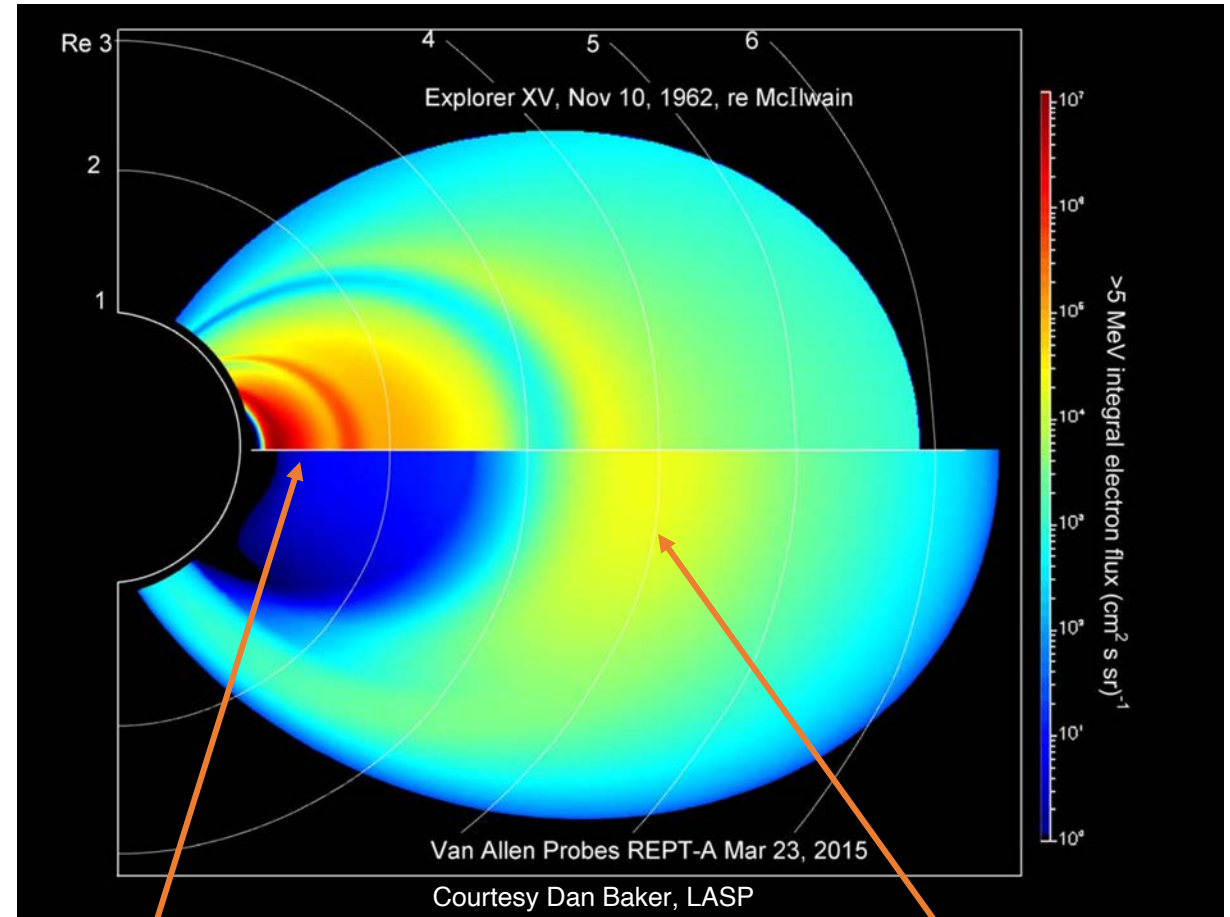
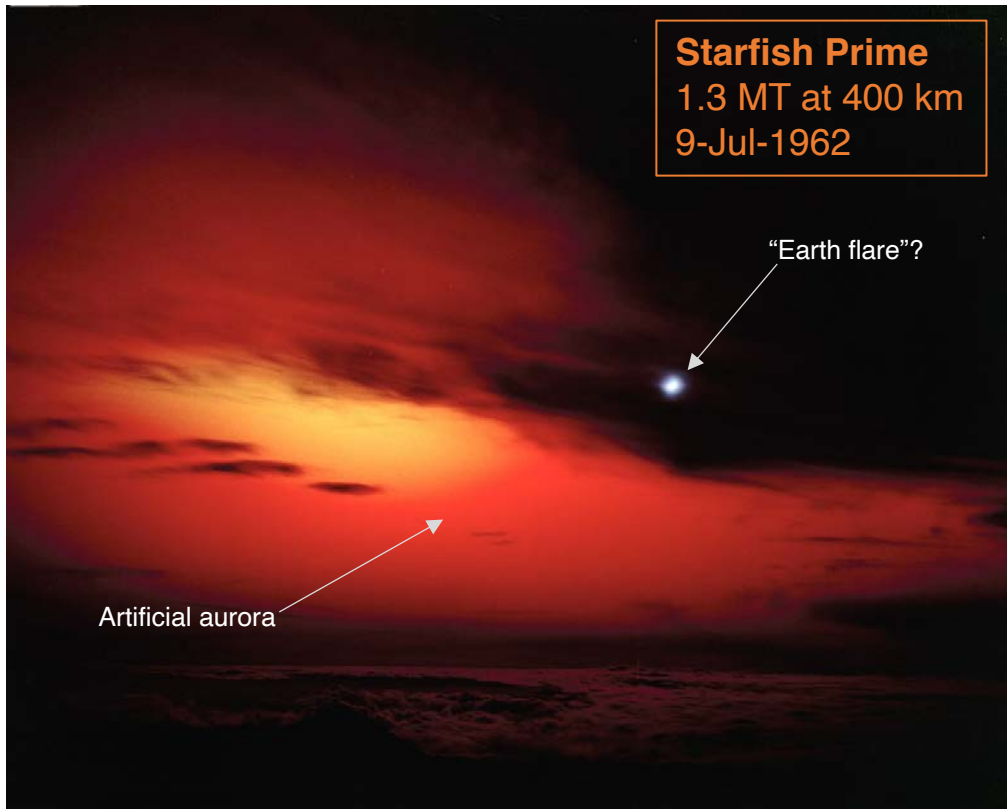
The Van Allen Radiation Belts & “killer electrons”



NASA's Van Allen Probes
Courtesy of Johns Hopkins Applied Physics Lab

- Radiation levels fluctuate during CME impact / geomagnetic storm
- Colors indicate flux of relativistic electrons: red is higher

High Altitude Nuclear Explosion → Artificial Van Allen Belts



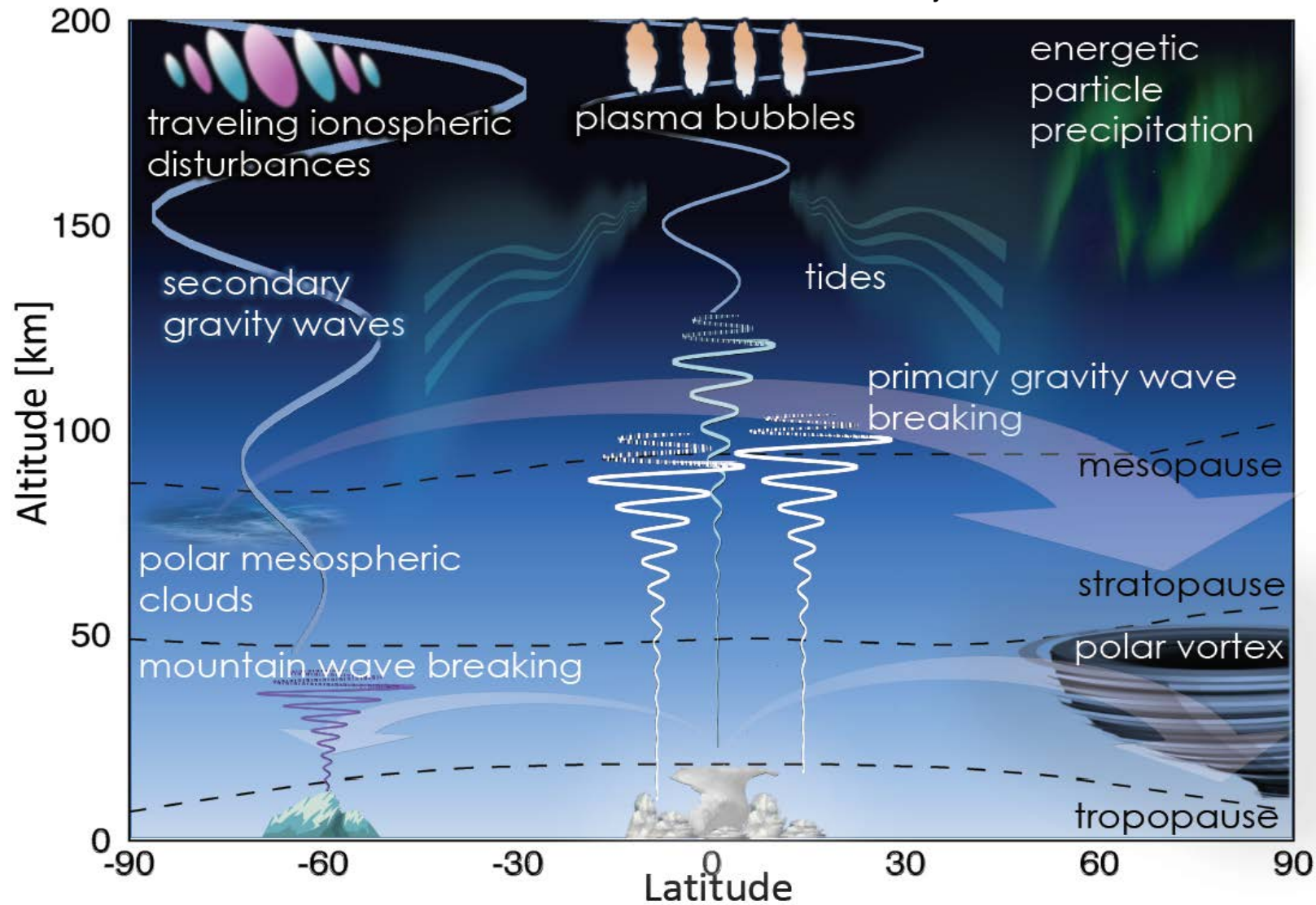
Starfish belt

St. Patrick's Day Storm 2015

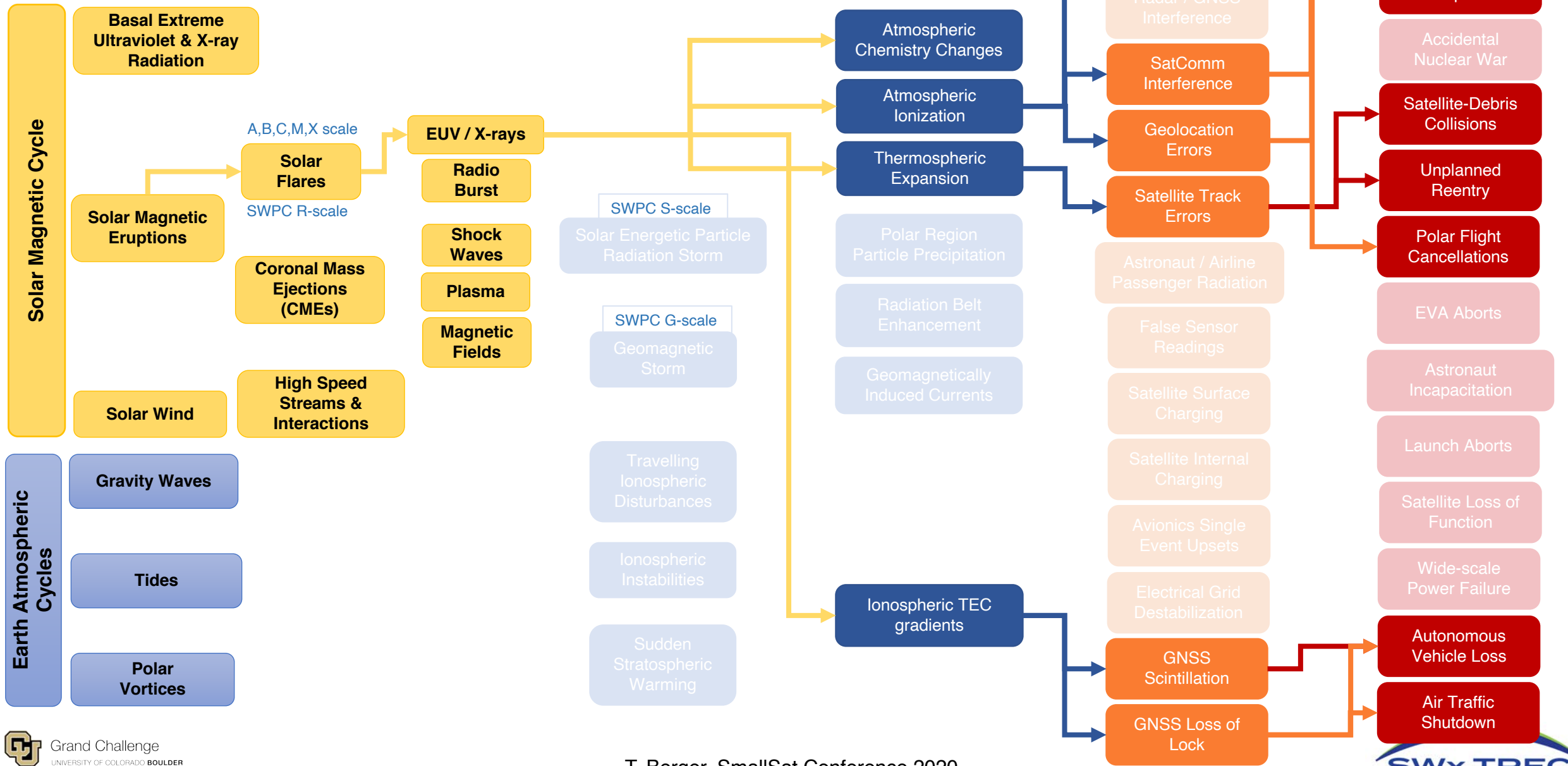
- “Man-made” space weather
- 2/3 of satellites in LEO in 1962 (not many...) damaged or destroyed

Space Weather from below

Courtesy: Laura Holt and Cora Randall



Space Weather Fault Tree



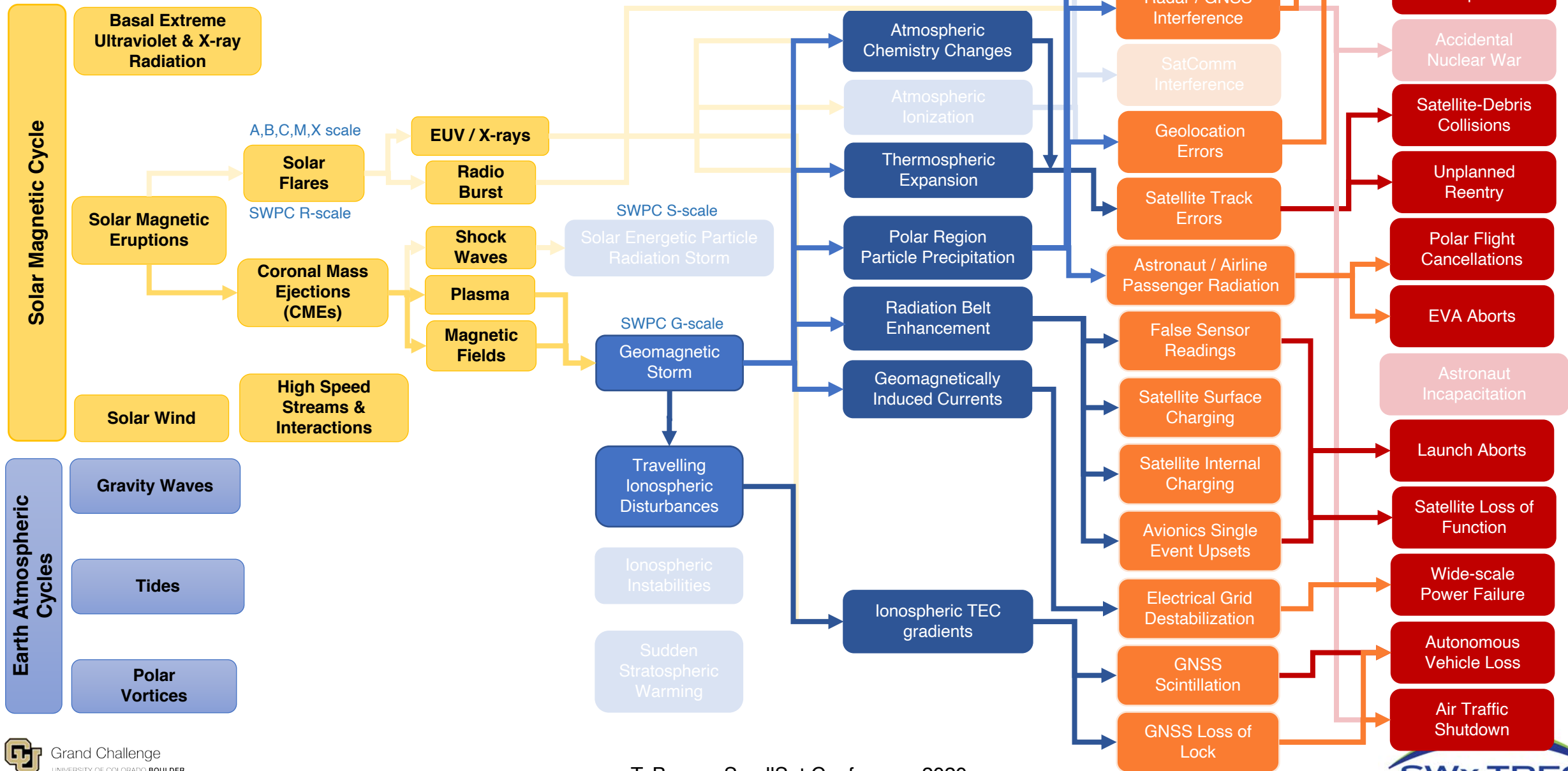
Space Weather Fault Tree



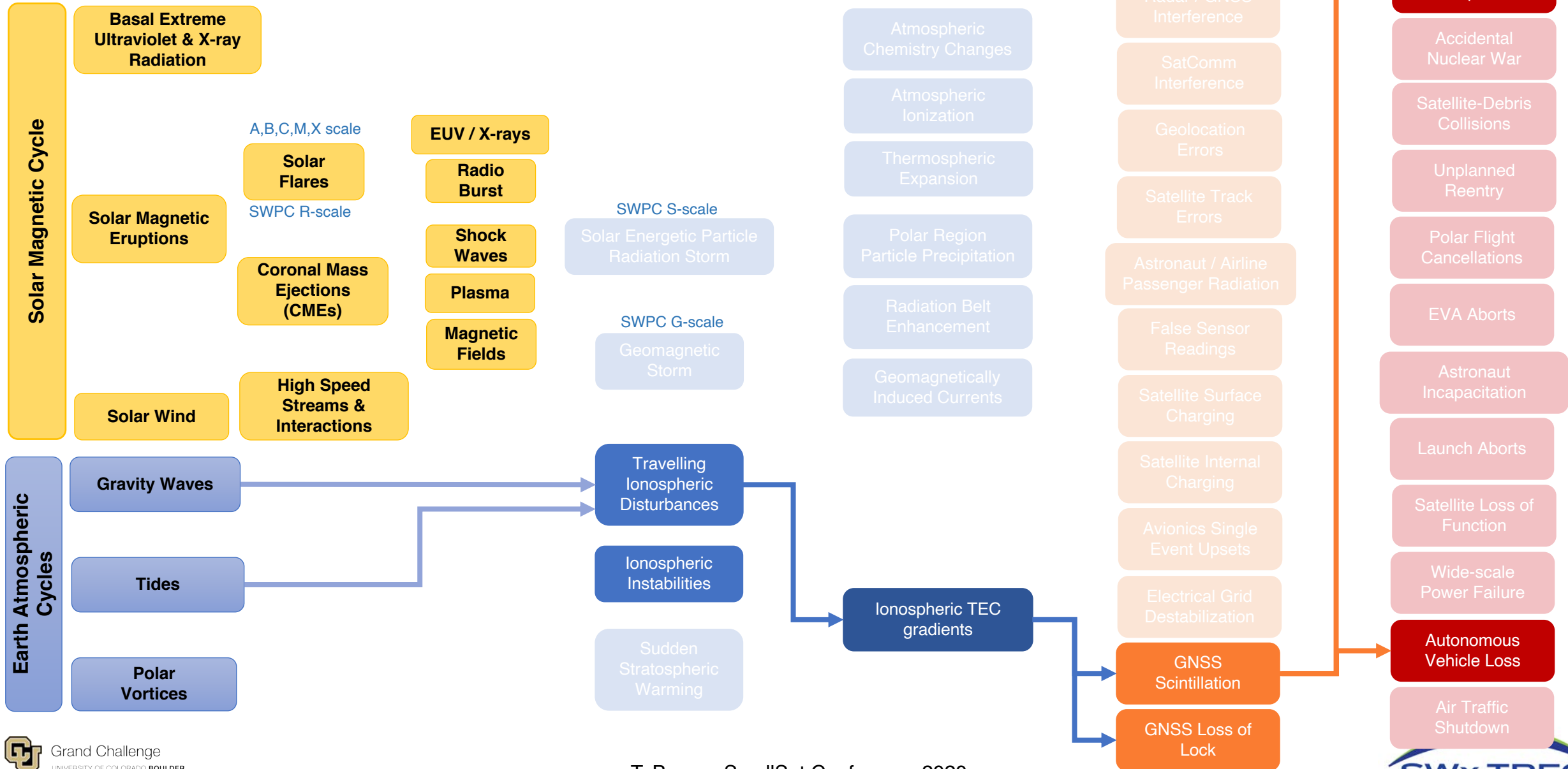
Space Weather Fault Tree



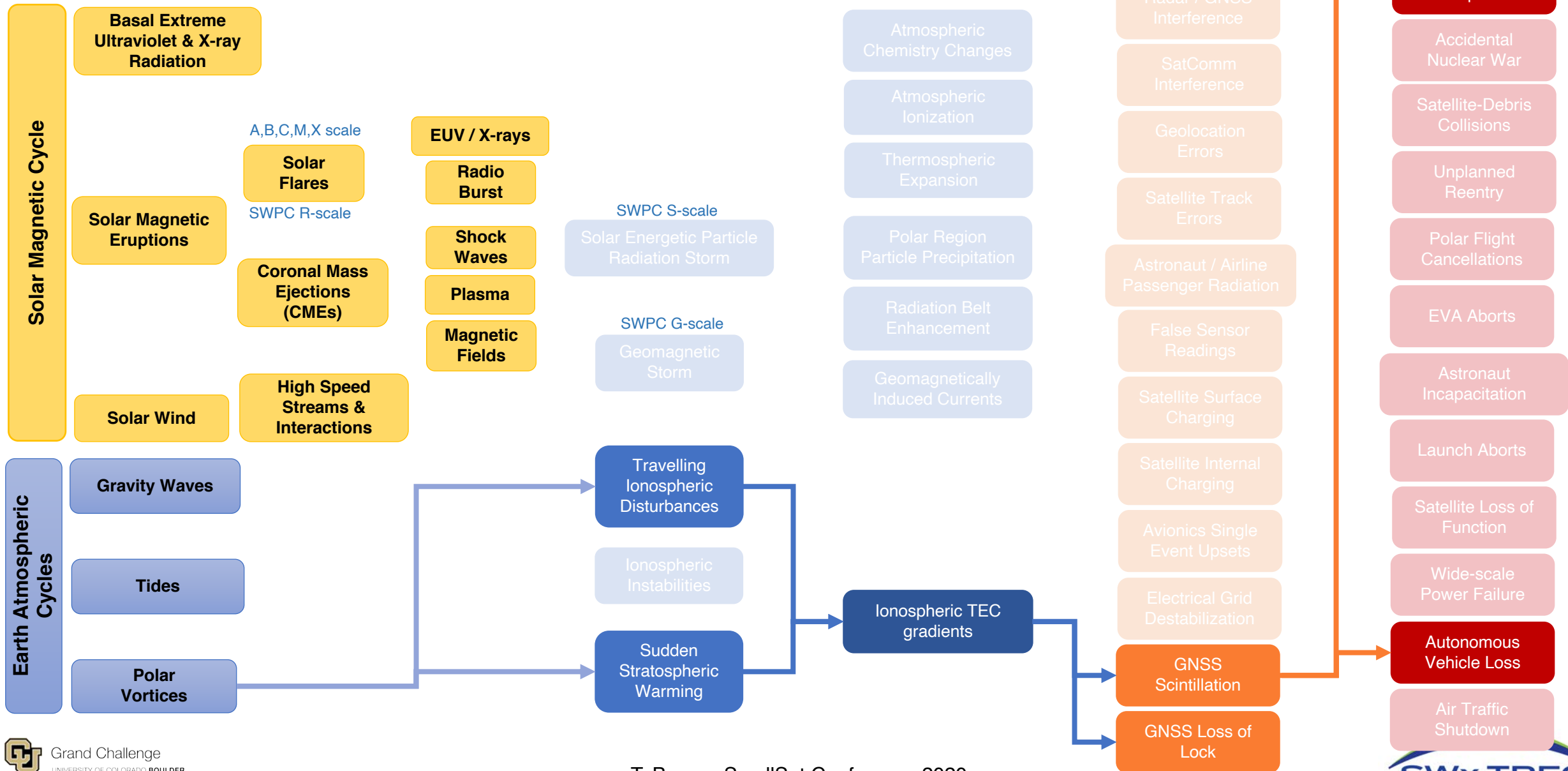
Space Weather Fault Tree



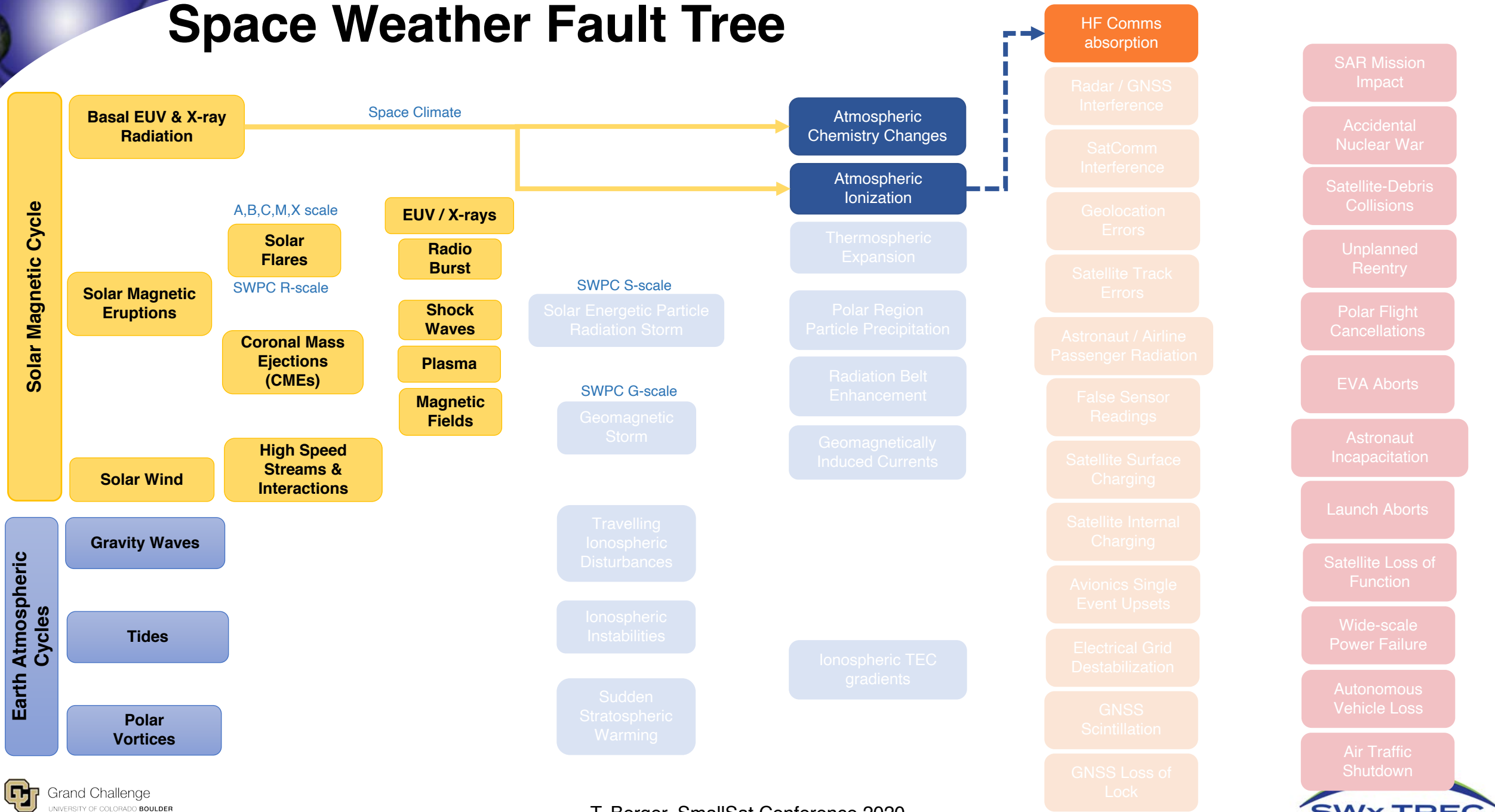
Space Weather Fault Tree



Space Weather Fault Tree



Space Weather Fault Tree



Space Weather Fault Tree



More Information

- <https://www.colorado.edu/spaceweather>
- <https://science.nasa.gov/heliophysics/focus-areas/space-weather>
- <https://www.swpc.noaa.gov>
- <https://www.spaceweather.com>
- <https://www.spaceweatherlive.com>
- <http://www.spaceweatherwoman.com>
- <https://solarmonitor.org>